# Challenges in simulation, reconstruction, and optimisation of ITS3 geometry

A. Kalweit (CERN), F. Grosa (CERN), A. Rossi (INFN Padua)
for WP1

ALICE Upgrade Week

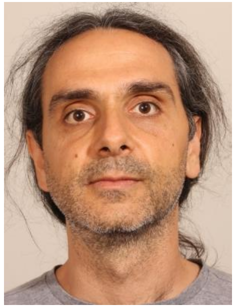
19–23 September 2022
House of CASTS
Novotného lávka 5, Prague, Czech Republic

# WP1 goals and general news

**The task of WP1 is to define the ITS3 physics goals and determine the achievable performance on both tracking and final physics observables**

Weekly slot for meeting: Wednesday 10:30 am
WP1 coordinators:

A. Kalweit



A. Rossi

F. Grosa

Alexander, who will be next Physics Coordinator, is stepping down.
Fabrizio Grosa will replace him from 1st October.

Thanks Alex for the great work, it was a pleasure working with you!
… and of course we will keep counting on you for the future of the project!
Welcome Fabrizio!

# WP1  Public Note status

**Goal**: document all performance studies done after LoI

**Status**: New draft uploaded to aliceinfo on 6th August:

[https://alice-notes.web.cern.ch/node/1327](https://alice-notes.web.cern.ch/node/1327)

**PC**: all those who contributed to preparation of figures/editing of text

Biswarup Paul, Matthew Daniel Buckland, Janik Ditzel, Benjamin Donigus, Mattia Faggin, Paraskevi Ganoti, Fabrizio Grosa, Jaime Norman, Stefano Politano,  Lucas Anne Vermunt, Andrea Rossi, Alexander Philipp Kalweit

**ARC:** D. Chinellato, X. Peng, C. Terrevoli

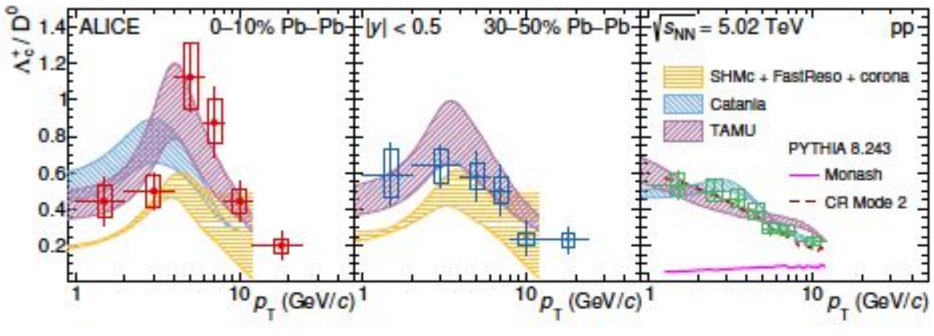
**Open points:**

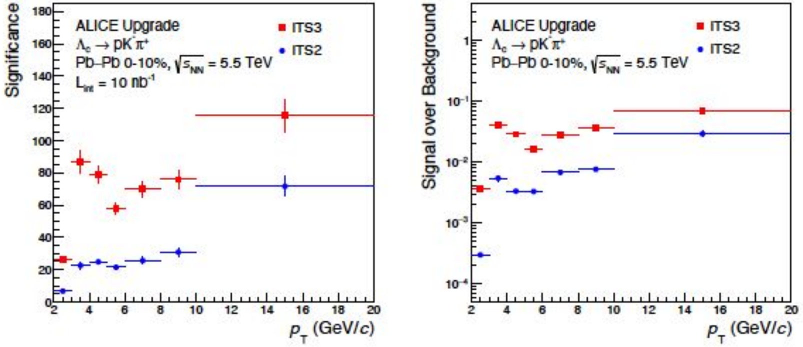
- refinements to graphics of some figures
- update assumptions on signal/event for some observables on the basis of recent measurements or theoretical developments ($\Lambda_c^+$, $D_s^+$, $\Xi_c^{0,+}$)

**Timeline**: to the Collaboration at the beginning of November

Contents





# Open points for TDR

- Get full simulation chain working in $O^2$
  - needed for many of the following points
  - crosscheck already estimated performances for at least 1 final observable
  - strangeness tracking
- Impact of inhomogeneous material di
  - radiation load
  - resolution
- Impact of dead zones
  - efficiency
  - resolution
  - performance on final observables
- Finalise detector layout. Extra layers?
  - single track efficiency
  - strangeness tracking

Digitizer step ok but Reco workflow for ITS3 needs to be updated after many recent changes were done to reconstruction code in $O^2$ (M. Concas contacted)

Then few selected layouts that must be tested should be added as geometry options.

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# Radiation load – previous estimates

Table 2: Expected maximum particle density in the layers of the ITS Inner Barrel.

| | Particle density ($cm^{-2}$) | | | |
|---|---|---|---|---|
| | LS2 Upgrade | | LS3 Upgrade | |
| Layer | Hadronic[a] | QED electrons[b] | Hadronic[a] | QED electrons[b] |
| 0 | 43 | 7 | 73 | 12 |
| 1 | 25 | 3 | 43 | 8 |
| 2 | 17 | 2 | 29 | 6 |

[a] maximum particle density in central Pb–Pb collisions (including secondaries produced in material) for a magnetic field of 0.2 T.
[b] for an integration time of 10 μs, an interaction rate of 50 kHz, a magnetic field of 0.2 T

ITS3 Inner Layers will be closer to the interaction point than ITS2
→ particle densities in the innermost layer, and correspondingly the radiation load, will increase

Density of hits for primary and secondary particles and QED electrons evaluated for the LOI

Particle density increases by about 70%
→ due to detector closer to interaction point
→ similarly radiation load is expected to increase by 60-70%, but still lower than $10^{13}$ 1 MeV $n_{eq}$ $cm^{-2}$ (NIEL) and 10 kGy (TID)
Radiation load to be evaluated for pp/PbPb and beam-gas interactions as done for Run 2 and 3 estimates (https://alice-notes.web.cern.ch/node/405)

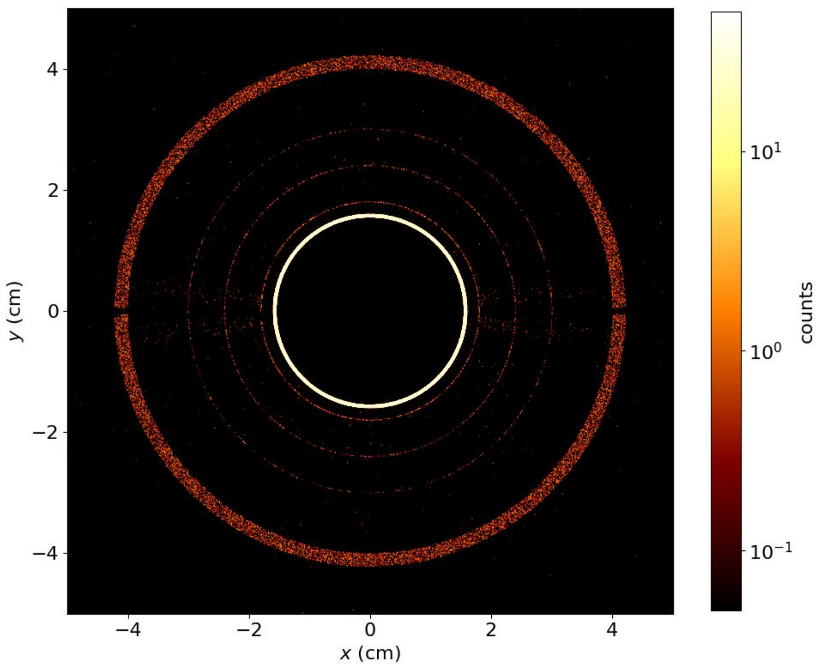
**More detailed R-z map for pp and Pb–Pb running scenarios wanted**

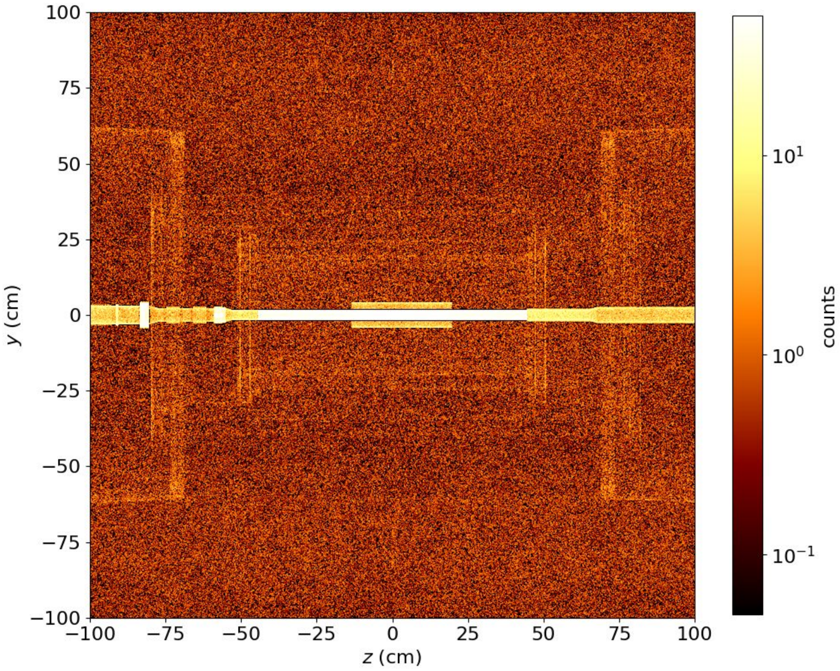
# Radiation load – ongoing studies

F. Grosa

First attempt of simulation with O2 using FLUKA for the transport of particles with ITS3 geometry

- ITS3 geometry to be revised (currently 4 layer setup introduced for first strangeness tracking studies)




Map of material obtained looking at production vertex of electrons and positrons from photon conversion
Settings to evaluate NIEL and TID under implementation in O2 (thanks A. Morsch!)

