Status and startup for physics with ATLAS

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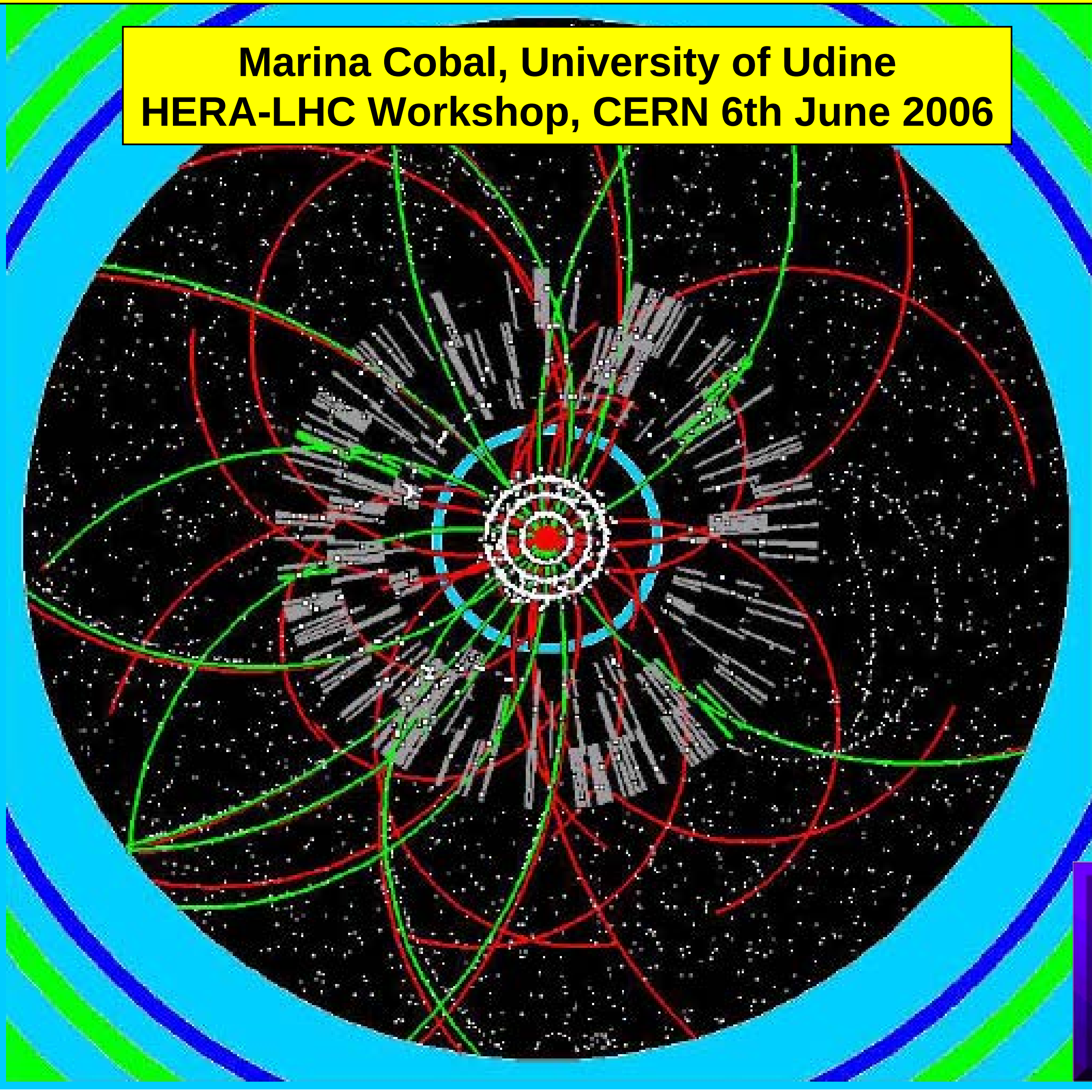
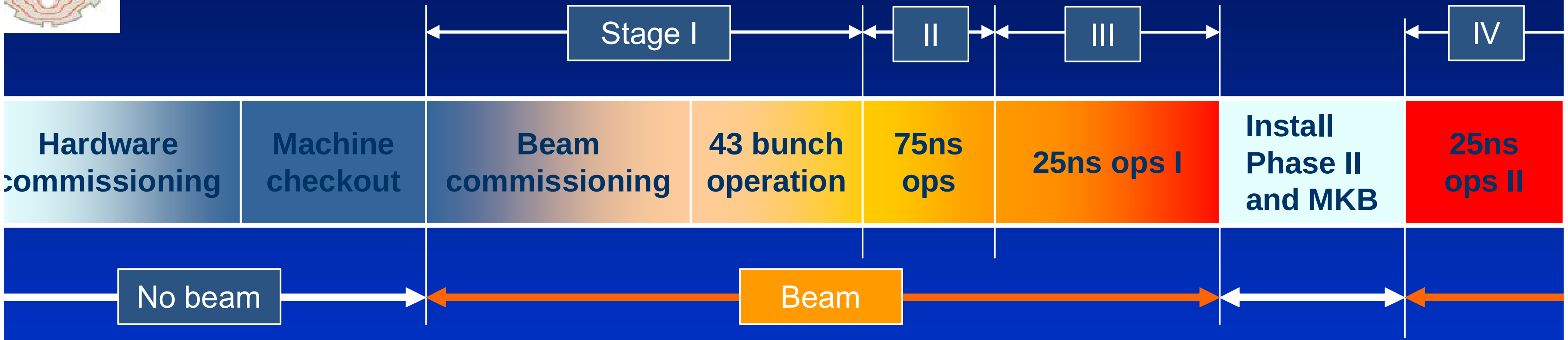
HERA-LHC Workshop, CERN 6th June 2006



Staged commissioning plan for protons



I. **Pilot physics run**
- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance (156 bunches, partial squeeze in 1 and 5, push intensity)
- Performance limit 10^{32} cm^{-2} s^{-1} (event pileup)

2007 ?

up to 100 pb^{-1} ?

II. **75ns operation**
- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle
- Performance limit 10^{33} cm^{-2} s^{-1} (event pileup)

early 2008

III. **25ns operation I**
- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal
- Performance limit 2 10^{33} cm^{-2} s^{-1}

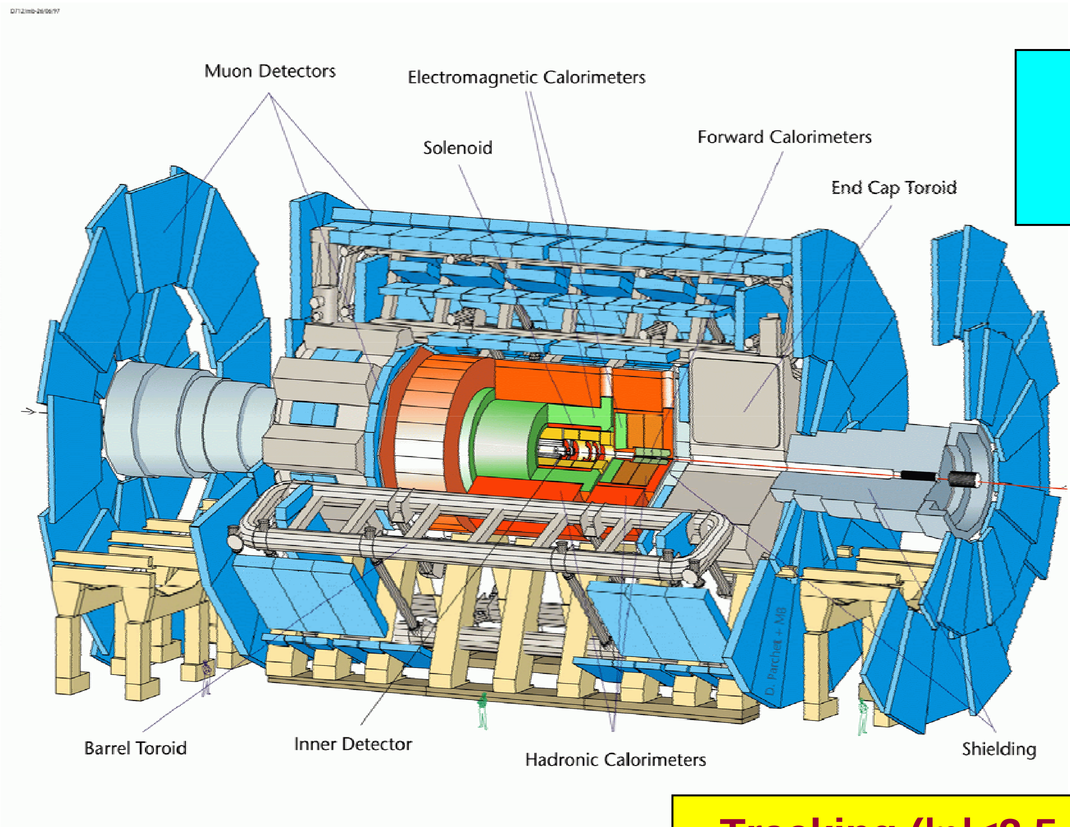
2008-2009

~ 5 fb^{-1} end 2008,
~ 20 fb^{-1} end 2009 ?

IV. **25ns operation II**
- Push towards nominal performance

≥ 2010

$O(100)$ fb^{-1}

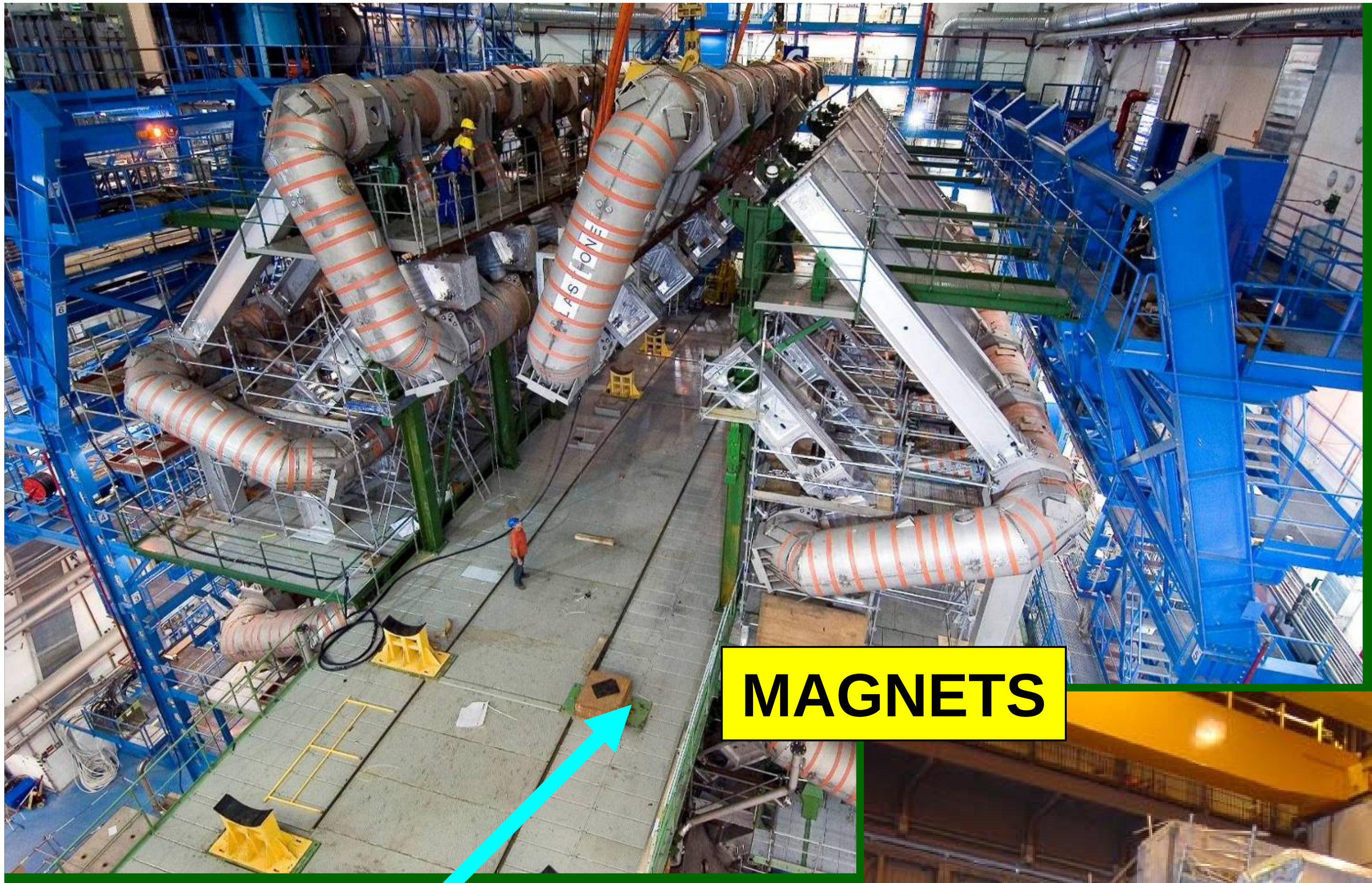


ATLAS

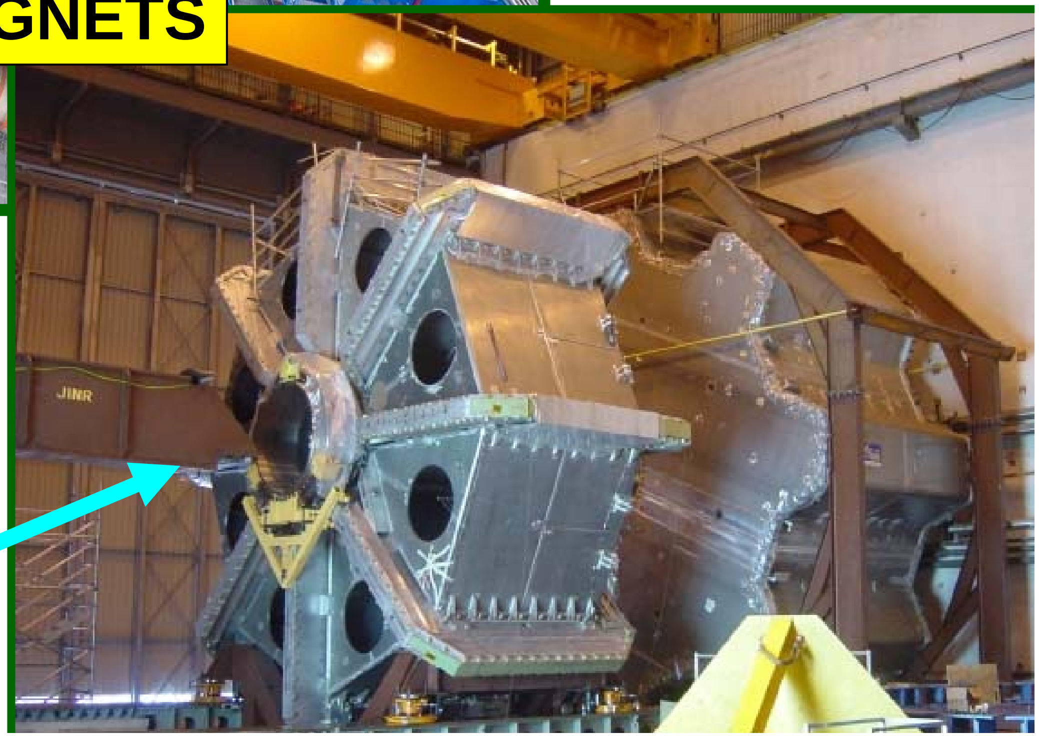
Length : ~45 m
Radius : ~12 m
Weight : ~ 7000 tons
Electronic channels : ~ 10^8
~ 3000 km of cables

- **Tracking ($|\eta|<2.5$, B=2T) :**
  - Si pixels and strips
  - Transition Radiation Detector (e/π separation)
- **Calorimetry ($|\eta|<5$) :**
  - EM : Pb-LAr
  - HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- **Muon Spectrometer ($|\eta|<2.7$) :**
  - air-core toroids with muon chambers

