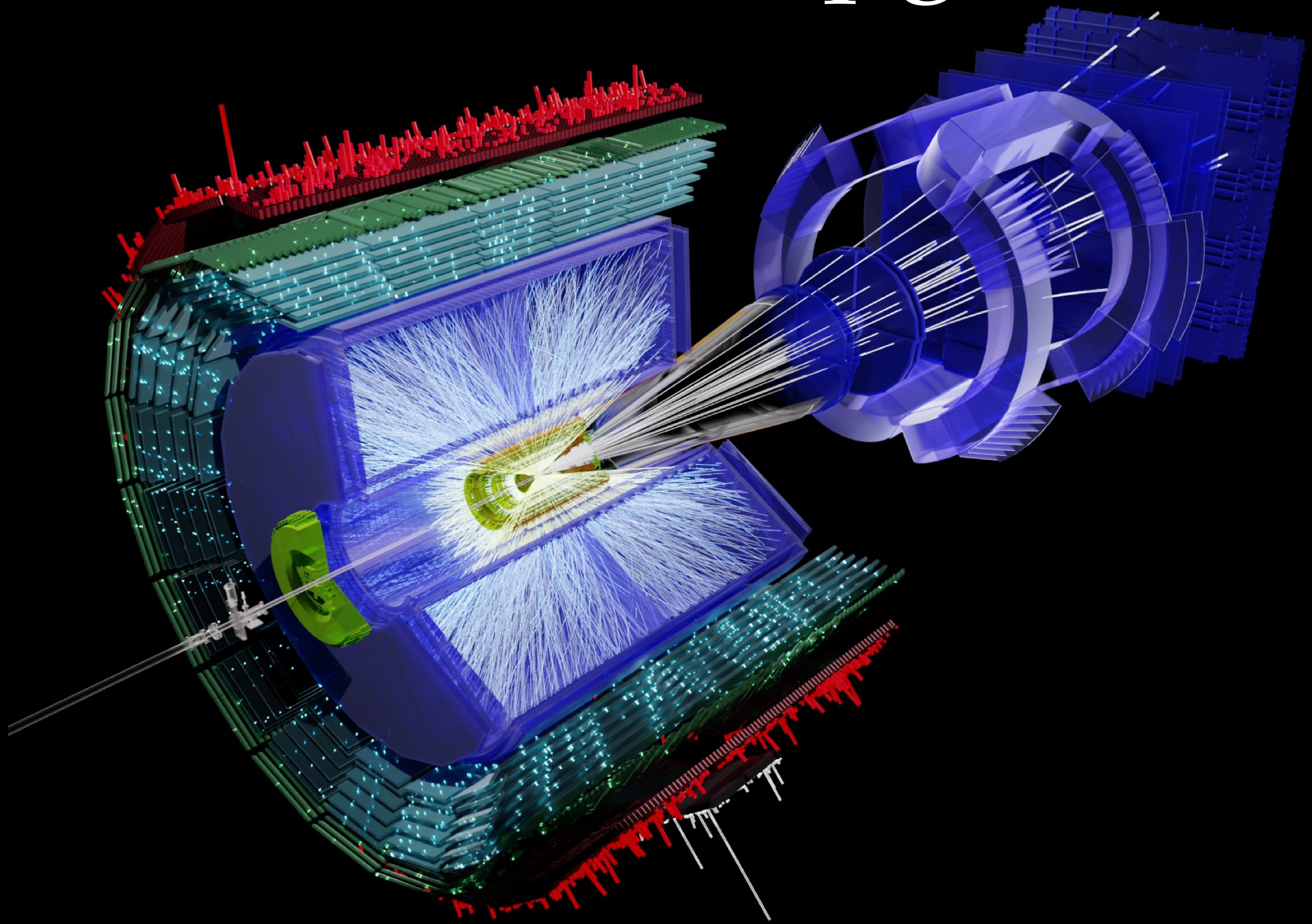
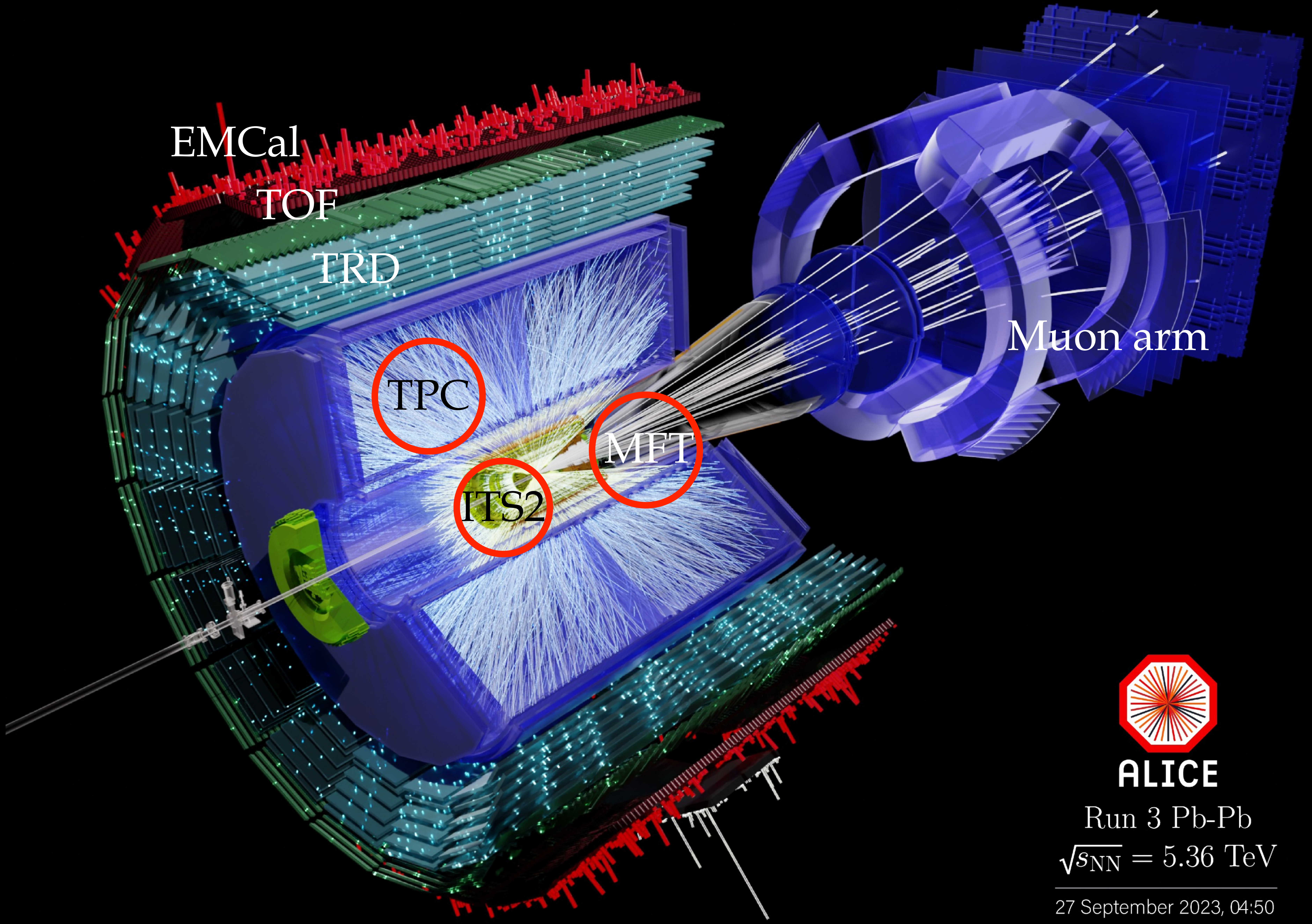
Performance and Upgrade of ALICE



Alexander Schmah for the ALICE Collaboration

LHC Days in Split - 2024

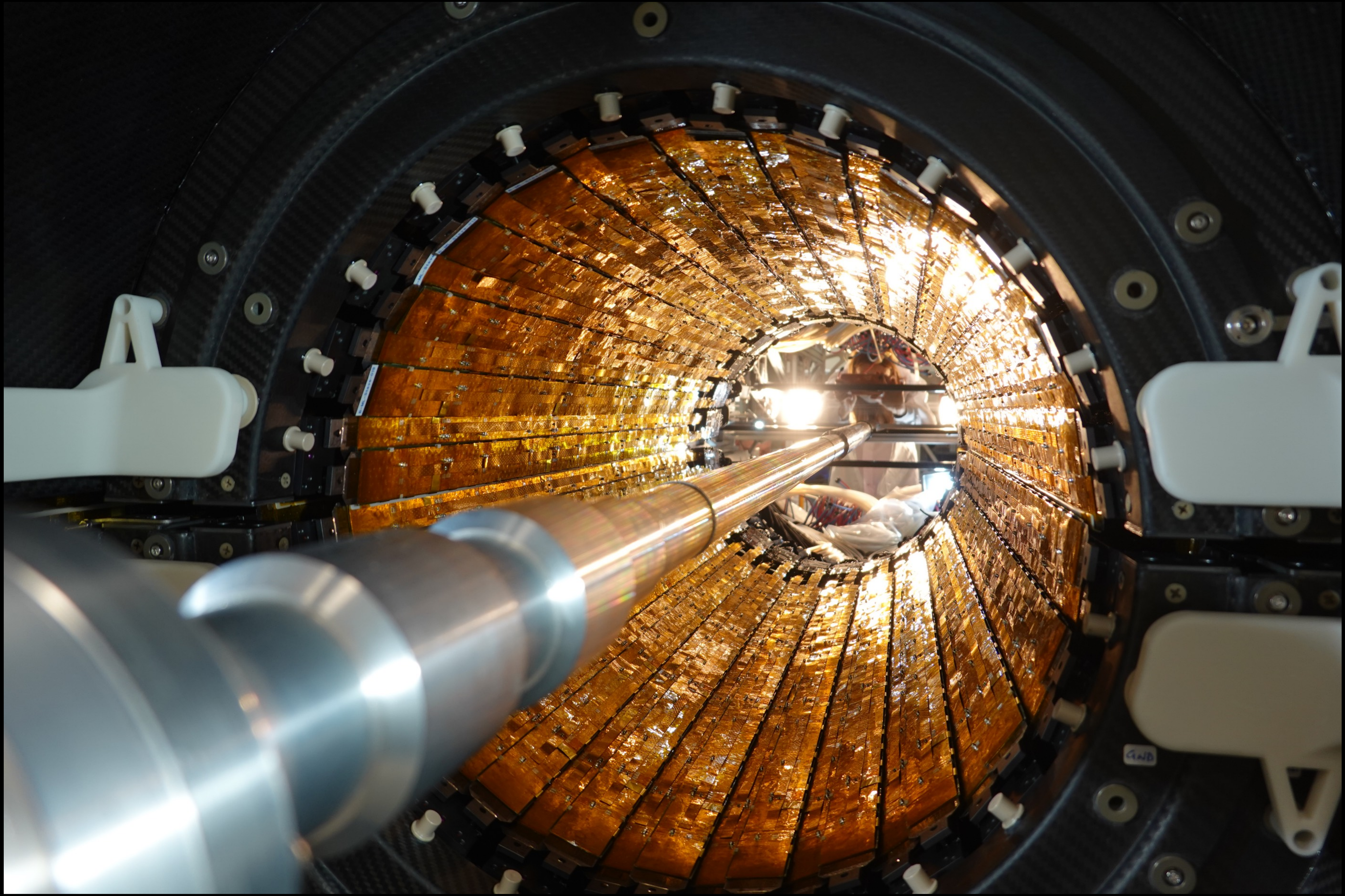

EMCal
TOF
TRD
TPC
ITS2
MFT
Muon arm
ALICE
Run 3 Pb-Pb
$\sqrt{s_{NN}} = 5.36$ TeV
27 September 2023, 04:50

Inner Tracking System (ITS2)

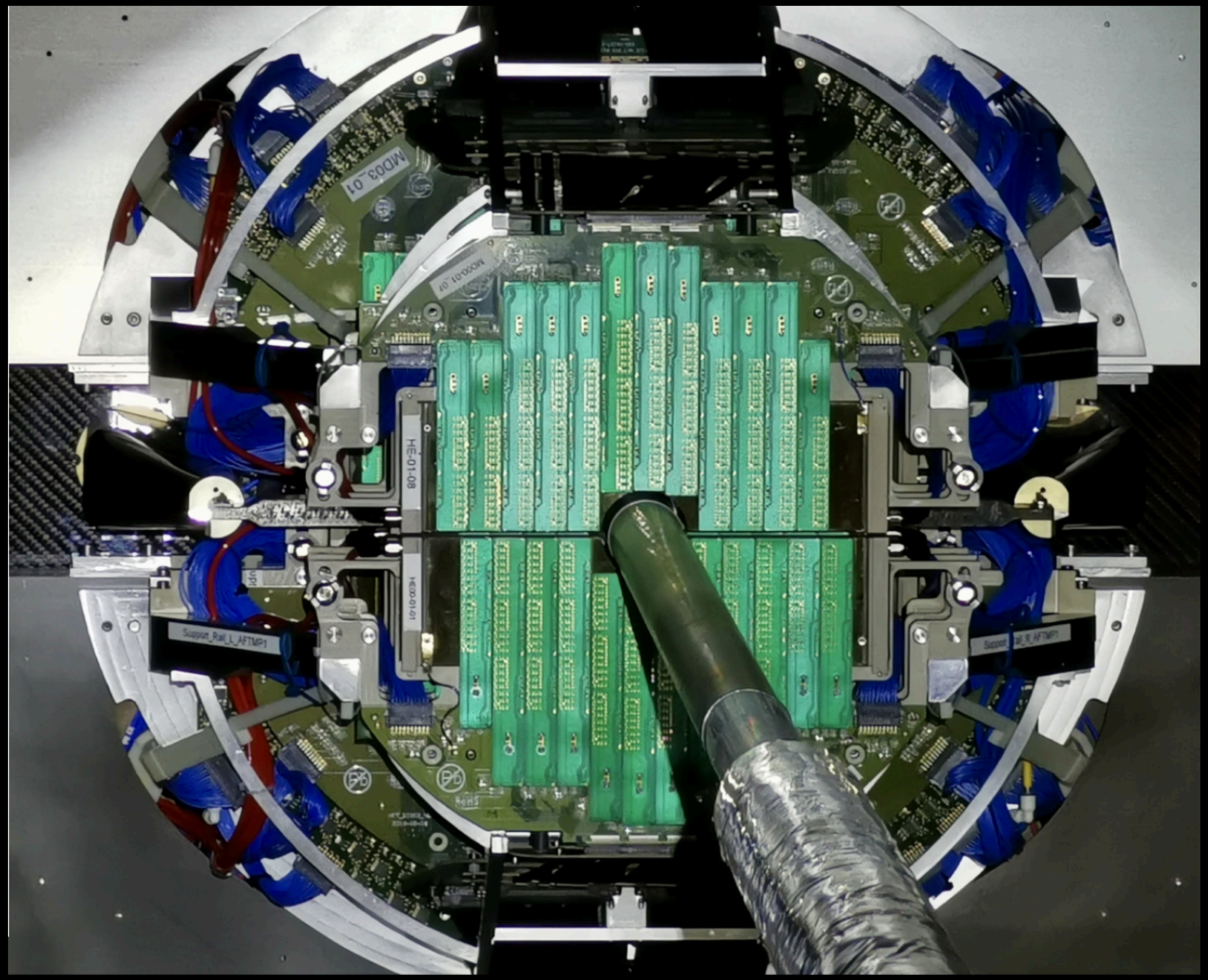
7 layers, 10 m^2 silicon
based on MAPS, 12.5 B pixels

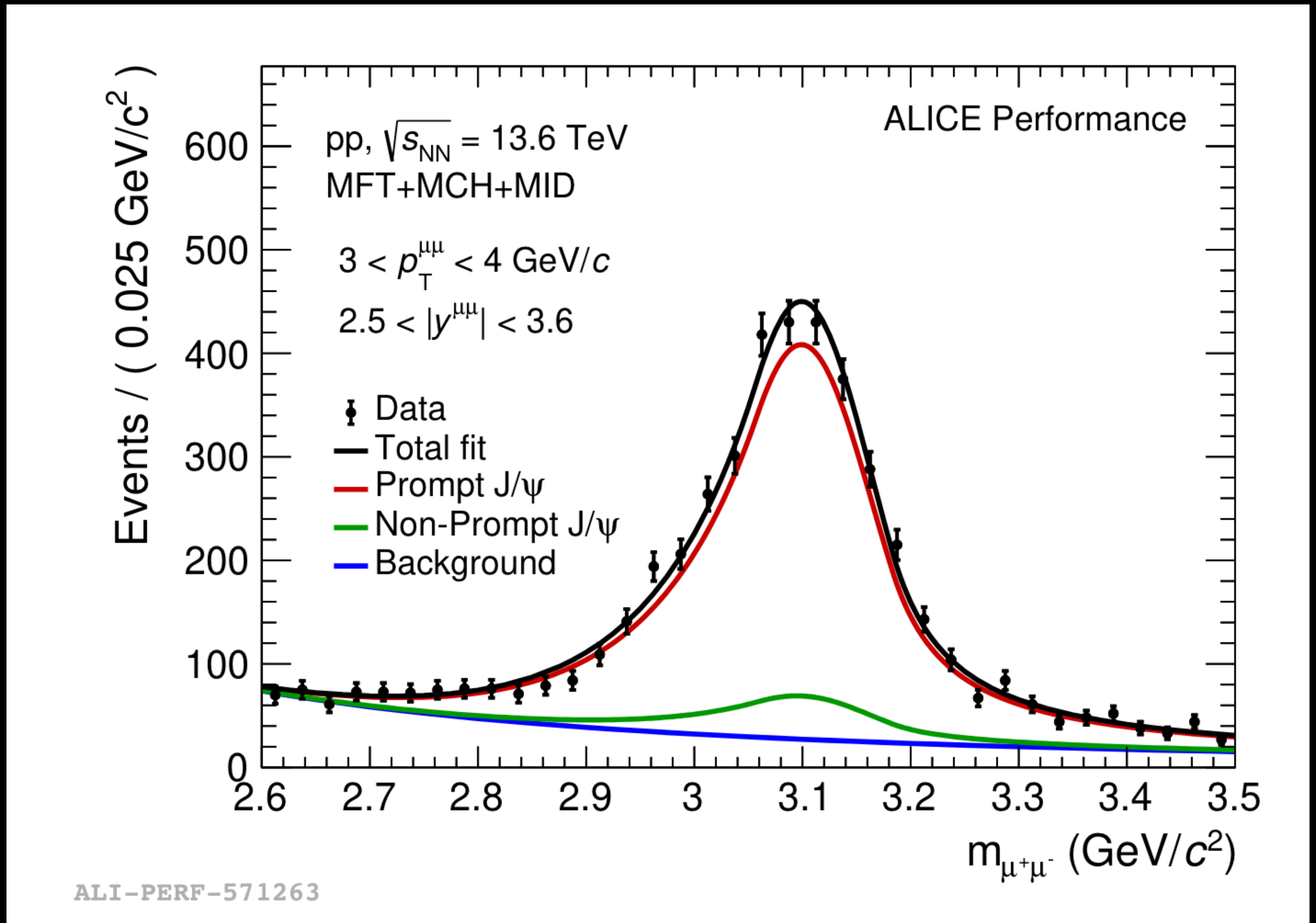
0.36% X_0 per layer
pixel size:
30 x 30 μm^2
beam pipe radius: 18mm
3x higher pointing resolution

TDR: CERN-LHCC-2013-024



Muon Forward Tracker (MFT)





TDR: CERN-LHCC-2015-001

Additional tracking in front of absorber to add charm/beauty separation capabilities.

MFT design:
- 936 ALPIDEs on 280 ladders
- 10 double-sided half-disks
- Position: 46 cm - 76.8 cm from the IP.
- Spacial resolution: 5 μm.

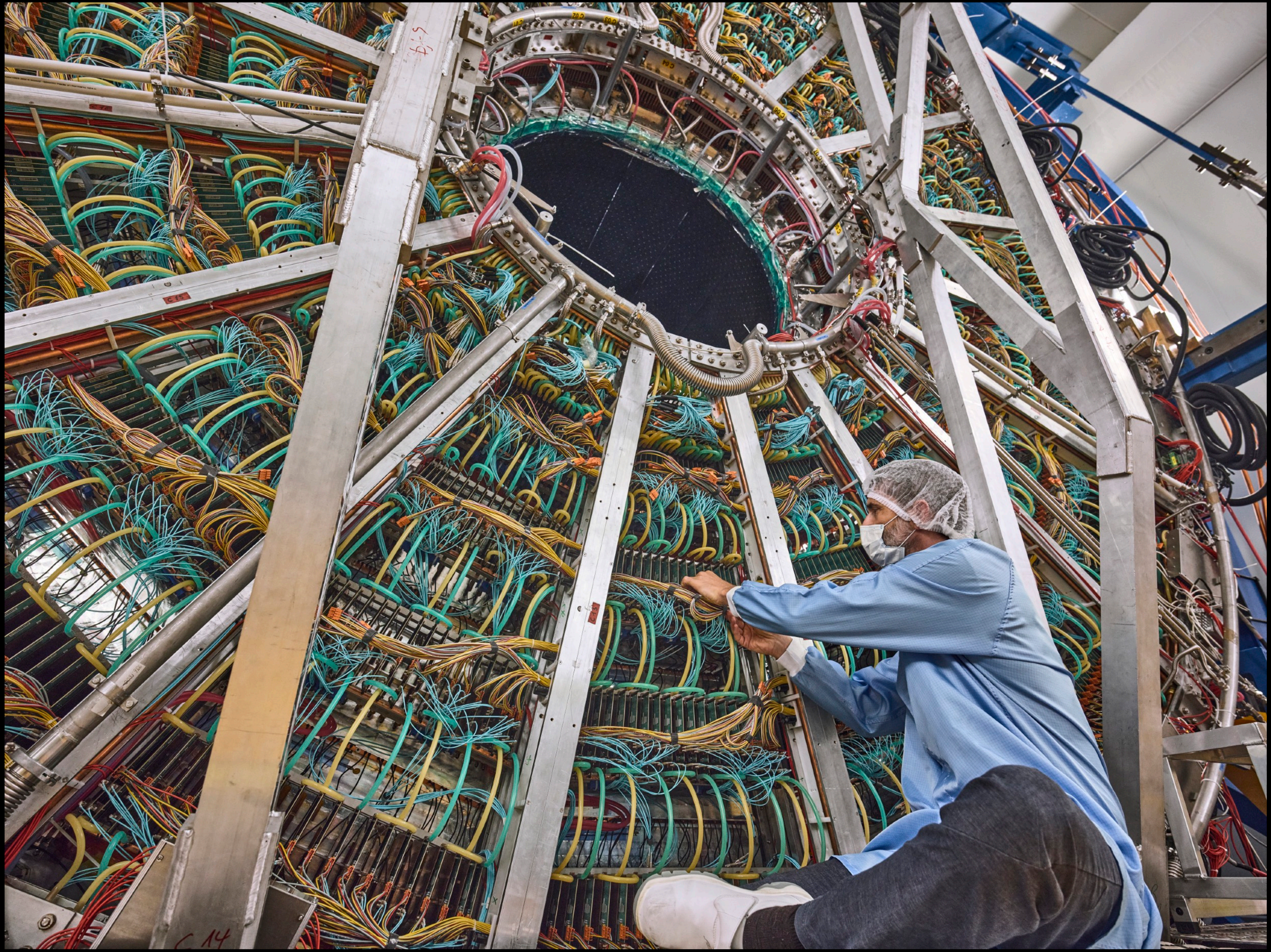
Reconstructed tracks:
- Acceptance: $2.4 < \eta < 3.6$ (limitation at high rapidity because of the beam pipe).
- Pointing resolution at IP region: ~ 100 µm (to be compared to $\gamma\beta c$ B ≈ 5 mm).

