Heavy Ion Collisions at the LHC

The Physics of ALICE

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University of Birmingham

Workshop on QCD in Nuclear and Hadronic Physics
3rd – 4th March 2005 - Daresbury

Outline of Talk

- Introduction to the physics of Quark Matter
  - Aims of Heavy Ion physics
  - The Quark-Gluon Plasma
- Quick Review of SPS Heavy-Ion Results
- Heavy Ion physics at the LHC
- ALICE physics potential
- Summary

Aim of Heavy Ion Physics

- **Study strongly interacting matter at extreme energy densities over large volumes and long time-scales. Study QCD on its natural scale (Λ_{QCD}).**

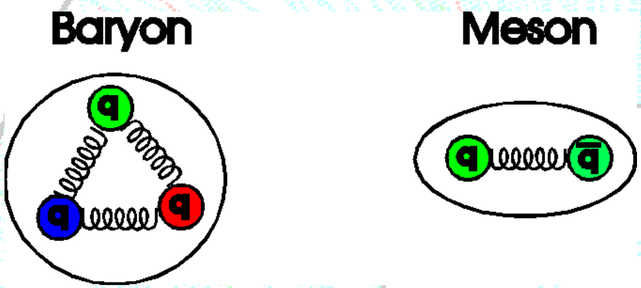
- **Study the QCD phase transition from hadronic matter to a deconfined state of quarks and gluons - The Quark-Gluon Plasma. Only phase transition predicted by the Standard Model within reach of laboratory experiments.**

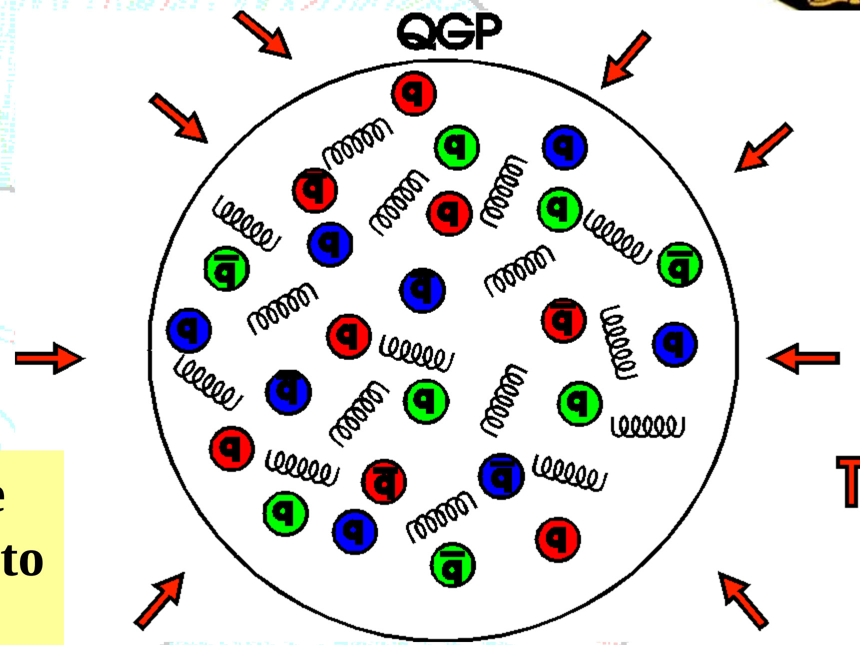
- **Study the physics of the Quark-Gluon Plasma.**

- **Study the role of chiral symmetry in the generation of mass in hadrons (accounts for 98% of mass of hadronic matter).**

The Quark-Gluon Plasma

Normal hadronic matter



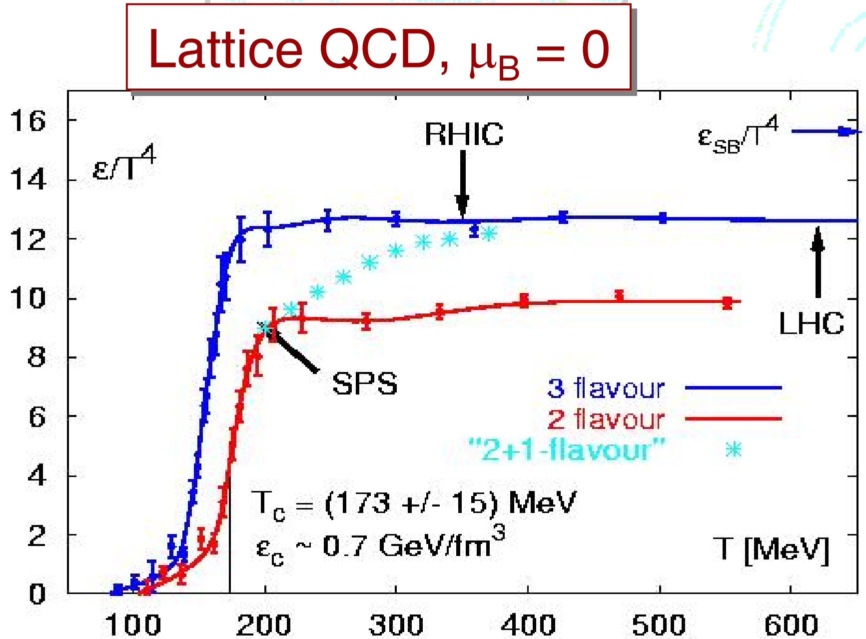


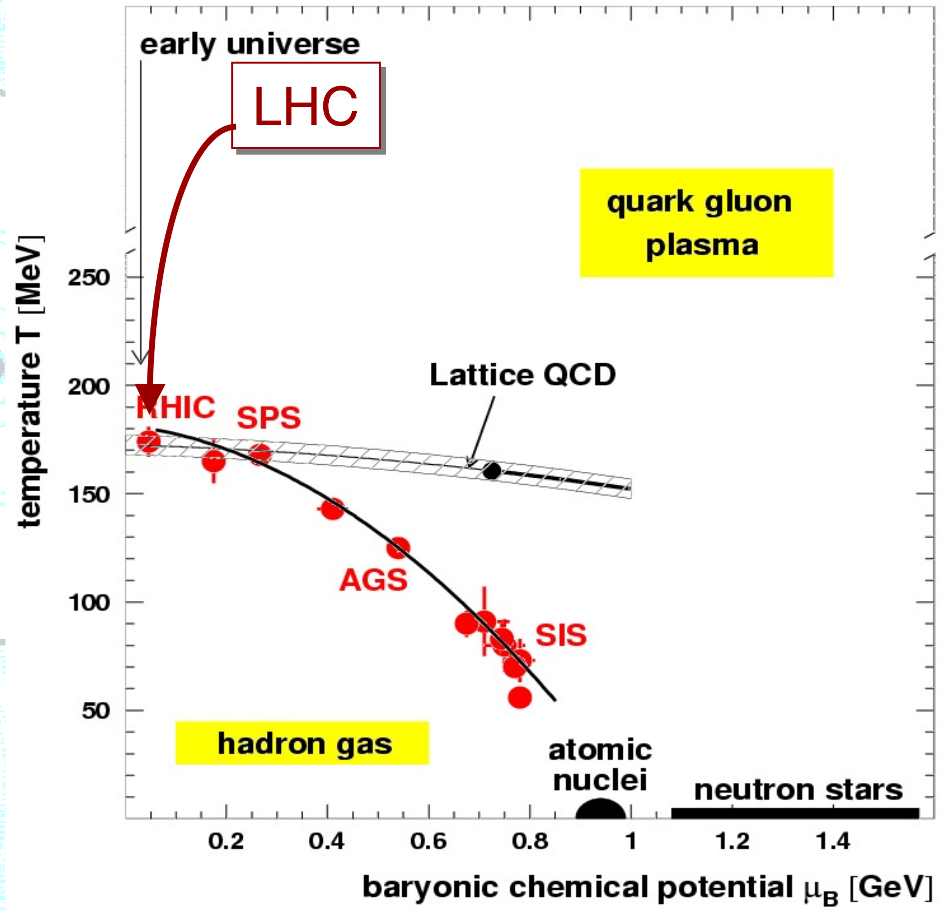
Under extreme conditions of temperature and/or density hadronic matter ‘melts’ into a plasma of free quarks and gluons.

❖ **Study of QCD and confinement under extreme conditions - test of non-perturbative QCD.**

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





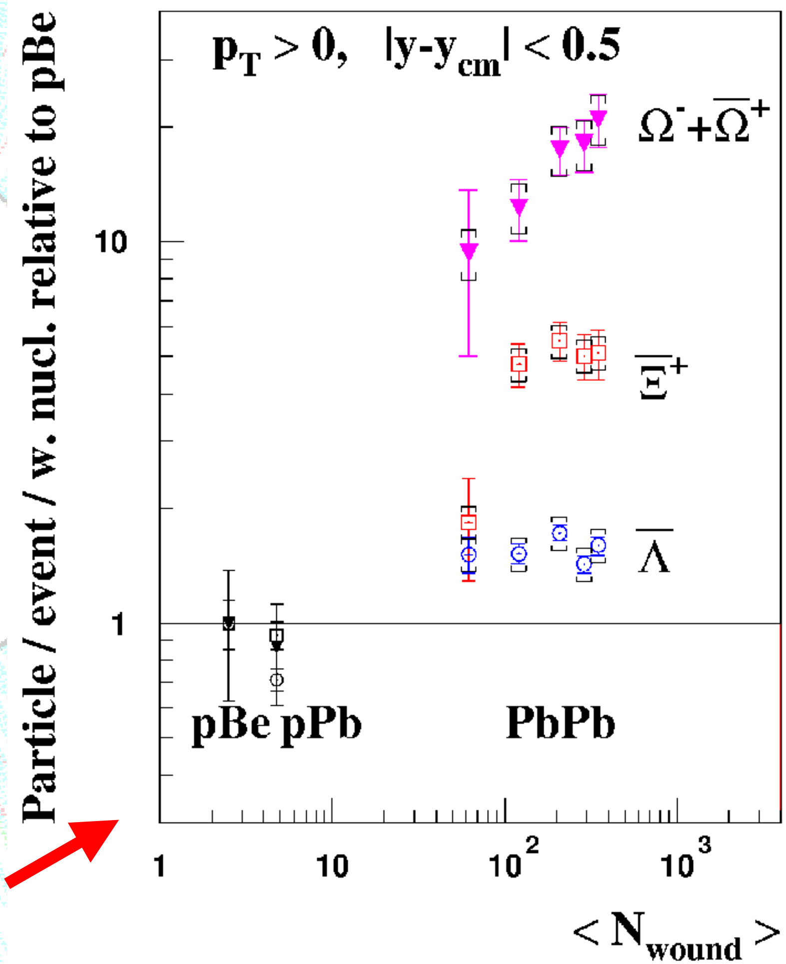
A Brief History

SPS heavy ion programme
- 1986 with Oxygen ions
- 1987 - 1993 Sulphur ions
- 1994 - 2000 Lead ions

Whole family of SPS experiments studying different observables (strangeness, J/ψ, photons, di-leptons ...

Feb 2000: CERN announces that deconfined Quark Matter observed.

