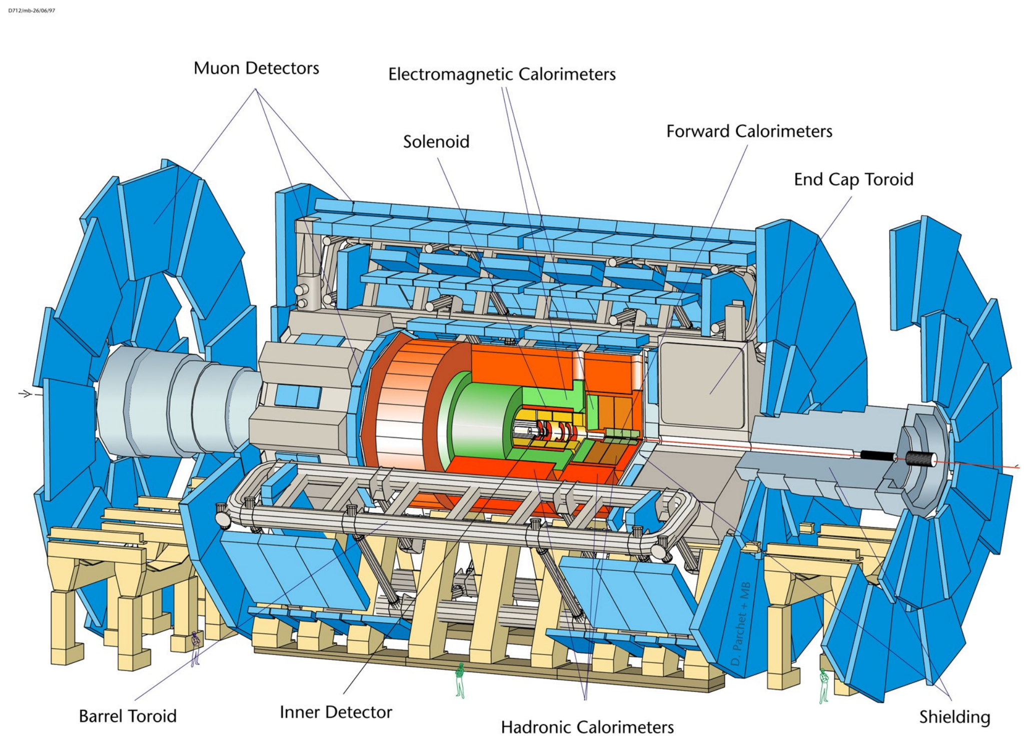
From now to 2008: the path to first data at the LHC

Giacomo Polesello

INFN, Sezione di Pavia

The ATLAS detector



Length ∼45 m

Radius ∼12 m

Weight ∼7000 m

Silicon pixel Detector: $\sim 1.4 \times 10^8$ Channels

SemiConductor Tracker: $\sim 6 \times 10^6$ Channels

Transition Radiation Tracker: $\sim 4 \times 10^5$ Channels

Liquid Argon Calorimeters $\sim 1.8 \times 10^5$ Channels

Tile Hadronic Calorimeter $\sim 10^5$ Channels

Muon Precision Chambers and Trigger $\sim 1.2 \times 10^6$ Channels

Many subsystems

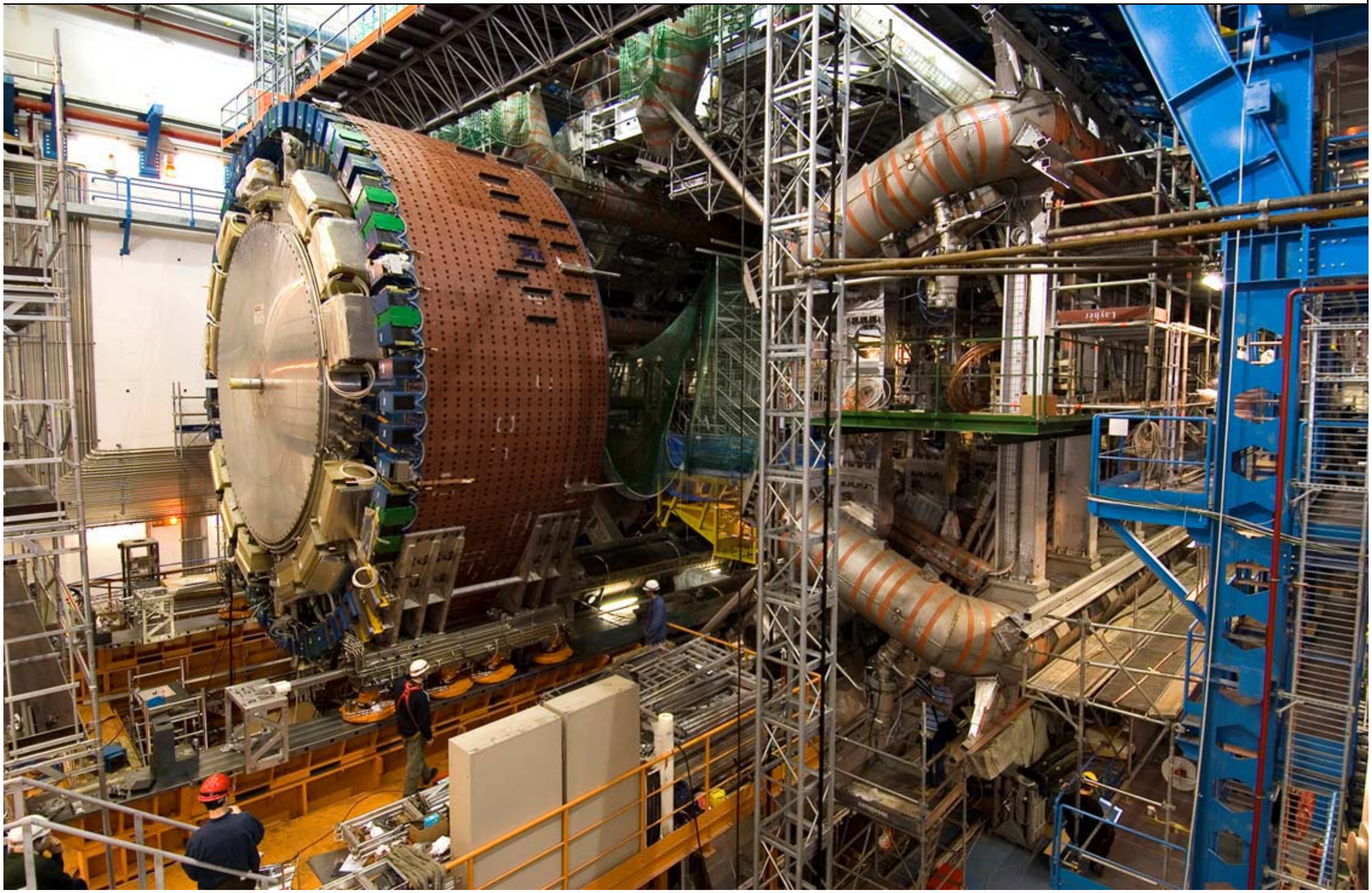
Many readout channels

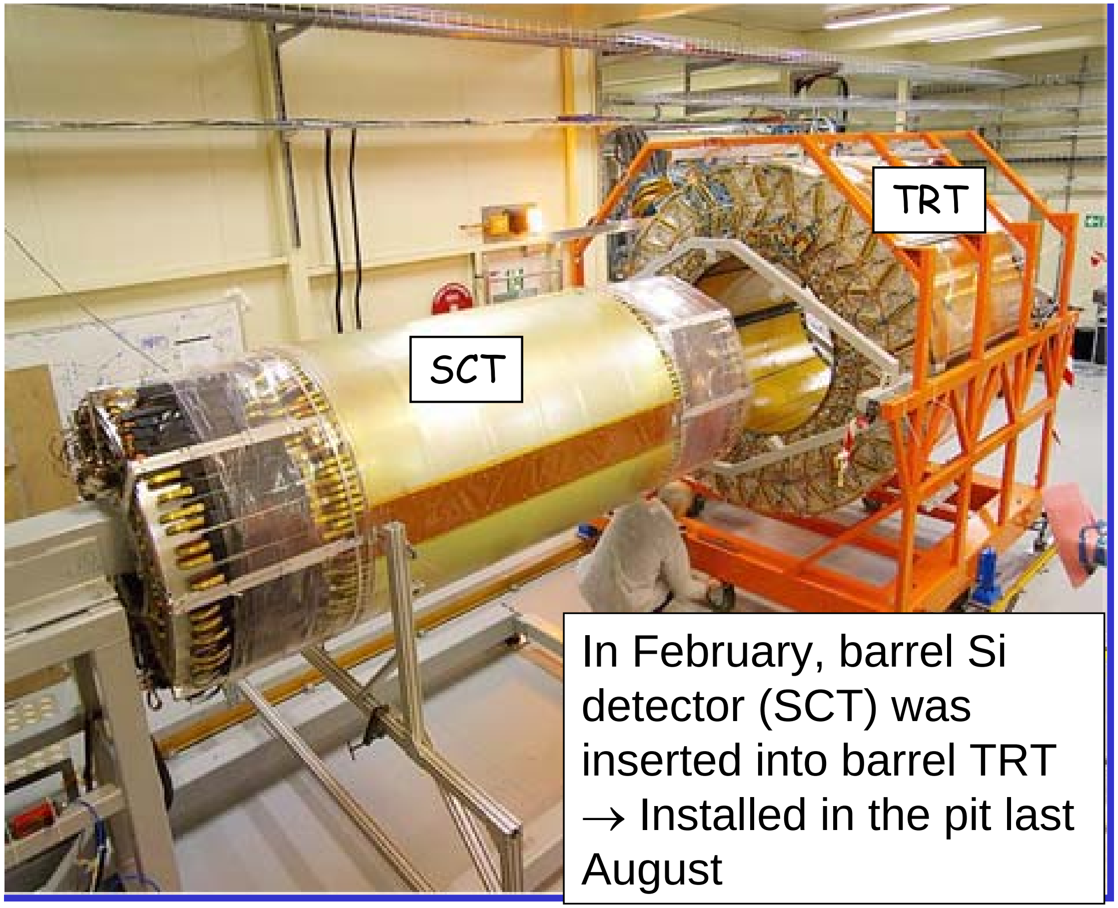
Complex commissioning

and integration

The detector is getting together in the pit....

