Lambda Production in mCBM
(Paper Draft Status)

CBM Collaboration Meeting

University of Heidelberg

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Outline

- Introduction
- Experimental setup
- Data analysis
- Conclusions

Introduction

- **Final mCBM runs** successfully executed in 2025, marking **project completion**
- Lessons learned on detector operation, readout electronic chain with free streaming DAQ, etc.
- Huge amount of data collected, with the possibility of replaying in real time
- Data enables **assessment of detector performance** and **readiness for CBM**

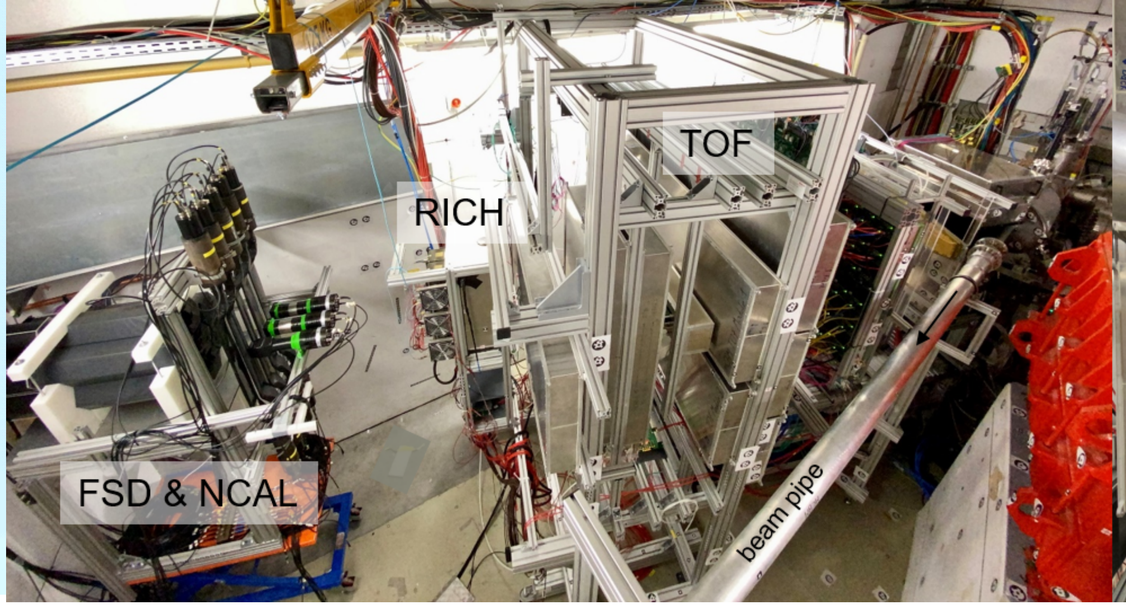
- Summarize what we have learnt in the form of publications

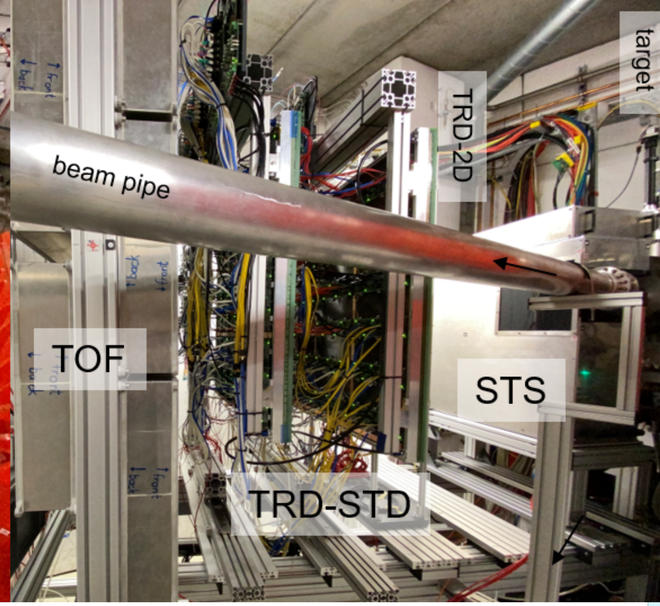
“Demonstrating Λ Reconstruction in Ni + Ni Collisions with the mCBM experiment at SIS18 of GSI/FAIR”

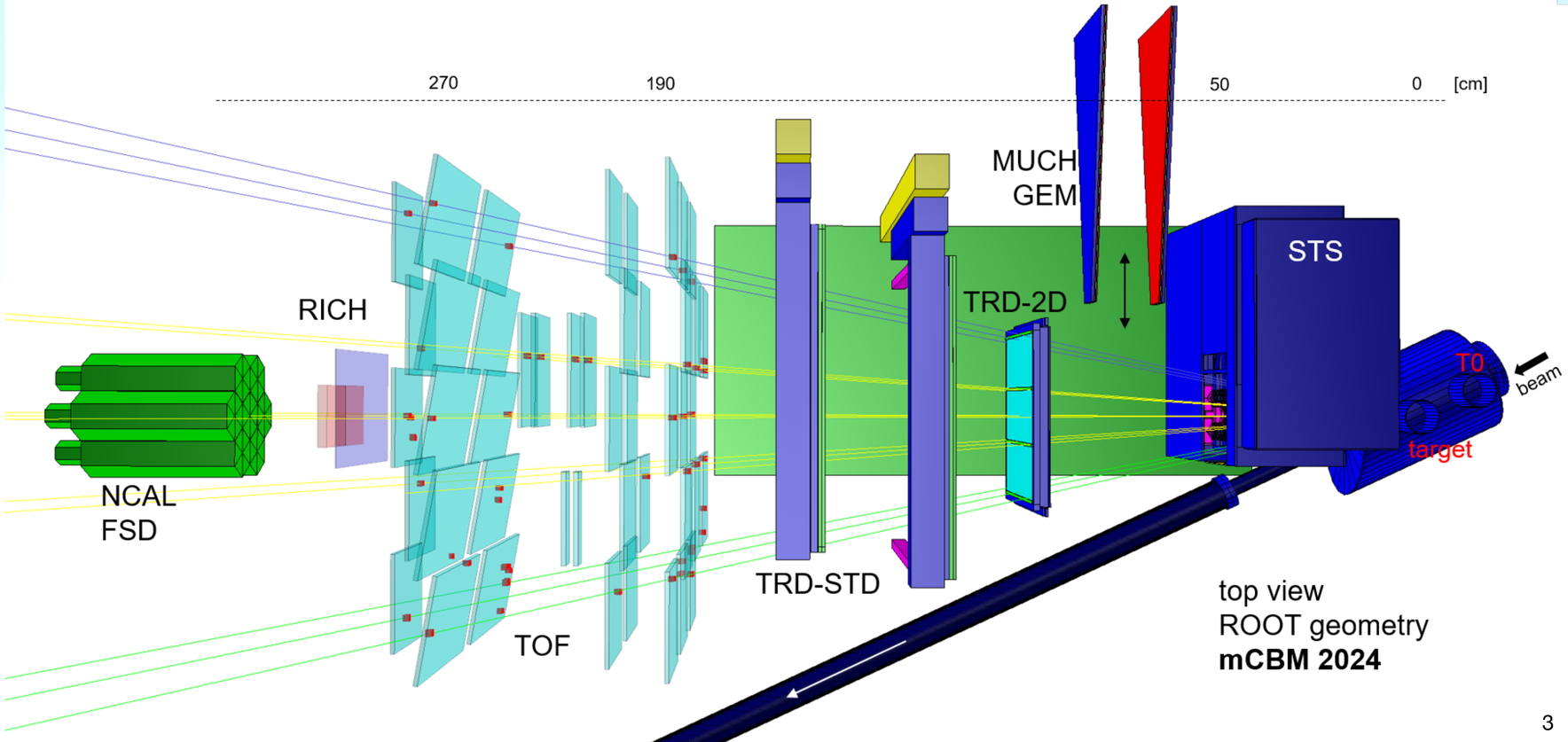
- **Submitted to the CEB for 1st internal review!**
  (https://indico.gsi.de/event/23332/)

