ATLAS: Status & Early Prospects

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March 24, 2007

Outline

- Introduction
- Status of LHC accelerator
- Status of ATLAS
- Physics capabilities
- Upgrades…and haven't even started!

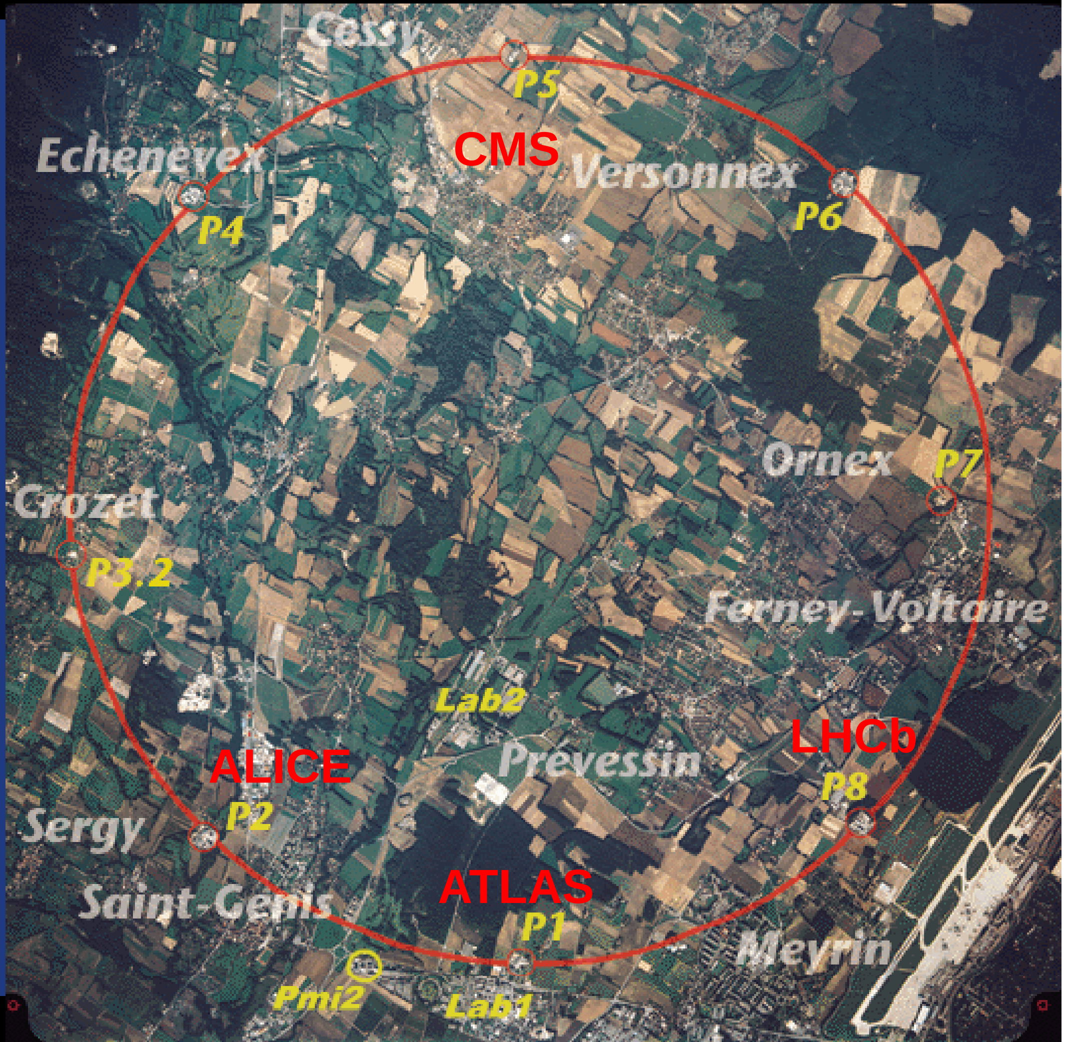
ATLAS Collaboration

- 35 Countries
- 164 Institutions
  - Total 41 U.S. Institutes
- 1,800 Scientific Authors
- “The sun never sets on the ATLAS empire!”

- 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, 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, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Yale, Yerevan

LHC Accelerator

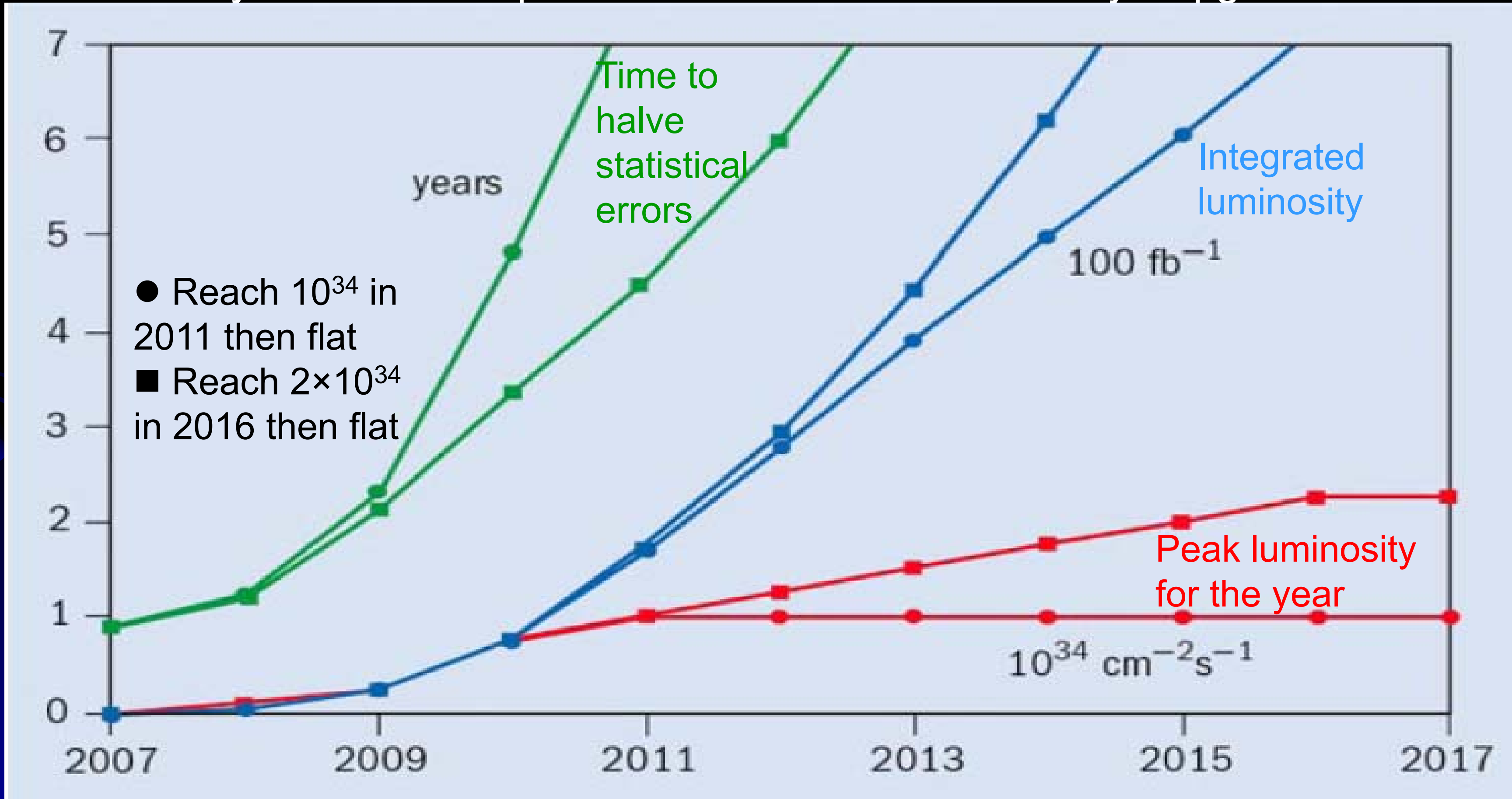
Particles used: Protons and heavy ions (Lead, full stripped 82+)
Circumference: 26,659 m.
Injector: SPS
Injected beam energy: 450 GeV (protons)
Nominal beam energy in physics: 7 TeV (protons)
Magnetic field at 7 TeV: 8.33 Tesla
Operating temperature: 1.9 K
Number of magnets: ~9300
Number of main dipoles: 1232
Number of quadrupoles: ~858
Number of correcting magnets: ~6208
Number of RF cavities: 8 per beam; Field strength at top energy ≈ 5.5 MV/m
RF frequency: 400.8 MHz
Revolution frequency: 11.2455 kHz.
Power consumption: ~120 MW
Gradient of the tunnel: 1.4%
Difference between highest and lowest points: 122 m.



