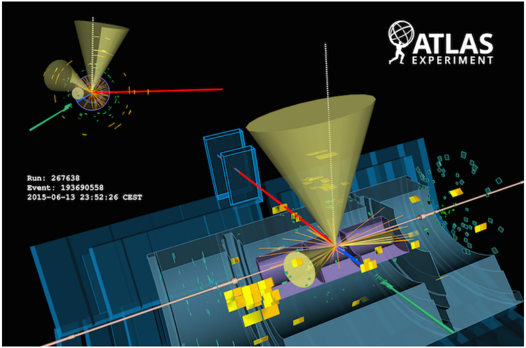
The ATLAS experiment

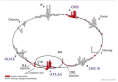


Detectors and Instrumentation

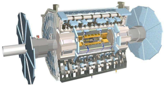
Garching, May 31, 2016

Richard Nisius (MPP München)
Richard.Nisius@mpp.mpg.de

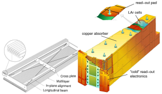
The plan of this presentation

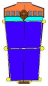


The Large Hadron Collider

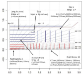


The ATLAS detector





MPP contributions and performance of the ATLAS detector



The new inner detector for the high luminosity LHC

Conclusions and outlook

The LHC – a proton–proton accelerator

Alice

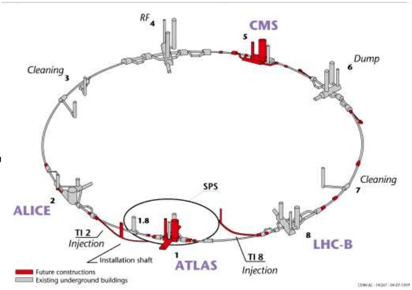
Heavy Ions, ...

LHC-B

Matter $\leftrightarrow$ Antimatter, ...

ATLAS / CMS

Higgs production, precision physics, ...



Technical details (design)

L = 26.7 km
E_p = 6.5 (7) TeV
n_b = 1177 (2808) / beam
N_p = $1 \cdot 10^{11}$ / bunch
t_{BC} = 25 ns

Accumulated luminosity

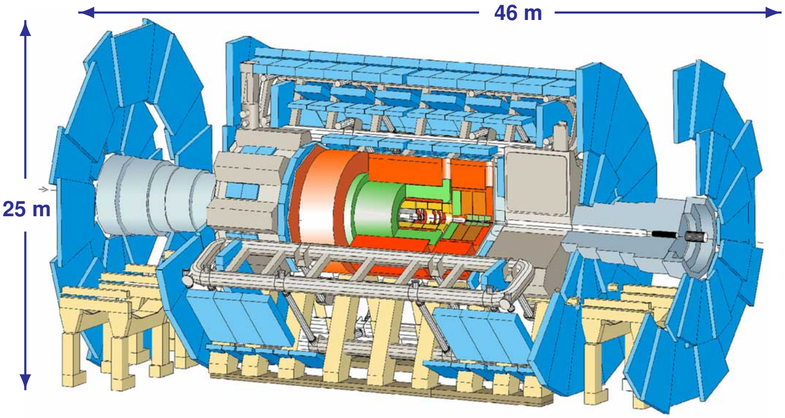
$5\ \text{fb}^{-1}$ at $\sqrt{s} = 7$ TeV
$20\ \text{fb}^{-1}$ at $\sqrt{s} = 8$ TeV
$3\ \text{fb}^{-1}$ at $\sqrt{s} = 13$ TeV

$\Rightarrow$ 8.5 Million $t\bar{t}$ pairs.

The heart of the LHC – the super-conducting magnets

Length	= 15 m
Weight	= 23.8 t
B-field	= 8.3 T
Temperature	= 1.9 K
Current	= 12000 A
Energy	= 7.1 MJ

The ATLAS detector - general layout

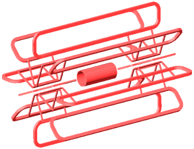


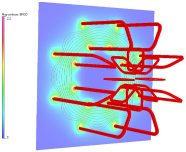
$M = 7000\,\mathrm{t}$
$V = 22580\,\mathrm{m}^3$
$\Rightarrow$ ATLAS could swim.

