Getting ready for the LHC

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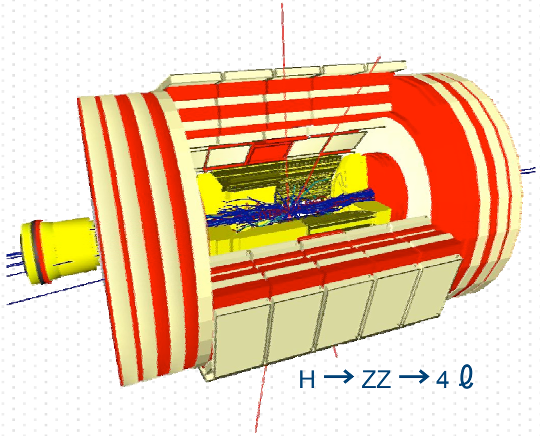
Outline

- Introduction

- Now : Status of the
  - Machine
  - Detectors
- Pretty soon :
  Commissioning and start-up scenarios of the
  - Machine
  - Detectors
- Soon
  - Pilot and first Physics run



- Further aspects
  - Learn amap from the data
  - Some comments

What I will (not) offer here:

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- I **will talk** about
  - A very brief overview of the hardware preparations of
    - the machine
    - ATLAS and CMS
  - Explain the startup
    - Why is the LHC startup planned in this particular way?
    - What are the initial challenges for the detectors
  - Pilot run and first year
    - What can we do with pilot run data?
    - First the first year’s data
  - Some comments about
    - Use of data to constrain backgrounds, MCs
    - Use of MCs
- I **will not talk** about
  - LHCb and ALICE (sorry for that…)
  - All the wonderful physics we can do (from NNNMSSM to Black Holes)
  - All the details of Higgs and SUSY searches
  - Data challenges, Data flow, ATLAS Blind test

Our future play ground

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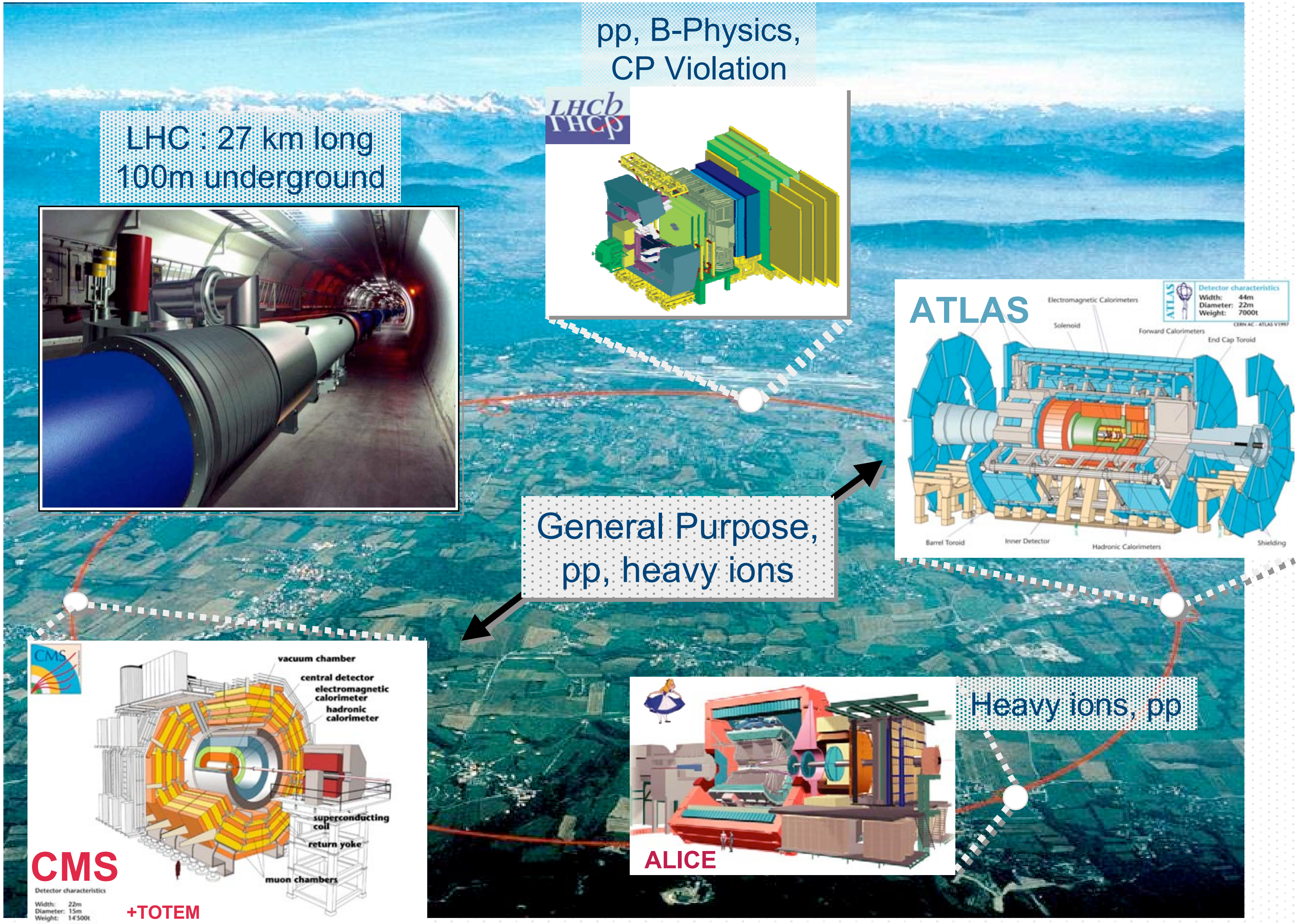

Now :
Status of the LHC and the Detectors

"The greater the obstacle, the more glory in overcoming it." (Moliere)

The LHC : Basic parameters

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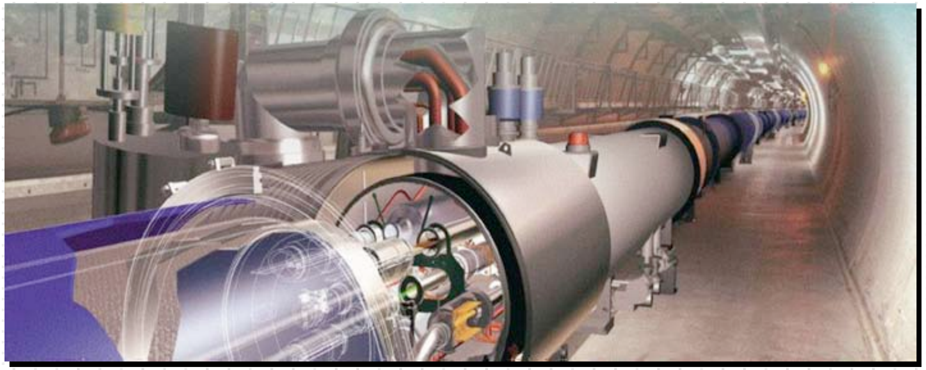

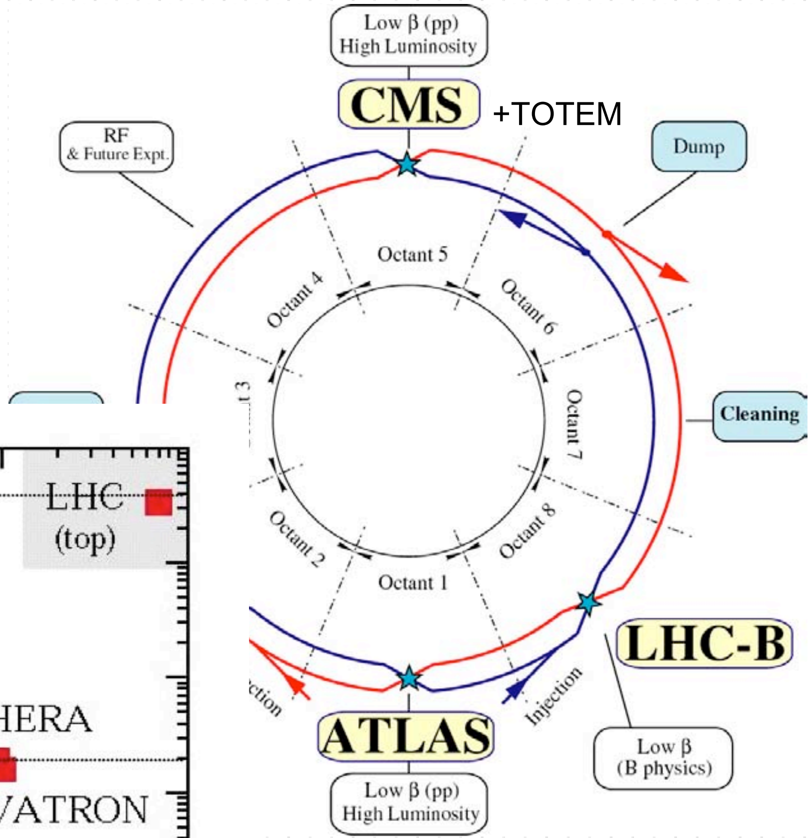

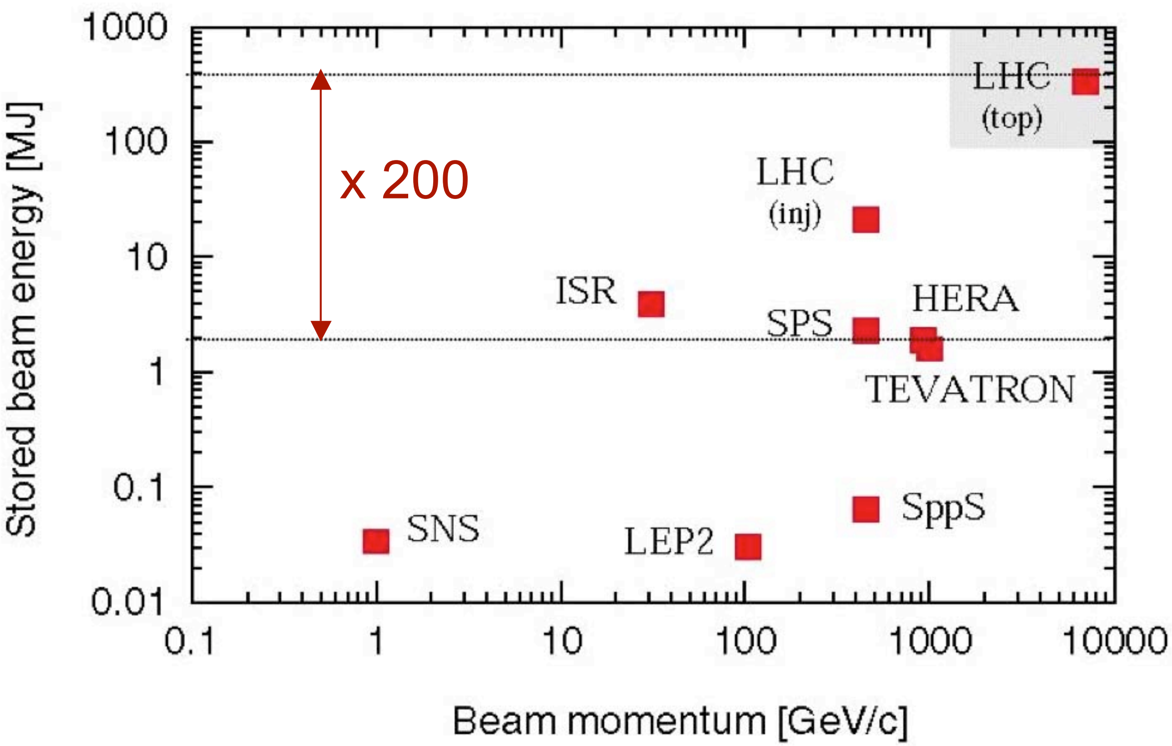

stored in magnets

The LHC : Status report

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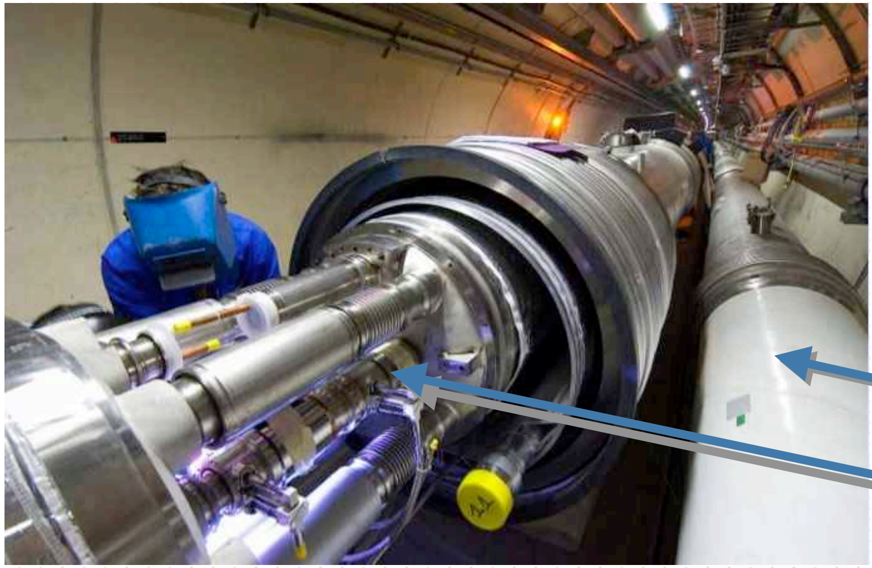
Lowering of the first dipole into the tunnel (March 2005).

