Heavy Ion Physics at LHC with the ATLAS Detector

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Plan for this presentation

i. The ATLAS detector

ii. Performances Relevant to Physics

iii. A heavy ion physics program for ATLAS

iv. List of ions for the heavy ion program

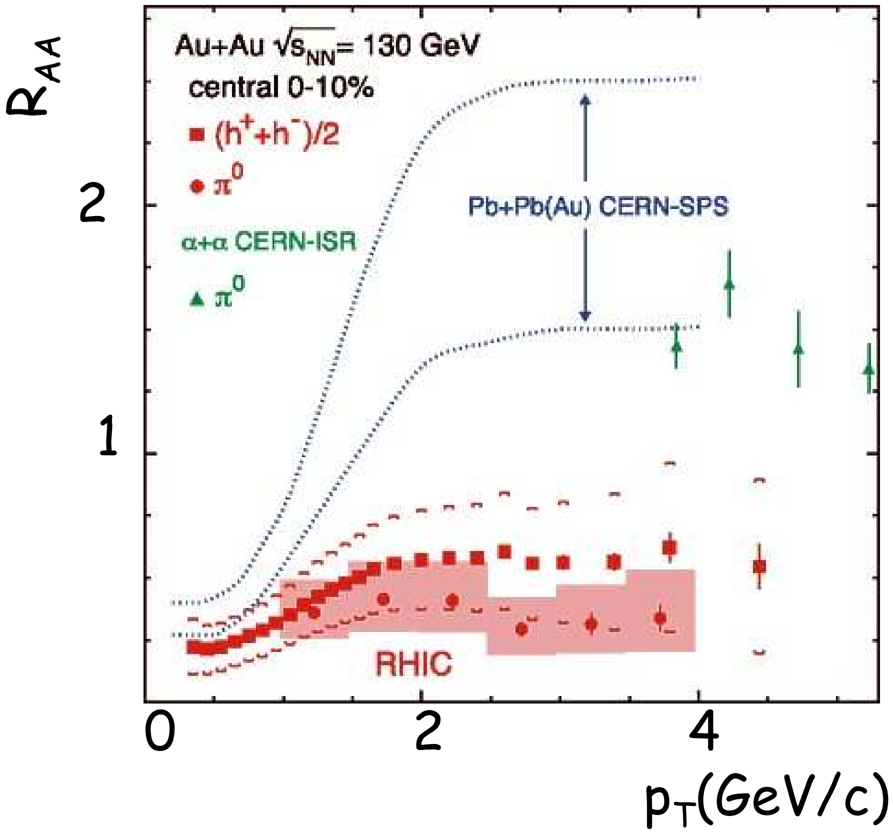
v. Summary and conclusions

ATLAS and Heavy Ions

✓Recent RHIC data suggests that jets may be *quenched.*

✓CERN theorists have been sponsoring a one year long workshop on hard probes in heavy ion physics.

✓This has sparked renewed interest by a group of physicists within ATLAS to revisit the heavy ion physics program with the detector.

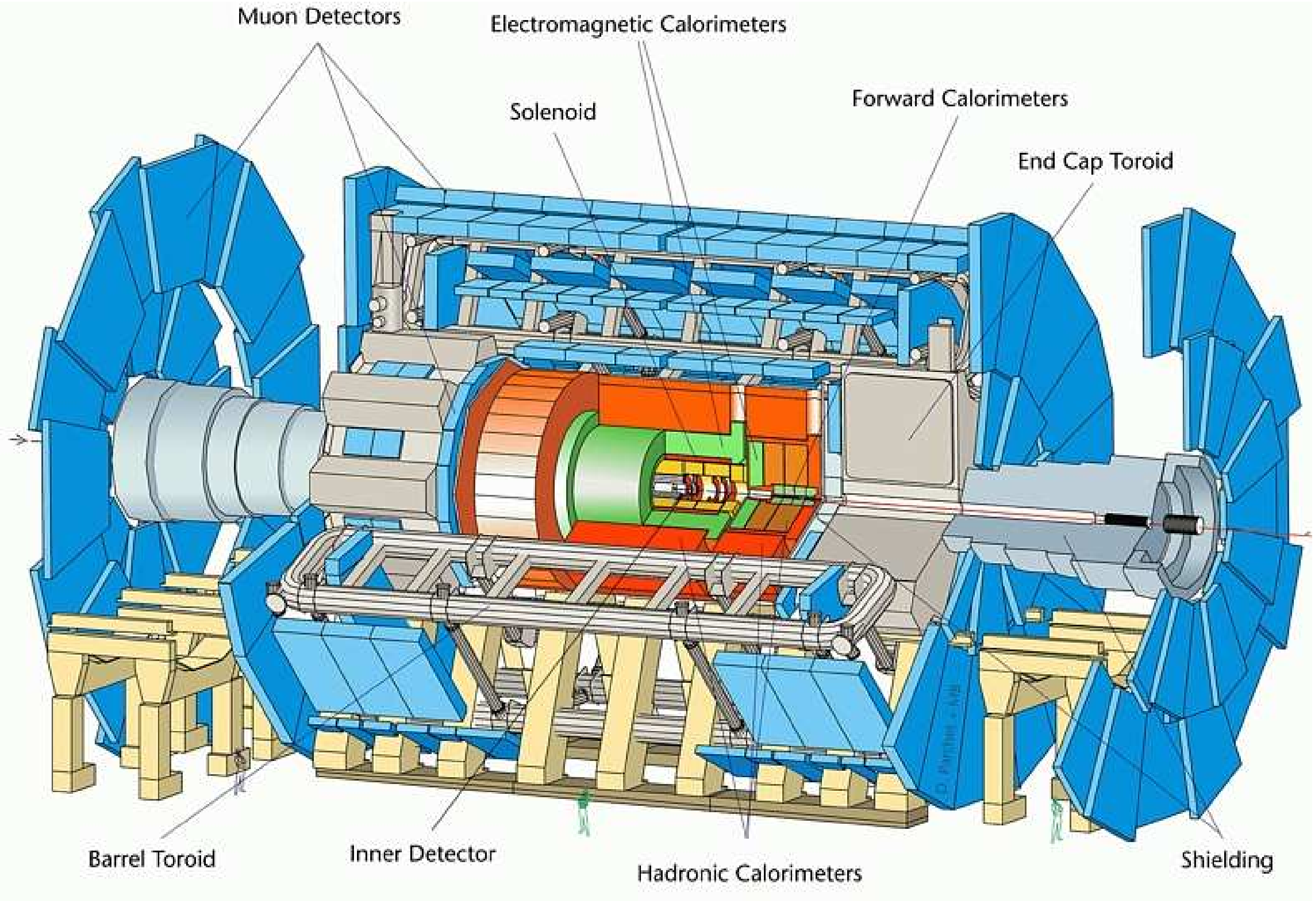


ATLAS has strong interest in heavy ion physics. Detailed evaluation of the potential has only recently started and involves people from the following institutions:

Bern, BNL, CERN, Columbia, Helsinki, Geneva, Prague and Rio de Janeiro.

This presentation outlines our current and preliminary ideas.

