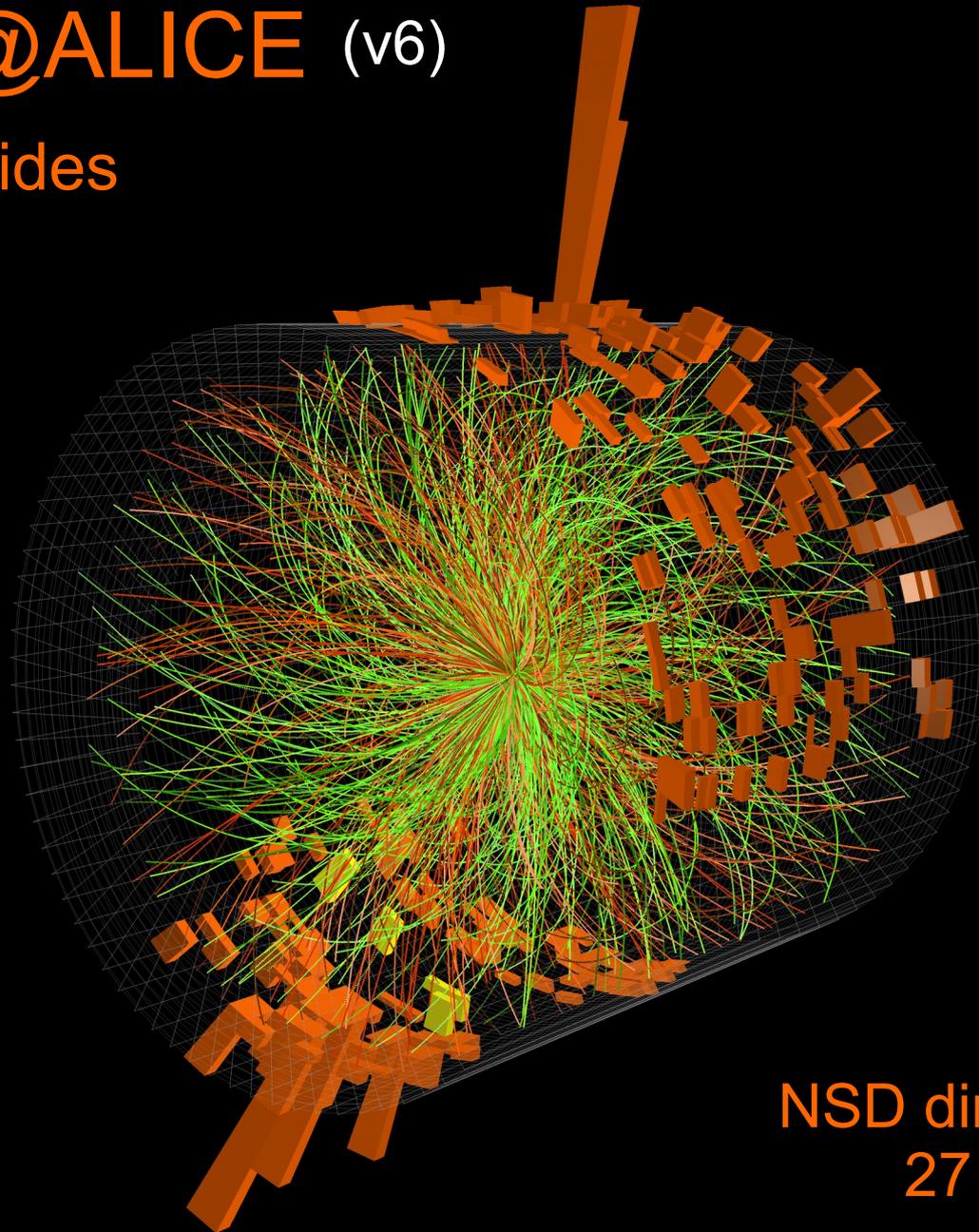


Physics results from RNC@ALICE (v6)

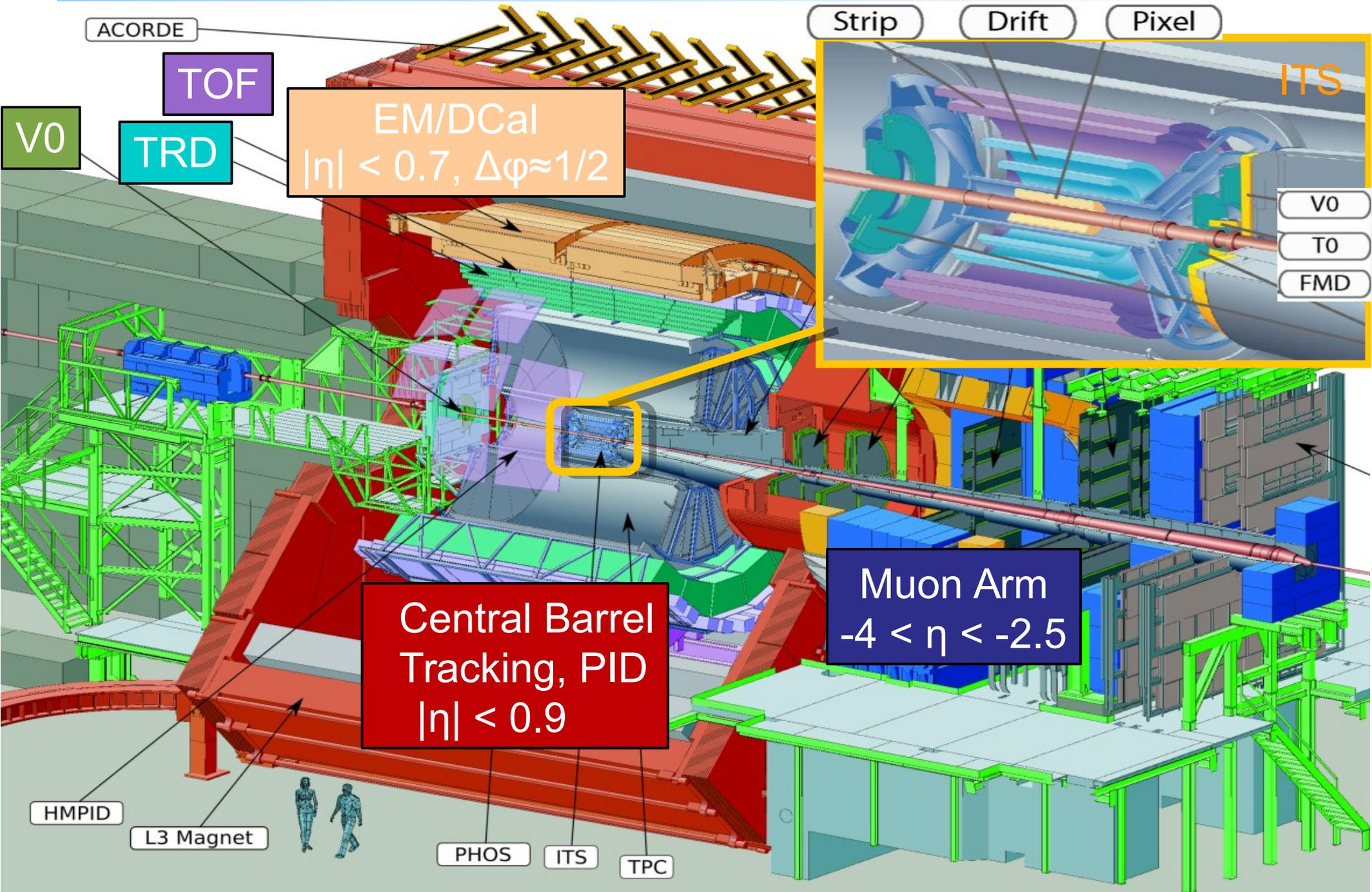
Constantin Loizides



NSD director's review
27 Oct 2016

The ALICE detector

2



Papers from 2013 and now

3

16 publications with at least one RNC member as lead author (+few prel. results)

- High-pT electron production from heavy-flavour hadron decays in Pb-Pb at 2.76 TeV, [arXiv:1609.07104](#)
- Jet-like correlations with π^0 triggers in pp and central Pb-Pb collisions at 2.76 TeV, [arXiv:1608.07201](#)
- Multipion Bose-Einstein correlations in pp, p-Pb, and Pb-Pb collisions, [PRC 93 \(2016\) 054908](#)
- Direct photon production in Pb-Pb collisions at 2.76 TeV, [PLB 754 \(2016\) 235-248](#)
- Elliptic flow of HF muons at forward rapidity in Pb-Pb collisions at 2.76 TeV, [PLB 753 \(2016\) 41-56](#)
- Forward-central two-particle correlations in p-Pb collisions at 5.02 TeV, [PLB 753 \(2016\) 126-139](#)
- Measurement of jet quenching with semi-inclusive hadron-jet distributions in PbPb, [JHEP 1509 \(2015\) 170](#)
- Measurement of jet suppression in central Pb-Pb collisions at 2.76 TeV, [PLB 746 \(2015\) 1-14](#)
- Multiparticle azimuthal correlations in p-Pb and Pb-Pb collisions, [PRC 90 \(2014\) 054901](#)
- Neutral pion production at midrapidity in pp and Pb-Pb collisions at 2.76 TeV, [EPJC 74 \(2014\) 3108](#)
- Freeze-out radii extracted from three-pion cumulants in pp, p-Pb and Pb-Pb, [PLB739 \(2014\) 139-151](#)
- Long-range angular correlations on the near and away side in p-Pb at 5.02 TeV, [PLB 719 \(2013\) 29-41](#)
- Performance of the ALICE Experiment at the CERN LHC, [IJMPA 29 \(2014\) 1430044](#)
- Two- and three-pion quantum statistics correlations in Pb-Pb collisions at 2.76 TeV, [PRC 89 \(2014\) 024911](#)
- Directed flow at midrapidity relative to the spectator plane in Pb-Pb at 2.76 TeV, [PRL 111 \(2013\) 232302](#)
- Measurement of the inclusive differential jet cross section in pp at 2.76 TeV, [PLB 722 \(2013\) 262-272](#)

Papers from 2013 and now

4

16 publications with at least one RNC member as lead author (+few prel. results)

From last time
Nov 26, 2012

Summary & Plans

25

- In 2010-2012, significant contributions to measurements provided as input to the characterization of the QGP at the LHC
 - Examples discussed ($dN/d\eta$, v_2 , HF and jet R_{AA})
- Quantitative extraction of QGP properties needs strong interplay between theory + experiment
- In the upcoming years, we will
 - Study onset of collective effects in smaller systems
 - Address saturation physics with the upcoming p+Pb d
 - Develop more differential measurements to access parton energy loss
 - Relative to trigger particle (use of DCal)
 - PID inside jets and/or HF-tagged jets
 - Long-term (>2018) linked with ALICE (US) upgrade studies

Menu for today

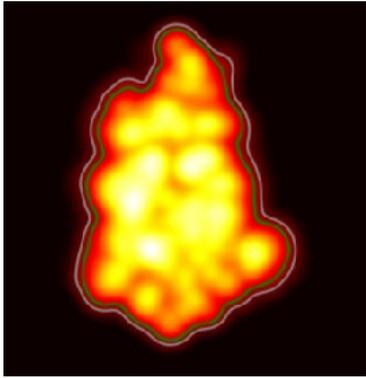
- Direct γ at low p_T
- HFE & meson production
- Inclusive jet suppression

- Discovery of double ridge
- Higher order cumulants
- Femtoscopic radii from 3pions
- Forward-central correlations
- Λ/K in and outside jets

- Semi-inclusive hadron-jets

- D0 in jets (ITS upgrade study)

Measurement of the inclusive differential jet cross section in pp at 2.76 TeV, PLB 722 (2013) 262-272

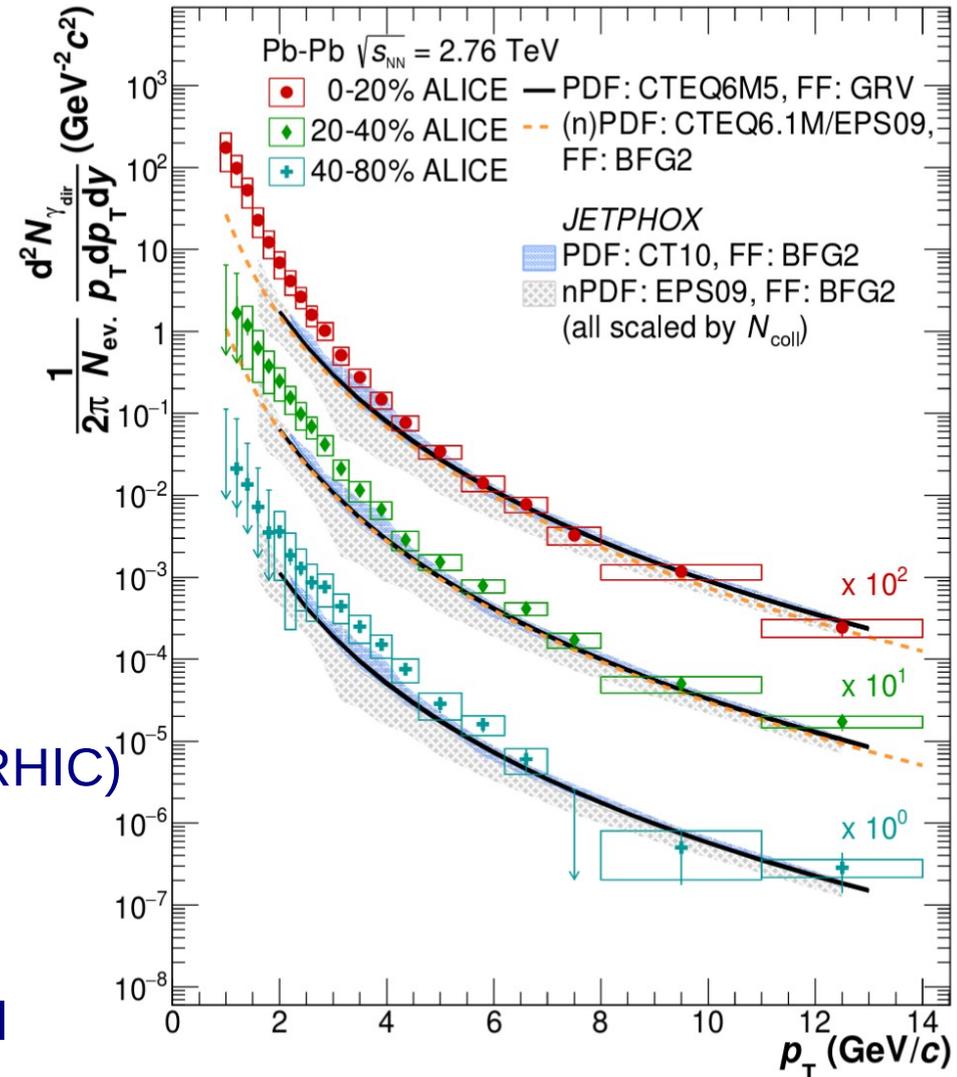


$$\gamma^{\text{dir}} = (1 - 1/R) \gamma^{\text{inc}}$$

$$R = \frac{(\gamma/\pi^0)_{\text{inc}}}{(\gamma/\pi^0)_{\text{mc}}}$$

EPJC 74 (2014) 3108
 PLB 754 (2016) 235-248

- Measure direct photons by subtracting decay photons
 - Photon conversions and PHOS
- Find enhanced yield compared to scaled pQCD expectations
 - Extract T from model calculations
 - $T_{\text{init}} \approx 550 \pm 175$ MeV (30% increase wrt RHIC)
- Near- and long-term prospects
 - Measure direct photon flow
 - Tagging of decay photons using EMCal
 - Study small systems
 - Low-mass dileptons with run-3



