PID & Physics @ UII

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PID physics @ UII

We will collect a vastly increased yields

Existing analyses can be more precise
Swathes of new avenues of analysis become available

- Maintain performance
- Look for ways to improve performance
  - Detector design
  - Analysis design
- Change in mind-set. Optimisation is no longer about S/sqrt(S+B)

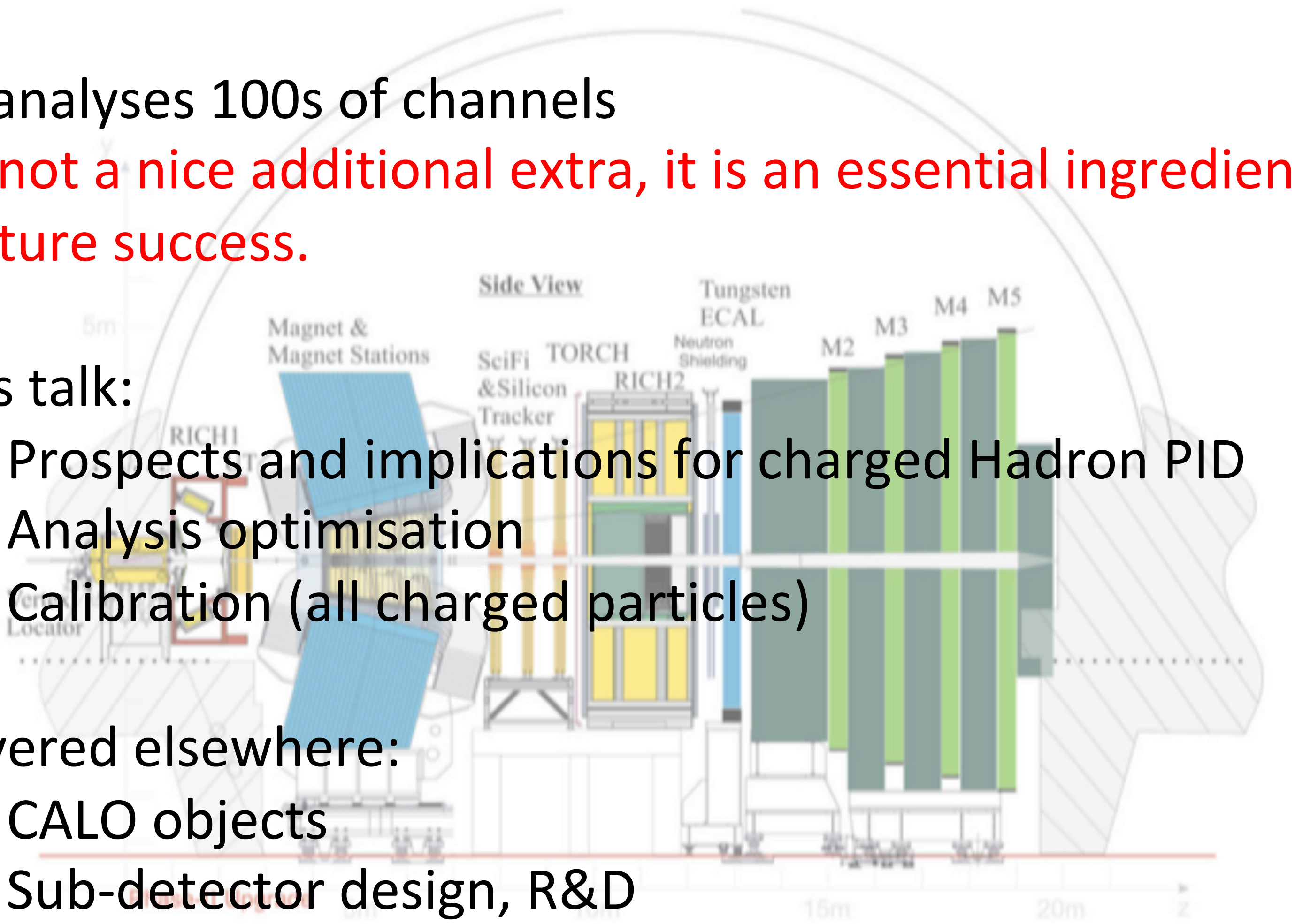
PID physics @ UII

LHCb analyses 100s of channels

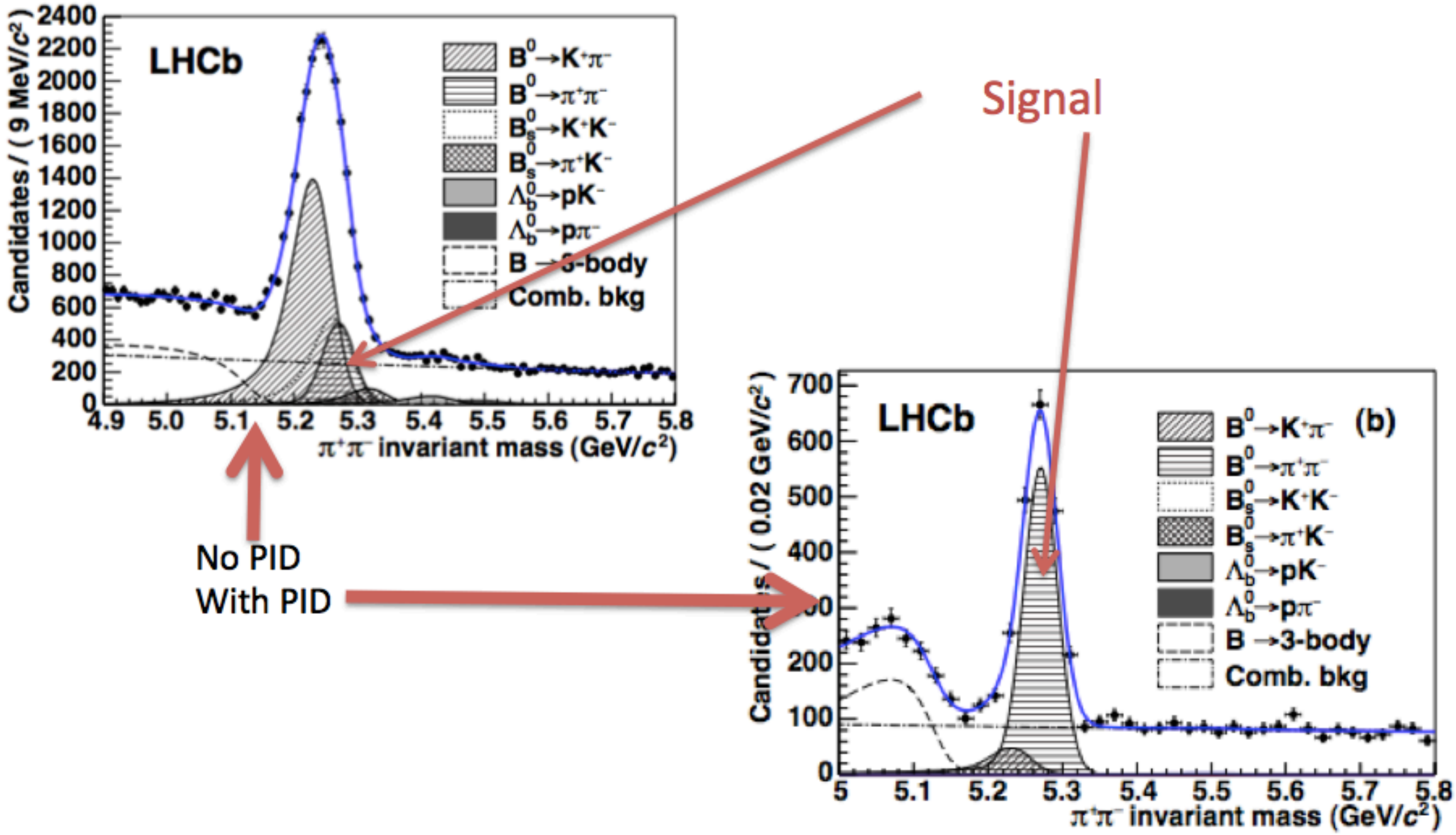
PID is not a nice additional extra, it is an essential ingredient to our future success.

