Preparing for physics with ATLAS experiment at LHC

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15/11/2005

Machine start up scenario


First dipole in the tunnel - March ‘05


Magnets in place

~ *January 2007 - March 2007 machine cool-down*

~ *April 2007 : start machine commissioning (in part with single beam)*

~ *July 2007 : two beams in the machine (first collisions)*

start with $L = 6\ 10^{31}\ cm^{-2}\ s^{-1}$

4 months with up to $L > 5\ 10^{32}\ cm^{-2}\ s^{-1}$

2-3 months shut-down

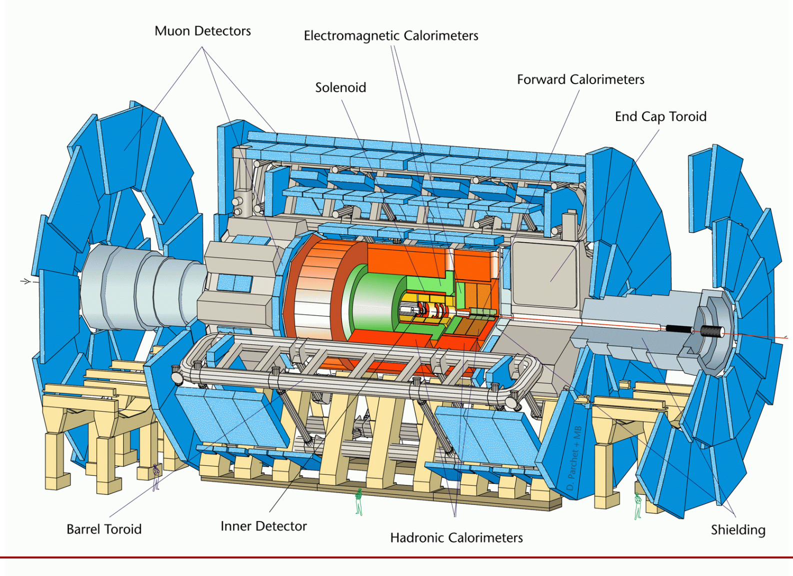
7 months of physics run up to $L = 2\ 10^{33}\ cm^{-2}\ s^{-1}$

6 months at $L_{peak} = 10^{32}$ (10^{33}) $cm^{-2}\ sec^{-1}$ at 50% efficiency makes 1(10) fb^{-1}

Which detector the first year?

2 pixel layers/discs instead of 3?

TRT acceptance over |η| < 2.0 instead of 2.4



Deferals of the high-level Trigger/DAQ processors
LVL1 output rate limited to ~ 40kHZ instead of 75kHz

Length : ~45 m
Radius : ~12 m
Weight : ~ 7000 tons
Electronic channels : ~ 10^8

- Tracking (|η|<2.5, B=2T) :
  - -- Si pixels and strips
  - -- Transition Radiation Detector (e/π separation)
- Calorimetry (|η|<5) :
  - -- EM : Pb-LAr
  - -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- Muon Spectrometer (|η|<2.7) :

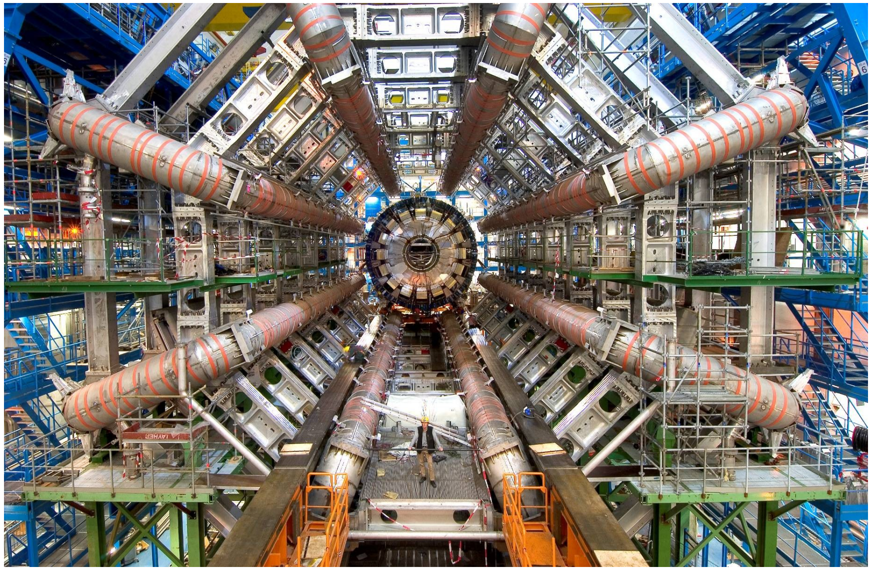
  air-core toroids with muon chambers

Impact on physics visible but acceptable

Main loss: B-physics programme strongly reduced (single μ threshold 14-20 GeV)

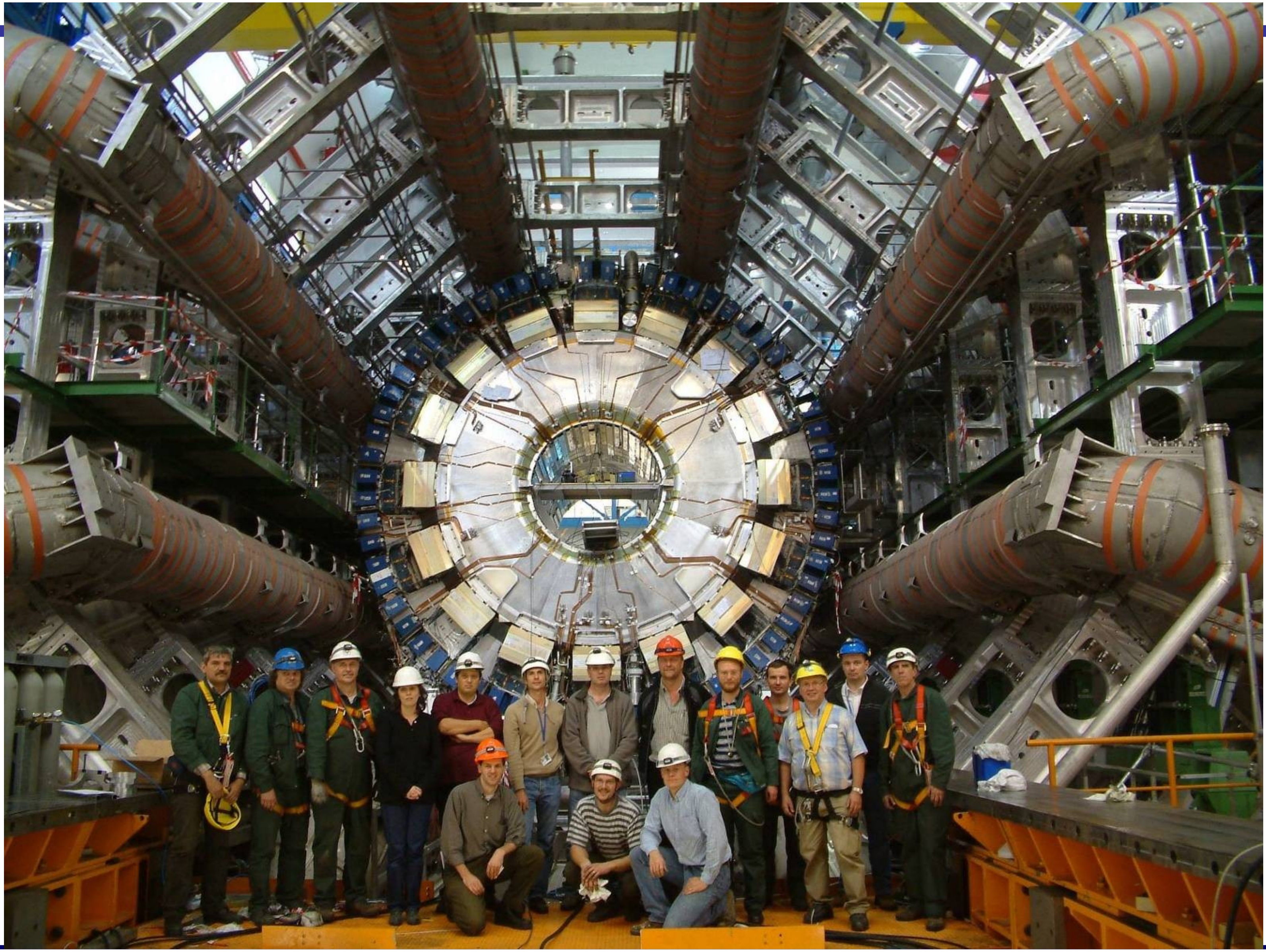
Commissioning in the cavern

The last Barrel Toroid coil was moved into position on 25th August and the structure was released from the external supports on 29th September



The barrel LAr and Tile calorimeters have been ready since some time in the cavern in their ‘garage Position’, moved into their final position on November 4th

November 4th Night: *Calorimeter barrel after its move to the center of the ATLAS detector*



The Physics Programme

- **Understand the origin of particle masses and EWSB mechanism**
  - **look for Higgs(es) from the present LEP limits up to ~ 1 TeV**

- **Look for physics beyond the SM (hierarchy, quantum gravity)**
  - **SUSY models: explore masses up to ~ 2 TeV**
  - **other scenarios: additional W/Z bosons up to M ~ 5 TeV, leptoquarks, extra-dimension, technicolor…**

- **Perform precision measurements beyond sensitivity of previous experiments**
  - **W, top**
  - **QCD**
  - **B-physics and CP violation**

Which detector performance on day one?

A few educated guesses *based on the test beam results and simulation studies*

	Expected performance day 1	Final goals	Physics samples to improve (examples)
ECAL uniformity	~ 1%	0.7%	Minimum bias, $Z \rightarrow ee$
e/γ scale	1-2%	0.1%	$Z \rightarrow ee$
HCAL uniformity	2-3%		Single pions, QCD jets
Jet scale	< 10%	1%	$Z(\rightarrow ll)$+1j, $W \rightarrow jj$ in tt
Tracking alignment	20-500 μm in Rϕ?	5 μm	generic tracks, isolated μ, $Z \rightarrow \mu\mu$

Large$^{(*)}$ statistics at beginning (events on tape for 1 fb^{-1}), then face systematics....

E.g. tracking alignment : 100 μm (1 month) $\rightarrow$ 20 μm (4 month) $\rightarrow$ 5 μm (1 year)

To achieve the detector goal performance?

→ Stringent construction requirements and quality controls (piece by piece...)

→ Equipped with redundant calibration/alignment hardware systems

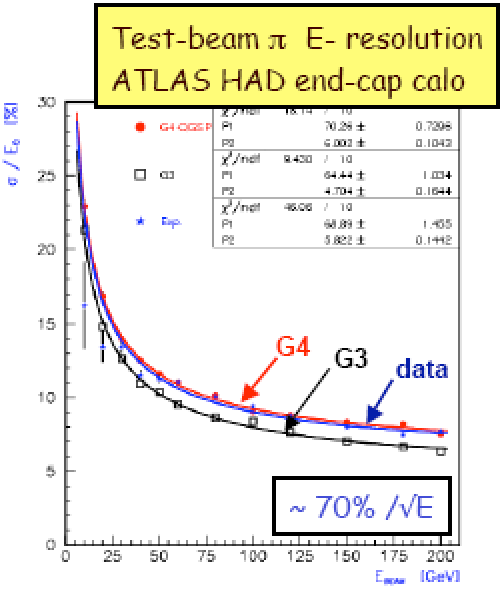
→ Prototypes and part of final modules extensively tested with test beams (allows also validation of Gean4 simulation)

→ In situ calibration at the collider
(accounts for material, global detector, B-field, long-range miss-calibrations and miss-alignments) includes:

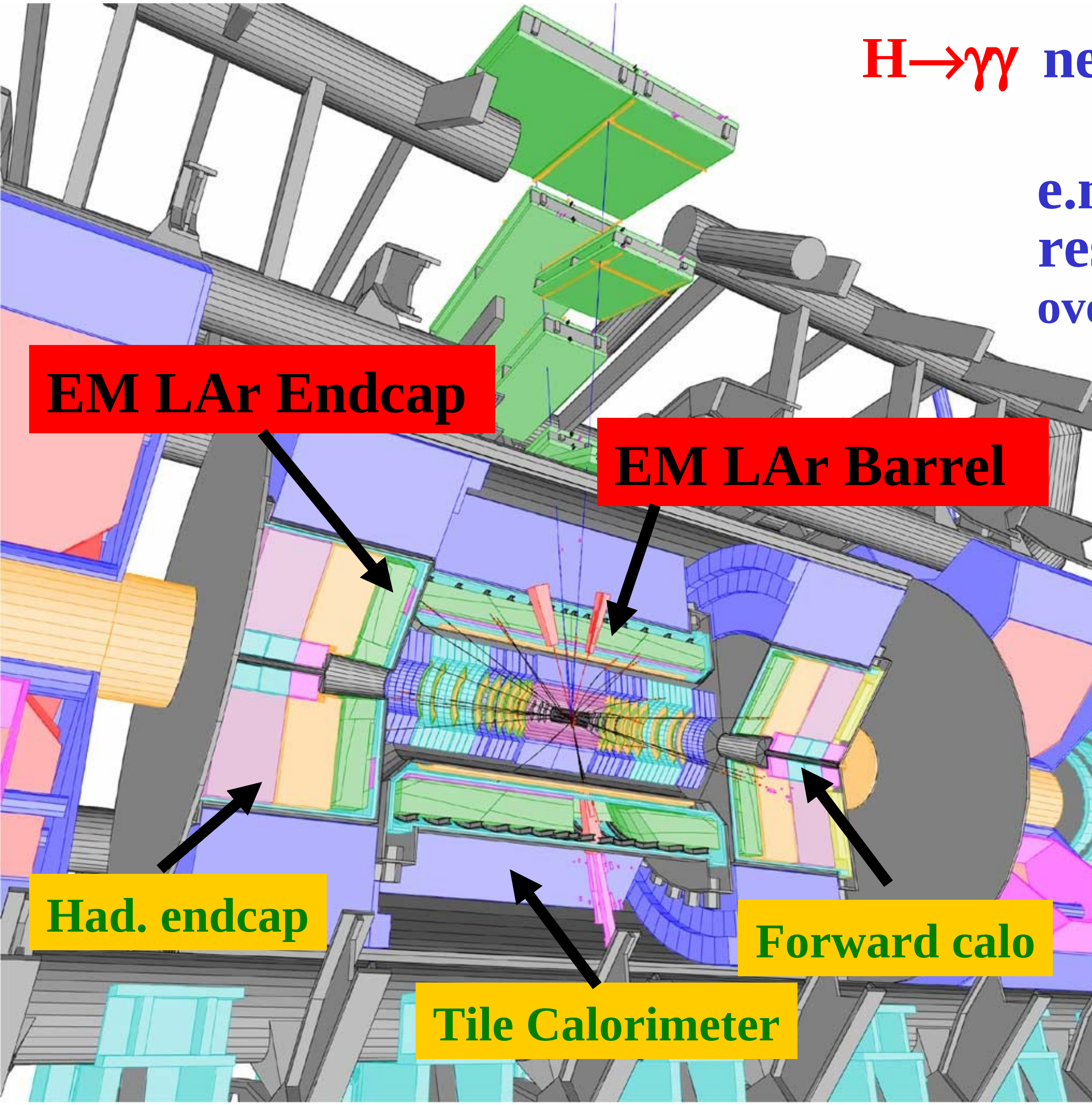
-- cosmic runs:
end 2006 – beg 2007 during machine cool-down

-- beam-gas events:
beam-halo muons during single-beam period

-- calibration with physics samples
(e.g. Z → ee, μμ, ττ, etc.)



