Low p PID with ps-TOF detector at EIC

EIC RNC meeting (04/26/2022)

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Low p threshold for RICH detectors

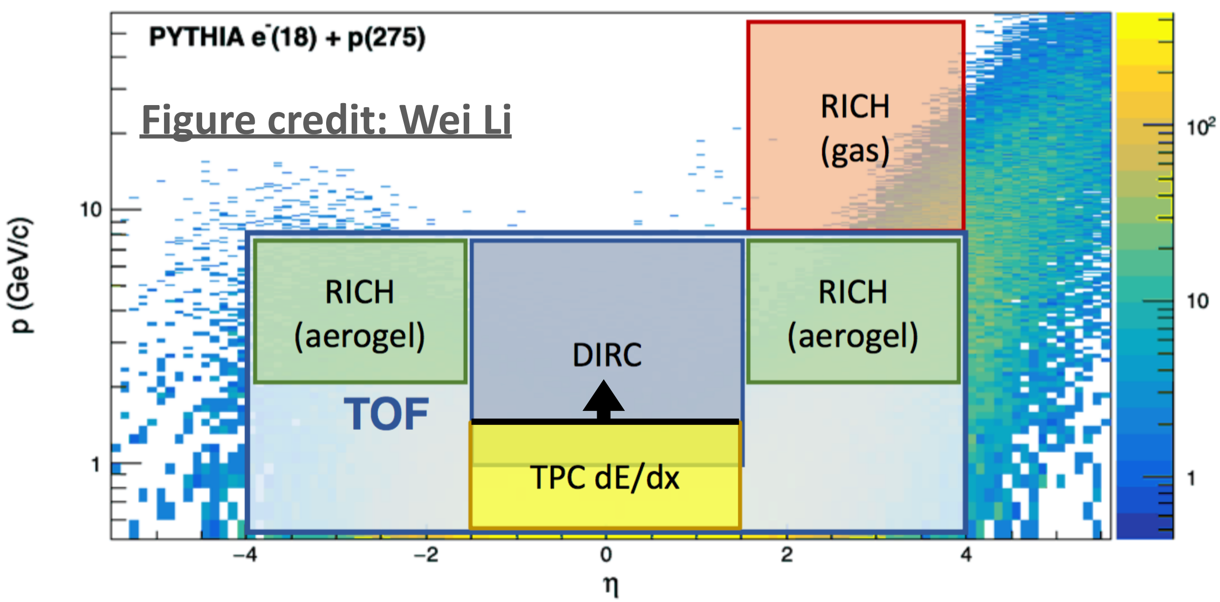
Physics requirements:

Rapidity	π/K/p and π0/γ	e/h	Min pT (E)
-3.5 – -1.0	7 GeV/c	18 GeV/c	100 MeV/c
-1.0 – 1.0	8-10 GeV/c	8 GeV/c	100 MeV/c
1.0 – 3.5	50 GeV/c	20 GeV/c	100 MeV/c

EICUG YR

radiator	index	Threshold (GeV/c) e	π	K	p
quartz (DIRC)	1.473	0.00048	0.13	0.47	0.88
aerogel (mRICH)	1.03	0.00207	0.57	2.00	3.80
aerogel (dRICH)	1.02	0.00245	0.69	2.46	4.67
C_2F_6 (dRICH)	1.0008	0.01277	3.49	12.34	23.45
CF_4 (gRICH)	1.00056	0.01527	4.17	14.75	28.03

Table 11.23: Table of Cherenkov thresholds for various media.