- This talk:
  - Prospects and implications for charged Hadron PID
  - Analysis optimisation
  - Calibration (all charged particles)

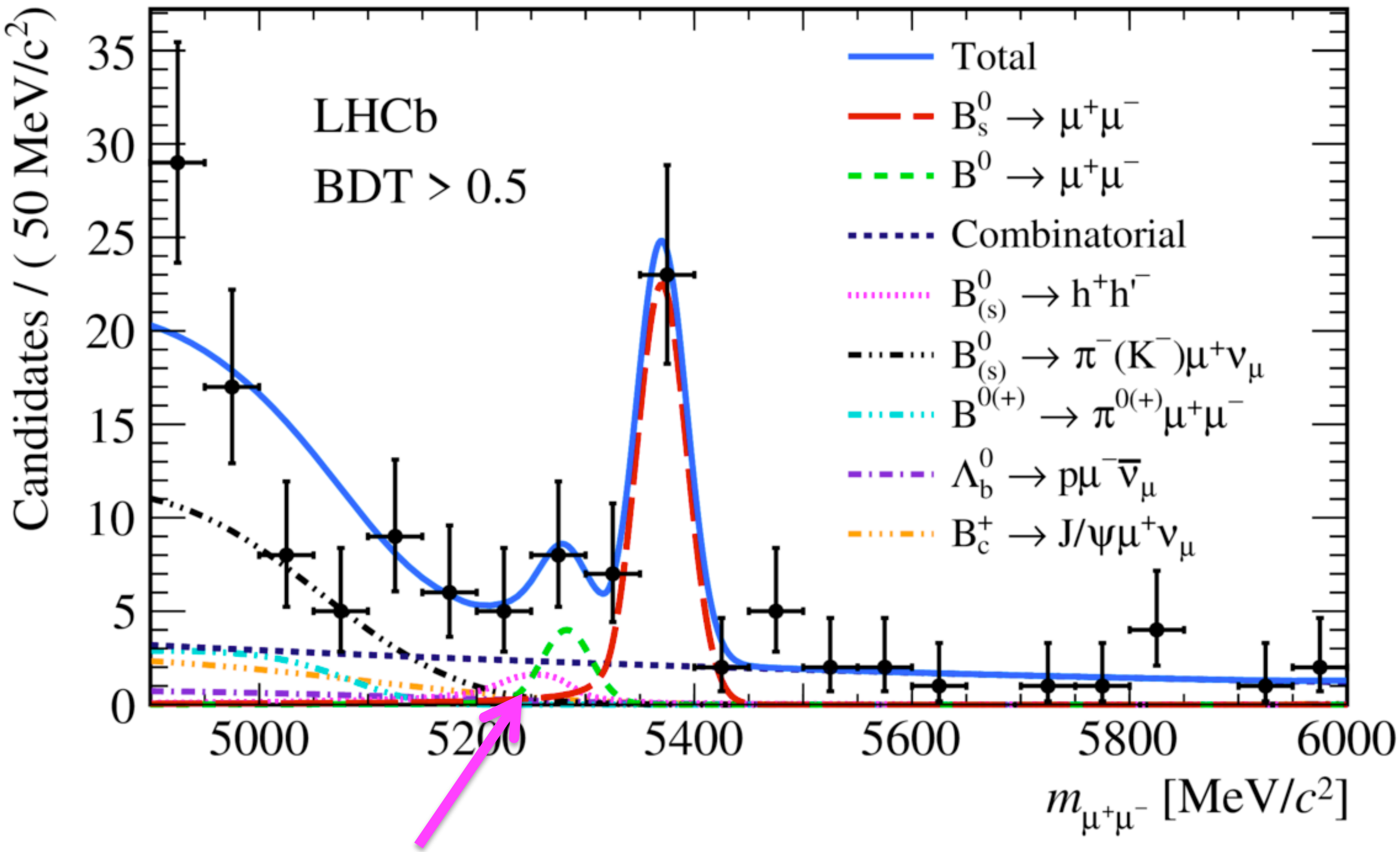
- Covered elsewhere:
  - CALO objects
  - Sub-detector design, R&D



Signal selection



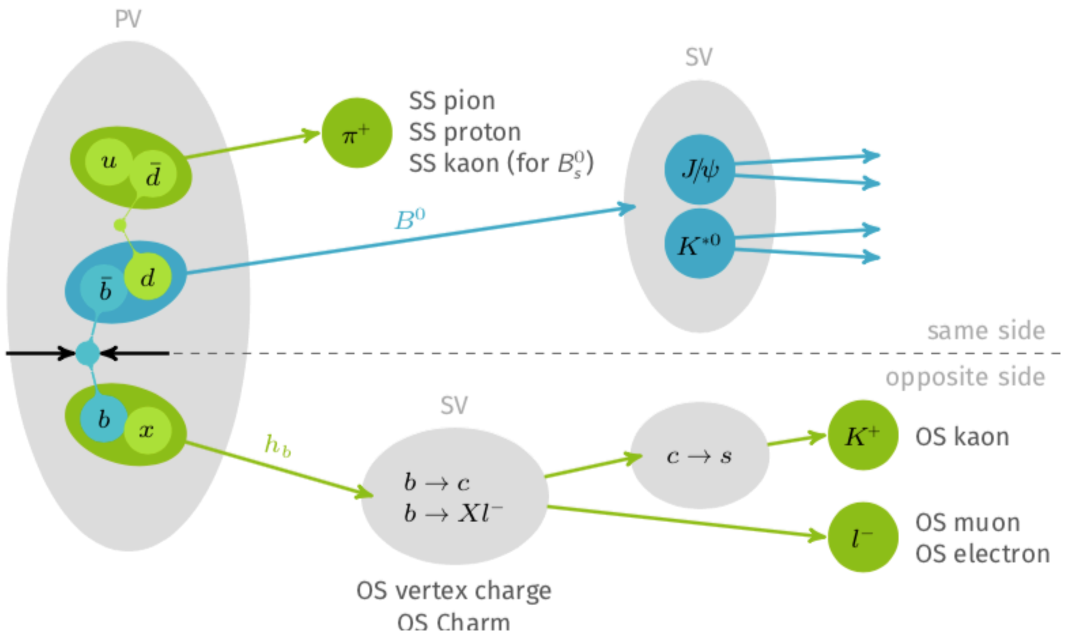
Suppressing backgrounds



Example: Flavour Tagging

Ability to know the flavour of a neutral B meson is fundamental to many CPV studies
Maintaining performance as the nPV increases will be difficult.

Tagging hadrons are typically low momentum



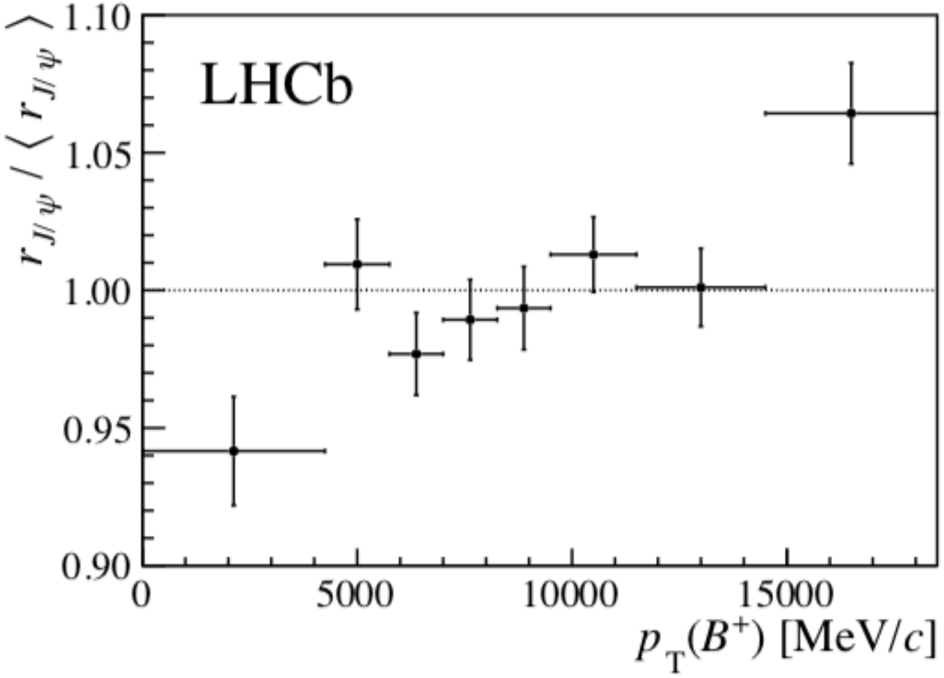
Total tagging performance ~ 4%
(depends strongly on decay)

$B_s \rightarrow J/\psi\ KK$

Category	$\epsilon_{\rm tag} D^2 (\%)$
OS only	0.88 ± 0.04
SSK only	1.38 ± 0.30
OS & SSK	2.47 ± 0.15
Total	4.73 ± 0.34

