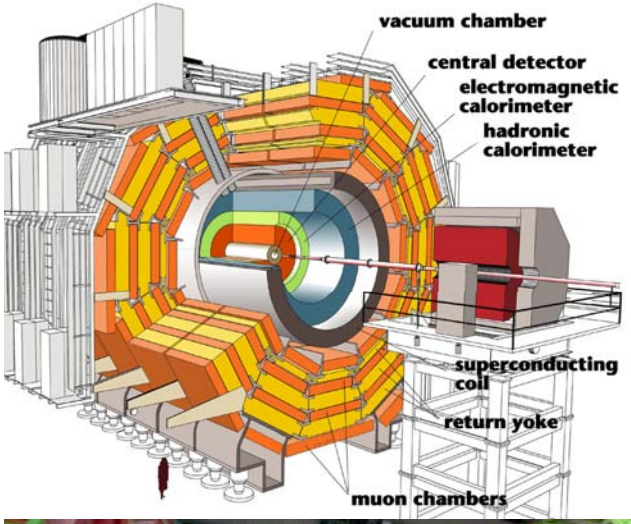
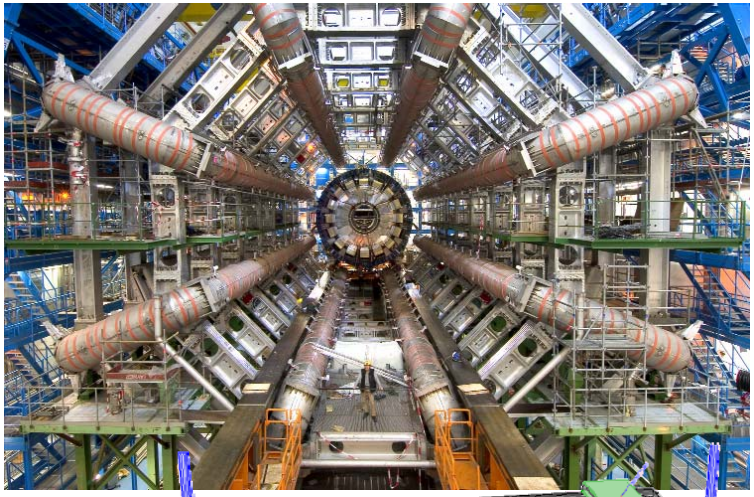
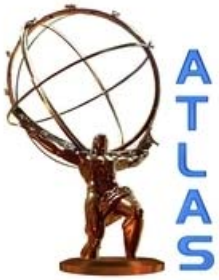
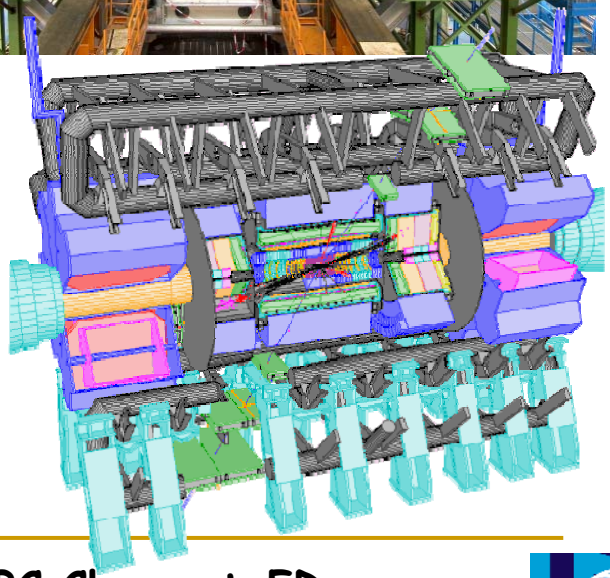
Top Physics at the LHC

introductory talk









Université Blaise Pascal

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TOP 2006 Coimbra

LHC: A new Factory for Top quarks

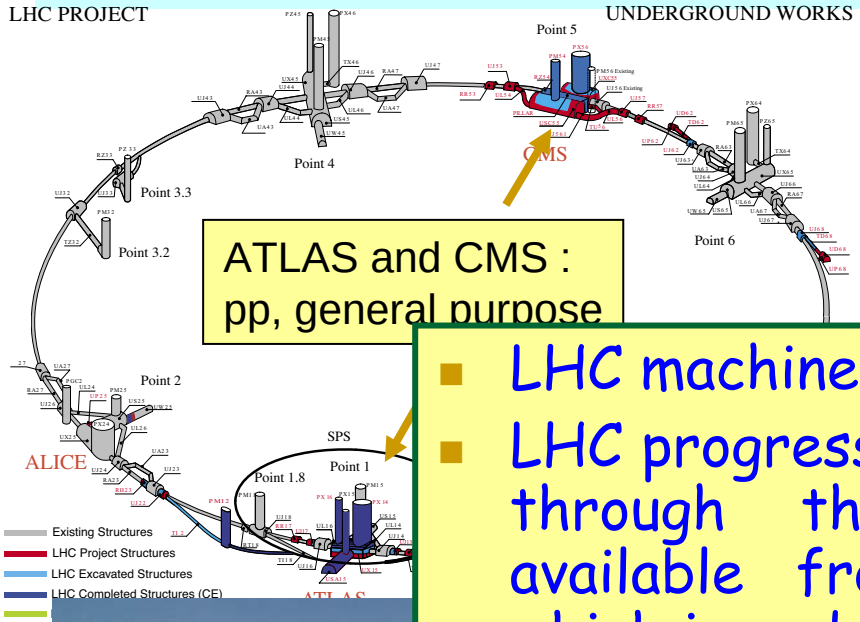
- The Top quark is studied with an increasing level of precision at Tevatron

  However most of the measurements are still statistically limited
- Data taking will continue up to 2009 at Tevatron allowing experiments to perform precision measurements on the Top.

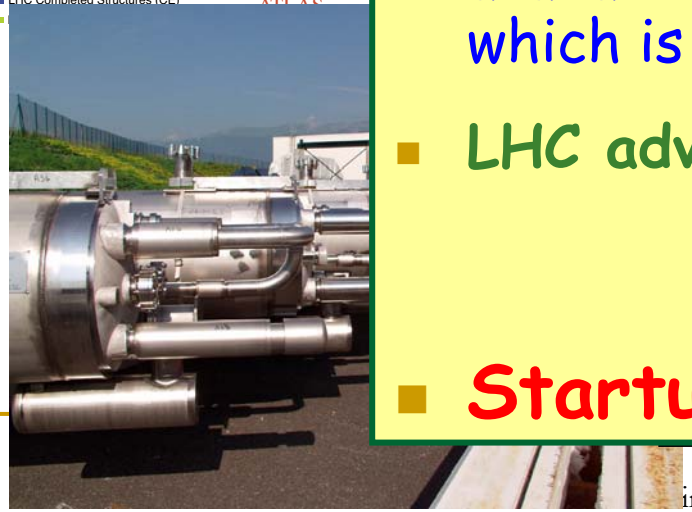
  In the meantime the Large Hadron Collider will enter into operation.
- The LHC will open a new opportunity for precision measurements of Top quark properties.