End-cap calorimeter (LAr EM, LAr HAD, LAr Forward inside same cryostat, surrounded by HAD Fe/Scintillator Tilecal) being moved inside the barrel toroid





In February, barrel Si detector (SCT) was inserted into barrel TRT → Installed in the pit last August

...now we have to commission it, to understand its behaviour, and to bring it to the required performance

Ambitious physics program driving severe performance requirements

- Lepton measurement: $p_T \sim \mathrm{GeV} \rightarrow 5\mathrm{TeV}$ ($b \rightarrow lX$, W', Z')
- Mass Resolution (m~ 100 GeV):

  $\sim 1\%$ $(H \rightarrow \gamma\gamma, 4l)$

  $\sim 10\%$ ($W \rightarrow jj$, $H \rightarrow bb$)

- Calorimeter coverage: $|\eta| < 5$ (E_T^{miss}, forward jet tag)
- Particle identification :

  $\epsilon_b \sim 50\%$ $R_j \sim 100$ ($H \rightarrow bb$, SUSY)

  $\epsilon_\tau \sim 50\%$ $R_j \sim 100$ $(A/H \rightarrow \tau\tau)$

  $\epsilon_\gamma \sim 80\%$ $R_j \sim 10^3$ $(H \rightarrow \gamma\gamma)$

  $\epsilon_e > 50\%$ $R_j \sim 10^5$

- Trigger: 40 MHz$\rightarrow$ 100 Hz reduction

Precision measurements require excellent control of performance

- Absolute luminosity: Goal: $< 5\%$

  Use: Machine, Optical theorem, Cross-Section for known processes

  (W, Z production, QED $pp \to pp\ell\ell$)

- Lepton energy scale: Goal: 0.1% (General)

  0.02% (W mass)

  Use: $Z \to \ell\ell$ (1 ev/s at low L)

  High precision possible for W, low mass h as mass close to Z

- Jet energy scale: Goal: 1%

  Use: $Z + jets(Z \to \ell\ell)$, $\gamma + jets$, $W \to jj$ from top decay, multi-jet balance

  Needed for for SUSY parameter, top mass, jet cross-section

  Limited by physics effects

Commissioning scenarios

Summing up:

- Complex detector with tens of millions of channels and many different subsystems
- Ambitious performance goals

Large amount of work (and time) required to control detector at desired level

Need however to be ready to optimally exploit the very first LHC data

Final understanding of detectors only with real collisions in LHC environment

Develop strategy to exploit time from now to collisions to achieve detector understanding adequate to fully take advantage of data from the first day

Main variables: readiness of detectors, time before LHC is running at full steam, building up of integrated luminosity

Tentative LHC schedule (CERN council June 2006)

- Last magnet installed — March 2007
- Machine and experiments closed — 31 August 2007
- First collisions ($\sqrt{s} = 900$ GeV, $\mathcal{L} \sim 10^{29}\ cm^{-2}s^{-1}$) — November 2007
- Commissioning run at 900 GeV (~ 30 days) — until end 2007
- Shutdown — 3-4 months (?)
- First collisions at 14 TeV (followed by physics run) — 2^{nd} half June 2008

Two sectors fully commissioned up to 7 TeV in 2006-2007

If other sectors commissioned to to 7 TeV no circulating beam in 2007

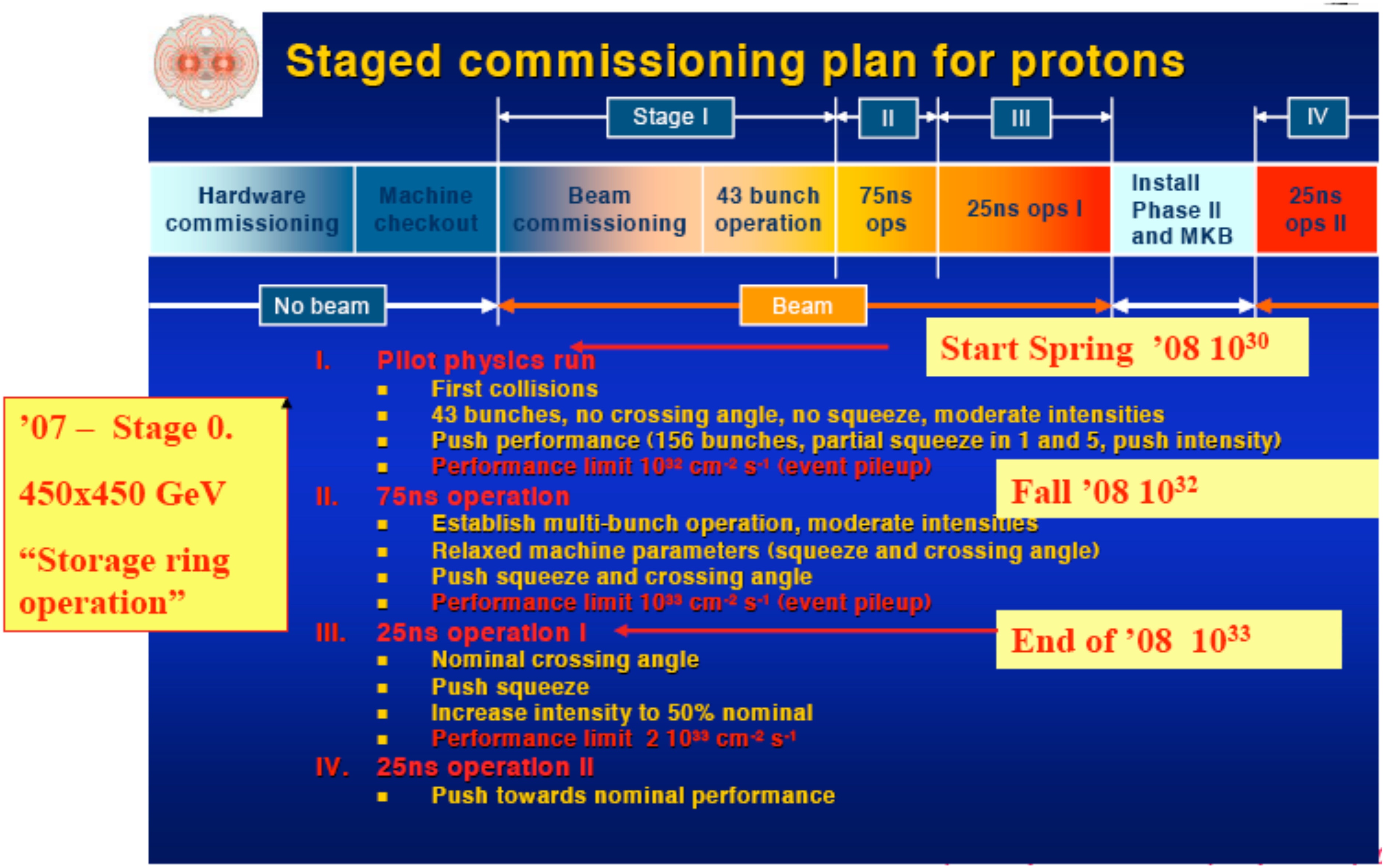
$\Rightarrow$ commission other sectors up to field needed for degaussing

Initial operation at 900 GeV (CM) with static machine (no ramp, no squeeze)

$\longrightarrow$ use for debugging of machines and detectors

Full commissioning up to 7 TeV during winter 2008 shutdown

Possible scenario for machine startup (machine presentation)



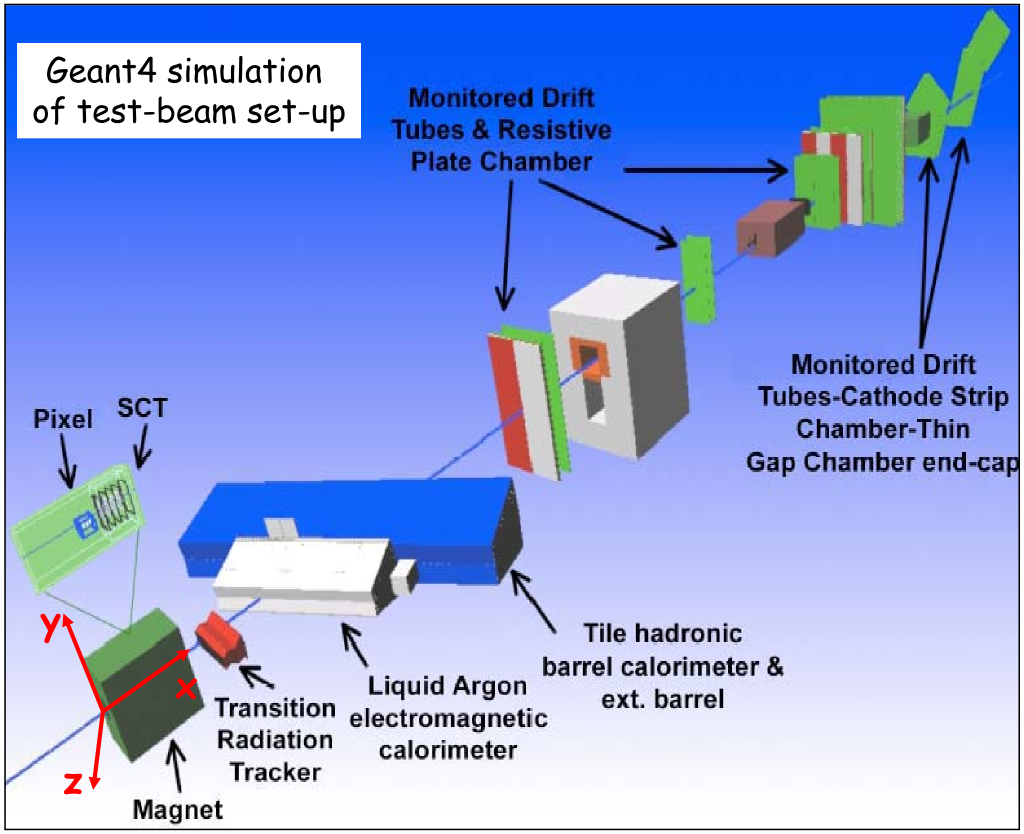
Integrated luminosities and dates: presentation by H. van der Schmitt