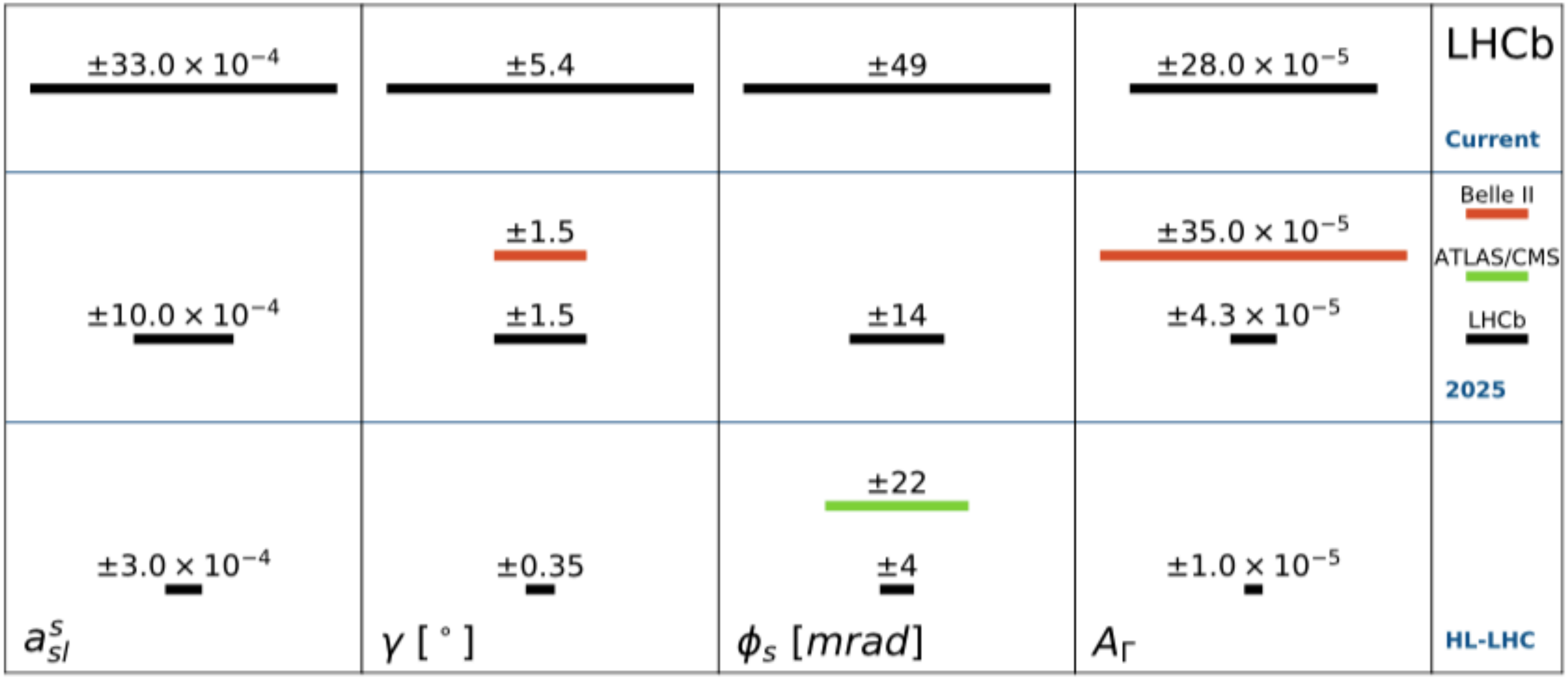
EPJC 79 (2019)706

Determining the efficiency



- Measurements require you to know the rate at which you select/suppress signals
- e.g Electrons and Muons have very different efficiencies, in part due to the PID
- Without the ability to correct the efficiencies we'd be unable to trust LUV analyses

