Particle Identification Summary

Guy Wilkinson and Stephane Monteil

4th FCC Physics and Experiments Workshop, November 2020

PID sessions

Two lively PID sessions, on Weds pm and Thurs am:

16:00 **Study of Bs -> Ds K at FCC-ee and constraints on detector**
Speaker: Roy Aleksan (Université Paris-Saclay (FR))
FCCee-week-2020_... FCCee-week-2020_...

16:25 **Time of flight (TOF) review**
Speaker: Jerry Vavra (SLAC)
Vavra_invited_talk_...

16:50 **Timing layers**
Speaker: Chih-Hsiang Yeh (National Central University (TW))
Slides.pdf

17:10 **PID at EIC**
Speakers: Thomas Hemmick (Stony Brook University), Thomas Hemmick
PIDatEIC.pdf PIDatEIC.pptx

09:00 **Particle Identification at the Z factory**
Speaker: Francesco Grancagnolo
FCCee_PId.pdf FCCee_PId.pptx

09:25 **PID with high granularity dE/dx**
Speaker: Ulrich Einhaus (DESY)
2020_11_12_FCC_...

09:50 **Flavour tagging in W decays**
Speaker: Paolo Azzurri (INFN Sezione di Pisa, Universita' e Scuola Normale Superiore, P)
azzurriFCCeeWHF.pdf

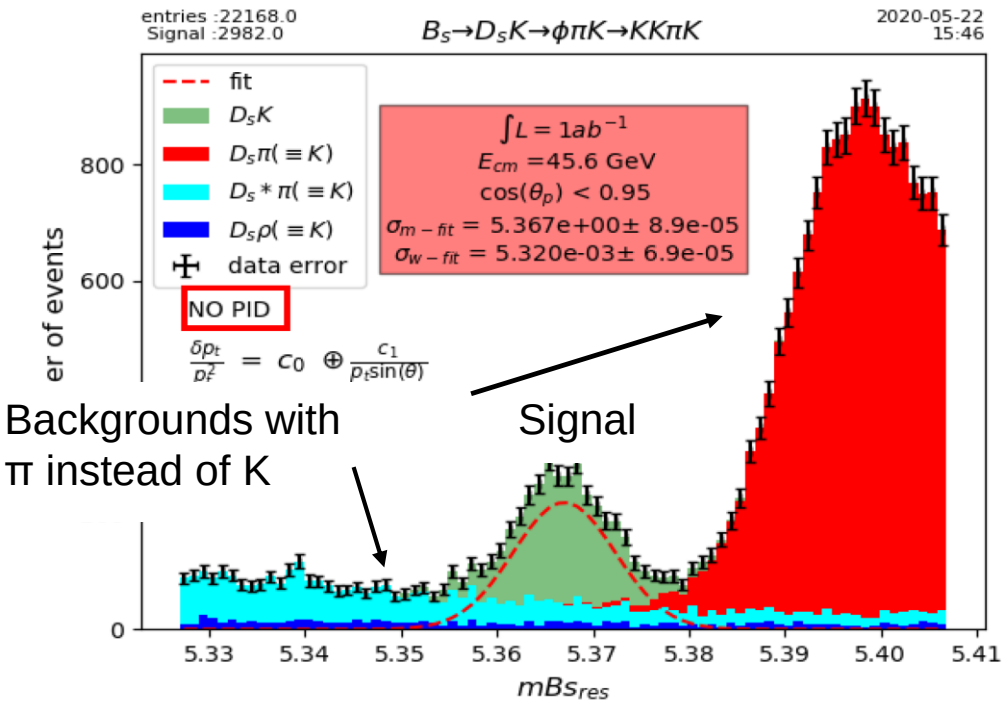
Physics drivers

B-physics

Benchmark CP-violation channel $B_s \rightarrow D_s K$ investigated by Roy Aleksan with toy MC and parametrised FCC-ee detector response.

Firstly look at fully charged track final state, *e.g.* with $D_s \rightarrow \phi\pi$.

Mass spectra without PID



It seems that the excellent mass resolution can do a great job…

…but be careful, there is still background lying under the peak, and in reality the mass spectrum is more complicated than this, and the exquisite statistical precision demands the utmost systematic control…

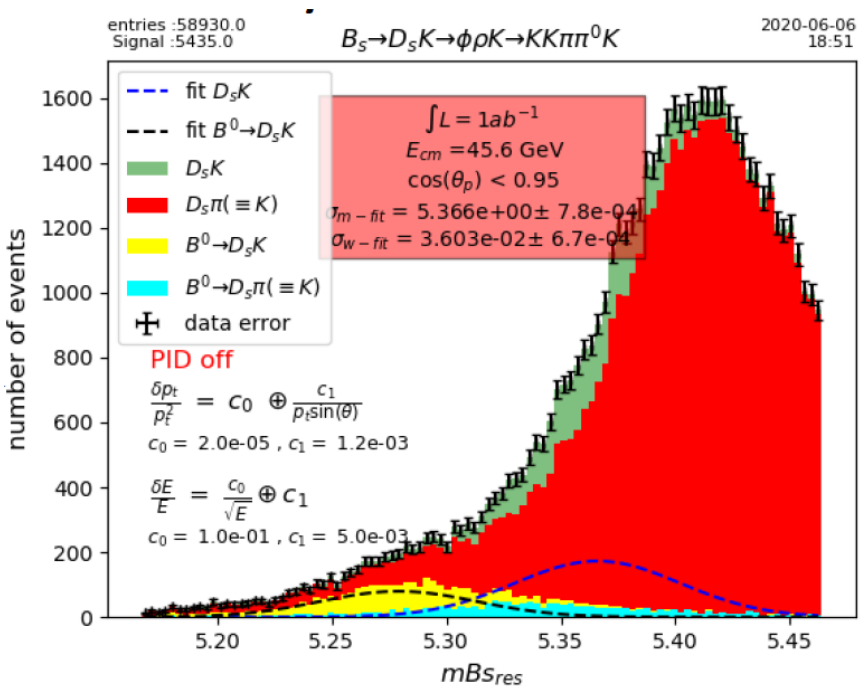
…so PID still highly desirable !