Based on this information develop start-up strategy

- Last few years: extensive test-beam activities with final detector components
  - Standalone Detector test beams: Basic calibration of calorimeter modules, test of electronics and alignment procedures
  - ATLAS combined test-beam of full slice of detector: test in real life particle ID algorithms, procedures of inter-detector alignment, validation of detailed simulation
- Now, extending up to most of 2007:
  - Computing System Commissioning (CSC), Calibration Data Challenge (CDC): Develop software tools for performing calibration and alignment and perform analysis on non-ideal detector: asymmetric, misaligned, miscalibrated.
  - Cosmics data taking: detector timing and alignment

- From first injections: beam-halo and beam-gas interactions. More specialised alignment work
- 900 GeV interactions: First shake-down of detector with real collisions, some physics measurements (Minimum bias, jets)
- First 14 TeV interactions:
  - Understand and calibrate detector and trigger in situ using well-known physics samples:
    - $Z \rightarrow ee, \mu\mu$: tracker, ECAL, muons system
    - $tt \rightarrow b\ell\nu bjj$: Jets scale, b-tag performance, $\not{E}_T$
  - Understand basic SM physics at 14 TeV: first checks of MonteCarlo
    - jets and W, Z cross-section top mass and cross-section
    - Event features: Min. bias, jet distributions, PDF constraints
  - Prepare road to discovery: background to discovery from tt, W/Z + jets.

Combined test beam



Full slice of ATLAS detector

($\sim$ 1% ATLAS)

$\sim$6 months of run in 2004

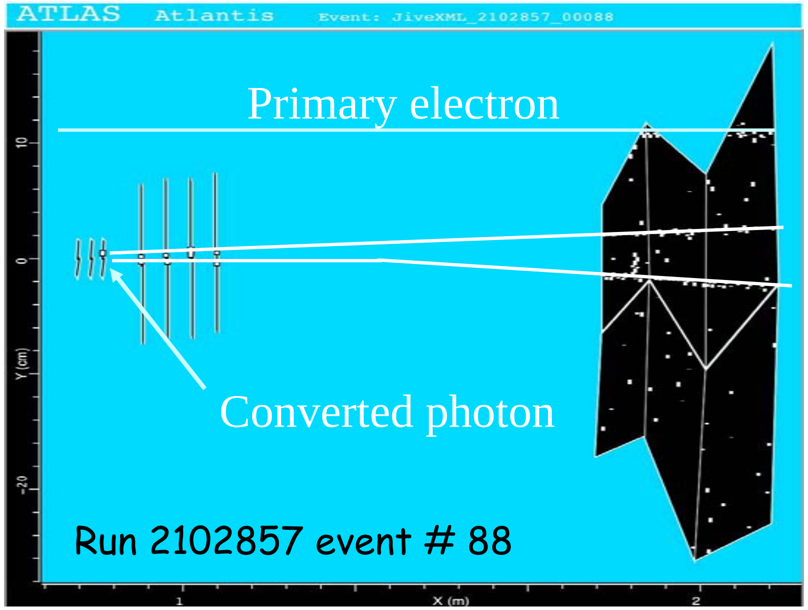
~ 90 Mevents collected

All ATLAS sub-detectors (and LVL1 trigger) integrated and run together with common DAQ and monitoring

Data analyzed with common ATLAS software. Analysis still ongoing

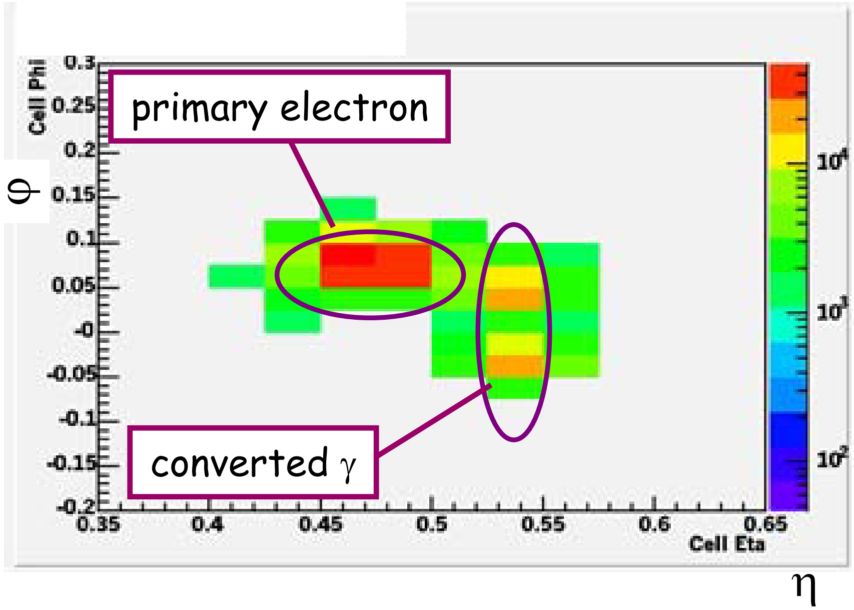
Experience of global operation and interaction among detector communities

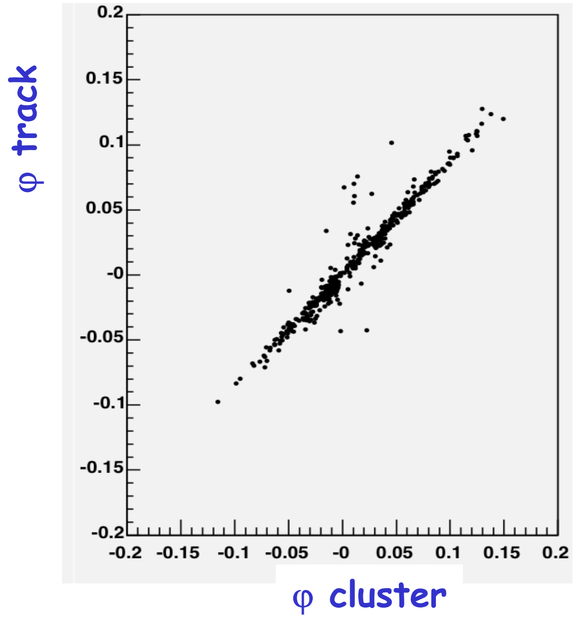
Example: study of photon conversions



In ATLAS γ-conversion probability in tracker$> 30\% \rightarrow$ need to develop efficient reconstruction tools. Unique occasion to validate these tools in real life.

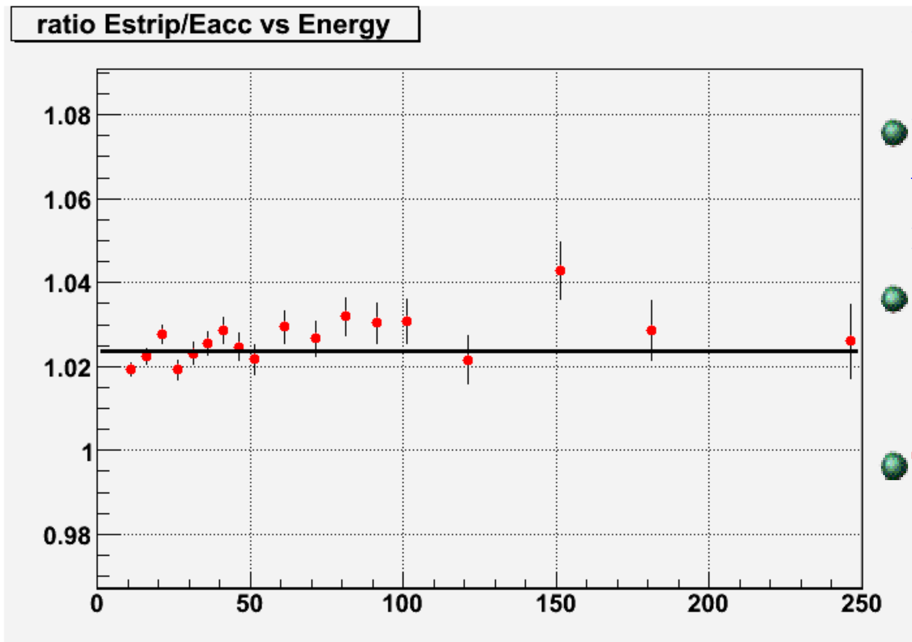
Below: correlation between track in ID and cluster in calo





From detector to physics: CTB (6)

I. Wingerter



- Absolute lead thickness was nominal; it is now as measured during construction (+1%)
- Until now, lead thickness was taken at warm: at cold, lead gets denser and X^0 reduces
- Ratio Strips/Middle increases by 2% (1.4% from increased lead thickness + 0.6% from effect at cold)
- Two effects going the *right* way.

Lead thickness + contraction at cold

Computing System Commissioning and physics

Assess our readiness for physics analysis through a detailed study of key channels with (almost) final software.

