Marietta Blau Institute for Particle Physics

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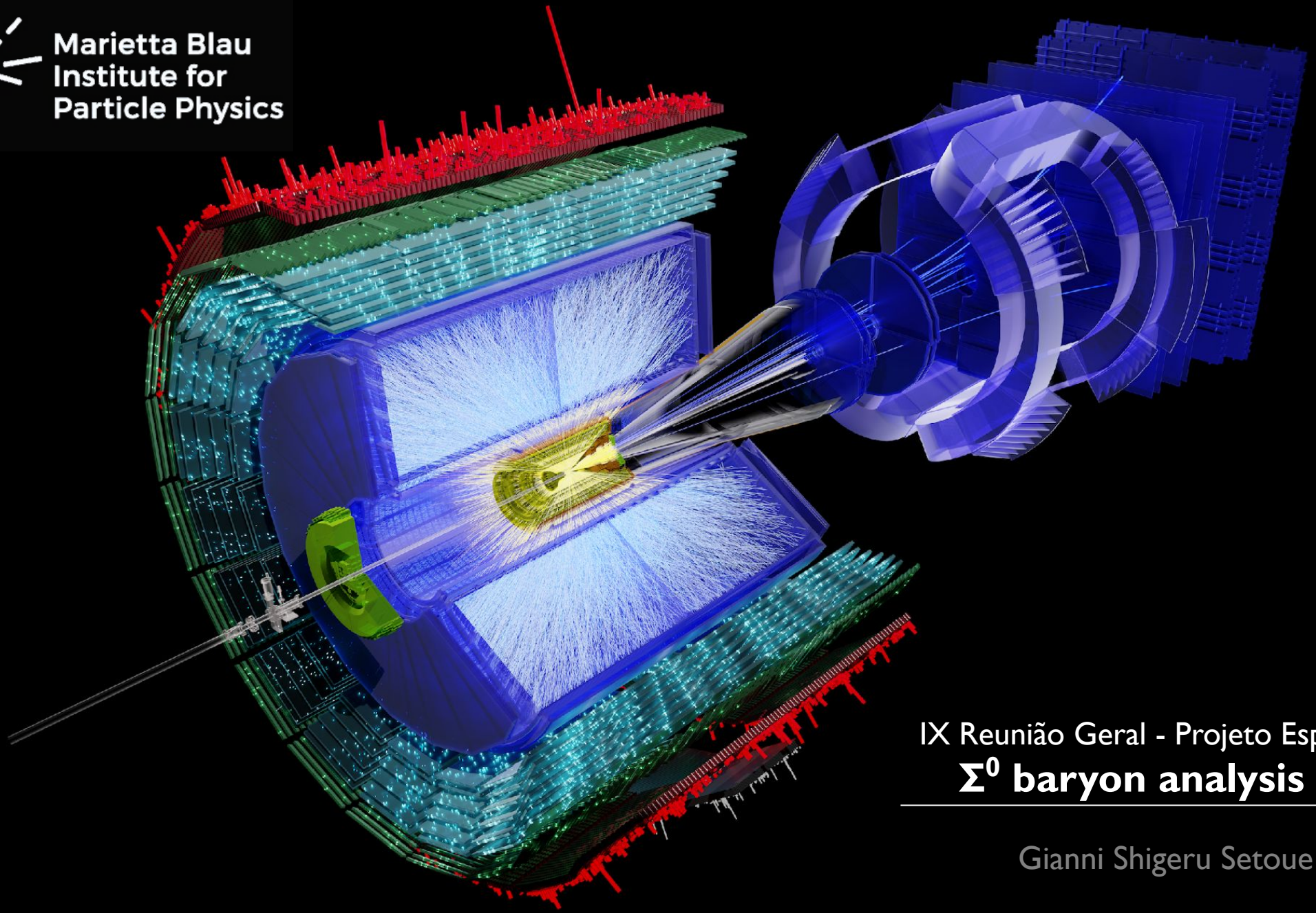


IX Reunião Geral - Projeto Especial FAPESP

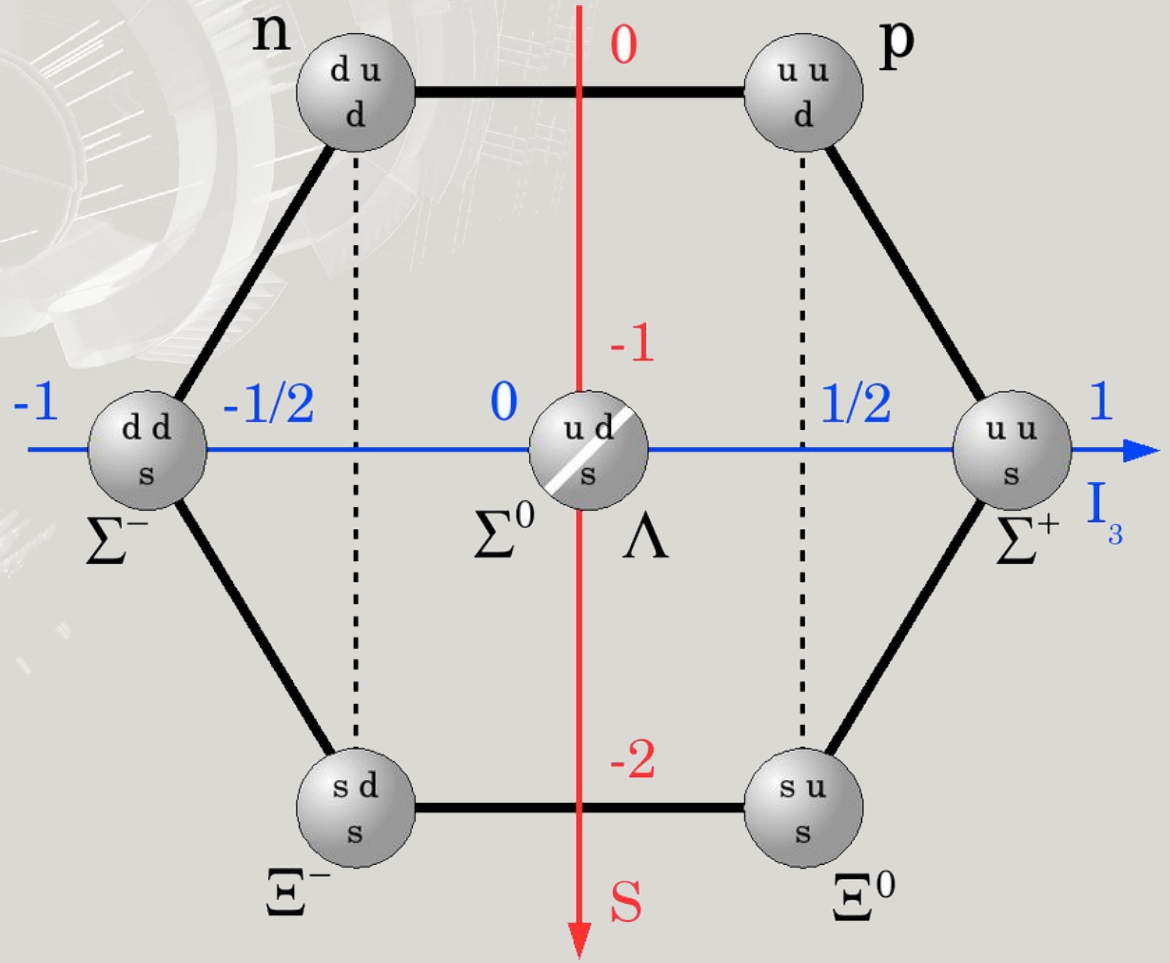
Σ^0 baryon analysis in Run 3

Gianni Shigeru Setoue Liveraro

Motivation

Physics Motivation

- Test of **Isospin symmetry**:
  - Theory predicts: $\Sigma^0/\Lambda = 1/3$



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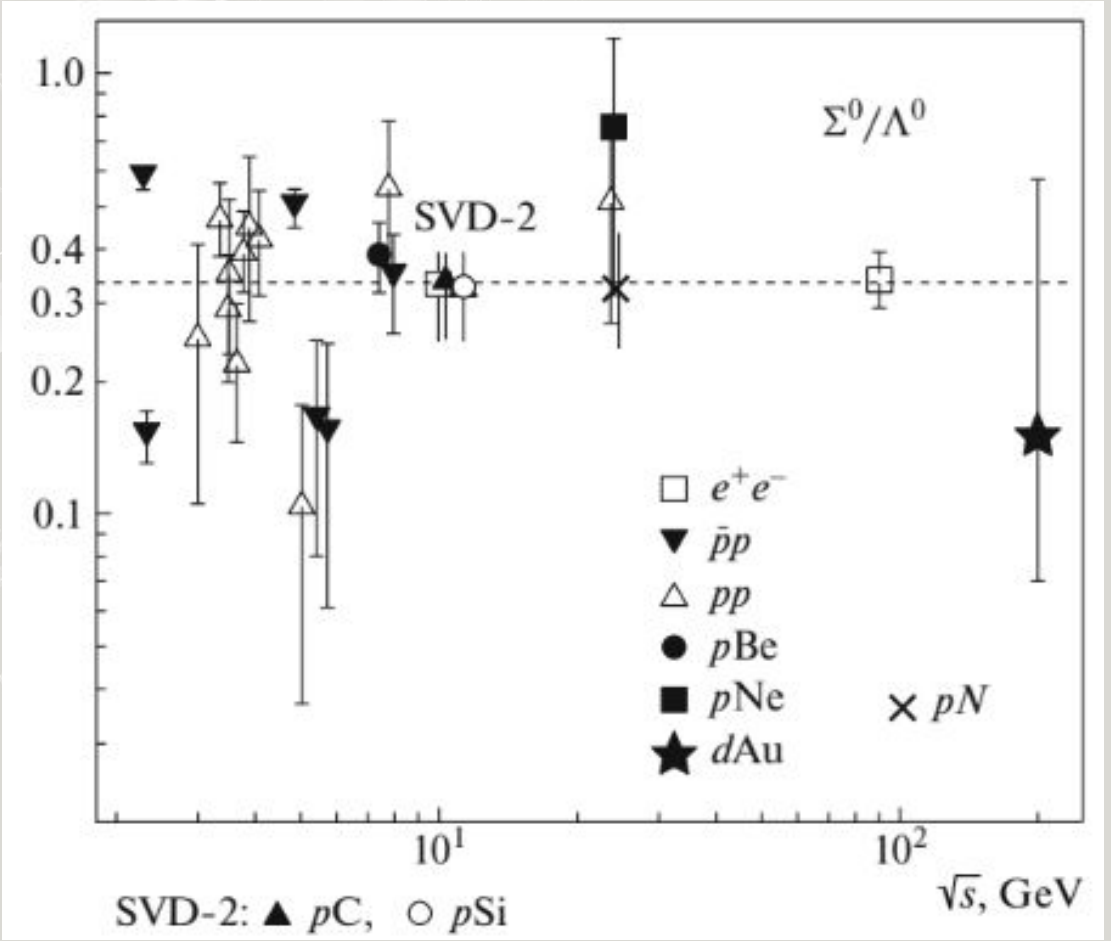

https://link.springer.com/article/10.1134/S1063778821030169

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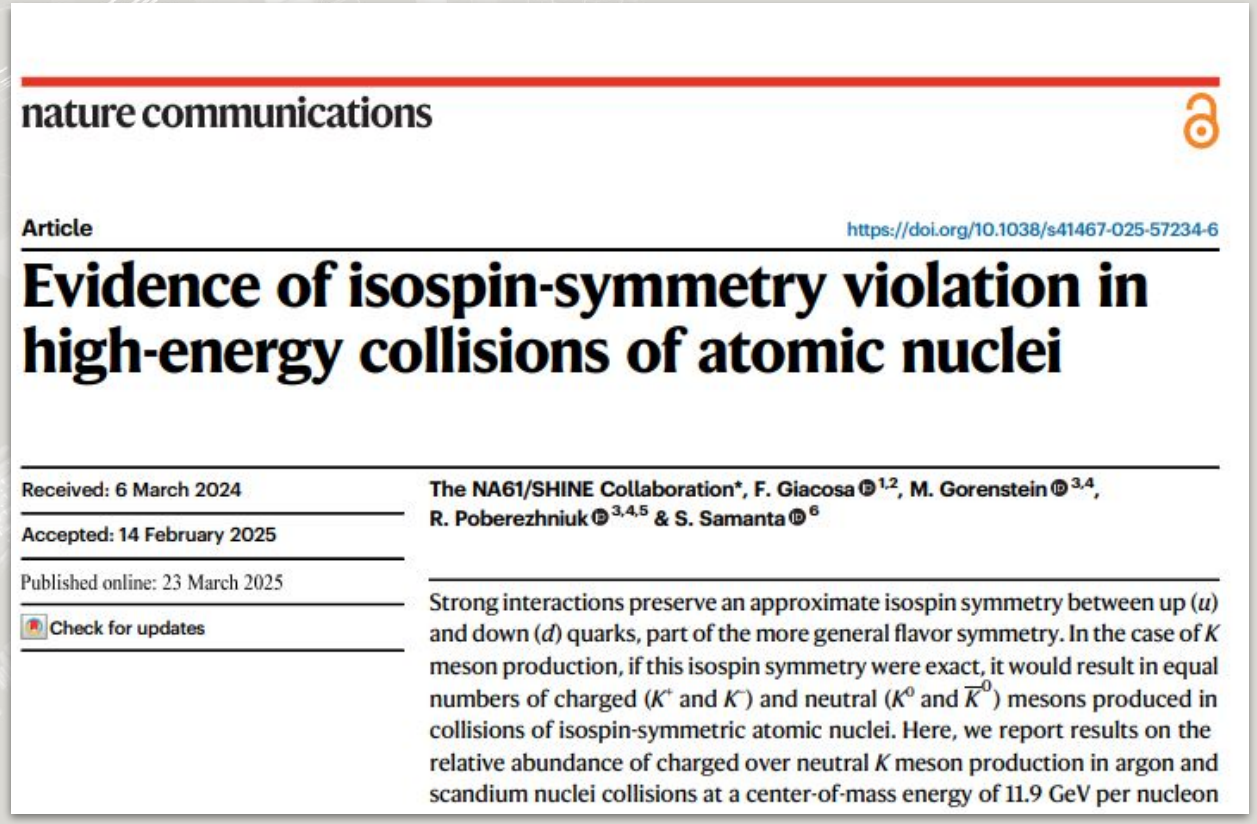

nature communications

Article

https://doi.org/10.1038/s41467-025-57234-6

Evidence of isospin-symmetry violation in high-energy collisions of atomic nuclei

Received: 6 March 2024

Accepted: 14 February 2025

Published online: 23 March 2025

Check for updates

The NA61/SHINE Collaboration*, F. Giacosa[1,2], M. Gorenstein[3,4], R. Poberezhniuk[3,4,5] & S. Samanta[6]

Strong interactions preserve an approximate isospin symmetry between up (u) and down (d) quarks, part of the more general flavor symmetry. In the case of K meson production, if this isospin symmetry were exact, it would result in equal numbers of charged (K^+ and K^-) and neutral (K^0 and $\overline{K}^0$) mesons produced in collisions of isospin-symmetric atomic nuclei. Here, we report results on the relative abundance of charged over neutral K meson production in argon and scandium nuclei collisions at a center-of-mass energy of 11.9 GeV per nucleon

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  - Enables cross-checks with other experiments
- **System-size** effect:
  - Comparing **pp**, **pO**, **OO**, **NeNe**, **pPb** and **PbPb** results could provide insight into the mechanisms driving Σ^0 production

