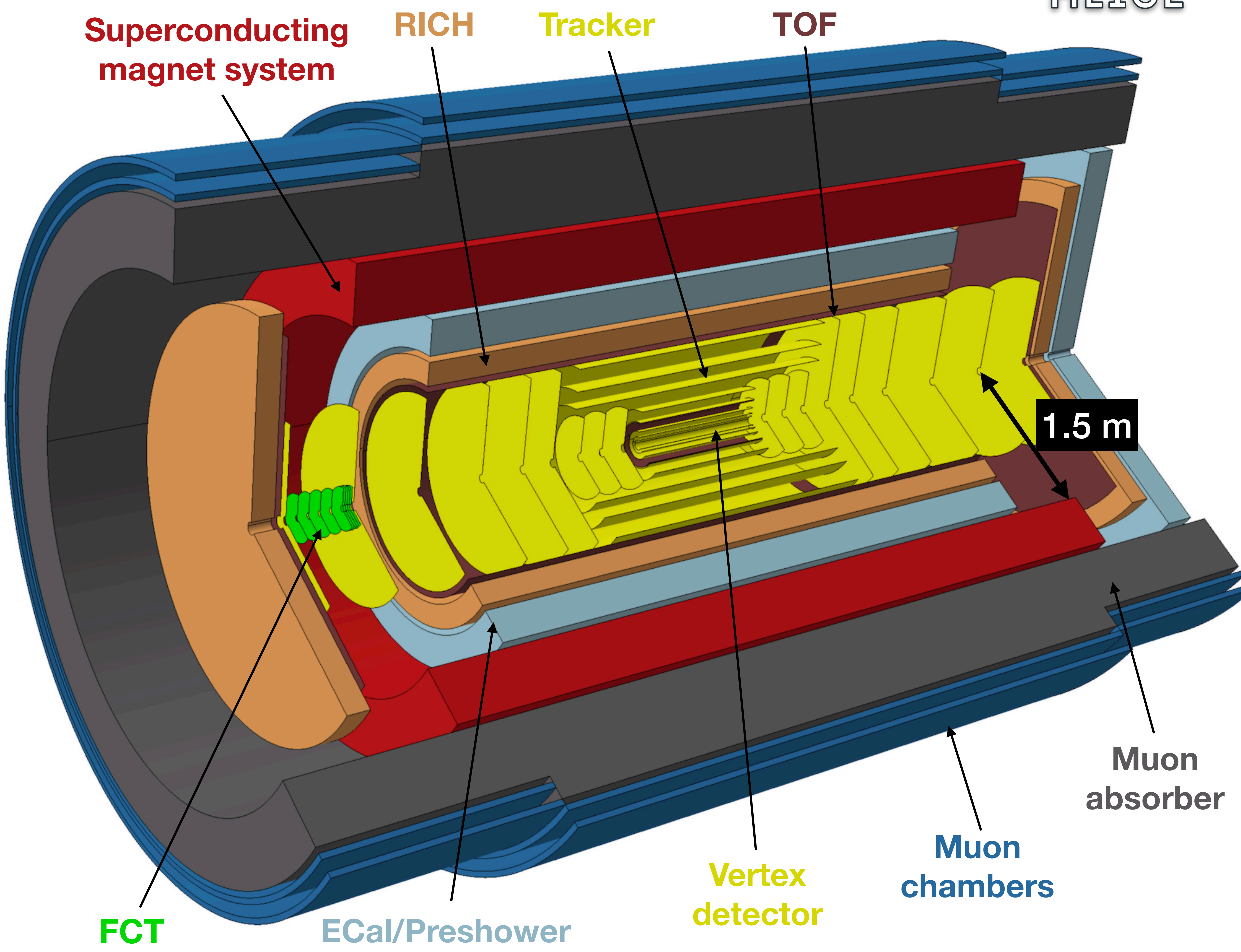
ALICE 3

Overview

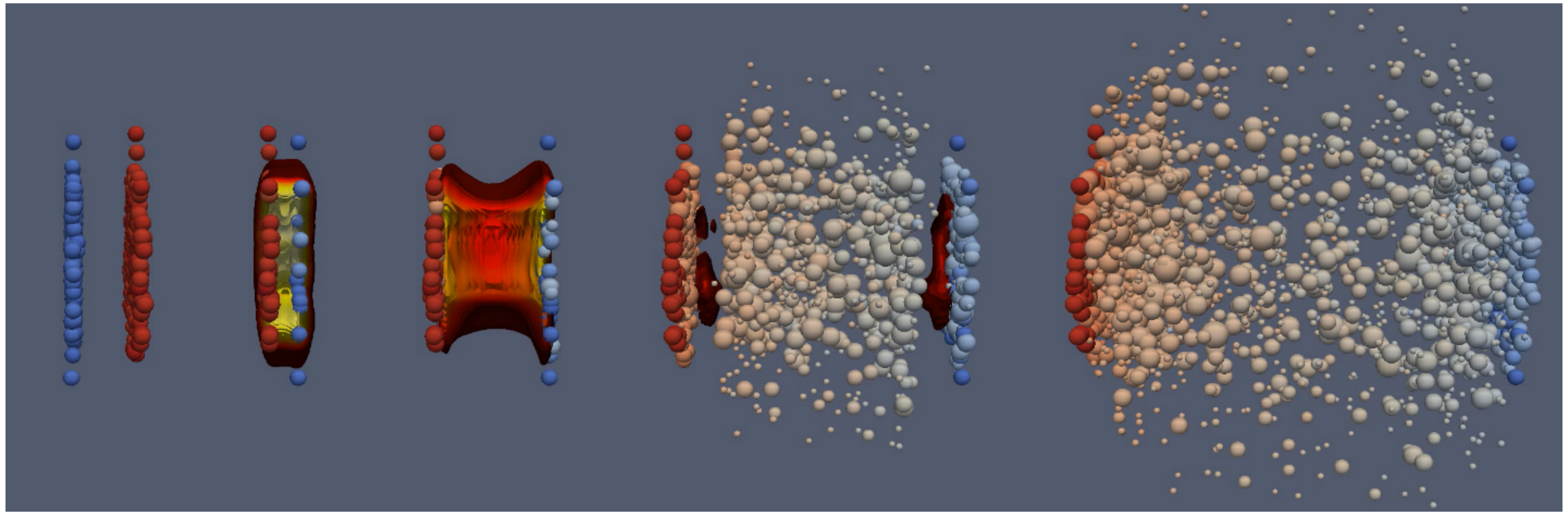
Marco van Leeuwen (Nikhef)



Context and time line

- Idea for **next-generation heavy-ion programme** at the LHC developed within ALICE in the course of 2018/19
  - Discussed at the **heavy-ion town meeting** (CERN, October 2018)
  - Initiative supported by **European Strategy for Particle Physics Update**
    - Expression of Interest submitted to the Granada meeting
- Further development of detector concept and physics studies within ALICE
  - ***ALICE 3 workshops*** in October 2020 and June 2021
- Letter of Intent prepared for submission to LHCC

Heavy-ion collisions



Initial stages

Gluon-dominated
Color Glass Condensate?
Isotropisation/
hydrodynamisation

QGP fluid expansion

Equation of State
Shear, bulk viscosity: η, ζ
Heavy quark transport
⇒ approach to thermalisation
Parton energy loss
Melting of quarkonia

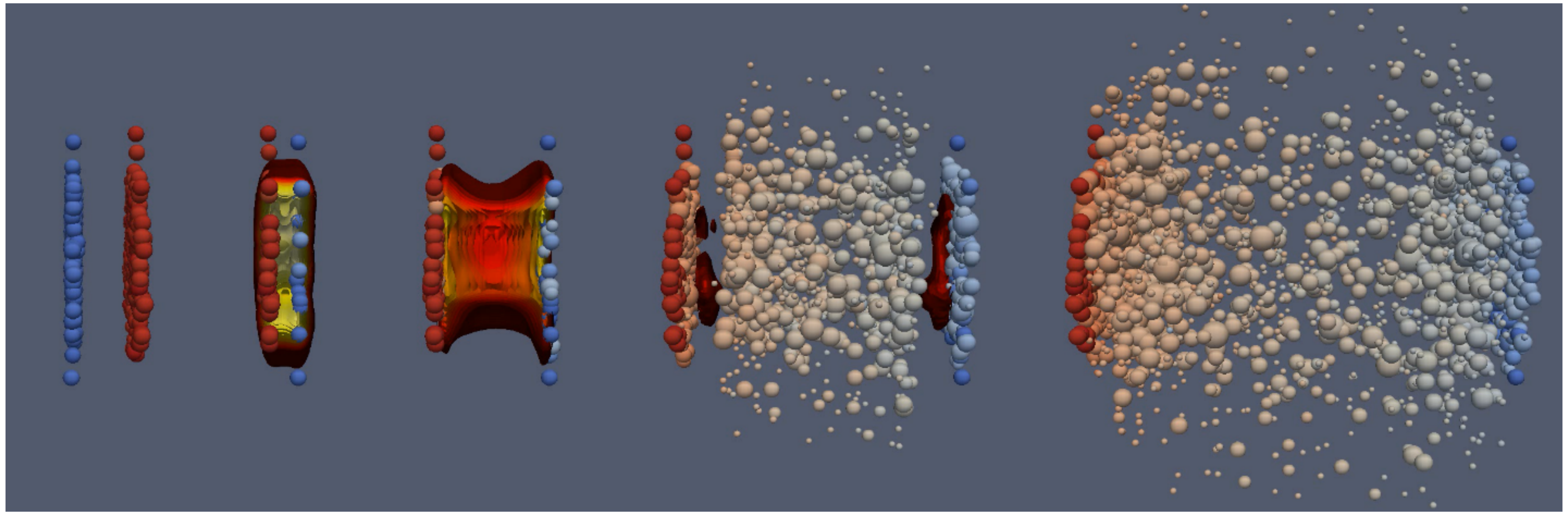
Hadronisation

Chiral symmetry breaking
Statistical hadronisation
Quark (re-)combination

Final state scattering

Resonance decays
Laboratory for hadron physics

Heavy-ion collisions



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Laboratory for hadron physics

Electromagnetic radiation ($\propto T^2$)

Hadron momentum distributions, azimuthal anisotropy

Hadron abundances 'hadrochemistry'