Time Projection Chamber (TPC)

Time Projection Chamber (TPC)
V = 88m³, ΔT < 0.1 K

Quadruple-GEM readout
Continuous readout
3.4 TeraBytes/second

TDR: CERN-LHCC-2013-020



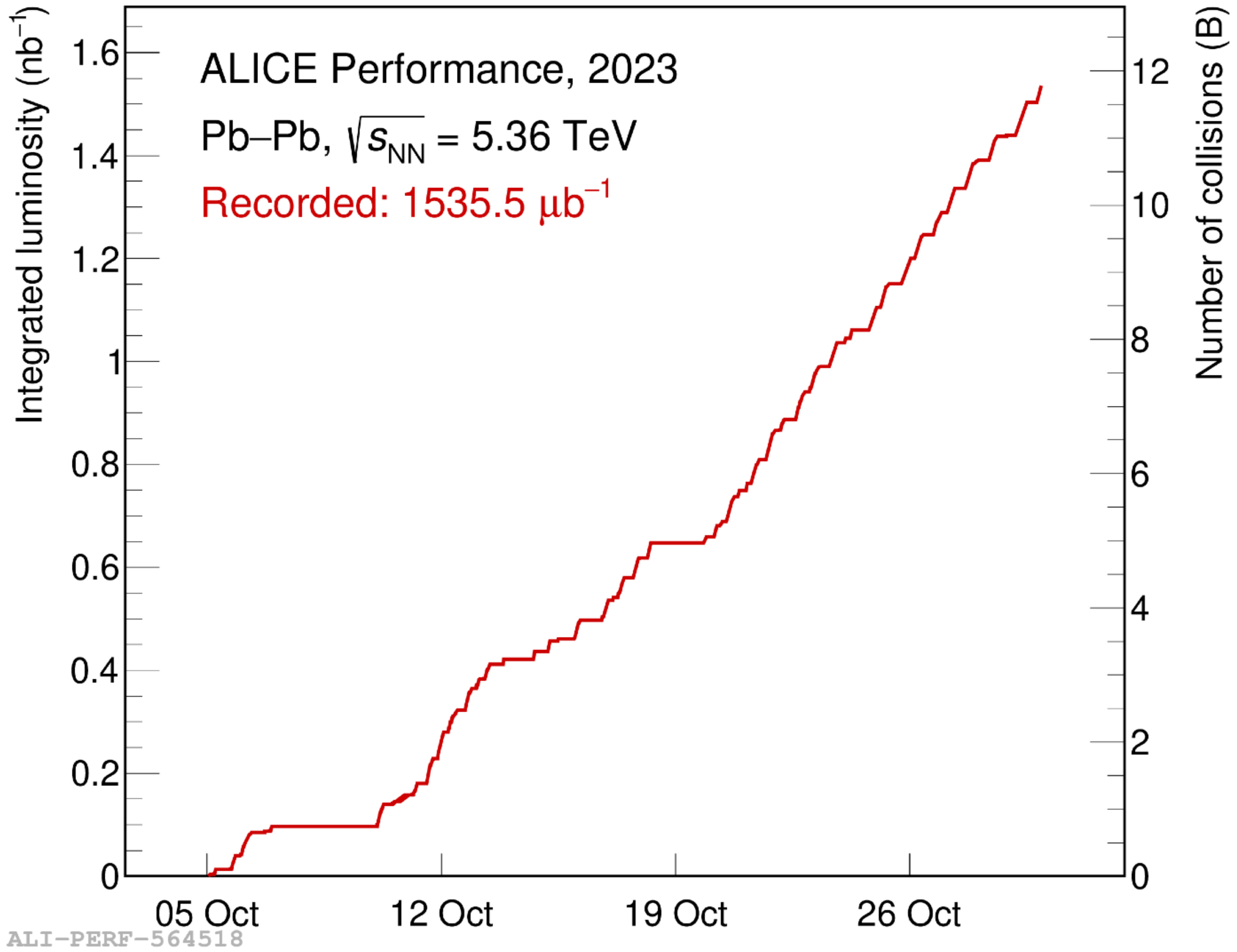
ALICE computing

3.6 TeraBytes/s raw data
→ up to 170 GBytes/s to disk
50k CPUs
2700 GPUs
130 PetaBytes disk

New online/offline system (O^2)

TDR (O^2): CERN-LHCC-2015-006

Pb-Pb integrated luminosity 2023



Run 1 + 2 (2009 - 2018)

pp : 0.032pb^{-1} minimum bias collisions, 2 billion events

Pb-Pb : 315 million minimum bias collisions, 149 million 0-10% central collisions

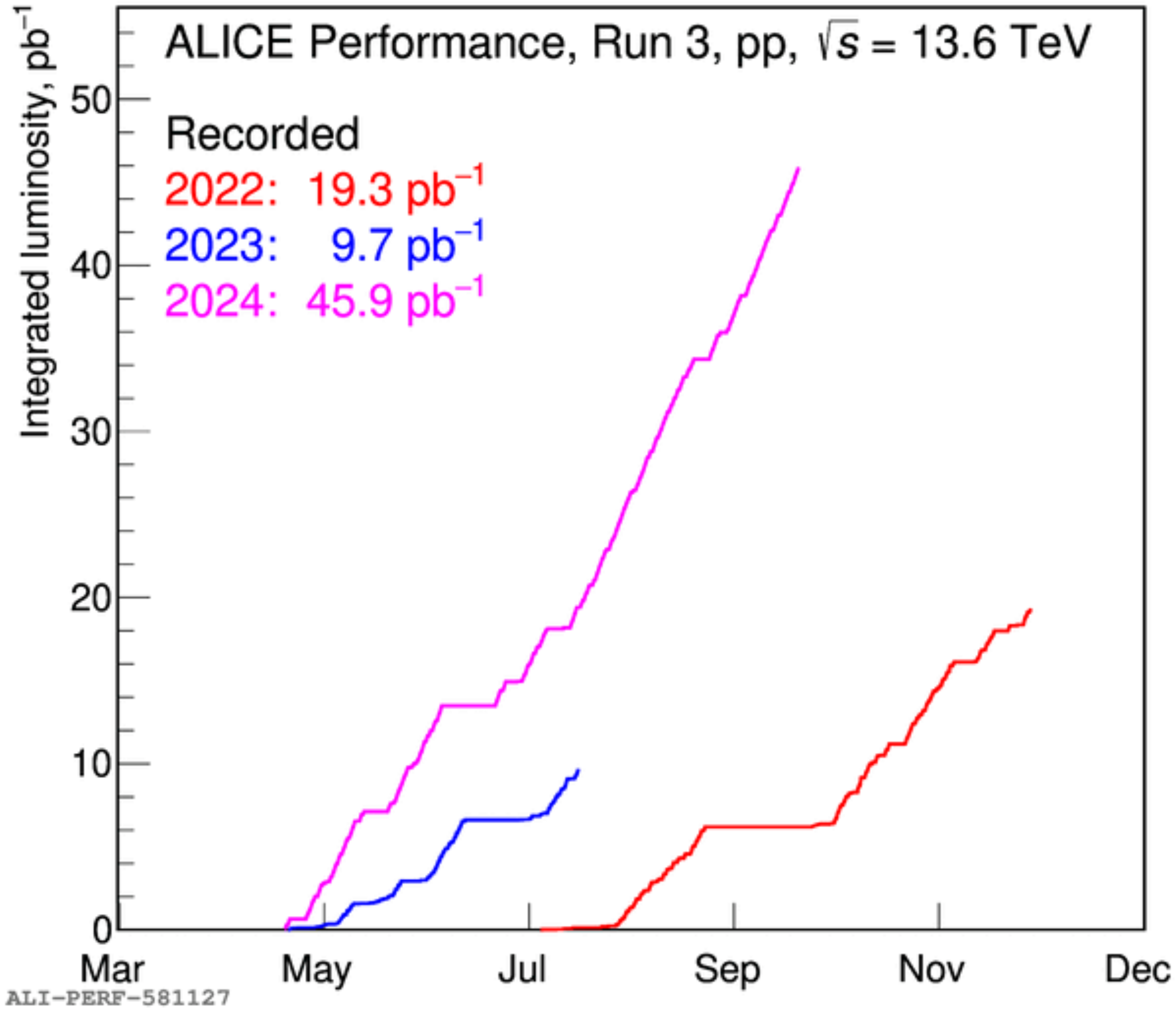
Run 3 (2022 - now)

2022 pp: 19.3pb^{-1} or 1000 billion minimum bias collisions

2023 pp: 9.7pb^{-1} or 500 billion minimum bias collisions

2023 Pb-Pb: 1.5nb^{-1} or 12 billion minimum bias collisions

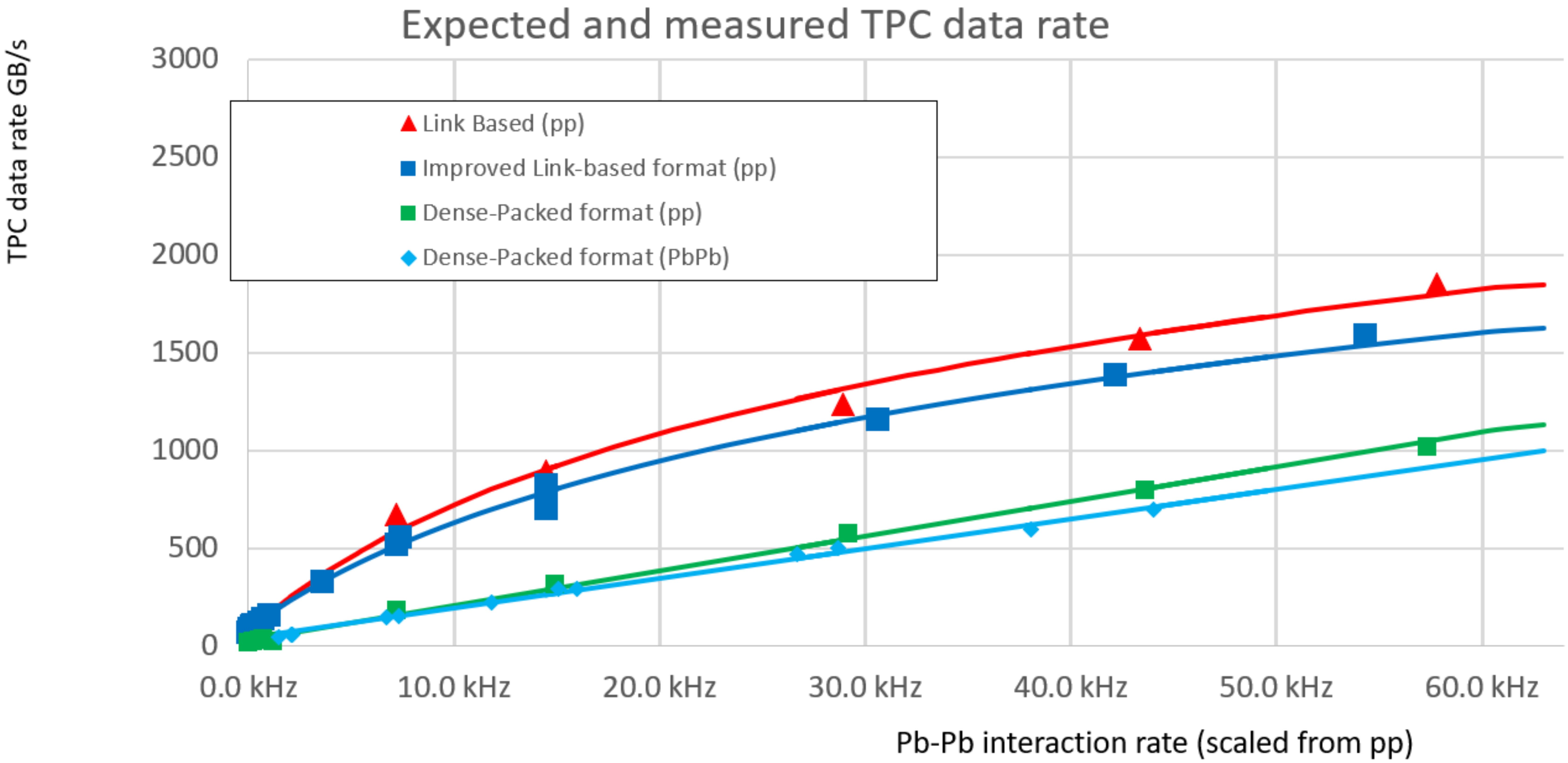
p-p integrated luminosity



- 2024 integrated luminosity is larger than initial goal.

TPC Performance

TPC data rates in Run 3



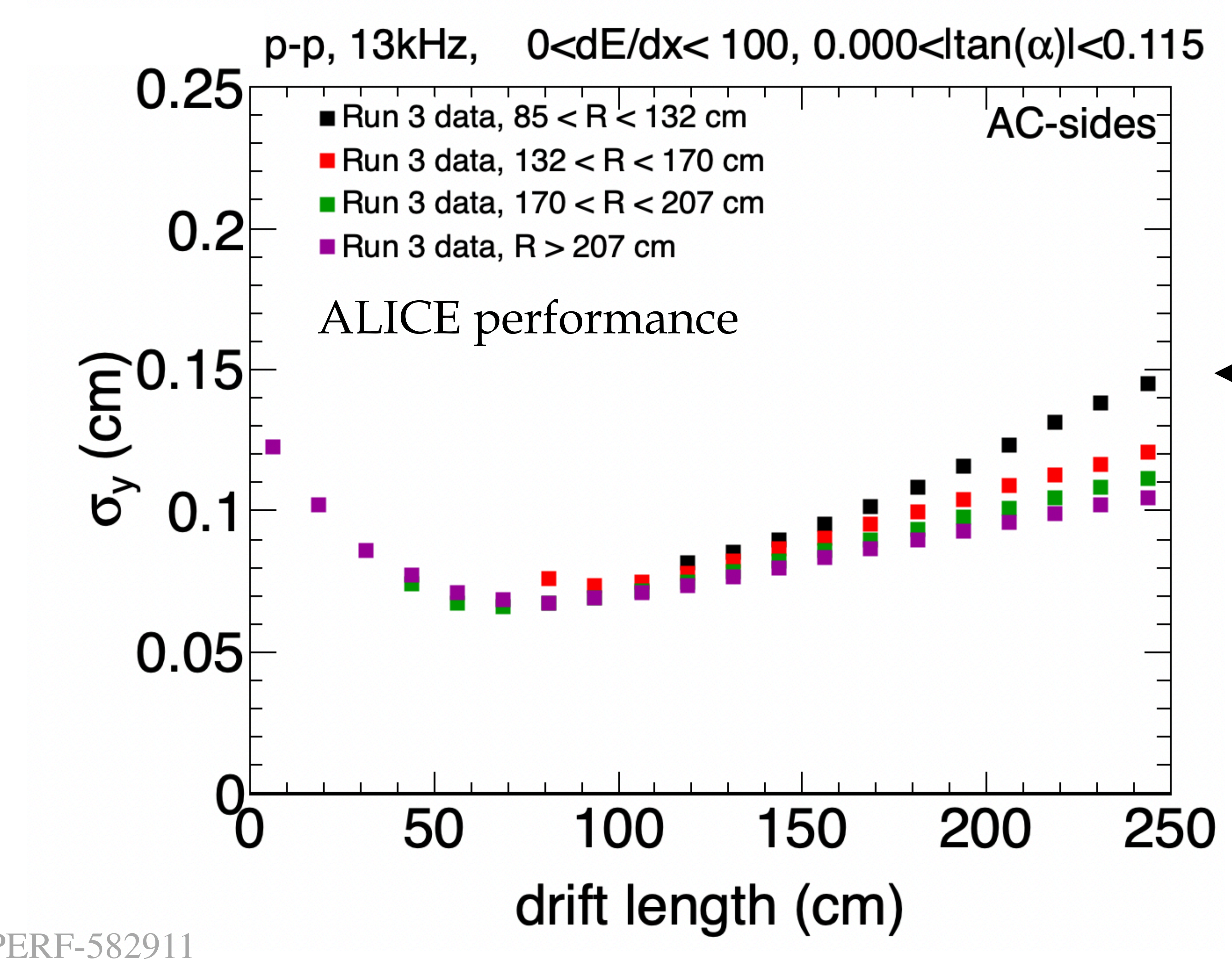
Dense packed format

~50 kHz Pb-Pb: 800 GBytes/s (CRU - Common Readout Unit)

→still about 20% margin to readout limit

Intrinsic TPC resolution

TDR: CERN-LHCC-2013-020



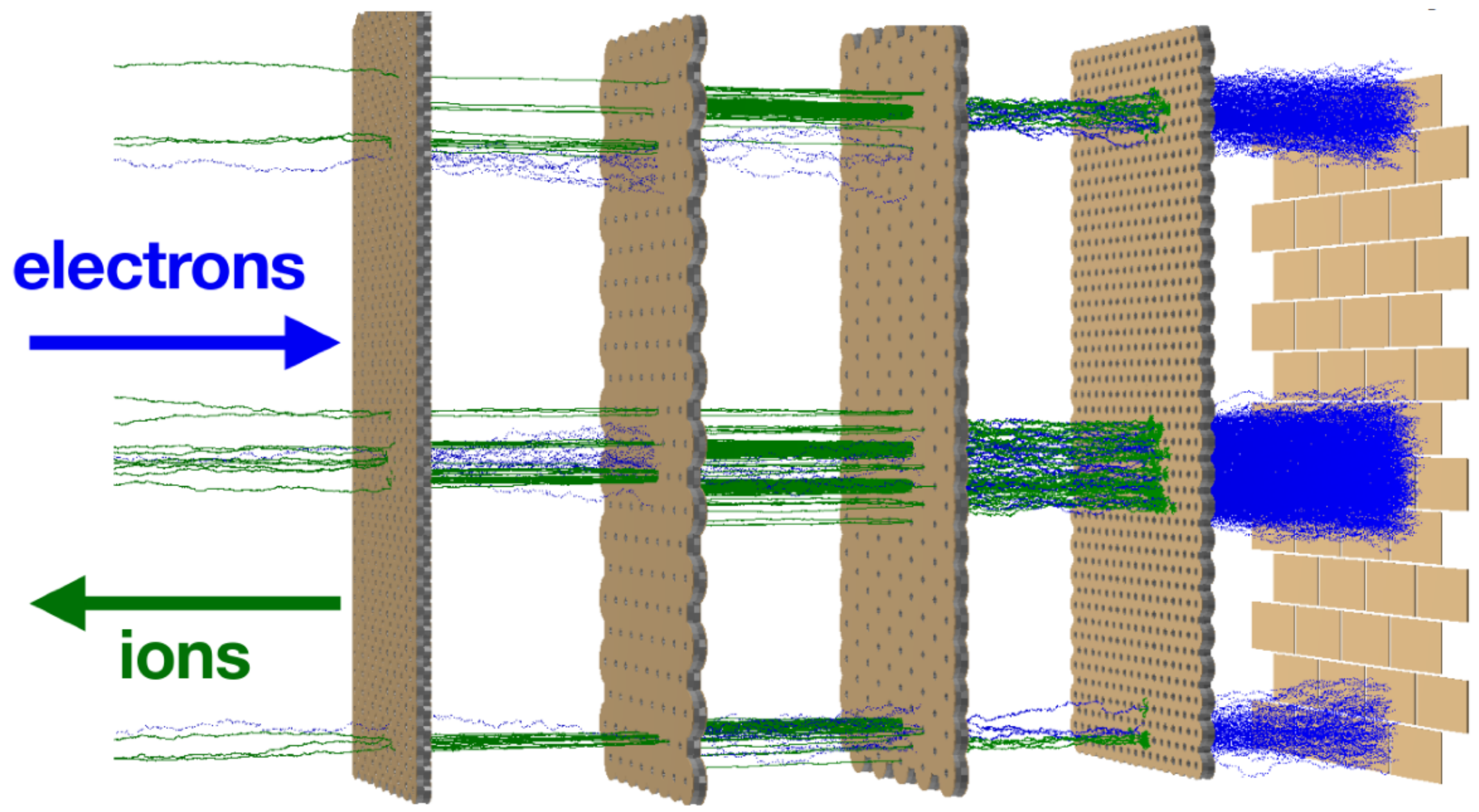
IROC value from TDR, including used GEM settings.