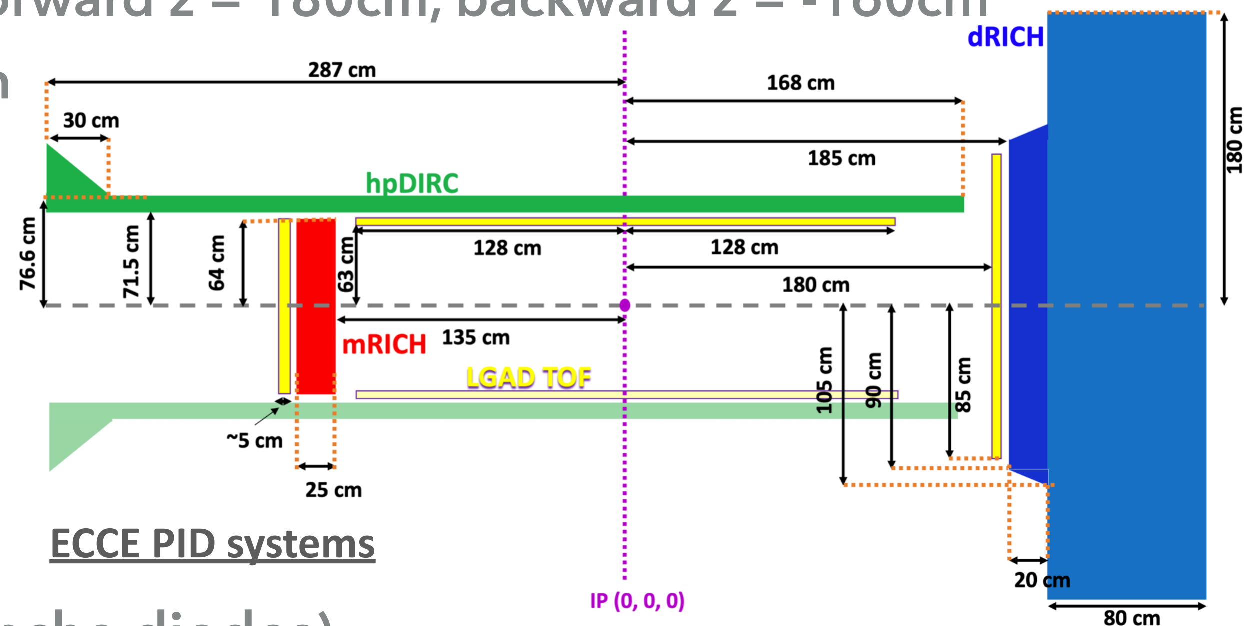
Magnetic field can also affect the low p_T range

Low p PID can be covered by TPC or TOF

TOF: LGADs, SPADs

Ultra-Fast Silicon Detectors: LGAD and SPAD

- AC-LGAD (AC-coupled low gain avalache diodes)
  - R&D goal: <=25ps for timing, 30um for spacial resolution (eRD112)
  - In ECCE: barrel R = 63cm, forward z = 180cm, backward z = -160cm
  - In ATHENA: barrel R = 52cm



ECCE PID systems

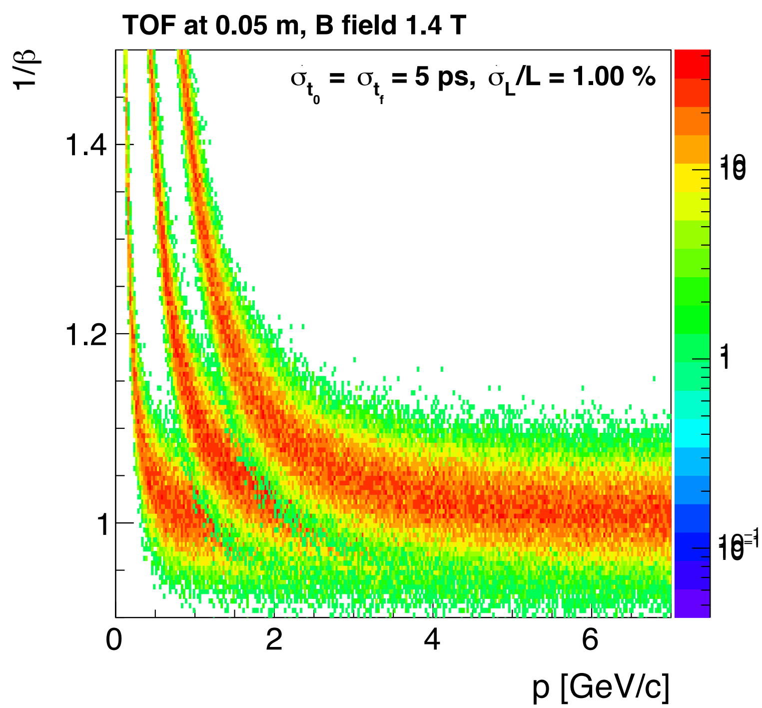
- SPAD (single-photon avalanche diodes)
  - Keeping nice feature of MAPS, and a timing resolution as low as 6.7ps
  - No device suitable for large-scale use has been made yet but early (recent) studies show that <10ps timing resolution is achievable
  - https://arxiv.org/pdf/2111.09998.pdf, Yuan's presentation: https://conferences.lbl.gov/event/827/contributions/5535/attachments/3753/3017/PsMAPSdev.pdf

