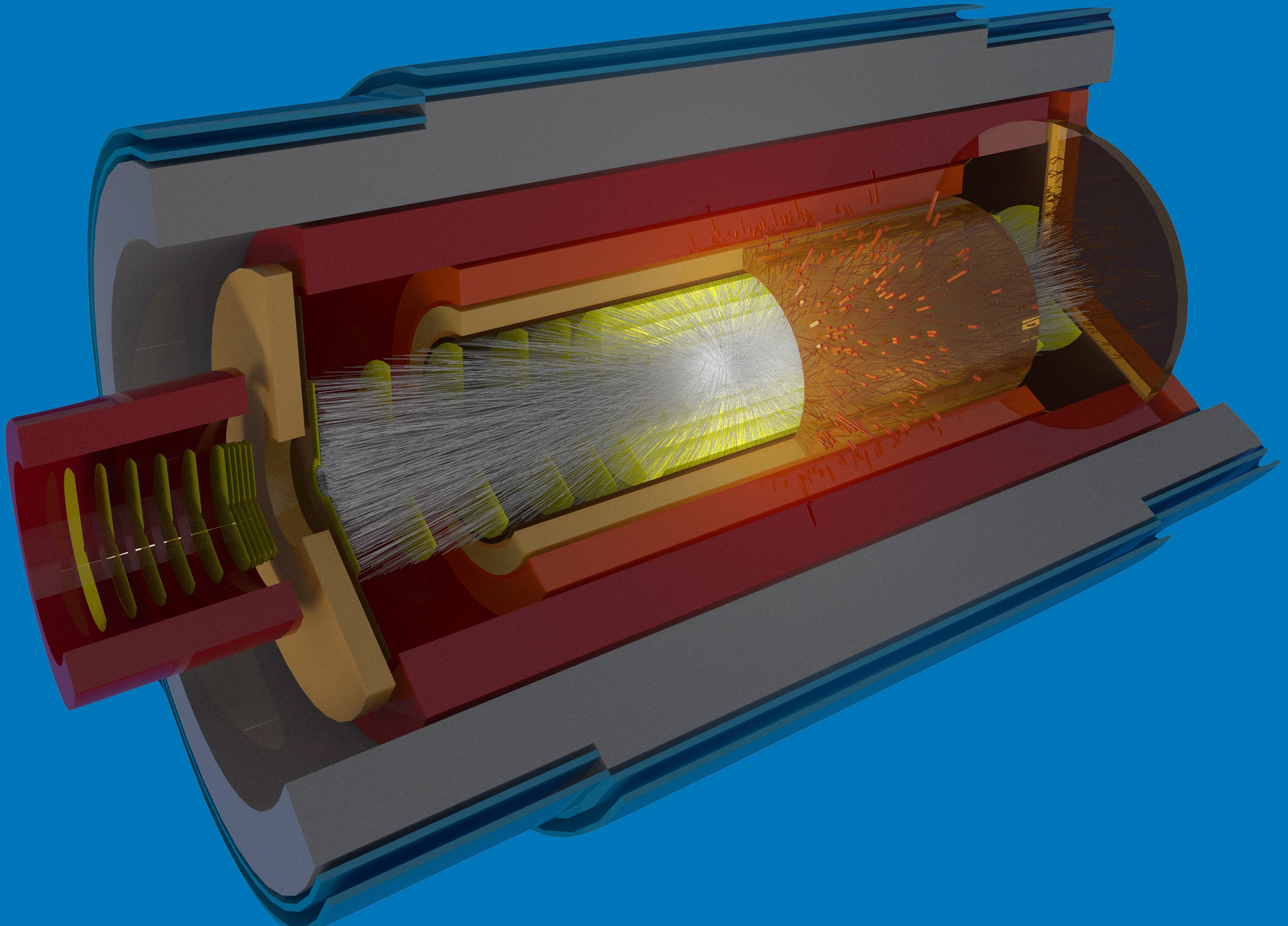
ALICE 3

Nicolò Jacazio (Bologna University)
on behalf of the ALICE Collaboration

ALICE



Vysoke Tatry 09-13 December 2024

QGP physics

Eur. Phys. J. C 84 (2024) 813

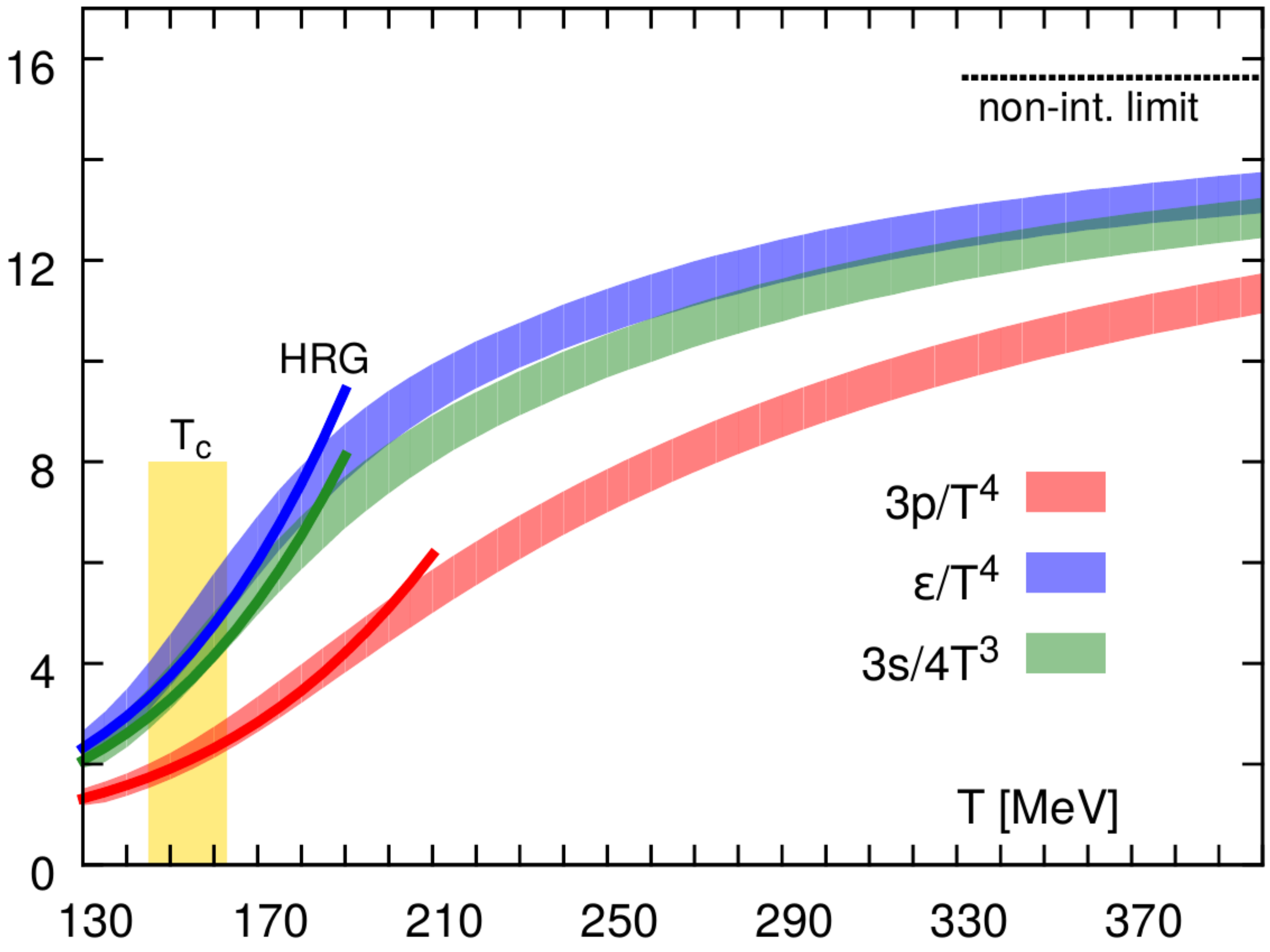
Lattice QCD predicts rapid change in hadronic thermodynamic properties

Formation of Quark-Gluon Plasma QGP

- For $T > T_c$ quarks and gluons no longer confined into hadrons but form the DOFs of the system

For matter-antimatter symmetric system: crossover phase transition from hadronic matter to QGP

- Chiral Symmetry Restoration predicted at the same temperature T_c



QGP phase

- QGP produced at LHC has highest temperature and expected largest matter-antimatter symmetry
- Lower energies at SPS (CERN), RHIC, FAIR, NICA search for QCD critical point and thresholds of QGP formation

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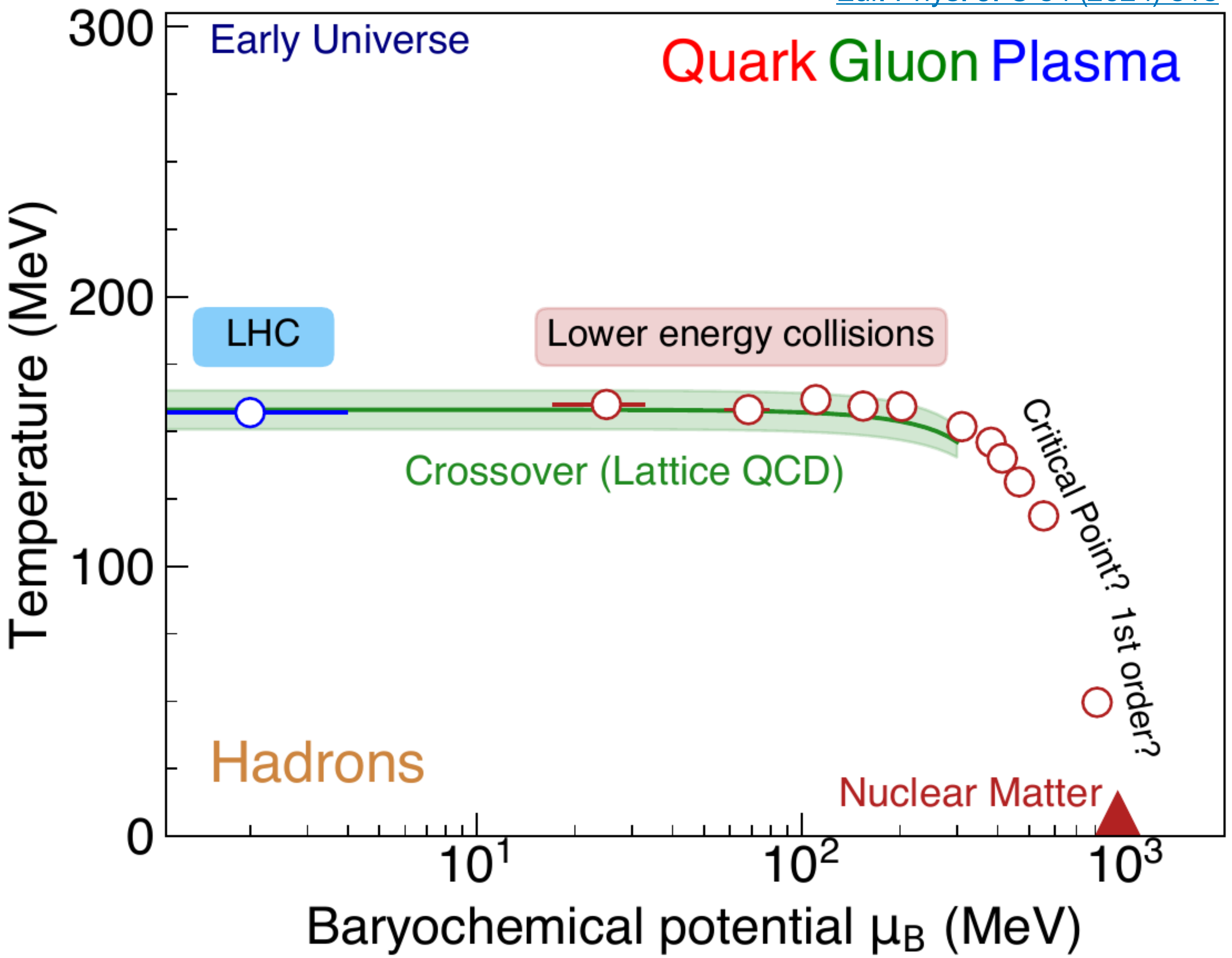
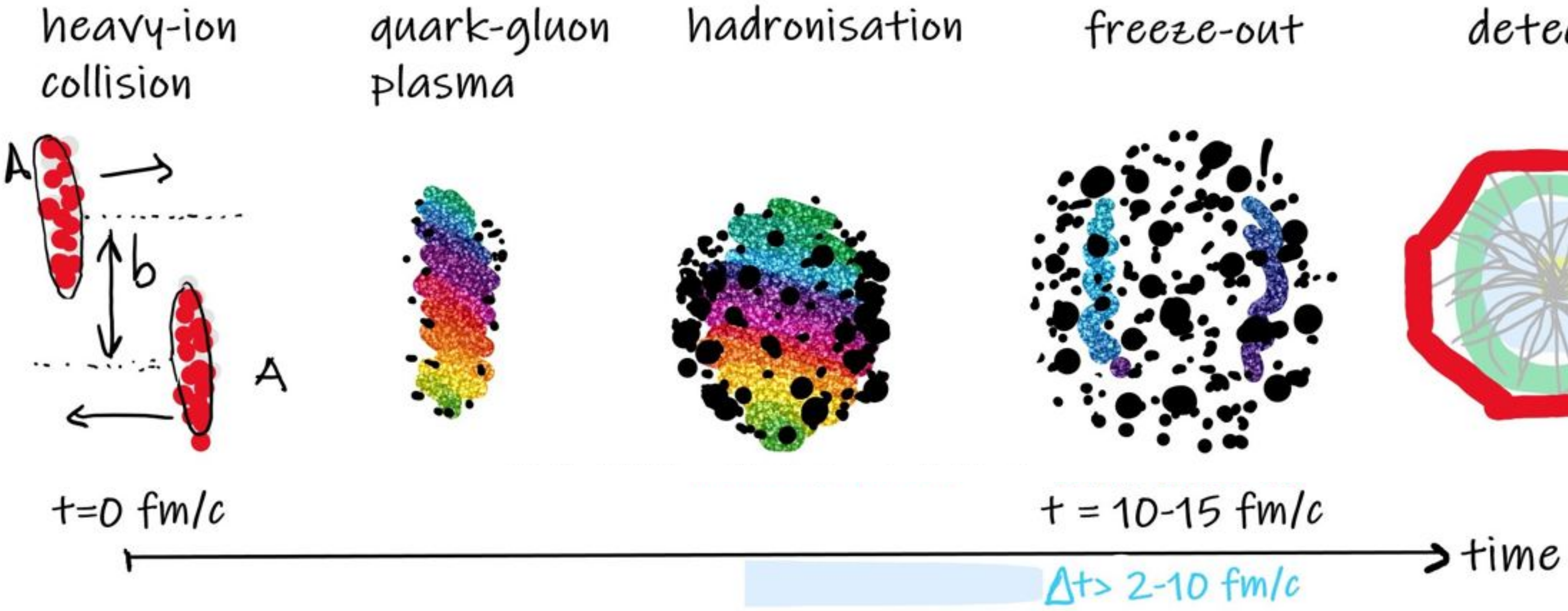
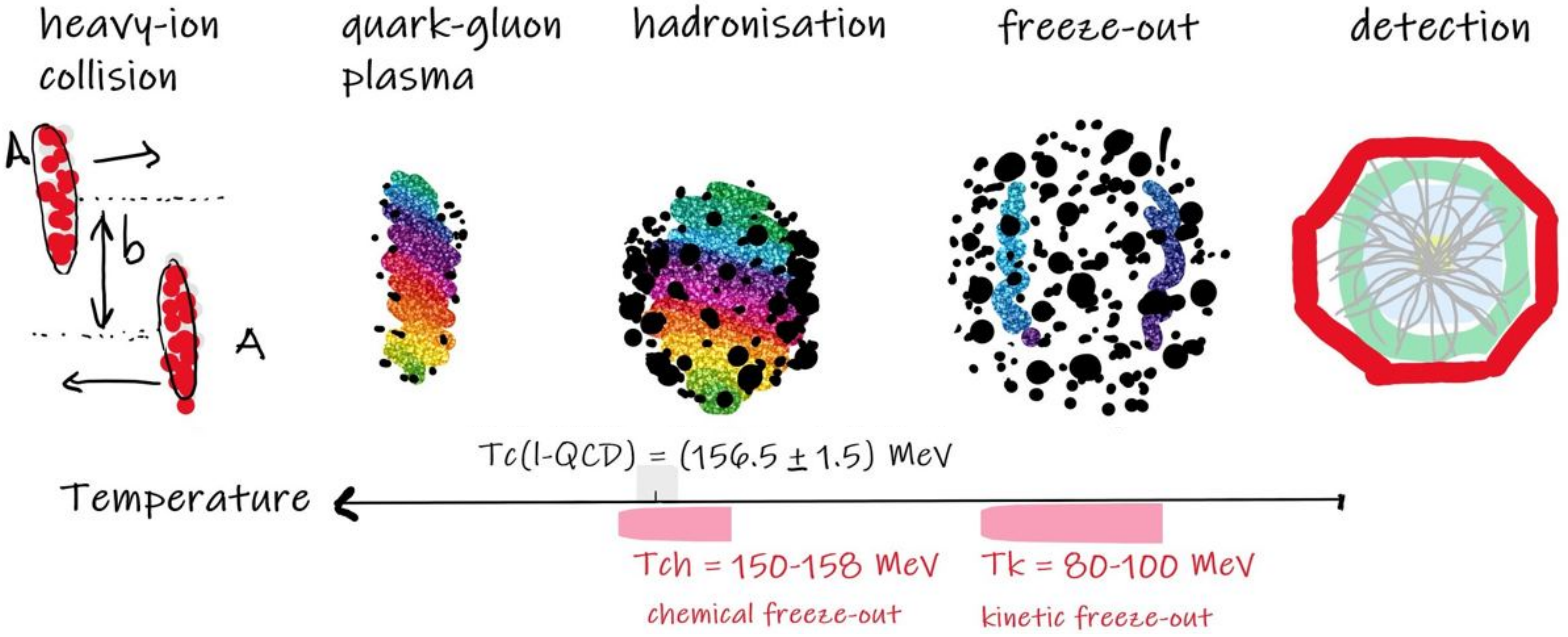


Investigating QCD at its extreme



- Energy density reached in relativistic heavy ion collisions enough to form a medium with deconfined QCD degrees of freedom
- The system formed expands while cooling down → QCD degrees of freedom reconfined into hadrons
- Final state carries the memory of its initial stage (hadrochemistry, hadron spectral shapes, hard probes suppression)
- ALICE investigates the QGP and QCD not only with Pb-Pb data, but with the entire pp running of the LHC

Investigating QCD at its extreme



ALICE Collaboration Phys. Rev. C 101, 044907

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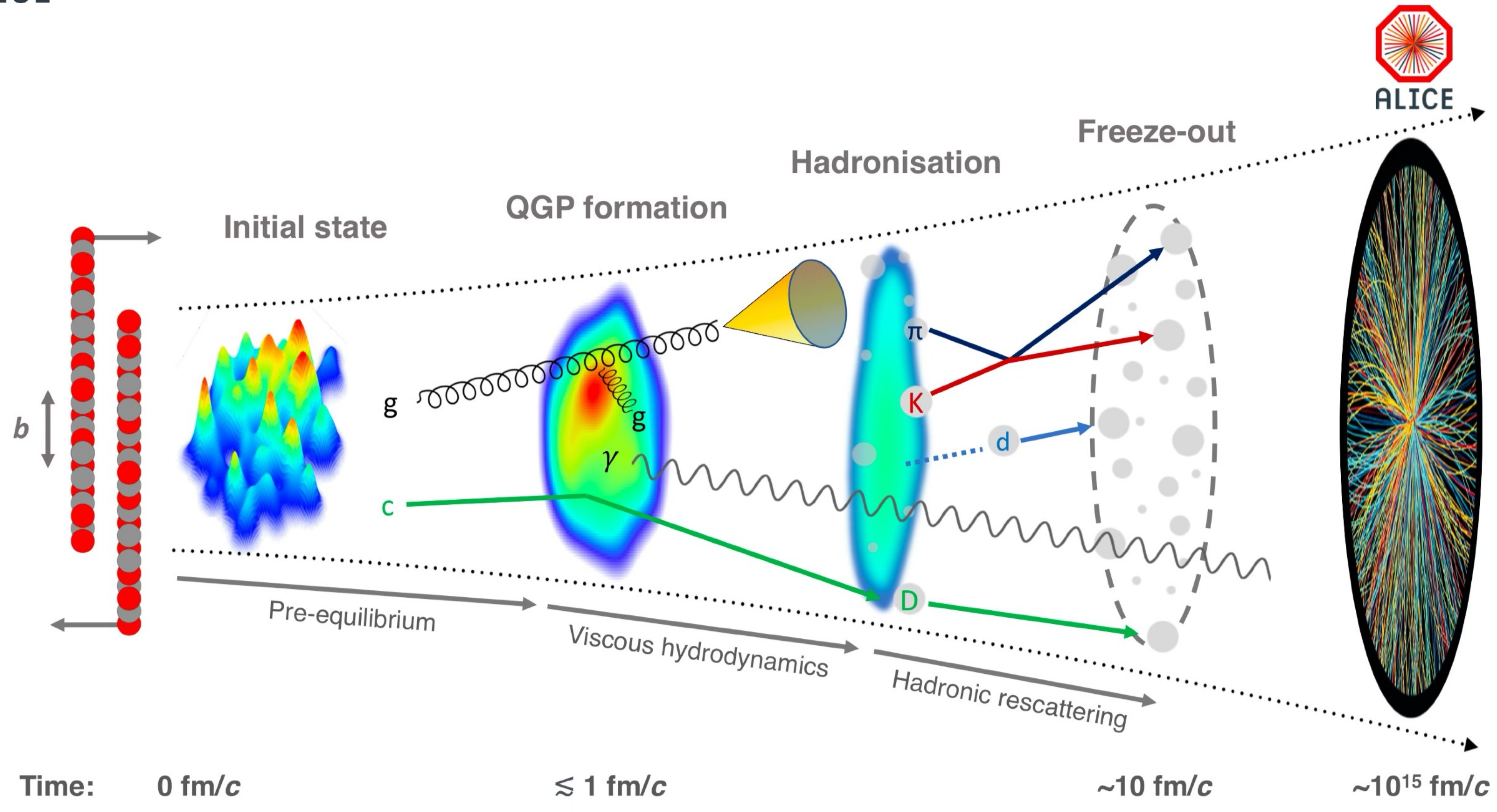
Reconstructing the fireball evolution



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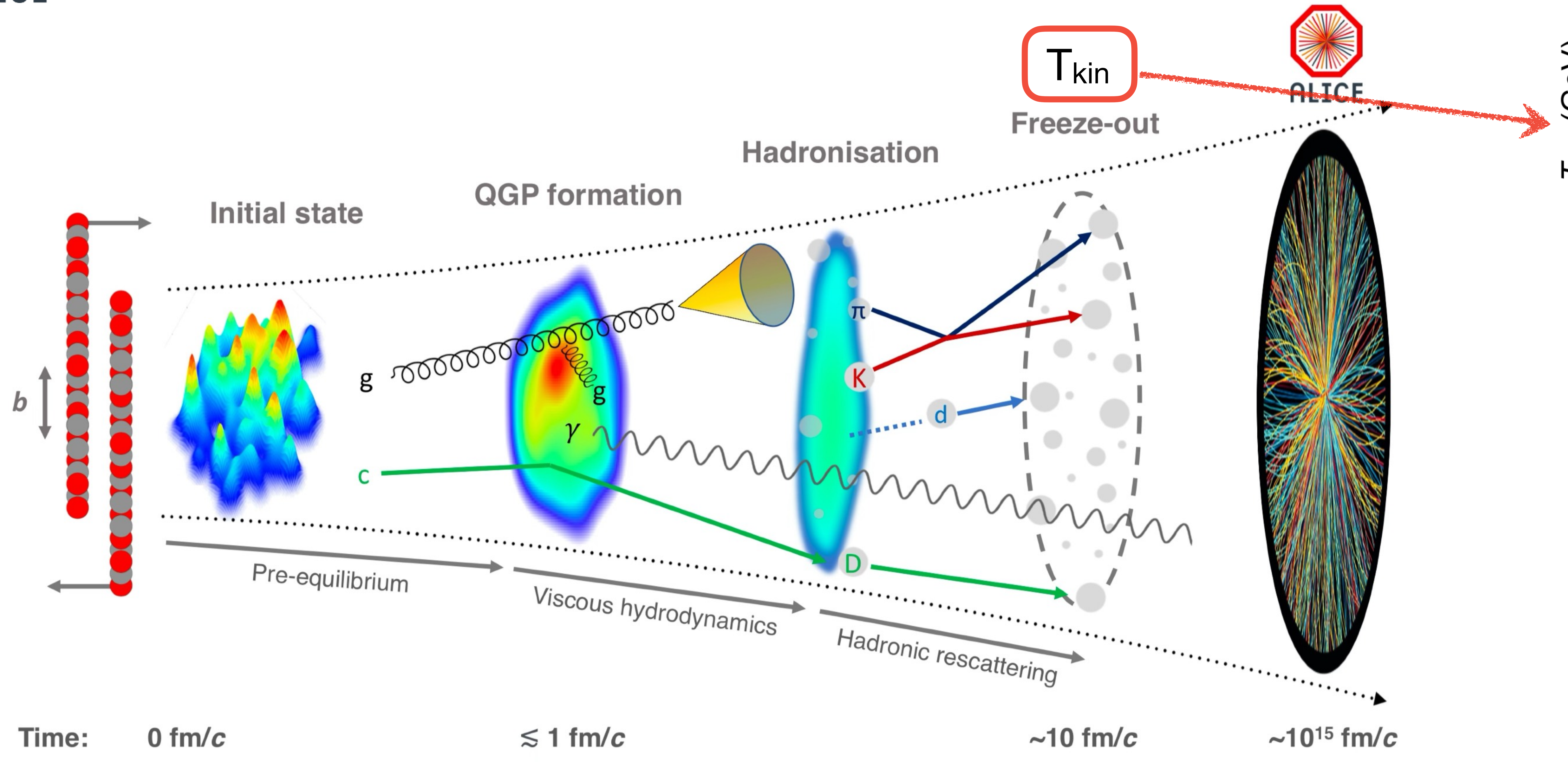
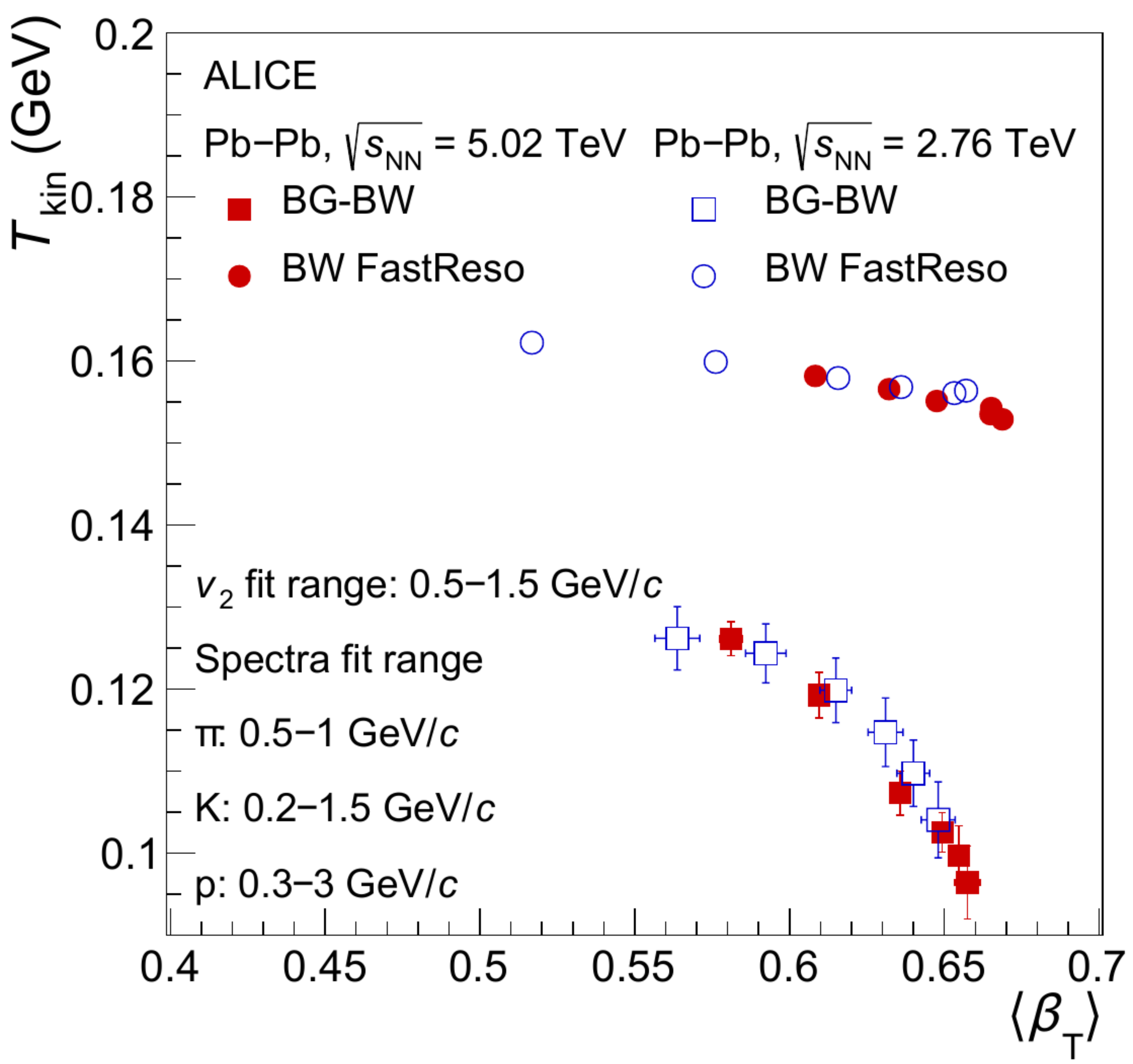
Reconstructing the fireball evolution





- Spectral shapes defined at the kinetic freeze-out

- Final state carries the memory of its initial stage (hadrochemistry, hadron spectral shapes, hard probes suppression)
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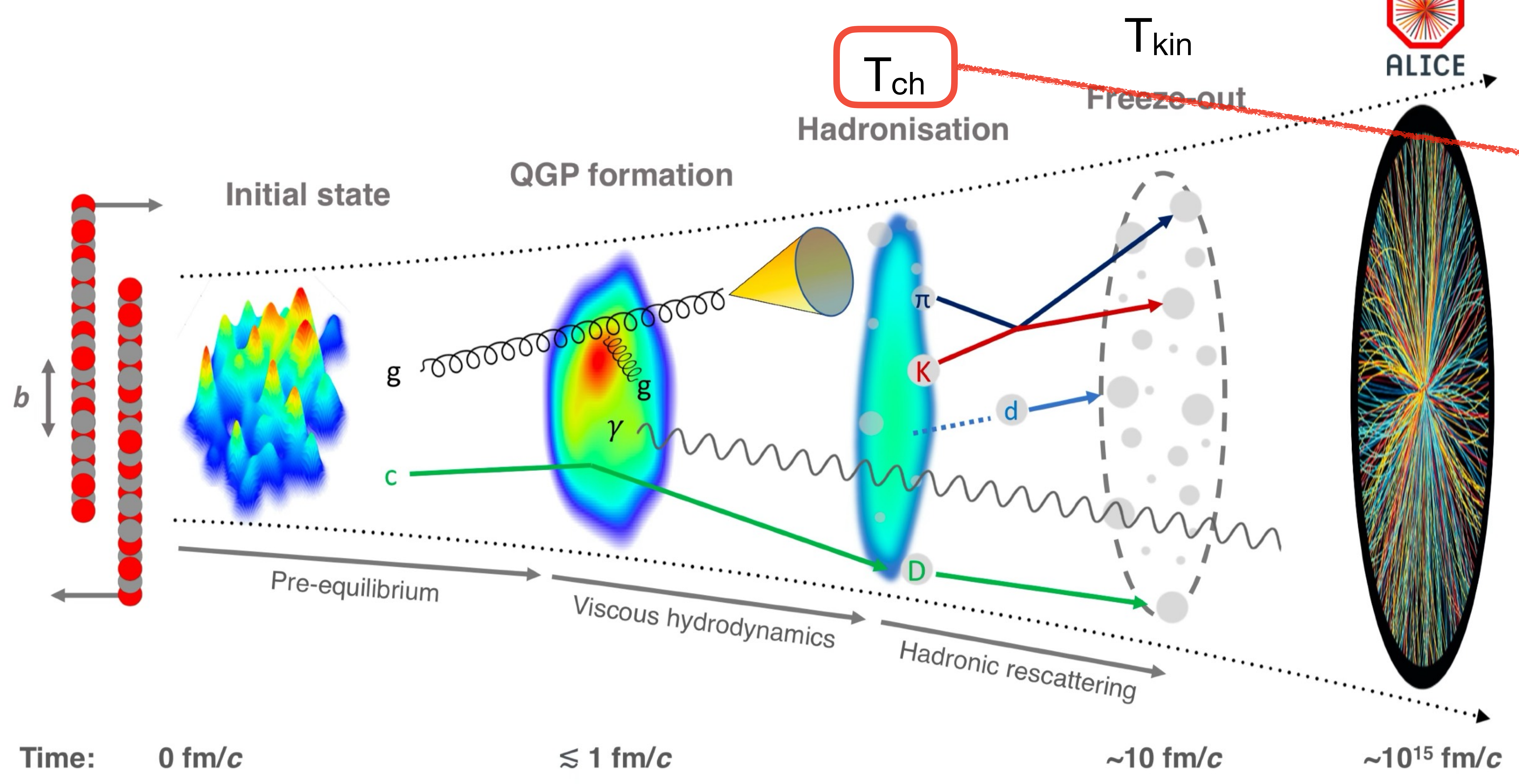
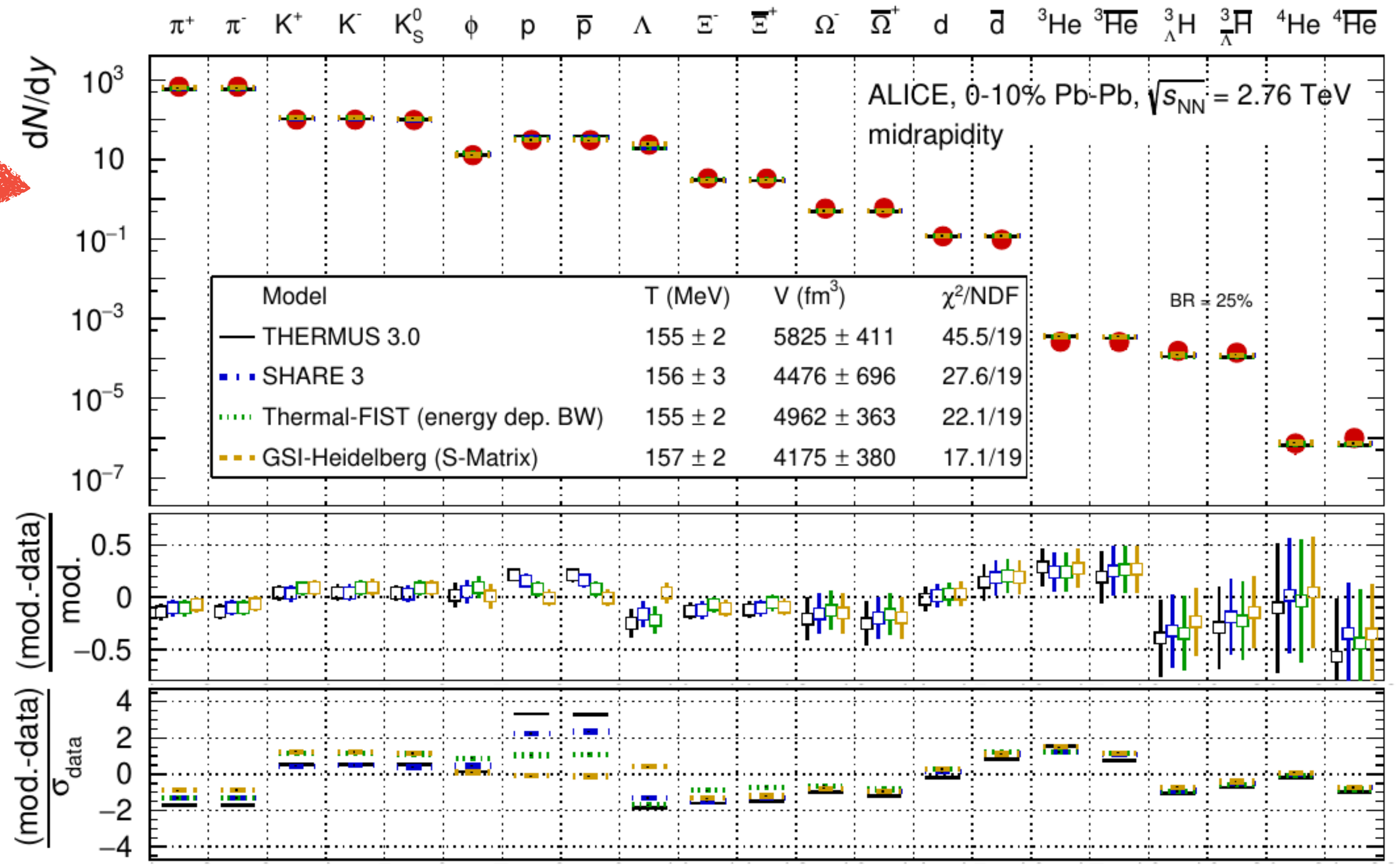
Reconstructing the fireball evolution

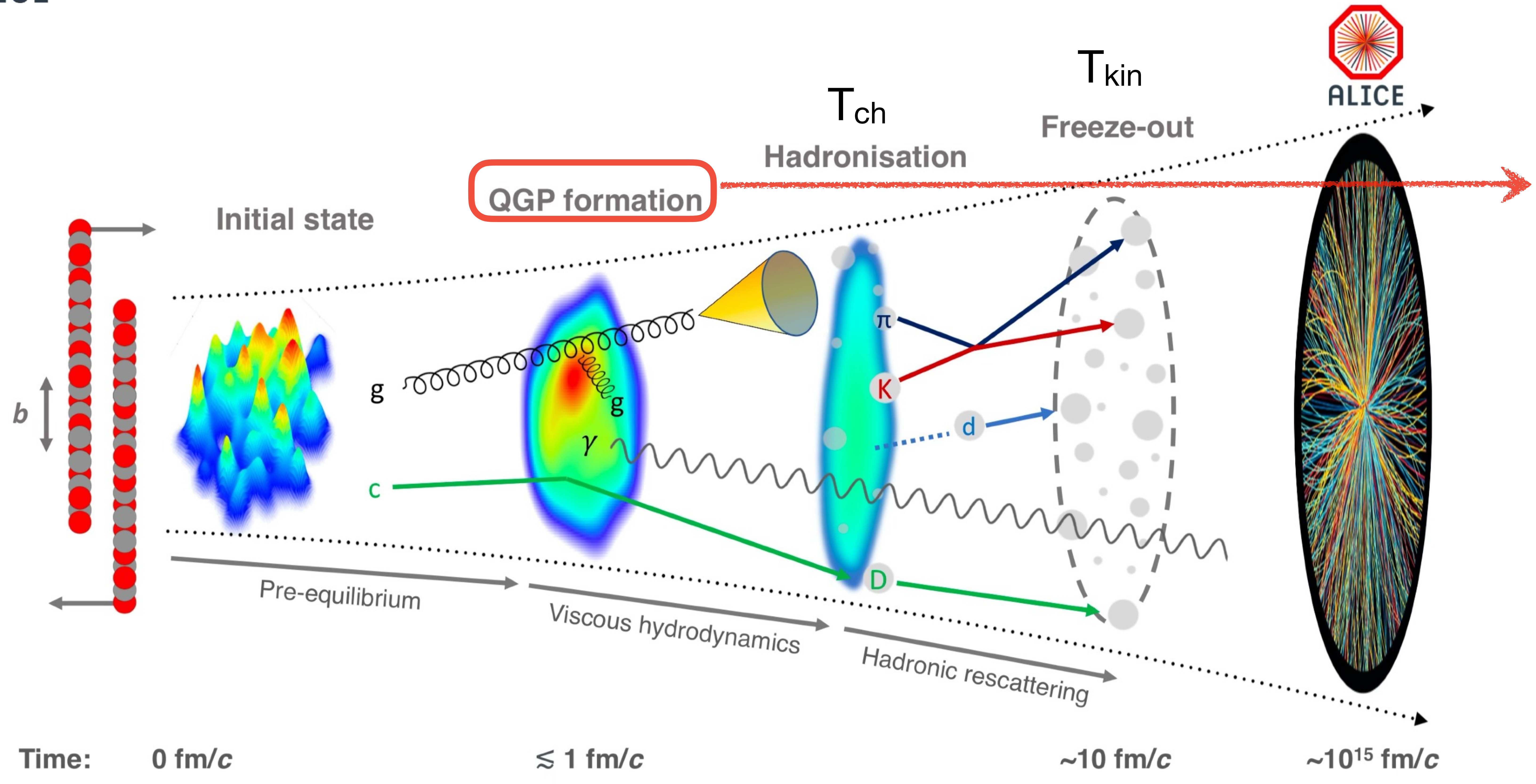


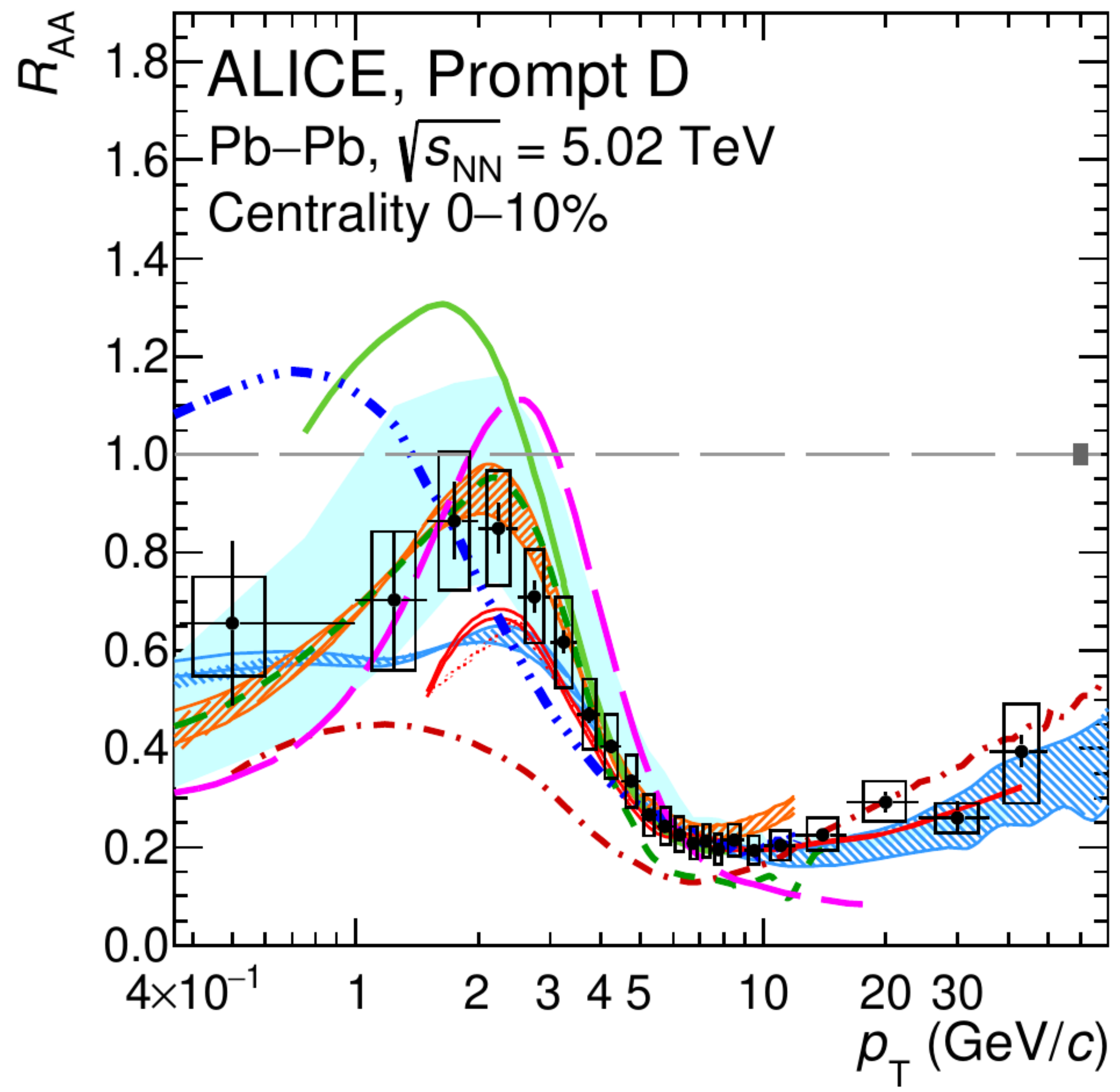


- Hadron abundances defined at the chemical freeze-out

- Final state carries the memory of its initial stage (hadrochemistry, hadron spectral shapes, hard probes suppression)
  → final state can be used to reconstruct the fireball evolution

Reconstructing the fireball evolution

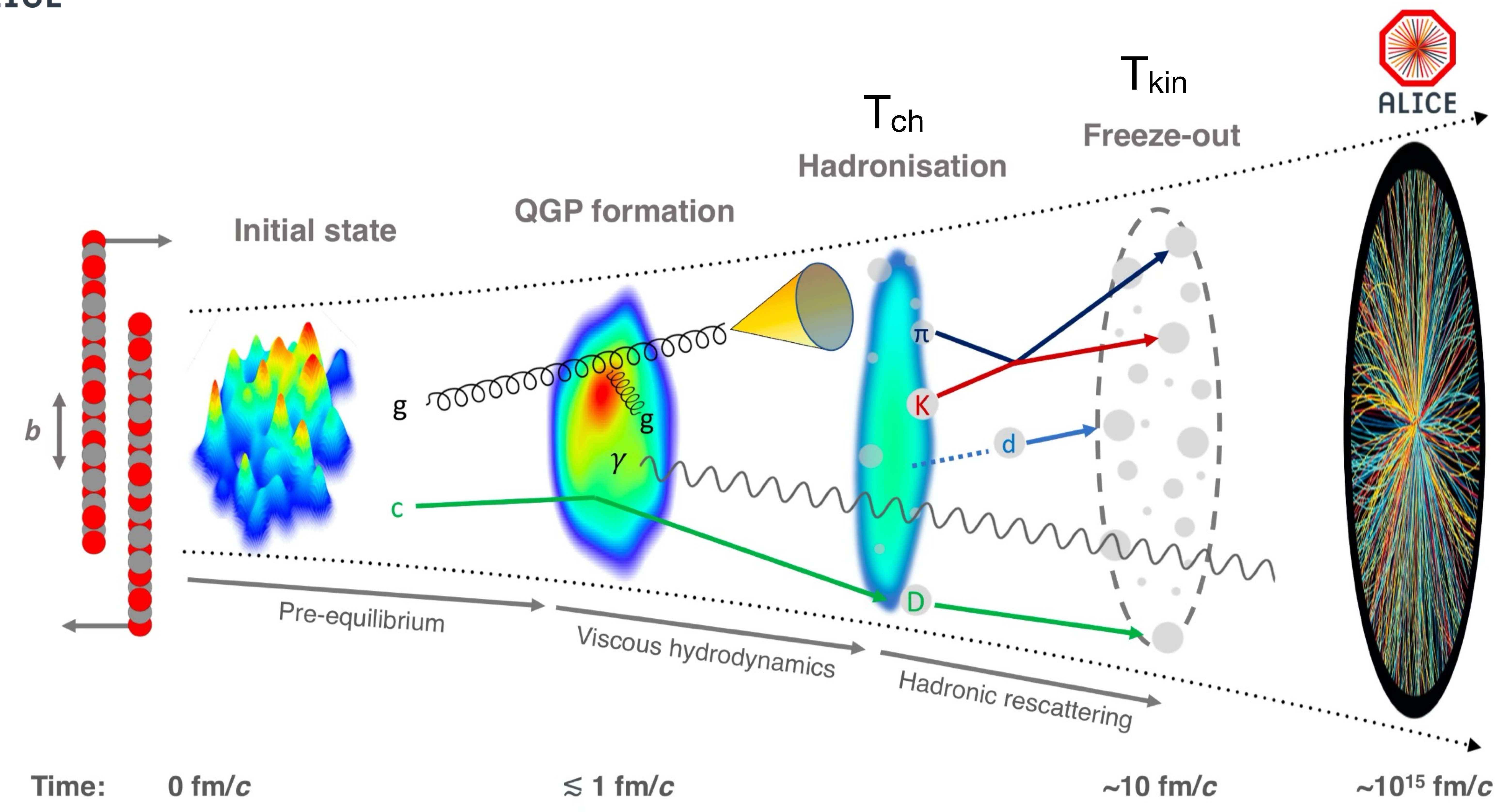




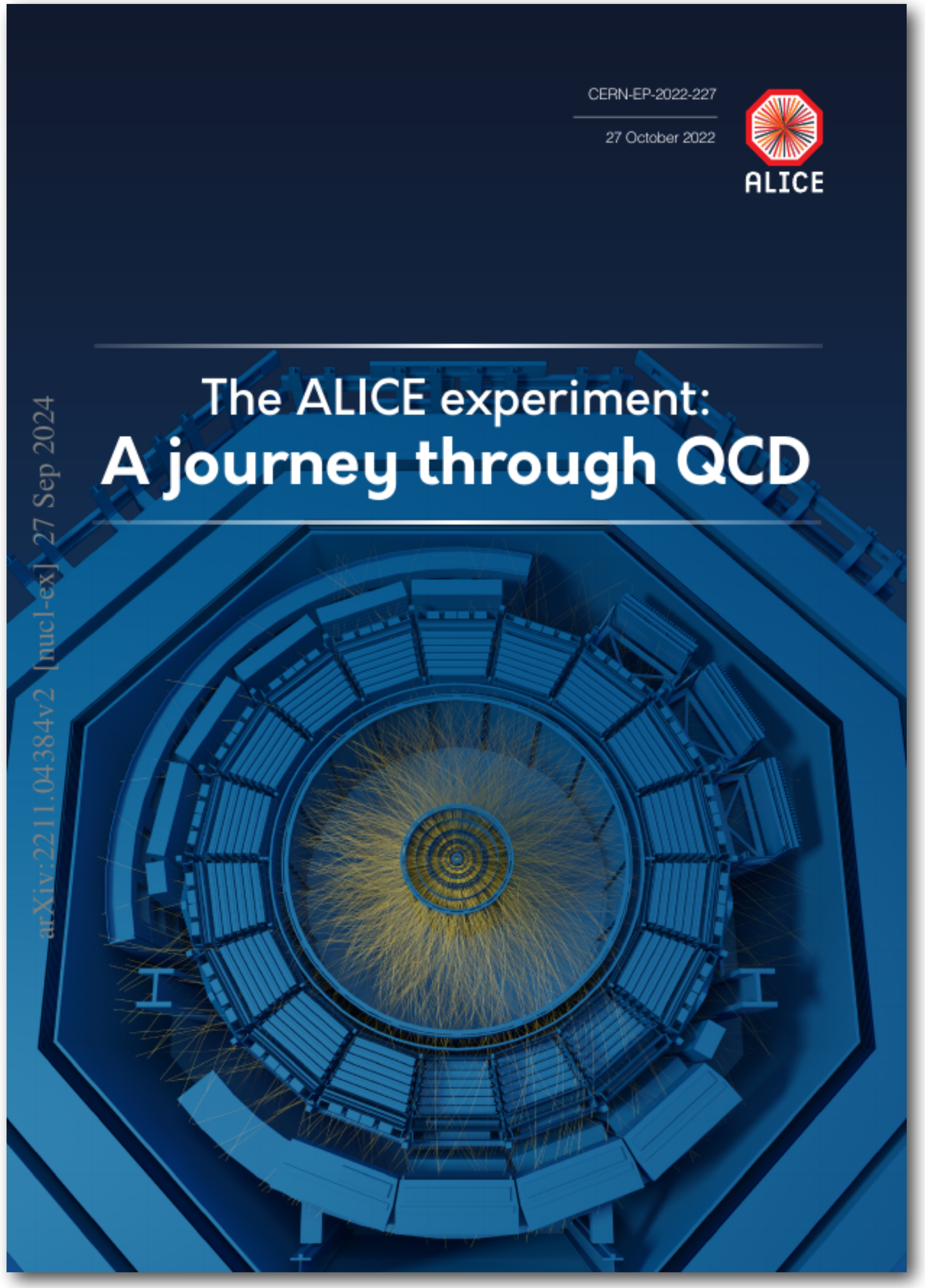
- Heavy quarks are produced in the initial stages of the collision

- Final state carries the memory of its initial stage (hadrochemistry, hadron spectral shapes, hard probes suppression)
  → final state can be used to reconstruct the fireball evolution

Reconstructing the fireball evolution



And many more!