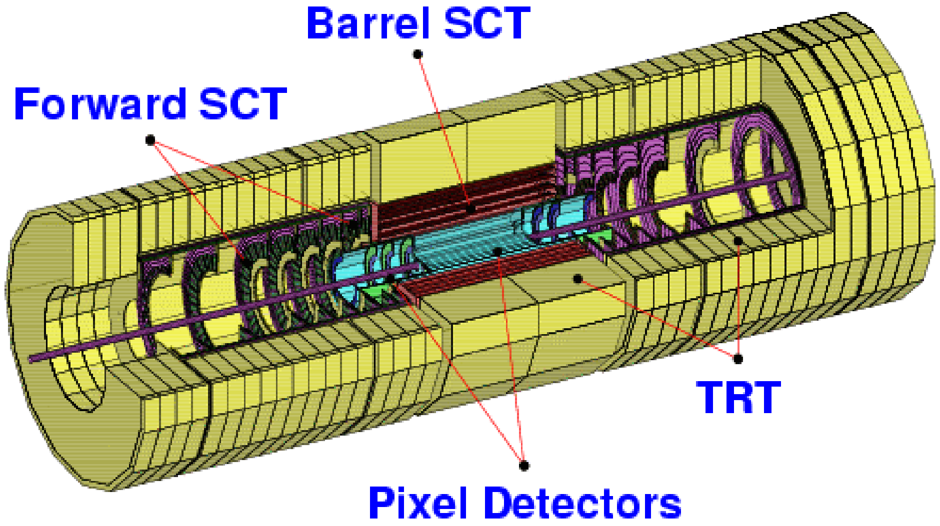
The ATLAS detector



Inner Detector

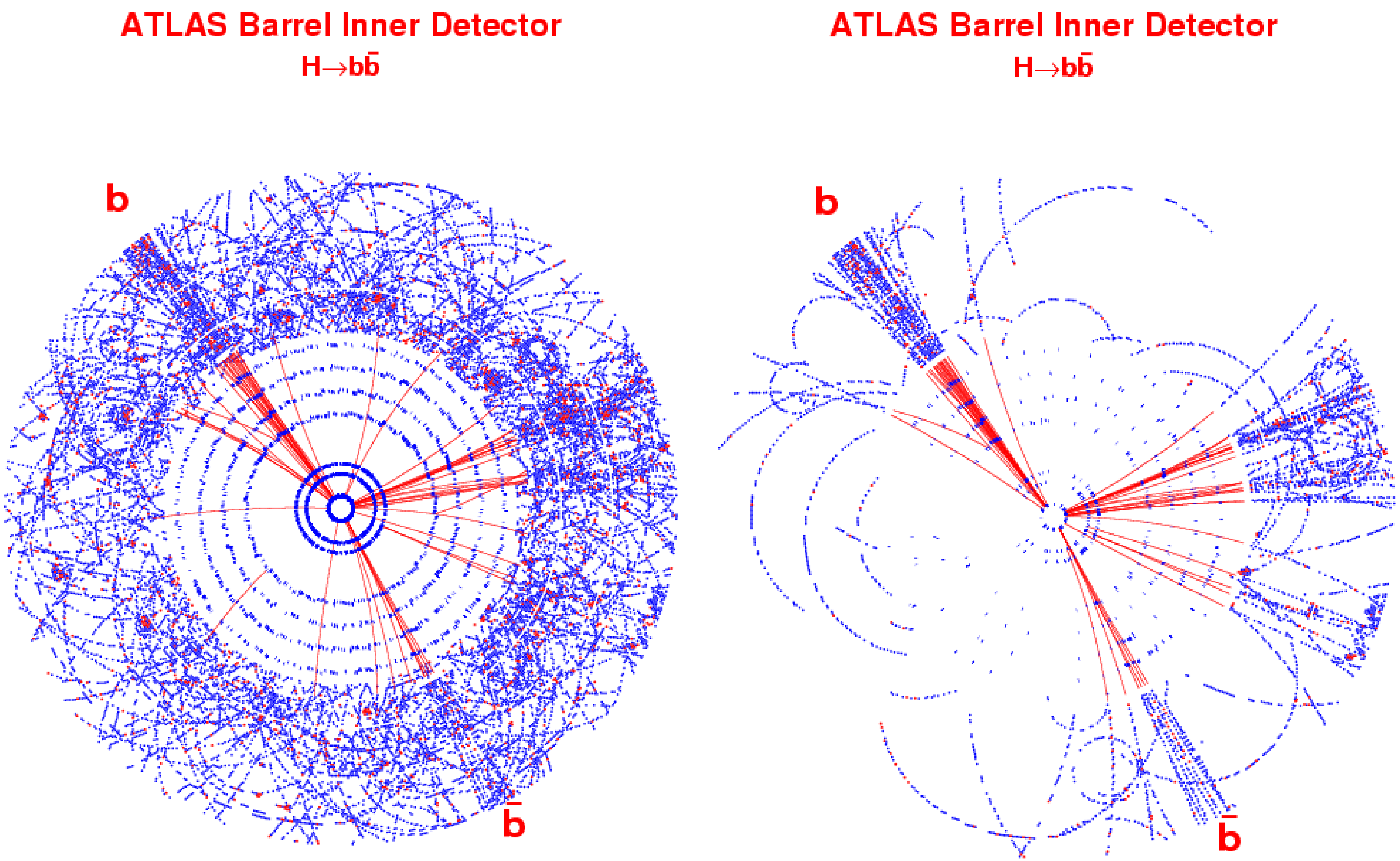
The ATLAS inner detector is composed of three systems: Pixel, SCT and TRT

Coverage of inner Detector is $|\eta|<2.5$



The first pixel layer is located at ~5cm from the beam line.

Inner Detectors



The same event, $H \to b\bar{b}$ in full and low luminosity running conditions.

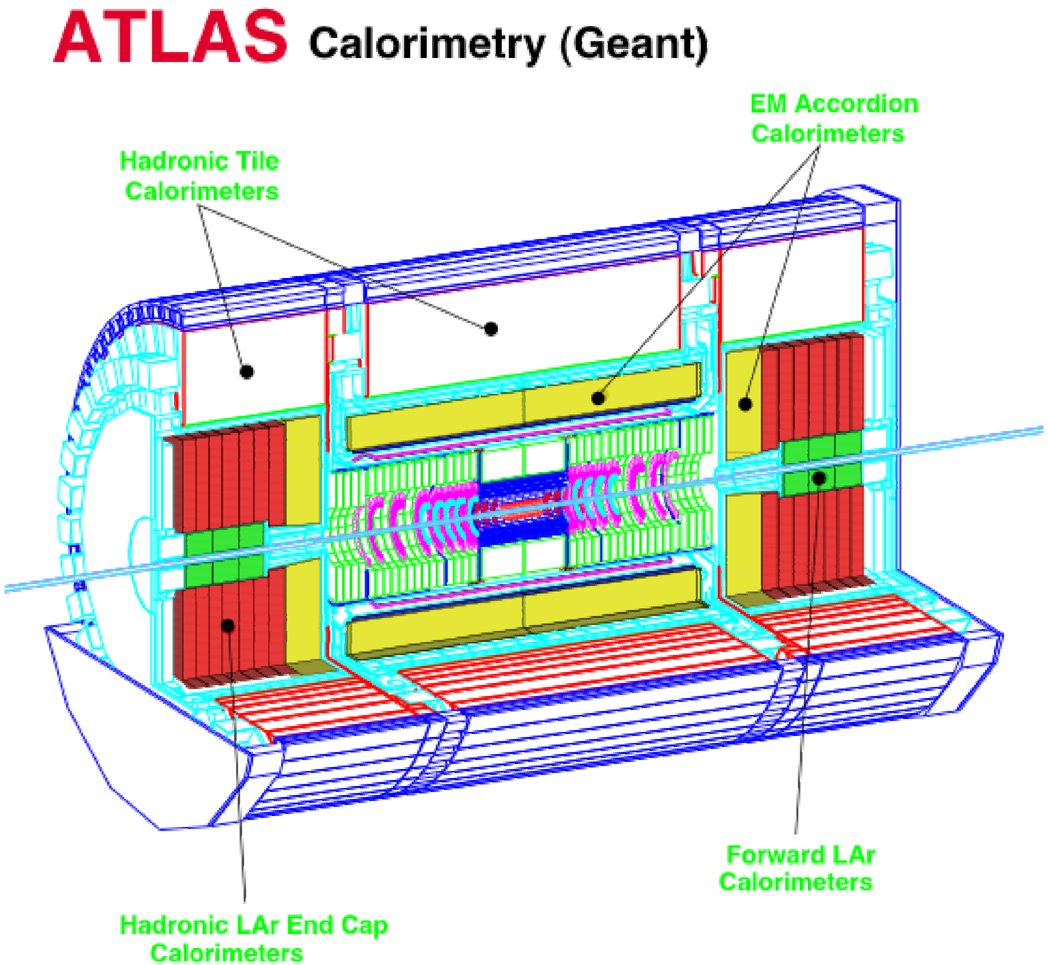
Calorimeters

✓Calorimeters in ATLAS cover a wide range of pseudo-rapidity, $|\eta|<5$.

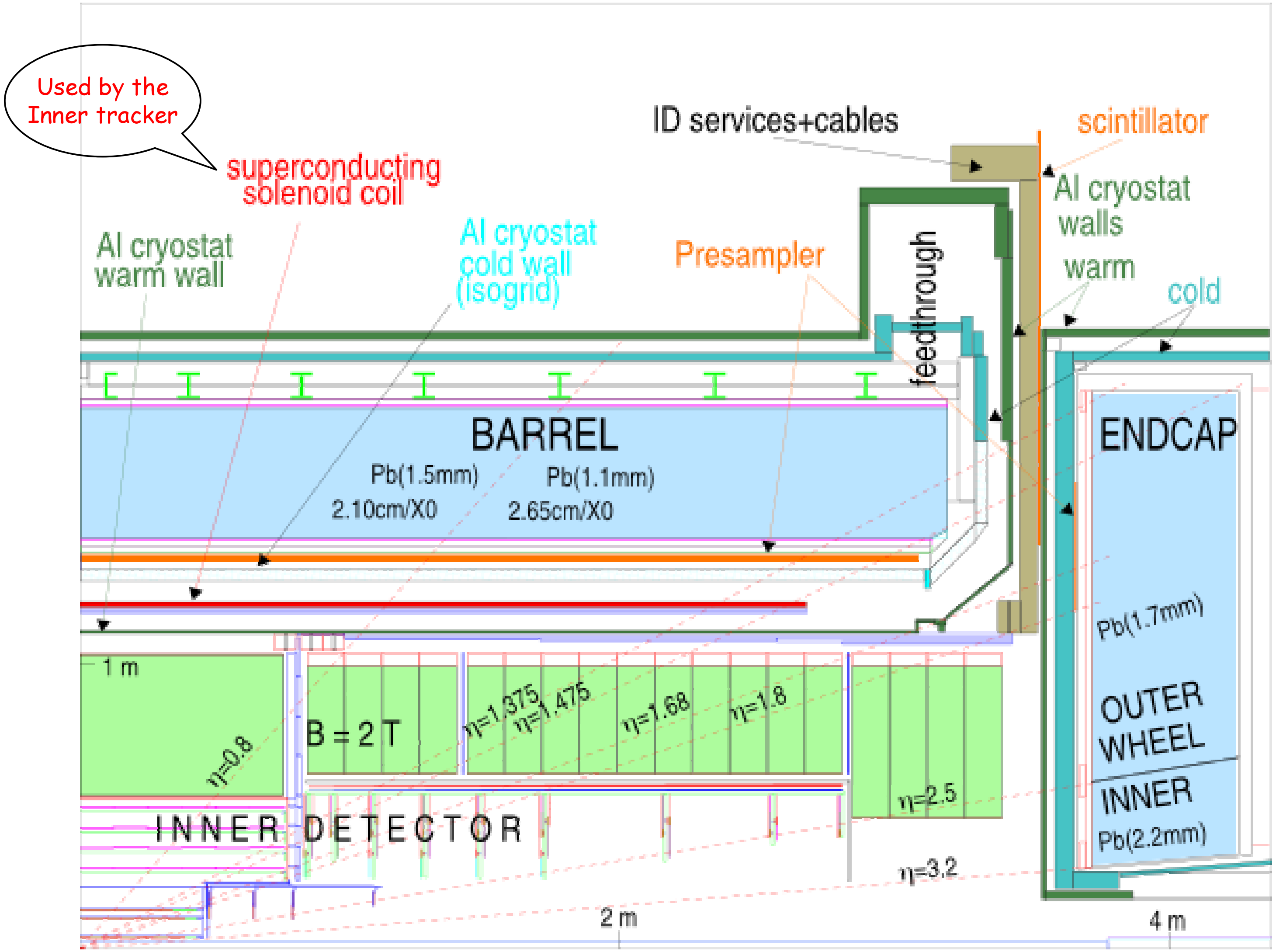
✓The electromagnetic calorimeter is realized in liquid argon technology

✓The hadronic calorimeter is implemented as a iron-scintillator device in the central region and Lar in the forward region.