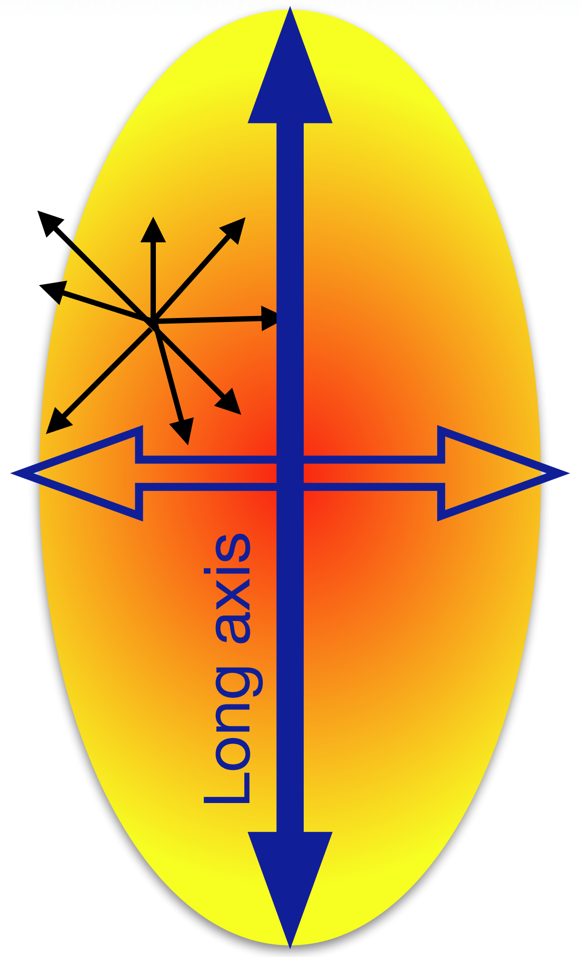
Heavy flavour probes of thermalisation

$$\langle r^2 \rangle = 6\, D_s\, t$$

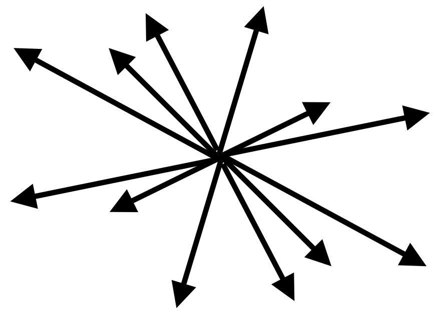
*D*s: heavy quark diffusion coefficient

$$\tau_Q = (m_Q/T)\, D_s$$

relaxation time



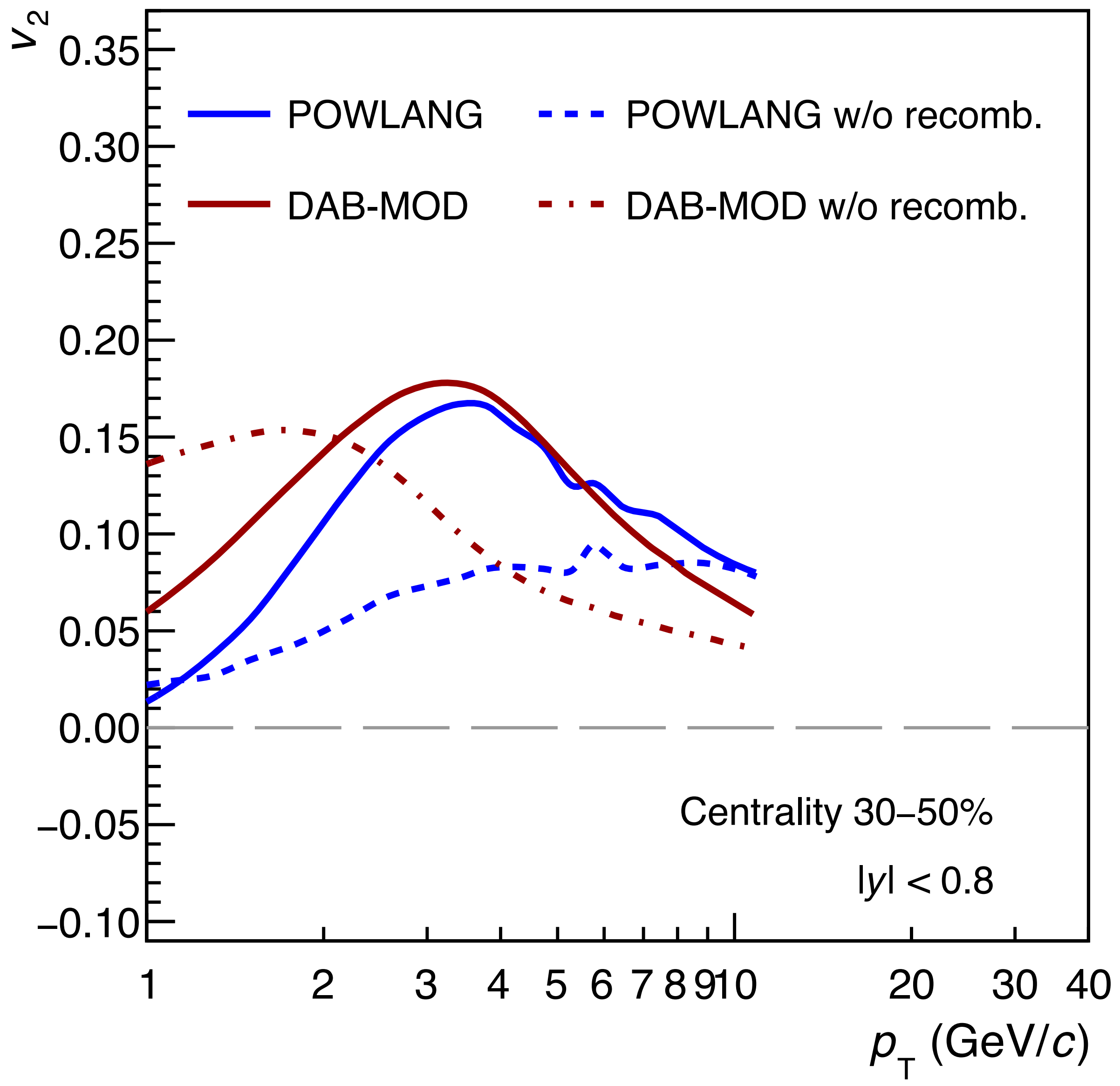
Elliptic flow
Azimuthal anisotropy



Heavy quark diffusion produces azimuthal anisotropy

- **Interactions — diffusion lead to thermalisation** of heavy quarks
  - Large **charm v_2:** close to fully thermalised?
  - **beauty** farther from thermalisation: **more sensitive**
- **Hadronisation from the QGP**
  - Quark coalescence/recombination important at low p_T: mix light and heavy flavour flow

D meson v_2



Goal: understand relation between thermalisation of heavy quarks and hadrochemistry

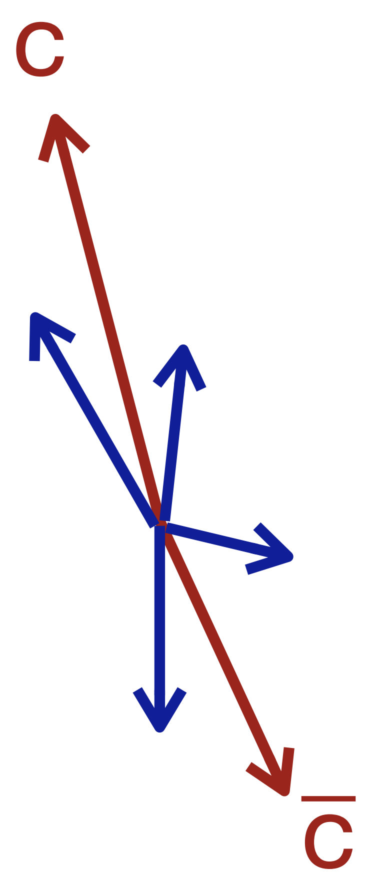
Key observables:
heavy meson and **baryon** R_{AA}, **v_2, v_3**
multi-charm baryons

GM Innocenti 14:45, S Bass 15:45
F Prino 16:45

Heavy-quark propagation

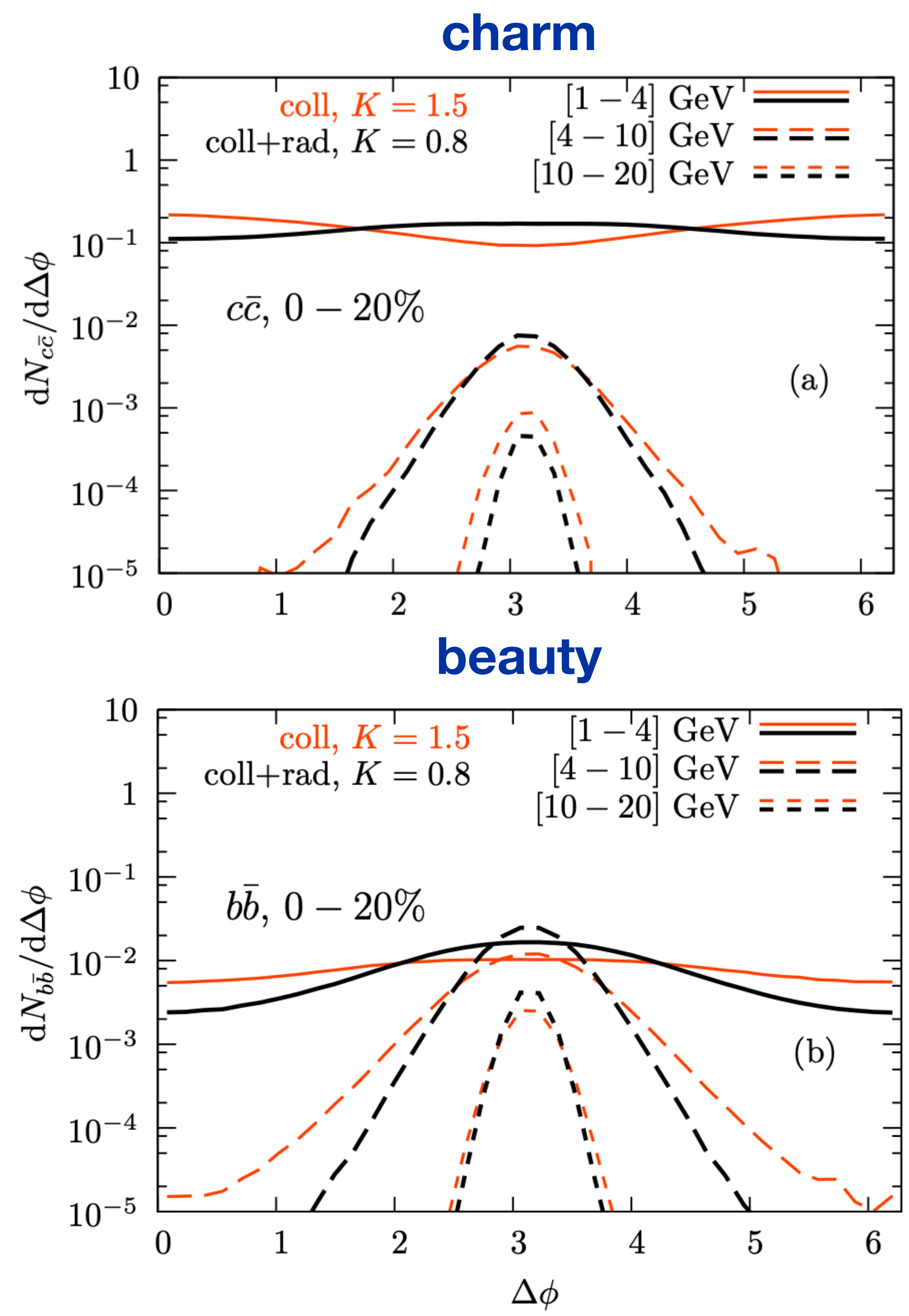
$$\langle r^2 \rangle = 6\, D_s\, t$$

heavy quark diffusion
⇒ collisional broadening



$$\hat{q} = \frac{\langle q_\perp^2 \rangle}{\lambda}$$

$\hat{q}$: semi-hard scattering
⇒ radiative energy loss



M Nahrgang et al, PRC 90, 024907

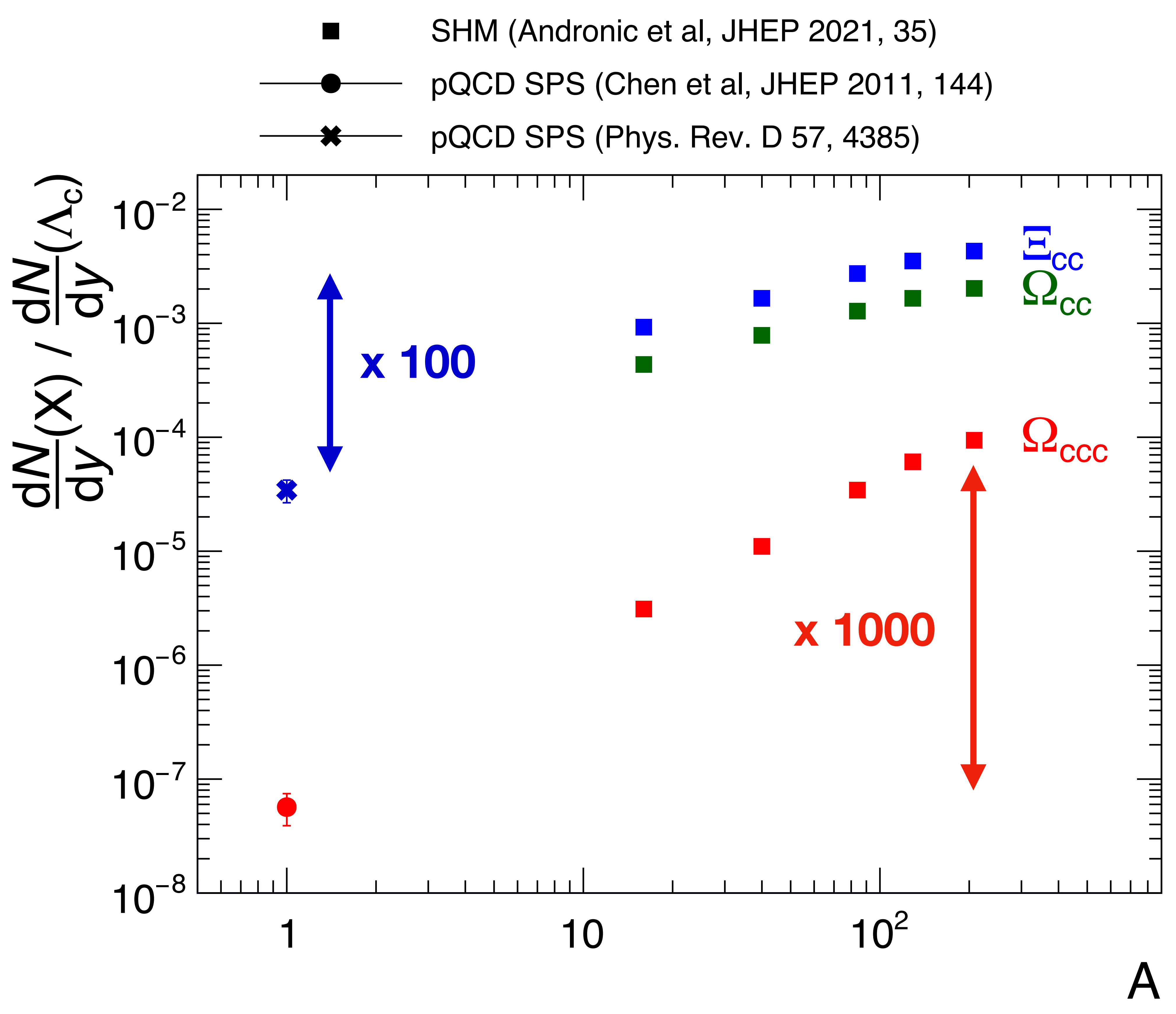
- Azimuthal correlations between DD̄, BB̄ pairs
  - Decorrelation measures momentum diffusion ⇒ thermalisation
  - Low p_T shows largest effects; optimise sensitivity of observables
  - Complementary to heavy flavour flow

Need large statistics, large purity for D (B) mesons, large η coverage

GM Innocenti 14:45
S Bass, 15:45

Hadronisation: multicharm states

- **Multi-charm baryons**: unique probe of hadron formation
  - Requires **production of multiple charm quarks**
  - Single-scattering contribution very small
- Statistical hadronisation model: **very large enhancement** in AA
  - How is thermalisation approached microscopically?
- Measure multiple states to test thermalisation and hadronisation
  - Dependence on flavour, hadron size, binding energy, etc

