Electron Ion Collider User Group Meeting 2016
UC Berkeley, January 9th 2016

LHeC status and plans

http://cern.ch/lhec

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for the **LHeC Study Group**

Contents:

1. Introduction.

2. Accelerator.

3. Detector.

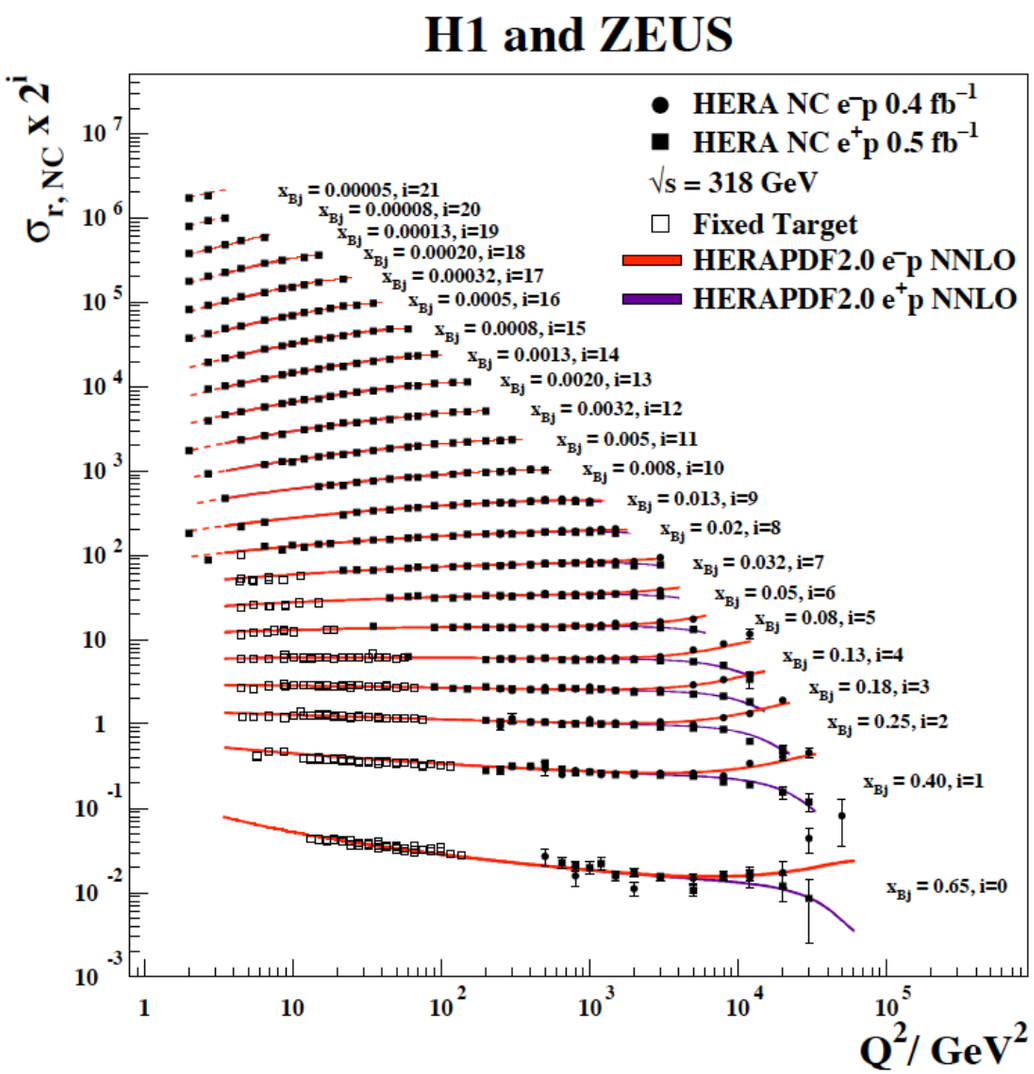
4. Physics case (some highlights):
   - ➜ Precision QCD.
   - ➜ Top and EW.
   - ➜ Higgs.
   - ➜ BSM.
   - ➜ Small x and eA.

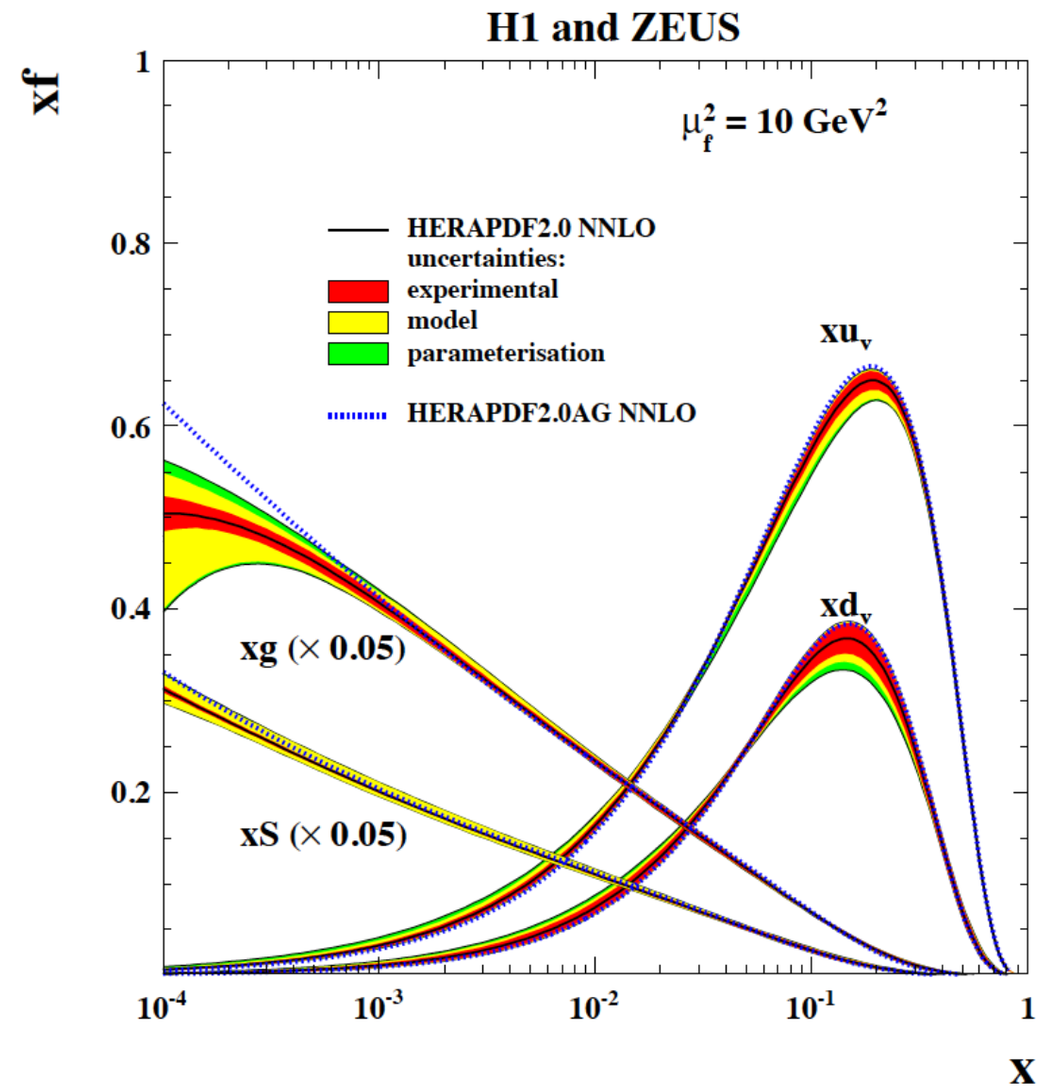
5. Organisation and plans.

CDR:1206.2913; 1211.4831; 1211.5102; Brüning & Klein, 1305.2090;
Klein & Schöpper, CERN Courier, June 2014;
Newman & Stasto, Nature Physics 9 (2013) 448;
2015 LHeC Workshop http://indico.cern.ch/event/356714/.

Legacy from HERA:

- Structure functions in an extended x-Q^2 range, $xg \propto 1/x^{\lambda}$, $\lambda>0$: PDFs for the LHC.
- Large fraction of diffraction $\sigma_{diff}/\sigma_{tot} \sim 10\%$.
- **But**: eA/eD, kinematical reach at small x, luminosity for high x /for searches (odderon,...), flavour decomposition, GPDs,...





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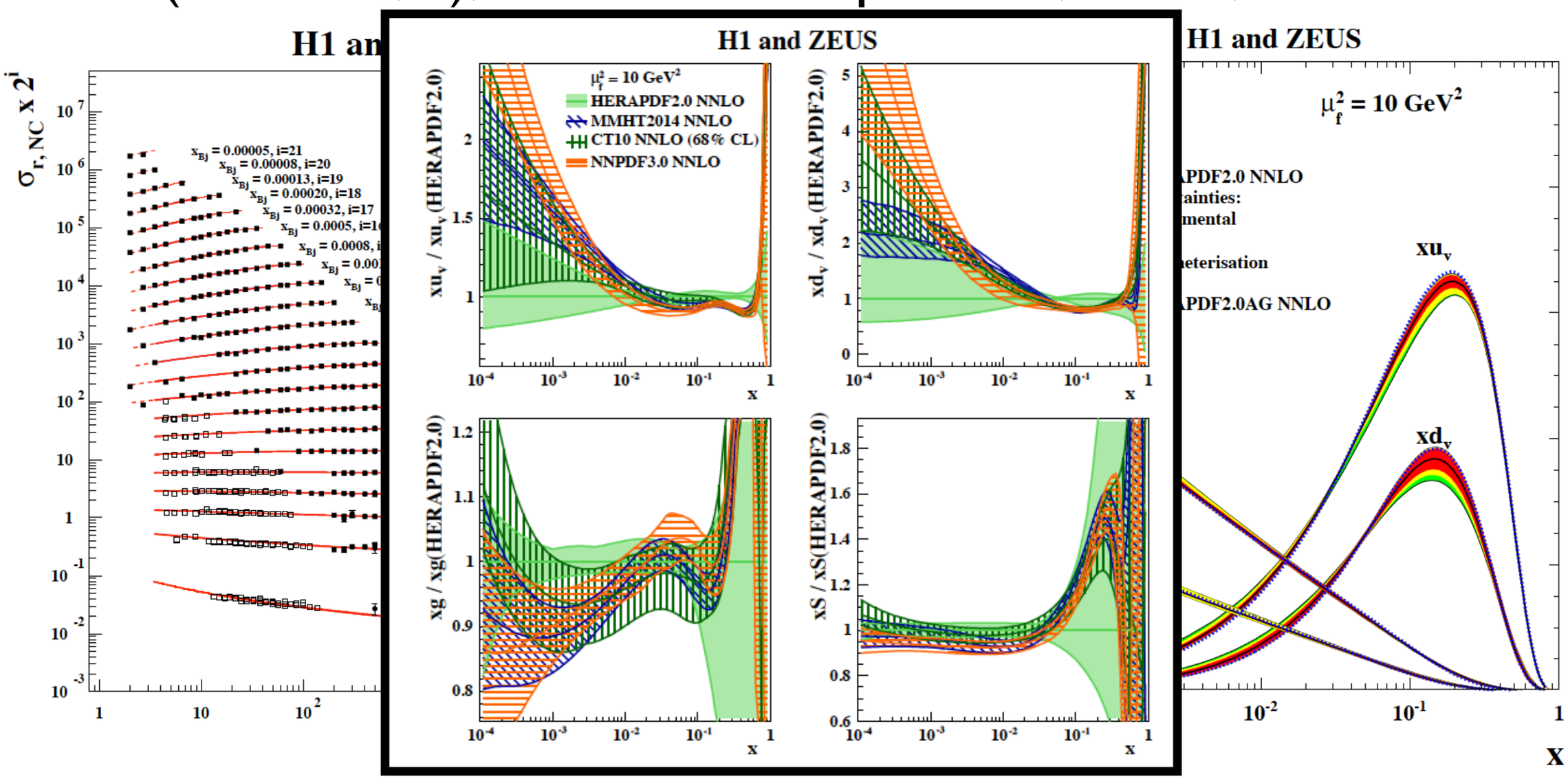

DIS at the LHC:

Guido Altarelli (1941-2015)

CERN-ECFA workshop, Lausanne, March 1984:
a Large Hadron Collider in the LEP tunnel

PHYSICS OF ep COLLISIONS IN THE TeV ENERGY RANGE

G. Altarelli*), B. Mele*) and R. Rückl,
CERN, Geneva, Switzerland
(Presented by G. Altarelli)

ABSTRACT

We study the physics of electron-proton collisions in the range of centre-of-mass energies between $\sqrt{s} \simeq 0.3$ TeV (HERA) and $\sqrt{s} \simeq (1\text{-}2)$ TeV. The latter energies would be achieved if the electron or positron beam of LEP [$E_e \simeq (50\text{-}100)$ GeV] is made to collide with the proton beam of LHC [$E_p \simeq (5\text{-}10)$ TeV].

- 2006: proposal of the Large Hadron Electron Collider (hep-ex/0603016), taken in 2007 by CERN, ECFA and NuPECC.

- Study group formed in 2008, series of regular workshops.

The LHeC:

- **LHeC@CERN** → ep/eA experiment using p/A from the LHC: E_p=7 TeV, E_{Pb}=2.75 TeV/nucleon, and possibly from the FCC (FCC-he): E_p=50 TeV, E_{Pb}=19.7 TeV/nucleon.
- New e^+/e^- accelerator: E_{cm}~1-2 (3-5) TeV (E_e=50-150 GeV).

- Requirements:
  * Luminosity~1-10×10^{33} $cm^{-2}s^{-1}$.
  * Acceptance: 1-179 degrees (low-x ep/eA, Q^2~1 GeV^2, nominal energy).
  * Tracking to 0.1 mrad.
  * EMCAL calibration to 0.1 %.
  * HCAL calibration to 0.5 %.
  * Luminosity determination to 1 %.
  * **Total wall plug power < 100 MW.**
  * **Compatible with synchronous LHC operation.**

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- Require
  * Lu
  * Ac eV^2,
  non
  * Tr
  * EM
  * H
  * Lu
  * To
  * C

Requirements	LHeC	HERA	How?
high lumi for high x and Q^2	1-10×10^{33}	1-5×10^{31}	ER technique
large acceptance	1-179 deg.	7-177 deg.	kinematic coverage
tracking	0.1 mrad	0.2-1 mrad	modern Si
EMcal	0.1 %	0.2-0.5 %	kinematic reconstruction
Hcal	0.5 %	1 %	tracking + calo e/h
accurate lumi/pol	0.5 %	1 %	demanding

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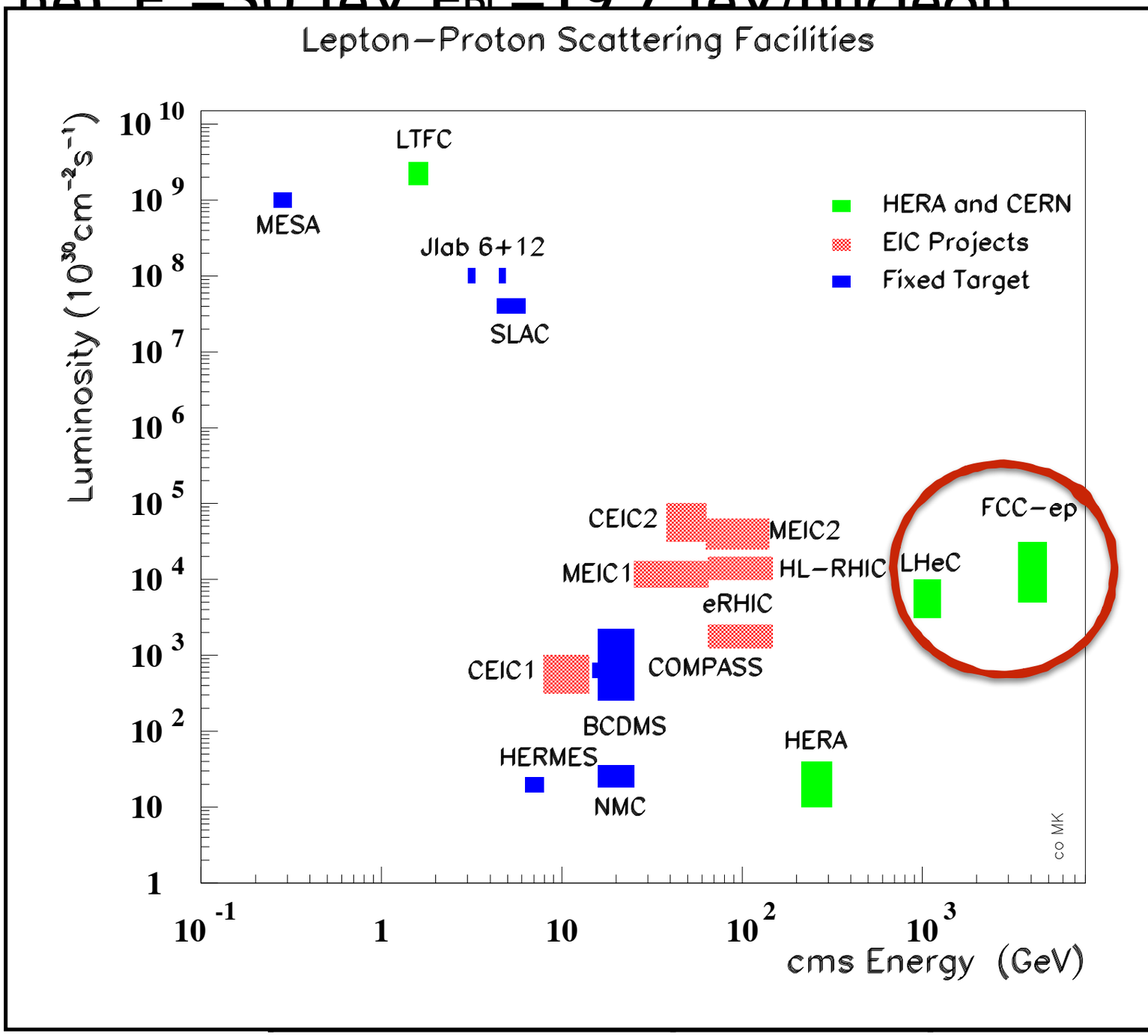

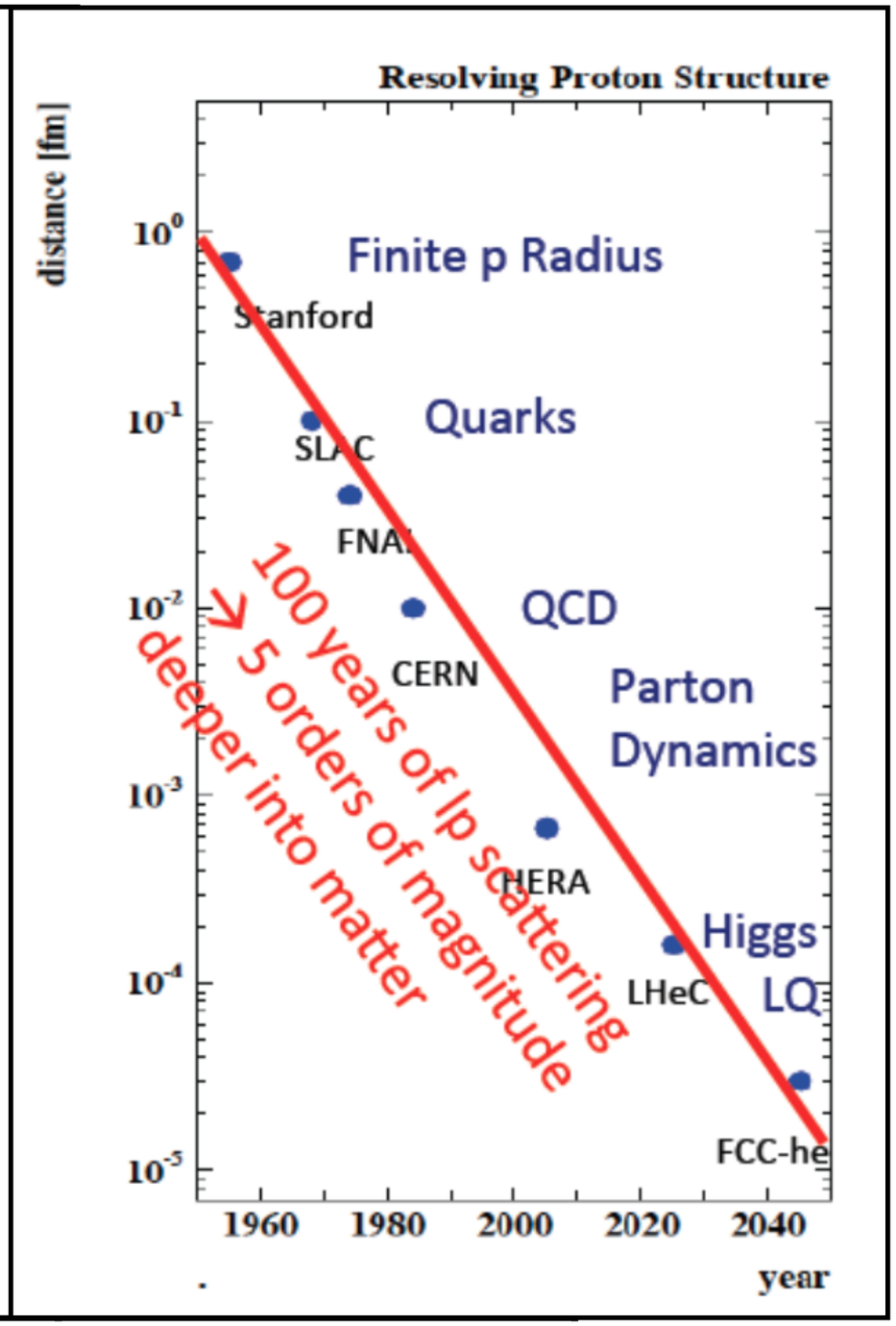

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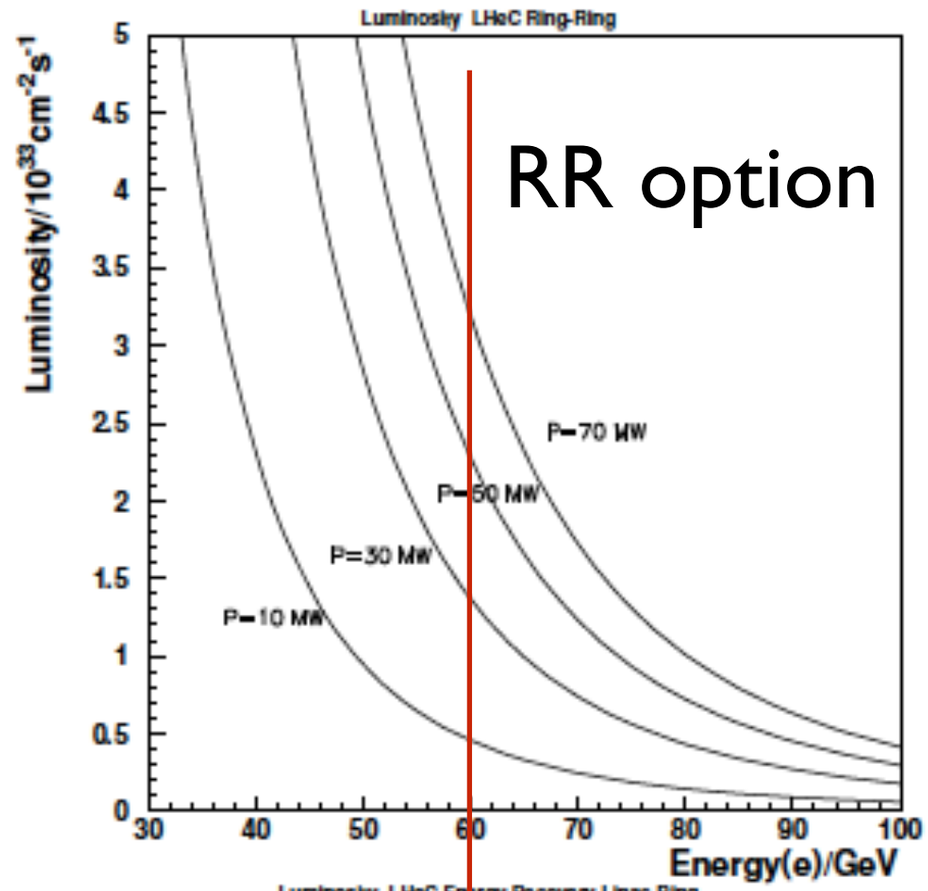
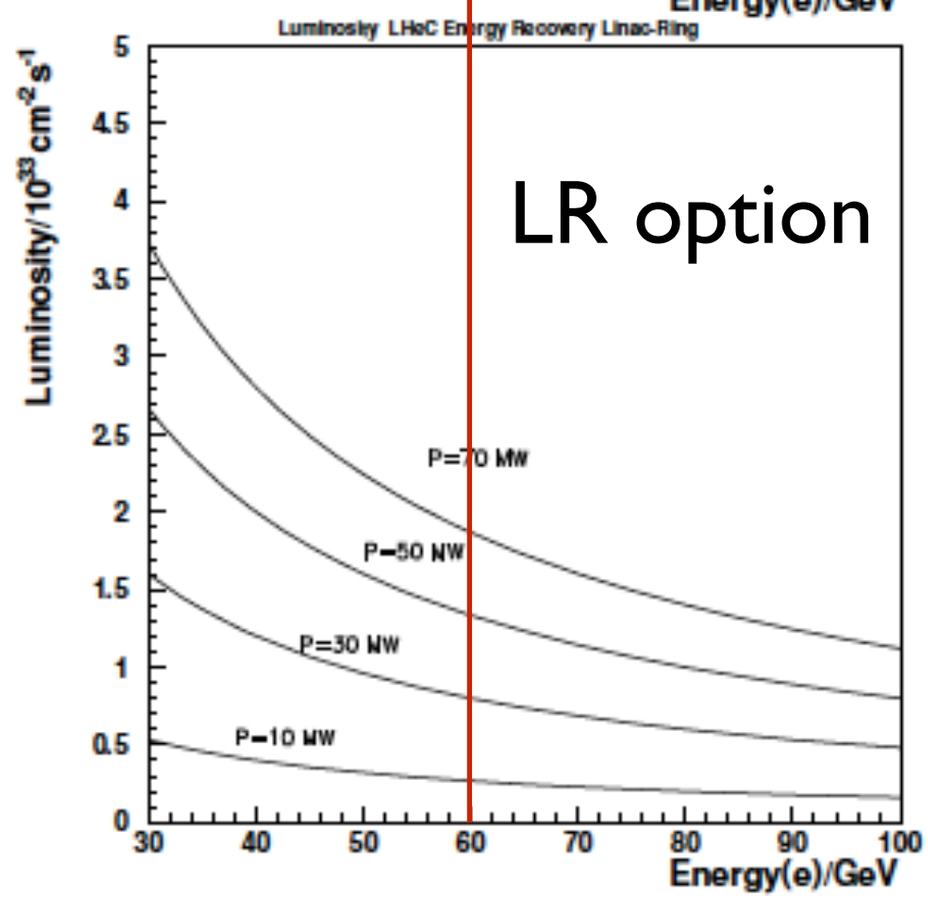
Power constraints and design considerations:

CDR numbers

	Ring	Linac
electron beam 60 GeV		
e^- (e^+) per bunch N_e [10^9]	20 (20)	1 (0.1)
e^- (e^+) polarisation [%]	40 (40)	90 (0)
bunch length [mm]	10	0.6
tr. emittance at IP $\gamma\epsilon^e_{x,y}$ [mm]	0.58, 0.29	0.05
IP β function $\beta^*_{x,y}$ [m]	0.4, 0.2	0.12
beam current [mA]	131	6.6
energy recovery intensity gain	–	17
total wall plug power [MW]	100	100
syn rad power [kW]	51	49
critical energy [keV]	163	718
proton beam 7 TeV		
protons per bunch N_p [10^{11}]	1.7	1.7
transverse emittance $\gamma\epsilon^p_{x,y}$ [μm	3.75	3.75
collider		
Lum e^-p (e^+p) [10^{32}cm^{-2}s^{-1}]	9 (9)	10 (1)
bunch spacing [ns]	25	25
rms beam spot size $\sigma_{x,y}$ [μm]	30, 16	7
crossing angle θ [mrad]	1	0
$L_{eN} = A\ L_{eA}$ [10^{32}cm^{-2}s^{-1}]	0.3	1





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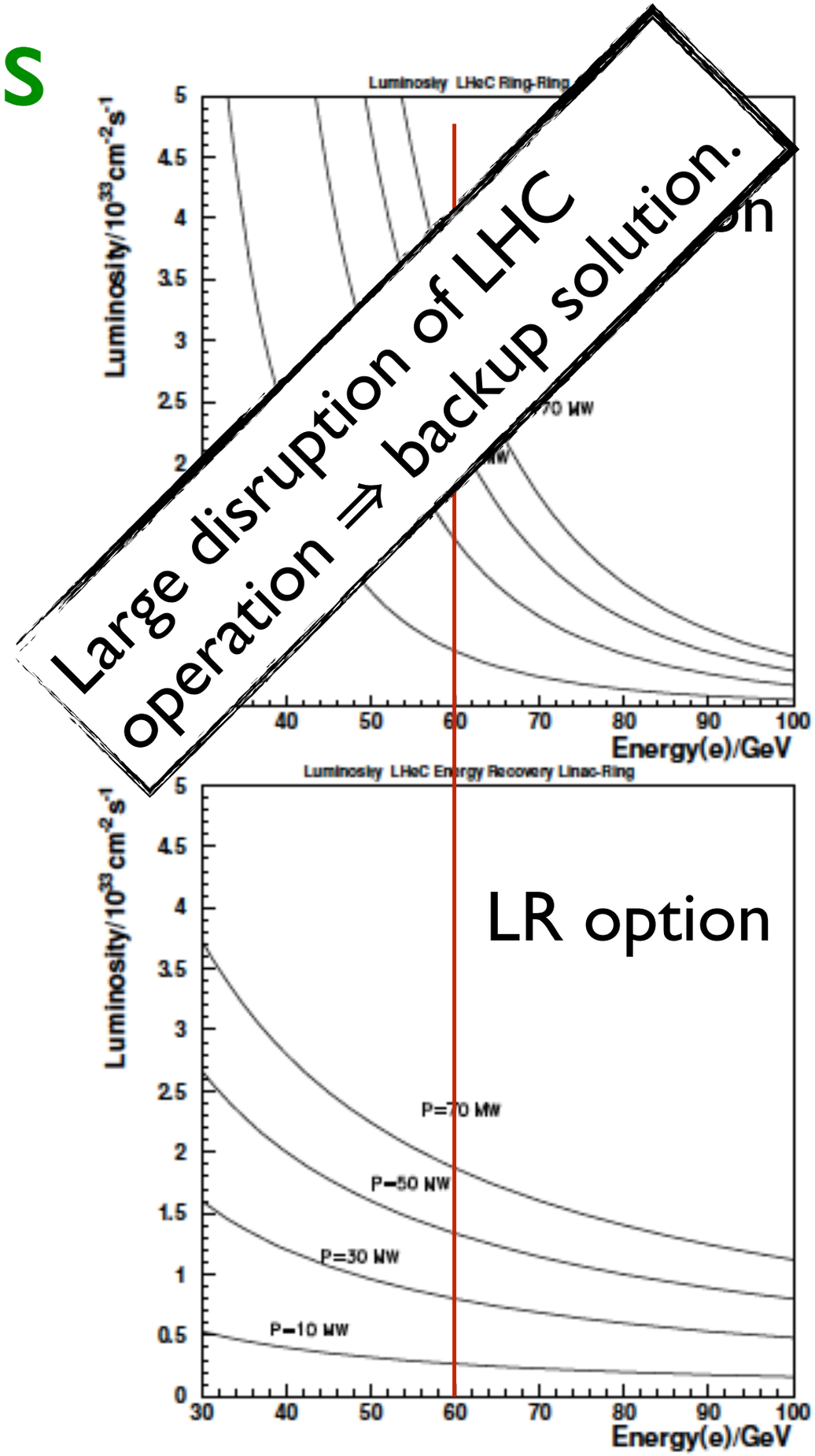


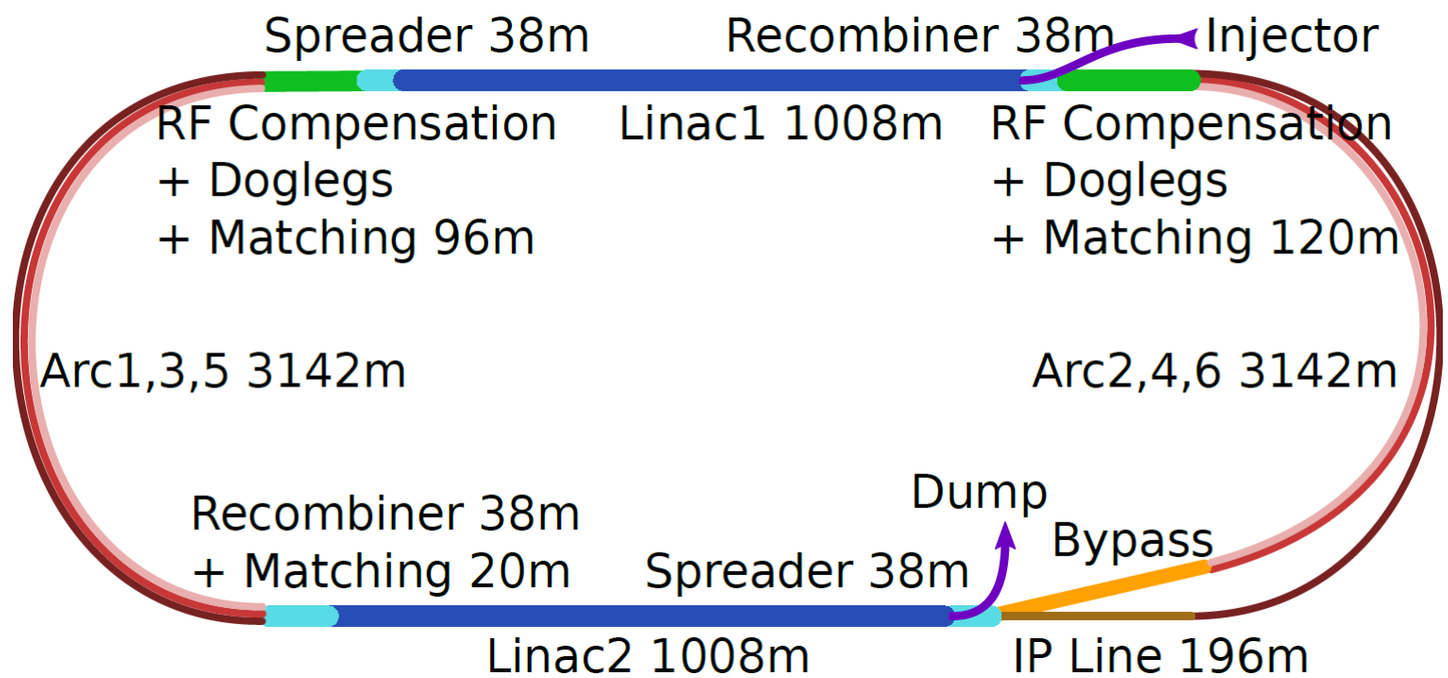
Large disruption of LHC operation ⇒ backup solution.

ERL:

- Nominal case: 60+7000.

Possible to lower the energy of both beams (e.g. for F_L).

- 1 ab^{-1} in ten years within reach.



Post CDR ← CDR

10^{34} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60	7000	60
Luminosity [10^{33}cm^{-2}s^{-1}]	16	16	1	1
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	2.5	20	3.75	50
Beta Funtion $\beta^*_{x,y}$ [m]	0.05	0.10	0.1	0.12
rms Beam size $\sigma^*_{x,y}$ [μm]	4	4	7	7
rms Beam divergence $\sigma'^*_{x,y}$ [μrad]	80	40	70	58
Beam Current [mA]	1112	25	430 (860)	6.6
Bunch Spacing [ns]	25	25	25 (50)	25 (50)
Bunch Population	$2.2*10^{11}$	$4*10^{9}$	$1.7*10^{11}$	$(1*10^{9})$ $2*10^{9}$
Bunch charge [nC]	35	0.64	27	(0.16) 0.32

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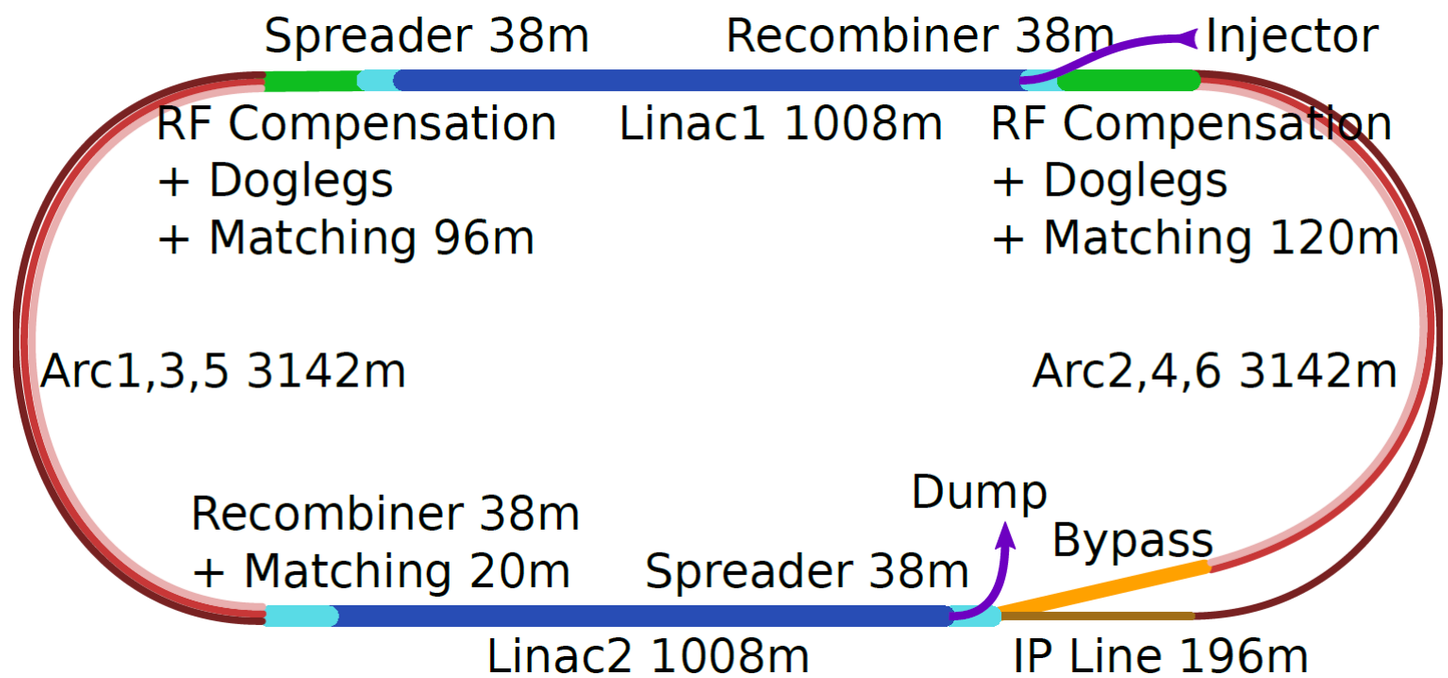

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$$L_{eN} = \begin{cases} 9 \times 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} & \text{(Nominal Pb)} \\ 1.6 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} & \text{(Ultimate Pb)} \end{cases}$$

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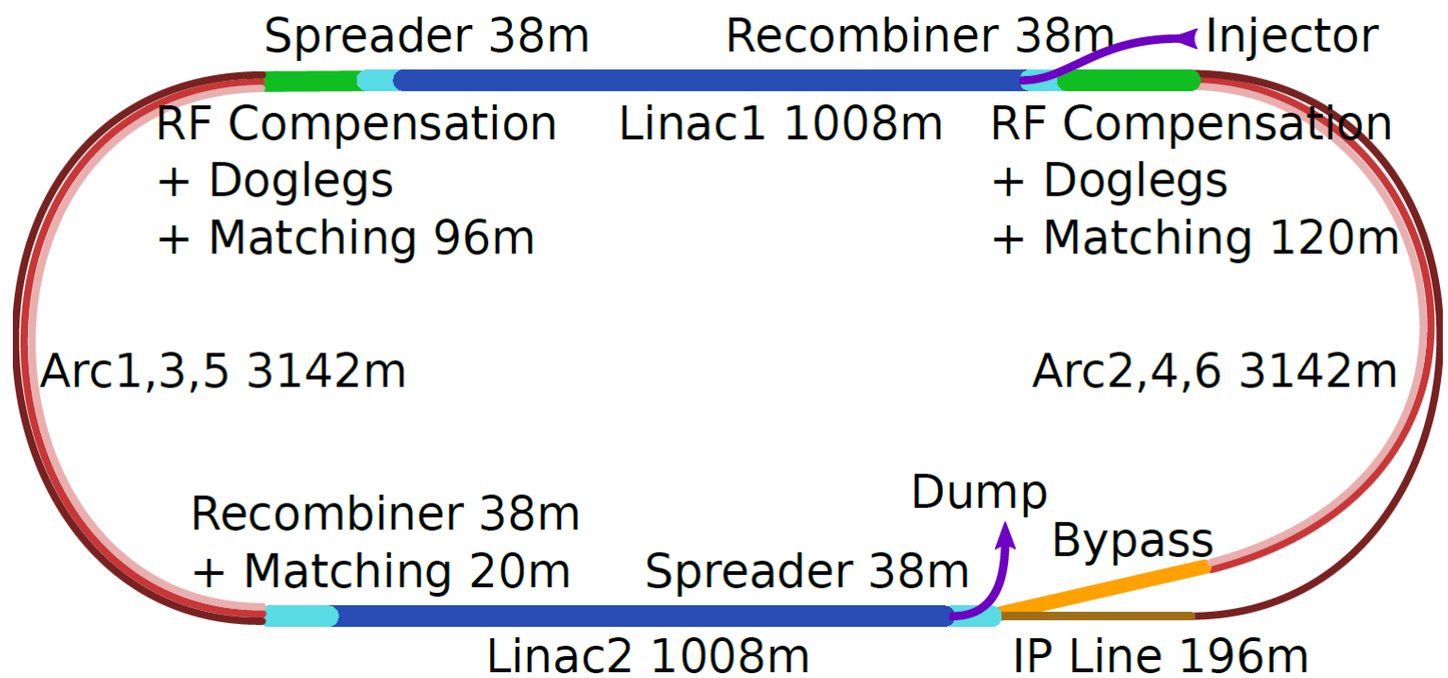

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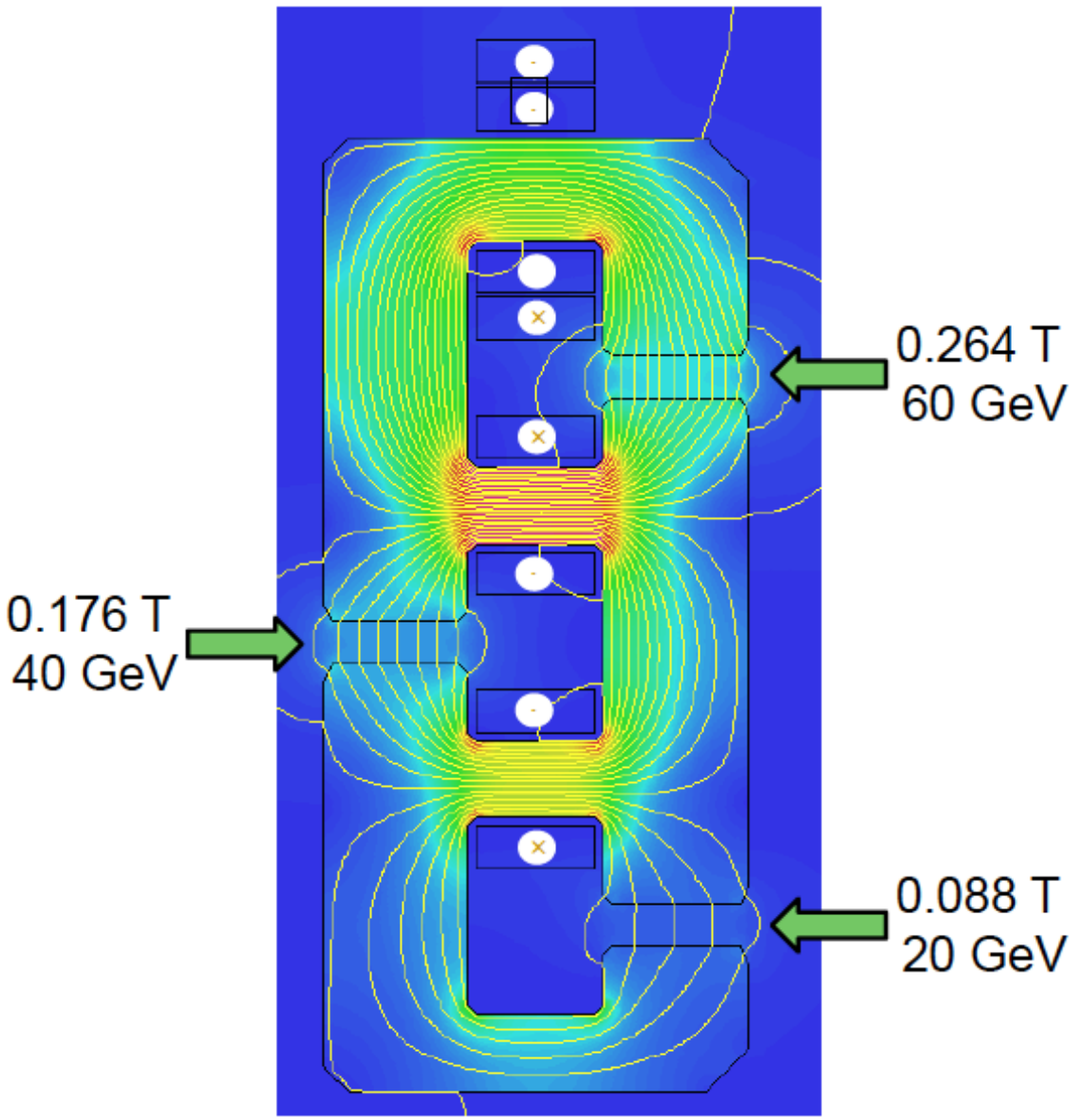
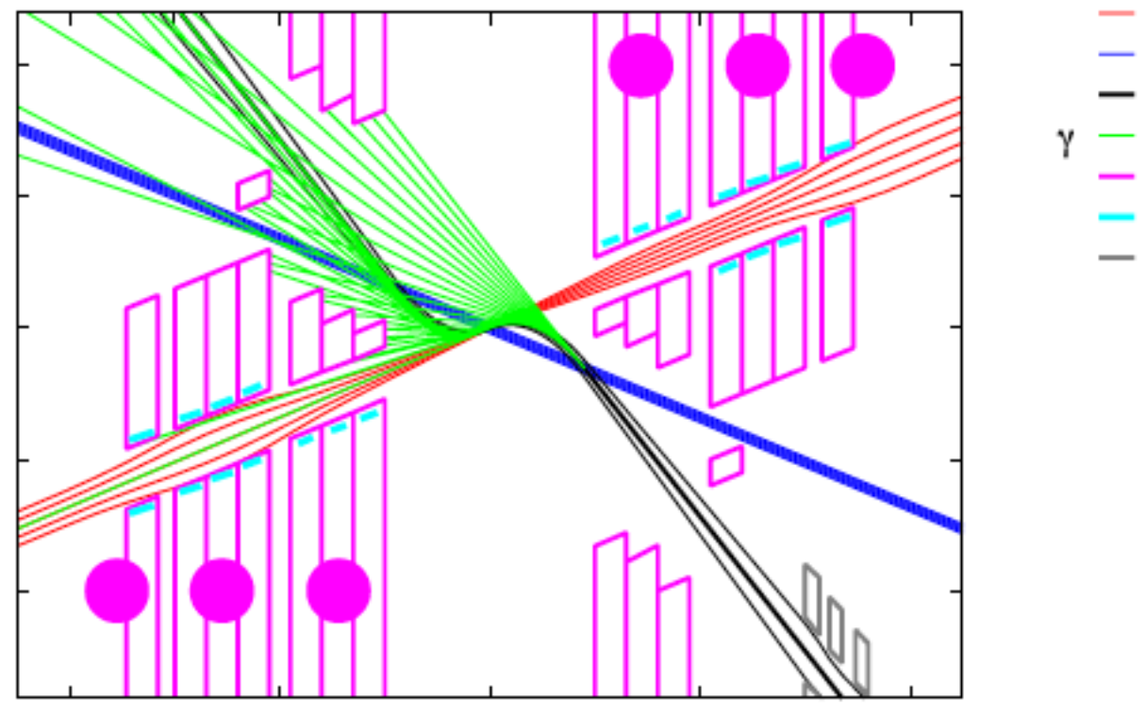
eD: $L_{eN}=AL_{eA}>\sim 3\times 10^{31}$

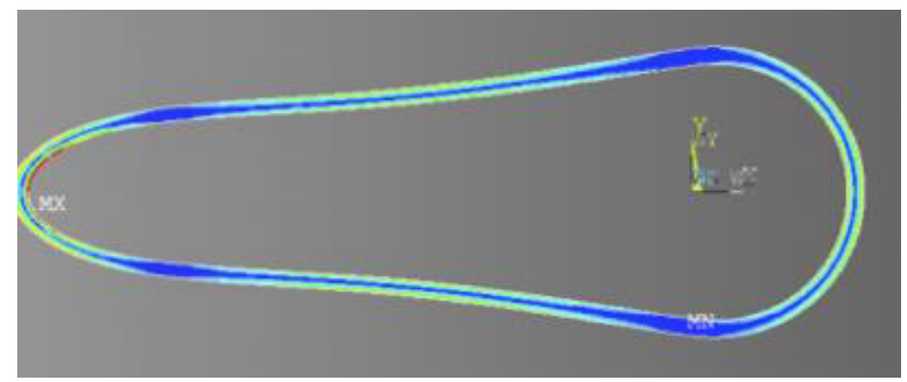
Some details:

Return arcs (A. Milanese)



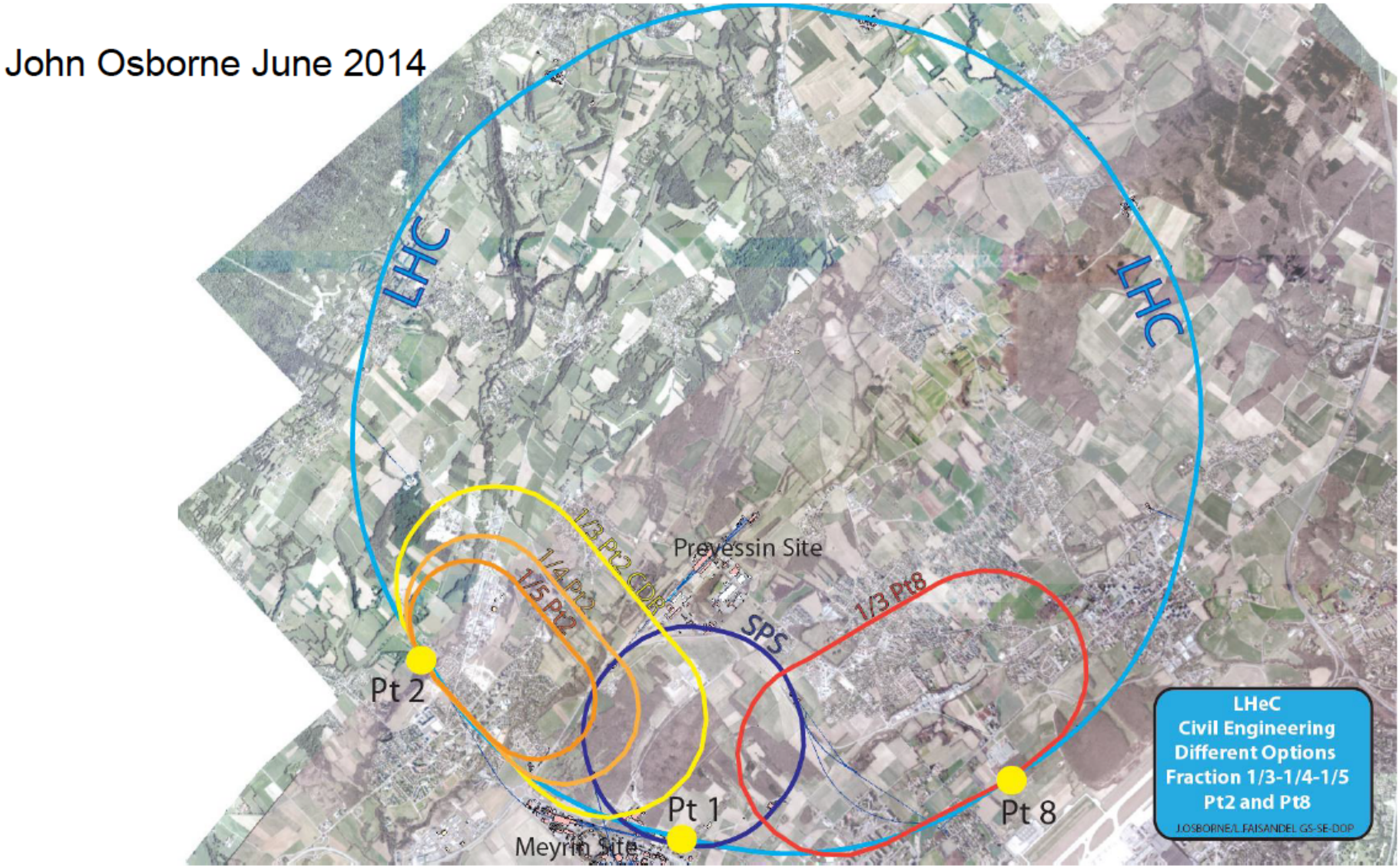
IR: crucial point for updated CDR





- SC RF: HL-LHC bunch spacing requires bunch spacing with multiples of 25 ns (40.079 MHz).
- Choice of 802 MHz for optimisation and synergies with FCC, CERN-JLab cooperation: two cavities to be built in 2016.

