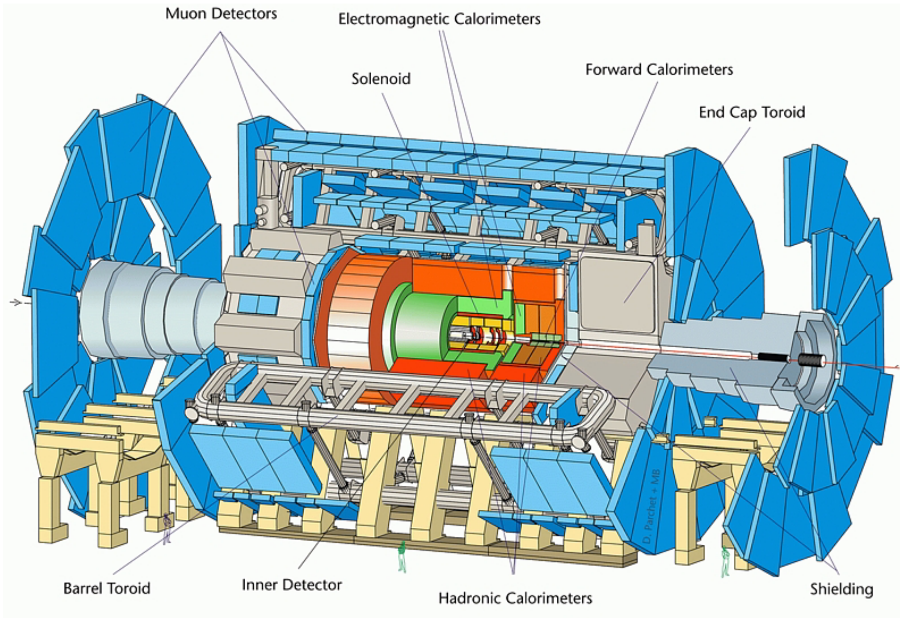
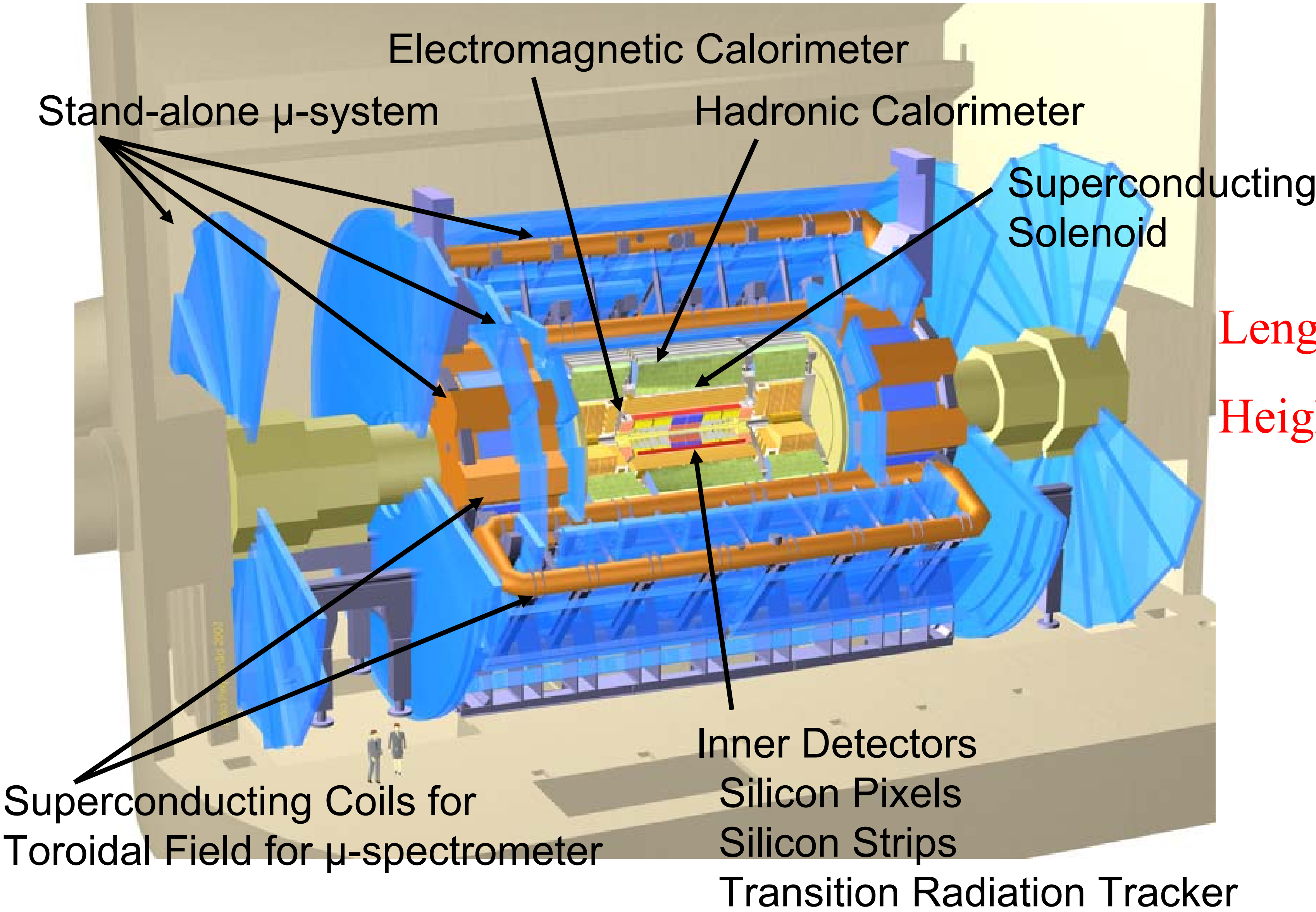
Heavy-ion Physics with the ATLAS Detector



Laurent Rosselet

The ATLAS detector



Length 44m

Height 22m

Some striking features:

Designed for p-p $L=10^{34}\ cm^{-2}\ s^{-1}$

Hermetic calorimeter $|\eta|<4.9$ ~10 units of rapidity!

Electromagnetic+hadronic

Fine granularity $\Delta\eta\Delta\Phi=0.025\text{x}0.025$ (e.g.) EM; 0.1x0.1 hadronic

with longitudinal segmentation (3 layers both in EM and hadronic)

Good jet resolution

Large acceptance μ-spectrometer $|\eta|<2.7$

Silicon Tracker $|\eta|<2.5$

Finely segmented pixel and strip detector (SCT)

Good momentum resolution; tracking particles with $p_T \geq 0.5$ GeV

The Atlas detector is well suited for high p_T physics.

ATLAS heavy-ion working group

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and many people who have participated to discussions.

Constraint: no modification to the apparatus, except trigger software and peripheral instrumentation.

