SQM2022

The 20th International Conference on Strangeness in Quark Matter
13-17 June 2022 Busan, Republic of Korea

Physics program of the ALICE 3 experiment for the LHC Runs 5 and 6

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ALICE 3

ALICE timeline

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

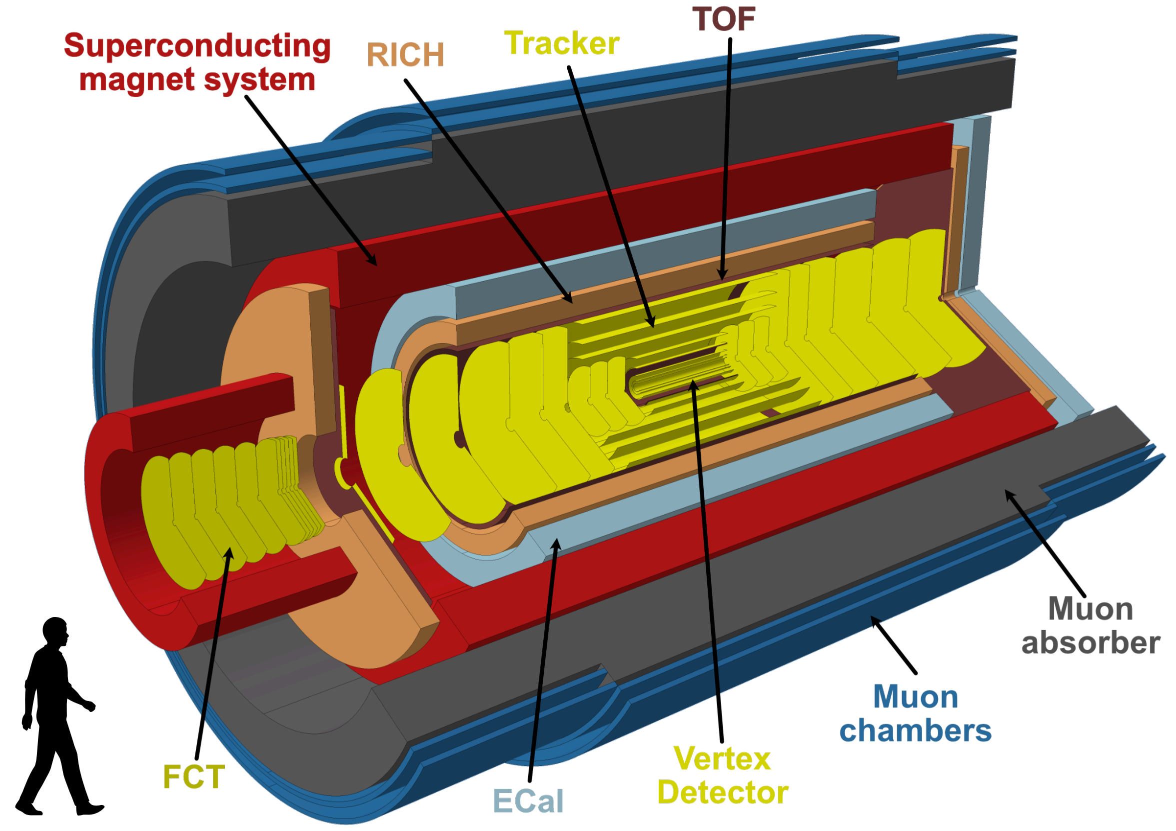
Run 1 2009 - 2013	Run 2 2015 - 2018	Run 3 2022 - 2025	Run 4 2029 - 2032	Run 5	Run 6
ALICE 1		ALICE 2	ALICE 2.1 upgrade	ALICE 3 upgrade	

European Particle Physics Strategy Update recommends **full exploitation of the LHC, incl. heavy-ion programme**

Run 3 & 4 (covered by previous talk Sarah Porteboeuf)

Beyond Run 4 (this talk):

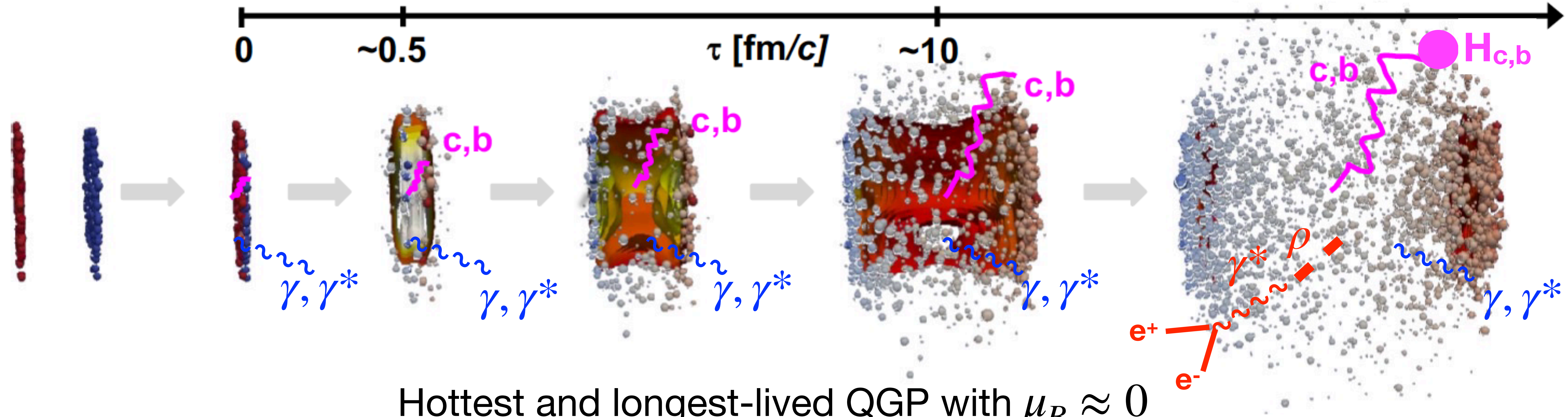
- Address fundamental questions still open:
  - → First ideas at Heavy-Ion town meeting 2018 D.Adamova et al. ArXiv:1902.01211
  - → Letter of Intent for **ALICE 3:** Review concluded with very positive feedback by the LHCC in March 2022 ALICE CERN-LHCC-2022-009



Intermediate upgrade | Major upgrade

Heavy-ion physics at the LHC

https://doi.org/10.1007/978-3-030-71427-7_8



Hottest and longest-lived QGP with $\mu_B \approx 0$

Run 3 + 4 will allow comprehensive measurements of:

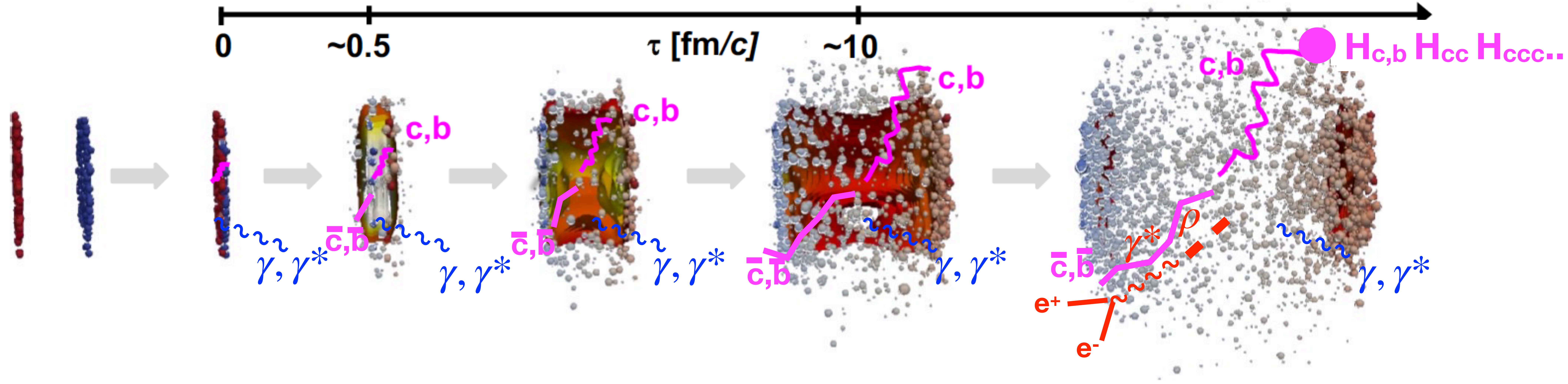
- Medium effects and hydrochemistry of single heavy-flavour (mostly charm)
- Time-averaged thermal QGP radiation
- Patterns indicative of chiral symmetry restoration
- Collectivity from small to large systems

→ **Understanding of QGP still incomplete**

Plenary talk by Sarah Porteboeuf

Heavy-ion physics at the LHC

https://doi.org/10.1007/978-3-030-71427-7_8



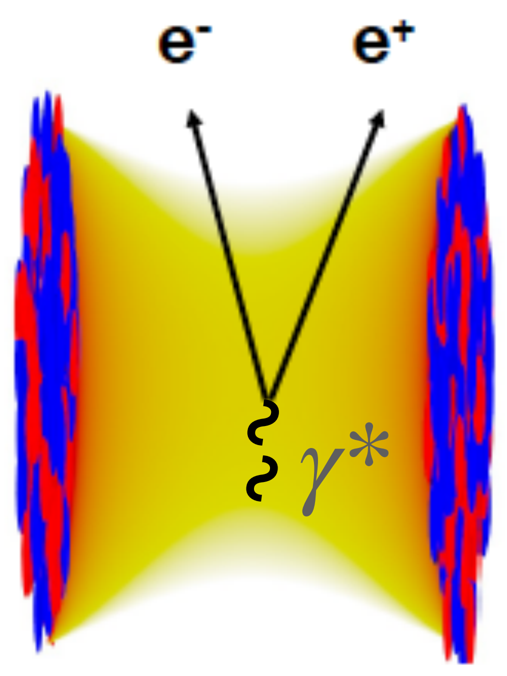
Fundamental questions will remain open:

- Fundamental QGP properties driving its constituents to equilibration
- Hadronisation mechanisms of the QGP
- Partonic equation of state and its temperature dependence
- Underlying dynamics of chiral symmetry restoration

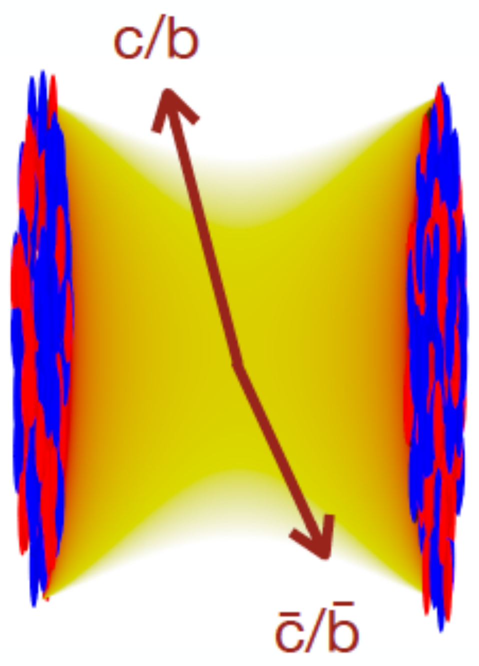
Physics beyond Run 4

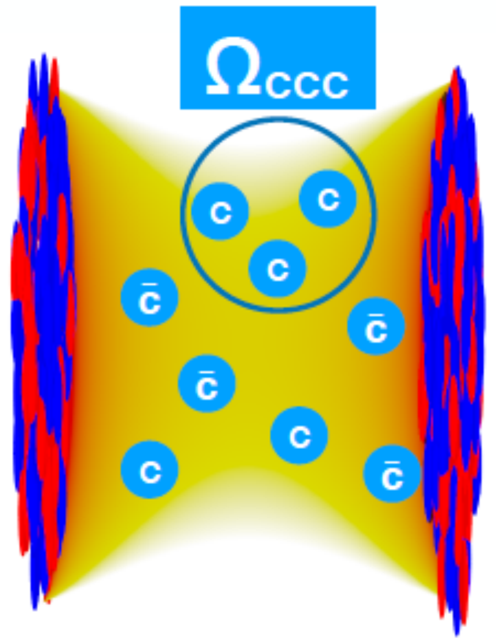
Relies on:

- **Precision differential measurements of dileptons**
  - Evolution of the quark-gluon plasma
  - Mechanisms of chiral symmetry restoration



- **Systematic measurements of (multi-)heavy-flavoured hadrons down to low p_T**
  - Transport properties in the QGP down to thermal scale
  - Mechanisms of hadronisation from the QGP

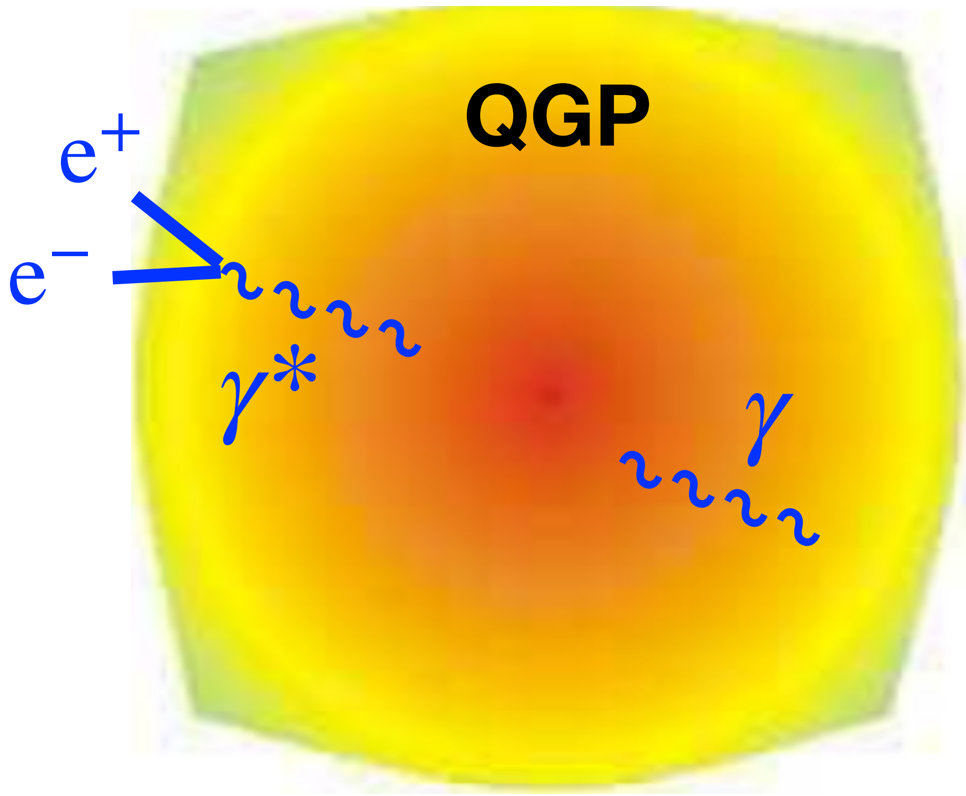




- **Hadron interaction and fluctuation measurements**
  - Existence and nature of heavy-quark exotic bound states
  - Search for super-nuclei (light nuclei with c)
  - Search for critical behaviour in event-by-event fluctuations of conserved charges

Qualitative steps needed in detector performance and statistics
→ next-generation heavy-ion experiment

Electromagnetic radiation

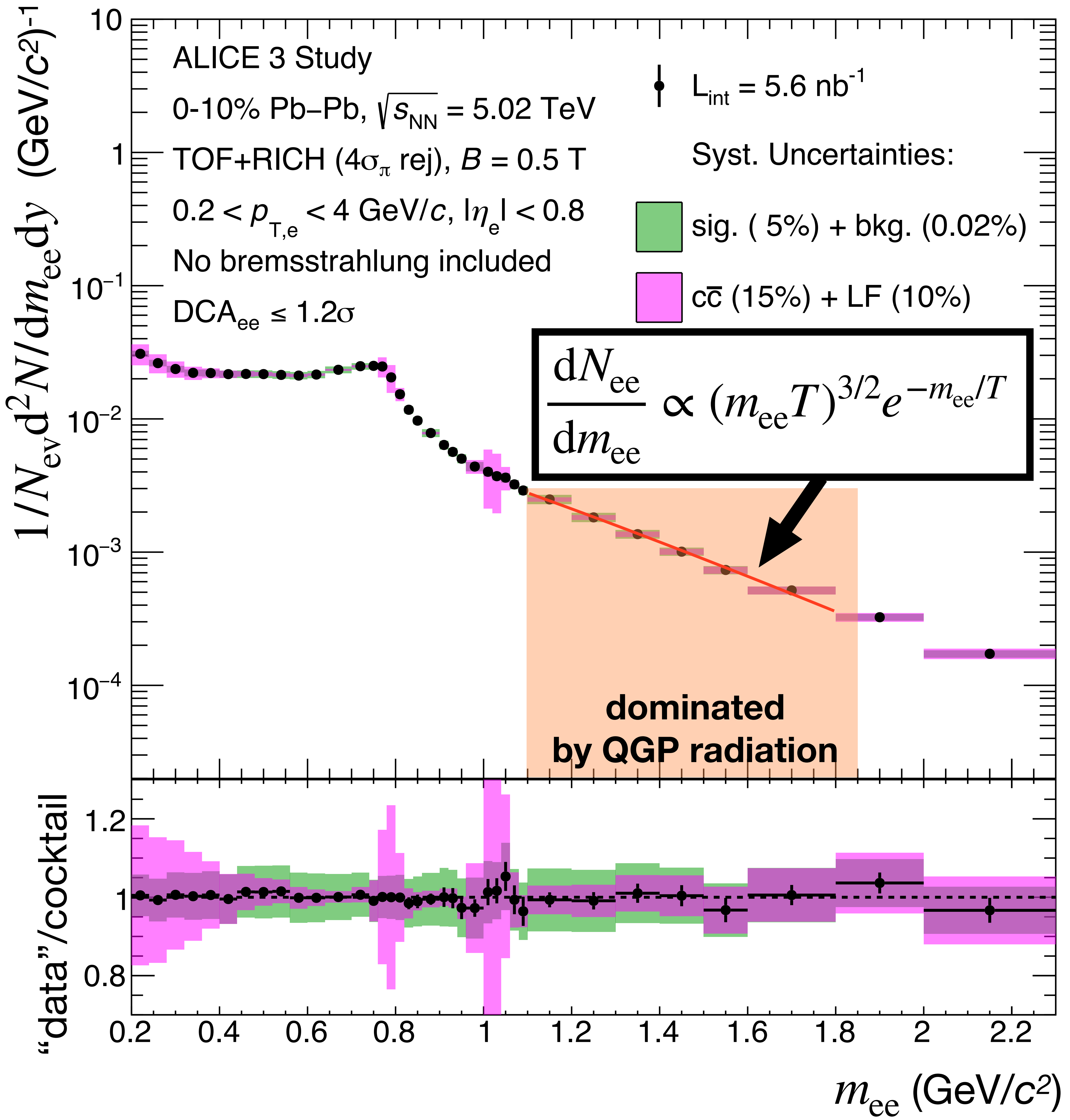


Averaged temperature T of the QGP using thermal dielectron m_{ee} spectrum at $m_{ee} > 1.1$ GeV/c^2

Need:

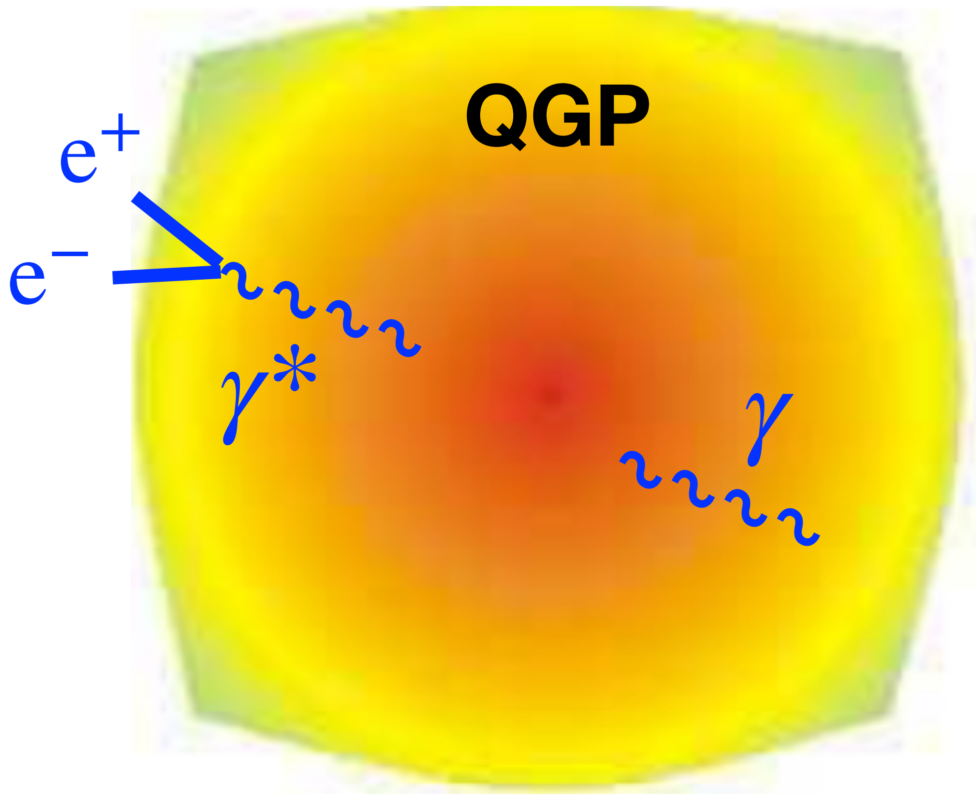
- Very good electron identification down to low p_T
- Small detector material budget (γ conversion background)
- Excellent pointing resolution (heavy-flavour decay background)

Projection for thermal dielectron m_{ee}
ALICE 3, one month Pb—Pb



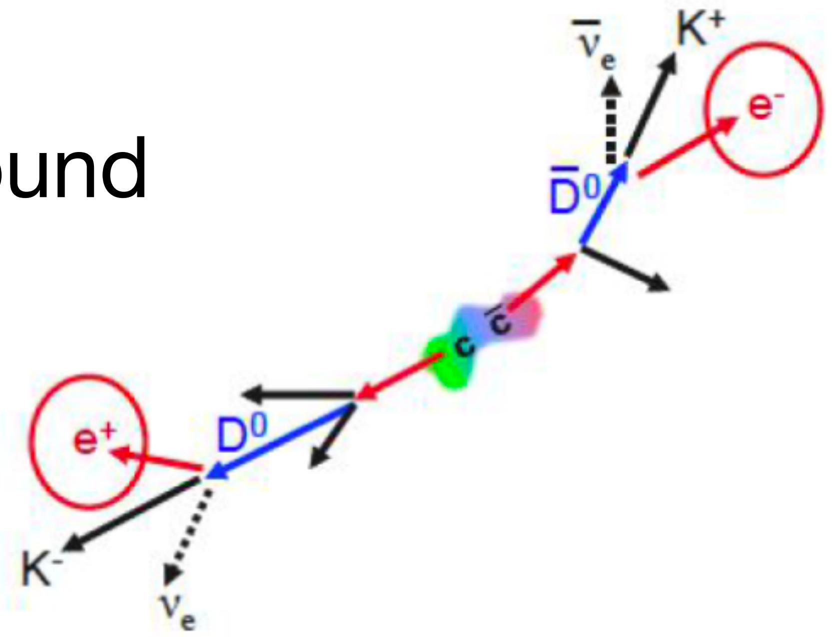
R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253
P.M Hohler and R. Rapp, Phys. Lett. B 731 (2014) 103
ALICE CERN-LHCC-2022-009

Electromagnetic radiation

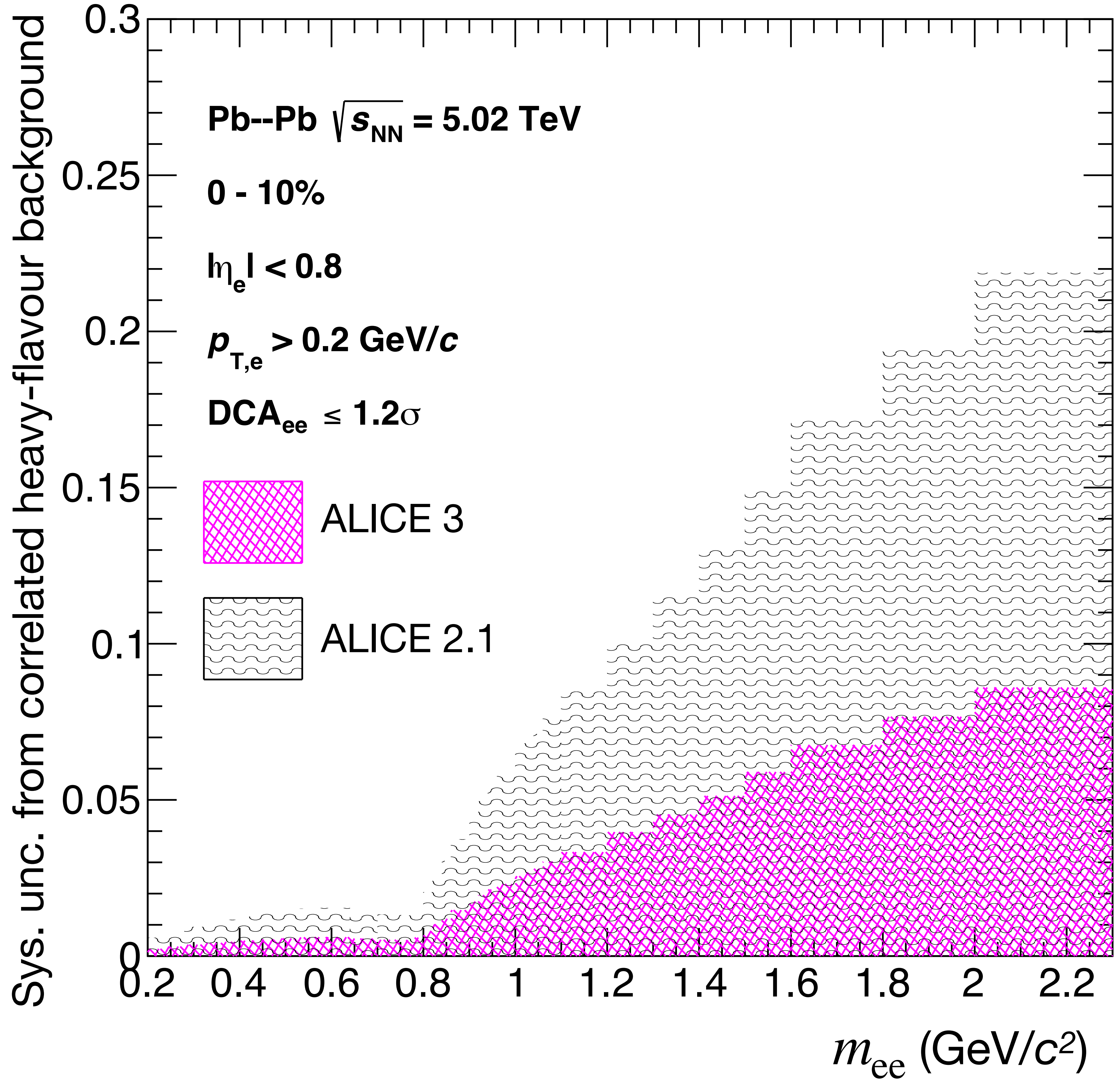


Averaged temperature T of the QGP using thermal dielectron m_{ee} spectrum at $m_{\mathrm{ee}} > 1.1$ GeV/c^2

- Heavy-flavour decays produce correlated background
- Large for $m_{ee} \gtrsim 1\,\mathrm{GeV}/c^2$
- **Can be effectively suppressed with ALICE 3**
  Thanks to excellent pointing resolution