✓The FCAL is integrated in the endcap cryostat.

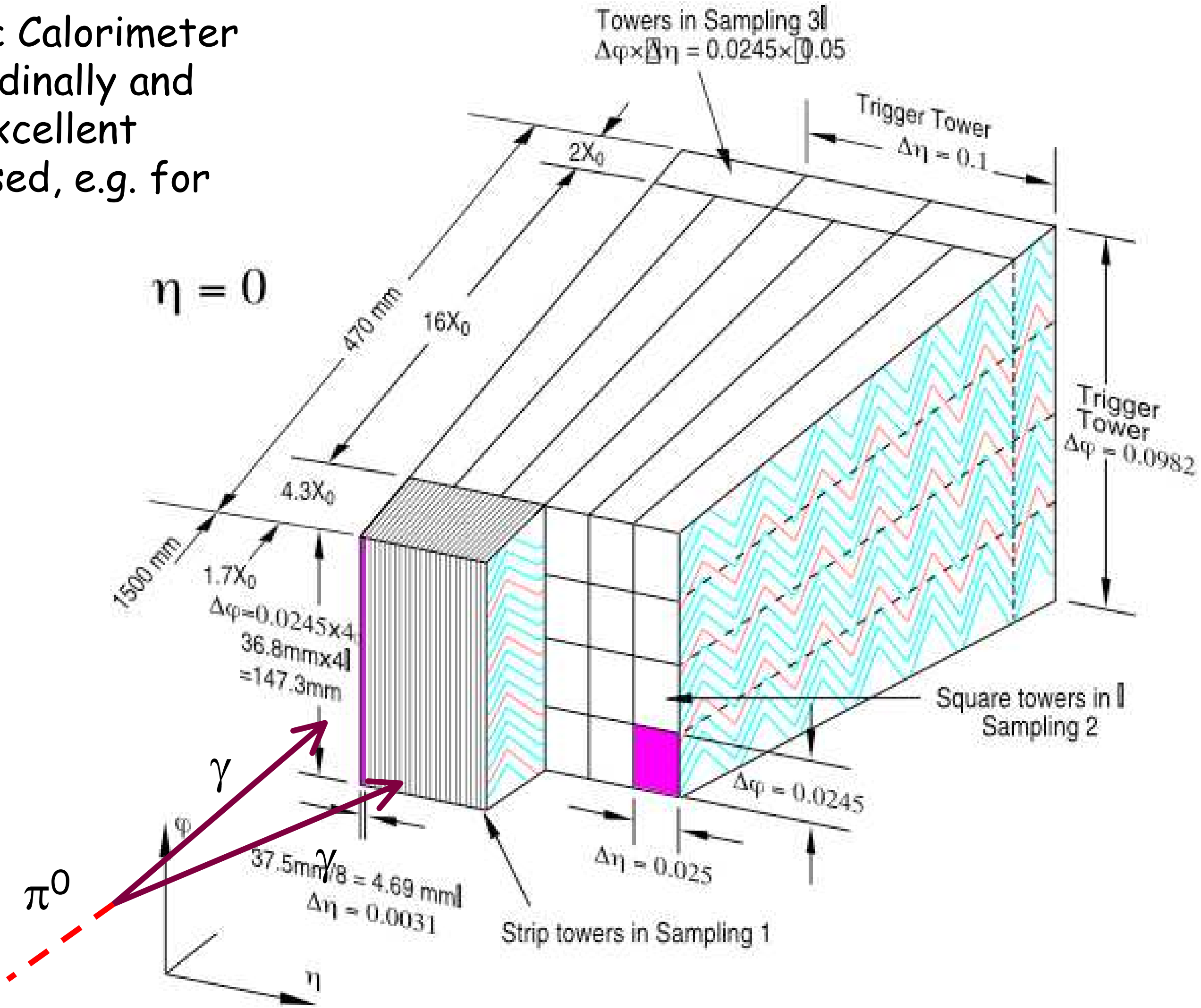


Electromagnetic Calorimeter

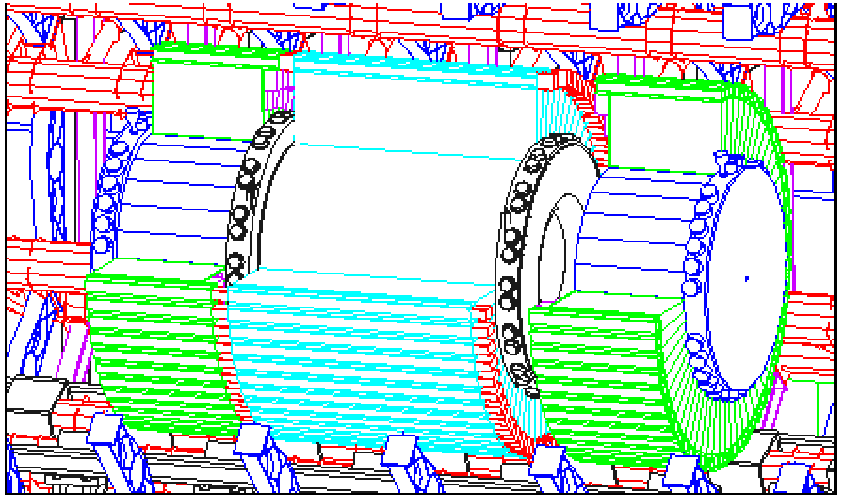


Electromagnetic Calorimeter Segmentation

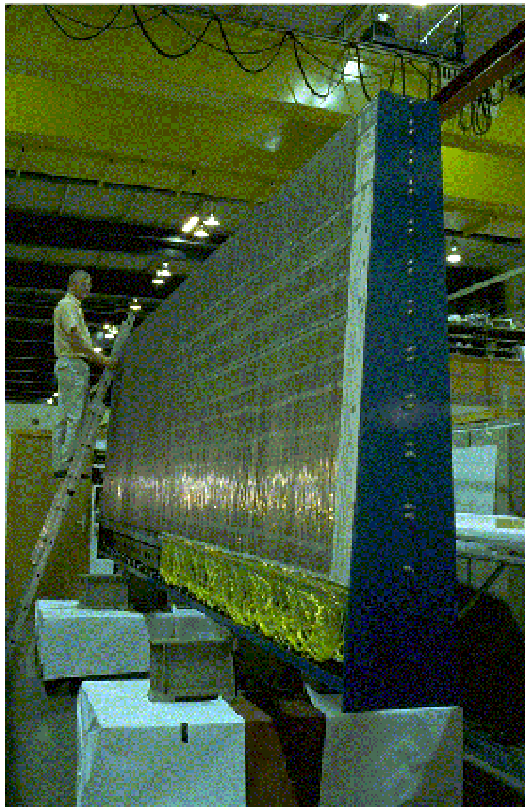
The Electromagnetic Calorimeter is segmented longitudinally and transversely. This excellent granularity will be used, e.g. for π^0 identification.



Hadronic Tile Calorimeter



The hadronic tile calorimeter 'hugs' the liquid argon electromagnetic calorimeter. It is built in iron-scintillator technology and readout by WLS optical fibers.



Calorimeters Granularity

- ATLAS calorimeters covers a large pseudo-rapidity range $|\eta|<5.0$
- Both EM and Hadronic calorimeters are segmented longitudinally in several compartments.
- The first section of the EM calorimeter is finely segmented in eta strips.