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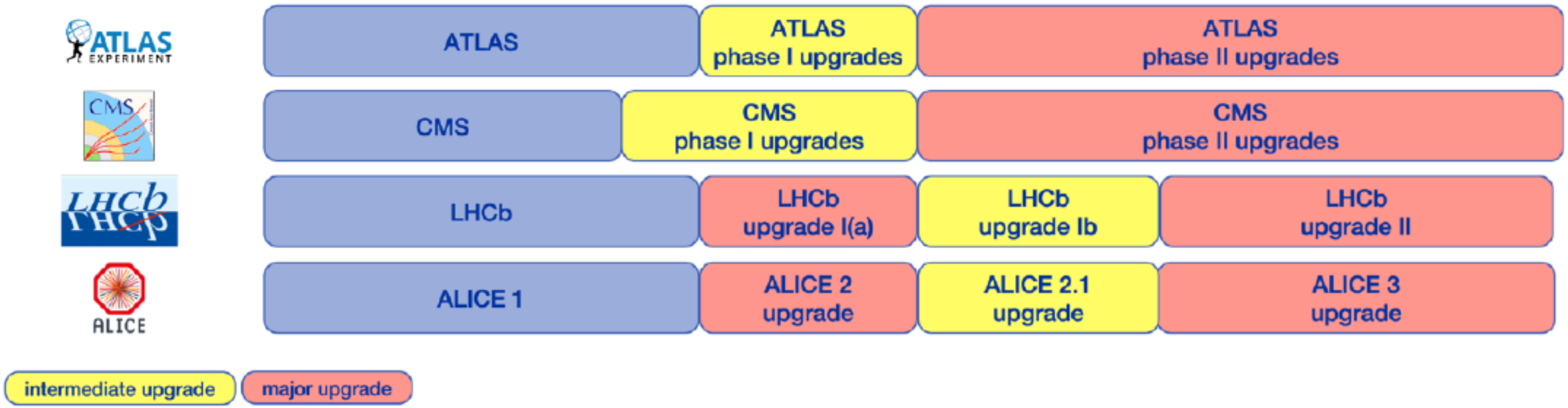
Full report Eur. Phys. J. C 84 (2024) 813

Timeline of the LHC

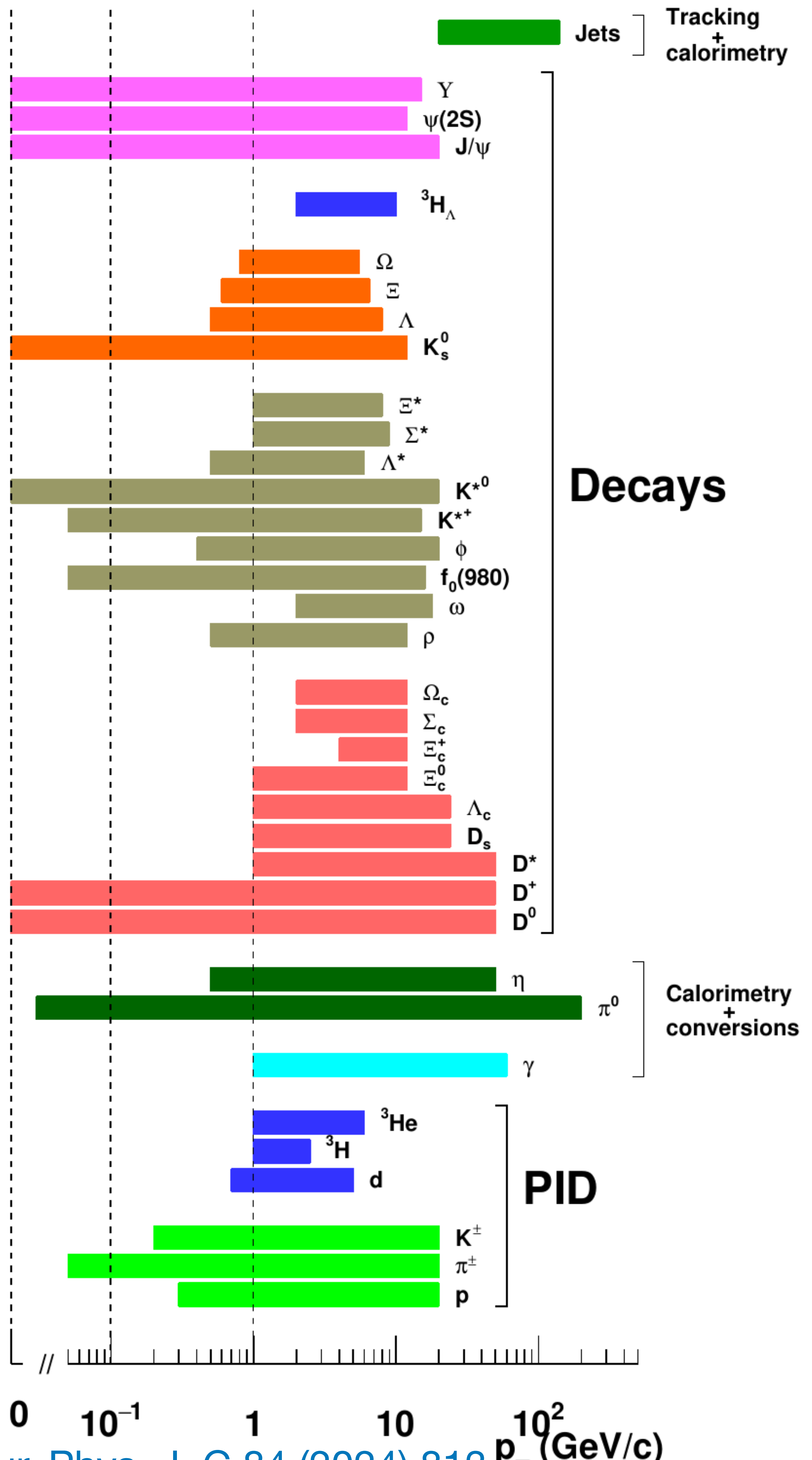
Long term planning with (lighter) ions



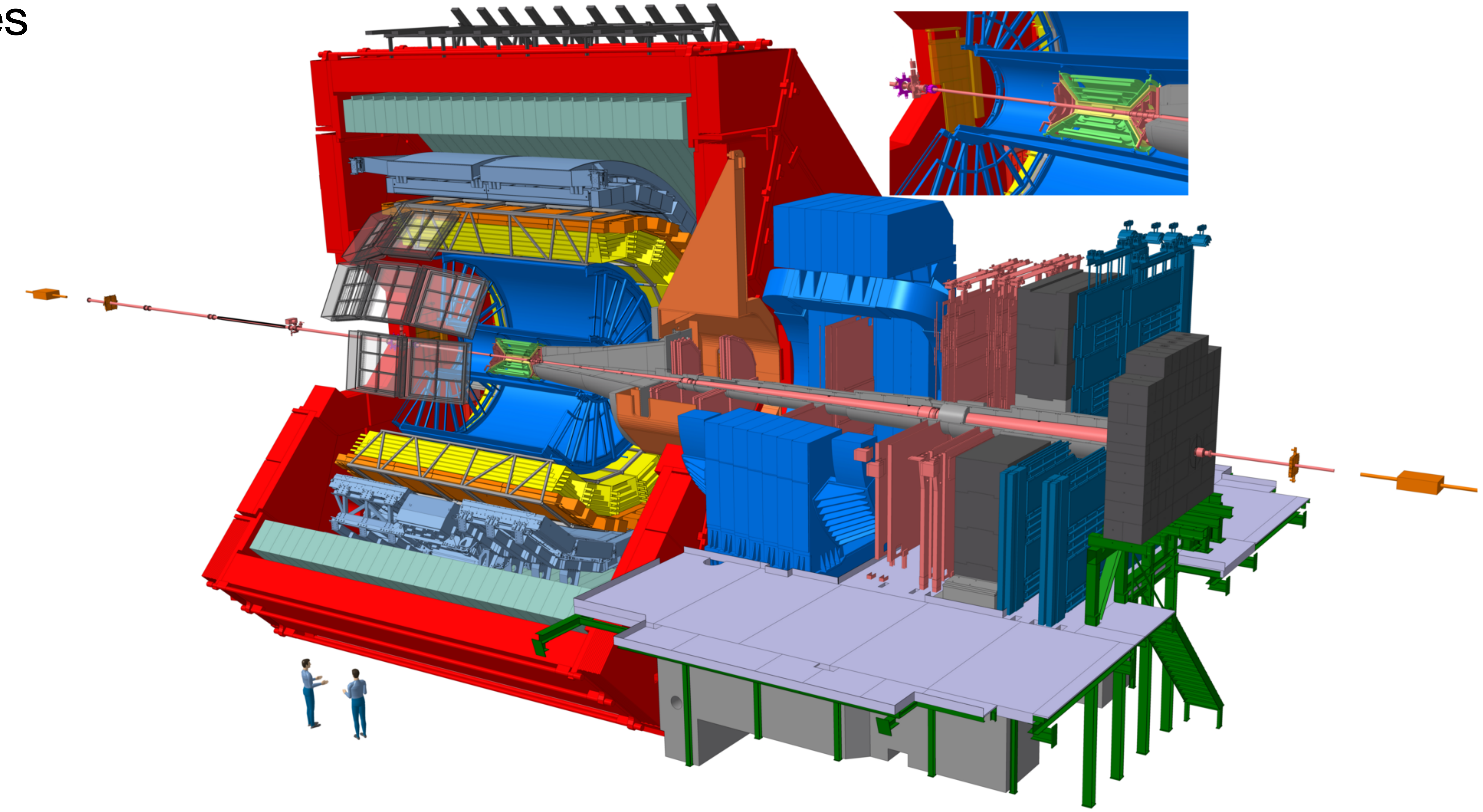
Upgrades are needed to take advantage of the physics reach

ALICE 1.0 (Run 1 and Run 2)

Leading particle identification with all known techniques



[Eur. Phys. J. C 84 (2024) 813](https://doi.org/)



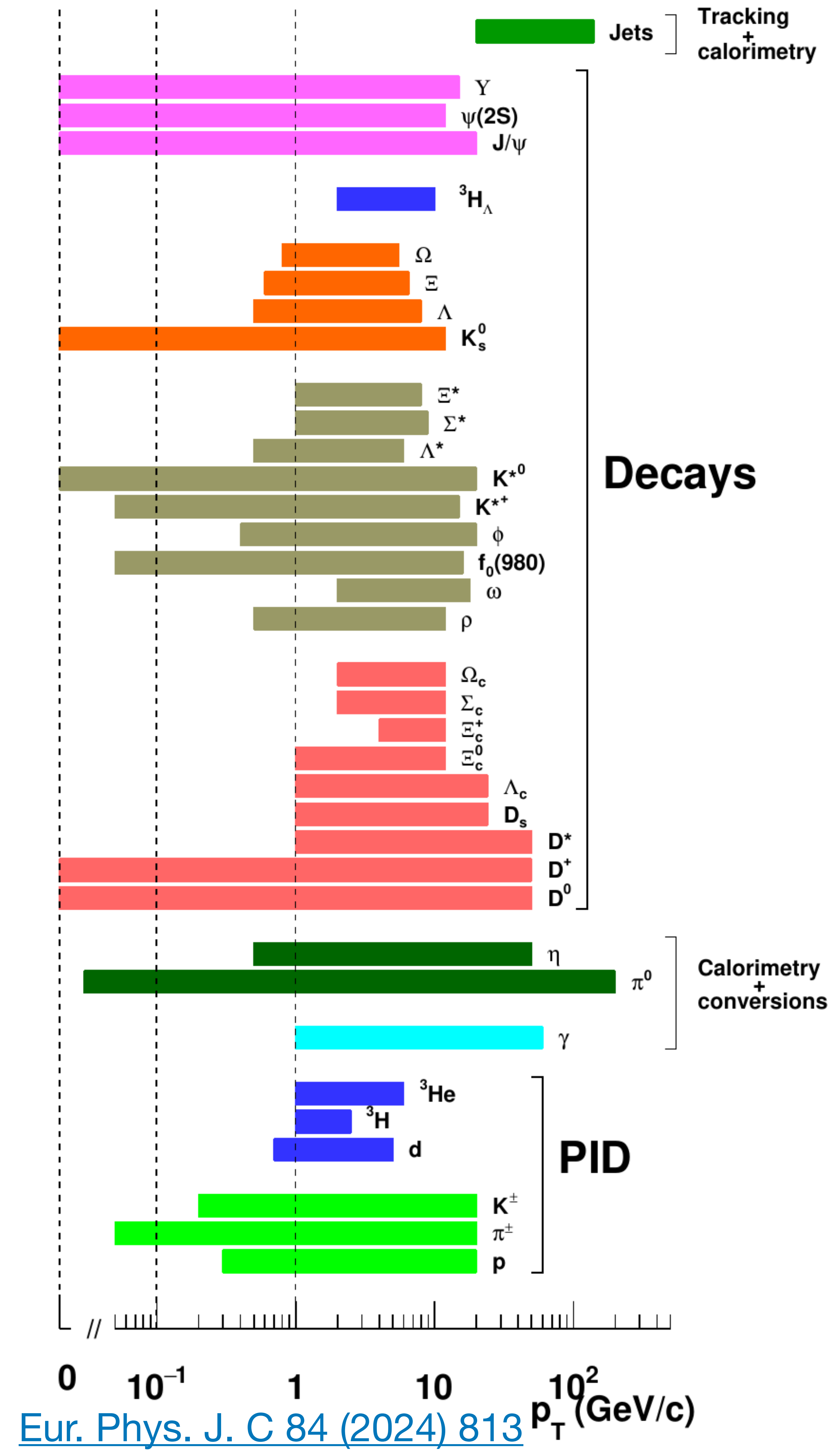
System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	L_{int}	N_{MB}
Pb–Pb	2010, 2011	2.76	75 μb^{-1}	1.3×10^{8}
Pb–Pb	2015, 2018	5.02	800 μb^{-1}	6×10^{8}
Xe–Xe	2017	5.44	0.3 μb^{-1}	1.1×10^{6}
p–Pb	2013, 2016	5.02	18 nb^{-1}	8×10^{8}
p–Pb	2016	8.16	25 nb^{-1}	1.3×10^{8}
pp	2009	0.9	200 μb^{-1}	0.5×10^{6}
pp	2011	2.76	100 nb^{-1}	1.3×10^{8}
pp	2010, 2011	7	1.5 pb^{-1}	1.6×10^{9}
pp	2012	8	2.5 pb^{-1}	3.1×10^{8}
pp	2015, 2017	5.02	1.3 pb^{-1}	10^{9}
pp	2015 - 2018	13	36 pb^{-1}	6×10^{9}

Broad momentum acceptance (0.1 - 100 GeV/*c*) + hadron PID (0.1 - 20 GeV/*c*)

Probes for all aspects of QGP behavior

ALICE 1.0 (Run 1 and Run 2)

Leading particle identification with all known techniques



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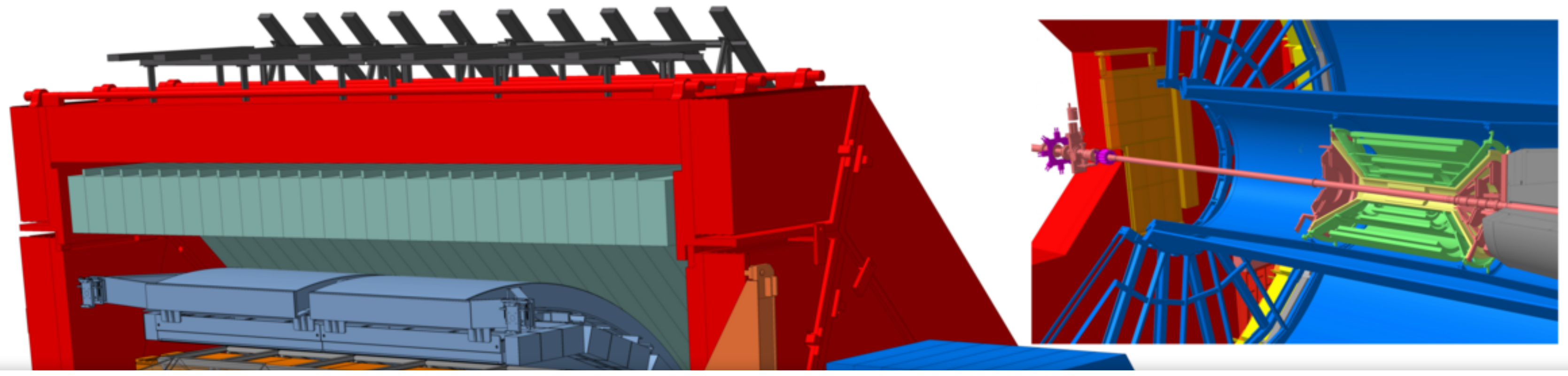

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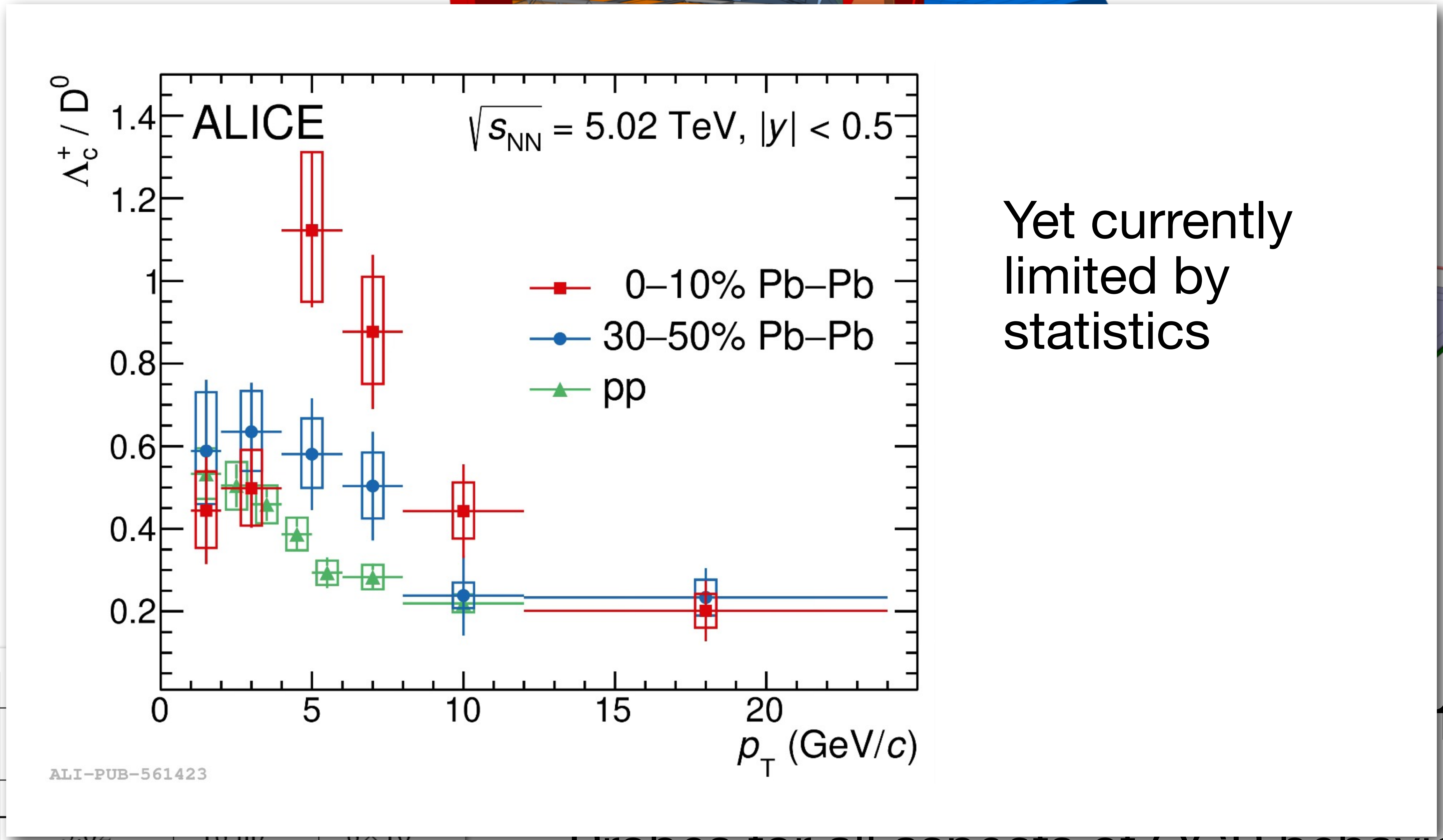


Yet currently limited by statistics

100

Probes for all aspects of QGP behavior

ALICE upgrades in the LS2

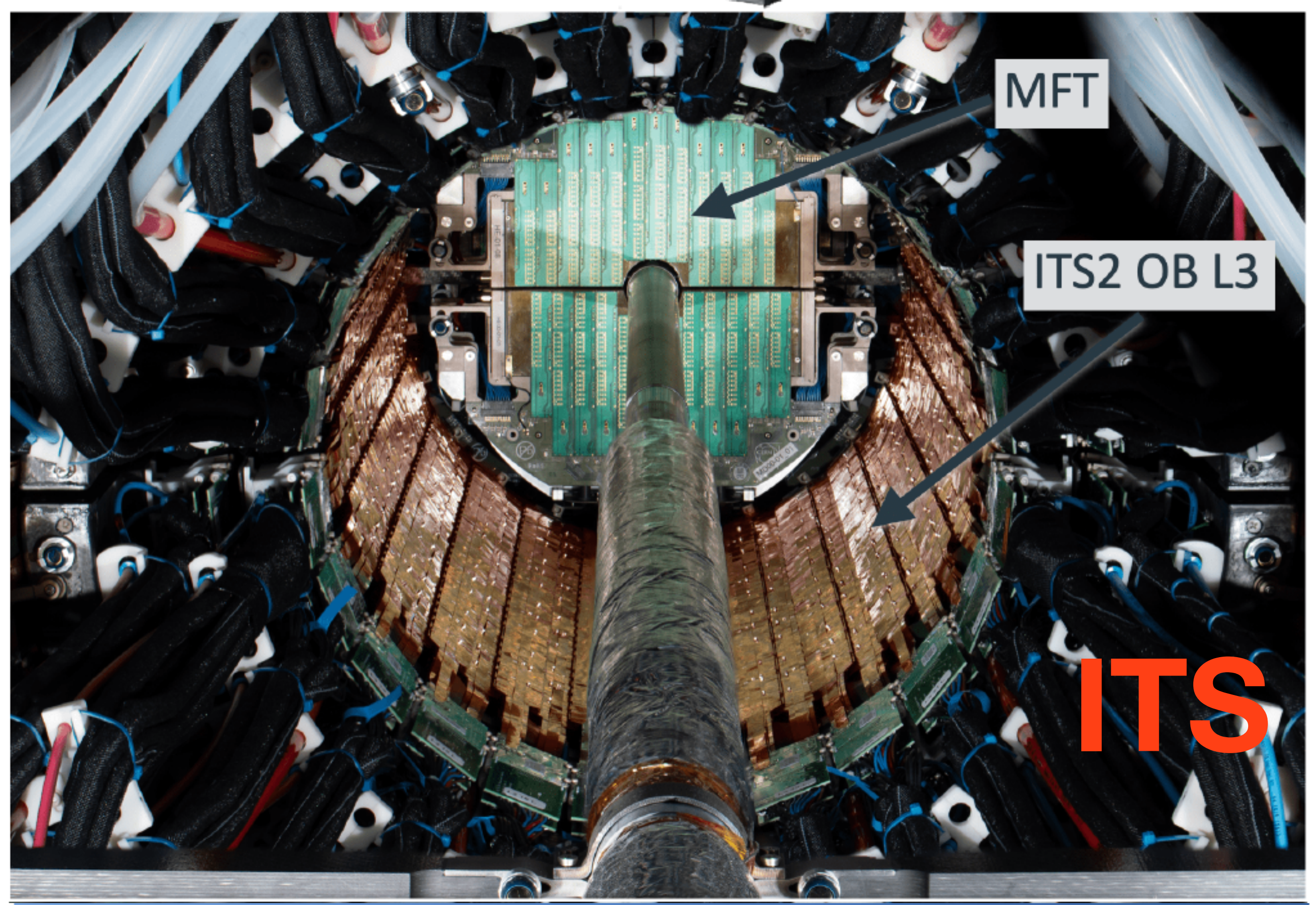
- **Major upgrade in LS2**

  Inner Tracking System → 7 layers of pixel detectors
  - Time Projection Chamber → GEM readout
  - New Muon Forward Tracker → secondary vertex
  - New Forward Interaction Trigger → triggering, event time
  - New Even Processing Farm → event reconstruction
  - Readout upgraded for most detectors to allow continuous readout
- **Continuous readout at high rate**
  - pp data taking at 500 kHz (x 1000 Run 2)
    - Intermediate data storage on disk buffer
    - Asynchronous (offline) trigger, selectivity ~ 10^{-4}
  - Pb-Pb data taking at 50 kHz (x 50 Run 2)
    - All Compressed Time Frame data stored on tape

Detailed in the new report

ALICE upgrades during the LHC Long Shutdown 2

ALICE 2024 JINST 19 P05062

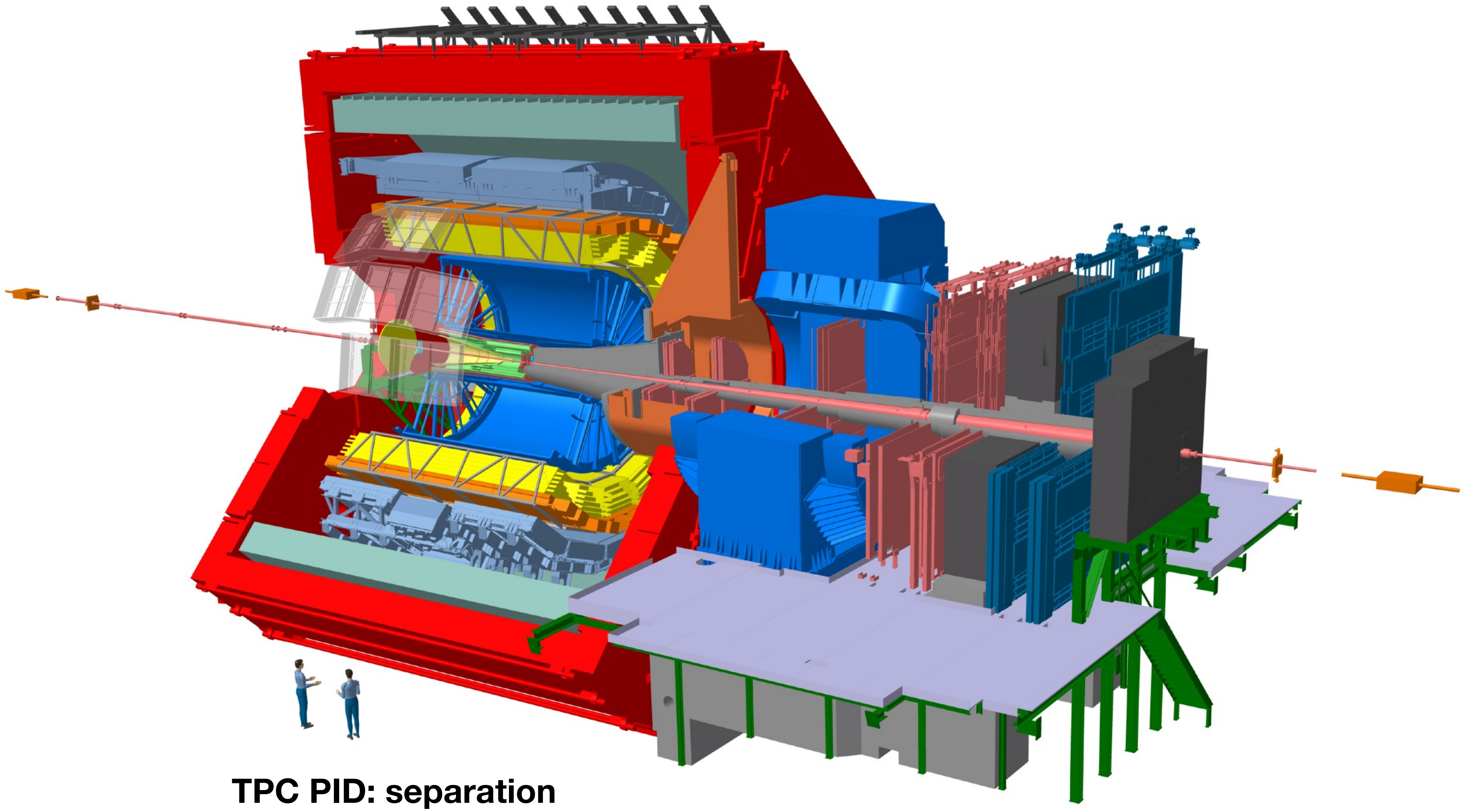


ALICE in Run 3

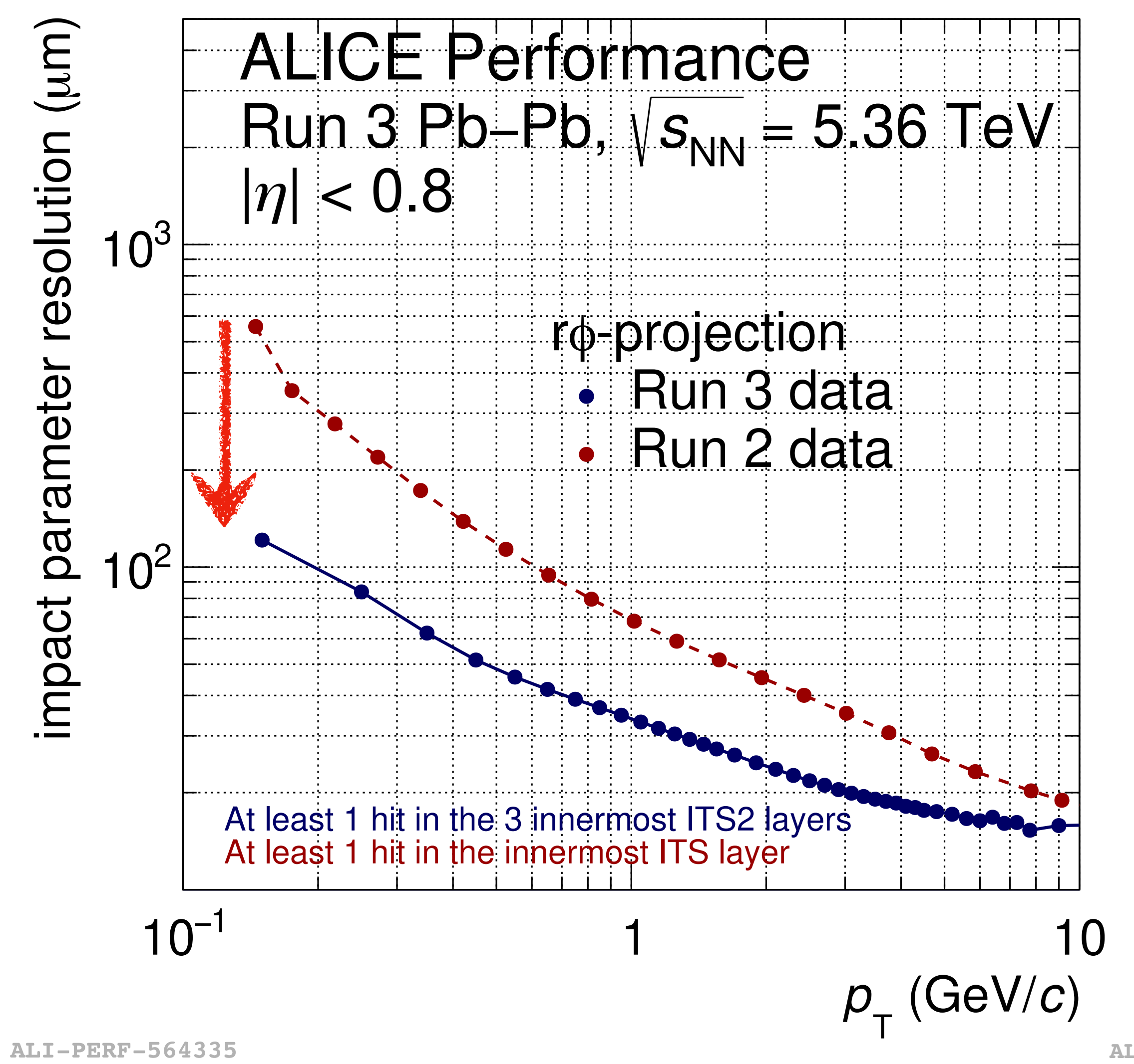
Recent upgrades for Run 3

Improved tracking, IR tolerance, kept PID capabilities

- Precision era for jet, heavy-flavor and electromagnetic probes in large & small systems
- Deeper explorations of proton/nuclear structure and rare hadron interactions

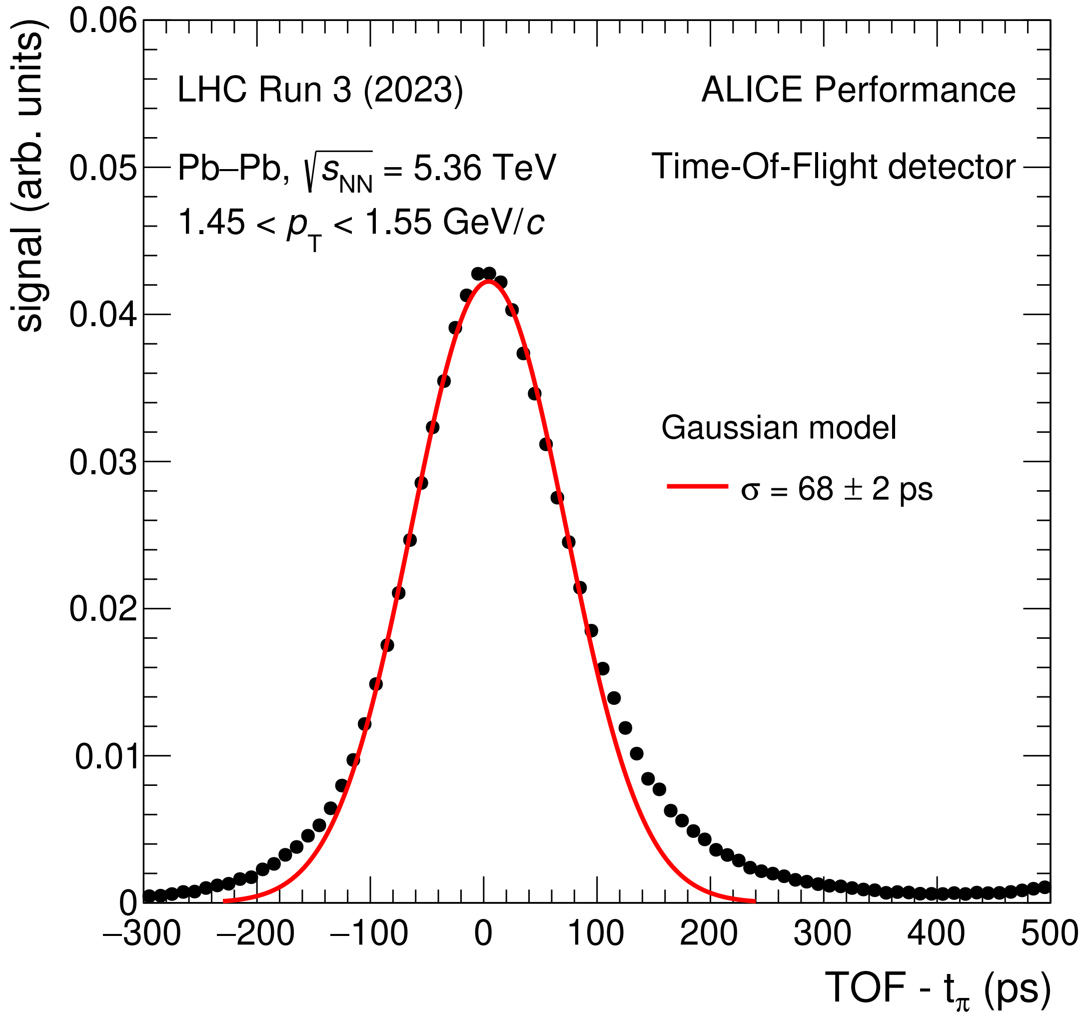


Tracking: impact parameter



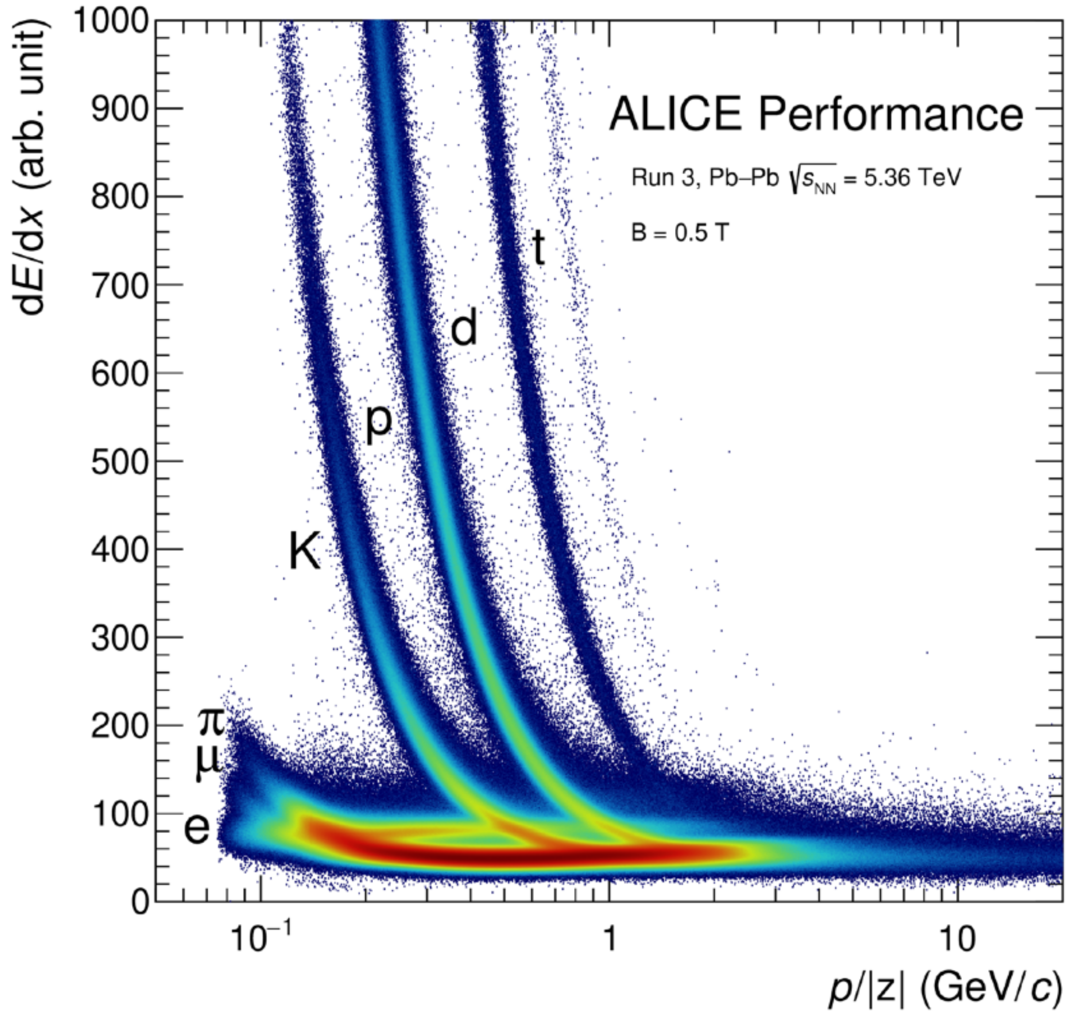
ALI-PERF-564335

TOF PID: resolution



ALI-PERF-568539

TPC PID: separation

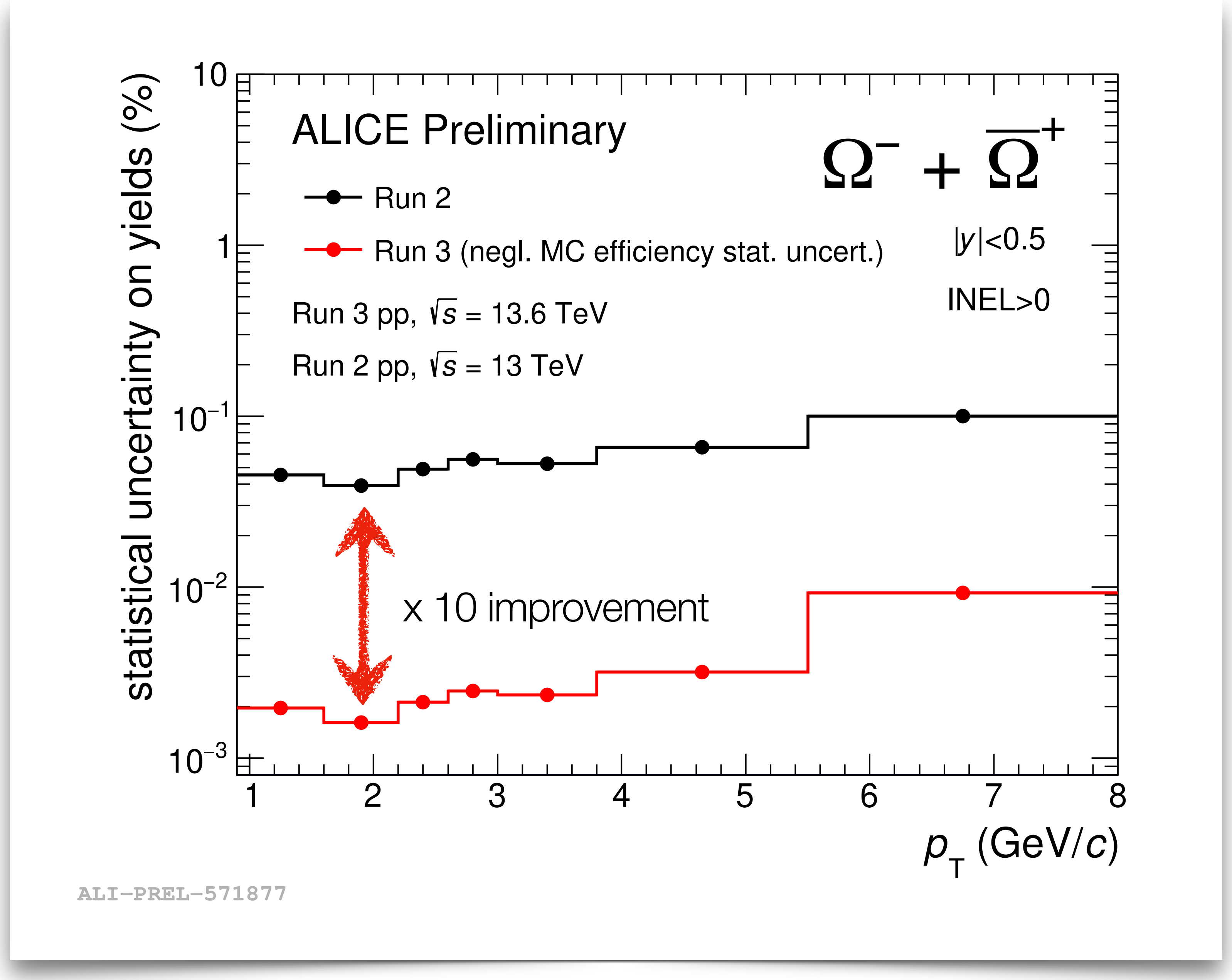


ALI-PERF-529714

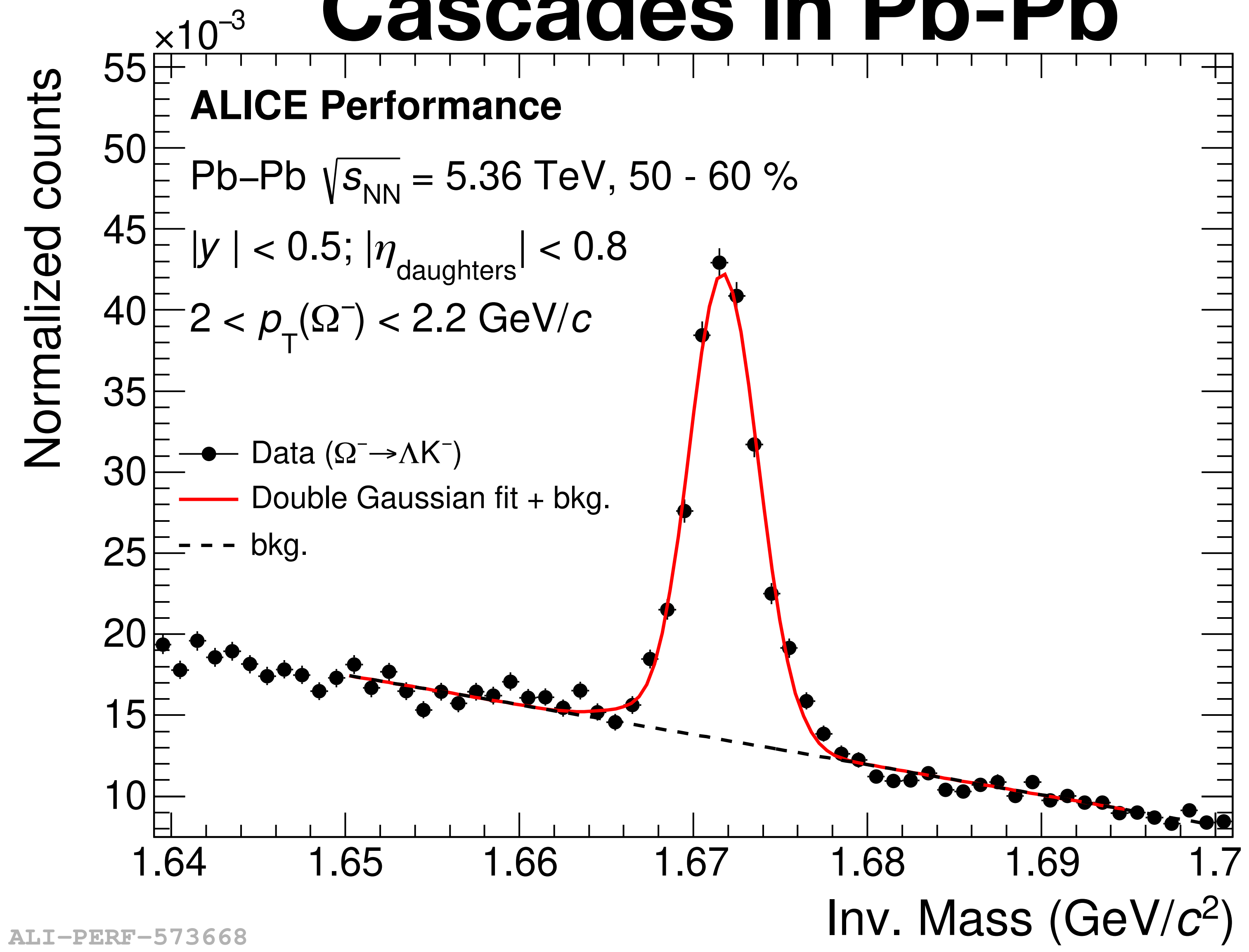
- Improved pointing resolution in both rϕ and z directions
- Particle identification capabilities are conserved

