Particle Identification at the FCC-ee

Guy Wilkinson
University of Oxford
15/1/20

With thanks to Nathan Jurik for many of the plots !

Outline

Current baseline designs for FCC-ee experiments do not include a dedicated detector for hadron identification (henceforth referred to as PID), although IDEA drift chamber may have strong capabilities in this area.

PID essential for flavour physics, & useful for many other applications. In this brief session we will consider what requirements are, & how these could be met.

- Reminder – the chequered history of RICH detectors at high-energy e^+e^-
- Requirements, especially on momentum range (focus on B physics at the Z^0)
- Candidate technologies

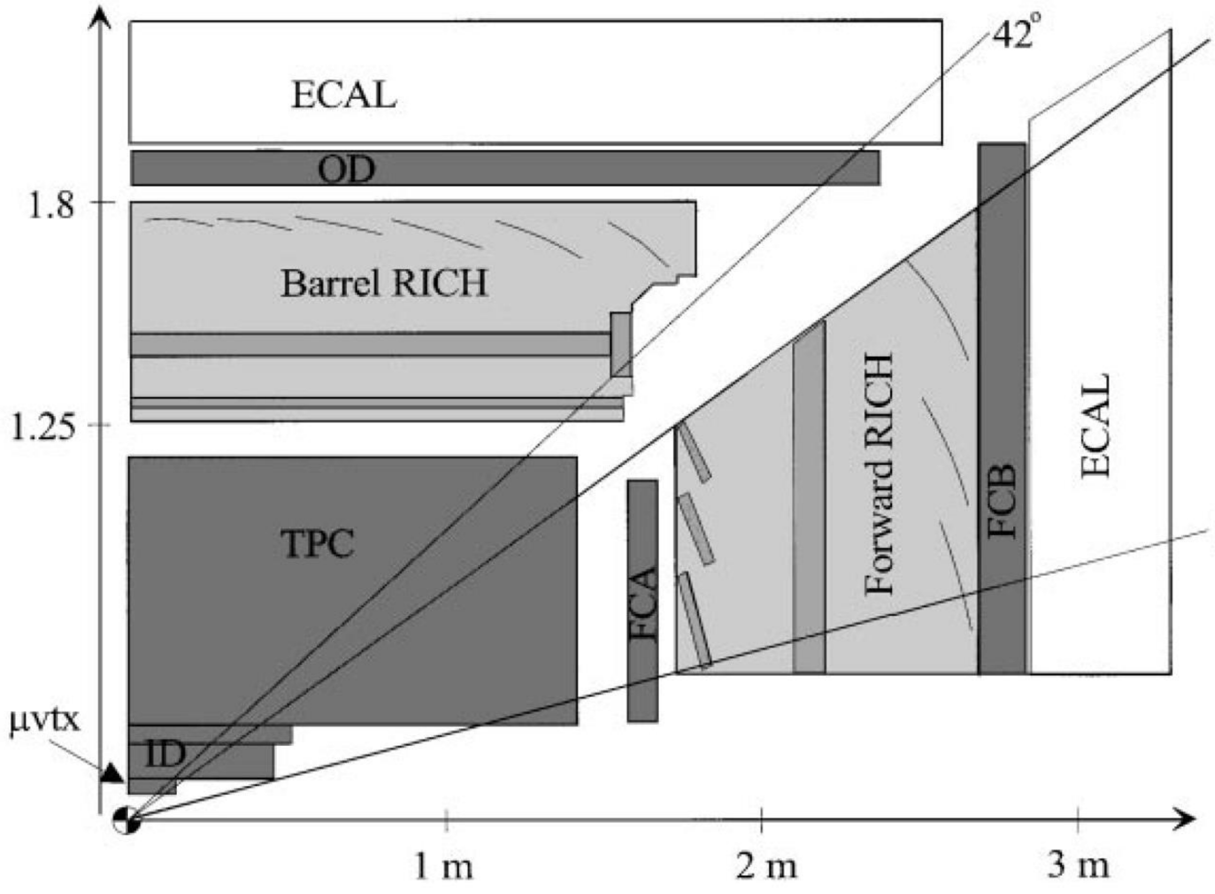
A reminder:
RICH detectors at the Z^0

Many low-energy e^+e^- experiments have featured successful dedicated PID detectors, *e.g.* CLEO, BaBar, Belle. But these cases benefit from having a narrow momentum range of interest.

At higher energies, things get more tricky…

DELPHI and SLD RICH systems

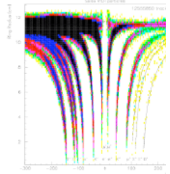
DELPHI at LEP was equipped with a RICH, as was SLD at SLC (a ‘CRID’).



Google readily throws up common opinion on DELPHI / SLD RICH adventure

SLD CRID at SLAC !

how not to do RICH PID



Alternative design

- TMAE wire chambers to detect UV Cherenkov photons.

In this case (and some, but not all, others) dozens of people spent a dozen years and a dozen M$ for very small gains.

KISS

- pay for photodetectors that work

This lesson was learned

- the DIRC at Babar works well

SLAC-PUB 59
November 199
(I)