The Large Hadron Collider

- pp collision cm : 14 TeV (x7 Tevatron)
- 25 ns bunch spacing
- 1.1 10^{11} proton/bunch
- Design luminosity 10^{34} $cm^{-2}s^{-1}$
  100 fb^{-1} /year; ≈ 20 int./x-ing
- Initial/low lumi $L \leq 10^{33}$ cm^{-2} s^{-1}
  10 fb^{-1} /year ; ≈ ≤2 int./x-ing



- LHC machine represents a challenge
- LHC progress/status can be tracked through the "LHC Dashboard", available from CERN's homepage, which is updated monthly
- LHC advance well,
  completion by end 2006
- **Startup in April 2007**



Possible LHC startup scenario

Machine startup in 4 phases gradually to nominal L

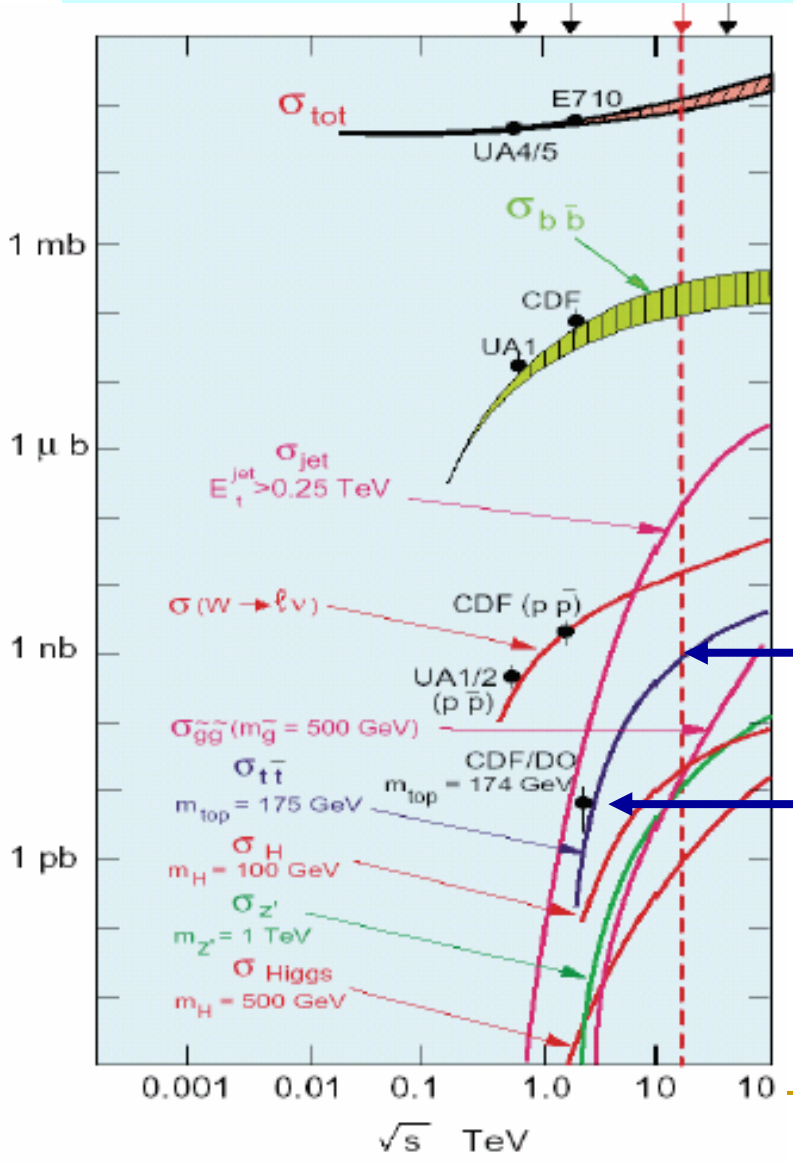
Summer 2007	**first collisions**	
2007	(43+43 to 156+156 bunches)	**1/100 nominal L**
2008	(936+936 bunches; 75ns)	**1/10 nominal L**
2009-2010	(2808+2808 bunches; 25ns)	**up to nominal L**

http://lhc-commissioning.web.cern.ch/lhc-commissioning/ (Mike Lamont)

A lot of uncertainties here: a more precise schedule in spring 2006

expect 1 - 10 fb-1 /expt on tape by end 2008

Cross-Sections at the LHC (examples)



process	σ(pb)	ev/s	ev/y Low L	Comparison with other experiments
bb	5×10^{8}	10^{6}	10^{13}	10^{9} Belle/Babar
Z→ee	1.5×10^{3}	~3	10^{7}	10^{7} LEP
W→ev,μv	3×10^{4}	~60	10^{8}	10^{5} LEP 10^{8} FNAL
WW→evX	6	10^{-2}	10^{5}	
tt	830	~1.7	10^{7}	10^{4} Tevatron
H(130GeV/c²)	2	4×10^{-3}	10^{5}	?
H(700GeV/c²)	1	2×10^{-3}	10^{4}	?

