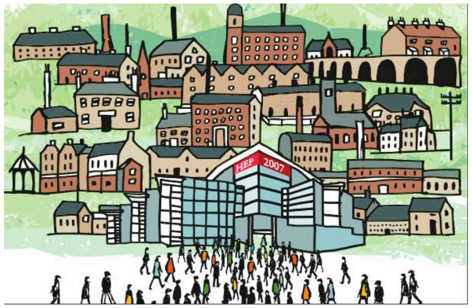
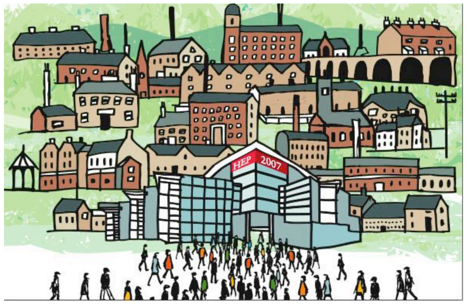
LHC Detectors: Construction Status, Commissioning, and Early Physics



Oliver Buchmüller (CERN)

2007 Europhysics Conference on High Energy Physics in Manchester

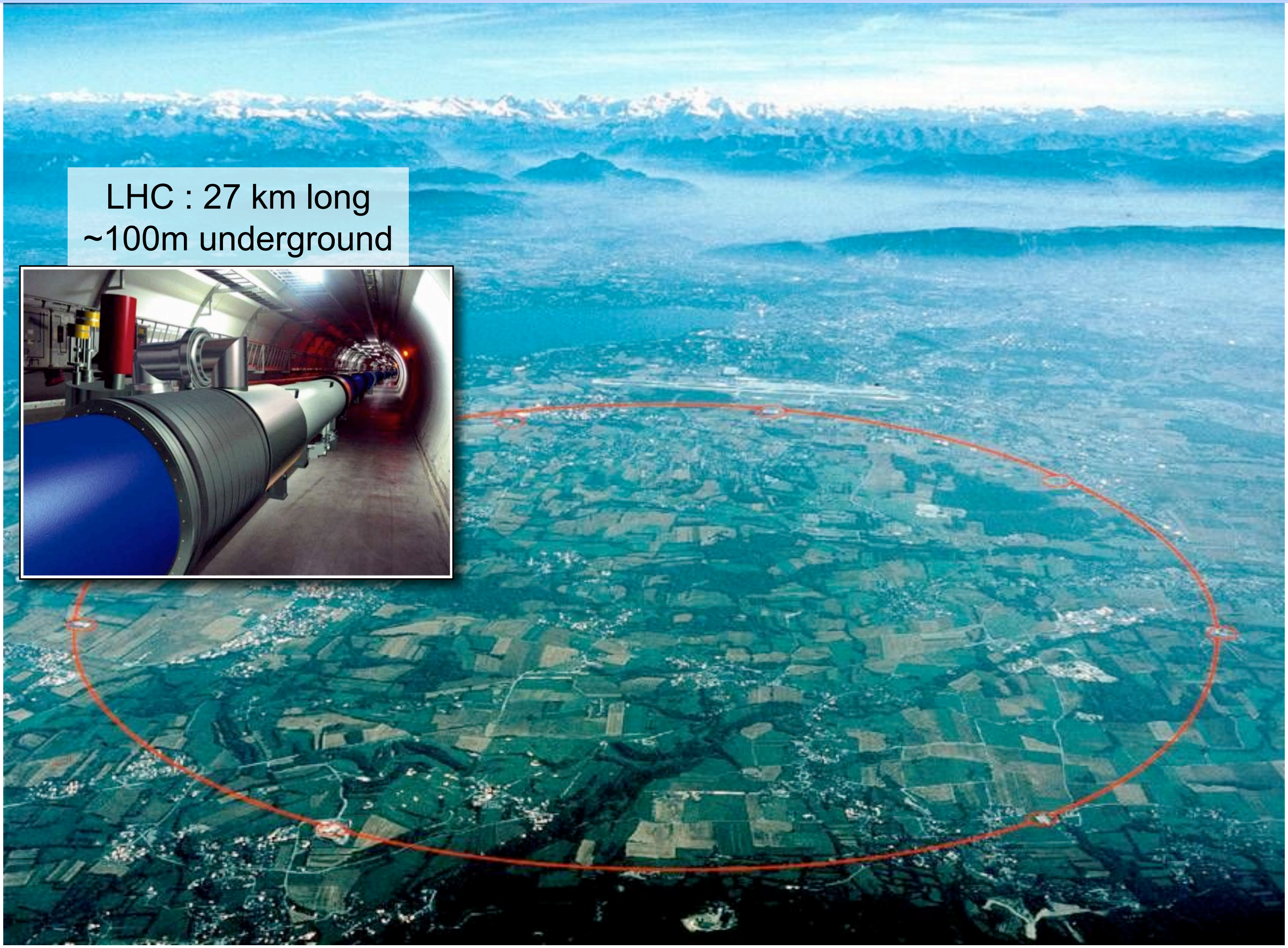


- *Construction Status of the LHC Experiments*
- *Commissioning Strategy*
- *Early Physics Reach*