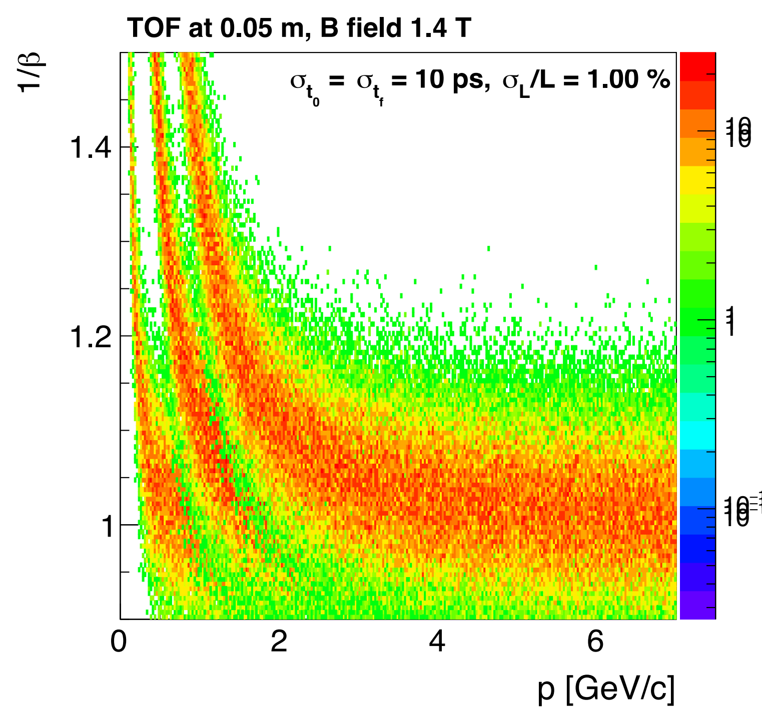
Toy MC to extract the π/K/p separation power

- Throw particles (π, K, proton) of different p and η
  - Calculate time of flight t_{flight} = L/velocity
  - Truth: $t_0 = 0$, $t_f = t_0 + t_{flight}$ = L/velocity
  - $\beta = L^{reco} / [(t_f^{reco} - t_0^{reco}) \cdot c]$
  - t_f^{reco} and t_0^{reco}: smear t_f and t_0 by 5, 10, 20, 30, 50 ps
  - L^{reco} : smear L by 0.05%, 0.1%, 1%

More realistic situation: smear L by the uncertainties extracted from full simulation

