

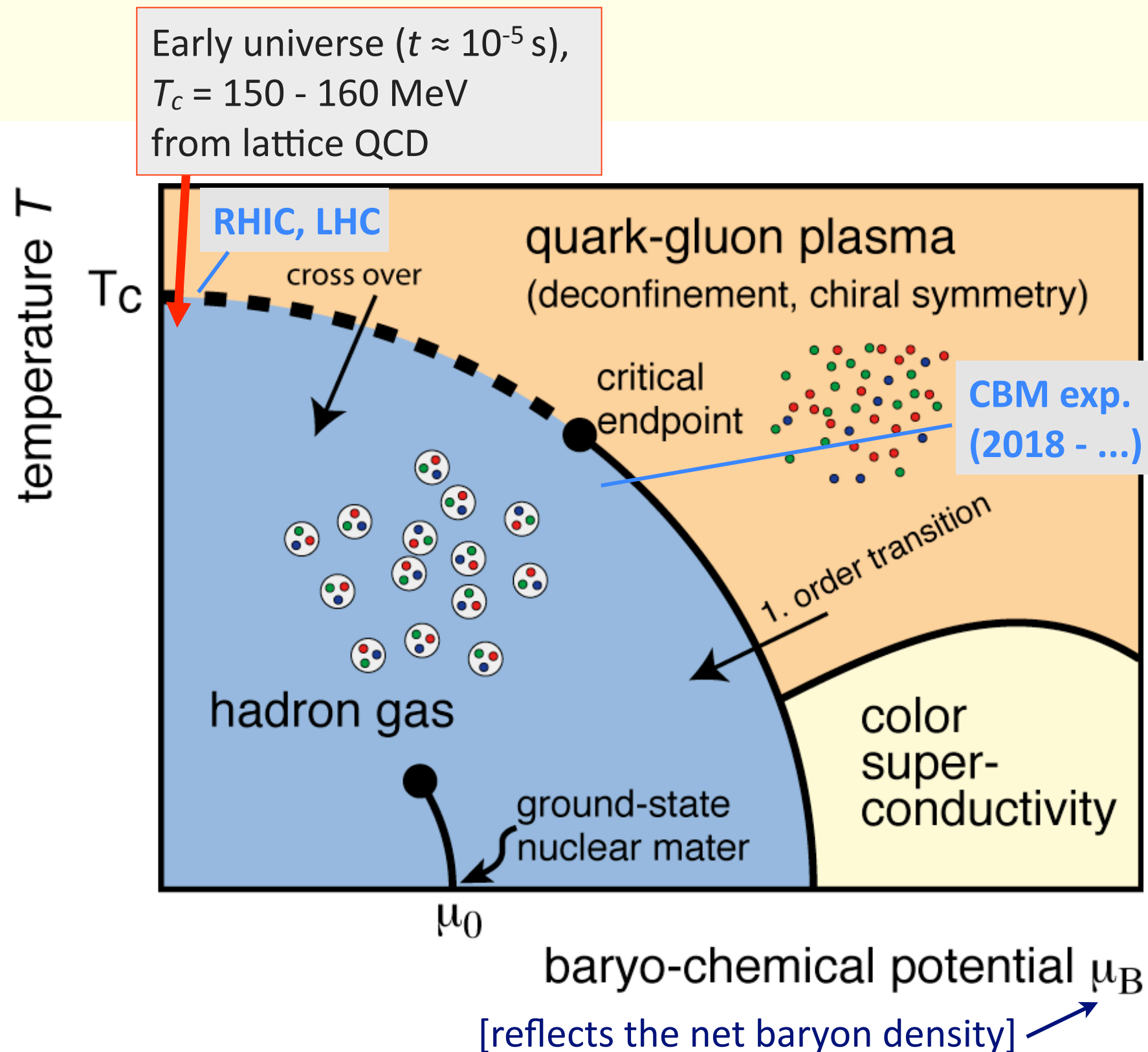
Heavy-Ions: Summary

43. Arbeitstreffen „Kernphysik“, Schleching, 23-Feb-2012

Klaus Reygers

Physikalisches Institut
University of Heidelberg, Germany

Exploring the QCD Phase Diagram



■ LHC

- ▶ Very high initial energy densities ($\epsilon > 12 \text{ GeV/fm}^3$) and temperatures
- ▶ Long QGP lifetimes
- ▶ Abundant production of hard probes (jets, heavy-quarks, ...)

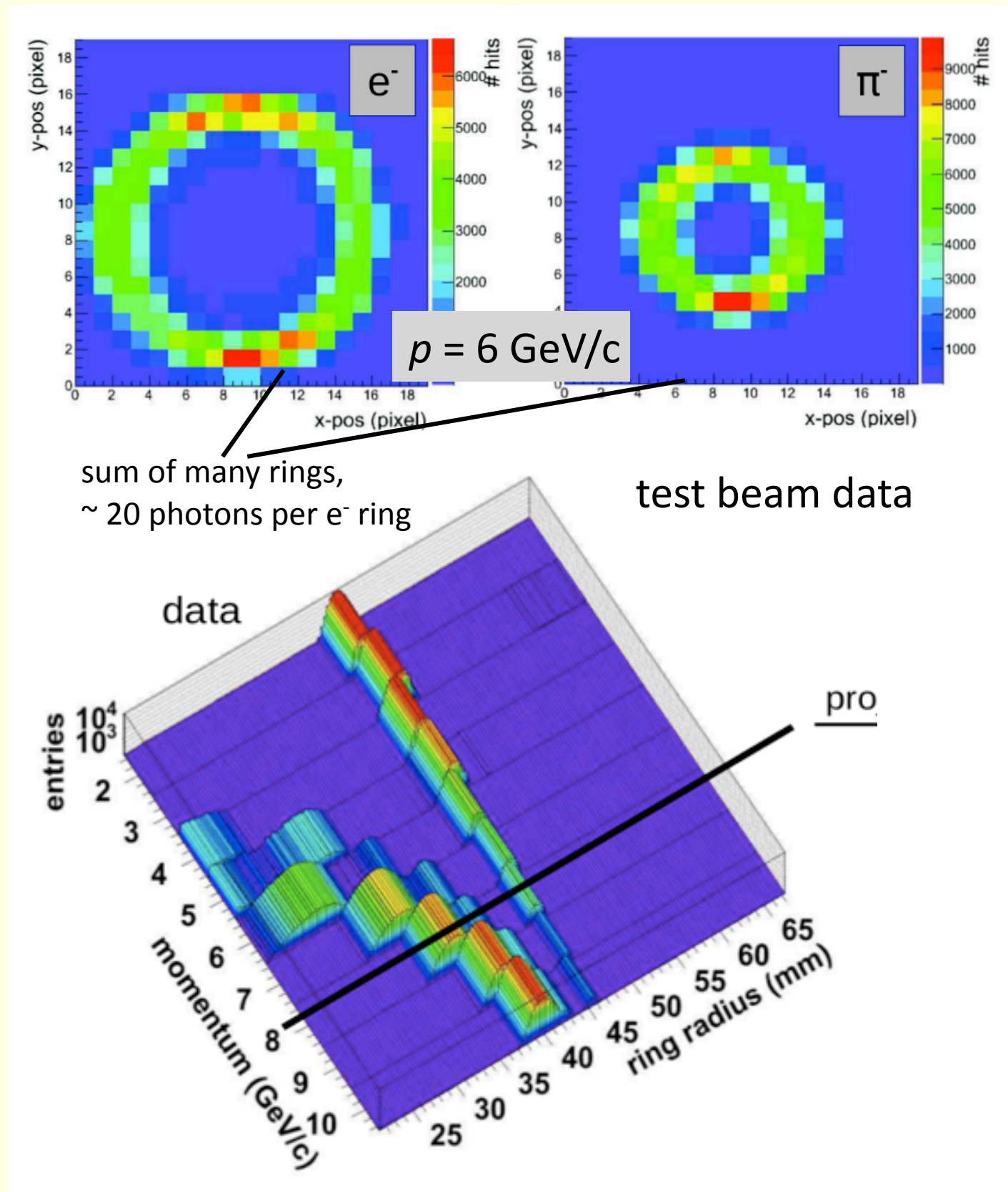
■ FAIR-CBM

- ▶ High beam intensities: study dense, baryon rich nuclear matter with rare probes