Experimental setup in 2024

- Silicon Tracking System (STS)
- Muon Chamber system (MUCH)
- Transition Radiation Detector system (TRD)
- Time-Of-Flight detector system (TOF)
- Ring Imaging Cherenkov detector system (RICH)
- Forward Spectator Detector system (FSD) with the Neutron Calorimeter (NCAL)
- Time-zero detectors of the Beam Monitoring system (BMON)

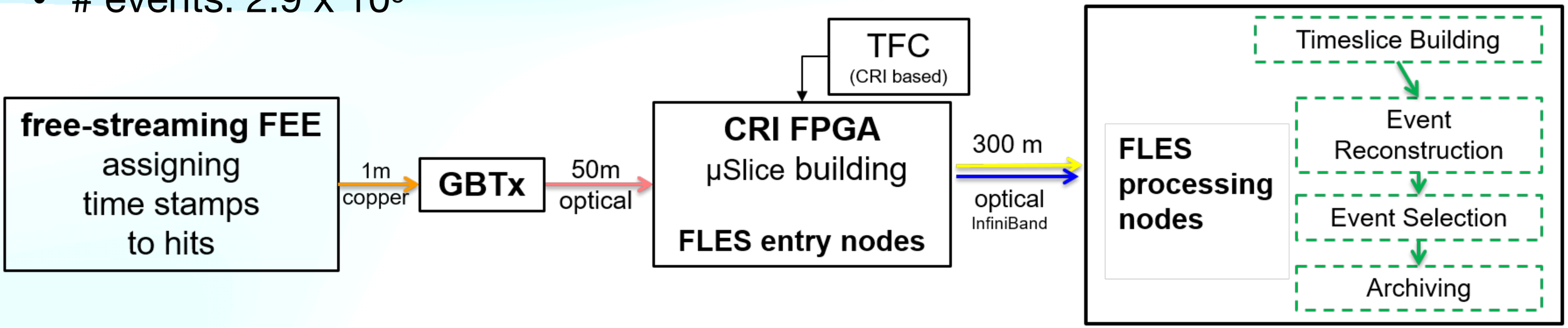






Data Set, Data Acquisition and Data Transport System

- Year: 2024
- Species: Ni+Ni
- Beam kinetic energy: 1.93 A GeV ($\sqrt{s_{NN}}$=2.67 GeV)
- Ions per spill: 4 x 10^7
- Averaged collision rate: 500 kHz
- Duration: 5:30 hours (4 runs on May 9, 2024)
- # events: 2.9 x 10^9



- **CBM DAQ and data transport system** is used in the mCBM experiment

Tracking and Particle Identification

- Silicon Tracking System (STS)
- Time-Of-Flight detector system (TOF)

→ **Cellular Automaton (CA)** algorithm is used for track reconstruction

No B-field!

- Time-zero detectors of the Beam Monitoring system (BMON)

Tracking and Particle Identification

- Silicon Tracking System (STS)

- Time-Of-Flight detector system (TOF)
- Time-zero detectors of the Beam Monitoring system (BMON)

Time information from BMON and TOF detectors is combined to obtain precise time and **velocity measurements**

- TOF Calibration (See draft for details)

Tracking and Particle Identification

- Silicon Tracking System (STS)
- Time-Of-Flight detector system (TOF)
- Time-zero detectors of the Beam Monitoring system (BMON)

The precise spatial information from the STS enables effective **statistical discrimination of proton and pion tracks via the DCA to the primary vertex**

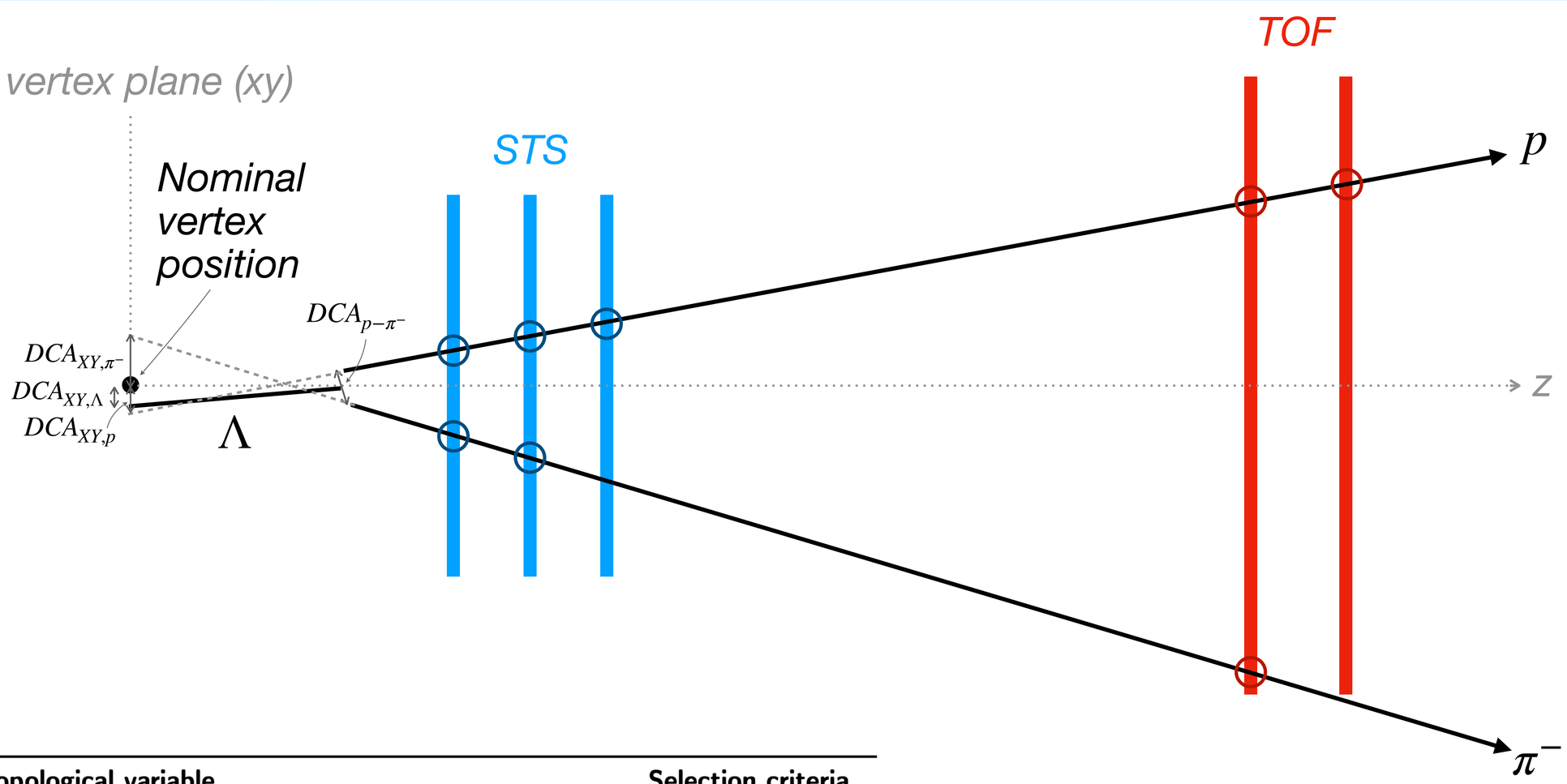
- DCA_{XY} = (0.5,1.5) cm: proton
- DCA_{XY} > 1.5cm: pion
- Detector alignment (See draft for details)