Physics program

- **Global variable measurement**

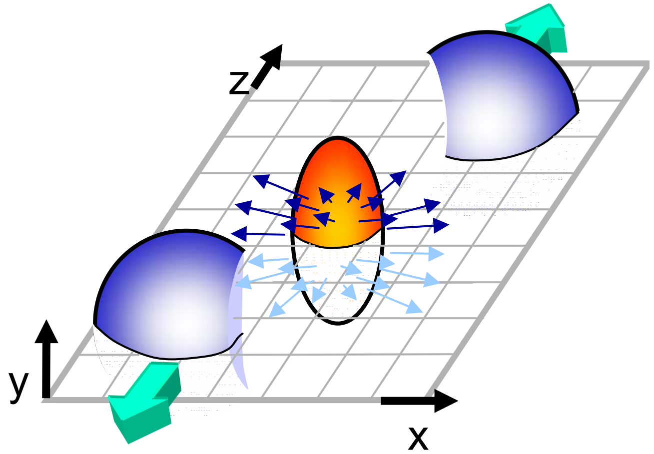
  $dN/d\eta$ $dE_T/d\eta$ elliptic flow

  azimuthal distributions

- **Jet measurement and jet quenching**
- **Quarkonia suppression**

  J/Ψ Υ

- **p-A physics**
- **Ultra-Peripheral Collisions (UPC)**



Direct information from QGP

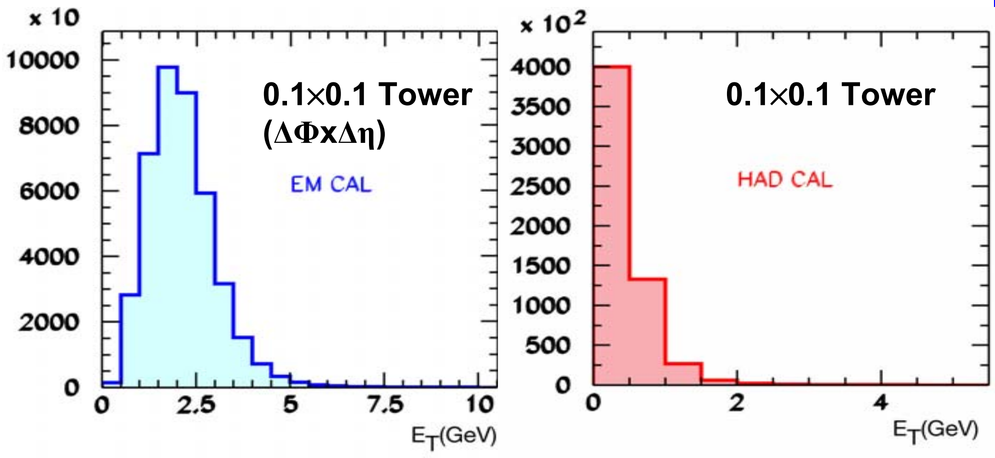
Idea: take full advantage of the large calorimeter and μ-spectrometer

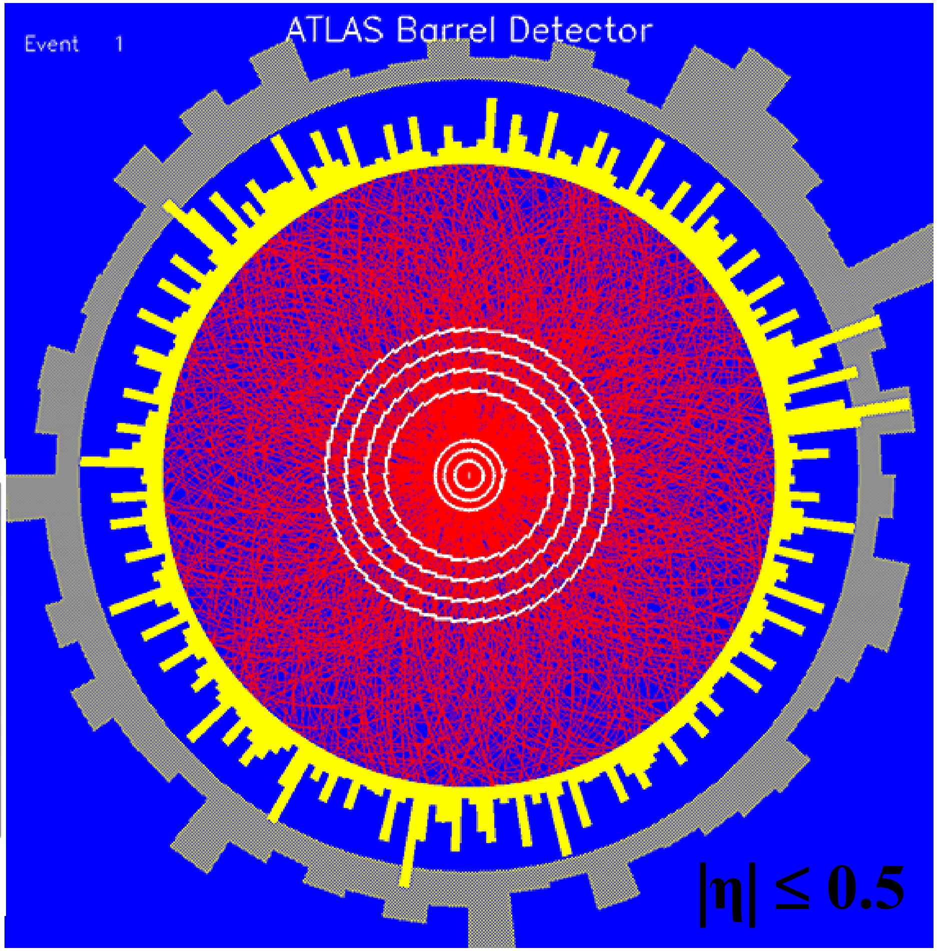
Central Pb-Pb collision (b=0-1 fm)

- Simulation: HIJING+GEANT3

  $dN_{ch}/d\eta|_{max}$~ 3200 in central Pb-Pb

  c.f. 1200 from RHIC extrapolation





- Large bulk of low p_T particles are stopped in the first layer of the EM calorimeter

Track reconstruction

—Only Pixel and SCT detectors

—At least 10 hits out of 11 per track

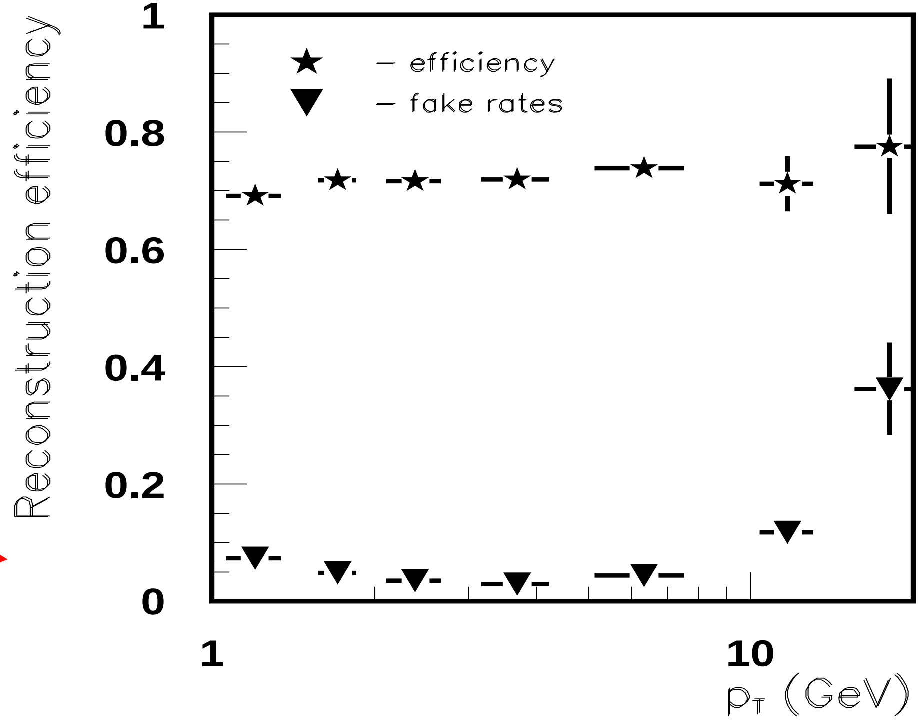
—At most 1 shared hits

—For p_T: 1 - 10 GeV/c:

efficiency > 70%

fake rate ~ 5%

p_T-resolution ~3%



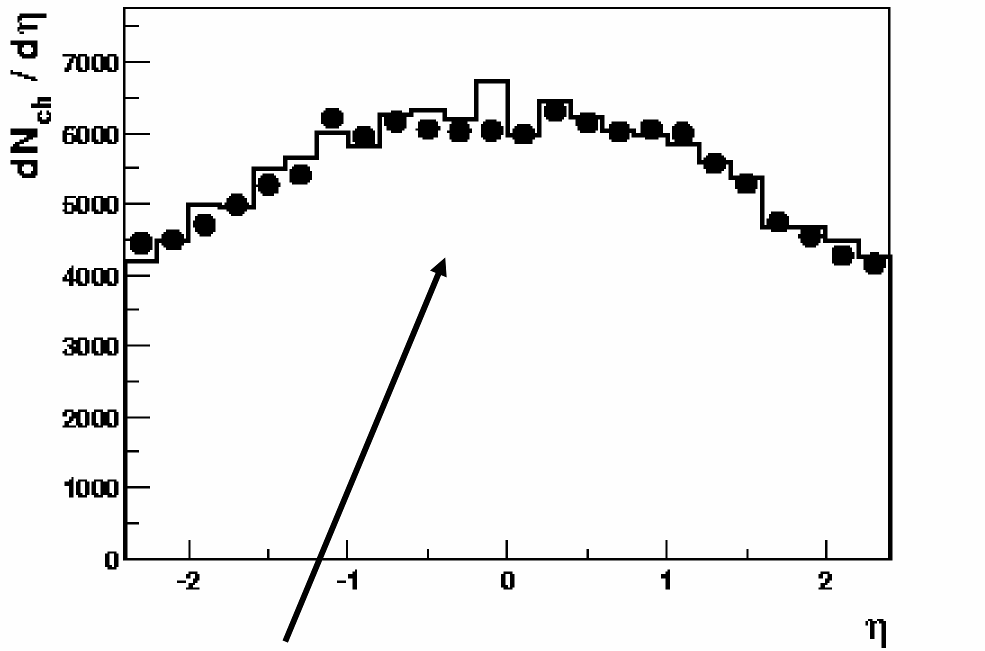
• 2000 reconstructed tracks from HIJING (b=0) events with $p_T > 1$ GeV and $|\eta| < 2.5$

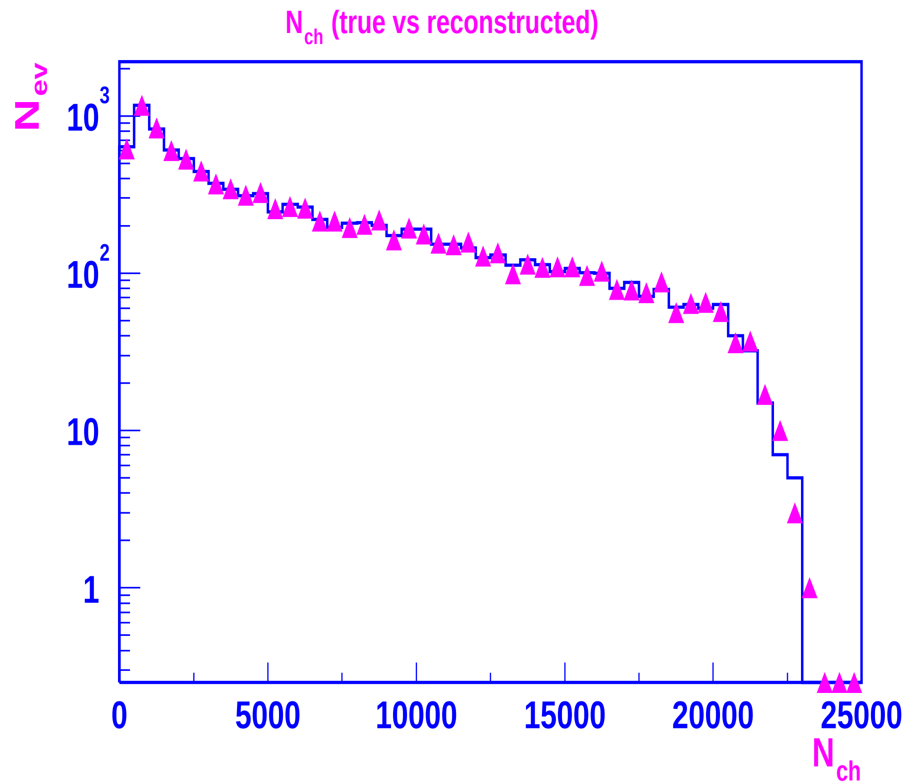
• Fake rate at high p_T can be reduced by matching with calorimeter data

Global observables

Day-one measurements: **N_{ch}, $dN_{ch}/d\eta$, ΣE_T, $dE_T/d\eta$, b**

e.g. $dN_{ch}/d\eta$ and charged particle multiplicity distribution





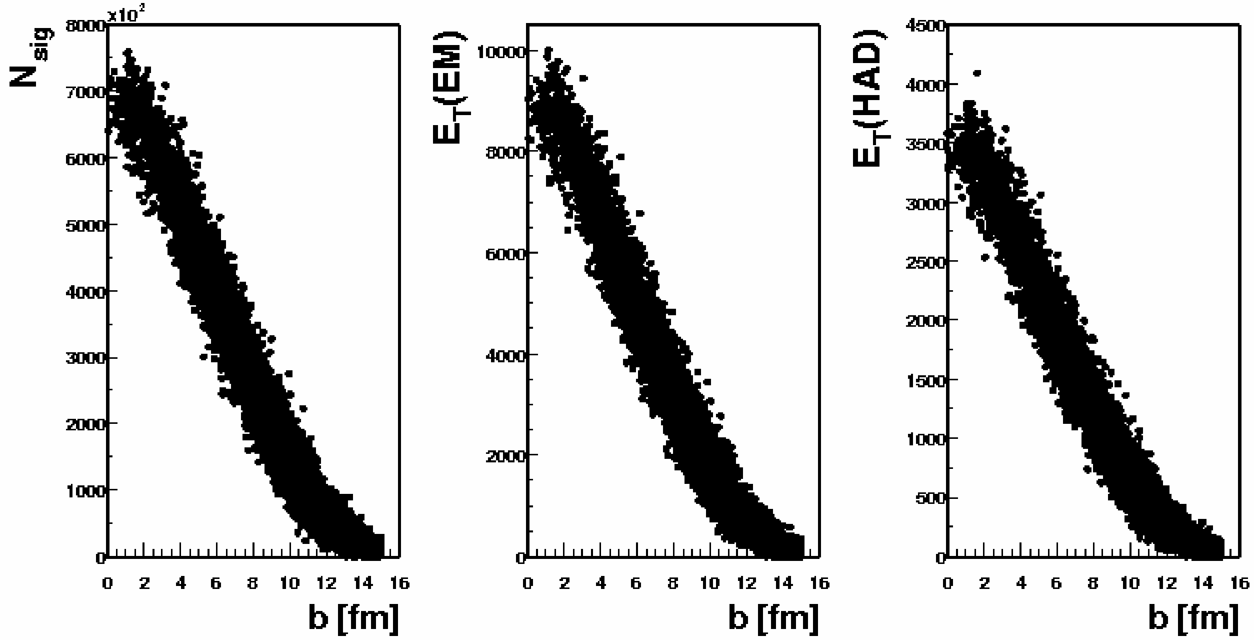
single Pb-Pb event b=0-1 fm

error ~5%

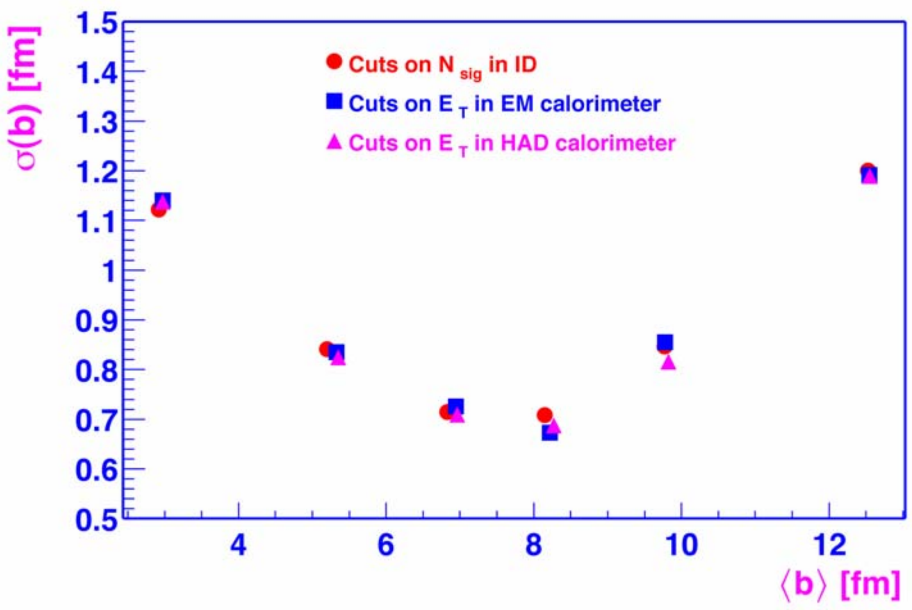
generated vs estimation from pixel counting, **no track reconstruction!**

