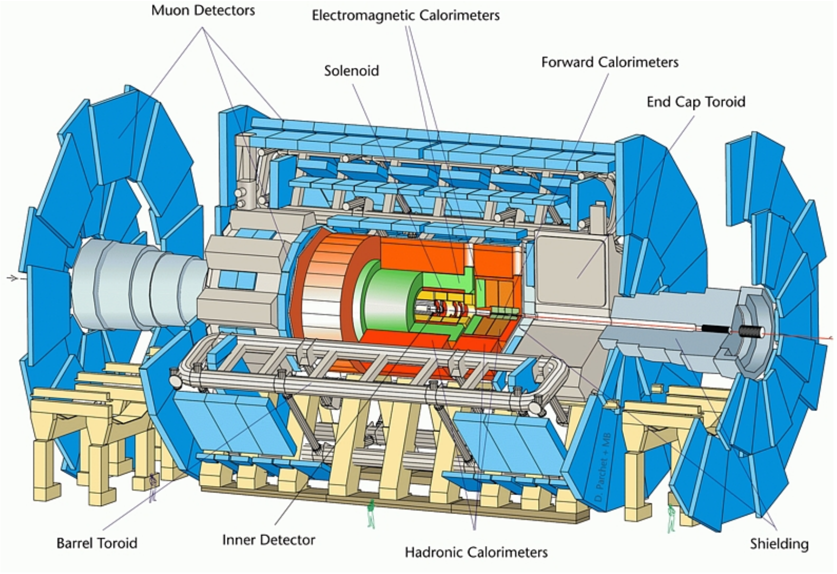
Heavy Ion Physics with the ATLAS Detector



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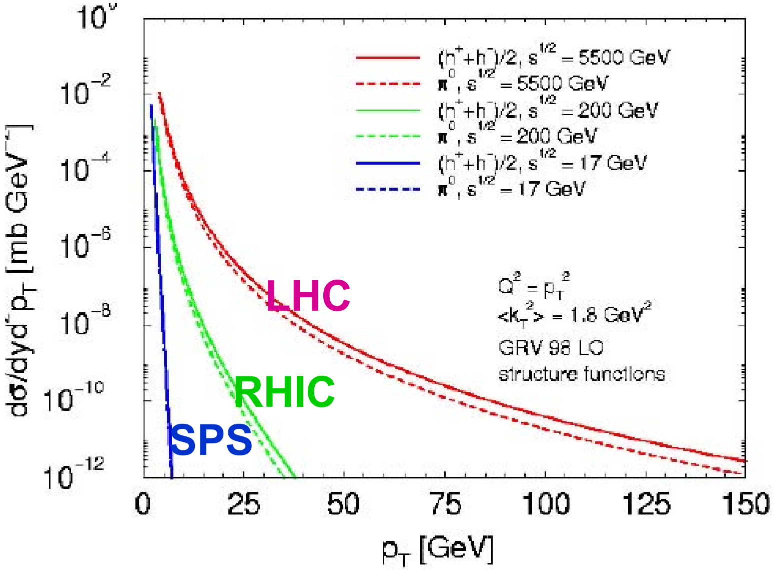
On behalf of the ATLAS Collaboration

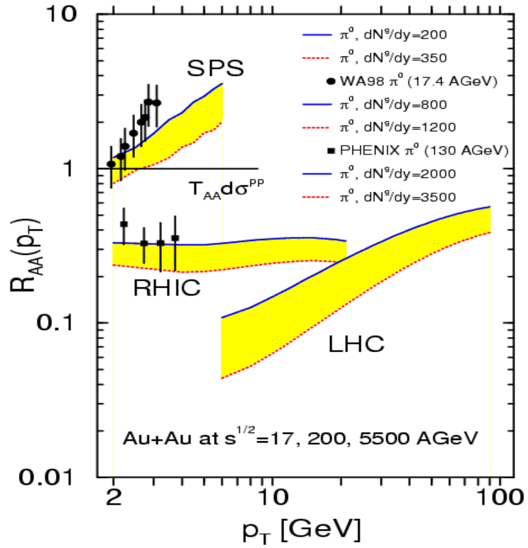
From RHIC to LHC

$\sqrt{s_{NN}}$: 200 GeV → 5,500 GeV

Super-hot QCD: Will we see a weakly coupled QGP??

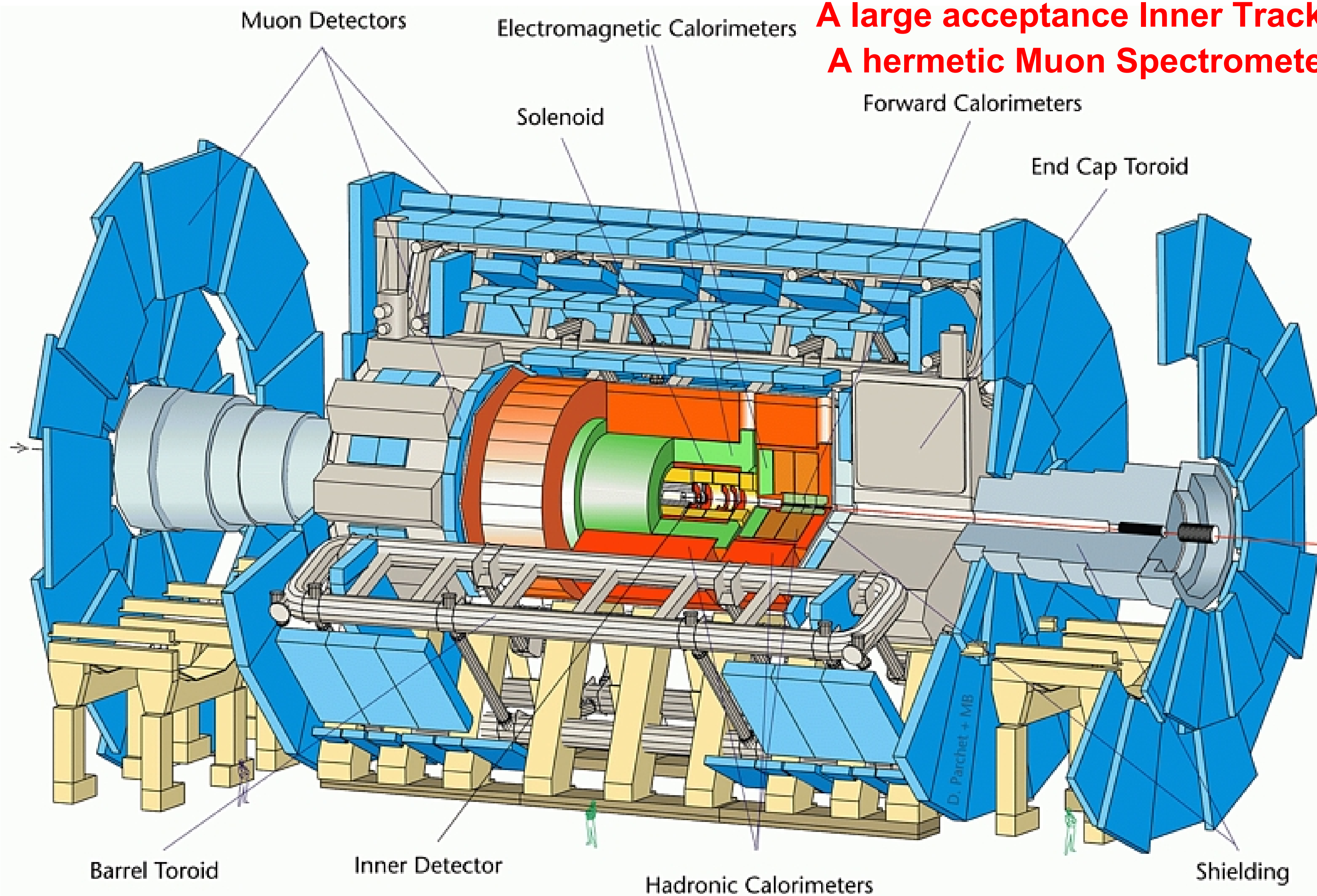
- Initial state fully saturated (CGC)
- Enormous increase of high-p_T processes over RHIC
- Plenty of heavy quarks (b,c)
- Weakly interacting probes become available (Z^0, $W^{\pm}$)