MPP

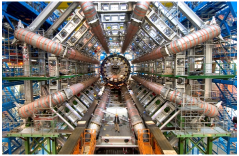
- Silicon tracker (Pixel, SCT)
- Transition radiation tracker (Xe)
- Central solenoid ($B = 2$ T)
- Electromagnetic calorimeter (Pb, LAr, 25 X_0)
- Hadronic tile calorimeter (Fe, Szi, 11 λ)
- Hadronic end cap (Cu, LAr, 10 λ)
- Forward calorimeter (Cu/W, LAr, 11 λ)
- Air toroid magnet ($B = 4$ T)
- Muon spectrometer (MDT/CSC, RPC/TGC)

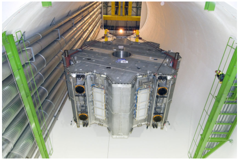
The ATLAS magnet system

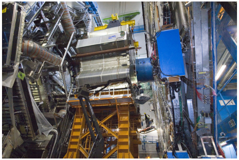




- Solenoid $B_z = 2\mathrm{T}$ for inner tracker. B-field lines are closed within the hadronic calorimeter, but dead material in front of the calorimeter.
- Central toroidal field of $B_{r\varphi} = 4\mathrm{T}$ outside. No need for a return joke, $\int \vec{B}\, d\vec{L}$ ist large, but relatively complex and inhomogeneous field.





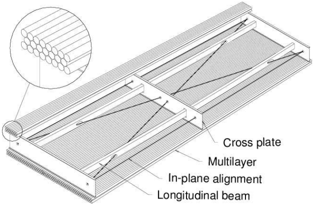


- Additional endcap toroids to produce B-field for measuring muons in the forward region.

The largest magnet system ever.

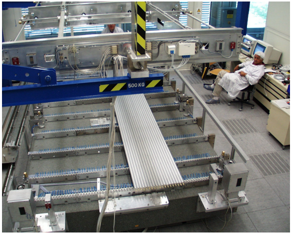
MDT chambers - general layout and performance

Schematic view of an MDT chamber



- 432 tubes of 3.8 m length with 20 μm precision.
- 1728 gas connection.
- 350 kg weight.

Mounting of tubes



An assembled BOS chamber

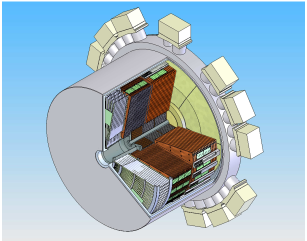
Some properties of MDT chambers

- The single wire resolution is 80 μm and the chamber resolution is 35 μm.
- The p_{T} resolution for muons is better than 10% up to 1 TeV.
- The mass resolution e.g. for $H \to ZZ^{\star} \to 4\mu$ is about 2% for $M_H = 125$ GeV.

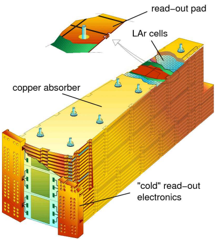
At MPP we have built 88 MDT chambers.

The ATLAS HEC - construction of the wheels

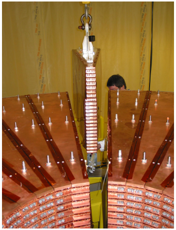
Schematic view of an endcap



Schematic view of a HEC module



Completing a wheel



The ATLAS hadronic endcap (HEC)

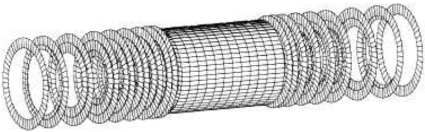
- The sensitive material is liquid Argon, LAr.
- The absorber is made of 25 and 50 mm thick copper plates with a total thickness of about 10λ.
- The measured resolution for e/π showers is:

$$\frac{\sigma(E_e/E_\pi)}{E} = \frac{23.3/76.2\,\%}{\sqrt{E/GeV}} \oplus 0.0/6.7\,\%.$$

At MPP we have built 27 of 64 HEC modules.