- Extract the high p limit of 3σ separation for different TOF locations





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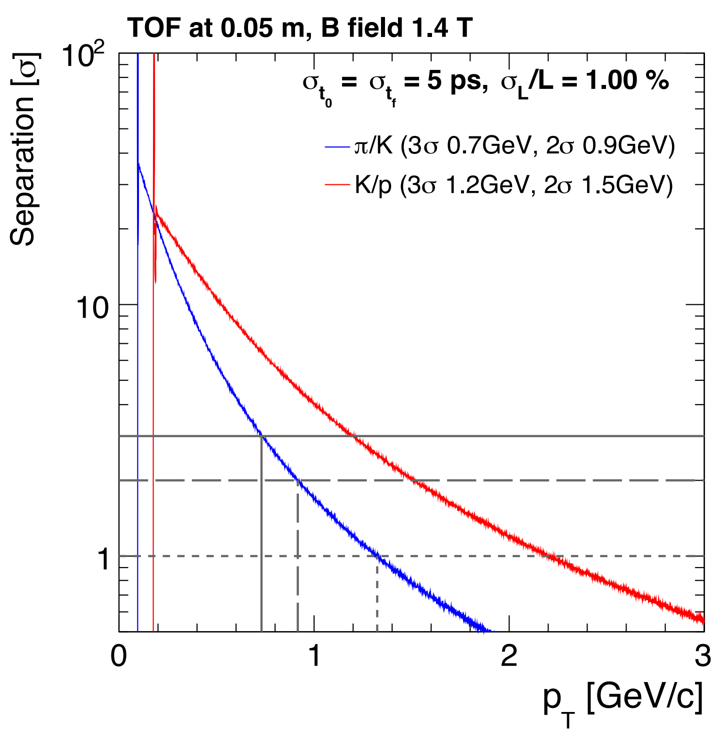
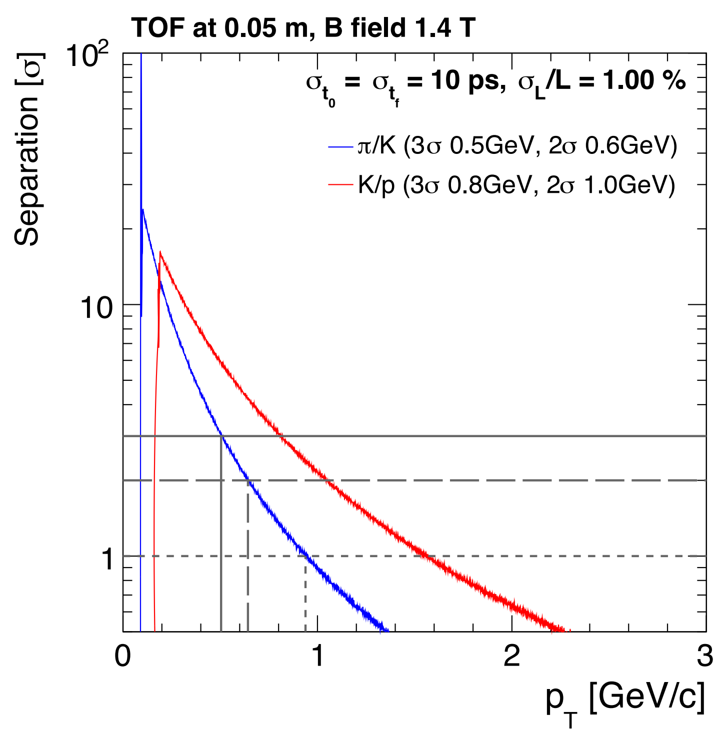




Low p PID at mid-rapidity for 1.4T

- TOF can be complementary to DIRC
  - Particles which can not reach DIRC (not really a problem with 1.4 T)
  - Particles below the DIRC firing threshold (0.47GeV for K, 0.88GeV for p)

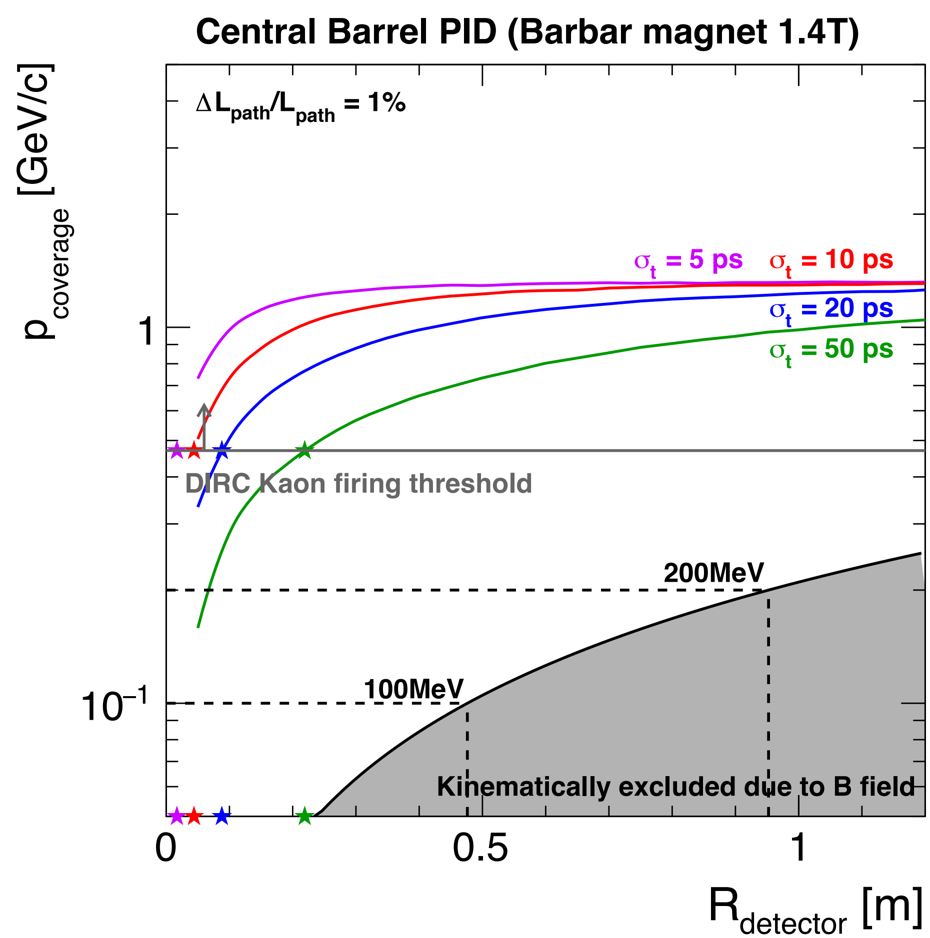
Easier to perform low p PID (DIRC, TOF, dE/dx) with low B field: 0.2 GeV paricles can reach detector ~1m