Relative systematic uncertainties
from correlated heavy-flavour background



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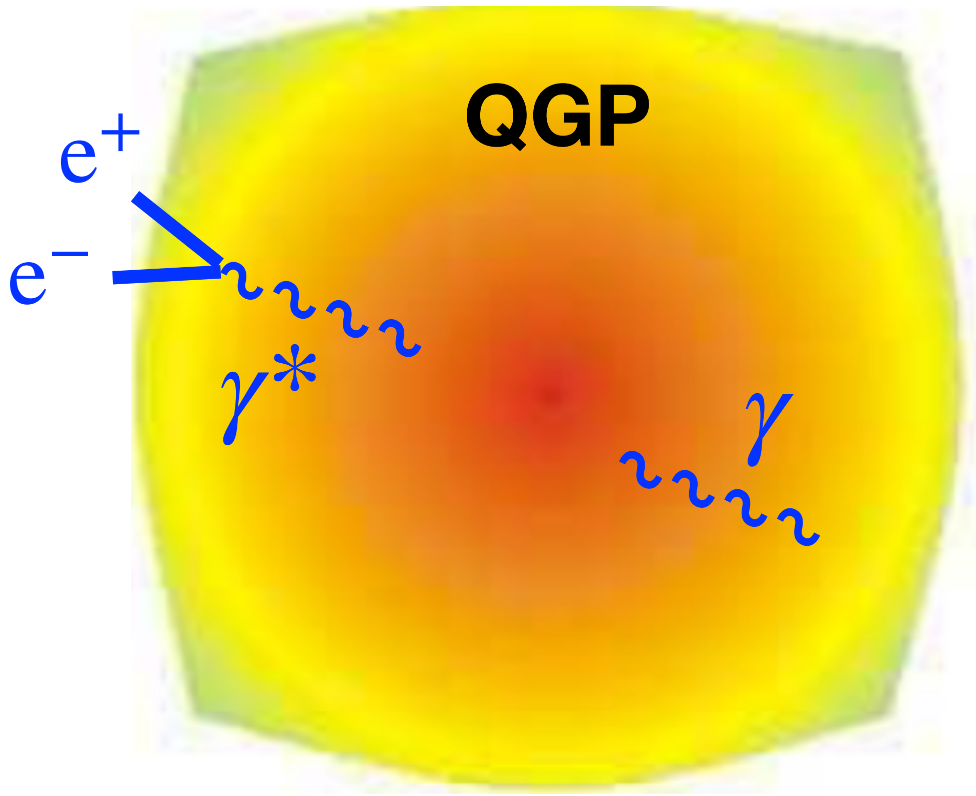
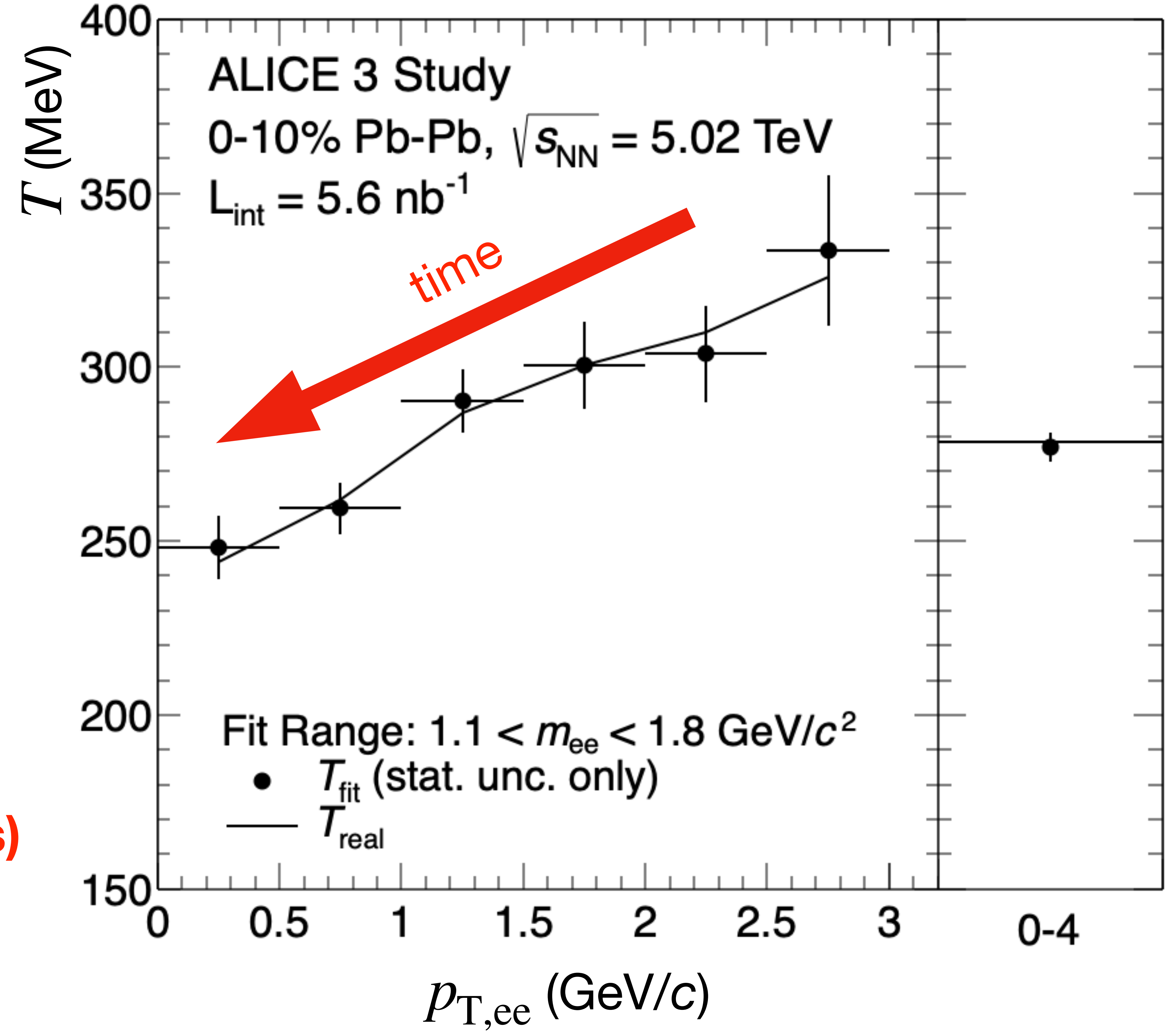
Electromagnetic radiation



Expected statistical errors of T as a function of $p_{T,ee}$
ALICE 3, one month Pb—Pb



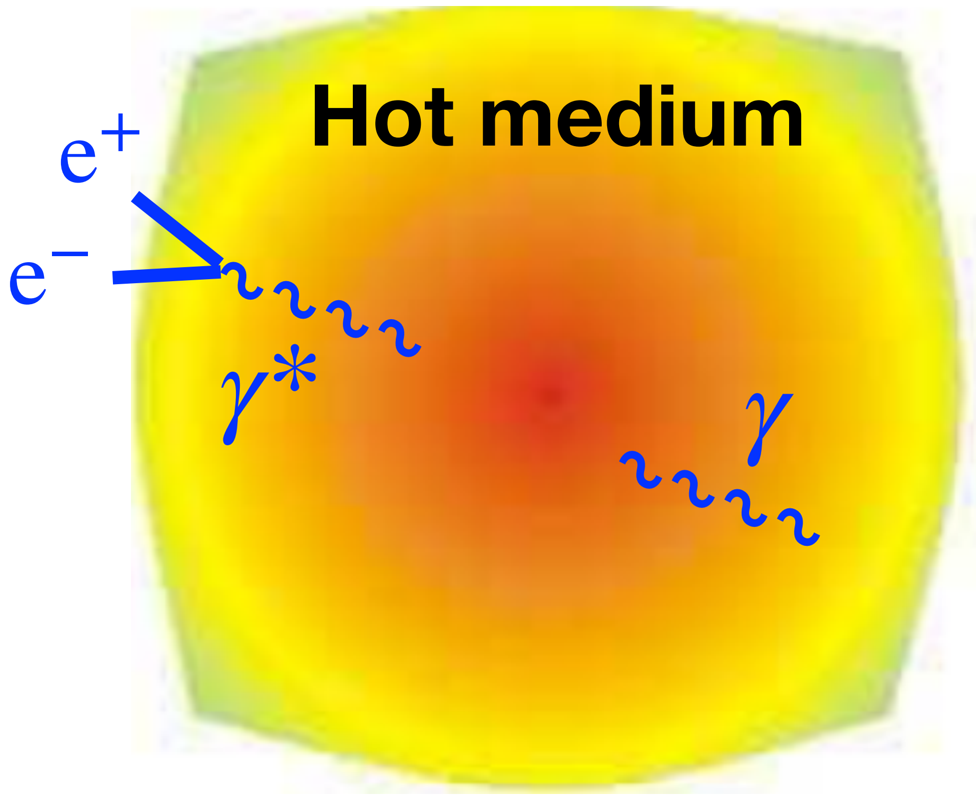
- First T measurements in Run 3 and 4
- **ALICE 3: Probe time dependence of *T***

  Double-differential spectra in reach: *T* vs mass, $p_{T,ee}$

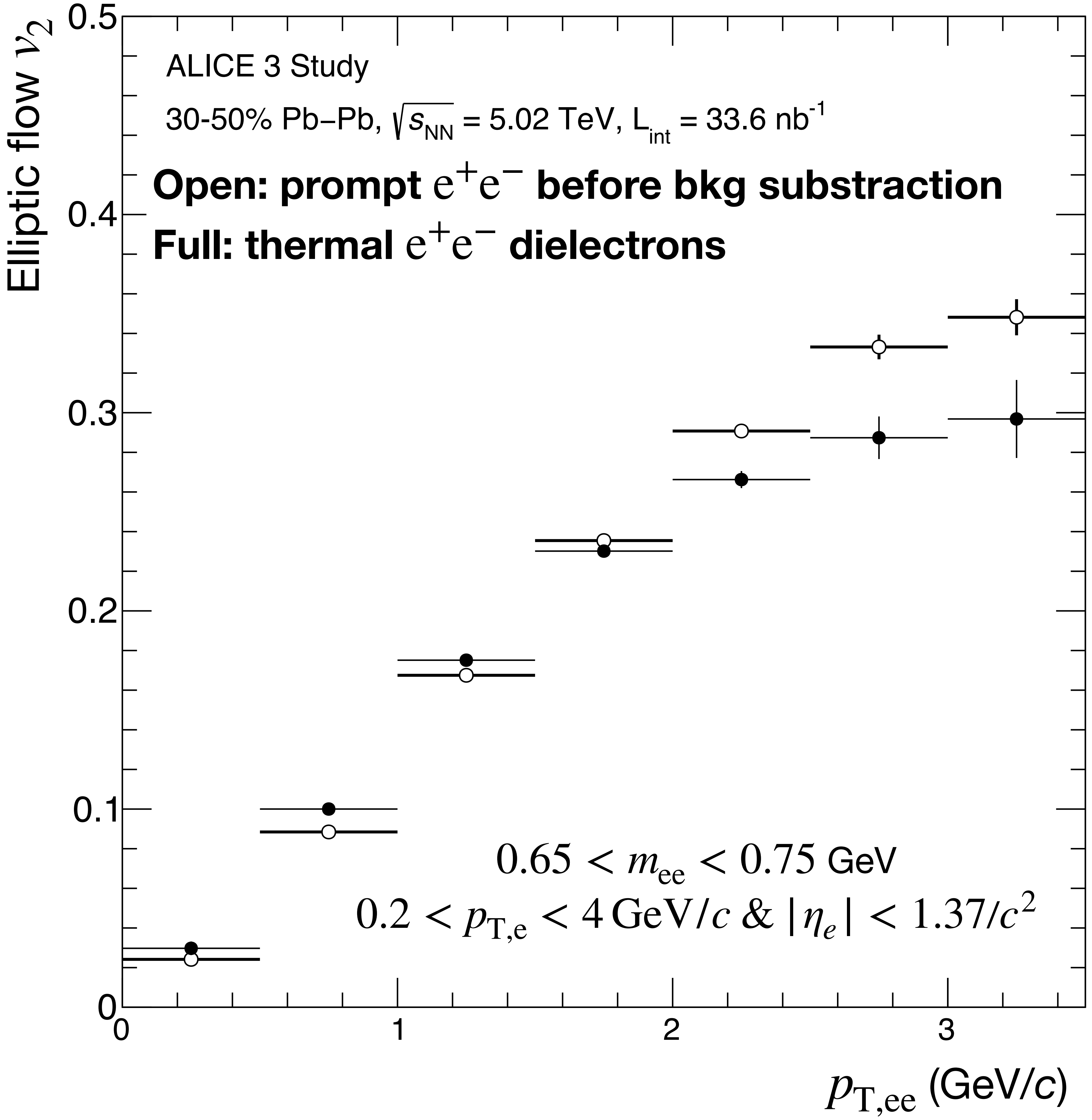
Complementary measurements with real photons
(With different systematic uncertainties → Reduce overall uncertainties)

R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253
P.M Hohler and R. Rapp, Phys. Lett. B 731 (2014) 103
ALICE CERN-LHCC-2022-009

Electromagnetic radiation



Expected statistical errors for $v_2^{e^+e^-}$
ALICE 3, 6 years Pb—Pb running



- First *T* measurements in Run 3 and 4
- **ALICE 3: Access time evolution and flow field ("photon puzzle")**

  Double-differential spectra: *T* vs mass, $p_{T,ee}$

  Dilepton v_2 vs mass and $p_{T,ee}$ possible

  Complementary measurements with real photons

  (With different systematic uncertainties → Reduce overall uncertainties)

v_2 from G. Vujanovic et al., PRC 101 (2020) 044904
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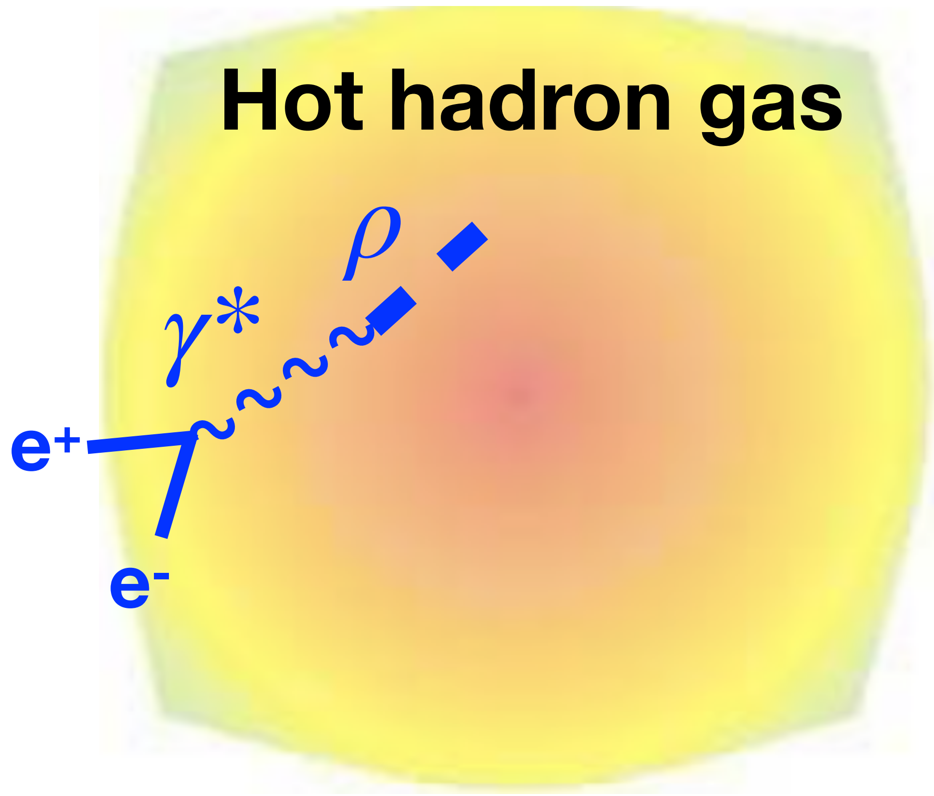
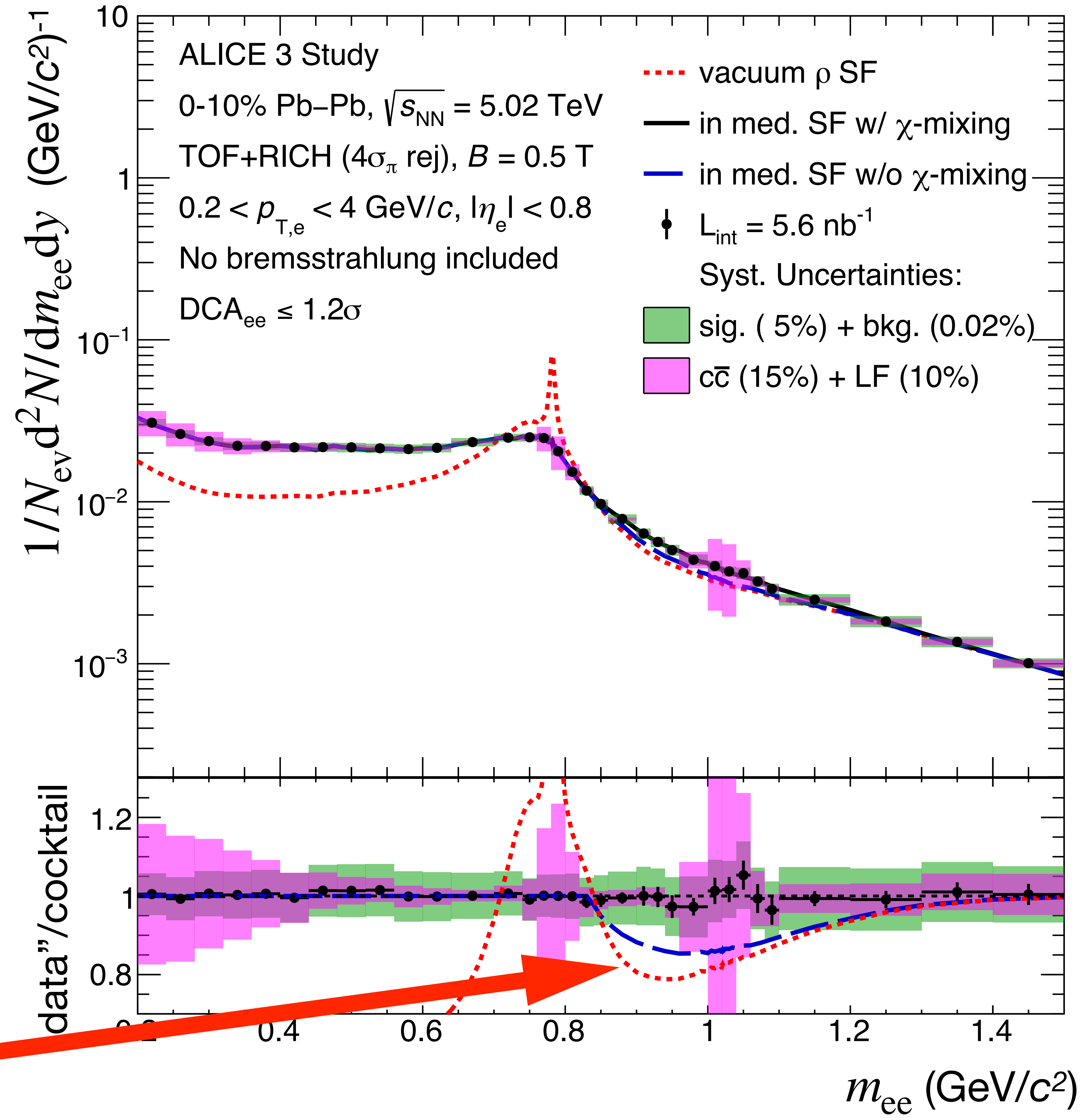
Chiral symmetry and thermal emission



Projection for thermal dielectron m_{ee}
ALICE 3, one month Pb—Pb



Study chiral symmetry restoration (CSR) mechanisms using thermal dielectron m_{ee} spectrum at $m_{ee} < 1.2$ GeV/c^2

- Thermal production of ρ
- ρ sensitive to surrounding medium ($\tau_\rho = 1.3\,\text{fm} < \tau_{\text{fireball}}$)

→ Modification of ρ spectral function related to CSR

High precision measurement with ALICE 3

→ Access to CSR mechanisms like $\rho - a_1$ mixing

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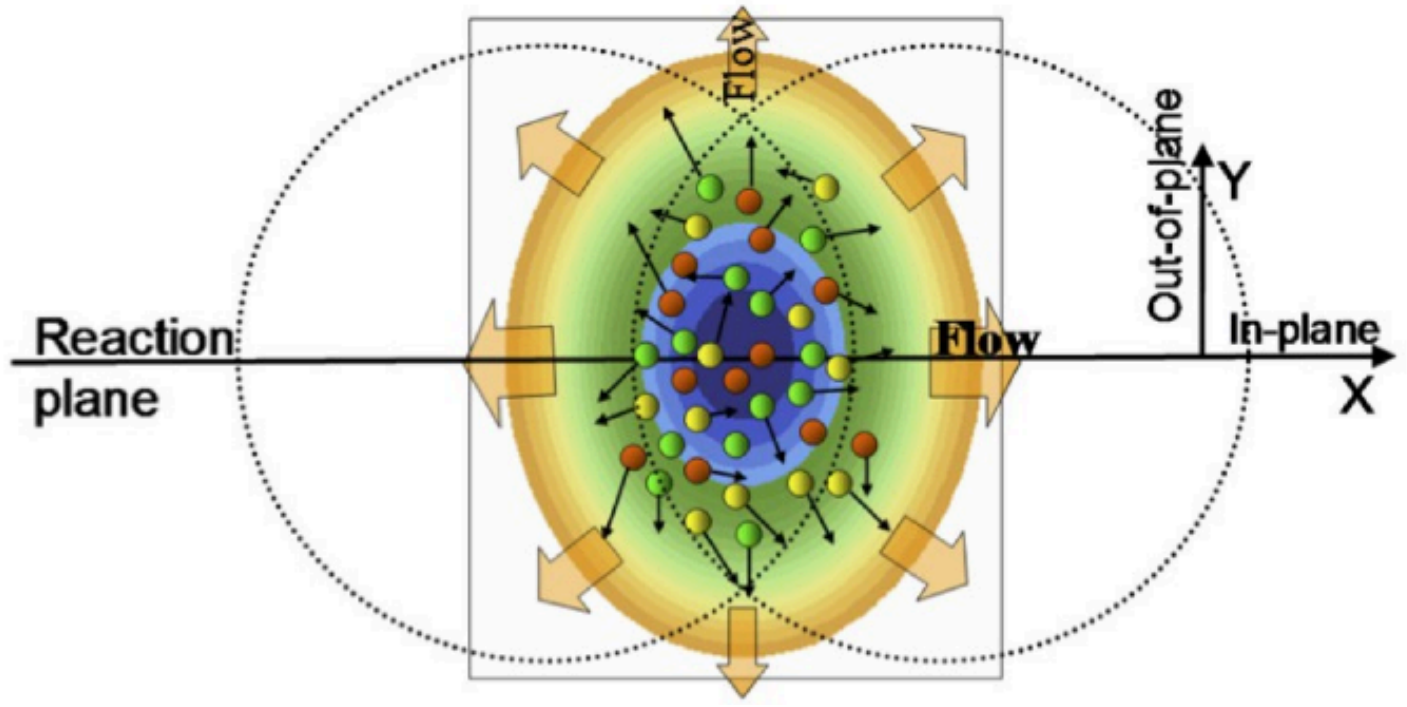
Heavy-quark transport

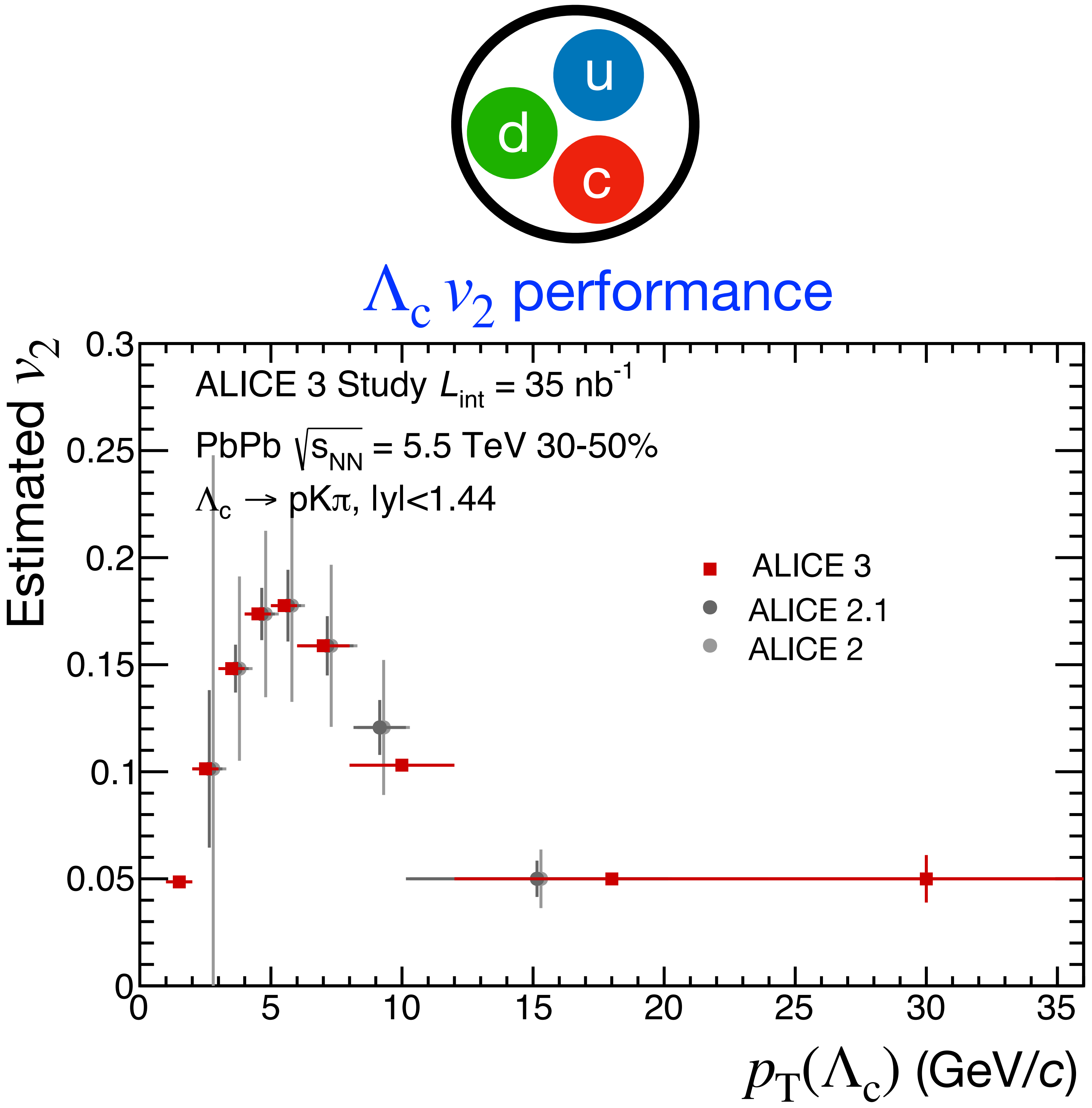
Non-central collision



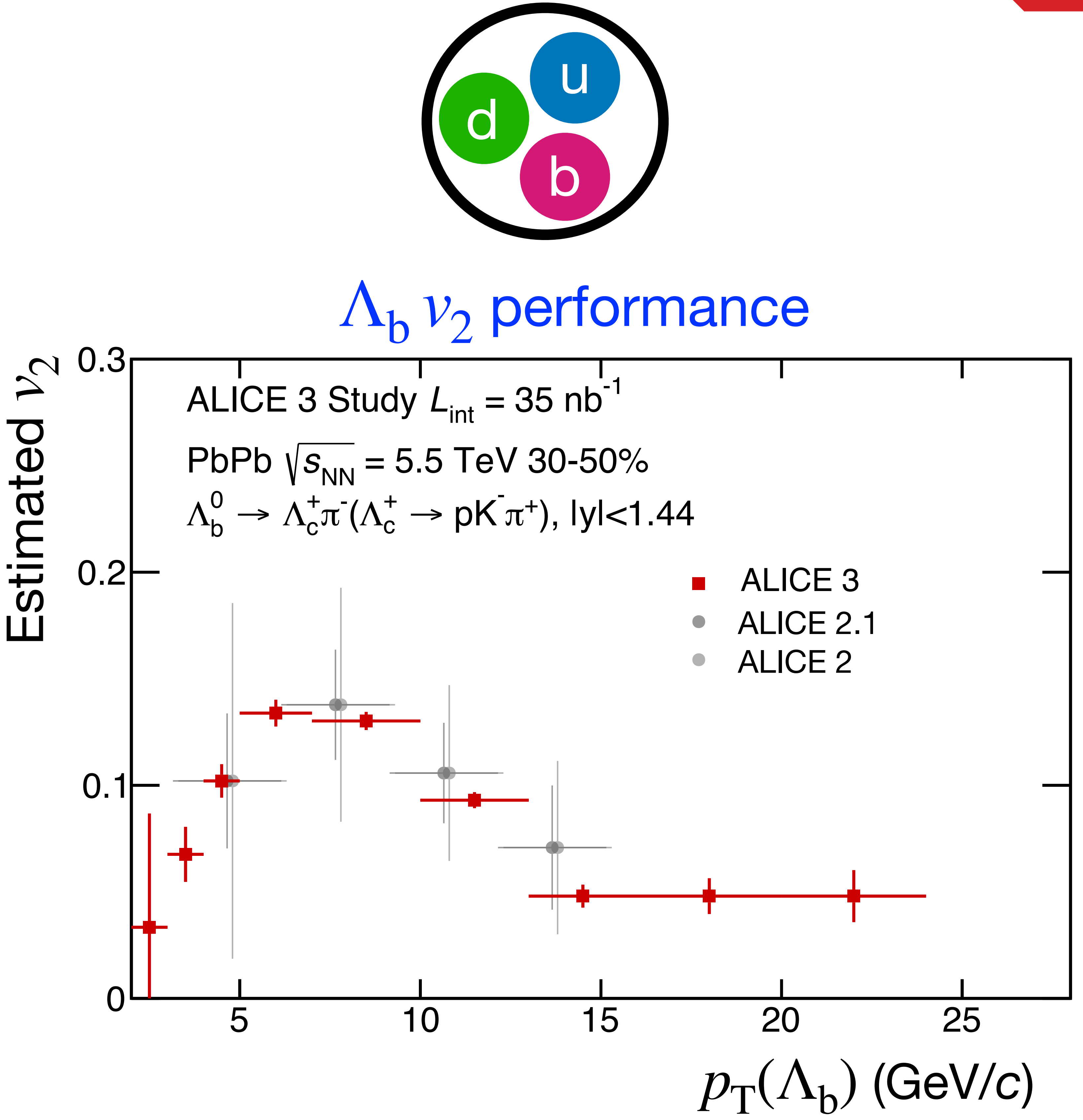
Interactions with the plasma generate azimuthal anisotropy v_2:

$$\frac{dN}{d\phi} \propto 1 + 2\, v_2 \cos 2(\varphi - \psi)$$

Λ_c v_2 performance



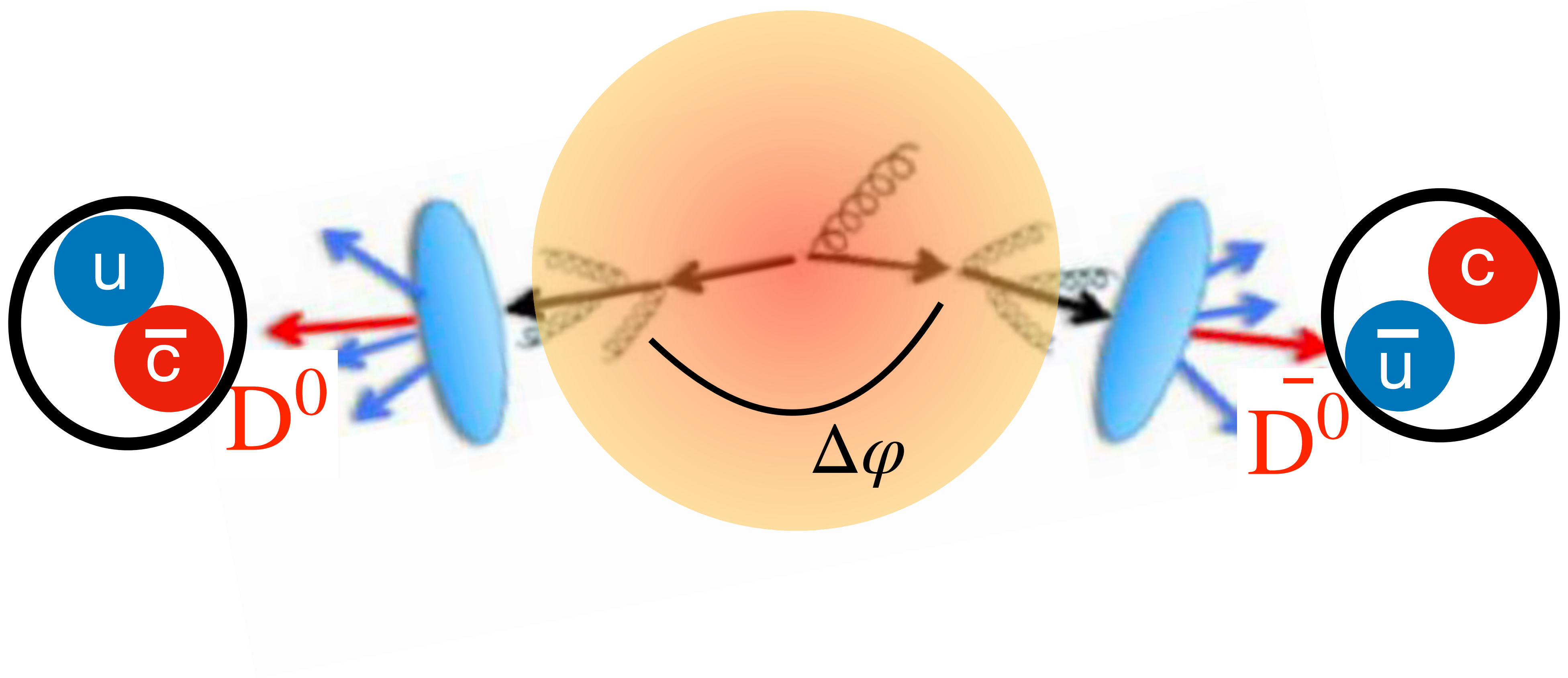
Λ_b v_2 performance



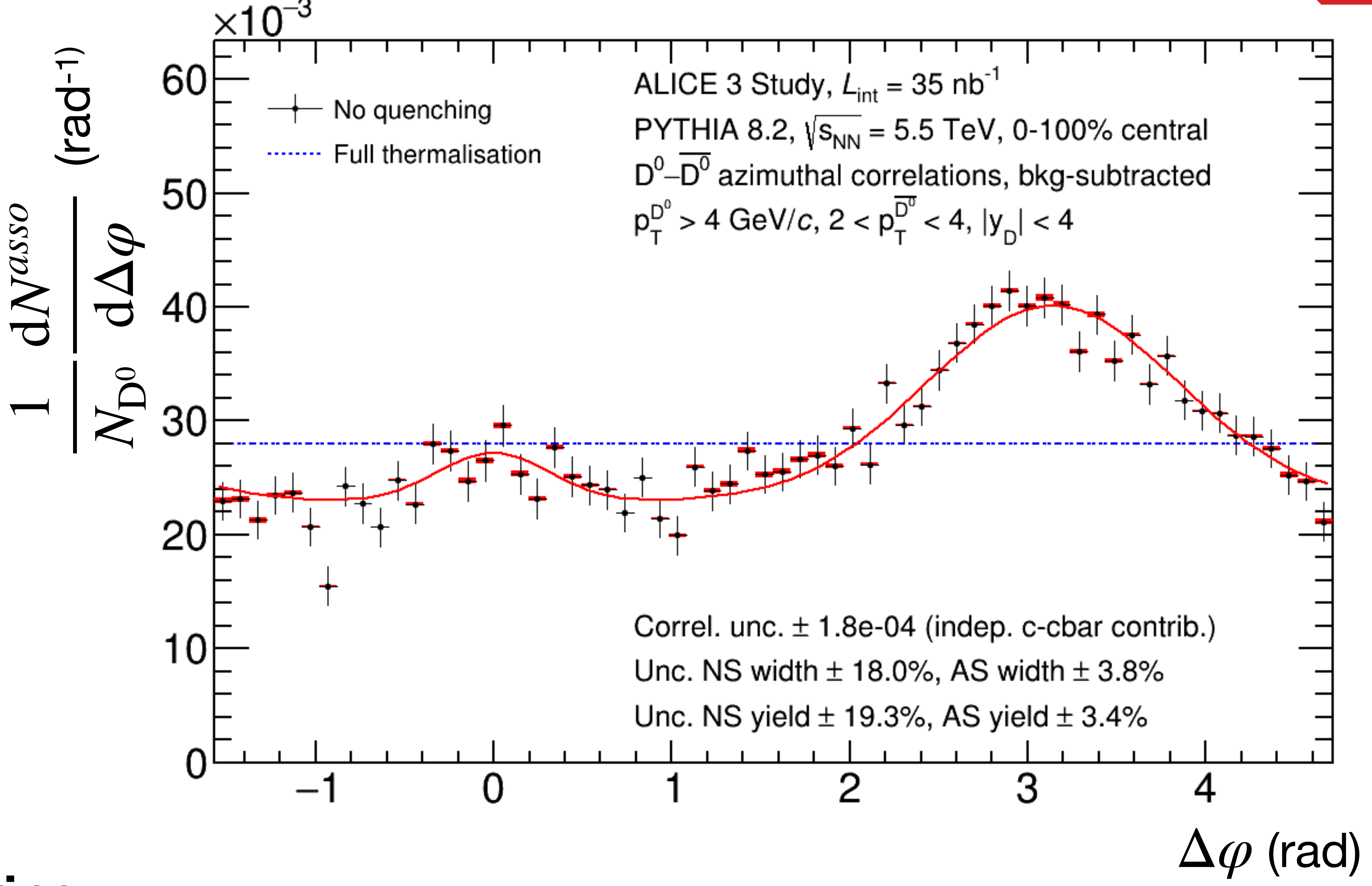
- Access to **(heavy-)quark transport properties in the QGP** at hadron level
  - Precise R_{AA} and v_2 measurements of charm and beauty hadrons down to low p_T → **diffusion coefficients D_s**
  - Expect beauty thermalisation slower than charm → smaller v_2

→ **Need ALICE 3 performance (pointing resolution, acceptance) for precise measurements down to low p_T**

Heavy-quark correlations



ALICE 3 projection: $D^0\bar{D}^0$ correlation

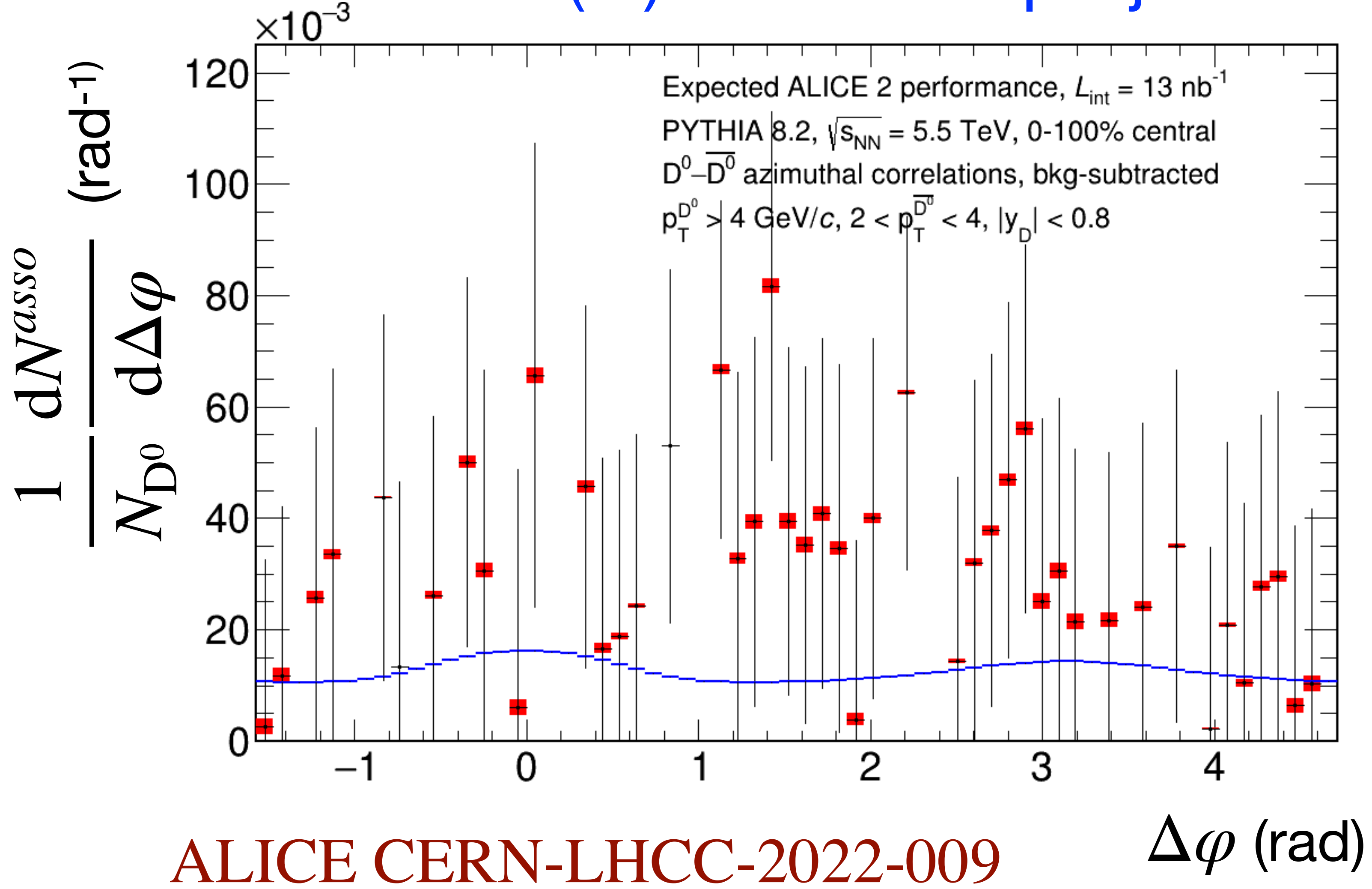


Angular decorrelation of heavy-flavour hadrons → **probe QGP scattering**

- Sensitive to energy loss mechanisms, degree of thermalisation
- Strongest signal at low p_T
- Require high purity, efficiency and large η coverage

→ Heavy-ion measurement only possible with ALICE 3

ALICE 2(.1) Run 3 + 4 projection



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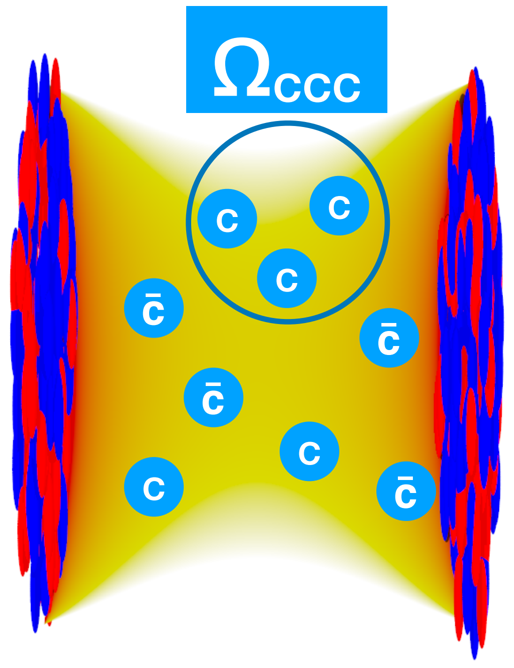
Hadron formation

Multi-charm baryons: unique probe of hadron formation

- Require production of multiple charm quarks
- Contribution from single parton scattering very small

Very large enhancement predicted by Statistical hadronisation model in Pb—Pb collisions → **Test degree of thermalisation**

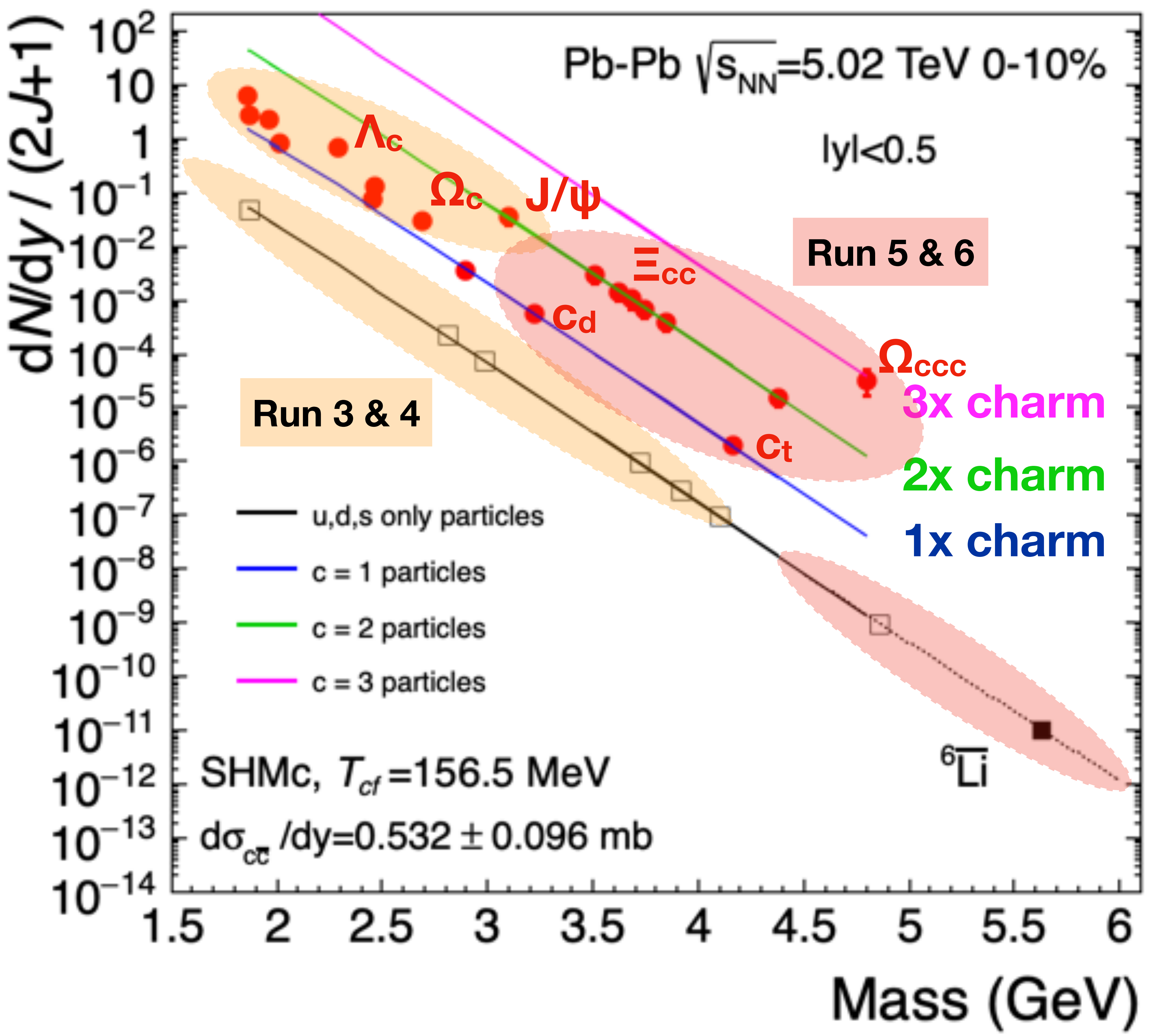


ALICE 2(.1):
- (Anti-)hypernuclei up to A = 4
- Single-charm states (c = 1)

ALICE 3:
- (Hyper-)nuclei with A > 4
- Multi-charm states (c > 1)

With ALICE 3 measure additional states to test physical picture
Large η acceptance → Probe charm density dependence

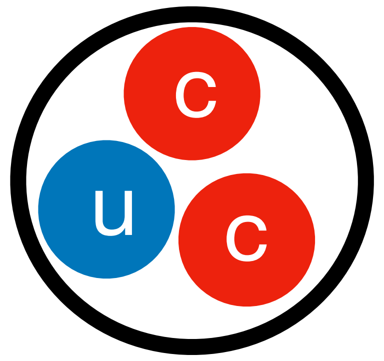
Hadron yields in statistical hadronisation model



Scaling with g_c^n for n-charm states

A. Andronic, P. Braun-Munzinger, M. K. Koehler, A. Mazeliauskas, K. Redlich, J. Stachel, V. Vislavicius, JHEP 07 (2021) 035

Multi-charm baryon reconstruction



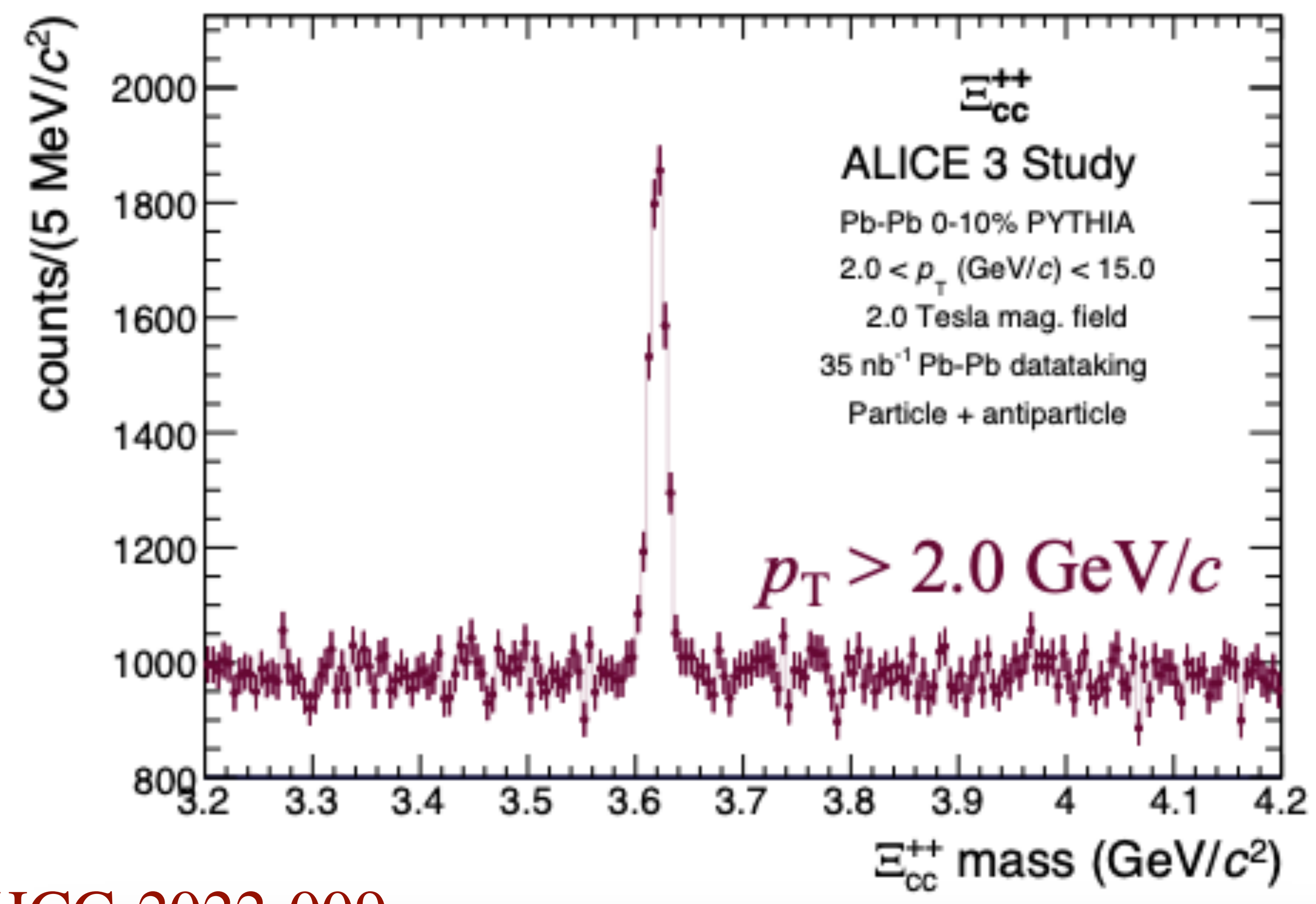
$$\Xi_{cc}^{++} \rightarrow \Xi_c^+ + \pi^+$$
$$\Xi_c^+ \rightarrow \Xi^- + 2\pi^+$$

First ALICE 3 tracking layer at 5 mm:

- Track strange baryon (Ξ^-) before it decays
- High selectivity thanks to pointing resolution of Ξ baryon

→ Unique experimental access with ALICE 3 in Pb—Pb collisions

Expected mass peak for Ξ_{cc}^{++} in Pb—Pb



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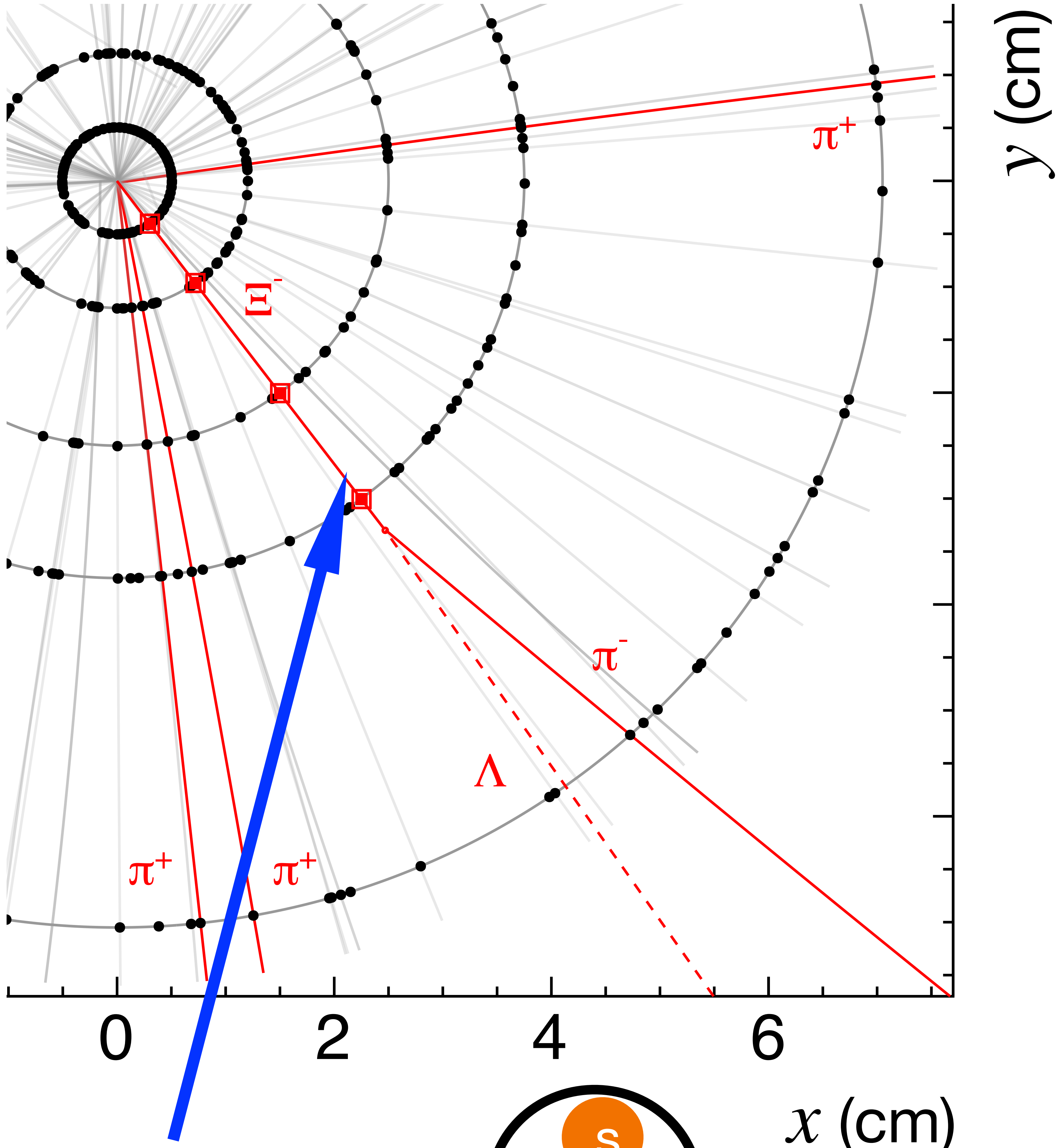
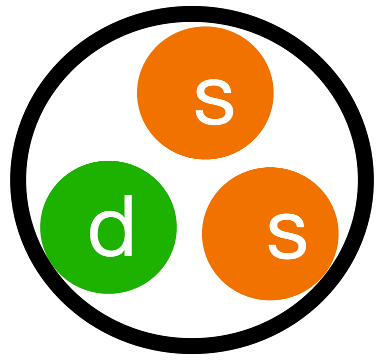
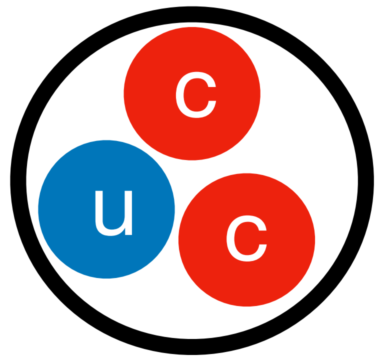
One reconstructed Ξ_{cc}^{++} decay in the ALICE 3 tracker





