ALICE Performance

- Physics motivation
- Experimental conditions
- Physics performance

LHC Energy

For A-A collisions:

$E_{cms} = 5500\, A$ GeV

$E_{lab} = E_{cms}^2 / (2A\, m_N) = 1.6 \times 10^7\, A$ GeV

for lead ions $E_{lab\ Pb\text{-}Pb} = 3.3 \times 10^9$ GeV $= 3.3 \times 10^{12}$ MeV $= 0.5$ kg $\times 10$ cm g

And for pp collisions:

$E_{lab\ pp(14TeV)} = 70$ g $\times 2$ cm g

For those who don't like to be seated on a lead ion (and to fly inside LHC vacuum pipe)

$E_{cms\ Pb\text{-}Pb} = 5500\, A$ GeV $= 1.14 \times 10^9$ MeV $= 1$ g $\times 2$ cm g

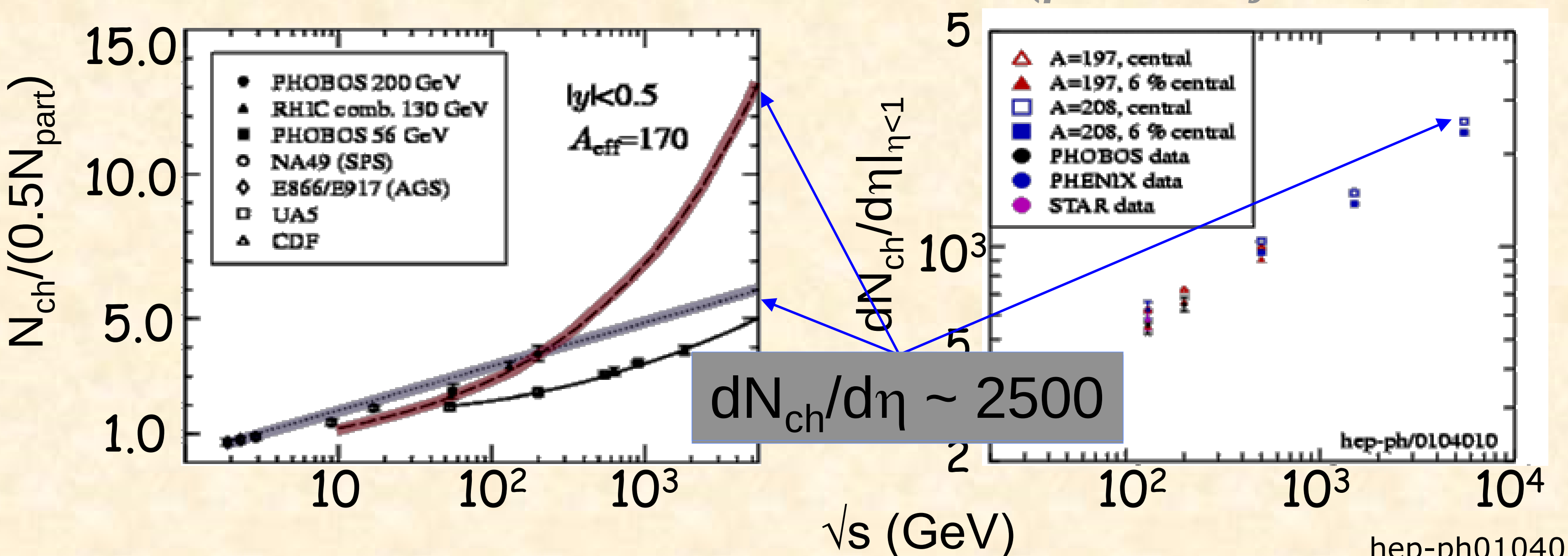
Still, macroscopic energy !!! (one can actually hear it)

But the size of ions
is by factor more than 10^{-12} smaller

What multiplicity do we expect?

old estimates: $dN_{ch}/dy = 2000 – 8000$,
now we can extrapolate from RHIC data

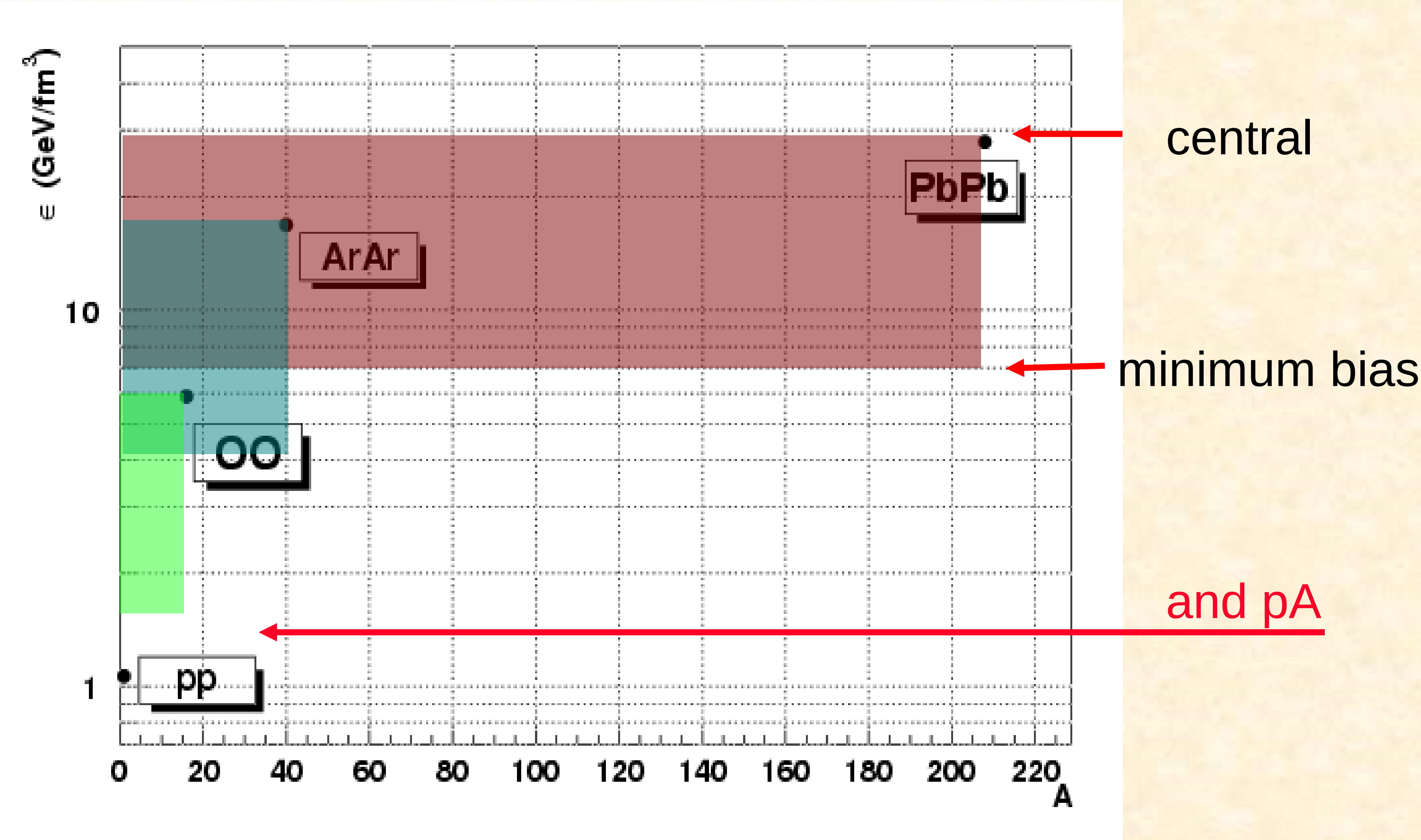
(from K.Kajantie, K.Eskola)



hep-ph0104010

- **Still no safe way to extrapolate**
  - ⇨ **shadowing/saturation (might decrease charged multiplicity)**
  - ⇨ **jet quenching (might increase it dramatically)**
  - ⇨ **A-scaling (importance soft vs. hard changes with energy)**
- **ALICE optimized for dN_{ch}/dy = 4000**
- **Checked up to 8000 (reality factor 2)**

Use different Ion species to vary the energy density



ALICE Physics Program

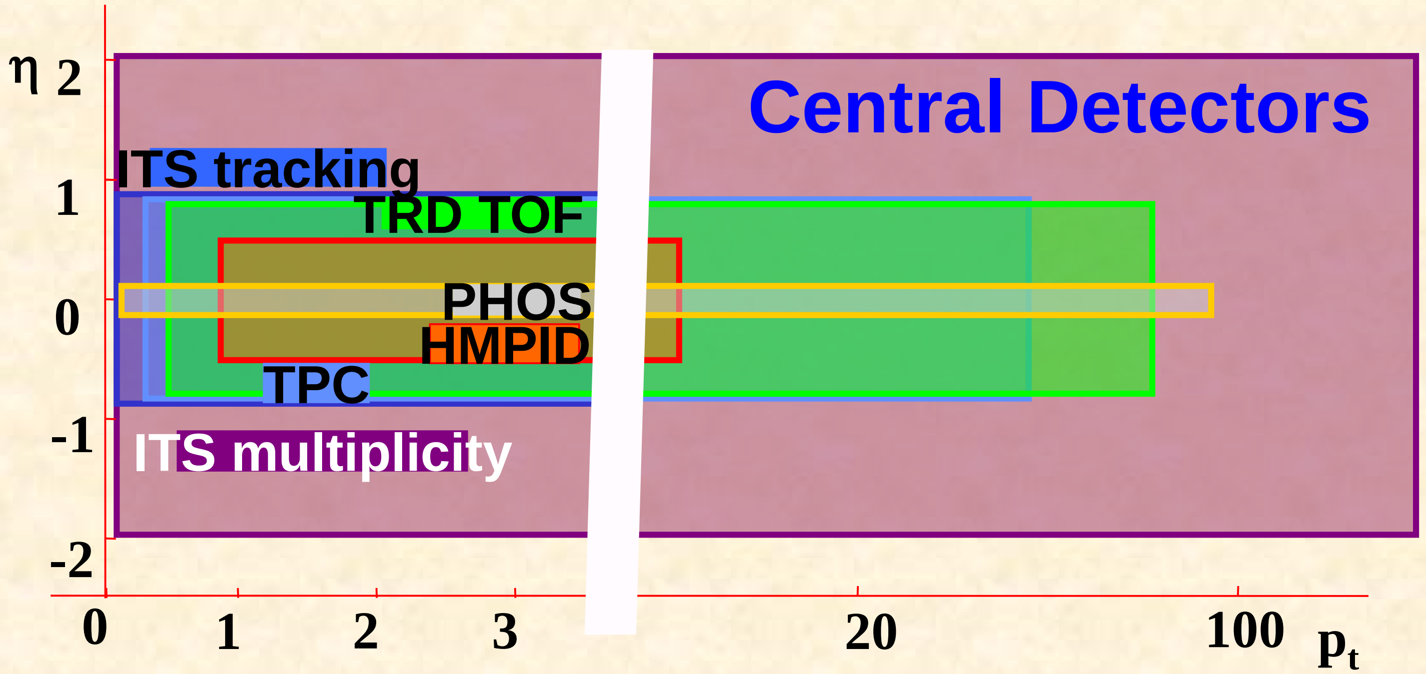
(has to cover in one experiment what at the SPS was covered by 6-7 experiments, and at RHIC by 4!!)

- **Global observables:**
  - **multiplicities, η distributions**
- **Degrees of freedom as a function of T:**
  - **hadron ratios and spectra**
  - **dilepton continuum, direct photons**
- **Geometry of the emitting source:**
  - **HBT, impact parameter via zero-degree energy**
- **Early state manifestation of collective effects:**
  - **elliptic flow**

ALICE Physics Program

- **Deconfinement:**
  - **charmonium and bottomium spectroscopy**
- **Energy loss of partons in quark gluon plasma:**
  - **jet quenching high pt spectra**
  - **open charm and open beauty**
- **Chiral symmetry restoration:**
  - **neutral to charged ratios**
  - **resonance decays**
- **Fluctuation phenomena - critical behavior:**
  - **event-by-event particle composition and spectra**
- **pp collisions in a new energy domain**

ALICE detector acceptance



Muon arm 2.4<η<4

PMD 2.3<η<3.5

FMD -5.4<η<-1.6, 1.6<η<3

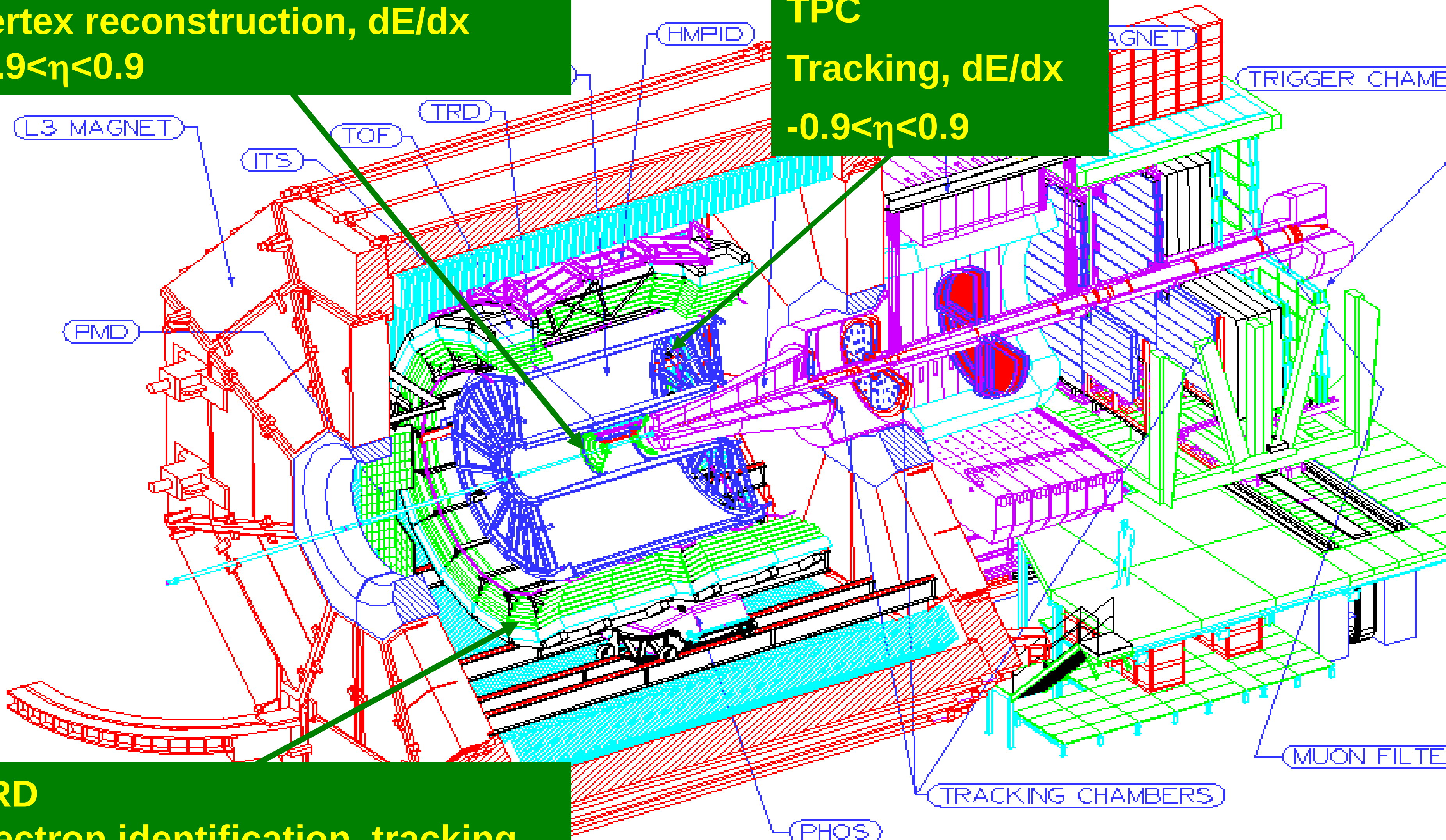
ALICE LAYOUT: TRACKING
(and event characterization)

Inner Tracking System (ITS):
6 Si Layers (pixels, drift, strips)
Vertex reconstruction, dE/dx
$-0.9<\eta<0.9$