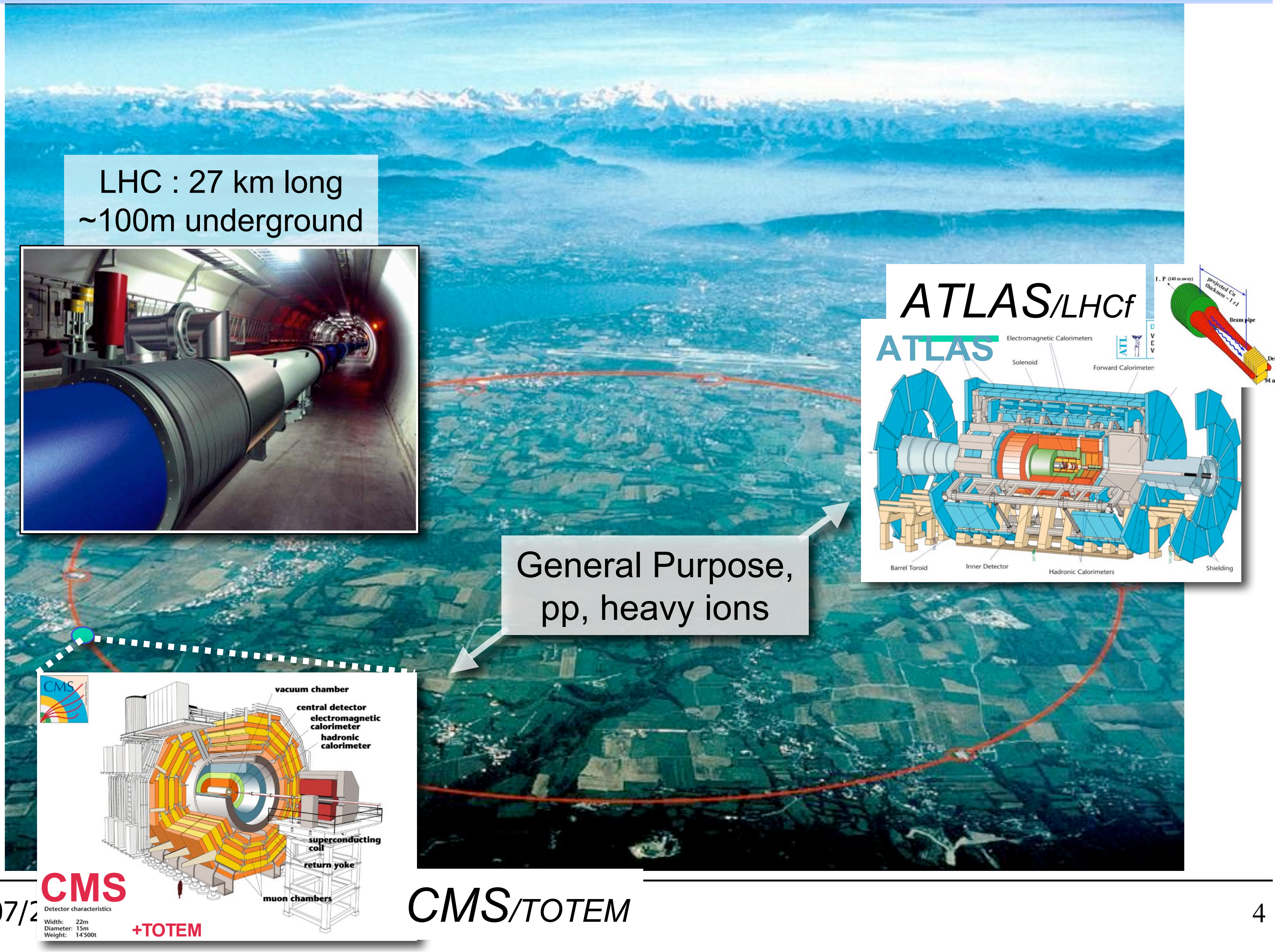
HEP 2007 25/07/2007

The Large Hardon Collider at CERN

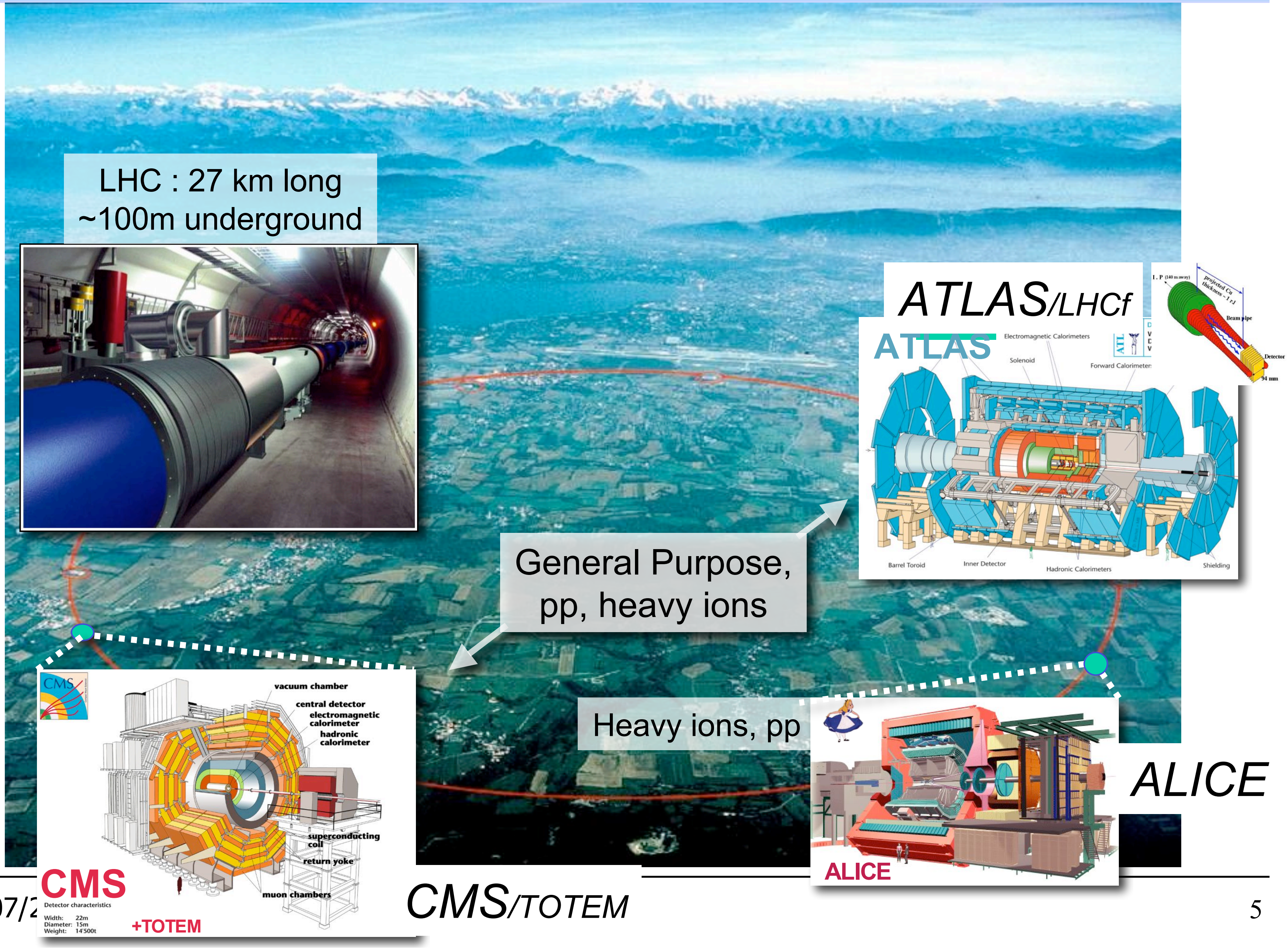
The Large Hardon Collider at CERN



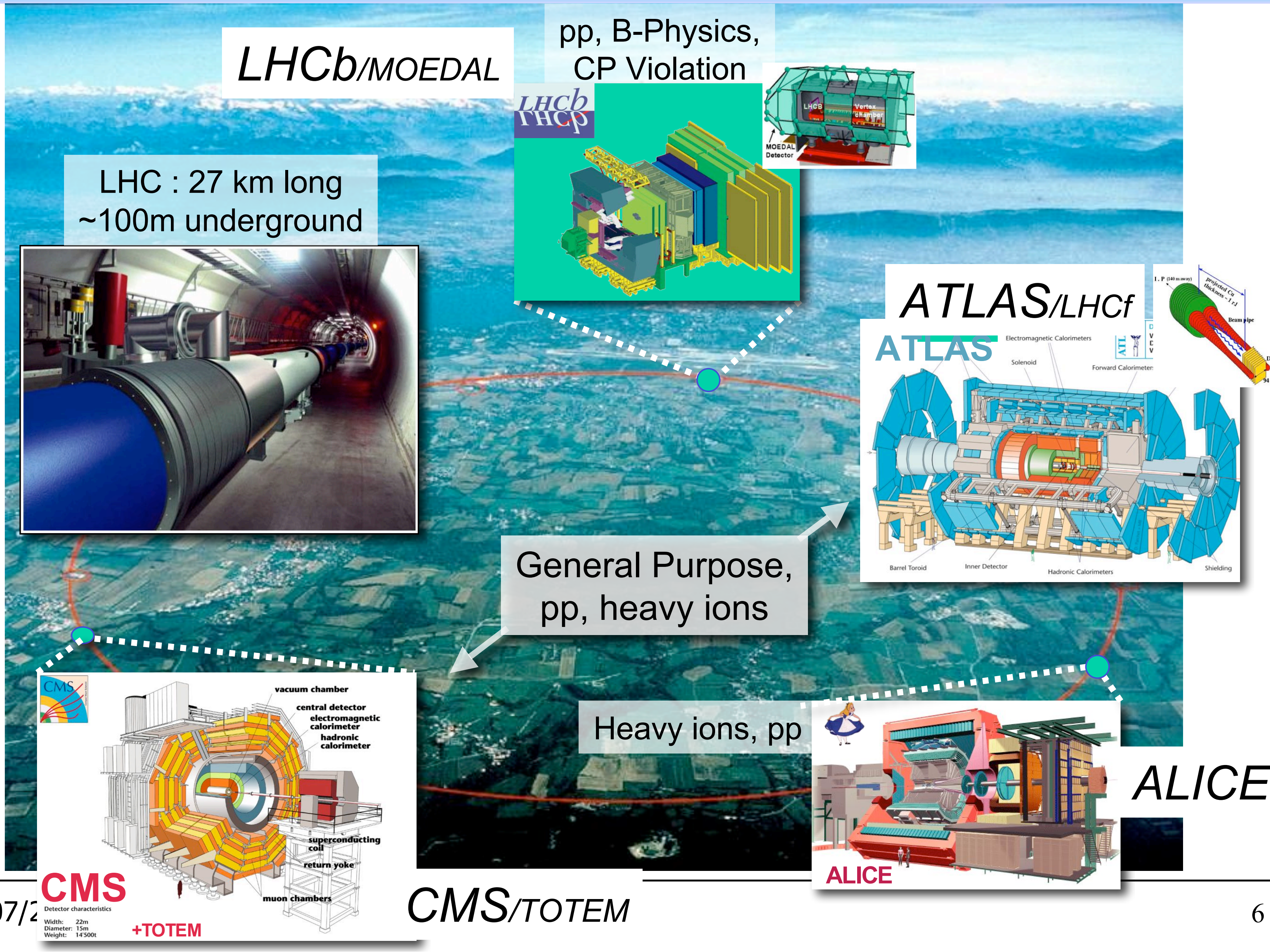
The Large Hardon Collider at CERN



The Large Hardon Collider at CERN

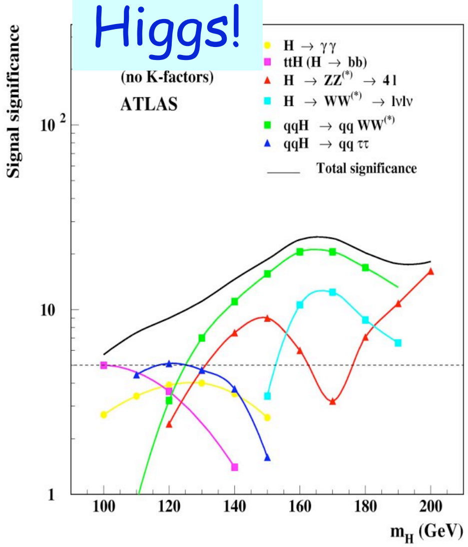


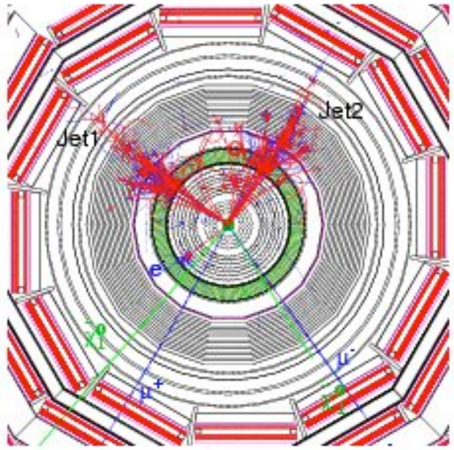
The Large Hardon Collider at CERN



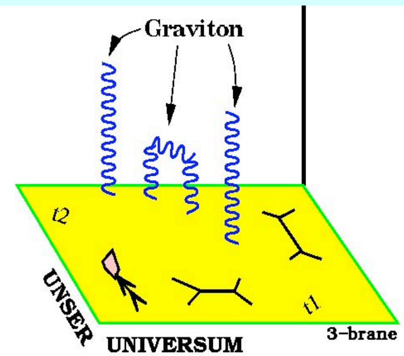
A Glimpse at the LHC Physics Program

Higgs!

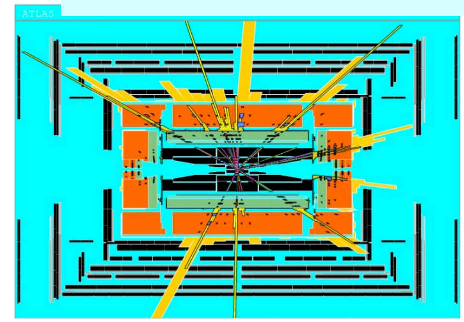




Extra Dimensions??

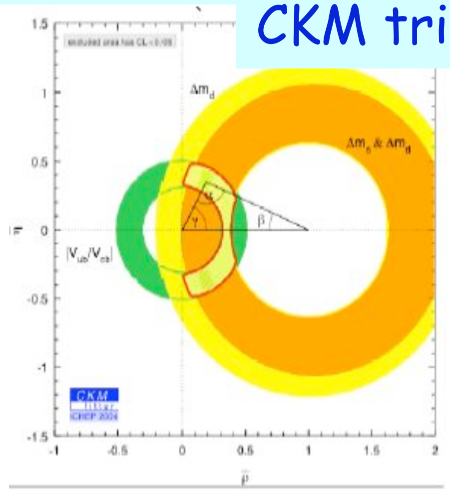


Black Holes???

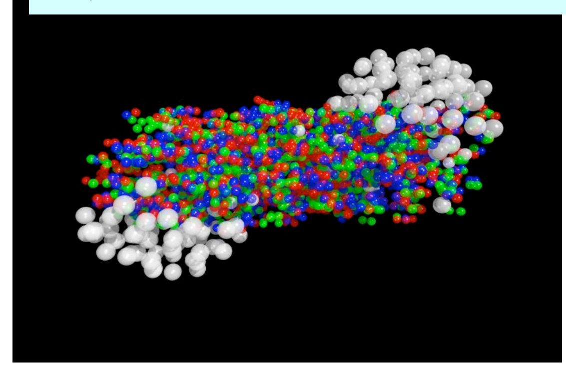


Supersymmetry?

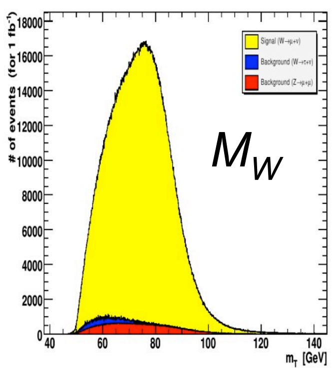
CKM triangle!

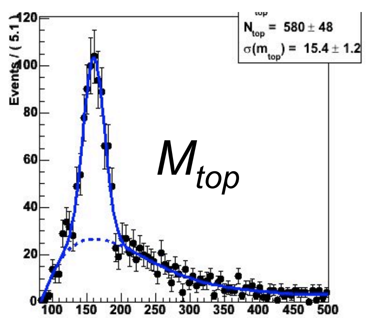


Quark Gluon Plasma?



Precision Electroweak!



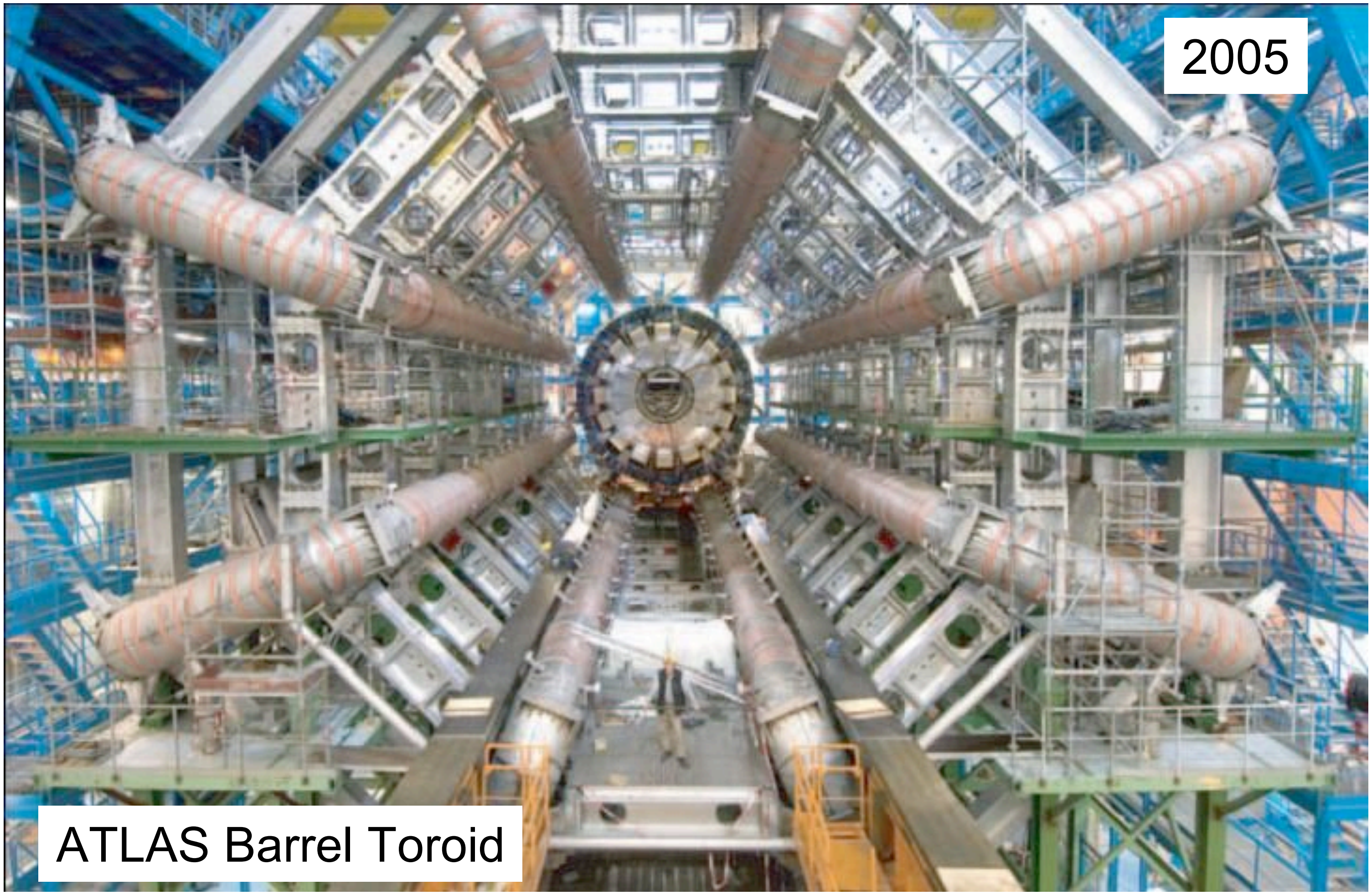


Physics at a new energy frontier!

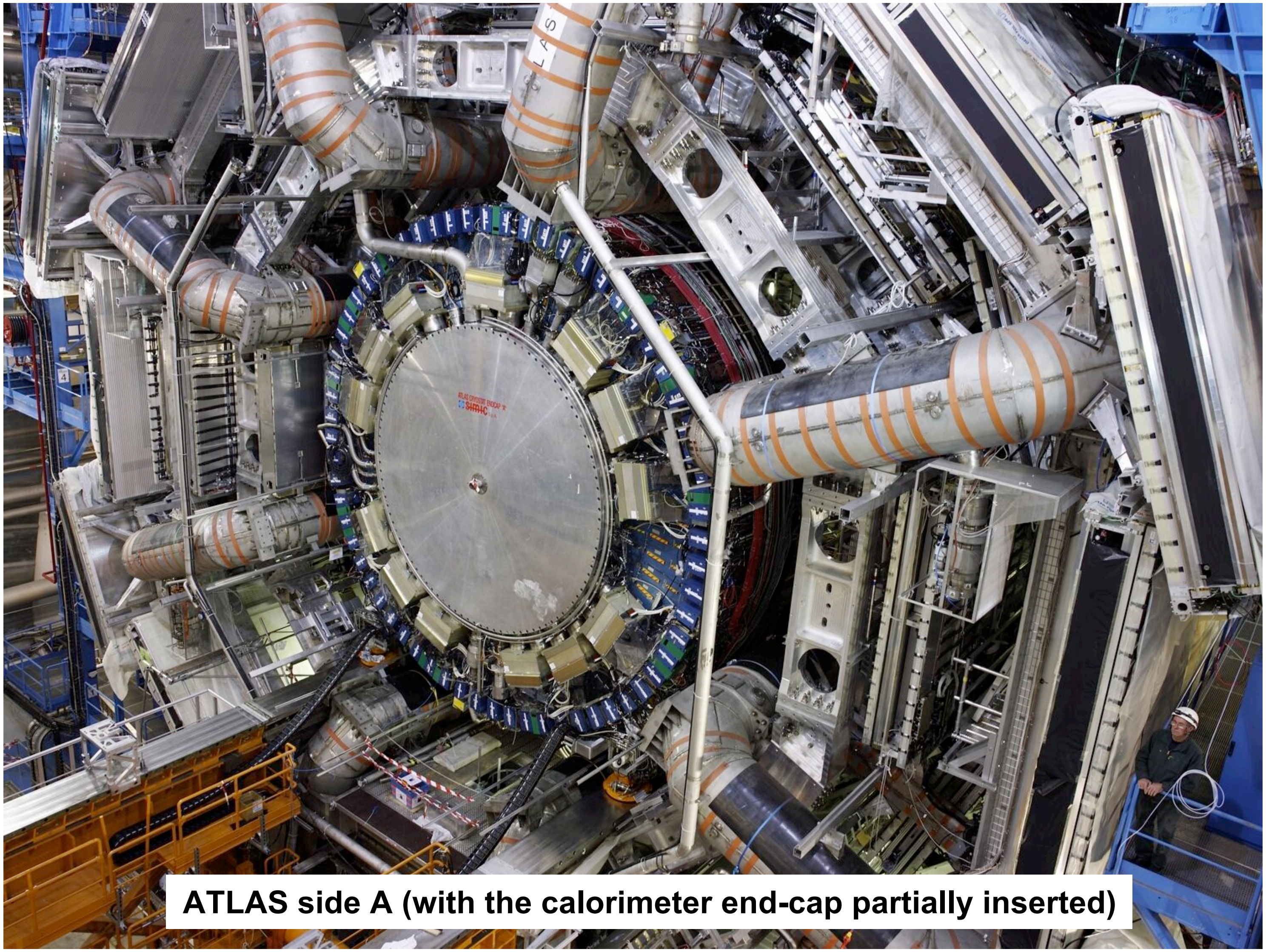
Construction Status of the 4 Experiments

ATLAS installation

Atlas being assembled in the cavern: « ship in the bottle »