Some key modes (I) – all reliant on PID



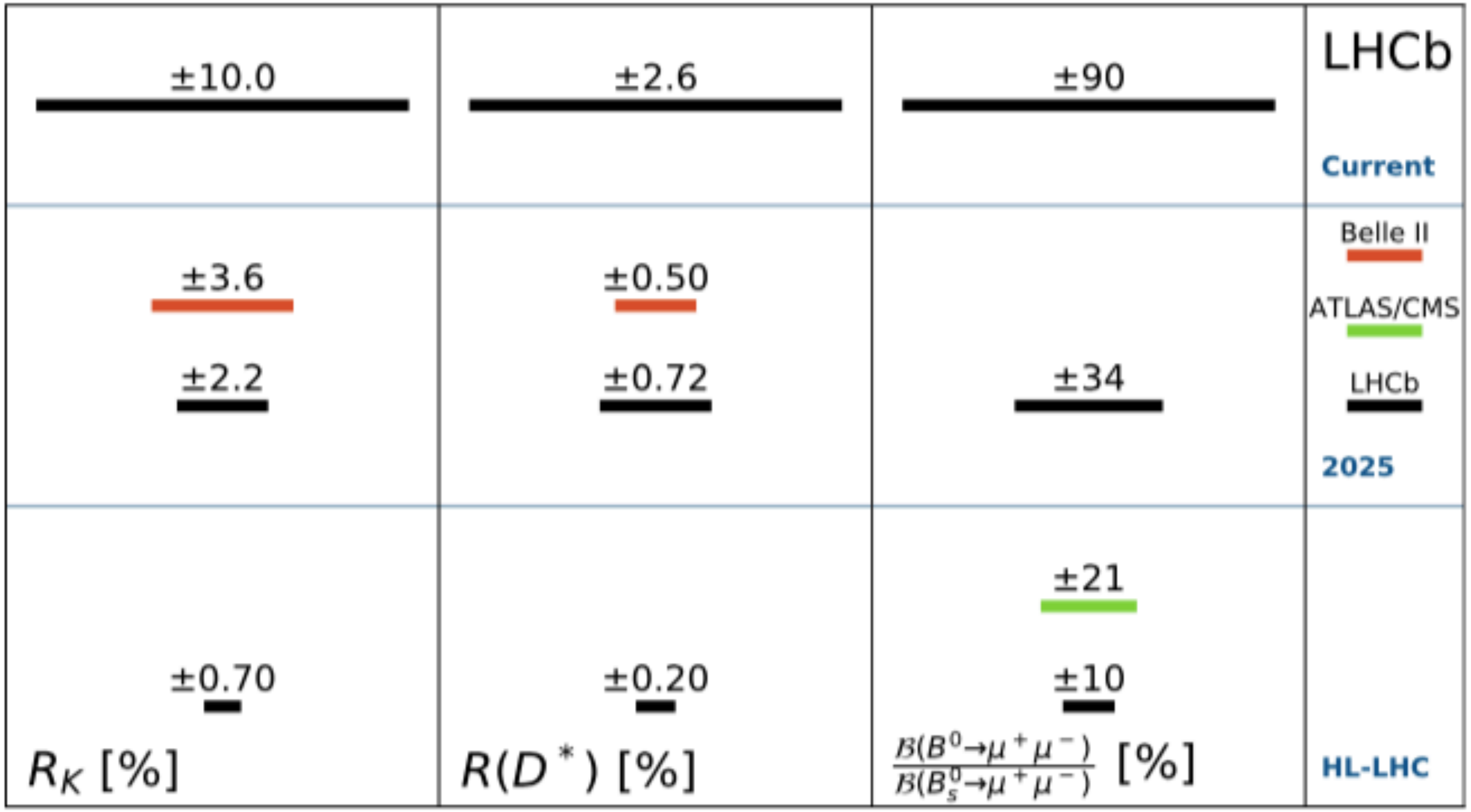
Hadronic D decays + FT

Pure hadronic modes

FT

Pure hadronic modes

Some key modes (II) – all reliant on PID

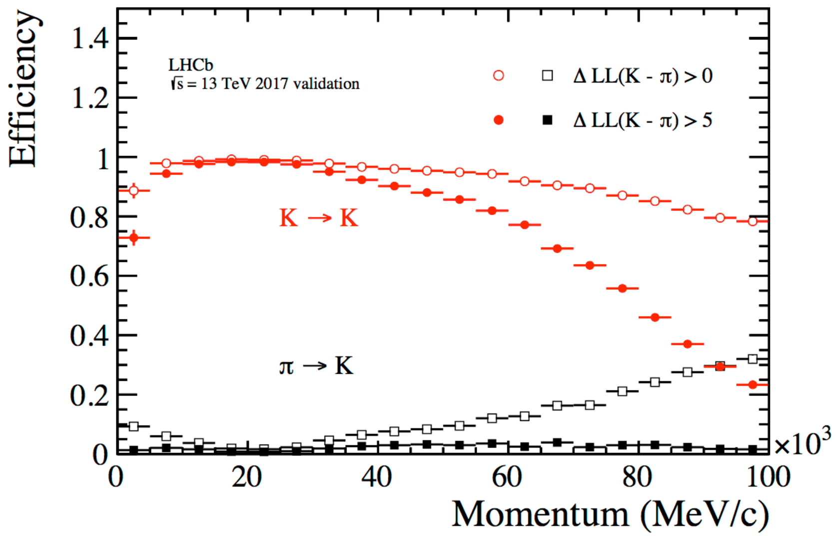


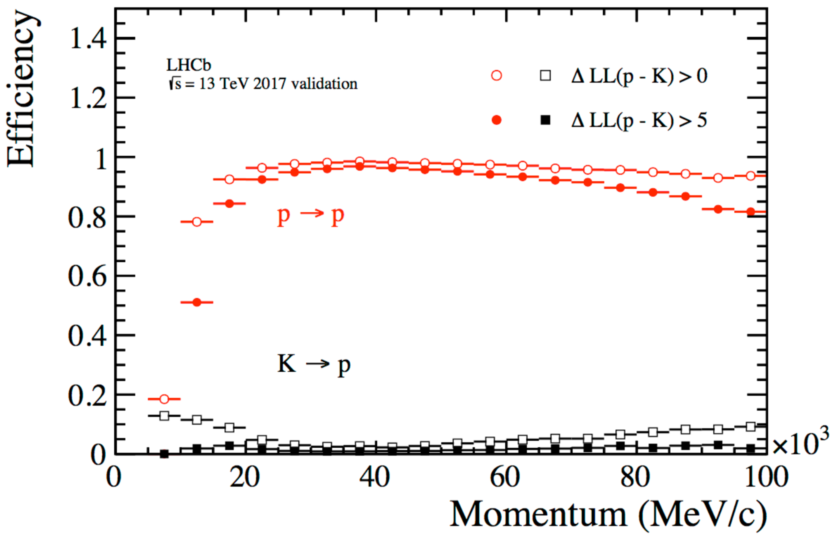
Calibration of Electron ID

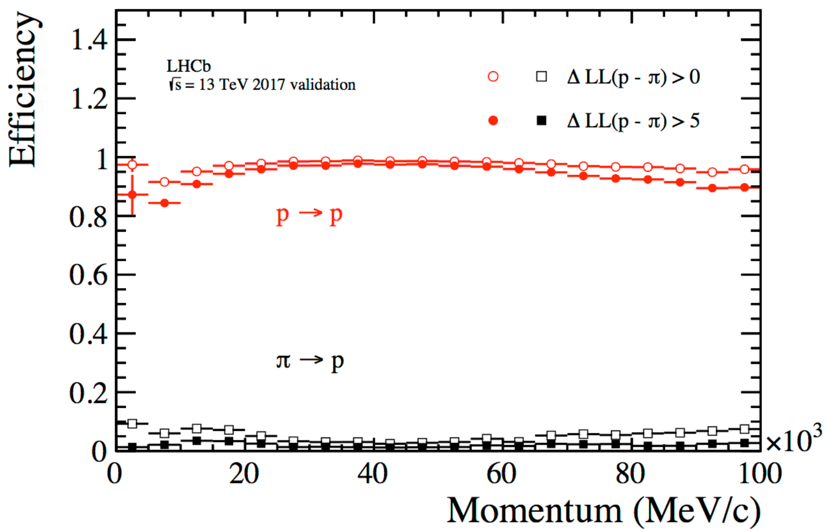
Background supression

Mis-id supression

Current performance



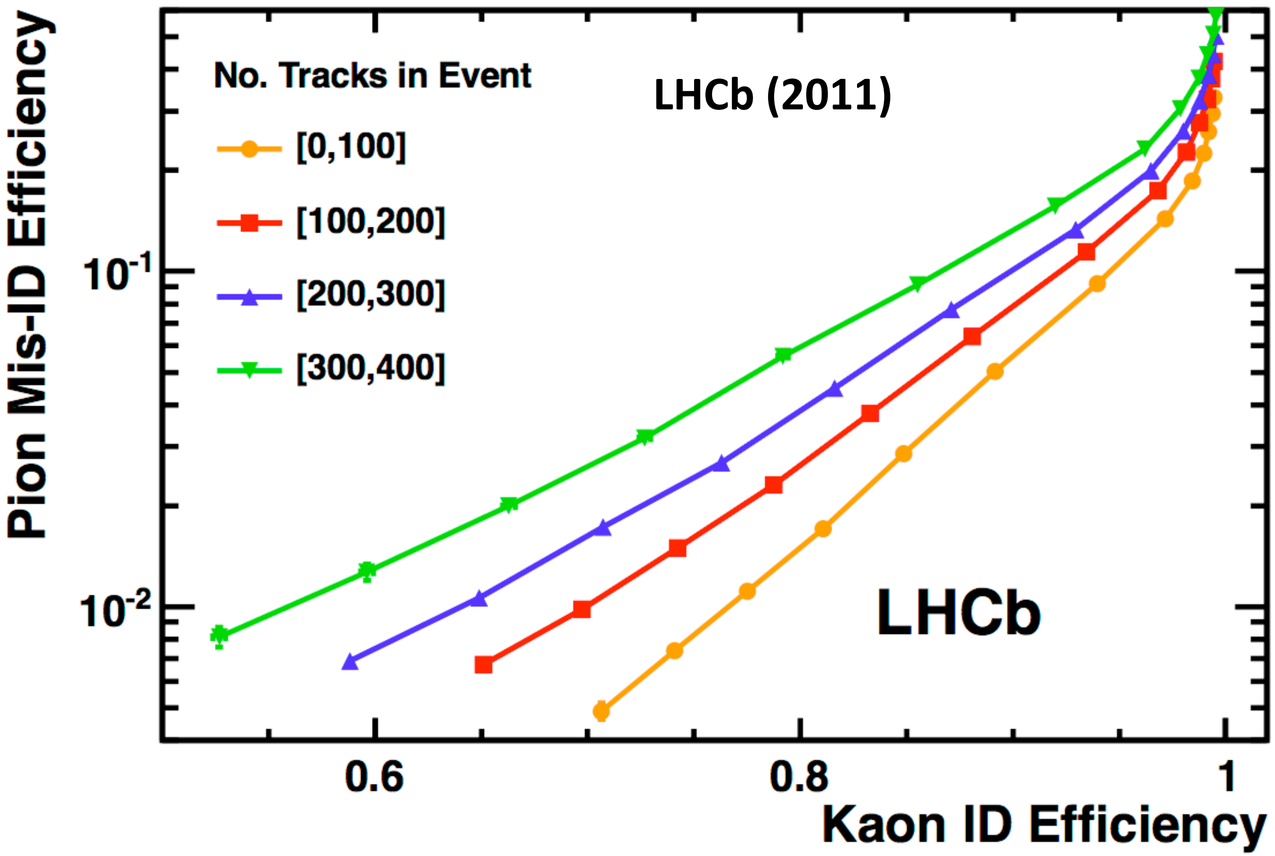




For the central momentum region we have enjoyed the benefits of excellent particle identification capabilities

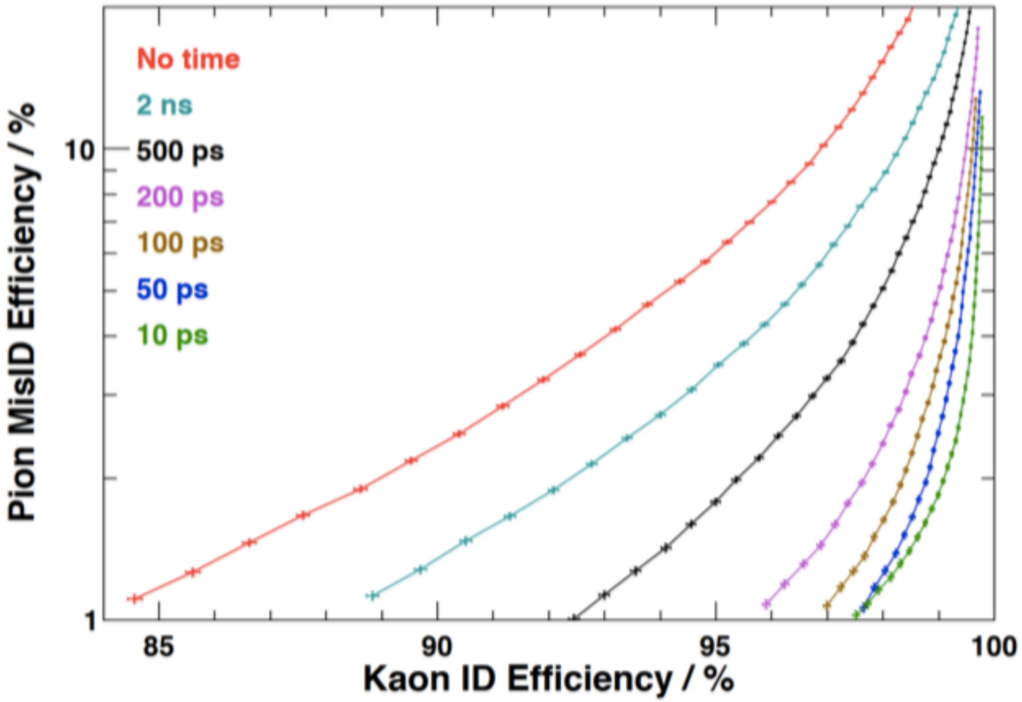
Maintaining this performance is no trivial feat but crucial for physics. See RICH talks later

Effects of occupancy



Loss of performance in higher occupancy tracks – UII will have many, many more tracks per event

Mitigation via timing information?



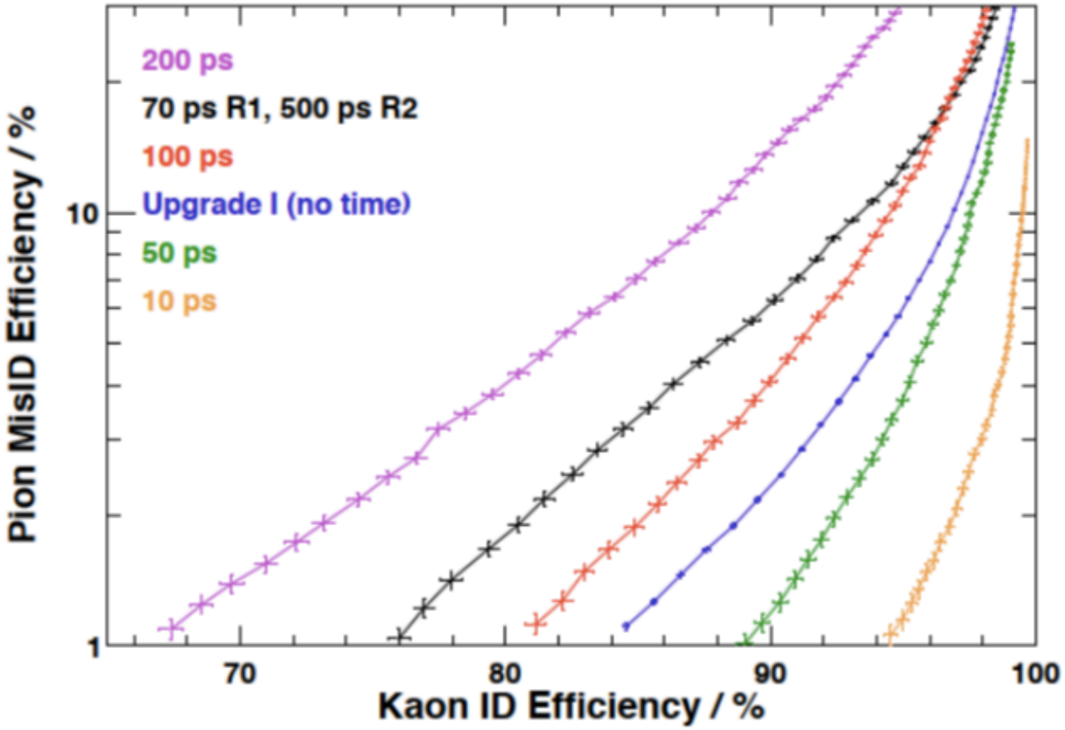
Numbers preliminary, focus on trends

First look at possibility of using timing information in U1b

“Effective reduction in tracks”