Tracking and Particle Identification

- Silicon Tracking System (STS)
- Time-Of-Flight detector system (TOF)
- Time-zero detectors of the Beam Monitoring system (BMON)

→ Combining timing and spatial data from all detectors allows reconstruction of ***Globaltracks*** **with full spatial and momentum information**

Λ Candidate Selection

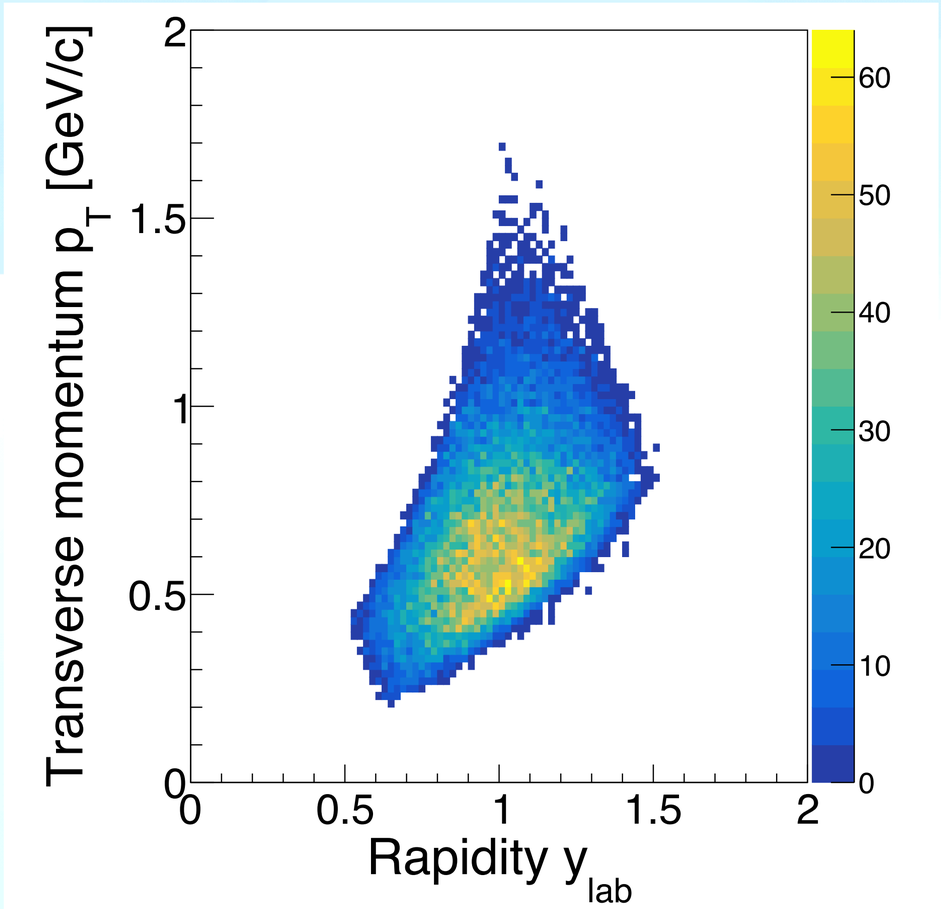


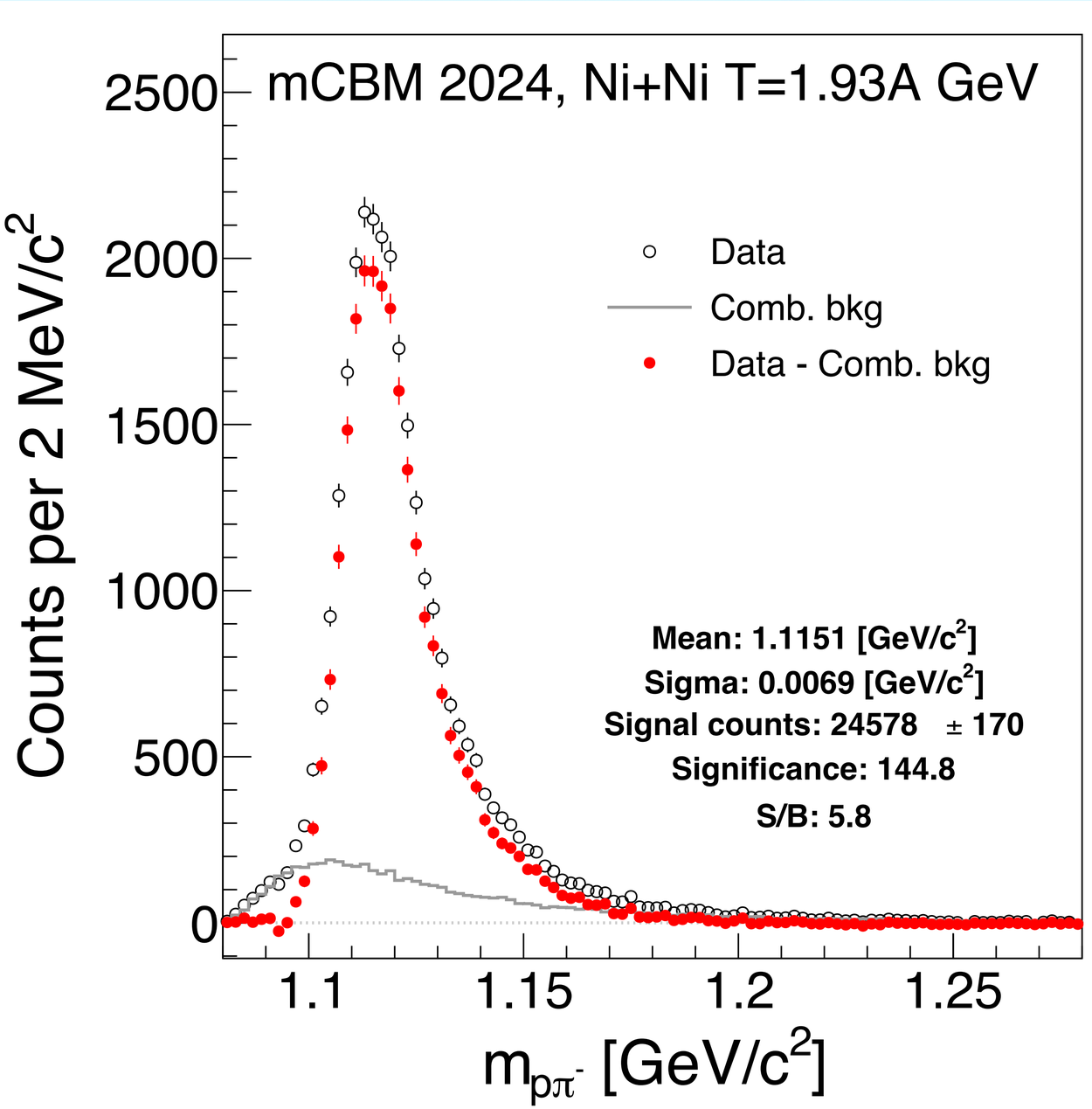
Topological variable	Selection criteria
DCA_{XY,π^-} (cm)	> 1.5
$DCA_{XY,p}$ (cm)	$0.5 - 1.5$
$DCA_{XY,\Lambda}$ (cm)	< 0.25
$DCA_{p-\pi^-}$ (cm)	< 0.3
Opening angle between p and π^- (rad)	> 0.01
Reconstructed z-vertex (cm)	< 17.2
Decay length (cm)	$5.0 - 25.0$