Strangeness enhancement from NA57



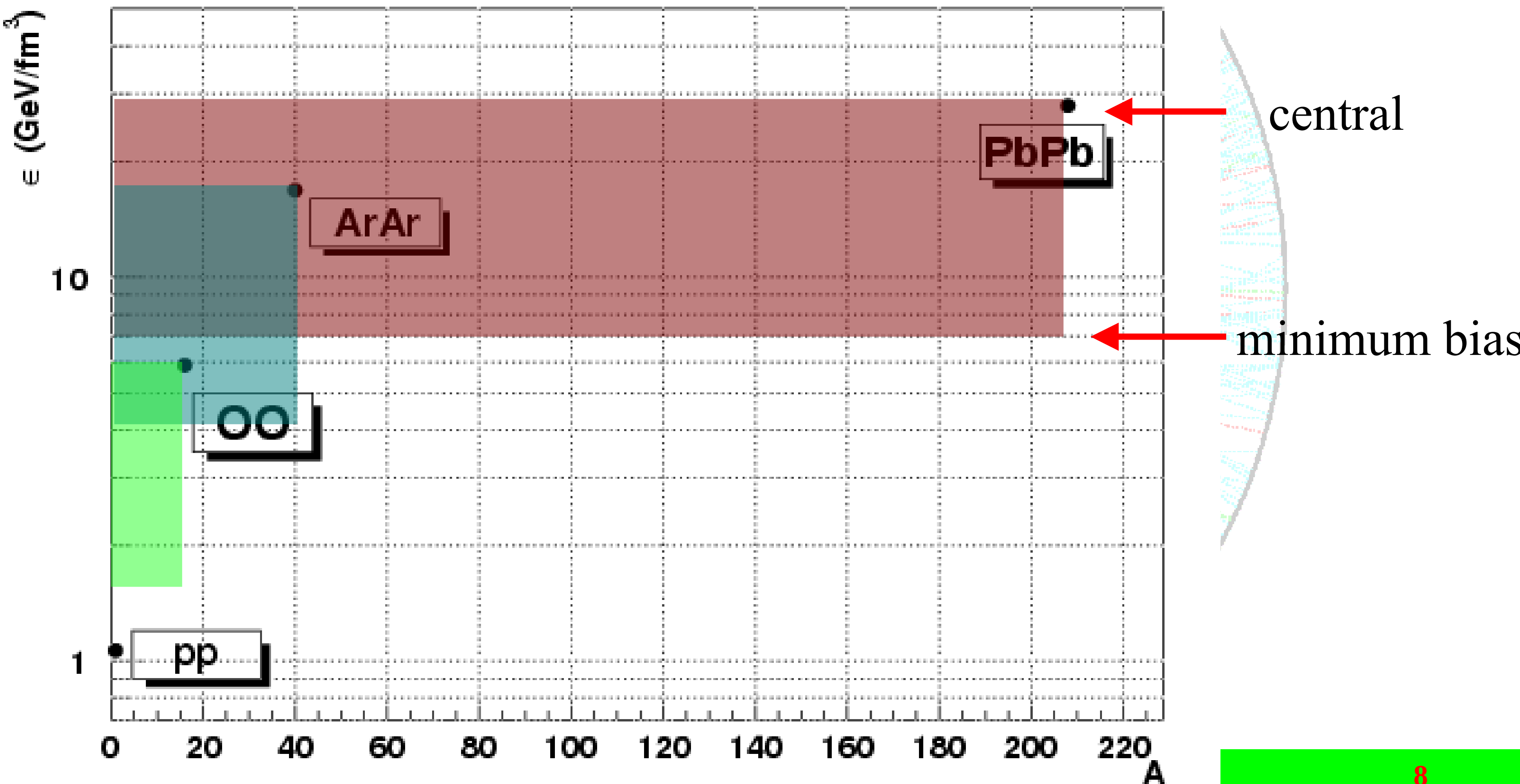
Why Heavy Ions @ LHC ?

factor 30 jump in $\sqrt{s}$

hotter - bigger -longer lived

Central collisions	SPS	RHIC	LHC
$s^{1/2}$(GeV)	17	200	5500
dN_{ch}/dy	500	650	3-8 $\times 10^3$
ε (GeV/fm^3)	2.5	3-5	15-40
V_f(fm^3)	10^3	7×10^3	2×10^4
τ_{QGP} (fm/c)	<1	1.5-4.0	4-10
τ_0 (fm/c)	~1	~0.5	<0.2

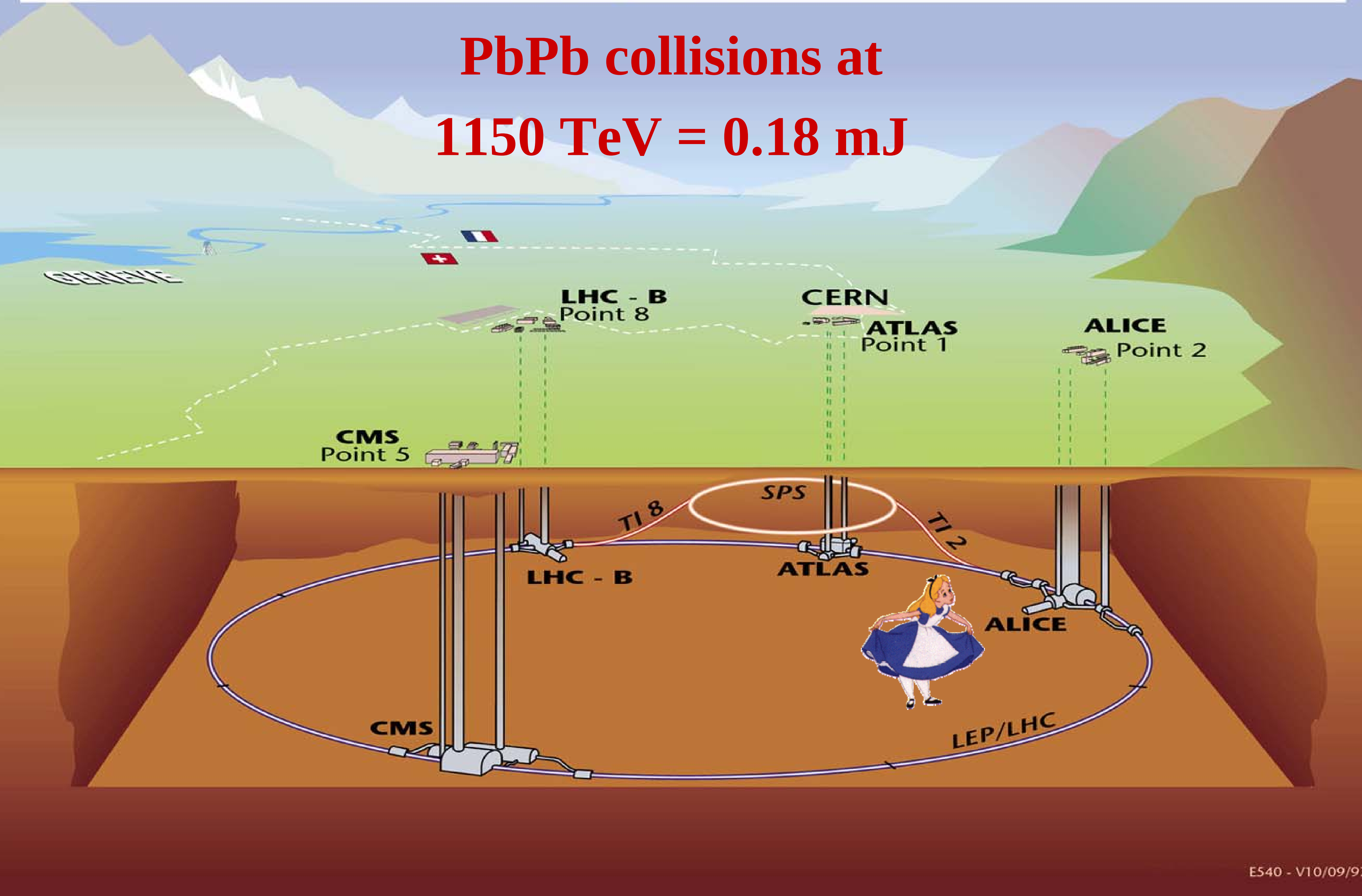
Use different Ion species to vary the energy density



Overall view of the LHC experiments.