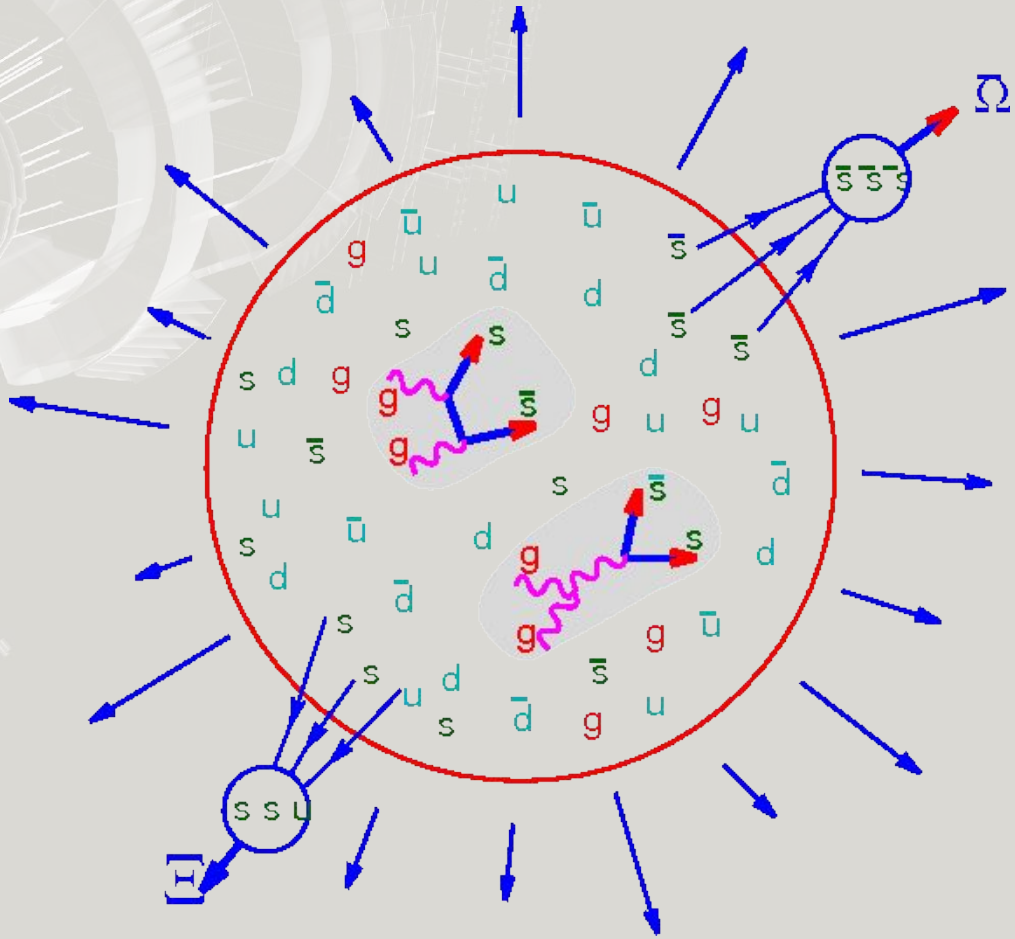

Figure from arXiv:0710.2142

Physics Motivation

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- **Femtoscopy** studies

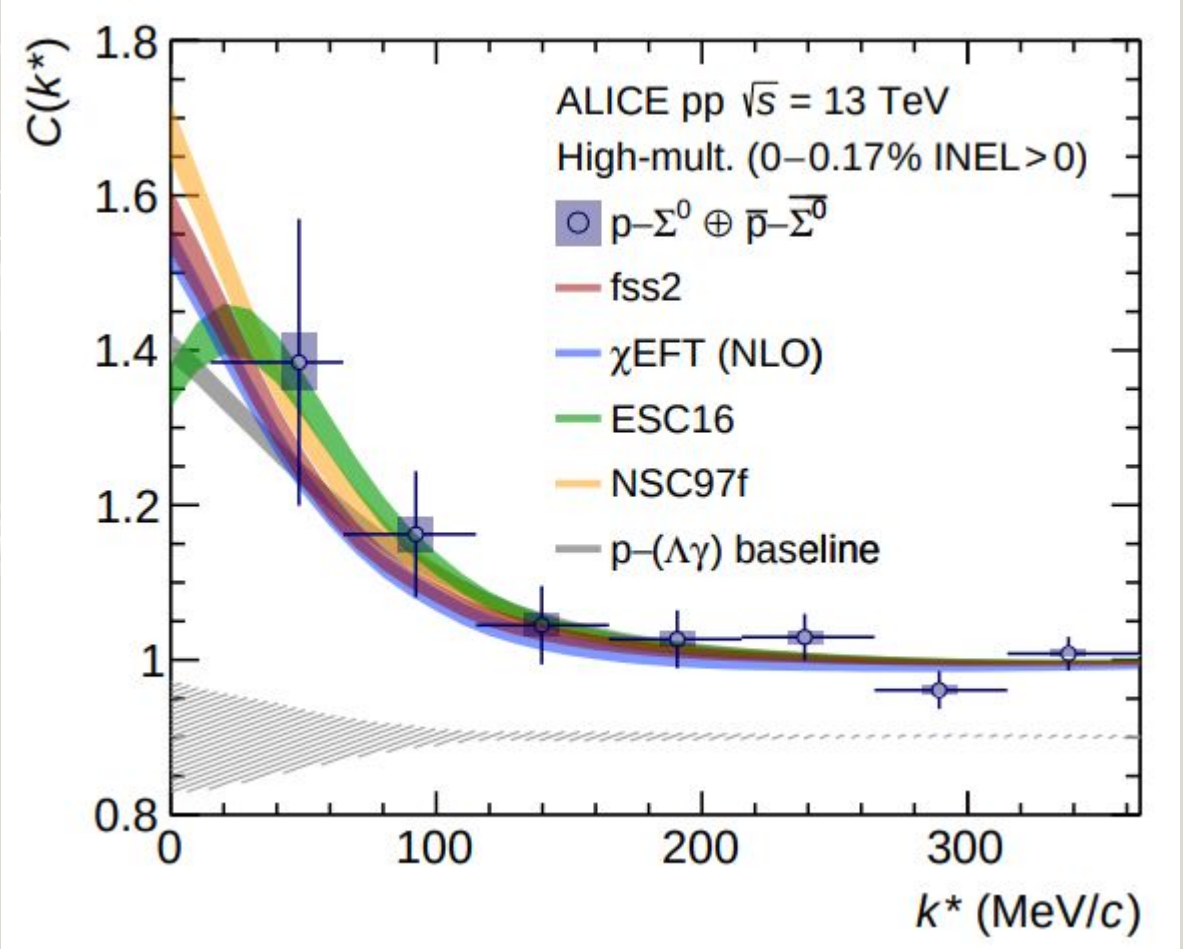
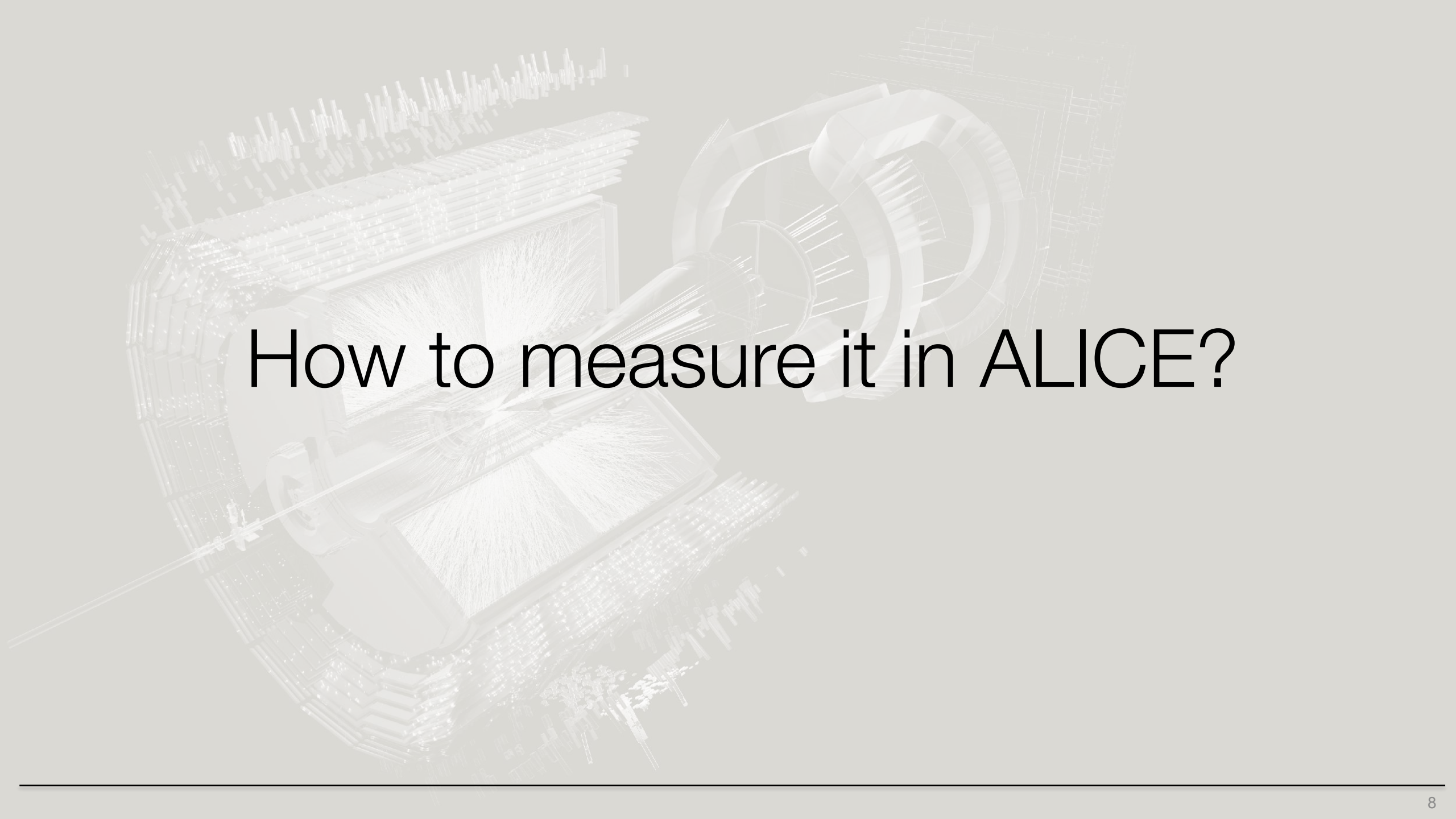


Figure from arXiv:1910.14407



How to measure it in ALICE?

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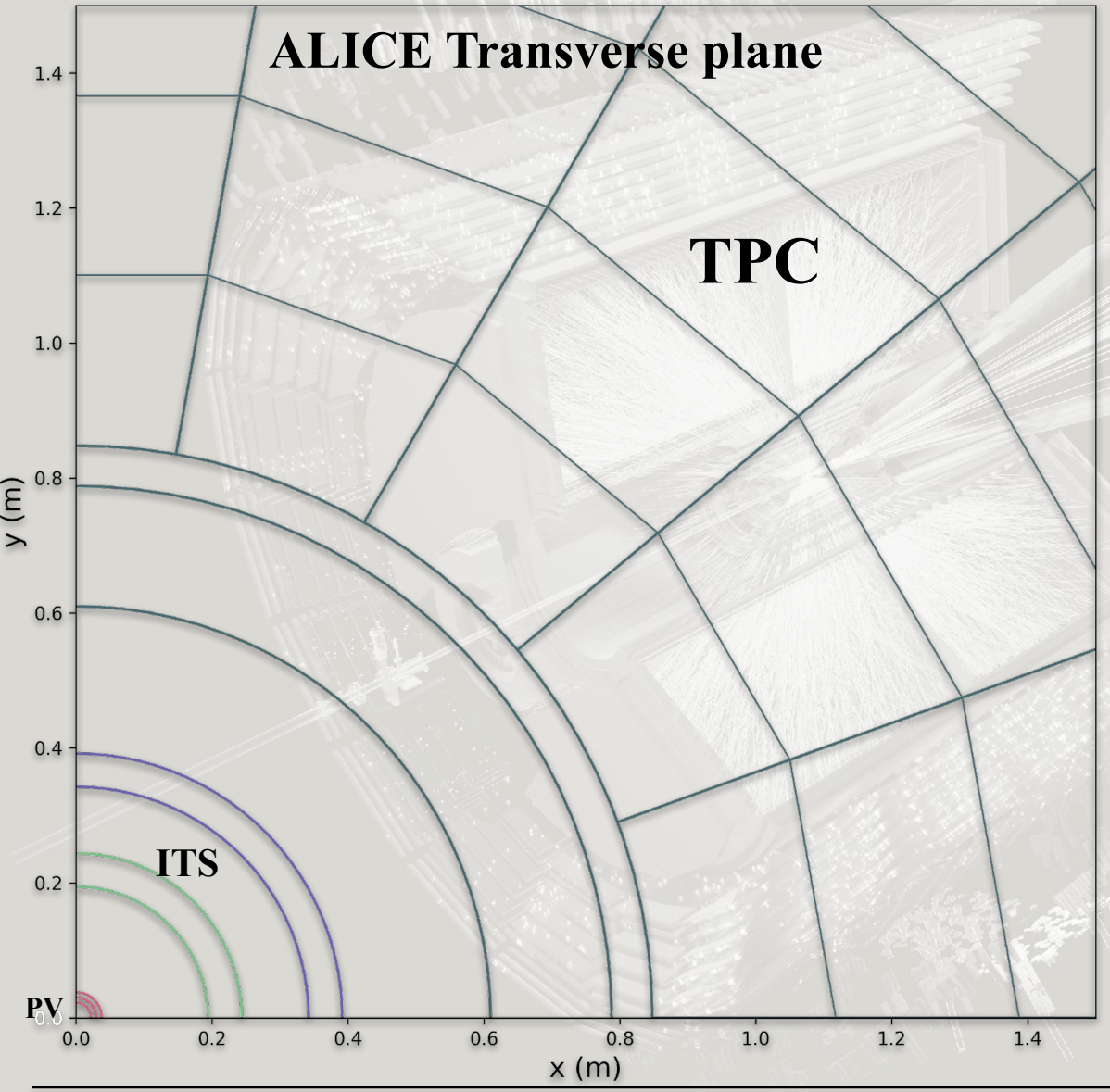