TPC

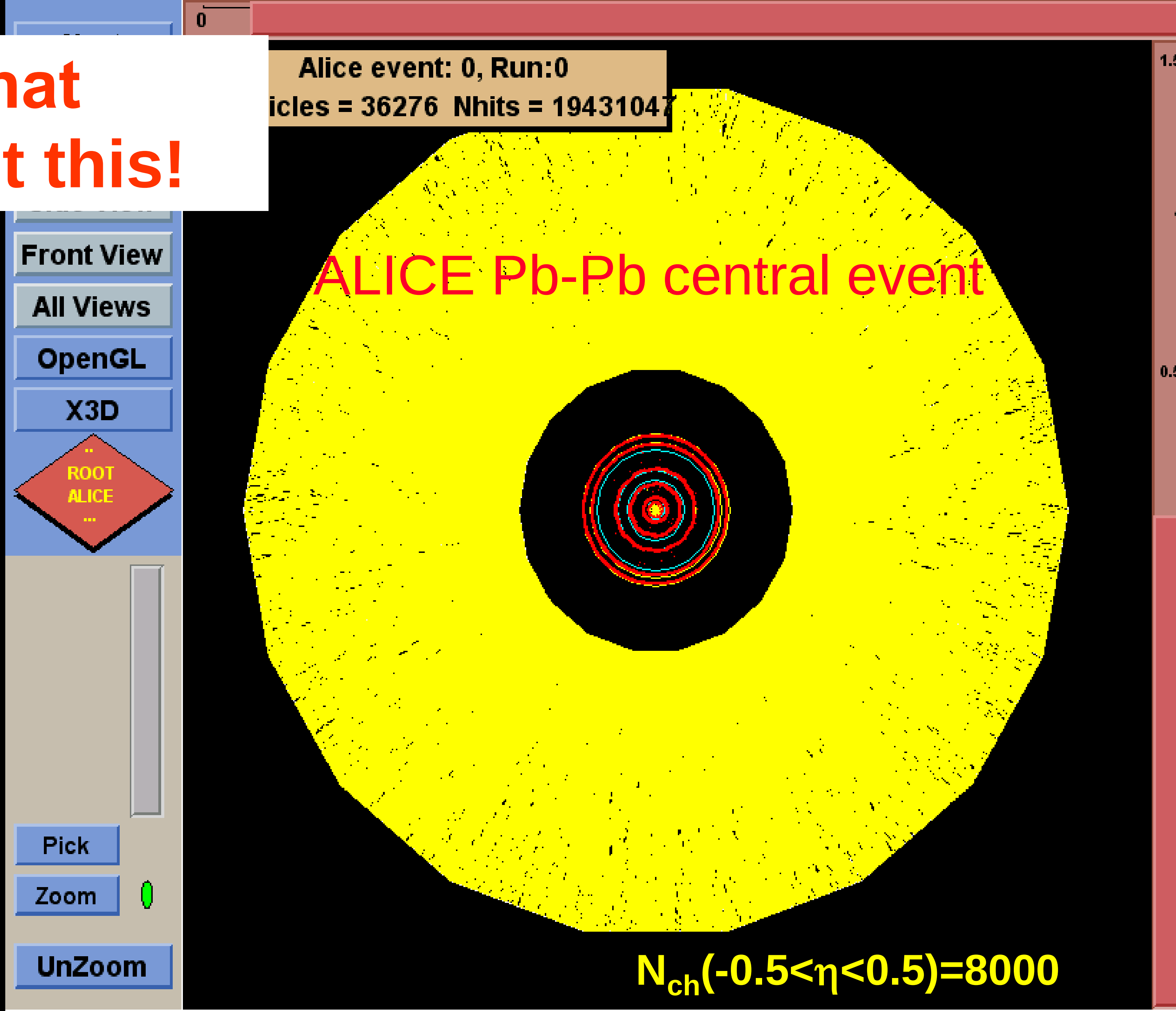
Tracking, dE/dx

$-0.9<\eta<0.9$

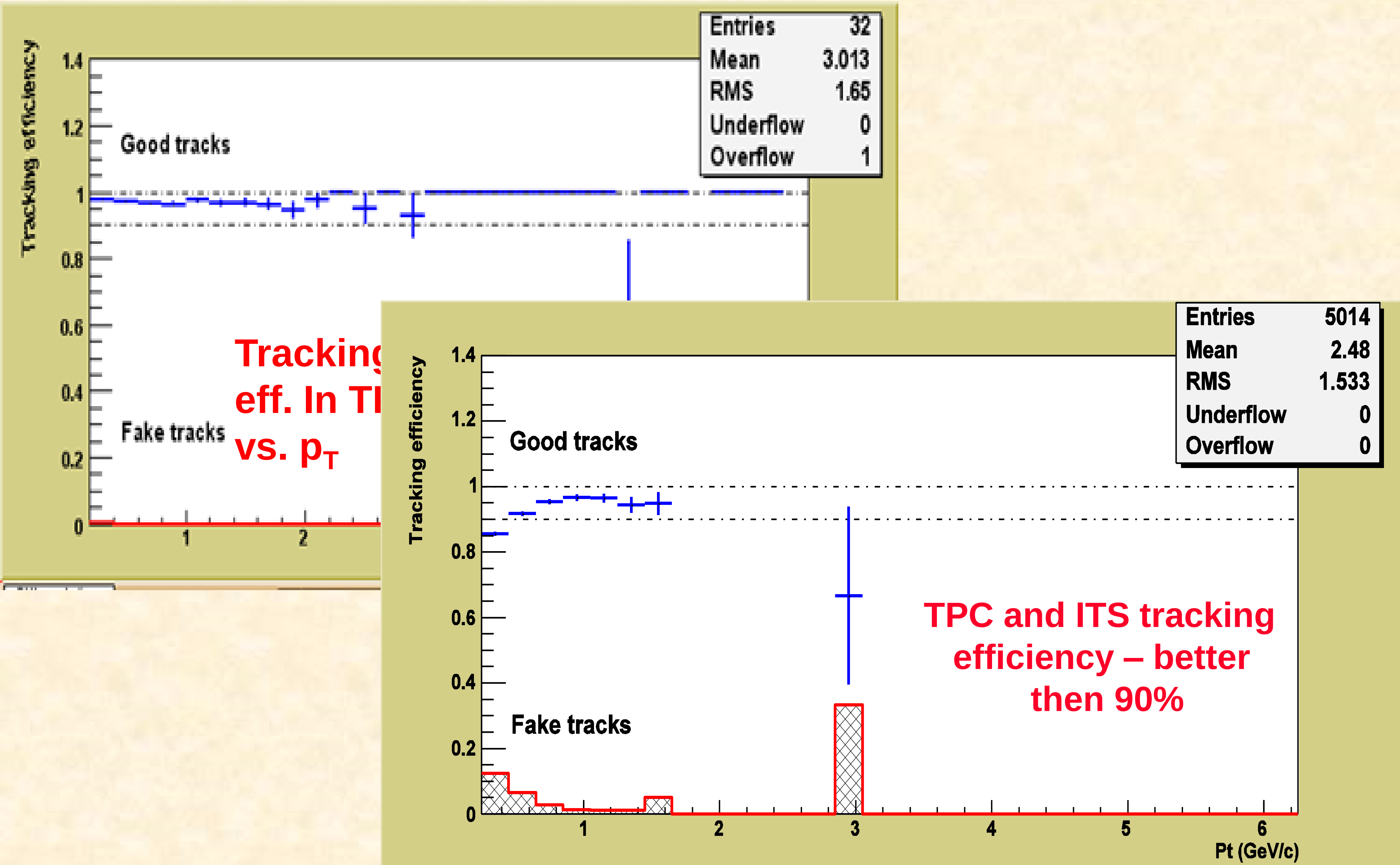


TRD
electron identification, tracking
$-0.9<\eta<0.9$

… what about this!

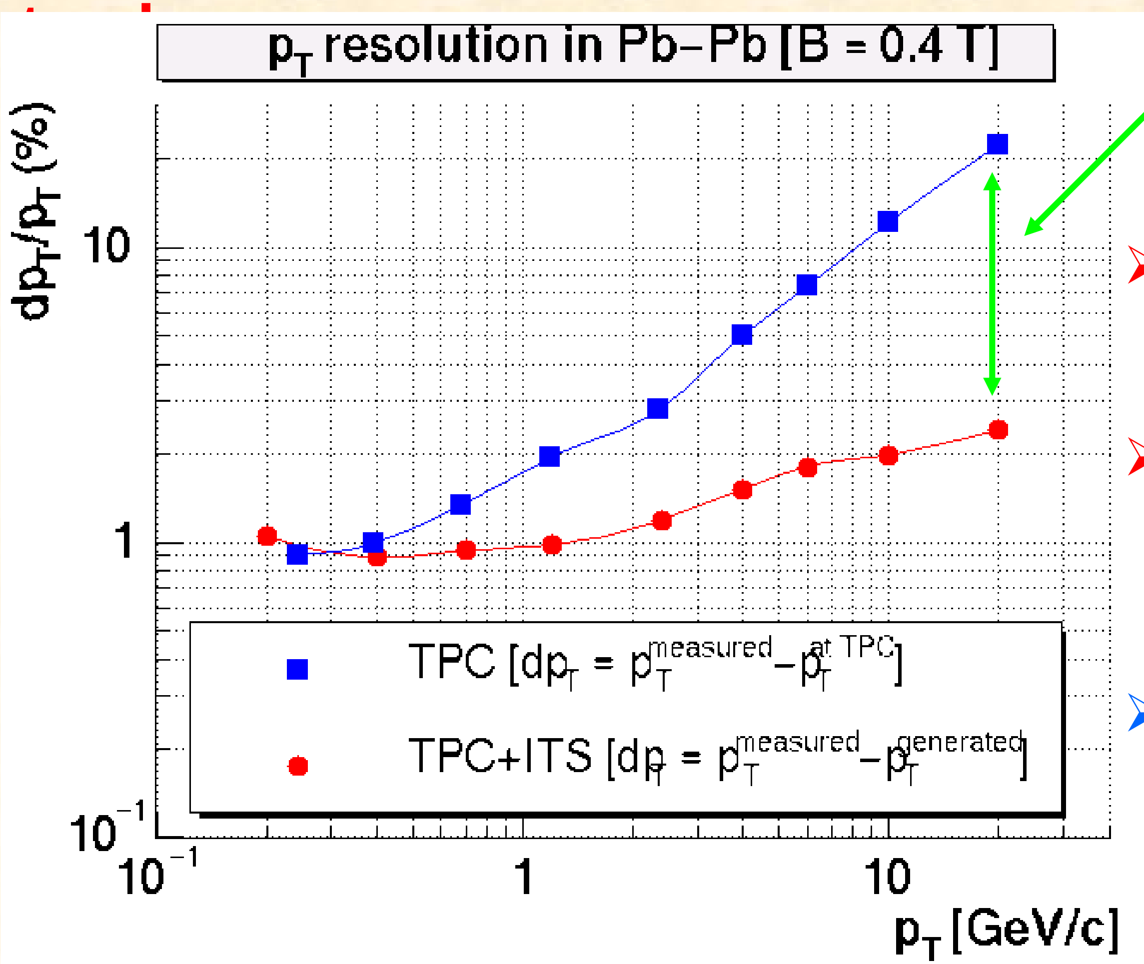


Tracking performance



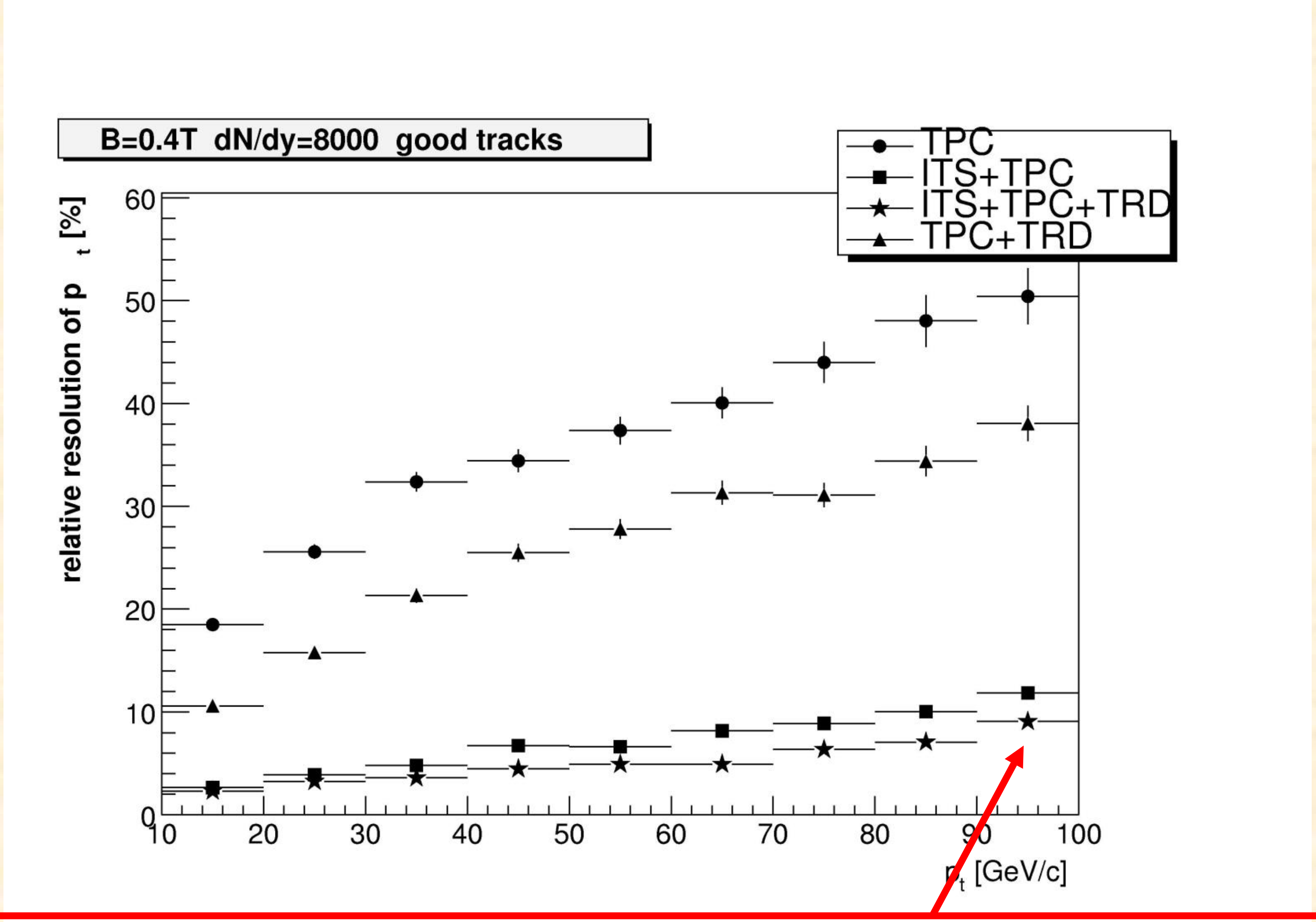
Track reconstruction in TPC-ITS p_T resolution

- The track momentum is measured (mainly) by TPC
- With ITS: resolution improves by a factor ~10 for high p_T



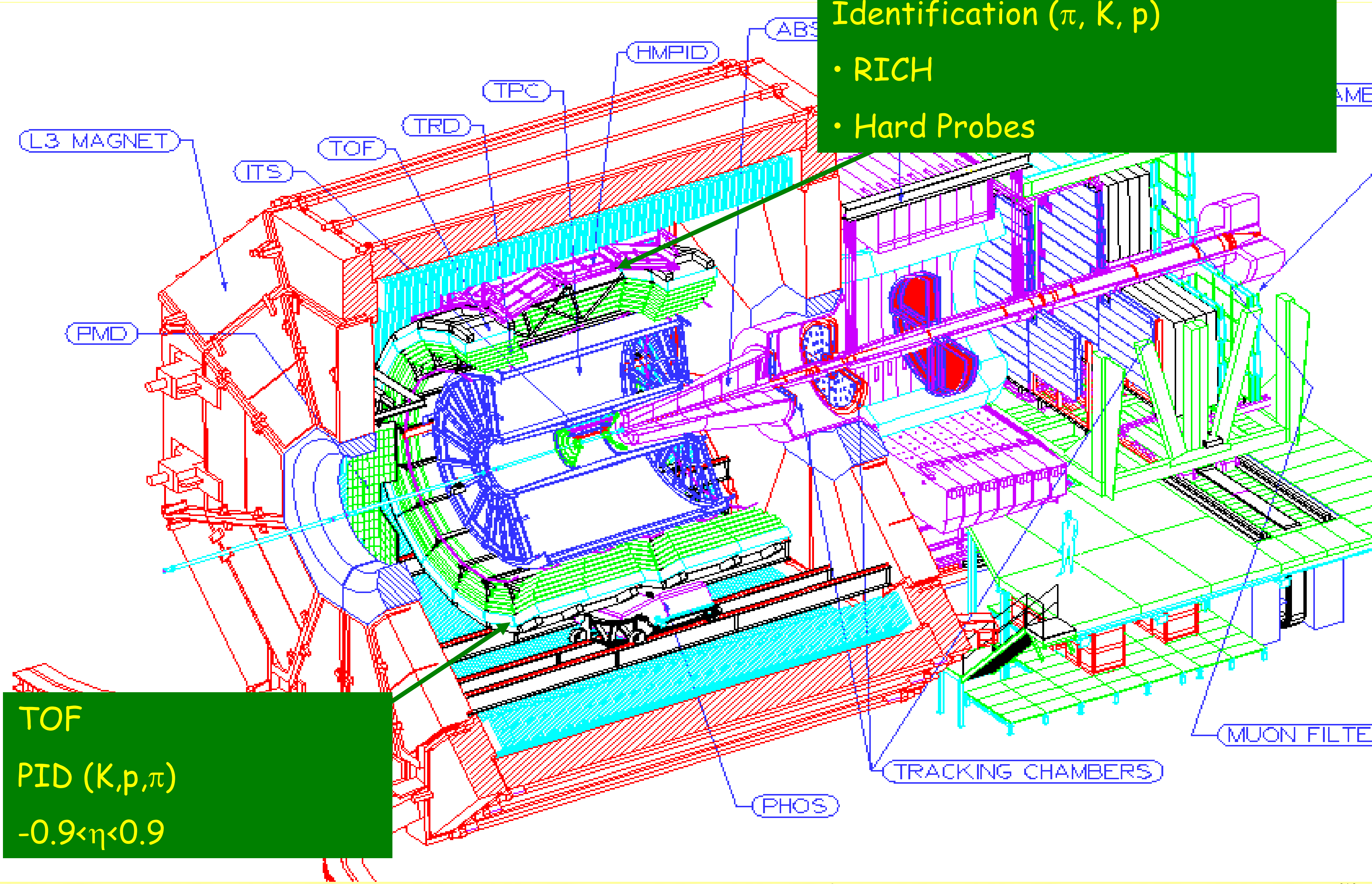
- Lever arm larger by 1.5 accounts for a factor ~ 2
- Remaining effect due to high resolution of points measured in ITS
- More improvement comes including the TRD in the tracking

Tracking-II: Momentum resolution



resolution ~ 9% at 100 GeV/c
excellent performance in hard region!