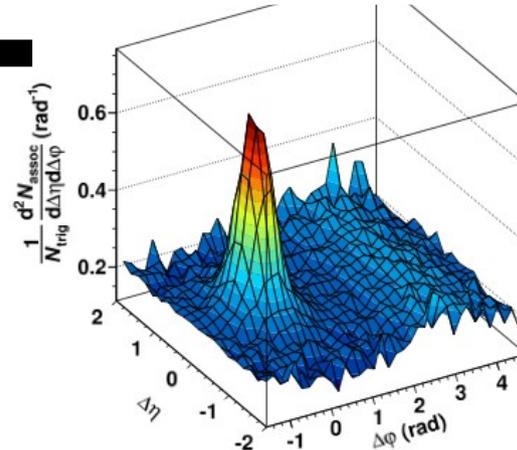
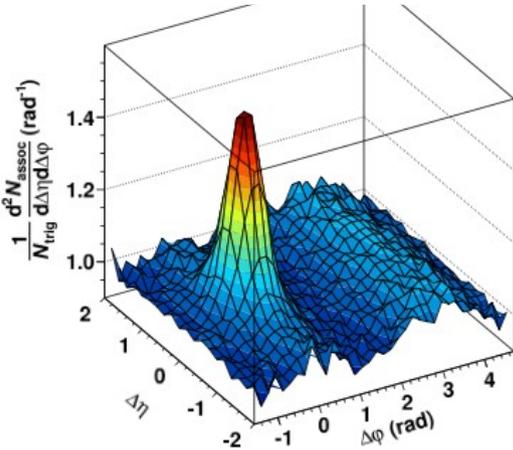
Discovery of pPb double ridge

6

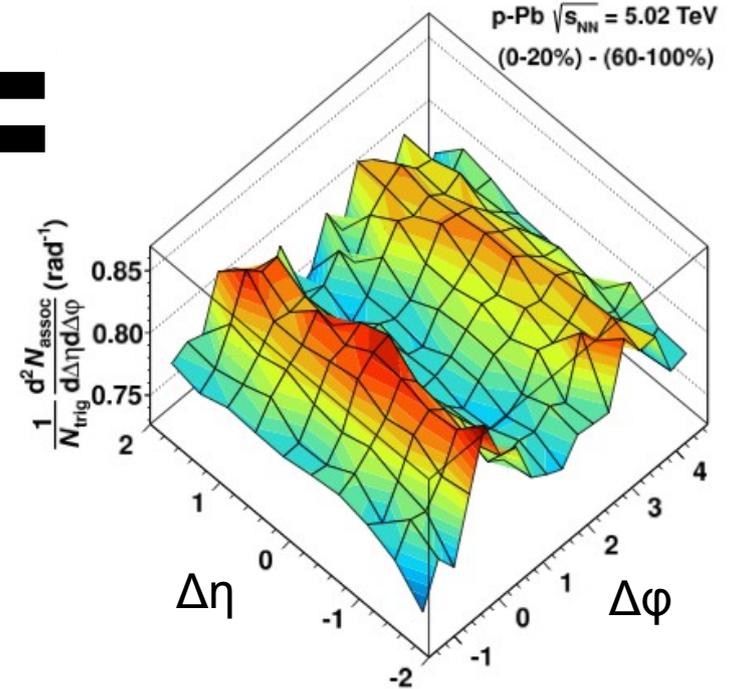
PLB 719 (2013) 29-41

0-20%
(High-Mult)

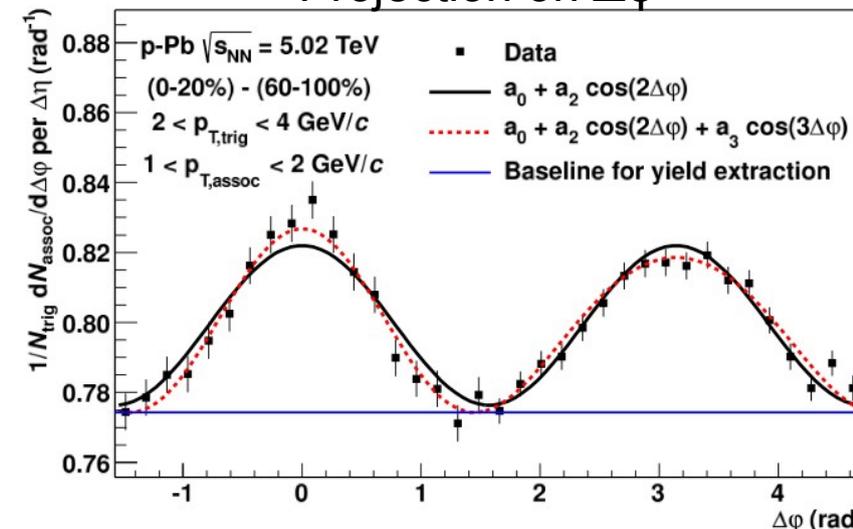
60-100%
(Low-Mult)



==



Projection on $\Delta\phi$

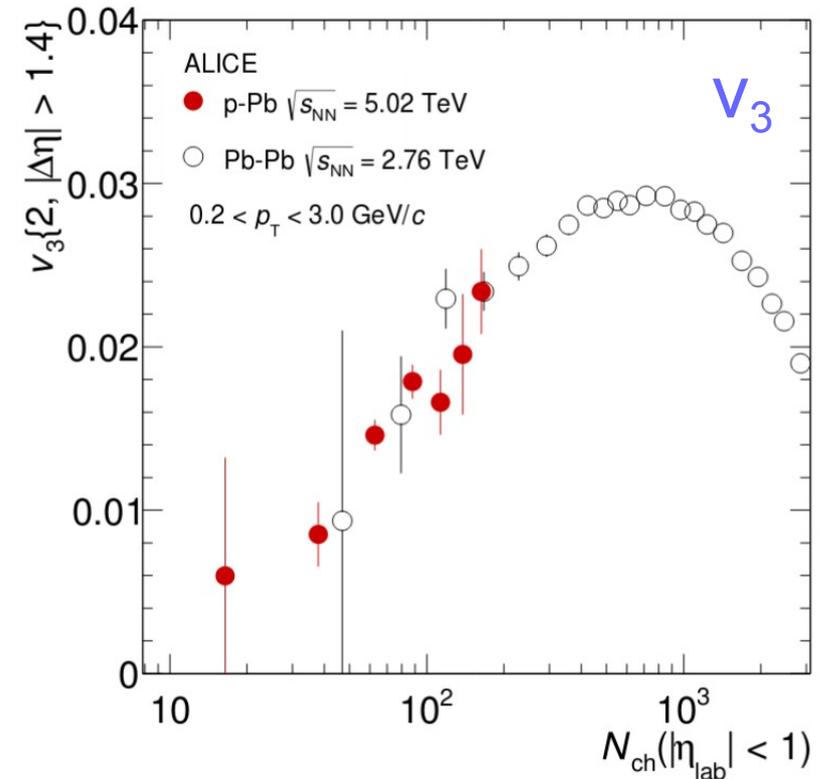
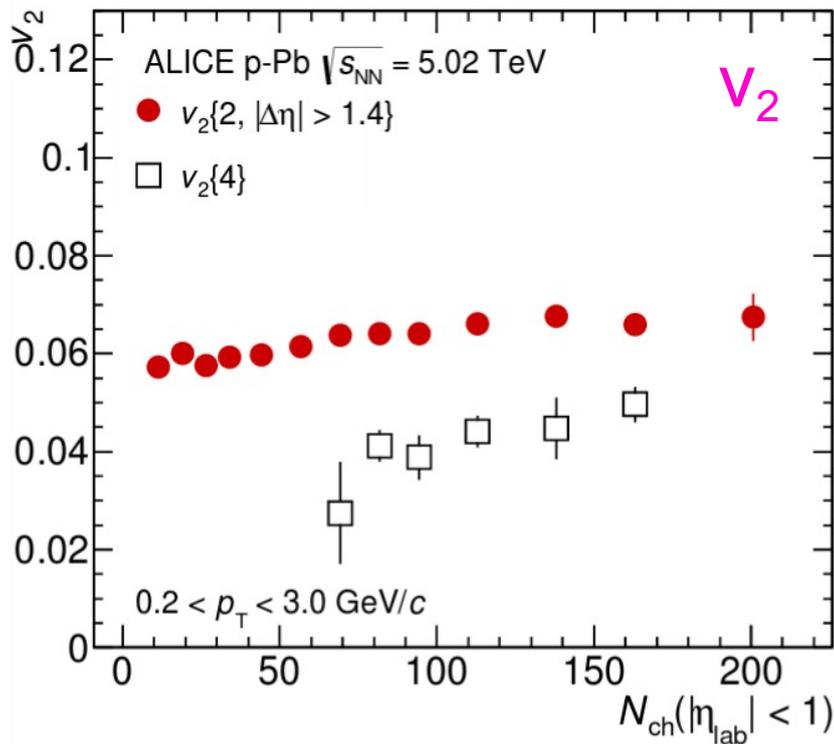


- Two-particle angular correlations
 - Subtract per-trigger yield in low-multiplicity class from the one in high-multiplicity class
- Characteristic double-ridge structures
 - Fourier decomposition to extract v_2 (and v_3)
- Strong impact on the field as it questions the role of IS and FS
 - Collective response due to initial pressure gradients as in PbPb?
 - In pp/pPb alternative approaches based on initial state alone (eg. GLASMA graphs)

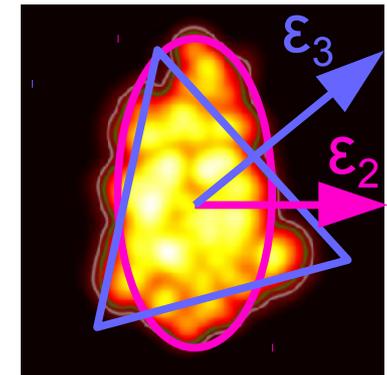
Multiparticle correlations

7

PRC 90 (2014) 054901



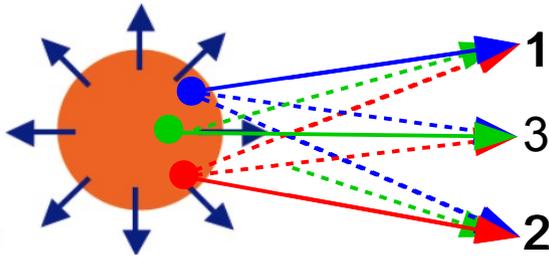
- Measured v_2 from 4-particle cumulants finite
 - Reveals many(4)-particle nature of effect since 2-particle contributions were subtracted
 - NB: Strong interplay between STAR/ALICE
- Measured v_3 surprising similar to that in PbPb
 - → Geometric engineering (p/d/He3-Au RHIC runs)