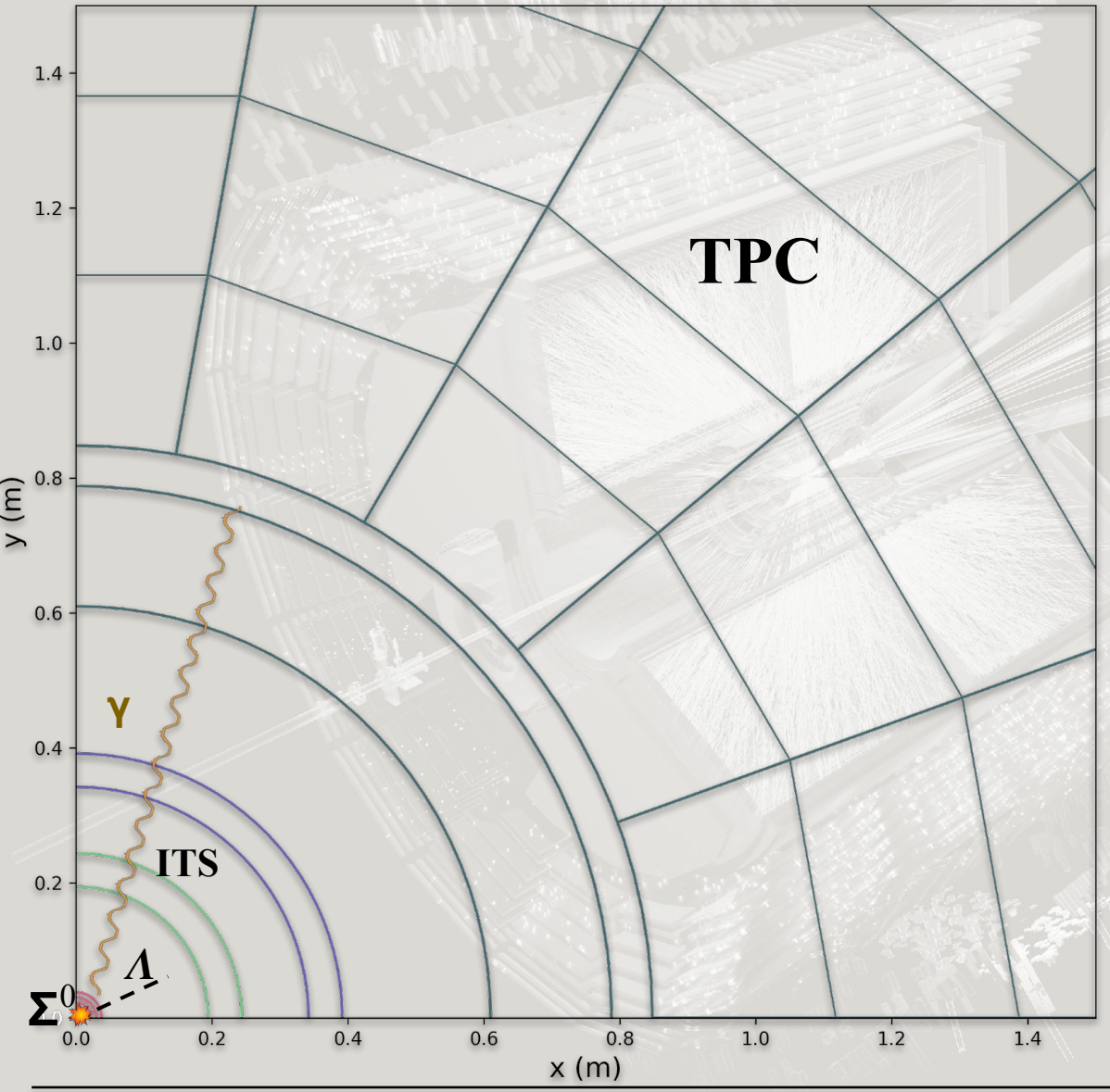
Σ^0 production in the PV

PV: **P**rimary **V**ertex

ITS: **I**nner **T**racking **S**ystem

TPC: **T**ime **P**rojection **C**hamber

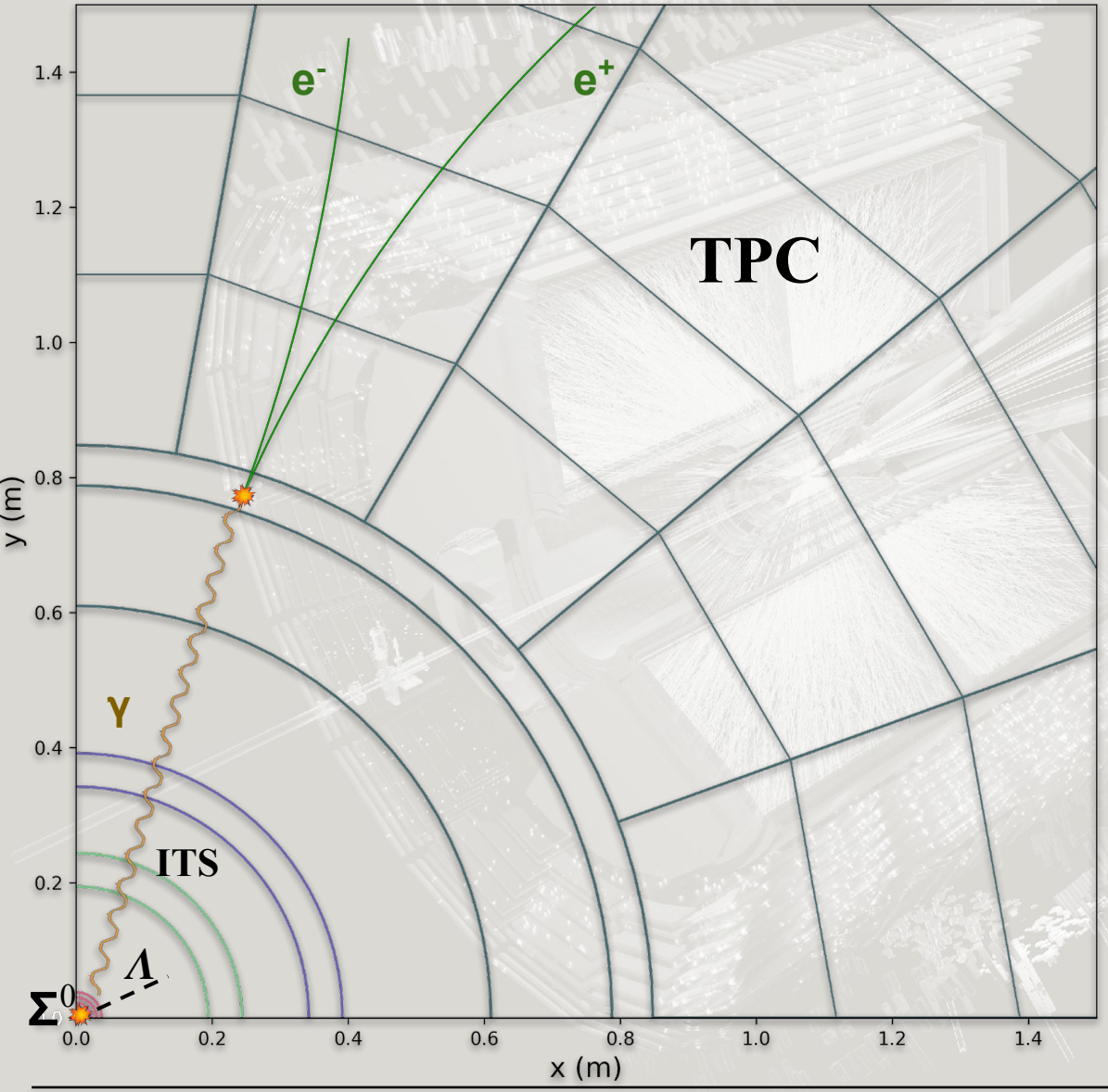
How to measure it in ALICE?



Σ^0 production in the PV

- Decay into $\gamma + \Lambda$

How to measure it in ALICE?



Σ^0 production in the PV

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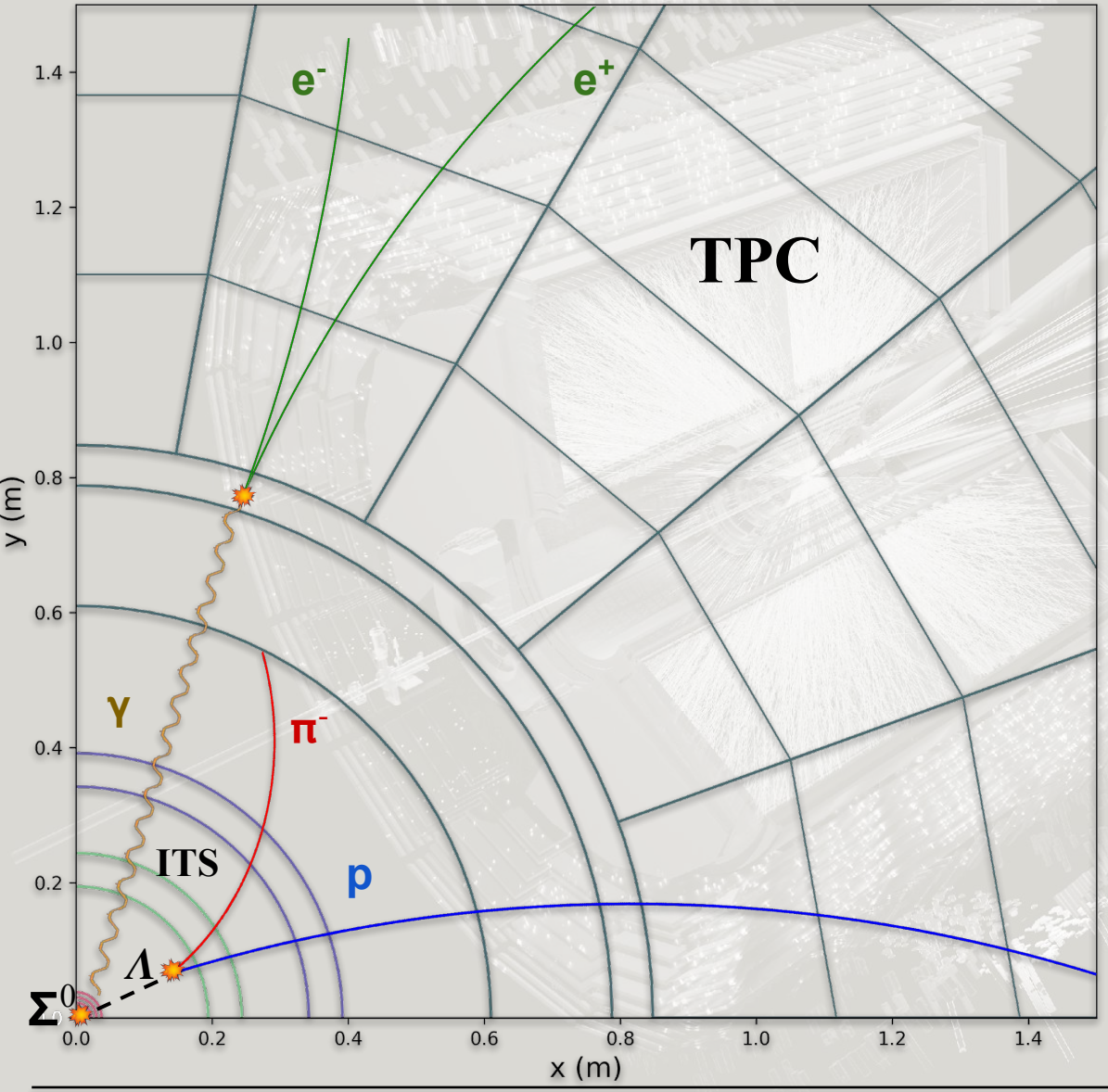
➢ γ : Conversion in detector material ($e^+ + e^-$)

How to measure it in ALICE?



Σ^0 production in the PV

- Decay into $\gamma + \Lambda$

  ➢ γ : Conversion in detector material ($e^+ + e^-$)

  ➢ Λ: Decay into π^- and p

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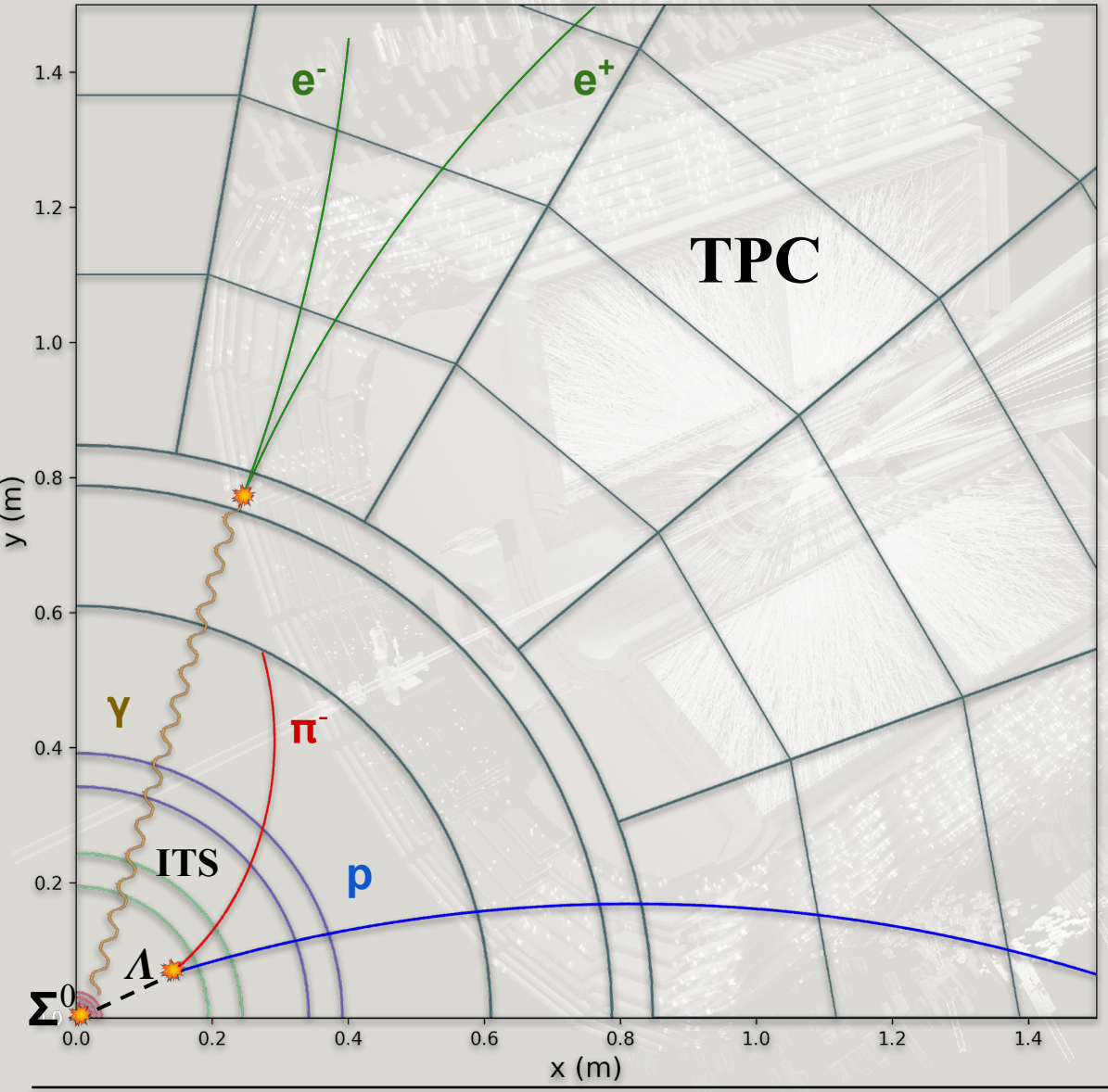

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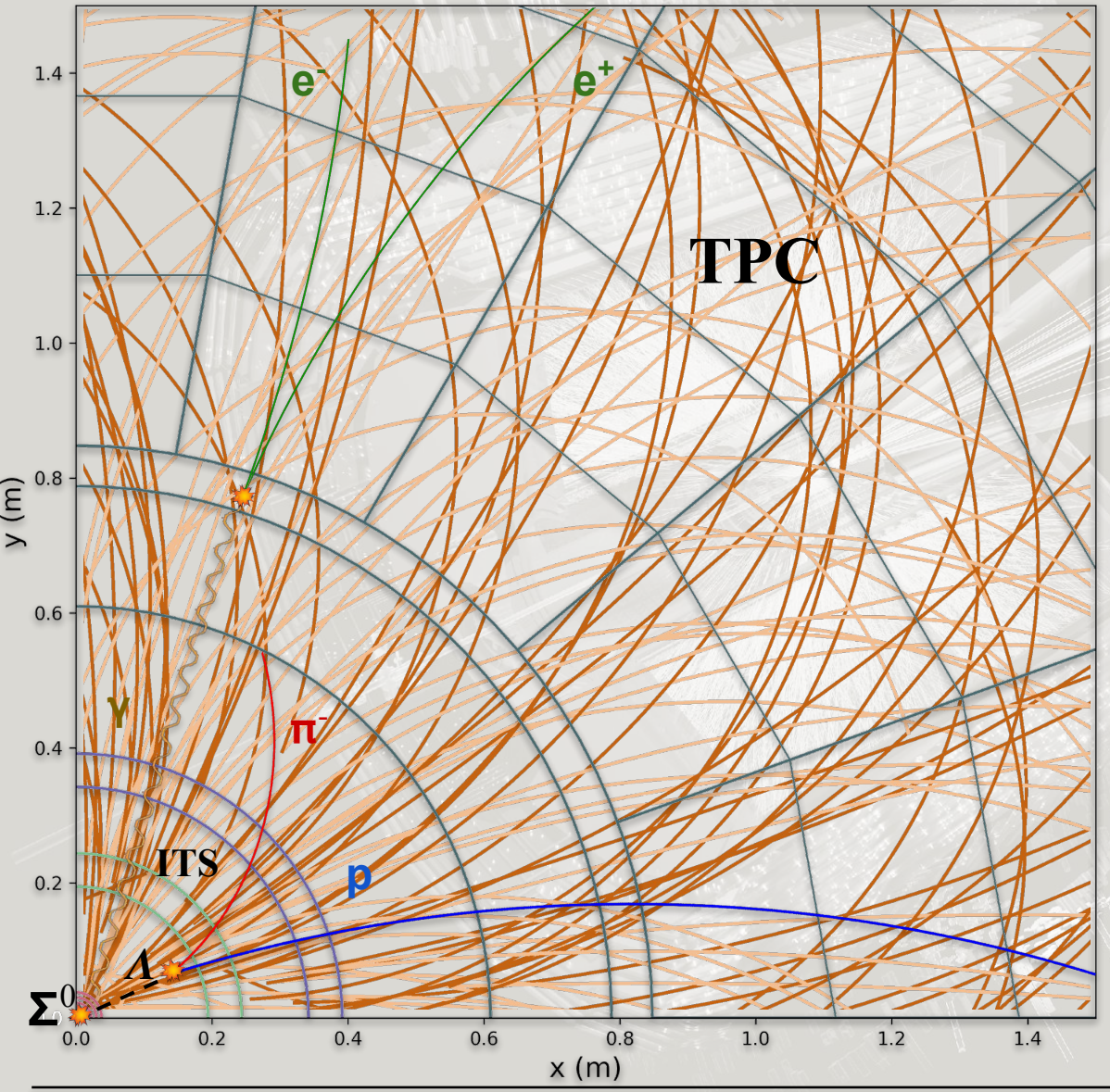