ATLAS as a Heavy Ion Detector is:

An Excellent Calorimetry
A large acceptance Inner Tracker
A hermetic Muon Spectrometer



ATLAS as a Heavy Ion Detector

1. Excellent Calorimetry

- Hermetic coverage up to $|\eta| < 4.9$
- High granularity (.025x.025 electromagnetic, .1x.1 hadronic) with fine longitudinal segmentation (~7 sections)
- Very good jet energy resolution (50%/sqrt(E) in pp)

High p_T probes (jets, jet shapes, jet correlations, π^0)

2. Large Acceptance Muon Spectrometer

- Coverage up to $|\eta| < 2.7$

Muons from Υ, J/ψ, Z^0 decays

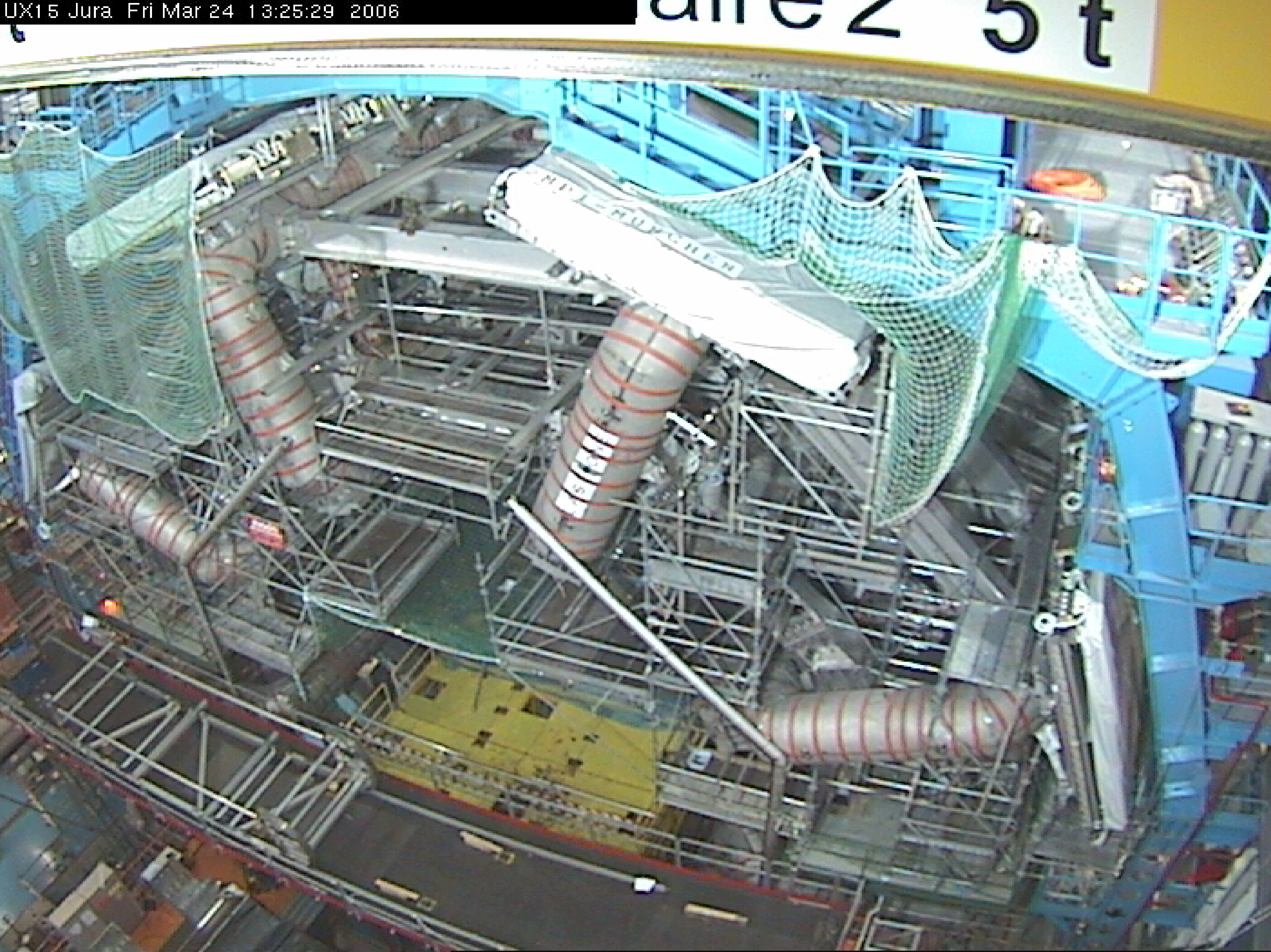
3. Inner Detector (Si Pixels and Strips, no TRT used)

- Large coverage up to $|\eta| < 2.5$
- High granularity pixel and strip detectors (o~1%,10%)
- Good momentum resolution (dp_T/p_T~3% up to 15GeV)

Tracking particles with $p_T \geq 0.5$ GeV/c

1.& 3. Global event characterization ($dN_{ch}/d\eta$, $dE_T/d\eta$, flow); Jet quenching study