Estimate of collision centrality

Monotonic relation between number of hits in the Pixel detector and b



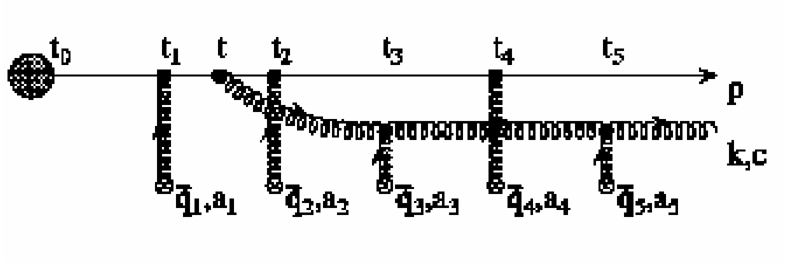
Accuracy on the determination of b with 3 distinct techniques

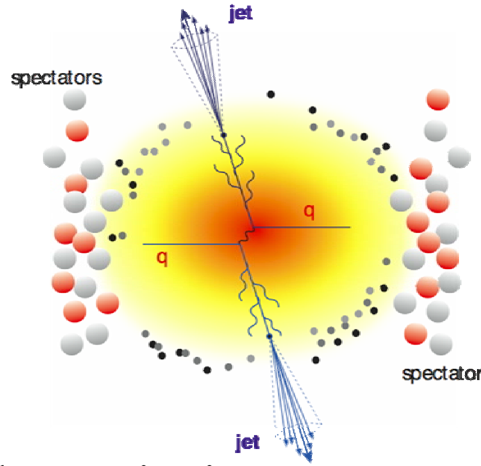


Jet quenching

Energy loss of fast partons by excitation and gluon radiation

larger in QGP





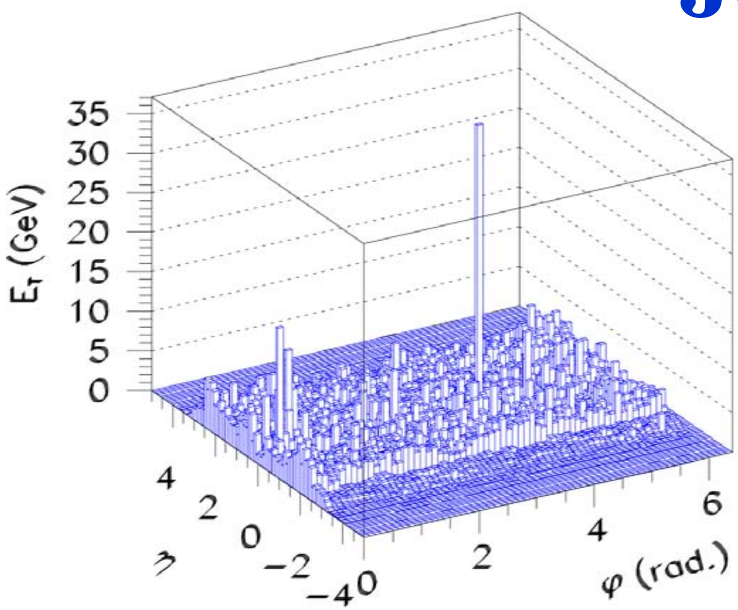
- Suppression of high-z hadrons and increase of hadrons in jets.

- Induced gluon radiation results in the modification of jet properties like a broader angular distribution.

Could manifest itself as an increase in the jet cone size or an effective suppression of the jet cross section within a fixed cone size.

- **Measuring jet profile is the most direct way to observe any change.**

Jet studies



PYTHIA jets embedded with
central Pb-Pb HIJING events

Reconstruction:

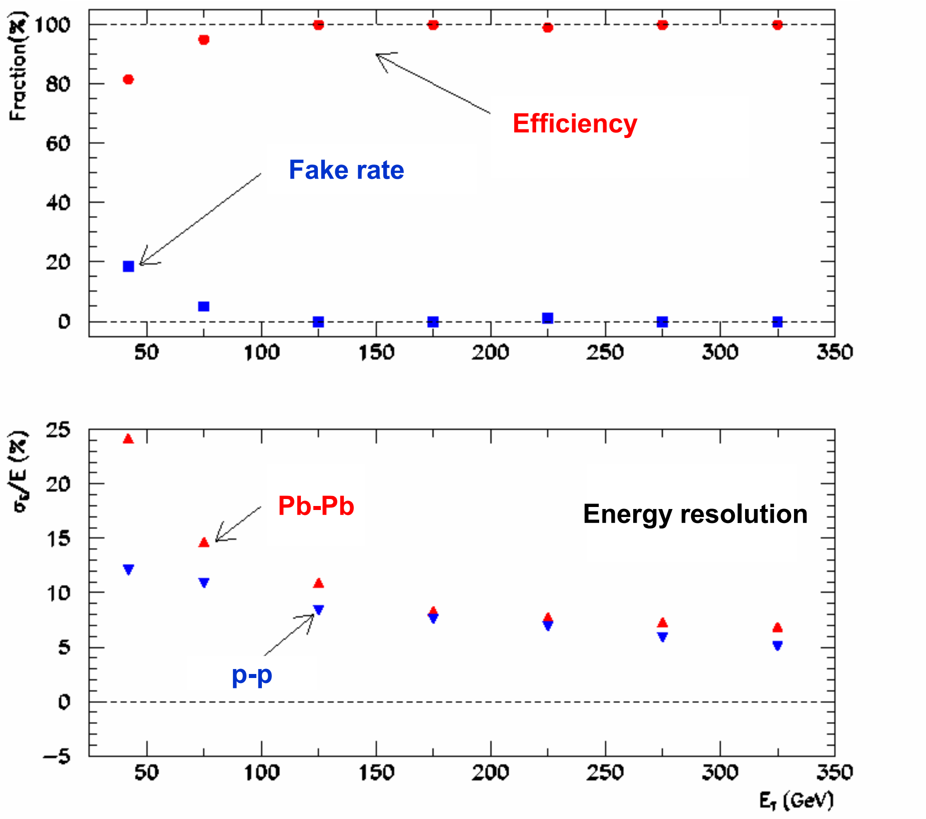
sliding window algorithm $\Delta\Phi x \Delta\eta$ =0.4x0.4 with splitting/merging
after background energy subtraction (average and local)