RICH meeting: https://indico.cern.ch/event/881465/, F. Keizer

Timing @ UII



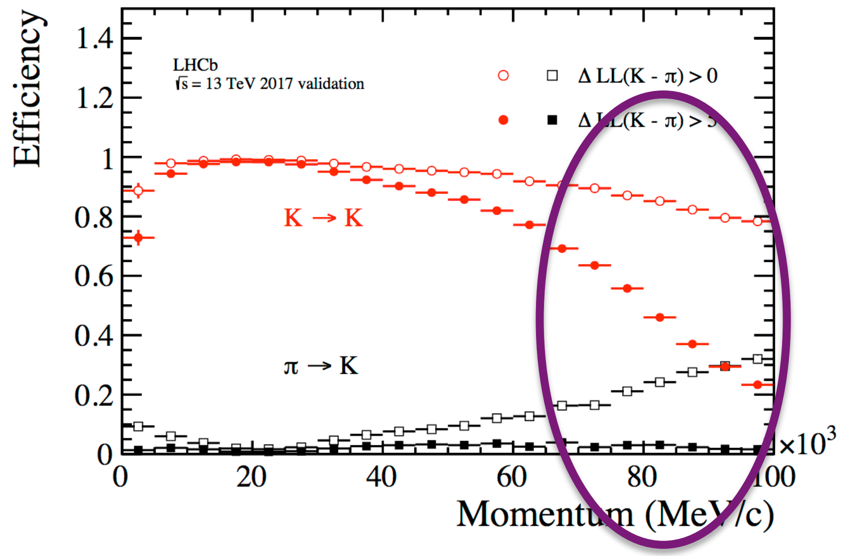
Again preliminary study

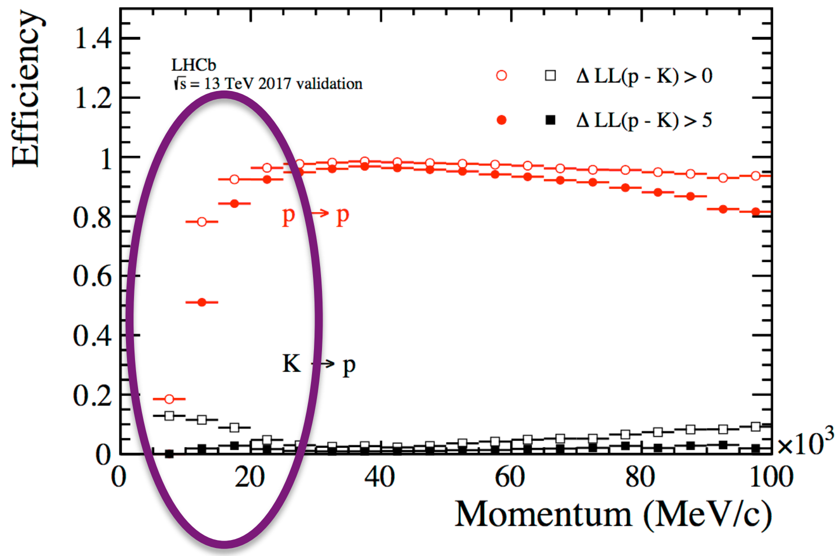
RICH hits from 6 other events combined to emulate UII conditions

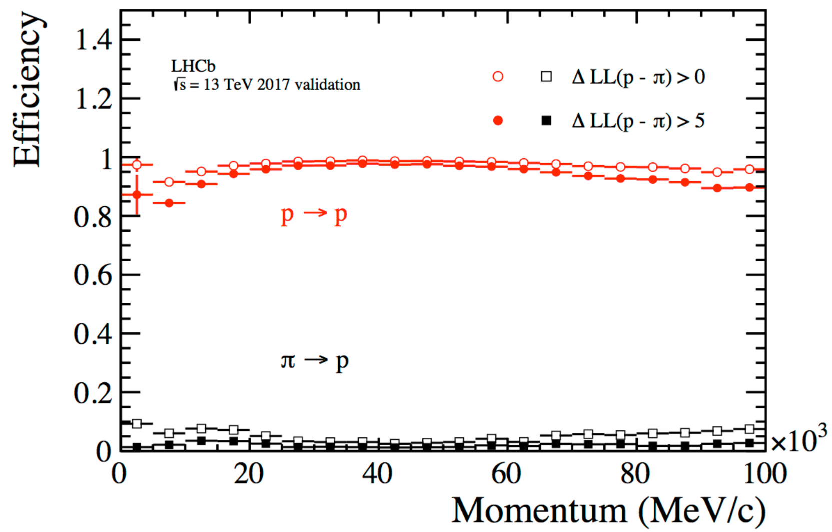
Expected U1 performance can be recovered with some timing information.

RICH meeting: https://indico.cern.ch/event/881465/, F. Keizer

Current performance







Can we improve the lower performing regions?

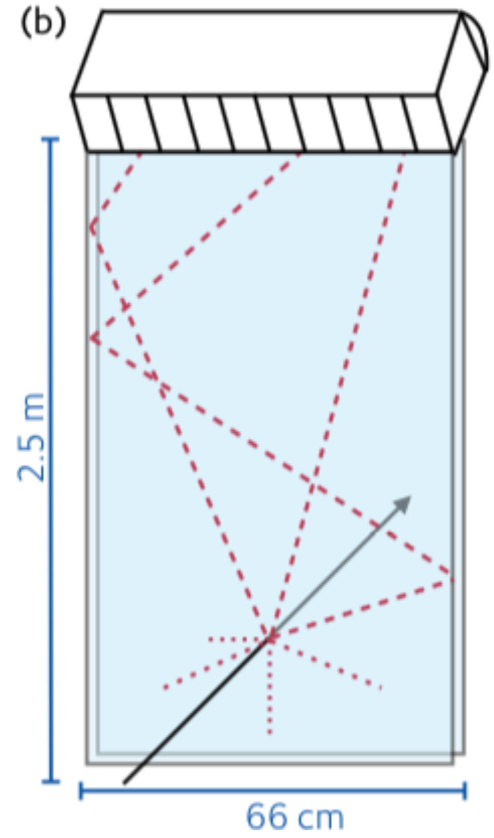
TORCH

TORCH: Time of internally reflected cherenkov light

Detailed detector reports follow

Over 10 m a 10 GeV Kaon and pion differ in their time-of-flight by ~35ps

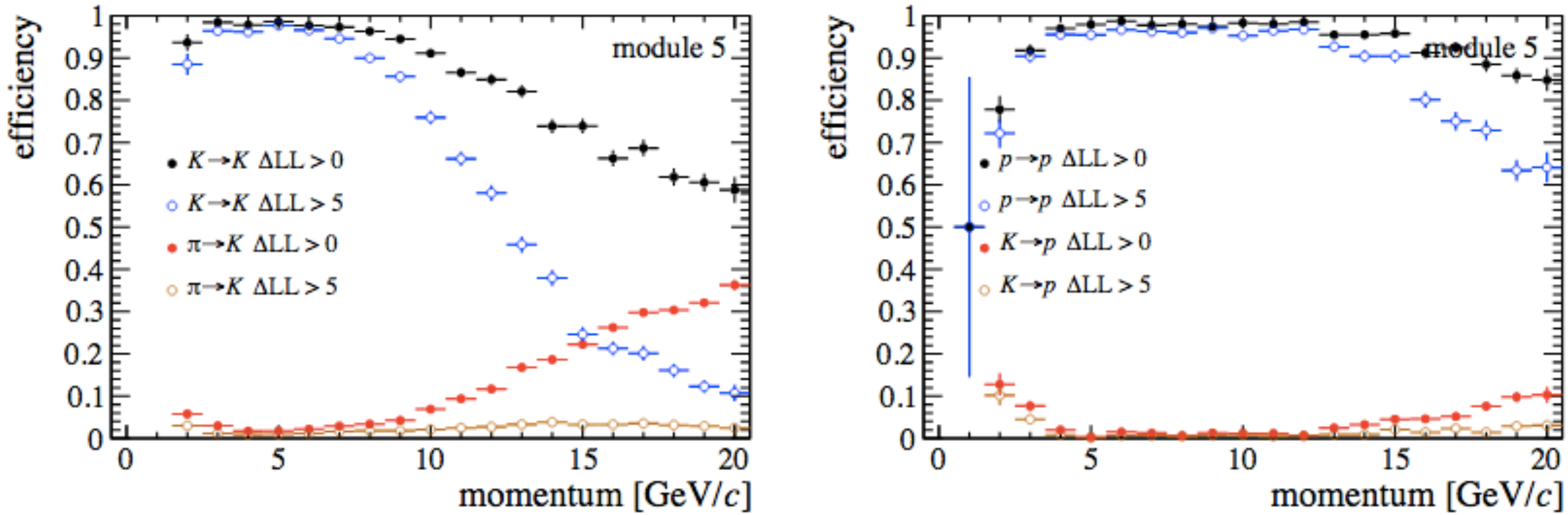
TORCH aims for 10-15 resolution per track for 3 sigma separation.