2.+ 3. Heavy quarks(b), quarkonium suppression(J/ψ ,Υ)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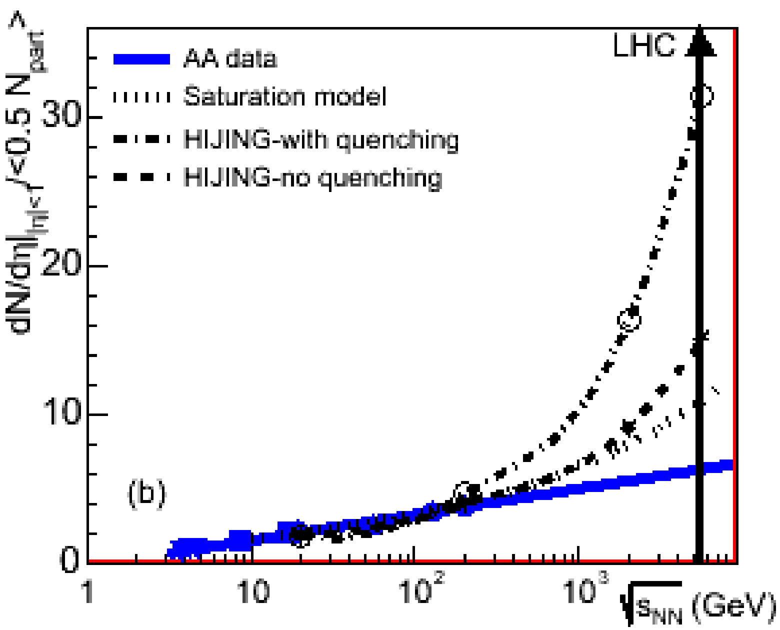
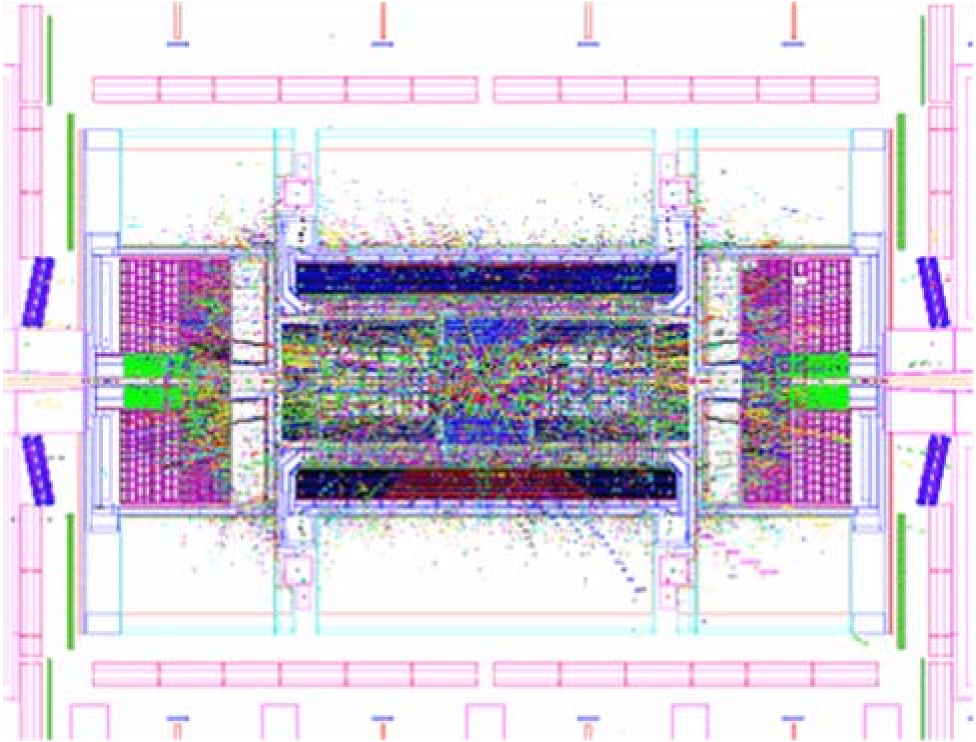
Studies of the Detector Performance

- **Constraint:** No modifications to the detector, except for trigger and probably very forward region
- **Simulations:** HIJING event generator, $dN_{ch}/d\eta = 3200$
  Full GEANT simulations of the detector response





- **Large event samples:**
  $|\eta| < 3.2$ impact parameter range: b = 0 - 15fm (27,000 events)
  $|\eta| < 5.1$ impact parameter range: b = 10 - 30fm (5,000 events)

Predicted Detector Occupancies

b = 0 – 1fm

Si detectors:

Pixels < 2%

SCT < 20%

TRT:

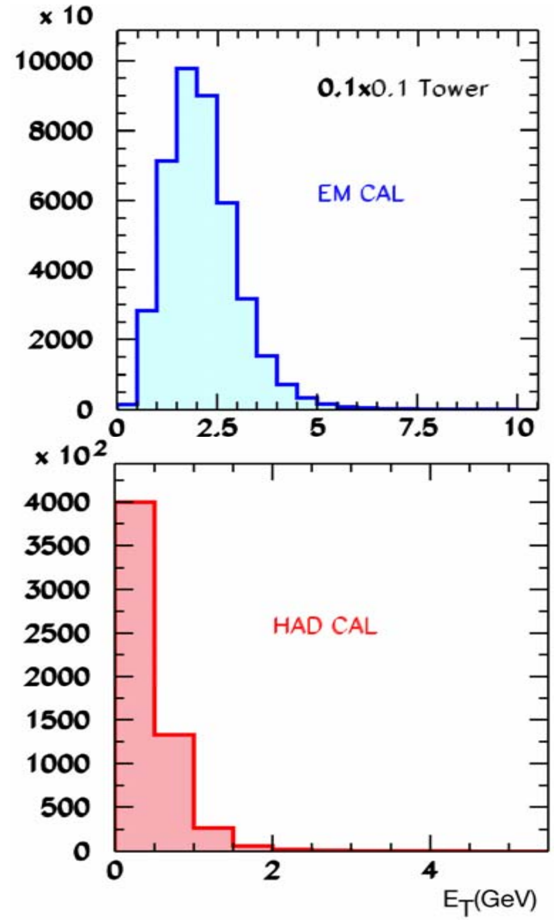
- High occupancy for tracking
- Still visible TR signal for electrons

-> Limited usage for AA collisions is under investigation
Will be fully useful for pA

Muon Chambers:

0.3 – 0.9 hits/chamber
(<< pp at 10^{34} cm^{-2} s^{-1})

Calorimeters (|n|< 3.2)



Average E_T (uncalibrated):

~ 2 GeV/Tower

~ .3 GeV/Tower

Tracking Performance

Standard ATLAS reconstruction for pp is used, not optimized for PbPb.

-Pixel and SCT detectors

-p_T threshold of 1 GeV

(used in this preliminary studies)

-tracking cuts:

- At least 10 hits out of 11(13) available in the barrel (end-caps)
- All three pixel hits
- At most 1 shared hits
- χ^2/dof < 4

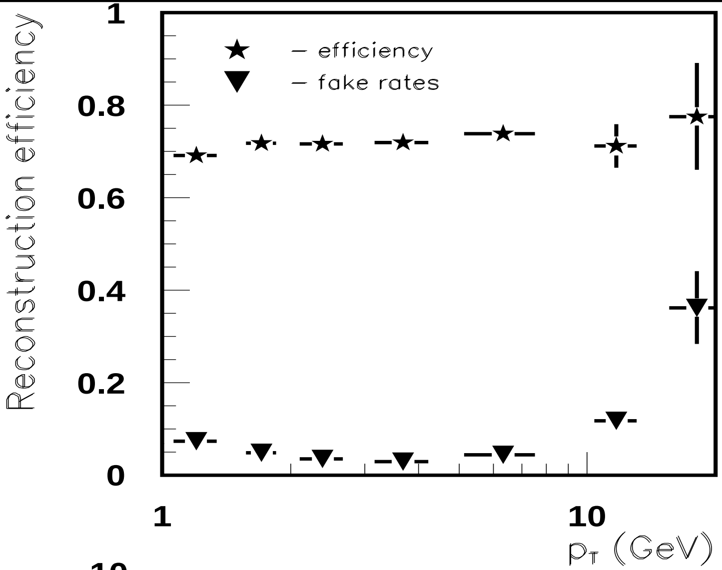
For p_T: 1 - 10 GeV/c:

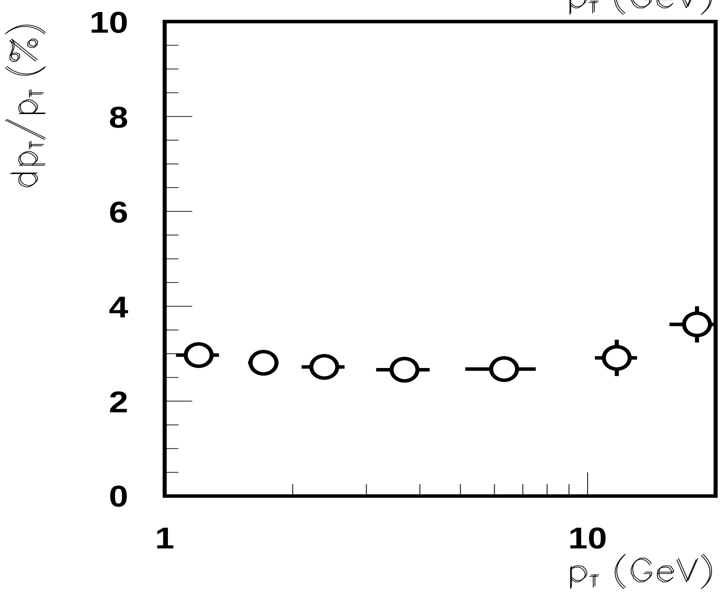
efficiency ~ 70 %

fake rate ~ 5%

Momentum resolution ~ 3%

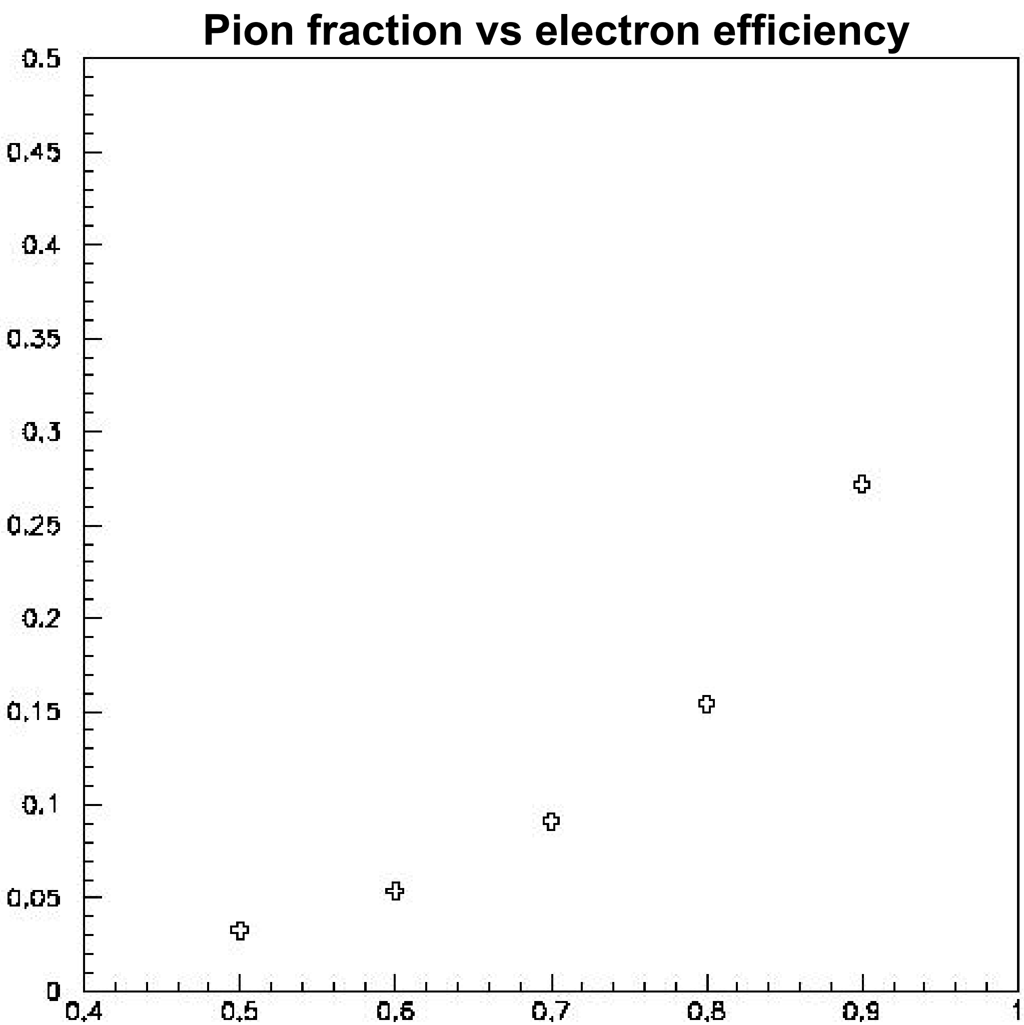
(2% - barrel, 4-5% end-caps)





Electron-pion separation in TRT

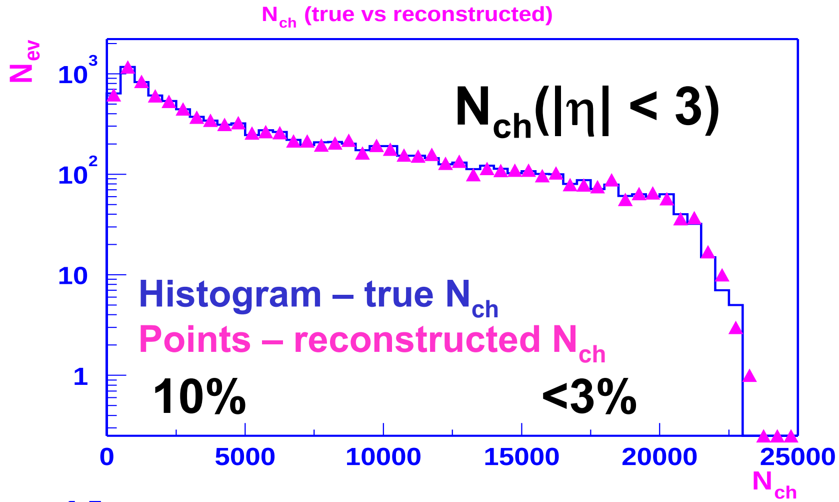
- In central Pb-PB collisions (3200 ch.particle per rapidity unit) factor 20 in pion rejection can be achieved by selecting a TR threshold corresponding to 50% electron efficiency