B-physics

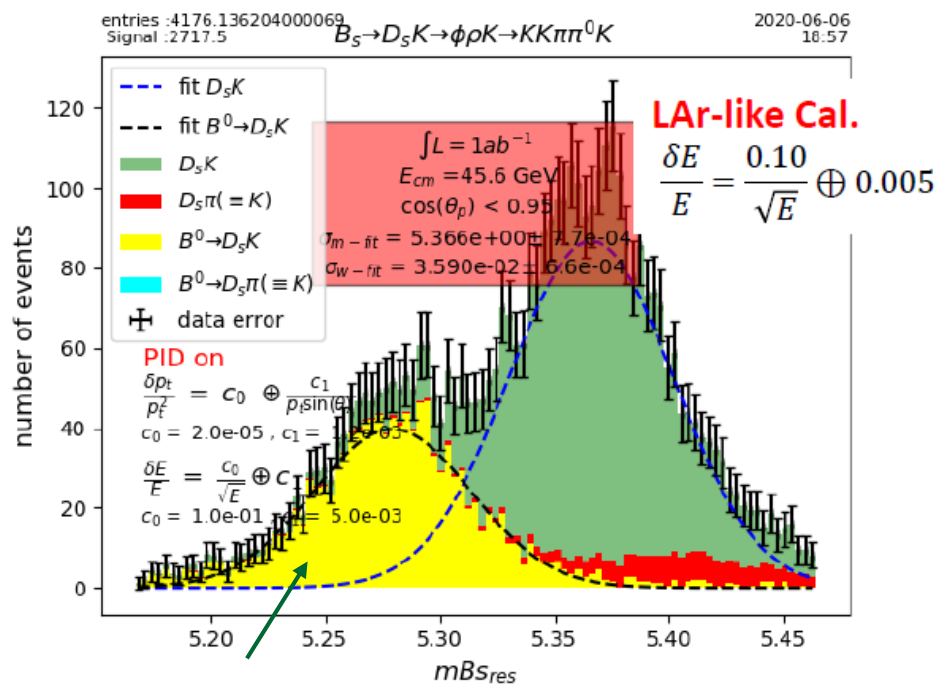
Benchmark CP-violation channel $B_s \rightarrow D_s K$ investigated by Roy Aleksan with toy MC and parametrised FCC-ee detector response.

Now consider a final state with neutrals, *e.g.* with $D_s \rightarrow \phi\rho(\pi\pi^0)$.

Mass spectra without PID



Mass spectra with PID



Here PID is clearly *essential* !

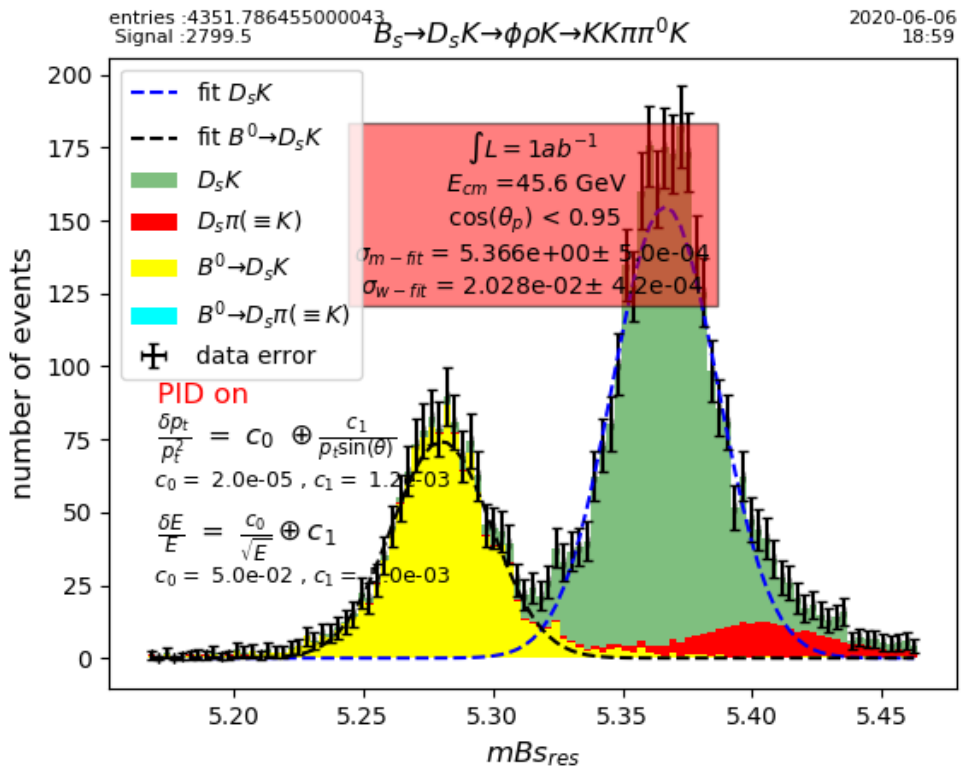
Now this, the identical final-state from B^0 decays, is the problem.