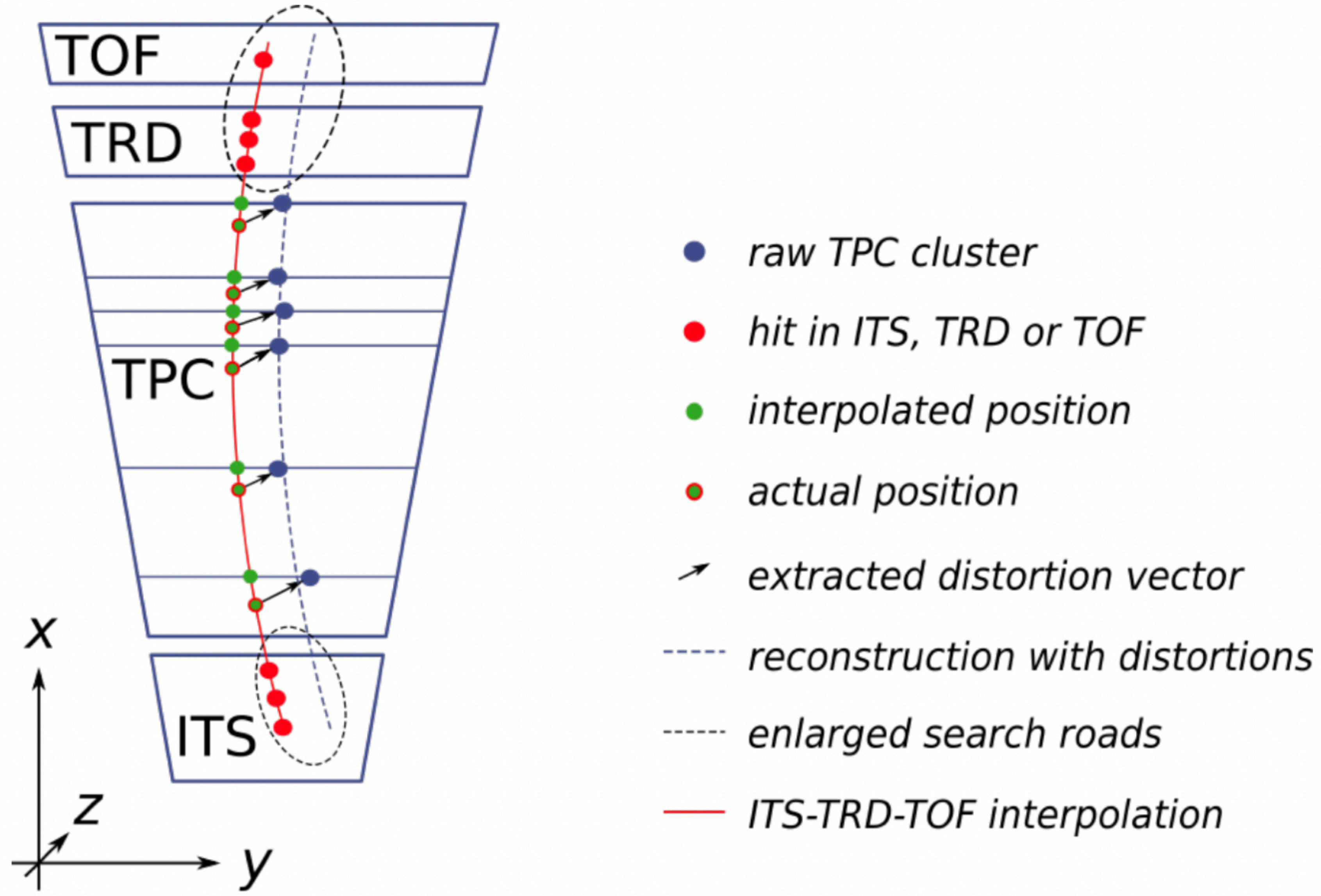
- Very low IR p-p → low occupancy → mainly TPC intrinsic effects.
- At low drift length we have a significant fraction of one pad clusters.
- At larger drift length diffusion is important and therefore multi-pad clusters dominate.
- **TPC intrinsic resolution is in perfect agreement with TDR expectations!**

Space Charge Distortions (SCD)

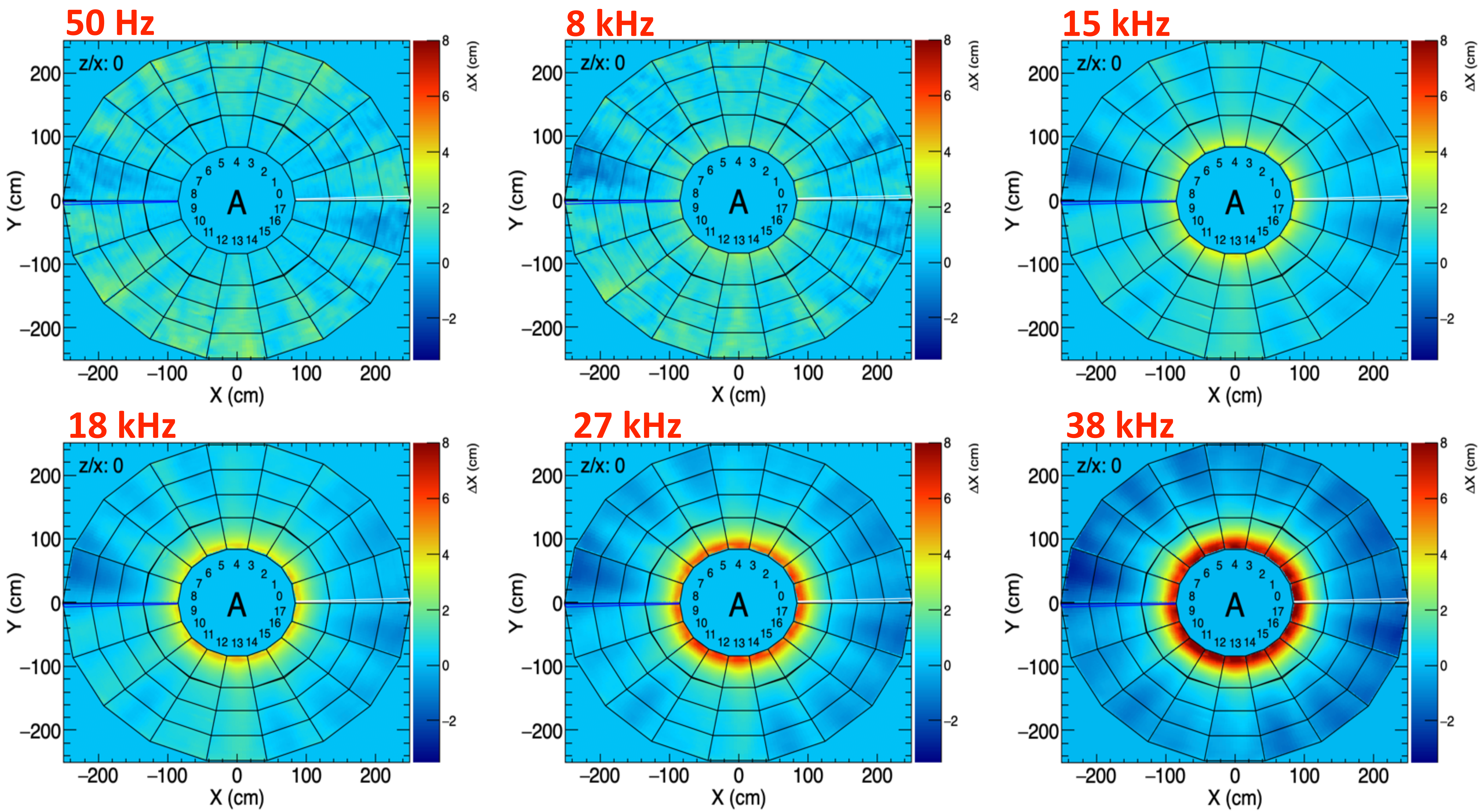
- Ions from the amplification stage move back into the drift volume

- Ions are slow (~200 ms for full drift)
  - Ions from large number of events pile up (~10k events @ 50 kHz IR)
  - Significant space-charge density (SCD) in drift volume
  - Large average distortions (O(5-10 cm))
  - Intrinsic TPC resolution: ~200 μm
  - Space charge density: $\rho_{SC} \sim I_{prim} \bullet gain \bullet IBF$ (ion back flow)
- Correction strategy based on reference tracks using ITS extrapolations.
- Corrections every few ms!
- Challenge for Run 3 with continuous readout



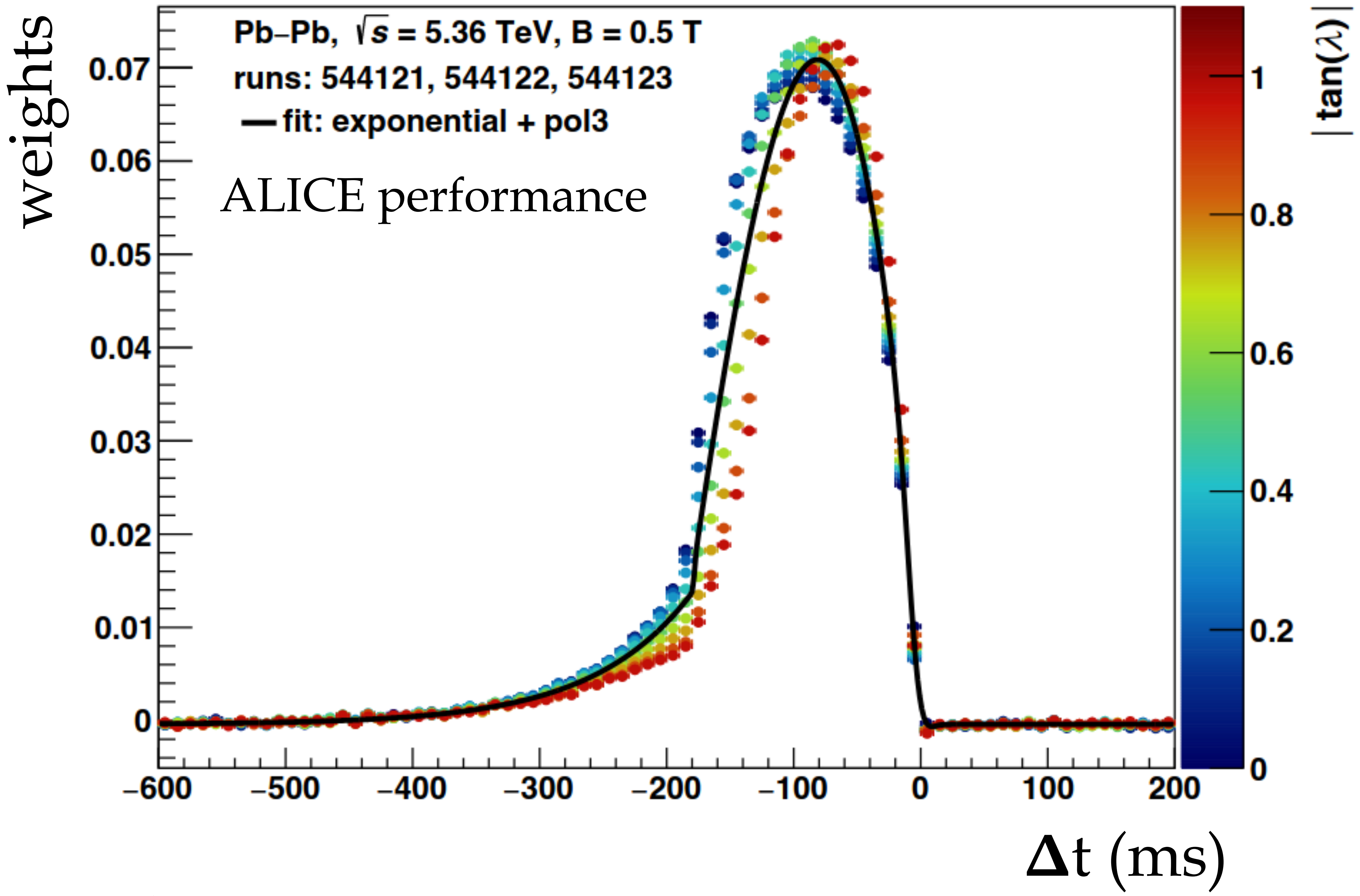


Space charge distortion maps

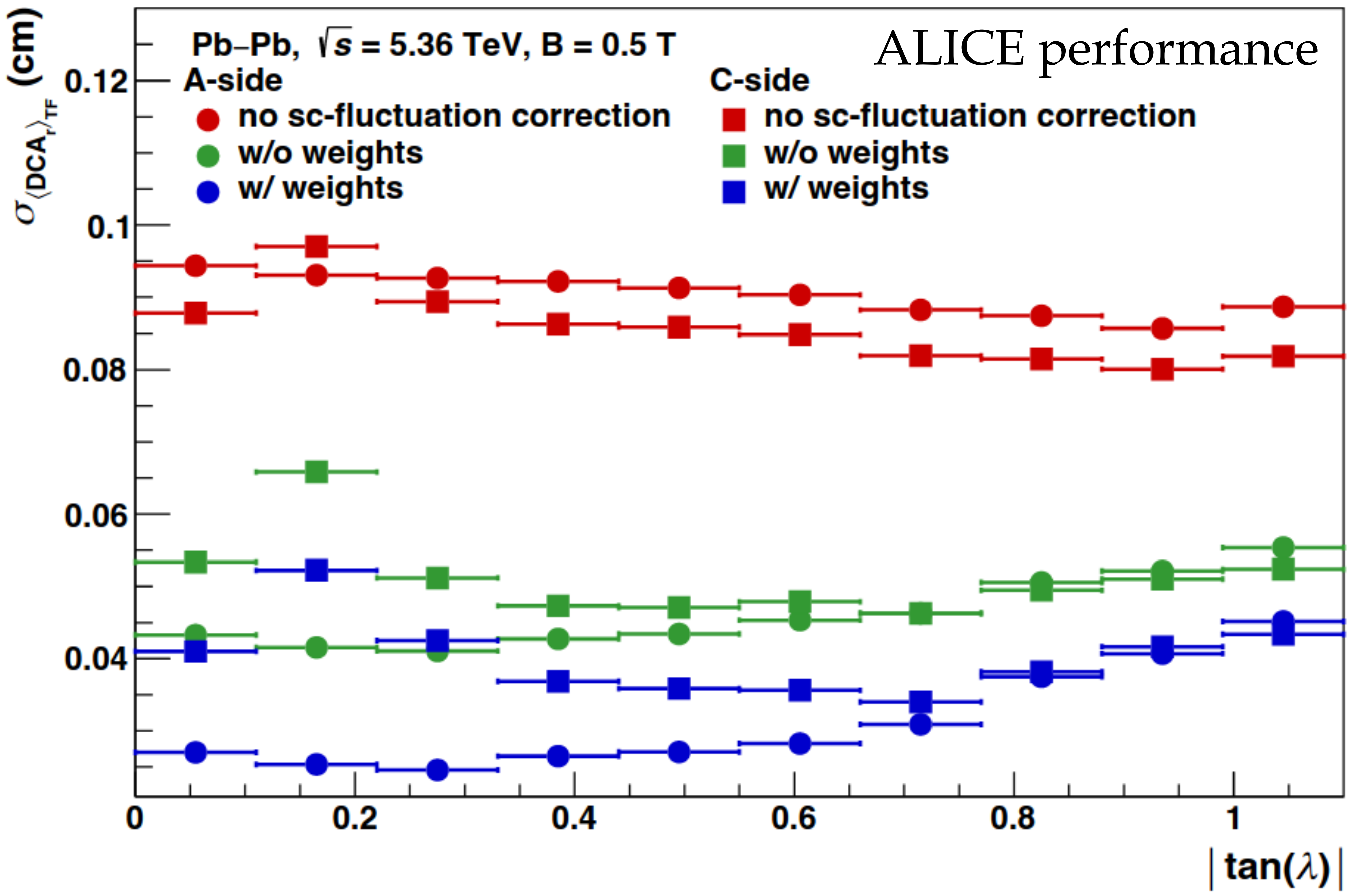


- Average maps calculated once per hour.
- Distortions up to ~8 cm in radial direction!

Fluctuation corrections

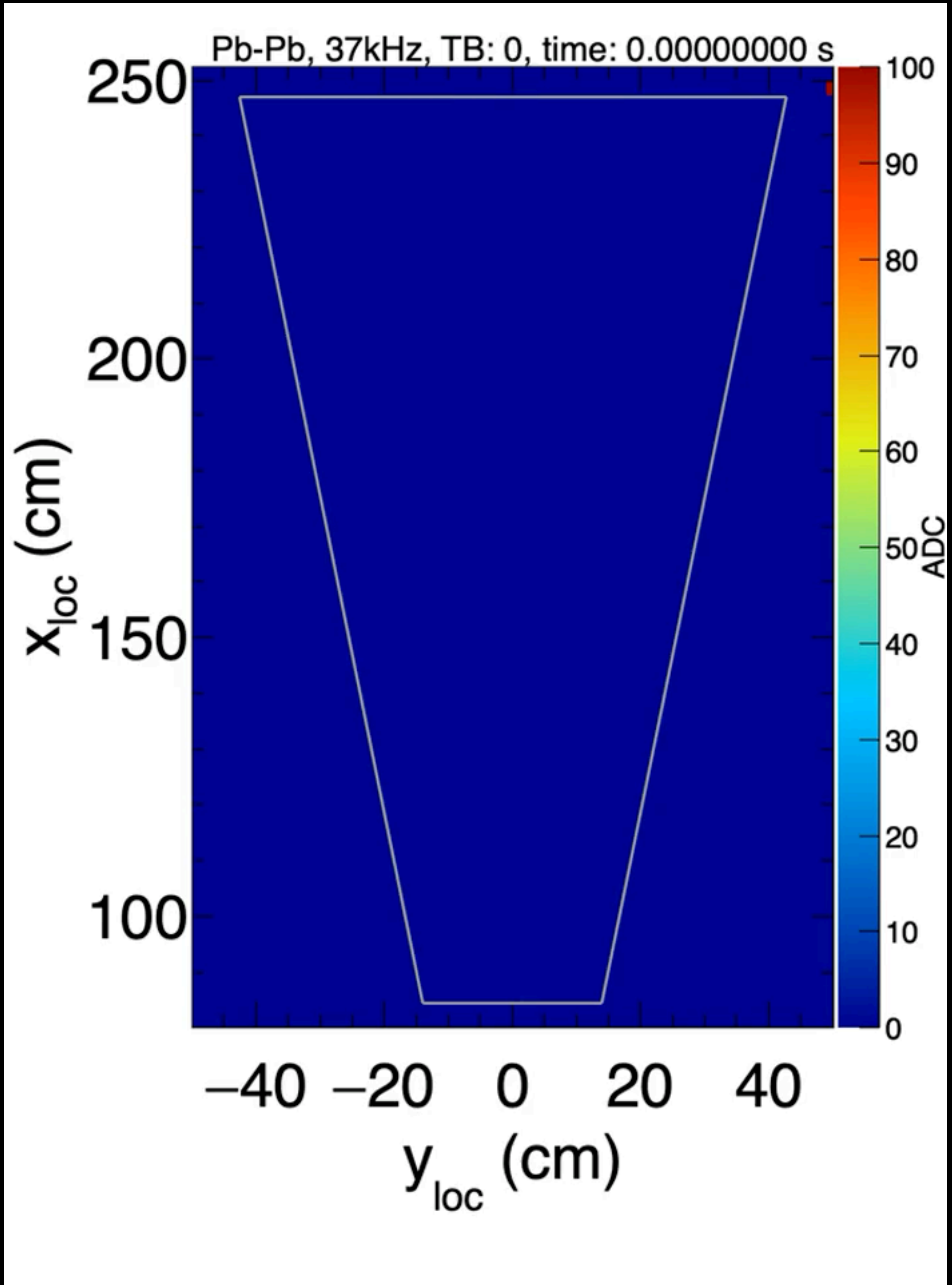


ALI-PERF-582921



ALI-PERF-582916

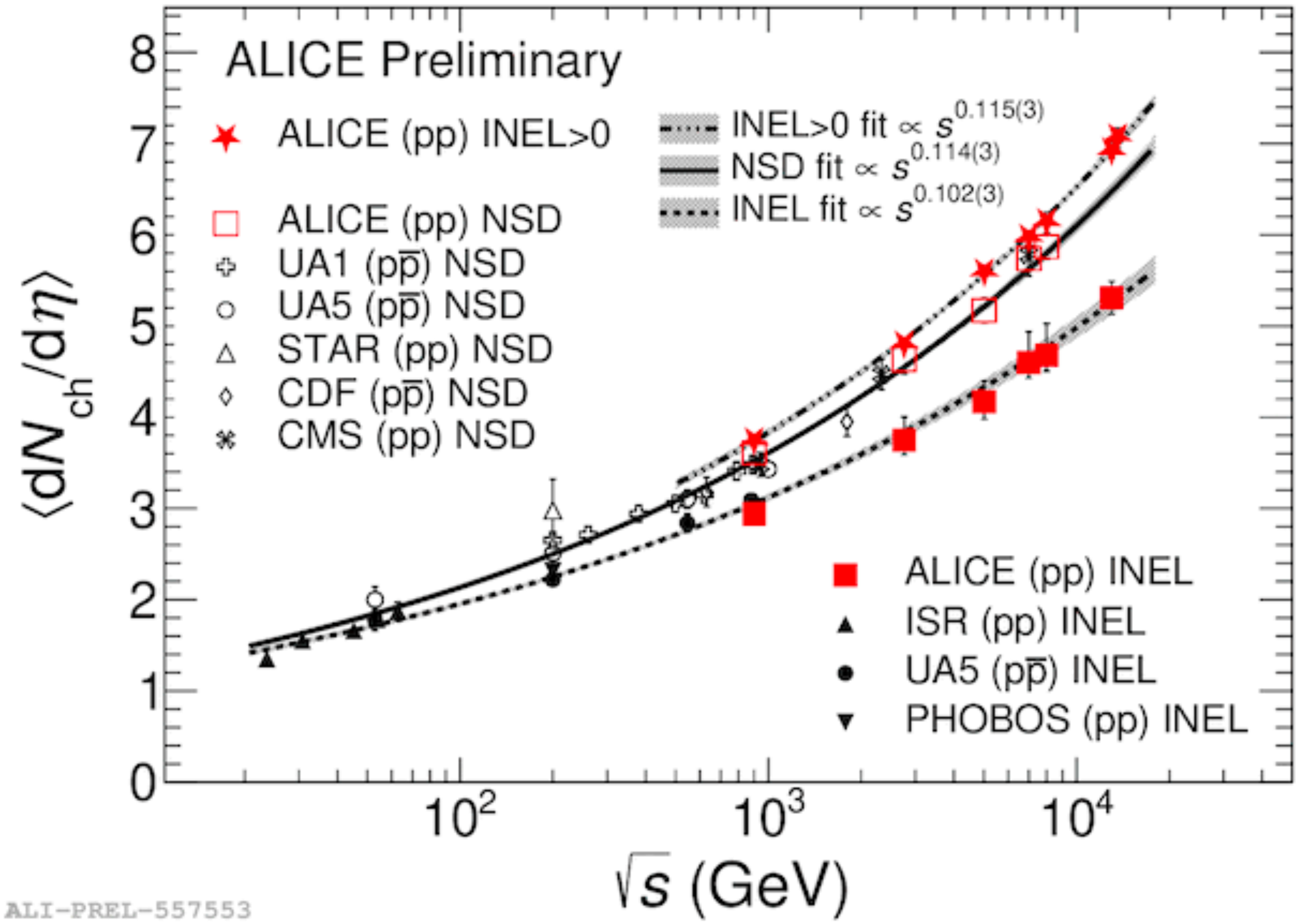
- Space-charge-distortion fluctuation correction done by scaling the average maps with the currents measured at the TPC pad planes every millisecond.
- Not all ions from the past 200 ms contribute equally to the distortions!
- Δt – dependent weights developed based on correlation with observed distortions (DCA_r).
- Significant improvement compared to flat weight.