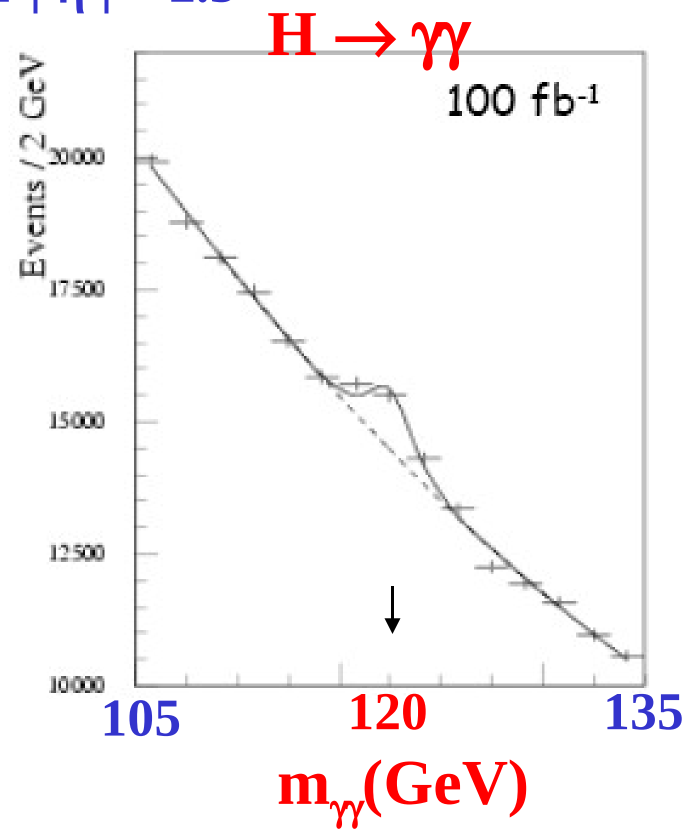
As example : LAr electromagnetic calorimeter



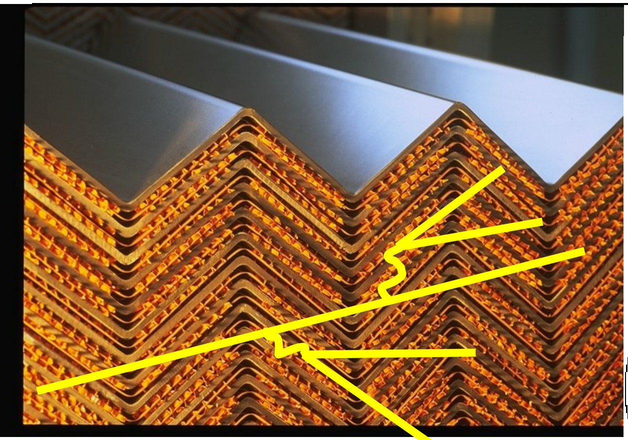
$H \rightarrow \gamma\gamma$ needs mass resolution ~ 1%

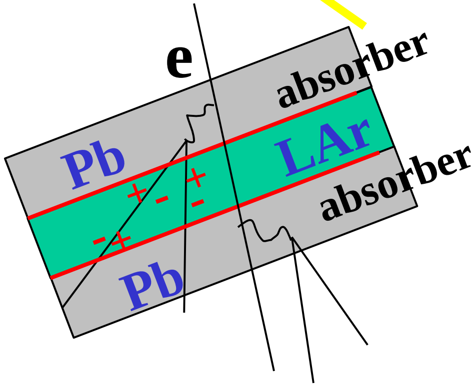
↓

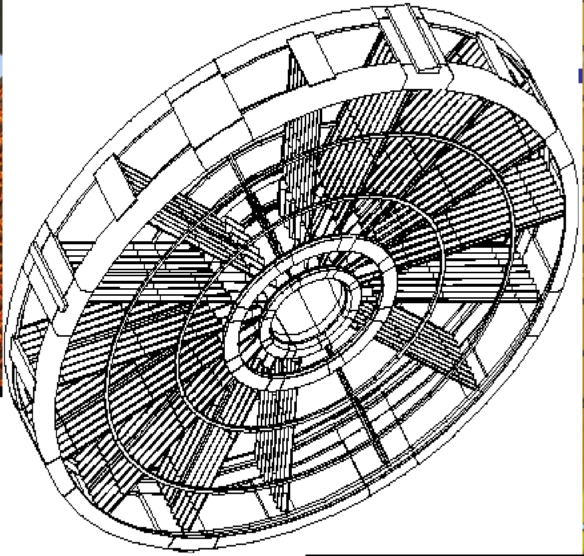
e.m. calorimeter energy response uniformity $\leq 0.7\%$ over $|\eta| < 2.5$

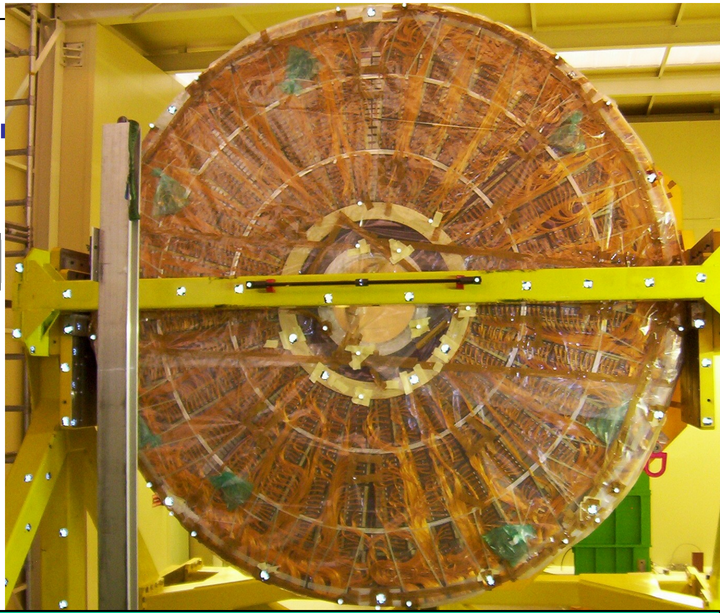


EM Endcap : Construction requirements



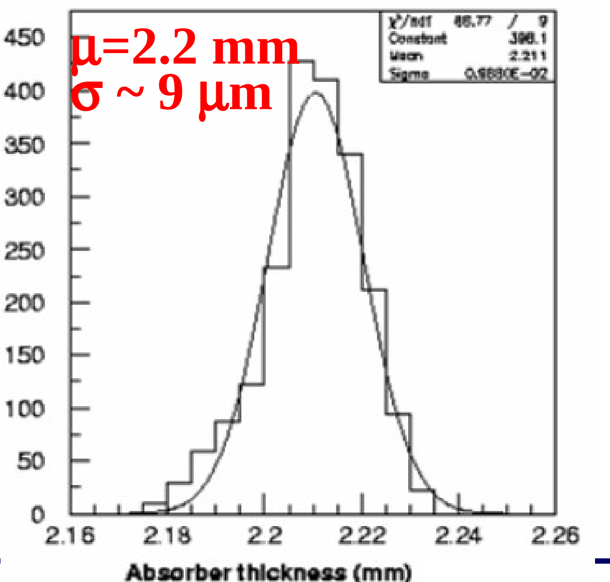




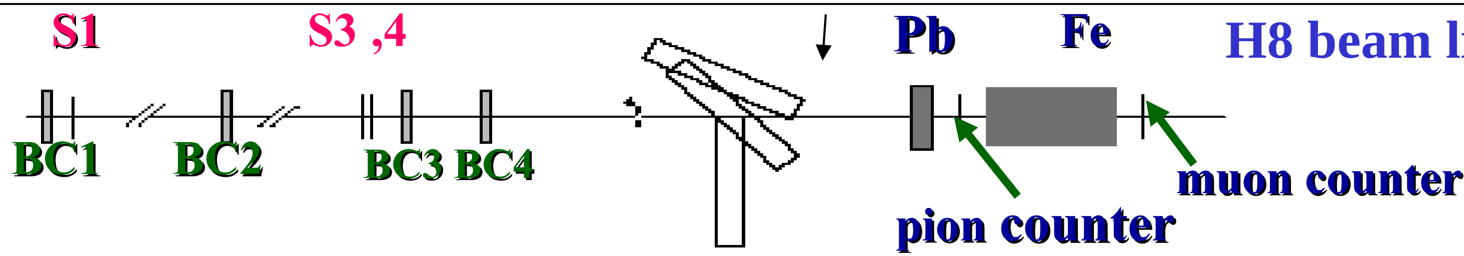


End-cap wheel in vertical position (24/6/03)

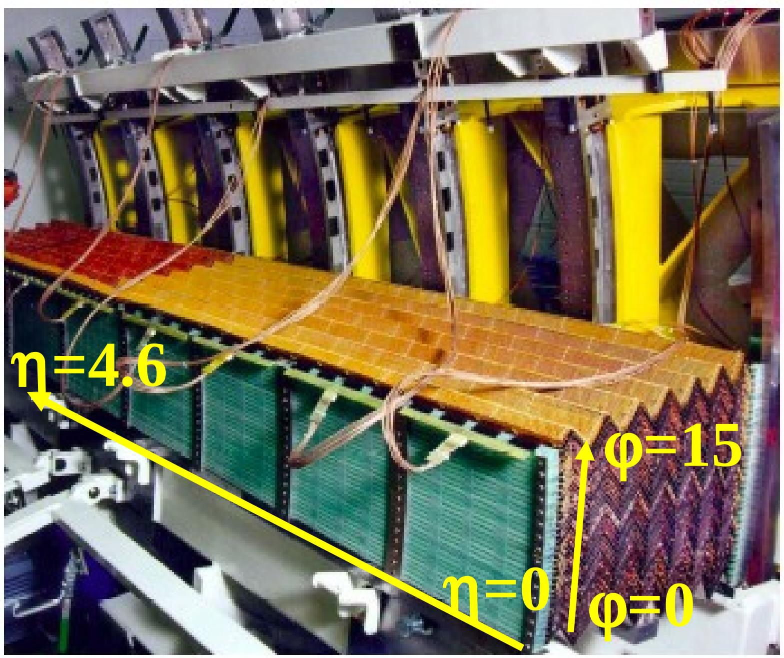
- To keep energy response uniform to ~ 0.2-0.3% thickness of Pb absorber plates must be uniform to ~ 0.5%(~ 10 μm)
- Thickness of 1536 plates for EM endcap measured with ultrasounds during construction →



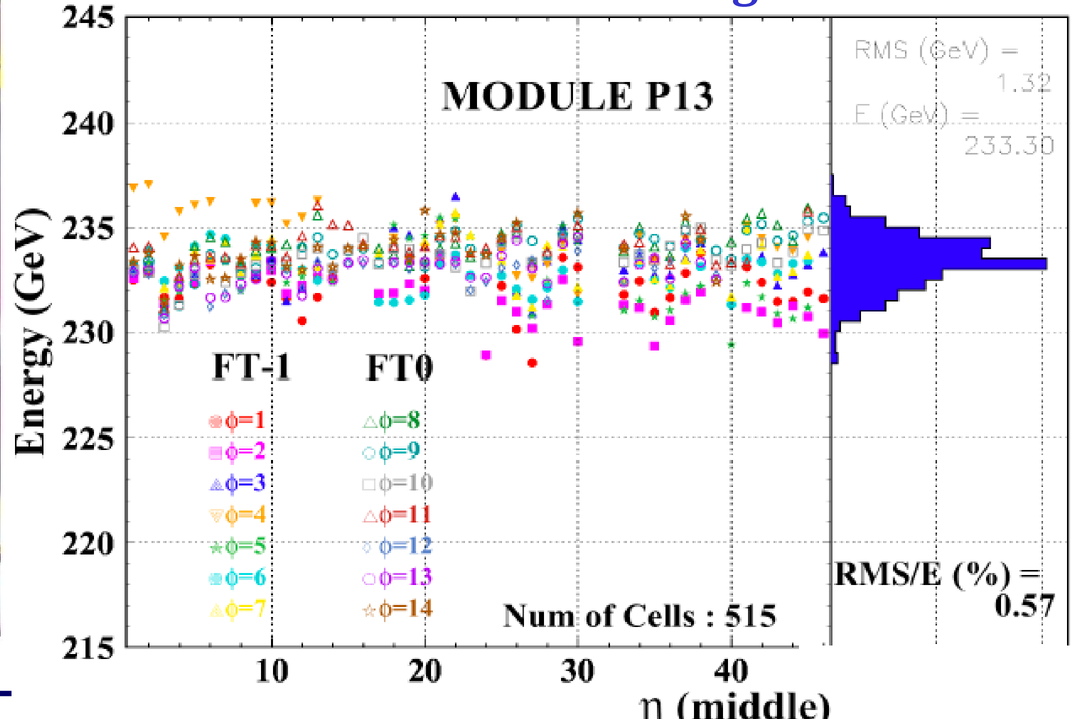
EM Barrel: 1999-2002 test beam



- Test of 4(out of 32) barrel, 3(out of 16) end-cap final modules
- Required uniformity in regions of size Δη x Δφ = 0.2 x 0.4 ~ 0.5%
  (440 regions in the full ECAL)

