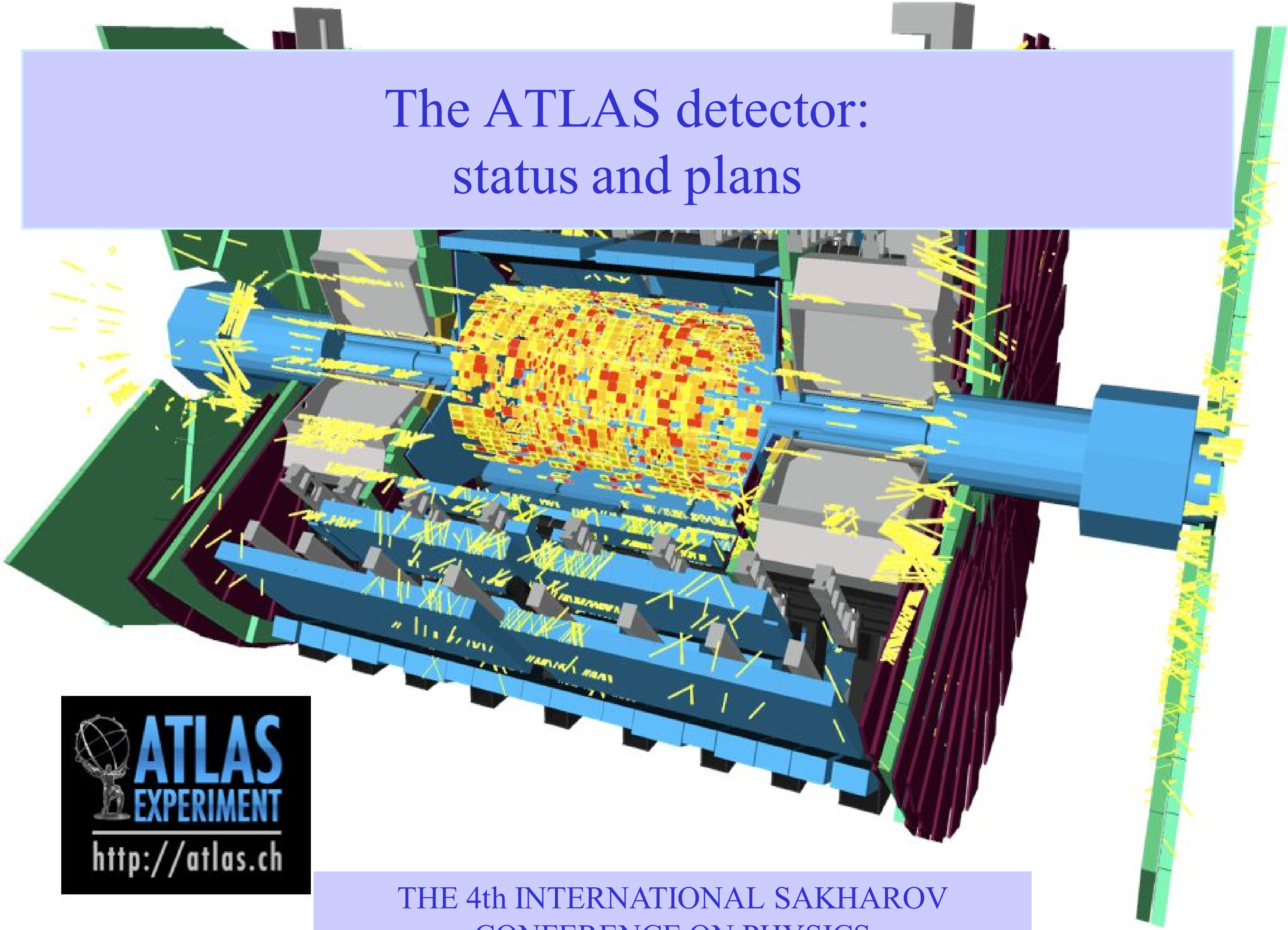
The ATLAS detector: status and plans



ATLAS EXPERIMENT
http://atlas.ch

THE 4th INTERNATIONAL SAKHAROV CONFERENCE ON PHYSICS
MOSCOW, May 18--23, 2009

A.Zaitsev

1981 International Symposium on Lepton and Photon Interactions at High Energies

Bonn, August 24-29, 1981

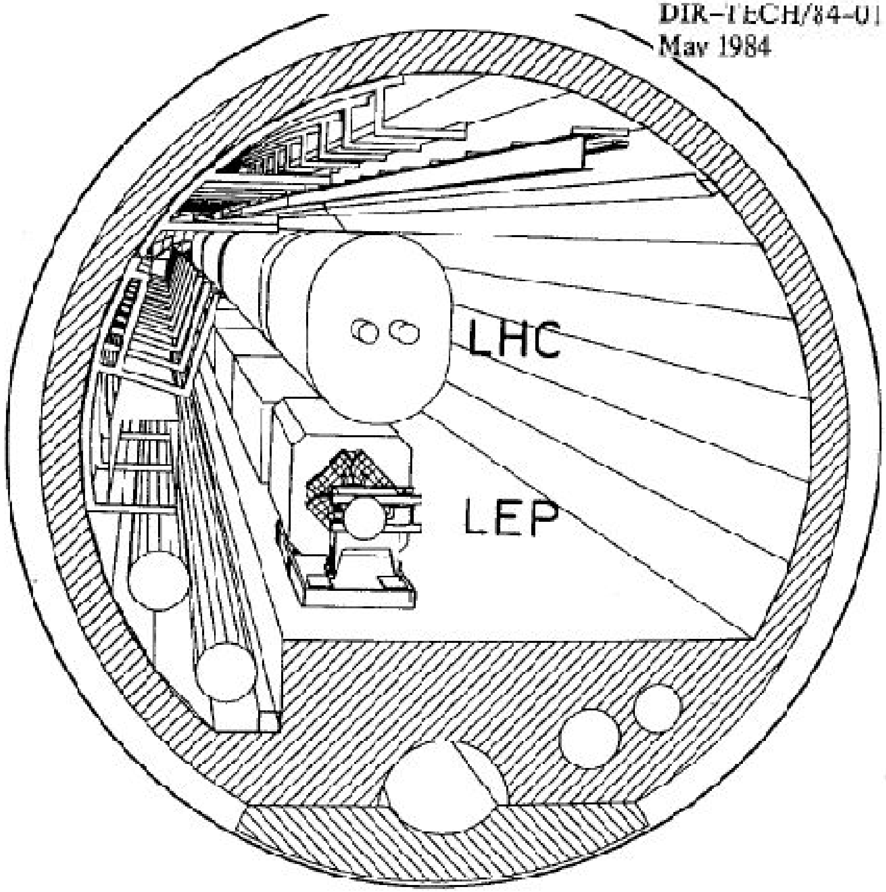
PARTICLE PHYSICS PROSPECTS: AUGUST ' 81

L.B. OKUN

At present the scalarland exists only in the dreams of theoreticians, who describe it in many ways, which are quite far from being selfconsistent. The aim of this talk is to urge experimentalists and accelerator builders to join their efforts in discovering this land, which lies below and not far above 1 TeV.

During the last 50 years physicists solve problems by inventing hypothetical particles, which eventually become real. It took 14 years to discover the first hypothetical spinless particle: the pion. It is now precisely 14 years that we live with a new type of hypothetical spinless bosons. Isn't it about time to discover them?

DIR-TECH/84-01
May 1984



LARGE HADRON COLLIDER
IN THE LEP TUNNEL

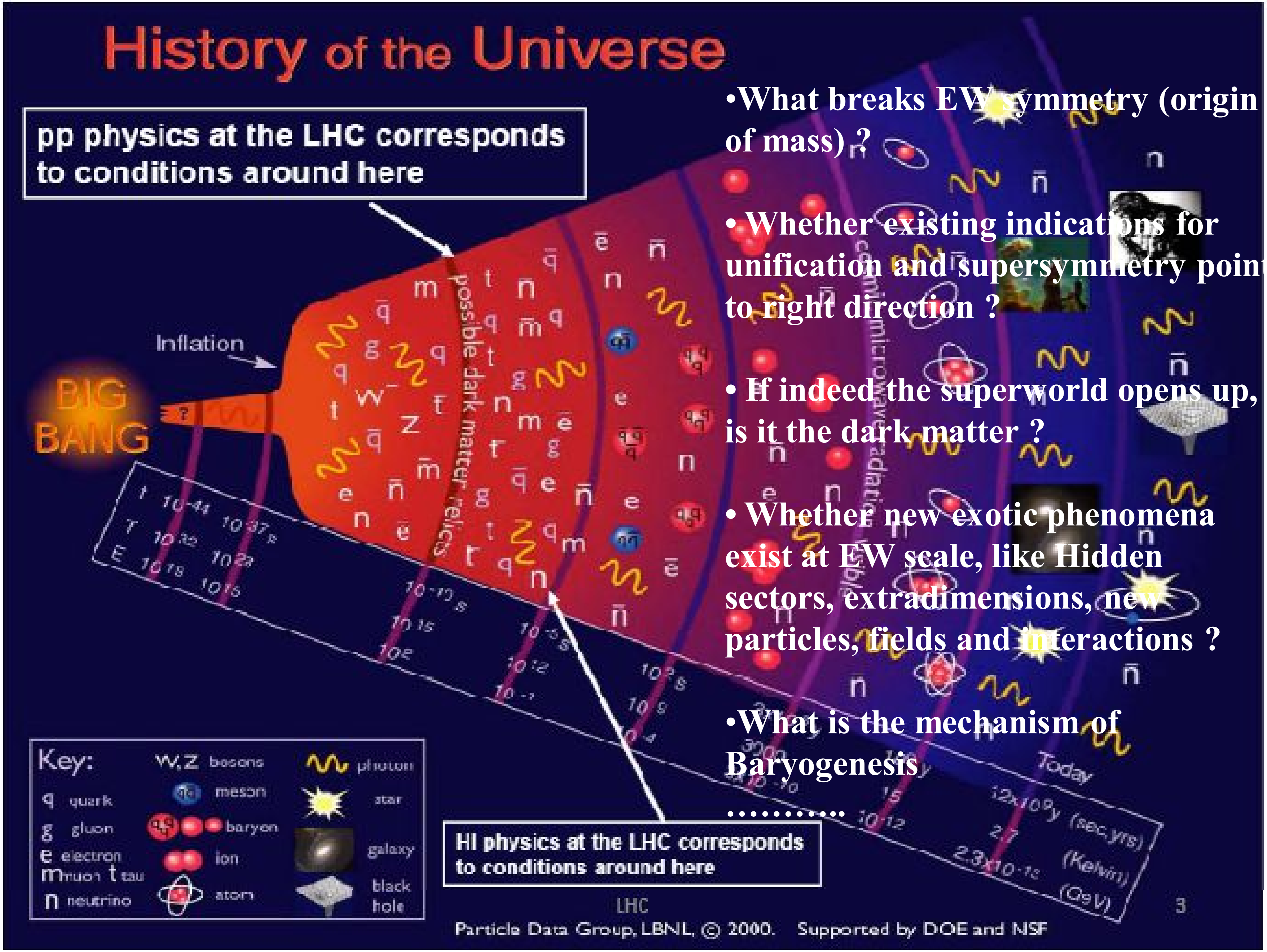
A feasibility study of possible options

by

The CERN Machine Group

- •1984 : first studies
- •1990 : Aachen workshop
- •Summer 1992 :Evian workshop
- •End 1992:
  ATLAS Letter Of Intent
- •No very significative
  change of detector design since
- •1994 The CERN Council approves the construction of the LHC
- •1998 The first prototype magnet with a 15 metre nominal length is tested
- •2008 First beam
- •2009 First collission
- •2010 First result
- •2014 Upgrade 1
- •2019 Upgrade 2
- •………..

≈ half of century project



- What breaks EW symmetry (origin of mass) ?
- Whether existing indications for unification and supersymmetry point to right direction ?
- If indeed the superworld opens up, is it the dark matter ?
- Whether new exotic phenomena exist at EW scale, like Hidden sectors, extradimensions, new particles, fields and interactions ?
- What is the mechanism of Baryogenesis

……….

