Getting ready for the LHC

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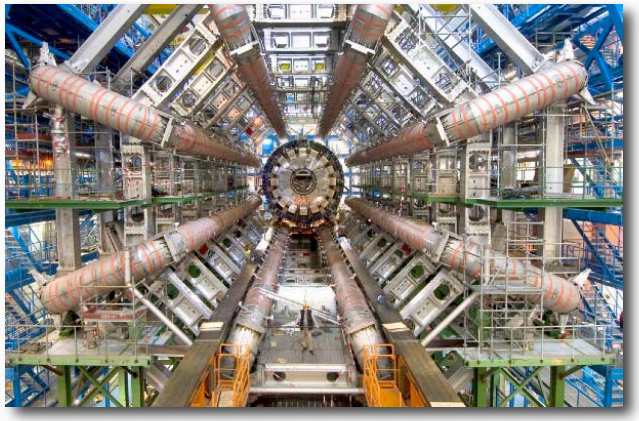
ETH Zürich

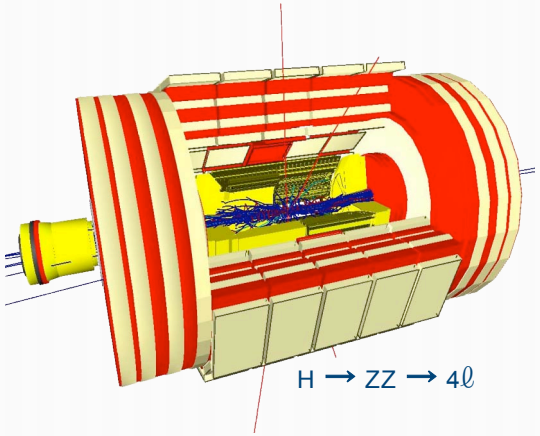
Planck'06
Paris
2.6.2006

Outline

- Introduction



- Now : Status of the
  - Machine
  - Detectors (ATLAS, CMS)
- 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



Our future play ground

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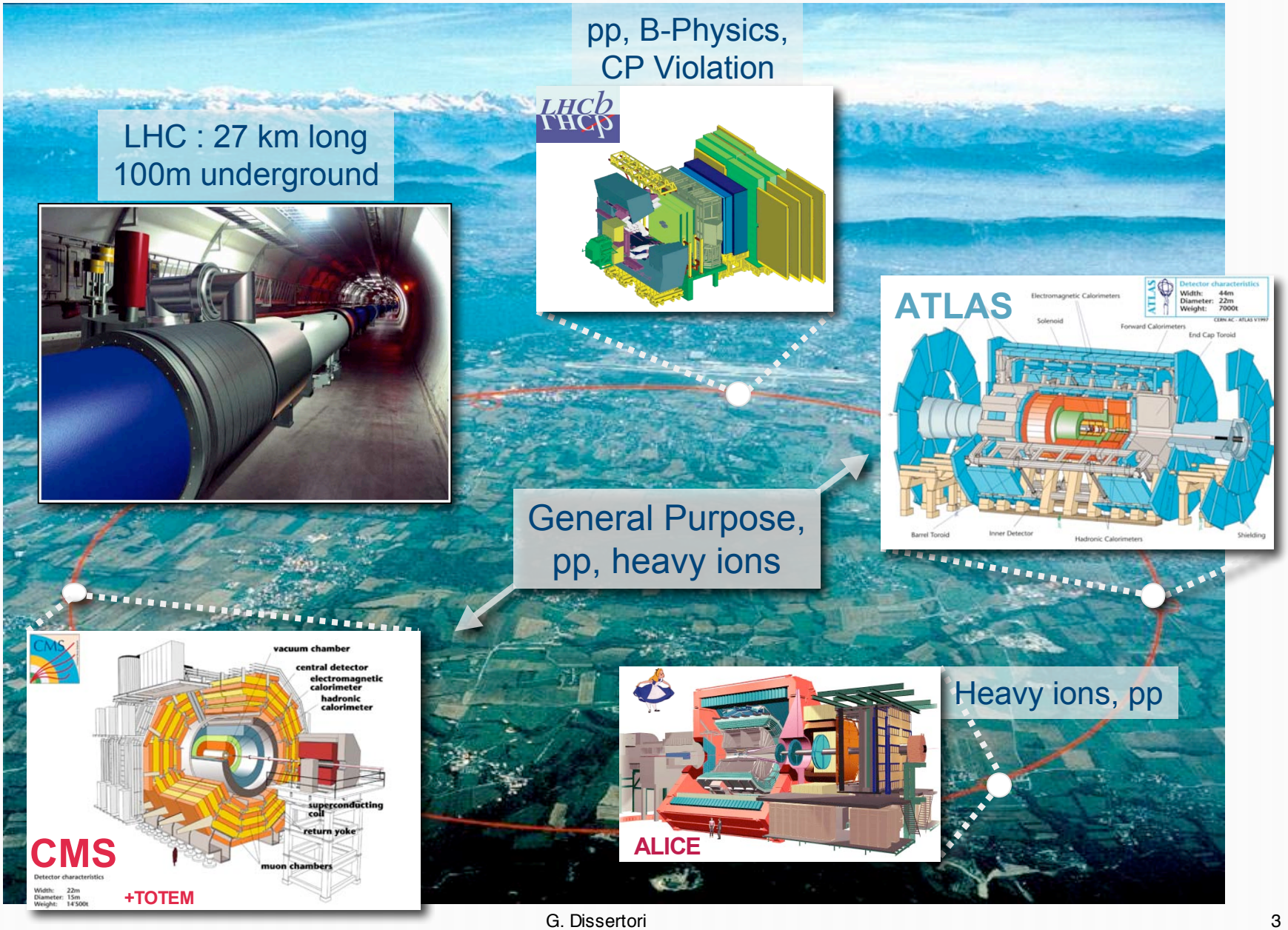
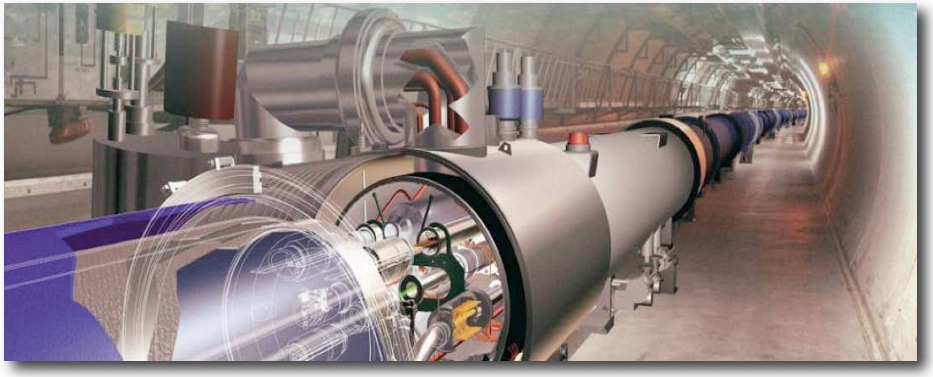
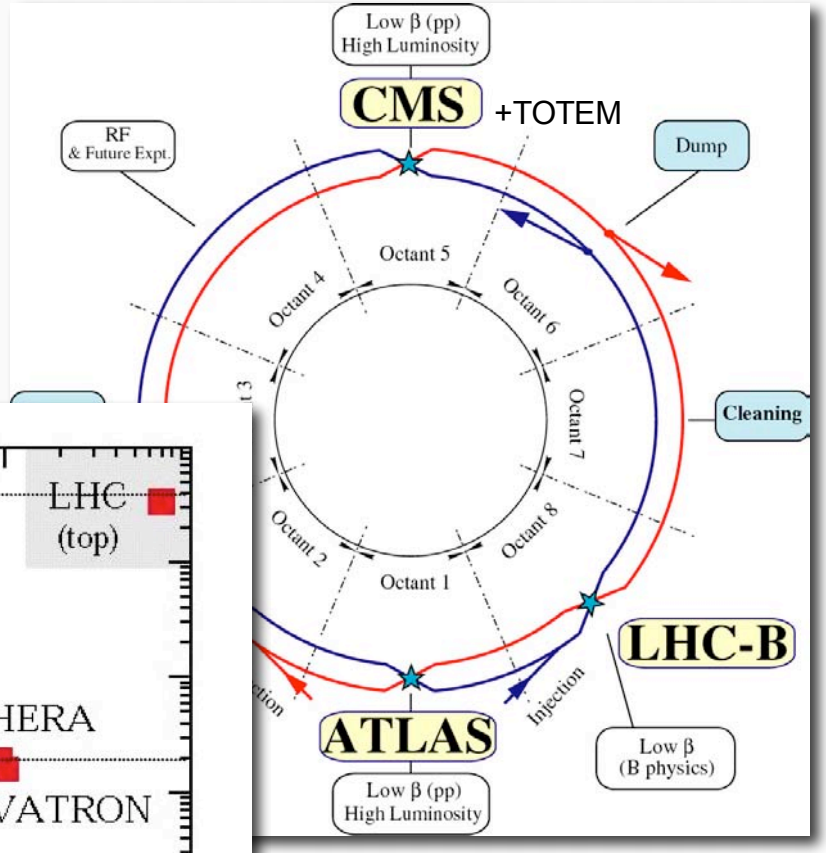


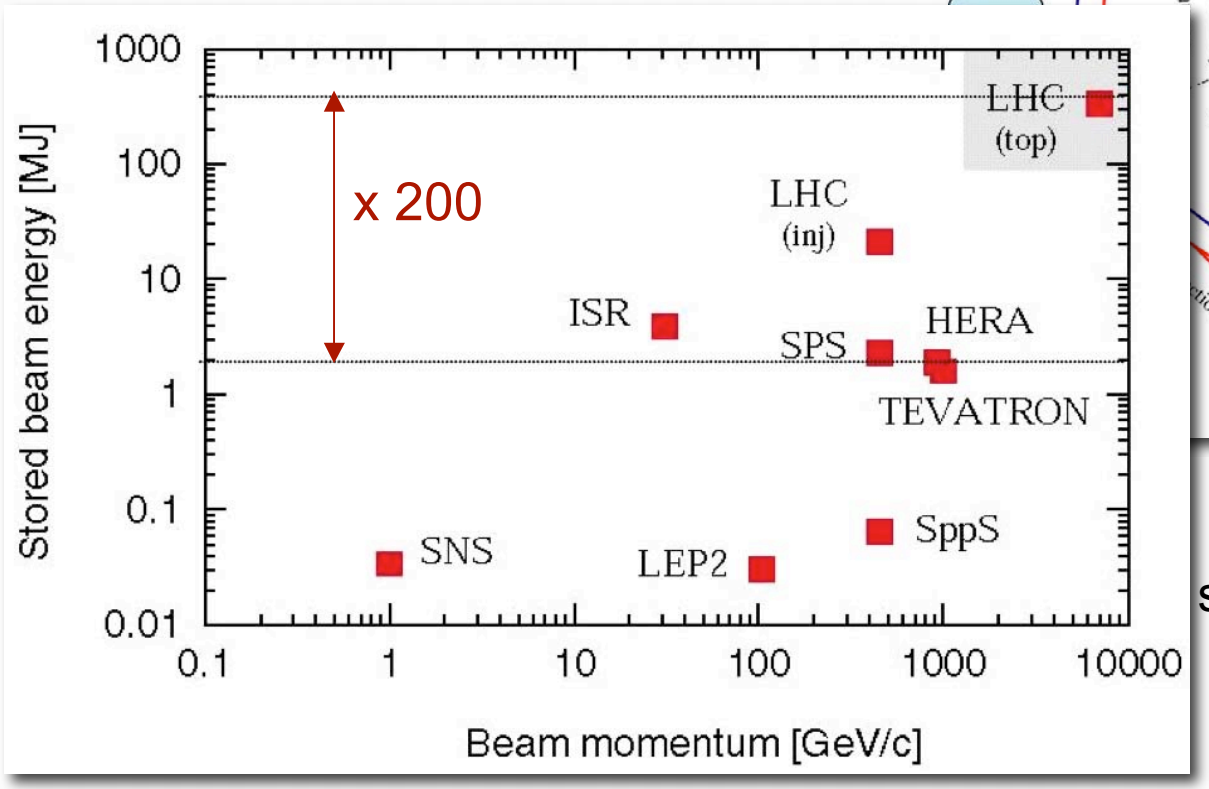
Now :
Status of the LHC and the Detectors

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

The LHC : Basic parameters







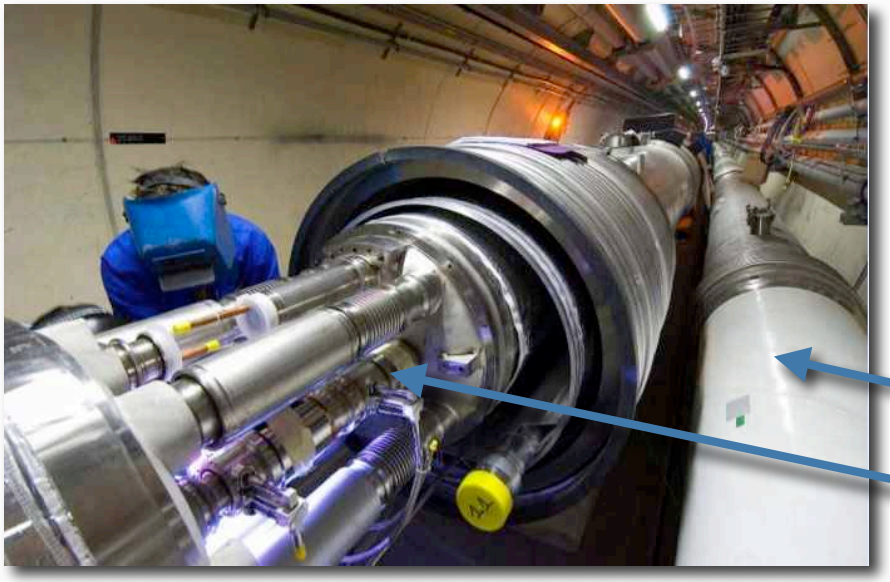
stored in magnets

The LHC : Status report

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

By now there are > 500 dipoles

Schedule review in Spring 2006.