Performance of the SLD Barrel CRID During the 1992 Physics Data Run*

K. Abe,[a] P. Antilogus,[b,1] D. Aston,[b] K. Baird,[c] A. Bean,[d] R. Ben-David,[e] T. Bienz,[b,2] F. Bird,[b,3] D. O. Caldwell,[d] M. Cavalli-Sforza,[f] J. Coller,[g] P. Coyle,[f,4] D. Coyne,[f] S. Dasu,[b,5] S. Dolinsky,[b,6] A. d'Oliveira,[h,7] J. Duboscq,[d,8] W. Dunwoodie,[b] G. Hallewell,[b,4] K. Hasegawa,[a] Y. Hasegawa,[a] J. Huber,[d,9] Y. Iwasaki,[a] P. Jacques,[c] R. A. Johnson,[h] M. Kalelkar,[c] H. Kawahara,[b] Y. Kwon,[b] D.W.G.S. Leith,[b] X. Liu,[f] A. Lu,[d] S. Manly,[e] J. Martinez,[h] L. Mathys,[d,10] S. McHugh,[d] B. Meadows,[h] G. Müller,[b] D. Muller,[b] T. Nagamine,[b] M. Nussbaum,[h] T. J. Pavel,[b] R. Plano,[c] B. Ratcliff,[b] P. Rensing,[b] A. K. S. Santha,[h] D. Schultz,[b] J. T. Shank,[g] S. Shapiro,[b] C. Simopoulos,[b,11] J. Snyder,[e] M.D. Sokoloff,[h] E. Solodov,[b,6] P. Stamer,[c] I. Stockdale,[h,12] F. Suekane,[a] N. Toge,[a,13] J. Turk,[e] J. Va'vra,[b] J.S. Whitaker,[g] D. A. Williams,[f] S. H. Williams,[b] R. J. Wilson,[i] G. Word,[c] S. Yellin,[d] H. Yuta[a]

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No PID performance curves ever shown

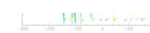
Google readily throws up common opinion on DELPHI / SLD RICH adventure

SLD CRID at SLAC

how not to do RICH PID

!

Harsh, and does not reflect extreme challenge of what was being attempted.



- Alternative design
  - TMAE wire chambers to detect UV Cherenkov photons.
- In this case (and some, but not all, others) dozens of people spent a dozen years and a dozen M$ for very small gains.
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  - pay for photodetectors that work
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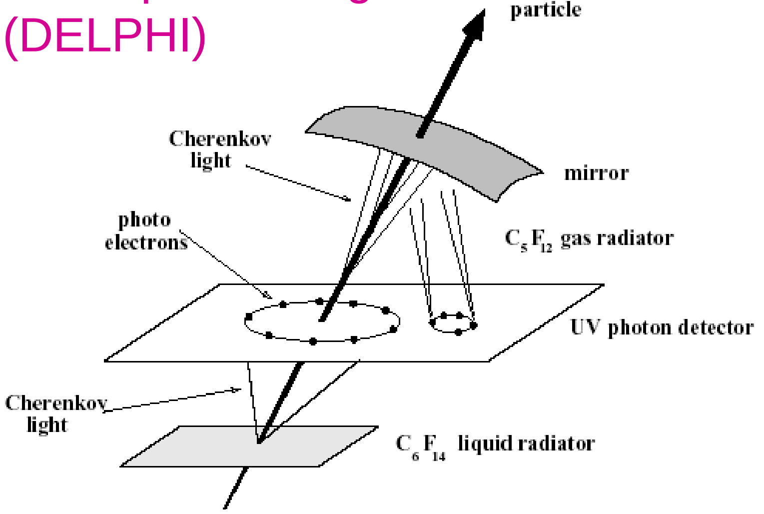
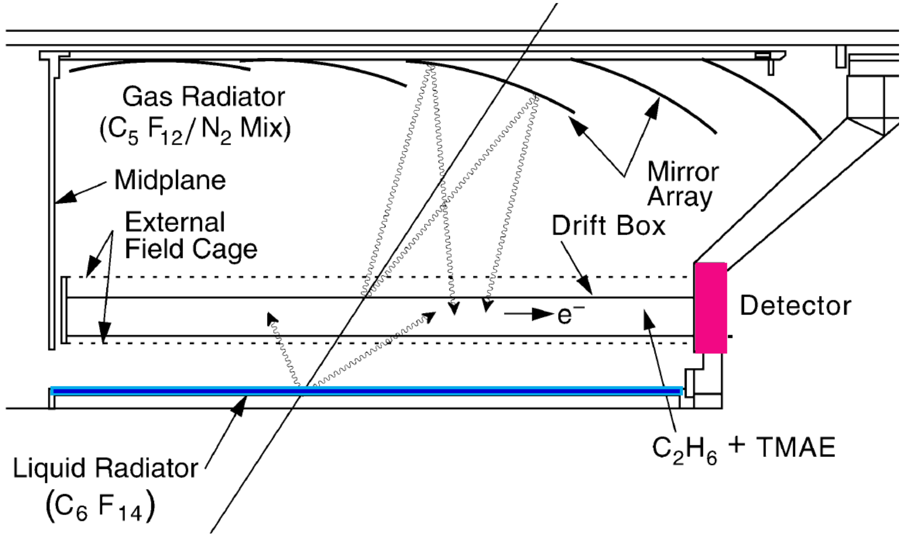
No PID performance curves ever shown

DELPHI and SLD RICH systems

Conceptual design (DELPHI)