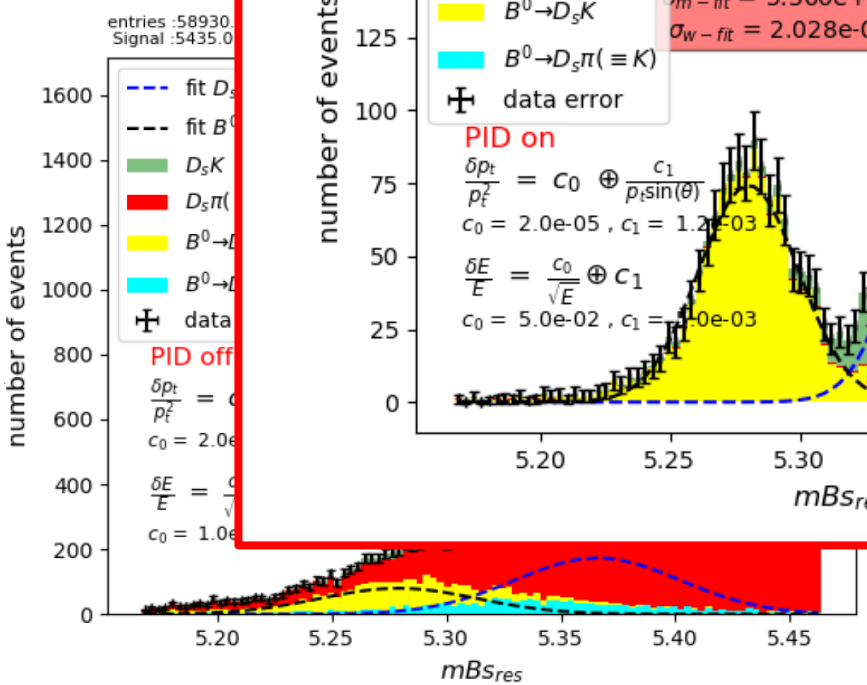
B-physics

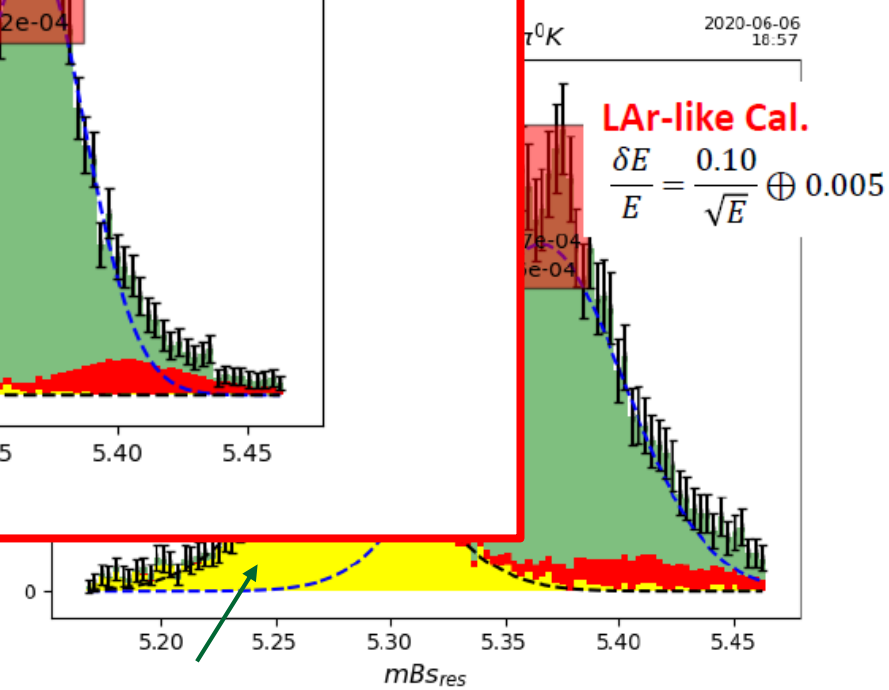
Benchm ksan
with toy
Now cor

M PID

Ameliorate with a higher resolution (*e.g.* crystal) ECAL







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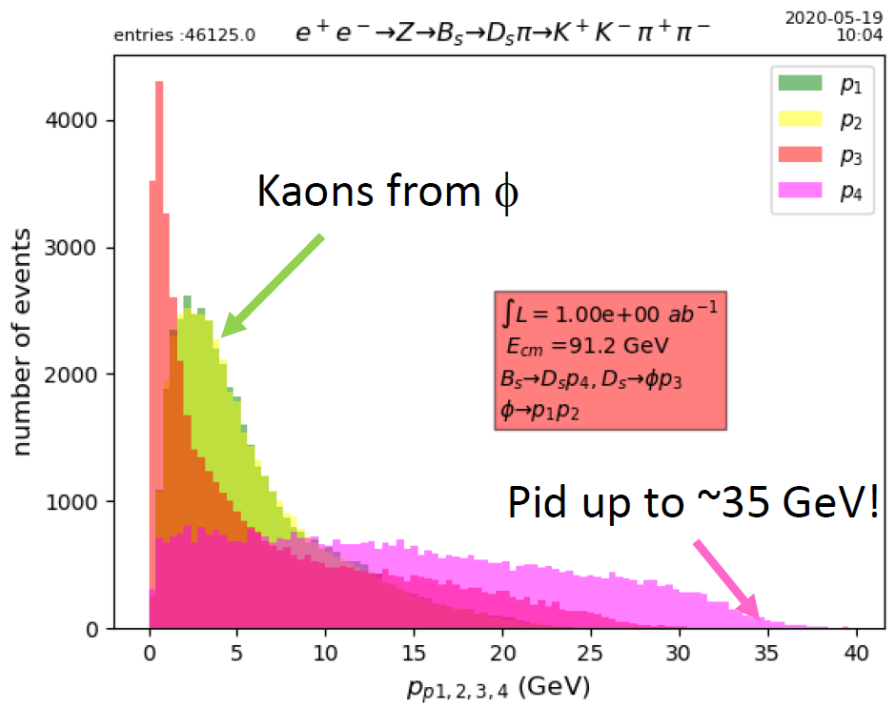
B-physics

Benchmark CP-violation channel $B_s \rightarrow D_s K$ investigated by Roy Aleksan with toy MC and parametrised FCC-ee detector response.

Momenta spectra



What momentum range needs to be covered ?