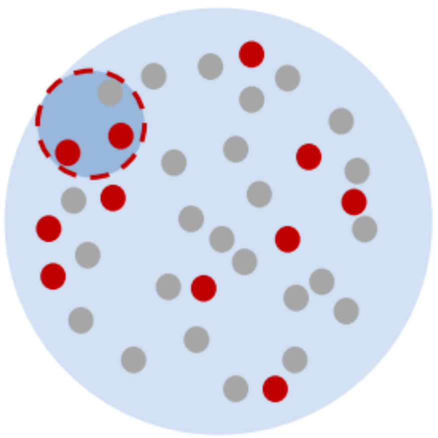


Single and double-charm baryons: Λ_c, Ξ_c, Ξ_{cc}, Ω_{cc}

Multi-flavour mesons: B_c, D_s, B_s, …

Tightly/weakly bound states J/ψ, $\chi_{c1}(3872)$, T_{cc}^+

Large mass light flavour particles: nuclei

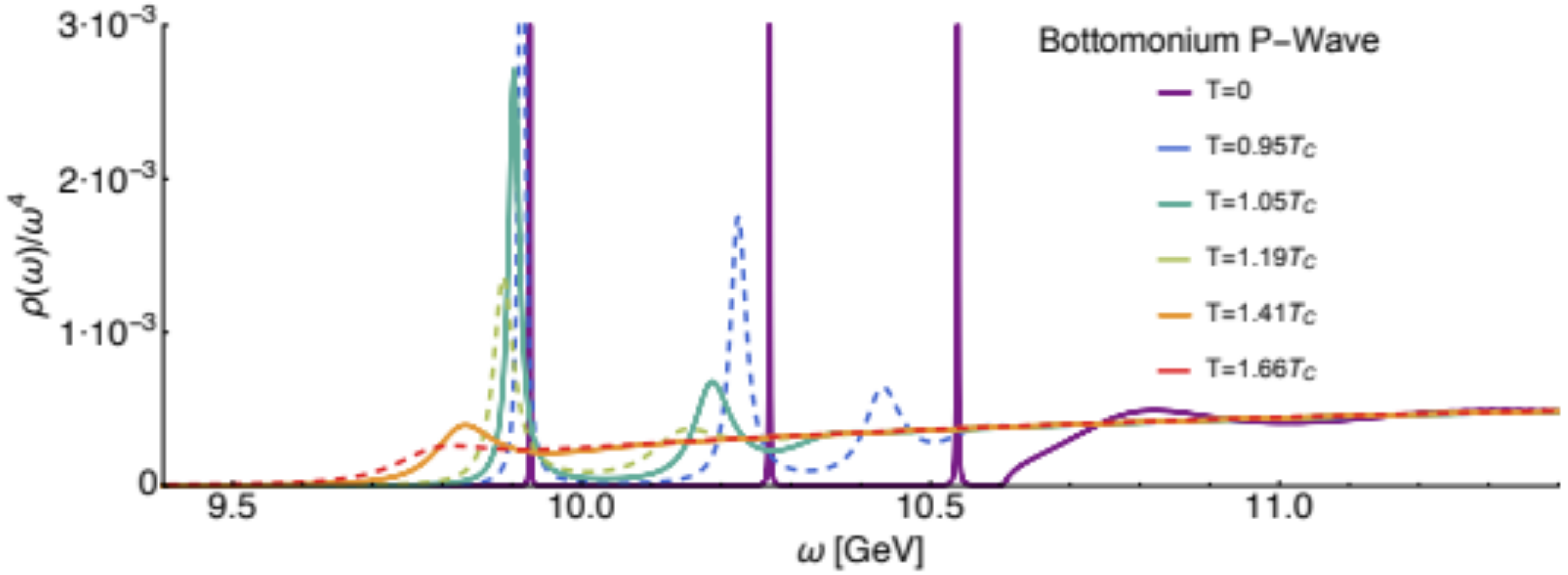


Need large samples, excellent pointing resolution, particle identification

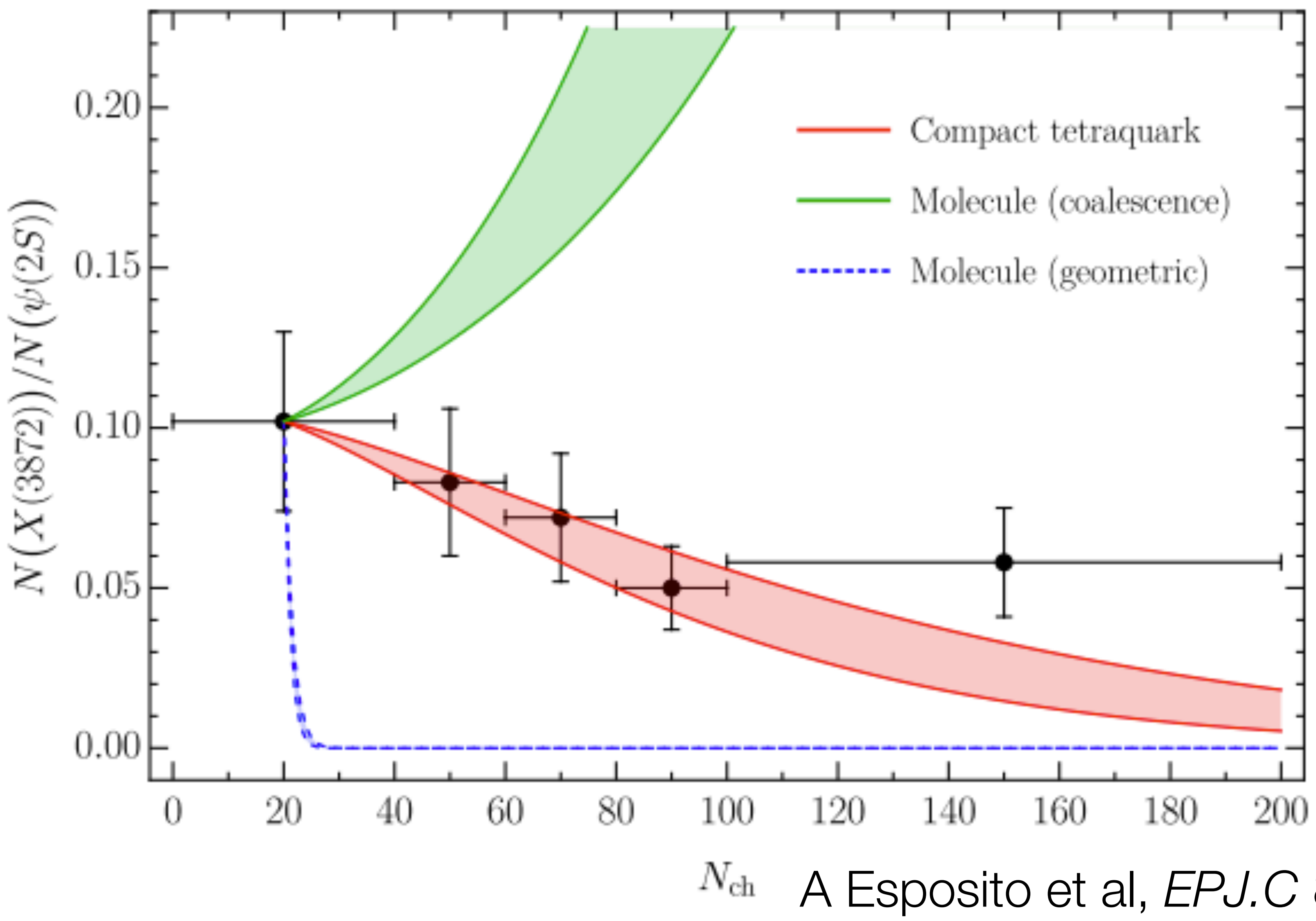
F Prino 16:45
D Dobrigkeit Chinellato 17:15

Bound states

- Quarkonium states
  - Explore new states: P-wave and pseudoscalars
  - Melting temperature depends on angular momentum
  - Measurements of χ_c ; χ_b test theory (lattice QCD, open quantum system approach)
- Exotic states: $\chi_{c1}(3872)$, T^{+}_{cc}, …
  - Nature of states: dissociation and regeneration ⇒ also studied with momentum correlations



Burnier et al, *JHEP* 10 (2016) 032



A Esposito et al, *EPJ.C* 86, 669

GM Innocenti 14:45
A Rothkopf 15:15

Need muon ID down to low p_T, photon ID

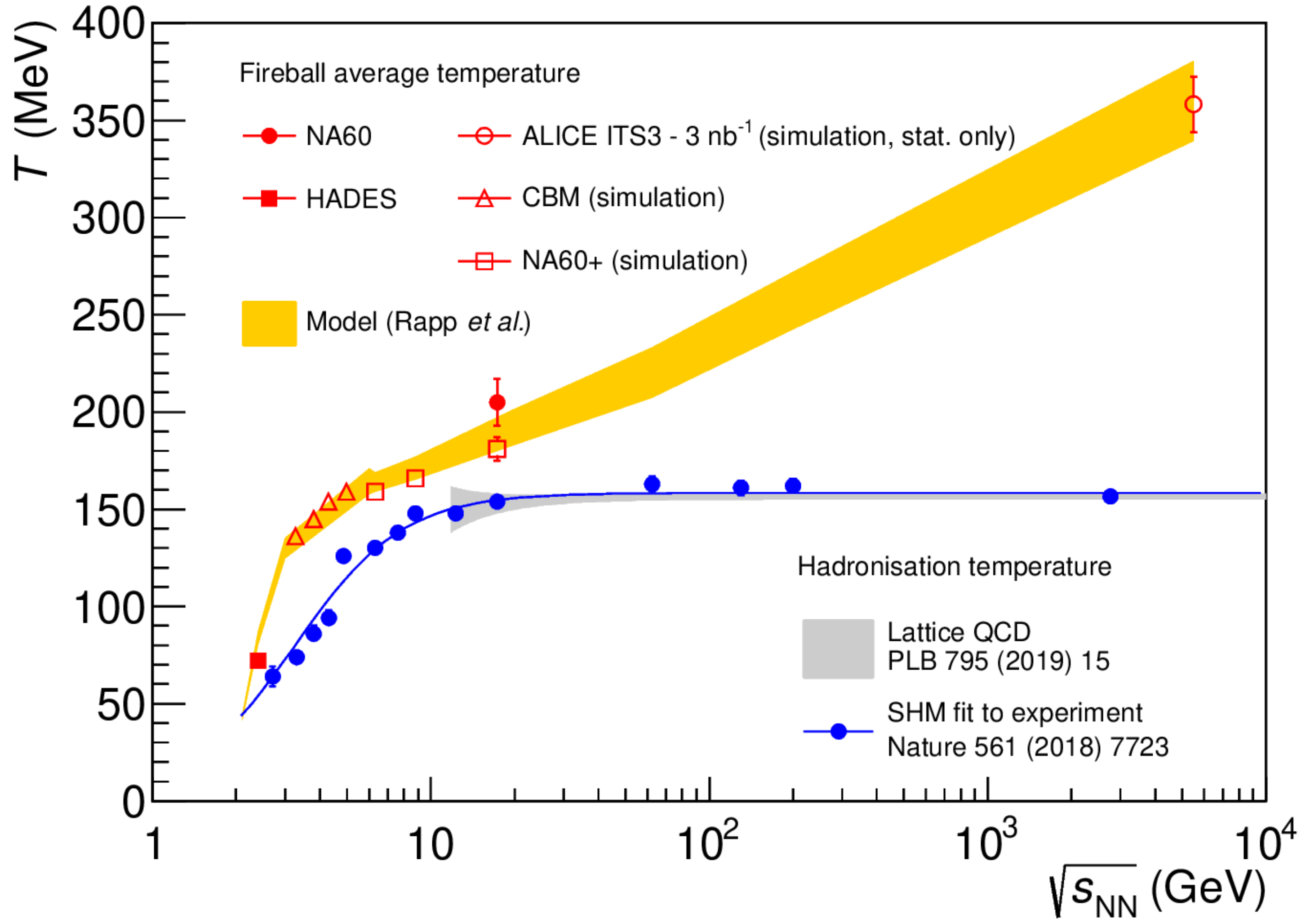
Electromagnetic radiation

R Rapp Tue 15:30
R Bailhache Tue 16:00

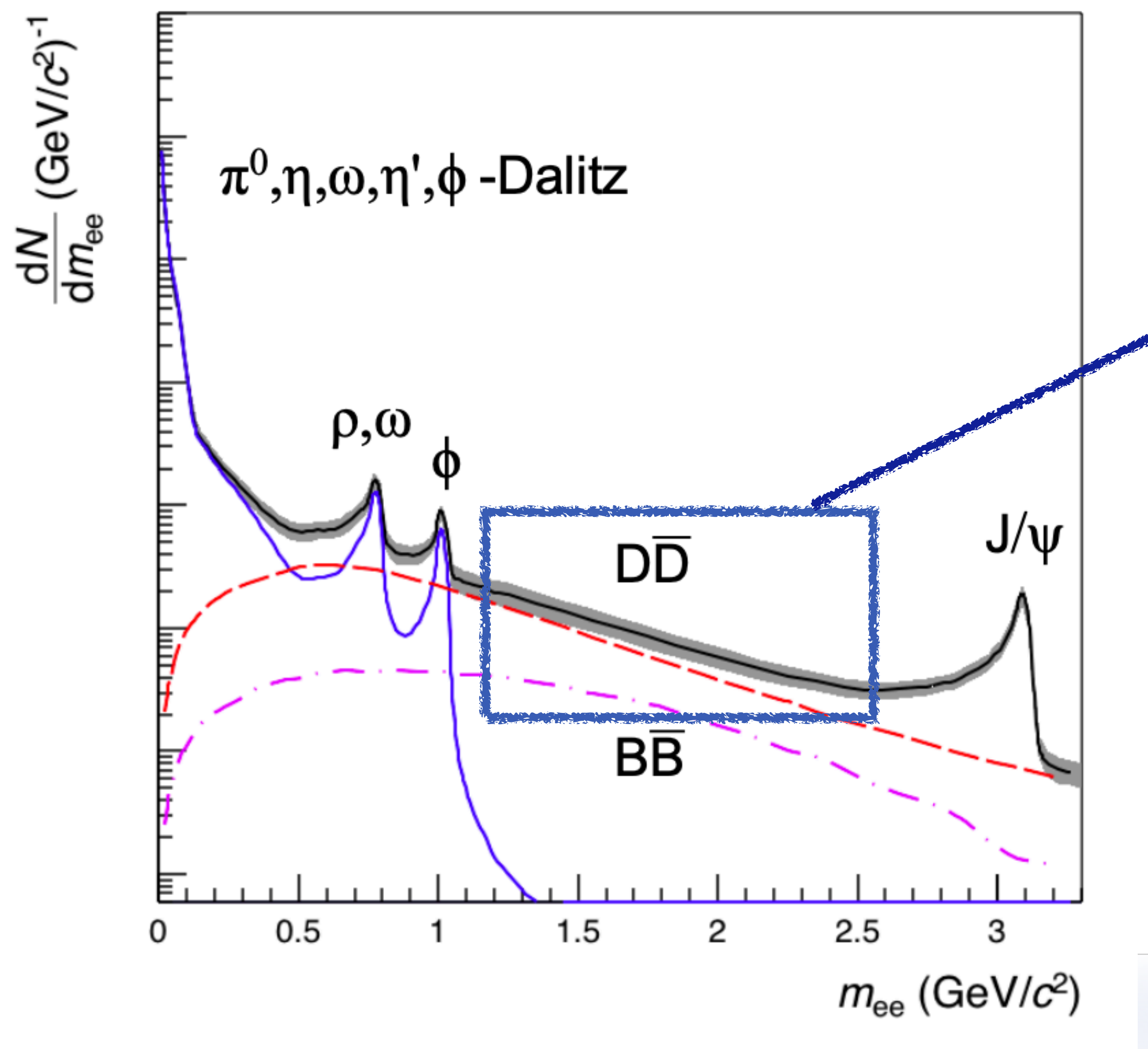
- Access to precise QGP temperature
  - First measurements in Run 3 and 4
- New measurements with ALICE 3
  - Dilepton v_2: sensitive to early vs late times
  - Double-differential mass-p_T: access time dependence
- Perform complementary measurements with photons