# Open points for TDR

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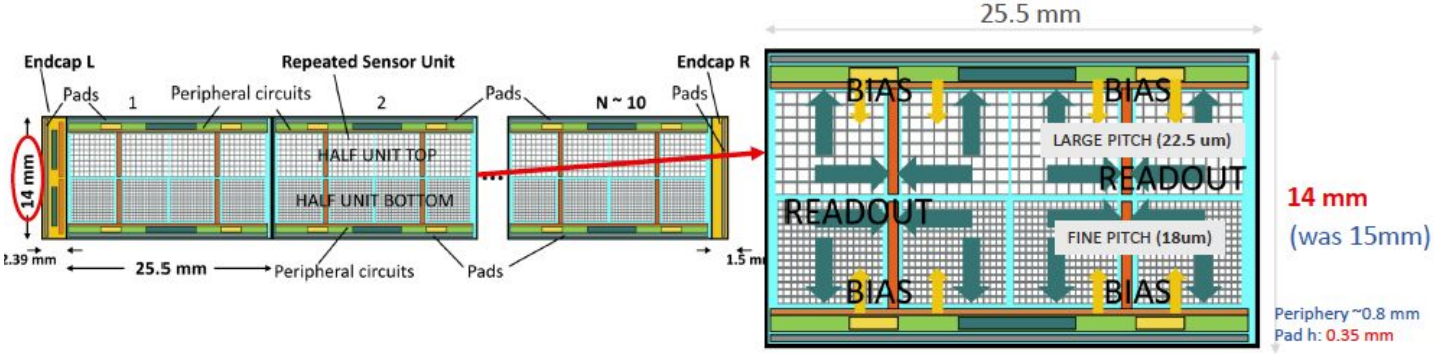
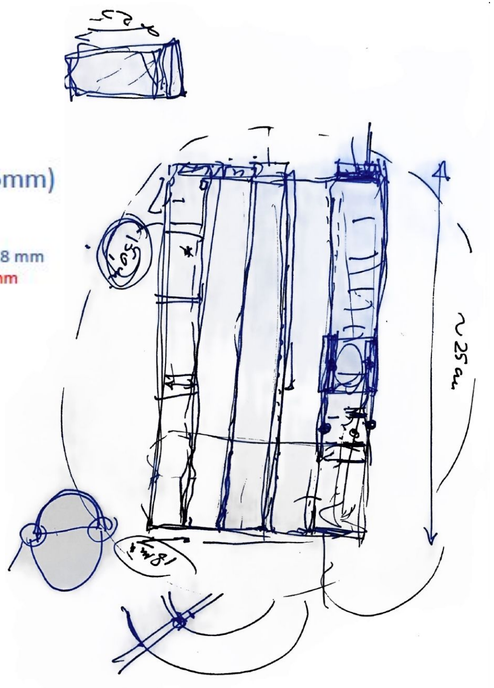
# Dead zones: recap



ITS3 will have only two sensors per layer (“hemi-cylinders”)
Still connection to periphery needed, resulting in introduction of dead areas.

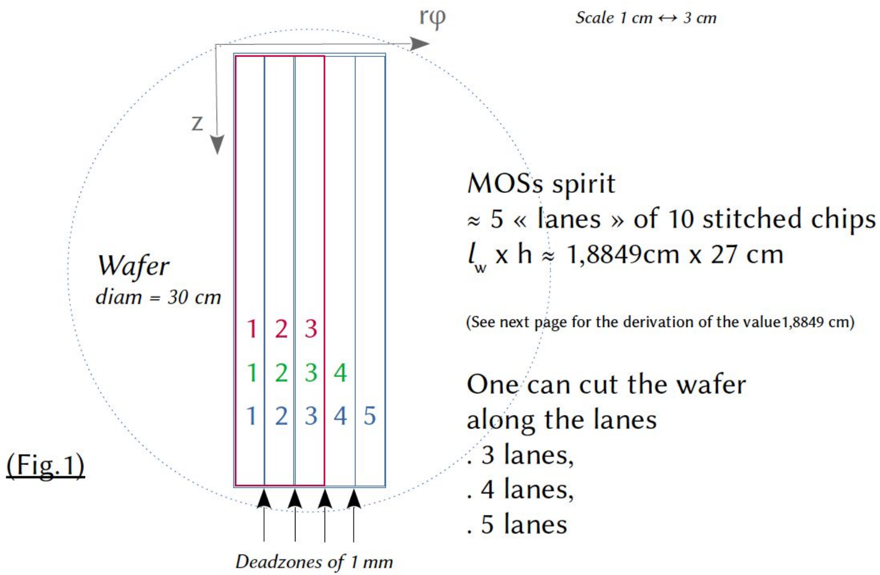
Discussion with G. Aglieri ongoing on possible settings:
guess that on final detector, dead-zone area from 5% to 10%

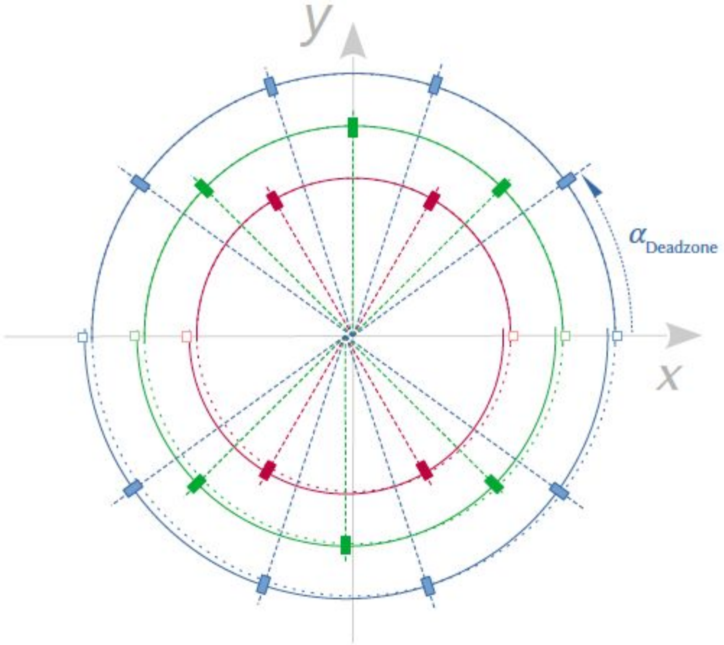
Initial assumption: **1 mm per side on each lane.**

Other possible dead areas (not considered in what follows):
- some O(20um) at the stitching boundaries
- case of hemi-cylinders splitted in two in z with a small gap (0.5-1 mm) at z=0 ($\Delta\eta_{\text{layer0, z PV=0}}$ ~0.03-0.056)

# Dead zones, recap

From A. Maire's presentation at WP1:
https://indico.cern.ch/event/1172076/contributions/4922667/attachments/2462432/4301206/Sketch-DeadzonesInITS3-2022.pdf

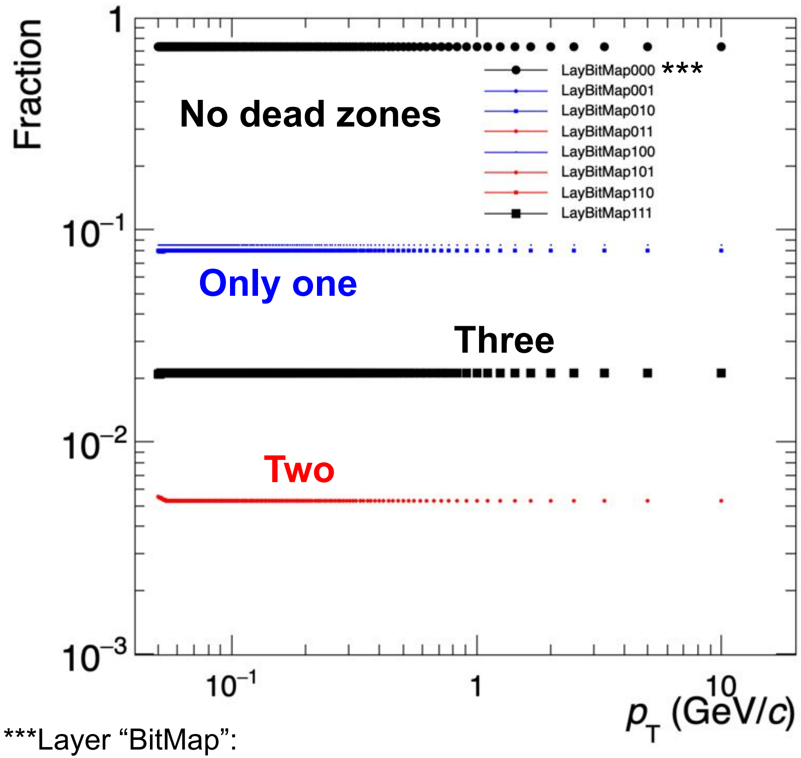


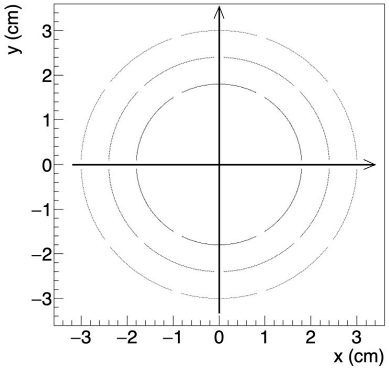

Dead-zones at hemisphere intersection might be removed by slightly displacing the hemispheres and introducing an overlap