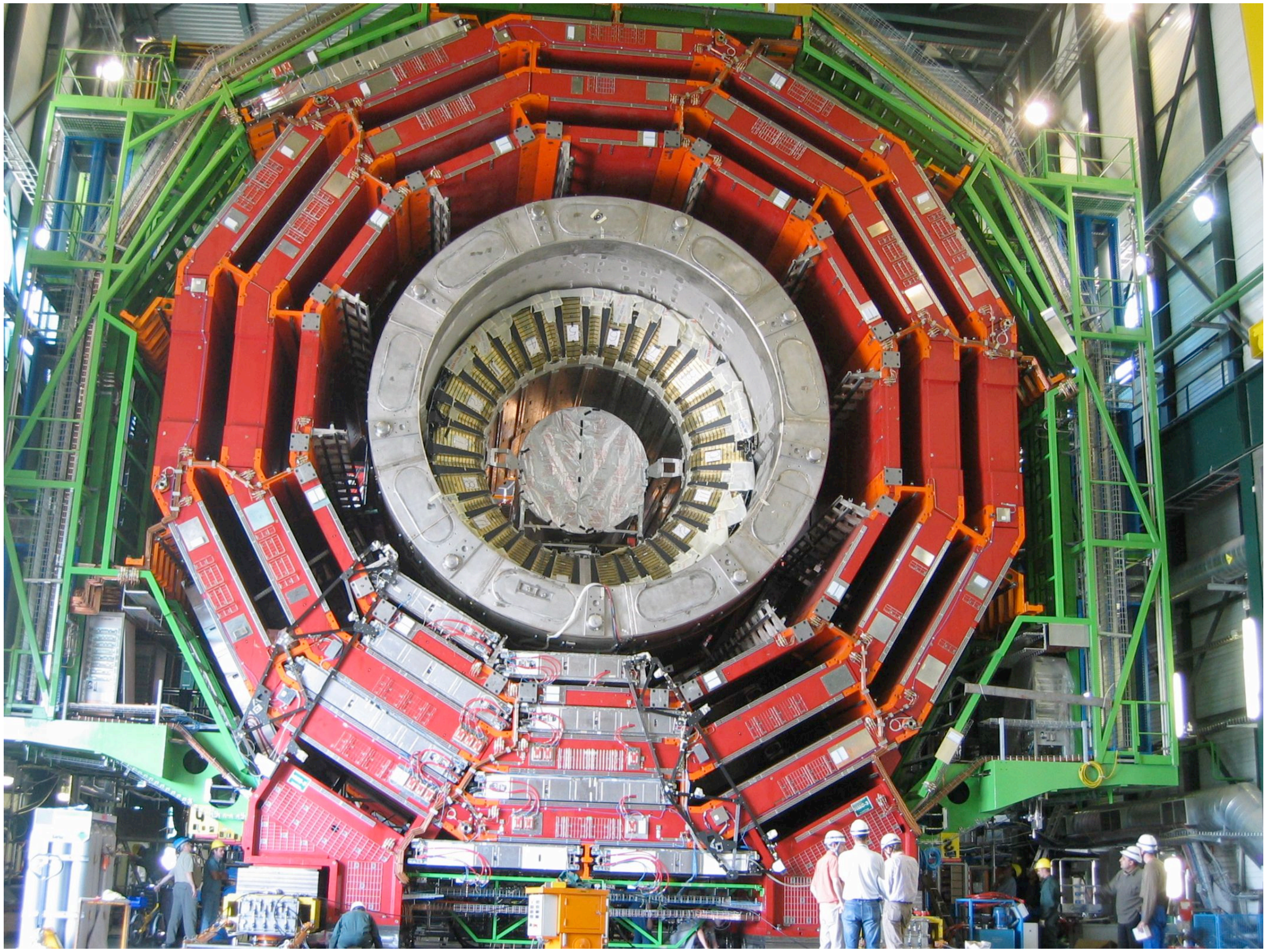
ATLAS Calorimeter



ATLAS side A (with the calorimeter end-cap partially inserted)

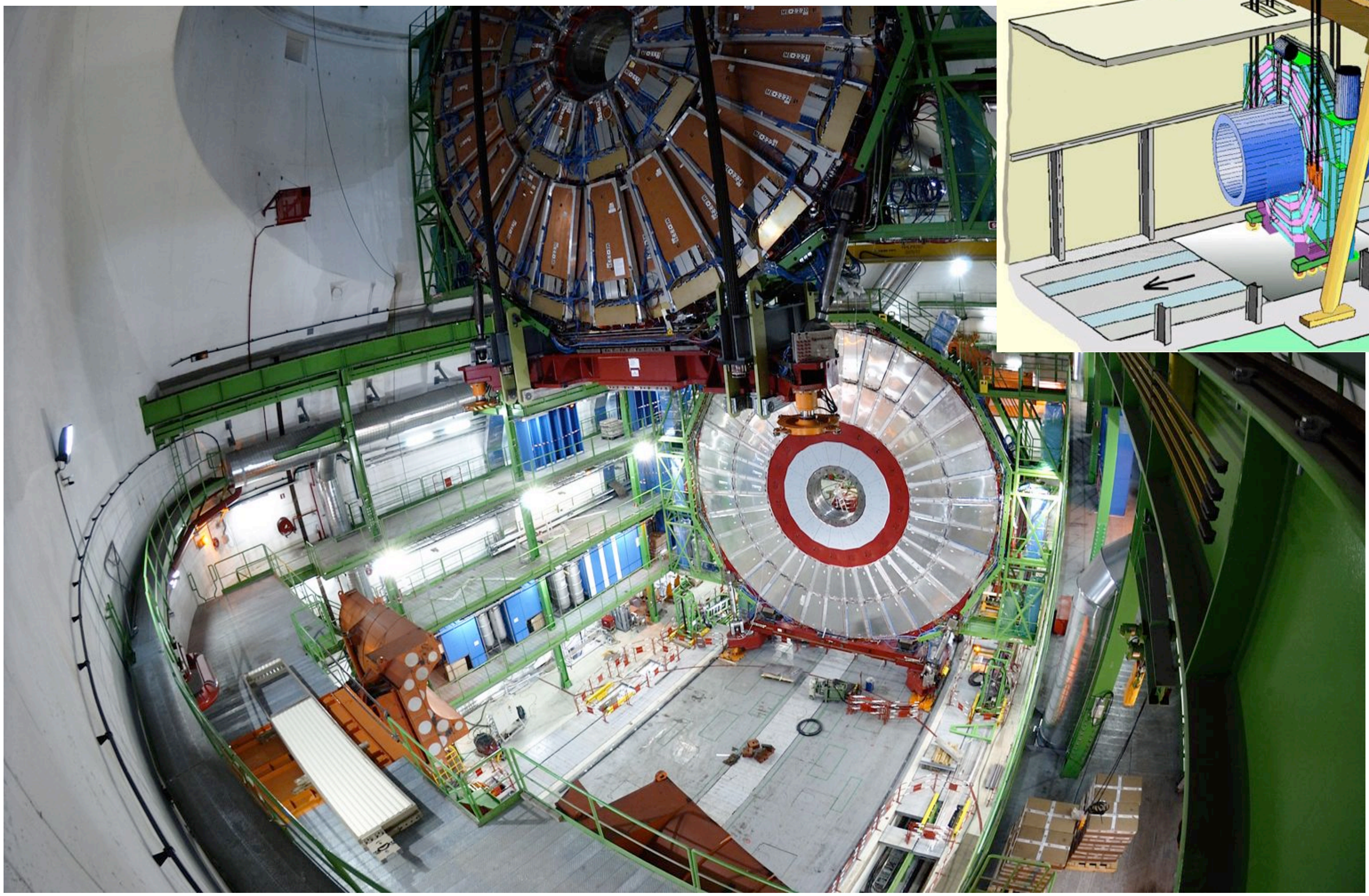
CMS installation

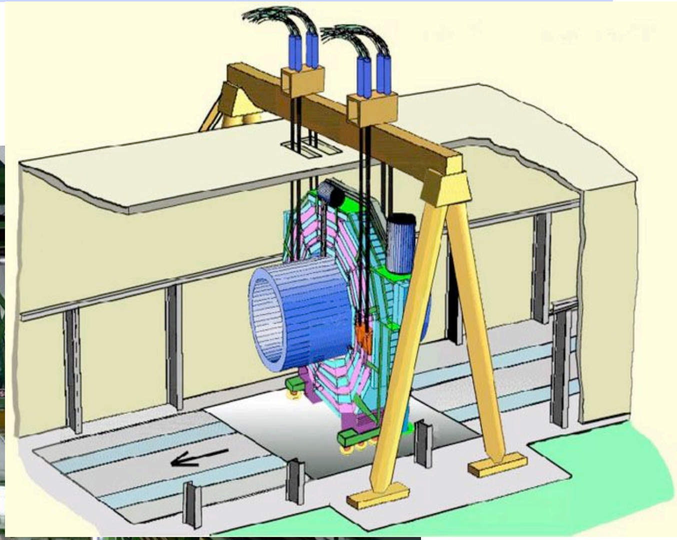
CMS: slices being assembled on the ground, then lowered in cavern

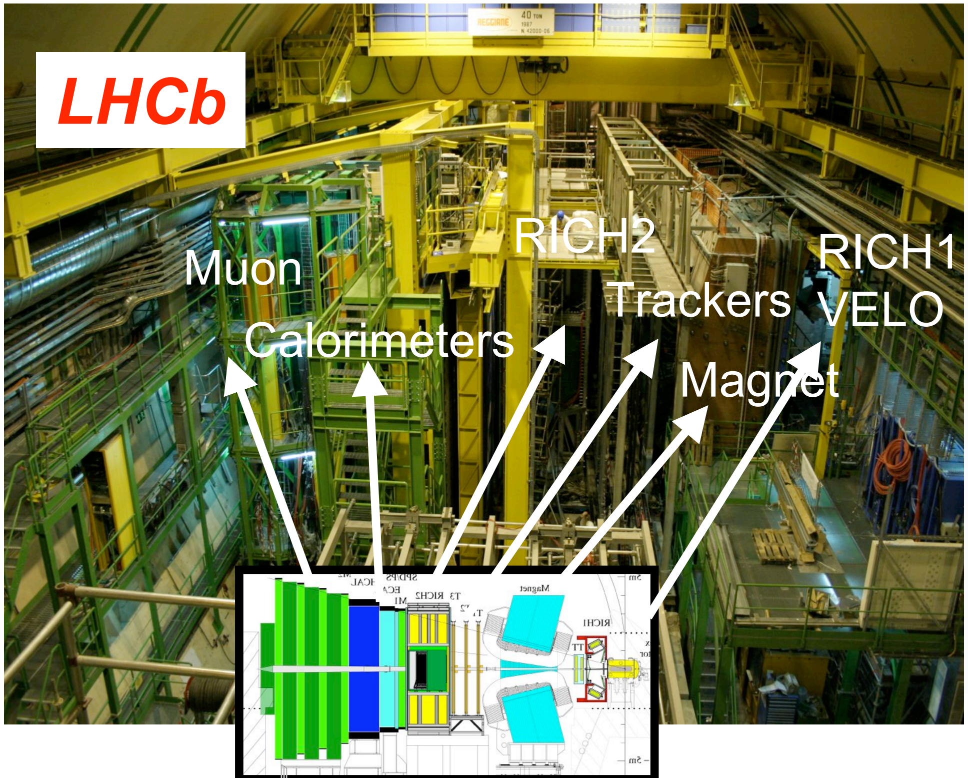


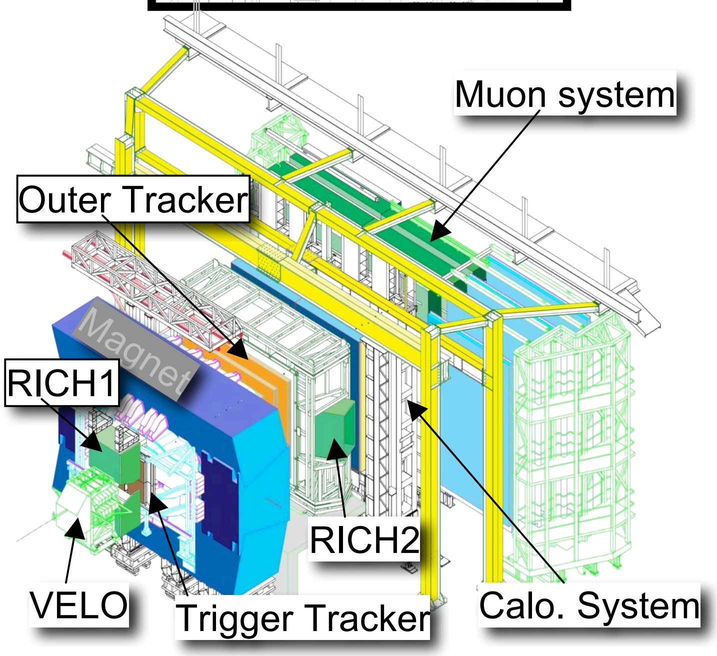
…CMS Installation

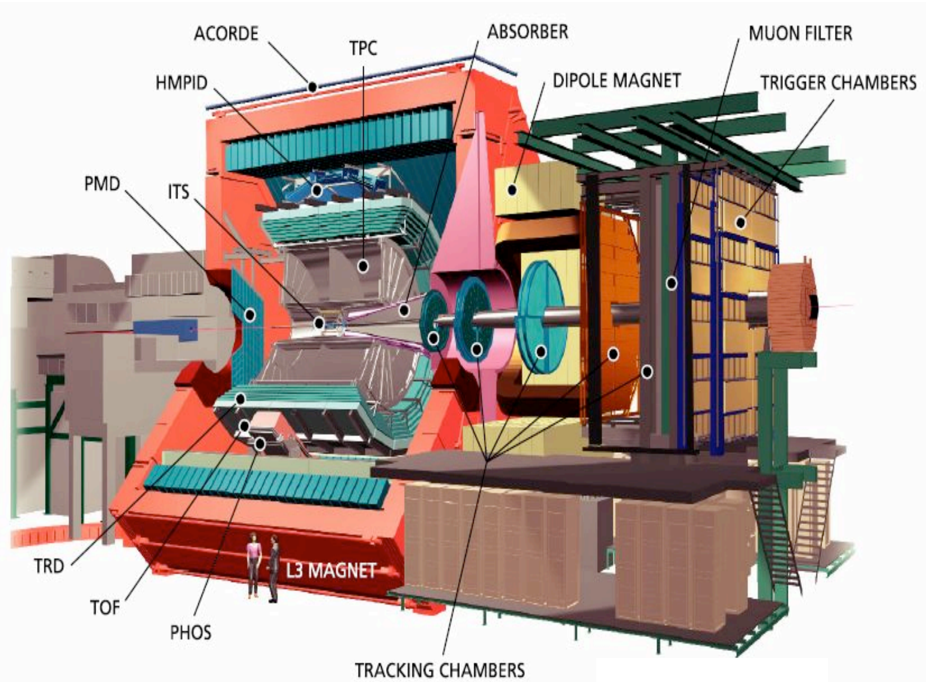
Lowering of YE2 12th December 2006






LHCb
Muon
Calorimeters
RICH2
Trackers
RICH1
VELO
Magnet


Muon system
Outer Tracker
Magnet
RICH1
RICH2
VELO
Trigger Tracker
Calo. System


ACORDE
TPC
ABSORBER
MUON FILTER
HMPID
DIPOLE MAGNET
TRIGGER CHAMBERS
PMD
ITS
TRD
TOF
PHOS
L3 MAGNET
TRACKING CHAMBERS

ALICE

General Commissioning Strategy of the Experiments

Commissioning: A Real Challenge

The commissioning of LHC machine and detectors
of unprecedented complexity, technology and performance
will be one of the biggest challenges in the next year!
Only with well commissioned experiments we will be able
to open the door to the new physics world!