ALICE LAYOUT: PID



HMPID: High Momentum Particle Identification (π, K, p)

- RICH
- Hard Probes

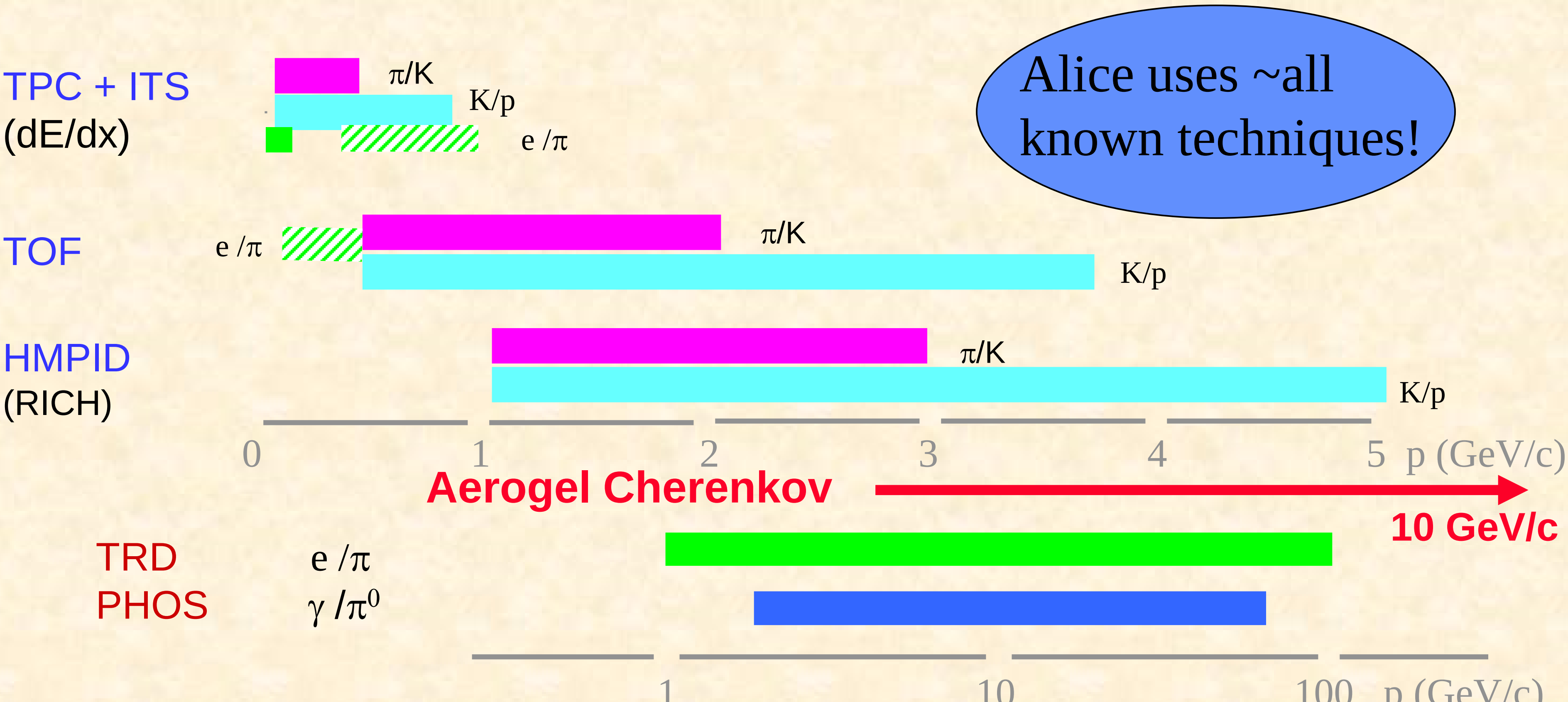
TOF

PID (K,p,π)

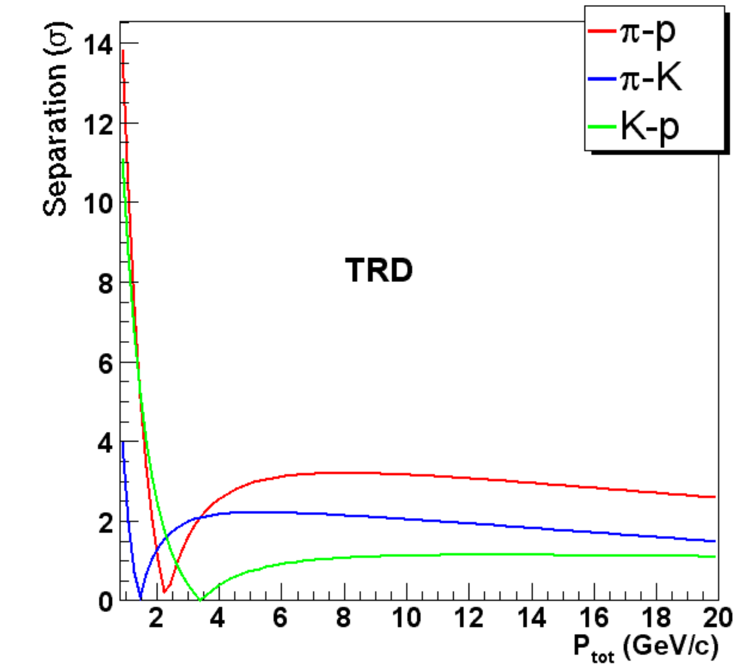
$-0.9<\eta<0.9$

ALICE PID

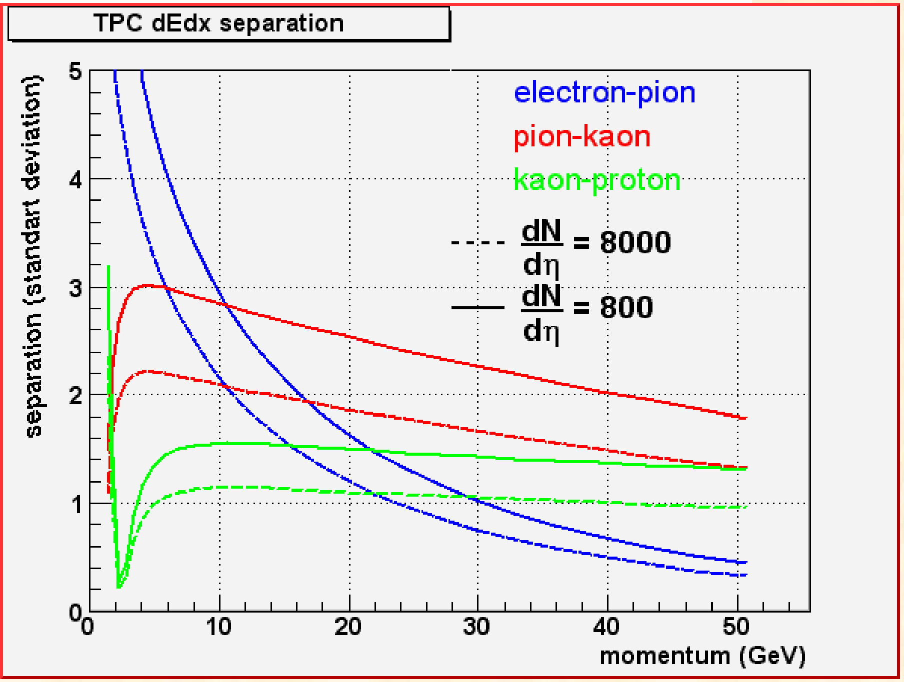
- π, K, p identified in large acceptance (2π * 1.8 units η) via a combination of dE/dx in Si and TPC and TOF from ~100 MeV to 2 (p/K) - 3.5 (K/p) GeV/c
- Electrons identified from 100 MeV/c to 100 GeV/c (with varying efficiency) combining Si+TPC+TOF with a dedicated TRD
- In small acceptance HMPID extends PID to ~5 GeV
- Photons measured with high resolution in PHOS, counting in PMD, and in EMC

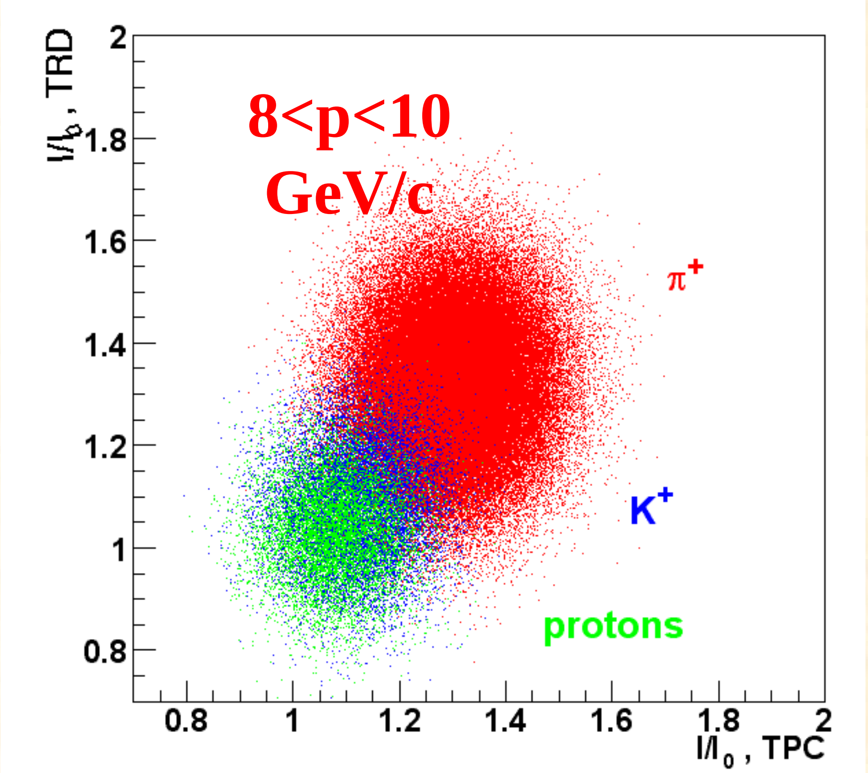


Under study: extension of PID to even higher momenta



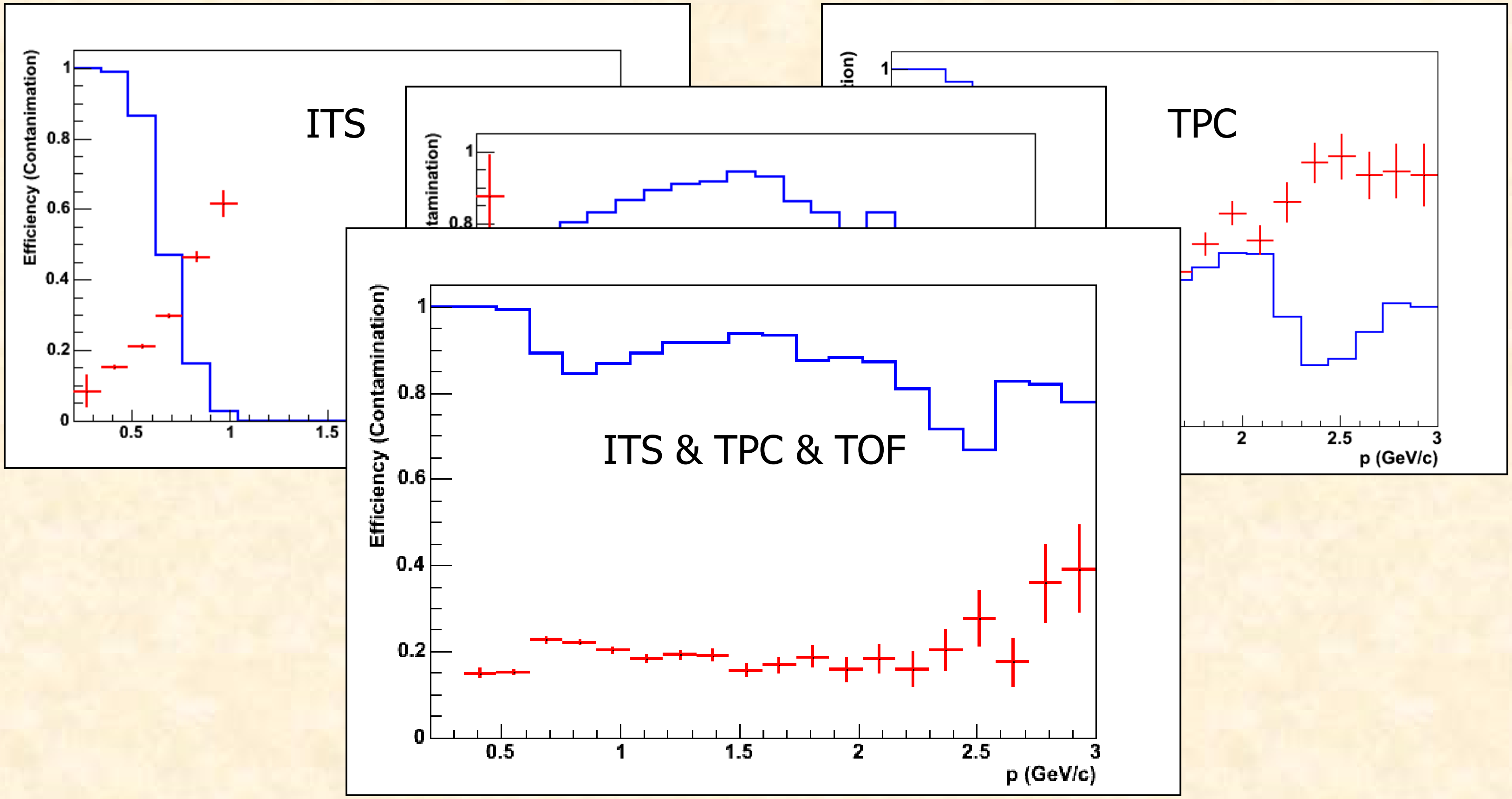
- Combine TPC and TRD dE/dx capabilities (similar number of samples/track) to get statistical ID in the relativistic rise region