By now there are > 500 dipoles

New schedule to be announced next week…



Cryogenic services line

inter-connections

The LHC : Status report

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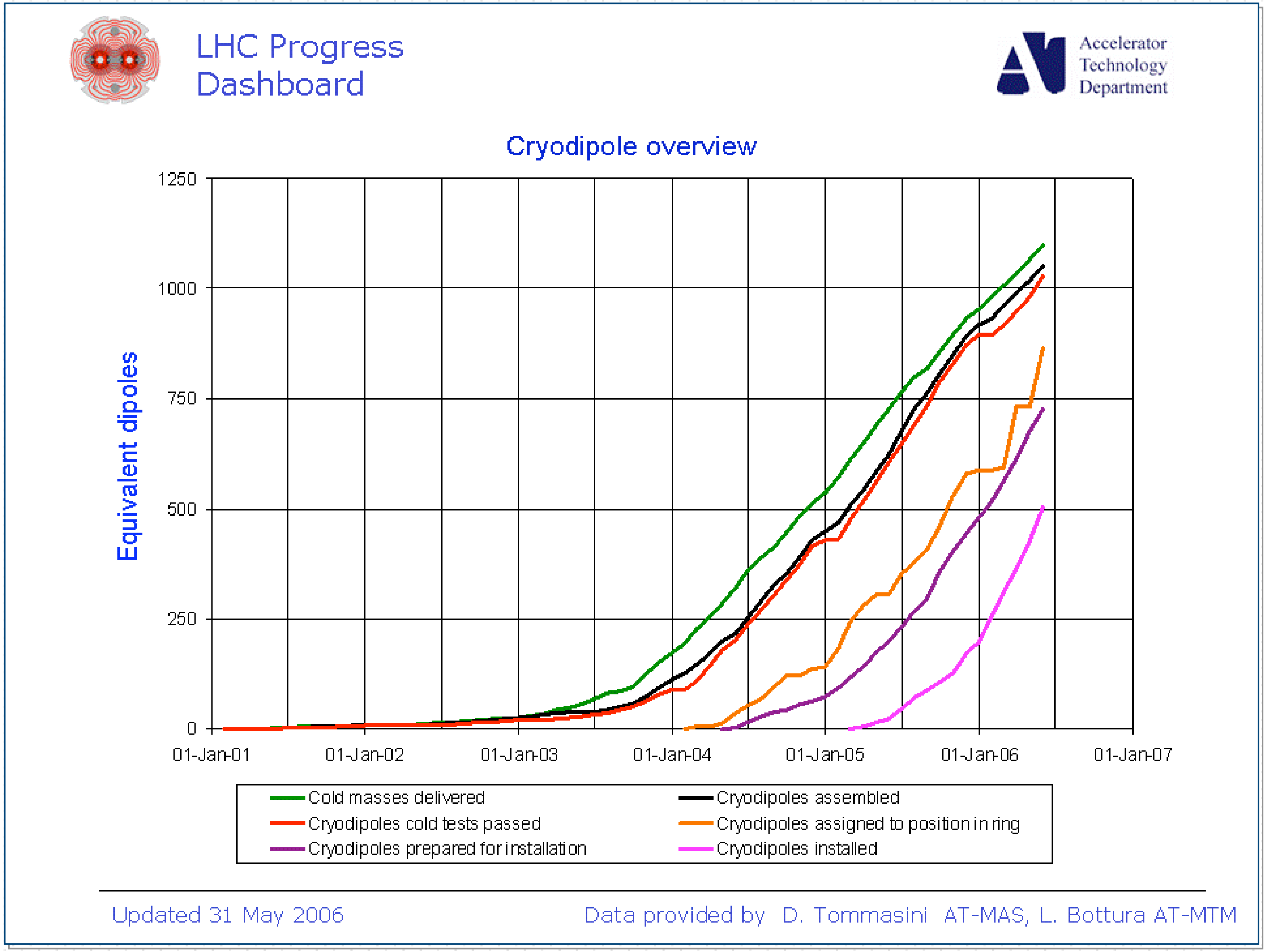

See : http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/DashBoard/index.asp

ATLAS

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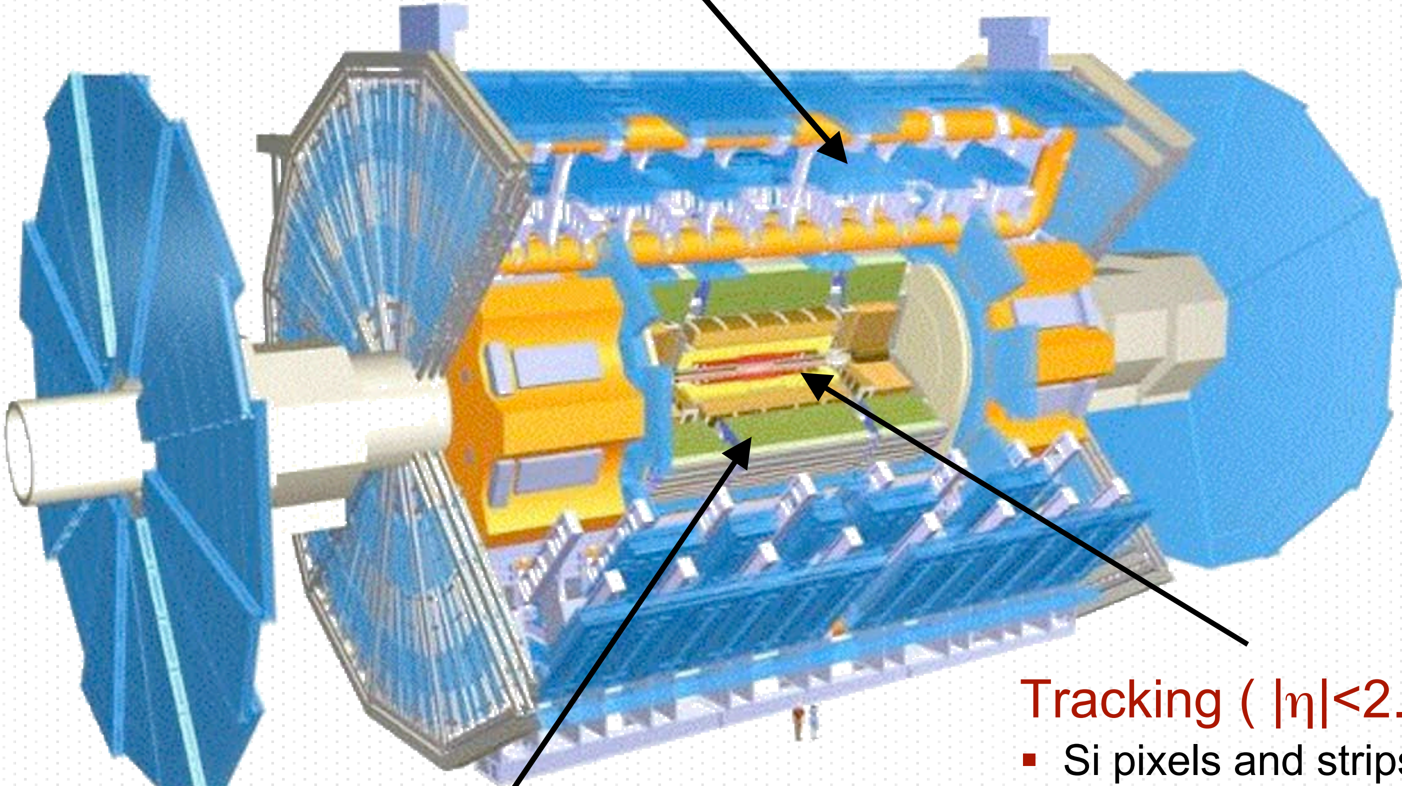
Muon Spectrometer ($|\eta|<2.7$)

- air-core toroids with muon chambers



Tracking ($|\eta|<2.5$, B=2T)

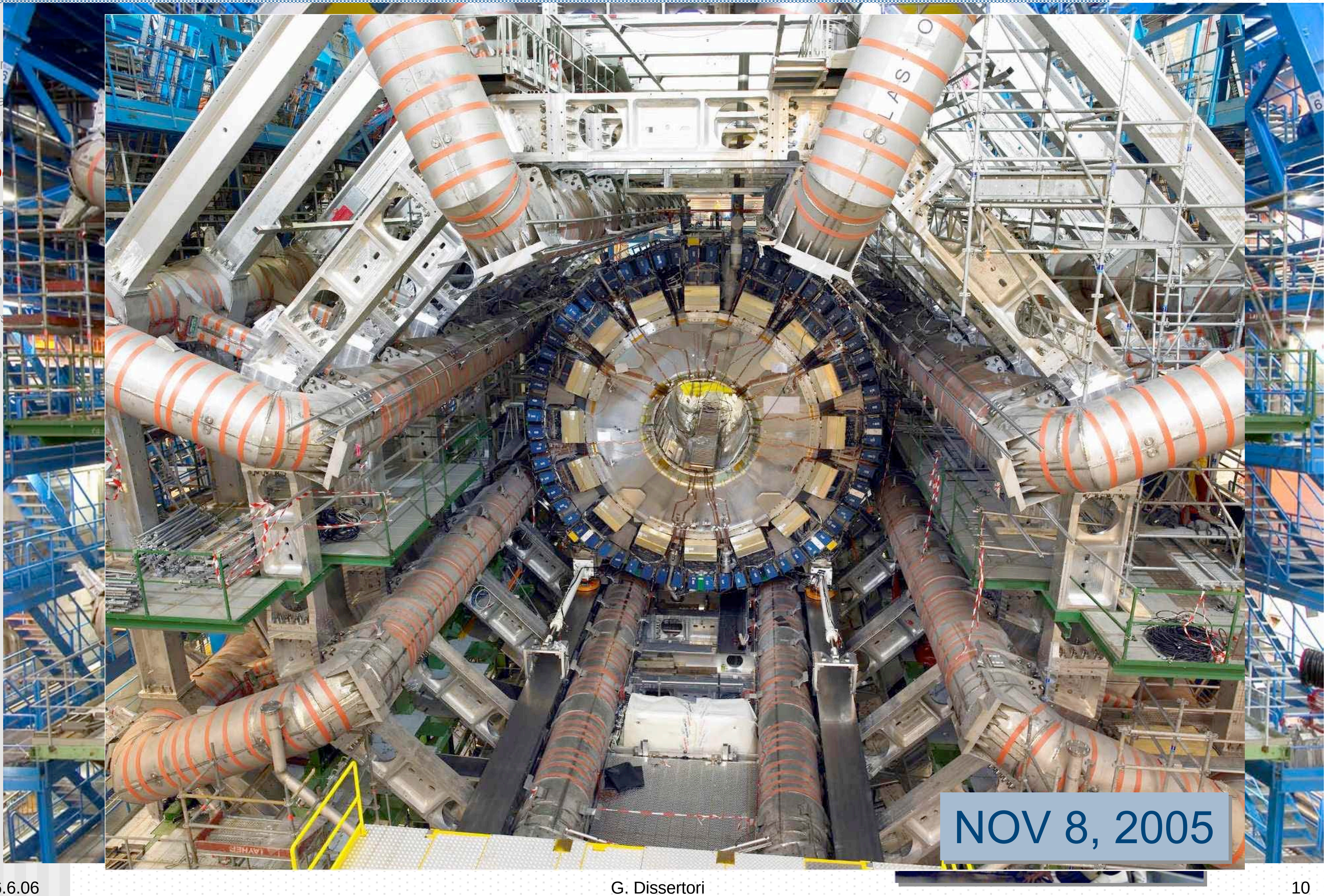
- Si pixels and strips
- TRD (e/π separation)

Calorimetry ($|\eta|<5$)

- EM : Pb-LAr
- HAD : Fe/scintillator (central),
  Cu/W-Lar (fwd)

Diameter	25 m
Barrel toroid length	26 m
End-cap end-wall chamber span	46 m
Overall weight	7000 tons