CERN Courier, 1993

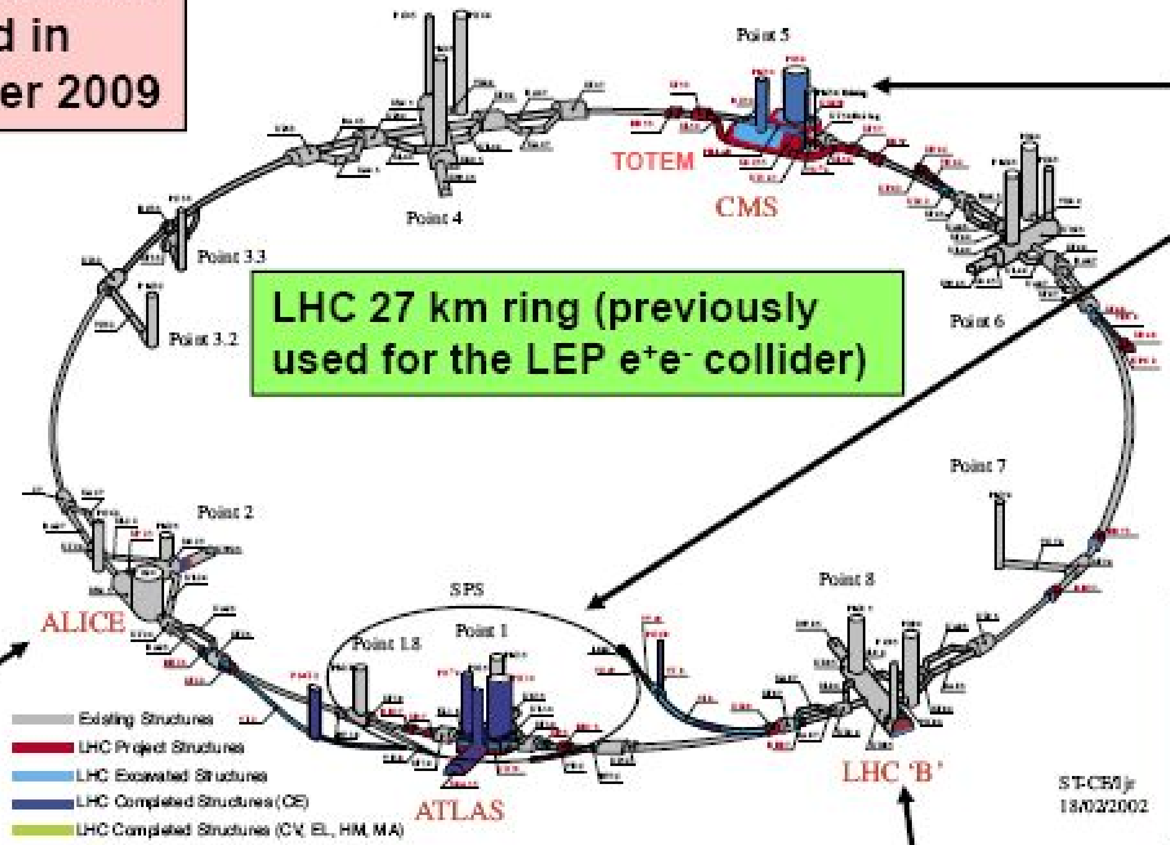
On 28 June, several days after the meeting of CERN's governing Council, Russian Science Minister Boris Saltykov (left) and CERN Director General Carlo Rubbia signed an updated cooperation agreement between Russia and CERN.

- pp $\sqrt{s}$ = 10-14 TeV $L_{design} = 10^{34}\ cm^{-2}\ s^{-1}$ (after 2012/3)
  $L_{initial} <$ few x $10^{33}\ cm^{-2}\ s^{-1}$ (before)

  Note: $\sqrt{s}$ is x7 Tevatron, L_{design} is x100 Tevatron
- Heavy ions (e.g. Pb-Pb at $\sqrt{s}$ ~ 1000 TeV)

First collisions: expected in November 2009

ATLAS and CMS : pp, general purpose



LHC 27 km ring (previously used for the LEP e^+e^- collider)

Plus two much smaller experiments with very forward detectors at
Point-1: LHCf
Point-5: Totem

ALICE : ion-ion, p-ion

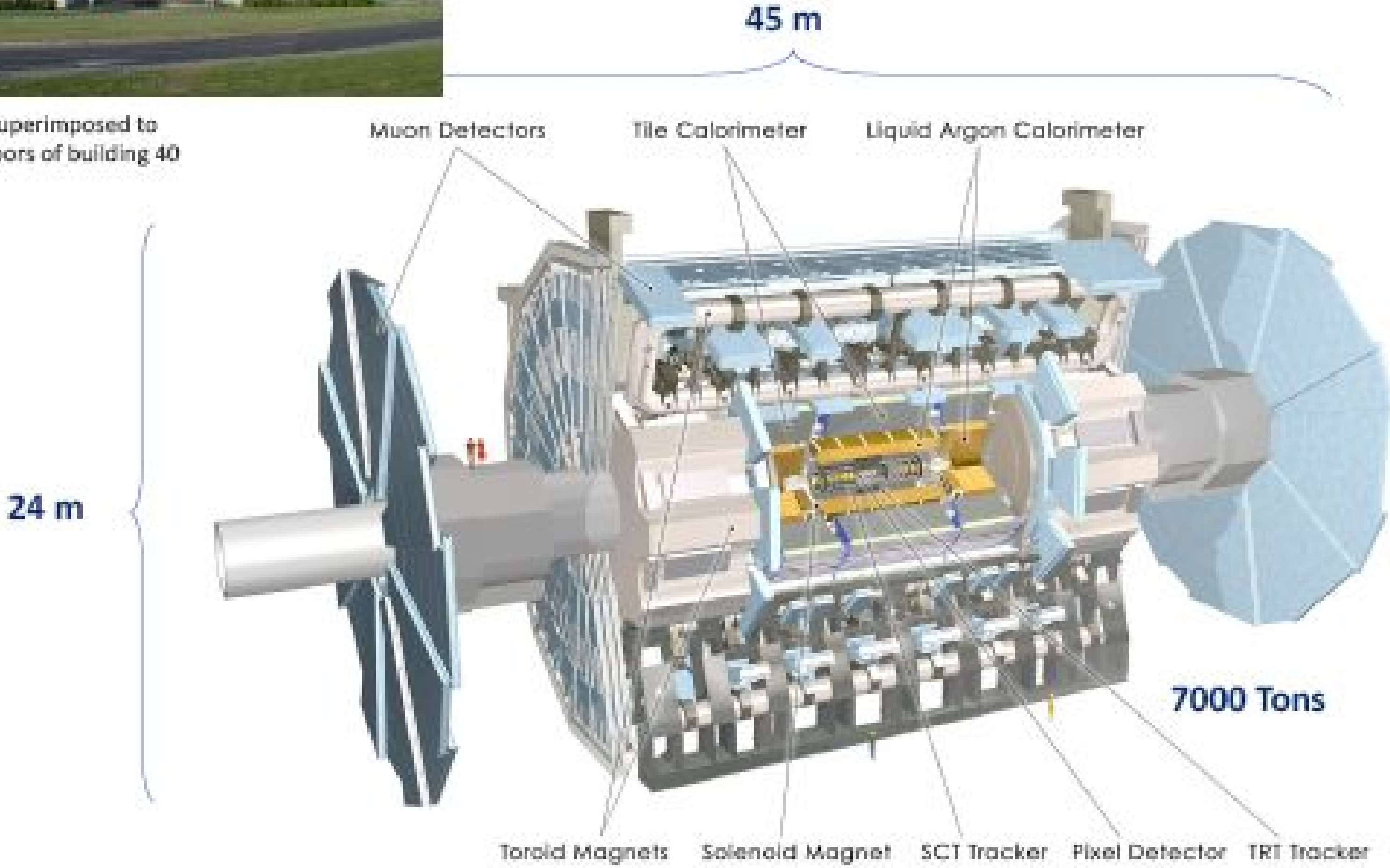
LHCb : pp, B-physics, CP-violation

Main parameters of the machine

	Design operation		
Beam energy	7	TeV	
Dipole field	8.4	T	
Dipole current	11700	A	
Instantaneous luminosity L	10^{34}	$cm^{-2}s^{-1}$	
Integrated luminosity/year	~ 100	fb^{-1}	
Circulating current/beam	0.53	A	
Number of bunches	2808+2808		← Tevatron: 36+36
Bunch spacing	25	ns	← Tevatron: 396 ns
Protons per bunch	10^{11}		
R.m.s. beam radius at IP1/5	16	μm	
R.m.s. bunch length	7.5	cm	
Stored beam energy	360	MJ	← x200 Tevatron
Crossing angle	300	μrad	
Number of events per crossing	~20		
Luminosity lifetime	10	hours	

The ATLAS Detector

ATLAS superimposed to
the 5 floors of building 40



ATLAS Collaboration

35 Countries
165 Institutions
2000 Scientific Authors total
(1600 with a PhD, for M&O share)

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, DESY, Dortmund, TU Dresden, **JINR Dubna,** Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, **FIAN Moscow**, **ITEP Moscow, MEPhI Moscow**, **MSU Moscow**, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, **BINP Novosibirsk**, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, **IHEP Protvino**, Regina, Ritsumeikan, UFRJ Rio de Janeiro, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, **NPI Petersburg,** Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Yale, Yerevan

Strategy to prepare the ATLAS detectors for physics

• Strict quality controls during detector construction in order to meet performance requirements

• 15 year long test beam campaign in order to understand (and calibrate large parts of the detectors) and validate/tune software tools

• Detailed simulation of realistic detector including misalignments, material non-uniformities, etc. in order to test and validate calibration/ alignment strategies

• Commissioning of completed detectors in the underground caverns using cosmic rays and "LHC beams"

• Commissioning and calibration with physics

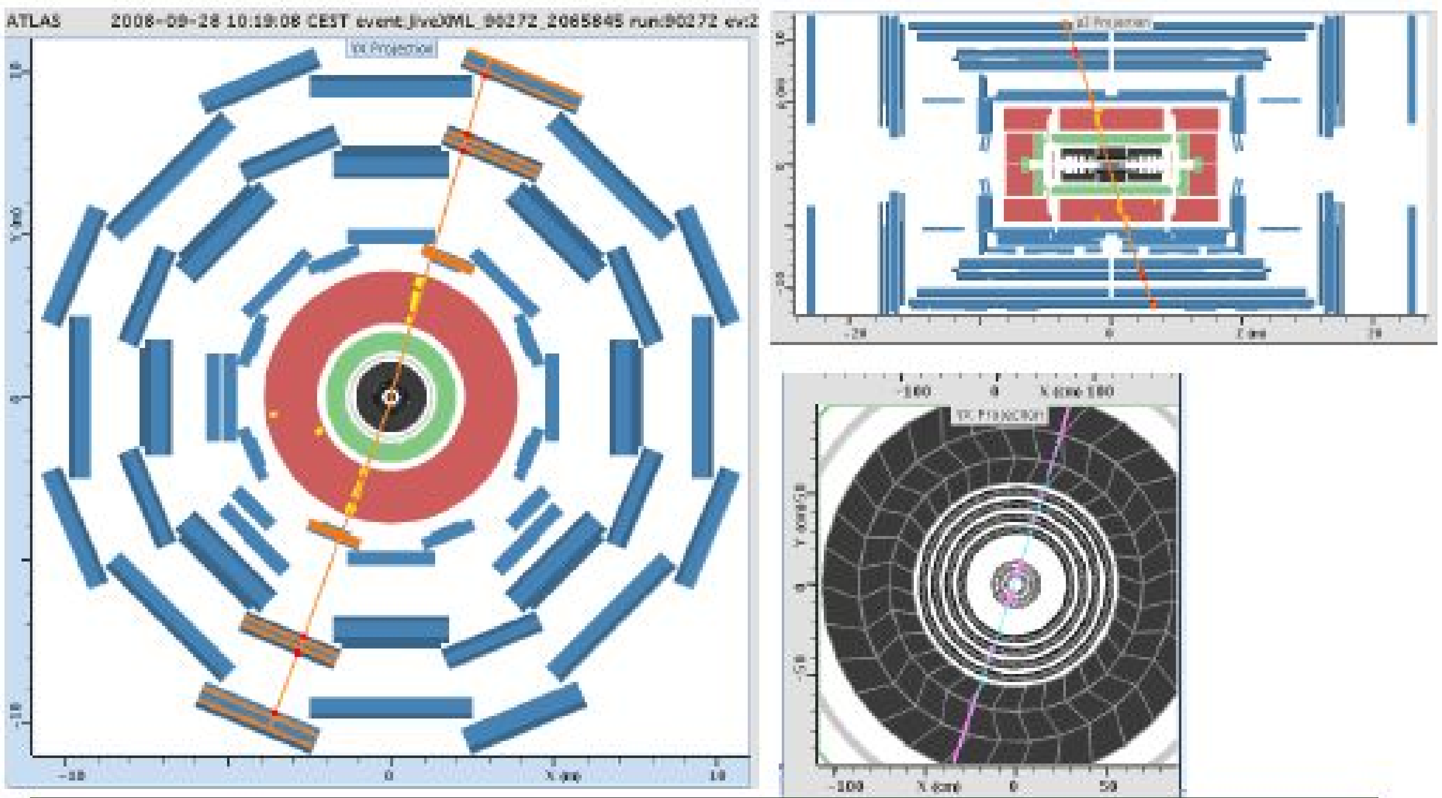
•Understanding SM backgrounds to New Physics