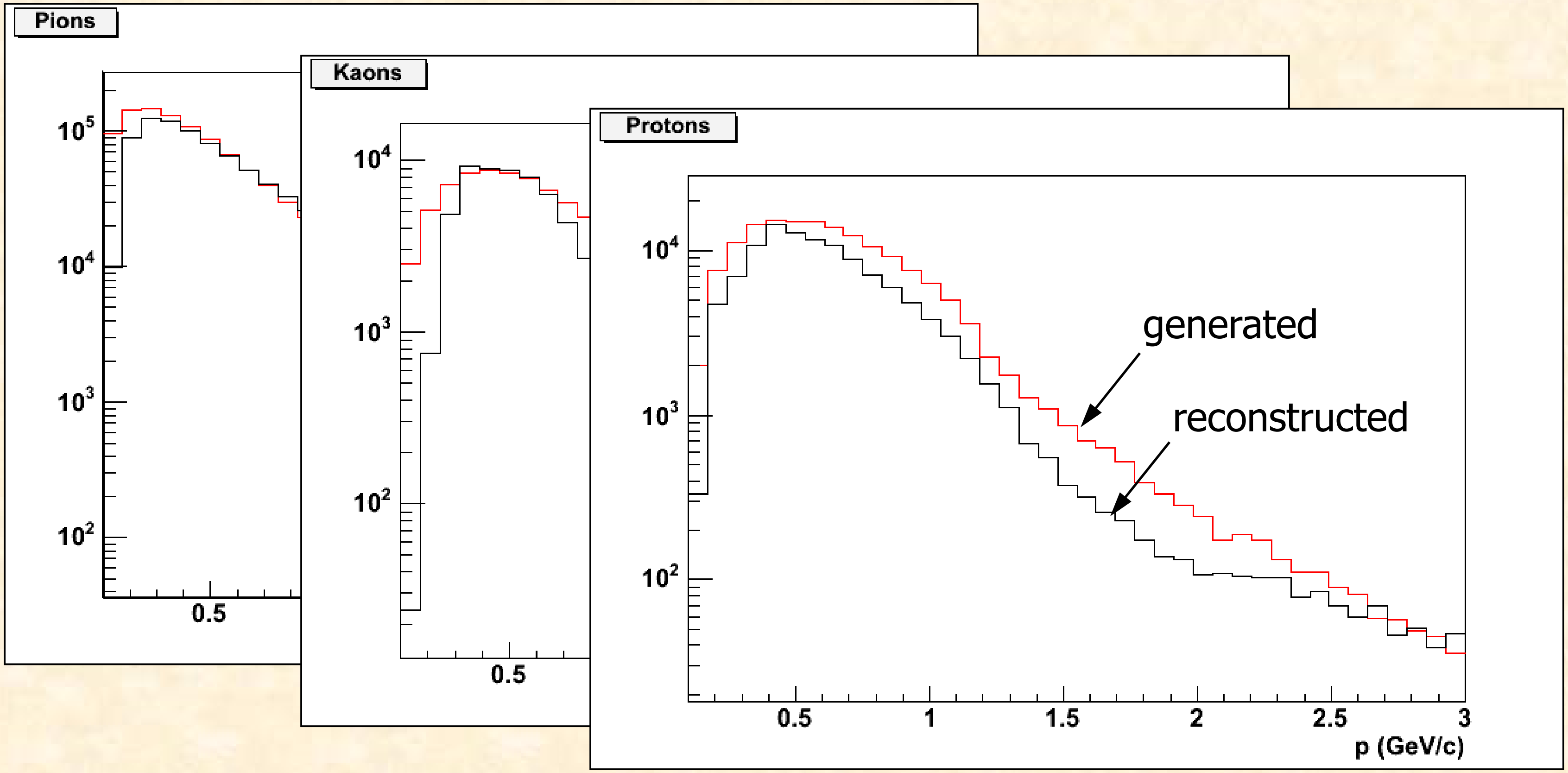
PID combined over ITS, TPC and TOF (Kaons)

Selection : ITS & TPC & TOF (central PbPb HIJING events)



Efficiency of the combined PID is higher and the contamination is lower than the ones given by any of the detectors stand-alone

Example : Particle spectra



Preliminary

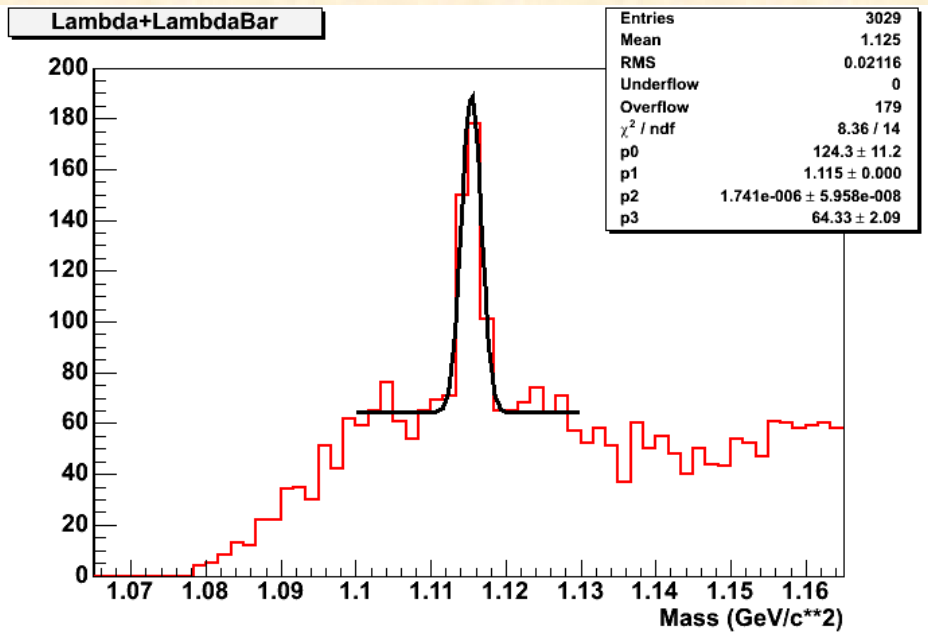
Needs corrections for decays, tracking and PID efficiency

Example: Λ analysis

(290 events from the jet production)

Fitted with p0*exp(-0.5*(x-p1)*(x-p1)/p2) + p3

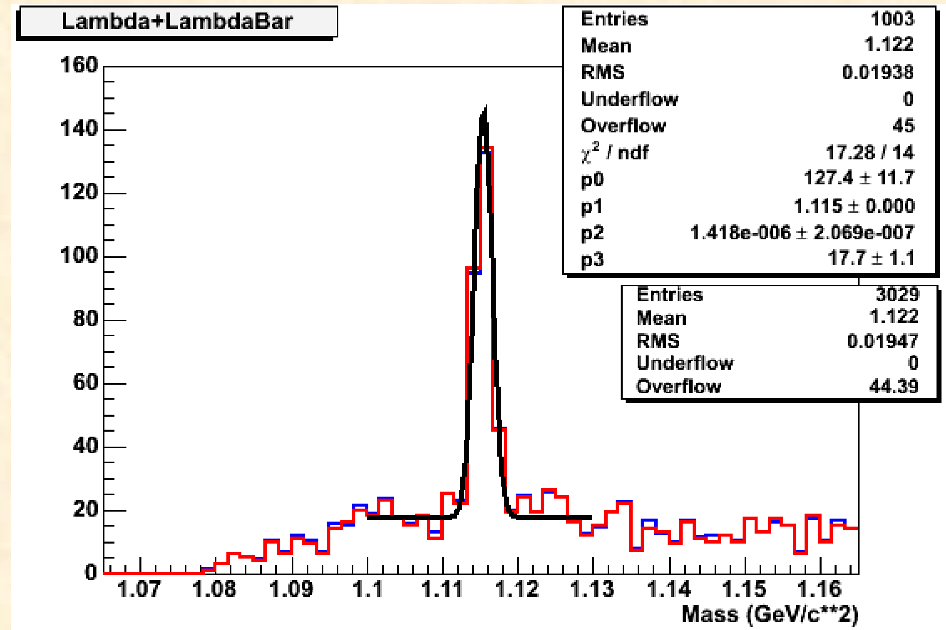
Mass=p1=1115 MeV   σ=√p1=1.3 MeV



All candidates from the ESD

S ~ p0 = 124

S/B ~ p0/p3 = 1.9

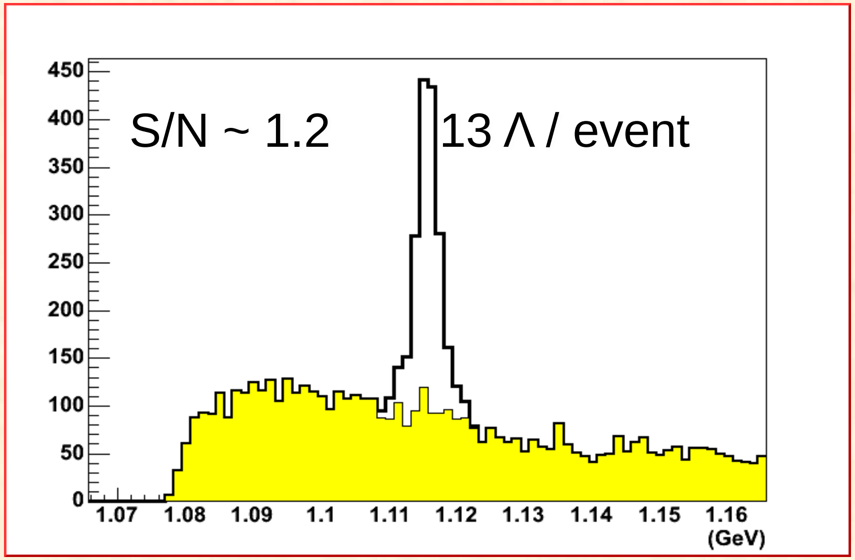


PID with $C_\pi : C_K : C_p = 1 : 0 : 1$

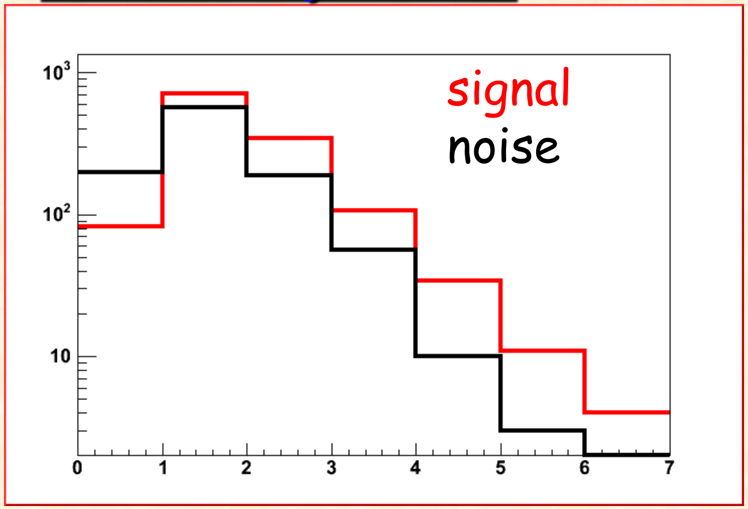
S ~ p0=127

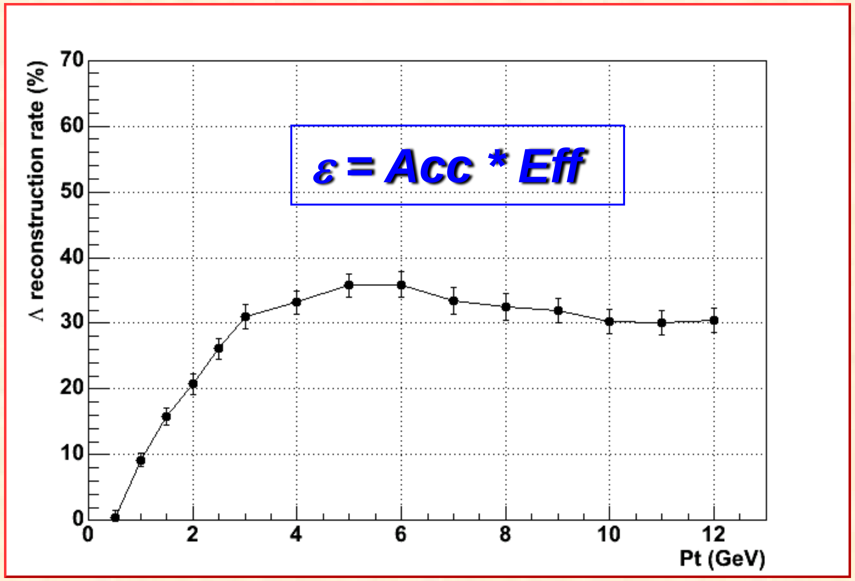
S/B ~ p0/p3 = 7.1

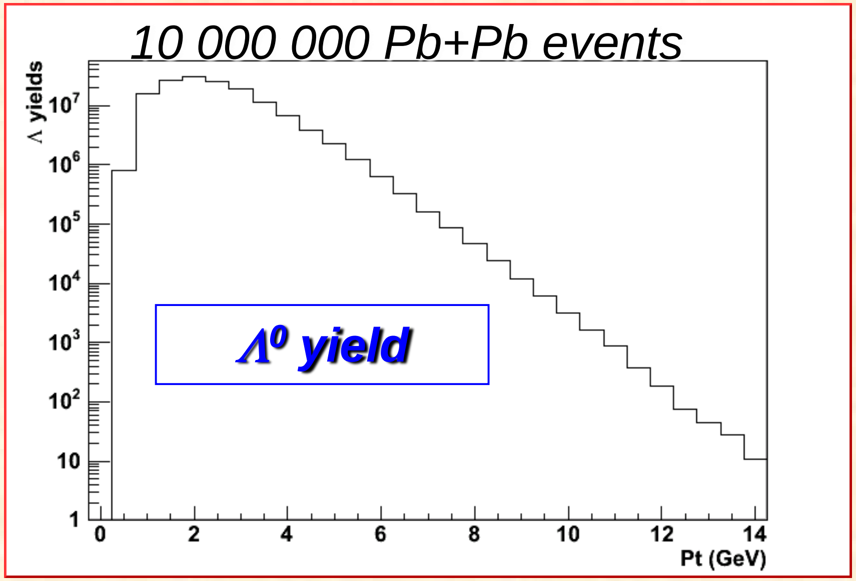
Λ Reconstruction with pt dependent geometrical cuts



⇒ Efficiency ~ 50 %







Parton Energy Loss

- **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**

Accessible transverse energy

Trigger Limit

2GeV | 20 GeV | 100 GeV | 200 GeV

Mini-Jets 100/event | 1/event | 100k/year

Event structure and properties p_T > 2GeV
'Underlying' Event Fluctuations

Event-by-event well distinguishable objects

Resolution limit

Inclusive (correlation) studies

Reconstructed Jets

Heavy Quarks – dead cone

- Heavy quarks **with momenta < 20–30 GeV/*c*** → $v \ll c$

- Gluon radiation is suppressed at angles < m_Q/E_Q

  → "dead-cone" effect

  ⇨ **Due to destructive interference**

  ⇨ **Contributes to the harder fragmentation of heavy quarks**

- **Yu.L.Dokshitzer and D.E.Kharzeev:** *dead cone implies lower energy loss*

→ **D mesons quenching reduced**

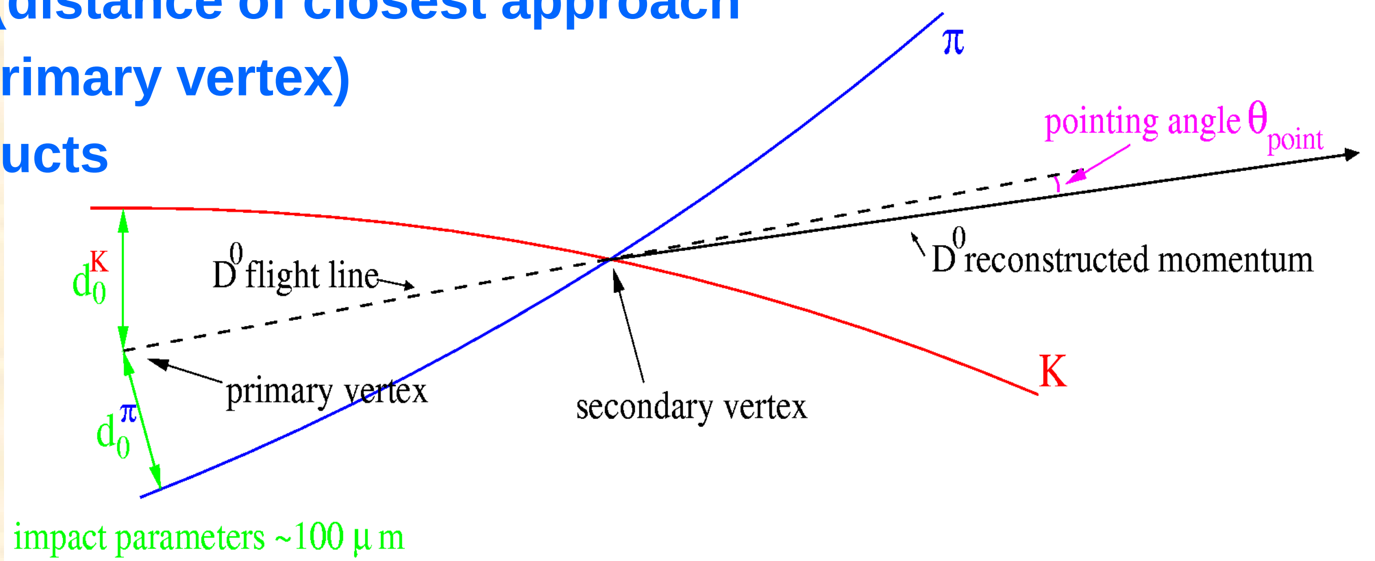
→ **Ratio D/hadrons (or D/π^0) enhanced and sensitive to medium properties**

Yu.L.Dokshitzer and D.E.Kharzeev, Phys. Lett. **B519** (2001) 199 [arXiv:hep-ph/0106202].