Produce a set of physics and performance notes based on simulated data produced during the Computing System Commissioning (CSC). Analysis include:

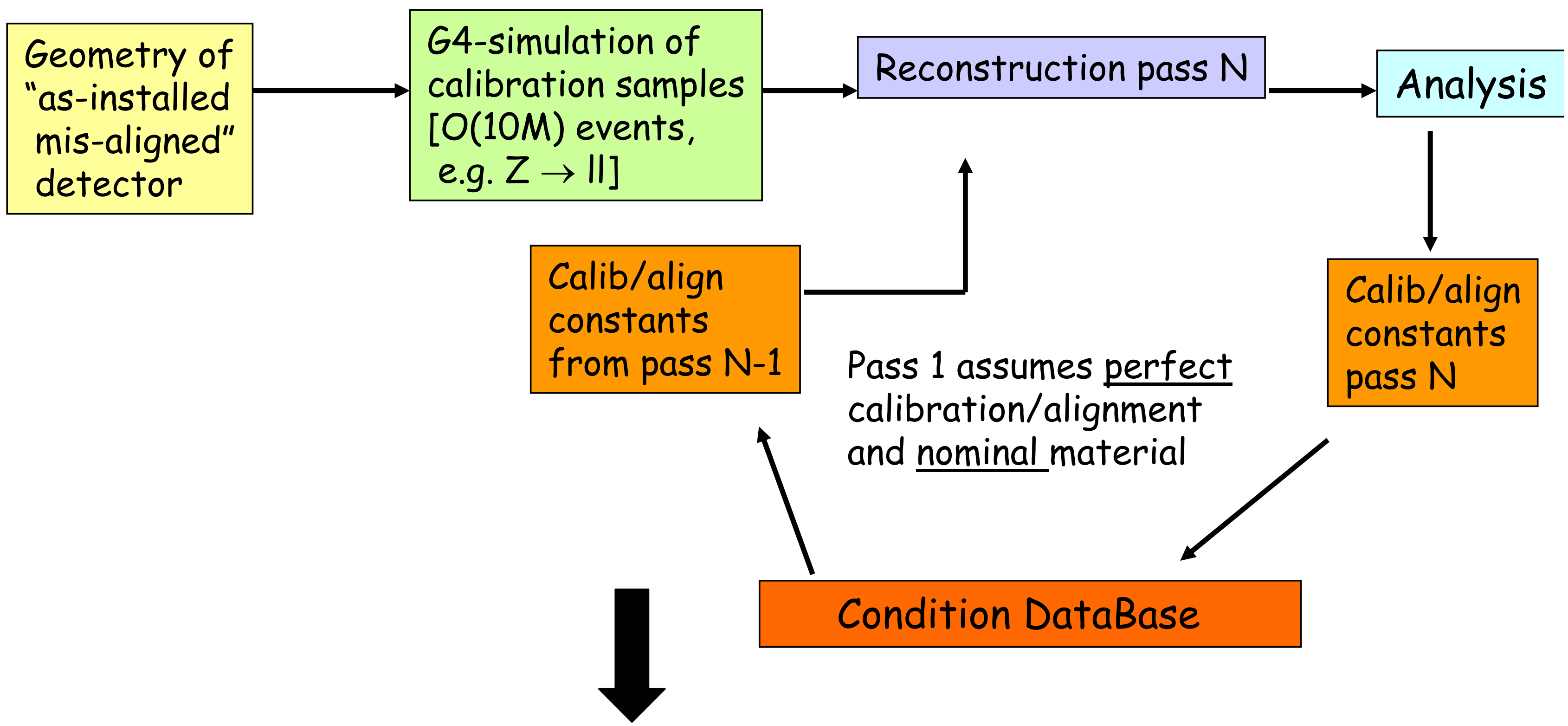
- Detector as built/installed, accurate description of dead material, dead channels, detector calibration as expected for day one, and alignment loop on detector $\Rightarrow$ connection with CDC
- Full trigger simulation, with the possibility of studying the impact of different trigger menus on early physics studies, and assess need for prescaled triggers for key early measurements

Based on $\sim 10^7$ events representative of the first $100\ pb^{-1}$ of data.

Emphasis on steps necessary to understand detector performance and to evaluate backgrounds from data

Careful work to understand activities in common among groups, (performance vs. physics), avoid duplication of effort create integration between working groups

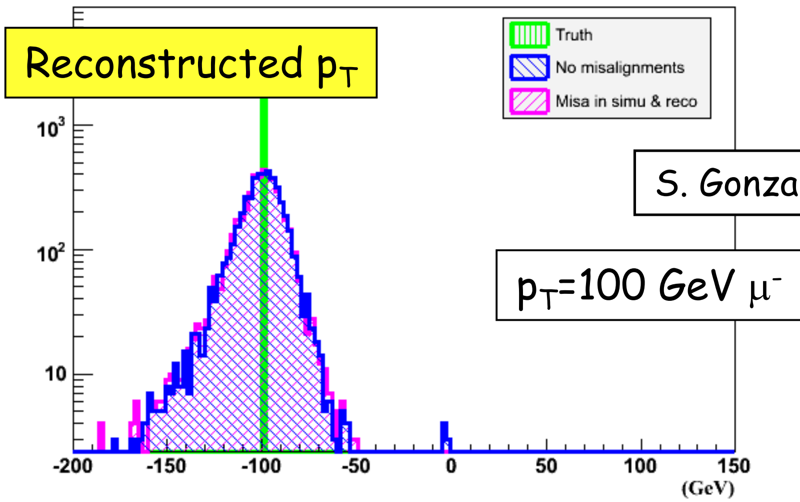
Calibration Data Challenge (CDC)



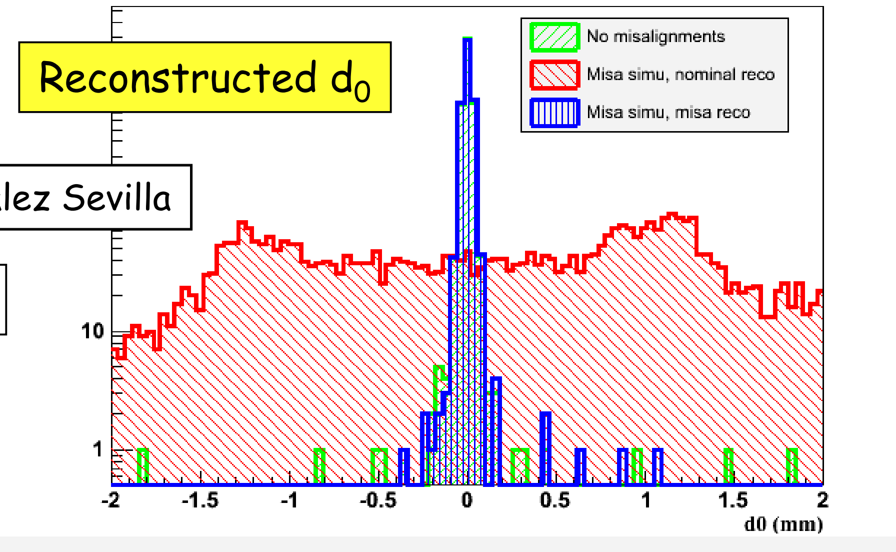
- Obtain final set of corrections, alignment and calibration constants
- Compare performance of "as-installed mis-aligned" detector after calibration and alignment to nominal (TDR) performance

From F. Gianotti

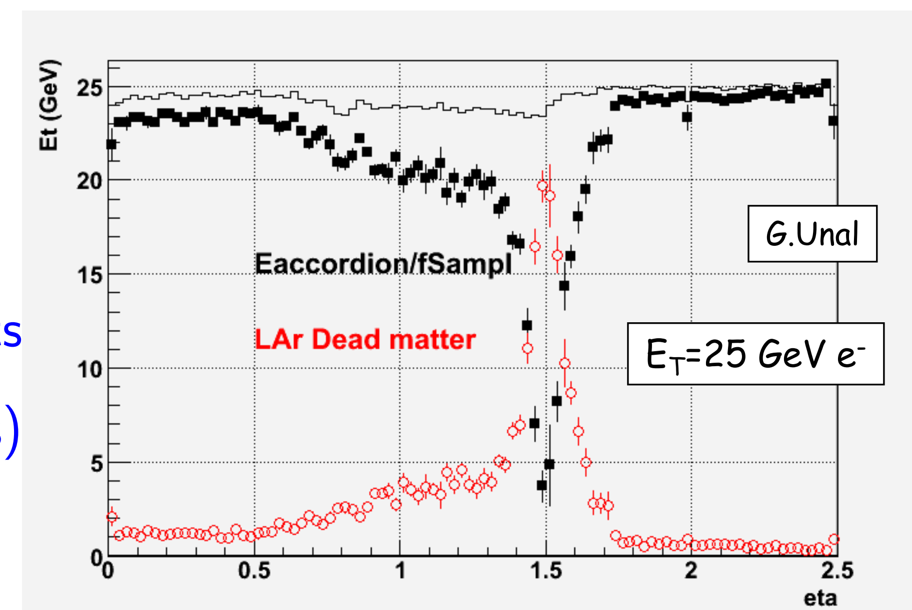
Validation of realistic geometry (12.0.3)



S. Gonzalez Sevilla



Dead material hits and calibration hits (energy released in calorimeter absorbers) available and debugged