EM Barrel and Endcap

Coverage	$\|\eta\|<3.2$
Longitudinal Segmentation	3
Segmentation 1 ($\Delta\eta \times \Delta\phi$)	0.003x01
Segmentation 2	0.025x0.025
Segmentation 3	0.05x0.25

Hadronic Tile

Coverage	$\|\eta\|<1.7$
Longitudinal Segmentation	3
Segmentation 1 ($\Delta\eta \times \Delta\phi$)	0.1x0.1
Segmentation 2	0.1x0.1
Segmentation 3	0.2x0.1

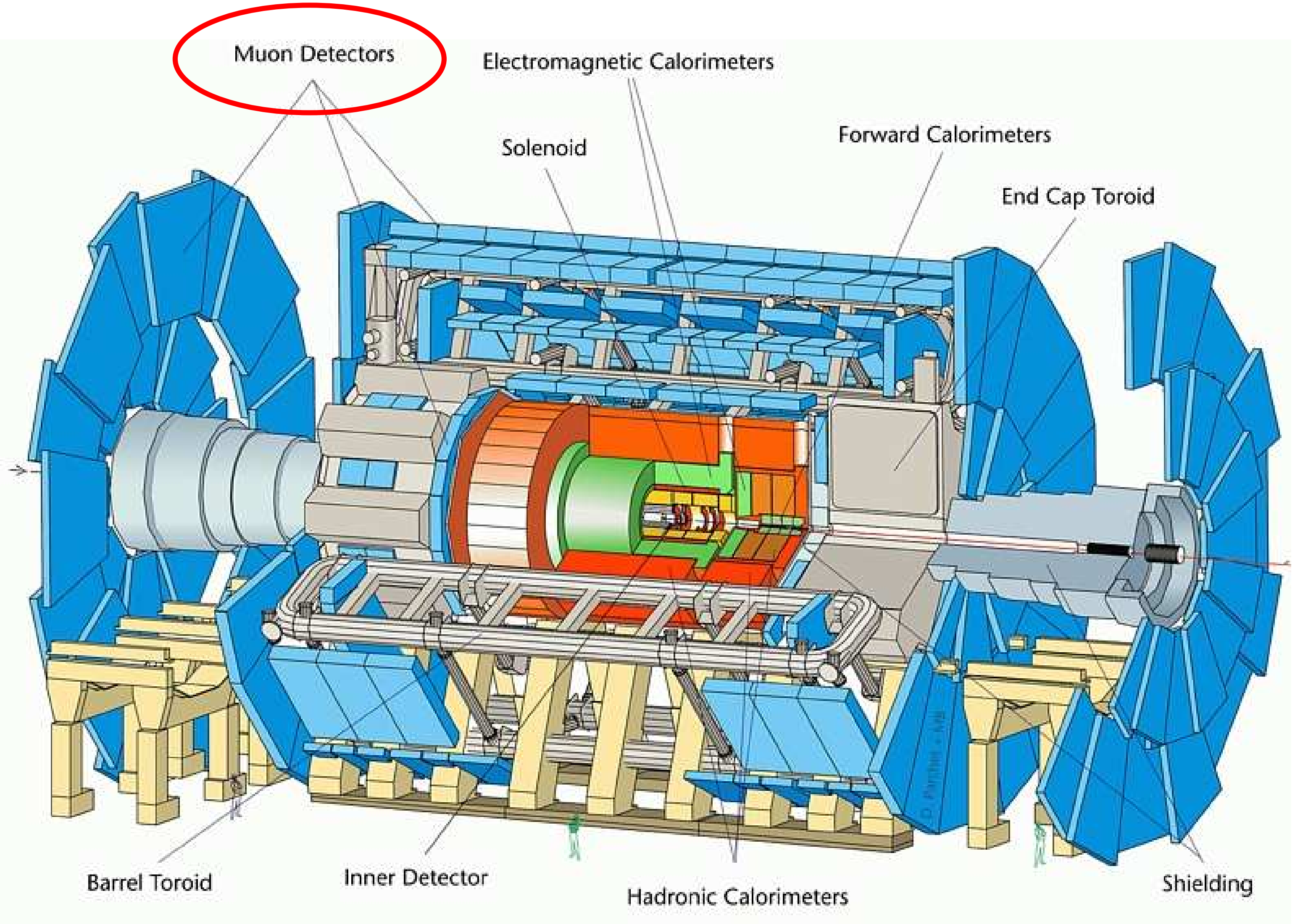
Hadronic LAr

Coverage	$1.5<\eta<3.2$
Longitudinal Segmentation	4
Segmentation $1.5<\eta<2.5$	0.1x0.1
Segmentation $2.5<\eta<3.2$	0.2x0.2

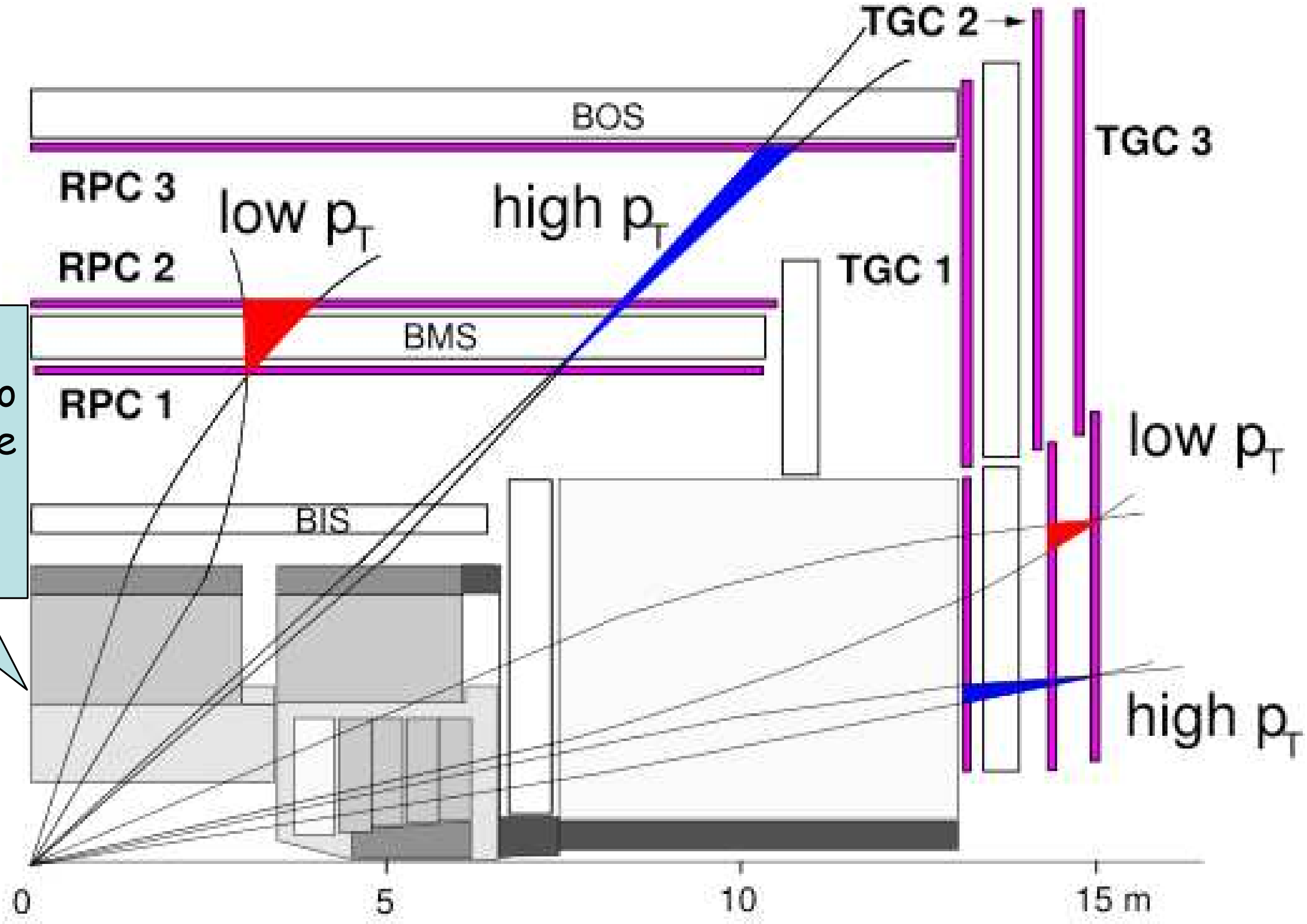
Forward Calorimeter

Coverage	$3.1<\eta<4.9$
Longitudinal Segmentation	4
Segmentation (all)	0.2x0.2

Muon Spectrometer



Muon trigger



It takes ~3 GeV to go through. The rest stops!

ATLAS and running parameters

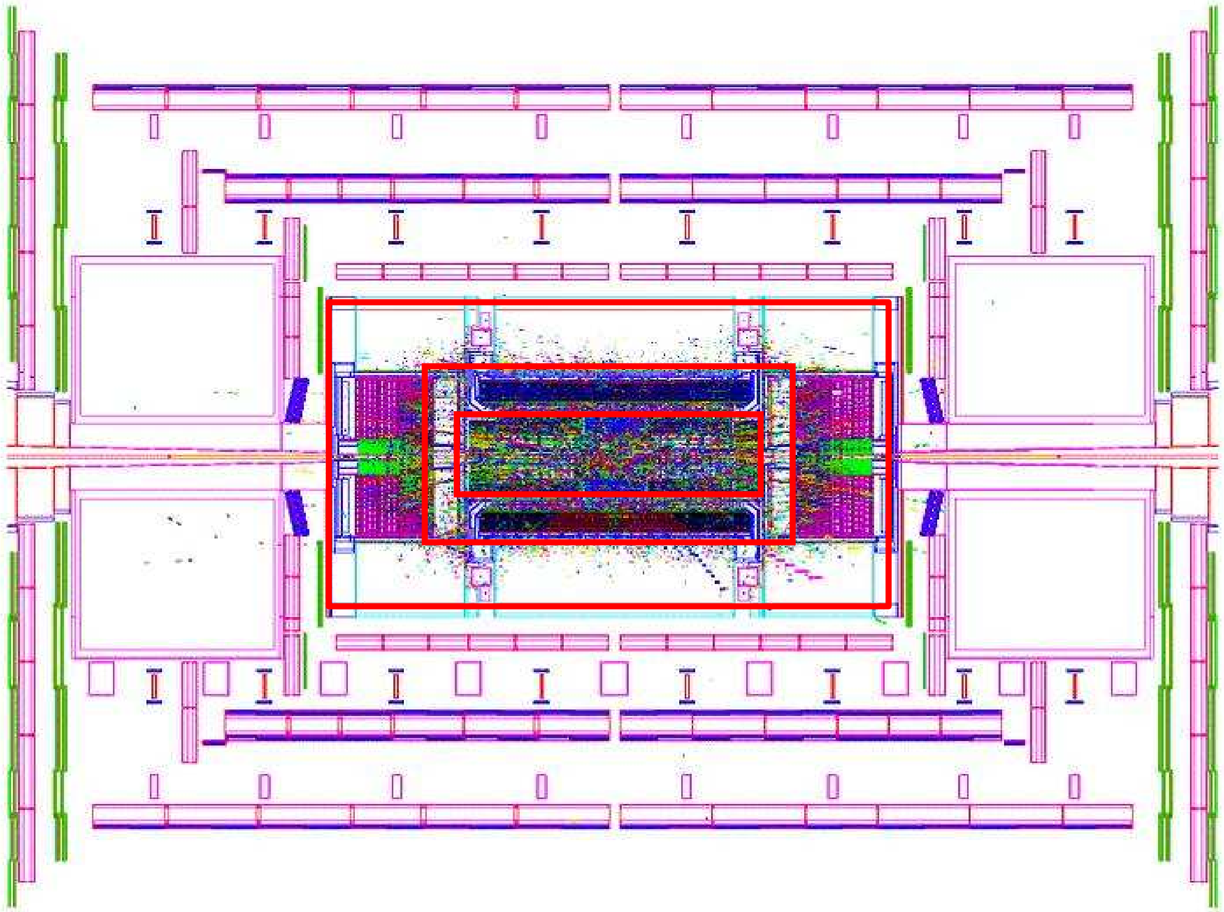
ATLAS has been designed to operate at full machine design luminosity for proton proton collisions. All subsystems, including trigger and DAQ, have been optimized for this luminosity.