Detection strategy for $D^0 \rightarrow K^- \pi^+$

- **Weak decay with mean proper length** $c\tau$ = 124 μm
- Impact Parameter **(distance of closest approach of a track to the primary vertex) of the decay products**

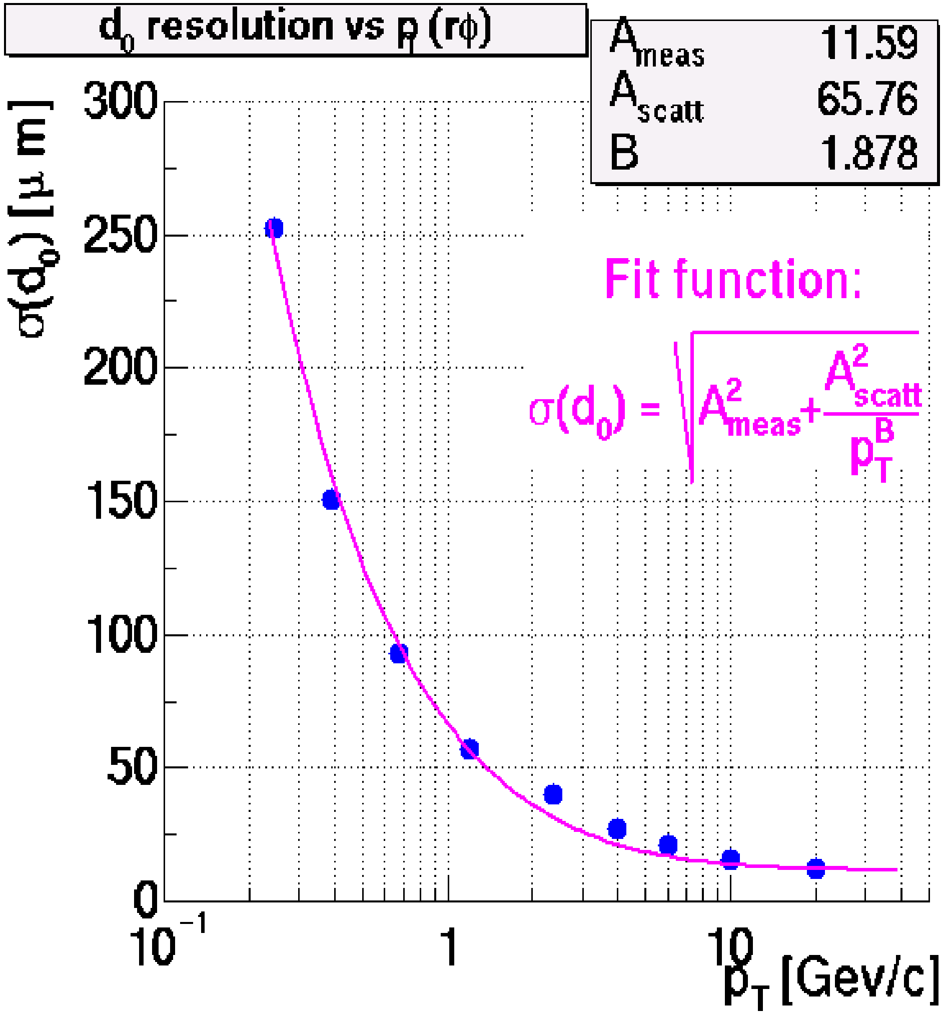
  d_0 ~ 100 μm

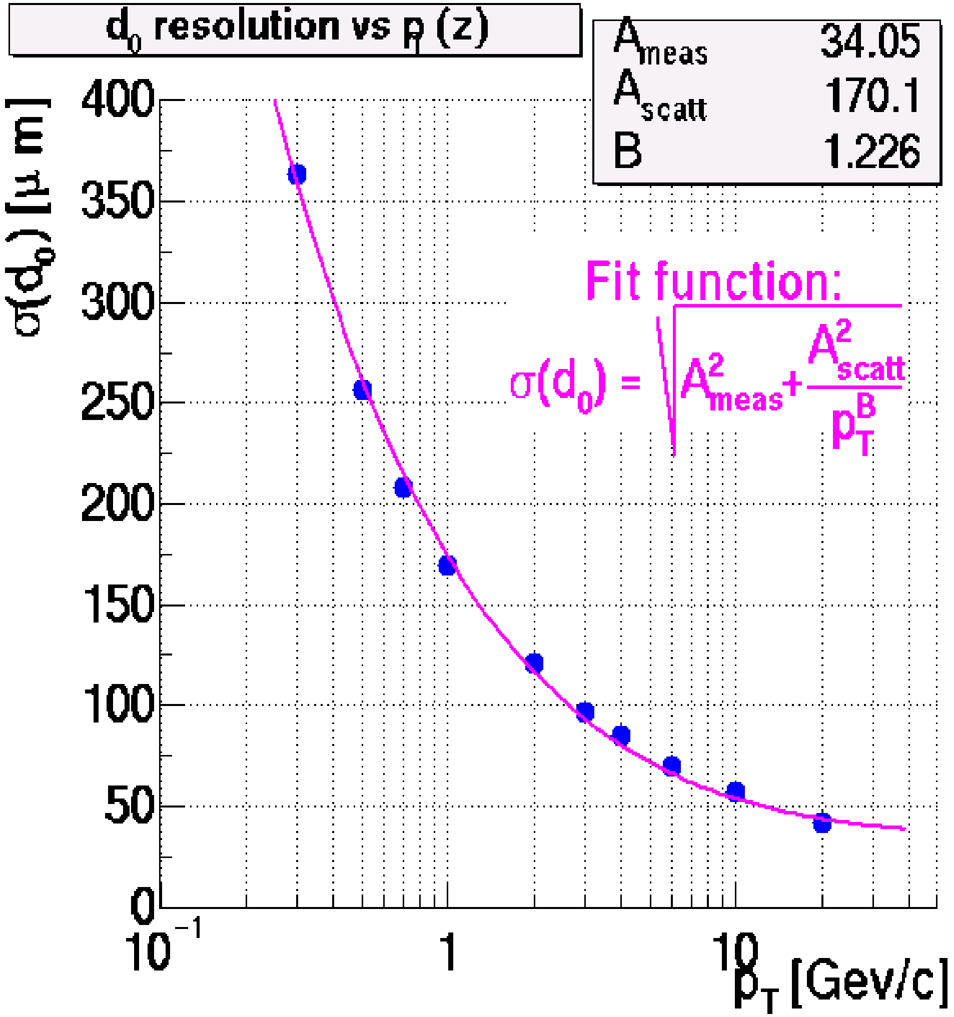


- **STRATEGY:** invariant mass **analysis of fully-reconstructed topologies originating from (displaced)** secondary vertices
  - ⇨ **Measurement of** Impact Parameters
  - ⇨ **Measurement of** Momenta
  - ⇨ Particle identification **to tag the two decay products**

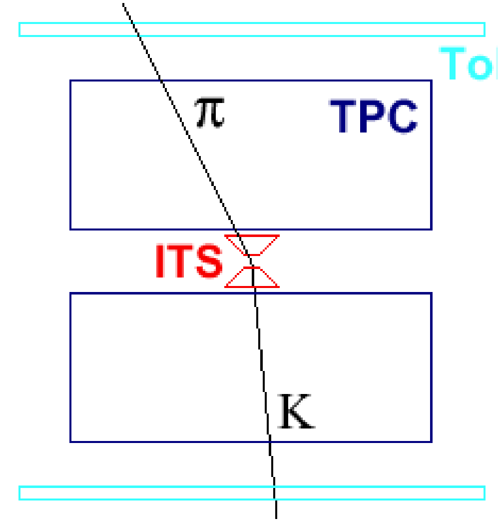
Track reconstruction in TPC-ITS d_0 measurement

Measurement of impact parameters is *crucial* for secondary vertex reconstruction





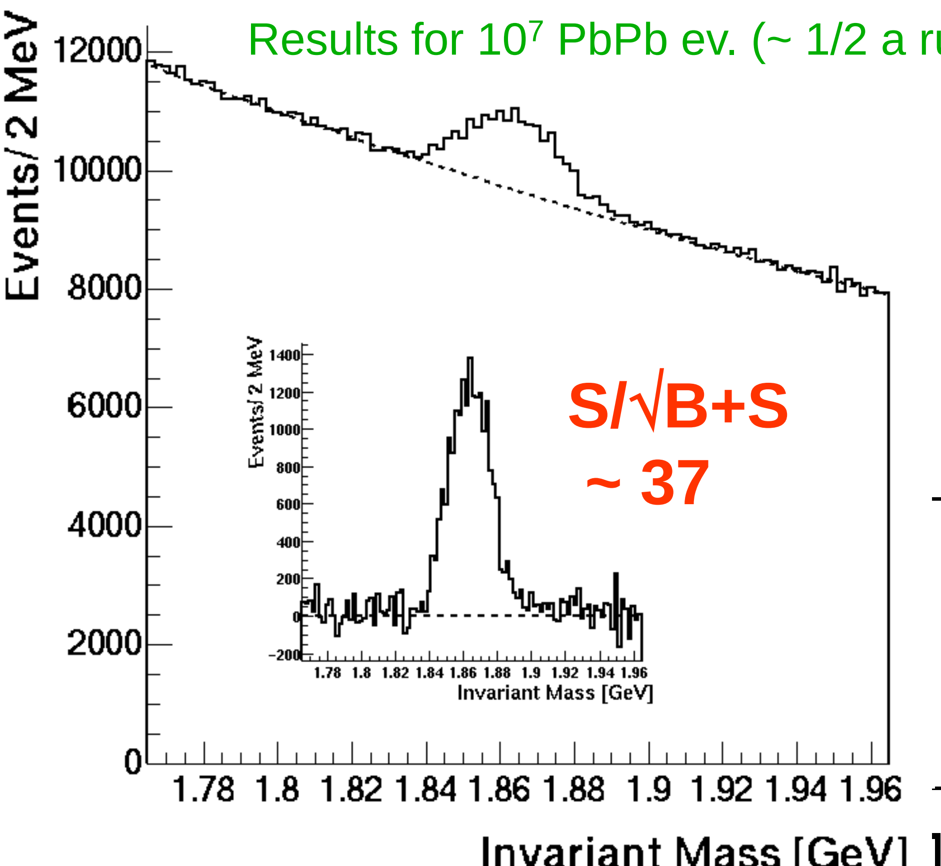
Hadronic charm

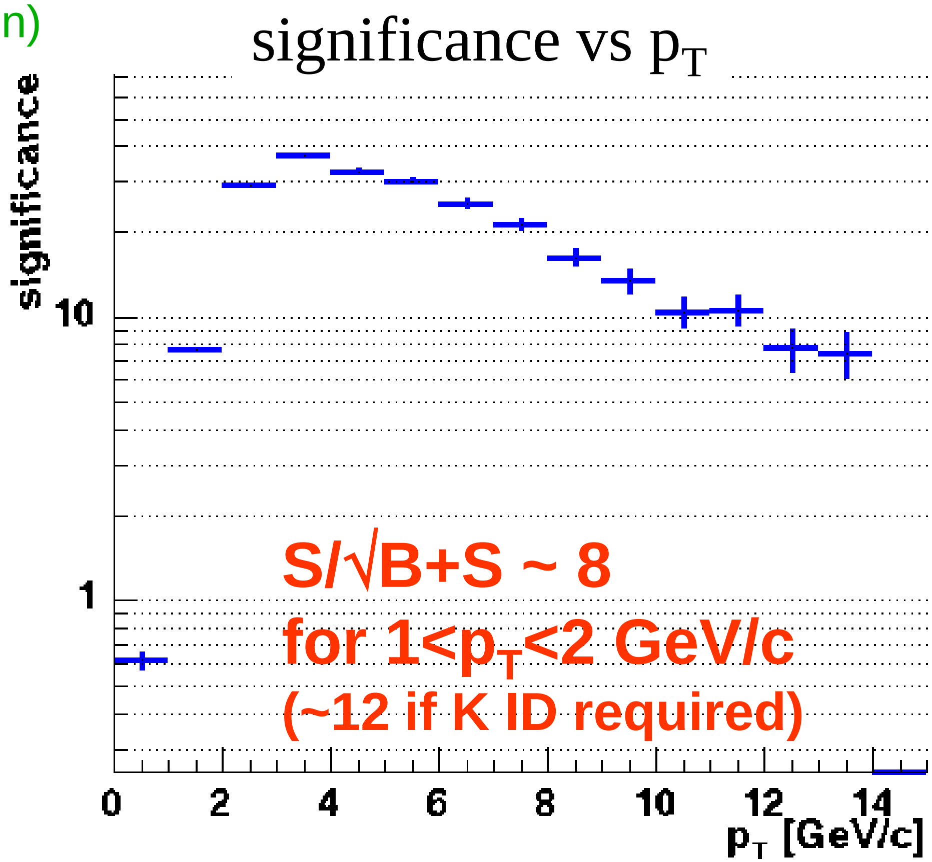


Combine ALICE tracking + secondary vertex finding capabilities (σ_{d0}~60μm@1GeV/c p_T) + large acceptance PID to detect processes as $D^0 \rightarrow K^- \pi^+$

~1 in acceptance / central event

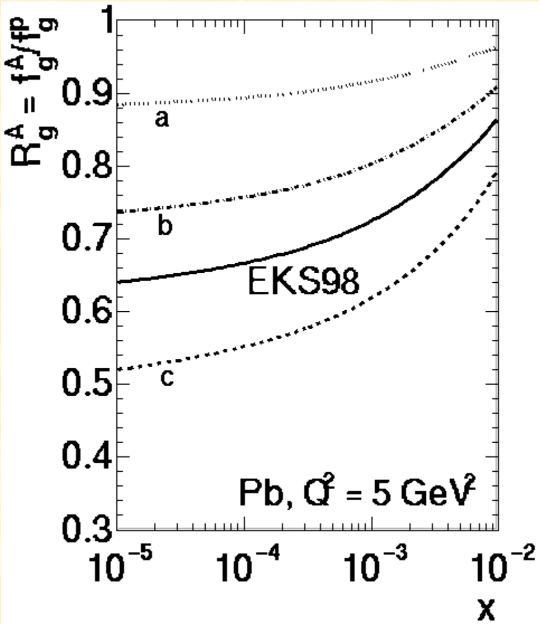
~0.001/central event accepted after rec. and all cuts