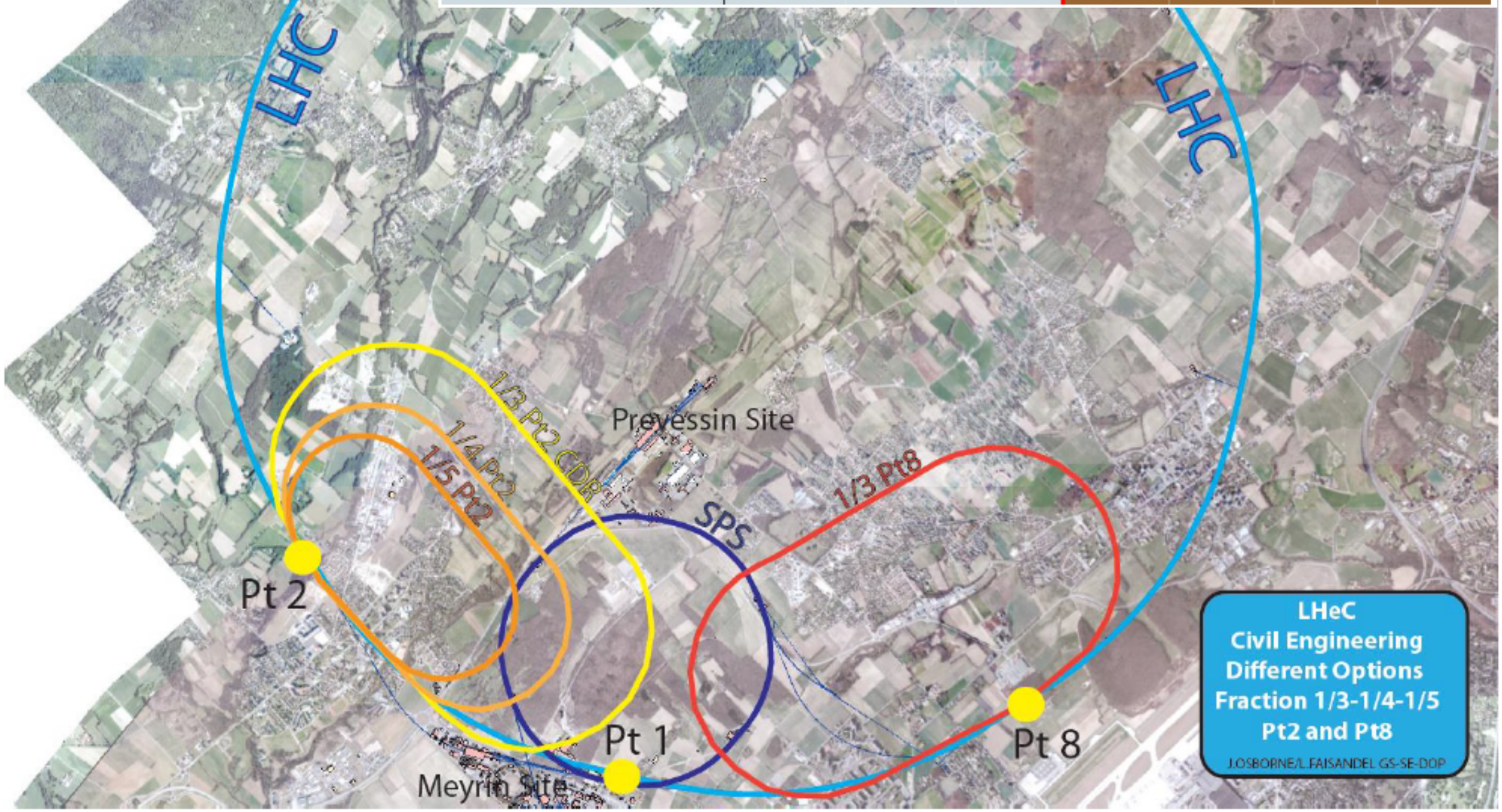
Footprint:


John Osborne June 2014
LHC
LHC
1/3 Pt2 CDR
1/4 Pt2
1/5 Pt2
Prevessin Site
SPS
1/3 Pt8
Pt 2
Pt 1
Pt 8
Meyrin Site
LHeC
Civil Engineering
Different Options
Fraction 1/3-1/4-1/5
Pt2 and Pt8
J.OSBORNE/L.FAISANDEL GS-SE-DOP

Footprint:

John Osborne June 2014

LHeC construction planning	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7
Land negotiations							
Environmental Impact Study							
Building permits							
Detailed design & tendering							
Construction							



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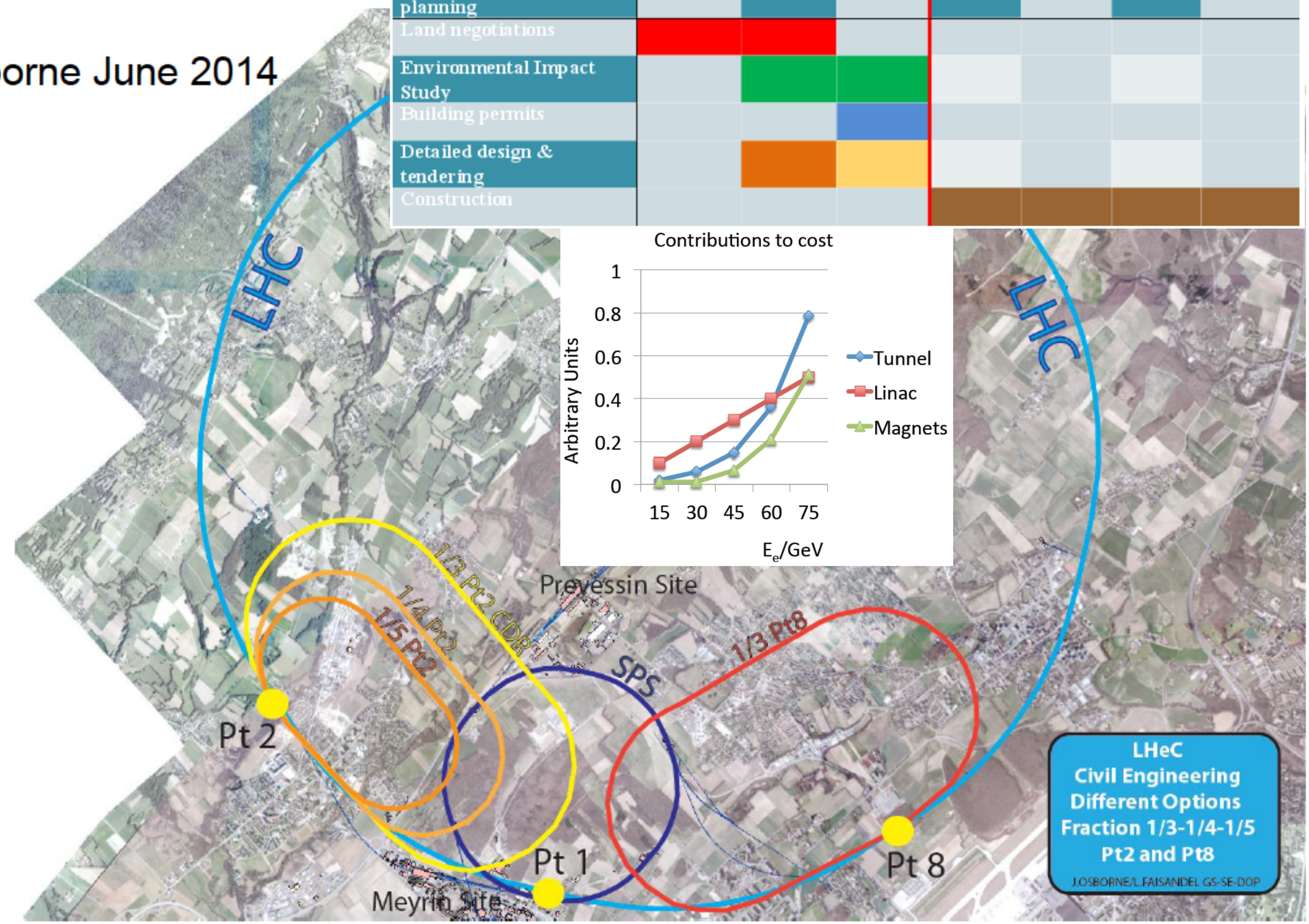


FCC:

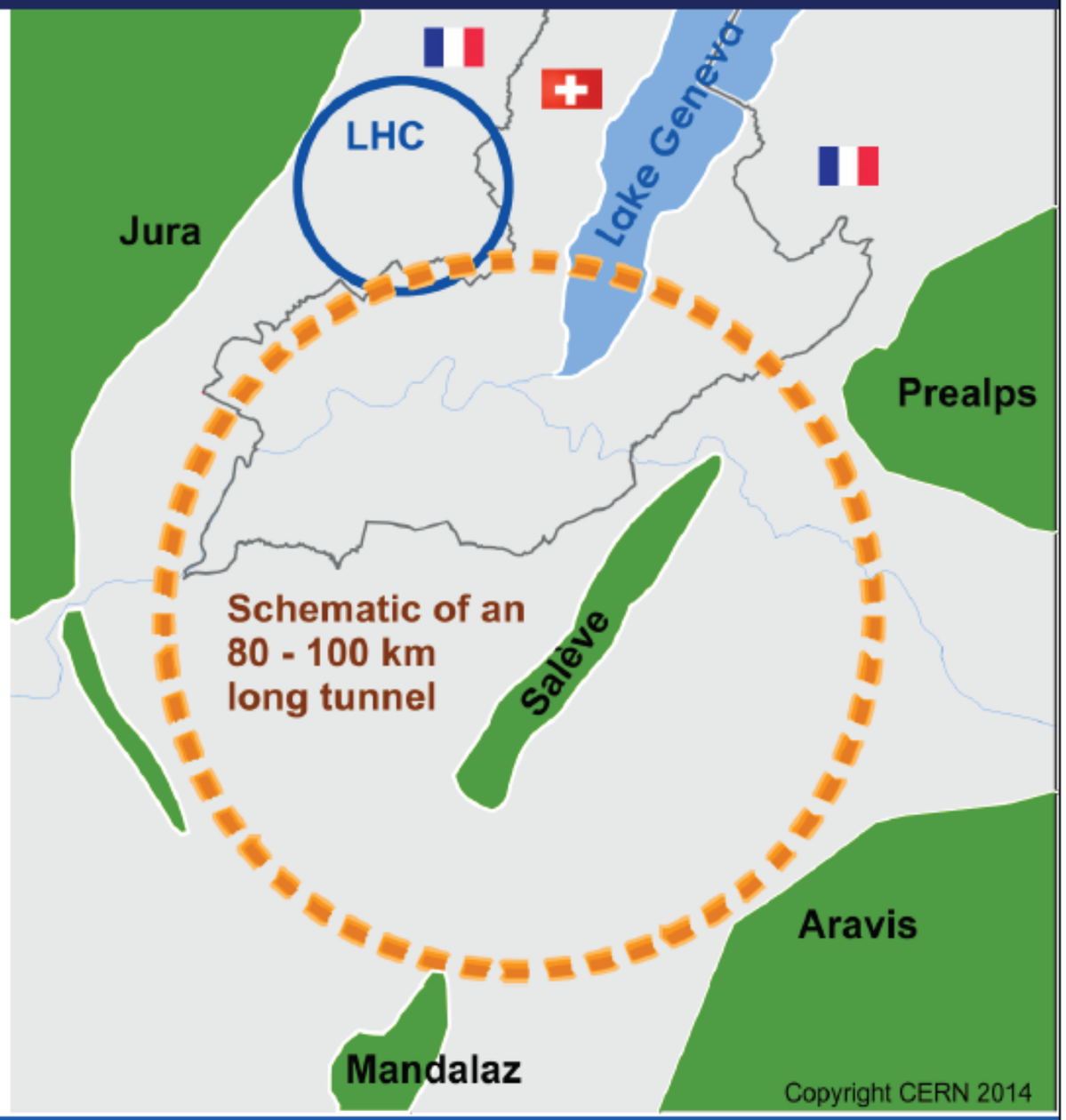
Future Circular Collider Study - SCOPE
CDR and cost review for the next ESU (2018)

Forming an international collaboration to study:

- ***pp*-collider (*FCC-hh*)**
  → defining infrastructure requirements

  ~16 T ⇒ 100 TeV *pp* in 100 km
  ~20 T ⇒ 100 TeV *pp* in 80 km

- **e^+e^- collider (*FCC-ee*)** as potential intermediate step
  120-350 GeV
- ***p-e* (*FCC-he*) option**
- **80-100 km infrastructure** in Geneva area



Future Circular Collider Study
Michael Benedikt
FCC Kick-Off 2014

5

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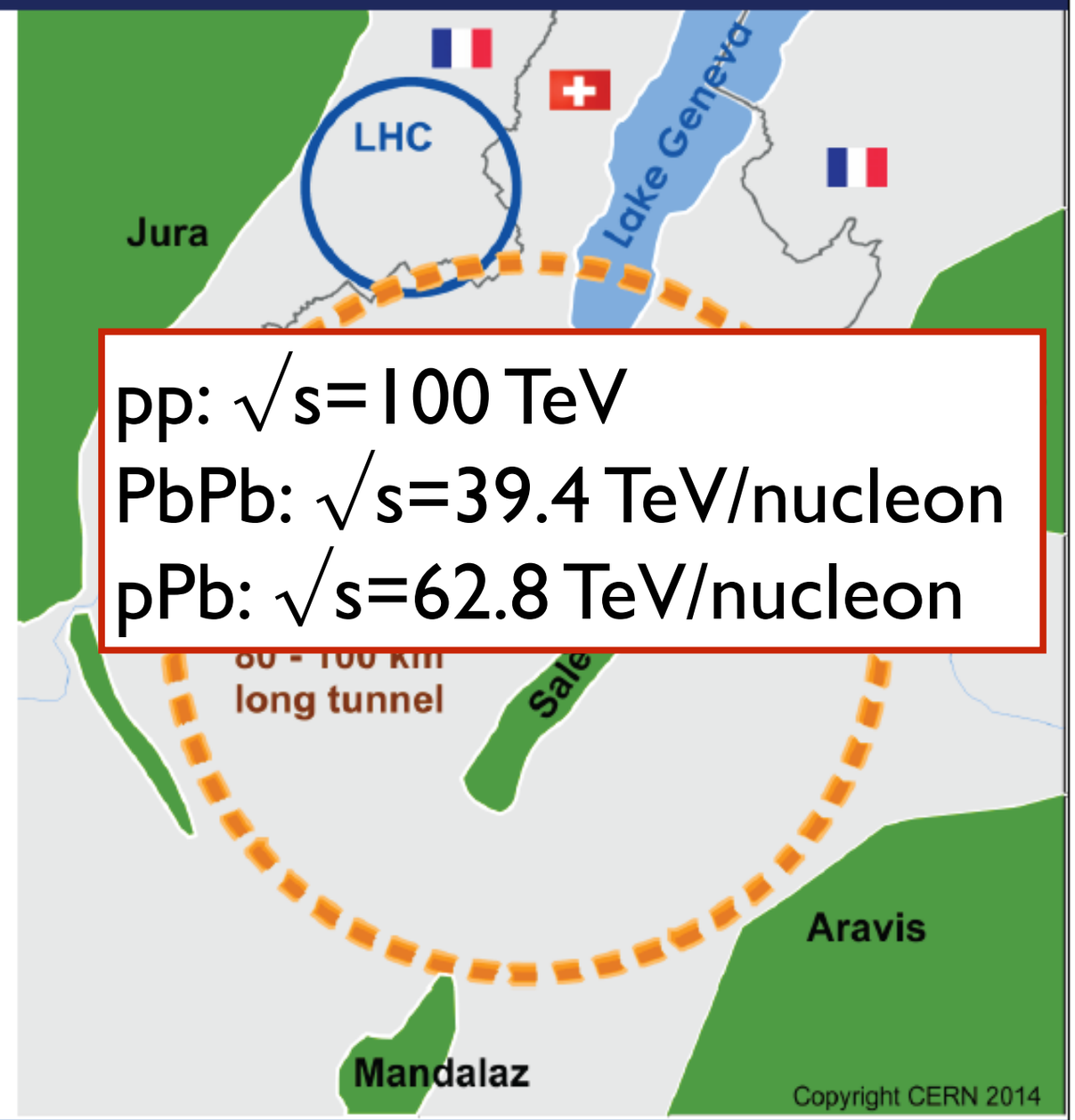

pp: $\sqrt{s}$=100 TeV
PbPb: $\sqrt{s}$=39.4 TeV/nucleon
pPb: $\sqrt{s}$=62.8 TeV/nucleon

Future Circular Collider Study
Michael Benedikt
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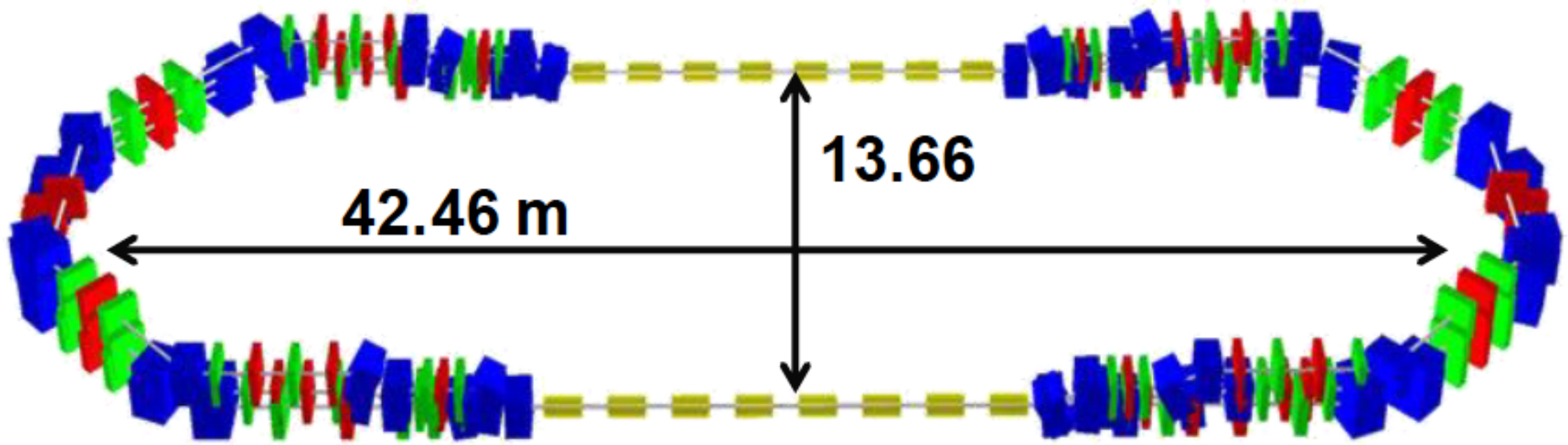
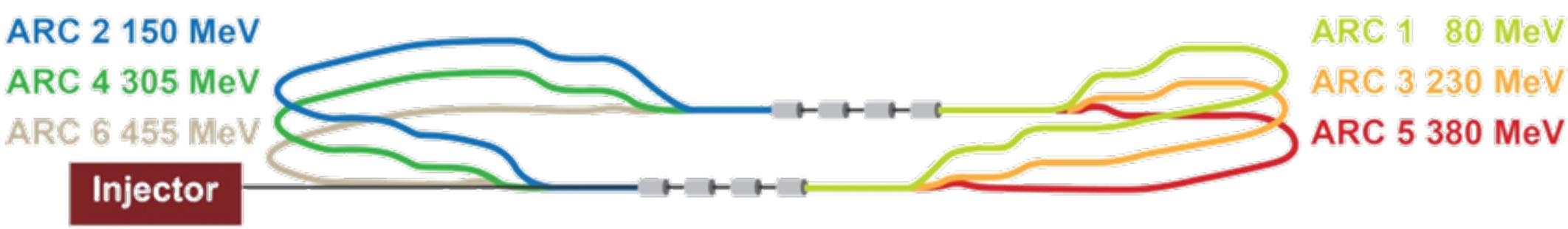
5

ERL facility for SCRF:



- PERLE: ambitious design (2×150 MeV linacs, 3 passes → 900 MeV), significant physics potential of its own (10^{40} cm^{-2} s^{-1} fixed target): EW physics, proton radius, photonuclear physics, dark photons … + accelerator development, magnet test, LHeC prototype/injector.
- Conceptual Design Report by spring 2016, under consideration a low energy but high current demonstrator with 3 passes.



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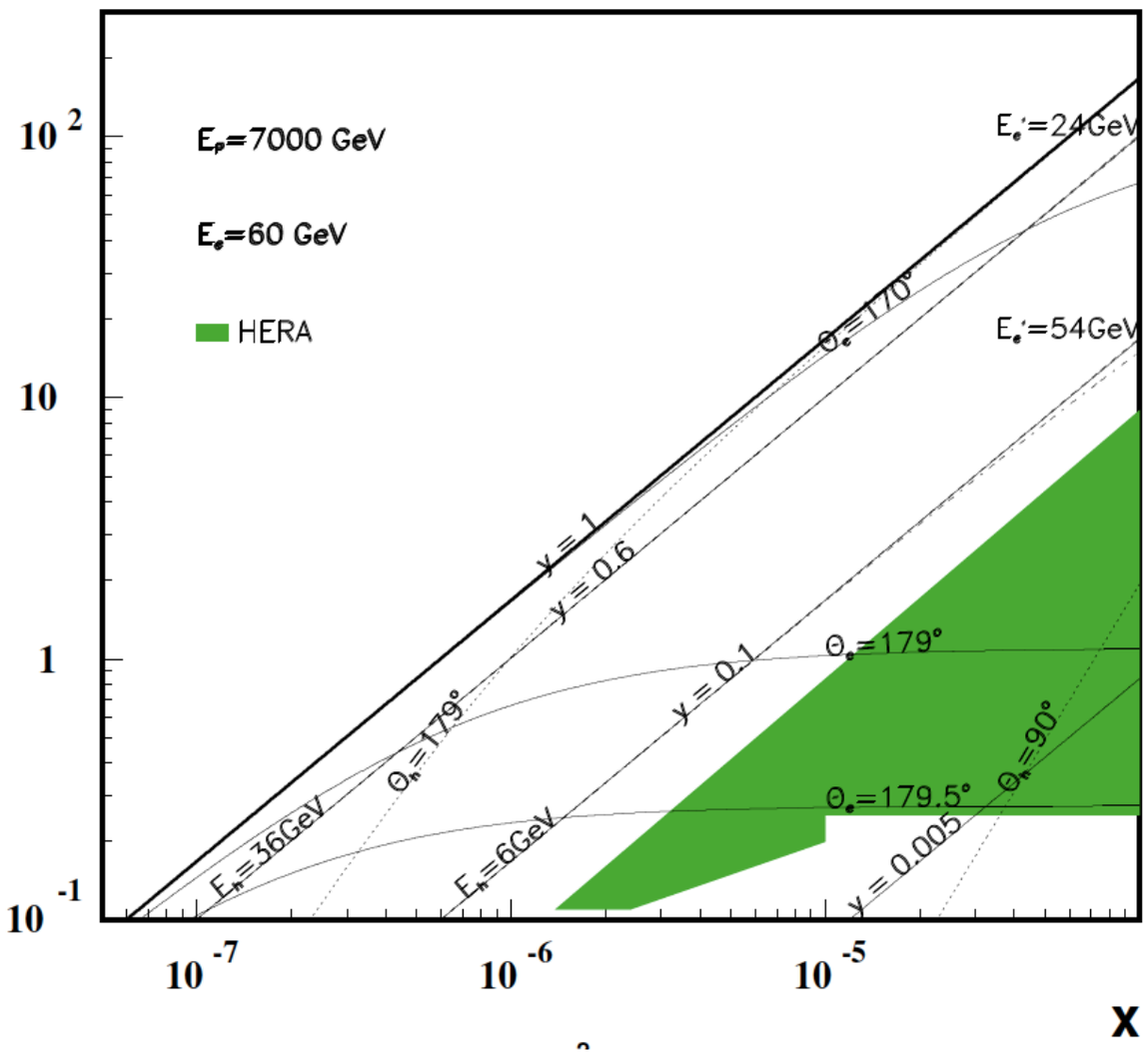

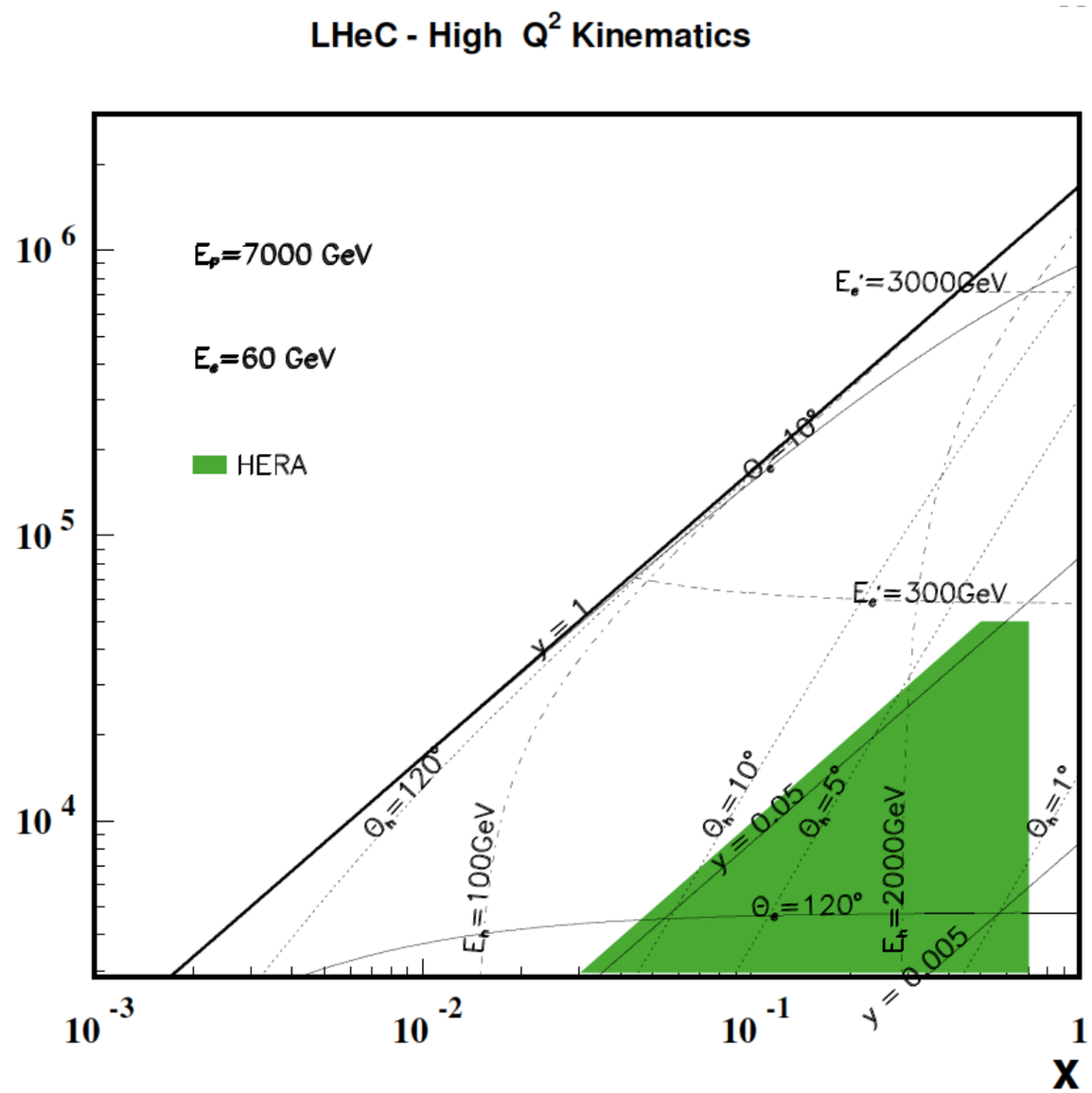

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- Higher luminosity would benefit high-x and Q^2 studies: linked to small x via DGLAP evolution (see HERA final analysis).

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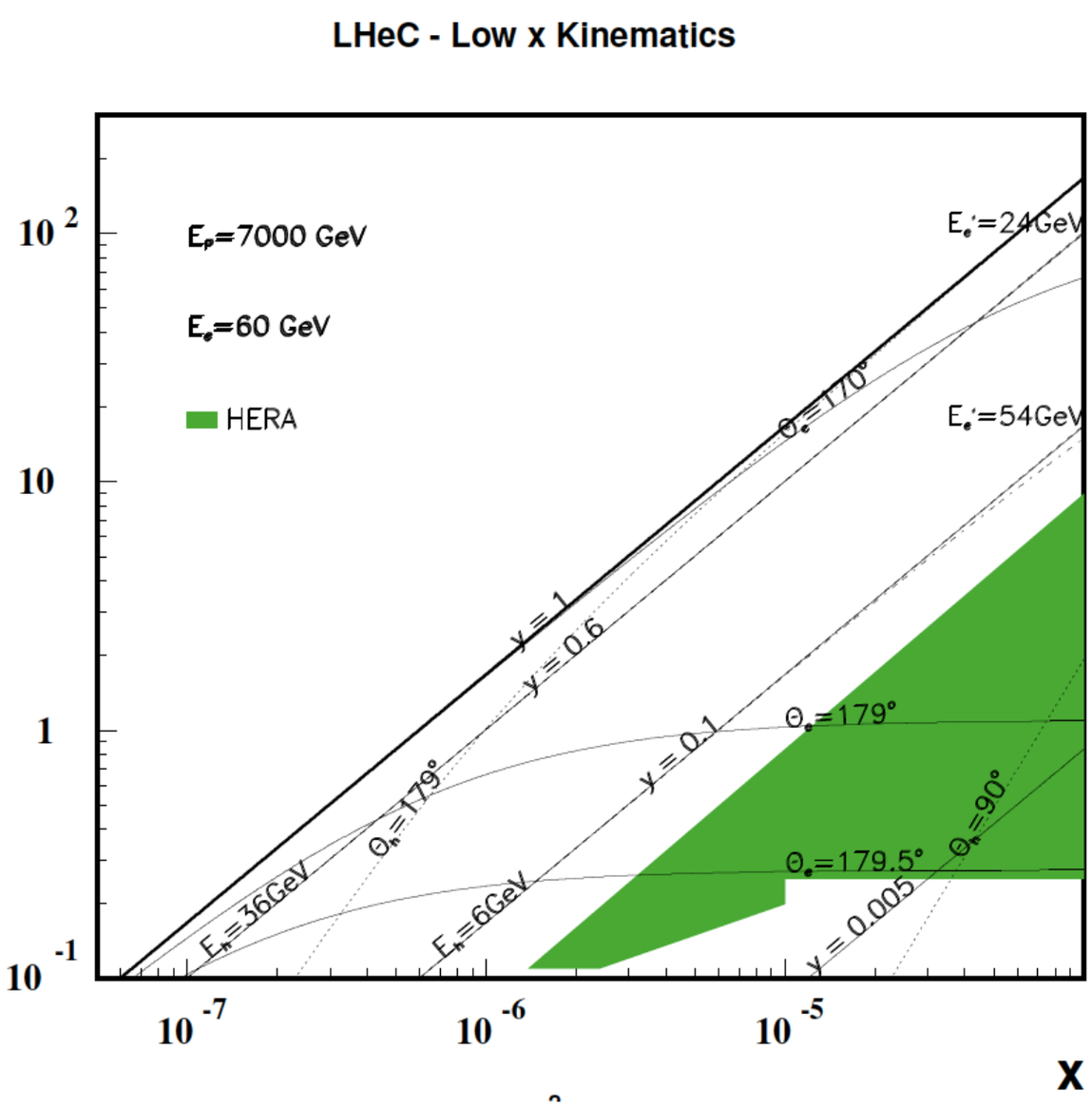

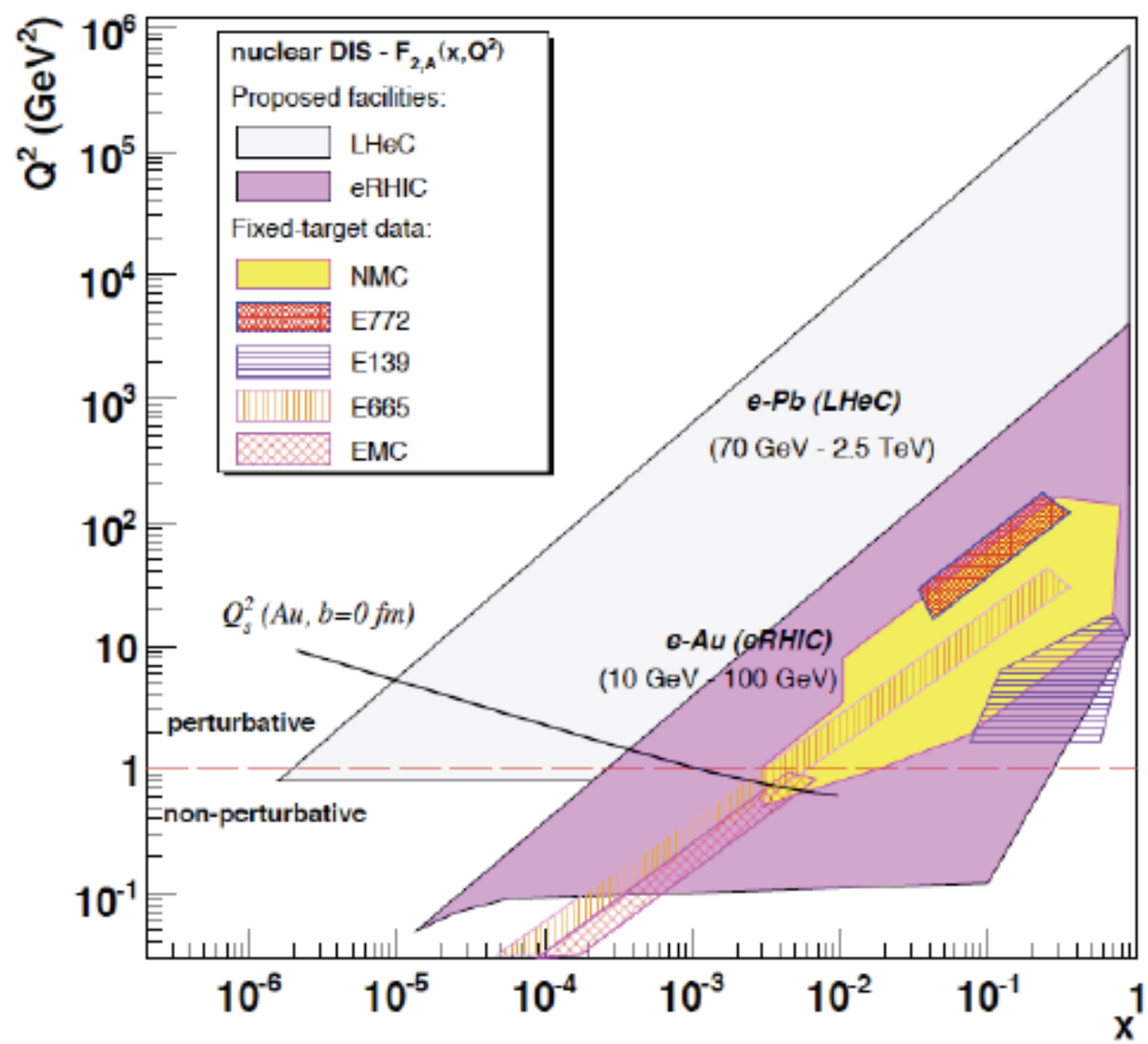

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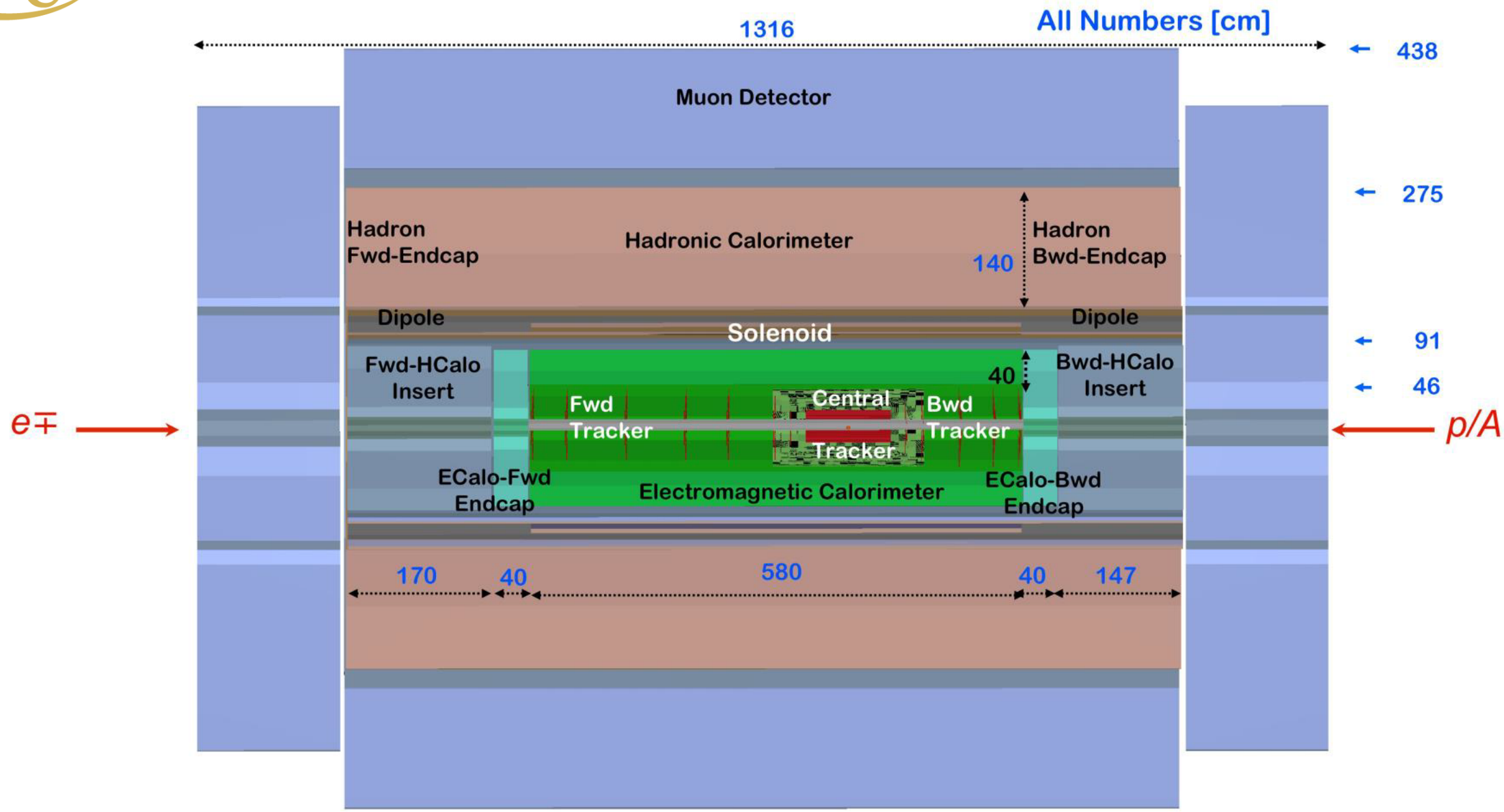
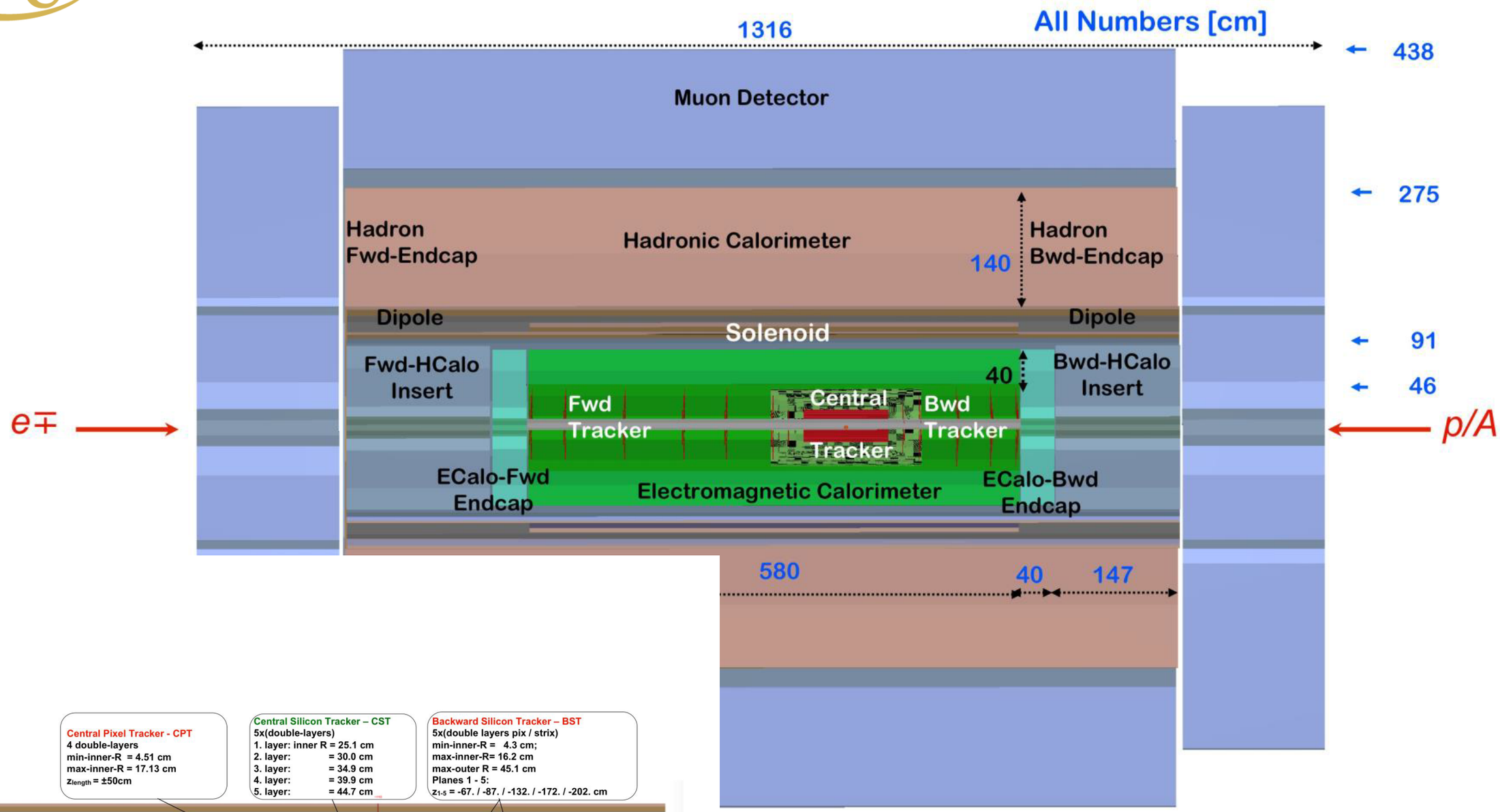
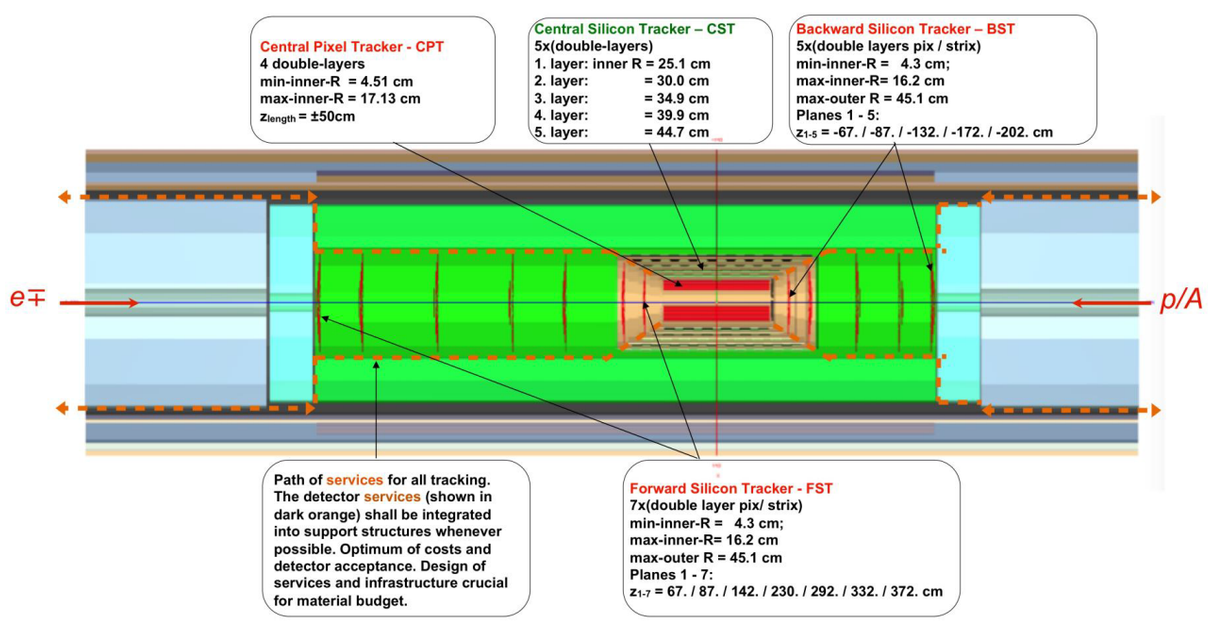
LHeC detector:



- Taggers at -62m (e), 100m (γ, LR), +100m (n), +420m (p).
- Present size < 14m x 9m (CMS 21m x 15m, ATLAS 45m x 25m).
- Developed in DD4HEP.

LHeC detector:

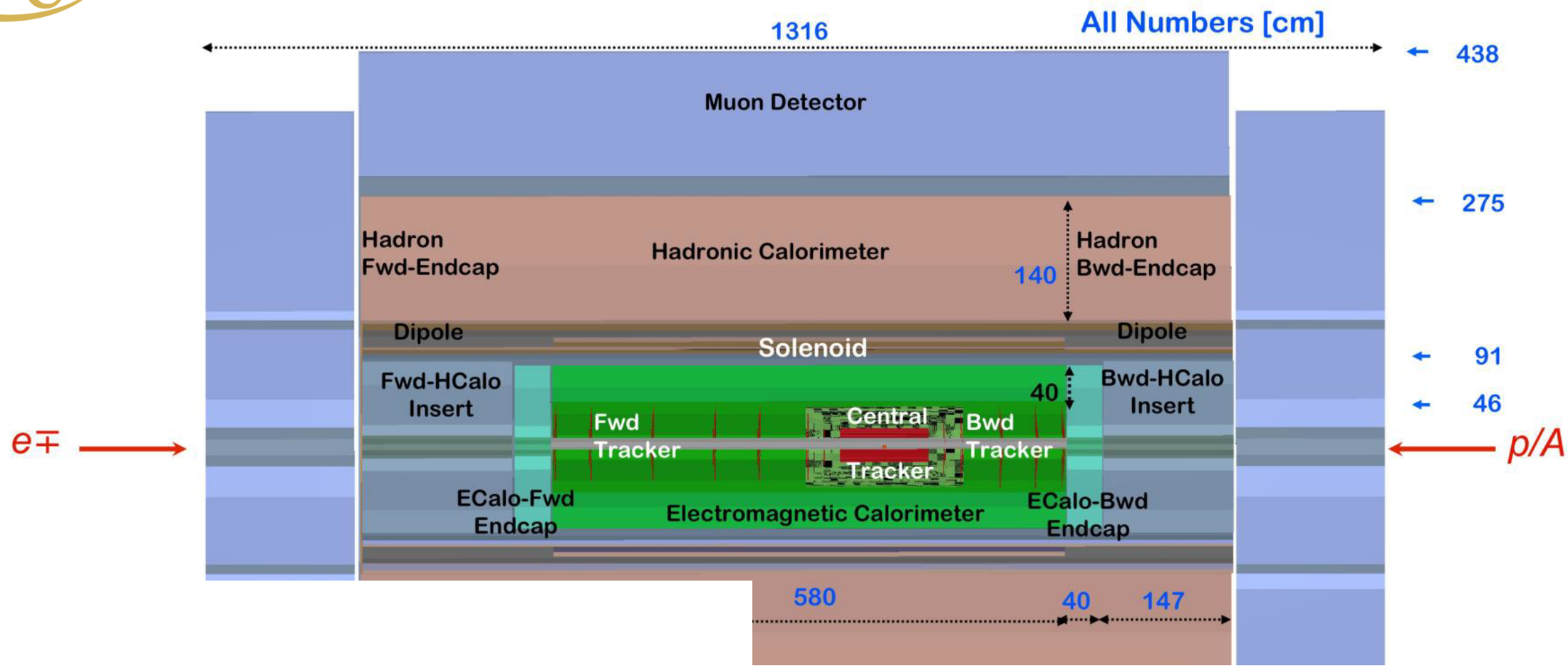


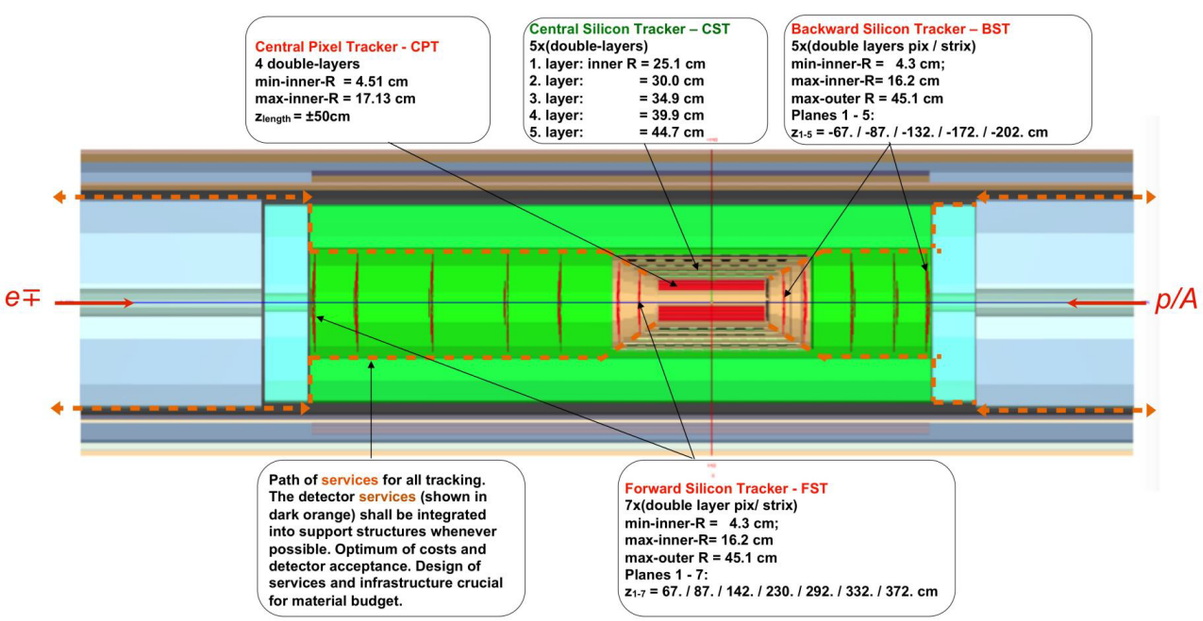


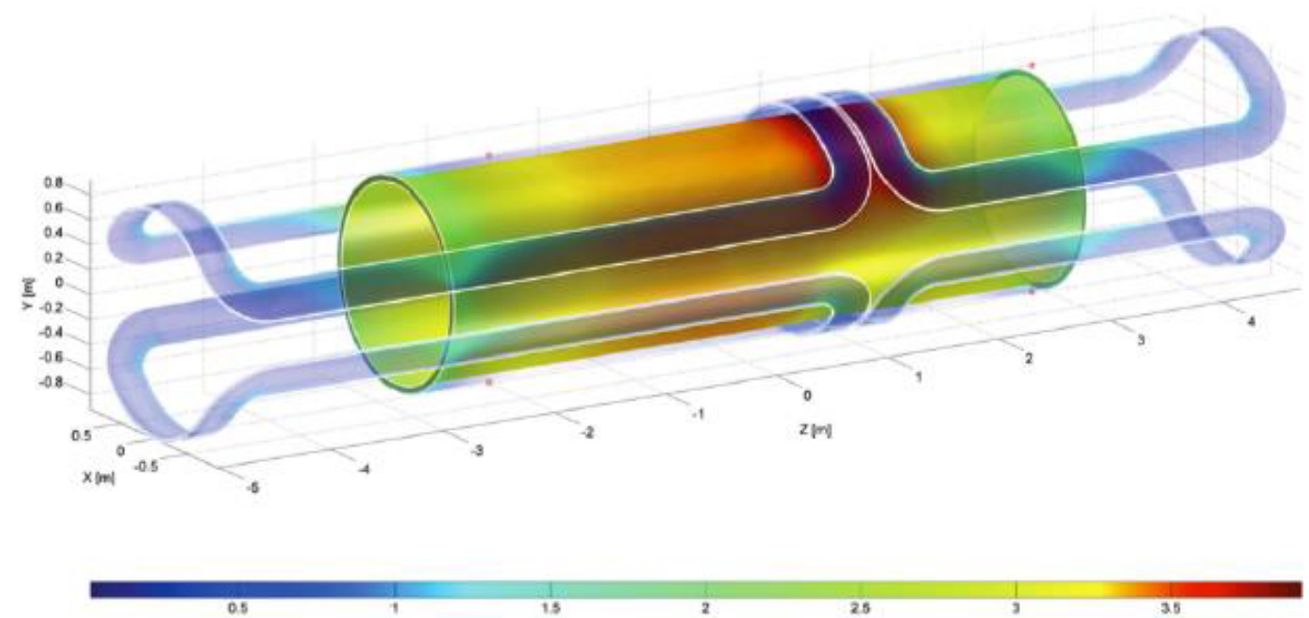
R), +100m (n), +420m (p).