Missing a point may increase tracking inefficiency, or probability of missing further points

# Probability of intersecting dead zones




***Layer "BitMap":
1 = dead zone intersected,   0 = dead zone not intersected
first digit (rightmost): innermost layer
e.g.  011 = dead zones intersected in innermost and intermediate layers




Probability of intersecting a dead zone in a given layer
**2 mm dead area / 18.8 mm "lane" → 10.6%**

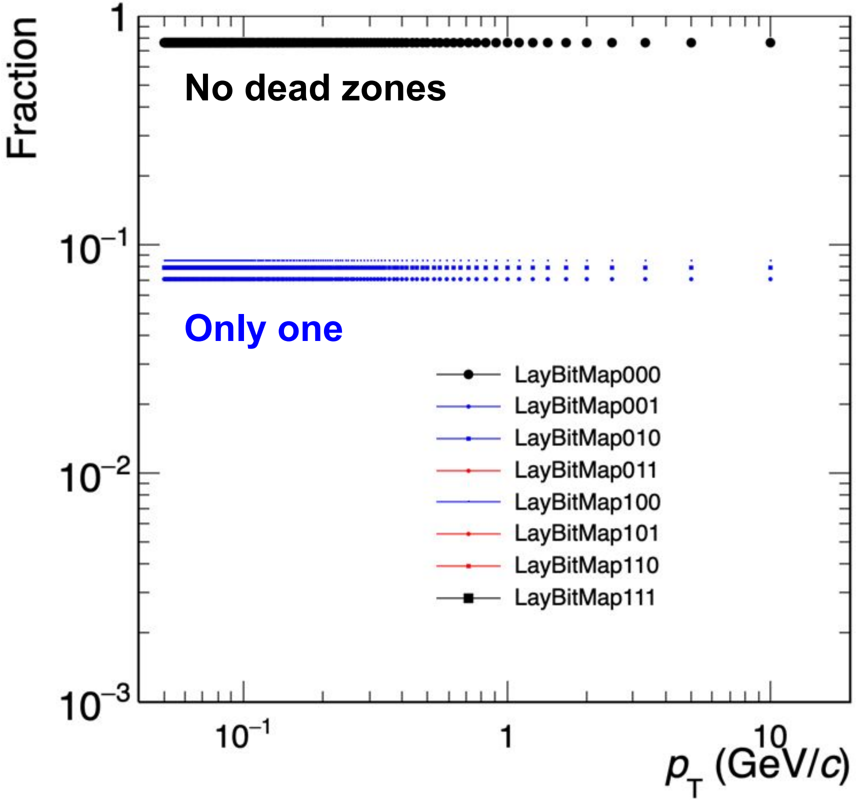
**No dead zones: ~73%**

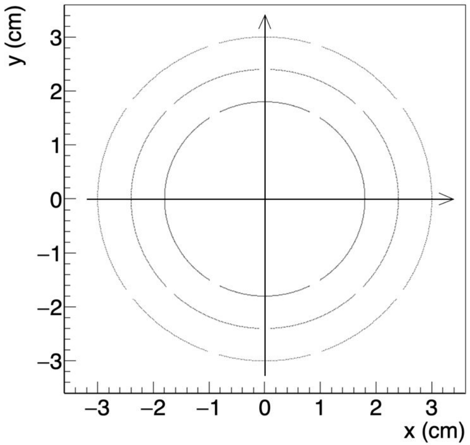
Probability of intersecting **multiple dead zones very small**
← all **from alignment of the dead zones at φ = 0, π**

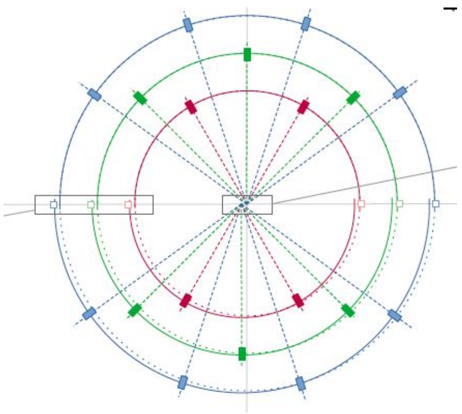
**Other intersections geometrically impossible** for primary particles and PV in (0,0)

- N.B. track radius = 33 [10] cm at 50 [15] MeV/c

# Probability of intersecting dead zones



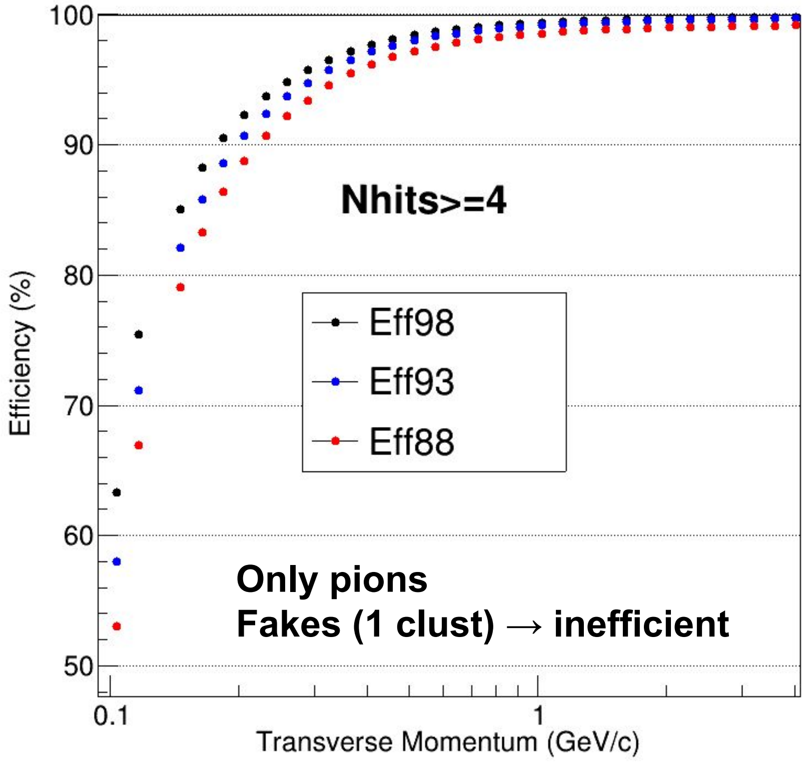



**Confirmed by removing dead zones at φ = 0, π**

- possible scenario (overlaps of hemi-cylinders)
- **dead-area per layer: 7.2% (innermost), 7.8%, 8.8%**
- No dead-zones: 76% probability

# Impact on efficiency for randomly distributed dead zones




**Ongoing studies with Fast Analytic Tool (FAT)**

- extensively used for past performance studies (ITS2,3 LoI, TDR, ALICE3 LoI)
- useful for quickly getting a **first idea and for exploring multiple options**

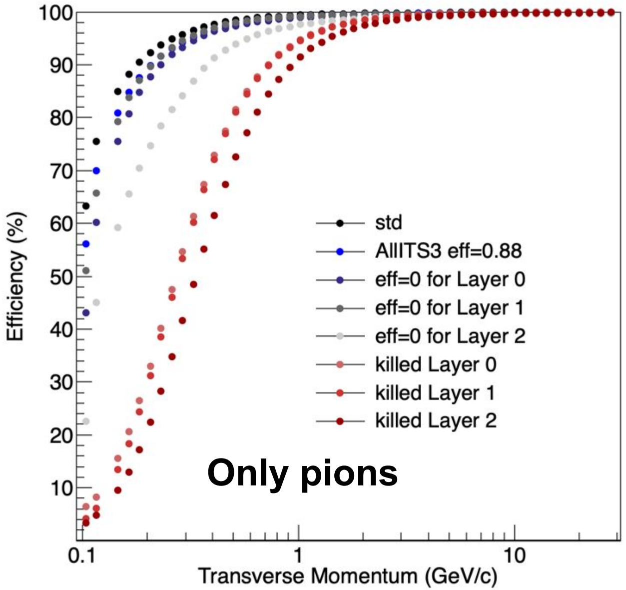
Crosscheck with full simulation needed for final assessment, also to assess effect using the actual tracking algorithm.