PbPb collisions at

1150 TeV = 0.18 mJ



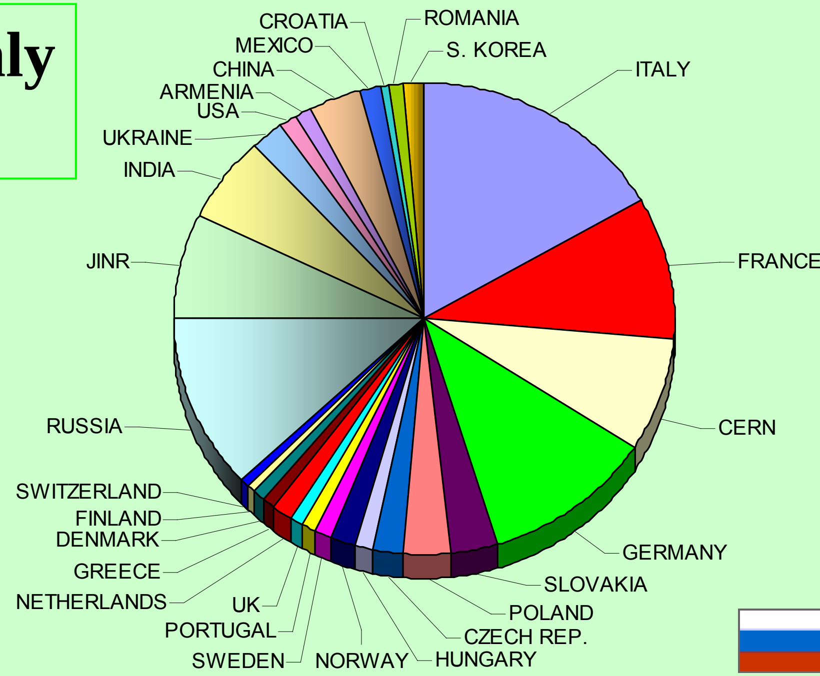
ALICE Collaboration

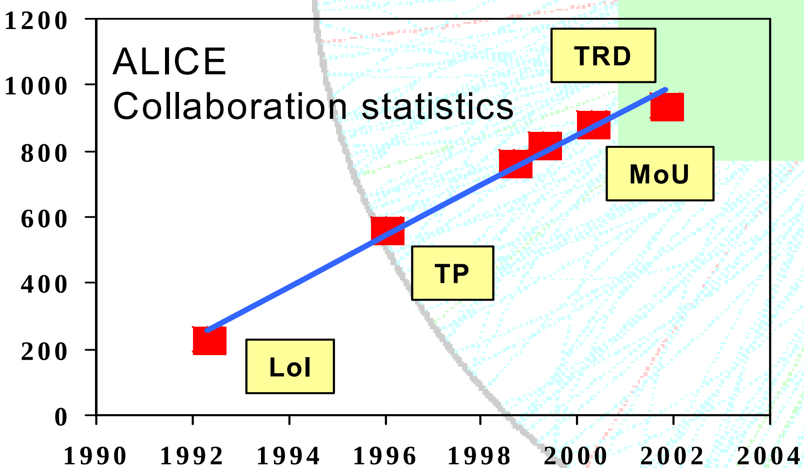
Birmingham is only UK institute

~1000 Members

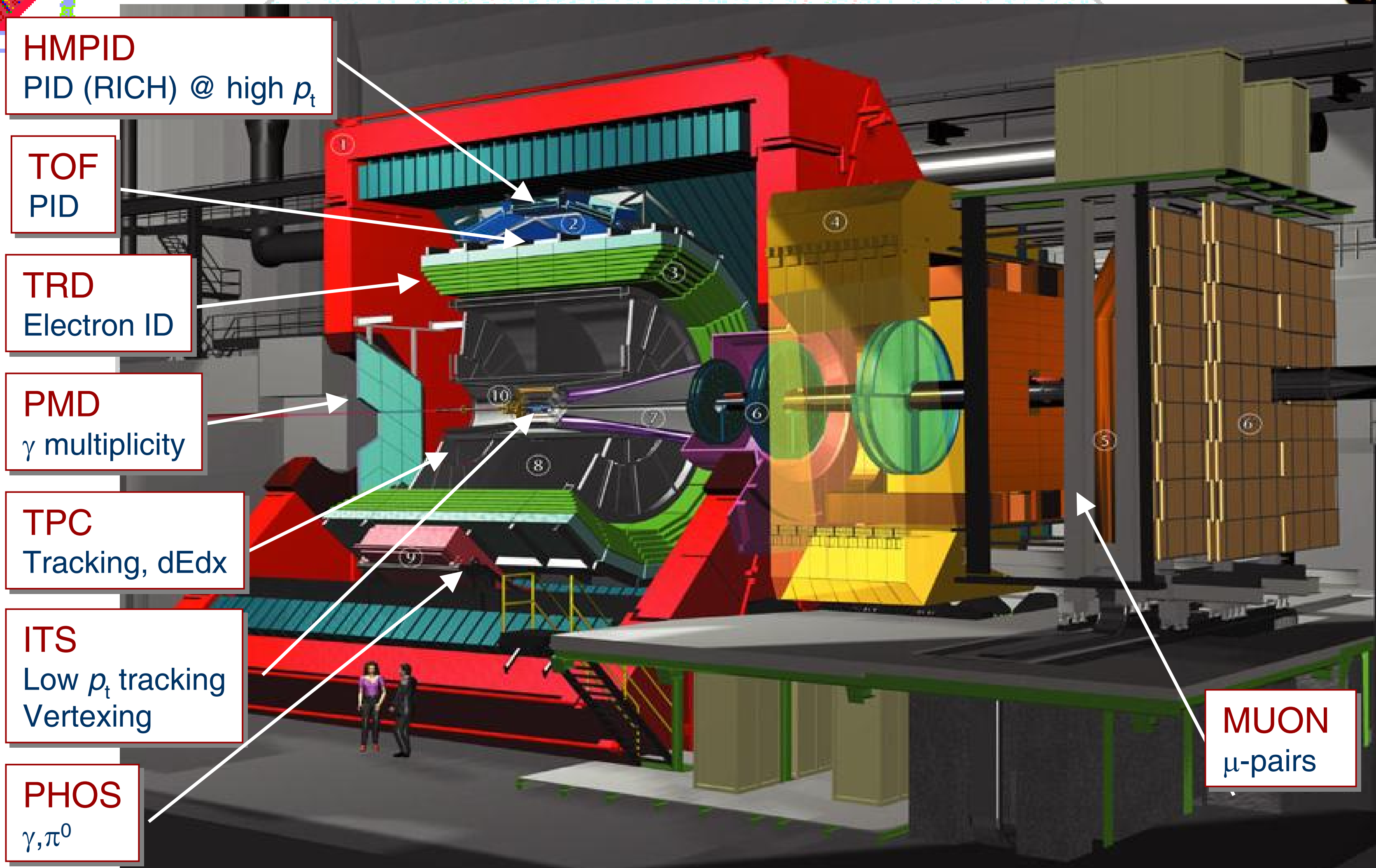
80 Institutes

30 Countries



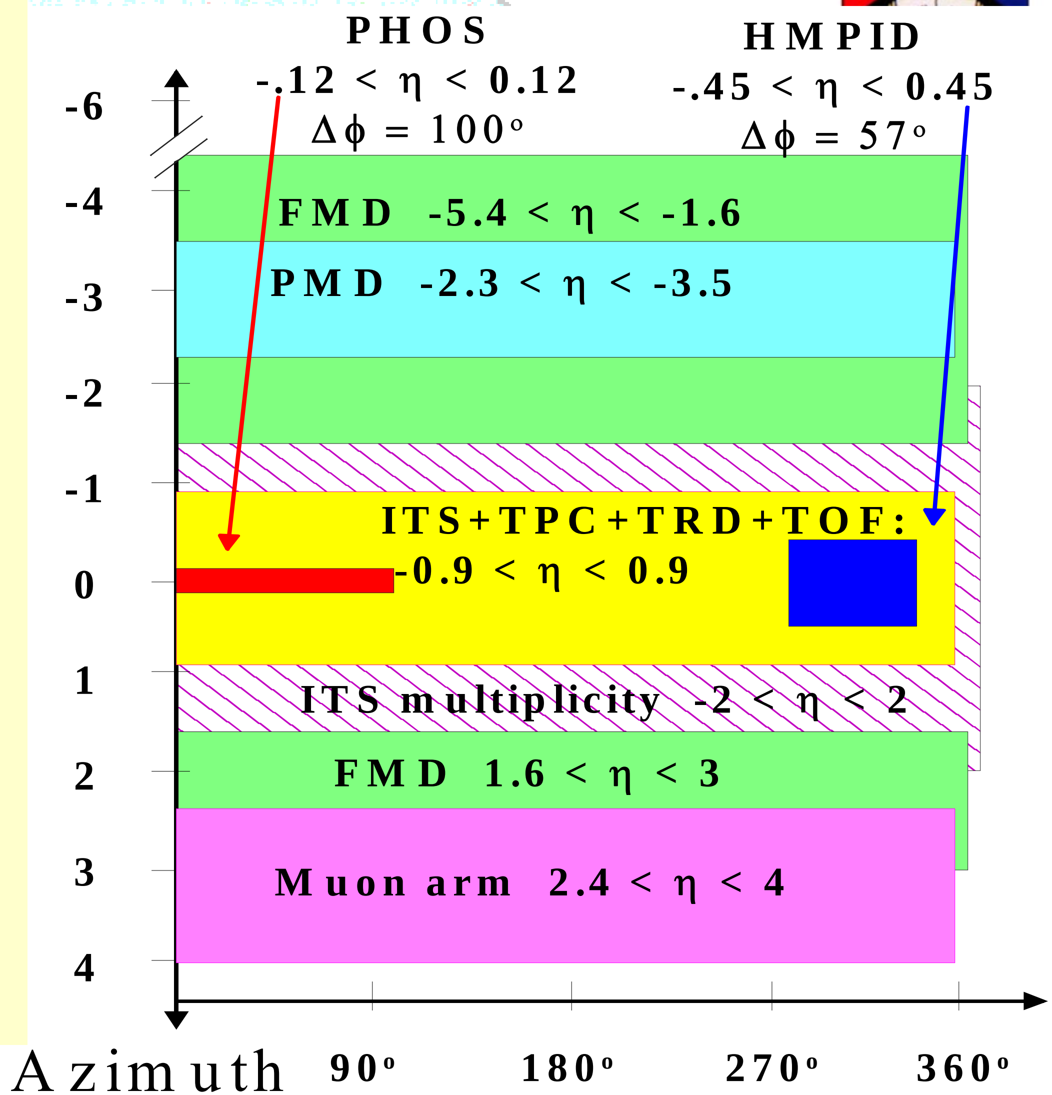


The ALICE Experiment



ALICE Acceptance

- **central barrel** -0.9 < η < 0.9
  - tracking, PID
  - single arm **RICH** (HMPID)
  - single arm **em. calo** (PHOS)
- **forward muon arm** 2.4 < η < 4
  - absorber, dipole magnet
    tracking & trigger chambers
- **multiplicity** -5.4 < η < 3
  - including photon counting in **PMD**
- **trigger & timing dets**
  - **Zero Degree Calorimeters**
  - **T0:** ring of quartz window PMT's
  - **V0:** ring of scint. Paddles

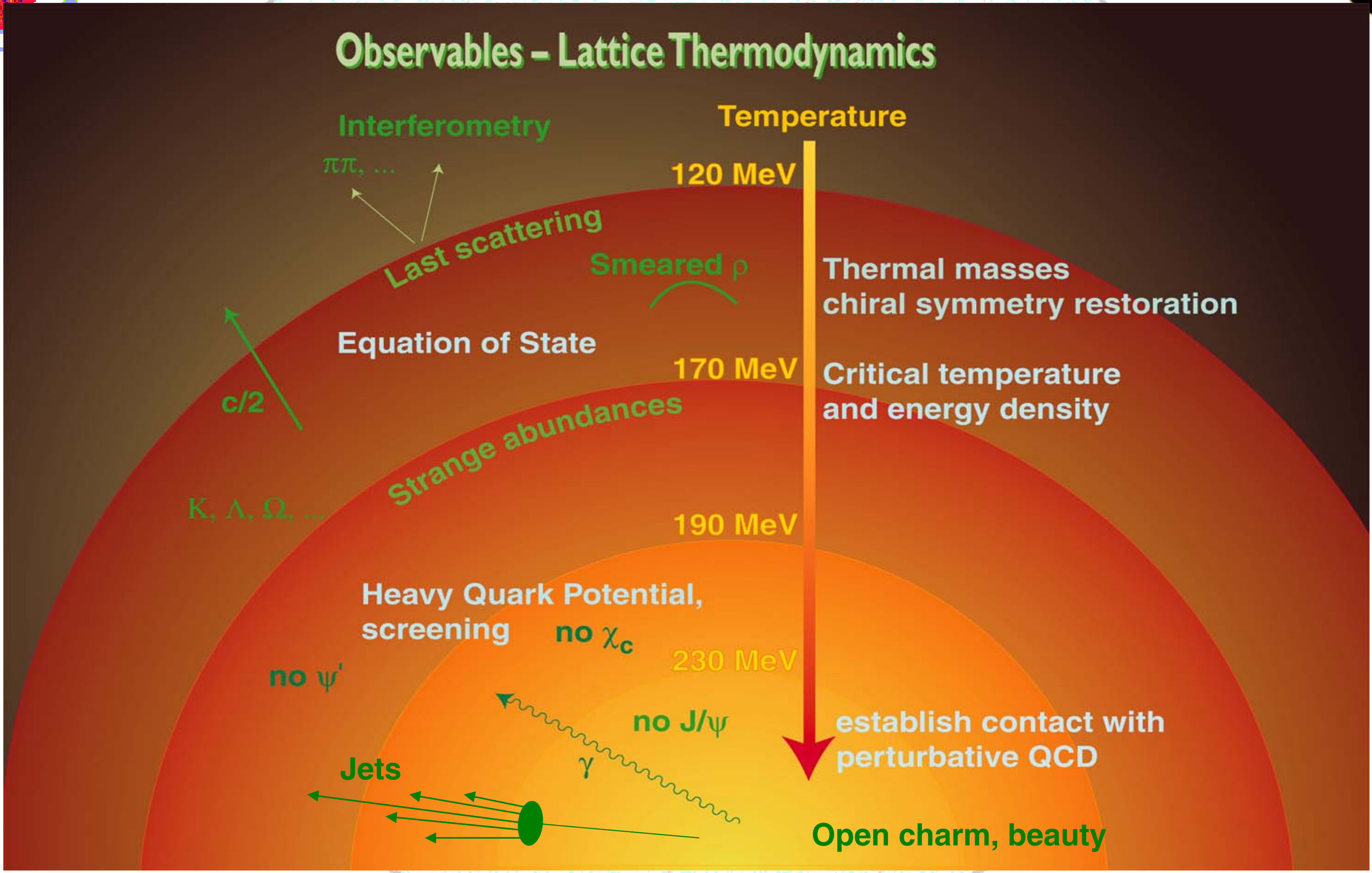


Experimental conditions @ LHC

- pp commissioning starts April 2007
- Wish list of the HI community for the LHC
  - Initial few years **(1HI 'year' = 10^7)**
    - **2 - 3 years Pb-Pb** — **L ~ 10^{27} cm^{-2}s^{-1}**
    - **1 year p - Pb 'like'** (**p**, d or α) — **L ~ 10^{29} cm^{-2}s^{-1}**
    - **1 year light ions** (eg Ar-Ar) — **L ~ few 10^{27} to 10^{29} cm^{-2}s^{-1}**

      plus, for ALICE (limited by pileup in TPC):
    - **reg. pp** run at $\sqrt{s}$ = 14 TeV — **L ~ 10^{29} and < 3×10^{30} cm^{-2}s^{-1}**
  - Later: different options depending on Physics results
- **Heavy Ion running part of LHC initial programme, 1 month of heavy ion running per year.**

Observables



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 soft and hard probes only possible within ALICE

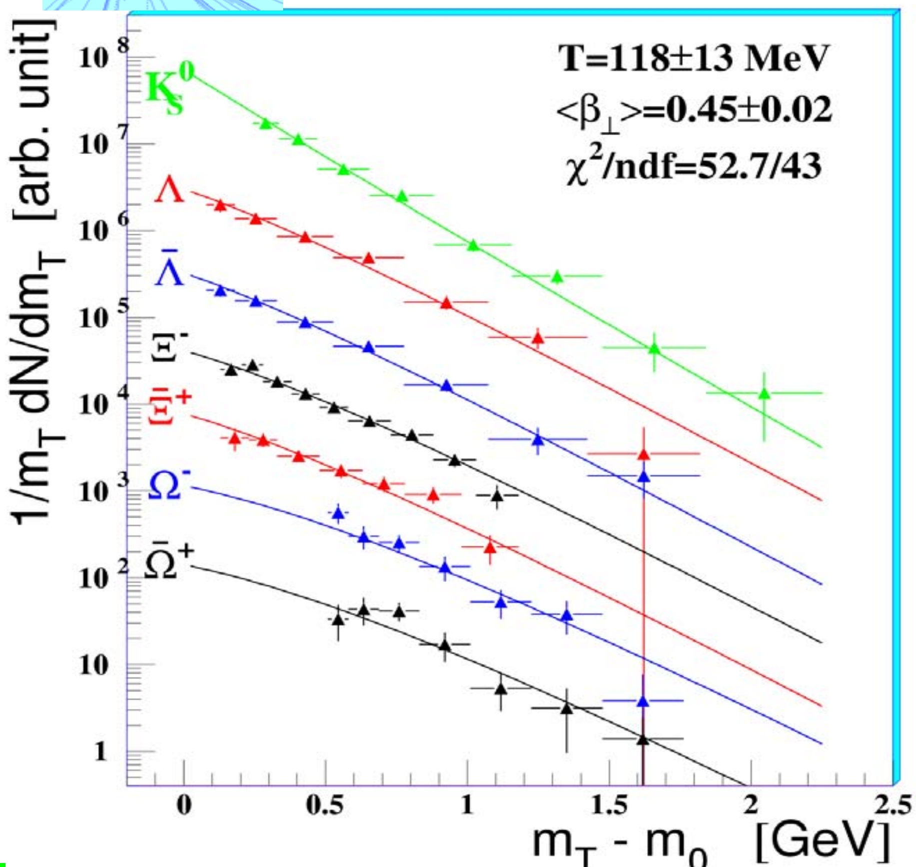
Transverse mass spectra

$$\frac{d^2 N_j}{m_T\, dy\, dm_T} = \int_0^{R_G} A_j m_T \cdot K_1\left(\frac{m_t \cosh \rho}{T}\right) \cdot I_0\left(\frac{p_t \sinh \rho}{T}\right) r dr$$