S 21m x 15m, ATLAS 45m x 25m).

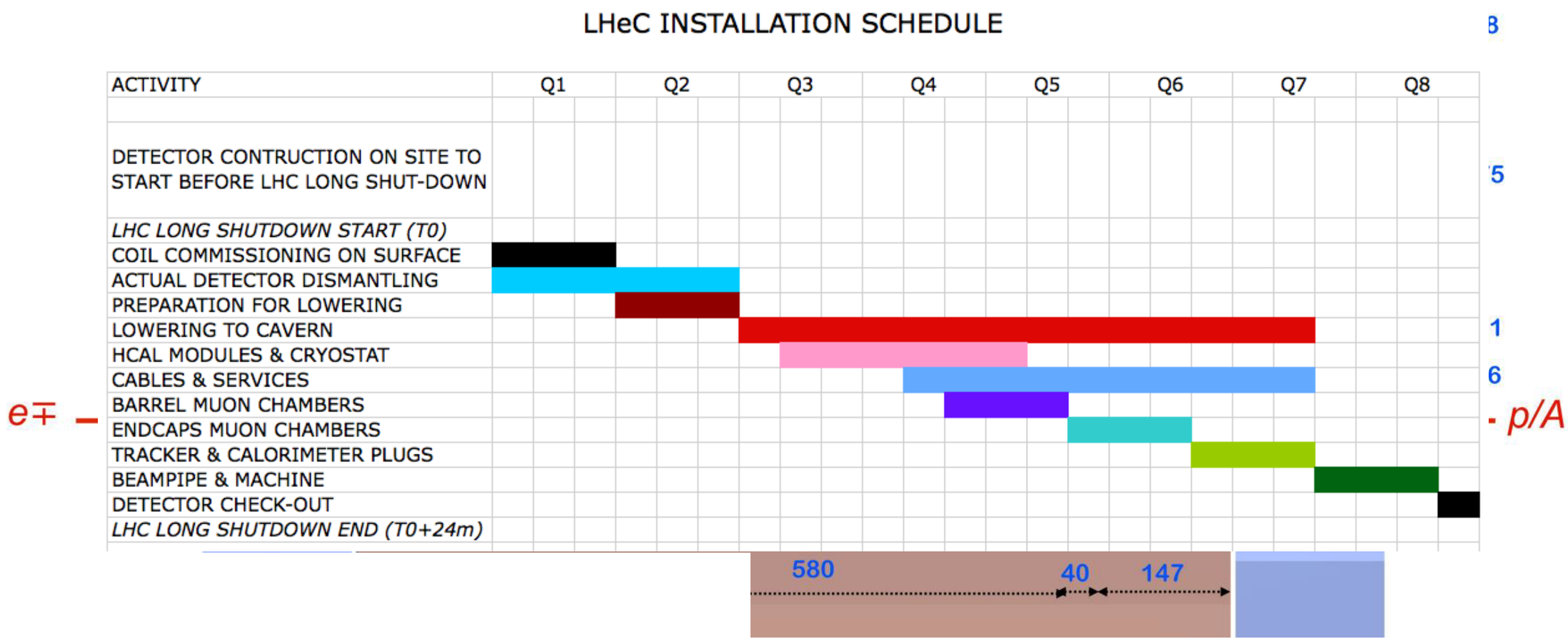
LHeC detector:

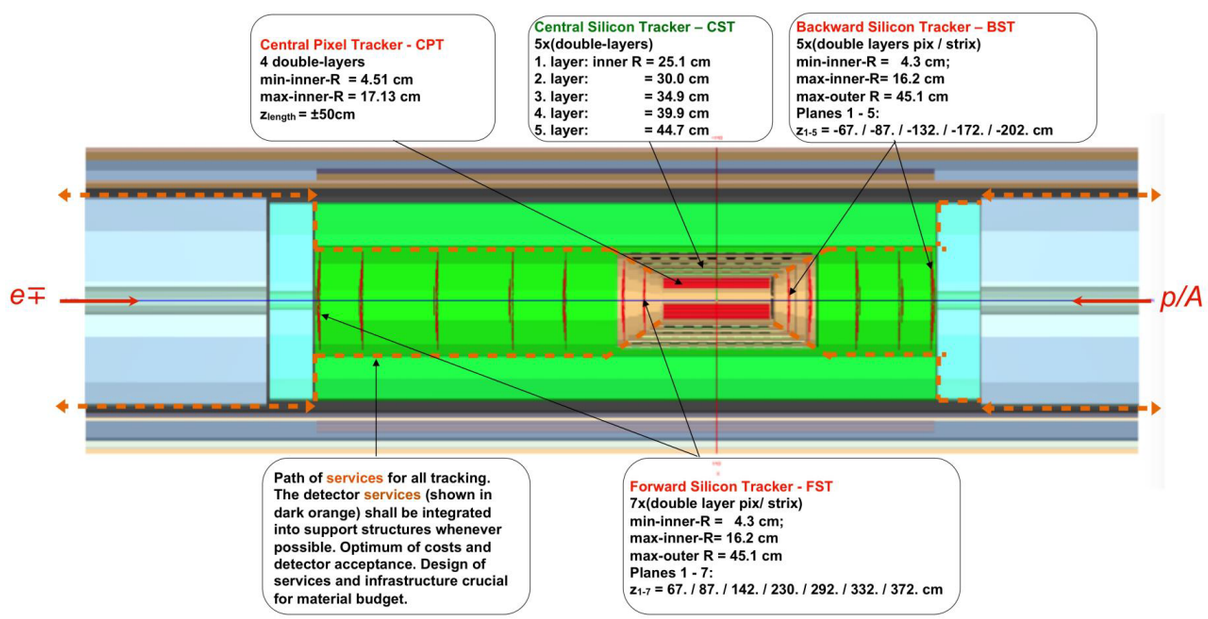


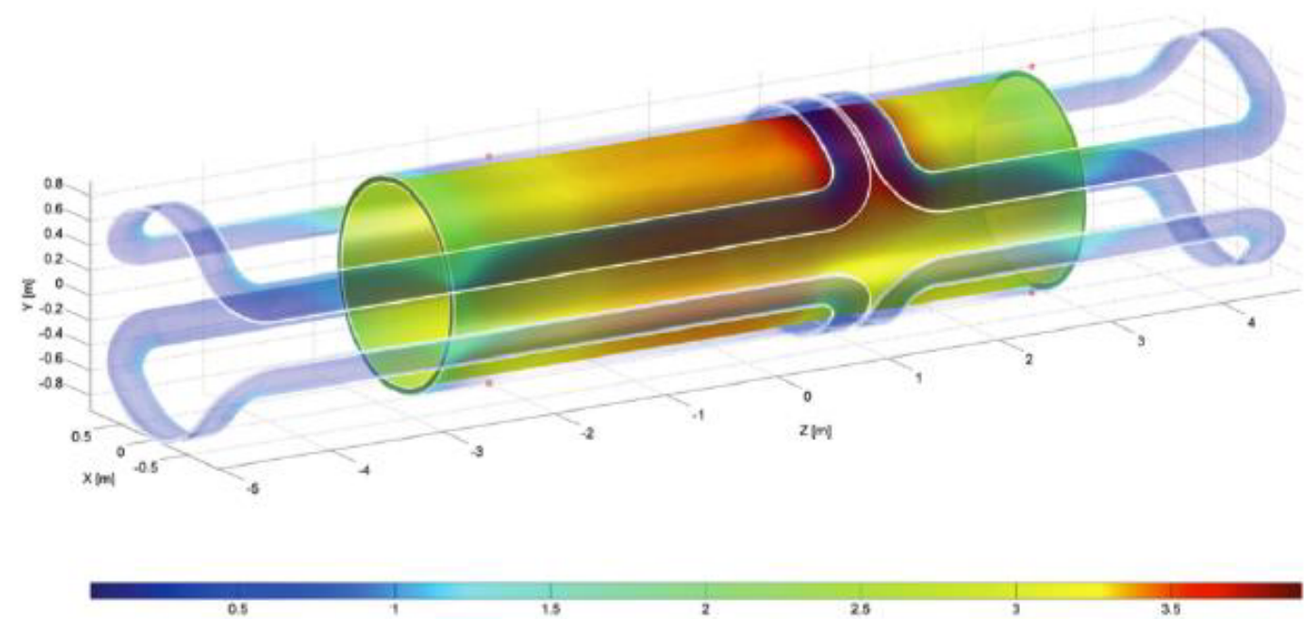




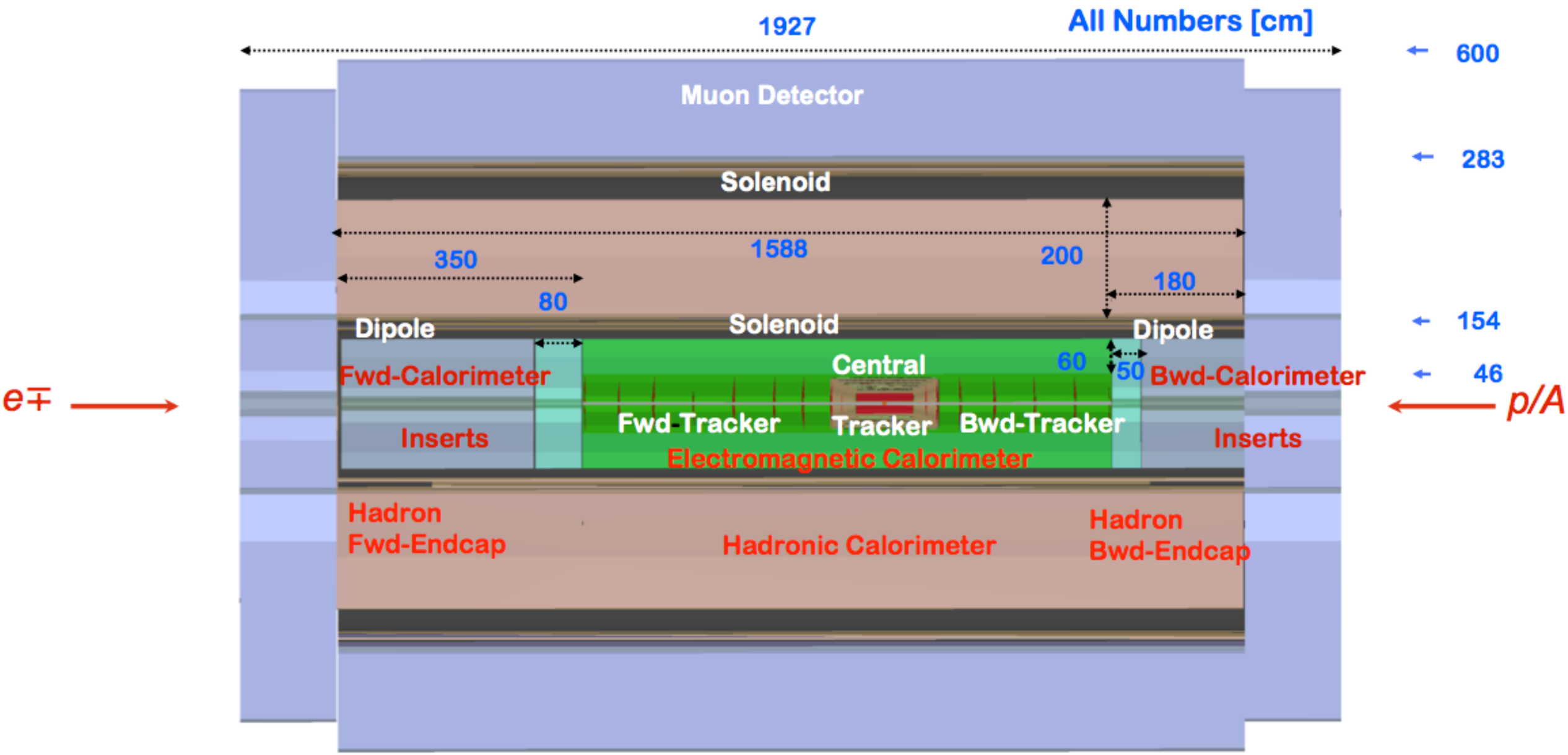
LHeC detector:





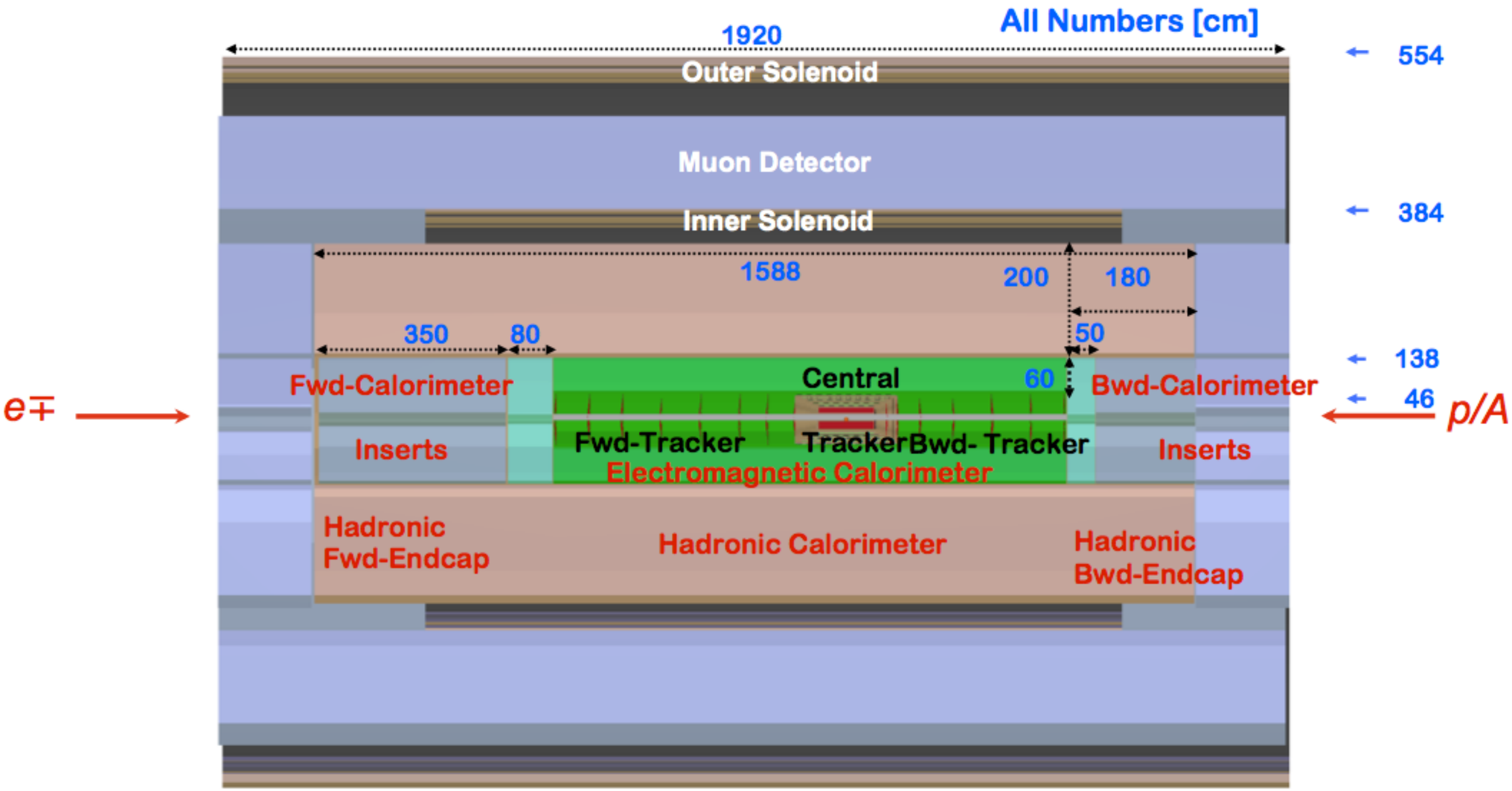


FCC-he detector:



- Size scales ~2 in forward, ~1.3 in backward.
- Preliminary version, size and cost of huge magnets (H→μμ) are the limiting factors.

FCC-he detector:



- Size scales ~2 in forward, ~1.3 in backward.
- Preliminary version, size and cost of huge magnets (H→μμ) are the limiting factors.

Contents:

1. Introduction.

2. Accelerator.

3. Detector.

4. Physics case (some highlights):
   - ➜ Precision QCD.
   - ➜ Top and EW.
   - ➜ Higgs.
   - ➜ BSM.
   - ➜ Small x and eA.

5. Organisation and plans.

CDR:1206.2913; 1211.4831; 1211.5102; Brüning & Klein, 1305.2090;
Klein & Schöpper, CERN Courier, June 2014;
Newman & Stasto, Nature Physics 9 (2013) 448;
2015 LHeC Workshop http://indico.cern.ch/event/356714/.

Summary:

A. Stasto

Beyond Standard Model

Leptoquarks
Contact Interactions
Excited Fermions
Higgs in MSSM
Heavy Leptons
4th generation quarks
Z'
SUSY
???
...

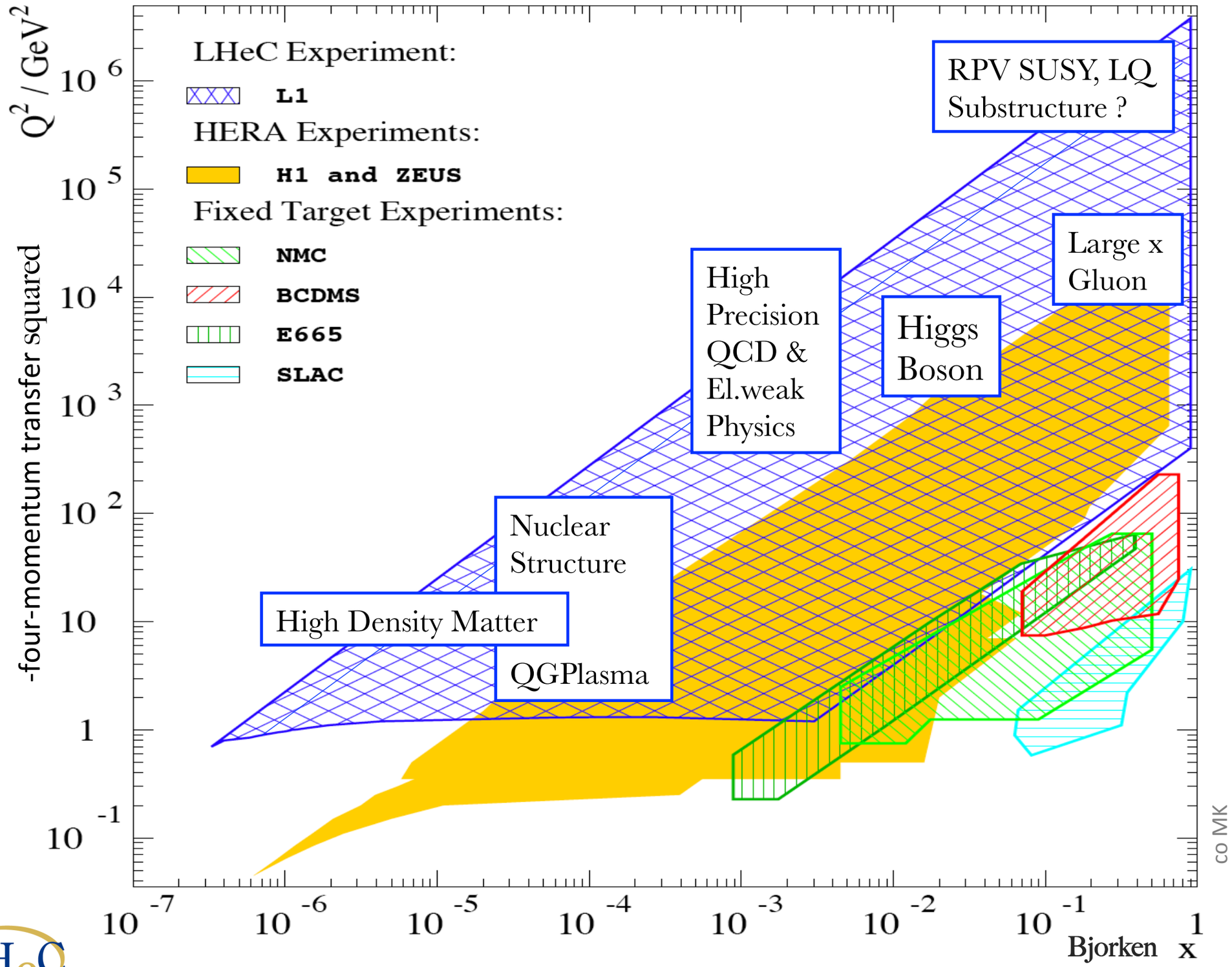
QCD and EW precision physics

Structure functions
Quark distributions from direct measurements
Strong coupling constant to high accuracy
Higgs in SM
Gluon distribution in extended x range to unprecedented accuracy
Single top and anti-top production
Electroweak couplings
Heavy quark fragmentation functions
Heavy flavor production with high accuracy
Jets and QCD in photoproduction
Partonic structure of the photon

Small x and high parton densities

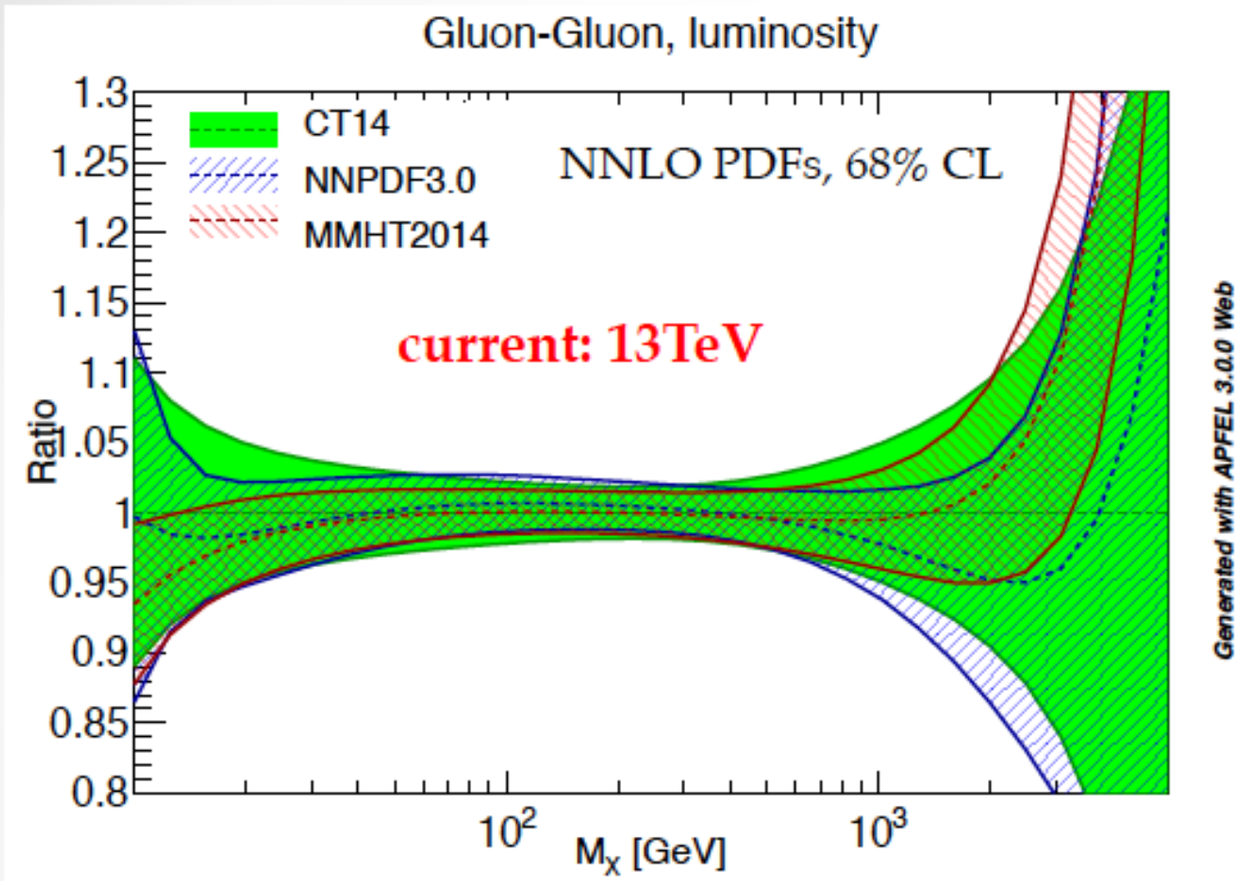
New regime at low x
Saturation
Diffraction
Vector Mesons
Deeply Virtual Compoton Scattering
Forward jets and parton dynamics
DIS on nuclei
Generalized/unintegrated parton distribution functions

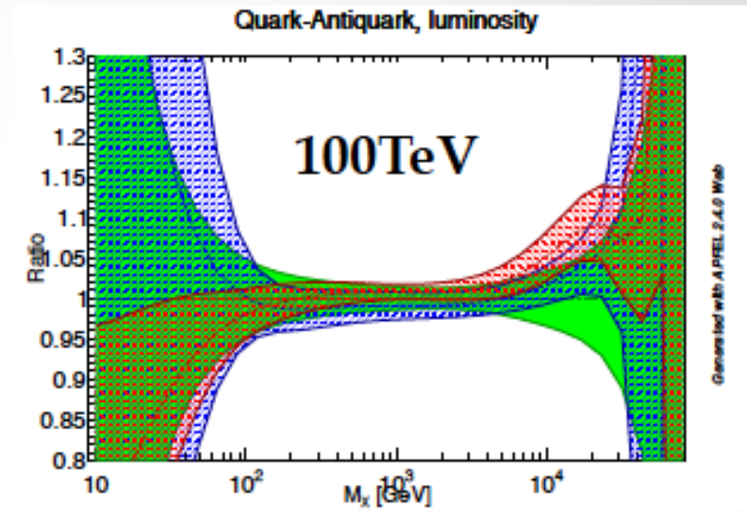
Summary:

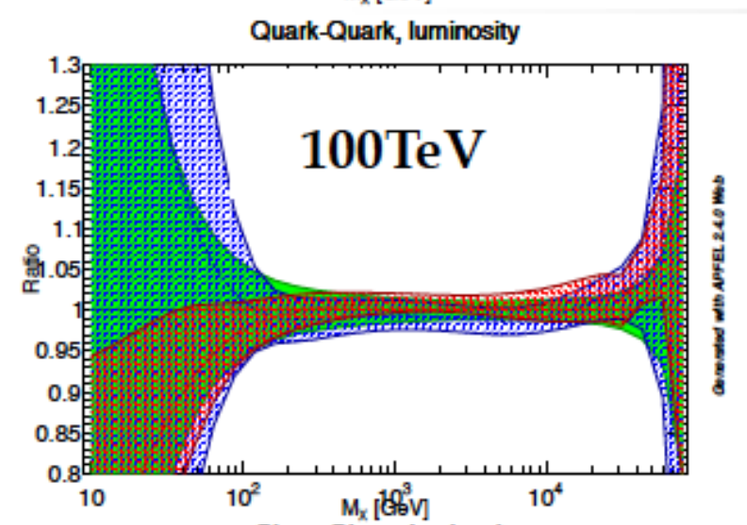

LHeC Experiment:
L1
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
RPV SUSY, LQ
Substructure ?
Large x
Gluon
High
Precision
QCD &
El.weak
Physics
Higgs
Boson
Nuclear
Structure
High Density Matter
QGPlasma
-four-momentum transfer squared
Q^2 / GeV^2
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
Bjorken x
co MK

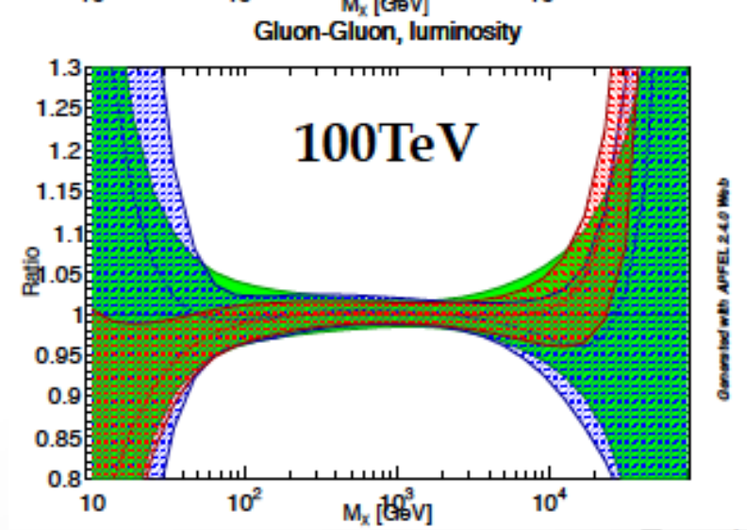
PDFs:

proton PDFs, today





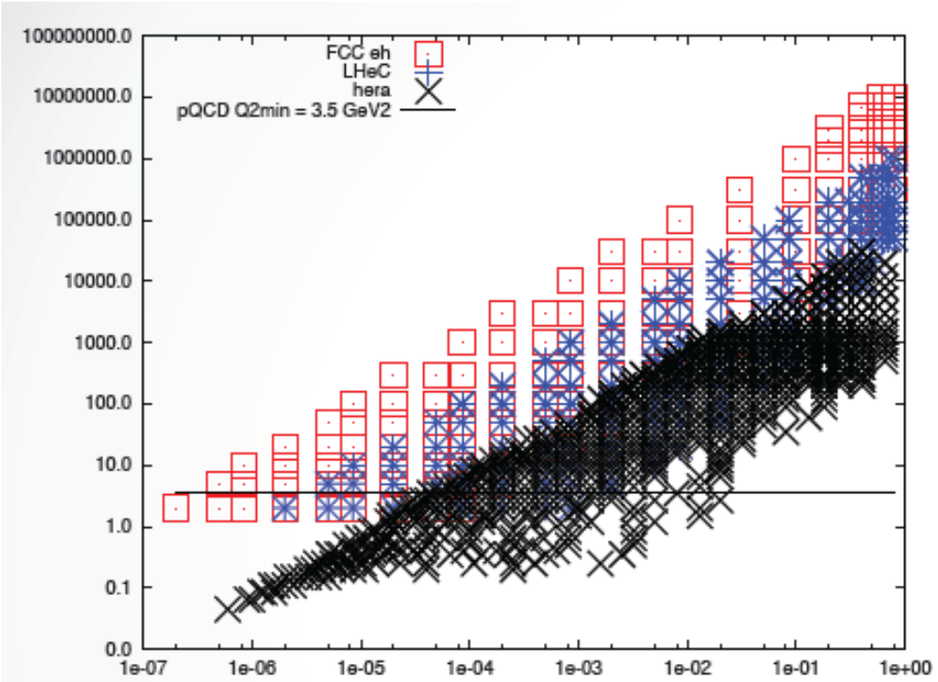




- **need to know PDFs much better than today, for:** nucleon structure; q-g dynamics; Higgs; BSM searches; future colliders, FCC-hh; and development of QCD
- LHC will provide further constraints, but cannot resolve precisely (shown are latest global PDFs, also including available LHC data)

C. Gwenlan, PDFs and QCD at the LHeC

PDFs:

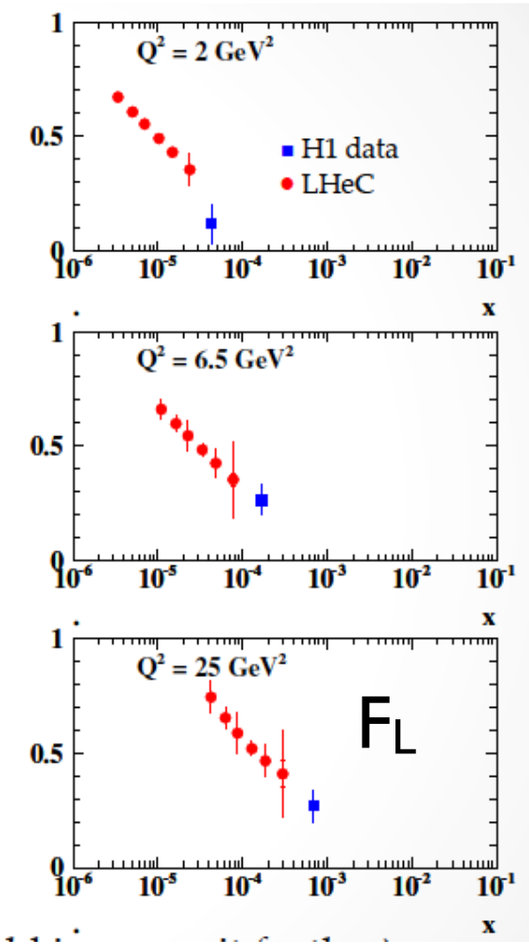


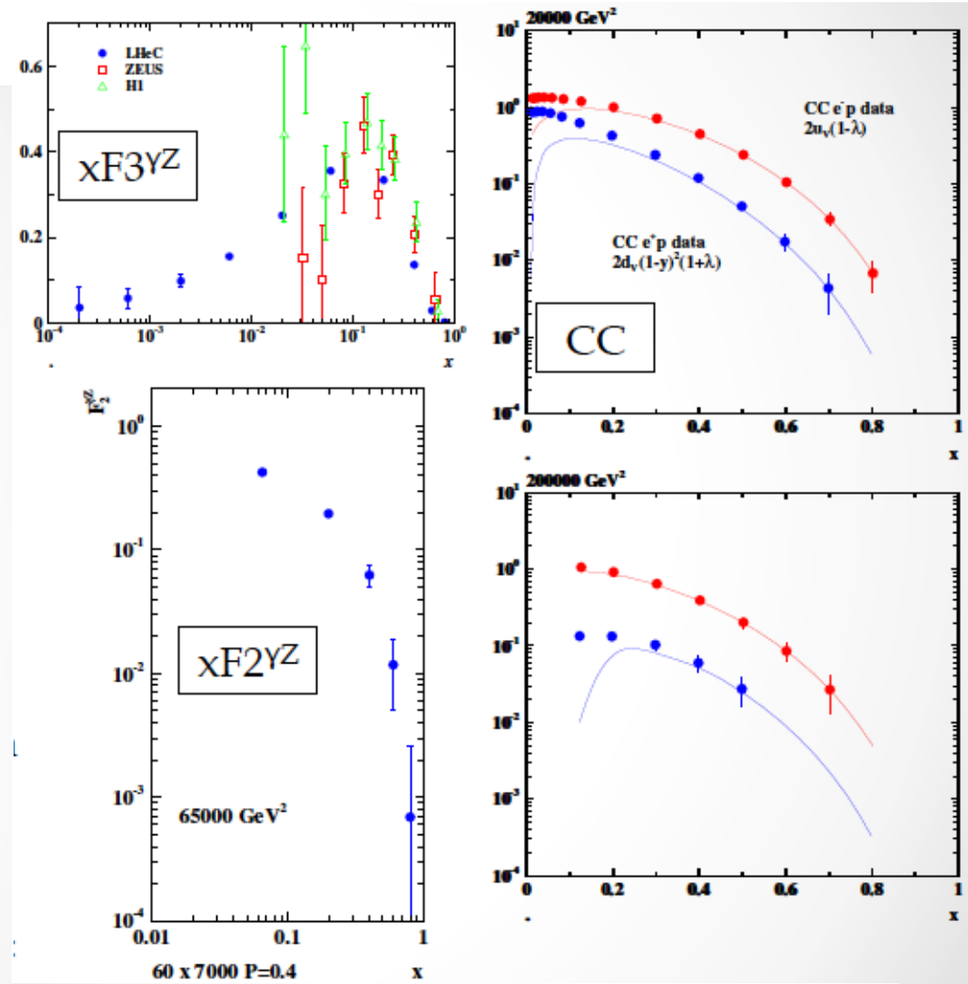
FCC-eh: Ep=50 TeV, Ee=100 GeV

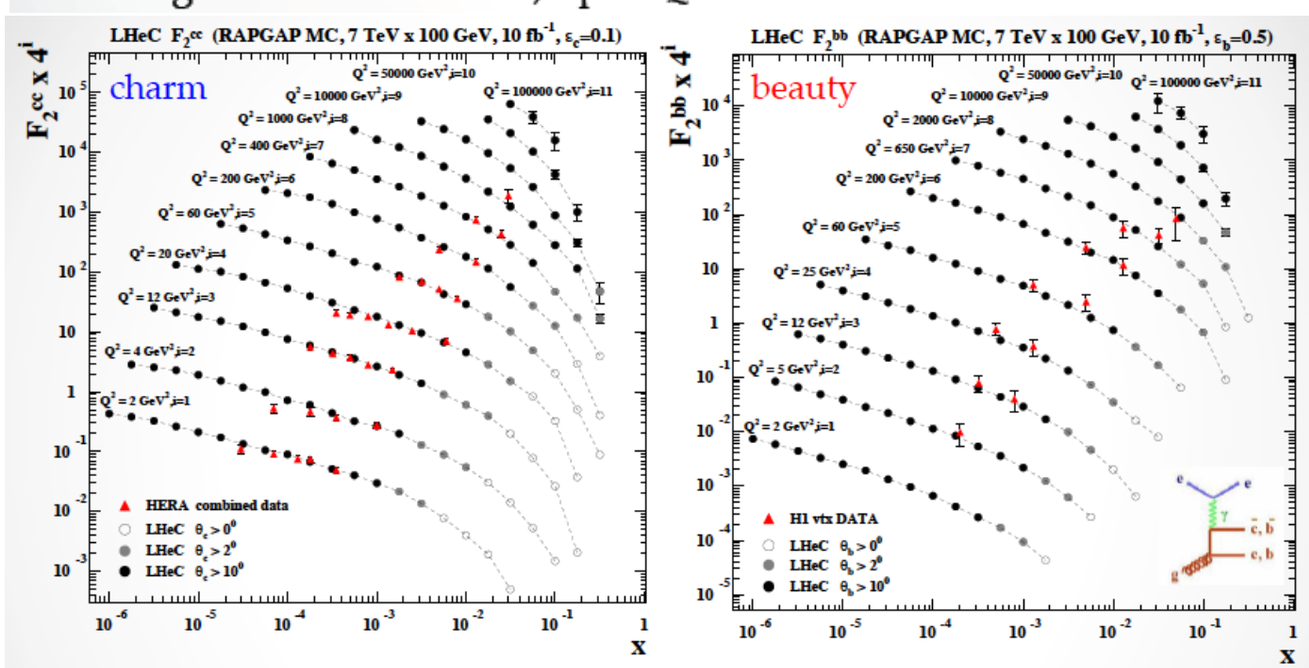
NC and CC: e-p, P=80%, 1000 fb^{-1}

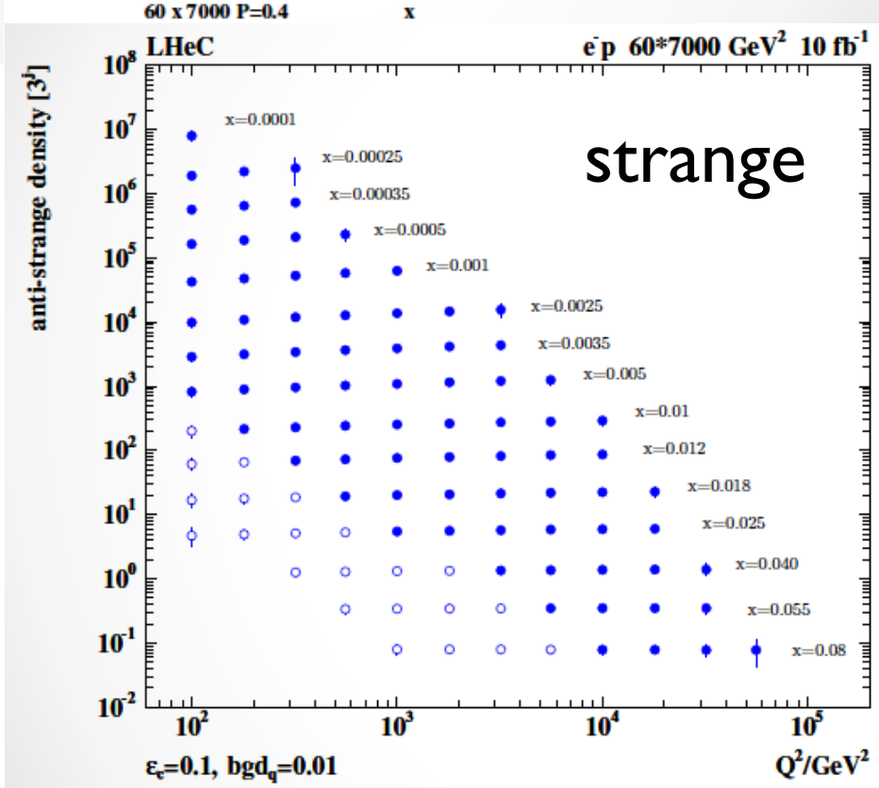
stat: 0.1 – 30%, uncor: 0.7%, syst: 1 – 5%

coverage down to x=2×10^{-7}, up to $Q^2 = 10^7$ GeV^2



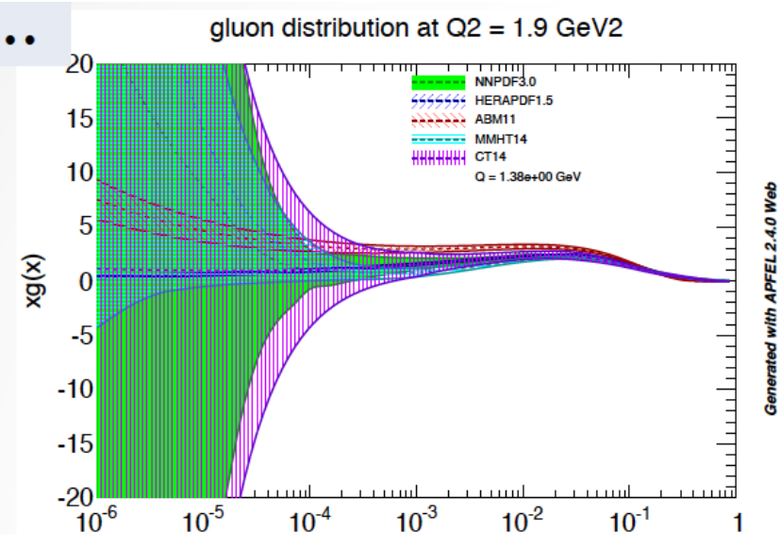




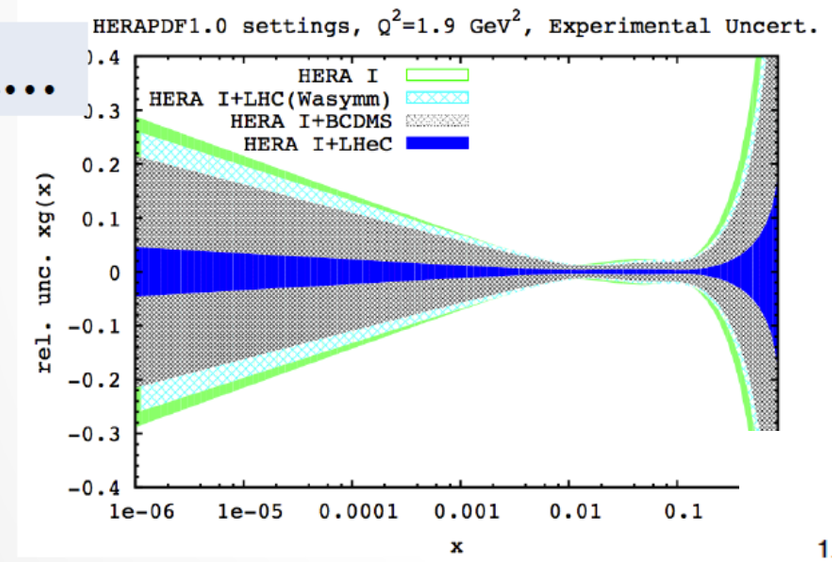


PDFs:

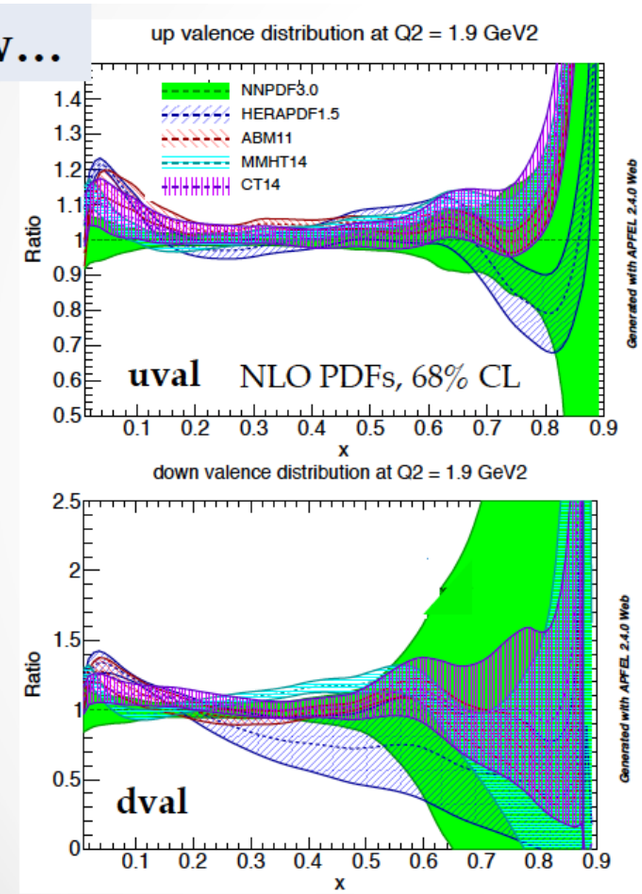
now…



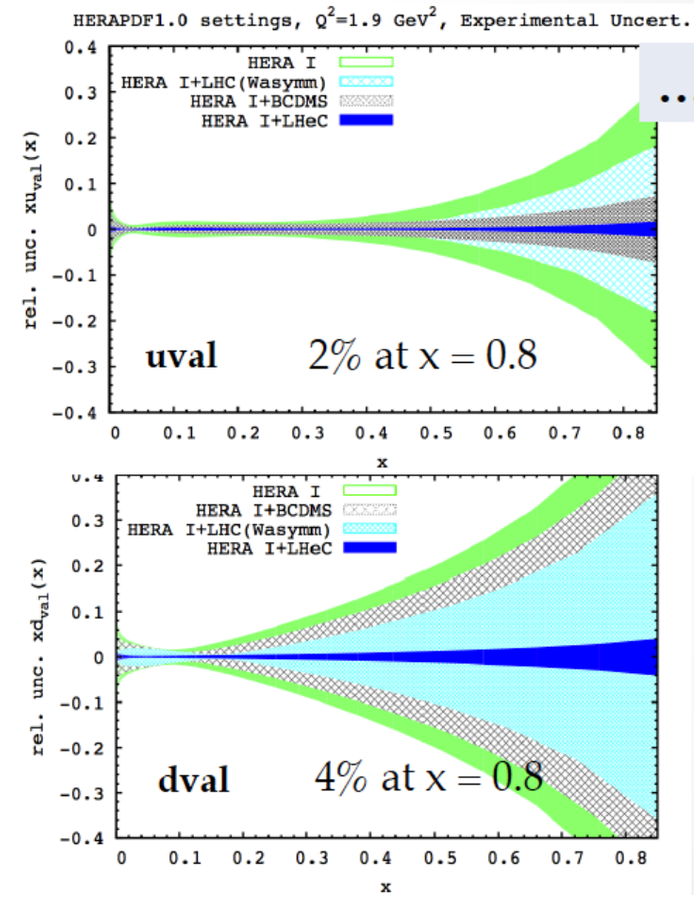
then…



now…



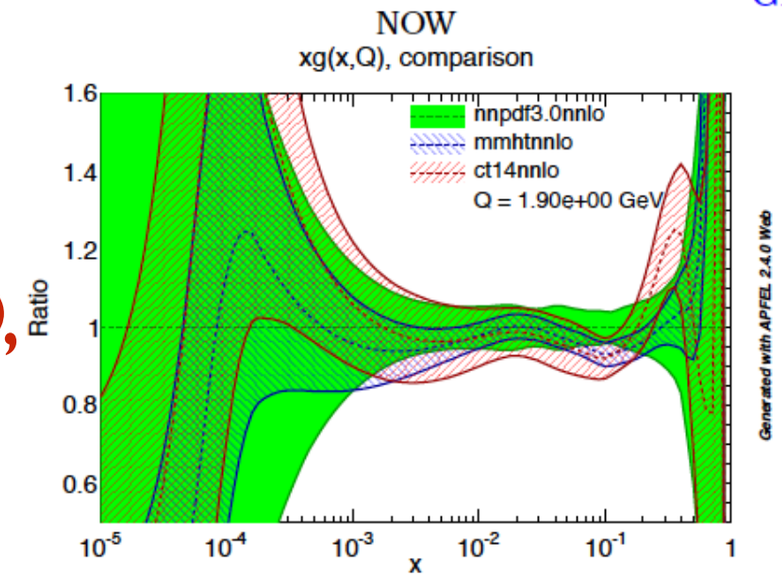
…then



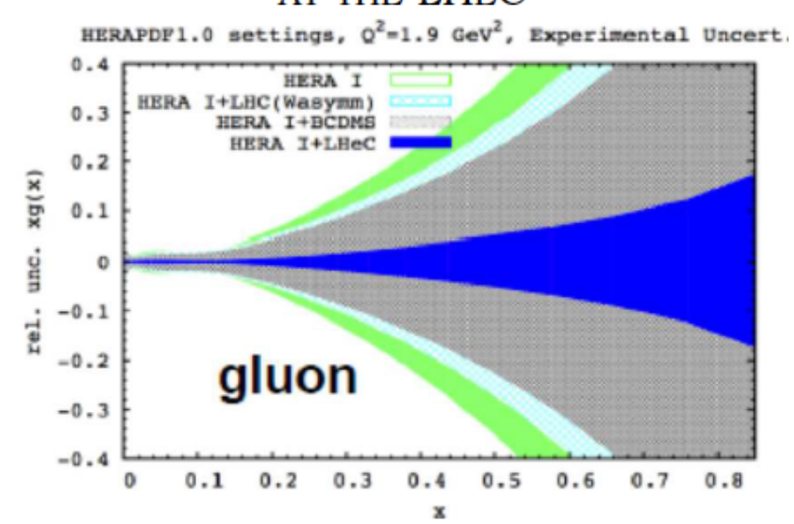
- Full flavour decomposition, also eD, possibility to release assumptions in fits.

GLUON

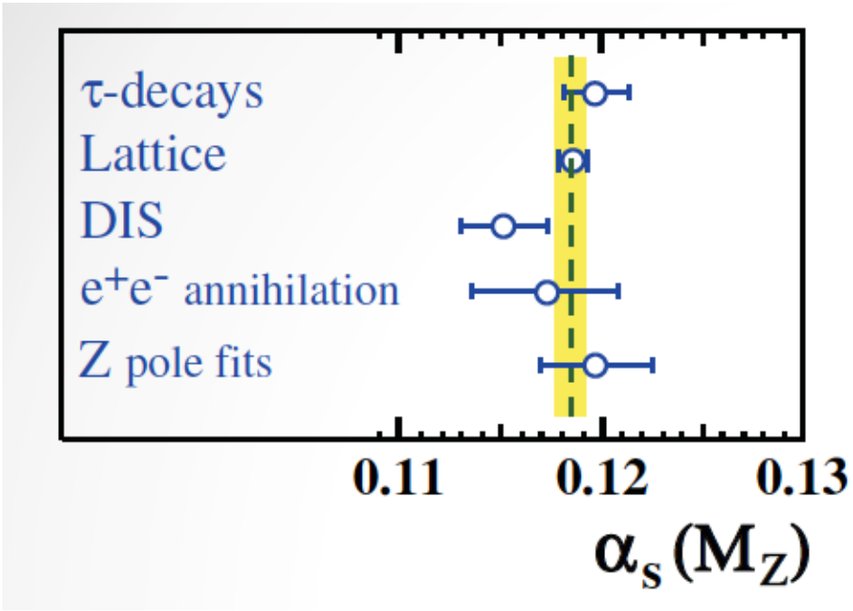
NOW



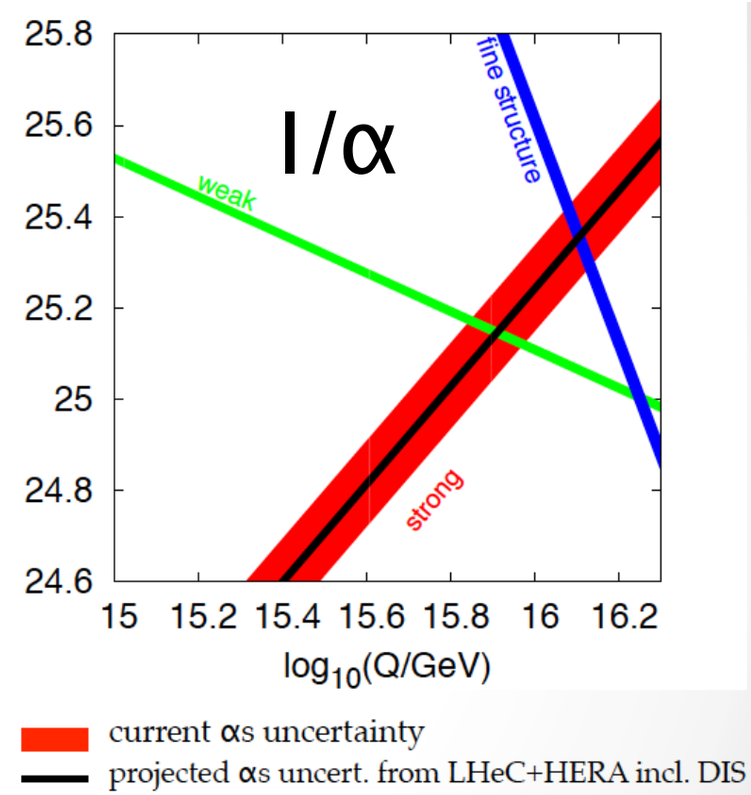
AT THE LHEC



α_s:



- Least known of all coupling constants.
- 0.1 % requires N³LO, Δm_c~5 MeV.