Average occupancy for pads above threshold is below 20% for 50kHz Pb-Pb.

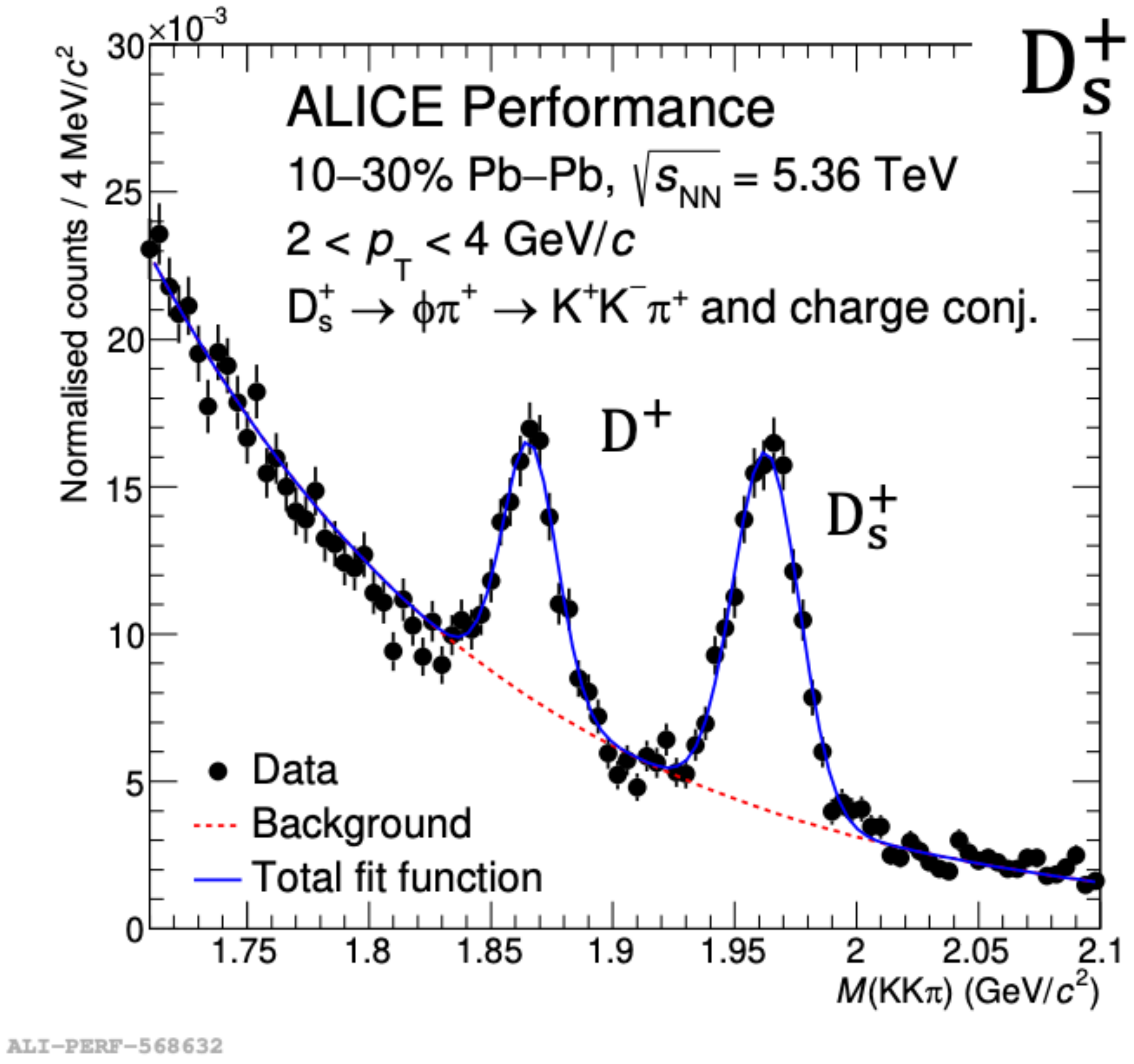
First Physics Performance Results from Run 3

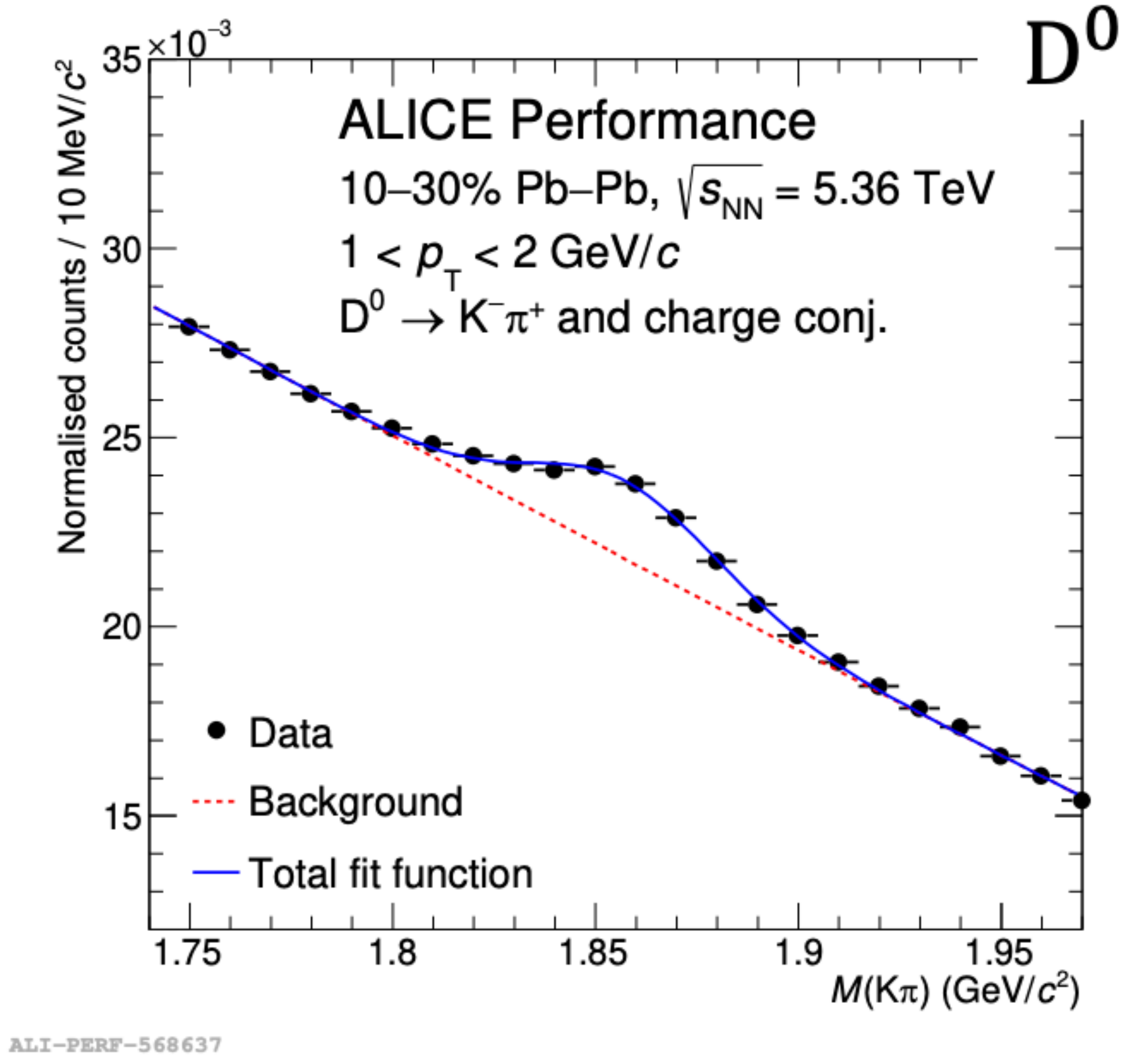
Charged particle multiplicity

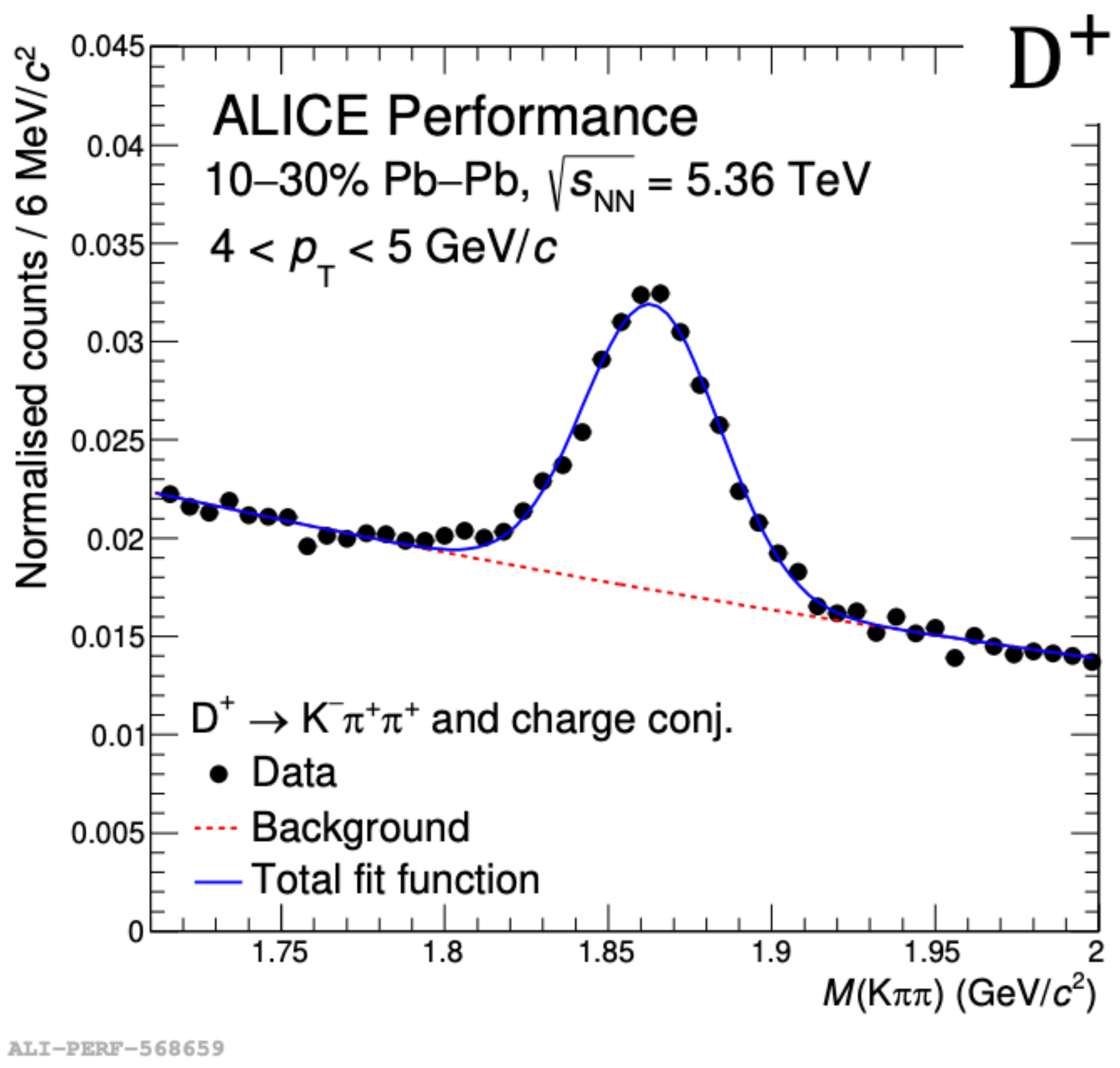


- Charged particle multiplicity from Run 3 in agreement with world data.

D mesons in Pb-Pb at 5.36 TeV

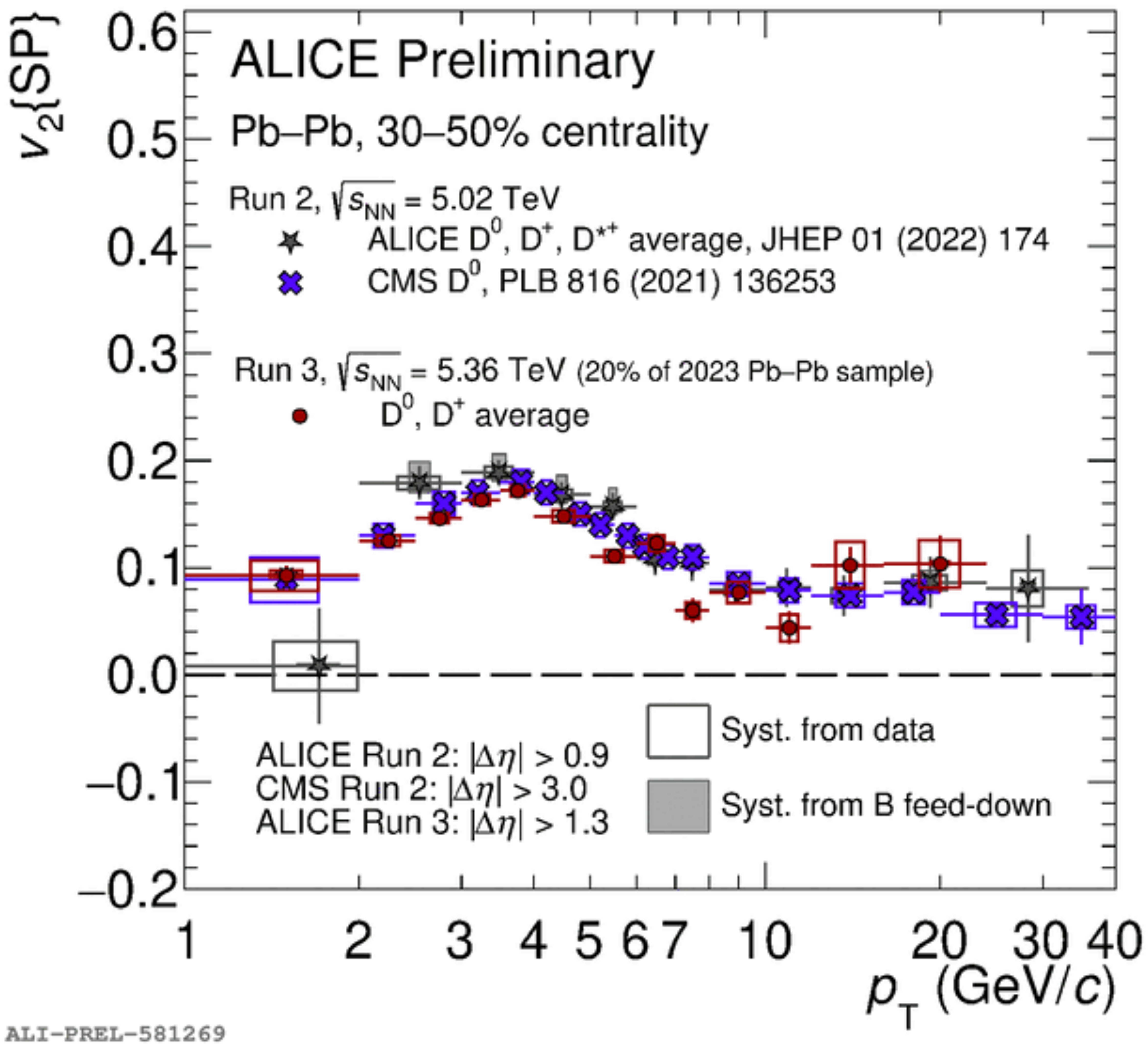






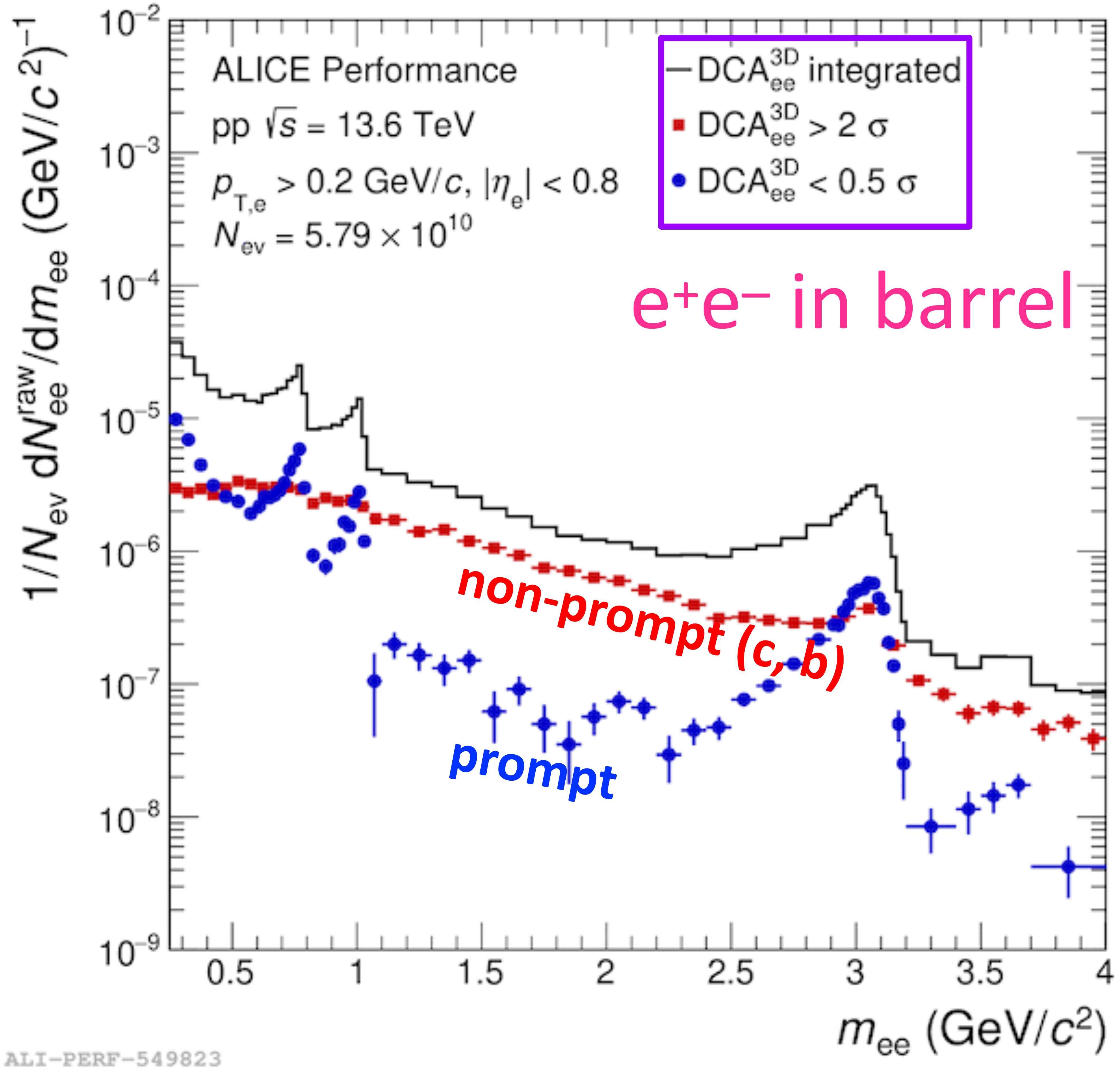
- Good performance in D-meson signal extraction in Run 3.

D-meson elliptic flow



- Prompt D-meson v2 measured using Pb-Pb Run3 data sample.

