Preparing for physics at the LHC ....

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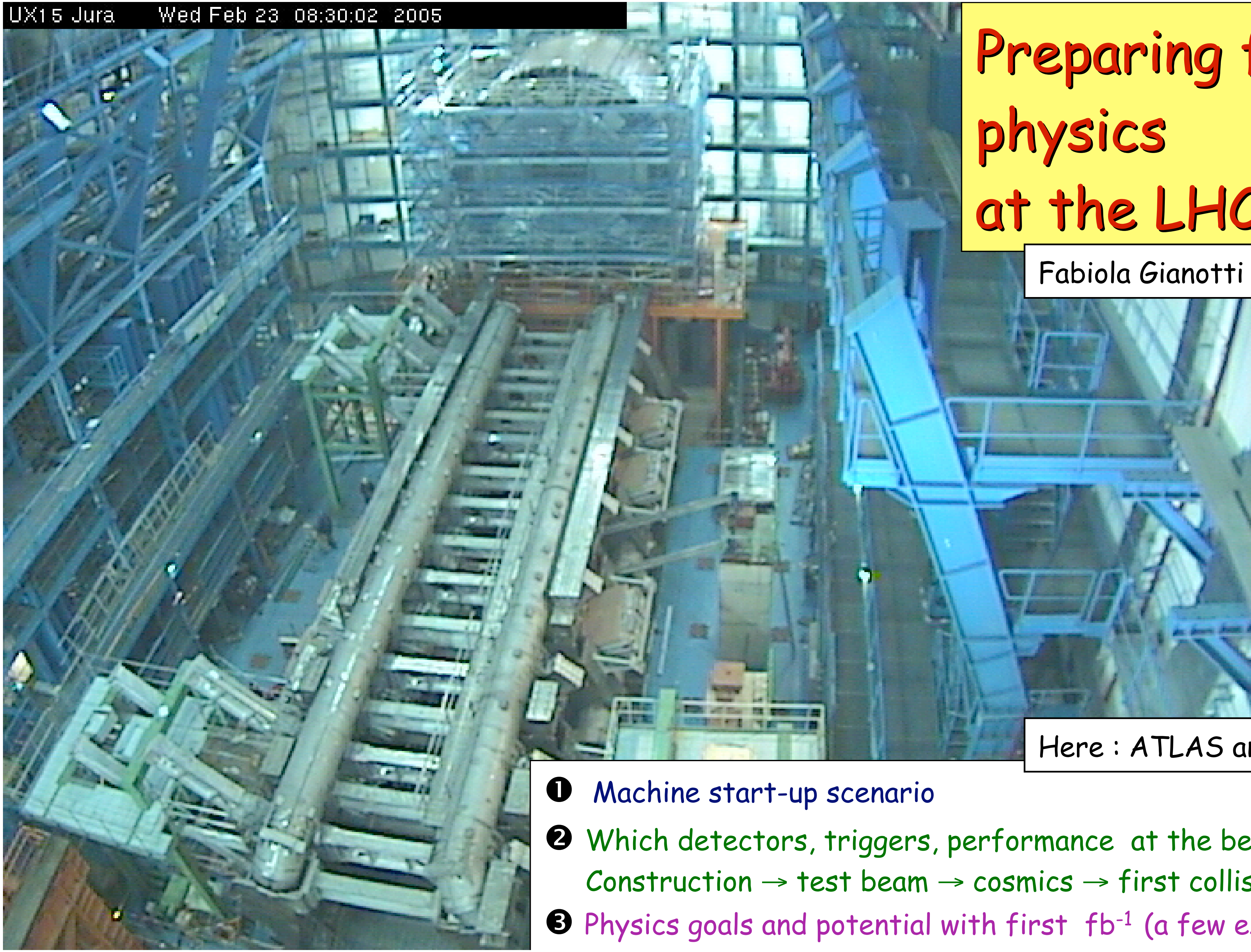


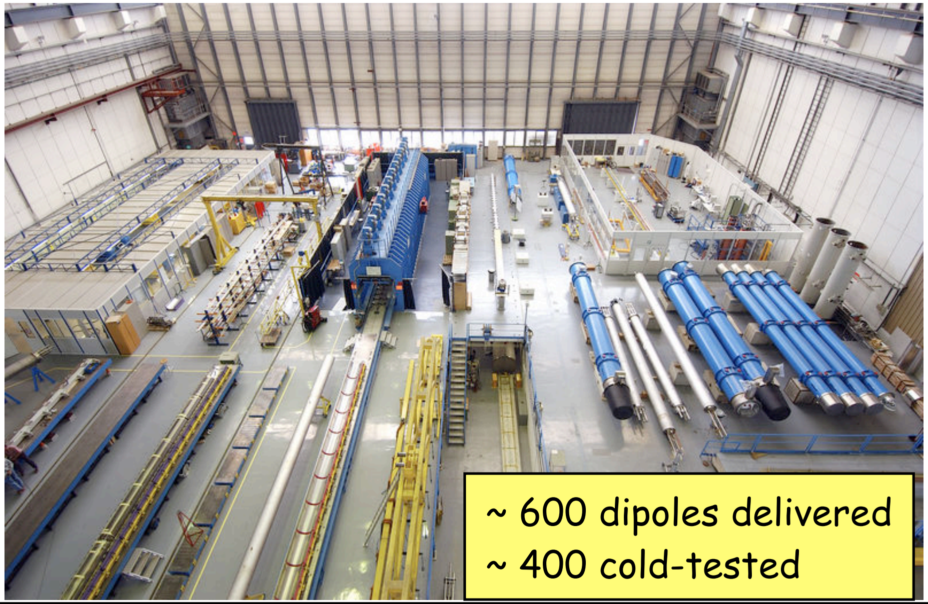
Here : ATLAS and CMS

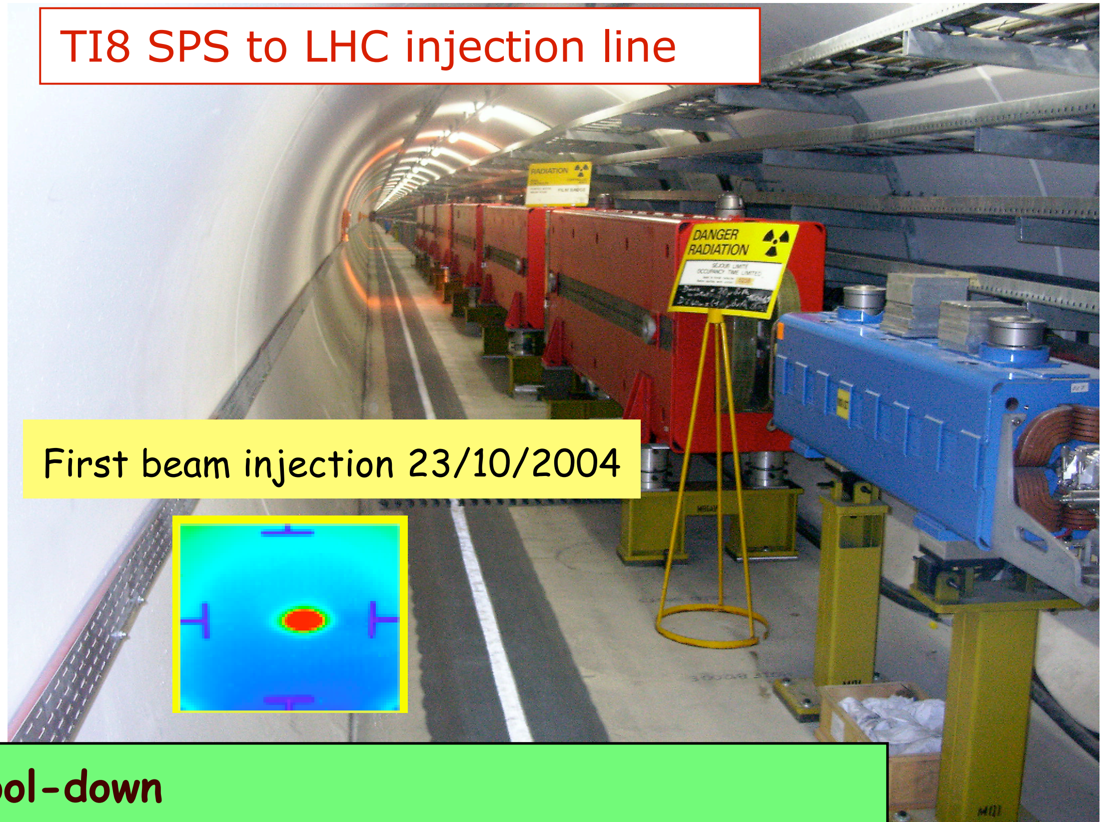
❶ Machine start-up scenario

❷ Which detectors, triggers, performance at the beginning ?
Construction → test beam → cosmics → first collisions

❸ Physics goals and potential with first fb^{-1} (a few examples)

❶ Machine start-up scenario





~ 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

-- 43 + 43 bunches, $L = 6 \times 10^{31}$ cm^{-2} s^{-1}
(possible scenario; tuning of machine parameters)

-- 936+936 bunches (bunch spacing 75 ns → 25 ns asap), $L > 5 \times 10^{32}$

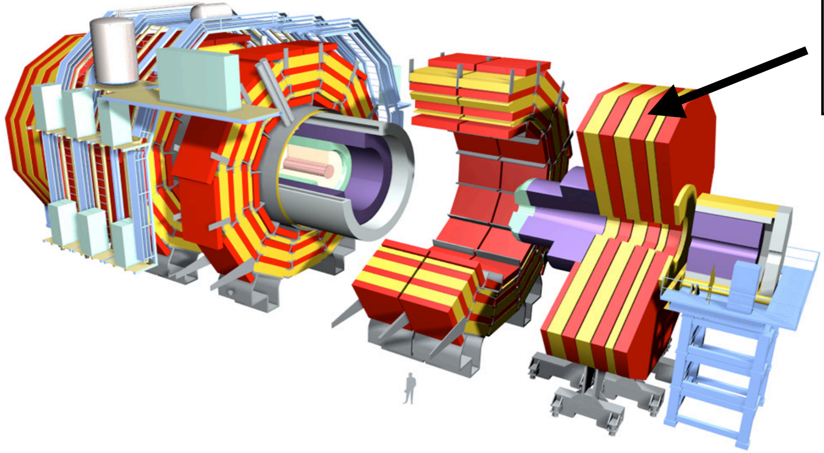
} ~ 4 months

-- 2-3 month shut-down ?

-- **2808 + 2808 bunches (bunch spacing 25 ns), L up to $\sim 2 \times 10^{33}$ (first year goal)**
→ ~ 7 months of physics run

A lot of uncertainties in this plan → here assume 1 - 10 fb^{-1} /expt on tape by end 2008

❷ Which detectors the first year ?

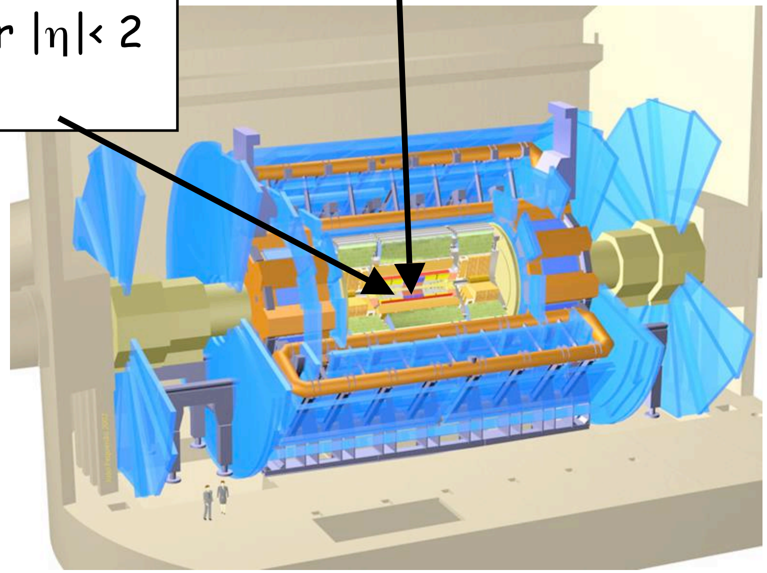


RPC over $|\eta|<1.6$ (instead of $|\eta|< 2.1$)
4^{th} layer of end-cap chambers missing

Pixels and end-cap ECAL installed during first shut-down

2 pixel layers/disks instead of 3 ?