- Λ reconstruction using **KFParticle Package implemented in CbmRoot**
- Topological selection cuts applied to suppress combinatorial background from primary tracks

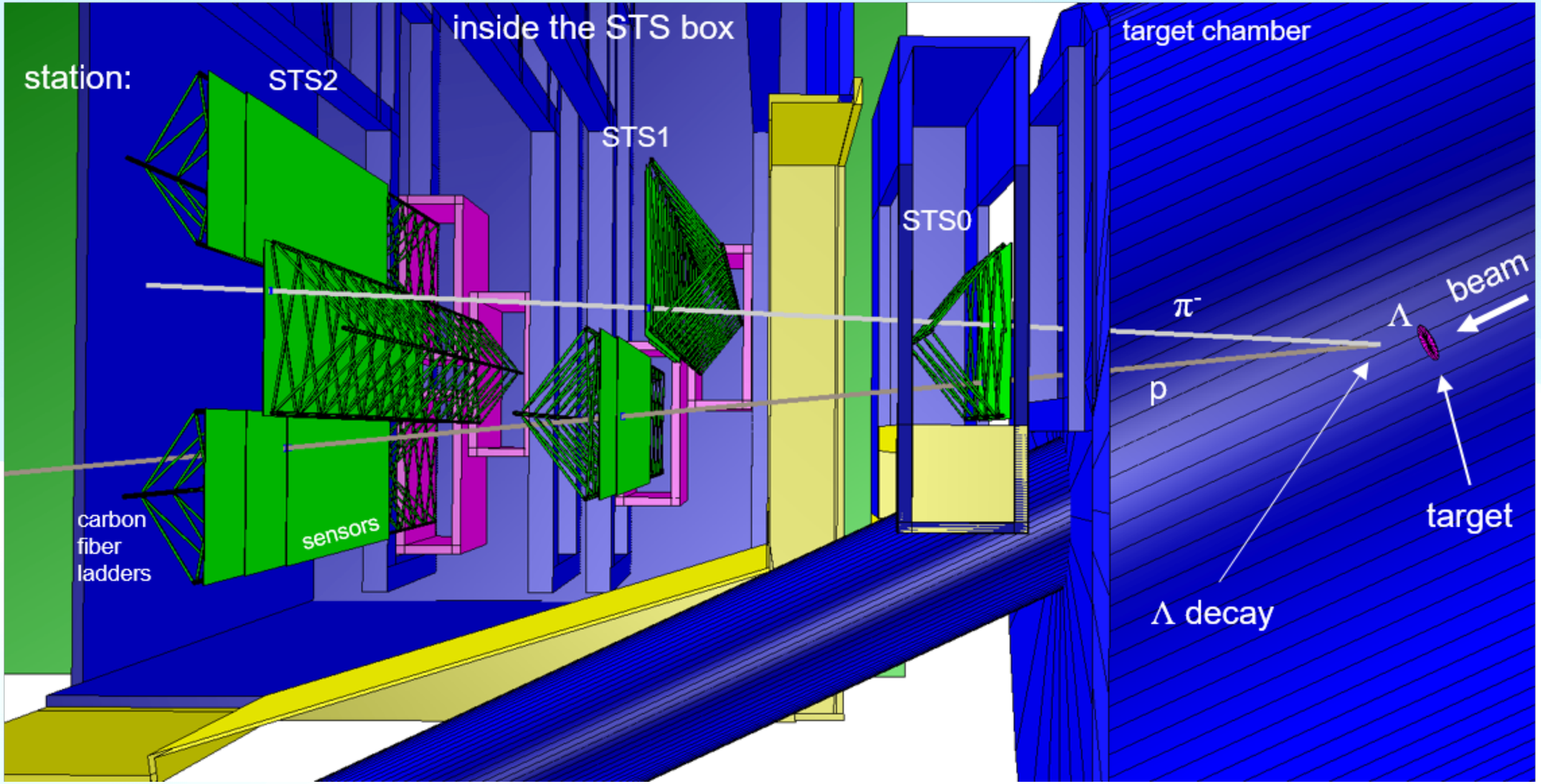
Invariant Mass Distributions

- Large excess w.r.t. mixed-event background
- Asymmetric mass distribution





GEANT Simulations



- Simulated Λ decay $\Lambda \rightarrow p + \pi^-$ is shown within the ROOT geometry of the mCBM setup 2024

Λ Source Parametrization

Thermal Boltzmann-like source

$$\frac{\mathrm{d}^2N}{\mathrm{d}p_\mathrm{T}\mathrm{d}y} \sim p_\mathrm{T} \cdot \sqrt{p_\mathrm{T}^2 + m_0^2} \cdot \exp\left(-\frac{\sqrt{p_\mathrm{T}^2 + m_0^2}}{T_\mathrm{B}}\right)$$

$$T_\mathrm{B} = T_\mathrm{eff}/\cosh(y_\mathrm{c.m.})$$

Gaussian rapidity distribution

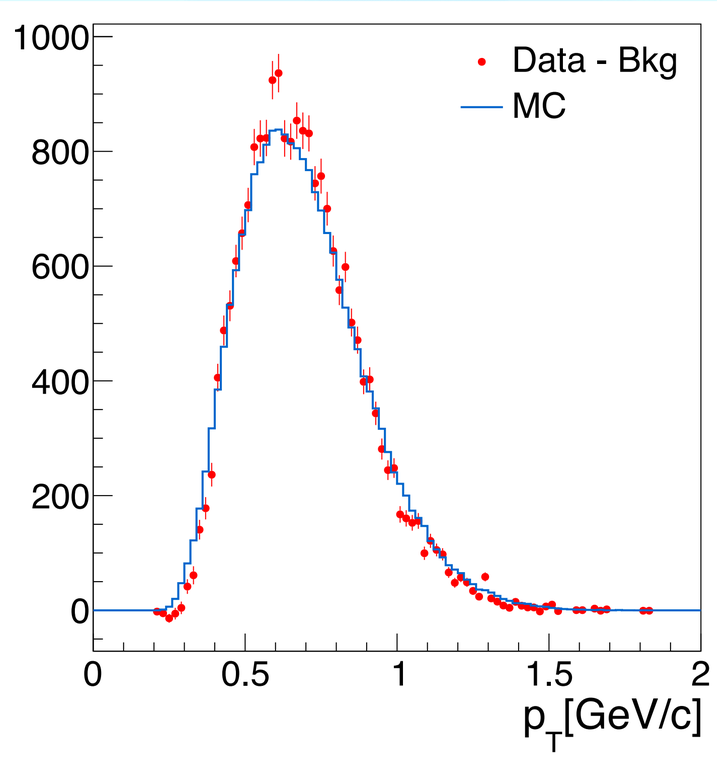
$$f(y_\mathrm{lab}) \sim \exp\left(-\frac{(y_\mathrm{lab} - \mu)^2}{2\sigma^2}\right)$$