Need excellent electron ID (hadron rejection),
low-mass detector (conversion bkg),
excellent pointing resolution (HF decay bkg)
Photon detection: conversions + ECAL

***T* vs energy**



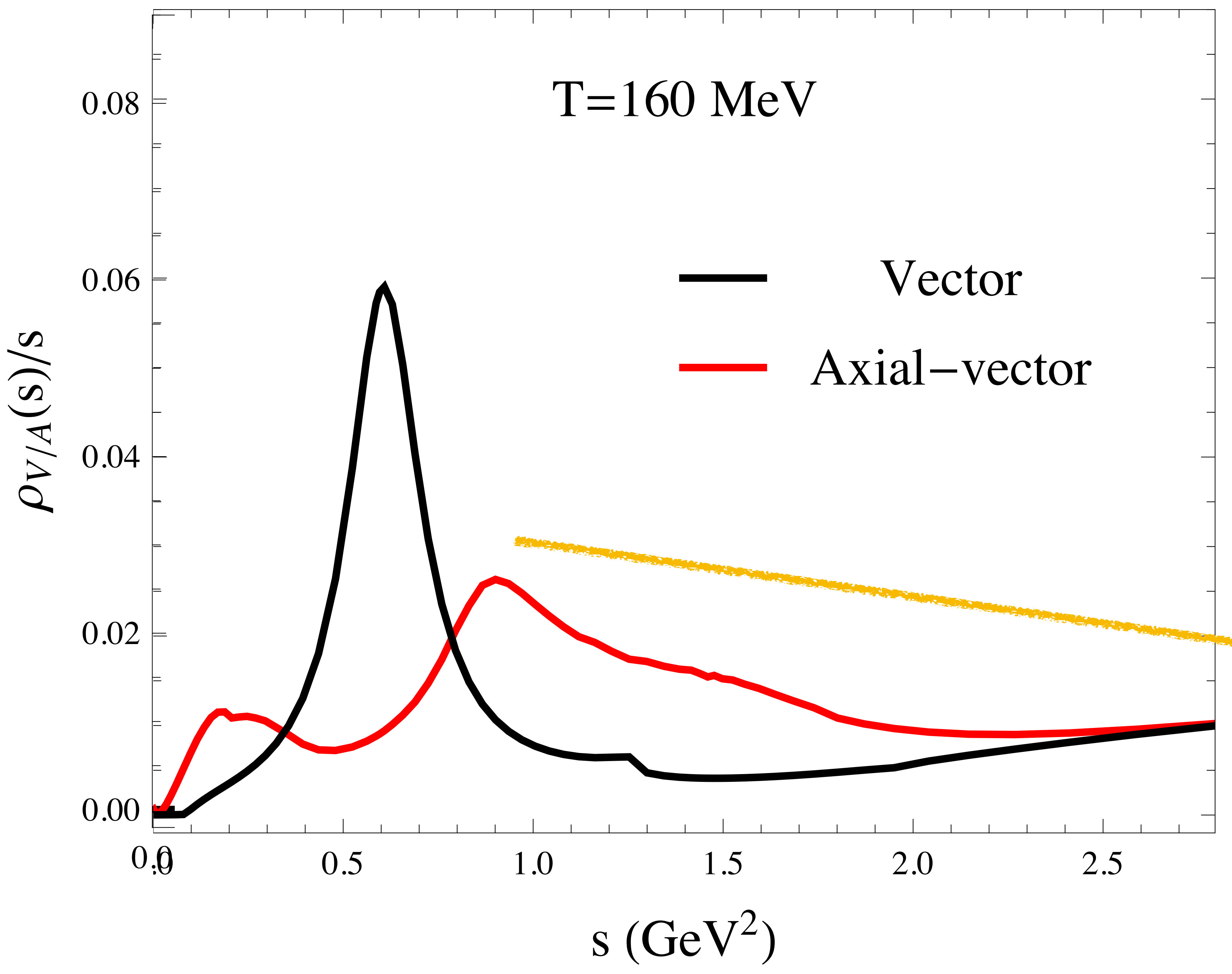
Dilepton mass



Direct measure of temperature

Chiral symmetry restoration

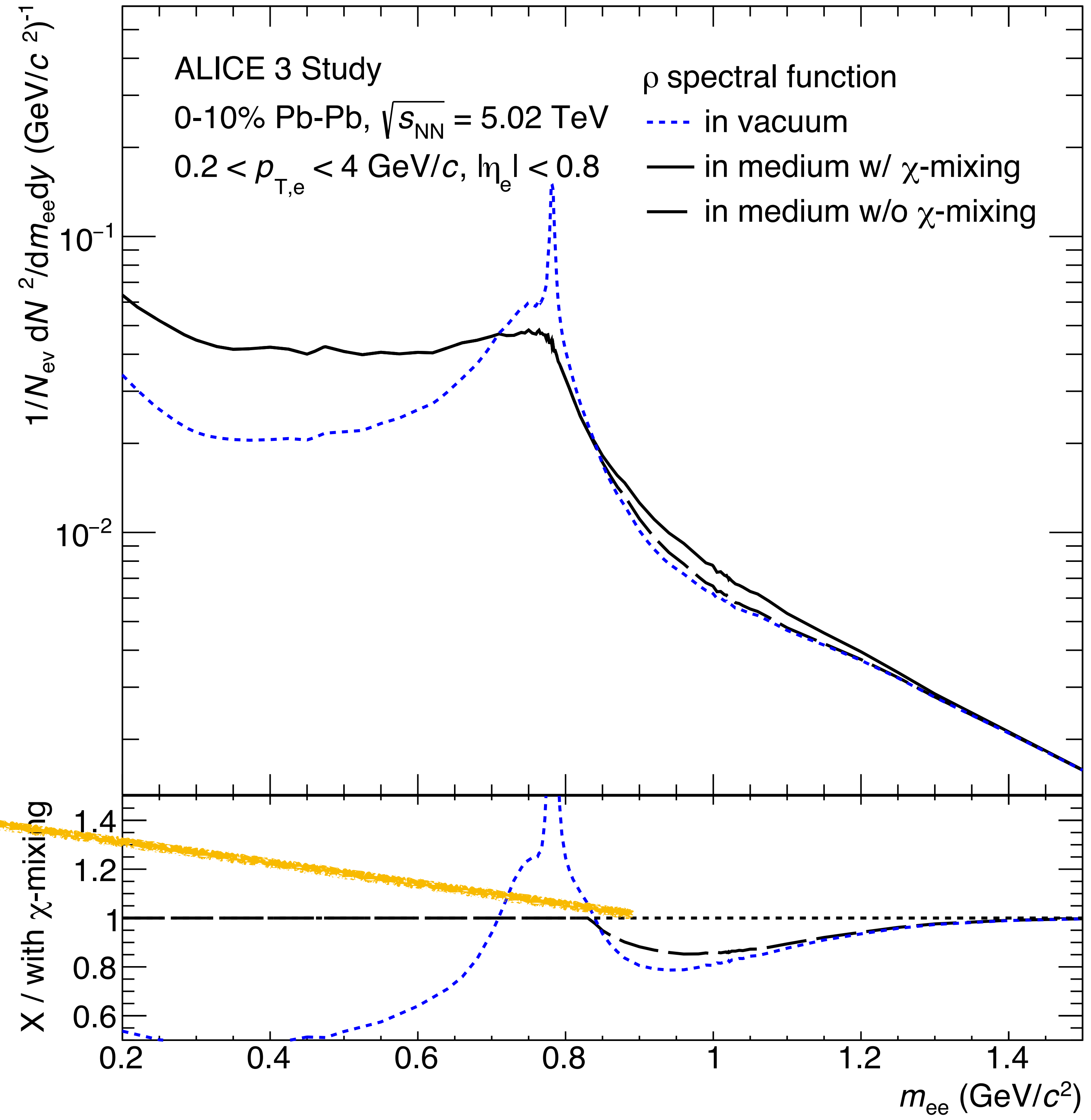
Spectral function at T = 160 MeV



Hohler, Rapp, PLB 731, 103

ρ-a_1 mixing

Dilepton mass distribution

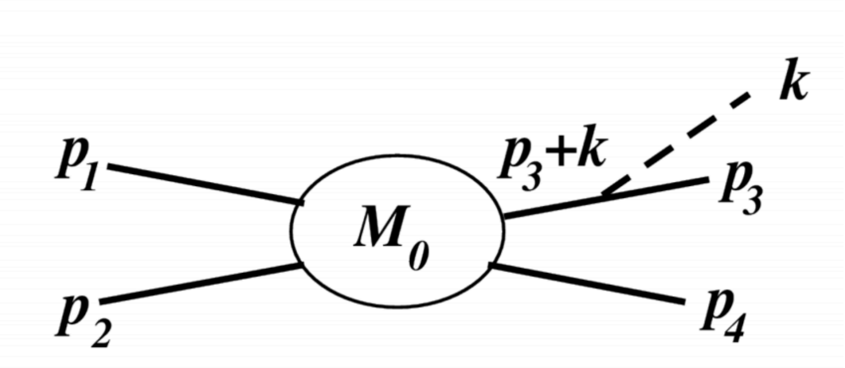


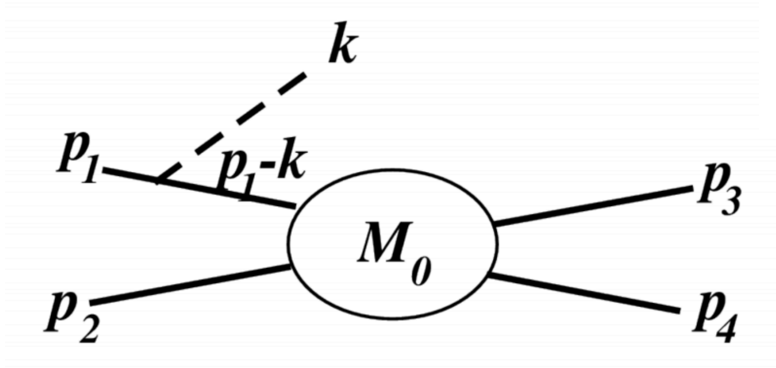
- **Chiral symmetry breaking generates hadron masses** — fundamental aspect of QCD
- Unique window on chiral symmetry restoration at high T: ρ-a_1 mixing
  - Requires **large precision** dilepton measurement at **mass 0.8-1.2 GeV/c^2**

