Track cluster size analysis for the ALICE ITS2

An ITS standalone performance study

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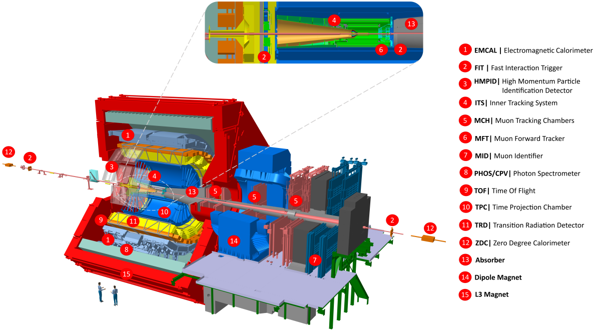
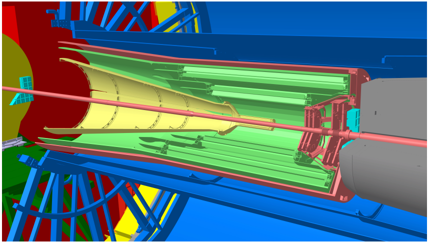
ALICE: A Large Ion Collider Experiment

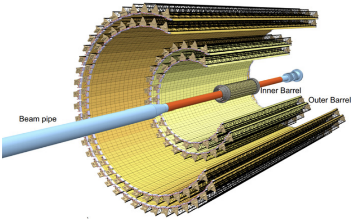
- Hermetic detector experiment at the Large Hadron Collider investigating **strongly-interacting matter** and the **quark-gluon plasma**
- Operating in *continuous** readout mode since Run 3
- $\sim$ 18 subdetectors: trackers, calorimeters, triggers, muon system, etc.



The Inner Tracking System (ITS)

- ITS $\rightarrow$ ITS2 upgrade during LS2
- **Seven** concentric layers (20-400 mm from beamline), $|\eta| < 1.22$
- **High tracking efficiency and pointing resolution**: 95% and 100 µm at $p_T = 200$ MeV
- 0.35% X/X_0 material budget per layer
- **Water-cooled** to room temperature (20-25°C)
- **12.5 Gpx** over 10.3 m^2 area
- The **AL**ICE **Pi**xel **De**tector (**ALPiDe**): CMOS-based MAPS

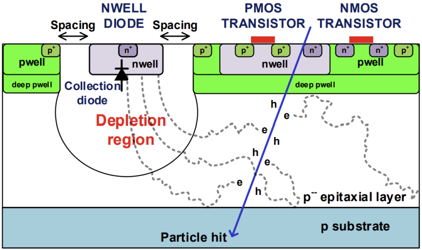




[1]

ALPIDE: KEY FEATURES

- 29 μm × 27 μm pixel pitch
- Implemented with *TowerJazz 180 nm CMOS Imaging Process*
- **Deep p-well**: full, complex CMOS logic within pixel matrix
- **In-pixel** amplification, shaping, discrimination, hit buffers
- **In-matrix** data sparsification via priority encoder



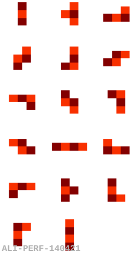
From [2]

Parameter	Value
Chip dimensions	15 mm × 30 mm ($r\phi \times z$)
Spatial resolution	5 μm
Detection efficiency	$>$ 99%
FHR	$\ll 1 \times 10^{-6}$ / event / pixel
Power density	$< 40\,\mathrm{mW/cm^2}$
TID radiation hardness	$>$ 270 krad
NIEL radiation hardness	$> 1.7 \times 10^{12}$1 MeV n_{eq}/c^2

From [3]

Cluster

Charge deposition spread across pixels from particle crossing



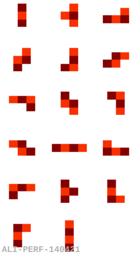
ITS tracking and vertexing

Cluster

Charge deposition spread across pixels from particle crossing

Track

Collection of clusters from different layers reconstructed as single particle



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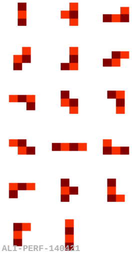
Cluster size

Total number of pixels in cluster on layer



Cluster

Charge deposition spread across pixels from particle crossing

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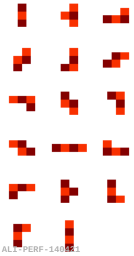
Collection of clusters from different layers reconstructed as single particle

Cluster size

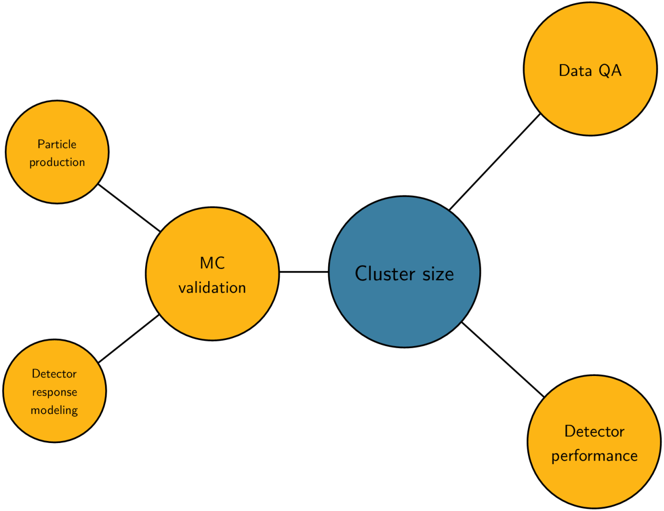
Total number of pixels in cluster on layer