Physics performance in Run 3

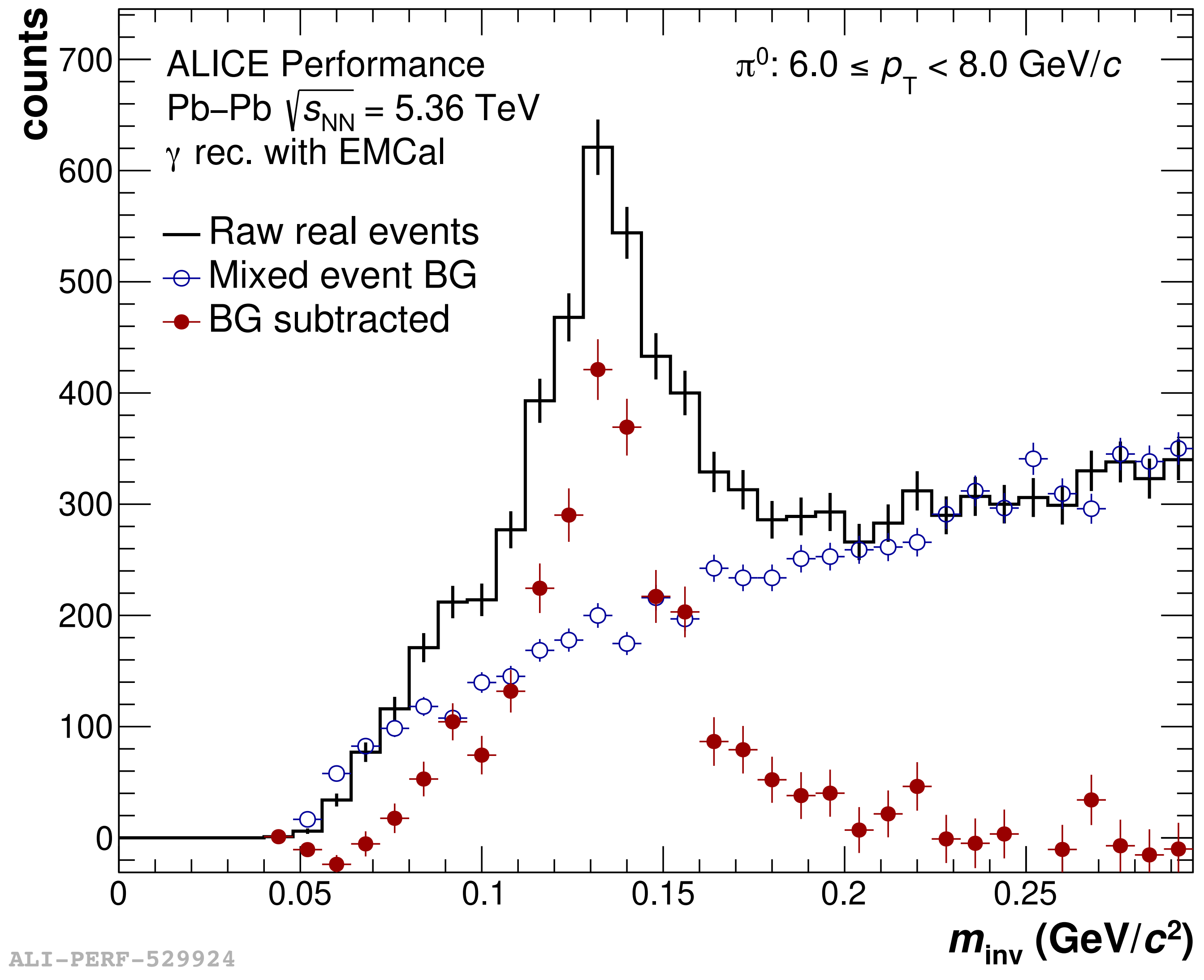
- Data ready for analysis covering all sectors
- Already improving on the observable statistical uncertainties



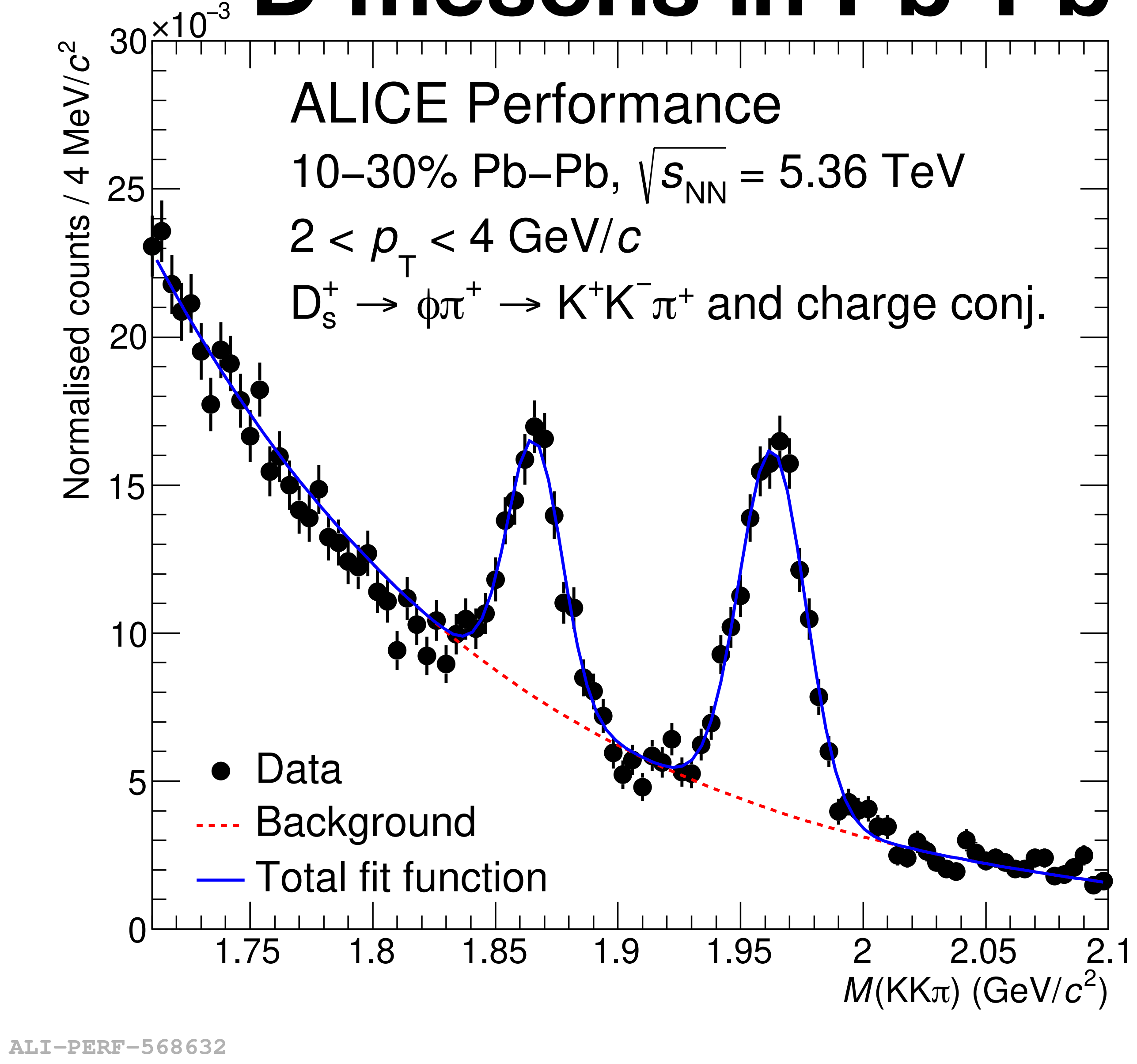
Cascades in Pb-Pb



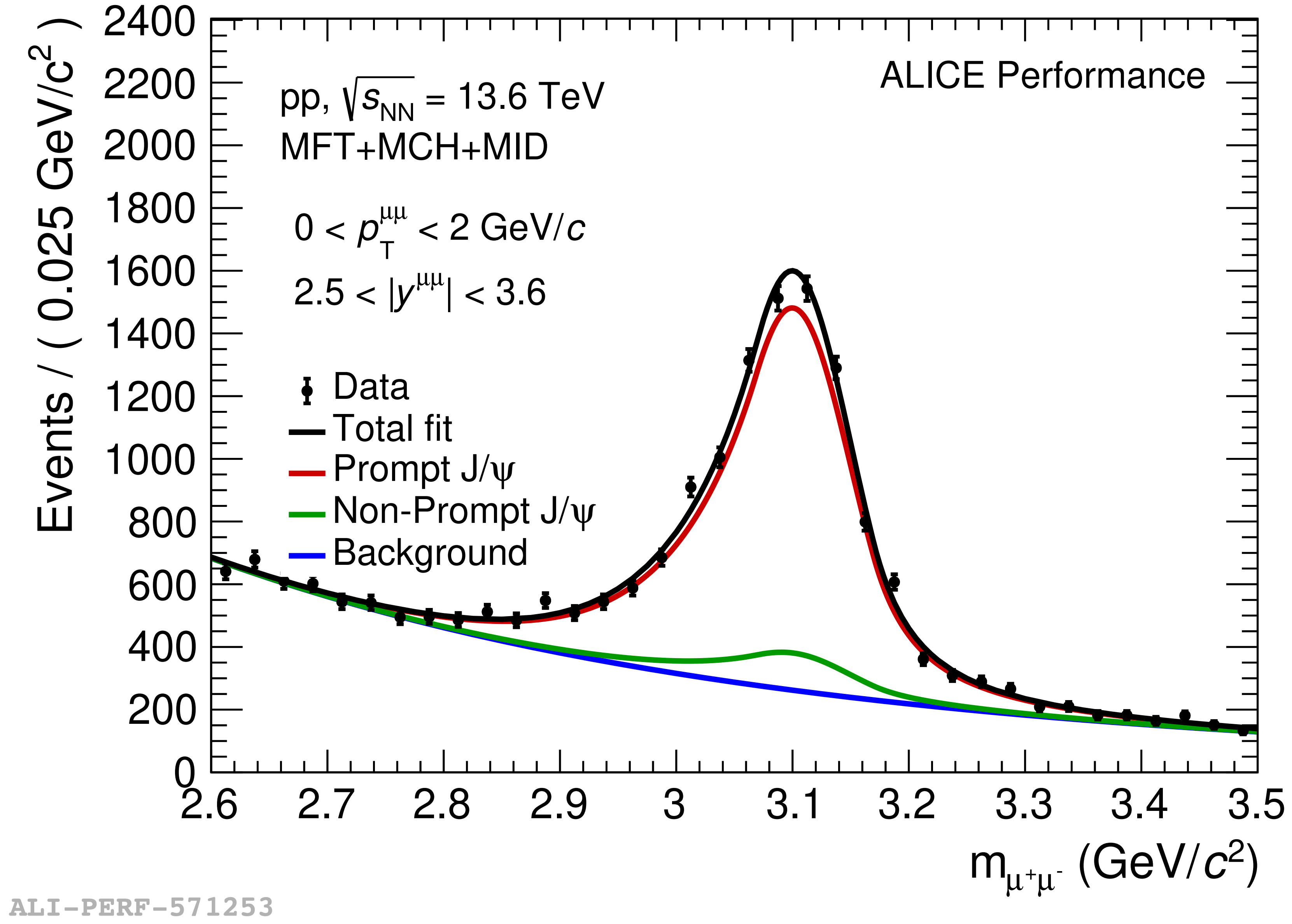
π^0 in Pb-Pb



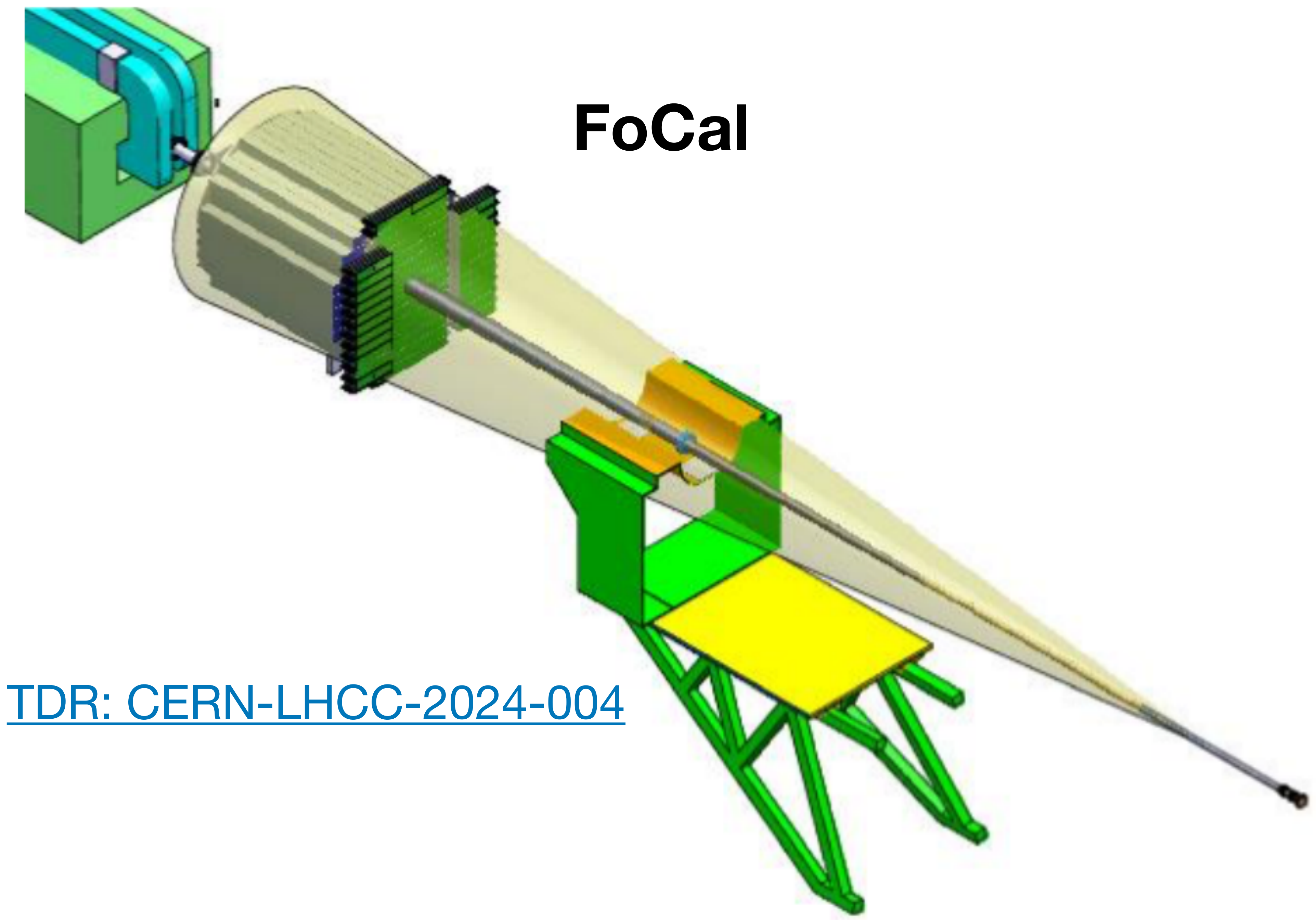
D mesons in Pb-Pb



Prompt J/ψ

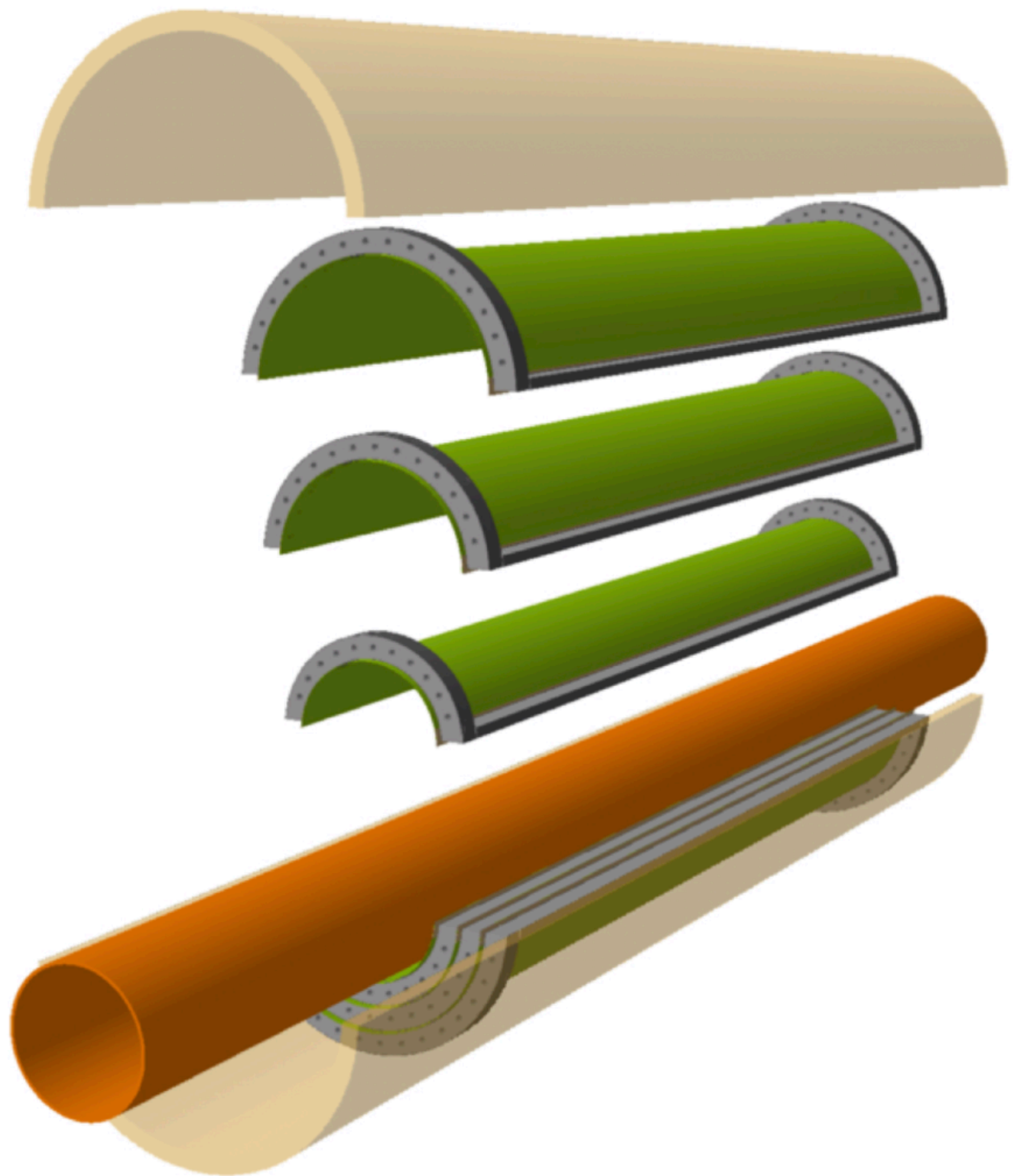


ALICE 2.1: FOCAL and ITS3



TDR: CERN-LHCC-2024-004

TDR: CERN-LHCC-2024-003



FoCAL (Forward Calorimeter)
- Parton distributions in protons and nuclei
- Long range correlations in pp and p-A
- Forward jets and ultra-peripherial collisions

ITS 3 (inner tracking system)
- Replacement of 3 innermost layers of ITS2
- Curved wafer-scale ultra-thin silicon sensors:
  - perfectly cylindrical layers
  - low power consumption → air cooling → low material
  - material budget: 0.05% X0 per layer
- High-precision, efficient low-p_T tracking

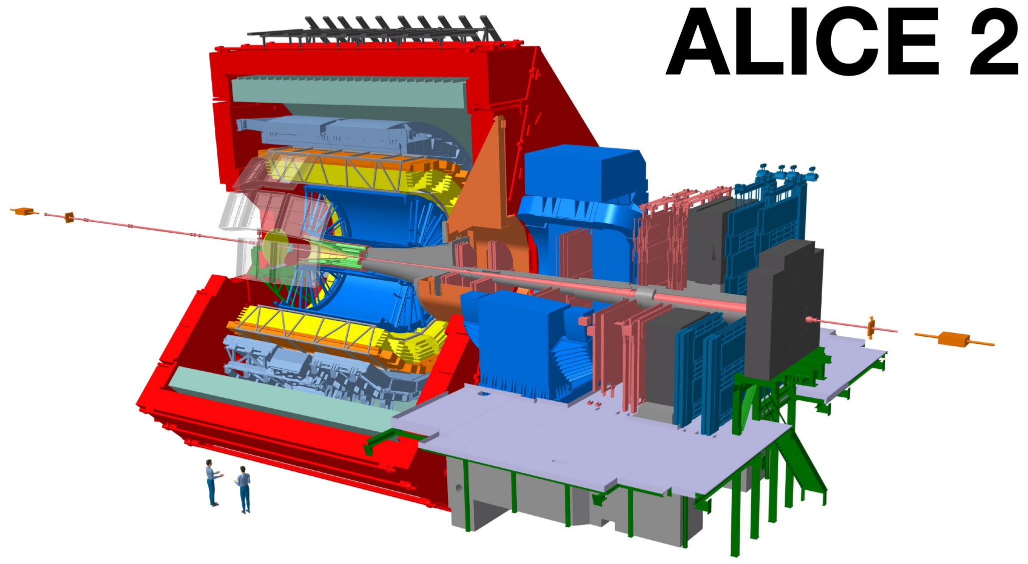
Milestones of the ALICE upgrade

High luminosity for ions | HL-LHC | Higher luminosities for ions

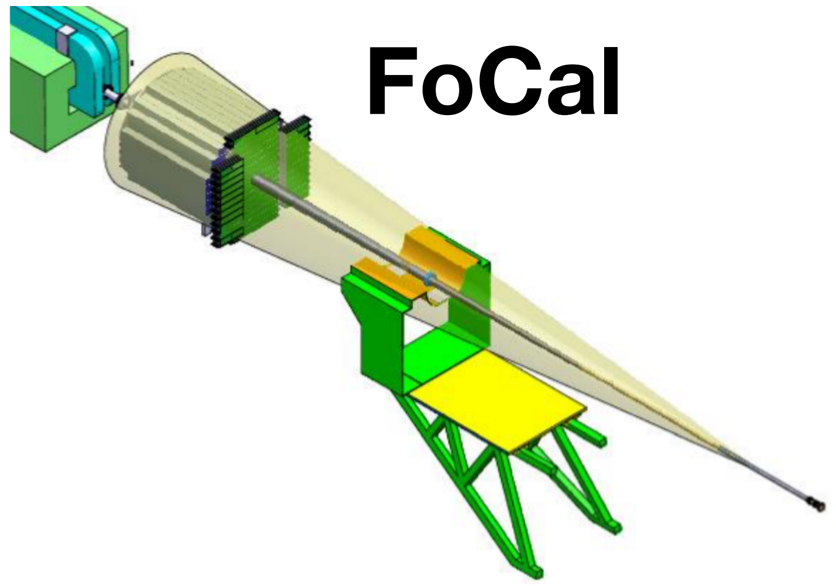
Run 1 2009 - 2013	Run 2 2015 - 2018	Run 3 2022 - 2025	Run 4 2030 - 2033	Run 5	Run 6

ALICE 1	ALICE 2	ALICE 2.1 upgrade	ALICE 3 upgrade

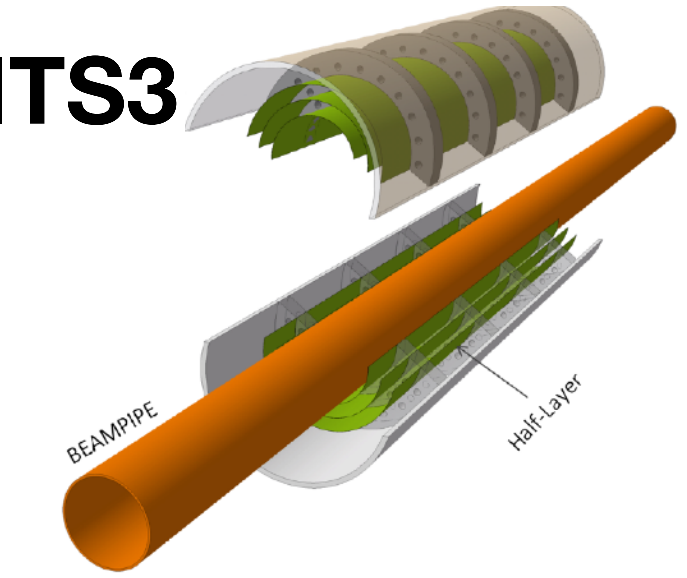
ALICE 2



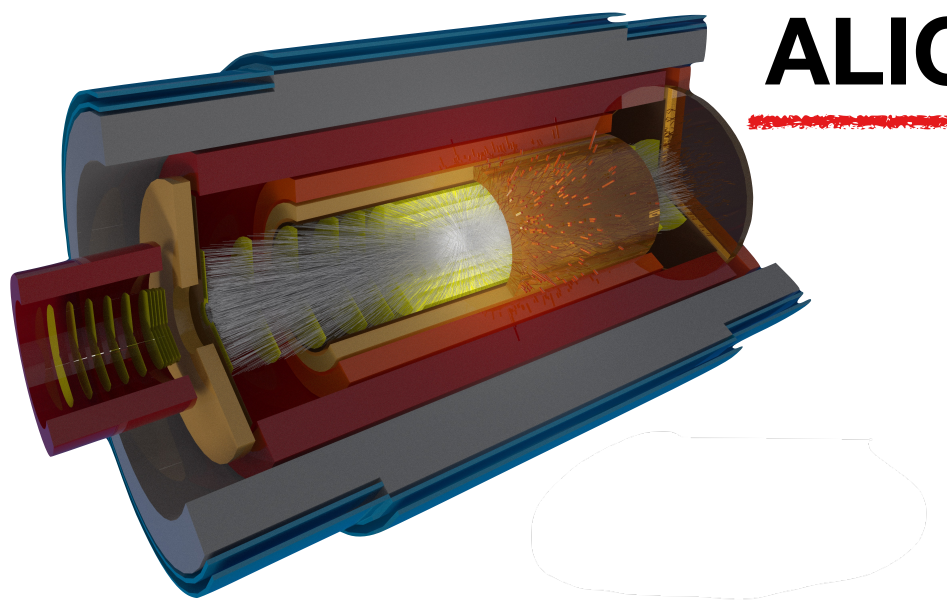
FoCal



ITS3



ALICE 3



TDR: CERN-LHCC-2024-004 TDR: CERN-LHCC-2024-003 LOI: CERN-LHCC-2022-009

Proposal for heavy-ion program in Run 5 and 6 with a next-generation experiment

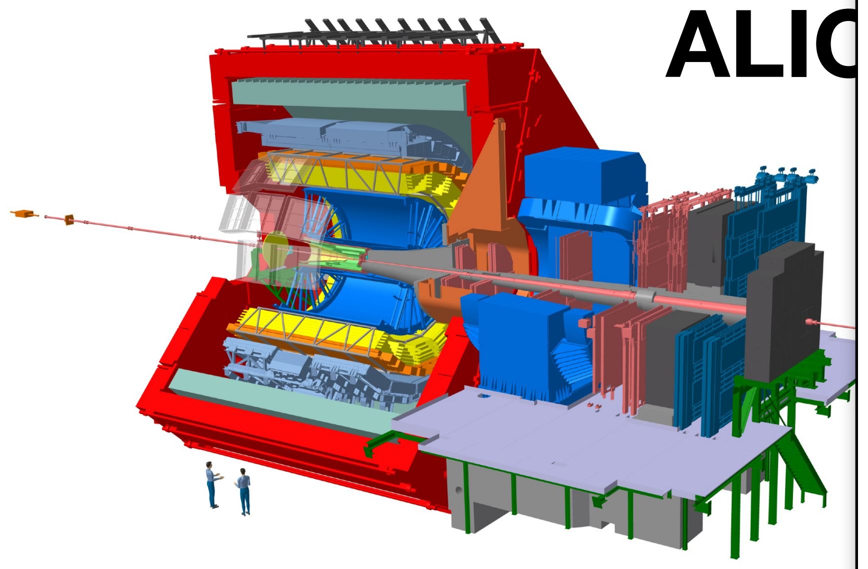
- Concept developed in **2018** and submitted to Strategy Update meeting in **2019**
- Three ALICE 3 **workshops** in 2020 and 2021
- **Letter of Intent submitted to LHCC** and reviewed late 2021/early 2022
    - **Very positive review** and recommendation to **proceed with R&D**

Milestones of the ALICE upgrade

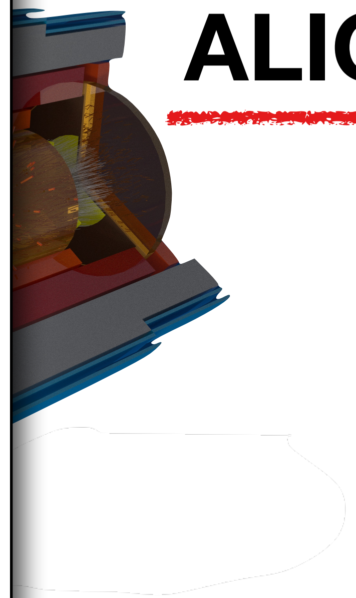
High luminosity for ions HL-LHC Higher luminosities for ions

Run 1
2009 - 2013

ALIC



ALICE 3



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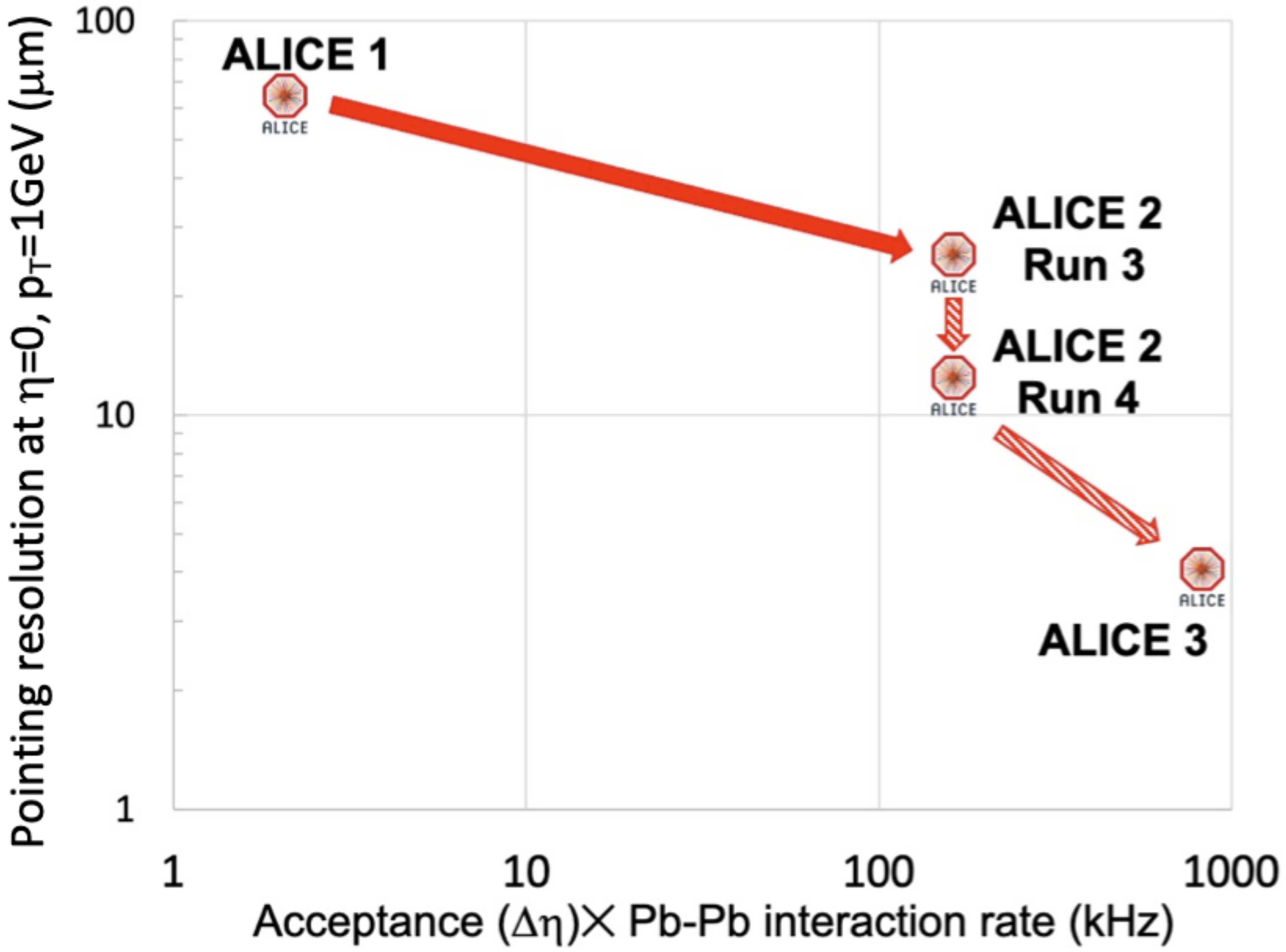

Improvement in both rate and pointing resolution for Run 5 and Run 6

Proposal for h... xperiment

- Concept develop...
- Three ALICE 3 w...
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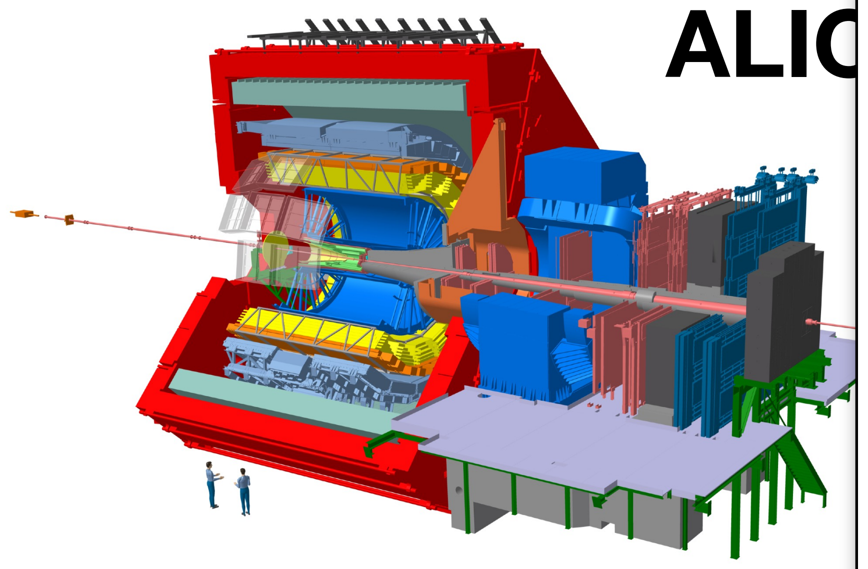
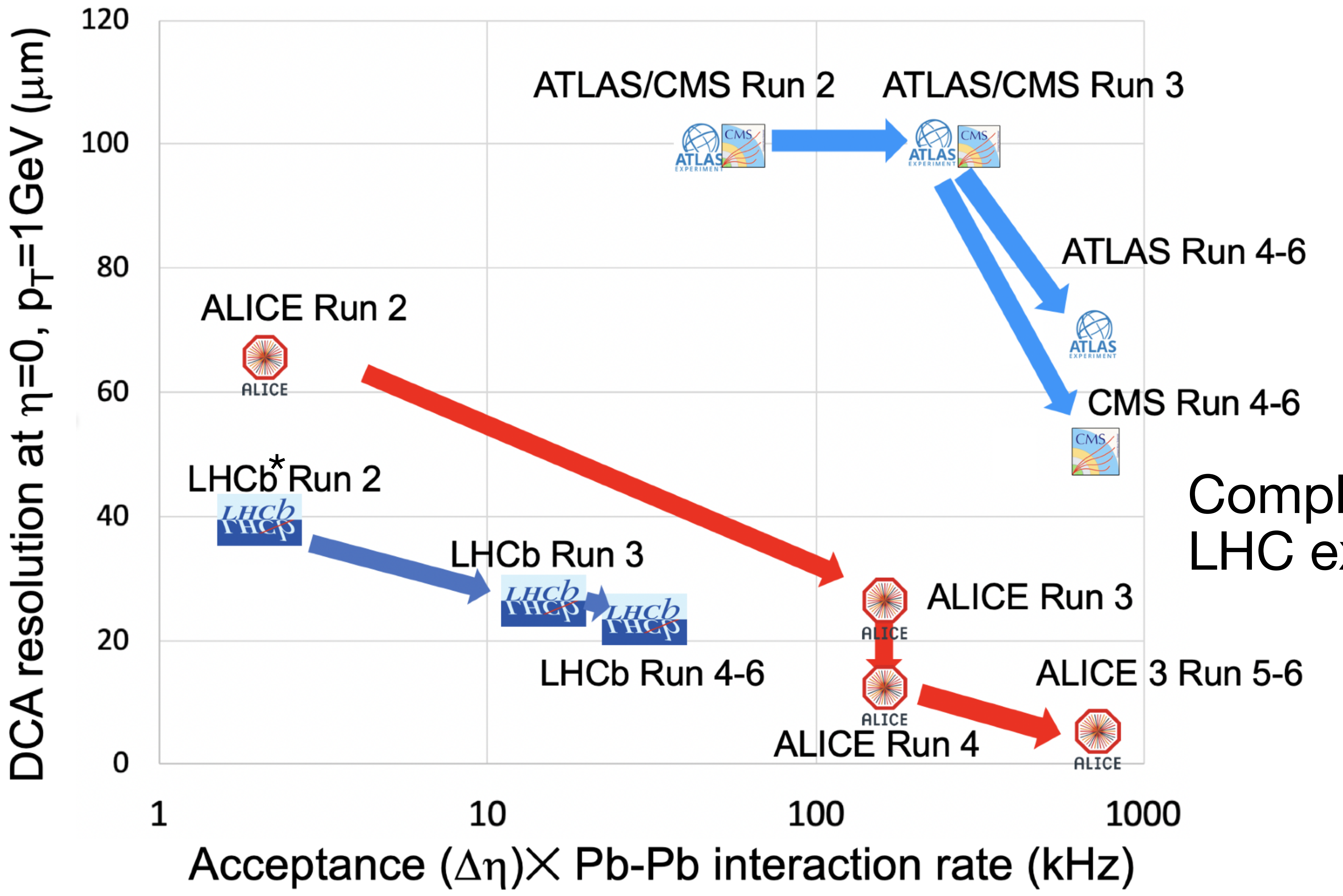
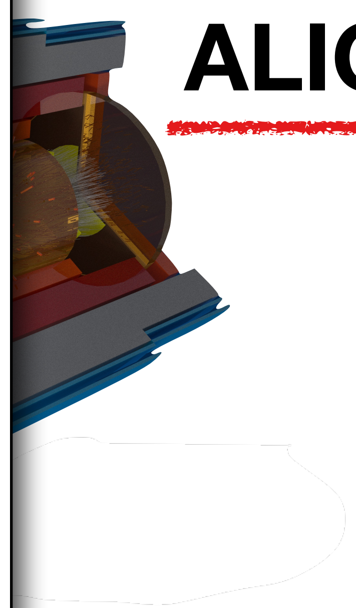




*LHCb at $\eta = 3.5$

ALICE 3



2-009

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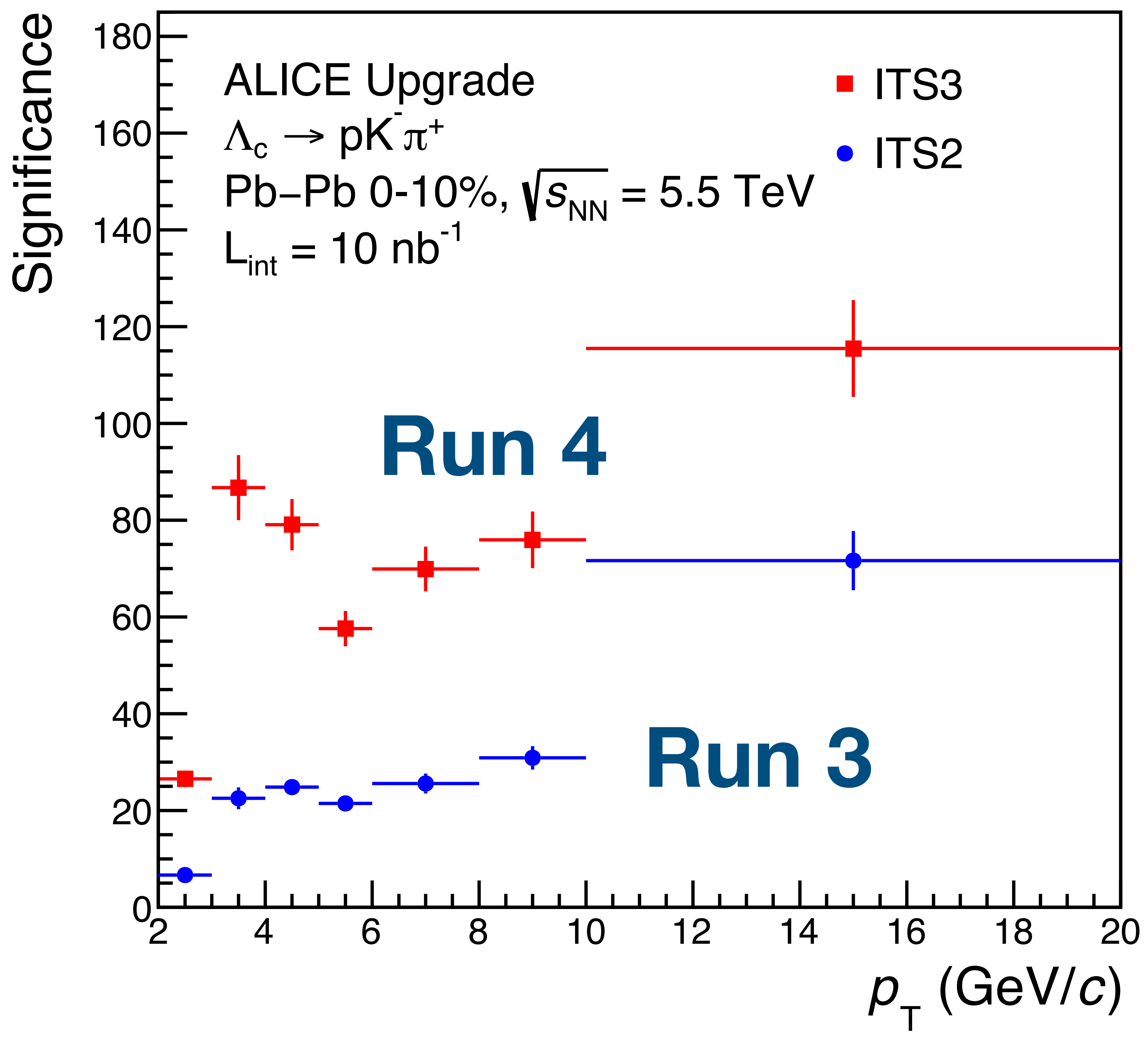
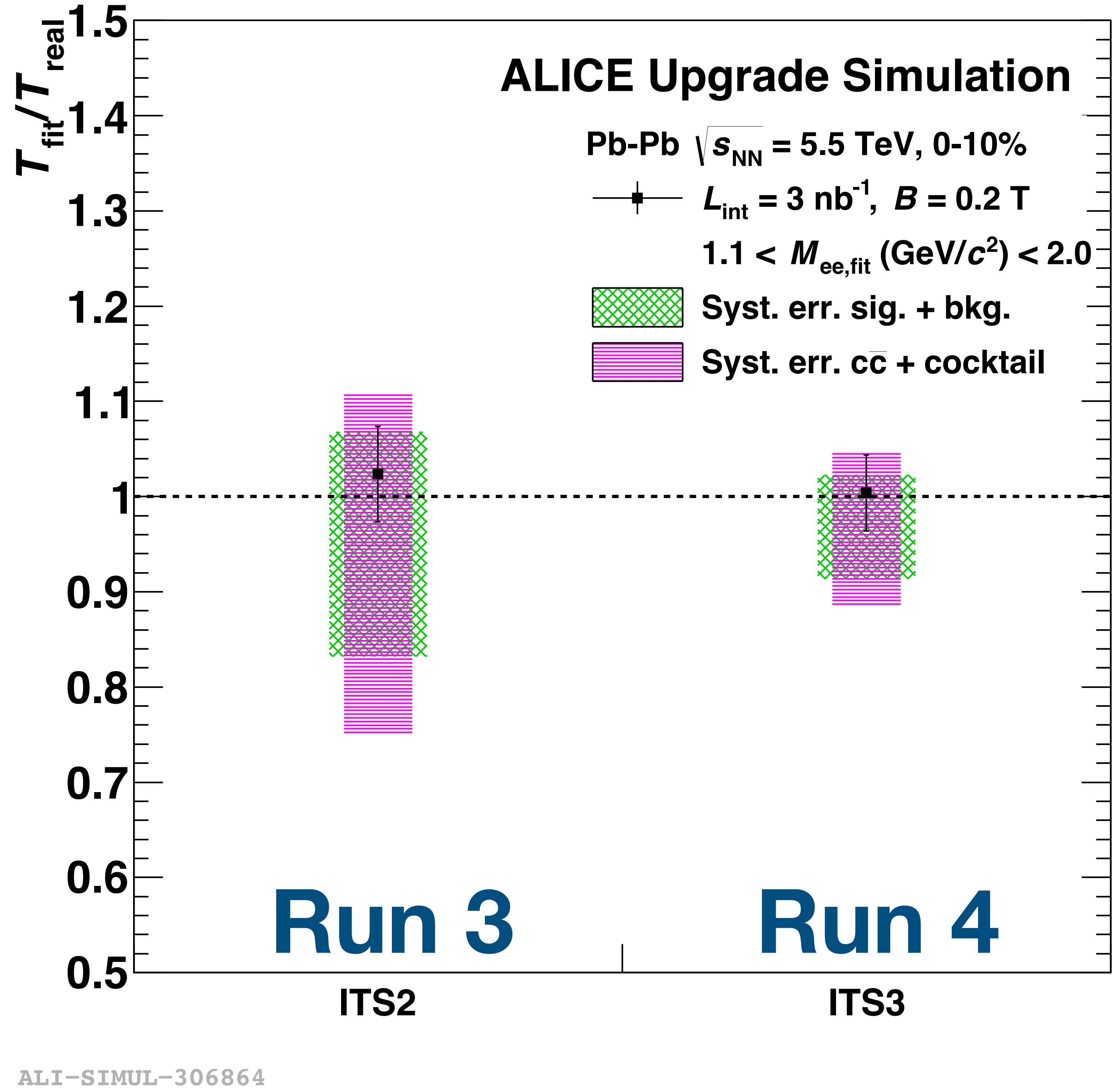
ALICE at the end of Run 4

significant improvement achieved after Run 4

New insights with Runs 3+4

- medium effects and **hadrochemistry** of single charm
- time-averaged **thermal radiation** from the quark-gluon plasma
- patterns indicative of **chiral symmetry** restoration
- **collectivity** from small to large systems



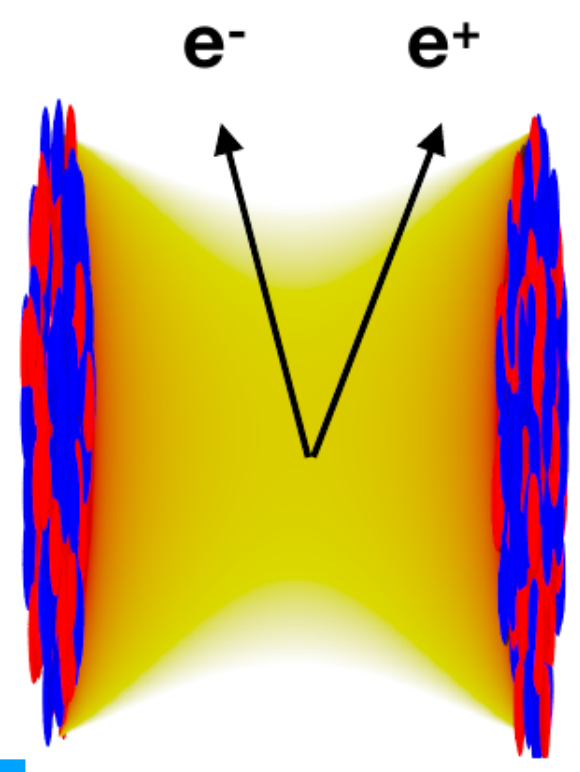


Precision measurements with Run 3 and 4 will help us understanding the QGP

More fundamental questions ahead!