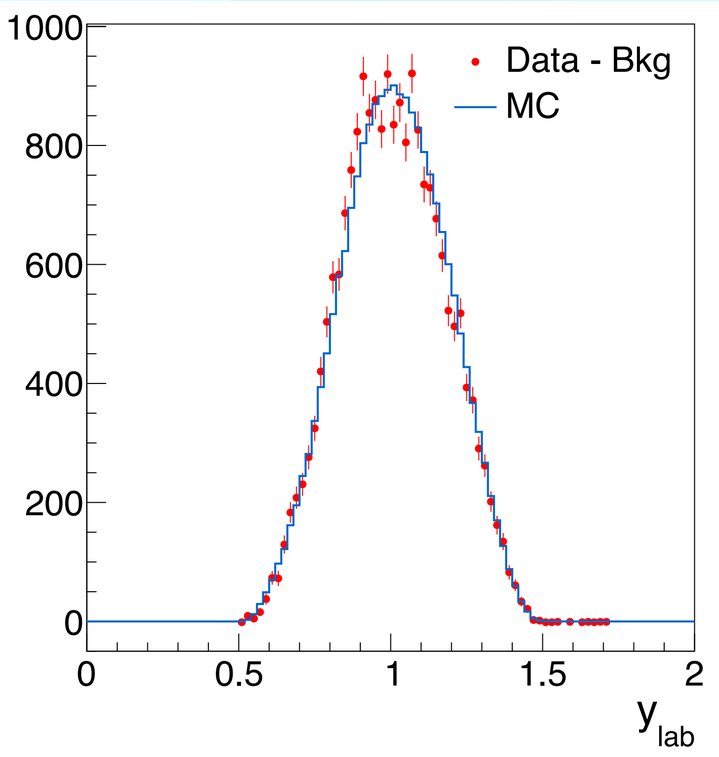
- Temperature T_{eff} and rapidity width σ constrained by FOPI measurements and PHQMD

$$T_\mathrm{eff} = 110 \pm 1\ (\mathrm{stat.})^{+9}_{-7}\ (\mathrm{syst.})\mathrm{MeV}$$

$$\sigma = 0.386 \pm 0.009\ (\mathrm{stat.})^{+0.047}_{-0.031}\ (\mathrm{syst.})$$

FOPI, Phys.Rev.C 76, 024906 (2007)
Phys.Rev.C 76 (2007) 024906

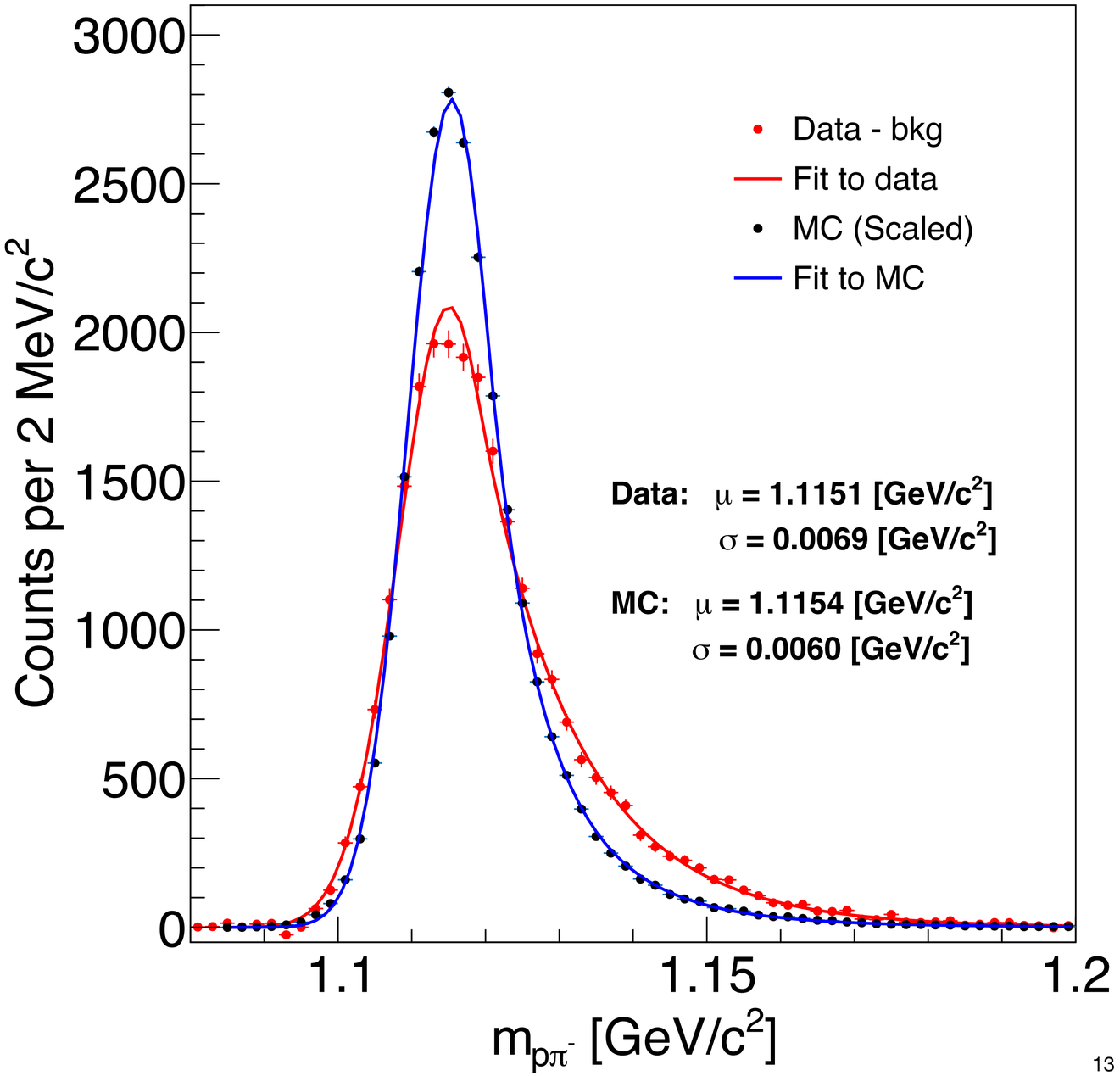




- **GEANT simulations describe the p_T and rapidity distribution in the data well**

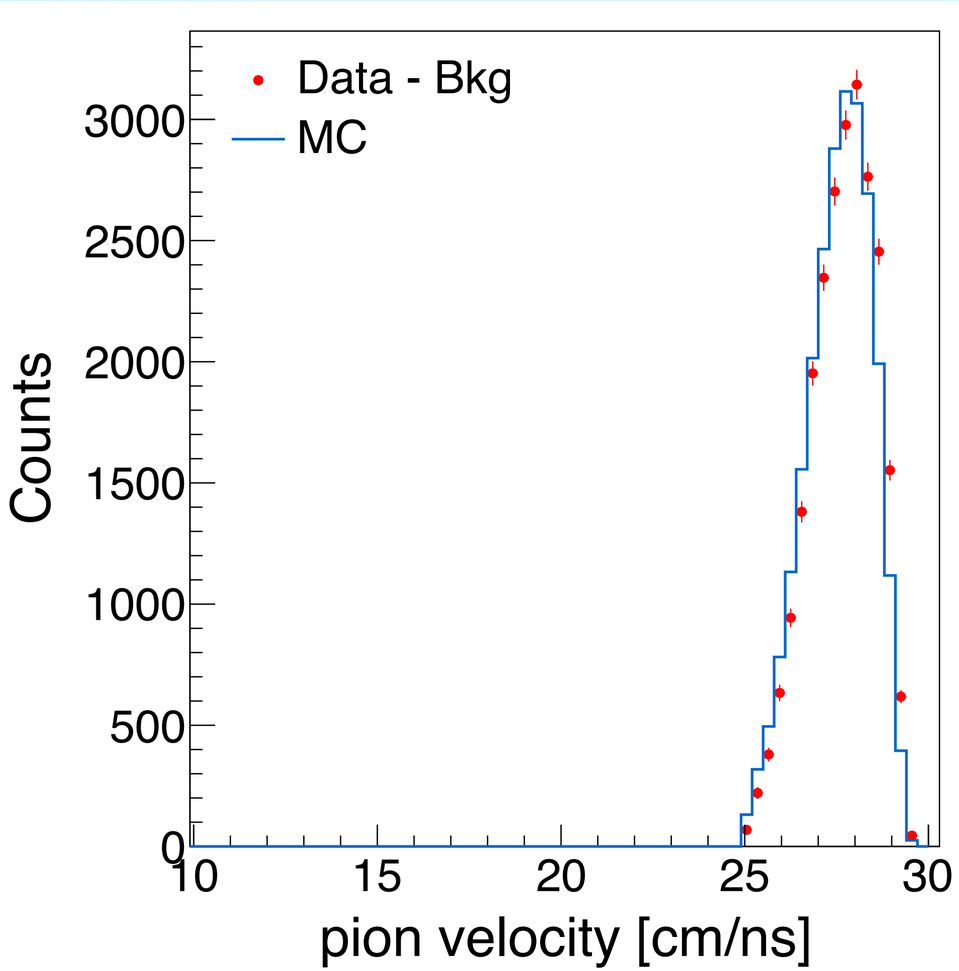
Invariant Mass Distributions (cont.)