Average cluster size

Average cluster size over clusters in single track

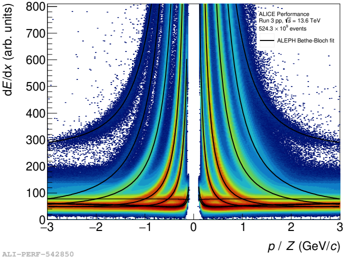


Why cluster size?



Particle selection: $\pi^{\pm}$ and $p^{\pm}$

- Particle-pixel interaction determined by Bethe-Bloch curve of particle species
- ITS standalone = only track-level information = no TPC PID!
- “Home-brewed” ITS standalone PID



ITS standalone PID

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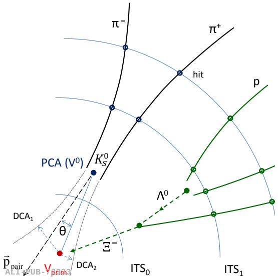

From [4]

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- Kinematic track topology cuts; mass hypotheses/competing decay rejection
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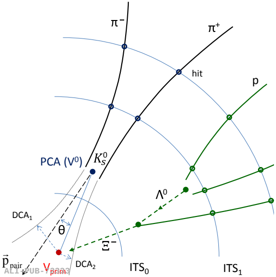
$K^0_S \to \pi^+\pi^-$ (69%)
$K^0_S \to \pi^0\pi^0$ (30%)



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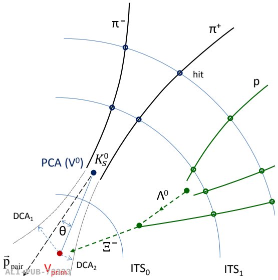
ITS STANDALONE PID

- Kinematic track topology cuts; mass hypotheses/competing decay rejection; *Armenteros-Podolanski variables*
- **Exploit neutral two-body (V^0) decays**:

$K_S^0 \rightarrow \pi^+\pi^-$ (69%) $\Lambda \rightarrow p\pi^-$ (64%) $\bar{\Lambda} \rightarrow p^-\pi^+$ (64%)

$K_S^0 \rightarrow \pi^0\pi^0$ (30%) $\Lambda \rightarrow n\pi^0$ (36%) $\bar{\Lambda} \rightarrow \bar{n}\pi^0$ (36%)



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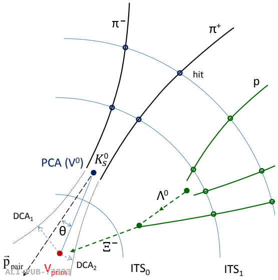
- Prioritize **purity** over **efficiency**



From [4]

	K_S^0	Λ
R_{V0} (cm)	< 15	
Prong DCA (cm)	< 0.02	
$\cos\theta_p$	> 0.998	
d^+ DCA (cm)	> 0.1	(0.1, 0.8)
d^- DCA (cm)	> 0.1	
V^0 DCA (cm)	< 0.2	
$\lvert m_\Lambda - m_{p\pi}\rvert$ (MeV/c^2)	$\times$	< 20
$\lvert m_{K_S^0} - m_{\pi\pi}\rvert$ (MeV/c^2)	< 20	> 50
α	$\times$	(0.3, 1)
p_{T,V^0} (GeV/c)	$\times$	(0.04, 0.12)

Weak decay topology

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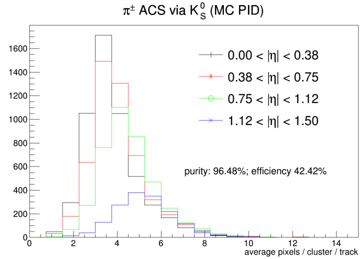
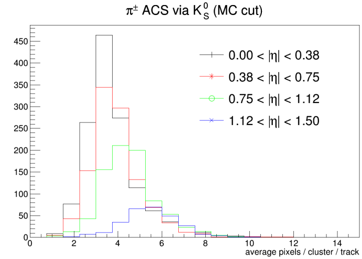
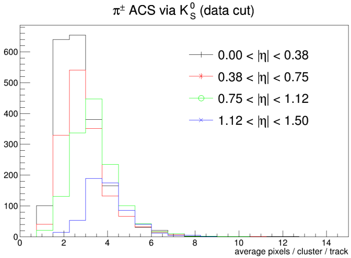
η DEPENDENCE