A few performance numbers …

	expected performance on "day one"	data samples (examples) to improve the performance
ECAL uniformity	~1% (~2%) in ATLAS (CMS)	minimum-bias, $Z \to ee$
electron energy scale	~2%	$Z \to ee$
HCAL uniformity	3%	single pions, QCD jets
jet energy scale	≤10%	$Z(\to \ell\ell)$+jet, $W \to jj$ in $t\bar{t}$ events
tracker alignment	20-200 μm in $R\phi$	generic tracks, isolated μ, $Z \to \mu\mu$

Just a few examples there are many more …

LHC Commissioning Stages

STAGE A
INITIAL COMMISSIONING
43 x 43 -> 156 x 156 3×10^{10} per bunch
Zero to partial squeeze

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

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

LONG SHUTDOWN

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

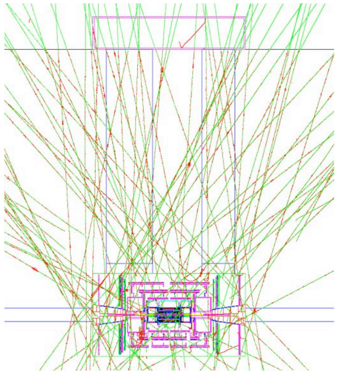
LHC commissioning strategy drives
Detector commissioning strategy

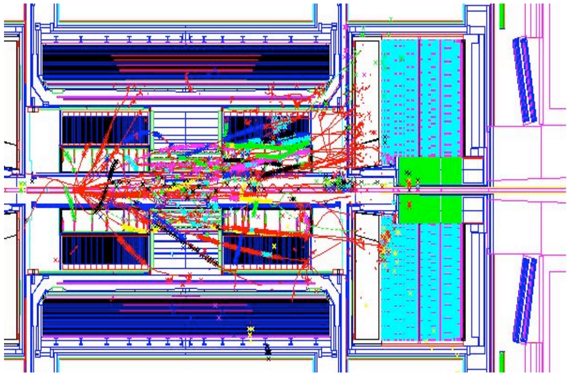
- Establish colliding beams as quickly as possible
- Safely
- Without compromising further progress
- ‘Default” scenario for 2008 running

- Initial optics:
  - β^*= 11 m in IR 1 & 5
  - β^*= 10 m in IR 2 & 8
- Crossing angles off
  - 1, 12, 43, 156 bunches per beam
  - No parasitic encounters - no long range beam-beam
  - Larger aperture in IRs

Physics Commissioning

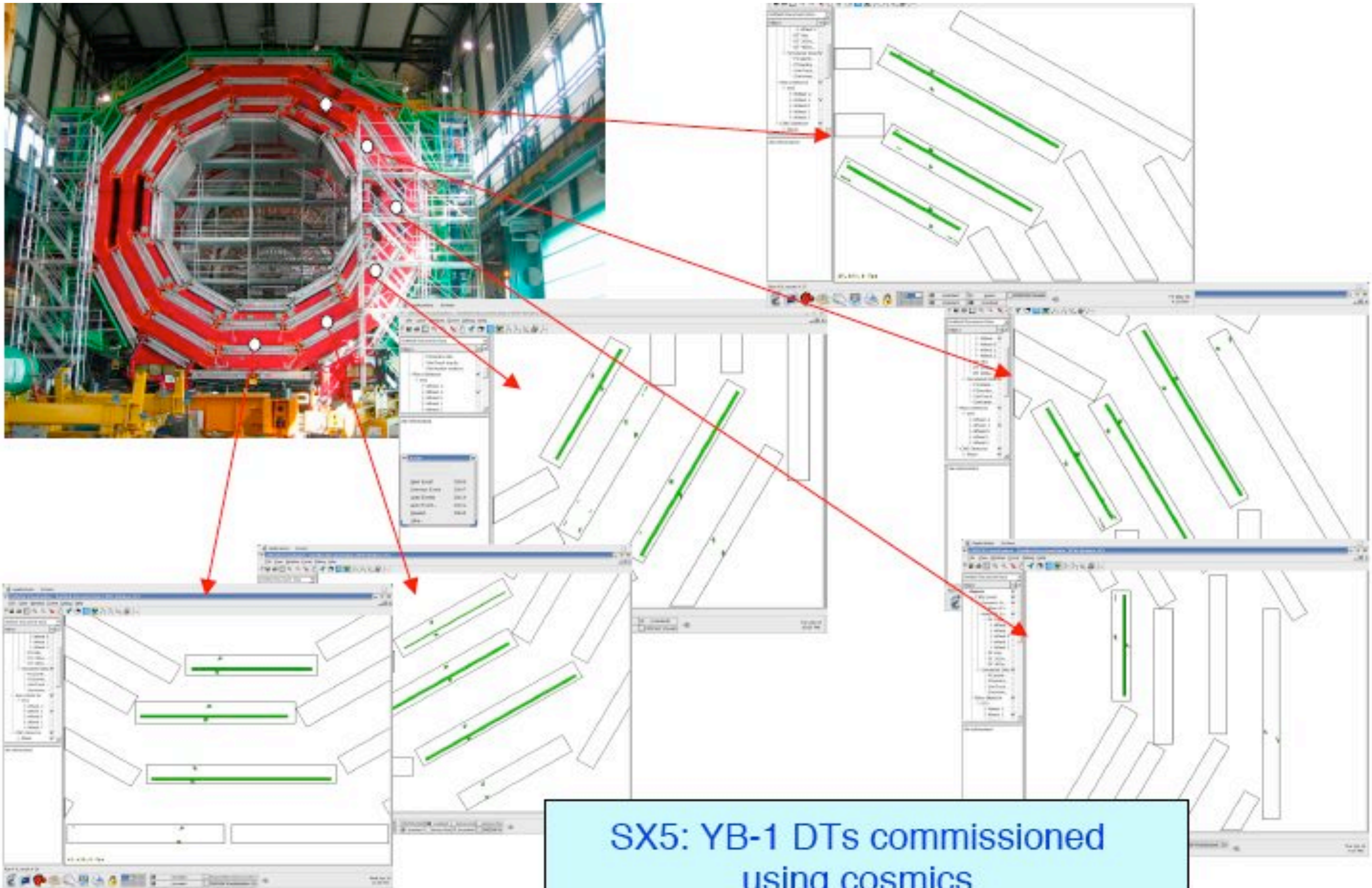
The path to early physics …





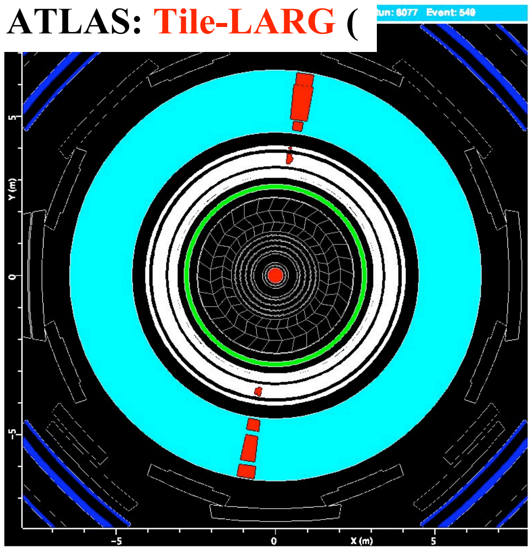
- No beam:
  - Cosmic muons
- Single beam
  - beam halo muons, beam gas interactions
- First Collisions - Stage A
  - mainly minimum bias and QCD dijet; first sign of SM candles
- Low lumi running - Stage B
  - Full access to classical calibration candles like Z, W but also Top

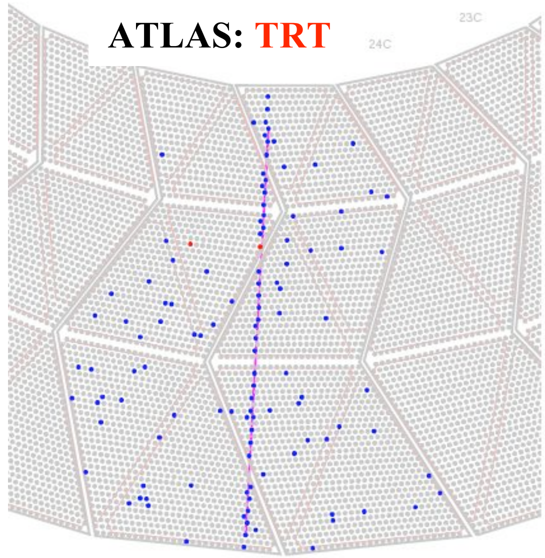
CMS Muon System & Cosmic

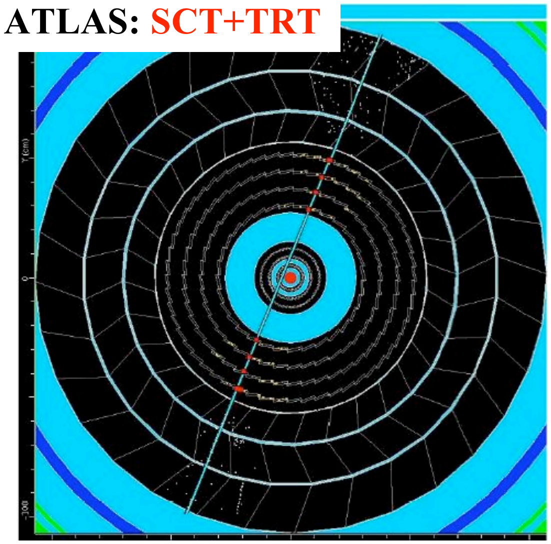


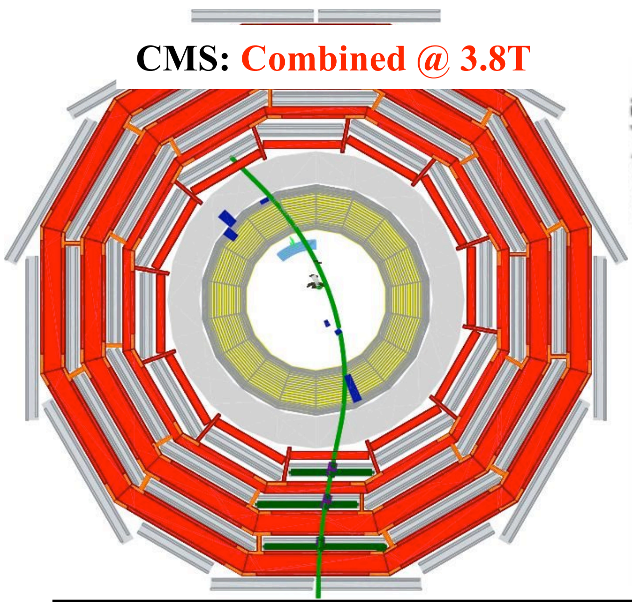
SX5: YB-1 DTs commissioned using cosmics