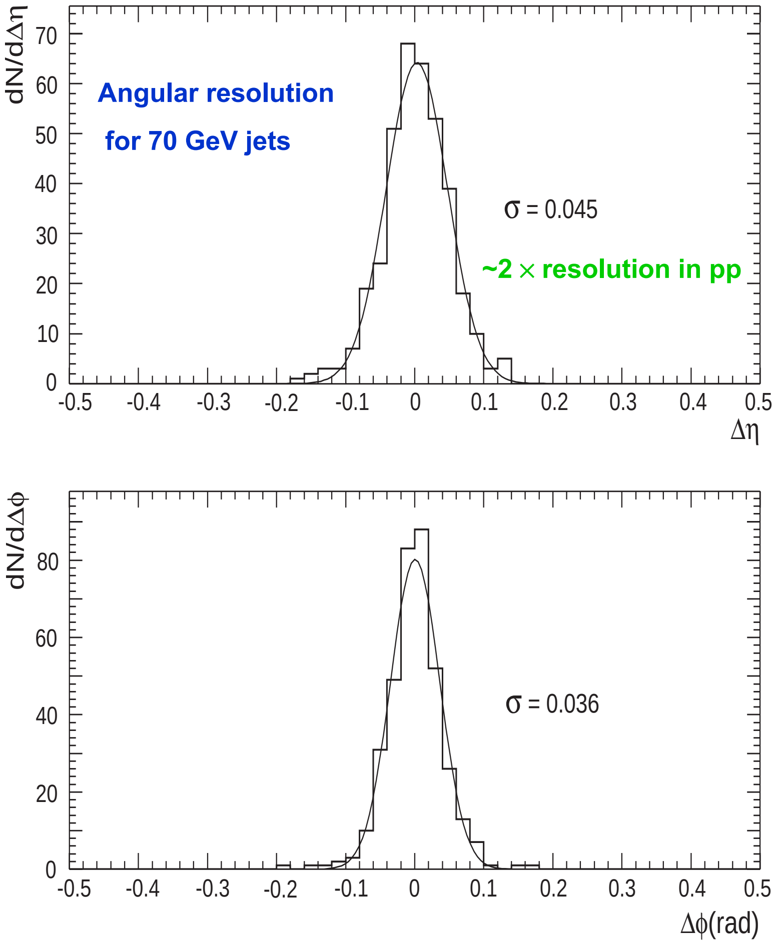
Average background 50 ±11 GeV (Pb-Pb Hijing, b=0-1 fm)
=> threshold for jet reconstruction ~30-40 GeV in calorimeter
cf p-p ~ 15 GeV

algorithm is not fully optimized yet

Jet reconstruction efficiency

Pb-Pb collisions (b= 0 –1 fm)





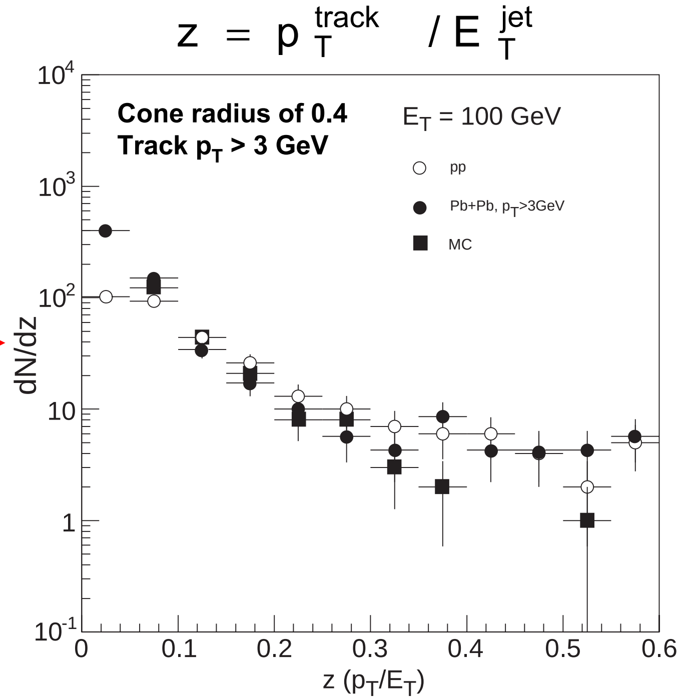
- For E_T > 75GeV: efficiency > 95%, fake < 5%
- Good energy and angular resolution

•Next: use tracking information to lower the threshold and reduce the fakes

▪Measure:

- Fragmentation function using tracks

Reconstructed PbPb ≈ HIJING ≈ pp

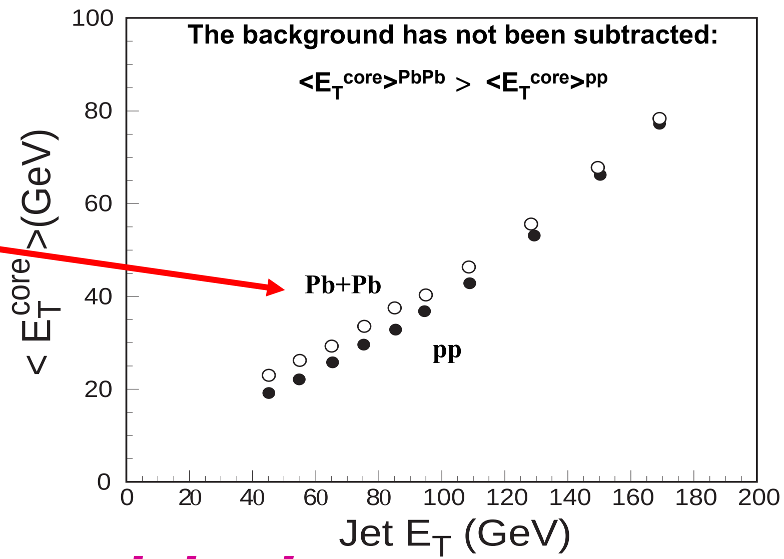


- Jet profile using calorimeters

- Core E_T using calorimeters

Energy deposited in a narrow cone R~0.1 selects leading hadrons, reduces effects of fluctuation in fragmentation.

$\langle E_T^{core} \rangle$ sensitive to ~10% change in E_T^{jet}

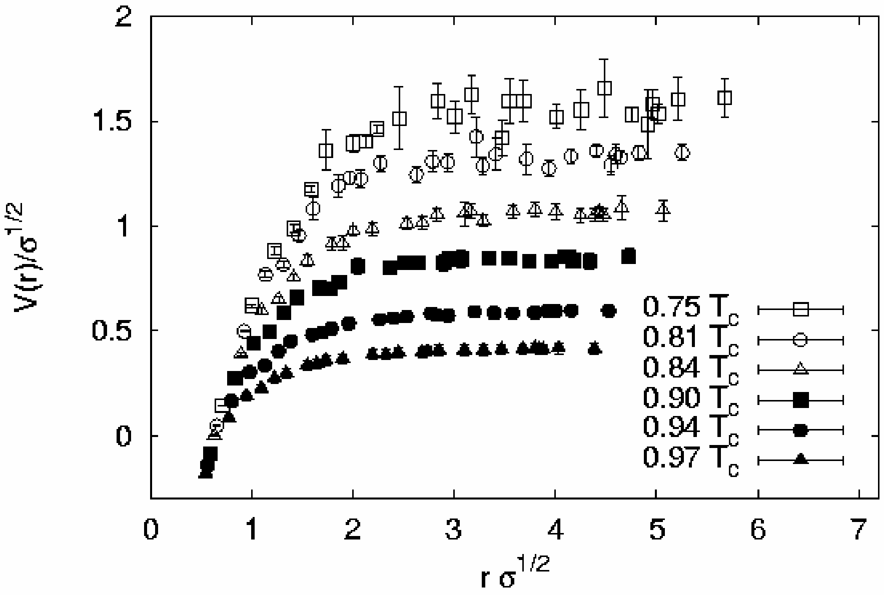


- Neutral leading hadrons using EM calorimeters

First look, but already promising!