Σ^0 production in the PV

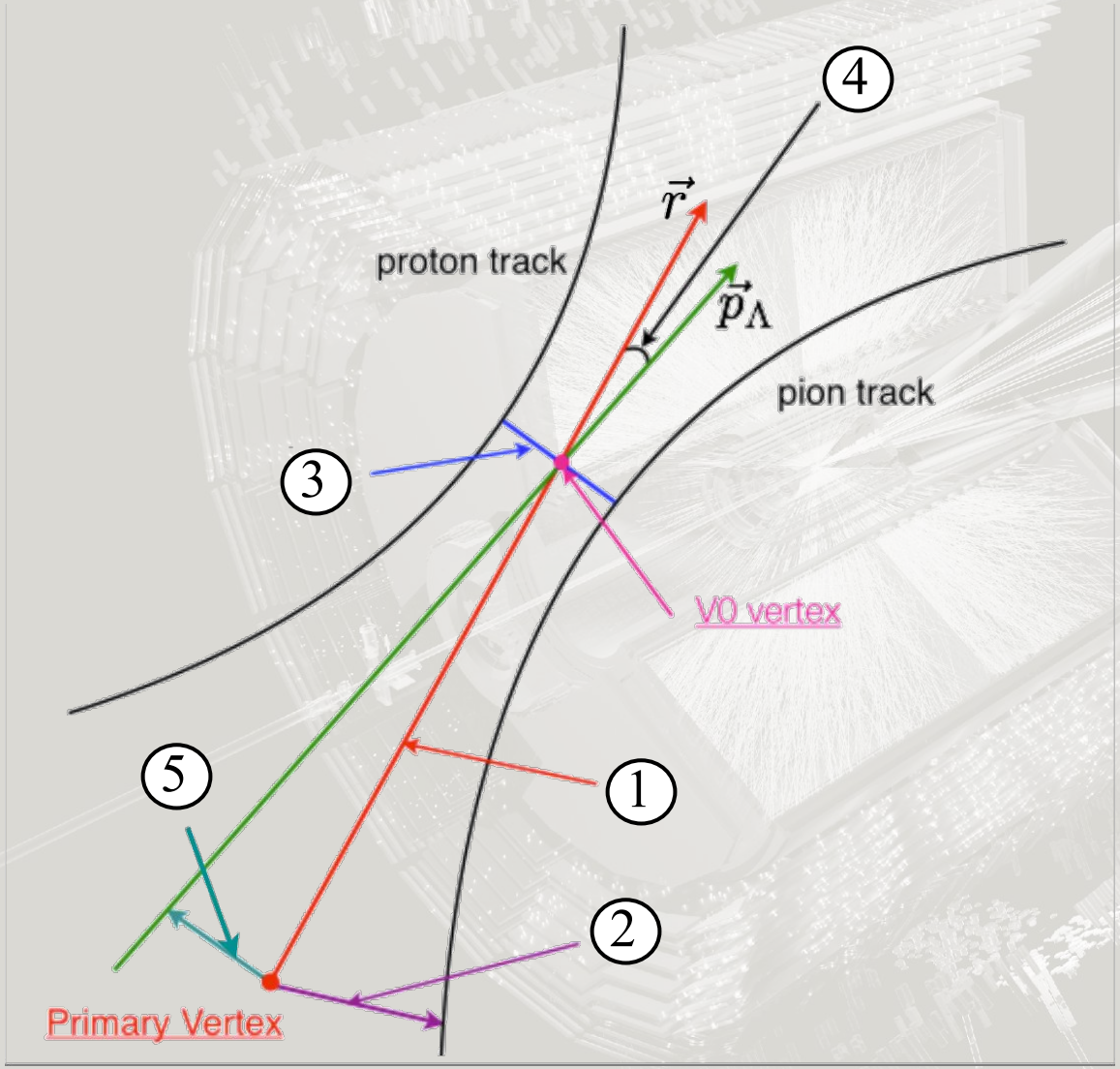
- Decay into $\gamma + \Lambda$

  ➢ γ : Conversion in detector material ($e^+ + e^-$)

  ➢ Λ: Decay into π^- and p

- We need to combine them to reconstruct Σ^0
- In practice: a **lot** of background
  - Standard solution: apply selections based on the **V0 decay topology**

How to measure it in ALICE?

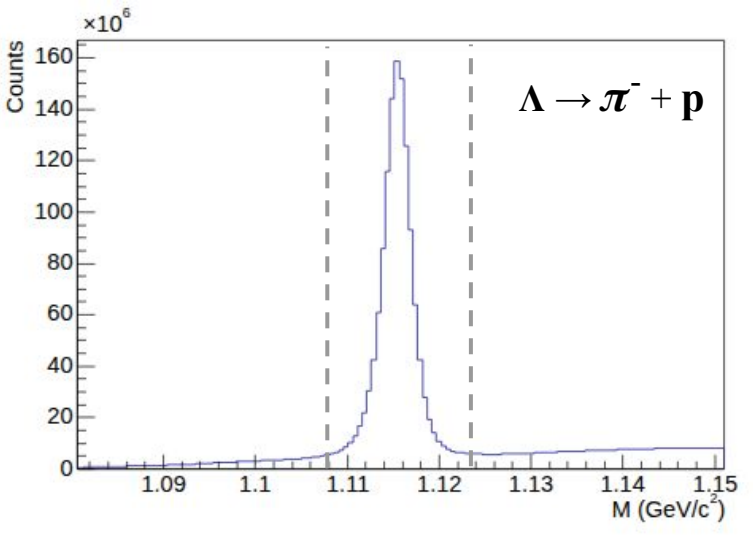


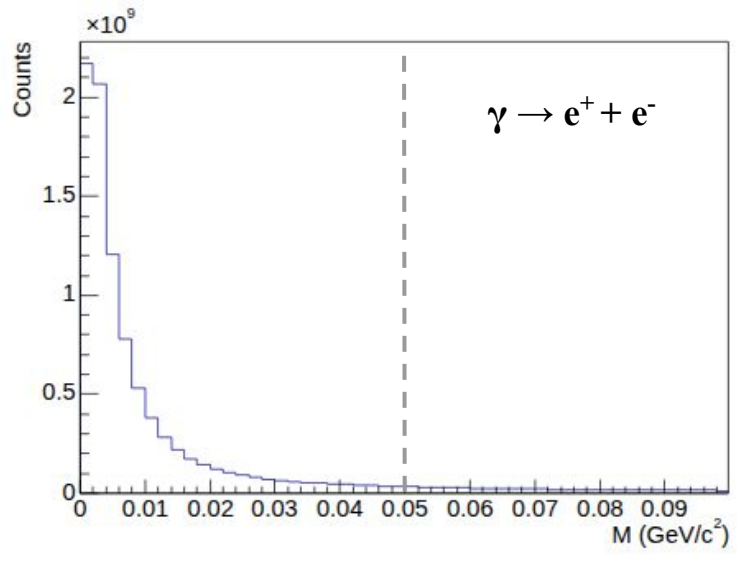
V0 reconstruction/topology

1) V0 Radius
2) DCA of Daughter to Primary Vertex
3) DCA between Daughters
4) V0 Pointing Angle
5) DCA V0 to Primary Vertex

DCA: **D**istance of **C**losest **A**pproach

How to measure it in ALICE?





V0 reconstruction/topology

1) V0 Radius
2) DCA of Daughter to Primary Vertex
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Further kinematic selections can be made:

PID, Mass Window, Pseudorapidity, tracking, …

DCA: **D**istance of **C**losest **A**pproach

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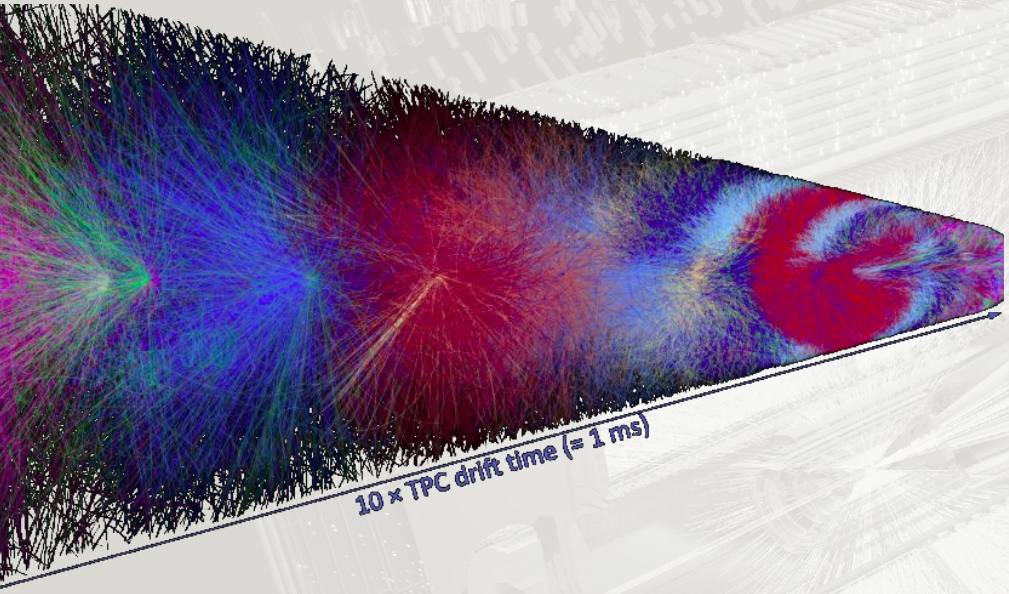

Continuous Readout

- In Run 3 detectors record and stream data from every single particle collision without waiting for a hardware trigger
- Increased statistics

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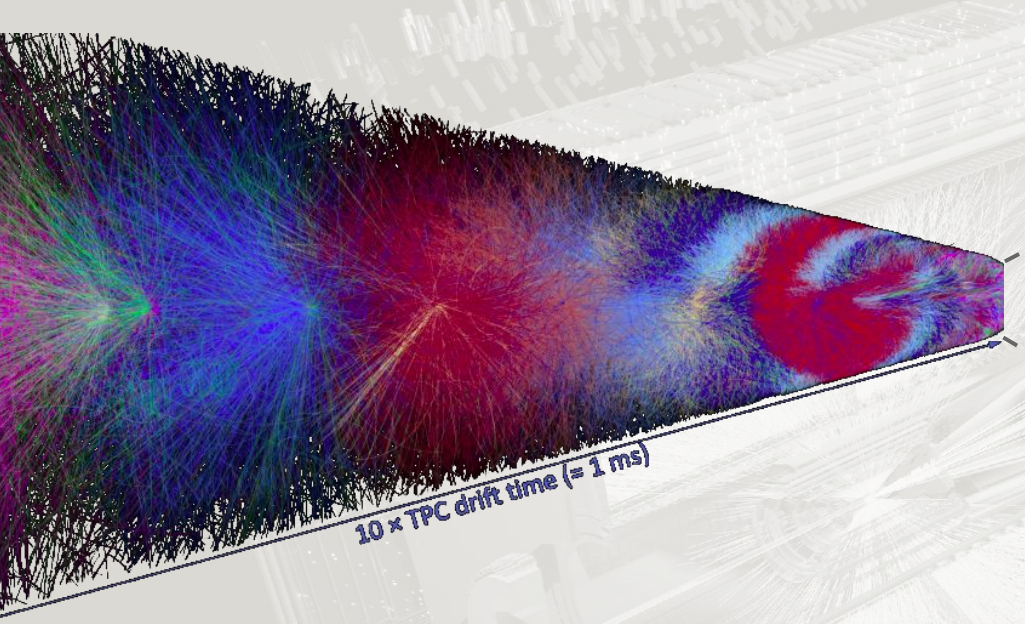

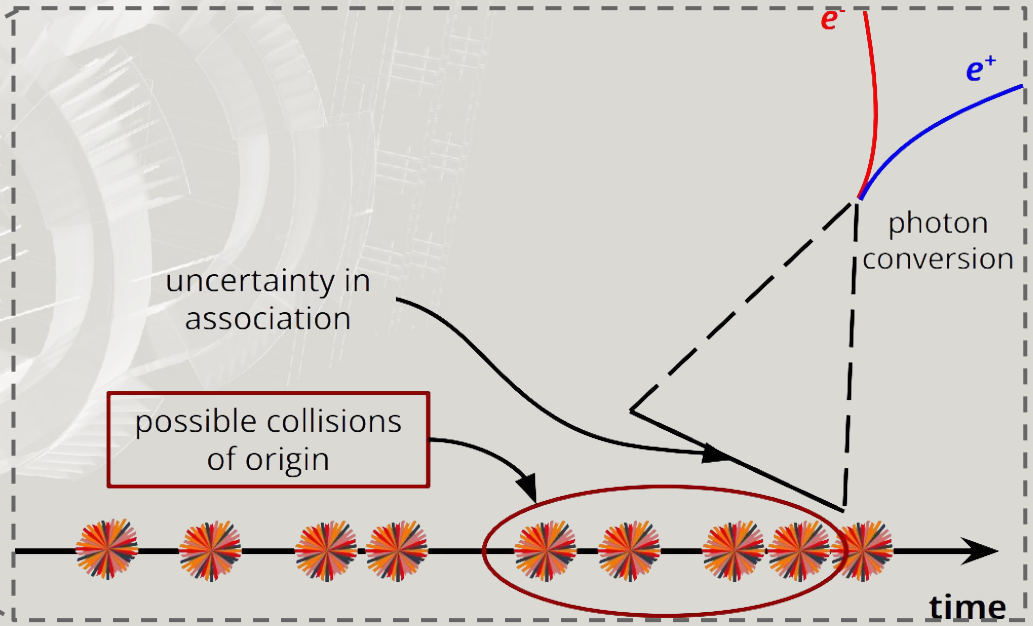

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- In Run 3 detectors record and stream data from every single particle collision without waiting for a hardware trigger
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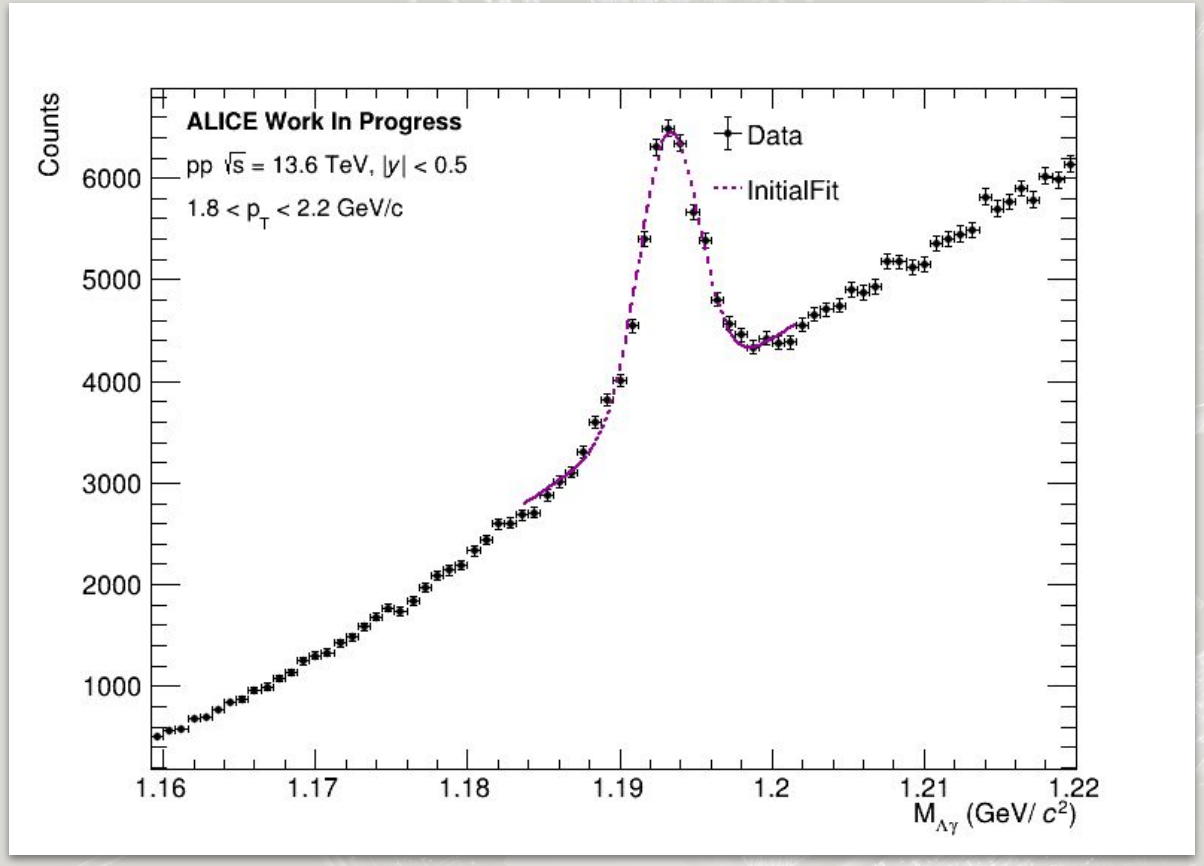
Impact in photon reconstruction