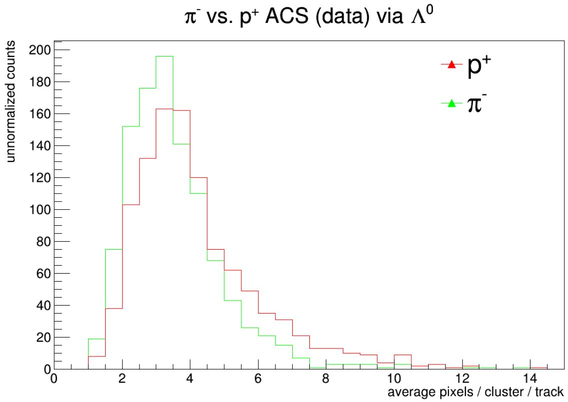






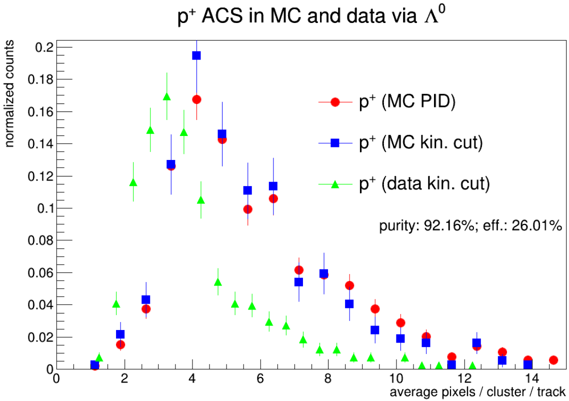
- Higher η crosses layers at steeper angles: higher ACS

Particle species dependence



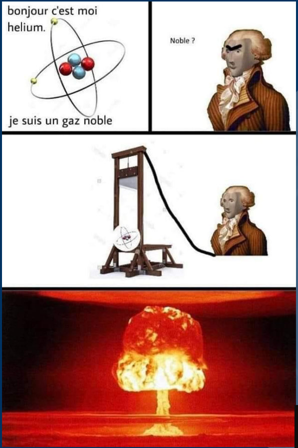
- ACS shifted to higher size for protons, as expected from Bethe-Bloch

Monte Carlo to data comparison

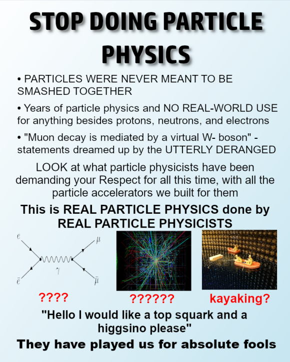


- $>$ 90% purity with α and p_T cuts
- Data exhibits lower ACS than MC

- Track ACS is a **useful performance metric** for a pixel silicon tracker, **influenced by many important aspects of tracking**
- High-purity PID via kinematic cuts empowers average cluster size to **isolate tracker effects and be data source-agnostic**
- Analysis **confirms general expectations** about cluster size:
  - Higher η (steeper angular crossing) deposits more charge on average
  - Different particle species have different ACS curves
- **Discrepancies between simulation and data** can flag areas for improvement in simulation


bonjour c'est moi
helium.
je suis un gaz noble
Noble ?

Thank you!


STOP DOING PARTICLE PHYSICS
• PARTICLES WERE NEVER MEANT TO BE SMASHED TOGETHER
• Years of particle physics and NO REAL-WORLD USE for anything besides protons, neutrons, and electrons
• "Muon decay is mediated by a virtual W- boson" - statements dreamed up by the UTTERLY DERANGED
LOOK at what particle physicists have been demanding your Respect for all this time, with all the particle accelerators we built for them
This is REAL PARTICLE PHYSICS done by REAL PARTICLE PHYSICISTS
????
??????
kayaking?
"Hello I would like a top squark and a higgsino please"
They have played us for absolute fools


SOLID-STATE PHYSICIST HEARING NEWS ABOUT ROOM TEMPERATURE SUPERCONDUCTORS FOR THE 2ND TIME IN THIS YEAR
Don't do that.
Don't give me hope.
imgflip.com

[1] B. Abelev, J. Adam, D. Adamová, *et al.*, "Technical Design Report for the Upgrade of the ALICE Inner Tracking System," Tech. Rep., 2014. DOI: 10.1088/0954-3899/41/8/087002. [Online]. Available: https://cds.cern.ch/record/1625842.

[2] D. Kim, G. A. Rinella, C. Cavicchioli, *et al.*, "Front end optimization for the monolithic active pixel sensor of the alice inner tracking system upgrade," *Journal of Instrumentation*, vol. 11, no. 02, p. C02042, Feb. 2016. DOI: 10.1088/1748-0221/11/02/C02042. [Online]. Available: https://dx.doi.org/10.1088/1748-0221/11/02/C02042.

[3] F. Reidt, "Upgrade of the ALICE ITS detector," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 1032, p. 166 632, Jun. 2022. DOI: 10.1016/j.nima.2022.166632. [Online]. Available: https://doi.org/10.1016%2Fj.nima.2022.166632.

[4] "Performance of the ALICE experiment at the CERN LHC," *International Journal of Modern Physics A*, vol. 29, no. 24, p. 1 430 044, Sep. 2014. DOI: 10.1142/s0217751x14300440. [Online]. Available: https://doi.org/10.1142%2Fs0217751x14300440.