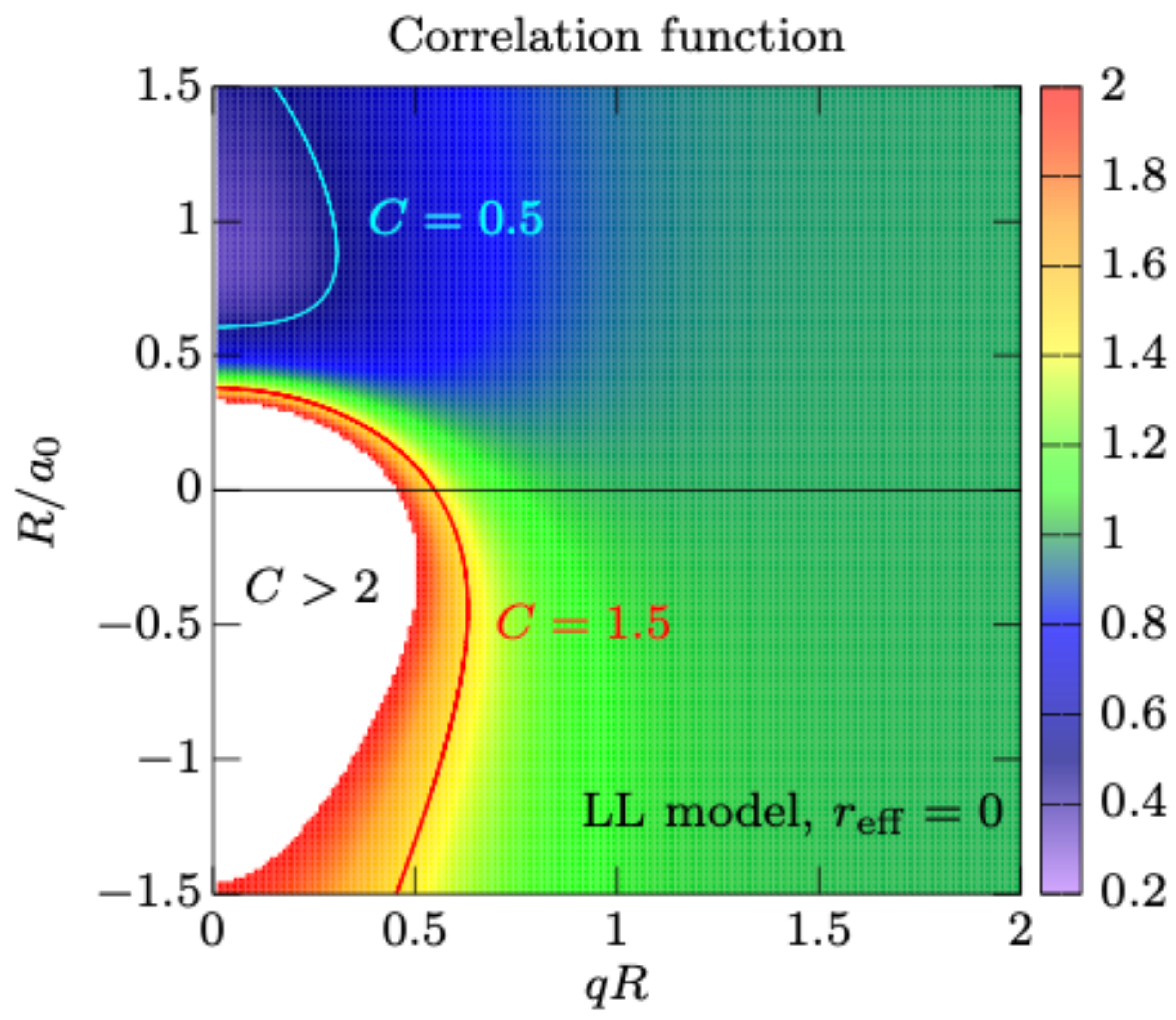
R Rapp Tue 15:30
R Bailhache Tue 16:00

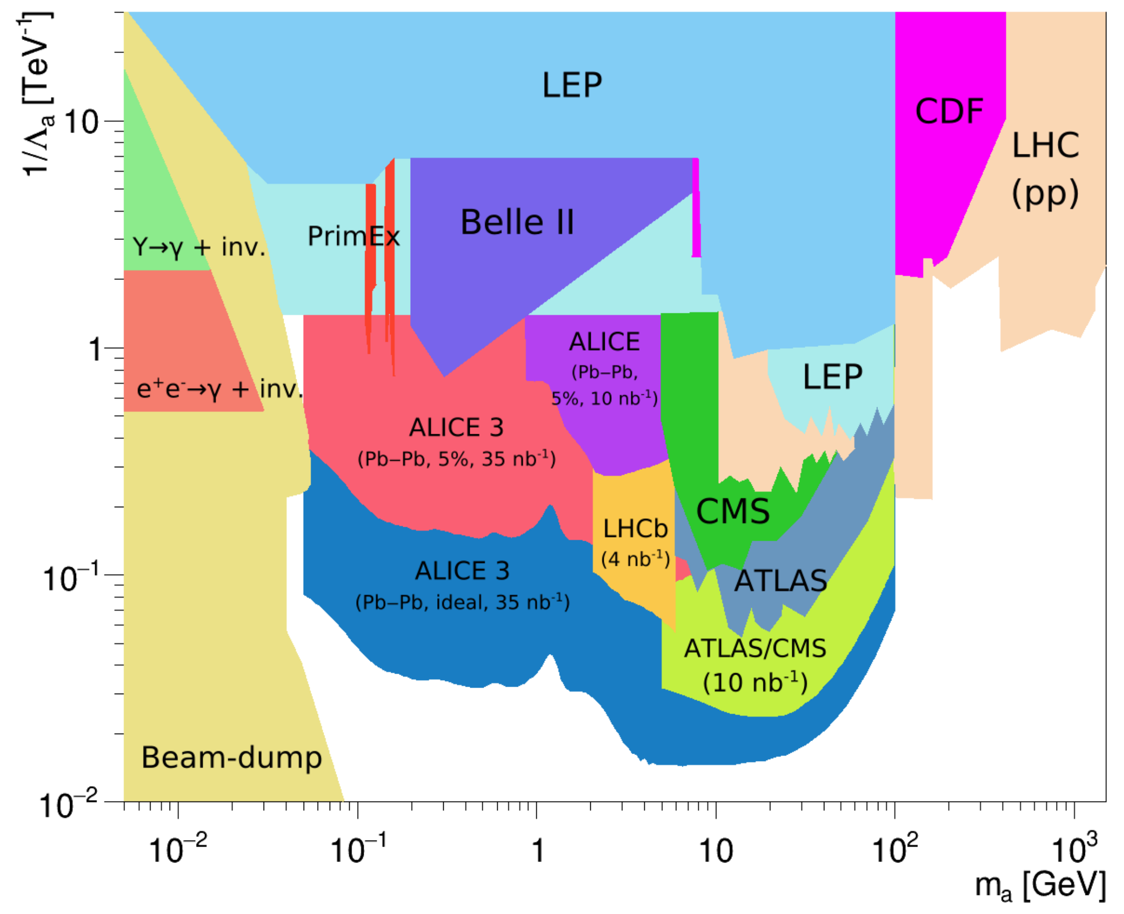
Physics motivation (cont'd)

- Charm meson (and baryon) **interaction potentials**
  - Bound states: meson molecules, pentaquarks
- pp, p-Pb at high multiplicity: approach to QGP density
- **Search for new hadronic states**
  - Charm nuclei, anti-nuclei
- **Ultra-soft photons**
  - Test Low's theorem
  - Soft photons from stopping
- **BSM physics**
  - Axion-Like Particles in UPC
  - Dark photons, long lived particles, …









A Kalweit Tue 13:00
L Fabbietti 17:45
K Reygers Tue 15:30

Ions at the LHC

- High luminosity key for rare probes, e.g. multi-charm baryons
- Explore use of smaller nuclei to increase luminosity
  - Ongoing discussions with machine groups
- Current assumptions for physics projections:

	levelling	limited by machine			
	pp	Ar-Ar	Kr-Kr	Xe-Xe	Pb-Pb
$\langle L_{AA} \rangle$ (cm^{-2} s^{-1})	$3.0 \cdot 10^{32}$	$2.0 \cdot 10^{29}$	$5.0 \cdot 10^{28}$	$1.6 \cdot 10^{28}$	$3.3 \cdot 10^{27}$
$\langle L_{NN} \rangle$ (cm^{-2} s^{-1})	$3.0 \cdot 10^{32}$	$3.3 \cdot 10^{32}$	$3.0 \cdot 10^{32}$	$2.6 \cdot 10^{32}$	$1.4 \cdot 10^{32}$
$\mathscr{L}_{AA}$ (nb^{-1} / month)	$510 \cdot 10^{3}$	340	84	26	5.6
$\mathscr{L}_{NN}$ (pb^{-1} / month)	505	550	510	434	242

Run 3 + 4
13 nb^{-1} Pb-Pb
200 pb^{-1} pp

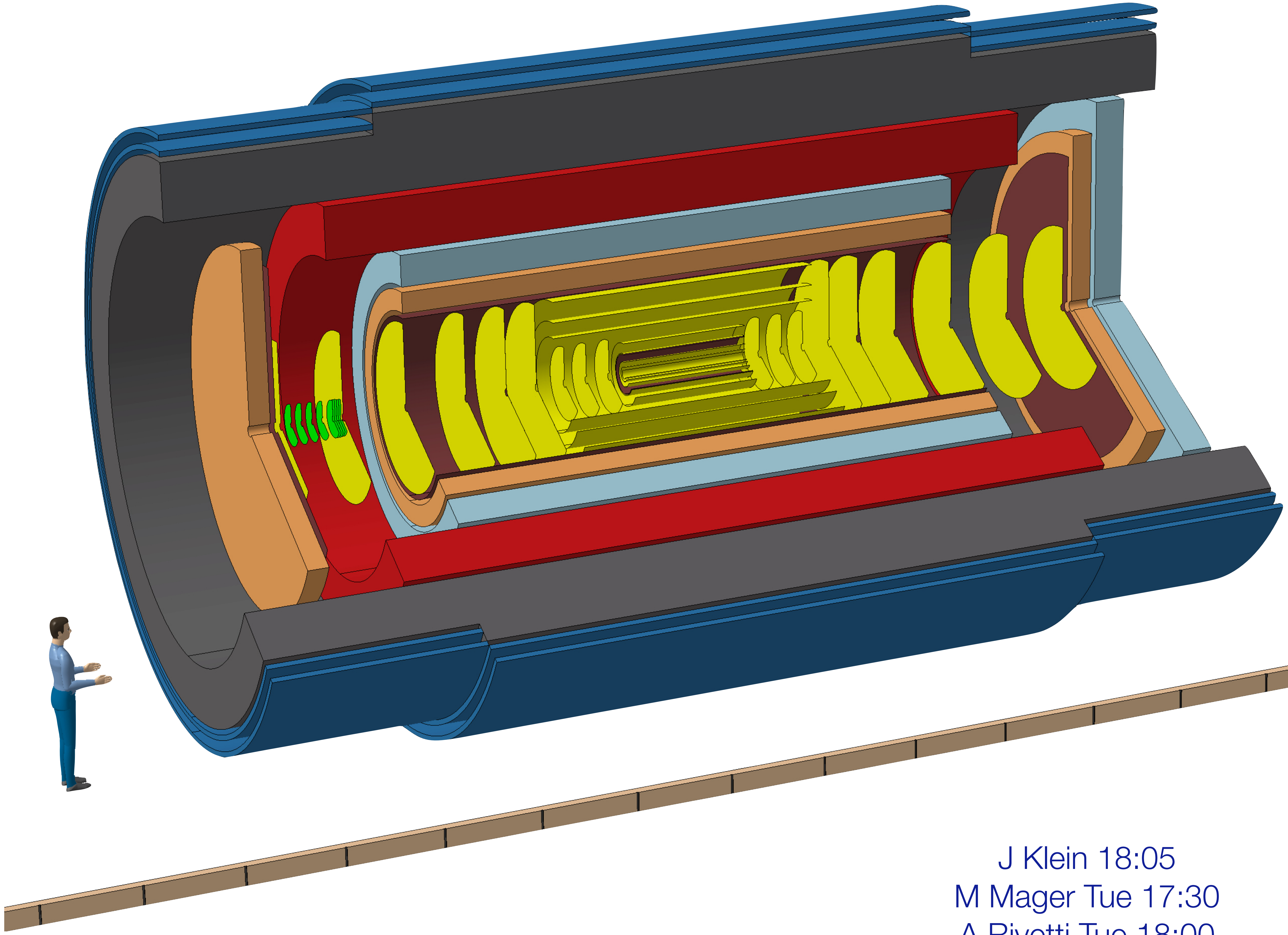
~10x AA luminosity
(3 fb^{-1} per year)

~5x total AA luminosity w.r.t. Run 3 + 4
(depending on collision system)

Physics performance studies performed with Pb-Pb:
Experimentally most challenging — largest QGP effects

Detector concept

- Compact all-silicon tracker with high-resolution vertex detector
- Superconducting magnet system
- Particle Identification over large acceptance
- Fast read-out and online processing