Raphaelle Bailhache

Multi-charm baryon reconstruction



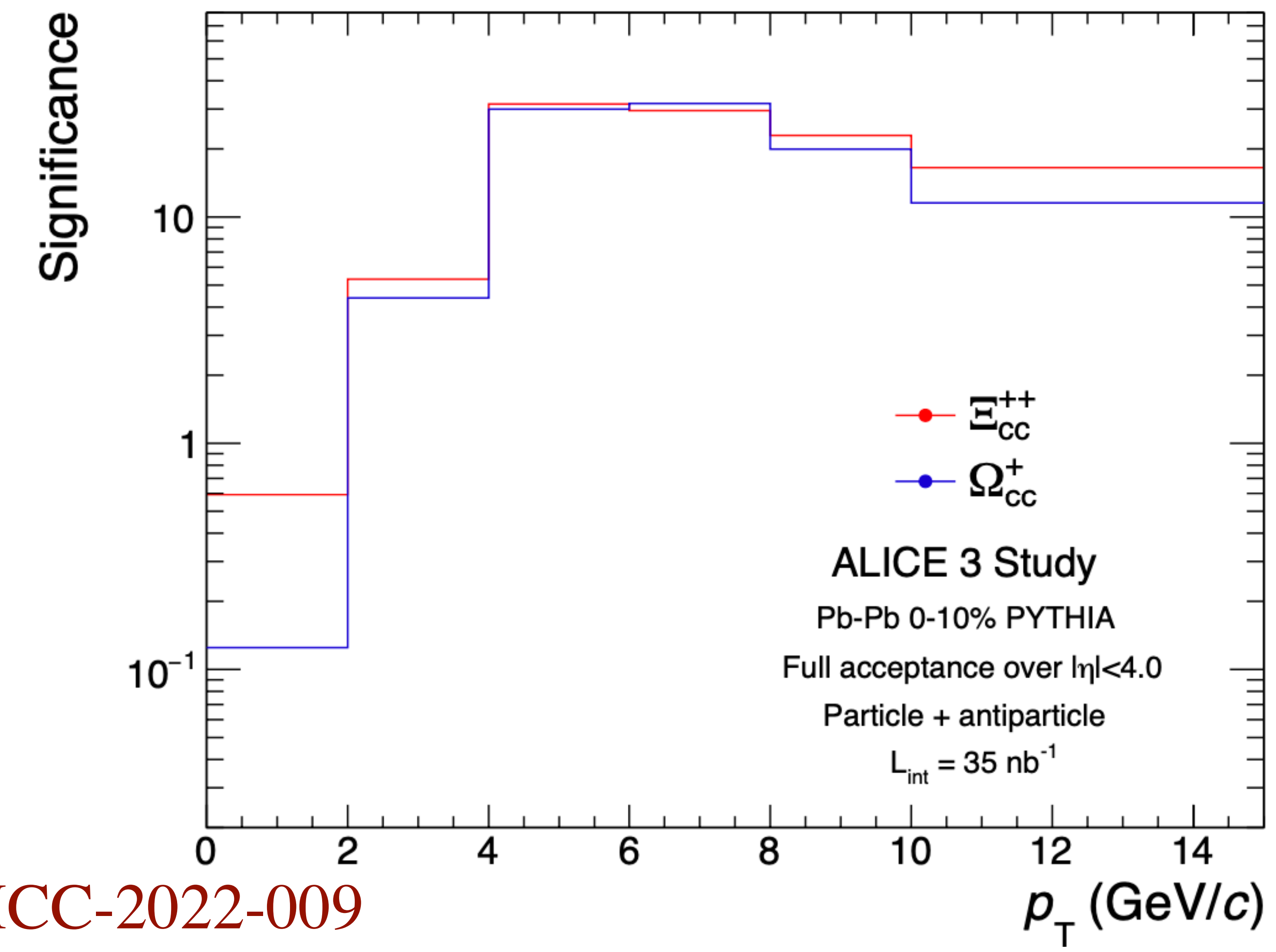
$$\Xi_{cc}^{++} \rightarrow \Xi_c^{+} + \pi^{+}$$
$$\Xi_c^{+} \rightarrow \Xi^{-} + 2\pi^{+}$$

First ALICE 3 tracking layer at 5 mm:

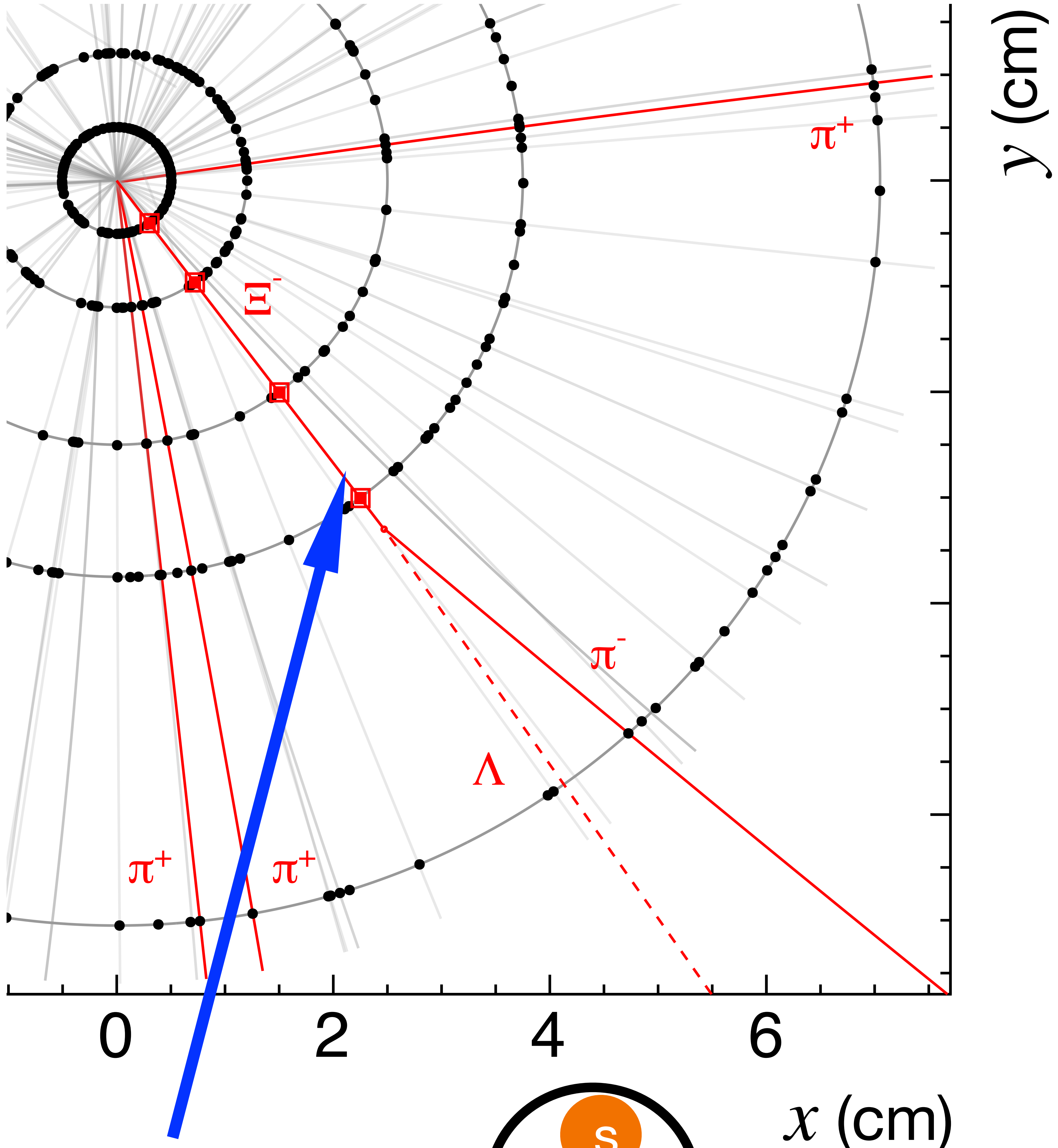
- Track strange baryon (Ξ^{-}) before it decays
- High selectivity thanks to pointing resolution of Ξ baryon

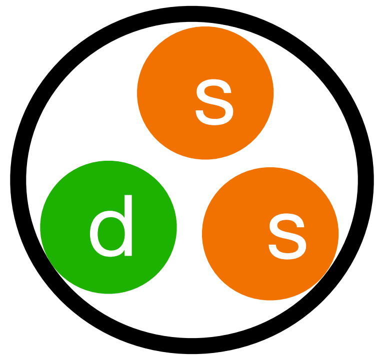
→ Unique experimental access with ALICE 3 in Pb—Pb collisions

Expected significance for Ξ_{cc}^{++} , Ω_{cc}^{+} in Pb—Pb



One reconstructed Ξ_{cc}^{++} decay in the ALICE 3 tracker





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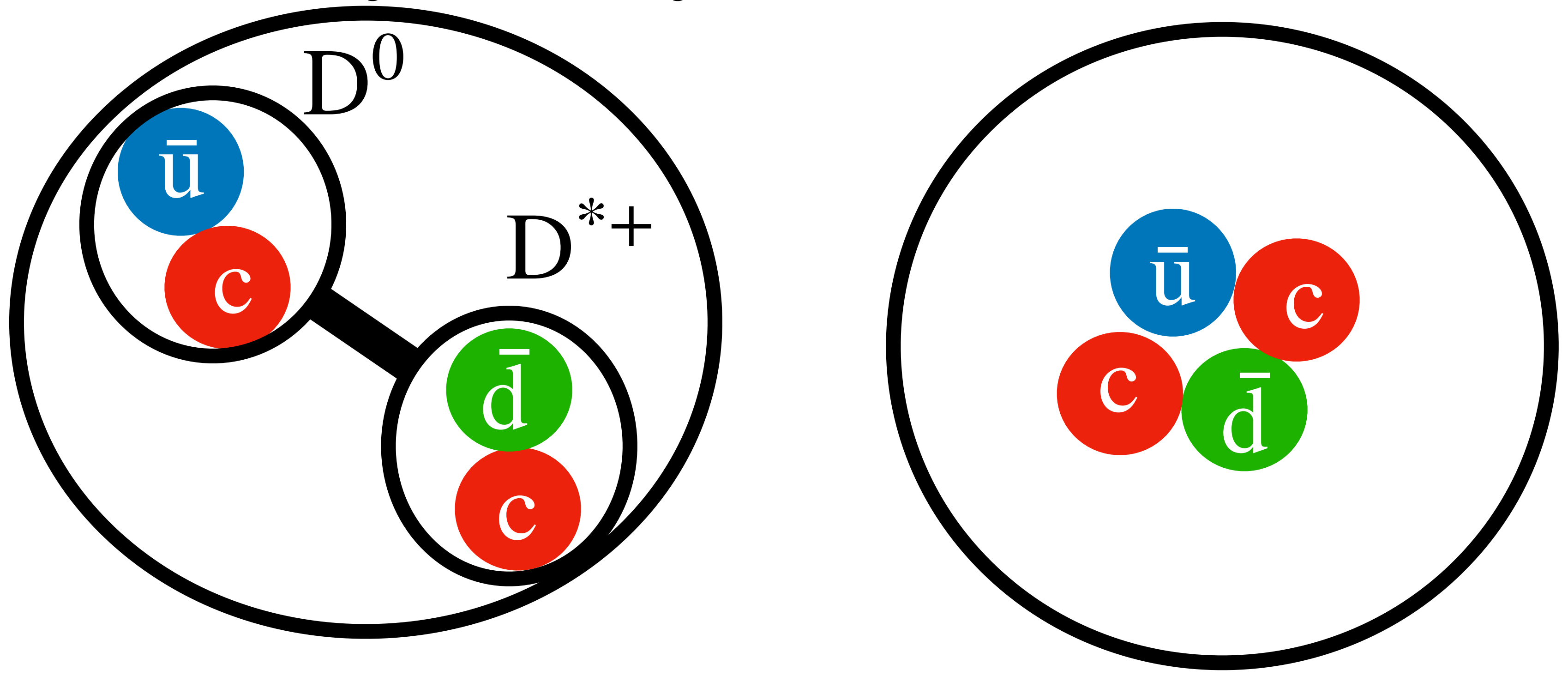
Nature of exotic bound states

T_{cc}^{+} discovered
in July 2021 by LHCb CERN-EP-2021-165



Search for possible DD bound states using two particle momentum correlation

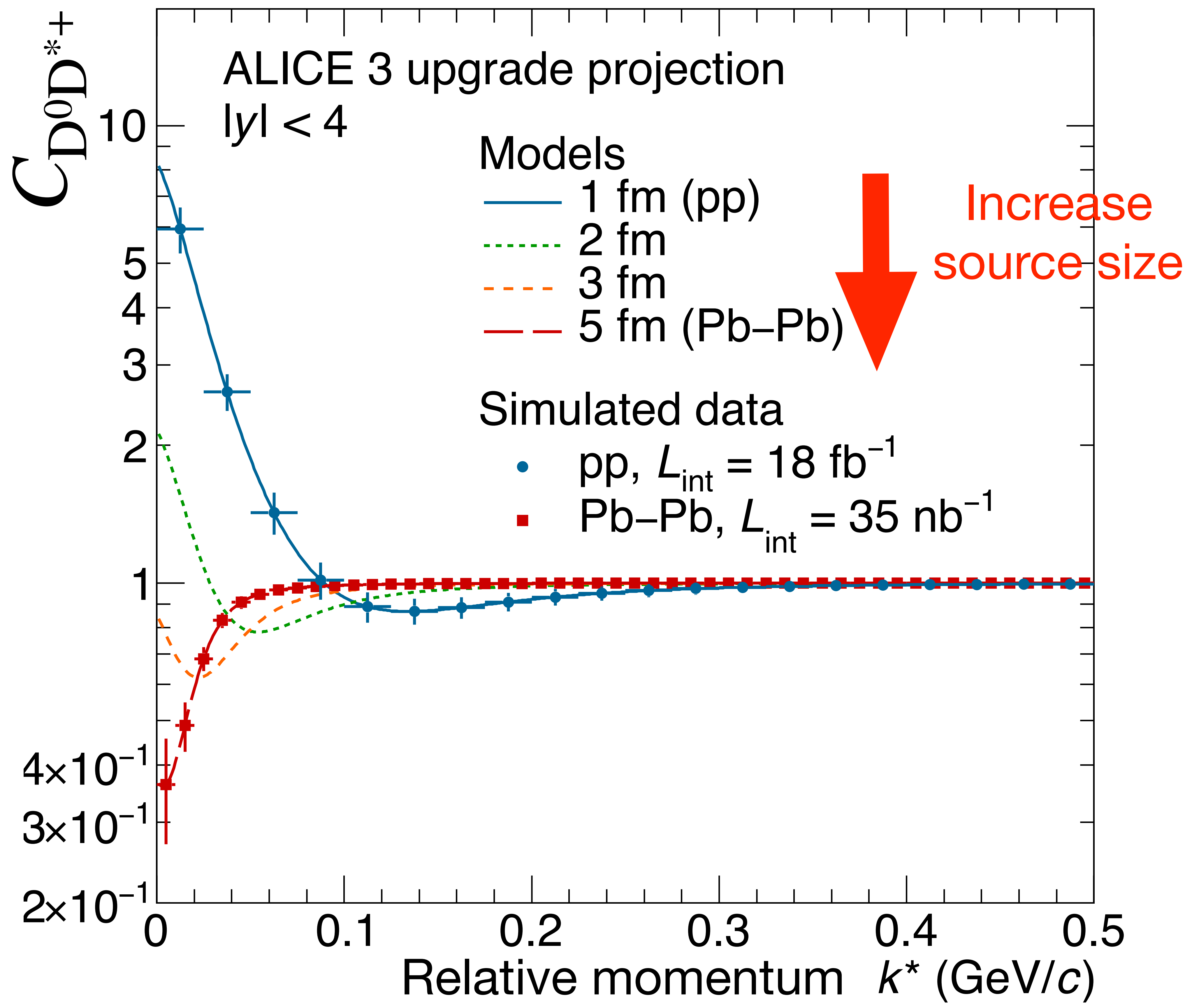
$$C(k^*) = \int \mathrm{d}^3 r^* S(r^*) |\Psi(k^*, r^*)|^2$$

connected to source function/size and two-particle wave function

Behaviour of $C(k^*)$ → Get information on interaction potential

Possible with ALICE 3 thanks to pointing resolution + large acceptance

Projection for D^0D^{*+} momentum correlation



$$k^* = 1/2\,|\mathbf{p}^*_{\mathbf{D^0}} - \mathbf{p}^*_{\mathbf{D^{*+}}}|$$

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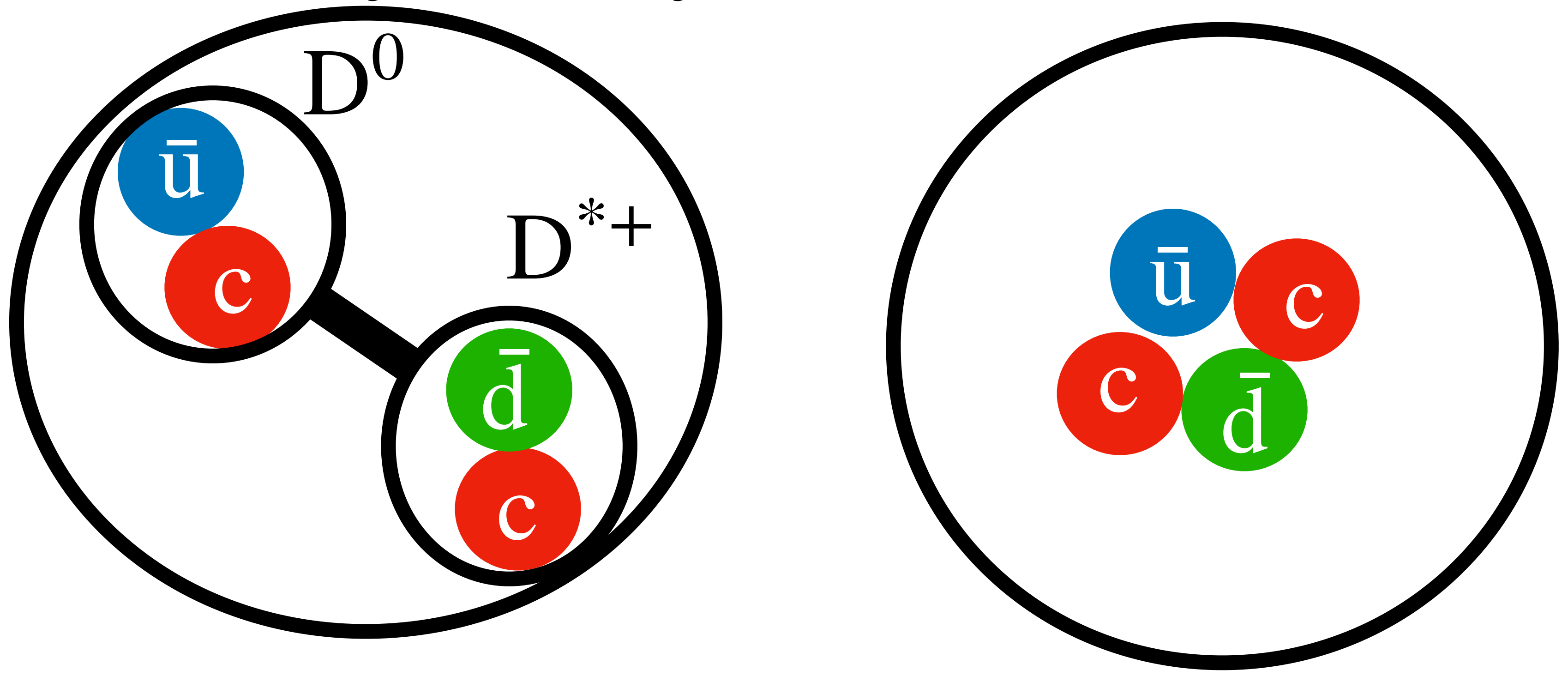
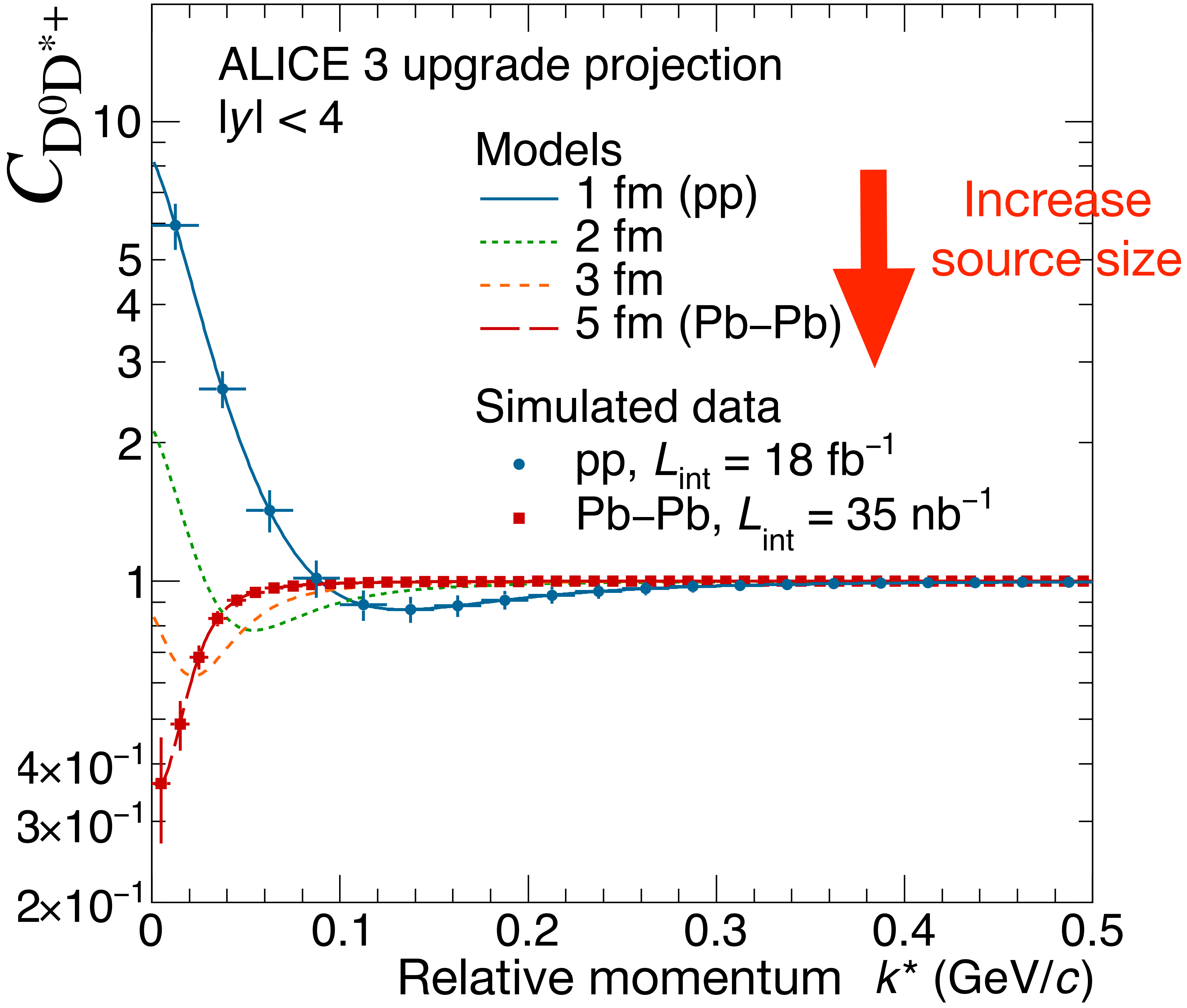


Search for possible DD bound states using two particle momentum correlation
Possible with ALICE 3

Understand dissociation and regeneration of exotic states in QGP
Unique access to low p_{T} $\chi(3872)(\rightarrow J/\psi\pi^{+}\pi^{-})$ with ALICE 3

Projection for $D^{0}D^{*+}$ momentum correlation



$$k^{*} = 1/2\,|\mathbf{p}^{*}_{\mathbf{D^0}} - \mathbf{p}^{*}_{\mathbf{D^{*+}}}|$$

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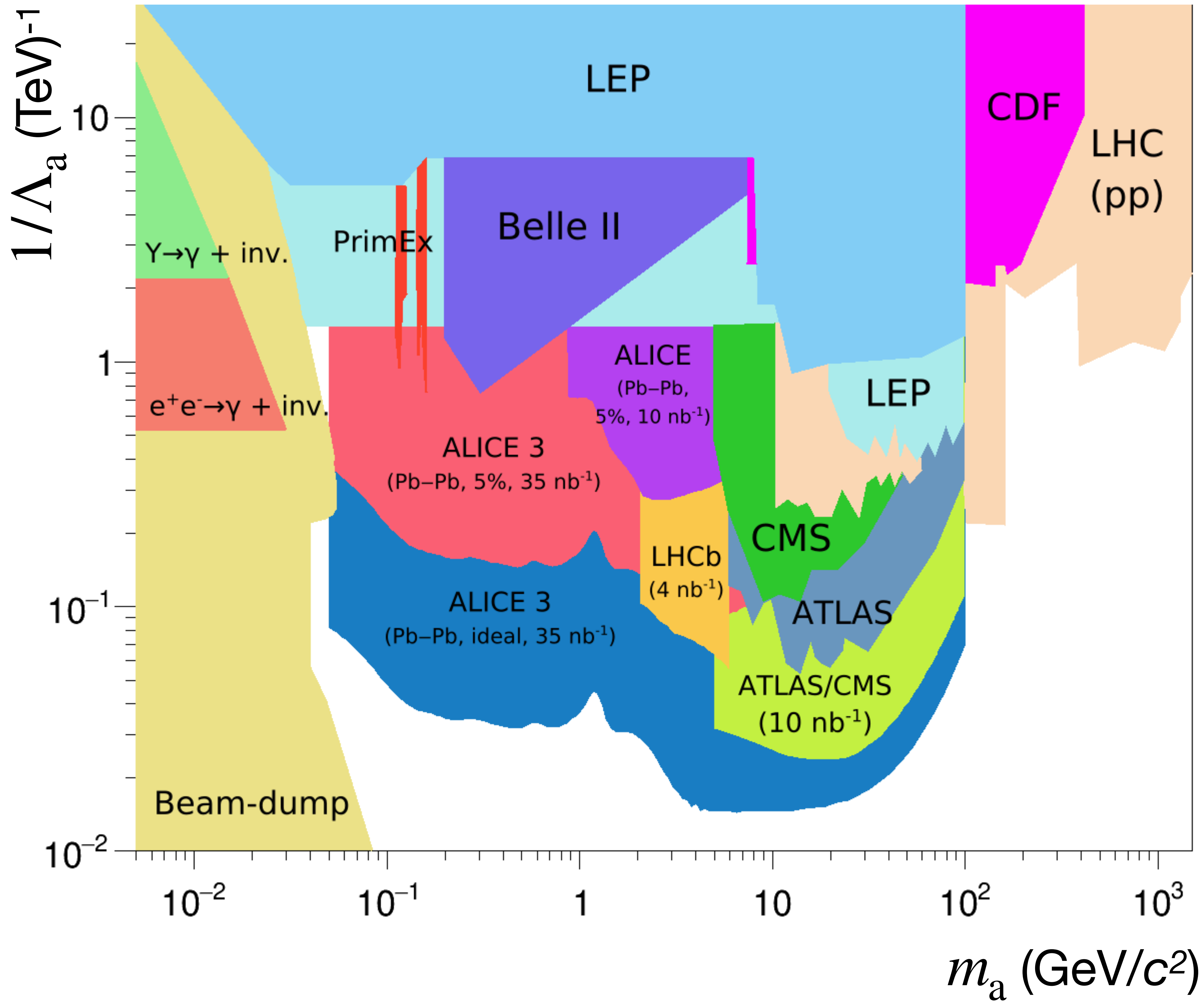
Beyond QGP physics