• **Discovery of New Physics …**

Commissioning with cosmics in the underground cavern

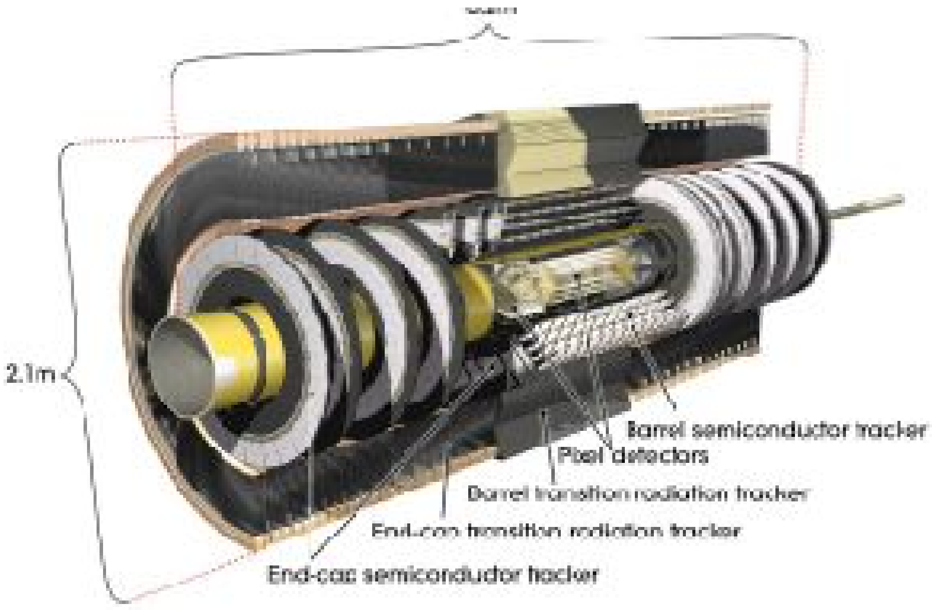
Started more than three years ago. Very useful to:

- Run an increasingly more complete detector with final trigger, data acquisition and monitoring systems. Data analyzed with final software
- Shake-down and debug the experiment in its final position → fix problems
- Perform first calibration and alignment studies



~ 500 million cosmics muons recorded August-November 2008 (1.2 PB raw data)

Inner Detector



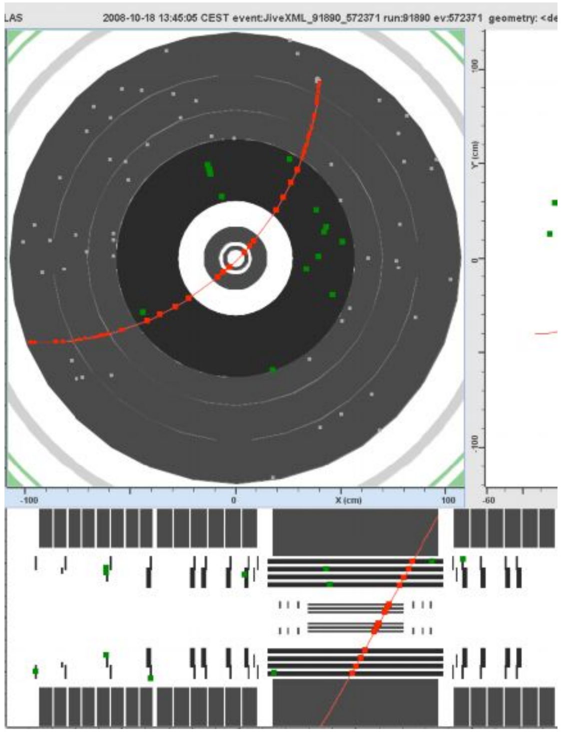
The Inner Detector (ID) is organized into three sub-systems:

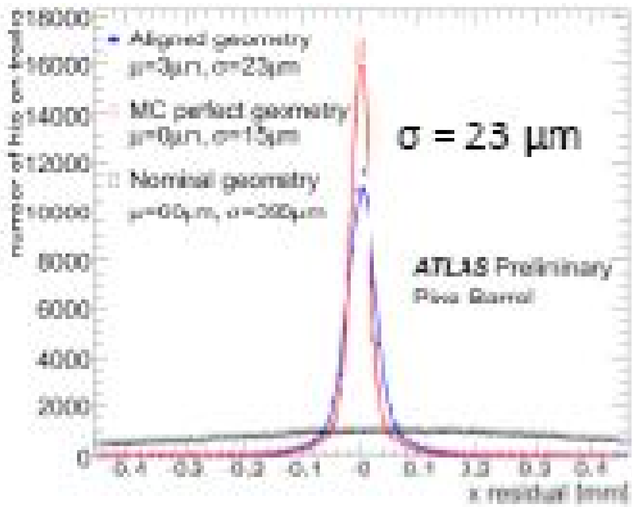
Pixels
($0.8\ 10^8$ channels)

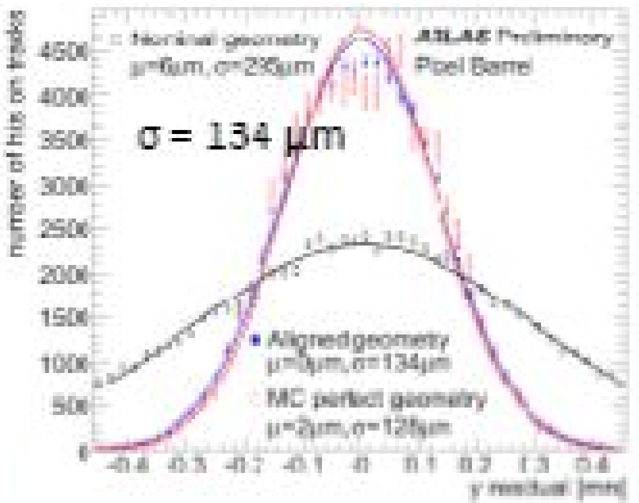
Silicon Tracker (SCT)
($6\ 10^6$ channels)

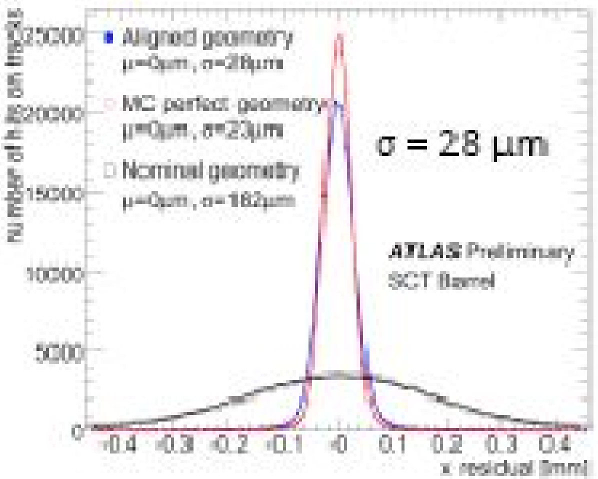
Transition Radiation Tracker (TRT)
($4\ 10^5$ channels)

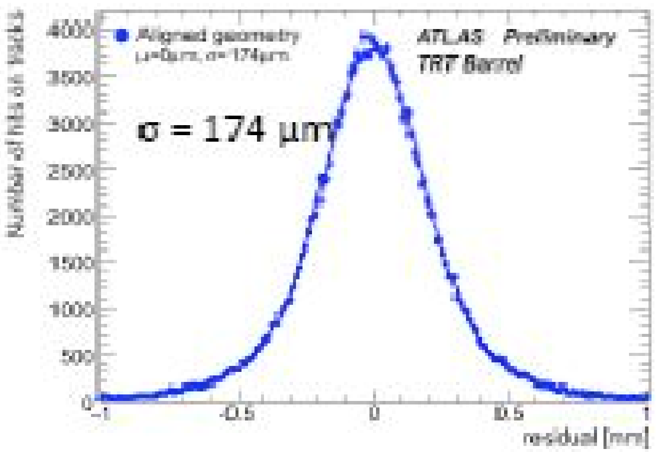
Inner Detector - Alignment with tracks







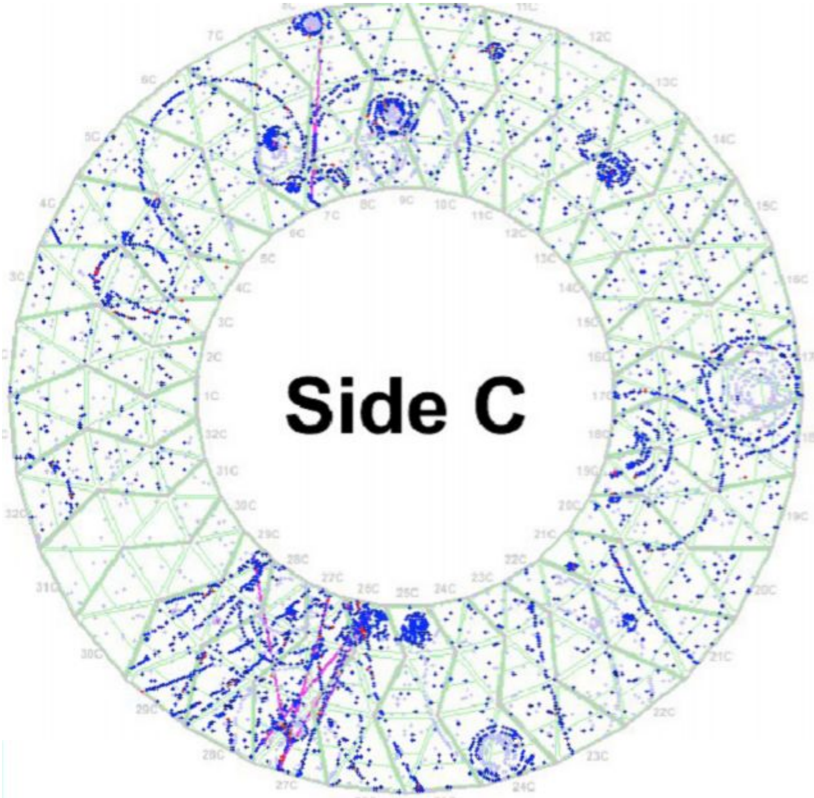




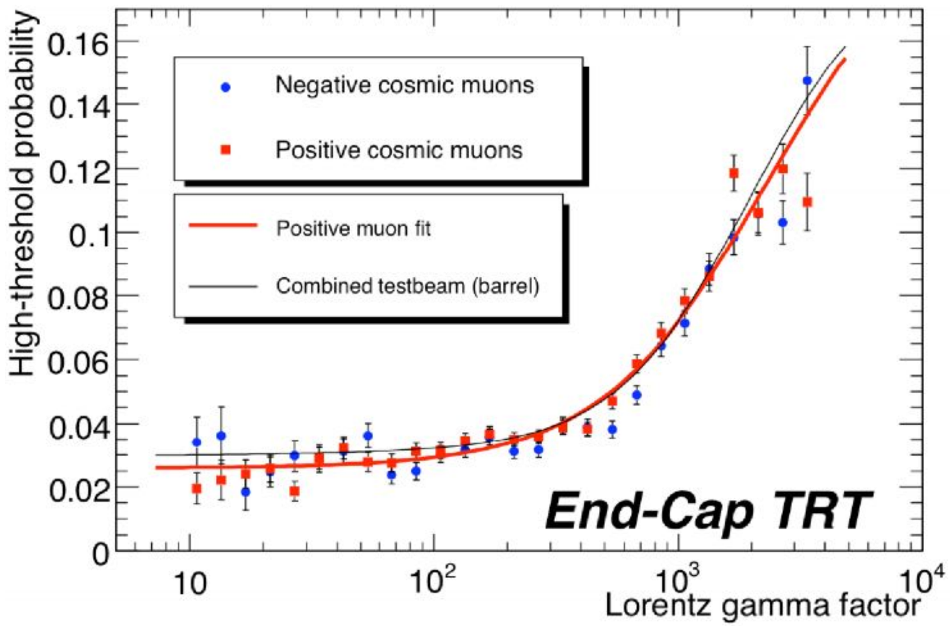
Track residuals close to perfect geometry

(residual – distance between the fitted track and the hit in the layer)