Collision	R (fm)	Luminosity ($cm^{-2}s^{-1}$)	dN_{ch}/dy (maximum)	Interaction rate
p+p	~1	1×10^{34}	<250	1 GHz
$^{208}Pb+^{208}Pb$	7.1	1×10^{27}	<8000	8 kHz
$^{40}Ar+^{40}Ar$	4.1	6×10^{28}	<800	200 kHz
$p+^{208}Pb$		1×10^{30}	<150	2 MHz
$p+^{40}Ar$		1×10^{31}	<120	6 MHz

For pA multiplicities are comparable to design pp luminosity.

The Heavy Ion Environment

Event Display for $^{208}Pb+^{208}Pb$, b=0, standard ATLAS



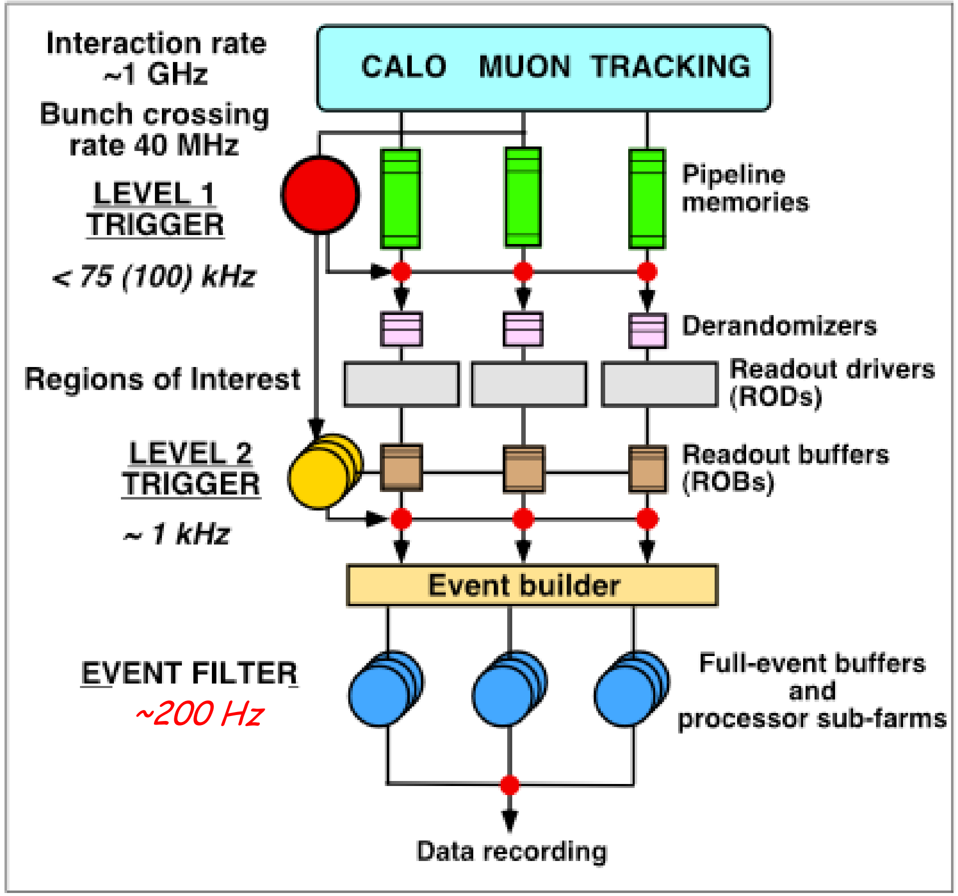
The Heavy Ion Environment (2)

Occupancy of inner detectors and average energy deposited in calorimeters for Pb+Pb collisions (b=0,dN/dy~8,000).

Detector	Occupancy (%)
Pixel	~5
SCT layer 1	~30
SCT layer 2	~20
SCT layer 3	~15
SCT layer 4	~12

Detector	$\Delta\eta x \Delta\phi$	Energy (GeV)
EM barrel	.04x.04	~2
Tile	0.1x0.1	~0.5

Trigger DAQ



For Pb+Pb collisions the interaction rate is 8kHz factor of 10 smaller than LVL 1 output rate at design pp luminosity.

We expect further reduction to 1kHz by requiring central collisions and pre-scaled minimum bias events (or high pt jets or muons).

The event size for a central collision is ~ 5 Mbytes.

Similar bandwidth to storage as pp at design L implies that we can afford ~ 50 Hz data recording.

Performance relevant to HI

The following performance issues relevant to heavy ion physics are shown here for the nominal pp design luminosity.

- EM energy resolution, angular and time resolutions
- Jet Energy Resolution
- γ/π^0 separation, γ/η, γ/jet separation
- b tagging
- muon momentum resolution
- total E_T energy resolution
- Lower E_T thresholds for reconstruction

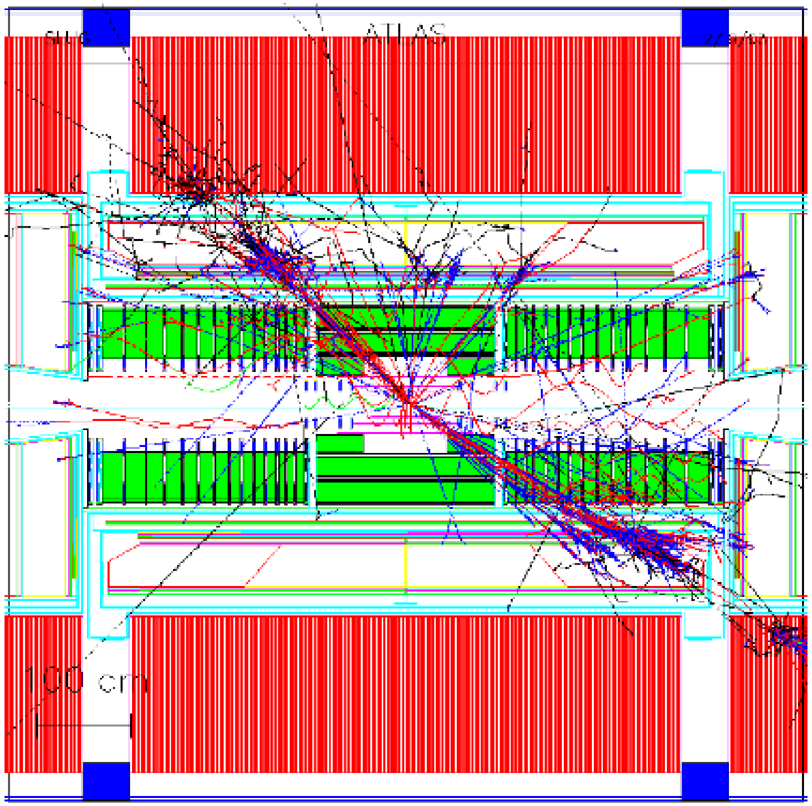
Examples of Calorimeter Performance

Electromagnetic Energy Resolution	$\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E}} \oplus 0.3\%$
EM Angular Resolution	$\sigma_\theta = \frac{60 mrad}{\sqrt{E}}$
EM Timing Resolution	$\sigma_\tau = \frac{4}{E} ns \bullet GeV$
Hadronic Calorimeter Energy Resolution	$\frac{\sigma_E}{E}(\pi) = \frac{50\%}{\sqrt{E}} \oplus 3\%$