- Most of conversion photons are ***TPC-only***
- Bad time resolution = Hard to associate to the right collision
- Strategy:
  - Use some criteria (e.g, the **Pointing Angle**) to get the best V0-Collision pair

Analysis Details

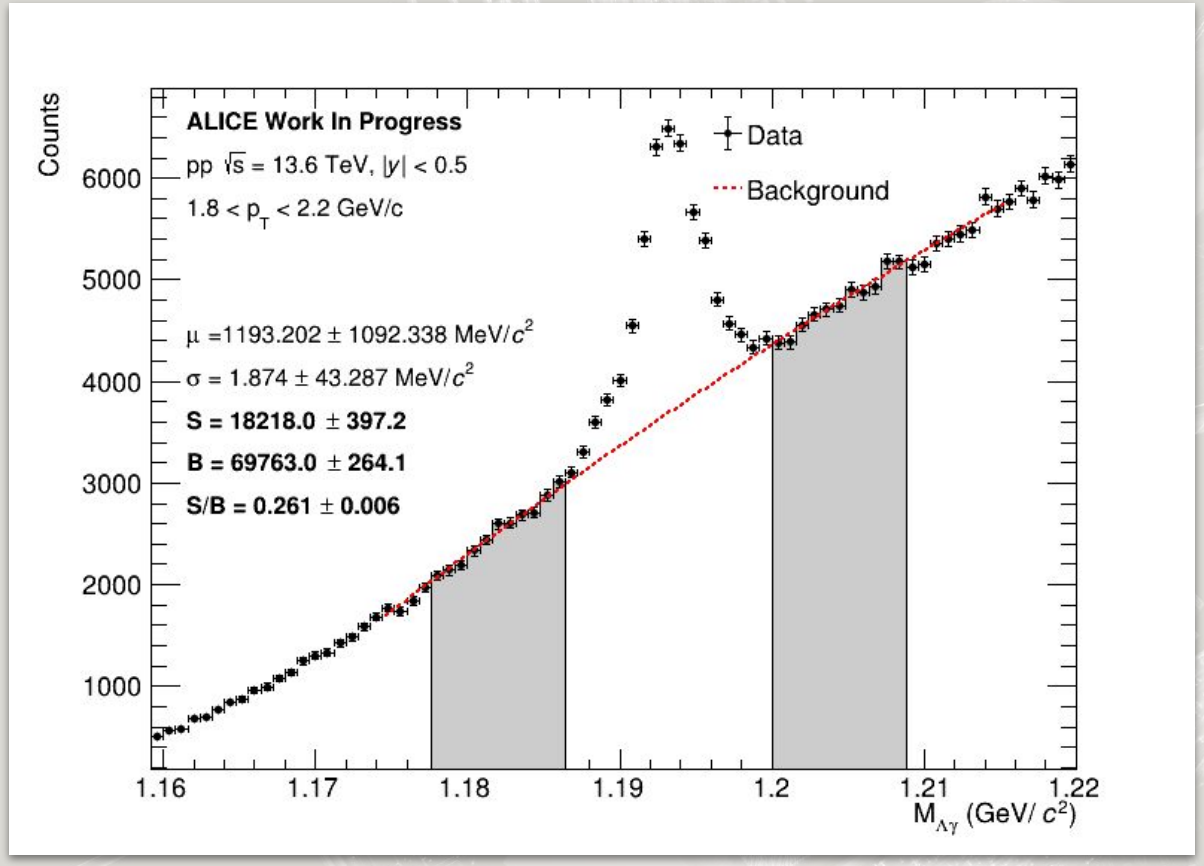
Invariant Mass Distributions



Signal Extraction

- Initial peak fit: Gaussian + 3rd order polynomial function

Invariant Mass Distributions



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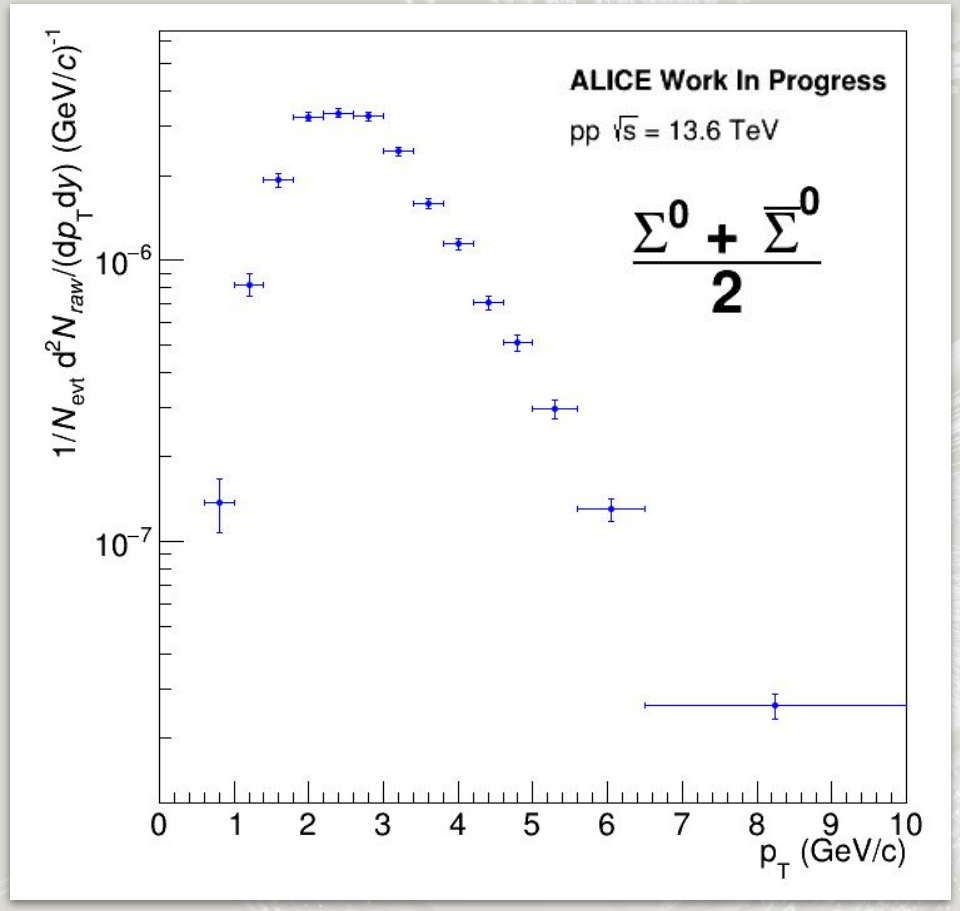
- Initial peak fit: Gaussian + 3rd order polynomial function
- From the mean and width, we estimate:
  - $(S + B)_{counts}$: counts in signal region
  - $B_{Integral}$: Integral in the Bkg region

- Signal region: [μ - 4σ, μ + 4σ]
- Bkg *fit* region: [μ - 12σ, μ - 4σ] ∪ [μ + 4σ, μ + 12σ]
- Bkg for subtraction: [μ - 8σ, μ - 4σ] ∪ [μ + 4σ, μ + 8σ]

Raw spectrum



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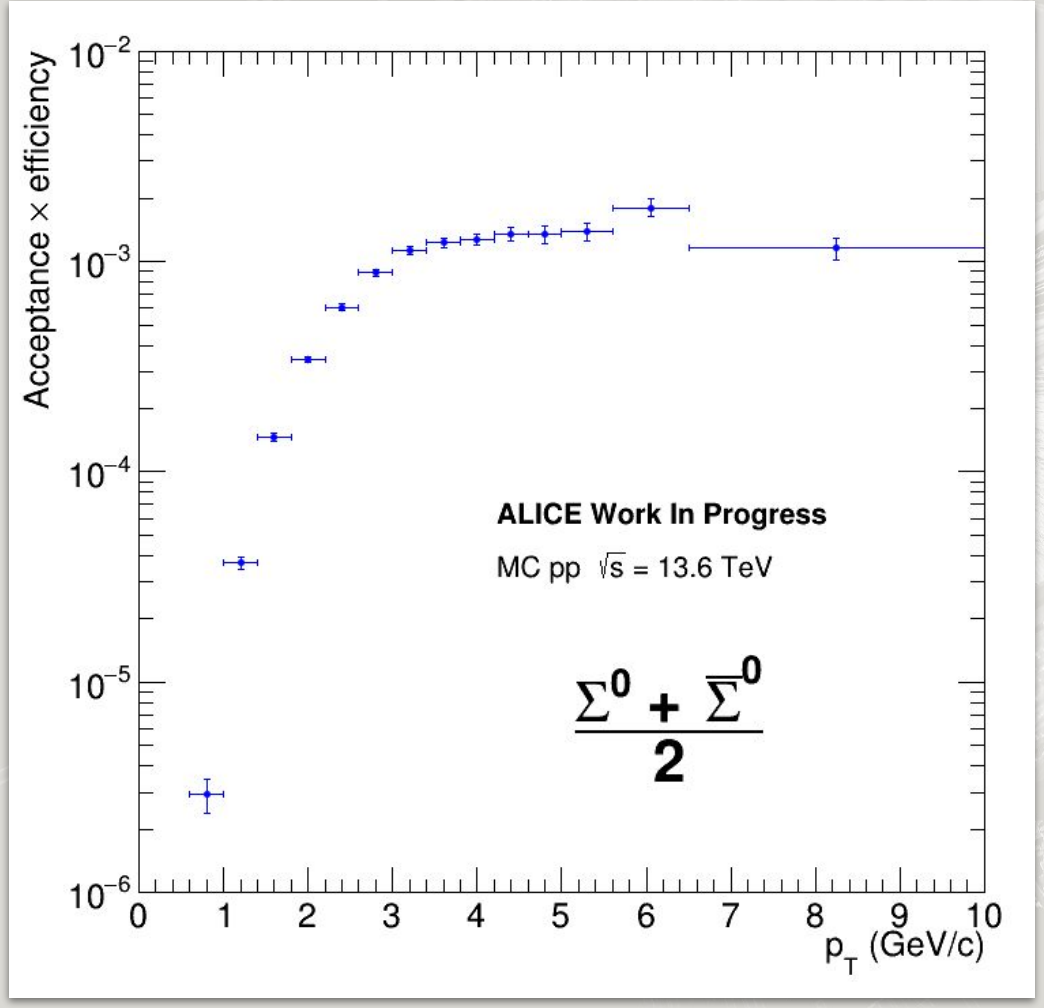
  - ○ $(S + B)_{counts}$: counts in signal region
  - ○ $B_{Integral}$: Integral in the Bkg region
- ➢ Raw signal counts:

$$S_{Raw} = (S + B)_{counts} - B_{Integral}$$

Correction factors - Efficiency

$$\frac{1}{N_{evt}^{corr}}\frac{d^2N_{corr}}{dP_T dy} = \frac{1}{N_{evt}}\frac{d^2N_{raw}}{dP_T dy}\frac{1}{A \times \varepsilon \times B.R}\frac{\varepsilon_{\text{event loss}}}{\varepsilon_{\text{event splitting}} \times \varepsilon_{\text{signal loss}}}$$

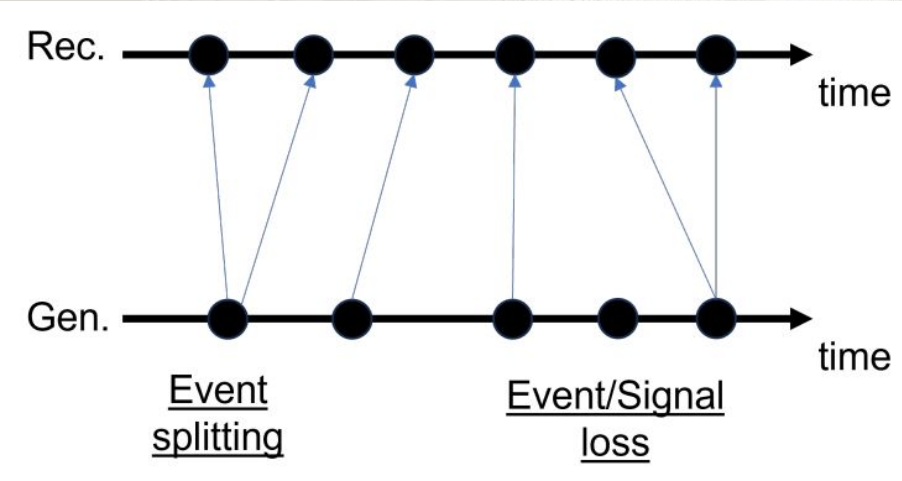


$$A \times \varepsilon = \frac{N_{\Sigma^0 s,\ \text{recoed}}}{N^{\text{recoed evt}}_{\Sigma^0 s,\ \text{gen.}}}$$

- **Efficiency increases with pT**
  - Expected: same happens with Lambdas and photons separately

Correction factors - Signal & Event Loss

$$\frac{1}{N_{evt}^{corr}}\frac{d^2N_{corr}}{dP_T dy} = \frac{1}{N_{evt}}\frac{d^2N_{raw}}{dP_T dy}\frac{1}{A\times\varepsilon\times B.R}\frac{\varepsilon_{\text{event loss}}}{\varepsilon_{\text{event splitting}}\times\varepsilon_{\text{signal loss}}}$$



$$\varepsilon_{\text{event loss}} = \frac{N_{\text{gen. evt}}^{\text{evt reco. at least once}}}{N_{\text{gen. evt}}} \qquad \varepsilon_{\text{event splitting}} = \frac{N_{\text{gen. evt}}^{\text{evt reco. at least once}}}{N_{\text{reco. evt}}}$$

- **Event loss (or *event finding*):** 58.44 %
- **Event splitting:** 99.74%

} **for pp**

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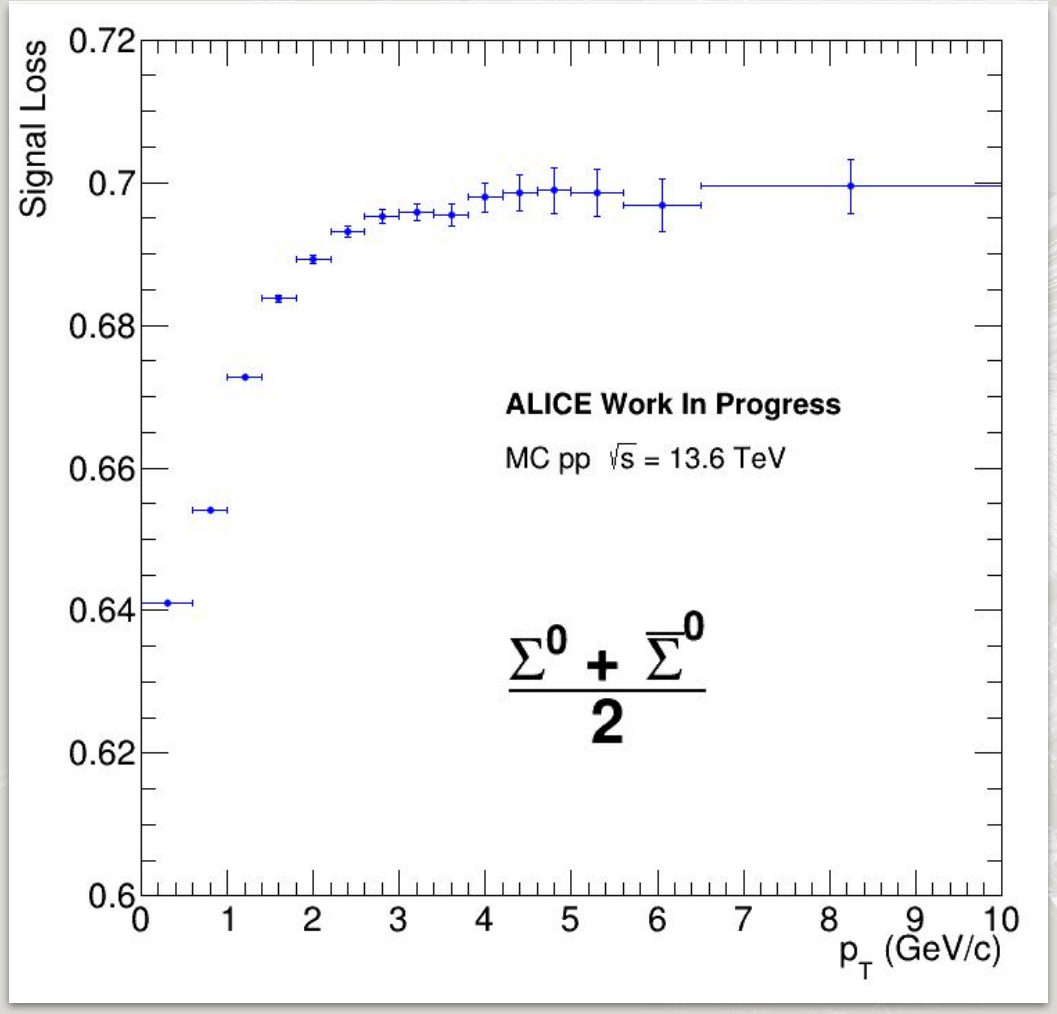