ATLAS : Status report



CMS

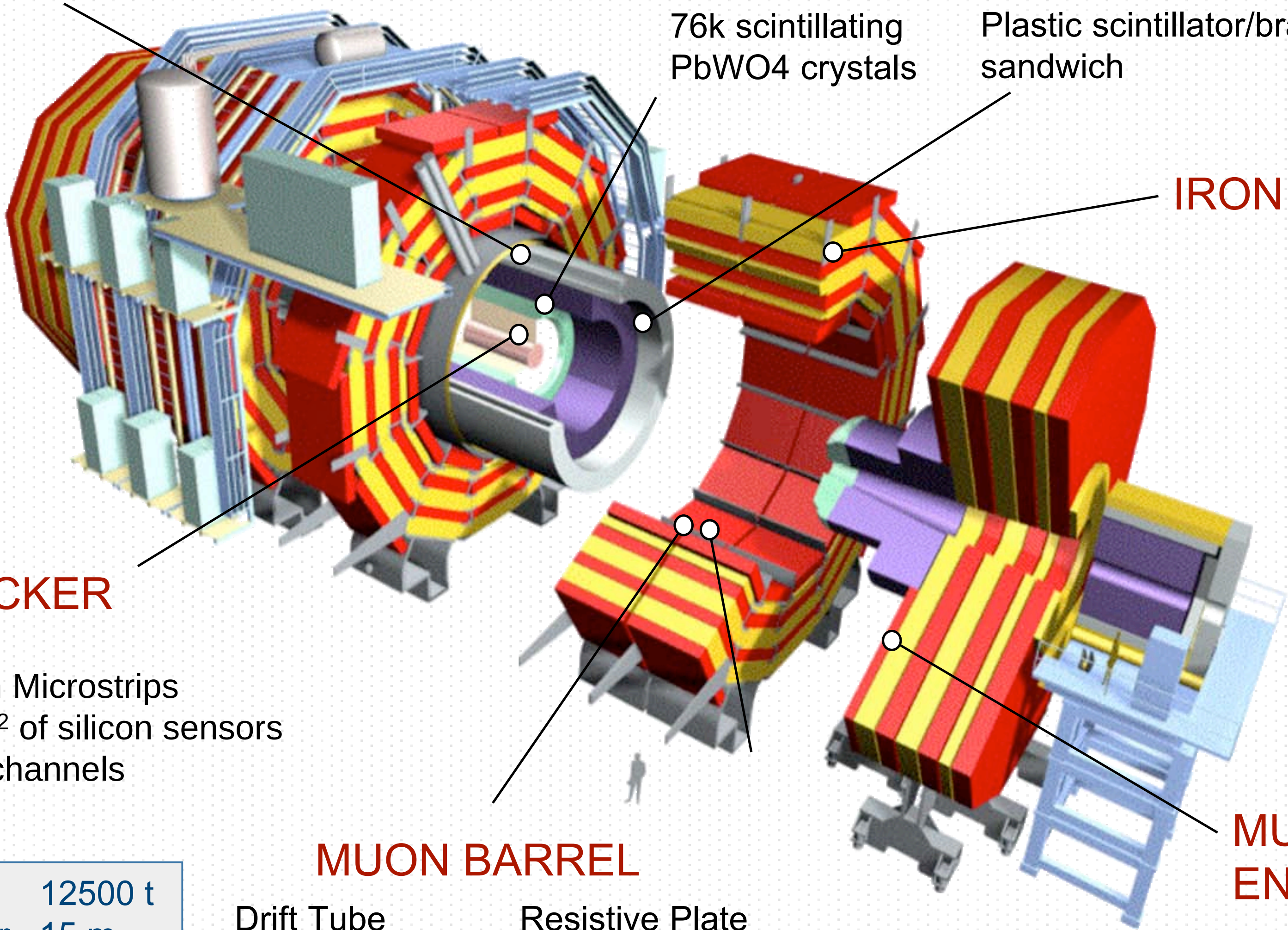
Superconducting Coil, 4 Tesla

CALORIMETERS

ECAL
76k scintillating PbWO4 crystals

HCAL
Plastic scintillator/brass sandwich

IRON YOKE



TRACKER
Pixels
Silicon Microstrips
210 m^2 of silicon sensors
9.6M channels

MUON BARREL

Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

MUON ENDCAPS

Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

Total weight	12500 t
Overall diameter	15 m
Overall length	21.6 m

CMS : Status report

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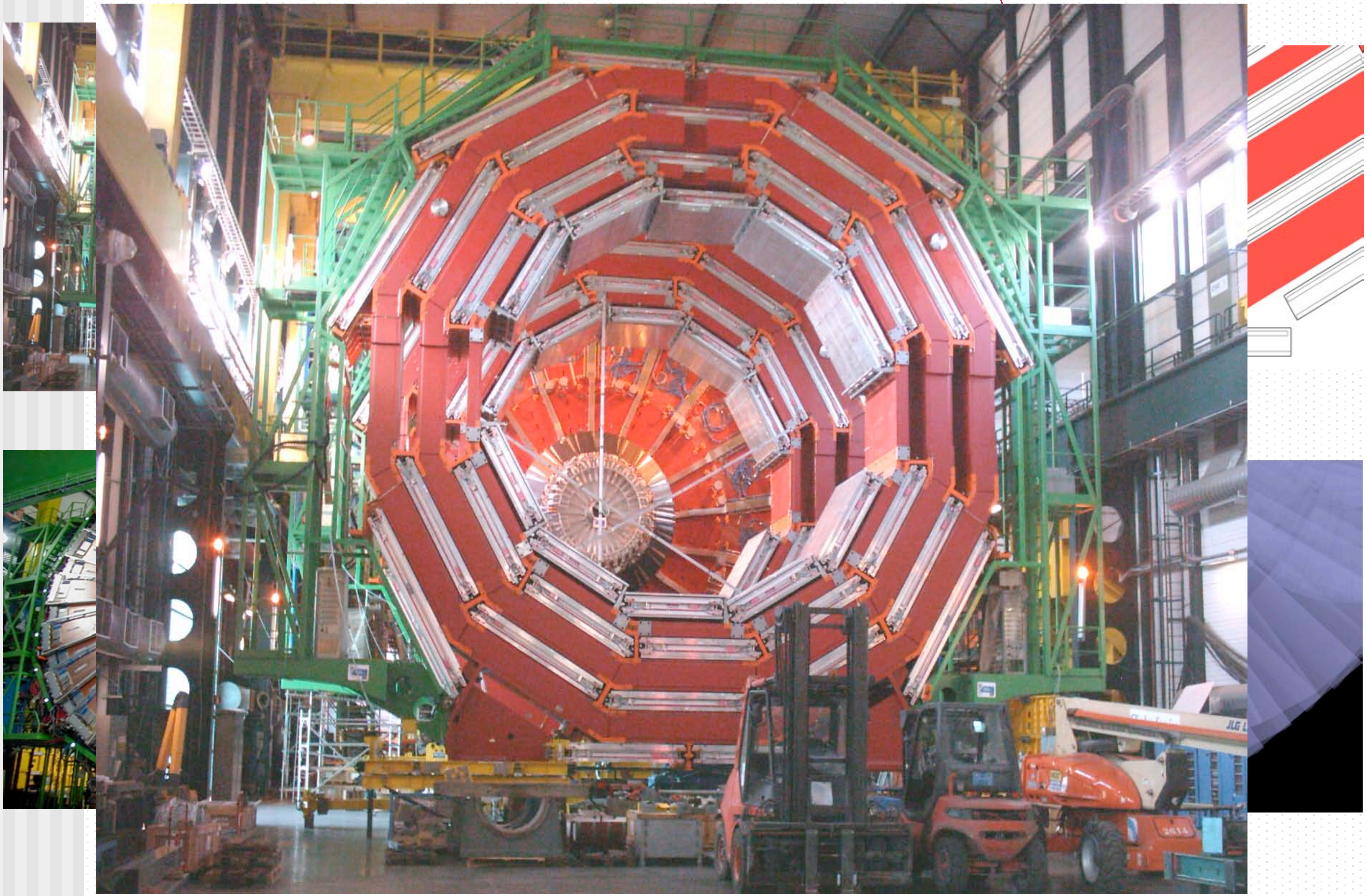
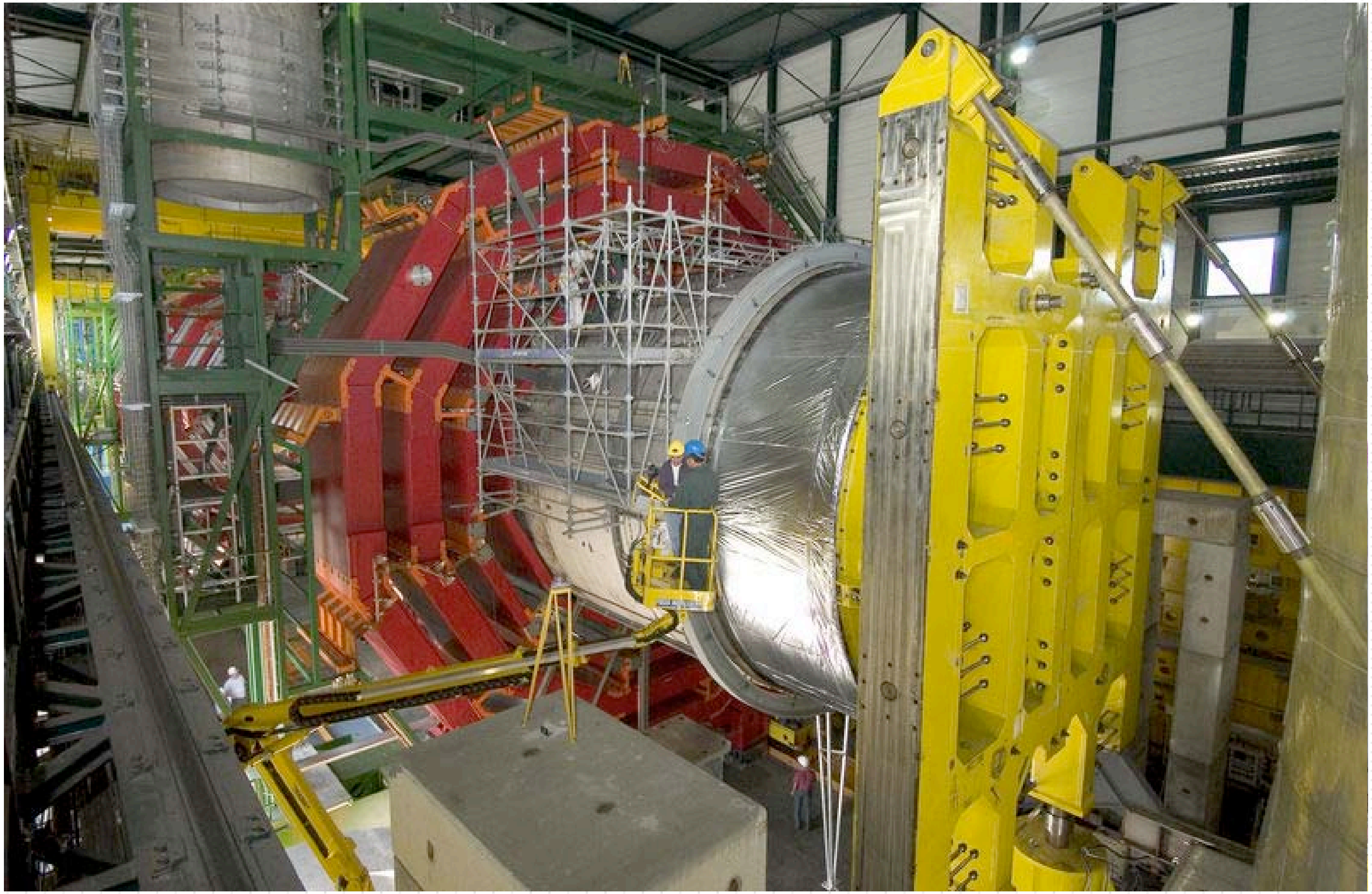