TORCH module

TORCH performance

Upgrade 1b conditions. Module 5 (highest occupancy)



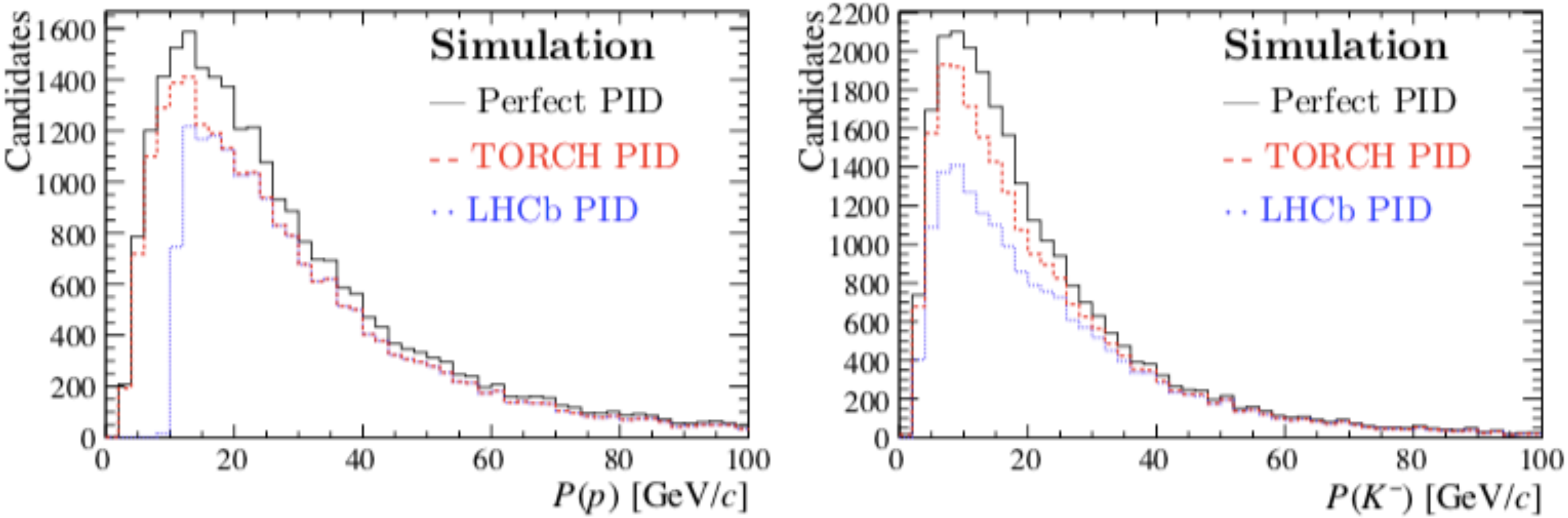
Large improvement in K/p separation compared to the RICH

Performance in UII expected to be similar : the degraded performance (due to higher occupancy) can be mitigated with changes to module design/granularity in the hottest regions.

Example: Impact on $\Lambda_b \rightarrow J/\psi pK$(1)

Analysis challenges:

Contamination from mis-ID backgrounds → loss of signal efficiency due to tight PID requirements

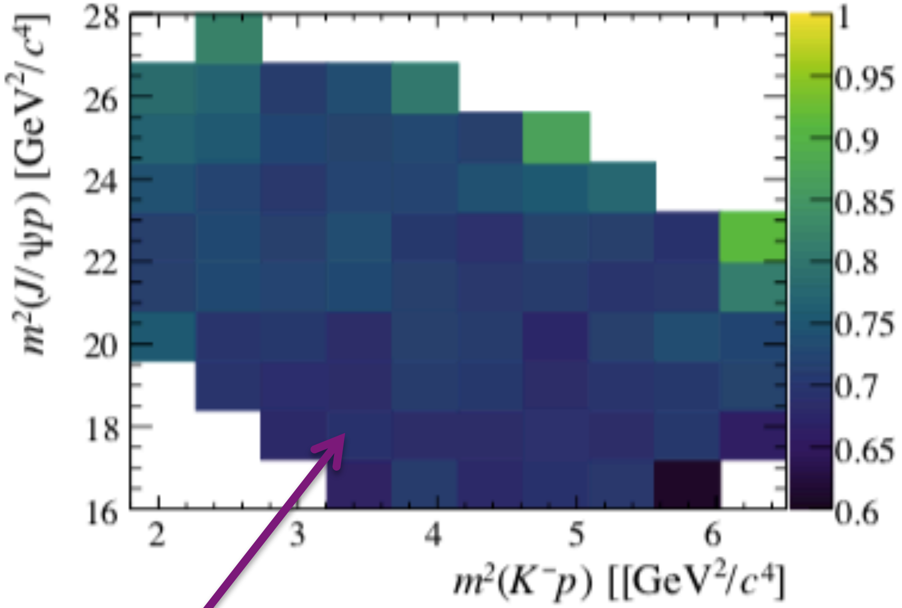


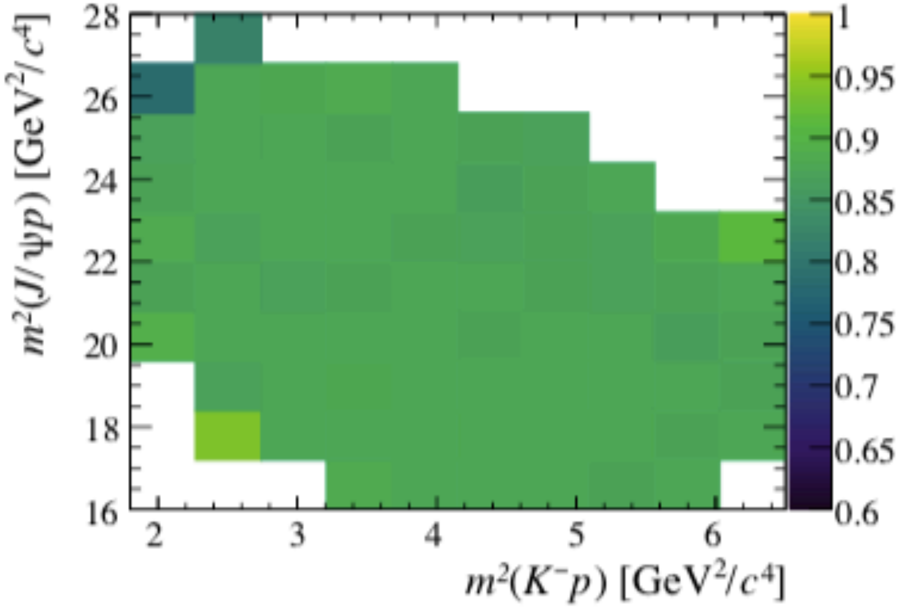
Analysis of baryon decay (contain protons) are stepping up with Run 2 data.
Expect that the study of baryons will expand further with more data, ability to surpress "fake protons" welcome

Example: Impact on $\Lambda_b \rightarrow J/\psi pK$(2)

Analysis challenges:

Amplitude analysis required. Non-flat acceptance unwanted and hard to model



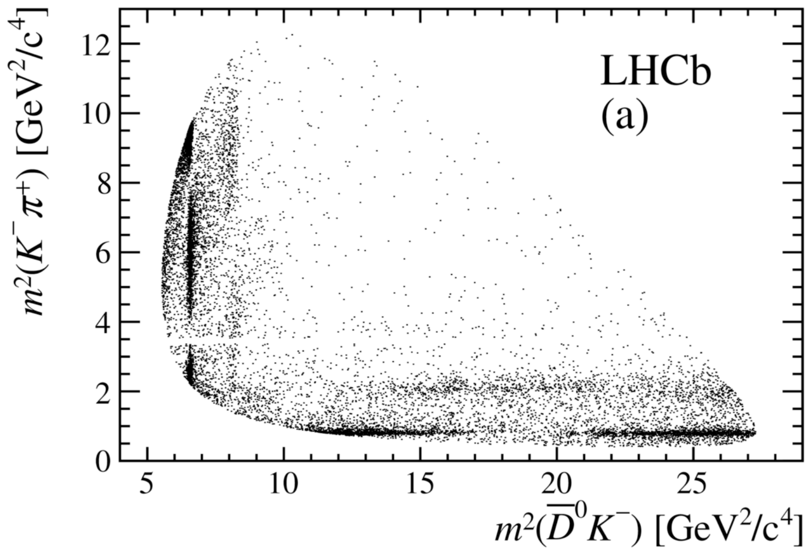


This drop is due to the low momentum performance of current selection

Recovered due to better PID performance

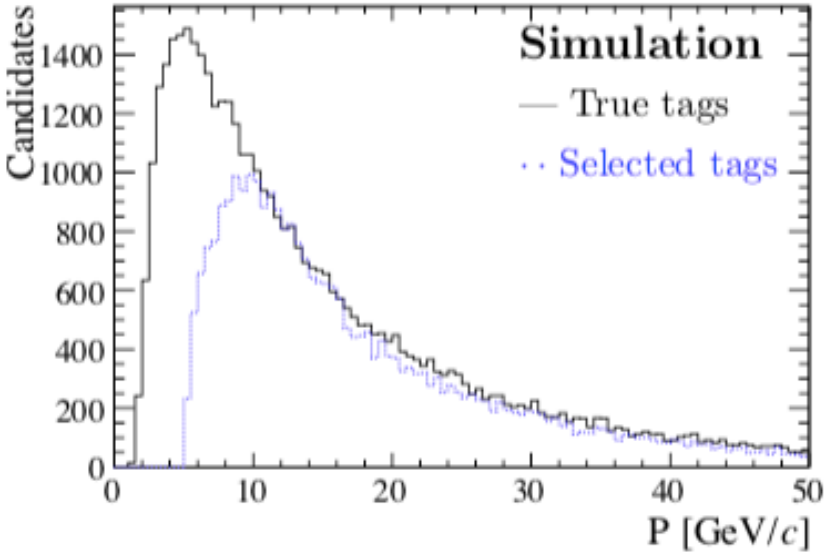
Flatter Dalitz plot acceptance– so what?