NA57

$$\rho(r) = \tanh^{-1} \beta_\perp(r)$$

$$\beta_\perp(r) = \beta_S \left[\frac{r}{R_G}\right]^n \quad r \le R_G$$



NA57 Pb-Pb at √s=17GeV

Transverse mass spectra

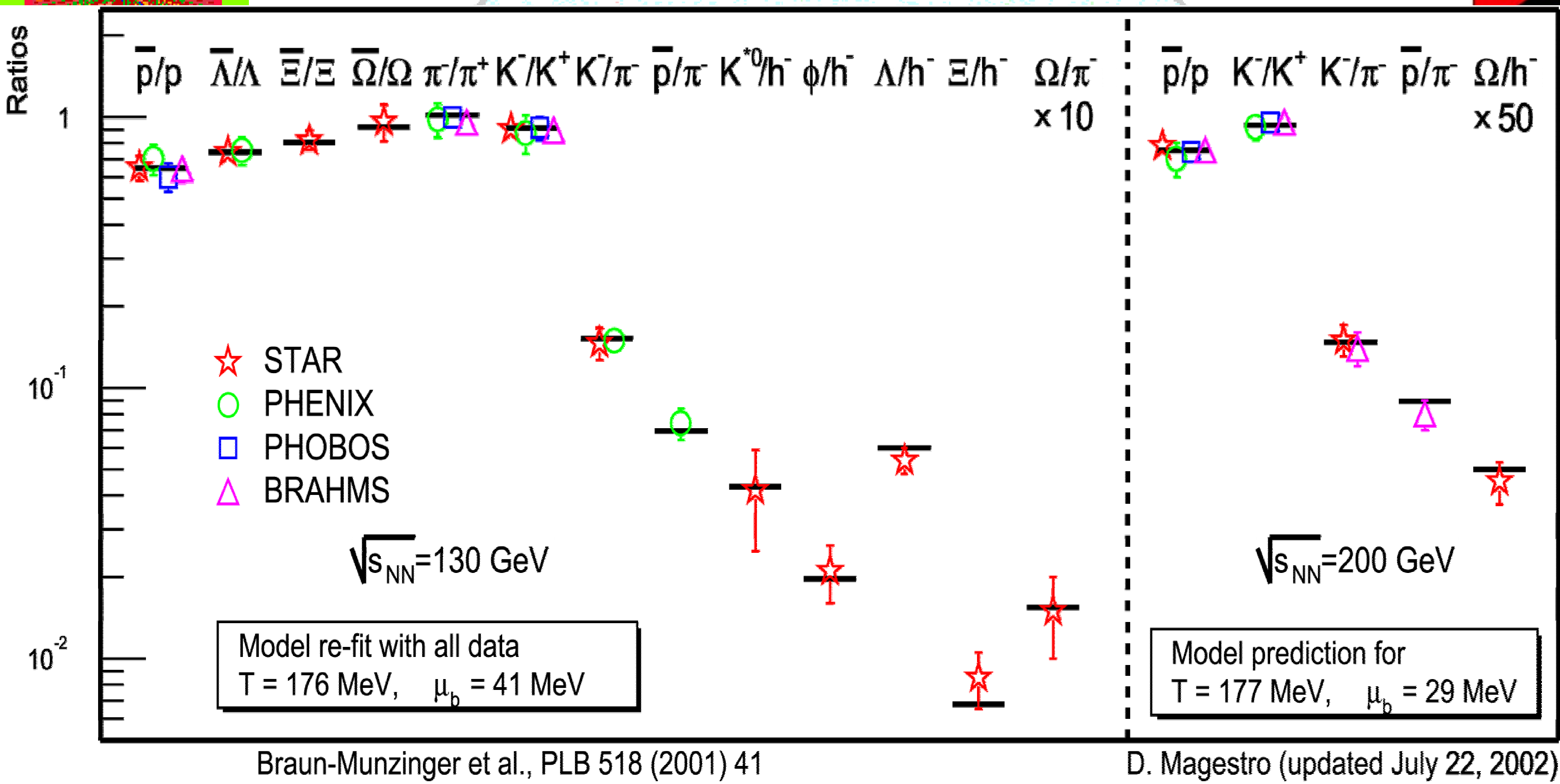
⇓

Freeze out temperature

Transverse flow

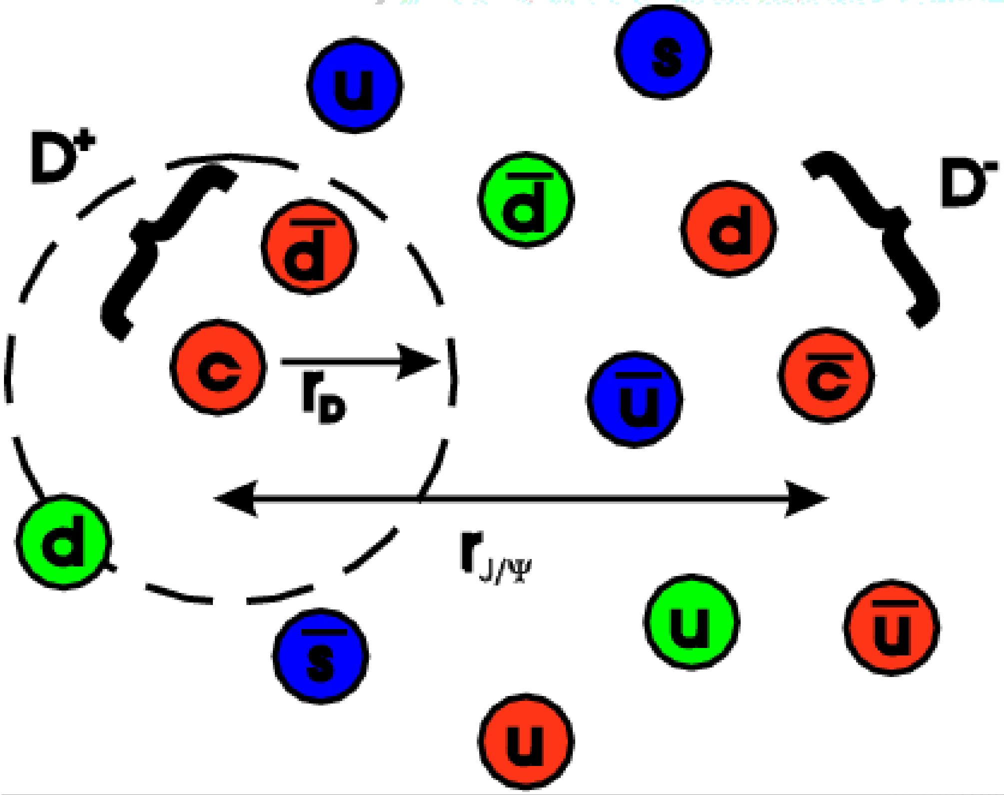
5% most central events

Hadron Ratios



Degree of chemical equlibrium:⇒ Constraint on timescales of flavour production mechanism

J/ψ Suppression



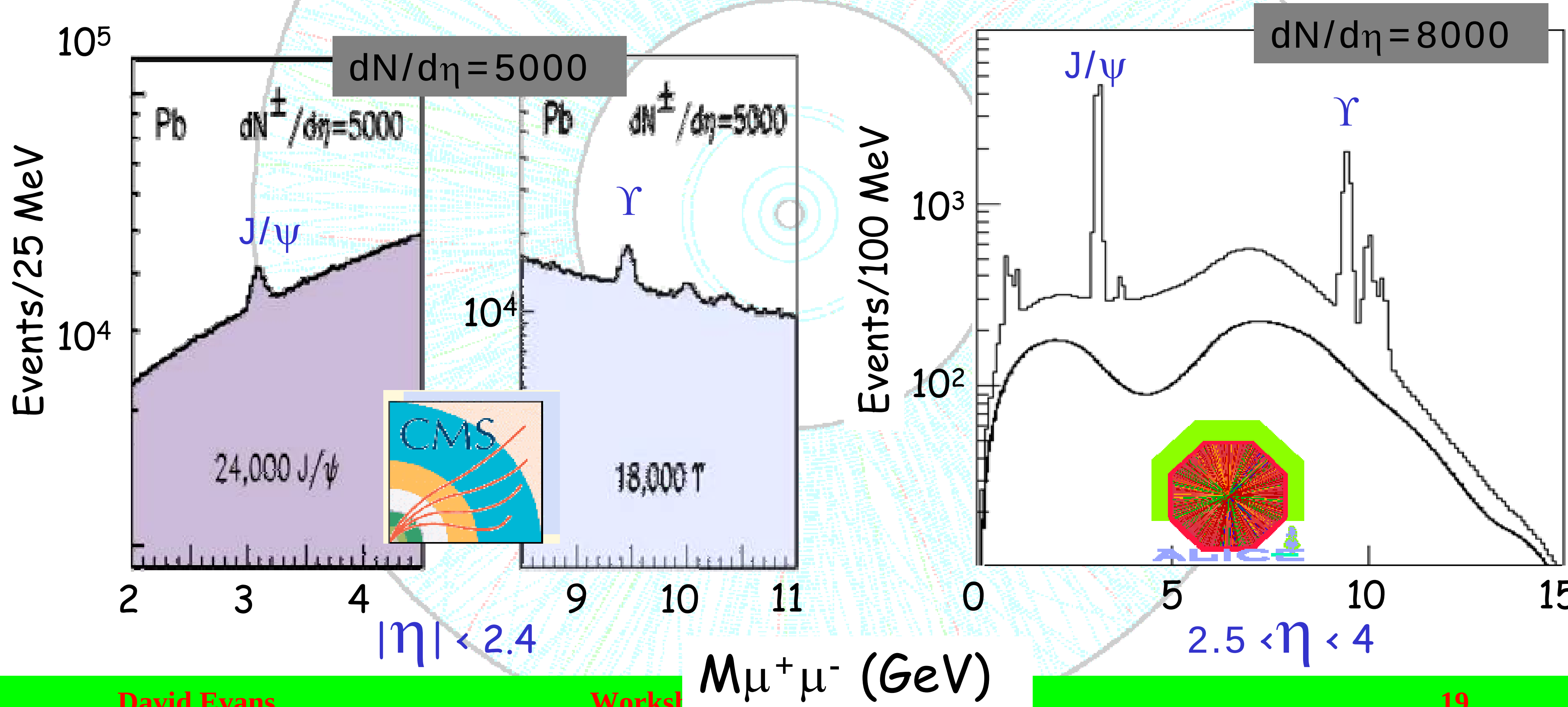
Colour screening in QGP:
Screening radius < size of J/ψ (~0.5 fm)
So $c\bar{c}$ bound state cannot survive in QGP.
Seen at SPS energies

At LHC energies, colour screening could be strong enough to break-up ϒ ($b\bar{b}$) or maybe just ϒ' or ϒ''.

c/b Quarkonia

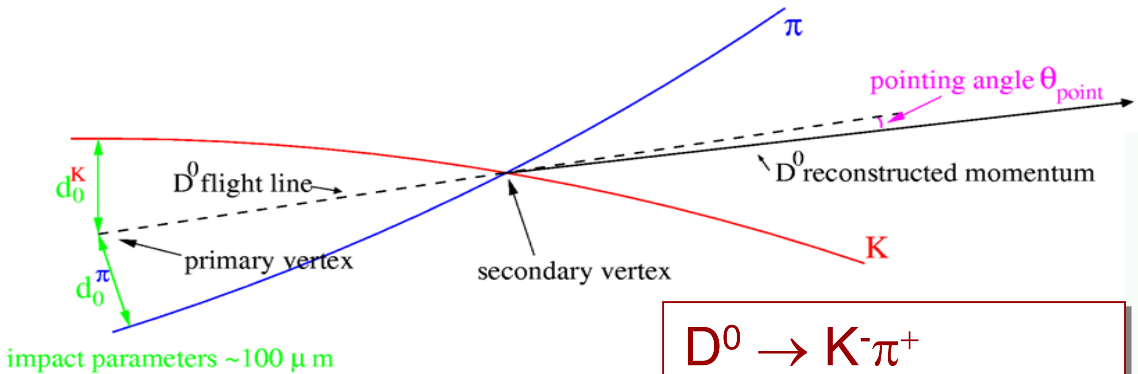
via dimuons

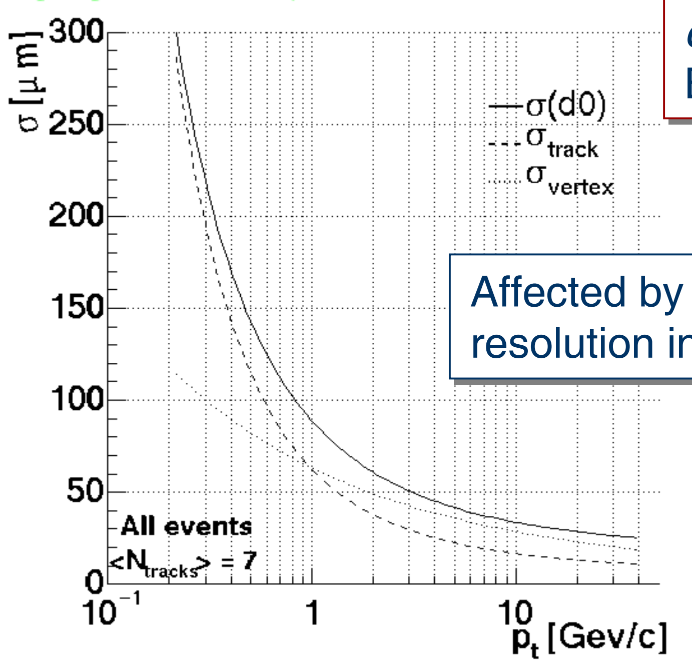
- 1 month statistics of PbPb $\sqrt{s_{NN}}$=5.5 TeV;