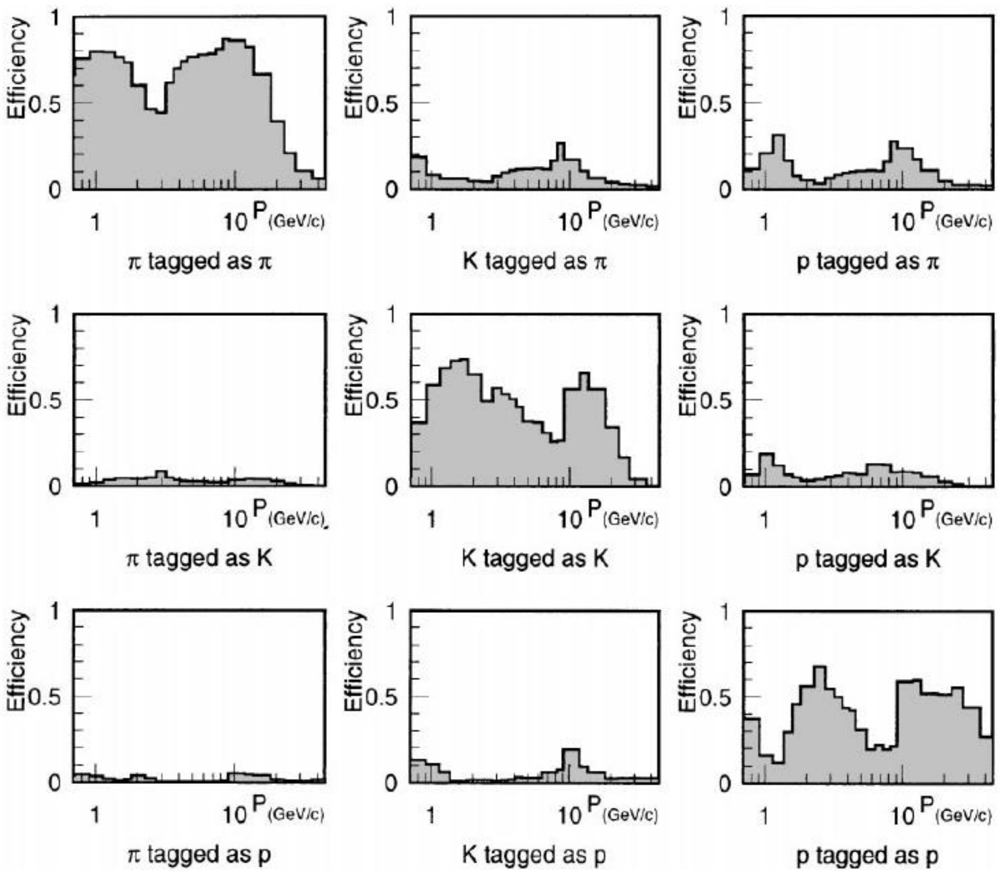
SLD barrel CRID



Highly challenging and delicate systems, similar in design for both:

- Liquid / gas / gas (C_6F_{14} / TMAE / C_5F_{12}) together in tight, inaccessible volume – plumbing nightmare. All kept at 40º to avoid C_5F_{12} condensation.
- Photoconverter gas TMAE (Tetrakis diMethylAmine Ethylene) the substance from hell ("it it glows you're screwed, if it doesn't glow you're screwed" – SLD CRID group's "Laws of TMAEDYNAMICS").
- Long TPC-like drift distances for the photoelectrons – sensitive to distortions.

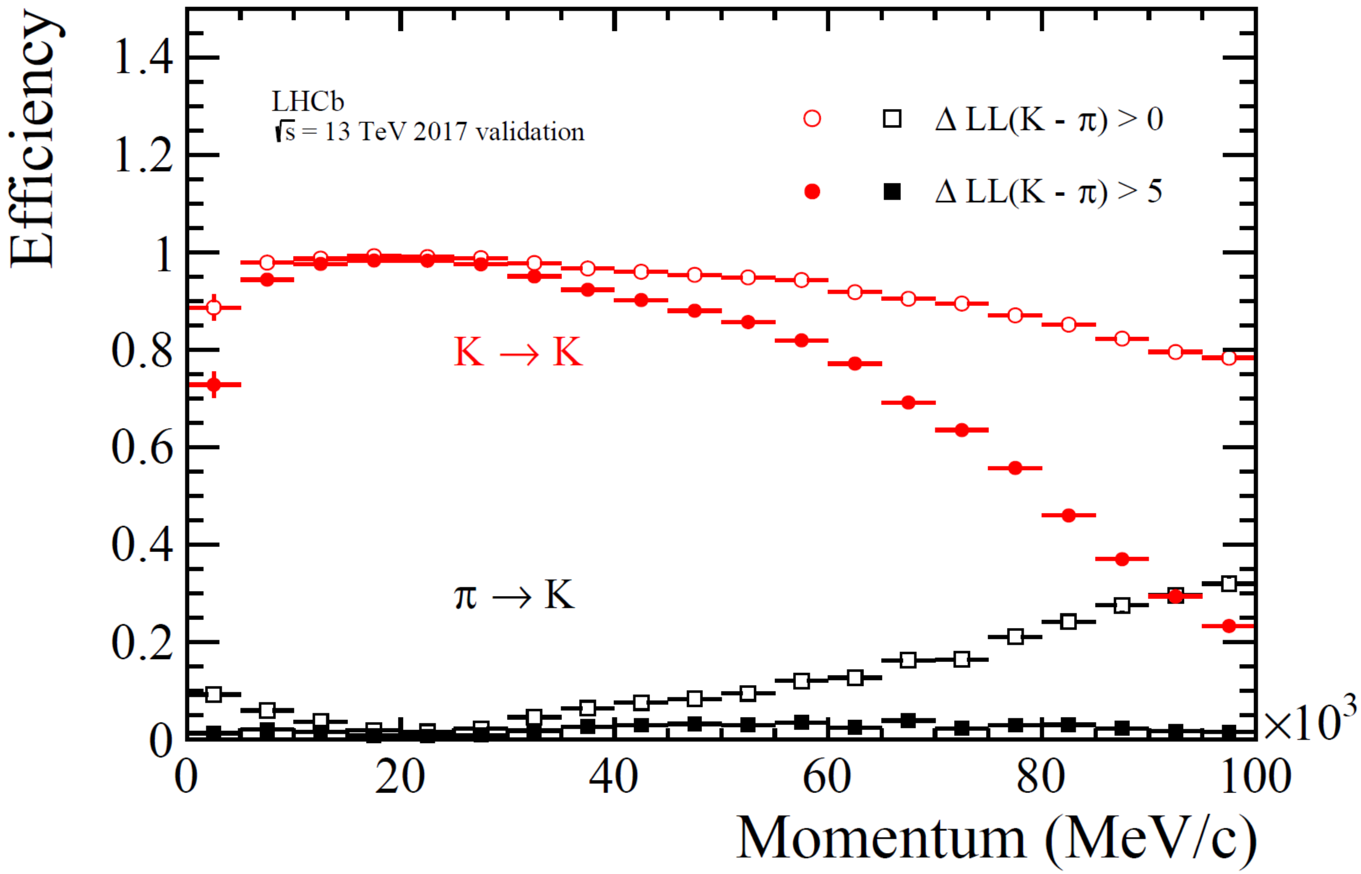
Efficiency matrix of DELPHI RICH



[Battaglia and Kluit, NIMA 433 (1999) 252]

Kaon id efficiencies generally < 50%, and range limited to p < 20 GeV/*c* .