MAGNETS



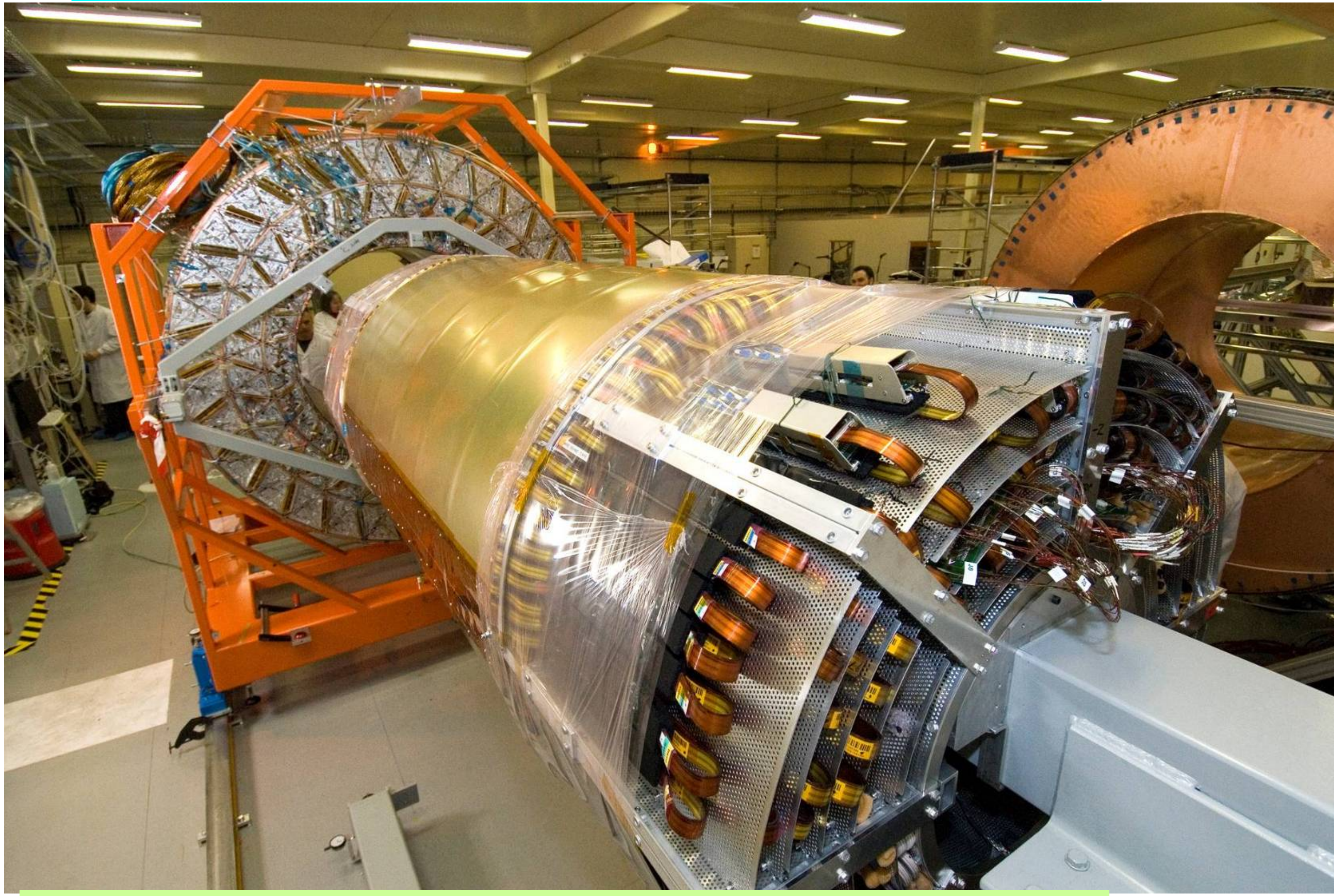
Barrel toroid: cool down starting April 2006, first full current excitation end of May



End-cap toroids will go to the pit in August and November 2006

INNER DETECTOR

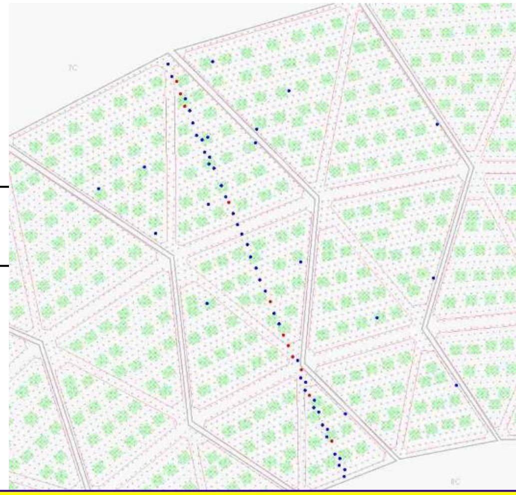
End of February: barrel SCT inserted into the barrel TRT
$\rightarrow$ ready for the installation in the pit in June 2006



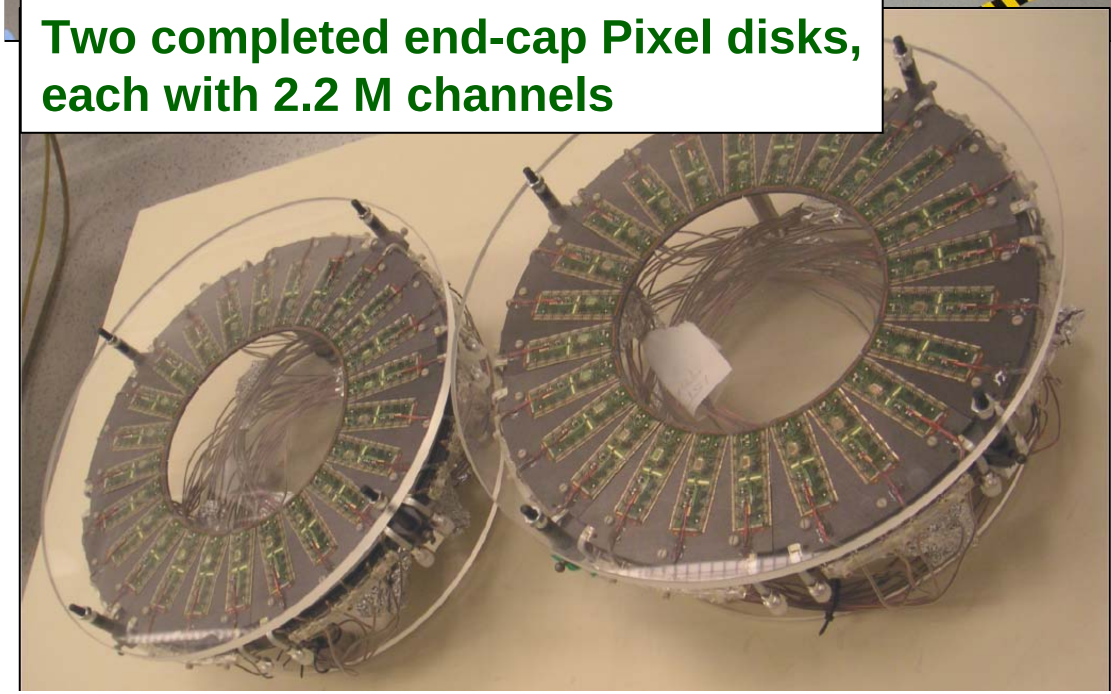
Each of 4 Si layer tested: 99.7% of channels fully functional

One end-cap TRT fully assembled

TRT: will contribute to tracking and to electron/pion separation by detecting transition radiation X-rays in gas mixture with ~ 70% Xe



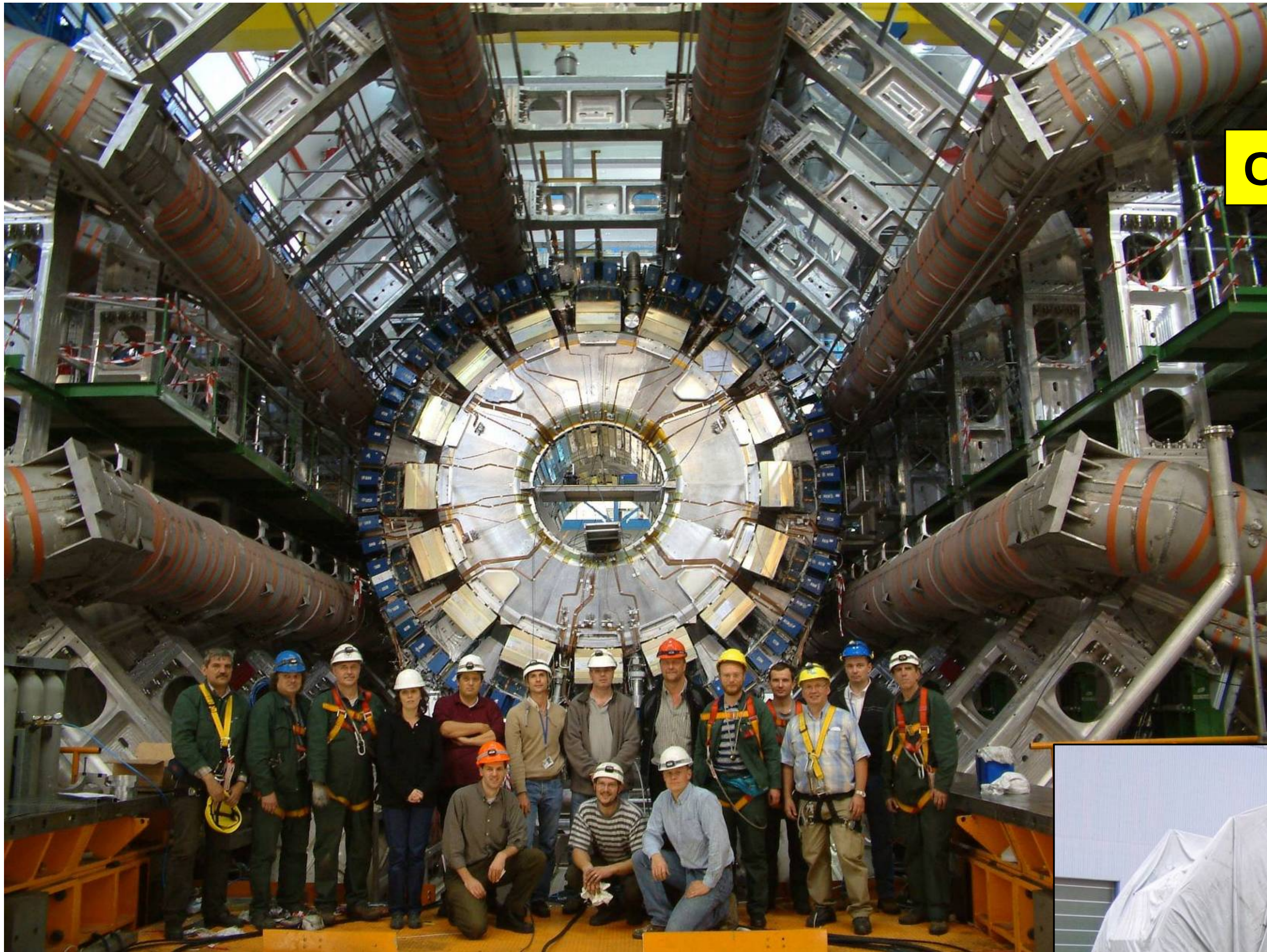
Cosmic muon registered in the barrel TRT in surface clean room



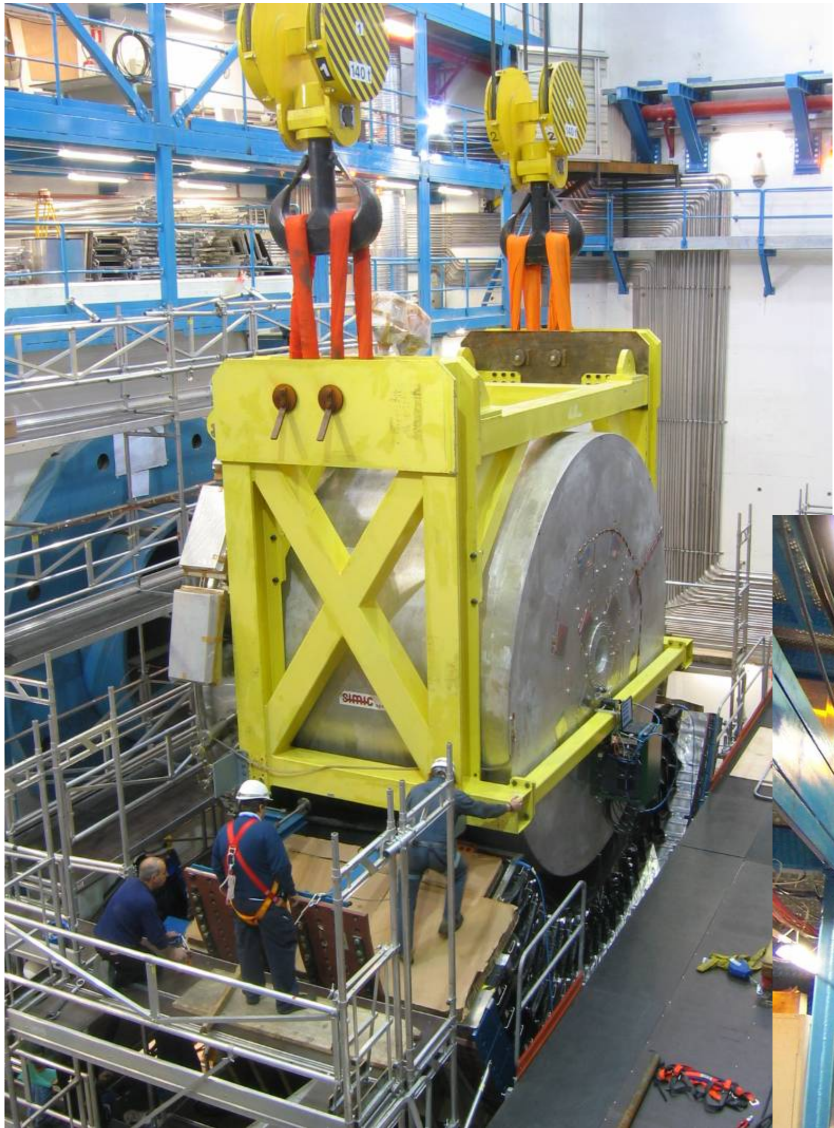
Two completed end-cap Pixel disks, each with 2.2 M channels

Inner Detector end-caps in the pit in October-November 2006

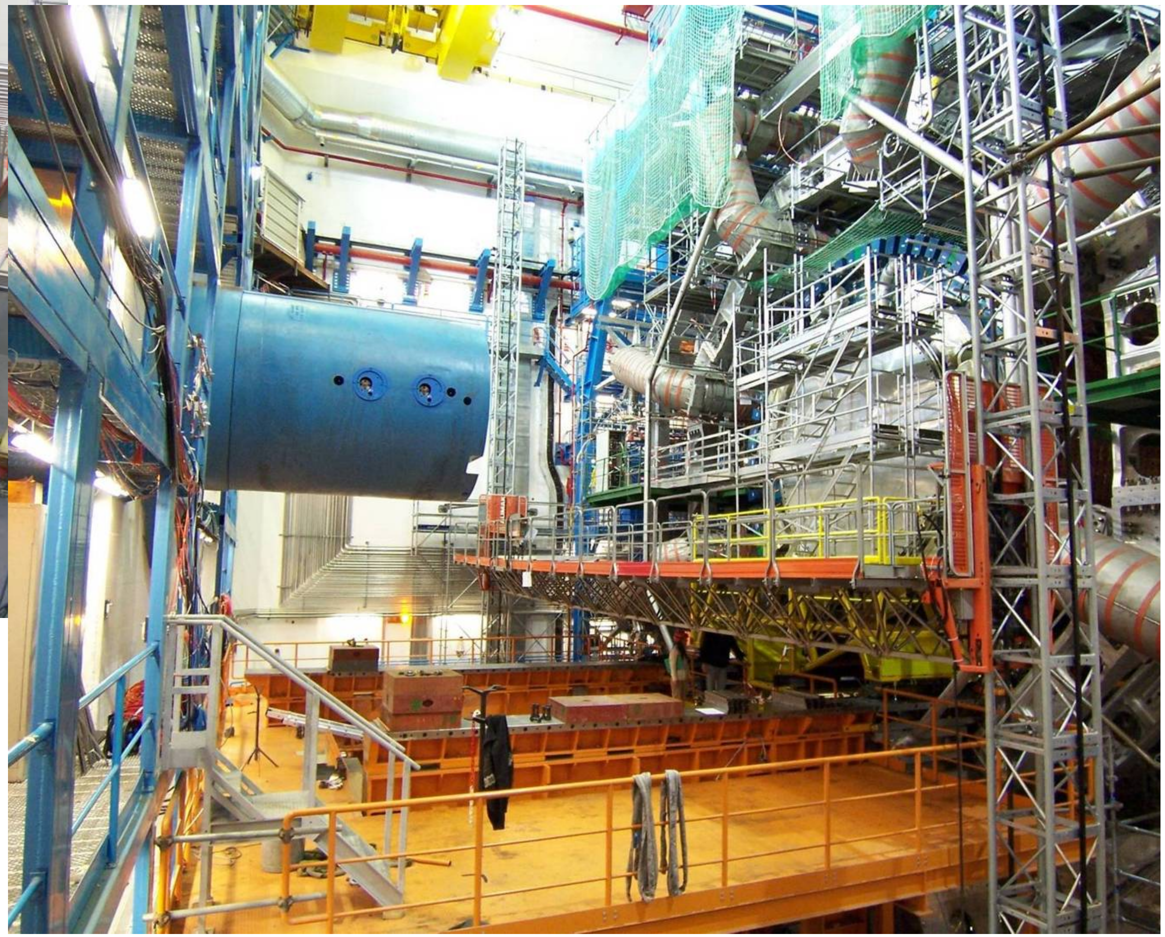
CALORIMETERS



Barrel calorimeter (EM LAr + Fe/scintillator Tilecal)
in final position at Z=0
Cool down of barrel EM calorimeter started
(barrel and end-cap LAr calorimeters tested at cold
on the surface : <1% of dead channels)