Inner Detector - Results

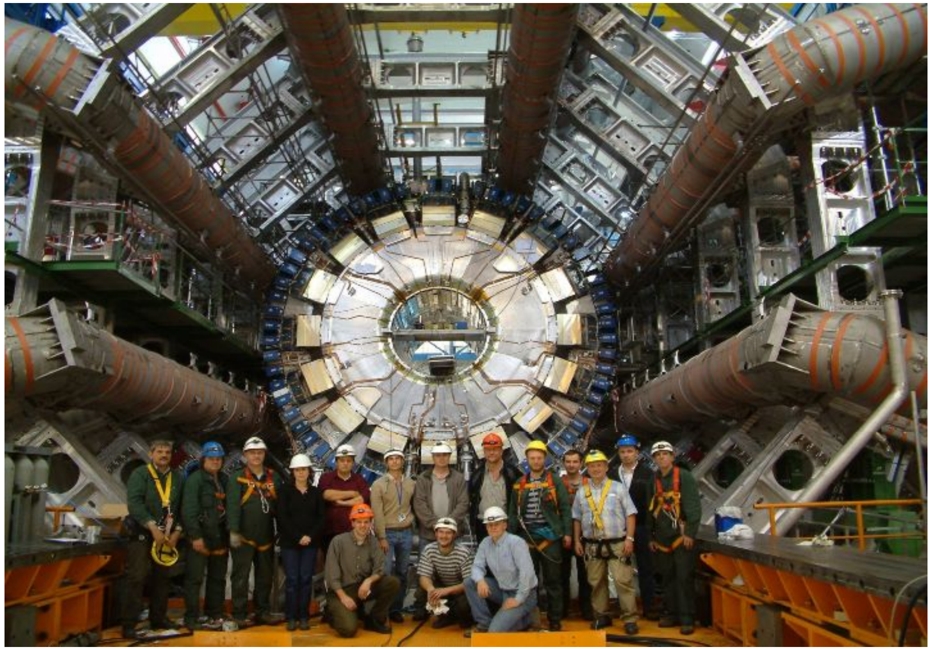


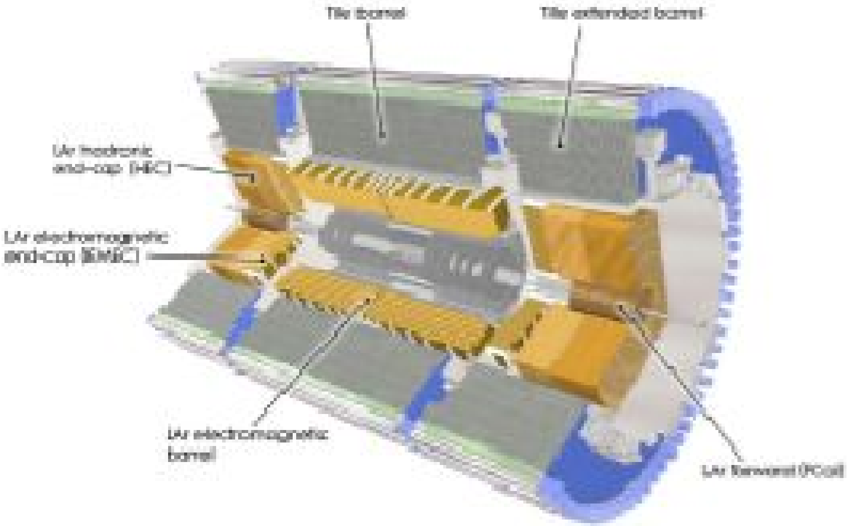
Bubble chamber like picture in barrel TRT
(cosmic shower)



Probability of high amplitudes
(due to transition radiation).
Good agreement with test beam data.

Calorimetry





Electromagnetic energy resolution:

$$\sigma(E)/E = 10\%/\sqrt{E} \oplus 0.7\%$$

Hadronic energy resolution:

$$\sigma(E)/E = 50\%/\sqrt{E} \oplus 3\% \quad (\eta < 3.2)$$

$$\sigma(E)/E = 100\%/\sqrt{E} \oplus 10\% \quad (\eta > 3.1)$$

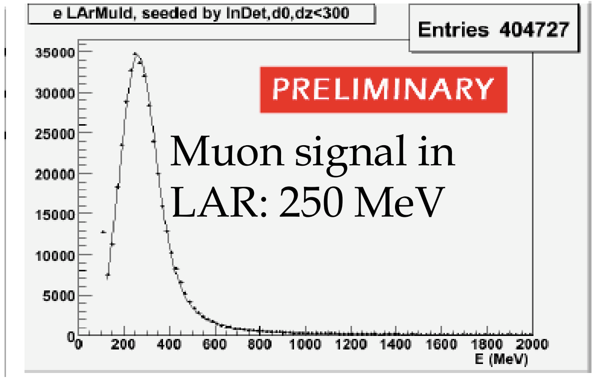
Liquid Argon Calorimeter

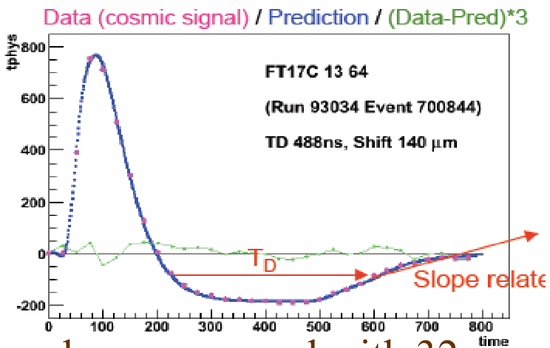
- Electromagnetic (barrel+endcap) Pb-LAr accordion geometry
- Endcap hadronic Cu-LAr
- Forward hadronic Cu/W-LAr
- Electronic calibration

Tile Calorimeter (barrel hadronic)

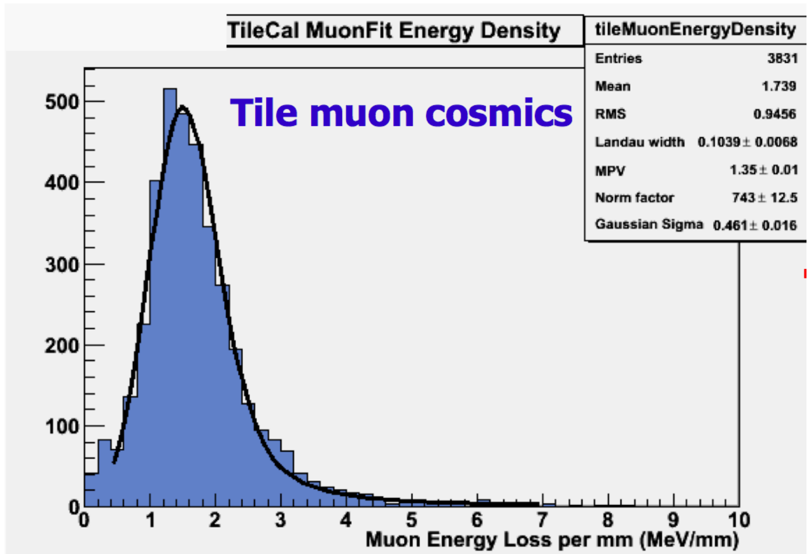
- Iron scintillator tales (3 longitudinal samples)
- Calibration system (Cs source, Laser, charge injecton)

Calorimetry - Status





Pulse shape measured with 32 samples

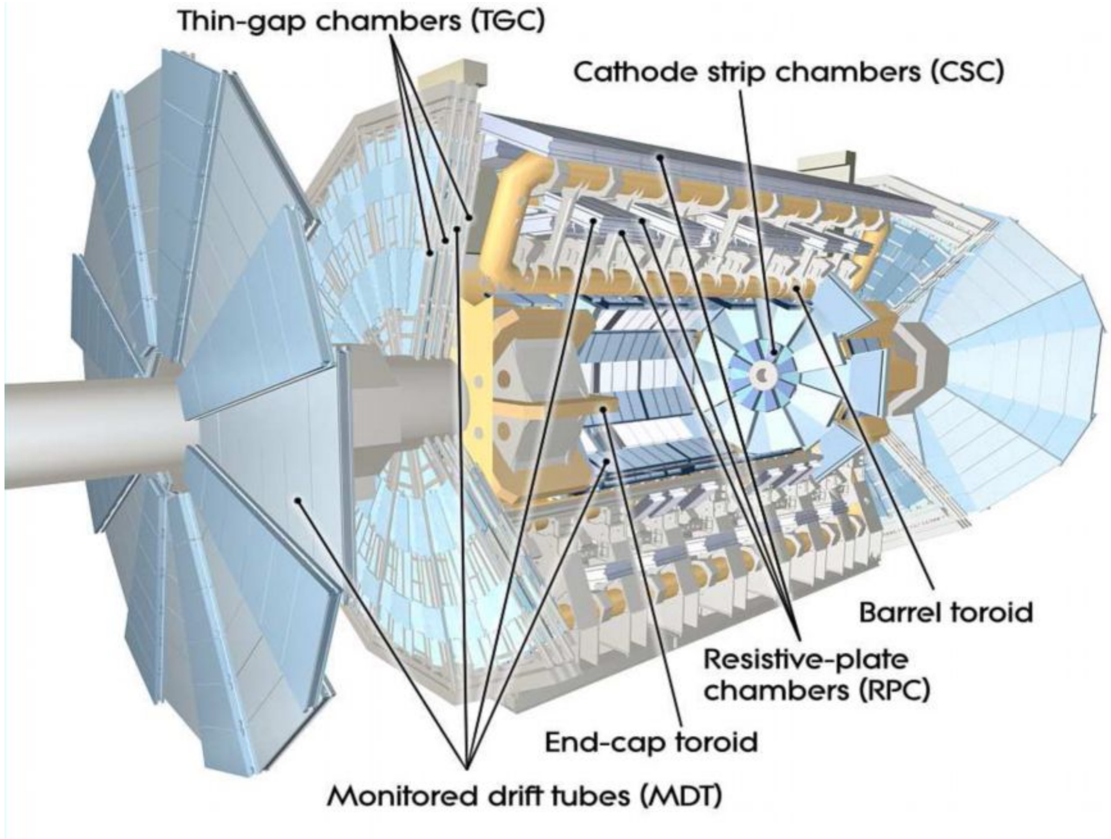


Muon energy Loss in Tilecal

Very small # of non-working channels.
During 2008 run one HEC power supply not working.
Very stable pedestals
Enough data was taken to check parameterization.
Timing is already set to within a few ns.

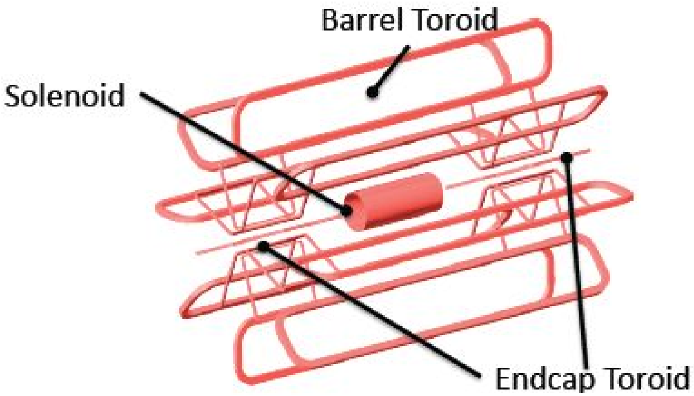
Dead channels: < 1.4% to be repaired during shutdown
Timing has been set for all modules at the level of a few ns.
Energy response for cosmic MUONs is uniform across the full calorimeter.
Good position matching is being achieved between Tile-LAr and ID tracks.