- **Beyond Standard Model studies**
  - Search for axion-like particles (ALP) in ultra-peripheral (UPC) Pb—Pb collisions
  - **ALICE 3: Potential to fill the gap from 0.05 to 5 GeV in m_a**
- **Understanding of ultra-soft photon production**
  - Cross sections computable using Low-theorem
  - Large excess observed at lower $\sqrt{s}$ in association with hadrons
  - **ALICE 3: systematic study of very soft γ production ($p_T \leq 10$ MeV/c) with dedicated Forward Conversion Tracker**
- **Resonance production in UPC**
- **Nuclear states**
  - Search for super-nuclei (c-deuteron , c-triton)
  - Anti nuclei from b quarks ($\bar{\Lambda}_b^0 \rightarrow {}^3\bar{\text{He}}$ decays)

ALP search: expected sensitivity as a function of m_a and ALP-γ coupling $1/\Lambda_a$



Existing limits from ATLAS, JHEP 03, 243 (2021)
Projections for ATLAS/CMS from PRL 118 (2017), 171801
Projections for LHCb from Goncalves et al. EPJC 81 (2021), 522

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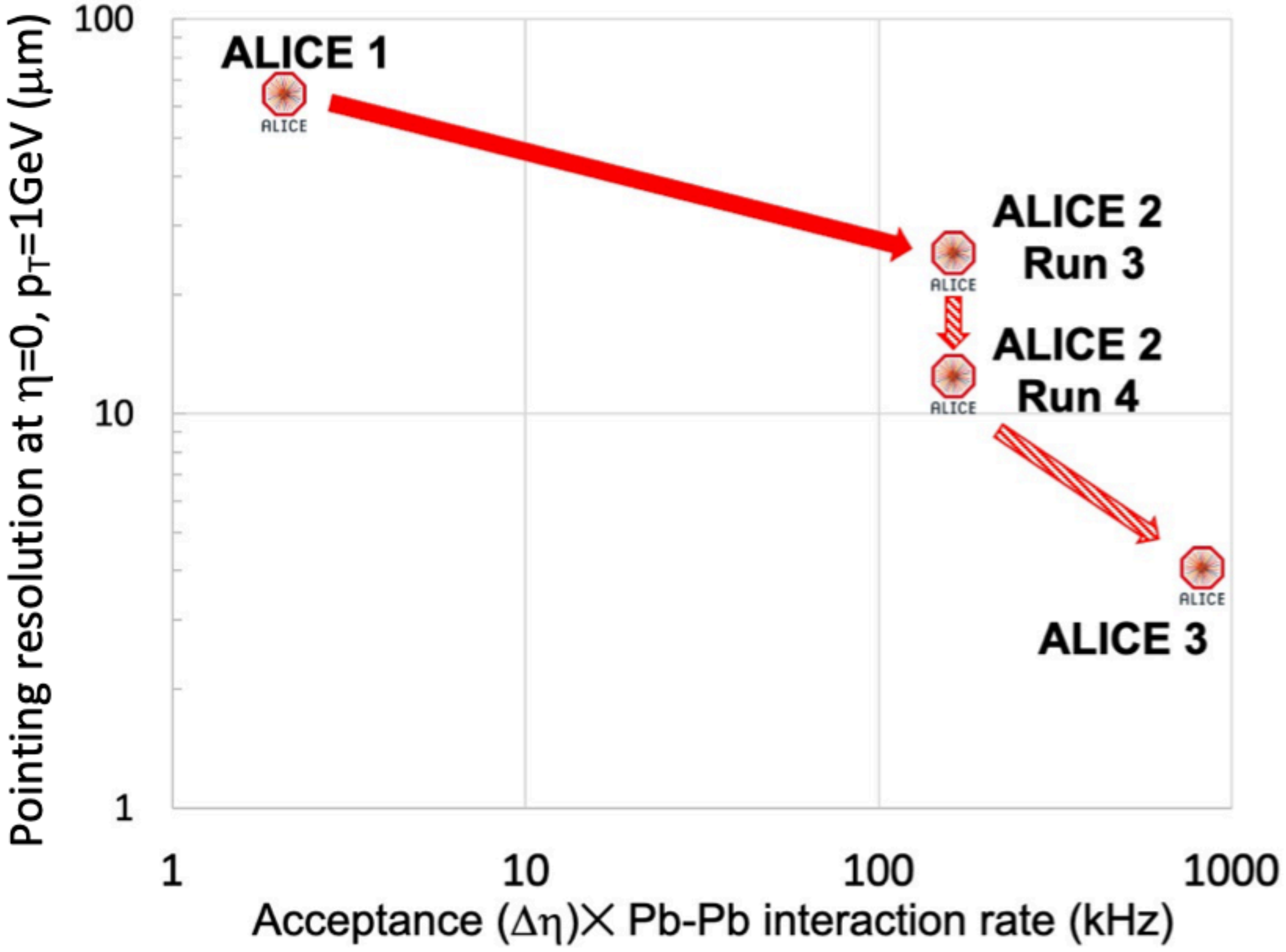
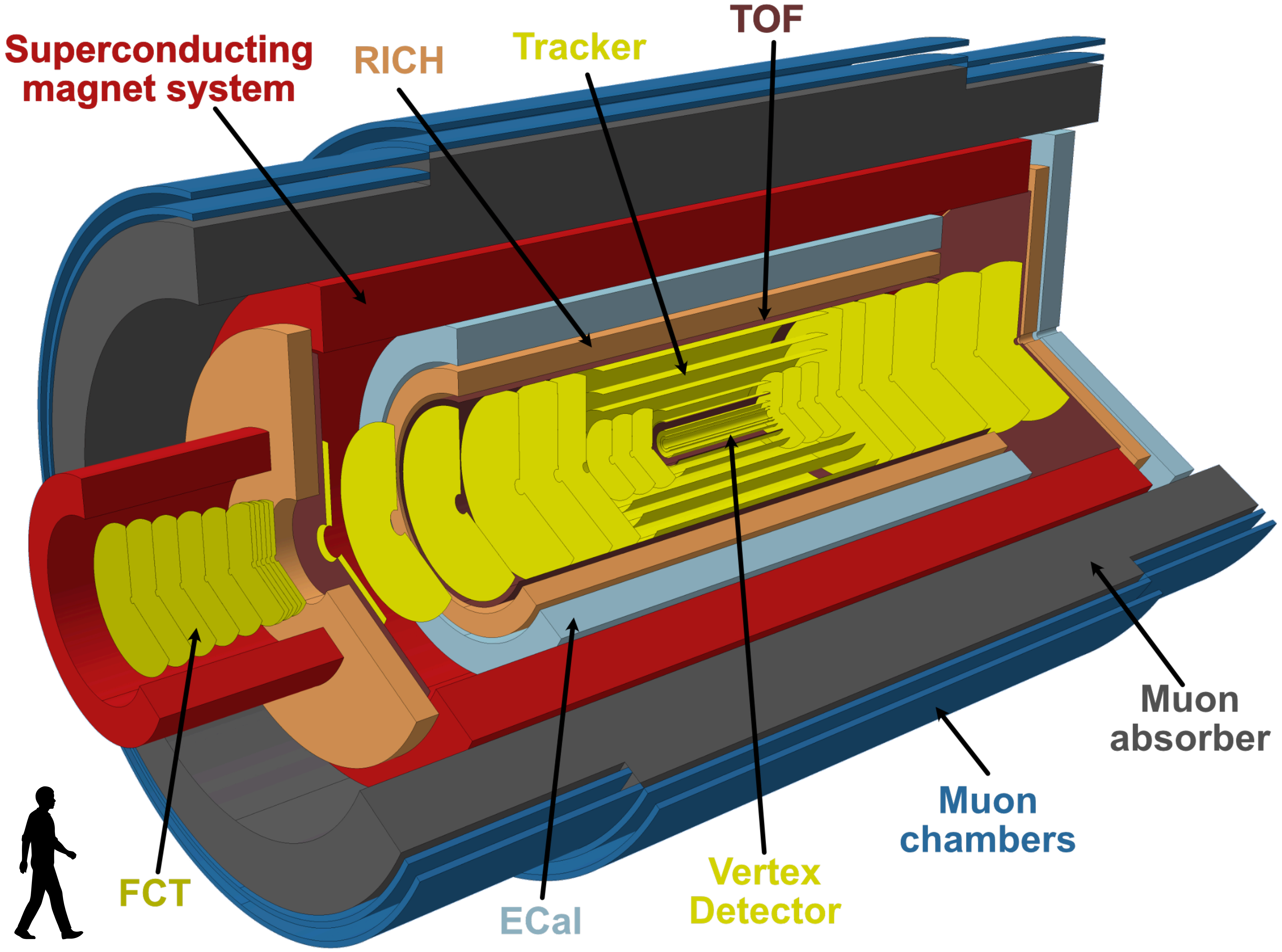
ALICE 3 detector concept

- Compact all-silicon tracker with high-resolution vertex detector
- Particle identification $\gamma, e^{\pm}, \mu^{\pm}, K^{\pm}, \pi^{\pm}$
  - Over large acceptance ($-4 < \eta < 4$)
  - Down to very low p_T

Improved pointing resolution and effective statistics (Run 5 + 6)



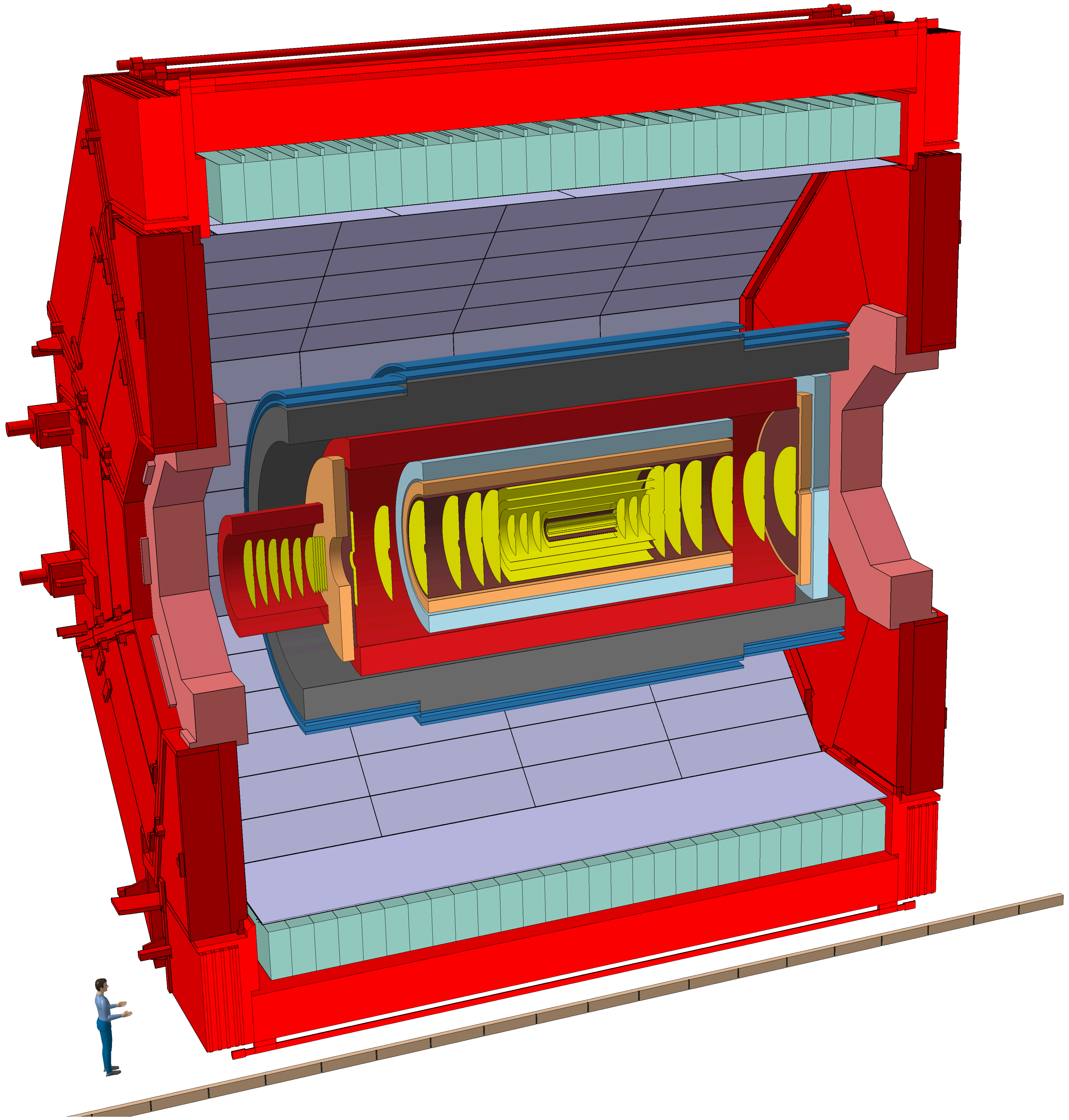


D.Adamova et al. ArXiv:1902.01211
ALICE CERN-LHCC-2022-009

Integration and running scenario

- **Installation** of ALICE 3 inside of ALICE L3 magnet (not used)

- **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 $\sqrt{s}$ = 14 TeV: 3 fb^{-1} / year x 100 compared to Run 3 + 4



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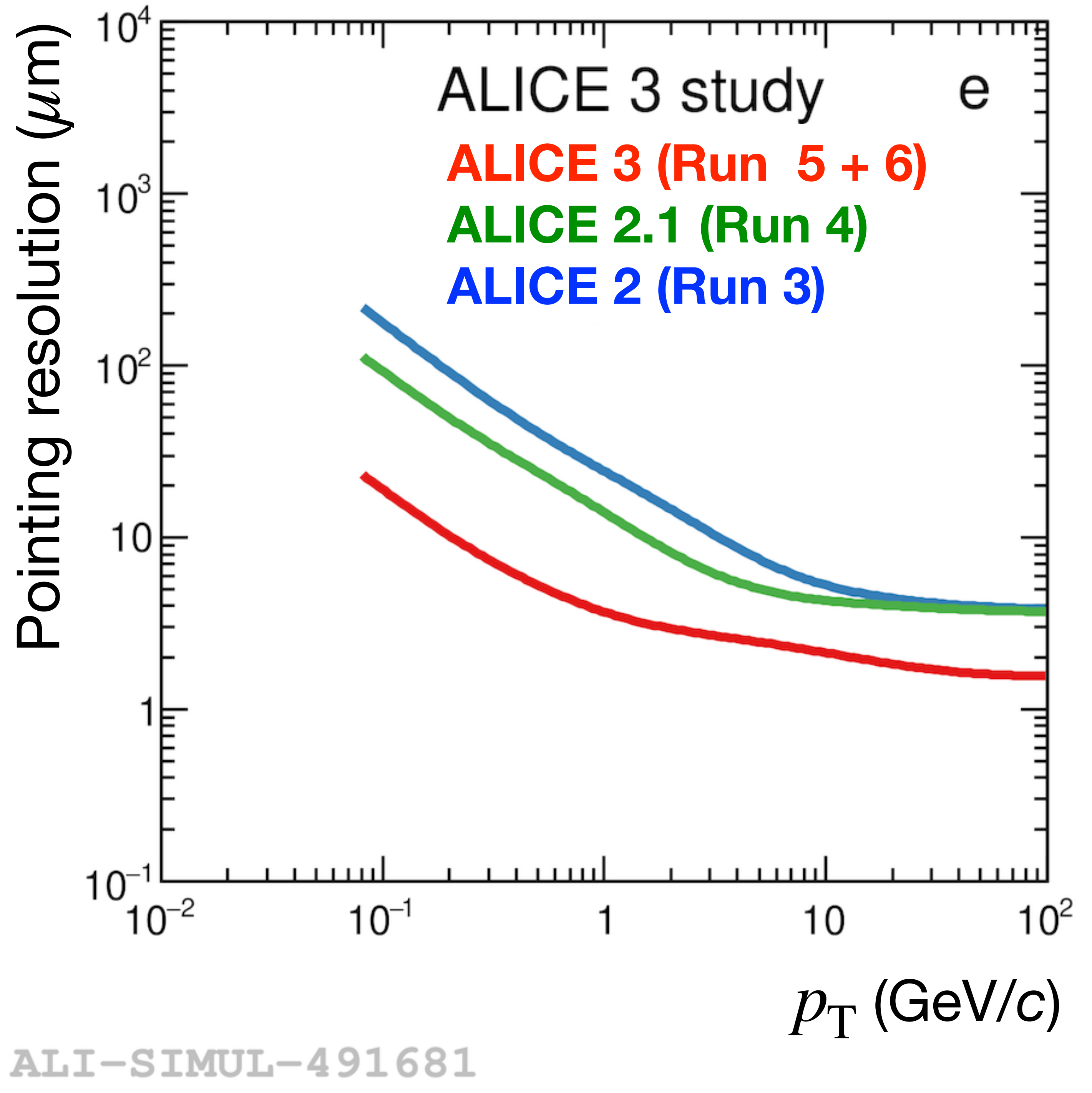
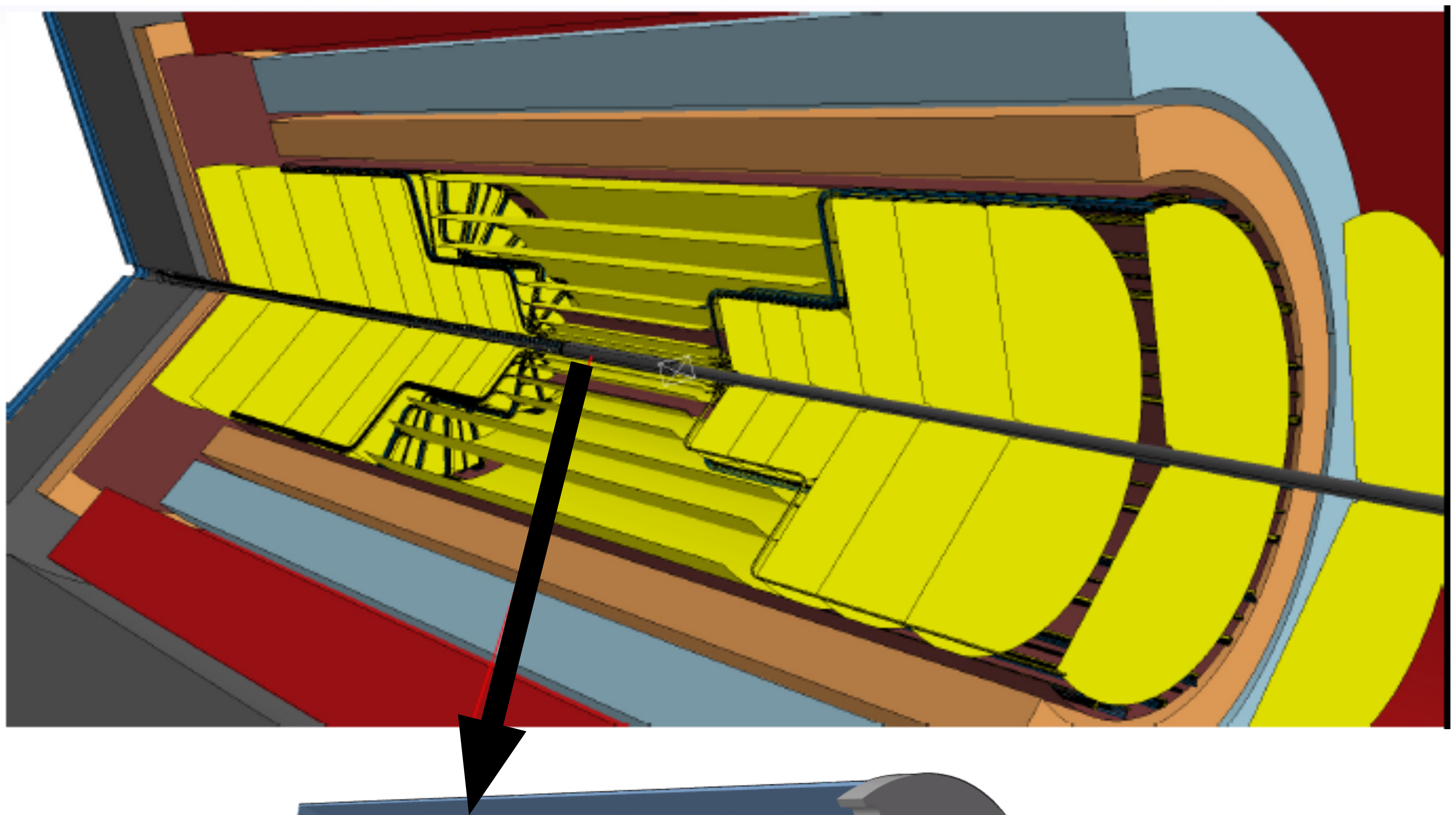
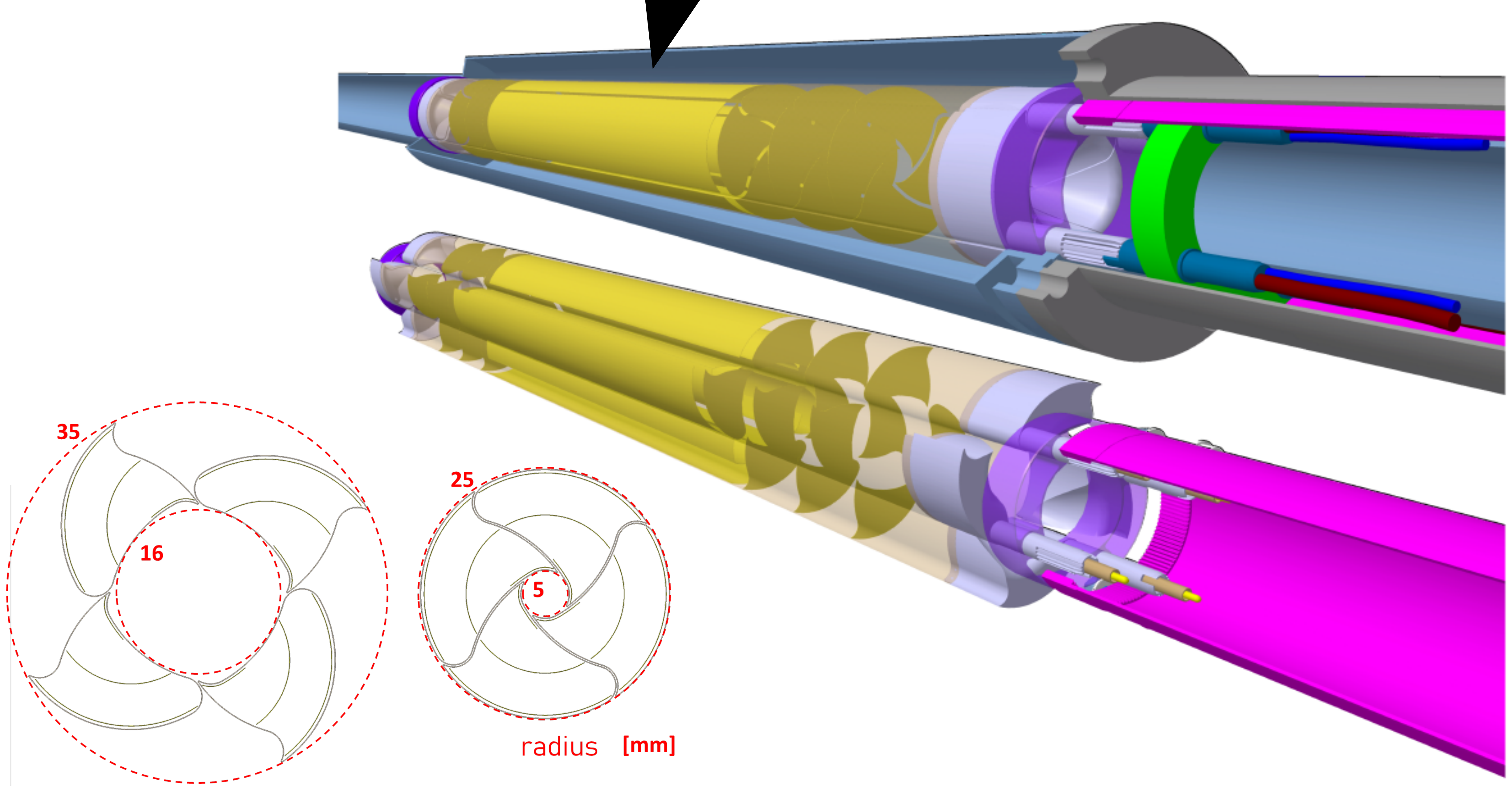
Tracker

- Larger/longer MAPS-based tracker than for ALICE 2
- Position of first layer at mid-rapidity:
  $r = $ **5 mm** (ALICE 2.1: 18 mm; ALICE 2: 22mm)
  Talk by Alperen Yuncu yesterday
- Achieved with a retractable vertex detector inside of the beam pipe in secondary vacuum



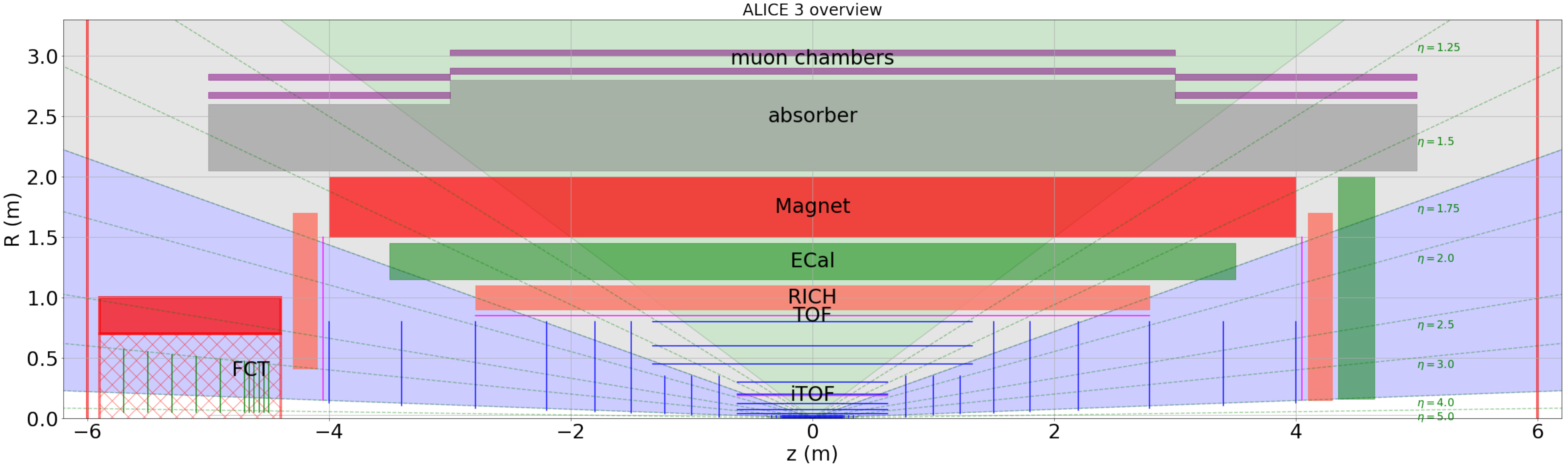




Observables and detector requirements

- **Heavy-flavour hadrons** ($p_{\mathrm{T}} \rightarrow 0$, wide η range)
  → Vertexing, tracking, hadron identification
- **Quarkonia and Exotica** ($p_{\mathrm{T}} \rightarrow 0$)
  → Muon and γ identification
- **Nuclei**
  → Identification of $z > 1$ particles
- **Dielectrons** ($p_{\mathrm{T}} \sim 0.05 - 3$ GeV/c, $m_{\mathrm{ee}} \sim$ 0.1 - 4 GeV/c^2)
  → Vertexing, tracking, electron identification
- **Photons** ($E_{\gamma} \sim$ 0.1 - 50 GeV/c, wide η range)
  → Photon conversion, electromagnetic calorimeter
- **Ultra-soft photons** ($1 \leq p_{\mathrm{T}} \leq 10$ MeV/c)
  →Dedicated Forward Conversion Tracker detector (FCT)