If one want to use dE/dx (cluster counting) or TOF to cover low p, it needs to sits at a moderate R (<50cm if one want PID ~0.1 GeV)

20ps LGAD 10-50cm can cover 0.1 GeV to DIRC firing threshold

10ps (5ps) SPAD 5-50cm (2-50cm) can cover 0.1 GeV to DIRC firing threshold

- ***The smaller the cheaper***
- ***Addtional material inside trackers addtional M.S.***

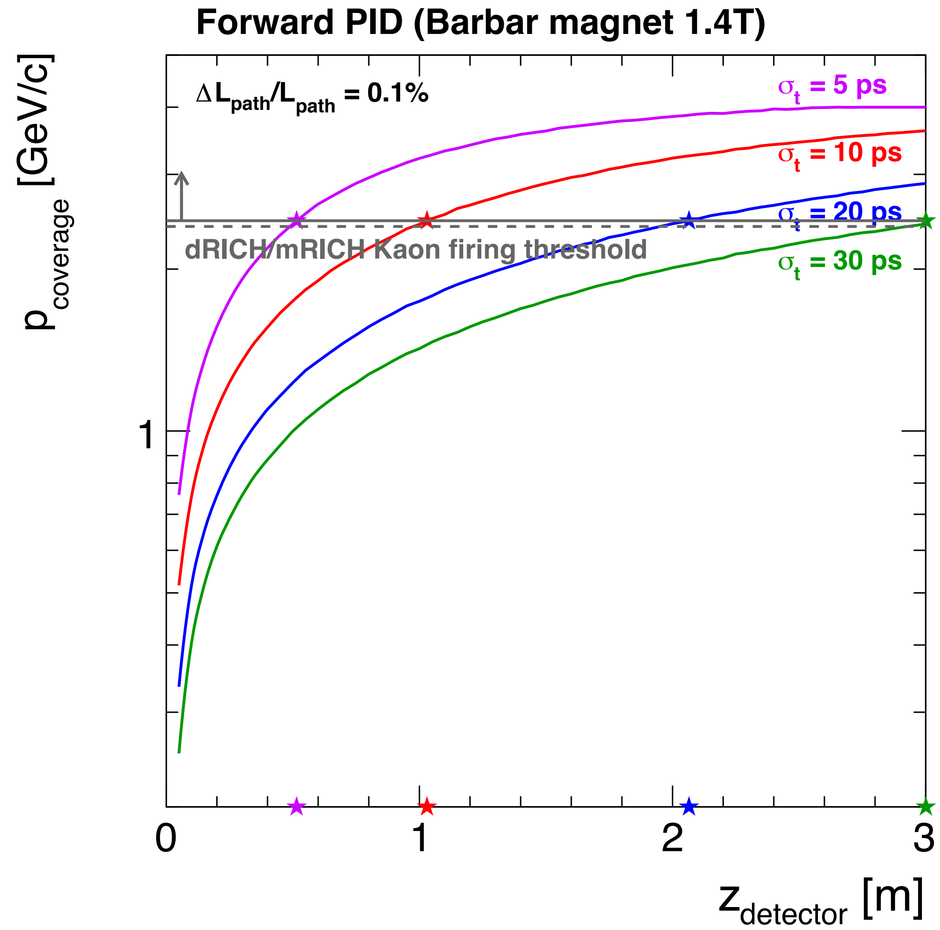


Low p PID at forward-rapidity for 1.4T

- TOF can be complementary to dRICH
  - Particles below the dRICH firing threshold (2.46GeV for K, 4.67GeV for p)