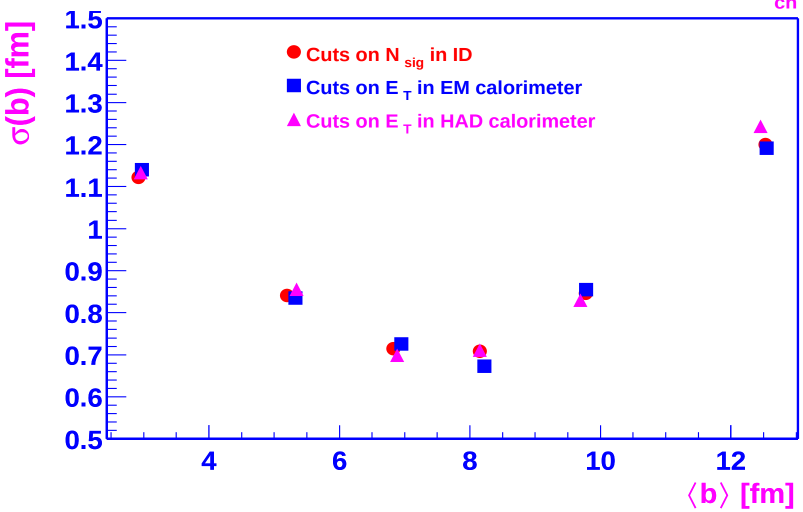
Day One Physics with ATLAS

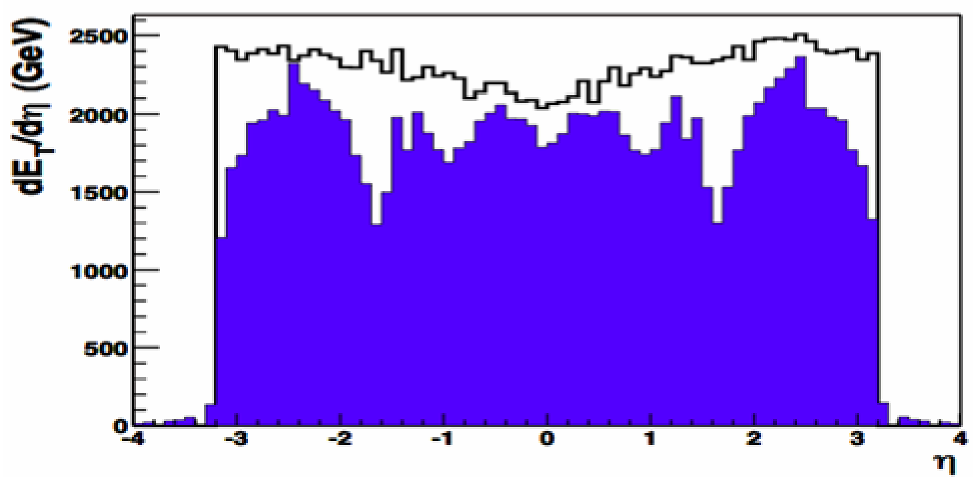
Global Event Characterization

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



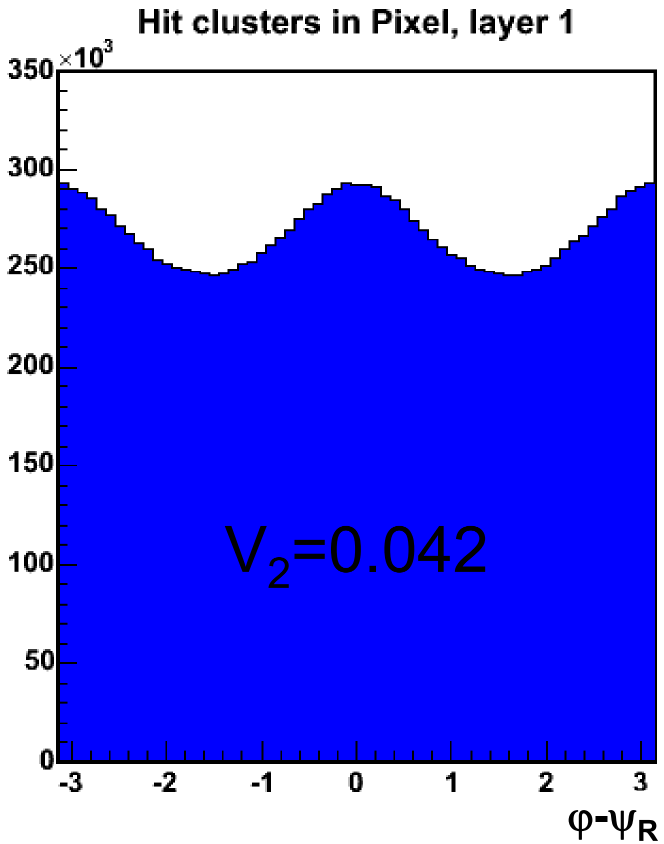
Single Pb+Pb event, b =0-1fm





No track reconstruction, only Nhits calibrated with *pp*

Correlation of Signals with Flow



Data Type	$\langle V_2(\psi_R) \rangle$
Hit clusters, Pixel layer 1	0.042
Hit clusters, Pixel layer 2	0.036
Hit clusters, Pixel layer 3	0.032
EM Barrel Calo	0.029
EM EndCap Calo	0.031
EM FCAL Calo	0.036
HAD FCAL Calo	0.025
	$v_2^{Truth} = 0.05$

Distribution of azimuthal angle φ (v_2) vs true reaction plane position, ψ_R

Jet Physics

Jet Rates

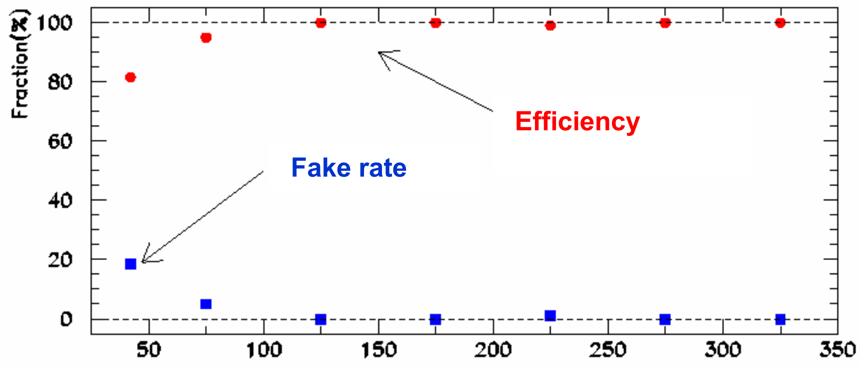
For a 10^6s run with Pb+Pb at $L=4\times10^{26}\ cm^{-2}\ s^{-1}$ we expect in $|\eta| < 2.5$:

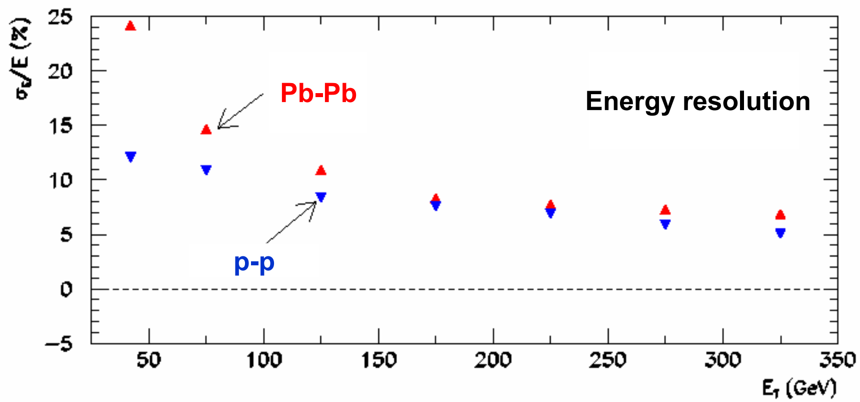
E_T threshold	N_{jets}
50 GeV	30×10^6
100 GeV	1.5×10^6
150 GeV	$.19 \times 10^6$
200 GeV	44×10^3