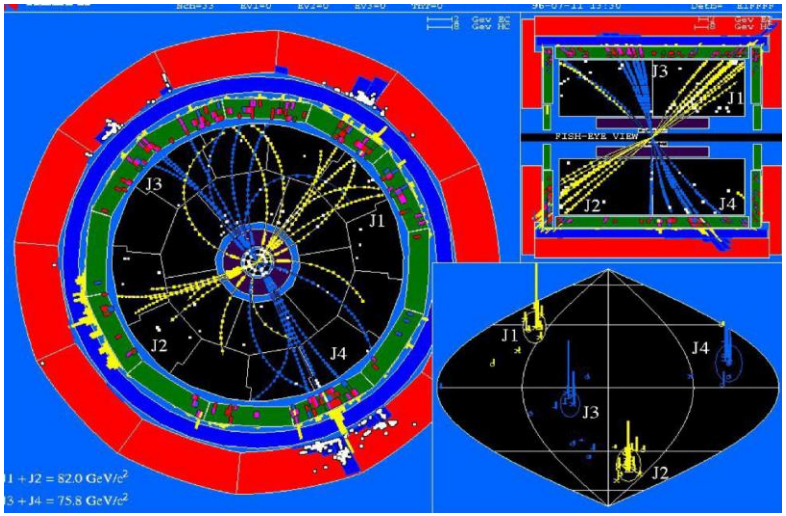
- From ~1 GeV/*c* up to at least 20 GeV/*c*;
- Going still higher is desirable;
- Note spectrum of 'tagging' kaons not shown here, but these are soft.

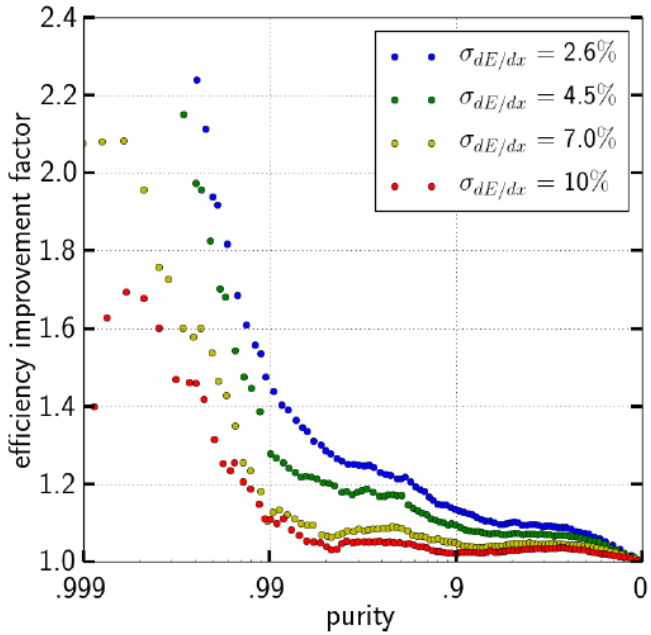
Consistent with earlier studies.

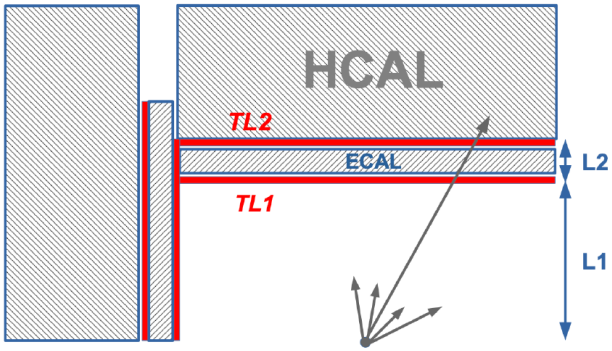
Beyond b-decays

Paolo Azzurri: flavour tagging W jets for V_{cs}, V_{cb} & V_{ub} measurements. Exciting opportunity, but requirements and impact of PID to be evaluated.