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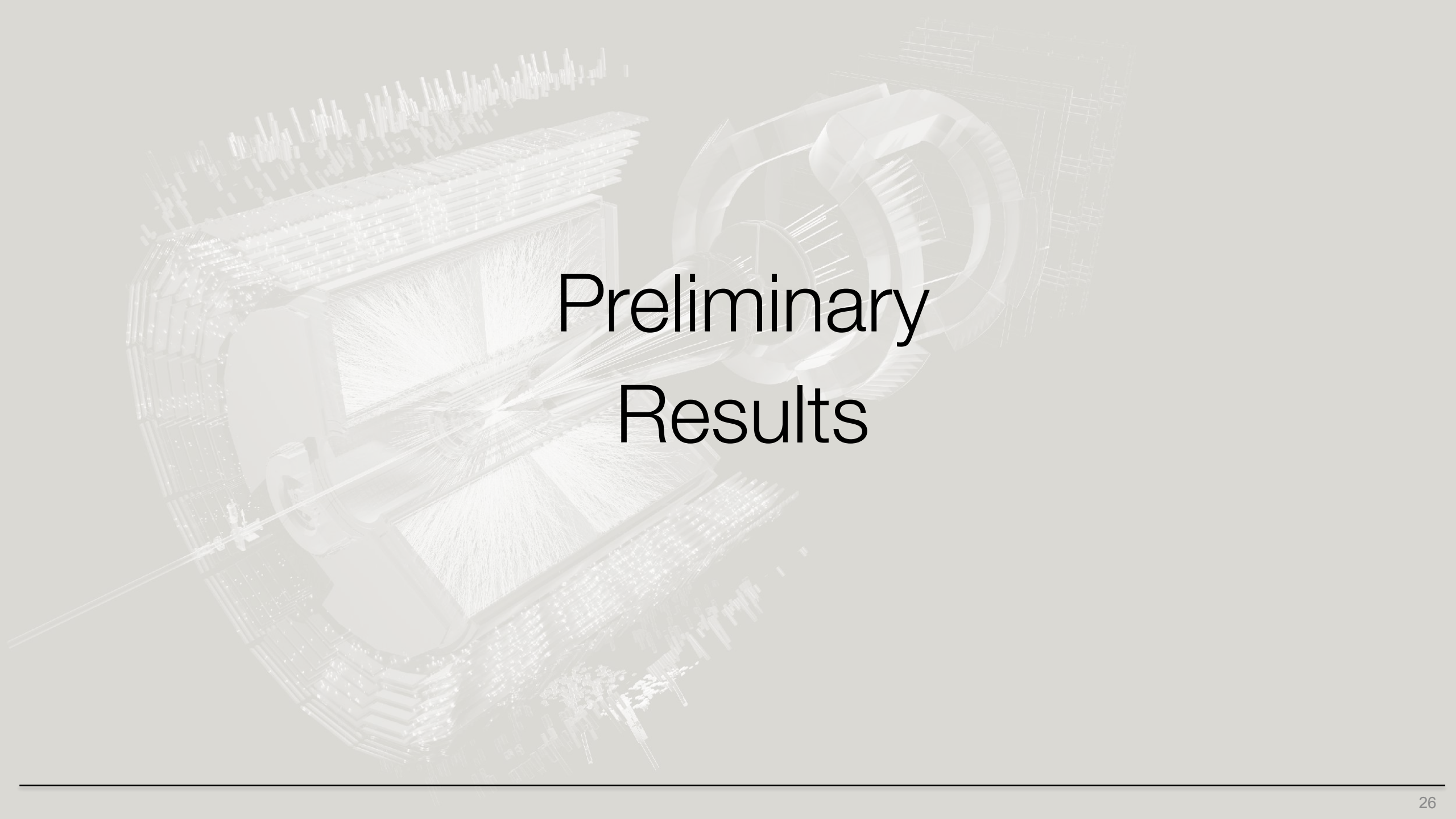
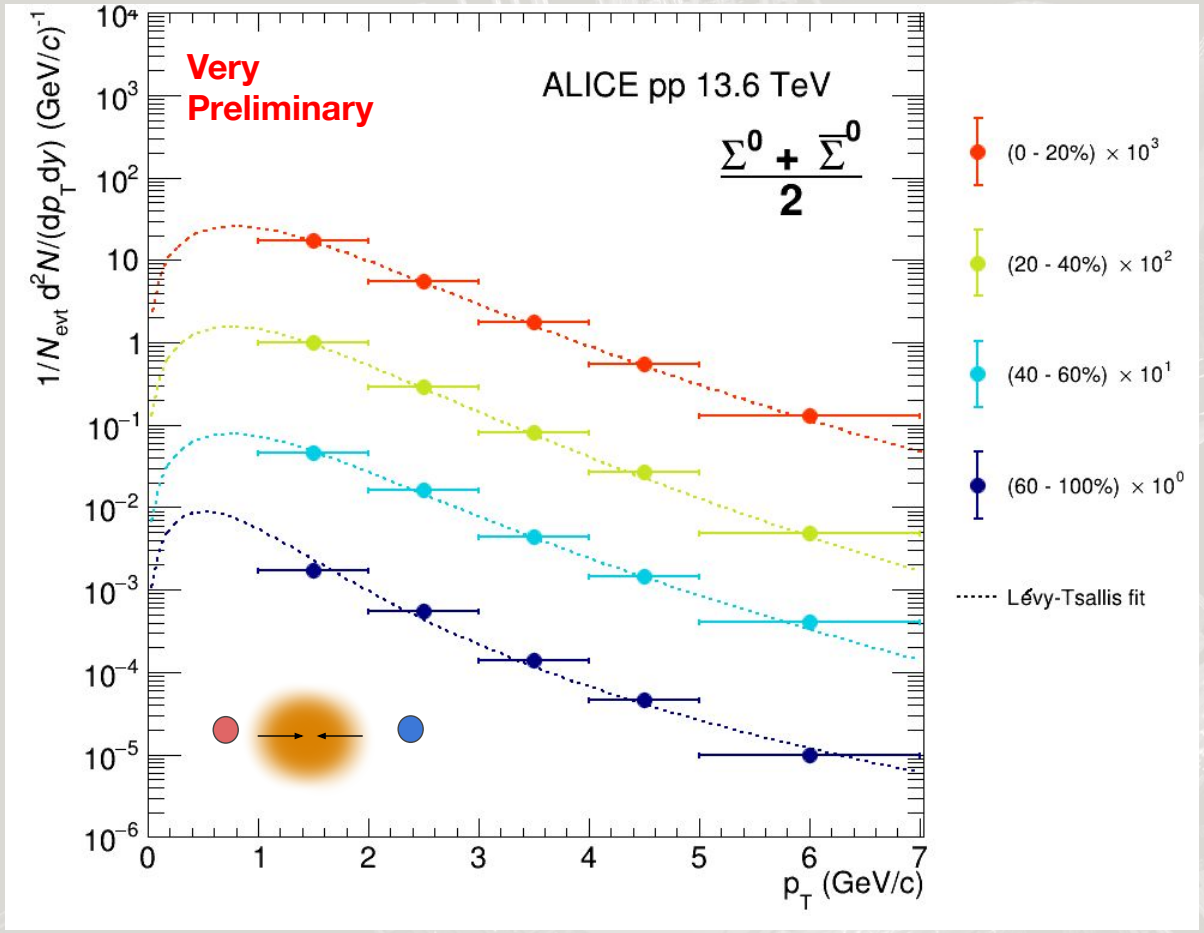
$$\varepsilon_{\text{signal loss}} = \frac{N_{\Sigma^0 s,\ \text{gen.}}^{\text{recoed evt}}}{N_{\text{gen. }\Sigma^0 s}}$$

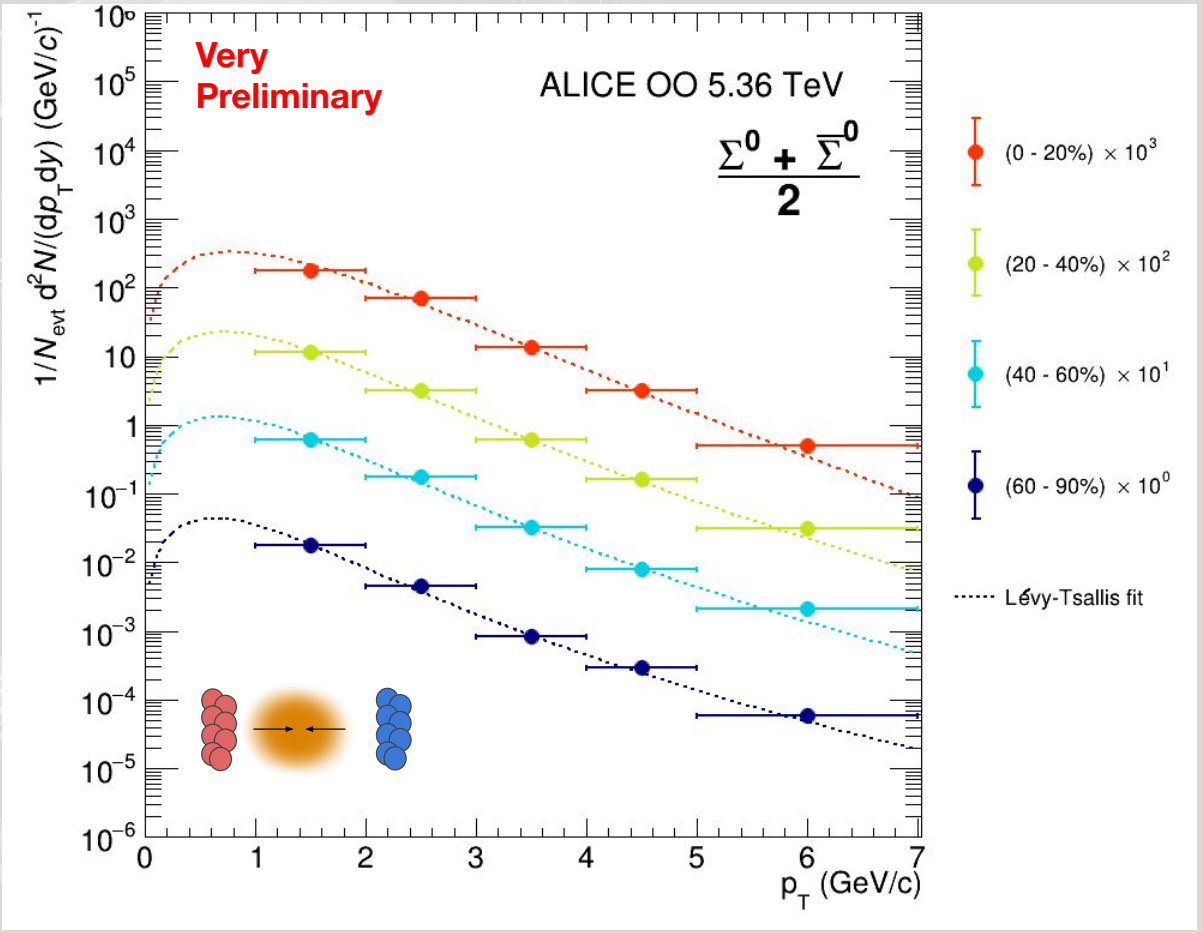
- N.B: Requirement of **Σ⁰** baryons from **MC Generator**
  - We can have secondaries from material