Heavy Quarks

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





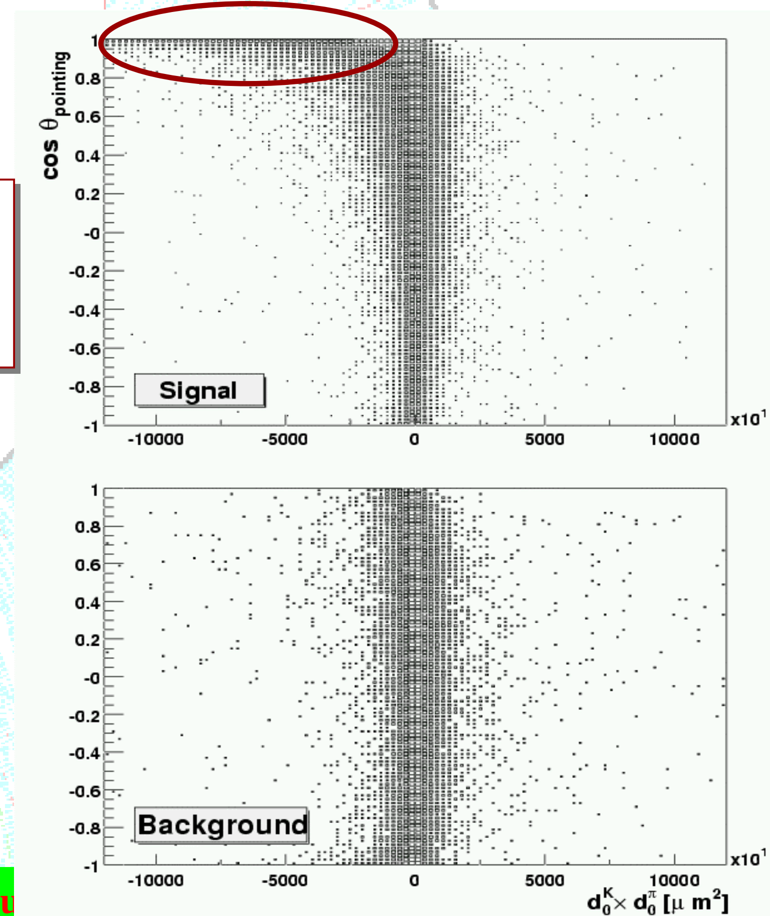
$D^0 \rightarrow K^-\pi^+$

$c\tau = 123.7 \pm 0.8$ μm

BR: (3.83 ± 0.09) %

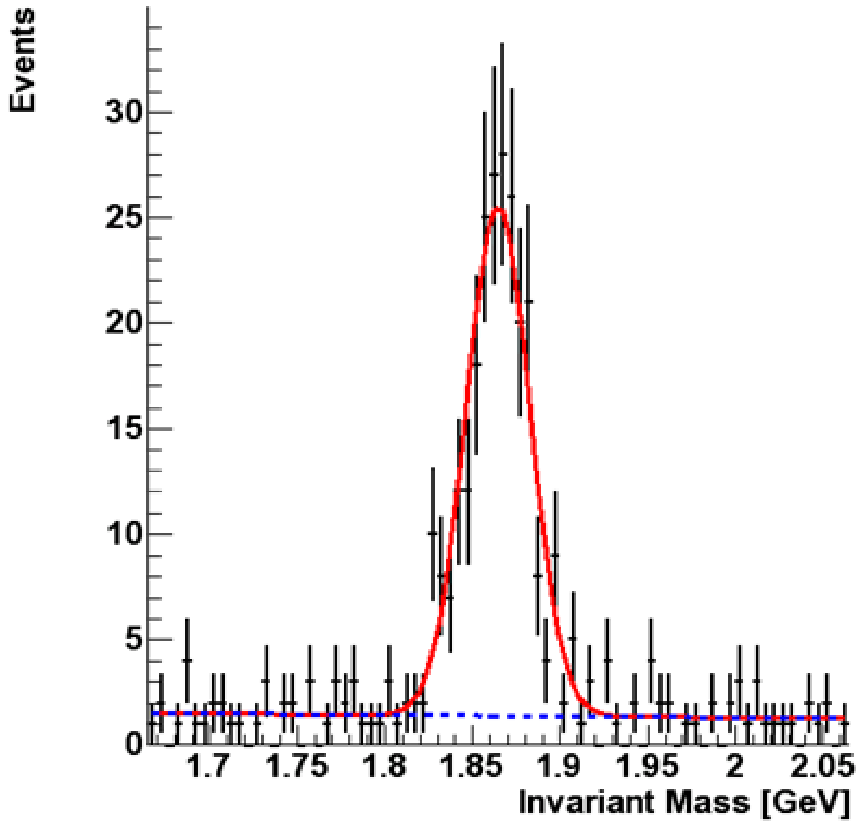
Affected by main vertex resolution in p+p case

