Physics Potential of the ALICE Experiment

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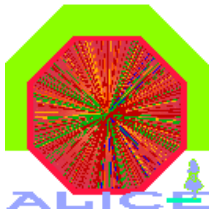
for the ALICE Collaboration

The Physics Potential of the ALICE Experiment

Outline

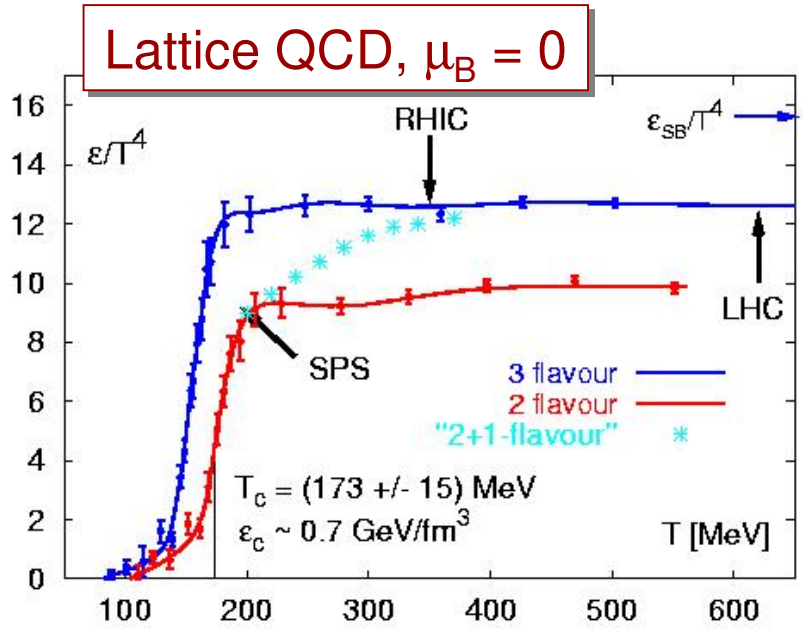


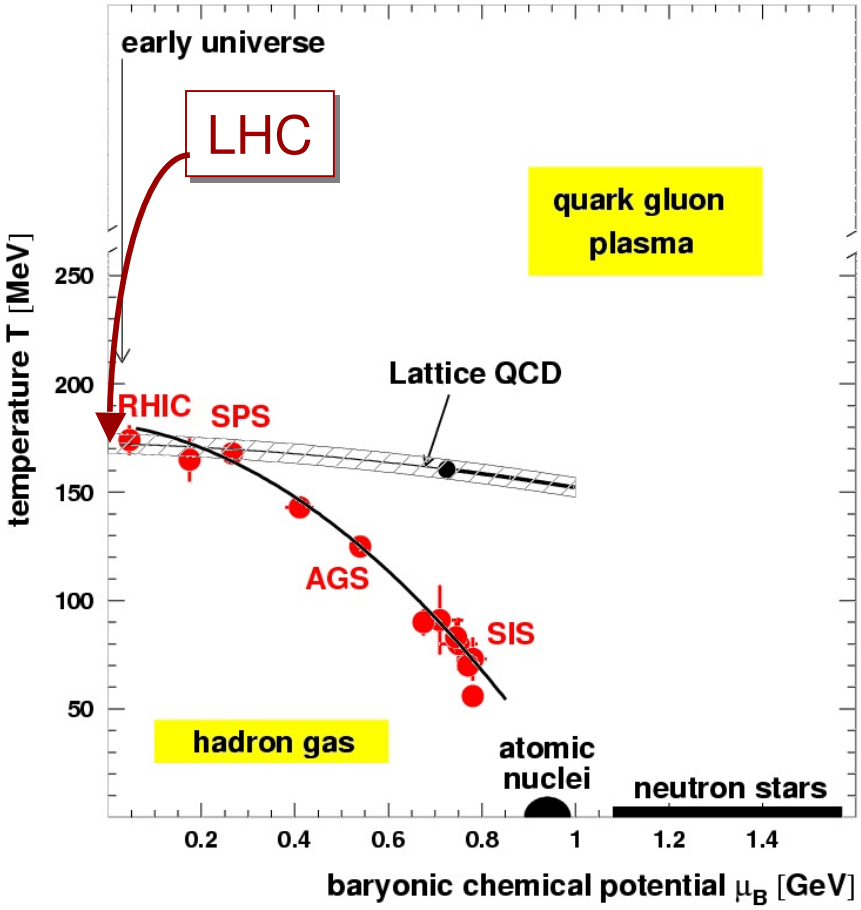
- ALICE physics
  - Strongly interacting matter
  - Observables
  - p+p physics
- Low p_t physics examples
  - HBT
  - Resonances
- Heavy quarks
  - Open charm
  - Open beauty
  - Quarkonia family
- Parton energy loss
  - High p_t particle spectra
  - Jets via correlations

ALICE Physics

Phases of Strongly Interacting Matter

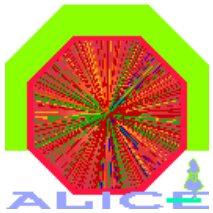
- Exploring the phase diagram of strongly interacting matter
- LHC provides access to the high *T*, vanishing μ_B QGP phase





ALICE Physics

Properties of QGP Phase @ LHC



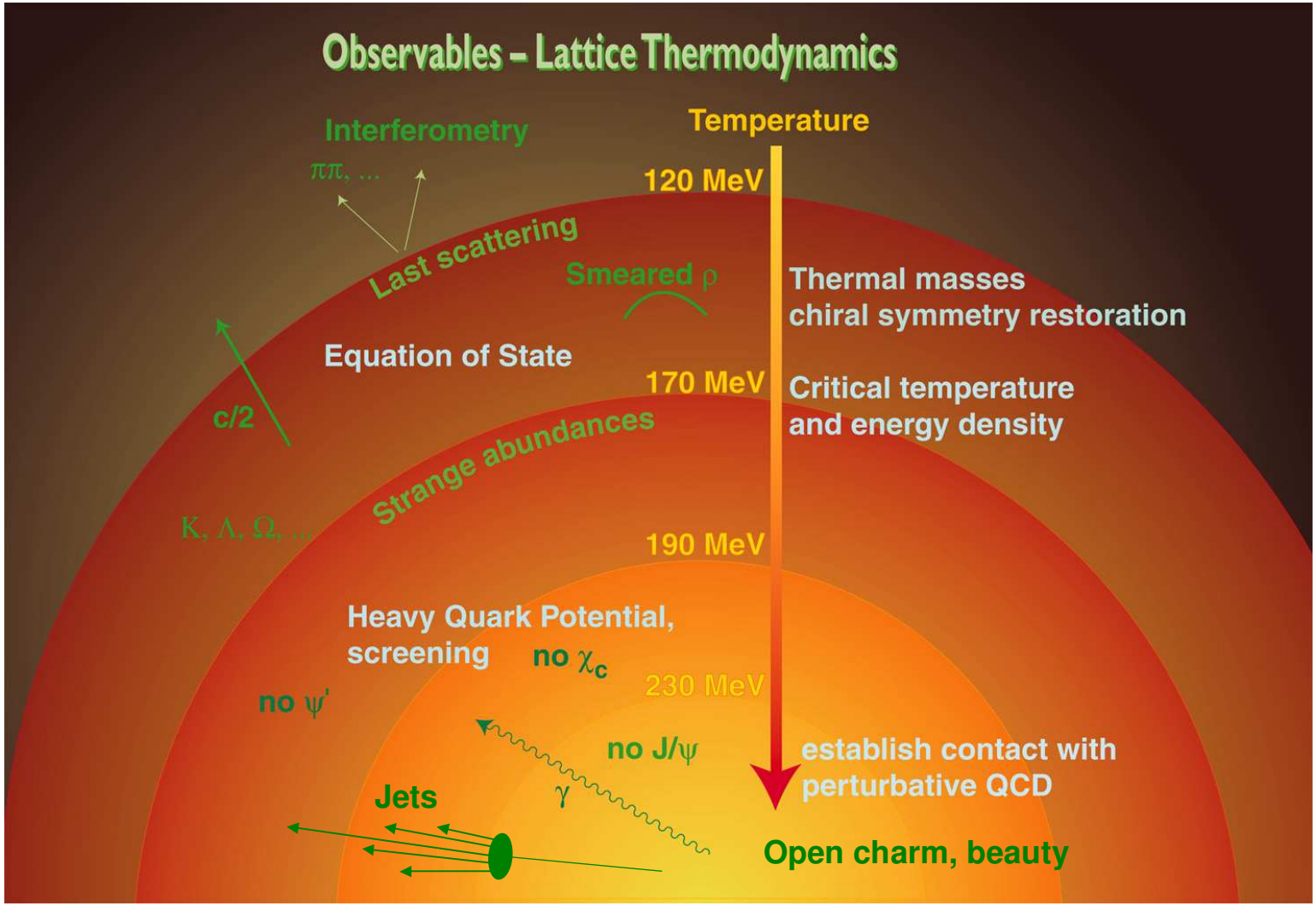
- Initial conditions

Energy density ε	$\leq$ 1000 GeV/fm^3
Temperature T	$\leq$ 1 GeV

- ...so LHC is deep in QGP phase
- Hard processes
  - Probe of early state of reaction
  - Pertubative QCD
  - Significant part of cross section
- High density parton distributions
  - Bulk of partons at $x \leq 10^{-3}$
  - Saturated gluon densities
- Evolution of system will be dominated by partons
  - Longer lifetime of QGP phase
  - Collective effects will be strongly influenced by parton dynamics
    $\rightarrow$ partonic flow

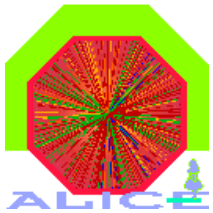
ALICE Physics

Observables



ALICE Physics

Observables



Hard Regime

p_t > 10 GeV/c

perturbative

- Hard photons
- Open beauty, Υ
- Jets

→ initial collisions

Semi-hard Regime

p_t = 2–5/10 GeV/c

- Thermal photons
  → temp. evolution
- Open charm, J/Ψ
  → plasma screening
- p_t-Spectra
  → mini-jets

Soft Regime

p_t = 0–2 GeV/c

non-perturbative

- Particle yields
  → chem. freeze-out
- HBT interferometry
  → thermal freeze-out
- Flow
  → expansion

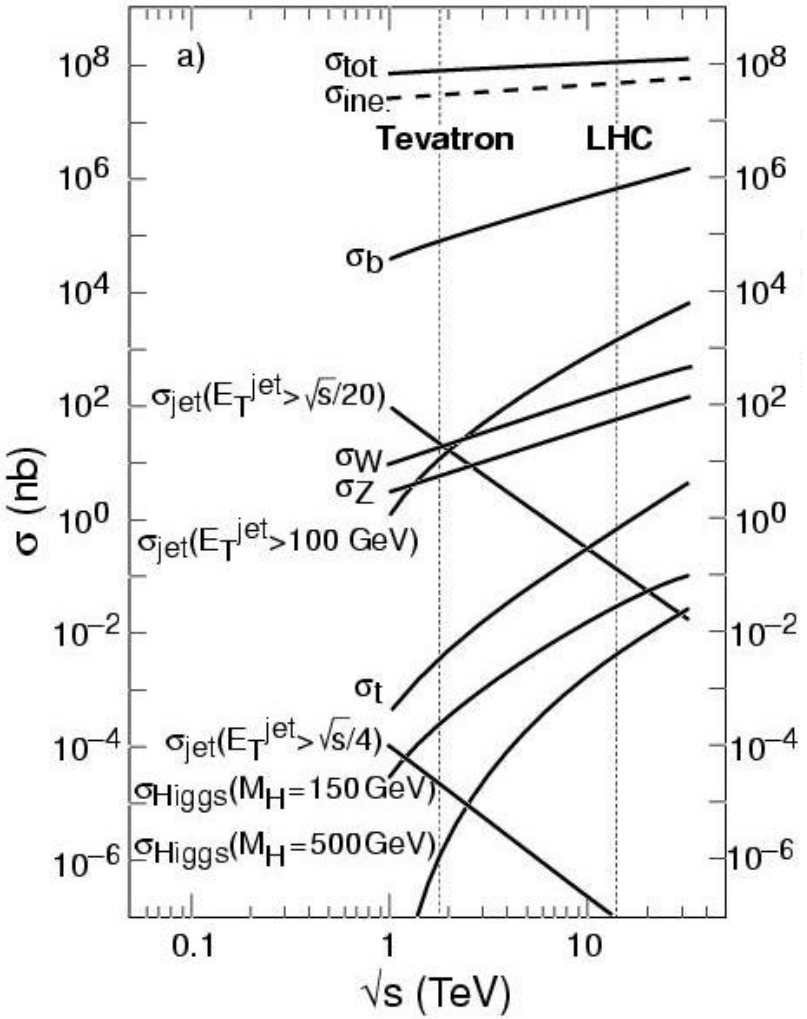
→ ALICE will cover the transition from the hard (partonic) to the soft (hadronic) regime