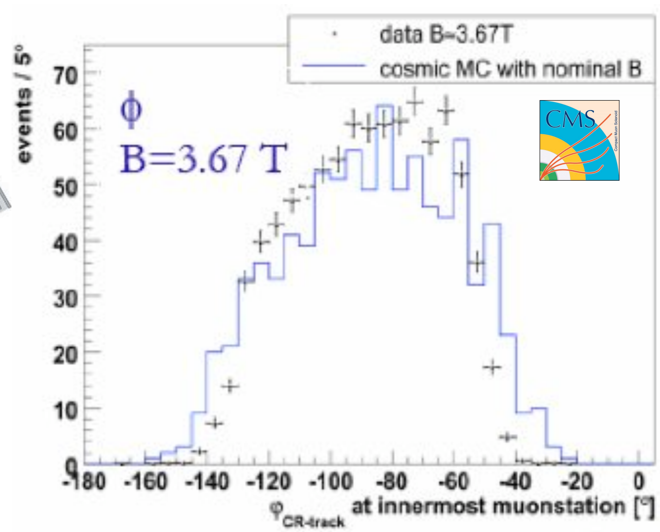
More Commissioning with Cosmic

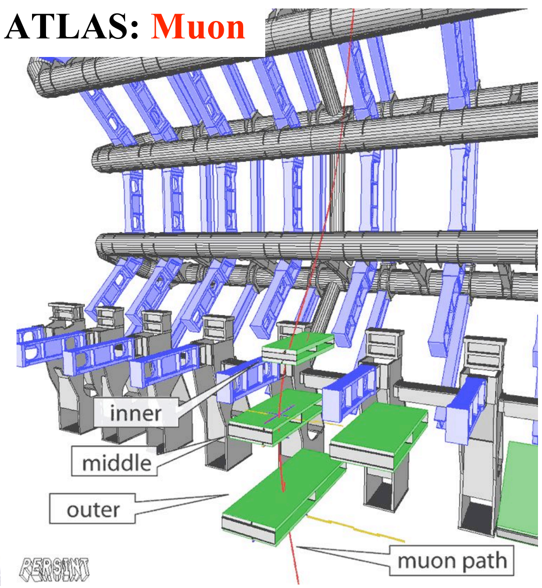






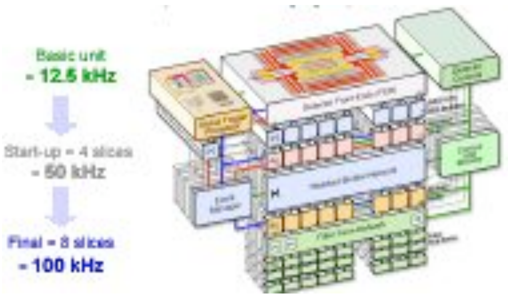


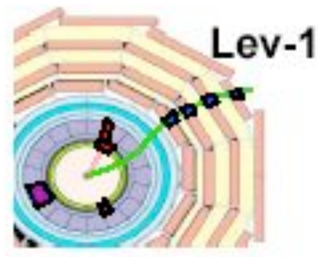


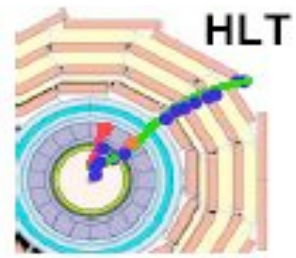


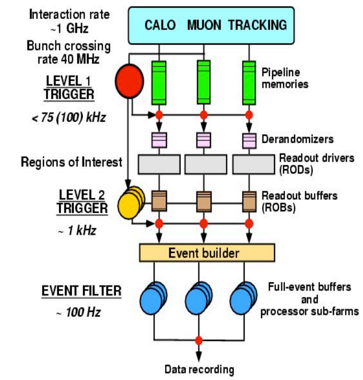
Major Commissioning Challenges

Efficient operation of Trigger and DAQ System



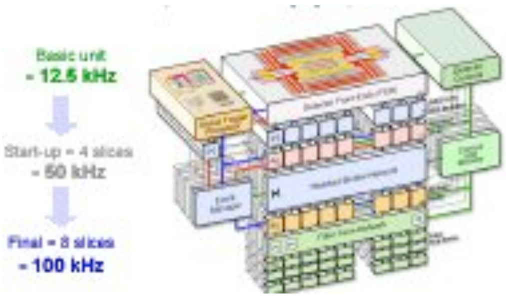


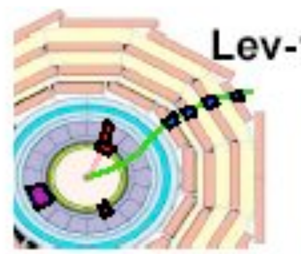


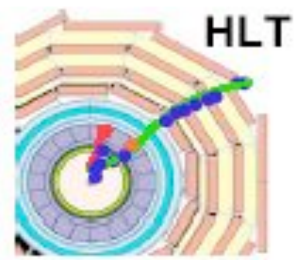


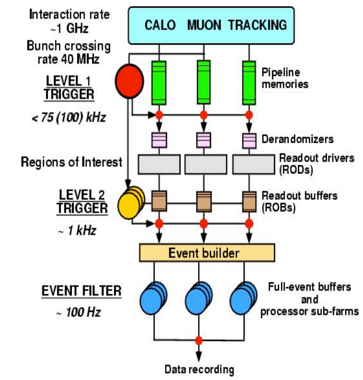
Major Commissioning Challenges

Efficient operation of Trigger and DAQ System

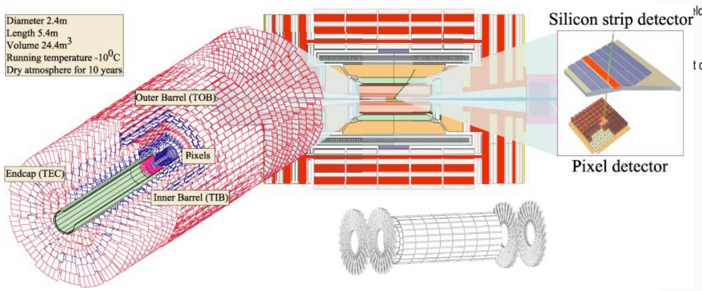


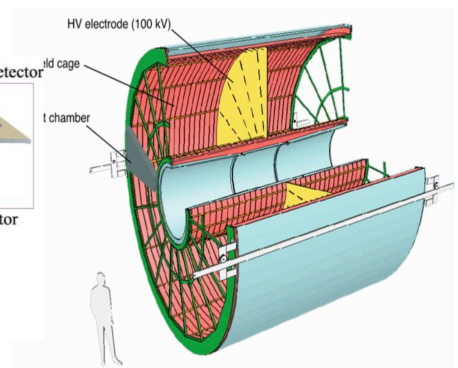


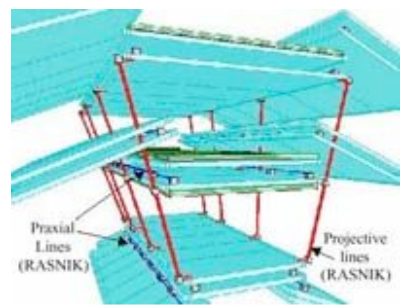


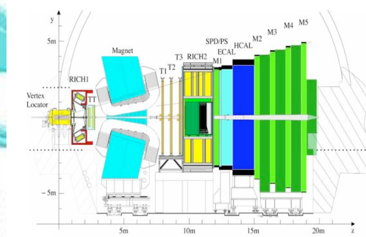


Alignment of the inner tracking devices and muon systems



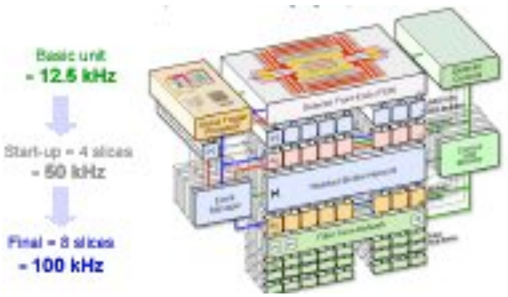


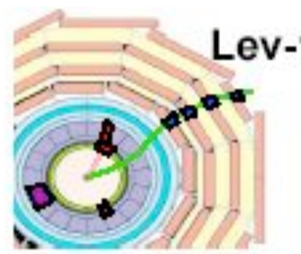


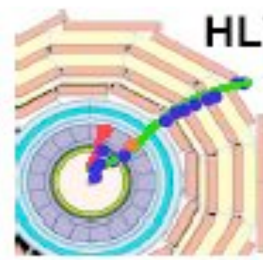


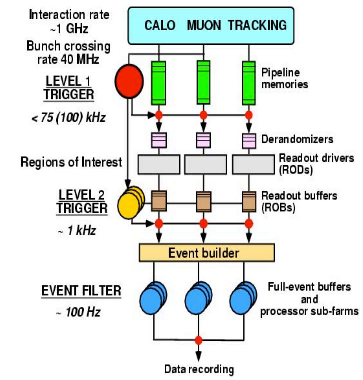
Major Detector Commissioning Challenges

Efficient operation of Trigger and DAQ System

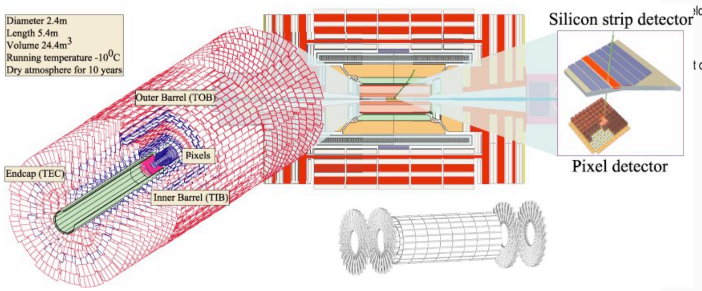


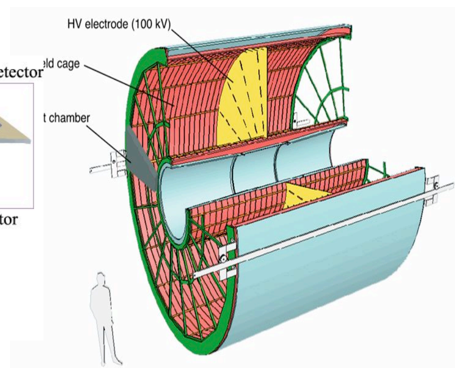


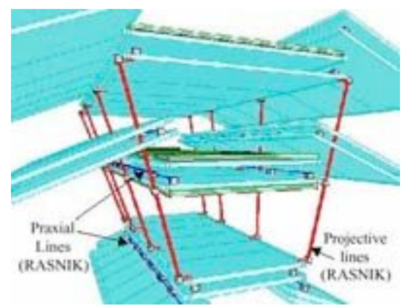


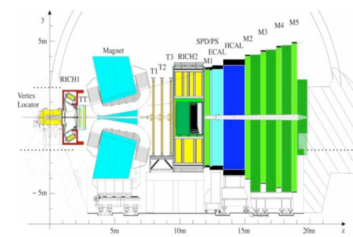


Alignment of the inner tracking devices and muon systems

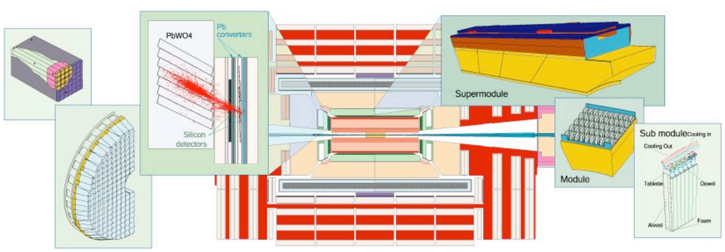


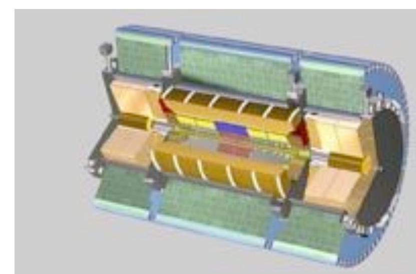






Calibration of the Calorimeter Systems



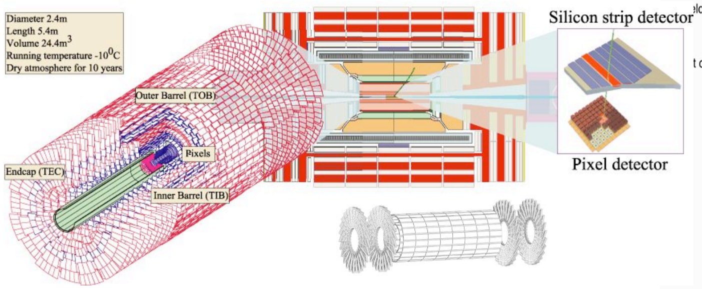


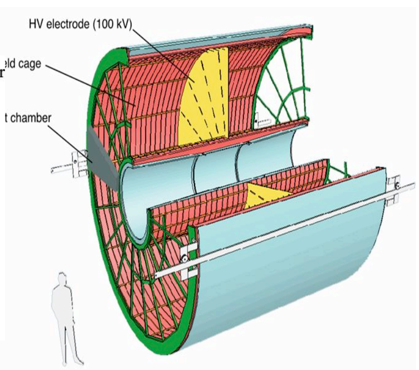
Major Detector Commissioning Challenges

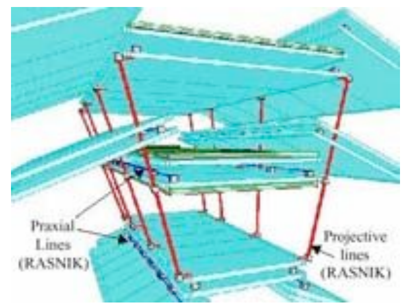
It is impossible to cover all important commissioning tasks in one talk - Concentrate on only one example:

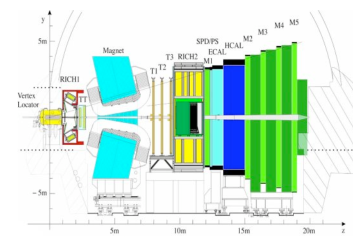
Inner tracker commissioning

Alignment of the inner tracking devices and muon systems







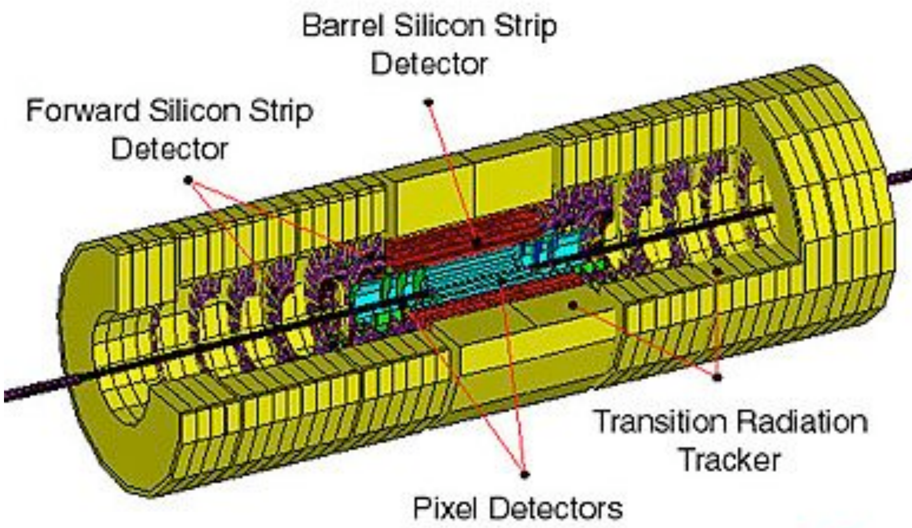


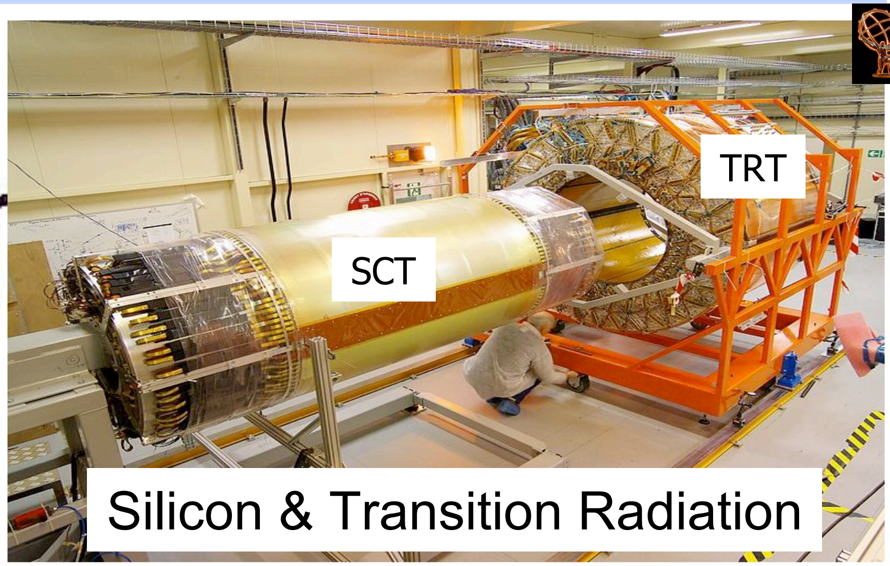
Note: Many important commissioning topics were discussed in detail during the HEP parallel sessions:

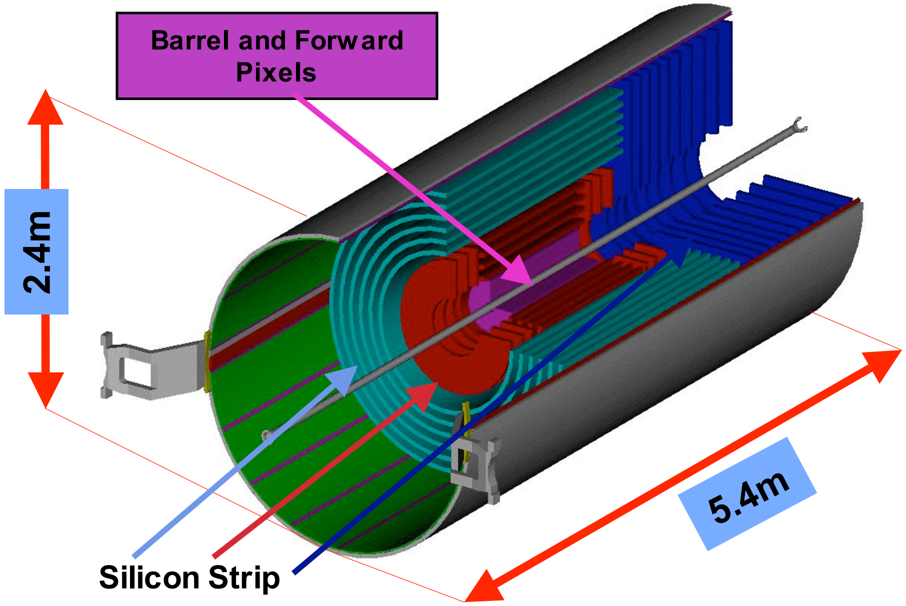
"Detector and Data Handling Session"

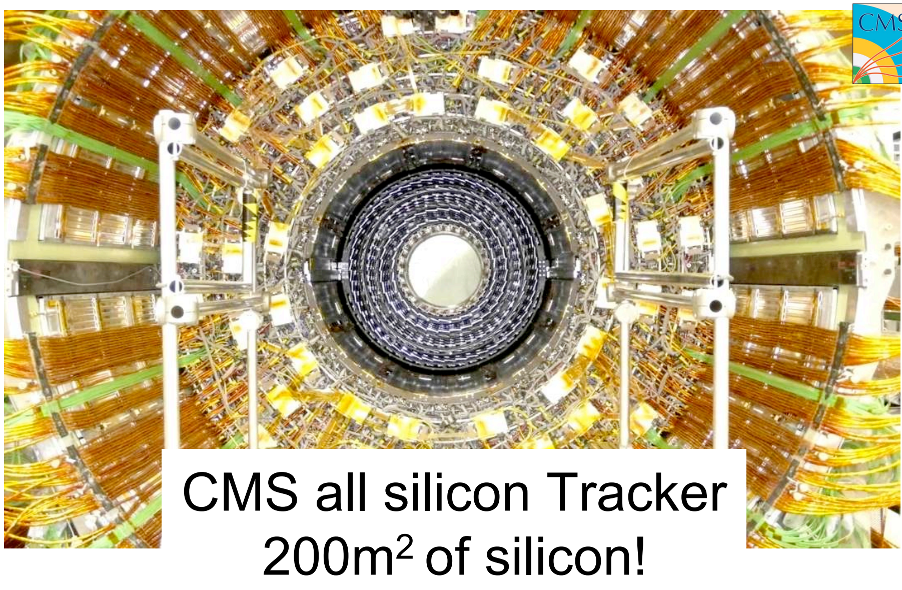
Have a look at slides!