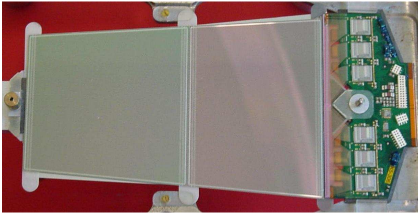
The ATLAS SemiConductor Tracker (SCT)

The Layout



- Barrel: 4 layers.
- Endcaps: 2x9 discs.
- Modules: 4088 (total), 2112 (barrel) and 1976 (endcaps).
- Resolution: 16 μm (perpendicular) and 580 μm (parallel) to the strips.

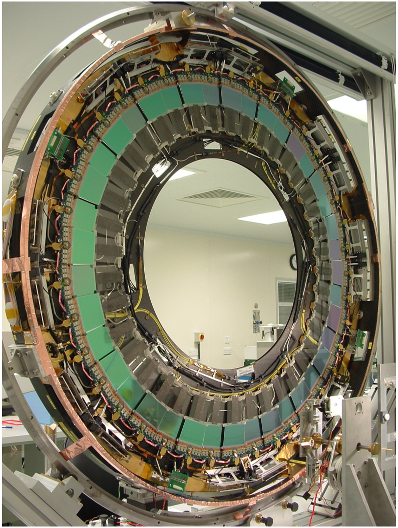
An endcap module



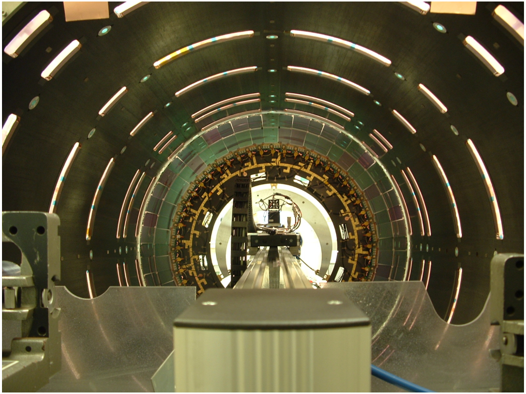
- 768 single sided p-in-n strips with 50-90 μm pitch.
- Two sided hybrid with 6 chips per side, binary read out.
- Mounting points with 20 μm precision.

SCT - from modules to superstructures

First of 9 discs with MPP modules

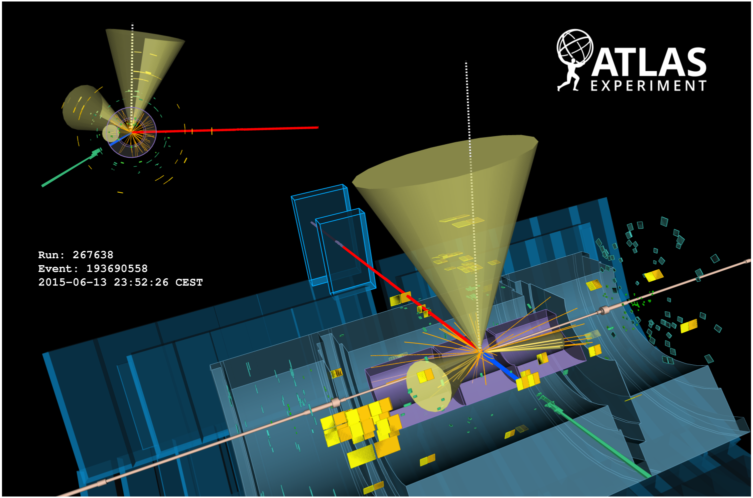


The first disc in a cylinder



At MPP we produced 424 endcap modules.