Snowmass13 report – arXiv:1310.5189

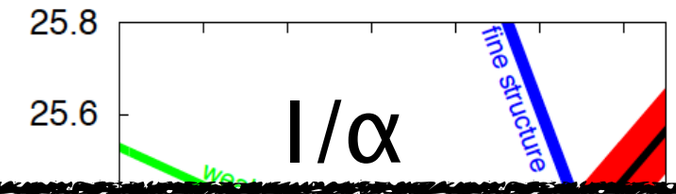
Method	Current relative precision	Future relative precision
e^+e^- evt shapes	expt ~ 1% (LEP) thry ~ 1–3% (NNLO+up to N³LL, n.p. signif.) [27]	< 1% possible (ILC/TLEP) ~ 1% (control n.p. via Q^2-dep.)
e^+e^- jet rates	expt ~ 2% (LEP) thry ~ 1% (NNLO, n.p. moderate) [28]	< 1% possible (ILC/TLEP) ~ 0.5% (NLL missing)
precision EW	expt ~ 3% (R_Z, LEP) thry ~ 0.5% (N³LO, n.p. small) [9, 29]	0.1% (TLEP [10]), 0.5% (ILC [11]) ~ 0.3% (N⁴LO feasible, ~ 10 yrs)
τ decays	expt ~ 0.5% (LEP, B-factories) thry ~ 2% (N³LO, n.p. small) [8]	< 0.2% possible (ILC/TLEP) ~ 1% (N⁴LO feasible, ~ 10 yrs)
ep colliders	~ 1–2% (pdf fit dependent) [30, 31], (mostly theory, NNLO) [32, 33]	0.1% (LHeC + HERA [23]) ~ 0.5% (at least N³LO required)
hadron colliders	~ 4% (Tev. jets), ~ 3% (LHC $t\bar{t}$) (NLO jets, NNLO $t\bar{t}$, gluon uncert.) [17, 21, 34]	< 1% challenging (NNLO jets imminent [22])
lattice	~ 0.5% (Wilson loops, correlators, ...) (limited by accuracy of pert. th.) [35–37]	~ 0.3% (~ 5 yrs [38])

per mille

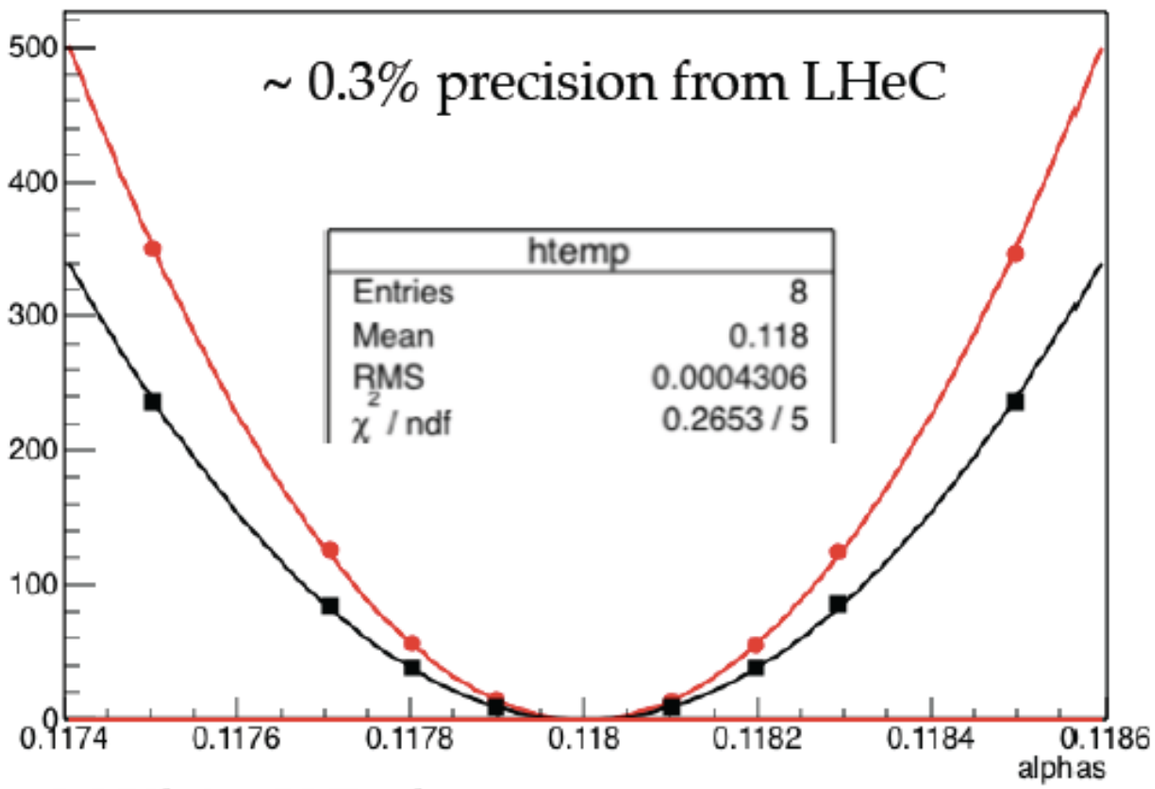
per mille

α_s:

- Least known of



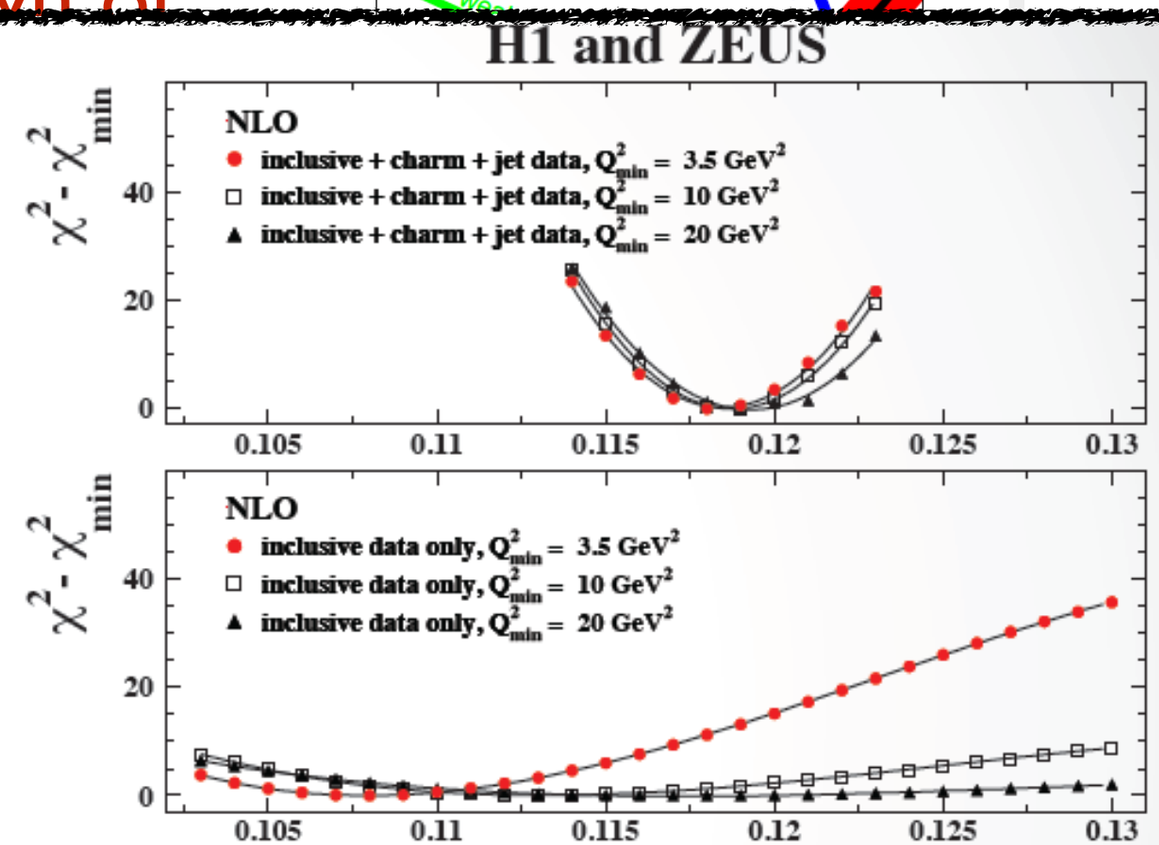
combined fit to PDFs+αs using LHeC data

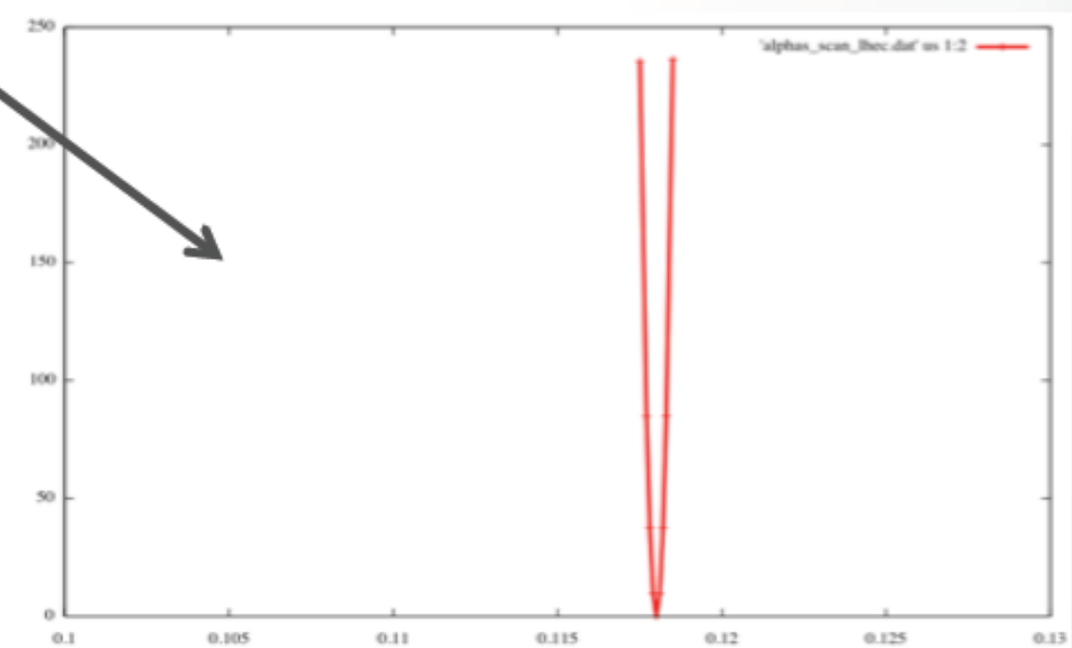


M Klein, V Radescu

NC,CC

NC,CC+F2c





LHeC could resolve a > 30-year old puzzle:

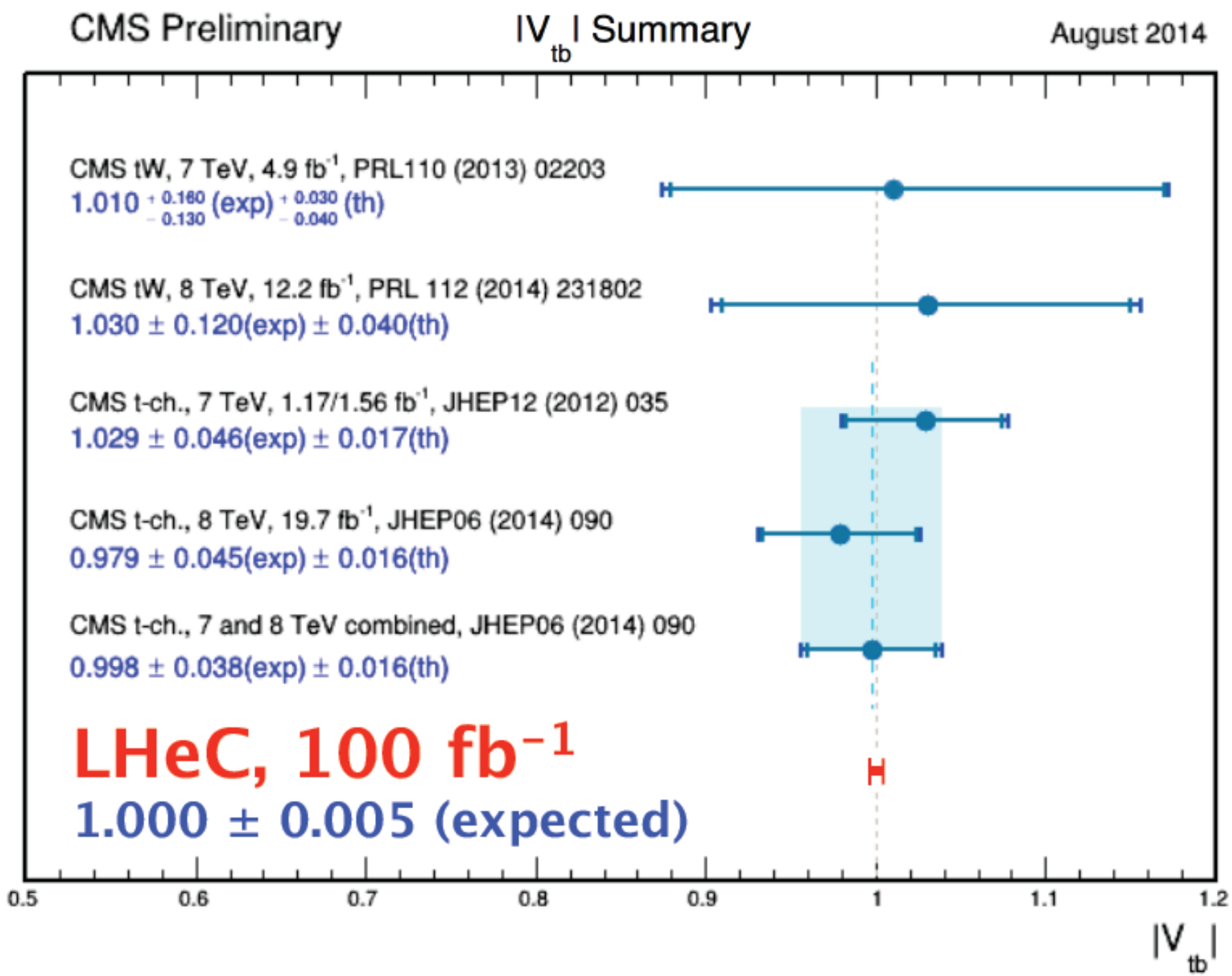
αs consistent in inclusive DIS, versus jets?

expected 0.1% precision when combined with HERA

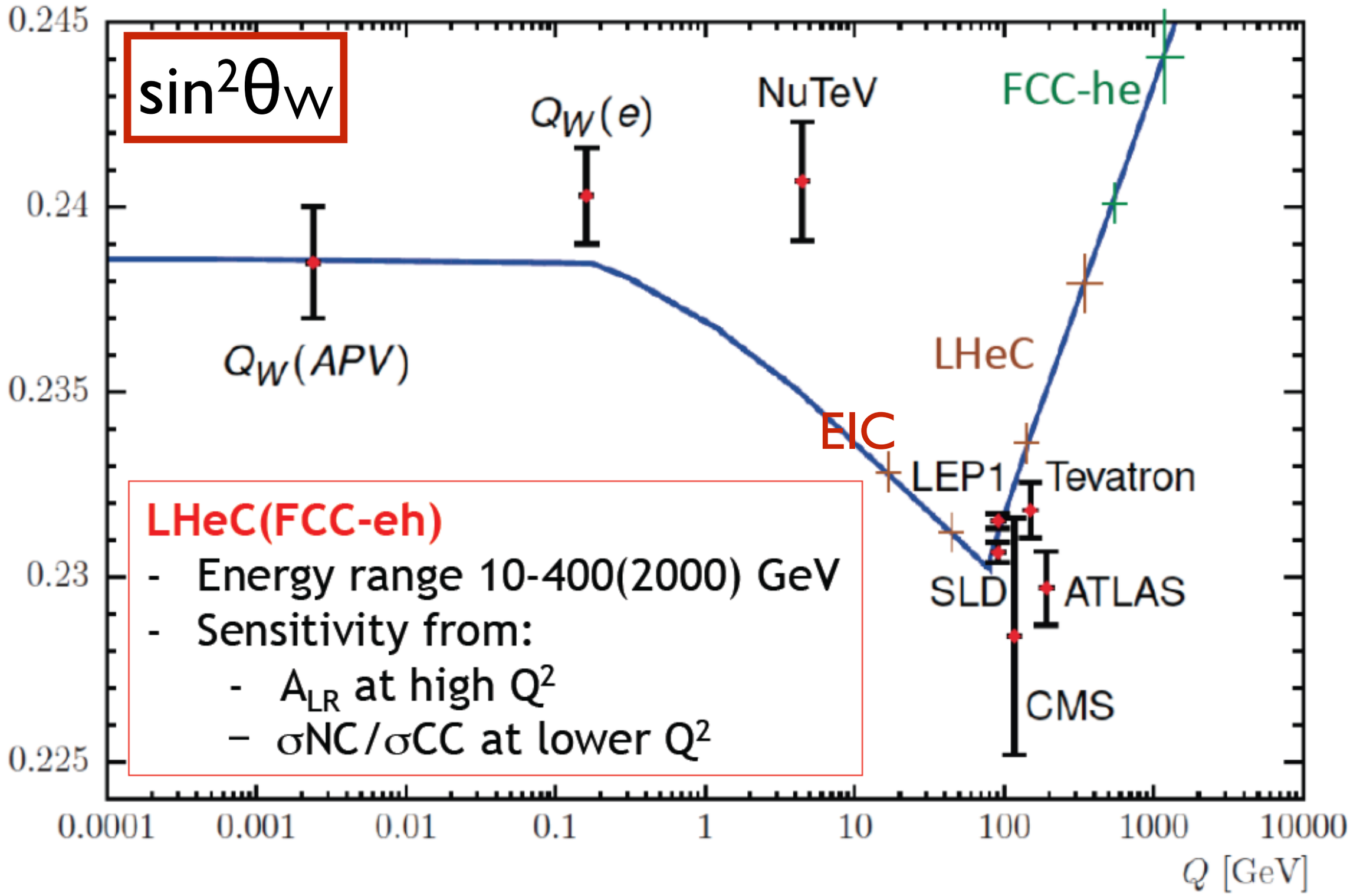
	(limited by accuracy of pert. th.)	[35–37]	(∼ 5 yrs [38])

Top and EW physics:

High precision measurements of Vtb



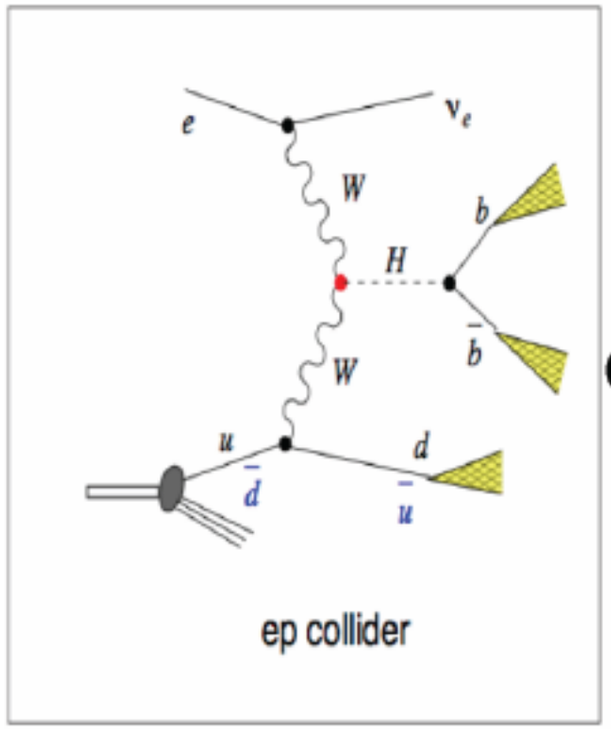
Top and EW physics:



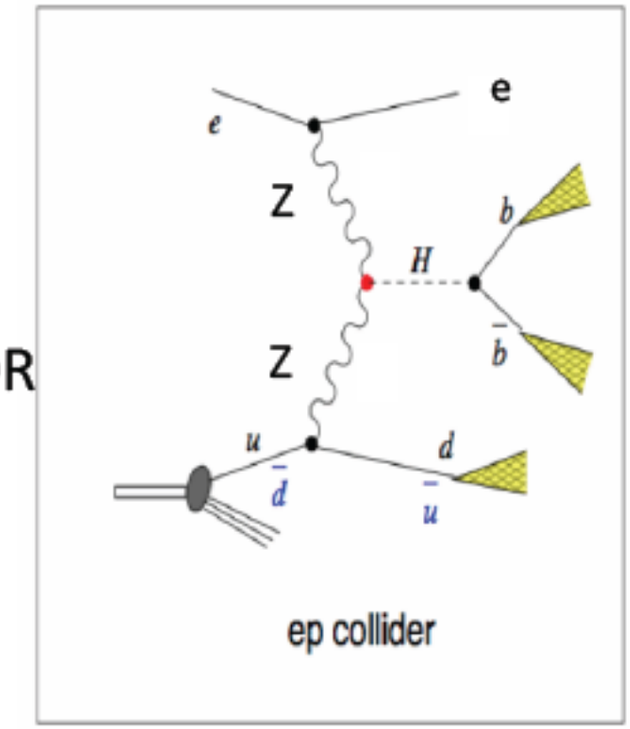
LHeC(FCC-eh)

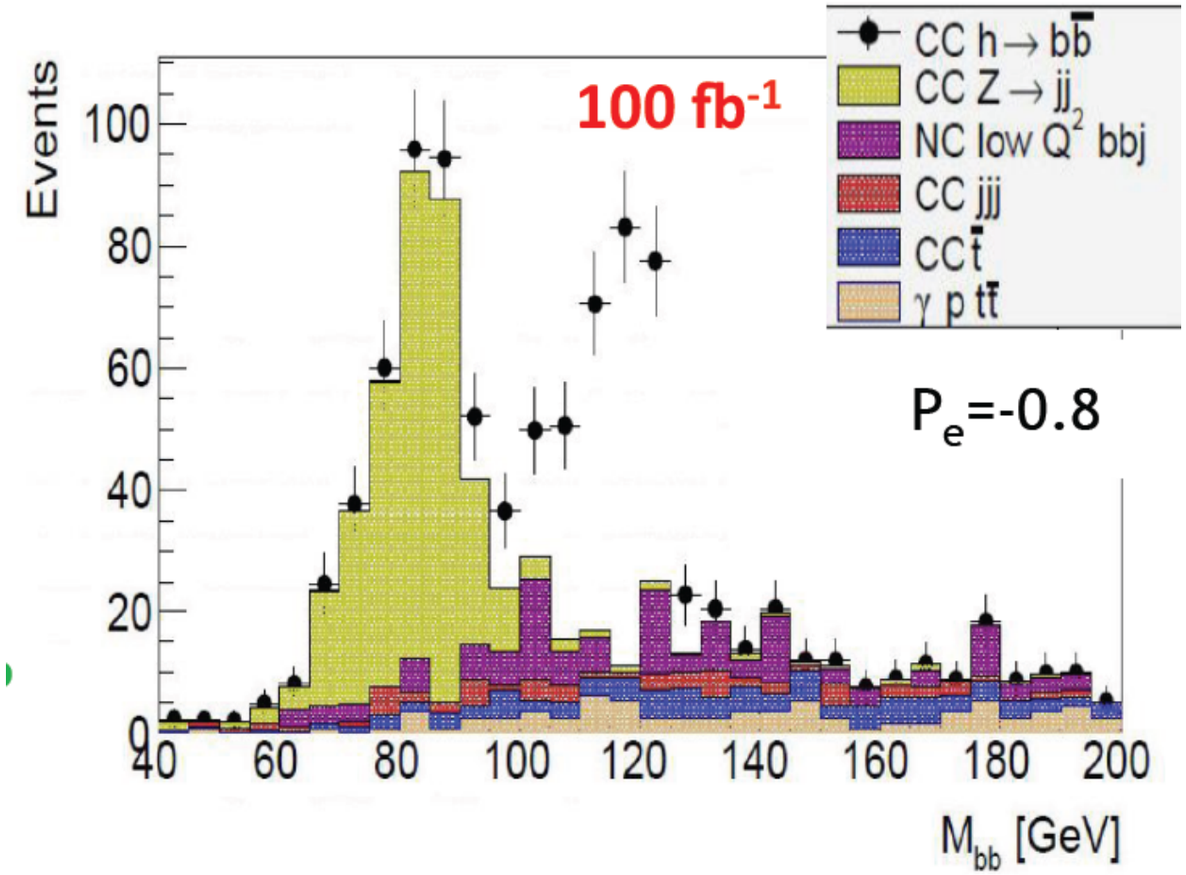
- Energy range 10-400(2000) GeV
- Sensitivity from:
  - A_{LR} at high Q^2
  - $\sigma NC/\sigma CC$ at lower Q^2

Higgs at the LHeC:



OR



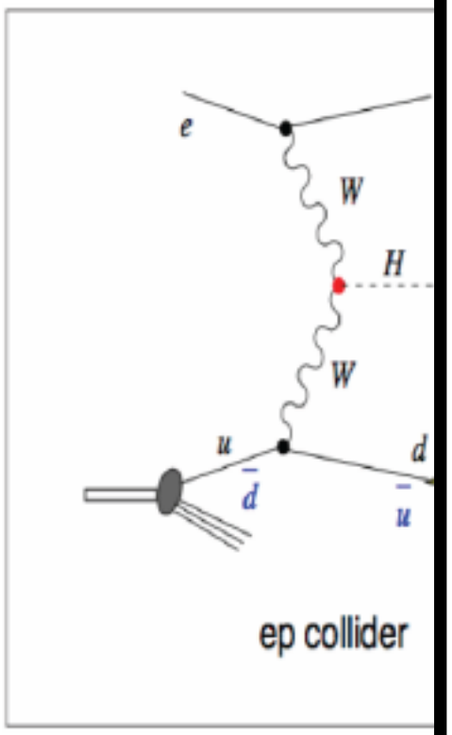


Higgs in e^-p		CC - LHeC	NC - LHeC	CC - FHeC
Polarisation		-0.8	-0.8	-0.8
Luminosity [ab^{-1}]		1	1	5
Cross Section [fb]		196	25	850
Decay	BrFraction	N^H_{CC}	N^H_{NC}	N^H_{CC}
$H \to b\bar{b}$	0.577	113 100	13 900	2 450 000
$H \to c\bar{c}$	0.029	5 700	700	123 000
$H \to \tau^+\tau^-$	0.063	12 350	1 600	270 000
$H \to \mu\mu$	0.00022	50	5	1 000
$H \to 4l$	0.00013	30	3	550
$H \to 2l2\nu$	0.0106	2 080	250	45 000
$H \to gg$	0.086	16 850	2 050	365 000
$H \to WW$	0.215	42 100	5 150	915 000
$H \to ZZ$	0.0264	5 200	600	110 000
$H \to \gamma\gamma$	0.00228	450	60	10 000
$H \to Z\gamma$	0.00154	300	40	6 500

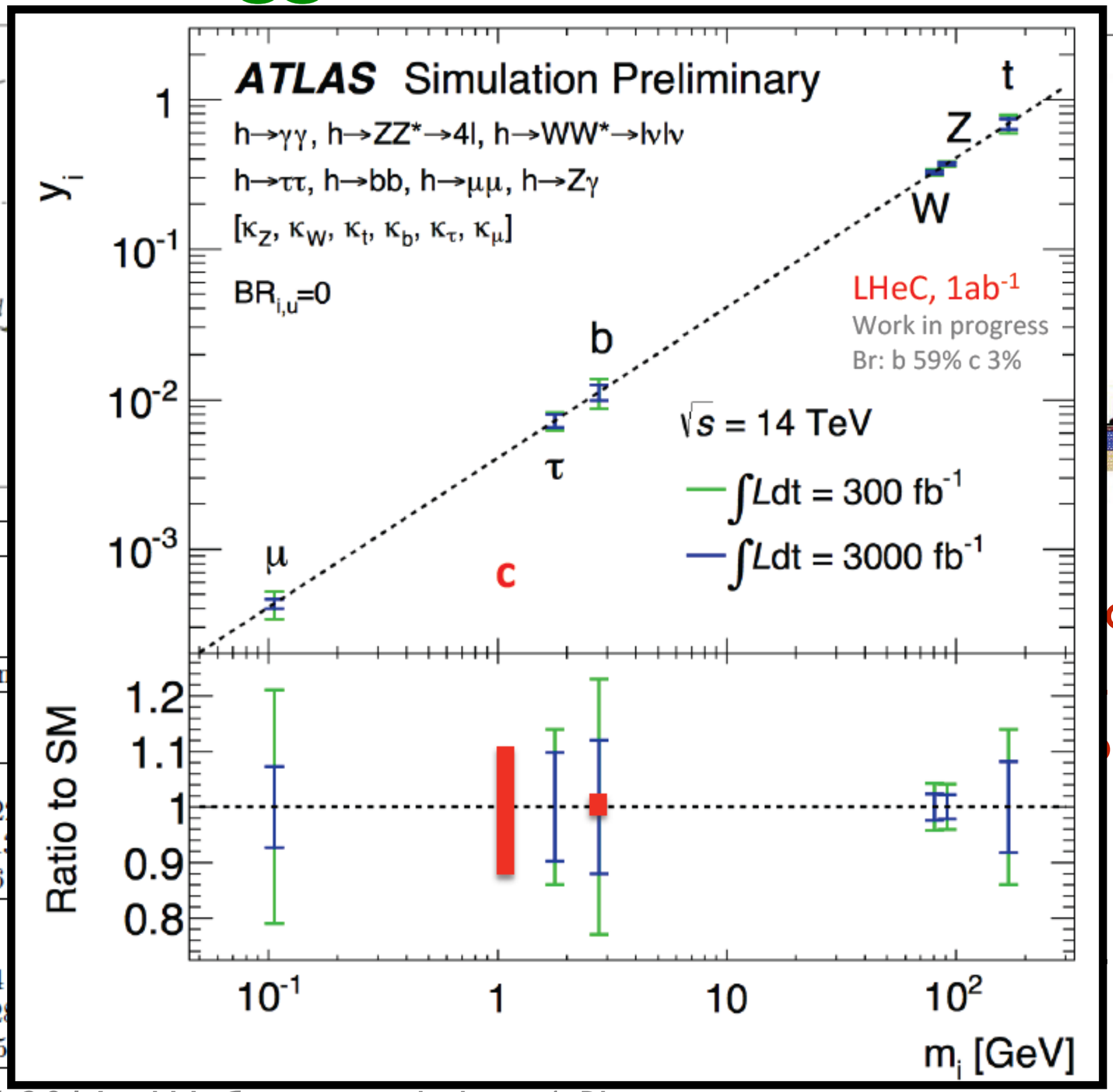
- (VBF) cross section comparable to that at the ILC, clear separation of WWH and ZZH.

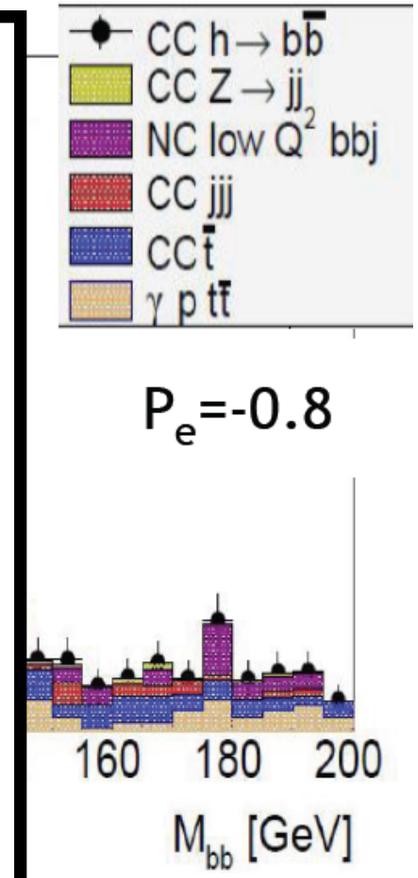
- No pileup (0.1 at 10^{34}), S/B~1.

Higgs at the LHeC:



Higgs in e^-p	
Polarisation	
Luminosity [ab^{-1}]	
Cross Section [fb]	
Decay	BrFraction
$H \to b\bar{b}$	0.577
$H \to c\bar{c}$	0.029
$H \to \tau^+\tau^-$	0.063
$H \to \mu\mu$	0.0002
$H \to 4l$	0.0001
$H \to 2l2\nu$	0.0106
$H \to gg$	0.086
$H \to WW$	0.215
$H \to ZZ$	0.0264
$H \to \gamma\gamma$	0.0022
$H \to Z\gamma$	0.0015

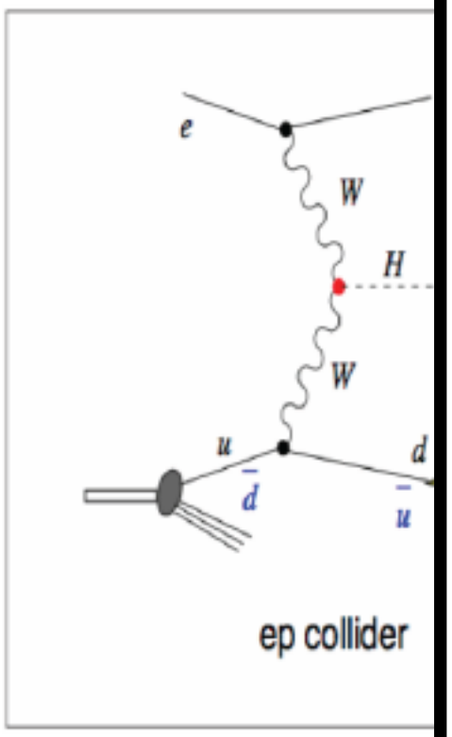




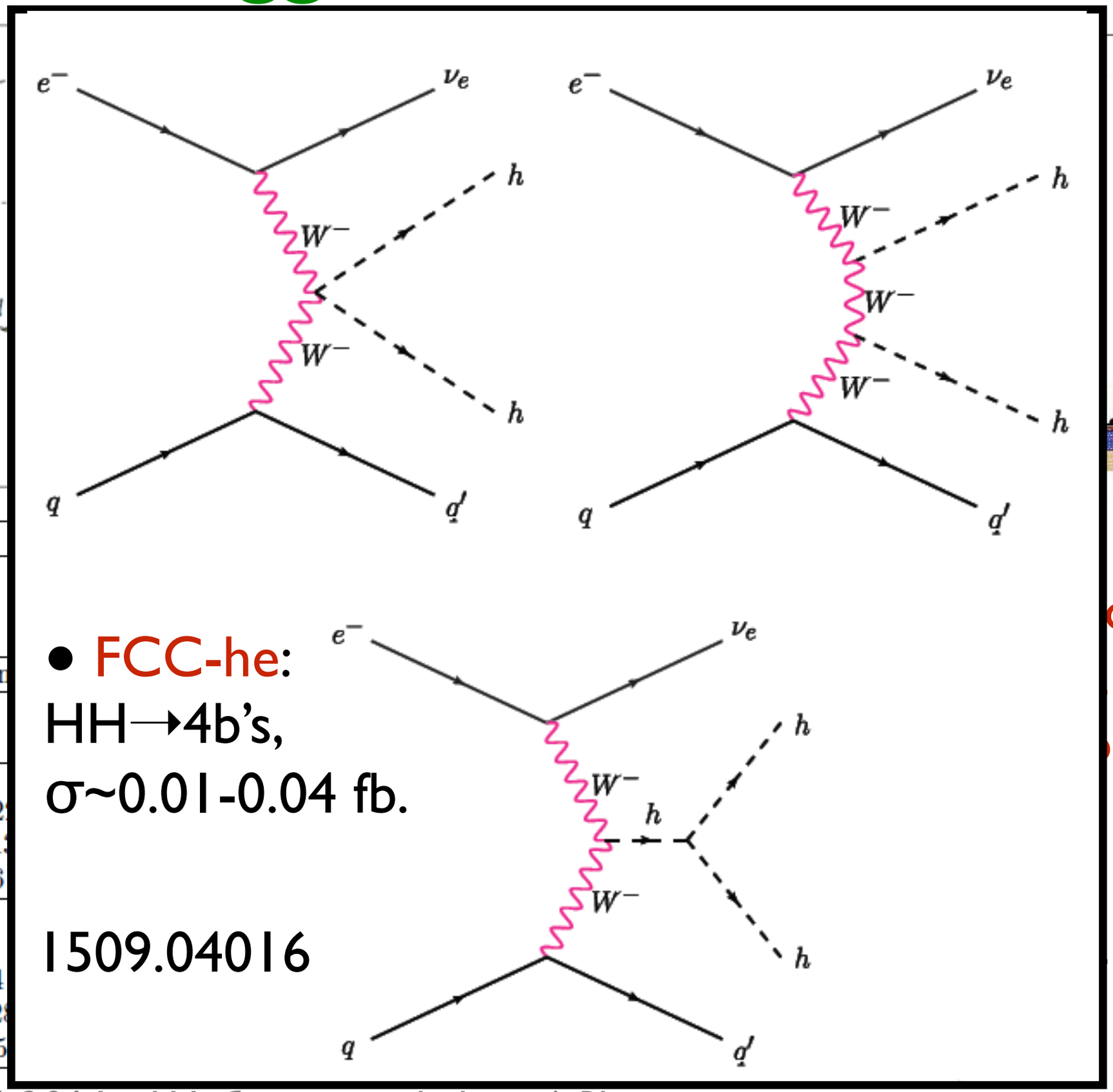
on
at the
n of

10^{34}),

Higgs at the LHeC:



Higgs in e^-p	
Polarisation	
Luminosity [ab^{-1}]	
Cross Section [fb]	
Decay	BrFraction
$H \to b\bar{b}$	0.577
$H \to c\bar{c}$	0.029
$H \to \tau^+\tau^-$	0.063
$H \to \mu\mu$	0.0002
$H \to 4l$	0.0001
$H \to 2l2\nu$	0.0106
$H \to gg$	0.086
$H \to WW$	0.215
$H \to ZZ$	0.0264
$H \to \gamma\gamma$	0.0022
$H \to Z\gamma$	0.0015

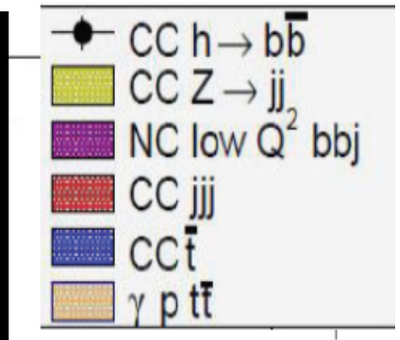


- FCC-he:

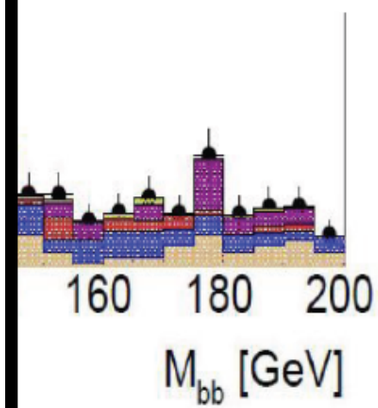
HH→4b's,

σ~0.01-0.04 fb.

1509.04016



P_e=-0.8



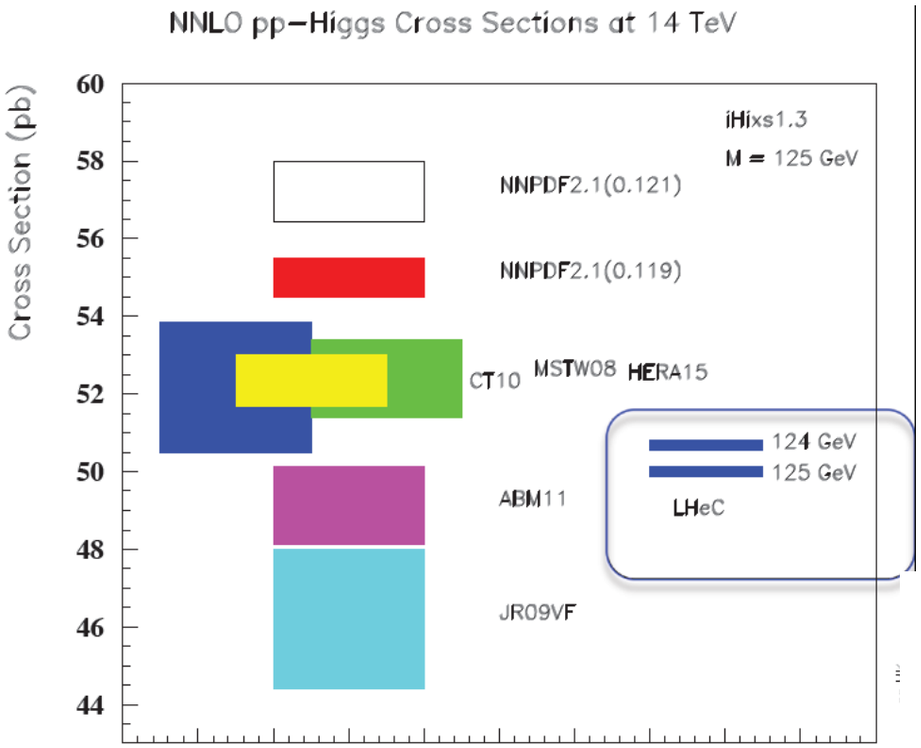
on

at the

n of

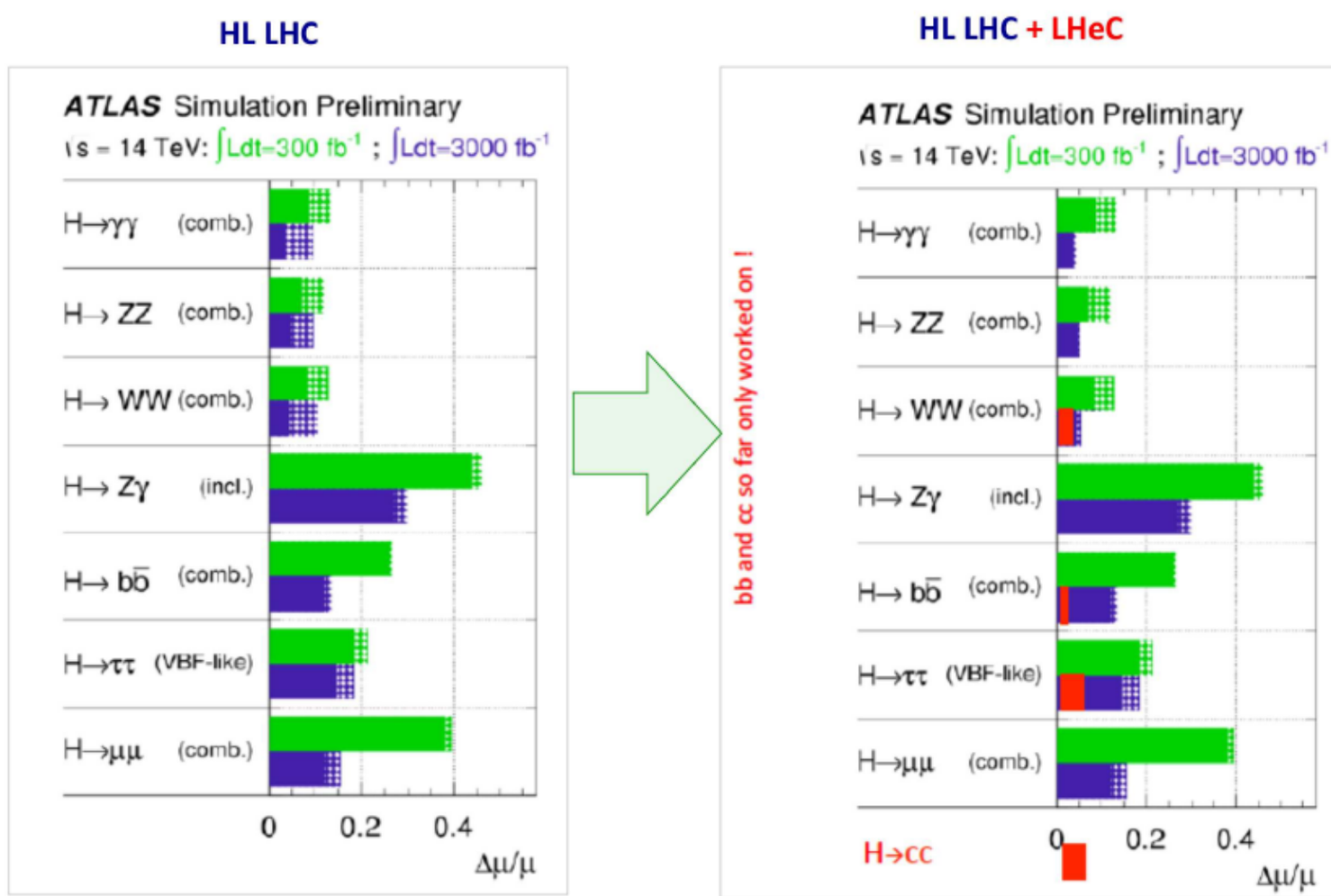
10^{34}),

Higgs at the HL-LHC:

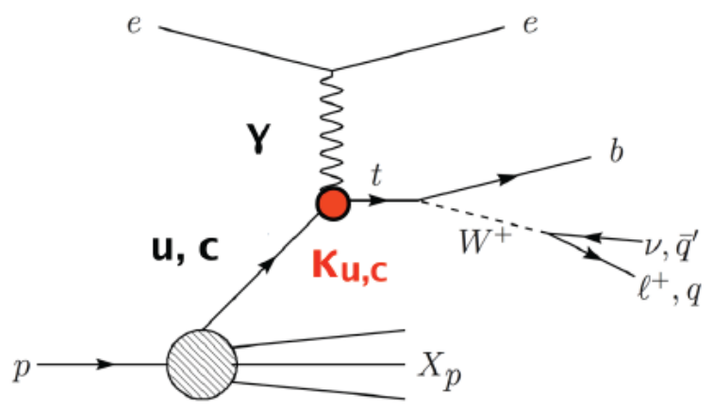


- αs and PDFs dominate the uncertainties on the cross section e.g. Δαs=0.005 means 10 % for the cross section.
- Sensitivity to the Higgs mass cannot be achieved due to these reasons.

- The LHeC would turn HL-LHC into a precision Higgs machine.

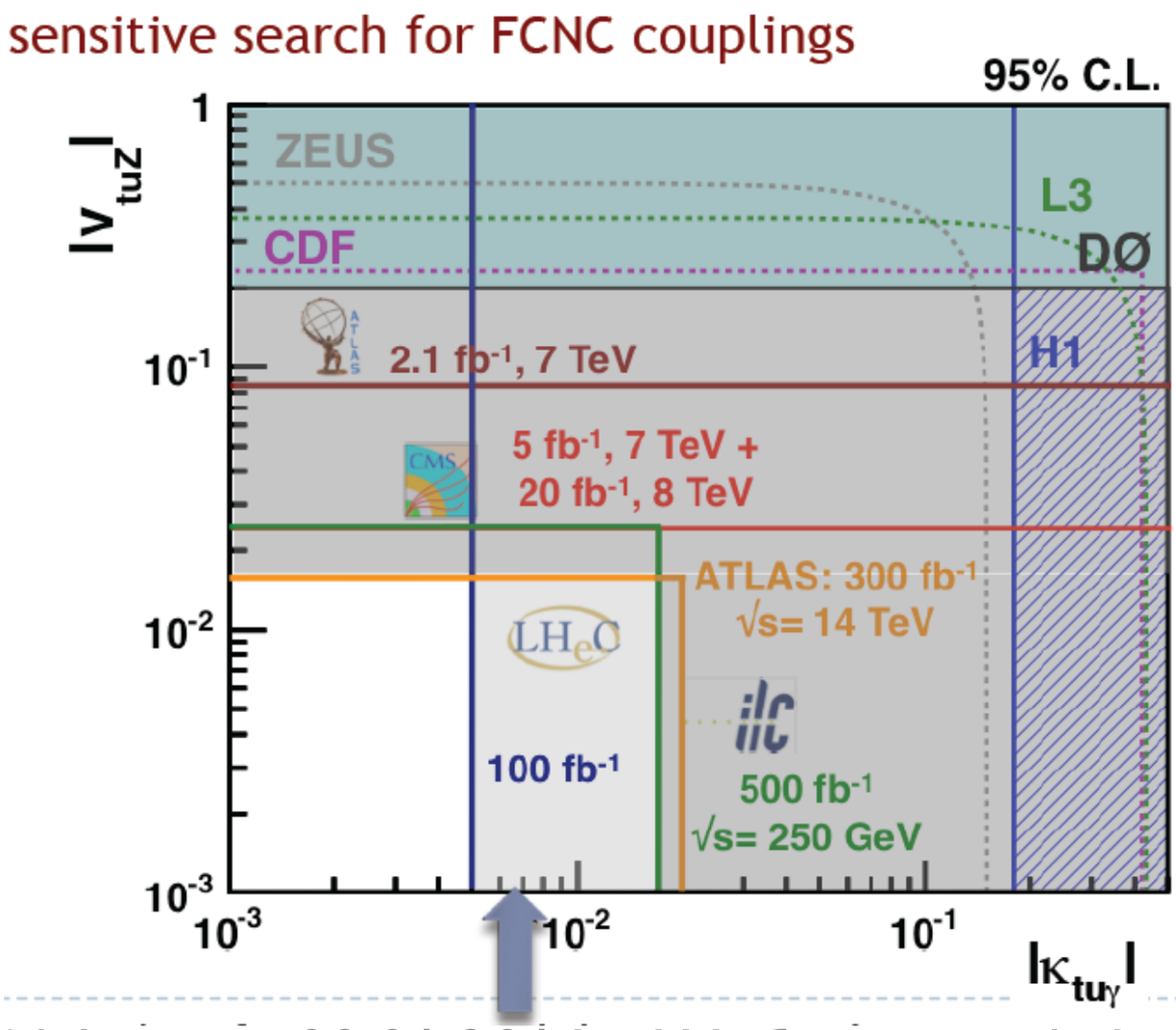


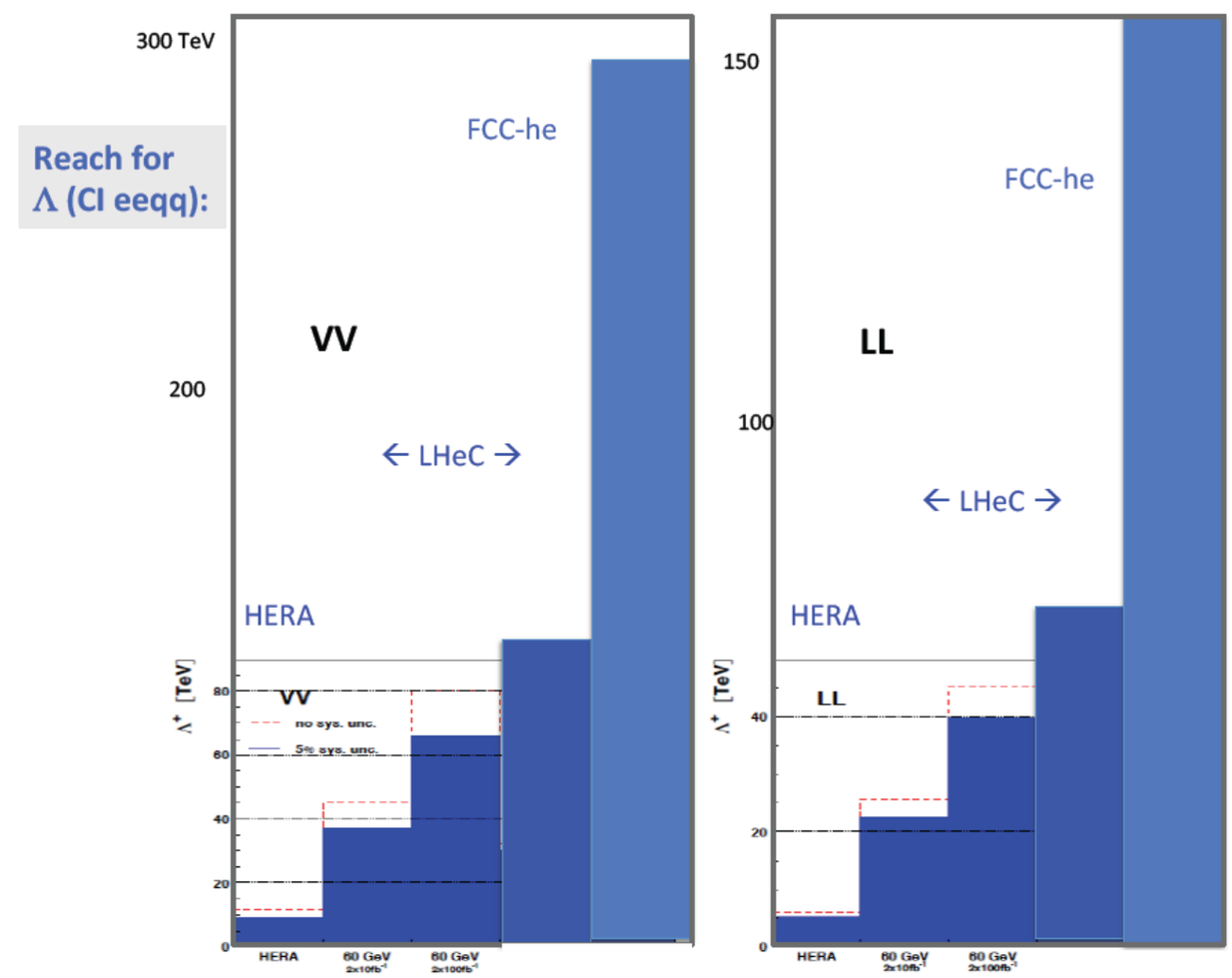
BSM:



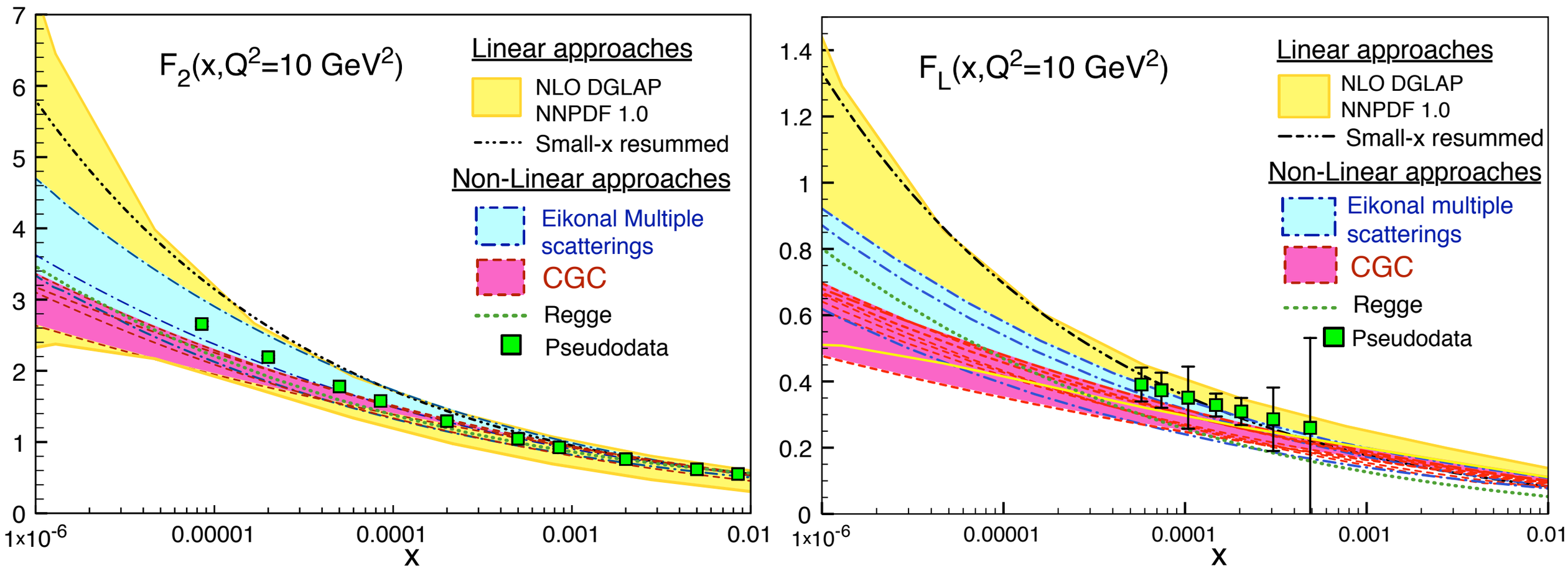
- FCNC: new physics models (SUSY, TC, little H, ED,…) predict BR=O(10^{-5}) accesible @ LHeC.

