The ATLAS Heavy Ion Program:
The Past, the Present, and the Future

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Outline

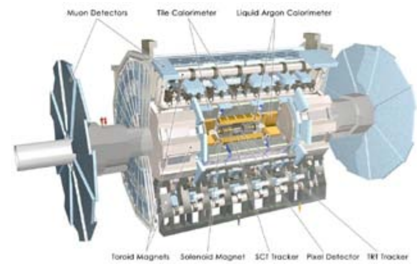
- **Atlas detector**

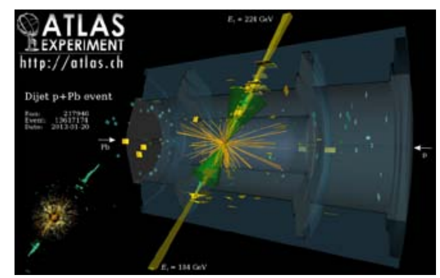
- **Accomplishments**
  - Pb+Pb
  - p+Pb

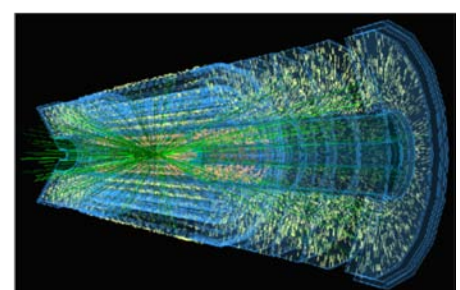
- **Present and LS1 activities**

- **The Future**
  - LHC heavy ion operation
  - ATLAS detector upgrades
  - Planned heavy ion program prior to LS3

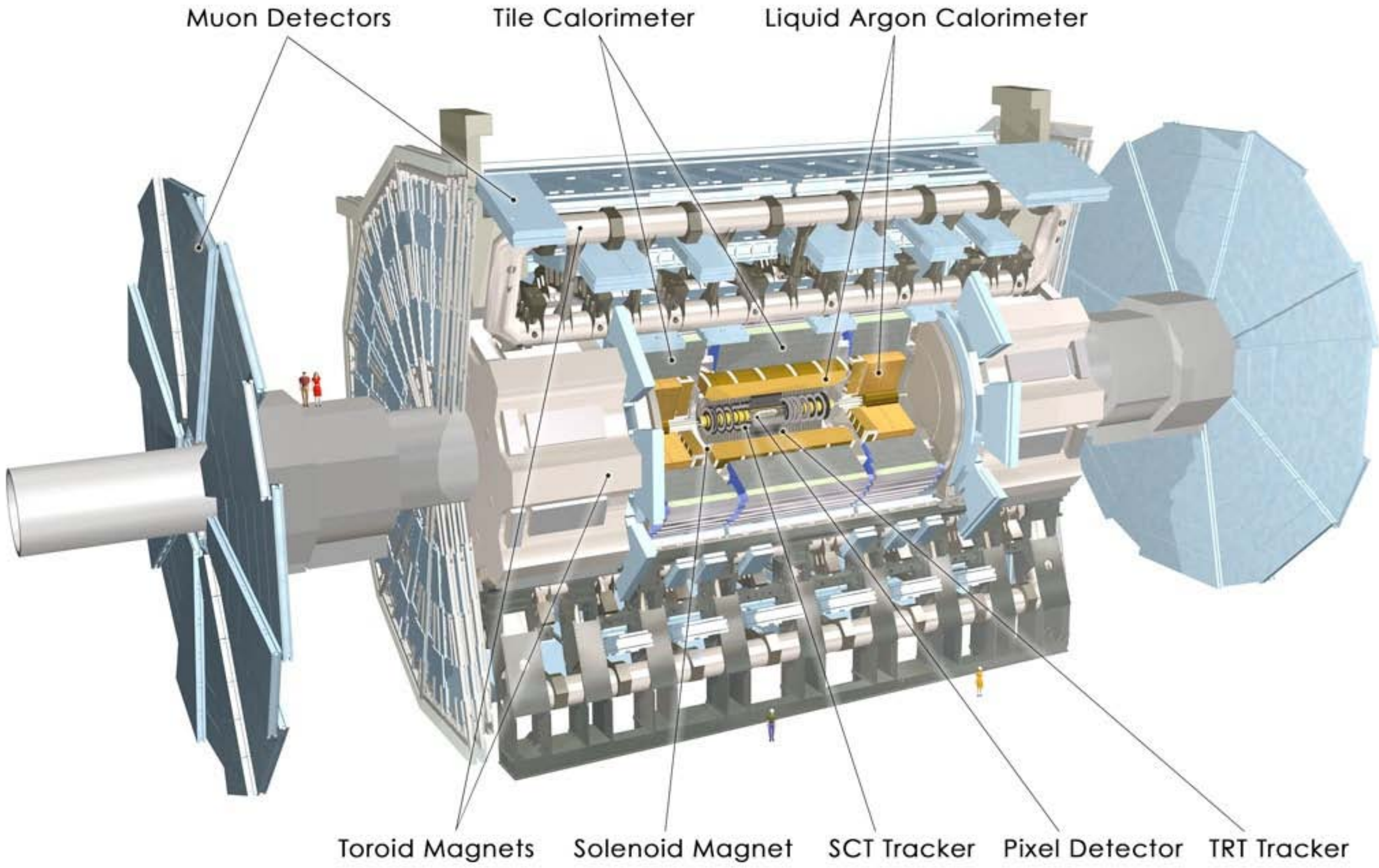
- **Summary**







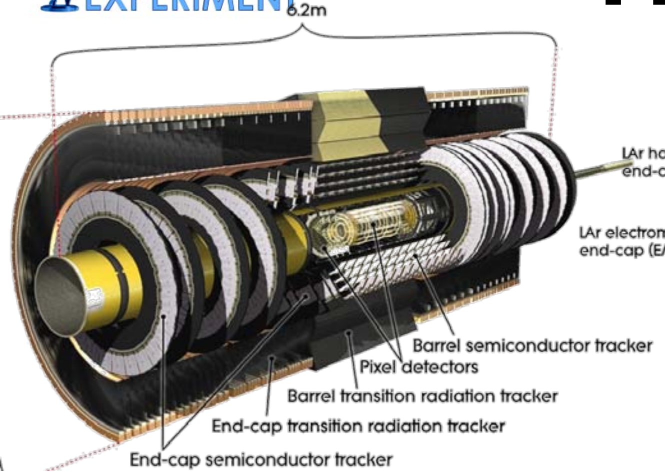
The ATLAS detector

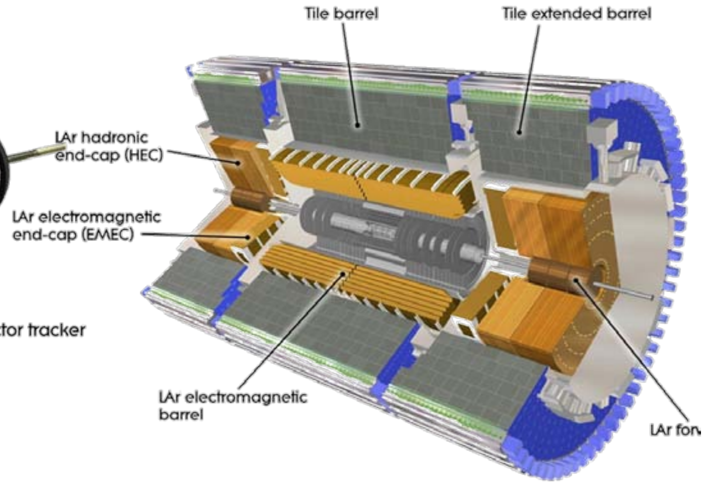


Three main subsystems with a full coverage in azimuth:

- **Inner Detector – tracking $|\eta|<2.5$**
- **Calorimetry – $|\eta|<4.9$**
- **Muon Spectrometer - $|\eta|<2.7$**

The ATLAS Detector





EM calorimeter

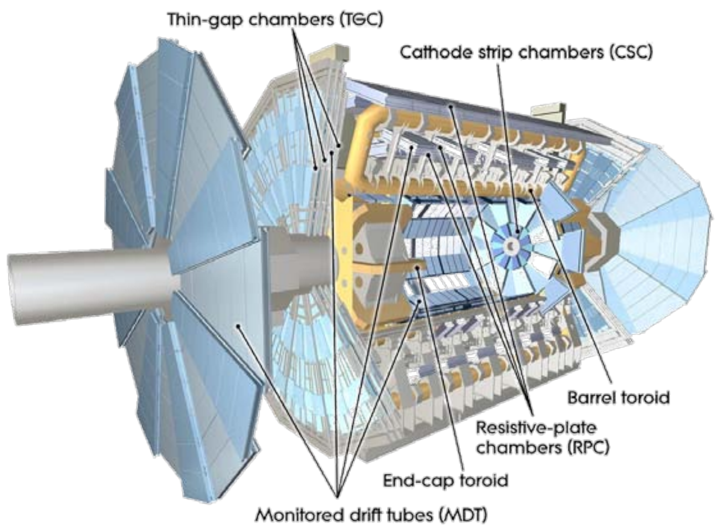
Pb-LAr($22X_0$)
$|\eta|<3.2$, full ϕ
3 longitudinal samplings
(first $\Delta\eta=0.003$)
+ presampler
e/γ trigger, identification;
Granularity: 0.025x0.025

Inner Detector(ID)

$|\eta|<2.5$, B (axial) =2T
<u>Pixels</u> (Si):
σ = 10 μm [rφ]
80M channels
3 layers and 3 disks
<u>SCT</u> (106 Si strips)
σ = 17 μm [rφ]
4 double layers, 9 disks

Hadronic calorimeter

Fe/Scint. Tiles (central)
Cu/W-Lar (forward)
$|\eta|<4.9$, full ϕ
Trigger, jets, $E_{T,miss}$



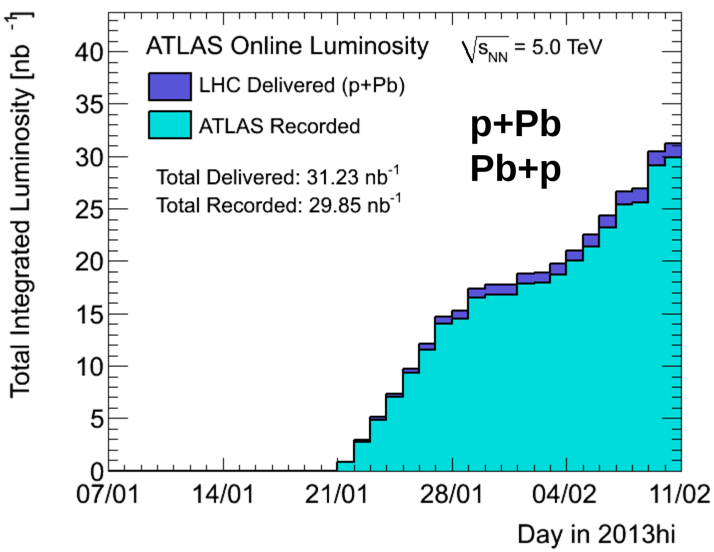
Muon spectrometer

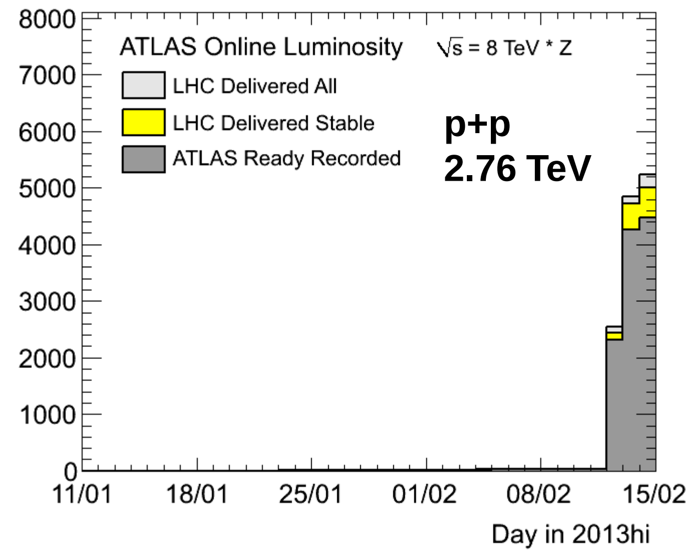
$|\eta|<2.7$
Shielded by Calorimeter
Air-core toroid system
Bending power: 1-7.5 Tm
μ tracking, triggering

MBTS: $2.1<|\eta|<3.9$ timing
ZDC: $8.1<|\eta|$ trigger, centrality

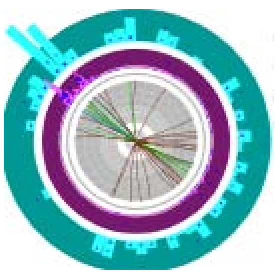
Data samples

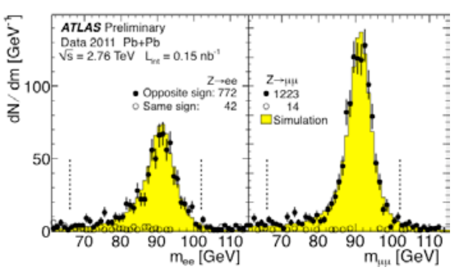
System	$\sqrt{s_{NN}}$ [TeV]	When	Integrated $\mathcal{L}$
Pb+Pb	2.76	2010+2011	0.17 nb^{-1}
p+p	2.76	2011	200 nb^{-1}
p+Pb	5.02	2012	0.001 nb^{-1}
p+Pb	5.02	2013	19 nb^{-1}
Pb+p	5.02	2013	~11 nb^{-1}
p+p	2.76	2013	~4.5 pb^{-1}