A candidate event for $t\bar{t} \rightarrow \mu\nu\, e\nu\, b\bar{b} + X$



Data objects

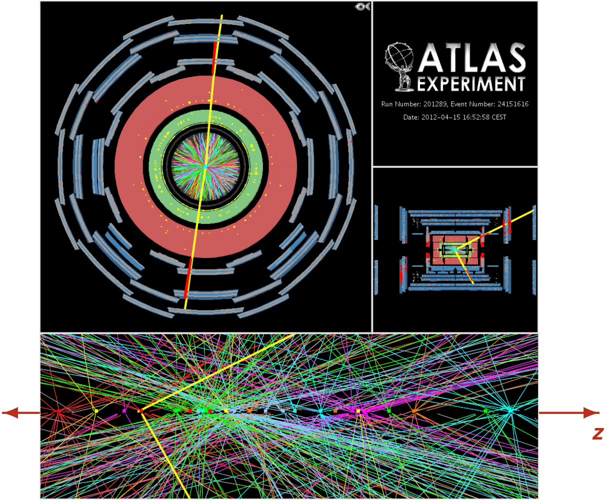
- Vertices
- Leptons
- Jets, *b*-jets
- E_T^{miss}

Things to look at

- Vertex reconstruction
- *b*-tagging
- Jet energy scales

The interplay of all subdetectors is crucial for precise measurements of complex final states.

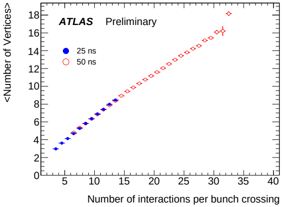
Vertexing for $Z \rightarrow \mu\mu + X$ events



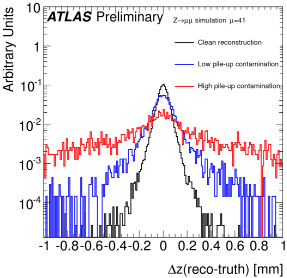
– 8 TeV data, 3-Pix + 6-SCT hits, $p_{\mathrm{T}}^{\mathrm{trk}} > 0.4$ GeV.

$\Rightarrow$ 25 reconstructed vertices a few mm apart in z.

Number of vertices vs. μ

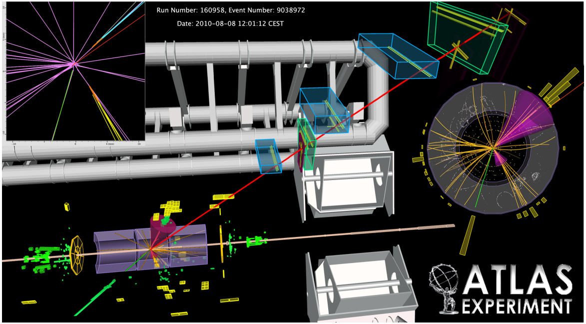


Vertex resolution in z



Vertexing in a very dense environment.

b-tagging for $t\bar{t} \rightarrow \mu\nu\ e\nu\ b\bar{b} + X$ events



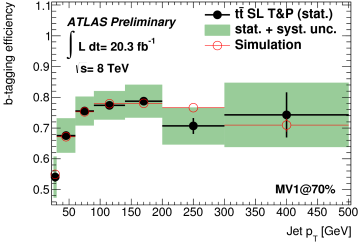
— Use features like: tracks with large impact parameters, or tracks pointing at displaced vertices.

— Combine various methods within a likelihood.

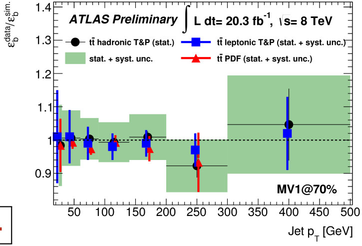
— Performance: $\epsilon_b = 70\%$ at $\epsilon_c = 1/5$ and $\epsilon_q = 1/137$.