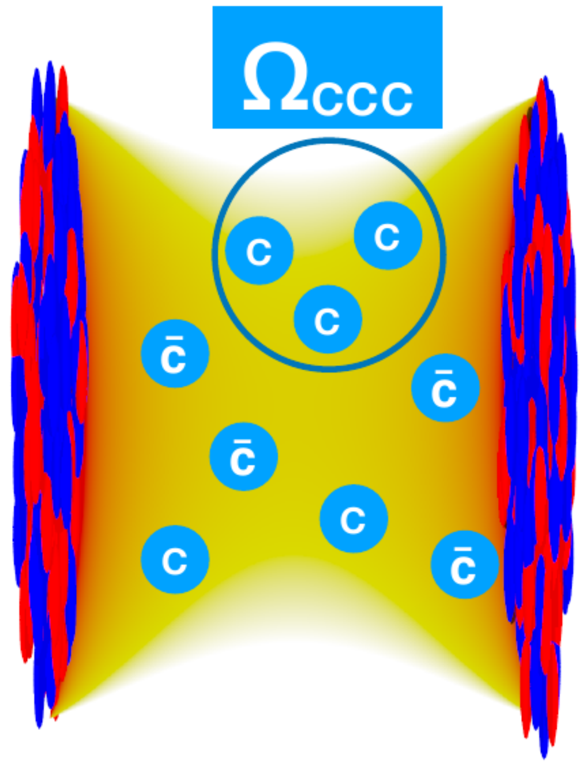
- QGP properties driving its constituents to equilibration
- microscopic mechanisms leading to strong partonic collectivity
- mechanisms for hadronisation from the quark-gluon plasma
- partonic equation of state and its temperature dependence
- underlying dynamics of chiral symmetry restoration

QGP physics beyond Run 4



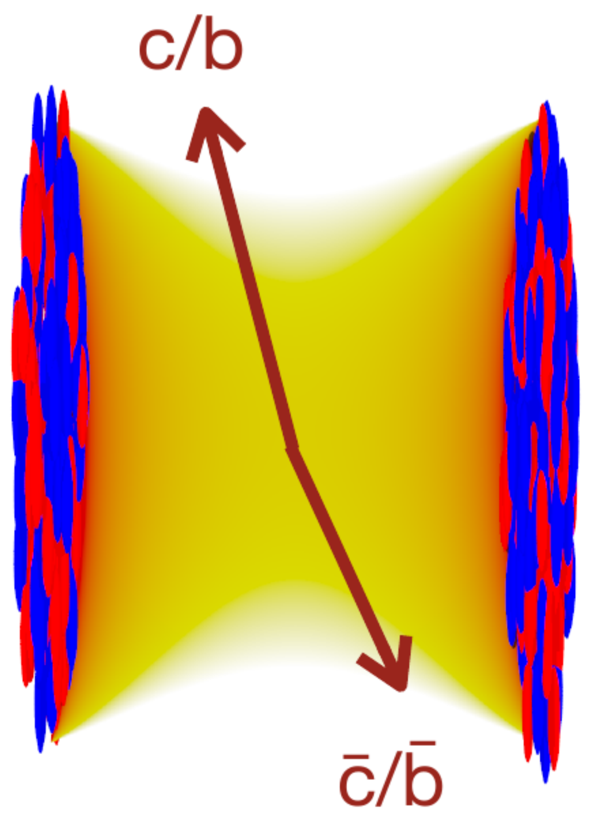
Precision measurements of dileptons

- accessing the evolution of the quark-gluon plasma
- mechanisms of chiral symmetry restoration in the quark-gluon plasma



Systematic measurements of (multi-)heavy-flavoured hadrons

- accessing parton propagation mechanisms in QGP
- study equilibration of heavy quark equilibration and diffusion in QGP
- mechanisms of hadronisation from the quark-gluon plasma



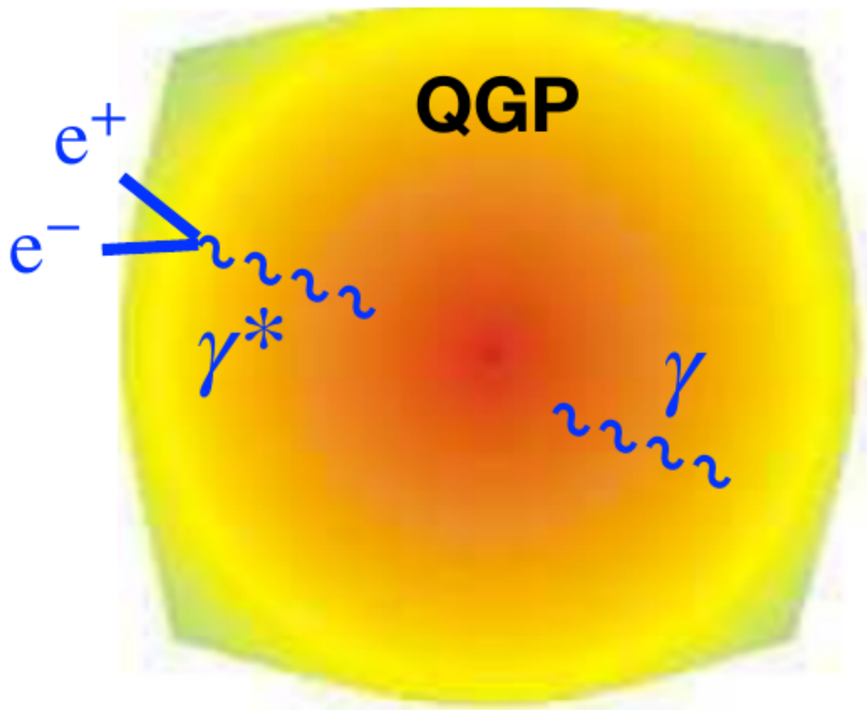
Hadron correlations and fluctuations

- interaction potentials and charmed-nuclei
- susceptibility to conserved charges

To achieve all this, the next leap is needed in detector performance and statistics

→ **next-generation heavy-ion experiment!** ←

Electromagnetic radiation



Accessing the QGP temperature

In Run 3 and 4:

- First measurement of average QGP temperature using thermal dielectron spectrum at $M_{ee} > 1.1$ GeV/c^2

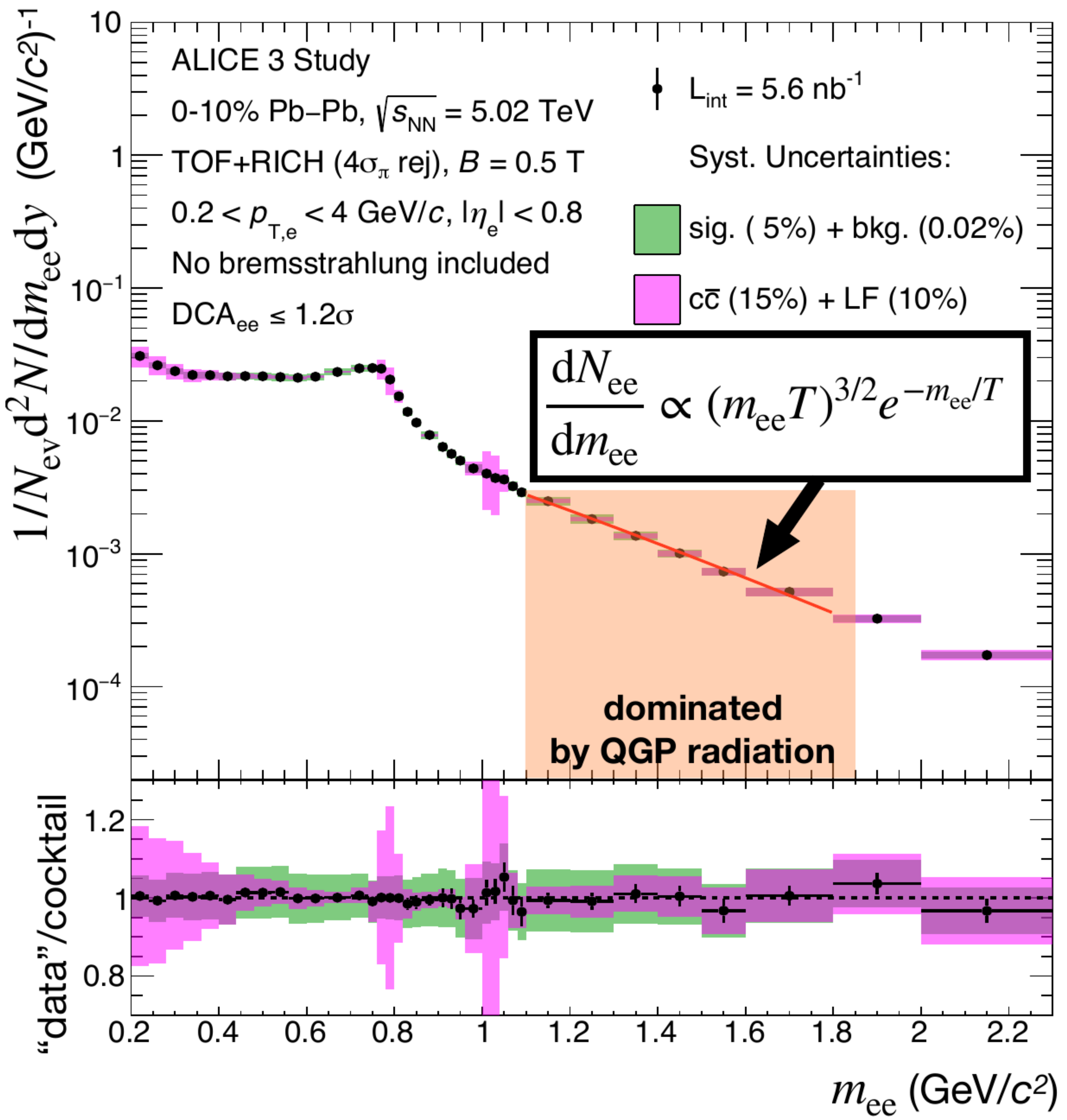
In Run 5 with ALICE 3:

- probe **time dependence** of the QGP temperature
- double-differential spectra: T vs mass, p_T
- Excellent pointing resolution
  - Large background for $M_{ee} \gtrsim 1$ GeV/c^2 due to heavy-flavour decays can be effectively suppressed with ALICE 3
- Complementary to measurements with real photons

Experimental challenge

- γ conversion background
- open heavy-flavor production

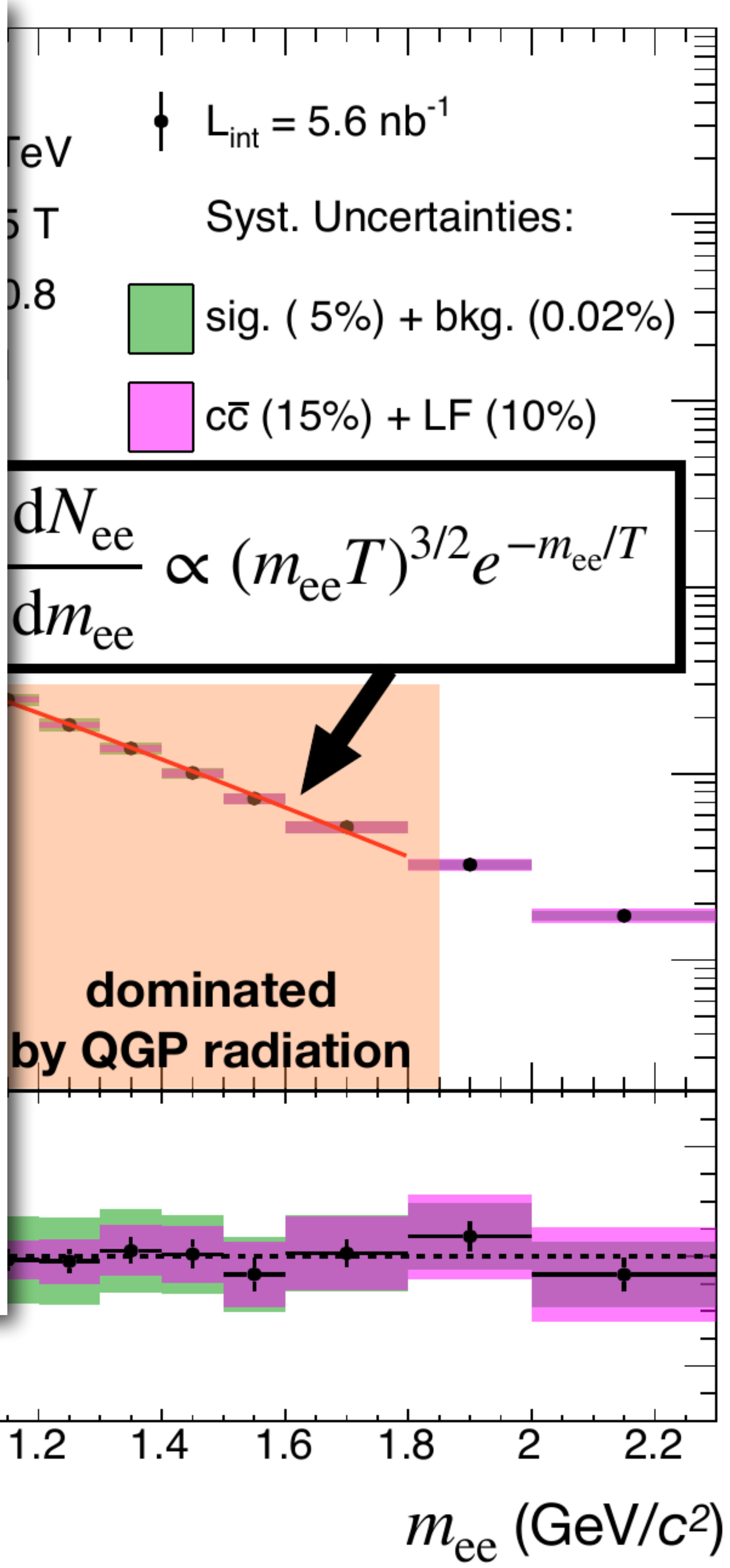
Projection for one month Pb—Pb with ALICE 3



R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253
P.M Hohler and R. Rapp, Phys. Lett. B 731 (2014) 103

Electromagnetic radiation

Projection for one month Pb—Pb with ALICE 3



Accessing the QGP

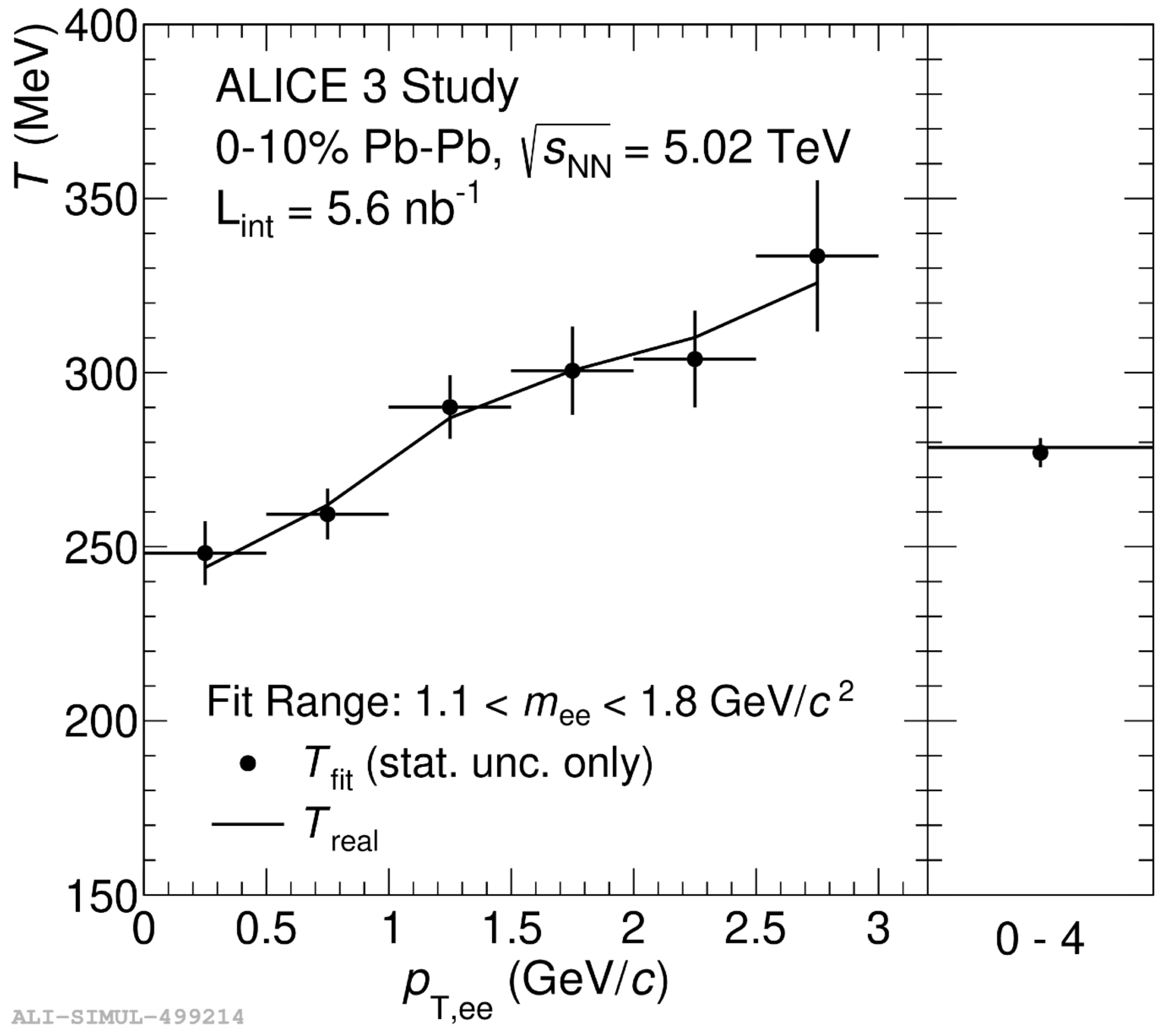
In Run 3 and 4:

- First measurement o
  thermal dielectron sp

In Run 5 with ALICE 3:

- probe **time depende**
- double-differential sp
- Excellent pointing resol
  - Large background fo
    decays can be effec
- Complementary to measurements with real photons

Probing the time evolution of the QGP temperature

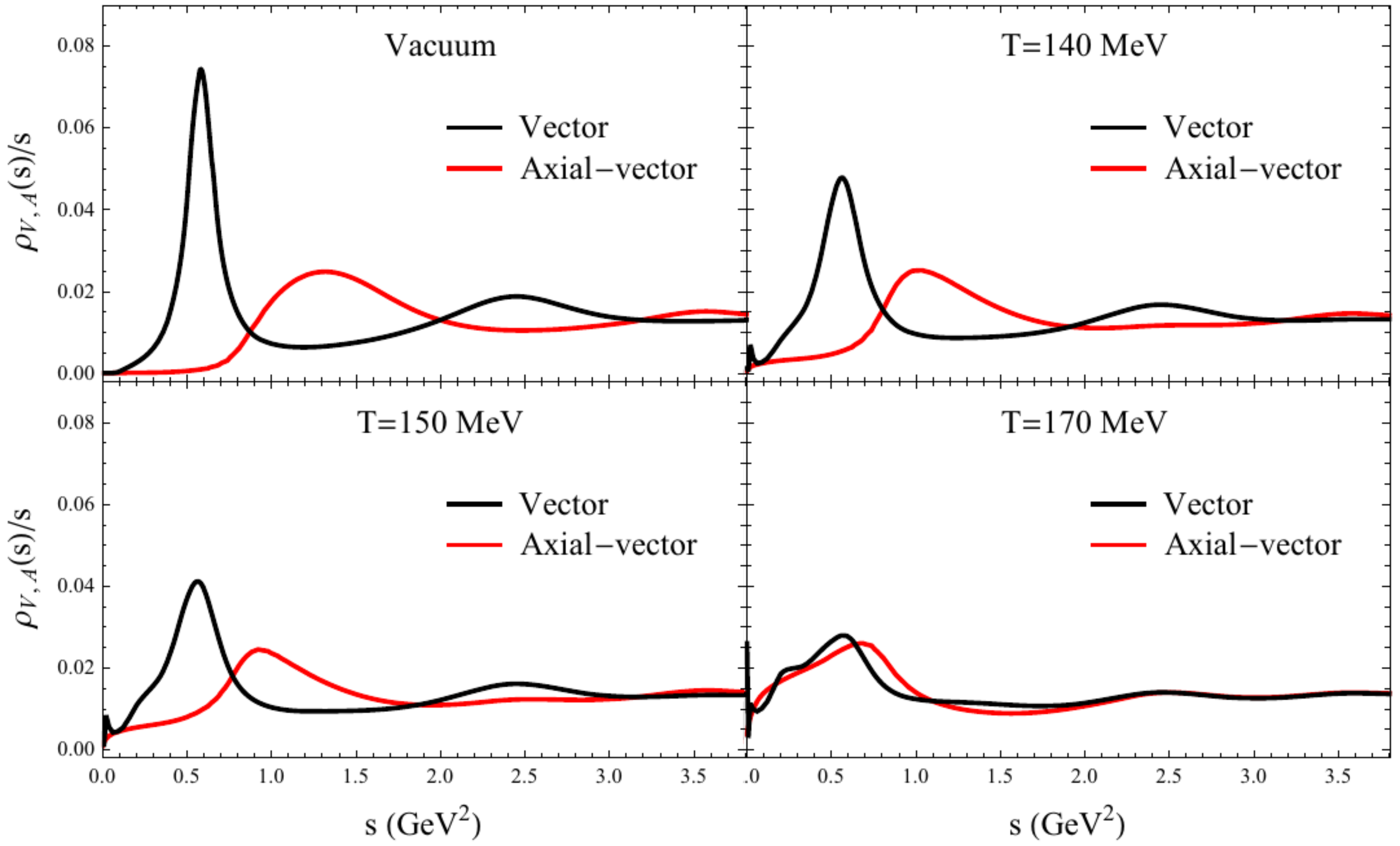


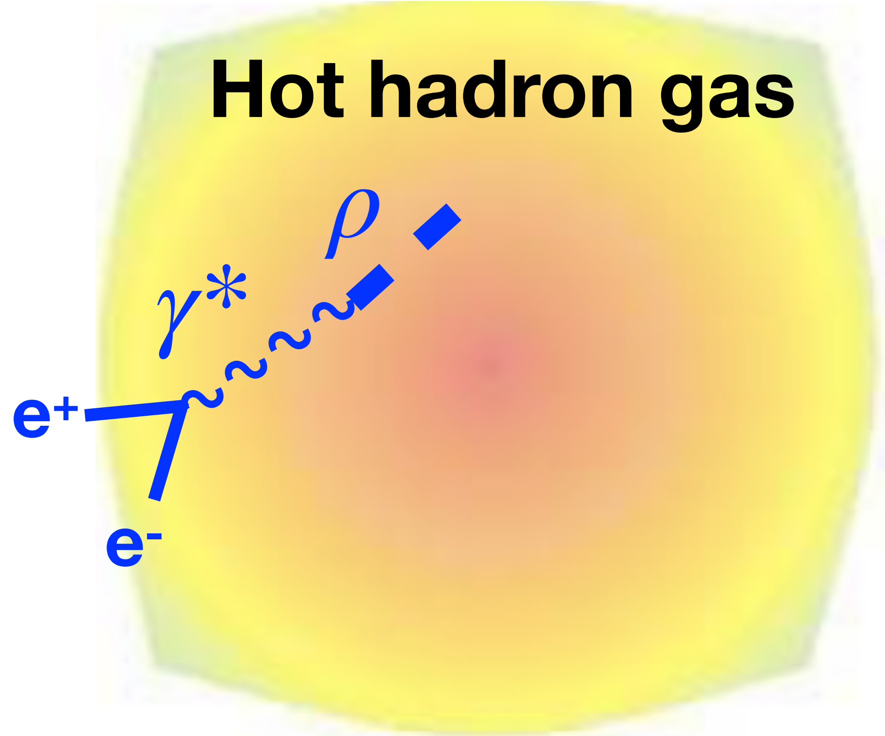
Experimental challenge

- γ conversion background
- open heavy-flavor production

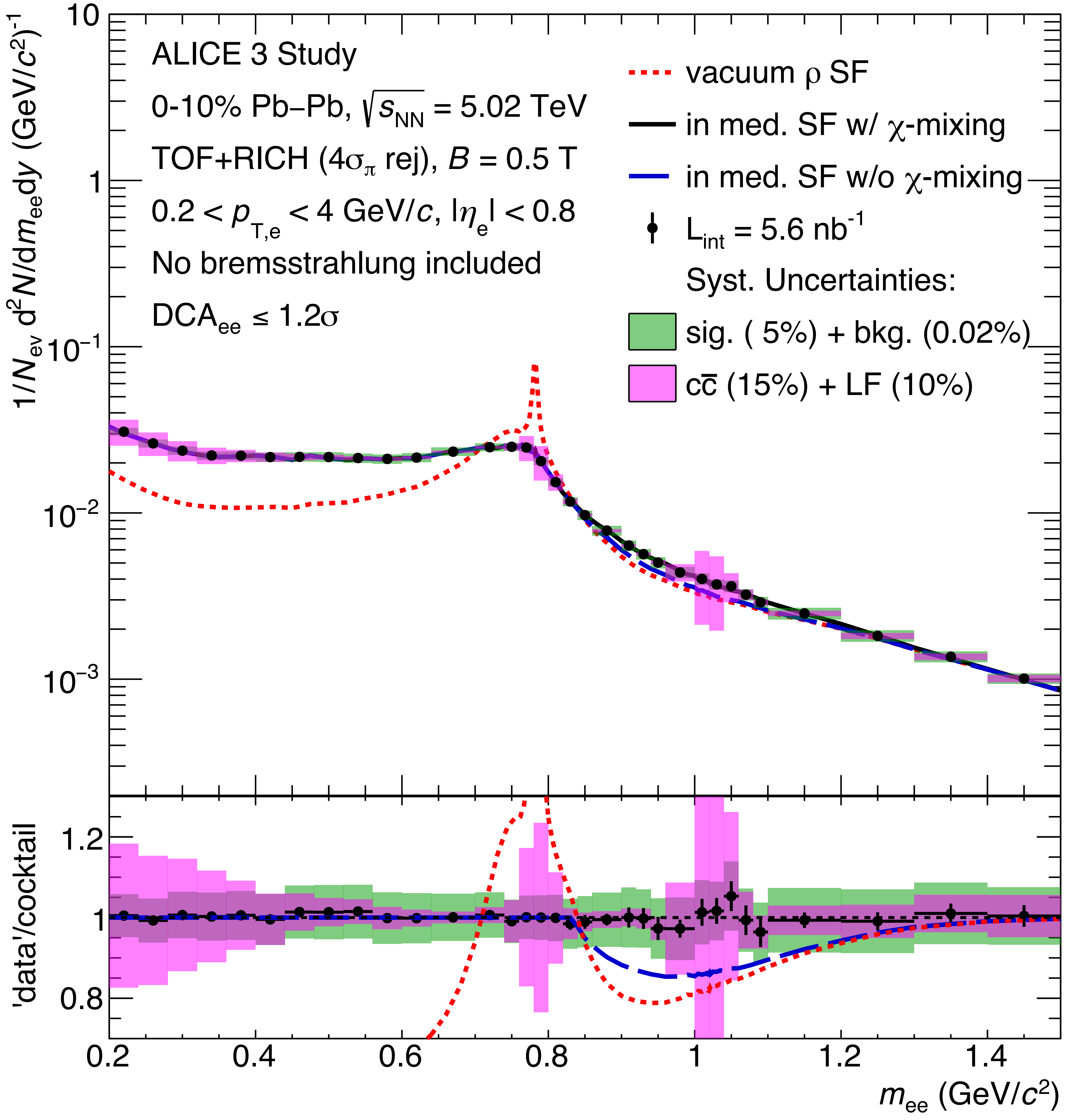
[R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253](#)
[P.M Hohler and R. Rapp, Phys. Lett. B 731 (2014) 103](#)

Chiral symmetry restoration





Projection for one month Pb—Pb with ALICE 3



Chiral symmetry restoration

- using thermal dielectron spectrum at M_{ee} < 1.2 GeV/c²

Thermal production of ρ

- ρ sensitive to surrounding medium (τ_ρ = 1.3 fm < $\tau_{fireball}$)

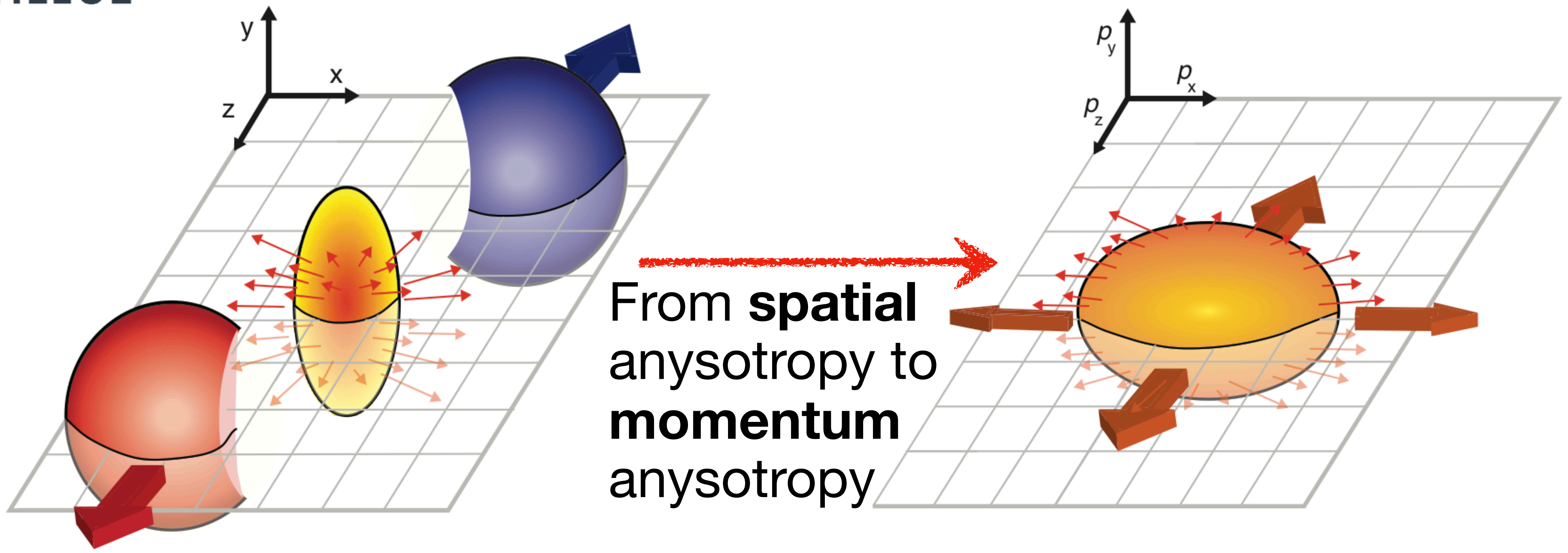
→ **ρ spectral function modification related to chiral symmetry restoration**

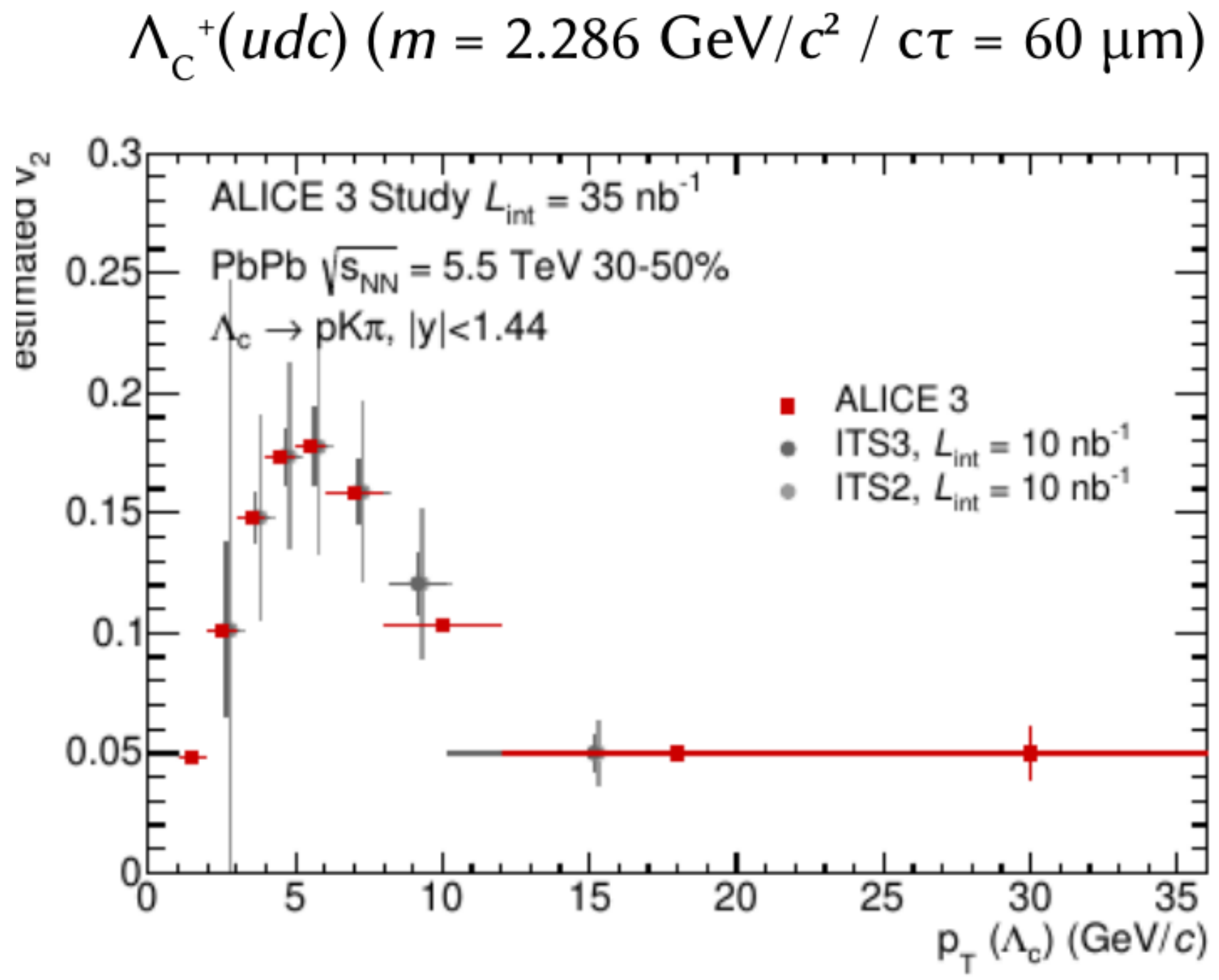
- High precision measurement with ALICE 3

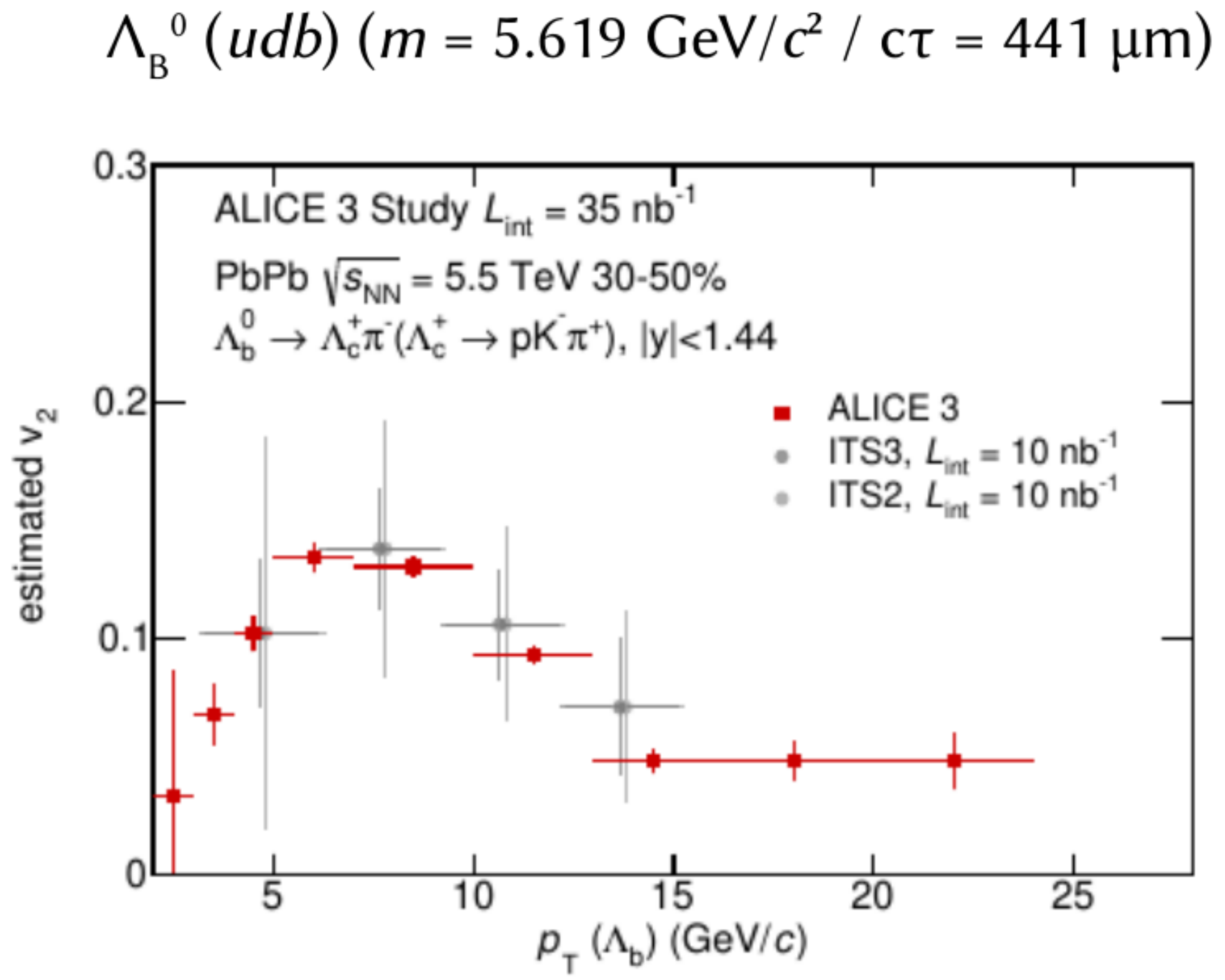
→ Access to chiral symmetry restoration mechanisms like ρ – a1

R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253
P.M Hohler and R. Rapp, Phys. Lett. B 731 (2014) 103

Flow of heavy quarks







$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+2\sum_{n=1}^{\infty} v_n \cos[n(\varphi-\Psi_n)]\right)$$

Semi-central collisions: pressure anisotropy in the QGP → final-state azimuthal anisotropy (“flow”)

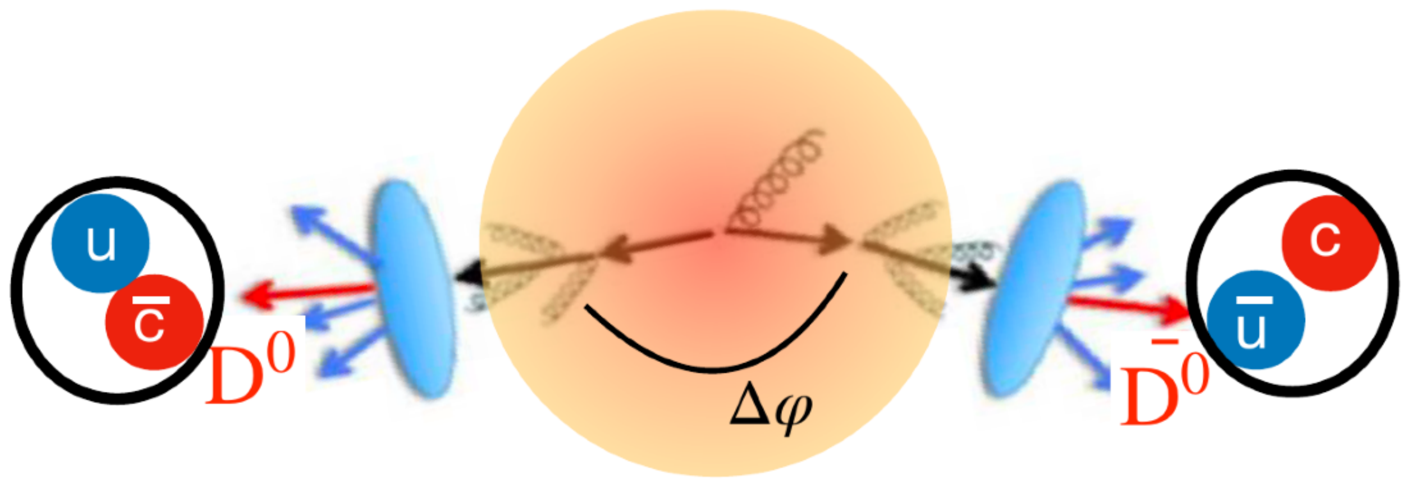
Azimuthal anisotropy: access to heavy quark transport properties in the QGP at hadron level

- Assess the charm quark degree of thermalization, diffusion coefficients
- Weaker beauty thermalization → Smaller v_2 expected
- How much smaller than v2(charm) is v2(beauty) ? Is v2(beauty) ≠ 0 ?
  → Examples of accuracy for single-HF baryons

Driving factor:

pointing resolution, efficiency and acceptance are needed for flow measurements down to low p_T → i.e. ALICE 3

Heavy quark correlations



Charm quark energy loss in QGP

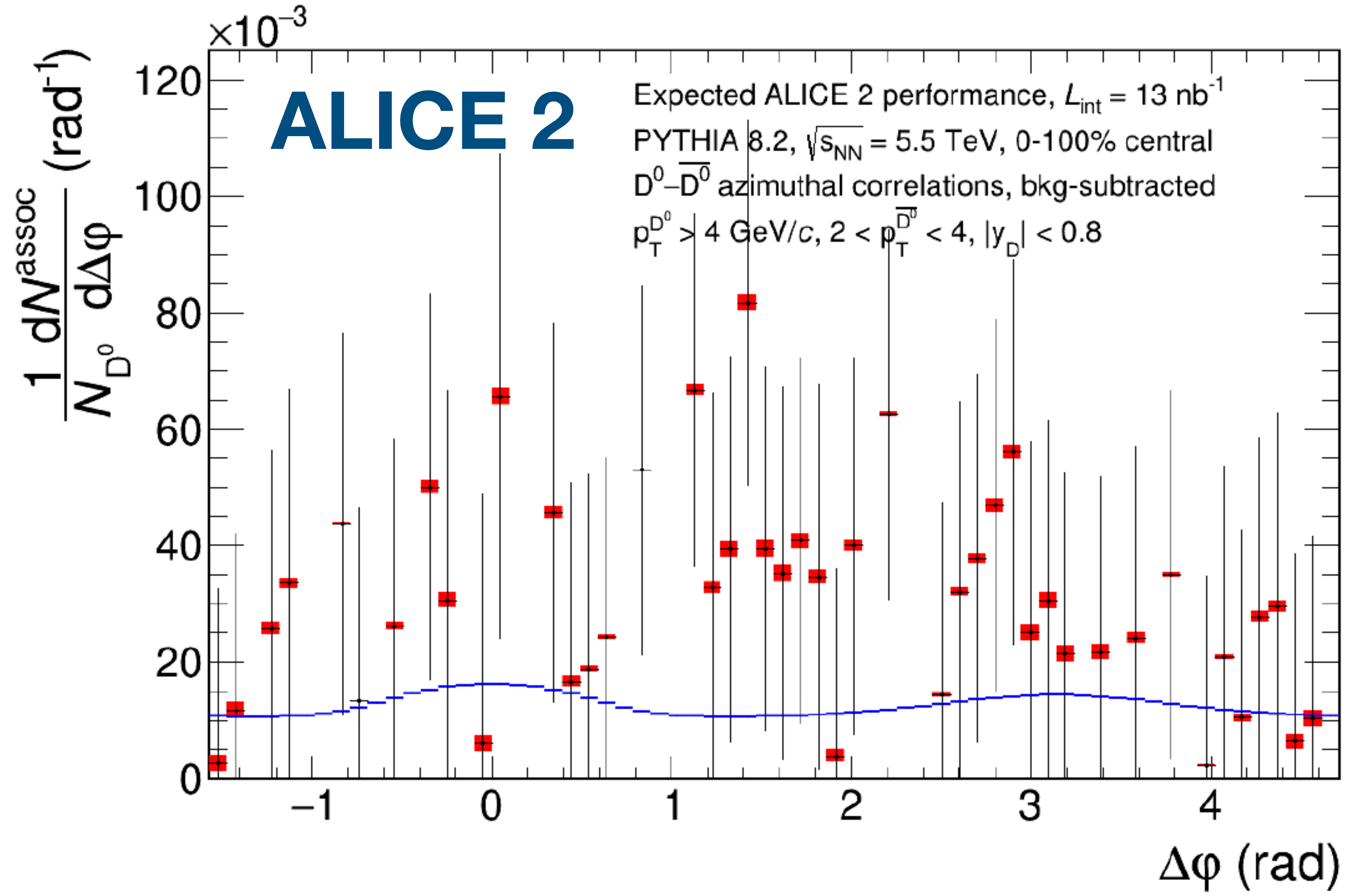
Angular decorrelation of $D^0\overline{D^0}$ mesons
→ probe heavy quark rescattering in QGP