LHC σtt ~830 pb

X100

Tevatron σtt ~ 6,7 pb

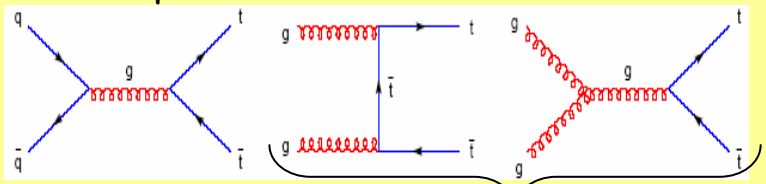
LHC Low L 10^{33} cm^{-2}s^{-1}

Tevatron 10^{32} X10

Prod Rate X1000

Top Production @ LHC

Pair production

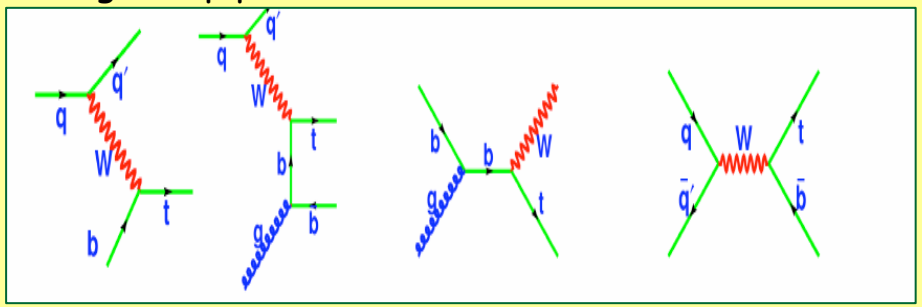


$q\bar{q} \to t\bar{t}$ ~10%

$gg \to t\bar{t}$ ~90%

Opposite to Tevatron

Single Top production



	t channel	Wt channel	s channel
Tev	1.47 pb	0.15 pb	0.75 pb
LHC	250 pb (4%)	60 pb (8%)	10 pb (8%)

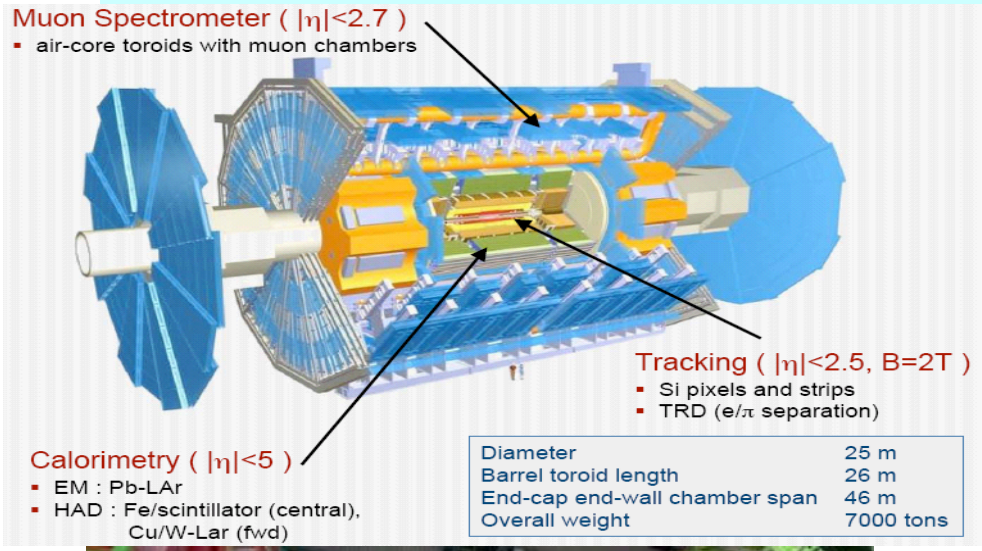
$1y@10^{32}$	$1y@10^{33}$
800 K	8 millions
2007?	2008?

At nominal Luminosity,
~ One top pair produced per second

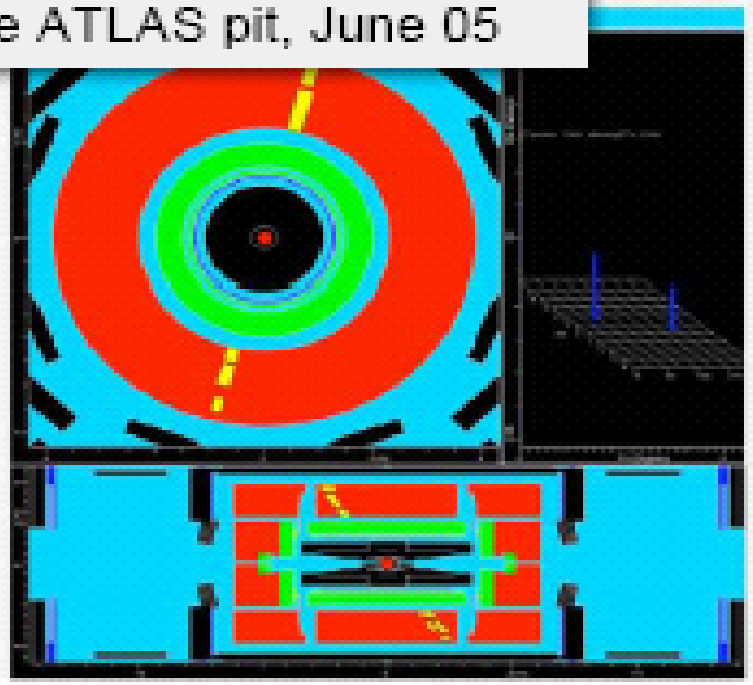
LHC is a Top factory

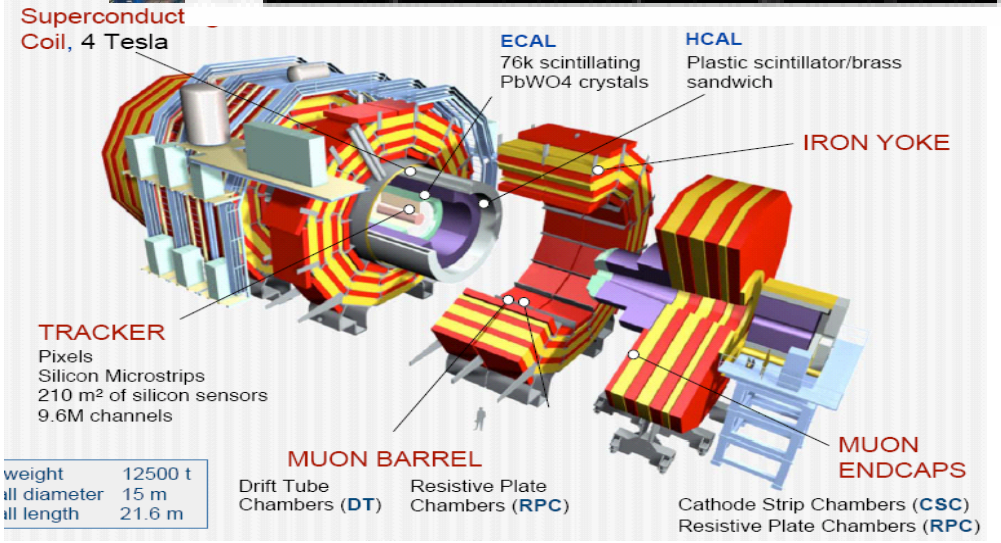
Year	Max Lumi	Top pairs Produced /day	Top pairs(l+j) after selection /day
2007	10^{32}	7000	~20-100
2008	10^{33}	70000	~200-1000
2009--2010	10^{34}	700000	~2000-10000