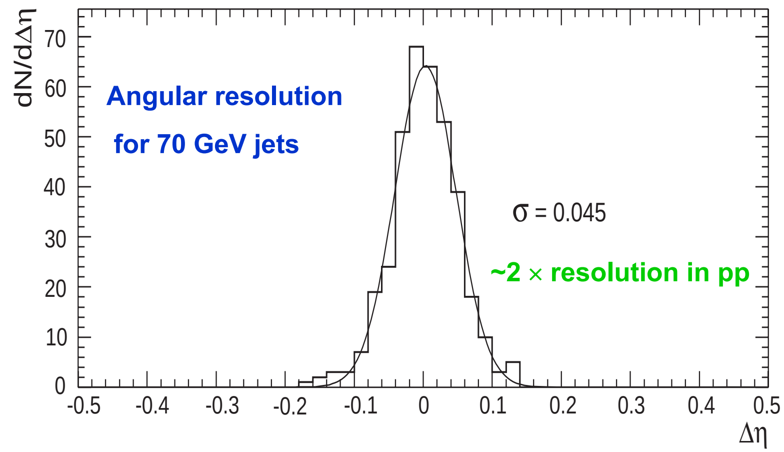
And also: ~10^6 γ + jet events
~500 $Z^0(\mu\mu)$ + jets with E_T > 40 GeV

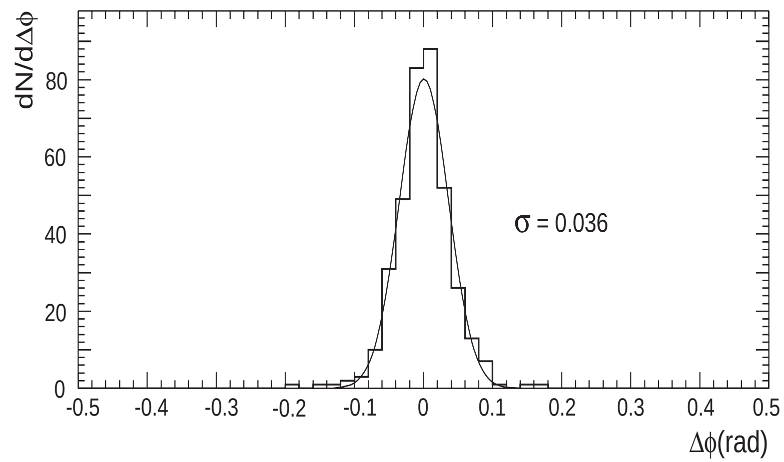
Jet reconstruction efficiency

Pb-Pb collisions (b= 0 –1 fm)



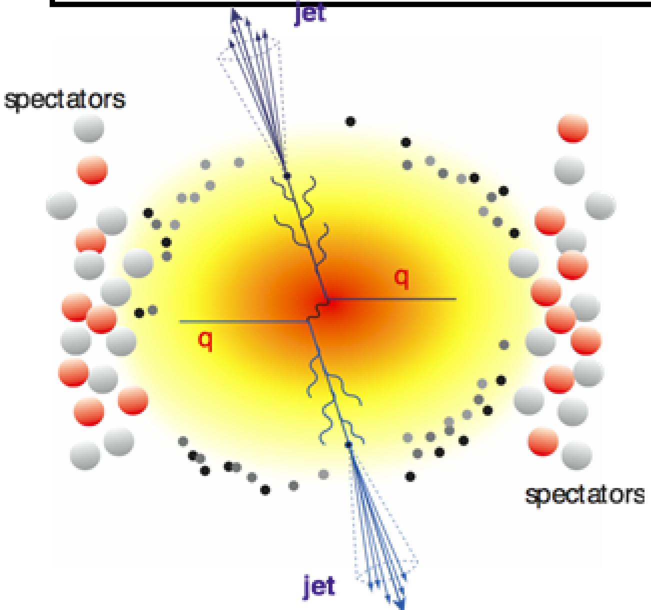


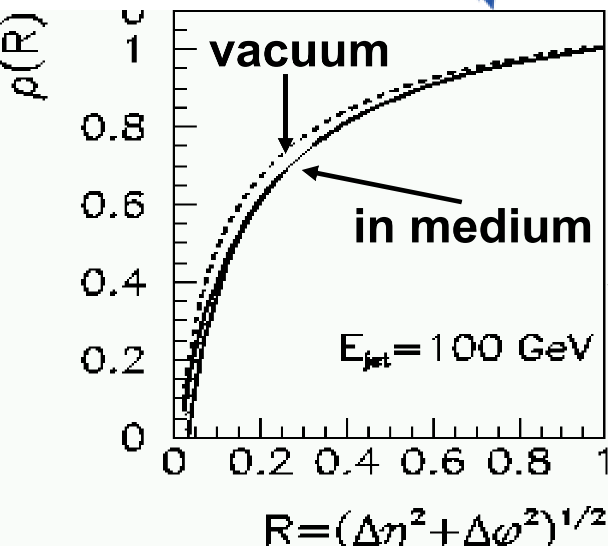




- Two jet finder algorithms testet up to now - Sliding Window and Cone Fit
- For E_T > 75GeV: efficiency > 95%, fake < 5%
- Good energy and angular resolution

Jet Quenching Studies





Most of energy is radiated inside a narrow cone (Salgado & Wiedemann hep-ph/0310079)

To determine medium properties we need to measure jet shapes

3 methods explored so far:

- **Fragmentation function using tracking**
- **Core ET and jet profile using calorimeters**
- **Neutral leading hadrons using EM calorimeters**

Quenching may depend on quark flavor:

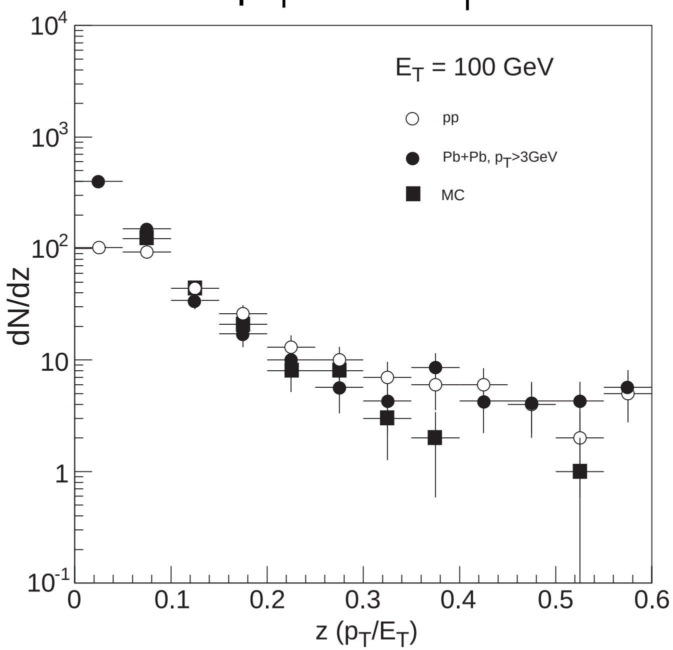
- **Tagging of b-jets using impact parameter**