- B Dalitz plot typically have activity concentrated close to the edge of the DP
- Corners are where one particle has low momentum
- Flatter DP – how accurate is the MC?
- Flatter DP, stops a physics feature being enhanced/supressed in rapidly changing regions



- We will move increasingly to more complex Amplitude analyses
- B -> 4 body is a 5-D space
- Correcting MC will become increasingly difficult –
    - Starting with a flatter acceptance has a far reaching impact

Tagging performance



Kaons for SSKaon
Selection = LHCb PID + momentum requirements

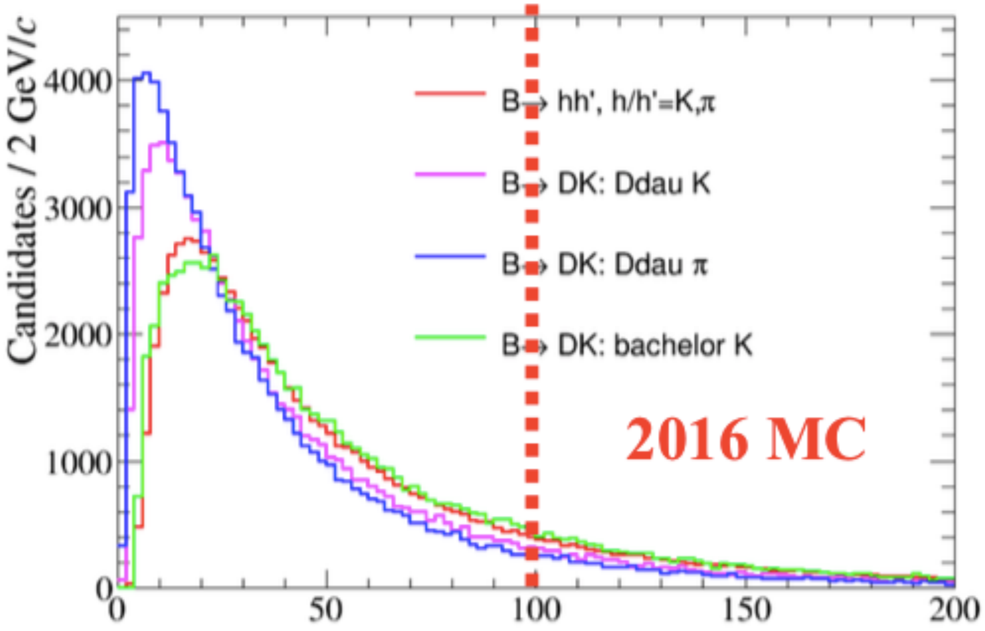
Tagging power improvements of 20-30% attained by including TORCH PID

Tagger	$B_s^0 \to D_s^+ \pi^-$		
	Nominal	TORCH	Perfect
SSKaon	$1.20 \pm 0.05\%$	$1.52 \pm 0.05\%$	$1.61 \pm 0.05\%$
OSKaon	$1.29 \pm 0.05\%$	$1.73 \pm 0.06\%$	$1.80 \pm 0.06\%$

Tagger	$B^+ \to J/\psi K^+$		
	Nominal	TORCH	Perfect
OSKaon	$1.06 \pm 0.04\%$	$1.51 \pm 0.05\%$	$1.61 \pm 0.05\%$

K/π separation at high momentum

Use of events with tracks above 100 GeV limited, as trade-off between small signal yield increases vs higher mis-ID background rates



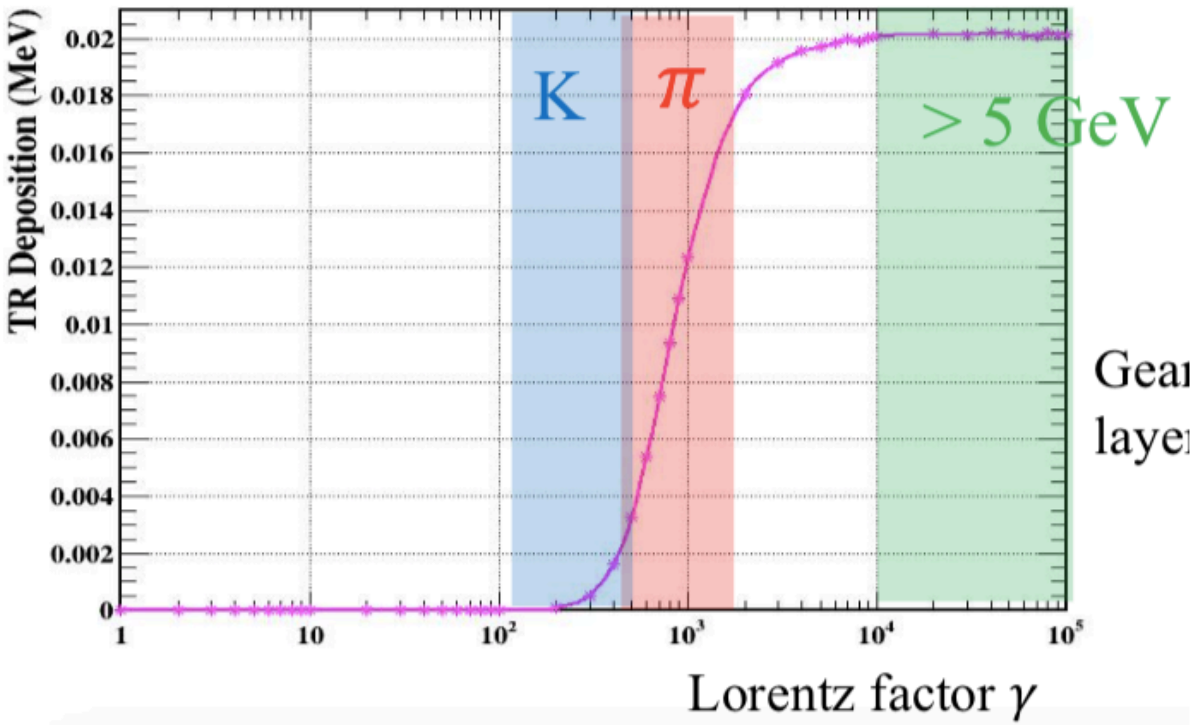
Track momentum

- ~ 18% of tracks are above the 100 GeV
- For multibody B decays this can potentially mean a large inefficiency.
- RICH: Large effort to improve photon resolution and pattern recognition
- These should improve the separation at higher momentum.

Other potential sub-detector idea

Transition radiation detector

Generated when charged particle passes through the boundary of two media with different dielectric constants. Radiation at X-Ray domain