From http://lhc-machine-outreach.web.cern.ch/lhc-machine-outreach/

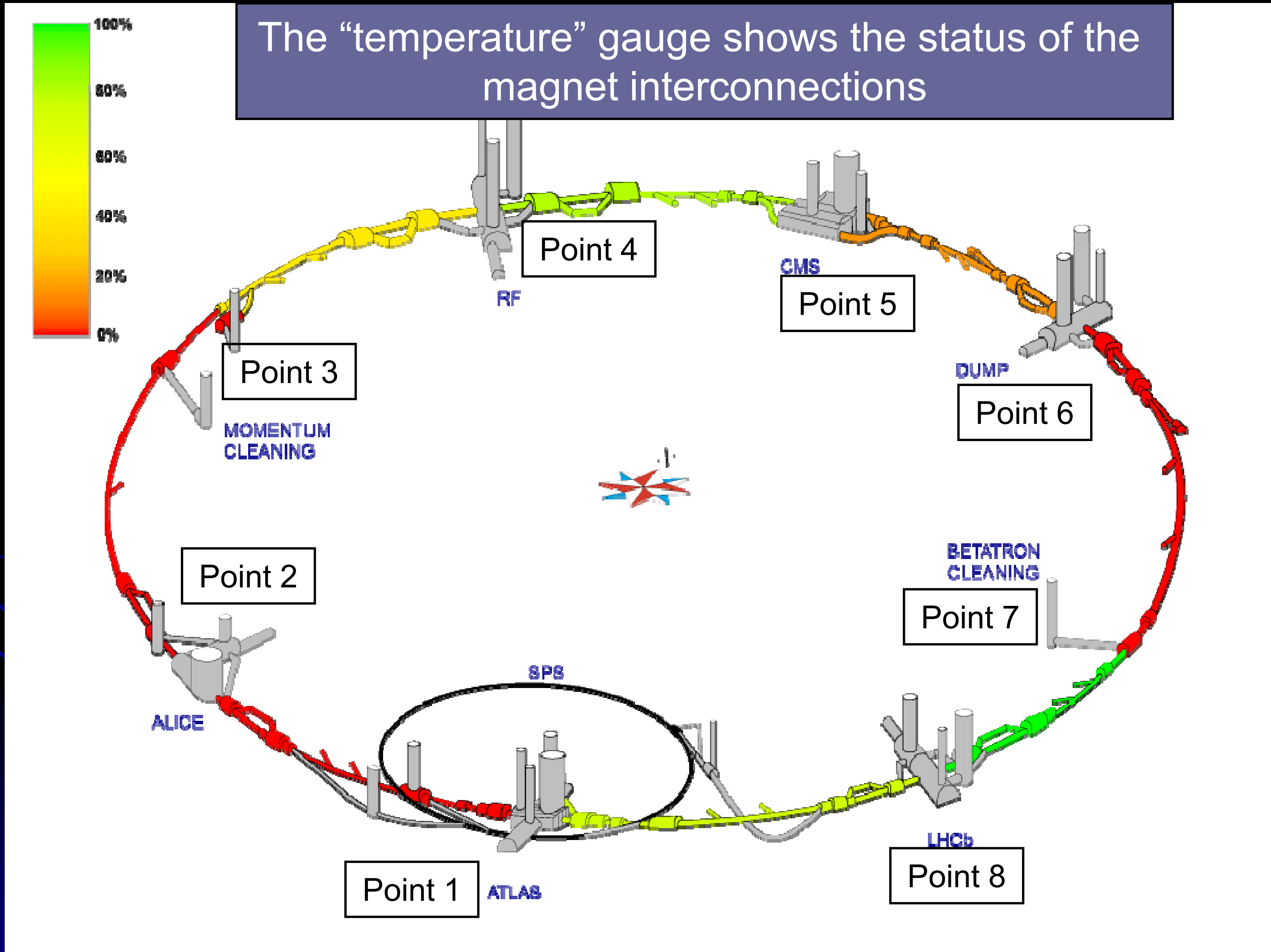
LHC Accelerator

- LHC: pp, $\sqrt{s}$ = 14 TeV, L = 10^{34} $cm^{-2}s^{-1}$ (nominal design)
  - Start at $10 fb^{-1}/yr \rightarrow 100 fb^{-1}/yr$ at nominal design
  - May be able to be pushed to 2.3×10^{34} without major upgrades



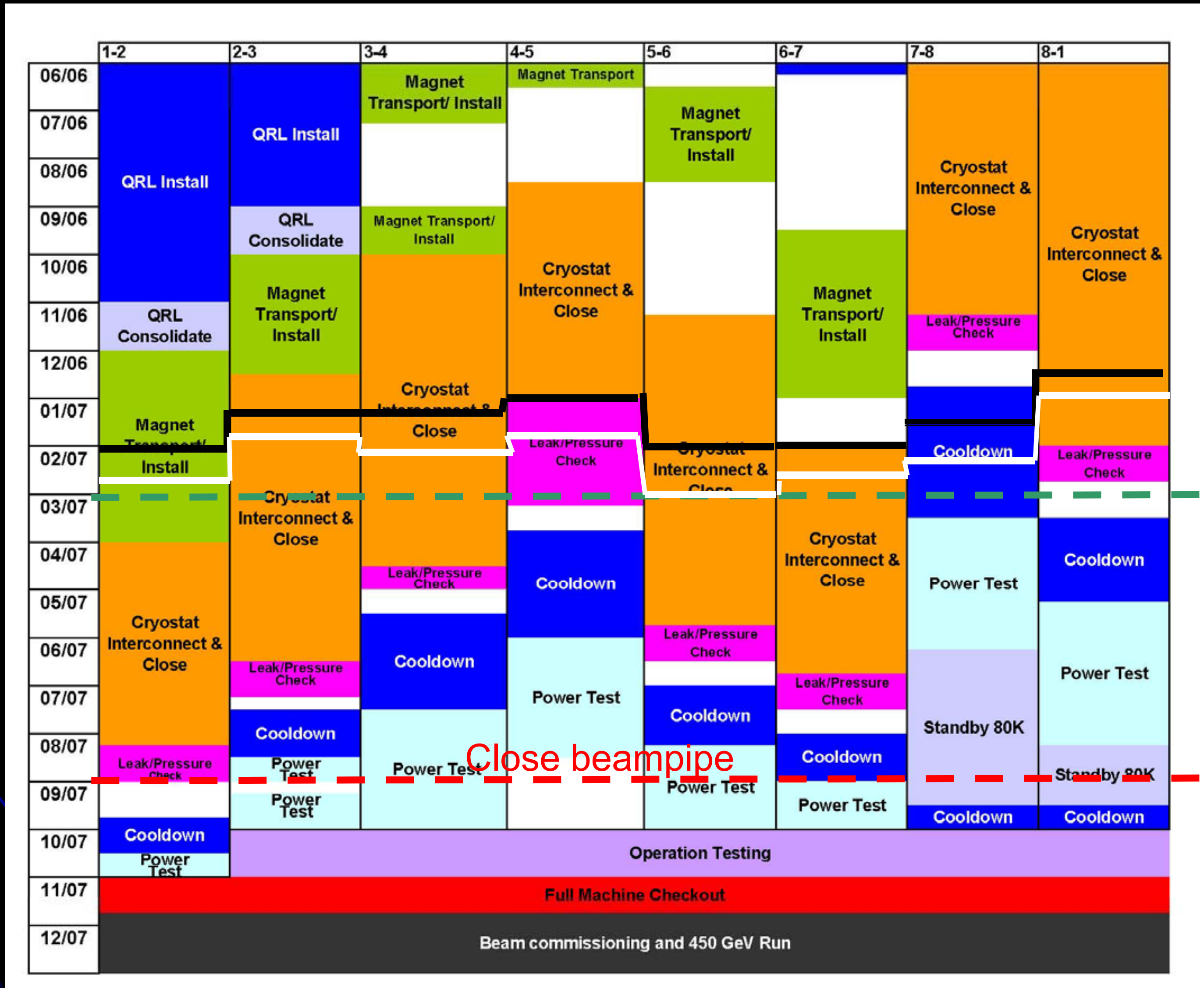
Jim Strait: http://www.cerncourier.com/main/article/45/3/29/1

LHC Experimental Areas

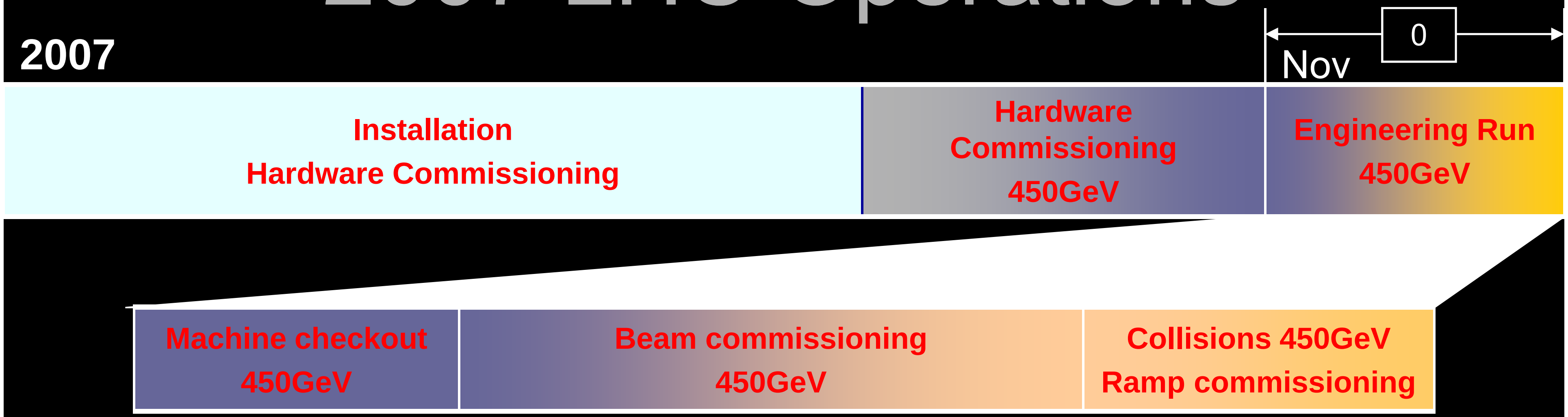


LHC Installation Schedule

- My simplified graphical view based on 10/1/06 detailed schedule in http://sylvainw.home.cern.ch/sylvainw/planning-follow-up/Schedule.pdf
- Status lines for 2/2/07 and 3/2/07 show slippage in some areas (0-8weeks)
- Lyn Evans at Council meeting reported current 5 wk delay

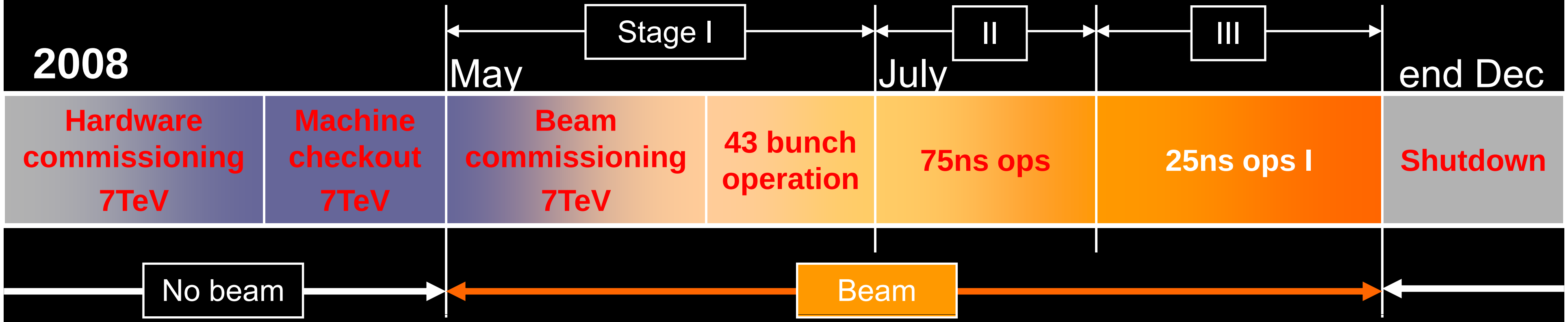


2007 LHC Operations



- 450+450 GeV Engineering run
  - Firm platform for eventual 7 TeV commissioning of machine
  - Commissioning opportunity for ATLAS
    - Low luminosity (~10^{30}), 43 bunches