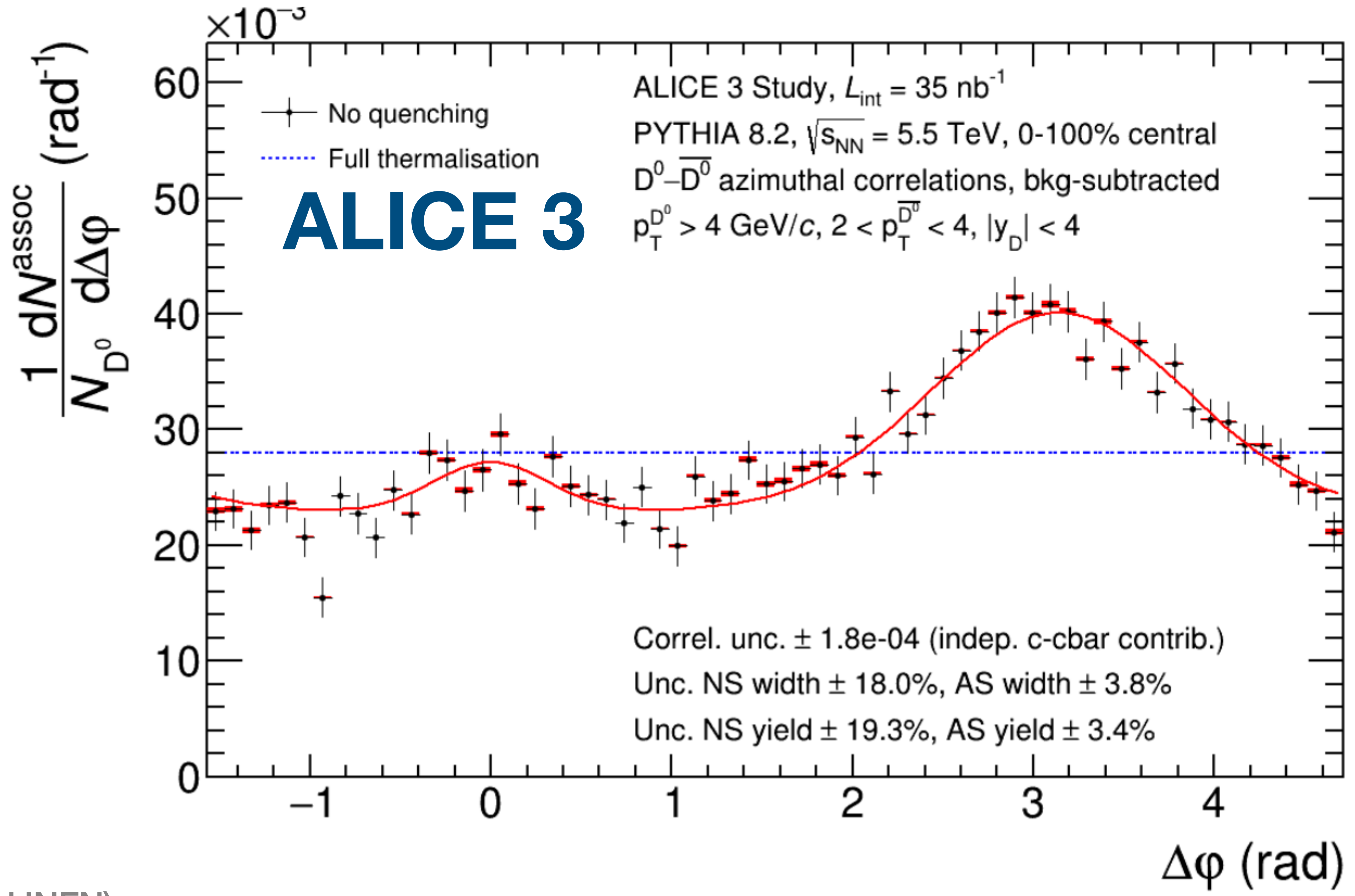
Sensitive to:

- Energy loss mechanisms
- Heavy quark thermalisation

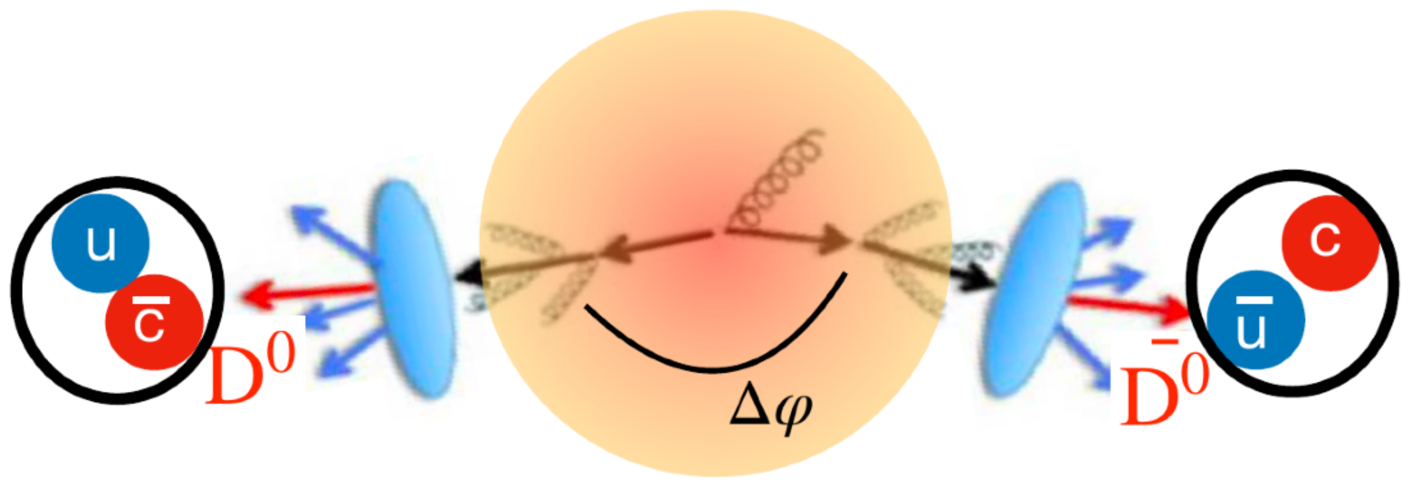
Strongest signal at low p_T → very challenging measurement

- Requires: high purity, efficiency and large η coverage
- **Heavy-ion measurement possible only with ALICE 3**





Heavy quark correlations



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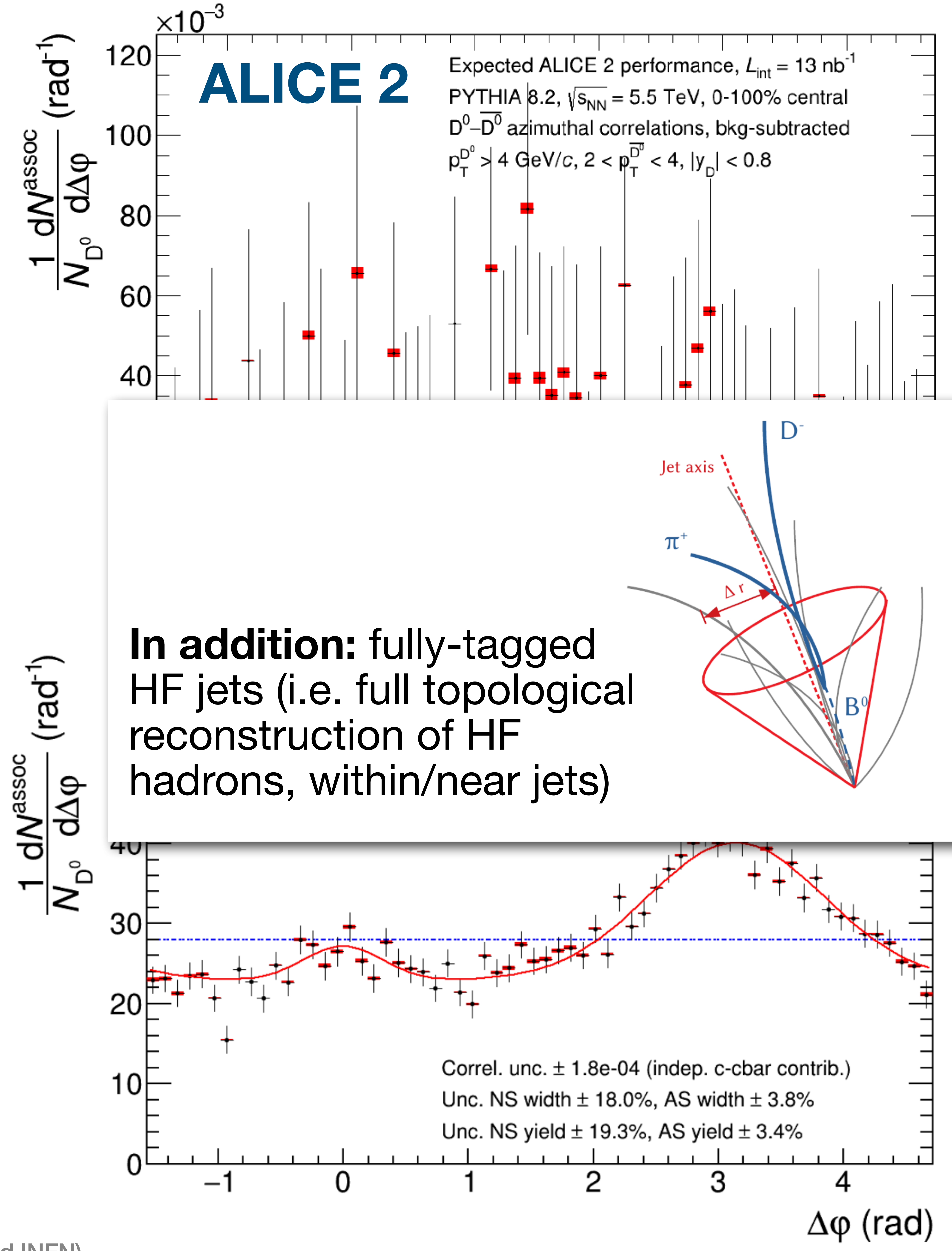
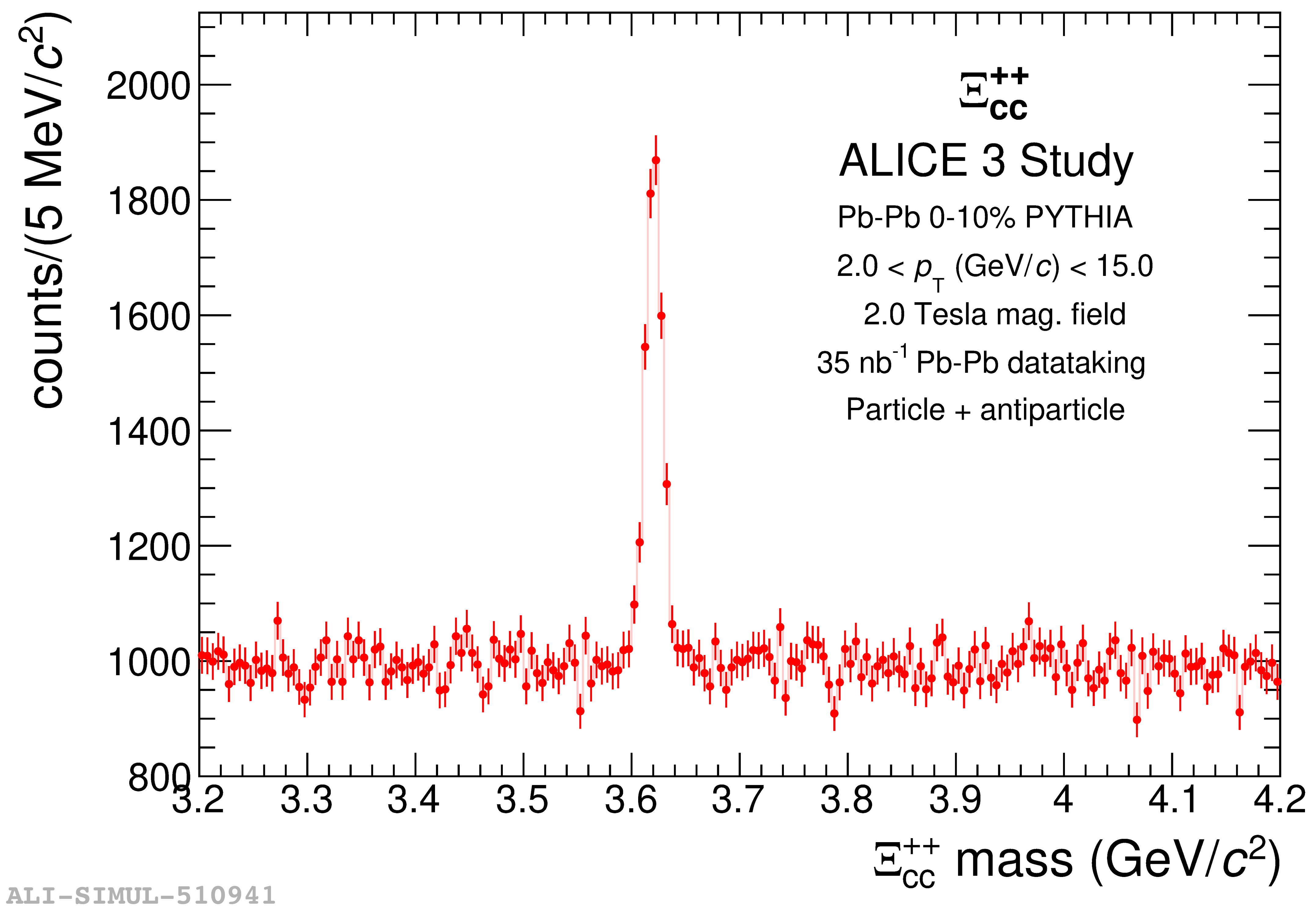
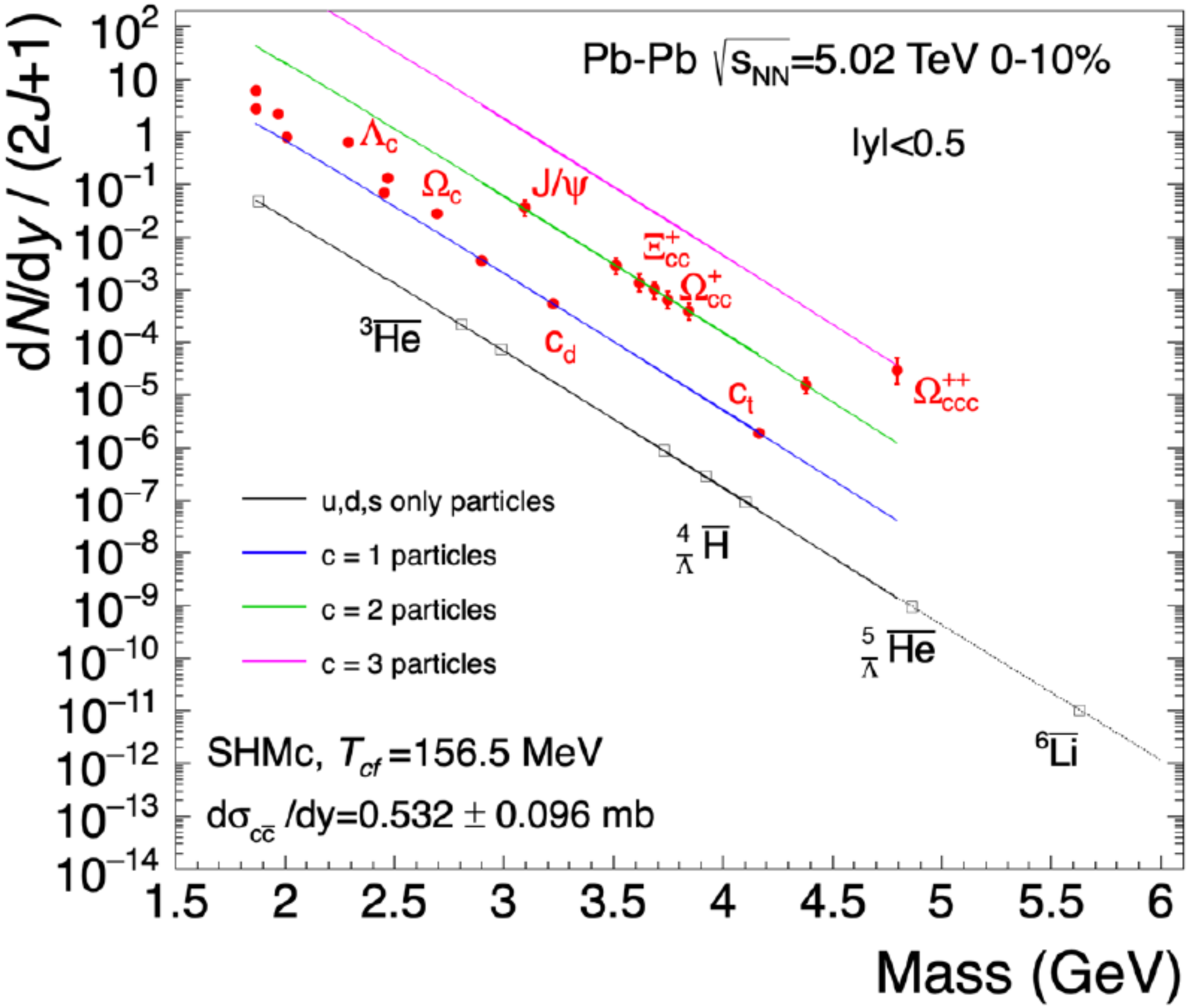


In addition: fully-tagged HF jets (i.e. full topological reconstruction of HF hadrons, within/near jets)

Multi-charm baryons



Unique experimental access to multicharm hadrons with ALICE 3 in Pb-Pb collisions

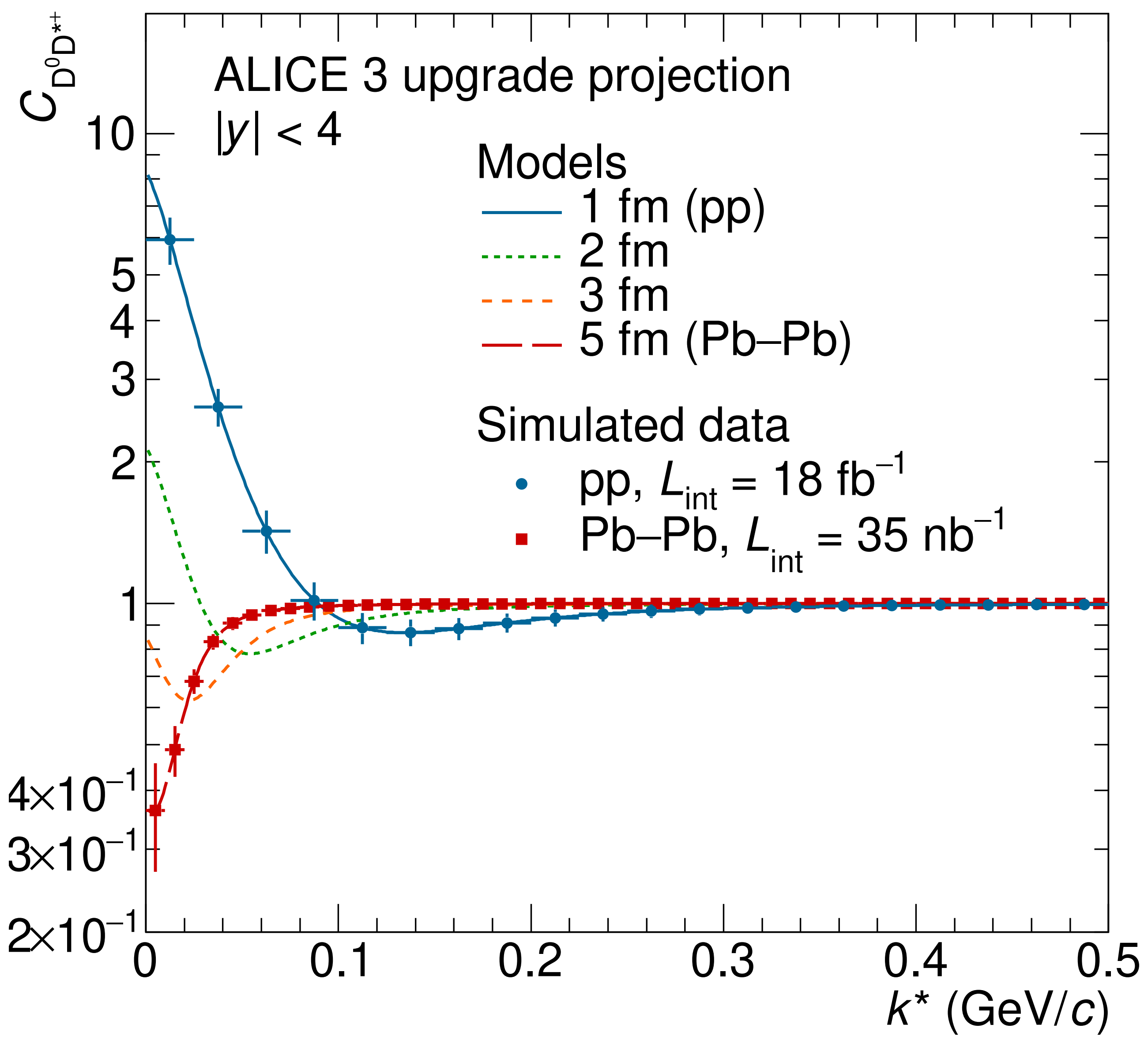


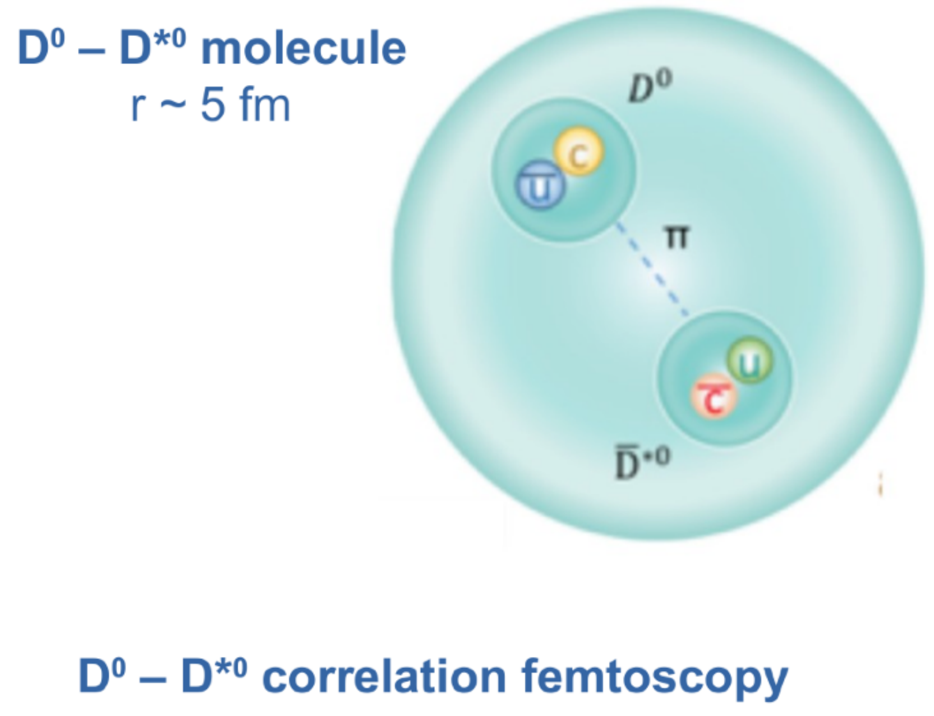
Hadronization of the heavy-flavor baryonic sector is still an open question.

- ALICE 3 is well-suited for the measurement of multi-charm baryons that can efficiently address this question

Exotic bound states

Charm hadron molecules

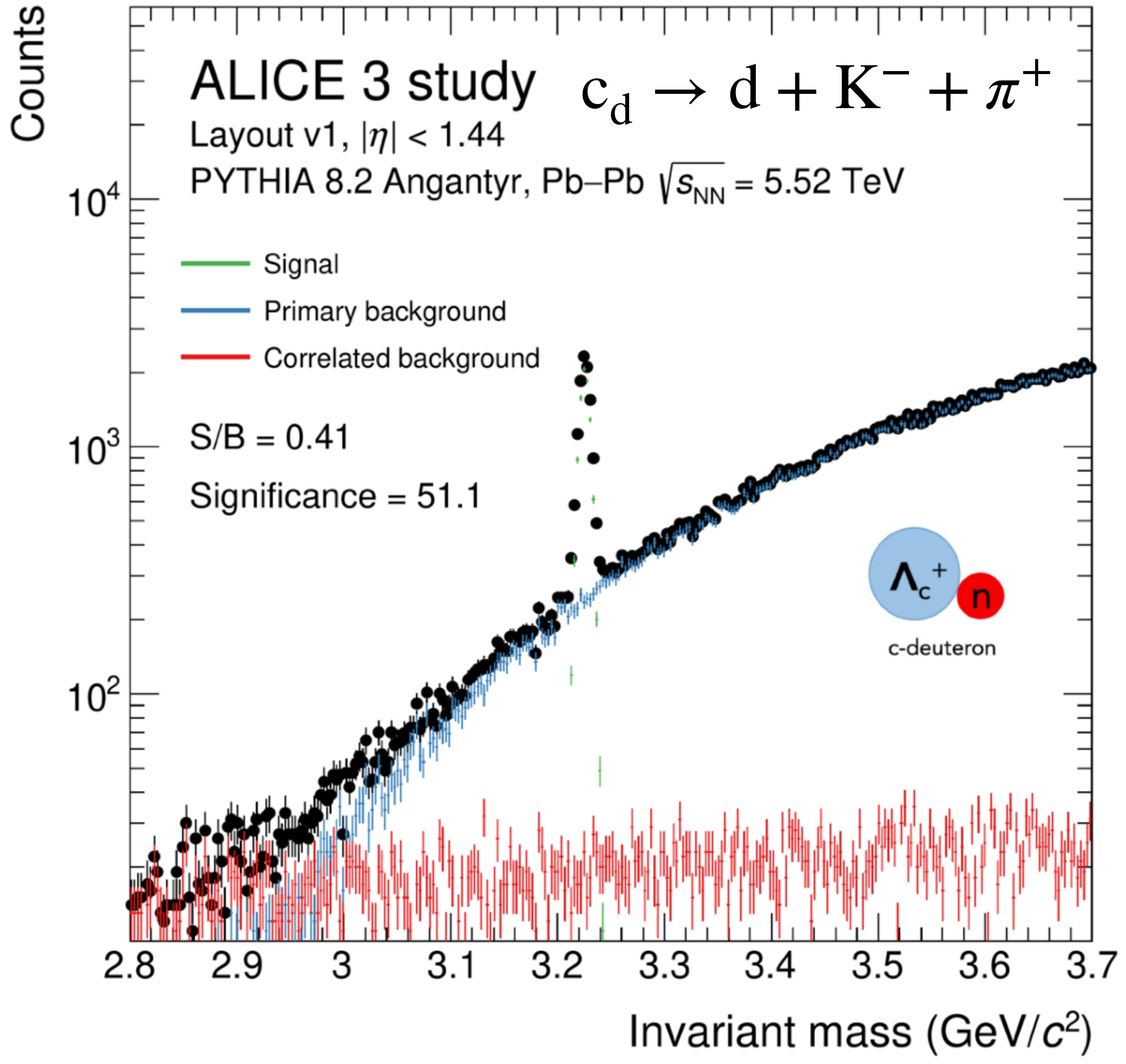




Search for possible DD bound states using momentum correlations

- D – D momentum correlations accessible via two-particlefemtoscopy measurements
- Unique tests of long range strong interaction with rare hadrons
- Investigation of the molecular nature of exotic states

High mass (charm-)nuclei



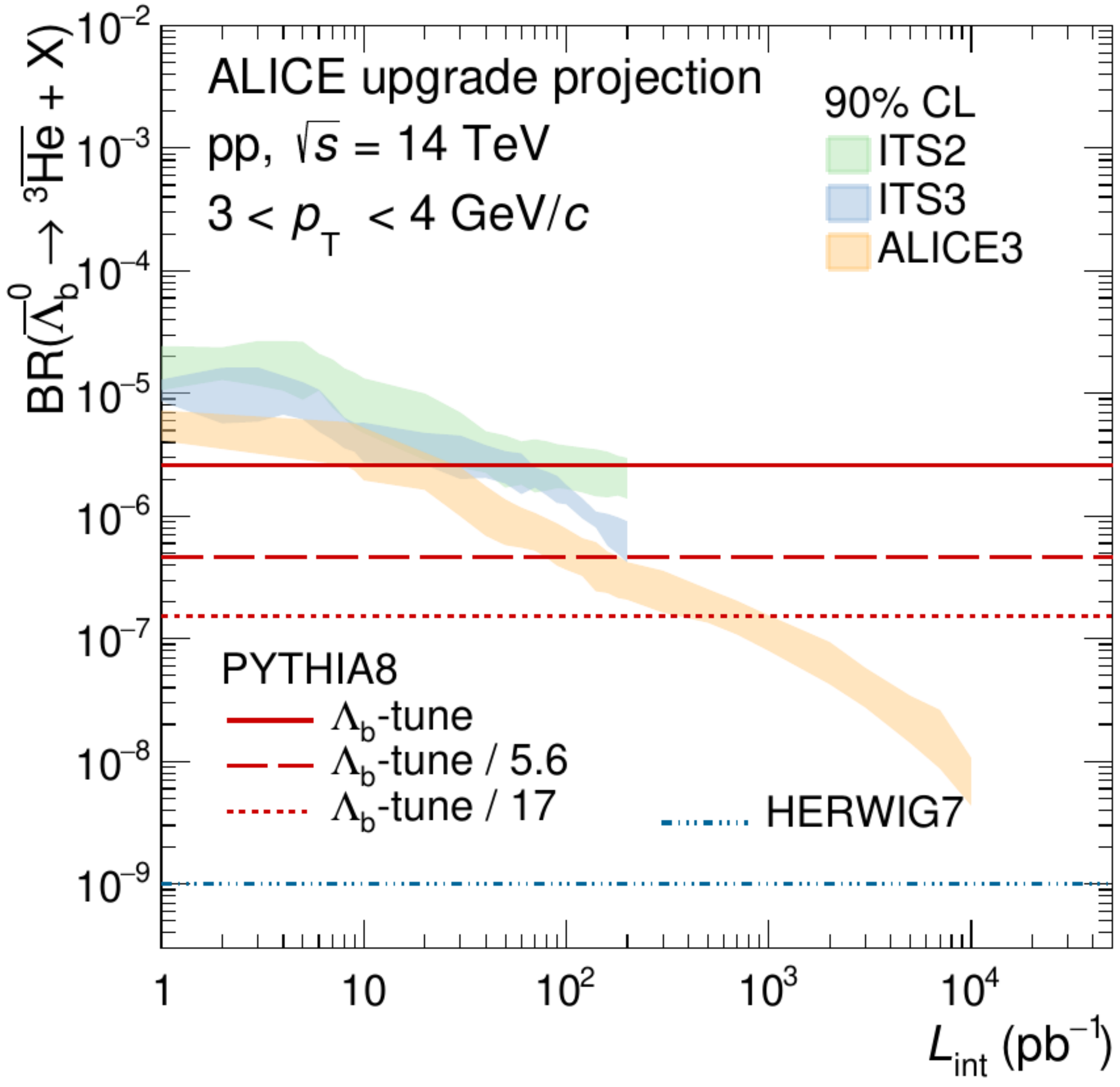
Unique sensitivity to undiscovered charm-nuclei: c-deuteron, c-triton

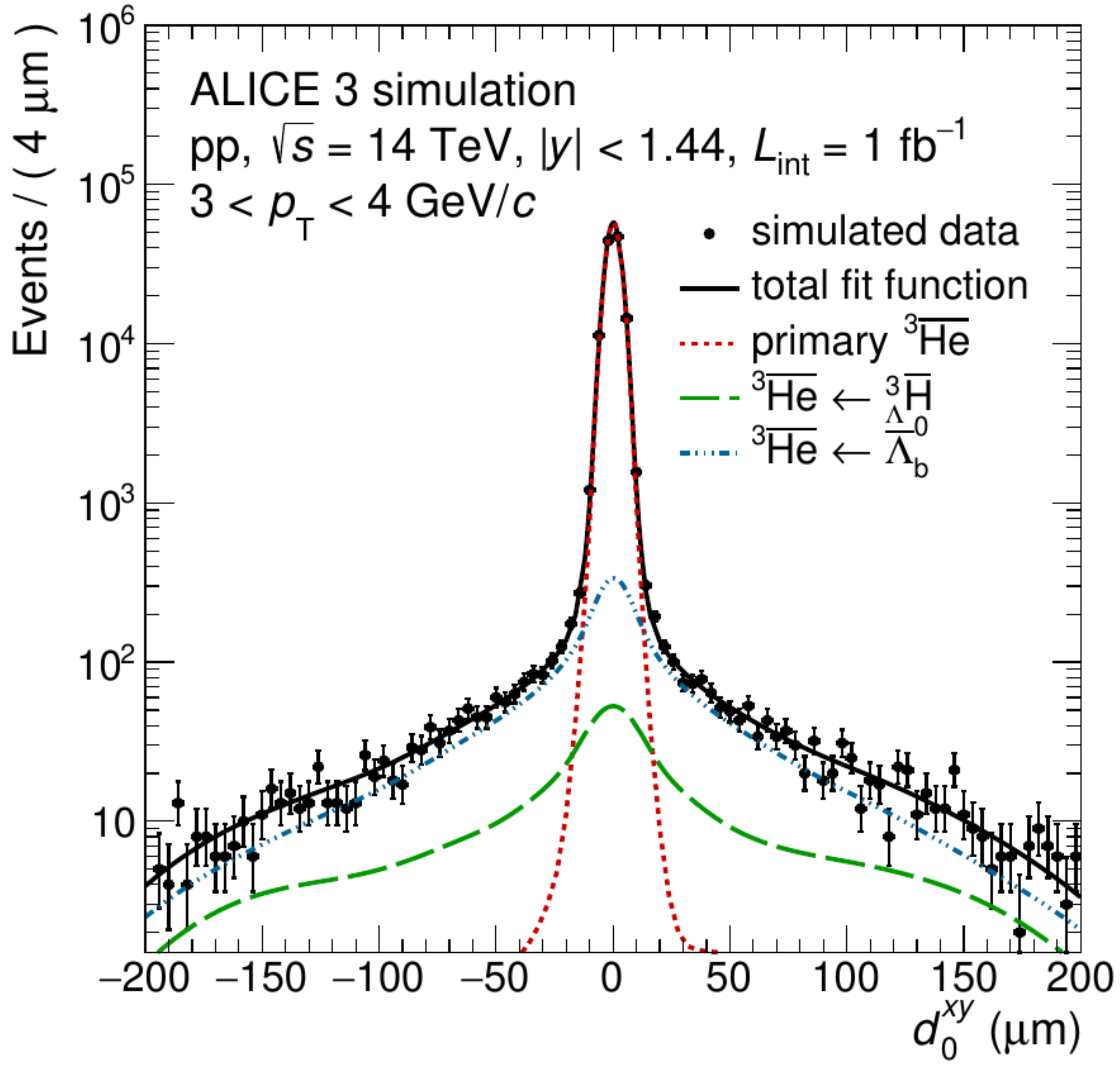
Super-nuclei: c-deuteron (c_d) and c-triton (c_t)

- first observation feasible

Search for anti-(hyper)nuclei with A>5 (e.g. $^{5}_{\Lambda}$He or ^{6}Li) and super-nuclei

Beyond the Standard Model





Anti-nuclei from b quarks

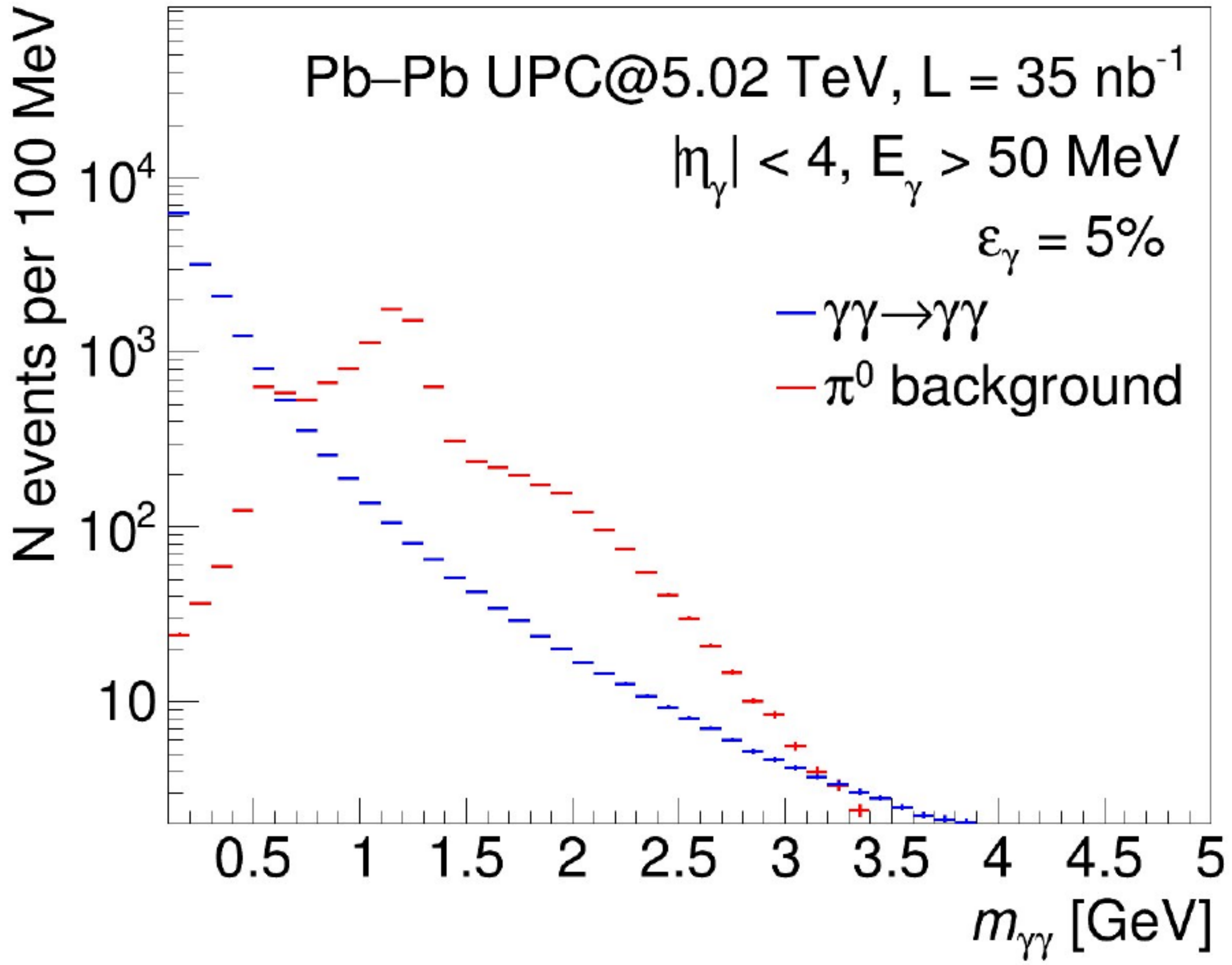
- Recent AMS preliminary observation of cosmic-ray anti-nuclei (^{3}He) can be a signature of the dark matter annihilation in space

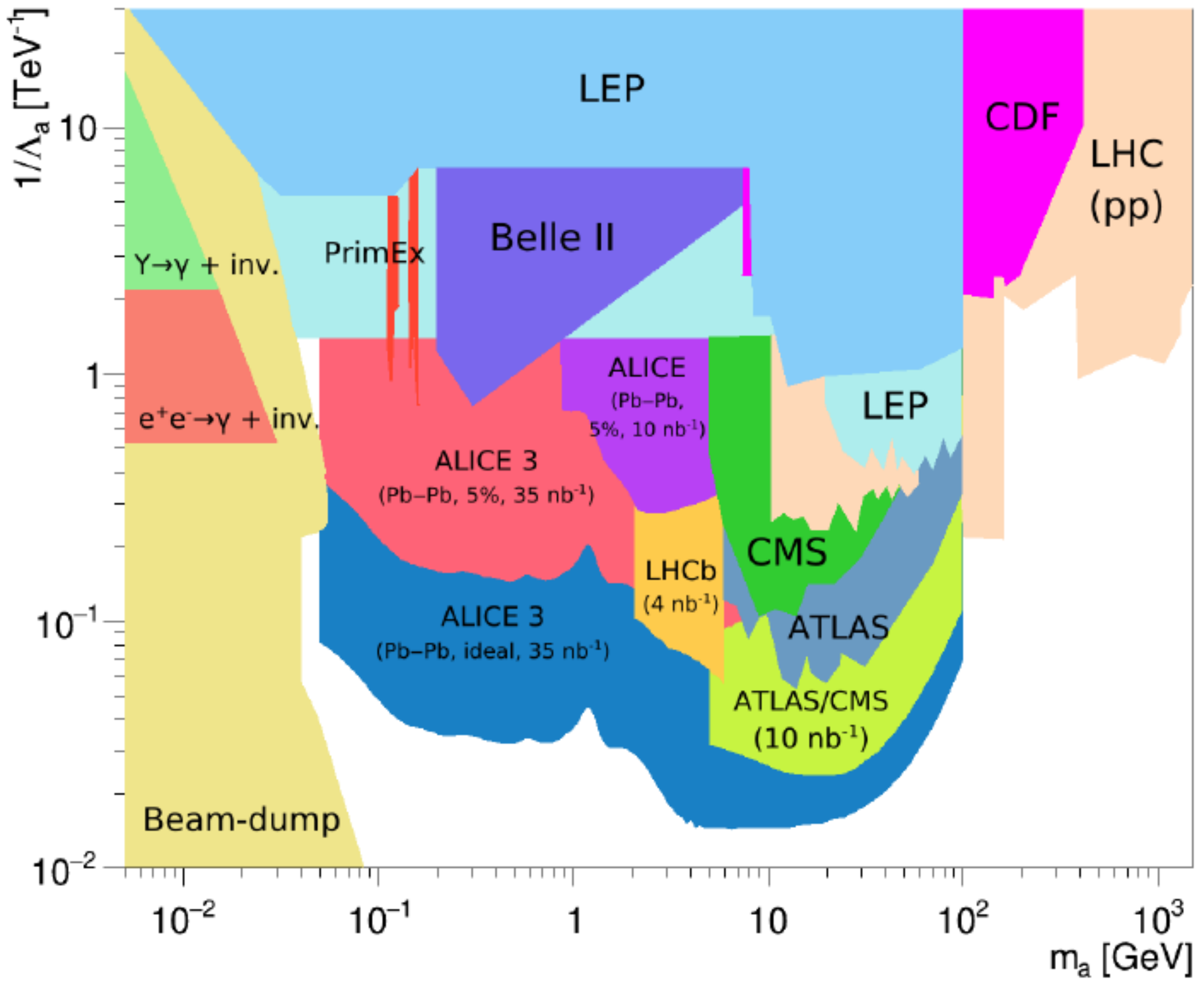
Decay of dark matter predicted to favor b quark pairs hadronizing into Λ_b

Question: how likely anti-nuclei can be formed from Λ_b decay?