Preliminary Results

Corrected pT-spectra Vs Multiplicity

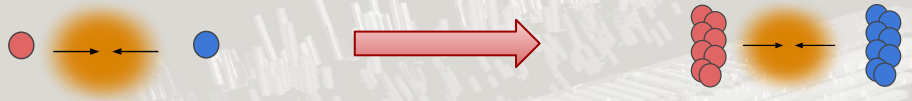


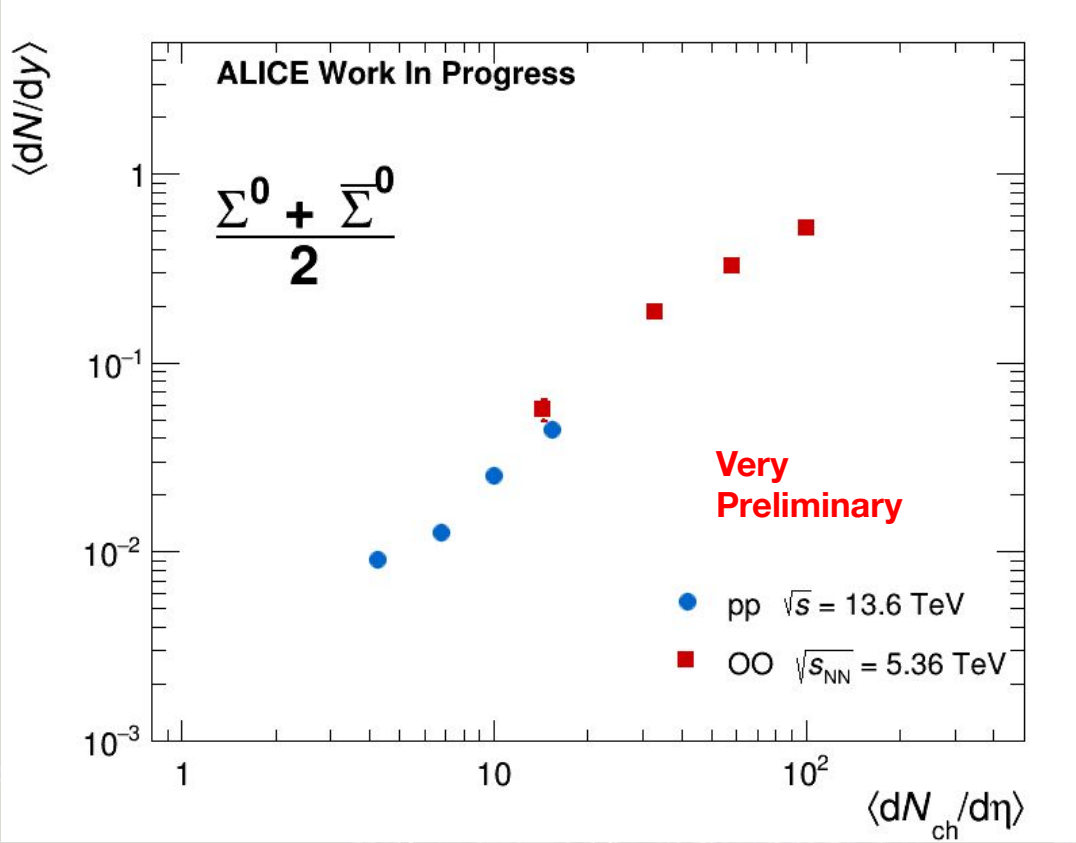


Centrality-dependent corrected spectra

- Hardening of the spectra from **peripheral** to **central** collisions

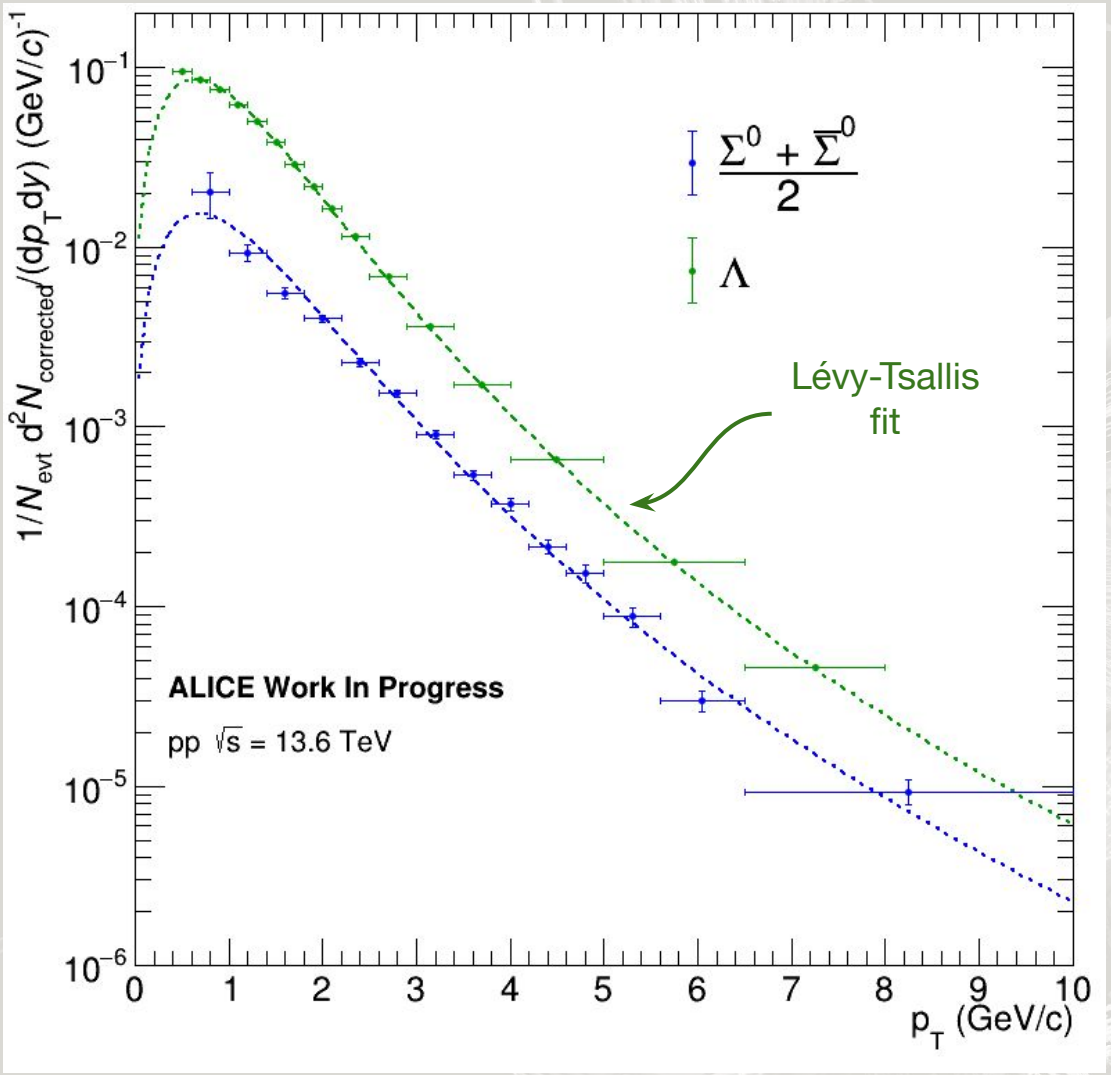
Comparison between different systems





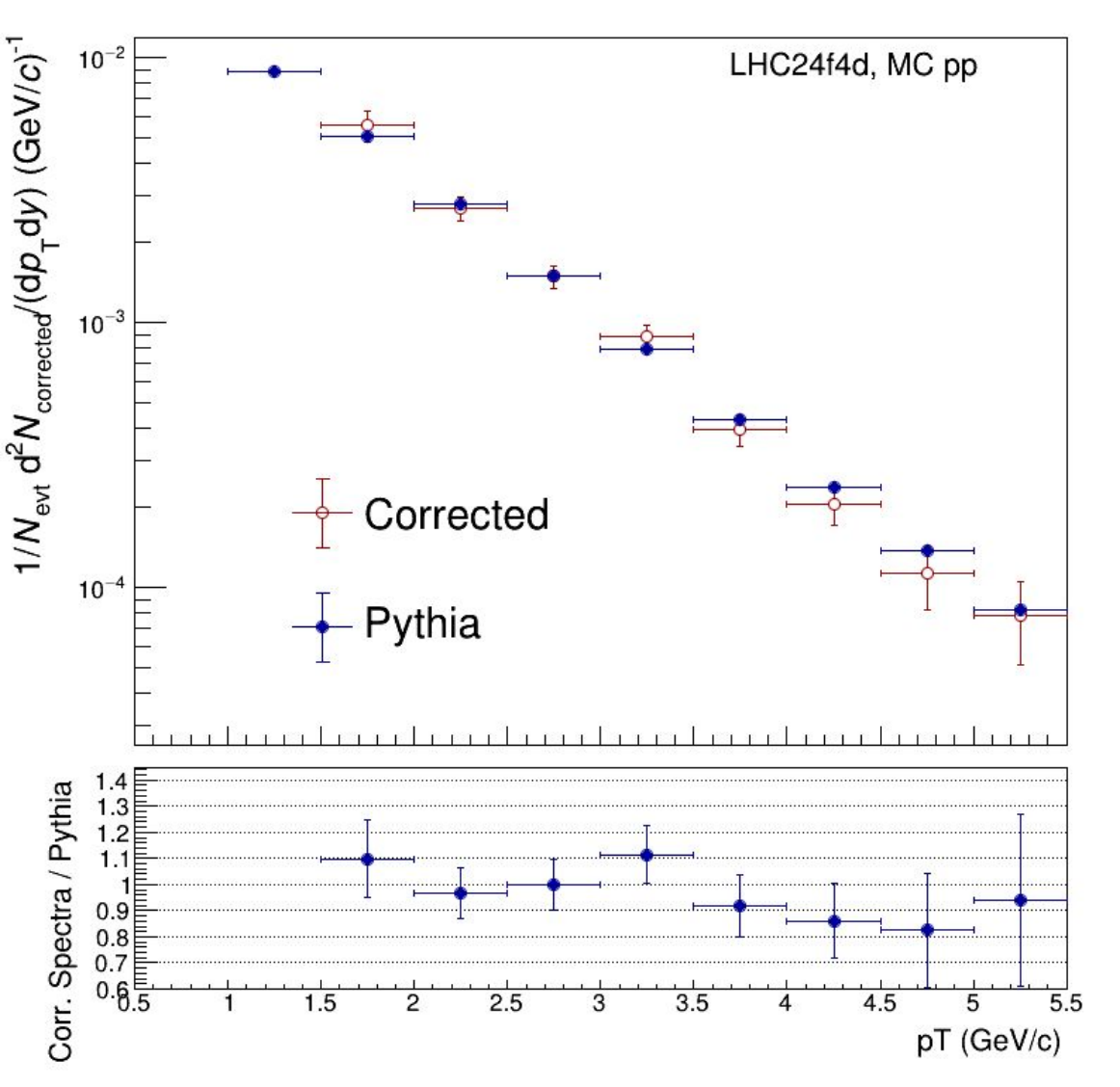
- Increase of the integrated Yields with multiplicity and system size
- Results in **pO** to be included
  - Interesting since it is an intermediate system

Comparison with Run 3 analyses



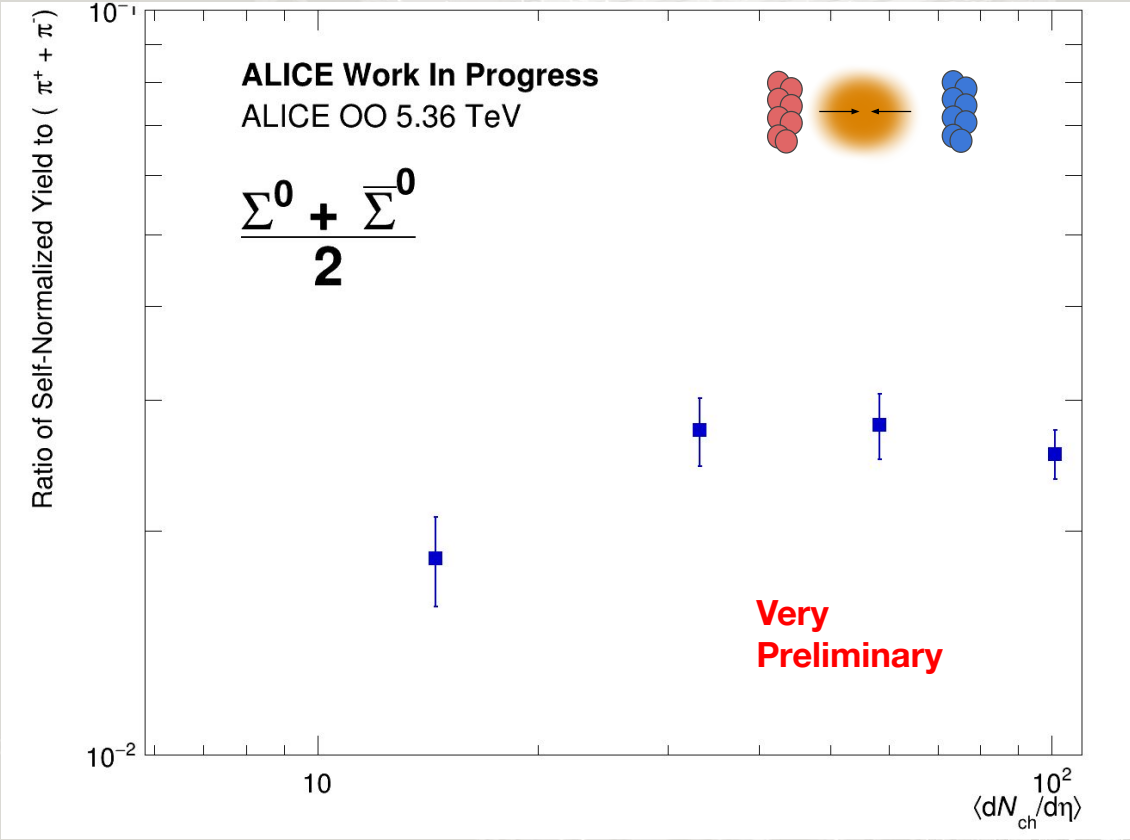
- Comparison with Lambda analysis in Run 3
- Simple extrapolation to low-pT done using **Lévy-Tsallis function**
- Integrated Yield comparison:
  - $(\Sigma^0 + \bar{\Sigma}^0) / (2\Lambda) \sim 0.19$
  - Expected: 1/3
- Almost a factor 2 difference…

MC Closure Test



- **Idea**: Analyzing MC as DATA
- Should detect if there's something wrong with the **correction factors** (or with the processing macros)
- **General agreement** with Pythia spectrum
  - Fluctuations due to the lack of statistics
- **Further investigations were done**
  - Everything points towards a bad description of low-pT photons in the MC

Self-Normalized results



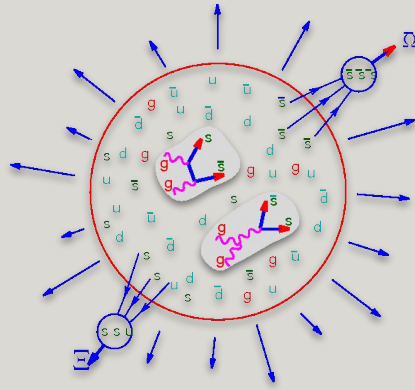
- Apparently this “factor 2” appears in all systems and multiplicities
- Strategy: divide yields per multiplicity class by the minimum bias sample
- **Example:** ratio to charged pions
  - With this we can still see the **strangeness enhancement** trend

Extra activities

Extra activities

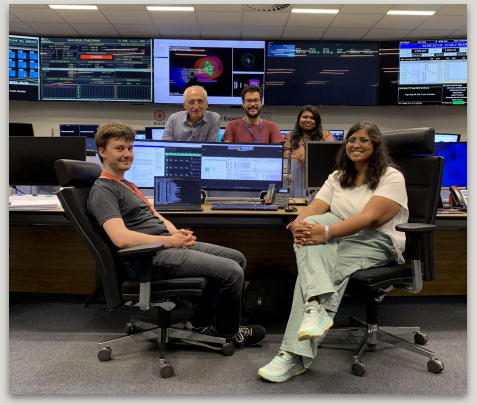
Analysis

- Contributing to the Σ^0 analysis in OO (*Turkey*)
- Contributing to $K^* \rightarrow \gamma + K^0_S$ and $\Lambda^* \rightarrow \gamma + \Lambda$ studies (*Austria*)



Service Work

- Responsible for generation of **derived data** for datasets of interest (PWGLF-Strangeness)
- Documentation / Basic QA
- Development/maintenance of the strangeness data model



Data taking

- Total of 5 shift blocks (2023 - 2026): **ECS** & **Shift-Leader** positions

Outreach

- Organization of the CERN International Masterclass in Vienna
- Moderator in the video conferences

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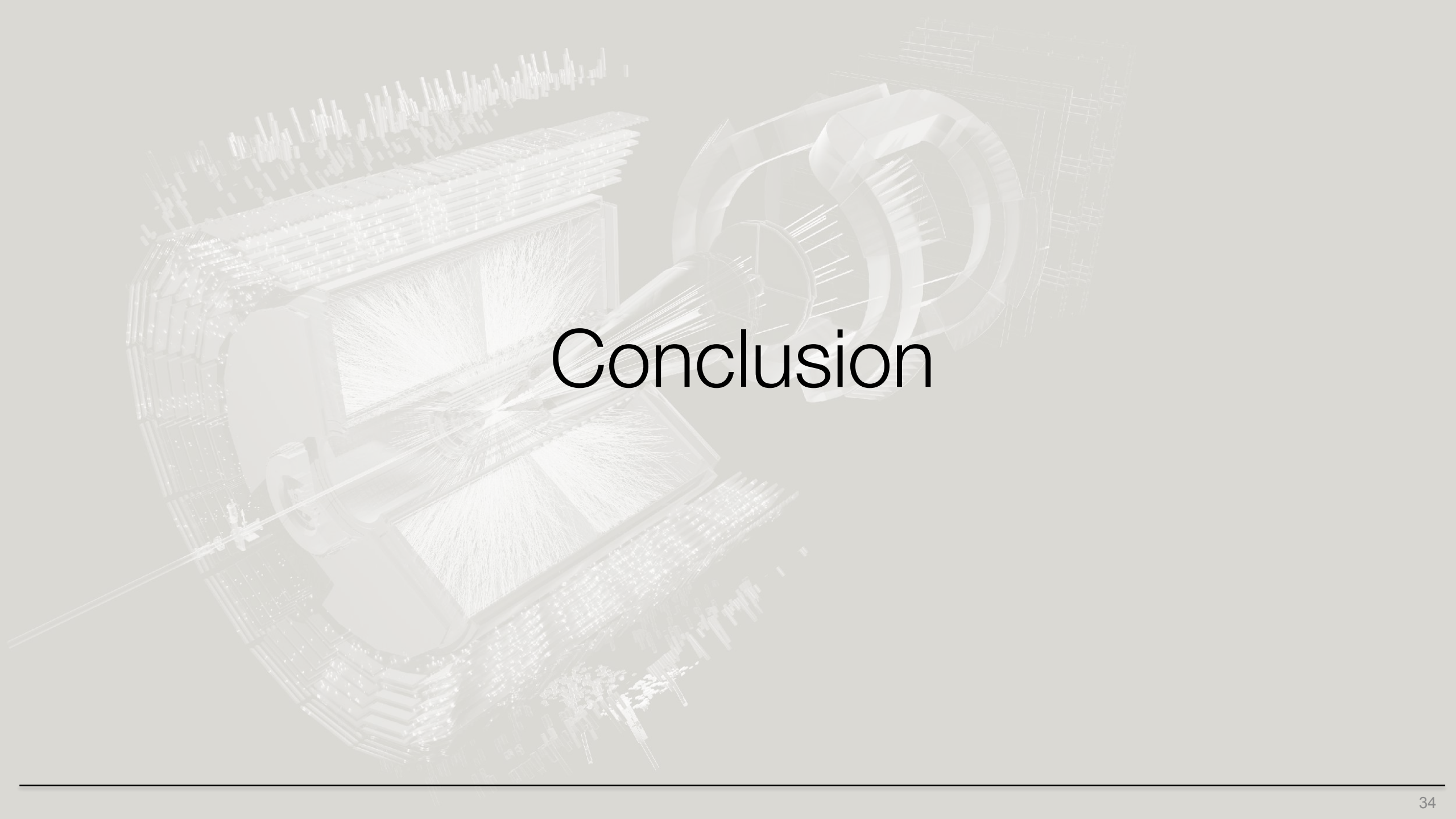