Cryogenic services line

inter-connections

The LHC : Status report

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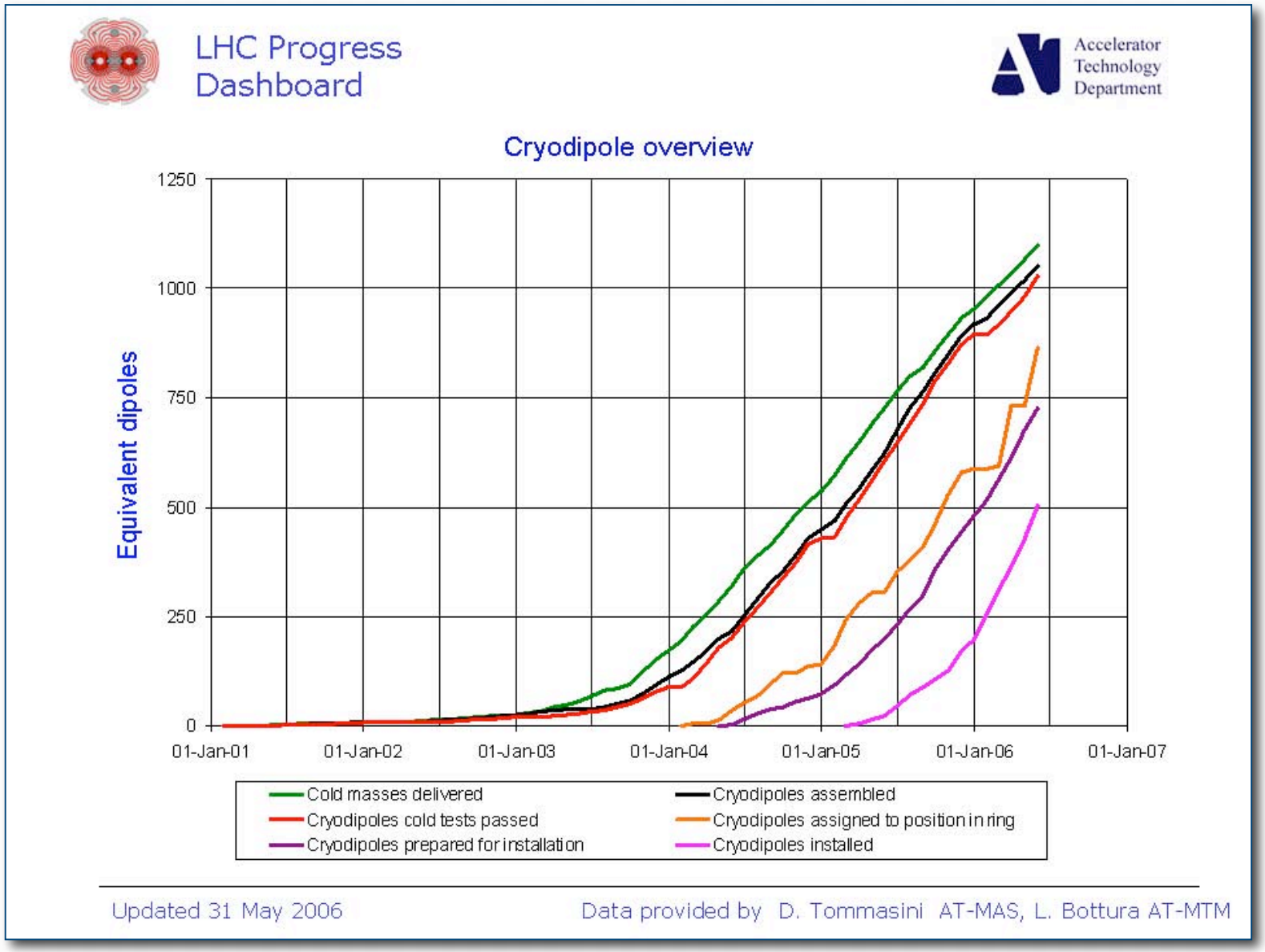
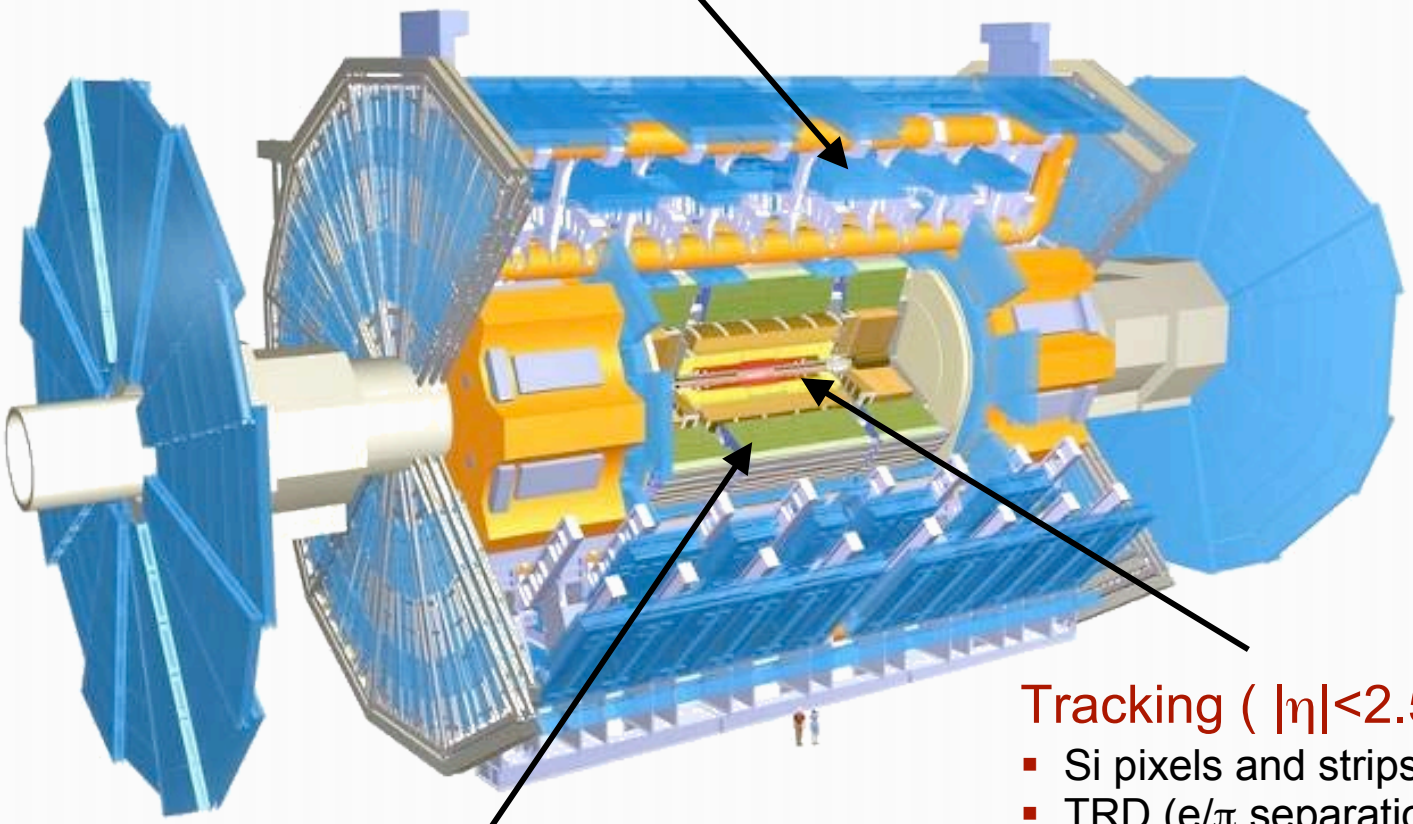


See : http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/DashBoard/index.asp

ATLAS

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

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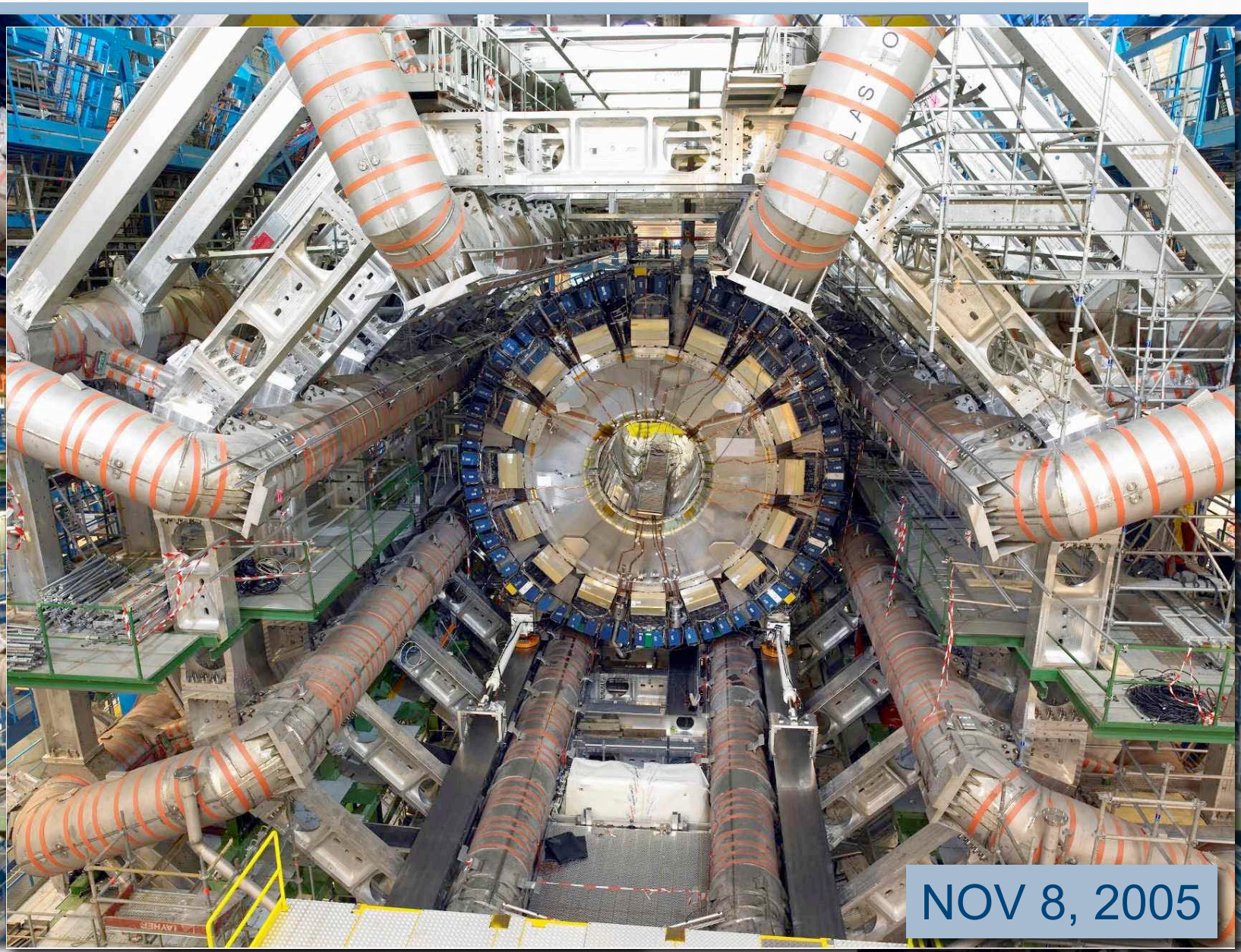