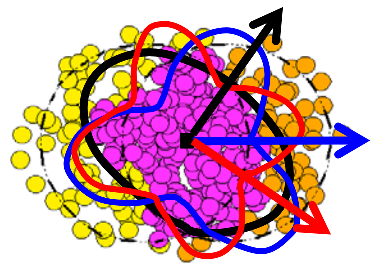


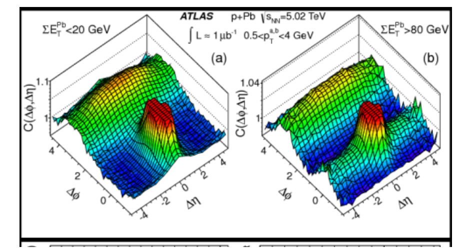


Accomplishments



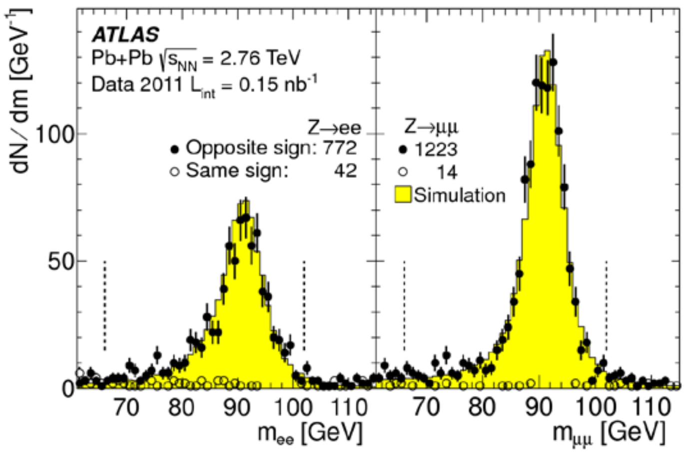


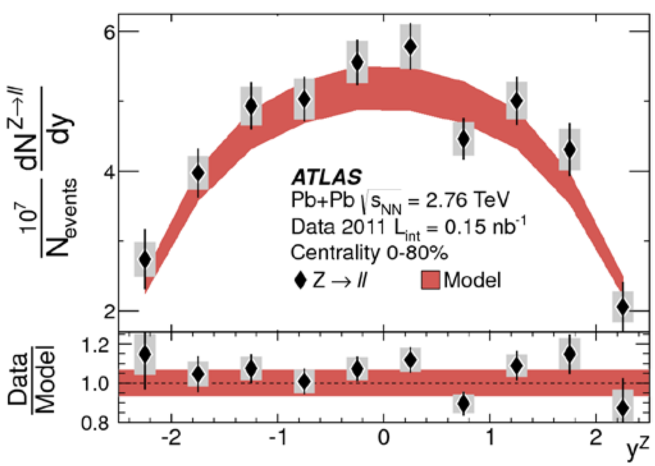


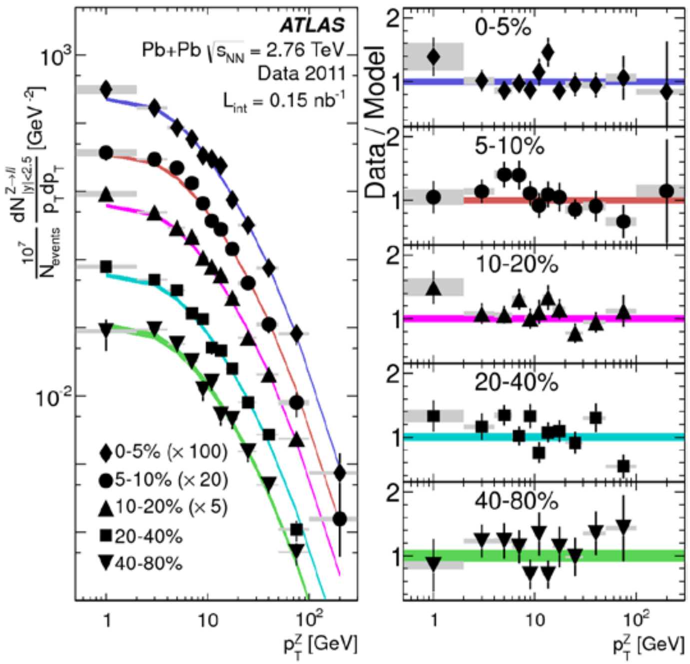


Measurement of $Z\to e^+e^-,\mu^+\mu^-$

- Calibration of hard scattering rates
  - Critical for jet quenching studies





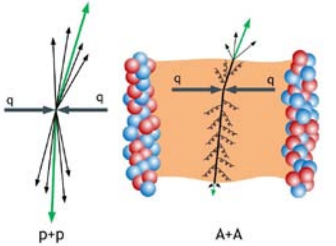


Phys. Rev. Lett. 110, 022301 (2013)

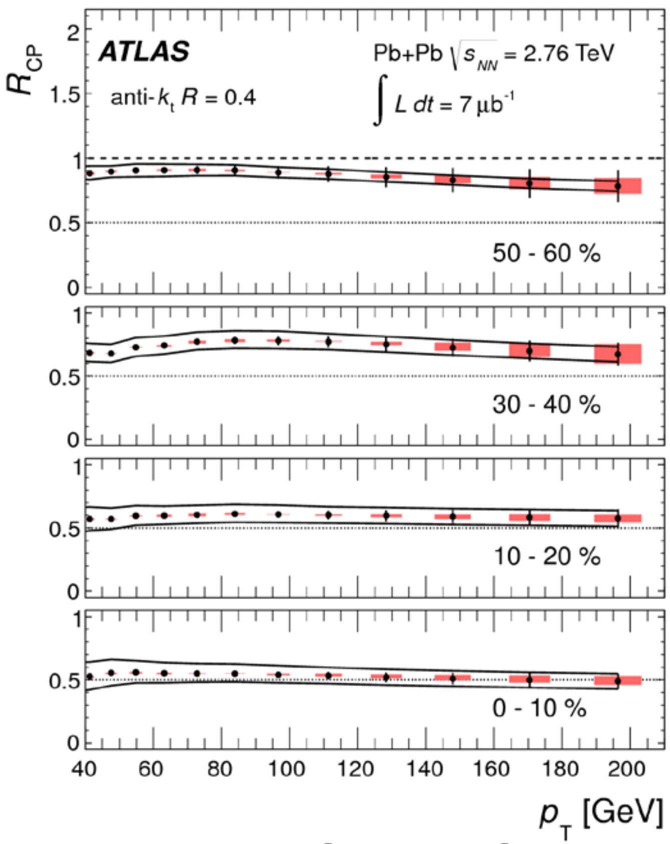
Yields consistent with N_{coll} scaling

p_T and y distributions consistent with Pythia simulations for pp with NNLO cross section × $\langle T_{AA}\rangle$