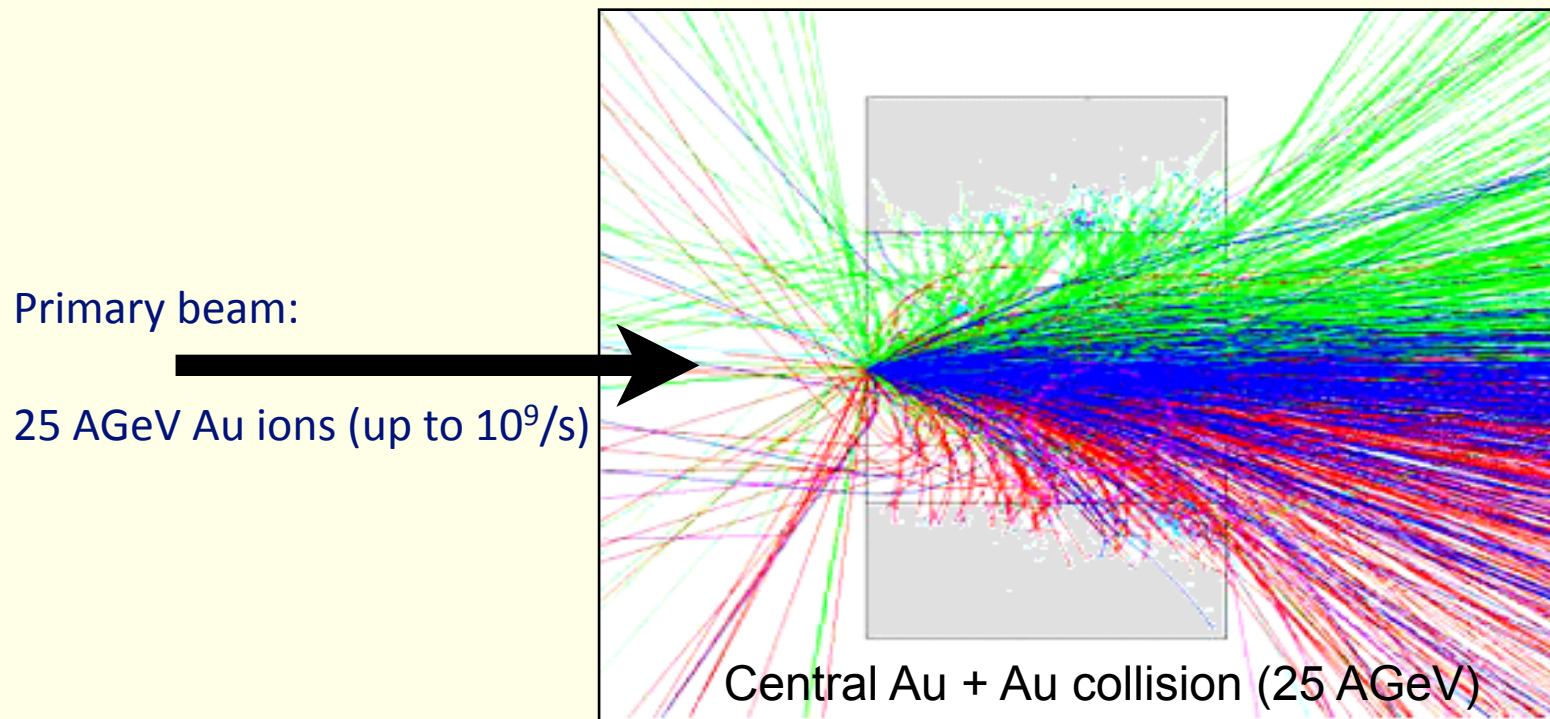
The CBM Experiment and the CBM-RICH

- CBM: fixed-target, A+A at 2-45 AGeV
- Dilepton probes as messengers of the early and dense phase of the fireball
 - ▶ $\rho, \omega, \Phi \rightarrow e^+ e^-$
 - ▶ $J/\psi, \Psi' \rightarrow e^+ e^-, \mu^+ \mu^-$
- D mesons
- These are rare probes!
- Needed:
 - ▶ reaction rates up to 10 MHz
 - ▶ fast detector systems
 - ▶ good particle ID
 - ▶ good pion suppression: 10^{-4}
- Example: CBM-RICH prototype

[Christian Pauly]

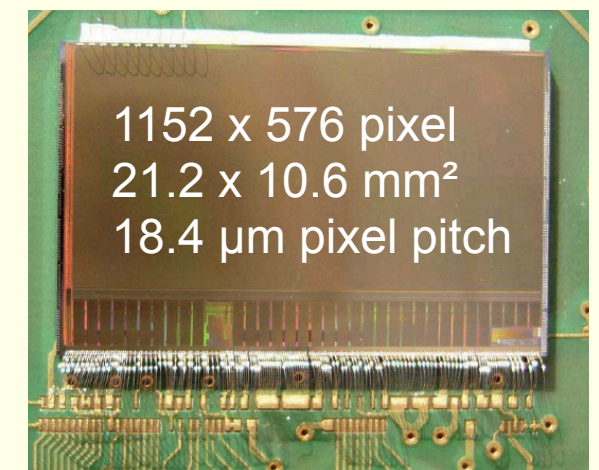


Monolithic Active Pixel Sensors (MAPS) for CBM

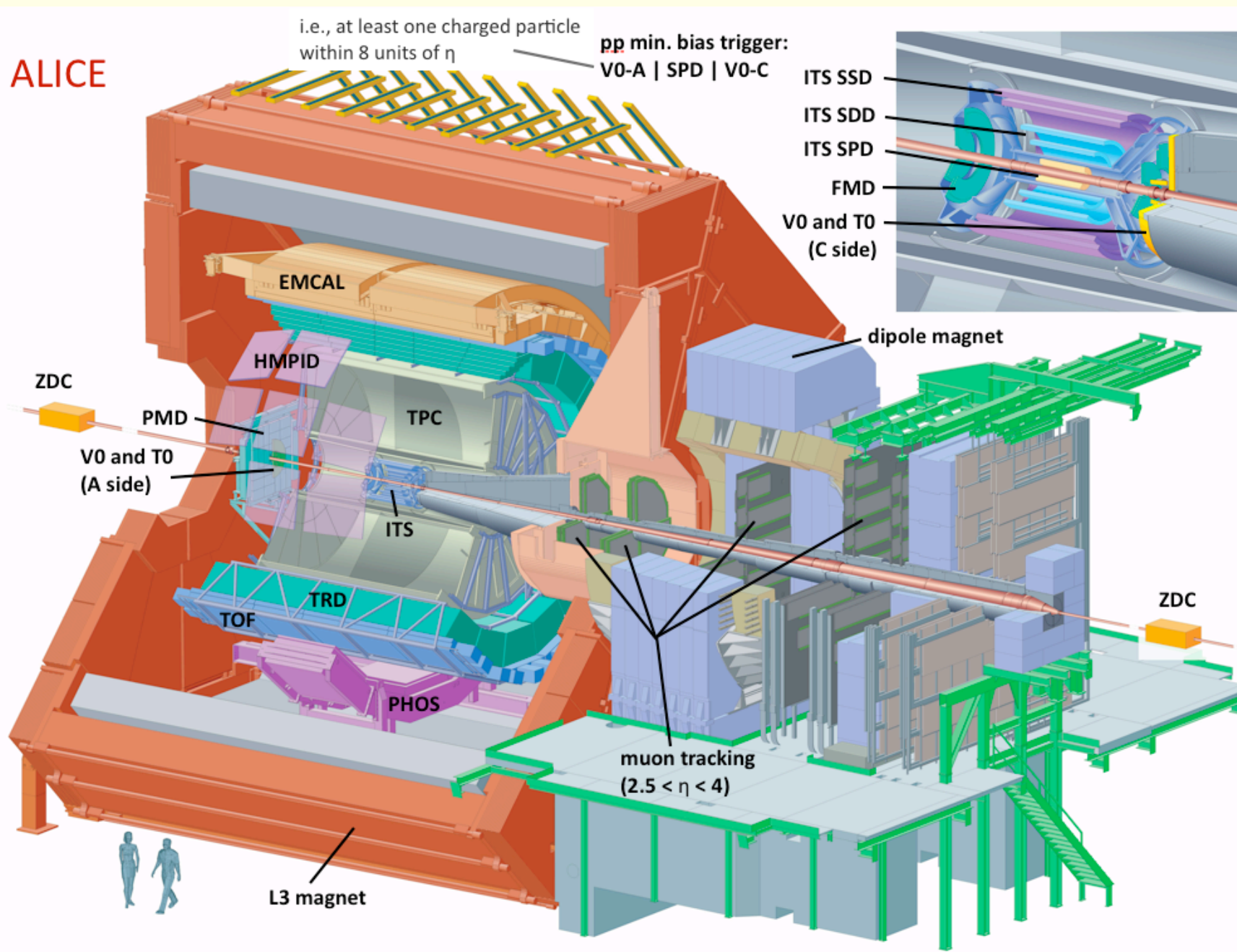


- MAPS provide a unique compromise between:
 - sensitivity
 - high rate capability
- Time resolution and radiation hardness as of 2003 needed improvement
- Requirements are met with current design

	Required	MAPS (2003)	MAPS (2011)
Single point res. [μm]	~ 5	3.5	3.5
Material budget [X_0]	$\sim 0.3\%$	$\sim 0.05\%$	$\sim 0.05\%$
Time resolution [μs]	10-100	~ 1000	~ 100
Rad. hardness [n/cm^2]	$> 10^{13}$	$> 10^{12}$	$> 10^{13}$