CMS

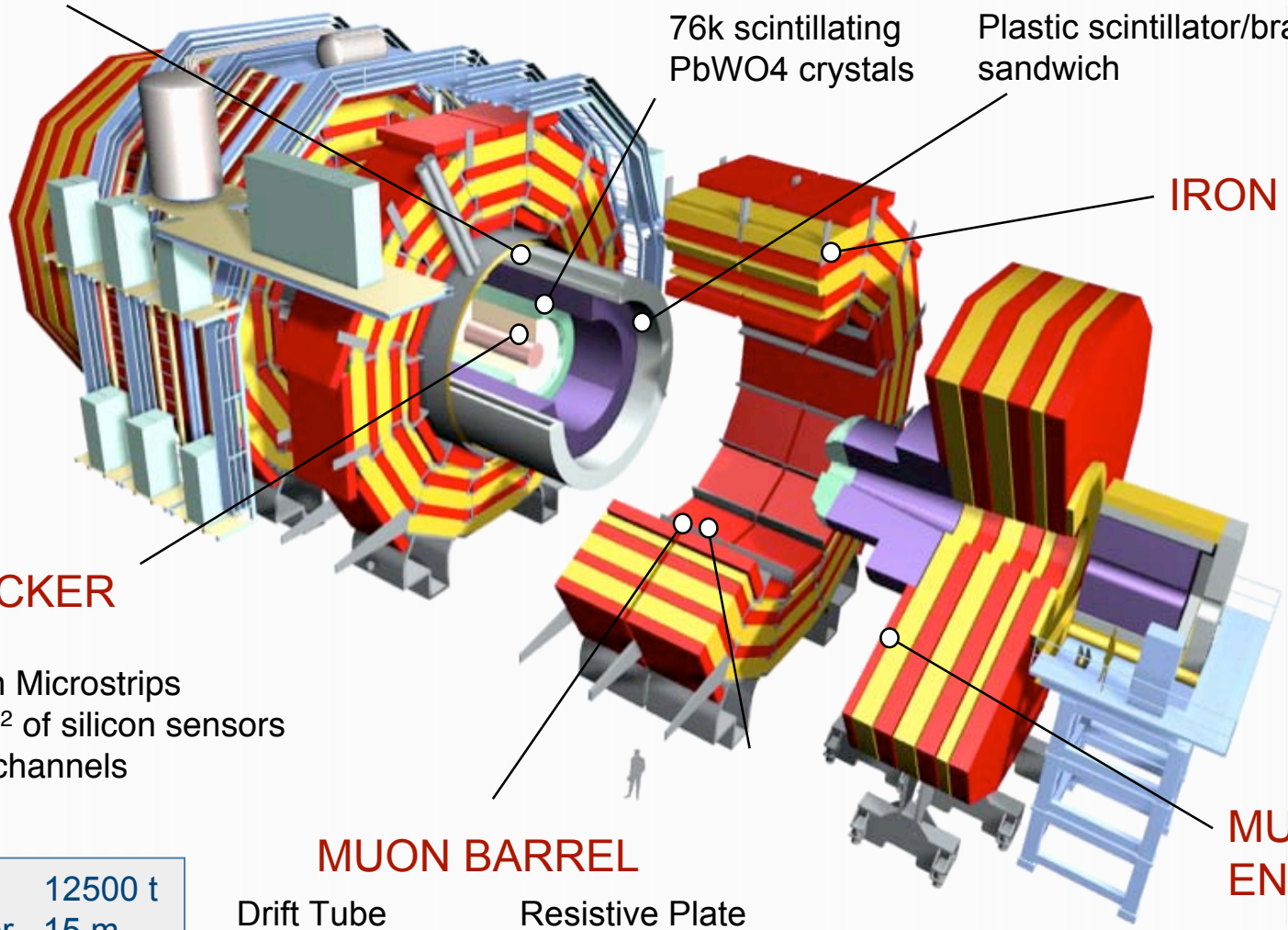
Superconducting Coil, 4 Tesla

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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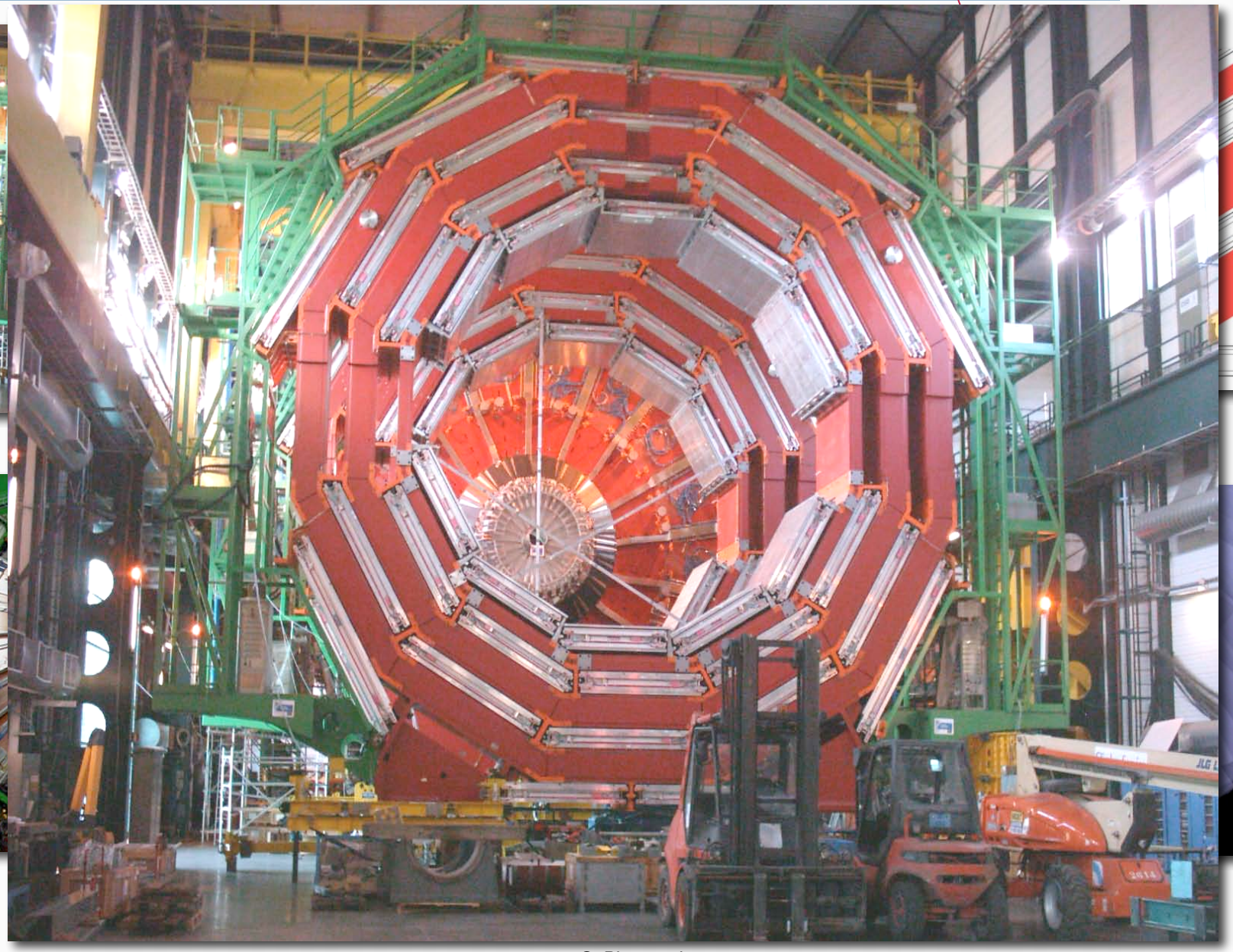

CMS : Status report

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Magnet Insertion: Autumn 05 ; Cooled down early in 2006

CMS : Status report

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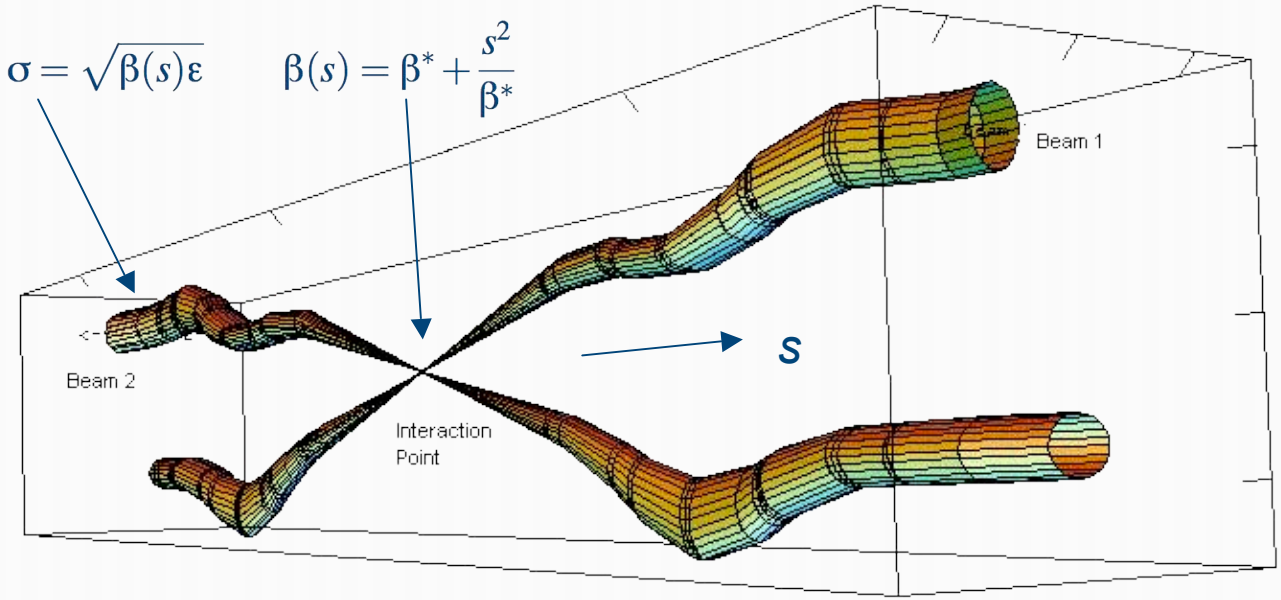
CMS : lowering

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

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



Relative beam sizes around IP1 (Atlas) in collision

σ^*=16.6μm $\xrightarrow{\sim 23m}$ 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

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

$L=3\times10^{28}$ - 2×10^{31}

Stage 2
75 ns operation
936x936, N=3-4×10^{10}
partial squeeze

$L=10^{32}$ - 4×10^{32}

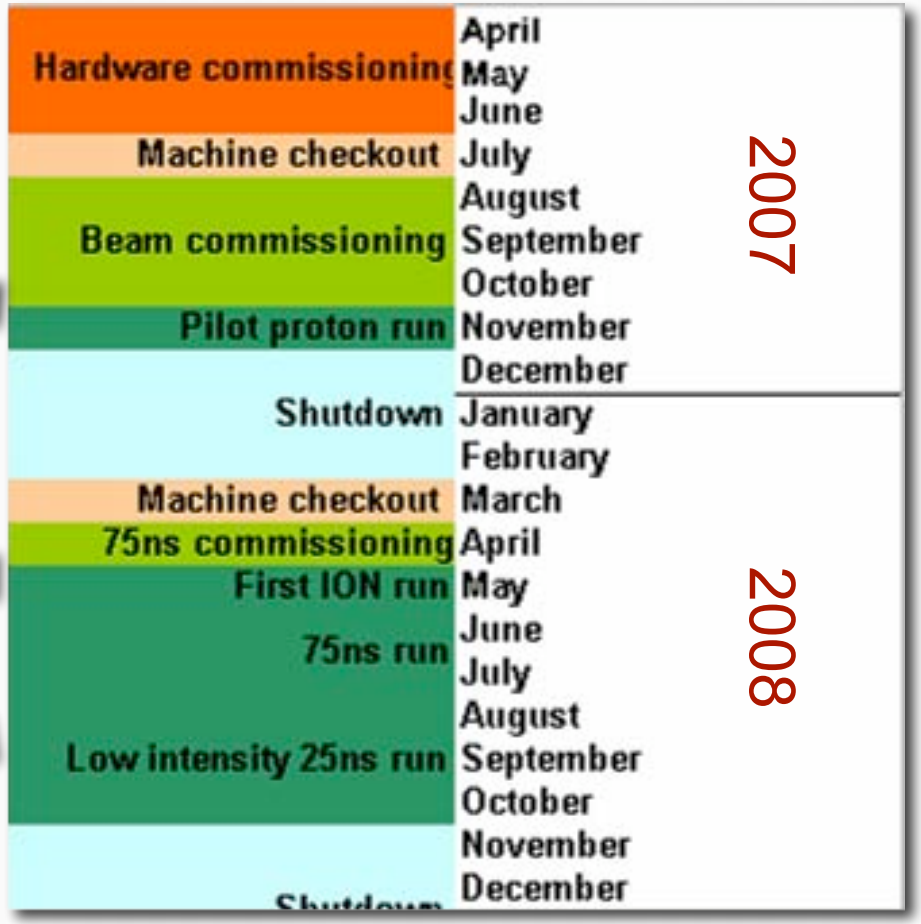
Stage 3
25 ns operation
2808x2808, N=3-5×10^{10}
partial to near full squeeze

$L=7\times10^{32}$ - 2×10^{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.



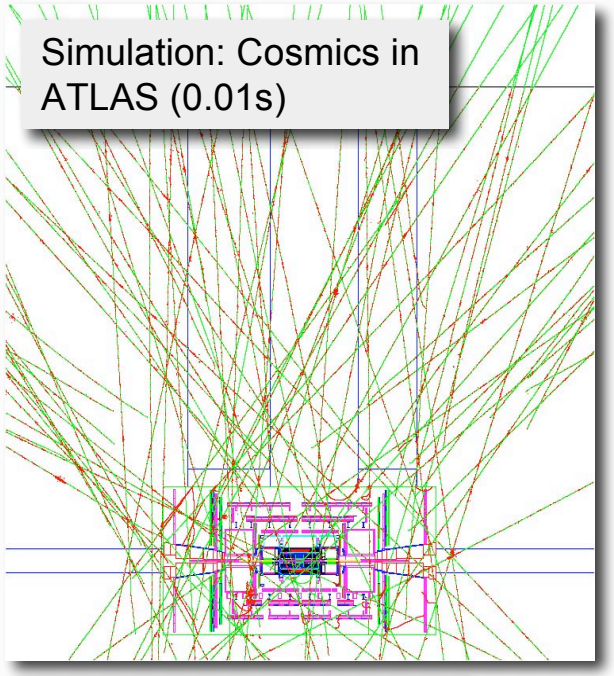
Detector Commissioning

- 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

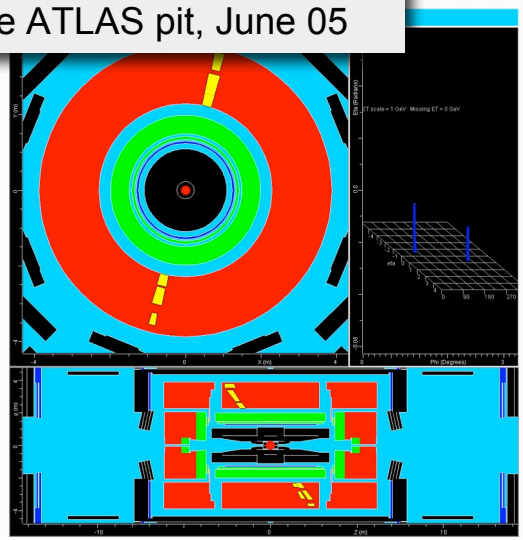
Detectors : Commissioning

- 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)



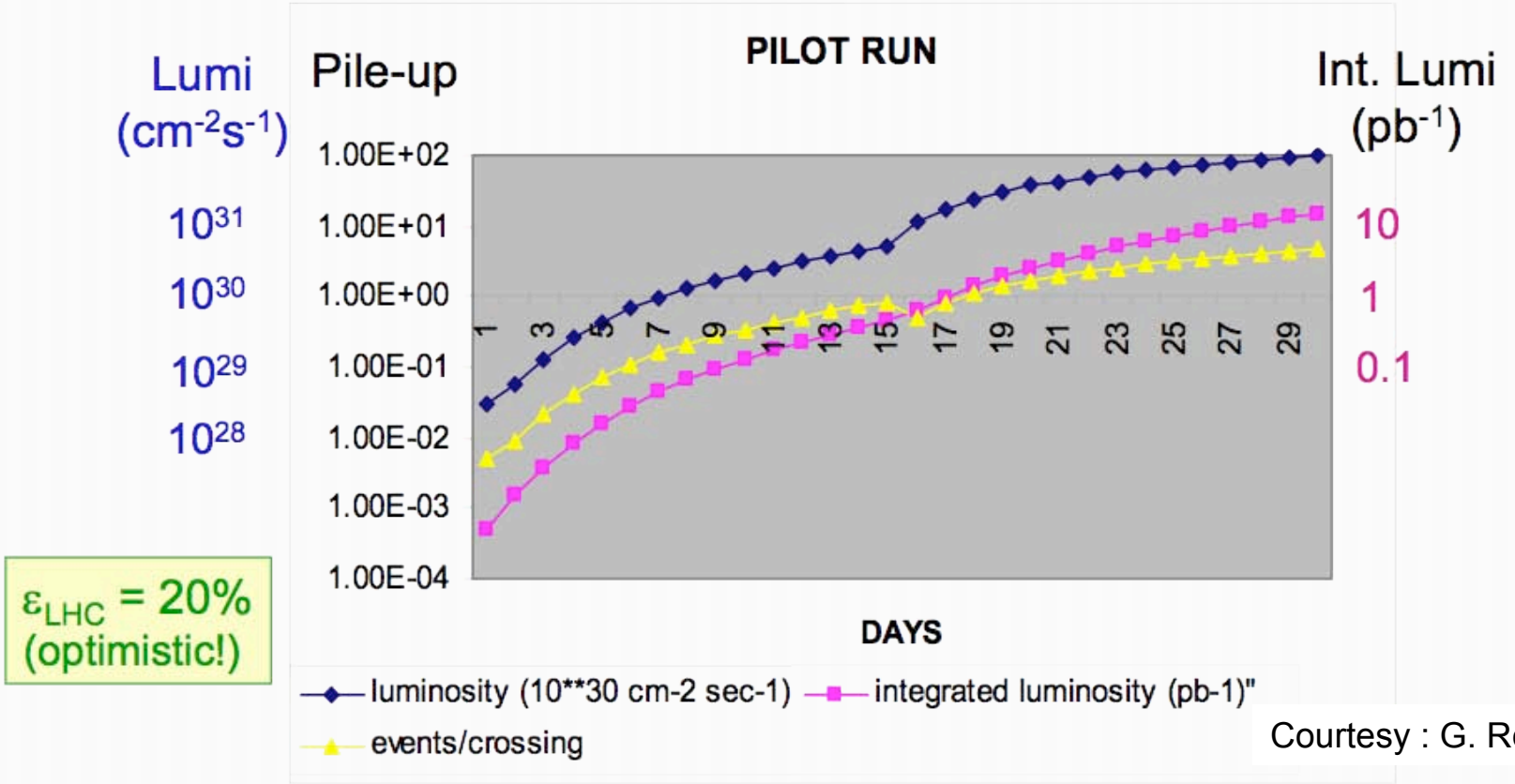
First real cosmics seen in the ATLAS pit, June 05