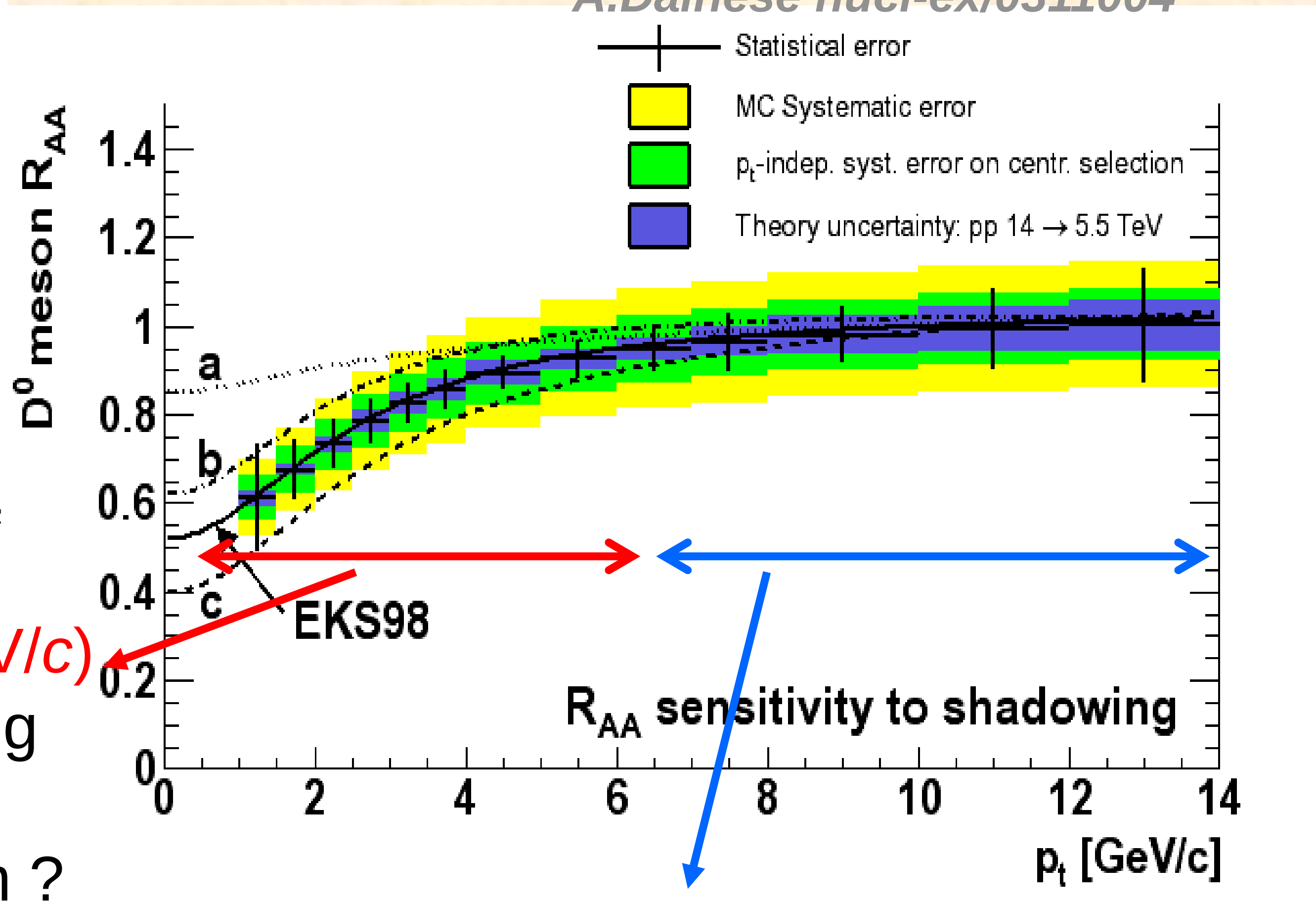




Sensitivity on R_{AA} for D^0 mesons

A.Dainese nucl-ex/0311004





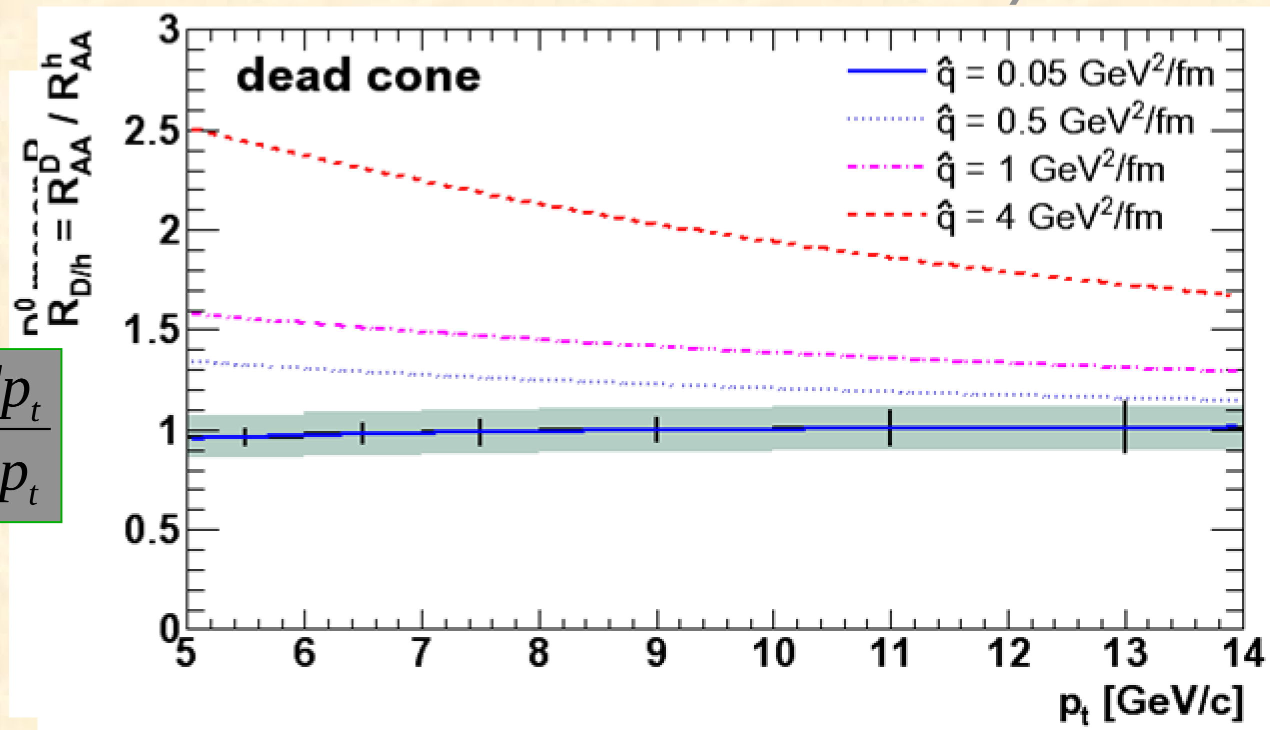
Low p_t (< 6–7 GeV/c)
Nuclear shadowing
+ k_t broadening
+ ? thermal charm ?

'High' p_t (6–15 GeV/c)
here energy loss can be studied
(it's the only expected effect)

D quenching ($D^0 \rightarrow K^- \pi^+$)

- **Reduced**

A.Dainese nucl-ex/0311004



$$R_{AA} = \frac{1}{N_{coll}} \times \frac{dN_{AA} / dp_t}{dN_{pp} / dp_t}$$

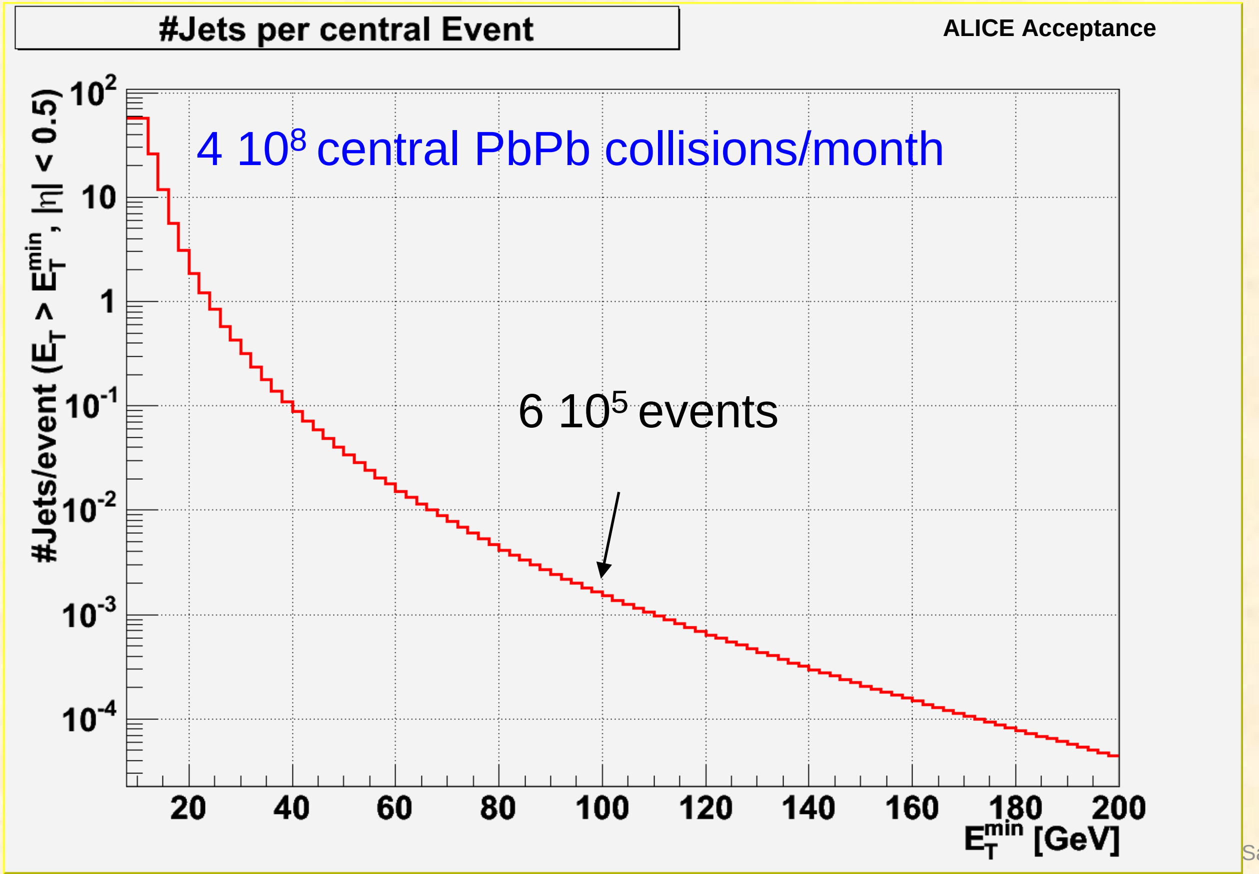
- **Ratio D/hadrons (or D/π^0) enhanced and sensitive to medium properties**

Jet reconstruction

- **Jets are produced copiously**

2 20 100 200 p_t (GeV)

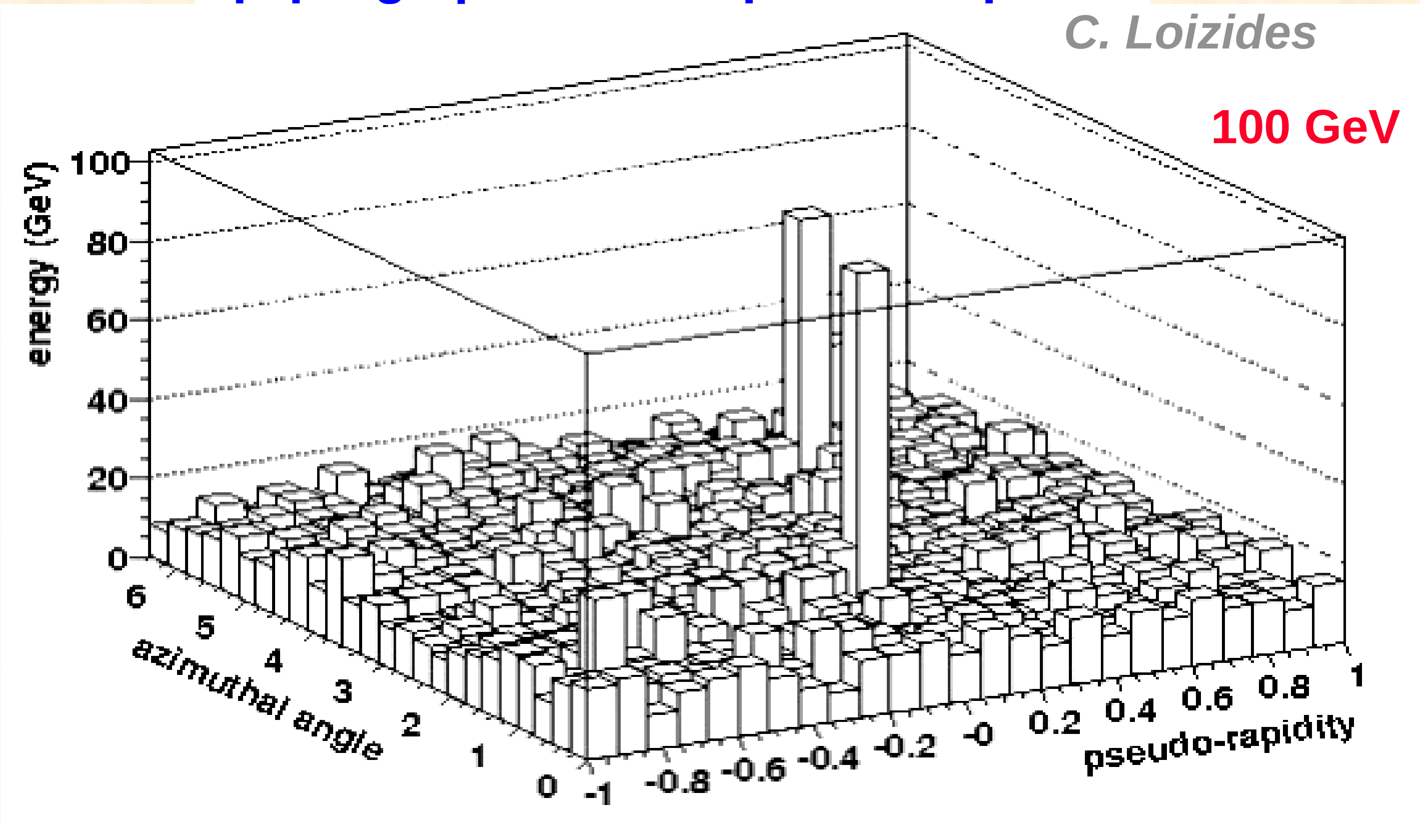
100/event 1/event 100K/year



50 – 100 GeV jets in Pb–Pb

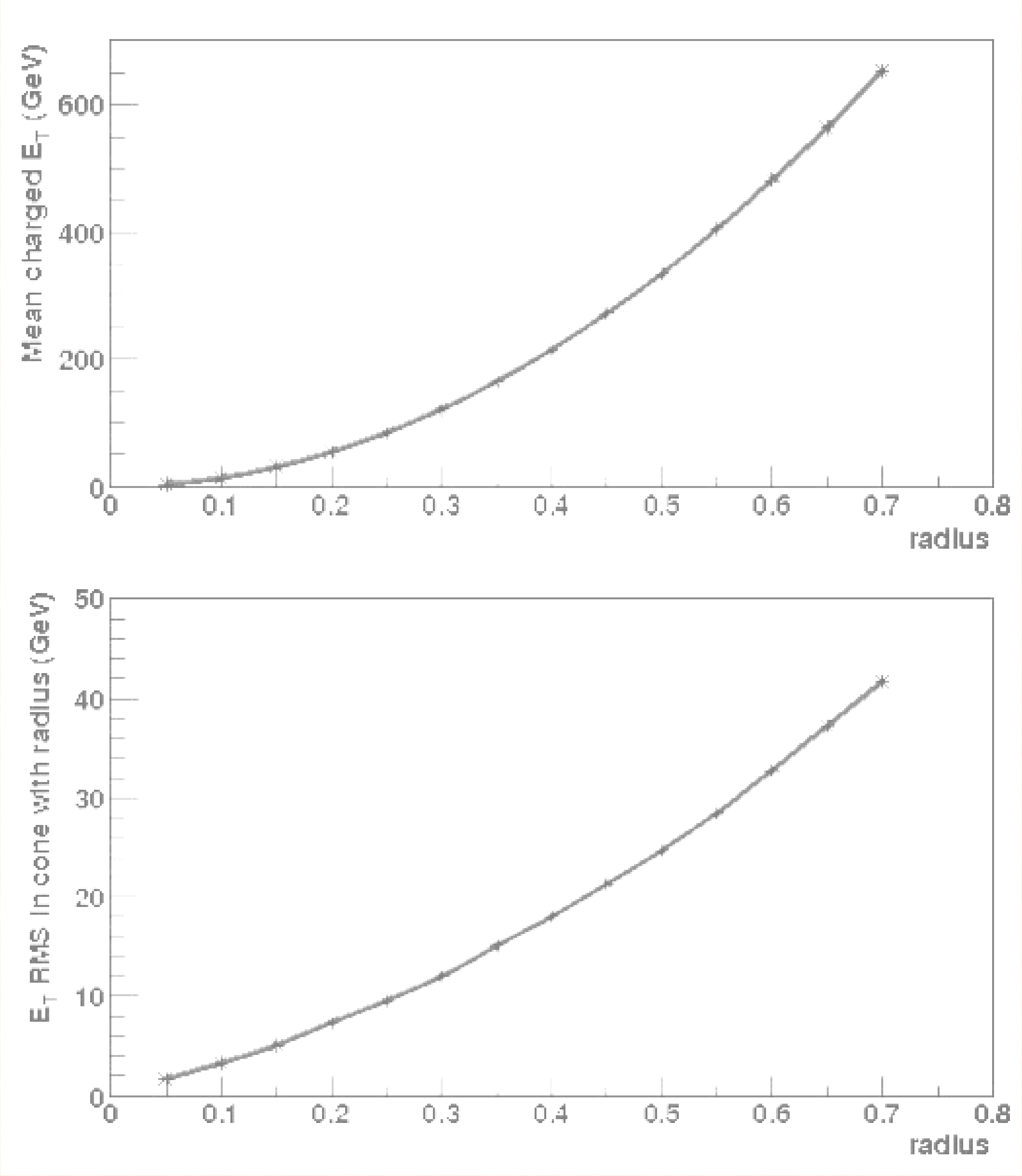
At large enough jet energy – jet clearly visible
But still large fluctuation in underlying energy

η–φ lego plot with Δη 0.08 × Δφ 0.25



Central Pb–Pb event (HIJING simulation) with 100 GeV di-jet (PYTHIA simulation)