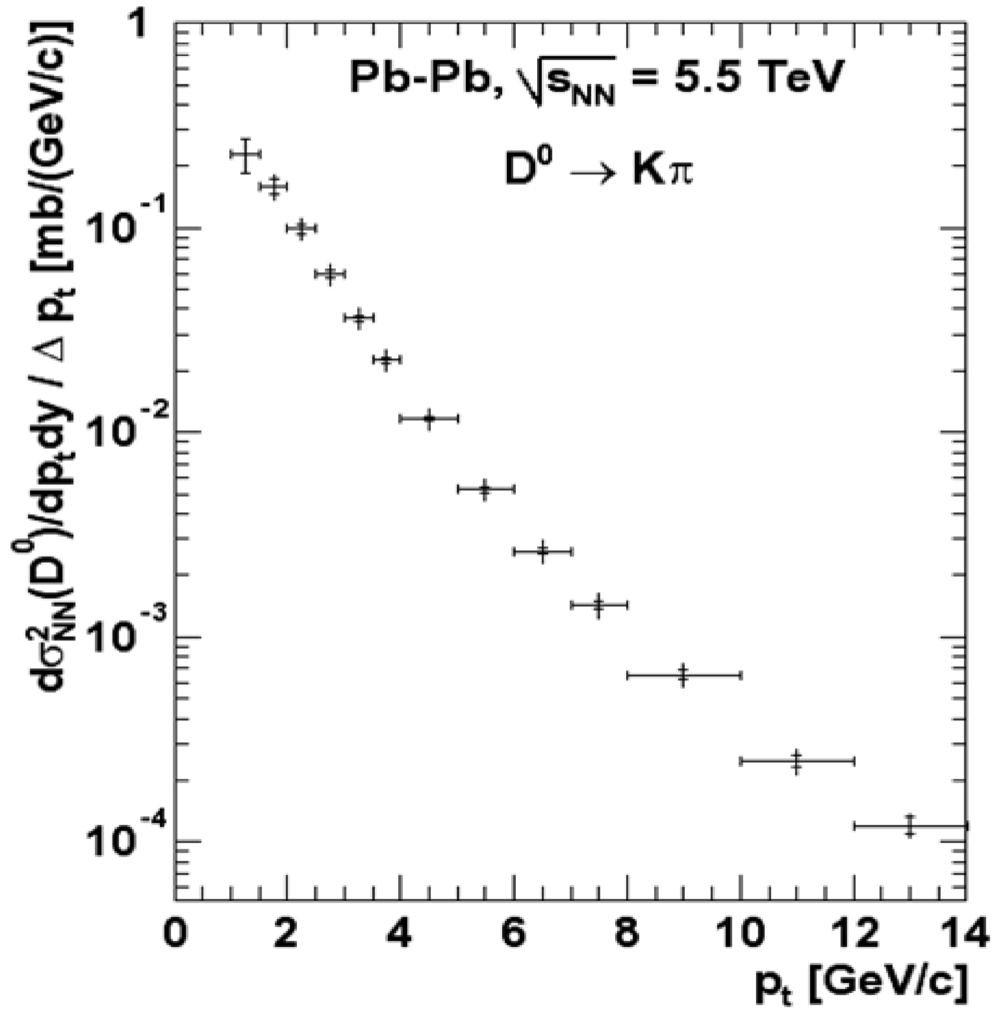
cuts depend on D^0 p_t



Heavy Quarks

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



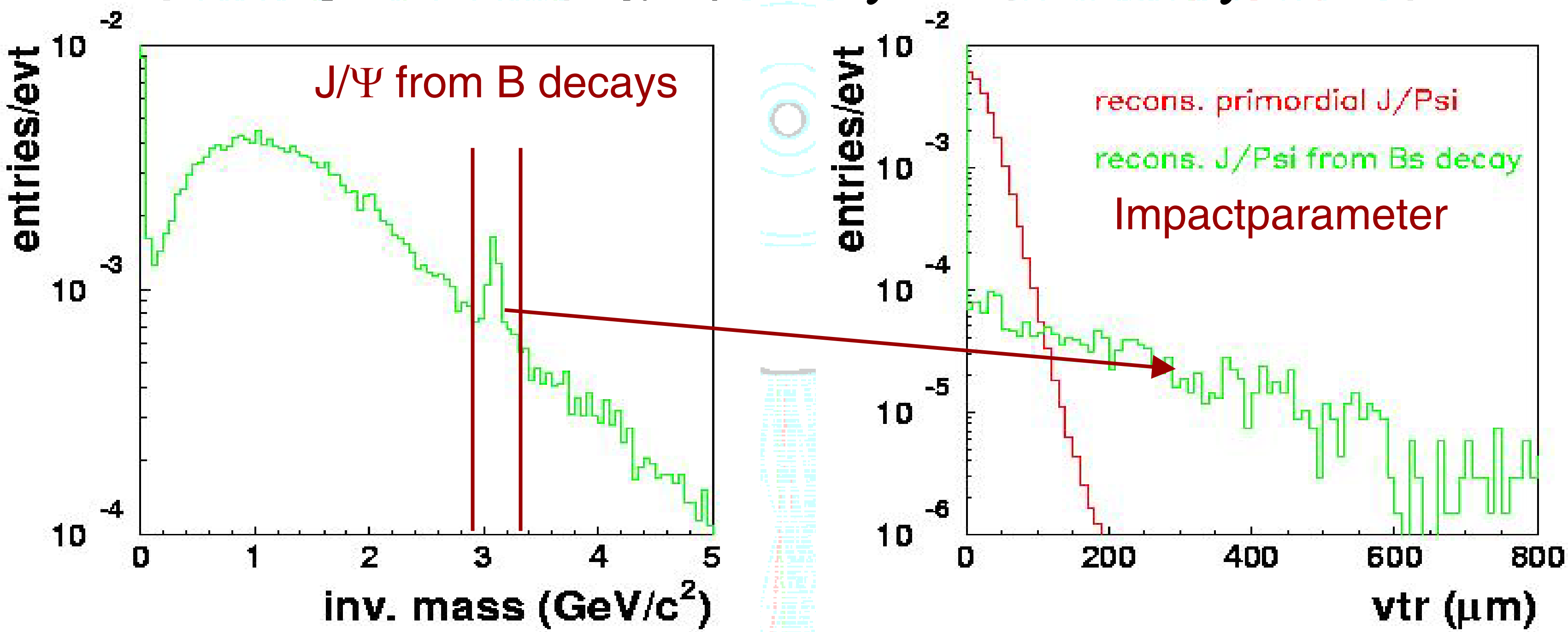


PbPb: p_T>1 GeV/c

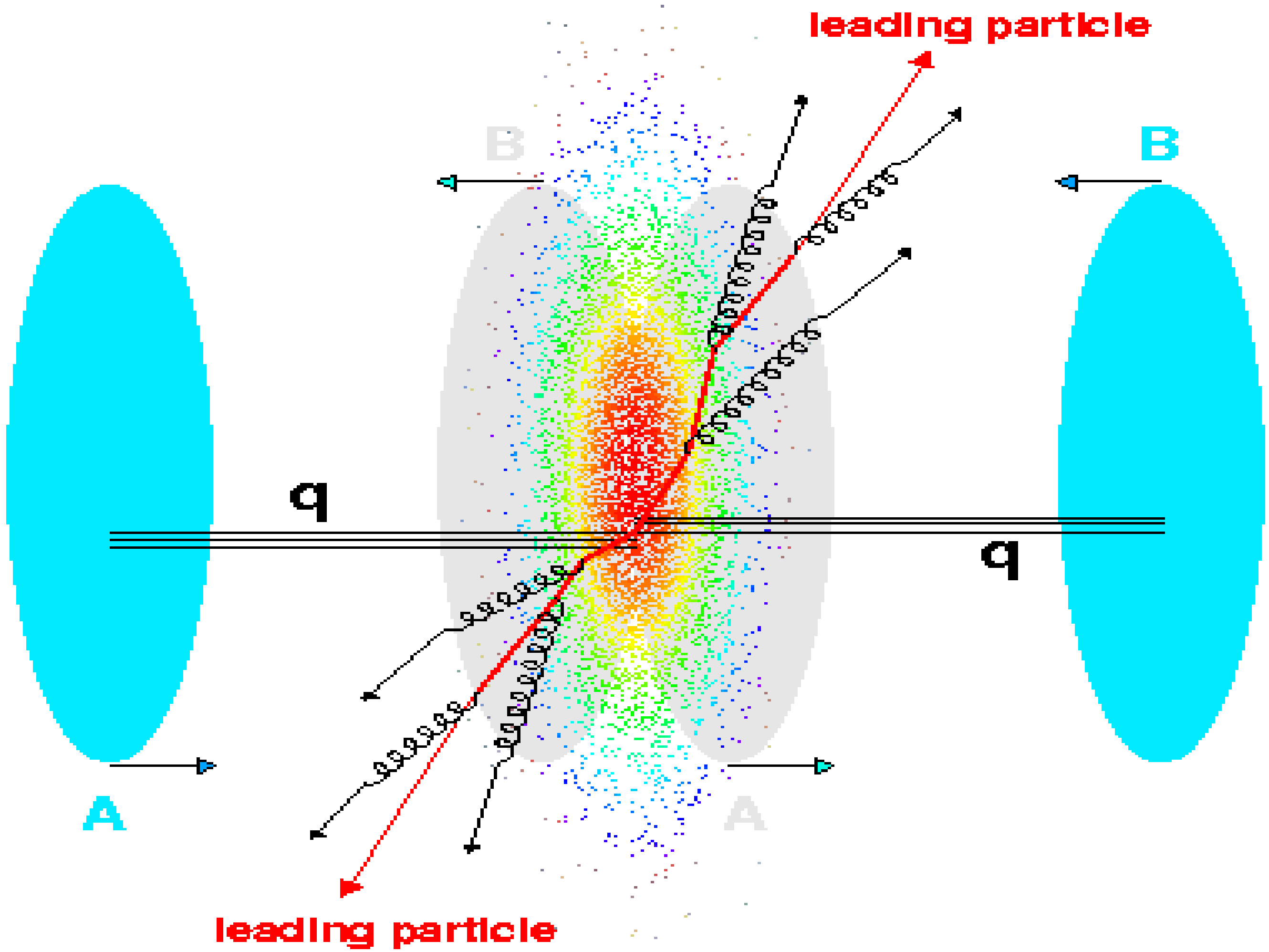
pp: p_T>0 GeV/c

Secondary J/Ψ from B Meson Decays

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



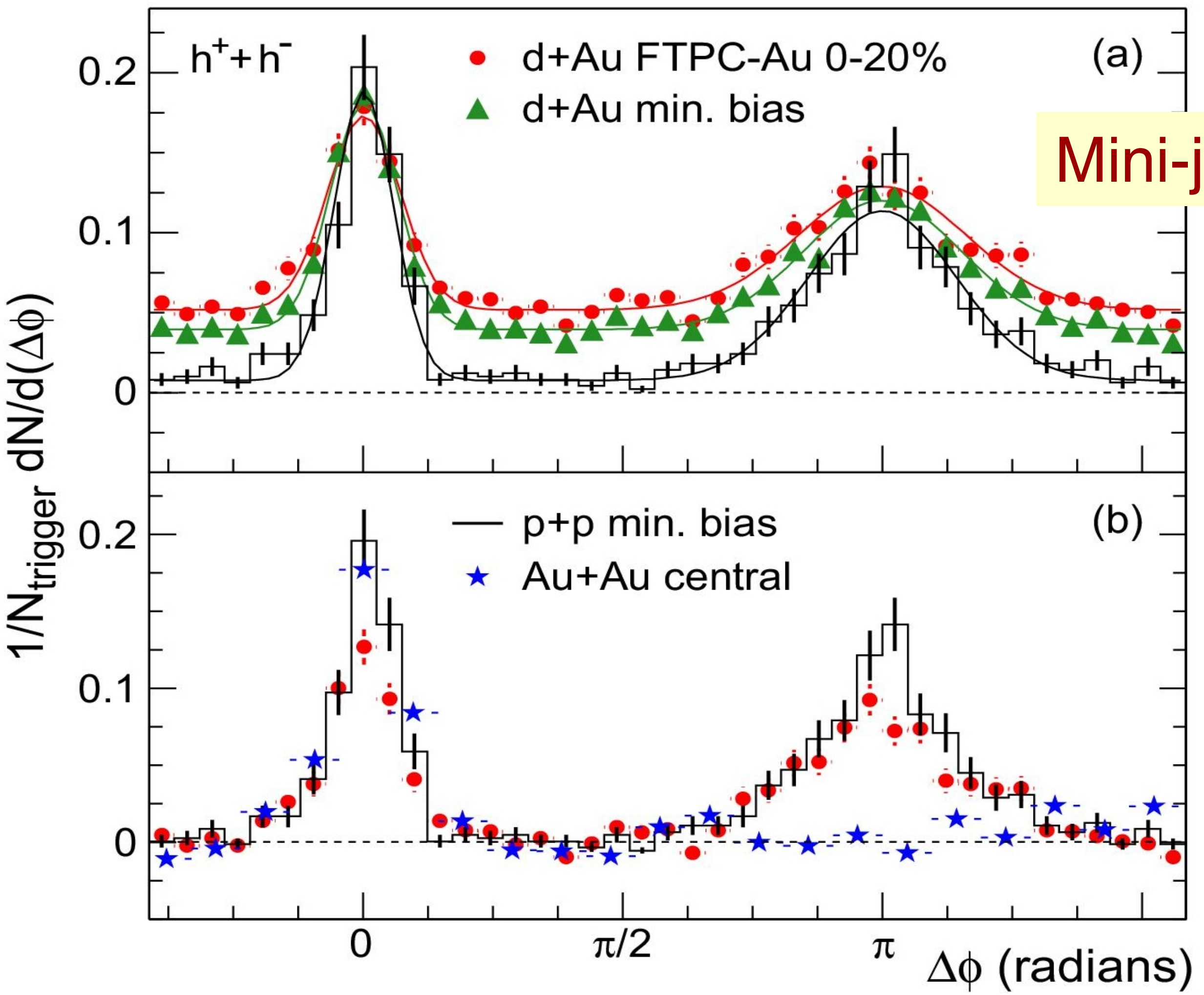
Parton Energy Loss



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 (p, K, p, L, 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 → reduction of jet energy, dijets, g-jet pairs
- **p+p and p+A measurements crucial**

Jets in Pb+Pb

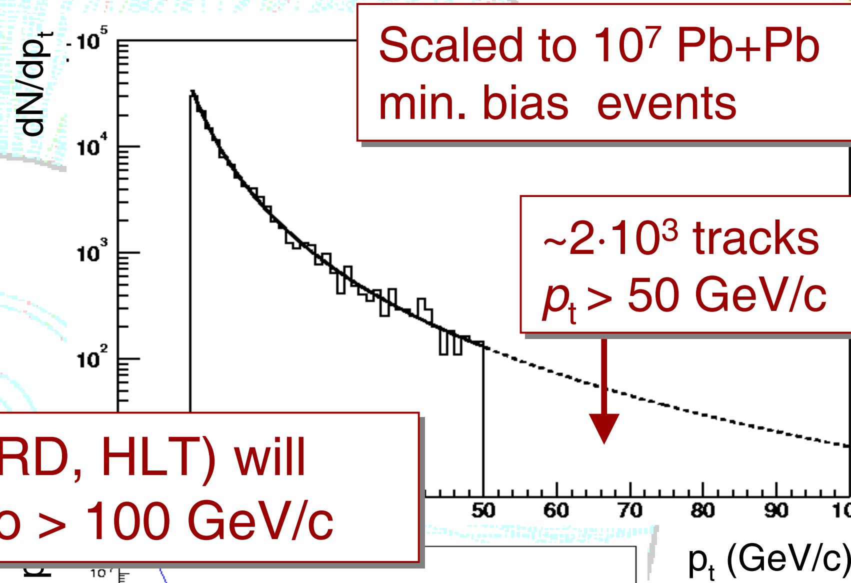


Mini-jets in Au+Au at RHIC

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

Minimum Bias Pb+Pb and p+p

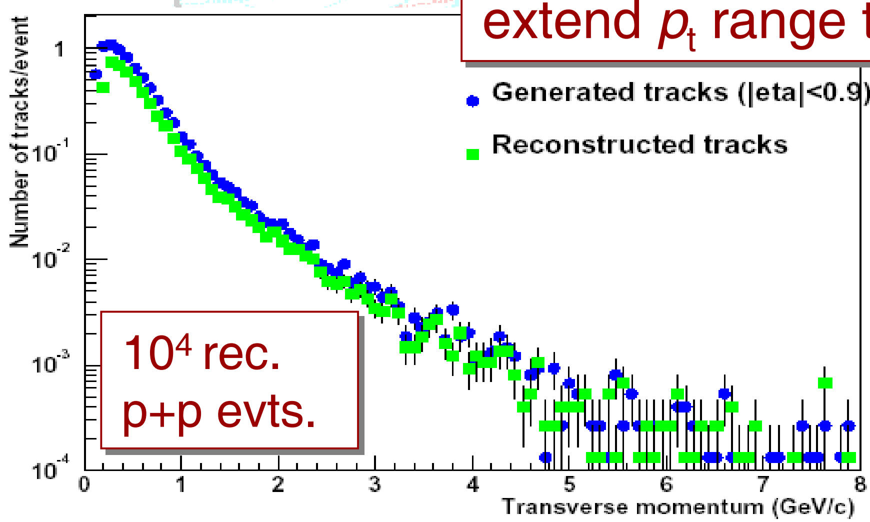
- Estimates for the p_t limit in one year ALICE running
  - 10^7 Pb+Pb events
  - 10^9 p+p events
- p+p simulation



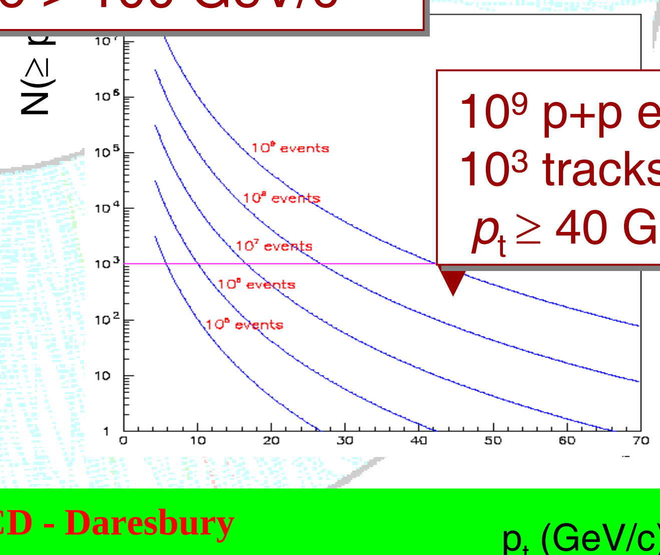
Scaled to 10^7 Pb+Pb min. bias events

~$2\cdot10^3$ tracks $p_t > 50$ GeV/c

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

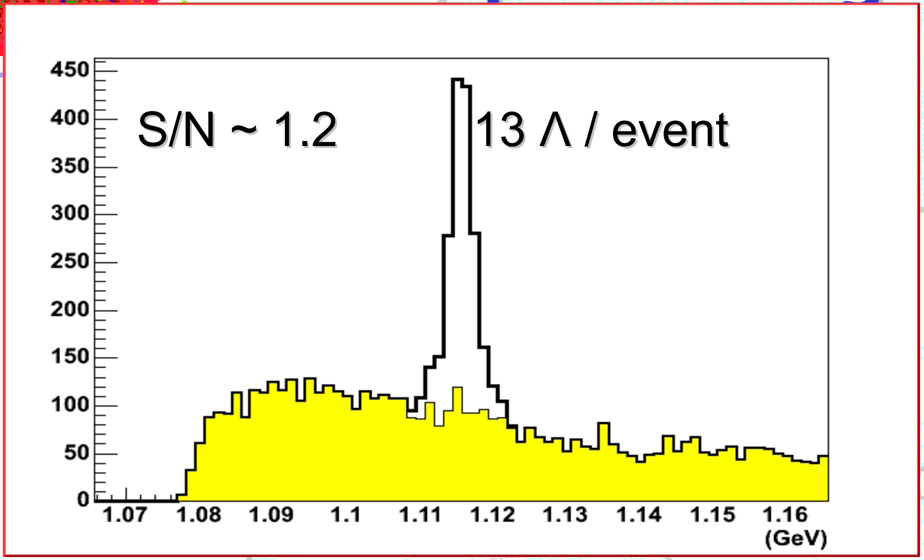


10^4 rec. p+p evts.