First end-cap calorimeter (EM, HAD LAr, FCAL inside common cryostat plus Tilecal) temporarily moved to final position; second end-cap being assembled in the pit



ATLAS calorimetry cold and fully operational end 2006

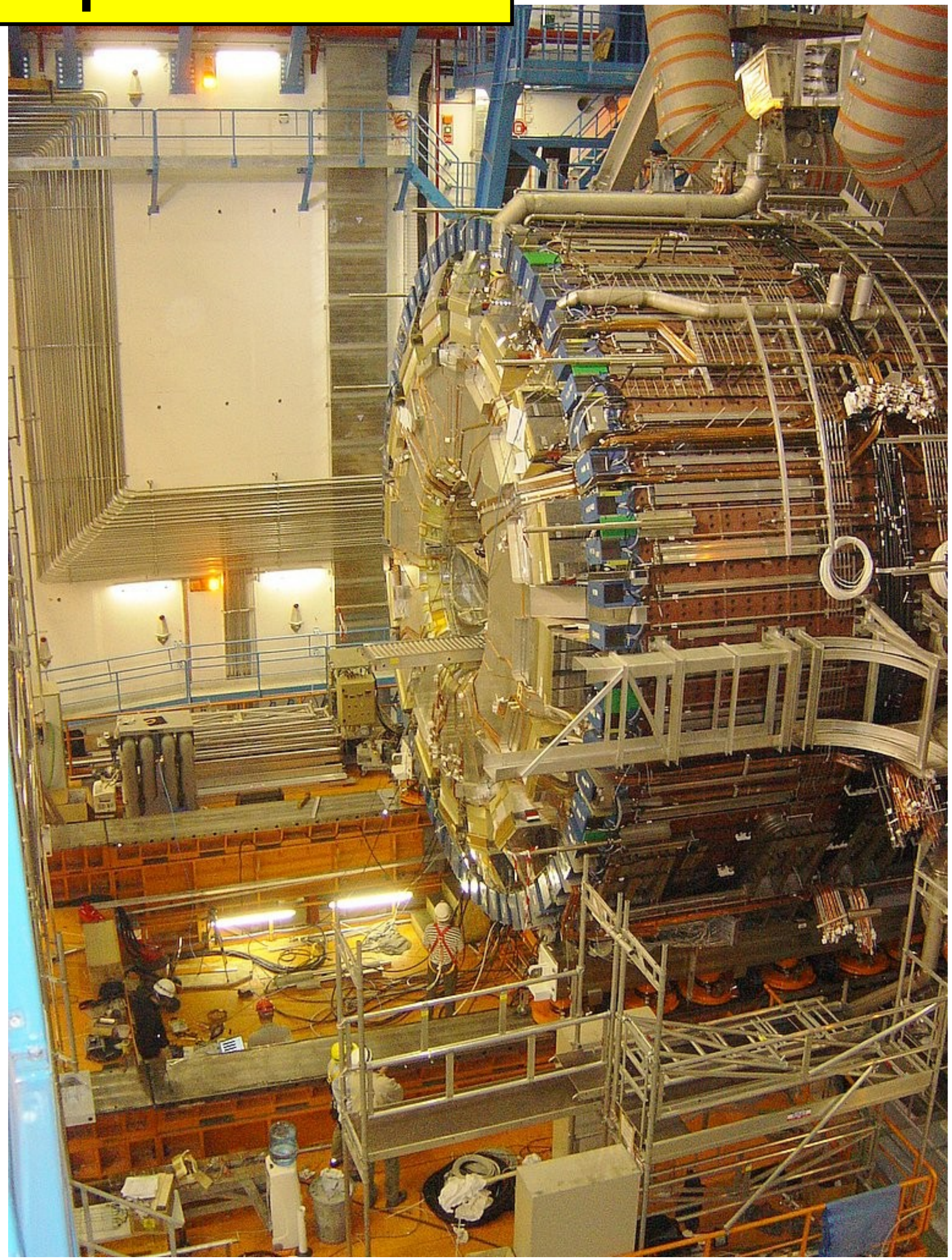
MUON SPECTROMETER

Measurement chambers: MDT, CSC (innermost forward)
Trigger chamber: RPC (barrel), TGC (end-cap)

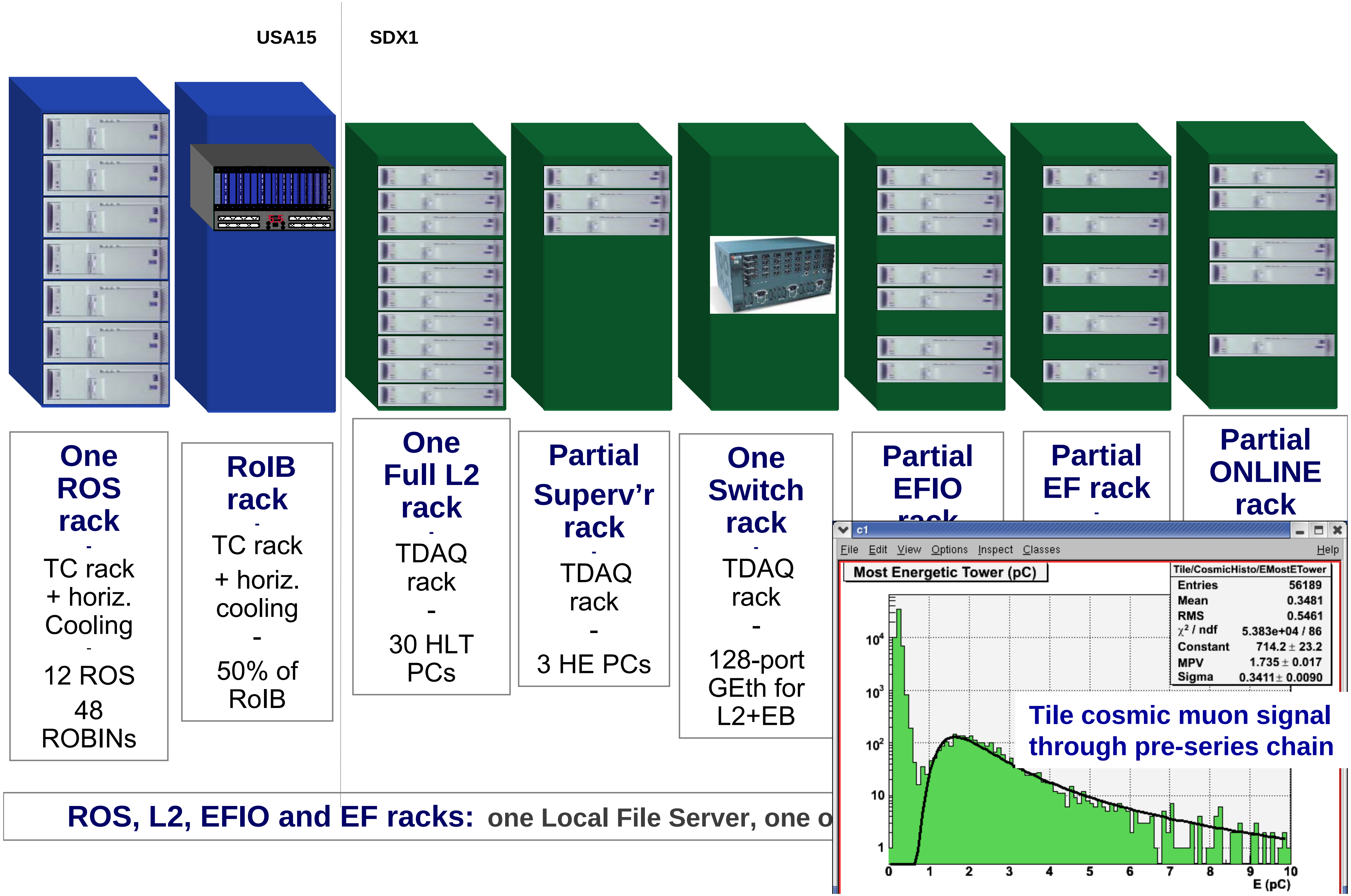
Construction completed;
now assembly, integration,
cosmic ray tests, installation

Barrel chamber installation to be completed
end Summer 2006

Spectacular operations …

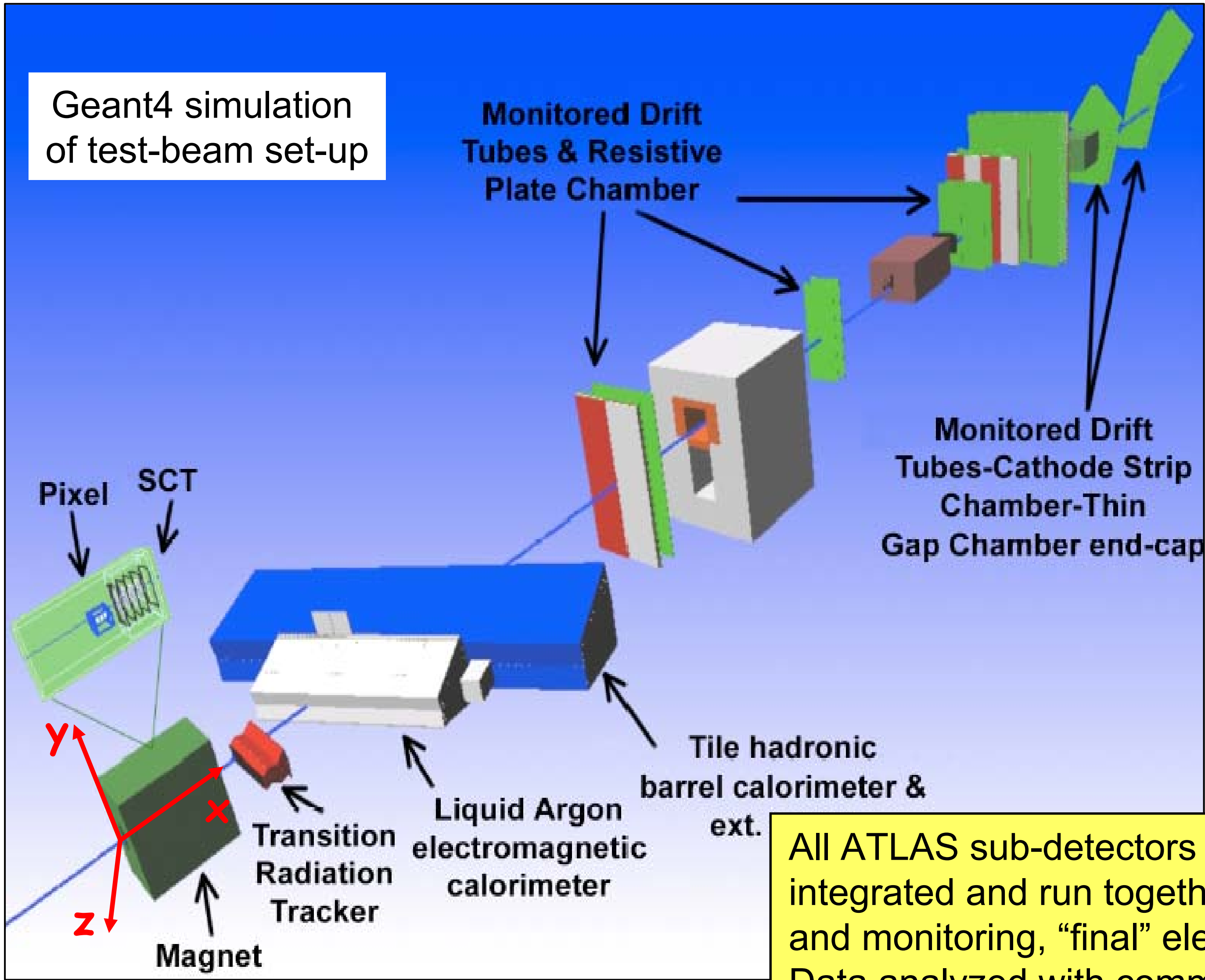


The pre-series of final TDAQ system with 8 racks (10% of final dataflow) is now in operation at the pit site



Towards Physics: the 2004 combined test beam

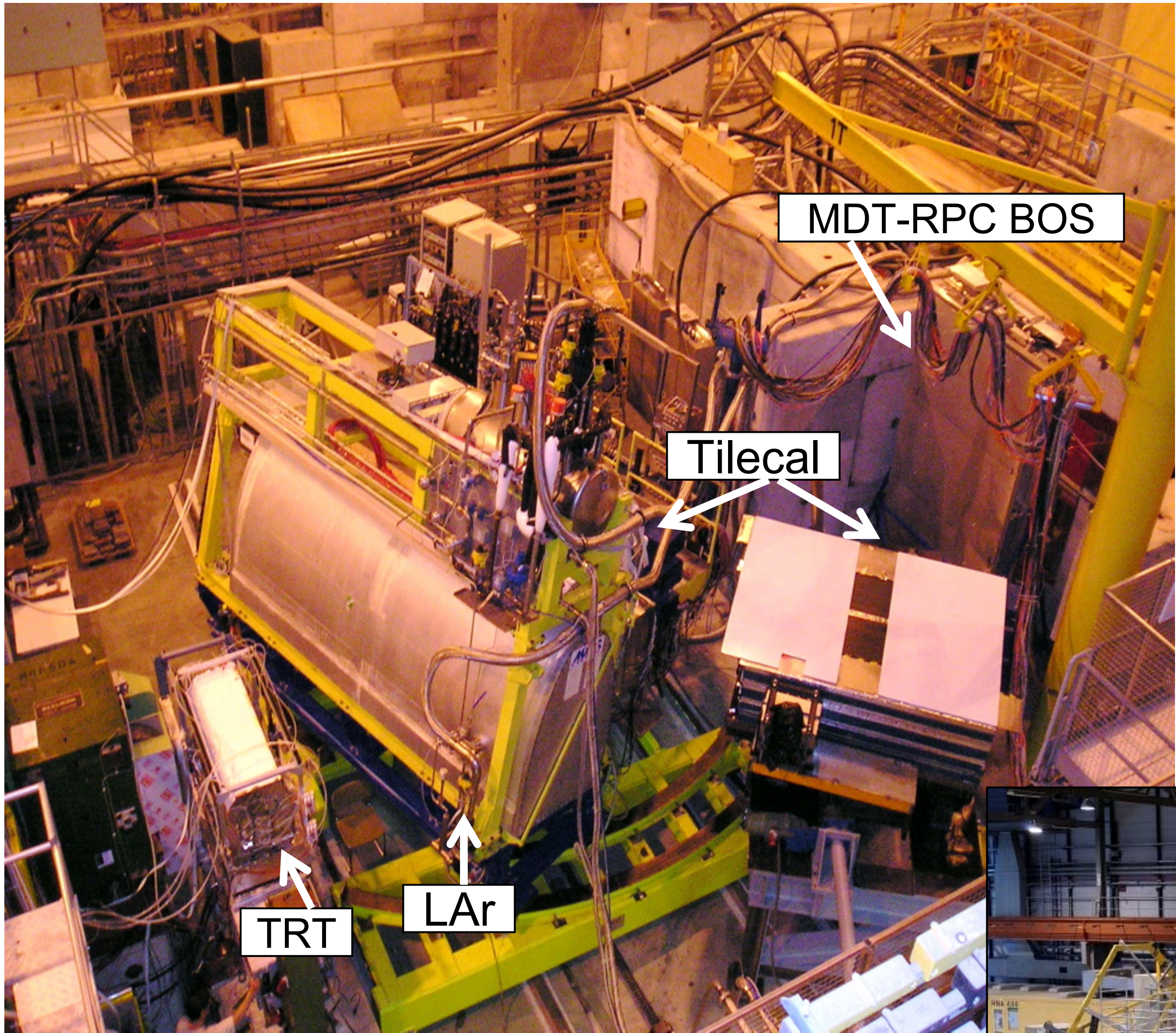
Full "vertical slice" of ATLAS tested on CERN H8 beam line May-November 2004



O(1%) of ATLAS

Production modules in most cases

All ATLAS sub-detectors (and LVL1 trigger) integrated and run together with common DAQ and monitoring, "final" electronics, slow-control, etc. Data analyzed with common ATLAS software.
6 month run.