→ Correlations between hard and soft probes only possible within ALICE

ALICE Physics

p+p Physics

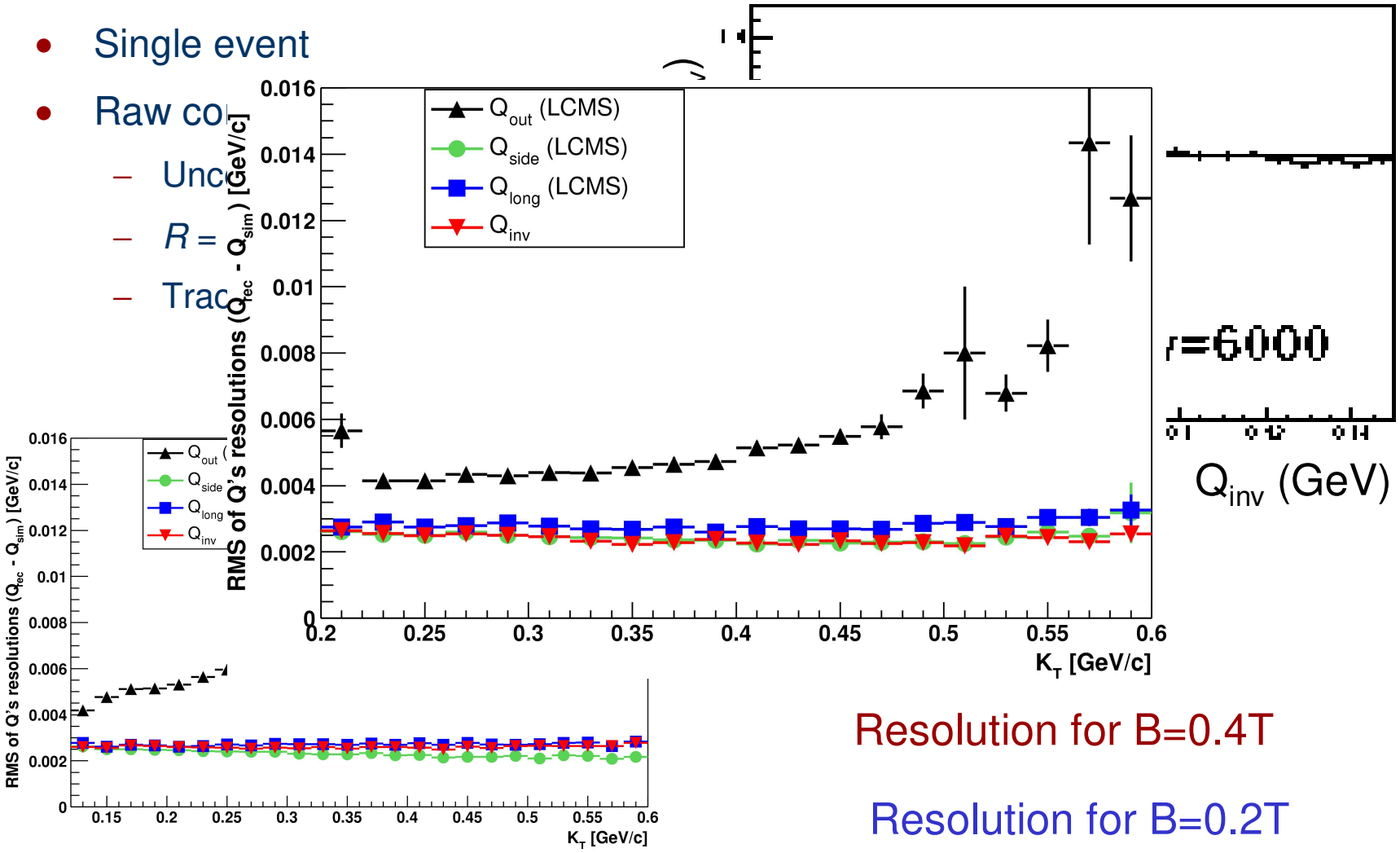
- Benchmark for Pb+Pb:
  - Multiplicities (strangeness)
  - J/Ψ and ϒ
  - Parton energy loss (jets)
  - Thermal photons
- High energy densities @ LHC:
  - $\varepsilon \approx 1.2$ GeV/fm^3
  - Comparable to N+N @ SPS/RHIC
- Bulk of cross section at low p_t
  - Investigation in a new energy regime
- p+A program
  - Nuclear structure functions
  - Benchmark for Pb+Pb



Low p_t Physics Examples

Event-by-Event $\pi^+\pi^+$ HBT

- Single event
- Raw co
  - Unc
  - R =
  - Trac



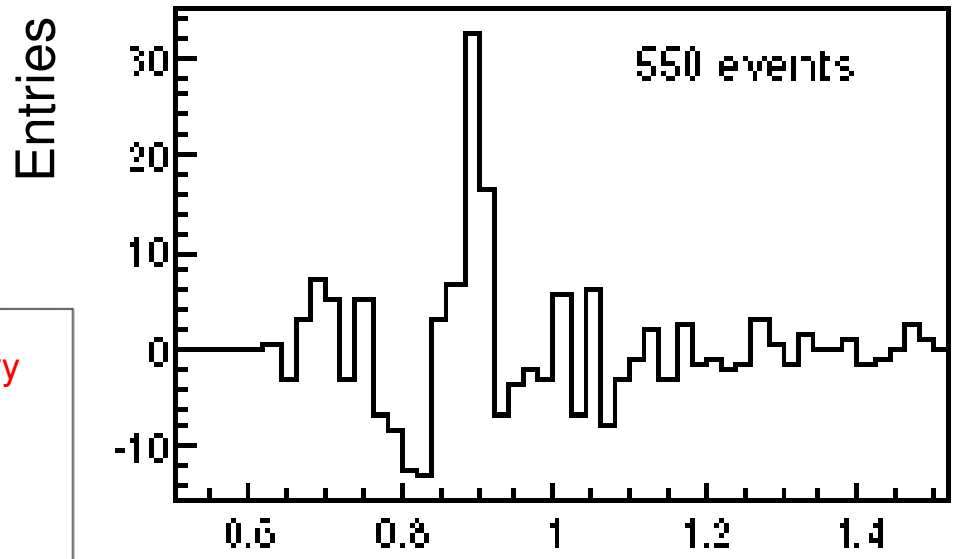
Resolution for B=0.4T

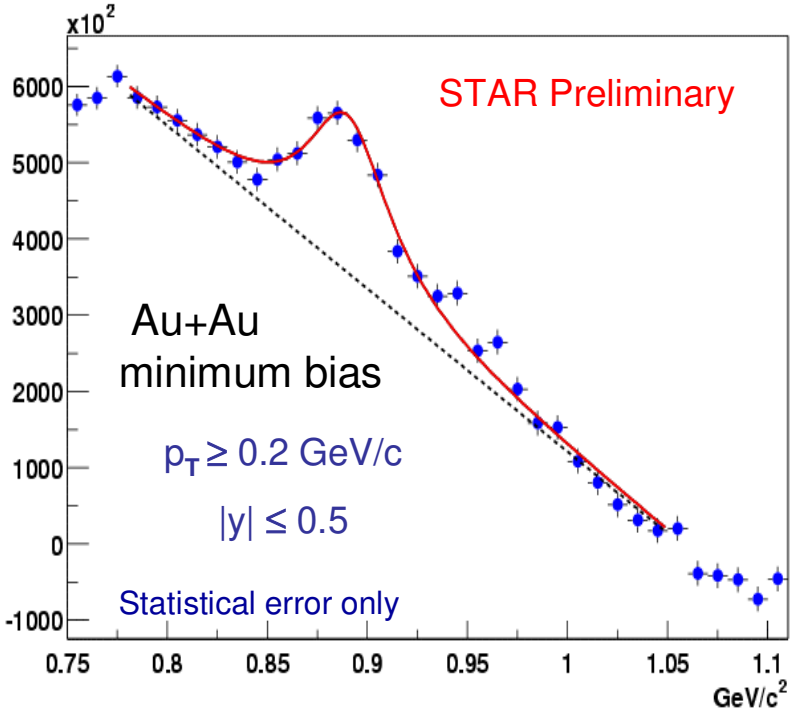
Resolution for B=0.2T

Low p_t Physics Examples

Resonances: K*

- Decay channel $K^* \rightarrow K^+\pi^-$
- Invariant mass distribution for 550 events



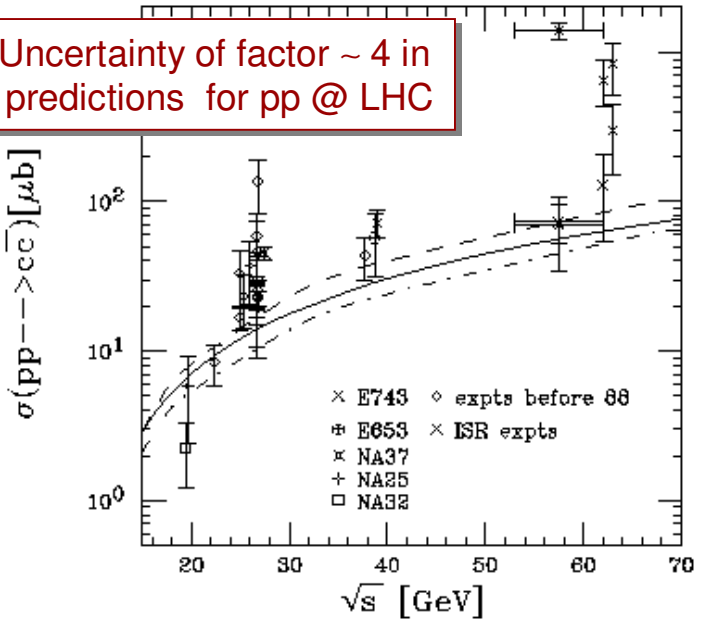


- STAR data shows clear K* on background
- Other resonances (ρ,ω,f^0...) are being extracted

Heavy Quarks

- Heavy quarks probe dynamics of early QGP phase
  - Perturbative in intial collisions
  - Thermal production in QGP
  - Direct measurement of heavy flavour in p+p and A+A mandatory
- Quarkonia (J/Ψ and ϒ states)
  - Binding energy in the order of mean energy in QGP
  - Sensitive to screening effects
- Aim: correlation of heavy quark and quarkonia production as function of p_t

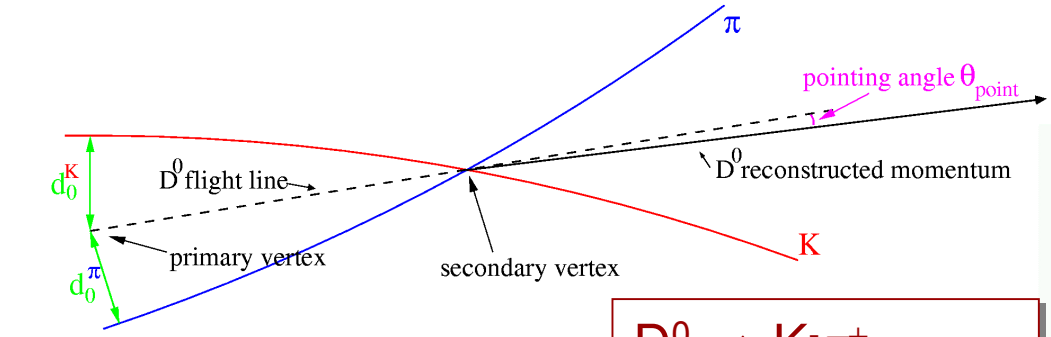
Uncertainty of factor ~ 4 in predictions for pp @ LHC



- Quarkonia → $\mu^+\mu^-$: MUON
- Quarkonia → e^+e^-: TPC+TRD
- D → Kπ, ITS+TPC+TOF
- Semileptonic decays of D + B: ITS+TPC+TRD
- $D\bar{D}$ ($B\bar{B}$) via eμ coincidences: TRD+MUON

Heavy Quarks

Open Charm via Hadronic Decays

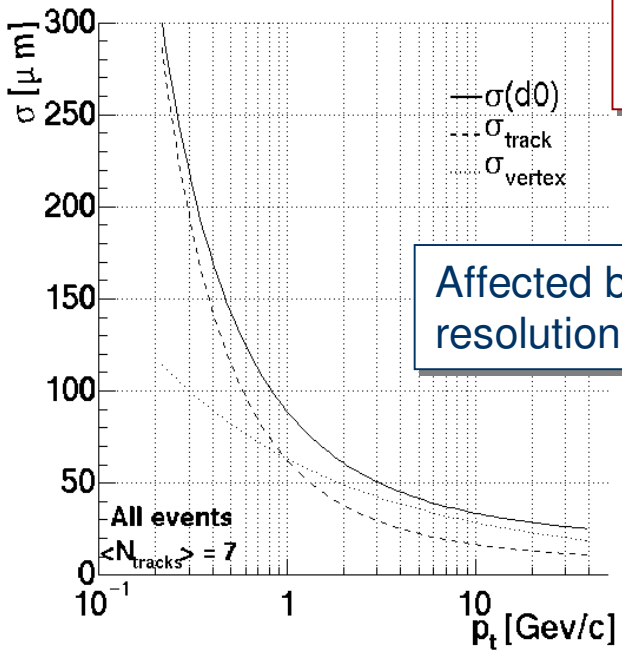


impact parameters ~100 μ m

$D^0 \rightarrow K^-\pi^+$

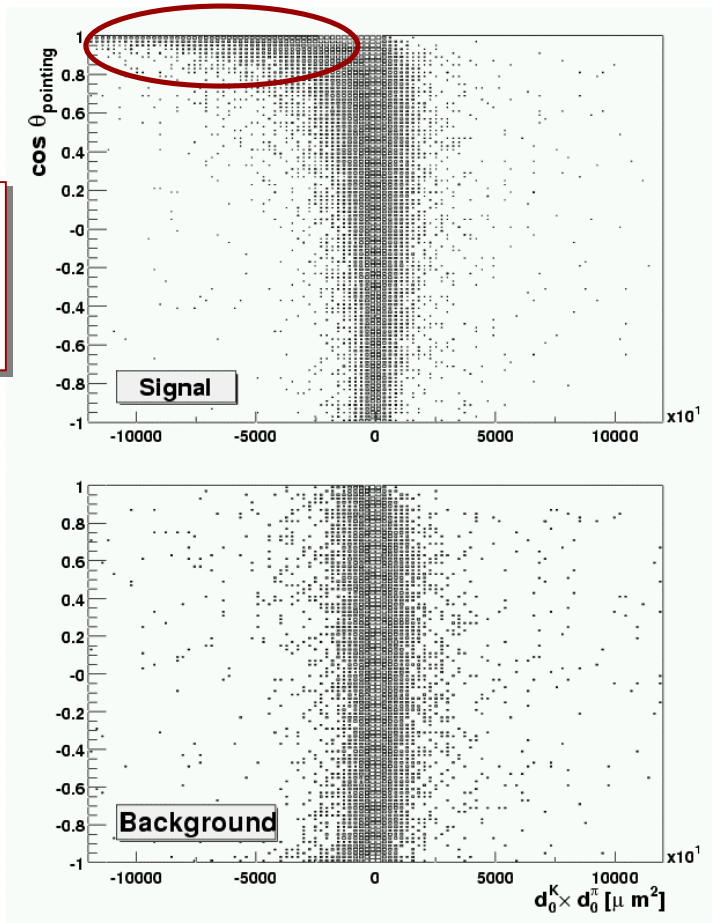
$c\tau$ = 123.7 ± 0.8 μm

BR: (3.83 ± 0.09) %



Affected by main vertex resolution in p+p case

cuts depend on D^0 p_t

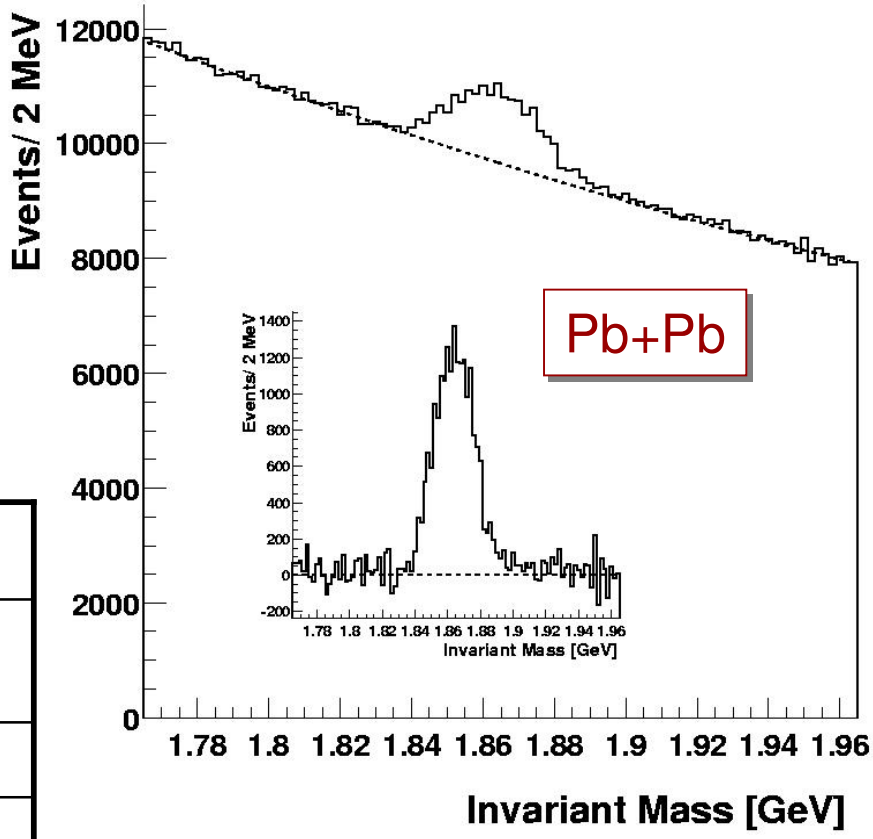


Heavy Quarks

Open Charm via Hadronic Decays

- Input to simulation
  - $c\bar{c}$: PYTHIA, tuned to NLO calculations, with CTEQ4L and nuclear shadowing EKS98
  - Background: HIJING
- Reconstruction effects included
- PID with TOF