To be compared with…



…but LHCb has much more space to play with, plus 20 years of RICH know-how.

PID requirements at FCC-ee

Applications of PID in Z^0 physics

Let's focus on the Z^0, where requirements are most clearly defined.

A good PID system, if available, would be exploited in many measurements, *e.g.*

- Complementary / redundant info to ECAL in searches for LFV Z decays;
- Separating π/K in tau final states;
- Help in flavour-tagging jets;
- Studies of particle production.

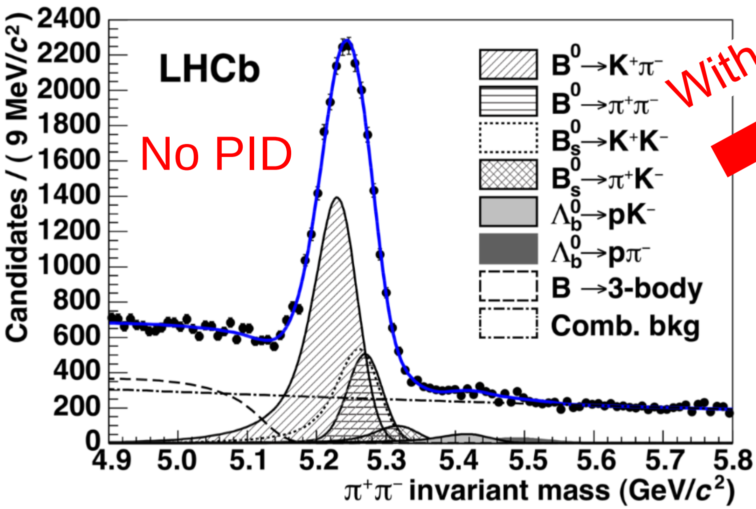
But in B physics and spectroscopy PID is *essential* !

Let's remind ourselves of why this is so, and then examine requirements.

PID requirements in b-physics & hadron spectroscopy

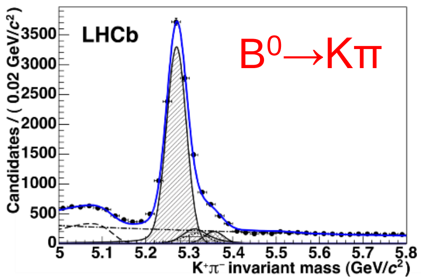
Hadron identification essential for a large set of flavour physics measurements.

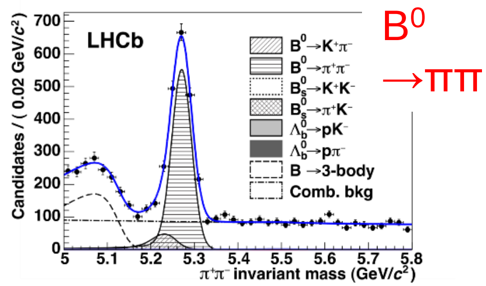
- Distinguishing between same topology final-states.

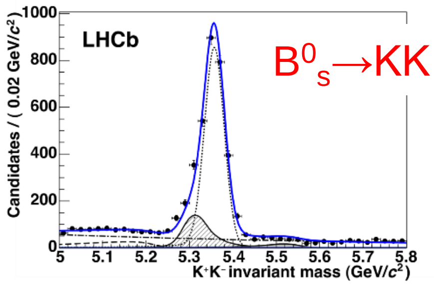


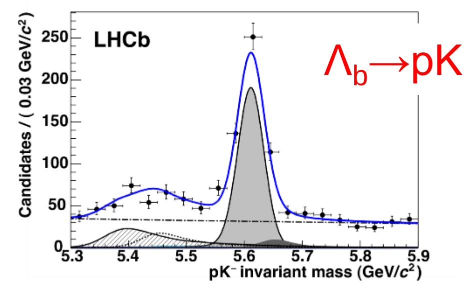
[LHCb, JHEP 10 (2012) 37]

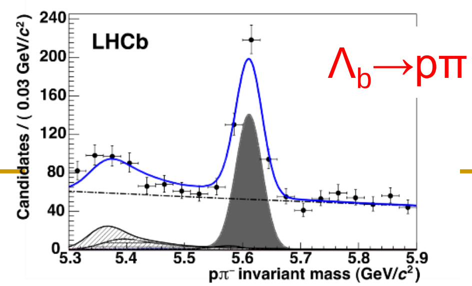
With PID







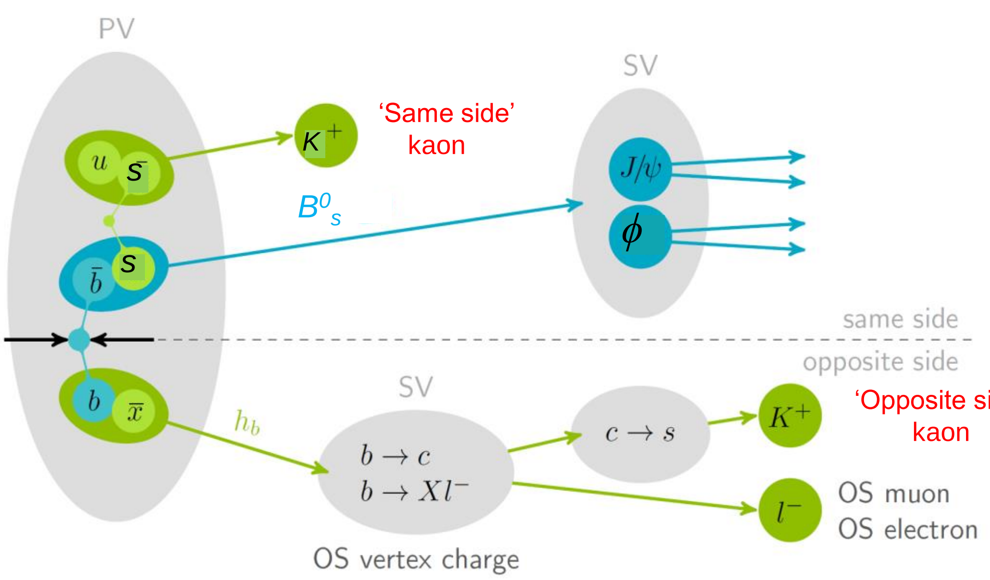




PID requirements in b-physics & hadron spectroscopy

Hadron identification essential for a large set of flavour physics measurements.