Soon : Pilot Run and First Physics

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

Pilot run : Luminosity

- 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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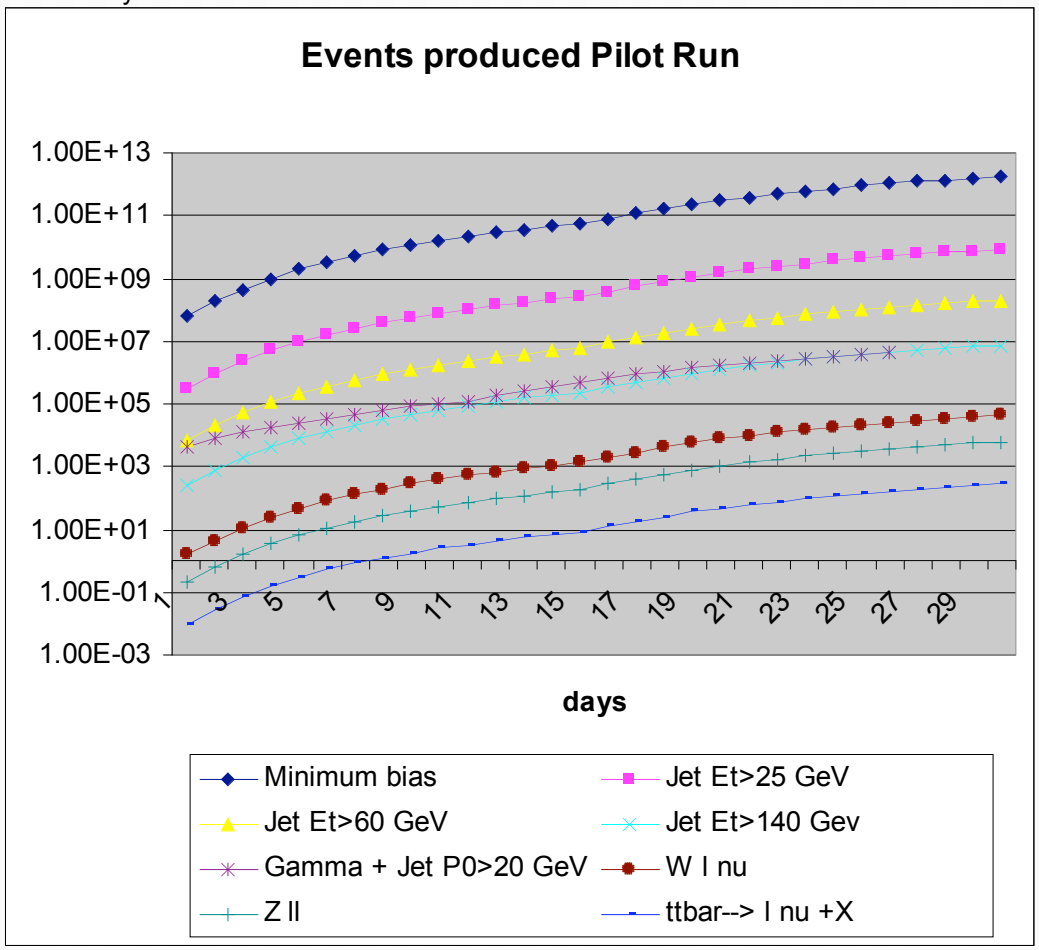
Courtesy G. Rolandi



Assumed efficiencies:

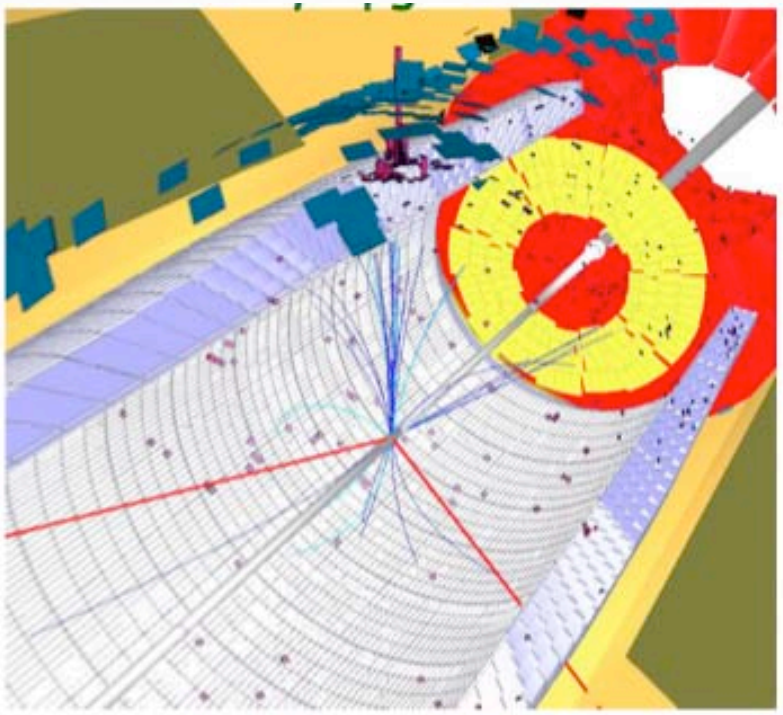
ε(jets) = 100%
ε(W) = 20%
ε(Z) = 20%
ε(ttbar) = 1.5%

Even within a few hours/days:

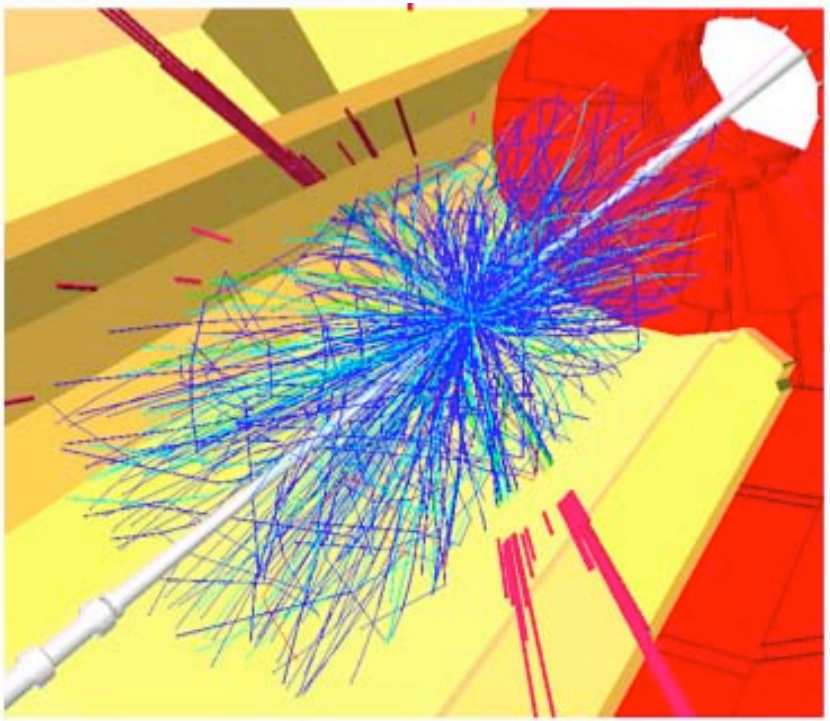
- About 10 million minimum bias evts (almost possible to trigger randomly)
- A few million di-jet events with E_T > 15 GeV
- Not much of anything else

Pile-Up

- Pile-up : additional mostly soft-interactions per bunch crossing
- Start-up Lumi : $2x10^{33}$ $cm^{-2}s^{-1}$ ⇒ 4 events / bunch crossing
- High Lumi : 10^{34} $cm^{-2}s^{-1}$ ⇒ 20 events / bunch crossing



LHC event - no pile-up

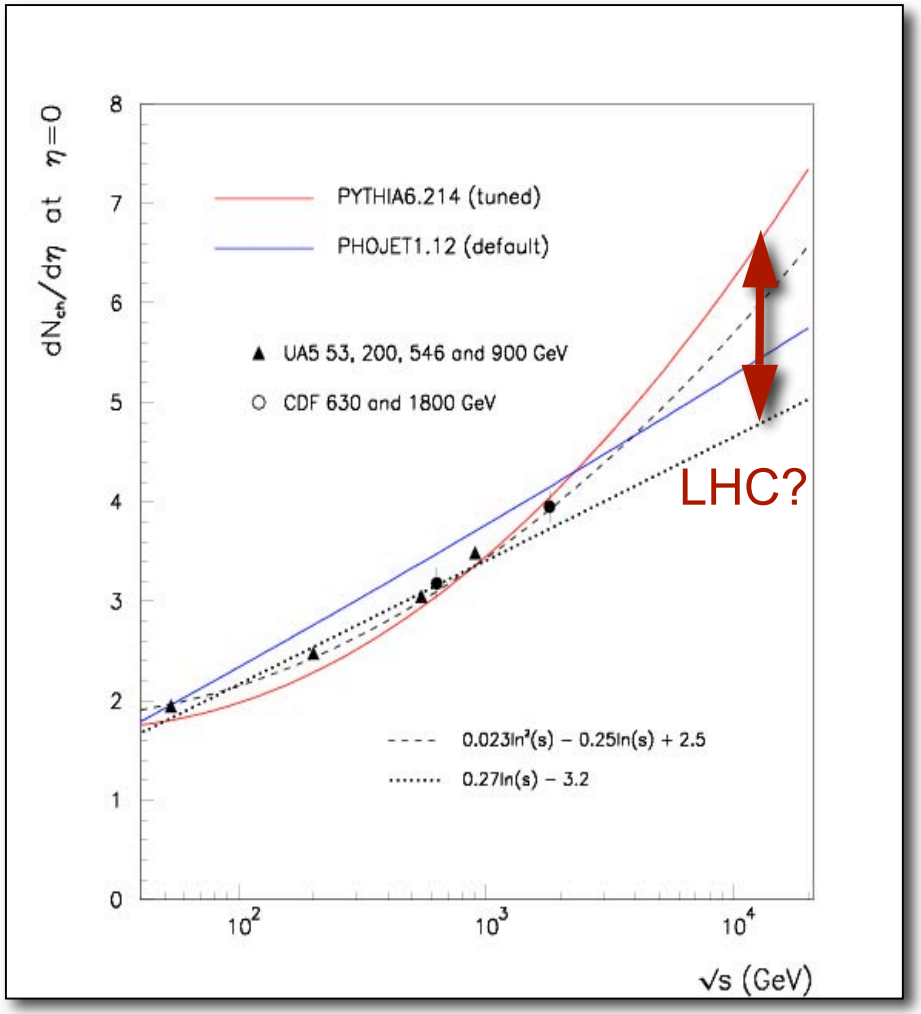


LHC event - 10^{34} $cm^{-2}s^{-1}$

Courtesy A. De Roeck

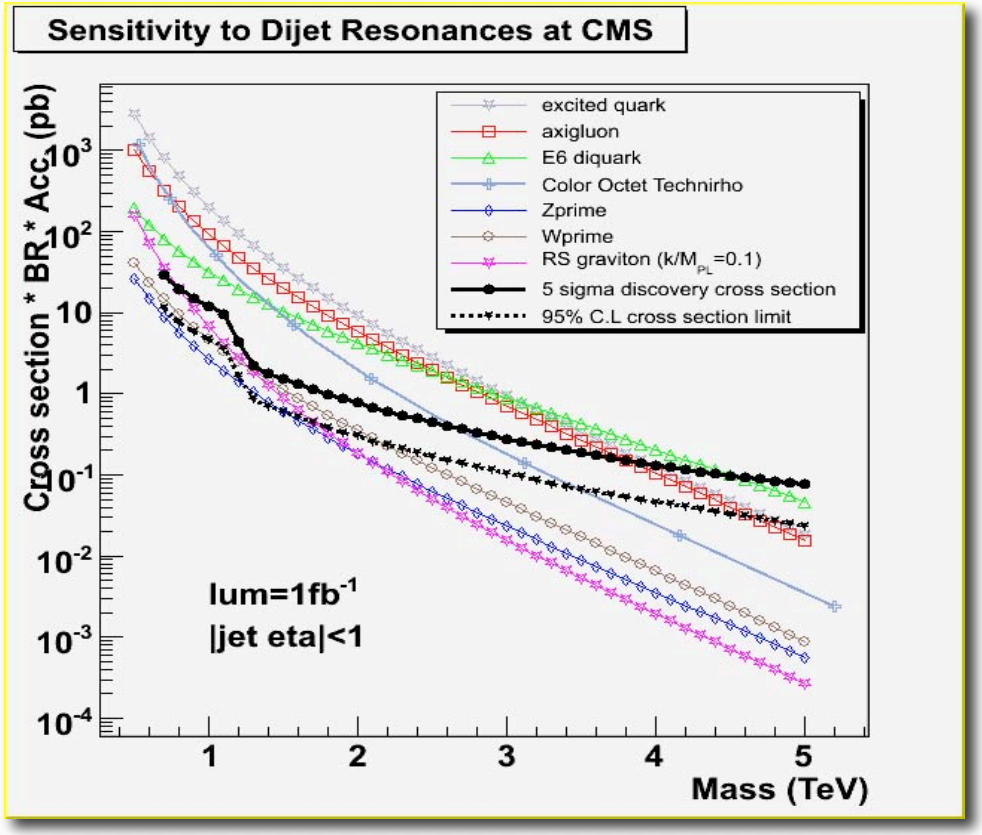
Modeling of the Underlying Event

- ~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



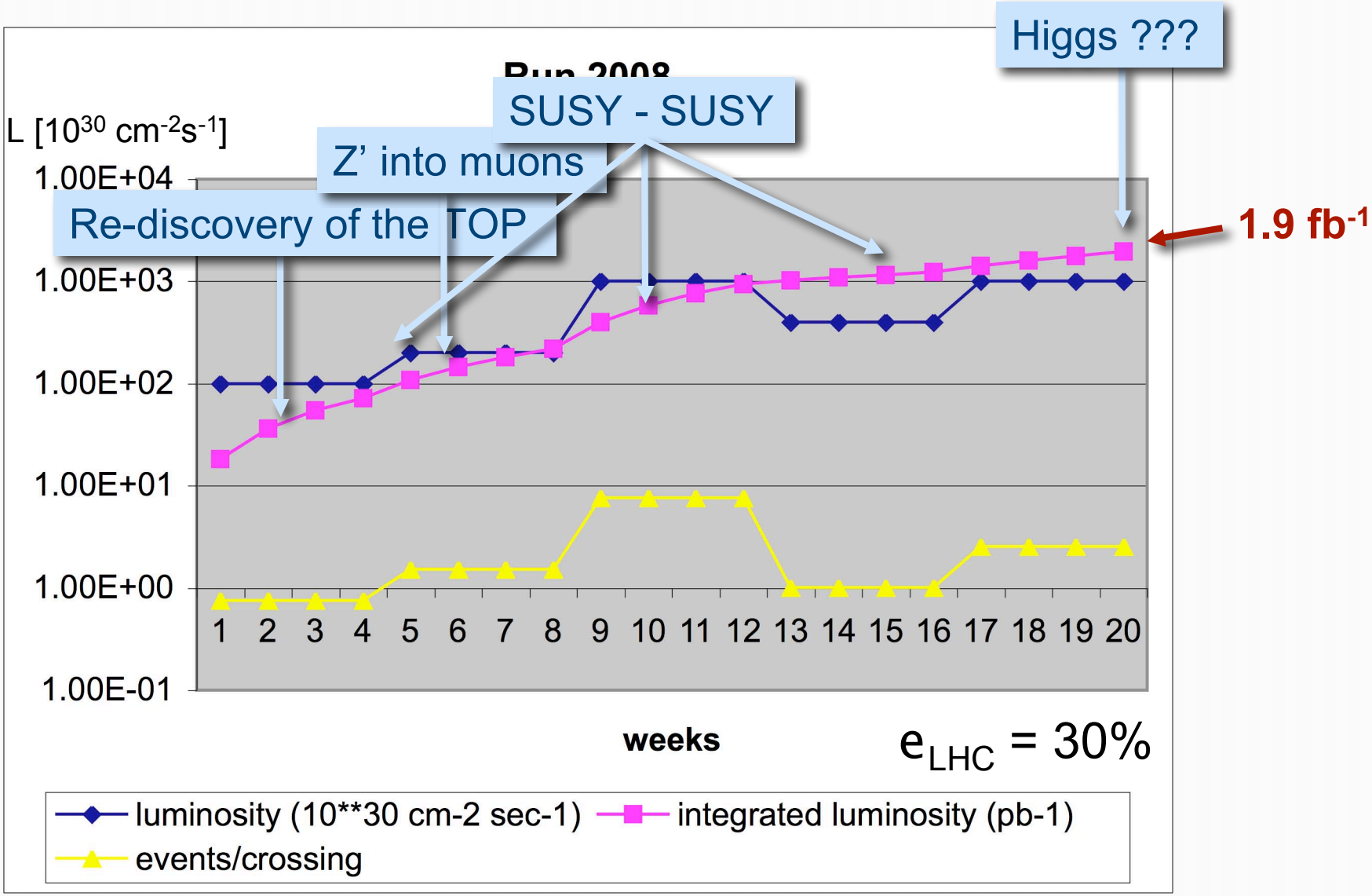
- QCD cross section between 1.9 - 2.1 TeV is 3.5 pb
- Excited quarks : 8 pb !
- CDF/D0 limits in the range 0.4 - 1 TeV
- With 15 pb^{-1} at 14 TeV we could extend this
- Crucial: energy resolution in measuring jet energy (narrow resonances)

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

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….