Energy fluctuation in UE

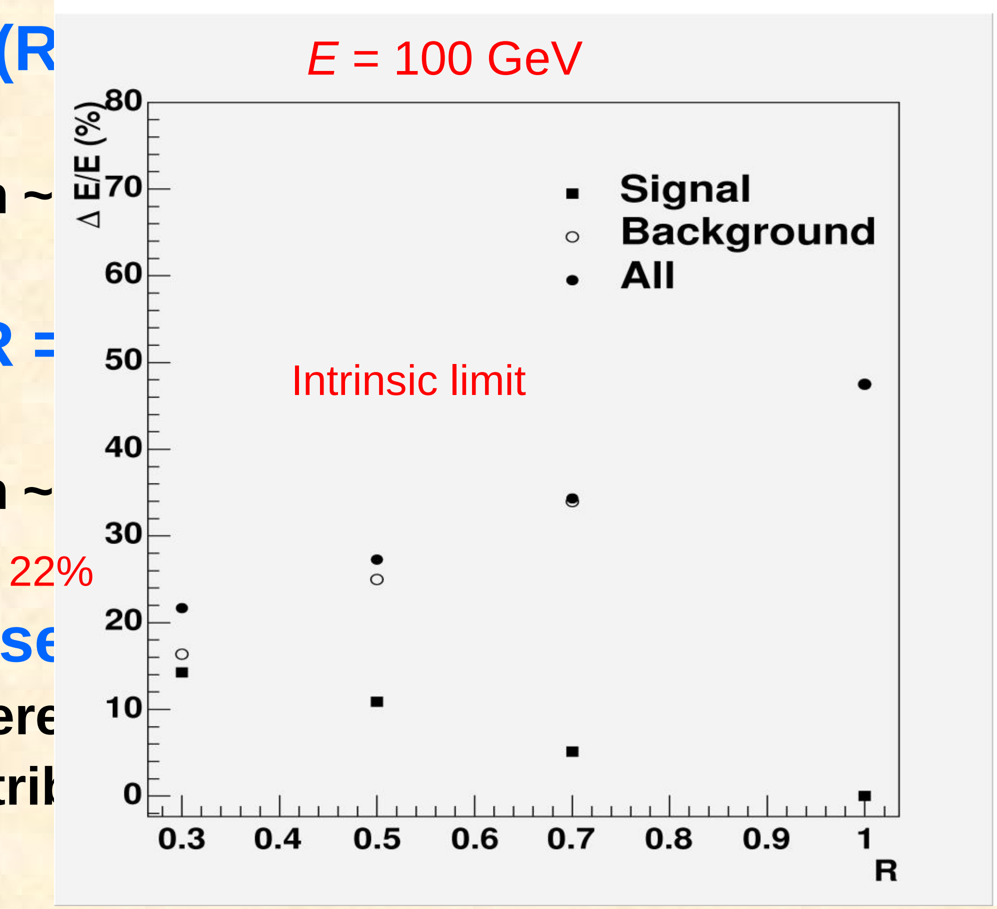


Mean energy in a cone of radius R coming from underlying event

Fluctuation of energy from an underlying event in a cone of radius R

Irreducible limits on jet energy resolution

- Small radius of jet cone (R
  - ⇨ we don't see 30% of energy
  - ⇨ underlying event fluctuation ~
- Larger jet-cone radius (R =
  - ⇨ we don't see 10% of energy
  - ⇨ underlying event fluctuation ~

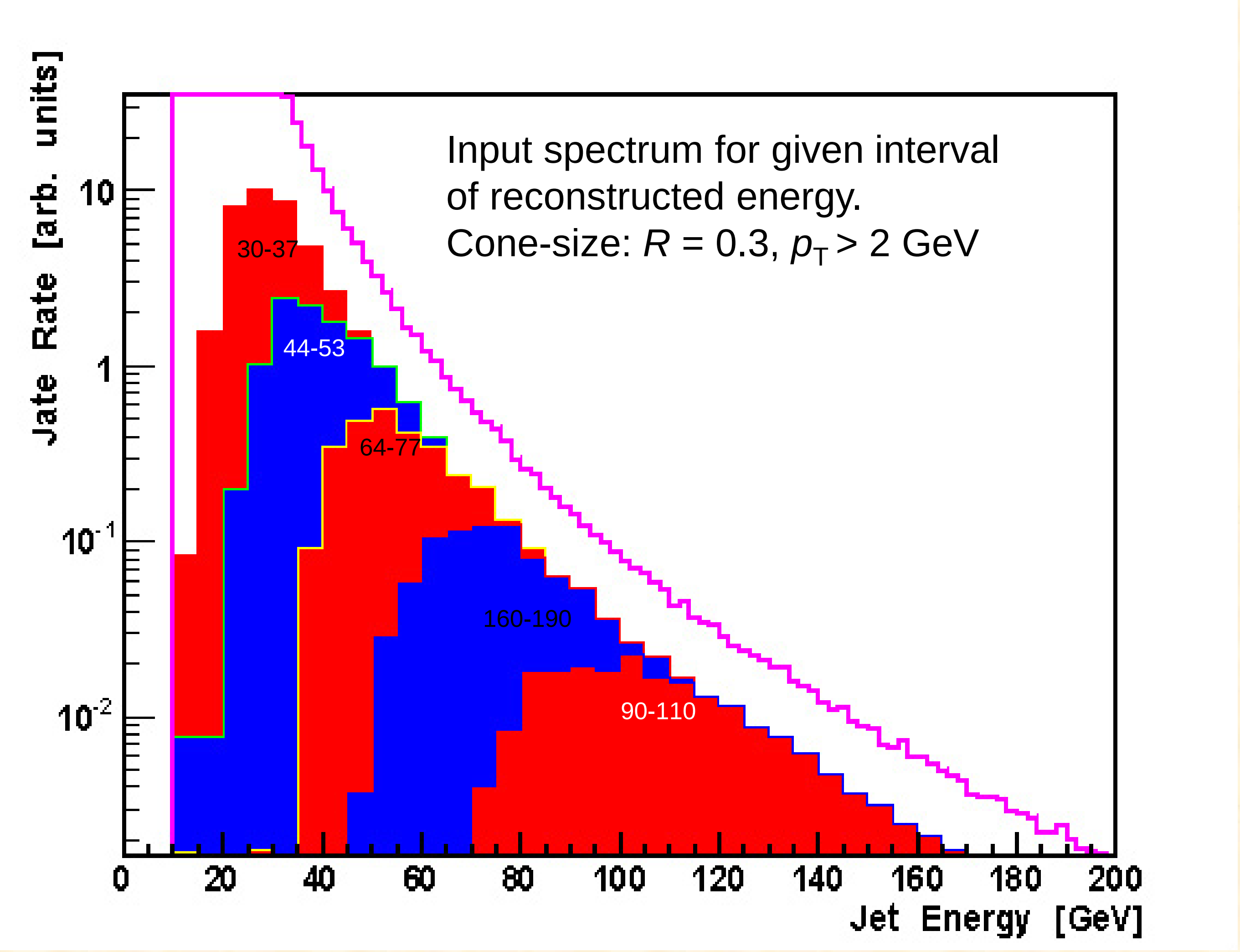


- We cannot just add non-se
  - ⇨ as is usually done in pp where
  - ⇨ that depends on energy distrib
- It's impossible to know jet energy better than 22 – 30% (for 100 GeV jets)
  - ⇨ we are now at 30 %, pretty close…

Jet energy resolution using charged particles

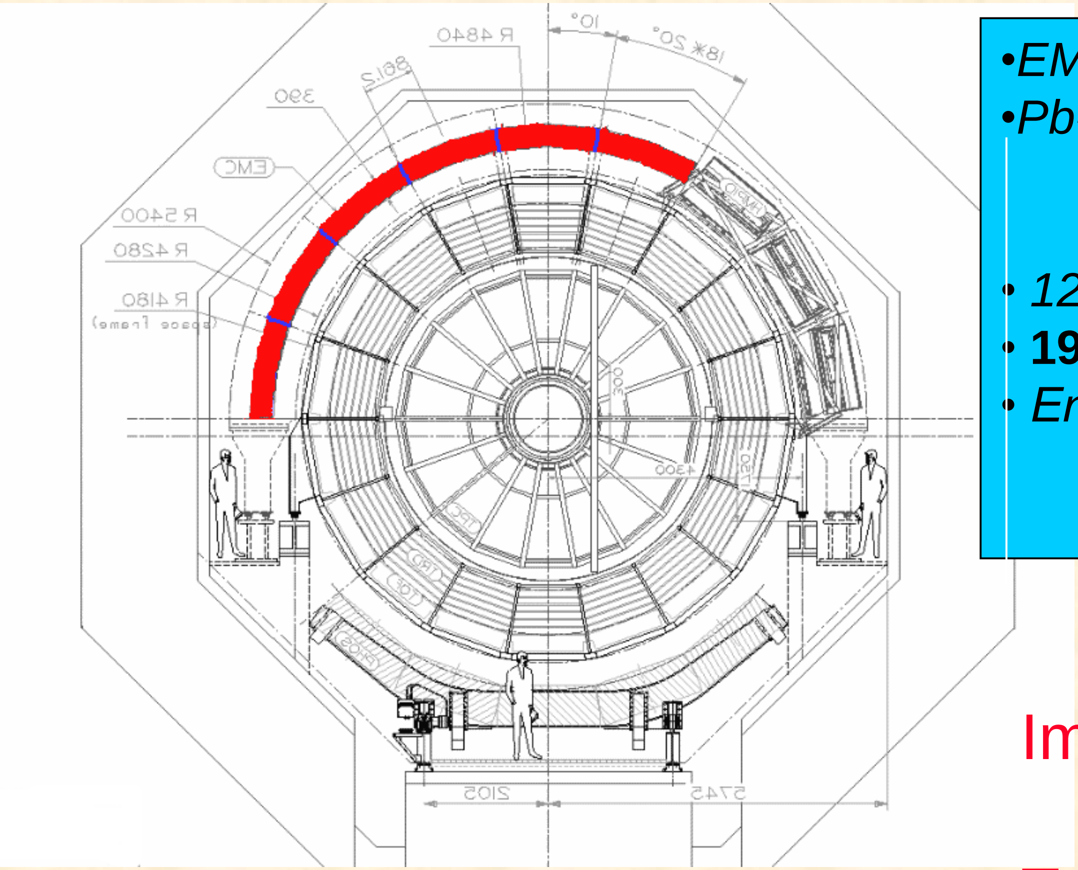
Charged/neutral fluctuations dominate:

***ΔE/E* > 50%**



(R<1 = parton energy)

Proposed ALICE EMCAL



- *EM Sampling Calorimeter (STAR Design)*
- *Pb-scintillator linear response*
    - $-0.7 < \eta < 0.7$
    - $\pi/3 < \Phi < \pi$
- *12 super-modules*
- **19152** *towers*
- *Energy resolution ~15%/√E*

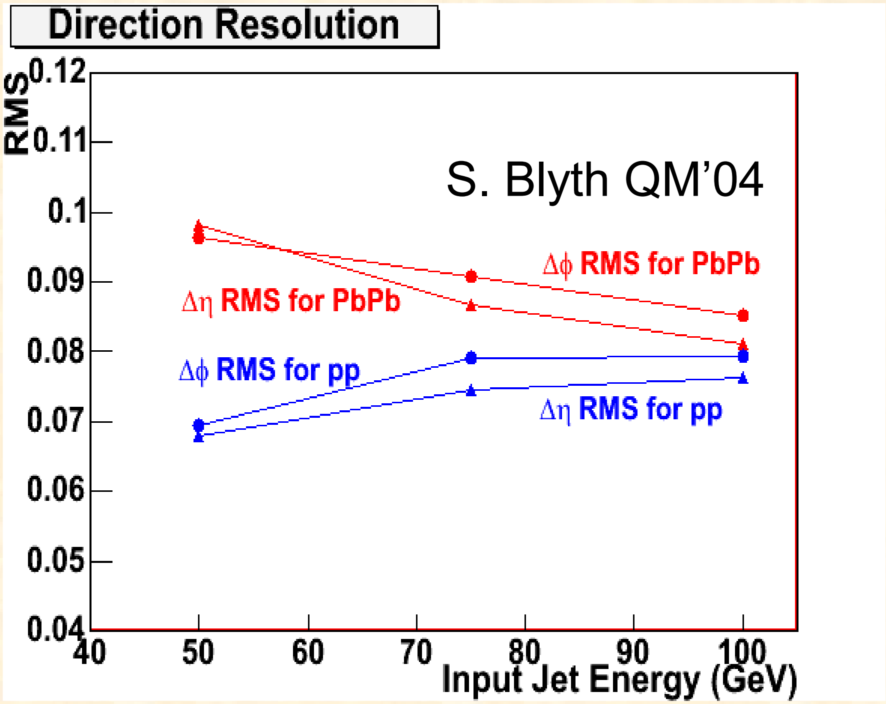
Improved jet-energy resolution

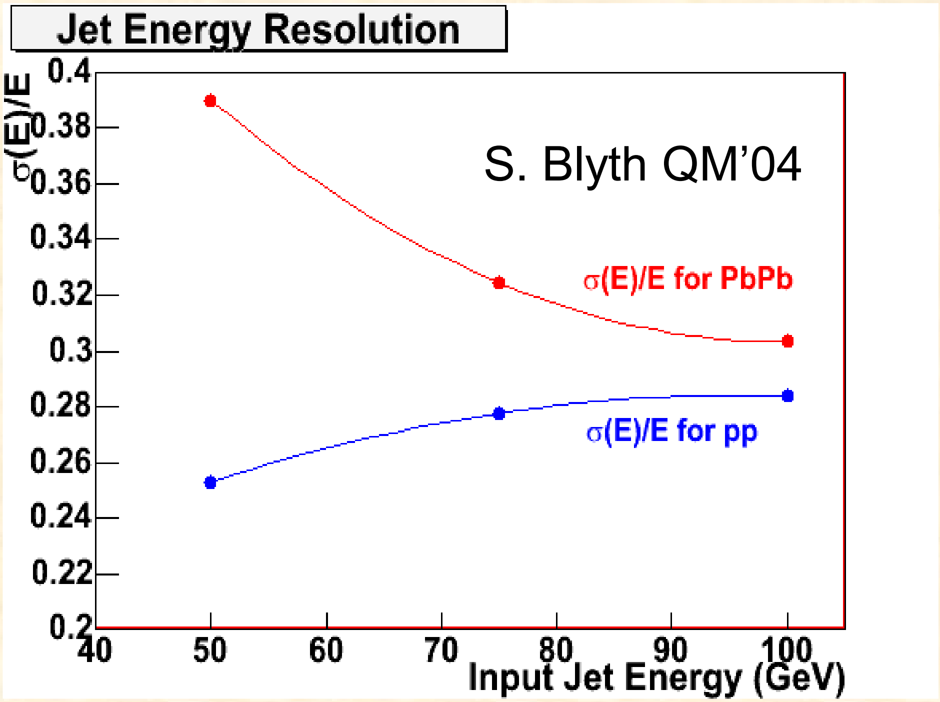
Trigger for high-energy jets

Larger acceptance for high-p_t γ

EMCAL
Directional and Energy Resolution

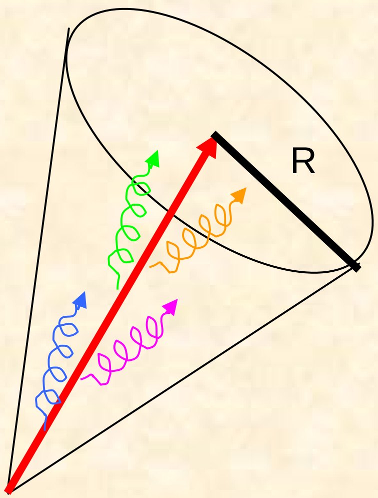
- Modified UA1 cone algorithm
- Uses combination of tracking and calorimeter information
- Cone Radius: *R* = 0.3, Seed 4.6 GeV, Minimum Jet energy 14 GeV
- Background HIJING PbPb *b* = 0-5 fm



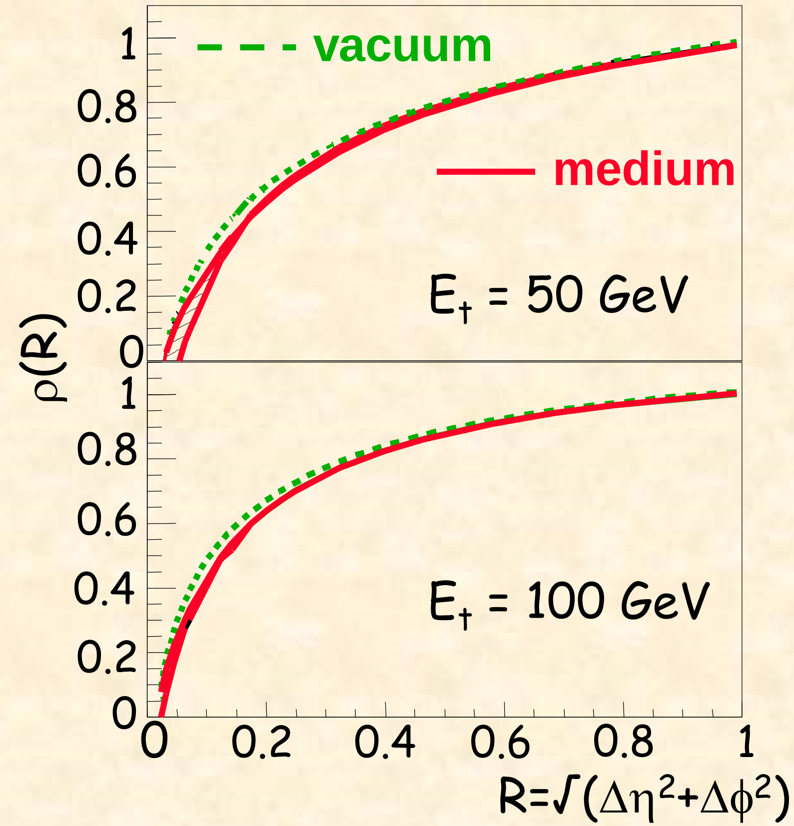


Jet quenching

- **Excellent jet reconstruction… but challenging to measure medium modification of its shape…**