Low mass dielectrons

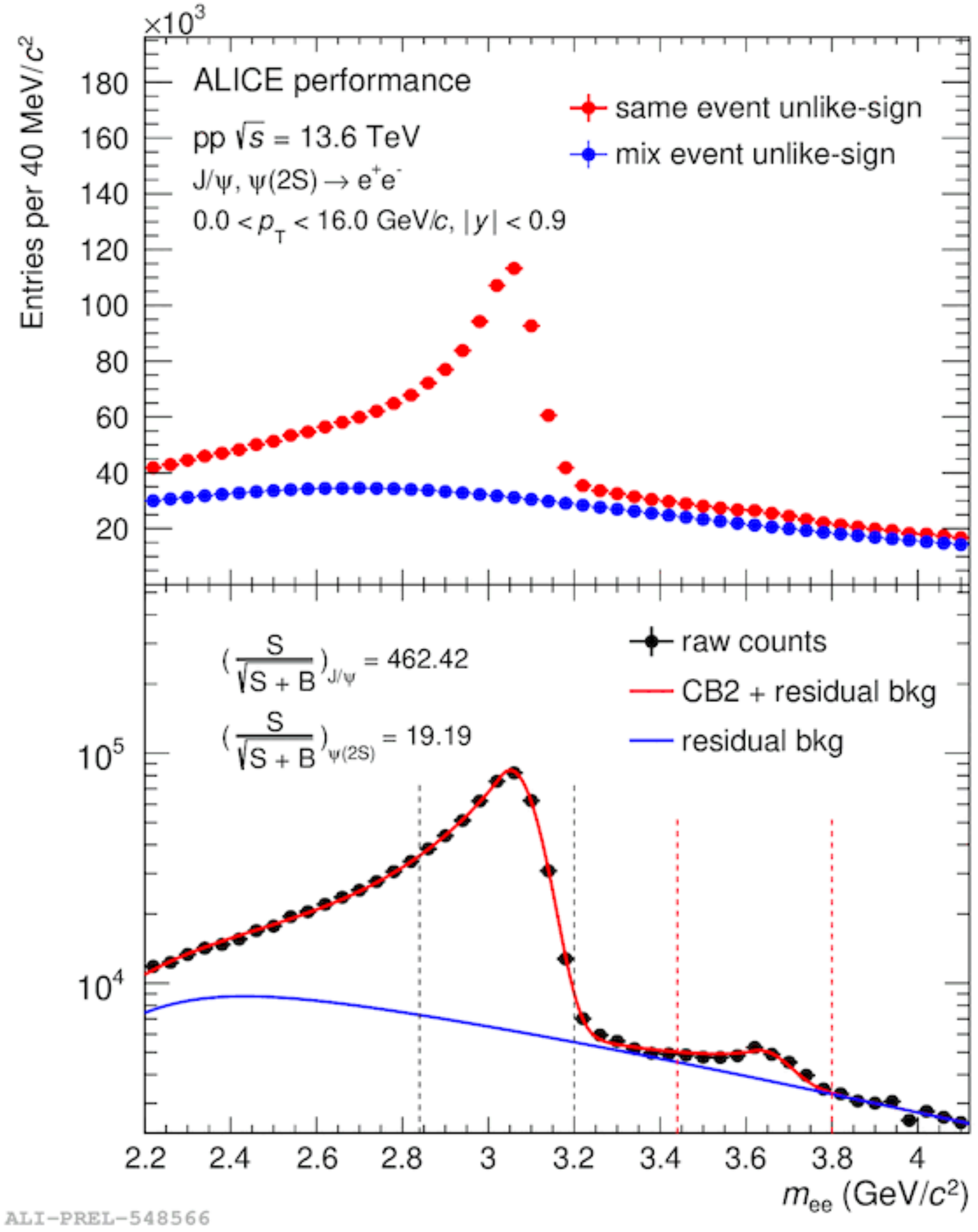


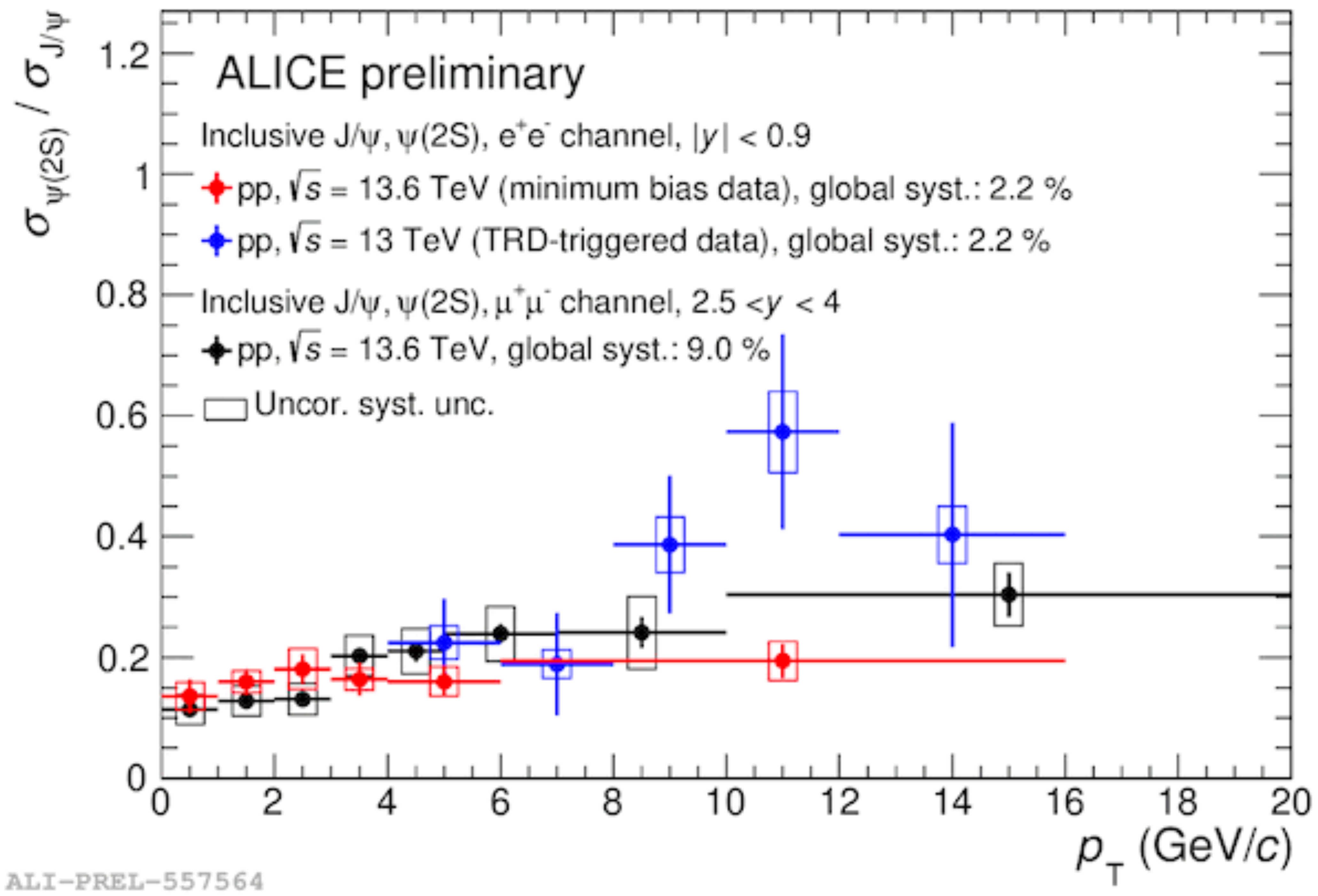
$c\tau$ ~150 μm for D mesons
$c\tau$ ~500 μm for B mesons

Huge pp statistics analyzed:

- 0.97 pb^{-1} (2022) for this figure
- 0.03 pb^{-1} in Run 2
- New ITS → improved DCA resolution, better control of charm & beauty background!
- Promising to look for thermal radiation in pp

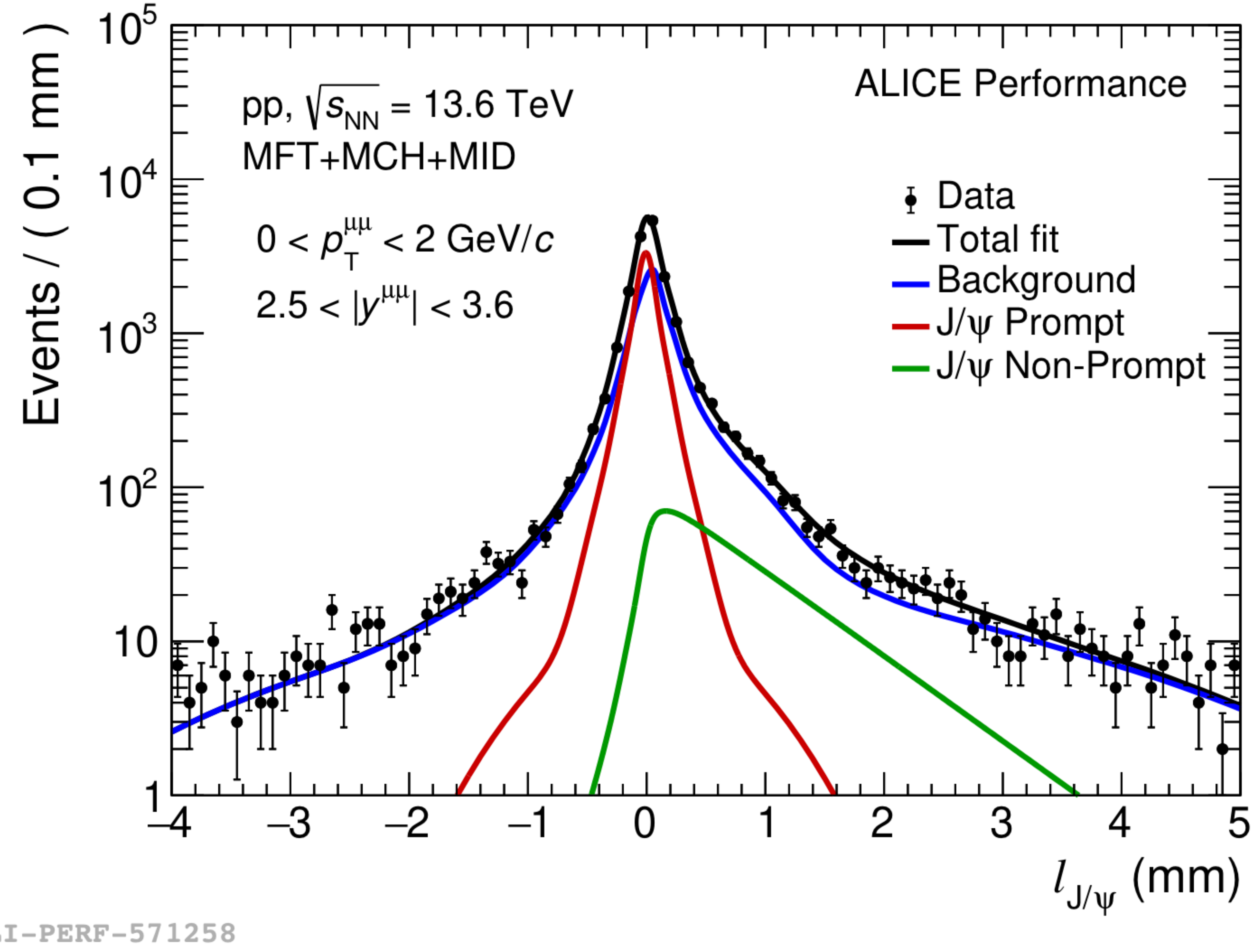
Quarkonia in pp at 13.6 TeV



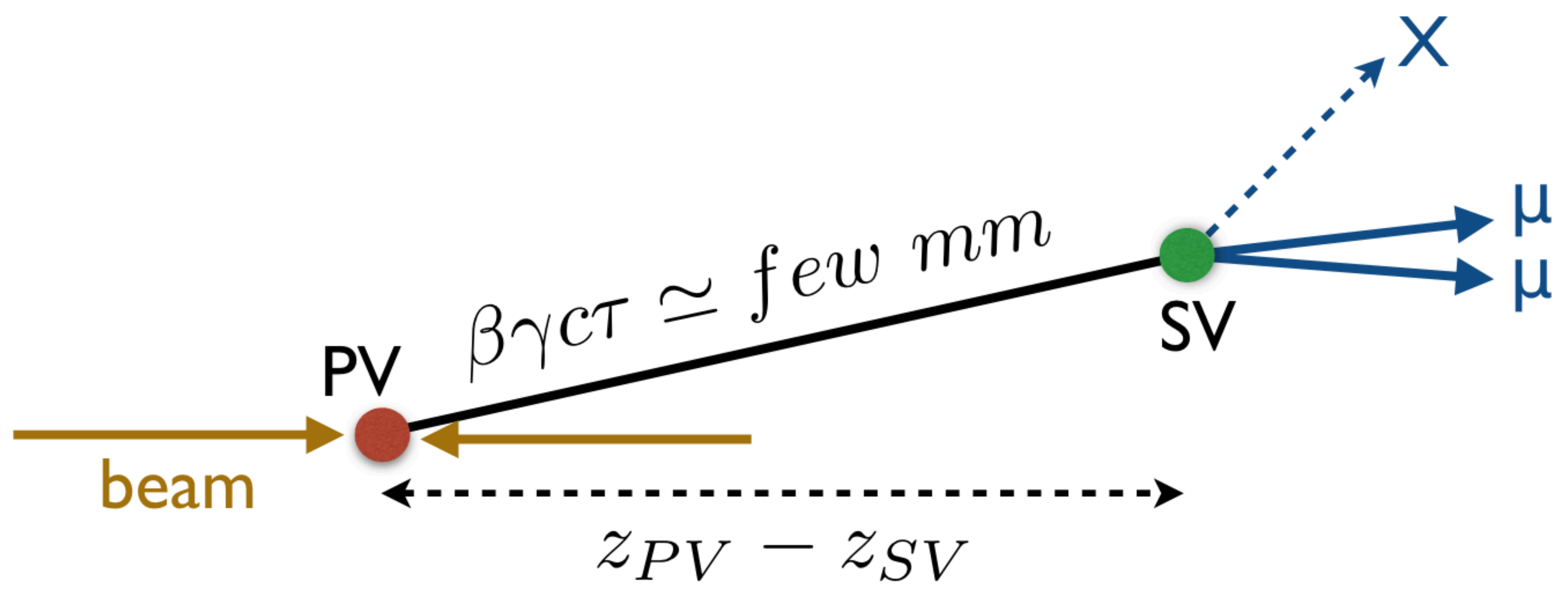


- First $\boldsymbol{\psi}$(2S) measurement in pp at mid-rapidity.
- Run 2: TRD triggered
- Run 3: Analysis trigger
- First quarkonium results in both barrel and MUON arm.

J/ψ in forward direction

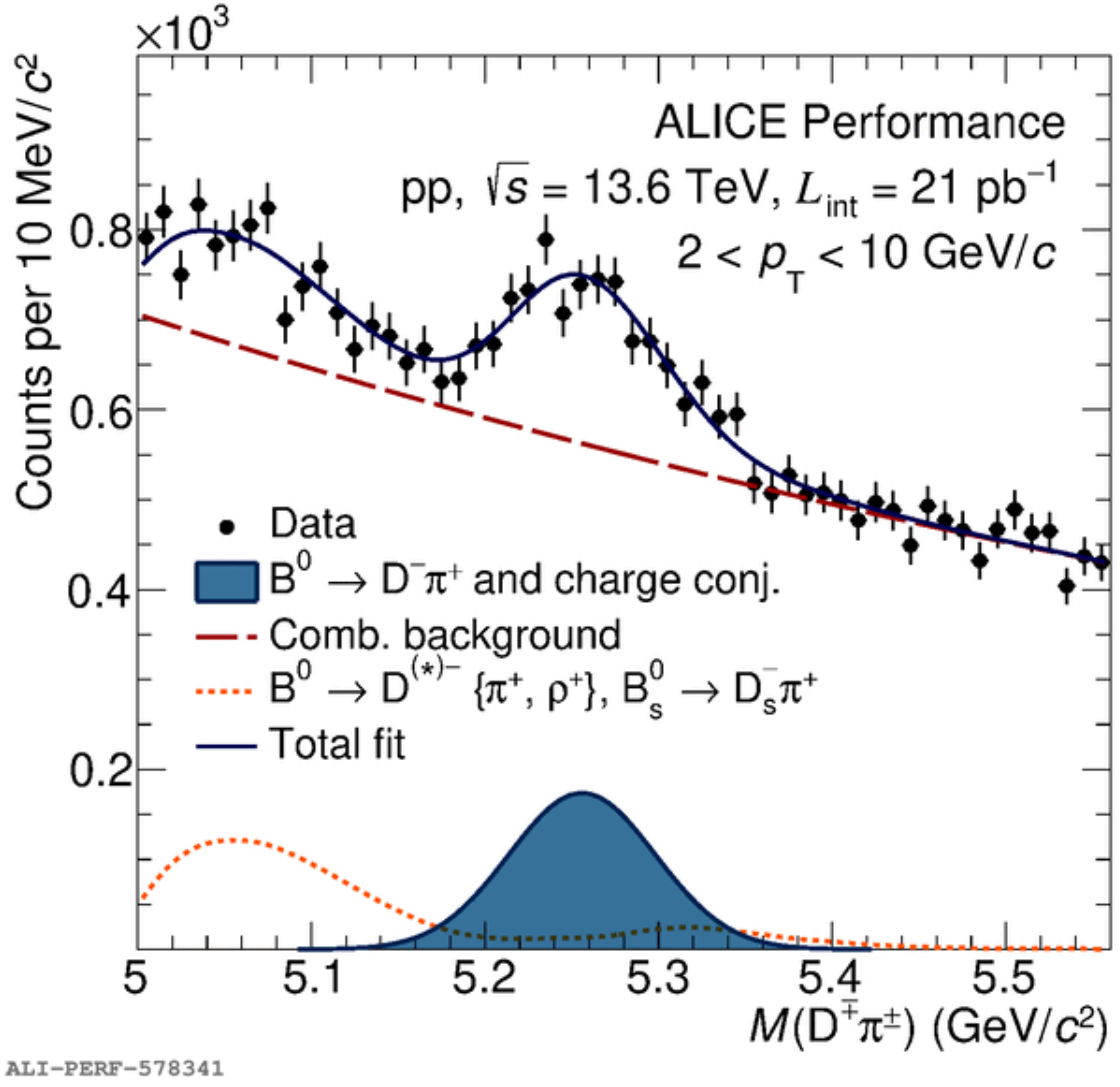


- Separation of J/ψ contributions in forward direction via MFT, based on measurement of pseudo-proper decay length.



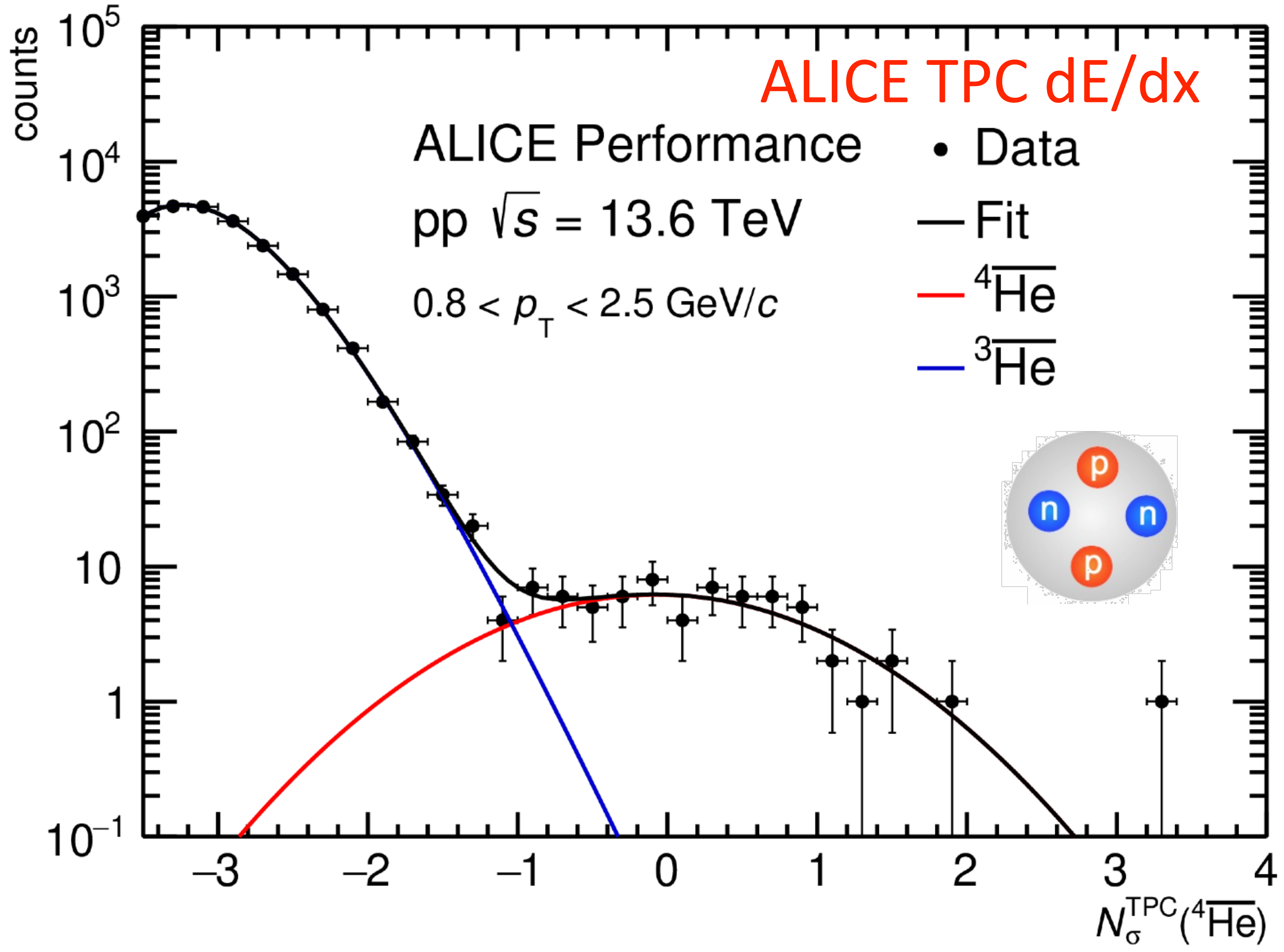
$$l_z = \frac{(z_{PV} - z_{SV}) \cdot Mc^2}{p_z c}$$

B-meson production in pp

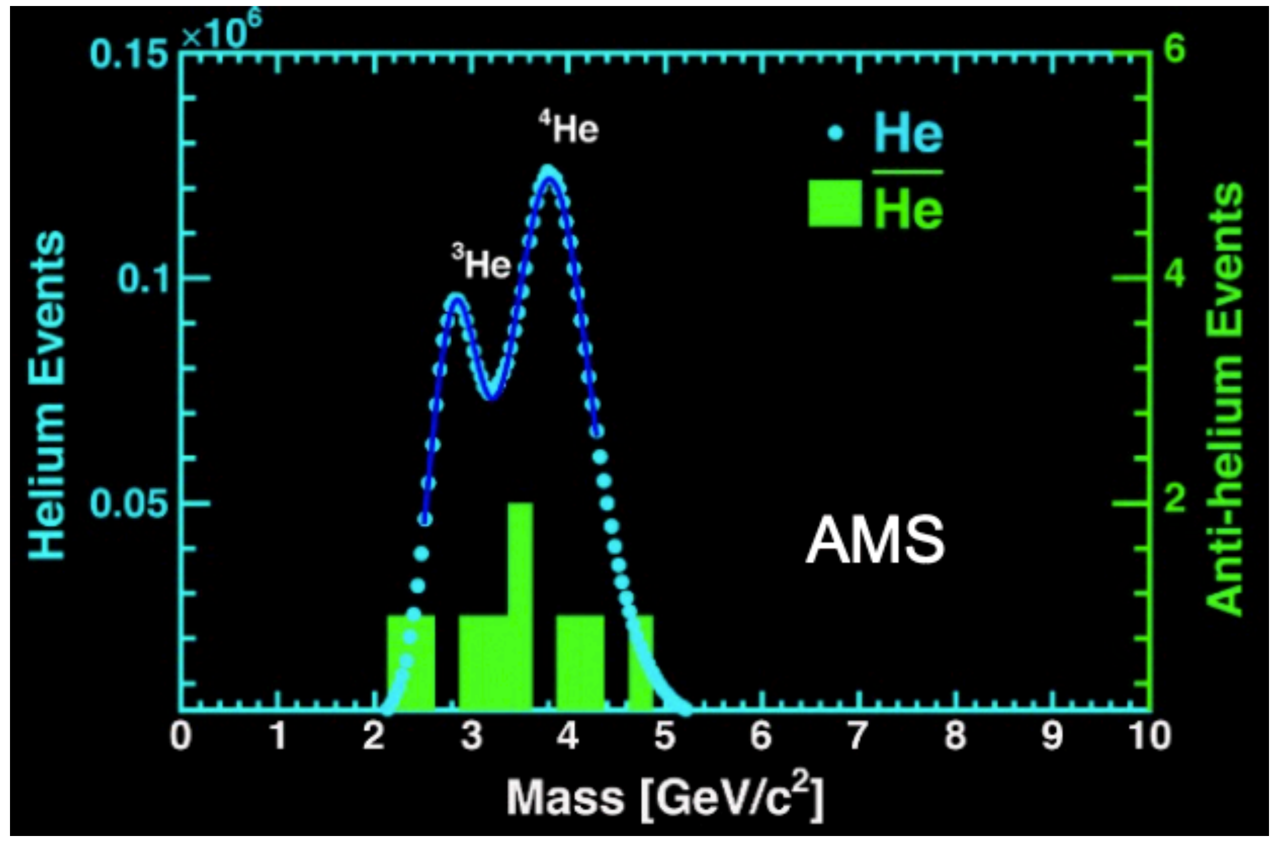


- First direct observation of B^0 meson in ALICE.
- Measured down to p_T = 2 GeV/c.
- Better constrain of the open beauty production.