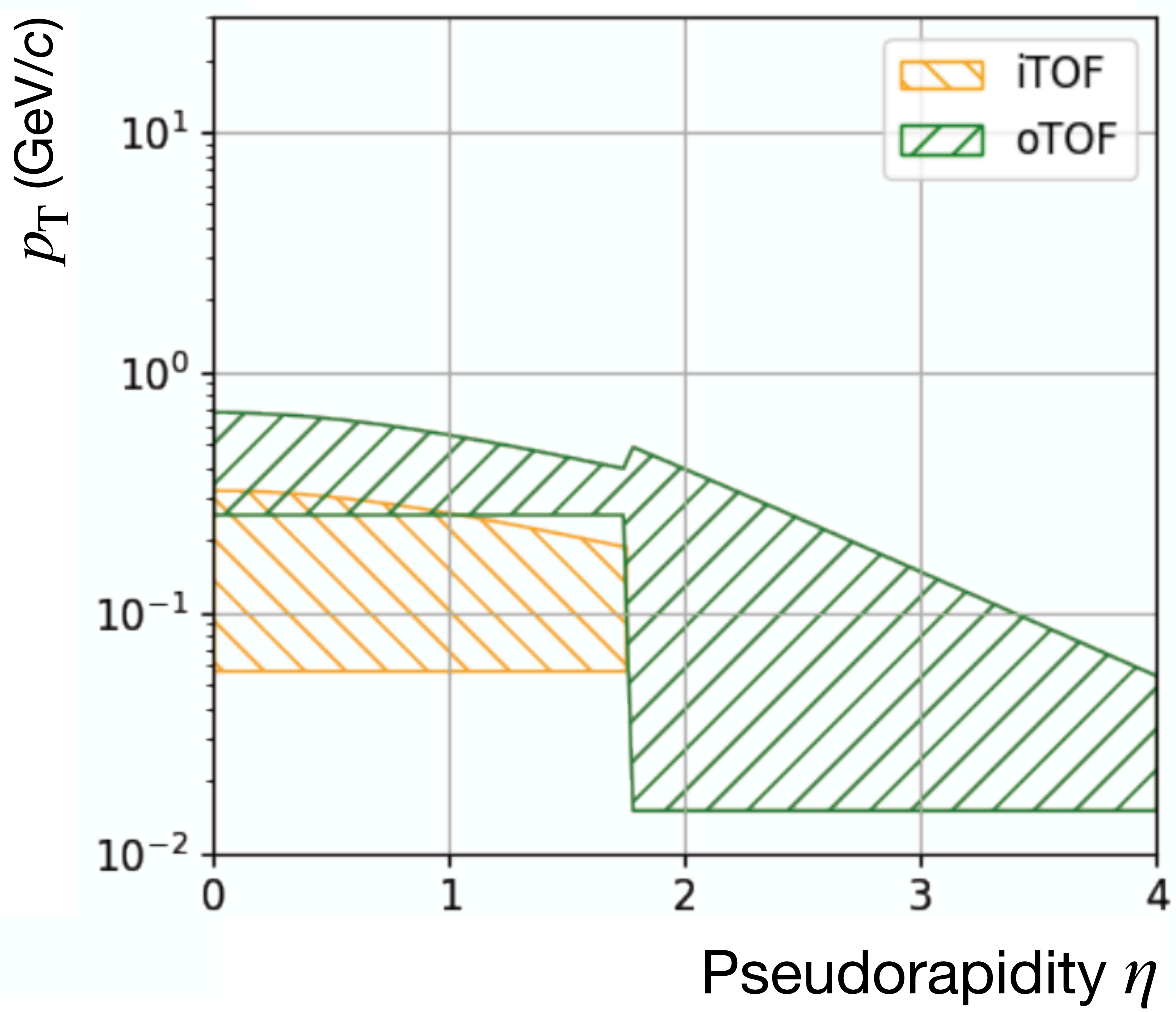
Use Time-of-flight detectors, Ring-imaging Cherenkov detectors, Calorimeters, muon chambers, FCT



Particle identification

- **Time-of-light detectors**
  - 2 barrel + 1 forward TOF layers ($R = 19$ & $85\,\text{cm}$, $z = 405\,\text{cm}$)
  - With silicon timing sensors ($\sigma_{\text{TOF}} \approx 20\,\text{ps}$)

3σ separation between e and π



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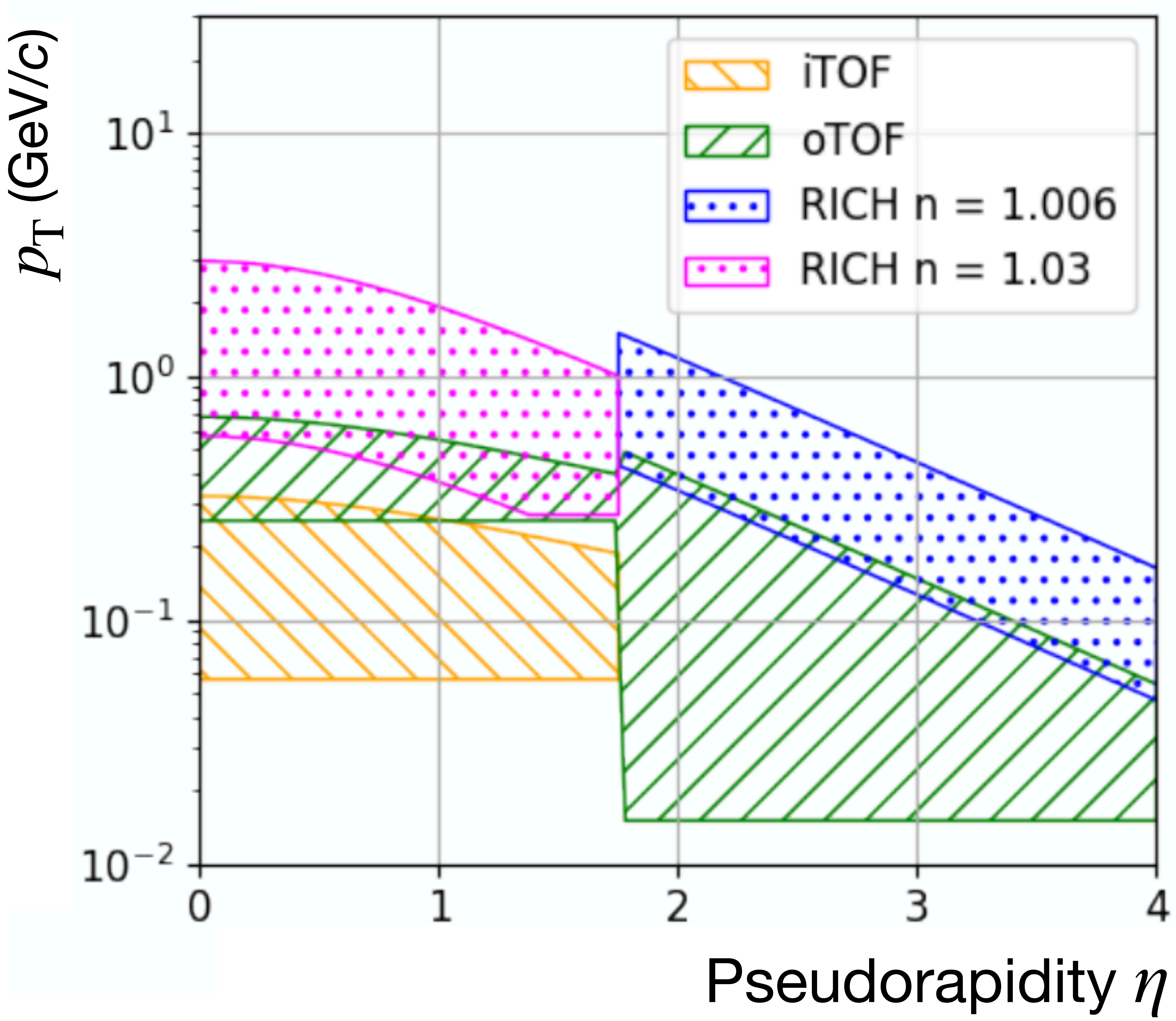
- **Ring-Imaging Cherenkov detectors**
  - 1 barrel + 1 forward layer
  - Aerogel radiators with continuous coverage from TOF

3σ separation between e and π



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Particle identification

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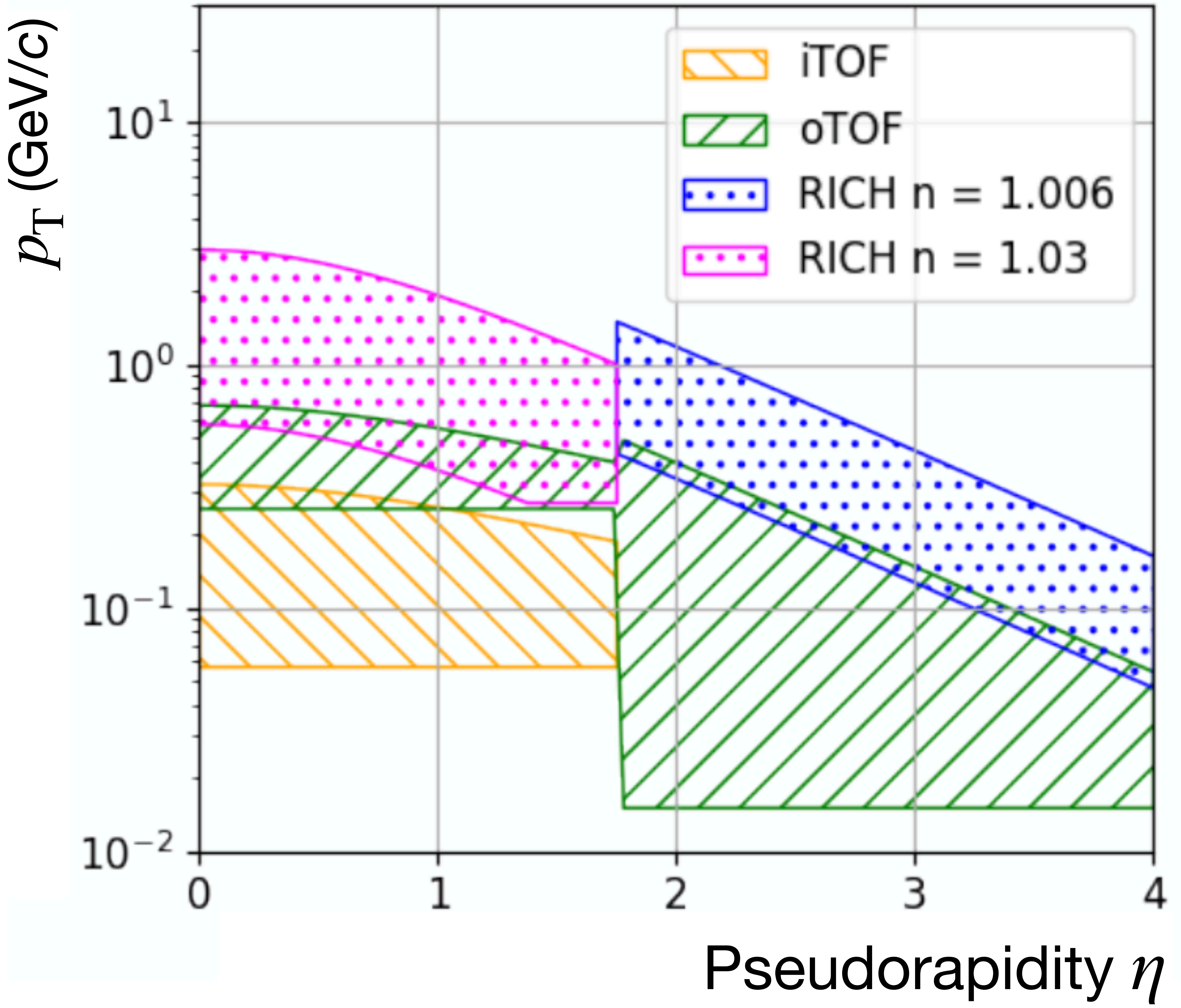
  - 2 barrel + 1 forward TOF layers ($R = 19$ & $85\,\mathrm{cm}$, $z = 405\,\mathrm{cm}$)
  - With silicon timing sensors ($\sigma_{\mathrm{TOF}} \approx 20\,\mathrm{ps}$)
- **Ring-Imaging Cherenkov detectors**
  - 1 barrel + 1 forward layer
  - Aerogel radiators with continuous coverage from TOF
- **Large acceptance Electromagnetic calorimeter**
  - Pb-scintillator sampling calorimeter + at $\eta \approx 0$ crystal calorimeter
  - Photons + high p electrons identification
- **Muon Identifier**
  - Absorber + 2 layers of muon detectors
  - Muons down to $p_{\mathrm{T}} \geq 1.5\,\mathrm{GeV}/c$
- **Forward conversion tracker**
  - Thin tracking disks in $3 < \eta < 5$ in its own dipole field
  - Very low p_{T} photons ($\leq 10\,\mathrm{MeV}/c$)

3σ separation between e and π



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Summary and outlook

ALICE 3 needed to unravel the microscopic dynamics of the QGP

Innovative detector concept to meet the requirements of the ALICE 3 physics program

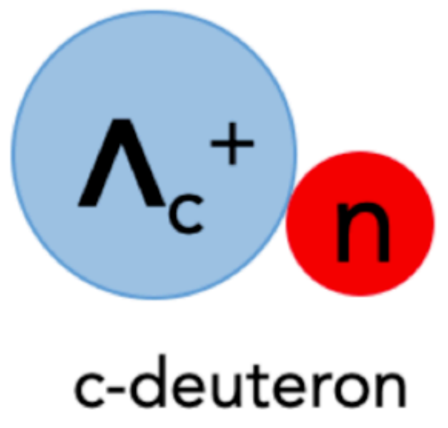
Outlook:

- 2023-25: Selection of technologies, small-scale proof of concept prototypes (≈ 25% of R&D founds)
- 2026-27: Large-scale engineered prototypes (≈ 75% of R&D funds)
  →Technical Design Reports
- 2028-32: Construction and testing
- 2033-34: Preparation of cavern and installation of ALICE 3

Thanks to the full ALICE 3 team for the huge work
in particular Jochen Klein and Marco Van Leeuwen

Back-up

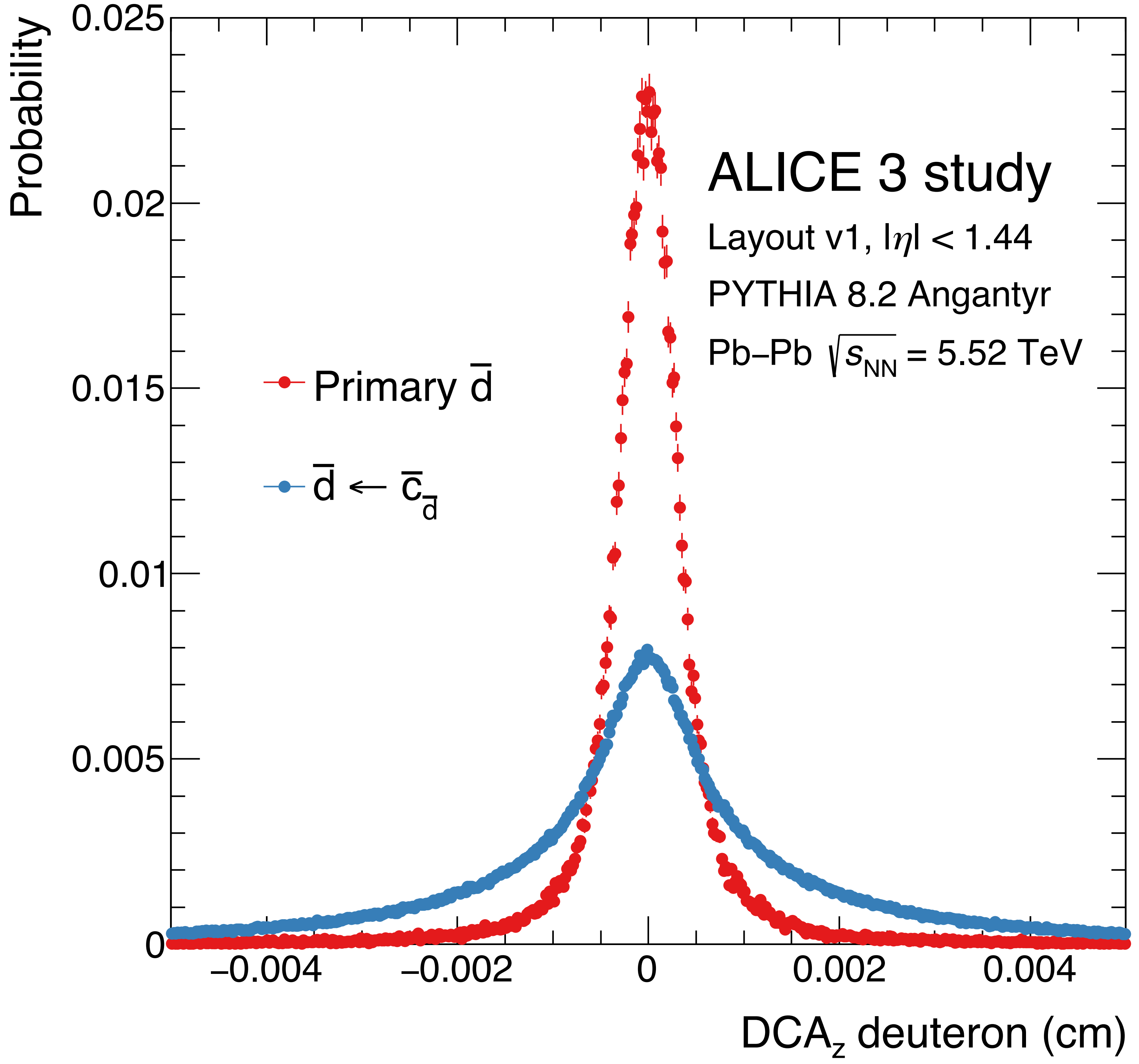
Nuclear states: charm-deuteron



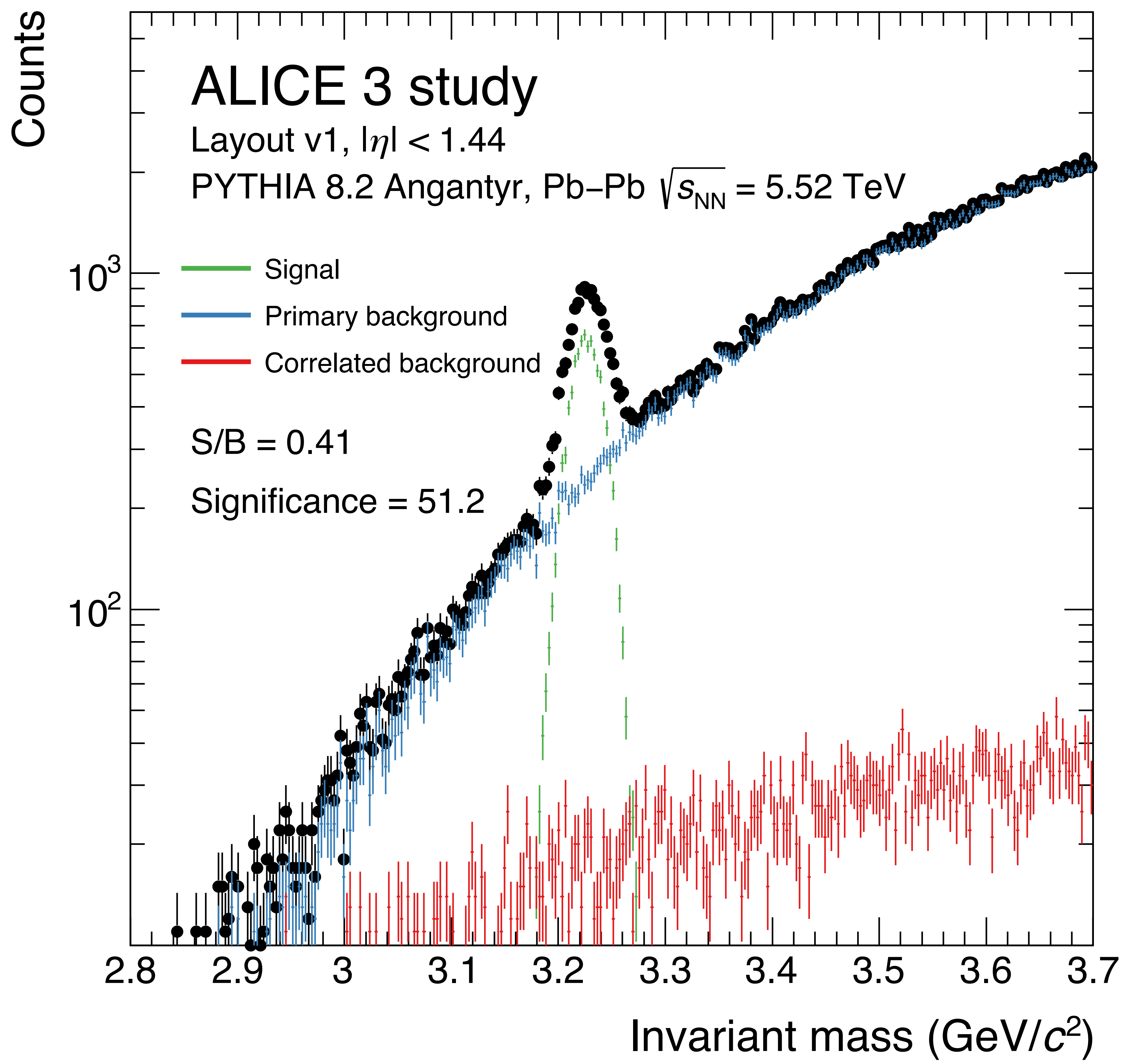
Study with the decay channel:
$c_{\mathrm{d}} \rightarrow d + K^{-} + \pi^{+}$

Assumed yield predicted by Statistic Hadronisation Model

Impact parameter distribution



Invariant mass distribution
in minimum-bias Pb—Pb collisions
On month data taking



Unique sensitivity to undiscovered charm-nuclei:

- For c-deuteron: reach significance of 50 for one month Pb—Pb fully integrated (centrality, p_{T}, η)
- For c-triton ($\Lambda_{c}nn$): 2.5 significance for one month Pb—Pb fully integrated

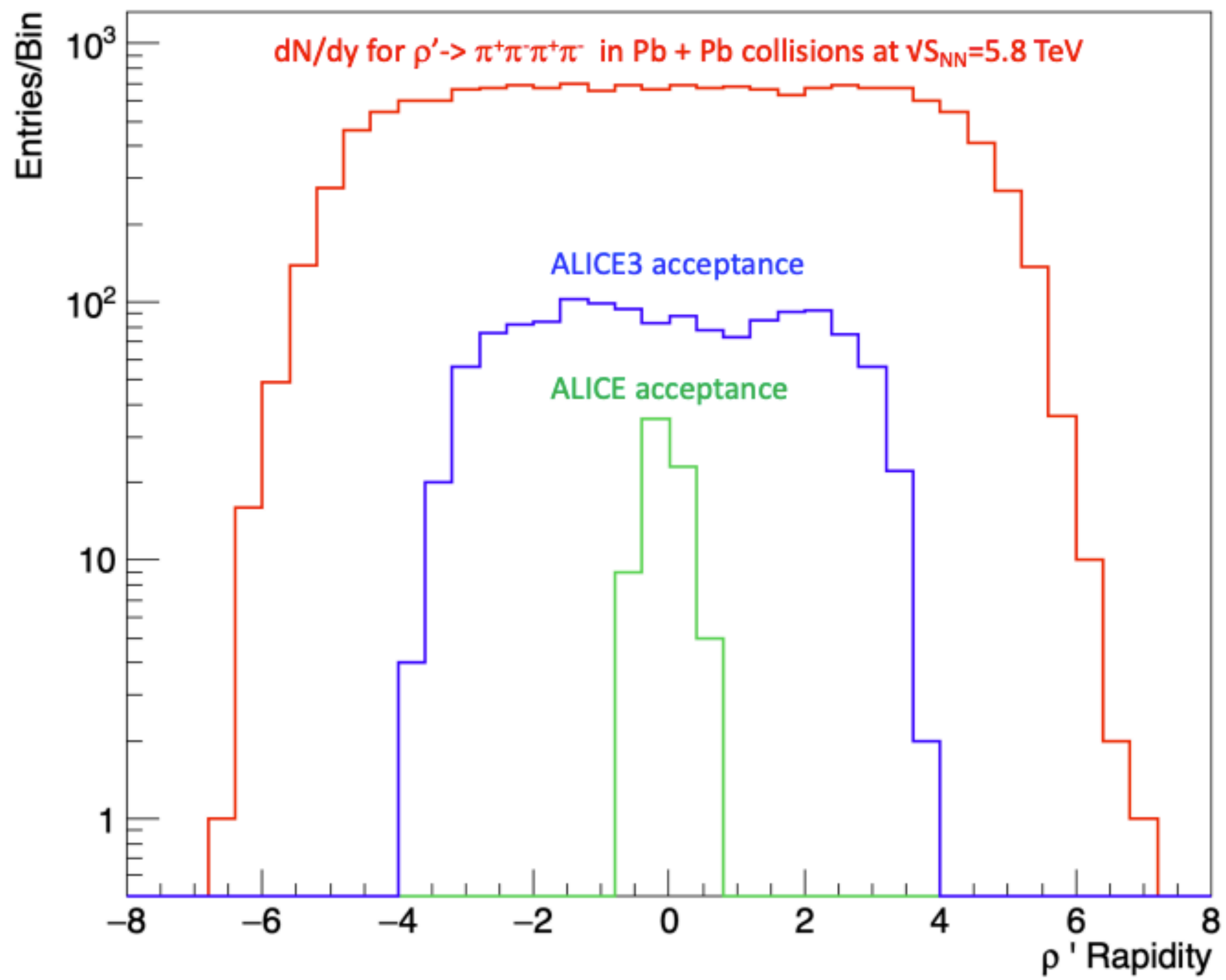
Photo-produced vector mesons

- Explore spectroscopy of higher excitations of ρ, ω, ϕ

- $\rho' \rightarrow \pi^+\pi^-\pi^+\pi^-$ measured by STAR:
  (STAR, PRC 81 (2010) 044901)
  - Shape consistent with one single resonance
  - But situation not yet 100% clear
    (Particle Data Group Collaboration, Phys. Rev. D 98 no. 3 (2018) 030001)

- Acceptance:
  - 0.4% with ALICE 2 ($|\eta| < 0.8$ & $p_T > 0.1$ GeV/c)
  - 8.4% with ALICE 3 ($|\eta| < 4.$ & $p_T > 0.1$ GeV/c)