2008 LHC Operations



I. **Pilot physics run**
- First collisions
- 43 bunches, no xing angle, no squeeze, mod. intensities
- Push performance (156 bunch, partial squeeze in 1 and 5, push intensity)

II. **75ns operation**
- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle

III. **25ns operation I**
- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal

IV. **25ns operation II**
- Push to nominal (Ib=3.2×10^{14}; 362MJ; 10^{34}; 19 ev/xing)

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

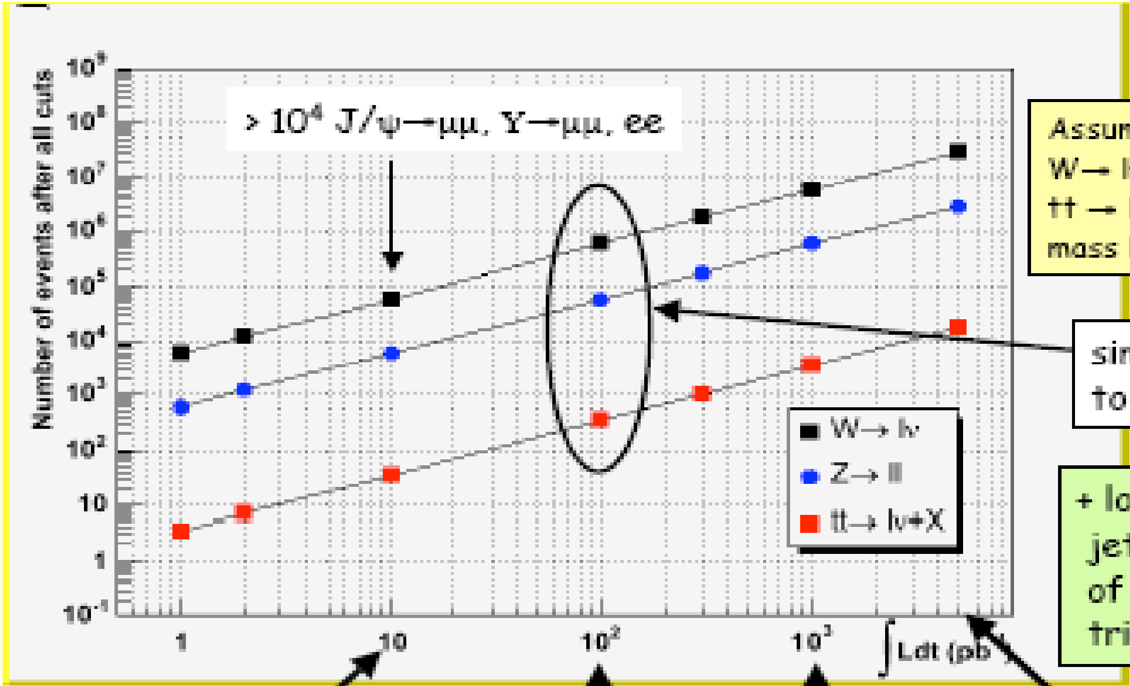
k_b	N ×10^{10}	β* (m)	I_b ×10^{12}	E_b (MJ)	Lum ×10^{30}	Evt/ xing
1	1	18	0.01	0.01	0.001	<<1
43	4	2	1.7	2	6.1	0.76
156	9	2	14	16	110	3.9
936	4	18	37	42	15	<<1
936	9	1	84	94	1200	7
2808	4	18	110	126	44	<<1
2808	5	.55	140	157	1900	3.6

LHC Physics Schedule

year	*energy*	*luminosity*	*physics beam time*
2007	450+450 GeV	$5x10^{30}$	protons - 26 days at 30% overall efficiency ➔ $0.7*10^6$ seconds
2008	7+7 TeV	$0.5x10^{33}$	protons - starting beginning July $4*10^6$ seconds ions - end of run - 5 days at 50% overall efficiency ➔ $0.2*10^6$ seconds
2009	7+7 TeV	$1x10^{33}$	protons:50% better than 2008 ➔ $6*10^6$ seconds ions: 20 days of beam at 50% efficiency ➔10^6 seconds
2010	7+7 TeV	$1x10^{34}$	TDR targets: protons: ➔ 10^7 seconds ions: ➔ $2*10^6$ seconds

From Roger Jones, ATLAS computing for planning purposes

What it means for ATLAS



l ≡ e or μ

Assumed selection efficiency:
W→ lν, Z→ ll : 20%
tt → lν+X : 1.5% (no b-tag, inside mass bin)

similar statistics to CDF, D0 today

+ lots of minimum-bias and jets (10^7 events in 2 weeks of data taking if 20% of trigger bandwidth allocated)

10 pb^{-1} ≡ 1 month at 10^{30} + < 2 weeks at 10^{31}, ε=50%

100 pb^{-1} ≡ few days at 10^{32} , ε=50%

1 fb^{-1} ≡ 6 month at 10^{32}, ε=50%

5 fb^{-1} ≡ 3 month at 10^{32} + 3 month at 10^{33}, ε=50%

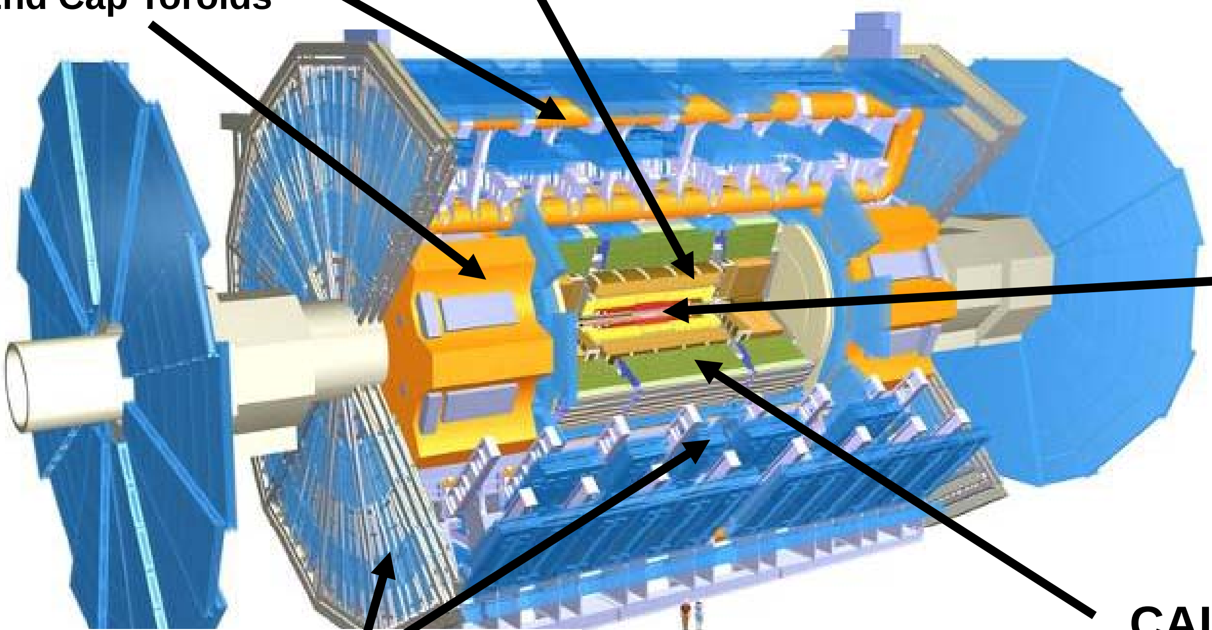
By end 2008?

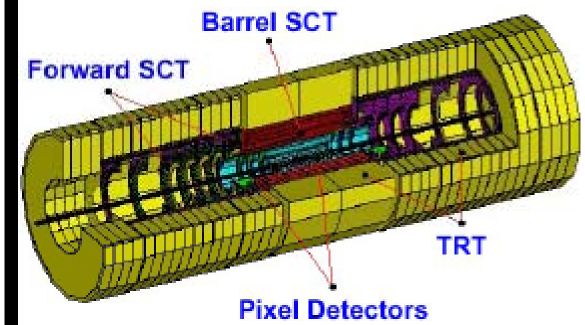
By end 2009?

ATLAS

- ATLAS = A Toroidal Lhc ApparatuS

MAGNETS
Central Solenoid (2T, 5m long, 2.4m bore, 6tons)
8 Barrel Toroids
End Cap Toroids





INNER DETECTOR
Pixels (80M ch)
Silicon Strip (6M ch) [SCT]
Transition Radiation Tracker (0.4M ch) [TRT]

CALORIMETERS
EM - Liquid Argon – Lead (190k ch)
HAD - Scintillator Tile (10k ch PMT)

MUON SYSTEM
Monitored Drift Tubes (354k ch)
Cathode Strip Chambers (31k ch)
Resistive Plate Chambers (374k ch)
Thin Gap Chambers (322k ch)

Diameter 25m
Length 46m
Weight 7,000 tons

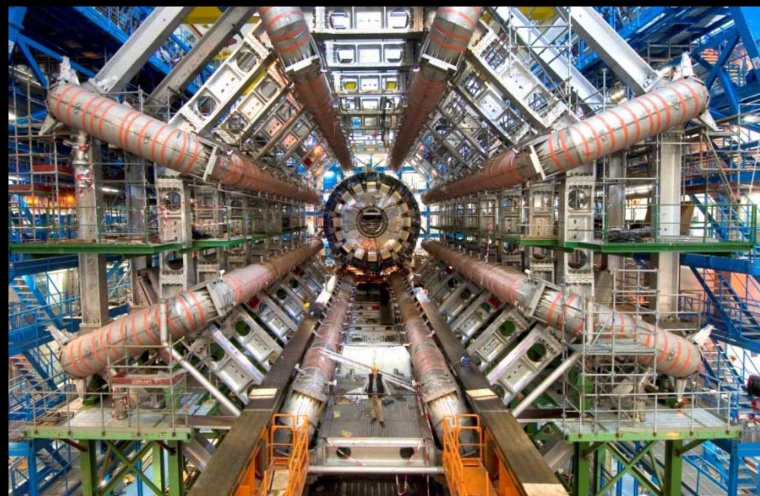
Toroids – Barrel & Endcap

- 8 superconducting coils
  - 25x5 m2, 1.6GJ, 20kA, 3.9T
  - Tested in pit @ full field