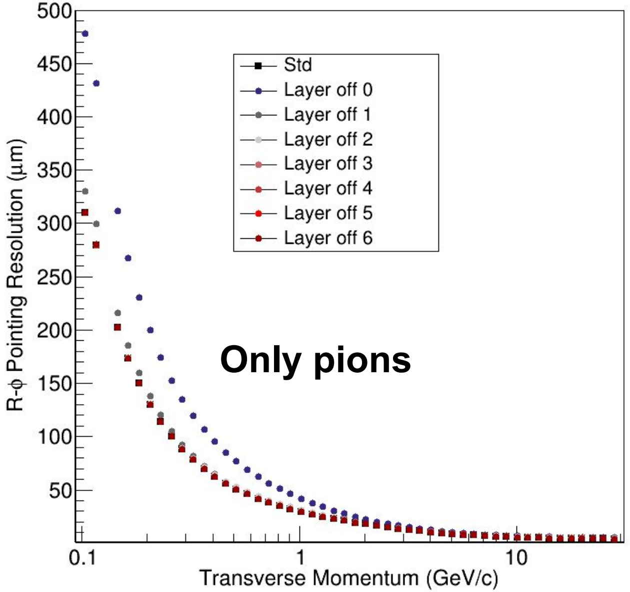
N.B. ACTS (P. Larionov yesterday) could also be considered.

**Test change of efficiency for all 7 layers (default: 98%)**

- inefficiency randomly distributed in space (no patterns)
- Close to (worse than) case in which probability that a track passes through dead-zones in multiple layers is zero
- With 10% reduction of layer efficiency:
  - **~4% additional inefficiency at 300 MeV/c**
  - **~1% additional inefficiency for $p_T$>1 GeV/c**

# Study impact of missing a point in a given layer with FAT




**Caveat**: two possible options in FAT

1) Kill layer → eff=0 for signals and no background (layer = material budget)
2) Eff=0 for signal only, background present

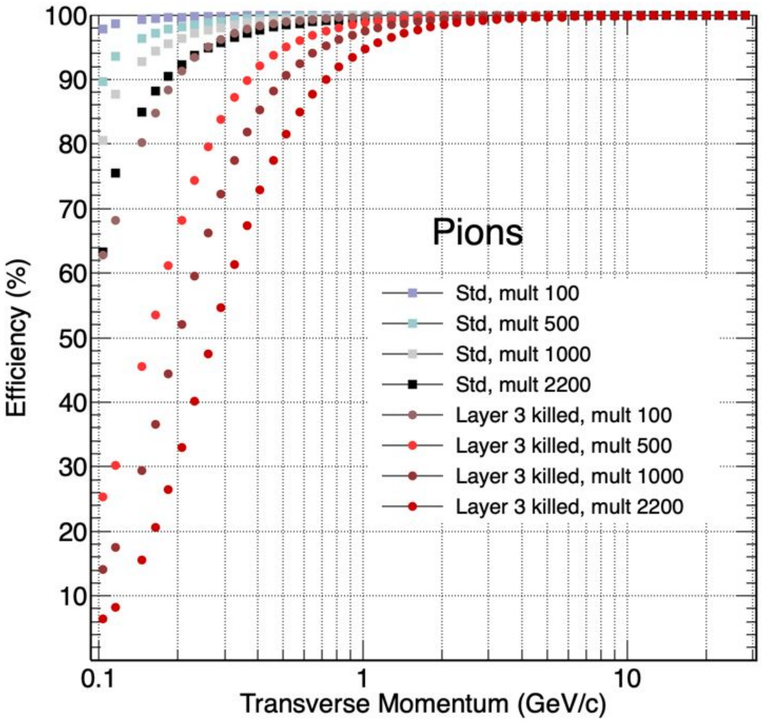
Expected case 2) to provide lower values, differently to what we obtain → **checking with Ruben (thanks!)**

**Case 1) (worst case) used in what follows just as a temporary working point**

**Efficiency: main effect from outer IB alyer**

**DCA**: as expected main effect from removing innermost layer (n.b. no fakes!)

# Cause behind loss of efficiency



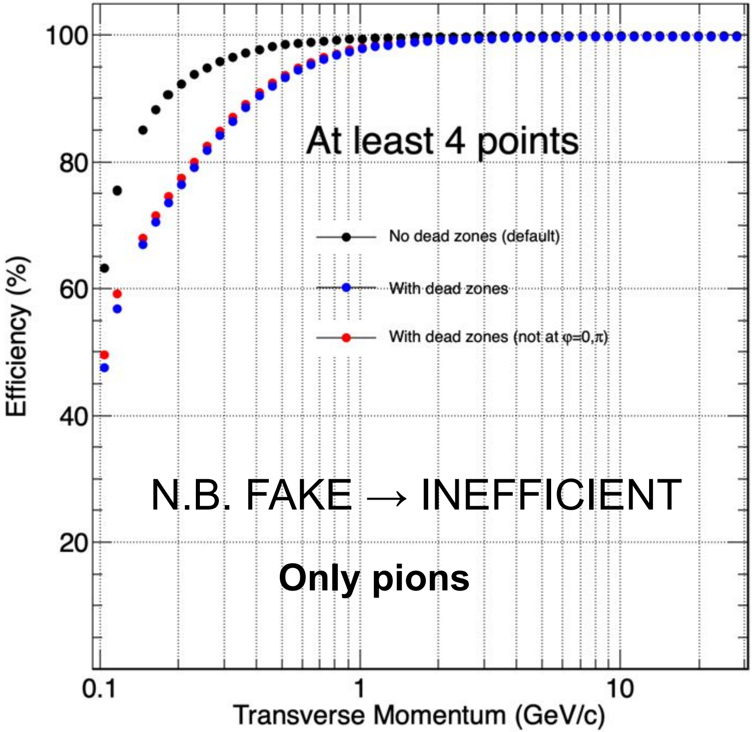

Tracks with 1 fake hit not counted as reconstructed

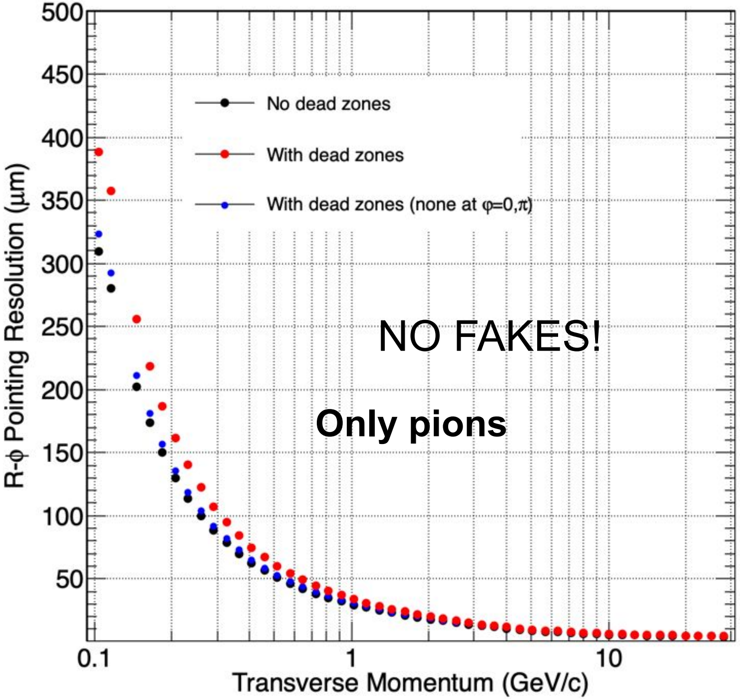
**Inefficiency shown derives from fake track-hit associations**

→ Assuming track with fake hit is lost as worst-case estimate
(further caveats listed in backup)

# Reweighting FAT efficiencies with dead-zone probabilities

Work in progress




Worse than what obtained with 10% randomly-distributed efficiency reduction in all layers.

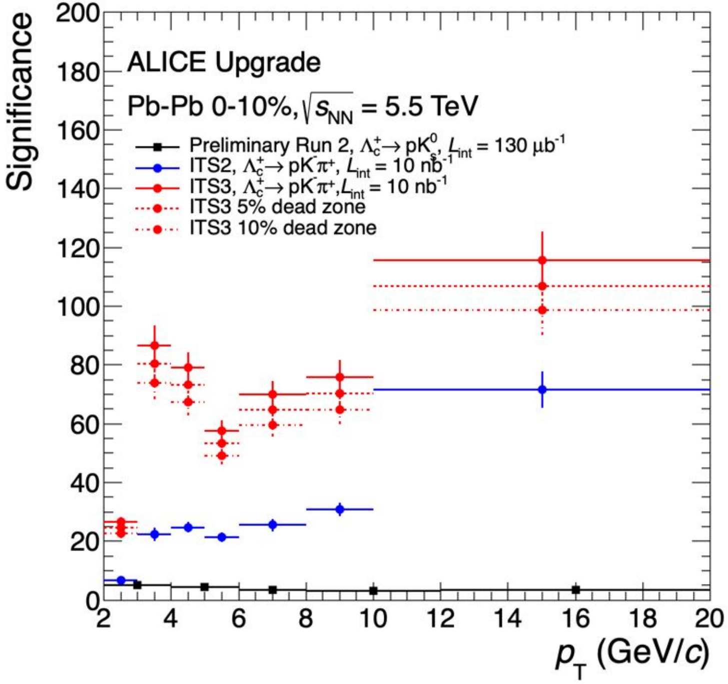
- about 10% additional inefficiency at 300 MeV/c, small effect for $p_T$>1 GeV/c

Larger effect for kaons and protons (see backup).