~ 90 million events collected
~ 4.5 TB of data:

$e^{\pm}$, $\pi^{\pm}$	$1 \rightarrow 250$ GeV
$\mu^{\pm}$, $\pi^{\pm}$, p	up to 350 GeV
γ	20-100 GeV

B-field (ID) = $0 \rightarrow 1.4$ T

Many configurations
(e.g. additional material in ID, 25 ns runs, etc.)

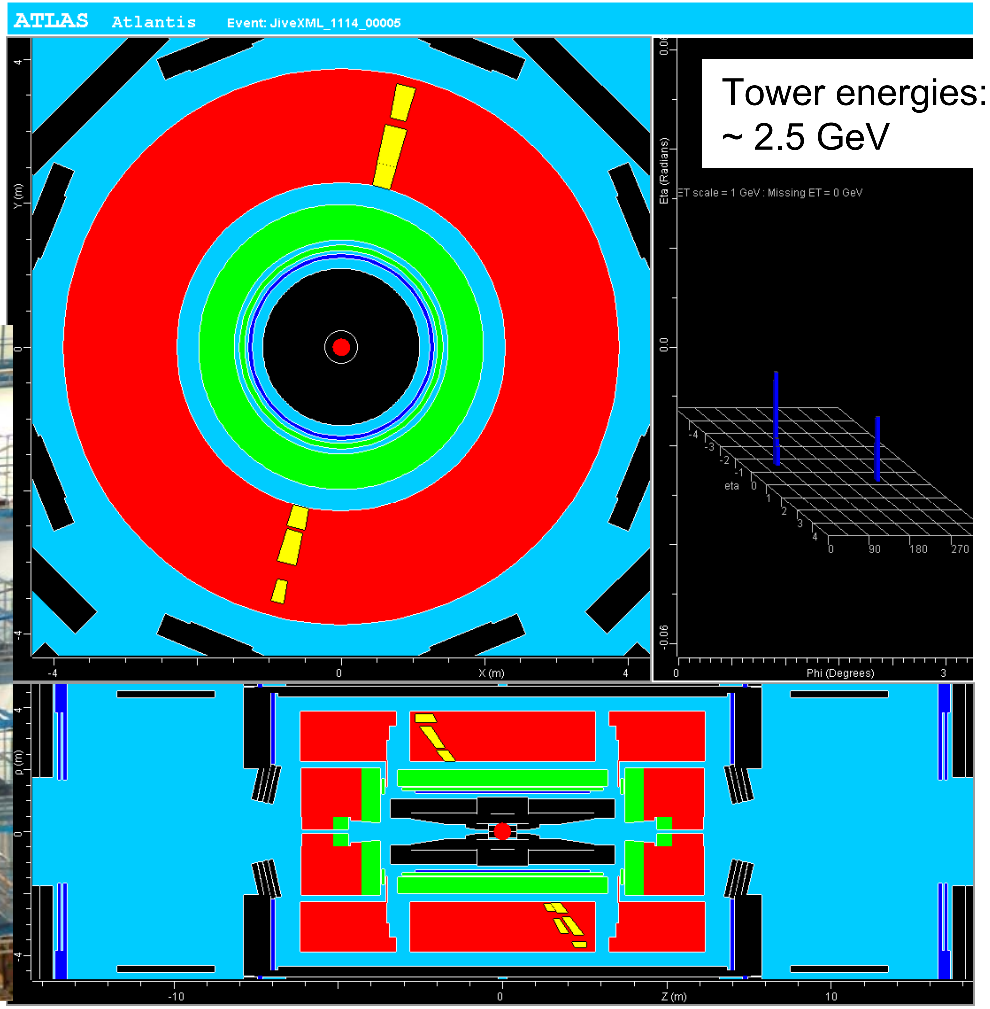
Towards Physics: cosmics ….

From ATLAS simulations and measurements in the underground cavern: rate is ~ Hz

→ expect few 10^6 events in ~ 2 months of data taking (at 30% efficiency)

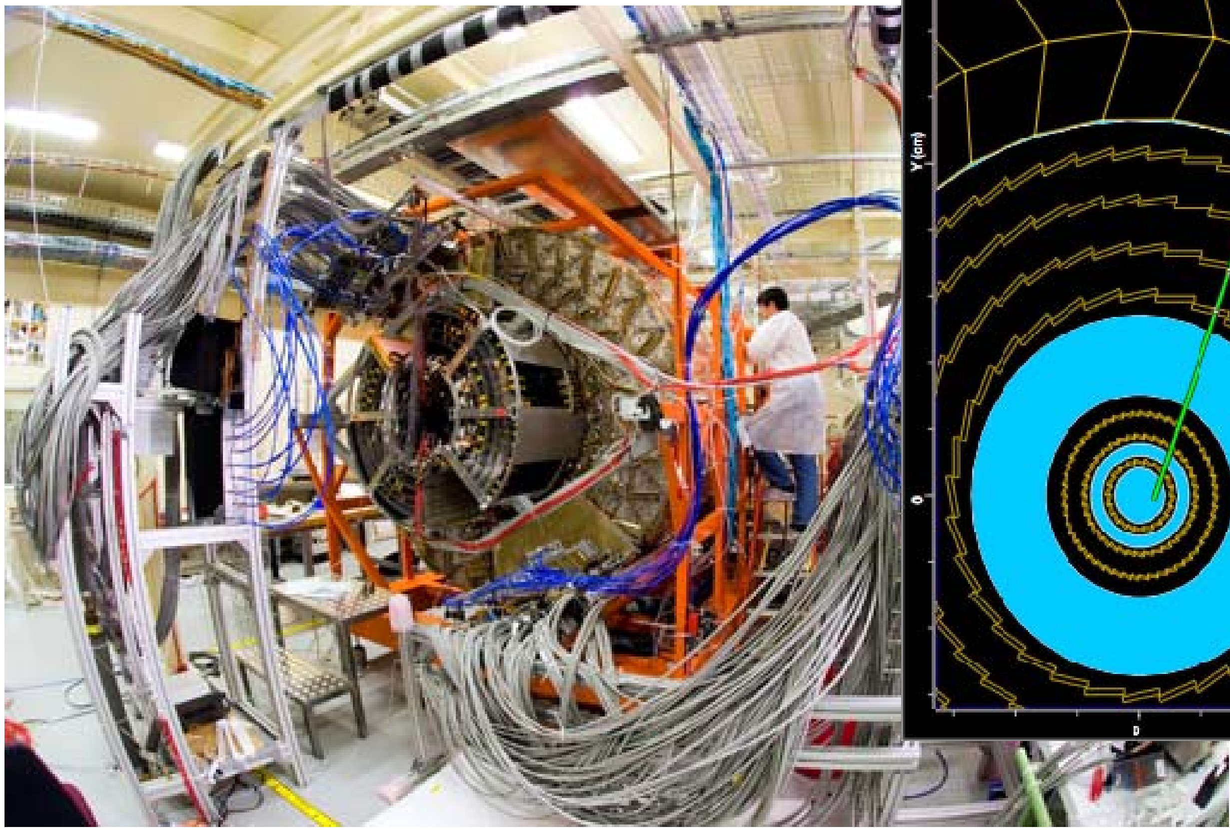
→ enough for initial shake-down, to catalog problems, to gain operation experience, for detector synchronization, for initial calibration/alignment

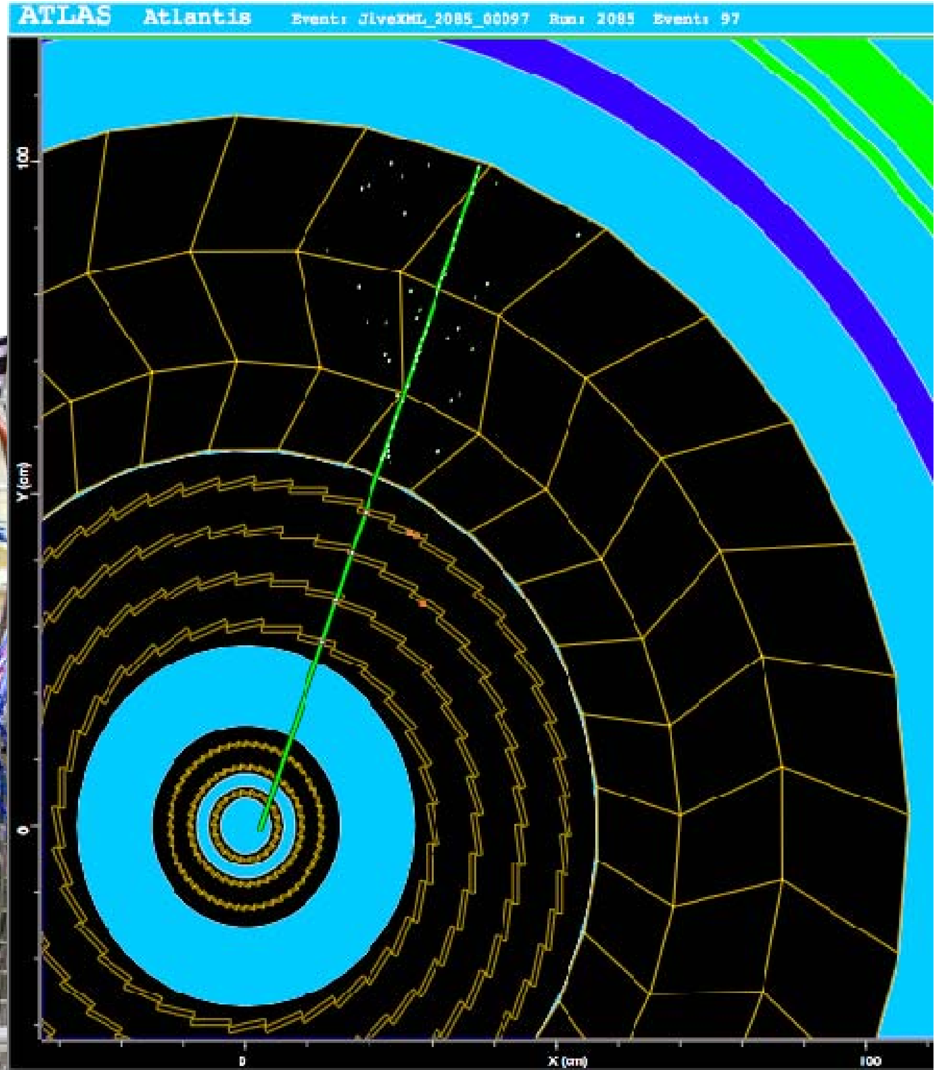
First cosmic muons observed by ATLAS in the pit on 20/6/2005 (recorded by hadron Tilecal calorimeter)



Cosmics test for ID

- Final TRT barrel
- Final SCT barrel
- 1 sector cabled for both





Which detector performance on day one ?

Based on detector construction quality, test-beam results, cosmics, simulation

	Expected performance day 1	Physics samples to improve
ECAL uniformity e/γ scale	~ 1% ~ 2 %	Minimum-bias, Z→ ee Z → ee
HCAL uniformity Jet scale events	~ 3 % < 10%	Single pions, QCD jets Z (→ ll) +1j, W → jj in tt
Tracking alignment →μm	20-200 μm in Rϕ ?	Generic tracks, isolated μ , Z

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

In the new physics era! The first 10-100 pb^{-1}

Understand/calibrate detector and trigger in situ using "candles" samples

e.g. - $Z \to ee, \mu\mu$ tracker, ECAL, muon chamber calibration and alignment, etc.

- $tt \to bl\nu\ bjj$ jet scale from W→jj, b-tag performance, etc.

Understand basic SM physics at $\sqrt{s}$ = 14 TeV

- measure cross-sections for e.g. minimum bias, W, Z, tt, QCD jets (to ~20 %),
- start to tune Monte CarOl
- measure top mass (to ~ 7 GeV ?) → give feedback on detector performance

Note : statistical error negligible with O(10 pb^{-1})

Prepare the road to discovery:

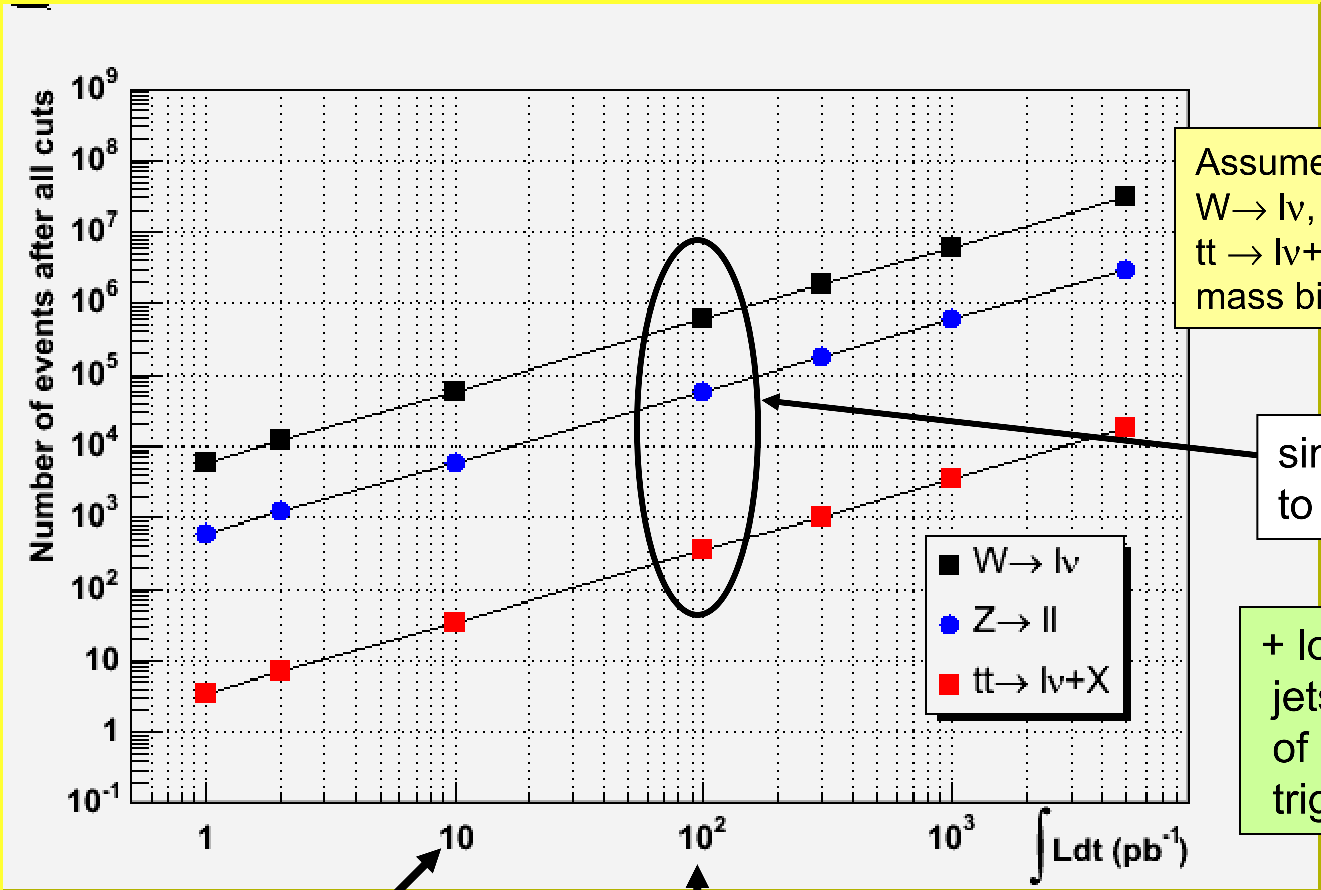
- measure backgrounds to New Physics : e.g. tt and W/Z+ jets (omnipresent …)
- look at specific "control samples" for the individual channels:

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

Look for New Physics potentially accessible in first year(s)

e.g. Z', SUSY, Higgs ?

How many events per experiment at the beginning ?