- Constraints on branching ratio at the LHC (preliminary measurement by LHCb)

Beyond the Standard Model





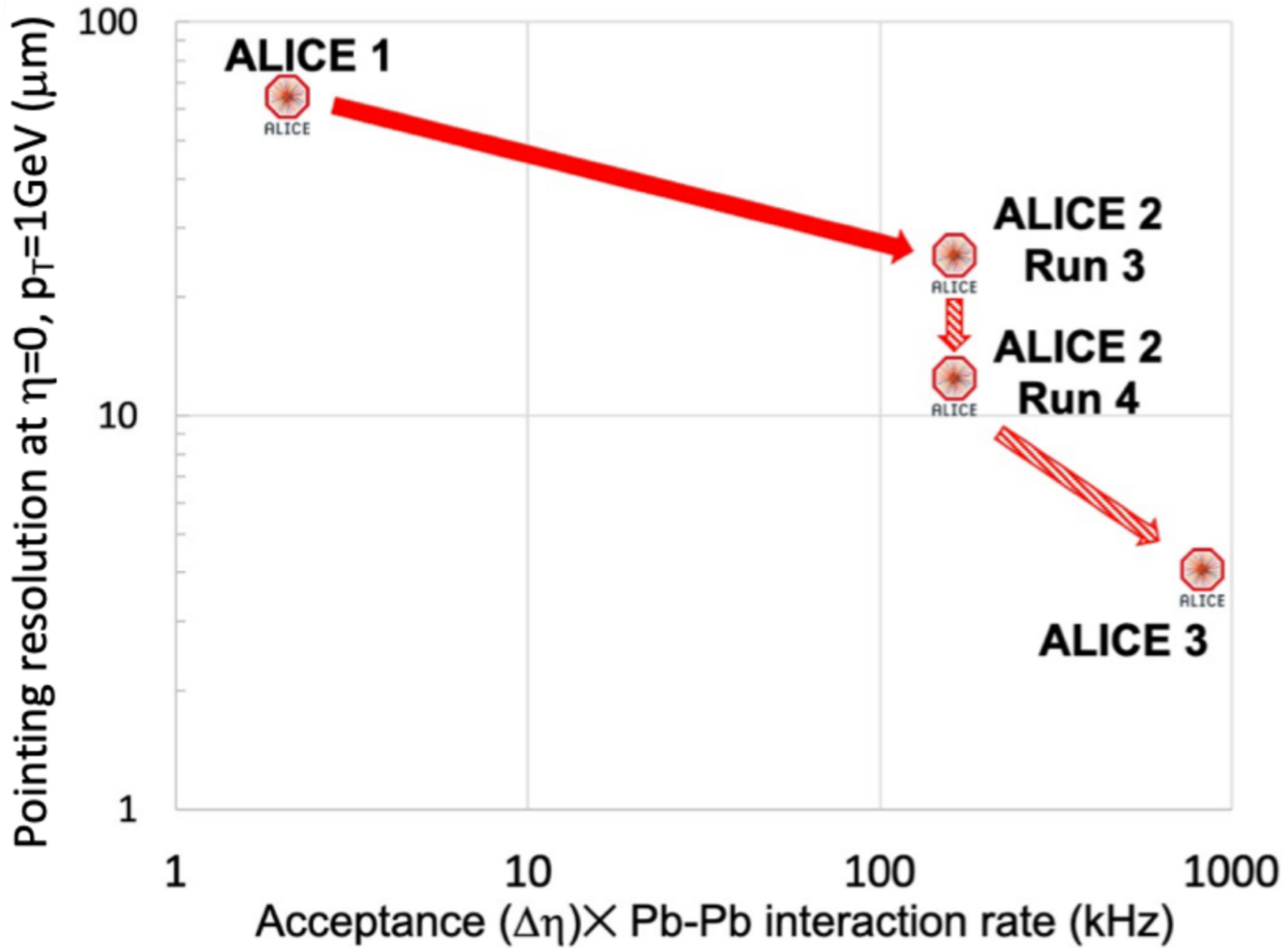
Light-by-light scattering for axion searches

- Competitive limits on axion searches
- UPCs provide a clean environment for di-photon final states
- final state photons reconstructed either via photon conversions or via ECal measurements

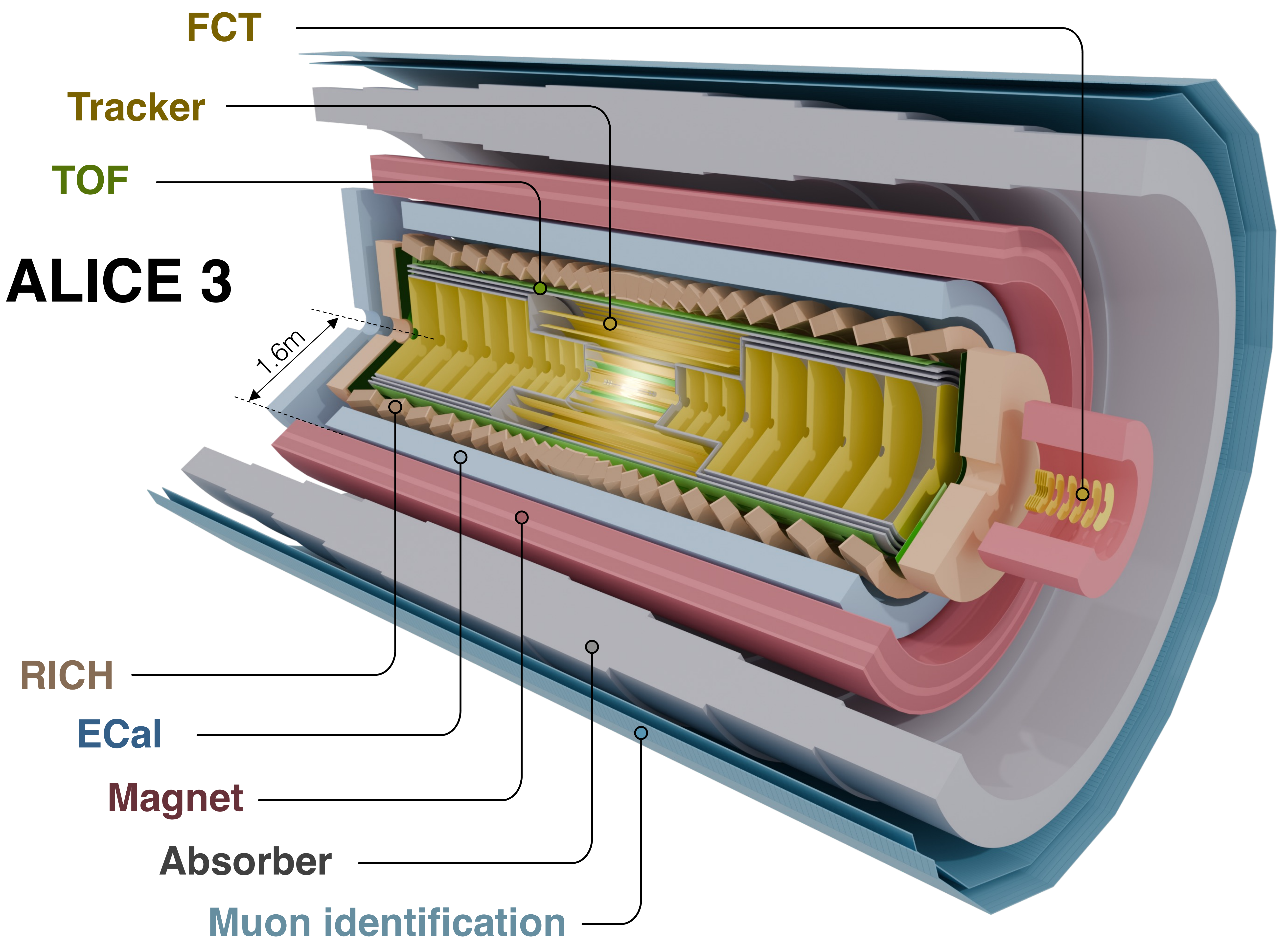
ALICE 3 detector concept

In few words:

Compact **all-silicon tracker**
with **high-resolution** vertex detector
Superconducting magnet system
Particle Identification over large acceptance:
muons, electrons, hadrons, photons
Fast read-out and online processing



For LHC Run 5 & 6
Improvement of pointing resolution and effective statistics



Requirements for vertexing

Pointing resolution crucial for:

- dileptons
- heavy flavour

Target pointing resolution

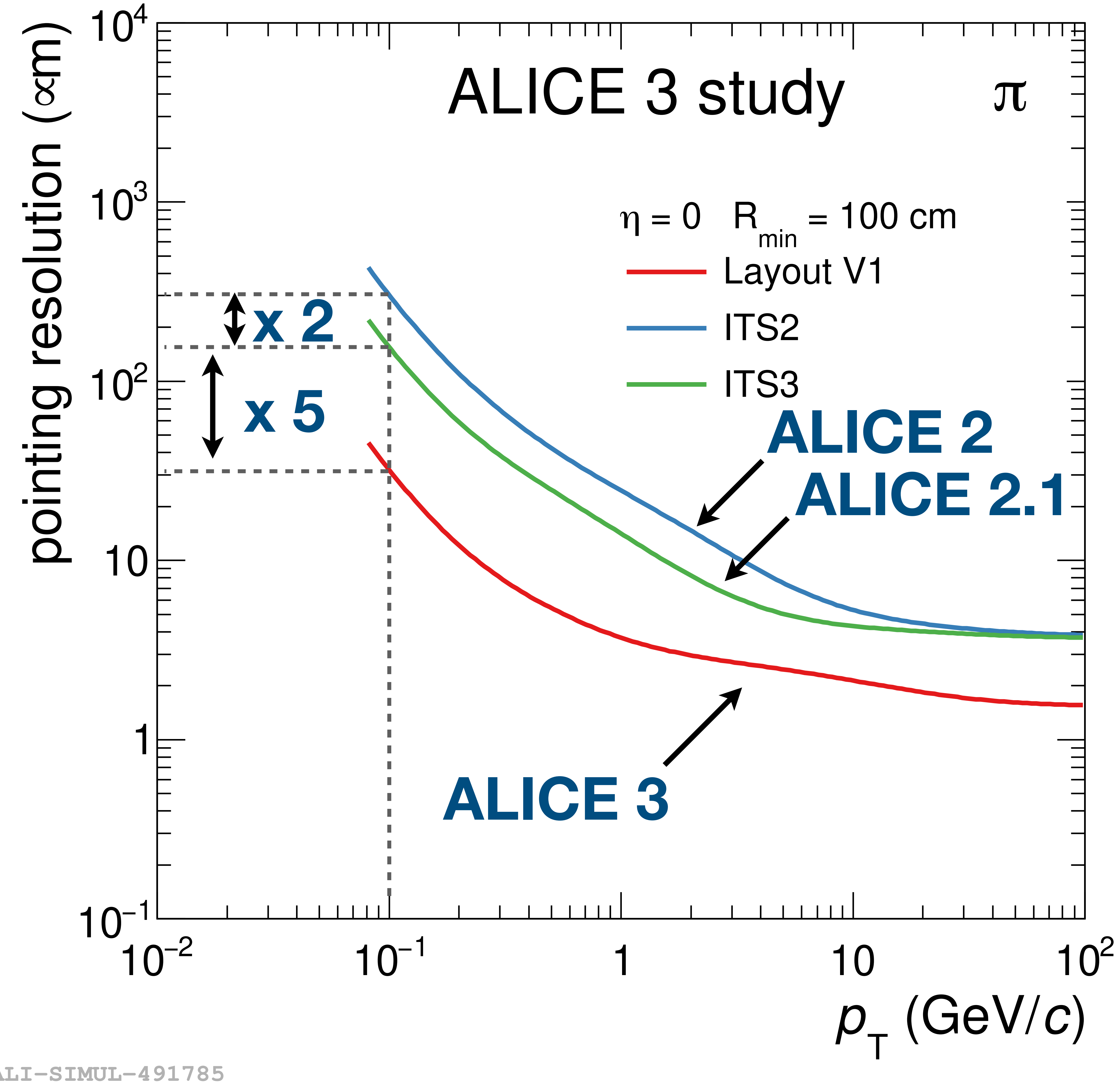
Pointing resolution $\propto r_0 \cdot \sqrt{x/X_0}$ (multiple scattering regime)

~10 µm @ p_T = 200 MeV/*c* → 5x better than ALICE 2.1

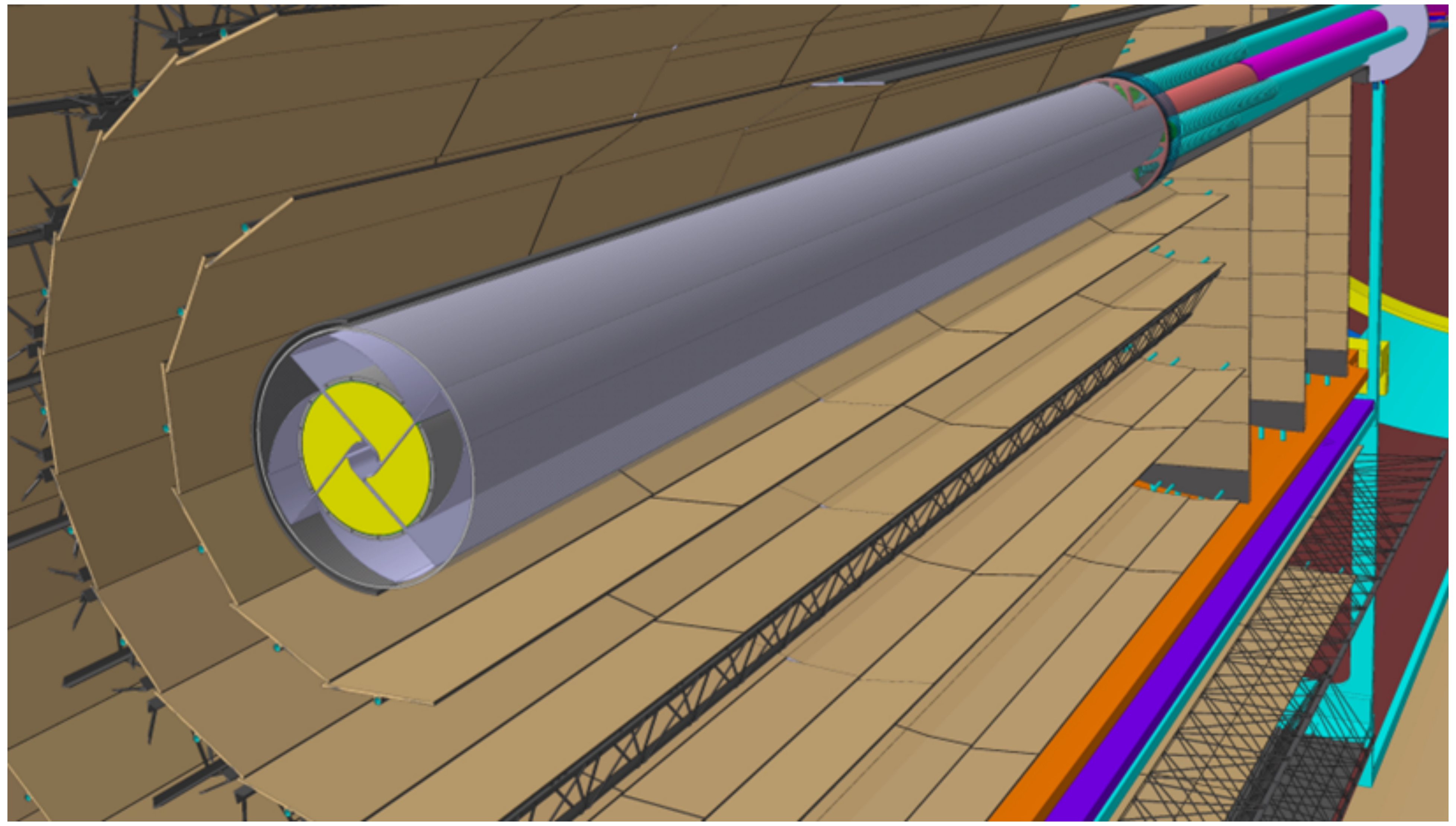
Unique pointing resolution at mid-rapidity at the LHC!

Critical for this step:

- radius and material thickness of first layers
- minimum radius limited by LHC



ALICE Vertex detector concept



Retractable vertex detector

3 layers within the beam pipe in secondary vacuum

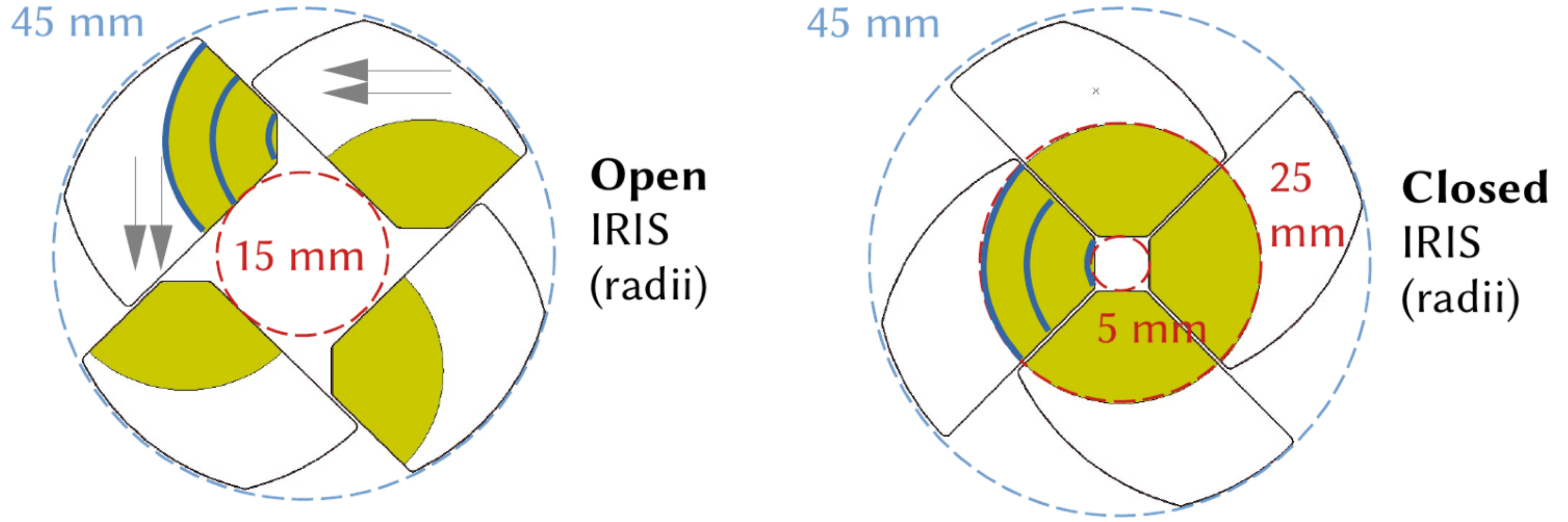
- wafer-sized, bent Monolithic Active Pixel Sensors
- σ_{pos} ~2.5 μm → 10 μm pixel pitch
- 1 ‰ X_0 per layer

rotary petals matching to beampipe parameters

- $R_{min} \approx$ 5 mm at top energy
- $R_{min} \approx$ 15 mm at injection energy

- feed-throughs for power, cooling, data

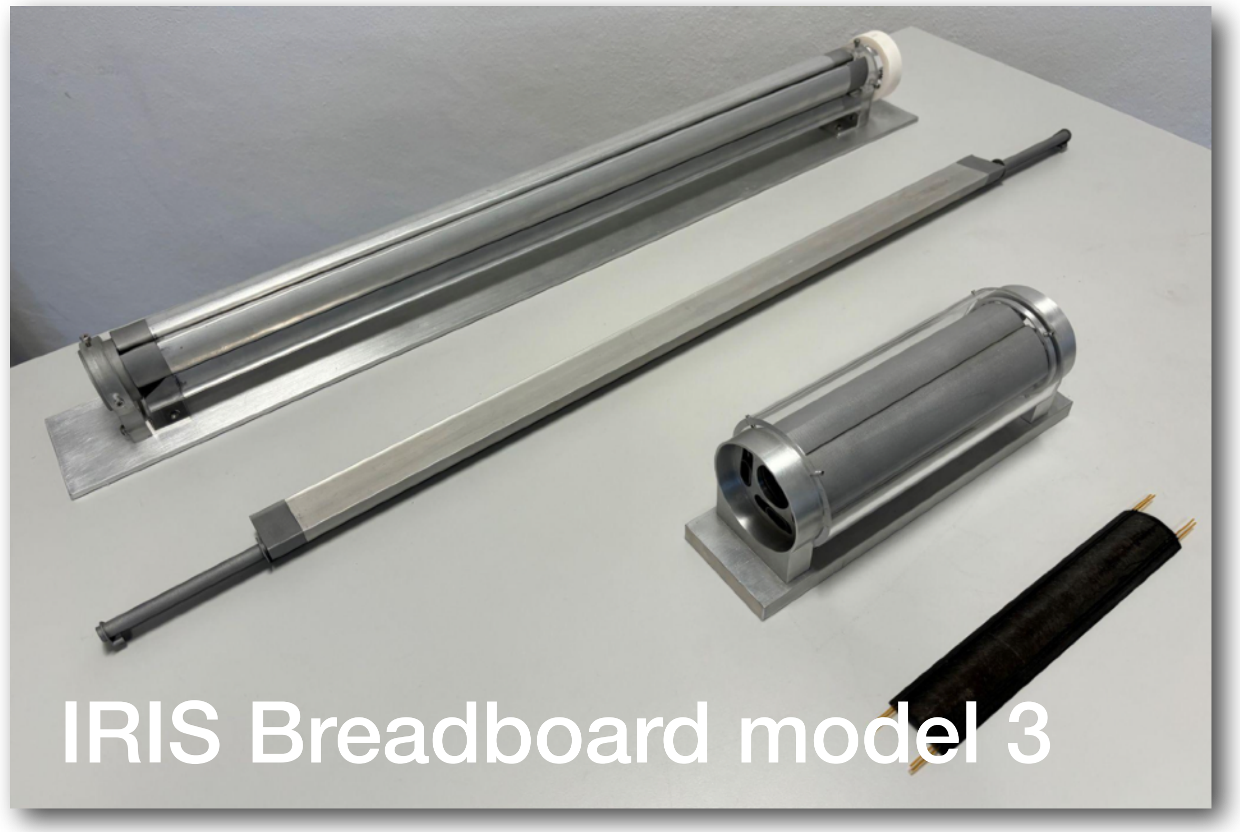
R&D ongoing: challenges on mechanics, cooling, radiation tolerance



Middle Layers:

various options for ultra-light layers, leveraging on ITS3 technology

benefits on tracking of soft electrons and of charged hyperons (Ξ^-, Ω^-)



IRIS system:

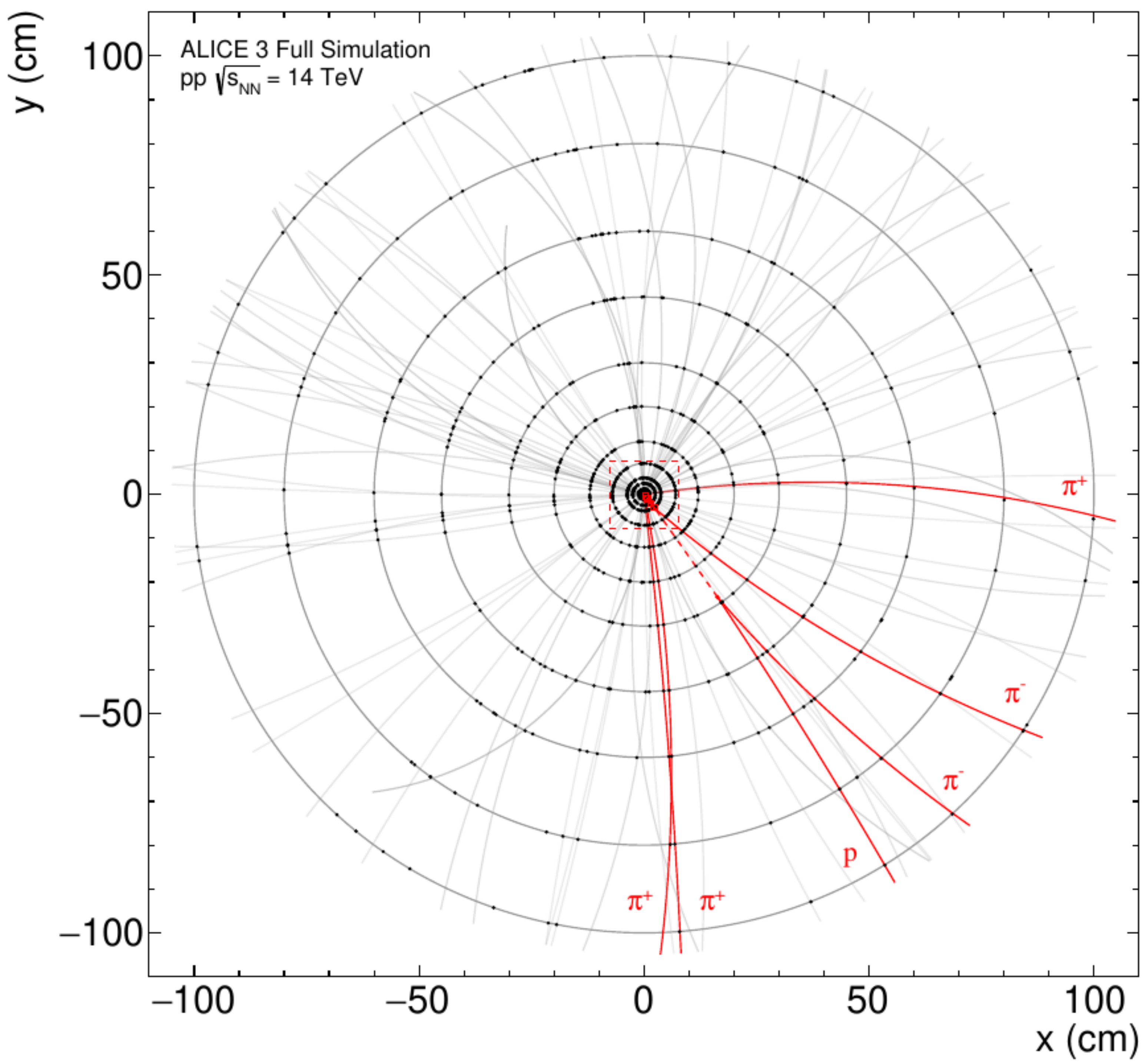
services integration being detailed

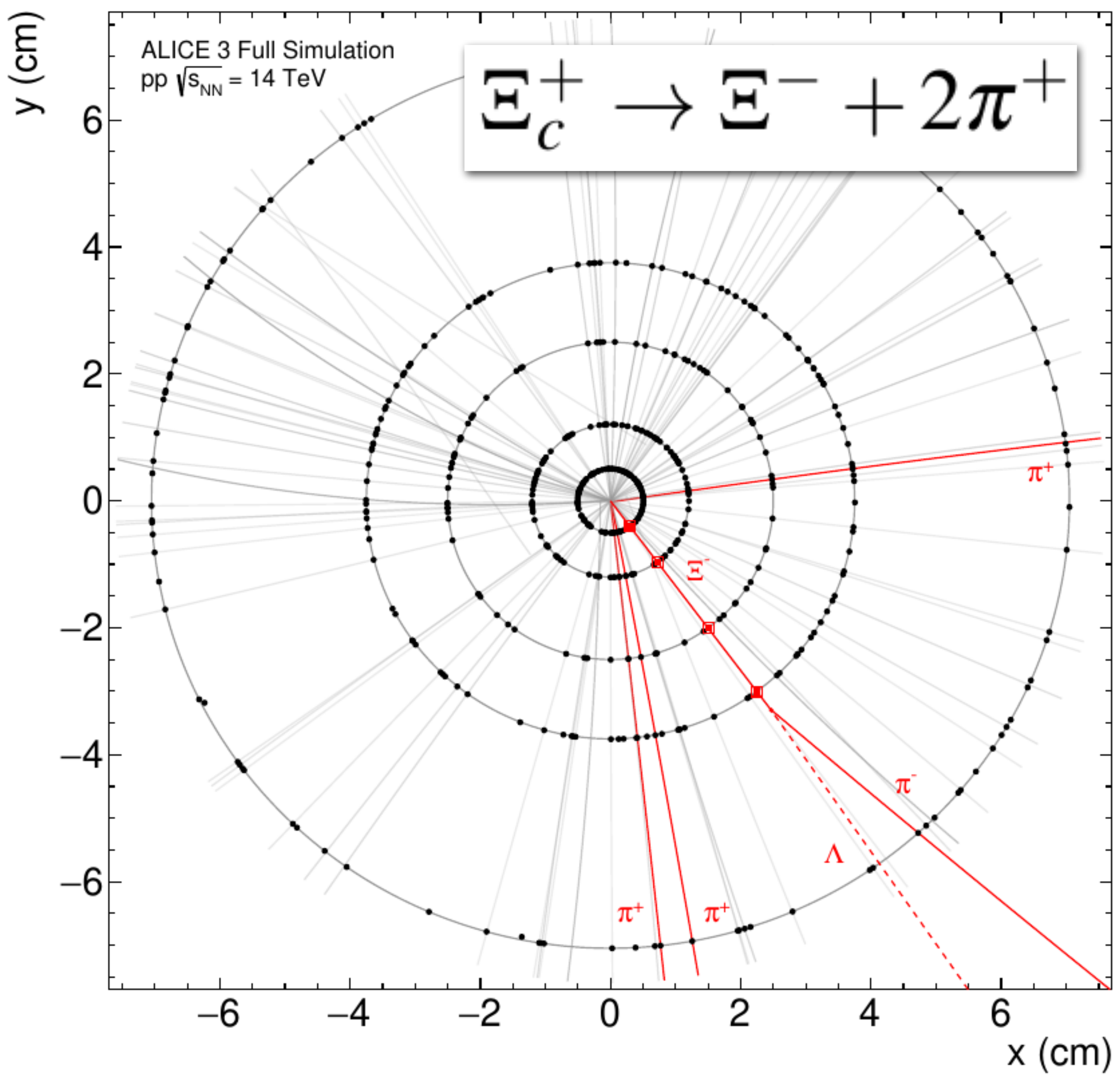
study of protection between primary and secondary vacuum

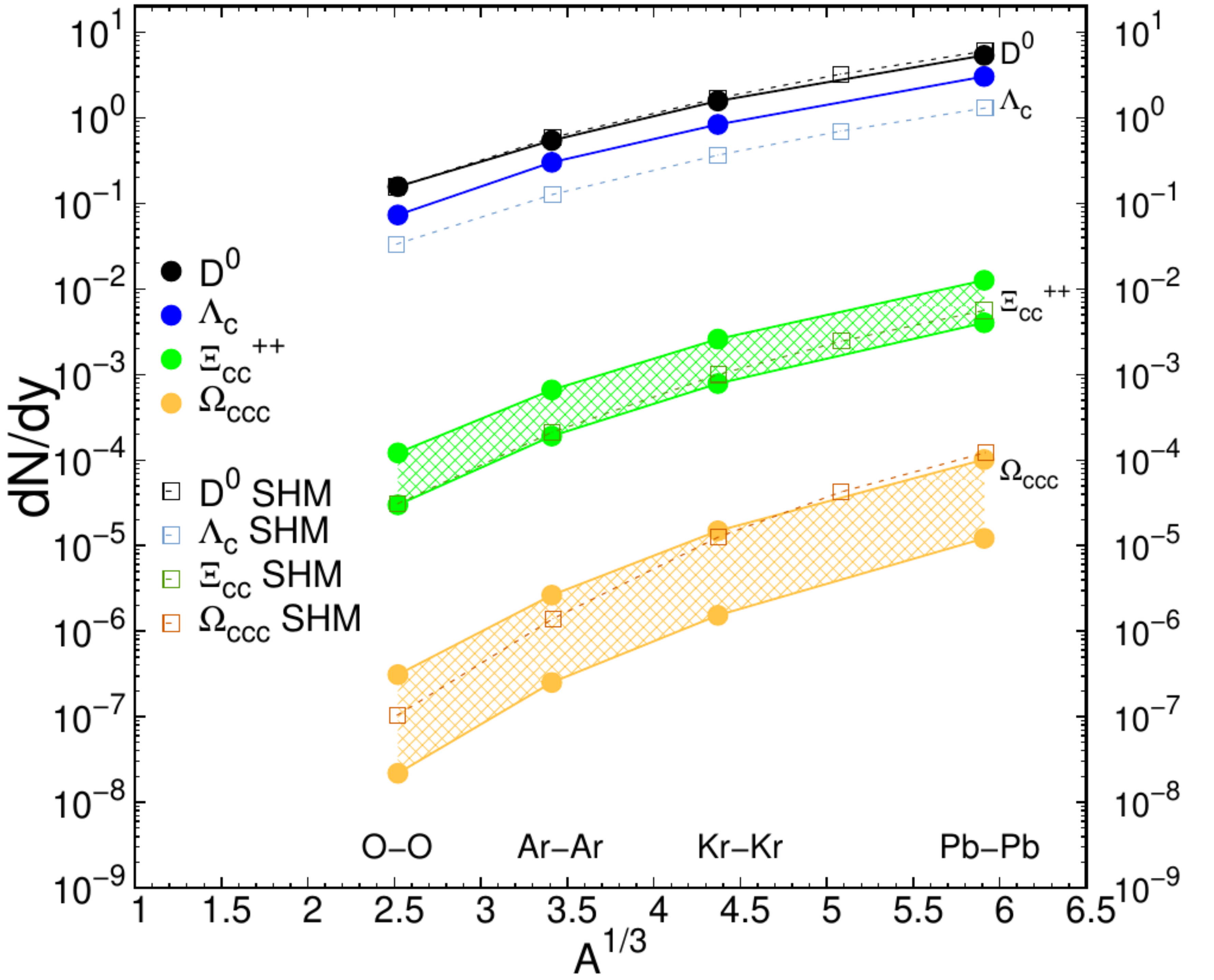
impact of vacuum on components, wire bonding, glued parts

Strangeness tracking to the maximum

V. Minissale et al. Eur.Phys.J.C 84 (2024) 3, 228







Full reconstruction of decay topology tracking charged strange decaying hadrons

Unique experimental access to multicharm hadrons with ALICE 3 in Pb-Pb collisions

Combined with possibility to run with lighter ions, test the system size dependence

Ξ_{cc}^{++}(ucc)$\rightarrow$ Ξ_c^+(usc) π^+ $\rightarrow$ [Ξ^-(dss) $\pi^+\pi^+$] π^+

Ω_{cc}^+(scc) ...

Ω_{ccc}^{++}(ccc)$\rightarrow$ Ω_{cc}^+(scc) π^+ $\rightarrow$ [Ω_c^0(ssc) π^+] π^+ ...

Requirements for tracking

Momentum resolution crucial for:

- dileptons
- heavy flavour
- jets

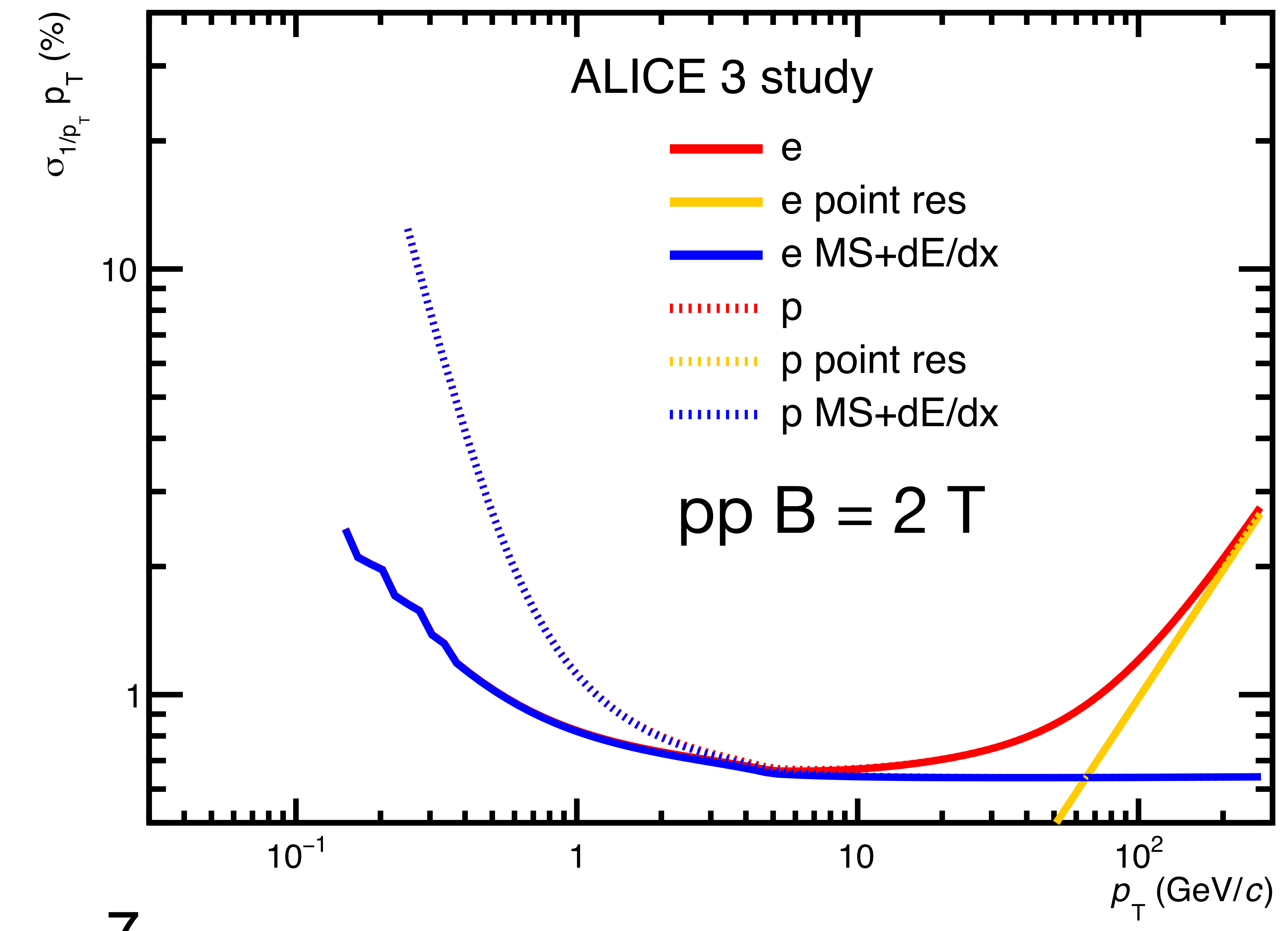
Target momentum resolution

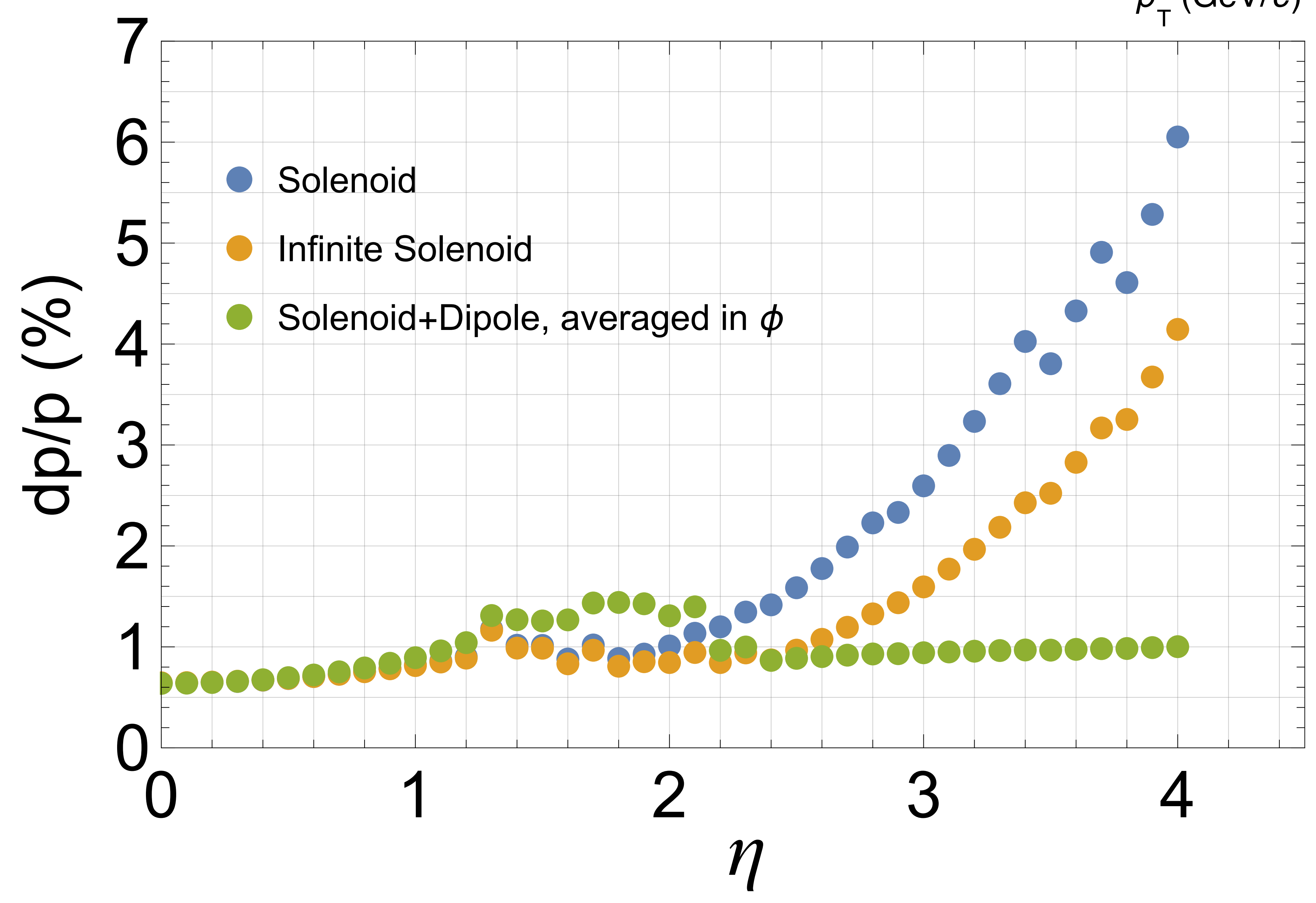
Relative p_{T} resolution $\propto \frac{\sqrt{x/X_0}}{B \cdot L}$ (limited by multiple scattering)

~1 % up to η = 4 → large coverage

Critical for this step:

- integrated magnetic field
- overall material budget

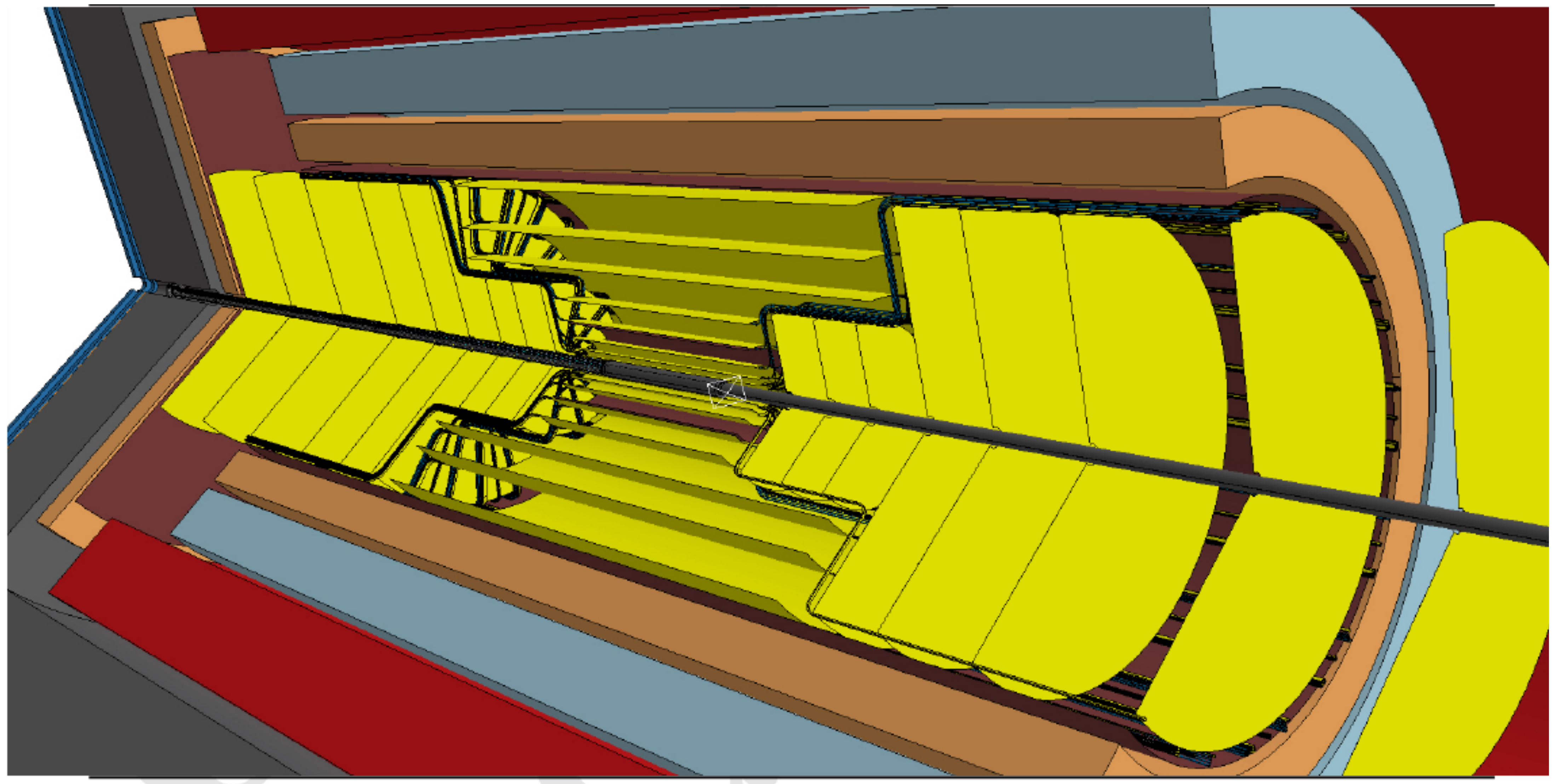




The outer tracker

Concept:

- ~8 layers and 9 disks tracking layers
- σ_{pos} ~10 µm → 40 µm pixel pitch
- $R_{out} \approx$ 80 cm and L ≈ 4 m
- timing resolution ~100 ns (→ reduce mismatch probability)
- carbon-fibre space frame for mechanical support
- material ~1 % X_0 / layer → overall x/X_0 = ~10 %
- Low power consumption ~20 mW/cm^2



R&D: build on the expertise of ITS2

Total silicon area ~ 67 m^2

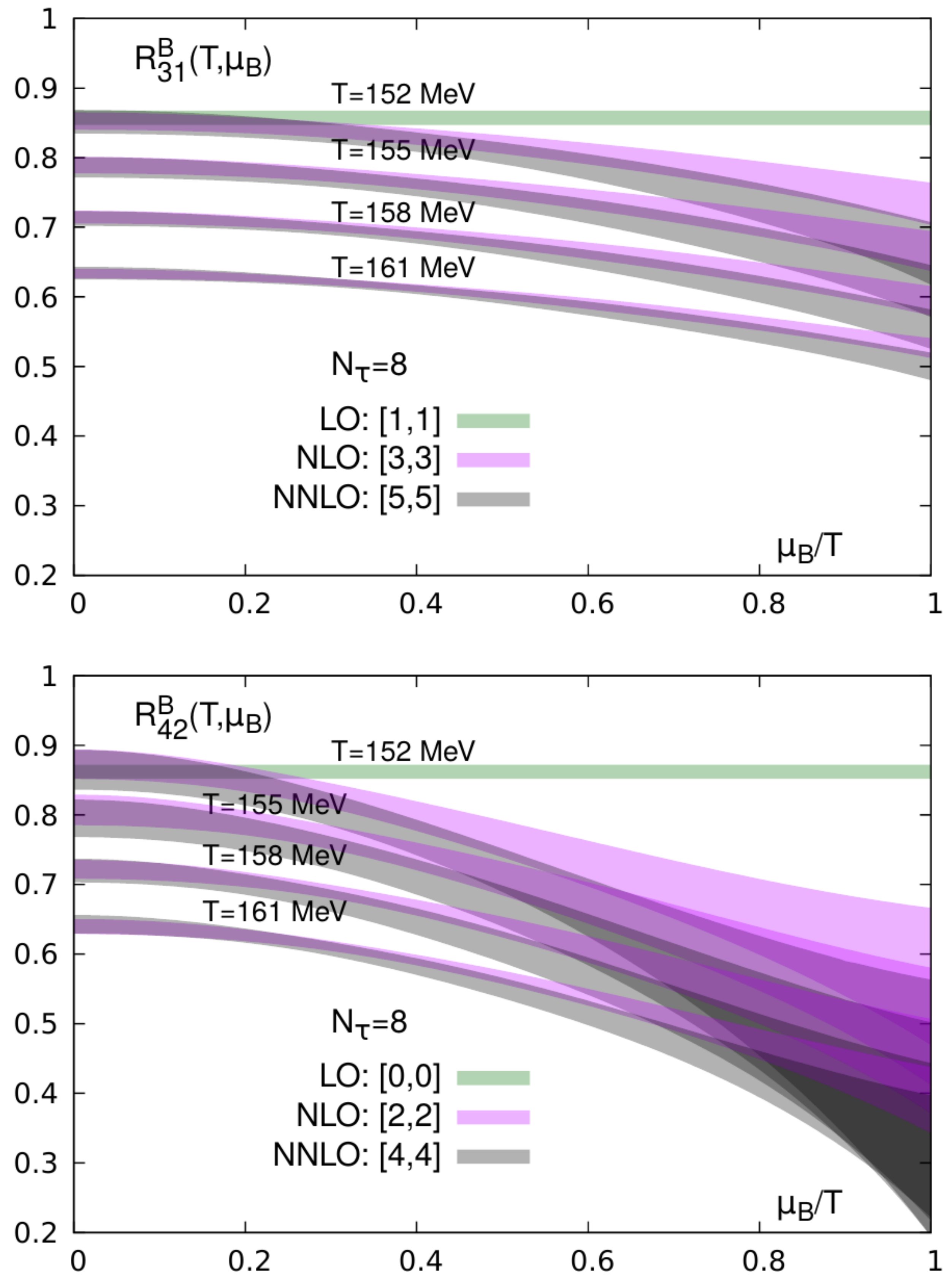
Why PID matters

Concept:

- Getting $dN/dp_T dy$ + v_T down to non-relativistic p_T (e.g. $p_T < 0.05$ GeV/c → $\beta(\pi) \approx 0.34$)
  → change from non-relativistic (linear) to relativistic hydrodynamic evolution (quadratic behaviour)
- Disoriented Chiral Condensate or π condensate
- if present at all, will be at $p_T < 1/2\ m_\pi$
- Driving factor: p_T reach and increased acceptance

$$R_{31}^B(T,\mu_B) = \frac{S_B\sigma_B^3}{M_B} = \frac{\chi_3^B(T,\mu_B)}{\chi_1^B(T,\mu_B)}$$

$$R_{42}^B(T,\mu_B) = \kappa_B\sigma_B^2 = \frac{\chi_4^B(T,\mu_B)}{\chi_2^B(T,\mu_B)}$$



HotQCD, arXiv:2001.08530

Bonus:

Measure event-by-event fluctuations into distributions with $p_T > 0$ GeV/c + over large y (i.e. p_T-integrated quantities)

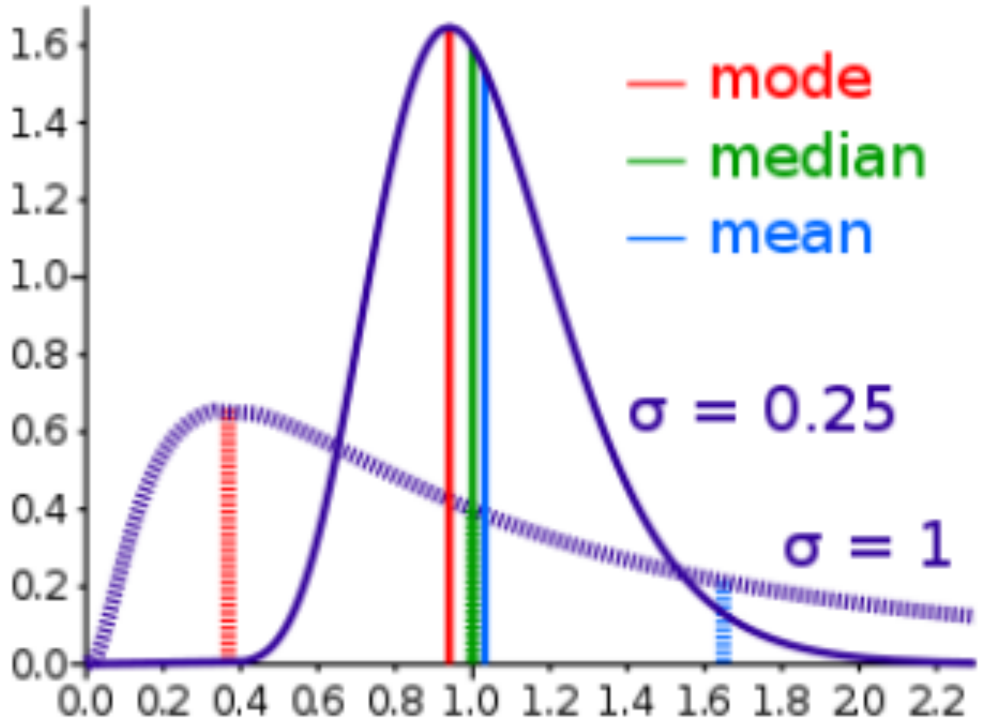
1st moment, m1 : mean M

2nd moment, m 2 : variance σ^2

3rd moment, m3 : ∝ skewness S

4th moment, m4 : ∝ kurtosis κ

5th moment, m5 : ...



Net quantum number fluctuations at (μB = 0)

Q : net charge (h+ - h-)

B : net baryon (p-$\bar{p}$, Λ-$\bar{\Lambda}$, ...)

S : net strangeness (K^+-K^-, Λ-$\bar{\Lambda}$, ...)