# Propagation to final observables: HF decays

Inefficiency → decrease signal and background
Missing point on innermost layer: worsen resolution

Worst-case scenario: consider inefficiency + rejection of tracks with missing point on 1st layer
N.B. one can keep tracks w/o e.g. 1st point if there is a gain




$$\mathcal{S} = \frac{S}{\sqrt{S+B}}$$

$$\mathcal{S}' = \frac{\epsilon^{nprong} S}{\sqrt{\epsilon^{nprong} S + \epsilon^{nprong} B}} = \sqrt{\epsilon^{nprong}}\,\mathcal{S}$$

where ϵ is the ratio track efficiency in the cases w/ and w/o dead zones
Values tested: 95% and 90%, flat in $p_T$
(n.b. for HF never all tracks below 300-400 MeV/c even if a 3-prong decay involved)

→ larger impact on signals involving many tracks
**3 prong**, e.g. Lc->pKpi: significance reduced by 7-15%

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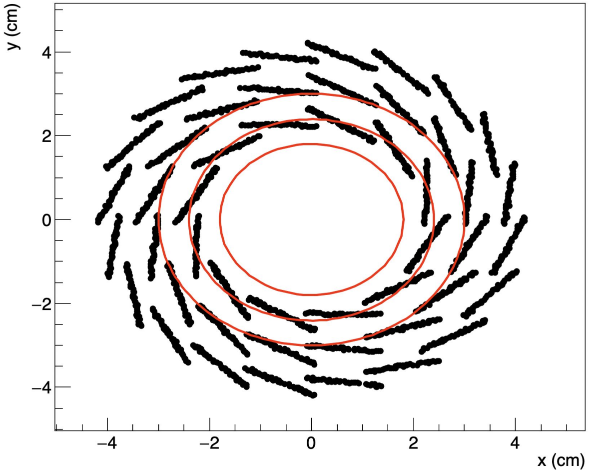
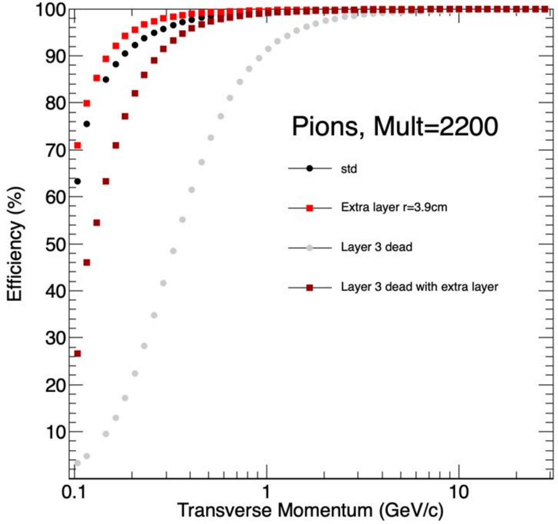
# Example: fitting ITS3 inside the outermost ITS2 IB layer

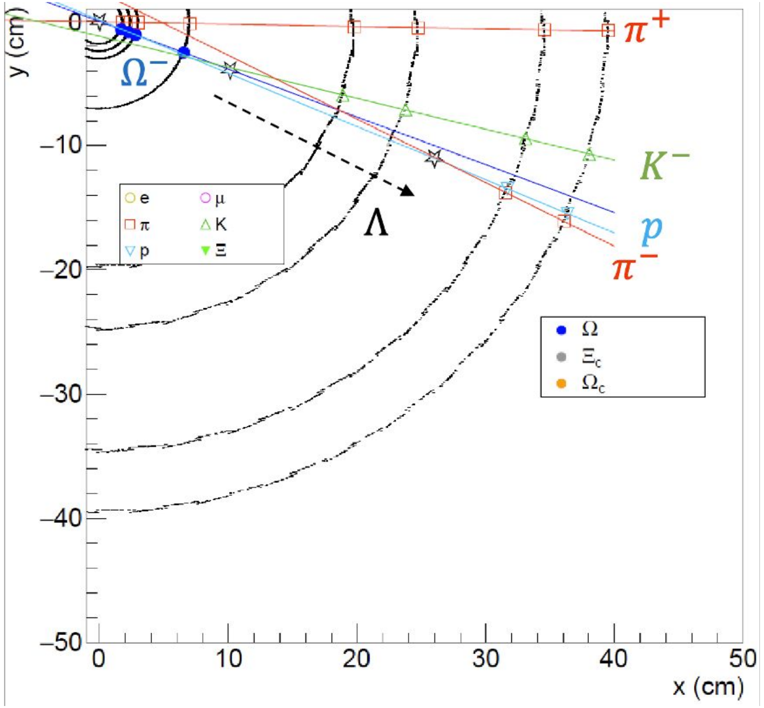
Option explored (just as an example) for first studies on strangeness tracking




- Advantages:
  - Improve matching between innermost outer barrel and outermost inner barrel layer
  - Effect of dead zones gets further reduced (requiring 3 out of 4 possible hits).
  - Positive impact on strangeness tracking: larger lever arm for tracklet and easier combinatorics.
- Disadvantages:
  - More material
  - The overall ITS3 project becomes more complex

# Extra layer & strangeness tracking




Strangeness tracking could boost performance of charm baryons heavier than $\Lambda_c^+$, already with ITS3

… years before starting of ALICE3!

Physics channels with larger sensitivity to detector layouts

Only first studies done so far (M. Faggin, E. Ganoti, D. Chinellato) on charm baryons and mini-kinks

**Effort needs to be revived (and people needed)**

→ Work on algorithm

→ Full performance study with full simulation

→ Explore different layouts

# Summary

Started to address important open points in view of TDR

- n.b. not discussed: ITS3 alignment (impact of global deformations, “weak modes”, how to implement them in simulation)

Main next step: get the full simulation chain working

**People needed on each topic! W/o additional person power very hard to complete all studies.**

Many of the studies we need to do are ideal for students:

- work for a new detector based on a conceptually new design
- think about basic problems
- sometimes rough calculations/simulations required → learn a lot!
  … more than working on an “established” analysis
- strangeness tracking: work since (almost) the beginning on an extremely interesting physics case

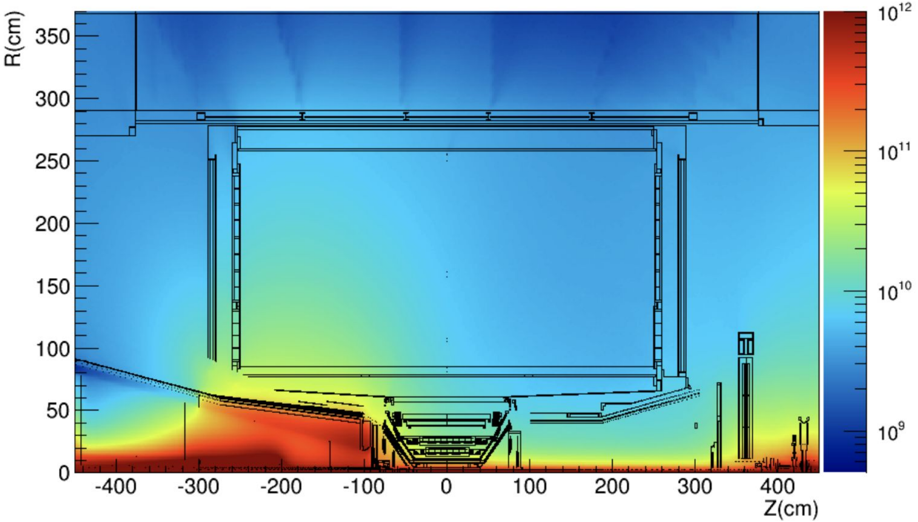
**Golden opportunity for students!**

# Extra

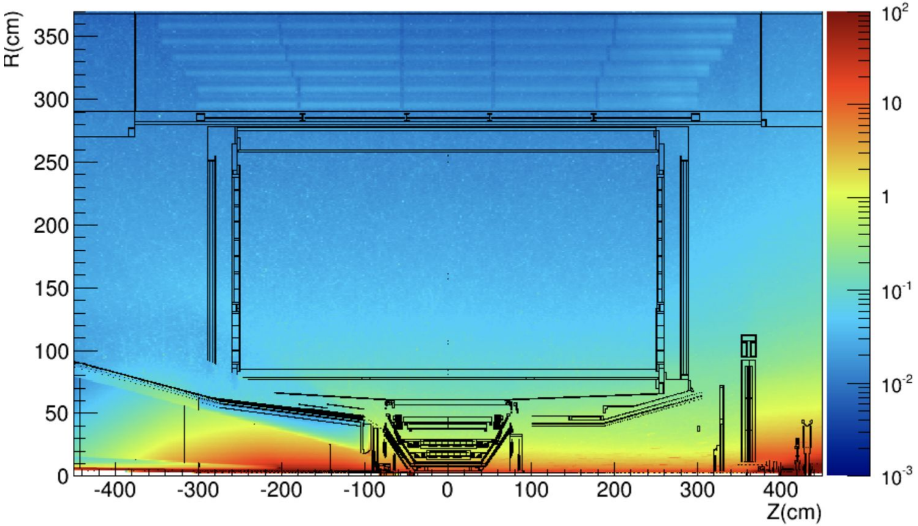
# Radiation load – more detailed studies to be performed