Source size from 3-pion HBT

8

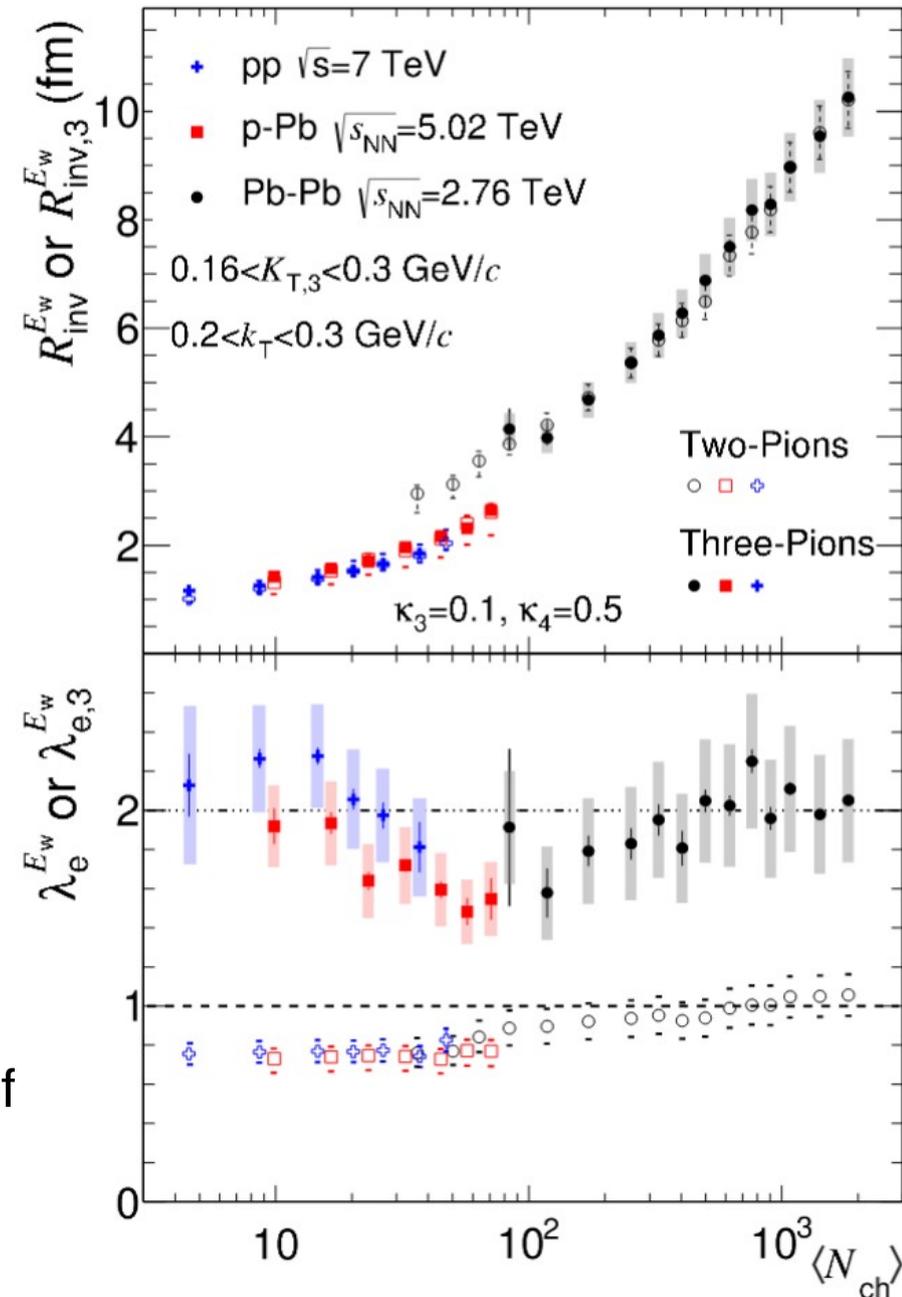
PLB739 (2014) 139-151



$$C(q) = \int S(r, q) |\Psi(r, q)|^2 d^4r$$

$$C^{QS}(q) = 1 + \lambda f(Rq) e^{g(Rq)}$$

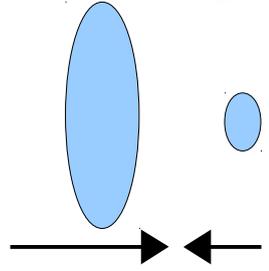
- HBT to extract source size
 - Developed 3-pion cumulants to suppress (mini-jet) background
- At similar M,
 - R in pPb is 5-15% larger than in pp
 - Hence models with significantly larger expansion are disfavored
 - R in PbPb 35-55% larger than in pPb
 - Large PbPb radii point to importance of initial state or significant final state effects already in peripheral collisions
 - Needs more experimental studies



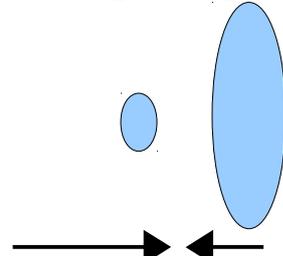
Forward-central correlations

9

Pb-going side

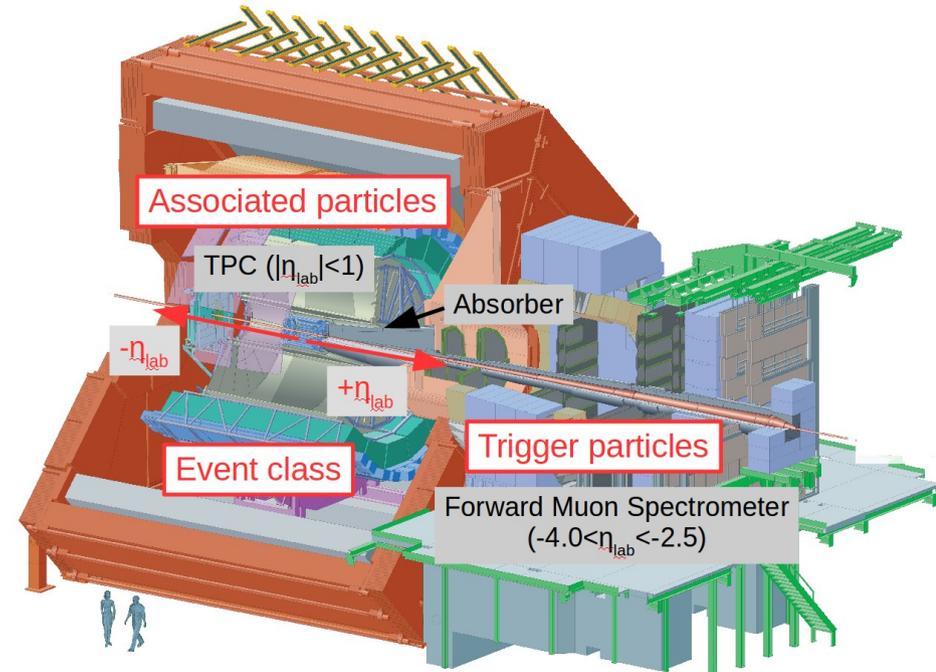


p-going side

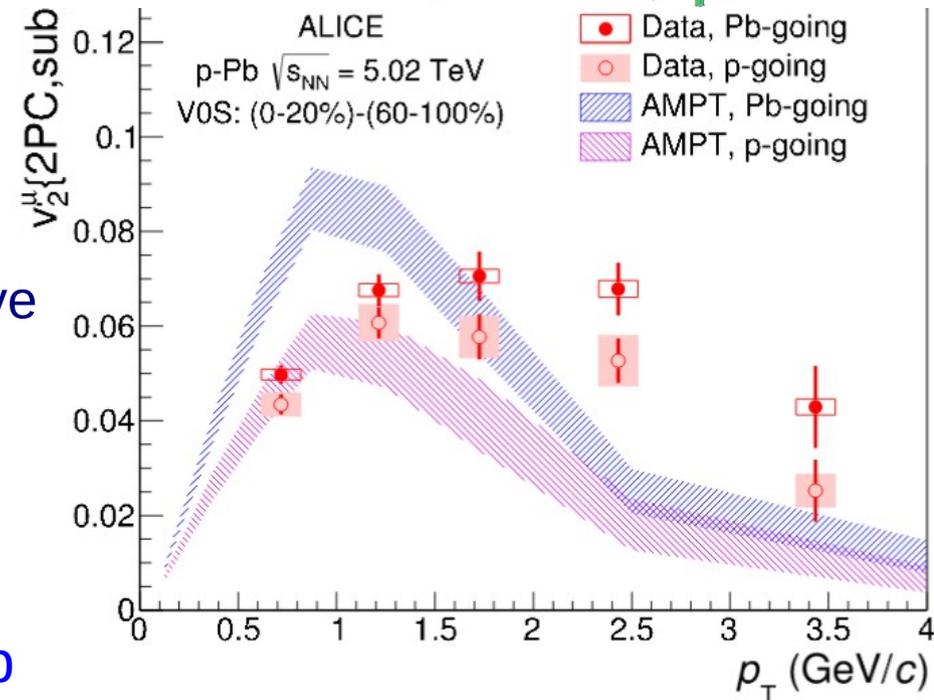


Large-x gluons in Pb
(small-x effects suppressed
but higher multiplicity)

Small-x gluons in Pb
(small-x effects enhanced
but lower multiplicity)

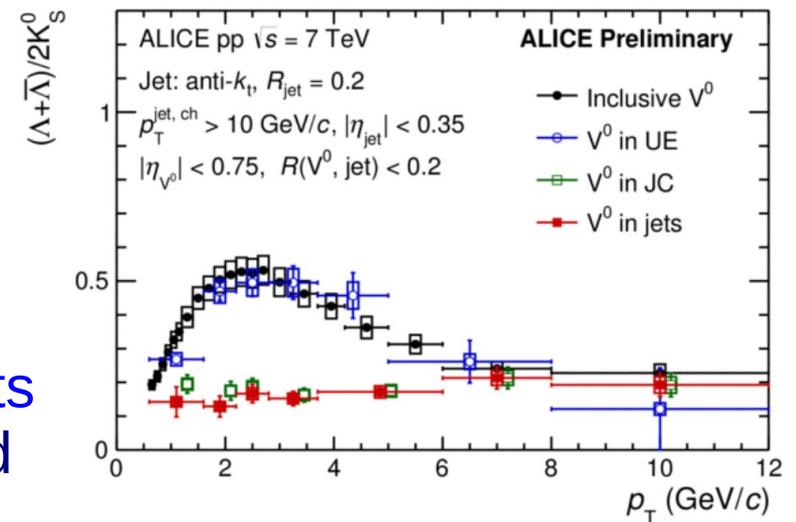
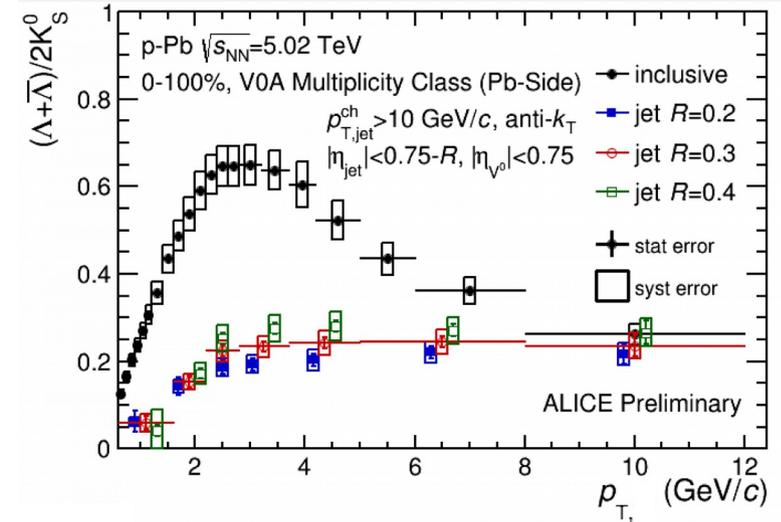
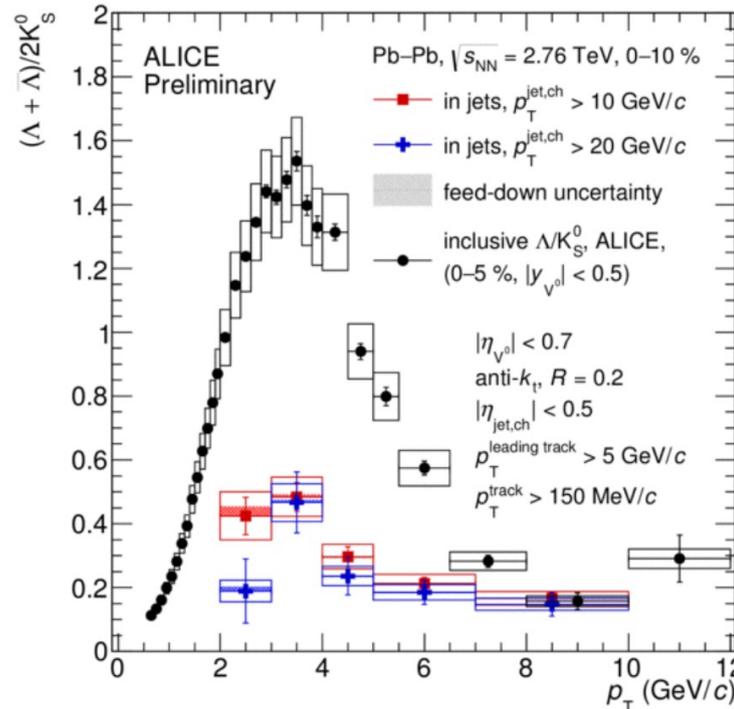
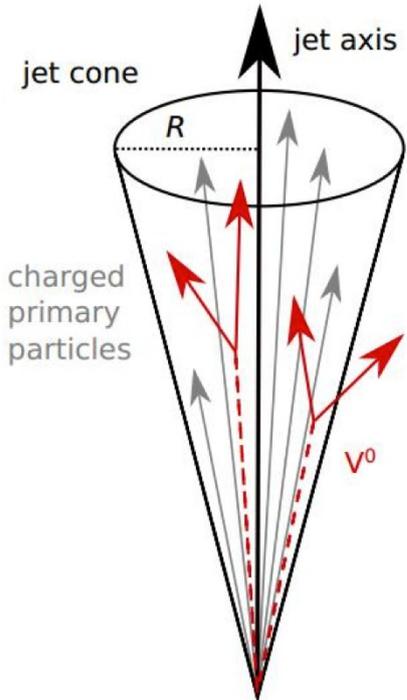


- Inclusive muon-hadron correlations to probe forward and backward in y
 - Observe double ridge
 - Consistent with final state picture since v_2 on Pb-side is 16% larger than on p-side
 - Above 2 GeV, the measurement is sensitive to muons from HF decays
 - Can be non-zero as in PbPb
 - Indicative of apparent HQ flow and/or parton energy loss?
- Near-Term: follow up in high-multiplicity pp