CMS : Status report



Magnet Insertion: Autumn 05 ; Cooled down early in 2006

CMS : Status report

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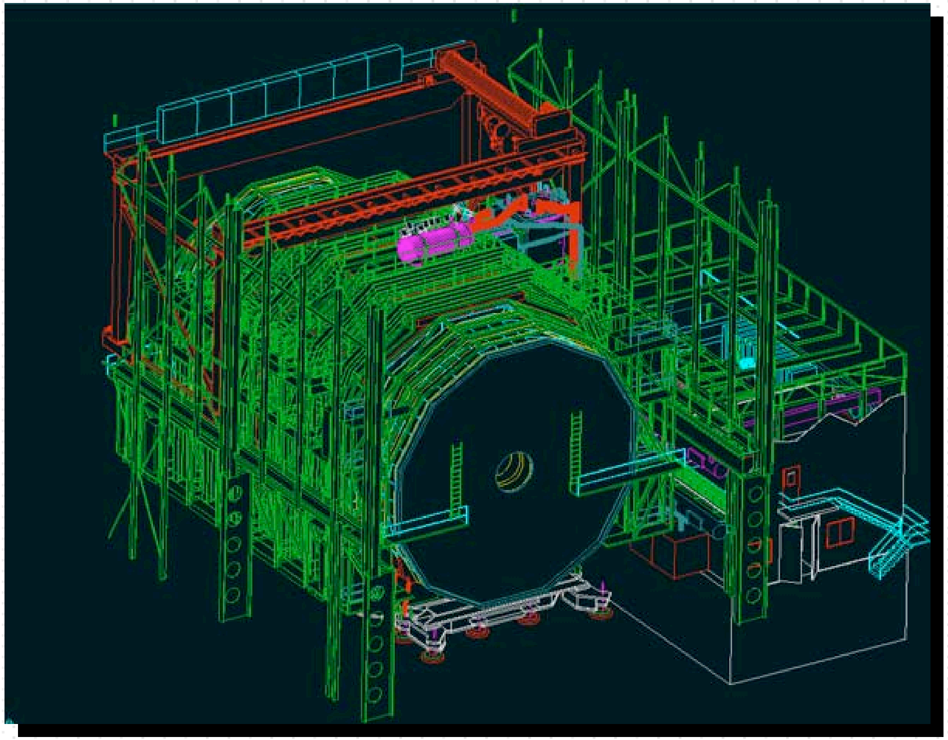
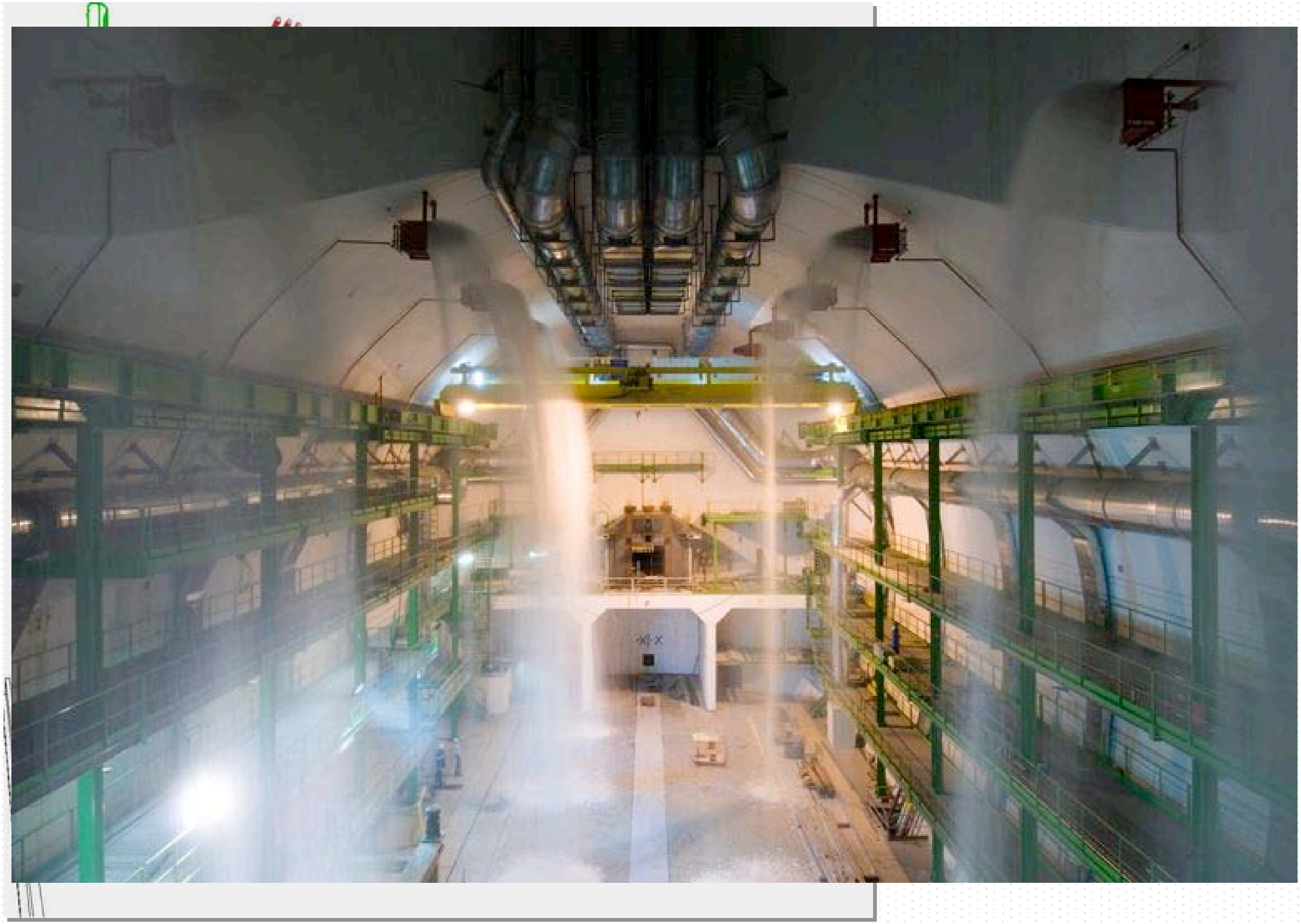
CMS closed for Magnet test in the SX5 surface building (April/May 2006)



- Check functionality of all magnet systems
- Map the magnetic field
- Check installation & cabling of
  - ECAL/HCAL/Tracker inside coil
- Test combined sub-detectors in 20 degree slice(s) of CMS with Magnet. Try out operation procedures for CMS (24/7 running)

CMS : lowering



Pretty soon: Commissioning and start-up scenarios

"If we wait for the moment when everything, absolutely everything, is ready, we shall never begin." (Ivan Turgenev)

LHC : Performance Limitations

Parameter/Effects	Limitations
Beam energy limited by maximum dipole field. Industrially available technology.	7 TeV
Bunch and total beam intensity beam-beam effect (tune spread), small allowed space in Q-space, collimators (impedance, collective instabilities), electron cloud, radiation	$N < 1.7\ 10^{11}$ $N_{nom} = 1.15\ 10^{11}$ $I < 0.85$ A
Normalized emittance Basically given by injector chain and limited by main dipole aperture	$\varepsilon_n < 3.75$ µm
Beam size at IP (β^*) Limited by (triplet) quadrupole aperture	$\beta^* > 0.55$ m $\sigma \sim 16$ µm
Number of bunches Limited by stored beam energy, electron cloud eff.	2808
Operation efficiency and L_{int} minimize quenches and beam aborts, collimators and cleaning important: $N_{lost} < 7\ 10^8$ /m = $2.2\ 10^{-6}$ N	Total beam intensity

Legend:

N : particles/bunch

n : nr. of bunches

I : current / beam

$\varepsilon_n = \varepsilon\gamma$, ε : emittance

β^* : β at IP

Beam size $\sigma^2 = \beta\varepsilon$

Q : tune (number of trans. oscil./turn)

Tune spread $\Delta Q \propto N / \varepsilon_n$

$$\mathcal{L} = \frac{N^2\, n\, f_{rev}}{4\pi\, \epsilon_n\, \beta^*}$$

LHC : Performance Limitations

Current in machine

$$\mathcal{L} = \frac{N^2 n f_{\mathrm{rev}}}{4\pi\epsilon_n\beta^*}$$

Luminosity

Beam size

N : particles/bunch

n : nr. of bunches

I : current / beam

$\varepsilon_n = \varepsilon\gamma$, ε : emittance

β^* : β at IP

Beam size $\sigma^2 = \beta\varepsilon$

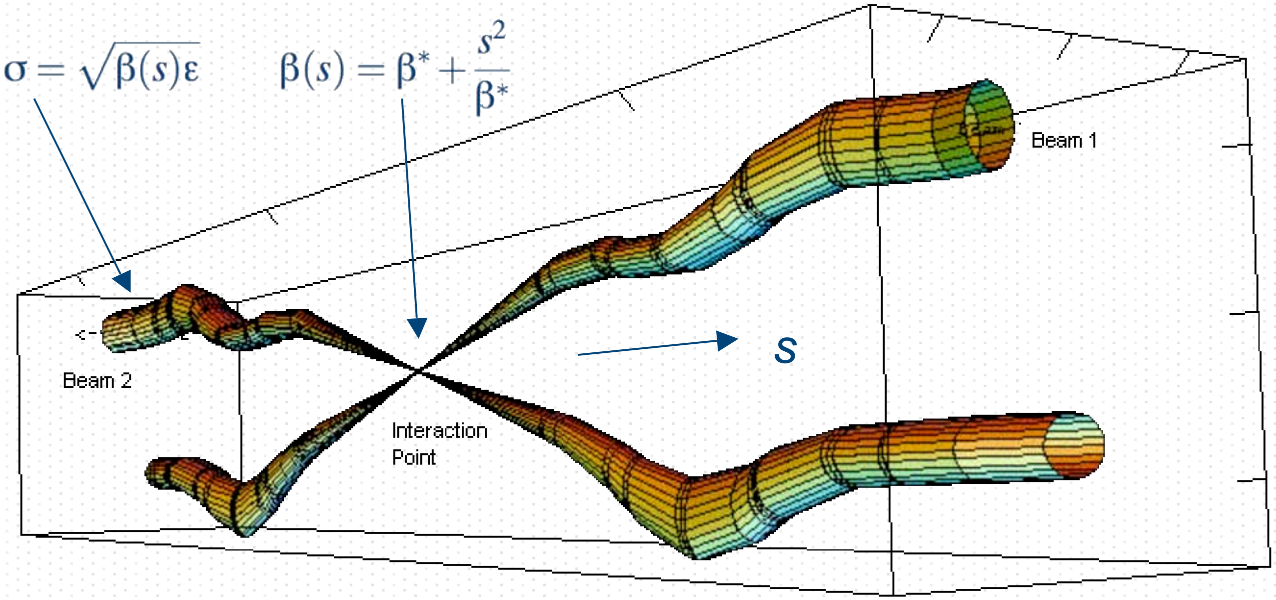
Q : tune (number of trans. oscil./turn)

Tune spread $\Delta Q \propto N / \varepsilon_n$

LHC : Performance Limitations

- Two Examples: Magnet aperture, beam-beam, collimators

$$\sigma = \sqrt{\beta(s)\varepsilon} \qquad \beta(s) = \beta^* + \frac{s^2}{\beta^*}$$



Relative beam sizes around IP1 (Atlas) in collision

σ^*=16.6μm —~23m→ σ(triplet)=1.54 mm

Badly conducting collimators : large wake fields : instability

Phase 1 : graphite (robust), I < 0.3 A
Phase 2 : Cu (good conduct.) I < 0.85 A

LHC : Start-up scenario

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Stage 1
Initial commissioning
43x43 to 156x156, $N=3\times10^{10}$
Zero to partial squeeze

$L=3\times10^{28} - 2\times10^{31}$

Stage 2
75 ns operation
936x936, $N=3\text{-}4\times10^{10}$
partial squeeze

$L=10^{32} - 4\times10^{32}$

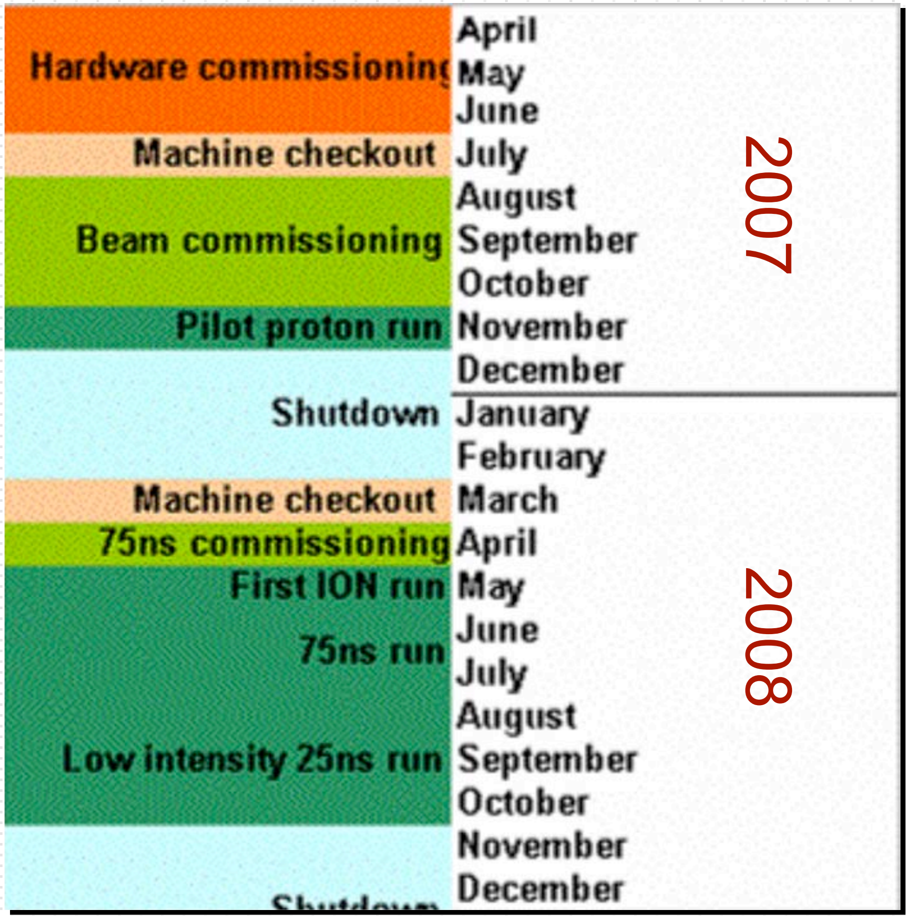
Stage 3
25 ns operation
2808x2808, $N=3\text{-}5\times10^{10}$
partial to near full squeeze

$L=7\times10^{32} - 2\times10^{33}$

Stage 4
25 ns operation
Push to nominal per bunch
partial to full squeeze

$L=10^{34}$

- Objective : establish colliding beams as quickly as possible, safely, without compromising further progress
- Take two moderate intensity multi-bunch beams to high energy and collide them : minimize problems due to electron cloud, event pile-up, equipment restrictions, use phase 1 collimators.