TRT acceptance over $|\eta|< 2$ (instead of $|\eta|< 2.4$)

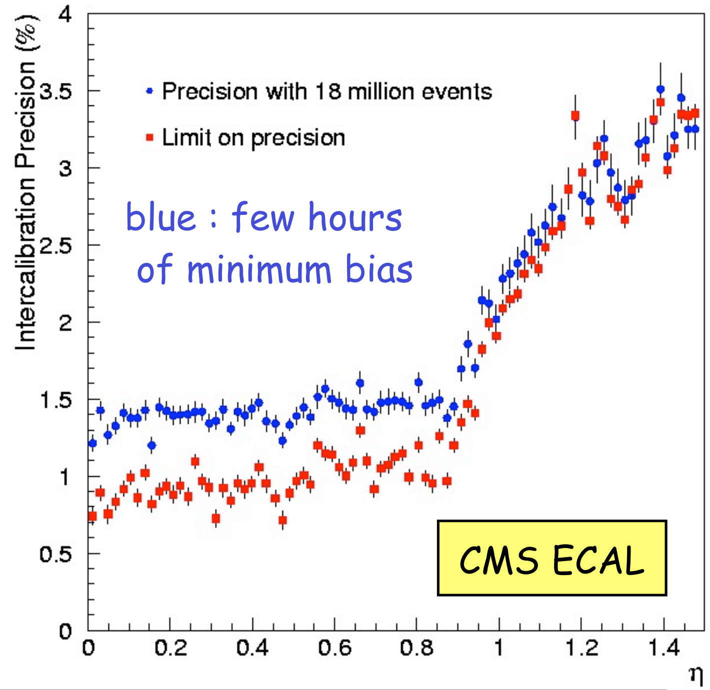


Both experiments:
deferrals of high-level Trigger/DAQ processors
→ LVL1 output rate limited to
~ 50 kHz CMS (instead of 100 kHz)
~ 40 kHz ATLAS (instead of 75 kHz)

Impact on physics visible but acceptable
Main loss : B-physics programme strongly reduced (single μ threshold $p_T > 14$-20 GeV)

Which detector performance on day one ?

A few examples and educated guesses
based on test-beam results and simulation studies

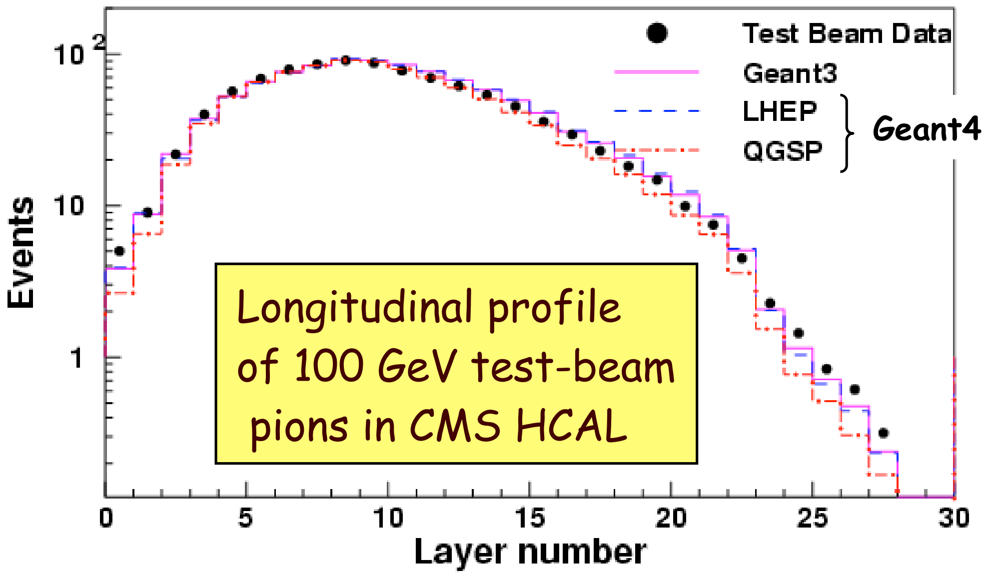


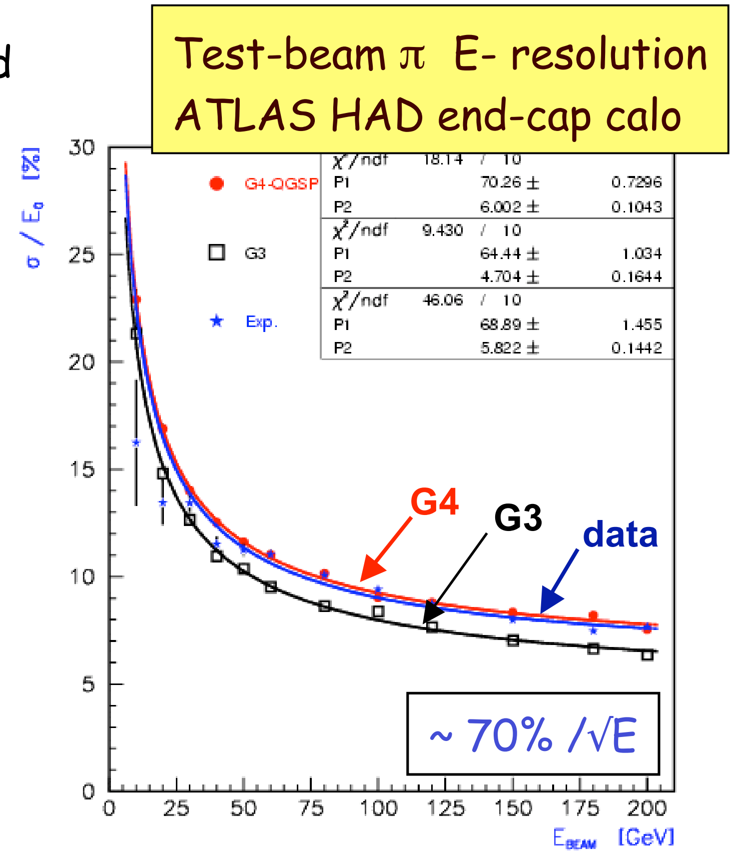
	Expected performance day 1	Physics samples to improve (examples)
ECAL uniformity e/γ scale	~ 1% (ATLAS), 4% (CMS) 1-2 % ?	Minimum-bias, $Z \rightarrow ee$ $Z \rightarrow ee$
HCAL uniformity Jet scale	2-3 % < 10%	Single pions, QCD jets $Z (\rightarrow ll)$ +1j, $W \rightarrow jj$ in tt events
Tracking alignment	20-500 μm in Rϕ ?	Generic tracks, isolated μ , $Z \rightarrow \mu\mu$

Ultimate statistical precision achievable after few days of operation. Then face systematics ....
E.g. : tracker alignment : 100 μm (1 month) $\rightarrow$ 20μm (4 months) $\rightarrow$ 5 μm (1 year) ?

Steps to achieve the detector goal performance

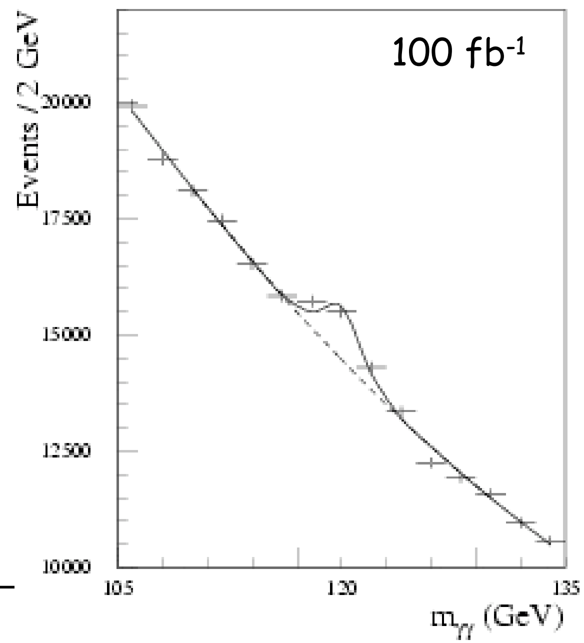
- Stringent construction requirements and quality controls (piece by piece …)
- Equipped with redundant calibration/alignment hardware systems
- Prototypes and part of final modules extensively tested with test beams (allows also validation of Geant4 simulation)
- In situ calibration at the collider (accounts for material, global detector, B-field, long-range mis-calibrations and mis-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→ ll, tt, etc.)





Example of this procedure : ATLAS electromagnetic calorimeter

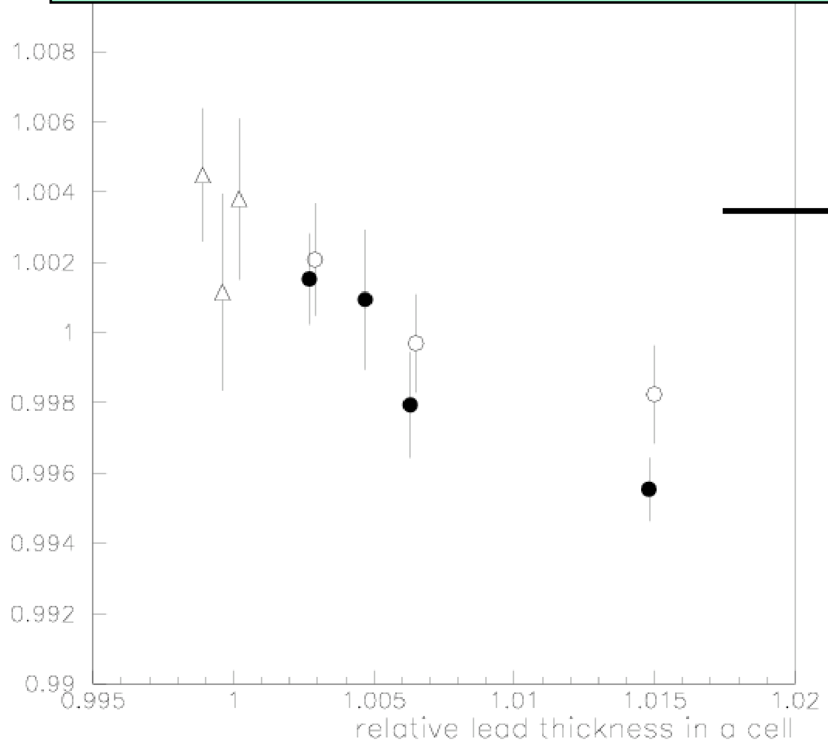
Pb-liquid argon sampling calorimeter
with Accordion shape, covering $|\eta| < 2.5$



$H \rightarrow \gamma\gamma$: to observe signal peak on top of huge $\gamma\gamma$ background need mass resolution of ~ 1% → response uniformity (i.e. total constant term of energy resolution) ≤ 0.7% over $|\eta| < 2.5$

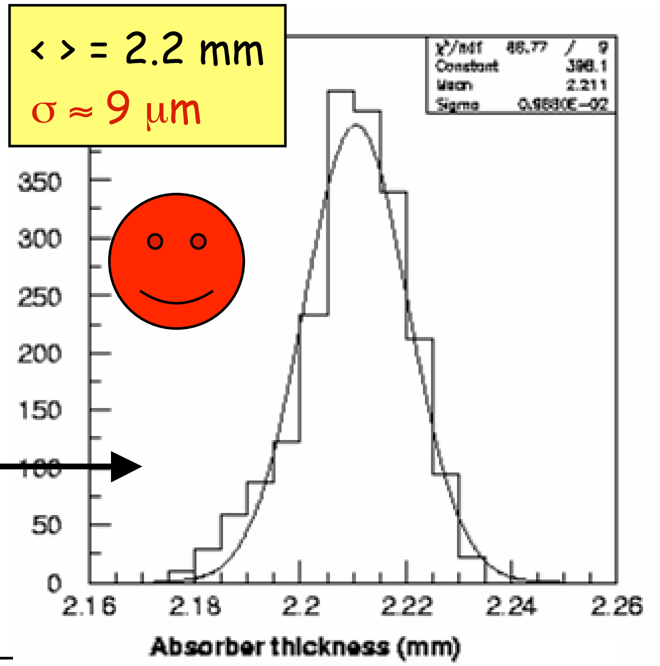
① Construction phase (e.g. mechanical tolerances):

287 GeV electron response variation with Pb thickness from '93 test-beam data



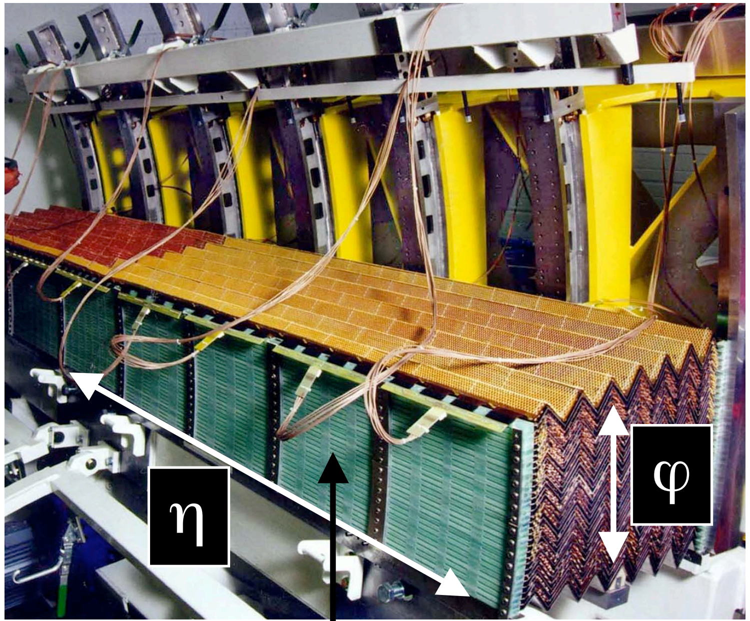
1% more lead in a cell → 0.7% response drop
→ to keep response uniform to 0.2-0.3%, thickness of Pb plates must be uniform to 0.5% (~ 10 μm)