Quarkonia suppression

Color screening prevents various ψ, ϒ, χ states to be formed when $T \rightarrow T_{trans}$ to QGP (color screening length < size of resonance)



Modification of the potential can be studied by a systematic measurement of heavy quarkonia states characterized by different binding energies and dissociation temperatures

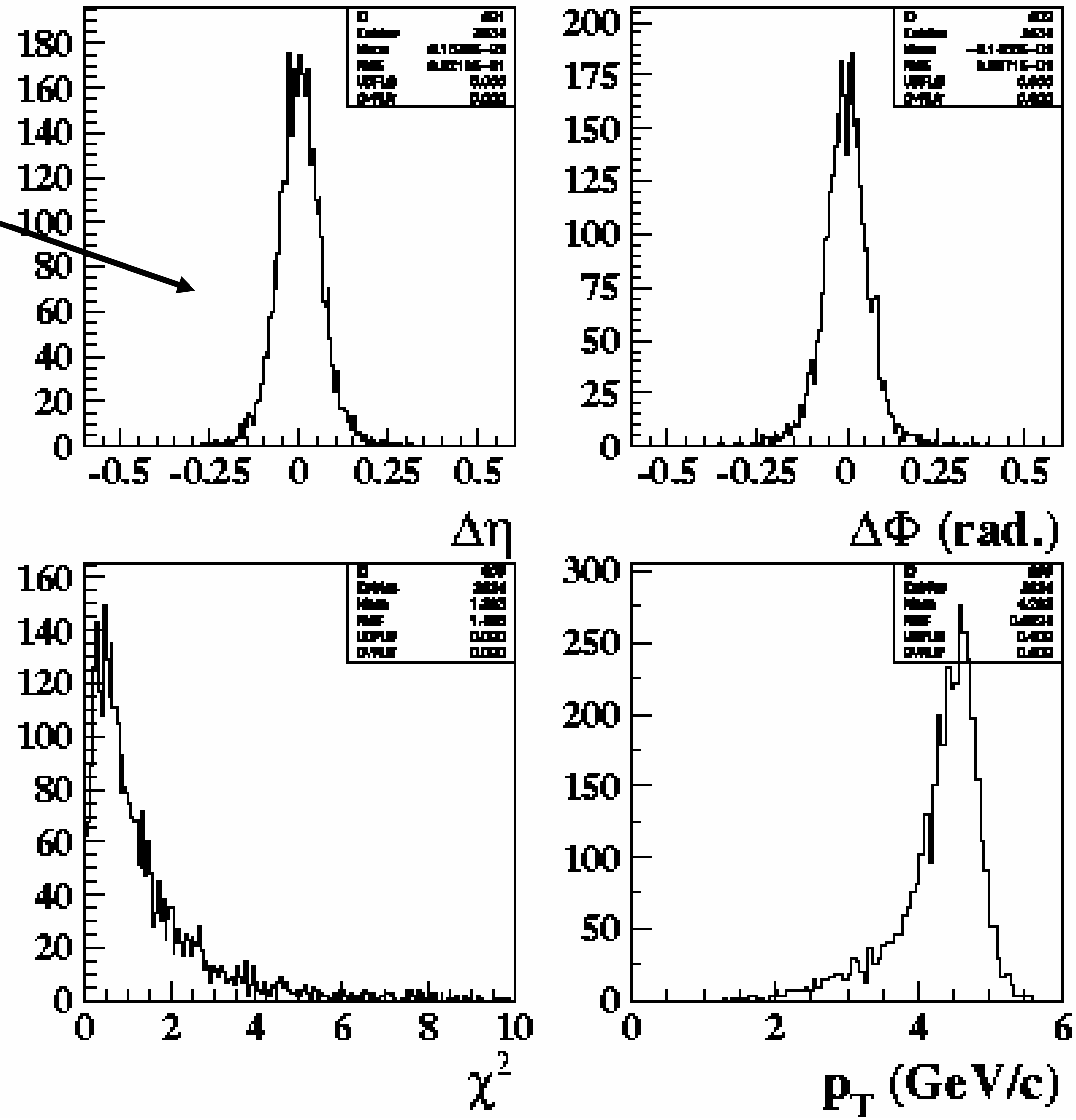
~thermometer for the plasma

Upsilon family	ϒ(1s)	ϒ(2s)	ϒ(3s)
→ Binding energies (GeV)	1.1	0.54	0.2
→ Dissociation at the temperature	$\sim 2.5T_{trans}$	$\sim 0.9T_{trans}$	$\sim 0.7T_{trans}$

=>Important to separate ϒ(1s) and ϒ(2s)

$\Upsilon \rightarrow \mu^+ \mu^-$ using combined info from ID and μ-spectrometer:

Single Upsilons



Δη, ΔΦ=difference between ID and μ-spectrometer tracks after back-extrapolation to the vertex for the best χ^2 association.

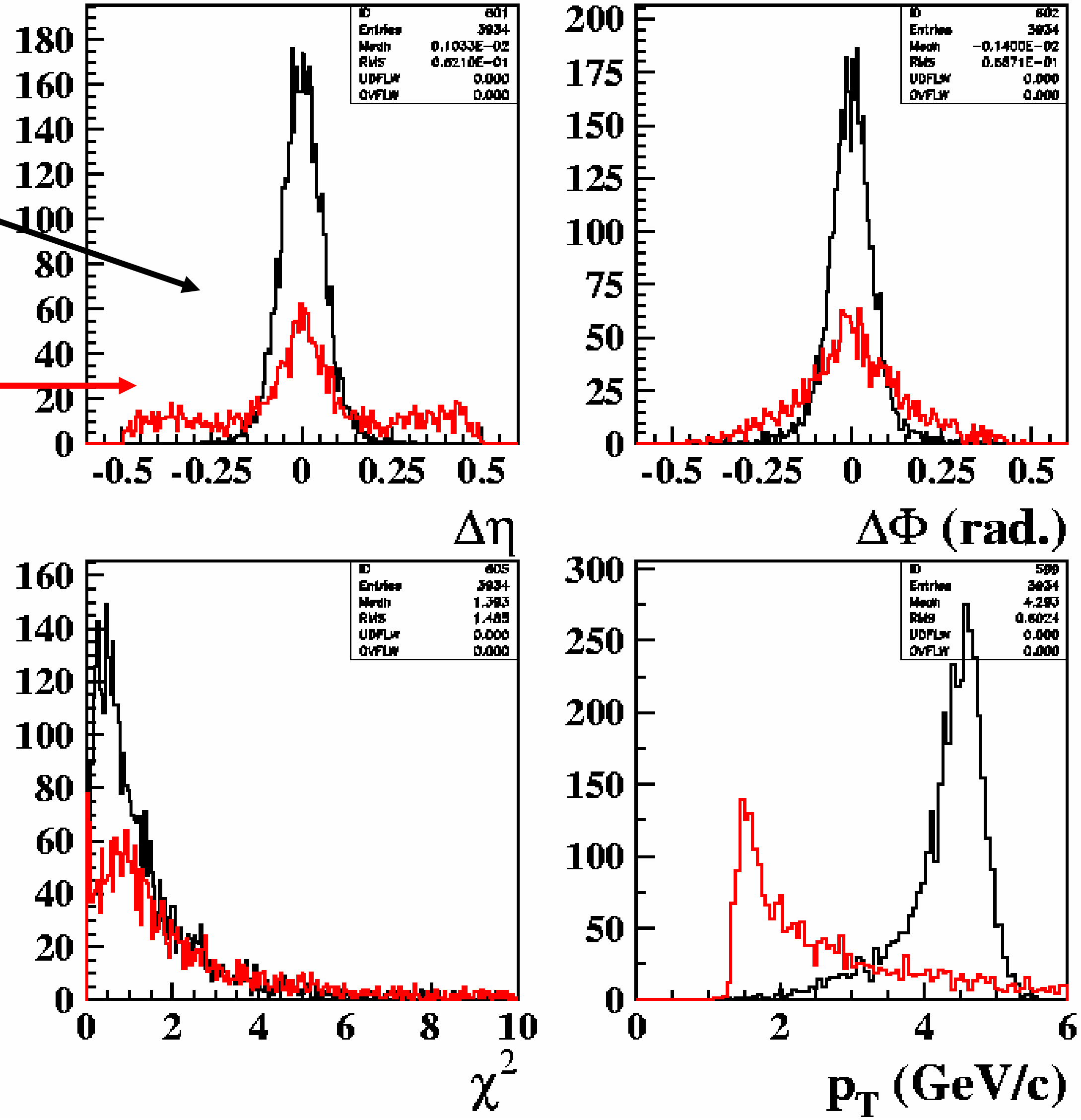
$\Upsilon \rightarrow \mu^+ \mu^-$ using combined info from ID and μ-spectrometer:

Single Upsilons

HIJING background

Half μ's from c, b decays, half from π, K decays for $p_T > 3$ GeV.