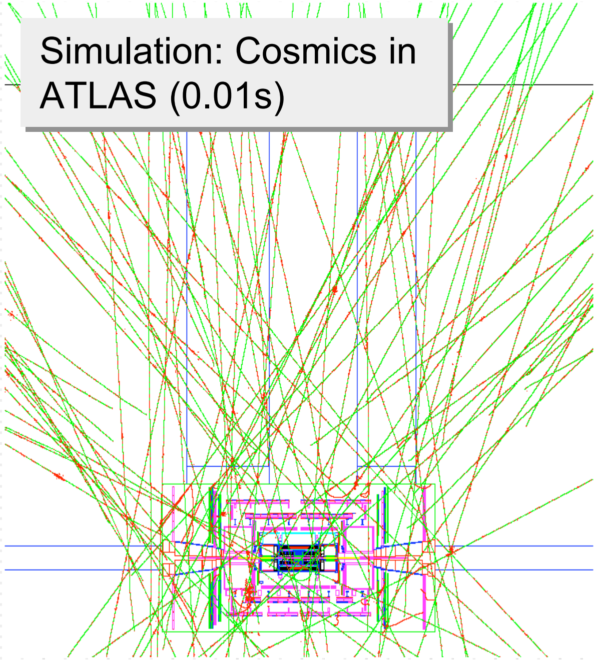
Detector Commissioning

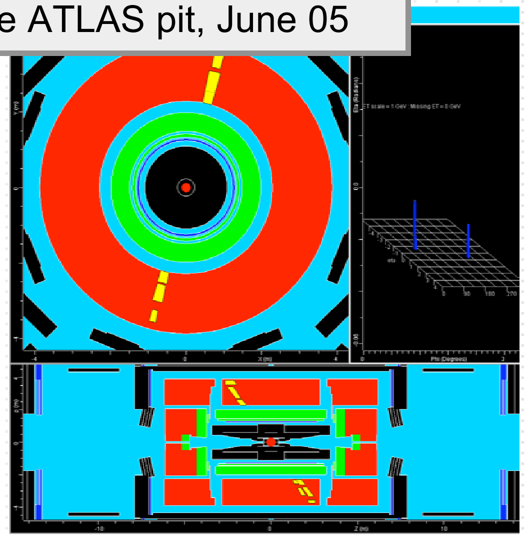
- Construction quality checks and beam tests of series detector modules show that the detectors as built should give a good starting-point performance
- However, a lot of data (and time …) will be needed at the beginning to
  - Commission the detector and trigger in situ
  - Reach the performance needed to optimize the physics potential
  - Understand "basic" physics at 14 TeV and normalize (tune) the MC generators
  - Measure backgrounds to new physics and extract "early" convincing signals
- Efficient/extensive/robust commissioning programme with physics data is therefore crucial to reach quickly the "discovery" mode

Detectors : Commissioning

- ## No Beam :
  - Cosmic Muons
  - Initial alignment/detector calibration (barrel)
  - Debugging, dead-channels mapping
  - Rates :
    - $E_{surface}$ > 10 GeV : ~ 1 - 5 kHz
      useful for calibration : ~ 0.5 Hz

- ## One Beam :
  - Beam-Halo Muons
    - Alignment/calibration in end-caps
    - Rate for E > 100 GeV : ~ 1 kHz
  - Beam-Gas events
    - resemble pp, with soft spectrum (p_T < 2 GeV)
    - 25 Hz of reco. Tracks with p_T> 1 GeV, |z|<20 cm
    - eg. first alignment of inner trackers to about 100 µm or better?


Simulation: Cosmics in ATLAS (0.01s)

First real cosmics seen in the ATLAS pit, June 05


Soon :
Pilot Run and First Physics

"The only place you'll find SUCCESS before WORK is in the dictionary" (May B. Smith)

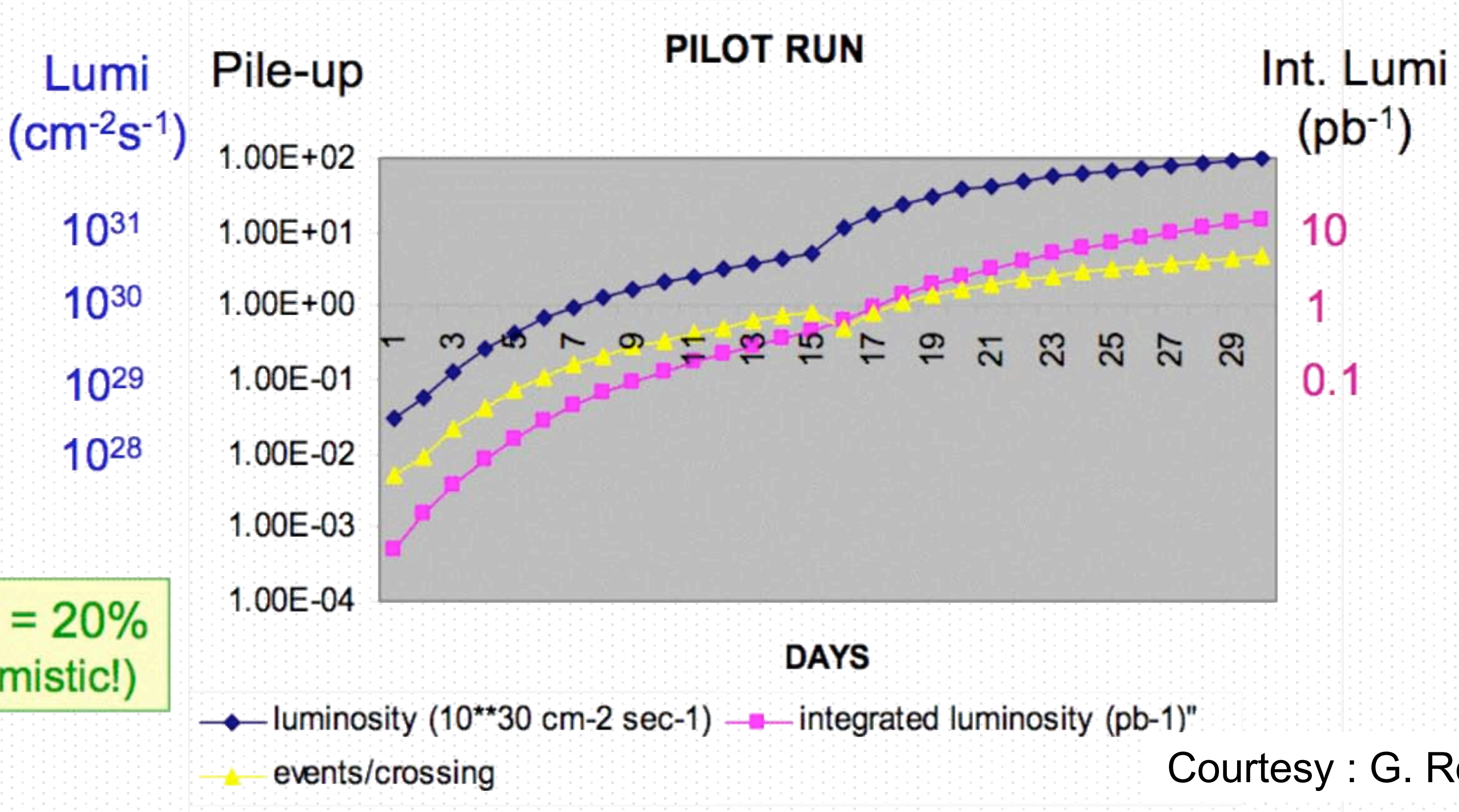
Pilot run

- The first time that we will see proton-proton collisions at 14 TeV !
- Pilot run is short (max 30 days) and data taking will happen only for a small fraction of time
- Important to use very efficiently this time optimizing between competing tasks
  - Changing conditions to commission the detector (eg. synchronization)
  - Stable data taking for tracker alignment & measurement of minimum bias (can be done with coarse synchronization)

Pilot run : Luminosity

- Introduction
- Status of
  - Machine
  - Detectors
- Startup of
  - Machine
  - Detectors.
- **First Physics**
- Comments

- 30 days maximum, probably less (?)
- 43x43 bunches, then 156x156 bunches



ε_{LHC} = 20% (optimistic!)

Courtesy : G. Rolandi

Pilot Run : Number of events

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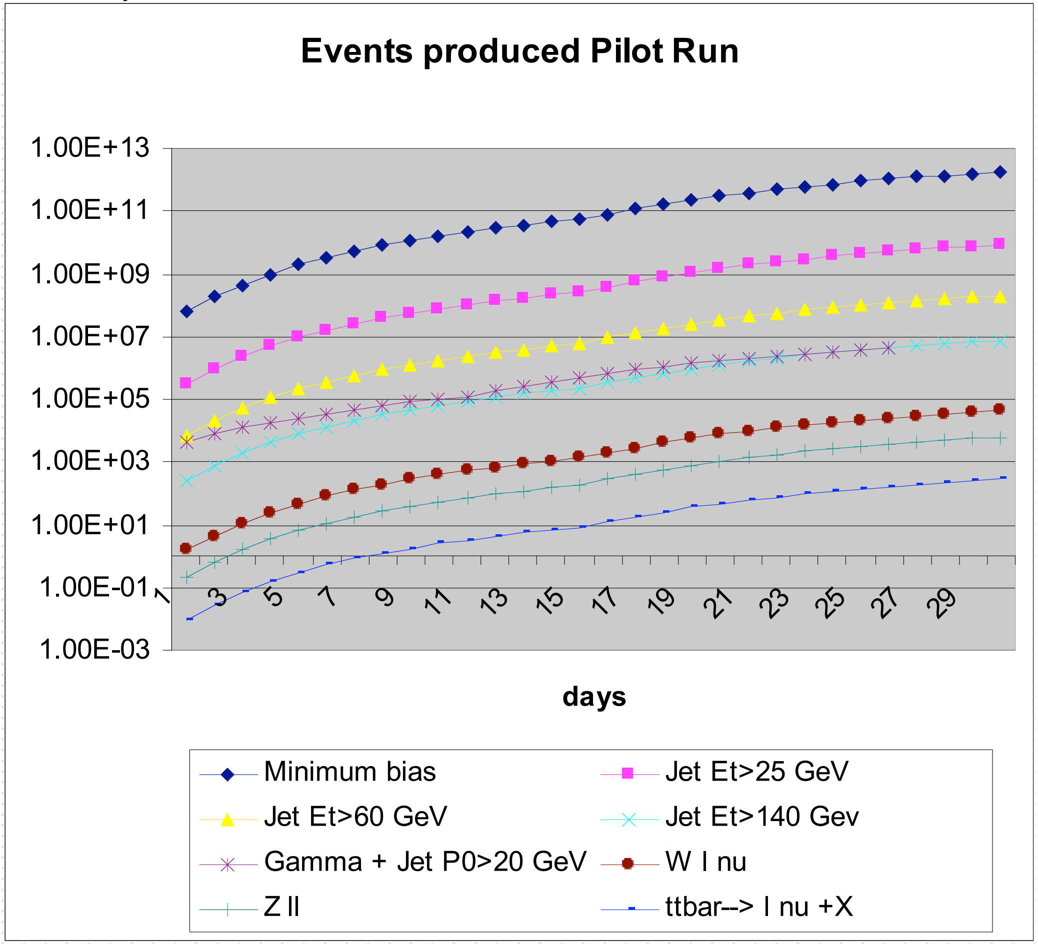
Courtesy G. Rolandi



Assumed efficiencies:

ε(jets) = 100%
ε(W) = 20%
ε(Z) = 20%
ε(ttbar) = 1.5%

Even within a few hours/days:

- About 10 million minimum bias evts (almost possible to trigger randomly)
- A few million di-jet events with E_T > 15 GeV
- Not much of anything else