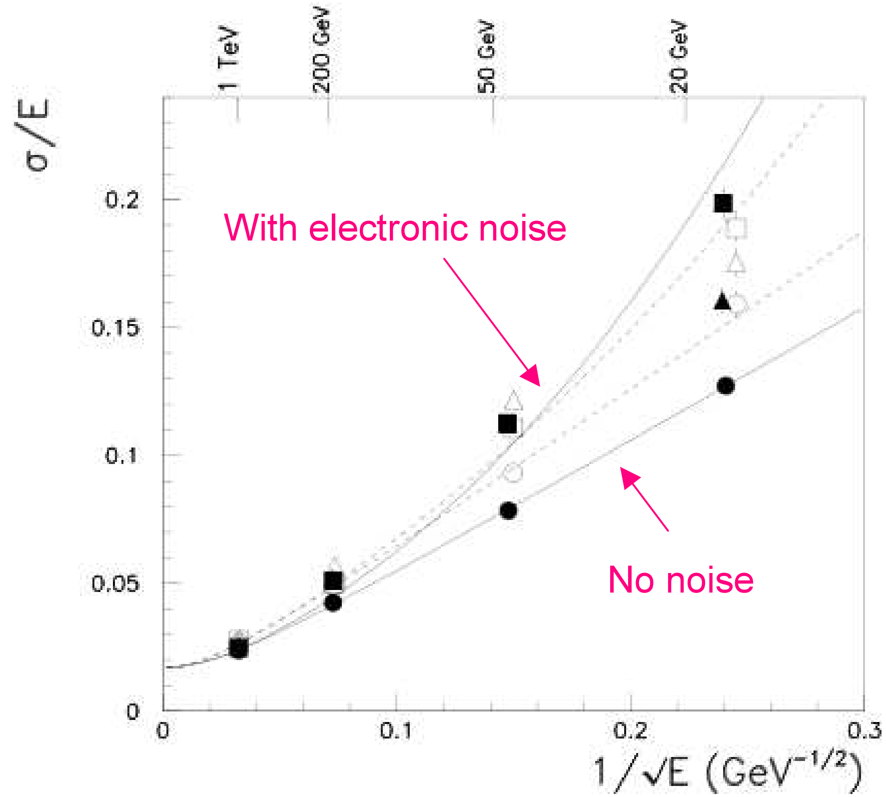
The above performance was achieved with test beam modules

Jet Energy Resolution

Jet Energy Resolution : $\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E}} \oplus 2\%$

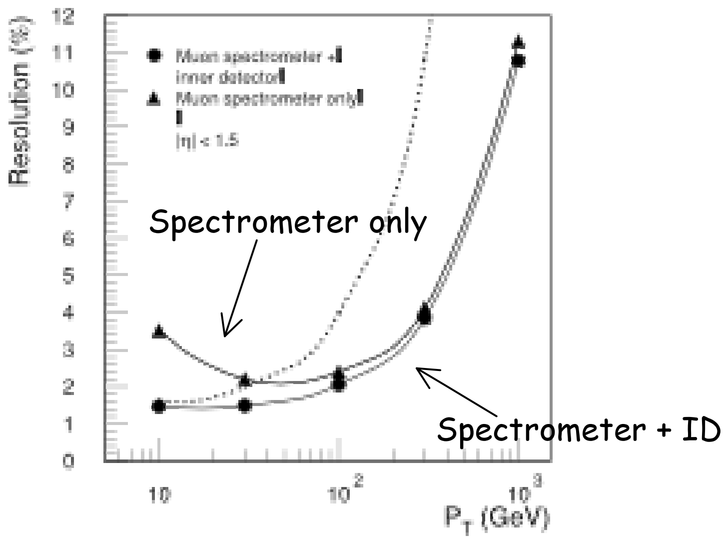


2 jet event in ATLAS

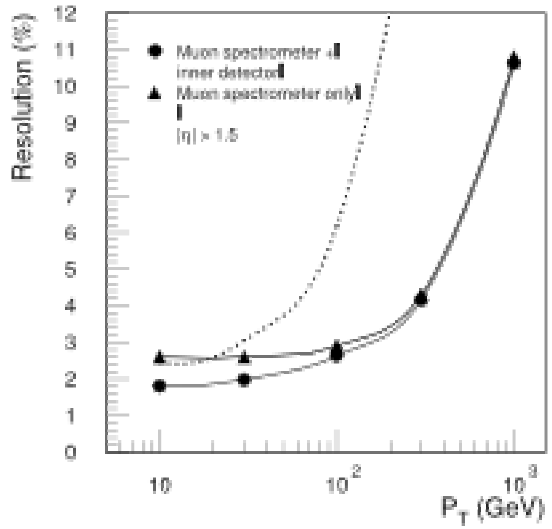


Muon Resolution Performance

Barrel



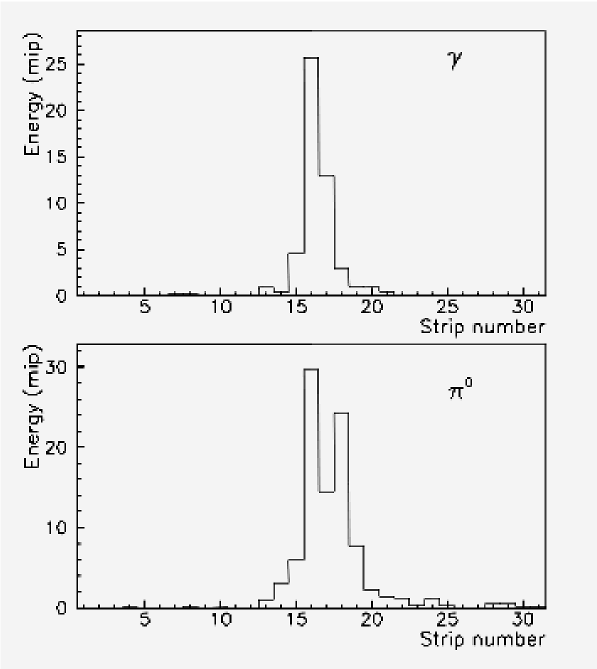
Endcap



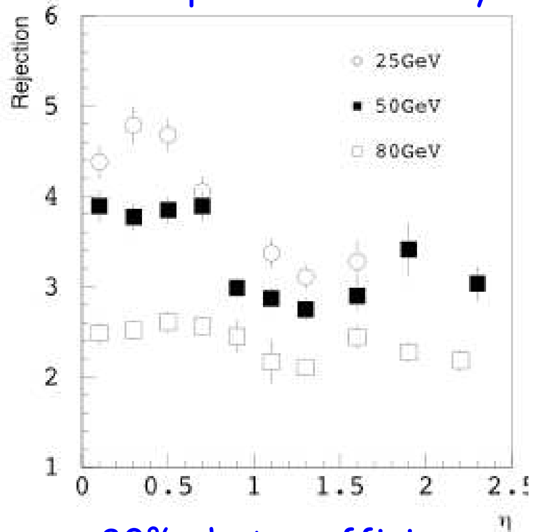
A $\Upsilon \rightarrow \mu^+\mu^-$ mass resolution at the level of 1% is expected but full simulation studies in the heavy ion environment with the relevant detector components are needed.

γ/π^0 and γ/jet separation

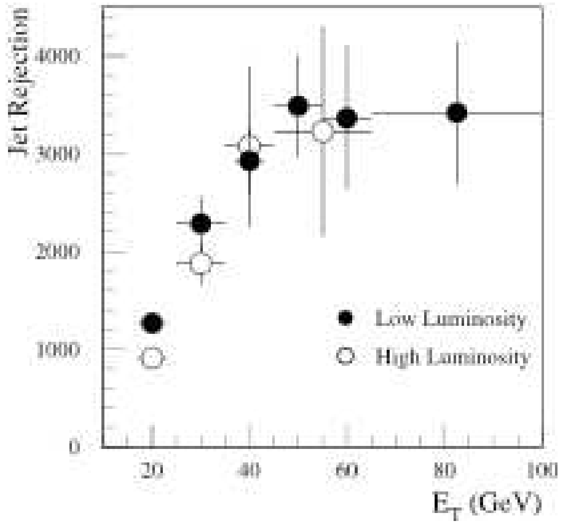
Single gamma and pi-zero shower profiles in the eta strips



90% photon efficiency



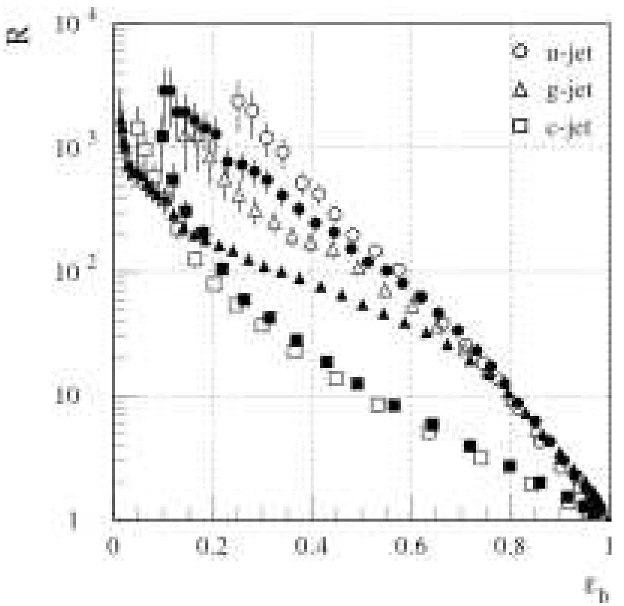
80% photon efficiency



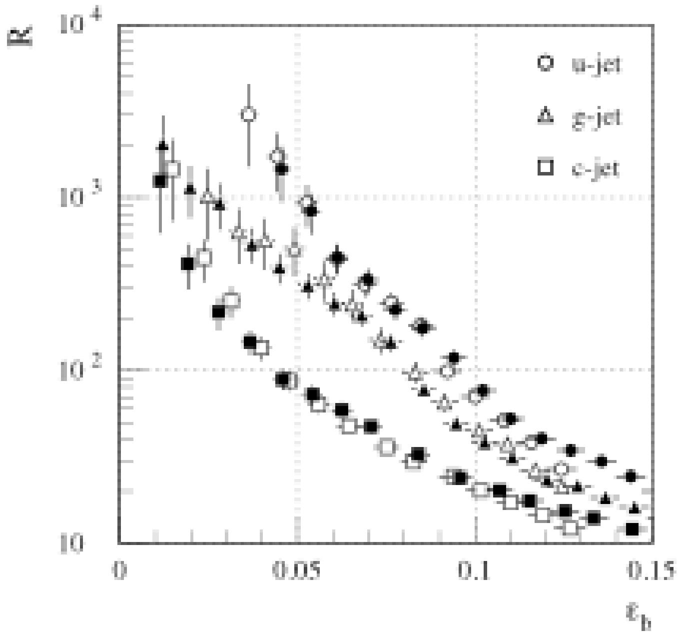
γ and π^0 reconstruction studied at p_T ~ 5GeV. Studies for higher p_T has started. Good η-strip performance for particle identification give some hope.