Background rejection based on χ^2 cut, geometrical Δη x ΔΦ cut and p_T cut.

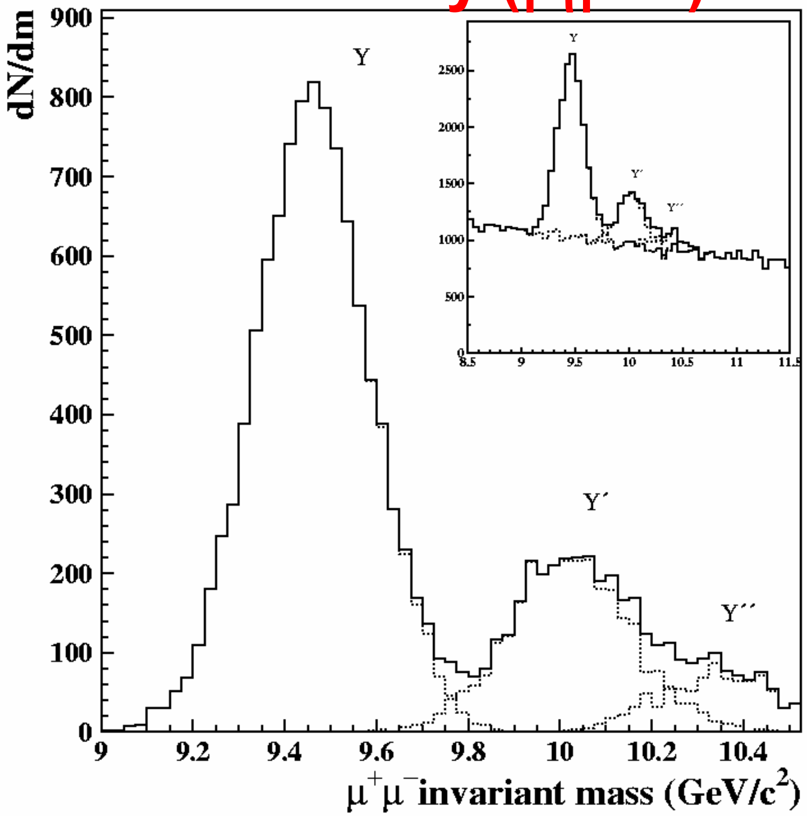


Δη, ΔΦ=difference between ID and μ-spectrometer tracks after back-extrapolation to the vertex for the best χ^2 association.

$\Upsilon \rightarrow \mu^+\mu^-$ reconstruction

	$\|\eta\| < 1$	$\|\eta\| < 2.5$
Acceptance +efficiency	4.9%	14.3%
Resolution	126 MeV	152 MeV
S/B	1.3	0.5
Purity	94-99%	91-95%

Barrel only ($|\eta| < 1$)



A compromise has to be found between acceptance and mass resolution to clearly separate Υ states with maximum statistics.

E.g. for $|\eta| < 1.2$ (6% acc+eff) we expect 10^4 Υ/month of 10^6s at $L=4\times10^{26}$ cm^{-2} s^{-1}

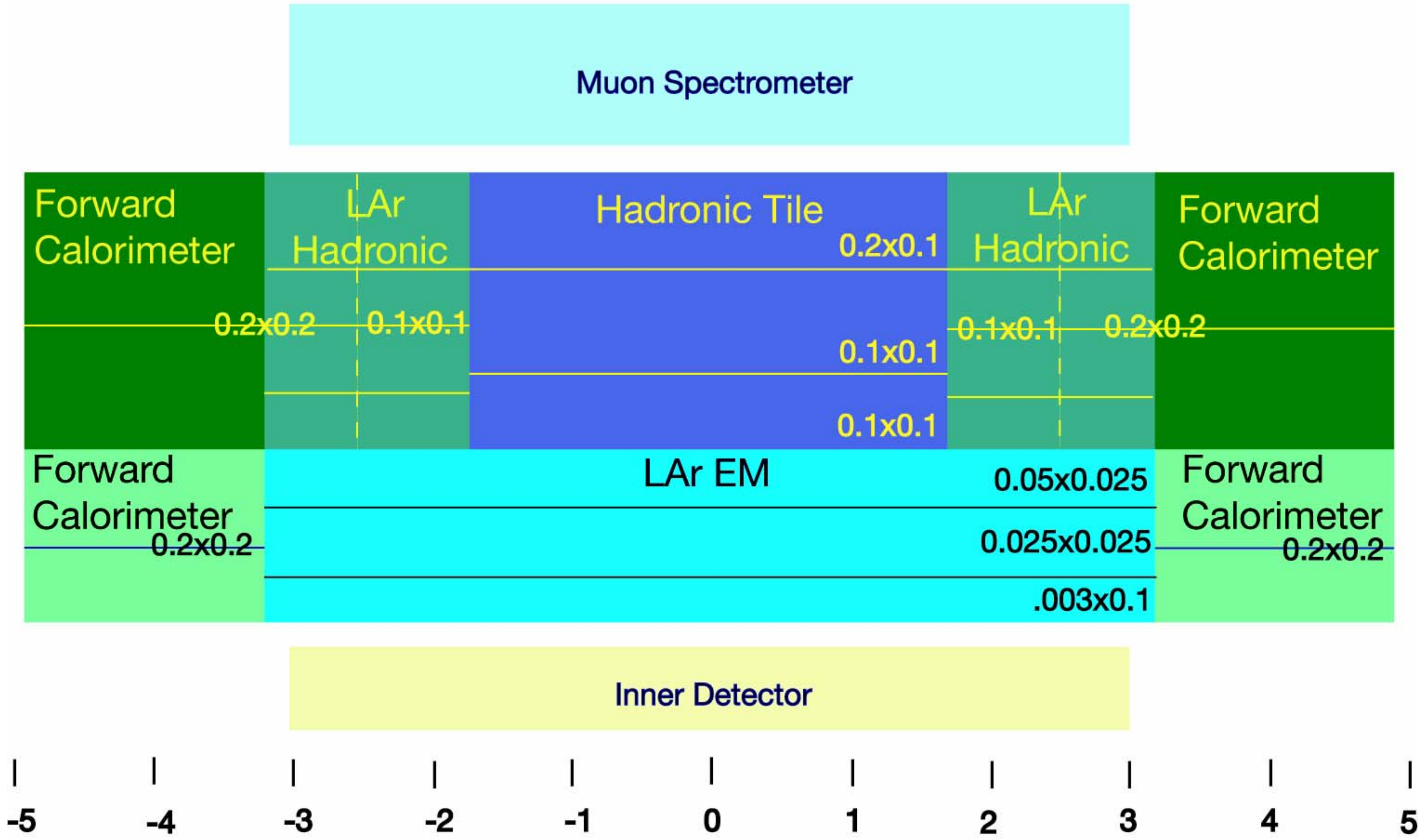
$J/\psi \rightarrow \mu^+\mu^-$ - a study is under way (σ_{mass} =53 MeV).