System ($\sqrt{s}$)	Pb-Pb (5.5 TeV)	pp (14 TeV)
Signal for 10^7 (10^9) evts	13000	20000
S/B	11 %	50 %
Significance for 10^7 (10^9) evts	37	84

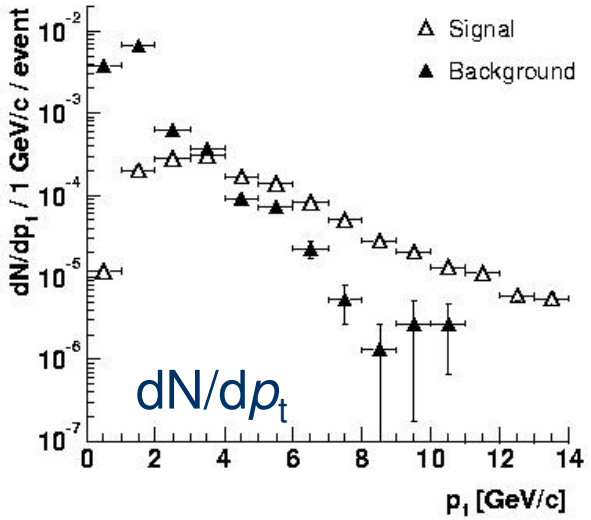


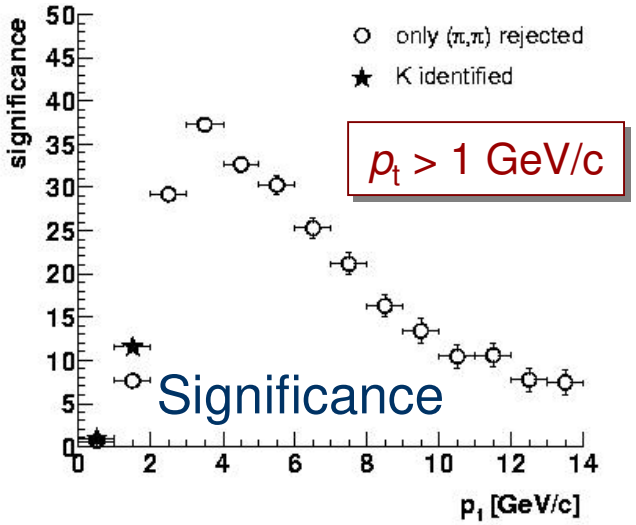
σ_{minv} = 12 MeV (B = 0.4T)

Heavy Quarks

Open Charm via Hadronic Decays

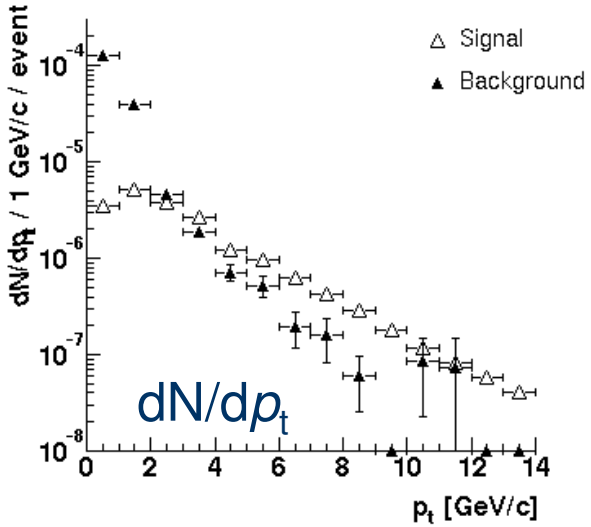
Pb+Pb:

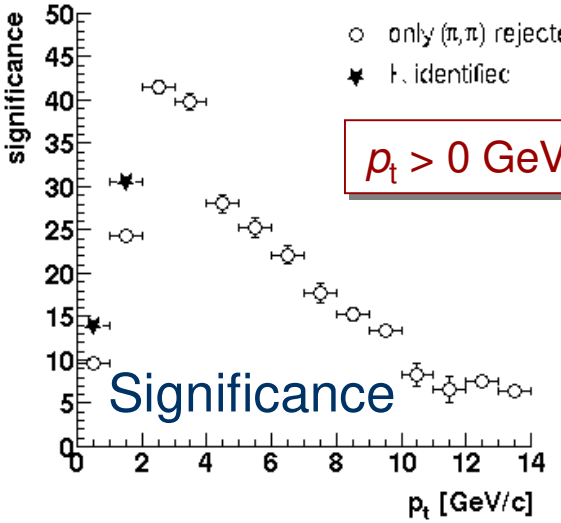




p_t > 1 GeV/c

p+p:





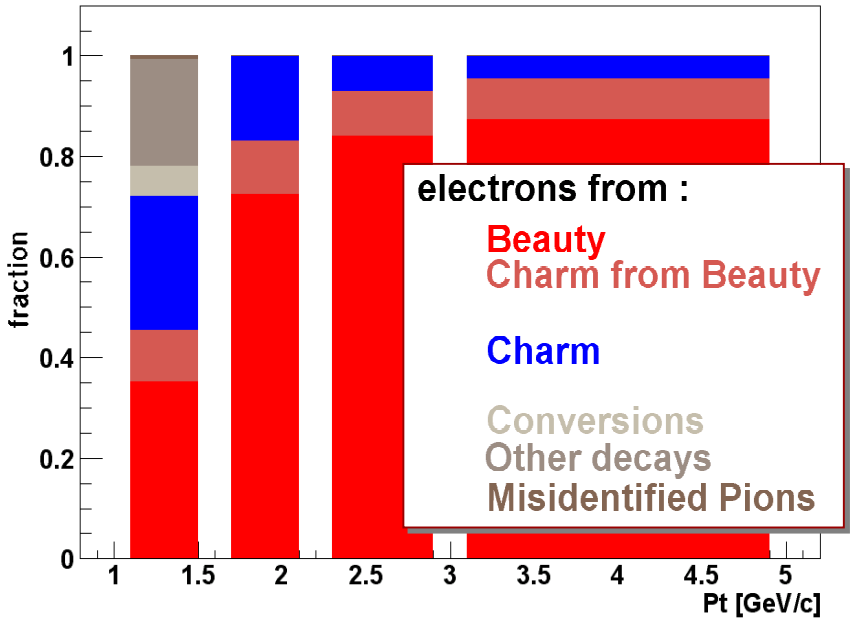
p_t > 0 GeV/c !

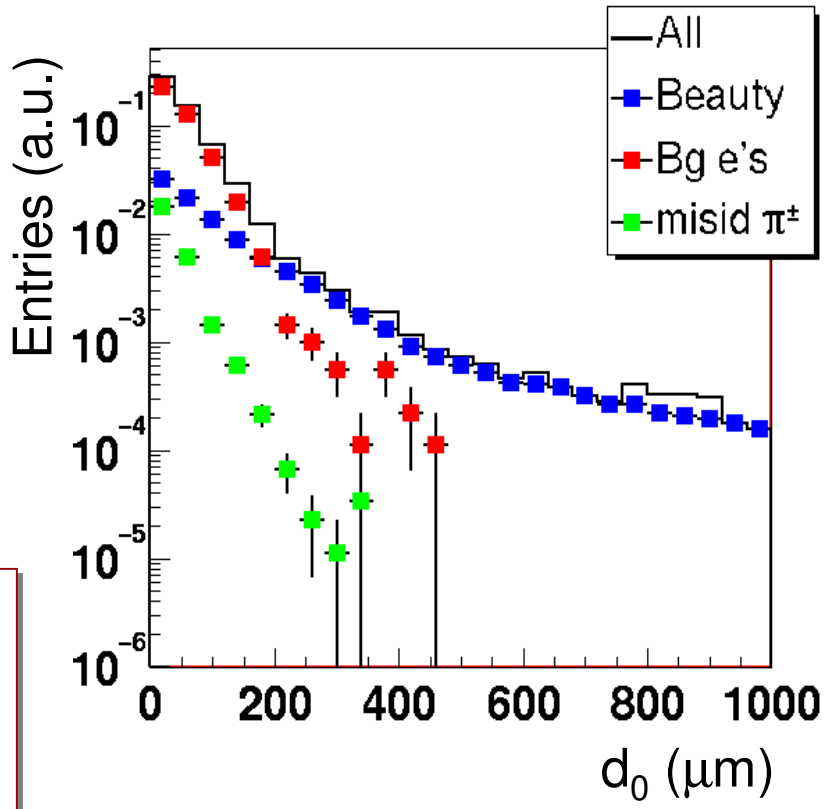
Significance = $S/\sqrt{S+B}$

Heavy Quarks

Open Beauty via Semileptonic Decays

- $B \rightarrow e^- + X$
- Electron ID in TPC + TRD
- Cuts:
  - Impact parameter d_0
  - Electron p_t



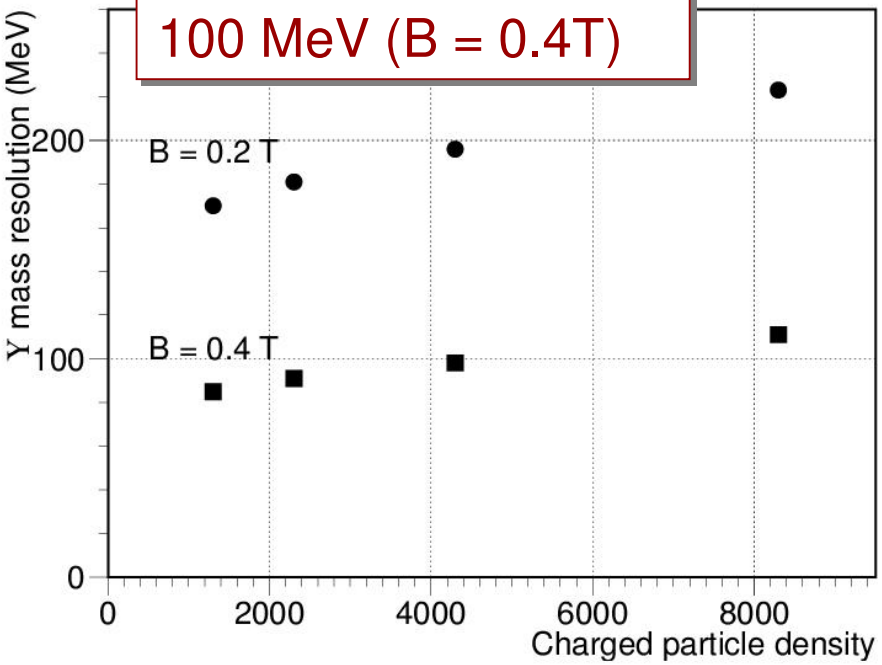


$p_t > 2$ GeV/c + $d_0 > 150$ μm:
5-10·10⁴ e with S/(S+B) = 90 %

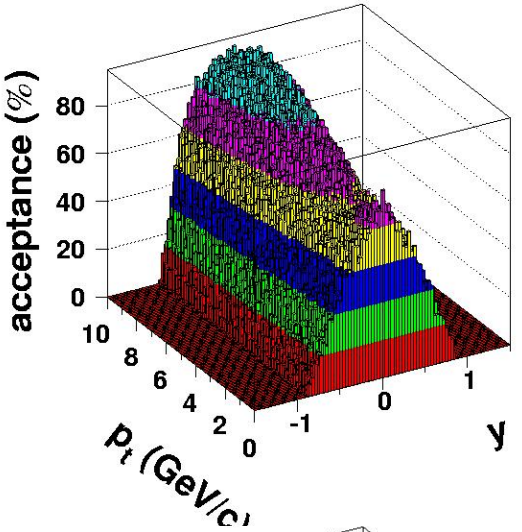
Heavy Quarkonia

J/Ψ and ϒ via Dielectrons

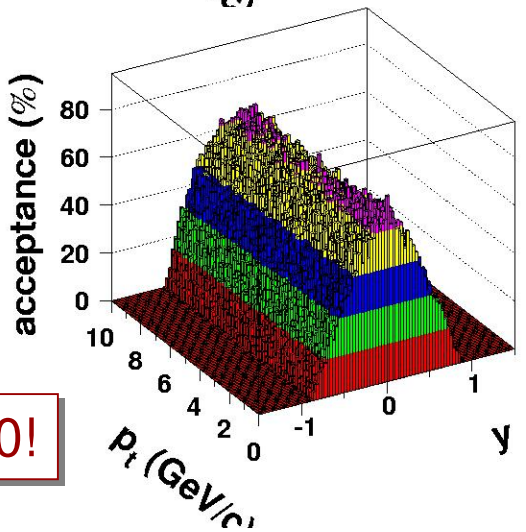
Mass resolution for ϒ:
100 MeV (B = 0.4T)