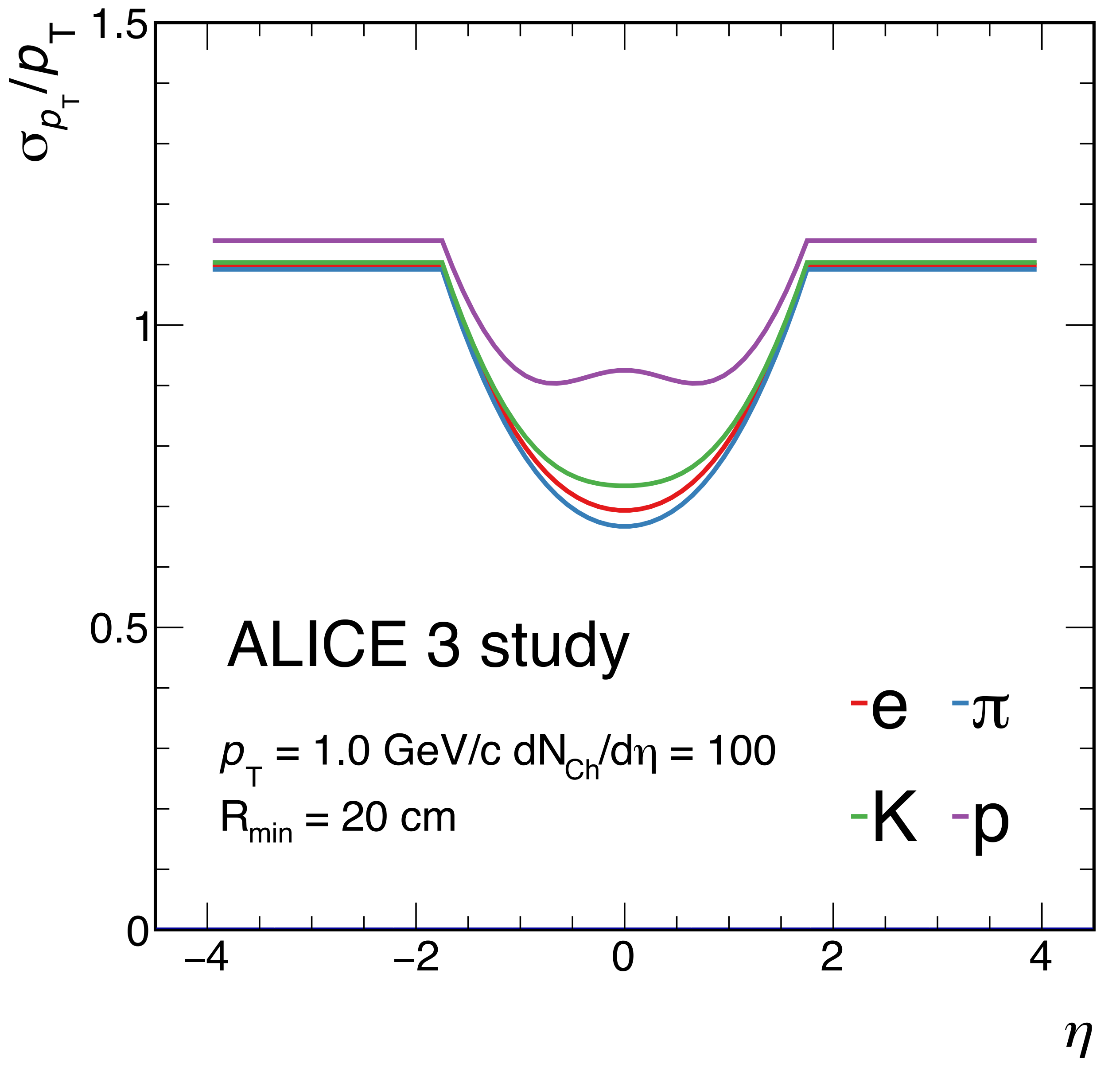


J Klein 18:05
M Mager Tue 17:30
A Rivetti Tue 18:00

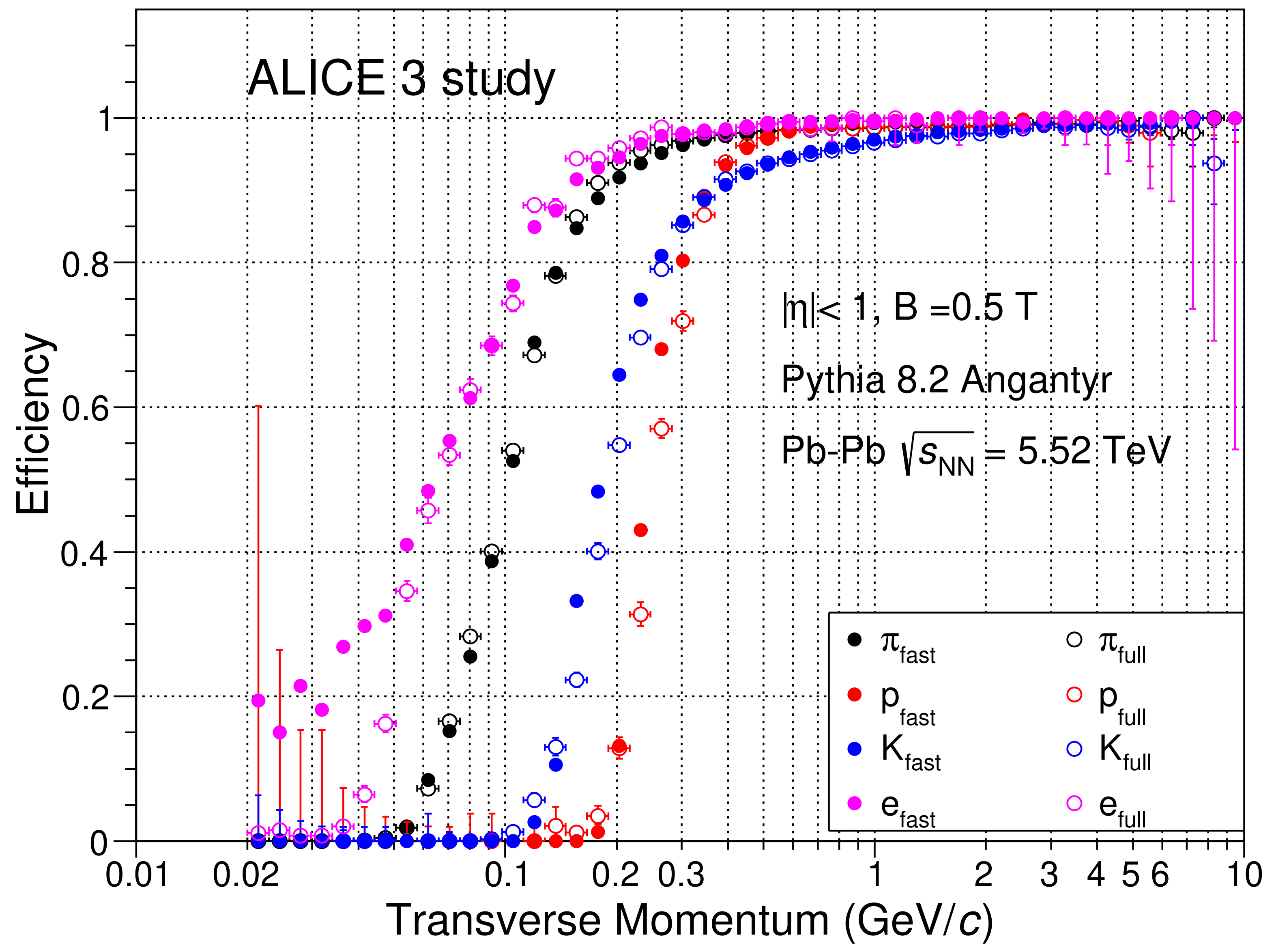
Tracking and vertexing

- 11 tracking layers in 2T solenoid+dipole field:
  - ~1% momentum resolution over full η range
  - Large efficiency down to low p_T
- Unique pointing resolution: ~10 μm at 200 MeV/*c*, ~2 μm at high p_T
  - First tracking layer at 5 mm from beam; retractable
  - Crucial for heavy flavour correlation studies, multi-charmed baryons, dilepton background

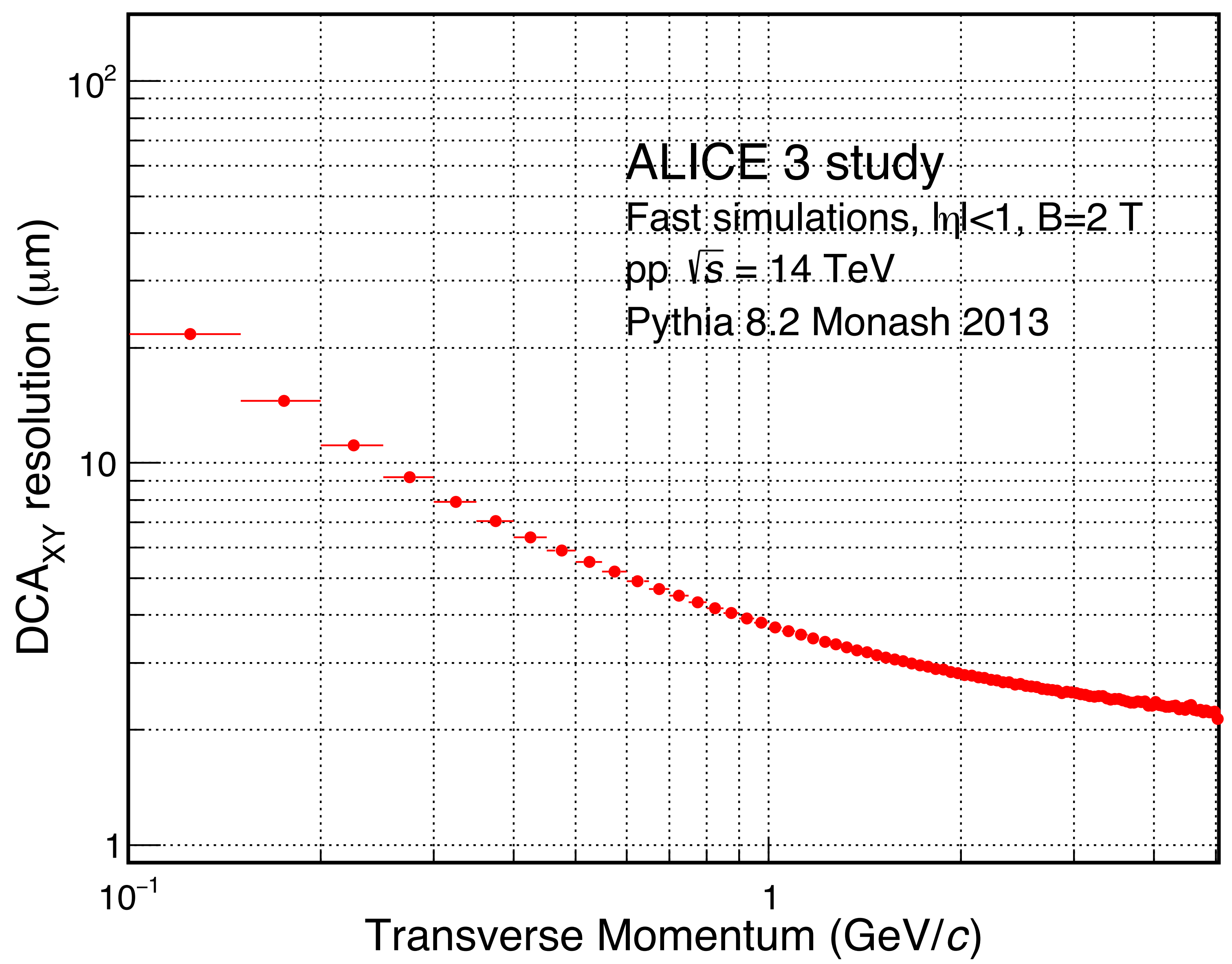
Momentum resolution



Tracking efficiency



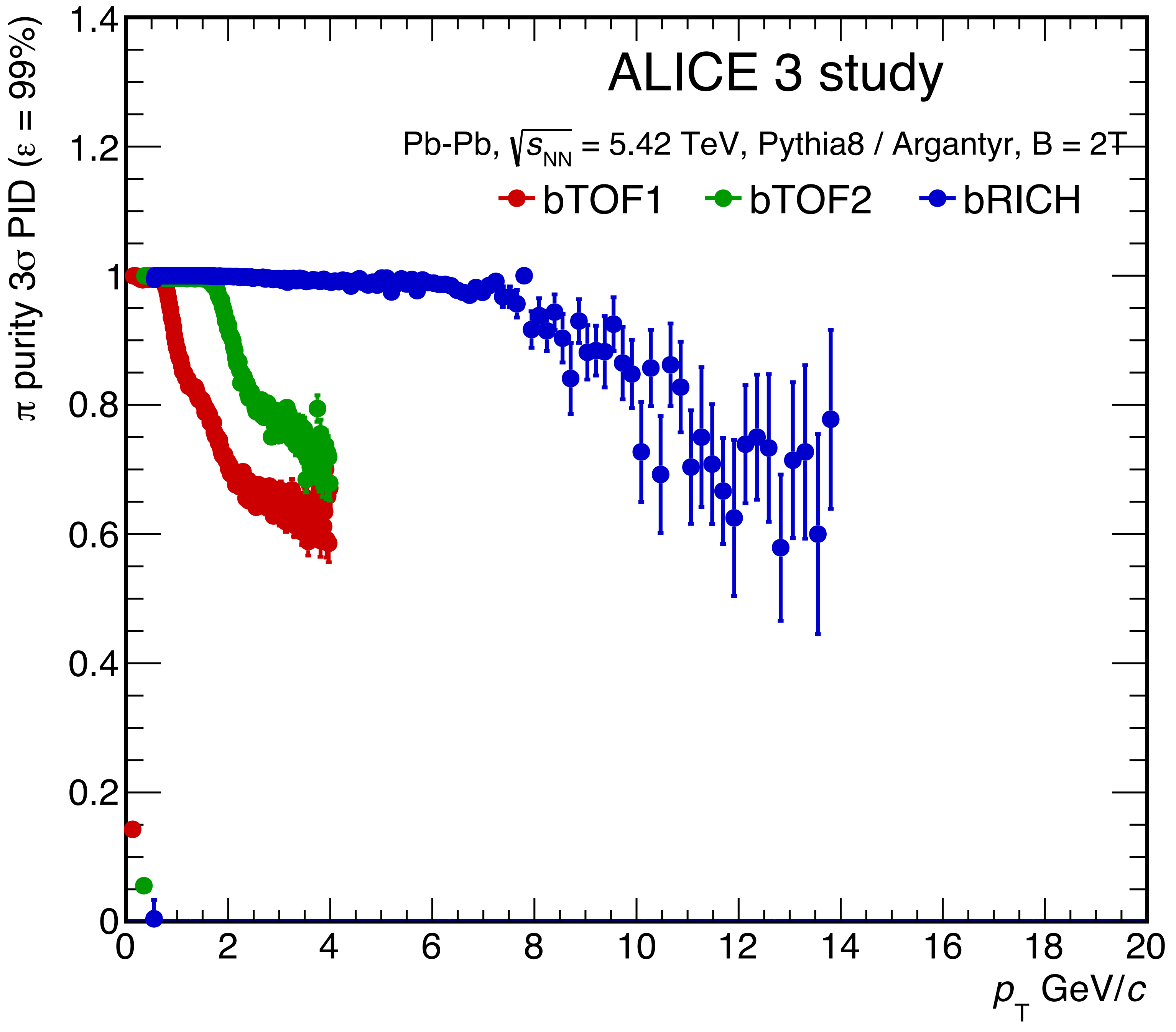
Impact parameter resolution



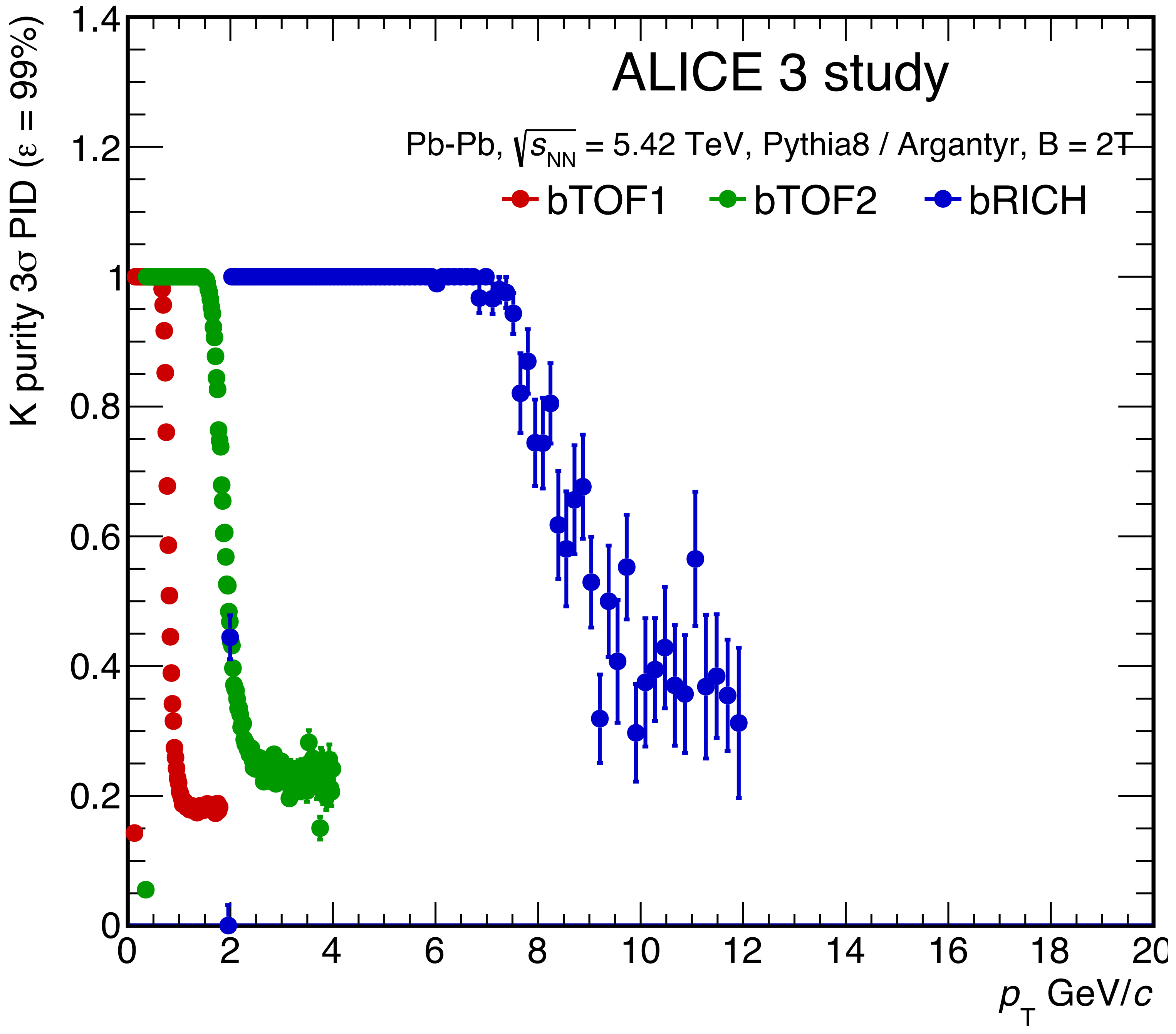
Particle identification

- Clean hadron identification up to O(10 GeV/*c*), e.g. ~8 GeV/*c* for π/K
  - Larger p_T reach than current ALICE setup (TOF)
- Important for high purity electrons, heavy flavour decays