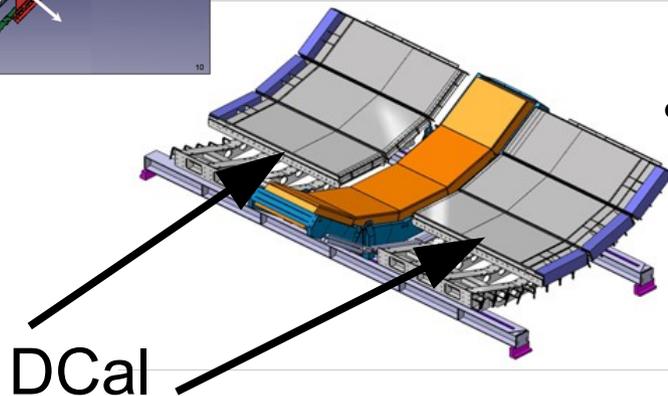
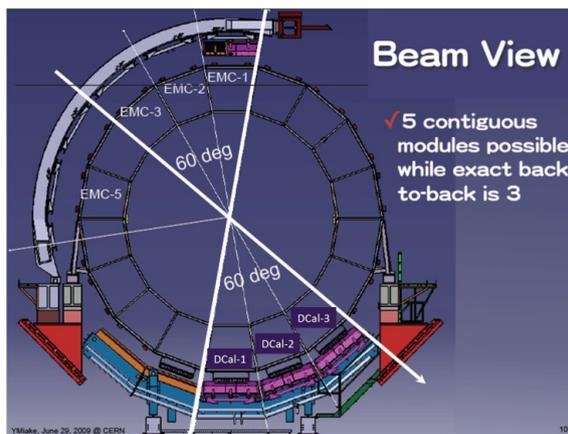
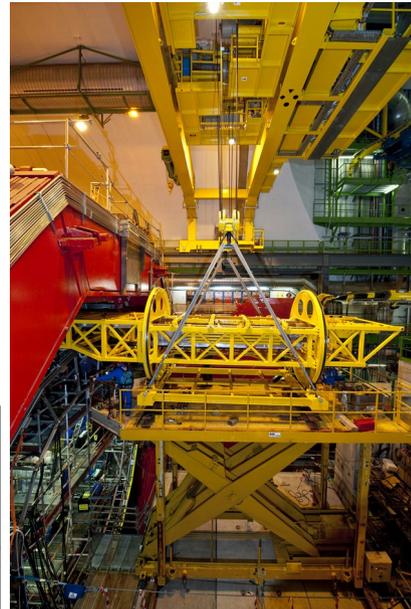
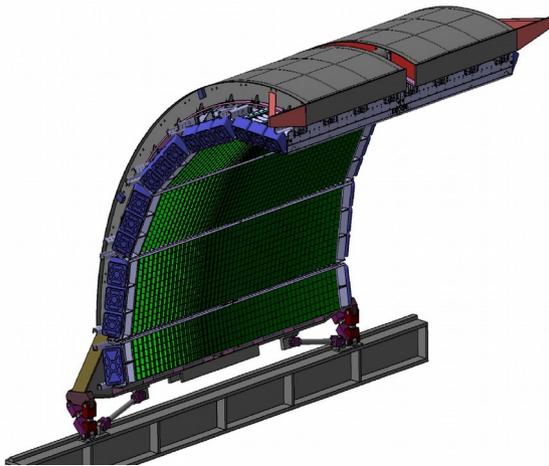
Λ/K ratio inclusive vs inside jets

10



- Measurement identified particles in/out jets
 - In all systems, inclusive Λ/K enhanced
 - Enhancement not found inside jet core
 - Mechanism the same in all 3 systems?

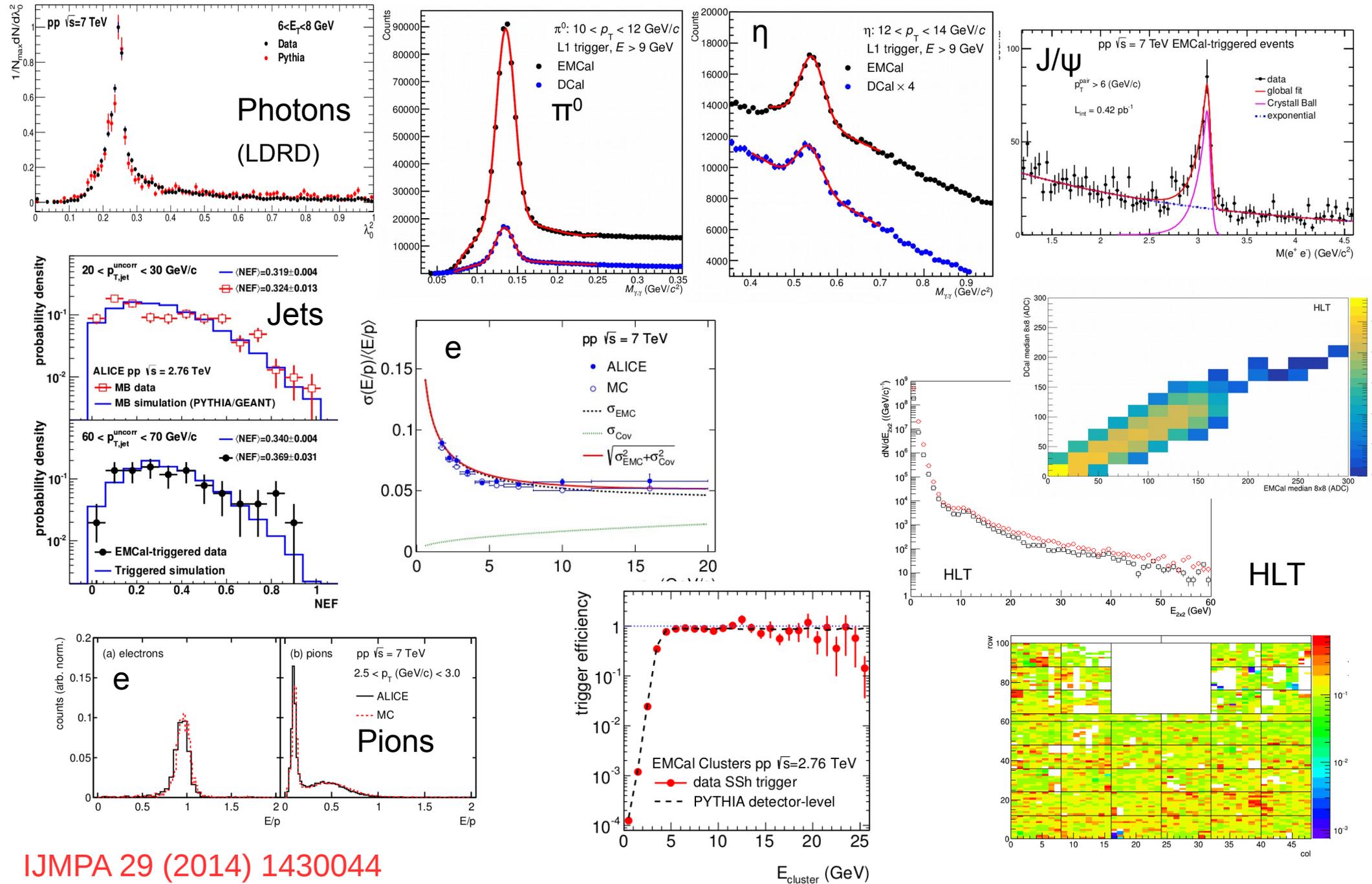
(publication in preparation)



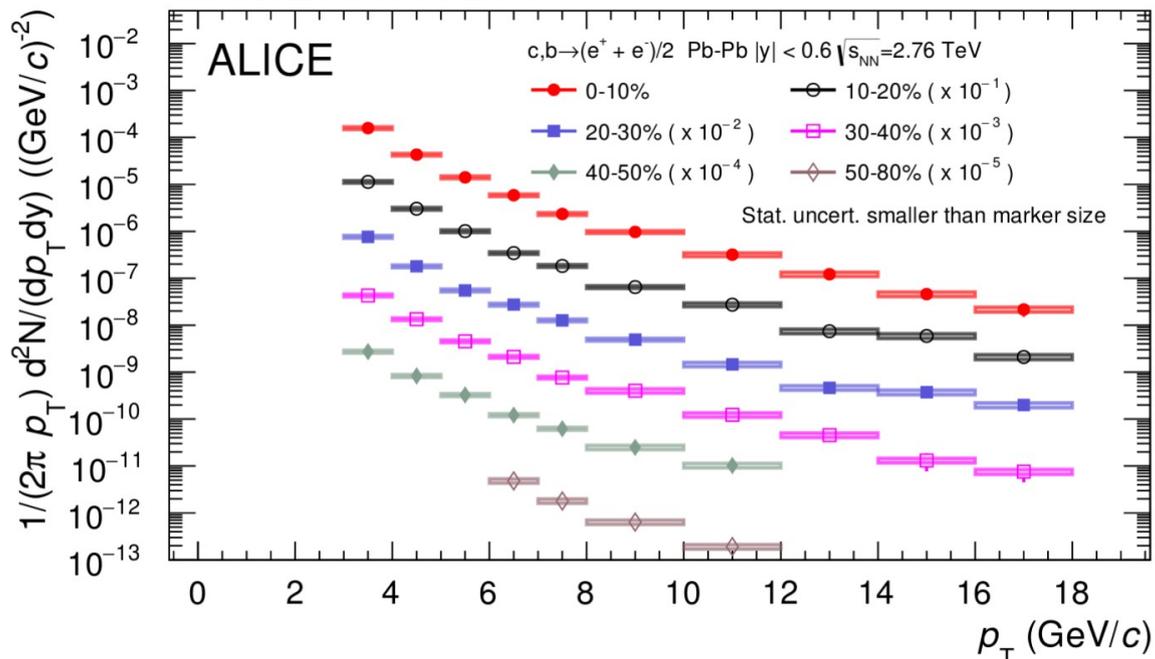
- **EMCal**
 - Pb-scintillator sampling calorimeter
 - Completed in 2012
 - $80 < \varphi < 187$ deg.; $R \sim 440$ cm; $-0.7 < \eta < 0.7$
 - 12288 towers
 - Single tower ($\Delta\varphi = \Delta\eta = 0.014$)
 - 6x6cm at $\eta = 0$
 - $X/X_0 \approx 20$
- **DCal**
 - Installed by 2015, now in operation
 - Back-to-back ($\Delta\varphi = 60$ deg) same technology; in tandem with PHOS
- **ALICE@RNC: led commissioning**
 - Reconstruction, software, trigger strategies, online monitoring, calibration, alignment, first physics results

EMCal performance

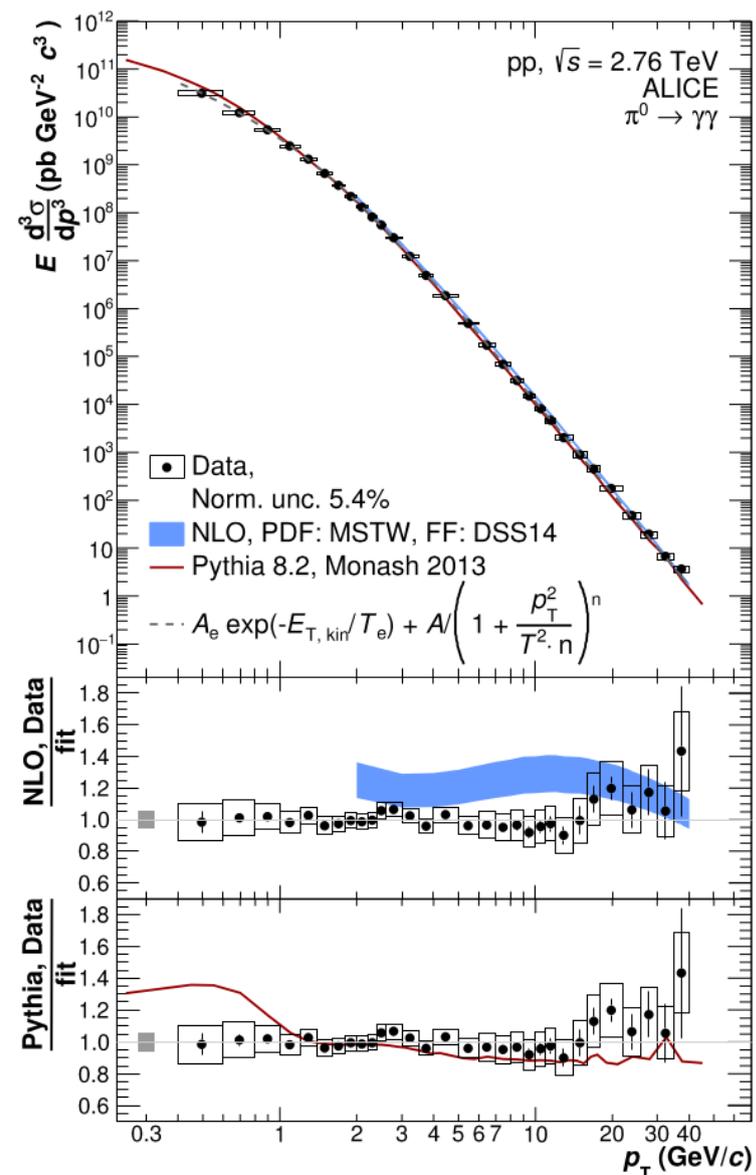
12



arXiv:1609.07104



- Latest measurements
 - HFE electrons up to high p_T
 - Uses EMCal trigger in PbPb
 - Meson spectra up to high p_T
 - Using variety of reconstruction techniques and EMCal trigger