- Kaons for *flavour tagging* (*i.e*. $B^0_{(s)}$ or $B^0_{(s)}$ bar) in time-dependent CPV studies.



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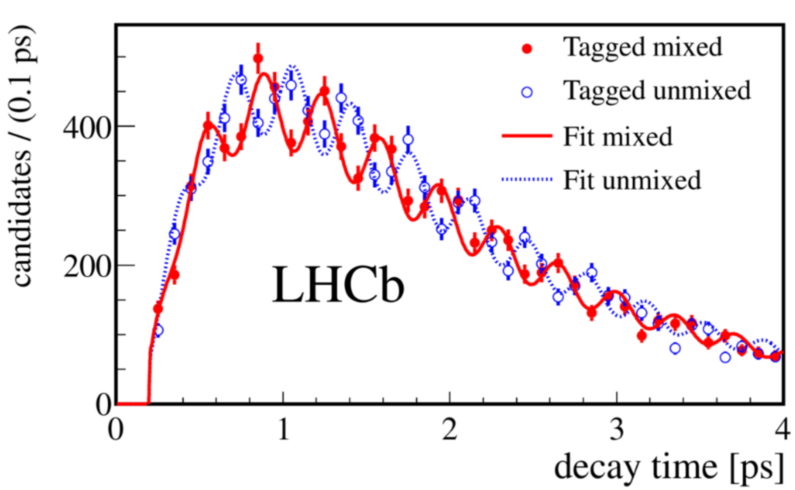
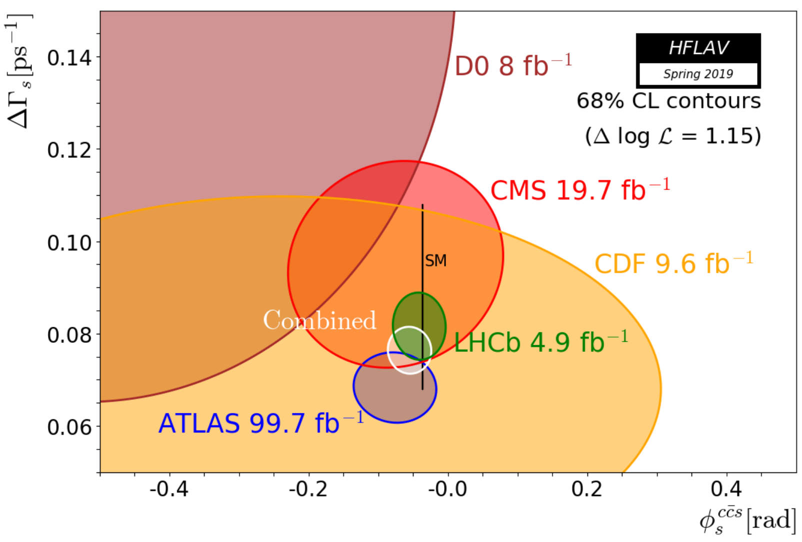
e.g. for B_s mixing measurements…



[LHCb, NJC 15 (2013) 053021]

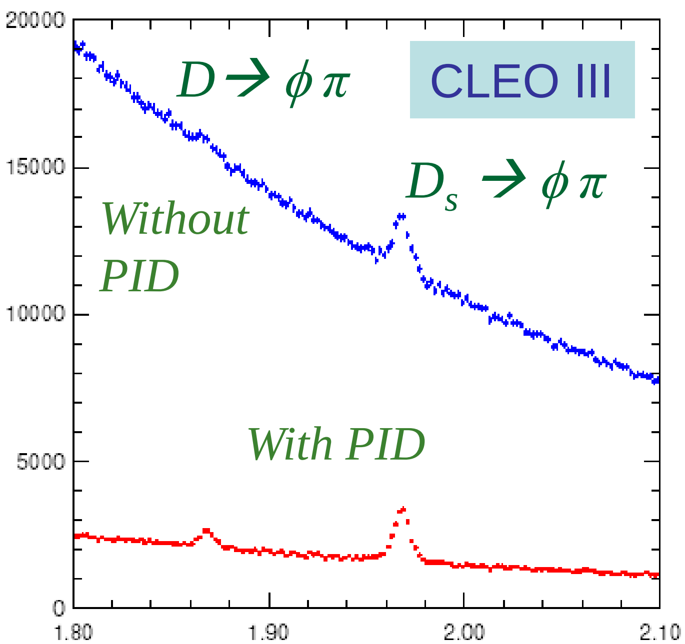
…& CPV ϕ_s measurements (where FCC-ee can make impact)