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}
$W \rightarrow en$	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
$b\bar{b} \rightarrow mX$	10^3	10^7
gluinos, m=1 TeV	0.001	10^3
Higgs, m=130 GeV	0.02	10^4

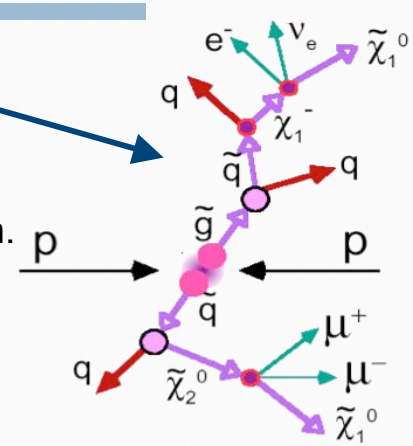
assuming 1% of trigger bandwidth

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)

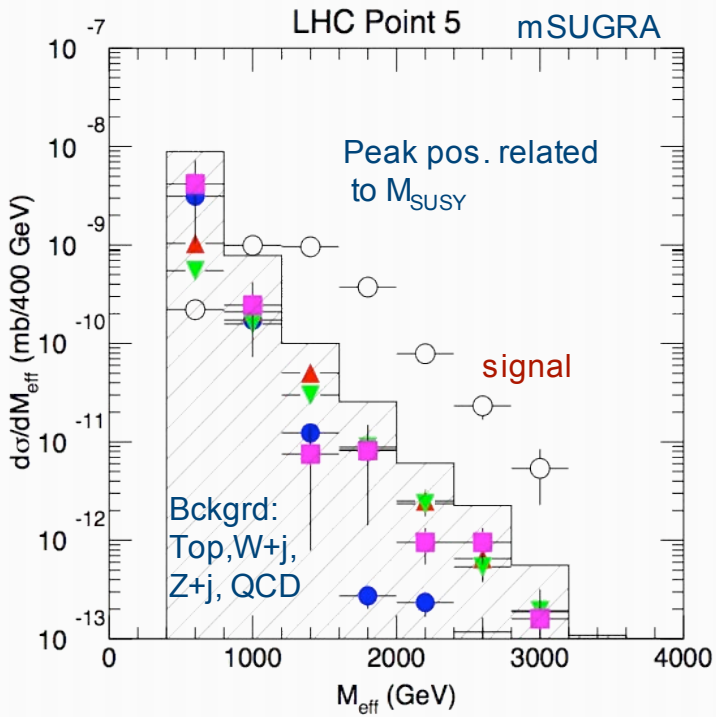
Early SUSY discovery?

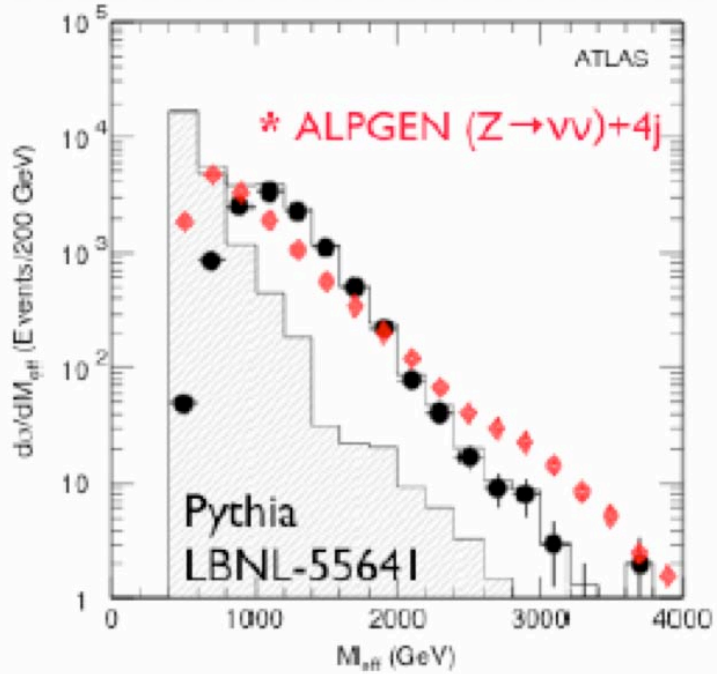
- Large squark/gluino pair prod. cross sections, ~100 evts/day at 10^{33} for m(squarks, gluinos) ~1 TeV. Spectacular signatures



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

$$\text{eg. } M_{\text{eff}} = E_{\text{T}}^{\text{miss}} + \sum_{\text{jets}} p_{\text{T}}(\text{j})$$





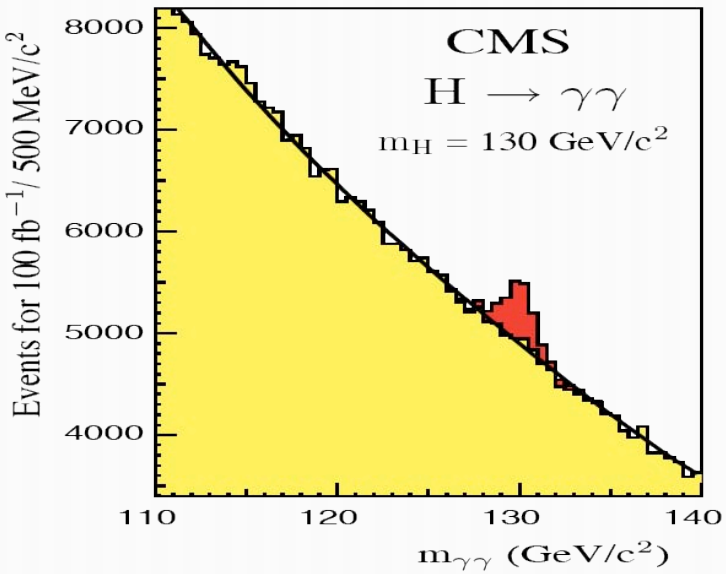
Beware ! : Good understanding of detector and SM bckgrds needed! eg. parton shower not enough!

Warnings…

- Always try to be as independent from the Monte Carlo simulation 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

Summary

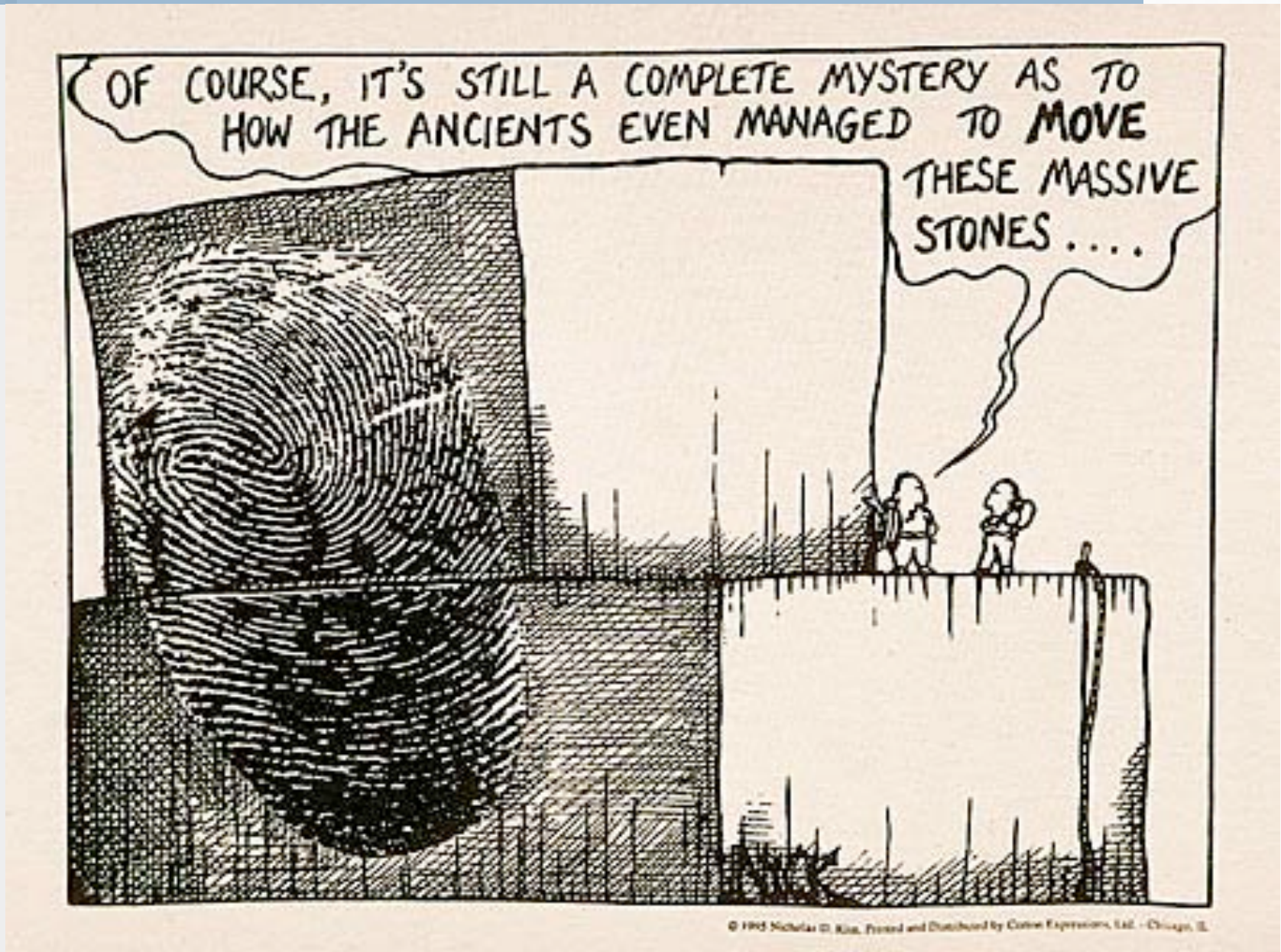
- We ARE getting ready for the LHC
- CERN is fully committed to the LHC project
  - Everybody (machine and detectors) is working like crazy to be in time
- Many efforts now concentrating on the very details of the start-up procedure
  - How to analyze the first data coming out
- Physics studies
  - be 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)

Acknowledgements

- Many thanks to all these people:
  - G. Rolandi, O. Brüning, F. Gianotti, P. Jenni, D. Treille, L. Pape, H. Burkhardt, F. Pauss, L. Evans, A. De Roeck, F. Moortgat, P. Janot, J. Virdee
- 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....

Backups

LHC : Performance Limitations

Parameter/Effects	Limitations

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)

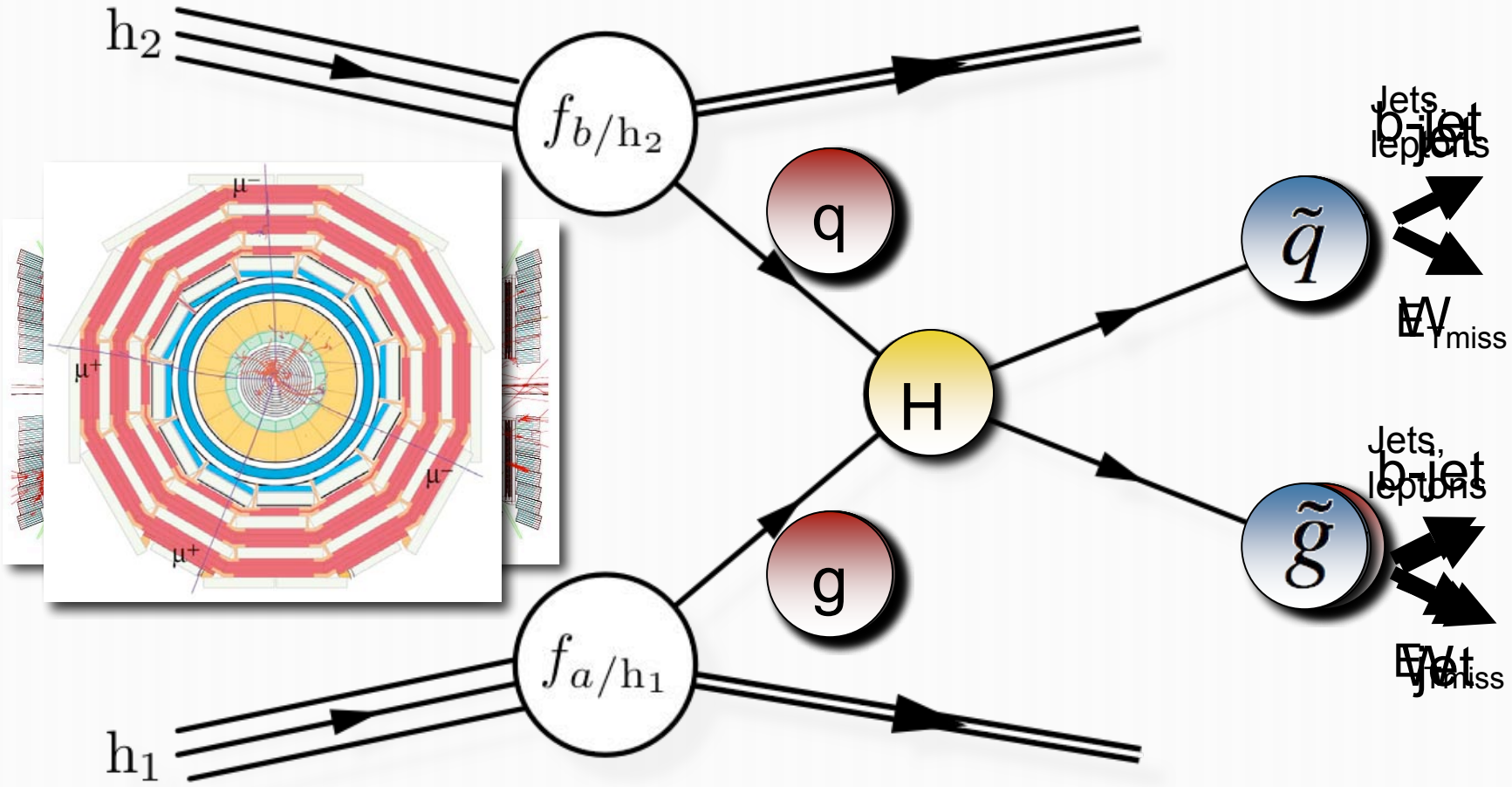
Tune spread $\Delta Q \propto N / \varepsilon_n$