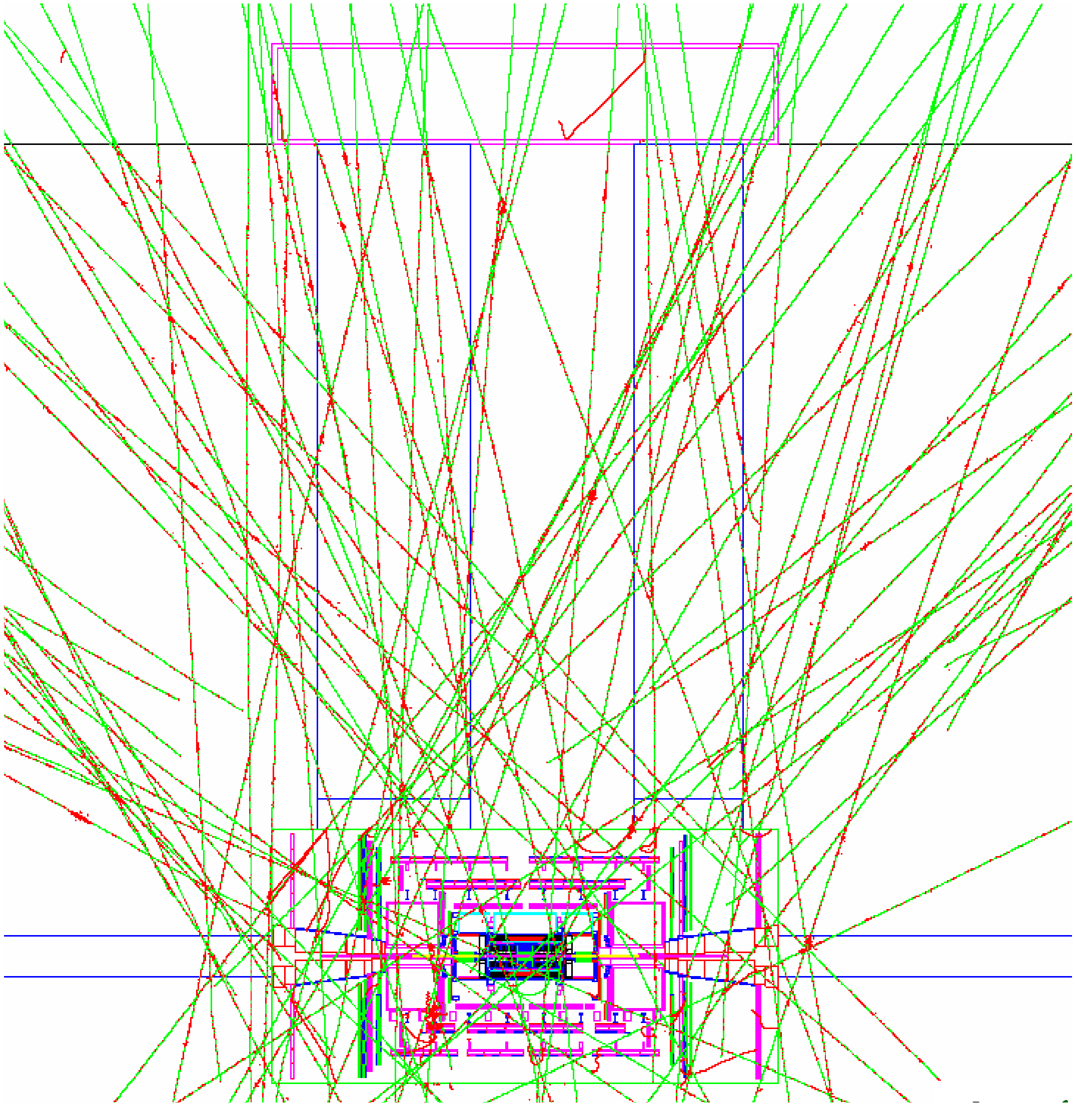
Pre-Collision phase

First detector understanding before commissioning with real collisions.

- Cosmics running (spring 2007)
  - Initial alignment of detector with particles
  - Timing-in of detectors
  - Debugging of sub-systems, mapping of dead channels, etc.
- One beam in the machine
  - beam halo muons and beam-gas events
  - more detailed alignment/calibrations for relevant detectors

Both ATLAS and CMS have developed simulation studies in order to better understand how to use these data

Cosmics



Rate from full simulation of ATLAS (including cavern overburden) validated by measurement with a scintillator telescope in cavern

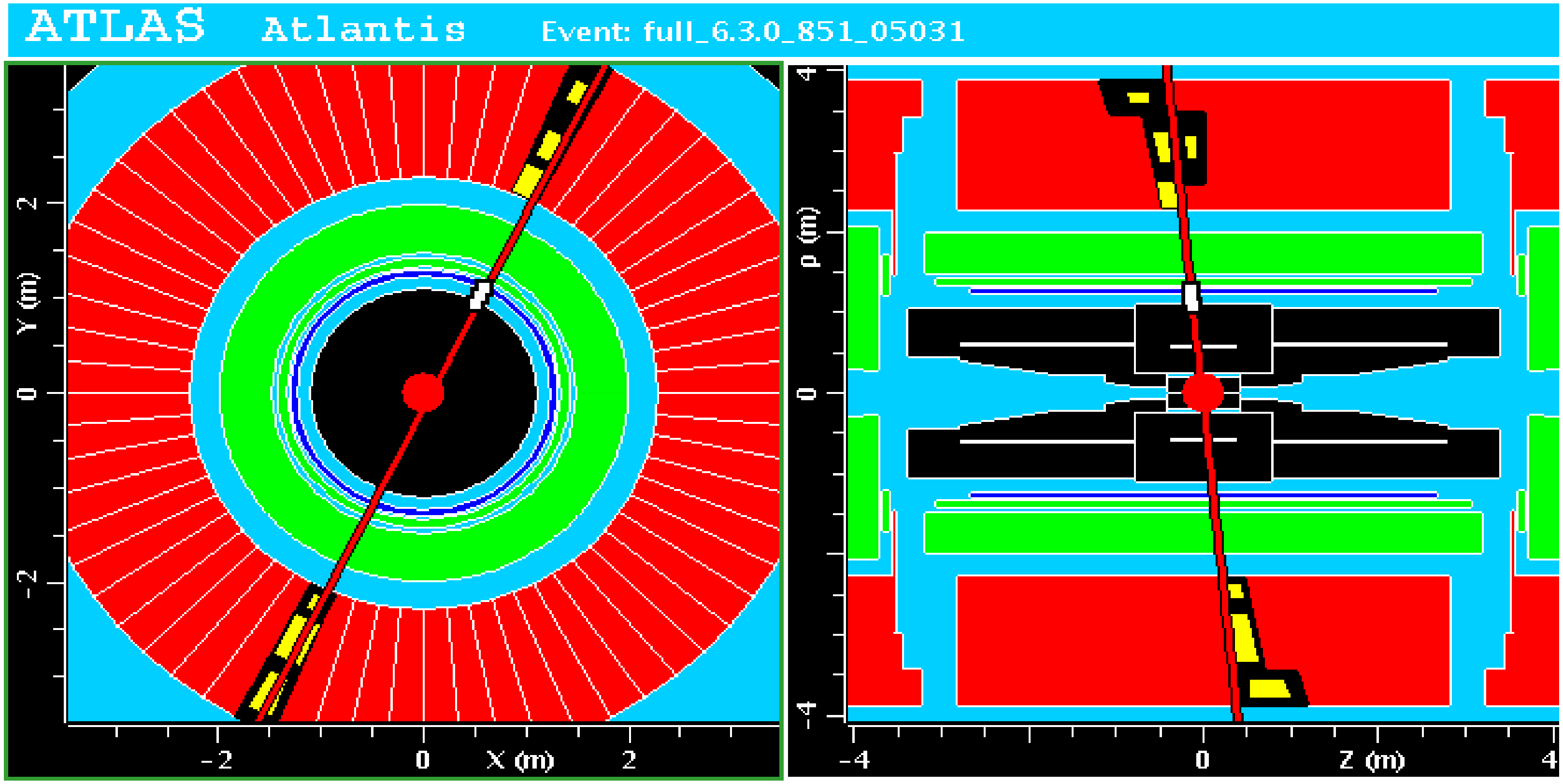
0.01 seconds shown in figure

Location	Cut	Rate (Hz) (E(surface) >10 GeV)
UX15		4900
Ecal	$E_T^{total} > 5$ GeV	0.4
Tile Cal	$E^{total} > 20$ GeV	1.2
HEC	$E^{total} > 20$ GeV	0.1
FCAL	$E^{total} > 20$ GeV	0.02

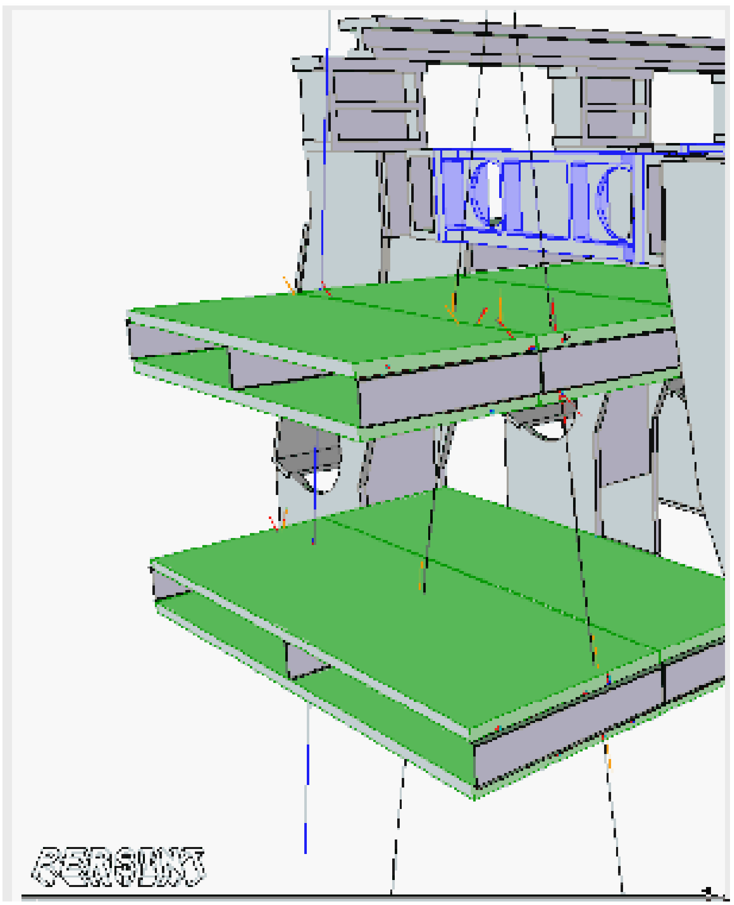
Every 10 s "Crossing" event, passing near interaction vertex