$\rho' \rightarrow \pi^+\pi^-\pi^+\pi^-$ acceptance



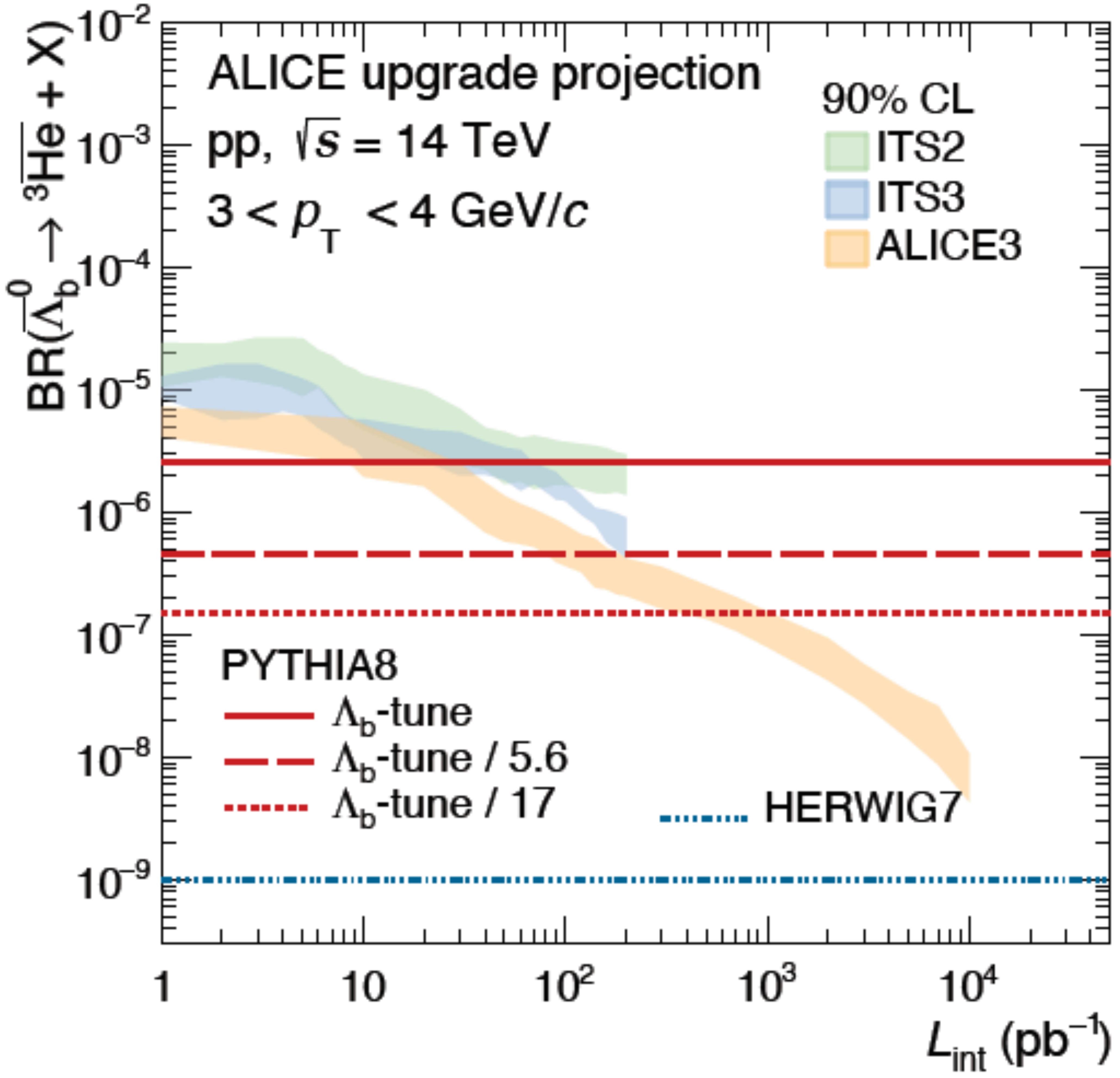
Study of b-quark decays into ^{3}He

- Detection of cosmic-ray antinuclei $^{3}\bar{He}$
  = promising signature of existence of
  weakly-interacting massive particles (WIMP)

- Preliminary evidence for cosmic-ray $^{3}\bar{He}$ by AMS experiment
  Possible production of $\bar{\Lambda}_b \rightarrow {}^{3}\bar{He} + X$ in dark-matter annihilation

With ALICE 3: precise measurement of decay branching ratio of $\Lambda_b \rightarrow {}^{3}He + X$

Upper limit at 90% CL on branching ratio

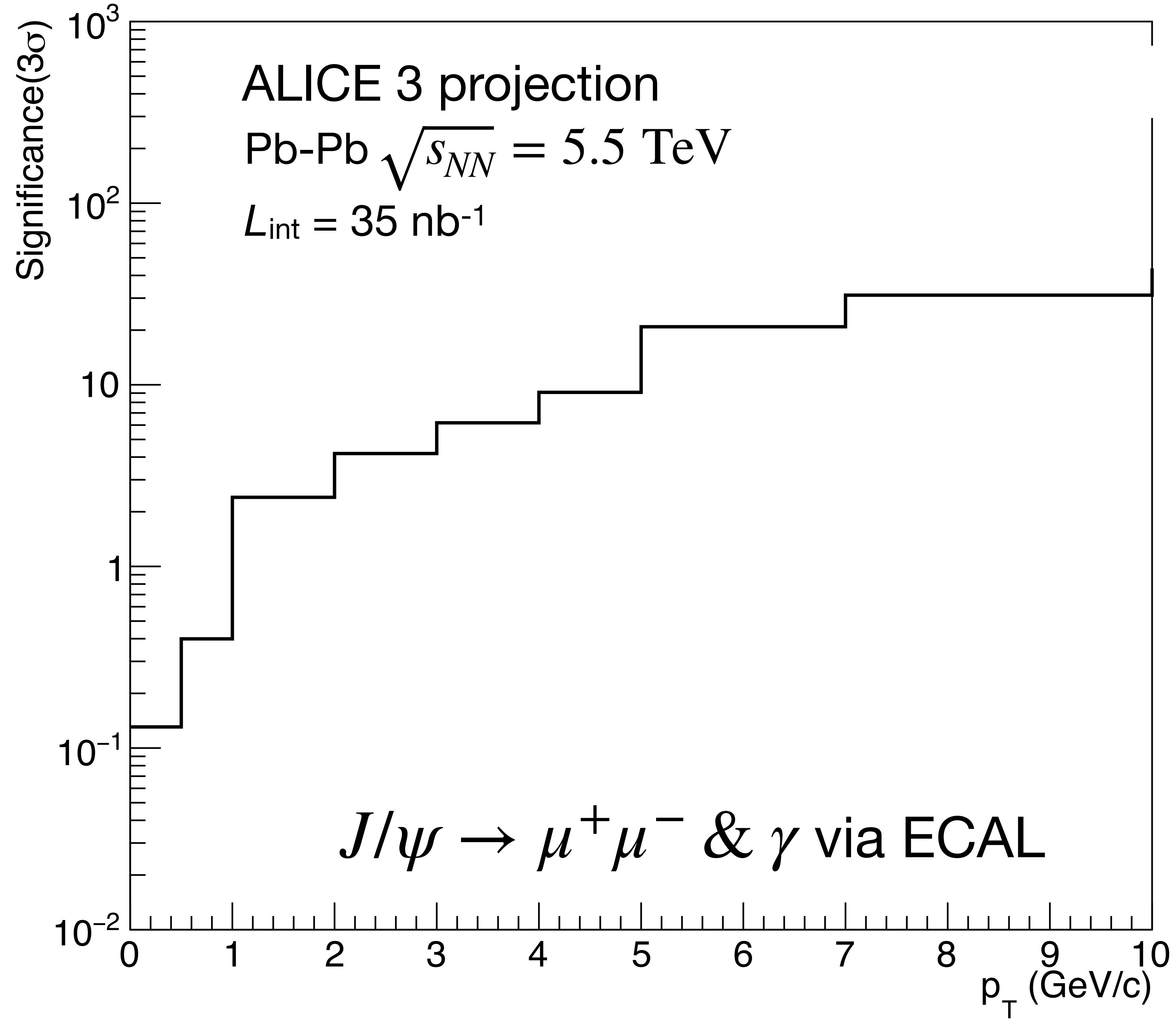


Other bound states: quarkonia

- Explore new states:
  - P-wave (L=1) states χ_c, χ_b
  - Pseudoscalar (L=1) states η_c, η_b
- Melting temperature depends on angular momentum…
- Measurement of χ_c, χ_b →Test theory

Require muon identification down to 1.5 GeV/*c* + photon detection

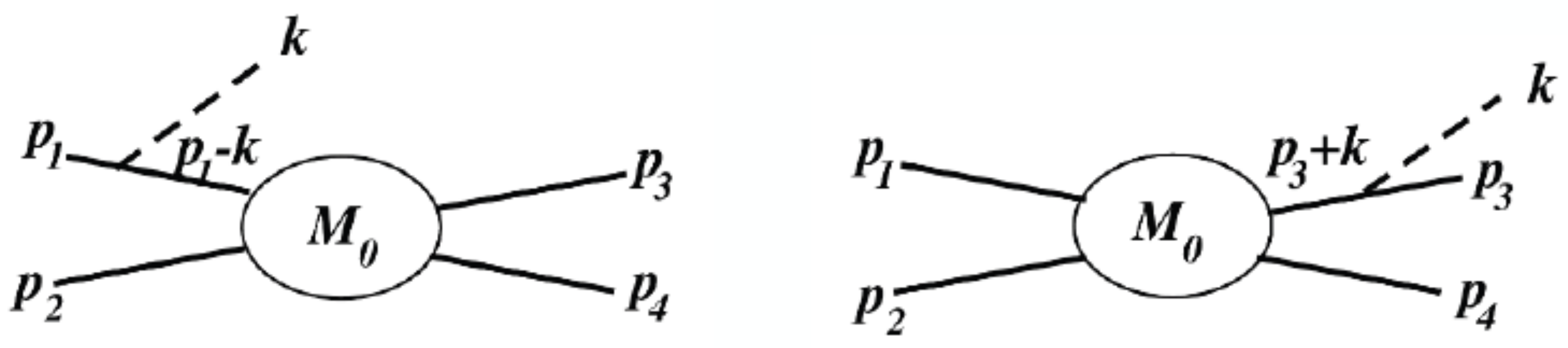
$\chi_c \to J/\psi + \gamma$ significance in Pb—Pb
six years of running



Ultra-soft γ production

HK 16.6

$p_1+p_2 \to p_3+p_4+k.$



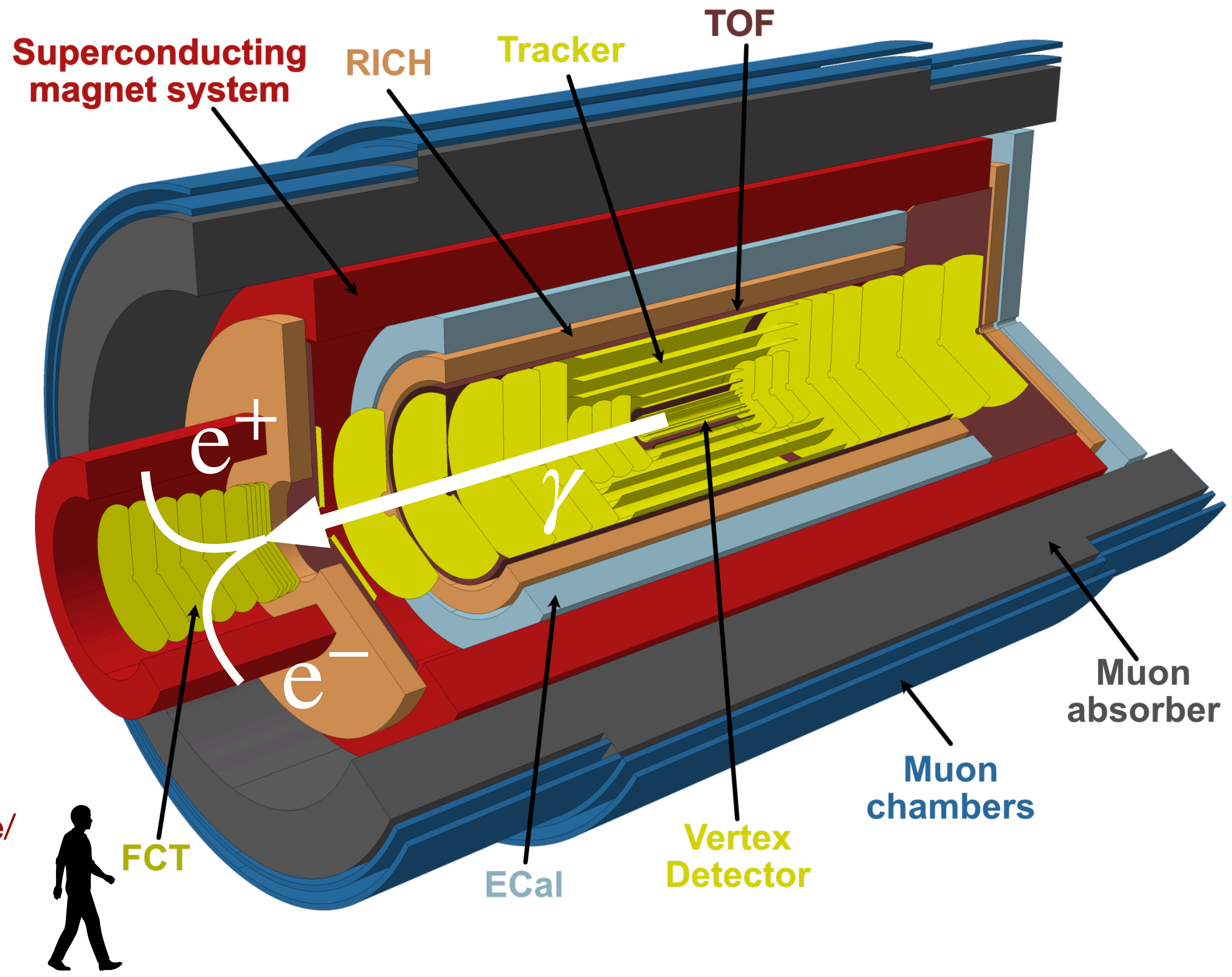
γ produced via inner bremsstrahlung

- **Observed yield not understood**
  - Cross section computable with Low-theorem
    → Related to infrared structure of quantum field theory
  - **Large excess observed at lower** $\sqrt{s}$ in association with hadrons

  Francis E. Low., Phys.Rev.Lett. 110 (1958) 468
  Overview: K. Reygers ALICE 3 Workshop https://indico.cern.ch/event/1063724/timetable/

- **Systematic study with ALICE 3:**
  - $\mathrm{pp} \to \mathrm{pp}\pi^+\pi^-\gamma$
  - $\mathrm{pp} \to \mathrm{pp}J/\psi\gamma \to \mathrm{ppe^+e^-}\gamma$ ($\approx$ purely leptonic final state)
  - Inclusive pp collisions as a function of charged particle multiplicity

Large η acceptance → clean selection of exclusive process



Forward Conversion Tracker (FCT, $3 \leq \eta \leq 5$)

$E_\gamma \geq$ 50 MeV with photon conversion

Measure γs with $1 \leq p_T \leq$ 10 MeV/c

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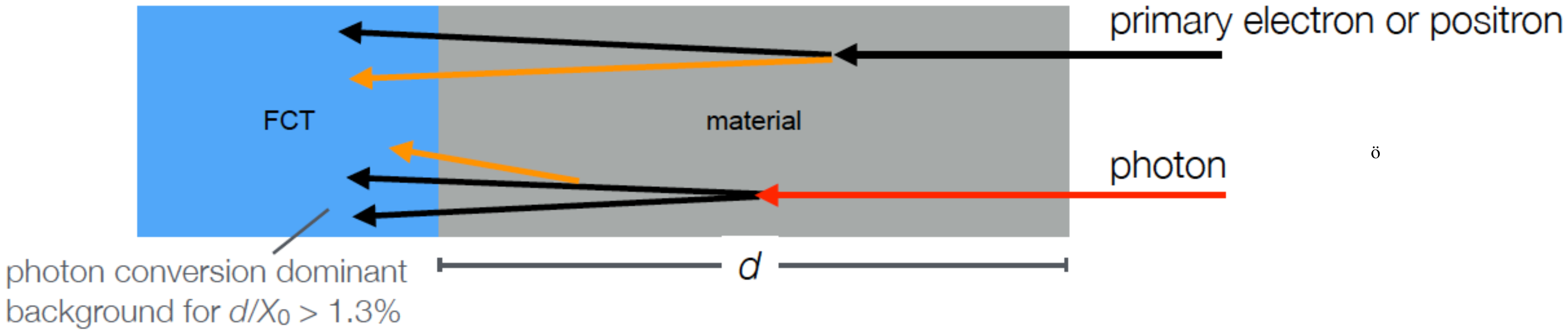
Ultra-soft γ in inclusive pp collisions

- **Signal:** inner Bremsstrahlung
- Background:
  - Decay photons ($\pi^0 \to \gamma\gamma$)
  - Secondary photons from material

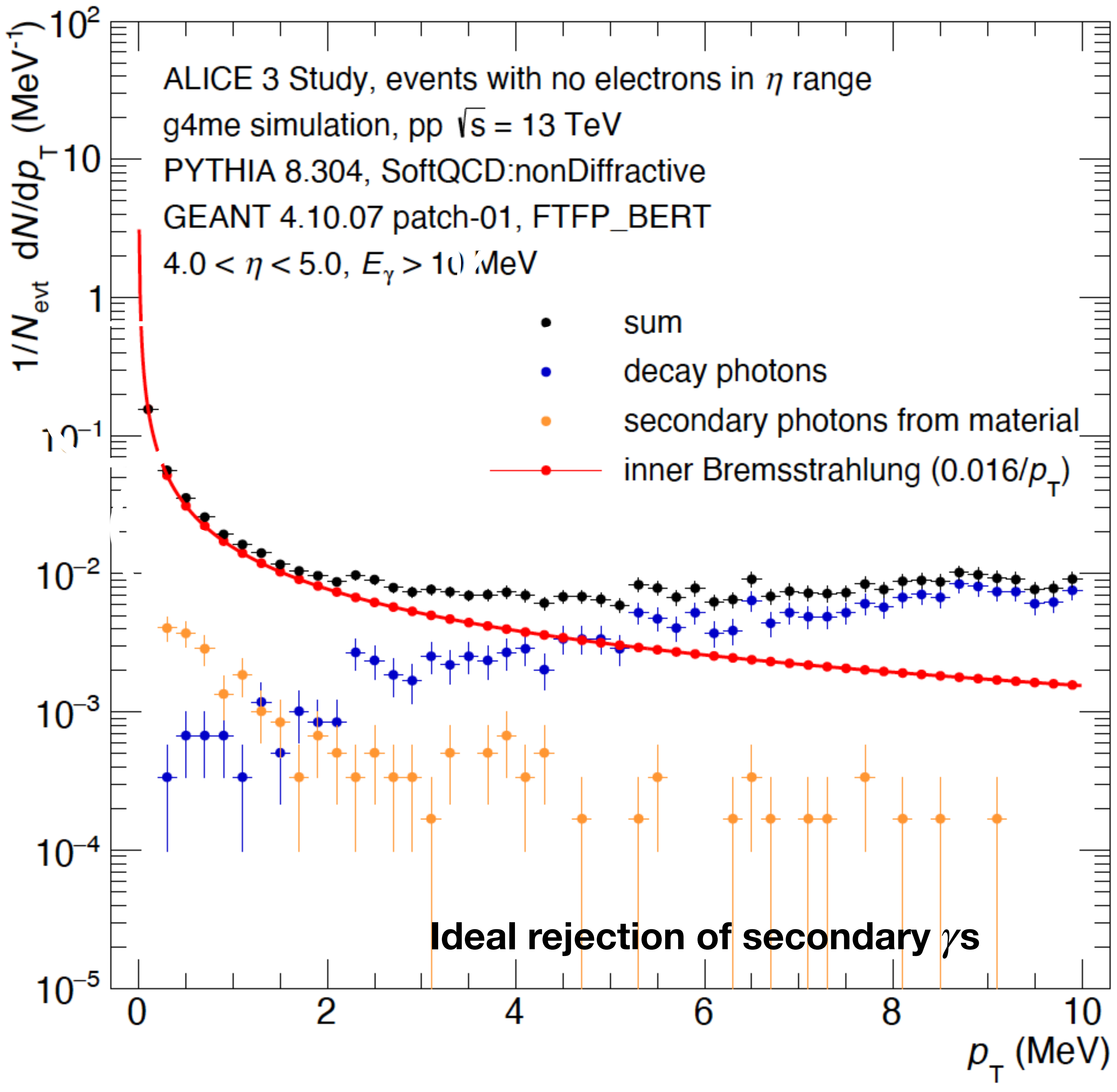


→Minimize material in front of FCT

→ Develop strategy to reject events with $e^\pm$ in the FCT η acceptance (here ideal case)

→ Expect 20% uncertainties in all planned reactions
Complementary ultra-soft e^+e^- measurements (lower p_T than ALICE 2)

Inclusive pp collisions at $\sqrt{s} = 13$ TeV
Expected yields for signal and backgrounds

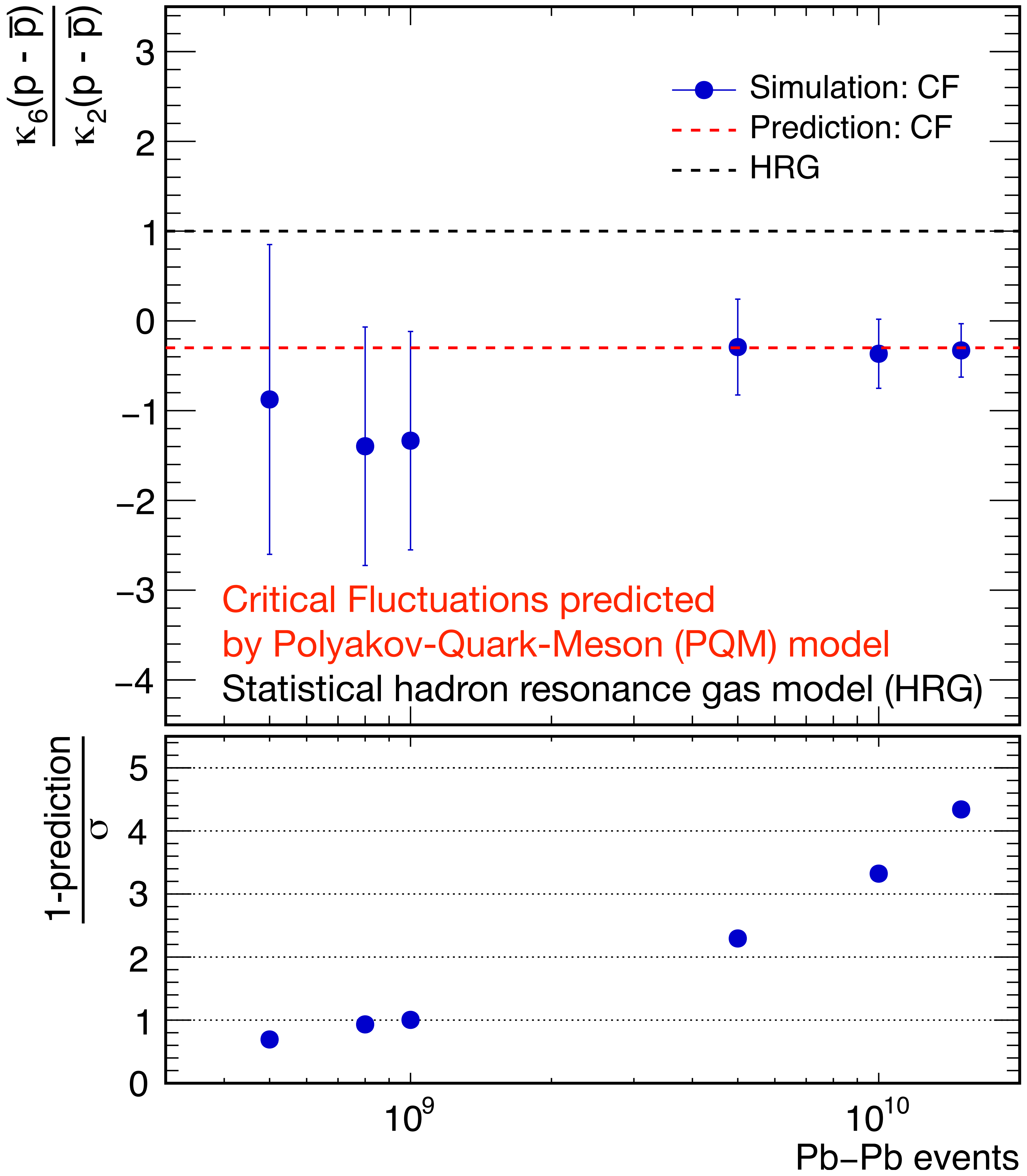


Fluctuations of conserved charge

- Baryon number susceptibility of QGP: calculable with lattice QGP
- Accessible via cumulants of net-proton number fluctuations
- Higher order cumulants: phase transition between QGP and HG
  → 4σ observation in reach with ALICE 3 ($\kappa_6(\mathrm{p}-\bar{\mathrm{p}})/\kappa_2(\mathrm{p}-\bar{\mathrm{p}})$)
- Lower-order cumulants: long-range rapidity correlations
  → Large acceptance crucial

Net-baryon fluctuation measurements profit from large ALICE 3 acceptance and very good PID
→ Can be extended to net-charm fluctuations (D mesons)

ALICE 3 Projection for 6th cumulant



G.A. Almasi, B. Friman, K. Redlich, PRD 96 no. 1 (2017) 014027
ALICE CERN-LHCC-2022-009

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  → **Large acceptance crucial**

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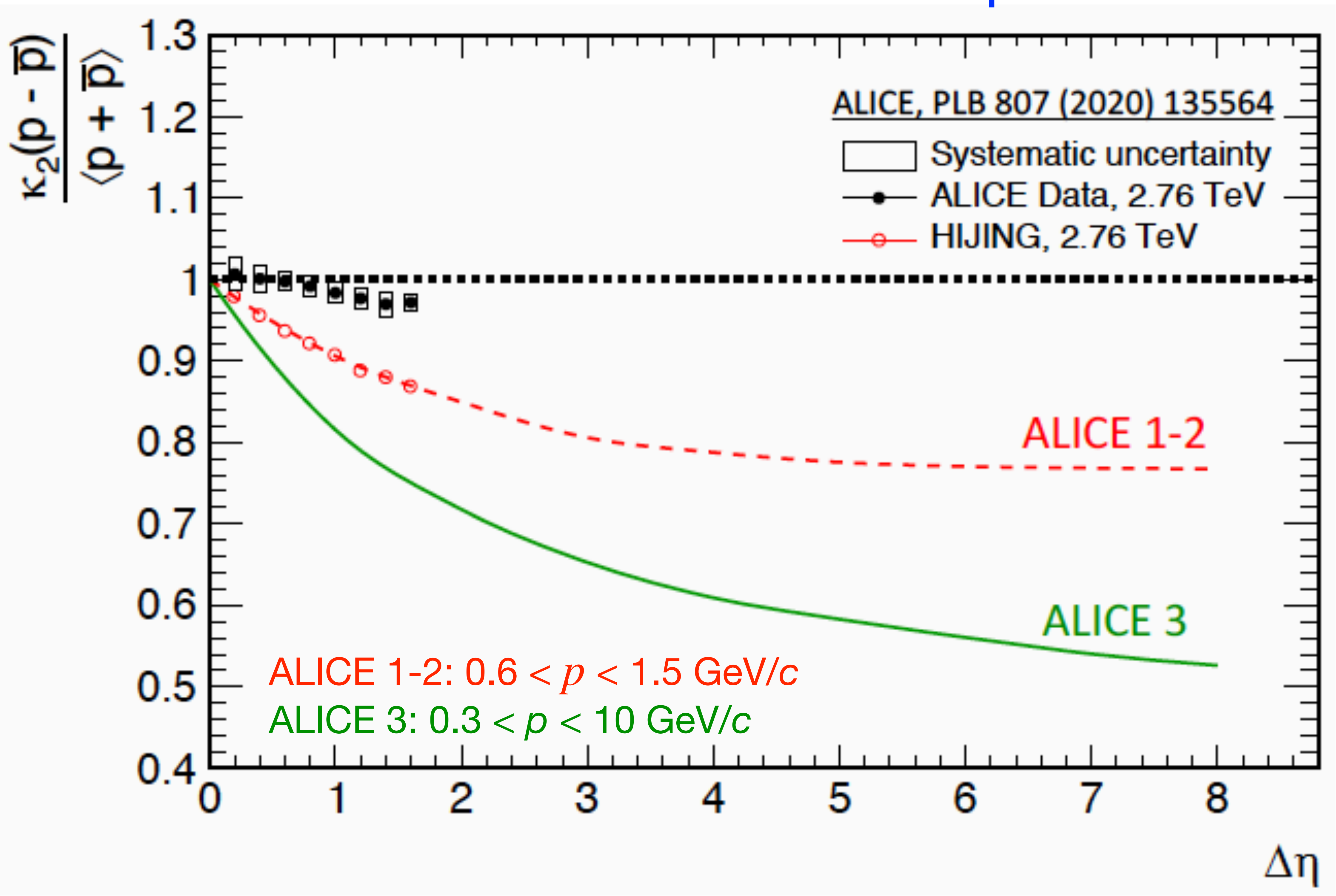
Pseudorapidity dependence of normalised second cumulants of net-protons