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

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)

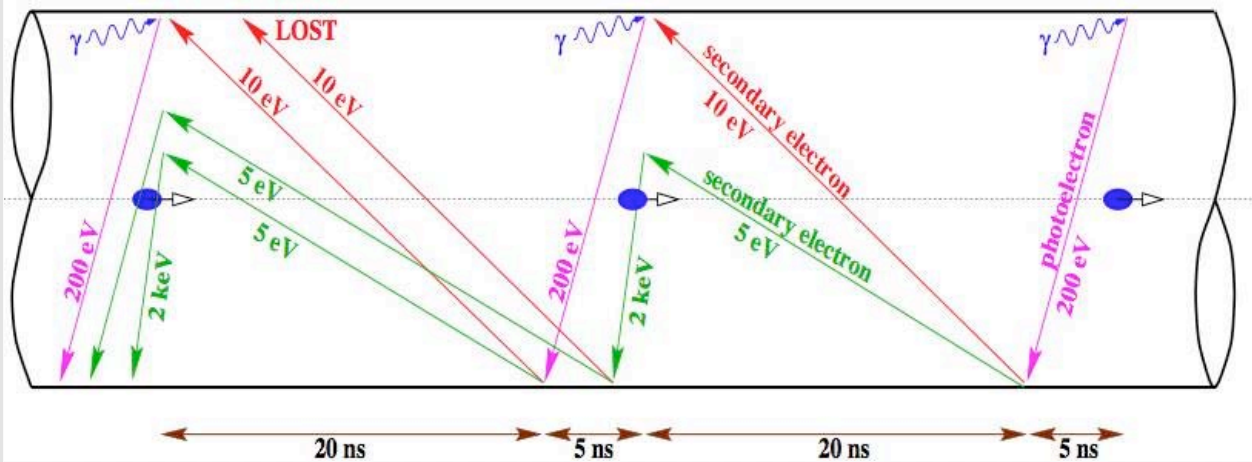
First Physics : Basic processes



$$d\sigma(h_1 h_2 \to cd) = \int_0^1 dx_1 dx_2 \sum_{a,b} f_{a/h_1}(x_1, \mu_F^2) f_{b/h_2}(x_2, \mu_F^2) d\hat{\sigma}^{(ab\to cd)}(Q^2, \mu_F^2)$$

LHC : Performance Limitations

- Electron cloud : heat load on the beam screen, larger for smaller bunch spacing

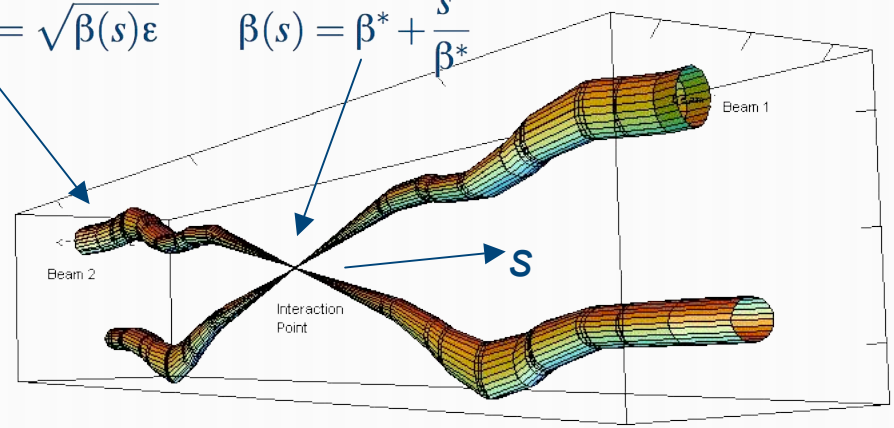


25 ns ok for well conditioned surfaces (➔ 2808 bunches)

12.5 ns : at the limit! Final conclusion only after LHC startup

- Magnet aperture, beam-beam, collimators

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



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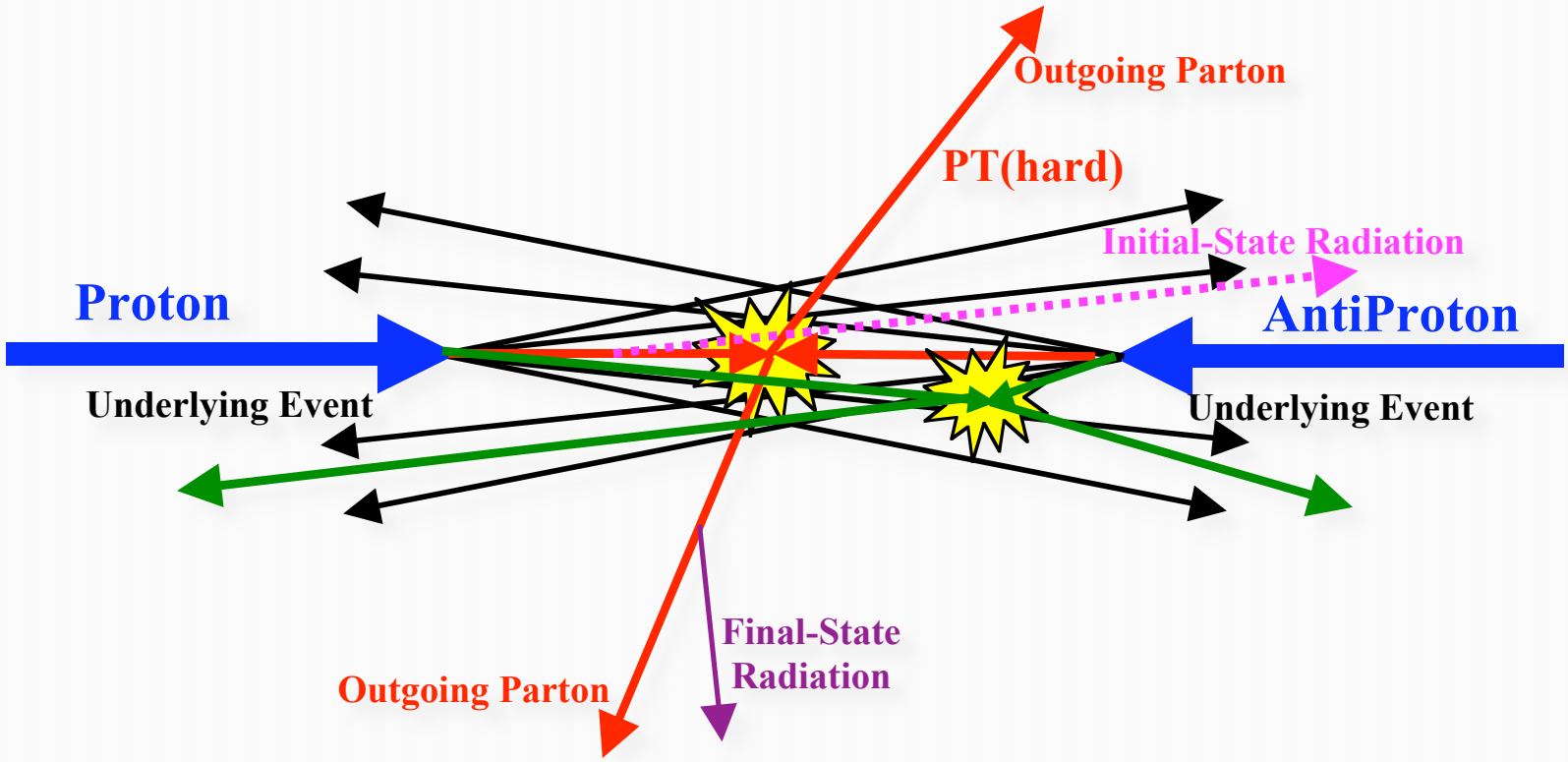
The Underlying Event



The Underlying Event:

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

Issues:

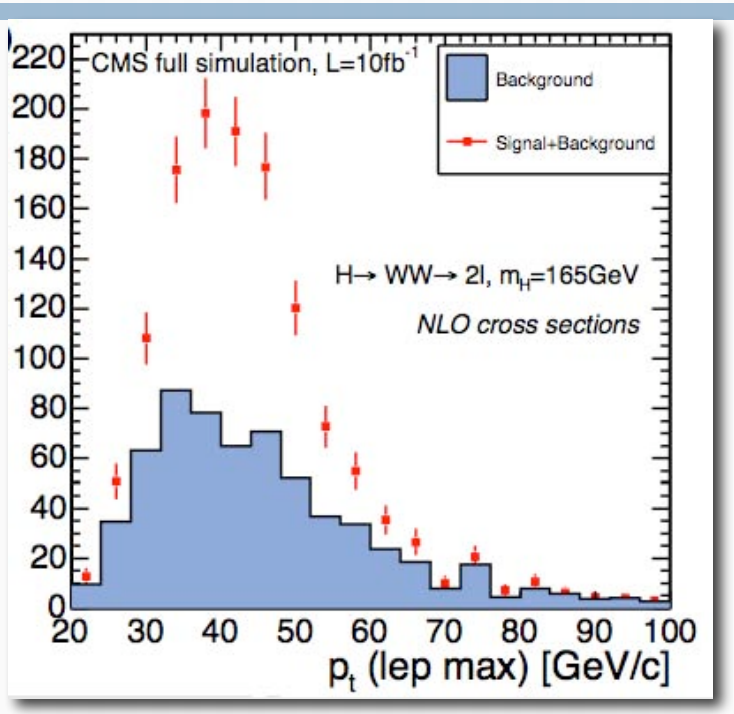
- modeling (learn from min. bias)
- extrapolation to LHC energies
- impact on selection efficiencies ?
  - isolation, trigger strategy
- have to tune MCs (eg. Pythia) asap

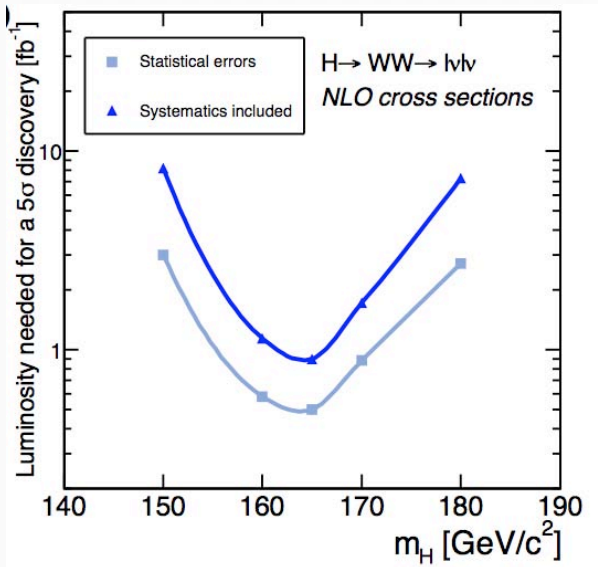
Example : CMS preparations for Pilot Run

- 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 !!

$H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$





Issues :

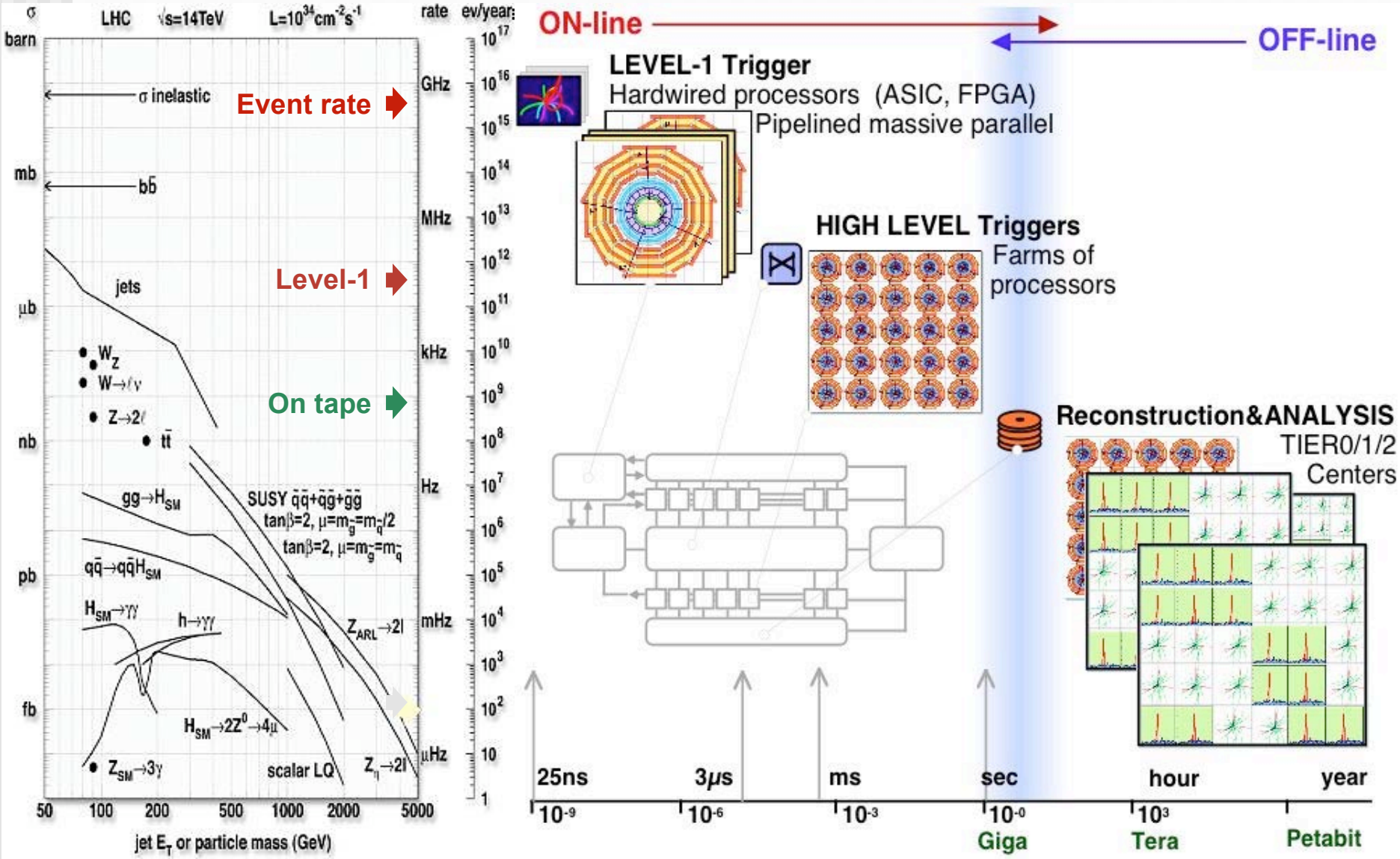
- Backgrounds : WW, tt (WbWb)
- central jet veto (suppresses WbWb)
- Lepton isolation
- different dynamics of signal and background, eg. lepton angles → good MCs needed!
- differential NNLO(+NNLL) Higgs cross section as function of Higgs p_T is important
  - resummation, Grazzini, Catani et al
  - NNLO on its way, Babis et al.