Pile-Up

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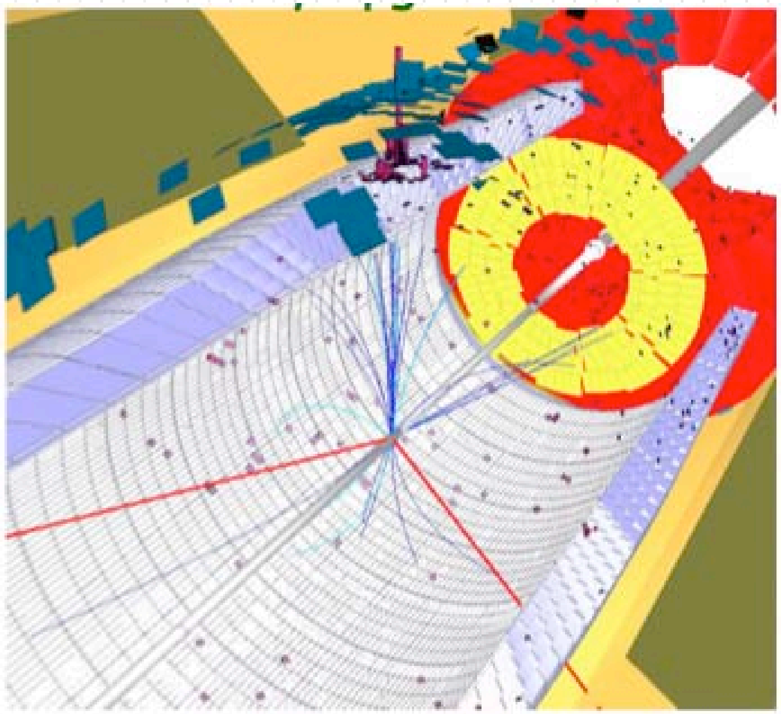
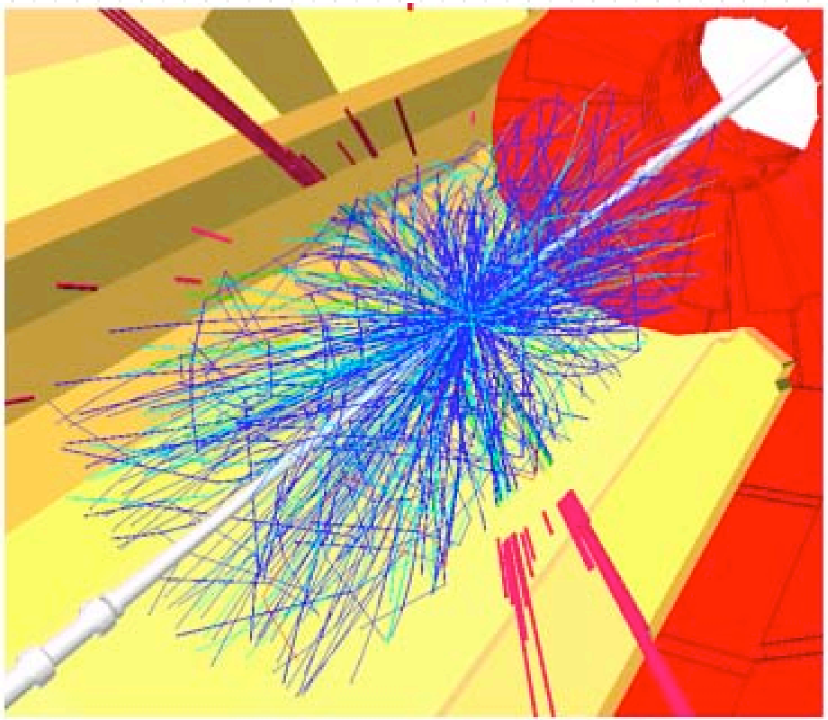
- Pile-up : additional mostly soft-interactions per bunch crossing
- Start-up Lumi : $2\text{x}10^{33}$ $cm^{-2}s^{-1}$ $\Rightarrow$ 4 events / bunch crossing
- High Lumi : 10^{34} $cm^{-2}s^{-1}$ $\Rightarrow$ 20 events / bunch crossing



LHC event - no pile-up



LHC event - 10^{34} $cm^{-2}s^{-1}$

Courtesy A. De Roeck

The Underlying Event

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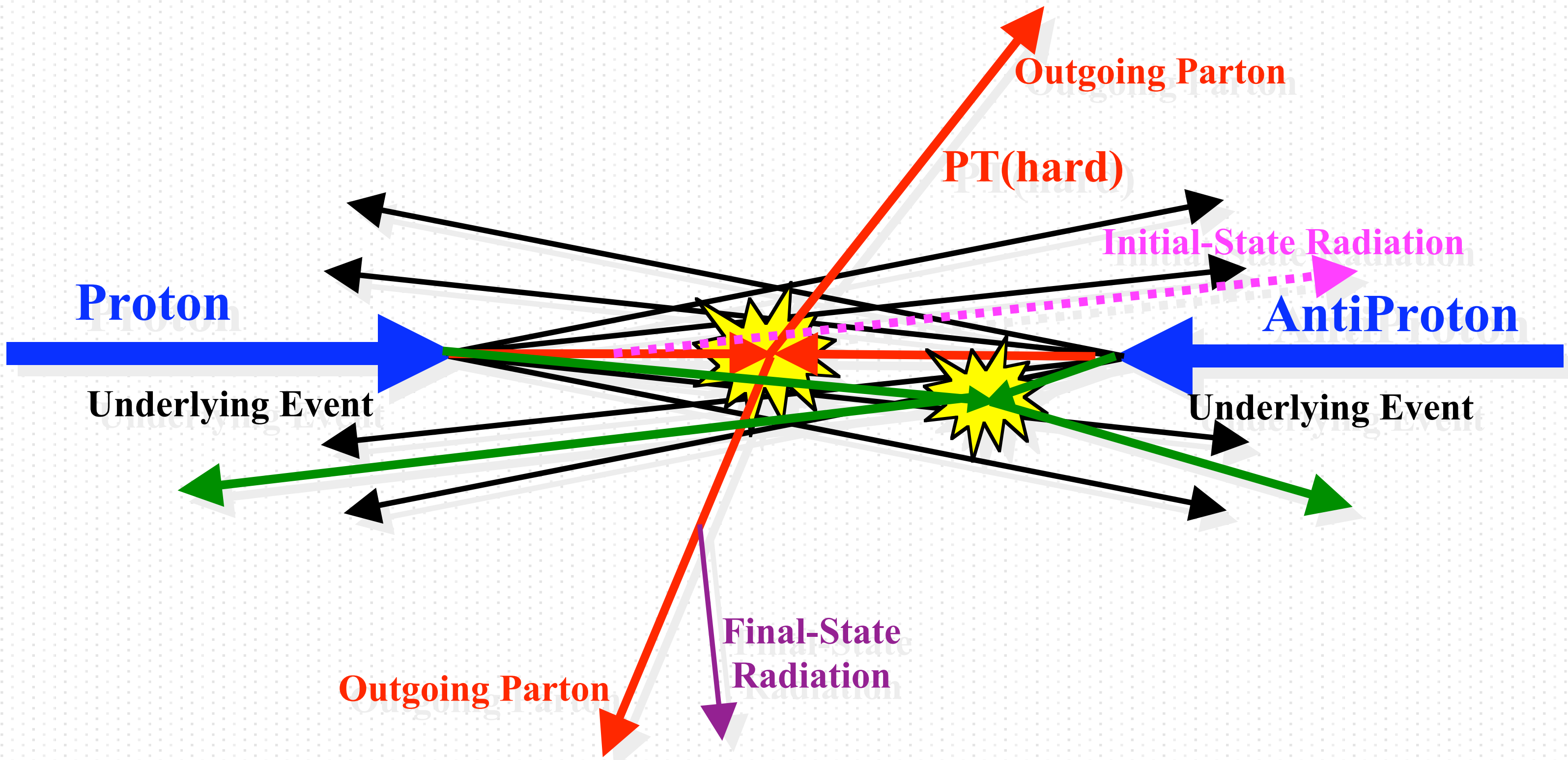


The Underlying Event:

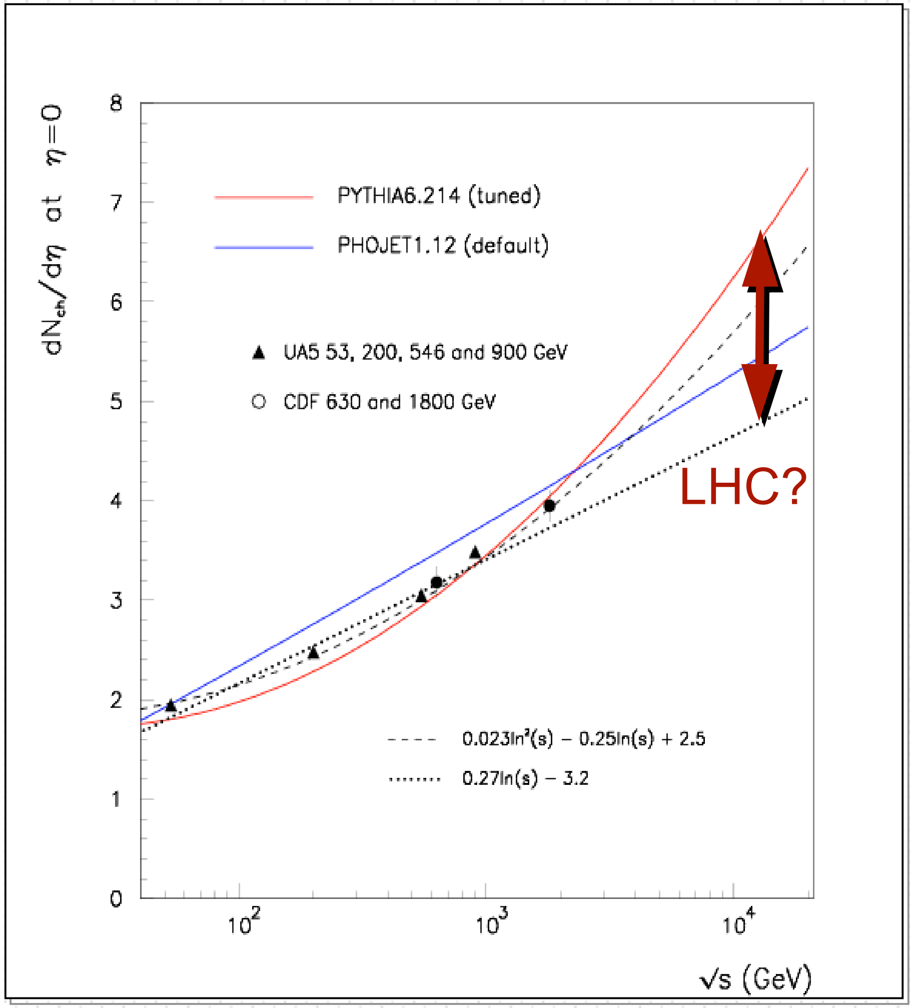
beam-beam remnants
initial-state radiation
multiple-parton interactions

Issues:

- modeling (learn from min. bias)
- extrapolation to LHC energies
- impact on selection efficiencies ?
  - isolation, trigger strategy
- have to tune MCs (eg. Pythia) asap

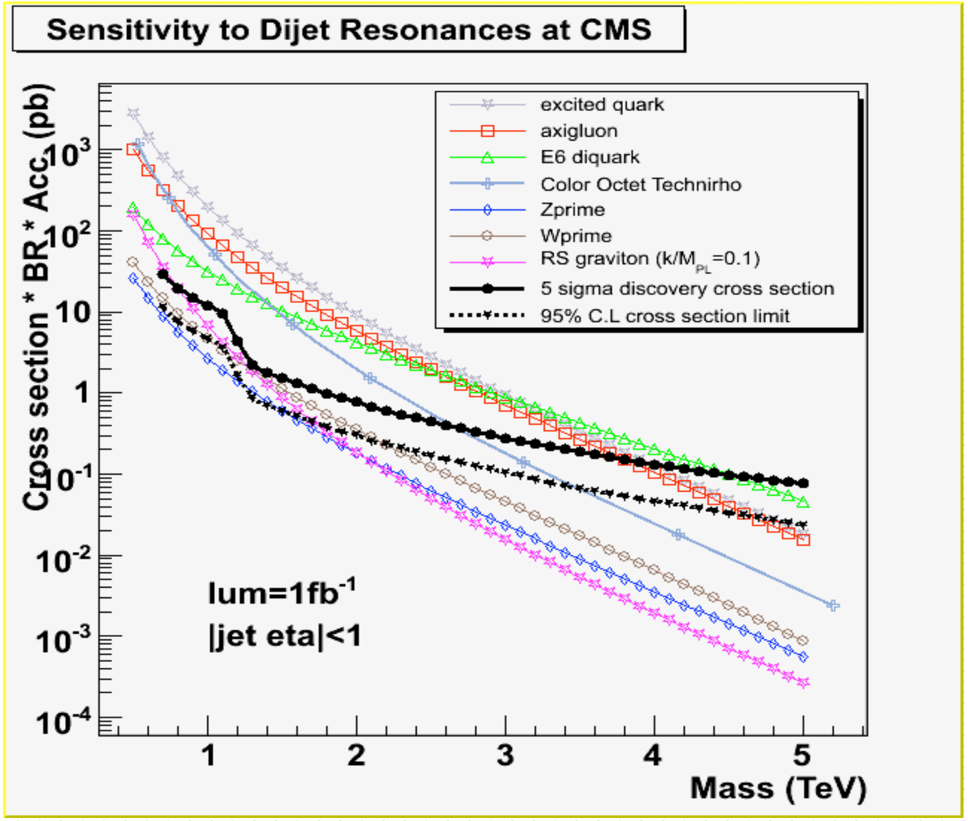
Modeling of the Underlying Event

- ~12 particles/evt in the barrel (+12 forward)
- Half of them curl in the tracker, ~50% reach outermost tracker layer



Di-Jets

- Produced at high rate
- Use for jet calibration by balancing jet transverse momentum
  - analyse (Δp_T / di-jet p_T) . Works well for low p_T, but low stat. at high p_T
- Physics interest in the high mass tail



- QCD cross section between 1.9 - 2.1 TeV is 3.5 pb
- Excited quarks : 8 pb !
- CDF/D0 limits in the range 0.4 - 1 TeV
- With 15 pb^{-1} at 14 TeV we could extend this
- Crucial: energy resolution in measuring jet energy (narrow resonances)

But … if we see a signal .. How can we be sure about the tails in the energy resolution?

Example : CMS preparations for Pilot Run

- Simulate 10 million min. bias evts and 1 million di-jets with p_T^{had} >10-15 GeV, using pilot run geometry
  - No pixel det., no ECAL endcaps
- Reconstruct these evts with latest reconstruction software
- "collect" the events
  - Ie. determine with which rate these events can be handled by the initial DAQ config.
  - Determine a trigger strategy to saturate it
    - Random, ECAL low energy photons, HCAL low thresholds, muons
  - Study trigger conditions as function of increasing luminosity

see CMS Physics TDR due this year !!