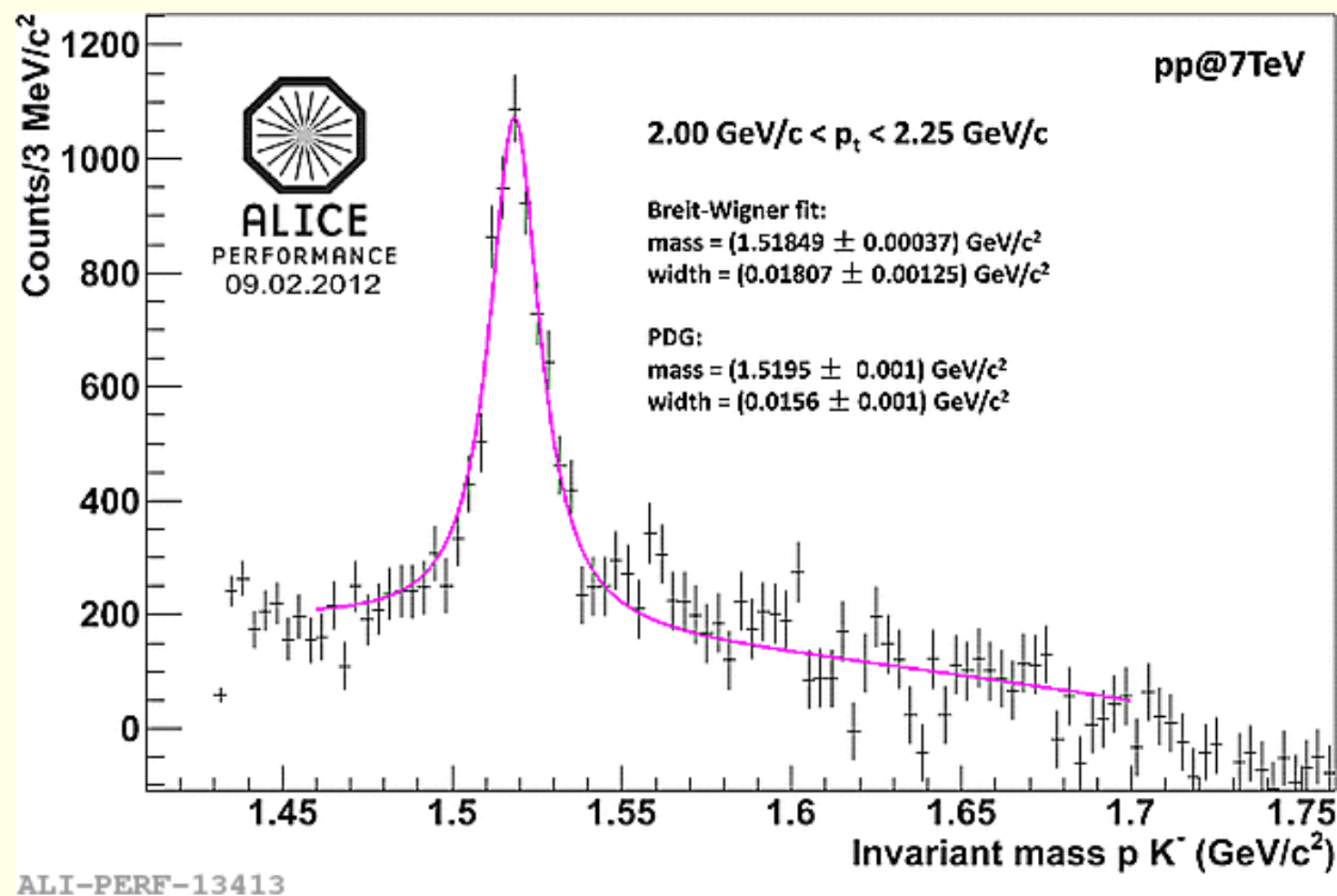
ALICE: Excellent Momentum Reconstruction + Particle ID a Low p_T



- ALICE designed for heavy-ion collisions
- Robust tracking over large p_T range ($\sim 0.1 \text{ GeV} < p_T < 100 \text{ GeV}$)
- PID over large p_T range
 - ▶ dE/dx
 - ▶ Time-of-flight
 - ▶ TRD
 - ▶ ...

Applications of ALICS's PID Capabilities (I): Reconstruction of Resonances

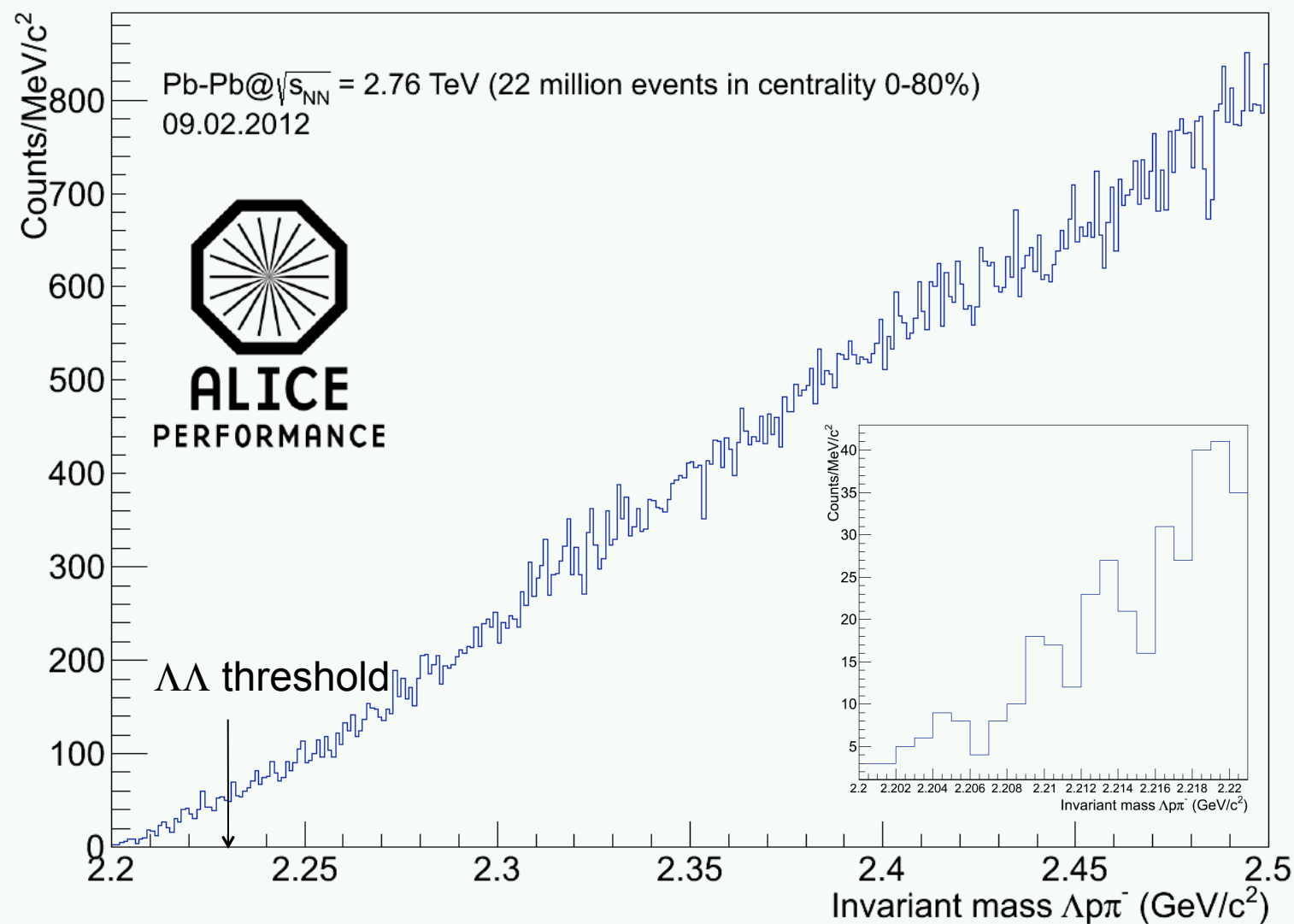
$$\Lambda(1520) \rightarrow p + K^- \quad (BR:22.5\%)$$



- Heavy-Ion Physics = QCD thermodynamics
- Statistical model:
 - ▶ Describes yields of all particles with three parameters
 - ▶ T, μ_B, V
- Test statistical model by measuring as many particle species as possible at low p_T
- Example: $\Lambda(1520)$

[Benjamin Dönigus]

Applications of ALICE's PID Capabilities (II): Search for Exotic Hadrons



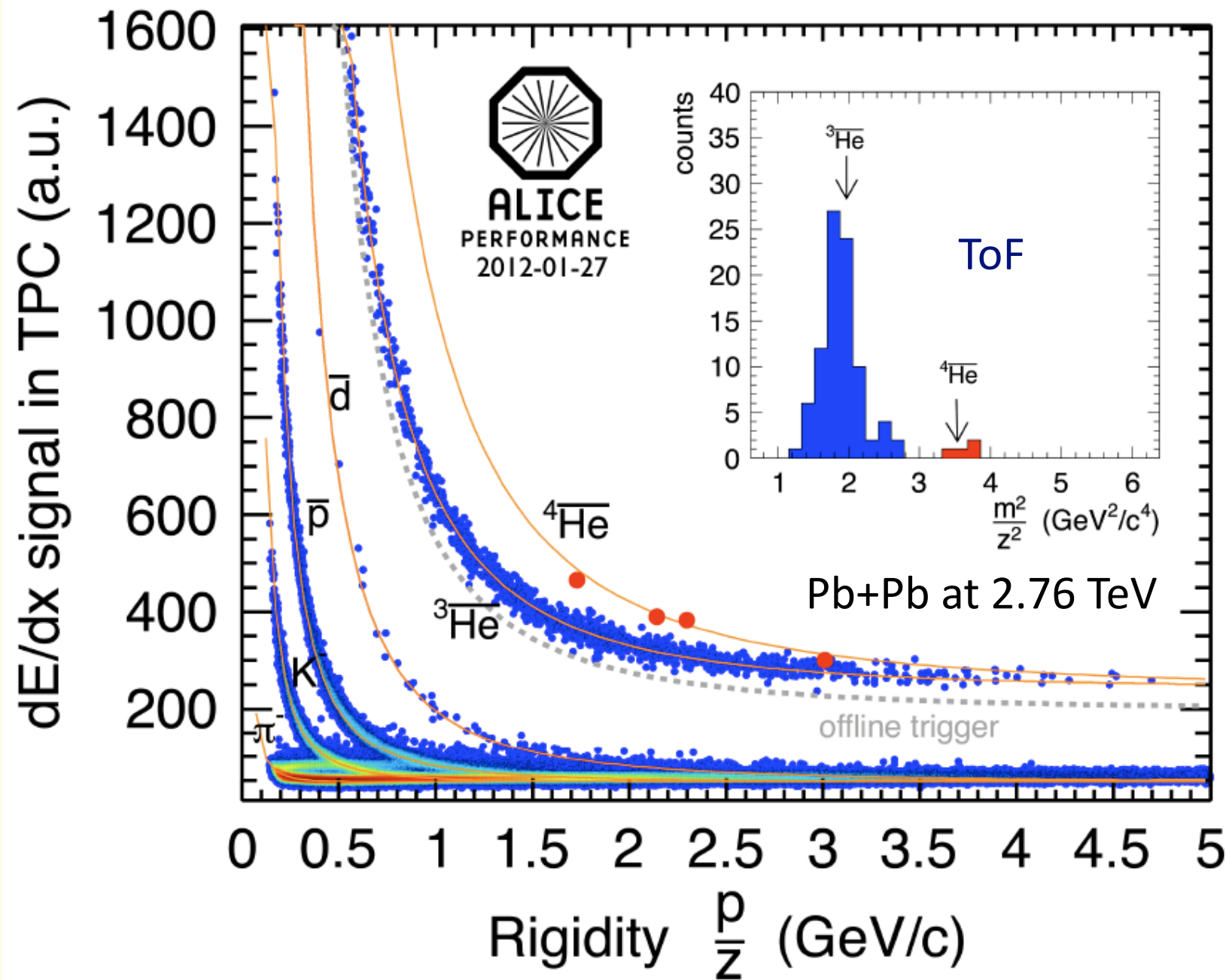
■ H^0 -Dibaryon

- ▶ bound state of udsuds (R. Jaffe, 1977)
- ▶ predicted mass: 2.21 GeV/c²
- ▶ $\Lambda\Lambda$ bound state or resonance with $H^0 \rightarrow \Lambda\Lambda$ decay channel