Coils tested @ 22kA on surface
Last one tested Jun 2005

First coil installed Oct 2004, last one Aug 2005

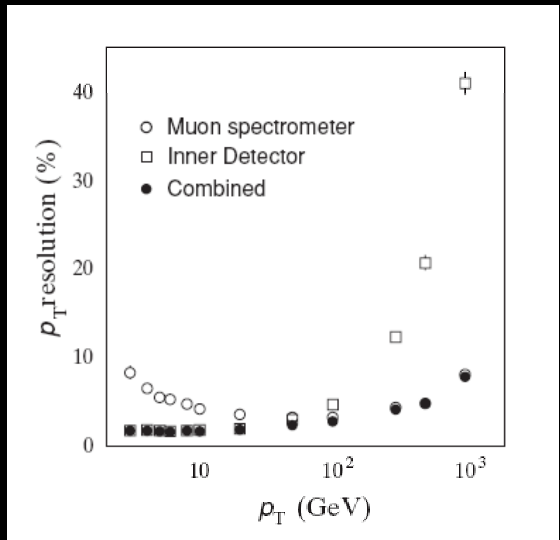
2 endcap toroids being assembled on surface: 10 m dia, 250MJ, 240 tons, 4.1T

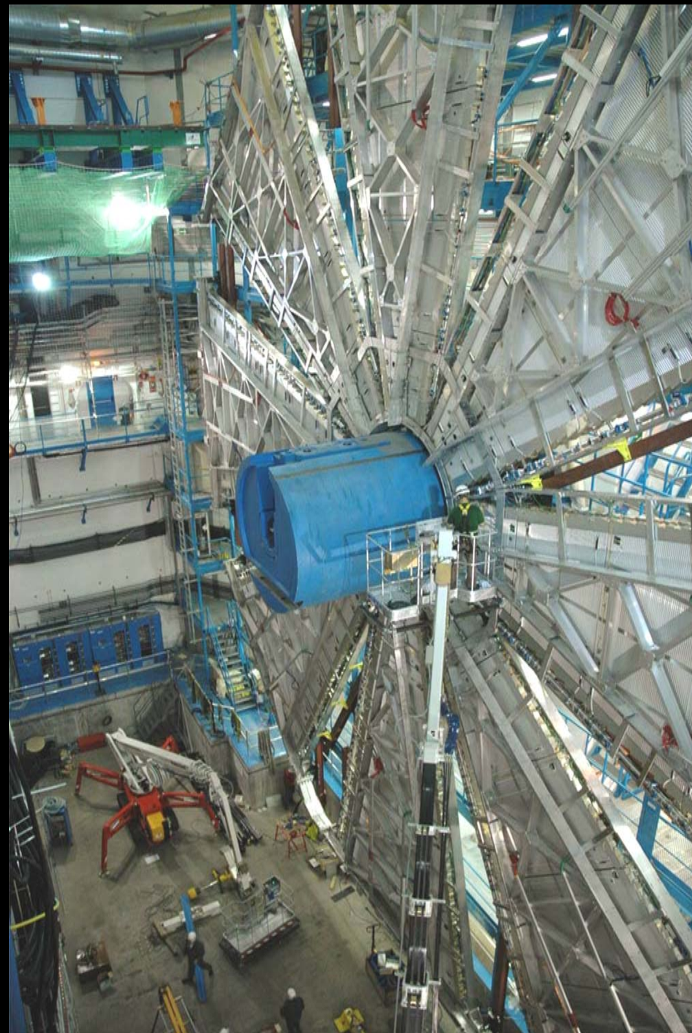


Oct 2005

Muon System

- Coverage to $|\eta|<2.7$
- Resolution averaged over coverage

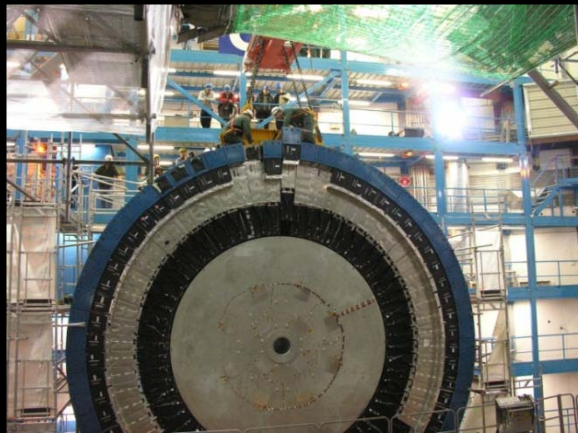




End Cap muon system

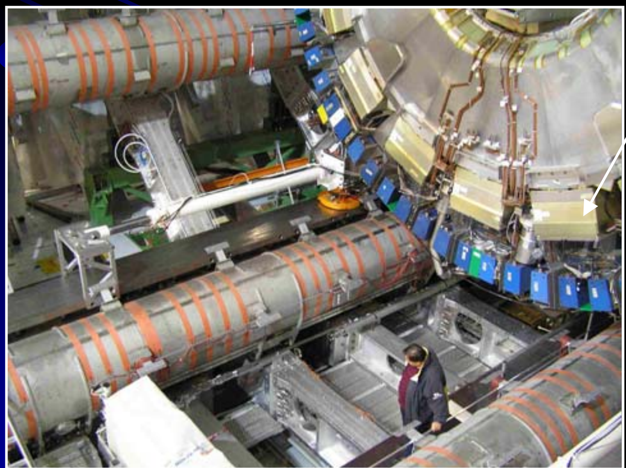
Calorimeter

End calorimeter



End calo w/ Tile Cal

Lowering down the shafth

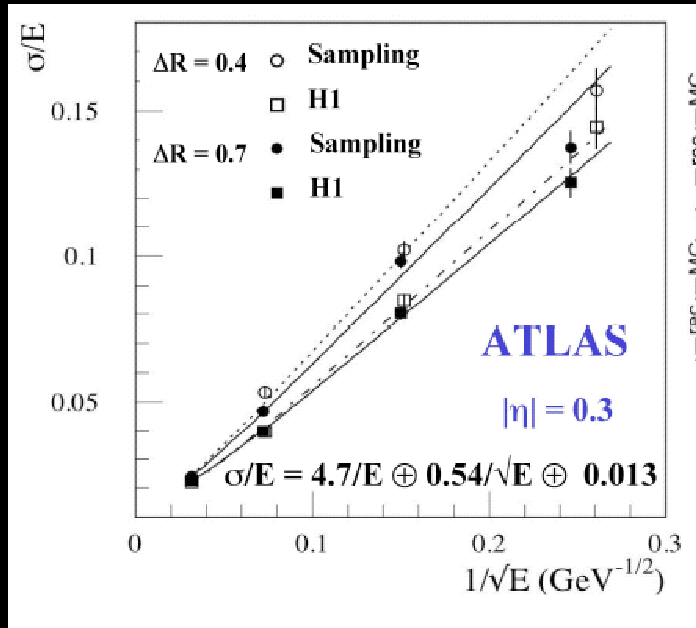


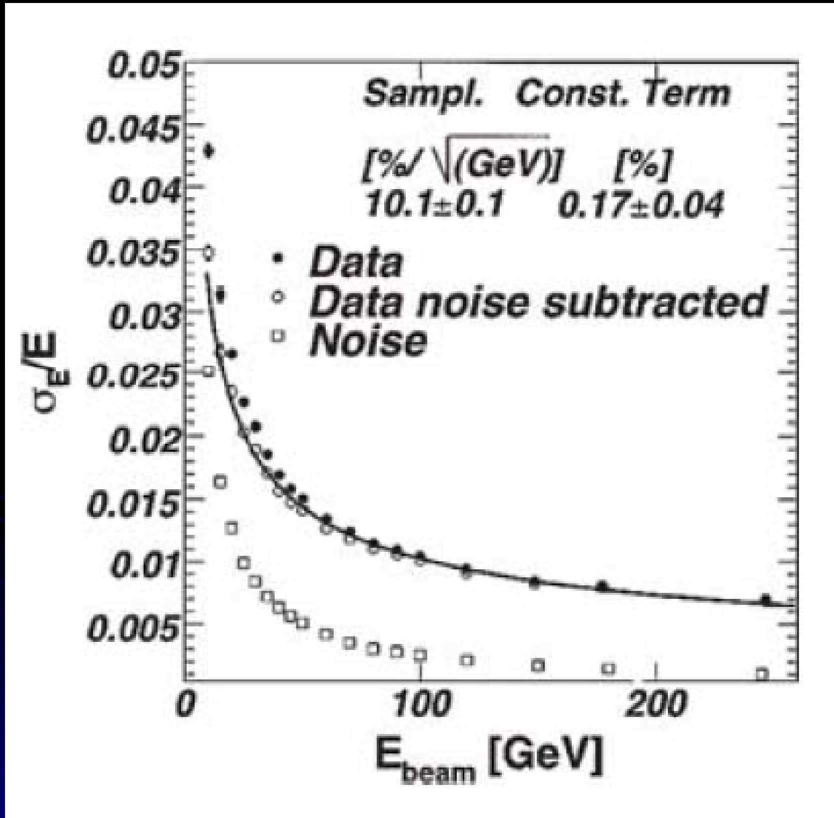
Barrel Calorimeter electronics

Barrel Calorimeters in pit since Jan 2005

Calorimeter Performance

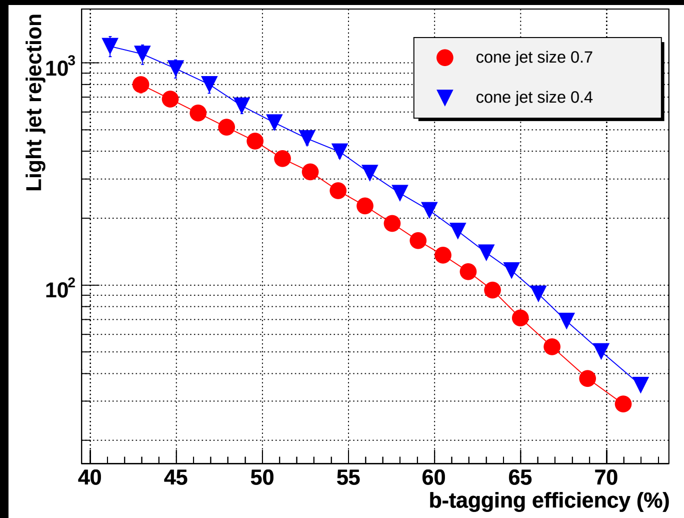
Jet energy resolution



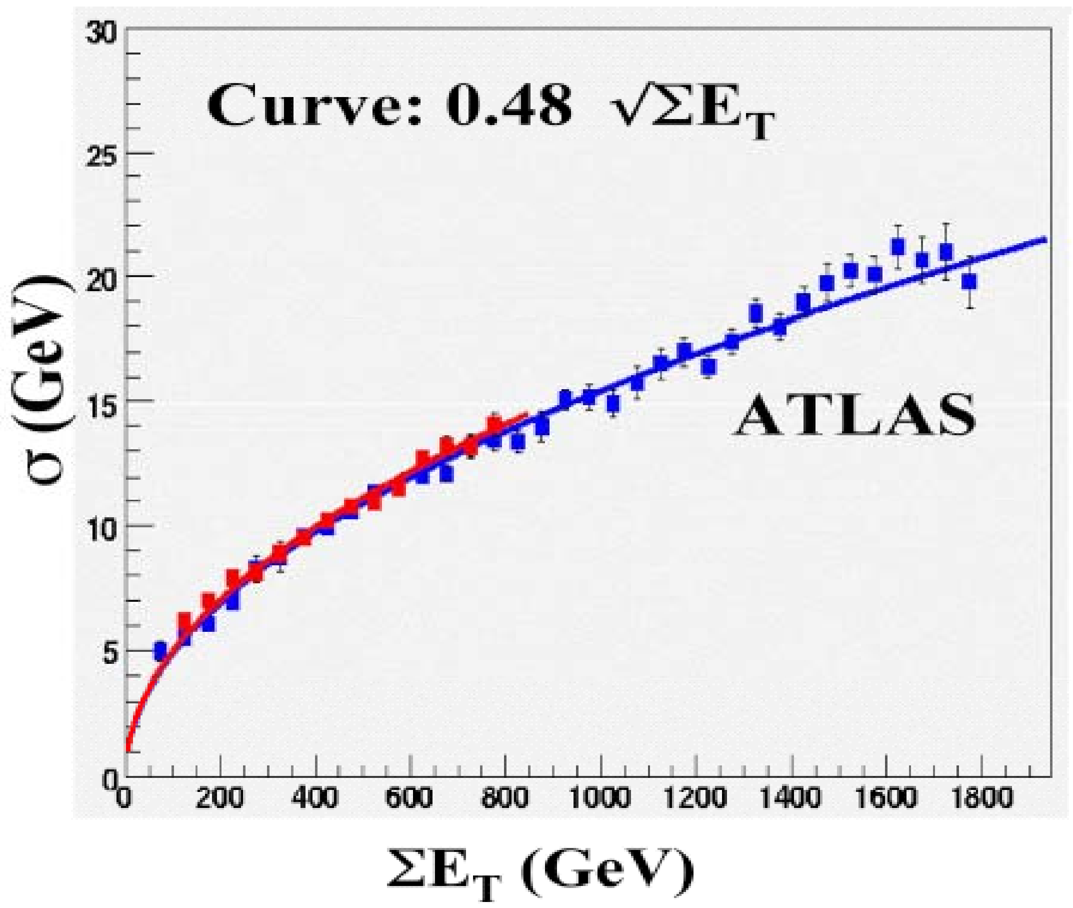


Electron energy resolution for EM module

B-tagging eff vs light jet rejection

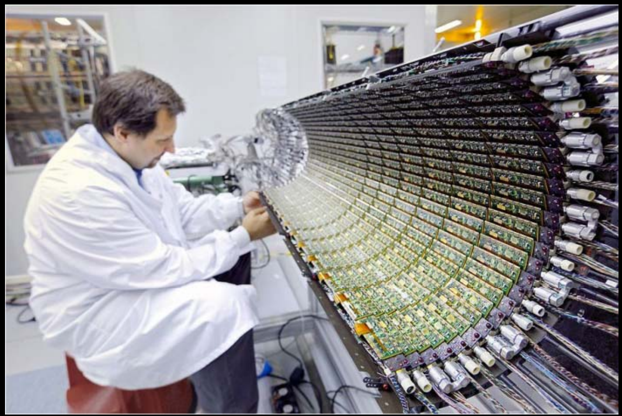


Missing E_T

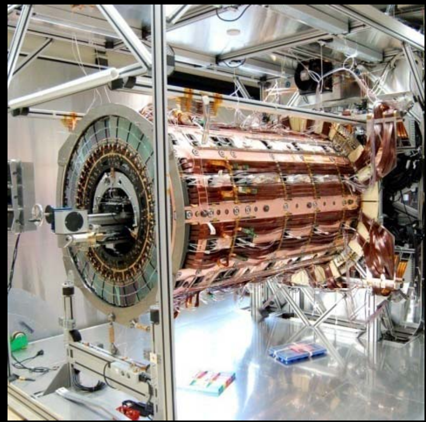