First Physics runs (2008…)

- After first "good" 10 pb^{-1}
  - ~20000 W, decaying to lepton + neutrinos
  - ~2500 Z, decaying into two leptons
  - ~200 semi-leptonic top-pair events
    - Measure rates, align and calibrate better
- After first "good" 100 pb^{-1}
  - W(Z)+jets rates well measurable
    - Jet calibration, MET calibration (for SUSY)
  - Inclusive leptons, di-leptons, photons, di-photon triggers (for Higgs)
- From 100 pb^{-1} to 1 fb^{-1}
  - Standard model candles
    - Top pair prod., W/Z cross sections, PDF studies, QCD studies, b-jet production
    - Do extensive MC tuning
  - Early Higgs boson search
    - $H \rightarrow \gamma\gamma$,WW,ZZ
  - Early SUSY-BSM searches
    - MET + anything, di-jet, di-leptons, di-photon, resonances….

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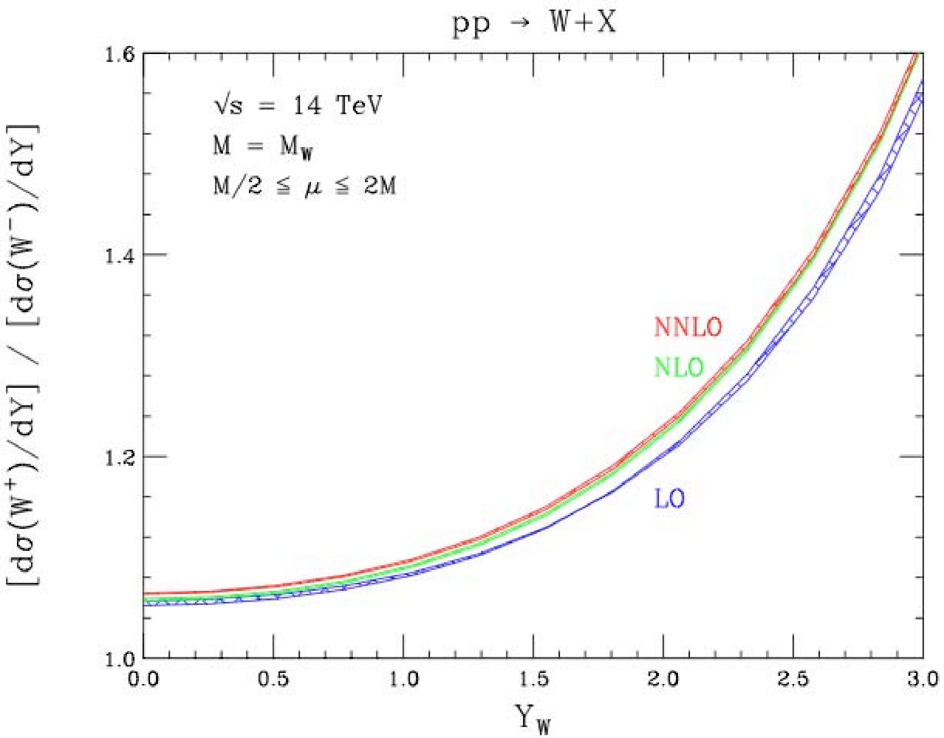
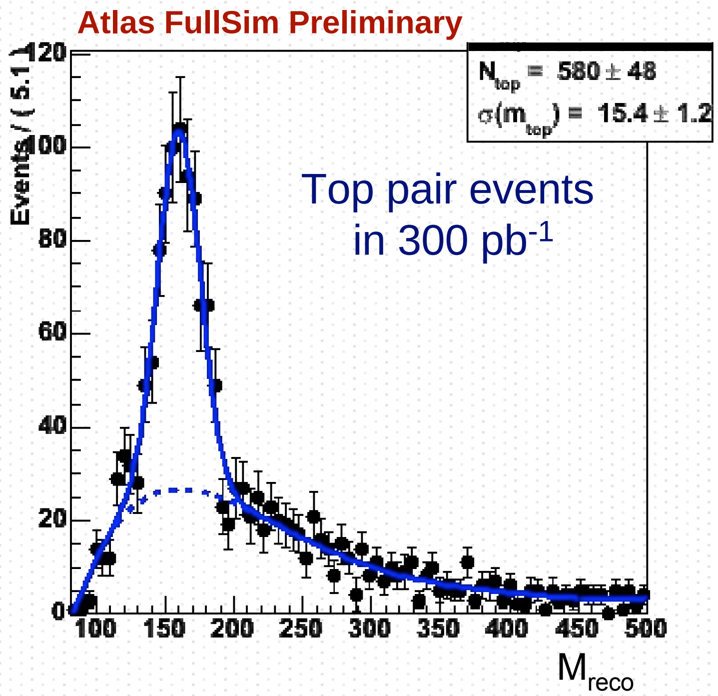
Standard Model measurements

- Drell-Yan (W, Z) production of lepton pairs
  - best known cross section at LHC, at NNLO : scale uncert. ~ 1% !



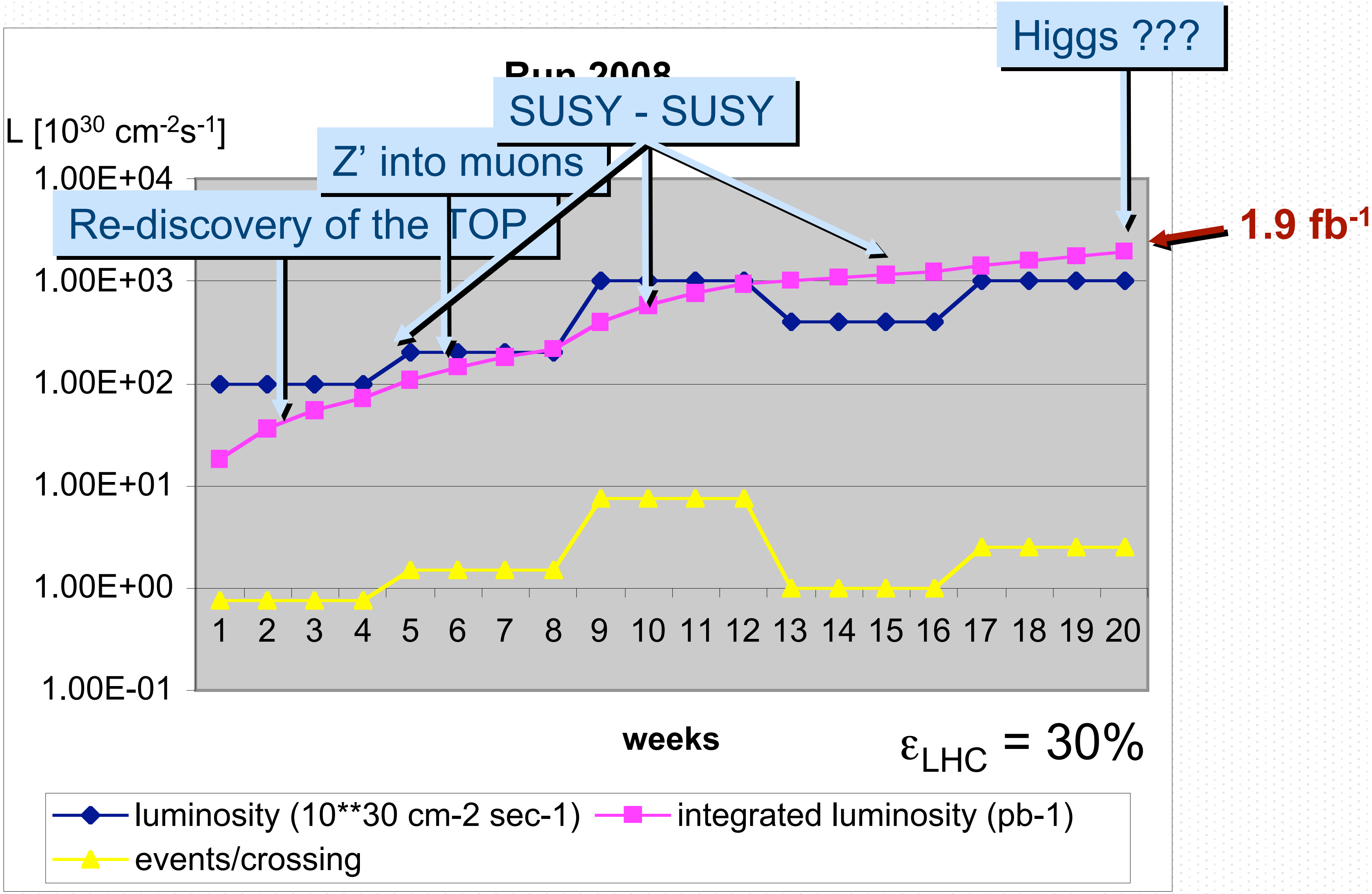
  - Similarly for W^+/W^- (ratios are good!!)
  - NNLO scale uncertainty 0.5 - 0.7 %
- Constrain PDFs, determine Lumi.

- Top-Physics
  - See the top immediately
  - simple selection : Missing E_T, 1 lepton, ≥4 jets , NO b-tag (!), cut on hadronic W mass



- Study the top quark properties
  - mass, charge, spin, couplings, production and decay, ΔM_{top} ~ 1 GeV ?
- important background for searches
- Jet energy scale from W→jet jet, commission b-tagging

The path to discovery



Courtesy G. Rolandi

Some comments

"Doing something ordinary is a waste of time" (Madonna)

Event rates

Event production rates at $L=10^{33}\ cm^{-2}\ s^{-1}$ and statistics to tape

Process	Events/s	Evts on tape, 10 fb^{-1}
$W \rightarrow e\nu$	15	10^8
$Z \rightarrow ee$	1	10^7
$t\bar{t}$	1	10^6
Minimum bias	10^8	10^7
QCD jets p_T>150 GeV/c	10^2	10^7
$b\bar{b} \rightarrow \mu X$	10^3	10^7
gluinos, m=1 TeV	0.001	10^3
Higgs, m=130 GeV	0.02	10^4

assuming 1% of trigger bandwidth

10^7 events to tape every 3 days, assuming 30% data taking efficiency, 1 PB/year/exp

⇒ statistical error negligible after few days (in most cases) !
⇒ dominated by systematic errors (detector understanding, luminosity, theory)

Our Master Equation

Stat vs syst errors, backgrounds from data or MC? Signal Significance

$$\sigma_{\mathrm{meas}} = \frac{N_{\mathrm{obs}} - N_{\mathrm{bkg}}}{\varepsilon \quad L}$$

Understand isolation, jet veto; p_T distributions at NLO; need calculations for detectable acceptance.

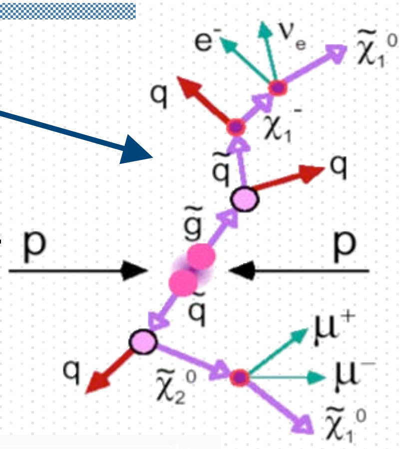
$$\sigma_{\mathrm{theo}} = PDF(x_1, x_2, Q^2) \otimes \hat{\sigma}_{\mathrm{hard}}$$

constrain, define uncertainties

HO calculations, implement in MC

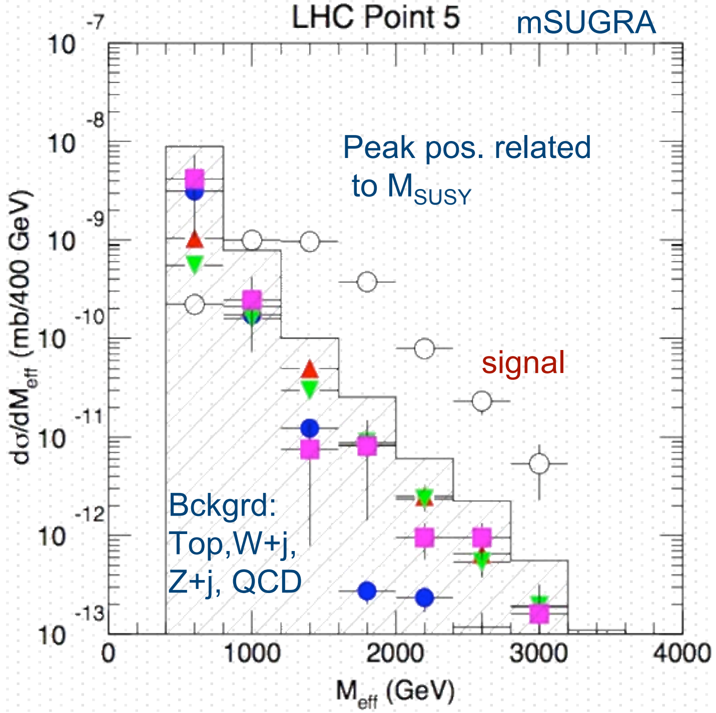
Early SUSY discovery?