J/Ψ:



ϒ:

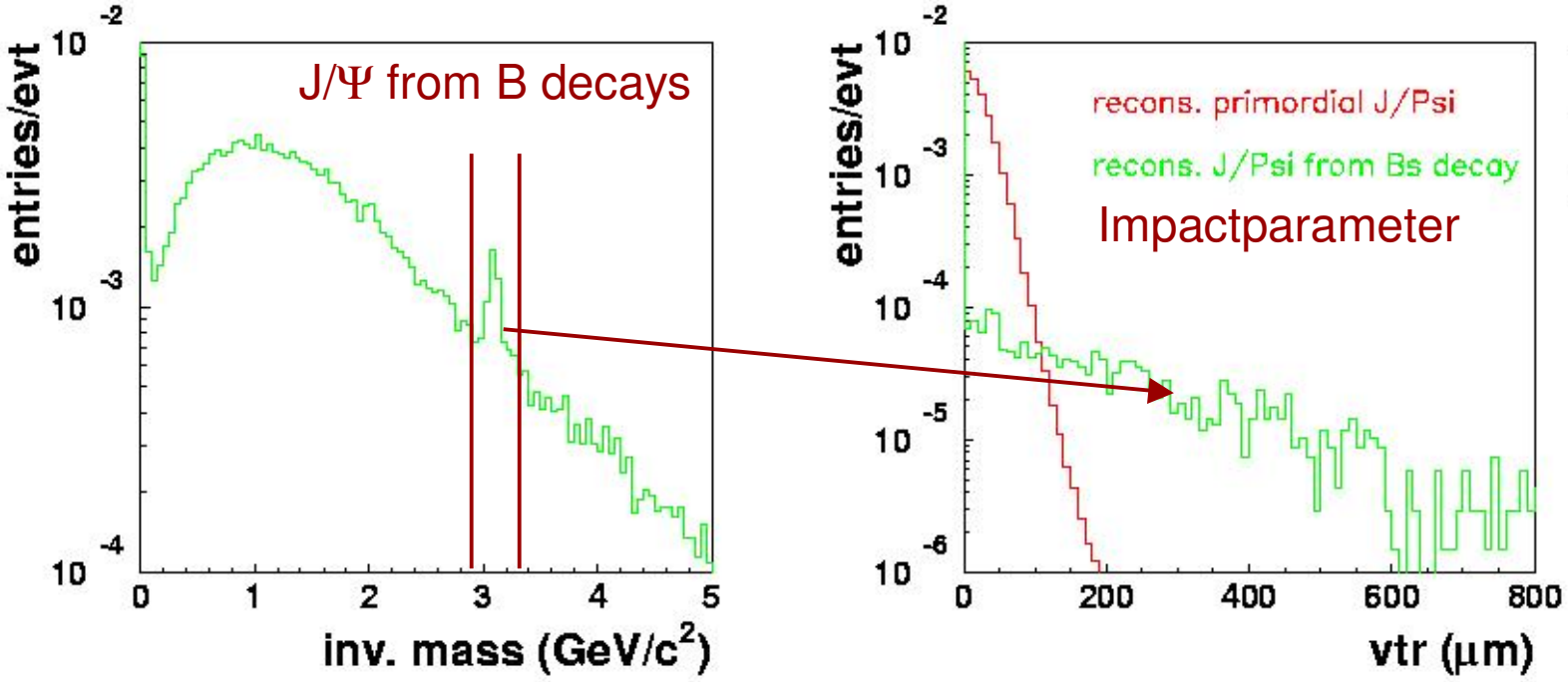


Acceptance down to $p_t = 0$!

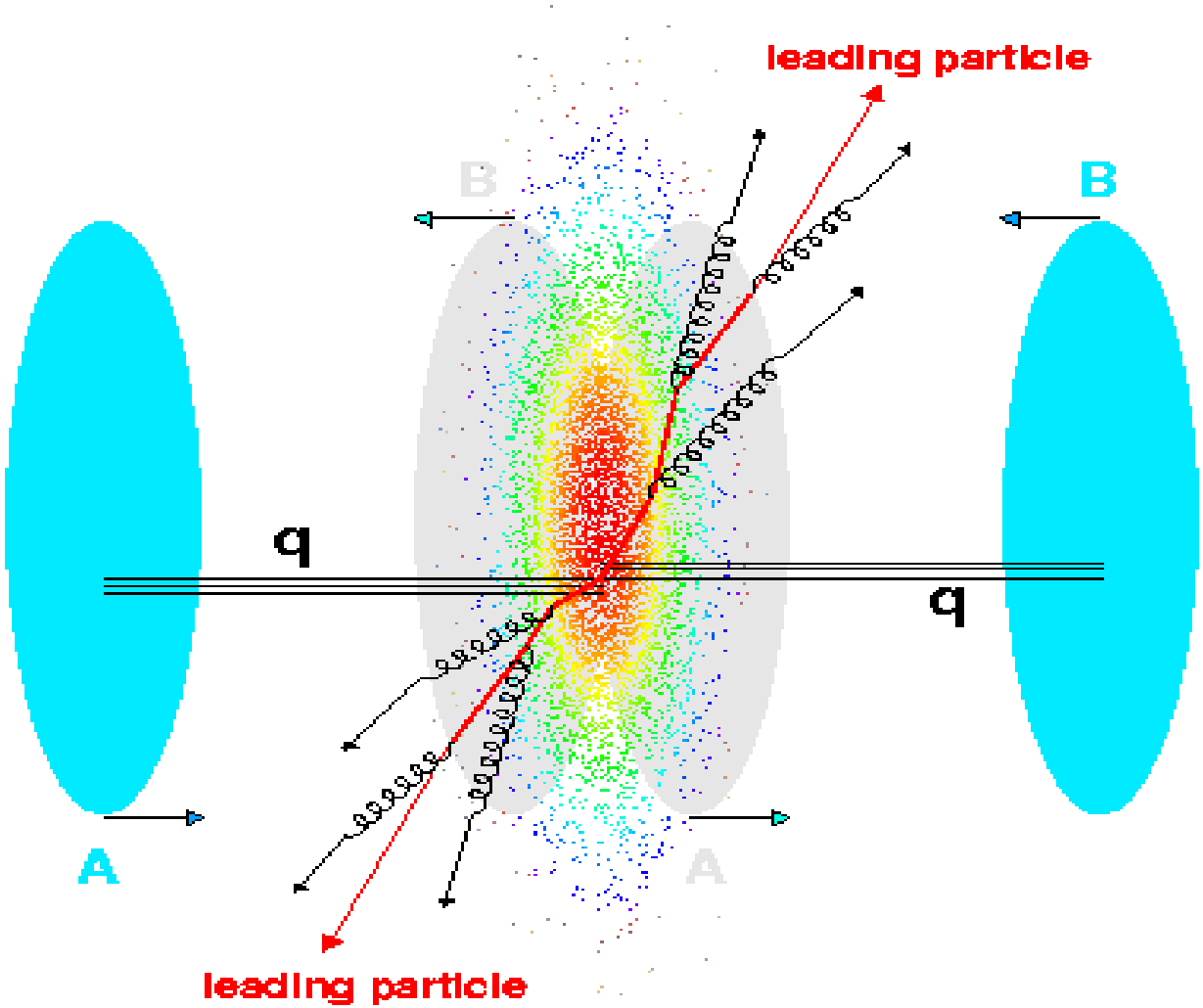
Heavy Quarks

Secondary J/Ψ from B Meson Decays

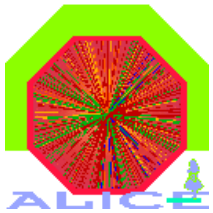
- B $\rightarrow$J/Ψ $\rightarrow$ e^+e^- (BR: ~1%)
- Large contribution to observable J/Ψ signal
- Possibility to disentangle primary and secondary J/Ψs



Parton Energy Loss

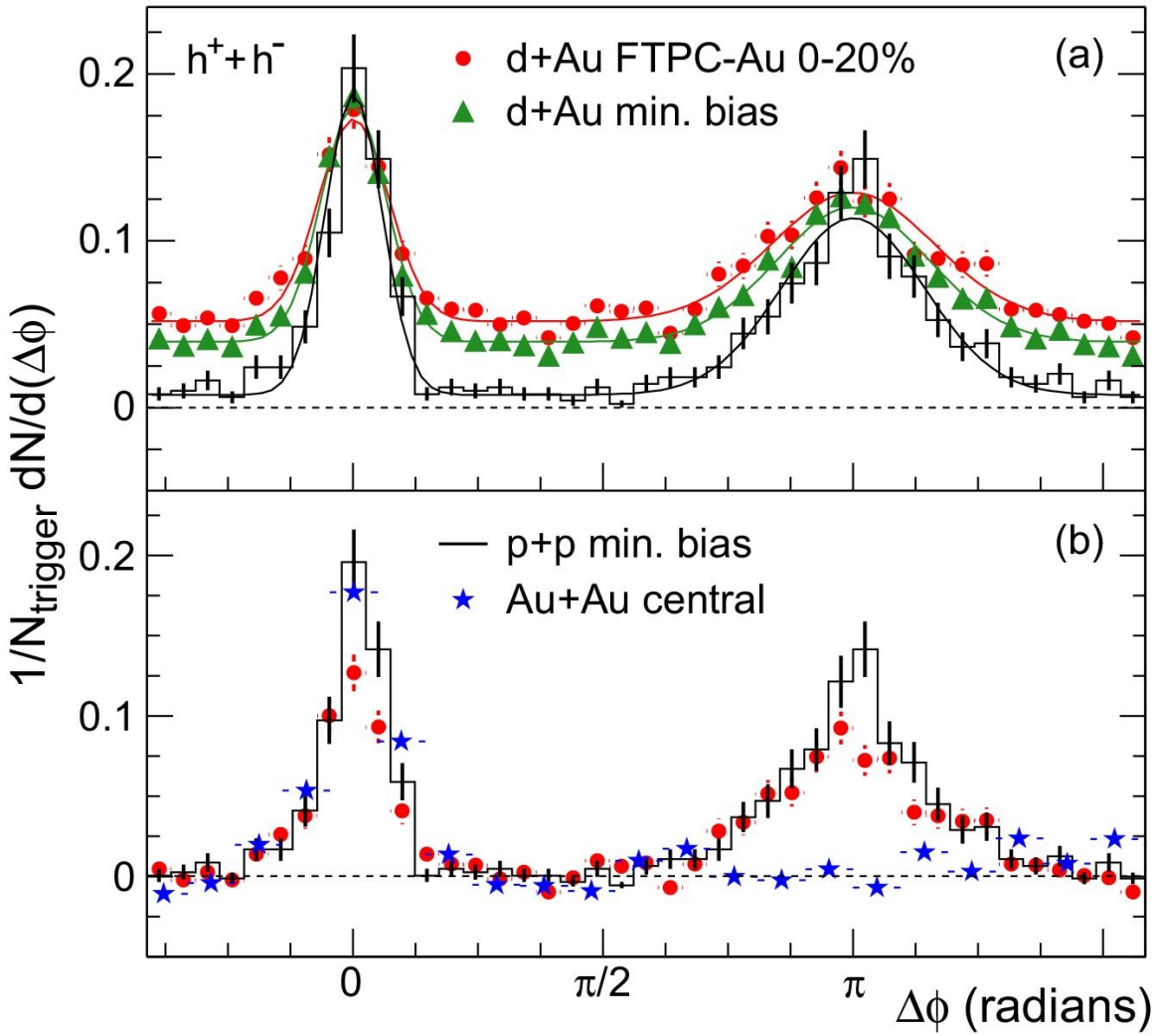


Parton Energy Loss



- Medium induced gluon radiation
  - Depends on traversed distance
    $\propto L^2$
  - Stronger in deconfined matter
- Effects:
  - Reduction of single inclusive high p_t particles
    - Parton specific (stronger for gluons than quarks)
    - Flavour specific (stronger for light quarks)
    - Measure identified hadrons (π, K, p, Λ, etc.) + partons (charm, beauty) at high p_t
  - Suppression of mini-jets
    - same-side / away-side correlations
  - Change of fragmentation function for hard jets (p_t >> 10 GeV/c)
    - Transverse and longitudinal fragmentation function of jets
    - Jet broadening $\rightarrow$ reduction of jet energy, dijets, γ-jet pairs
- p+p and p+A measurements crucial

Mini-jets in Au+Au at RHIC



In central Au-Au events,although trigger jet is clearly visible, “away-side” jet is not visible, as predicted from strong absorption in a high colour charge density volume, e.g. that produced in a QGP