Antihelium-4 in pp collisions



ALI-PERF-547176



Paolo Zuccon (Uni Trento + TIFPA), MIAPP 2022 at TUM "ANTINUCLEI IN THE UNIVERSE?", AMS02 Results

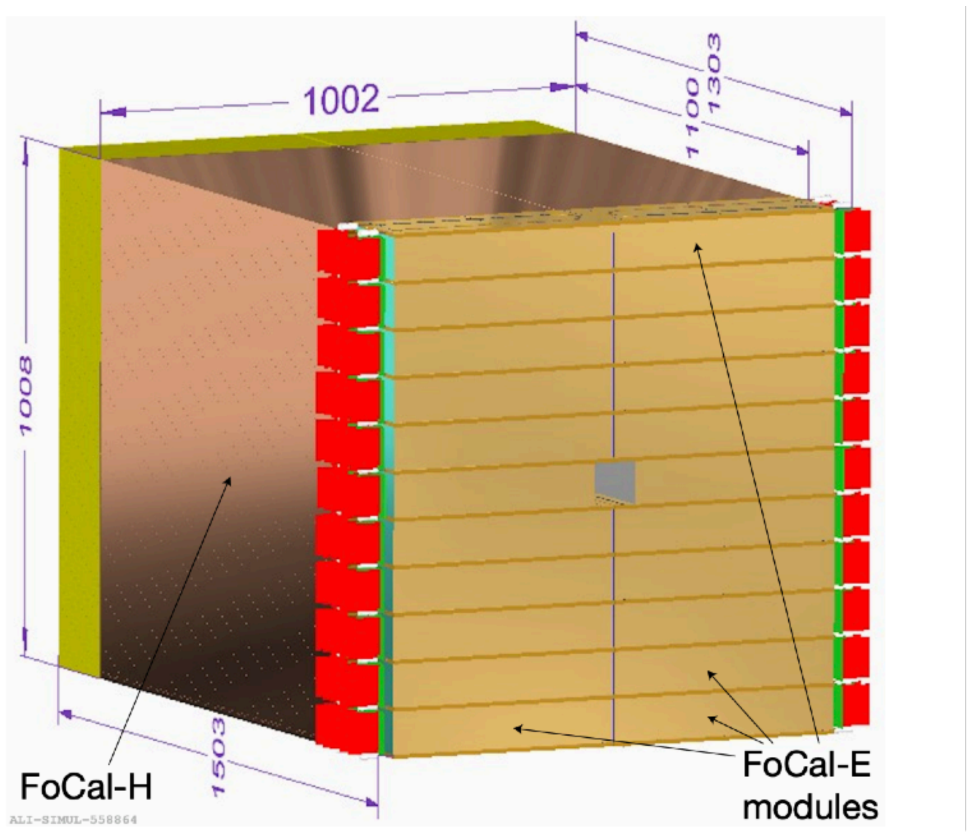
- First signal of $^4\overline{He}$ in pp collisions
- Fundamental to constrain $^4\overline{He}$ production in interactions between cosmic rays and interstellar medium

→ dominant background for dark matter searches in space experiments (AMS observes an unusual high flux)