Single jet suppression

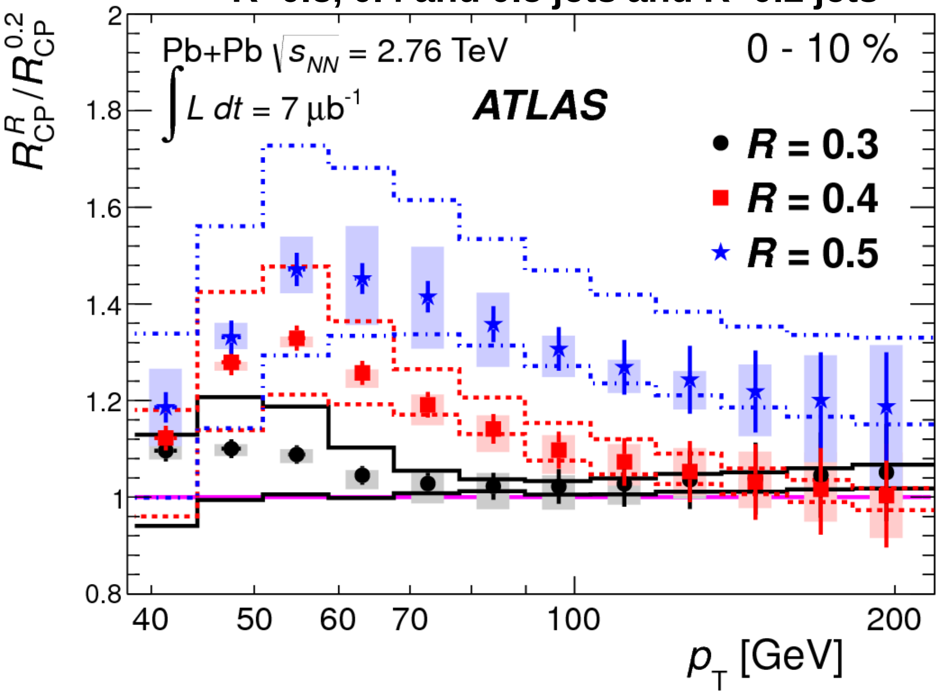


Rcp: Ratio of jet yields in central to peripheral collisions



Jet size dependence

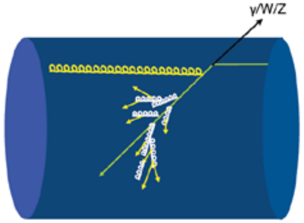
Ratio of R_{CP} values between R=0.3, 0.4 and 0.5 jets and R=0.2 jets



- A factor of ~2 suppression in 0-10% most central collisions
- Suppression independent of jet p_T
- Suppression dependent on jet radius (radiation?)

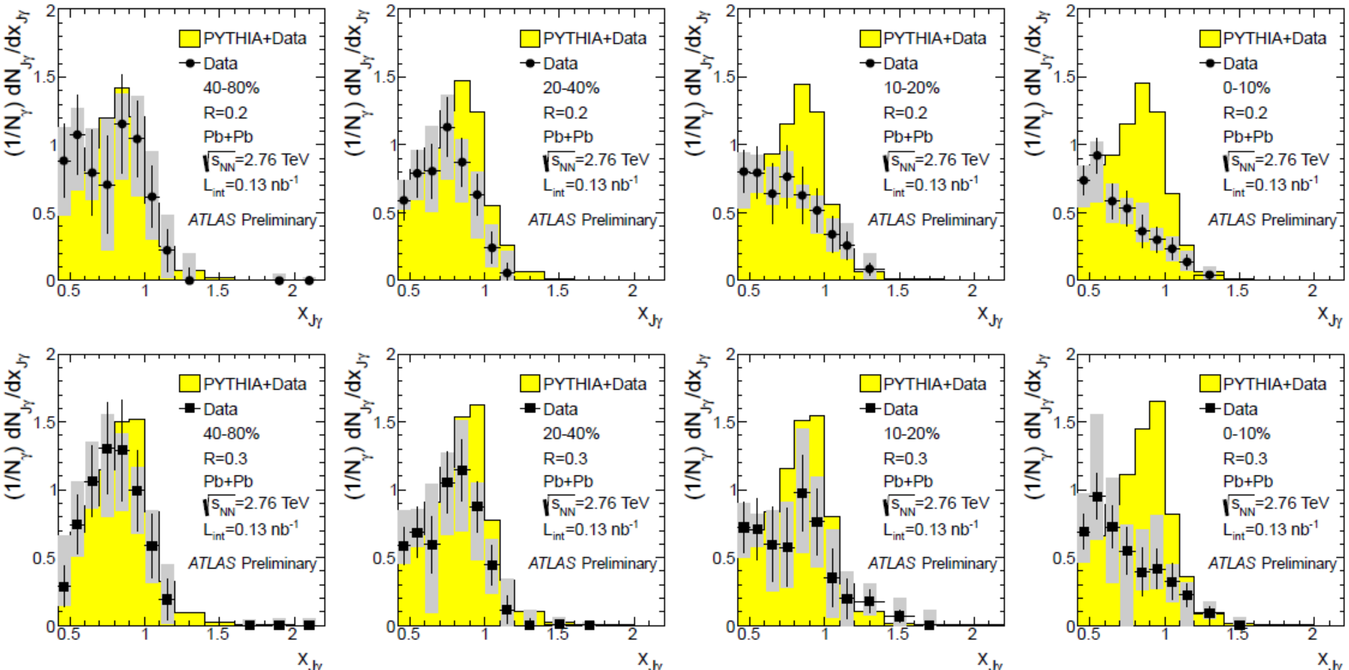
Phys. Lett. B719, 220 (2013)

Jet quenching via γ-jet



- $E\gamma$ > 60 GeV: 60-90 GeV, $|\eta|<1.3$
- Jet: anti-kT, R=0.2, 0.3, p_T>25 GeV, $|\eta|<2.1$
- γ-jet separation $\Delta\phi > 7\pi/8$ (back-to-back)

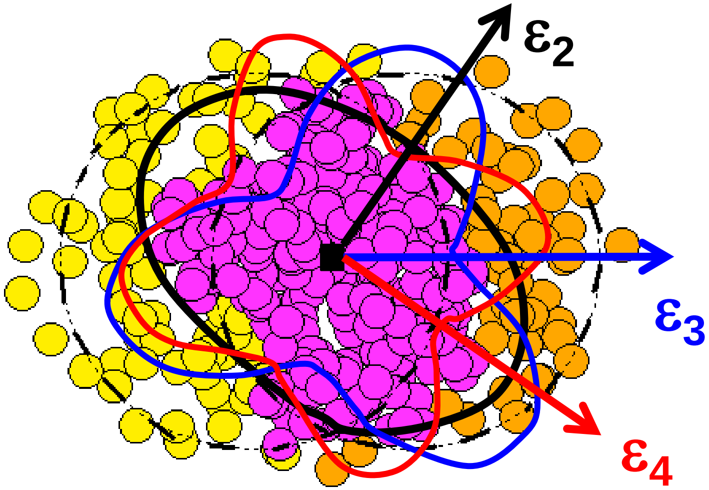
$$x_{J\gamma} = p_T^{jet} / p_T^{\gamma}$$



- Shape and integral compatible with PYTHIA for peripheral collisions
- With increasing centrality shift towards smaller $x_{J\gamma}$ and reduction of the integral