■ No signal observed in $\Lambda\rho\pi^- / \Lambda\Lambda$ channels

[Benjamin Dönigus]

Applications of ALICE's PID Capabilities (III): Anti Helium



■ Modeling the production of light nuclei

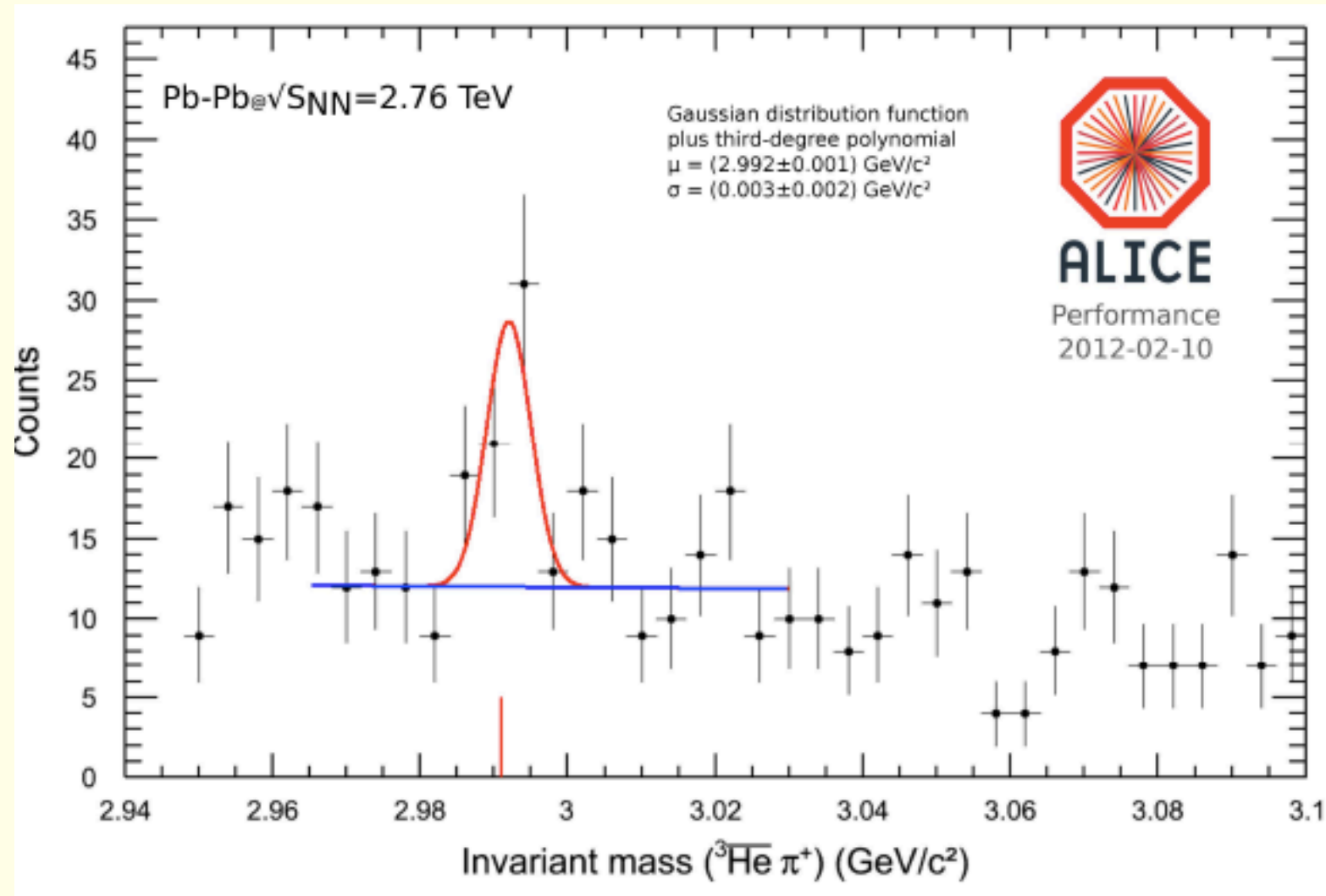
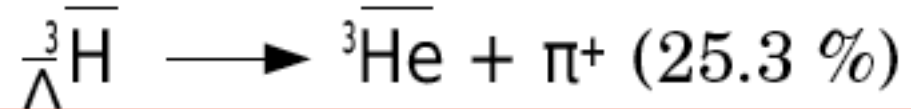
- ▶ Statistical model
- ▶ Coalescence: (e.g., can the yield of $\frac{3}{\Lambda}\bar{\text{H}}$ be computed from $\bar{\Lambda}$, $\bar{n}$, $\bar{p}$ phase space densities?)
- ▶ ...

■ Particle ID: dE/dx from TPC + ToF

- Anti-nuclei at low p_T experimentally easier than nuclei (knock-out of detector material)

[Nicole Martin]

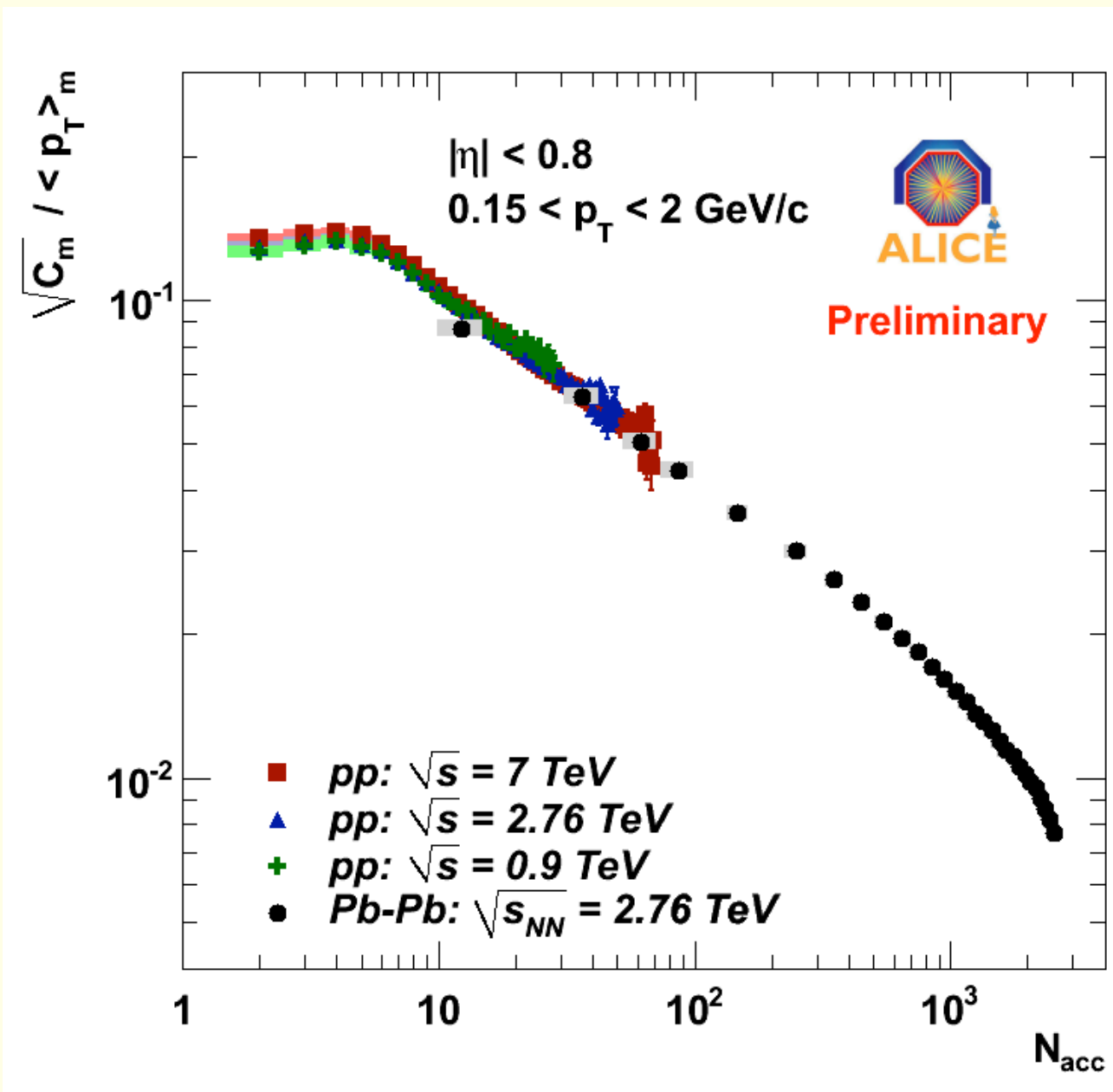
Applications of ALICE's PID Capabilities (IV): Anti-Hypertritons