Inner Tracker: ATLAS & CMS

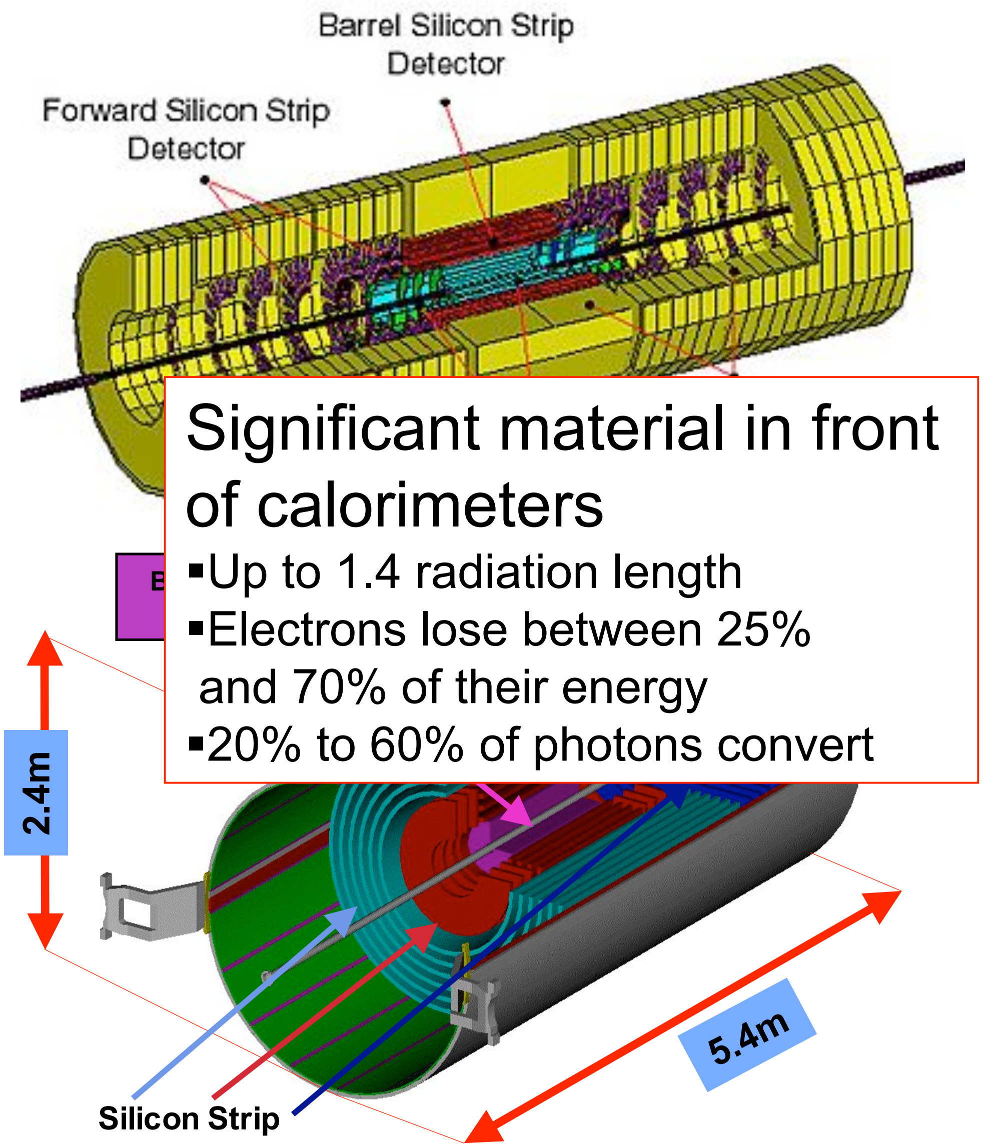






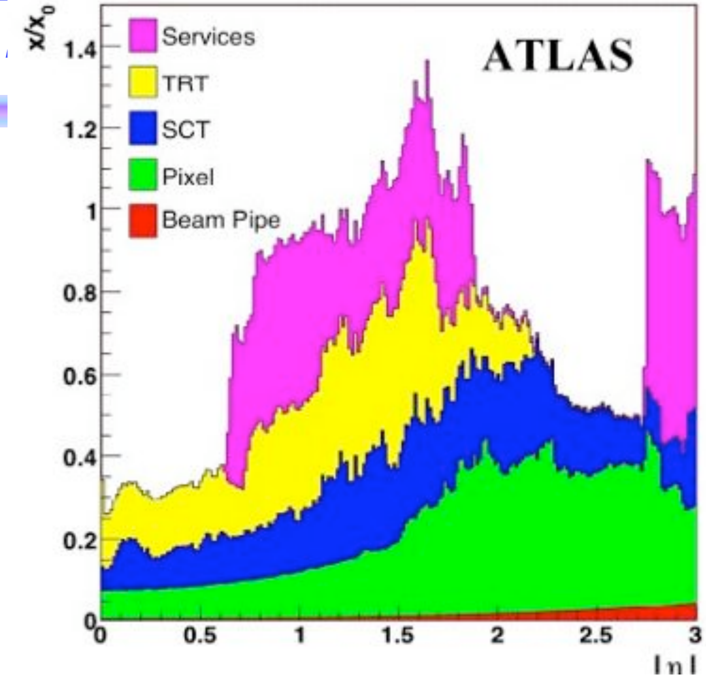


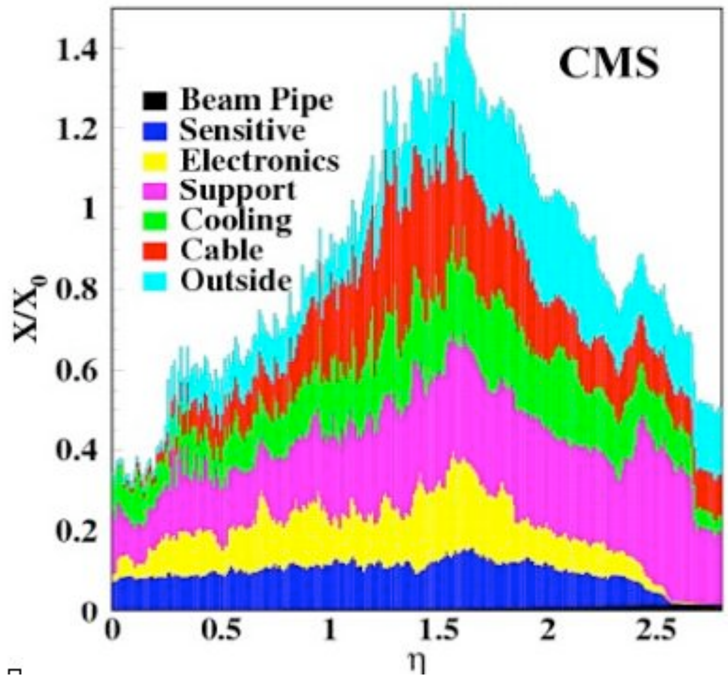
Inner Tracker: A



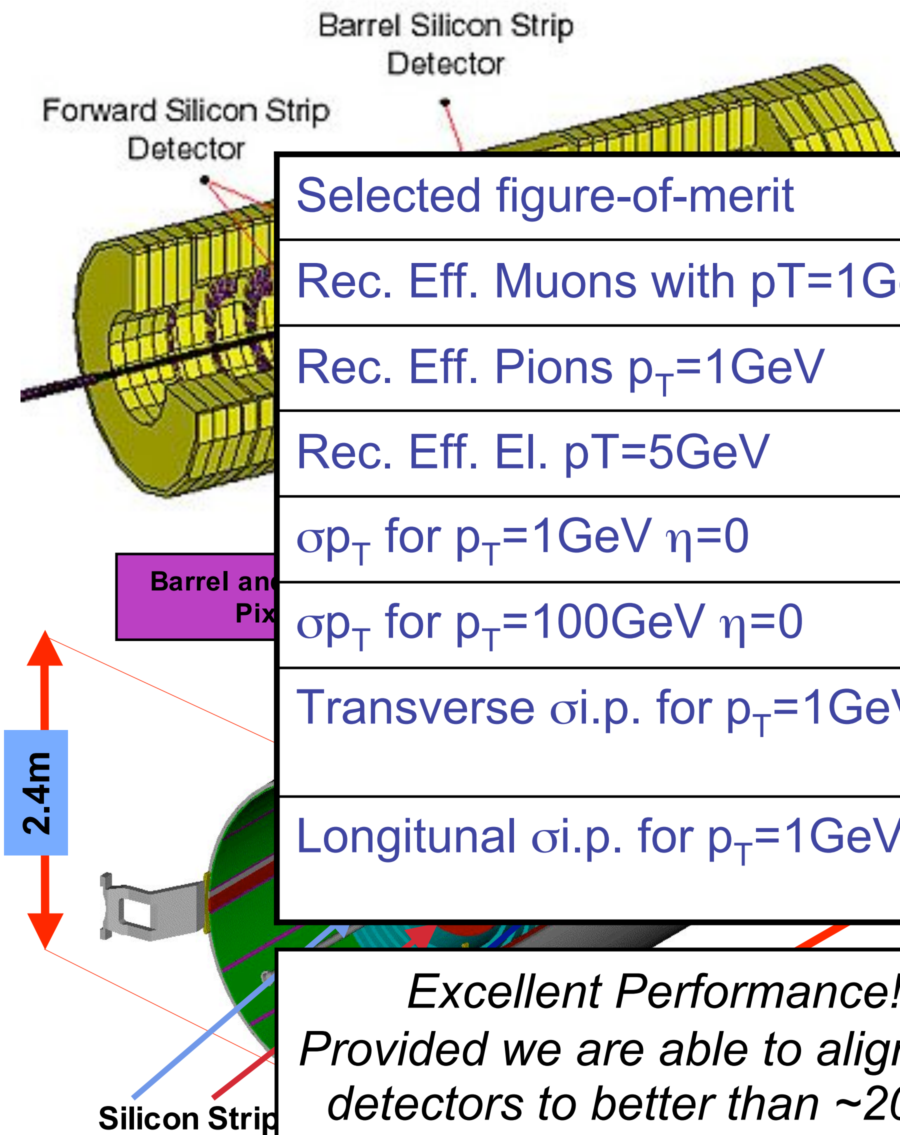
Significant material in front of calorimeters

- Up to 1.4 radiation length
- Electrons lose between 25% and 70% of their energy
- 20% to 60% of photons convert





Inner Tracker: ATLAS & CMS



similar performance!

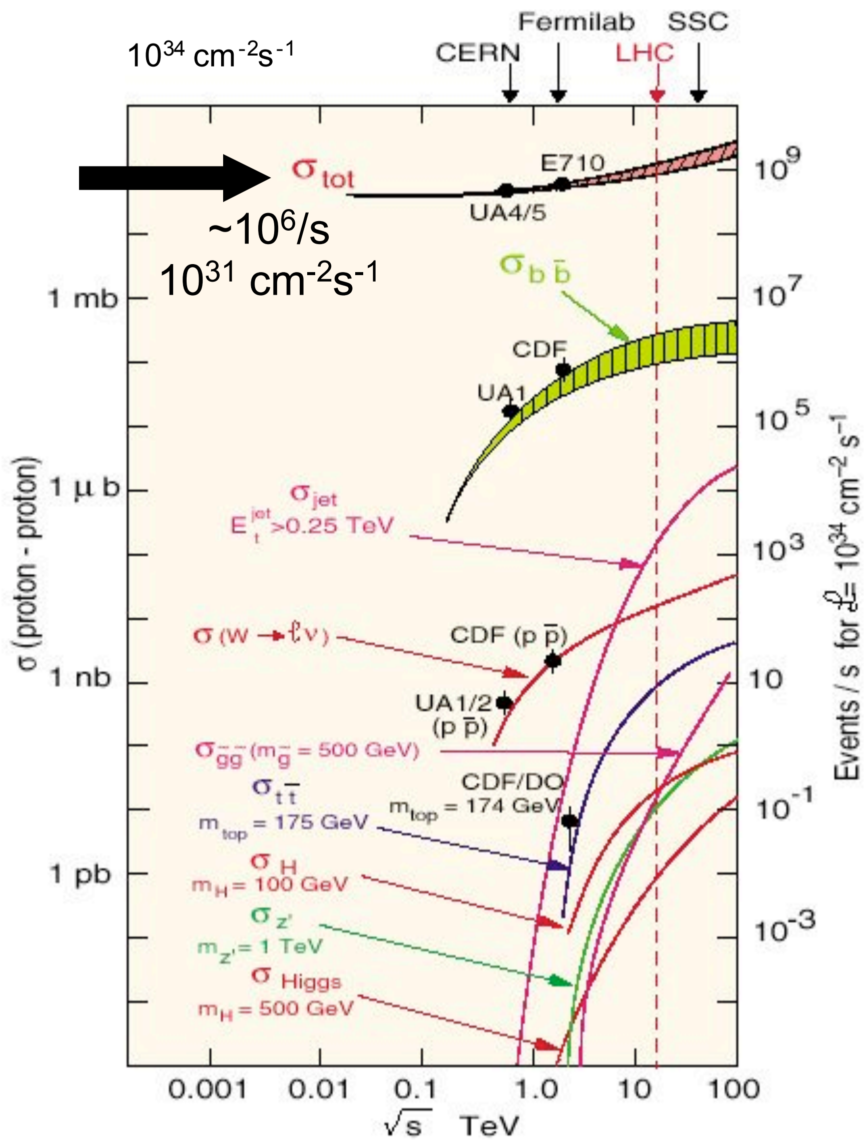
Selected figure-of-merit	ATLAS	CMS
Rec. Eff. Muons with pT=1GeV	97%	97%
Rec. Eff. Pions p_T=1GeV	84%	80%
Rec. Eff. El. pT=5GeV	90%	85%
σp_T for p_T=1GeV η=0	1.3%	0.7%
σp_T for p_T=100GeV η=0	3.8%	1.5%
Transverse σi.p. for p_T=1GeV	75μm	90μm
Longitunal σi.p. for p_T=1GeV	150μm	125μm