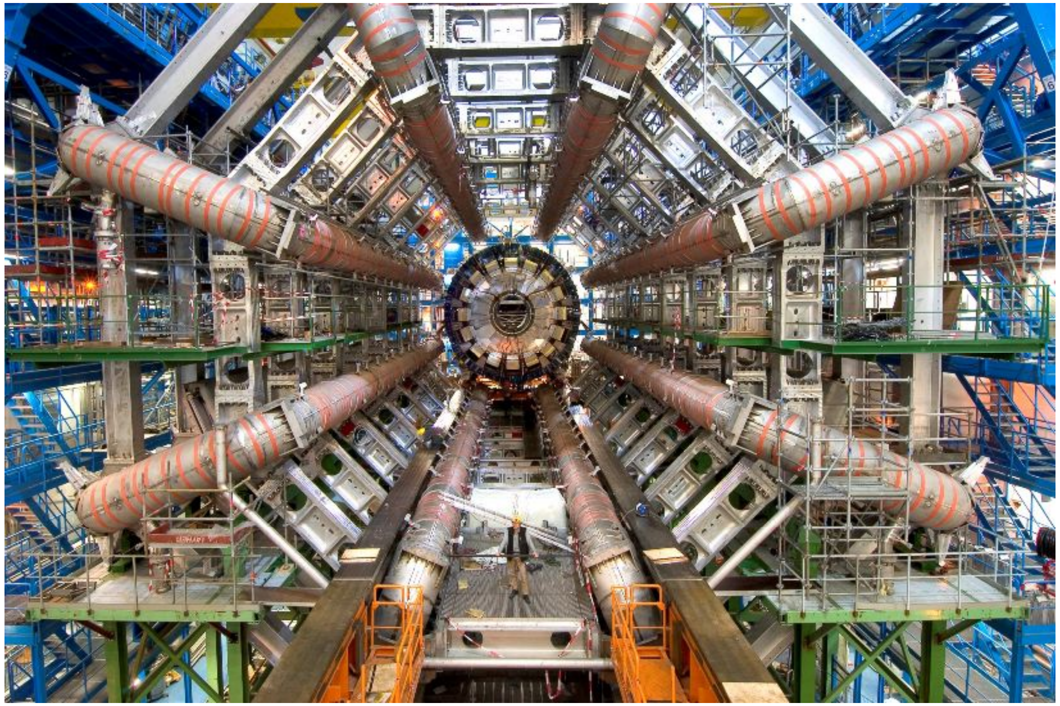
MUON Spectrometer



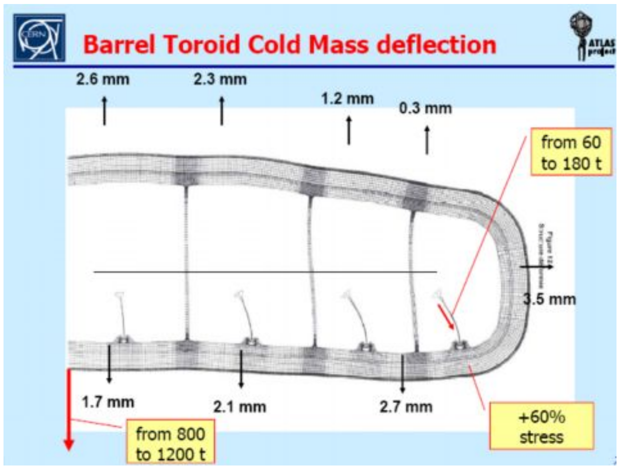
- System composed of:
  - Magnets
  - Tracking chambers (MDT and CSC)
  - Alignment system (Barrel and End-Cap)
  - Trigger Chambers (RPC and TGC)

Magnet system





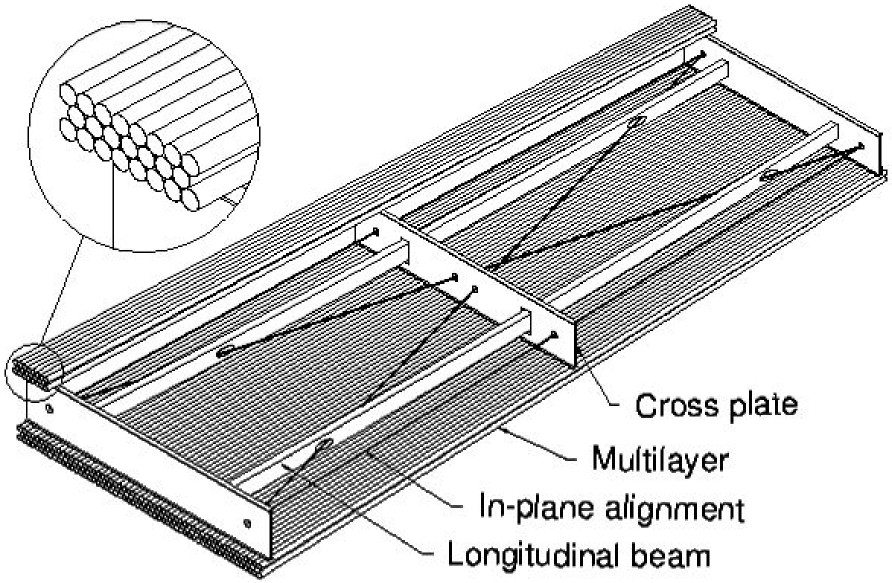
Solenoid (1 coil) 2 T field
Barrel Toroid (8 coils)
0.2-2.5 T field
Two end-cap toroids
(2 x 8 coils) 0.2-3.5 T
Status
Stable continuous operation at nominal field.
Stress and heat distributions during fast quench are safe.
Geometrical distortions of Barrel toroid with field on as expected.

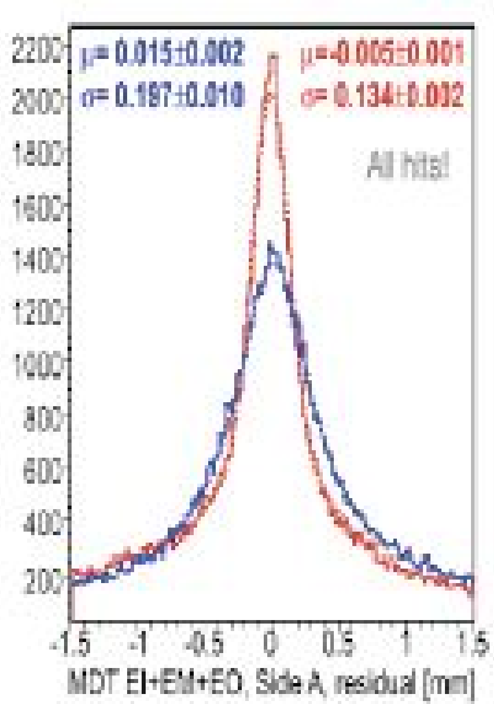


Magnetic Field knowledge:

Magnetic field was measured with probes on chambers to determined where the coils are located to within 1mm.

Muon tracking chambers



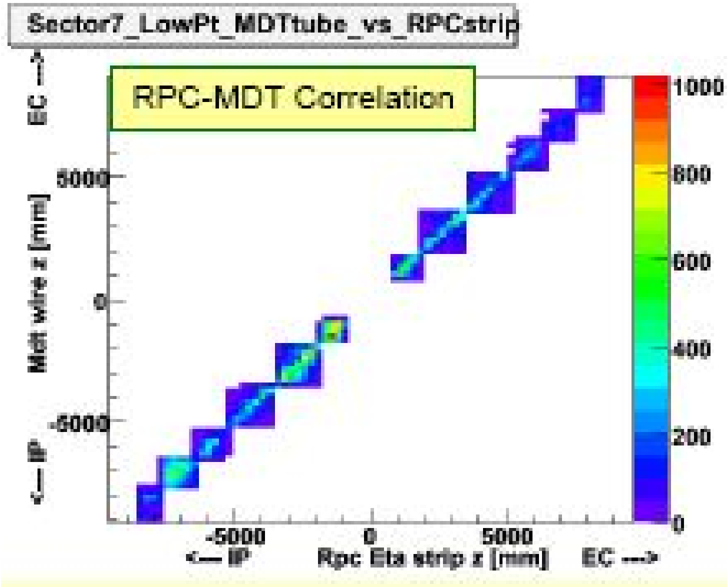


MDT eff.:
Find segment in 3rd
Station using other 2
99%

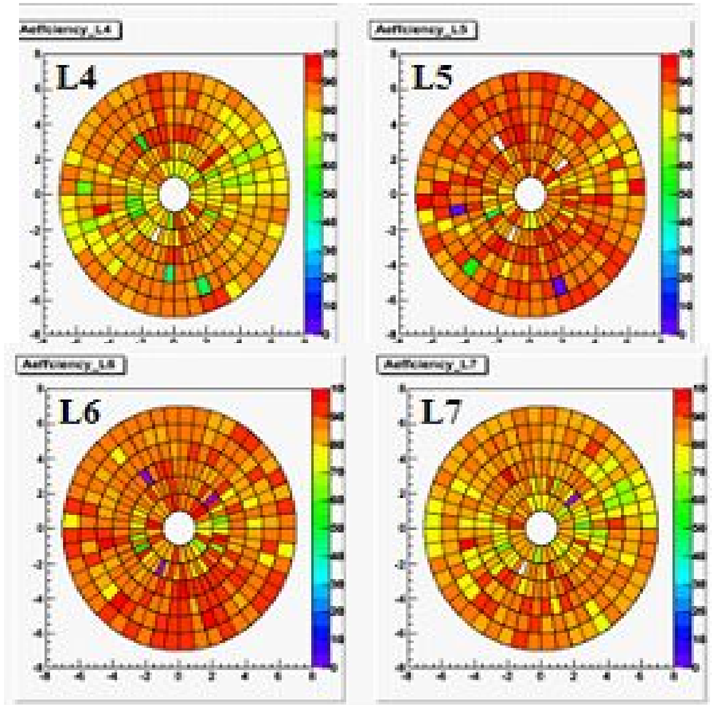
CSC started operation with
initial resolutions at the
mm level

Track residuals in barrel and End-Cap
(red after alignment corrections)
Sigma~135microns, goal 80 microns

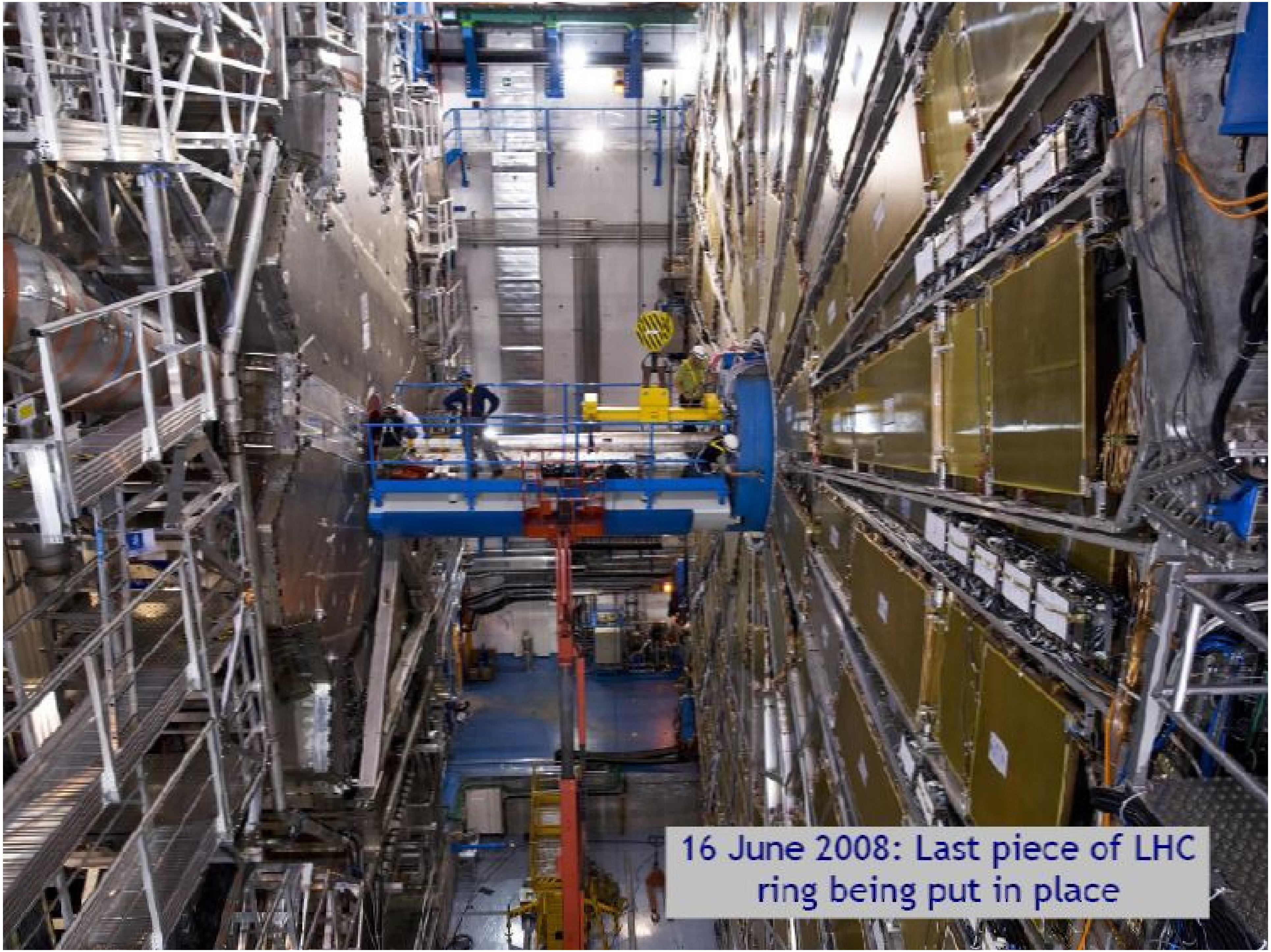
Trigger Chambers



More than 50% of the RPC towers have been timed-in.
Efficiency of individual layers and of coincidence is reaching its expected level.
Good matching between tracking and trigger chambers for finding the tracks.