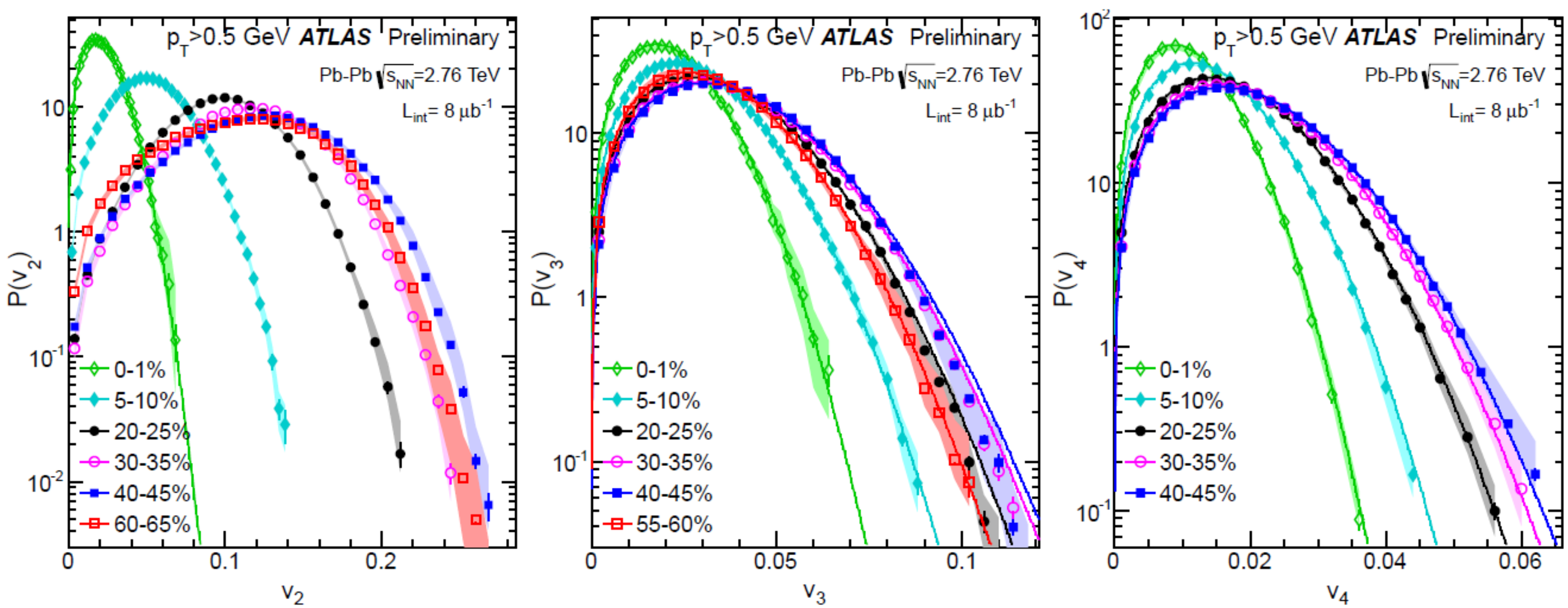
ATLAS-CONF-2012-121

Collective motion



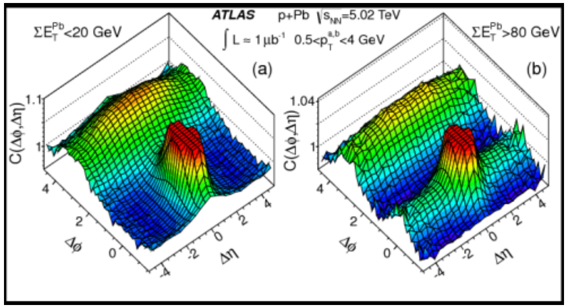
Event-by-event unfolded v_n distributions, for n=2 – 4

Provide information on the initial geometry and its fluctuations as well as constraints on the hydrodynamic evolution of the system

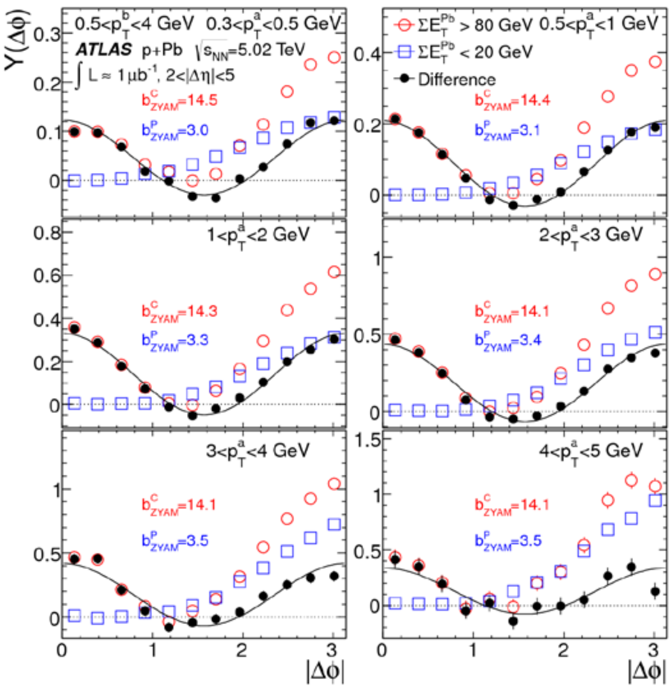


ATLAS-CONF-2012-114

Collective expansion in p+Pb?



`ridge' on the near- and away-side



The per-trigger yield distribution in high-multiplicity interactions, after subtracting the component due to momentum conservation, exhibits a pre-dominantly cos(2Δϕ) shape, resembling the elliptic flow modulation of distributions in Pb+Pb collisions.

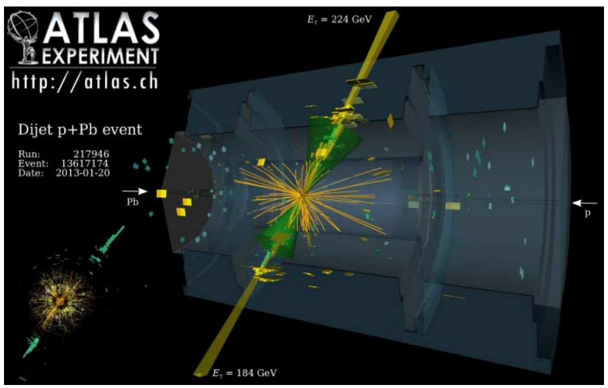
arXiv:1212.5198, submitted to Phys. Rev. Lett.

Initial- or final-state effect?