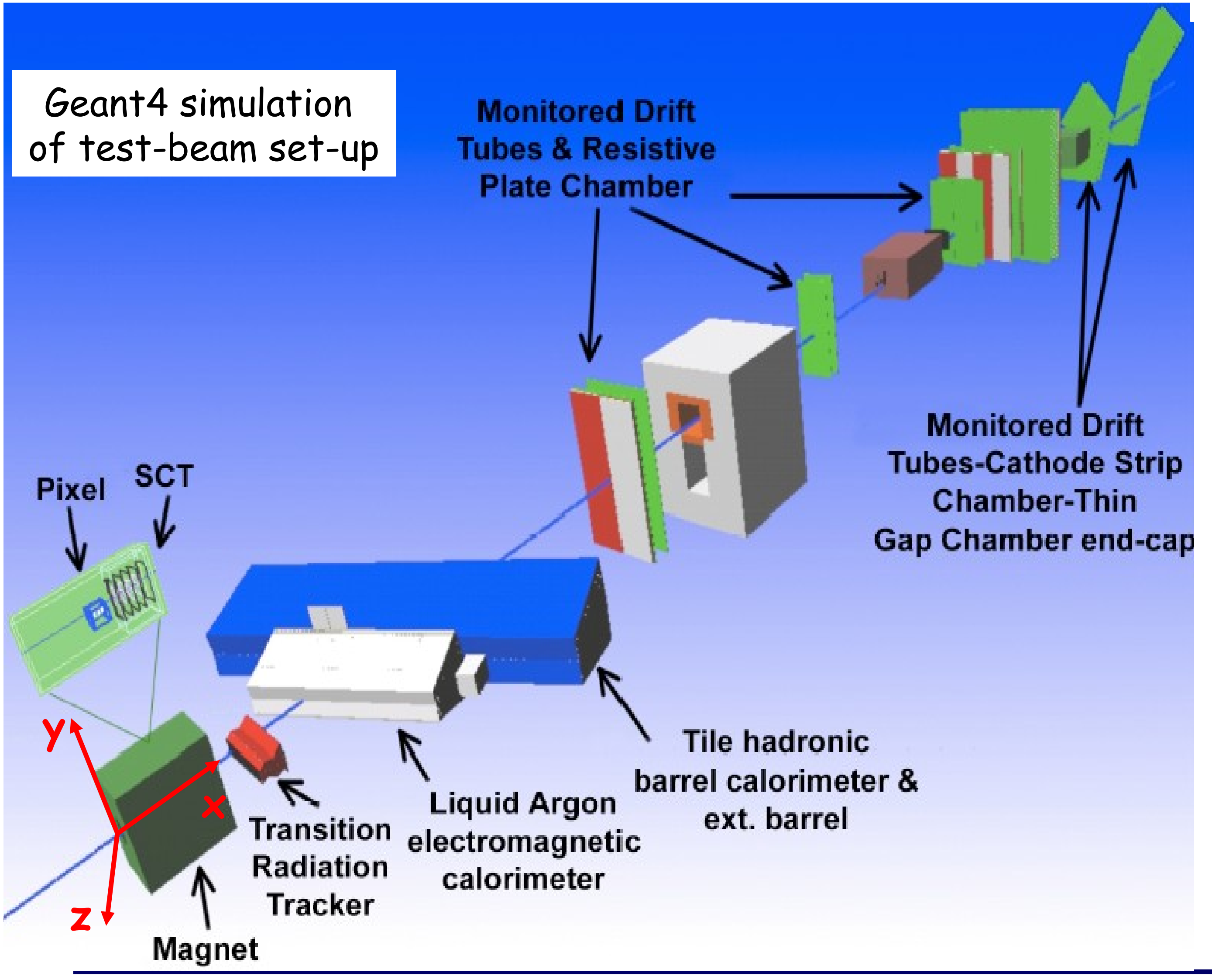


Barrel module scan with high E electrons



Toward Physics: 2004 ATLAS Combined Test Beam

~ O(1%) of ATLAS tested on CERN H8 beam line

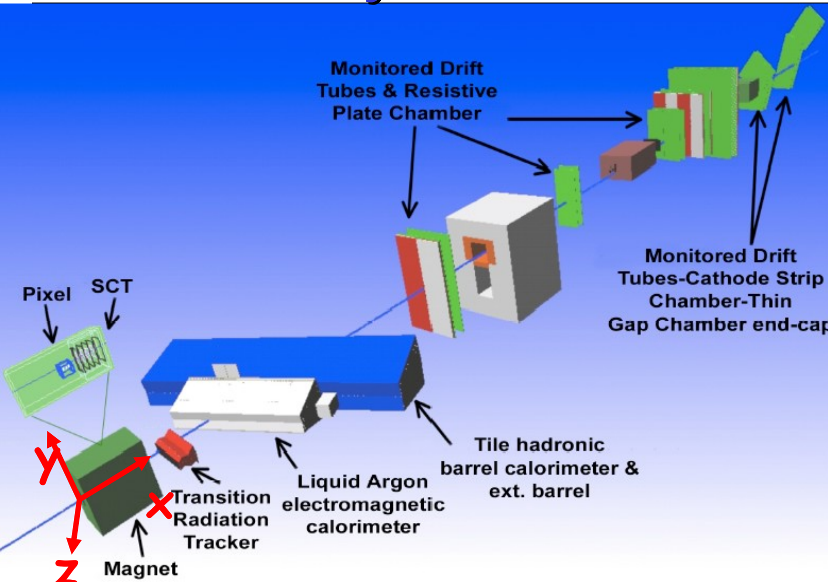


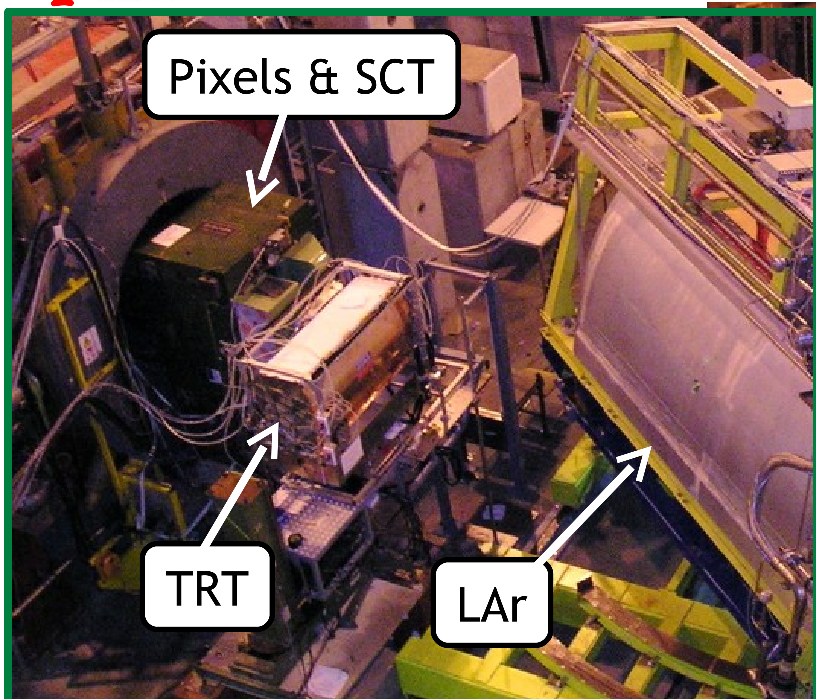
- «final» detector modules
- «final» electronics

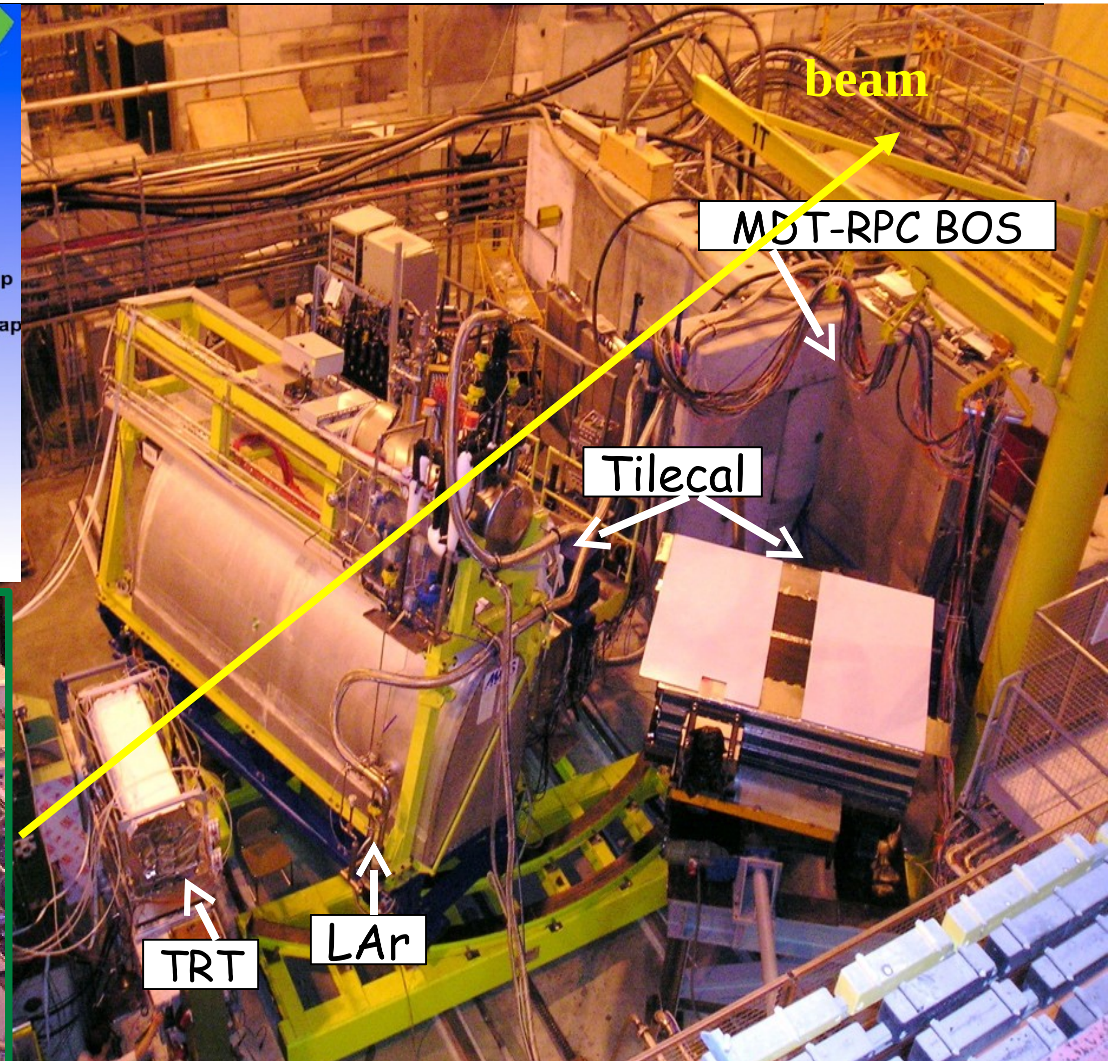
monitoring

- ATLAS software to analyze data.

Toward Physics: 2004 ATLAS Combined Test Beam

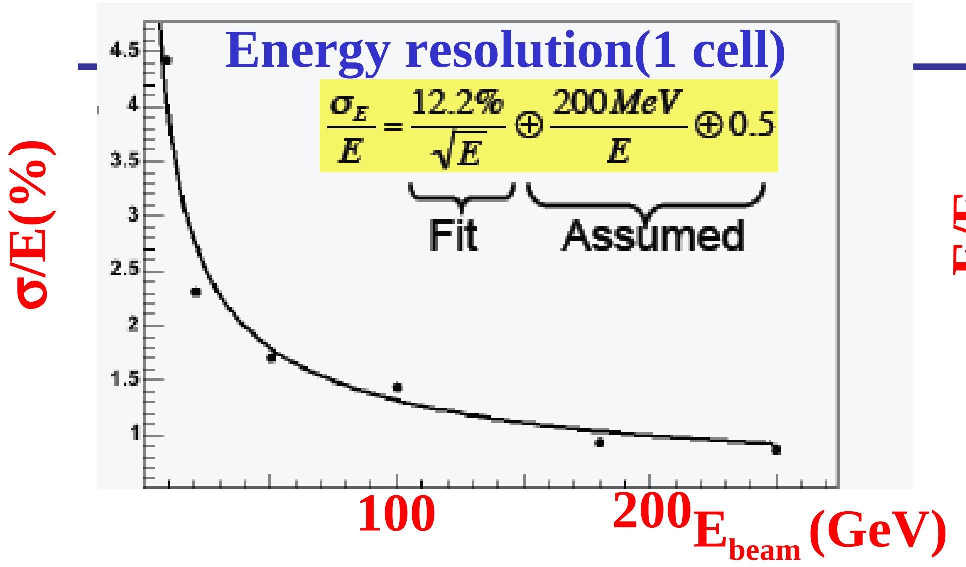


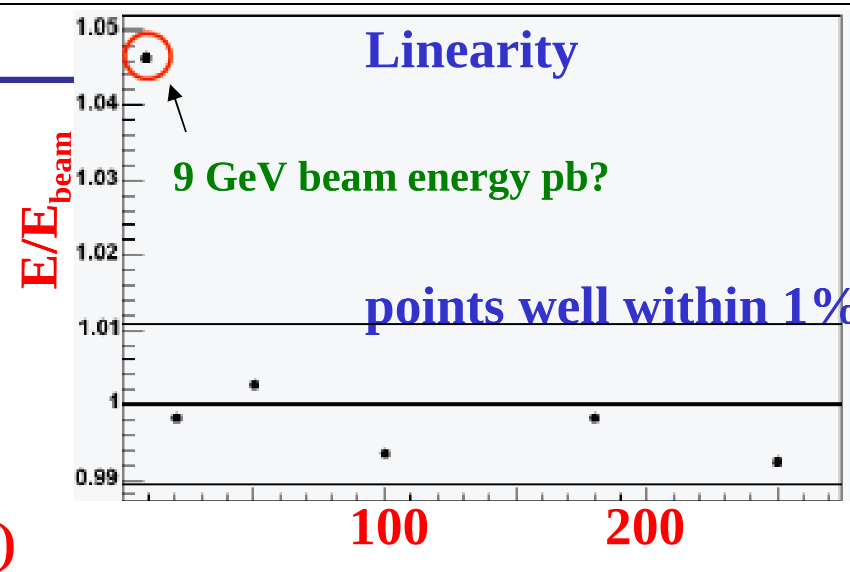


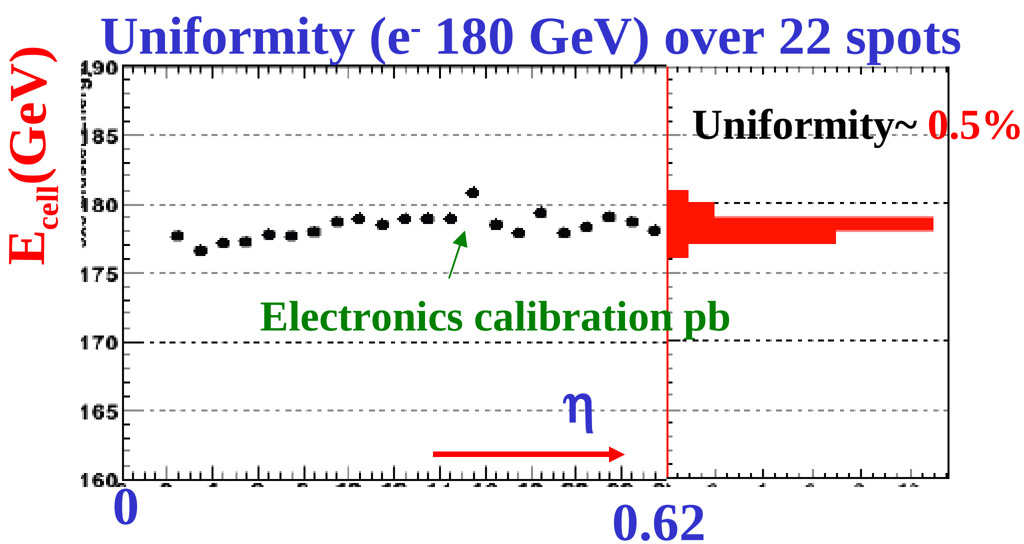


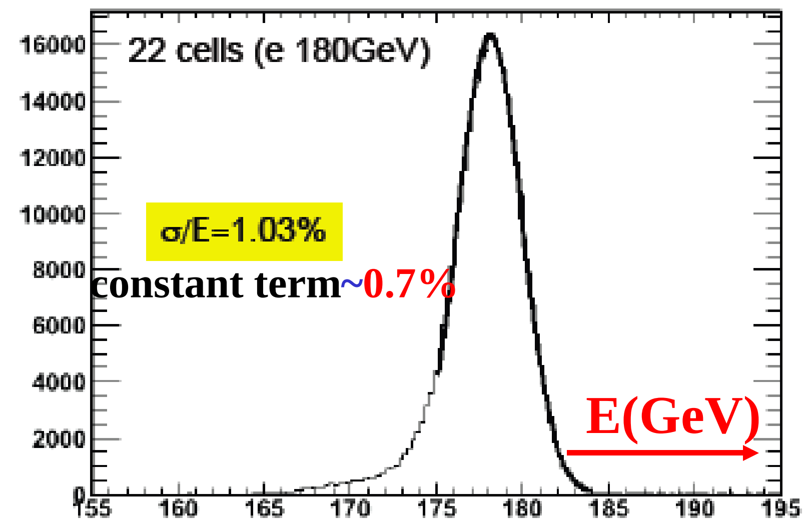
- 90 millions events collected(~ 4.5 TB)
- $e^{\pm}$, $\pi^{\pm}$, $\mu^{\pm}$, γ @ various energies, B=0→1.4 T

CTB: electron studies (preliminary results)