Conclusion

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Sigma0 production

- ➢ Discrepancies with other measurements
- ➢ Bad MC description for low-pT photons (*under investigation*)
- ➢ Studying the possibility to use correction weights

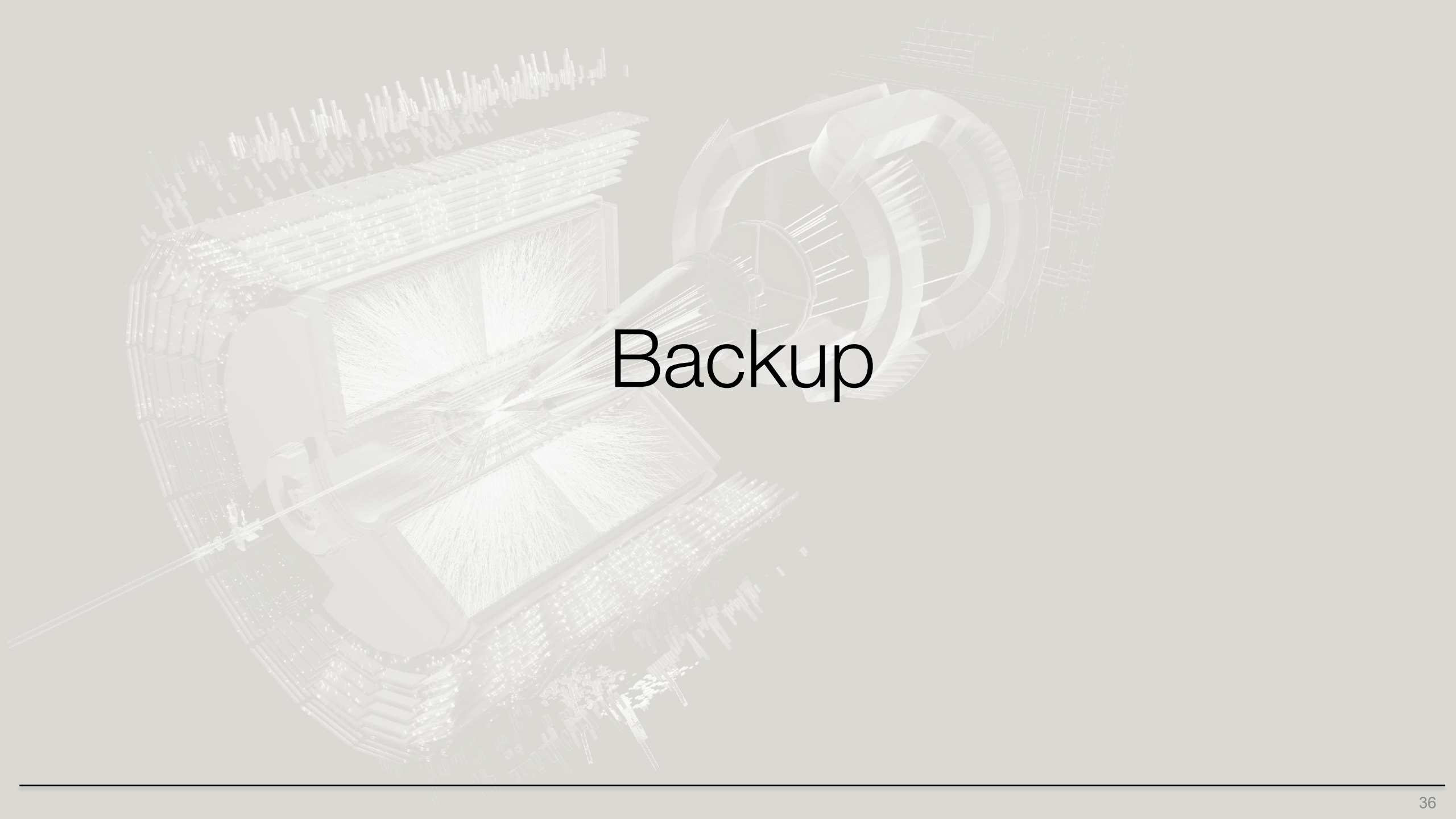
Self-normalized results

- ➢ Good alternative to reduce the MC description dependency
- ➢ Can be used for comparisons (Isospin test, strangeness enhancement, etc)

Plans for the approval (ICHEP)

- ➢ Perform systematic study
- ➢ Comparison with models (Pythia / THERMUS / EPOS4 / etc)

Thank you!



Backup

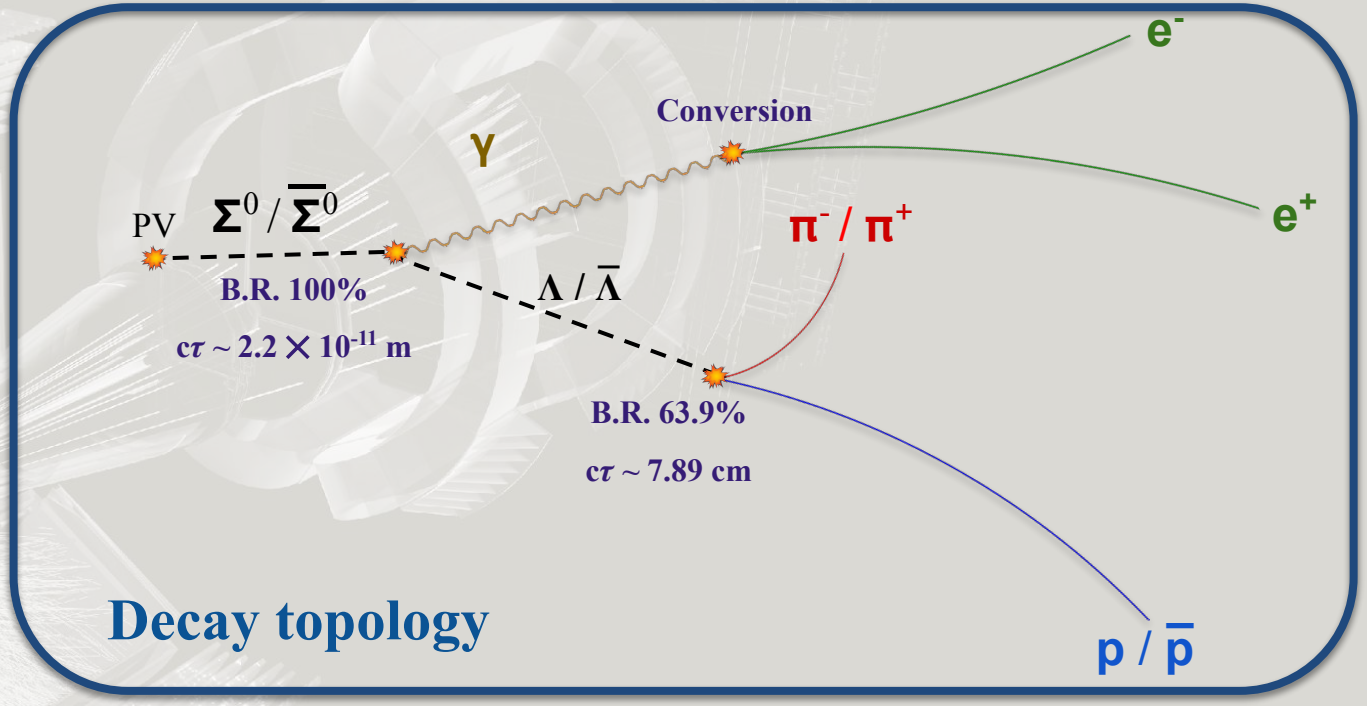
Candidate selection

V0 Selection	$\Lambda \to p + \pi^-$ $\bar{\Lambda} \to \bar{p} + \pi^+$	$\gamma \to e^+ + e^-$
DCA To PV (Pos)	> 0.05 cm	> 0.05 cm
DCA To PV (Neg)	> 0.2 cm	> 0.05 cm
DCA V0 Daughters	< 0.5 cm	< 1.0 cm
V0 Radius (R)	1.2 < R < 25 cm	3.0 < R < 115 cm
Cos(PA)	> 0.995	> 0.99
Inv. Mass	± 0.005 GeV/c²	< 0.05 GeV/c²
q_T	$0.01 < q_T < 0.11$	$0.05 < q_T$
α	$0.25 < \lvert\alpha\rvert < 1.0$	$\lvert\alpha\rvert < 0.95$
Daughter η	$\lvert\eta\rvert \leq 0.8$	$\lvert\eta\rvert \leq 0.8$
Rapidity	$\lvert y\rvert \leq 0.8$	$\lvert y\rvert \leq 0.8$
Lifetime	< 30	-
TPC Crossed Rows	> 70	>50
TPC N. Sigma	$\lvert n\sigma_e\rvert < 5$	$\lvert n\sigma_e\rvert < 5$
Min ITS clusters	2	-
V0 Type	1	7
$\Sigma^0 / \bar{\Sigma}^0$ Candidates		
Rapidity	$\lvert y\rvert \leq 0.5$	

Topological

Kinematic

Other



Main processing tasks

- **PropagationService:** Build V0s
- **sigma0builder:** build sigma0 candidates
- **sigmaanalysis:** process and selects sigma0 cand.

Candidate selection

V0 Selection	$\bar{\Lambda} \to \bar{p} + \pi^+$ $\Lambda \to p + \pi^-$	$\gamma \to e^+ + e^-$
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Topological

Kinematic

Other

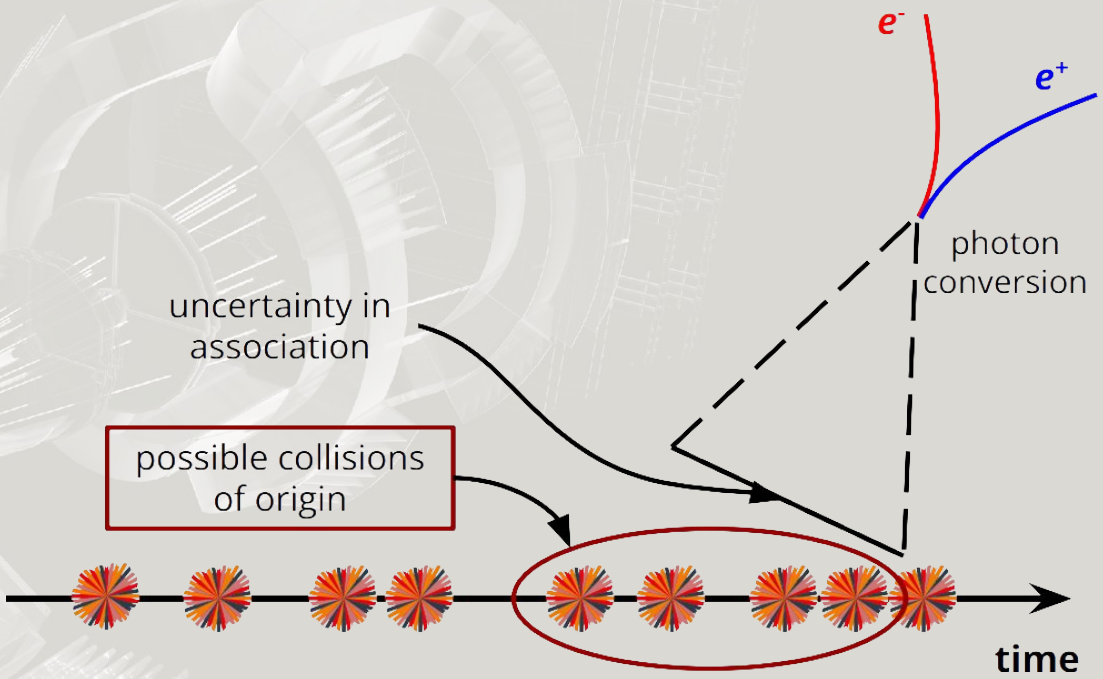


Figure from Yousef El Mard

N.B: Photon treatment

- Most of conversion photons are **TPC-only** == several compatible collisions
- **Reconstruction-level:** Each TPC-only V0 is cloned in all compatible collisions
- **Analysis-level:** "Deduplication" procedure to get **best** V0-Collision pair
- **This analysis:** Deduplication "mode 1" - Best **Pointing Angle** wins

Cross-check with EMCal

- **Idea:** how is the spectra measured using calorimetry?
  - Successful analysis with EMCal in Run 3
  - Good MC description

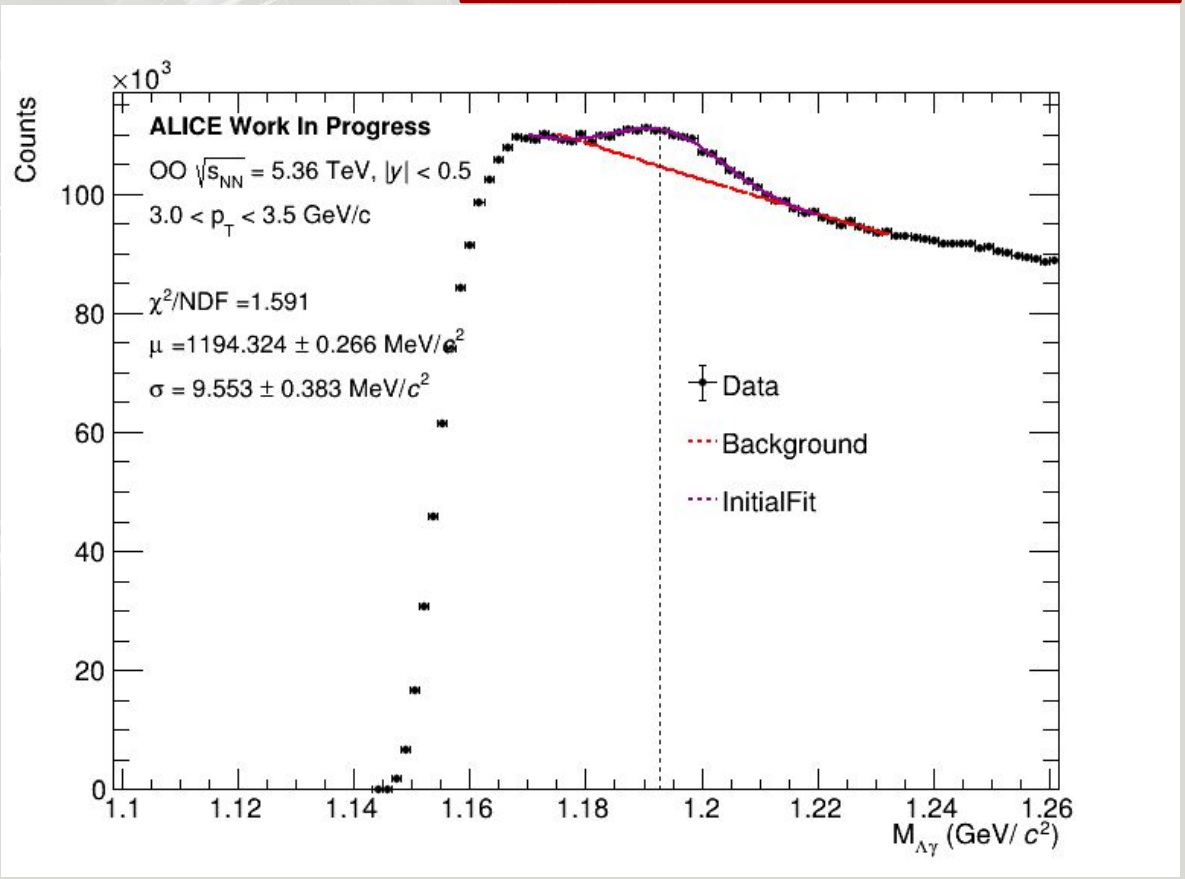
- EMCal clusters from emcalCorrectionTask.cxx
- Pairing **EMCal clusters** and **Lambdas**

EMCAL Cluster Selection	
Energy (E)	200 MeV < E < 450 MeV
Cluster Time (T)	-15 ns < T < + 15 ns
NCells	1
Remove matched track	Yes

Cross-check with EMCal

- **Idea:** how is the spectra measured using calorimetry?
  - Successful analysis with EMCal in Run 3
  - Good MC description

Feasibility test using OO data



- EMCal clusters from emcalCorrectionTask.cxx
- Pairing **EMCal clusters** and **Lambdas**

EMCAL Cluster Selection	
Energy (E)	200 MeV < E < 450 MeV
Cluster Time (T)	-15 ns < T < + 15 ns
NCells	1
Remove matched track	Yes

- Broad peak: EMCal has a *bad* momentum resolution
- Challenging signal extraction: testing *rotational background method* & *Event Mixing*