Thickness of all 1536 absorber plates (1.5m long, 0.5m wide) for end-cap calorimeter measured with ultrasounds during construction

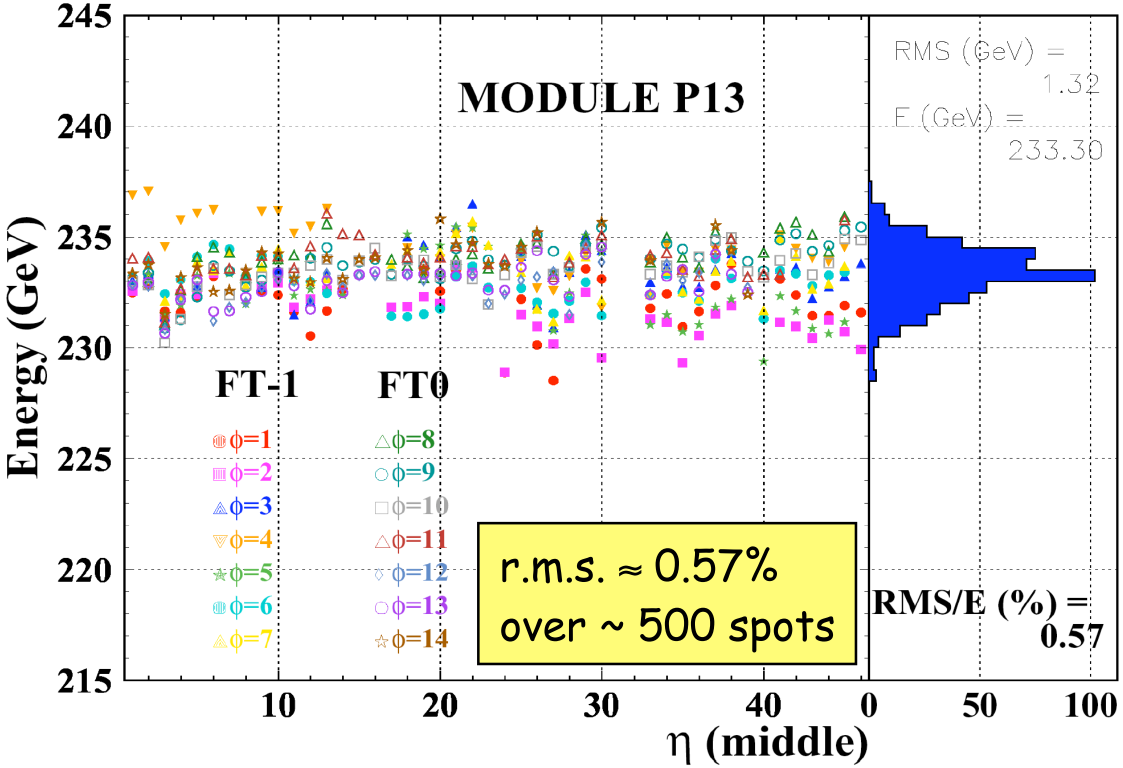


② Beam tests of 4 (out of 32) barrel modules and 3 (out of 16) end-cap modules:

1 barrel module:
$\Delta\eta \times \Delta\varphi = 1.4 \times 0.4$
≡~ 3000 channels

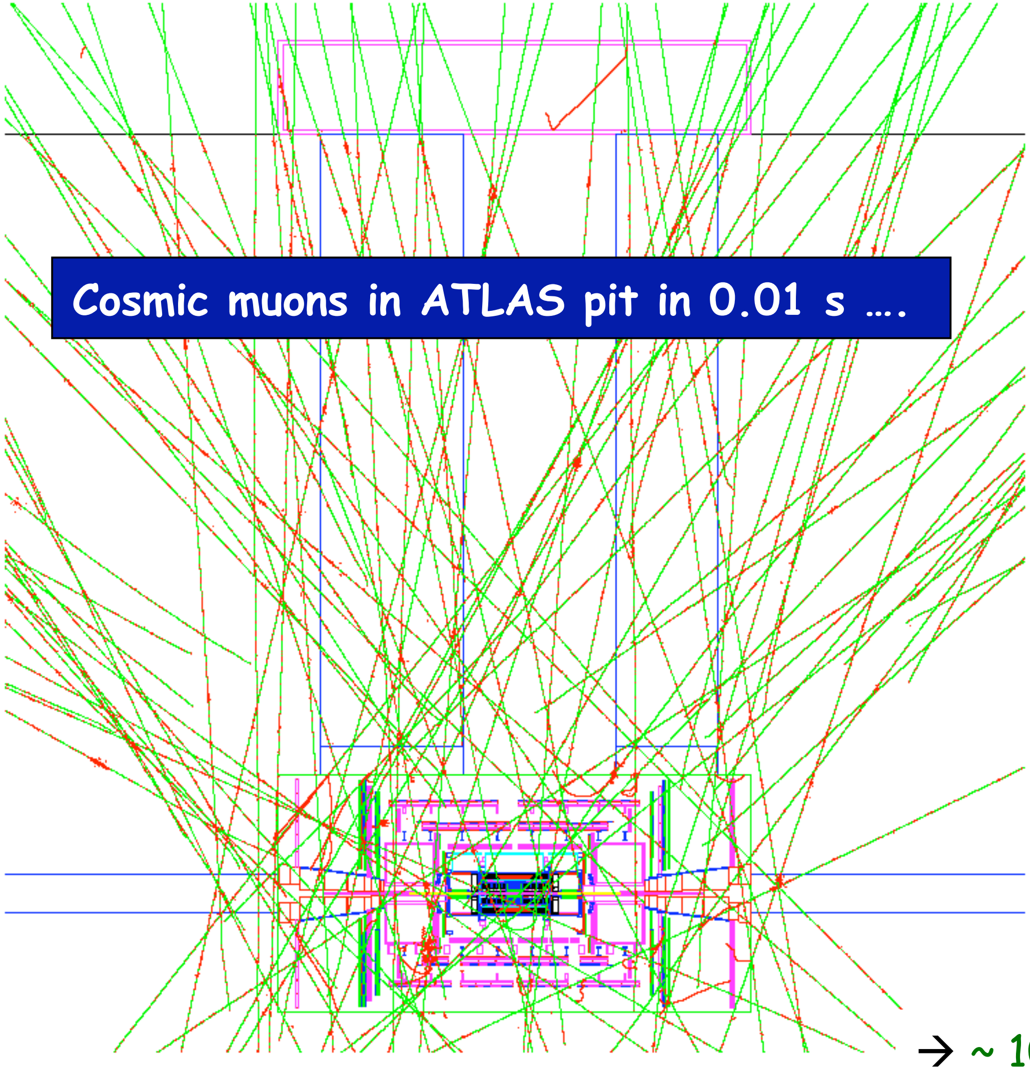


Scan of a barrel module with 245 GeV e^-



Uniformity over "units" of size
$\Delta\eta \times \Delta\varphi = 0.2 \times 0.4$: ~ 0.5%
400 such units over the full ECAL

③ Check calibration with cosmic muons:

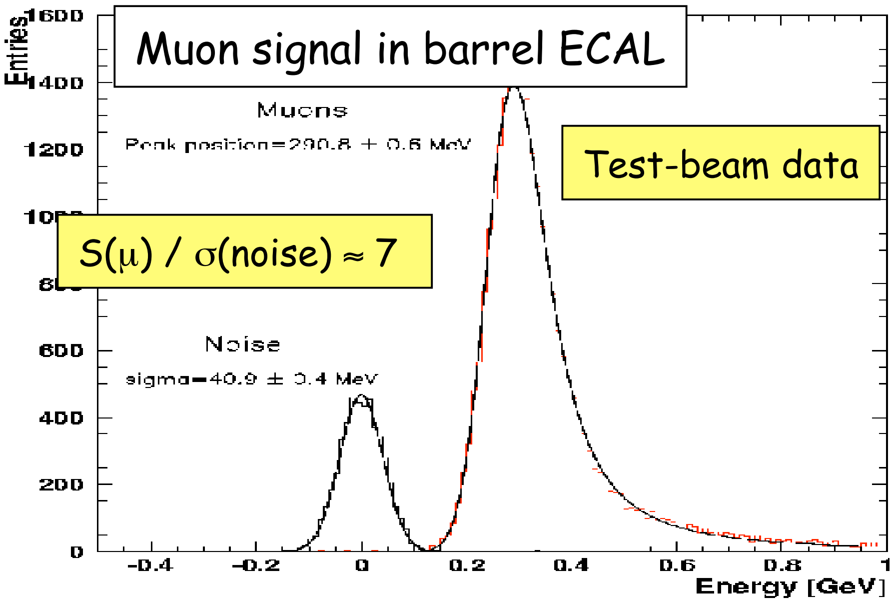


From full simulation of ATLAS (including cavern, overburden, surface buildings) + measurements with scintillators in the cavern:

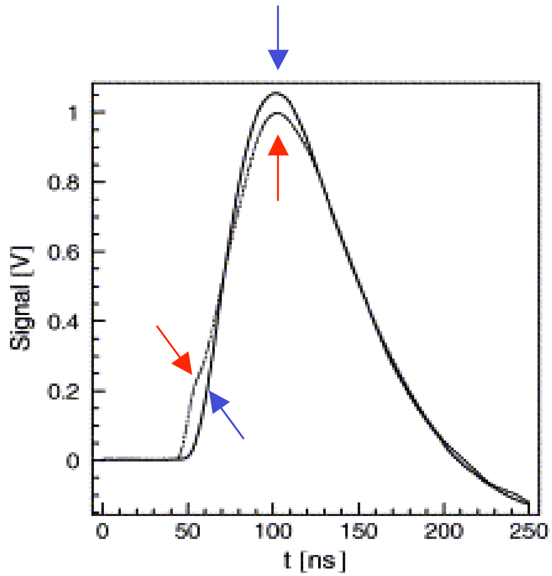
Through-going muons (hits in ID + top and bottom muon chambers)	~ 25 Hz
Pass by origin ($\|z\| < 60$ cm, $R < 20$ cm, hits in ID)	~ 0.5 Hz
Useful for ECAL calibration ($\|z\| < 30$ cm, $E_{cell} > 100$ MeV, ~ 90^0)	~ 0.5 Hz

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

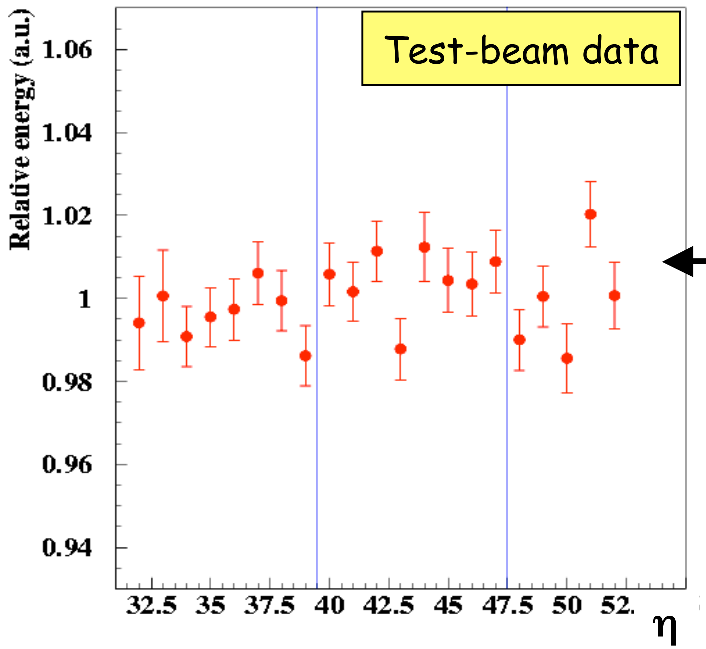
→ enough for initial detector shake-down (catalog problems, gain operation experience, some alignment/calibration, detector synchronization, ...)



Precision of ECAL readout calibration system : 0.25%.
But : η-dependent differences between calibration and physics signals



→ can be checked with cosmic muons



From studies with test-beam muons:
can check (and correct) calorimeter response variation vs η to 0.5% in < 3 months of cosmics runs

Note : not at level of ultimate calibration uniformity (~ 0.25%) but already a good starting point

④ First collisions : calibration with $Z \rightarrow ee$ events ← rate ~ 1 Hz at 10^{33}, ~ no background, allows ECAL standalone calibration

constant term

$c_{tot} = c_L \oplus c_{LR}$

$c_L \approx 0.5\%$ demonstrated at the test-beam over units $\Delta\eta \times \Delta\varphi = 0.2 \times 0.4$

$c_{LR} \equiv$ long-range response non-uniformities from unit to unit (400 total)

(module-to-module variations, different upstream material, etc.)