20ps LGAD >2m can cover up to the dRICH firing threshold

10ps (5ps) SPAD >1m (>0.5m) can cover up to the dRICH firing threshold



- ***The smaller the cheaper***
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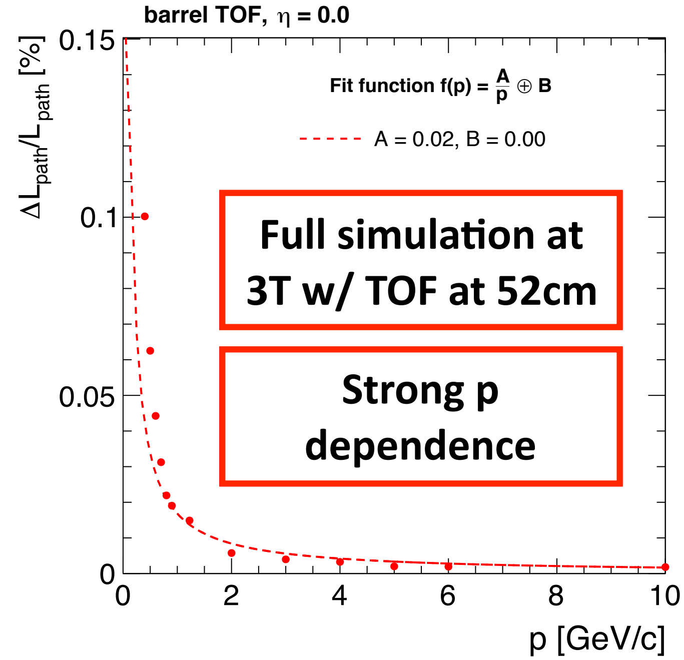
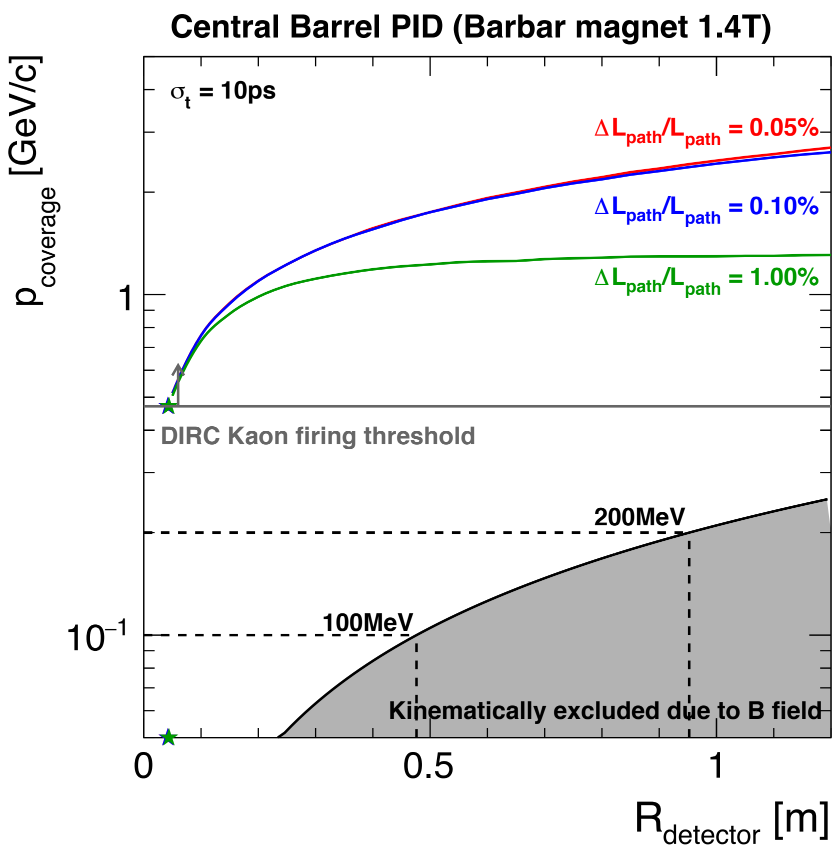
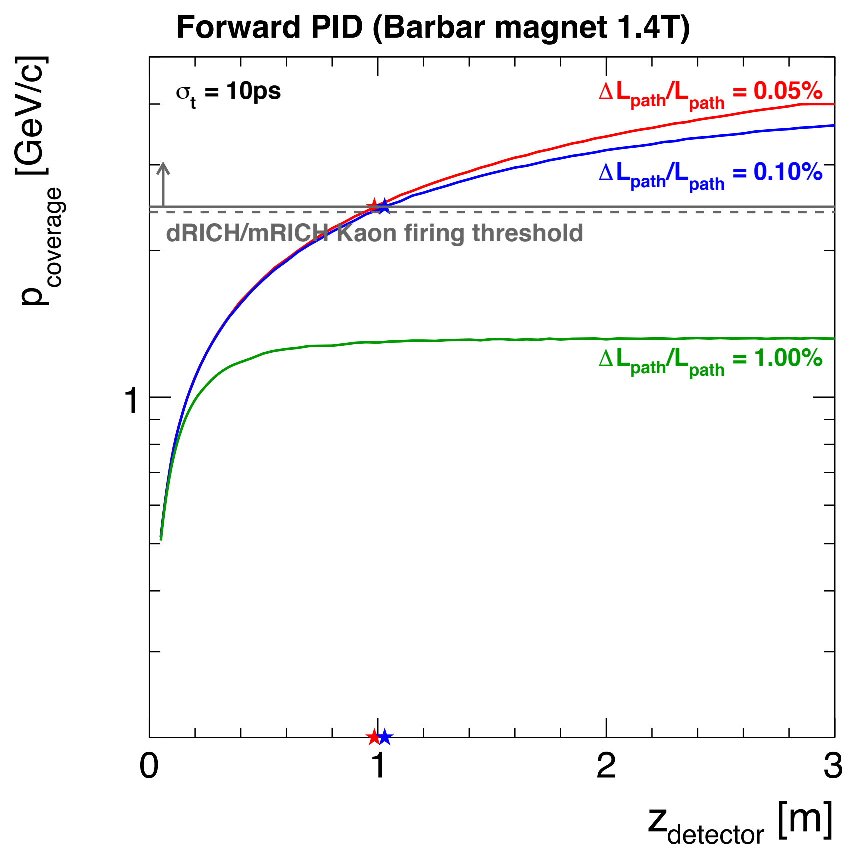
Path length uncertainties