- Work in progress to understand the material in the beam line

Toward Physics : 'In situ' commissioning

- **Cosmic muons (from 'now' till begin 2007):**

  Debugging, dead channels, prel. alignment/calibration, synchronization…

  Rates : ~ 0.5 Hz 'pass by origin'. First InnerTracker(IT) alignment
  tenth of μm statistical precision in some parts of IT
  useful for LAr EM studies (timing, uniformity …)

  Beam gas (7 TeV p on residual gas at rest):

  Rates: 25 Hz of reconstructed tracks (p_t > 1 GeV z<20 cm)

  Tracking alignment (100 μm or better)

  Timing

  Beam halo (straight tracks accompanying the beam):

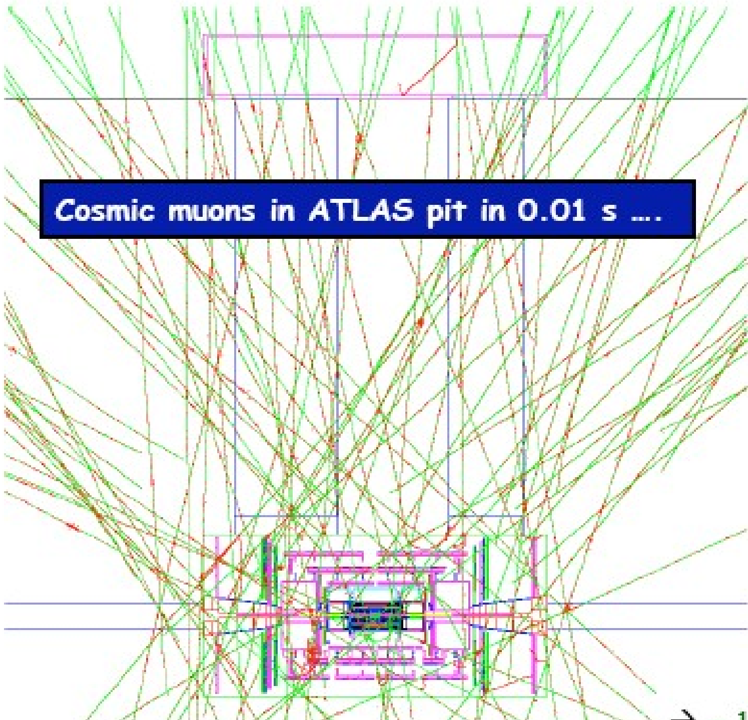
  Rates: 10 Hz with E > 100 GeV

  Timing

- **Calibration/alignment with (1rst) collisions**

Cosmic muons in ATLAS cavern

③ Check calibration with cosmic muons:



From full simulation of ATLAS (including cavern, overburden, surface buildings) + measurements with scintillators in the cavern:

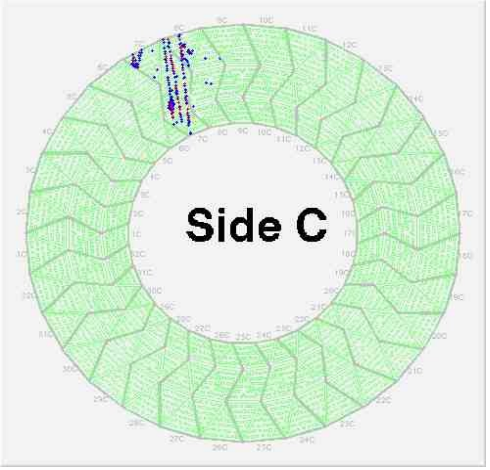
Through-going muons (hits in ID + top and bottom muon chambers)	~ 25 Hz
Pass by origin ($\|z\|$ < 60 cm, R < 20 cm, hits in ID)	~ 0.5 Hz
Useful for ECAL calibration ($\|z\|$ < 30 cm, E_{cell} > 100 MeV, ~ 90°)	~ 0.5 Hz

→ ~ 10^6 events in ~ 3 months of data taking

→ enough for initial detector shake-down (catalog problems, gain operation experience, some alignment/calibration, detector synchronization, ...)

F. Gianotti, La Thuile, 5/3/2005

Cosmic muons with ATLAS TRT



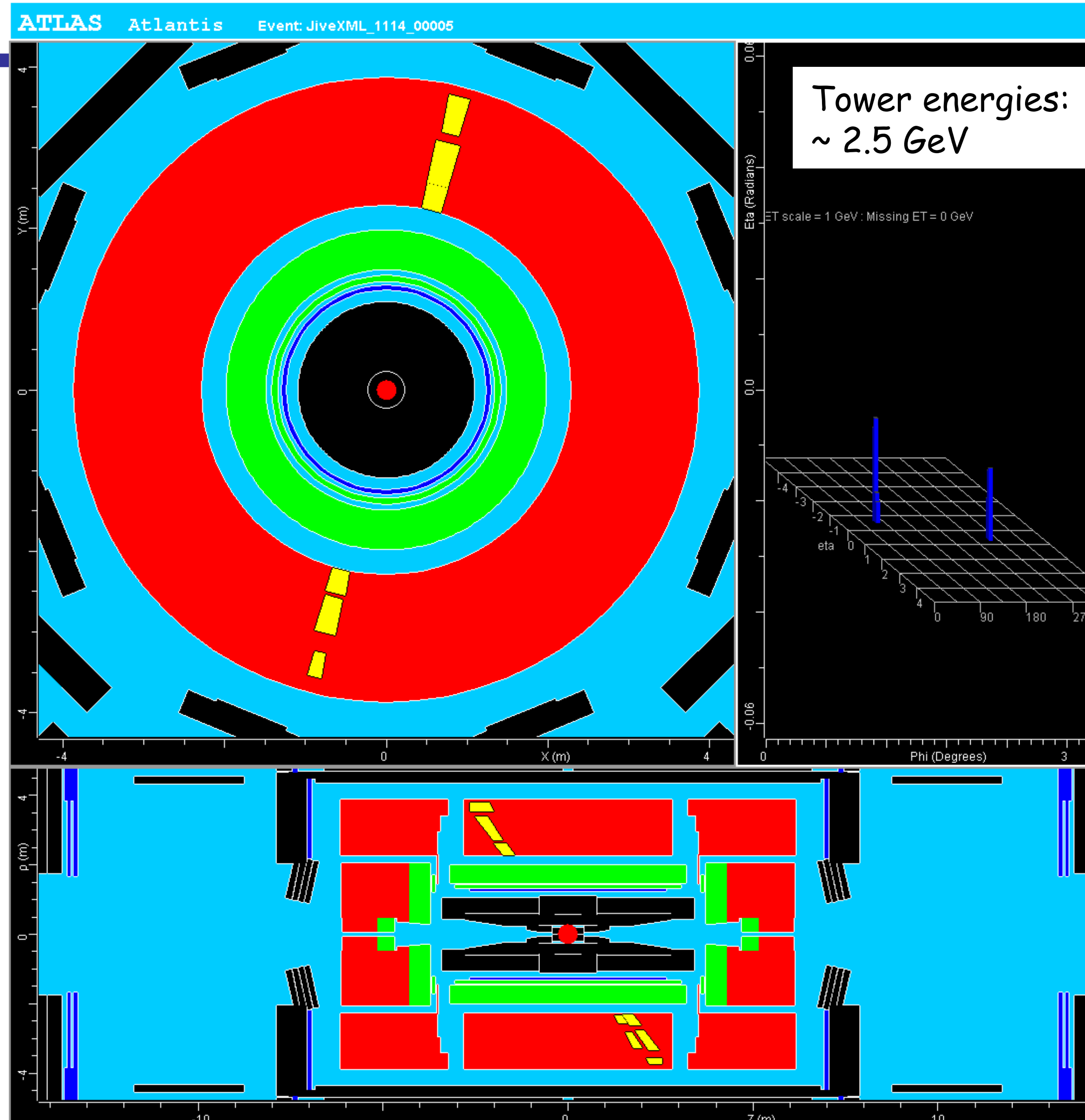
Cosmics recorded in the barrel TRT (on the surface)

Integrated end-cap TRT wheels of the initial detector for one side

Cosmic muons with TileCal

- First cosmic muons recorded by hadron Tilecal calorimeter on June 20th 2005

- Spring 2006 : calorimeters+ μ chambers (final position)
- April 2007 : global cosmic run

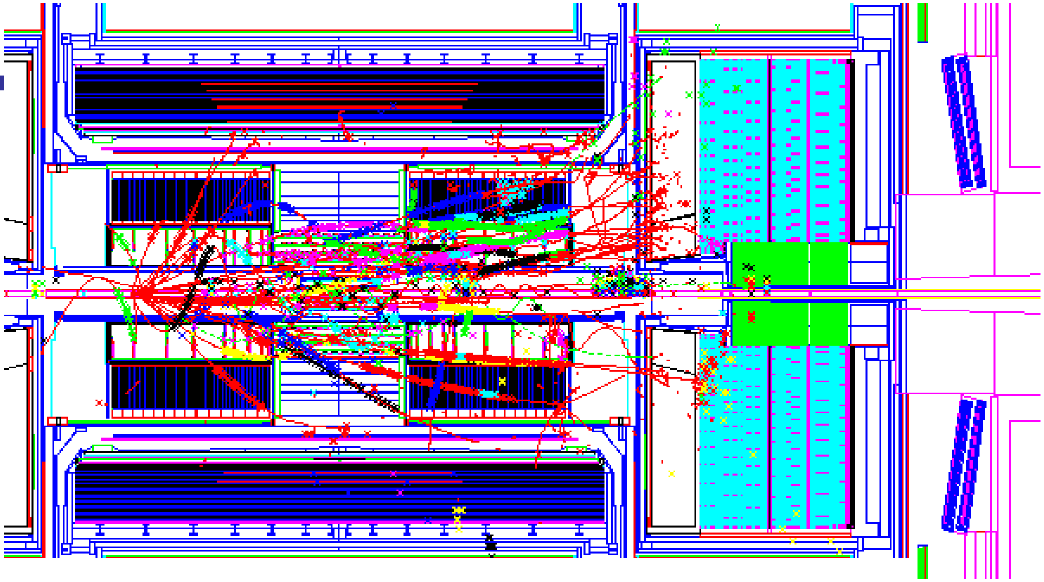


Single beam operation

- Beam-gas collisions:

  → essentially boosted minimum-bias events, low-p_T particles

  → Rate : ~ 2500 interactions/m/s

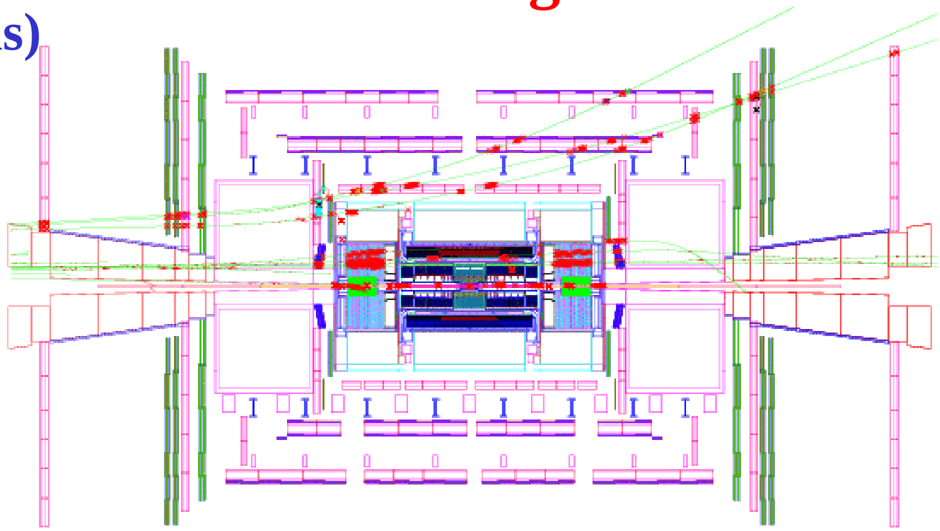


Beam-gas

Need dedicated scintillator trigger (beam halo @ small R & beam-gas)

- Beam-halo:

  Straight tracks



Beam Halo

Physic goals and potential in the first year

Channels (examples ...)	Events to tape for 10 fb^{-1} (per experiment)
$W \rightarrow \mu\nu$	7×10^7
$Z \rightarrow \mu\mu$	1.1×10^7
$tt \rightarrow WbWb \rightarrow \mu\nu + X$	0.08×10^7
QCD jets p_T>150	$\sim 10^7$
Minimum bias	$\sim 10^7$
$\tilde{g}\tilde{g}$ m = 1 TeV	$10^3 - 10^4$

1 fb^{-1} (10 fb^{-1}) ≡ 6 months at 10^{32} (10^{33}) $cm^{-2}s^{-1}$ at 50% efficiency → may collect several fb^{-1} per experiment by end 2008

1PB of data per year
→ challenging for software and computing

assuming 1% of trigger bandwidth (QCD jets, Minimum bias)

Already at first year large statistics expected from
→ known SM processes → understand detector at 14 TeV
→ several New Physics scenarios

Note: overall event statistics limited by ~ 100Hz rate to storage
~ 10^7 events to tape every 3 days assuming 30% data taking efficiency

Physic goals

Goal #1

Understand and calibrate detector and trigger in situ using well-known physics

$Z \to ee, \mu\mu$ tracker, ECAL, Muon chambers calib & alignment

$tt \to bl\nu\ bjj$ jet scale, b-tagging

Understand basic SM physics at 14 TeV $\to$ also first check of Monte Carlos

measure cross-sections for eg. mimimum bias, W, Z, tt, QCD jets (to 10-20%),

look at basic event features, first constraints of PDF's

measure top mass (to 5-7 GeV) $\to$ give feedback on detector performance

Note: statistical error negligible after few weeks run

Goal #2

Prepare the road to discovery:

-- measure background to New Physics: eg. tt and W/Z+jets

-- look at specific control samples for individual channels:

eg. ttjj with $j \neq b$ "calibrates" ttbb irreducible background to $ttH \to ttbb$

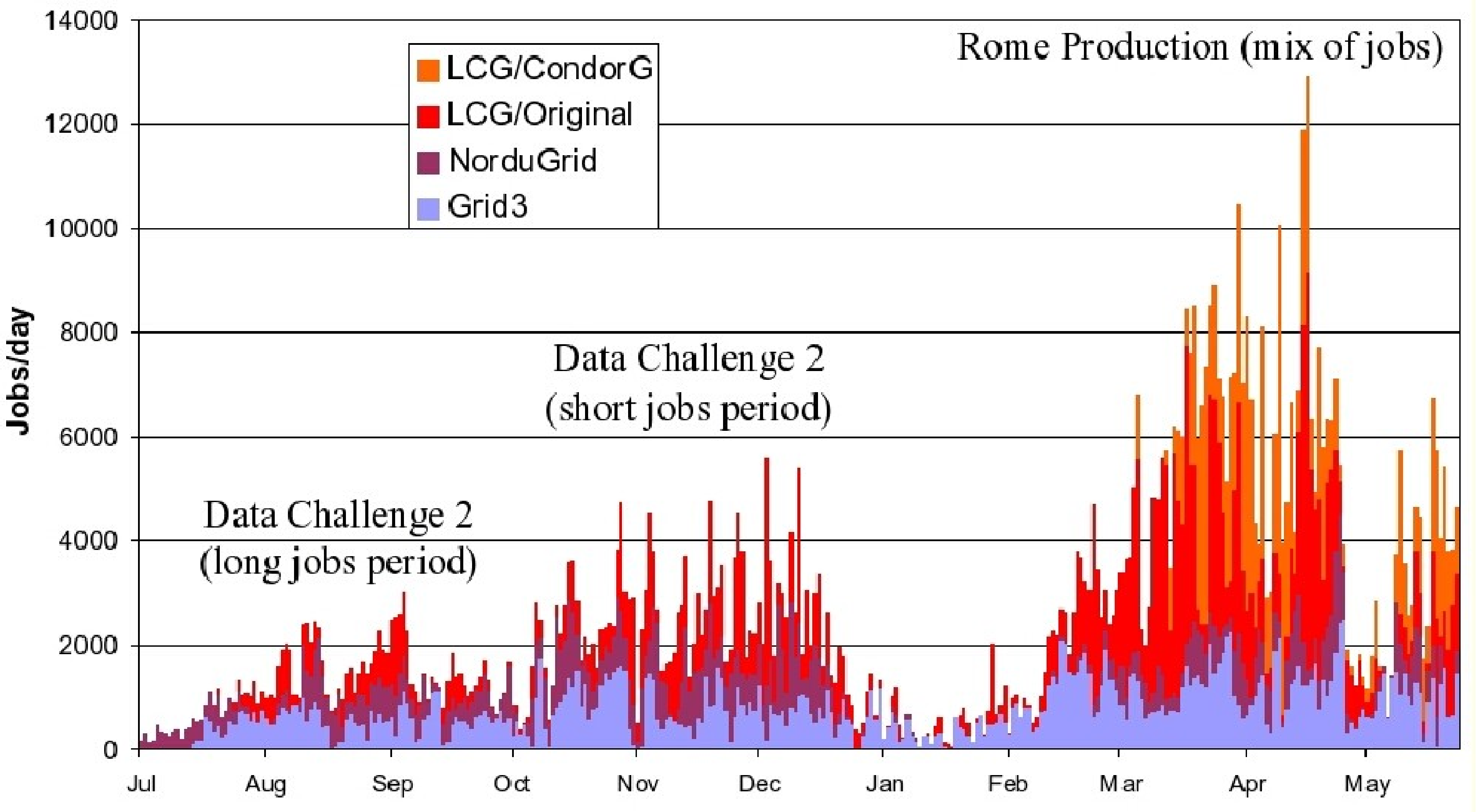
Goal #3

Look for New Physics potentially accessible in first year (SUSY, Higgs,...)