Missing E_T resolution
vs total transverse energy in event for high p_T jets

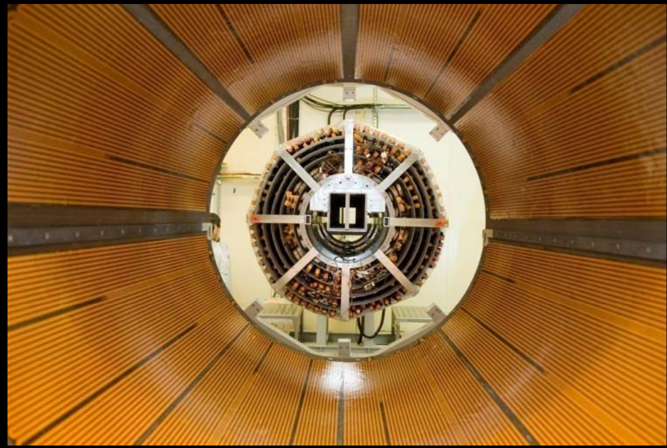
Inner Detector



Pixel barrel



SCT



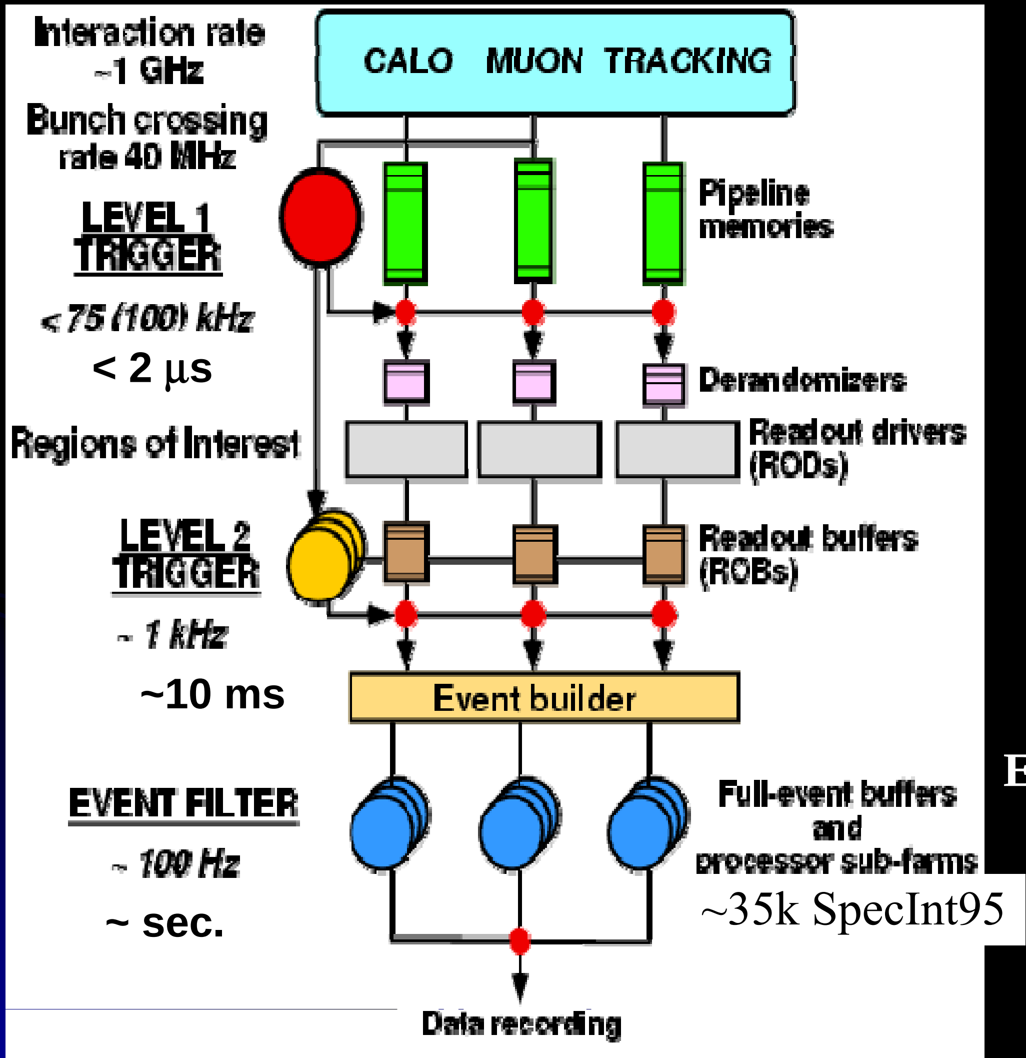
SCT being inserted in TRT

- Silicon pixels
- Silicon strips in barrel SCT (4 layers) & End barrels
  - 99.7% channels fully functional
- Transition Radiation Tracker (TRT)

Tracking performance

Selected figure-of-merit	ATLAS
Rec. Eff. Muons with p_T=1GeV	97%
Rec. Eff. Pions p_T=1GeV	84%
Rec. Eff. El. p_T=5GeV	90%
$\sigma(p_T)$ for p_T=1GeV η=0	1.3%
$\sigma(p_T)$for p_T=100GeV η=0	3.8%
Transverse σ(i.p.) for p_T=1GeV	75μm
Longitunal σ(i.p.) for p_T=1GeV	150μm

ATLAS Trigger/DAQ System



Physics selection of the 100 'best' events/sec:

40 MHz, 1 PB/sec

Level 1: Coarse calorimeter data and muon trigger chambers

75 kHz, 75 GB/sec

Level 2: Full information from all detectors in regions of interest

1 kHz, 1 GB/sec

Event Filter: Reconstruction of complete event using latest alignment and calibration data