ATLAS & CMS Detecto



First real cosmics seen in the ATLAS pit, June 05



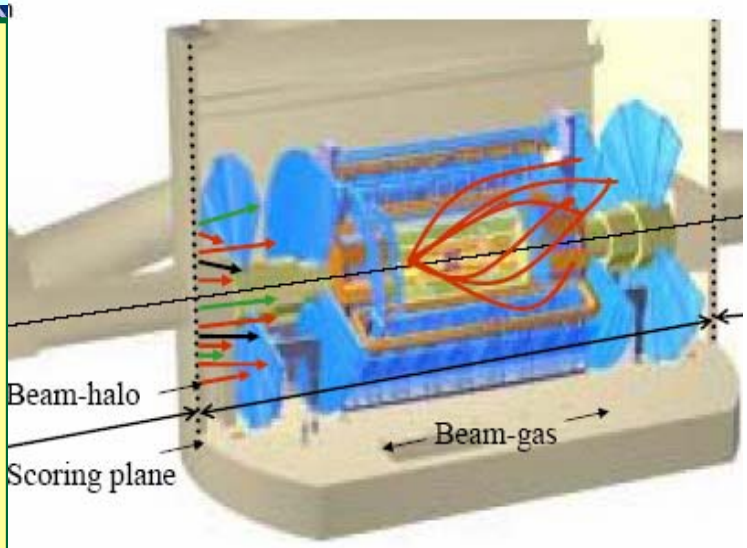


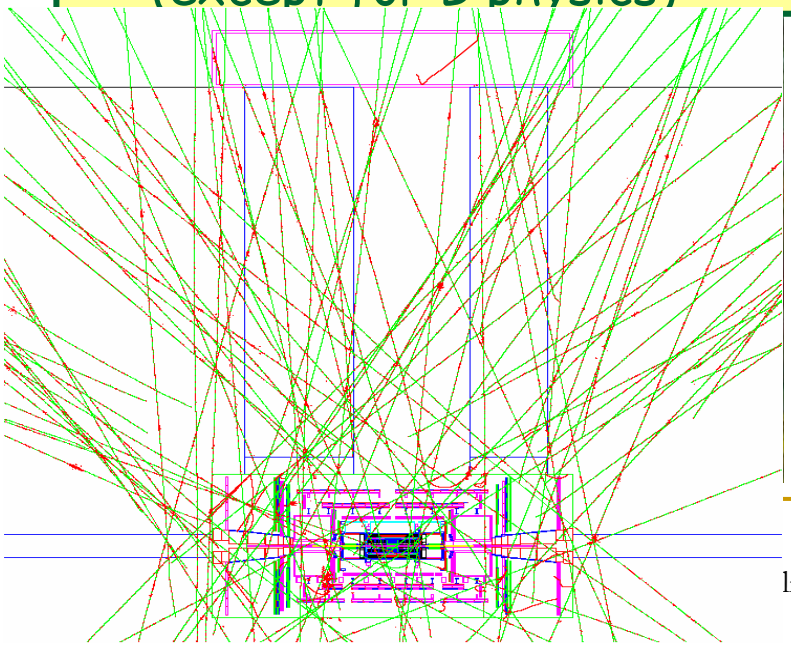
Detectors Status

Detectors will not be complete in 2007

- ATLAS because of staging TRT coverage over $|\eta|<2$ instead of 2.4
- CMS pixel and end-cap ECAL installed during first shutdown
- BOTH reduced trigger bandwidth due to deferrals on HLT processors (~50% of full capability)

Small impact on performances at low L (except for B physics)





- Proto and parts tested with test beams

To achieve the detector goal performance (dead channels mapping,alignement, DAQ…)

- Pre collision phase
  - Cosmic runs (end 2006-spring 2007)
  - Beam-gas events & beam-halo muons

Which detector performance on day one ?

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

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

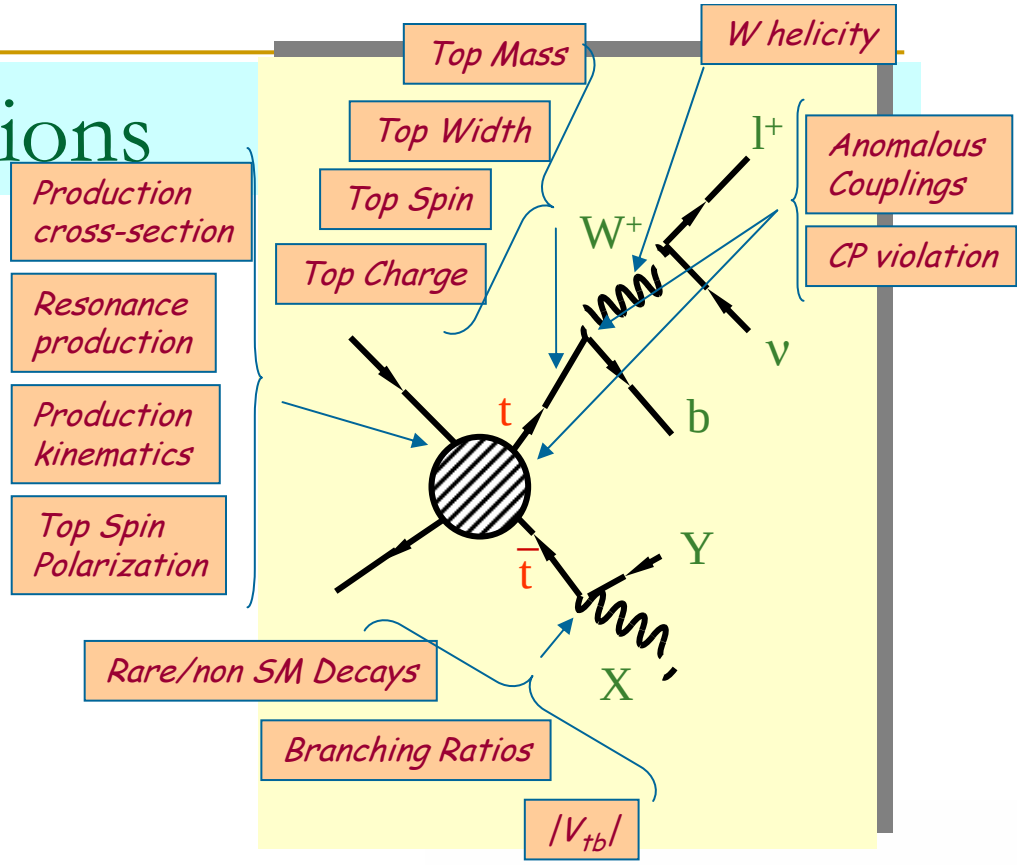
Impact on b tag : from 20μm to 5 μm R_u improved by a factor 1.5