Excellent Performance!
Provided we are able to align the detectors to better than ~20μm

*D.Rousseau, Aspen 2007
& Ann.Rev.Nucl.Part.Sci.56:375-440,2006

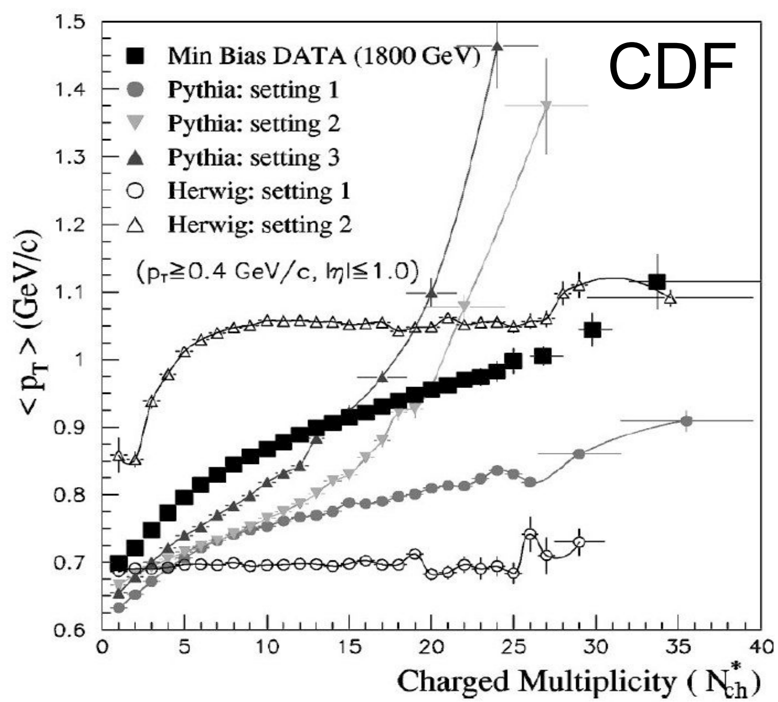
Physics Commissioning with the first collision data

First Phase at 14 TeV



"Why":Measure Charged Particle Density

- W,Z, ttbar cross sections known to ~3 to 10%
- Large uncertainties in minimum bias **$dN_{ch}/d\eta$** known to only ~50% (or worse)



Precise knowledge of $dN_{ch}/d\eta$ very important for *MC tuning, understanding underlying event*, pile-up etc

1 September 2008

Probably the first paper:
not Higgs, not SUSY
but rather "boring bread-and-butter" stuff

Charged particle multiplicity in pp collisions at $\sqrt{s} = 14$ TeV

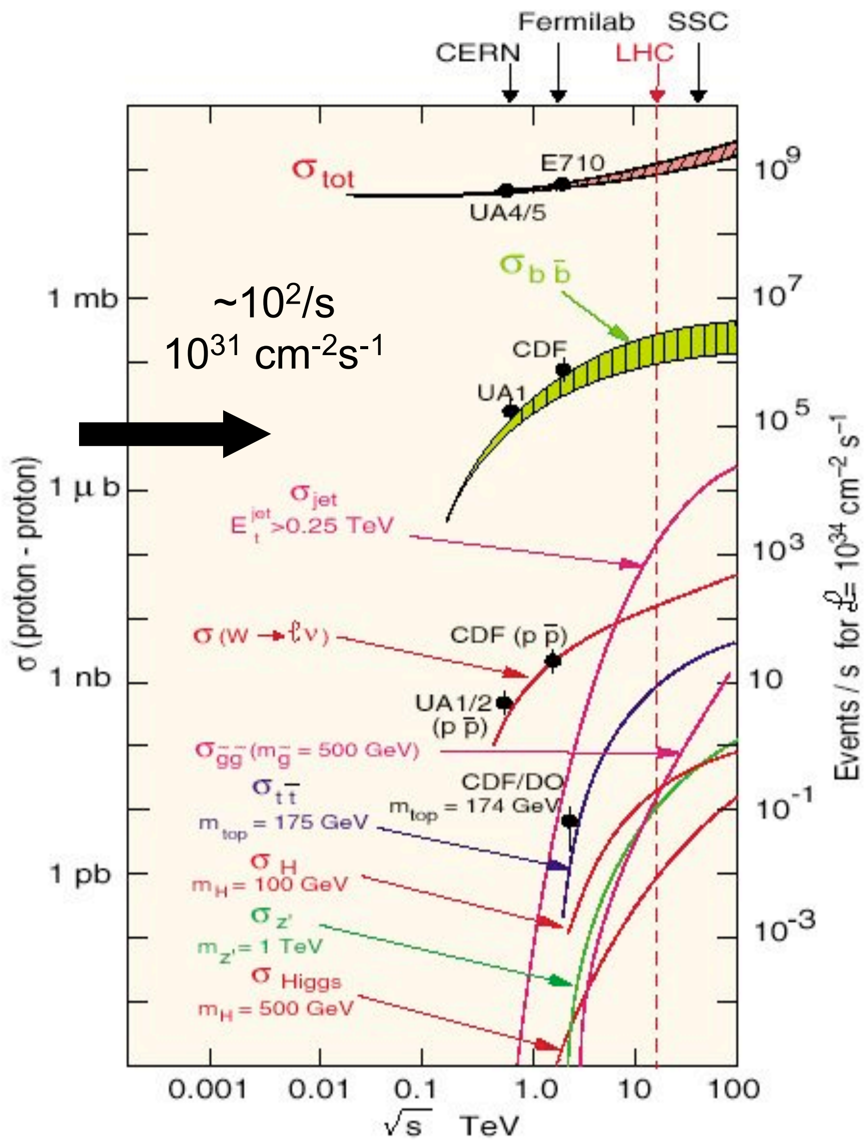
CMS collaboration

Abstract

We report on a measurement of the mean charged particle multiplicity in minimum bias events, produced in the central region $|\eta| < 1$, at the LHC in pp collisions with $\sqrt{s} = 14$ TeV, and recorded in the CMS experiment at CERN. The events have been selected by a minimum bias trigger, the charged tracks reconstructed in the silicon tracker and in the muon chambers. The track density is compared to the results of Monte Carlo programs and it is observed that all models fail dramatically to describe the data.

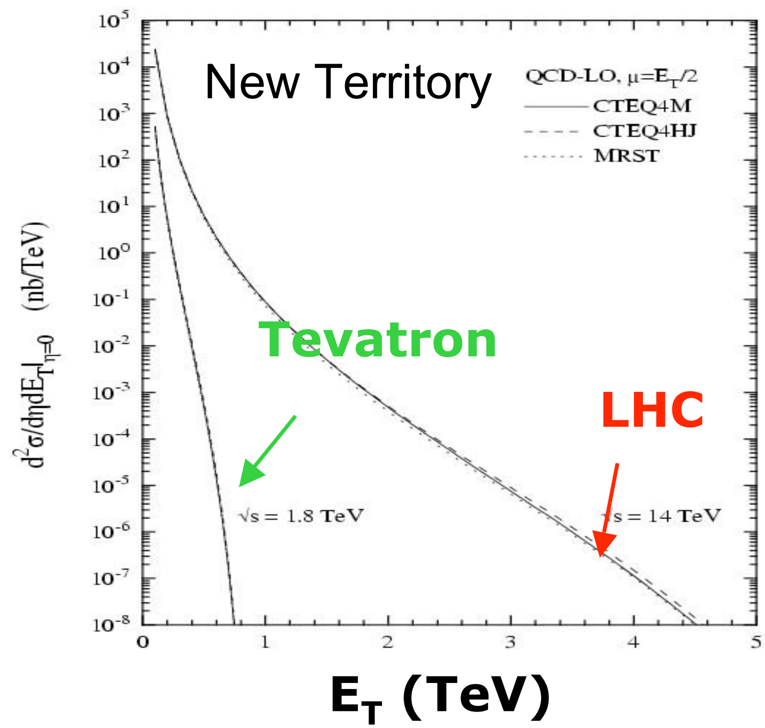
Submitted to *European Journal of Physics*

Second Phase at 14 TeV

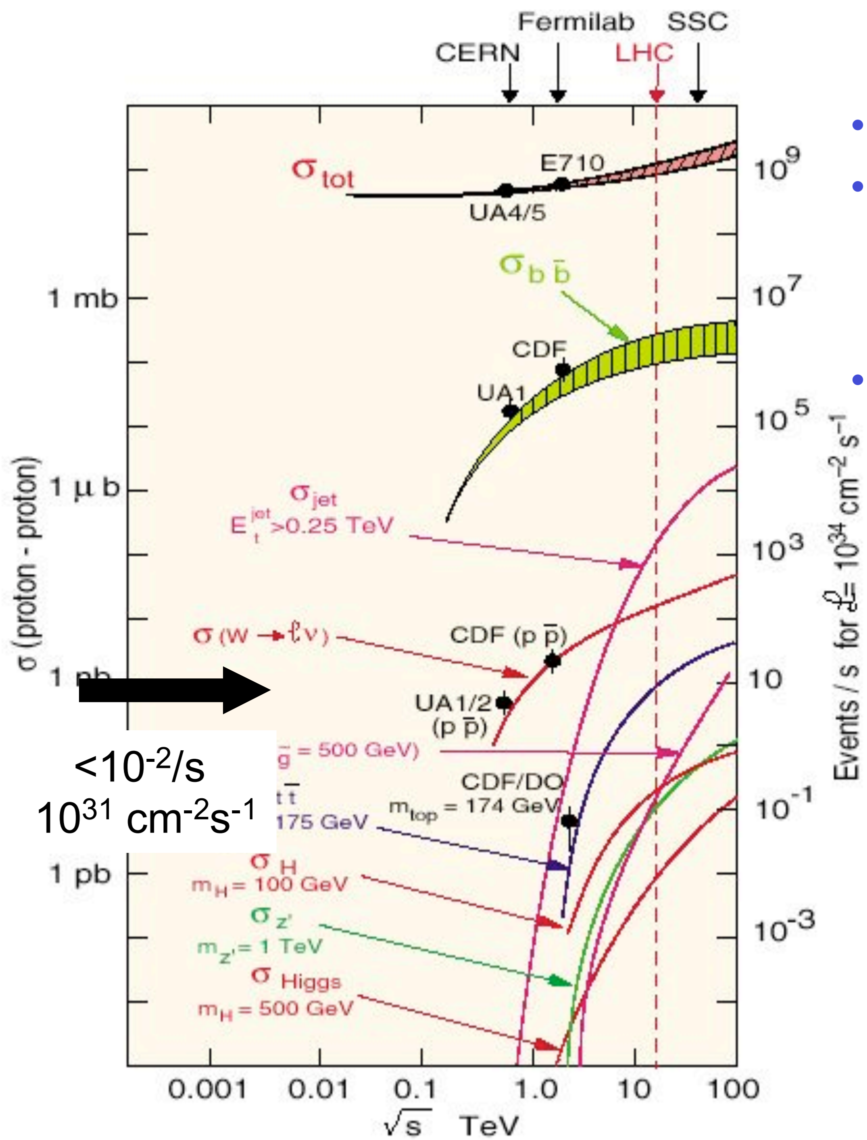


Measure Jet Cross Section

- E_T^{Jet} > 500 GeV after few weeks at startup
- Going fast beyond the reach of the Tevatron
- Early sensitivity to compositeness; requires understanding of the jet energy scale, PDF's, …



Third Phase at 14 TeV



Re-discover the SM

- Reestablish the Standard Model
- Most SM cross sections are significantly higher than at the Tevatron
  e.g. σ_{ttbar} (LHC)> 100 x σ_{ttbar} (Tevatron)
- Crucial for final Detector and Physics commissioning

THE path to new physics!

At Luminosity $10^{31} cm^{-2}s^{-1}$

bb production:	→ 10^3 Hz
W→ $\ell\ \nu$:	→0.1 Hz
Z→ $\ell\ \ell$:	→0.01 Hz
t t production:	→0.01 Hz
SM Higgs	→0.0001 Hz

At this stage the LHC becomes a real SM Factory!

Early (New) Physics Reach of the Experiments

Focus mainly on the physics reach for a few pb^{-1} up to $1fb^{-1}$

- *e.g. few hundred pb^{-1} expected for 2008*
- *interplay between commissioning and physics will be significant*

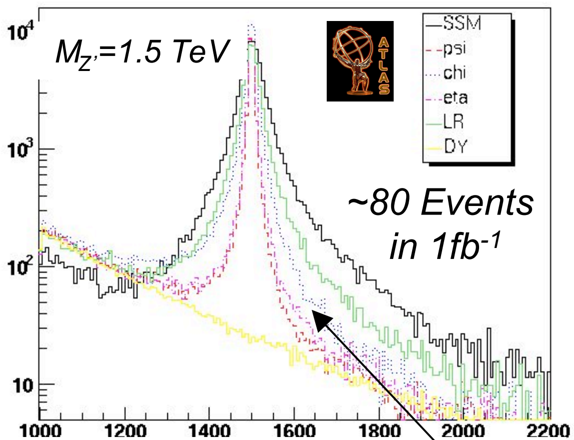
Focus mainly on the physics search at ATLAS and CMS

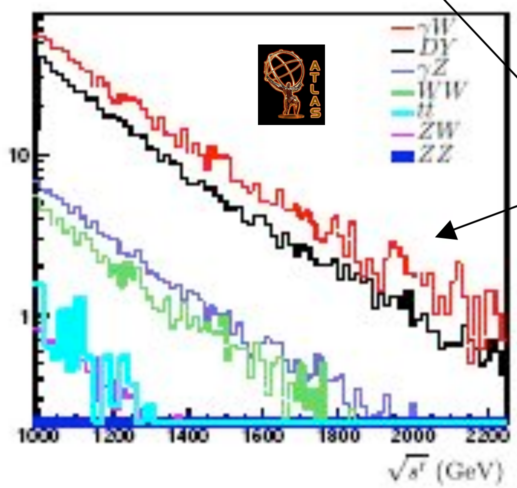
- *very early : Di-lepton pairs*
- *rather early : low mass SUSY*
- *early : SM-like Higgs (mainly exclusion)*

By far not an exhaustive list!
There are many more exciting (new) physics topic but no time to cover here!