→ key : ratios mj/mi (e.g. m_4^B / m_2^B) to access direct comparison to LQCD for (deconfinement d.o.f. + chiral restoration + nature of transitions)

Particle identification with Time Of Flight

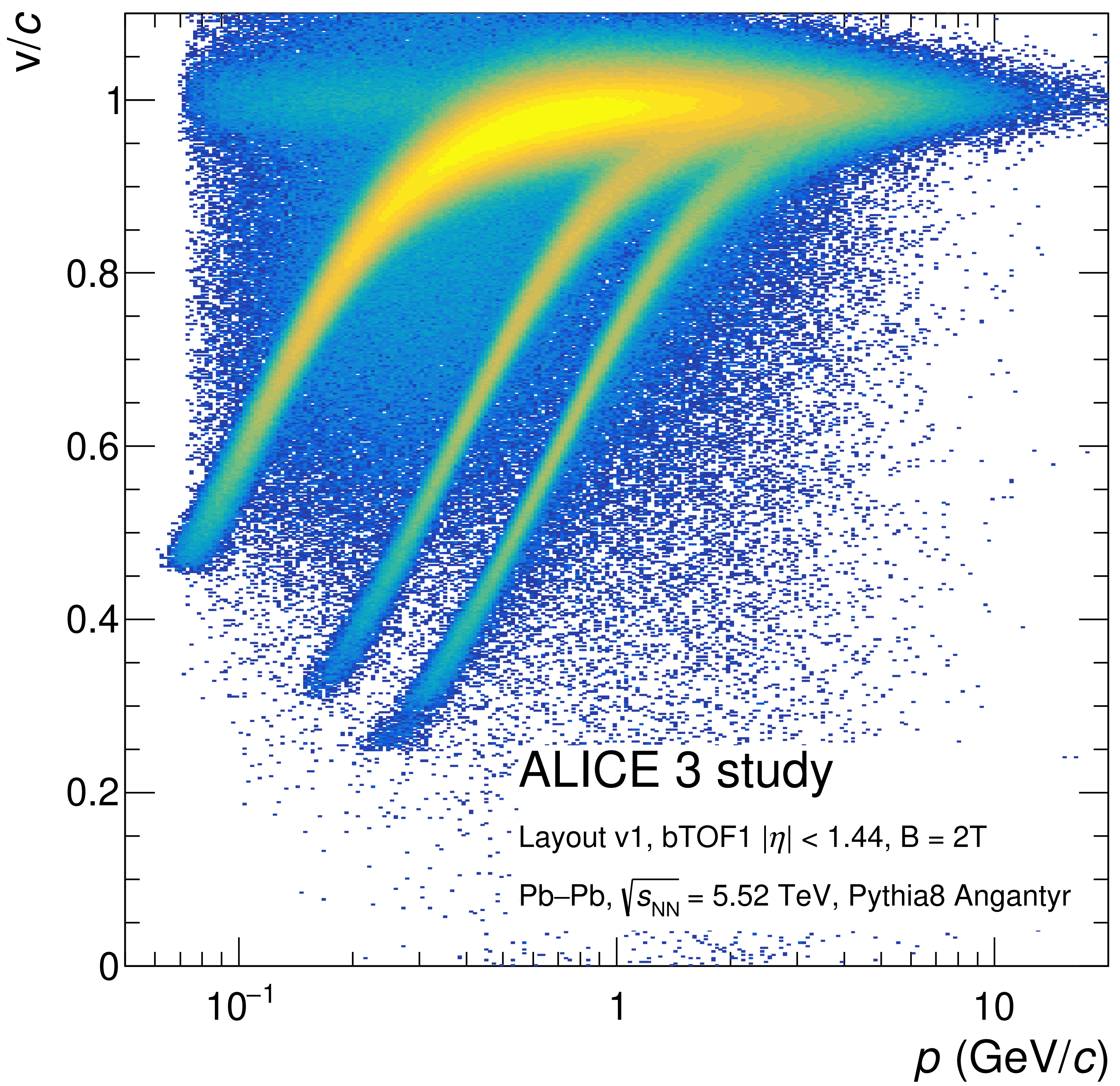
Separation power $\propto L/\sigma_{\mathrm{TOF}}$

Critical for this step:

- distance and time resolution crucial
- larger radius results in lower p_T bound

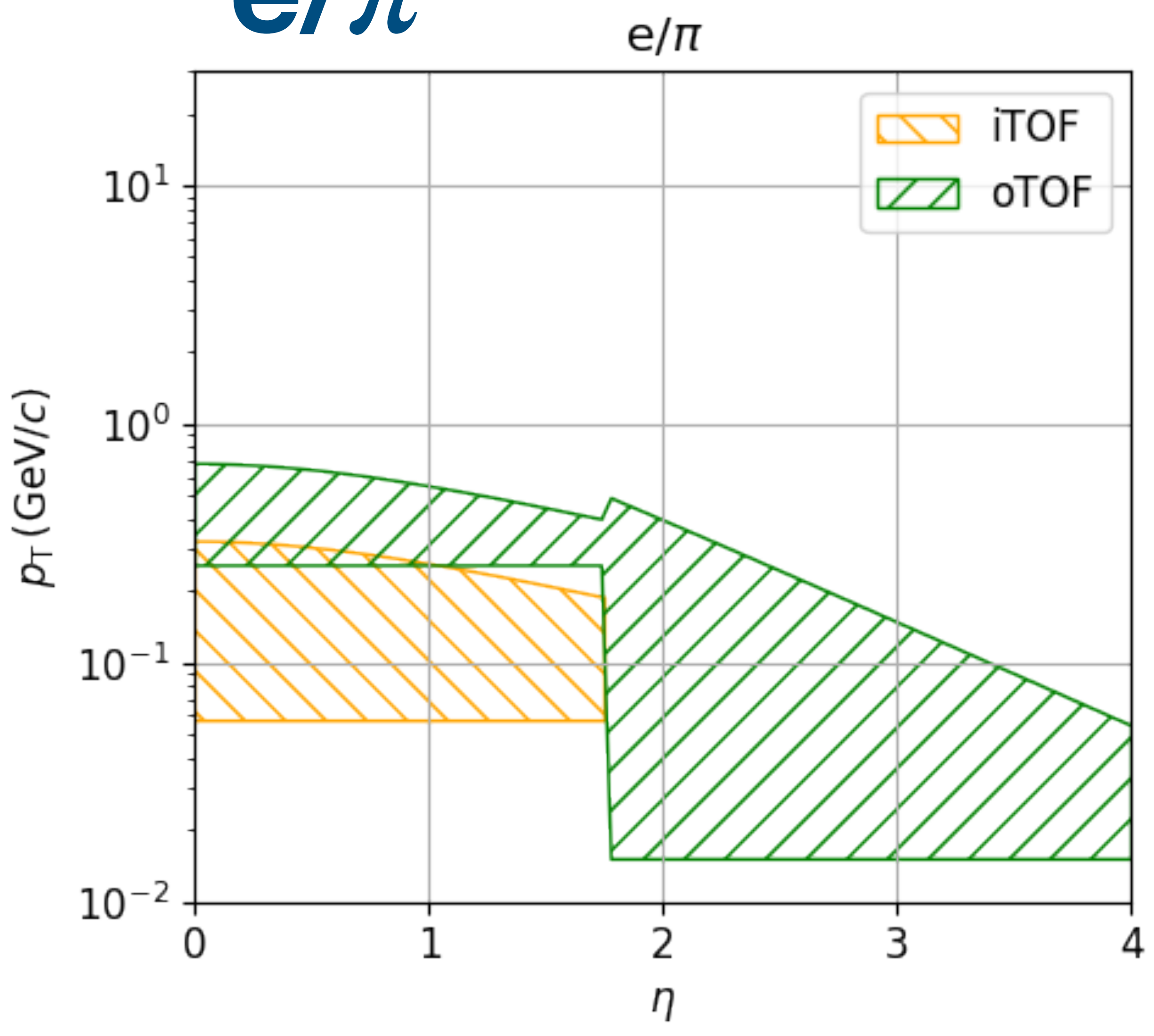
Concept:

- 2 barrel + 1 forward TOF layers
  - outer TOF at R ≈ 85 cm
  - inner TOF at R ≈ 19 cm
  - forward TOF at z ≈ 405 cm
- Silicon timing sensors ($\sigma_{\mathrm{TOF}} \approx$ 20 ps)
  - R&D on monolithic CMOS sensors with integrated gain layer

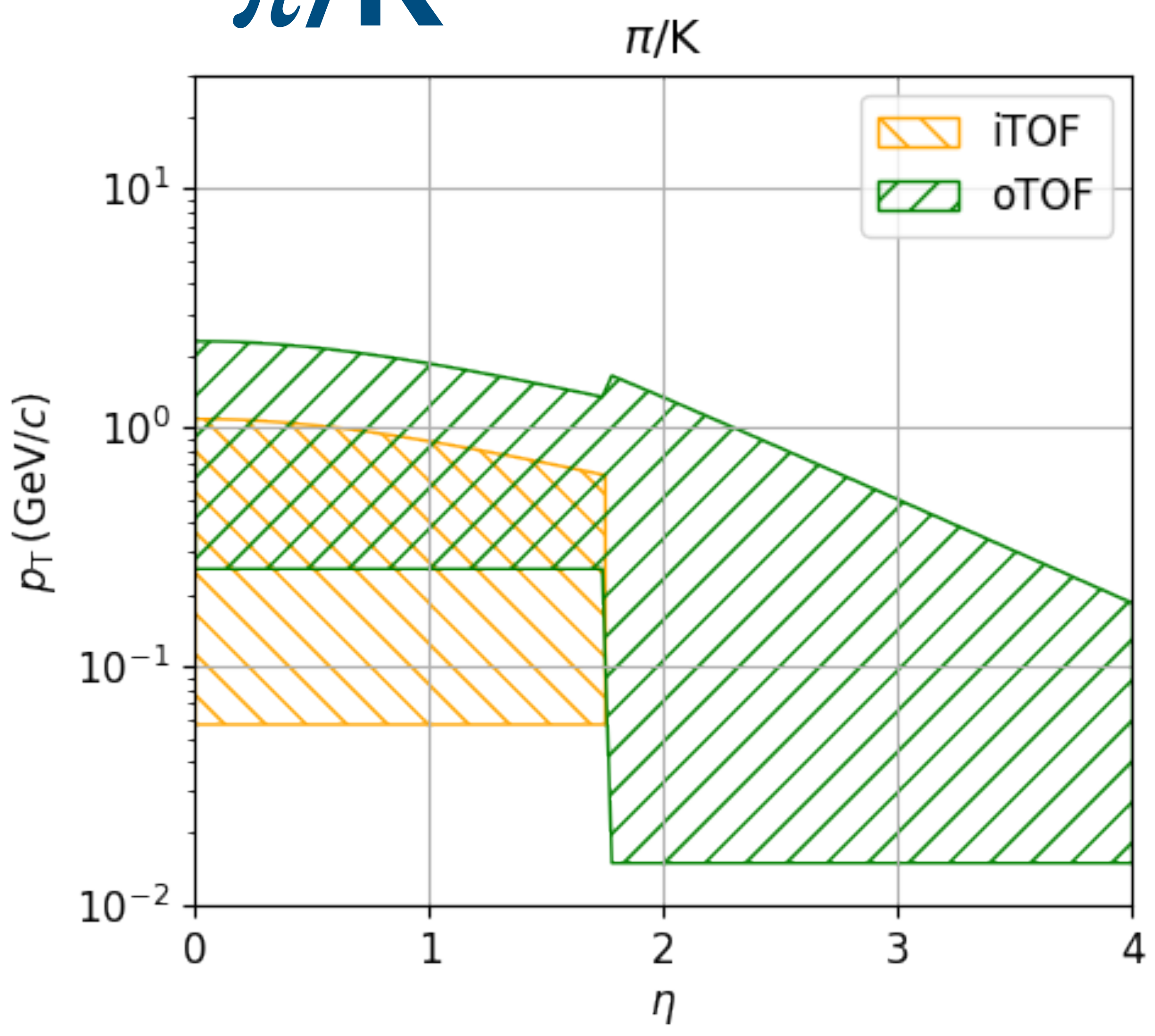


Total silicon area ~ 45 m²

e/π



π/K



Particle identification with Cherenkov light

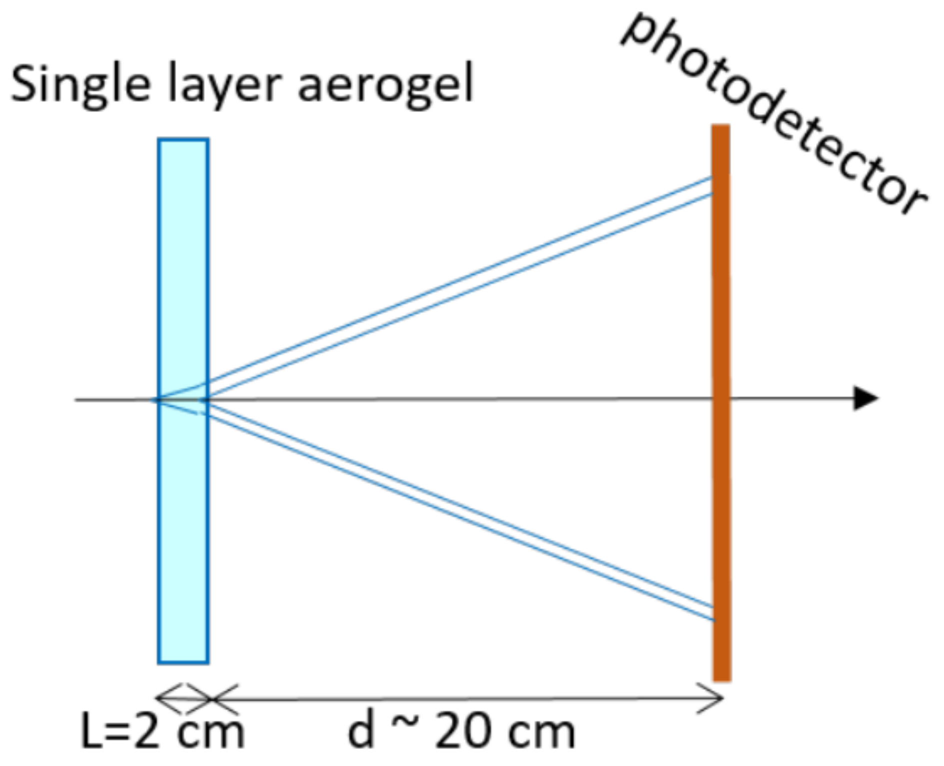
Complement PID reach of outer TOF to higher p_T with Cherenkov detector

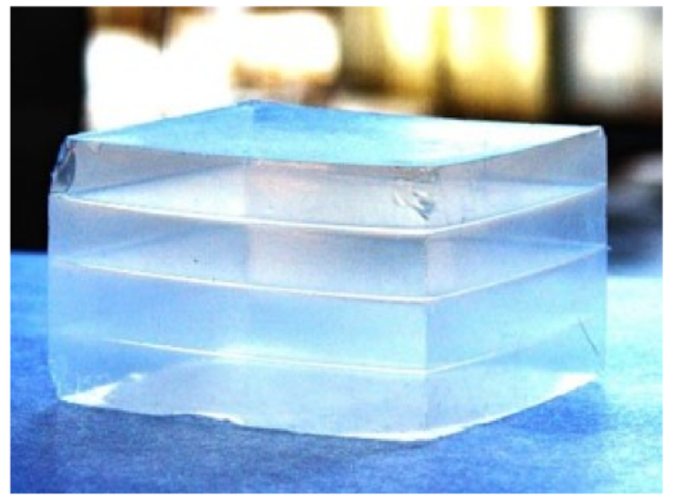
Critical for this step:

- ensure continuous coverage with the TOF system

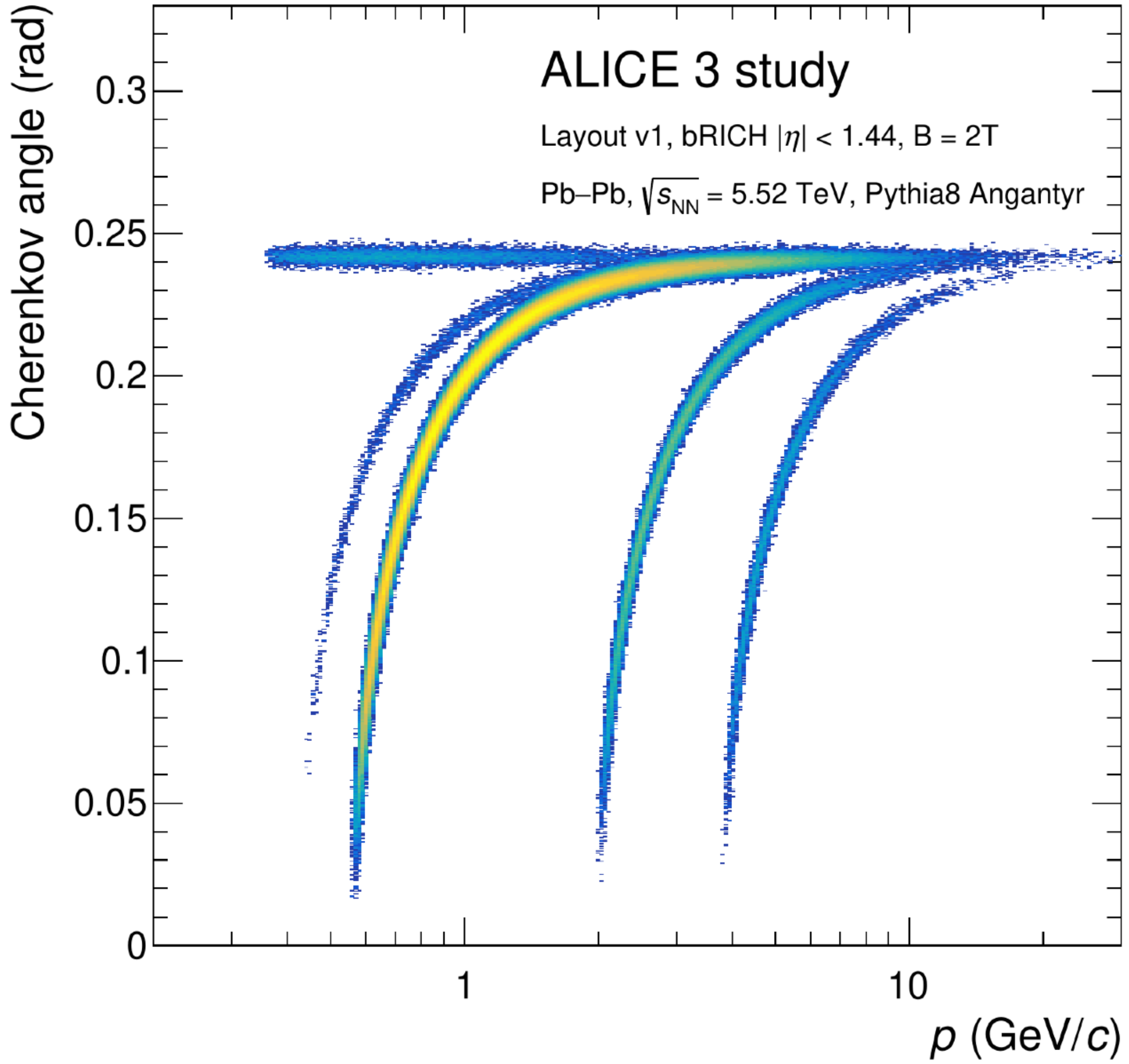
Concept:

- aerogel radiator
  - refractive index n = 1.03 (barrel)
  - refractive index n = 1.006 (forward)
- R&D on monolithic silicon photon sensors





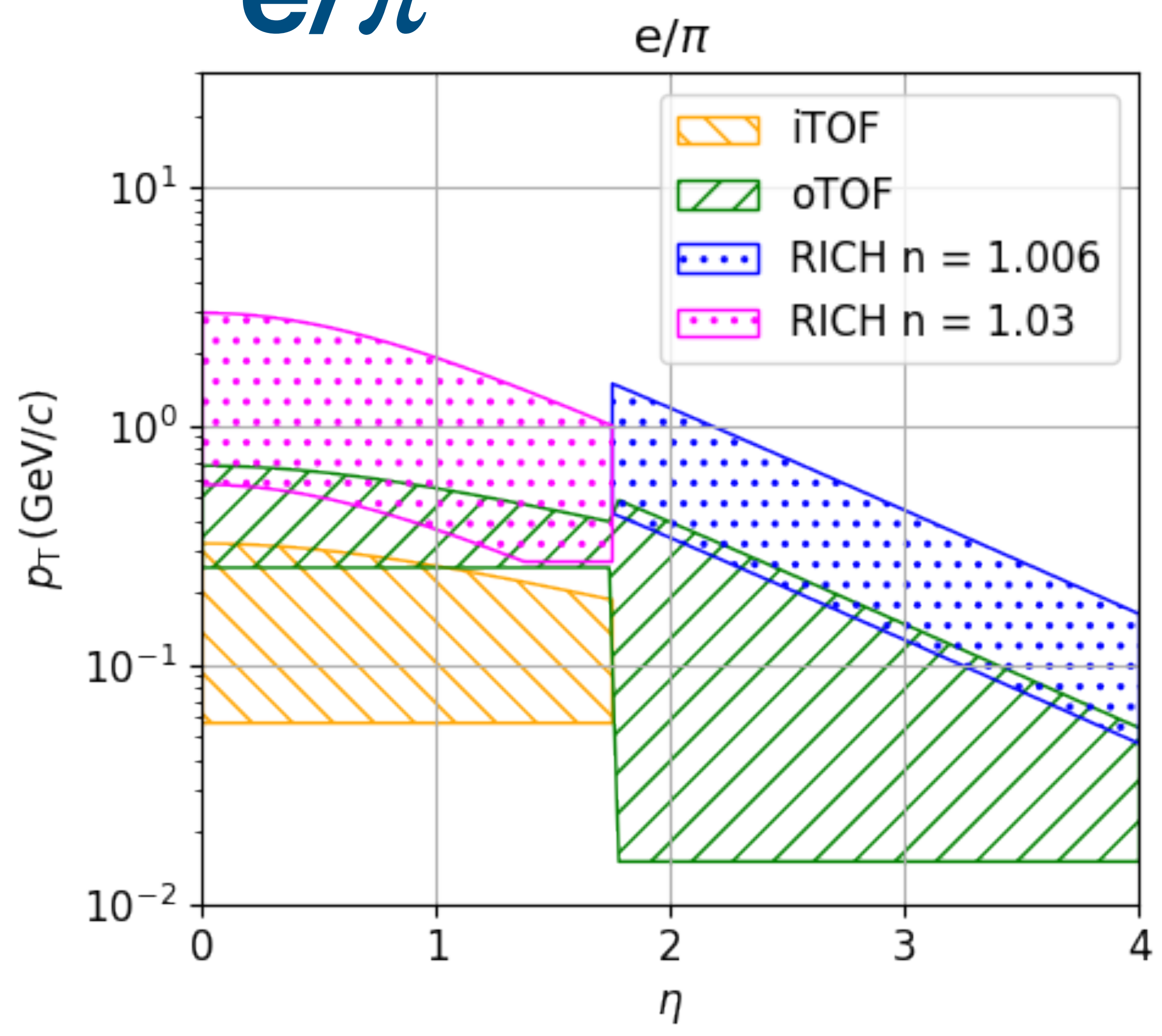
aerogel radiator



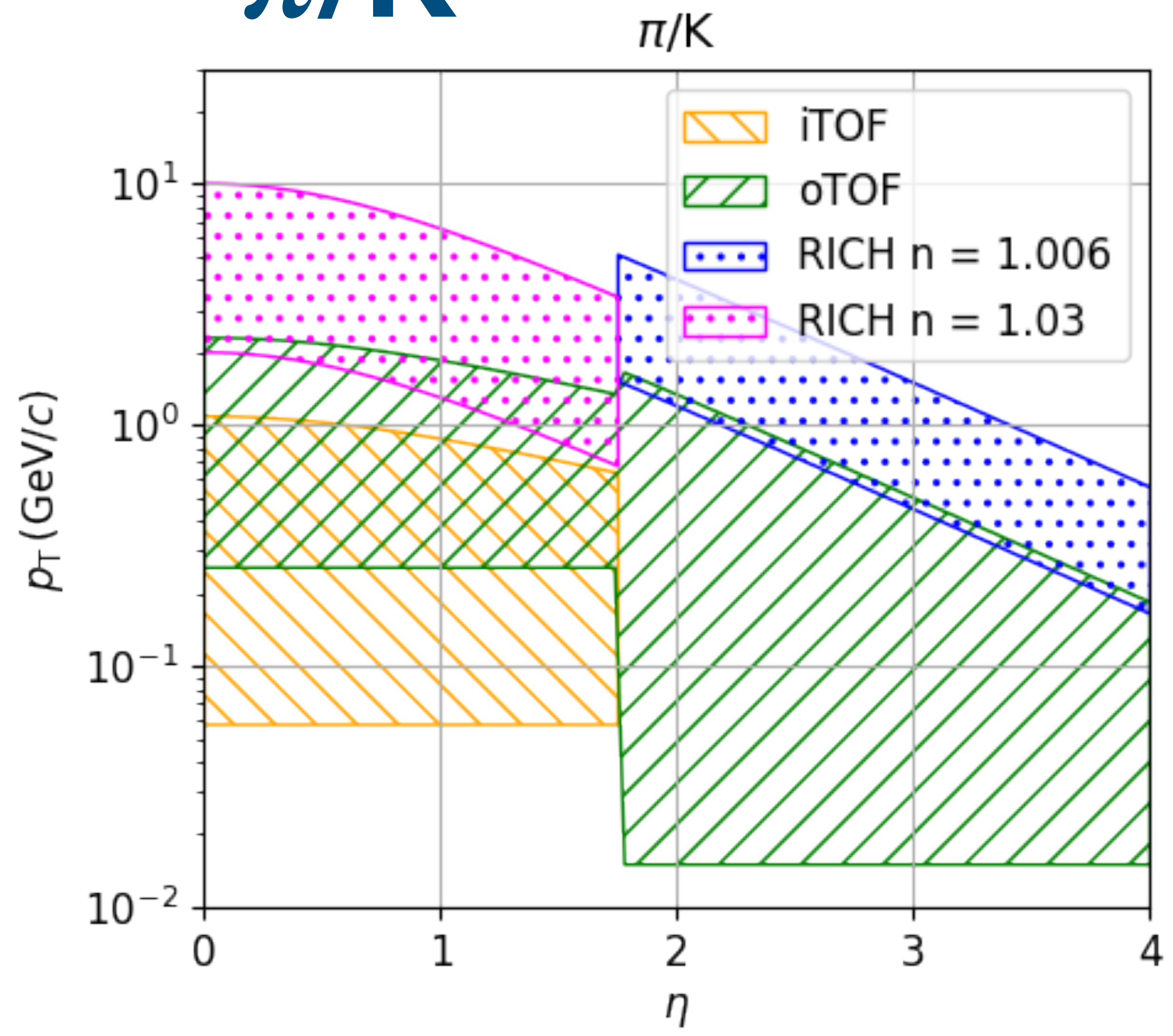
Total SiPM area ~ 40 m²

Continuous separation from 100 MeV/c to 10 GeV/c

e/π



π/K



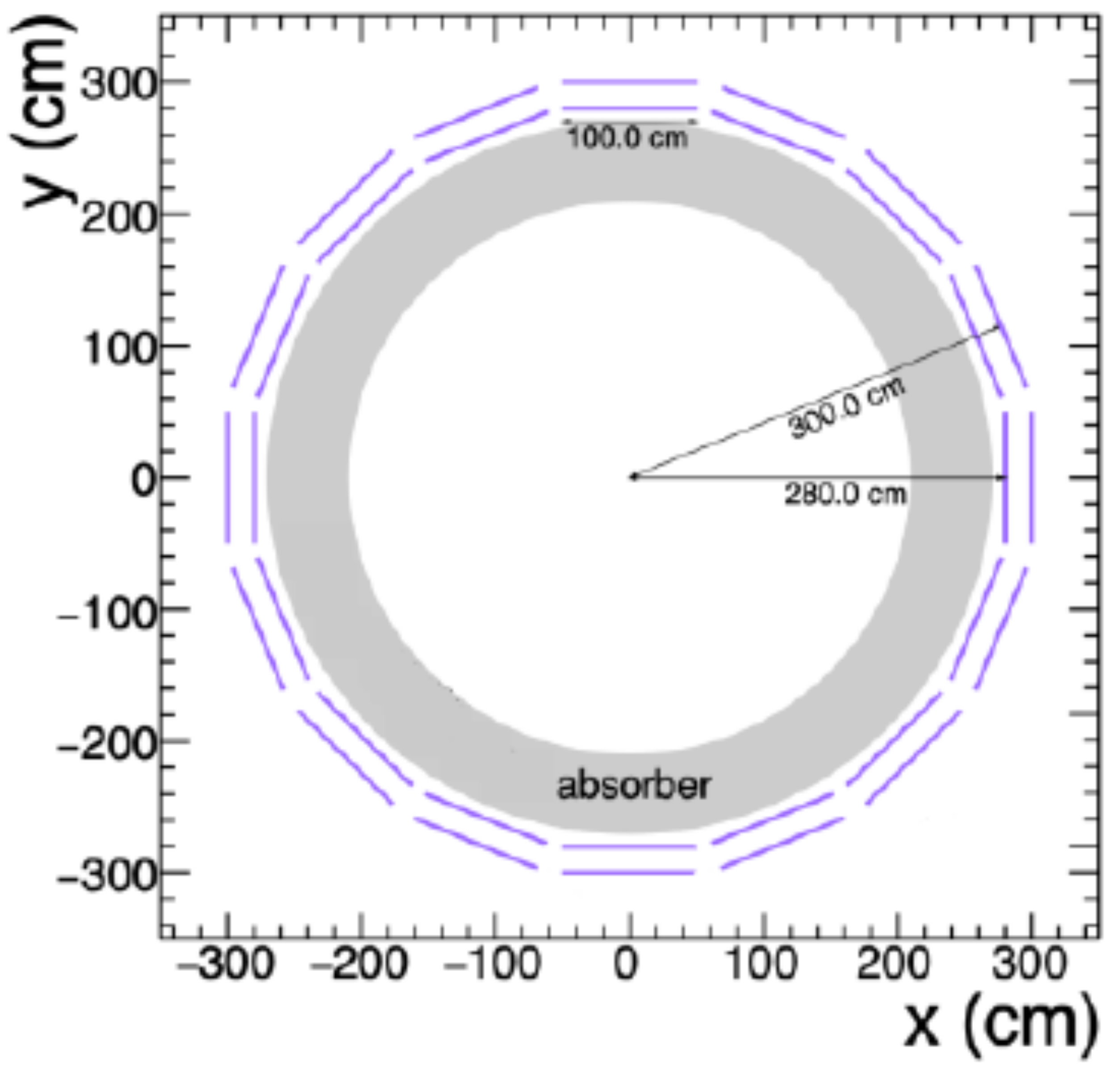
Muon identification

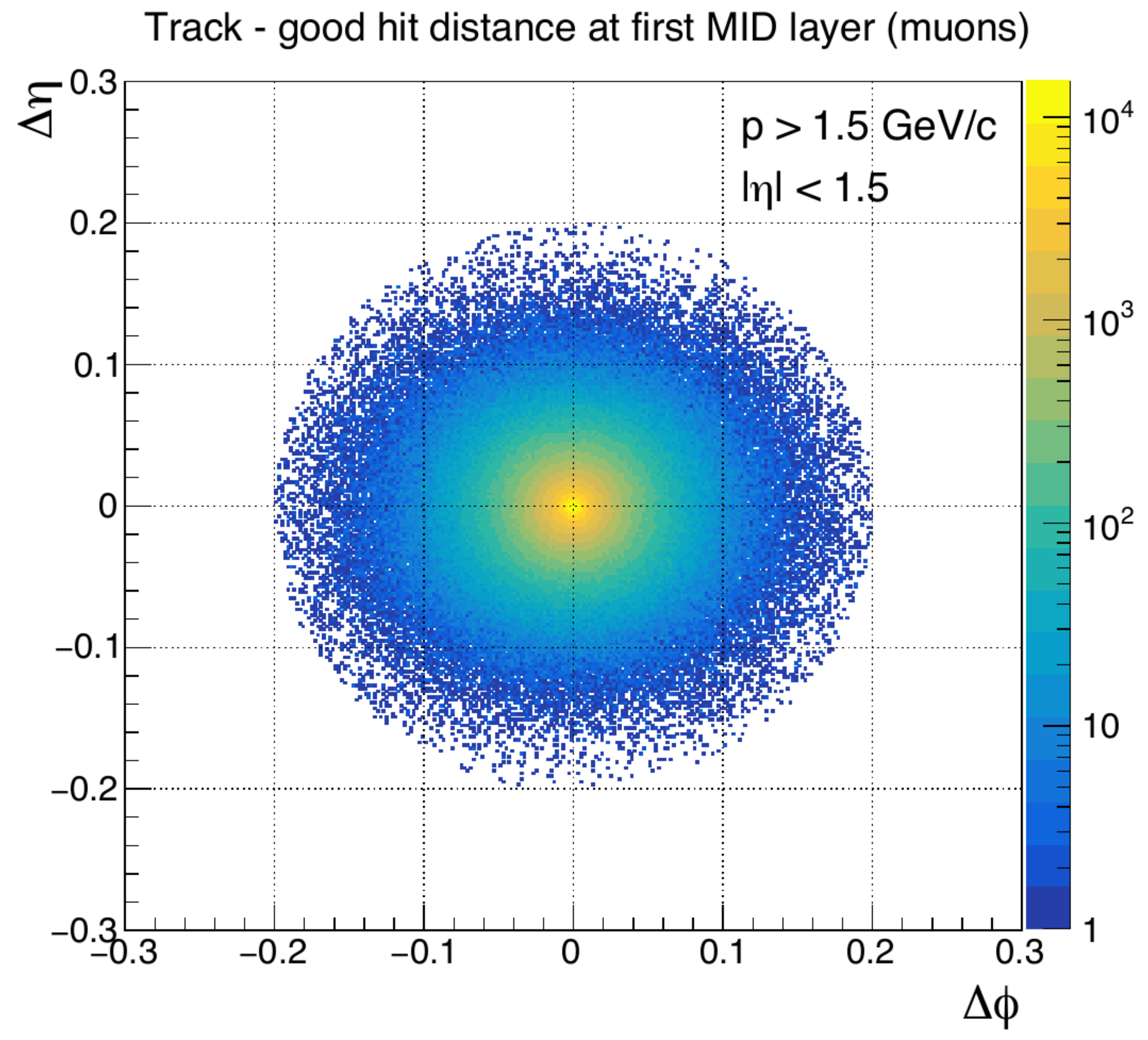
Muon chambers at central rapidity

- ~70 cm non-magnetic steel hadron absorber
- search spot for muons ~0.1 x 0.1 ($\eta \times \varphi$)
- ~5 x 5 cm^2 cell size
- matching demonstrated with 2 layers of muon chambers
  - scintillator bars
  - wave-length shifting fibers
  - SiPM read-out
  - possibility to use using RPCs as muon chambers

Muon identification down to $p_T \approx 1.5$ GeV/c

optimized for J/ψ reconstruction down to p_T 0 GeV/c





Digesting the data

ALICE O2 facility for Run 3 and 4:

Major upgrades during Long Shutdown 2 (continuous readout)

- Store all Pb-Pb collisions up to 50 kHz interaction rate → 3.5 TB/s raw detector data
- Fast online compression during data taking on heterogeneous architecture:
  FPGAs in FLP: 3.5 TB/s → 900 GB/s - **GPUs** in EPN: 900 GB/s → 170 GB/s

ALICE 3: novel and innovative detector concept

→ without TPC, much lower data volume / event but continuous read-out and online processing

Target interaction rates x2 in Pb-Pb and x50 in pp (24 MHz)
→ data throughput will be dominated by pp

→ Online compression scheme of Run 3 and 4 in Run 5 → leveraging technological speedup to handle higher pp rates

R&D activities

Silicon pixel sensors

- thinning and bending of silicon sensors
  - expand on experience with ITS3
- exploration of new CMOS processes
  - first in-beam tests with 65 nm process
- modularisation and industrialisation

Silicon timing sensors

- characterisation of SPADs/SiPMs
  - first tests in beam
- monolithic timing sensors
  - implement gain layer

Photon sensors

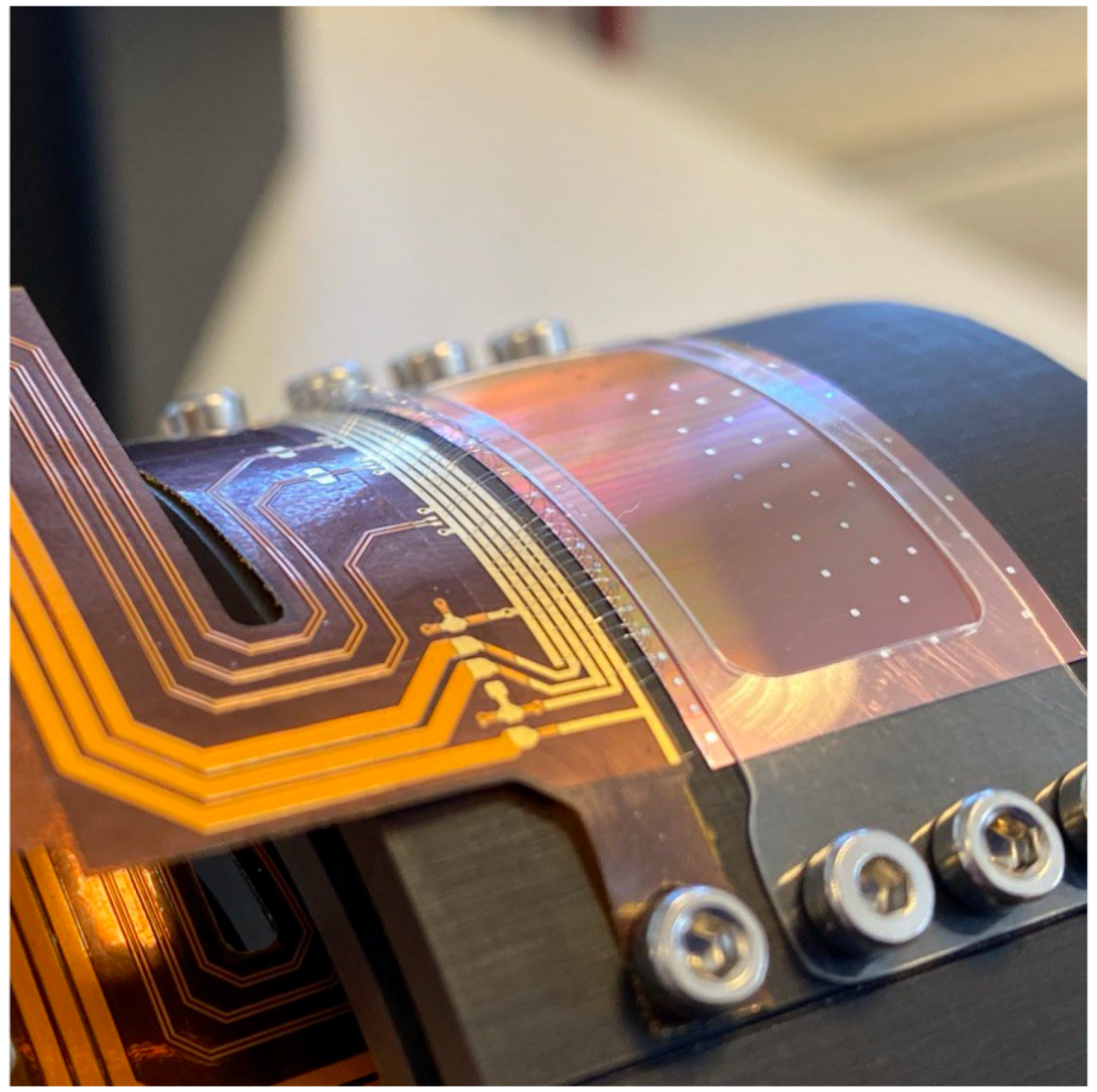
- monolithic SiPMs
  - integrate read-out

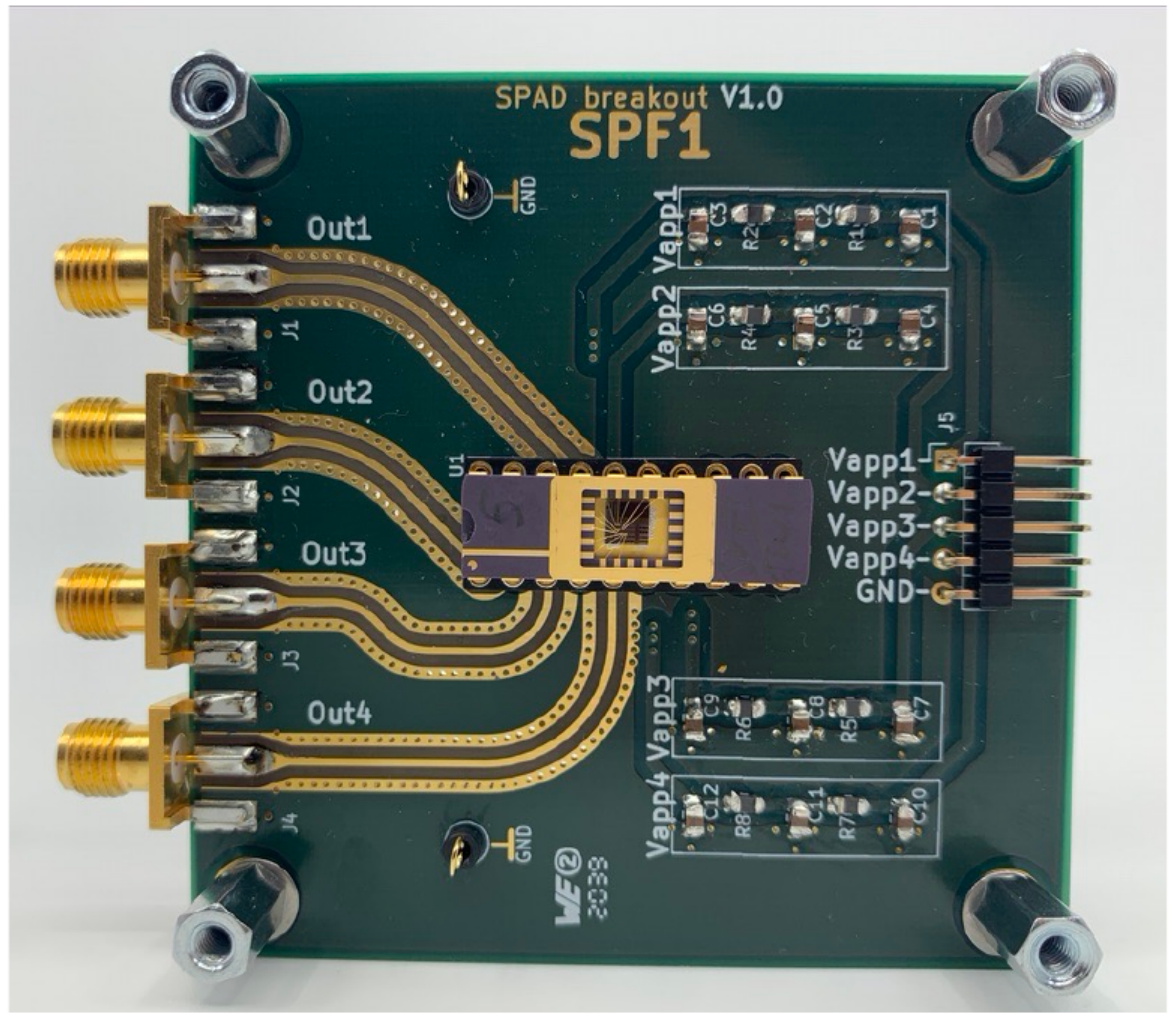
Detector mechanics and cooling

- mechanics for operation in beam pipe
  - compatibility with vacuum and beam impedance
- minimisation of material in the active volume
  - micro-channel cooling

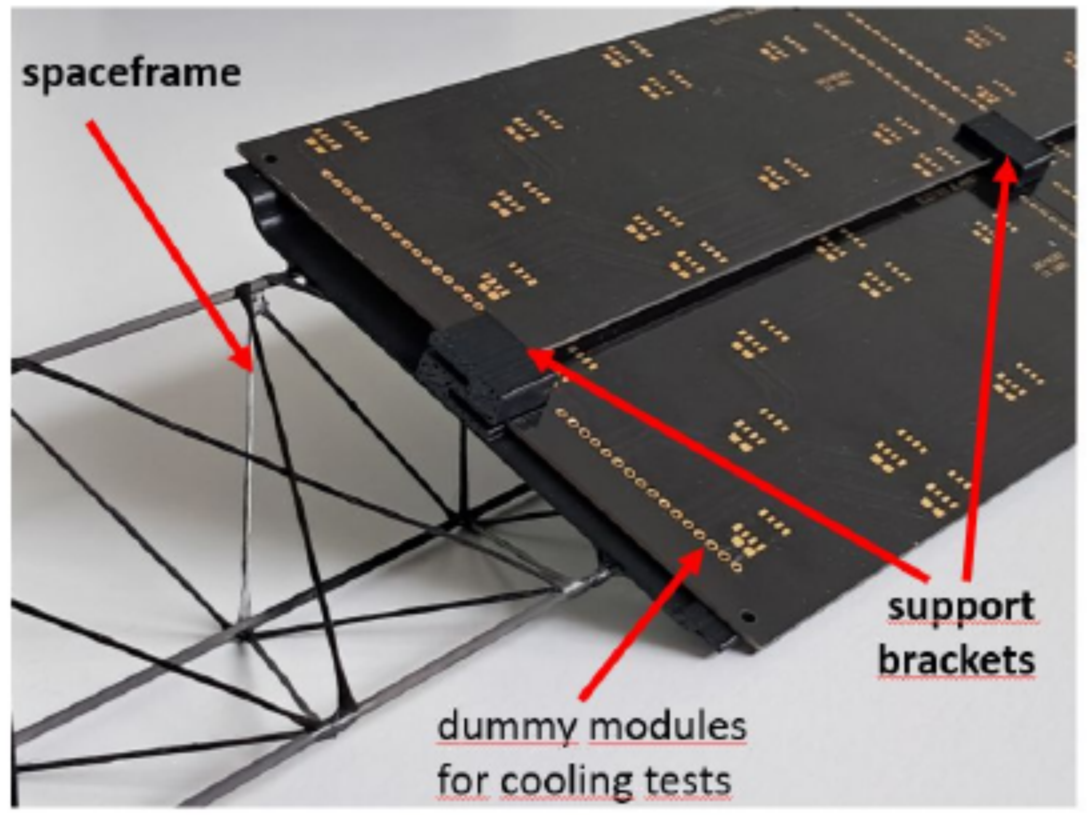
Unique and relevant technologies
→ Synergies with LHC, FAIR, EIC, ...

R&D has already started!