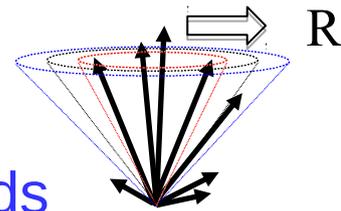
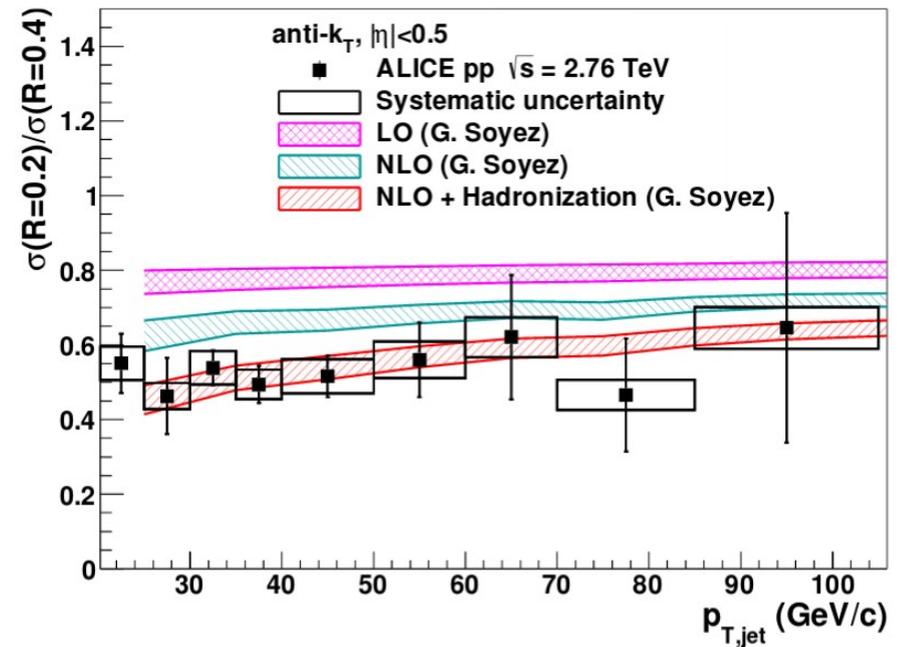
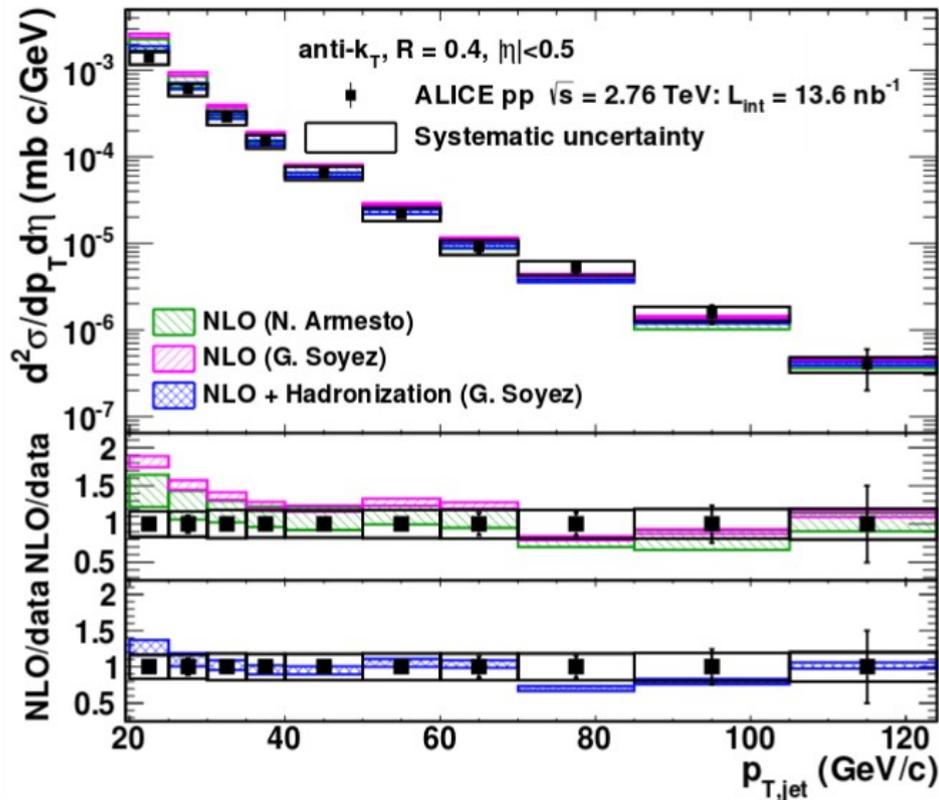


(publication in preparation)

First jet cross section in pp at 2.76

14

PLB 722 (2013) 262-272



Brief (1.5d) pp run in 2011; just 3 months after installing full Emcal

- Jets are corrected to hadron (not parton) level
- JER $\sim 18\%$, JES $\sim 3\%$

(NB: First analysis with EMCAL L0 trigger)

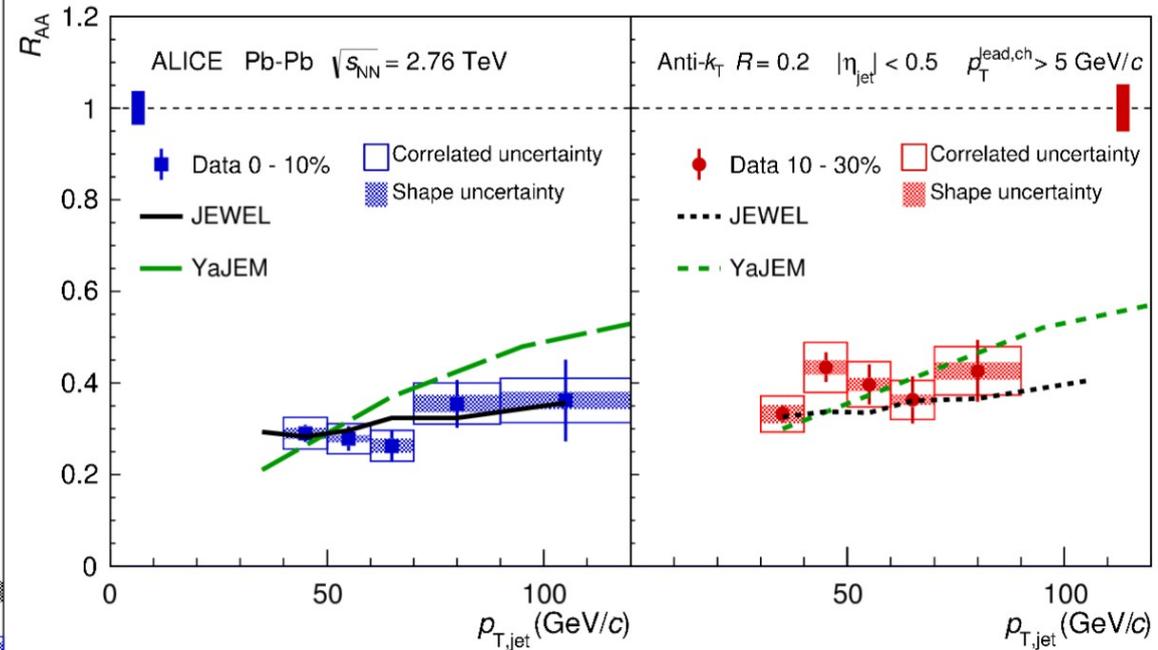
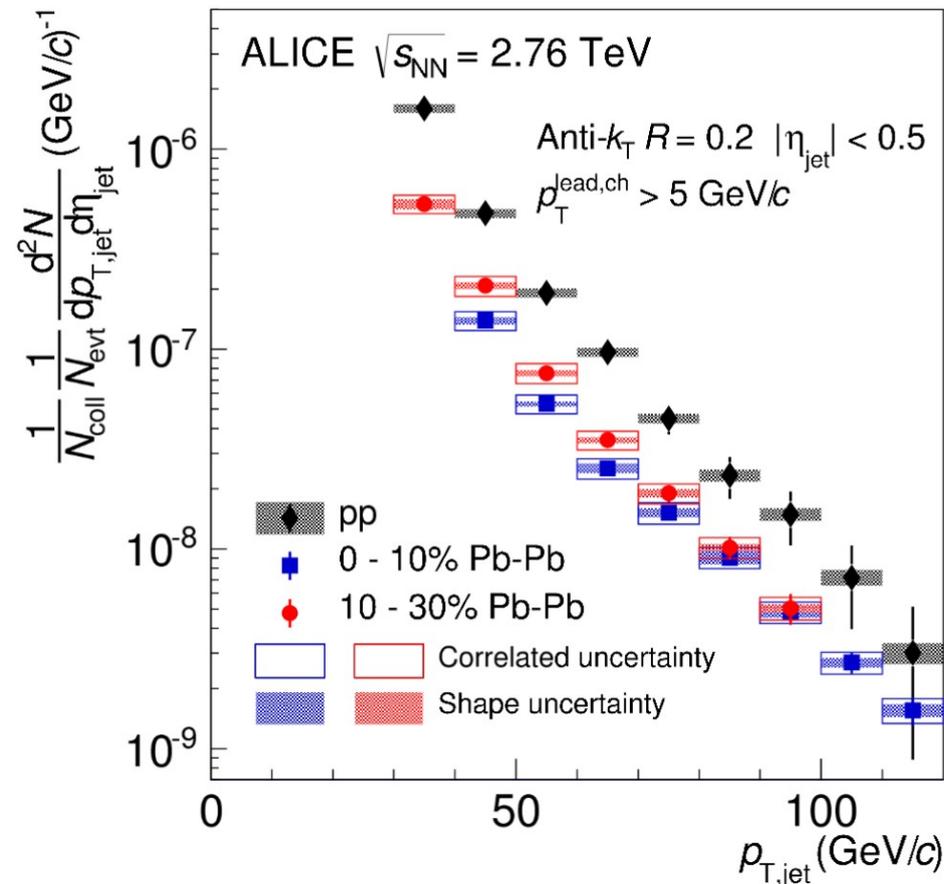
Ratio of inclusive yields at different R (new jet observable)

- Calculable in-vacuum via pQCD
- Measurable in-medium at low p_T and large R (with semi-inclusive observables)

Jet suppression in central PbPb

15

PLB 746 (2015) 1-14



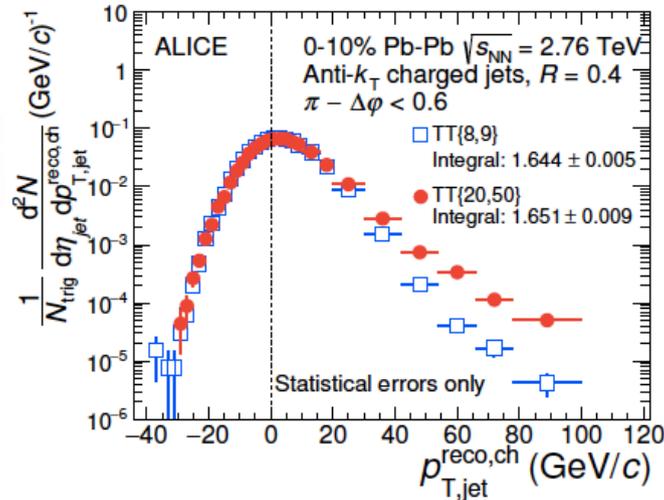
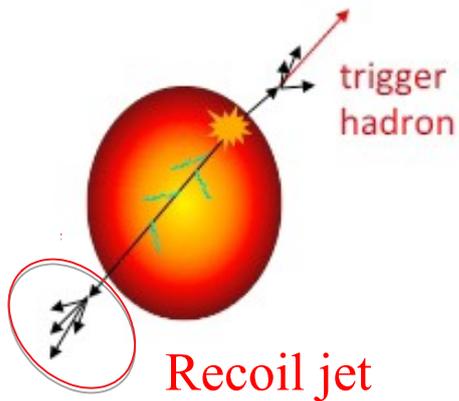
Jet measurements in PbPb must deal with large background and its fluctuations

- Our procedure in ALICE similar to the method first pioneered by us in STAR
- Jet spectrum after event-by-event background subtraction and unfolding of background fluctuations as well as detector resolution effects
- Systematic uncertainties $\sim 18\%$ from reconstruction method and detector

Semi-inclusive hadron jet measurements 16

JHEP 1509 (2015) 170

Trigger-normalized yield of jets recoiling from a high p_T hadron trigger



New observable of jet quenching

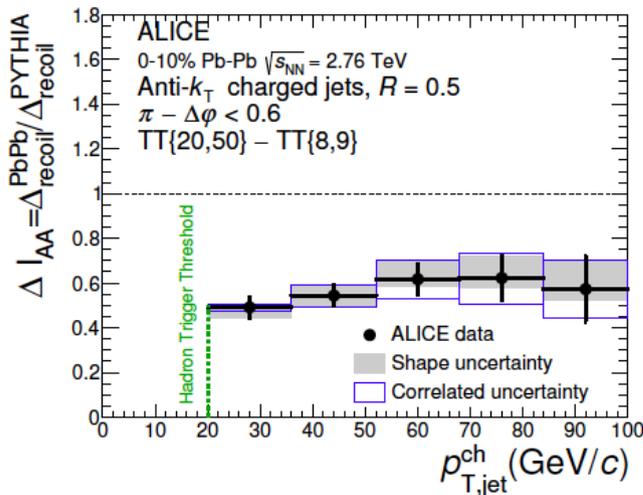
pp: calculable via pQCD

AA: vary p_T^{trig} for data-driven

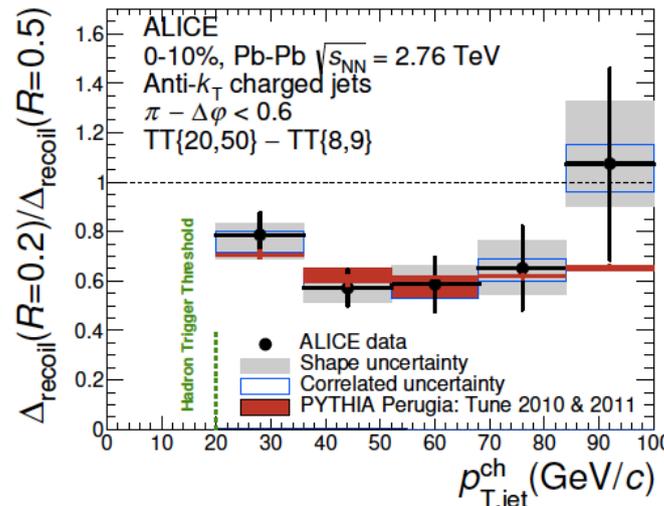
correction of large uncorrelated background

→ systematically well-controlled at low p_T^{jet} , large R

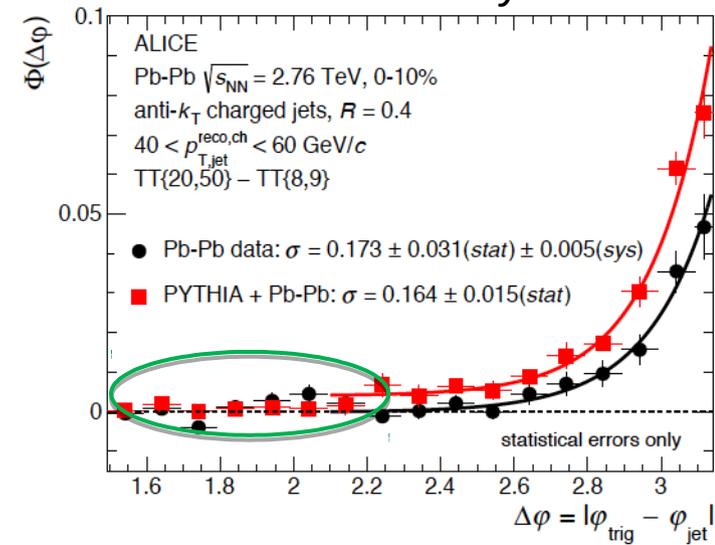
Yield suppression: out-of-cone energy loss ~ 8 GeV