The *b*-tagging is essential for background suppression.

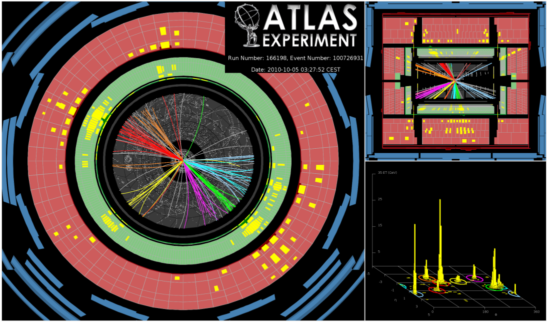
Efficiency as a function of jet-p_{T}



The data-to-simulation ratio



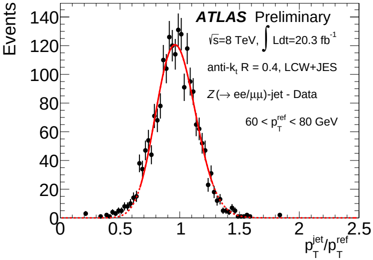
The Jet Energy Scale (JES) uncertainty



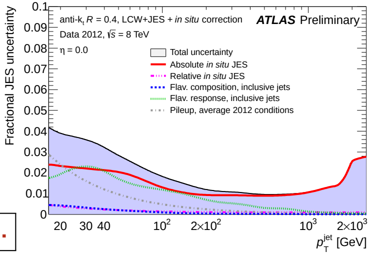
- An event with eight jets with $p_{\mathrm{T}} = 60$ GeV.
- The transverse momenta of the two highest-p_{T} jets are 290 GeV and 220 GeV.
- This event has $\Sigma E_{\mathrm{T}} = 890$ GeV and $E_{\mathrm{T}}^{\mathrm{miss}} = 21$ GeV.
- For precision measurements, one needs in addition in-situ calibration methods based e.g. on M_W.

A small JES-induced uncertainty is crucial for precision.

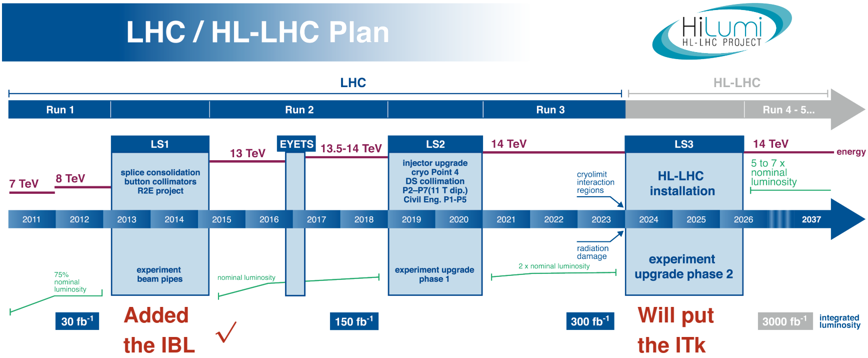
Calibration via p_{T}-balance



The JES uncertainty vs jet-p_t



ATLAS inner detector upgrades within the LHC plan



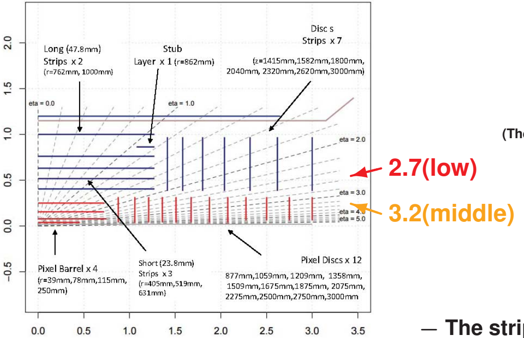
— **LS1:** A new innermost pixel layer the Insertable B-Layer (IBL) has been added. This is the first ATLAS tracker using CO_2 cooling, which is the choice for ITk.