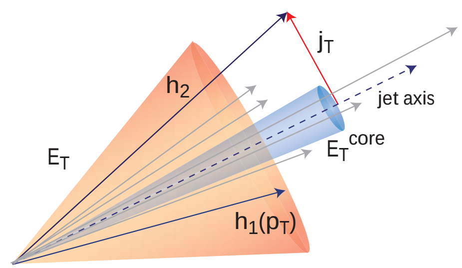
Jet Studies with Tracks

- Jets with E_T = 100 GeV
- Cone radius of 0.4
- Track p_T > 3 GeV

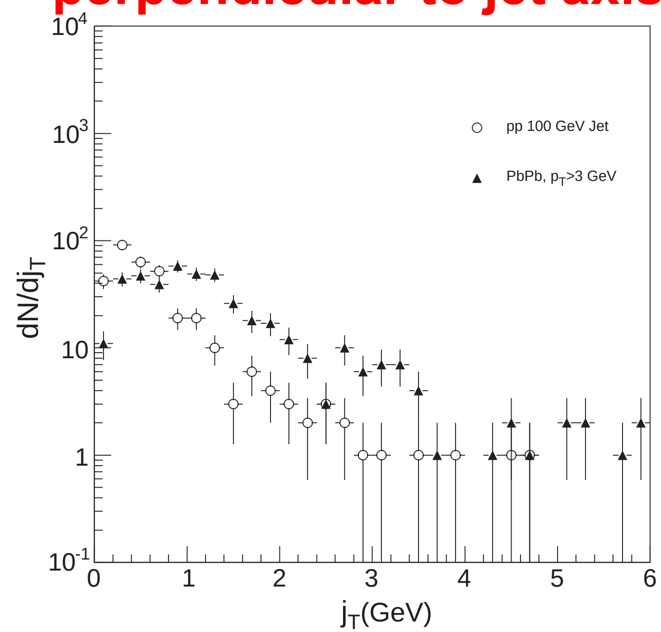
Fragmentation function

$$z = p_T^{track} / E_T^{jet}$$





Momentum component perpendicular to jet axis

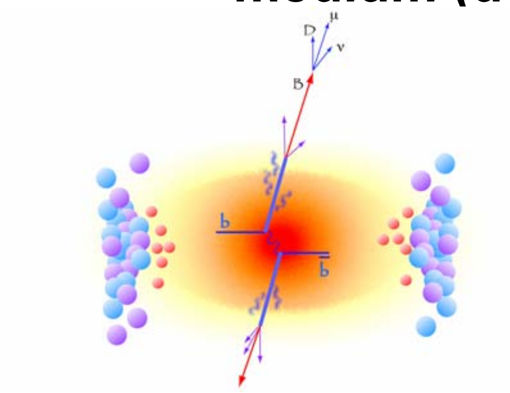


PbPb ≈ HIJING-unquenched ≈ pp

dN/dj_T broader in PbPb than in pp
(background fluctuations)

b-quark Jet Tagging

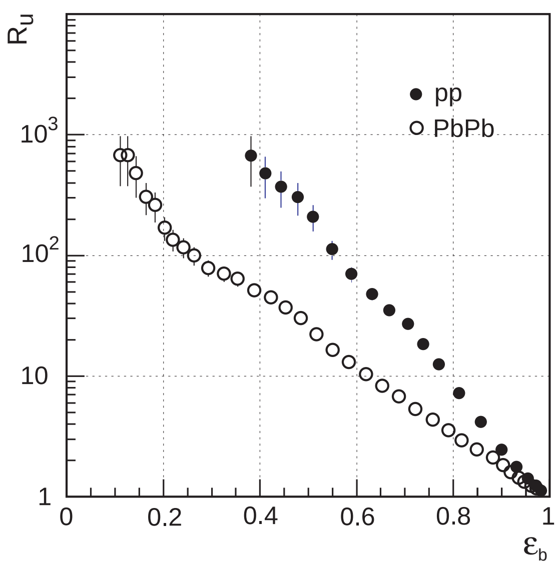
Motivation: **Heavy quarks may radiate less energy in the dense medium (dead-cone effect) than light quarks.**



b-tagging capabilities offer additional tool to understand quenching.

To evaluate b-tagging performance:

- **pp→WH→lνbb events overlayed on HIJING background have been used.**
- **A displaced vertex in the Inner Detector has been searched for.**



Rejection factor against u-jets ~ 100 for b-tagging efficiency of 25%

Should be improved by optimized algorithms and with soft muon tagging in the Muon Spec.

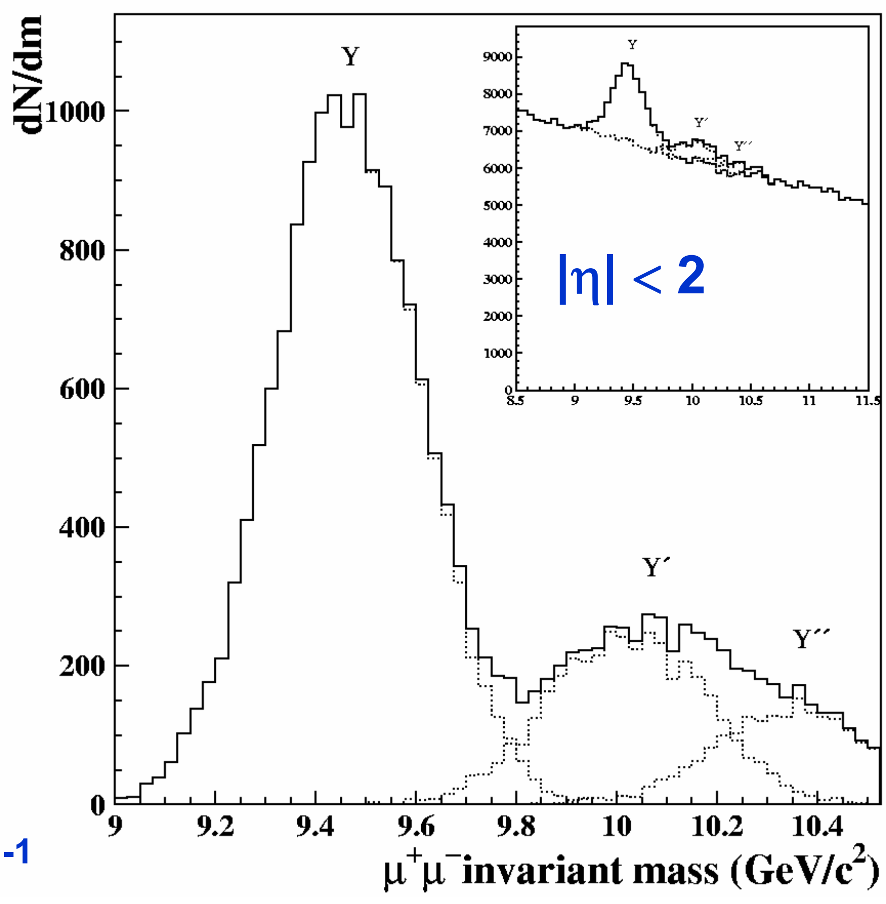
Physics with Muon Spectrometer

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

$\Upsilon \to \mu^+\mu^-$

Muons momenta measured by ID tracks tagged by coincidence with track segment in μ-spectrometer

	p_T^μ >3 GeV		
	$\lvert\eta\rvert < 1$	$\lvert\eta\rvert < 2$	$\lvert\eta\rvert < 2.5$
Acceptance + efficiency	4.7%	12.5%	17.5%
Resolution	123 MeV	145 MeV	159 MeV
S/B	0.3	0.2	0.2
$S/\sqrt{S+B}$	37	46	55
Rate/month		15,000	