- Present LHC constraints on scale of qqll CI: 15 – 26 TeV (40 @14 TeV).





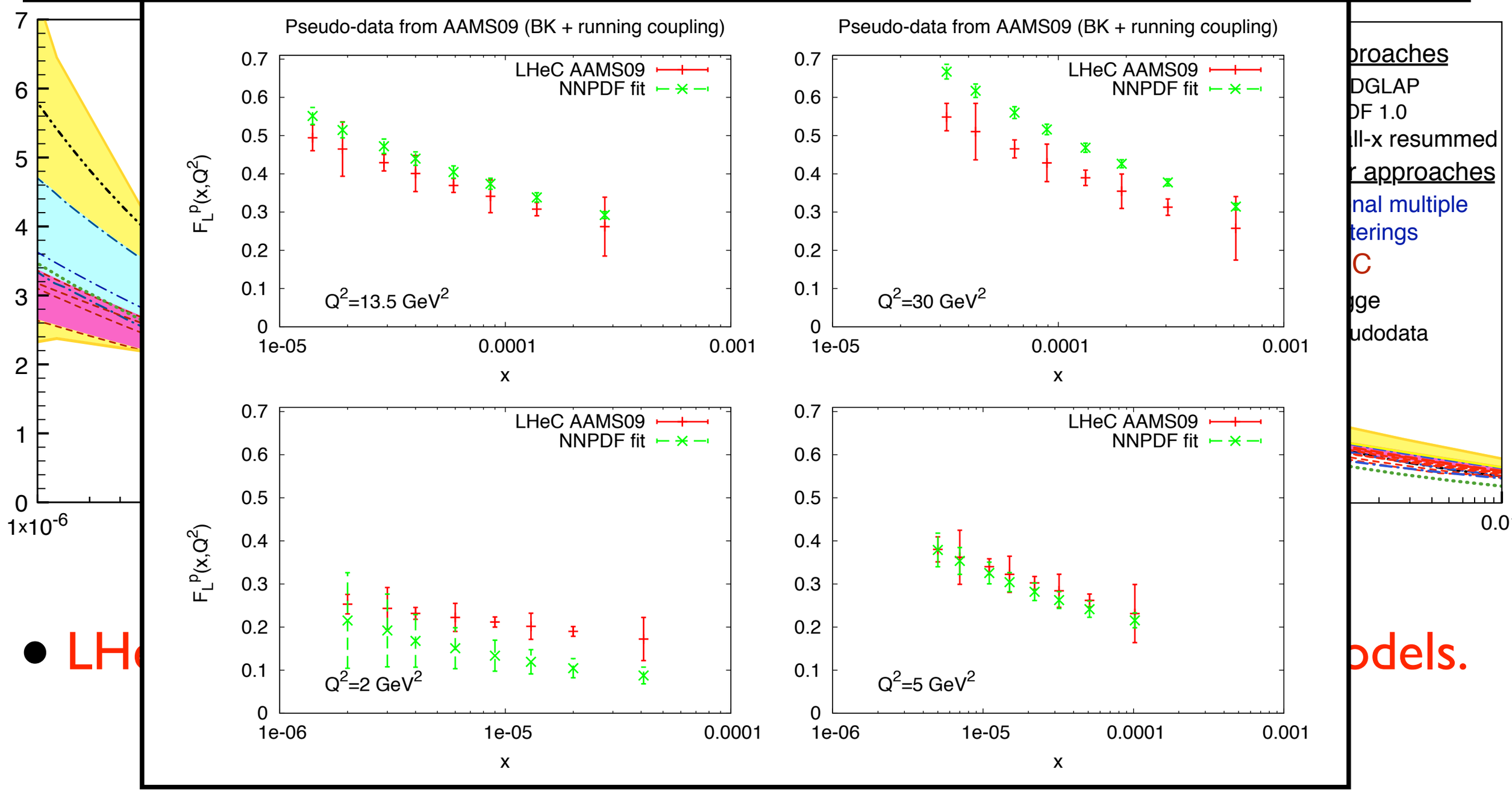
Small-x: inclusive



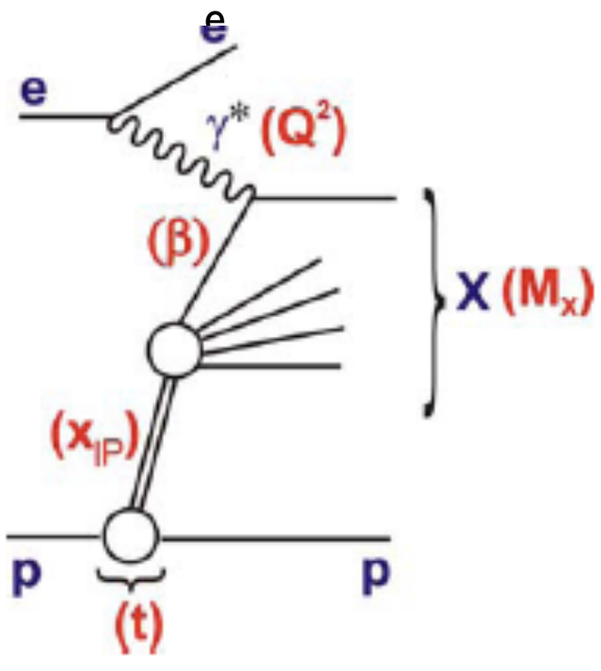
- LHeC F_2 and F_L data will have discriminatory power on models.

Small-x: inclusive

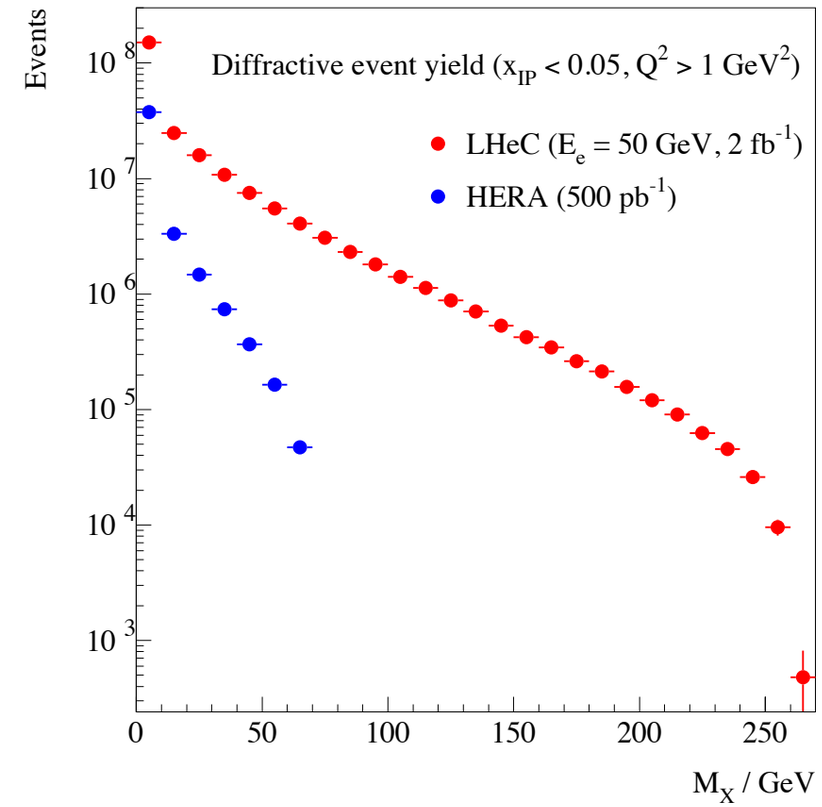
- NLO DGLAP cannot simultaneously accommodate LHeC F_2 and F_L pseudodata if saturation effects included according to current models. Two observables required (F_2-F_{2c}?).

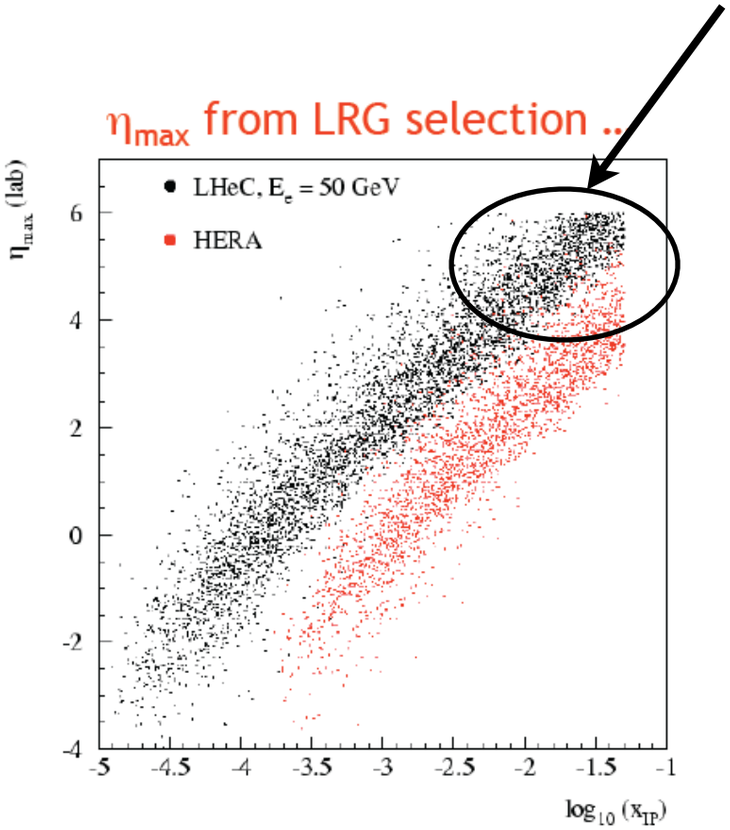


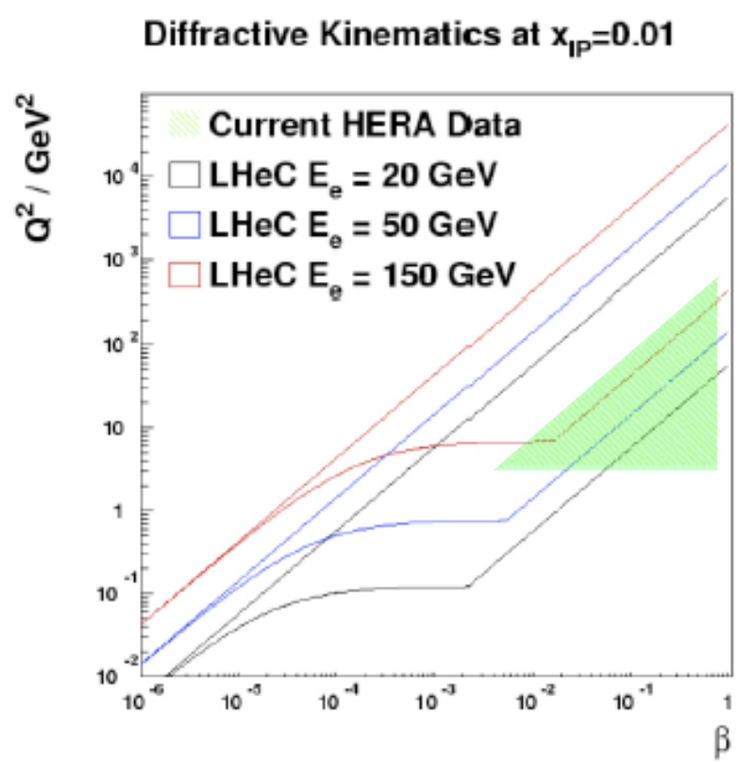
Small-x: diffractive

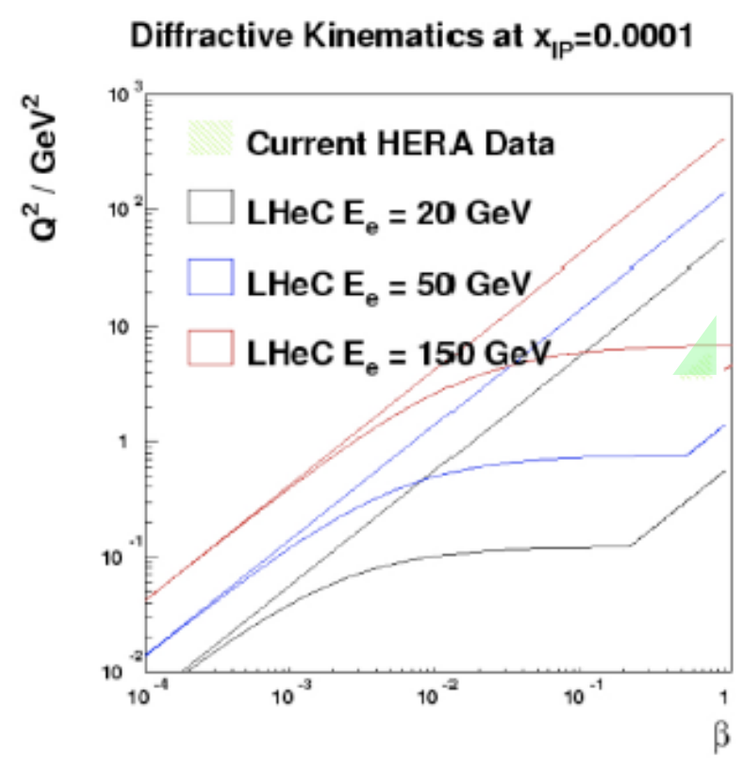


- Large increase in the M^2, $x_P=(M^2-t+Q^2)/(W^2+Q^2)$, $\beta=x/x_P$ region studied.
- Possibility to combine LRG and LPS.

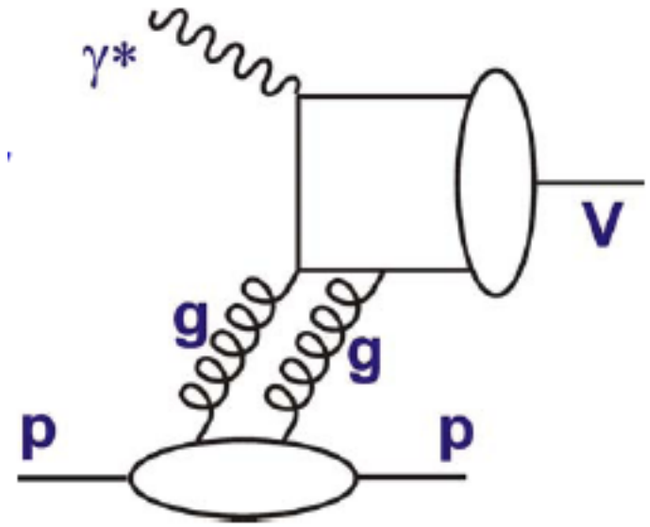


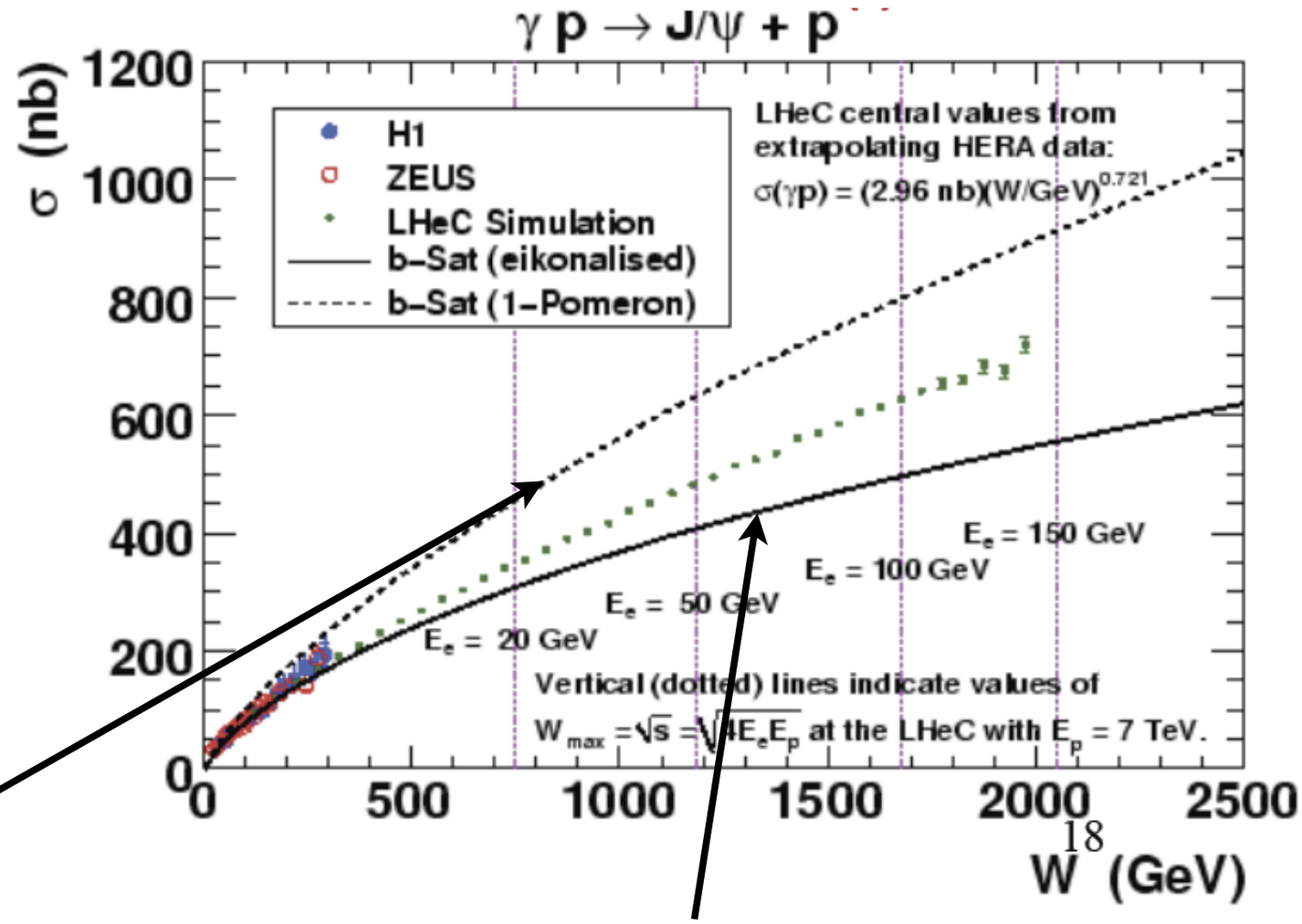




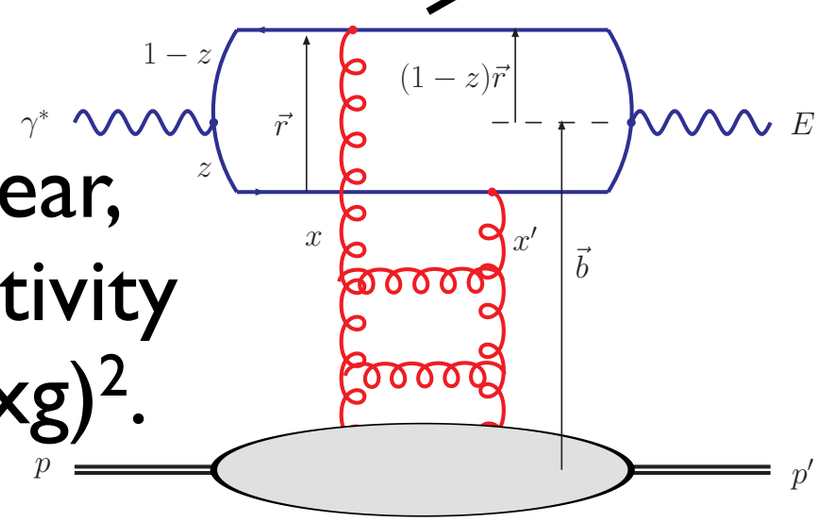


Small-x: diffractive

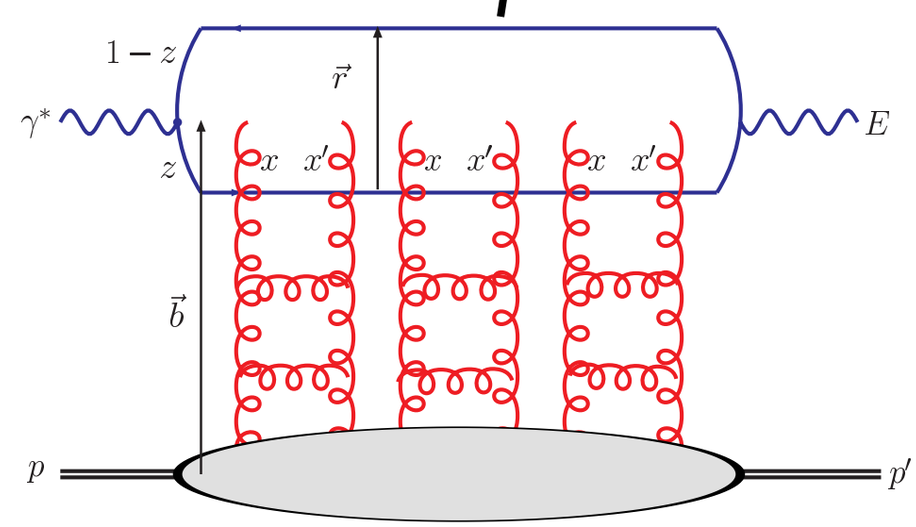




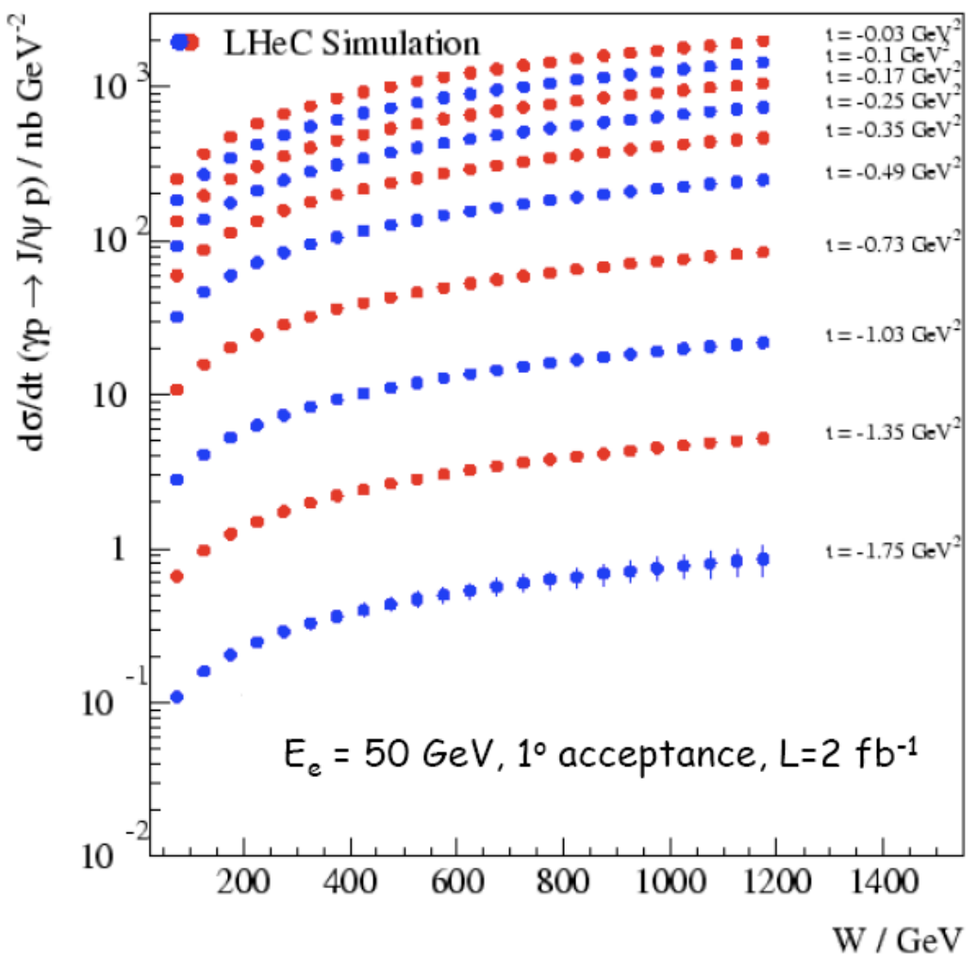
- Elastic J/ψ production appears as a candidate to signal saturation effects at work!!!

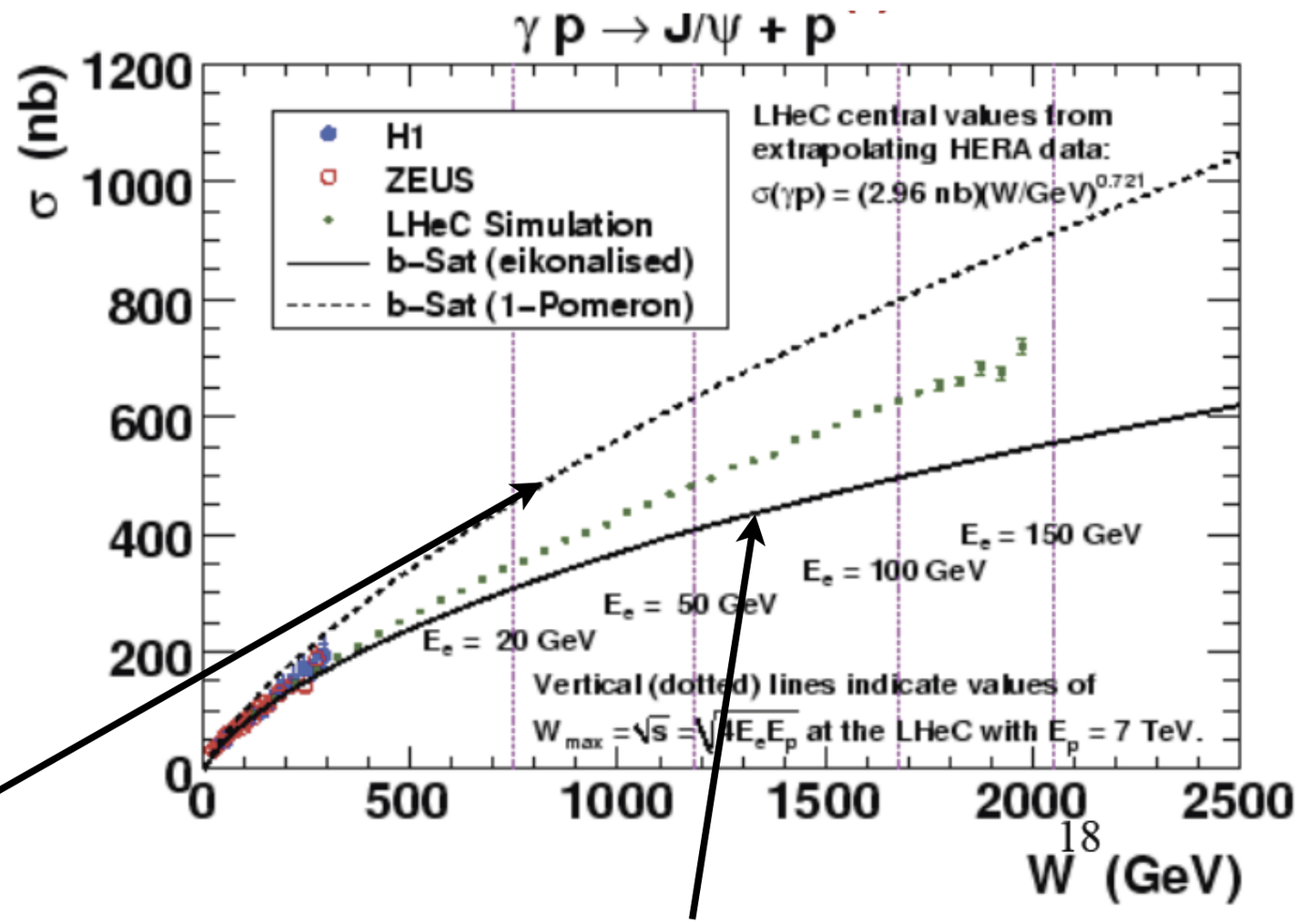


Linear, sensitivity to $(xg)^2$.

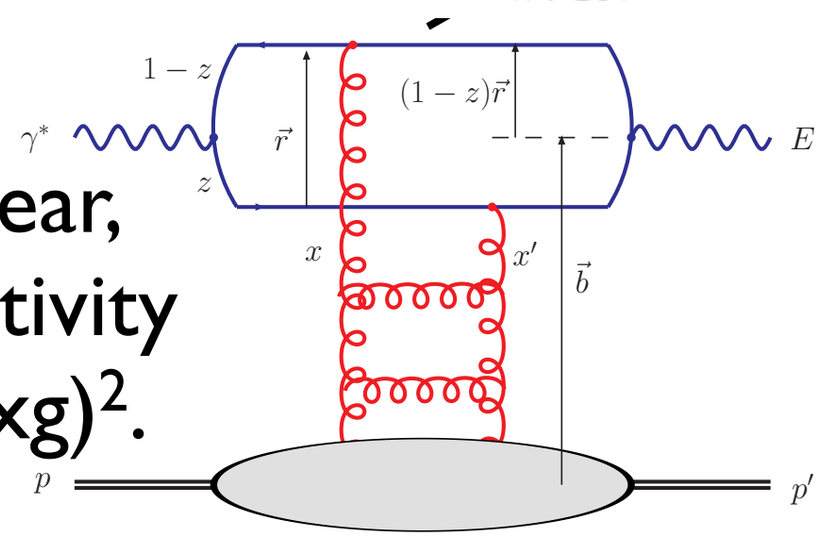


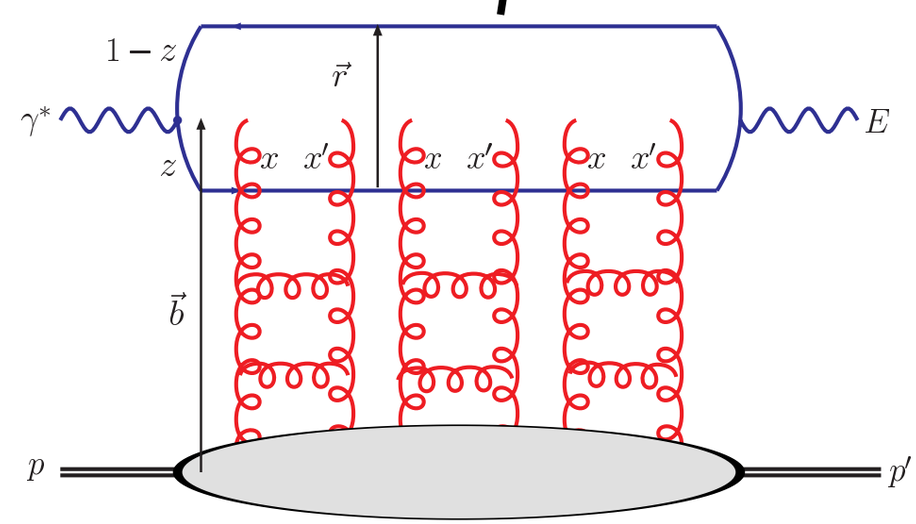
Small-x: diffractive





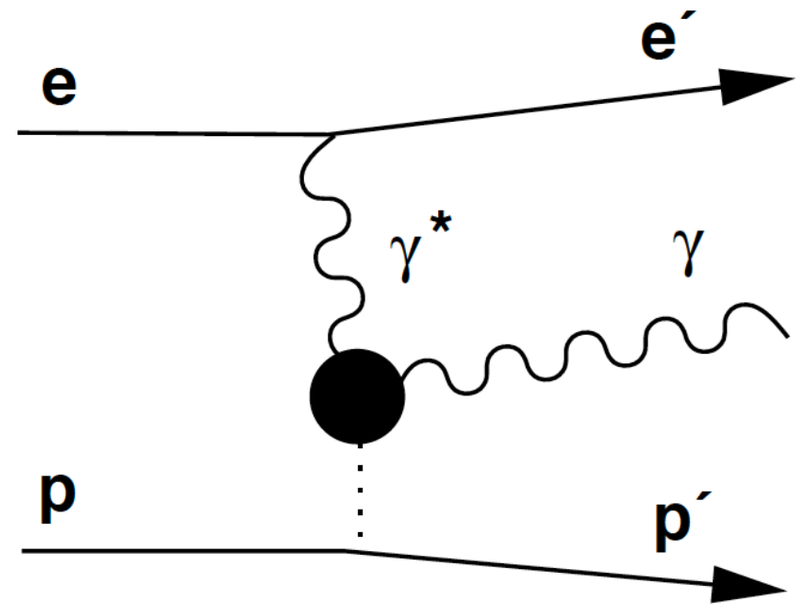
Linear, sensitivity to $(xg)^2$.



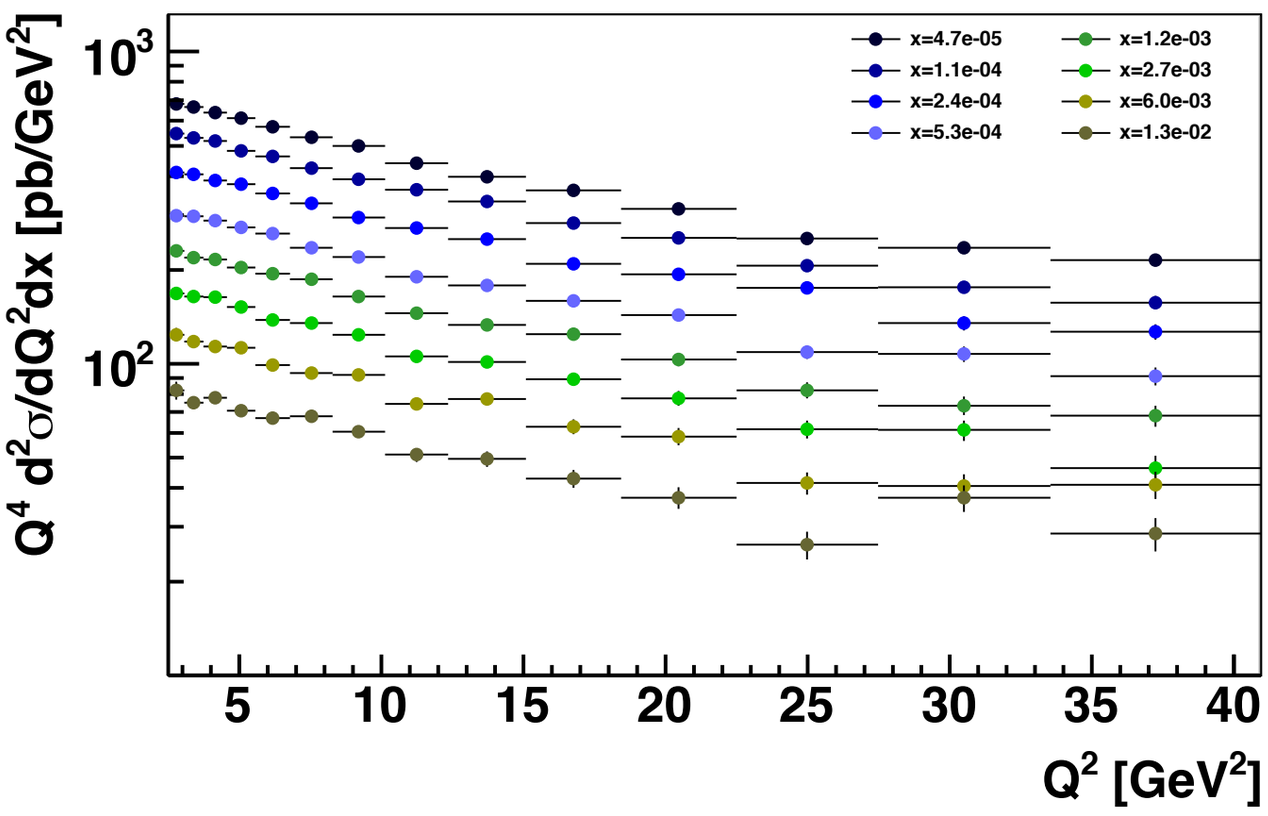


DVCS:

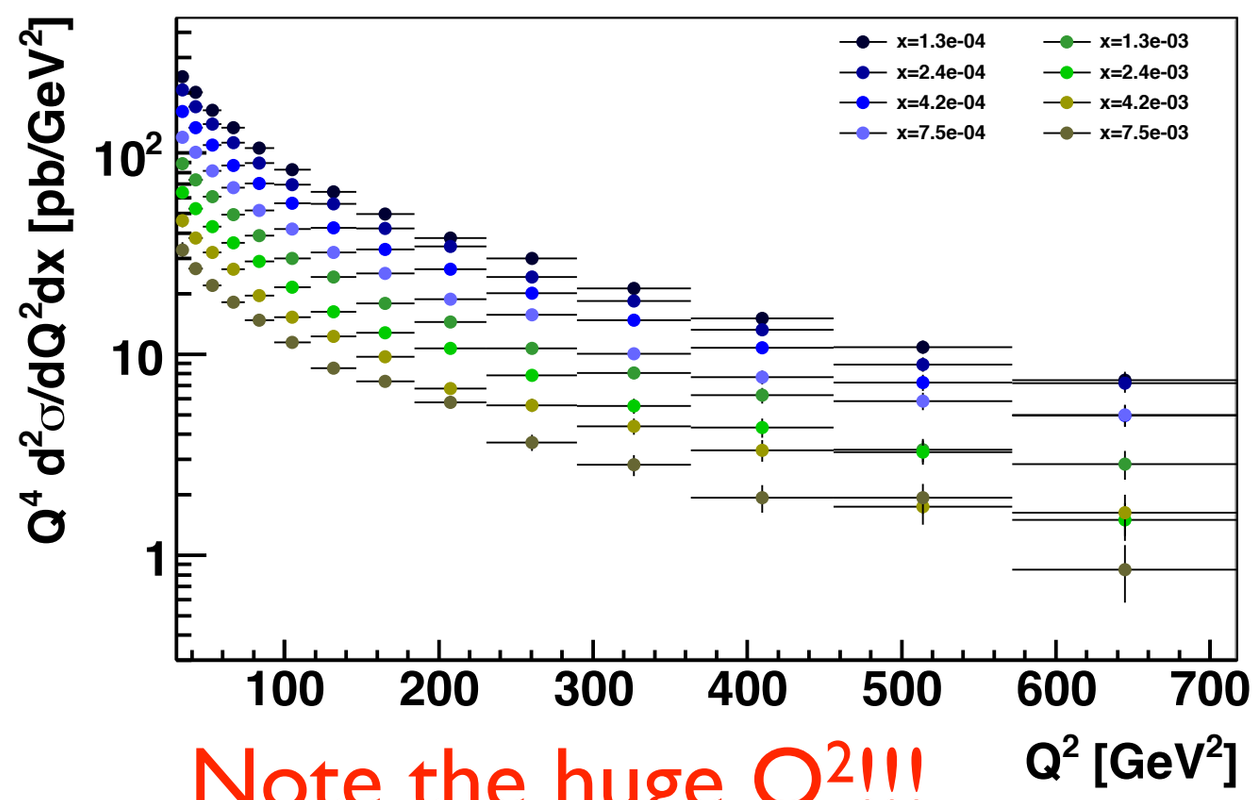
- Exclusive processes give information about GPDs, whose Fourier transform gives a transverse scan of the hadron: DVCS sensitive to the singlet.
- Sensitive to dynamics e.g. non-linear effects.



DVCS, E_e=50 GeV, 1°, $p_T^{\gamma,cut}$=2 GeV, 1 fb^{-1}



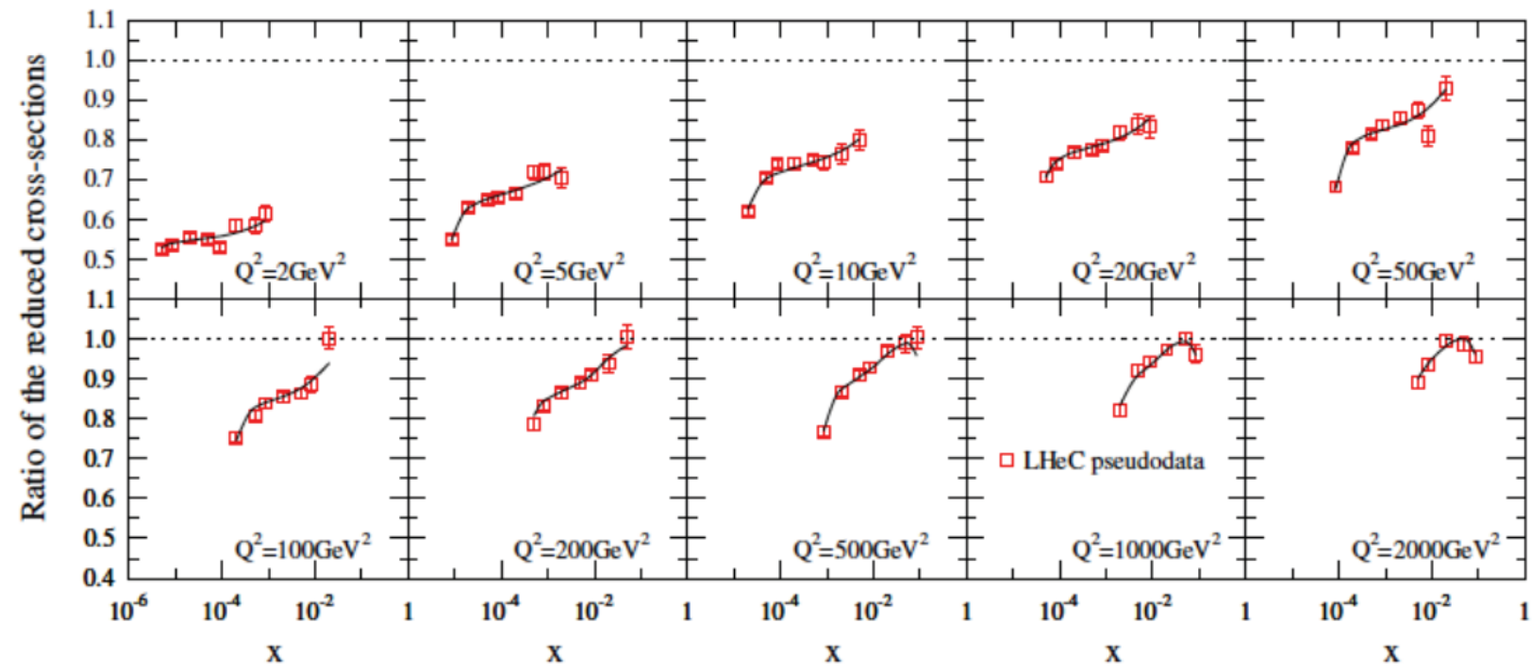
DVCS, E_e=50 GeV, 10° $p_T^{\gamma,cut}$=5 GeV, 100 fb^{-1}

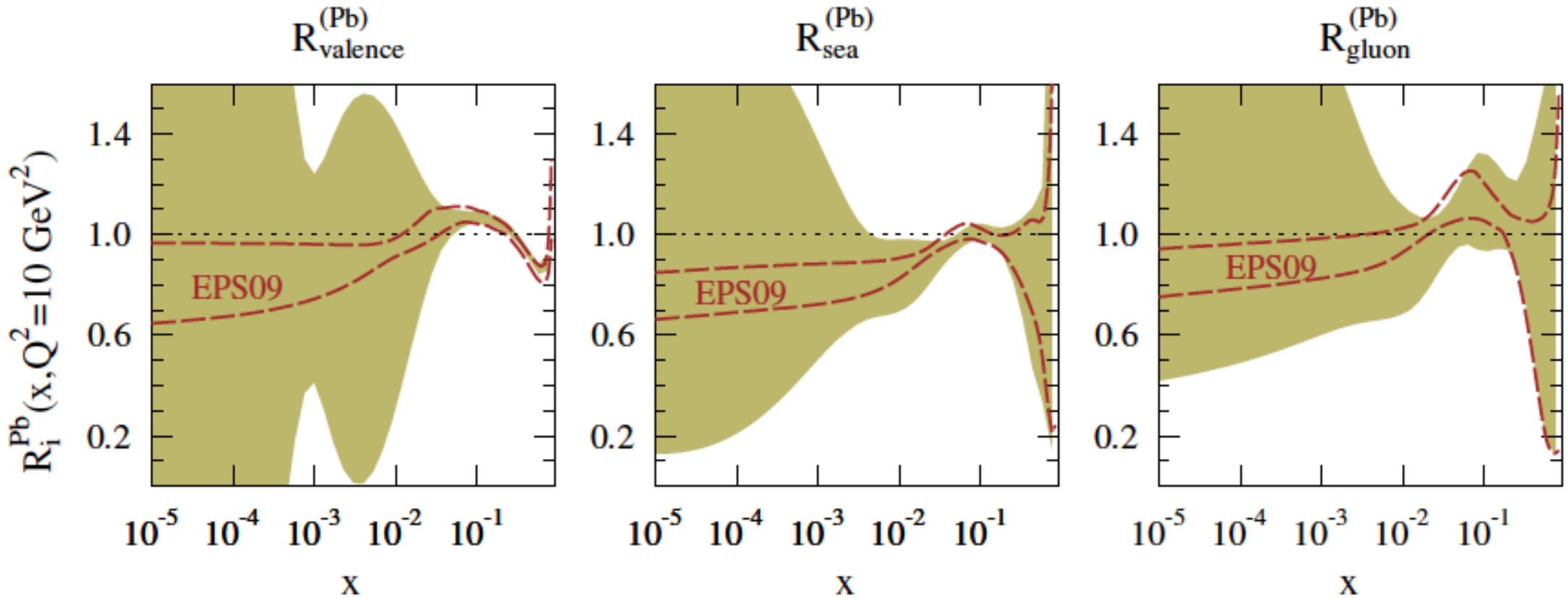


Note the huge Q^2!!!

eA: inclusive

- Large impact on nPDFs, possible to make a Pb fit without proton PDFs!!!
- Large room for improvements: NC+CC at several energies, flavour decomposition,…





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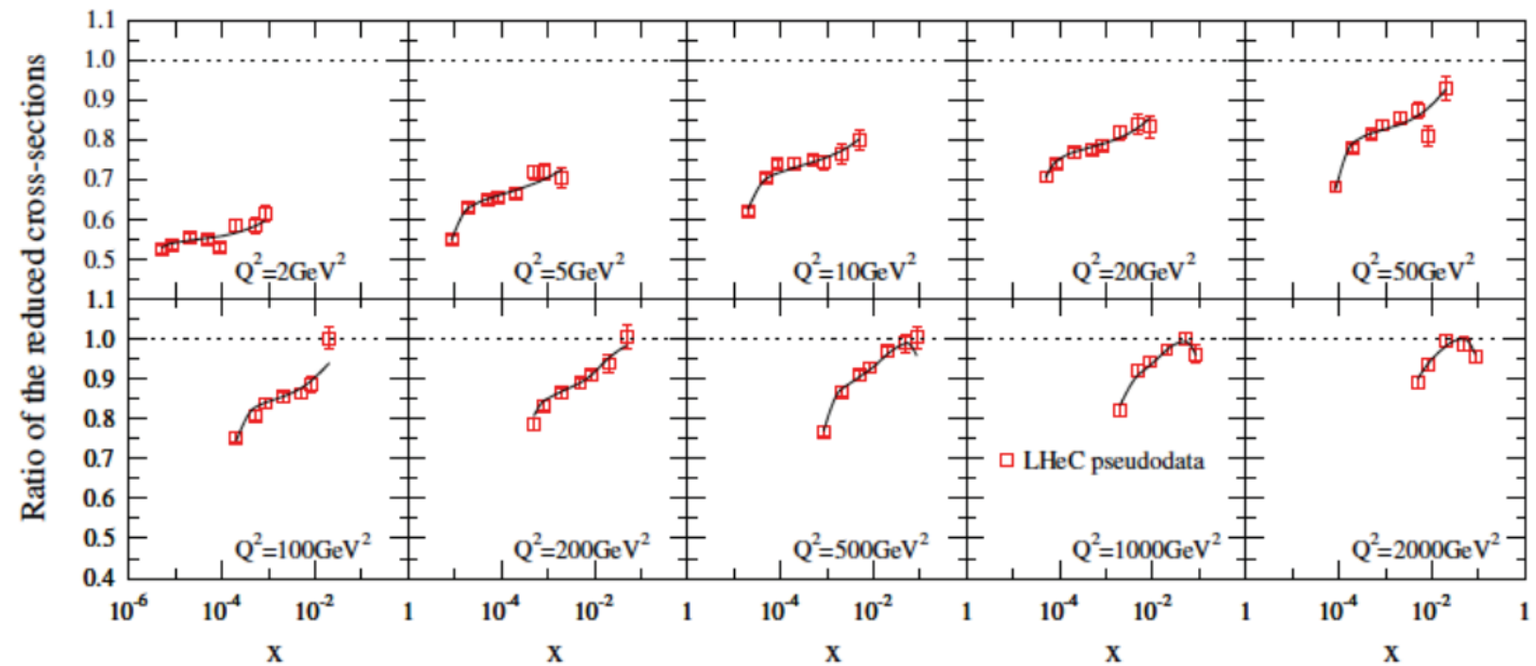
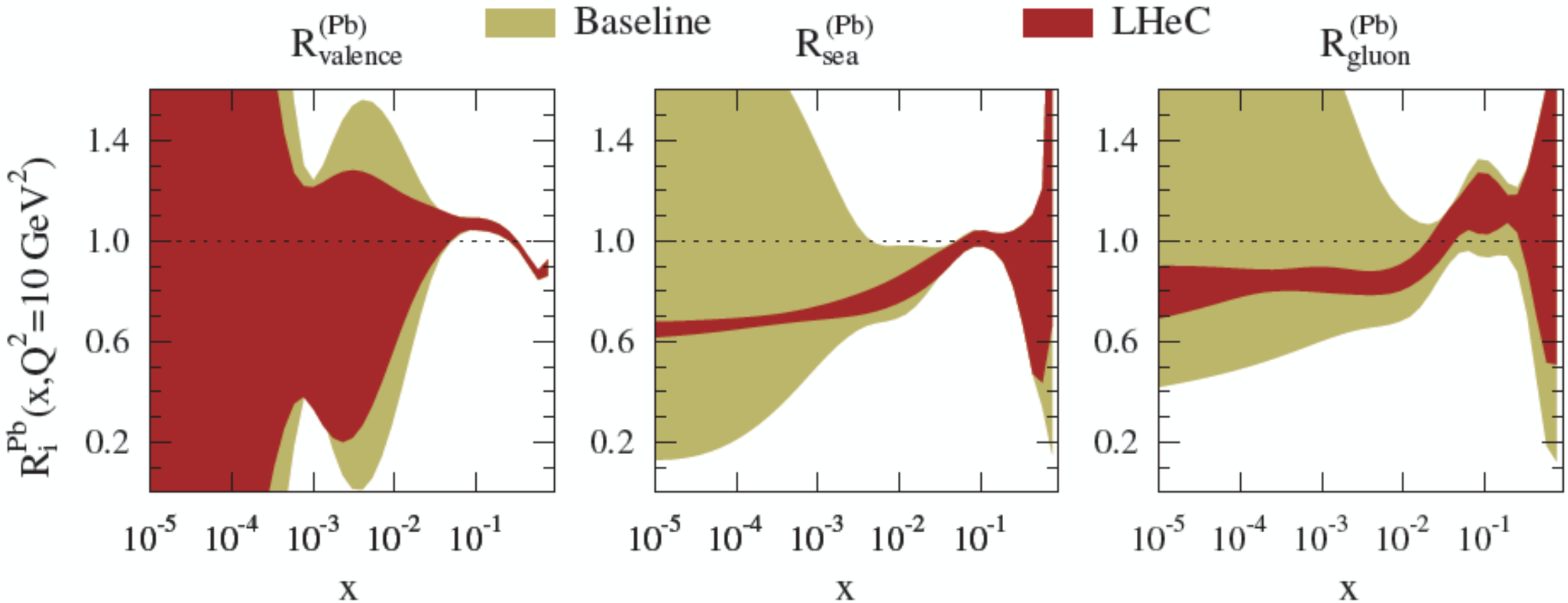
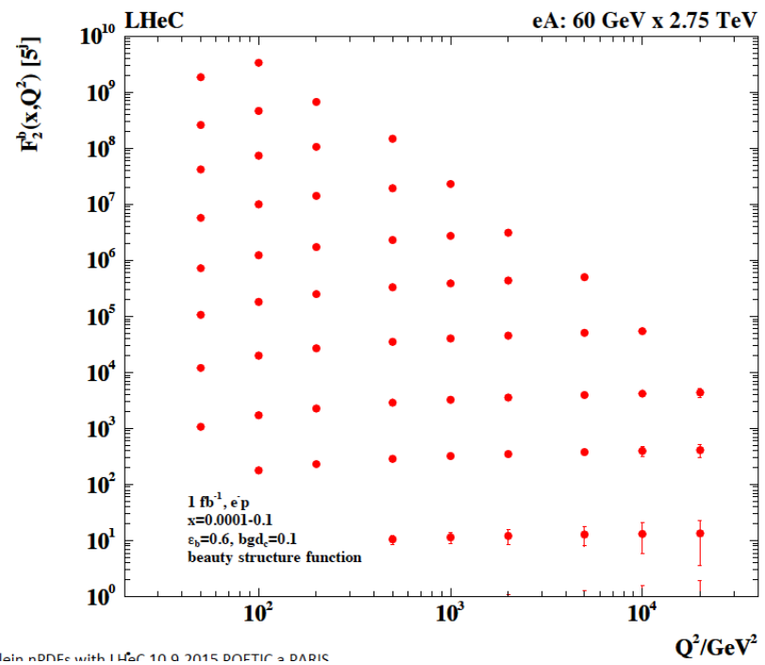