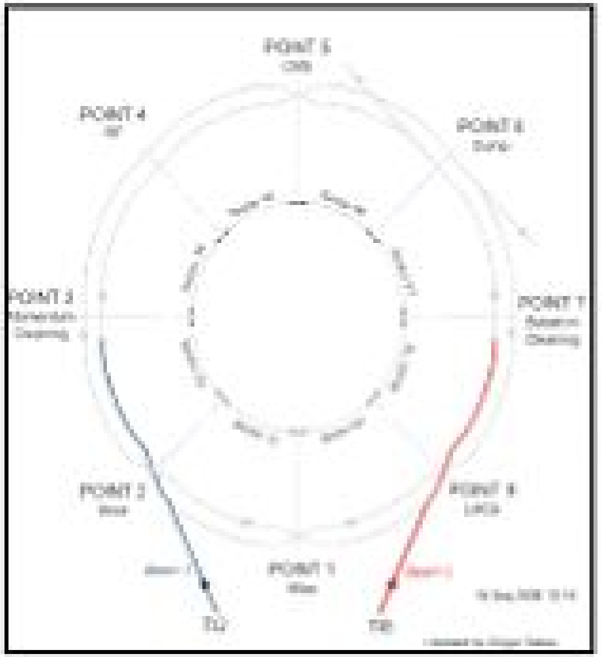


All TGC detectors have been timed-in for collisions.
The efficiency for each individual plane is as expected for cosmics (not well defined time of arrival).
Although without final TGC alignment, matching with MDT tracks is good

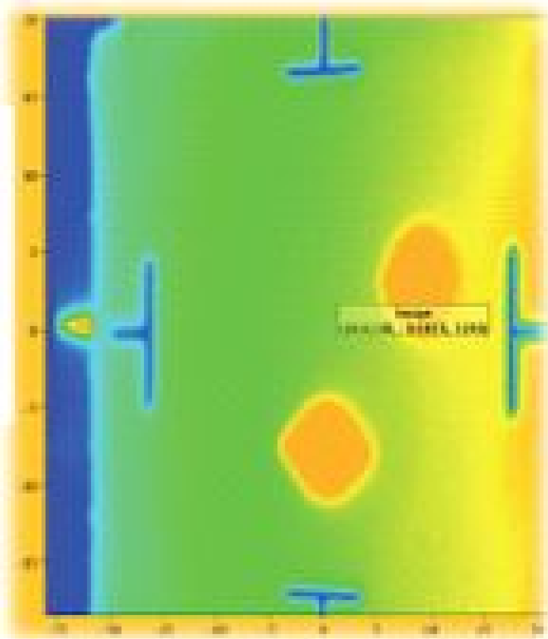


16 June 2008: Last piece of LHC ring being put in place

First Turn! 10 Sept 2008



10:30 am
Two beam spots on a screen near ALICE indicate that Beam 1 has made 1 turn



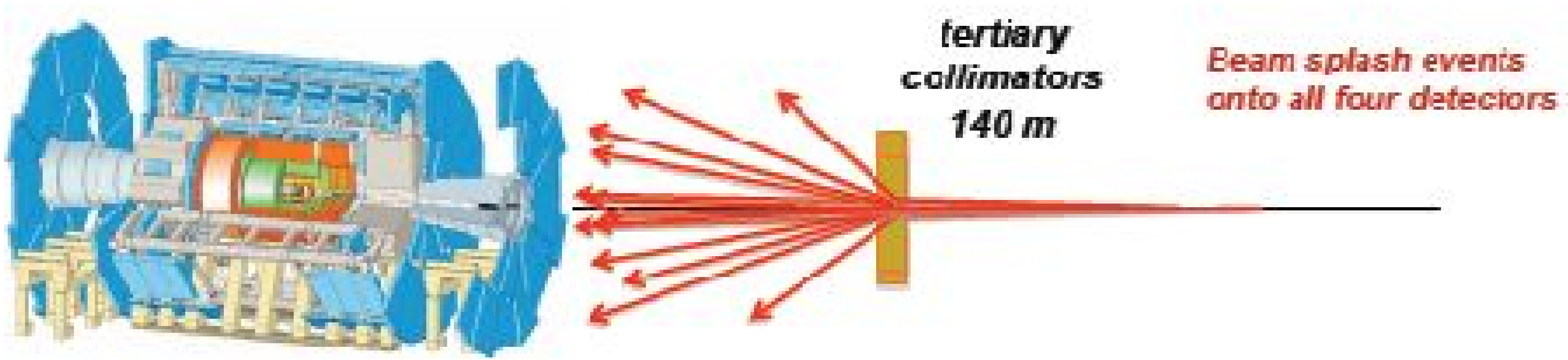
10:30 : Beam 1 (clockwise) around the ring (in ~ 1 hour), makes ~ 3 turns, then dumped

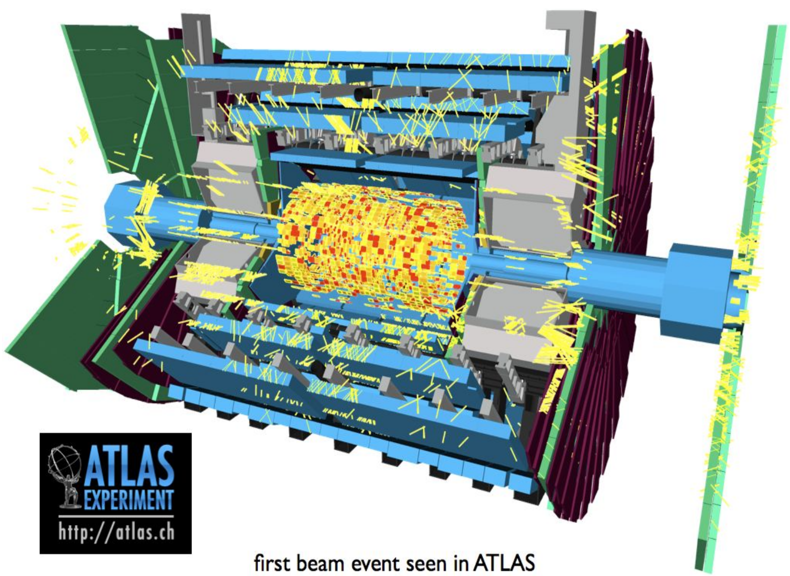
15:00 : Beam 2 (counter-clockwise) around the ring, makes 3-4 turns, then dumped

22:00 : Beam 2 circulates for hundreds of turns …

Beam Energy: 450 GeV, Beam Intensity: 2 x 10^9 protons per bunch

Beam splash events have been successfully recorded by ATLAS





first beam event seen in ATLAS

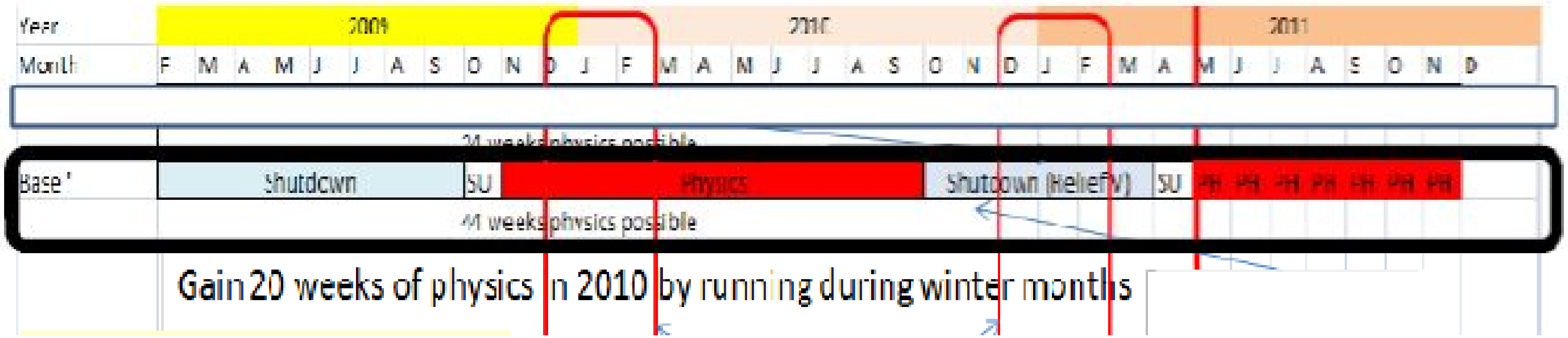
LHC Incident on 19 Sept. 2008

- Most likely, an electrical arc developed, which punctured the He enclosure
- Large amounts of He gas were released into the insulating vacuum of the cryostat

LHC repair and restart

- Broken magnets will be replaced or repaired
- Sectors will be equipped with extra pressure relief valves
- The quench protection system will be upgraded everywhere

Summary of the New LHC Schedule



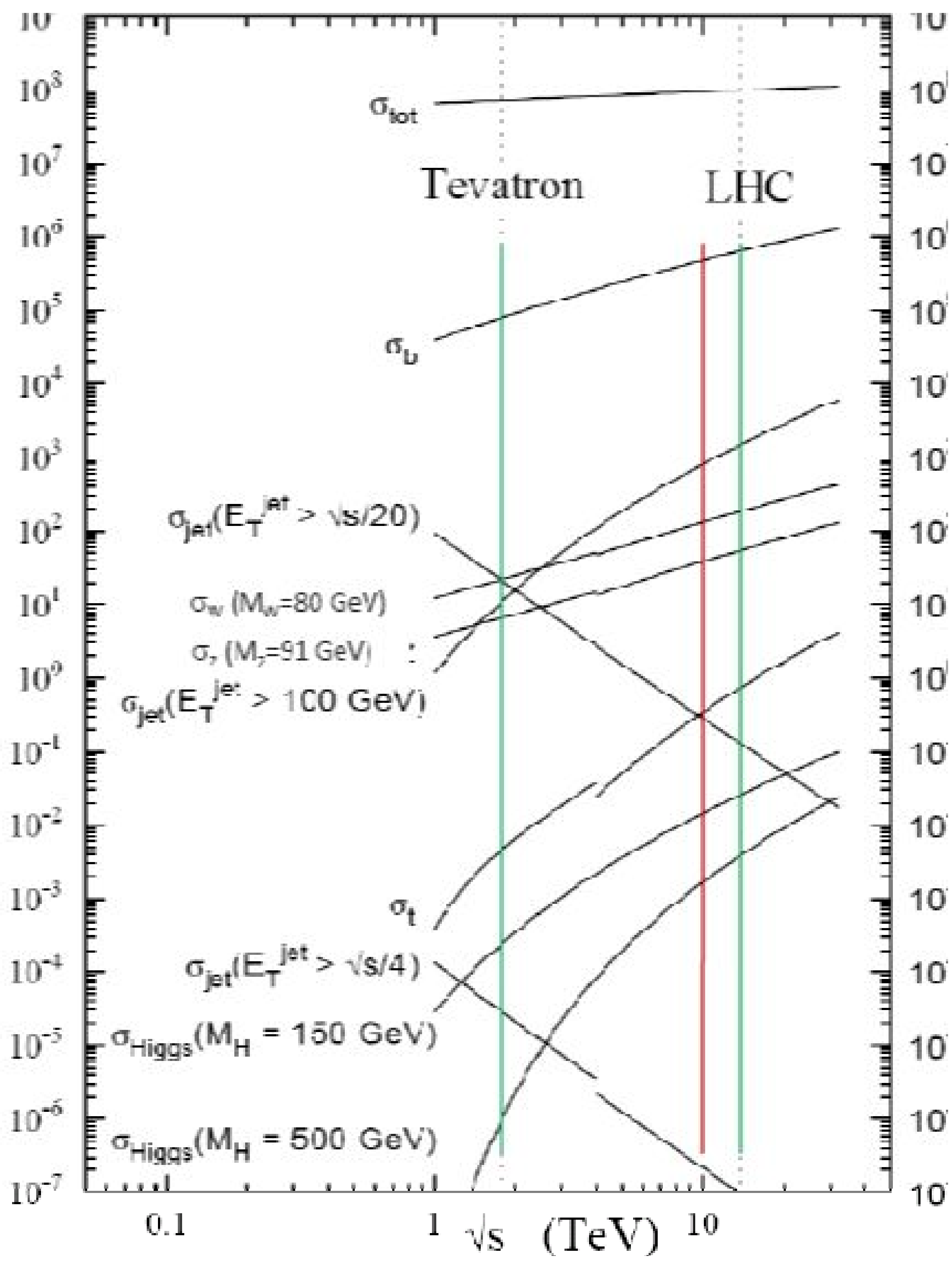
The plan is:

- Machine ready for start-up operation again in October 2009
- Run the LHC over winter until September 2010
- This first physics run will be at 10 TeV collision energy
- The end of the run, end of summer 2010
- Estimated integrated luminosity: from $\approx 100 pb^{-1}$ to $\approx 500 pb^{-1}$
- There will be also a first run with heavy ion collisions

What do we expect if centre-of-mass energy is reduced?