By chance, simulation result shown By Ulrich Einhaus on how tagging of W→cs decays can be enhanced with PID info (from dE/dx)







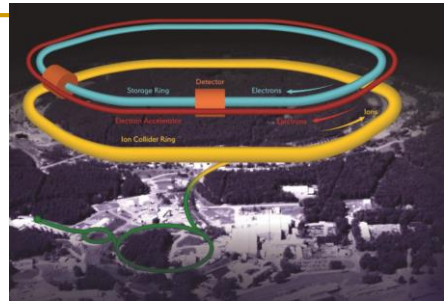
Something different (Chih-Hsiang Yeh). timing layers to detect slow-moving long-lived massive new-physics particles.

Possible solutions

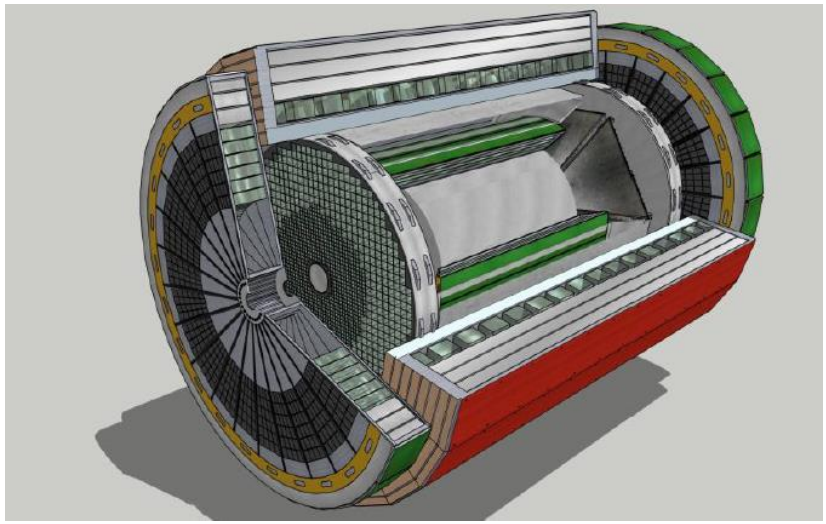
(No discussion this week on RICHes, as RICHes were well covered in January. But they remain a candidate detector of great interest !)

PID at the EIC

Thomas Hemmick



Asymmetric kinematics impose different π/K/p separation requirements in different regions of the detector



e.g. up to 50 GeV/*c* in forward endcap, up to 10 GeV/*c* in backward endcap, up to around 6 GeV/*c* in barrel

Hence a several solutions must be found. Many options under investigation, *e.g.*:

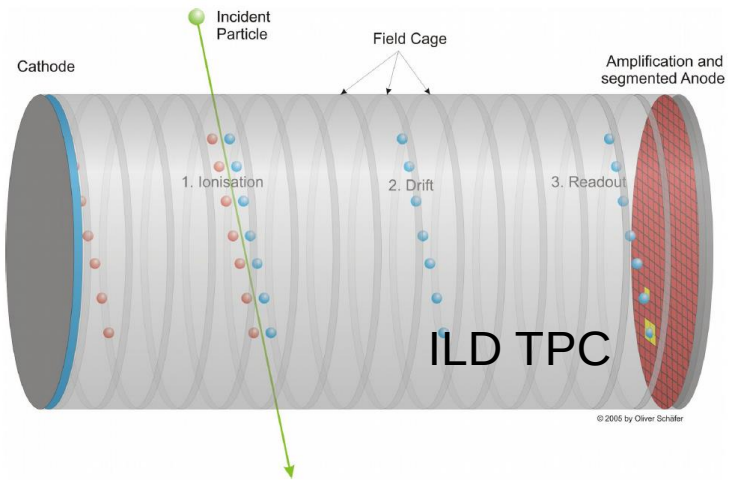
- dE/dx and cluster counting
- hpDIRC (barrel)
- Aerogel + gas RICH (forward)
- Aerogel RICH (backward) / transition radiation (for e-id)

Although the challenges are different, its exciting to see a PID system being developed for a new collider detector. For sure, there is much we can learn.

dE/dx + cluster counting

Several talks focused on dE/dx + cluster counting, & efforts to get best resolution

Ulrich Einhaus talking on behalf of Linear Collider TPC collaboration



Various readout solutions pursued:

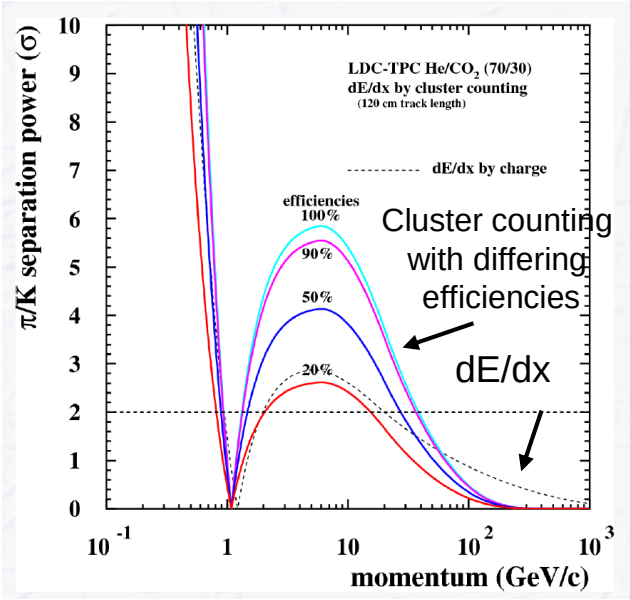
- GEMs or micromegas with pad-based readout
- Micromegas with pixel-based readout