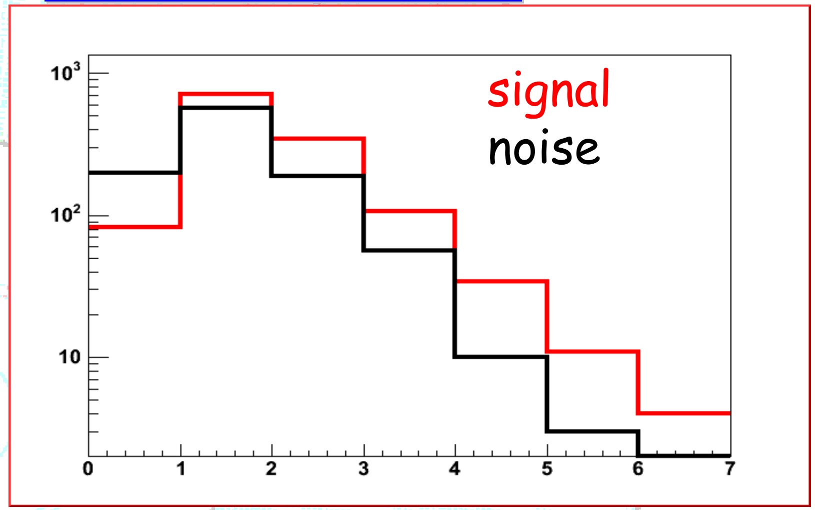


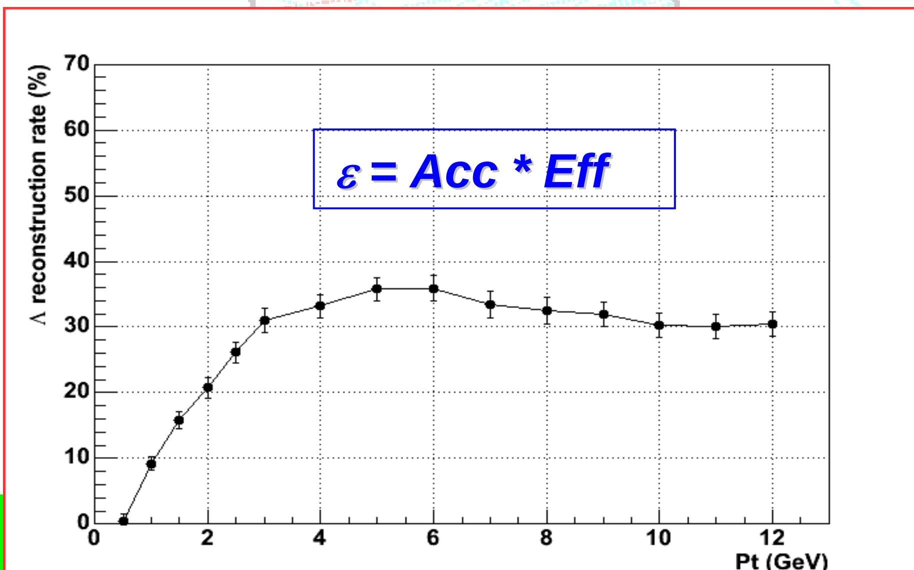
10^9 p+p events: 10^3 tracks with $p_t \geq 40$ GeV/c

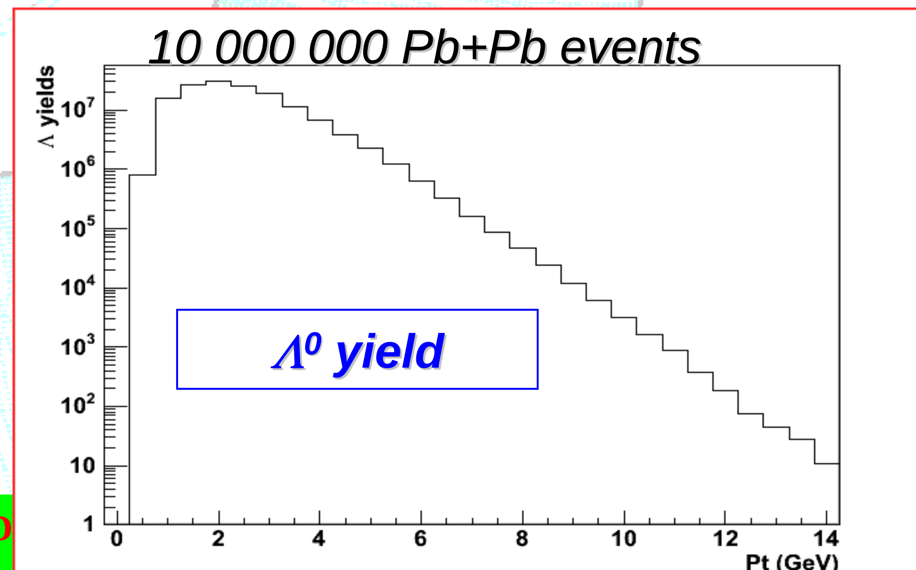
Λ Reconstruction with pt dependent geometrical cuts



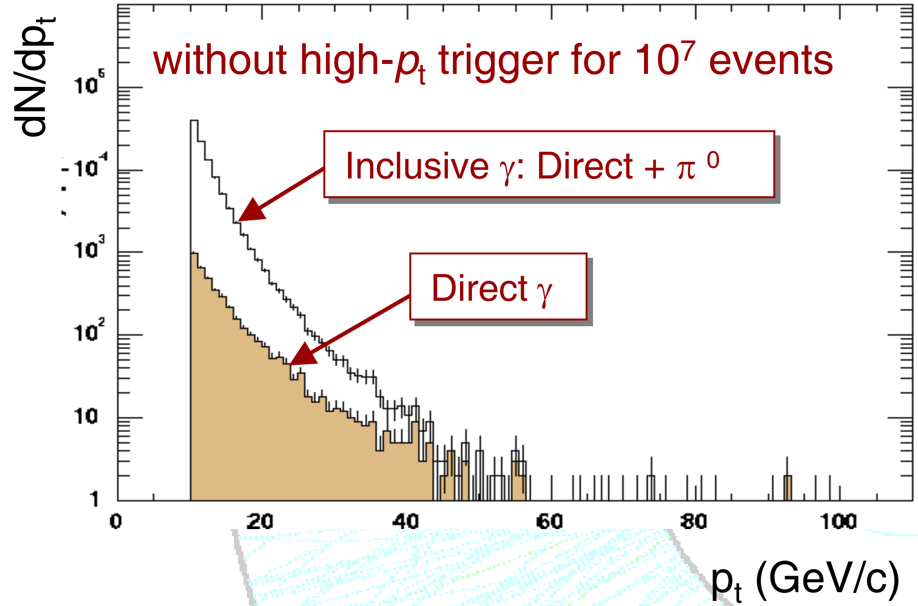
⇒ *Efficiency ~ 50 %*

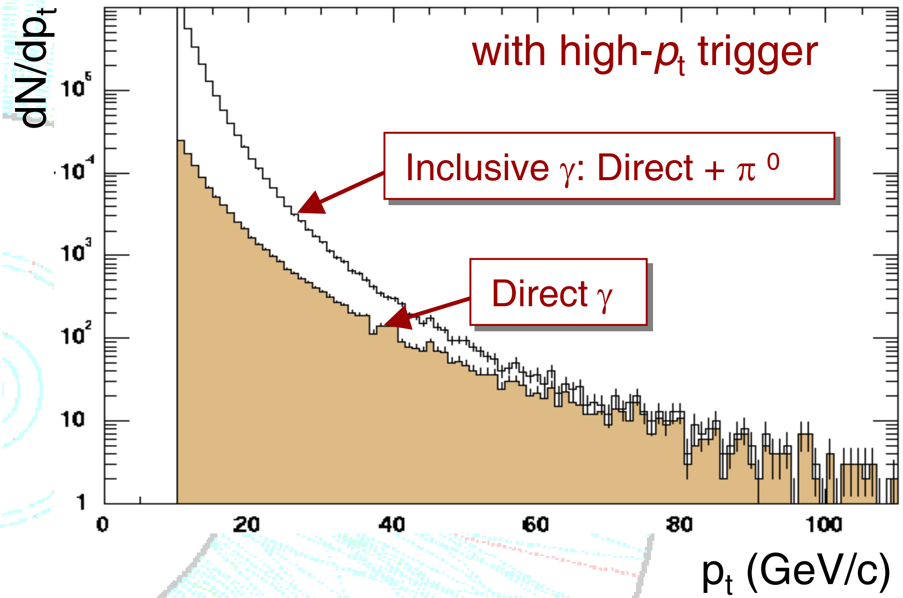






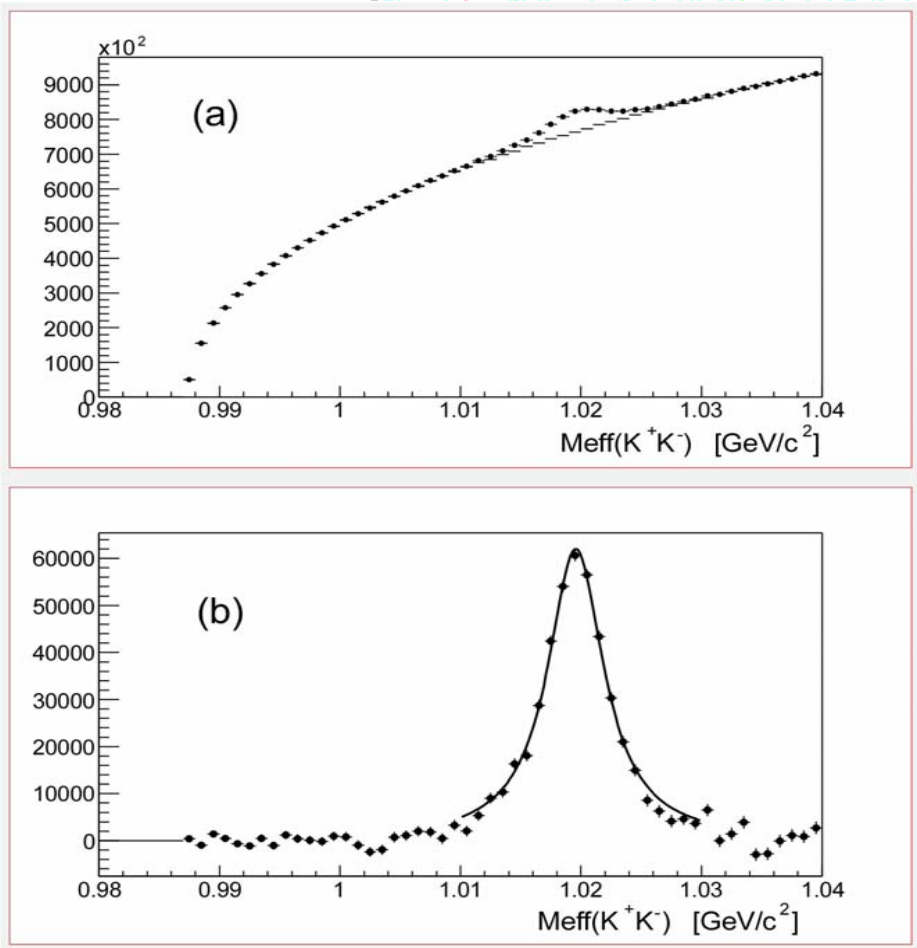
Identified Particles: $\gamma+\pi^0$





- 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)