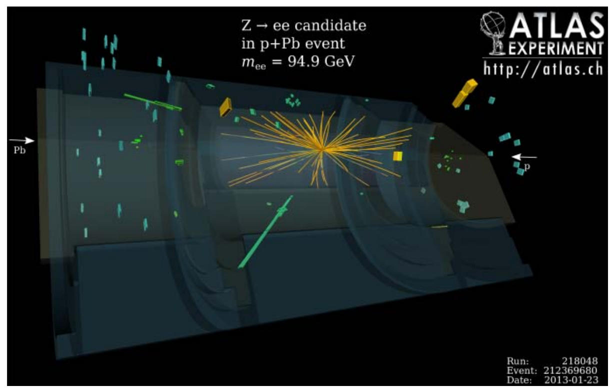
Present and LS1 activities

- 15^{+} Pb+Pb papers in the pipeline
- Similar number can be generated for p+Pb

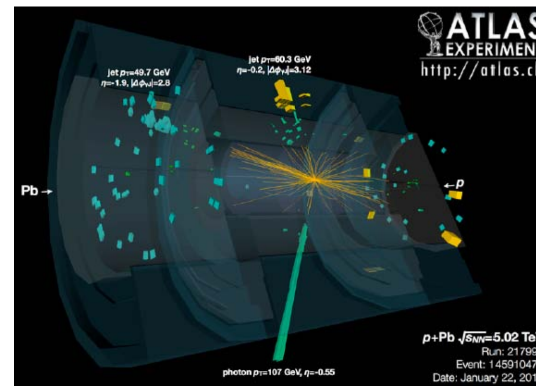
p+Pb



jet-jet



Z→e⁺e⁻



γ-jet

The future: LHC HI operation

System	Energy*Z per beam [TeV]	When	Integrated ℒ
Pb+Pb	7(6.5)	2015+2016	0.5 nb^{-1}
p+Pb or Pb+Pb	7(6.5)	2017	? or 0.25 nb^{-1}
Pb+Pb	7(6.5)	2019	+0.25 nb^{-1}
p+Pb	7(6.5)	2020	?
Ar+Ar	7(6.5)	2021	?
p+p	2.76(2.56)	???	10 pb^{-1}

LS2 2018

LS3 2022

Integrated luminosity of about 1 nb^{-1} for Pb+Pb before LS3

ATLAS EXPERIMENT

ATLAS detector upgrades

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	...	2030
				LS1					LS2				LS3			

"Phase-0" upgrade: consolidation
$\sqrt{s}$ = 13~14 TeV, 25ns bunch spacing
L_{inst} □1 x10^{34} $cm^{-2}s^{-1}$ (μ □27.5)
∫ L_{inst} □ 50 fb^{-1}

"Phase-I" upgrades:
ultimate luminosity
L_{inst} □2-3 x10^{34} $cm^{-2}s^{-1}$ (μ □55-81)
∫ L_{inst} □ 350 fb^{-1}

"Phase-II" upgrades:
L_{inst}□5 x10^{34} $cm^{-2}s^{-1}$ (μ □140) w. leveling
□6-7 x10^{34} $cm^{-2}s^{-1}$ (μ □192) no level.
∫ L_{inst} □ 3000 fb^{-1}

ATLAS has devised a 3 stage upgrade program to optimize the physics reach at each Phase

- New Insertable pixel b-layer (IBL)
- New Al beam pipe
- New pixel services
- New evaporative cooling plant
- Consolidation of detector elements (e.g. calorimeter power supplies)
- Add specific neutron shielding
- Finish installation of EE muon chambers staged in 2003
- Upgrade magnet cryogenics

- New Small Wheel (nSW) for the forward muon Spectrometer
- High Precision Calorimeter Trigger at Level-1
- Fast TracKing (FTK) for the Level-2 trigger
- Topological Level-1 trigger processors
- New forward diffractive physics detectors (AFP)

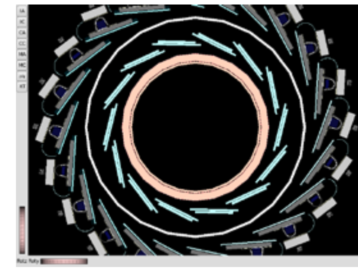
- All new Tracking Detector
- Calorimeter electronics upgrades
- Upgrade part of the muon system
- Possible Level-1 track trigger
- Possible changes to the forward calorimeters

ATLAS EXPERIMENT

ATLAS detector upgrades

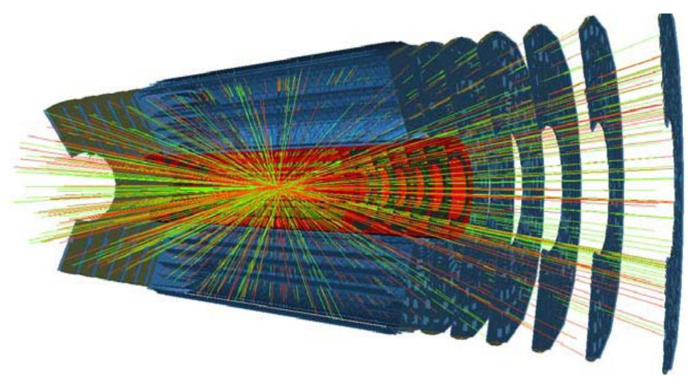
Multi-step upgrade strategy

- **Phase 0 – LS1 (2013-2014)**
  - **Insertable B Layer inside the current pixel detector**
    - **Fourth layer added closer to the beam pipe**
    - **A new smaller beam pipe**

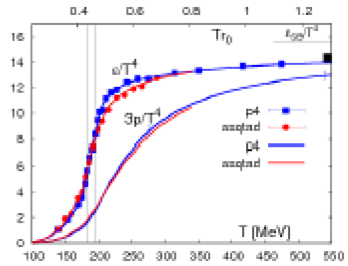


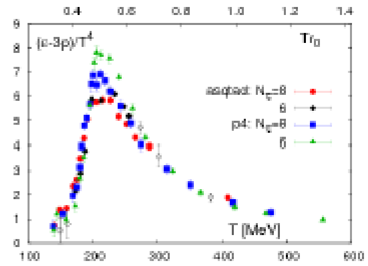
- **Phase 1 – LS2 (2018)**

  - **FTK – Fast tracking trigger**
  - **LAr calorimeter read-out and trigger**
  - **New forward muon detectors**
  - **Forward proton detectors and trigger/DAQ upgrades**
- **Phase 2 – LS3 (2022)**
  - **New Inner Detector**
  - **LAr upgrades**
  - **Tile upgrades**
  - **Trigger/DAQ**



ATLAS HI program prior to LS3





Is QCD weakly or strongly coupled at high T?

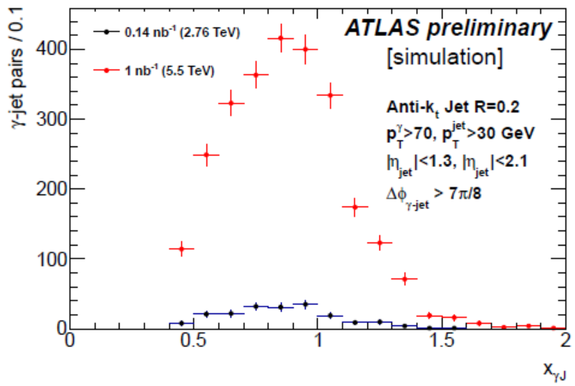
Study the interactions of color charges in the QGP:

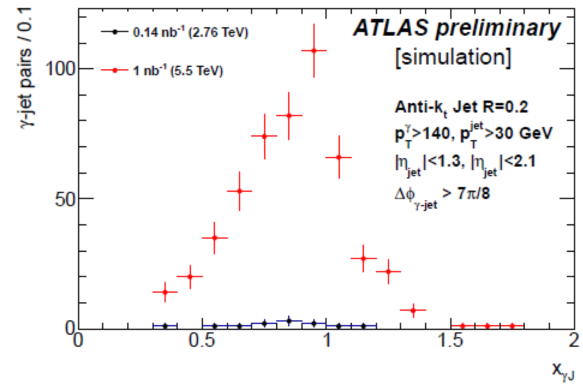
- Using high-p_T jets, dijets, and multi-jet final states
- Using b-tagged jets
- Perform precision measurements with γ-jet and Z-jet pairs.
- Use quarkonia, particularly the Υ(1S) and excited states, to study Debye screening in the QGP
- Study global features of the final state using charged particle measurements over $|\eta| < 2.5$ and calorimetric measurements over $|\eta| < 5$
- Study low-x and initial-state effects in p+A collisions

Concern – manpower (1/50th ALICE, 1/2 CMS)

ATLAS HI program prior to LS3

- **Better statistical precision (2×E, 6×$\mathcal{L}$)**
  - **16-40 increase in isolated prompt photons**
  - **improved statistics on γ-jet measurements**



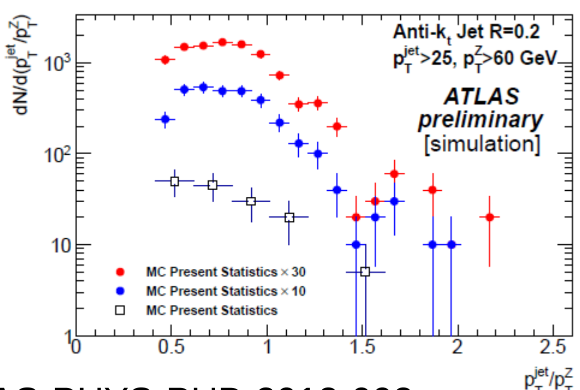


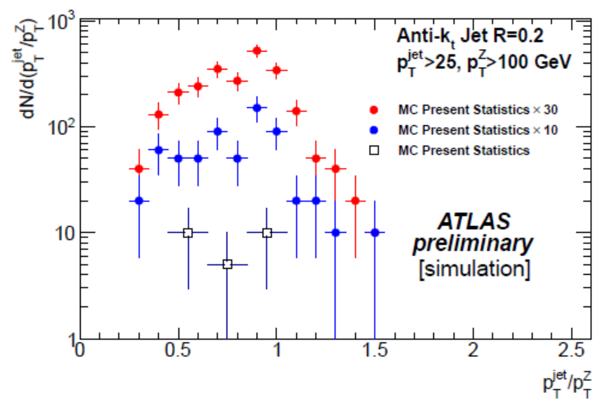
$$x_{J\gamma} = p_T^{jet} / p_T^{\gamma}$$

----- 2.76 TeV 0.14 nb^{-1}

----- 5.5 TeV 1 nb^{-1}

  - **improved statistics for Z-jet measurements**





$$p_T^{jet} / p_T^{Z}$$

ATLAS-PHYS-PUB-2012-002

Summary

- **ATLAS – excellent detector for heavy-ion studies**

- **Planned physics program for Pb+Pb with $\mathcal{L}$ =1 nb^{-1}**
  - **Measurements of jets**
  - **Jet quenching studies with di-jets, γ-jet, and Z-jet**
  - **Υ production**
  - **Global event properties**

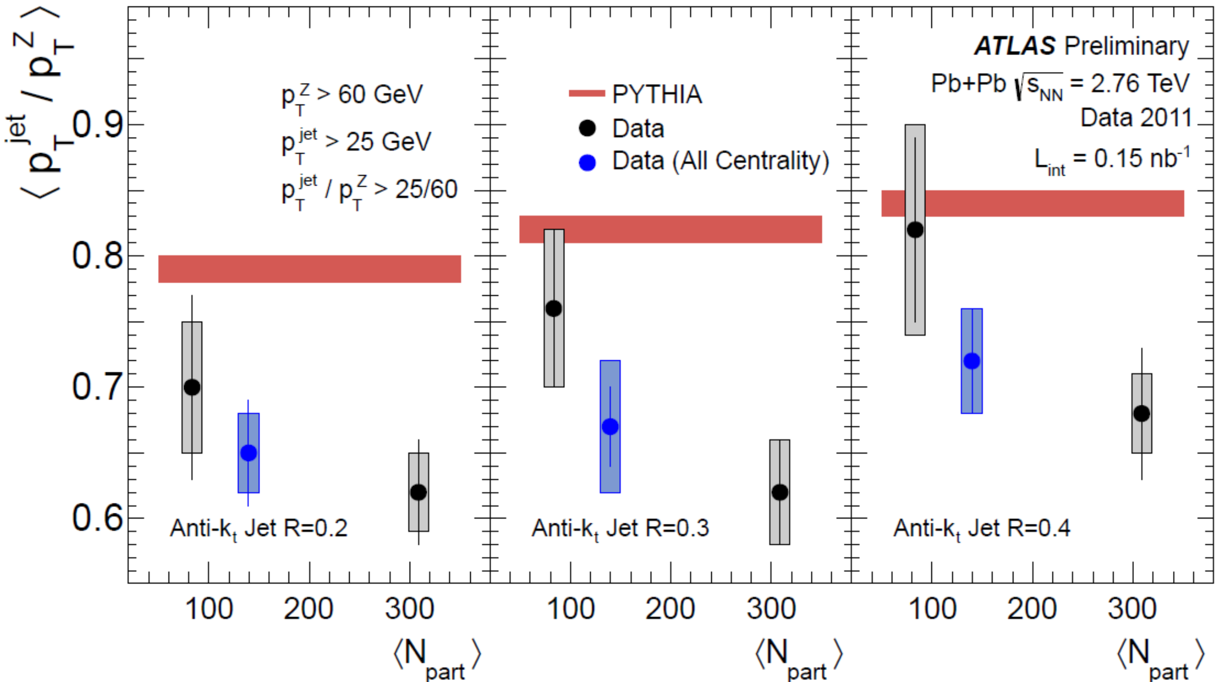
  → ***Statistics beyond 1 nb^{-1} will improve the precision of measurements***
  (might be difficult due to limitations in the store length)

- **Physics with p+Pb collisions**
  - **low-x physics (saturation, forward single- and di-hadron production)**
  - **Nuclear modifications of parton distribution functions**
  - **Reference for hard-scattering processes**

Back-up slides

Z - jet correlations

- $Z \to e^+e^-, \mu^+\mu^-$ p_T > 60 GeV
- Jet: anti-kT, R=0.2, 0.3, 0.4, p_T>25 GeV, $|\eta|$<2.1
- Z-jet separation > $\pi/2$ → 37 events for L_{int}=0.15 nb^{-1}