Improve dE/dx resolution by improving readout granularity

$$\sigma_{dE/dx} \sim L^{-0.47} \times G^{-0.13}$$

track length granularity

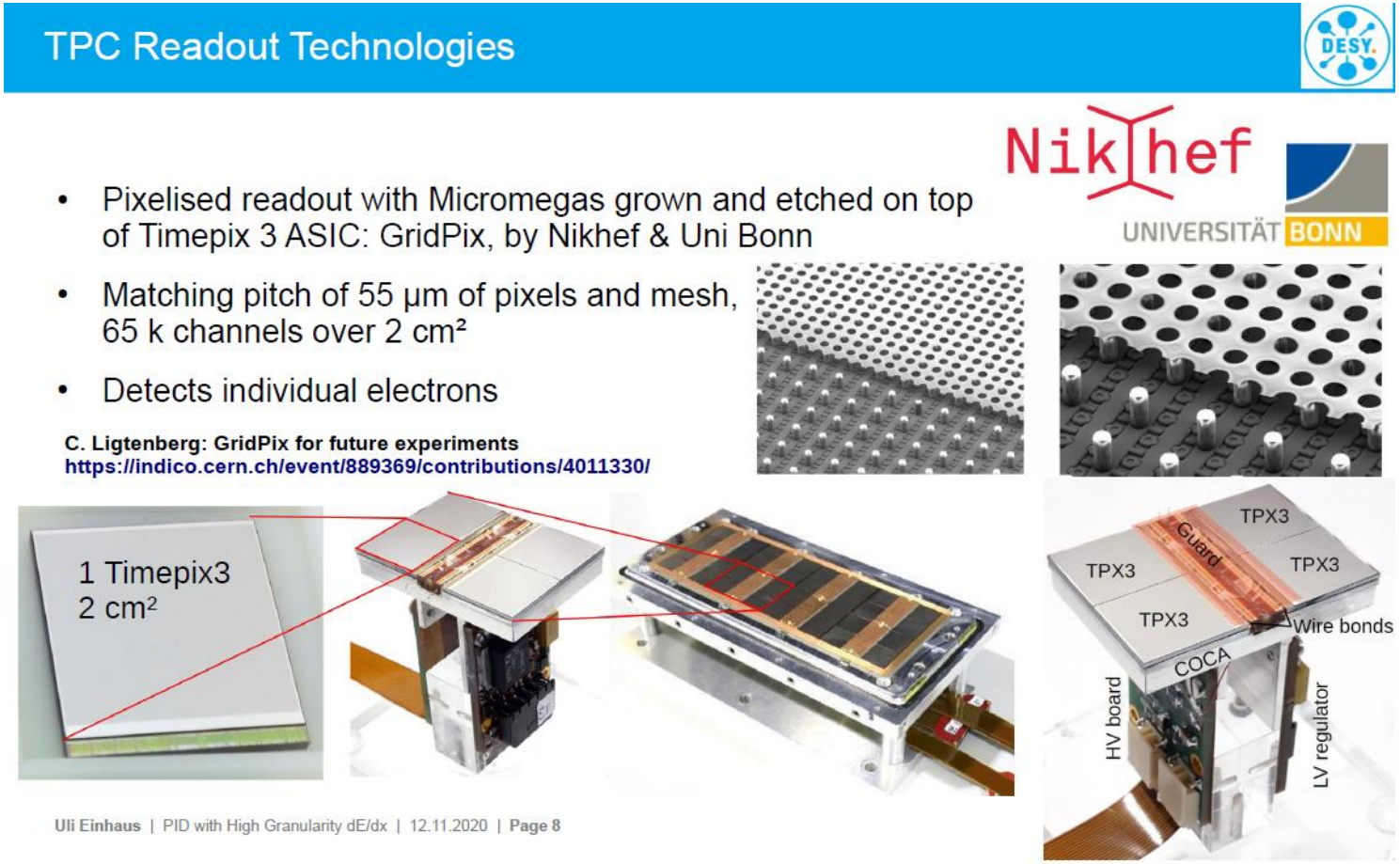
Or by counting clusters, rather than energy, which is less sensitive to Landau tails (here (high granularity readout also very helpful).



dE/dx and particle ID performance with cluster counting, M. Hauschild, Valencia, Nov 2006

dE/dx + cluster counting

Several talks focused on dE/dx + cluster counting, & efforts to get best resolution