Use $Z \rightarrow ee$ events and Z-mass constraint to correct long-range non-uniformities.

From full simulation : ~ 250 $e^{\pm}$ / unit needed to achieve $c_{LR} \leq 0.4\%$ → $c_{tot} = 0.5\% \oplus 0.4\% \leq 0.7\%$

~ 10^5 $Z \rightarrow ee$ events (few days of data taking at 10^{33})

Nevertheless, let's consider the worst (unrealistic ?) scenario : no corrections applied

- c_L = 1.3 % measured "on-line" non-uniformity of individual modules
- c_{LR} = 1.5 % no calibration with $Z \rightarrow ee$

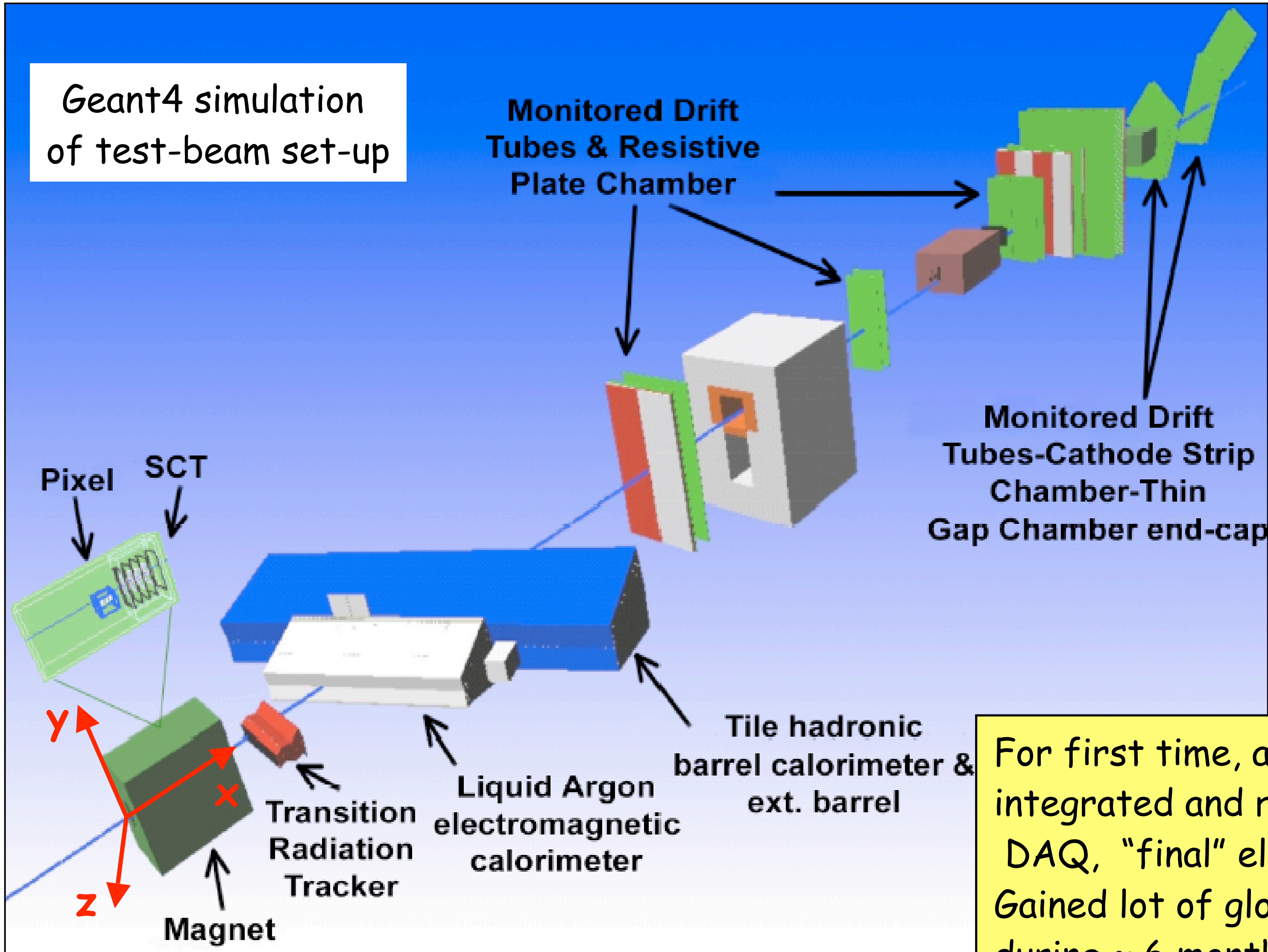
→ $c_{tot} \approx 2\%$

conservative : implies very poor knowledge of upstream material (to factor ~2)

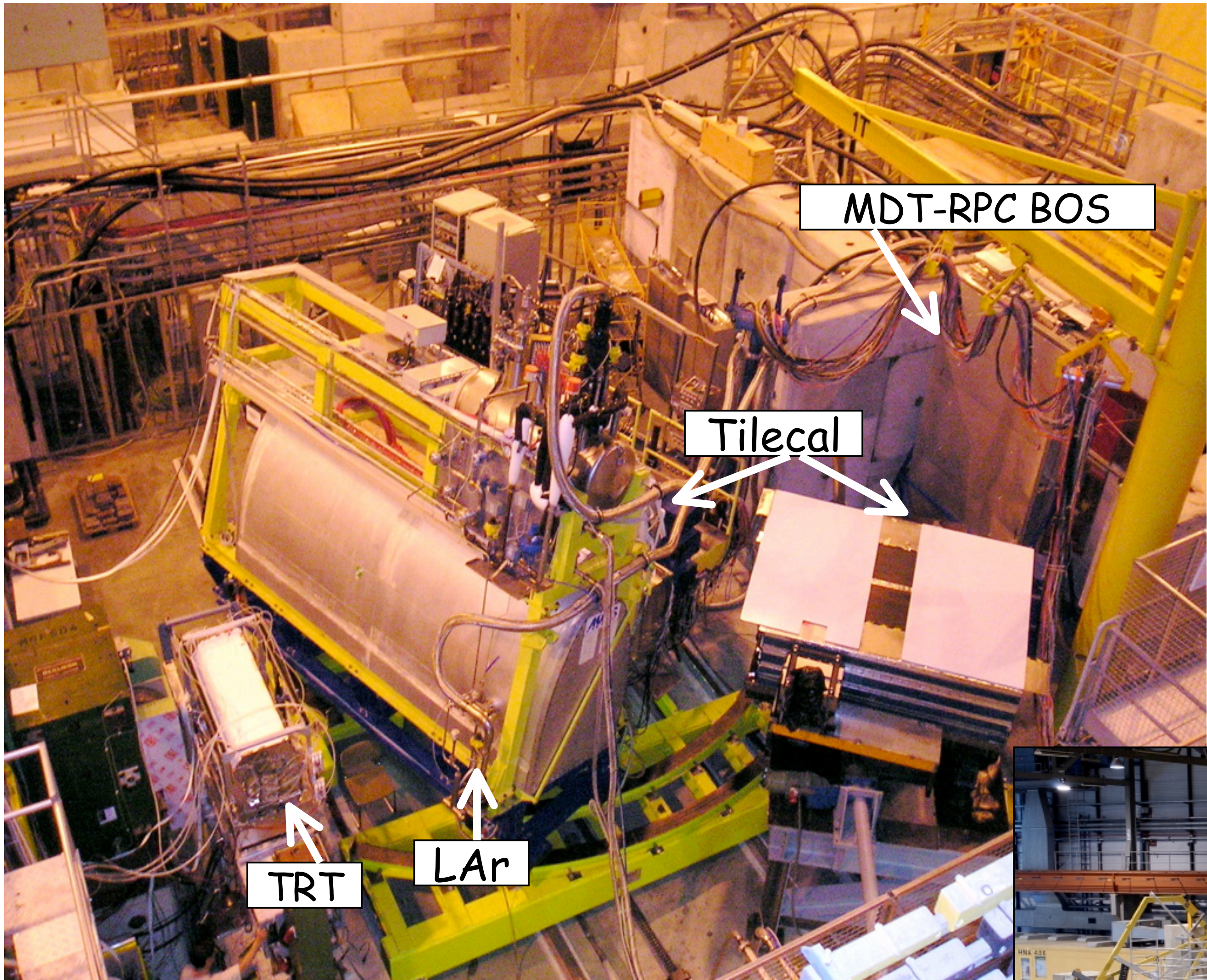
$H \rightarrow \gamma\gamma$ significance m_H~ 115 GeV degraded by ~ 25%
→ need 50% more L for discovery

Towards the complete experiment : ATLAS combined test beam in 2004

Full "vertical slice" of ATLAS tested on CERN H8 beam line May-November 2004



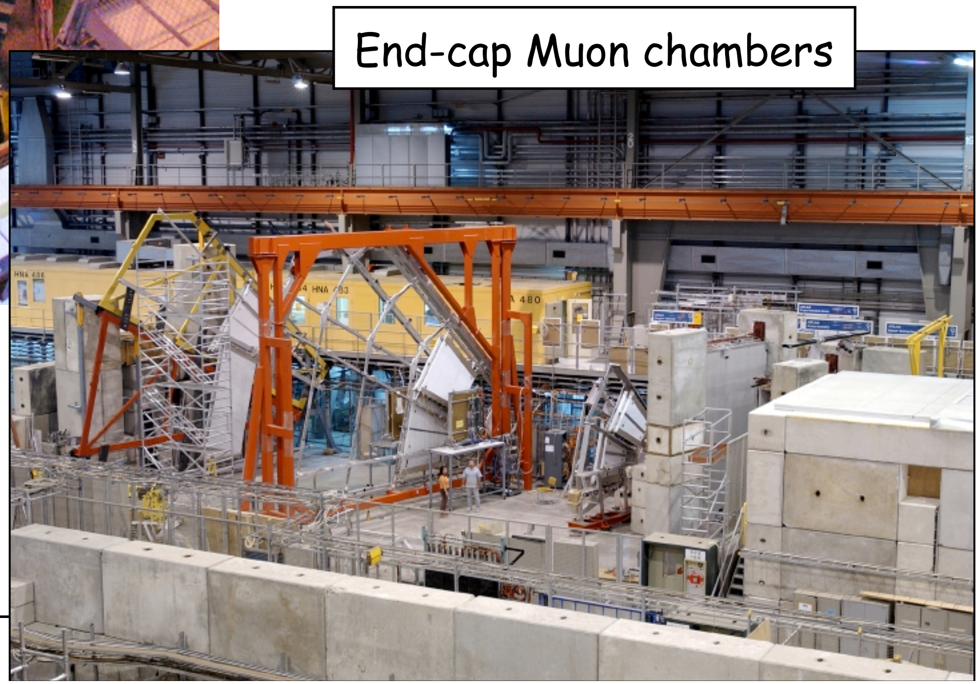
For first time, all ATLAS sub-detectors integrated and run together with common DAQ, "final" electronics, slow-control, etc. Gained lot of global operation experience during ~ 6 month run. Common ATLAS software used to analyze the data

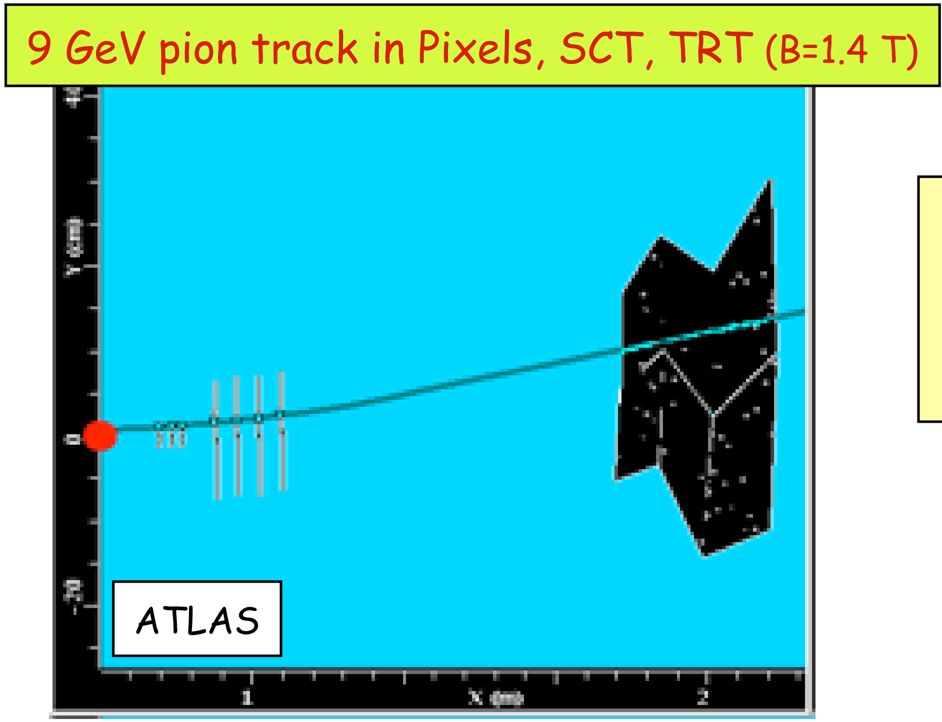


~ 90 million events collected
~ 4.5 TB of data:

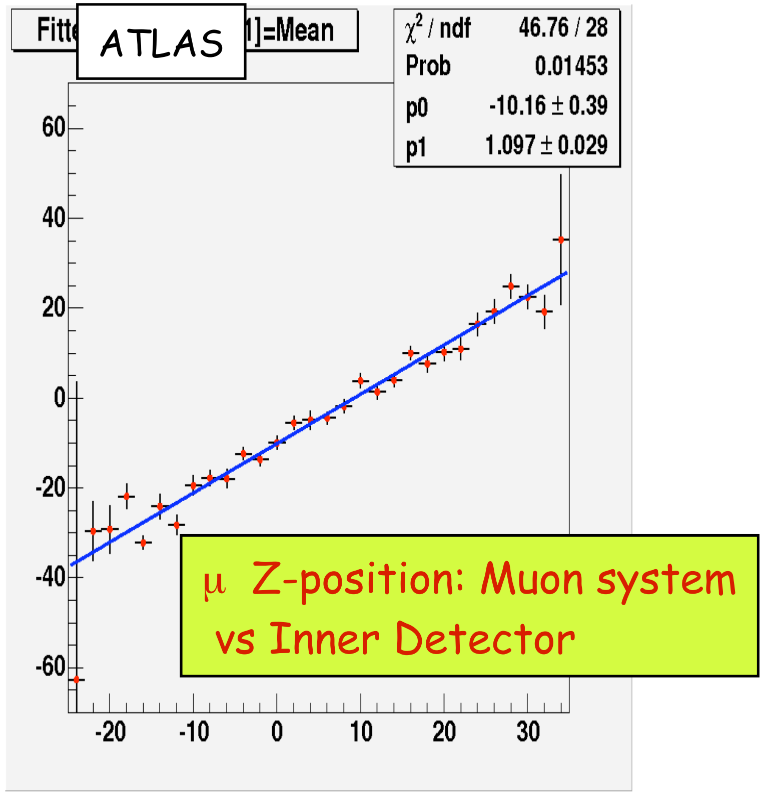
$e^{\pm}$, $\pi^{\pm}$	1 → 250 GeV
$\mu^{\pm}$, $\pi^{\pm}$, p	up to 350 GeV
γ	~ 30 GeV

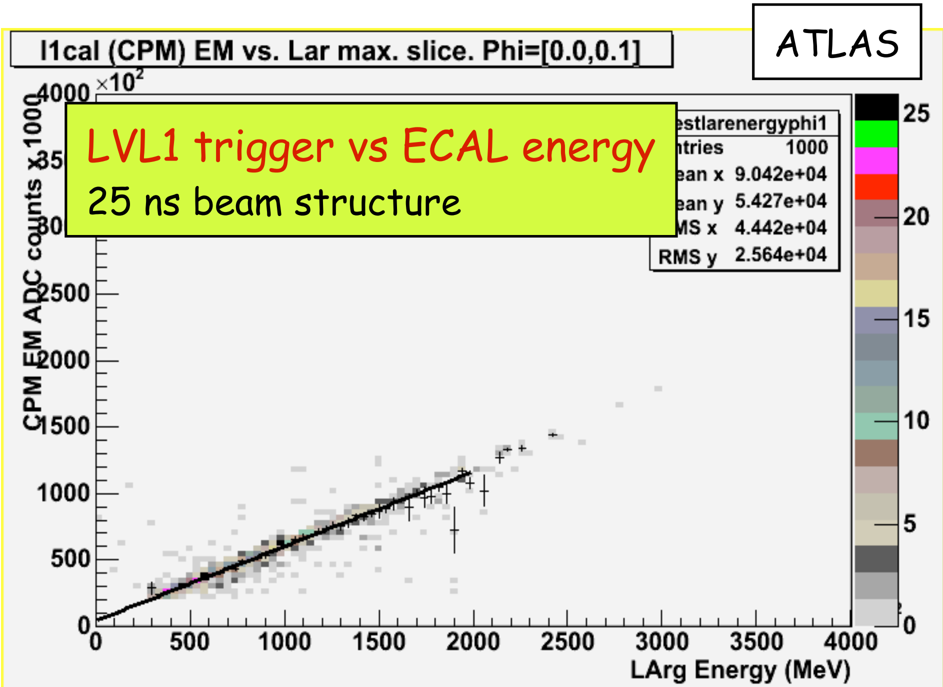
B-field = 0 → 1.4 T

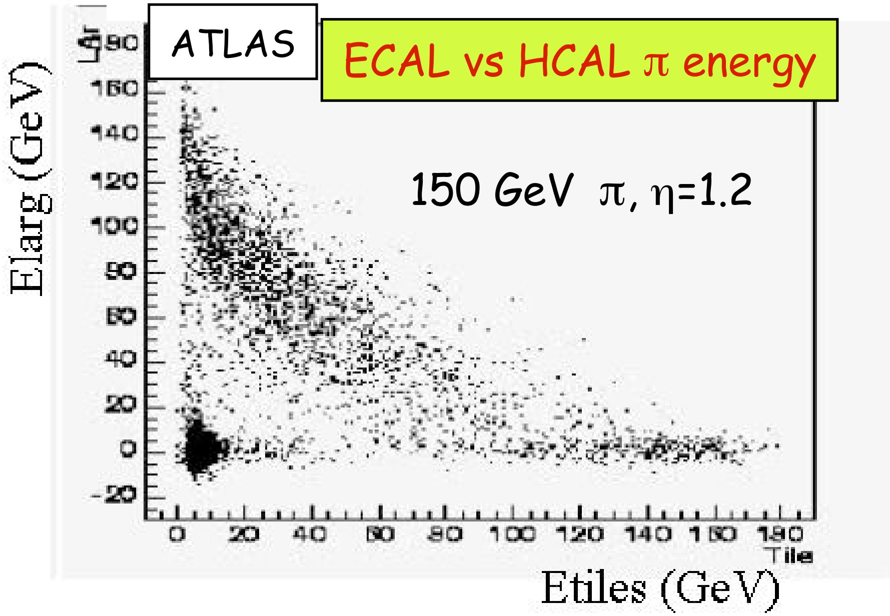




A few very preliminary results







❸ Physics goals and potential in the first year (a few examples ….)

Channels (examples …)	Events to tape for 10 fb^{-1} (per experiment)
$W \to \mu \nu$	7×10^7
$Z \to \mu \mu$	1.1×10^7
$tt \to W b W b \to \mu \nu + X$	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 PB of data per year per experiment → challenging for software and computing (esp. at the beginning …)

assuming 1% of trigger bandwidth

➡ Already in first year, large statistics expected from:
- -- known SM processes → understand detector and physics at $\sqrt{s}$ = 14 TeV
- -- several New Physics scenarios

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

Goal # 1

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

e.g. - $Z \rightarrow ee, \mu\mu$ tracker, ECAL, Muon chambers calibration and alignment, etc.

- $tt \rightarrow bl\nu\ bjj$ 10^3 evts/day after cuts → jet scale from W→jj, b-tag perf., etc.

Understand basic SM physics at $\sqrt{s}$ = 14 TeV → first checks of Monte Carlos

(hopefully well understood at Tevatron and HERA)

e.g. - measure cross-sections for e.g. minimum bias, W, Z, tt, QCD jets (to ~ 10-20 %), look at basic event features, first constraints of PDFs, etc.

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

Note : statistical error negligible after few weeks run

Goal # 2

Prepare the road to discovery:

-- measure backgrounds to New Physics : e.g. tt and W/Z+ jets (omnipresent …)

-- look at specific "control samples" for the individual channels:

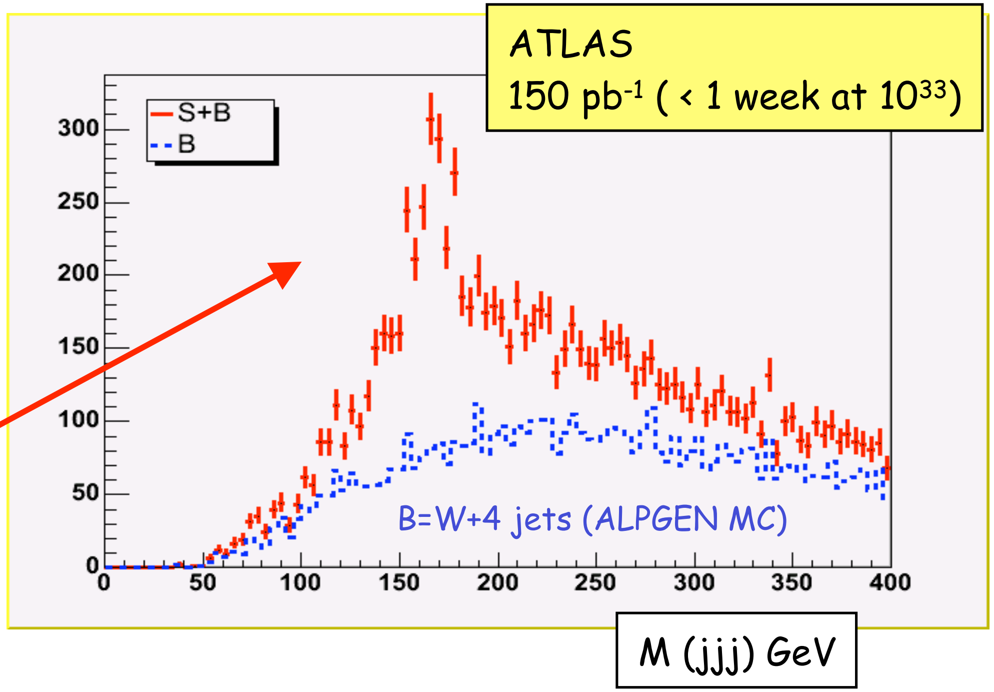
e.g. ttjj with $j \neq b$ "calibrates" ttbb irreducible background to ttH → ttbb

Goal # 3

Look for New Physics potentially accessible in first year (e.g. SUSY, some Higgs ? …)

Example of initial measurement : top signal and top mass

- Use gold-plated $t\bar{t} \rightarrow bW\ bW \rightarrow bl\nu\ bjj$ channel
- 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)
- Plot invariant mass of 3 jets with highest p_T

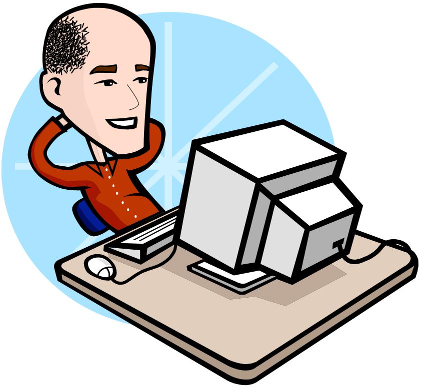


Time	Events at 10^{33}	Stat. error δM_{top} (GeV)	Stat. error $\delta\sigma/\sigma$
1 year	3×10^5	0.1	0.2%
1 month	7×10^4	0.2	0.4%
1 week	2×10^3	0.4	2.5%

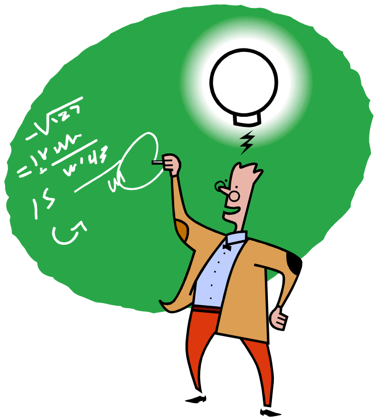
- top signal visible in few days also with simple selection and no b-tagging
- cross-section to ~ 20% (10% from luminosity)
- top mass to ~7 GeV (assuming b-jet scale to 10%)
- get feedback on detector performance :
  m_{top} wrong → jet scale ?
  gold-plated sample to commission b-tagging

What about early discoveries ?