- Measured so far
 - ▶ p+p:
anti-nuclei up to
anti-helium-3
 - ▶ Pb+Pb:
anti-helium-3 spectrum,
anti-alphas,
anti-hypertriton
- Expect much more with
higher statistics

31 ± 9 anti-hypertritons (2010 data)

Dynamical Fluctuations (I)



[Stefan Heckel]

- Two-particle correlator for a multiplicity class m

$$\sigma_{\text{dyn}}^2 \equiv C_m = \left\langle \left(p_{T,i} - \langle p_T \rangle_m \right) \cdot \left(p_{T,j} - \langle p_T \rangle_m \right) \right\rangle$$

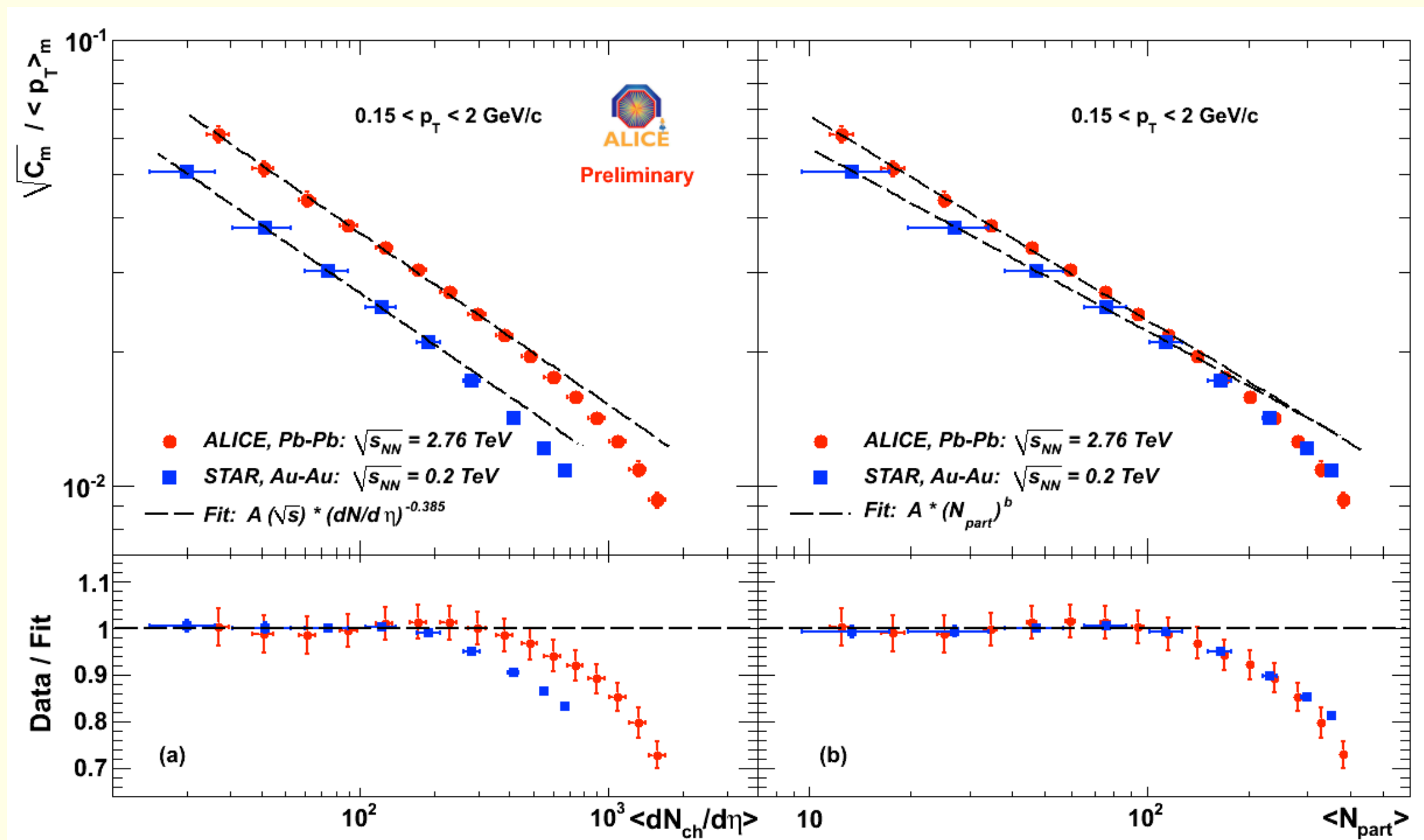
- By construction not sensitive to statistical fluctuations

- Relative fluctuations $\frac{\sqrt{C_m}}{\langle p_T \rangle_m} \equiv \frac{\sigma_{\text{dyn}}}{\langle p_T \rangle}$

- Pb+Pb follows p+p trend up to centrality class 30%-40% ($N_{\text{acc}} \approx 600$): Onset of thermalization?

- 30%-40% class:
 $N_{\text{part}} \approx 100$, $N_{\text{coll}} / (N_{\text{part}}/2) \approx 4$

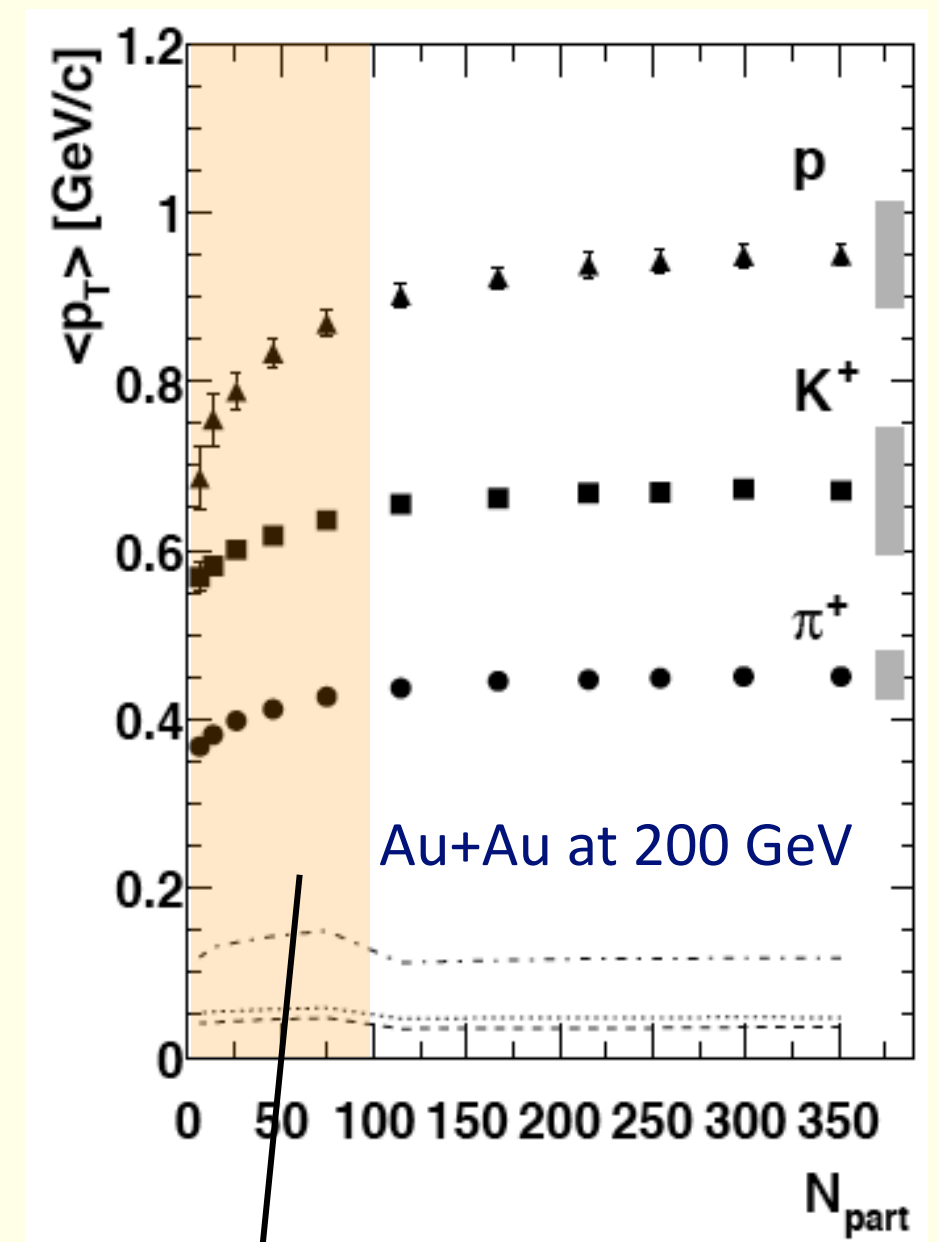
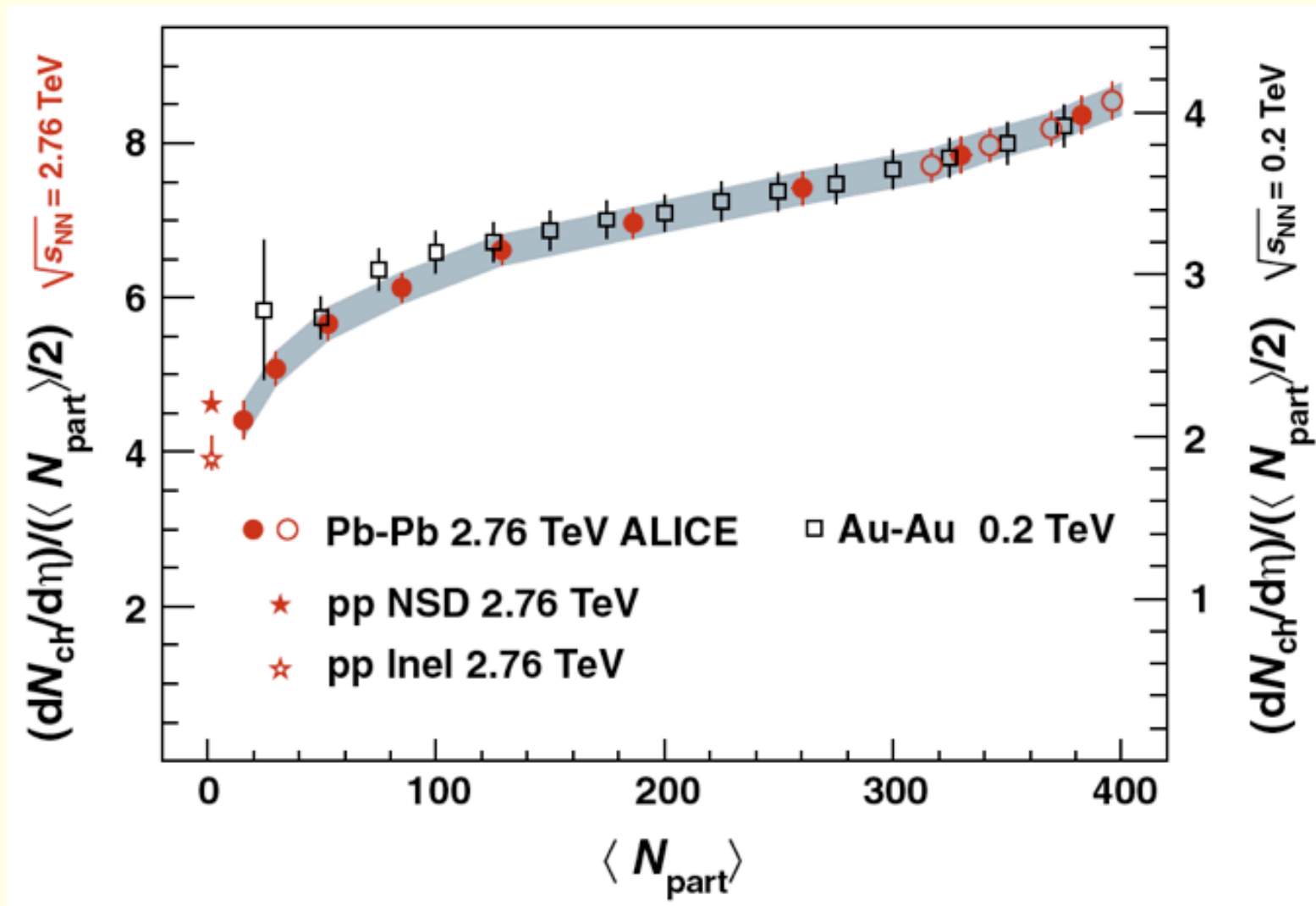
Dynamical Fluctuations (II): Comparison between LHC and RHIC