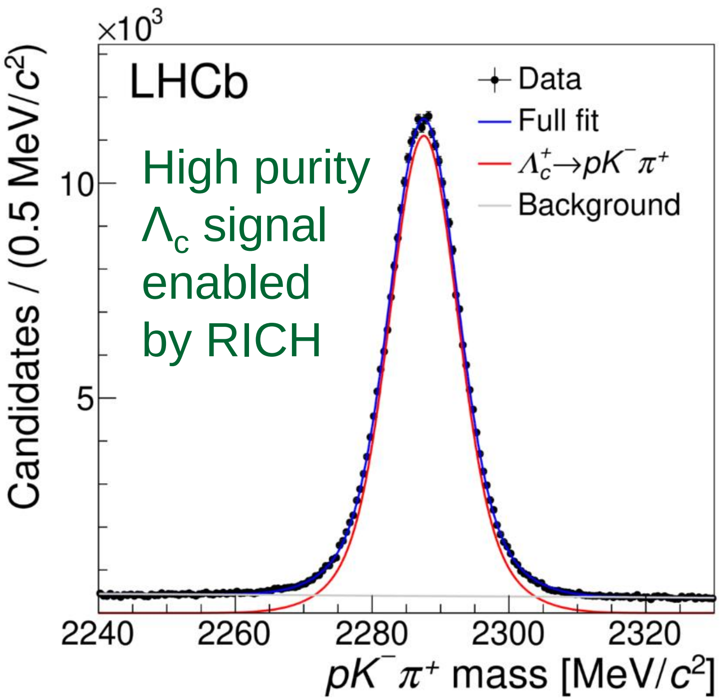


PID requirements in b-physics & hadron spectroscopy

Hadron identification essential for a large set of flavour physics measurements.

- Suppressing combinatorics.





[LHCb, PRD 100 (2019) 032001]

PID requirements in b-physics & hadron spectroscopy

Hadron identification essential for a large set of flavour physics measurements.

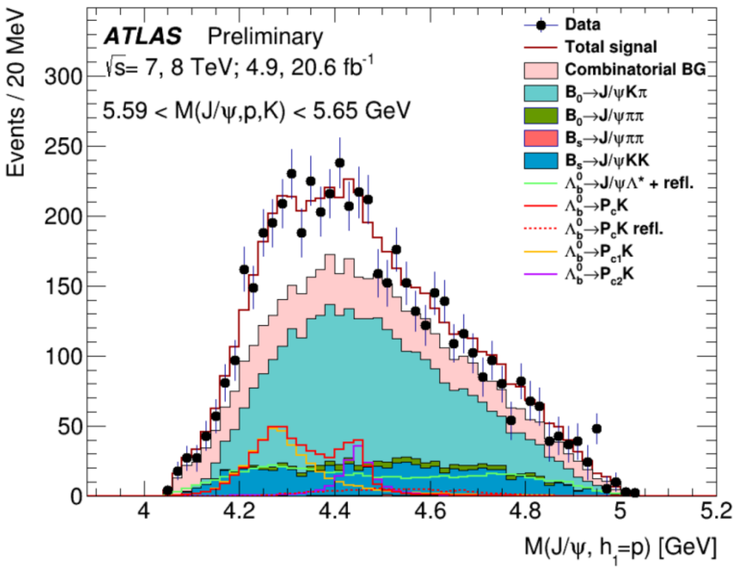
- K or proton identification for exotic spectroscopy studies.

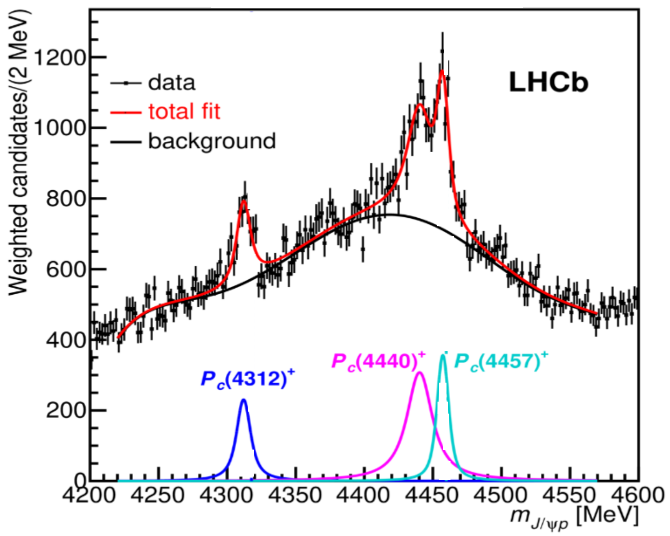
  e.g. pentaquarks seen in $\Lambda_b \to J/\psi pK$

Without PID

With PID ~ no background

[ATLAS-CONF-2019-048]





[LHCb, PRL 122 (2019) 222001]

Note that good mass resolution is also very helpful…

PID requirements in b-physics & hadron spectroscopy

Hadron identification essential for a large set of flavour physics measurements.

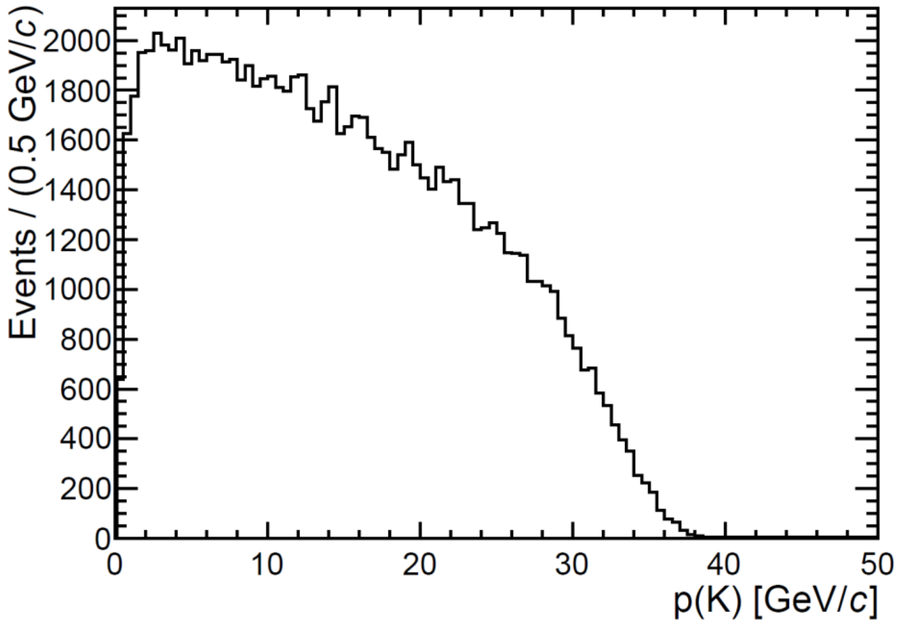
- Distinguishing between same topology final-states.
- Kaons for *flavour tagging* (*i.e.* $B^0_{(s)}$ or $B^0_{(s)}$ bar) in time-dependent CPV studies.
- Suppressing combinatorics.
- K or proton identification for exotic spectroscopy studies.