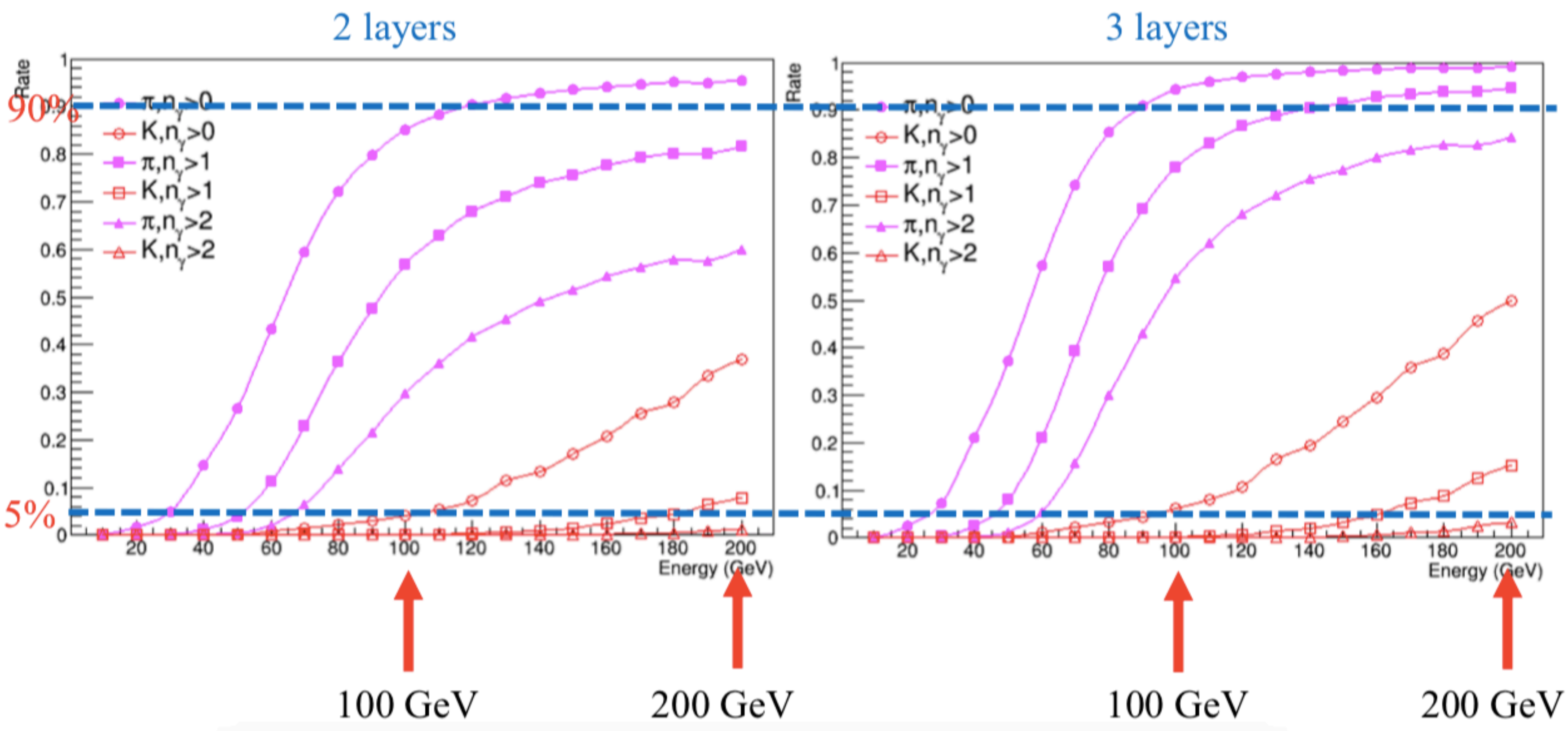
Gear
layer

- In a range 50-200 GeV:

Pions would generate TR, but kaons and protons would not

TRD

- With 2 or 3 layers of TRD and with simple selections of n_γ, can achieve good π efficiency with low K Mis-ID rate



W. Qian Tuesday meeting https://indico.cern.ch/event/861959/

Evolution of a typical* analysis over LHCb lifetime

What about your mis-ID background?

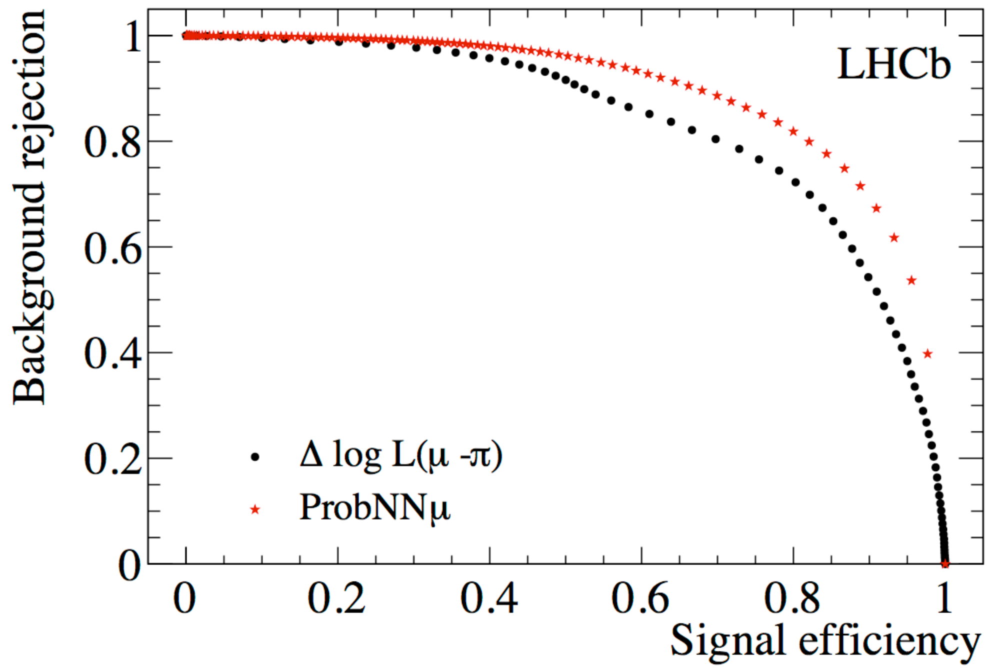
Reviewer Analyst

RUN	Answer
1	Negligible
2	Used PIDCalib. Slapped a systematic
3	Used PIDCalib. See 30 pages of crosscheck in ANA
4	It is now the dominant uncertainty
5	Used PIDCalib + new corrections Much more precise than Run 4

* Quite possibly mythical but it illustrates the point

Analysis optimisation

- DLL variables are the basic output
- More complex variables can be built using additional event/track information – development for Run3 ongoing using various ML techniques
- Potentially can use these to tune for specific types of performance ?
- Phase-space dependent PID selection ?
- Use of PID variables in ML selection ? Find ways to make this more reliable and mainstream.



Data driven calibration

The data-driven calibration will continue to serve us well for some time

But it has various limitations:

Assumes performance can be factorised in 3 variables

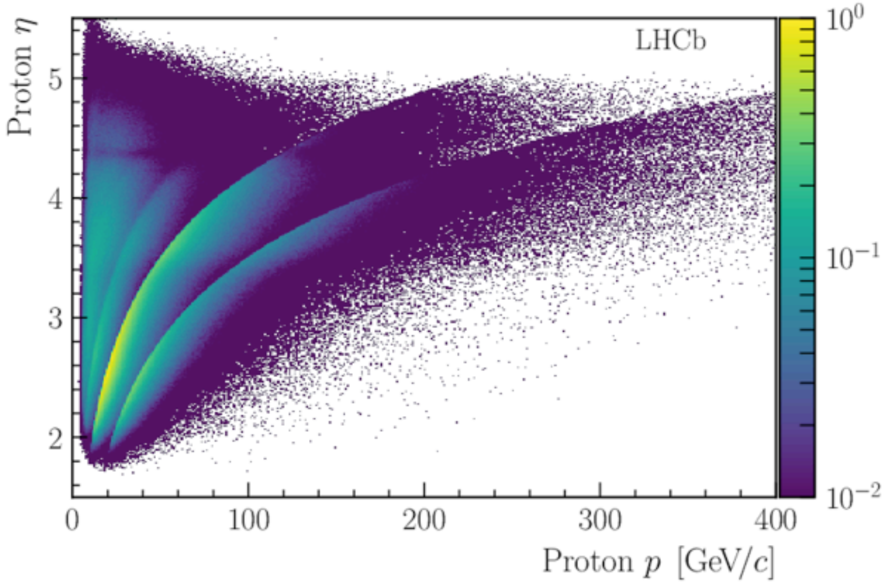
Is based on a “single track”, whereas multiple tracks in an event may have some performance correlations.

Inherently selects “good tracks” which make up resonances.

How do we improve the precision of the calibration by a few factors?

Selection of tracks from resonances where the ID is known without applying PID

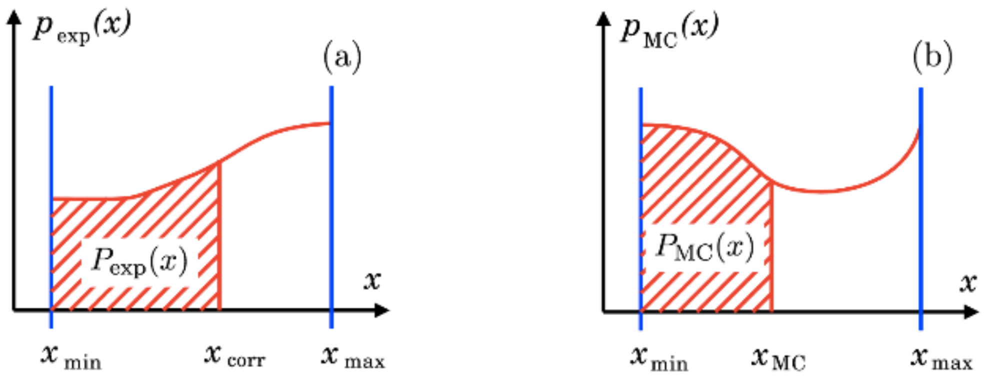
e.g $\Lambda \rightarrow p\,\pi$



Data driven calibration

How do we improve the precision of the calibration, or do more complex things with it?

Plenty of ideas bubbling away – most rely on some use of simulation.



Variable transformation to use PID in ML selection

LHCb-INT-2017-007

No reason to be pessimistic, there is time, ideas, and willingness, and plenty of current analyses to drive development.

Don't assume that the data-driven calibration can provide enough alone, better simulation is required

Summary

- PID is a vital ingredient for our physics analysis
- Sub-detector prospects are exciting
  - Necessary to maintain performance
  - Good chance to improve under-performant areas
- There will be analysis challenges to be overcome in this new era of precision.
- The future looks bright.