An easy case : a new resonance decaying into e+e-, e.g. a $Z' \rightarrow ee$ of mass 1-2 TeV



An intermediate case : SUSY



A difficult case : a light Higgs (m ~ 115 GeV)

An "easy case" : Z' of mass 1-2 TeV with SM-like couplings

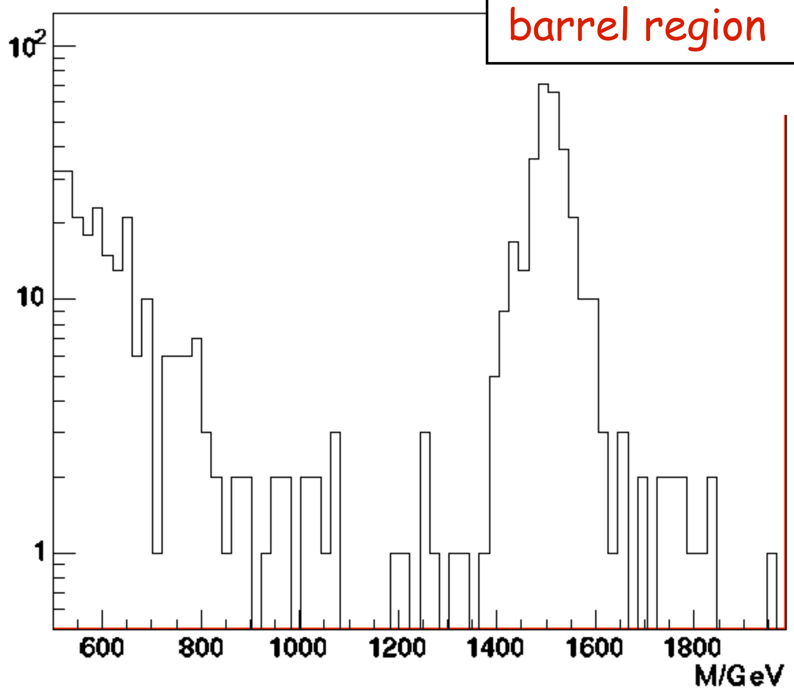
$Z' \to ee$, SSM

Mass	Expected events for 10 fb^{-1} (after all cuts)	$\int L\,dt$ needed for discovery (corresponds to 10 observed evts)
1 TeV	~ 1600	~ 70 pb^{-1}
1.5 TeV	~ 300	~ 300 pb^{-1}
2 TeV	~ 70	~ 1.5 fb^{-1}

- signal rate with $\int L\,dt$ ~ 0.1-1 fb^{-1} large enough up to m ≈ 2 TeV if "reasonable" Z'ee couplings
- dominant Drell-Yan background small (< 15 events in the region 1400-1600 GeV, 10 fb^{-1})
- signal as mass peak on top of background

$Z \to ll$ +jet samples and DY needed for E-calibration and determination of lepton efficiency

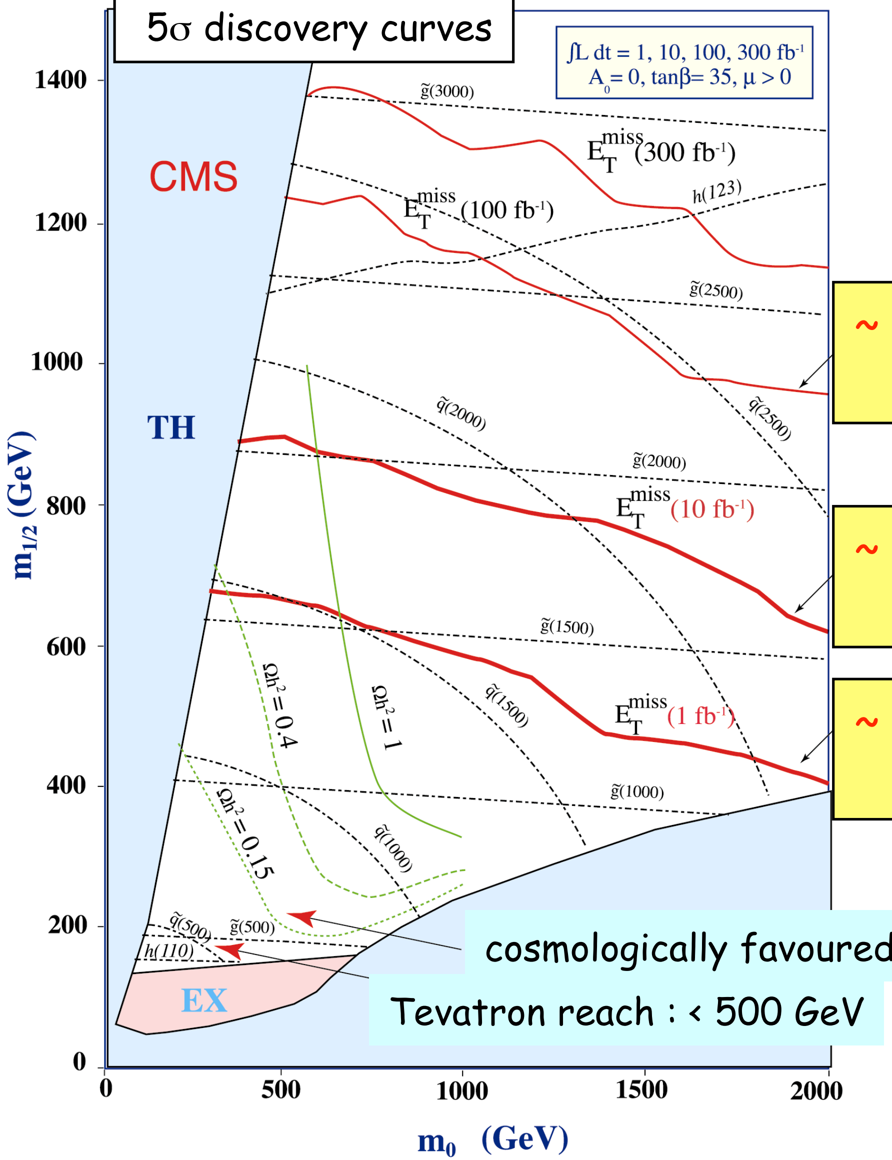
ATLAS, 10 fb^{-1}, barrel region



An "intermediate case" : SUPERSYMMETRY

Large $\tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ cross-section → ≈ 100 events/day at 10^{33} for $m(\tilde{q}, \tilde{g}) \sim 1$ TeV
Spectacular signatures → SUSY could be found quickly

5σ discovery curves

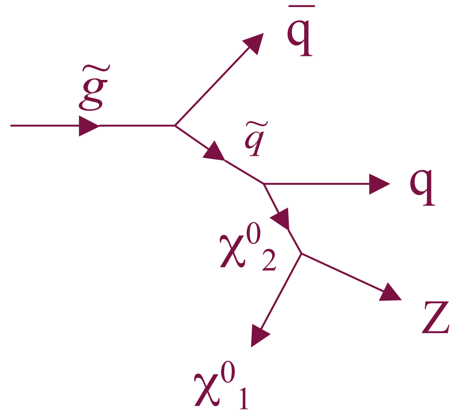


Using multijet + E_T^{miss} (most powerful and model-independent signature if R-parity conserved)

~ one year at 10^{34}: up to ~2.5 TeV

~ one year at 10^{33} : up to ~2 TeV

~ one month at 10^{33} : up to ~1.5 TeV

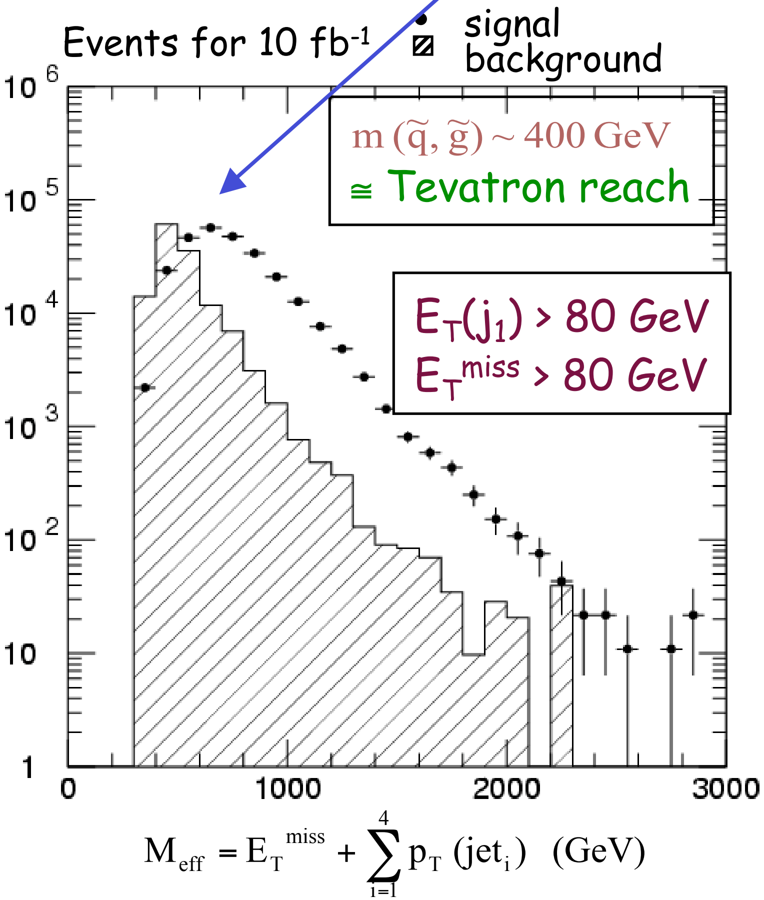


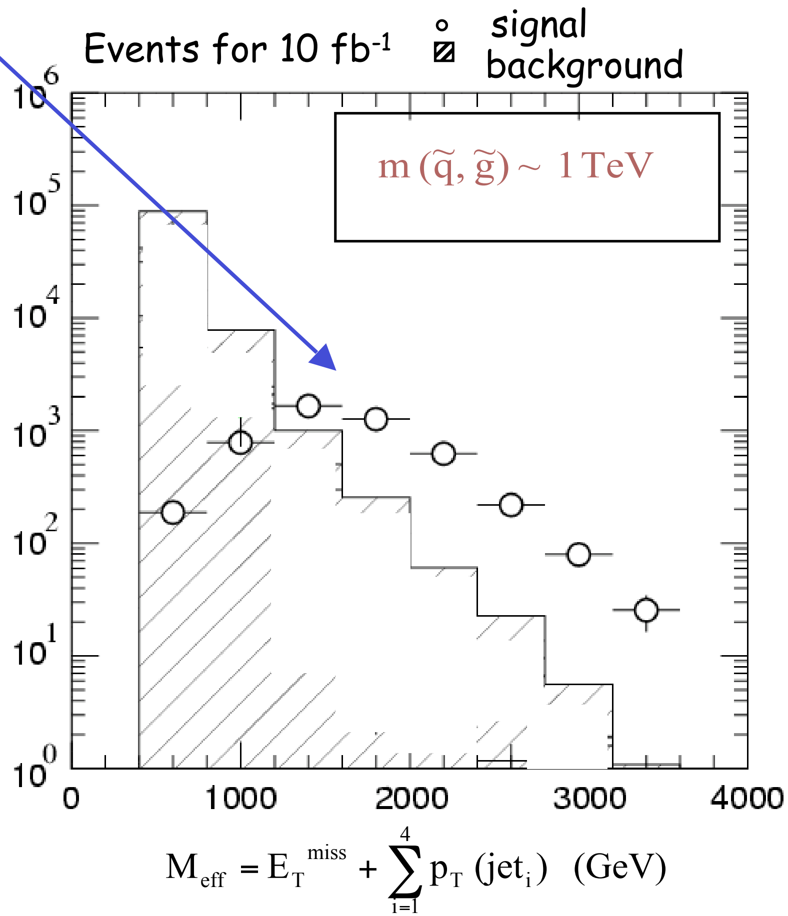
cosmologically favoured region

Tevatron reach : < 500 GeV

Measurement of sparticle masses likely requires > 1 year. However …

Peak position correlated to $M_{SUSY} \equiv \min(m(\tilde{q}), m(\tilde{g}))$





ATLAS

From M_{eff} peak → first/fast measurement of SUSY mass scale to ≈ 20% (10 fb^{-1}, mSUGRA)

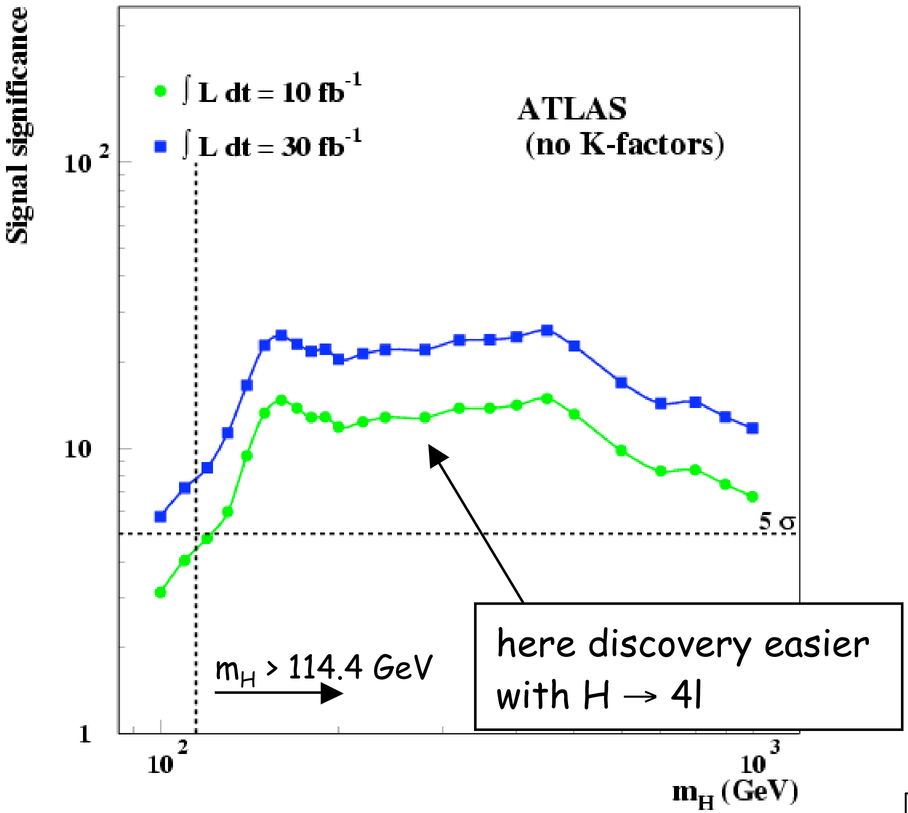
Detector/performance requirements:

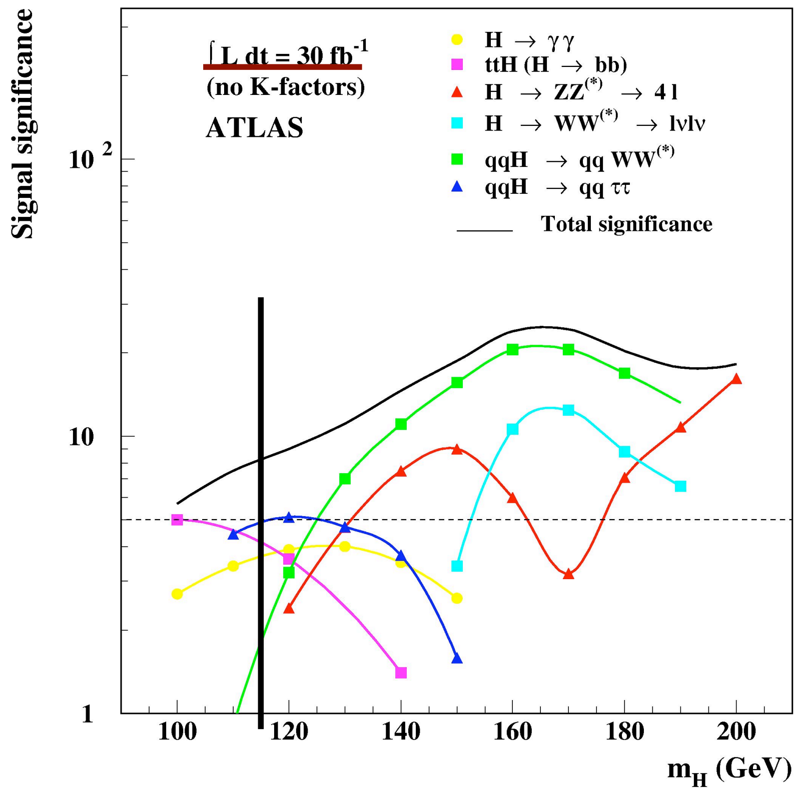
-- quality of E_T^{miss} measurement (calorimeter inter-calibration, cracks)

→ use control samples (e.g. $Z \to ll$ +jets)

-- "low" Jet / E_T^{miss} trigger thresholds for low masses at overlap with Tevatron region (~400 GeV)

A difficult case: a light Higgs ($m_H \sim 115$ GeV) ...





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

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

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

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

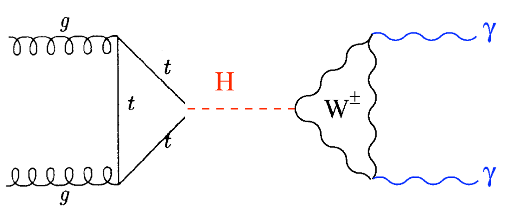
Full GEANT simulation, simple cut-based analyses

Remarks:

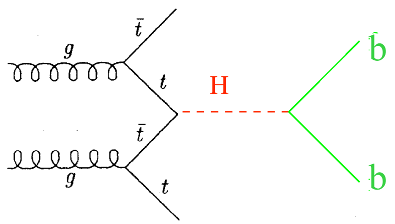
Each channel contributes ~ 2σ to total significance → observation of all channels important to extract convincing signal in first year(s)

The 3 channels are complementary → robustness:

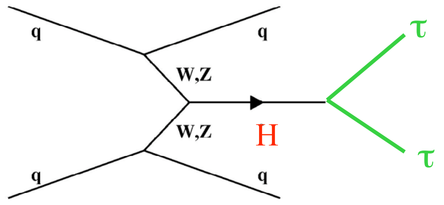
$H \to \gamma\gamma$



$ttH \to tt\, bb \to bl\nu\, bjj\, bb$



$qqH \to qq\tau\tau$



- different production and decay modes
- different backgrounds
- different detector/performance requirements:
  - -- ECAL crucial for $H \to \gamma\gamma$ (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 $qqH \to qq\tau\tau$: forward jet tag and central jet veto needed against background

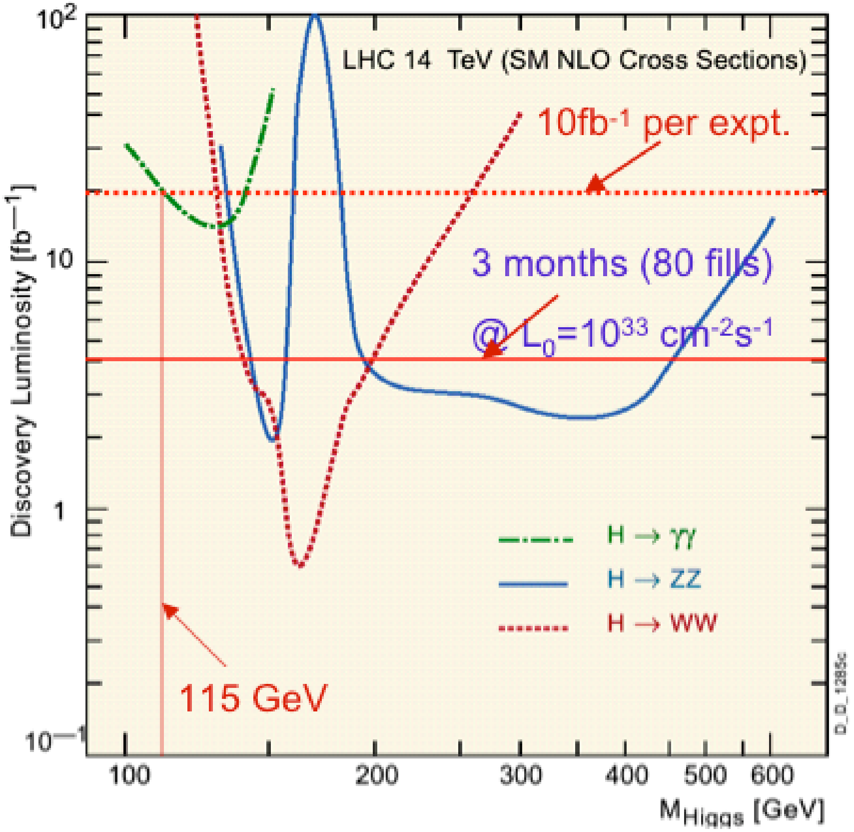
Note : -- all require "low" trigger thresholds

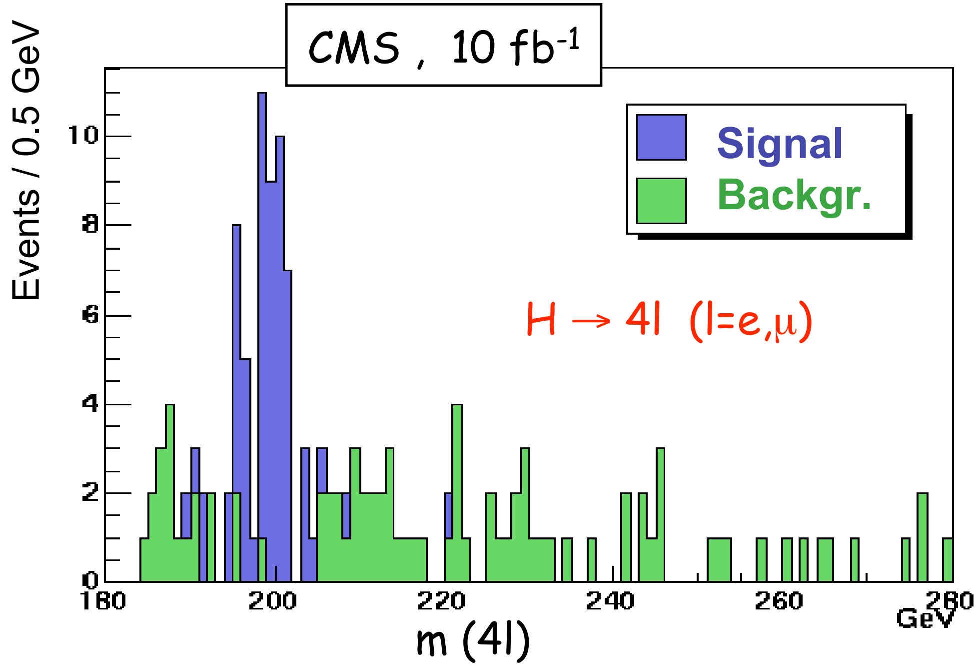
E.g. ttH analysis cuts : p_T (l) > 20 GeV, p_T (jets) > 15-30 GeV

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

If m_H > 180 GeV : early discovery may be easier with $H \to 4l$ channel

Luminosity needed for 5σ discovery (ATLAS+CMS)





- $H \to WW \to l\nu\, l\nu$: high rate (~ 100 evts/expt) but no mass peak → not ideal for early discovery …
- $H \to 4l$: low-rate but very clean : narrow mass peak, small background

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

-- σ/m ~ 1%, tails < 10% → good quality of E, p measurements in ECAL and tracker

Conclusions

- LHC has potential for major discoveries already in the first year (months ?) of operation
  Event statistics : 1 day at LHC at 10^{33} ≡ 10 years 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 year(s)
  (… but also complete and commissioned experiments)

- 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, …) is our next challenge
  Crucial to reach quickly the "discovery-mode" and extract a convincing "early" signal

Back-up slides

Backgrounds will be estimated using data (control samples) and Monte Carlo:

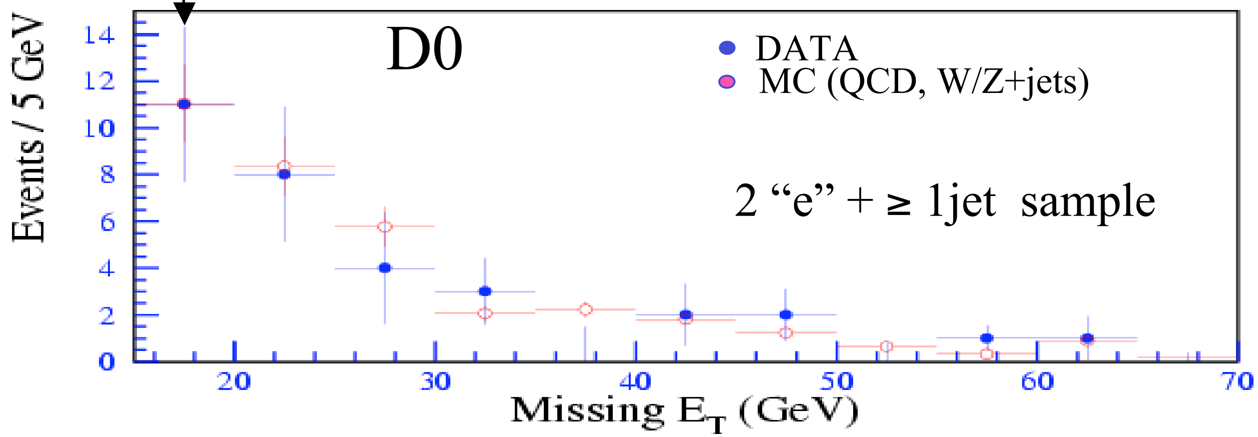
Background process (examples ….)	Control samples (examples ….)
Z (→ νν) + jets	Z (→ ee, μμ) + jets
W (→ τν) + jets	W (→ eν, μν) + jets
tt→ blνbjj	tt→ blν blν
QCD multijets	lower E_T sample

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.

-- HLT/DAQ deferrals limit available networking and computing for HLT → limit LVL1 output rate
-- Large uncertainties on LVL1 affordable rate vs money (component cost, software performance, etc.)