Outer Tracker R&D



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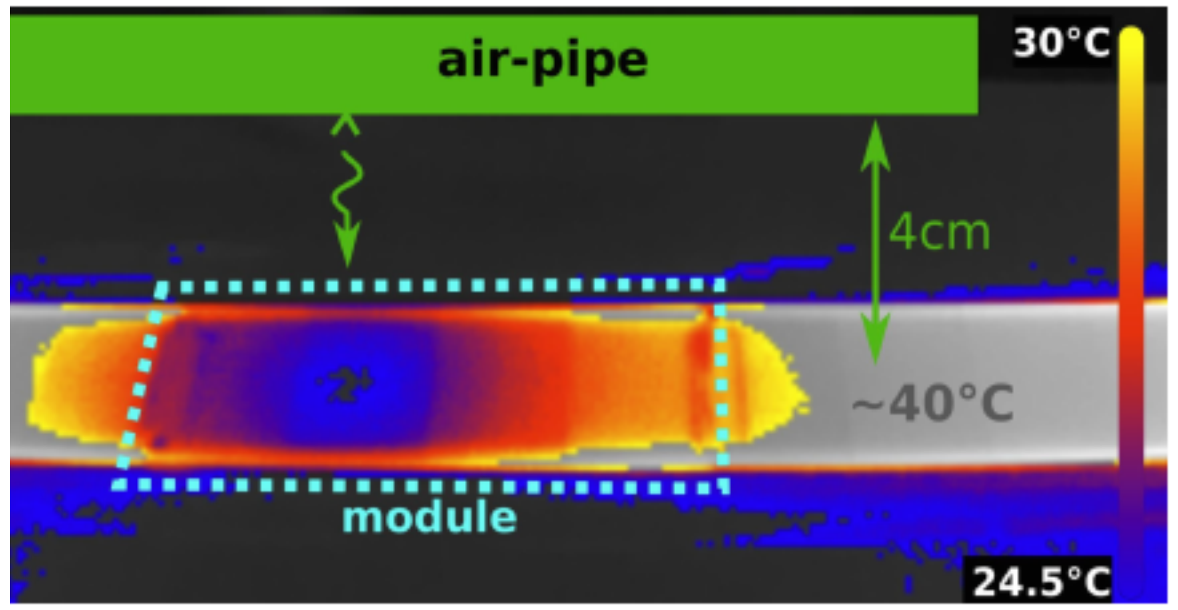
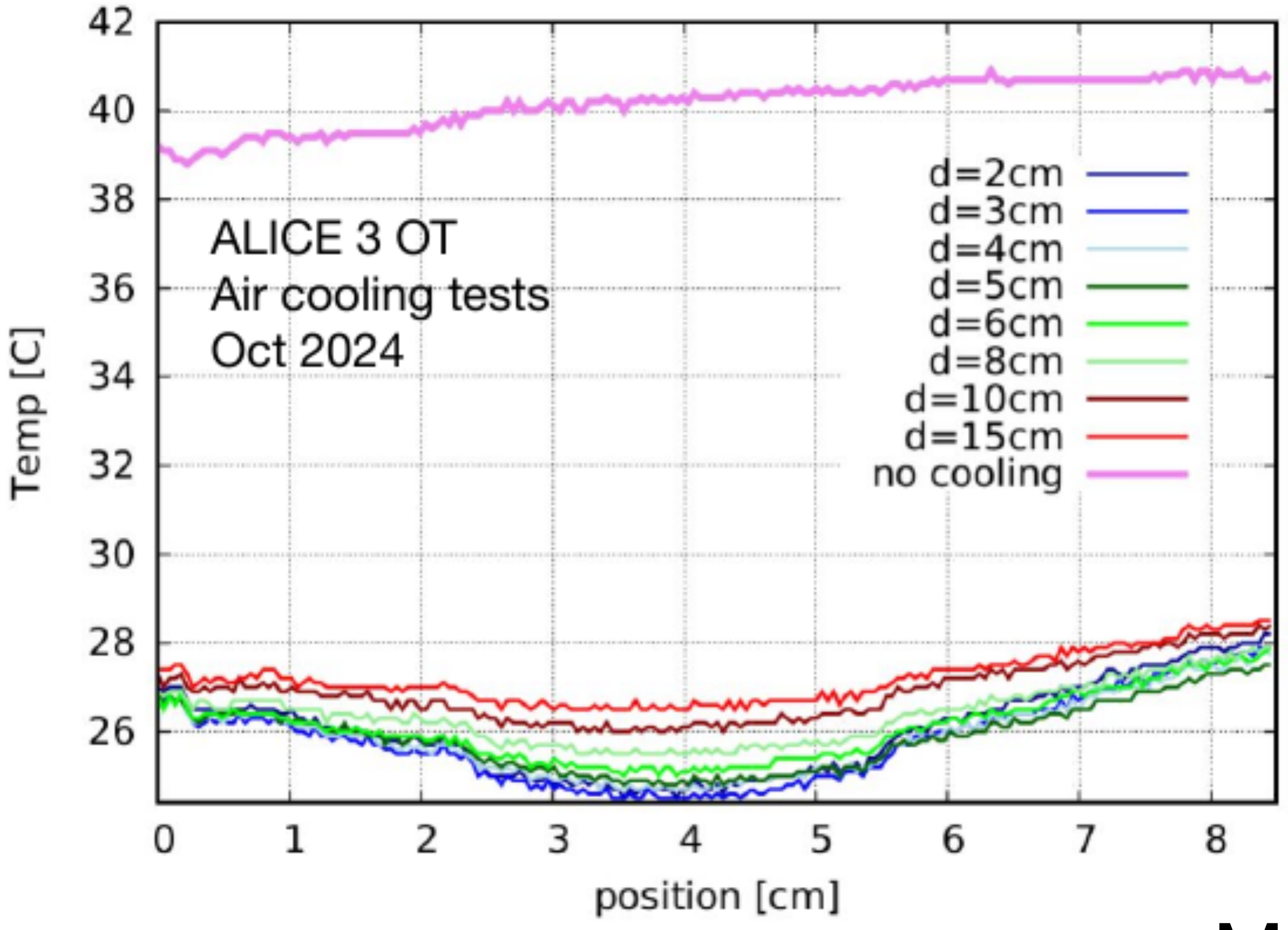


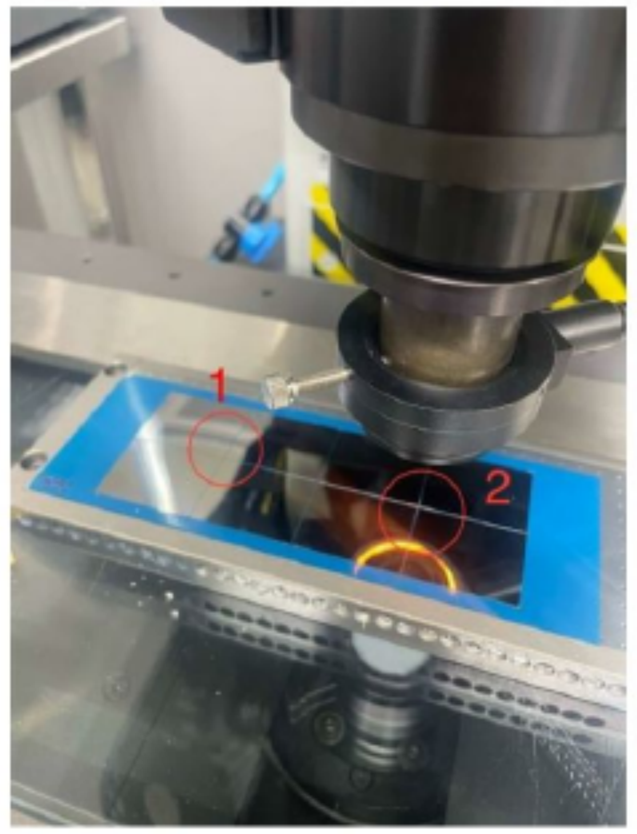
Endcap disks:

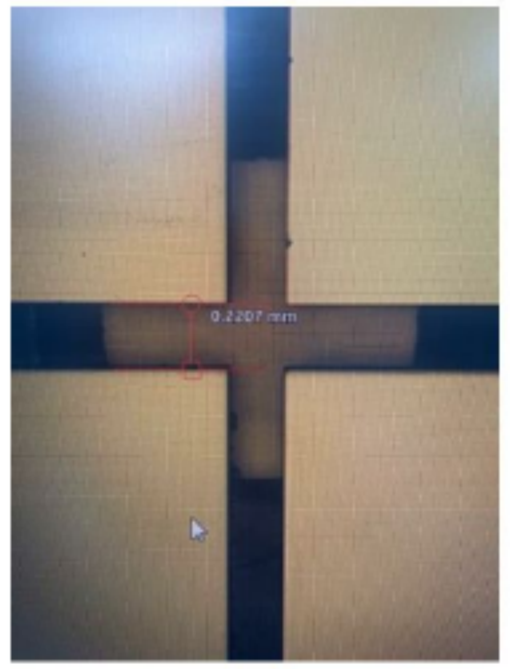
- double-sided layout of sensor modules
- material budget estimates

Barrel design:

- full-scale stave model
- mechanical support studies
- air cooling studies



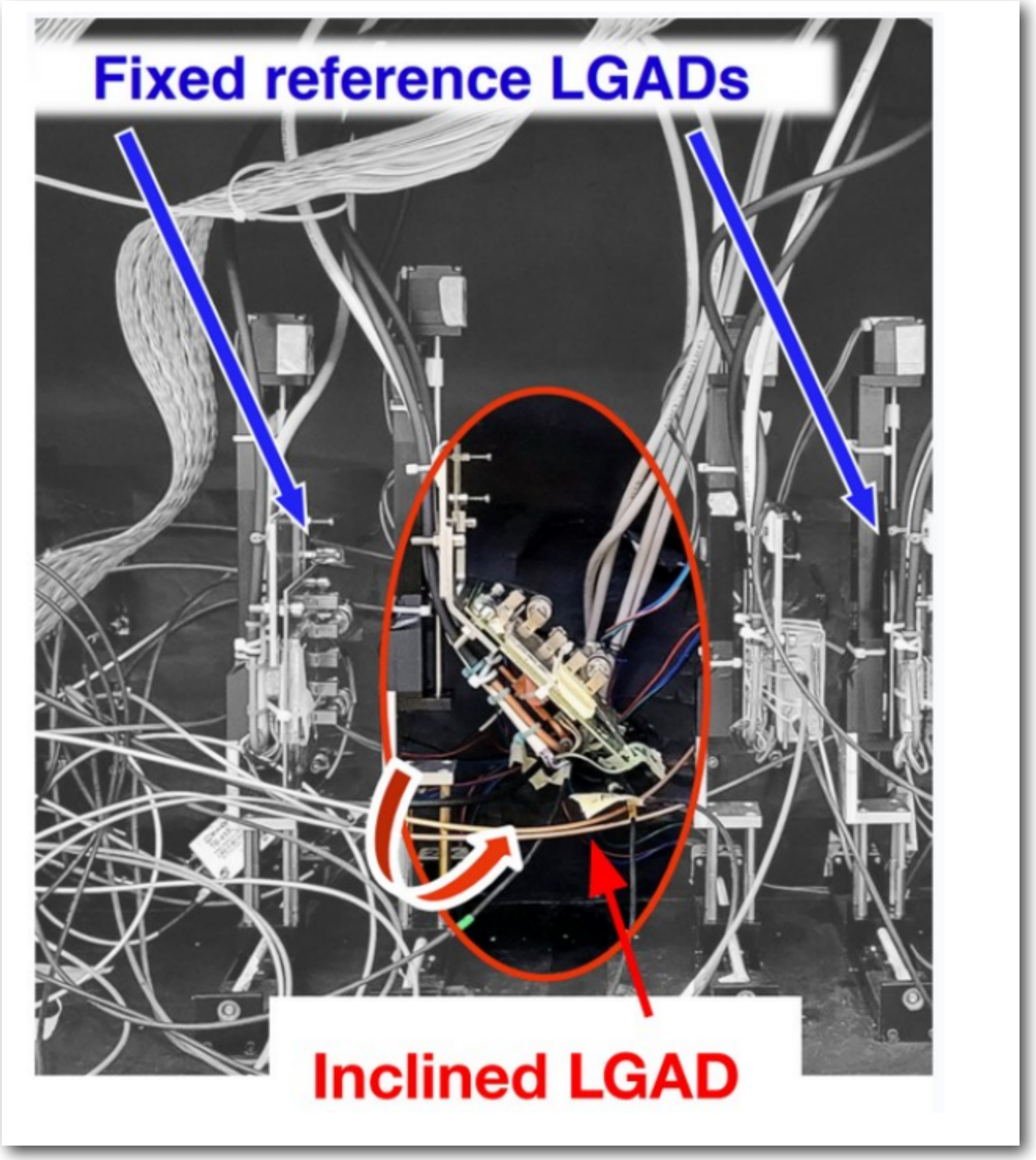


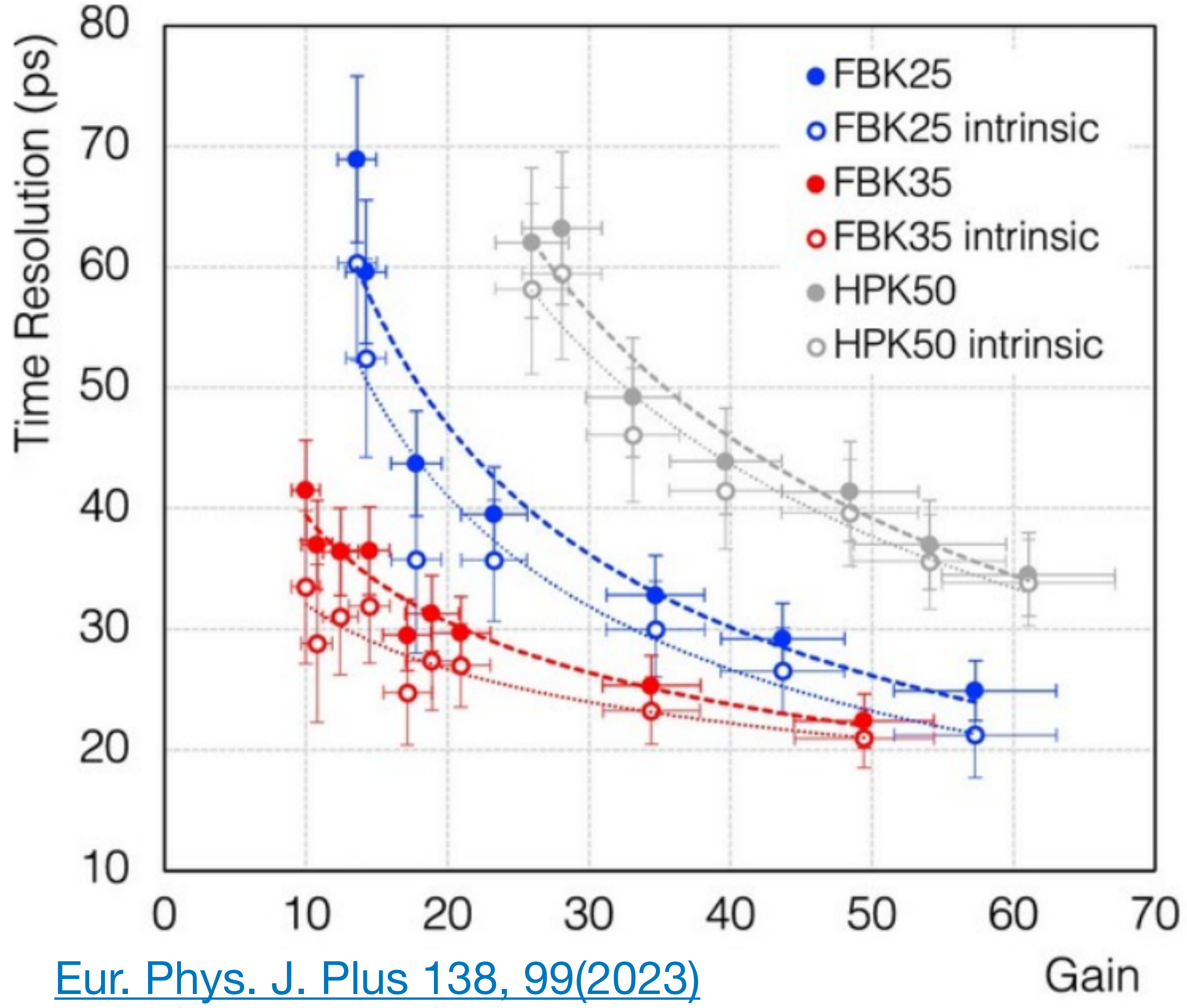


Module assembly in external companies:

- customization of die-bonder machine
- studies for sensor gluing and interconnections

TOF R&D





Eur. Phys. J. Plus 138, 99(2023)

Target time resolution: 20 ps

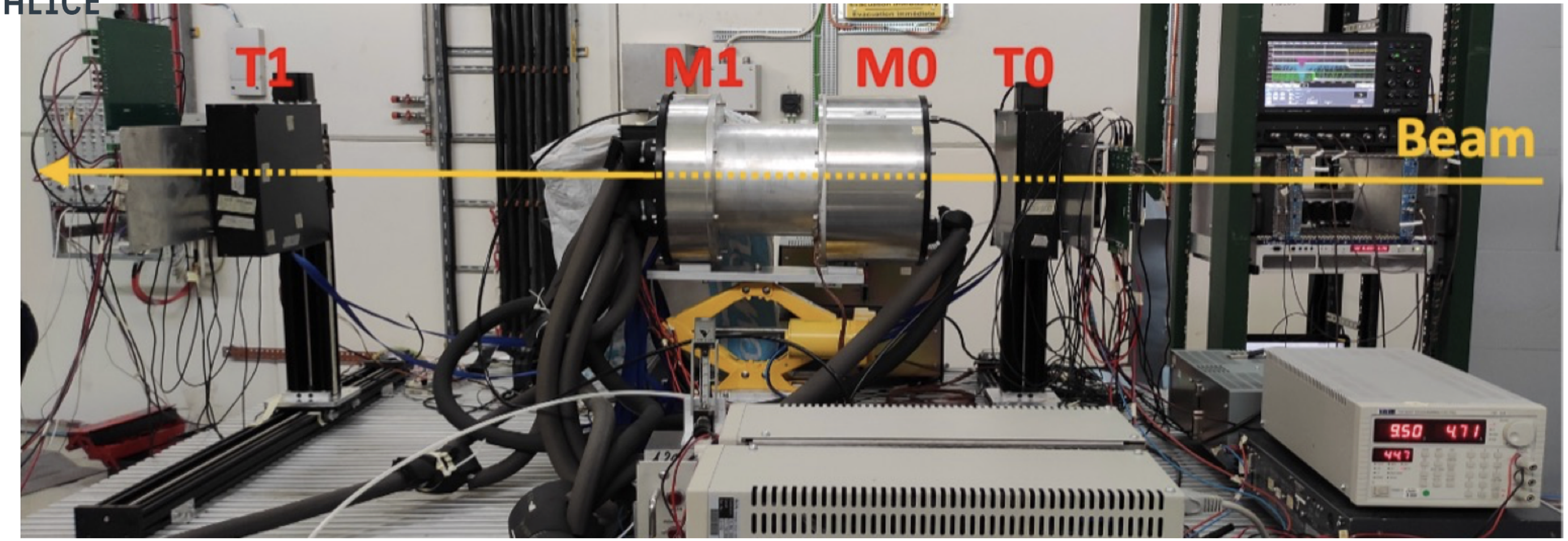
Several testbeams since 2022 (last October 2024)

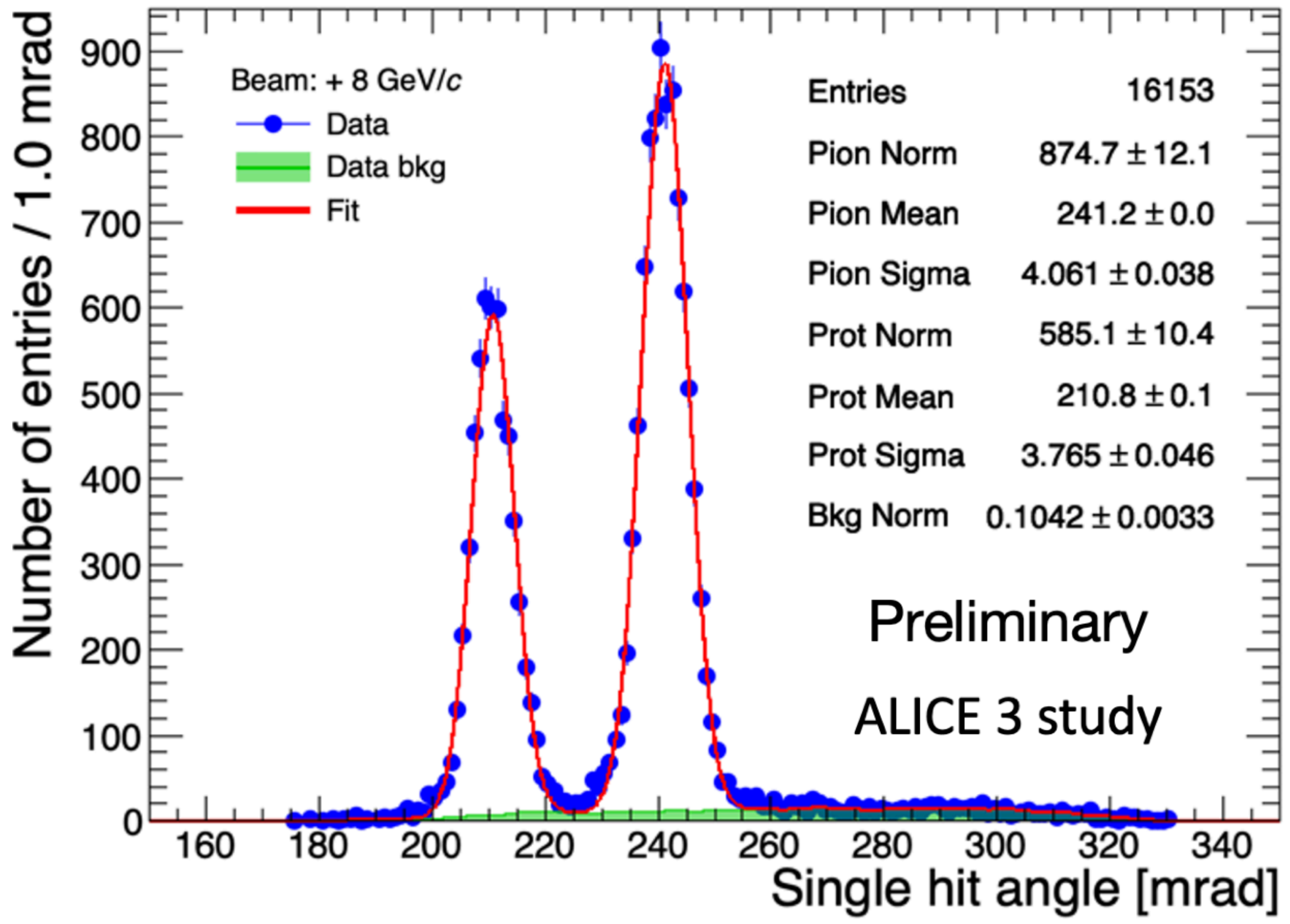
Various sensor options:

- SiPM coated with different resins (type, thickness)
- Single and double LGADs 20 μm, 25 μm, 35 μm thick
- 50 μm thick CMOS-LGAD (ARCADIA MAPS with gain layer) and with integrated FEE (MADPIX)

Target resolution achieved on individual sensor with SiPM and CMOS

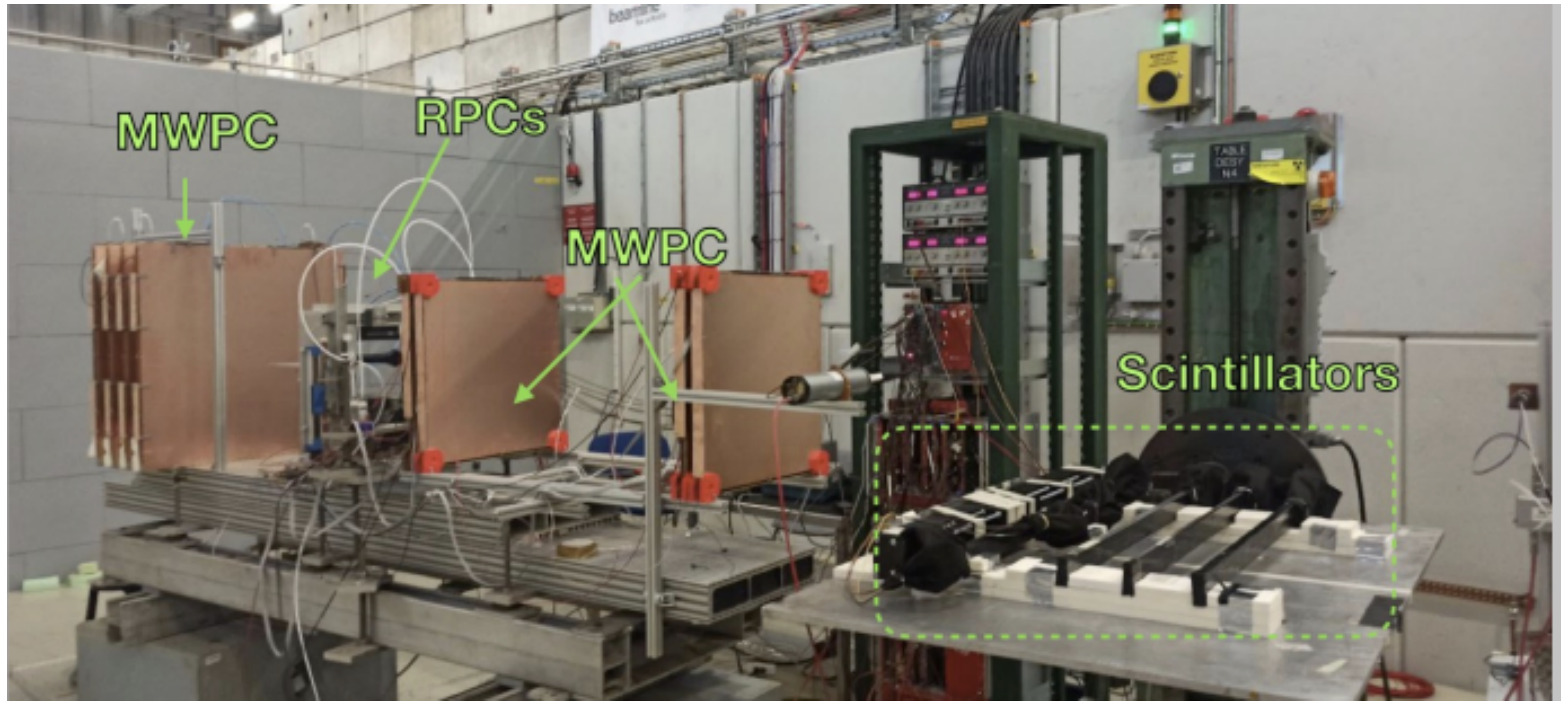
RICH R&D

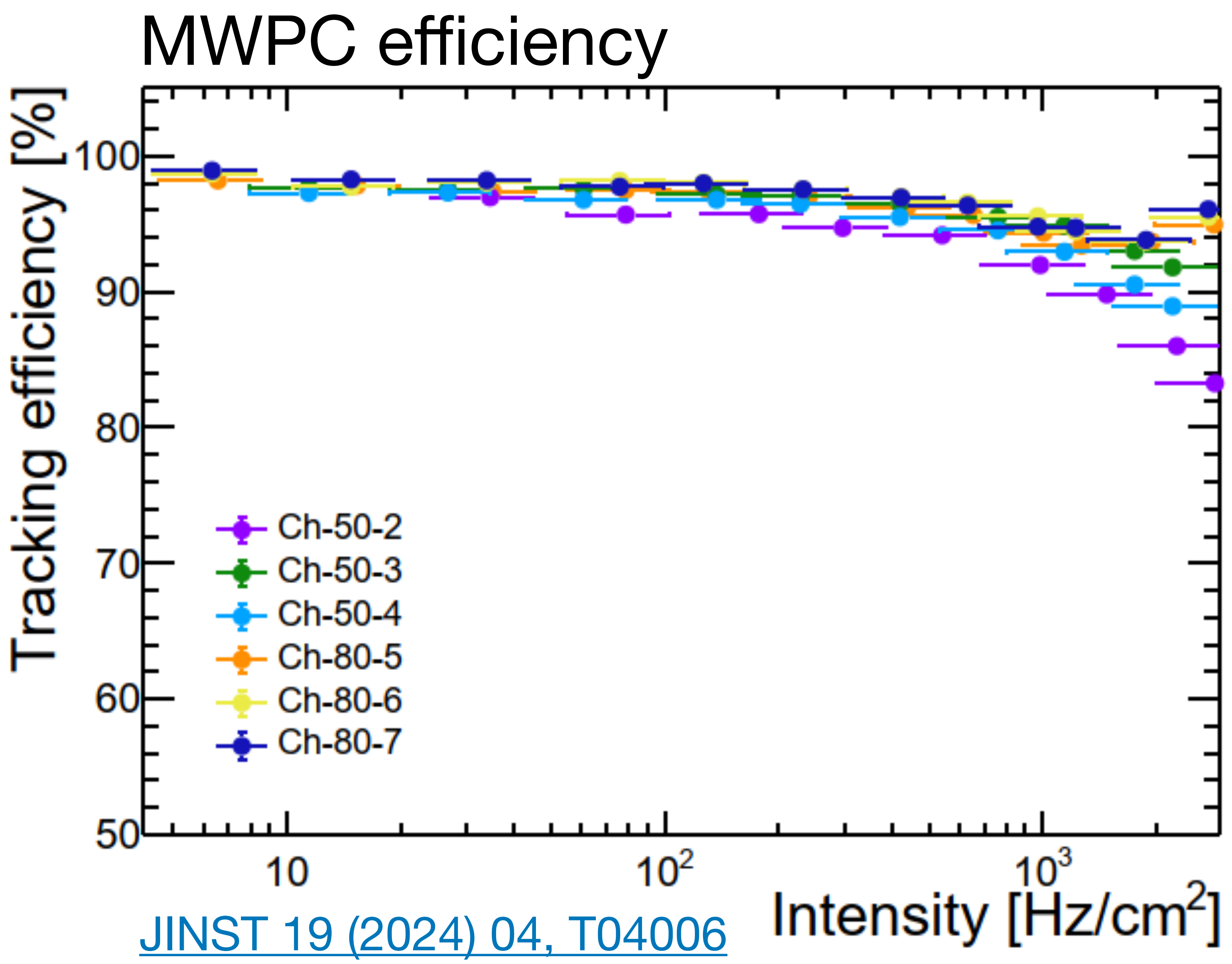




Target single-photon angle resolution: 6 mrad
Testbeam in October 2023 at CERN PS
Aerogel radiator by Aerogel Factory LTD (Japan)
8x8 SiPM matrices from HPK and FBK, various pixel sizes
Different radiator windows coupled to SiPM to test TOF+RICH integrated concept

MID R&D





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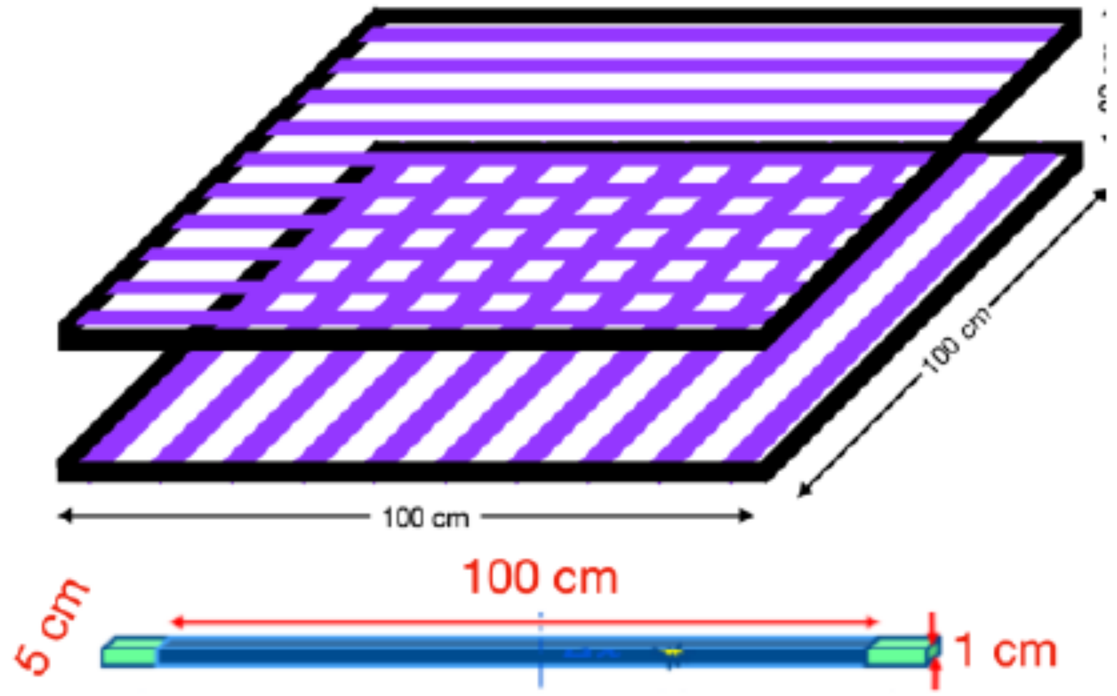
Test beam in July 2023 at CERN PS



Considered technologies:

- Plastic scintillators (FNAL-NICADD, ELJEN EJ208, Protvino) + SiPM
- Multiwire proportional chambers (8 mm, 12 mm pitch)
- Resistive plate chambers

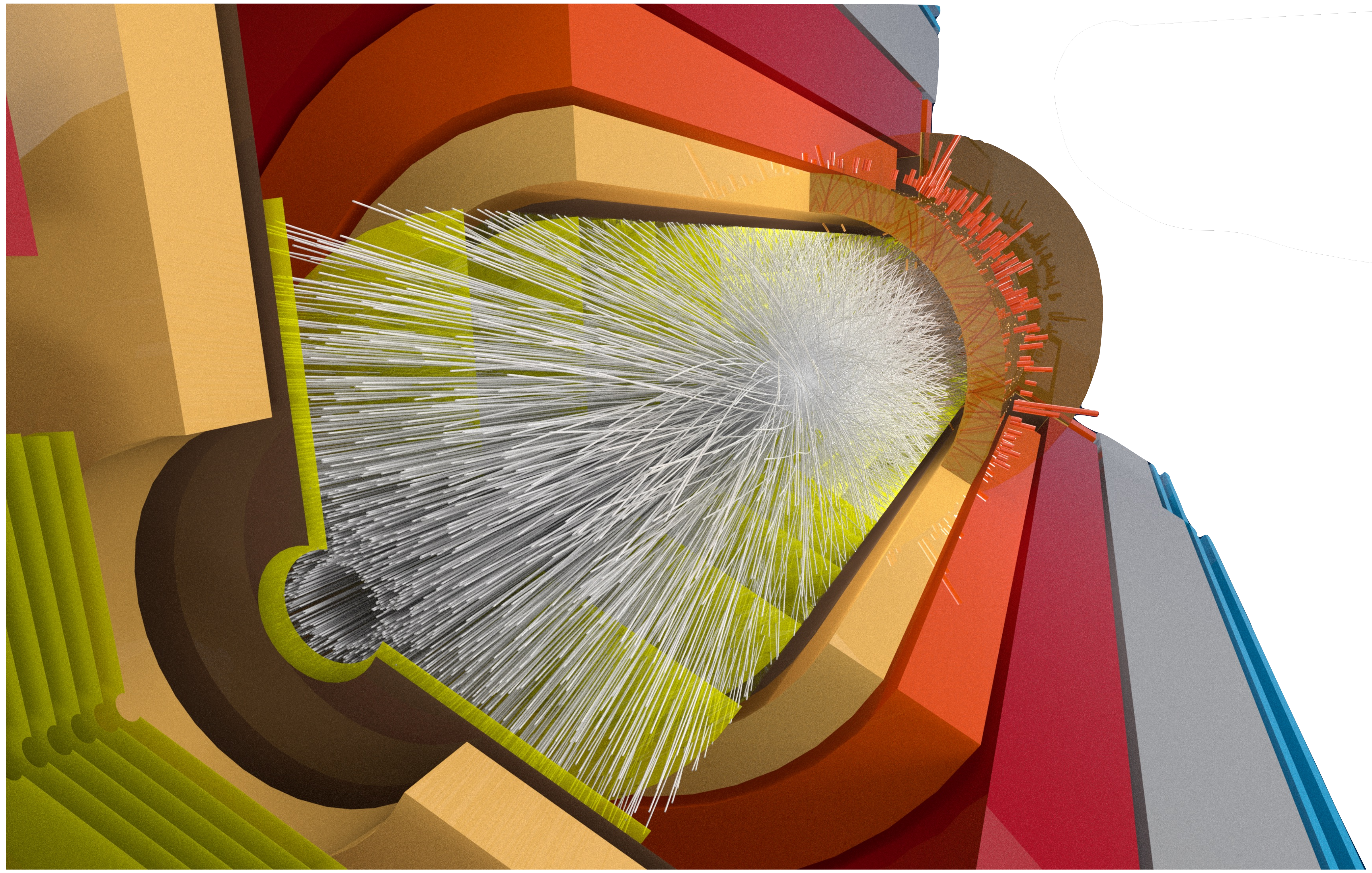
Summary and conclusions

ALICE 3 will unravel the QGP dynamics

- Evolution of thermal properties of the QGP
- Chiral symmetry restoration
- Hadronisation and nature of hadronic states
- Exotic states and charmed nuclei

Innovative detector concept

- focusing on **silicon technology**
- building on experience pioneered in ALICE upgrades
- requiring R&D activities in several strategic areas
- **R&D already started!**



6 years of running with ALICE 3

Heavy ions: 1 month/year

35 nb^{-1} for Pb-Pb

Under study:

→ lighter species for higher luminosity

pp at $\sqrt{s}$ = 14 TeV:

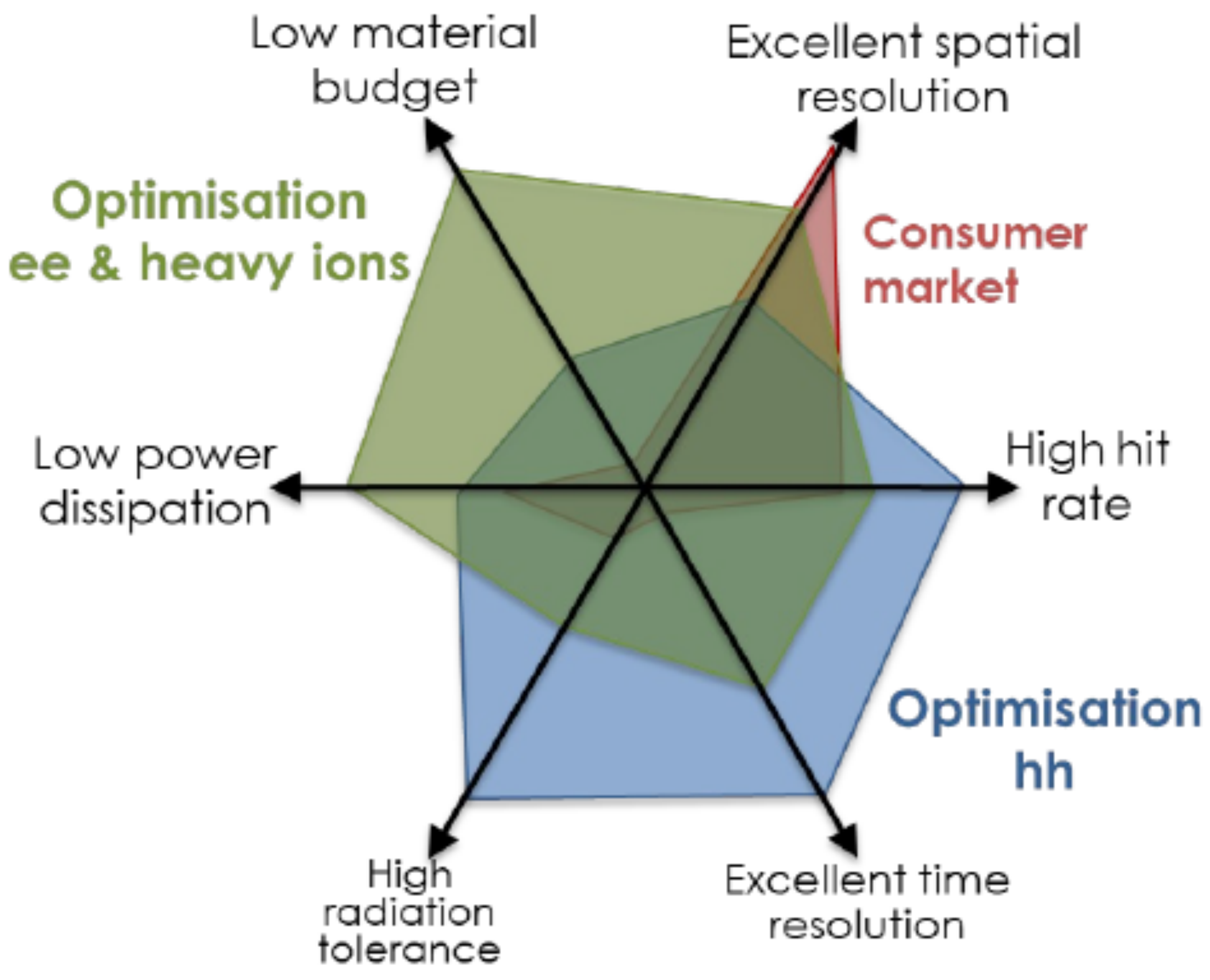
3 fb^{-1} / year → $\times\, 100$ compared to Run 3+4

More reasons

A. Conclusion 1 out of 4 (*2021 ECFA roadmap*) :

"Develop cost-effective detectors matching the precision physics potential of a next-decade Higgs factory with beyond state-of-the-art performance, optimised granularity, resolution and timing, and with ultimate compactness and minimised material budgets"

B. Overlap of specifications : eA, pA, AA // e^+e^- !



Courtesy J. Baudot

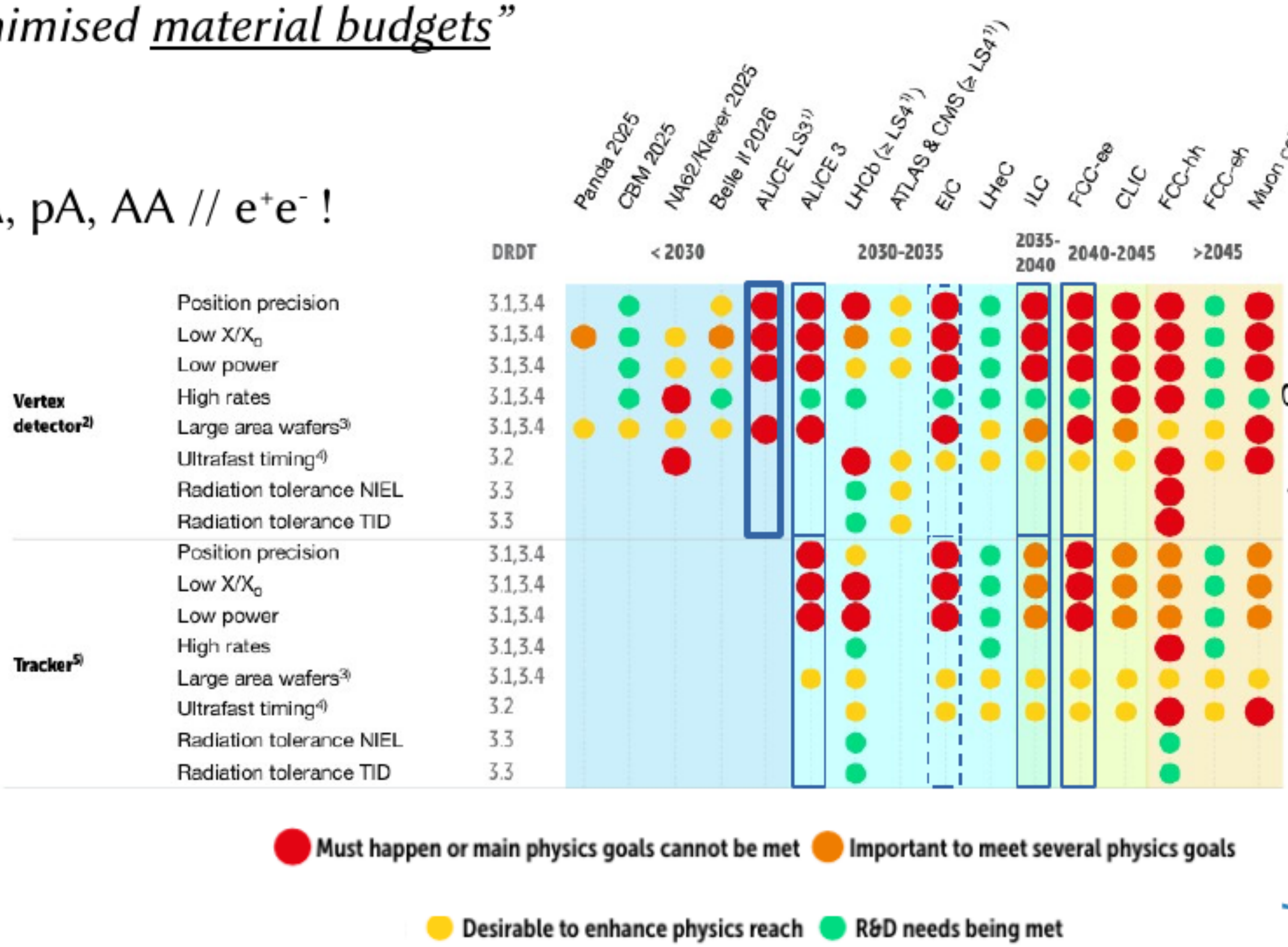


Fig. 3.1, 2021 ECFA roadmap

19 / 21

Antonin MAIRE (IPHC) / Perspectives in HENuclP

Thank you

Observables and requirements

Goal observables

Dileptons (p_T~0.1- 3 GeV/c, M_{ee} ~0.1-4 GeV/c^2)

- vertexing, tracking, lepton ID

Photons (100 MeV/c - 50 GeV/c, wide η range)

- electromagnetic calorimetry

Heavy-flavour hadrons ($p_T \to 0$, wide η range)

- vertexing, tracking, hadron ID

Quarkonia and Exotica ($p_T \to 0$)

- muon ID

Jets

- tracking and calorimetry, hadron ID

Ultrasoft photons (p_T = 1 - 50 MeV/c)

- dedicated forward detector

Nuclei and exotica

- identification of z > 1 particles

Key requirements

- Good tracking down to $p_T = 0$
- Low-mass detector
- Excellent pointing resolution
- Excellent particle identication
- Large acceptance
- High rates, large data samples

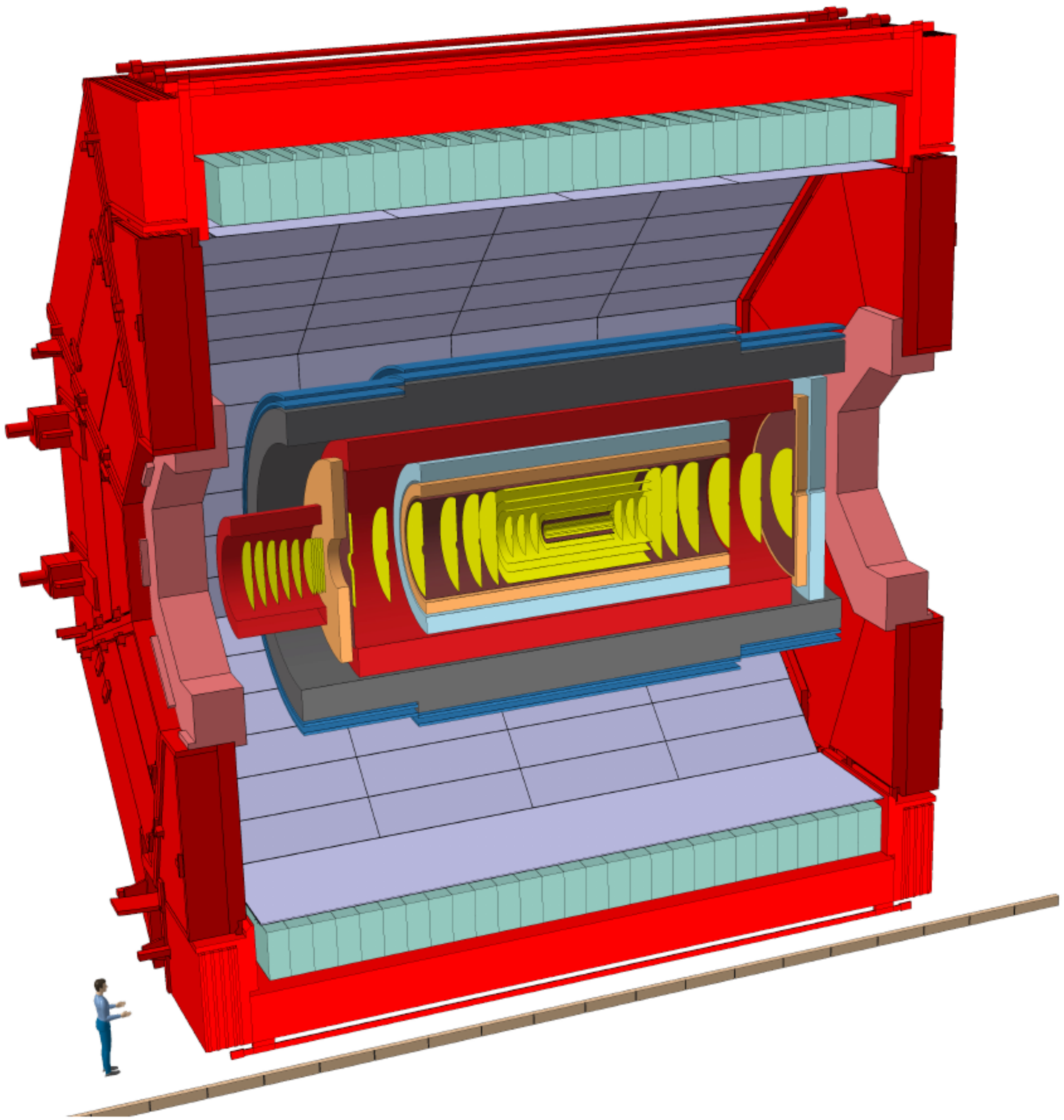
Performance summary

Component	Observables	$\lvert\eta\rvert$ < 1.75 (barrel)	1.75 < $\lvert\eta\rvert$ < 4 (forward)	Detectors
Vertexing	Multi-charm baryons, dielectrons	Best possible DCA resolution, $\sigma_{DCA} \approx$ 10 μm at 200 MeV/c	Best possible DCA resolution, $\sigma_{DCA} \approx$ 30 μm at 200 MeV/c	Retractable silicon pixel tracker: $\sigma_{pos} \approx$ 2.5 μm, $R_{in} \approx$ 5 mm, $X/X_0 \approx$ 0.1 % for first layer
Tracking	Multi-charm baryons, dielectrons	σ_{p_T} / p_T ~1-2 %		Silicon pixel tracker: $\sigma_{pos} \approx$ 10 μm, $R_{out} \approx$ 80 cm, $X/X_0 \approx$ 1 % / layer
Hadron ID	Multi-charm baryons	π/K/p separation up to a few GeV/c		Time of flight: $\sigma_{tof} \approx$ 20 ps RICH: aerogel, $\sigma_\theta \approx$ 1.5 mrad
Electron ID	Dielectrons, quarkonia, χ_{c1}(3872)	pion rejection by 1000x up to ~2 - 3 GeV/c		Time of flight: $\sigma_{tof} \approx$ 20 ps RICH: aerogel, $\sigma_\theta \approx$ 1.5 mrad possibly preshower detector
Muon ID	Quarkonia, χ_{c1}(3872)	reconstruction of J/Ψ at rest, i.e. muons from 1.5 GeV/c		steel absorber: L ≈ 70 cm muon detectors
Electromagnetic calorimetry	Photons, jets	large acceptance		Pb-Sci calorimeter
	χ_c	high-resolution segment		$PbWO_4$ calorimeter
Ultrasoft photon detection	Ultra-soft photons		measurement of photons in p_T range 1 - 50 MeV/c	Forward Conversion Tracker based on silicon pixel sensors

Installation at LHC

Installation of ALICE 3 around nominal IP2

L3 magnet can remain, ALICE 3 to be installed inside
Cryostat of ~8 m length, free bore radius 1.5 m, magnetic field configuration to be optimized



Running scenario:

6 running years with 1 month / year with heavy-ions

- 35 nb^{-1} for Pb—Pb x 2.5 compared to Run 3 + 4
- Lighter species for higher luminosity under study

pp at s = 14 TeV:

- 3 fb^{-1} / year x 100 compared to Run 3 + 4