- „Scaling“ in N_{part} , not in $dN_{ch}/d\eta$
- Hints at importance of nuclear geometry in heavy-ion collisions

The Unreasonable Effectiveness of ...

... Geometry in Heavy-Ion Physics



- Example: Shape of N_{ch}/N_{part} vs. N_{part} very similar between $\sqrt{s_{NN}} = 20 - 2760$ GeV
- Rather rapid transition from p+p-like behavior to A+A-like behavior

$\langle p_T \rangle \sim$ constant for $N_{part} > 100$

Heavy Flavors with ALICE

■ Method 1:

Measure $e^{-/+}$ from semi-leptonic decays, subtract cocktail of background $e^{-/+}$

- ▶ $D, B \rightarrow e + X$
- ▶ $B \rightarrow e + X$ (use $(c\tau)_B = 500 \mu\text{m}$)

$c \rightarrow e + X$	$\approx 9.6\%$
$b \rightarrow e + X$	$\approx 11\%$
$b \rightarrow c \rightarrow e + X$	$\approx 10\%$

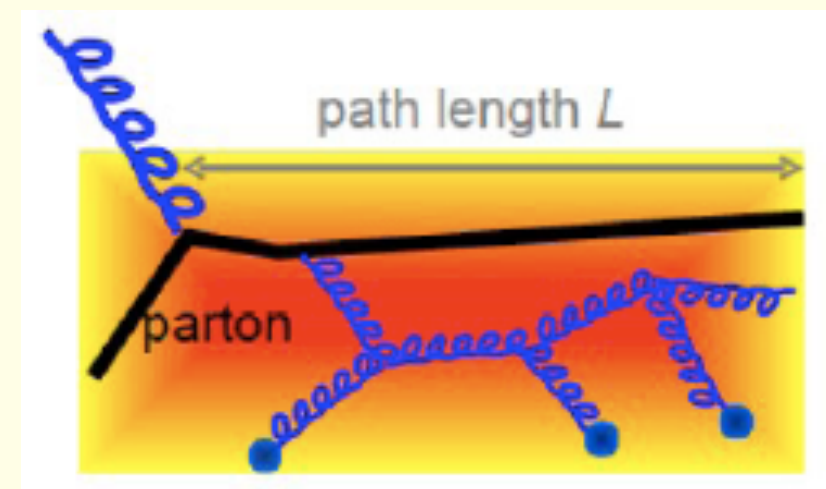
■ Method 2:

Reconstruction in hadronic decay channels

- ▶ $D^0 \rightarrow K \pi$
- ▶ $D^{+/-} \rightarrow K \pi \pi$
- ▶ $D^{*+/-} \rightarrow D^0 \pi$
- ▶ $\Lambda \rightarrow p K \pi$

■ Motivation

- ▶ p+p: test pQCD
- ▶ Pb+Pb: test parton energy loss models



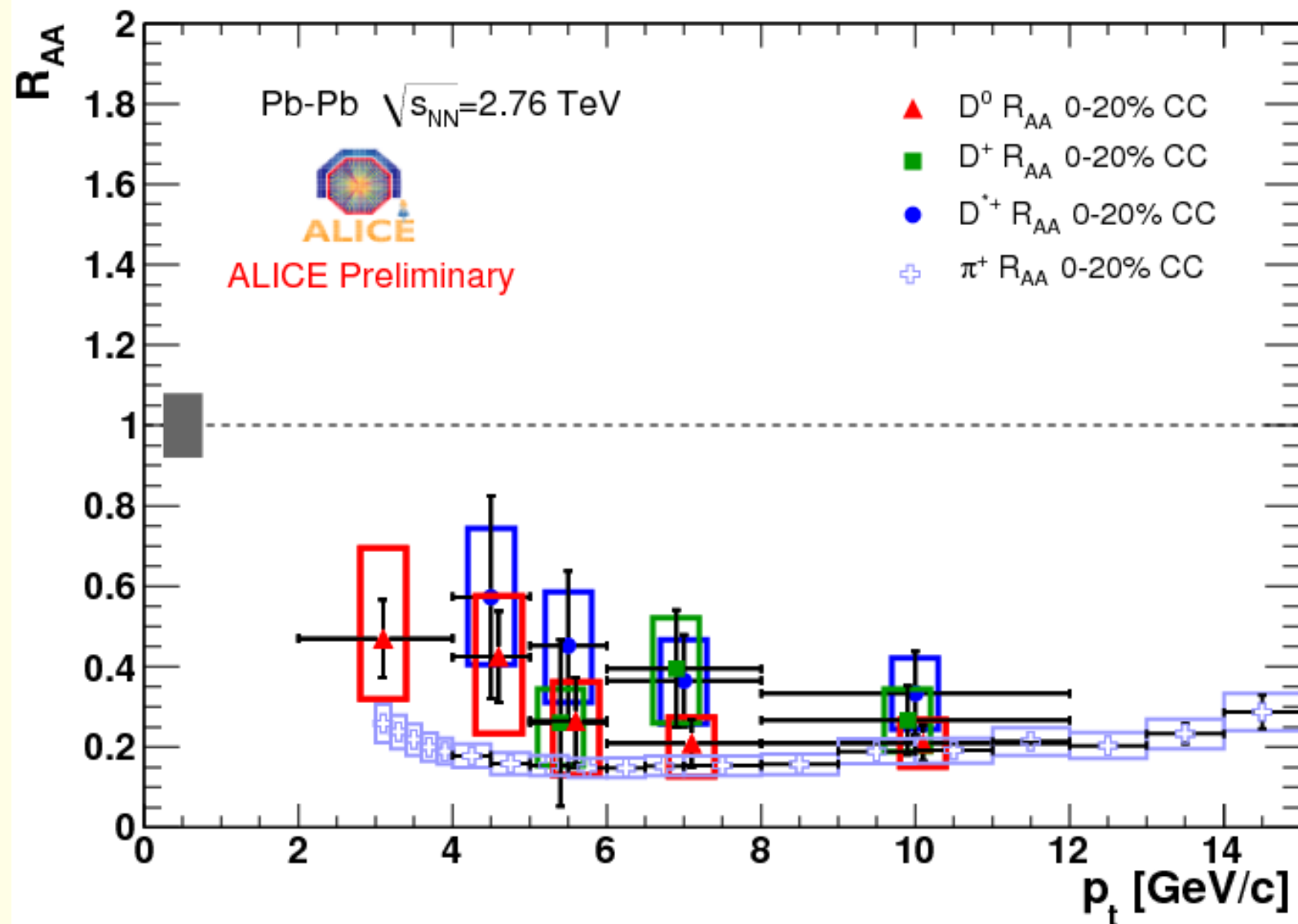
$$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$$

color factor dead cone effect

- p+p at 7 TeV (and 2.76 TeV), ALICE: Heavy flavor electrons and D meson spectra agree with pQCD (FONLL, GM-VFNS)