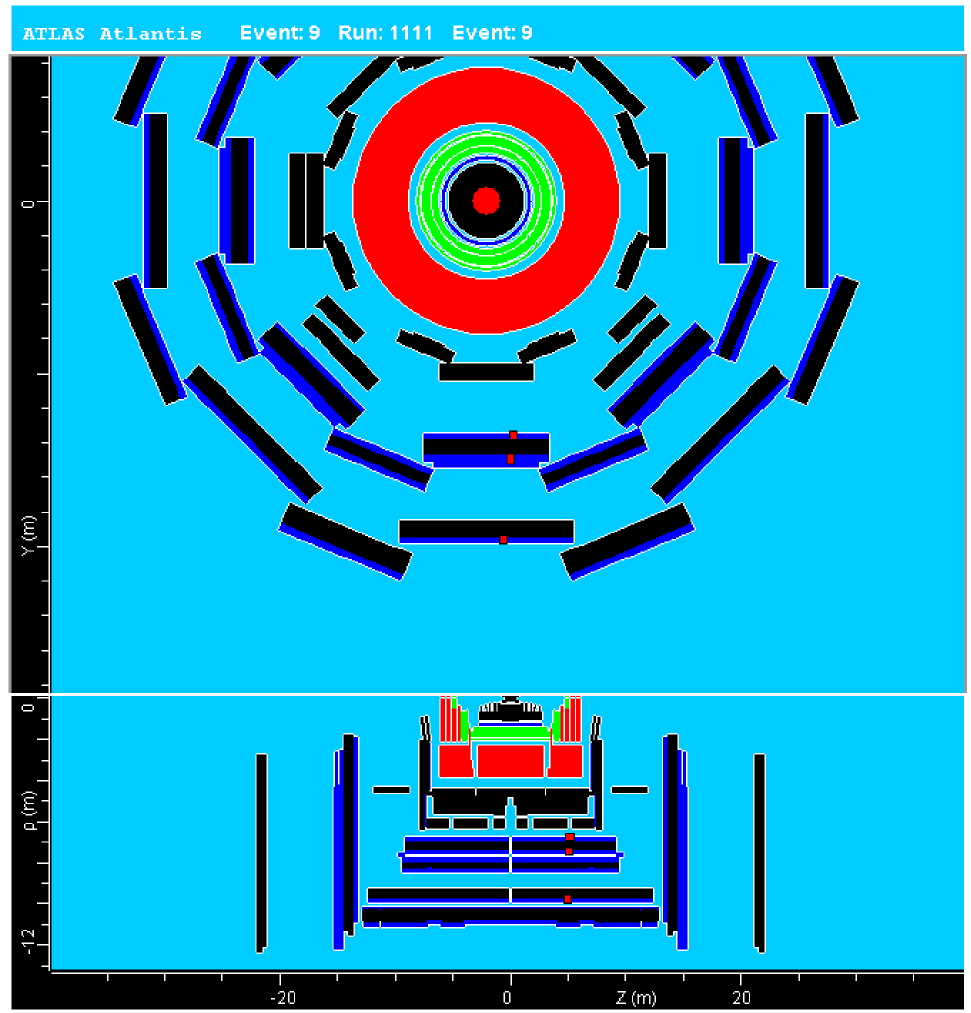
Cosmic data taking in the cavern with HCAL

Real, not simulation. Based on ad-hoc energy trigger in ECAL

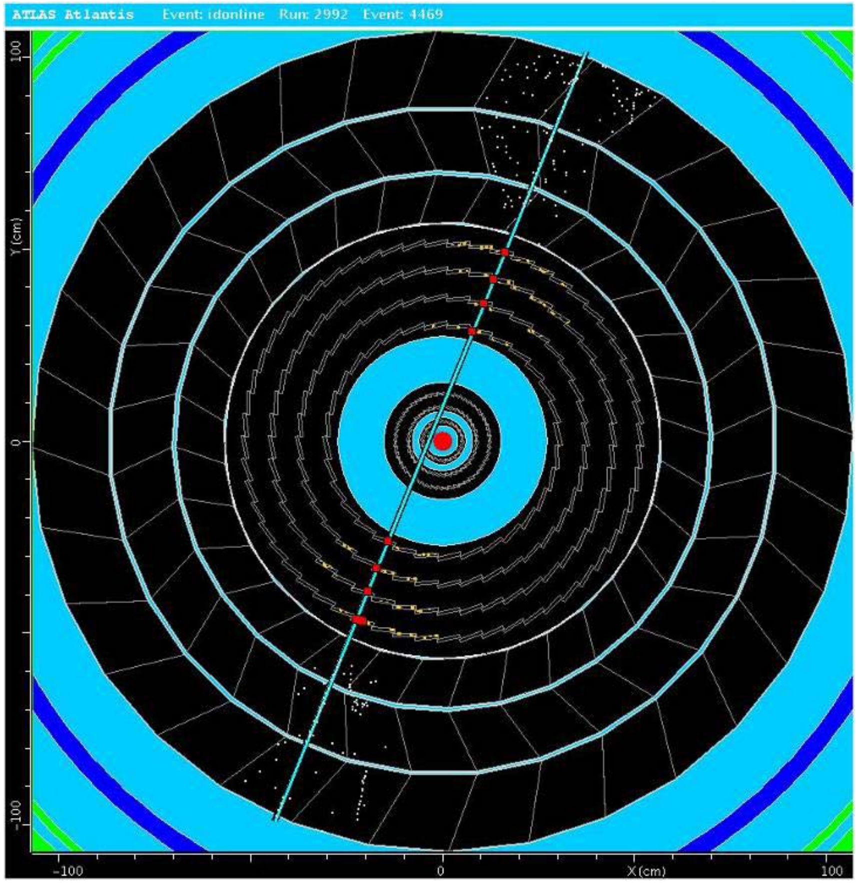


Cosmics in underground cavern with barrel muon chambers (MDT and RPC) and LVL1 μ-trigger





Cosmic data in in assembled SCT + TRT



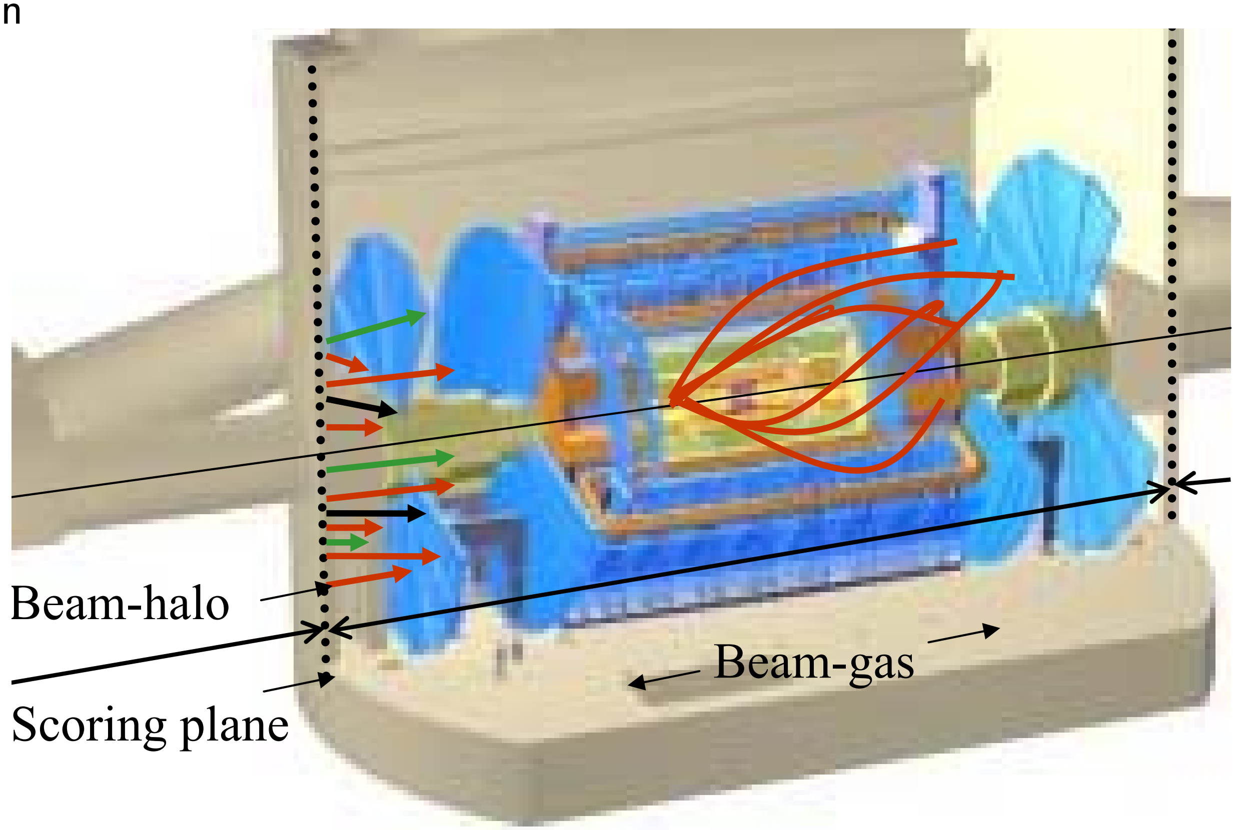
Data taken in surface building.