Recent full simul. CMS study

Davatz, Dittmar, Giolo-Nicollerat

- best channel for M_H~160-170 GeV
  5σ stat. significance for ~ 1 fb^{-1} !
- whole range M_H~150-180 GeV
  can be covered with ~ 10 fb^{-1}

CMS : Trigger/DAQ



CMS HLT table

ETH Institute for Particle Physics

These numbers from DAQ TDR.

$L = 2 \times 10^{33}\ cm^{-2}\ s^{-1}$

HLT ~ 2000 CPUs

Trigger	Threshold (GeV or GeV/c)	Rate (Hz)	Cuml. rate (Hz)
Inclusive electron	29	33	33
Di-electron	17	1	34
Inclusive photon	80	4	38
Di-photon	40, 25	5	43
Inclusive muon	19	25	68
Di-muon	7	4	72
Inclusive tau-jet	86	3	75
Di-tau-jet	59	1	76
1-jet * E_T^{miss}	180 * 123	5	81
1-jet OR 3-jet OR 4-jet	657, 247, 113	9	89
Electron * jet	19 * 45	2	90
Inclusive b-jet	237	5	95
Calibration etc		10	105
TOTAL			105

Computing TDR foresees some additional bandwidth (further SM rates, calibrations etc), so 150 Hz

CMS L1 Trigger Table

ETH Institute for Particle Physics

$L = 2 \times 10^{33}\ cm^{-2}\ s^{-1}$

Trigger	Threshold (GeV or GeV/c)	Rate (kHz)	Cumulative Rate (kHz)
Isolated e/g	*29*	*3.3*	*3.3*
Di-e/g	*17*	*1.3*	*4.3*
Isolated muon	*14*	*2.7*	*7.0*
Di-muon	*3*	*0.9*	*7.9*
Single tau-jet	*86*	*2.2*	*10.1*
Di-tau-jet	*59*	*1.0*	*10.9*
1-jet, 3-jet, 4-jet	*177, 86, 70*	*3.0*	*12.5*
JetE_T^{miss}*	*88*46*	*2.3*	*14.3*
*Electron*jet*	*21*45*	*0.8*	*15.1*
Min-bias		*0.9*	*16.0*
TOTAL			*16.0*

CMS HLT efficiencies

- With previous selection cuts

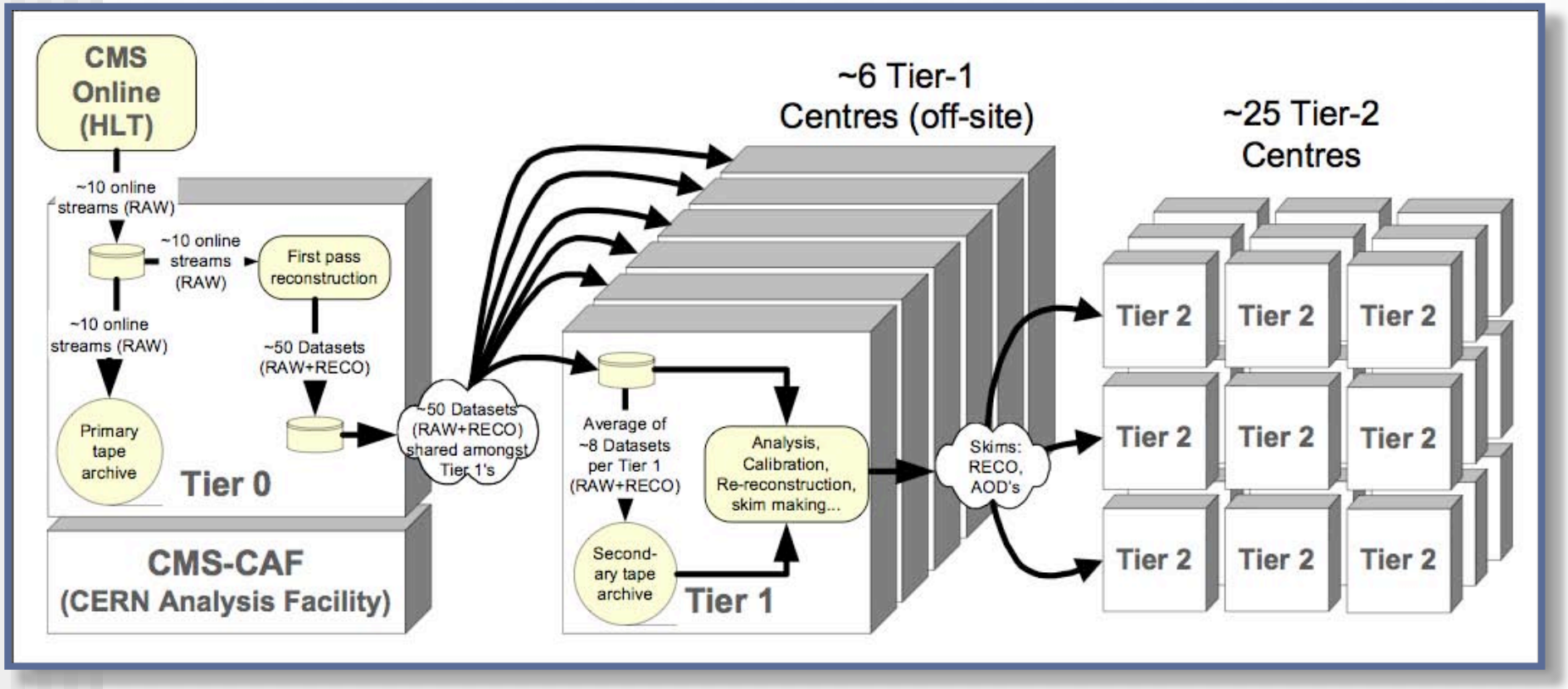
Channel	Efficiency (for fiducial objects)
H(115 GeV)®gg	*77%*
H(160 GeV)®WW ®2m*	*92%*
H(150 GeV)®ZZ®4m	*98%*
A/H(200 GeV)®2t	*45%*
SUSY (~0.5 TeV sparticles)	*~60%*
With R_P-violation	*~20%*
W®en	*67% (fid: 60%)*
W®mn	*69% (fid: 50%)*
Top®m X	*72%*

CMS Data Formats

ETH Institute for Particle Physics

Type	Description	Size [Mb/evt]
DAQ-RAW	Detector Data + L1 Trigger bits, input to online High Level Trigger (HLT)	1-1.5
RAW	Detector data after HLT + HLT trigger bits + objects created at HLT	1.5
RECO	Reconstructed Objects (Tracks, jets, electrons, muons, …) and reconstructed hits and clusters	0.25
AOD	Analysis Object Data : Reconstructed Objects + very localized hit information	0.05
TAG	Run/Event number, high-level physics objects, used to index events	0.01
FEVT	Term used to refer to RAW+RECO together (not a distinct format)	-

CMS Computing Model



- HLT output : 150 Hz, 10^7 seconds running ➔ 1.5 x 10^9 evts/year
- CMS-CAF : at CERN, services similar to Tier-1 and Tier-2, size of ~ 2 Tier-2, login for every CMS user

Upgrade scenarios

- SLHC : *The upgrade of an upgrade*
  - Phase 0 : Performance upgrade, without hardware modifications
  - Phase 1 : Performance upgrade with IR modifications
  - Phase 2 : Performance upgrade with major hardware modifications

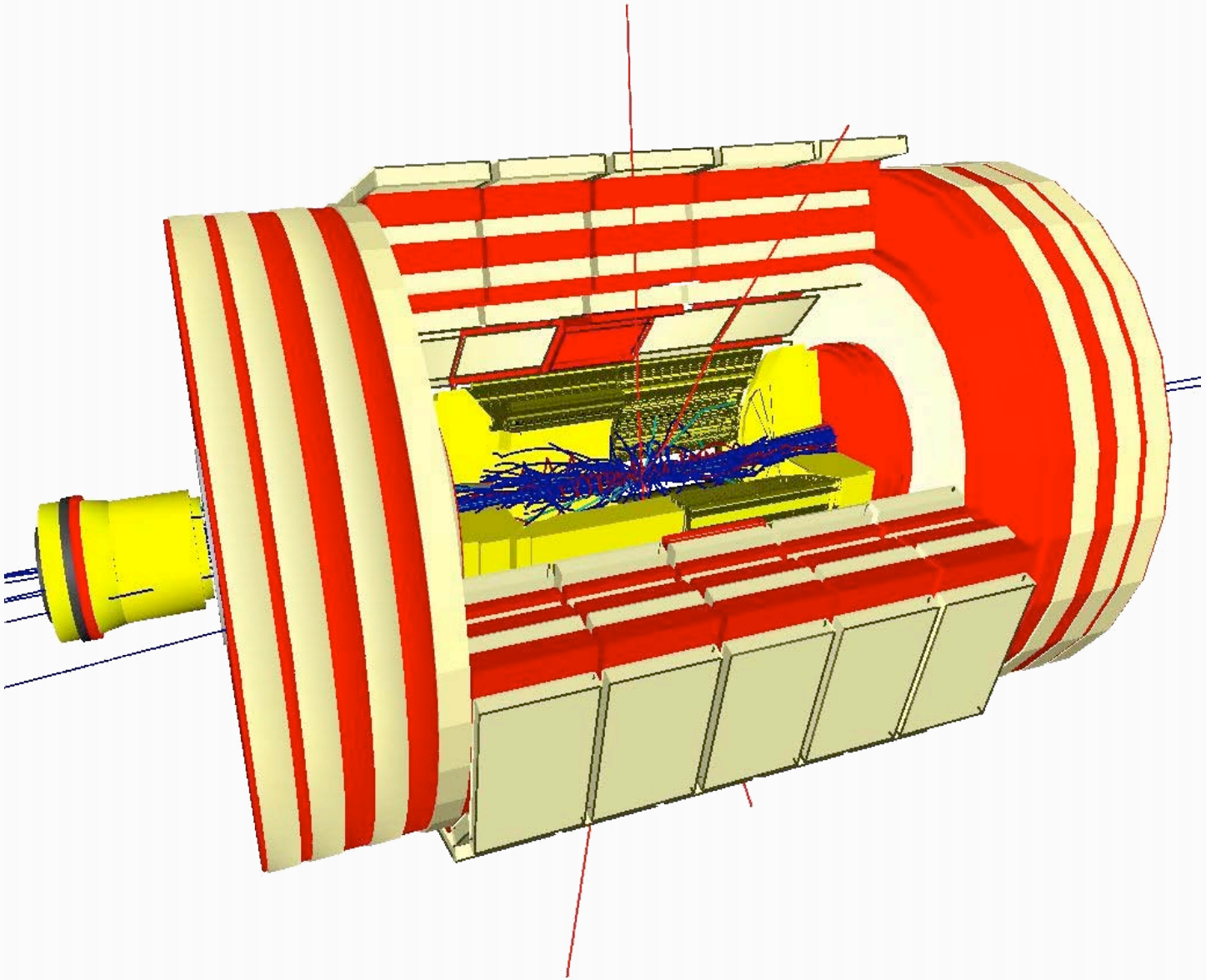
O. Bruning

parameter \ value	nominal	phase 0	phase 1
# bunches	2808	2808	5616
N / bunch	$1.15*10^{11}$	$1.70*10^{11}$	$1.70*10^{11}$
β^*	0.55 m	0.5 m	0.25 m
ε_n	3.75 μ m	3.75 μ m	3.75 μ m
σ^*	16.7 μ m	16 μ m	11.3 μ m
σ_L	7.55cm	7.55cm	3.8cm
full crossing angle	285 μ rad	315 μ rad	445 μ rad
events per crossing	19.2	44.2	88.4
peak luminosity	$1.0*10^{34}$ $cm^{-2}sec^{-1}$	$2.4*10^{34}$ $cm^{-2}sec^{-1}$	$9.6*10^{34}$ $cm^{-2}sec^{-1}$
luminosity lifetime	15 h	10 h	5 h → integrated
E[TeV]	7	7 –> 7.45	7 –> 7.45 luminosity and
E [MJ]	366	541	1082 → efficiency?

- Detectors :
  - Radiation hardness, faster and more granular (increased pile-up noise)
  - Forward regions particular under “pressure” : improved shielding?
  - Change L1 triggers if going to 12.5 ns bunch spacing

See eg.
Gianotti, NPB (Proc. Suppl)
D. Green, AIP Conf. Proc.

$H \rightarrow ZZ \rightarrow 4\ell$ (CMS)



Detectors : Commissioning

	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, W$\rightarrow$eν 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 $\rightarrow$ $\mu\mu$

F. Gianotti

- Using first collisions:
  - Trigger/DAQ:
    - Timing-in, data coherence, sub-system synchronization, calibration, debug algorithms, …
  - Calorimeter calibrations (example CMS ECAL & HCAL):
    - crystal inter-calibration : phi-symmetry of energy deposition (min-bias, jets) : ~2%
    - HCAL : cross check and complete source calibration : ~ 2%
  - Tracker and Muon alignment

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

Searches : general remarks

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- as significance (number of 'sigmas') one usually sees the definition (σ_{stat}(background) = $\sqrt{n_b}$ for large enough statistics)

$$n_\sigma = \frac{n_s}{\sqrt{n_b}}$$

- Adding a relative systematic uncertainty f ,

  σ_{syst}(background) = f n_b ,

  in quadrature to the statistical uncertainty, this becomes:

$$\tilde{n}_\sigma = \frac{n_s}{\sqrt{n_b + f^2 n_b^2}}$$

Searches : general remarks...

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- this can be rewritten as

$$\tilde{n}_\sigma = n_\sigma \cdot \left[1 + \left(\frac{f \cdot n_\sigma}{n_s / n_b} \right)^2 \right]^{\frac{1}{2}}$$

- limiting cases:

$$\frac{n_s}{n_b} \ll f \cdot n_\sigma \quad \Rightarrow \quad \tilde{n}_\sigma \approx \frac{n_s / n_b}{f}$$

dominated by systematics

$$\frac{n_s}{n_b} \gg f \cdot n_\sigma \quad \Rightarrow \quad \tilde{n}_\sigma \approx n_\sigma$$

dominated by statistics

Searches : general remarks...