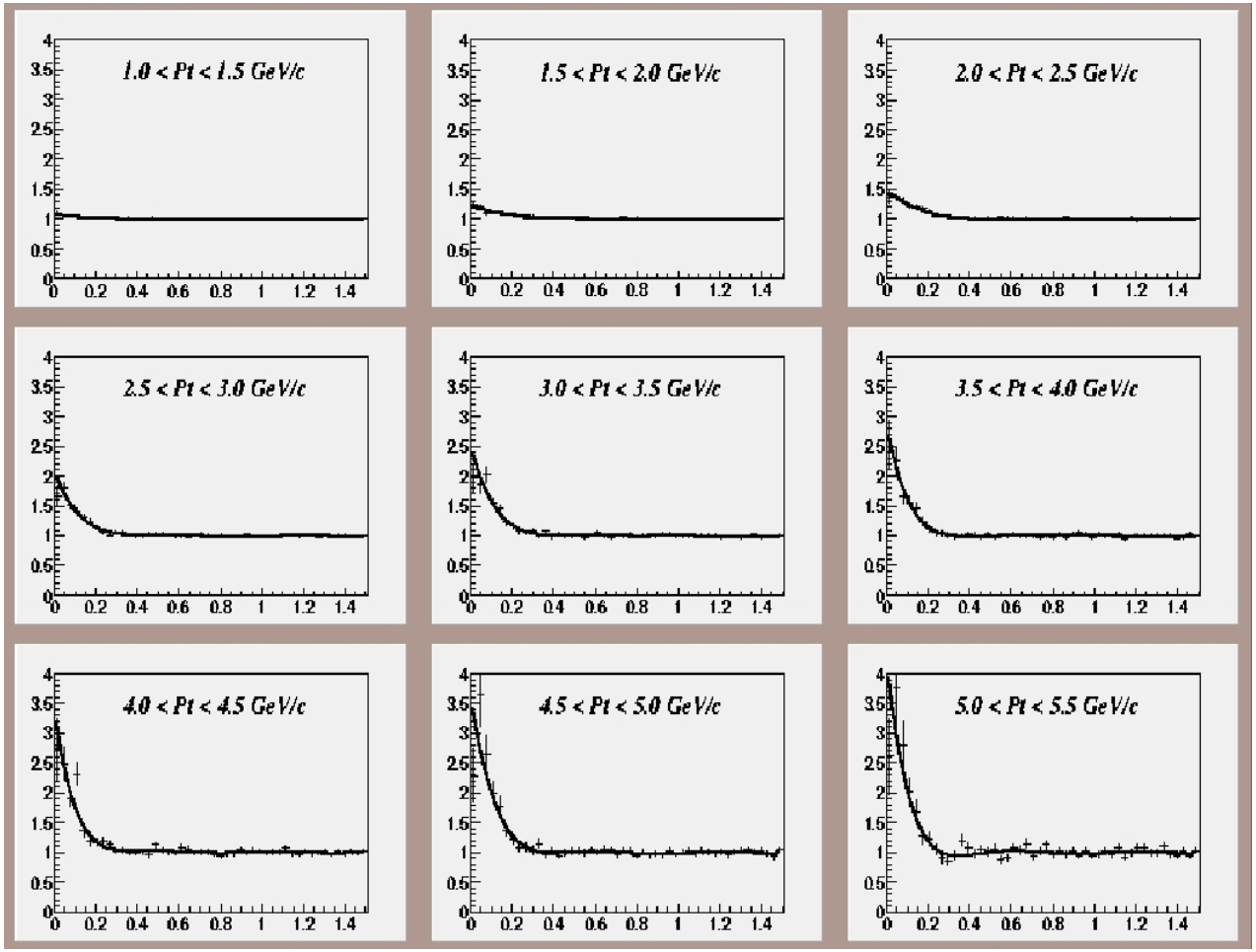
Jets in Pb+Pb

Two Particle Correlations

- Correlation increases with p_t
- Effect of gluon radiation
  - System size dependence
  - p+p

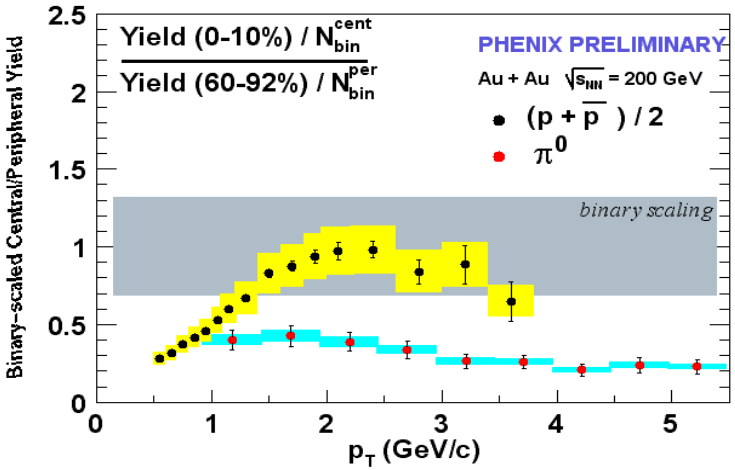
$$c(\alpha) = \frac{dN/d\alpha(\text{real})}{dN/d\alpha(\text{mixed})}$$

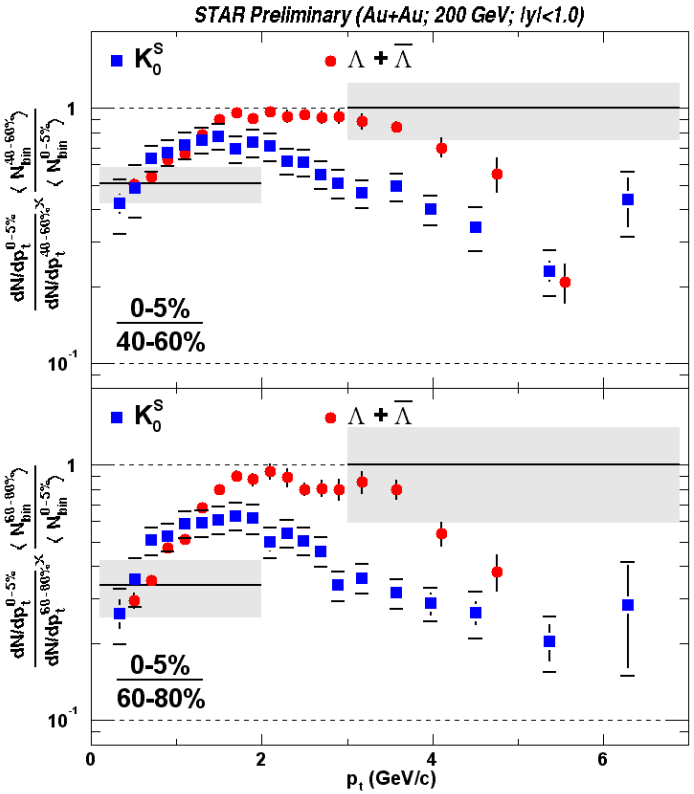
$$\alpha = \text{acos}\left(\frac{\vec{p}_1 \cdot \vec{p}_2}{\|\vec{p}_1\| \cdot \|\vec{p}_2\|}\right)$$



High p_t

RHIC Results





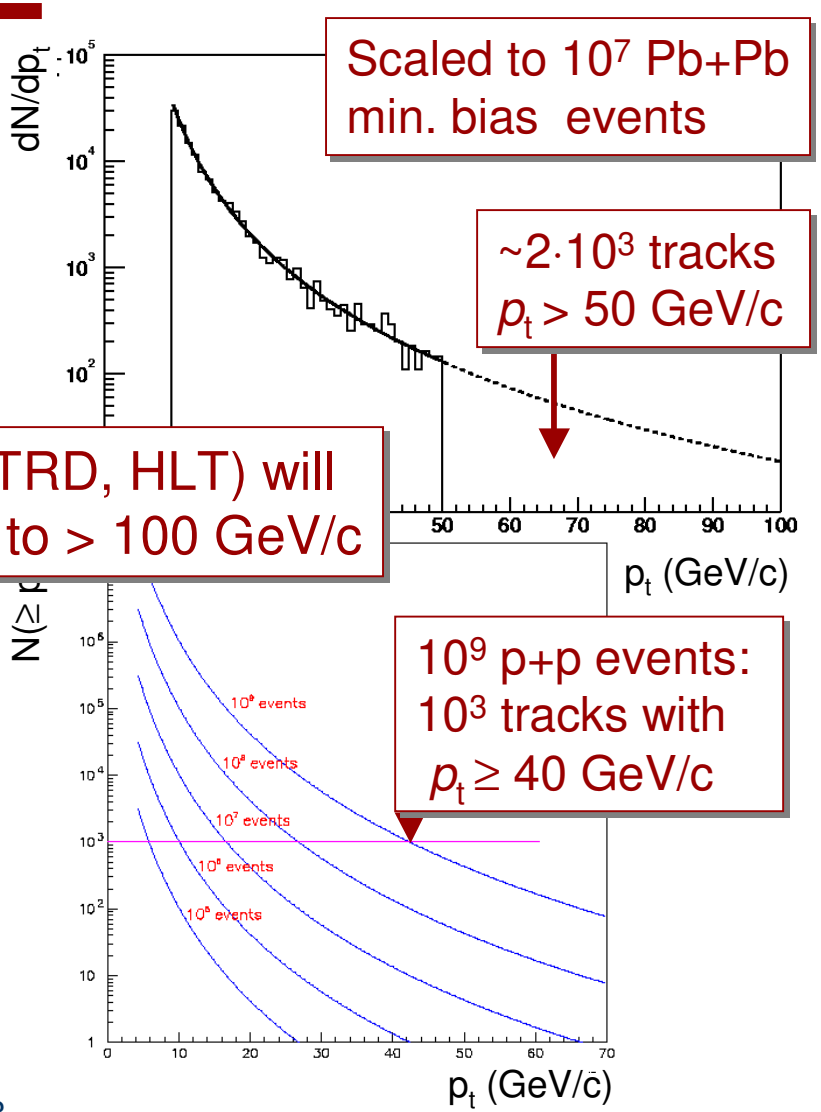
$$R_{AA}(p_t) = \frac{1}{N_{coll}} \cdot \frac{d\sigma(AA)/dp_t}{d\sigma(pp)/dp_t}$$

- R_{AA} clearly different between mesons and baryons
- Importance of PID at high p_t
- p+p baseline measurement!

High p_t

Minimum Bias Pb+Pb and p+p

- Estimates for the p_t limit in one year ALICE running
  - 10^7 Pb+Pb events
  - 10^9 p+p events
- p+p simulation PYTHIA 6.210 + CTEQ5L (default t

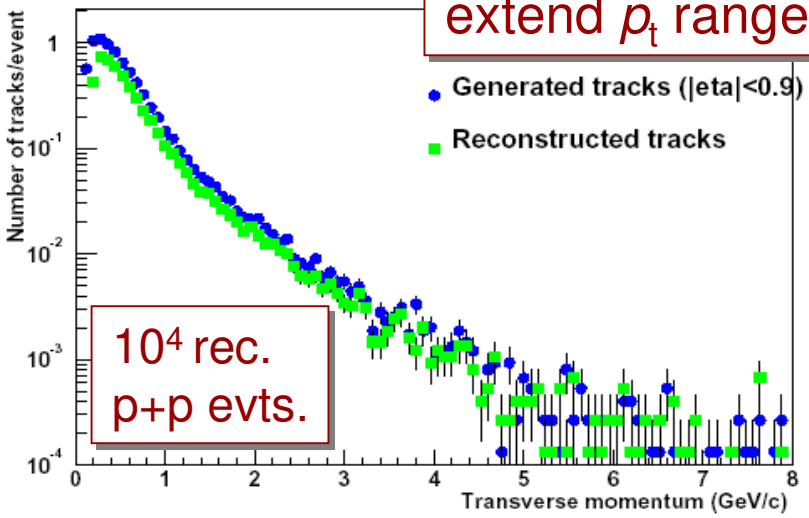


Scaled to 10^7 Pb+Pb min. bias events

~$2 \cdot 10^3$ tracks $p_t > 50$ GeV/c

High p_t trigger (TRD, HLT) will extend p_t range to > 100 GeV/c

10^9 p+p events: 10^3 tracks with $p_t \geq 40$ GeV/c

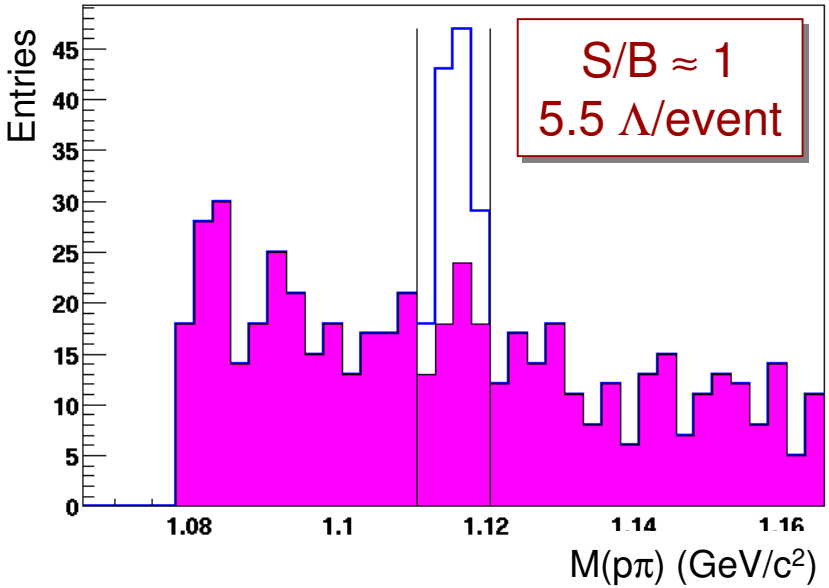


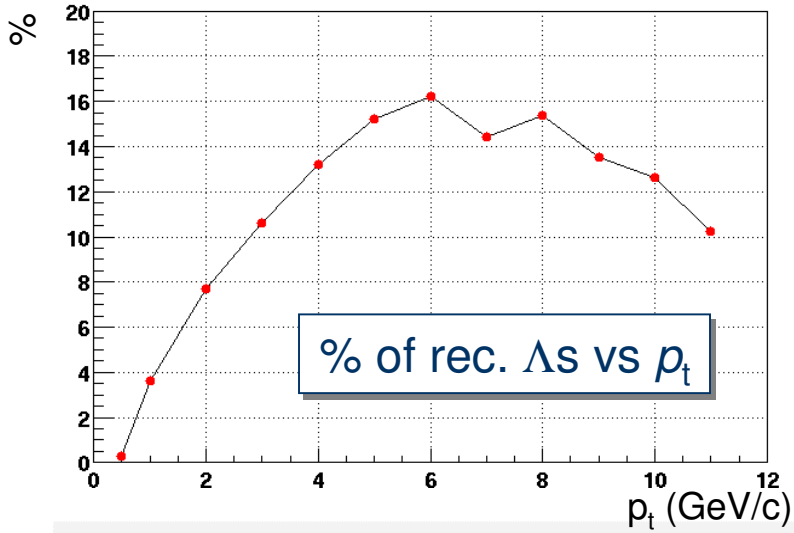
10^4 rec. p+p evts.