D meson R_{AA}

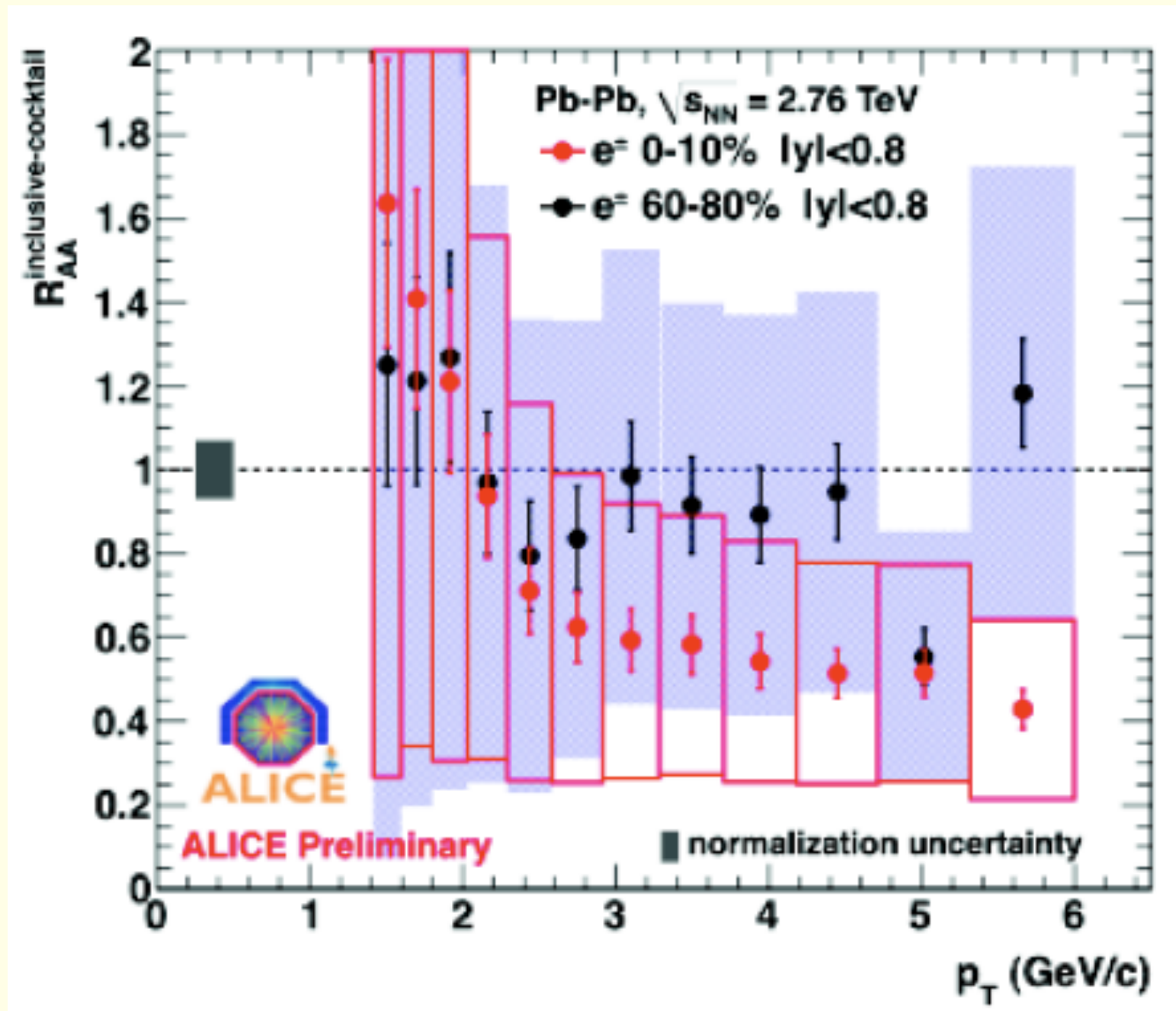
[Rosa Romita]



$$R_{AA}(p_T) = \frac{dN / dp_T (A + A)}{N_{\text{coll}} \cdot dN / dp_T (p + p)}$$

- Strong suppression for both D mesons and pions
- Surprisingly similar R_{AA} for D mesons and pions
 - ▶ pions mainly from gluons
 - ▶ dead cone effect
- However, some indication for $R_{AA}(D) > R_{AA}(\pi)$ at low p_T

R_{AA} for Electrons from Heavy Flavor Decays



[Raphaelle
Bailhache-Römer]

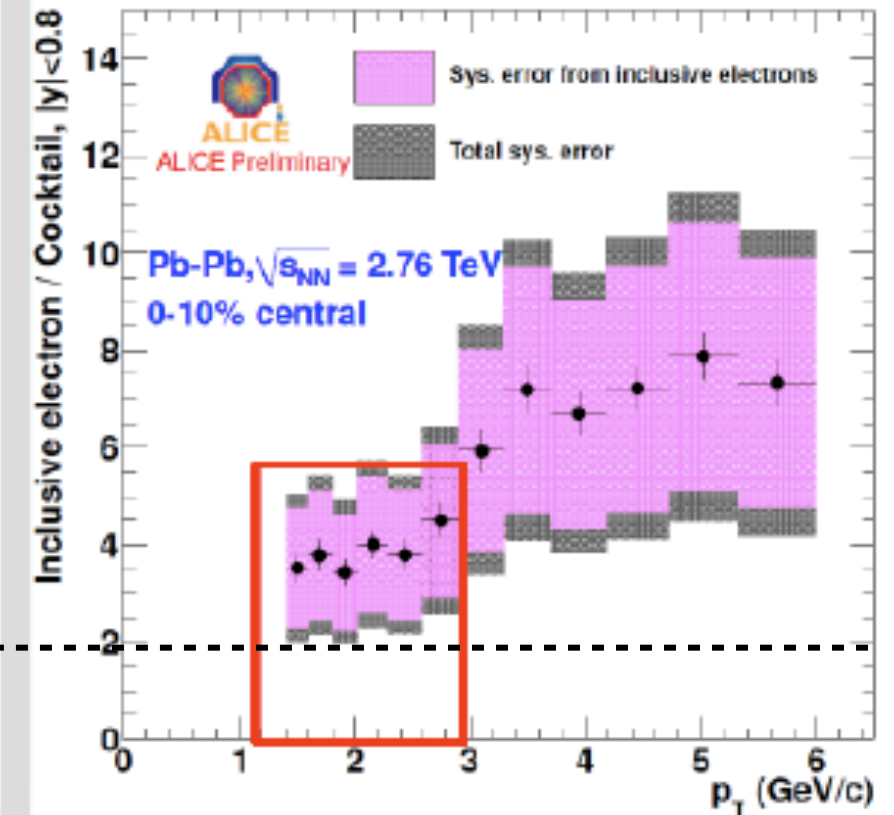
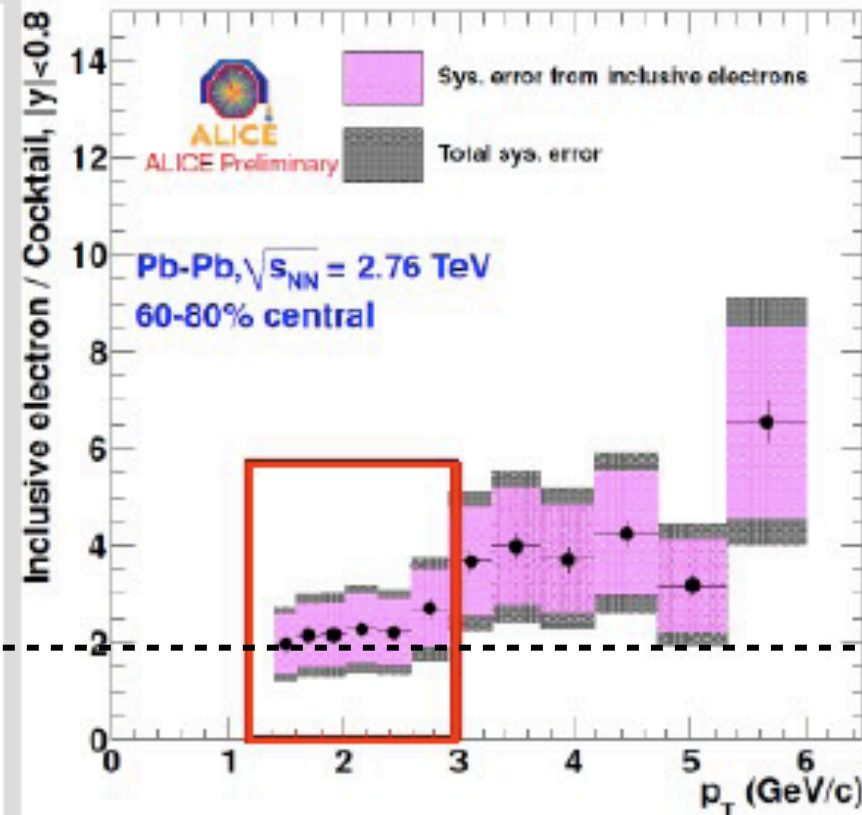
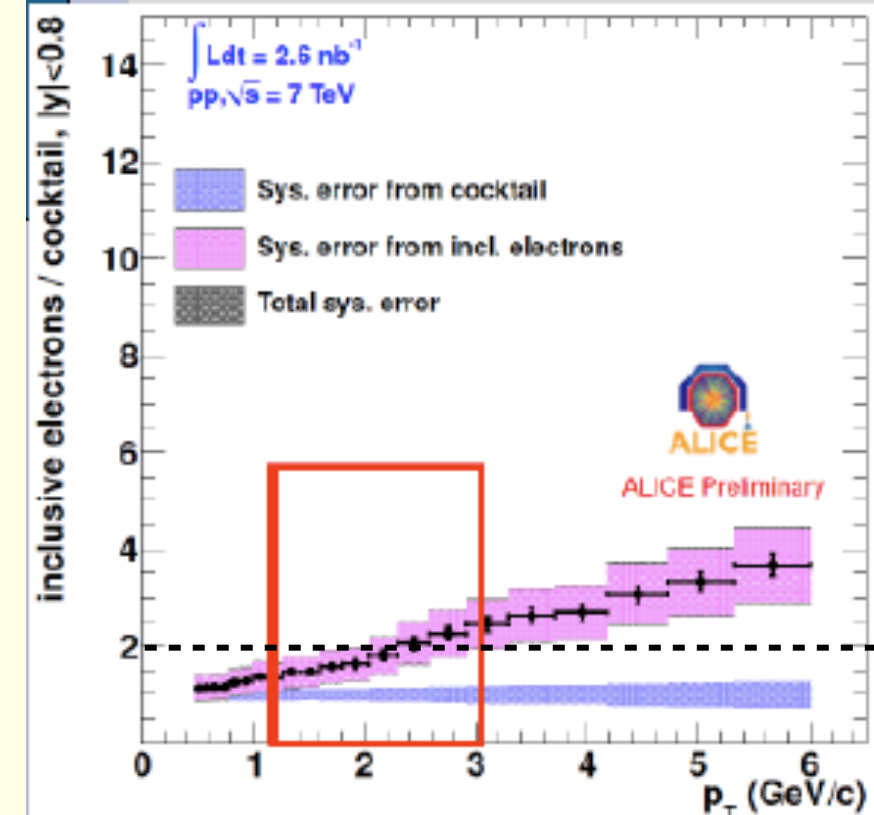
- Suppression in central Pb+Pb collisions (0-10%)