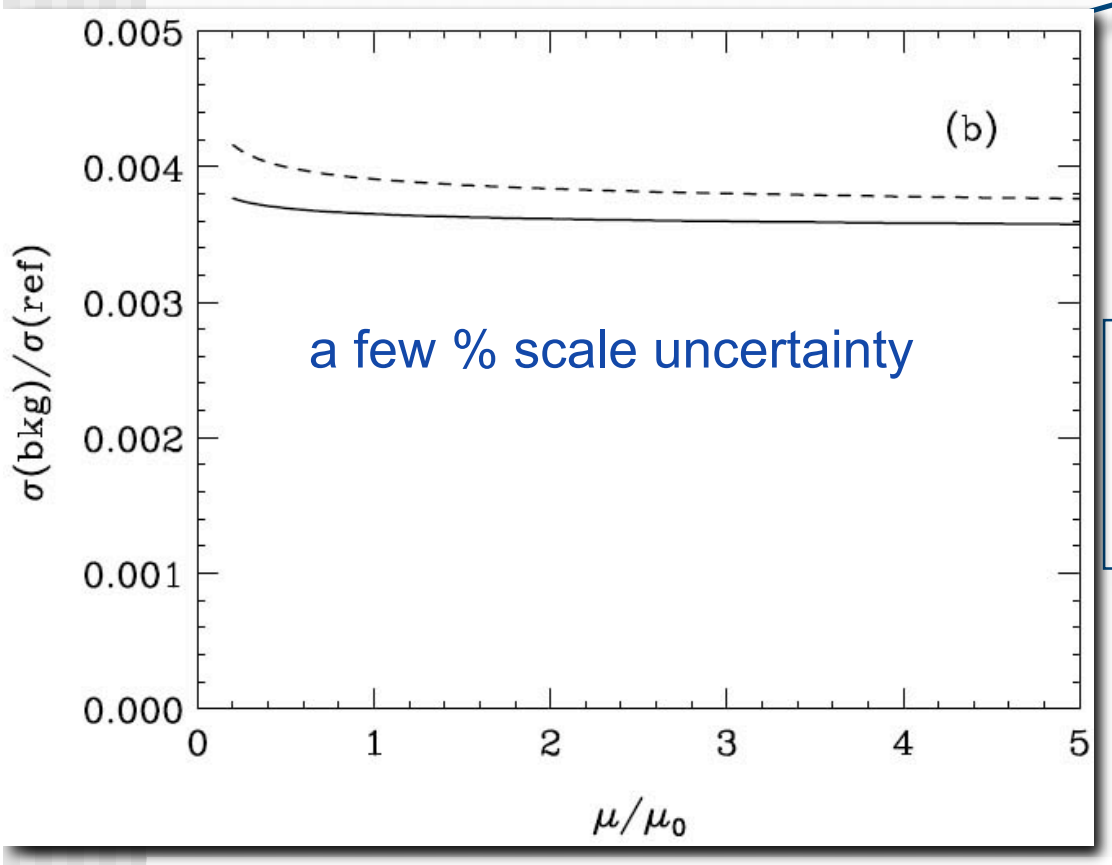
- a concrete example (10% background uncertainty)

n_s	n_b	n_s / n_b	n_σ	$\tilde{n}_\sigma$
50	100	0.5	5	3.5
500	10000	0.05	5	0.5

- in the second case, more luminosity will not improve the significance! (unless more data help to better understand the background)

Background extrapolation

Backgrounds to H→WW →$\ell\nu\ell\nu$: $t\bar{t}$ 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.

ATLAS : Combined test beam

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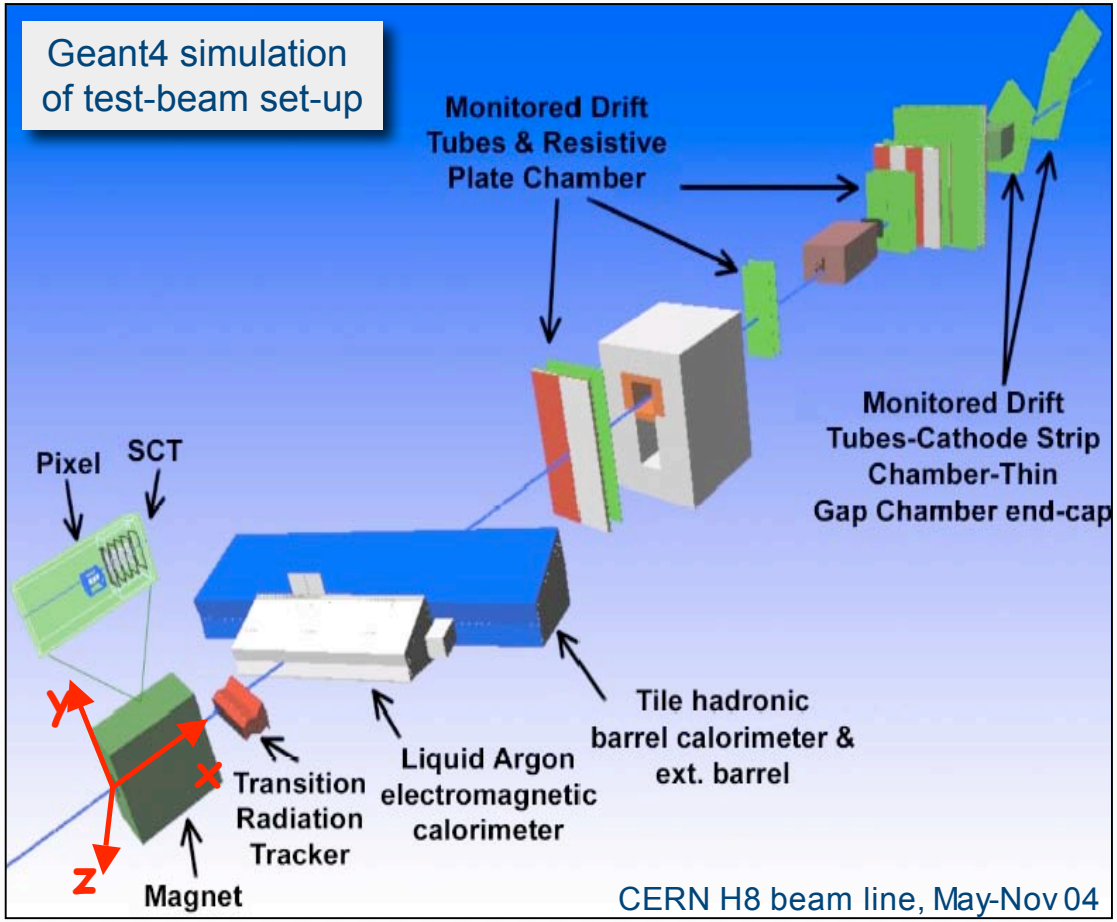
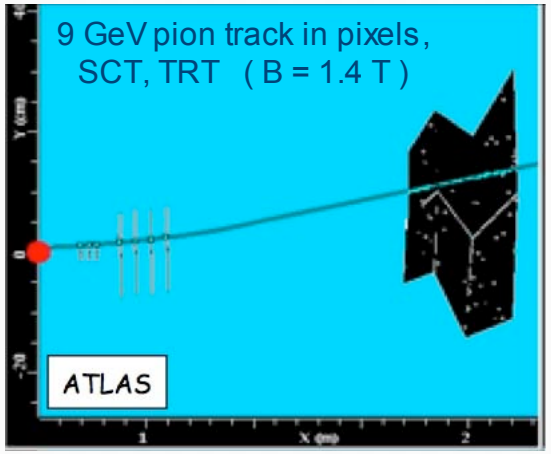
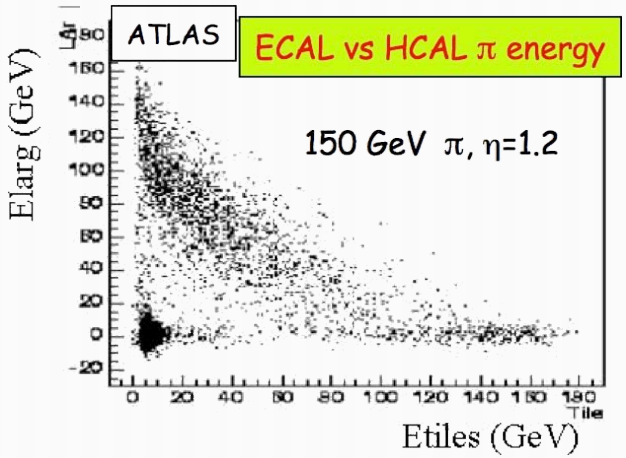




Preliminary results

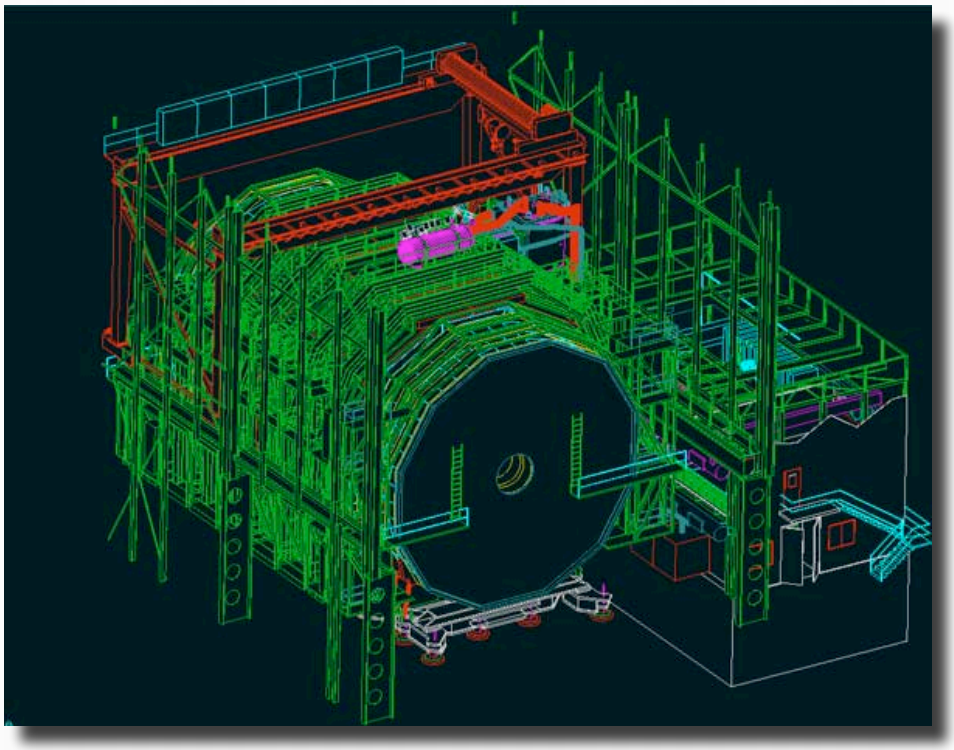


For the first time, all ATLAS sub-detectors integrated and run together with common DAQ, "final" electronics, DCS, etc.

Gained lot of global operation experience during ~ 6 month run. Common ATLAS software used to analyze the data (4.5 TB).

Magnet Test and Cosmic Challenge

CMS closed for Magnet test in the SX5 surface building (June/July 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)

Our Master Equation

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

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

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

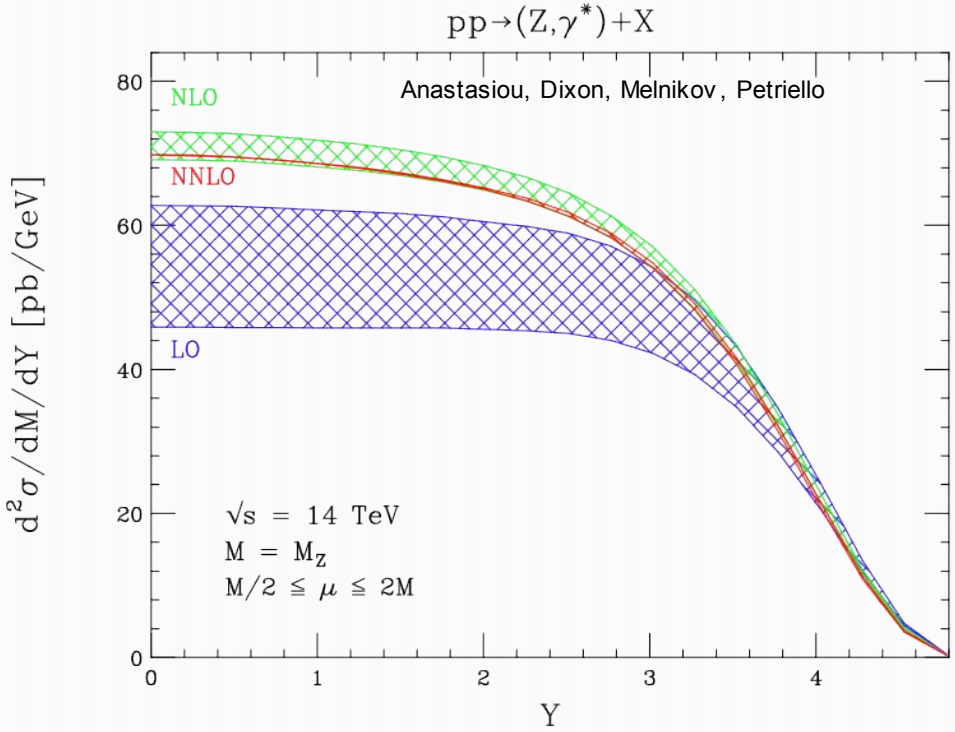
$$\sigma_{\text{theo}} = PDF(x_1, x_2, Q^2) \otimes \hat{\sigma}_{\text{hard}}$$

constrain, define uncertainties

HO calculations, implement in MC

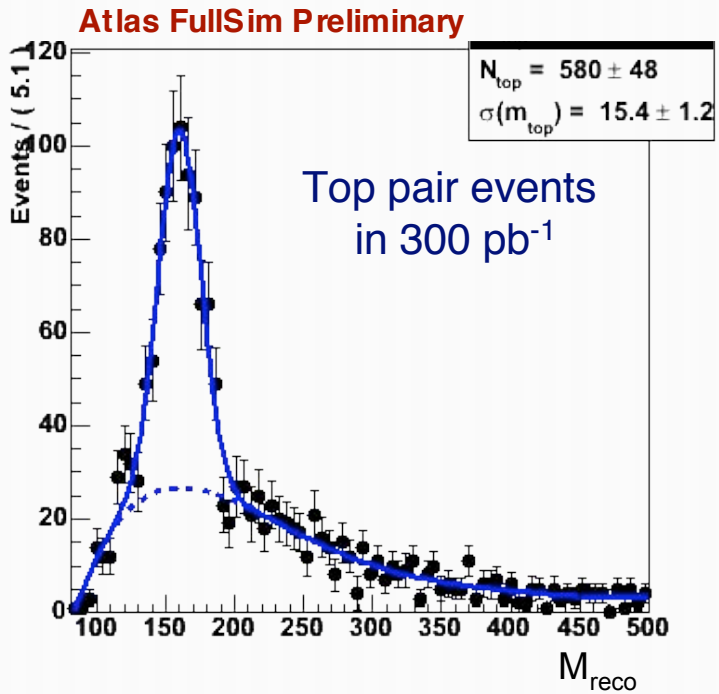
Standard Model measurements

- 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