— **LS3:** Given the radiation damage at the LHC, and the expected occupancy at the HL-LHC, a new, all silicon Inner Tracker (ITk) will be built.

The ITk will be an about 200 m^2 silicon detector with 700 Million read-out channels.

The ITk layout options

The Reference Layout



Area and number of channels

Detector	Silicon Area [m^2]	Channels [10^6]
Pixel barrel	5.1	445
Pixel end-cap	3.1	193
Pixel Total	8.2	638
Strip barrel	122	47
Strip end-cap	71	27
Strip total	193	74

(The numbers are for the letter of intent (i.e. low) layout $|\eta| = 2.7$)

The scoping options

	Reference	Middle	Low
ITk strips - changes w.r.t. LoI layout			
Remove Barrel layer 3			✗
Remove 1 Disc set		✗	✗
Remove 2 stereo layers			✗
Remove stub		✗	✗
ITk η-coverage	4.0	3.2	2.7

— **The strip/pixel TDRs are planned for 2016/2018.**

— **For any option, this is a very large Pixel detector (Now: Pix+IBL = 2.9 m^2, 86 M channels).**

— **By now, adding a fifth pixel barrel layer, replacing one strip layer, is very likely to happen.**

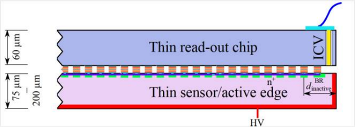
— **Germany intends to contribute about 15% to the ITk (pixel + strips).**

— **The German pixel institutes are BN, DO, GÖ, MPP, SI and W.**

A very large and challenging project is ahead of us.

The pixel module concept originally proposed by MPP/HLL in 2007

Our module concept



— First modules of this type (without ICVs) were produced at MPP/HLL, together with the Fraunhofer EMFT.

The key features of our concept

ATL-P-MN-0019

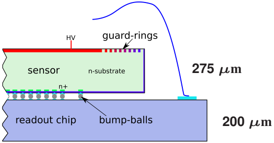
— Thin planar n-in-p silicon sensors on SOI wafer.

— Small inactive edges (by now 50 μm at VTT).

— SLID interconnection, achieved by EMFT, but not needed if using a single layer of read-out chips.

— Vertical integration of the read-out chip with Inter-Chip Via (ICV). Large ICVs, useable at the wire bonding pads, were achieved by IZM, LETI.

The old ATLAS pixel module



The improvements

— Improved radiation hardness (less trapping, lower V_{dep}).

— Reduced Si contribution to the radiation length.

— Large live fraction, only 1% loss at pixel edges. No geometrical overlap along the beam axis needed.

— No cantilever needed for bonding to read-out.

By now thin n-in-p planar sensors are the choice for outer layers in ATLAS and CMS.

Conclusions and outlook

- **The MPP ATLAS group has contributed many components to ATLAS. We continuously take part in their operation, calibration and upgrades.**
- **The ATLAS experiment has successfully taken 5/20/3 fb^{-1} of proton–proton collision data at centre-of-mass energies of 7/8/13 TeV.**
- **The detector understanding is steadily improving allowing for precision measurements.**
- **Frequently, the largest experimental uncertainty stems from the jet energy calibration.**
- **Experimental uncertainties are often already at par with theoretical uncertainties e.g. in the simulation of signal processes, which therefore start to limit the precision physics.**
- **The plan for the ATLAS upgrade for the high luminosity phase of the LHC is being shaped. For charge particle reconstruction, it contains a new, all silicon inner detector.**
- **The MPP driven pixel module technologies are well advanced and will be an integral part of the pixel detetctor technical design report in 2018.**

Thank you for your attention.