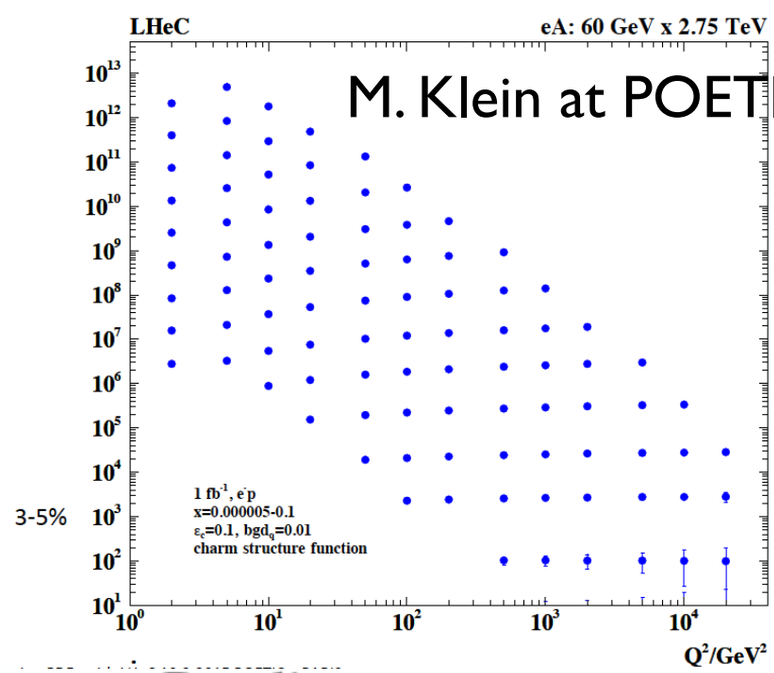


eA: inclusive

Heavy Flavour – Beauty in ePb - from NC



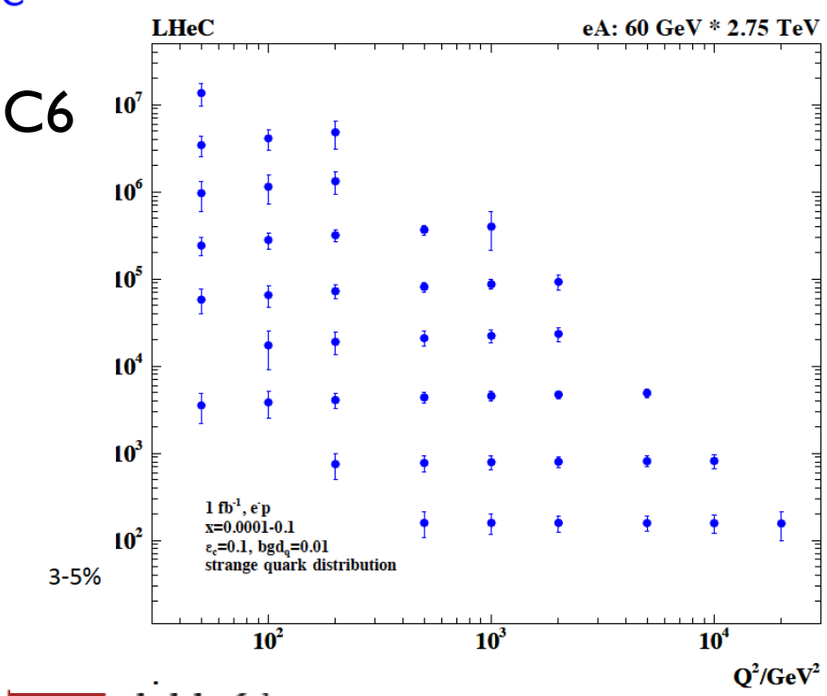
Heavy Flavour – Charm in eA - from NC



M. Klein at POETIC6

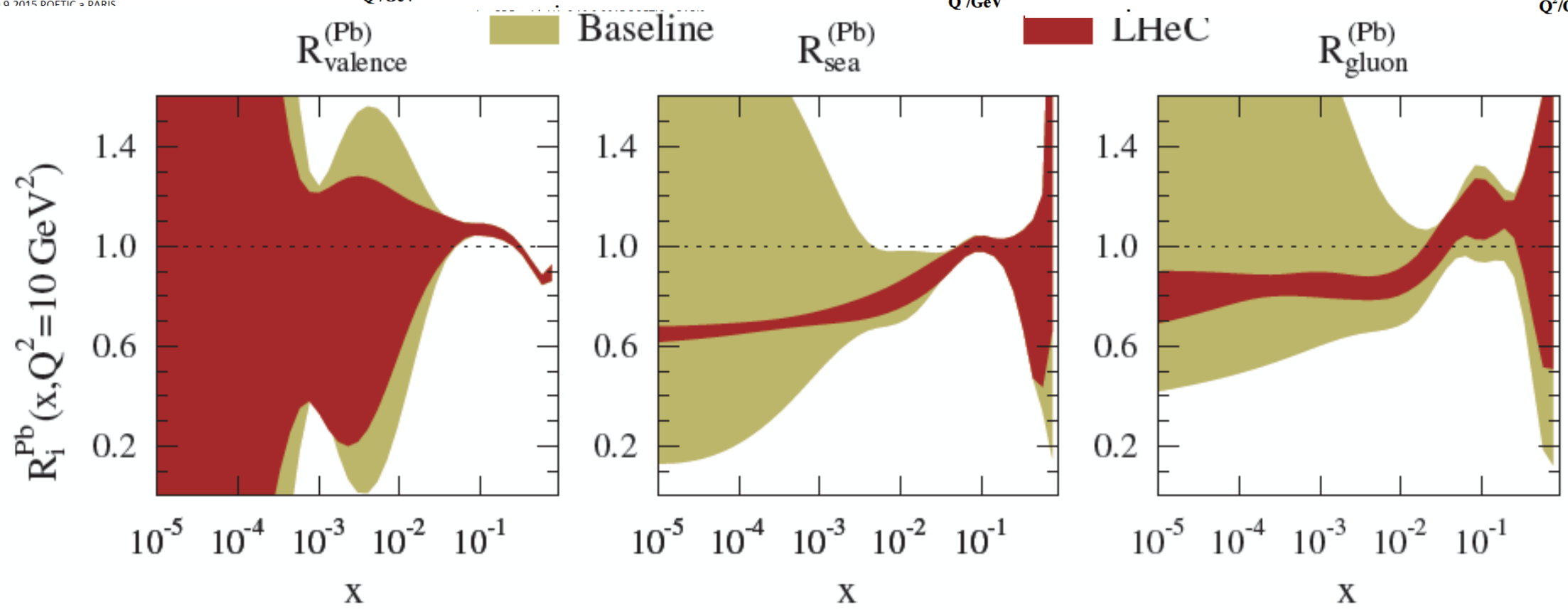
3-5%

Heavy Flavour – Strange in ePb - from CC

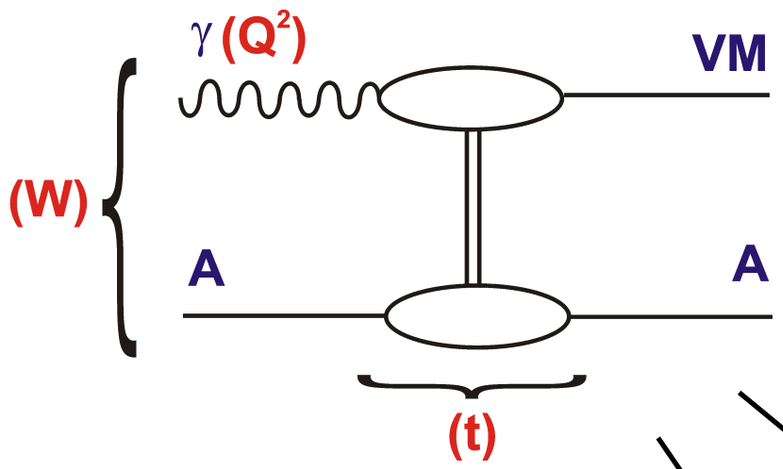


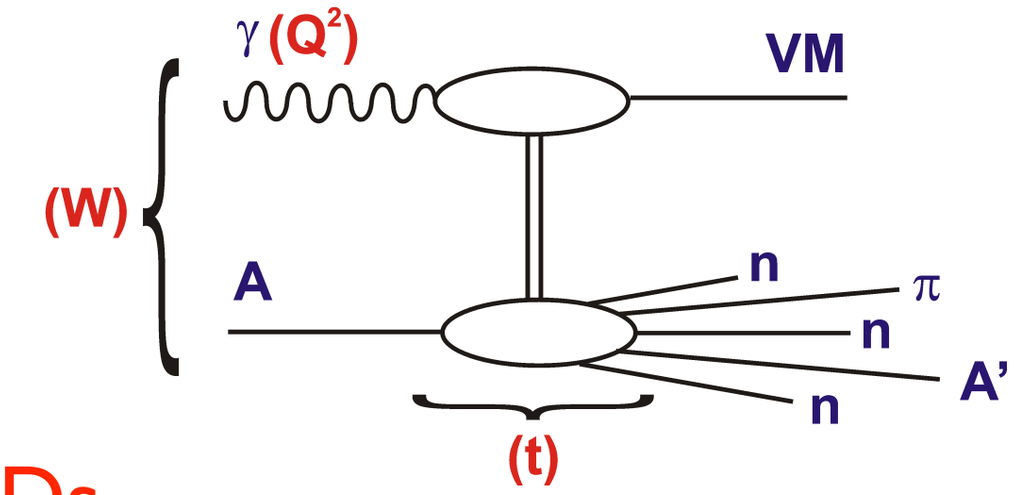
3-5%

10-20%

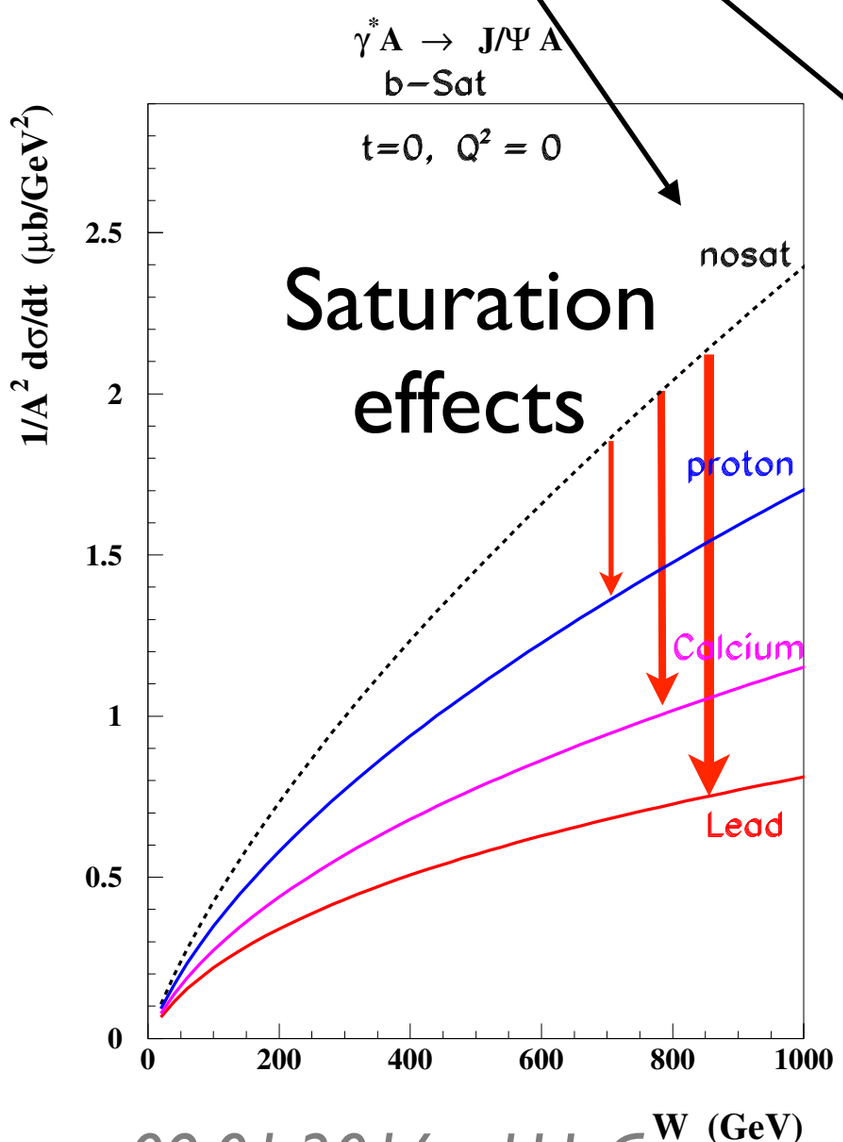


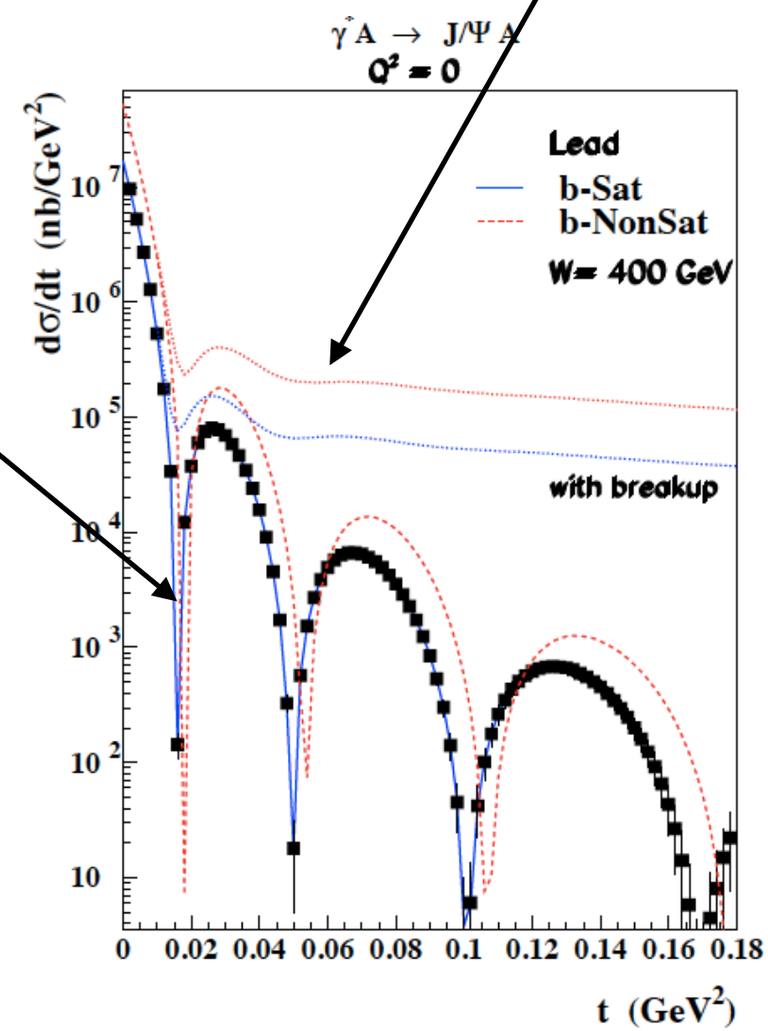
eA: diffractive





- Elastic VM: saturation, nGPDs.





The LHeC:

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], S.Alekhin[17,54], P.Allport[24], V.Andreev[34], R.B.Appleby[14,30], E.Arikan[39], N.Armesto[53,a], G.Azuelos[33,64], M.Bai[37], D.Barber[14,17,24], J.Bartels[18], O.Behnke[17], J.Behr[17], A.S.Belyaev[15,56], I.Ben-Zvi[37], N.Bernard[25], S.Bertolucci[16], S.Bettoni[16], S.Biswal[41], J.Blümlein[17], H.Böttcher[17], A.Bogacz[36], C.Bracco[16], G.Brandt[44], H.Braun[65], S.Brodsky[57,b], O.Brüning[16], E.Bulyak[12], A.Buniatyan[17], H.Burkhardt[16], I.T.Cakir[02], O.Cakir[01], R.Calaga[16], V.Cetinkaya[01], E.Ciapala[16], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[38], J.C.Collins[48], O.Dadoun[42], J.Dainton[24], A.De.Roeck[16], D.d'Enterria[16], A.Dudarev[16], A.Eide[60], R.Enberg[63], E.Eroglu[62], K.J.Eskola[21], L.Favart[08], M.Fitterer[16], S.Forte[32], A.Gaddi[16], P.Gambino[59], H.García Morales[16], T.Gehrmann[69], P.Gladkikh[12], C.Glasman[28], R.Godbole[35], B.Goddard[16], T.Greenshaw[24], A.Guffanti[13], V.Guzey[19,36], C.Gwenlan[44], T.Han[50], Y.Hao[37], F.Haug[16], W.Herr[16], A.Hervé[27], B.J.Holzer[16], M.Ishitsuka[58], M.Jacquet[42], B.Jeanneret[16], J.M.Jimenez[16], J.M.Jowett[16], H.Jung[17], H.Karadeniz[02], D.Kayran[37], A.Kilic[62], K.Kimura[58], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], G.Kramer[18], D.Kuchler[16], M.Kuze[58], T.Lappi[21,c], P.Laycock[24], E.Levichev[40], S.Levonian[17], V.N.Litvinenko[37], A.Lombardi[16], J.Maeda[58], C.Marquet[16], B.Mellado[27], K.H.Mess[16], A.Milanese[16], S.Moch[17], I.I.Morozov[40], Y.Muttoni[16], S.Myers[16], S.Nandi[55], Z.Nergiz[39], P.R.Newman[06], T.Omori[61], J.Osborne[16], E.Paoloni[49], Y.Papaphilippou[16], C.Pascaud[42], H.Paukkunen[53], E.Perez[16], T.Pieloni[23], E.Pilicer[62], B.Pire[45], R.Placakyte[17], A.Polini[07], V.Ptitsyn[37], Y.Pupkov[40], V.Radescu[17], S.Raychaudhuri[35], L.Rinolfi[16], R.Rohini[35], J.Rojo[16,31], S.Russenschuck[16], M.Sahin[03], C.A.Salgado[53,a], K.Sampei[58], R.Sassot[09], E.Sauvan[04], U.Schneekloth[17], T.Schörner-Sadenius[17], D.Schulte[16], A.Senol[22], A.Seryi[44], P.Sievers[16], A.N.Skrinsky[40], W.Smith[27], H.Spiesberger[29], A.M.Stasto[48,d], M.Strikman[48], M.Sullivan[57], S.Sultansoy[03,e], Y.P.Sun[57], B.Surrow[11], L.Szymanowski[66,f], P.Taels[05], I.Tapan[62], T.Tasci[22], E.Tassi[10], H.Ten.Kate[16], J.Terron[28], H.Thiesen[16], L.Thompson[14,30], K.Tokushuku[61], R.Tomás García[16], D.Tommasini[16], D.Trbojevic[37], N.Tsoupas[37], J.Tuckmantel[16], S.Turkoz[01], T.N.Trinh[47], K.Tywoniuk[26], G.Unel[20], J.Urakawa[61], P.VanMechelen[05], A.Variola[52], R.Veness[16], A.Vivoli[16], P.Vobly[40], J.Wagner[66], R.Wallny[68], S.Wallon[43,46,f], G.Watt[16], C.Weiss[36], U.A.Wiedemann[16], U.Wienands[57], F.Willeke[37], B.-W.Xiao[48], V.Yakimenko[37], A.F.Zarnecki[67], Z.Zhang[42], F.Zimmermann[16], R.Zlebcik[51], F.Zomer[42]

The LHeC:

Coordination Group

Gianluigi Arduini
Nestor Armesto
Oliver Brüning
Stefano Forte
Andrea Gaddi
Erk Jensen
Max Klein
Peter Kostka
Bruce Mellado
Paul Newman
Daniel Schulte
Frank Zimmermann

Physics Groups + Convenors

PDFs, QCD	Fred Olness, Voica Radescu
Higgs	Uta Klein, Masahiro Khuze
BSM	Georges Azuelos, Monica D'Onofrio
Top	Olaf Behnke, Christian Schwanenberger
Nuclei	Nestor Armesto
Small x	Paul Newman, Anna Stasto

Referees for Design Report

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

Tentative plans:

International Advisory Committee + Mandate

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Nichola Bianchi (Frascati)
Frederick Bordry (CERN)
Stan Brodsky (SLAC)
Hesheng Chen (IHEP Beijing)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (Chicago)
Victor A Matveev (JINR Dubna)
Shin-Ichi Kurokawa (Tsukuba)
Leandro Nisati (Rome)
Leonid Rivkin (Lausanne)
Herwig Schopper (CERN) – **Chair**
Jurgen Schukraft (CERN)
Achille Stocchi (LAL Orsay)
John Womersley (STFC)

IAC Composition June 2014, plus
Oliver Brüning Max Klein ex officio

Max Klein ICFA Beijing 10/2014

The IAC was invited in 12/13 by the DG with the following

Mandate 2014-2017

Advice to the LHeC Coordination Group and the CERN directorate by following the development of options of an ep/eA collider at the LHC and at FCC, especially with:

Provision of scientific and technical direction for the physics potential of the ep/eA collider, both at LHC and at FCC, as a function of the machine parameters and of a realistic detector design, as well as for the design and possible approval of an ERL test facility at CERN.

Assistance in building the international case for the accelerator and detector developments as well as guidance to the resource, infrastructure and science policy aspects of the ep/eA collider.

Tentative plans:

International Advisory Committee + Mandate

- Update of the CDR for 2017, ready for the next European Strategy of Particle Physics in 2018:
  - ➜ Update of physics case in view of LHC findings.
  - ➜ ERL test facility.
  - ➜ Accelerator: IR.
  - ➜ Detector.

- Ongoing discussions with the new CERN management. Next workshop: around September 2016.

- Any decision pending on LHC findings in Run II.

- In current schedule, LHC expected to operate until ~ 2037.

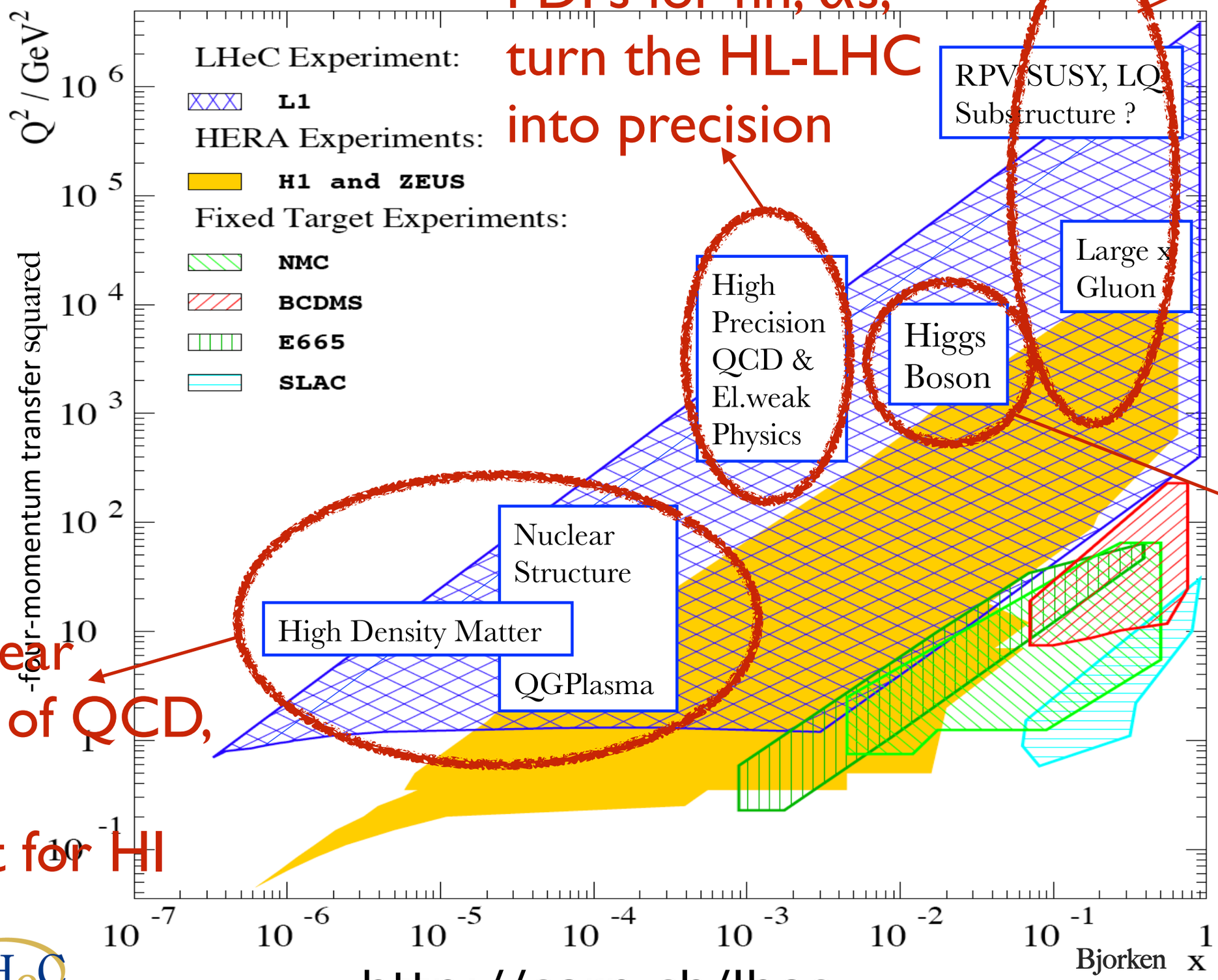
Oliver Brüning - Max Klein ex officio

Max Klein ICFA Beijing 10/2014

Summarising:

PDFs for hh, αs, turn the HL-LHC into precision

Direct BSM searches



Higgs factory

Non-linear domain of QCD, physics relevant for HI

http://cern.ch/lhec

Summarising:

Many thanks to:
➜ Anna, Hannu, Max, Paul,…
➜ The organisers for the invitation.
➜ You all for your attention!!!

PDFs for hh, αs, turn the HL-LHC into precision

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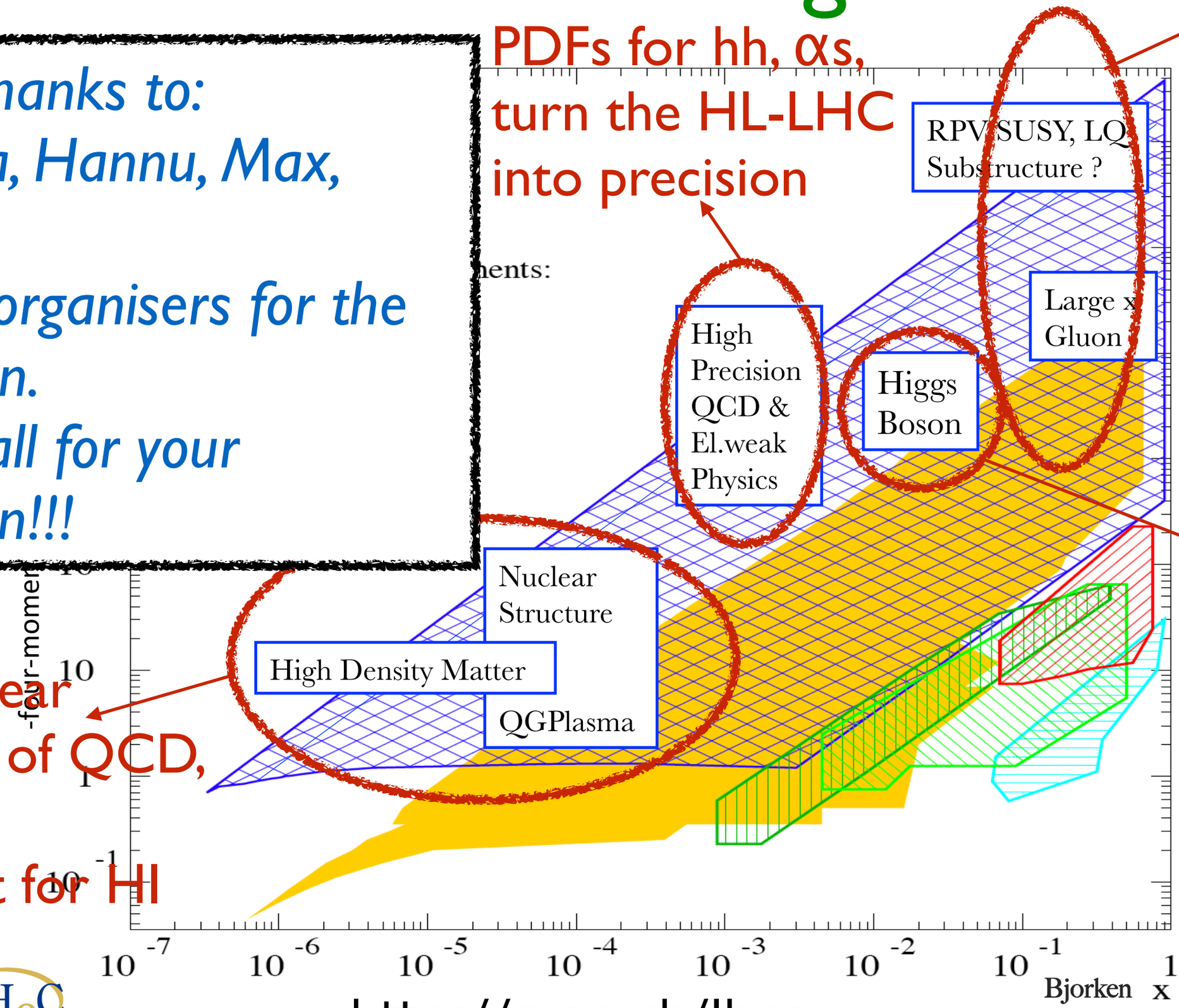

Higgs factory

Non-linear domain of QCD, physics relevant for HI

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Backup:

FCC:

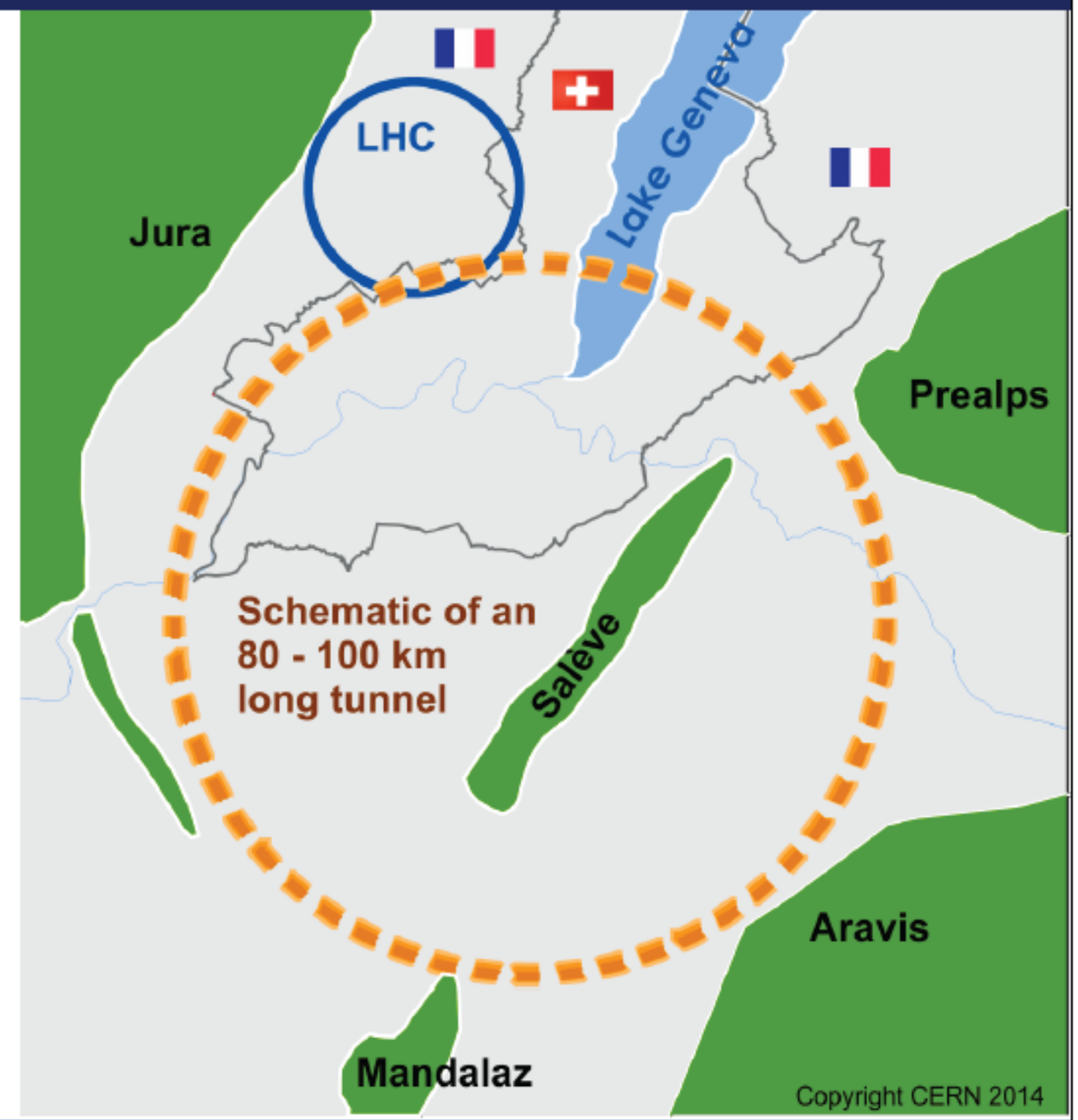
Future Circular Collider Study - SCOPE
CDR and cost review for the next ESU (2018)

Forming an international collaboration to study:

- ***pp*-collider (*FCC-hh*)**
  → defining infrastructure requirements

  ~16 T ⇒ 100 TeV *pp* in 100 km
  ~20 T ⇒ 100 TeV *pp* in 80 km

- **e^+e^- collider (*FCC-ee*)** as potential intermediate step
  120-350 GeV
- ***p-e* (*FCC-he*) option**
- **80-100 km infrastructure** in Geneva area



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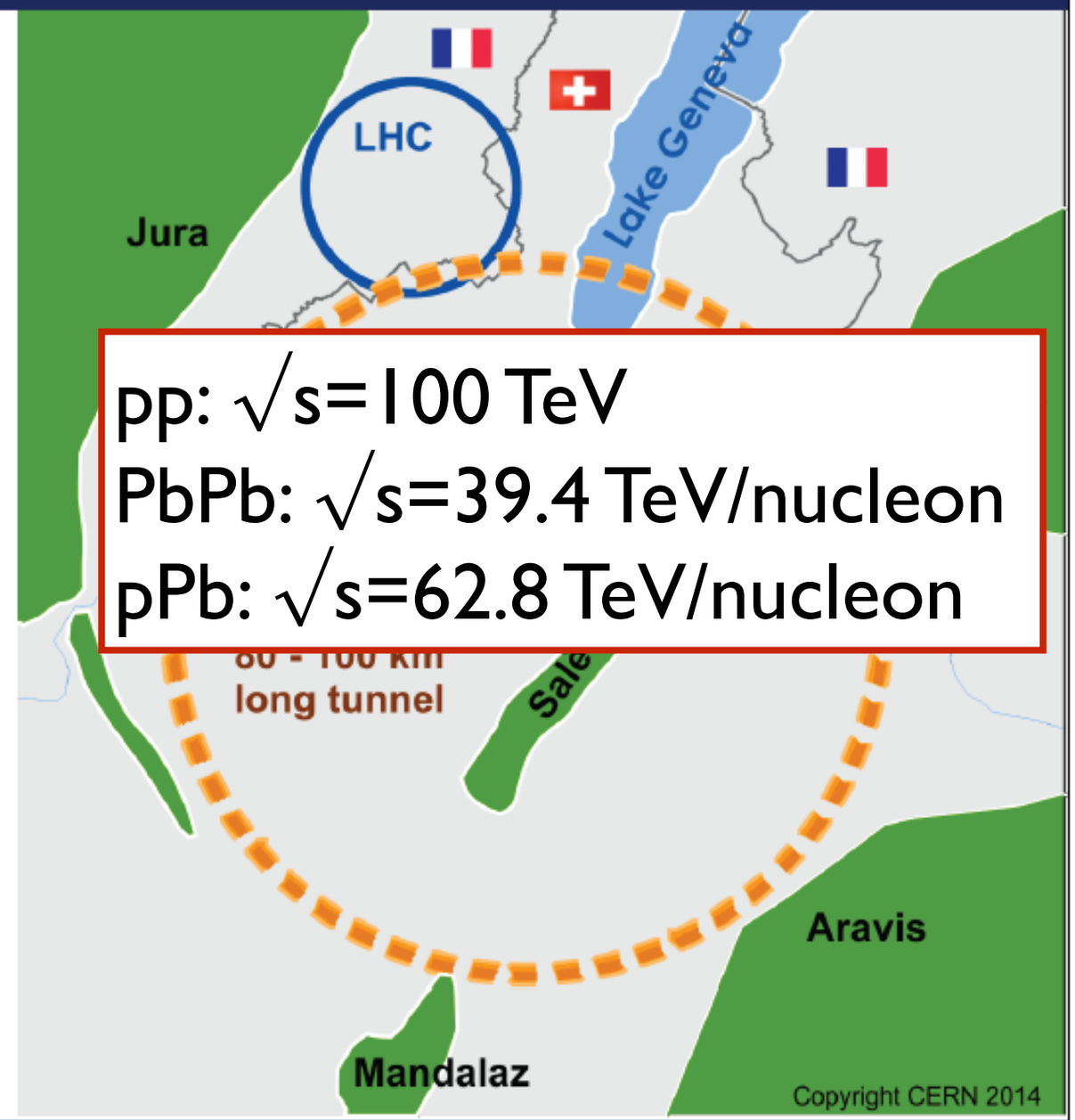


pp: $\sqrt{s}$=100 TeV
PbPb: $\sqrt{s}$=39.4 TeV/nucleon
pPb: $\sqrt{s}$=62.8 TeV/nucleon

Future Circular Collider Study
Michael Benedikt
FCC Kick-Off 2014
5

FCC:

93 km option (Lebrun in Washington DC)

Alignment | **Shaft Tools**

Choose alignment option

93km quasi-circular

Tunnel depth at centre: 286mASL

Gradient Parameters

Azimuth (°):	-15
Slope Angle x-x(%):	.3
Slope Angle y-y(%):	0

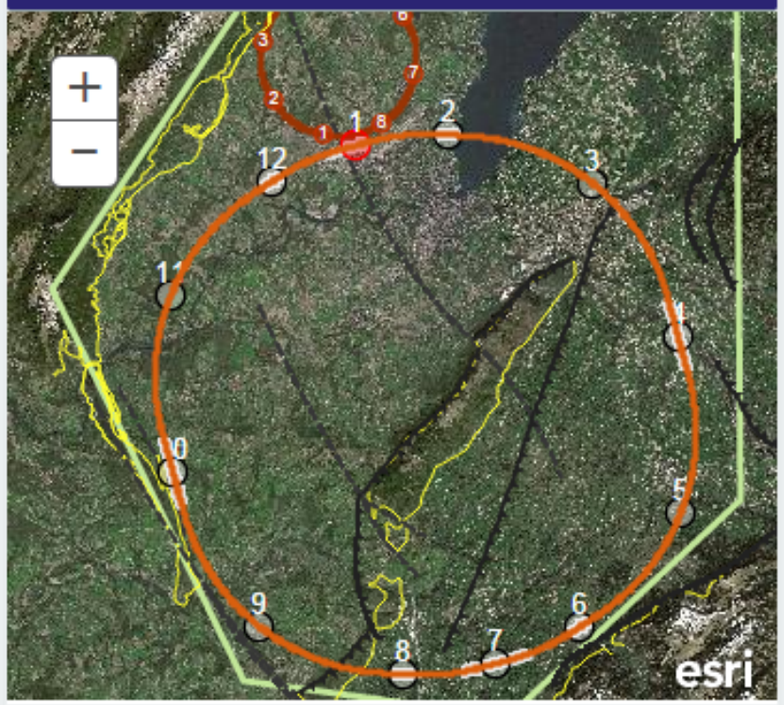
CALCULATE

Alignment centre

X: 2498923 Y: 1106695

LHC Intersection	IP 1	IP 2
Angle	1°	-1°
Depth	542m	542m

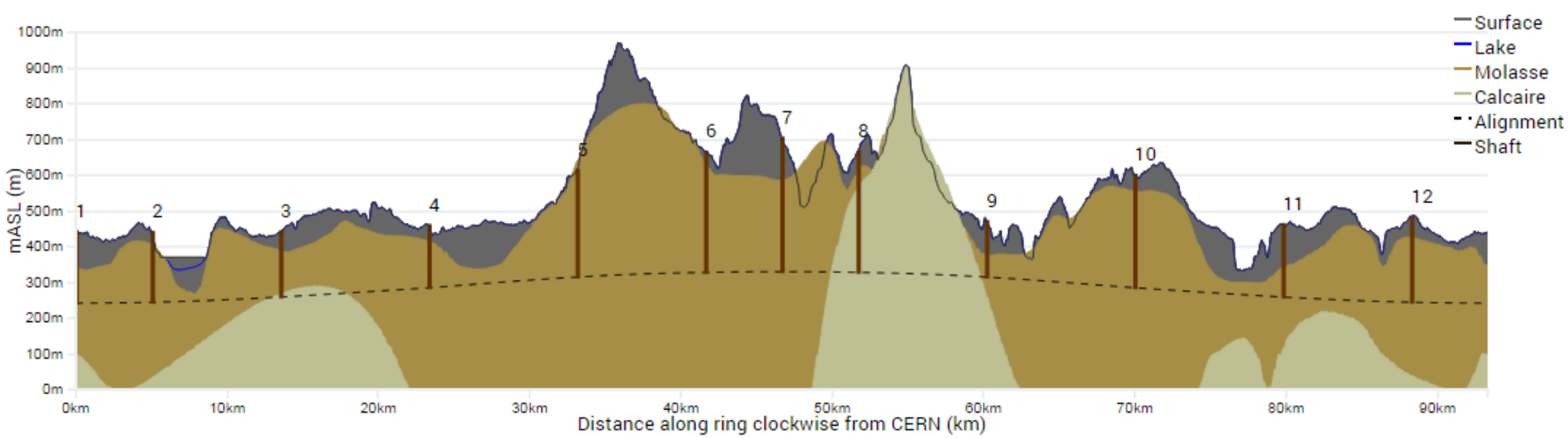
Alignment Location



Geology Intersected by Shafts | **Shaft Depths**

Shaft	Shaft Depth (m) Actual	Min	Mean	Max	Geology (m) Moraine	Molasse	Calcaire
1	200	195	197	200	92	108	0
2	196	143	181	211	34	162	0
3	183	175	184	194	53	121	9
4	174	146	166	178	44	130	0
5	299	286	311	350	0	325	0
6	336	325	339	350	35	302	0
7	374	349	377	412	119	256	0
8	337	318	341	366	44	56	237
9	155	131	145	167	94	61	0
10	315	305	320	336	46	269	0
11	203	199	202	204	122	81	0
12	239	229	238	243	58	181	0
Total	3014	2801	3001	3211	741	2052	247

Alignment Profile



FCC:

100 km option (Lebrun in Washington DC)

Alignment | **Shaft Tools**

Choose alignment option

100km quasi-circular

Tunnel depth at centre: 263mASL

Gradient Parameters

Azimuth (°): -20

Slope Angle x-x(%): .65

Slope Angle y-y(%): 0

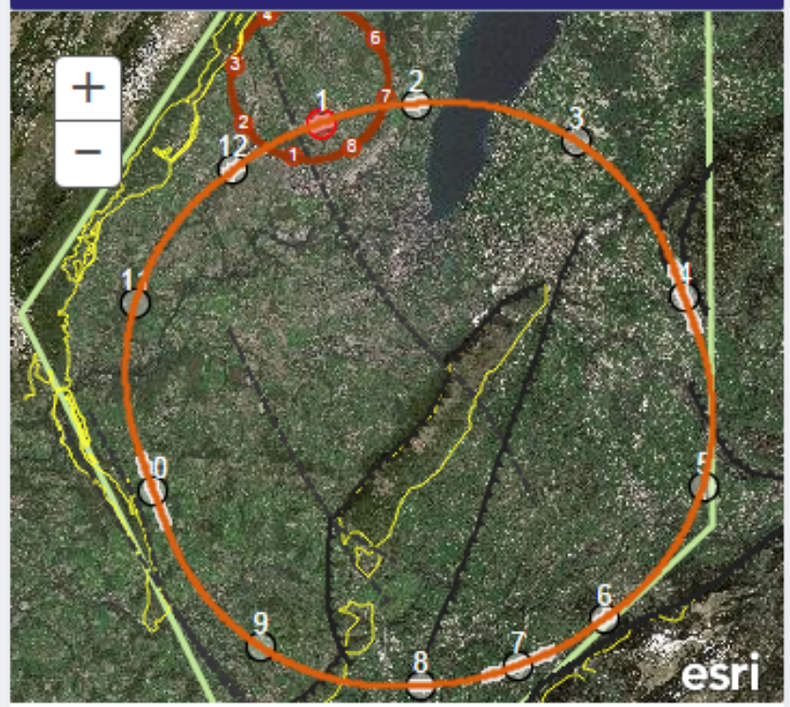
CALCULATE

Alignment centre

X: 2500119 Y: 1108575

LHC Intersection	IP 1	IP 2
Angle	-65°	65°
Depth	221m	180m

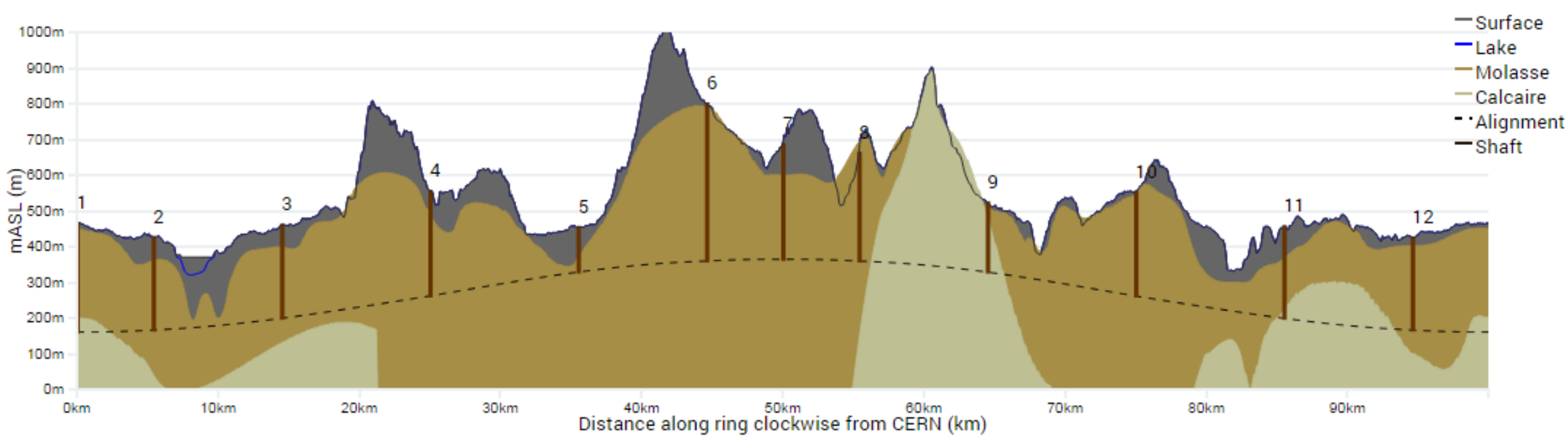
Alignment Location



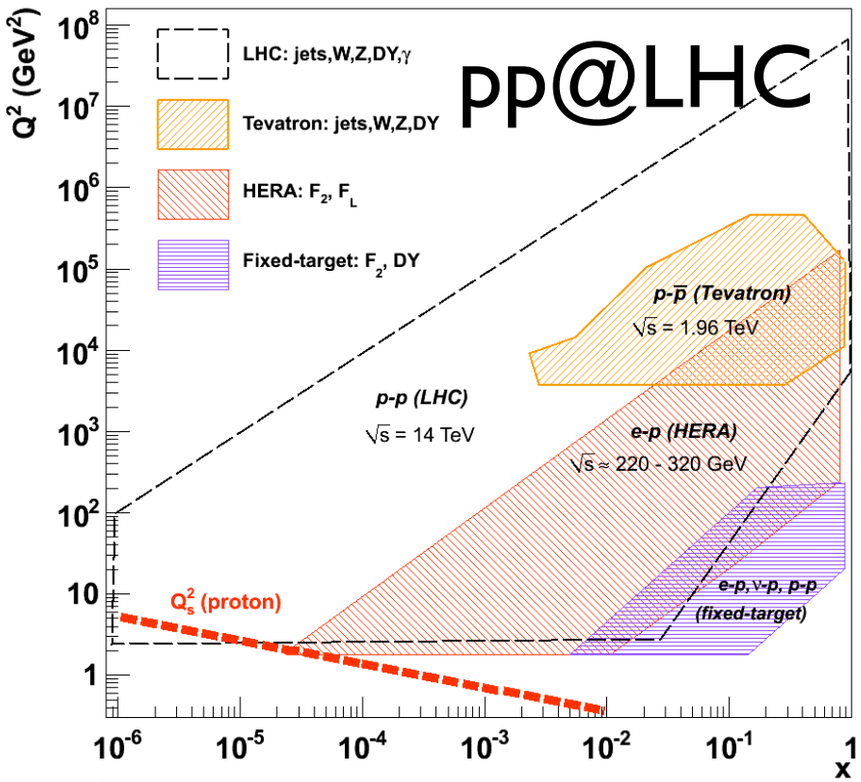
Geology Intersected by Shafts | **Shaft Depths**