F. Grosa

Radiation load has to be evaluated both for pp/PbPb collisions and for beam-gas interactions as done for Run 2 and 3 estimates (https://alice-notes.web.cern.ch/node/405)

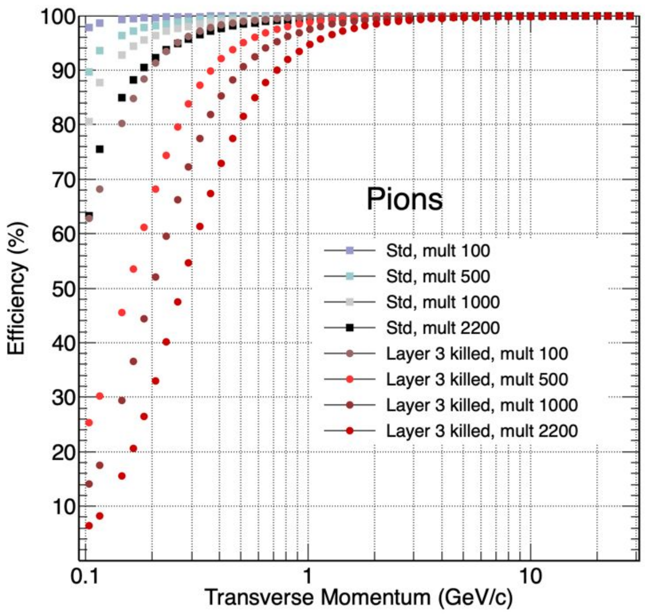



NIEL (1 MeV $n_{eq}$ $cm^{-2}$) for Pb–Pb $L_{int}$=10 $nb^{-1}$




TID (krad) for Pb–Pb $L_{int}$=10 $nb^{-1}$

# Cause behind loss of efficiency, caveats




Tracks with 1 fake hit not counted as reconstructed

**Inefficiency shown derives from fake track-hit associations**

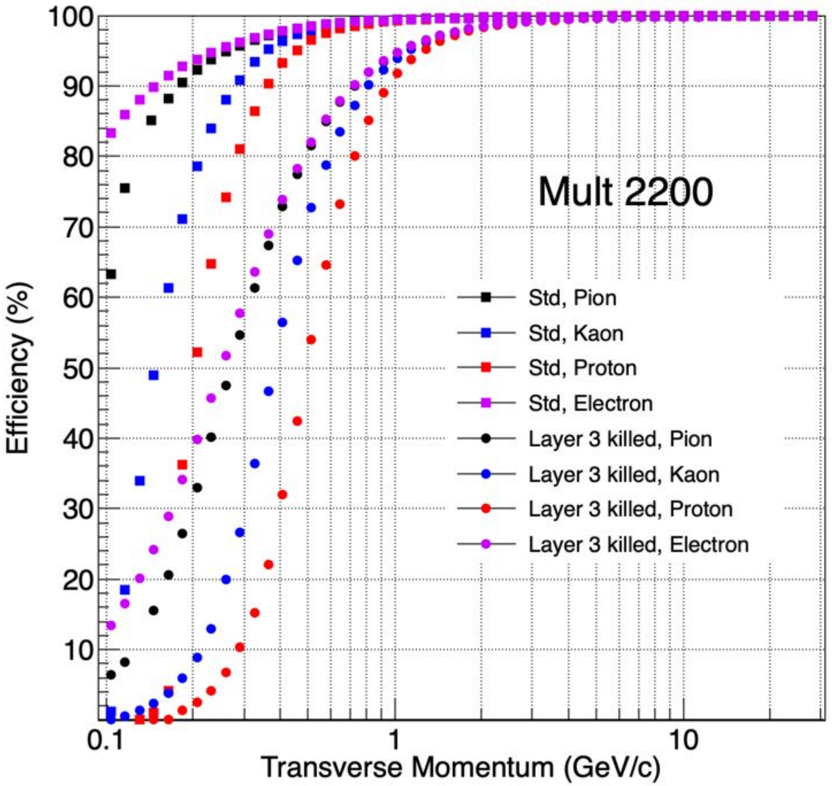
Caveat limiting deeper studies with FAT:

FAT not reliable for calculating the probability of having more than 1 fake-hit association

→ Assuming track with fake hit is lost as worst-case estimate

- but impact of fake-hits on DCA resolution not addressed
- On the other hand, FAT mimics “1 track reconstruction in a hit background”, it does not consider reduction of fake-hit association probability from reconstruction of all event tracks

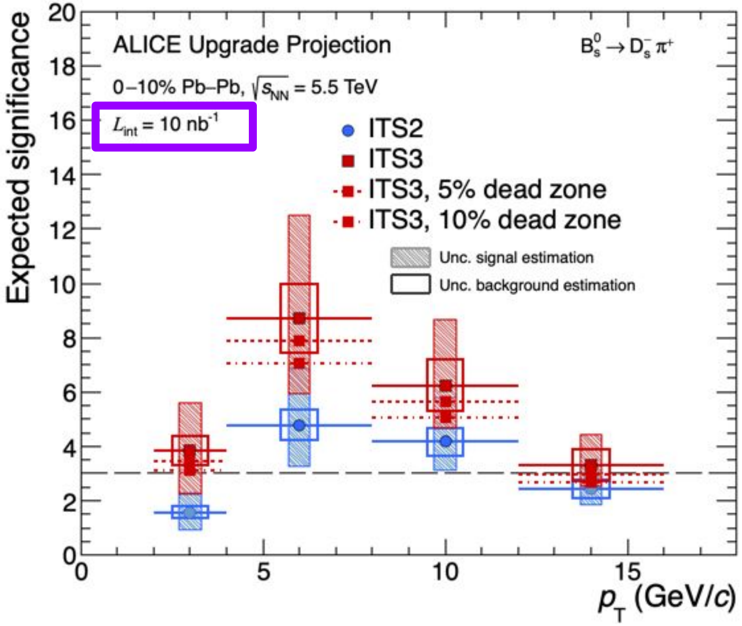
# FAT efficiency for different particle species



# Propagation to final observables: HF decays

Inefficiency → decrease signal and background
Missing point on innermost layer: worsen resolution

Worst-case scenario: consider inefficiency + rejection of tracks with missing point on 1st layer
N.B. one can keep tracks w/o e.g. 1st point if there is a gain




$$\mathcal{S} = \frac{S}{\sqrt{S+B}}$$

$$\mathcal{S}' = \frac{\epsilon^{nprong} S}{\sqrt{\epsilon^{nprong} S + \epsilon^{nprong} B}} = \sqrt{\epsilon^{nprong}}\,\mathcal{S}$$

**4 prong**, e.g. $B_s$->$D_s$( → KK$\pi$)$\pi$: significance reduced by 10-19%, possibly affecting low- $p_T$ reach

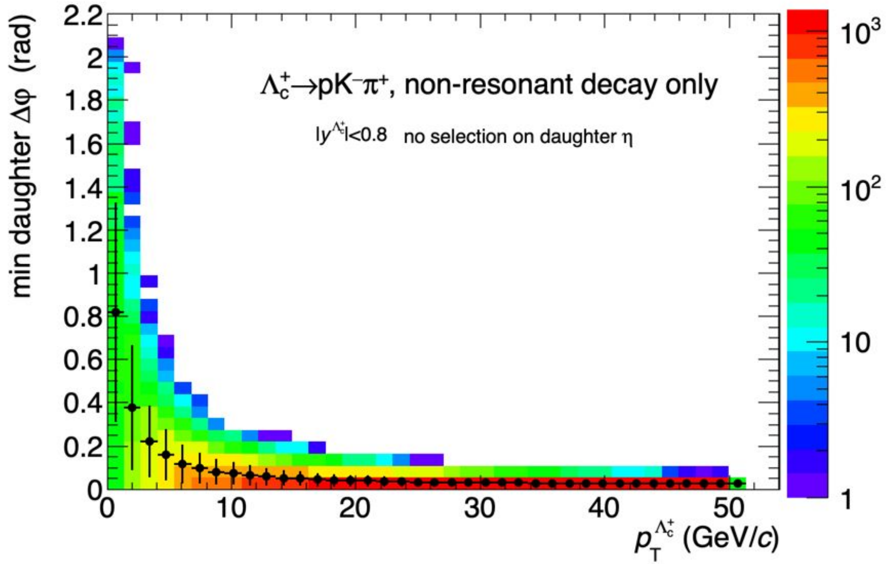
Note that $\epsilon^4$ varies from 92% to 60%, with $\epsilon$ decreasing from 98% to 88%