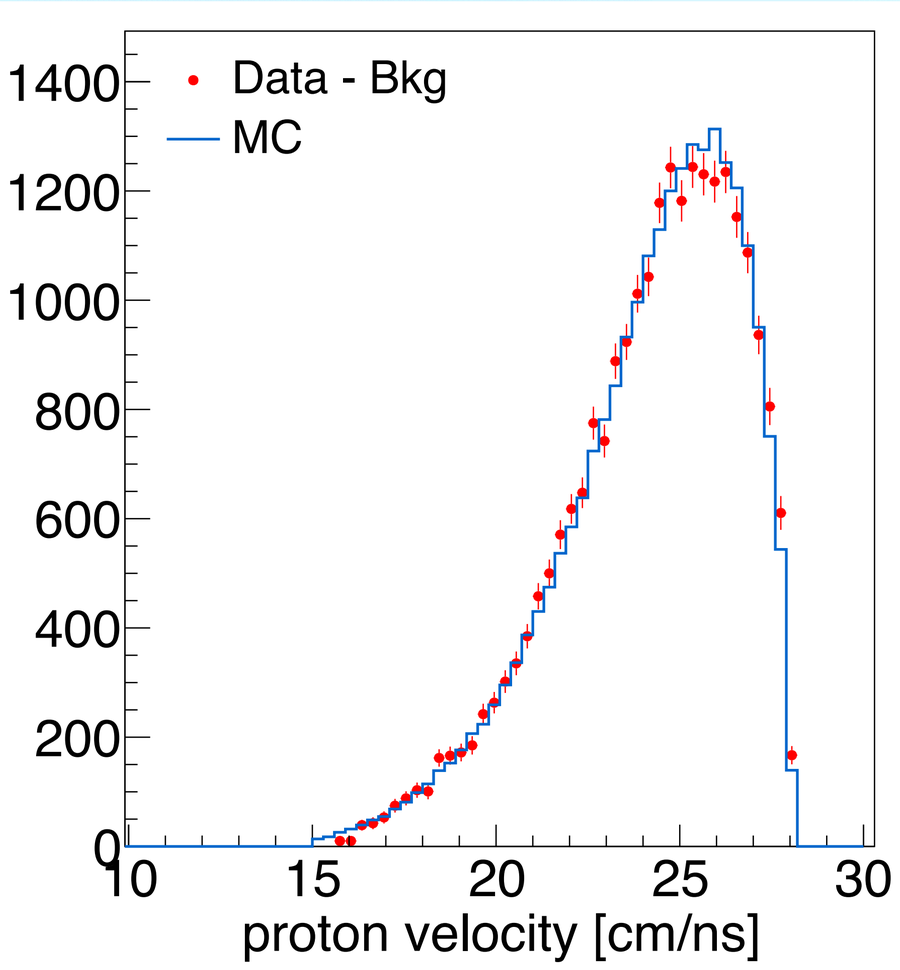
- GEANT simulations indicate an asymmetric distribution of invariant mass, similar to what is observed in the data
- Narrower width compared to data
  - Timing resolution in simulations
    - Set to 120ps
    - Quadrature sum of expected resolution from BMON and TOF
  - Misalignment in data



Particle Velocities

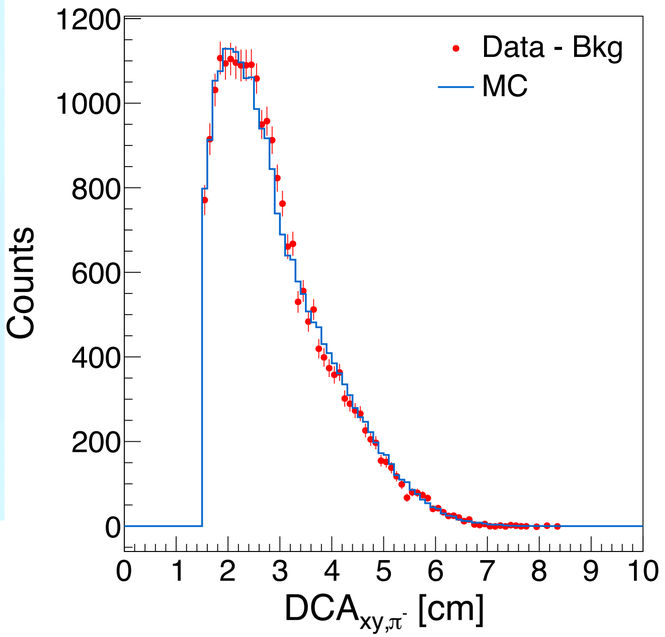
- Particle velocities measured using timing information from BMON and TOF
- **Well reproduced by the simulation**