Experiments have often 'got by' & produced very nice results without a dedicated PID detector (*e.g.* ALEPH, CDF, ATLAS/CMS), but essential for precise & transformative measurements, so mandatory at CLEO, Belle(II), BaBar & LHCb.

Requirements on PID for b physics at FCC-ee

Take as example decay $B_s \rightarrow D_s K$: interesting in itself as a powerful mode for measuring Unitarity Triangle γ, but also representative of many other channels.

Suffers from an order-of-magnitude higher same-topology background of $B_s \rightarrow D_s \pi$.
Separating $B_s \rightarrow D_s K$ vs $B_s \rightarrow D_s \pi$ with PID depends on *p*-spectrum of bachelor K/π.



In an ideal world then we would like PID up to 30-40 GeV/*c*. This very challenging for a RICH detector in constraints that exist. Coverage up to ~20 GeV/c still useful.

Requirements on PID for b physics at FCC-ee

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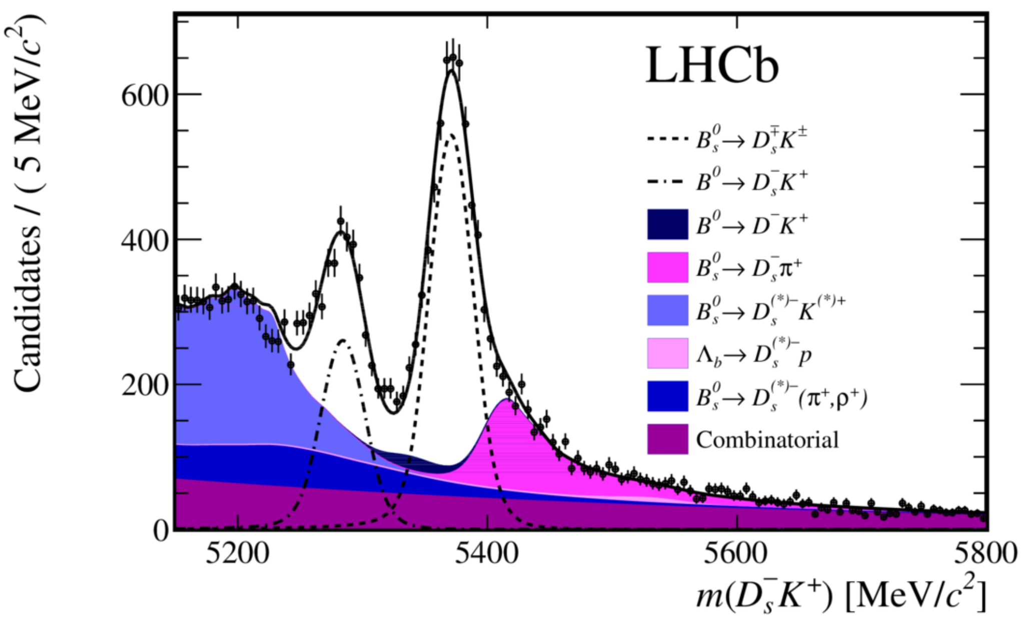
LHCb, after PID cuts.

(mass resolution on signal is ~15 MeV/c^2.)

Residual $D_s\pi$ background lies at higher masses.

Note that some background with missing particles, *e.g.* from D_s^* or ρ+, will always contaminate signal region.



[LHCb, JHEP 05 (2015) 019]

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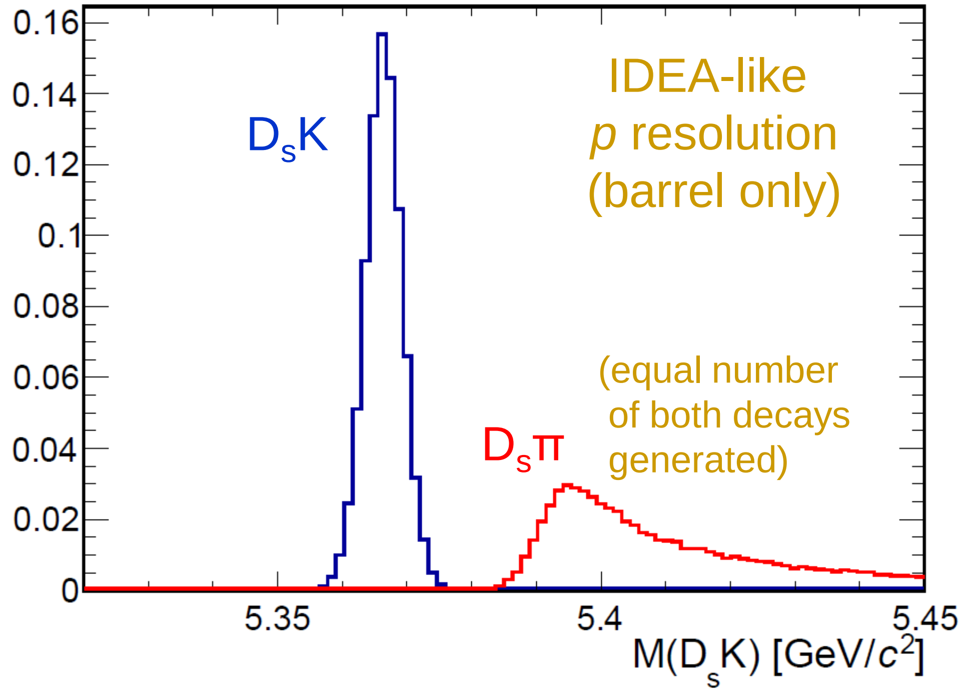
Mass resolution should be very good at FCC-ee.