ALICE Upgrades

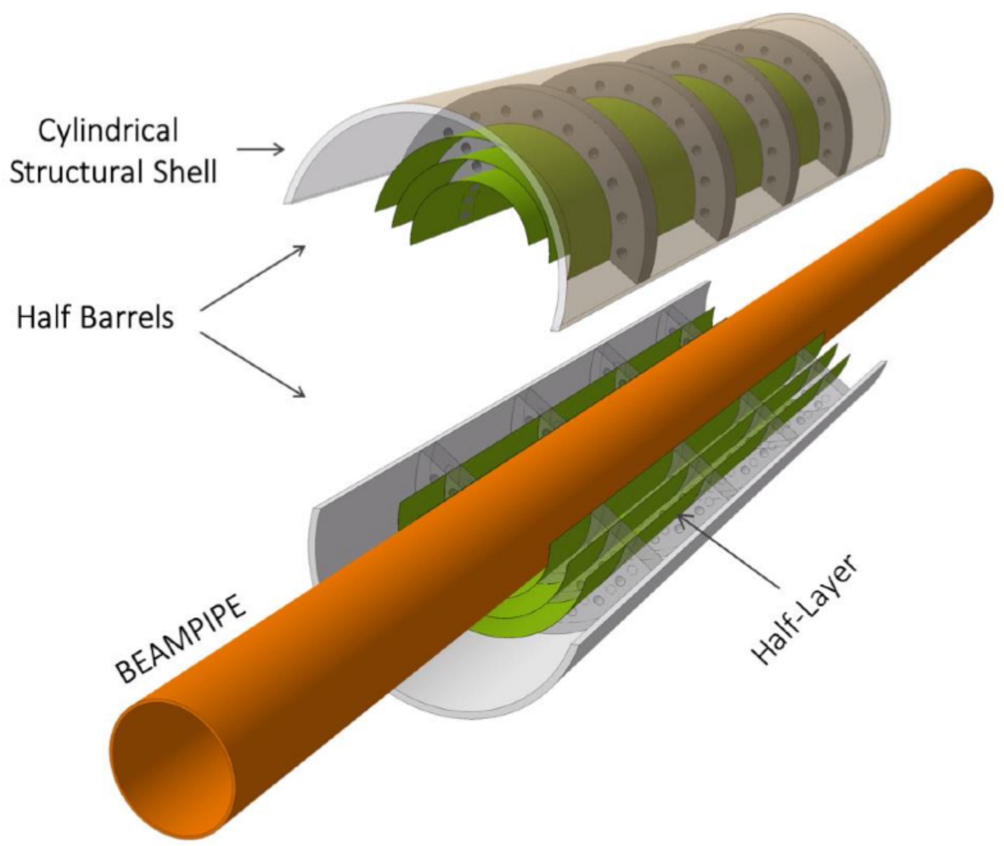
ALICE upgrades

Forward Calorimeter



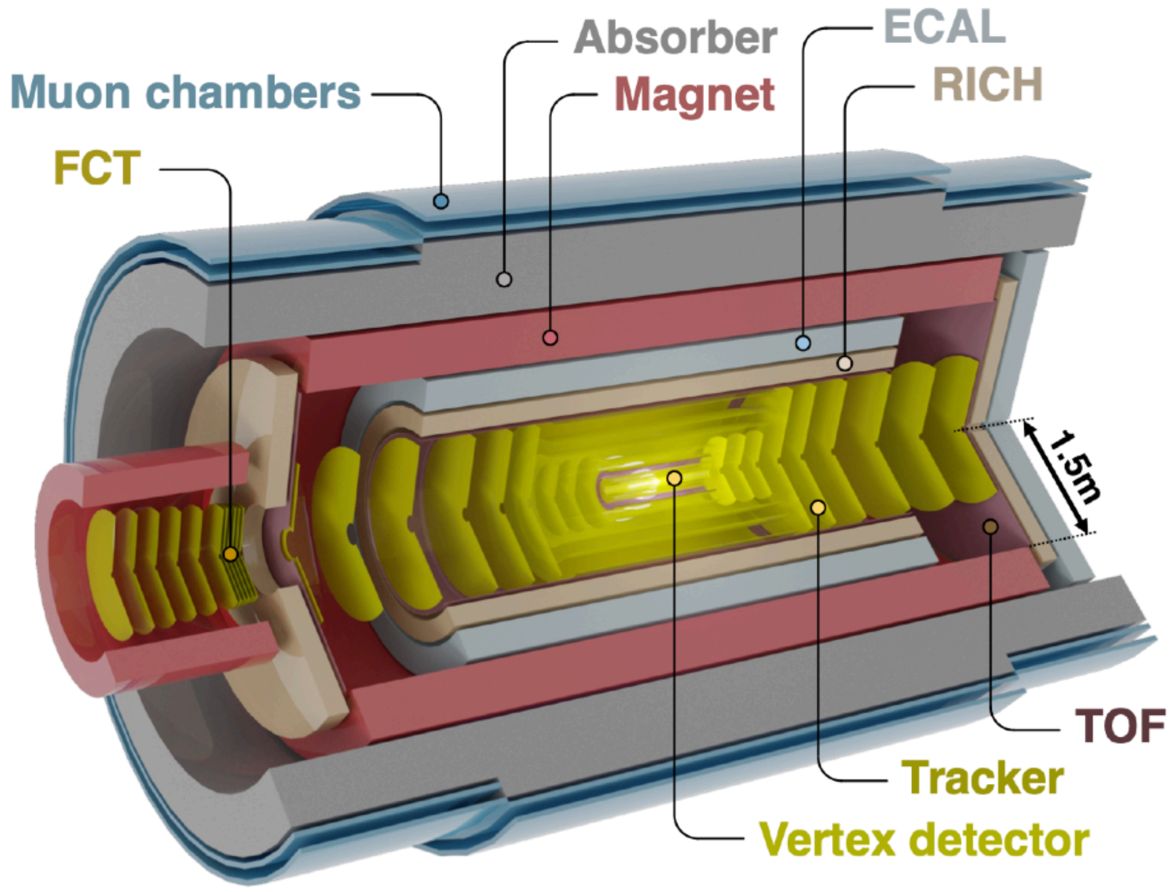
FoCal LoI:
CERN-LHCC-2020-009

ITS 3

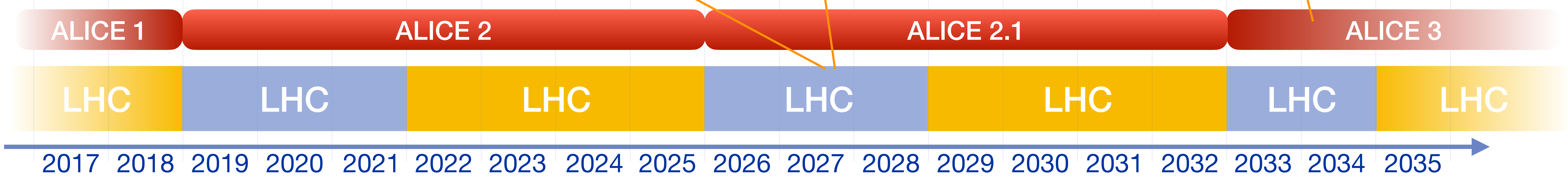


ITS3 LoI:
CERN-LHCC-2019-018

ALICE 3

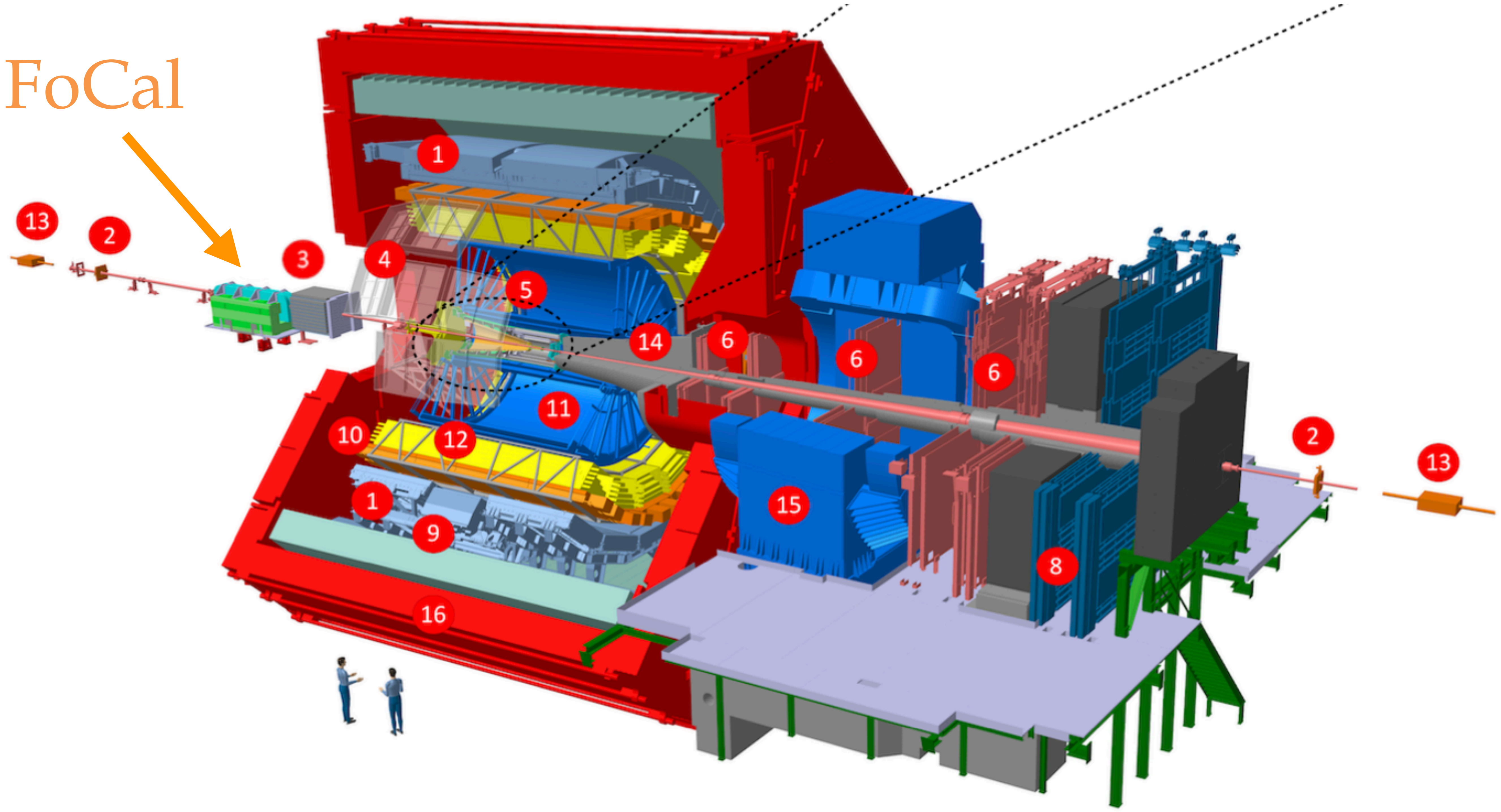


ALICE 3 LoI:
CERN-LHCC-2022-009

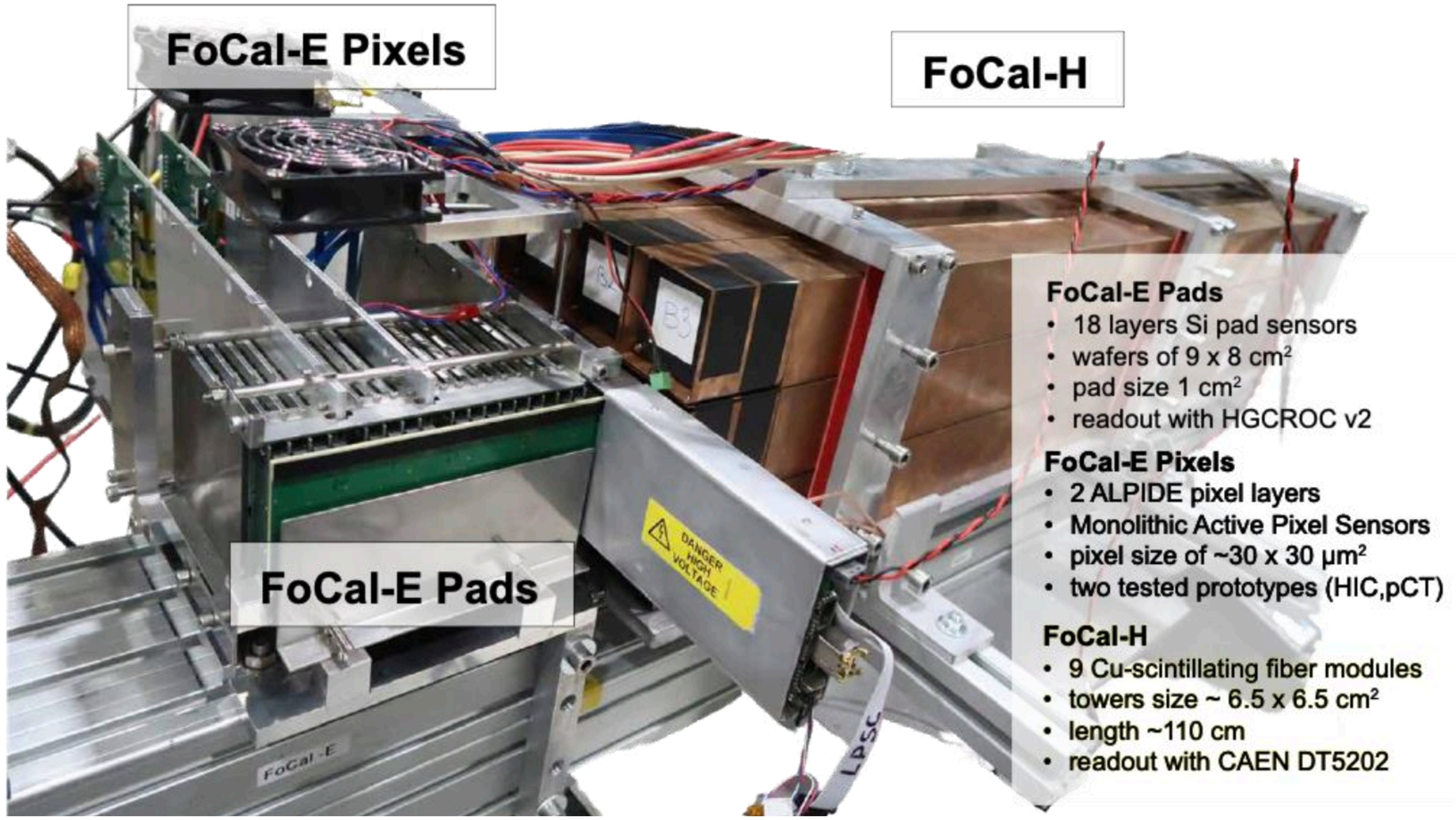


Forward calorimeter

FoCal



FoCal prototype

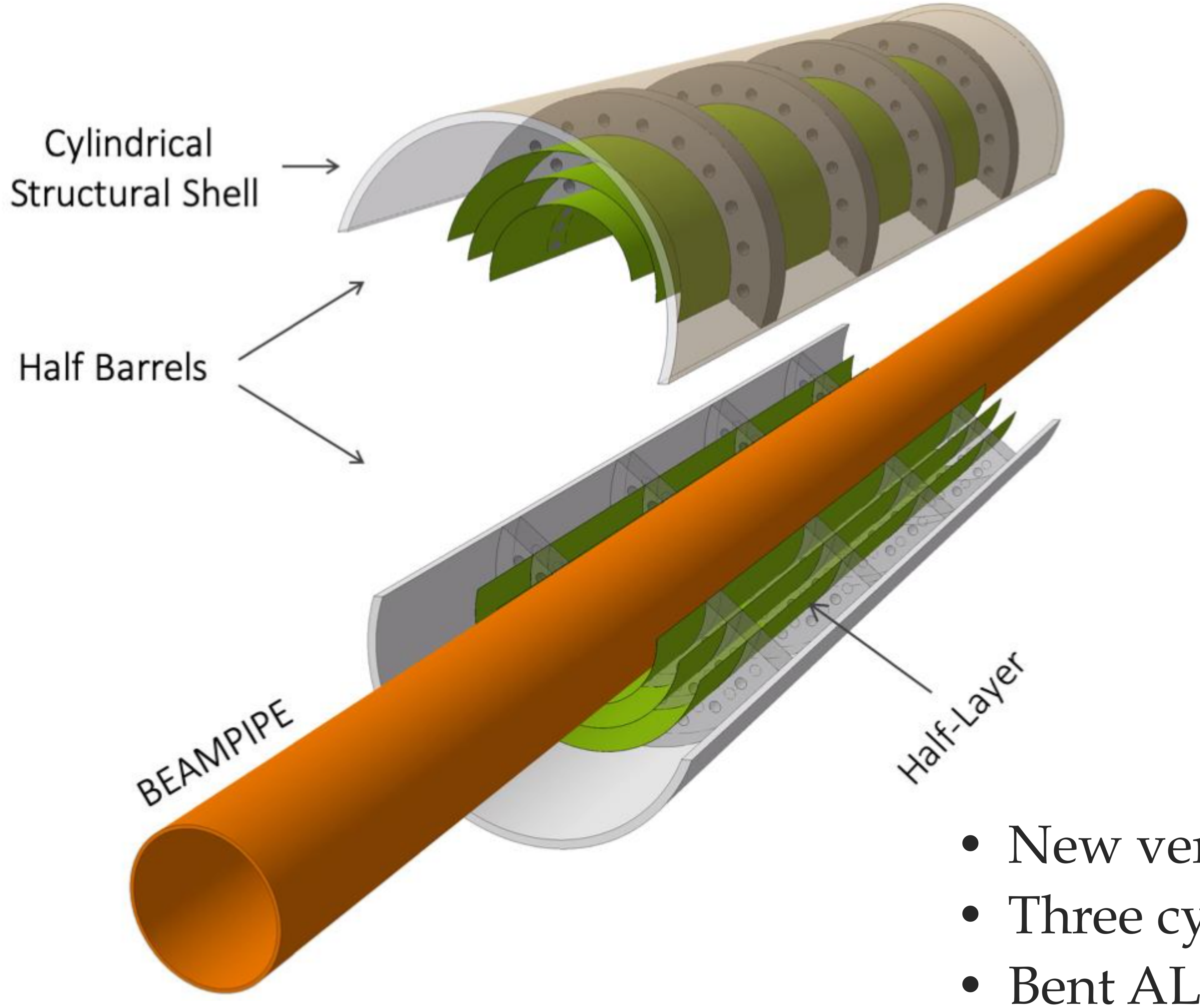


FoCal LoI:
CERN-LHCC-2020-009

TDR: CERN-LHCC-2024-004

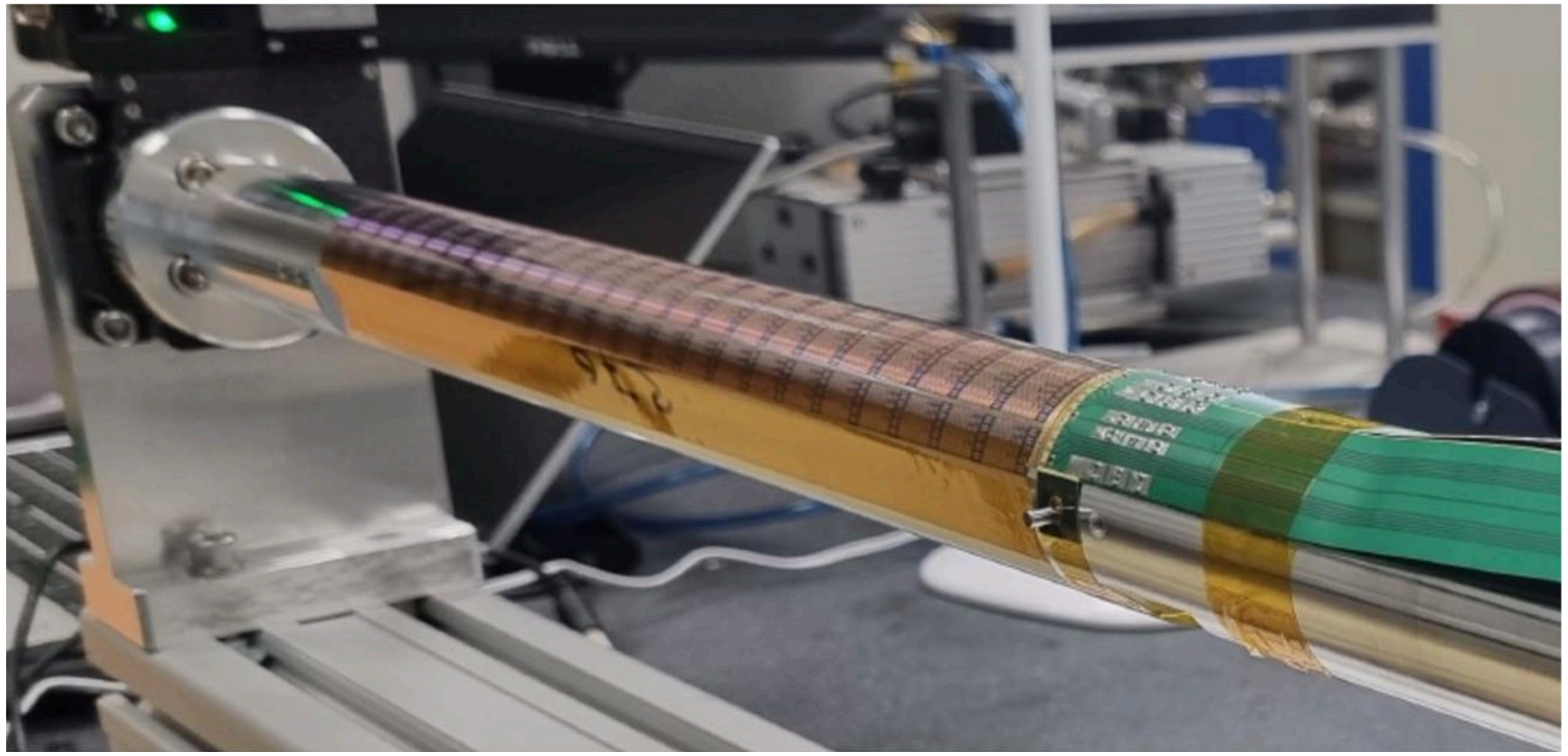
- FoCal-E: Direct photons and high p_T neutral pions in forward direction
- FoCal-H: Jets + photon isolation
- High-granular Si-W EM calorimeter + conventional hadronic sampling calorimeter
- $3.4 < \eta < 5.8$

Inner Tracking System (ITS3)



ITS3 LoI:
CERN-LHCC-2019-018

ITS3 prototype

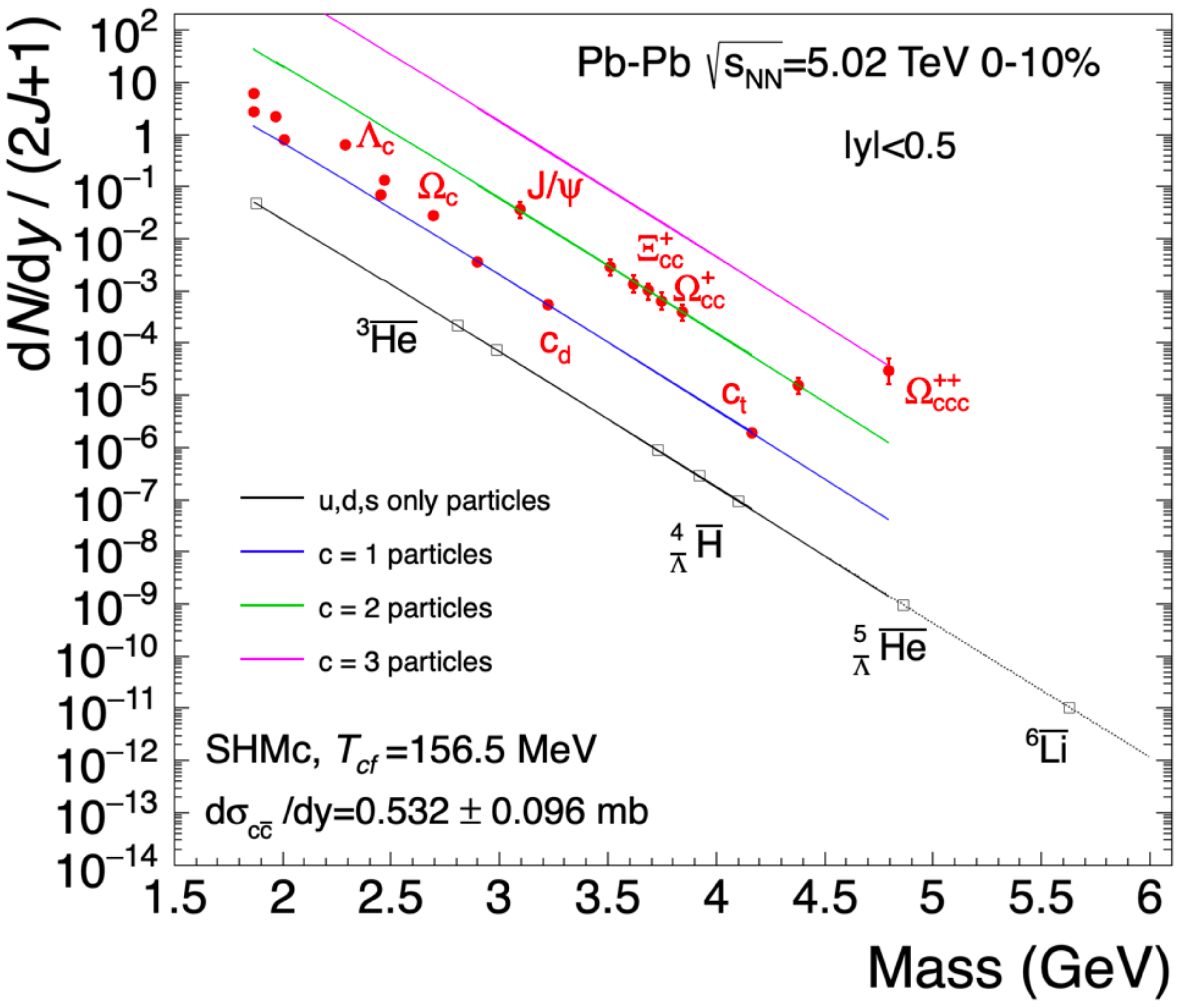


- New vertex detector for ALICE 2.
- Three cylindrical (bent) layers of Monolithic Active Pixel Sensors.
- Bent ALPIDE, performance unchanged after bending!
- 0.05% X_0 per layer (reduction of material budget by a factor of 6).

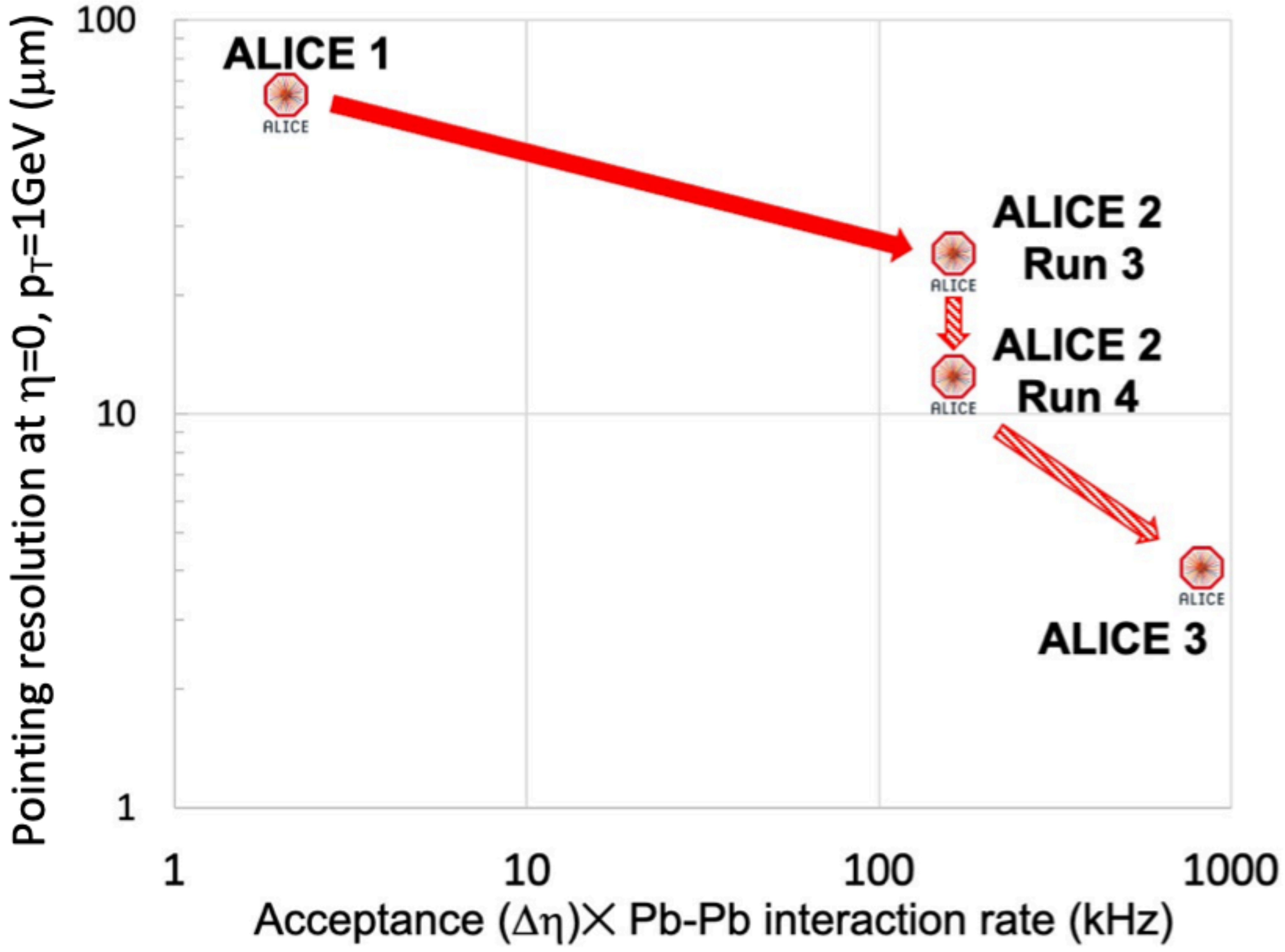
→ charm, beauty, low mass di-leptons!

ALICE 3

Acceptance x IR rate: new opportunities



A. Andronic et al. JHEP (2021)



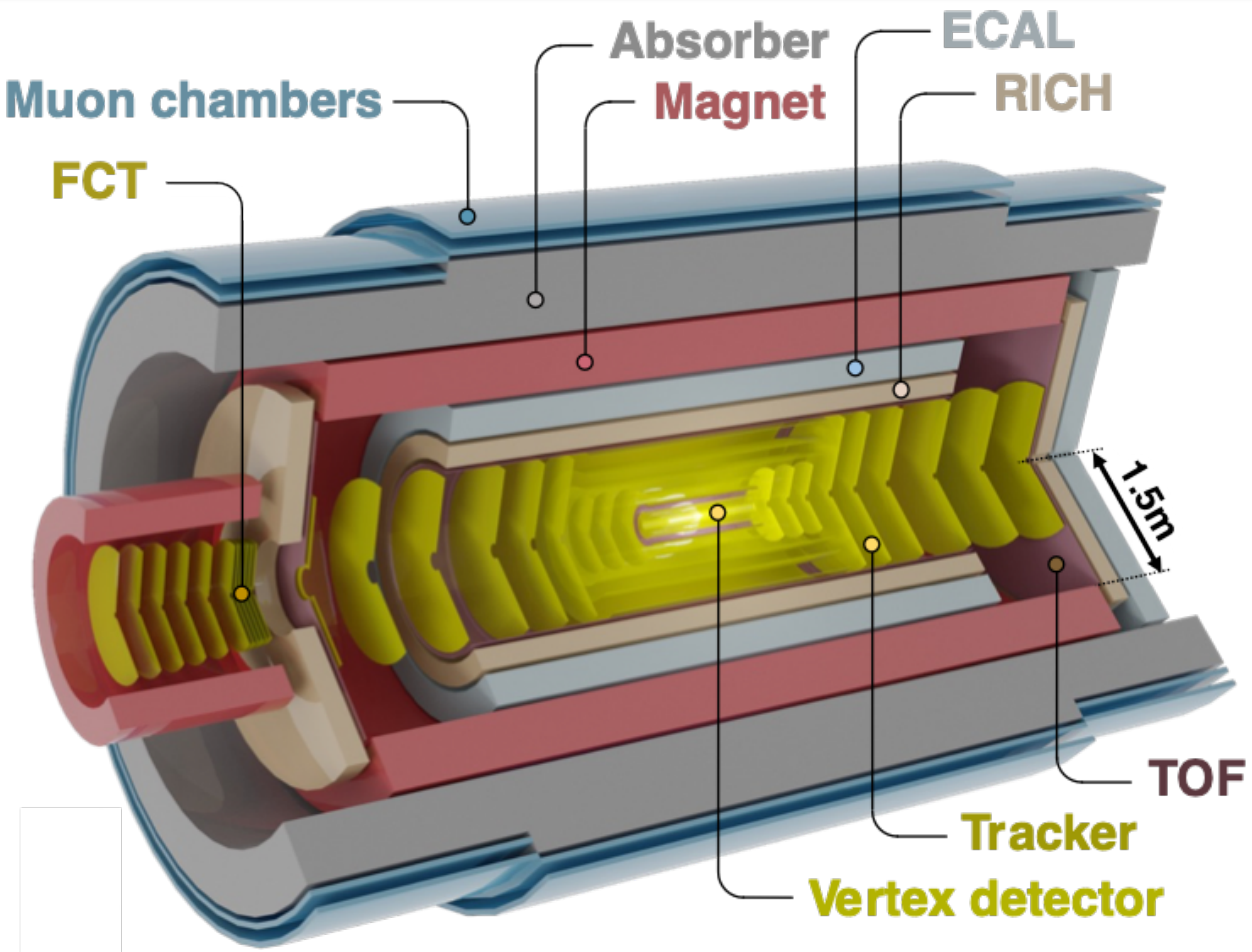
CERN-LHCC-2022-009

- Multi-charm baryons: unique probe of hadron formation.
- Requires recombination of multiple charm quarks.
- Statistical hadronisation model: very large enhancement in AA.

  → requires high statistics and excellent vertexing!

Detector overview

→ Tracking precision ✕ 3: <10 µm at p_T > 200 MeV/c
→ Acceptance ✕ 4.5: $|\eta| < 4$ (with particle ID)
→ A-A rate ✕ 5 (pp ✕ 25)

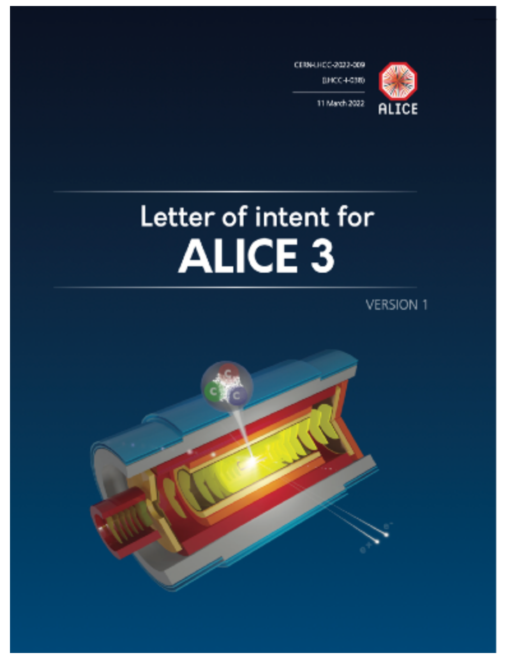


Enables unique physics in Runs 5-6:

- QGP thermal radiation and its time dependence
- Chiral symmetry restoration in QGP
- Multi-charm hadrons
- Charm - anticharm angular (de)correlation
- Charm h-h residual interaction
- Ultra-soft photons - infra red limit of QFT
- …

Letter of Intent: CERN-LHCC-2022-009

Positive review by LHCC in March 2022
Scoping document soon!

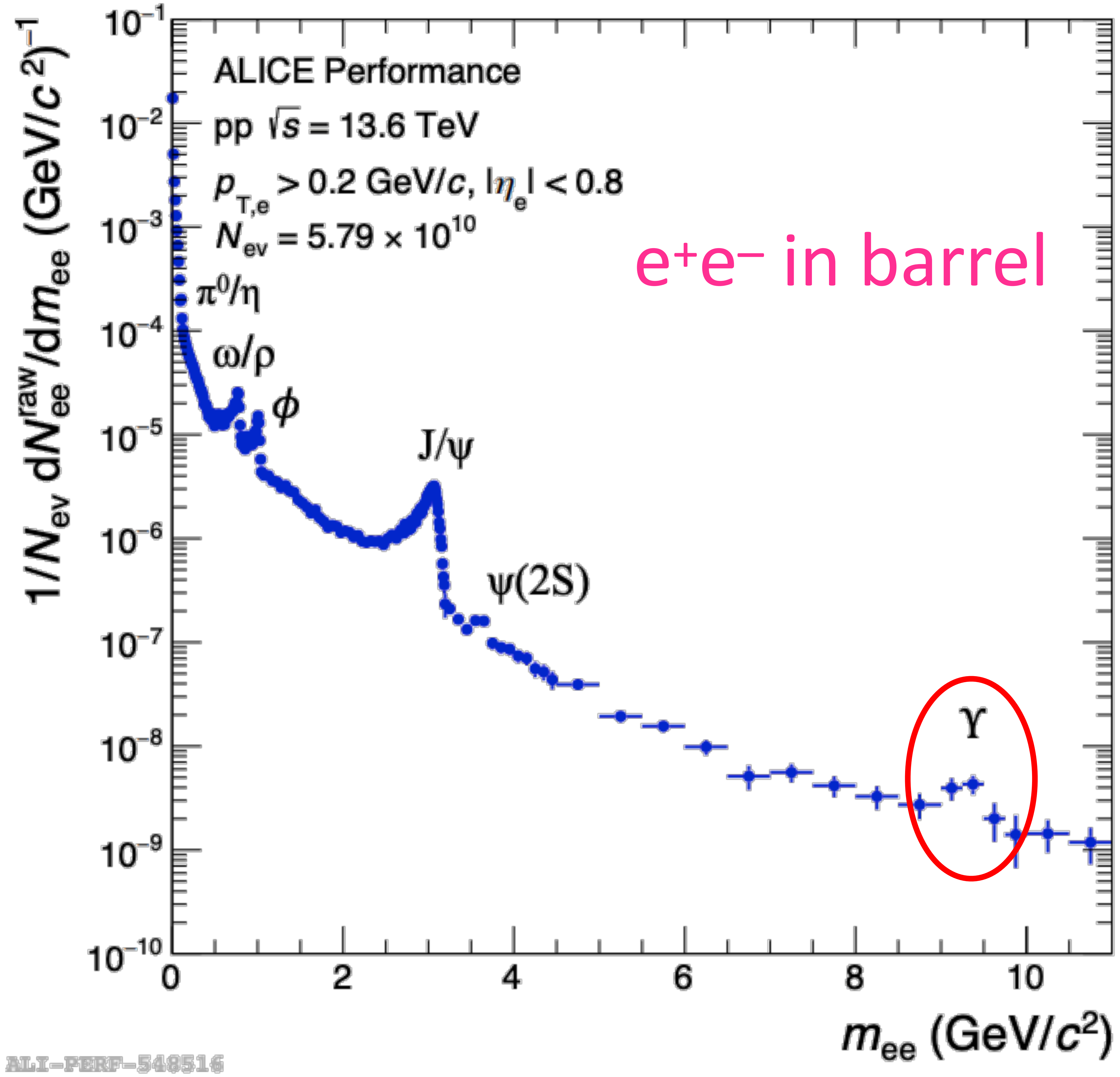


Conclusions

- Very successful Run 2 operations + publications!
- Huge amount of data already collected in Run 3 (7x central, 40x MB), first results from heavy flavour, di-leptons, elliptic flow, correlation, jets, forward J/ψ, etc. look very promising.
- Run 4: ITS3 and FoCal technical design reports endorsed by LHCC. First prototypes ready.
- ALICE 3 LoI endorsed by LHCC!
  $\rightarrow$ Moving forward to the R&D phase, scoping document submitted for LHCC review.