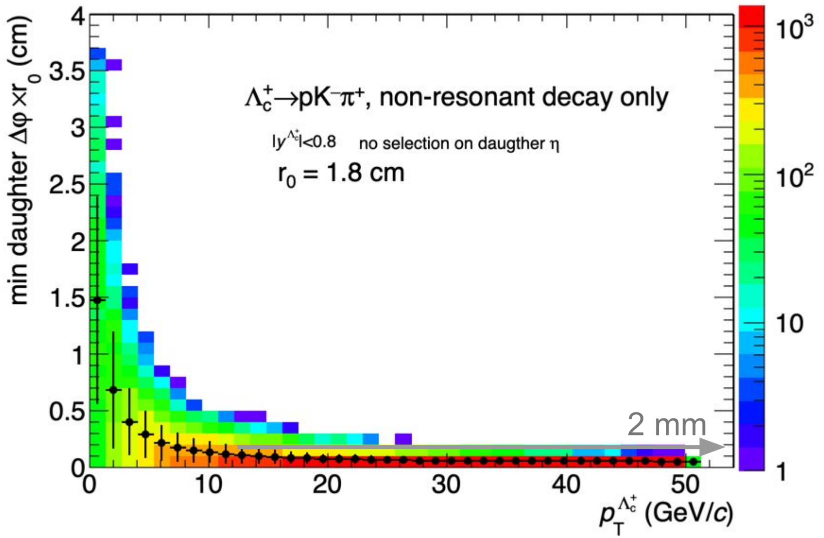
Different type of sensitivity for:

- $D^{*+}$, $\Sigma_c$ (soft pions)
- dielectrons
- Strangeness tracking
- jets, correlations

# Angular spread of decay particles

What is the probability that at least two daughters pass through the same dead-zone?




Not that small, very high for pt>10 GeV/c

Collimation from boost reduces the impact of dead zones for multi-prong channels

Independent angles limit (no collimation)

$$\mathcal{S}' = \frac{\epsilon^{nprong} S}{\sqrt{\epsilon^{nprong} S + \epsilon^{nprong} B}} = \sqrt{\epsilon^{nprong}}\,\mathcal{S}$$

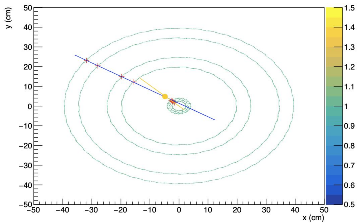
→ **worst case (valid only at $p_T$=0)**

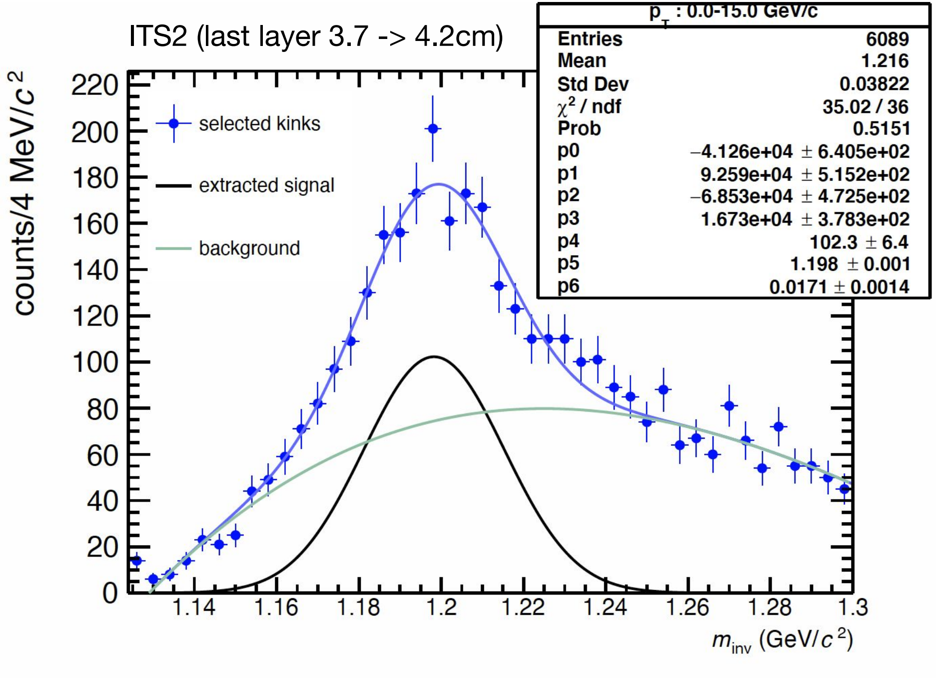
Full collimation limit (assuming B scales as S)

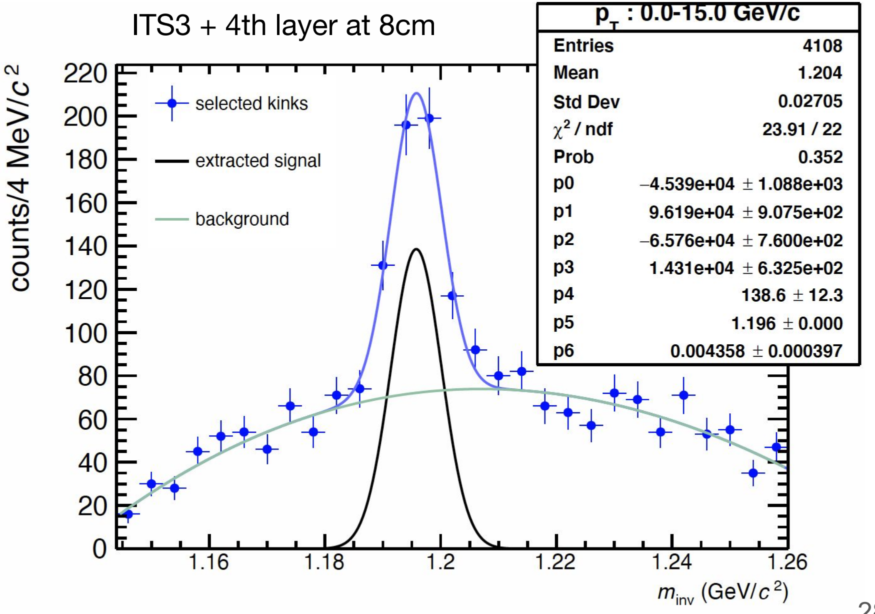
$$\mathcal{S}' \approx \sqrt{\epsilon}\,\mathcal{S}$$