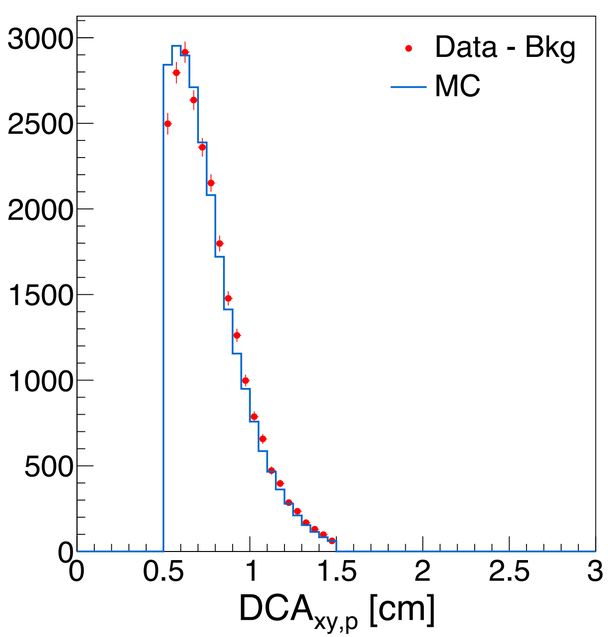


Topological Variables

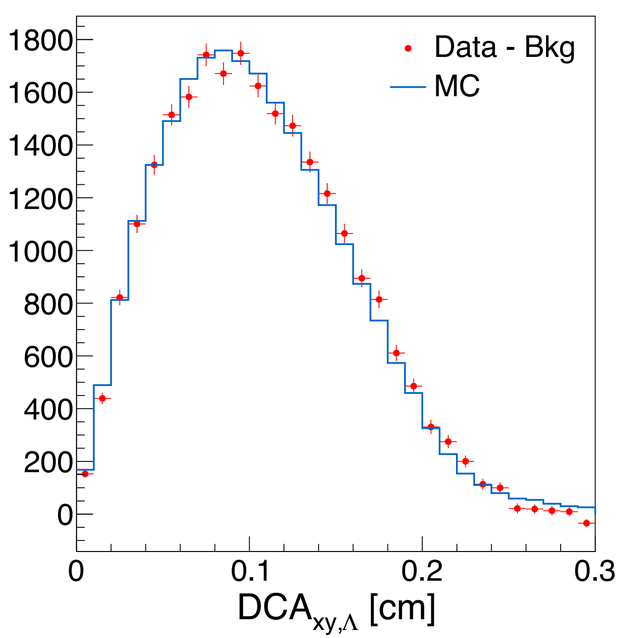
DCA$_{XY}$ of π^- to PV



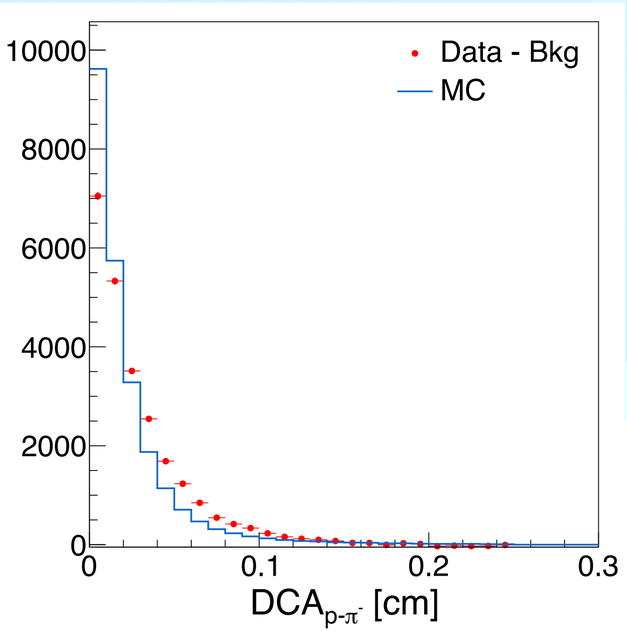
DCA$_{XY}$ of p to PV



DCA$_{XY}$ of Λ to PV



DCA b/w p & π^-



- Beam spot width in transverse plane set to 0.07 cm, consistent with the width observed during the experiment.
- DCA of π^-, p, Λ to PV very well described by the simulation
- DCA b/w π^- and p slightly narrower in simulations
  - Due to residual misalignment in data

Λ Lifetime Analysis

- If the excess in the data originates from real Λ decays, the **proper decay length ($L/\beta\gamma$)** distribution should follow an **exponential distribution**:

$$N(L/\beta\gamma) = N_0 e^{-L/(\beta\gamma c\tau)}$$

- Acceptance and efficiency $A\epsilon$ corrections according to:

$$\frac{dN}{d(L/\beta\gamma)} = \frac{1}{A\epsilon(L/\beta\gamma)} \frac{\Delta N_{\text{sig}}(L/\beta\gamma)}{\Delta(L/\beta\gamma)}$$

Acceptance X efficiency

Signal counts

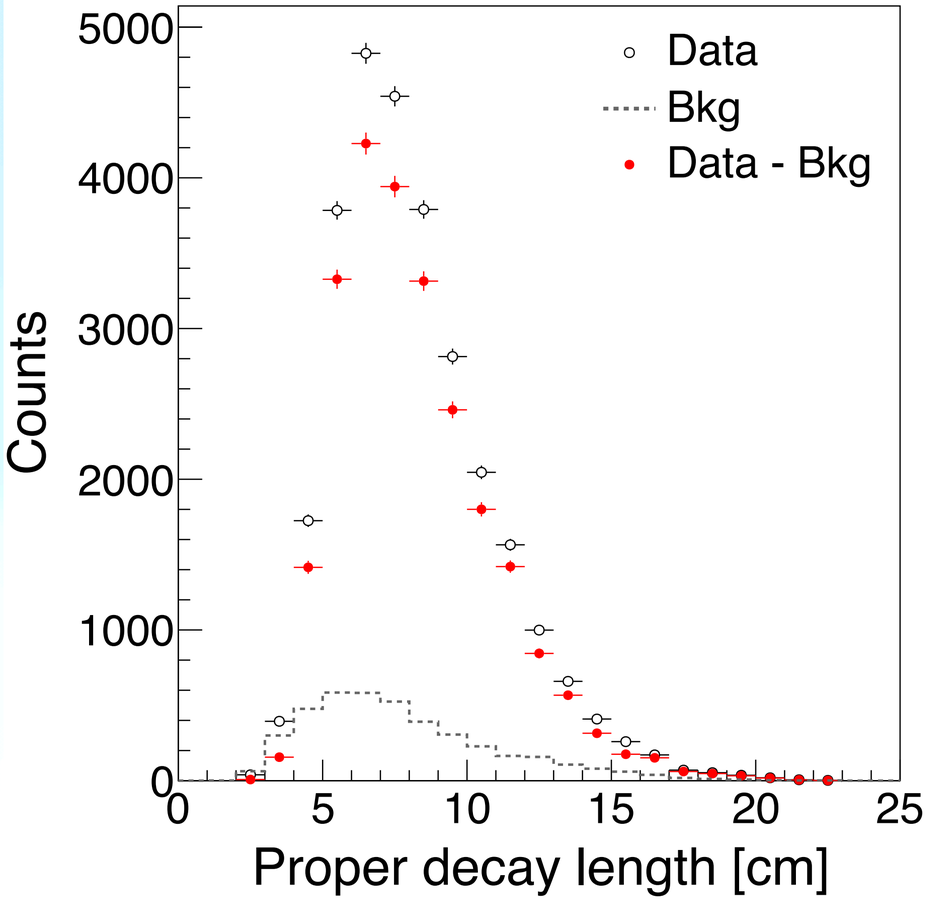
Λ Lifetime Analysis (cont.)

- Signal counts via bin counting method (1.095-1.180) GeV

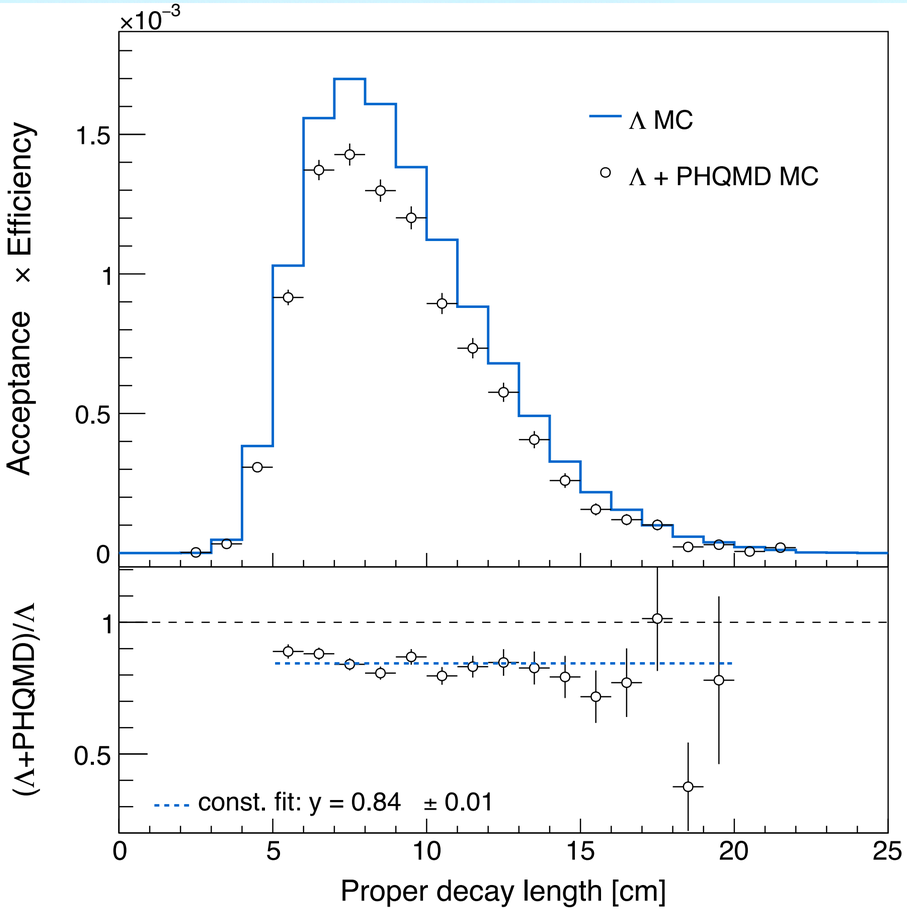
- Simulation:
  1. Pure Λ simulation
  2. Λ embed PHQMD