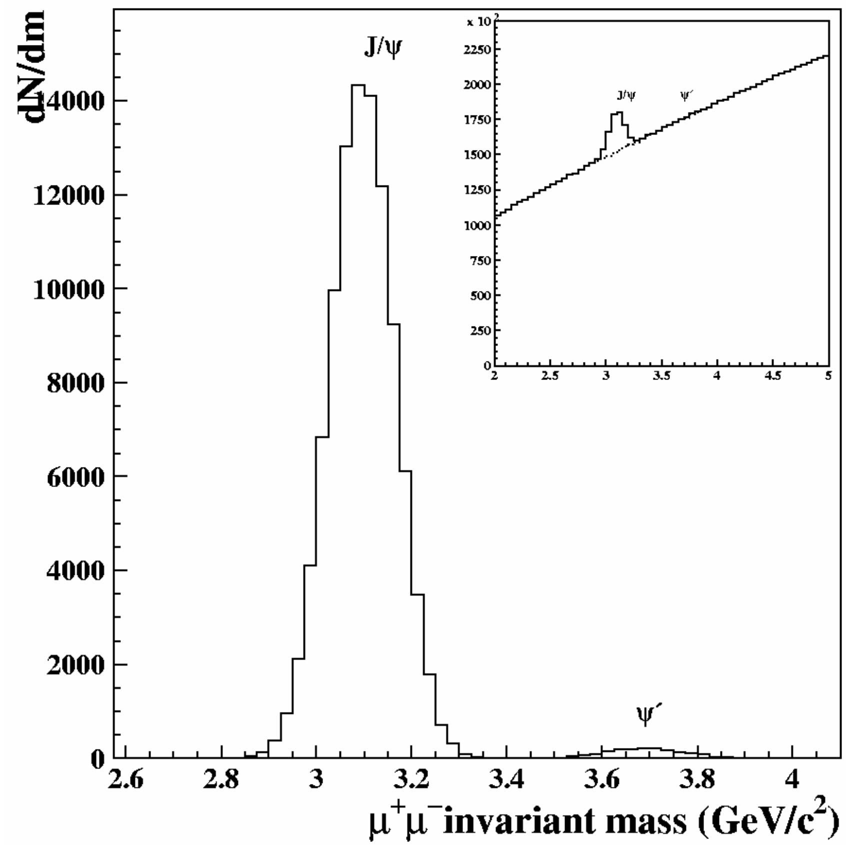
For $\lvert\eta\rvert < 2$ (12.5% acc+eff) we expect 15K Υ/month of 10^6s at $L=4\times10^{26}$ cm^{-2} s^{-1}

$J/\psi \rightarrow \mu^+\mu^-$ reconstruction

$J/\psi \rightarrow \mu^+\mu^-$

	$\|\eta\| < 2.5$	
	$p_T^\mu > 3$ GeV	$p_T^\mu > 1.5$ GeV
Acceptance + efficiency	0.055%	0.530%
Resolution	68 MeV	68 MeV
S/B	0.4	0.15
$S/\sqrt{S+B}$	56	113
Rate/month	11,000	104,000

$|\eta| < 2.5$, $p_T^\mu > 1.5$ GeV



We expect 8K to 100K $J/\psi \rightarrow \mu^+\mu^-$ per month of 10^6s at $L=4\times10^{26}$ cm^{-2} s^{-1}

If a trigger is possible forward with a muon p_T >1.5 GeV, we gain a factor 4 in statistics…A solution might be to reduce the toroidal field for HI runs

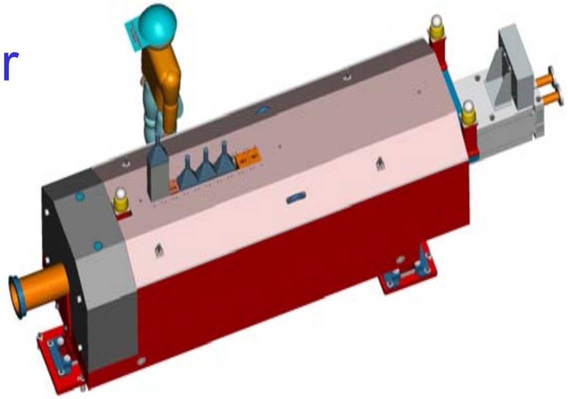
Other issues

Ultra-Peripheral Nuclear Collisions

High-energy γ-γ and γ-nucleus collisions

- Measurements of hadron structure at high energies (above HERA)
- Di-jet and heavy quark production
- Tagging of UPC requires a Zero Degree Calorimeter

Ongoing work on ZDC design and integration with the accelerator instrumentation:



Proton-Nucleus Collisions

- **Link between pp and AA physics**
- **Study of the nuclear modification of the gluon distribution at low x_F.**
- **Study of the jet fragmentation function modification**
- **Full detector capabilities (including TRT) will be available.**

L~10^{30} translates to about 1MHz interaction rate (compare to 40 MHz in pp)

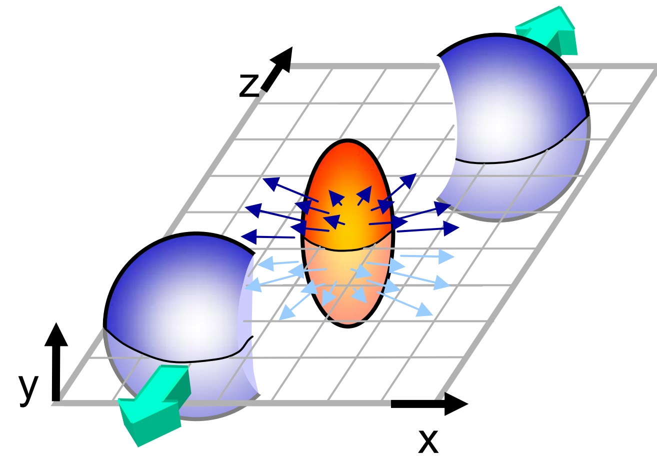
CONCLUSION

ATLAS has a very good potential for making a valuable and significant contribution to the LHC's heavy-ion physics programme:

- **Global variable measurement on Day1**

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

- **Jet measurement and jet quenching**
- **Quarkonia suppression** (J/Ψ, Υ)
- **p-A physics**
- **Ultra-Peripheral Collisions (UPC)**
- **More will come**



Direct information from QGP