B tagging

Vertex tagging and soft muon tagging

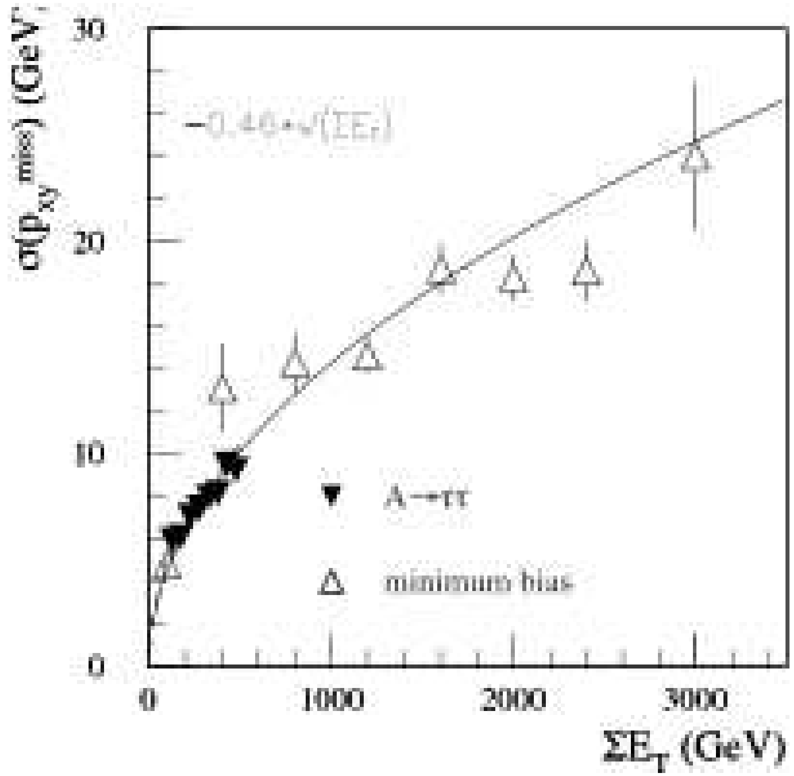


Jet rejection factors for vertex b-tagging method with high luminosity pile up. Open symbols for m_H=100 GeV, full symbols: m_H=400 GeV.



Rejection factors as function of b-jet efficiency for the muon tags. Both muon spectrometer and tile cal information are used.

(Missing) ET resolution



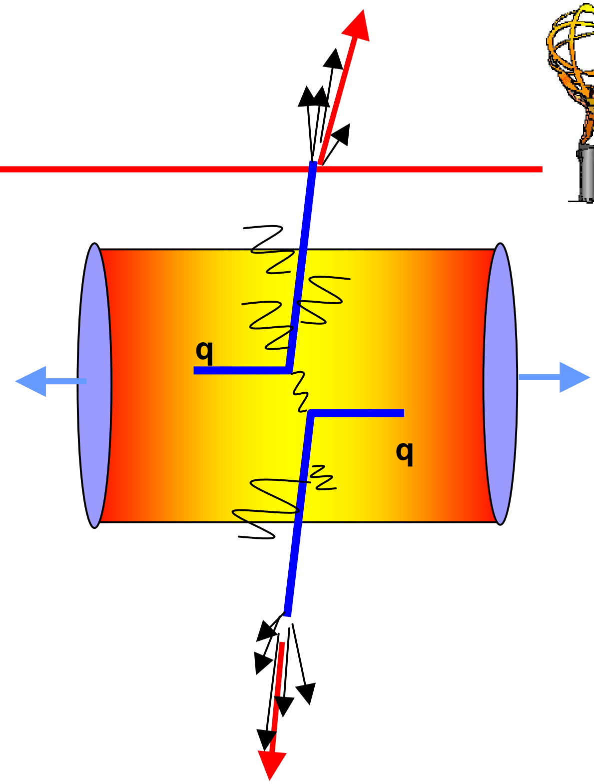
Excellent ΣE_T resolution can be parameterized as: $0.6 * \sqrt{\Sigma E_T}$

Thresholds for particle reconstruction

For proton-proton at full luminosity the approximate detection thresholds are the following:

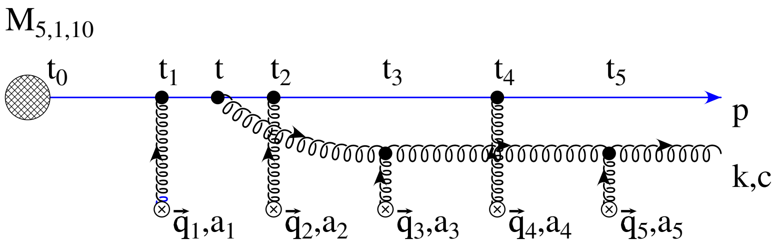
Muon	p_T > 3 GeV	
Electrons and Photons	E_T > 5 GeV	(5 GeV PbPb?)
Jets	E_T> 15 GeV	(40 GeV PbPb?)

Physics topics



Partons are expected to lose energy via induced gluon radiation in traversing a dense partonic medium.

Coherence among these radiated gluons leads to $\Delta E \propto L^2$



Baier, Dokshitzer, Mueller, Schiff, hep-ph/9907267
Gyulassy, Levai, Vitev, hep-pl/9907461
Wang, nucl-th/9812021
and many more…..

ATLAS calorimetry (excellent coverage, resolution and granularity) has good potential to study jet quenching with jet+jet, γ+jet, Z^0+jet.

By using different heavy ion species we can measure the modification of jet properties vs the gluon density and path length

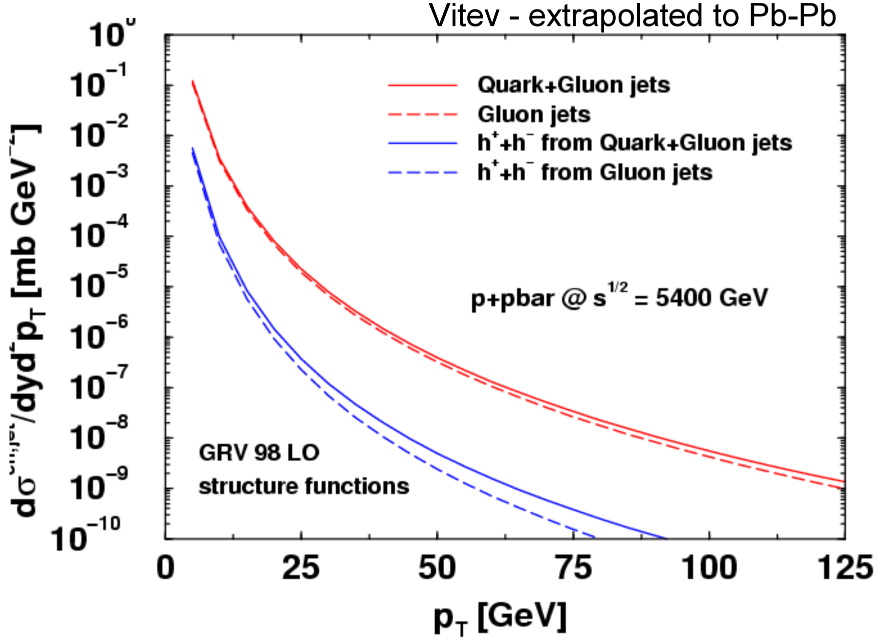
Jet Rates in ATLAS

In one month (10^6 s) of Pb-Pb running with three operational experiments at LHC, ATLAS will measure an enormous number of jets.

<u>ATLAS accepted jets for central Pb-Pb</u>

Jet p_T > 50 GeV	**30 million !**
Jet p_T > 100 GeV	**1.5 million**
Jet p_T > 150 GeV	**190,000**
Jet p_T > 200 GeV	**44,000**

Vitev - extrapolated to Pb-Pb



Note that every accepted jet event is really an accepted jet-jet event since ATLAS has a wide phase space coverage !