Larger decrease in cross section for high mass particles also due to less gluon and sea quarks at high x

Mass scale = $\sqrt{s} * \sqrt{x_1} * \sqrt{x_2}$



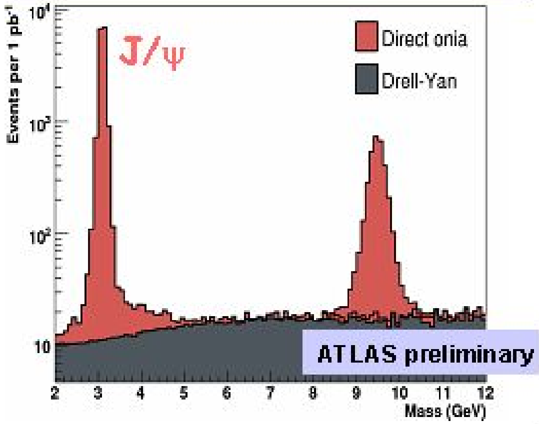
First physics data

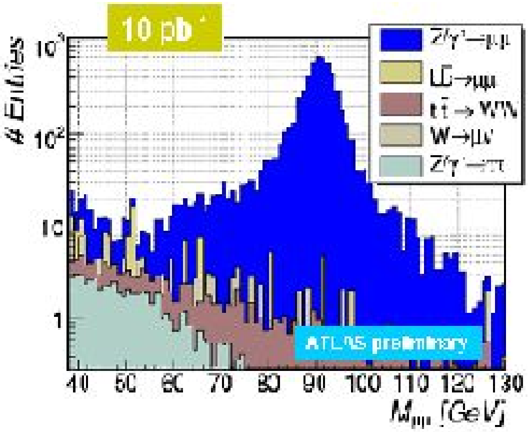
~100 pb-1 per experiment may be collected within a month

Channels (examples …)	Events to tape for 100 pb-1 (ATLAS)	Total statistics from LEP	and	Tevatron
$W \rightarrow \mu\, \nu$	$\sim 10^{6}$	$\sim 10^{4}$		$\sim 10^{6\text{-}7}$
$Z \rightarrow \mu\, \mu$	$\sim 10^{5}$	$\sim 10^{6}$		$\sim 10^{5\text{-}6}$
$tt \rightarrow W\, b\, W\, b \rightarrow \mu\, \nu + X$	$\sim 10^{4}$			$\sim 10^{3\text{-}4}$
QCD jets pT > 1 TeV	$> 10^{3}$			---
$\tilde{g}\tilde{g}$ m = 1 TeV	~ 50			---

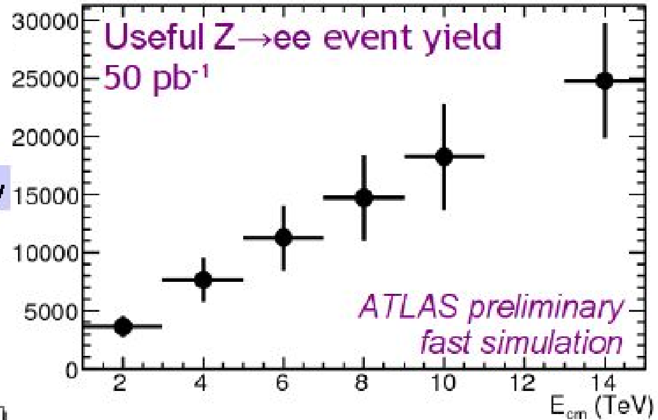
Calibration W, Z and J/Psi

1 pb^{-1} ≡ 3 days at 10^{31} at 30% efficiency



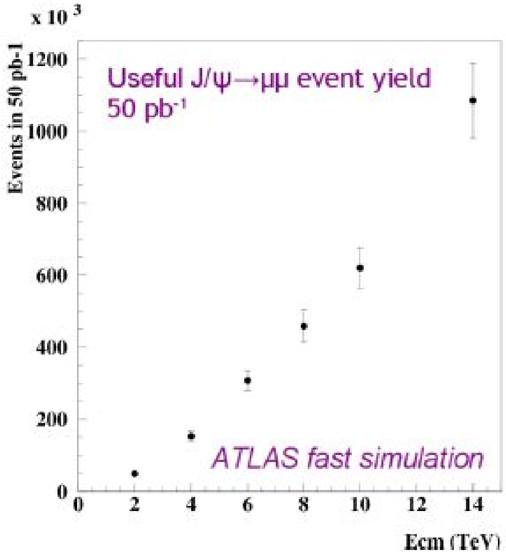


Full sim. study scaled using ATLFAST and simple acceptance cuts



Similar number of W and Z events as the Tevatron 2010 at √s=10 TeV with O(1) fb^{-1}

Yield with fiducial acceptance cuts: muon with p_T>6 GeV, and second with p_T>4 GeV, all with |eta|<2.5



Already with about O(50) pb-1 at 10 TeV enough W, Z and J/psi events for a quite good detector calibration

Electron scale < 1% in 0.2x0.4 eta-phi bins,

Muon momentum scale and alignment known at the 1% level

The first top quarks in Europe

A top signal can be observed quickly, even with limited detector performance and simple analysis …. and then used to calibrate the detector and understand physics

$\sigma_{tt} \approx$ **250 pb for tt $\rightarrow$ bW bW $\rightarrow$ blν bjj**

ATLAS preliminary

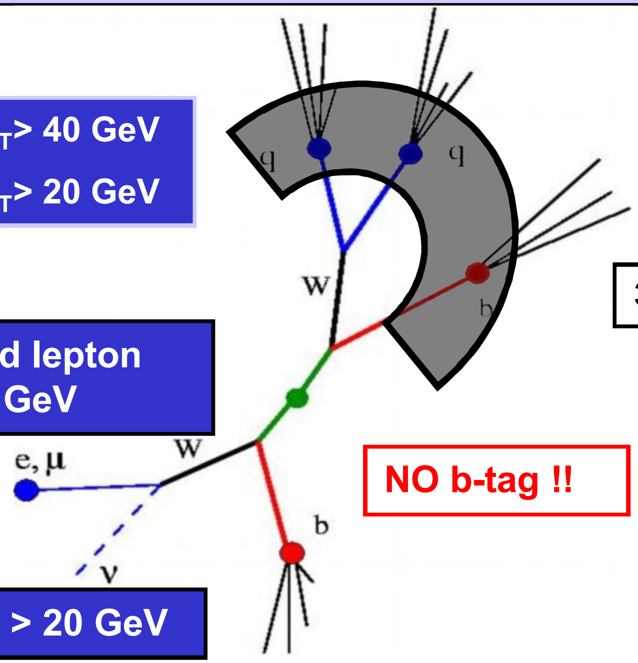
3 jets p_T> 40 GeV

1 jets p_T> 20 GeV

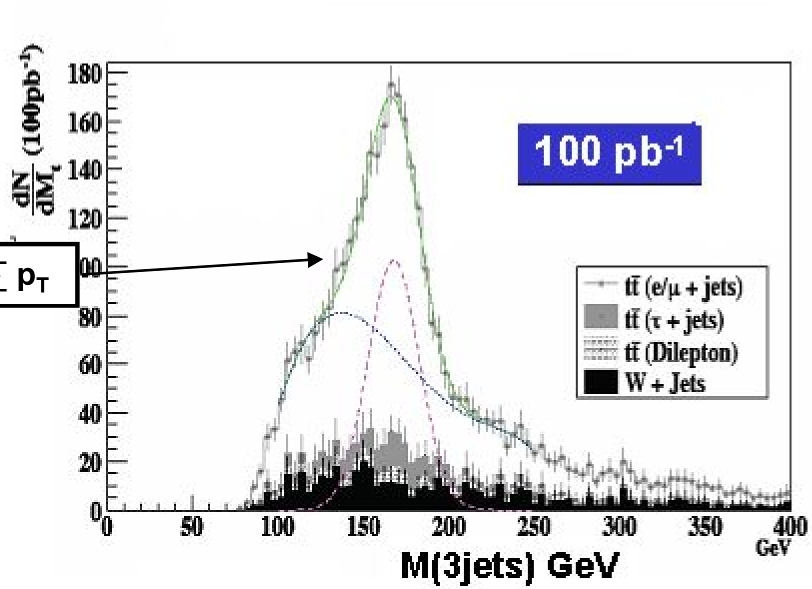
Isolated lepton p_T> 20 GeV

E_T^{miss} > 20 GeV

NO b-tag !!



3 jets with largest $\sum p_T$



Top signal observable in early days with no b-tagging and simple analysis
(~3000 evts for 100 pb^{-1}) $\rightarrow$ **measure σ_{tt} to ~20%, m_t to <10 GeV with 100 pb^{-1}?**
(ultimate LHC precision on m_t: ~ 1 GeV)
In addition, excellent sample to:

- **commission b-tagging, set jet E-scale using W $\rightarrow$ jj peak, …**
- **understand / constrain theory and MC generators using e.g. p_T spectra**

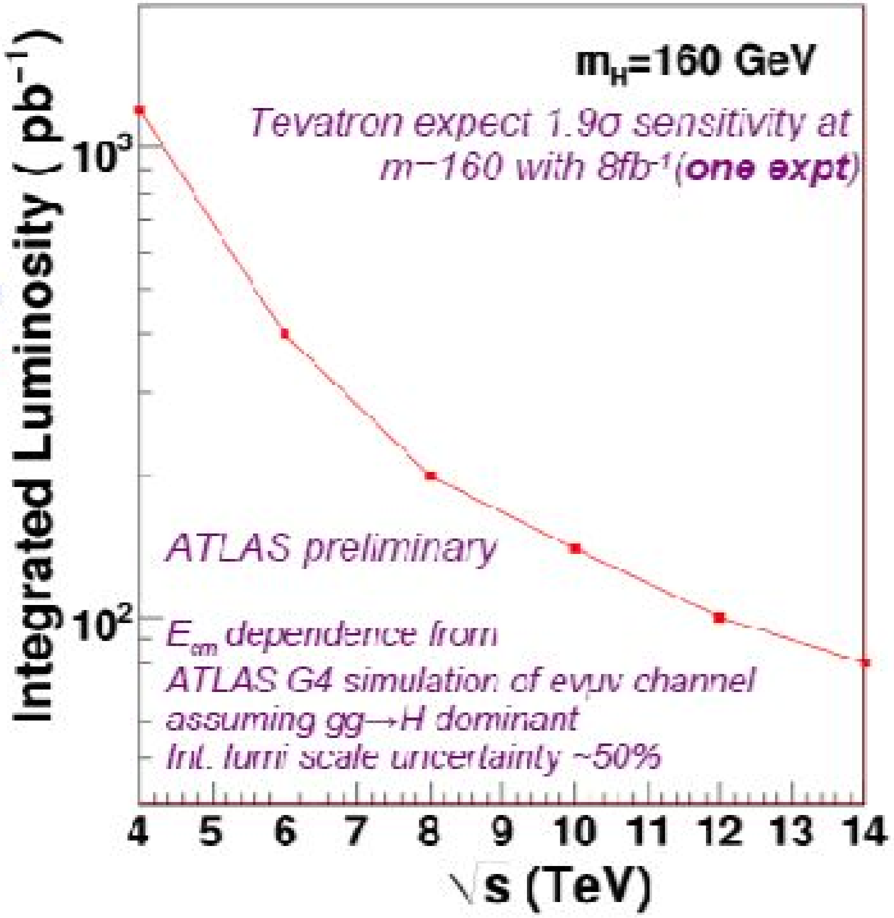
Standard Model Higgs

H→WW→ℓνℓν only

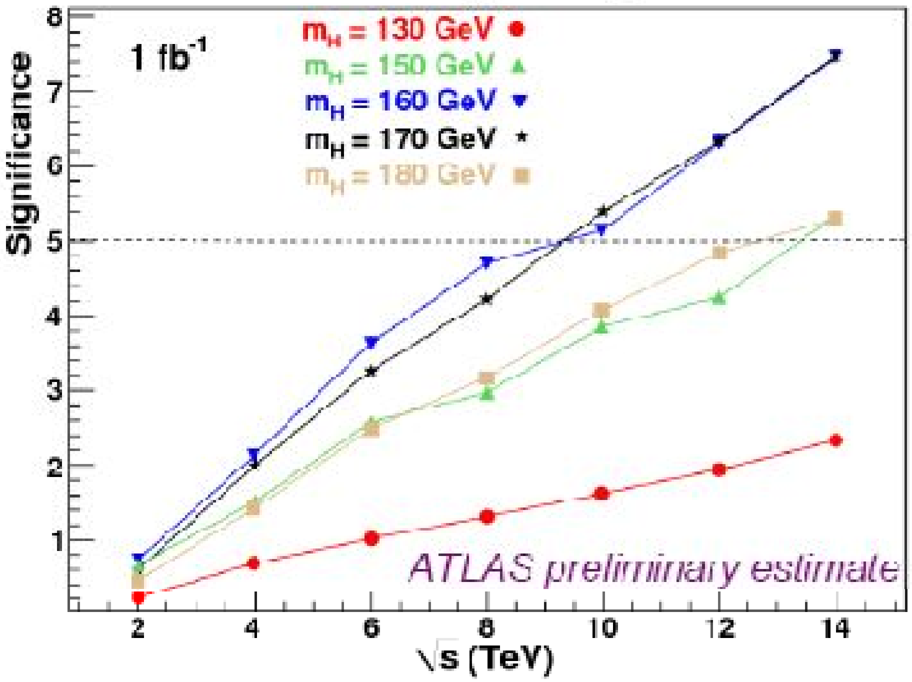
Compare sensitivity to Tevatron with 8 fb^{-1}