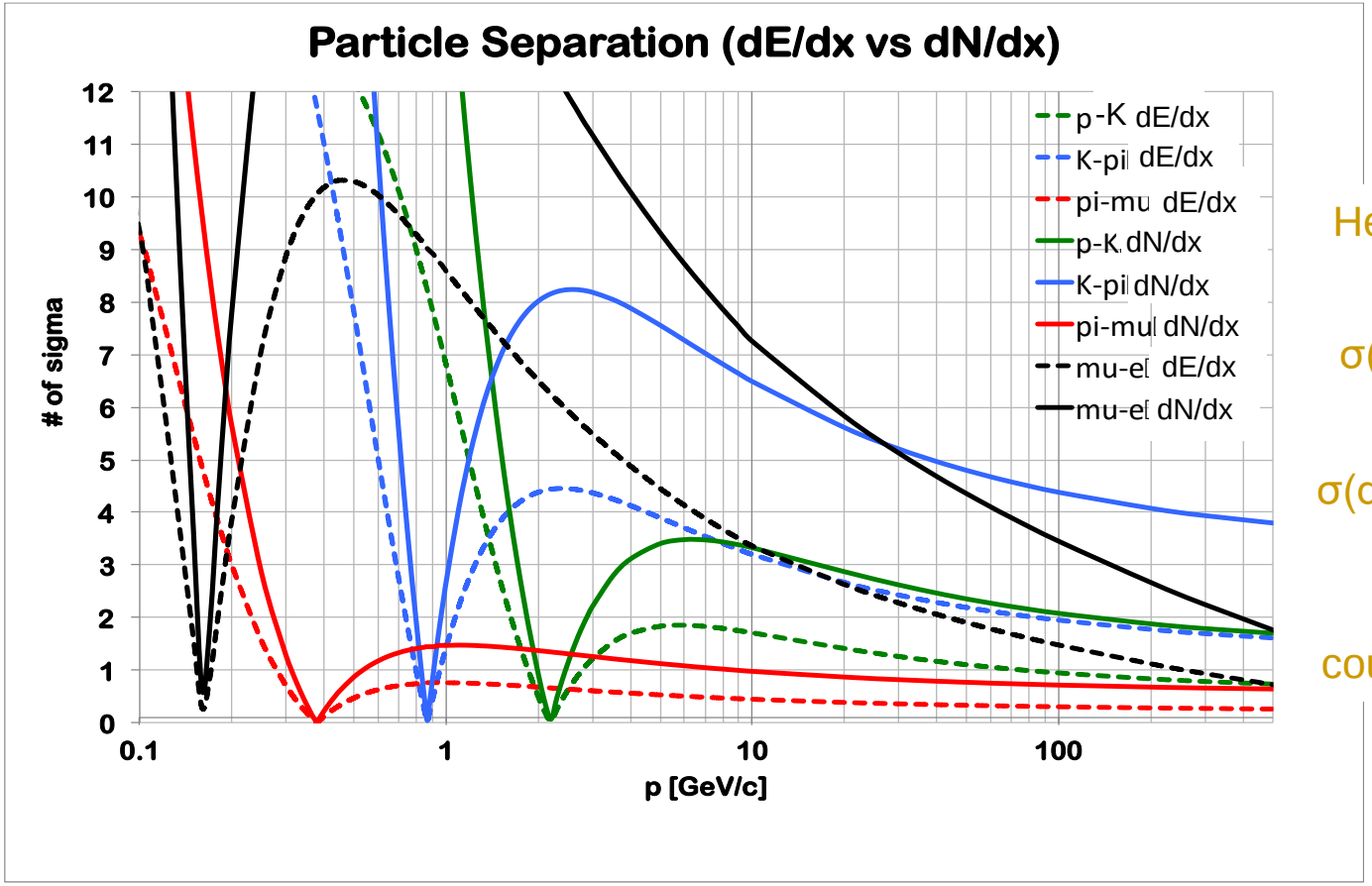
Ligentburg *et al.*, Performance of a GridPix TPC readout based on the Timepix3 chip, arXiv:1902.01987

Testbeam results indicate ~3% resolution for combined dE/dx + cluster counting

dE/dx + cluster counting

Several talks focused on dE/dx + cluster counting, & efforts to get best resolution

Expected from analytical calculation for IDEA Drift Chamber (Franco Grancagnolo)



He/iC4H10 90/10

δ_{cl}=12 cm^{-1}

$\sigma(dE/dx)/(dE/dx)$ =4.3%

$\sigma(dN_{cl}/dx)/(dN_{cl}/dx)$ =2.2%

80% cluster counting efficiency

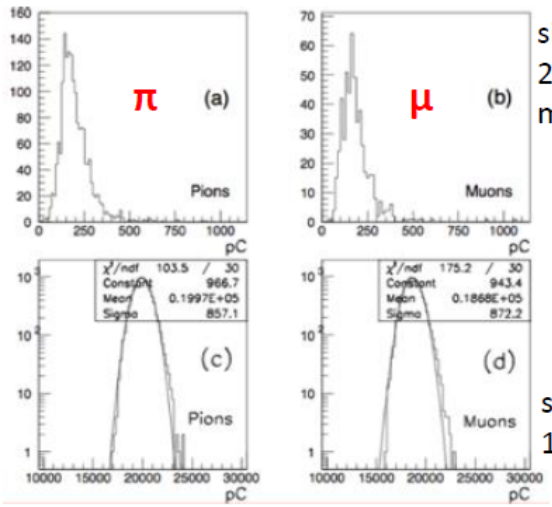
dE/dx + cluster counting

Several talks focused on dE/dx + cluster counting, & efforts to get best resolution