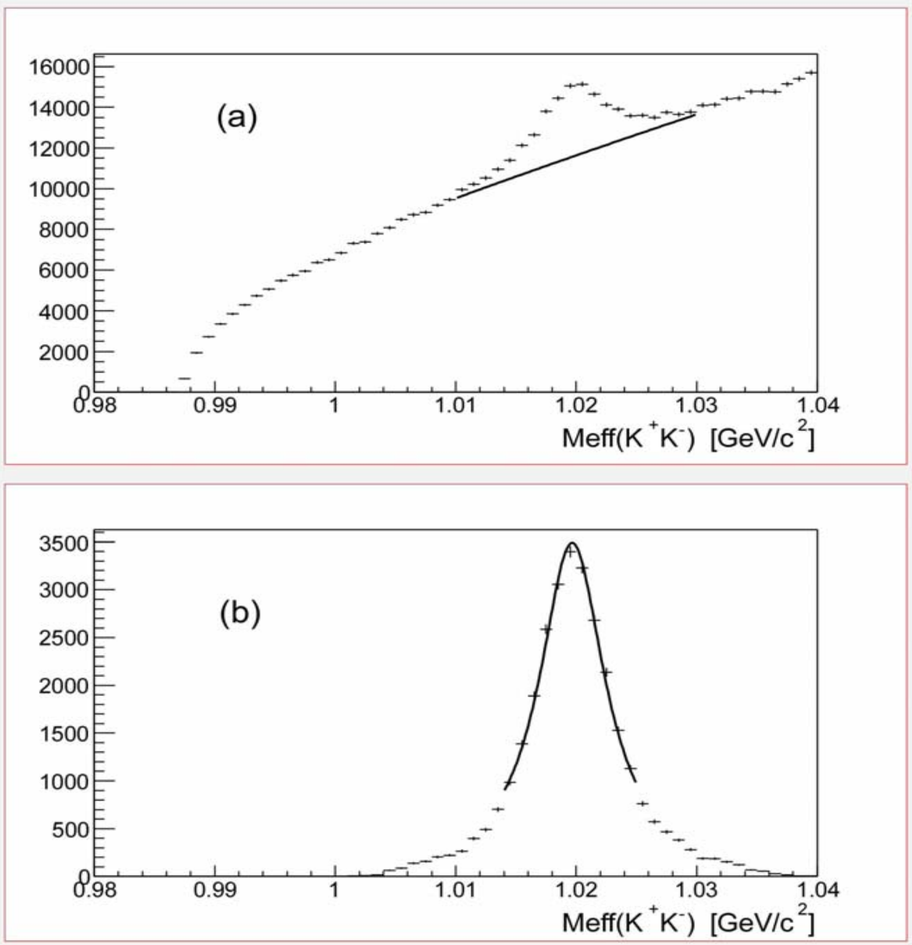
Φ Production



- Decay $\Phi \rightarrow K^+K^-$ simulated.
- PID from TPC and TOF
- Decays superimposed on HIJING events with dN/dy = 6000

p_T GeV/*c*	S	S/B	S/√(B+S)
<0.6	32263	0.00	9
0.6-0.8	115628	0.00	21
0.8-1.0	163148	0.01	32
1.0-1.2	121569	0.01	33
1.2-1.4	80384	0.01	31
1.4-1.6	57068	0.02	30
1.6-1.8	44640	0.02	30
1.8-2.0	38410	0.03	31
2.0-2.2	33464	0.03	32
>2.2	115217	0.06	80

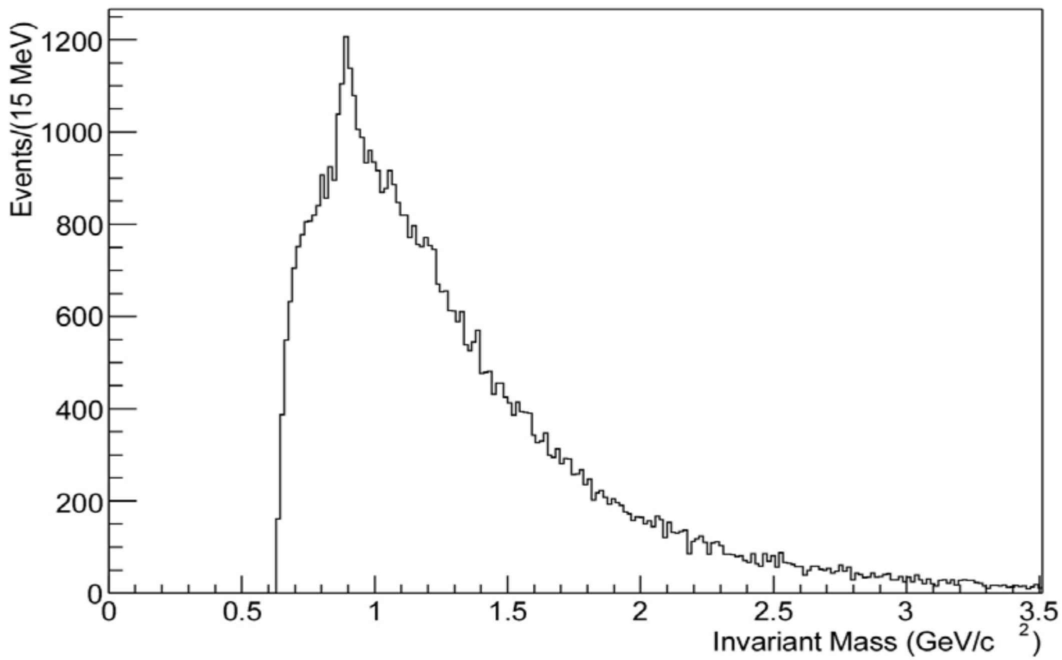
Φ Production II



- S/B is generally better at high p_T, but ultimately drops.

p_T GeV/*c*	S	S/B	$S/\sqrt{(B+S)}$
>3.0	730630	0.012	95
>3.5	586230	0.015	94
>4.0	374480	0.022	89
>5.0	136950	0.048	80
>6.0	55860	0.097	70
>6.5	35610	0.130	64
>7.0	23150	0.170	57
>7.5	15010	0.200	51

Other Resonances in ALICE



K+π- effective mass spectrum for pp interactions, assuming perfect PID.

- Resonance production studies in ALICE still in early stages
- This example shows K*(890) production in pp interactions.
- More soon.

pp physics

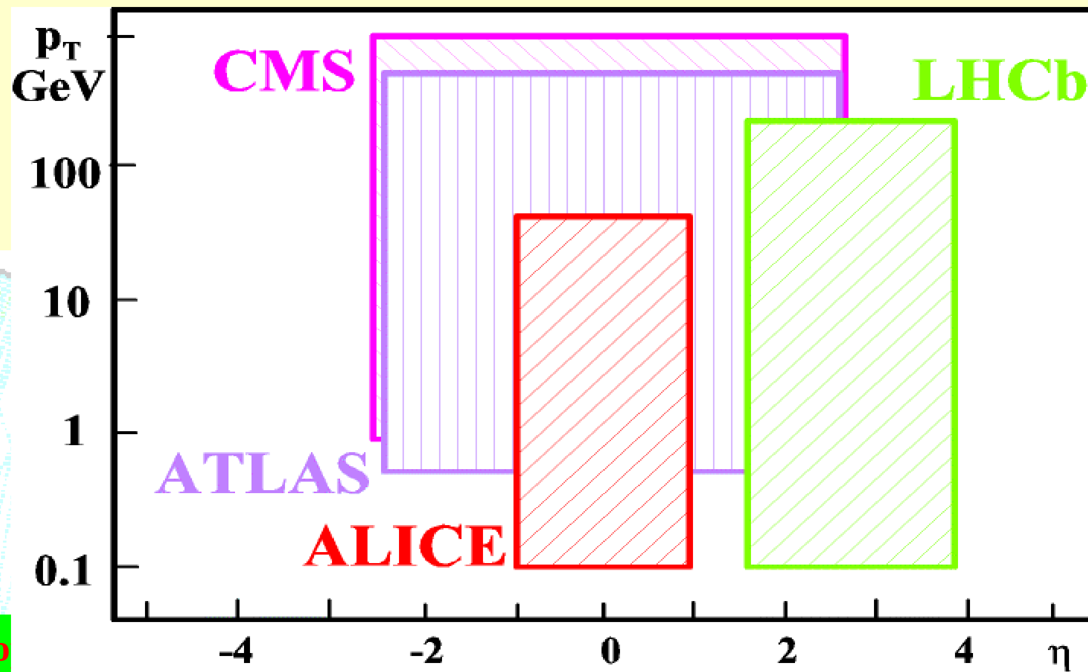
All HI observables have to be measured also in pp collisions for comparison with heavy-ion results

However, there are interesting questions regarding pp collisions themselves

- **charged multiplicity distribution**
- **correlations between mean p_t and multiplicity or strangeness**
- **study of diffractive events - with large rapidity gaps**
- **jets**
- **J/ψ cross-section**
- **Black holes**

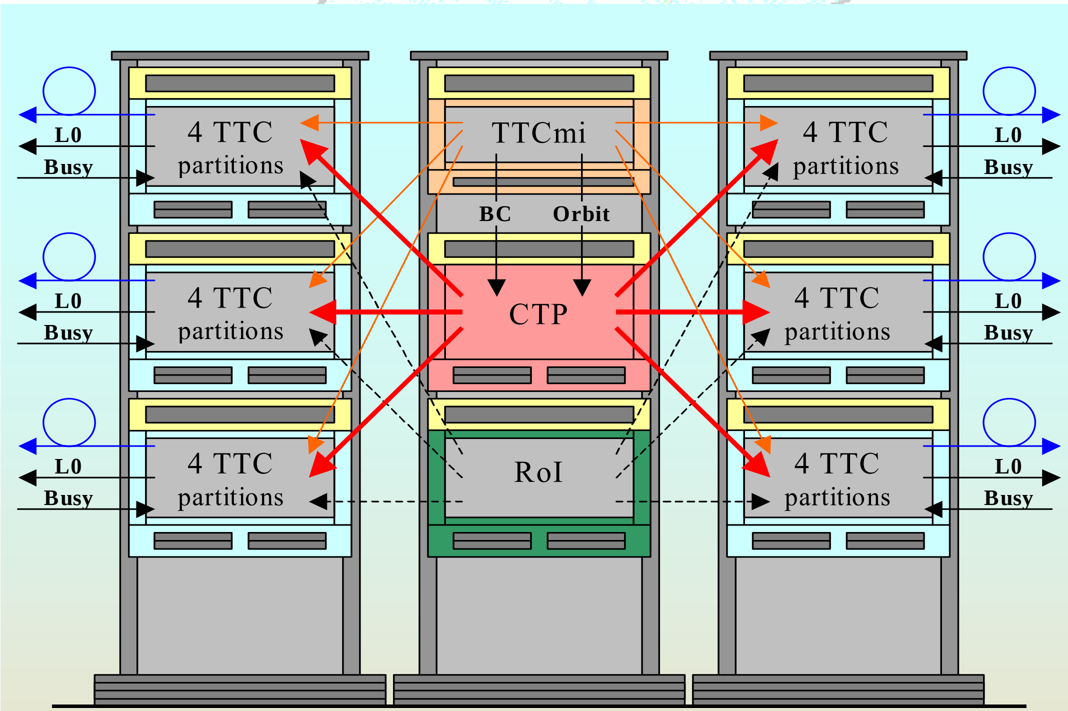
ALICE advantages wrt the other LHC experiments

- **lower p_T cut-off**
- **particle identification**



Birmingham Responsibility

The ALICE Trigger Electronics



(The CTP trigger inputs and the RoI inputs not shown)

The Birmingham Group is Responsible for designing, building and commissioning ALICE trigger electronics.

Gives us a high profile within ALICE Collaboration.

Birmingham's Physics Interests

Currently, the group is concentrating its efforts on proton-proton physics at ALICE – likely only to have protons in the first year, hence good to make an impact early.

Currently working on:

- **strangeness production**
- **strongly decaying resonance production**

Would like get involved in a wider range of physics – need more manpower.

Summary

- ALICE will be able to study the physics of quark matter in detail.
  - almost all known observables
  - from early to late stages of QGP
- UK (Birmingham) playing a key role
- Concentrating on proton physics for now.
- We look forward to lots of exciting physics from 2007.