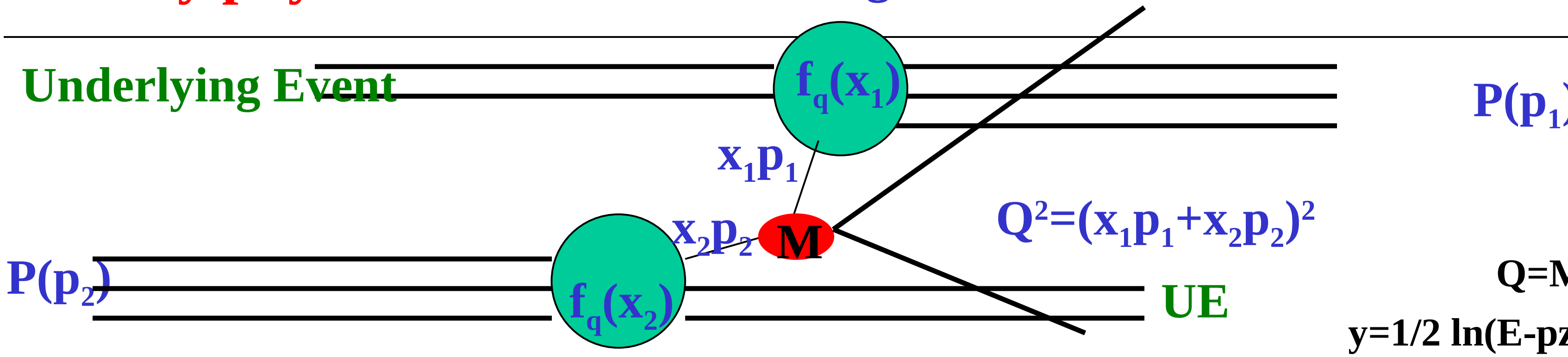
Physics simulation work on the grid for the Rome Physics WS

This is the first successful use of the grid by a large <u>user</u> community in ATLAS

Very instructive comments from the user feedback have been presented at the recent ATLAS Physics Workshop (obviously this was one of the main themes and purposes of the meeting)

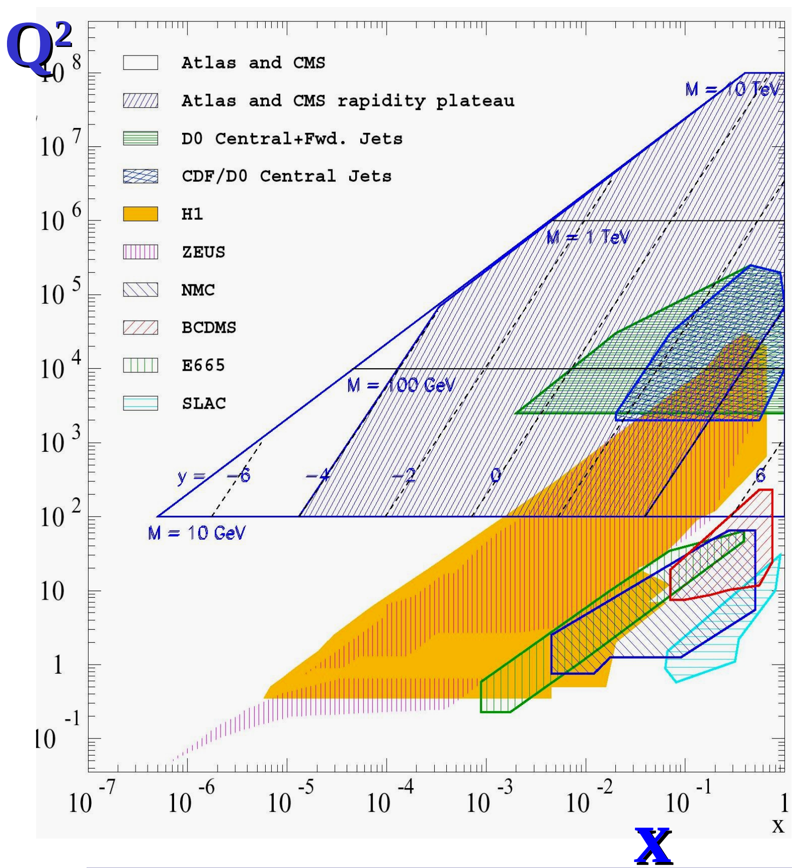


"Early physics": LHC kinematic regime



Q=M

y=1/2 ln(E-pz)/(E+pz)



- Kinematic regime for LHC much broader than currently explored

Tests of QCD

  - test of DGLAP evolution
  - improve information on high x-gluon distribution

- At Q ~ TeV New Physics cross-section predictions dominated by high-x gluon uncertainties

- At Q ~ M_w theoretical predictions for LHC dominated by low-x gluon uncertainties

“Early physics”: Minimum Bias (MB) & Underlying Events(UE)

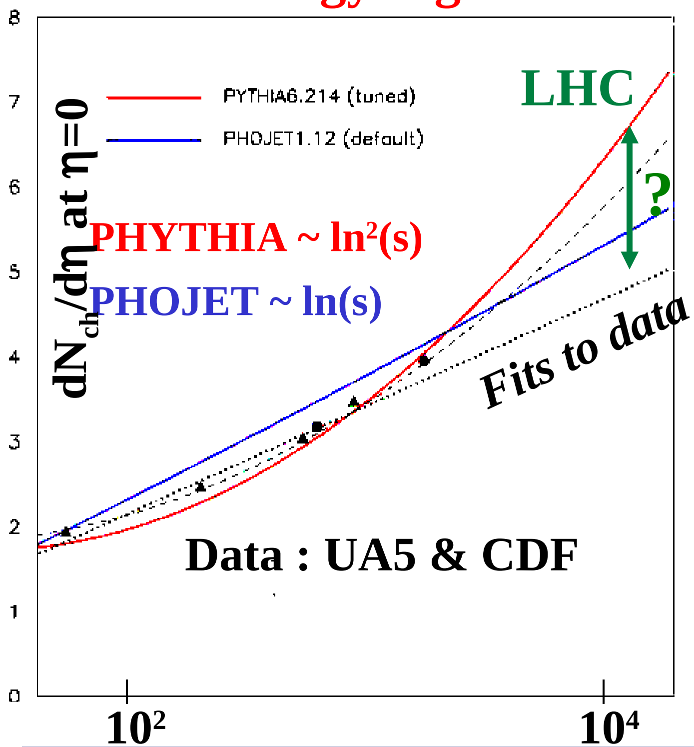
Use ‘MB trigger’ (~ 70 mb => for 10 fb^{-1} ~ 10^7 evts on tape) and ‘jet trigger’ to :

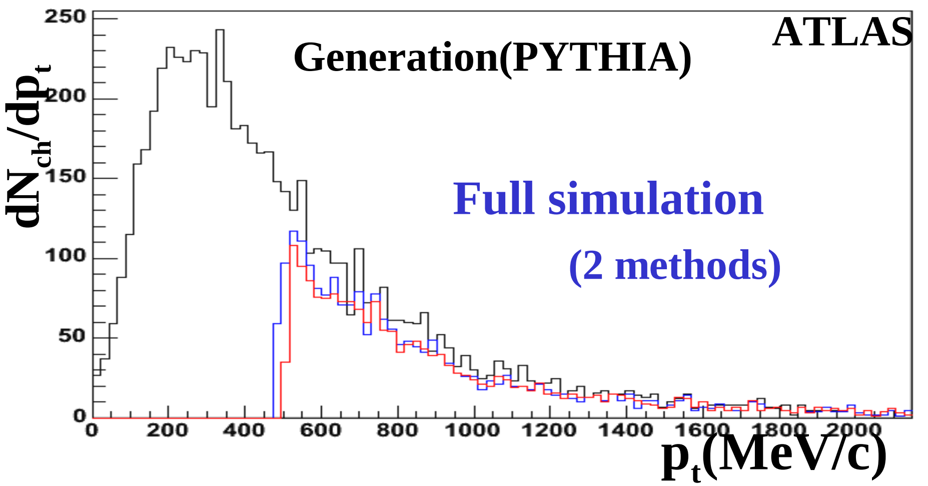
- Understand Pile Up & low p_T jets (fw jet tag & jet veto, etc…)
- Tune UE model (~ soft part of the pp interaction not described by PQCD)

Measure: $dN_{ch}/d\eta$, dN_{ch}/dp_t , … need Inner Tracker

(N_{ch} = number of charged particles)

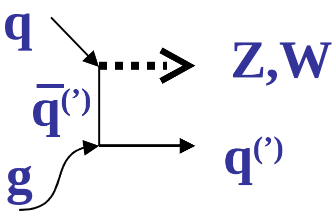
New energy regime !!





Special runs with lower solenoid field to get better efficiency for p_t ~ 200 MeV

"Early physics": gauge bosons W and Z



- **Best known cross sections at LHC: NNLO in PQCD**
  (1%scale uncertainty)
  input e.w. param.well known

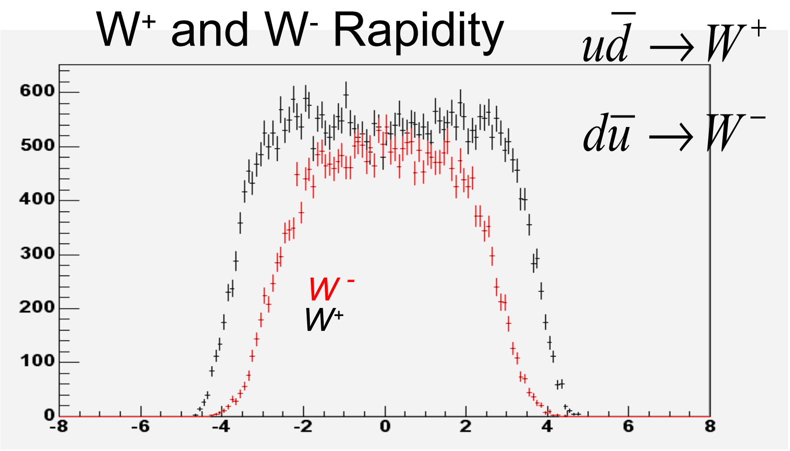
- **Uncertainties from PDF, luminosity (L)**

- **Tests of SM predictions : $R = d\sigma/dy(W^-)/ d\sigma/dy(W^+)$** } **not so sensitive to PDF&L (ratios)**
  W Asymmetry

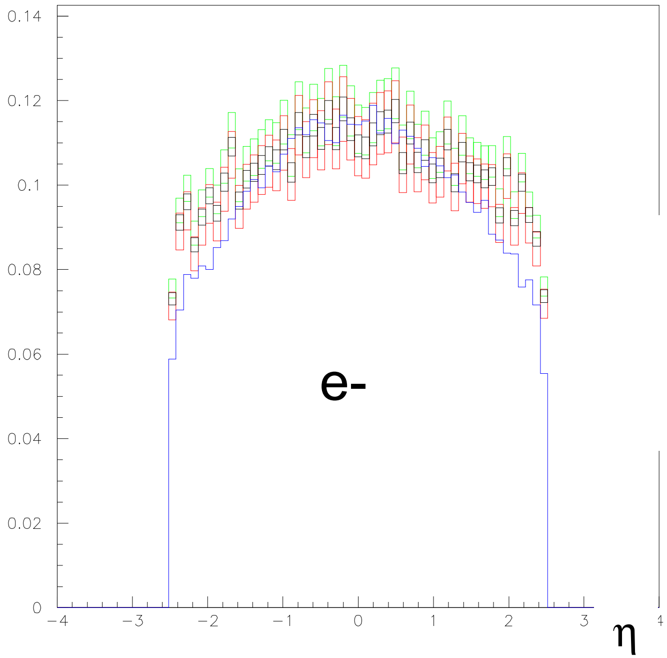
- **Constraining PDF: uncertainties on present PDF : 4-8%**
  ATLAS measurement of e (from $W \rightarrow e\,\nu$) angular distribution provide discrimination between different PDF if experimental precision ~ 3-5%

- **For L measurement: detector systematics:**
  Trigger, acceptance, identification efficiency and background

“Early physics”: Pdf determination using W bosons



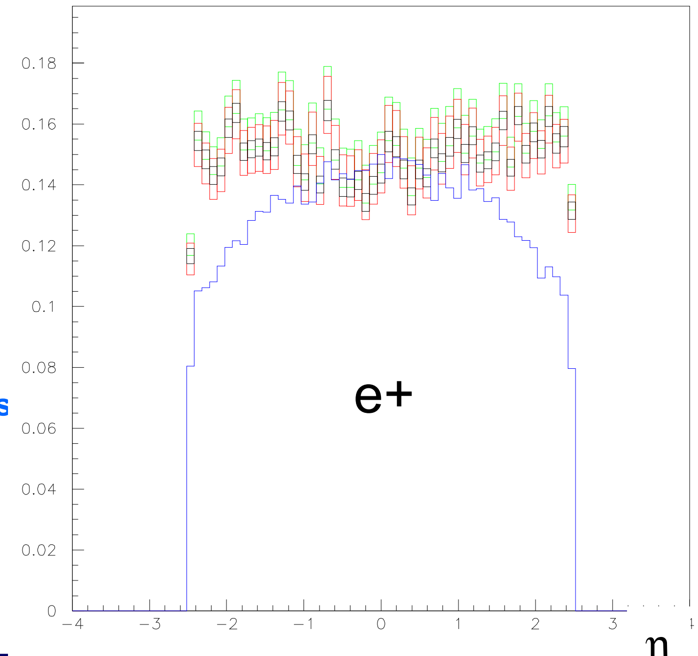
- Uncertainty in pdf transferred to sizeable variation in rapidity distribution electrons
- Limited by **systematic uncertainties**
  - To discriminate between conventional PDF sets we need to achieve an **accuracy ~3%** on rapidity distributions.