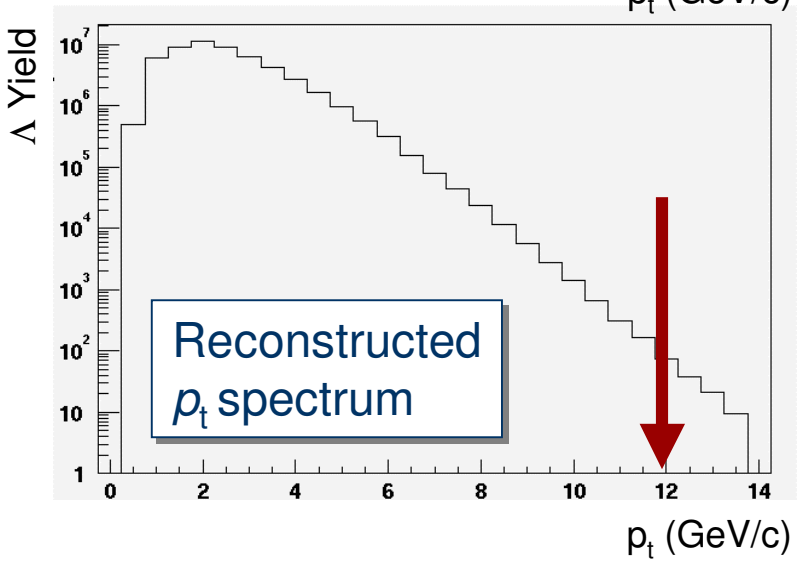
High p_t

Identified Particles: Λ

- One year of ALICE running
  (10^7 events)
  $\rightarrow$ Λs up to p_t = 12 GeV/c
- Topological signature, not reliant on identification of daughters

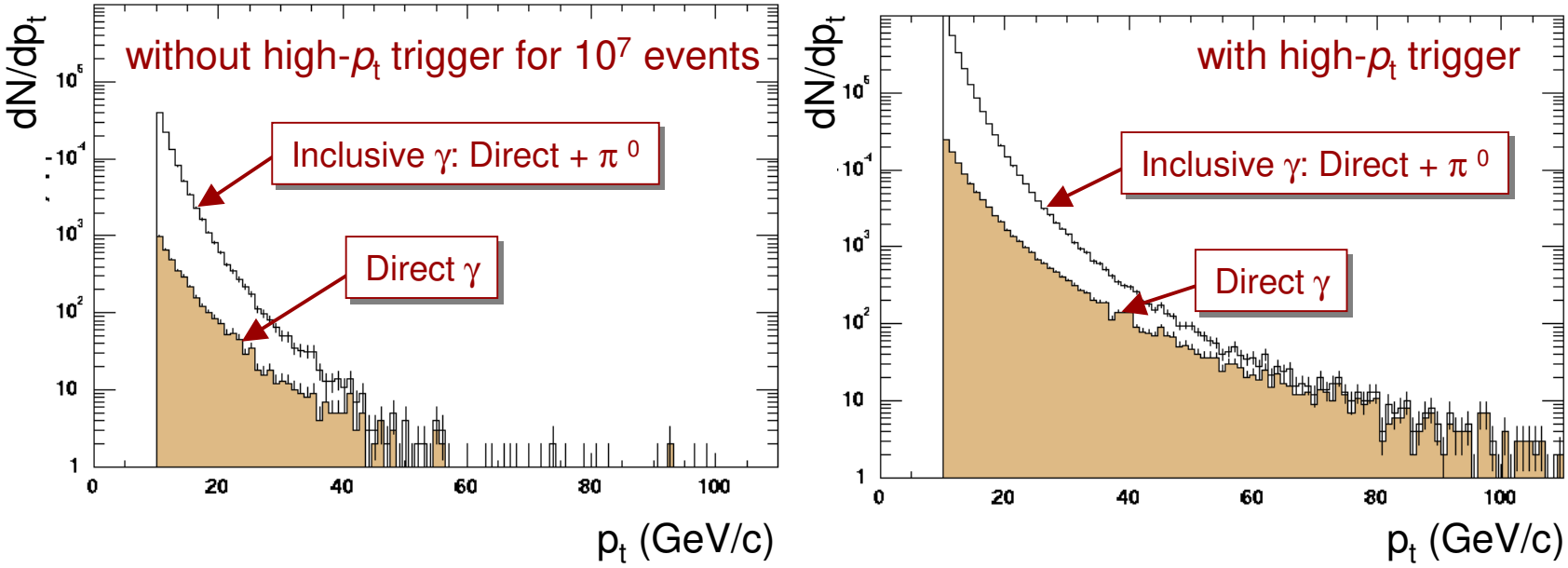






High p_t

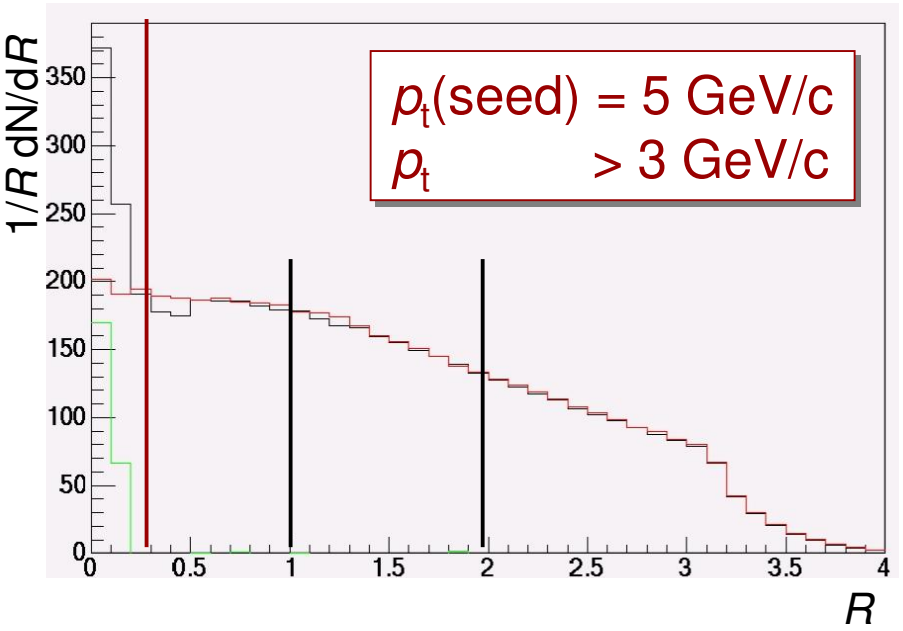
Identified Particles: $\gamma+\pi^0$

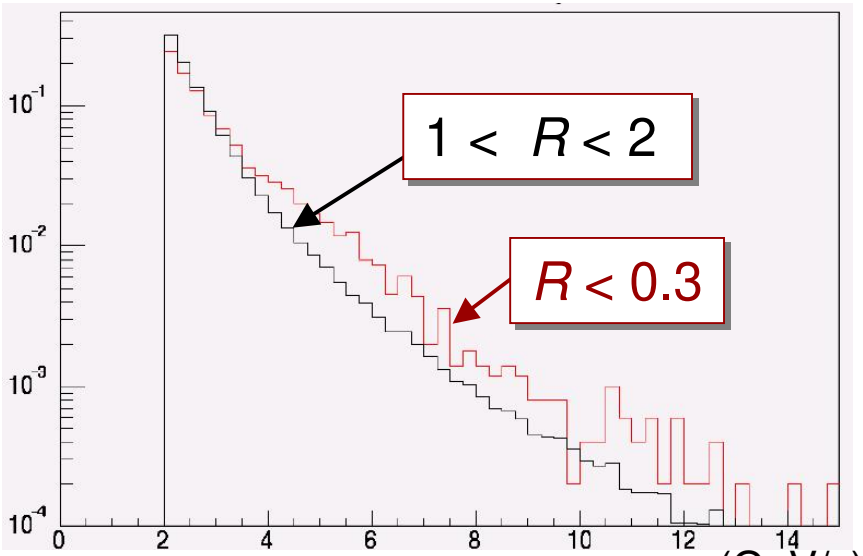


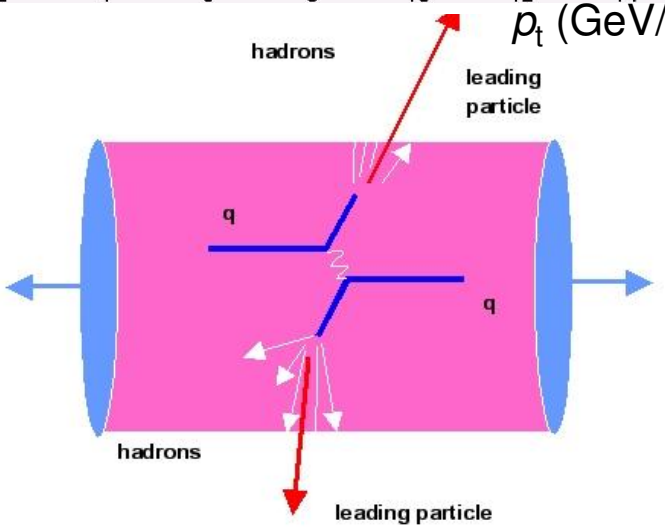
- Separation of γ/π^0 and π^0 detection up to 100 GeV/c
  - Statistically for low p_t (< 30-40 GeV/c)
  - E-by-E at higher p_t (> 30-40 GeV/c)

Jets in Pb+Pb

Correlations with Leading Particle







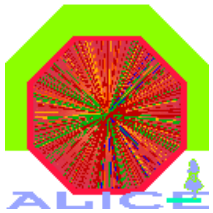
- Transformation

  $d^2N/d\phi d\eta \rightarrow 1/R\ dN/dR$

  with: $R^2 = \Delta\eta^2 + \Delta\phi^2$

- 1000 HIJING events (default)

Summary

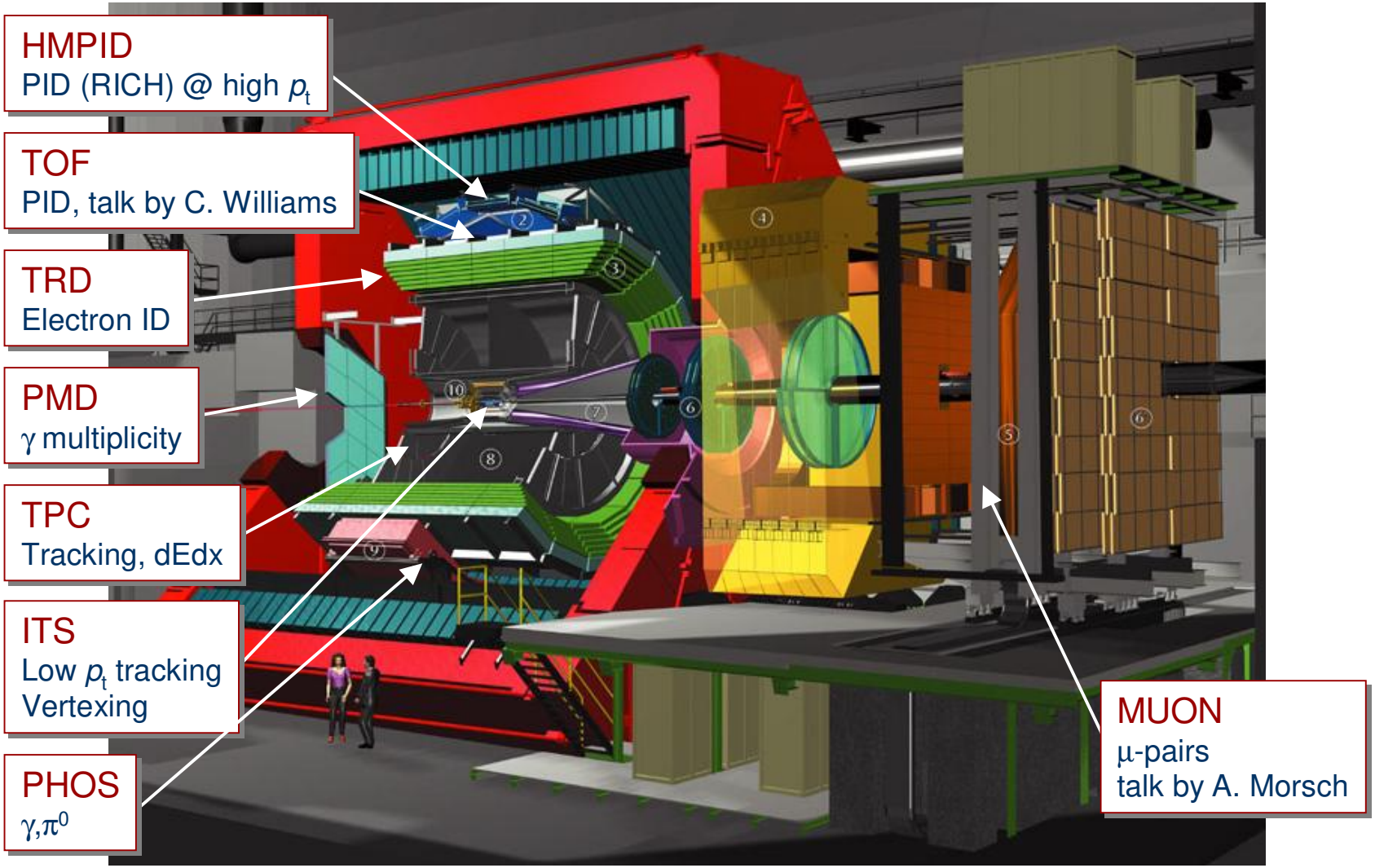


- ALICE physics reach extends from:
  - Low p_t > 0.1 GeV/c
    - Identified particles
    - Correlations, HBT
    - Event-by-event observables
    - Flow

  to:
  - High p_t ~ 100 GeV/c
    - Heavy quarks
    - Quarkonia
    - Photons
    - Jets

- p+p and p+A physics
  - Baseline for A+A
  - Important physics on its own
  - Integral part of ALICE physics program
- Physics Performance Report
  - Full simulations for all projected physics observables