Jet shape modification?
No broadening for $R < 0.5$

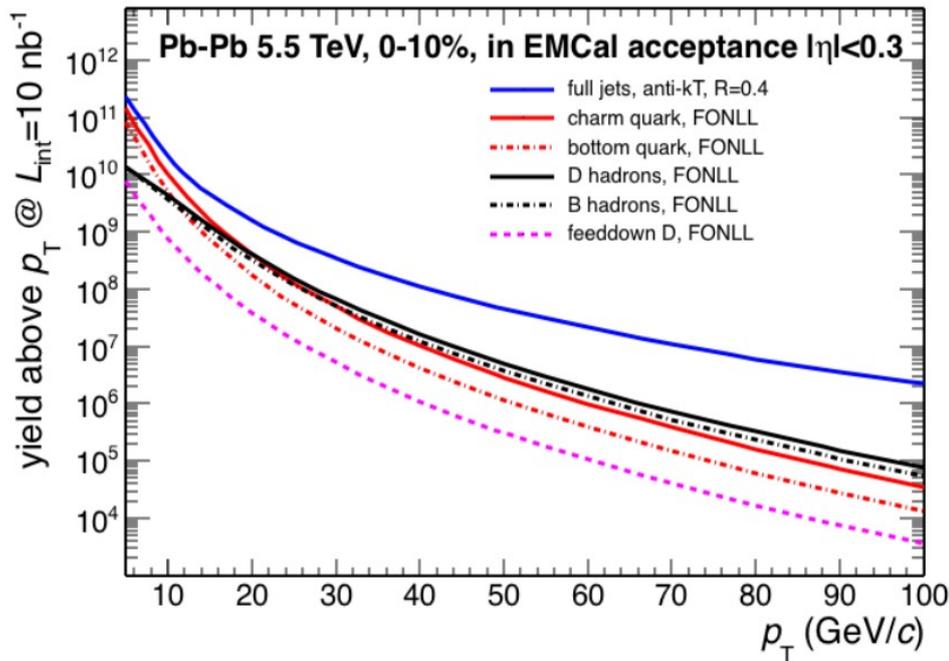


Moliere scattering?
No evidence yet



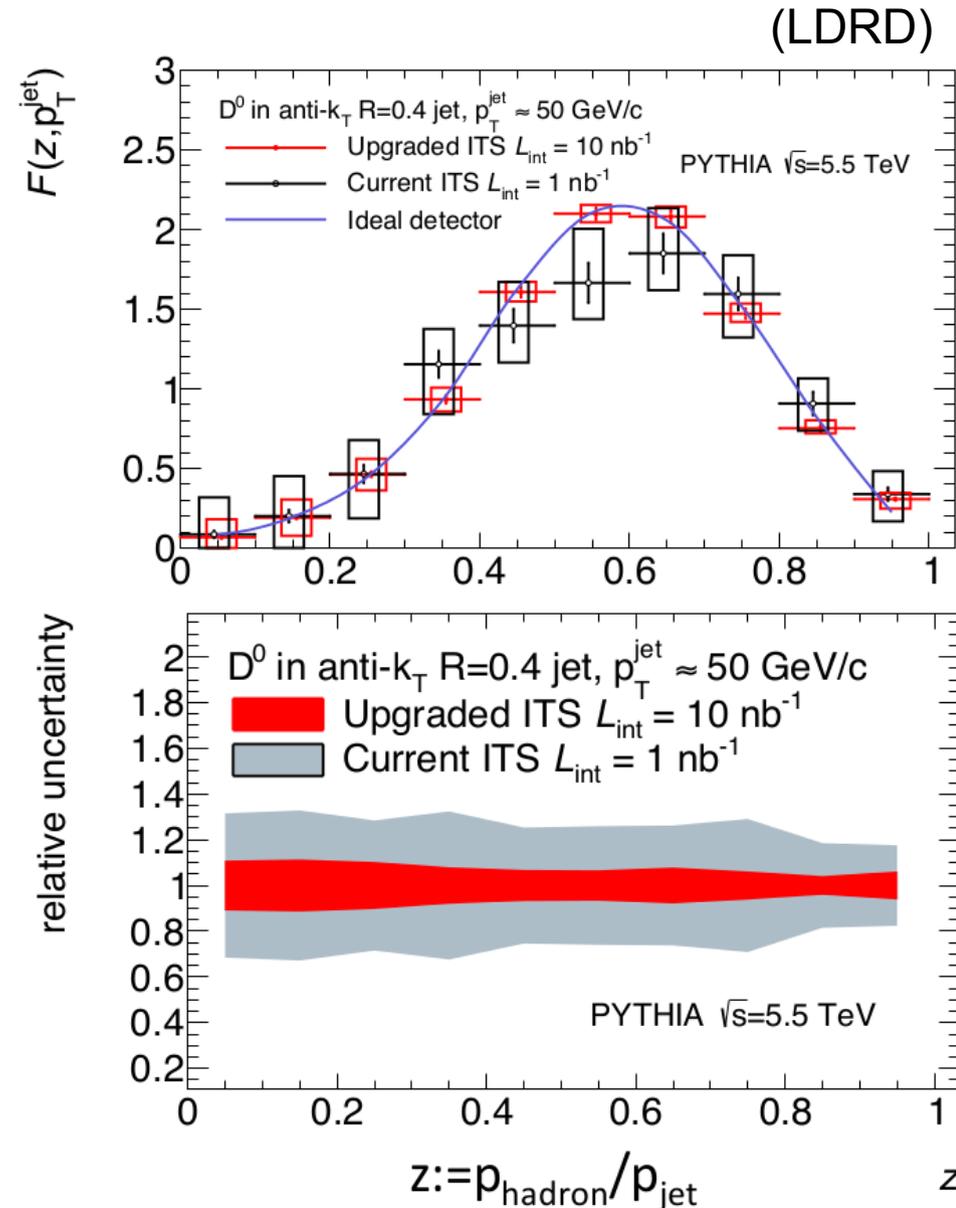
Run 3: Example D^0 in jets

17



Upgraded ALICE + $L_{int} \sim 10/nb$

- Heavy flavor in jets at all z
- Sub-leading charm calculable in QCD ($g \rightarrow c\bar{c}$)
- Map modified gluon shower
- Ultimately: Charm correlations in jets
- Strong synergy with EMCal/DCal
- NB: Kinematic overlap with RHIC



- In 2013-2016, significant #publications (16 equiv. to 10% of ALICE total)
 - Several outstanding, discovery-type or systematically new, measurements such as double ridge, 3-pion, muon-hadron, semi-inclusive jets, PID in jets
- In the next years with Run-2 data, we would like to study
 - Photons (at low and mid- p_T) with different techniques and systems
 - Semi-inclusive measurements with gamma or π^0 triggers
 - Use of Dcal and Emcal as trigger and/or for fully reconstructed jets
 - Focus on low p_T frontier (overlap with RHIC)
 - Jet substructure and quenching: explore new observables based on subjets and n-jettiness for background suppression without biasing jets
 - Small systems
 - Extend measurements to high mult. pp (eg. muon-hadron)
 - Explore and develop “jet-like” observables less sensitive to hadronization (with theory) and potentially apply to data
- ALICE in particular ITS upgrade for Run-3/4
 - Focus on instrumentation
 - Preparation of analyses and computing strategies

Who are we?

20

Staff

P.Jacobs,
M.Ploskon,
C.Loizides,
L.Greiner (instrumentation*)
J.Porter (computing*)
B.Jacak (since 2015, also UCB)

(*) also part of the STAR group



Dhevan Gangadharan (PRC) and Frederike Bock (Shift Leader) during first Run-2 collisions at ALICE in 2015

Postdocs and Phd students

Name	Supervisor	Period
M.Cosentino(^)	C.Loizides	03/2011-03/13
S.Sakai	M.Ploskon	09/2009-03/13
X.Zhang	M.Ploskon	03/2013-09/2015
D.Gangadharan	C.Loizides	09/2013-12/2015
F.Bock (grad.stud.)	C.Loizides	03/2013-now
M.Fasel(^)	M.Ploskon	03/2014-09/2016
L.Milano	P.Jacobs	09/2015-05/2016
Yue Shi Lai(^)	B.Jacak	03/2016-now
N.Apadula	L.Greiner	11/2016-now
A.Collu	L.Greiner	7/2015-now

+ UCB postdocs and students (^ with LDRD)
+ large # of external collaborators and students

Responsibilities and Leadership in ALICE

C.Loizides: Editorial Board co-chair (2014-now),
Physics Working Group co-convener (2012-13)

M.Ploskon: Deputy Physics Coordinator (2012-15)

B.Jacak, P. Jacobs: Editorial Board

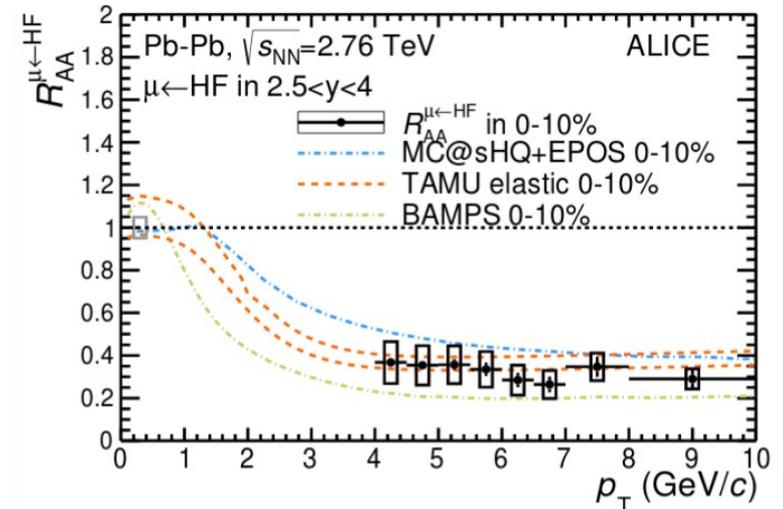
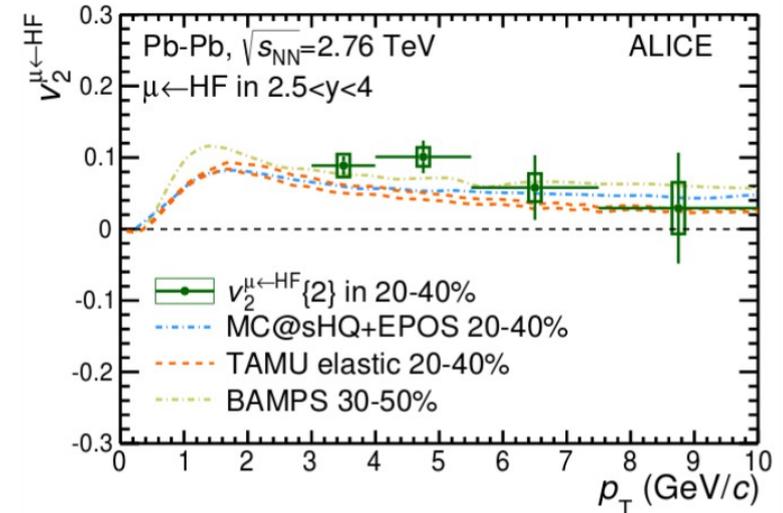
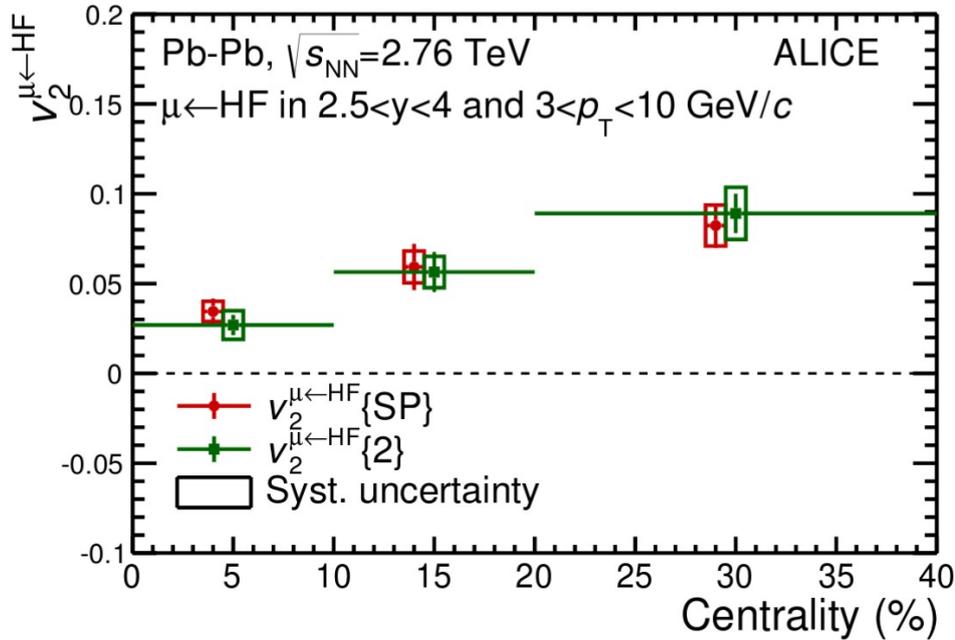
D.Gangadharan, F.Bock: Period Run Coordinator
in 2015,2016