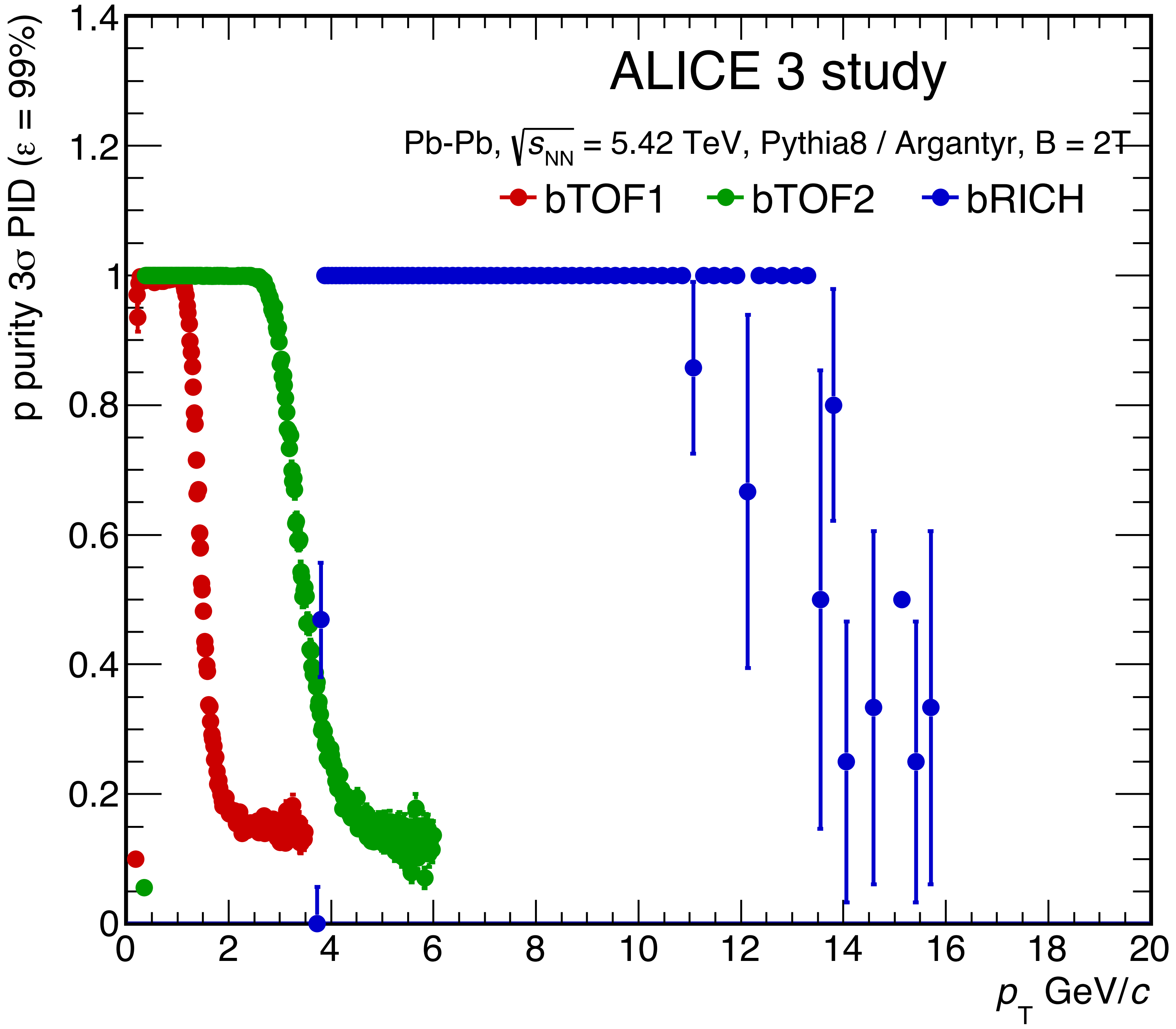
Pion purity



Kaon purity



Proton purity

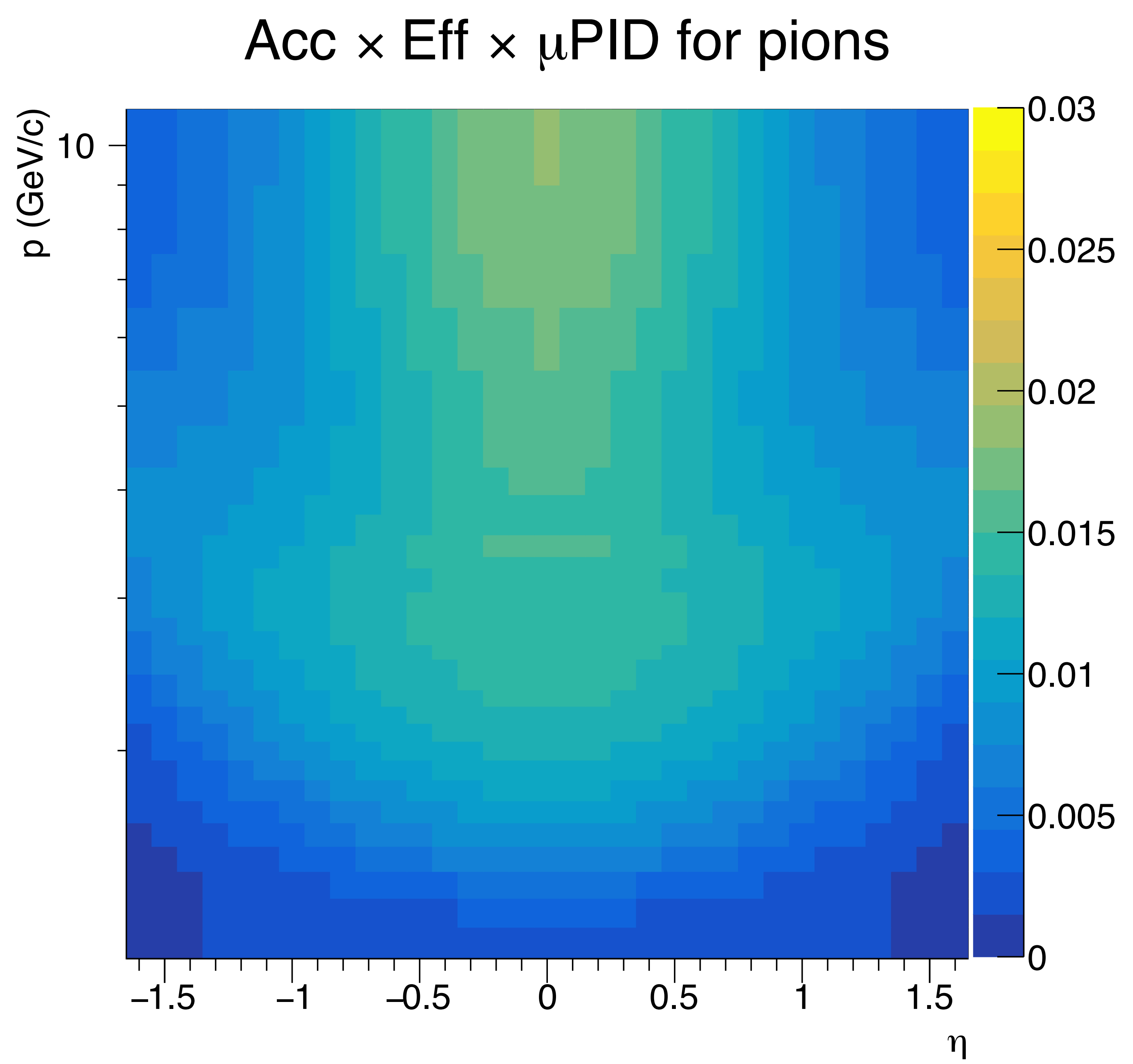


Muon identifier and ECAL

- Muon identifier
  - $L \approx 70$ cm steel absorber
  - Muons $p > 1.3$ GeV, J/ψ down to $p_T = 0$
- Electromagnetic calorimeter
  - Decay photons from χ_c , χ_b
  - High-resolution $PbWO_4$ ECAL (partial acceptance)

$$\frac{\sigma_E}{E} \propto \frac{0.02}{\sqrt{E}} + \ldots$$

  - Complemented with sampling calorimeter for larger acceptance (e.g. γ-jet γ-HF measurements)
- Forward conversion tracker
  - Ultra-soft photon detection



MID pion rejection: factor ≈ 50

Physics performance simulations

- **Detector response evaluated with**
  - Fast Analytical Tool: parametrised response based on detector description
  - Full simulation of tracking (O^2 framework with ALICE 3 geometry)
- Physics performance
  - **Fast simulation** parametrised response (**DelphesO2**)
    - Full covariance matrix for barrel tracking
    - Gaussian response for TOF + RICH
  - **Hybrid simulations**
    - Full simulation for weak strangeness decays + fast simulation for background

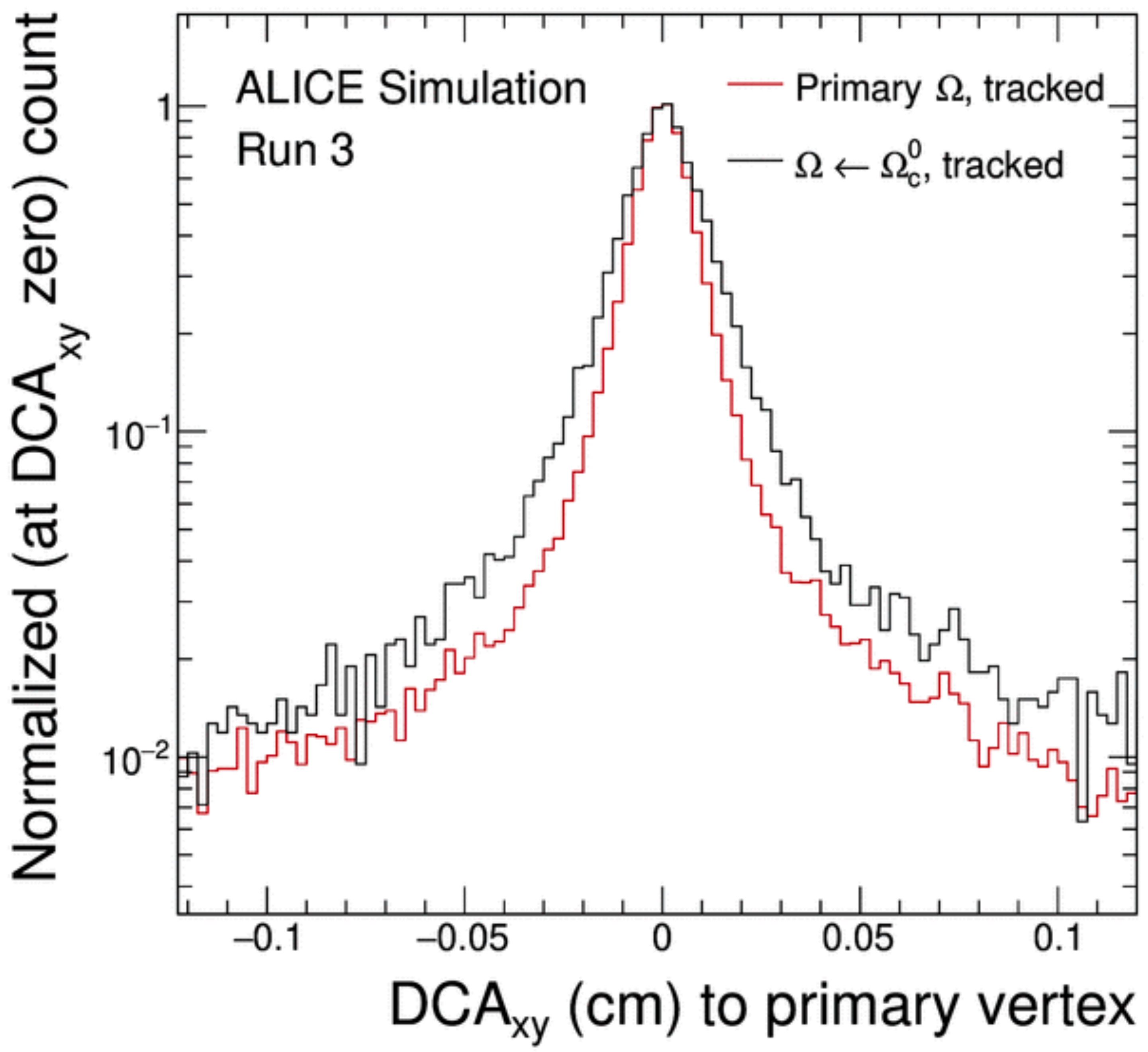
Workshop agenda

- Monday:
  - Heavy flavour programme
  - Detector concept
- Tuesday:
  - LHC run 3 and 4, RHIC programme
  - Electromagnetic probes
  - Detector R&D