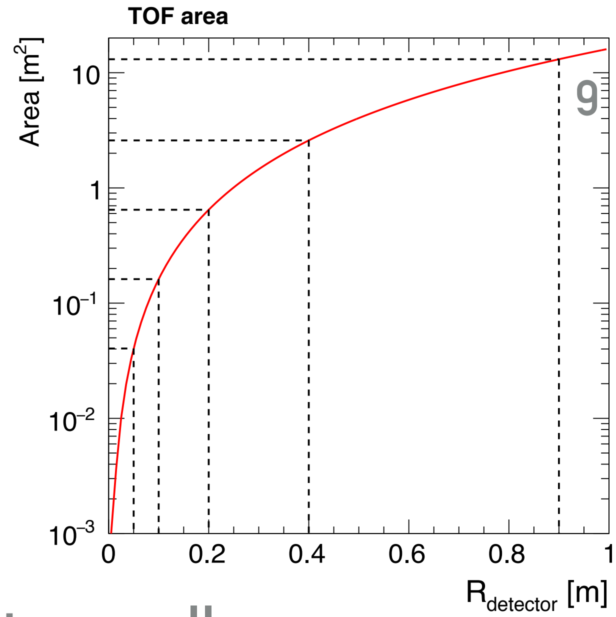
- Pathlength uncertainty: 0.05%, 0.1%, 1%
  - The p coverage is sensitive to the path length uncertainty
  - More realistic smearing on L_{path} will require full simulation to obtain ΔL_{path}(det location, p, η)







Summary



- TOF can cover the low p PID (complementary to Cherenkov detector)
  - Closer means low p tracks can easily reach the detector (in barrel region)
  - Closer also means smaller area => cheaper
  - Better intrinsic timing resolution => push the detector smaller
- Currently AC-LGAD is proposed in ECCE and ATHENA design
  - At least 25ps timing resolution and 30um spatial resolution
- Sub-10ps SPAD can be very interesting
  - Can go as close as ~2cm in the barrel region
  - Can go as close as ~50cm in the forward region
  - 4D tracking review: https://arxiv.org/pdf/1704.08666.pdf. Using timing to improve tracking from Spencer: https://iopscience.iop.org/article/10.1088/1748-0221/15/03/P03024