Assumed selection efficiency:
$W \to l\nu$, $Z \to ll$: 20%
$tt \to l\nu + X$: 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} and < 2 weeks at 10^{31}, ε=50%

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

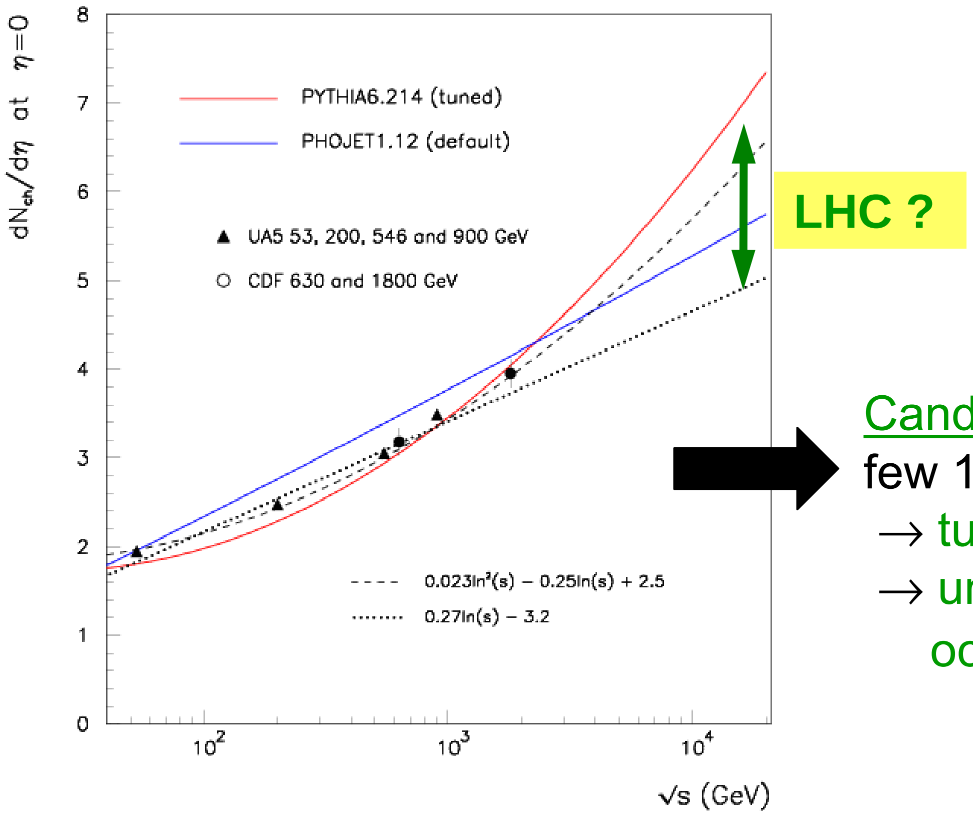
→ end 2007 ?

Knowledge of SM physics on day 1 ?

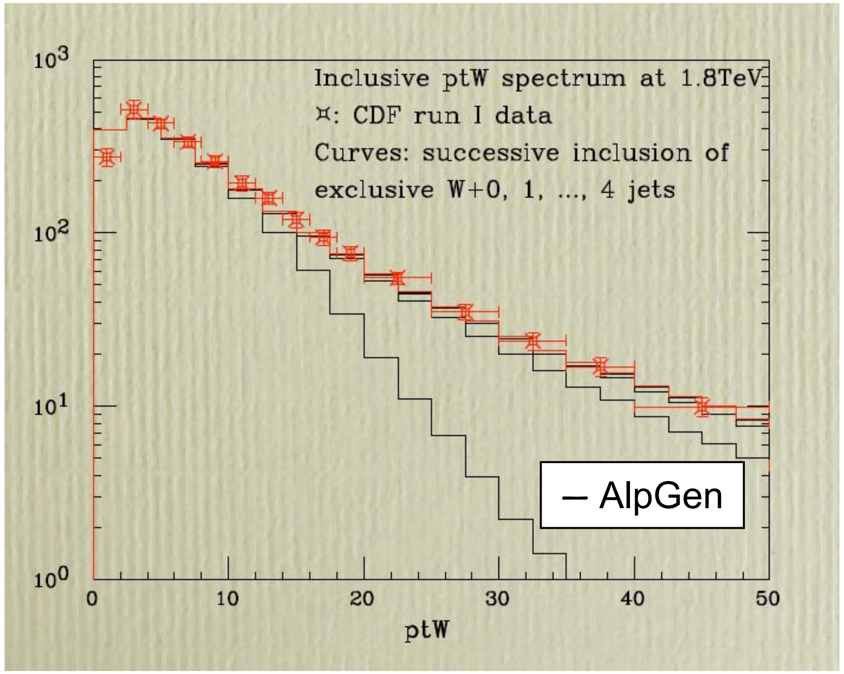
W, Z cross-sections: to 3-4%
(NNLO calculation → dominated by PDF)

tt cross-section to ~7% (NLO+PDF)

$<N_{ch}>$ at η =0 for generic pp collisions (minimum bias)



Lot of progress with NLO matrix element MC interfaced to parton shower MC (MC@ NLO, AlpGen,..)

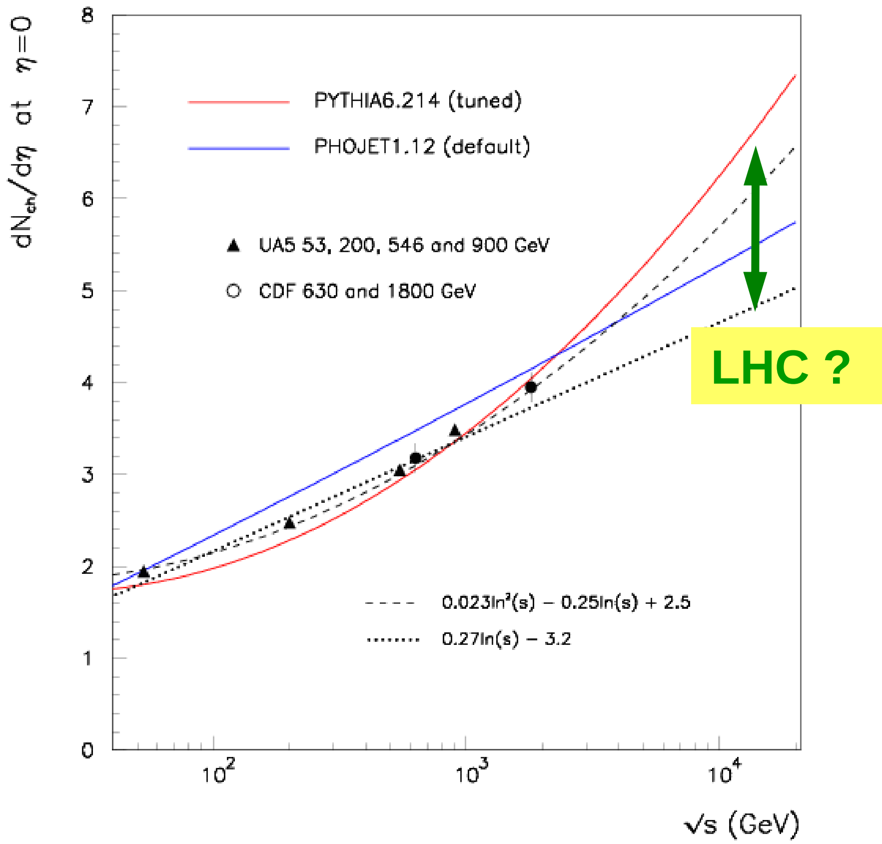


Candidate to very early measurement:
few 10^4 events enough to get $dN_{ch}/d\eta$, dN_{ch}/dp_T
→ tuning of MC models
→ understand basics of pp collisions, occupancy, pile-up, …

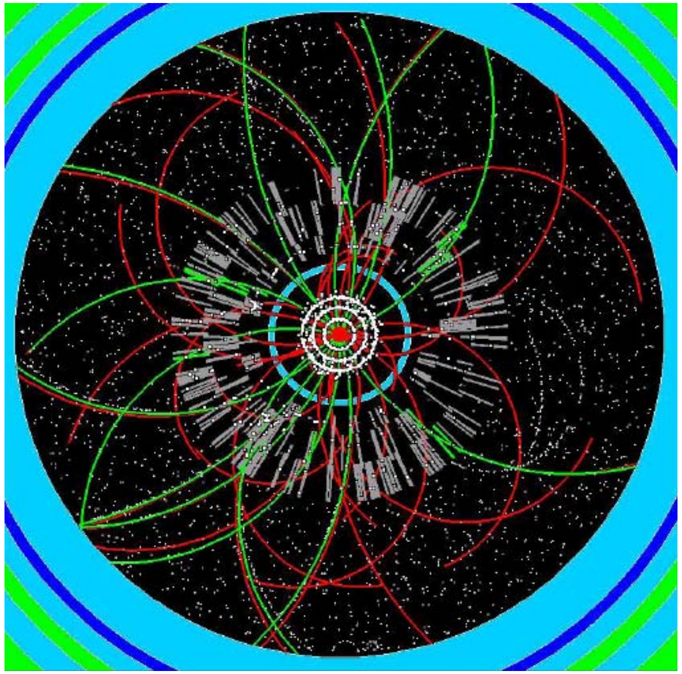
Minimum Bias

Not exactly what the LHC was built for! But…..

- Physics: measure dN/dη|η=0
  - Compare to NSD data from SppS and Tevatron
- MB samples for pile-up studies
  - Calorimeter
  - Physics analyses
- Overlap with UE
  - analyses eg VBF, Jets…
- Demonstrate that ATLAS is operational
- Intercalibrate detector elements
  - Uniform events
- Alignment



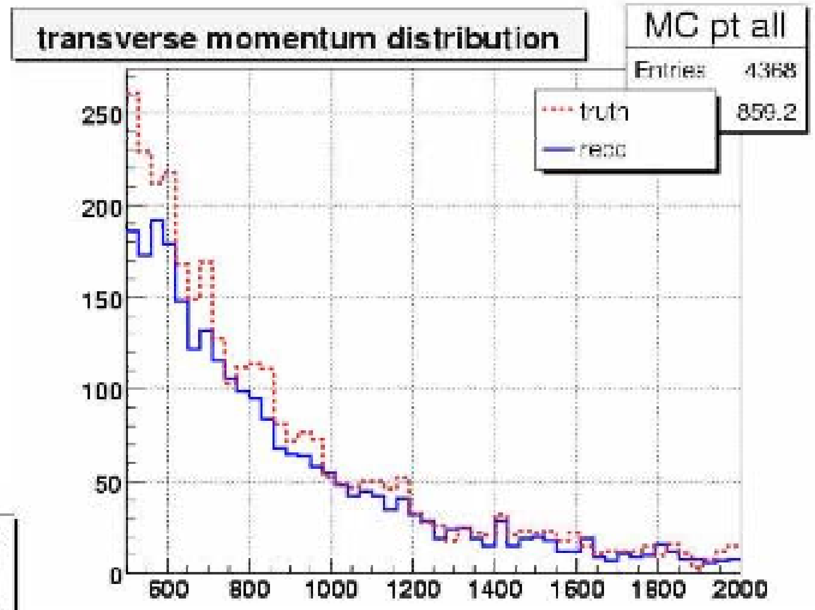
- Event characteristics
  - Non-single diffractive~non-diffractive inelastic
  - Soft tracks: p_T^{peak}~250MeV
  - Approx flat distribution in η to $|\eta|$~3 and in ϕ
  - N_{ch}~30; $|\eta|<2.5$

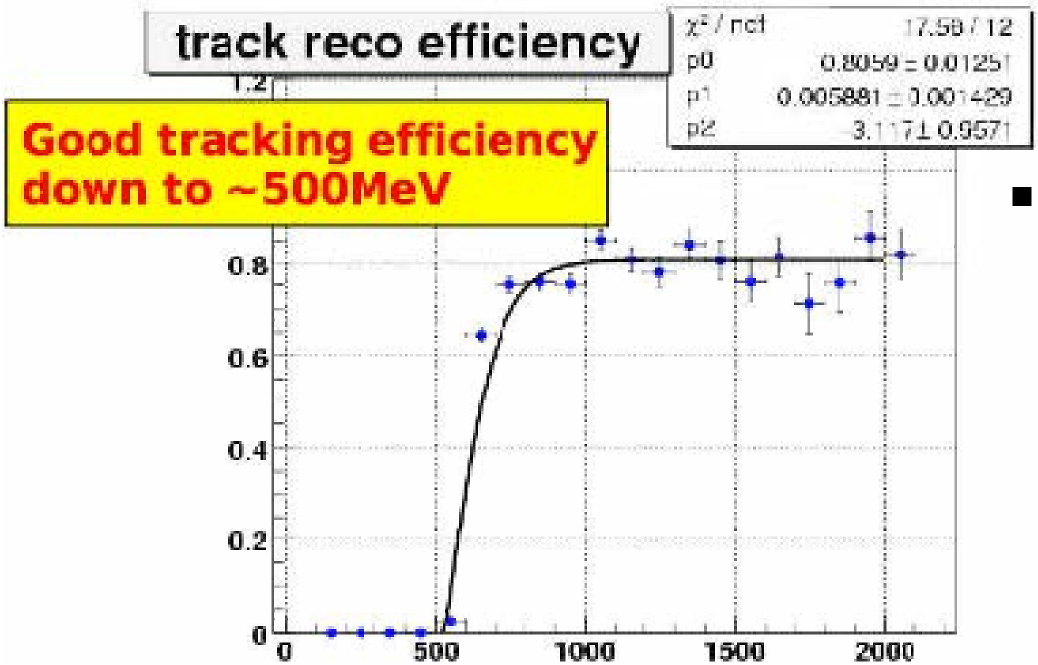


- Trigger rates
  - σ~70mb (NSD!)
  - R~700kHz @ L=$10^{31}cm^{-2}s^{-1}$
- For dN/dη require ~10k
- For UE need ~20M MB events to get some with leading jets P_T~30GeV

Tracking: Startup-Initial Alignment

- Very first alignment based on:
  - Mechanical precision
  - Detailed survey data
  - Cosmics data (SR1/Pit)
  - Minimum bias events and inclusive bb

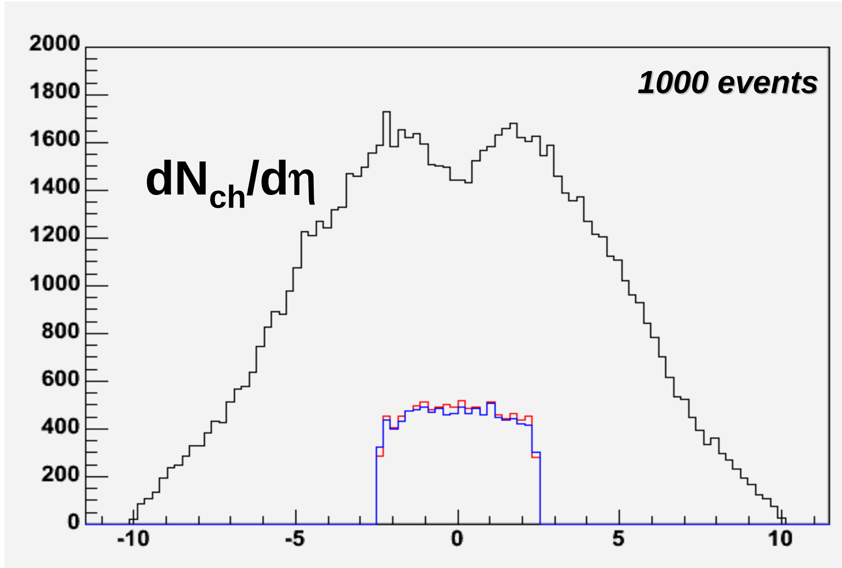




- Studies indicate good ε after initial alignment
  - Precision will need Zs and resonances to fix energy scales, constrain twists, etc…

Tracking in MB events

- Acceptance limited in η and p_T
- Rapidity coverage
  - Tracking covers $|\eta|<2.5$
- p_T problem
  - Need to extrapolate by ~x2
  - Need to understand low p_T charge track reconstruction

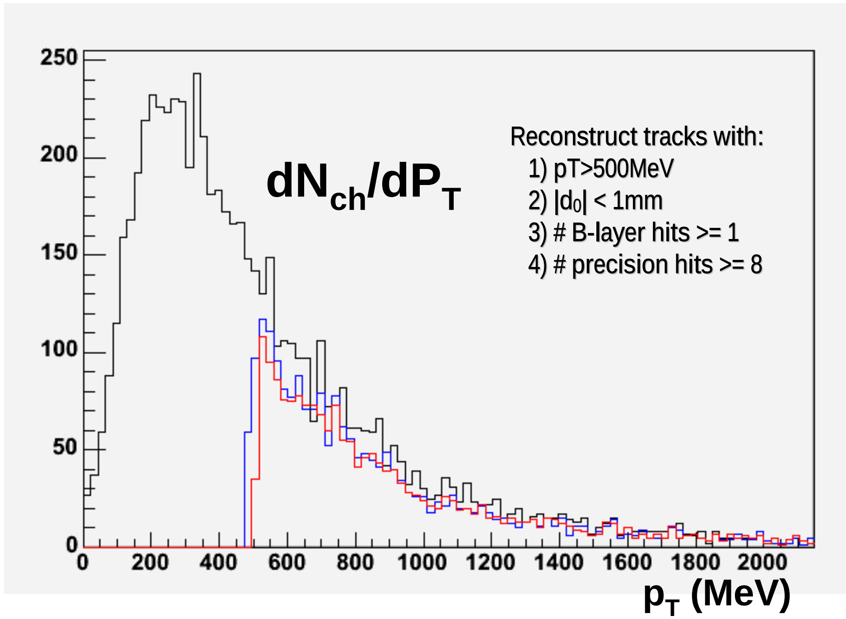


Black = Generated (Pythia6.2)