100 Hz, ~100 MB/sec

~10 TB/day, 1 Petabyte/year of recorded raw data

ATLAS Performance

- ATLAS TDR dates from 1999… needs updating
- Currently writing “CSC Notes” ~now
  - As-built simulation (distortions, mis calibrations, ~final material, etc)
  - New reconstruction algorithms
  - New generators
- In the meantime…

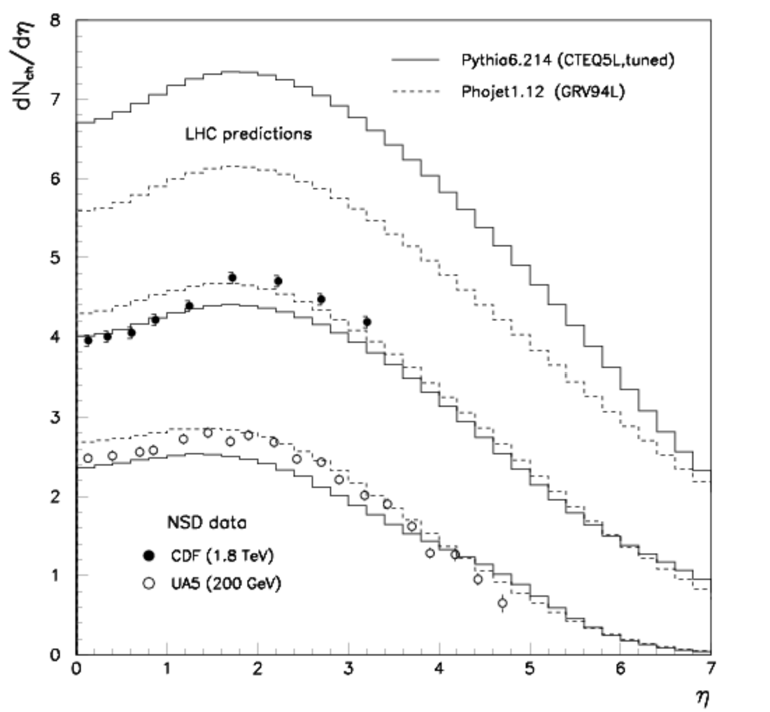
Performance at Start up

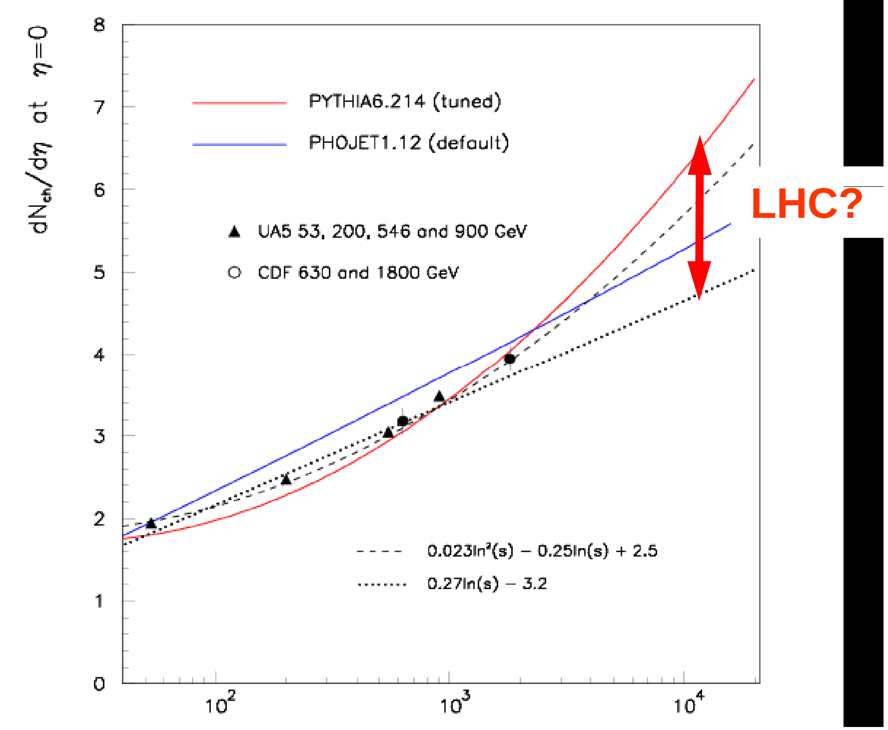
- At start up the detector will still need to be tuned up

	Expected Day 0	Goals for Physics
ECAL uniformity	~ 1% ATLAS	< 1%
Lepton energy scale	0.5—2%	0.1%
HCAL uniformity	2—3%	< 1%
Jet energy scale	<10%	1%
Tracker alignment	20—200 μm in Rϕ	$\mathcal{O}$(10 μm)

Minimum Bias

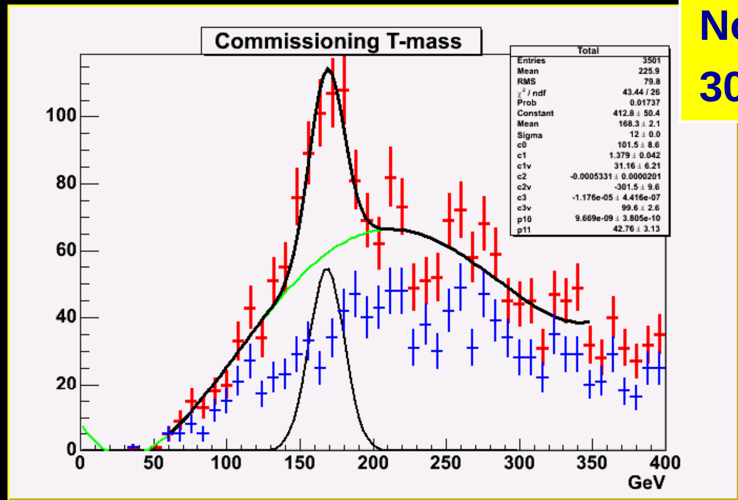
- Minimum bias particle density drives detector global occupancy even at « low » $\mathcal{L}=10^{33}cm^{-2}s^{-1}$
- Uncertainties up to 30% from extrapolation from lower energies
- Can be measured in a few days, but should always be kept in mind when defining startup scenarios (occupancies, rates….)
- (similar issue about underlying event)



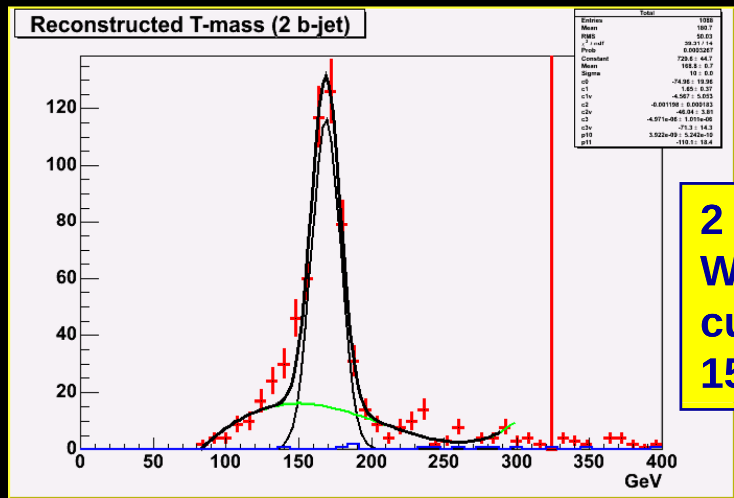


Top

- Reconstructed in tt→W(lν)bW(qq)b
  - Background W+4j
- Early running, no b-tag $\sigma(M_{top})$~3.2 GeV (30pb^{-1})
  - Isolated lepton with P_T>20 GeV
  - Exactly 4 jets (ΔR=0.4) with P_T>40 GeV
  - Reconstruction: Select 3 jets with maximal resulting P_T ; Identify W peak (also useful for jet energy scale calibration); select highest p_T 2 jet
- $\sigma(M_{top})$~0.8 GeV with b-tag (150pb^{-1})



No b-tag
30 pb^{-1}

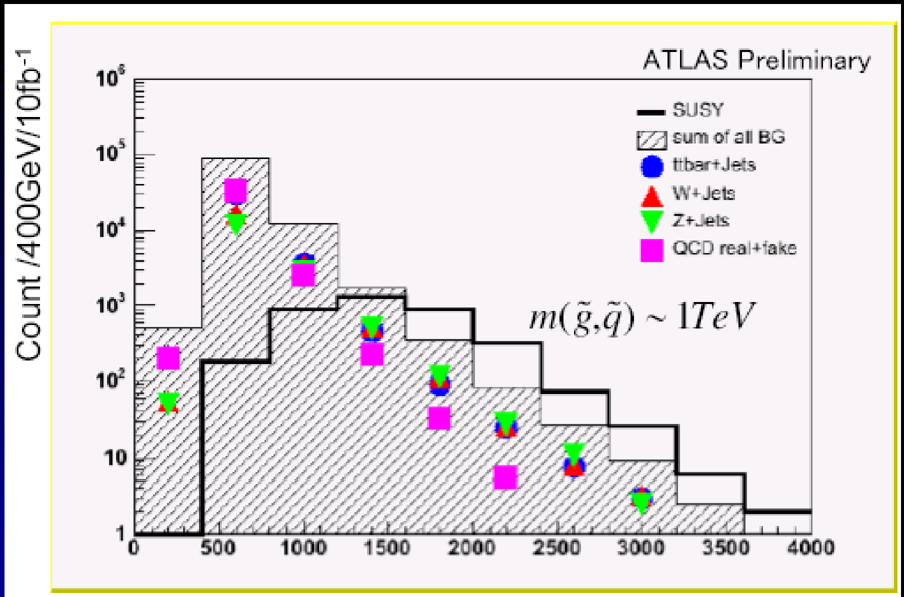


2 b-tags, W mass cut
150 pb^{-1}

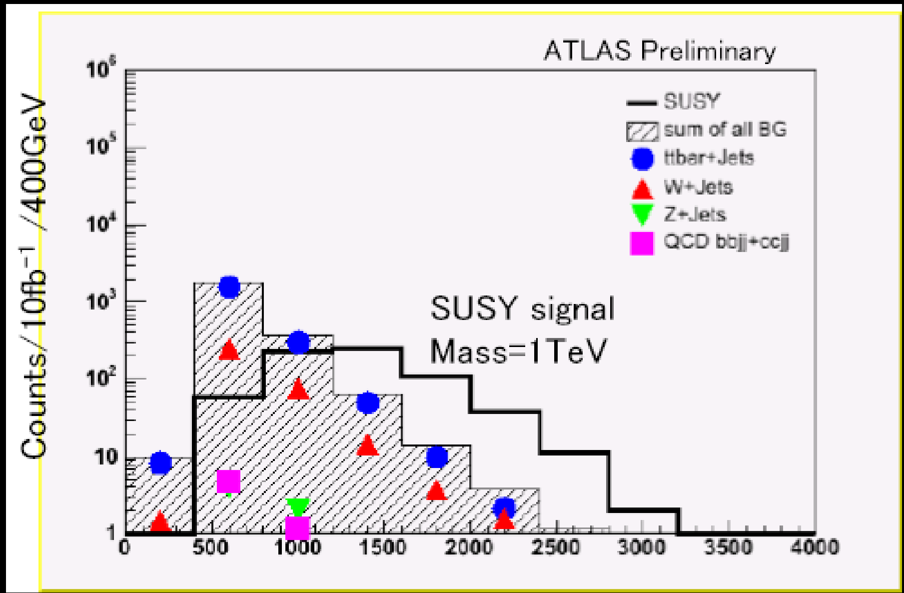
SUSY

- **10 fb^{-1}**
- **Backgrounds increased from TDR**
- **Now need to use lepton trigger**