The ALICE Experiment

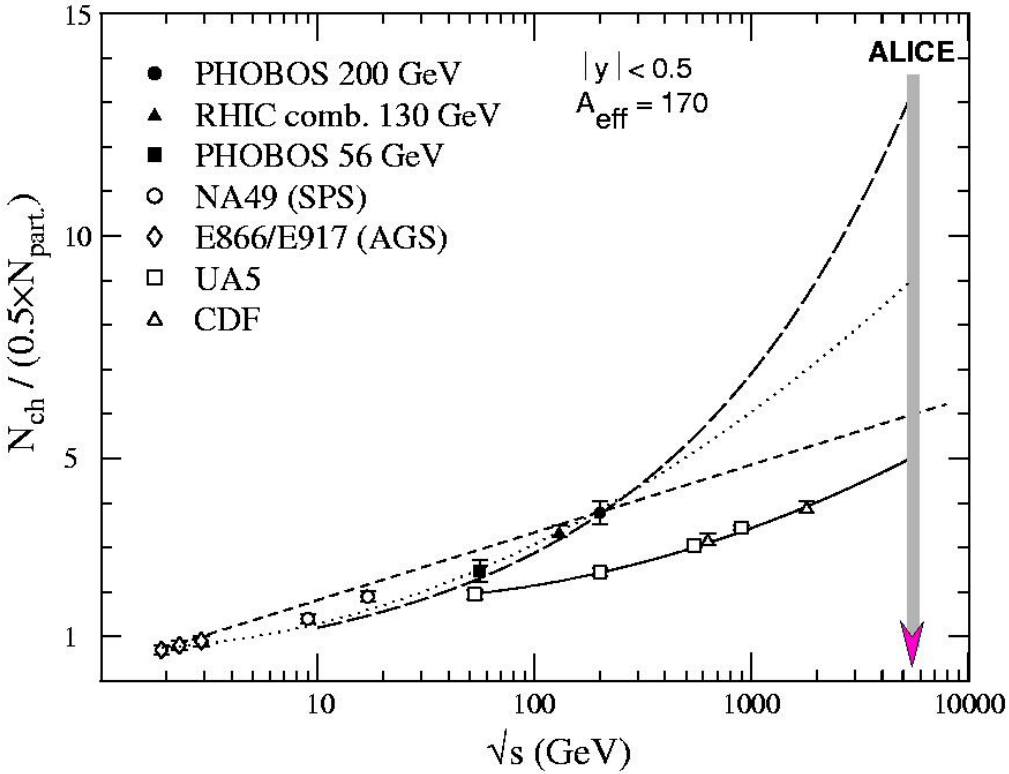


The ALICE Experiment

Running conditions for Pb+Pb

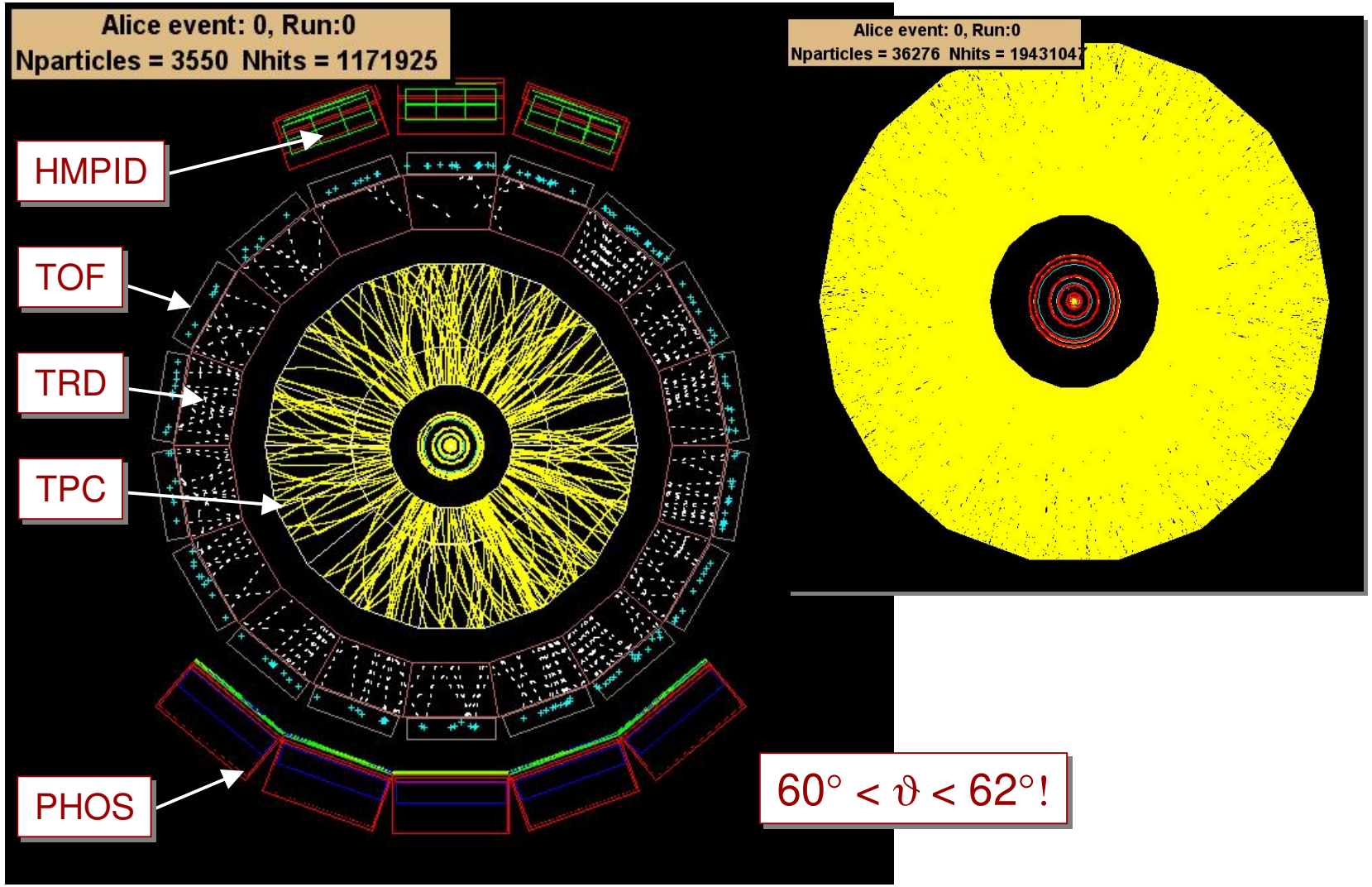
- Large charged multiplicity
  - Estimates quite uncertain
  - Design for $dN_{ch}/dy|_{max} = 8000$
- Luminosity:

  $\mathcal{L}_{max} = 1 \times 10^{27}\ cm^{-2}s^{-1}$
- Event rate:
  - 8000 minimum bias coll./ s
  - ~10^9 events/year
  - 1% collected
- Trigger for low cross section observables
  - MUON, PIXEL, PHOS, TRD
  - High-Level Trigger (HLT)



The ALICE Experiment

Event Display Pb+Pb



The ALICE Experiment

p+p Running Conditions

- "Low" luminosity:

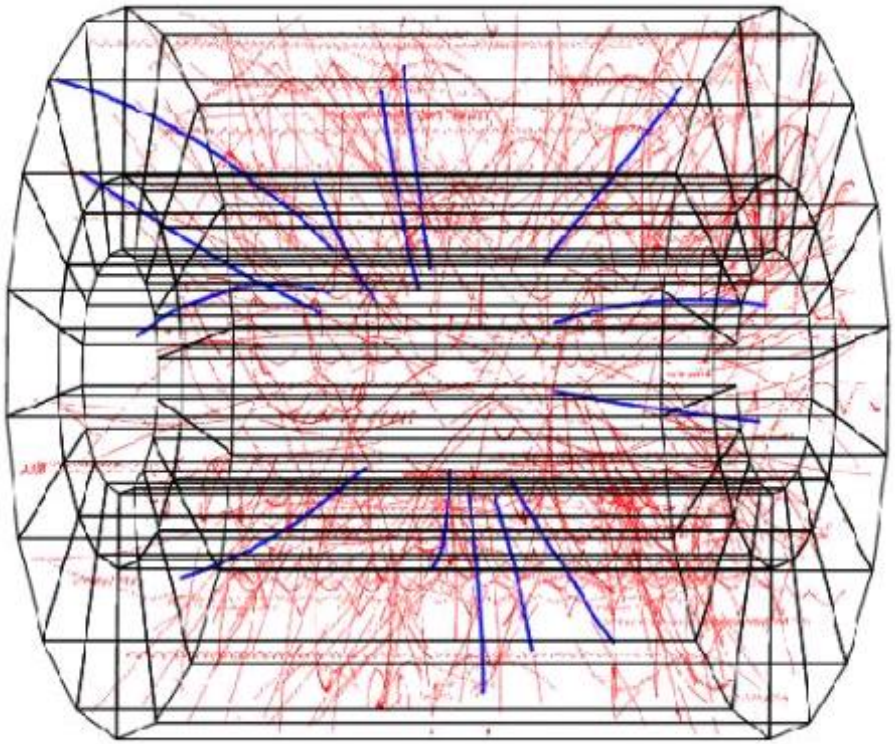
  $\mathcal{L}_{max}$ = 2-5 $\times$ 10^{30} cm^{-2} s^{-1}

- Event pile-up
  - TPC drift 88 μs
  - On average 25 events

    (for $\mathcal{L}_{max}$ = 2 $\times$ 10^{30} cm^{-2} s^{-1})
- Pile-up can be removed with High-Level Trigger
  - Reduction in data volume:

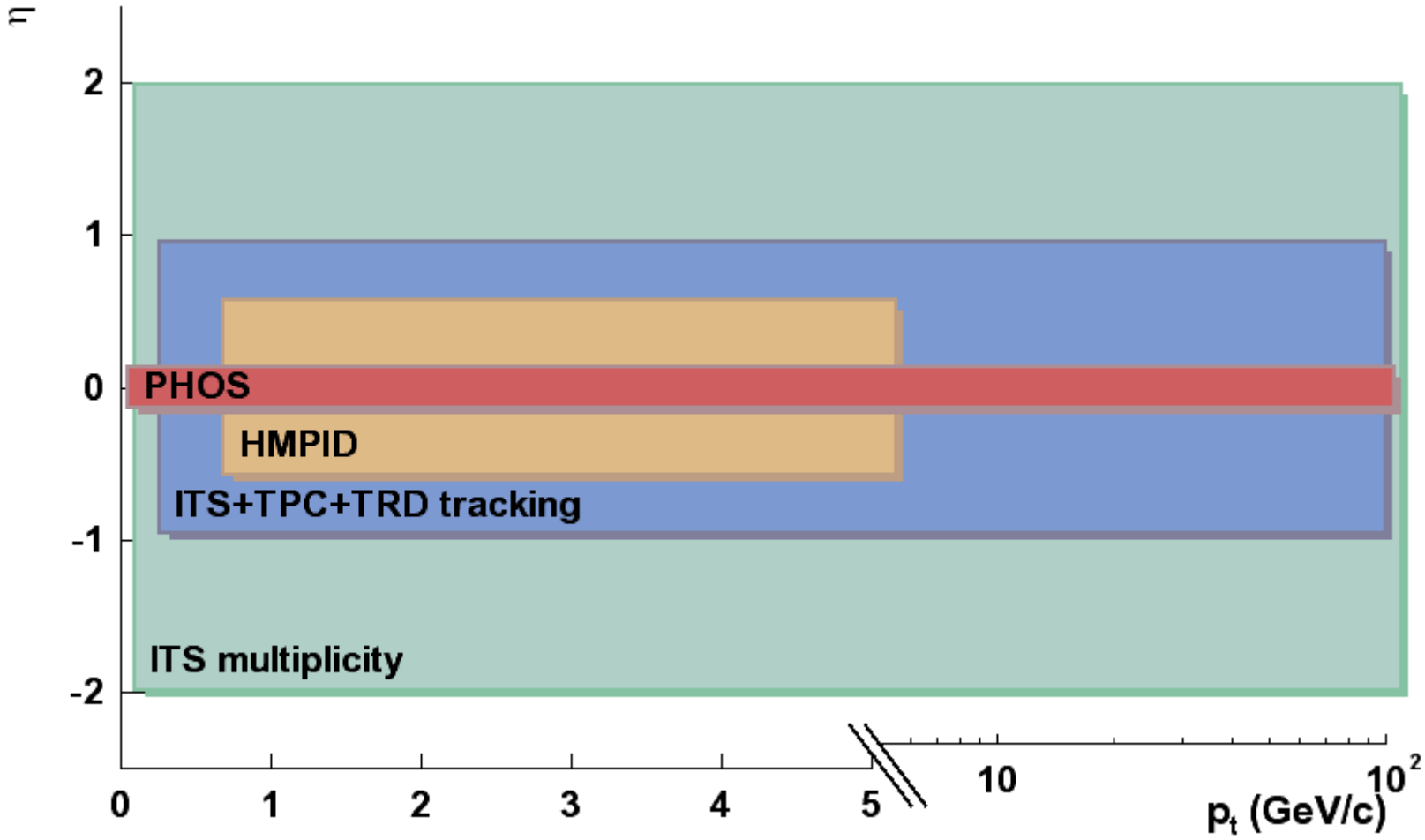
    ~ factor 5
- Short run periods with ''ultra-low' luminosity $\rightarrow$ no pile-up