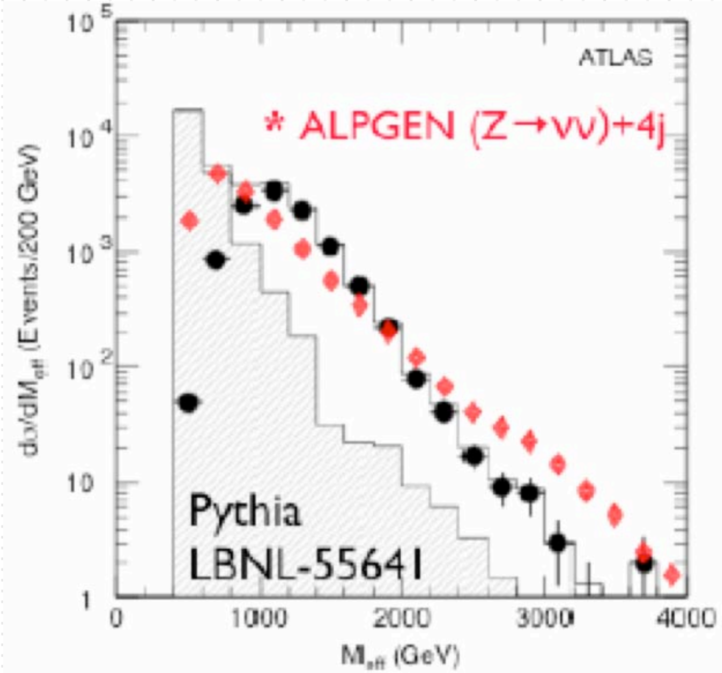
- Large squark/gluino pair prod. cross sections, ~100 evts/day at 10^{33} for m(squarks, gluinos) ~1 TeV. Spectacular signatures



Use multi-jet, multi-leptons and E_t^{miss} for discrimination.

$$\text{eg.} \quad M_{\text{eff}} = E_T^{\text{miss}} + \sum_{\text{jets}} p_T(\text{j})$$





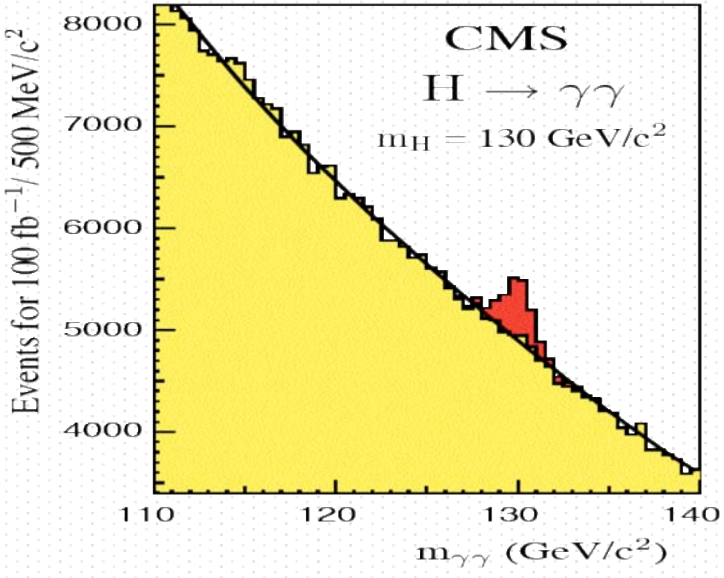
Beware ! : Good understanding of detector and SM bckgrds needed! eg. parton shower not enough!

Warnings…

- Always try to be as independent from the Monte Carlo as possible!
  - eg. find a "Standard Model candle" for calibration
  - Obtain backgrounds from the data whenever possible
    - Easy if we have mass peak (from sidebands)
    - More difficult in case of excess in high-energy tails, in particular in relation to MET or high-E_T jets
  - But what to do ?
    - Some examples in the following
    - Study carefully the validity of a Monte Carlo, and what it is exactly based on
      - eg. LO 2-to-2 process + parton shower, or 2-to-n + parton shower, or NLO+parton shower, or …
- Worry in particular about systematic errors in your search analysis when S/B << 1 !!
  - be careful with calculation of significance

Getting things from data

- **Calibrations**
  - **Electromagnetic calorimetry**
    - Z → ee, W→eν, Minimum-bias
  - **Hadronic calorimetry and jets**
    - Di-jet balance, Z (→ ll) +1j, W → jj in tt events, photon + jet
  - **MET**
    - Z (→ ll) +jets, then remove leptonic information
  - **Tracker and Muon alignment :**
    - Z → μμ, W→μν
  - **Lepton efficiencies, b-tagging**
    - Z → ee, Z → μμ
    - b-tag : use ttbar events to commission



- **Important kinematic properties**
  - W + n jets, p_t of W : take Z (→ ll) + n jets
  - Use bbZ (→ ll) as benchmark for bbA

- **Backgrounds**
  - Sidebands, or
  - normalize background via background-enhancing selection, use theory to extrapolate to signal-enhancing selection

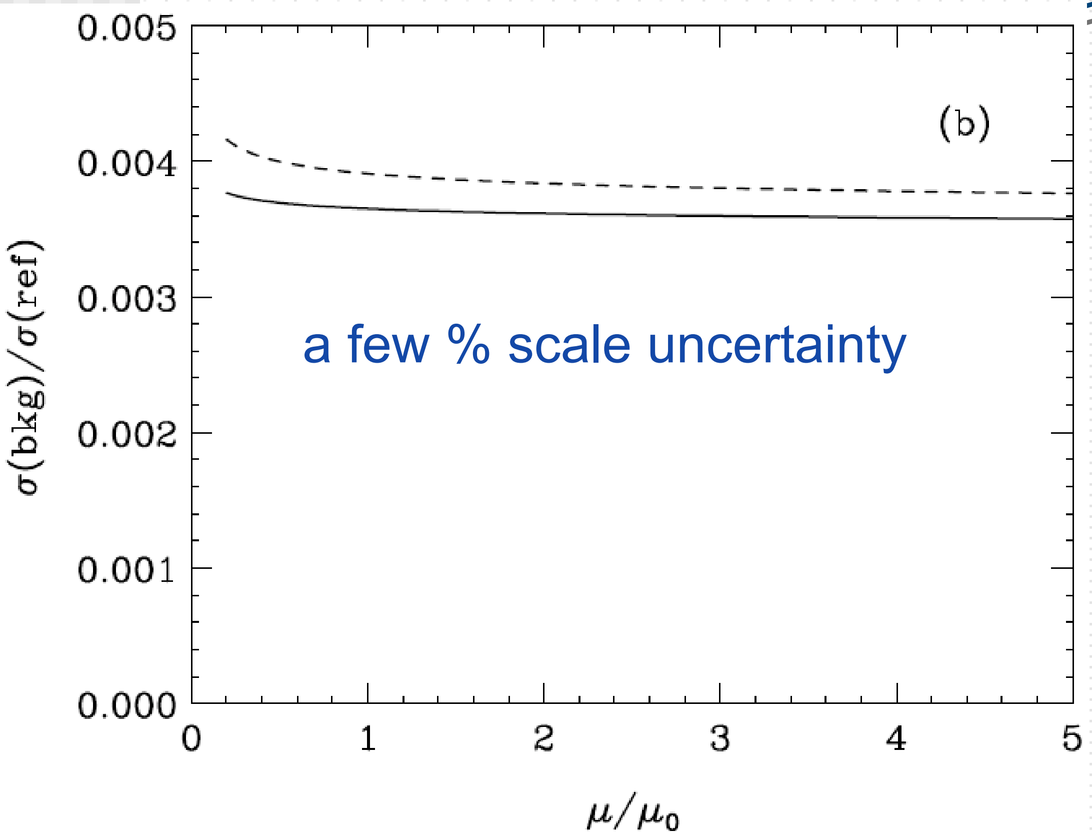
Background extrapolation

ETH Institute for Particle Physics

Introduction

Status of

Backgrounds to H WW ℓ|ℓ| : $t\bar{t}$ for gluon fusion, $t\bar{t}j$ for qqH



_ ~ 5% background uncertainty

Idea of extrapolation:

Cavelli, Kauer, Zeppenfeld

$$\sigma_{bkg} \approx \underbrace{\left(\frac{\sigma_{bkg,\,\mathrm{LO}}}{\sigma_{ref,\,\mathrm{LO}}}\right)}_{\text{low theoret. uncertainty}} \cdot \underbrace{\sigma_{ref}}_{\text{low experim. uncertainty}}$$

σ_{bkg} : background with cuts optimized for finding signal

σ_{ref} : background with cuts to enrich background (eg. revert the cuts above)

Further Remarks

- What are the important calculations needed, where is phenom. work wanted? Signal and Bkg:
  - NLO wherever possible
  - MC@NLO wherever possible!
  - NNLO, fully differential
    - at least for the basic processes
  - Backgrounds are important now, especially :
    - tt, ttj ,ttjj, W/Z+jets
    - Investigate ratio method for more processes
- Other interesting processes
  - Jet + photon/Z : gluon pdf
  - Excellent understanding of incl. jet and di-jet prod.

Summary

- We ARE getting ready for the LHC
- CERN is fully committed to the LHC project
  - Everybody (machine and detectors) is working like crazy to be in time
- Many efforts now concentrating on the very details of the start-up procedure
  - How to analyze the first data coming out
- Physics studies
  - be careful when using Monte Carlo programs for background (and signal) evaluation
  - The ingenuity of the experimenters really becomes visible when working on methods to get as much as possible from the data

"If we don't succeed, we run the risk of failure" (B. Clinton)

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ETH Institute for Particle Physics

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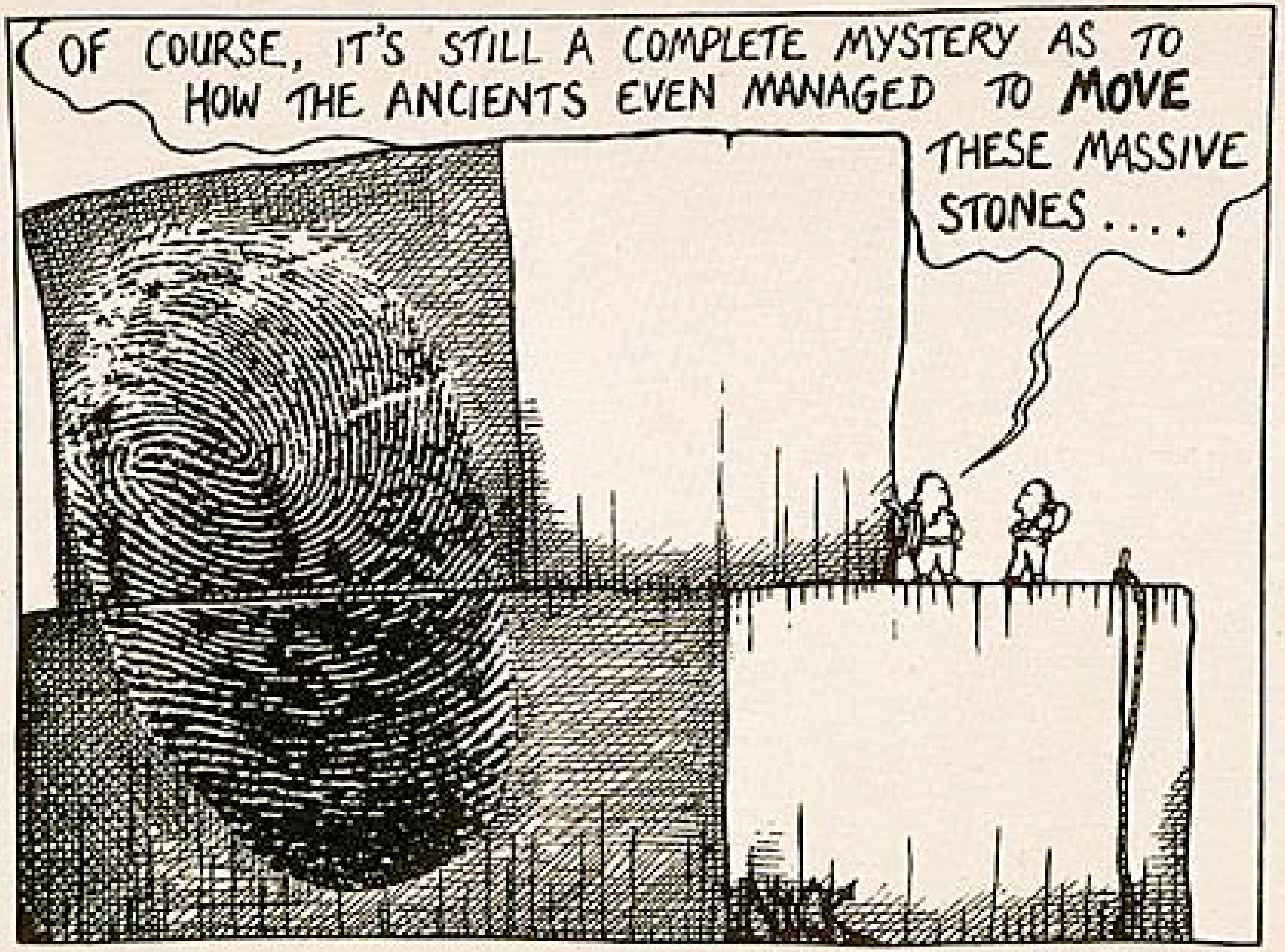
- Thanks for the invitation!
- My hope for the LHC:


OF COURSE, IT'S STILL A COMPLETE MYSTERY AS TO HOW THE ANCIENTS EVEN MANAGED TO MOVE THESE MASSIVE STONES....