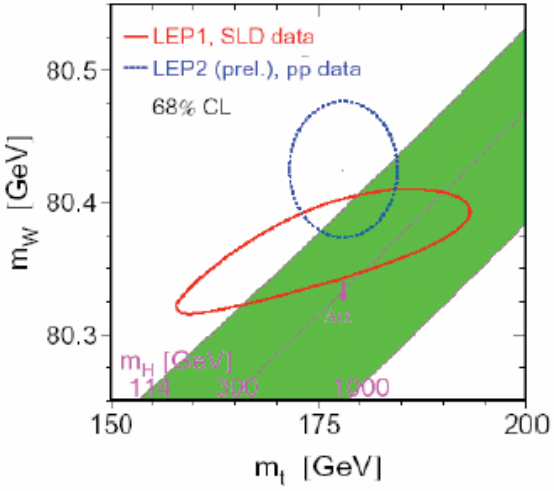
physics samples to improve performances

Top physics: Motivations

1. **Precision Measurements**
   - **Precise Top Mass determination**
     - Provide Higgs mass constraint
     - W mass & Top mass are important measurements to scrutinize SM
   - **Cross sections**
     - Main background for searches beyond the Standard Model at the LHC
     - Vtb
   - **Top properties**
     - Top electric charge
     - Top spin polarization, W polarisation
     - Top quark decays & coupling ,fcnc, rare decays
     - Possible deviations due to New physics Beyond SM?

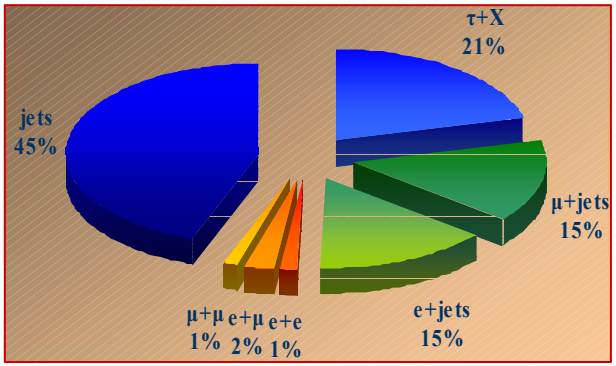
2. **Detector Commissioning with early data**
   - Use Top as calibration tool for jet scale, b-tagging
   - Crucial parameters for Top physics: jet energy scale, b tagging, trigger,luminosity

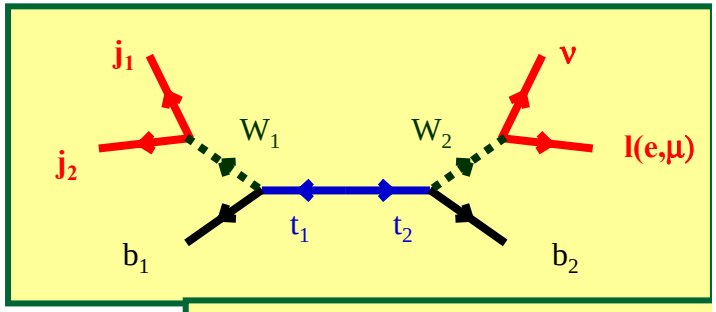




Early Top studies 2007 (2008)

- Top production is an ideal laboratory for initial studies
  - Lepton+jet channel contains :
    - 2 b jets
    - 2 light jets
    - 1 lepton+ 1 ν
  - Involves many detector properties :
    - Lepton measurements and Identification
    - Jet reconstruction and calibration
    - Missing transverse Energy
    - b-tagging



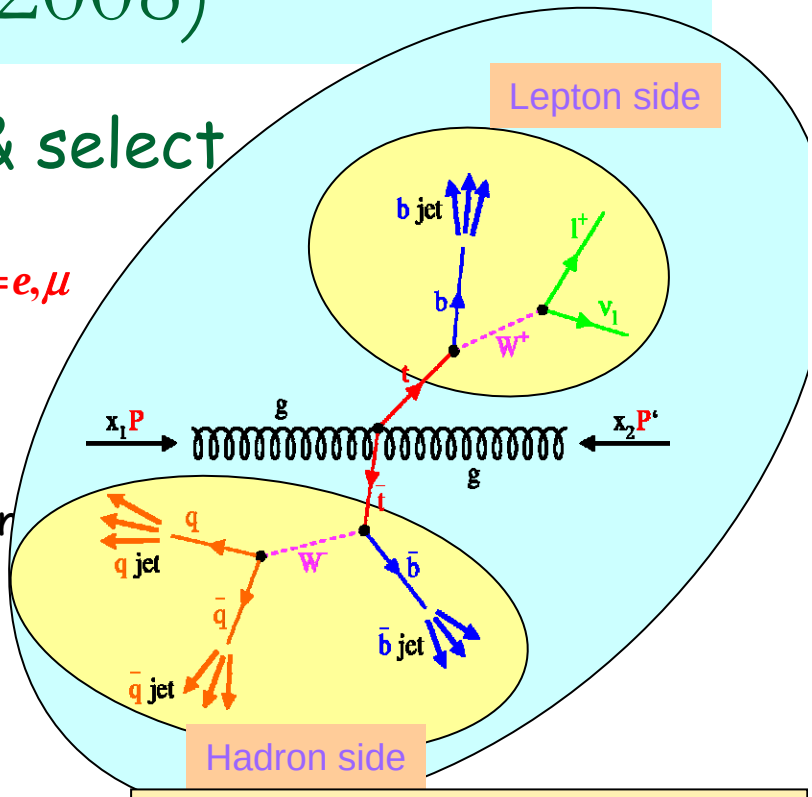


$t\bar{t} \rightarrow WbW\ \bar{b} \rightarrow l\nu b\ \bar{b}jj$

☞ Two Aspects of early Top studies (≤ 1fb^{-1})
  - Top quark useful as calibration tool
    to give feedback on detector performance
  - Initial ‚measurement of mass and cross section