Summary

- ATLAS has an excellent calorimeter/muon-spectrometer coverage suitable for heavy-ions physics
- Except TRT, detector performances are not significantly deteriorated
- Global observables can be measured accurately even on ev-by-ev basis
- Jet physics (jet quenching) is very promising,
  - jet reconstruction is possible despite the additional background
  - jet energy resolution comparable to pp for E_T>100 GeV
- Heavy-quarkonia physics (suppression in dense matter) well accessible,
  - capability to measure and separate ϒ and ϒ', and
  - to reduce background from π and K at an acceptable level

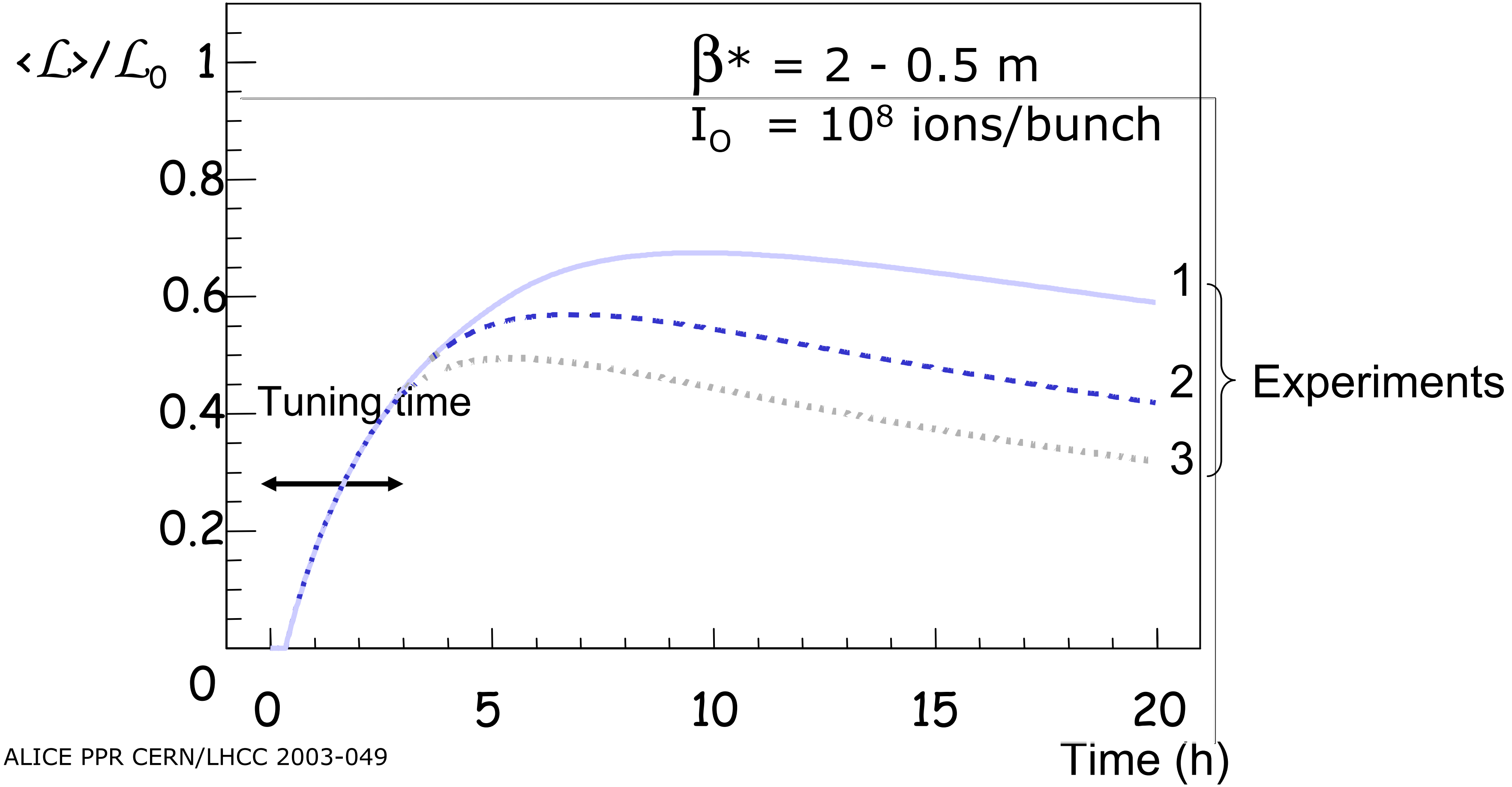
Extra slides:

ATLAS Calorimeters



Luminosity Issues

Yves Schutz, QM'2004



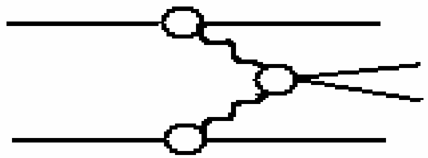
ALICE PPR CERN/LHCC 2003-049

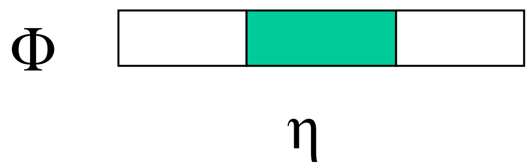
20% reduction for 3 experiments as opposed to 2 experiments

Ultra-Peripheral Collisions (UPC)

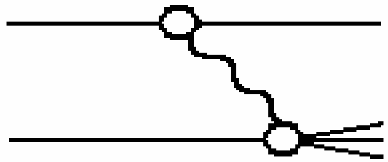
$b > 2R$ only electromagnetic interactions

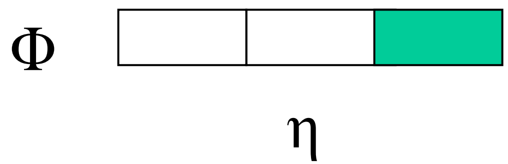
γ–γ



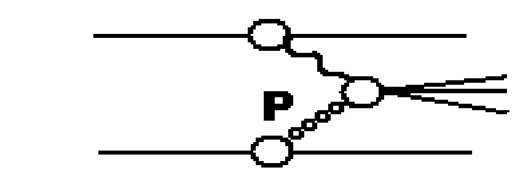


γ–N

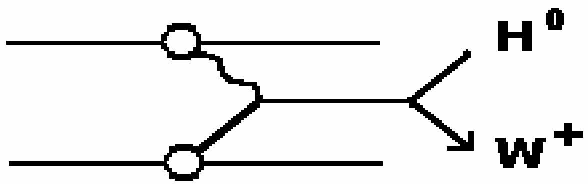




γ–P with/without nucleus diffraction



γ–W



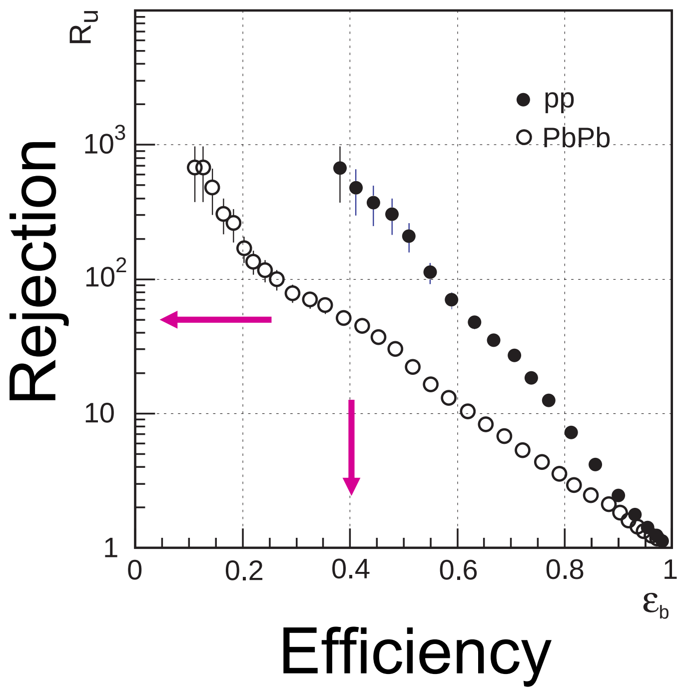
$\sigma(\gamma\text{–}\gamma) \sim Z^4$ W γ–γ $< 2\gamma\hbar c/R_A$ =200 GeV for Pb

b-tagged jets

Motivation: radiative energy loss is different for heavy/light quarks.

1st attempt based on impact parameter cuts

Rejection factors against light quarks vs b-tagging efficiency:



To evaluate b - tagging performance:

- **$pp \rightarrow WH \rightarrow l\nu b\bar{b}$ and $l\nu u\bar{u}$ on top of HIJING background events.**
- **A displaced vertex in the Inner Detector has been searched for.**

Rejection factor against u- jets ~ 50 for b-tagging efficiency of 40% in central Pb-Pb collisions

Should be improved when combined with μ tagging