Blue = TrkTrack: iPatRec

Red = TrkTrack: xKalman

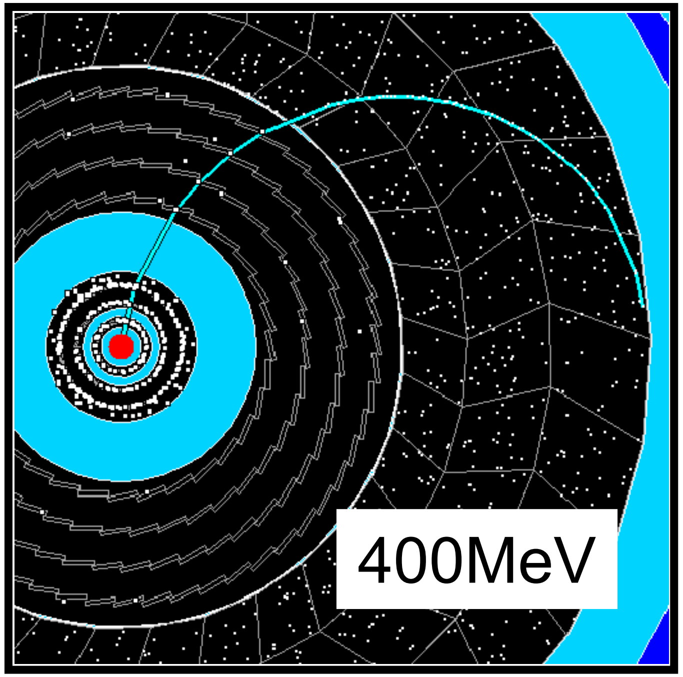
η

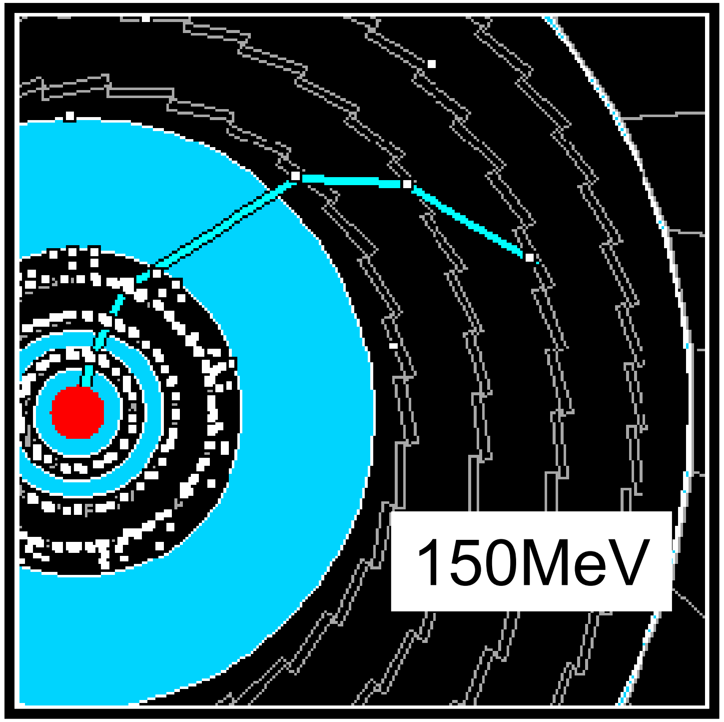


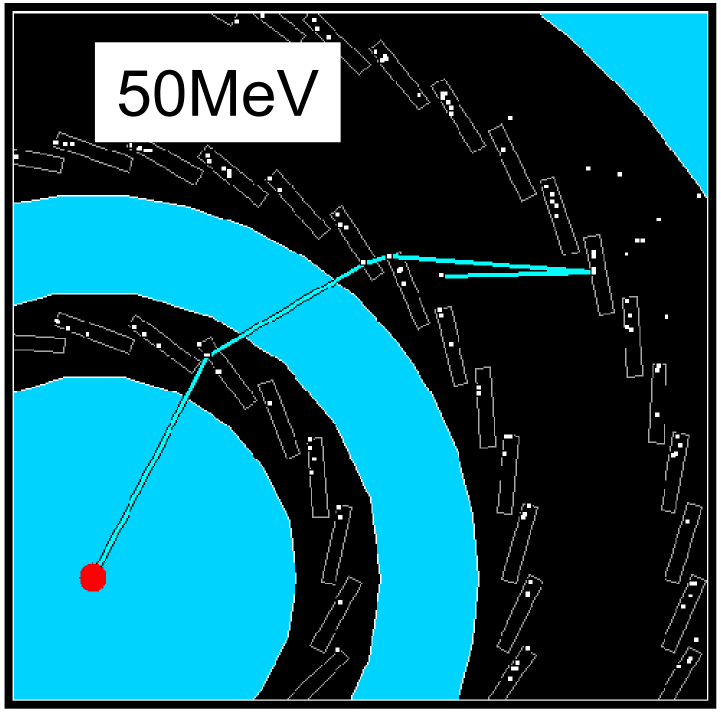
What is the momentum limit?

- Tracker is in principle sensitive to soft tracks
  P_T = 400 MeV - tracks reach end of TRT
  P_T = 150 MeV - tracks reach last SCT layer
  P_T = 50 MeV - tracks reach all Pixel layers

  → Do not need to run with low field







PDFs

- In most of relevant x regions accessible at LHC, HERA data are important source of information in PDF determinations (low-x sea and gluon PDFs)

- HERA now in second stage of operation (HERA-II)
  - substantial increase in luminosity
  - possibilities for new measurements

- HERA-II projection: improvement to high-x PDF uncertainties

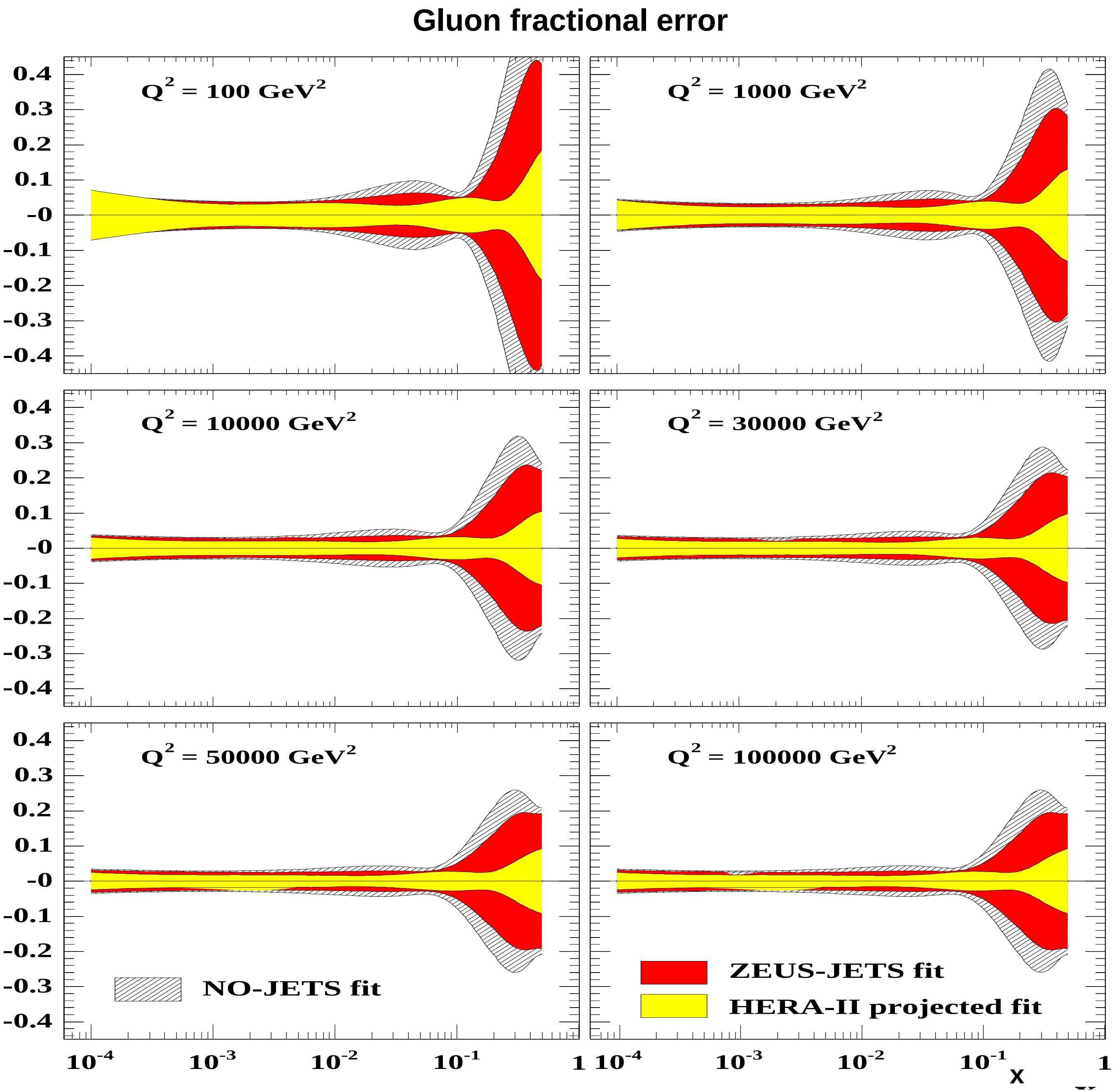
$\Rightarrow$ relevant for high-scale physics at the LHC

$\rightarrow$ where we expect new physics !!

-significant improvement to valence-quark uncertainties over all-x

-significant improvement to sea and gluon uncertainties at mid-to-high-x

-little visible improvement to sea and gluon uncertainties at low-x

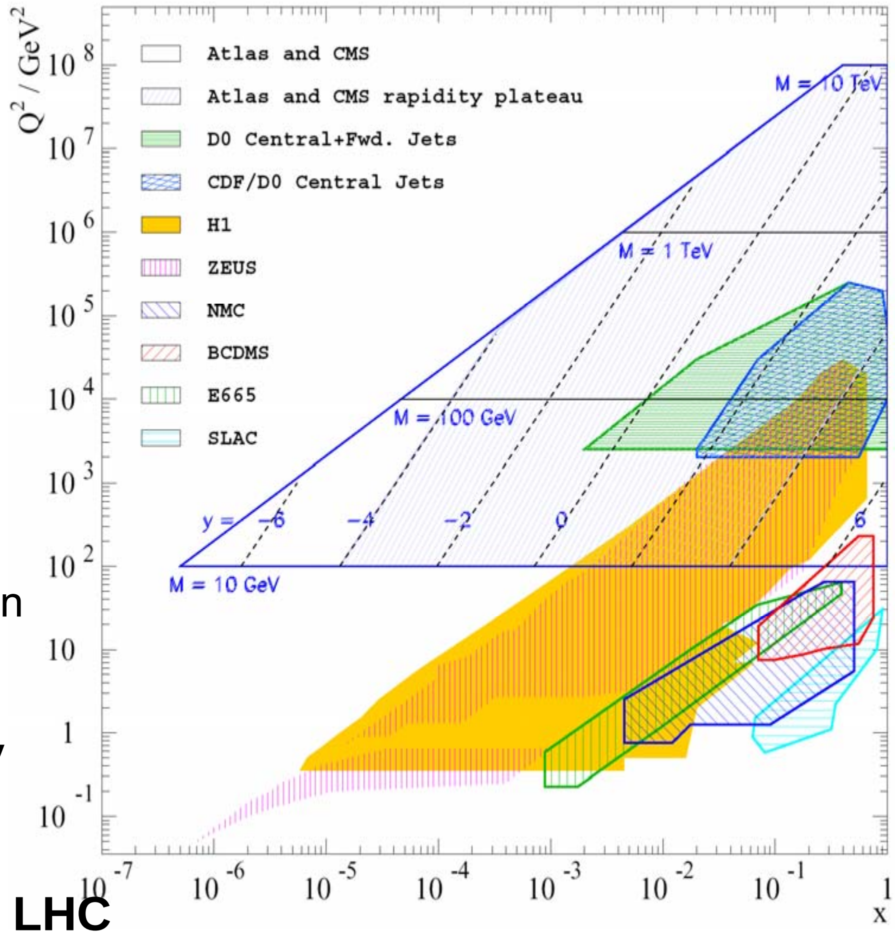

Gluon fractional error
Q² = 100 GeV²
Q² = 1000 GeV²
Q² = 10000 GeV²
Q² = 30000 GeV²
Q² = 50000 GeV²
Q² = 100000 GeV²
NO-JETS fit
ZEUS-JETS fit
HERA-II projected fit
0.4
0.3
0.2
0.1
-0
-0.1
-0.2
-0.3
-0.4
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
x

LHC Kinematic regime

Kinematic regime for LHC much broader than currently explored

→ Test of QCD:

- Test DGLAP evolution at small x:
  - Is NLO DGLAP evolution sufficient at so small x ?
  - Are higher orders $\sim \alpha_s^n \log^m x$ important?
- Improve information of high x gluon distribution



$$x_{1,2} = \frac{M}{\sqrt{s}} \exp(\pm y) \qquad Q = M \qquad y = \frac{1}{2} \ln\left(\frac{E + p_z}{E - p_z}\right)$$

At TeV scale New Physics σ's predictions are dominated by high-x gluon uncertainty
(not sufficiently well constrained by PDF fits)

At the EW scale theoretical predictions for LHC are dominated by low-x gluon uncertainty
(i.e. W and Z masses) => see later slides

How can we constrain PDF's at LHC?

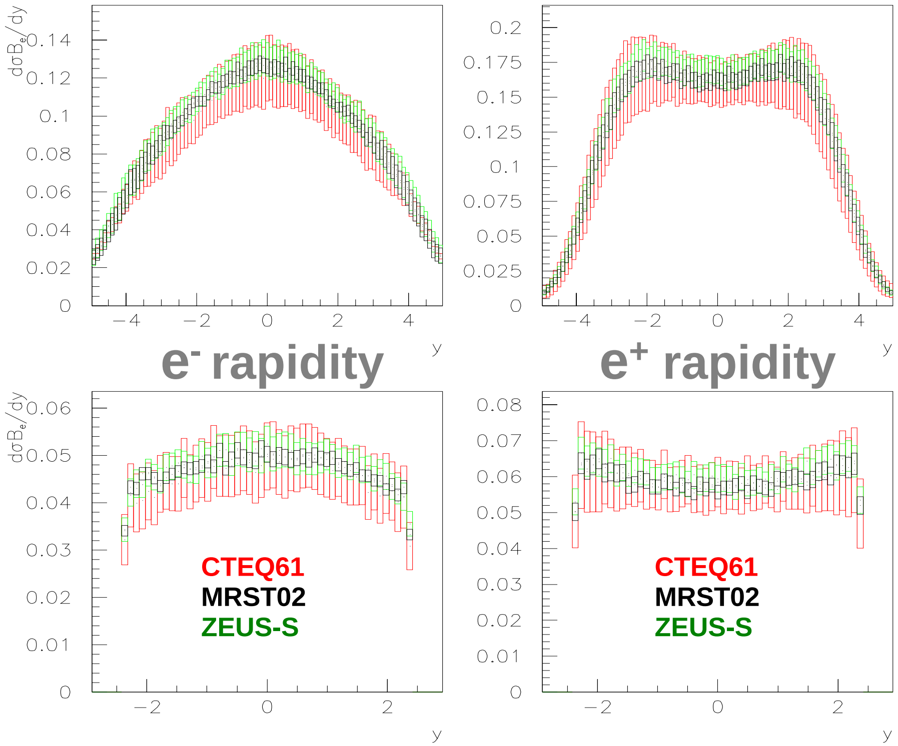
$W \rightarrow e\nu$ rapidity distributions

$$x_{1,2} = \frac{M}{\sqrt{s}} \exp(\pm y)$$

⇒ W production over |y|<2.5 at LHC involves $10^{-4} < x_{1,2} < 0.1$

⇒ region dominated by $g \rightarrow qq$

HERWIG MC Simulations with NLO Corrections



← Generator Level

Error boxes are the Full PDF Uncertainties

← ATLAS Detector Level with sel. cuts

At y=0 the total PDF uncertainty is
~ ±5.2% from ZEUS-S ~ ±3.6% from MRST01E ~ ±8.7% from CTEQ6.1M
ZEUS-S to MRST01E central value difference ~5%
ZEUS-S to CTEQ6.1 central value difference ~3.5%