Shaft	Shaft Depth (m) Actual	Min	Mean	Max	Geology (m) Moraine	Molasse	Calcaire
1	304	303	305	306	16	248	40
2	260	260	263	271	65	195	0
3	261	249	258	262	62	199	0
4	293	269	296	322	64	229	0
5	125	124	127	129	85	40	0
6	440	432	441	451	10	431	0
7	321	302	332	368	85	235	0
8	302	235	304	358	0	333	0
9	195	184	195	204	15	18	161
10	291	289	296	307	7	285	0
11	257	247	252	257	89	149	19
12	259	258	262	266	23	236	0
Total	3309	3152	3331	3501	521	2597	220

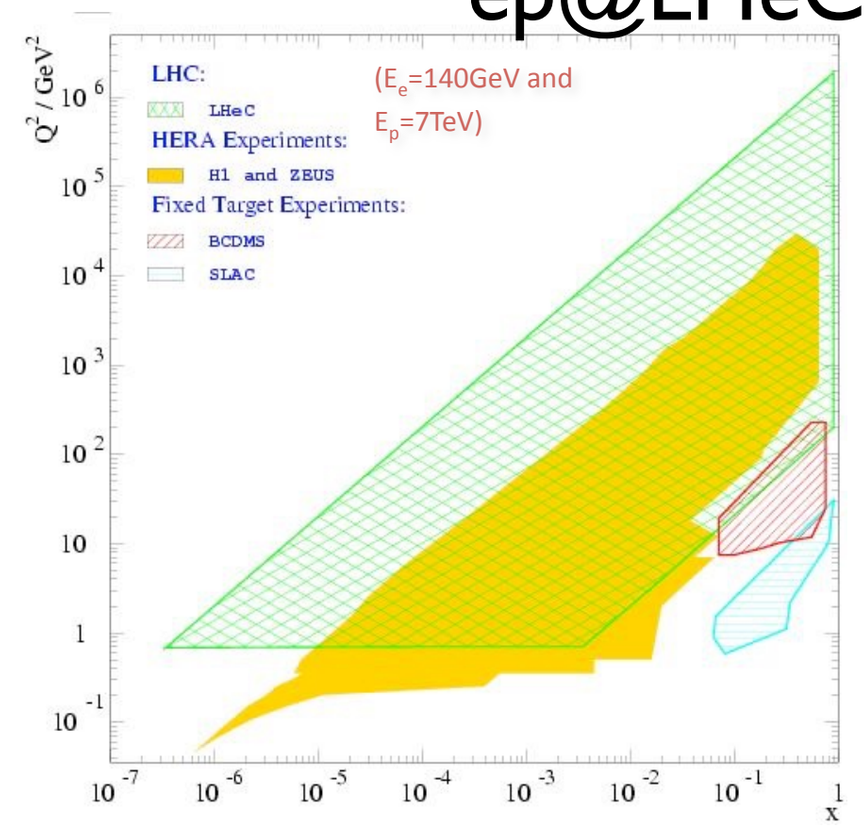
Alignment Profile

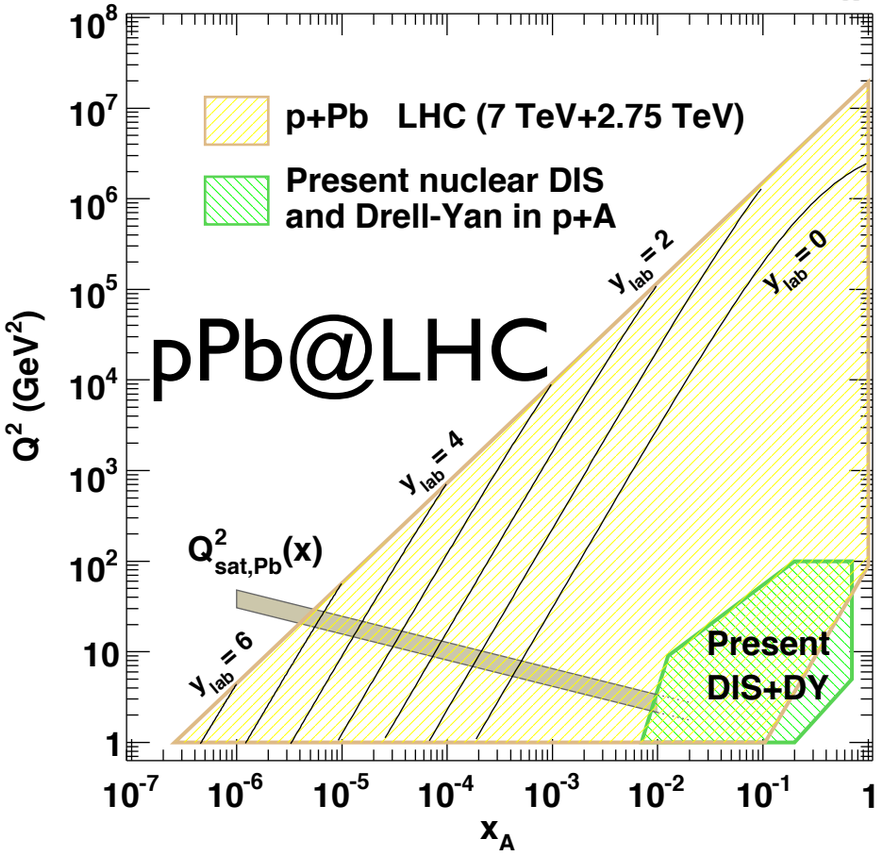


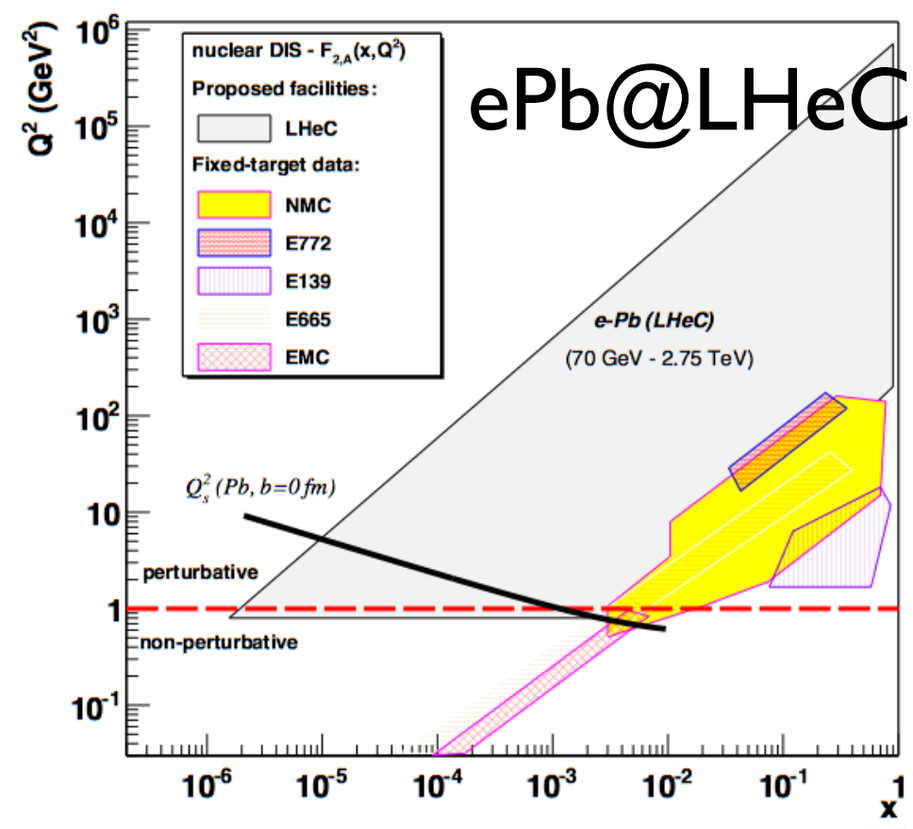
LHC vs. LHeC:



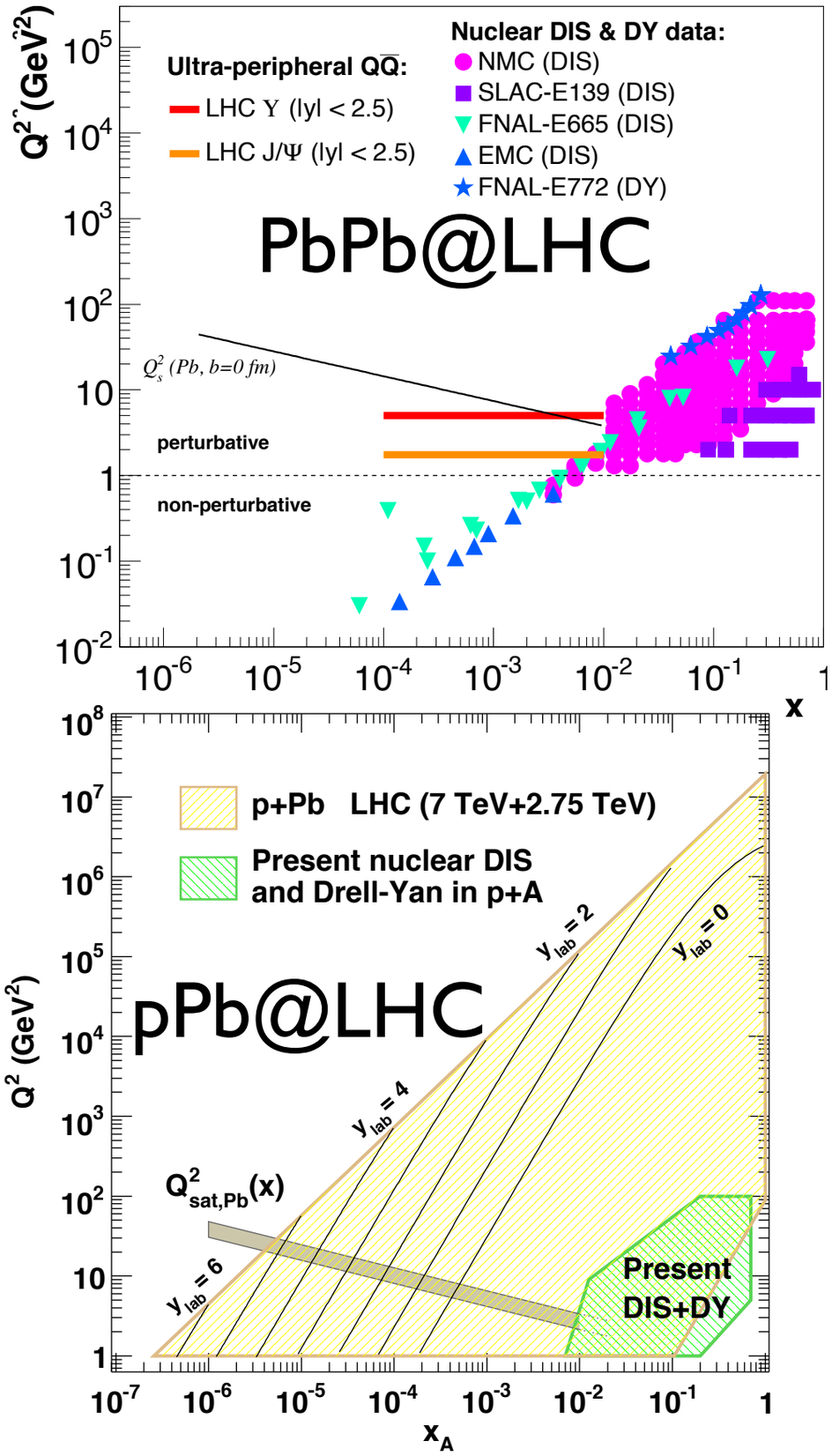
ep@LHeC



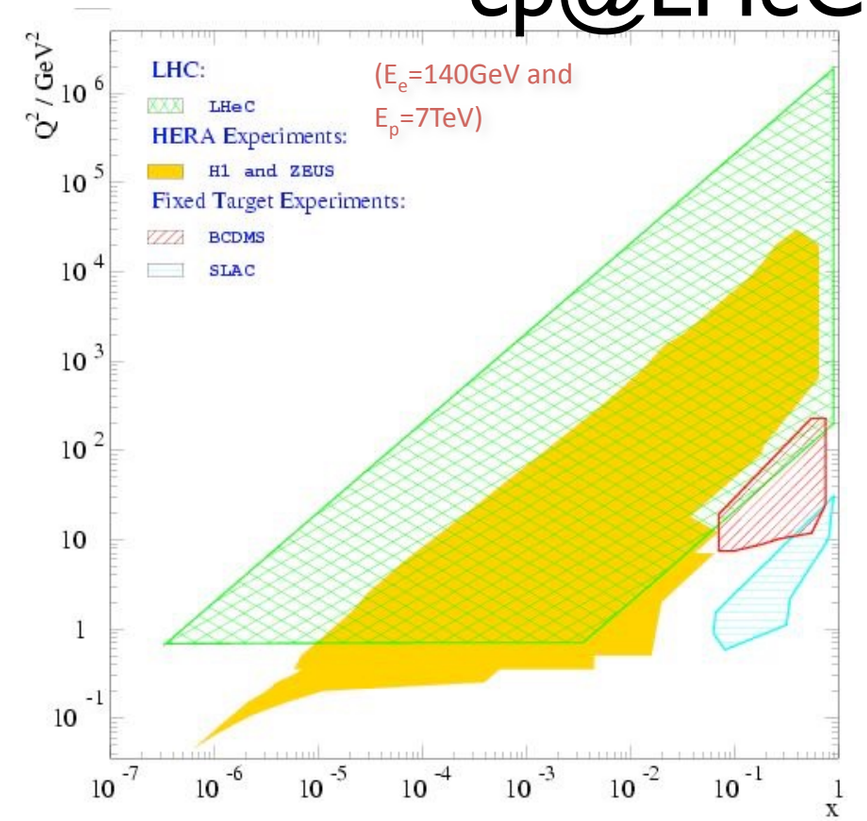




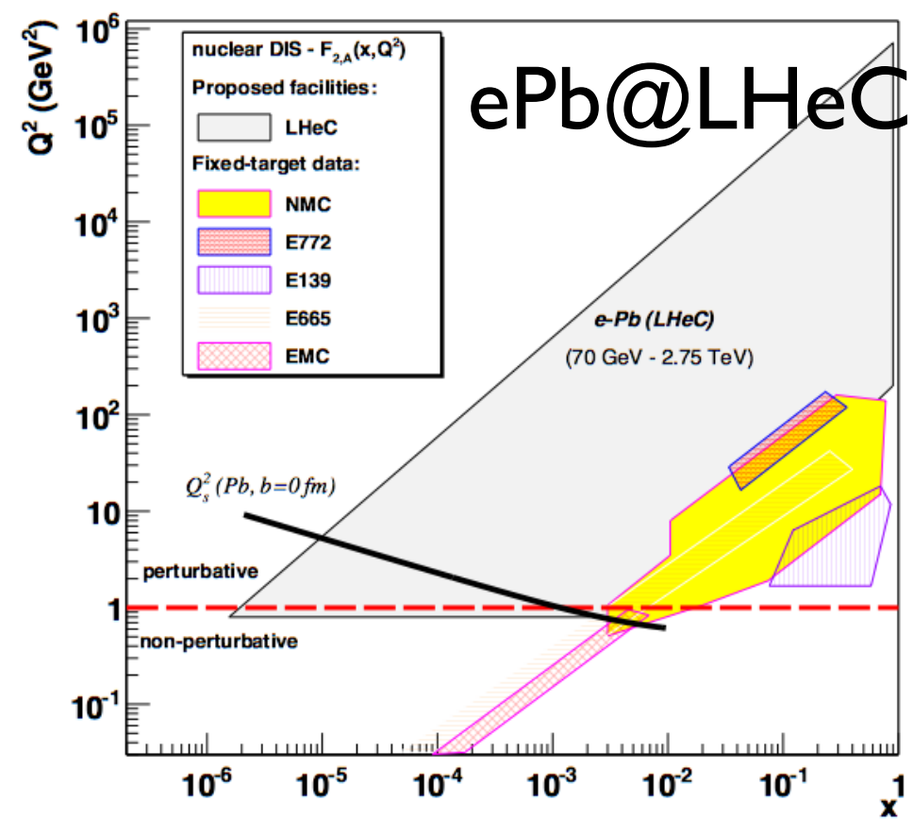
LHC vs. LHeC:



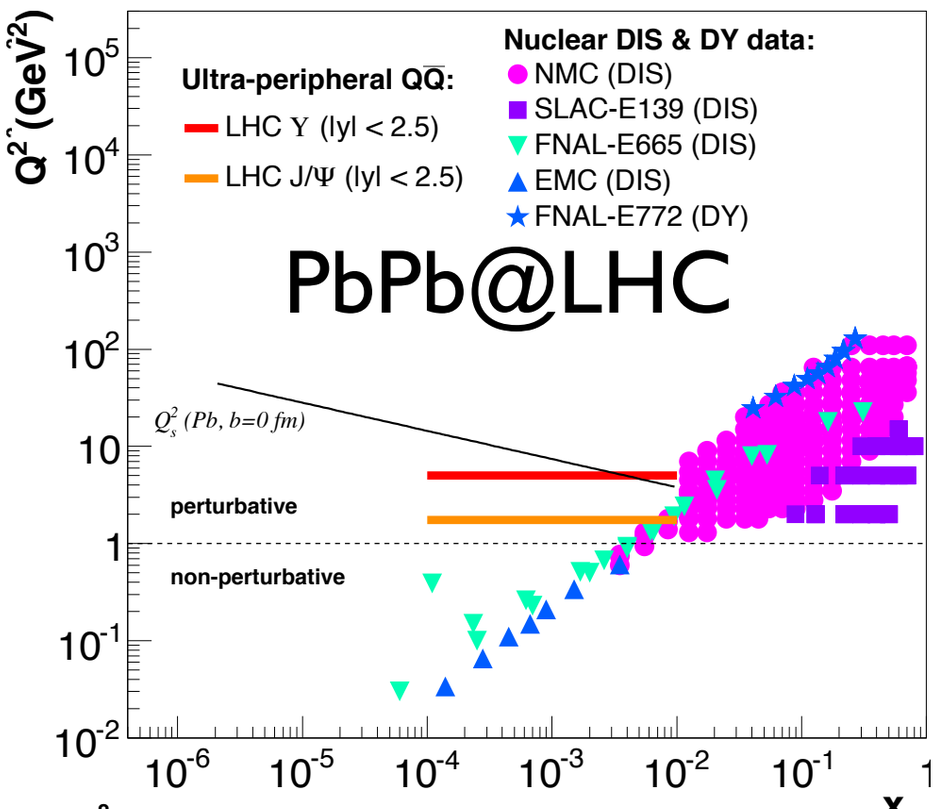
ep@LHeC

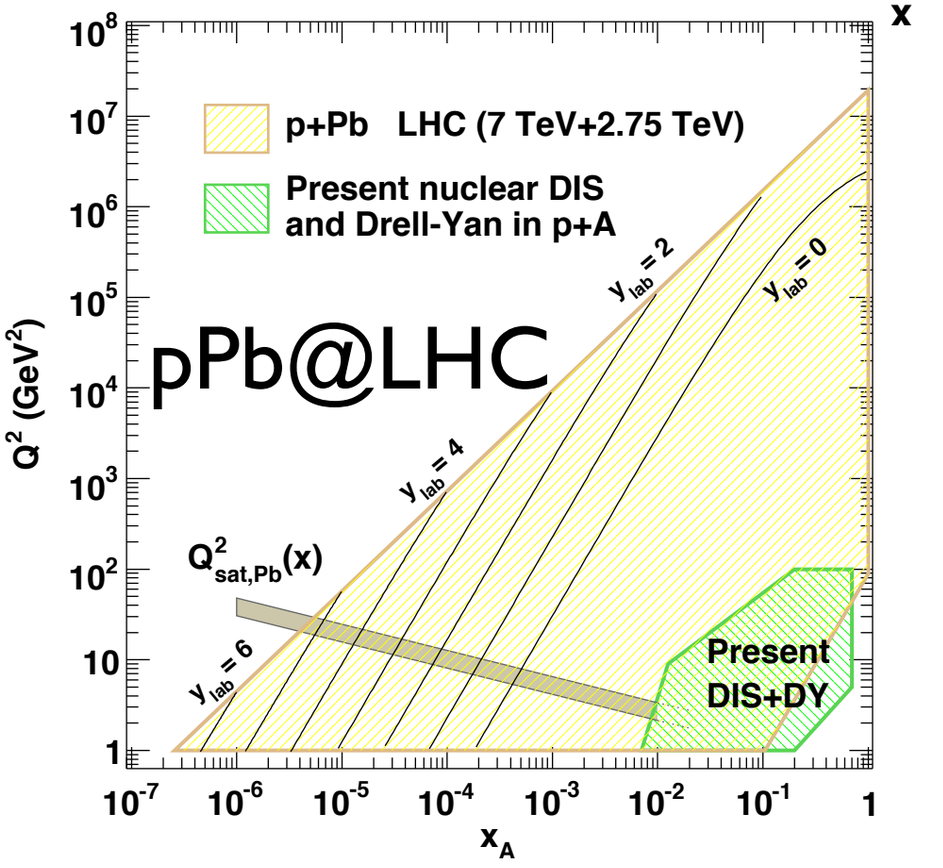


ePb@LHeC



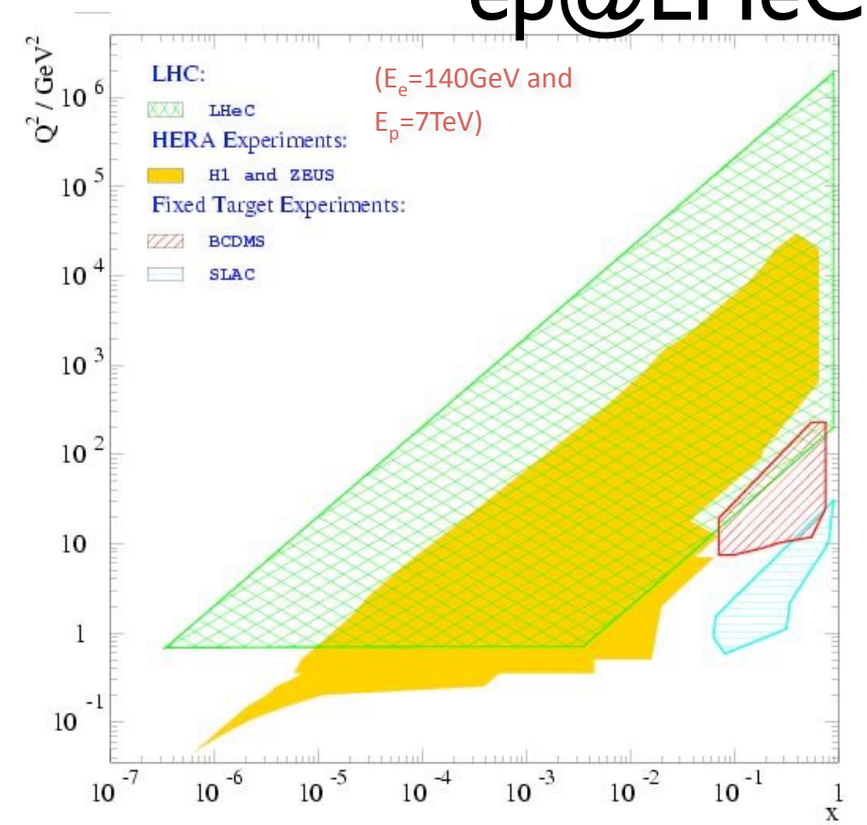
LHC vs. LHeC:

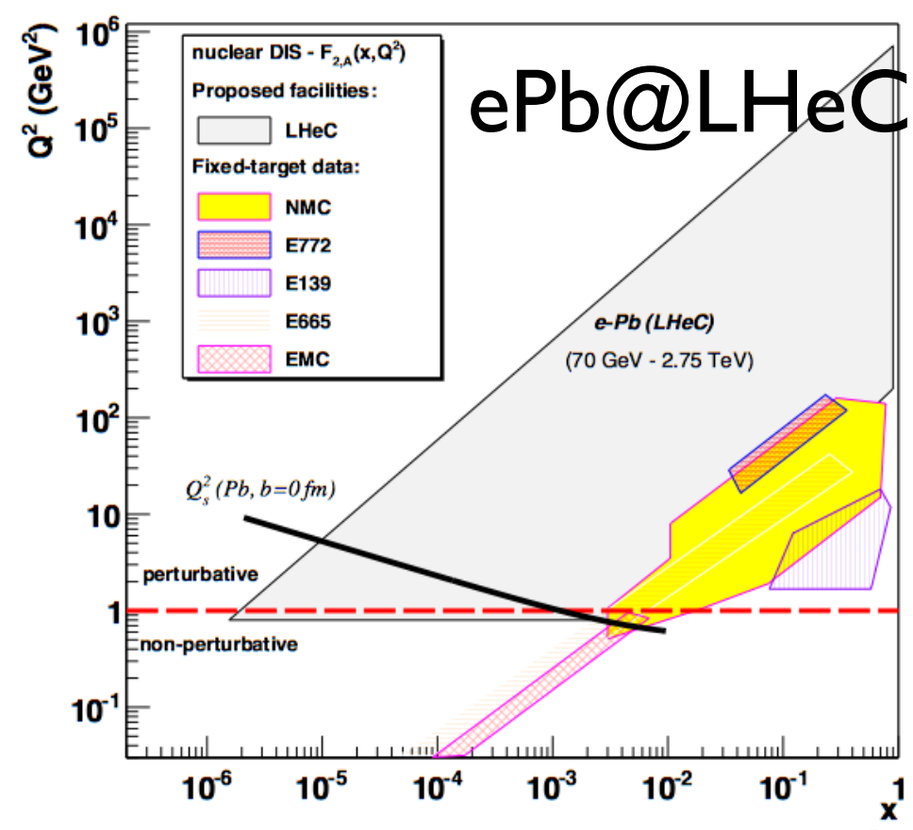




- The LHeC will explore a region overlapping with the LHC:
  - ➜ in a cleaner experimental setup;
  - ➜ on firmer theoretical grounds.

ep@LHeC





PDFs with LHC:

S. Forte at ECFA, Nov. 2015

HERA AND LHC DATA: WHAT IS THE RELATIVE IMPACT?

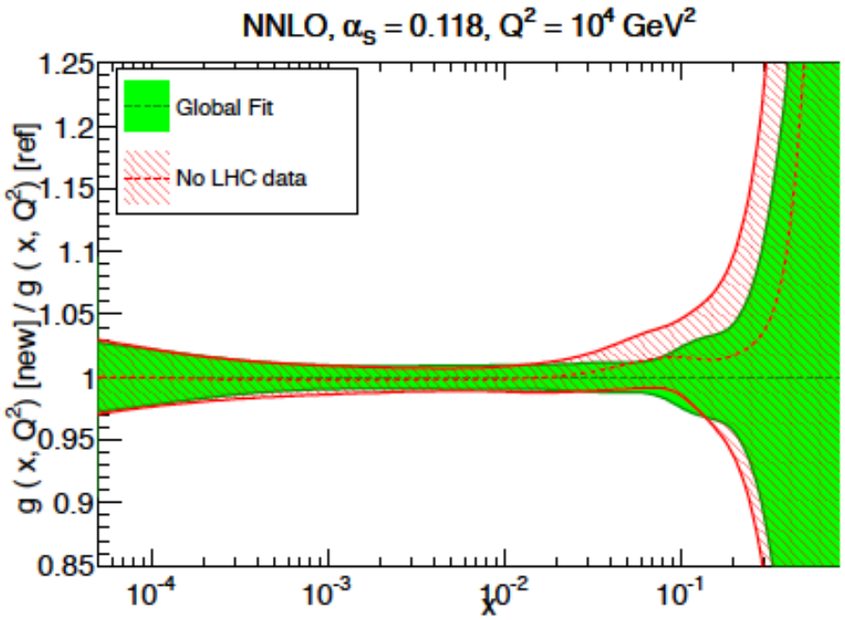
- OVERALL MEASURE OF IMPACT: $\varphi \Rightarrow$ FIT UNCERTAINTY/DATA UNCERTAINTY
- HERA-II IMPACT SIZABLE
- IMPACT OF LHC DATA MODERATE BUT VISIBLE
- IMPACT OF CMS OR ATLAS COMPARABLE TO (MODERATE) IMPACT OF NON-LHC, NON-HERA DATA

FRACTIONAL UNCERTAINTY

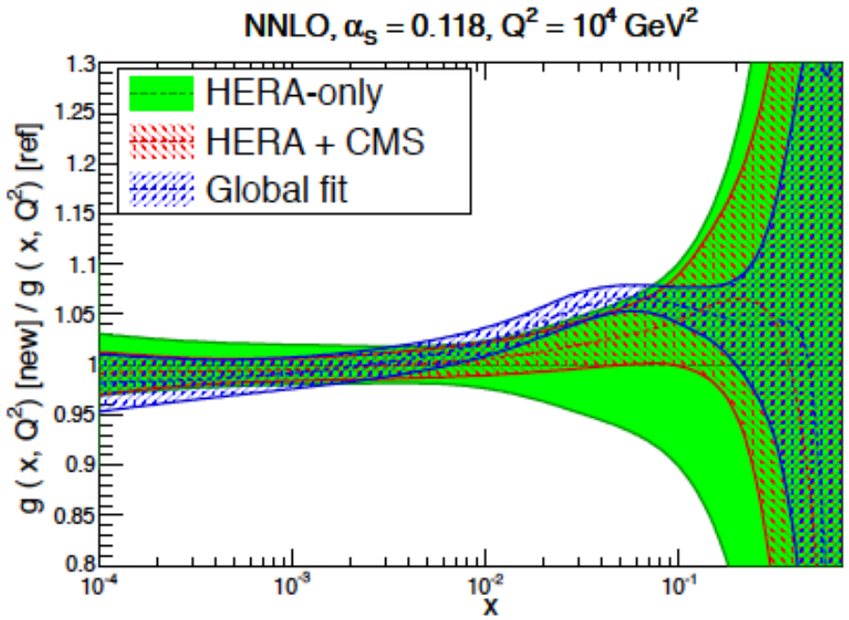
Dataset	φ NLO	φ NNLO
Global	0.291	0.302
HERA-I	0.453	0.439
HERA all	0.375	0.343
HERA+ATLAS	0.391	0.318
HERA+CMS	0.315	0.345
no LHC	0.312	0.316

THE GLUON

GLOBAL VS NO LHC



GLOBAL VS HERA+CMS



PDFs with LHC:

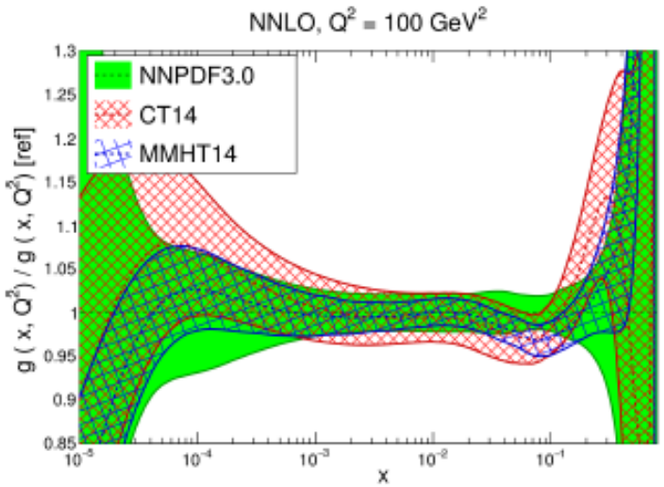
S. Forte at ECFA, Nov. 2015

PDFS AT LHC RUN II

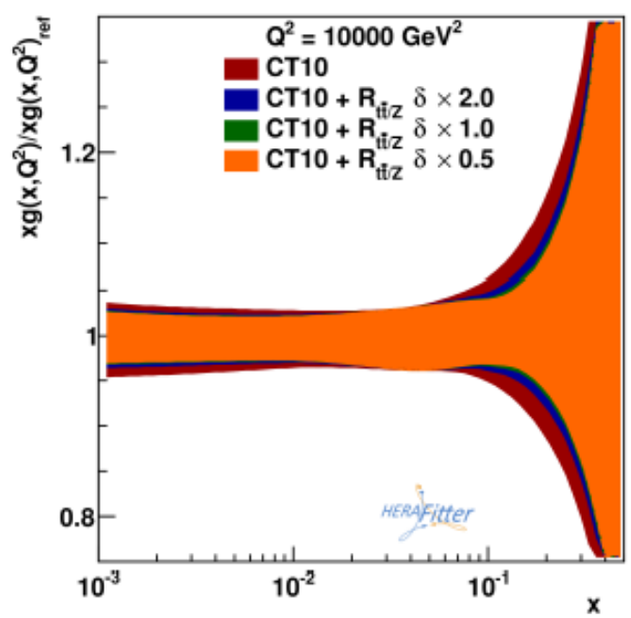
- DATA AT HIGHER CM ENERGY & INFO ON CORRELATION TO LOW ENERGY
  → EXTENDED KINEMATIC COVERAGE & REDUCED SYSTEMATICS
- EXPECT REDUCTION IN MODEL DEPENDENCE
- MODERATE REDUCTION IN UNCERTAINTY

GLUON

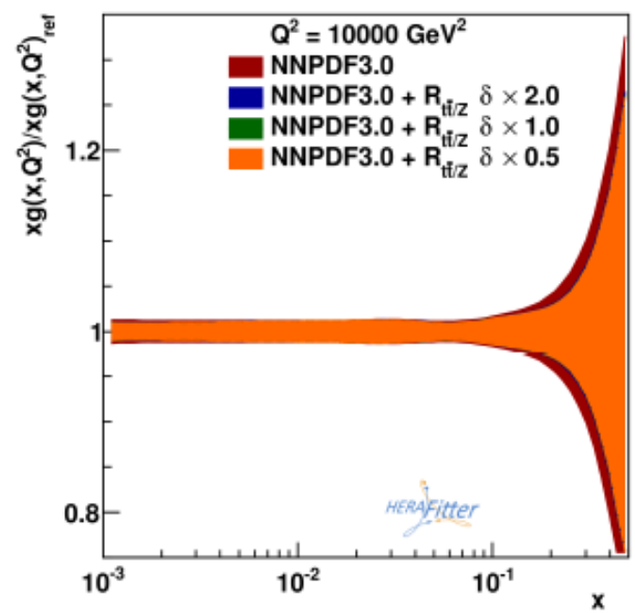
NOW



CTEQ AFTER RUN II



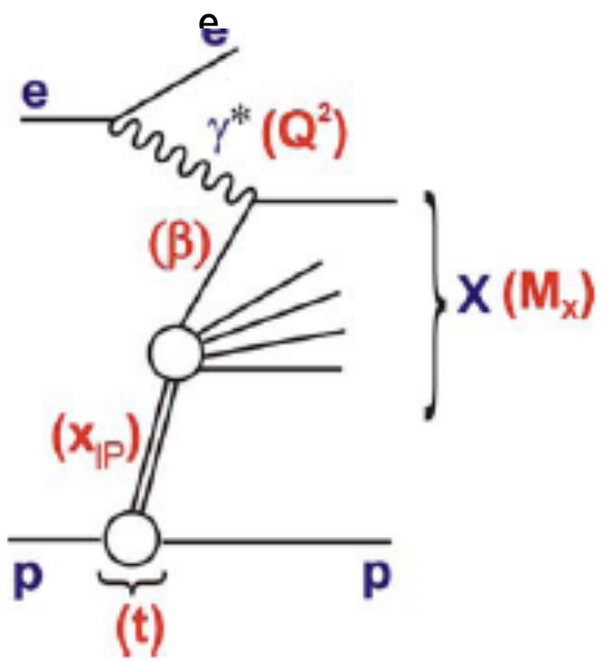
NNPDF AFTER RUN II

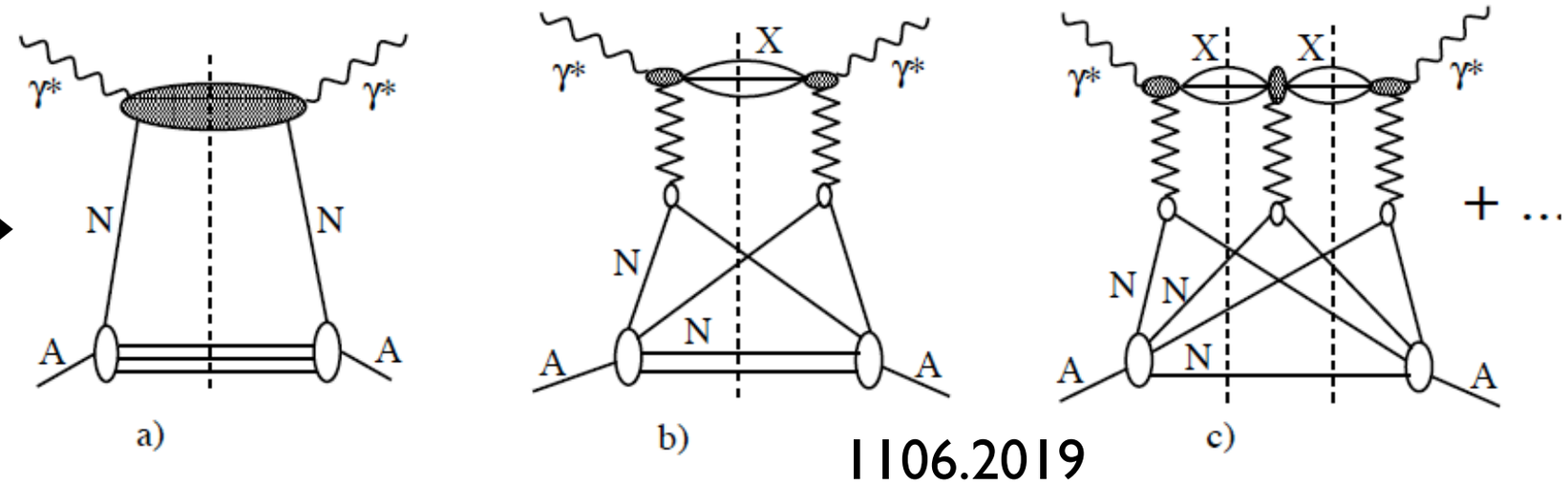


(PDF4LHC: 1507.00556)

VERY DIFFICULT TO REDUCE UNCERTAINTIES BELOW 3-4% LEVEL
AT A HADRON COLLIDER

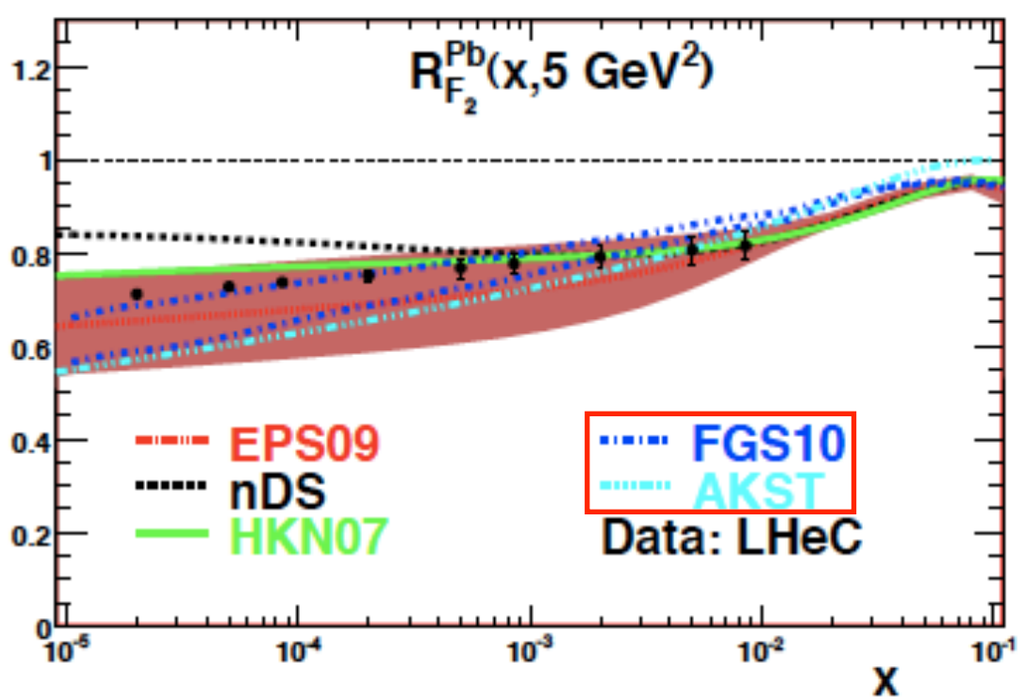
Diffraction in ep and shadowing:

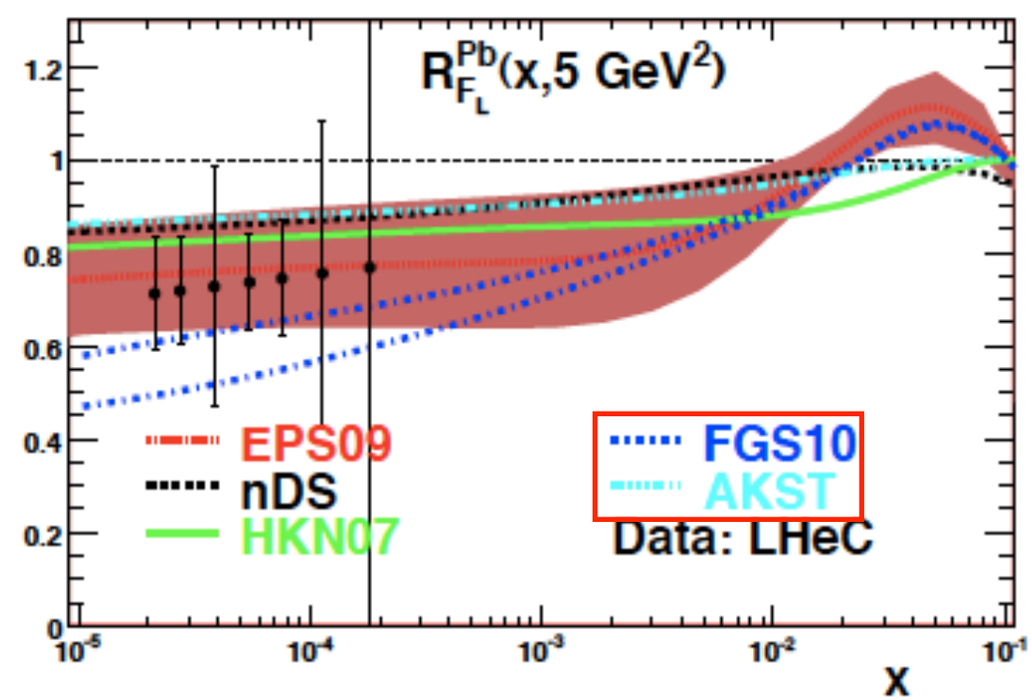




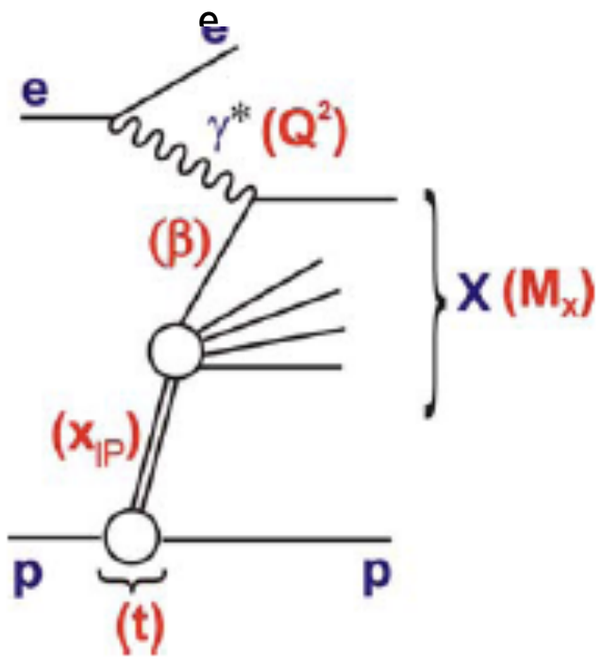
1106.2019

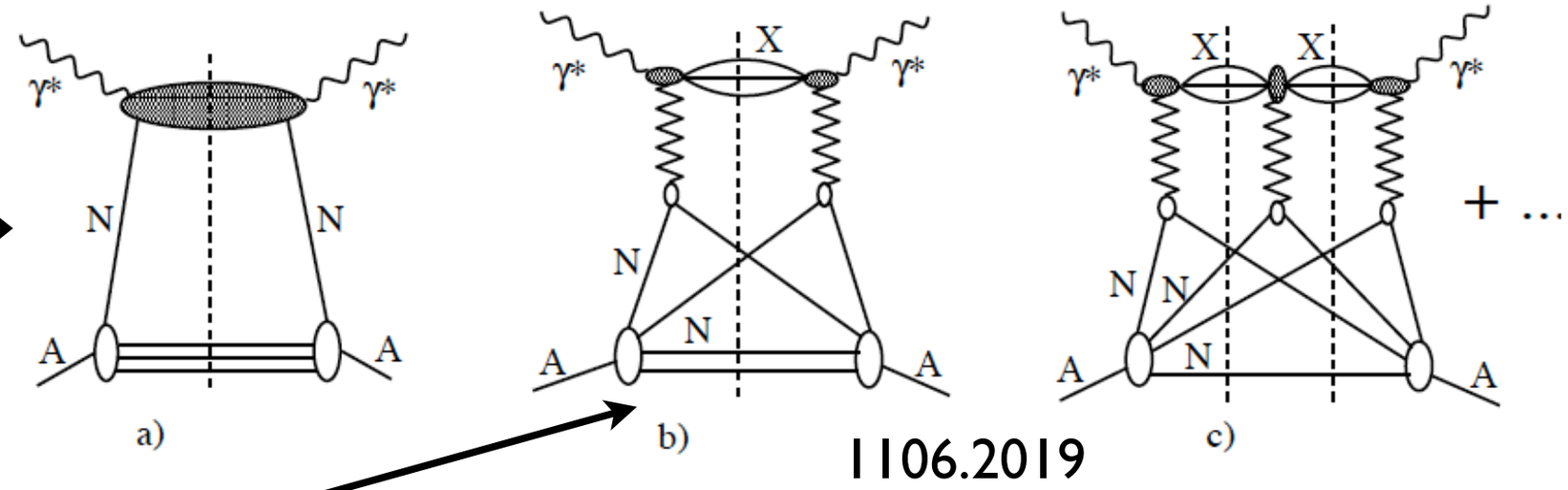
- Diffraction is linked to nuclear shadowing through basic QFT (Gribov): eD to test and set the 'benchmark' for new effects.