BACKUP

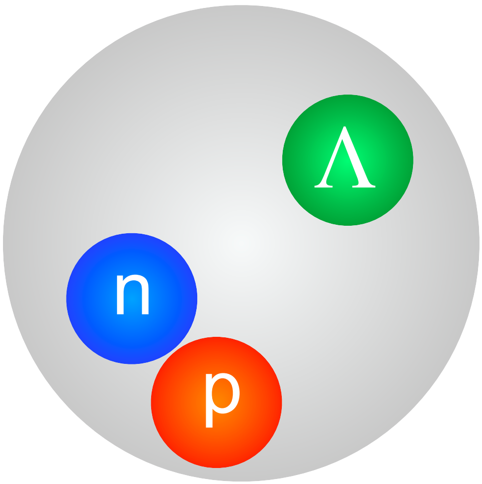
Low mass dielectrons



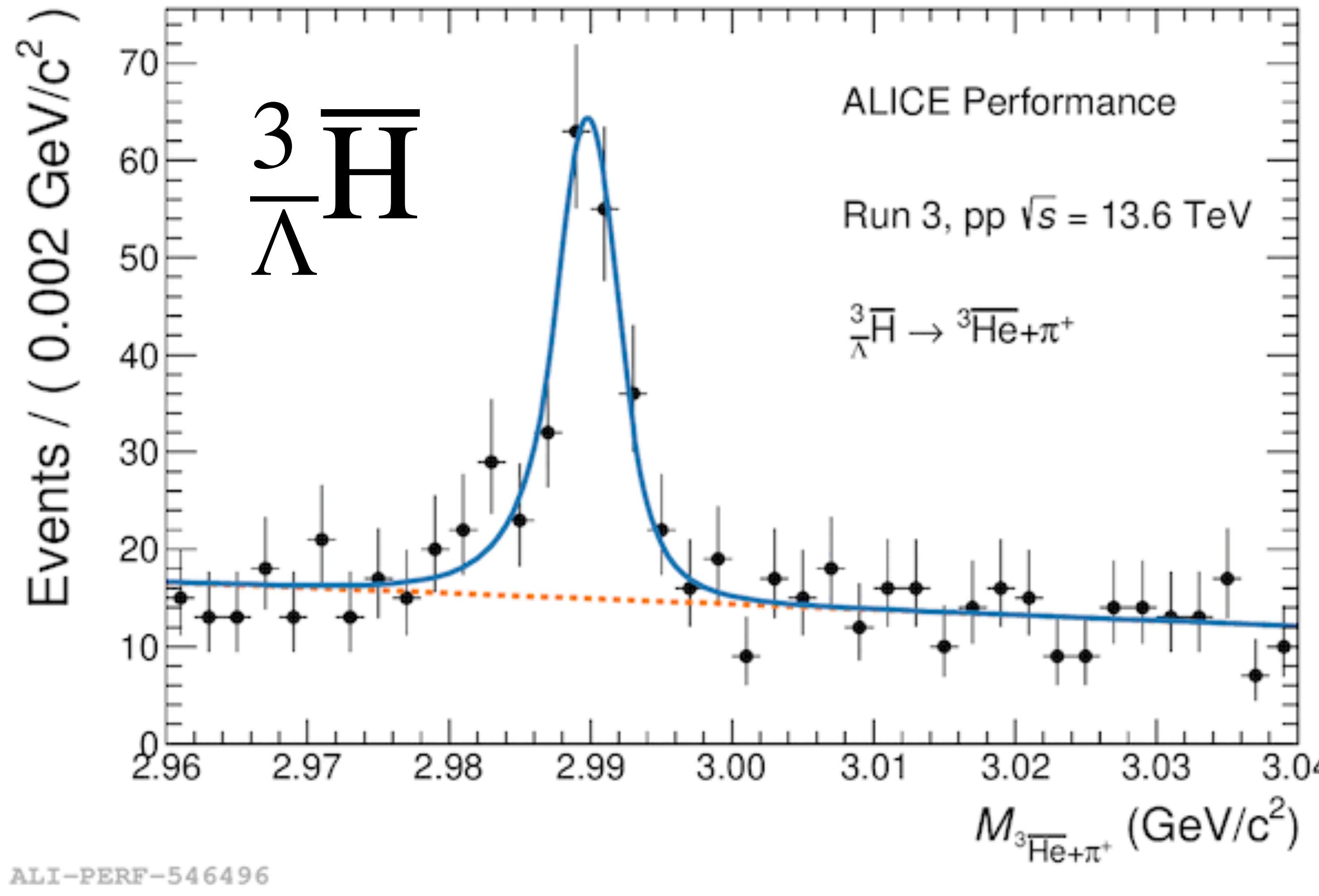
Huge pp statistics analyzed:

- 0.97 pb^{-1} (2022) for this figure
- 0.03 pb^{-1} in Run 2

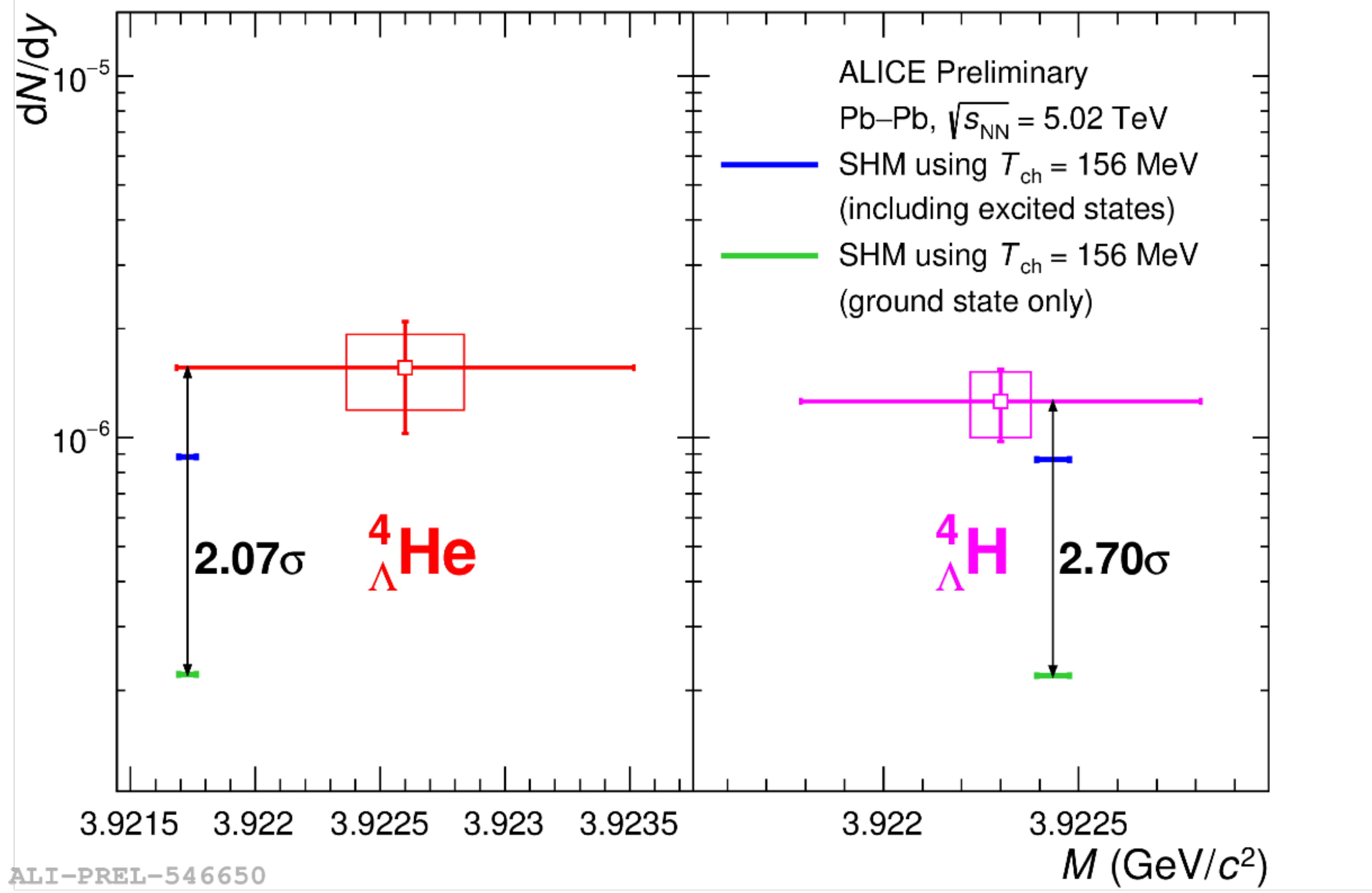
Antihypernuclei in small systems

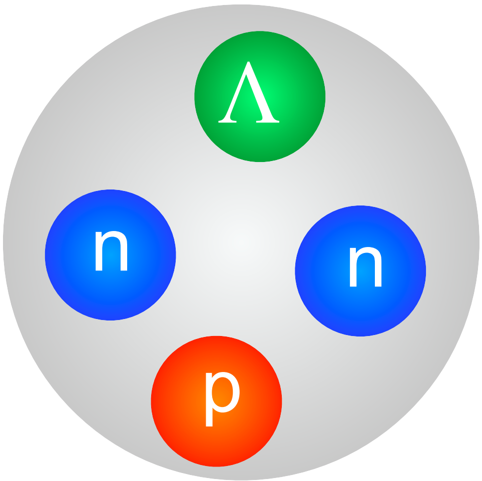


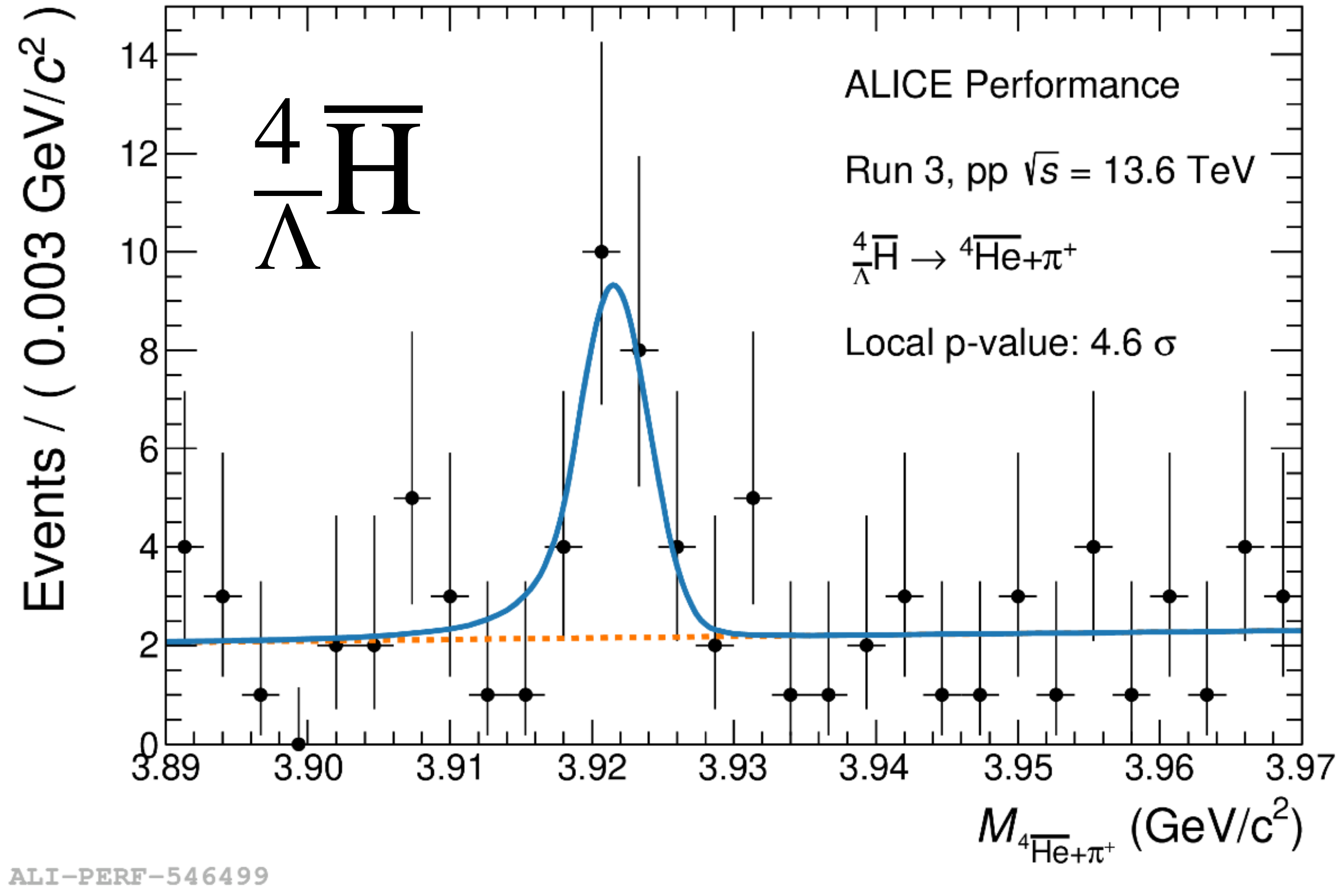
Run 3 pp



Run 2 Pb-Pb





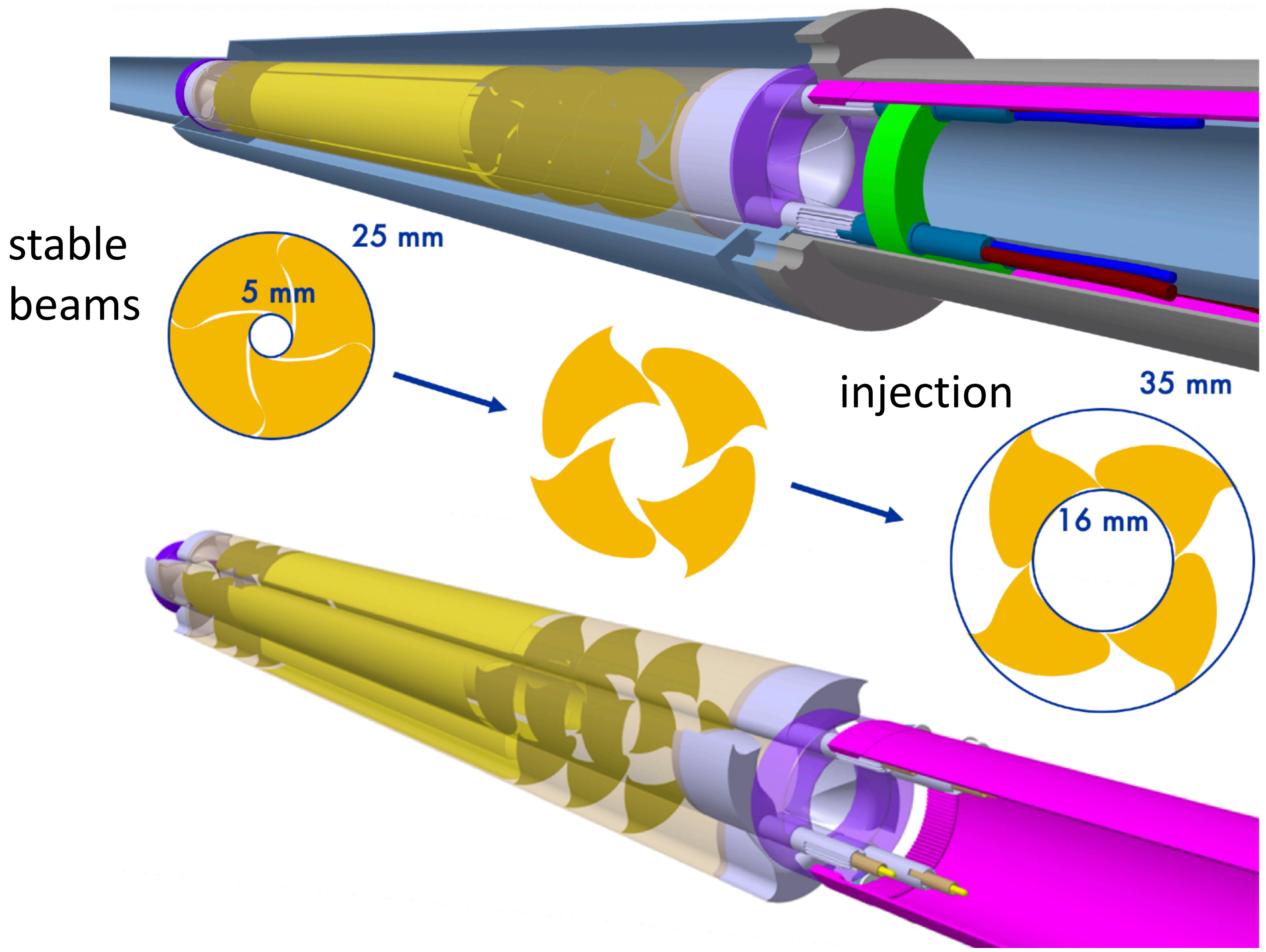


- Observation of $^{3}_{\Lambda}\overline{\mathrm{H}}$ and $^{4}_{\Lambda}\overline{\mathrm{H}}$ in Run 3 minimum-bias pp collisions at 13.6 TeV.
- Measurements of their yields will be crucial to constrain production models of such heavy and loosely-bound states.

Vertex detector

Retractable vertex detector concept inside beampipe (Iris):

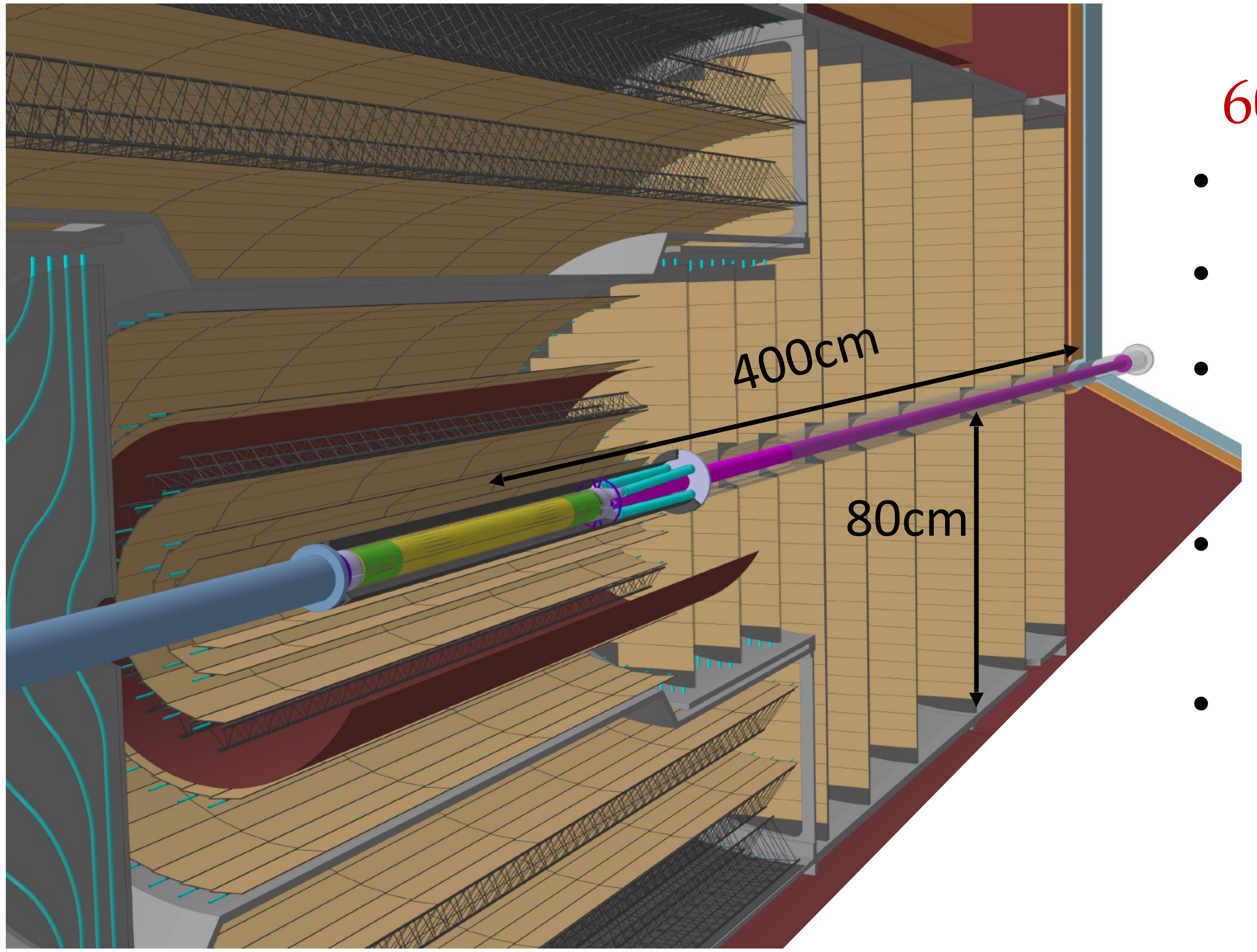
- closed to R_{inner} = 5 mm during *stable beams*
- opened to R_{inner} = 16 mm for beam injection/adjustments



Component	Material	Thickness	Radiation length	
		(µm)	(cm)	($\%X_0$)
Sensor	Si	30	9.37	0.032
Support	Be	250	35.28	0.071
Glue		50	35	0.014
Total				0.117

Table 9: Material for the first layer of the vertex detector.

ALICE 3 outer tracker



60 m² silicon pixel detector

- large coverage: 8 pseudorapidity units
- compact: $R_{out} \approx 80$ cm, $z_{out} \approx \pm 400$ cm
- high-spatial resolution: $\sigma_{pos} \approx 10$ µm

  →pixel size ~ 50x50 µm²
- low material budget: $x/X_0 \sim 1\%$ per layer
- low power density: ≈ 20 mW/cm²

R&D focusses on

- concept of module ~10 x 10 cm² based on industry-standard processes for assembly and testing
- services: reduce (eliminate) interdependence between modules (→replacement of single modules)