Selections (examples ...) Real thresholds set for 95% efficiency at these E_T	LVL1 rate (kHz) L= 1 x 10^{33} no deferrals	LVL1 rate (kHz) L= 2 x 10^{33} no deferrals	LVL1 rate (kHz) L= 2 x 10^{33} with deferrals An example for illustration...
MU6,8,20	23	→ 19	→ 0.8
2MU6	---	0.2	0.2
EM20i,25,25	11	→ 12	→ 12
2EM15i,15,15	2	4	4
J180,200,200	0.2	0.2	0.2
3J75,90,90	0.2	0.2	0.2
4J55,65,65	0.2	0.2	0.2
J50+xE50,60,60	0.4	0.4	0.4
TAU20,25,25 +xE30	2	2	2
MU10+EM15i	---	0.1	0.1
Others (pre-scaled, etc.)	5	5	5
Total	~ 44	~ 43	~ 25

LVL1 designed for 75 kHz
→ room for factor ~ 2 safety

Likely max affordable rate,
no room for safety factor

❸ Which data samples ?

Total trigger rate to storage at 2×10^{33} reduced from ~ 540 Hz (HLT/DAQ TP, 2000) to ~ 200 Hz (now)

High-Level-Trigger output

⬇

Selection (examples …)	Rate to storage at 2×10^{33} (Hz)	Physics motivations (examples …)
e25i, 2e15i μ20i, 2μ10	~ 40 (55% W/b/c → eX) ~ 40 (85% W/b/c → μX)	Low-mass Higgs (ttH, H→ 4λ, qq$\tau\tau$) W, Z, top, New Physics ?
γ60i, 2γ20i	~ 40 (57% prompt γ)	H → $\gamma\gamma$, New Physics (e.g. X → γ yy m_X~ 500 GeV) ?
j400, 3j165, 4j110	~ 25	Overlap with Tevatron for new X → jj in danger …
j70 + xE70	~ 20	SUSY : ~ 400 GeV squarks/gluinos
τ35 + xE45	~ 5	MSSM Higgs, New Physics (3rd family !) ? More difficult high L
2μ6 (+ m_B)	~ 10	Rare decays B → $\mu\mu$X
Others (pre-scaled, exclusive, …)	~ 20	Only 10% of total !
Total	~ 200	No safety factor included.

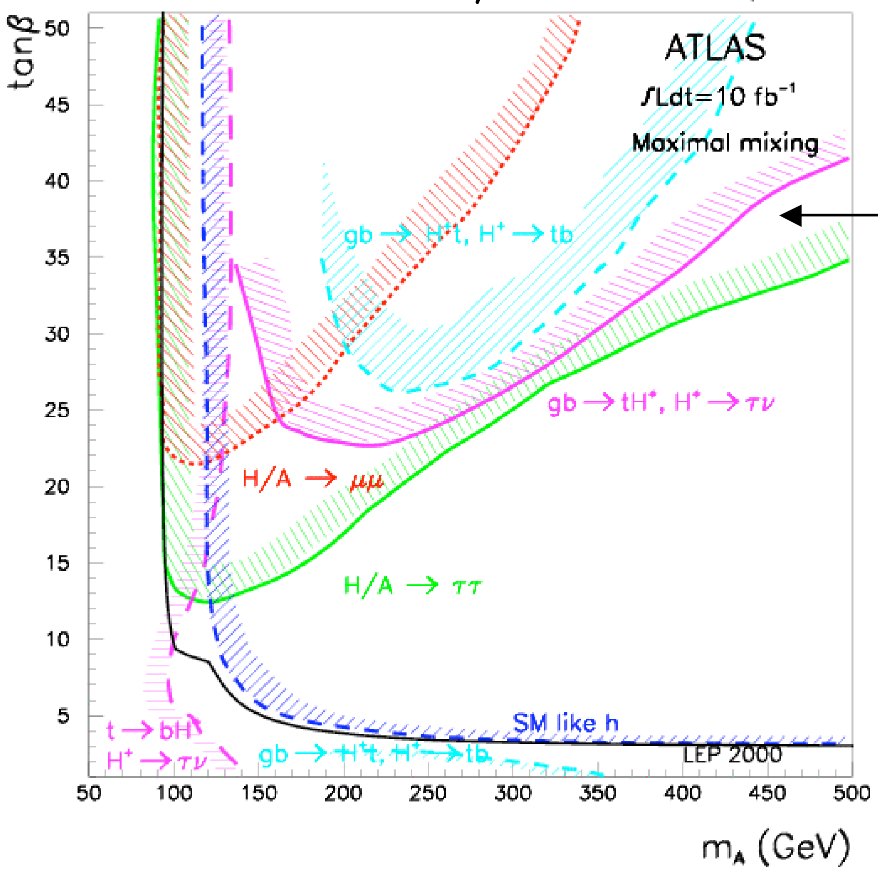
Best use of spare capacity when L < 2×10^{33} being investigated

"Signal" (W, γ, etc.) : ~ 100 Hz

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

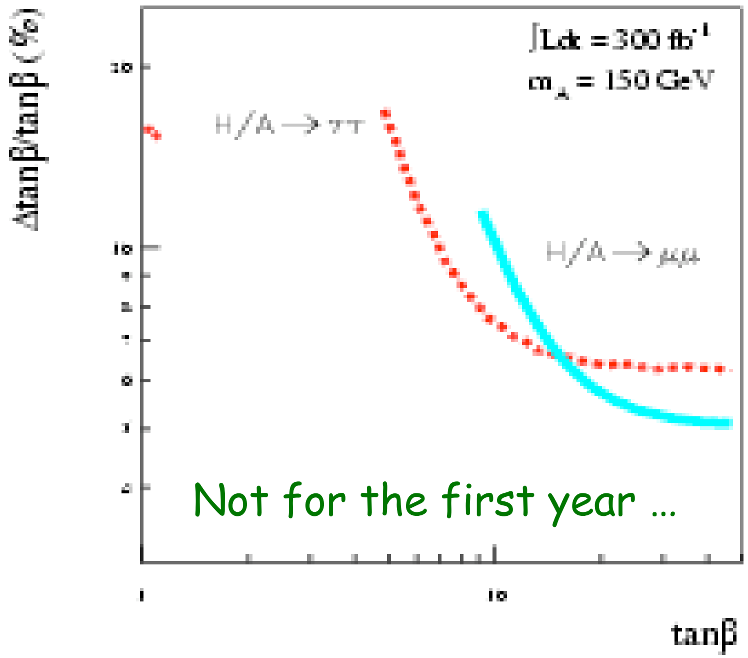
$m_h < 135$ GeV
$m_A \approx m_H \approx m_{H\pm}$ at large m_A

5σ discovery curves



-- A, H, $H^{\pm}$ cross-section ~ $tg^2\beta$
-- best sensitivity from A/H → ττ, $H^{\pm}$ → τν
(not easy the first year ...)
-- A/H → μμ experimentally easier
(esp. at the beginning)

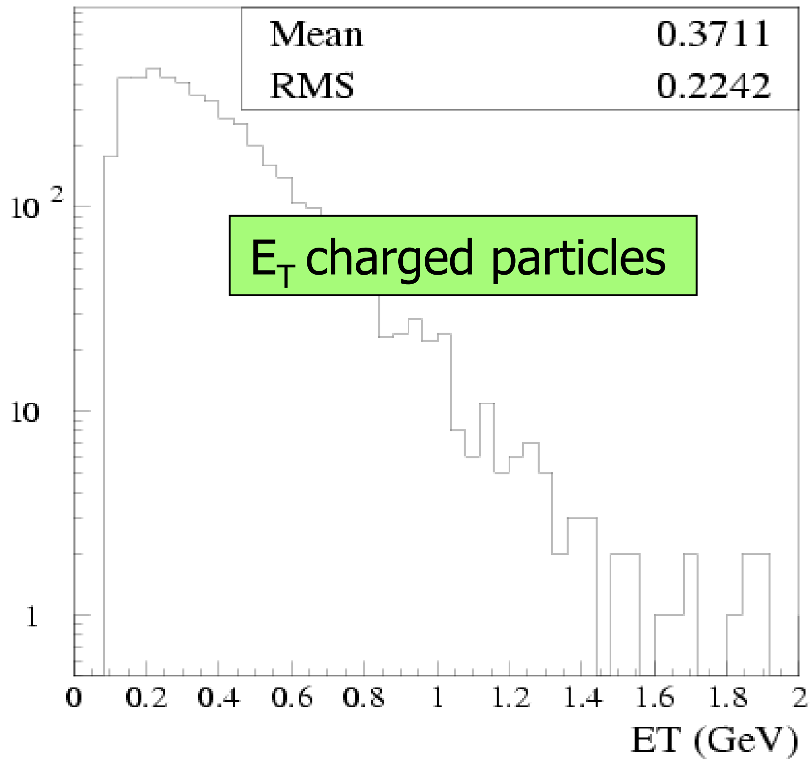
Measurement of tg β

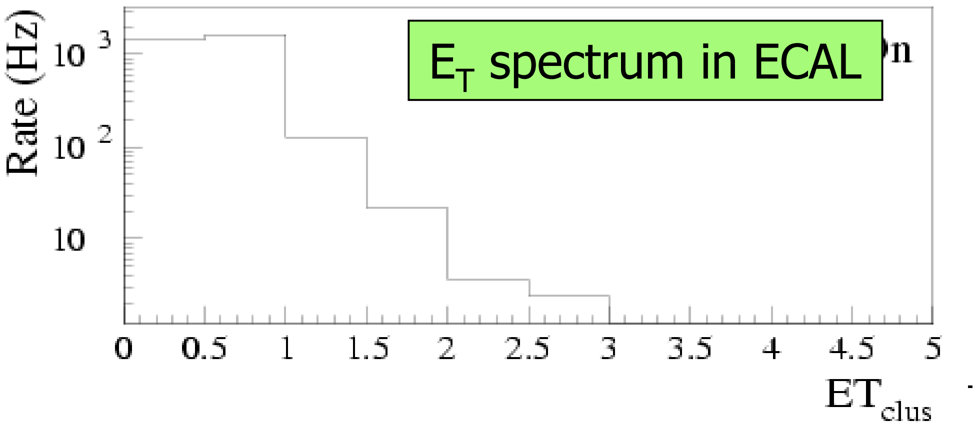


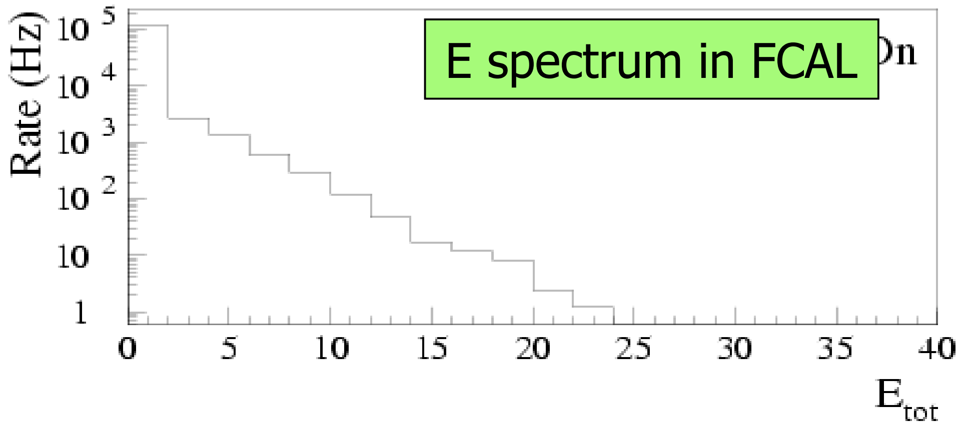
- Large variety of channels and signatures accessible
- bbA/H → 4b is more difficult than at the Tevatron (because of huge QCD background)

Expected rates of beam-gas events

Vertex z-position	Rate (Hz)	Total (2 months, ε=30%)
±23 m	$1.2\ 10^5$	$2.1\ 10^{11}$
± 3 m	$1.6\ 10^4$	$2.4\ 10^{10}$
± 20 cm	$1.1\ 10^3$	$1.6\ 10^9$
$\pi^\pm$ p_T > 1 GeV inside ± 3m	$1.0\ 10^3$	$1.5\ 10^9$
γ p_T > 1 GeV inside ± 3m	$0.3\ 10^3$	$5.6\ 10^8$







Expected rates of beam-halo muons

- Rates for initial period scaled from high-luminosity rates by assuming 3 x 10^{10} p per bunch and 43 bunches → ~ 200 times lower current
- Expected optics and vacuum for commissioning period not included yet (need input from machine people) → these results are very preliminary
- Total rates are for two months of single-beam with 30% data taking efficiency
- Simple definition of "useful tracks" : 2-3 segments in MDT, 3-4 disks in ID end-cap

Very preliminary

Detector	Rate (B-field off)	Total (B-field off)	Rate (B-field on)	Total (B-field on)
MDT barrel	15 Hz	2.5 10^7	72 Hz	1.5 10^8
MDT end-cap	145 Hz	2.5 10^8	135 Hz	2.5 10^8
Pixel/SCT	1.8/17 Hz	3 10^6 / 3 10^7	2/19 Hz	3 10^6 / 3 10^7
EM E > 5 GeV	2 Hz	3.5 10^6	1 Hz	1.7 10^6
Tile/HEC E > 20 GeV	1.7/1.2 Hz	2.9/2.1 10^6	1.6/0.9 Hz	2.8/1.6 10^6