To match Tevatron with E_{cm} of 10 TeV, need 100-200 pb^{-1}

Massive loss of sensitivity below 6 TeV

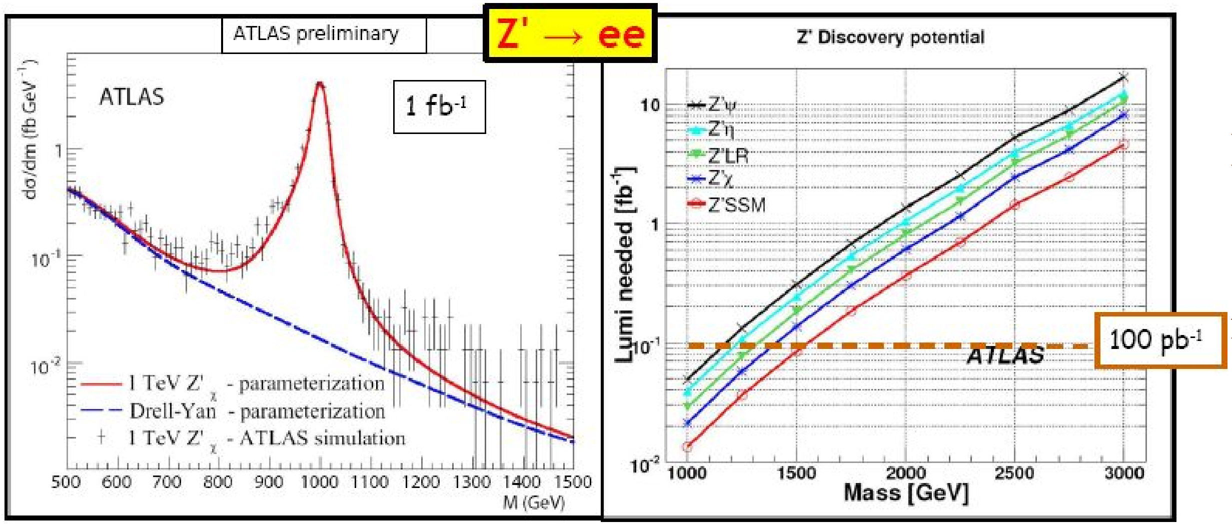


Combination of 0j and 2j, H to WW to ll

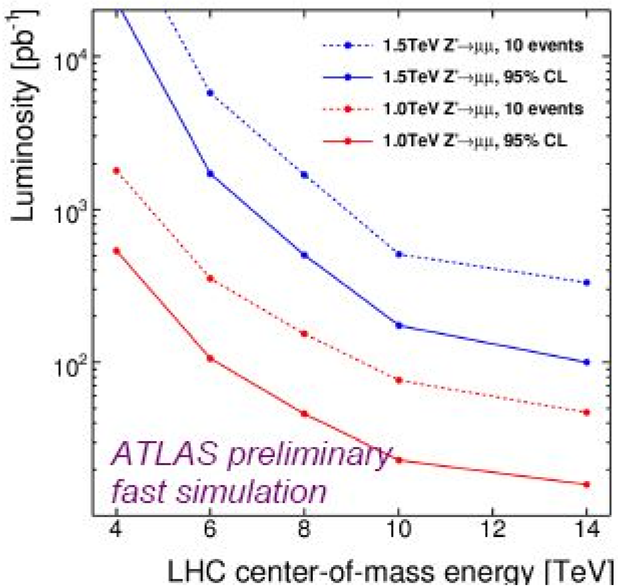


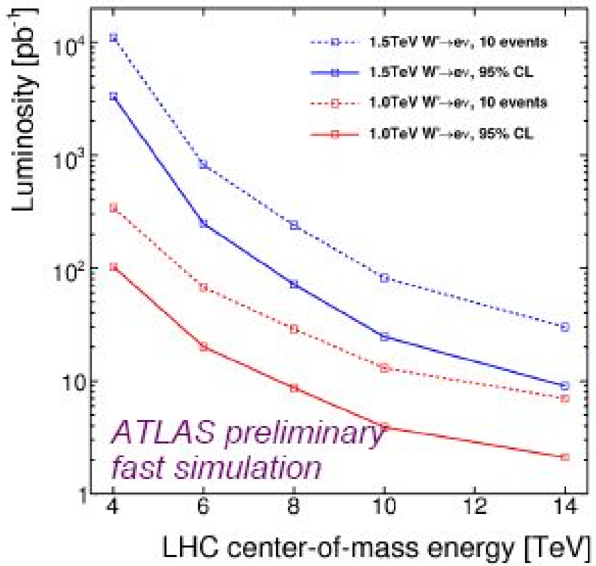
With 1 fb^{-1}, 5σ discovery reach opens, provided E_{cm} above 8 TeV

Z' and W' – candidates for new physics

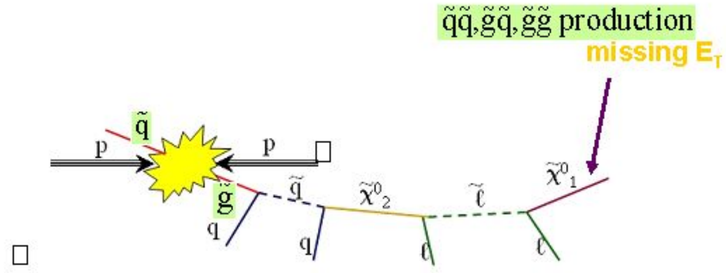


- Z' mass peak on top of small Drell-Yan background
- with 100 pb-1 large enough signal for discovery up to m ~ 1.5 TeV in sequential SM
- current Tevatron 95% CL limit ~ 1 TeV





σ(10 TeV) ~ ½ σ(14 TeV)



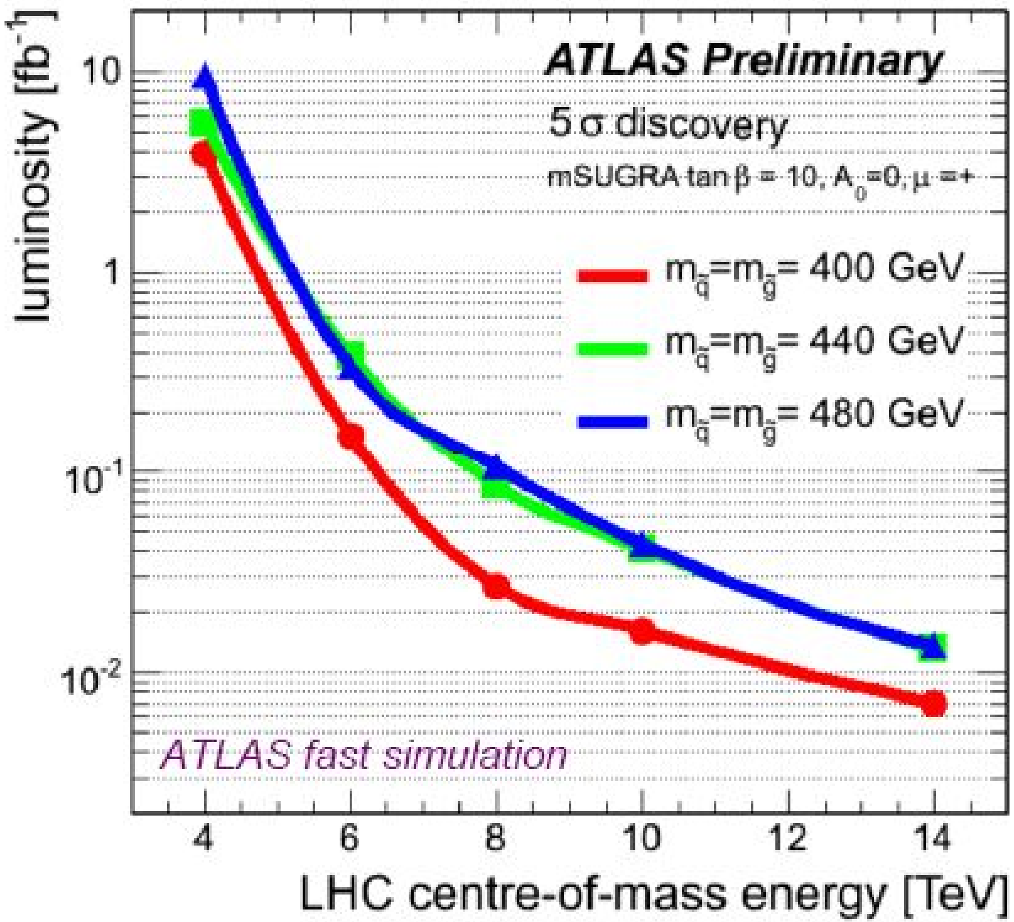
Supersymmetry

l+jets+missing-E_T channel

- Not most sensitive, but will be usable before inclusive jets+missing-E_T analysis

Tevatron limit currently is 380 GeV in this model ($m_{\sim q}$=$m_{\sim g}$)

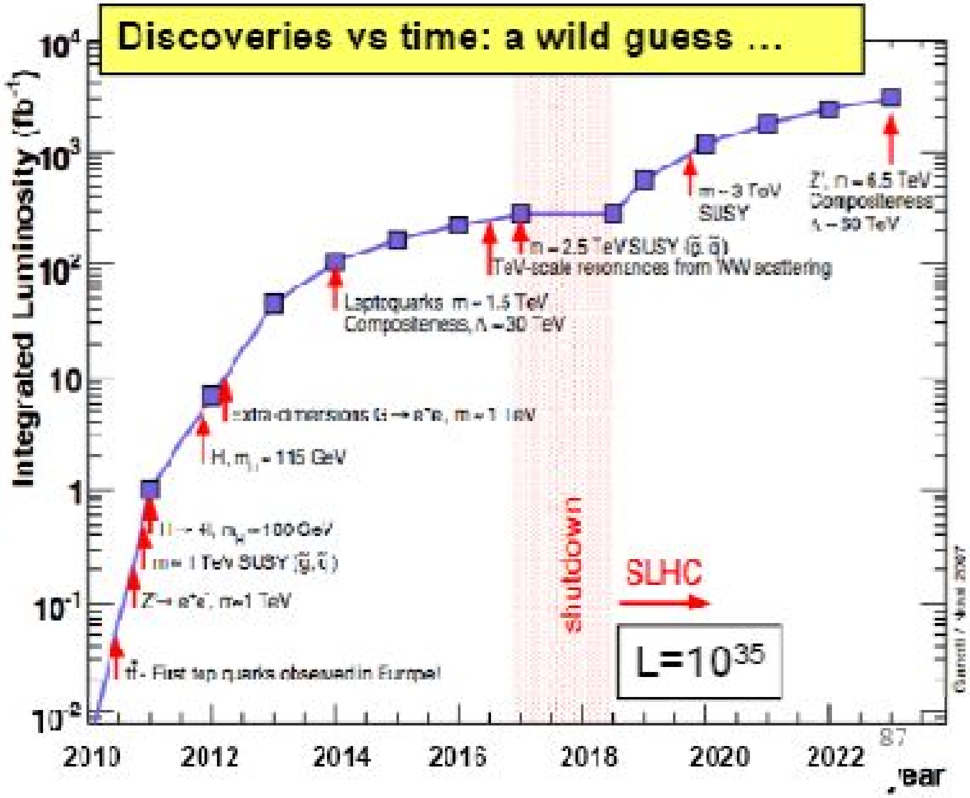
5σ discovery beyond current Tevatron limits possible with ~20 pb^{-1} at 10 TeV



With time and data, the LHC can also discover:

Excited quarks $q^* \rightarrow \gamma q$:	up to $m \approx 6$ TeV
Leptoquarks:	up to $m \approx 1.5$ TeV
Monopoles $pp \rightarrow \gamma\gamma pp$:	up to $m \approx 20$ TeV
Compositeness:	up to $\Lambda \approx 40$ TeV
$Z' \rightarrow ll$, jj:	up to $m \approx 5$ TeV
$W' \rightarrow l\nu$:	up to $m \approx 6$ TeV
etc.... etc....	

Large number of scenarios studied
Main conclusions:
- ⇒ LHC direct discovery reach up to m ~ 5-6 TeV
- ⇒ demonstrated detectors sensitivity to many signatures
  - → robustness, ability to cope with unexpected scenarios



8% of the ATLAS detector made in Russia