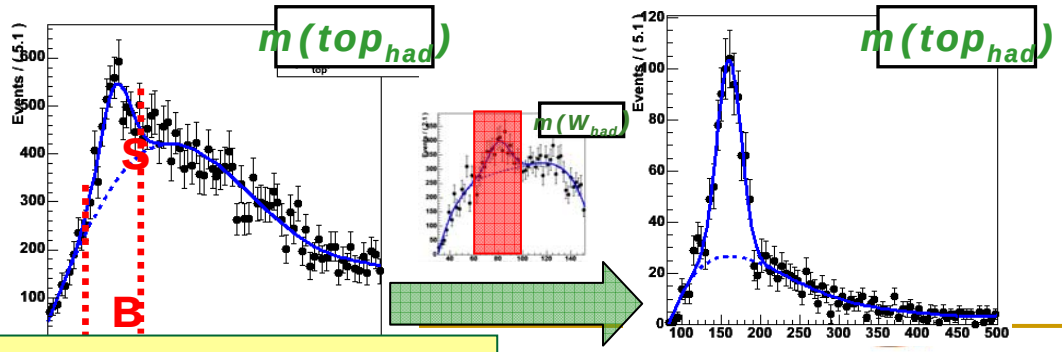
Early Top studies 2007 (2008)

- l+jets signature easy to trigger & select
  - Golden plated channel $t\bar{t} \rightarrow Wb\bar{W}\bar{b} \rightarrow l\nu b\,\bar{b}jj \;;\; l = e,\mu$
    BR~30%
    - Selection and reconstruction simple
      - Clean trigger from isolated lepton
      - W reconstruction and top reconstruction
      - b-tag to reduce BKG



1 Hadronic top:
Three jets with highest vector-sum pT as the decay products of the top

2 W boson:
Two jets in hadronic top with highest momentum in reconstructed jjj C.M. frame.



Hadron side No b-tag
L=300 pb^{-1}

D. Pallin TOP2006 ; Coimbra - 01/2006

Typical selection :

- Isolated lepton P_T>20 GeV
- E_T^{miss}>20 GeV
- 4 jets with E_T>40 GeV
- >1 b-jet ($\varepsilon_b \approx 50\%$, $\varepsilon_{uds} \approx 10^{-3}$, $\varepsilon_c \approx 10^{-2}$)
- BKG <2% W/Z+jets,WW/ZZ/WZ

efficiency: ~1-2%:

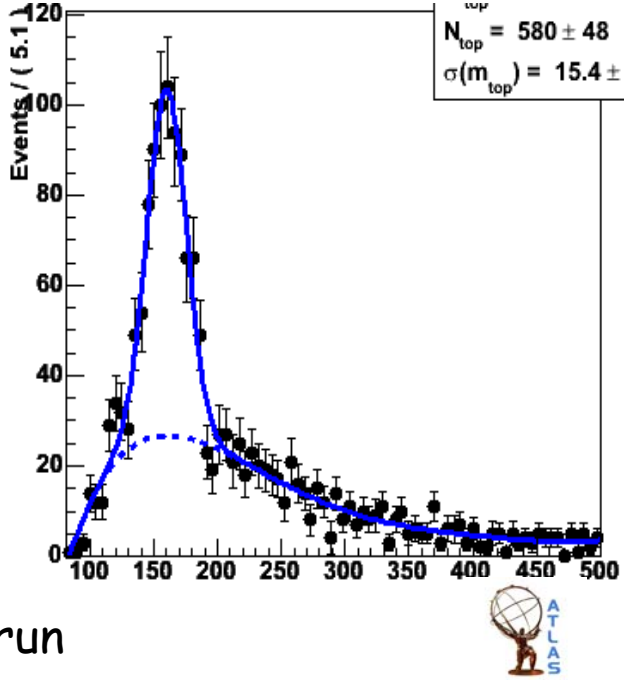
Early Top studies (≤ 1fb^{-1}) 2007 (2008)

Physics goals and potential in the first year

- ***Observation of Top signal should be very fast***

- **In a few weeks, a clean sample of several thousands top-quarks will be available for physics measurements and detector calibration**

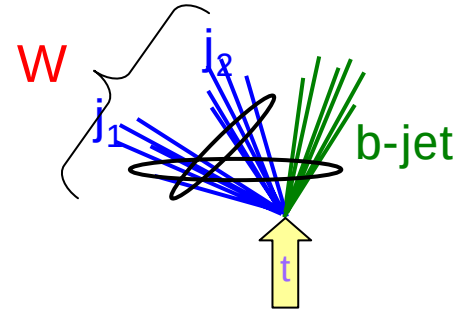
- ☞ Road to an initial measurement of Top mass (5-7 GeV?) and cross section (15-20%?



Note : statistical error negligible after few weeks run

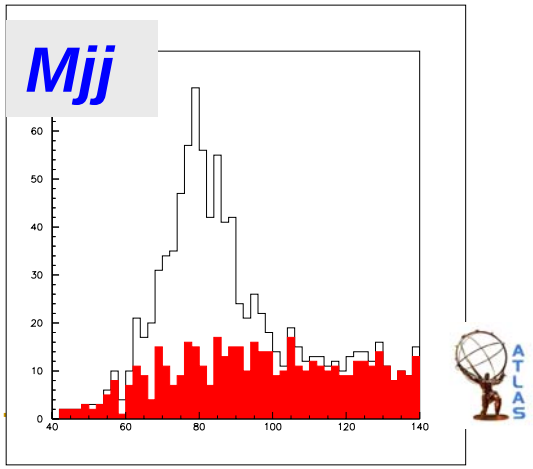
Early Top studies ($\leq 1 fb^{-1}$)

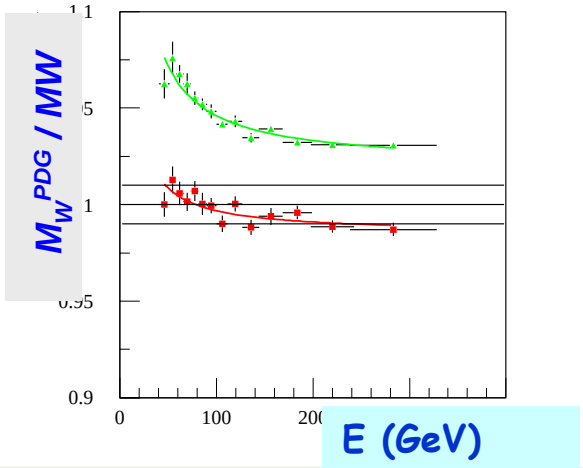
- Exploiting ttbar signal : get the light jet energy scale
  - A clean W->jj sample (up to 80%) can be extracted from l+jets Top events
  - shift of the W mass peak related to the absolute energy scale



☞ extract absolute jet energy scale $\alpha(E_{jet})$

from data (jet E_T>40 GeV) without calibration function hypot.