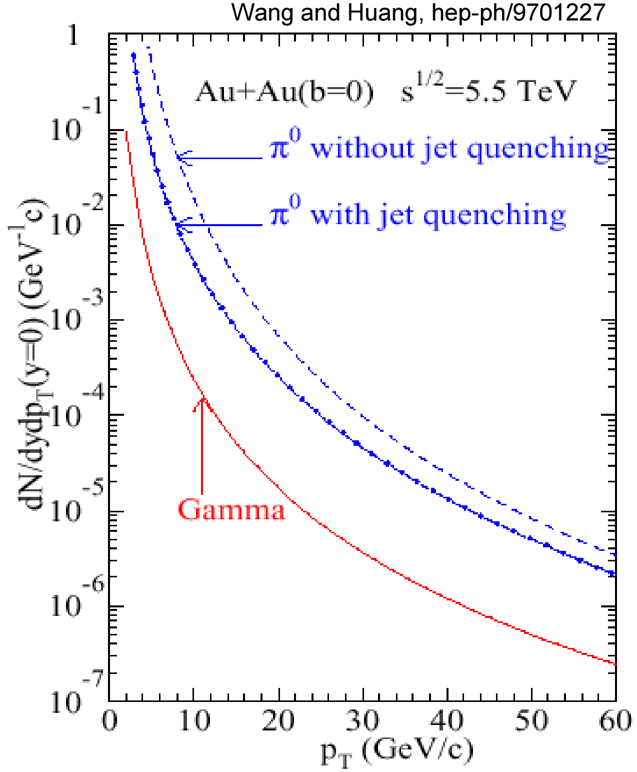
Event Rates for jet-quenching

✓In one month (10^6 s), over 1000 events with γ of p_T = 60 GeV in a 1 GeV bin! Or 10^6 events above p_T > 40 GeV.

✓In one month in central Pb-Pb, ATLAS would accept ~10,000 events with p_T > 40 GeV in the γ^* (μ+ μ-) + jet.

✓Z^0-jet reconstruction is possible, but less than 500 total Z^0 events per month.

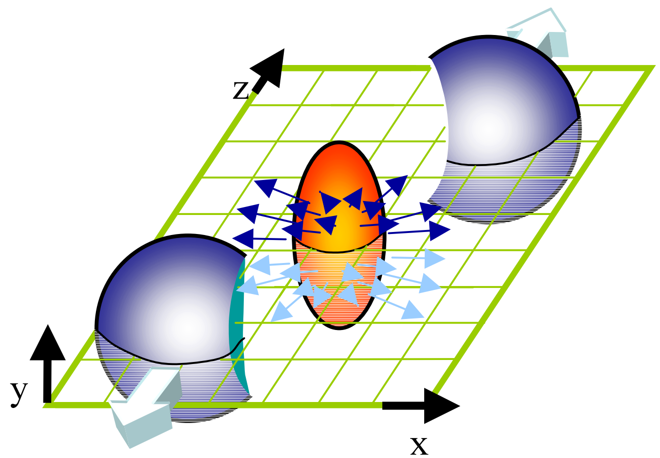
Wang and Huang, hep-ph/9701227



Global Variables

ATLAS should be able to measure global observables and have high statistics for correlating them with high p_T probes, for example:

- ✓ Transverse energy (with very good resolution) and energy flow.
- ✓ Charged particle multiplicity (in pixel + SCT)
- ✓ Jet observables as function of reaction plane
- ✓ Azimuthal distribution of high p_T π^0 and η

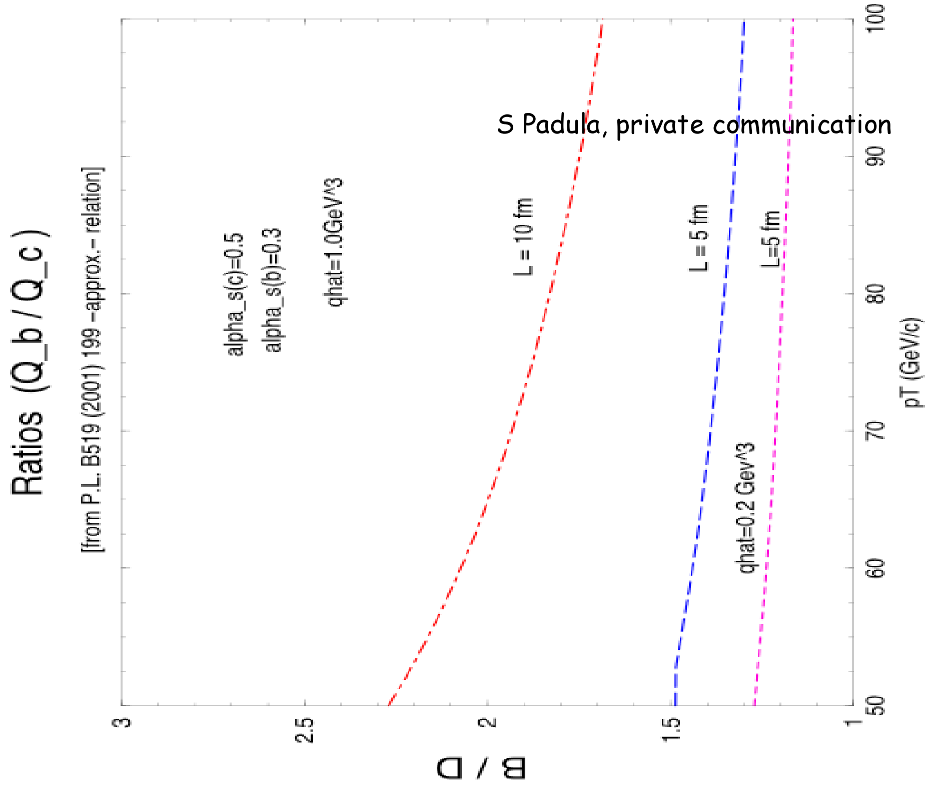


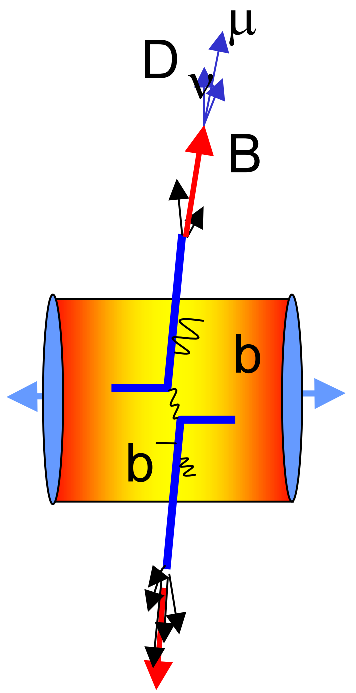
Heavy Quarks

Radiative quark energy loss is qualitatively different for heavy and light quarks.

b-quarks lose less energy than light quarks.

ATLAS can tag b jets via soft muon tag and compare their energy loss with light quarks.





Y.L.Dokshitzer and D.E. Kharzeev, hep-ph/0106202

Different HI species are useful because the effect depends on the size of colliding system.

pA physics

- Study of p-A collisions is important @ LHC
  - To provide baseline for heavy ion measurements.
  - Physics intrinsically compelling
    - Nuclear Structure function
    - Mini-jet production, multiple semi-hard scattering.
    - Gluon saturation – probe QCD @ high gluon density
    - Etc...
- In the pA environment we can fully benefit from ATLAS detector capabilities, e.g. tracking, because particle multiplicities are lower than in pp collisions at design luminosity.
- Because of this “low” particle multiplicity we can run at high luminosity, e.g. 10^{31}.

Peripheral collisions

We have interest in studying the very peripheral interactions in heavy ion collisions. The physics that one can address is:

✓Exclusive production $\gamma\gamma\rightarrow X$

✓γ+nucleon interaction

Peripheral collision studies require forward detector implementation in ATLAS interaction region, e.g. Zero Degree Calorimeter.

Heavy Ions running scenarios

Signatures discussed here depends on the size of the colliding nuclei. For example parton energy loss in hot QCD matter has a L^2 dependence, where L is the size of the system.

The same signatures may depend on the overall energy density and therefore different beam energies will be desirable.

Cold QCD matter may fake signatures of the above and pA systems should be studied.

pA physics is interesting on its own and matches very well to the ATLAS full detector capabilities.

Therefore we would like to have pA and AA collisions with different A species and energies.

Ion	Mass	dN/dy	R (fm)	Luminosity
Pb	208	<8,000	7.1	10^{27}
Sn	120		5.9	1.7×10^{28}
Kr	84	<900	5.3	6.6×10^{28}
Ar	40	<800	4.1	10^{30}
O	16		3.0	10^{29}
p+Pb,Ar		<200		10^{31}
d+Pb,Ar				10^{31}
p+p		250		10^{34}

Beam Energy: 2.75 and 1.00 Tev/nucleon

Summary of ions

The desired species for a systematic HI study are as follow

Collision	R (fm)	Luminosity ($cm^{-2}s^{-1}$)	dN_{ch}/dy (maximum)	Interaction rate
p+p	~1	1×10^{34}	<250	1 GHz
$^{208}Pb+^{208}Pb$	7.1	1×10^{27}	<8000	8 kHz
$^{40}Ar+^{40}Ar$	4.1	6×10^{28}	<800	200 kHz
$p+^{208}Pb$		1×10^{30}	<150	2 MHz
$p+^{40}Ar$		1×10^{31}	<120	6 MHz

In addition different colliding energies would provide for the study of different energy densities.

Conclusions and Outlook

ATLAS is general purpose detector with excellent performance for high p_T physics.

Features like calorimeter coverage, granularity and resolution give us good potential for high p_T probes in heavy ion collisions, e.g. jet quenching. ATLAS is complementary to ALICE and CMS.

The physics topics outlined in this presentation can be likely addressed with the present detector layout (except for zero degree calorimetry).

For pA and light AA collisions the experimental environment is quieter than pp collisions at design L and therefore we can benefit from the full detector performance capabilities.

Heavy ion physics studies in ATLAS have started with the aim of preparing a Letter of Intent to LHCC by first half of 2003.