Papers (with at least one lead author from RNC) 21

- Measurement of high-pT electron production from heavy-flavour hadron decays in Pb-Pb at 2.76 TeV, [arXiv:1609.07104](#) (M.Ploskon,S.Sakai)
- Jet-like correlations with neutral pion triggers in pp and central Pb-Pb collisions at 2.76 TeV, [arXiv:1608.07201](#) (C.Loizides)
- Multipion Bose-Einstein correlations in pp, p-Pb, and Pb-Pb collisions, [PRC 93 \(2016\) 054908](#) (D.Gangadharan,C.Loizides)
- Direct photon production in Pb-Pb collisions at 2.76 TeV, [PLB 754 \(2016\) 235-248](#) (F.Bock,C.Loizides)
- Elliptic flow of muons from heavy-flavour hadron decays at forward rapidity in Pb–Pb collisions at 2.76 TeV, [PLB 753 \(2016\) 41-56](#) (X.Zhang)
- Forward-central two-particle correlations in p-Pb collisions at 5.02 TeV, [PLB 753 \(2016\) 126-139](#) (C.Loizides)
- Measurement of jet quenching with semi-inclusive hadron-jet distributions in central Pb-Pb collisions at 2.76 TeV, [JHEP 1509 \(2015\) 170](#) (P.Jacobs)
- Measurement of jet suppression in central Pb-Pb collisions at 2.76 TeV, [PLB 746 \(2015\) 1-14](#) (C.Loizides)

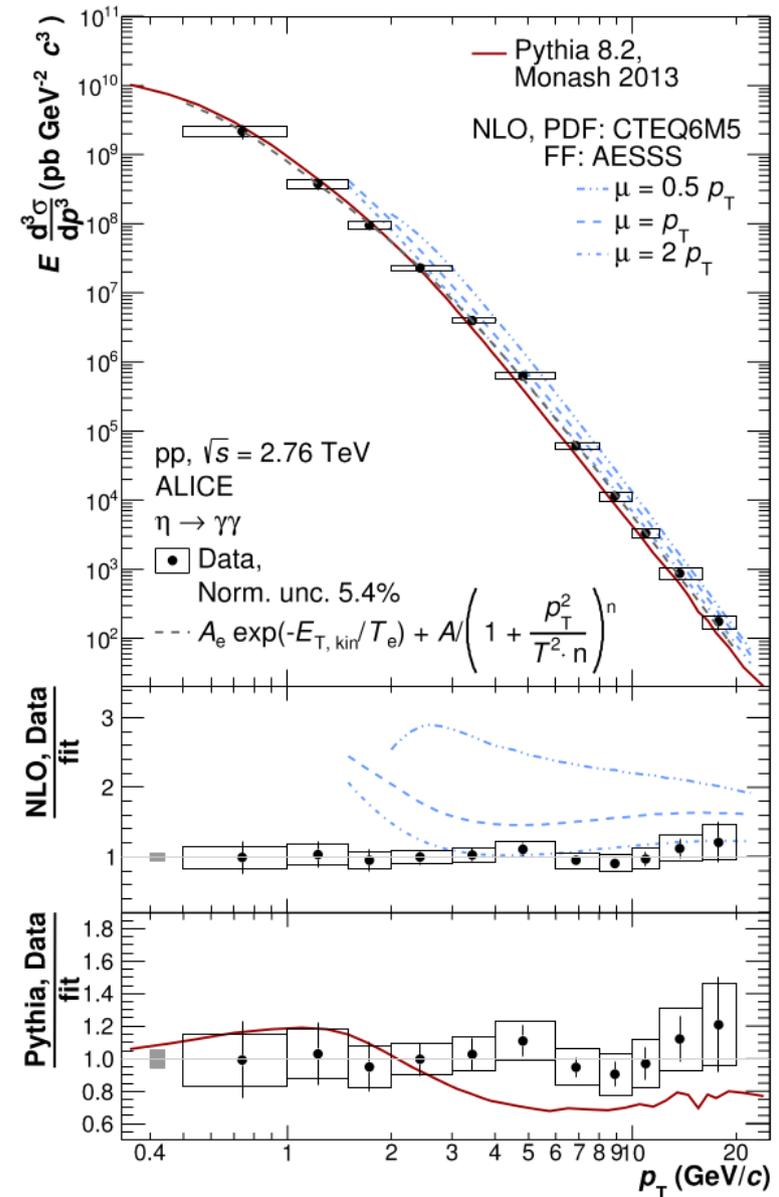
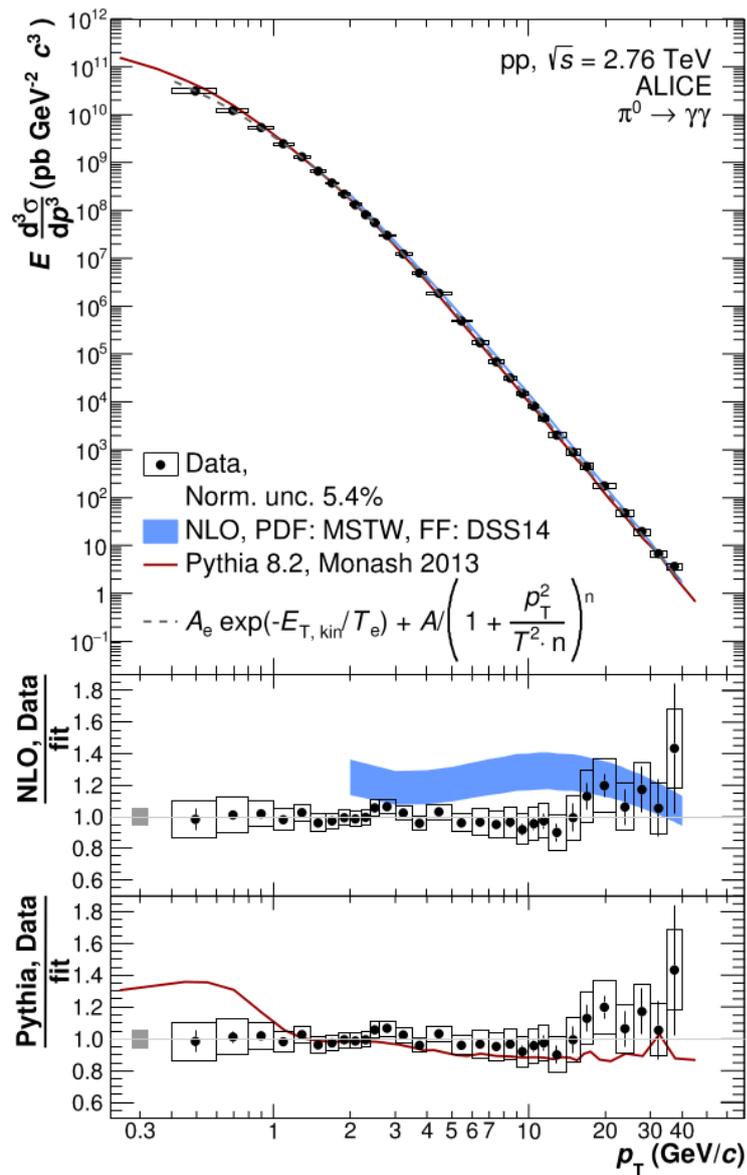
- Multiparticle azimuthal correlations in p-Pb and Pb-Pb collisions at the CERN Large Hadron Collider, [PRC 90 \(2014\) 054901](#) (C.Loizides)
- Neutral pion production at midrapidity in pp and Pb-Pb collisions at 2.76TeV, [EPJC 74 \(2014\) 3108](#) (F.Bock,C.Loizides)
- Freeze-out radii extracted from three-pion cumulants in pp, p-Pb and Pb-Pb collisions, [PLB739 \(2014\) 139-151](#) (D.Gangadharan, C.Loizides)
- Long-range angular correlations on the near and away side in p-Pb collisions at 5.02 TeV, [PLB 719 \(2013\) 29-41](#) (C.Loizides)
- Performance of the ALICE Experiment at the CERN LHC, [IJMPA 29 \(2014\) 1430044](#) (F.Bock,P.Jacobs,C.Loizides,M.Ploskon)
- Two- and three-pion quantum statistics correlations in Pb-Pb collisions at 2.76 TeV, [PRC 89 \(2014\) 024911](#) (D.Gangadharan)
- Directed flow of charged particles at midrapidity relative to the spectator plane in Pb-Pb at 2.76 TeV, [PRL 111 \(2013\) 232302](#) (C.Loizides)
- Measurement of the inclusive differential jet cross section in pp collisions at 2.76 TeV, [PLB 722 \(2013\) 262-272](#) (P.Jacobs)

- Pseudorapidity density of charged particles in p-Pb collisions at 5.02 TeV, [PRL 110 \(2013\) 032301](#) (C.Loizides)
- Charge separation relative to the reaction plane in Pb-Pb collisions at 2.76 TeV, [PRL 110 \(2013\) 012301](#) (J.Thomas)
- Measurement of electrons from semileptonic heavy-flavour hadron decays in pp collisions at 7 TeV, [PRD 86 \(2012\) 112007](#) (S.Sakai)
- Measurement of event background fluctuations for charged-particle jet reconstruction in Pb-Pb at 2.76 TeV, [JHEP 1203 \(2012\) 053](#) (P.Jacobs)
- Harmonic decomposition of two-particle angular correlations in Pb-Pb collisions at 2.76 TeV, [PLB 208 \(2012\) 249-264](#) (C.Loizides)
- Higher harmonic anisotropic flow measurements of charged particles in Pb-Pb collisions at 2.76 TeV, [PRL 107 \(2011\) 032301](#) (C.Loizides)
- Centrality dependence of the charged-particle multiplicity density at mid-rapidity in Pb-Pb at 2.76 TeV, [PRL 106 \(2011\) 032301](#) (C.Loizides)
- Charged-particle multiplicity density at mid-rapidity in central Pb-Pb collisions at 2.76 TeV, [PRL 105 \(2010\) 252301](#) (C.Loizides)



- Measured of HF muon flow
 - Significant flow above 3 GeV
 - Data challenge models that aim at calculating the nuclear modification and v_2

Meson spectra to unprecedented p_T

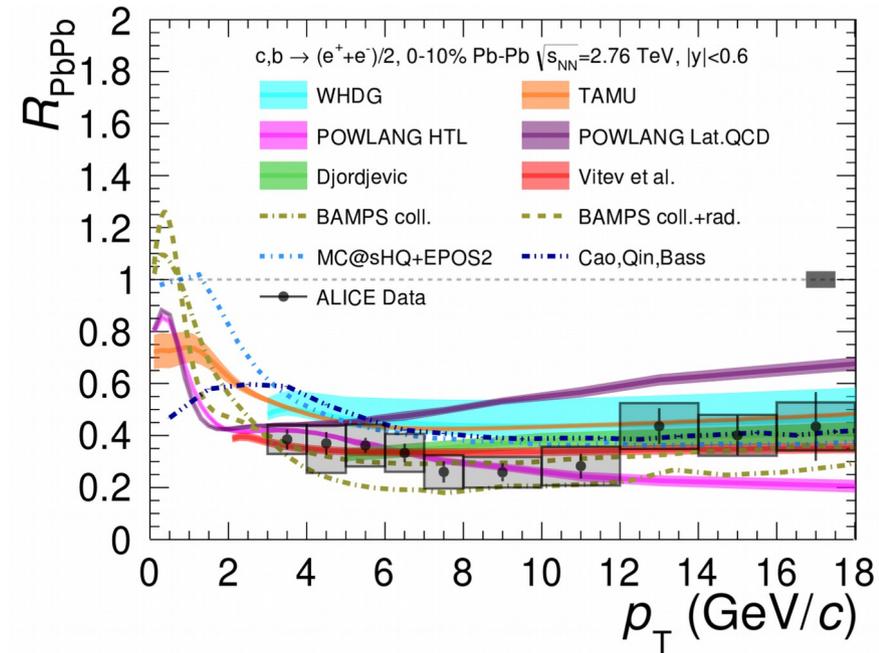
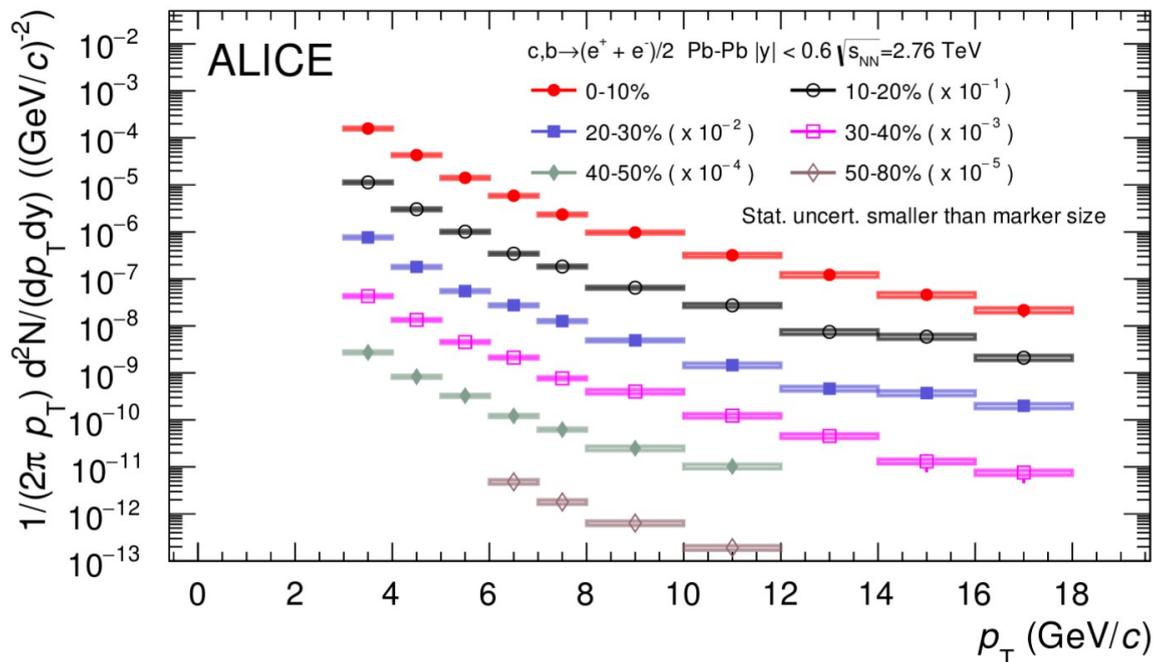