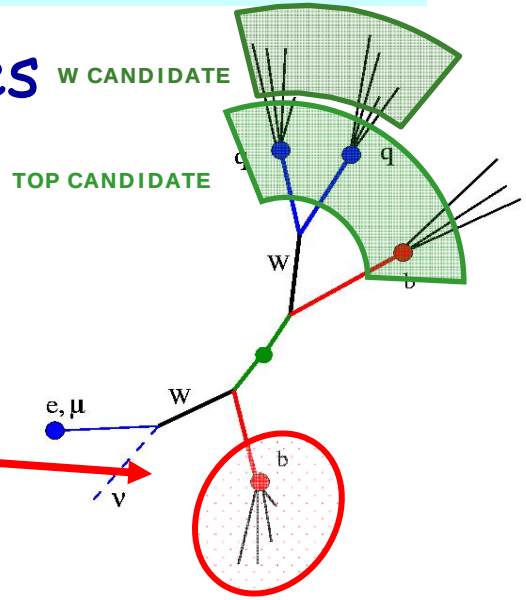


2-3% reachable on absolute scale in 2007

Early Top studies ($\leq 1 fb^{-1}$)

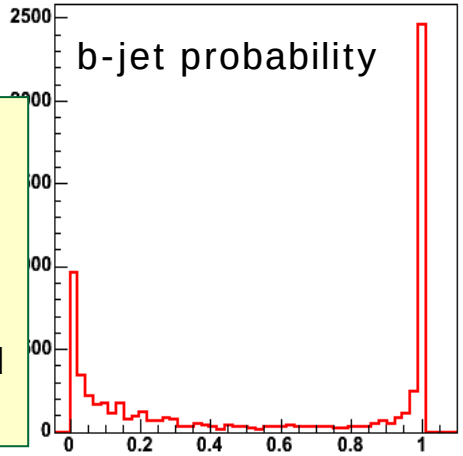
- Exploiting ttbar signal : b-tagging studies

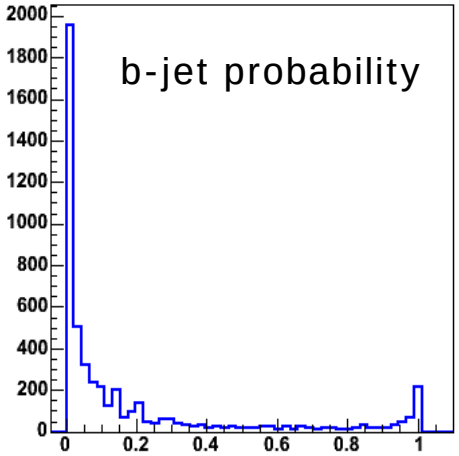
  - An enriched sample of b-jets can be extracted from L+jets Top events
  - Cut on $m(W_{had})$ and $m(top_{had})$ masses
  - Look at b-jet prob for 4^{th} jet (must be b-jet if all assignments are correct)



ttbar (signal)

'always b jet if all jet assignment are OK'
b enrichment expected and observed





W+jets (background)

'random jet',
no b enhancement expected

Top Physics at the LHC: goals @ 10fb-1

Does the Top quark behaves as expected in the SM?

- Top pair production

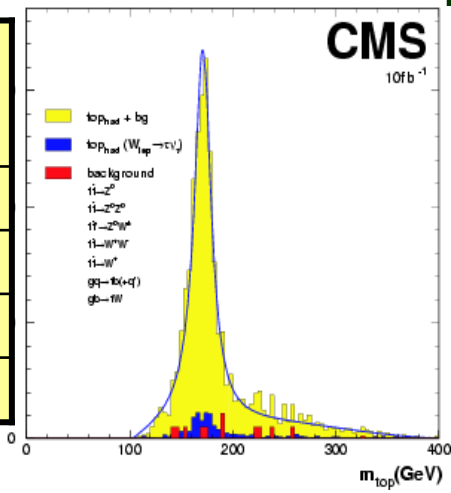
  Top mass, cross section , W&Top polarisations ≈ same event selection

  - stat error negligible on measurements, syst Limitations from jet scale FSR, PDF, lumi

  Top properties measurements

  - Test the top decay with W Polarisations F0 F^L F^R (1-2%)
  - Test the Top production with ttbar spin correlations
  - ttbar invariant mass distribution

channel	Selected @10fb^{-1}
lvb jjb	70K
lvb jjb (high pt)	3,6K
lvb lvb	20K
jjb jjb (high pt)	3,4K



Precision	Tevatron @2fb^{-1}	LHC goals 10fb^{-1}
Top Mass	<2%	<1%
Cross section	10%	<10%?
Top properties		
BR Wb	20%	
W pol	40%	2%
Spin corr		4%
Charge	Exclude -4/3	Exclude-4/3
fcnc		Improvex100
Single Top	5σ discovery?	Measure separately cross sections
Understand Top as BKG		

Top Physics at the LHC: goals @ 10fb-1

Does the Top quark behaves as expected in the SM?

- Single Top :
  - Use leptonic decay of the W
  - Measure cross sections separately
  - Even if statistical precision range from ~2% (t channel) to ~8% (s channel), studies will be mainly on BKG understanding to assess systematics which are dominant.
  - First results are expected with 30fb-1. cross sections and vtb..

channel	Selected @10fb-1
t channel	2,5K
WT channel	1,5K
s channel	0,5K

Precision	Tevatron @2fb^{-1}	LHC goals 10fb^{-1}
Top Mass	<2%	<1%
Cross section	10%	<10%?
Top properties		
BR Wb	20%	
W pol	40%	2%
Spin corr		4%
Charge	Exclude -4/3	Exclude-4/3
fcnc		Improvex100
Single Top	5σ discovery?	Measure separately cross sections
Understand Top as BKG		

Top studies with $10fb^{-1}$ and more

- This session :

  More details in dedicated talks on Top at LHC :