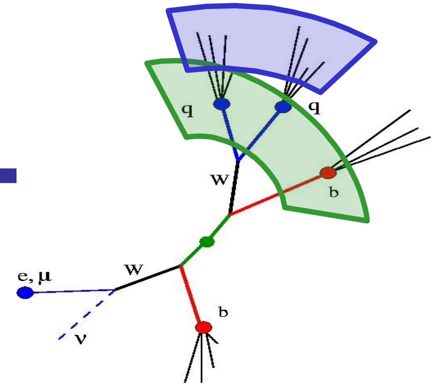
Error boxes:
The full PDF
Uncertainties

CTEQ61 (MC@NLO)
MRST02 (MC@NLO)
ZEUS02 (MC@NLO)
MRST03 (Herwig+k-Factors

Stat ~6 hours at low Lumi.



“Early physics”: top signal & mass



Use gold-plated tt → bWbW → blν bjj channel

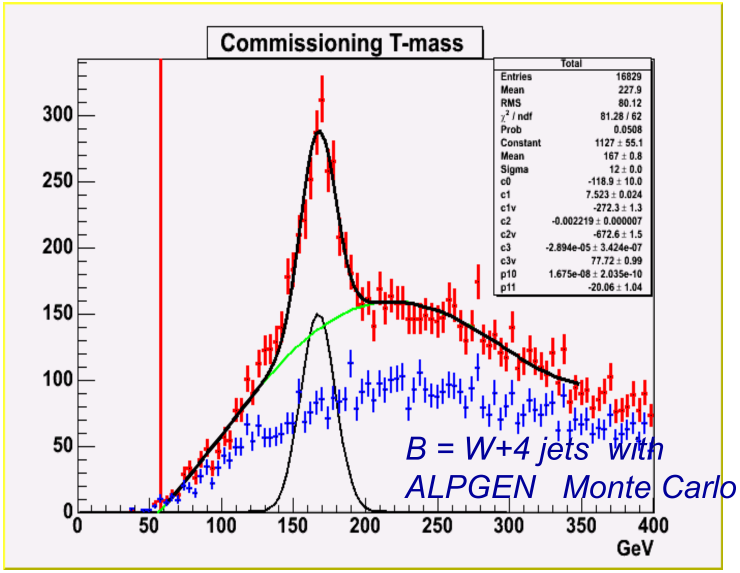
(σ_{tt} ~ 830 pb ⇒ 10^7 tt/y at 10^{33})

Very simple selection:

- -- isolated lepton (e,μ) p_T > 20 GeV
- -- exactly 4 jets p_T > 40 GeV
- -- no kinematic fit
- -- no b-tagging required (pessimistic, assumes trackers not yet understood

Time	Events at 10^{33}	Stat. error δM_{top} (GeV)	Stat. error $\delta\sigma/\sigma$
1 year	3×10^5	0.1	0.2%
1 month	7×10^4	0.2	0.4%
1 week	2×10^3	0.4	2.5%

Top signal visible in few days also with simple selection and no b-tagging



Cross-section to ~ 20% (10% from luminosity)

Top mass to ~7GeV (assuming b-jet scale to 10%)

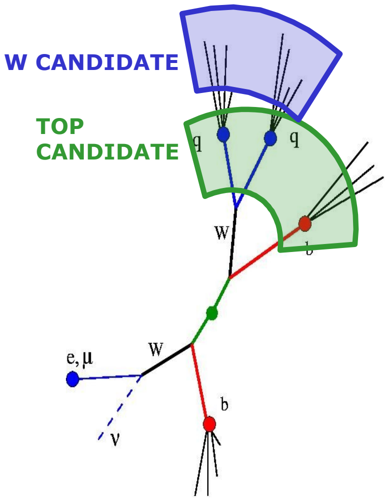
Get feedback on detector performance:

m_{top} wrong → jet scale?

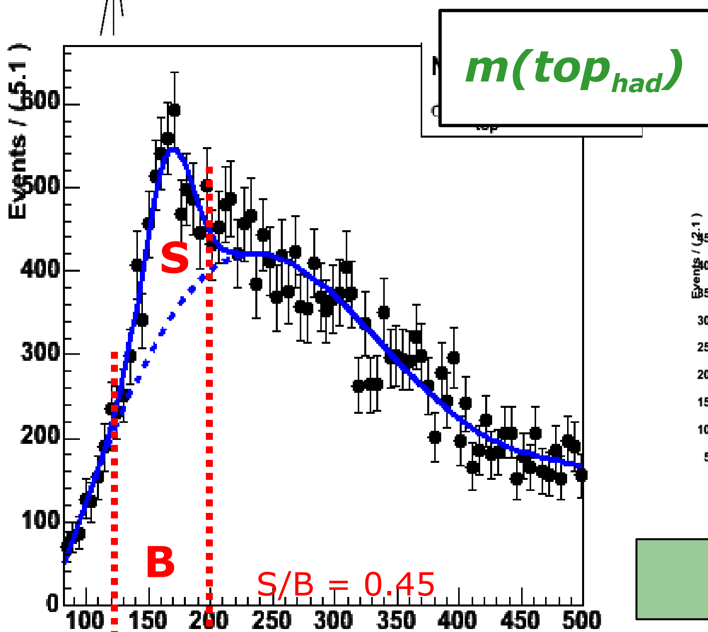
gold-plated sample to commission b-tagging

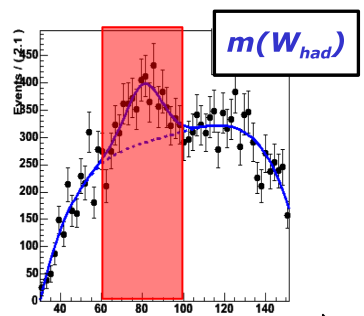
Understand the interplay between using the top signal as tool to improve the understanding of the detector (b-tagging, jet E scale, ID, etc..) and top precision measurements

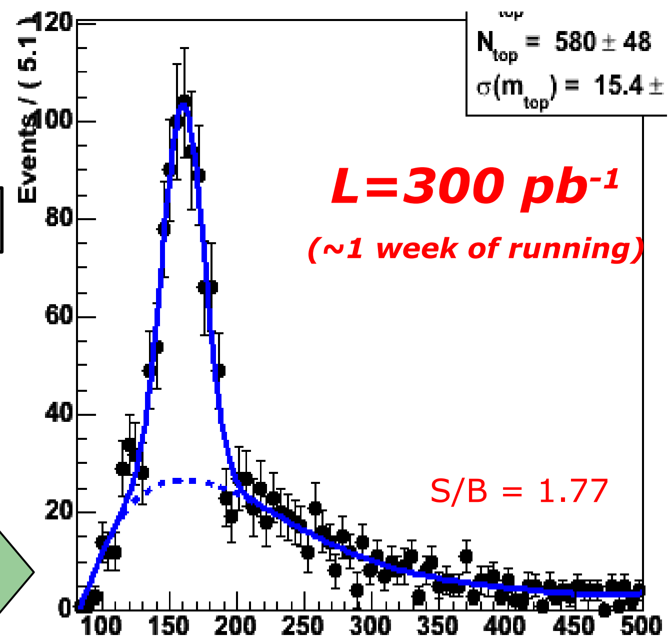
Detector commissioning with top events



- Now also exploit correlation between m(top_{had}) and m(W_{had})
  - Show m(top_{had}) only for events with |m(jj)-m(W)|<10 GeV

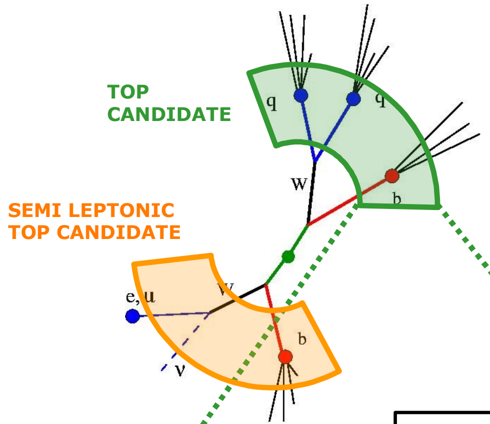


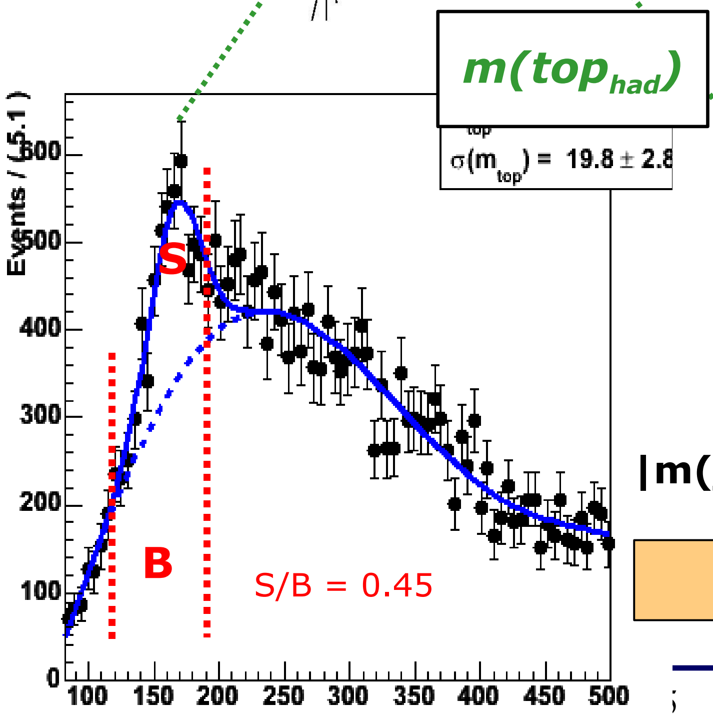




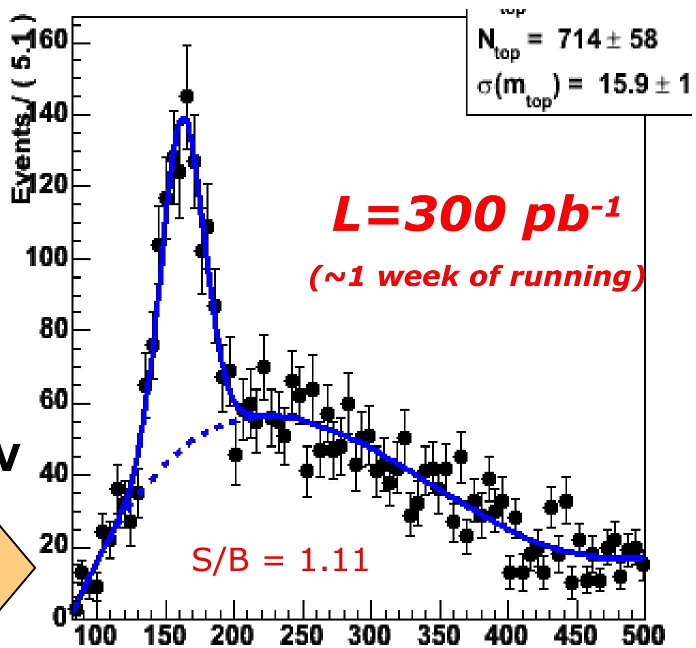
Detector commissioning with top events

- Can also clean up sample by with requirement on m(jlν) [semi-leptonic top]
  - NB: There are two m(top) solutions for each candidate due to ambiguity in reconstruction of p_z of neutrino
- Also clean signal quite a bit
  - m(W) cut not applied here





|m(jlν)-m_t|<30 GeV

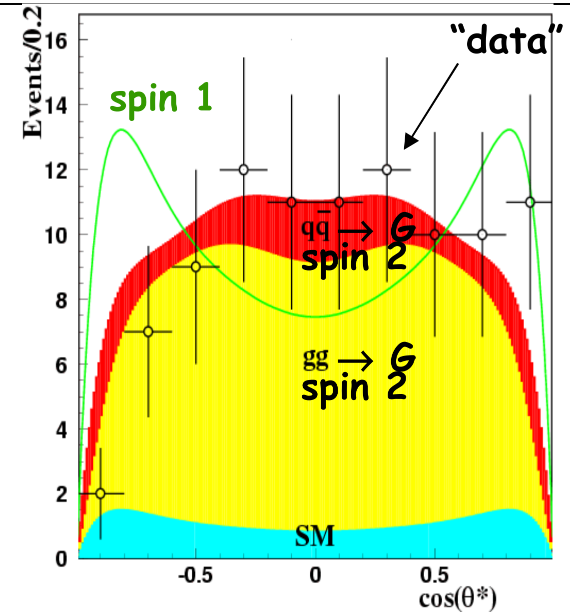


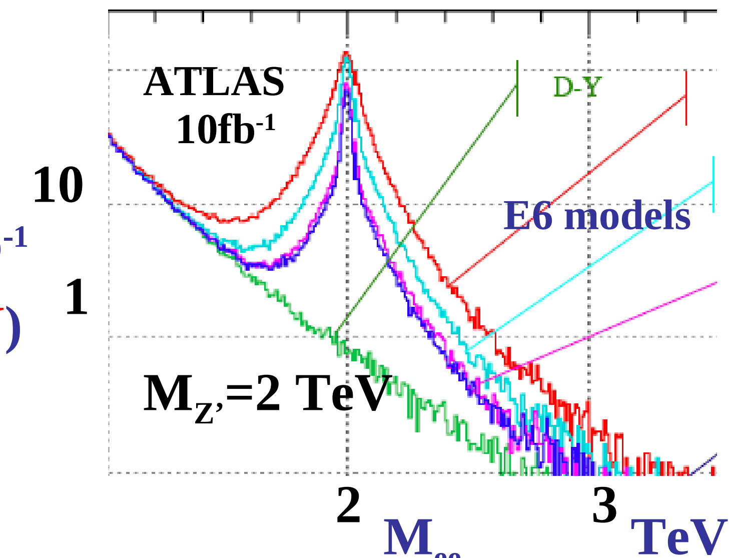
Early discoveries: Z',G

- Dilepton (ee or μμ) resonance with
  m ~ 1 TeV :
  (current limits (depend on models) $m_{Z'}$ > 600-700 GeV)

  Z' generic for new heavy neutral gauge bosons
  (GUT, little Higgs, …)
  G for massive particles forseen in
  Extra Dimension theories
- « Easy discovery» :
  signal = mass peak above low background :
  (Drell-Yan mainly)
  Ldt needed for discovery ($m_{Z'}$=1 TeV)
  ~ 0.07-0.70 fb^{-1} (depends on models)
  Ldt needed for discovery (m_G=1 TeV) ~ 4 fb^{-1}
  (with 300 fb^{-1} discovery possible up to ~10 TeV)
- More statistics needed to distinguish models (using : σ·Γ, asymmetry, rapidity)