Result of simple attempt to simulate expected *p* resolution of IDEA in barrel region.

Looks very promising (but again, do not forget additional backgrounds that will always appear under peak).



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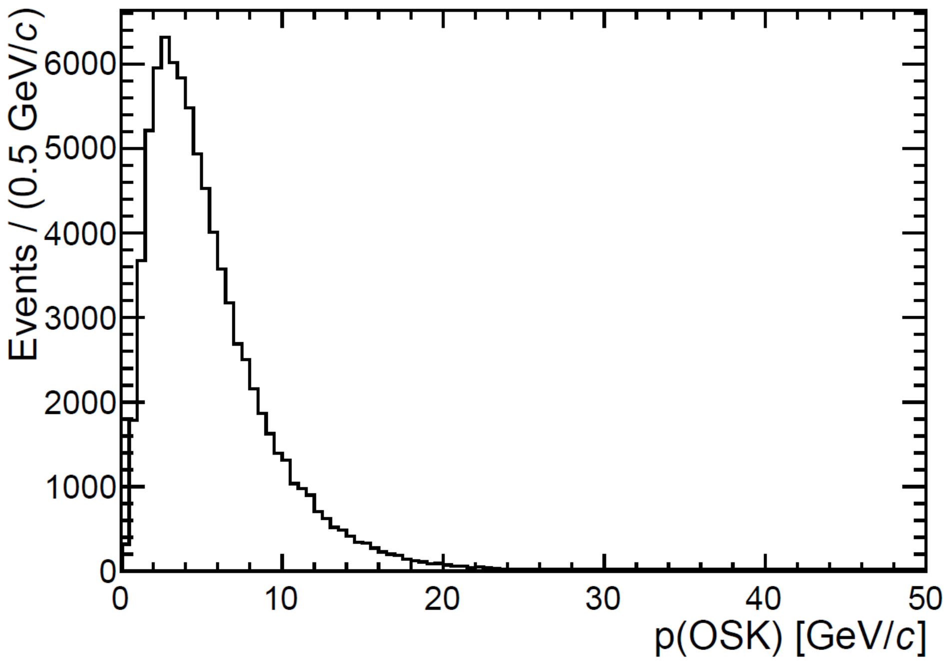
Spectrum of kaons for ‘opposite side’ tagging from $b \rightarrow c \rightarrow s$ decay chain.



Most of action lies below 10 GeV/*c*. (Story will be even truer for ‘same side’ kaons.)

Requirements on PID for b physics at FCC-ee

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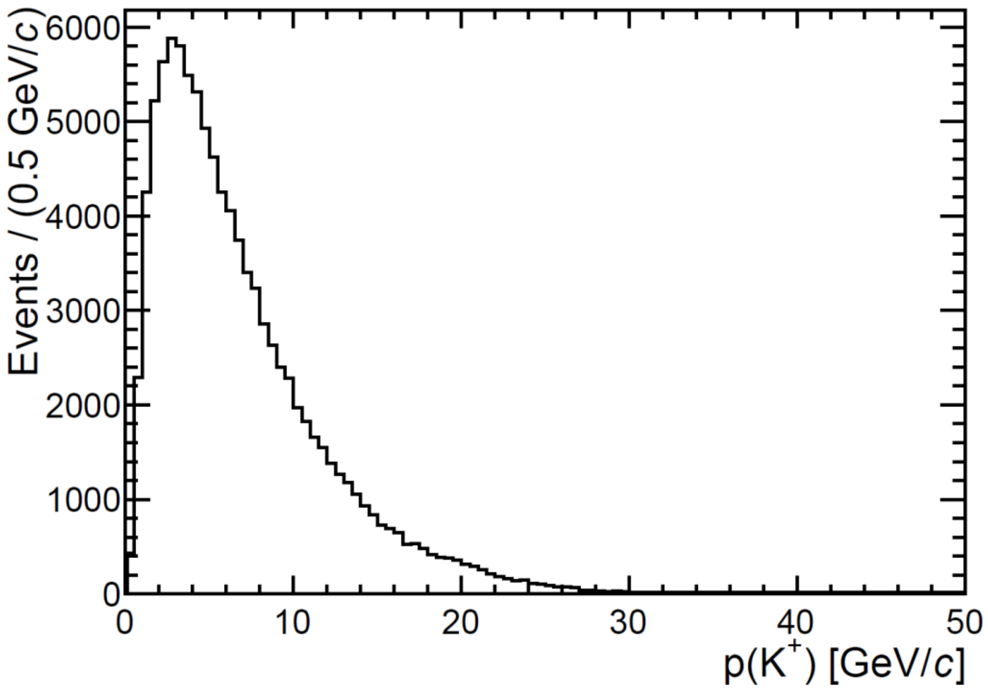
Kaons from $D_s \rightarrow KK\pi$ decays (here demands on π/K separation less stringent):



Candidate technologies

Candidate detector solutions

Classical RICH detector [see Silvia's talk]

- A suitably designed system could cover full momentum range of interest.
- RICHes have come a long way since DELPHI and SLD. Much progress in photodetectors, mirrors and operating experience.
- Main challenge is to obtain sufficient photoelectrons given space constraints.

DIRC (BaBar) / TOP counter (Belle II) /TORCH-like detector [see Maarten's talk]

- Elegant solution that has main advantage of requiring little space (although this is true for the radiator, rather than photodetector, where ingenuity is required).
- Limited to lower momenta – unrealistic to expect it to cover full range of interest.

TOF

- Low momentum only. Recall TORCH is a TOF device; fast Si another option.

dE/dx / cluster counting

- Classical dE/dx in drift chamber limited to low momentum.
- Cluster counting proposed for IDEA drift chamber would go much higher.
- If this works, then great ! But other detector designs need other solutions.