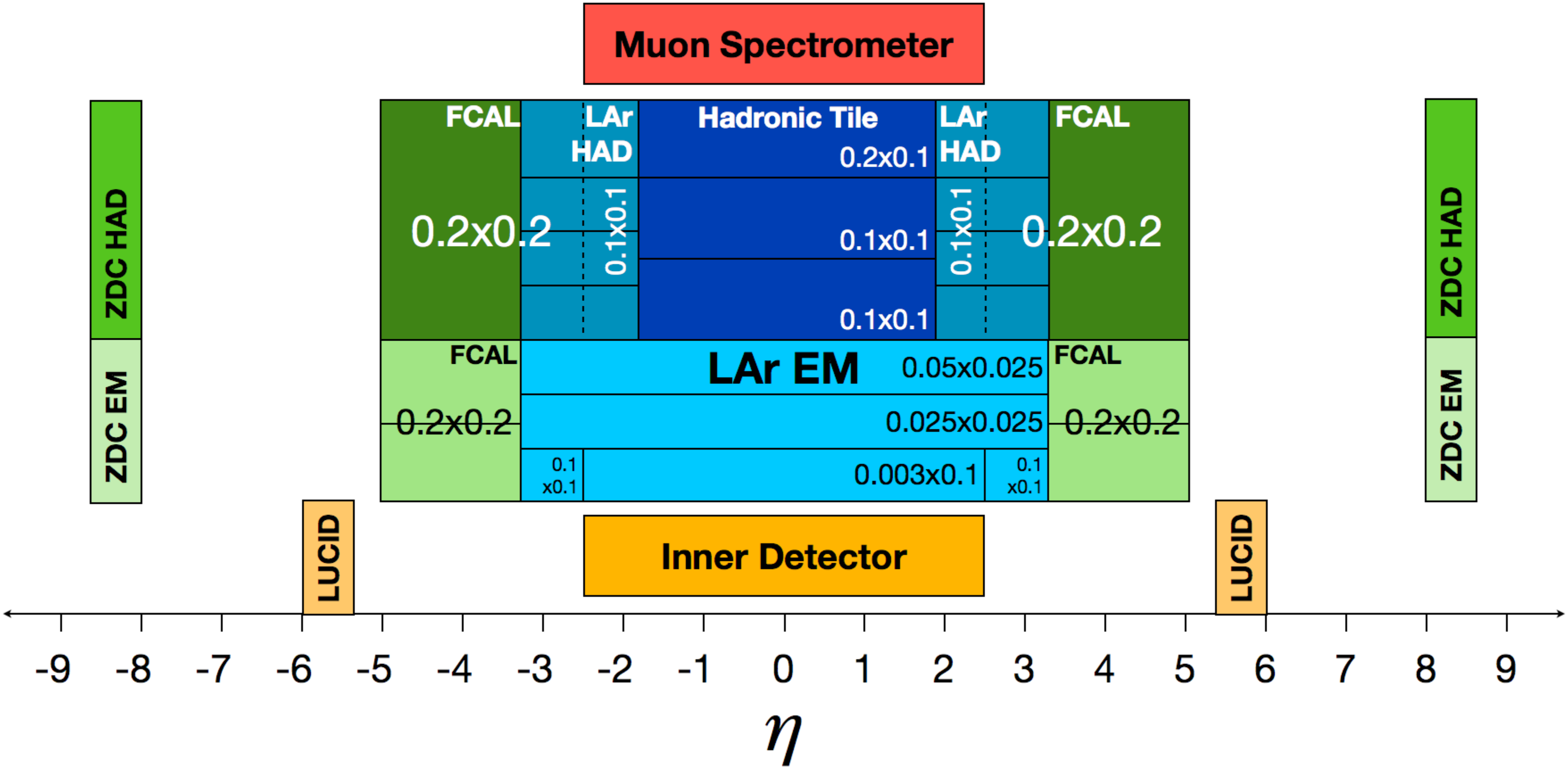
20-80% **0-80%** **0-20%**

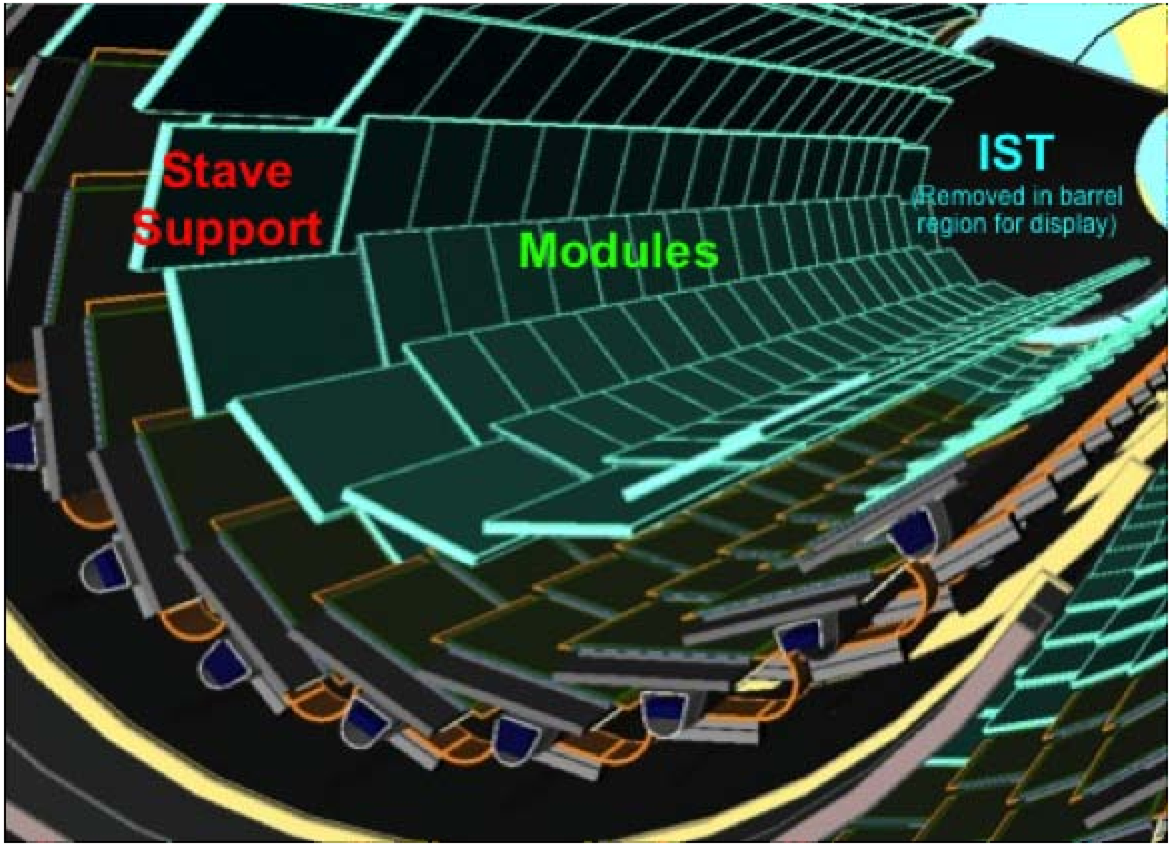
$\left\langle p_T^{jet} / p_T^Z \right\rangle$

- Suppression of the $\left\langle p_T^{jet} / p_T^Z \right\rangle$ relative to MC simulations with no energy loss (PYTHIA: Z+jet events)
- Stronger suppression for more central collisions

ATLAS-CONF-2012-119

The ATLAS detector

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Support
Modules
IST
(Removed in barrel
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