Medium induced redistribution of jet energy occurs inside cone

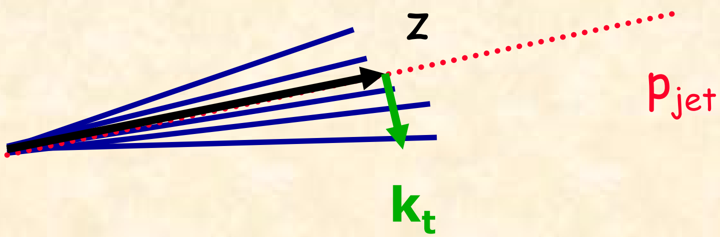


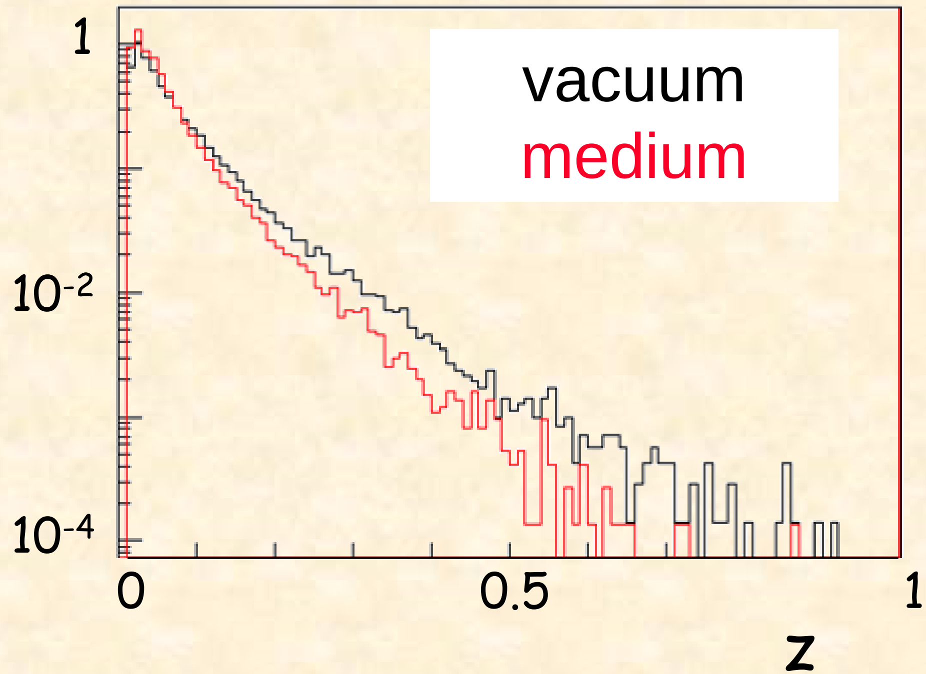
C.A. Salgado, U.A. Wiedemann hep-ph/0310079

- **E_t=100 GeV (reduced average jet energy fraction inside R):**
  - **Radiated energy ~20%**
  - **R=0.3 $\Delta E/E$=3%**
  - **E_t^{UE} ~ 100 GeV**

$z=p_t/p_{jet}$

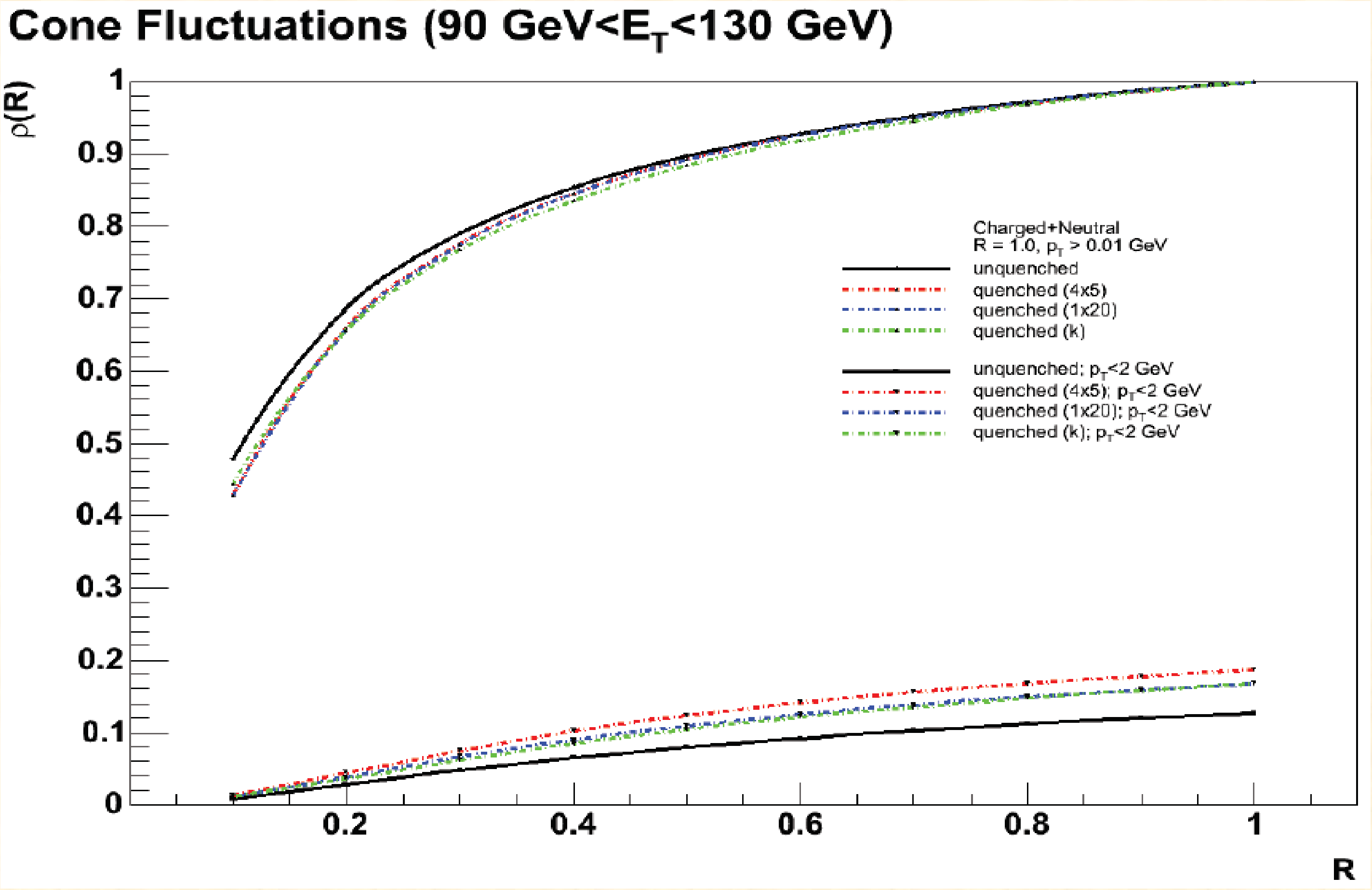
Fragmentation functions





Look also for transverse fragmentation function (k_t)

Fraction of energy inside cone
all particles – and low p_t



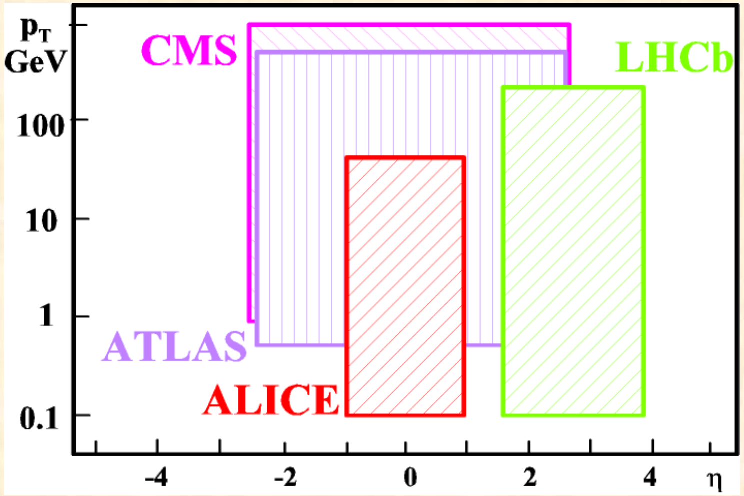
pp physics

- All of previously mentioned observables have to be measured also in pp collisions for comparison with heavy-ion results

- However, there are interesting questions regarding pp collisions themselves, for example
  - ⇨ charged multiplicity distribution
  - ⇨ correlations between mean p_t and multiplicity or strangeness
  - ⇨ study of diffractive events - with large rapidity gaps
  - ⇨ jet physics
  - ⇨ …

- ALICE advantages w.r.t. other pp detectors
  - ⇨ lower p_t cut-off
  - ⇨ particle identification

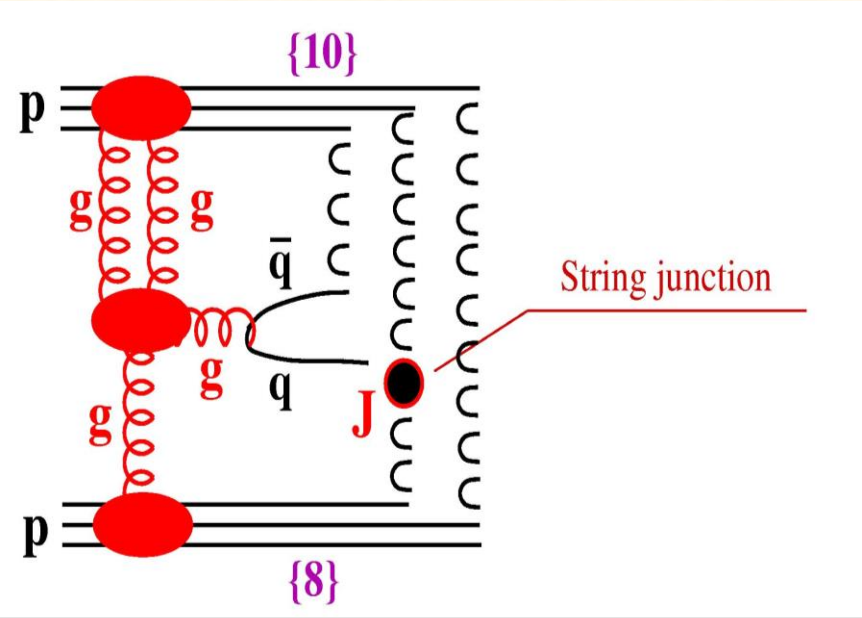
(see ALICE Note: P.Giubellino, K.S. et al.: Day One…)



Who carry baryon number

- **Standard point of view**
  - quarks have baryon charge 1/3
  - gluons have zero baryon charge
- **Baryon number is carried by quarks, not by gluons**

- **It is not obvious**
  - baryon number can be transferred by specific configuration of gluon field

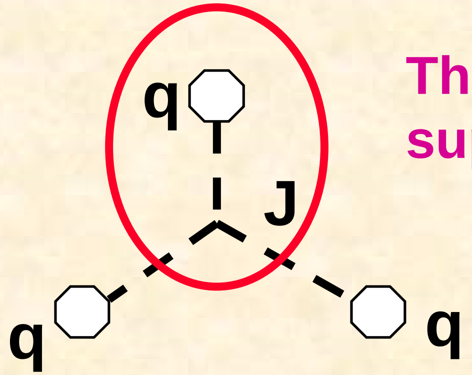


Exchange in t-channel

- **Exchange of spin 1/2 (quark)**

  $\propto \exp(-1/2\ \Delta y) \quad (\sim s^{-1/2})$

  ⇨ **strong damping with rapidity interval (i.e. for annihilation with energy)**

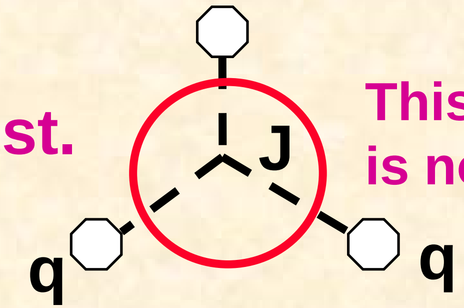


This exchanged is suppressed

- **Exchange of spin 1 (gluon)**

  $\propto$ const.

  ⇨ **no damping at all**

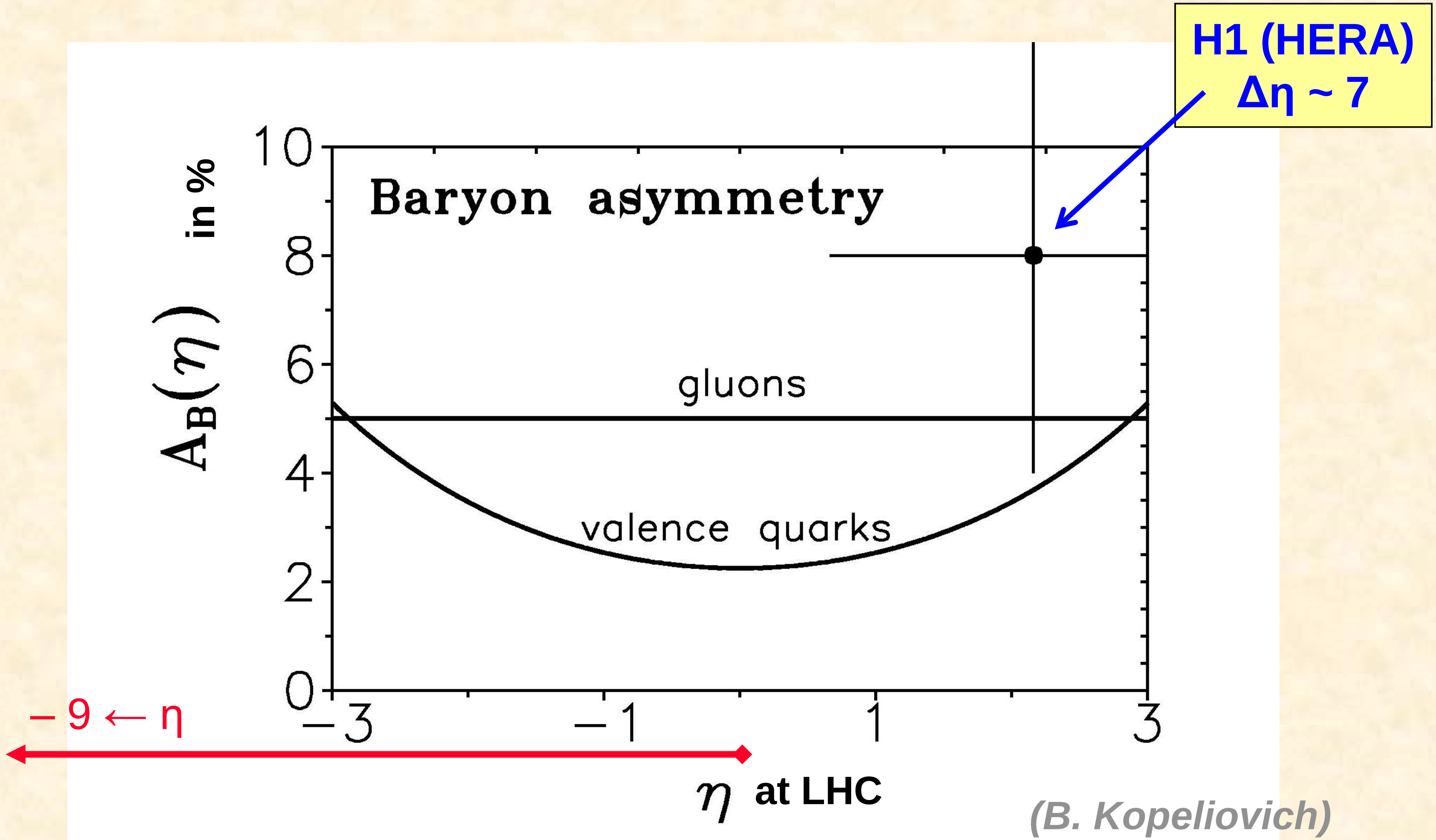


This exchange is not

- **Q: what is actually exchanged ?**

Central region at LHC

Asymmetry A_B = 2 * (B – anti-B) / (B + anti-B)



(B. Kopeliovich)

Statistics needed

- **For proton – antiproton one needs precision ~ 1%**
  - **the effect is about 7%, compare to 3 % in 'normal' case**
  - **using ALICE acceptance, efficiency etc. this needs few times 10^4 minimum bias pp events, i.e. something like first 100 sec of running**

- **Larger effect expected for strange particle, Lambda – anti-Lambda about 15%**
  - **for this few times 10^5 events will do**

- **For Omega – anti-Omega a huge effect is expected (under some assumptions even 100%)**
  - **100 Omegas would be enough for that – order of 10^7 events**
  - **a 'good day' of running will do it all**

ALICE is open for new ideas