Diffraction in ep and shadowing:





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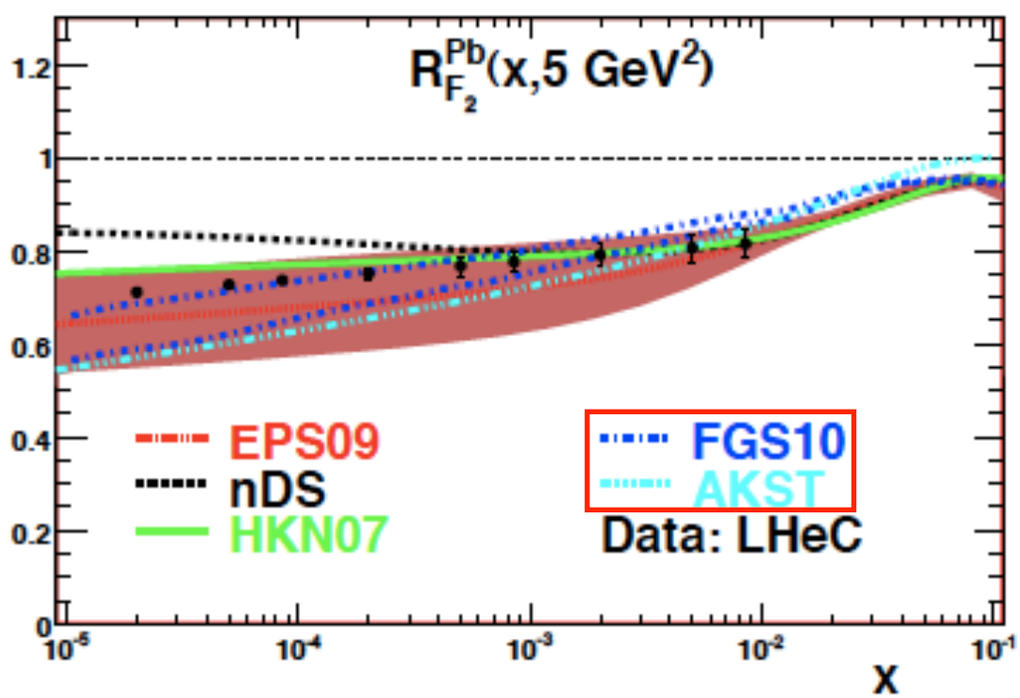
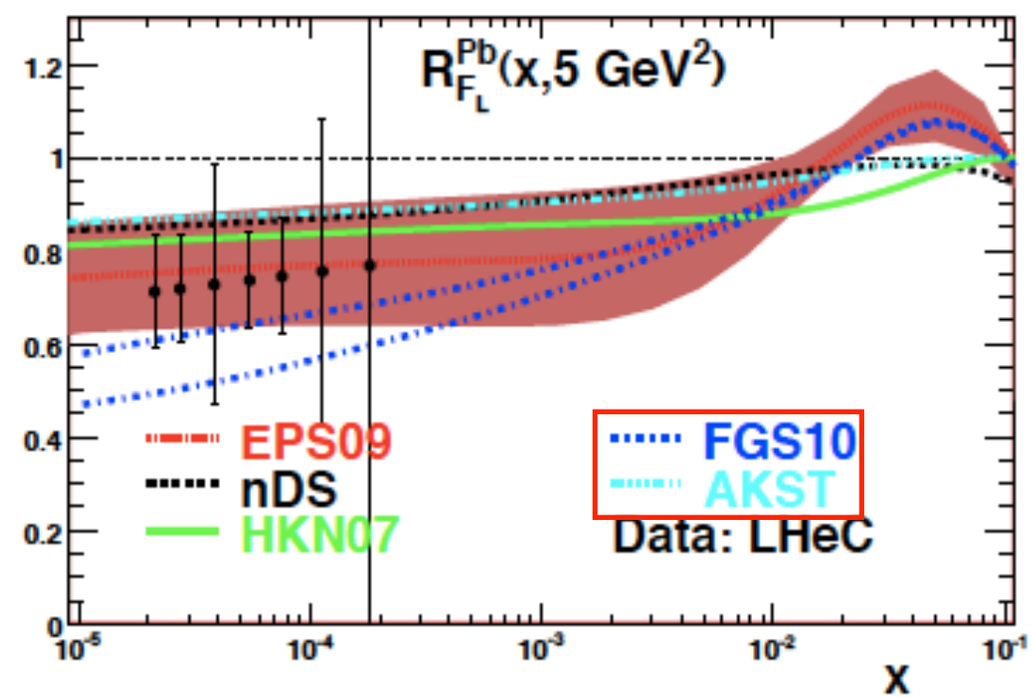
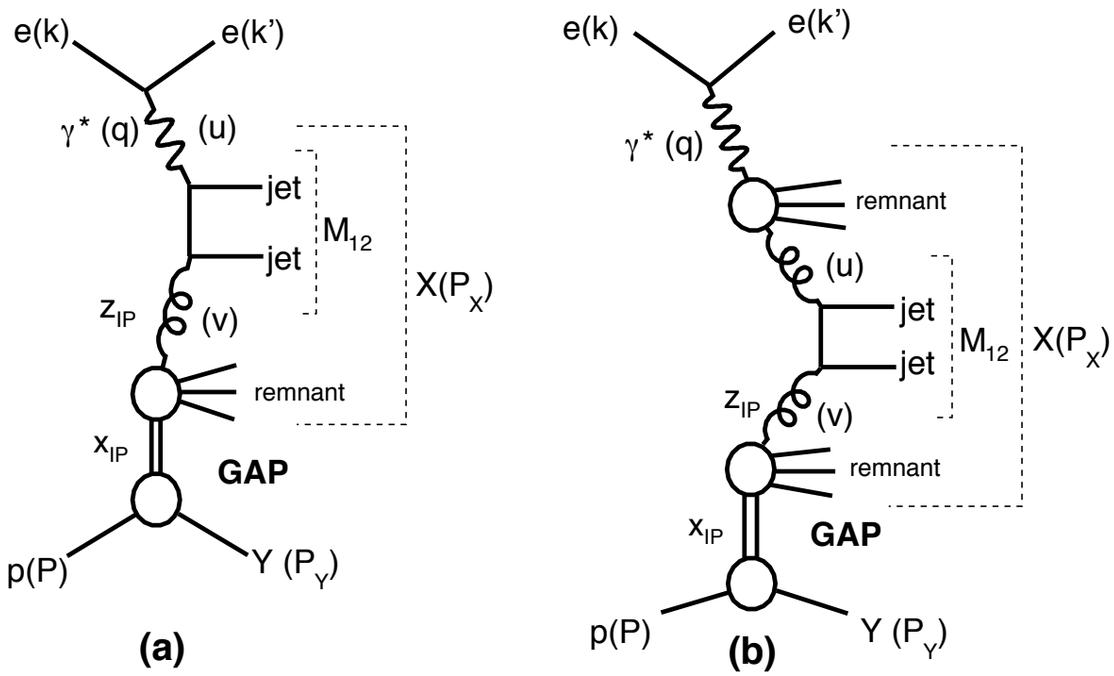
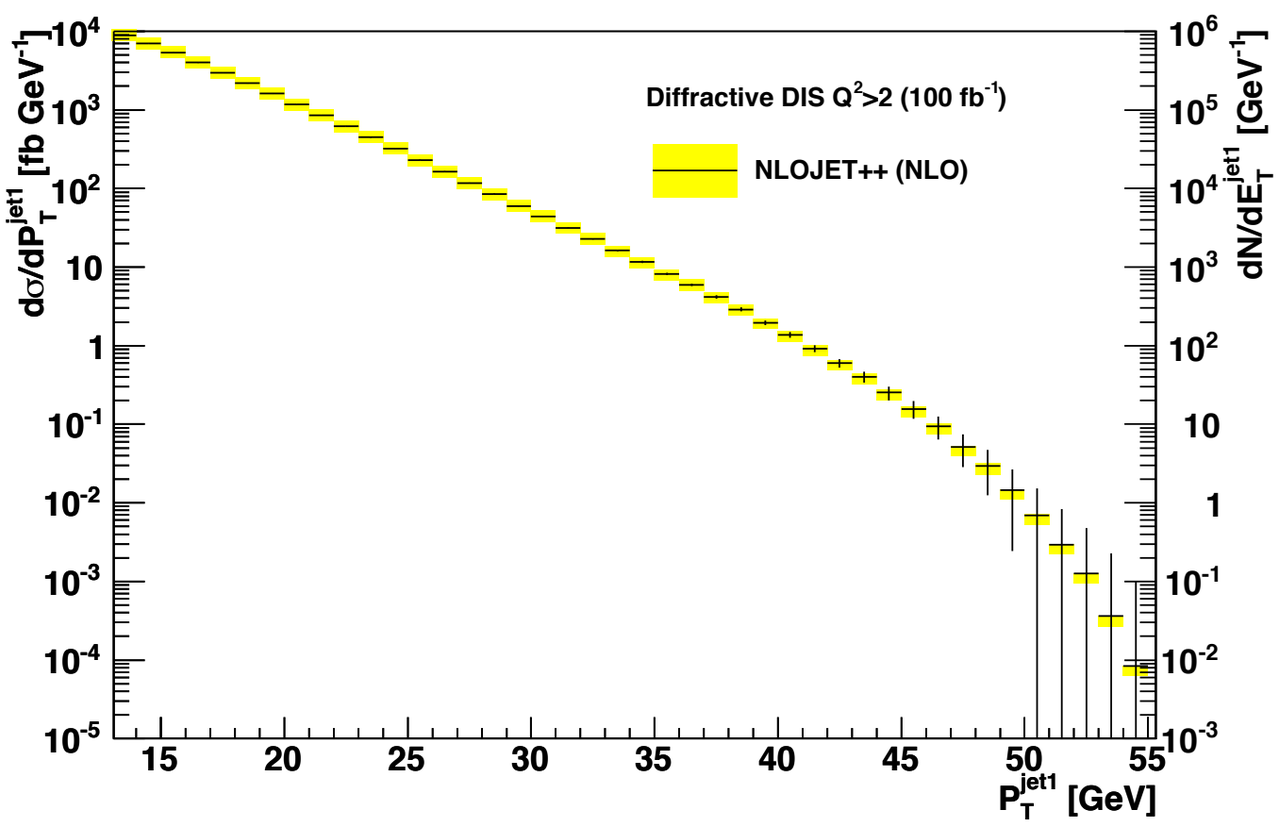




Diffractive dijets:

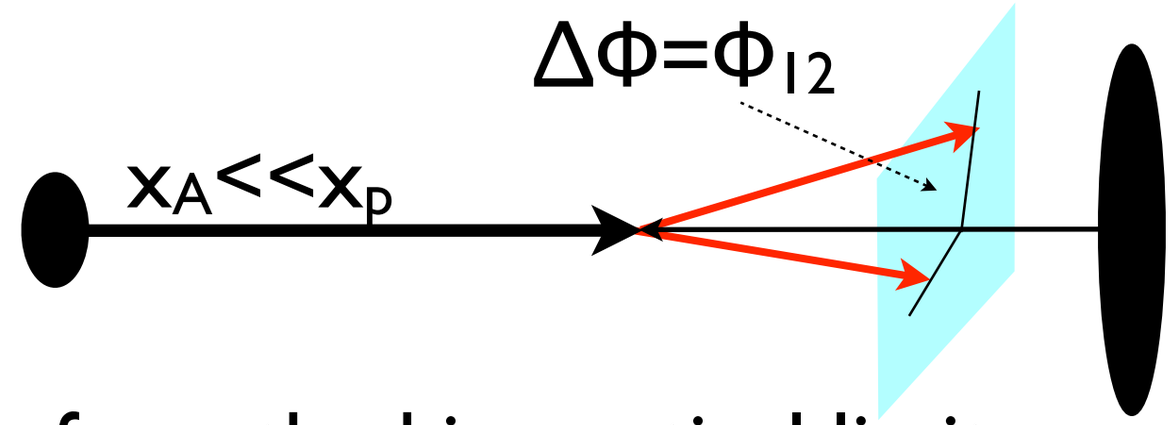




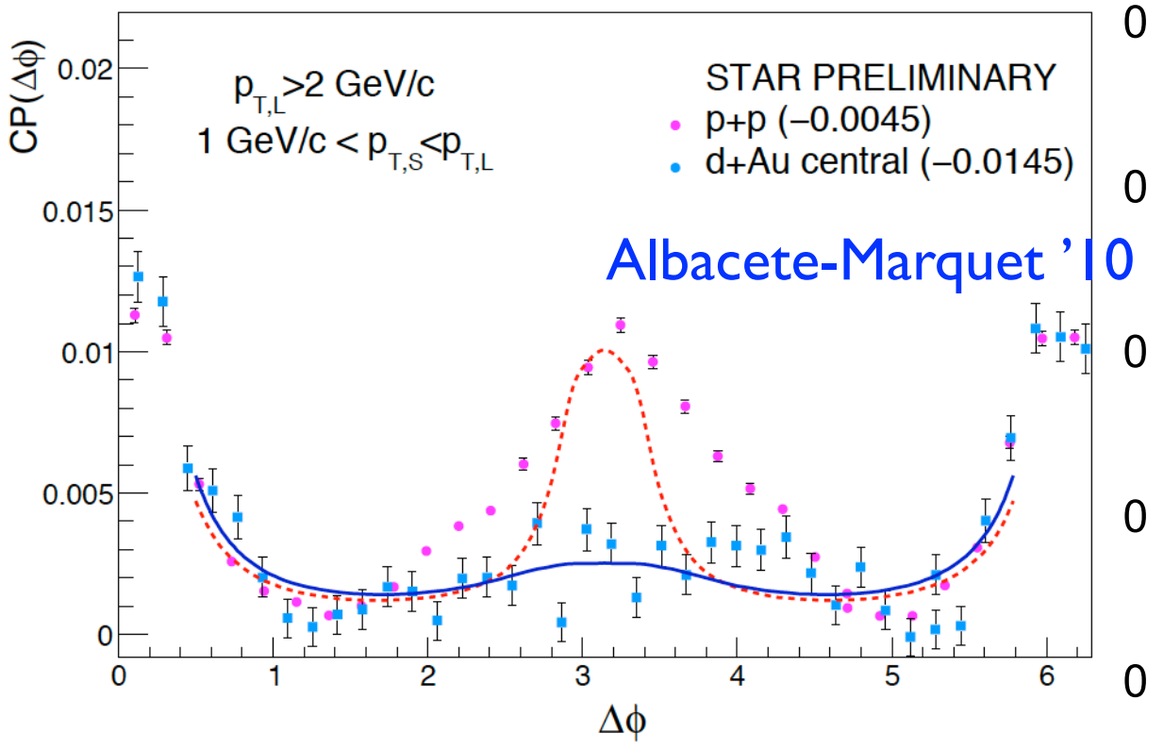
- Diffractive dijet and open heavy flavour production offer large possibilities for:
  - ➜ Checking factorization in hard diffraction.
  - ➜ Constraining DPDFs.
- Large yields up to large p_T^{jet}.
- Direct and resolved contributions: photon PDFs.

Dihadron azimuthal decorrelation:

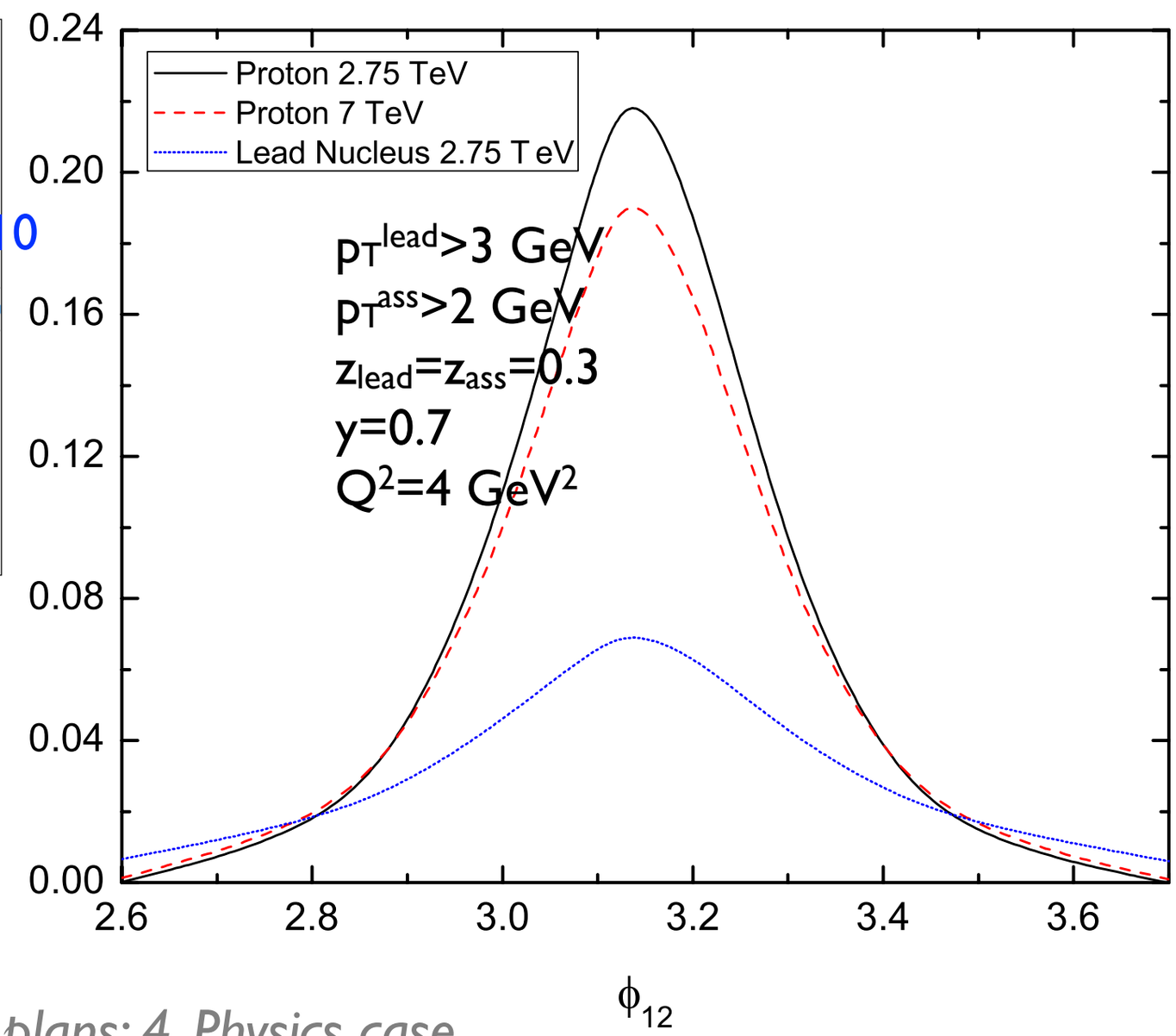
- Dihadron azimuthal decorrelation: currently discussed at RHIC as suggestive of saturation.



- At the LHeC it could be studied far from the kinematical limits.



$$C(\phi_{12}) = \frac{1}{\frac{d\sigma(\gamma^* N \to h_1 X)}{dz_{h1}}} \frac{d\sigma^{\gamma^* N \to h_1 h_2 + X}}{dz_{h1} dz_{h2} d\phi_{12}}$$



Dijet azimuthal decorrelation:

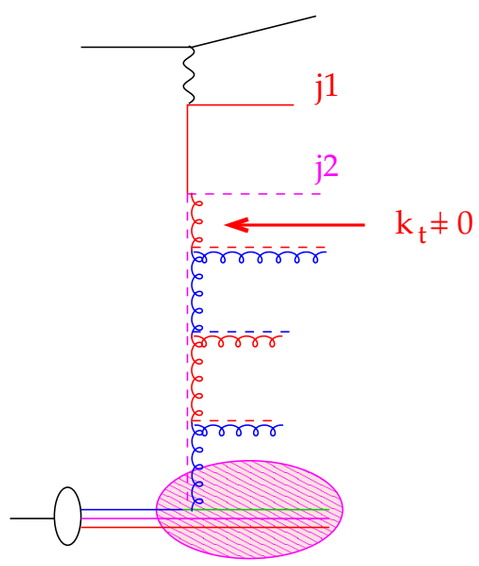
- Studying dijet azimuthal decorrelation or forward jets ($p_T \sim Q$) would allow to understand the mechanism of radiation:

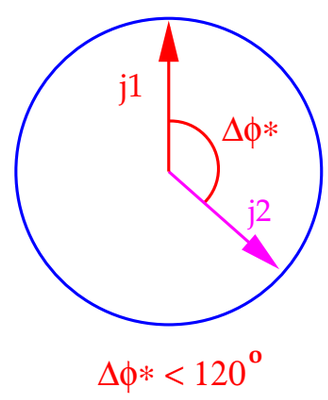
➜ k_T-ordered: DGLAP.

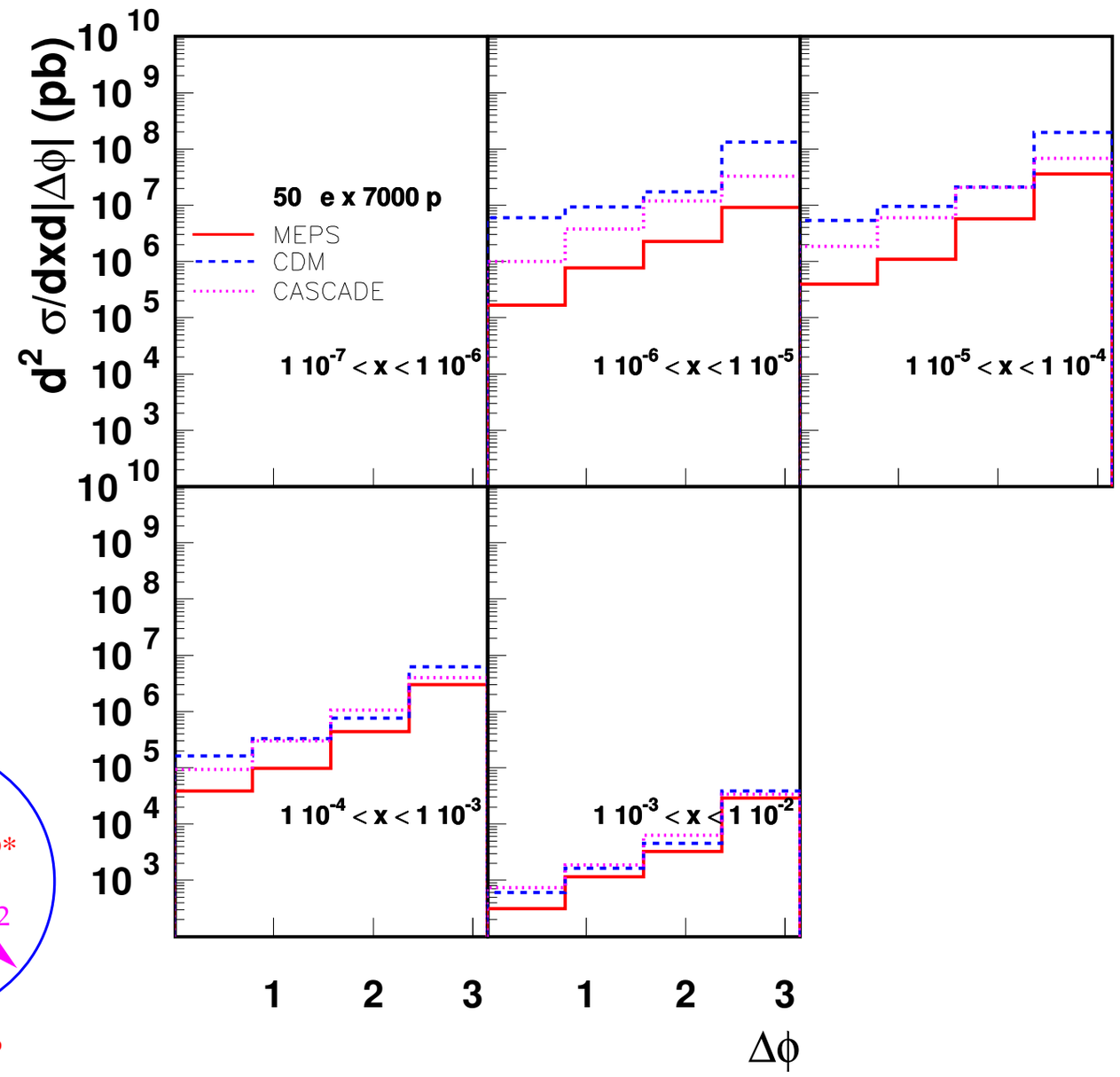
➜ k_T-disordered: BFKL.

➜ Saturation?

- Further imposing a rapidity gap (diffractive jets) would be most interesting: perturbatively controllable observable.







Forward jets:

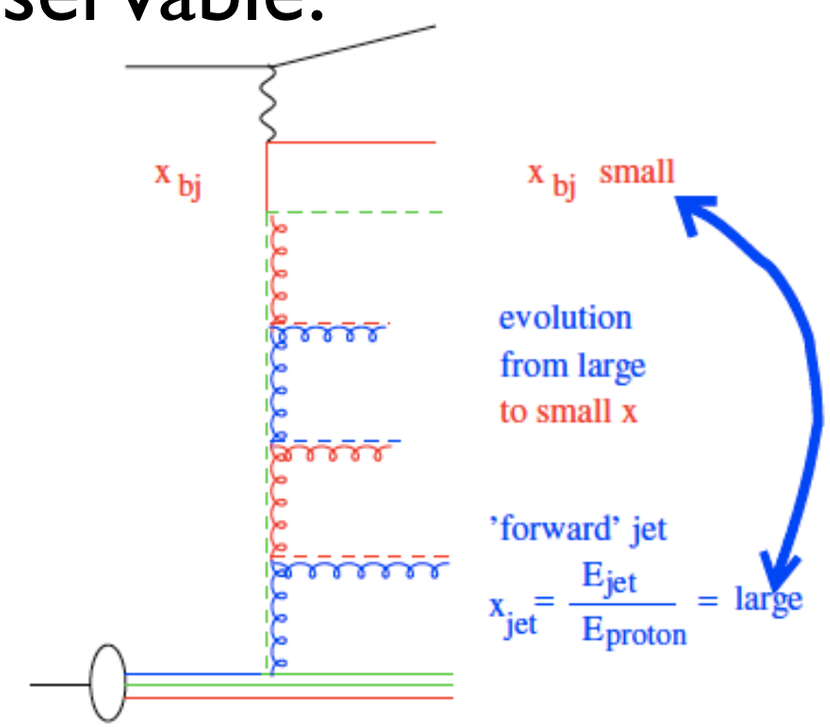
- Studying dijet azimuthal decorrelation or forward jets ($p_T \sim Q$) would allow to understand the mechanism of radiation:

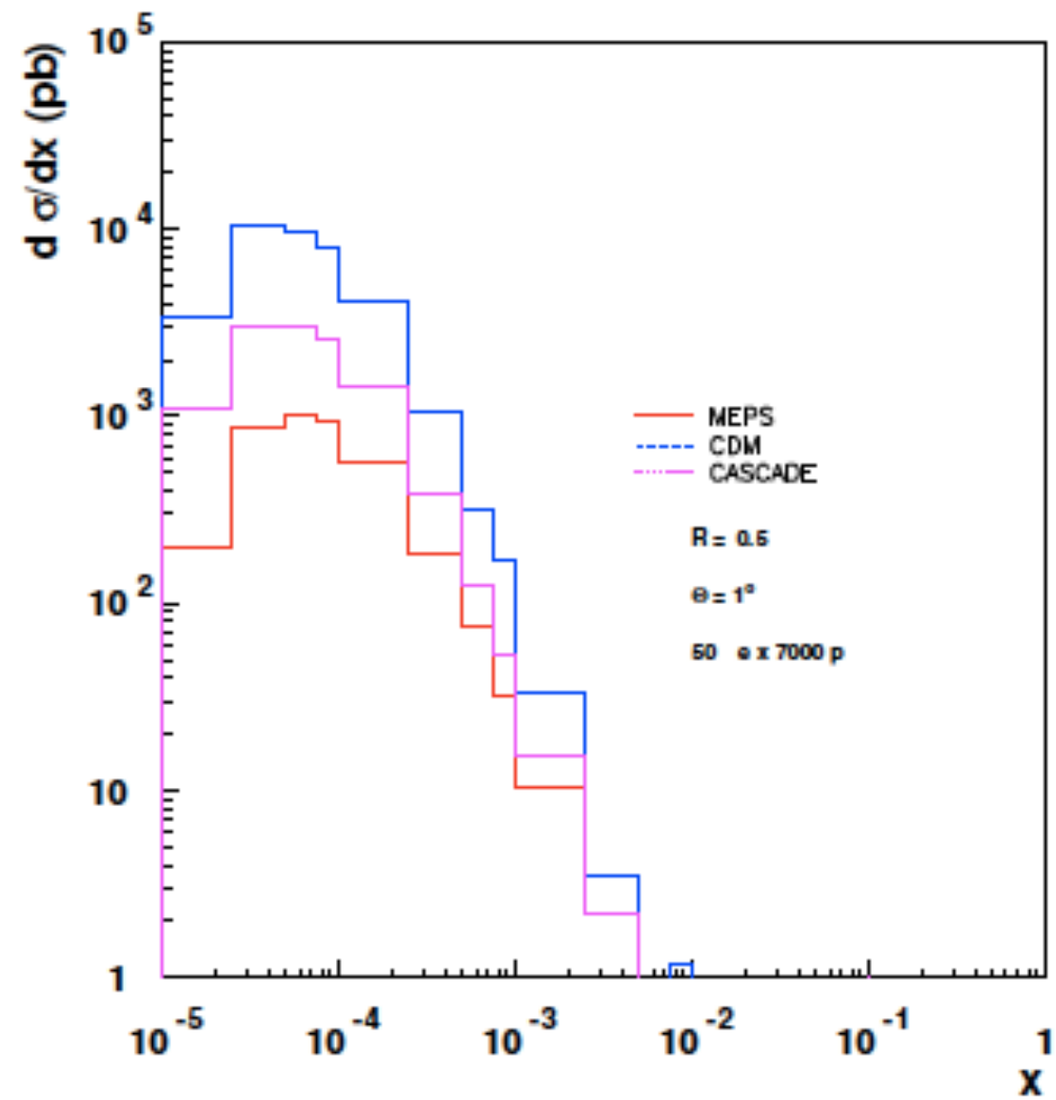
➜ k_T-ordered: DGLAP.

➜ k_T-disordered: BFKL.

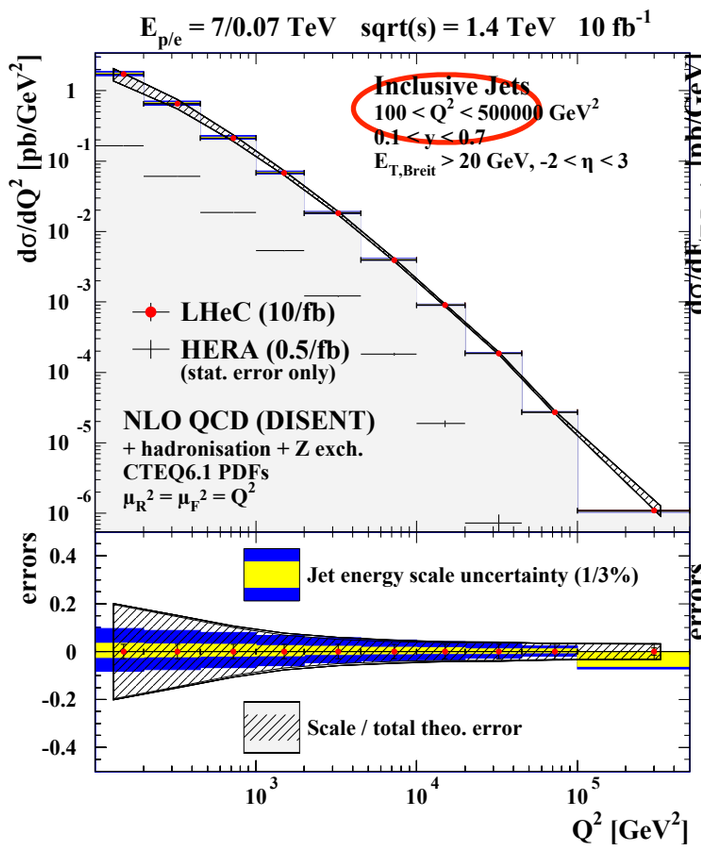
➜ Saturation?

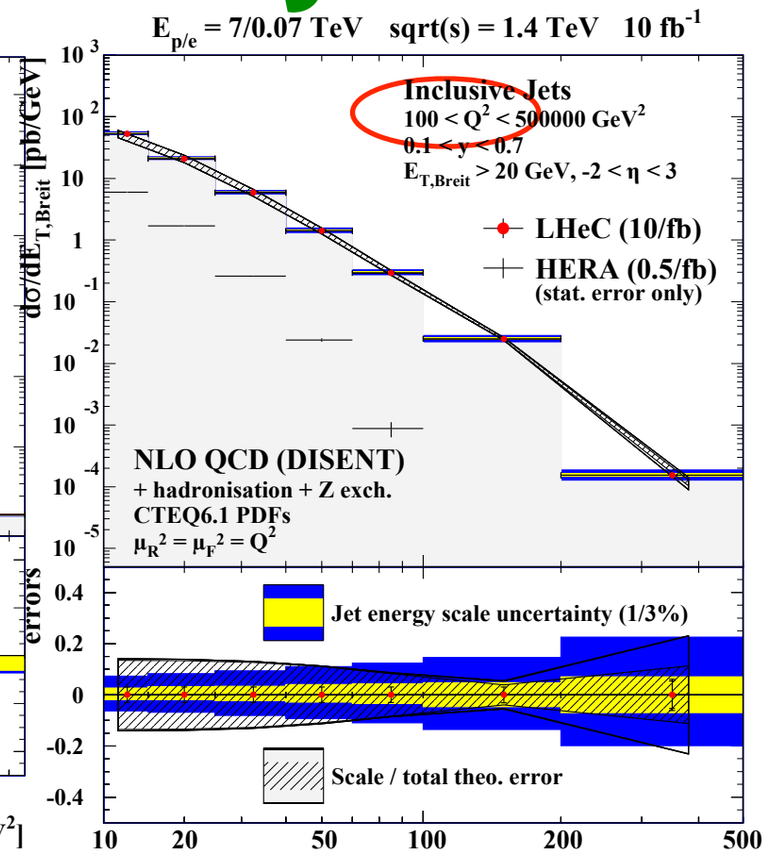
- Further imposing a rapidity gap (diffractive jets) would be most interesting: perturbatively controllable observable.

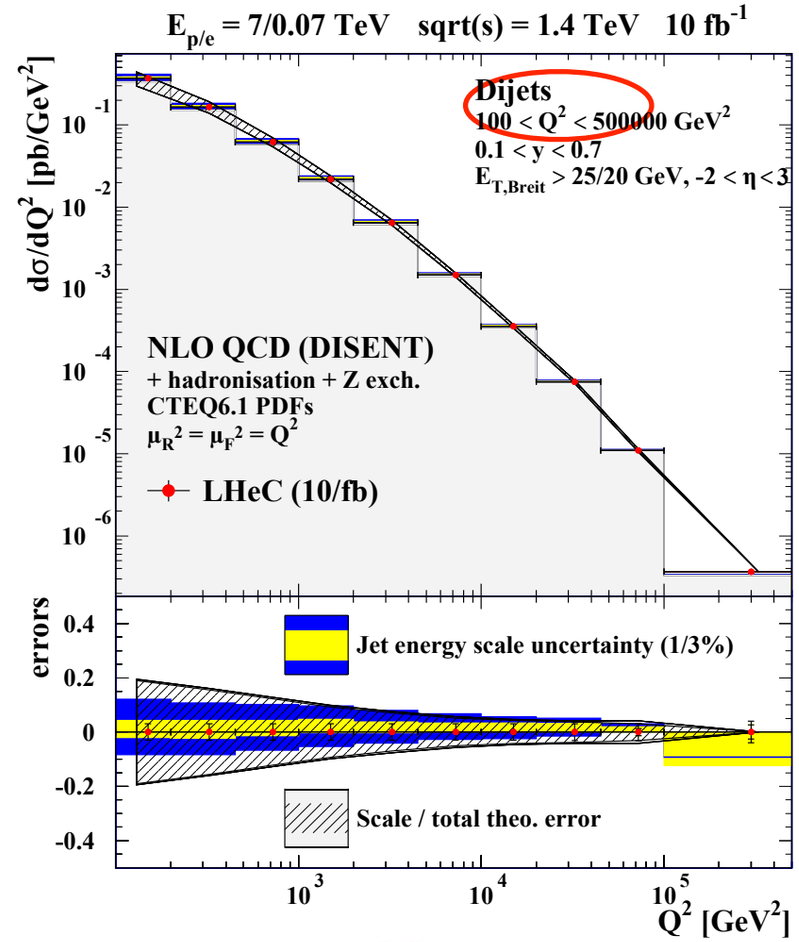




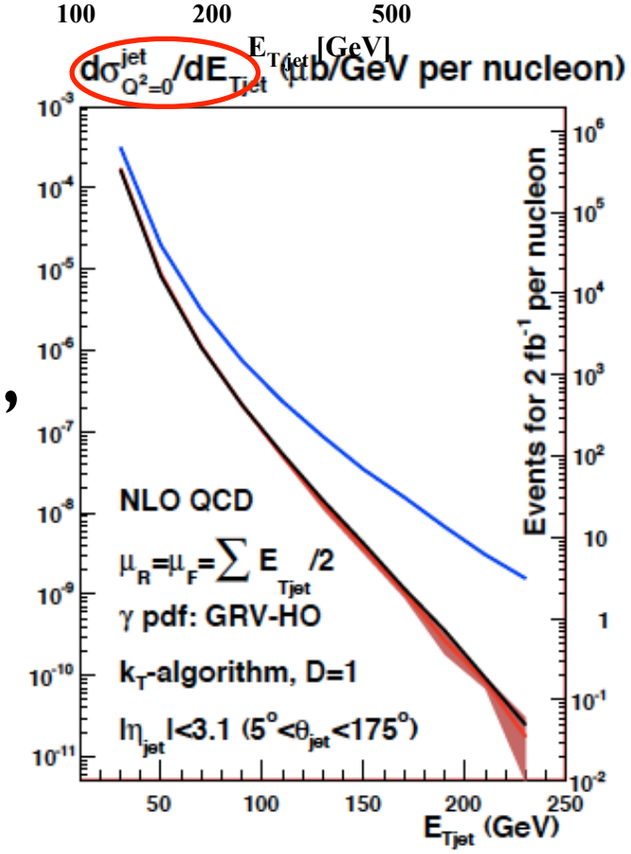
Jets:

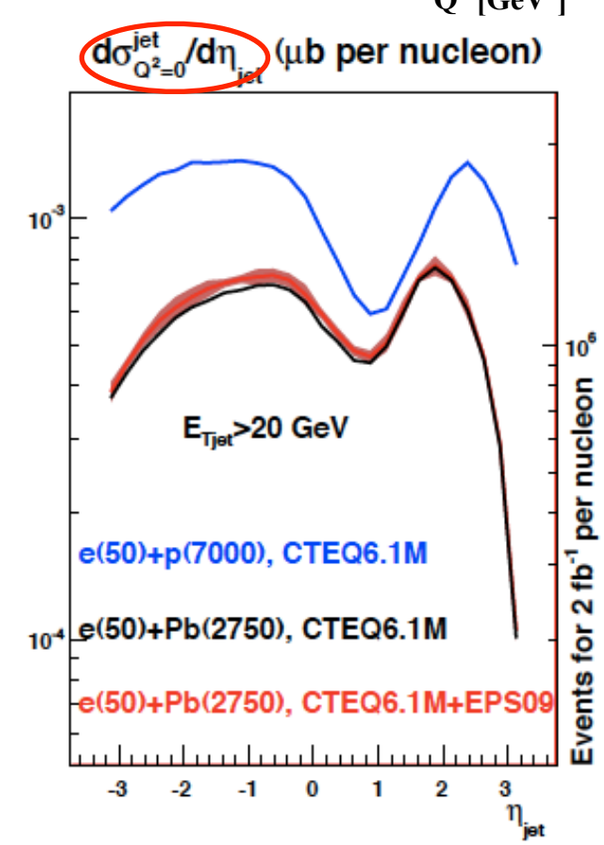






- Jets: large E_T even in eA.
- Useful for studies of parton dynamics in nuclei (hard probes), and for photon structure.
- Background subtraction, detailed reconstruction pending.



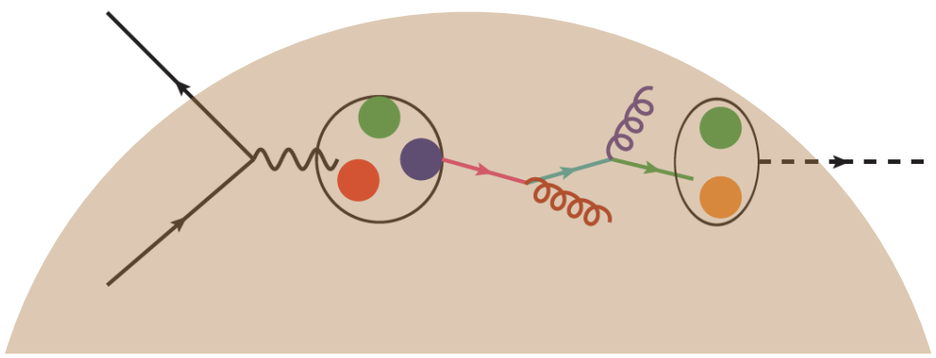


Radiation and hadronization:

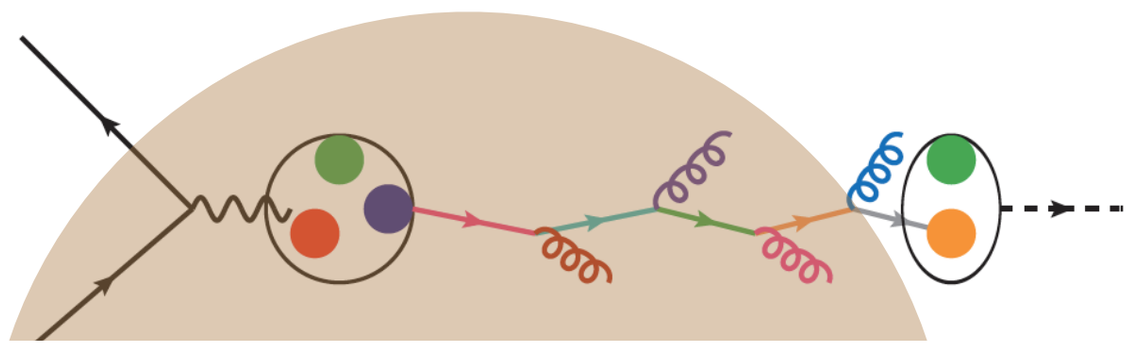
- LHeC: dynamics of QCD radiation and hadronization.
- Most relevant for particle production off nuclei and for QGP analysis in HIC.

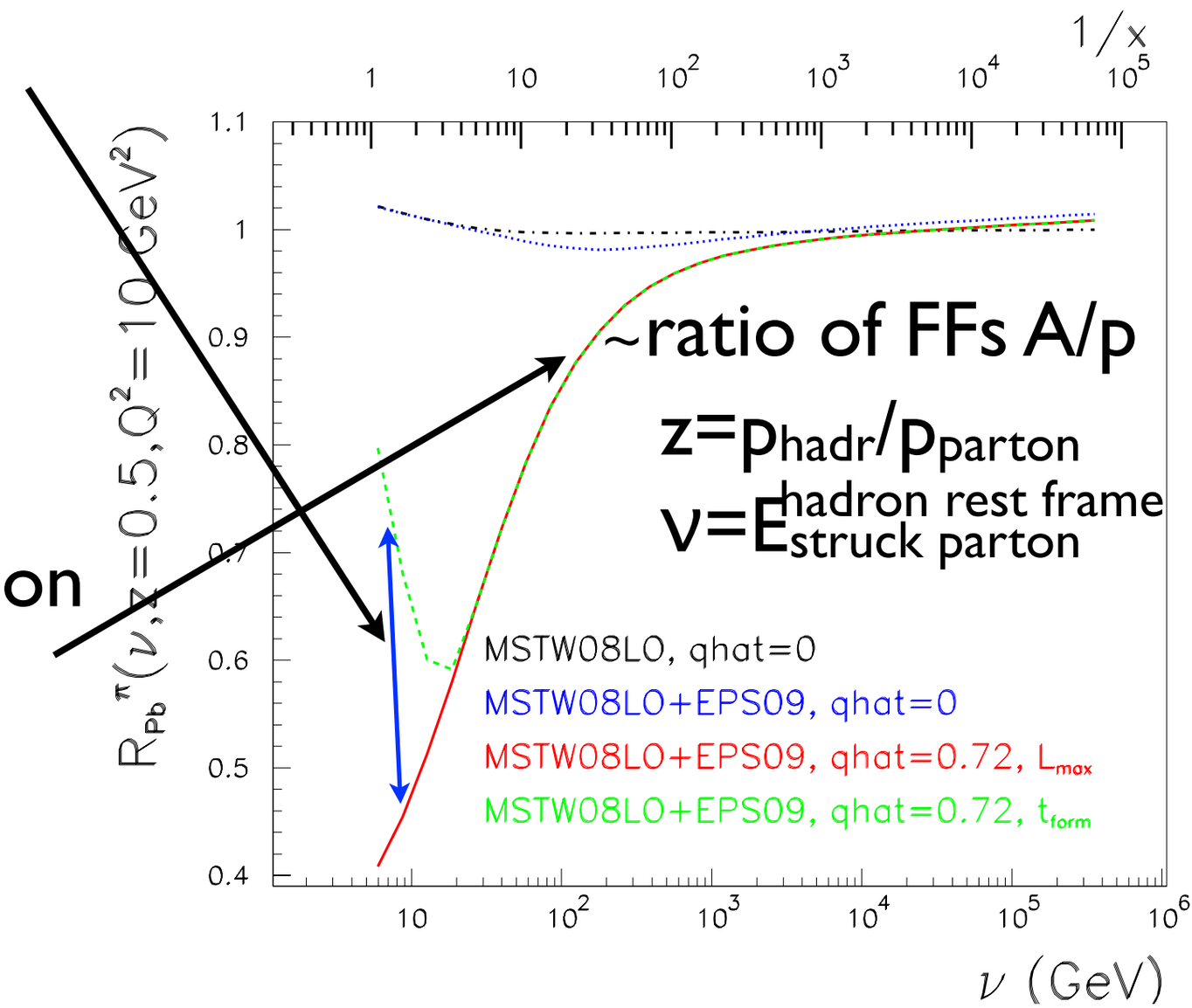
$$R_A^h(z,\nu) = \frac{1}{N_A^e}\frac{\mathrm{d}N_A^h(z,\nu)}{\mathrm{d}\nu\,\mathrm{d}z} \Big/ \frac{1}{N_D^e}\frac{\mathrm{d}N_D^h(z,\nu)}{\mathrm{d}\nu\,\mathrm{d}z}$$

- Low energy: hadronization inside → formation time, (pre-)hadronic absorption,...



- High energy: partonic evolution altered in the nuclear medium.





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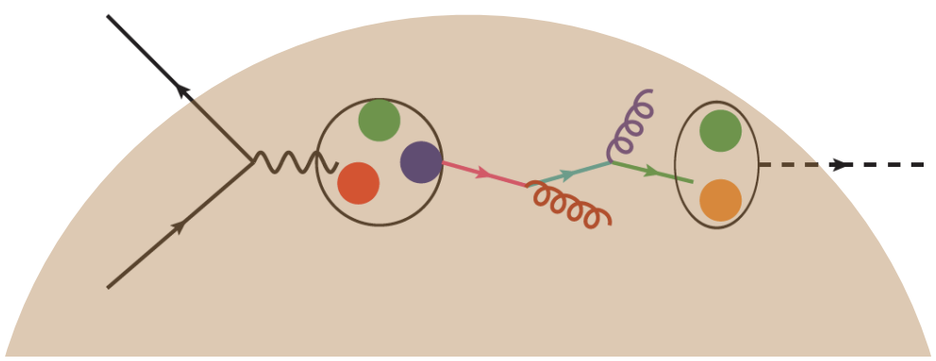

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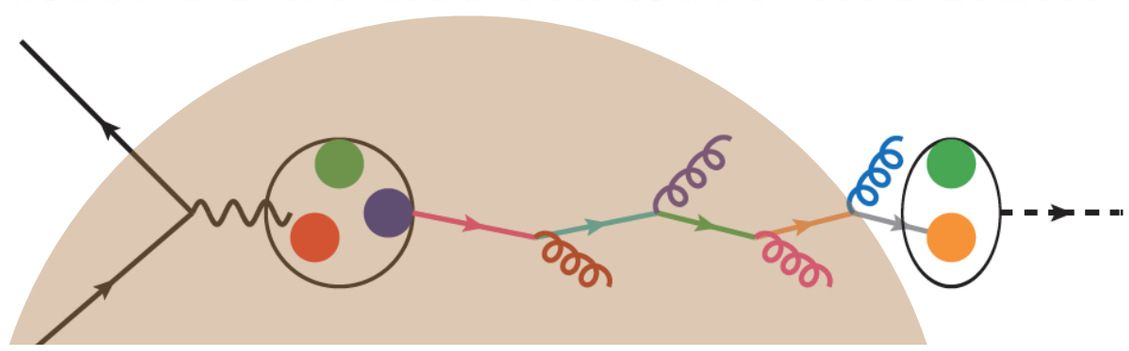
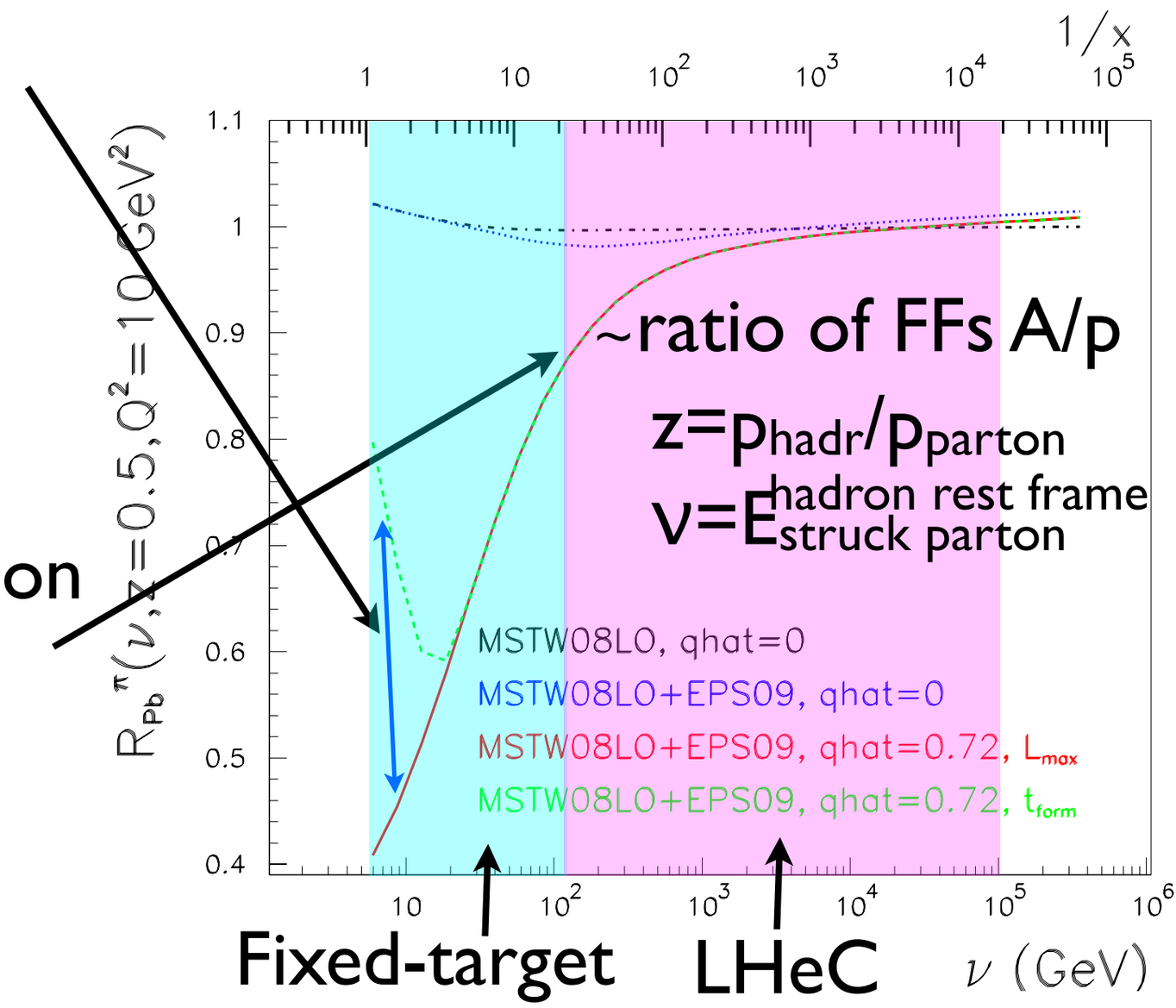
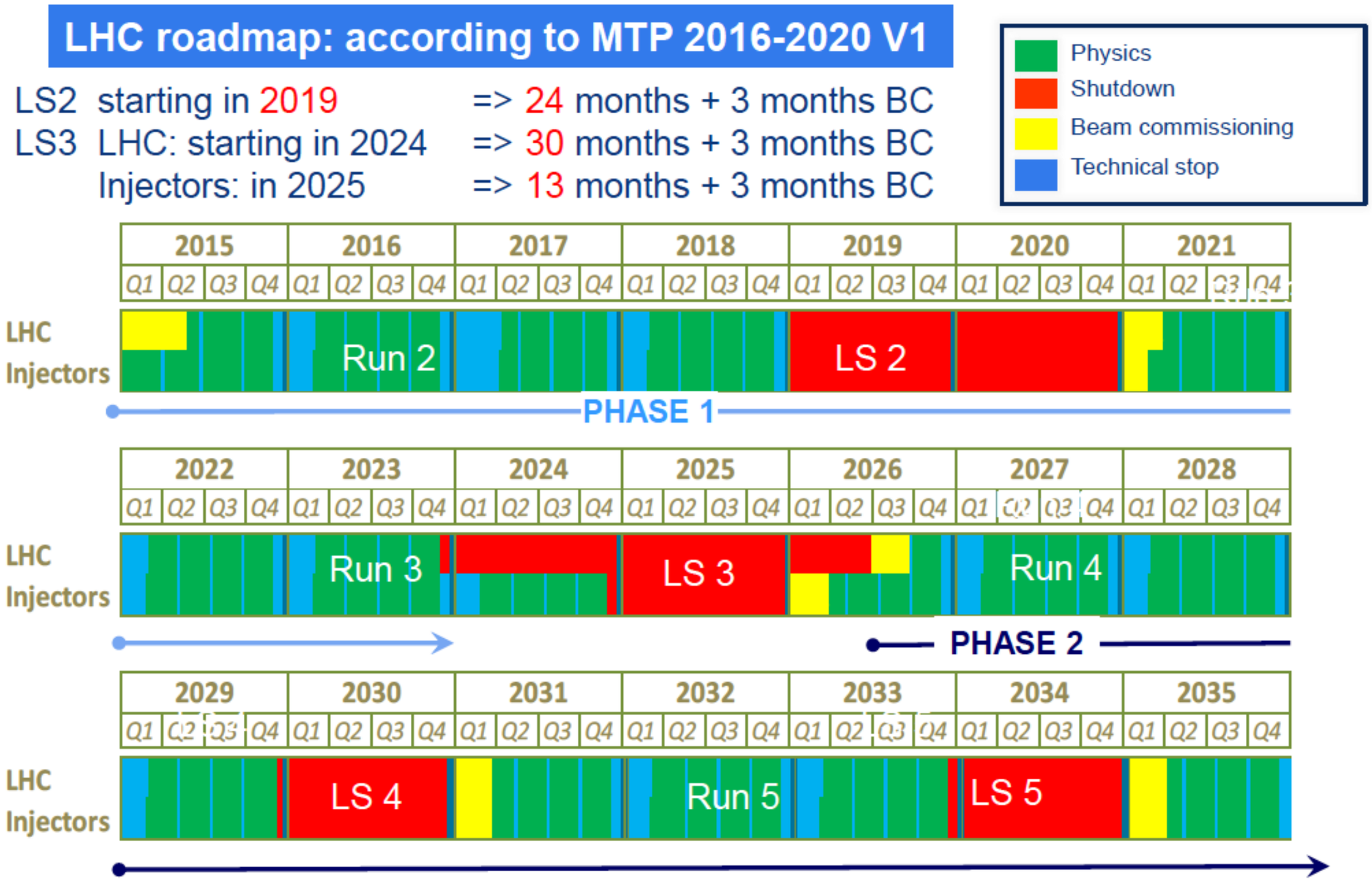




LHC schedule:



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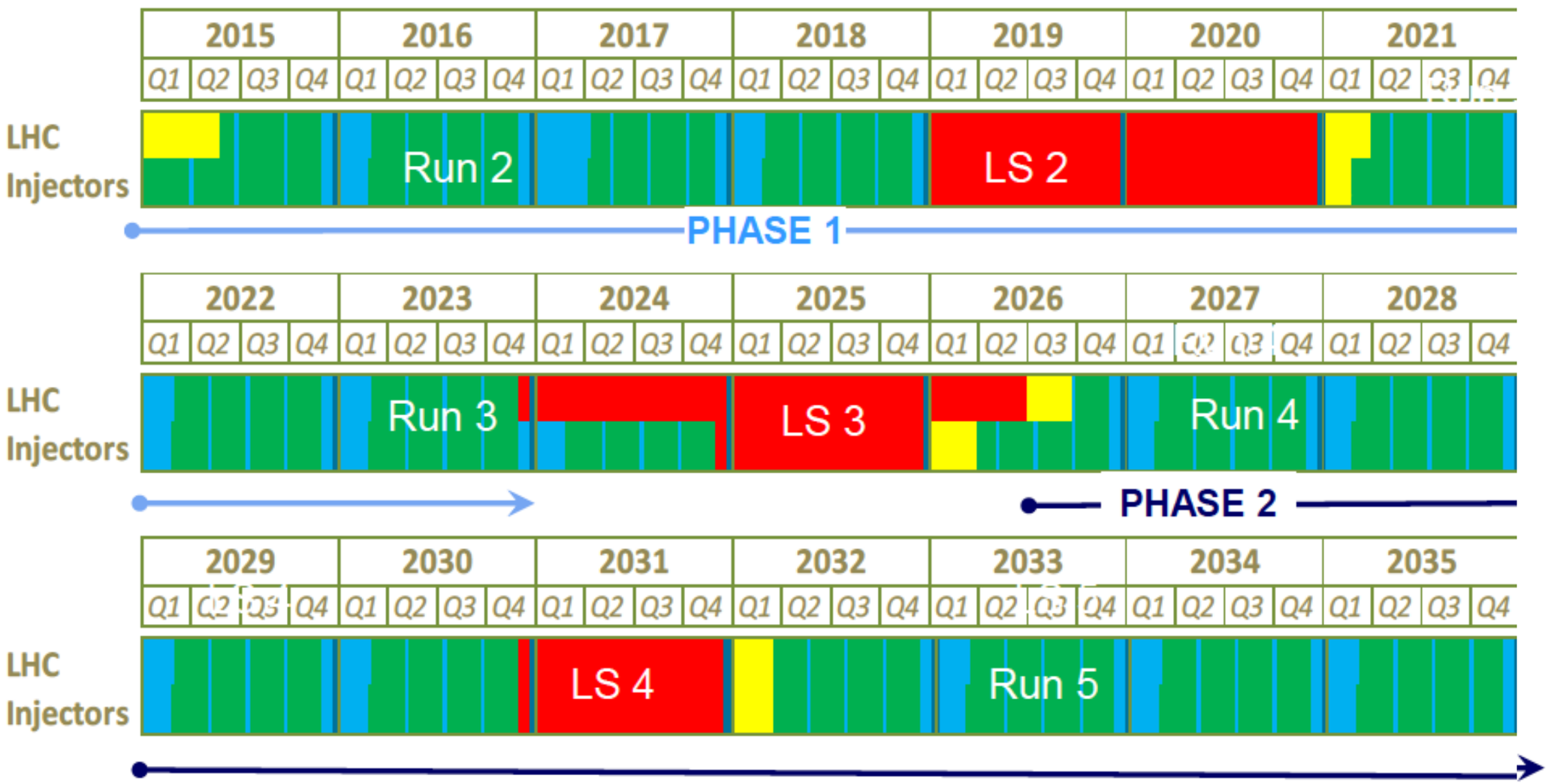
LHC schedule:

LHC roadmap: according to MTP 2016-2020 V2

LS2 starting in 2019 => 24 months + 3 months BC
LS3 LHC: starting in 2024 => 30 months + 3 months BC
Injectors: in 2025 => 13 months + 3 months BC



Frederick Bordry to the SPC and FC, June 2015

N. Armesto, 09.01.2016. - LHeC status and plans.