ATLAS, 100 fb^{-1}, m_G=1.5 TeV

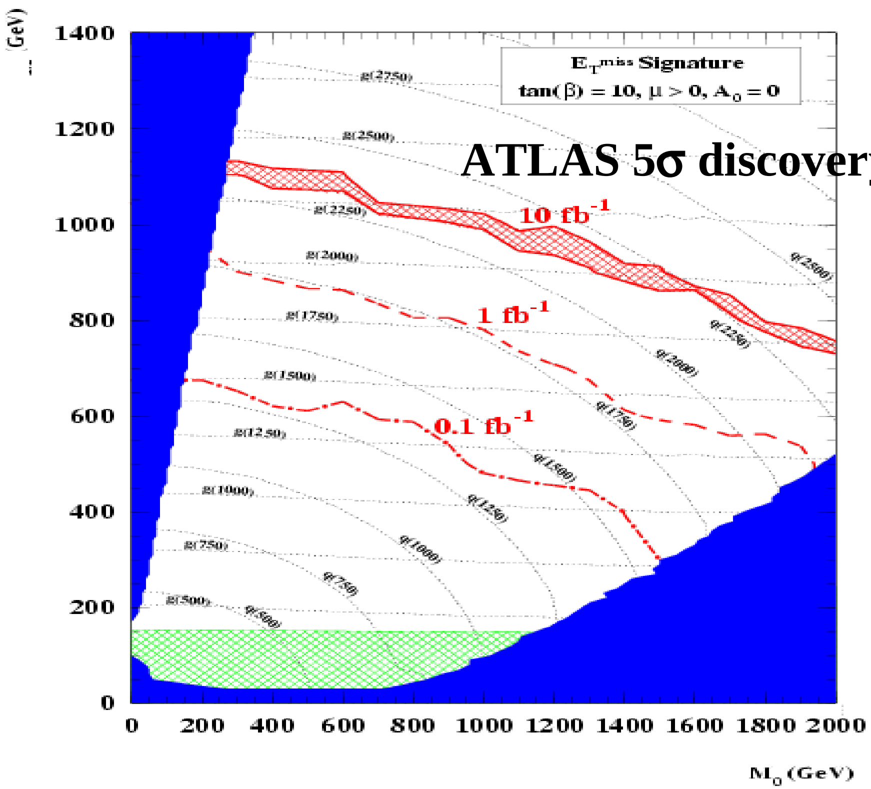




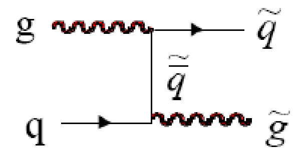
Early discoveries :SUSY

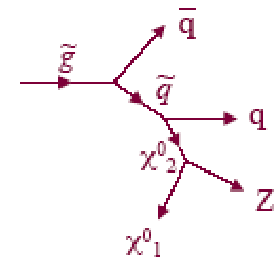
Large $\tilde{q}\tilde{q}$ $\tilde{g}\tilde{g}$ cross-sections (for $m(\tilde{q},\tilde{g}) \sim 1$ TeV) $\Rightarrow$ ~ 100 evt/day at 10^{33}

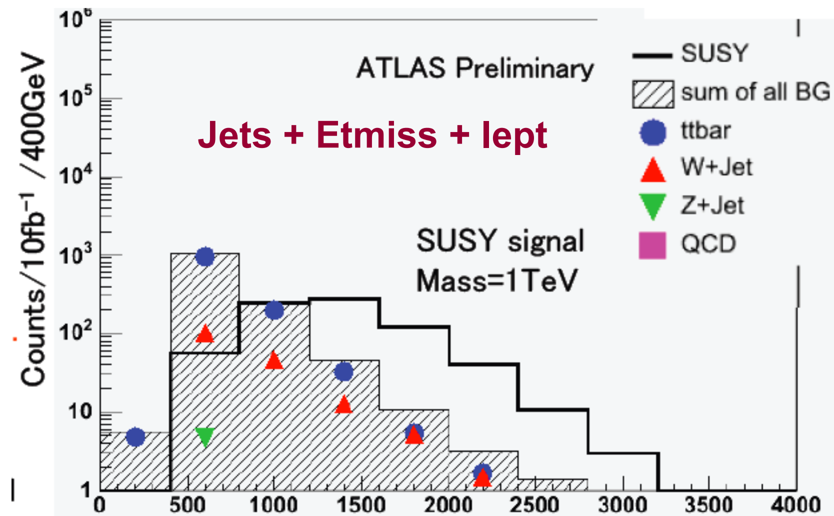
+ spectacular signature = **early discovery ?**



M_0(GeV)







$M_{eff}(GeV) = E_T^{miss} + E_T^{l} + \Sigma_{j=1,4}\, p_{T,j}$

Strategy for background estimates

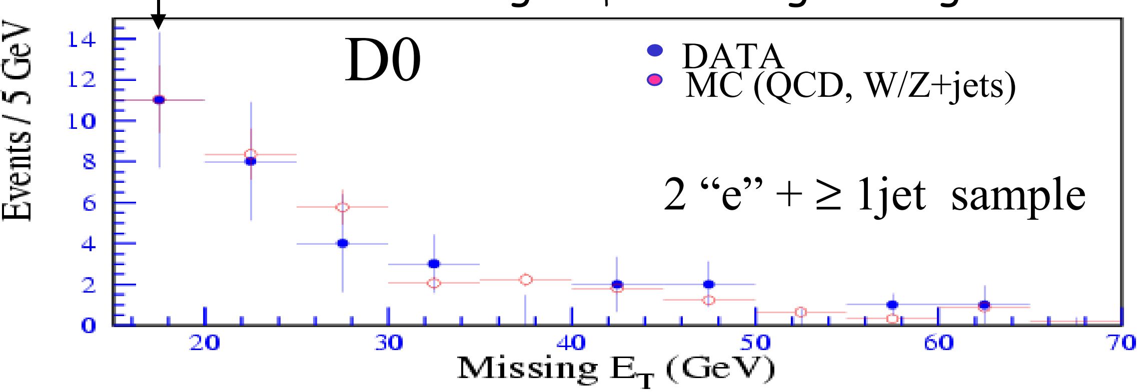
Background process (examples ….)	Control samples (examples ….)
Z (→ νν) + jets W (→ τν) + jets tt→ blνbjj QCD multijets	Z (→ ee, μμ) + jets W (→ eν, μν) + jets tt→ blν blν lower E_T sample

Can estimate background levels also varying selection cuts (e.g. ask 0,1,2,3 leptons …)

A lot of data will most likely be needed !

normalization point

normalise MC to data at low E_T^{miss} and use it to predict background at high E_T^{miss} in "signal" region



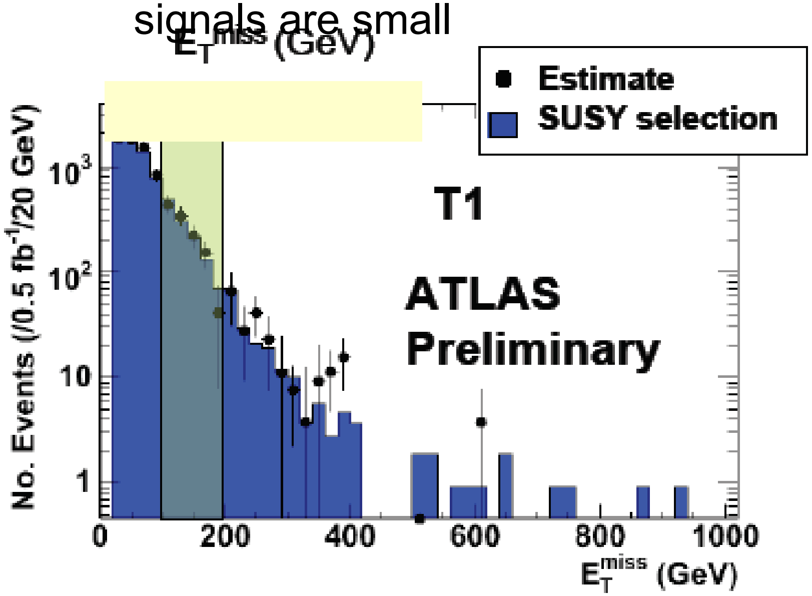
Hard cuts against fake E_T^{miss} :

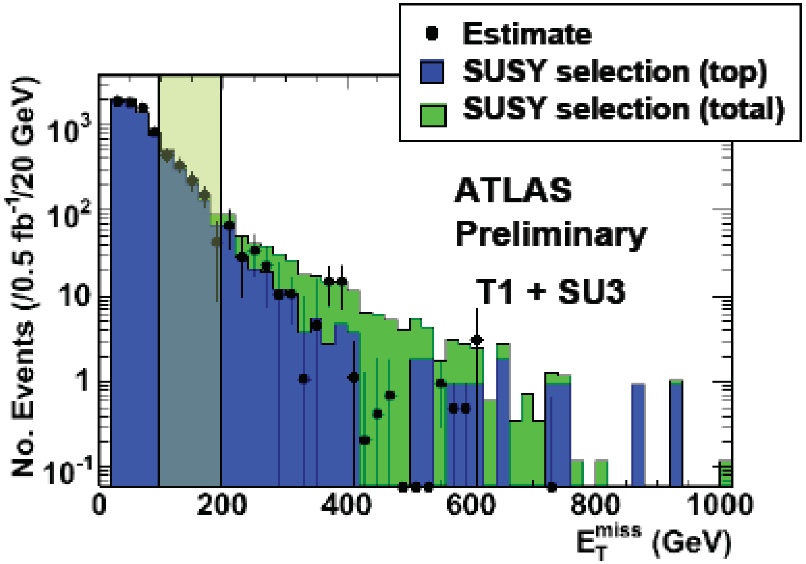
- -reject beam-gas, beam-halo, cosmics
- primary vertex in central region
- reject event with E_T^{miss} vector along a jet or opposite to a jet
- -reject events with jets in cracks
- etc. etc.

Strategy for background estimates

- Obtain the E_T^{miss} distribution from data using top events
  - By fixing the top mass in the leptonic channel, predict E_T^{miss}
  - Select top without b-tagging
- E_T^{miss} for top signal minus sideband
  - Reduce combinatorical background
  - Normalise at low E_T^{miss}, where SuSy signals are small

- Add SuSy
  - Repeat procedure with SuSy signal included
  - E_T^{miss} distribution from data
  - Clear excess from SuSy at high E_T^{miss} observed: method works!



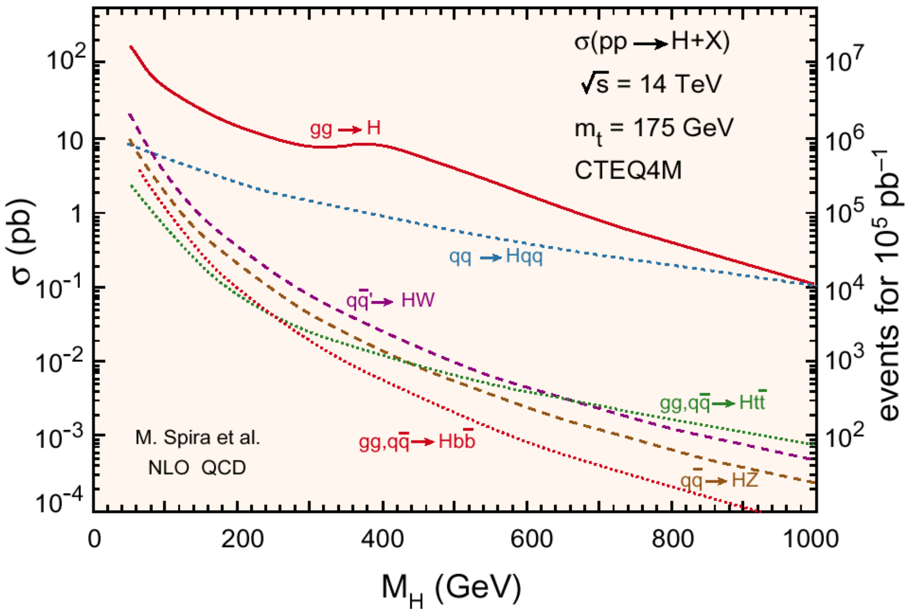


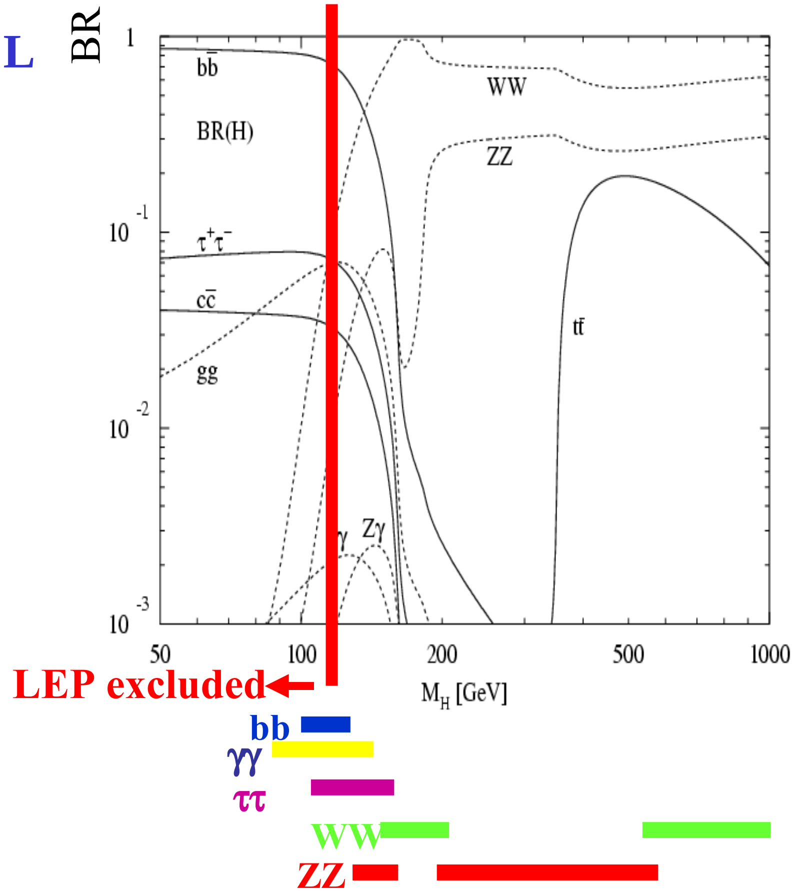
SM Higgs signal

Present limits :

direct searches(LEP) $M_H > 114.4$ GeV

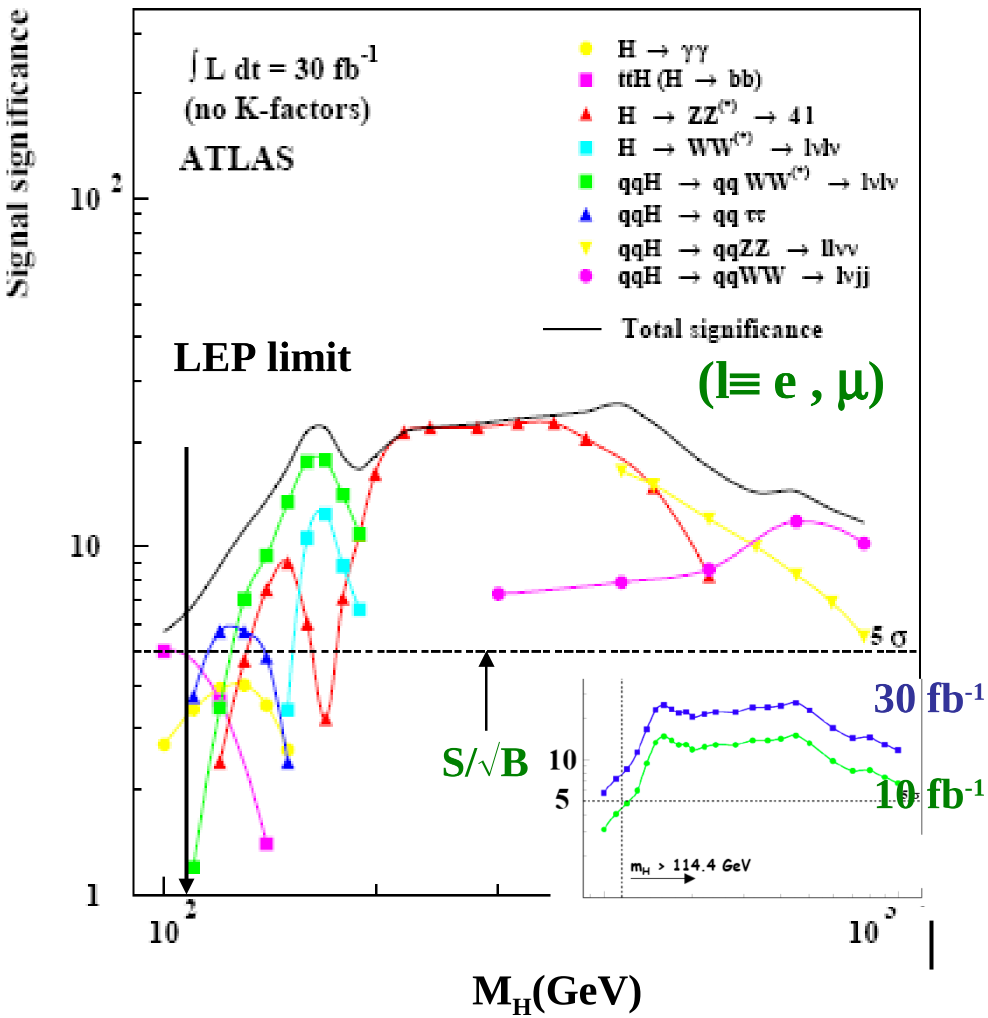
+ e.w. fit constraints $M_H < 219$ GeV @ 95% CL