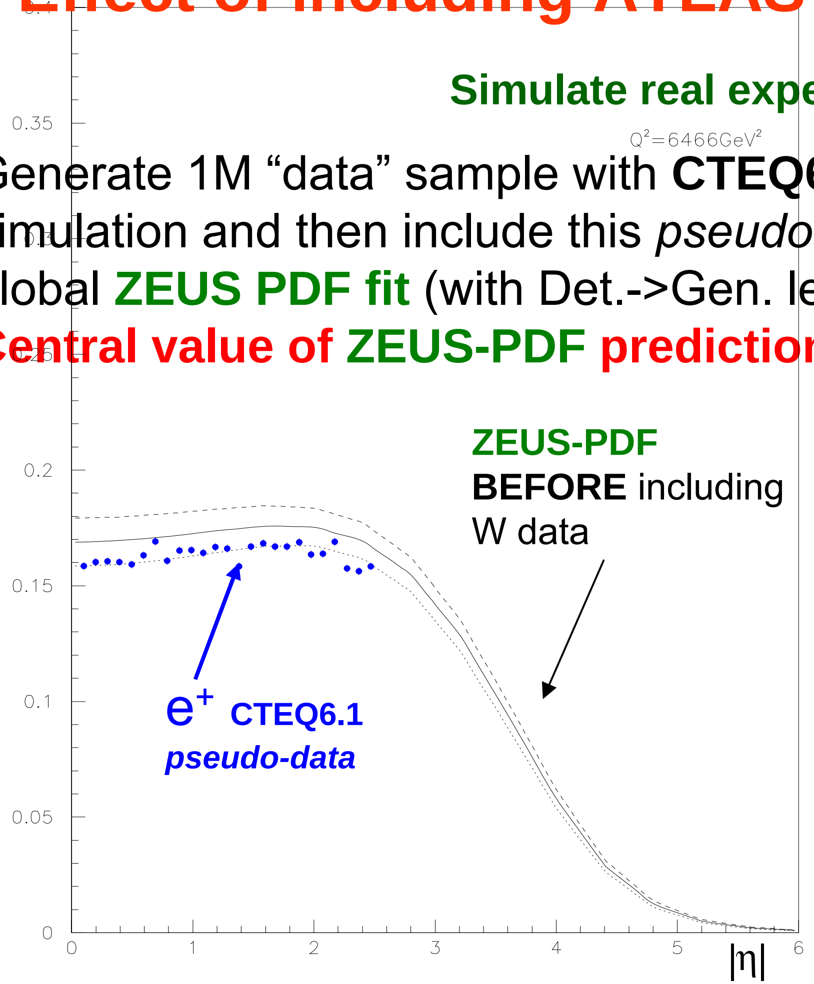
➡ **GOAL: syst. exp. error ~4%**

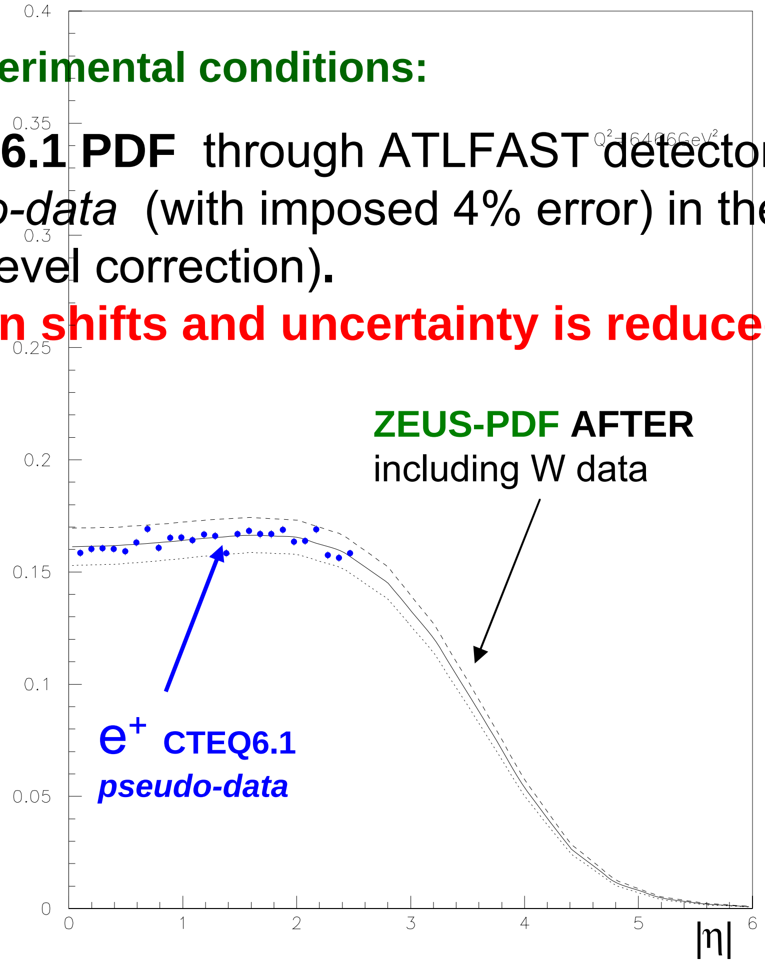
Effect of including ATLAS data on PDF fits

Simulate real experimental conditions:

Generate 1M “data” sample with **CTEQ6.1 PDF** through ATLFAST detector simulation and then include this *pseudo-data* (with imposed 4% error) in the global **ZEUS PDF fit** (with Det.->Gen. level correction).

Central value of ZEUS-PDF prediction shifts and uncertainty is reduced:





low-x gluon shape parameter λ, $xg(x) \sim x^{-\lambda}$

BEFORE $\lambda = -0.199 \pm 0.046$

AFTER $\lambda = -0.181 \pm 0.030$

41% error reduction

In few day stat. of LHC at low Luminosity

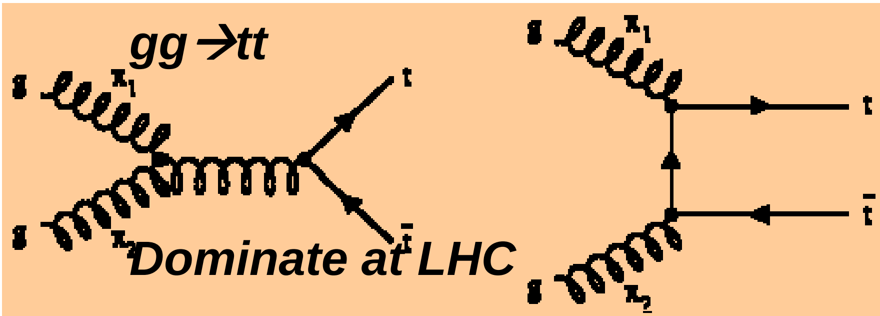
Systematics (e.g. $e^{\pm}$ acceptance vs η) can be controlled to few % with $Z \to ee$ (~ 30000 events for 100 pb^{-1})

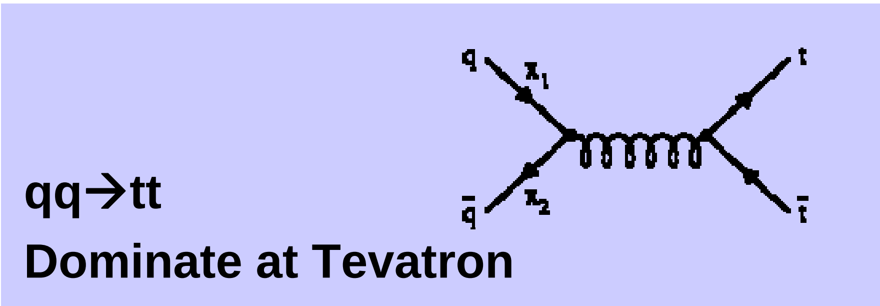
Top events to calibrate ATLAS!

Large ttbar production cross section at LHC

Effect of large √s at LHC → threshold for ttbar production at lower x

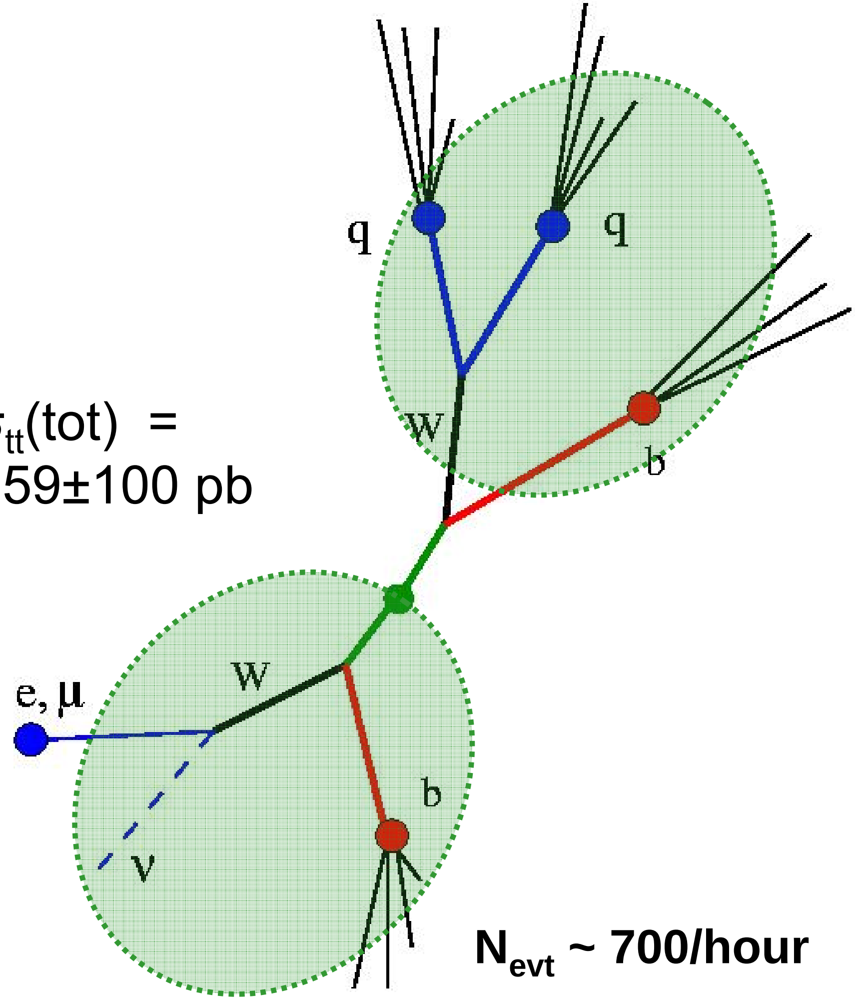
$\hat{s} = s x_1 x_2 \quad ; \quad x_1 x_2 \sim 10^{-3}$



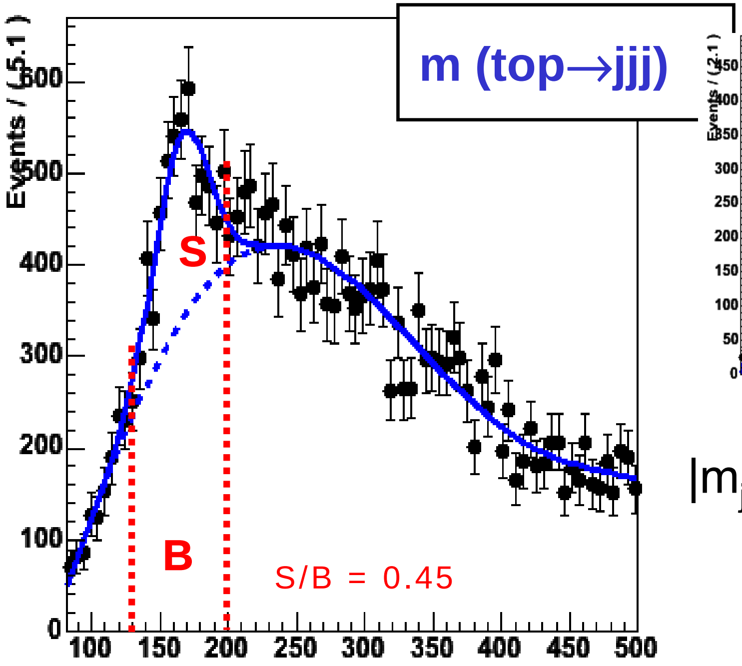


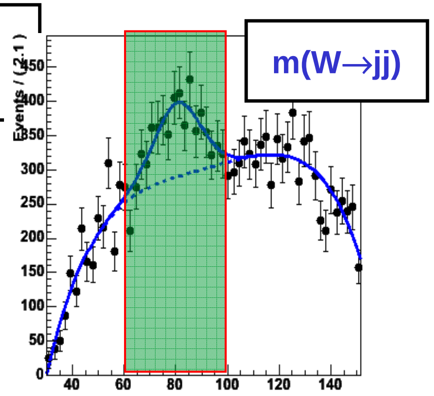
σ_{tt}(tot) = 759±100 pb

σ about 100 times larger than at Tevatron (lumi also much larger)

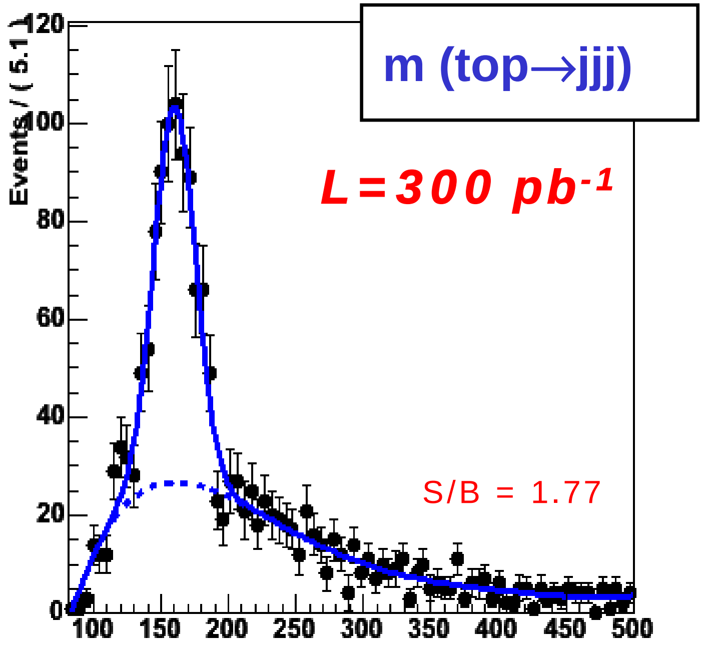


N_{evt} ~ 700/hour





$|m_{jj}-m_W| < 10$ GeV



S : MC @ NLO

B : AlpGen x 2 to account for W+3,5 partons (pessimistic)

Expect ~ 100 events inside mass peak with only 30 pb^{-1}

→top signal observable in early days with no b-tagging and simple analysis

→ W+jets background can be understood with MC+data (Z+jets)

tt excellent sample to:

- commission b-tagging, set jet E-scale using W→jj peak and MW constraint
- understand detector performance and reconstruction tools (e, μ, jets, b-jets, missing E_T, ..)
- understand / tune MC generators using e.g. p_T spectra

Early discovery: Z' with SM-like couplings

Mass	Expected events for 1 fb^{-1} (after all cuts)	∫L dt needed for discovery (corresponds to 10 observed evts)
1 TeV	~ 160	~ 70 pb^{-1}
1.5 TeV	~ 30	~ 300 pb^{-1}
2 TeV	~ 7	~ 1.5 fb^{-1}

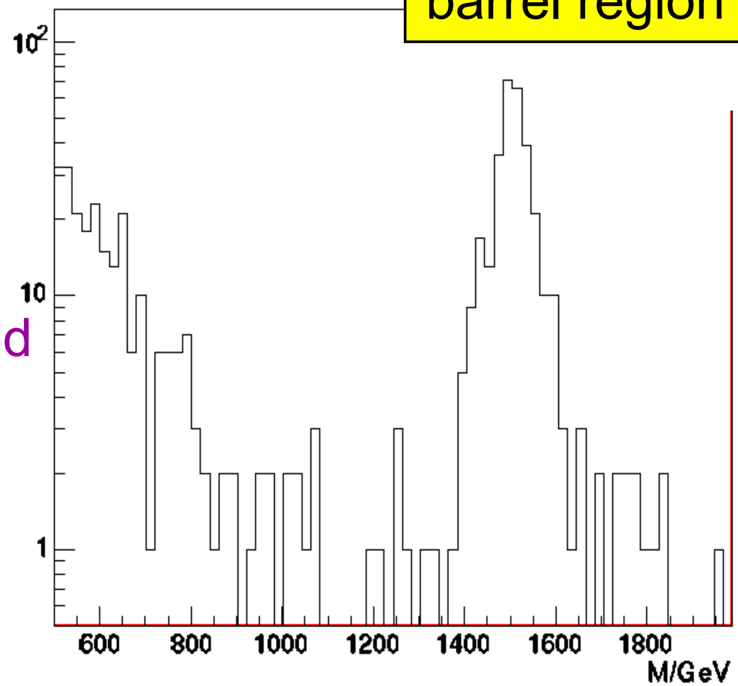
$Z' \rightarrow ee$, SSM

- large enough signal sample with ∫L dt ~ 100 pb^{-1} up to m ≈ 1 TeV if "reasonable" Z'ee couplings