Topic	See talk from
Tools	V. Kostyukhin
Top Mass (all channels)	AI Etienvre,N Giokaris, J Heyninck
Top production	R. Chierici,B Kersevan
Top properties	B Resende
Single Top	A. Giammanco
Beyond SM	N. Castro
Understand Top as BKG	M. Zanetti, S Paktinat

Summary

- LHC is on the road
  - First collisions in Summer 2007
  - Initial measurements in 2 years from now
  - First precision measurements in 3 years from now with 1-10fb^{-1}
- A huge work needed prior to initial measurements
  - to understand the detectors & control systematics(BKG, PDF..)
  - Early top signals will also be critical to commissioning the detectors

- LHC has a great potential for Top physics
- Some of the earliest LHC physics results, and earliest sensitivity to new physics, could come from top physics
  - An enormous amount of Top quarks will be produced
    1 day at $10^{33} \approx 10$ years at Tevatron for SM processes
    Measurements with negligible stat uncertainties

☞ Improvement of Top understanding & window BSM

BACKUP

STAGE 1
INITIAL COMMISSIONING
43 x 43 -> 156 x 156 $3x10^{10}$ per bunch
Zero to Partial squeeze

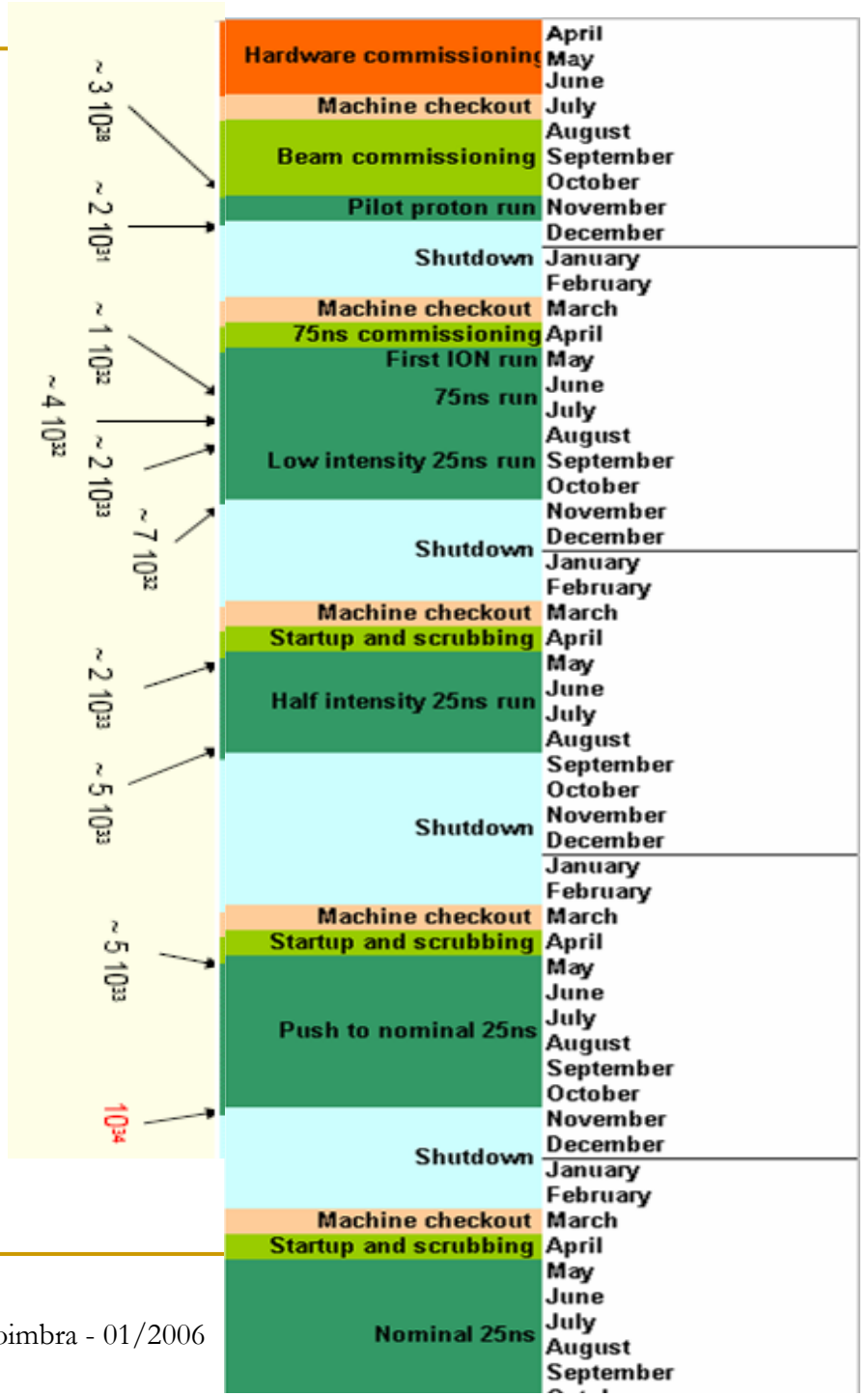
SHUTDOWN

STAGE 2
75 ns OPERATION
3-4 x 10^{10} per bunch
Partial squeeze

STAGE 3
25 ns OPERATION
3-4 x 10^{10} per bunch
Partial to near full squeeze

LONG SHUTDOWN

STAGE 4
25 ns OPERATION
push to nominal per bunch
Partial to full squeeze



Phase 2 Collimation
Full Beam Dump
Scrubbed

	ATLAS	CMS
MAGNET (S)	Air-core toroids + solenoid in inner cavity Calorimeters outside field 4 magnets	Solenoid Calorimeters inside field 1 magnet
TRACKER	Si pixels+ strips TRD → particle identification B=2T $\sigma/p_T \sim 5\times10^{-4}\ p_T \oplus 0.01$	Si pixels + strips No particle identification B=4T $\sigma/p_T \sim 1.5\times10^{-4}\ p_T \oplus 0.005$
EM CALO	Pb-liquid argon $\sigma/E \sim 10\%/\sqrt{E}$ uniform longitudinal segmentation	$PbWO_4$ crystals $\sigma/E \sim 2\text{-}5\%/\sqrt{E}$ no longitudinal segmentation
HAD CALO	Fe-scint. + Cu-liquid argon (10 λ) $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$	Brass-scint. (> 5.8 λ +catcher) $\sigma/E \sim 100\%/\sqrt{E} \oplus 0.05$
MUON	Air → σ/p_T < 10 % at 1 TeV standalone; larger acceptance	Fe → $\sigma/p_T \sim 5\%$ at 1 TeV combining with tracker