In the meanwhile barrel SCT+TRT installed in ATLAS (Aug 2006)

Single beam period

Beam halo:

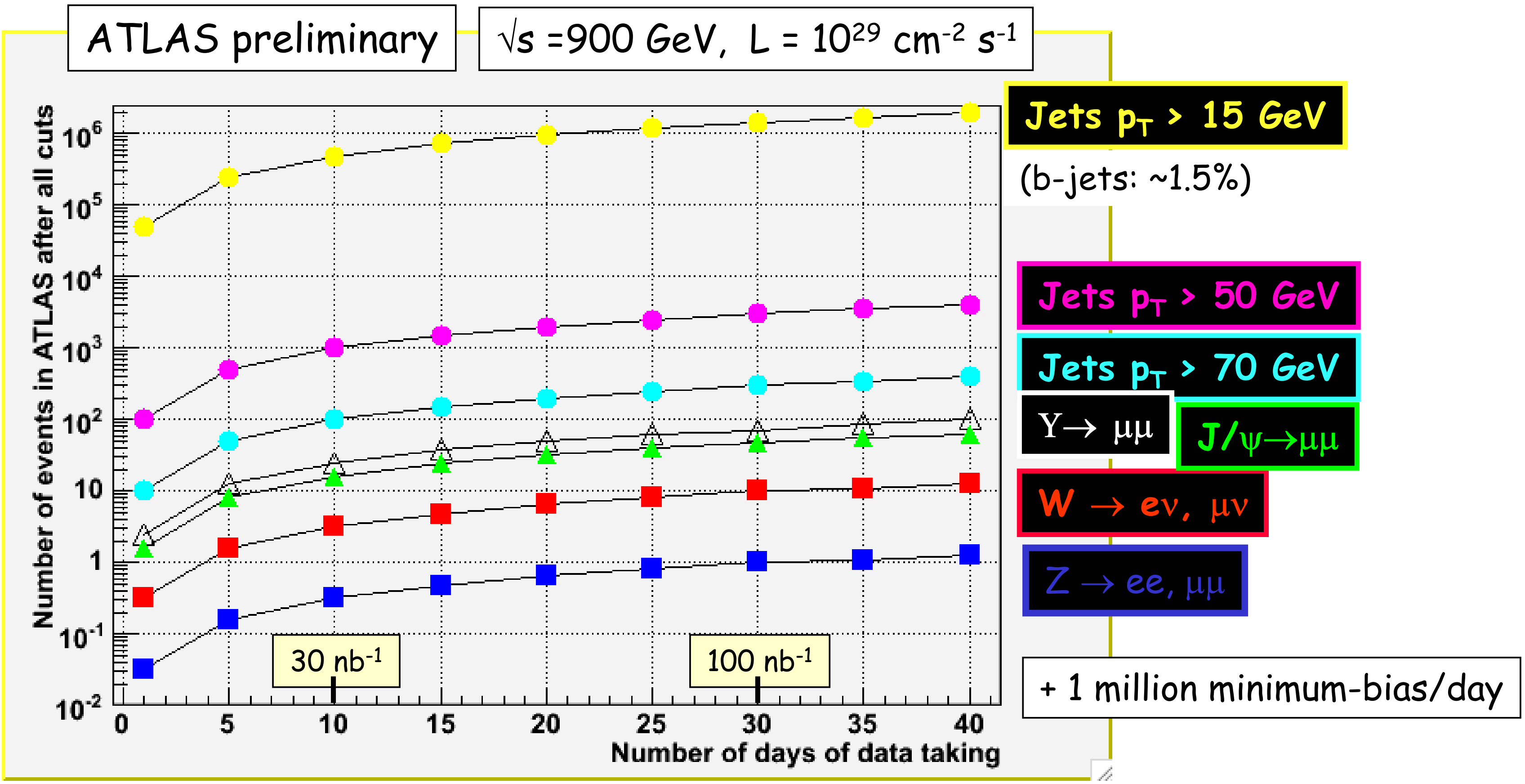
- Low p_T muons particles from the machine
- Simulation of machine background by machine experts (V. Talanov), transported into full simulation of detectors
- Use for alignment and calibration in endcaps



Beam-gas

- Vacuum not perfect 3×10^{-8} Torr
- Proton-nucleon p(7 TeV)+p(rest)
- Resemble collision events but with soft spectrum

900 GeV run: which data samples?



30% data taking efficiency included

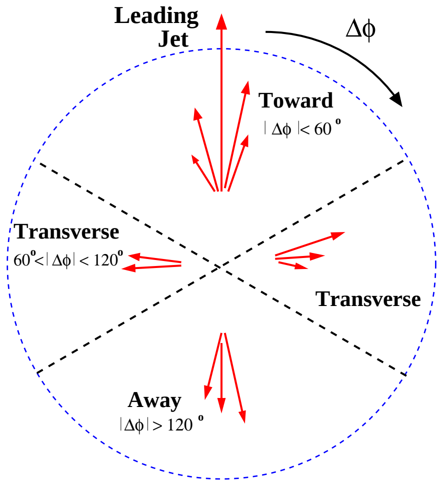
Start to commission trigger and detectors with collision data

Possibly first physics measurements (minimum bias, underlying event, jets)

Observe a handful of $W \to \ell\nu$, $Y \to \mu\mu$, $J/\psi \to \mu\mu$

Few thousand muons from b semileptonic decays

Underlying event at 900 GeV

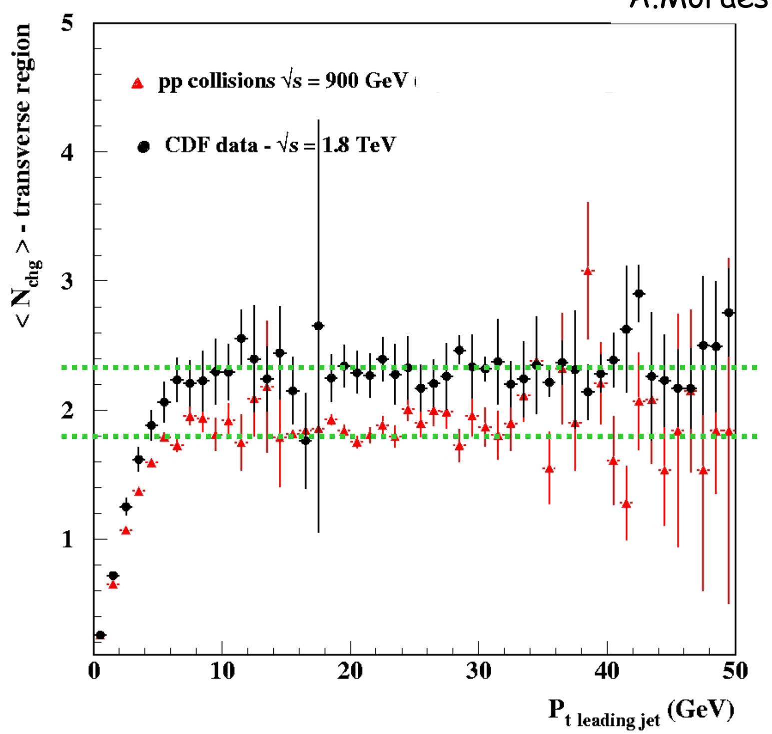


Study multiplicity of charged particles with $p_T > 0.5$ GeV and $|\eta| < 1$ in region transverse to leading jet

Comparison of plateau between LHC and Tevatron will tell if detector performance, reconstruction tools and physics are under control

$\sim$15 days of data-taking enough to cover up to p_T(leading jet)$\sim$40 GeV

A.Moraes



Physics with early 14 TeV data

Realistic approach: assume low selection efficiency for interesting events

Process	$\sigma \times BR$		Events selected for 100 pb^{-1}
$W \to \ell\nu$	20 nb	$\sim 20\%$	~ 400000
$Z \to \mu\mu$	2 nb	$\sim 20\%$	~ 40000
$\bar{t}t$ (semileptonic)	370 pb	$\sim 1.5\%$	< 1000

Jets and minimum bias statistics only limited by allocated trigger bandwidth

Even from pilot run expect significant statistics from interesting physics processes

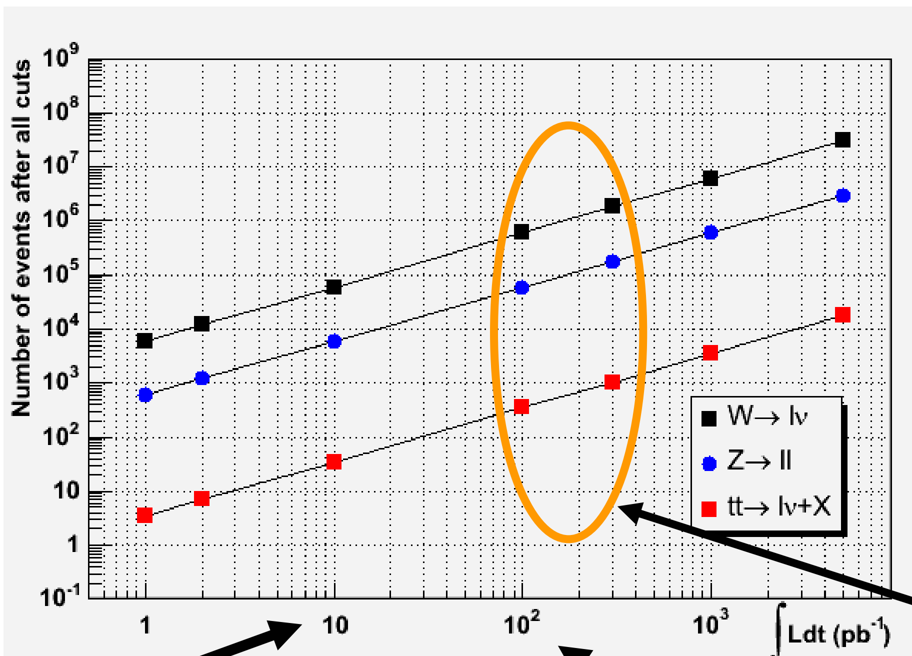
Many possible uses for early physics events:

- Calibrate/understand the detector
- Perform SM physics measurements
- Start understanding SM processes as background for new physics

It is mandatory to demonstrate that we understand LHC physics through SM measurement before going for discovery physics