- Embedding simulation indicates slightly lower efficiency
  - likely from an increase of fake tracks from **hit misassociation**

Raw counts from data



Acceptance and efficiency from simulation

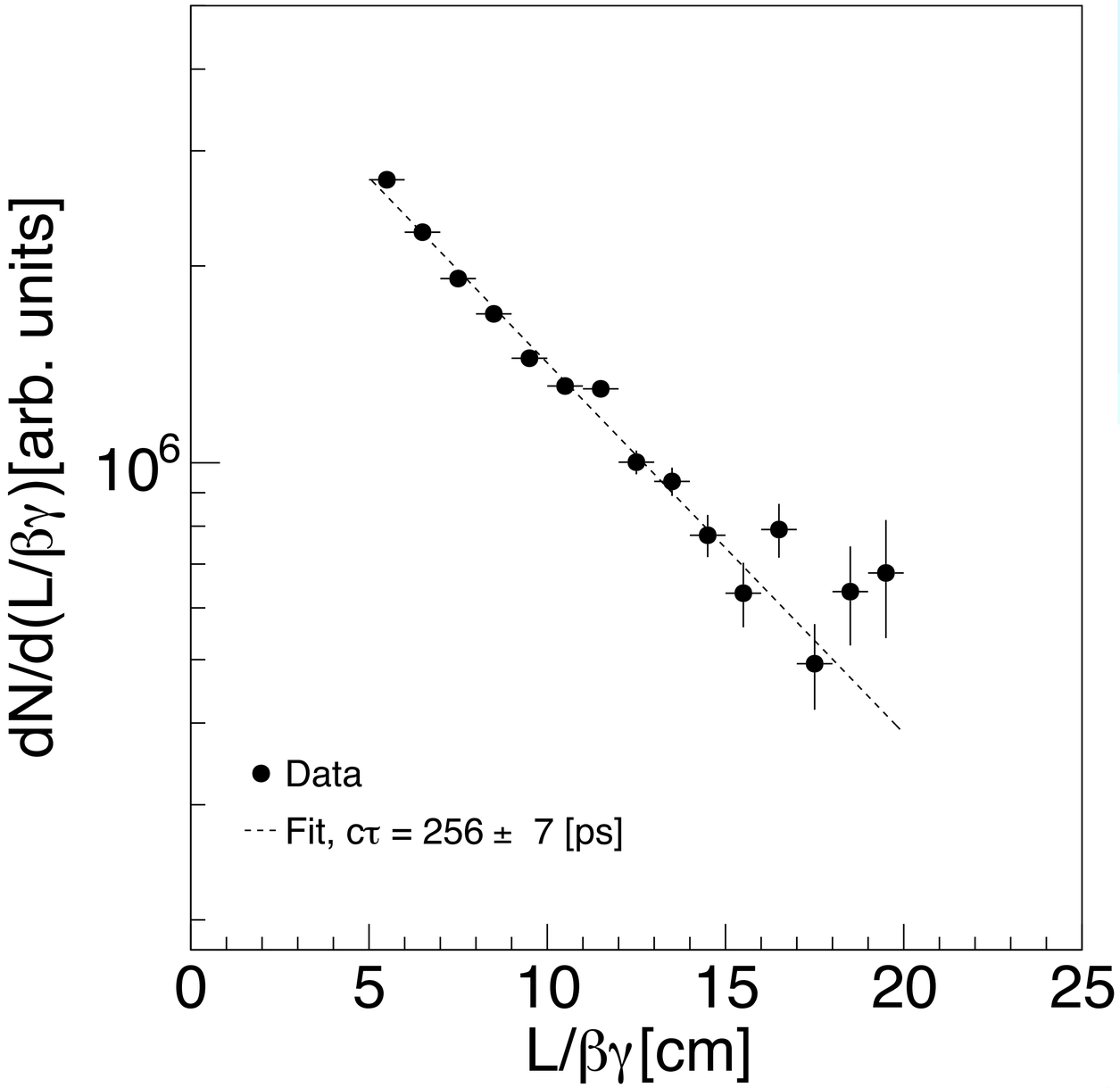


Λ Lifetime Analysis (cont.)

- Corrected distributions are well-described by an **exponential**
- Systematic uncertainties analysis:

Source	Uncertainty
Signal extraction	15 ps
Tracking efficiency	9 ps
Topological variable modeling	7 ps
Input kinematic distributions	20 ps
Total	27 ps

- **Measured lifetime:**
  - **256 ± 7 (stat.) ± 27 (syst.) [ps]**
- PDG:
  - PDG: 263 ± 2 [ps]



Λ multiplicity

- **Observed Λ count** $= 2.5 \cdot 10^4$

FOPI, Phys.Rev.C 76, 024906 (2007)
PHQMD, Phys.Rev.C 101 (2020) 4, 044905

- Expected Λ yield in MB collisions $M_\Lambda = \boxed{(0.137 \pm 0.005)} \times \boxed{0.22} = 0.030 \pm 0.001$

FOPI measurement in central collisions

Scaling factor from PHQMD

- **Expected Λ count** $= \boxed{M_\Lambda} \times \boxed{N_{events}} \times \boxed{\varepsilon_{acc}} \times \boxed{\varepsilon_{reco}} \times \boxed{\varepsilon_{det}}$

Expected MB yield

#events

Acceptance

Λ reconstruction efficiency

Detector efficiency

$$= 0.030 \times (2.9 \cdot 10^9) \times (6.2 \cdot 10^{-3}) \times (6.5 \cdot 10^{-2}) \times 0.86$$

$$= 3.0 \cdot 10^4$$

- Agrees within 25% and within estimated uncertainties (30%)

Conclusions

- Successful operation of the mCBM, demonstrator of CBM, at SIS18
- Λ hyperons reconstructed from Ni+Ni collisions at T=1.93 AGeV using prototype **TOF**, **STS**, **BMON**, and CBM reconstruction software (**CA** + **KFParticle**)
- Overall, 24578 ± 170 signal counts are observed, with a significance of 144.8 and a S/B ratio of 5.8
- Good agreement of kinematic and topological distributions with GEANT simulations
- Λ lifetime measured: 256 ± 7(stat.) ± 27(syst.) ps, consistent with literature

Demonstrated the complete data processing chain — from front-end acquisition to high-level analysis of a rare signal — validating the performance and readiness of hardware and software components for CBM measurements

Thank you for listening!!