0-lepton

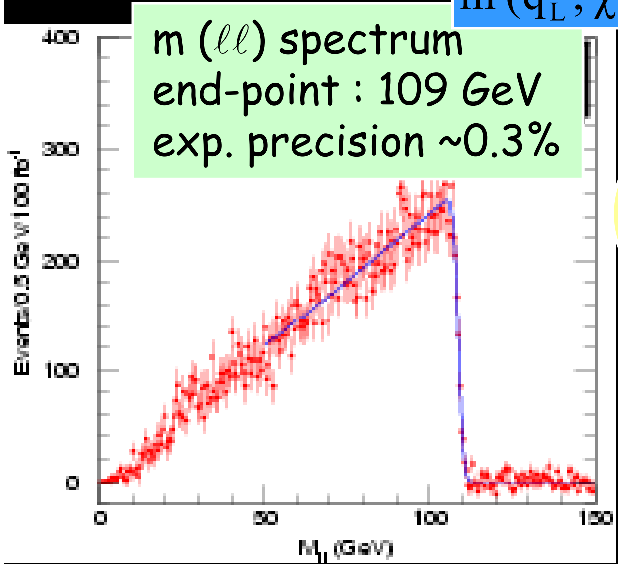


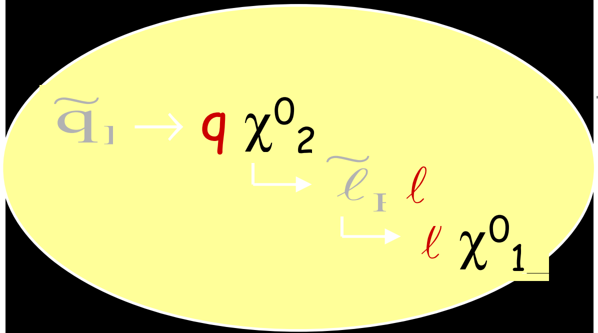
1-lepton

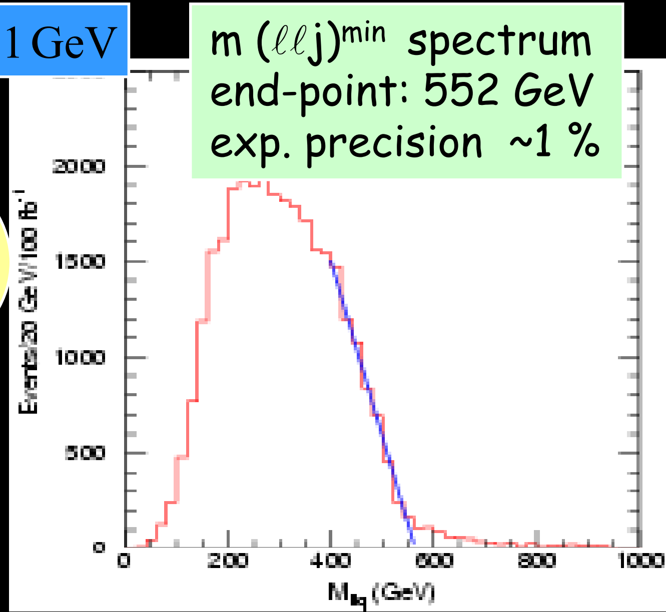


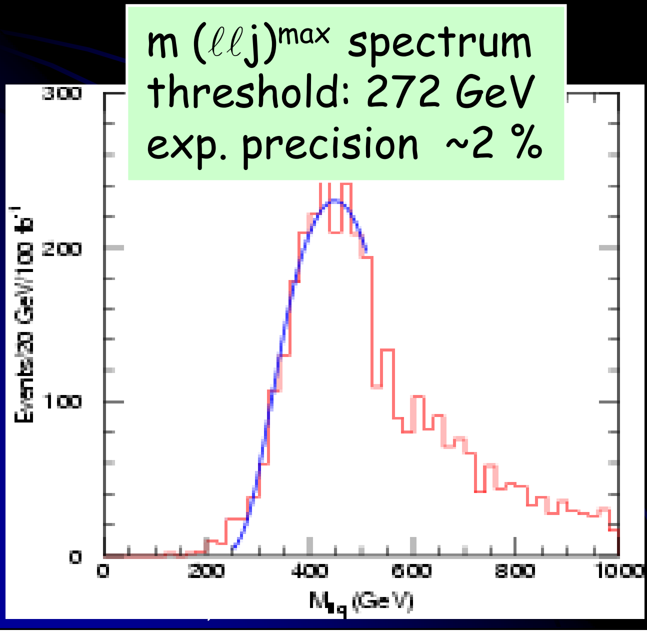
Example Reconstruction of SUSY Decay Chain