Standard Model topics

- Minimum bias and underlying events: talk by C. Buttar



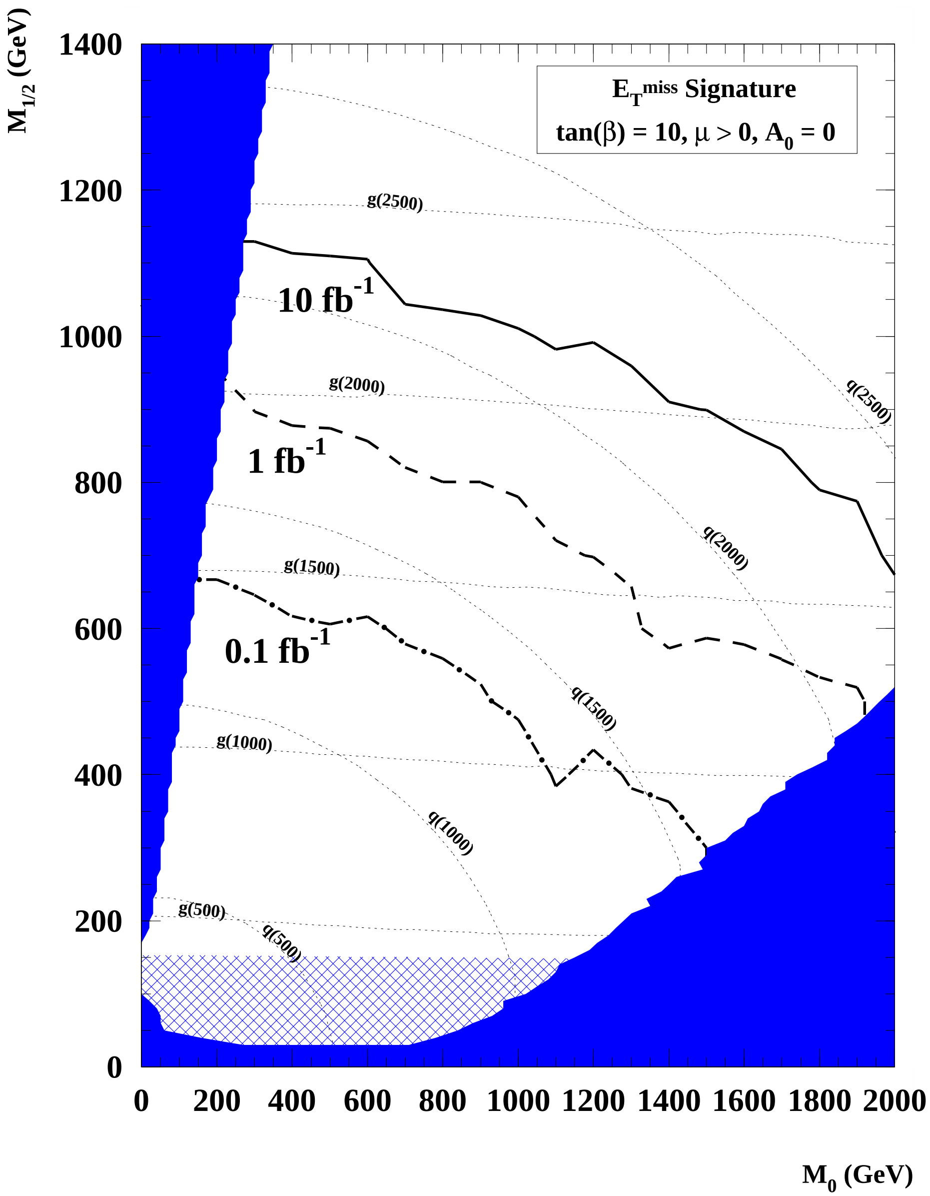
similar statistics to CDF, D0 today

~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%

- W and Z studies: talk by A. Tricoli
- Early top physics: talk by S. Bentvelsen

Early discovery of new physics: the SUSY case



- $\sim$1300 GeV in 100 pb^{-1}
- $\sim$1800 GeV in 1 fb^{-1}
- $\sim$2200 GeV in 10 fb^{-1}

Fast discovery from signal statistics

Time for discovery determined by:

- Time to understand detector performance ($\not{E}_T$ tails, lepton id, jet scale)
- Time to collect sufficient statistics of SM control samples: W, Z+jets, $\bar{t}t$

Two main background classes:

- Instrumental $\not{E}_T$
- Real $\not{E}_T$ from neutrinos

Backgrounds to $\not\!\!E_T +$ jets analysis

Instrumental $\not\!\!E_T$ from mismeasured multi-jet events:

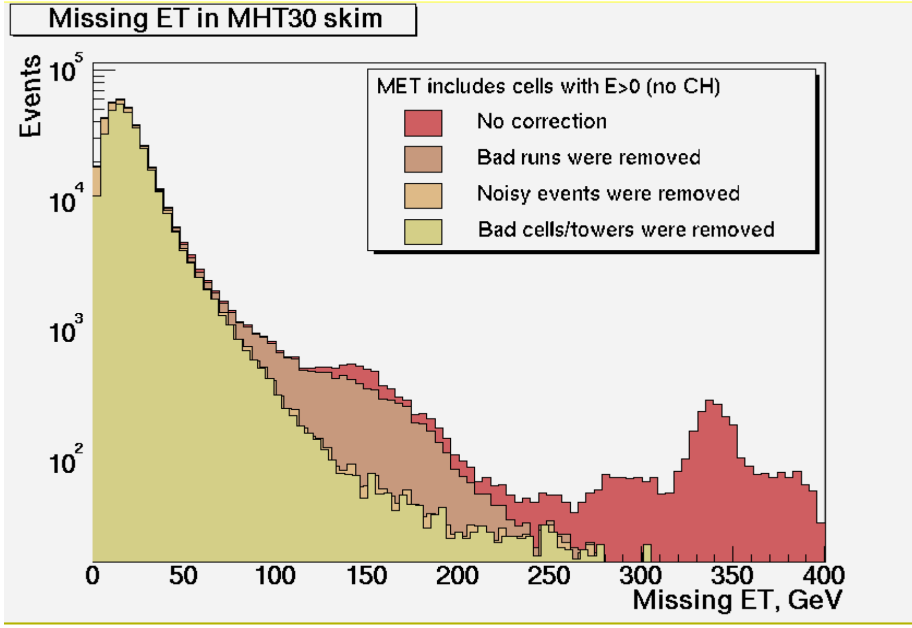
Many sources: gaps in acceptance, dead/hot cells, non-gaussian tails, etc.

Require detailed understanding of tails of detector performance.

Reject events where fake $\not\!\!E_T$ likely.

- beam-gas and machine backgrounds
- displaced vertexes
- hot cells
- $\not\!\!E_T$ pointing along jets
- jets in regions of poor response

See effect of $\not\!\!E_T$ cleaning in D0



All detector and machine garbage will end up in $\not\!\!E_T$ trigger Long and painstaking work before all the sources of instrumental $\not\!\!E_T$ are correctly identified

Control of $\not{E}_T$ from Standard Model processes

Dominant SM background to $\not{E}_T$+jets is $Z \to \nu\nu$+jets.

Use well-reconstructed $Z \to ee$ events to evaluate this background

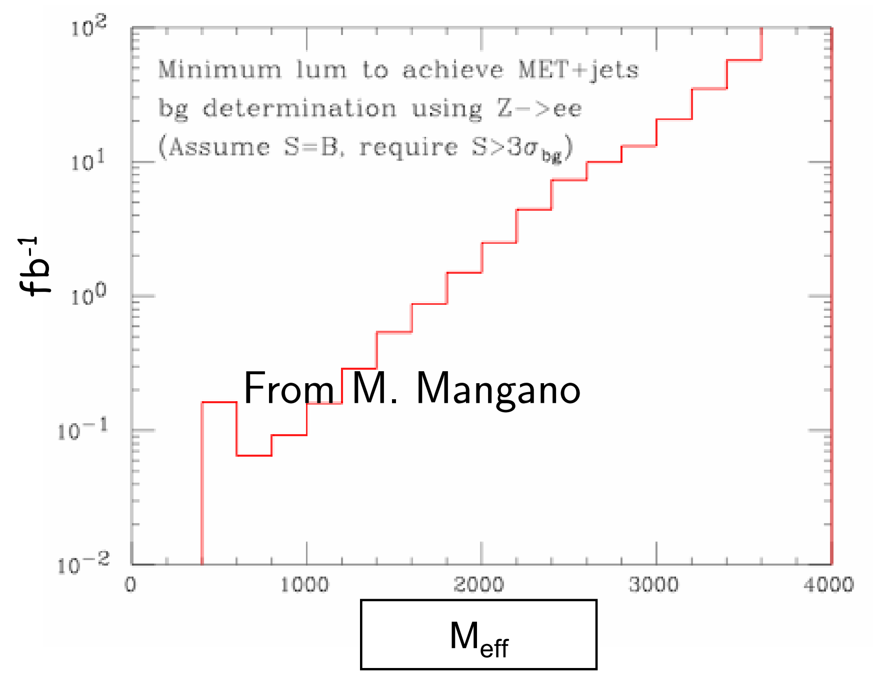
Normalisation needs to be multiplied by $BR(Z \to \nu\nu)/BR(Z \to ee) \sim 6$

Assuming SUSY signal $\sim Z \to \nu\nu$ bg, evaluate luminosity necessary for having $N_{SUSY} > 3 \times \sigma_{bg}$

Stat error on background:

$$\sigma_{bg} = \sqrt{N(Z \to ee)} \times \frac{BR(Z \to \nu\nu)}{BR(Z \to ee)}$$

For each bin where normalisation required, need ~ 10 reconstructed $Z \to \ell\ell$ events. Need to consider acceptance/efficiency factors as well



Several hundred pb^{-1} required. Attempts on $W \to \mu\nu$ ongoing to improve statistics

Conclusions

LHC startup will require a long period of development and understanding for both machine and detectors

Detailed commissioning plan for detectors: plan to achieve baseline 'reasonable' calibration and alignment before collisions using cosmics and machine development periods

As soon as interactions at 14 TeV happen, interesting physics available in data

Parallel processes of using data to further 'technical' detector understanding and to perform benchmark SM physics measurements

Goal is to arrive at high statistics (few fb^{-1}) data-taking ready to go for early discovery physics

Even discovery advertised as "easy", e.g. SUSY will require long understanding effort

Ideal playground for young people with brilliant ideas!