SM Higgs signal significance

$S/\sqrt{B}$

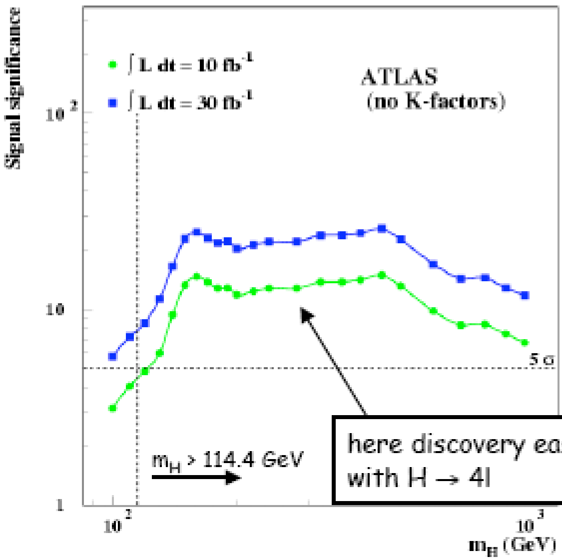


30 fb^{-1} enough for SM Higgs discovery

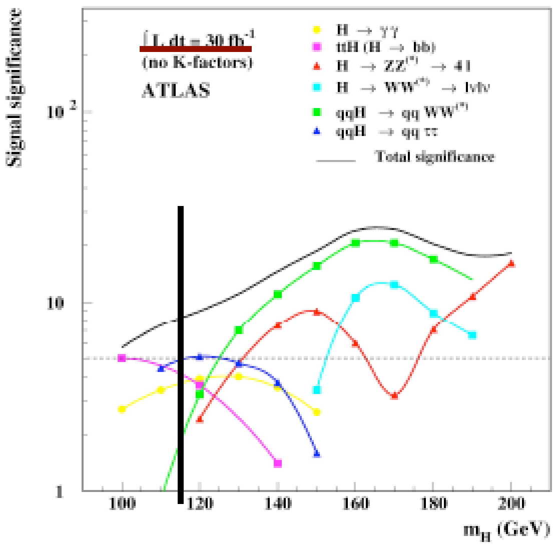
Early discovery (with ~ 10 fb^{-1}):

- **M_H ~ 180 -> 600 GeV easier mainly due to H -> 4l**
- **M_H < 180 GeV more challenging:**
  - **M_H ~ 115 GeV in particular: observation of 3 channels needed to extract convincing signal in first year**
  - **H-> l ν lν high rate but no mass peak => not ideal for early discovery**
- **M_H > 600 GeV**
  H-> 4l limited statistically
  => use H -> ll νν, lν jj

SM Higgs with mass below 200 GeV



here discovery easier with H → 4l



$m_H \sim 115$ GeV 10 fb^{-1}

ATLAS	$H \to \gamma\gamma$	$t\bar{t}H \to t\bar{t}b\bar{b}$	$qqH \to qq\tau\tau$ (ll + l-had)
S B	130 4300	15 45	~ 10 ~ 10
S/ √B	2.0	2.2	~ 2.7

total $S/\sqrt{B} \approx 4^{+2.2}_{-1.3}$

K-factors ≡ σ(NLO)/σ(LO) ≈ 2 not included

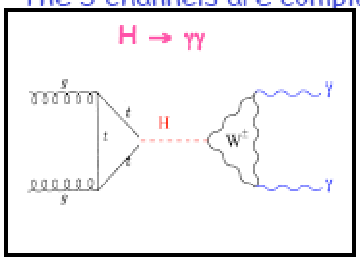
Full GEANT simulation, simple cut-based analyses

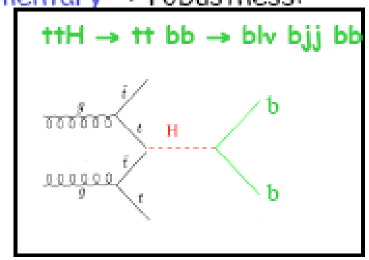
SM Higgs with mass below 200 GeV

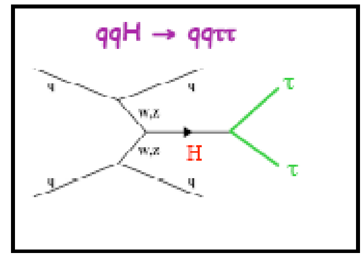
Remarks:

Each channel contributes ~ 2σ to total significance → observation of all channels important to extract convincing signal in first year(s)

The 3 channels are complementary → robustness:







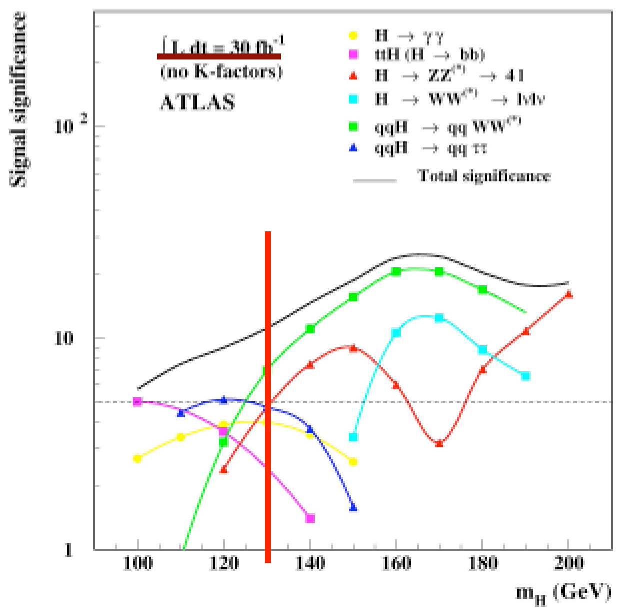
- different production and decay modes
- different backgrounds
- different detector/performance requirements:
  - -- ECAL crucial for $H \rightarrow \gamma\gamma$ (in particular response uniformity) : $\sigma/m \sim 1\%$ needed
  - -- b-tagging crucial for ttH : 4 b-tagged jets needed to reduce combinatorics
  - -- efficient jet reconstruction over $|\eta| < 5$ crucial for $qqH \rightarrow qq\tau\tau$: forward jet tag and central jet veto needed against background

Note : -- all require "low" trigger thresholds

E.g. ttH analysis cuts : p_T (l) > 20 GeV, p_T (jets) > 15-30 GeV

-- all require very good understanding (1-10%) of backgrounds

SM Higgs with mass below 200 GeV



$m_H \sim 130$ GeV 10 fb^{-1}

λ= e,μ

	$H \to \gamma\gamma$	$qqH \to qq\tau\tau$ (ll + l-had)	$H \to 4l$	$qqH \to qqWW$
S B	120 3400	~ 8 ~ 6	~ 5 < 1	18 15
$S/\sqrt{B}$	2.0	~ 2.7	2.8	3.9

↑ K – factor = 2 not included ↑

total $S/\sqrt{B} \approx 6$

- 4 complementary channels for physics and for detector requirements
- $S/\sqrt{B}$ < 3 per channel (except qqWW counting channel) → observation of all channels important in first year
- $H \to 4l$ low rate but very clean: small background, narrow mass peak

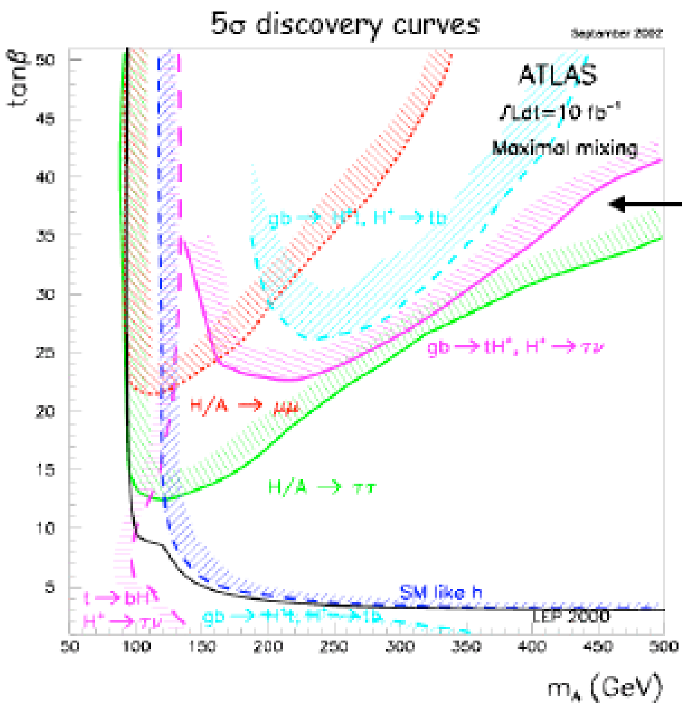
  Detector requirements:

  -- ≥ 90% e, μ efficiency at low p_T (analysis cuts : $p_T^{1,2,3,4}$ > 20, 20, 7, 7, GeV)

  → in particular low di-lepton LVL1 thresholds

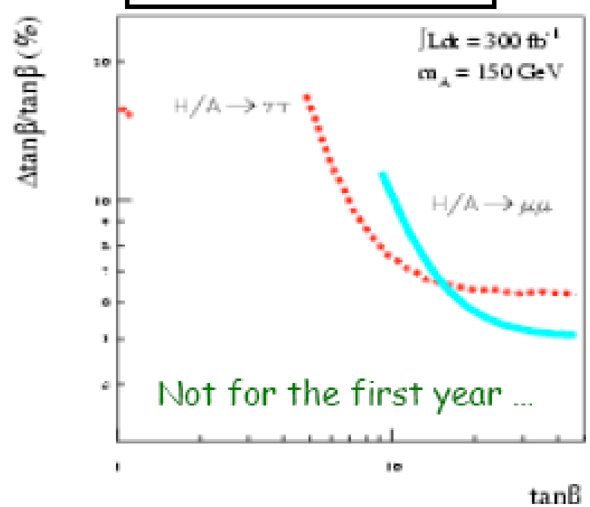
MSSM Higgs bosons h,H,A,$H^{\pm}$

m_h < 135 GeV
$m_A = m_H = m_{H\pm}$ at large m_A



-- A, H, H± cross-section ~ tg²β
-- best sensitivity from A/H → ττ, H± → τν
(not easy the first year ...)
-- A/H → μμ experimentally easier
(esp. at the beginning)

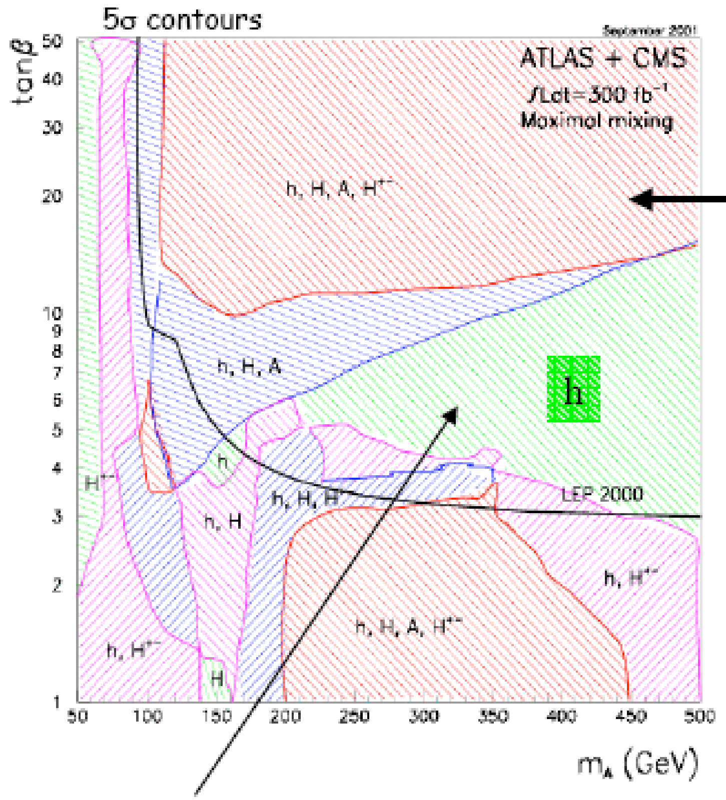
Measurement of tg β



- Large variety of channels and signatures accessible
- bbA/H → 4b is more difficult than at the Tevatron (because of huge QCD background)

MSSM Higgs bosons h,H,A,H$^{\pm}$

$m_h < 135$ GeV , $m_A \approx m_H \approx m_{H\pm}$



H, A → μμ, ττ
H$^{\pm}$ → τν , tb

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

Assuming decays to SM particles only

Here only h (SM - like) observable at LHC, unless A, H, H$^{\pm}$ → SUSY

→ LHC may miss part of the MSSM Higgs spectrum

Observation of full spectrum may require high-E ($\sqrt{s} \approx 2$ TeV) Lepton Collider

Conclusions

- LHC has potential for major discoveries already in the first year (months ?) of operation
  Event statistics : 1 day at LHC at 10^{33} ≡ 1 year at previous machines for SM processes
  SUSY may be discovered "quickly", light Higgs more difficult … and what about surprises ?

- Machine luminosity performance will be the crucial issue in first 1-2 years

- Experiments: lot of emphasis on test beams and on construction quality checks
  → results indicate that detectors "as built" should give good starting-point performance.

- However: lot of data (and time …) will be needed at the beginning to:
  -- commission the detector and trigger in situ (and the software !!! …)
  -- reach the performance needed to optimize the physics potential
  -- understand standard physics at $\sqrt{s}$ = 14 TeV and compare to MC predictions
  [Tevatron (and HERA) data crucial to speed up this phase …]
  -- measure backgrounds to possible New Physics (with redundancy from several samples …)

- Efficient/robust commissioning with physics data in the various phases (cosmics, one-beam period, first collisions, …), as well as solid preparation of MC tools, are our next challenges.
  Both are crucial to reach quickly the "discovery-mode" and extract a convincing "early" signal