- dominant Drell-Yan background small (< 0.2 events in the region 1.4-1.6 TeV, 100 pb^{-1})

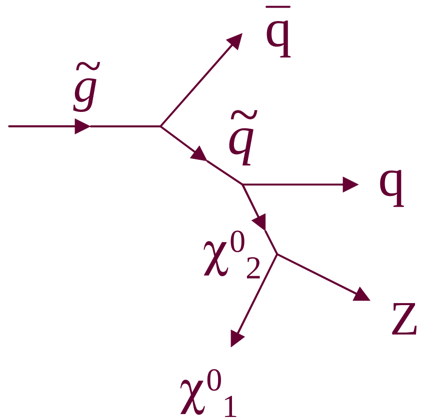
- signal as <u>mass peak</u> on top of background

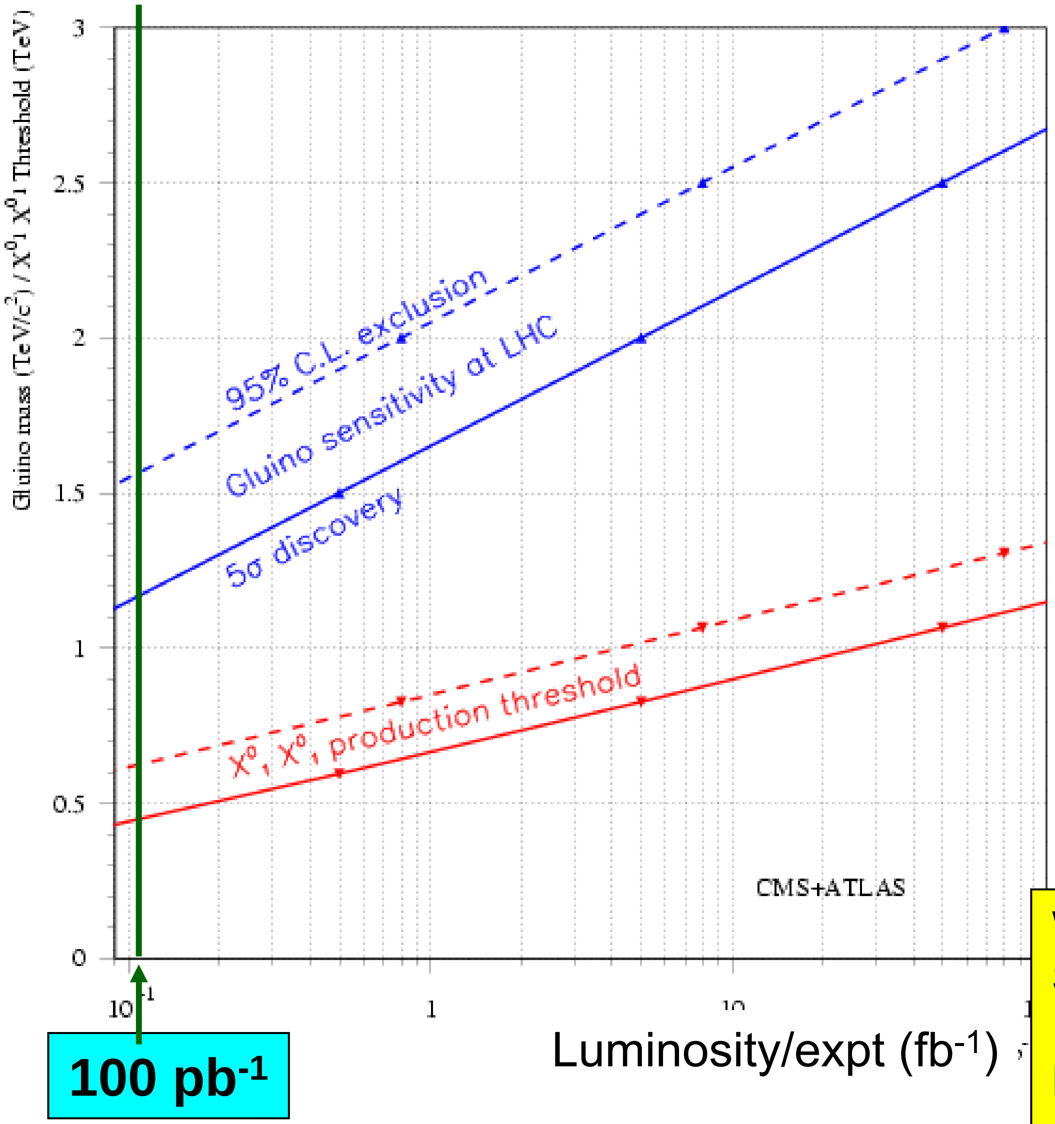
ATLAS, 10 fb^{-1}, barrel region



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

Early discovery: SUSY ?





If SUSY stabilizes m_H → at TeV
→ could be found quickly ….

thanks to:

- large $\tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ cross-section → ≈10 events/day at 10^{32} with $m(\tilde{q}, \tilde{g}) \sim 1$ TeV

- spectacular signatures (many jets, leptons, missing transverse energy)

With 100 (good) pb^{-1} LHC can say if SUSY accessible to 1 TeV linear collider

But : it will take a lot time to understand detectors and backgrounds …

Main backgrounds to SUSY searches in jets + E_T^{miss} topology (one of the most "dirty" signatures …) :

- W/Z + jets with $Z \rightarrow \nu\nu$, $W \rightarrow \tau\nu$, tt; etc.
- QCD multijet events with fake E_T^{miss} from jet mis-measurements (calorimeter resolution and non-compensation, cracks, …)
- cosmics, beam-halo, detector problems overlapped with high-p_T triggers,

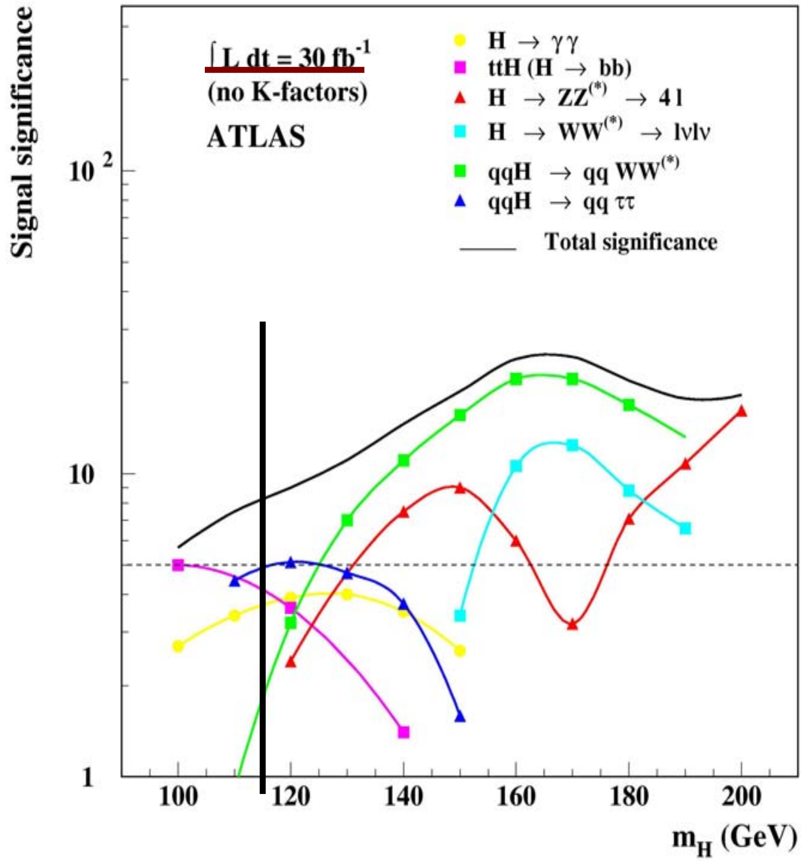
Estimate backgrounds using as much as possible da (control es) and MC

Understanding E_t^{miss} spectrum:

one of most crucial experimental issues for SUSY searches at hadron colliders.
Note: can also use final states with leptons (cleaner …)

Background process (examples ….)	**Co (exam**
$Z (\rightarrow \nu\nu)$ + jets	$Z (\rightarrow$ e
$W (\rightarrow \tau\nu)$ + jets	W (
tt→ blνbjj	tt→ blν blν
QCD multijets	lower E_T sam

Early discovery: Higgs ?



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

1 fb^{-1}: 95% C.L. exclusion
5 fb^{-1}: 5σ discovery
over full allowed mass range

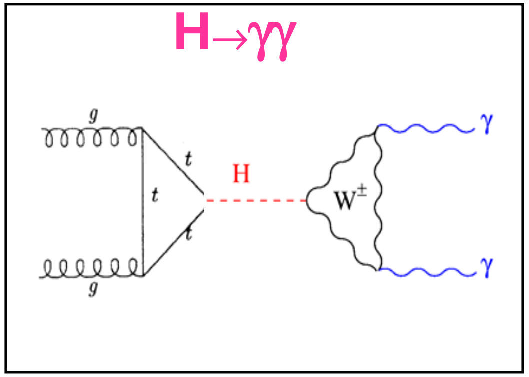
total S/ √B ≈ $4^{+2.2}_{-1.3}$

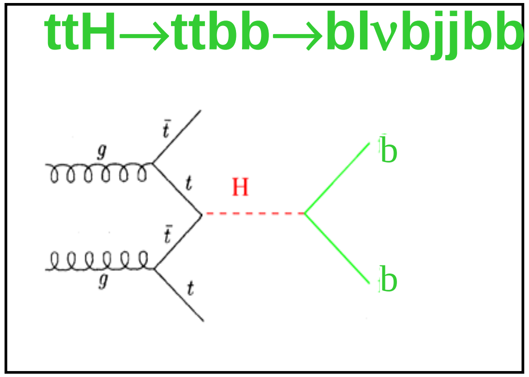
m_H ~ 115 GeV 10 fb^{-1}

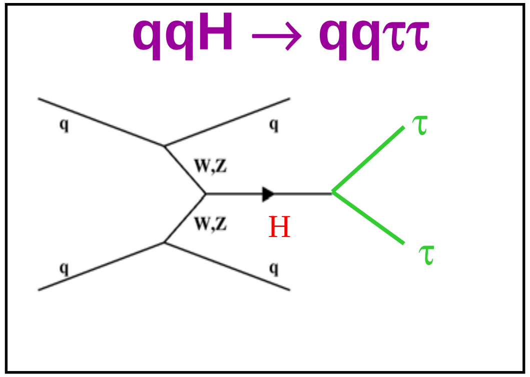
ATLAS	**H → γγ**	**ttH → ttbb**	**qqH → qqττ (ll + l-had)**
S B	130 4300	15 45	~ 10 ~ 10
S/ √B	2.0	2.2	~ 2.7

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

3 channels are complementary → robustness:







- different production and decay modes
- different backgrounds
- different detector/performance requirements:
  - -- ECAL crucial for H → γγ (in particular response uniformity) : σ/m ~ 1% needed
  - -- b-tagging crucial for ttH : 4 b-tagged jets needed to reduce combinatorics
  - -- efficient jet reconstruction over |η| < 5 crucial for qqH → qqττ : 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

Conclusions

- **Main goals for 2007:**
  - complete installation by February 2007
  - deliver first collisions in Summer 2007

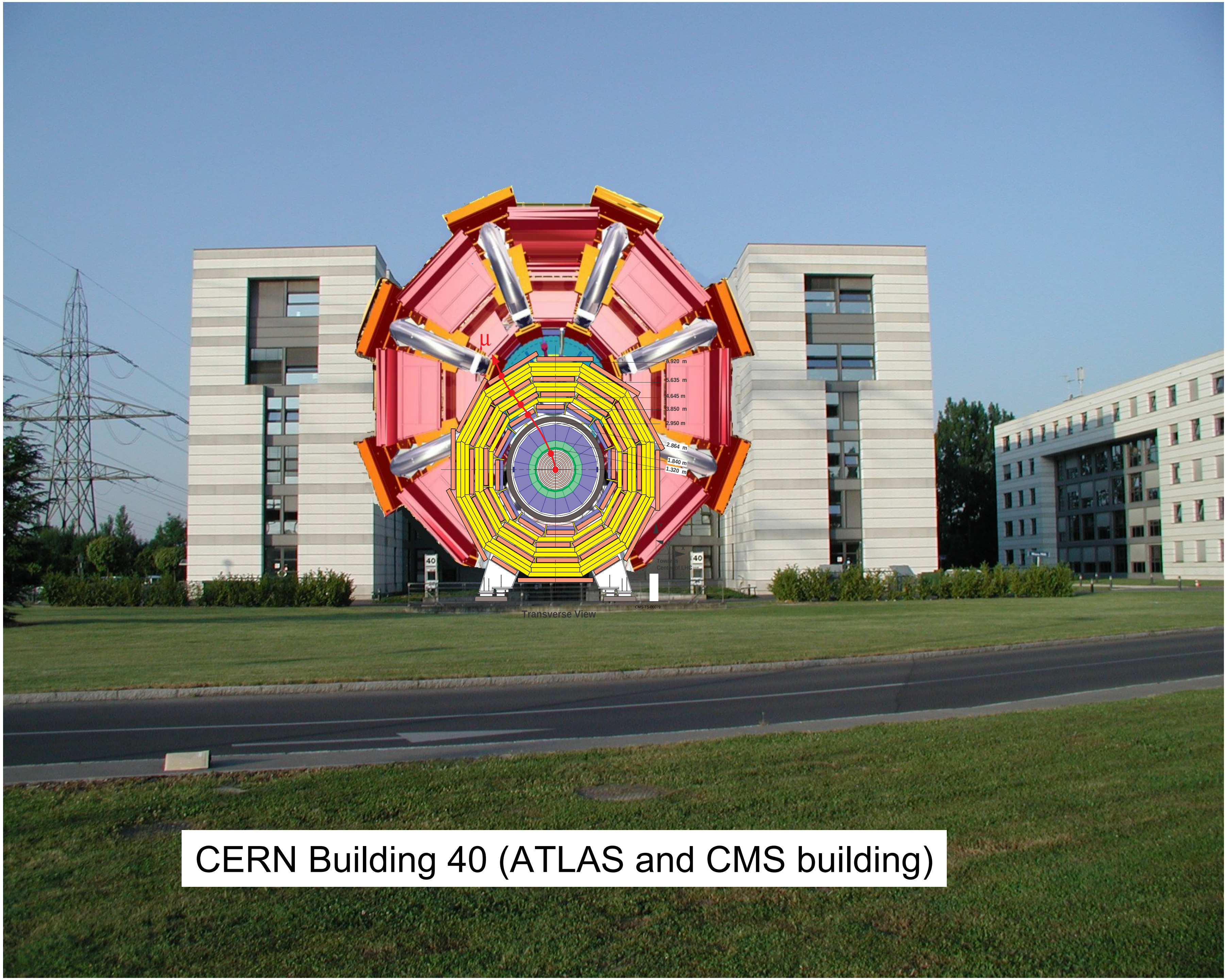
- **Emphasis now on integration, installation, commissioning**
  Unprecedented complexity, technology and performance

- **With first data measure and understand:**
  - detector performance in situ ⇔ physics
  - particle multiplicity in minimum bias
  - QCD jets (>10^3 events with E_T (j) > 1 TeV with 100 pb^{-1}) and UE
  - W,Z cross-sections: to 15% with <10 pb^{-1} and 10% with 100 pb^{-1}?
  - top signal with ~ 30 pb^{-1}
  - σ(tt) to 20% and M_{top} to 7-10 GeV with 100 pb^{-1} ?
  - PDF (low-x gluons !) with W/Z (O(100) pb^{-1} ?)
  - first tuning of MC (MB, UE, tt, W/Z+jets, QCD jets,…)

And, later on ….

The LHC will explore in detail the highly-motivated TeV-scale with a direct discovery potential up to m ≈ 5-6 TeV

- if New Physics is there, the LHC will find it
- it will say the final word about the SM Higgs mechanism and many TeV-scale predictions
- it may add crucial pieces to our knowledge of fundamental physics → impact also on astroparticle physics and cosmology
- It will tell us which are the right questions to ask, and how to go on



CERN Building 40 (ATLAS and CMS building)