Backup

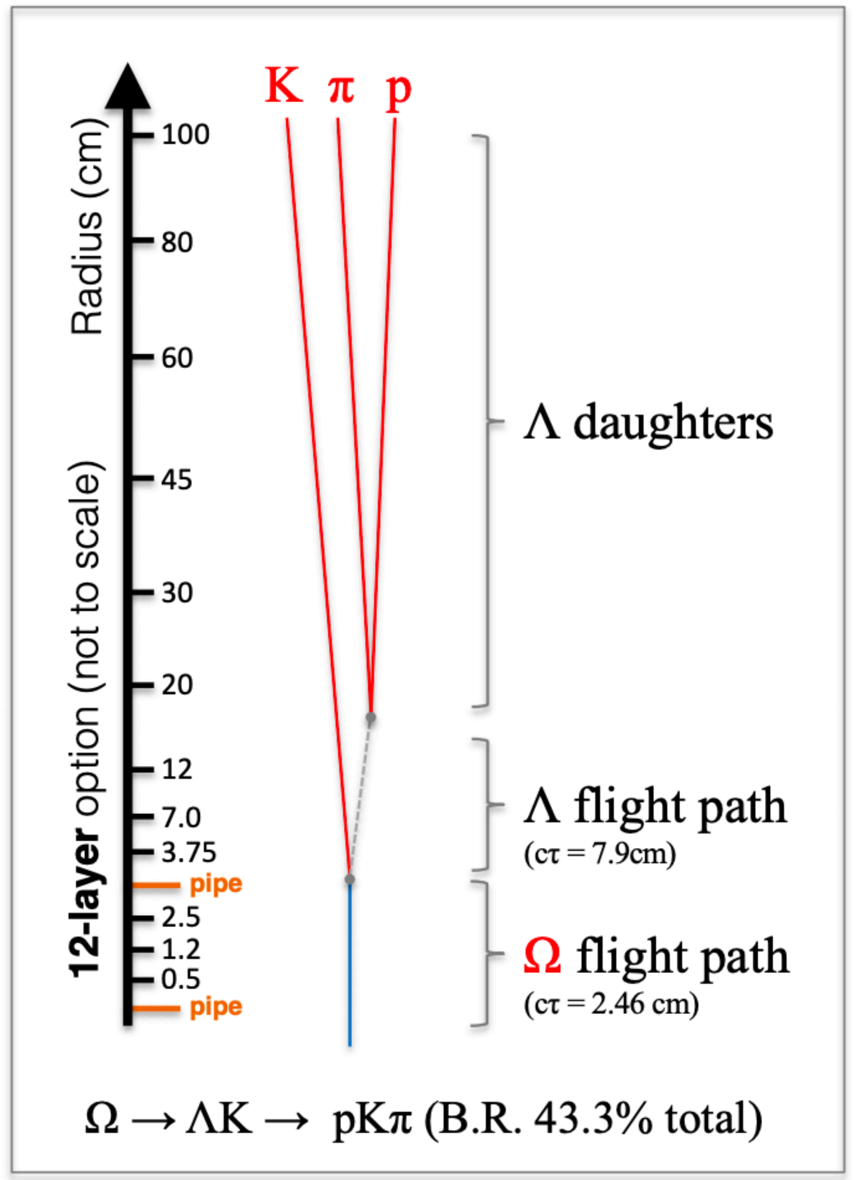
Tracker design with retractable layer

$\Omega_c \longrightarrow \Omega$ strangeness tracking with ITS2

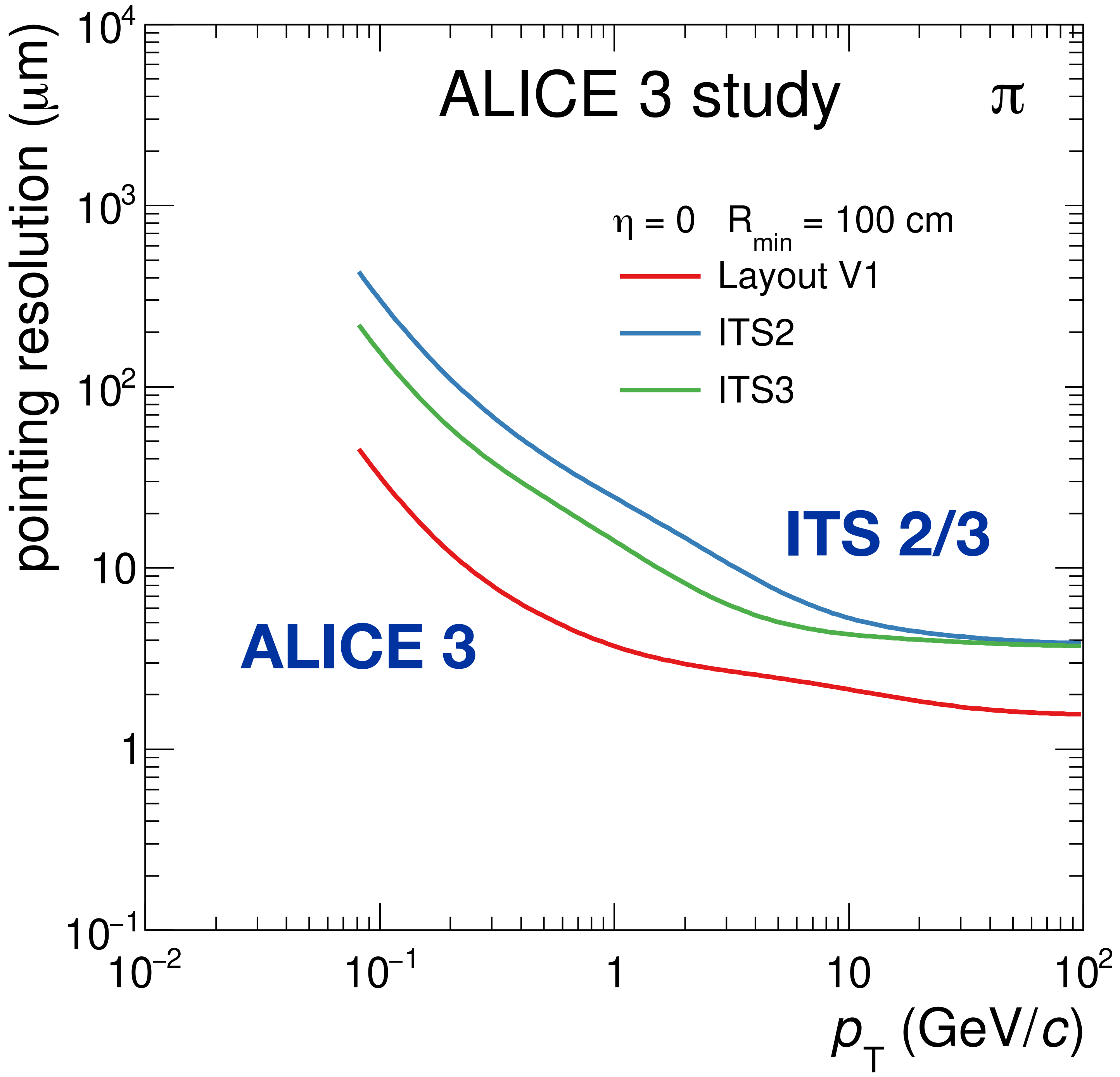


ALI-SIMUL-489593

Strangenes tracking ALICE 3

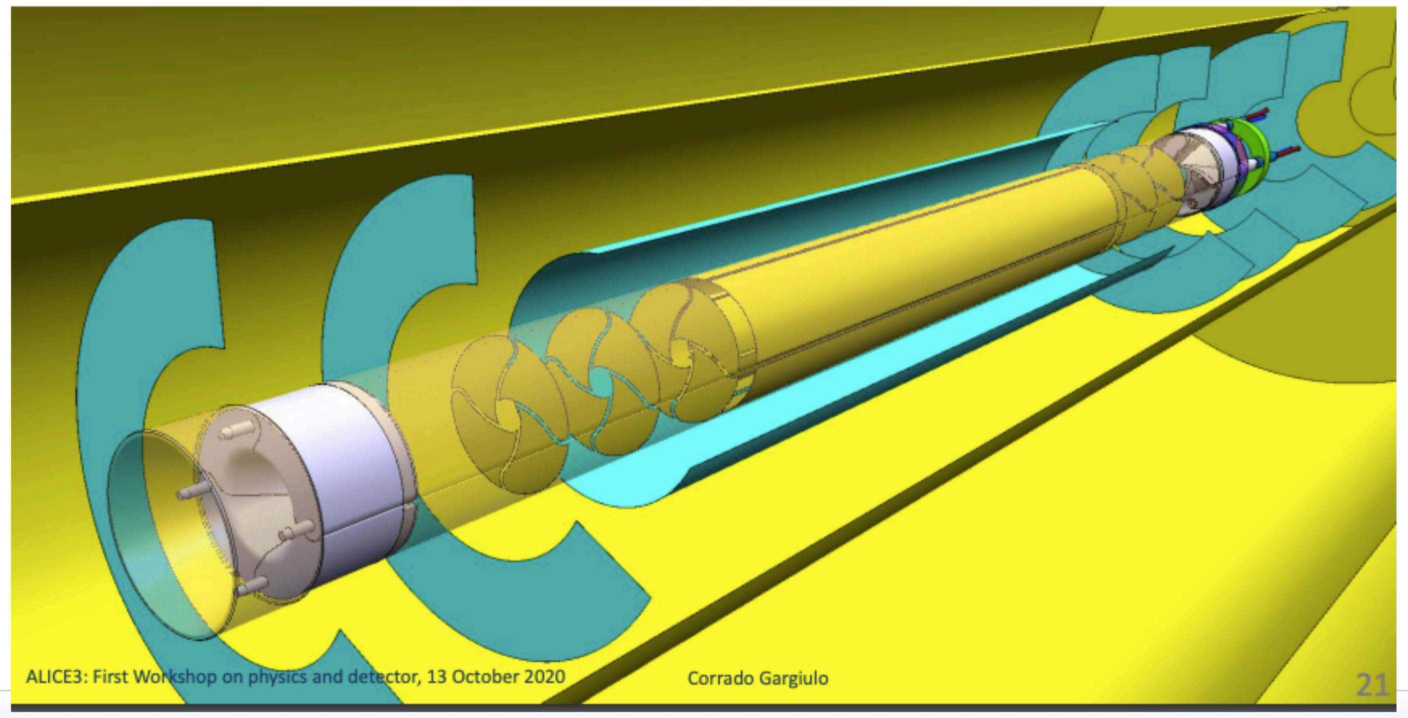


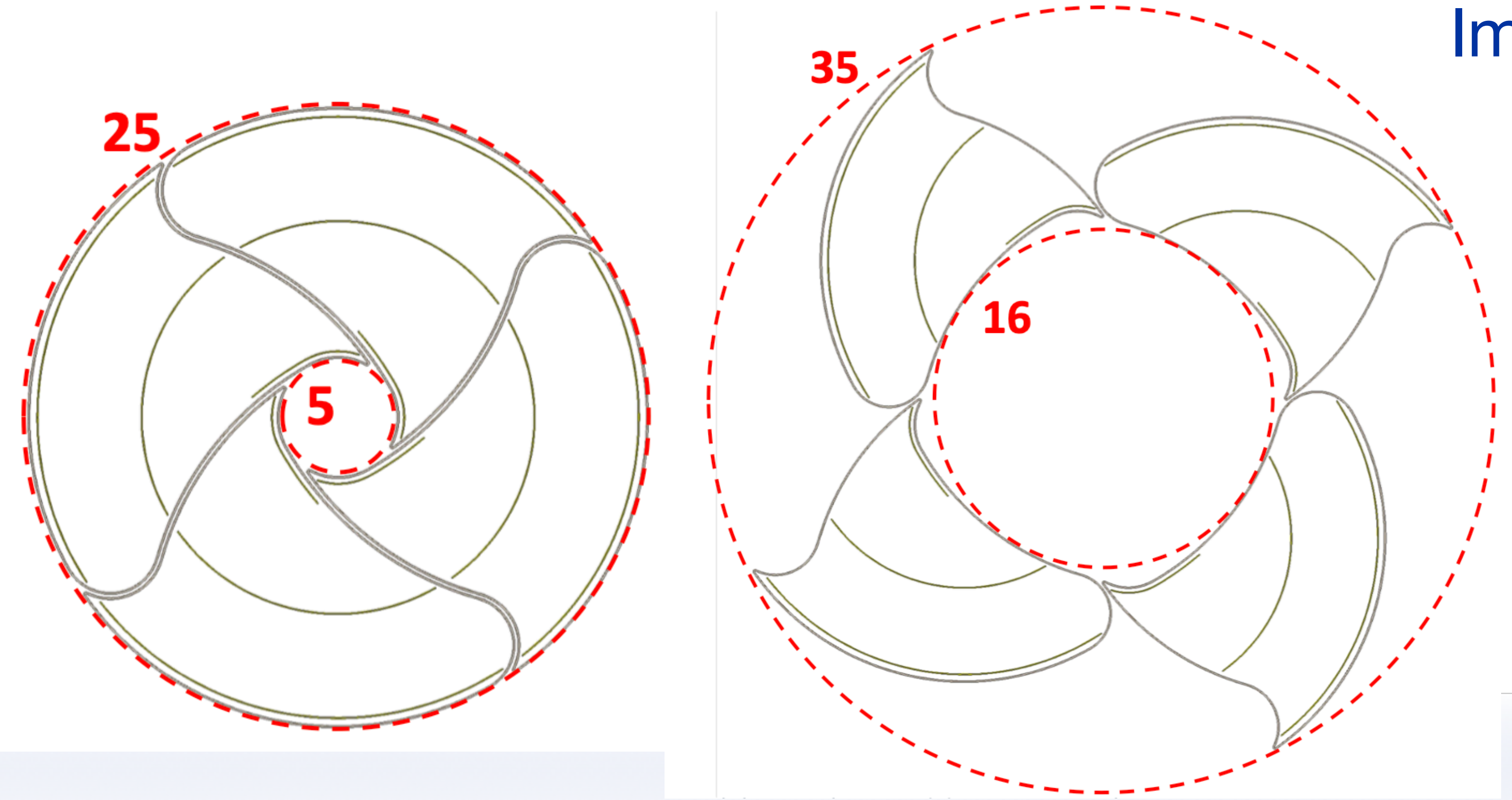
Impact parameter resolution with retractable layer



ALI-SIMUL-491785

Impact parameter resolution < 10 μm for p_T > 0.2 GeV





Performance simulations for multi-charm ongoing (heavy flavor WG)