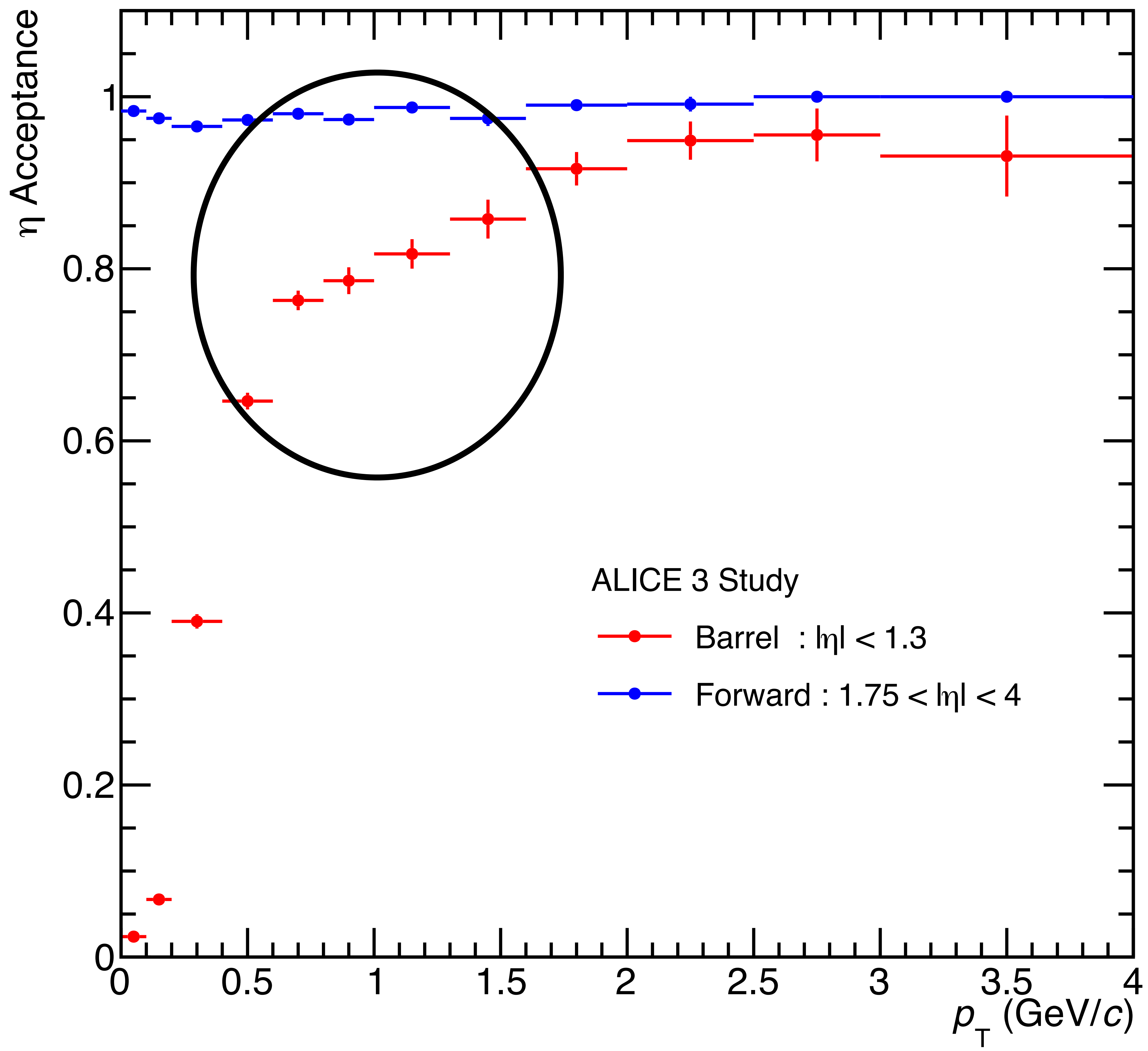
Measurement of η (and π^0) down to $p_{\mathrm{T}} = 0$

- p_{T} spectrum of direct photons
  → **Alternative method of *T* determination**
  with different systematic uncertainties

- Main background: π^0, η decays:
  Can be measured down to very low p_{T} for $1.75 < \eta < 4$
  Not possible with ALICE 2

Significant reduction of uncertainties expected

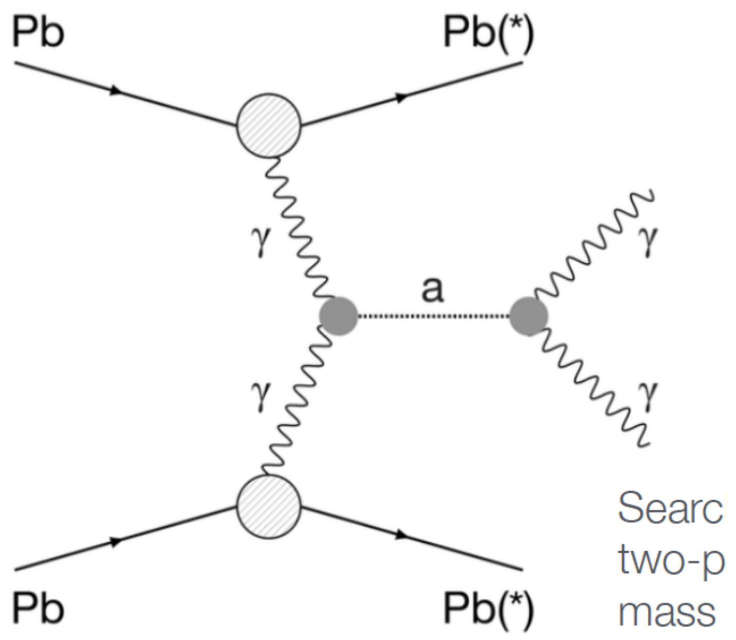
Acceptance for
$\eta \to \gamma\gamma$ with $p_\gamma > 100\,\mathrm{MeV}/c$



Beyond QGP physics

- **Axion-like particles (ALPs)** = elementary pseudoscalar particles appearing in many BSM extensions as Goldstone bosons (Dark matter candidates/mediators)

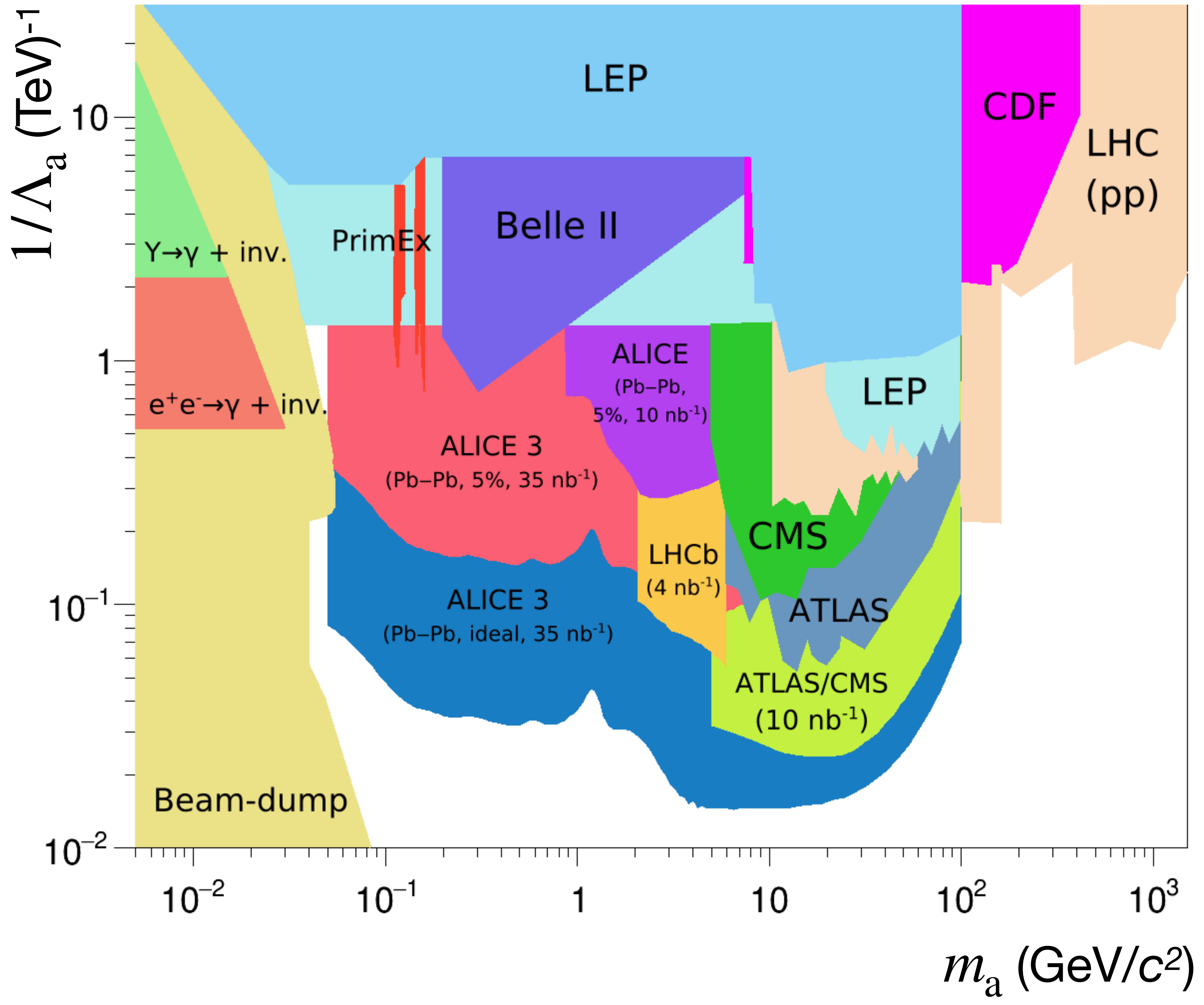
- **Search for ALPs in ultra-peripheral collisions**



Look for peak in the two-photon invariant mass spectrum
Background considered: $\pi^0\pi^0$ photo-production, light-by-light scattering

- **With ALICE 3 take advantage of:**
  - Large rapidity coverage $|\eta| \leq 4$
  - Capability to measure γ down to small E ($E \geq$ 50-100 MeV)

ALP search: expected sensitivity
as a function of m_a and ALP-γ coupling $1/\Lambda_a$



Existing limits from ATLAS, JHEP 03, 243 (2021)
Projections for ATLAS/CMS from PRL 118 (2017), 171801
Projections for LHCb from Goncalves et al. EPJC 81 (2021), 522

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Heavy-ion species

- Maximise statistics for rare probes → Identify species best suited for physics programm
- Limitation in the injection complex:
  - Injection of bunches with higher intensities possible for lighter ions (lower charges)
  - For lighter ions:
    - Expect larger nucleon-nucleon luminosities(determine rate of hard probes)
    - But smaller collision system and QGP effects for lighter ions
- Performance studies done with Pb—Pb (most challenging in term of signal-to-background)

Nucleon-nucleon luminosity:

$$\mathscr{L}_{\mathrm{NN}} = A^2 \cdot \mathscr{L}_{\mathrm{AA}}$$

optimistic scenario	O-O	Ar-Ar	Ca-Ca	Kr-Kr	In-In	Xe-Xe	Pb-Pb
$\langle L_{AA} \rangle$ (cm^{-2} s^{-1})	$9.5 \cdot 10^{29}$	$2.0 \cdot 10^{29}$	$1.9 \cdot 10^{29}$	$5.0 \cdot 10^{28}$	$2.3 \cdot 10^{28}$	$1.6 \cdot 10^{28}$	$3.3 \cdot 10^{27}$
$\langle L_{NN} \rangle$ (cm^{-2} s^{-1})	$2.4 \cdot 10^{32}$	$3.3 \cdot 10^{32}$	$3.0 \cdot 10^{32}$	$3.0 \cdot 10^{32}$	$3.0 \cdot 10^{32}$	$2.6 \cdot 10^{32}$	$1.4 \cdot 10^{32}$
$\mathscr{L}_{AA}$ (nb^{-1} / month)	$1.6 \cdot 10^{3}$	$3.4 \cdot 10^{2}$	$3.1 \cdot 10^{2}$	$8.4 \cdot 10^{1}$	$3.9 \cdot 10^{1}$	$2.6 \cdot 10^{1}$	$5.6 \cdot 10^{0}$
$\mathscr{L}_{NN}$ (pb^{-1} / month)	**409**	**550**	**500**	**510**	**512**	**434**	**242**

Strength of QGP effects
(e.g. charm abundance, quenching, also background)

Luminosity

System	$\mathscr{L}^{\text{month}}$	$\mathscr{L}^{\text{Run5+6}}$
pp	$0.5\,\text{fb}^{-1}$	$18\,\text{fb}^{-1}$
pp reference	$100\,\text{pb}^{-1}$	$200\,\text{pb}^{-1}$
A–A		
Xe–Xe	$26\,\text{nb}^{-1}$	$156\,\text{nb}^{-1}$
Pb–Pb	$5.6\,\text{nb}^{-1}$	$33.6\,\text{nb}^{-1}$

Table 2: Integrated luminosities for different collision systems

Integrated luminosity for Run 3+4

$200\ \text{pb}^{-1}$ at 13.6 TeV with high-multiplicity and rare probe selection

$13\ \text{nb}^{-1}$ with Pb—Pb

Ring-Imaging Cherenkov

- **Separation power** $\propto \frac{L}{\sigma_{\text{tof}}}$
    - distance and time resolution crucial

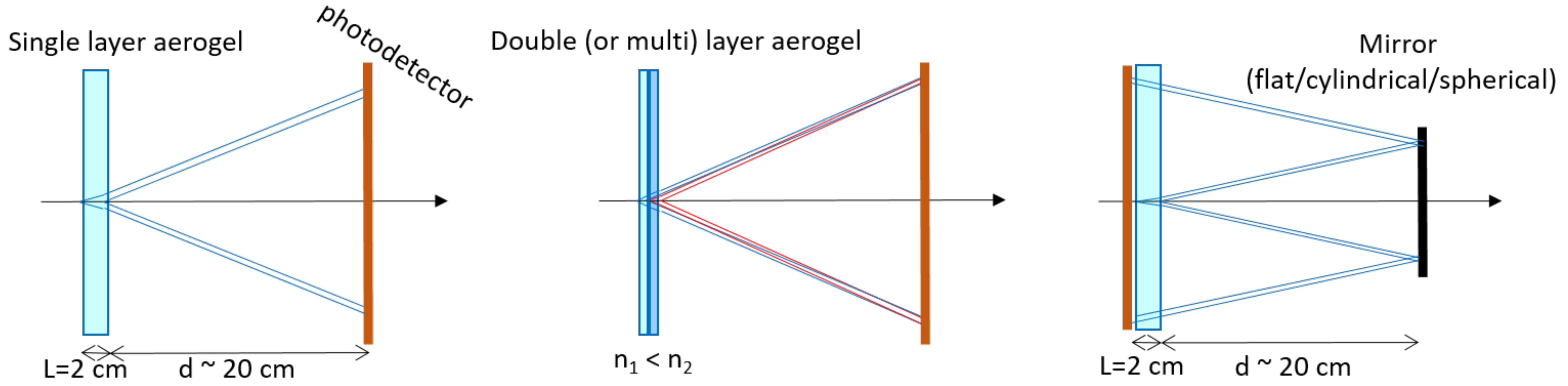
- **2 barrel + 1 forward TOF layers**
    - outer TOF at R ≈ 85 cm
    - inner TOF at R ≈ 19 cm
    - forward TOF at z ≈ 405 cm

- **Silicon timing sensors** ($\sigma_{TOF} \approx$ 20 ps)
    - Total silicon surface ~45 m^2
    - **R&D programme** on
      monolithic CMOS sensors with integrated gain layer

Ring-Imaging Cherenkov

Extend PID reach of outer TOF to higher p_T
➟ Cherenkov

- 2 cm thick **aerogel radiator**
  to ensure continuous coverage from TOF
  → refractive index n = 1.03 (barrel)
  → refractive index n = 1.006 (forward)
- **Silicon photon detection layer at 20 cm from the radiator:**
  - Total SiPM surface ~60 m^2
  - **R&D programme** on monolithic photon sensors
- Cherenkov angular resolution ≈ 1.5 mrad
- Cherenkov emission threshold determines low p_T reach



Electromagnetic calorimeter

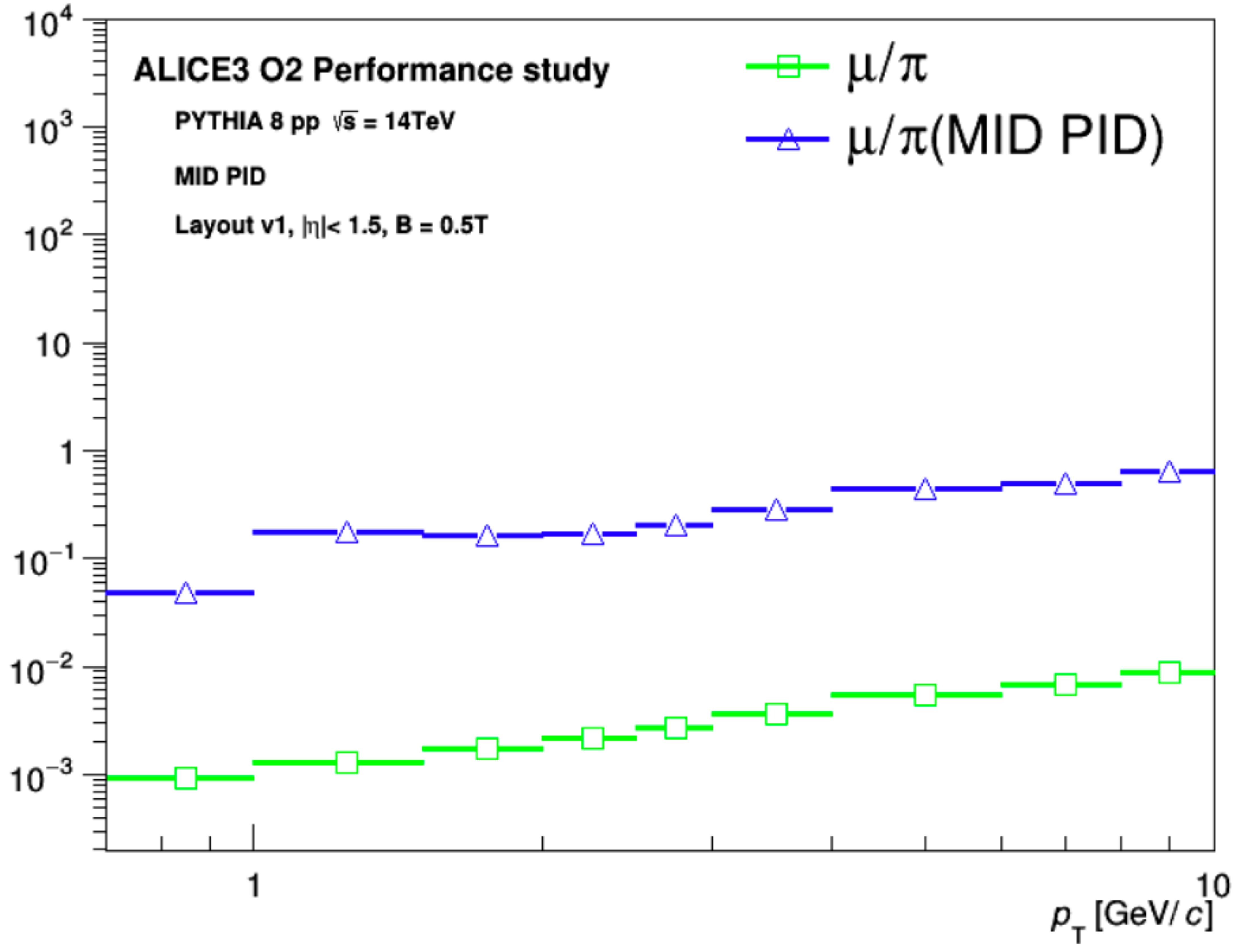
- **Large acceptance ECal**
  → sampling calorimeter (à la ALICE EMCal/DCal):
  O(100) layers (1 mm Pb + 1.5 mm plastic scintillator)

- **Additional high energy resolution segment** at mid-rapidity
  → $PbWO_4$-based (à la ALICE PHOS)

ECal module	Barrel sampling	Endcap sampling	Barrel high-precision
acceptance	$\Delta\varphi = 2\pi$, $\lvert\eta\rvert < 1.5$	$\Delta\varphi = 2\pi$, $1.5 < \eta < 4$	$\Delta\varphi = 2\pi$, $\lvert\eta\rvert < 0.33$
geometry	$R_{in} = 1.15$ m, $\lvert z\rvert < 2.7$ m	$0.16 < R < 1.8$ m, $z = 4.35$ m	$R_{in} = 1.15$ m, $\lvert z\rvert < 0.64$ m
technology	sampling Pb + scint.	sampling Pb + scint.	$PbWO_4$ crystals
cell size	30×30 mm^2	40×40 mm^2	22×22 mm^2
no. of channels	30 000	6 000	20 000
energy range	$0.1 < E < 100$ GeV	$0.1 < E < 250$ GeV	$0.01 < E < 100$ GeV

Muon Identifier

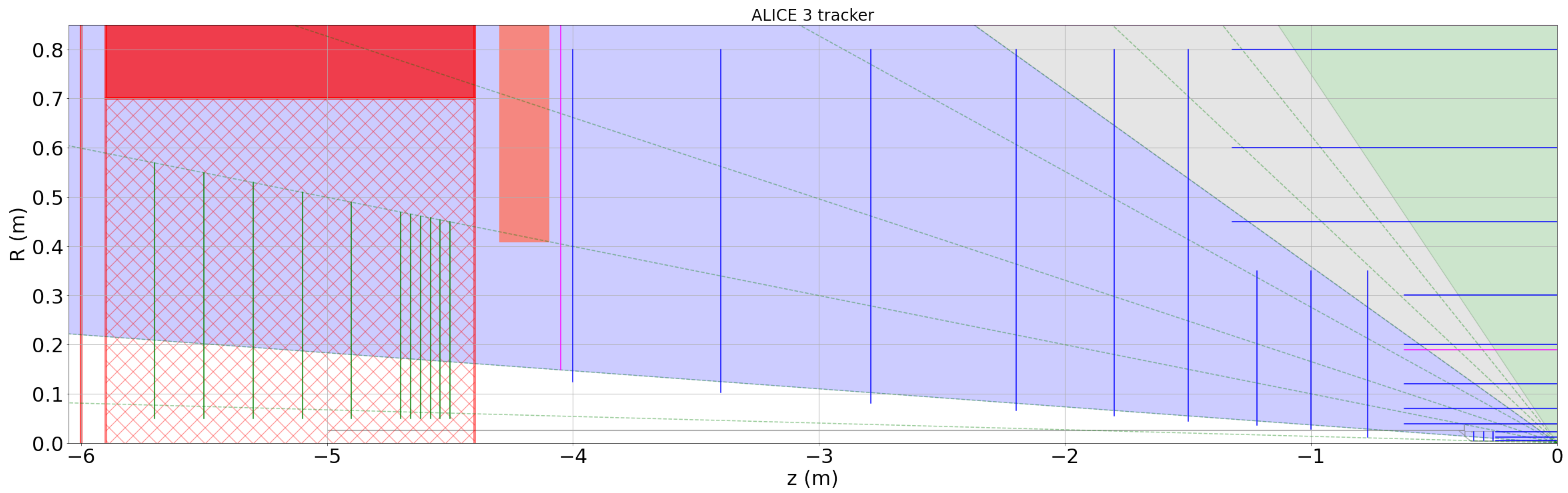
- **Hadron absorber**
  - ~70 cm non-magnetic steel
- **Muon chambers**
  - search spot for muons ~0.1 x 0.1 (eta x phi)
    → ~5 x 5 cm² cell size
  - matching demonstrated with 2 layers of muon chambers
    - scintillator bars
    - Equipped with wave-length shifting fibres
    - Read-out with SiPM



Forward conversion tracker

- **Thin silicon pixel disks** to cover $3 < \eta < 5$
  - A few 0.1% of radiation length per layer
  - Position resolution < 10 μm

- **Own dipole magnet**
  - Dipole field component $B_{\mathrm{y}} \approx$ 0.3 T
- R&D programme on
  - Minimisation of material in front of FCT
  - Operational conditions



ALICE timeline

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

Run 1 2009 - 2013	Run 2 2015 - 2018	Run 3 2022 - 2025	Run 4 2029 - 2032	Run 5	Run 6
ALICE 1		ALICE 2	ALICE 2.1 upgrade	ALICE 3 upgrade	

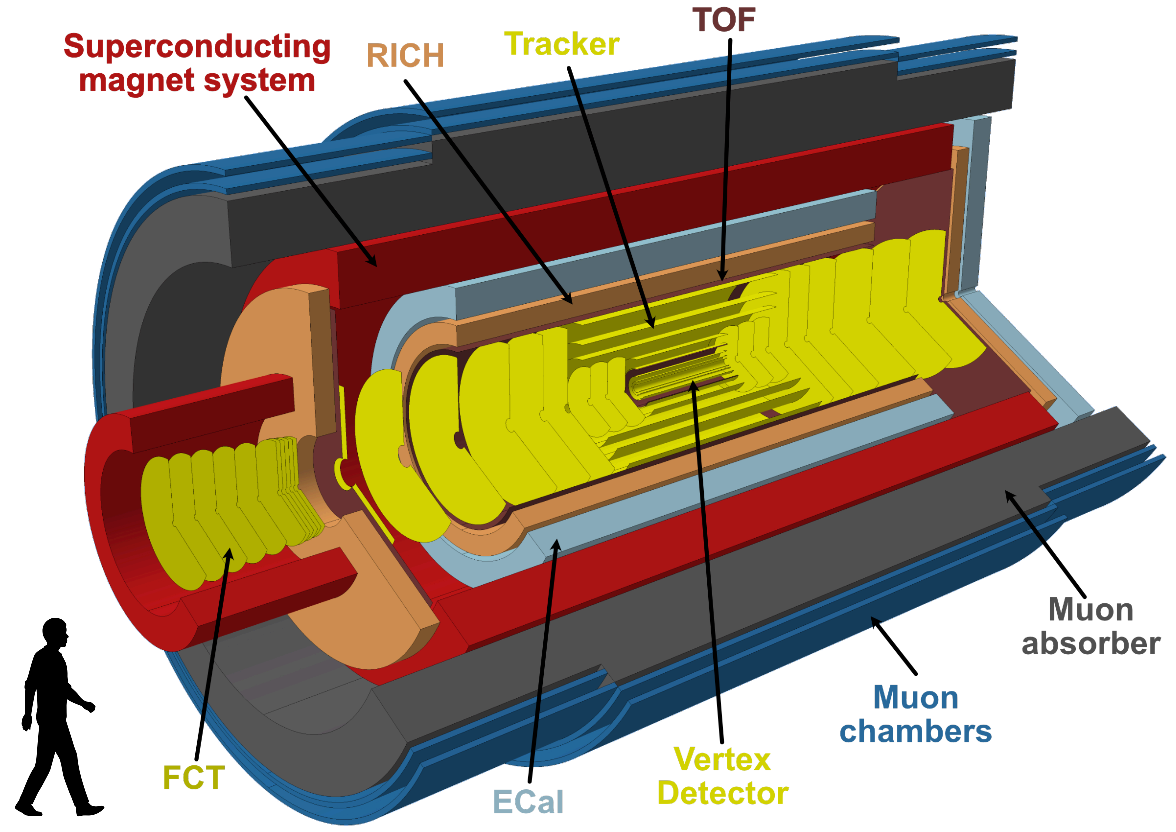
Run 3 & 4 (covered by previous talk Sarah Porteboeuf)

- ALICE 2 upgrades ready for high-luminosity heavy-ion collisions
- Preparation for Technical Design Reports for intermediate upgrades with ALICE 2.1

Beyond Run 4 (this talk):

- Address fundamental questions still open:
  - → First ideas at Heavy-Ion town meeting 2018 D.Adamova et al. ArXiv:1902.01211
  - → Letter of Intent for **ALICE 3:**
    Review concluded with very positive feedback by the LHCC in March 2022
    ALICE CERN-LHCC-2022-009

European Particle Physics Strategy Update recommends **full exploitation of the LHC, incl. heavy-ion programme**



Intermediate upgrade | Major upgrade