# Strangeness tracking: adding a 4th layer at 8cm

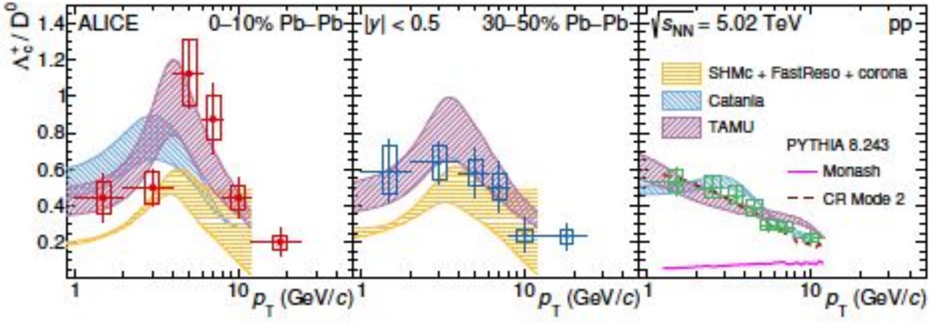
$$\Sigma^+ \rightarrow n\,\pi^+$$

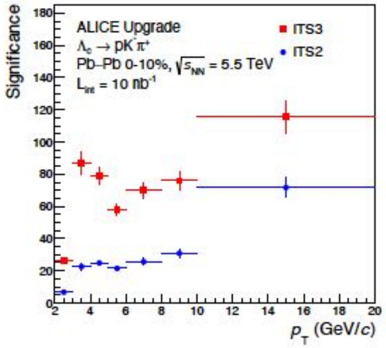


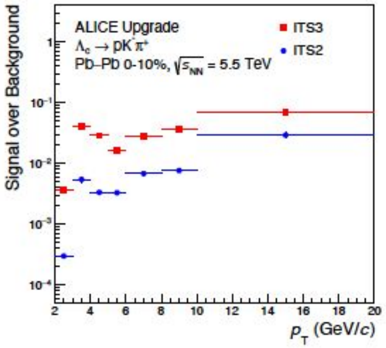


# Open points, predictions/assumptions used: $\Lambda_c^+$



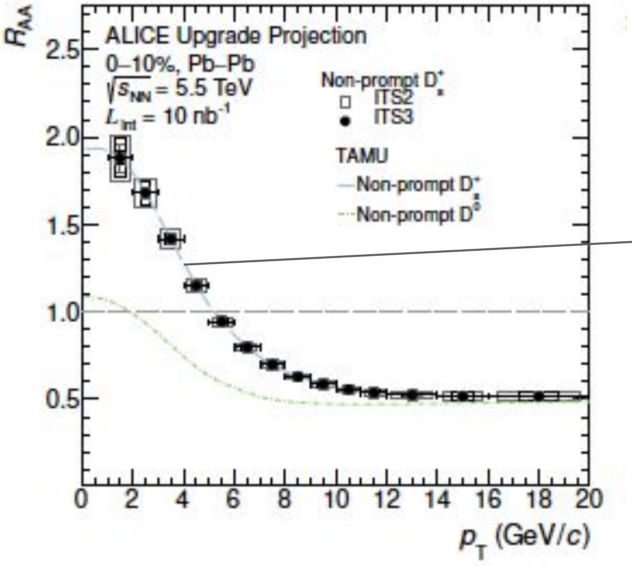



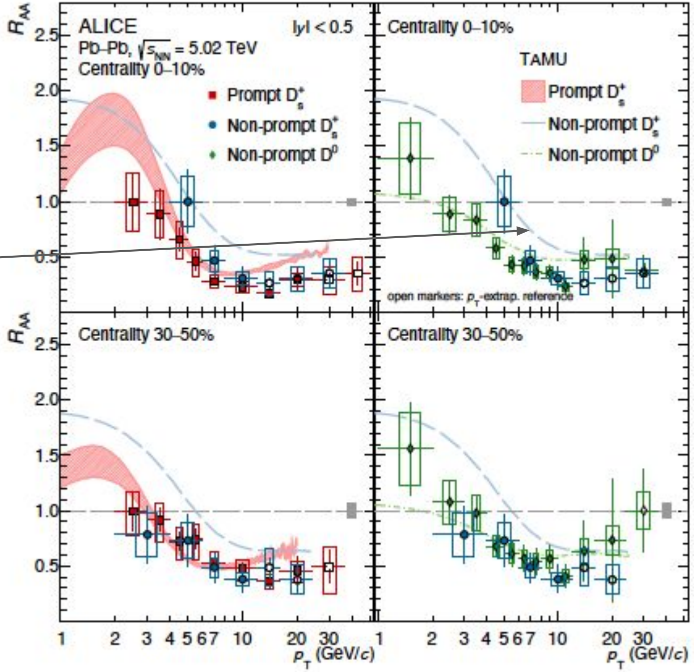




of events corresponding to the target integrated luminosity. Specifically, in the $\Lambda_c^+$ case, the same assumptions done for the ITS2 TDR [2]. The $p_T$-integrated yield was calculated by scaling the FONLL [88] cross section of $c\bar{c}$ production by the branching fraction $c \to \Lambda_c^+$ obtained from the PYTHIA6 [9] event generator and by the average nuclear overlap function, $\langle T_{AA} \rangle$, which for 0–10% central Pb–Pb events is 23.07 mb$^{-1}$. This value was used to normalise a $p_T$ shape obtained by modifying the FONLL $dN/dp_T$ of the $D^{*+}$ meson, which has a mass close to that of the $\Lambda_c^+$, by a $R_{AA}$ factor equal to unity for $p_T < 4$ GeV/$c$ and decreasing with $p_T$ down to 0.3 for $p_T > 6$ GeV/$c$. Though these assumptions result in yields lower by up to a factor of about two than those recently measured by ALICE [72] for $p_T < 6$ GeV/$c$, they were kept for consistency with the estimates done for the the ITS2 TDR [2].

We may want to avoid this, but we can also live with that….
We will see how much the results differ (C. Terrevoli) and then decide

# Open points, predictions/assumptions used: $D_s^+$

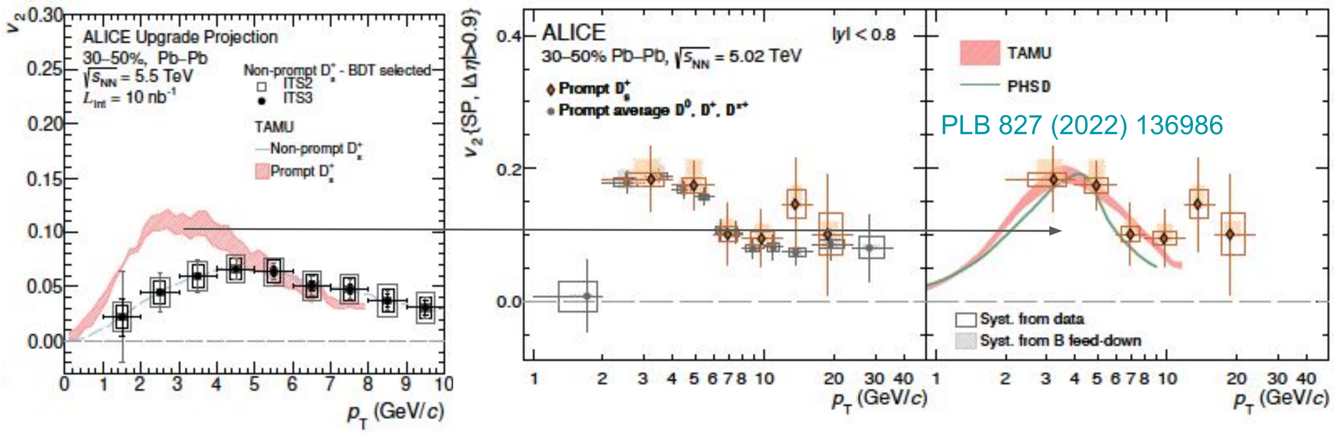


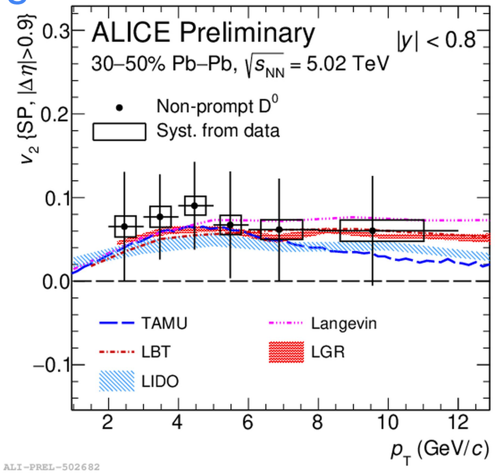

arXiv:2204.10386

$R_{AA}$: TAMU does not catch well non-prompt $D_s^+$ $R_{AA}$ (overestimates it up to a factor of 2 for pt>5 GeV/c)
No big impact on message we want to deliver… we can stay with what we have

# Open points, predictions/assumptions used: $D_s^+$



PLB 827 (2022) 136986



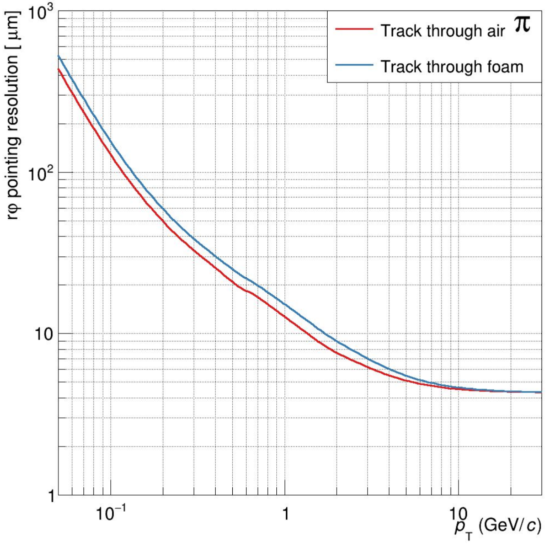

$v_2$: **old TAMU predictions for prompt $D_s^+$** (no space-momentum correlations). Underestimate measured D meson $v_2$ by about a factor of 2 at intermediate pt. We probably should update the figure.
→ **impacts a bit the message we deliver**, since if the difference between prompt and np-D $v_2$ is larger, less experimental precision would be required for observing it. Still **below 3 GeV/c the change is not large**

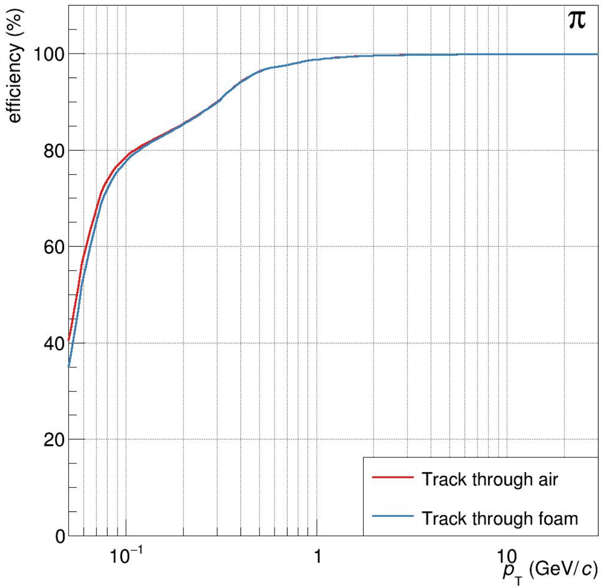
Need to contact again R. Rapp to see whether they have new ones for non-prompt $D_s^+$

- **Non-prompt $v_2$ data a bit higher than TAMU** (and other models) but not a large discrepancy

# Impact of material distribution

→ Last time studied by N. Jacazio (Apr 2021): No significant deterioration of performance expected in simple simulations (fast analytic tool used as input to DELPHES)




→ At most ~20% decrease in performance in point

→ Influence on performance for conversion-rejection (di-leptons) still to be evaluated. However, they mostly originate from the beam-pipe, so only a minor effect is expected.

→ Study to be revived!