Comprehensive paper in preparation

Heavy-flavor electrons

26

arXiv:1609.07104

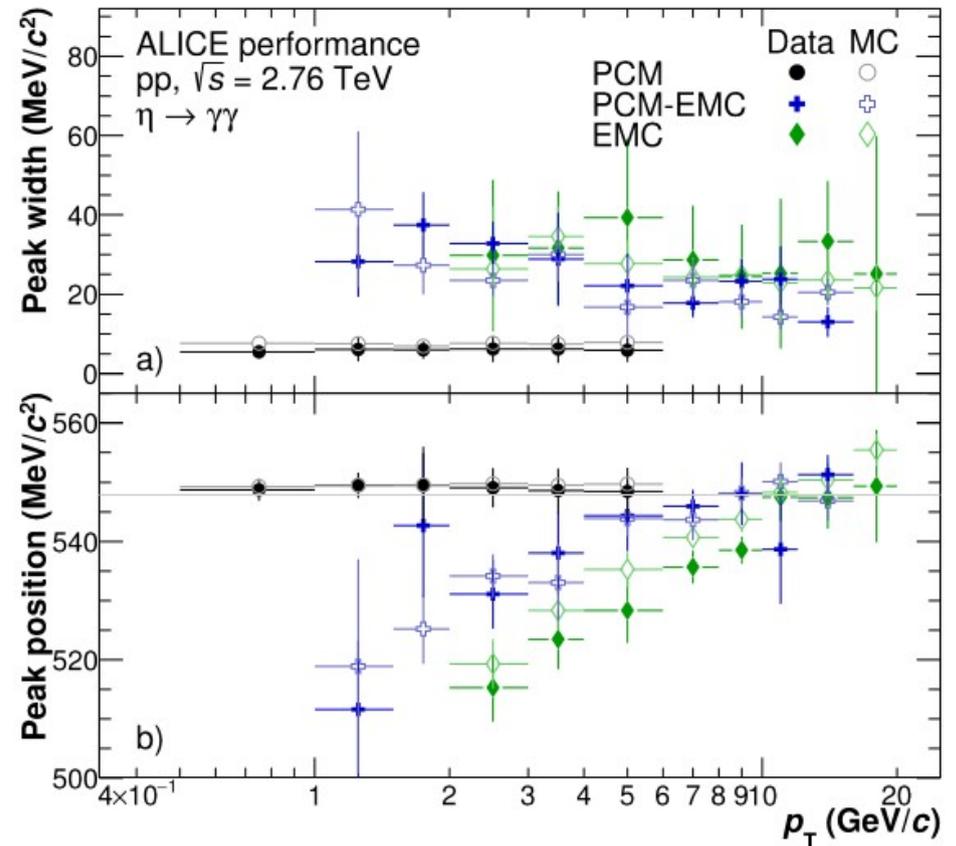
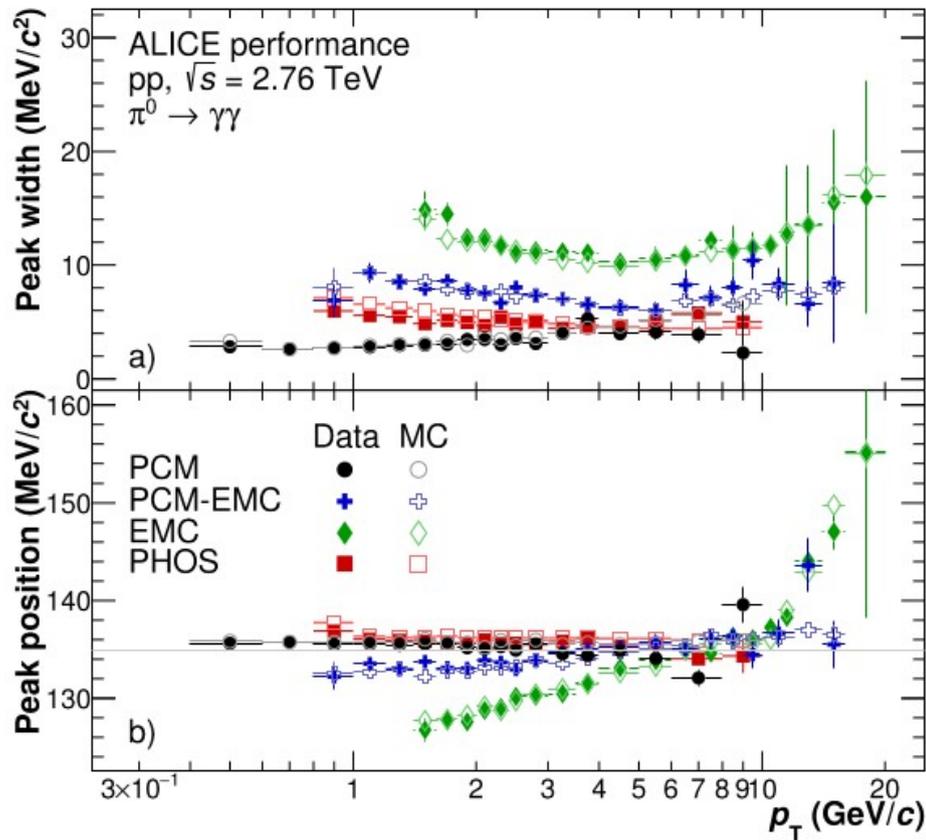


Strong suppression of electrons originating from heavy-flavor decays observed in central Pb-Pb collisions.

(NB: Uses EMCAL trigger in Pb+Pb)

Mass peak and width

27



Reached very high relative precision between MC and data (<0.3%)

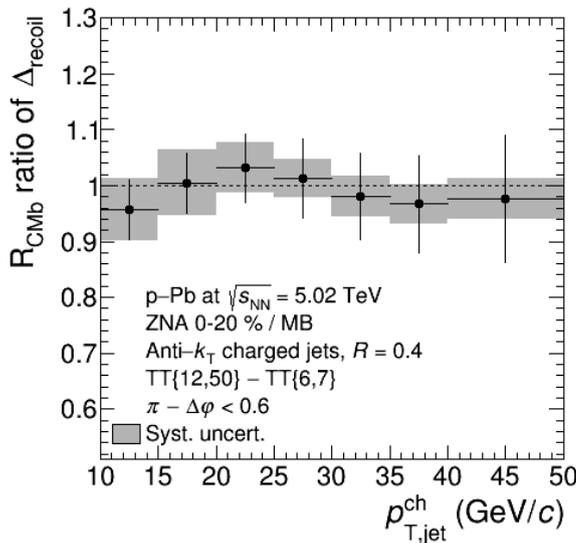
Semi-inclusive h+jet:

- Sensitive to quenching in A+A
- Δ_{recoil} : fully removes multi-partonic component
- Self-normalized: reference does not require T_{pPb}
 →no geometric modeling, no “centrality” bias
- Look at ratio of “centrality”-selected to MB

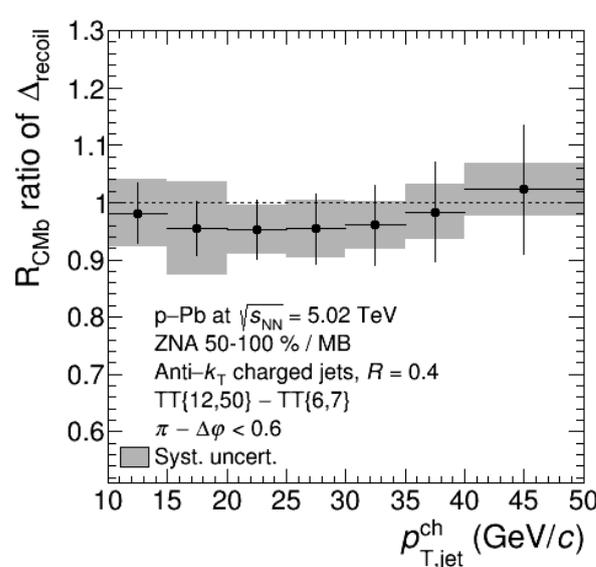
$$\frac{1}{N_{\text{trig}}^h} \frac{dN_{\text{jet}}}{dp_{T,\text{jet}}} = \frac{1}{\sigma^{AA \rightarrow h+X}} \frac{d\sigma^{AA \rightarrow h+\text{jet}+X}}{dp_{T,\text{jet}}}$$

$$= \frac{1}{\sigma^{pp \rightarrow h+X}} \frac{d\sigma^{pp \rightarrow h+\text{jet}+X}}{dp_{T,\text{jet}}} \times \frac{T_{\text{pPb}}}{T_{\text{pPb}}}$$

“central” ZNA/MB



“peripheral” ZNA/MB



- No evidence of jet quenching seen in “central” p+Pb to better than 10%,
- including low p_T^{jet} , large R
- paper in progress

Run 16: DCal trigger on π^0/γ , fully-reconstructed jets in EMCAL

- Improved sys and stat precision, greater kinematic reach

Semi-inclusive jet measurements:

- DCal trigger: π^0 , g
- EMCAL: fully reconstructed recoil jets
- improved systematics, kinematic reach, compare g vs p^0 -triggered recoil jets

Low p_T^{jet} frontier:

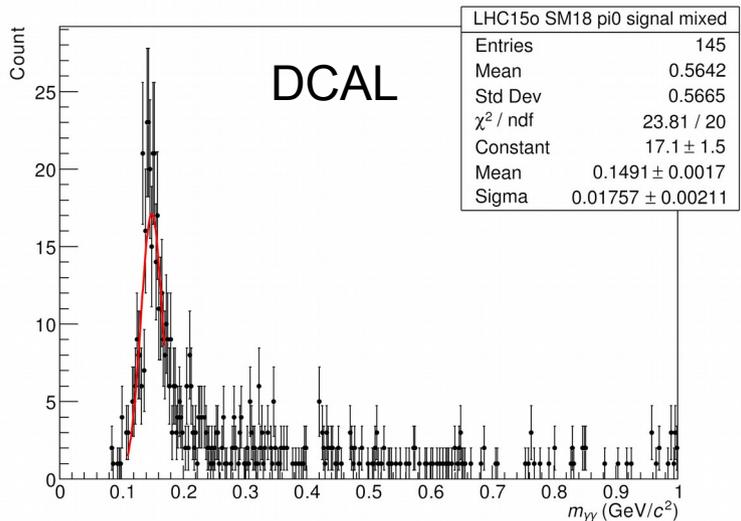
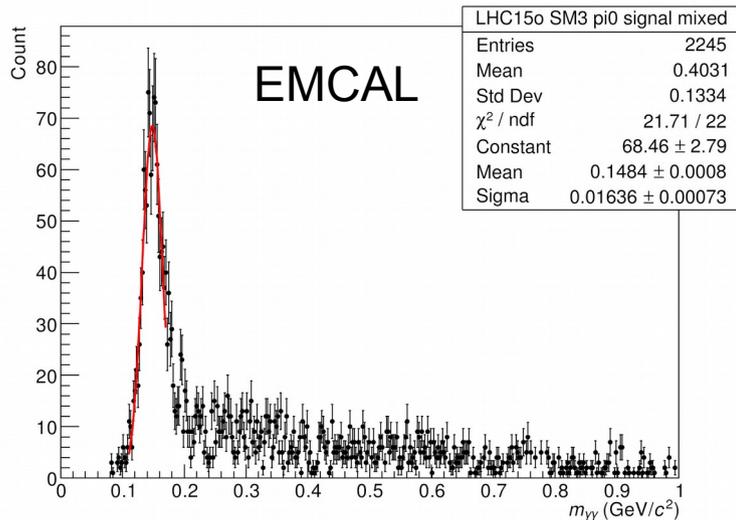
- challenging S/B but analysis techniques now in place
- Acoplanarity distribution with high statistics: direct measurement of q_{hat} ; search for Moliere scattering

Jet substructure and quenching: explore new observables based on n-jettiness

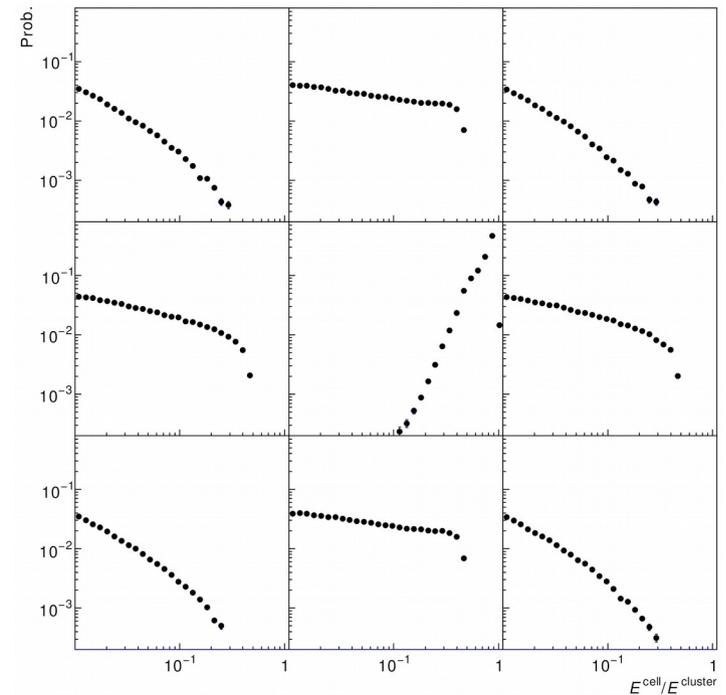
- Background suppression without jet grooming (do not modify quenched jets)
- Similar emphasis on full kinematic range, large-R jets

Search for CGC and collective effects in small systems (p+p, p+Pb):

- Want to study gluon correlations but can only measure hadrons at low p_T
- N-hadron correlations vs. QCD calculations: large hadronization corrections (factor ~ 2 for v_2 ; Schenke et al. 2016)
- Develop observables less sensitive to hadronization (with BNL Theory)
 - “jet-like” low p_T observables
 - if successful, apply to ALICE p+Pb and p+p data



3x3 cell energy fraction distribution for photon candidates in Monte Carlo simulation



- Work to prepare for Run-2 prompt photon + hadron correlations
 - Calibration of EMCa/DCa
 - Development of improved photon discriminator(s)
 - LDRD supported