  $\mathcal{L}_{max} \propto 10^{29}$ cm^{-2} s^{-1}



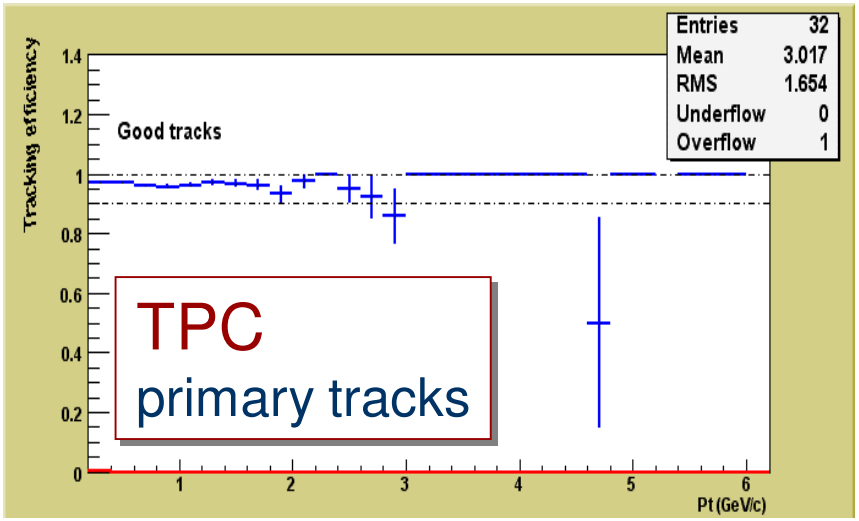
The ALICE Experiment

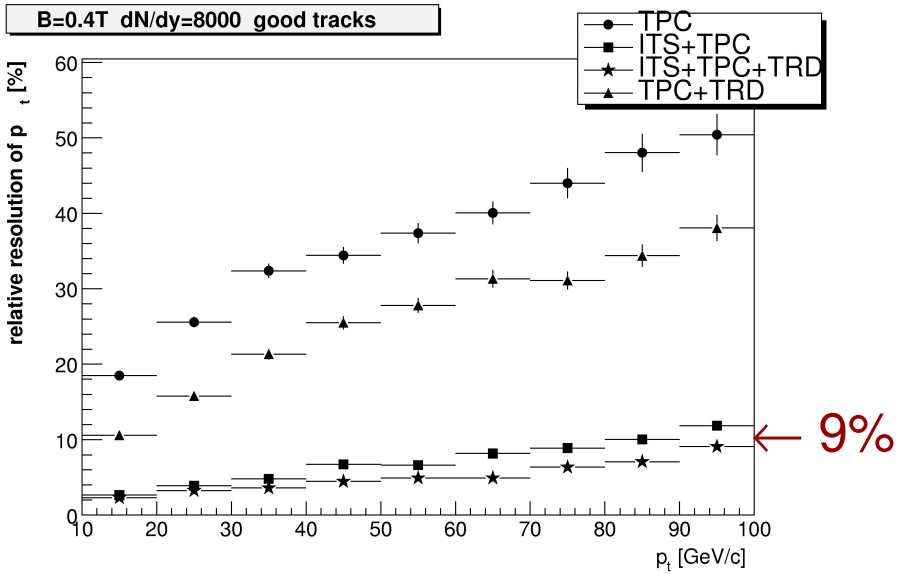
Acceptance Central Barrel



The ALICE Experiment

Tracking Performance



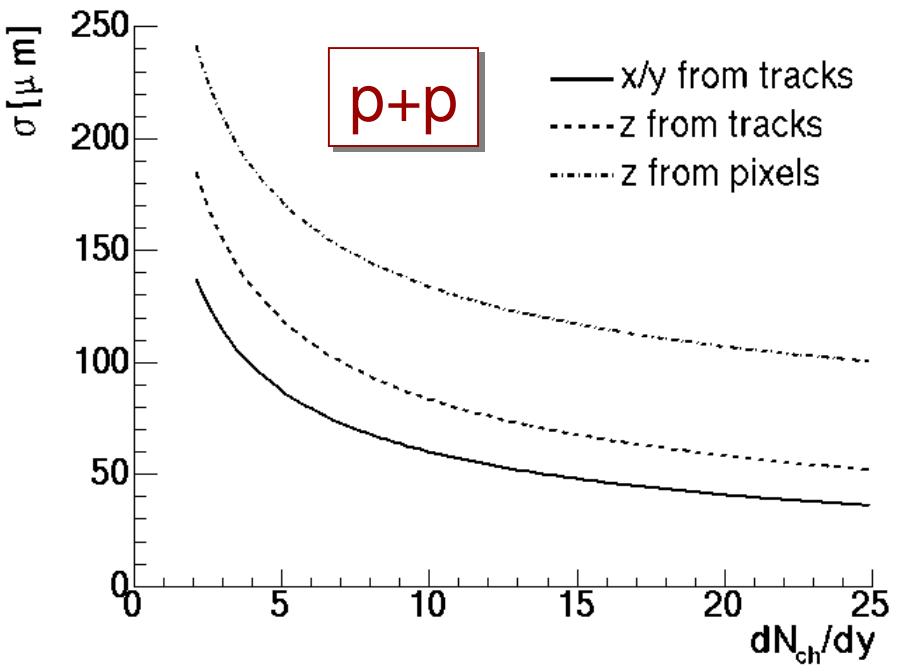


- Reconstruction efficiency
  - dN_{ch}/dy = 8000, B = 0.4T
  - 98% in TPC
  - Acceptance at high p_t: ~90%
- Momentum resolution:
  - dN_{ch}/dy = 8000, B = 0.4T
  - Combined tracking ITS+TPC+TRD
  - 9% (p_t = 100 GeV/c)

The ALICE Experiment

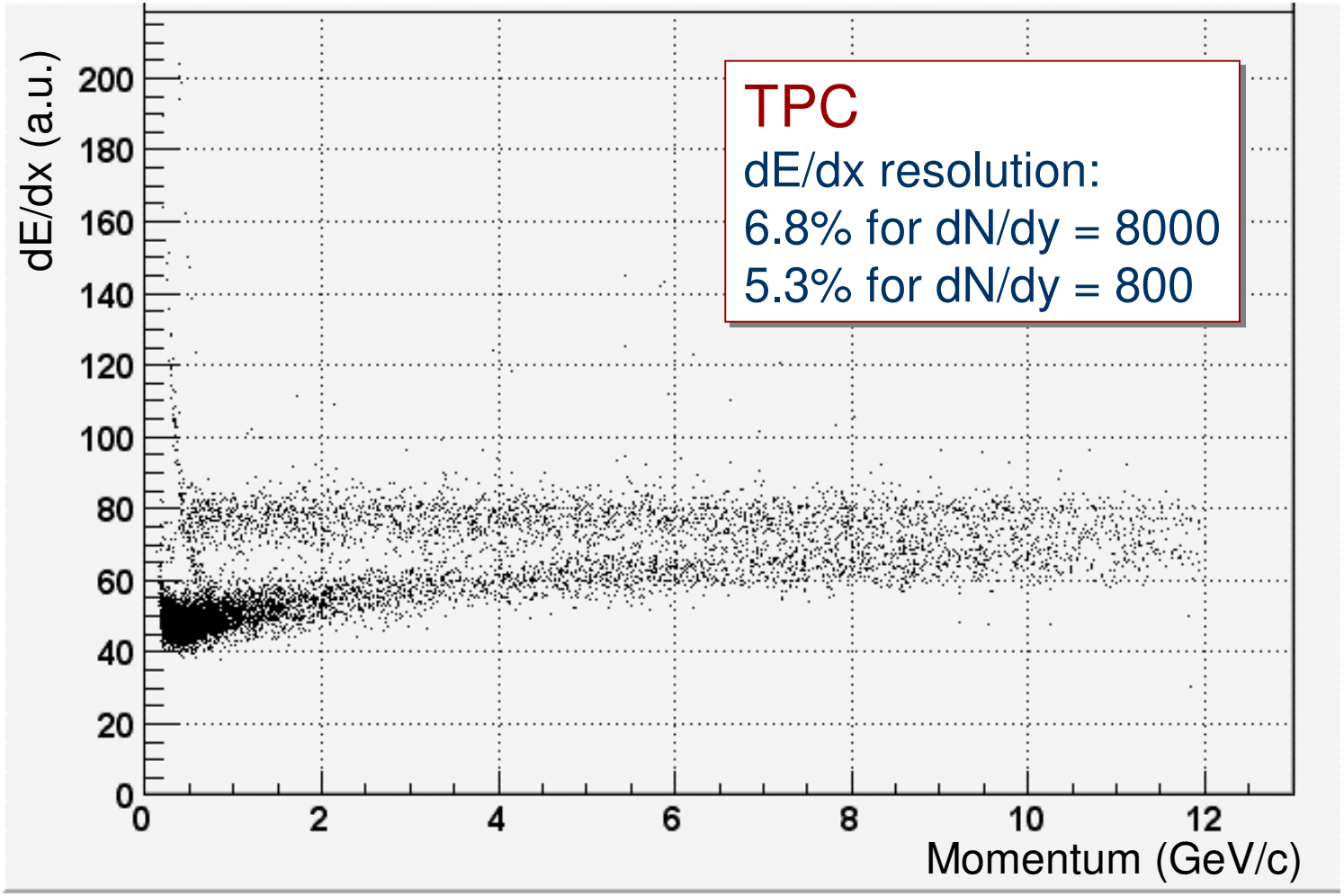
Main Vertex Determination

- For heavy-ion collisions
  - Large track statistics
  - Resolution in bending projection:
    10–15 μm (beam spot 15 μm)
  - Resolution in non-bending projection:
    better than 10 μm
- For p+p collisions
  - Low track statistics
  - Effect on charm measurement



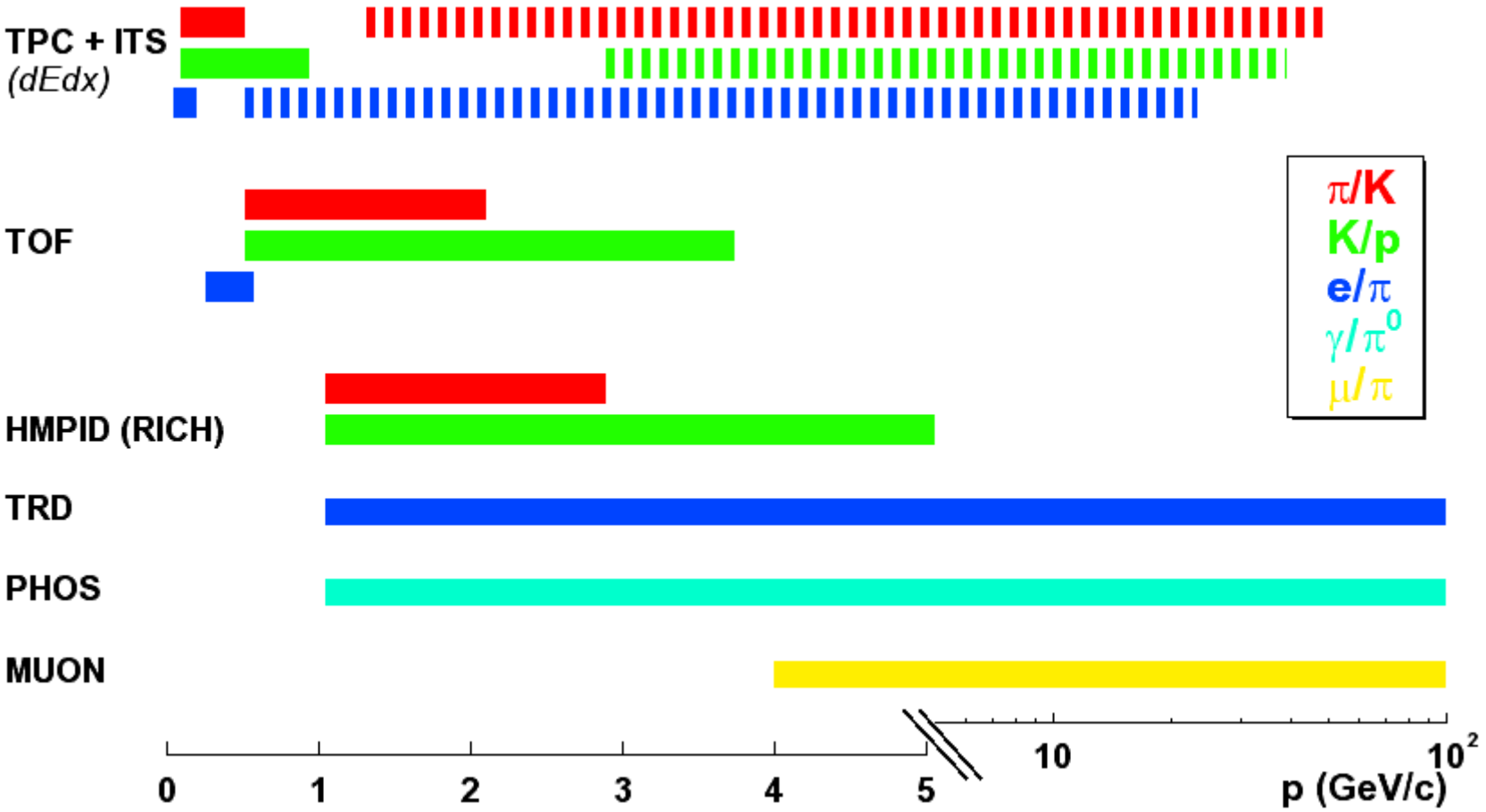
The ALICE Experiment

Particle Identification

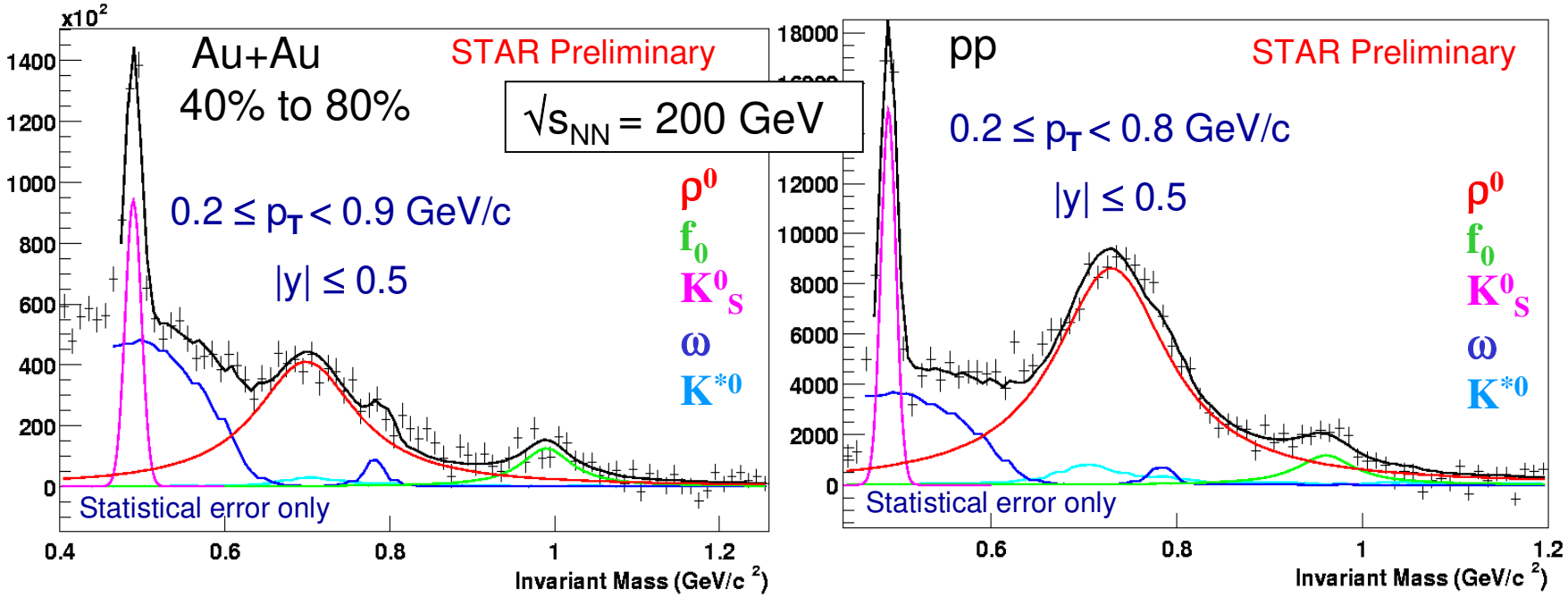


The ALICE Experiment

PID Summary



$\pi^+ \pi^-$ Invariant Mass Distribution from Data



- 2.1×10^6 Au+Au minimum bias events and 4.7×10^6 pp events
- Follow previous e^+e^- and pp measurements that do not extract I = 1 ρ^0 production
- Breit-Wigner $\Rightarrow$ fixed width $\Rightarrow$ ρ^0 Γ = 150 MeV and f_0 Γ = 75 MeV
- ρ^0 and f_0 masses $\Rightarrow$ working on understanding of scale $\Rightarrow$ p_T vs. m_T