$m(\tilde{q}_L, \chi^0_2, \tilde{\ell}_R, \chi^0_1) = 690, 232, 157, 121$ GeV

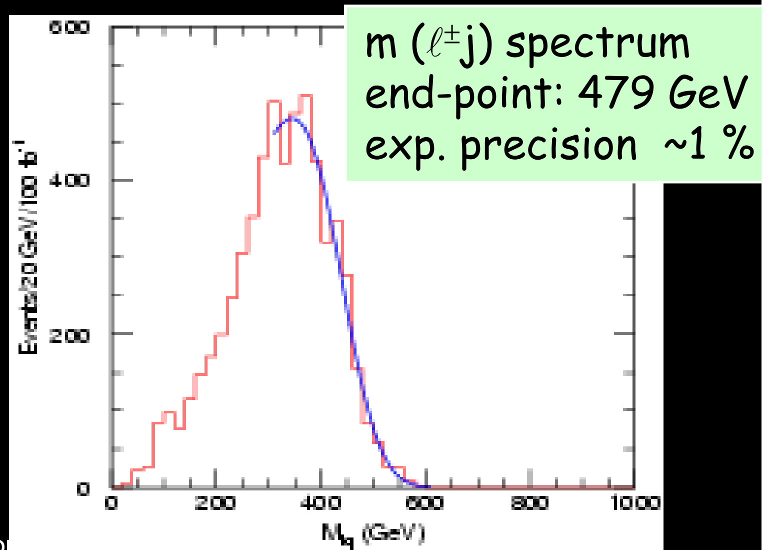






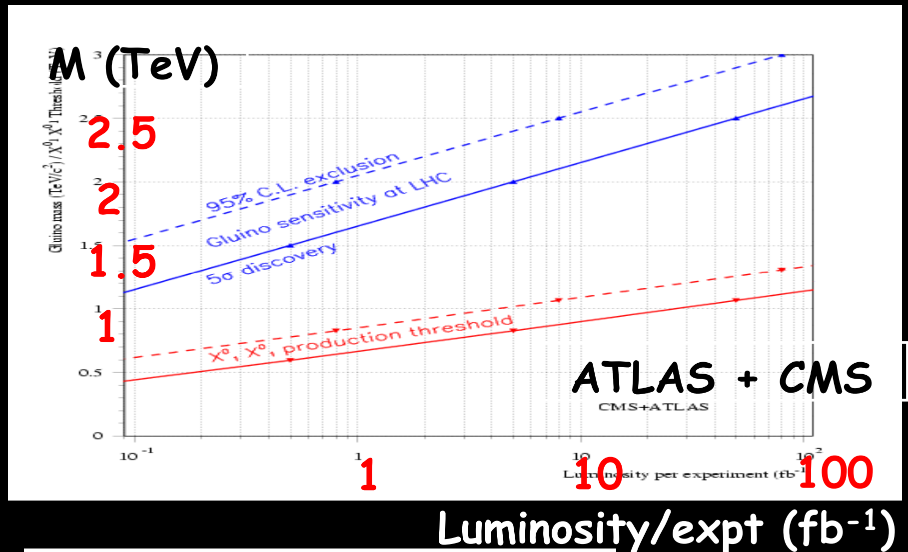


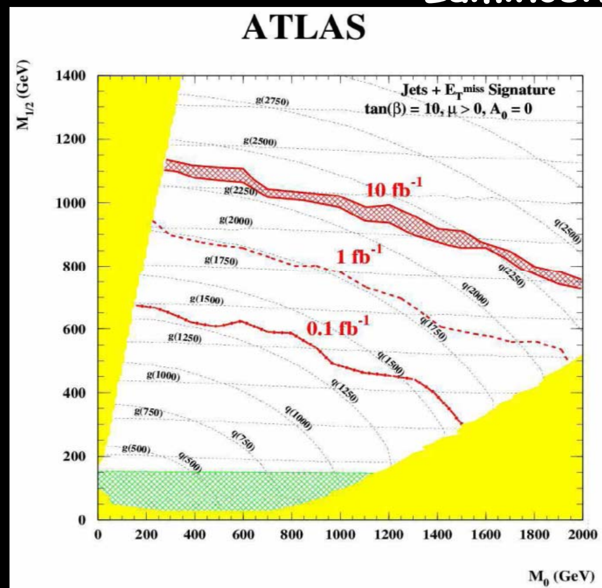
ATLAS
100 fb^{-1}
LHC Point 5



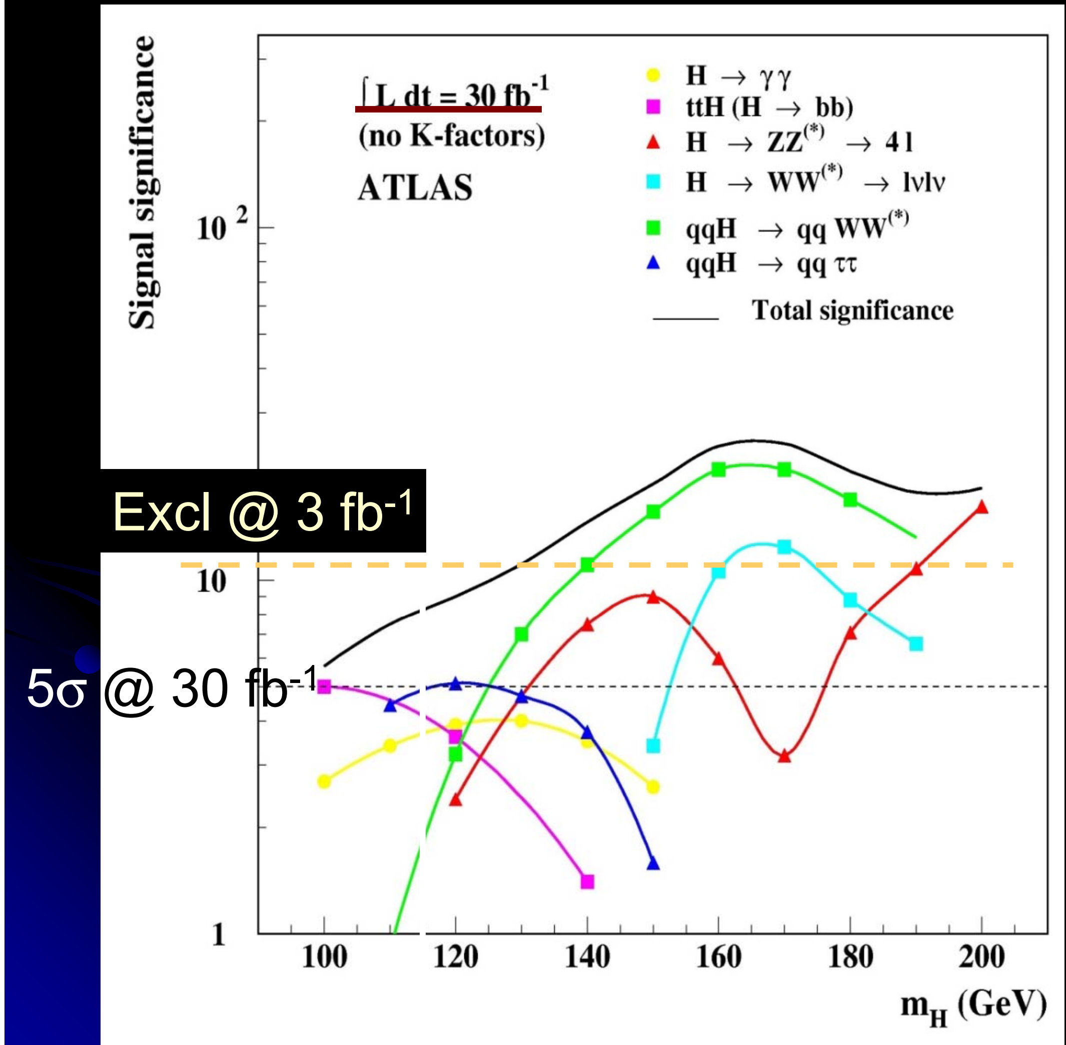
mSUGRA Reach

- Fairly robust with $1fb^{-1}$ or less
- Of course 1 month of data does not mean 1 month to get results!





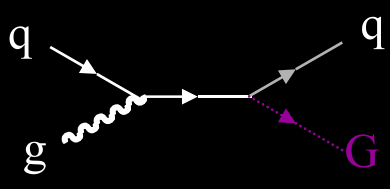
SM Higgs search



- Changes since TDR
  - New channels added - VBF
- M_H>150 GeV could be visible in 2008??
- Lower masses need more luminosity
- Plot is for ~ 3years of running at 1/10 of design luminosity (30fb^{-1})

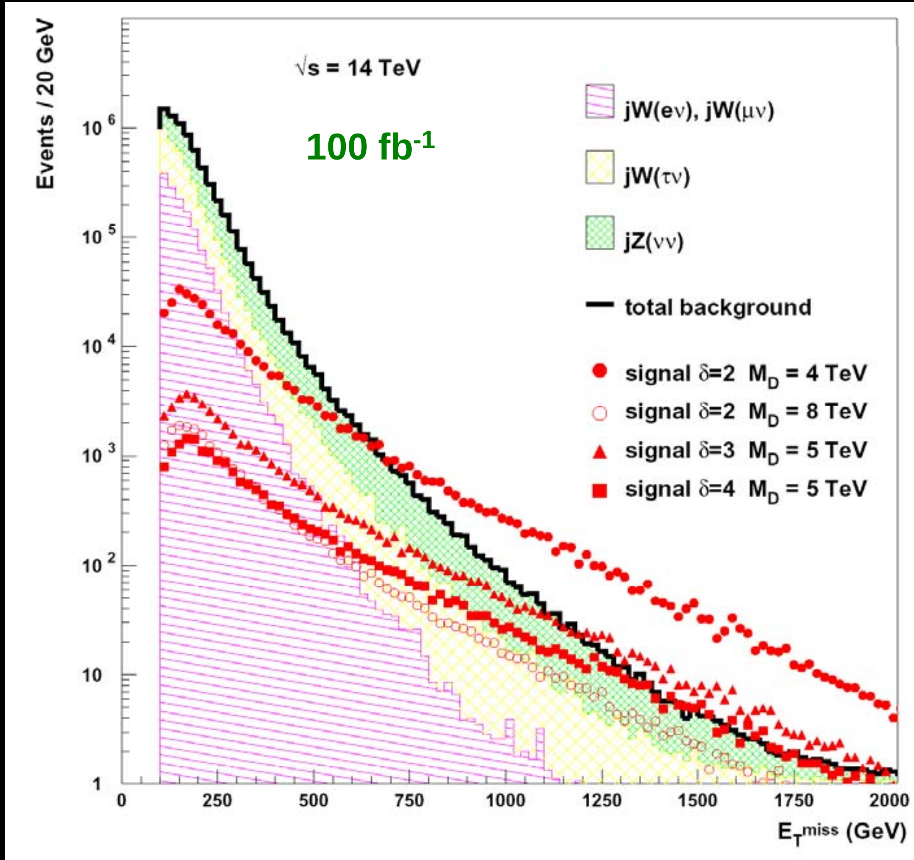
Extra Dimensions

- Many different theoretical variants exist:
  - **Large extra dimensions (ADD)**
  - **Randall-Sundrum models with "warped" extra dimensions**
  - **Strong gravity at the TeV scale (with Black Hole production!)**
  - **…**
- ADD example:



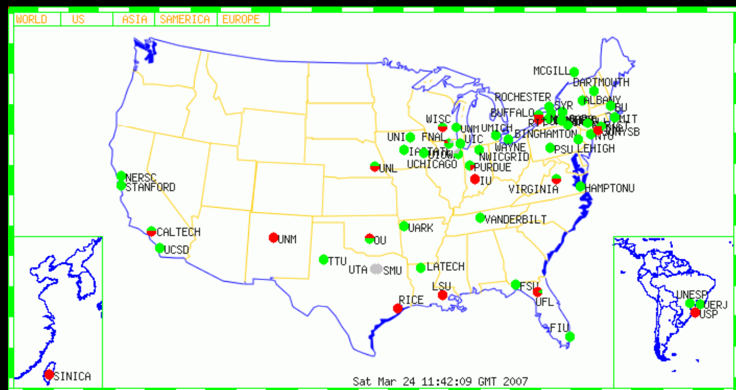
$$\left.\begin{array}{l} \bar{q}q \rightarrow gG^{(k)}, \gamma G^{(k)} \\ qg \rightarrow qG^{(k)} \\ gg \rightarrow gG^{(k)} \end{array}\right\} \text{jets} + \not{E}_T,\ \gamma + \not{E}_T$$

δ	M_D^{max} (TeV) LL, 30 fb^{-1}	M_D^{max} (TeV) HL, 100 fb^{-1}	M_D^{min} (TeV)
2	7.7	9.1	~ 4
3	6.2	7.0	~ 4.5
4	5.2	6.0	~ 5



Computing

- Massive data loads demand worldwide computing resources
- Similar overall structure for CMS & ATLAS
  - Tier 0 (at CERN)
    - Raw data, reconstruction
  - Tier 1 (National Centers)
    - Each host part of raw data, re-reconstruction, derived data sets, analysis
    - BNL (US ATLAS one of ~10): total ATLAS need in 2008 is 24 MSI2k; 14 PB
  - Tier 2 (“Regional” Centers)
    - Simulations, derived data sets, calibration, analysis
    - Total ATLAS 2008 need 20MSI2k; 8 PB (5 T2 sites in US)
  - Tier 3 (Institutional clusters)
- Computing grid(s) link these sites
  - 3 grids in use (LCG, OSG, Nordugrid)
  - Many 10k’s of CPU



OSG

Upgrade – Physics Motivation

- Luminosity upgrade
  - $10^{34} \rightarrow 10^{35}$ cm^{-2}s^{-1}
  - Silicon dies, radiation damage
- Extend LHC mass reach by ~30%
  - Less demanding on detector upgrade because of robust signals
- Improve on precision measurements
  - SM parameters, Higgs couplings
  - Parameter measurements for new physics (e.g. SUSY)
  - More demanding on detector upgrade because of pileup environment
- Increased sensitivity to rare processes and rare decay modes
  - More demanding on detector upgrade because of pileup environment
- Both ATLAS and CMS are developing the necessary R&D in preparation for ~2015 installation

Conclusions

- Construction is winding down, operations are starting to ramp up
- Accelerator seems on schedule
  - CERN management seems committed to that date
  - Engineering 900 GeV may occur in late 2007
  - 14 TeV running start in mid 2008
- ATLAS is on schedule for LHC startup
  - Commissioning underway
- 2008 is not far away!

- See real data at the next Workshop? (maybe…but surely in '09 workshop)

Backup

MSSM Higgs Discovery Potential

- 2 Higgs doublets ⇒ physical Higgs states are h, H, A, $H^{\pm}$
- At least one Higgs observable over entire mA-tanβ plane (covered almost completely already with 10 fb^{-1})
- Sizeable region with SM-like h gets better covered if include decays to sparticles, but then very model dep.

4 Higgs observable
3 Higgs observable
2 Higgs observable
1 Higgs observable