dE/dx and dN_{cl}/dx

μ/π separation at 200 MeV/c in He/iC_4H_{10} – 95/5 100 samples 3.7 cm

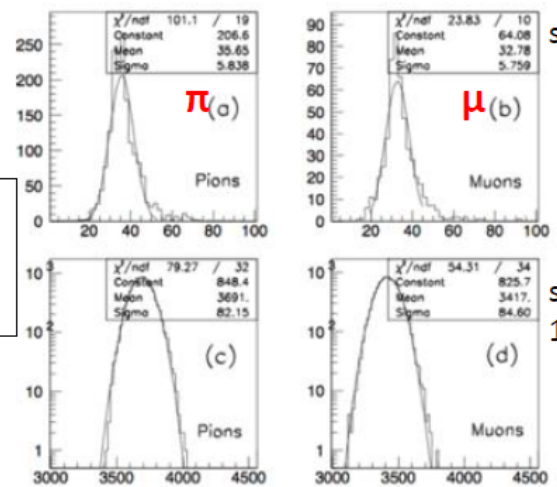
gas gain 2×10^5, 1.7 GHz – gain 10 amplifier, 2GSa/s – 1.1 GHz – 8 bit digitizer



single sample
20% truncated mean

test beam data

sum over
100 samples



single sample

π: σ/√N_{cl}=0.978
μ: σ/√N_{cl}=1.006

sum over
100 samples

π: σ/√N_{cl}=1.35
μ: σ/√N_{cl}=1.45

integrated charge
expected 2.0 σ separation
measured 1.4 σ separation

cluster counting
expected 5.0 σ separation
measured 3.2 σ separation

27/10/20 F. Grancagnolo - PId @ Z 13

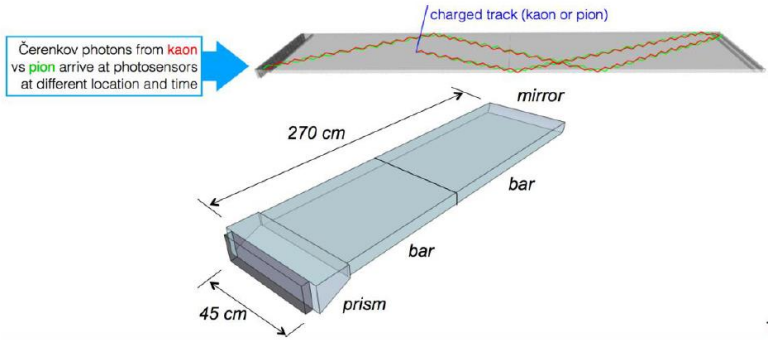
(*NIM A386 (1997) 458-469* and references therein)

TOF detectors – a valid solution for low momentum

Franco Grancagnolo, Jerry Va'vra

Successful operating systems: ALICE mRPC TOF, ATLAS forward TOF, Belle II TOP

Several planned based on Cherenkov light (like Belle II TOP): Panda DIRC, TORCH



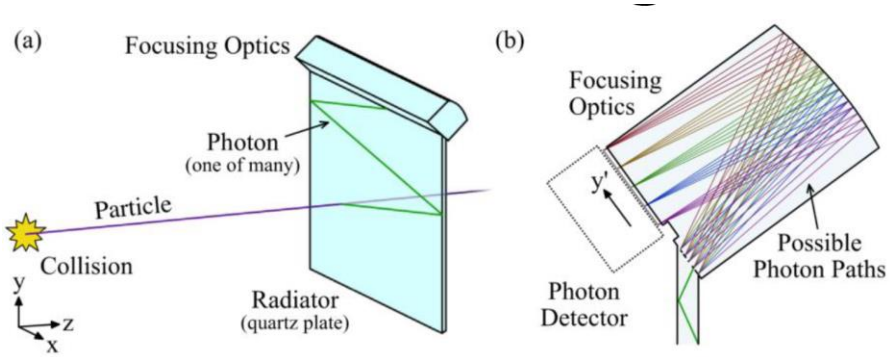
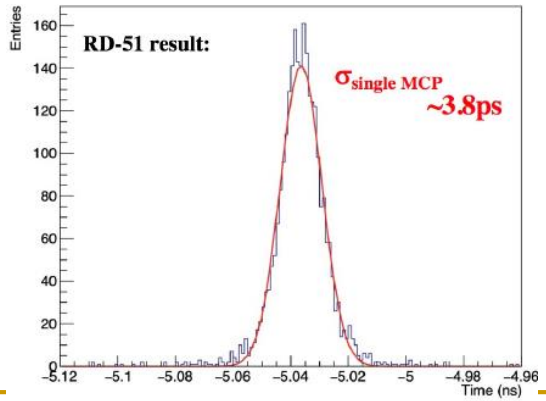


Photo-detector of choice: MCPs, which possess exquisite time resolution for MIPs in single pixels.

Challenging to maintain this resolution in large system (see magisterial talk of J. Vavra), but a few 10's of ps is achievable and adequate for FCC.



L. Sohl et al., Elba 2018

Status and outlook

PID requirements at FCC-ee:

- Essential for flavour physics. Required momentum range well understood.
- More work required to evaluate impact on other physics areas.

Many promising solutions under consideration. Here's a superficial summary:

- RICH (more fully discussed in January) offers robust, high-performant solution suitable for high momentum. Space and material a challenge.
- TOF detectors, including those based on Cherenkov radiation (*e.g.* TORCH), work well at low momentum and can be reasonably compact.
- Cluster counting offers possibility to extend dE/dx to medium and high momentum. Need a gaseous tracker (obviously), and R&D at early stage.

Personal remark from convenors: for flavour physics we have a growing feeling it would be valuable to perform a detector optimisation that considers entangled demands of PID, vertexing, tracking and calorimetery.