Electron Excess in Central Pb+Pb

pp 7 TeV

Pb-Pb  60-80%

Pb-Pb  0-10%

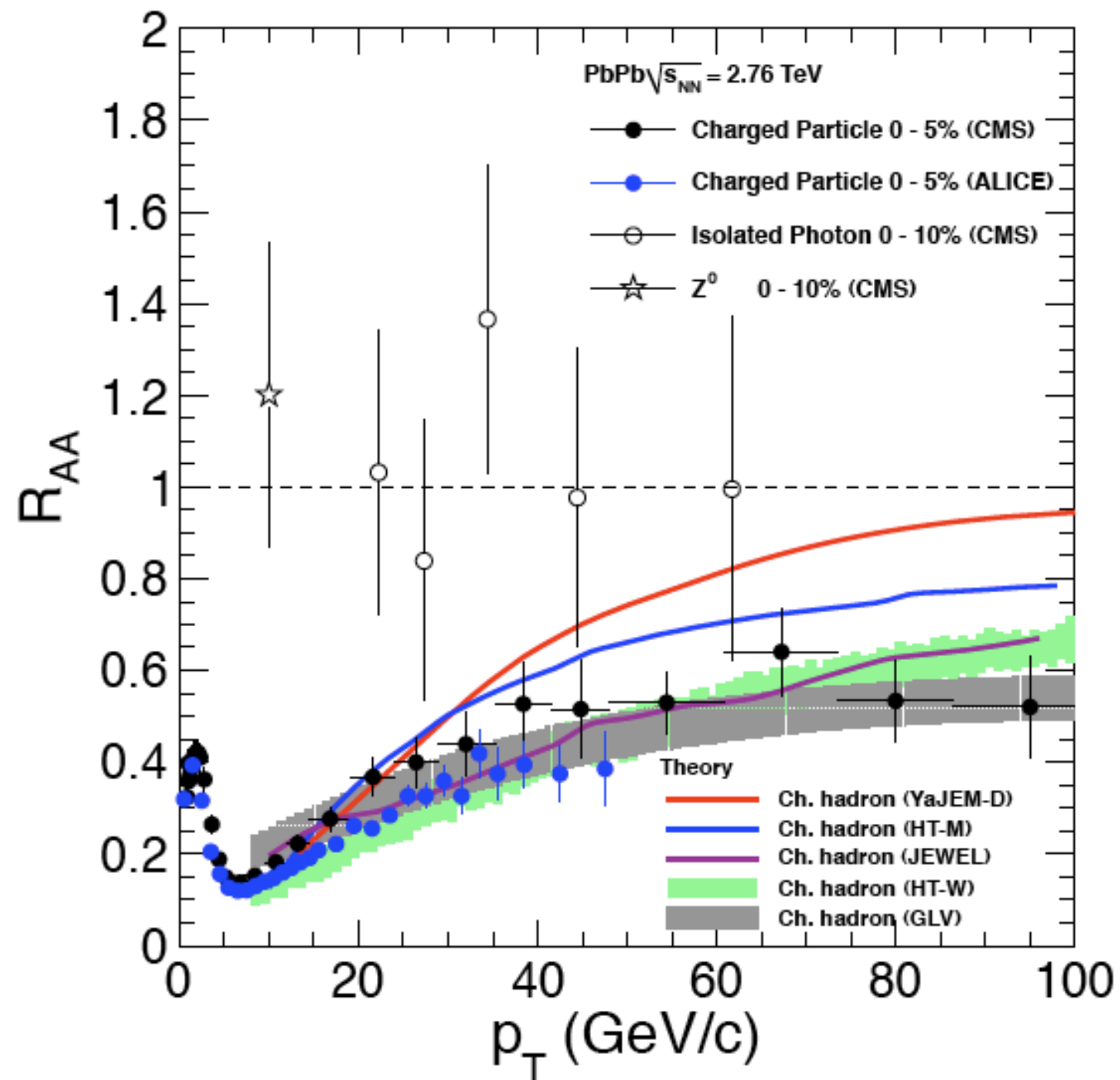


- Hint for low p_T electron excess in central Pb+Pb
- Related to thermal direct photons? Thermal Charm production?
Effect of $R_{AA}(D) > R_{AA}(\pi)$?

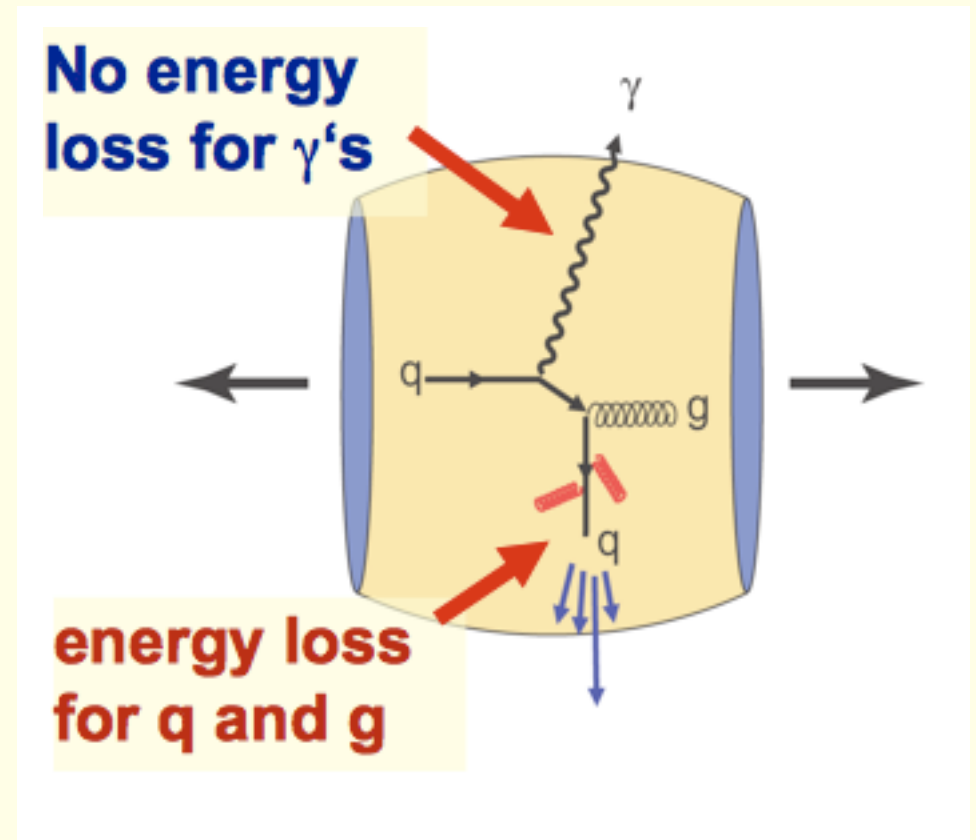
Jet Quenching (I)

- In heavy-ion physics, particles at high p_T and jets are of great interest because
 - ▶ they are produced in the early stage of a heavy-ion collisions, prior to the formation of the quark-gluon plasma
 - ▶ their initial production rate can be calculated with perturbative QCD („calibrated probe“)
- Observables related to jet quenching may help to
 - ▶ understand the mechanism of parton energy loss (talk by Markus Bluhm)
 - ▶ characterize the new state of matter above T_c
- Many open questions in the theoretical description
 - ▶ dependence on parton species
 - ▶ elastic vs. radiative energy loss
 - ▶ path length dependence
 - ▶ ...

Jet Quenching (II)



$$R_{AA}(p_T) = \frac{dN / dp_T (A + A)}{N_{\text{coll}} \cdot dN / dp_T (p + p)}$$



- Large p_T reach at the LHC sheds light on E dependence of parton energy loss ΔE