Di-lepton Resonances (Example Z')

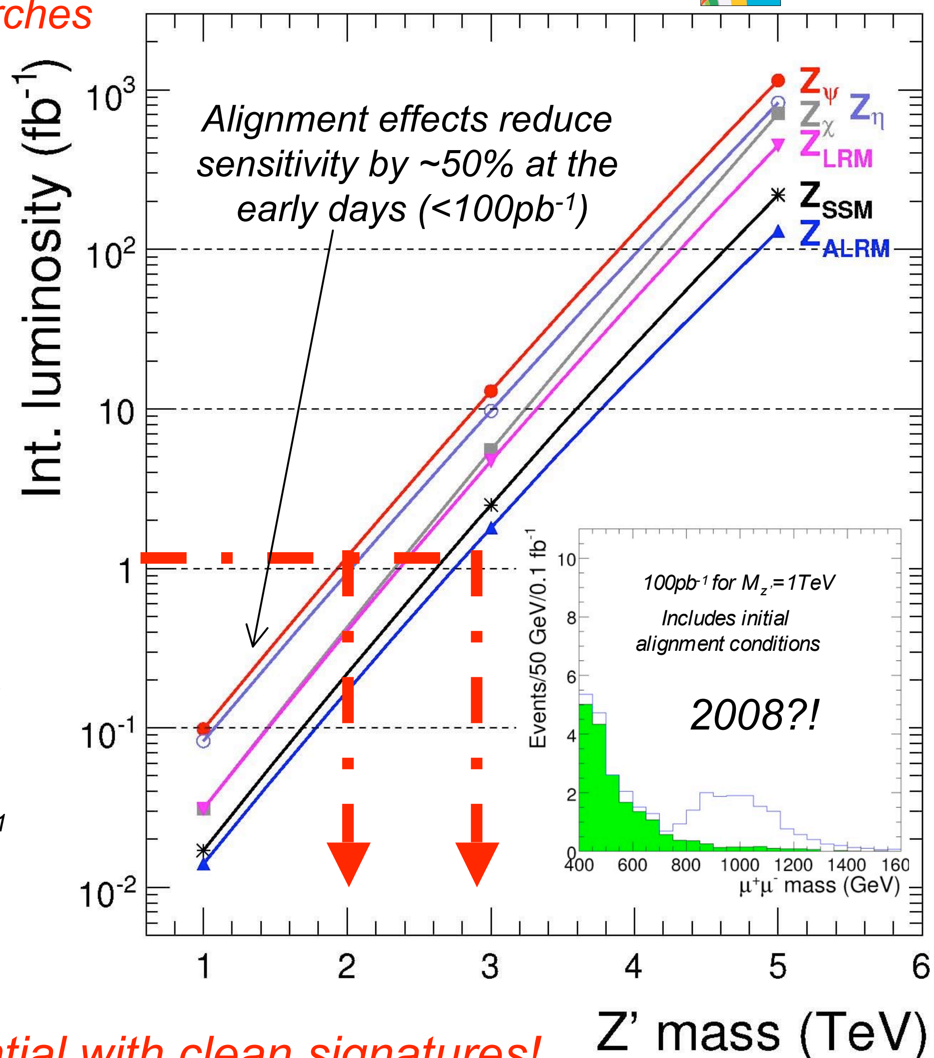
Because of their clear signature di-lepton resonances have always been subject of new physics searches





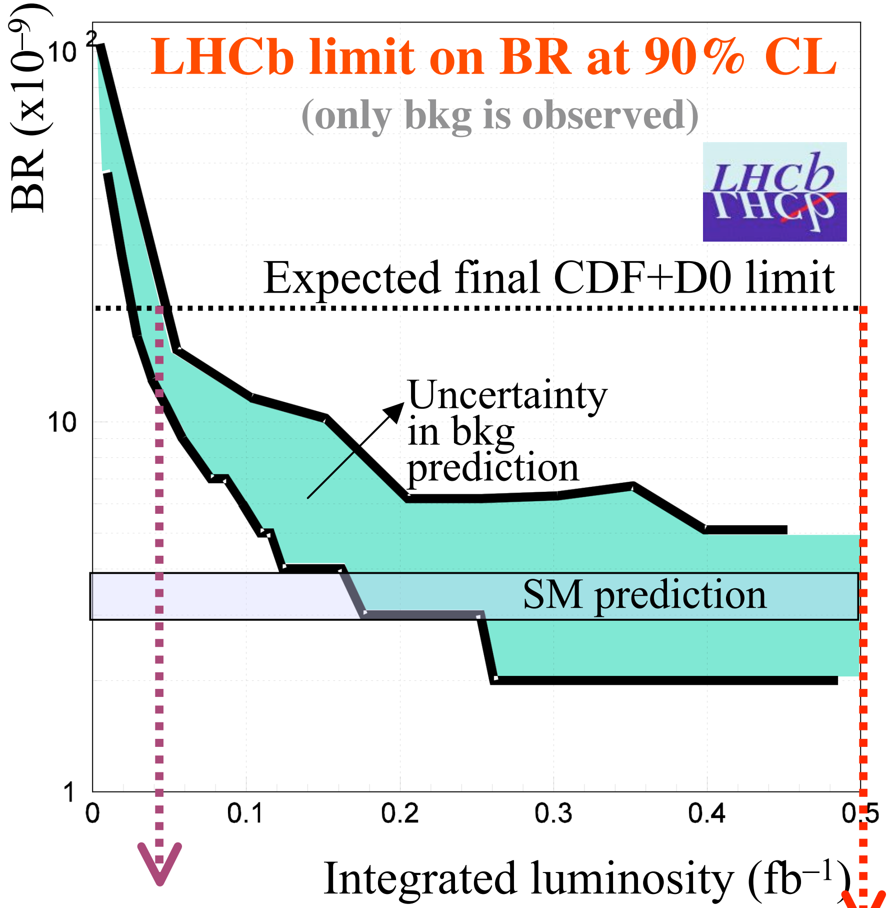
Main background:
Drell-Yan:
<1 event for
M>1.5 TeV in $1fb^{-1}$

Di-muon channel



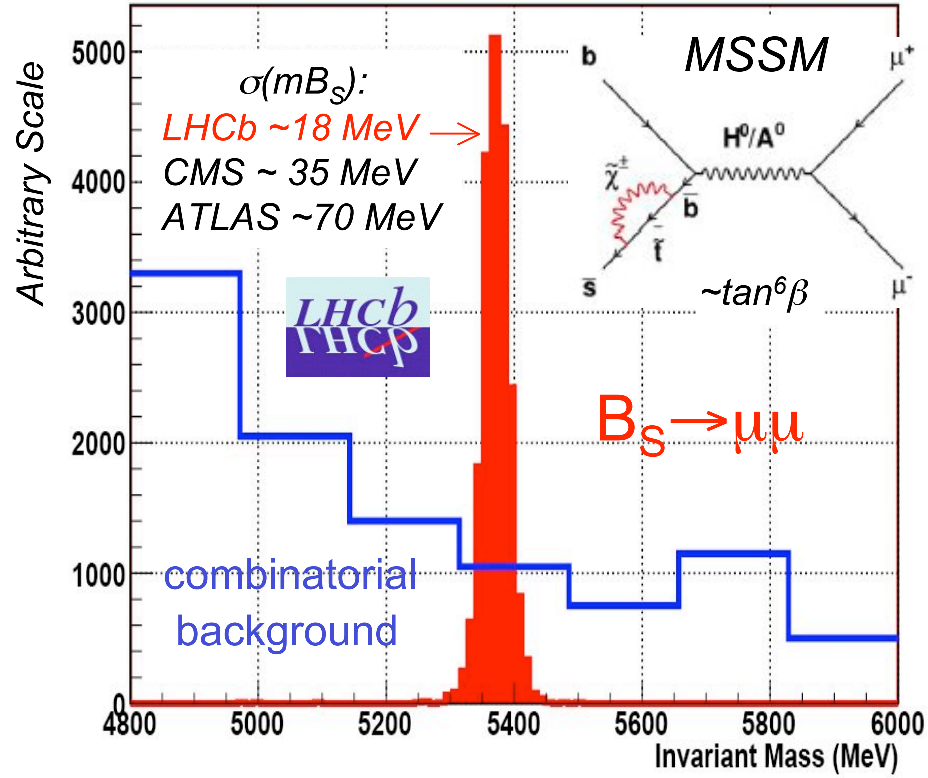
Very early discovery potential with clean signatures!

Indirect NP Search: $B_S \rightarrow \mu\mu$



0.05fb^{-1} to overtake CDF&D0

0.5fb^{-1} for 90% exclusion at SM value



Integral LHC Luminosity	Signal ev. after cuts	BG ev. after cuts	ATLAS upper limit at 90% CL	CDF&D0 upper limit at 90% CL
100 pb^{-1}	~0	~0.2	6.4×10^{-8}	8×10^{-8}
10 fb^{-1}	~7	~20	7.0×10^{-9}	
30 fb^{-1}	~21	~60	6.6×10^{-9}	

today

CMS comparable sensitivity

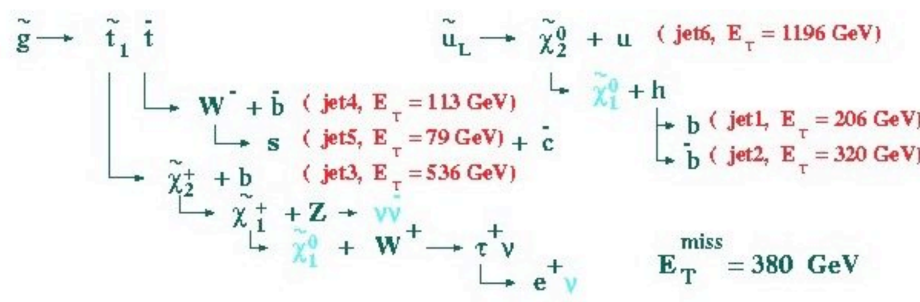
Early discovery possible!

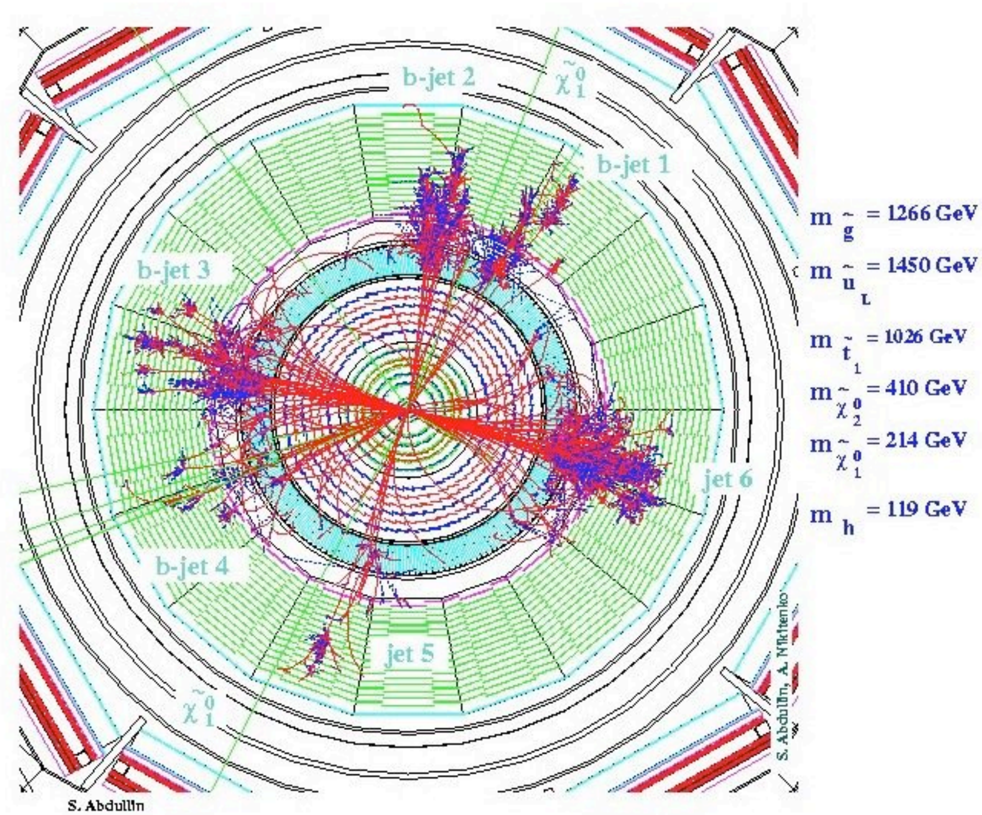
SUSY signatures at the LHC

- Many hard Jets
- Large missing energy
  - 2 LSPs
  - Many neutrinos
- Many leptons
- In a word:
  - Spectacular!

M_{sp}(GeV)	σ (pb)	Evts/yr
500	100	10^6-10^7
1000	1	10^4-10^5
2000	0.01	10^2-10^3

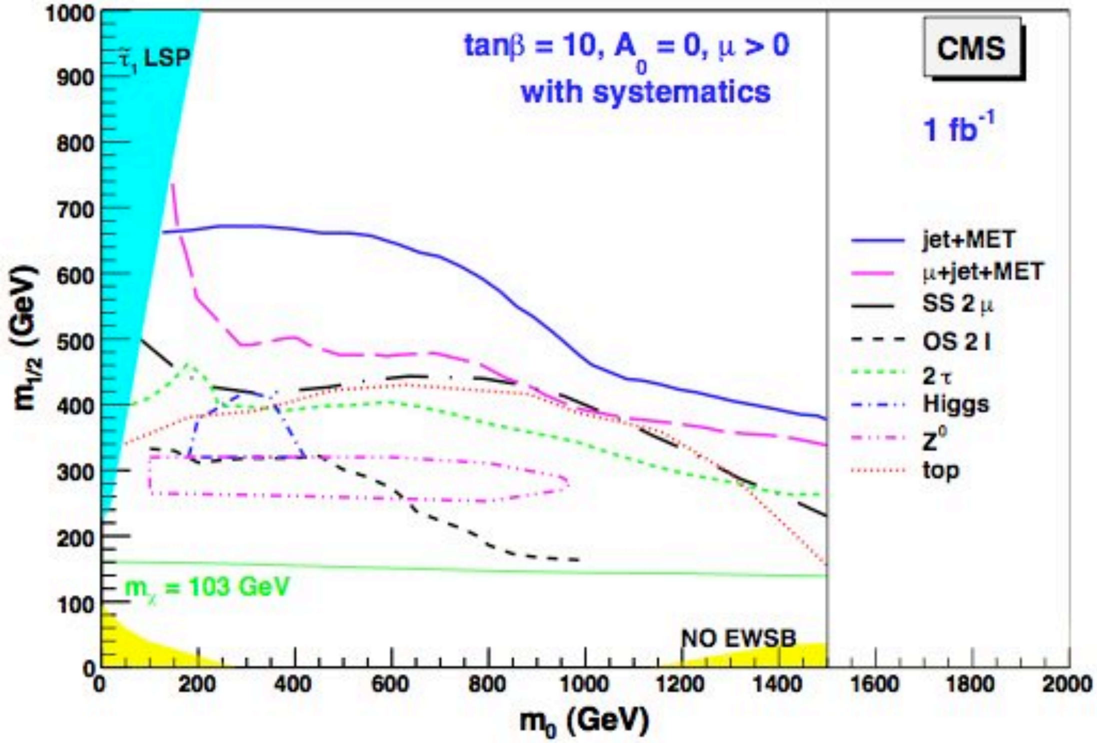
For low masses the LHC becomes a real ***SUSY factory***





SUSY Discovery Potential

CMS Reach for 1fb^{-1} (ATLAS similar)



SUSY Discovery Potential

Important signatures for the star Inclusive Search:

- *Jet+Missing E_t &*
  - *0 Lepton (e,μ)*
  - *1 Lepton*
  - *2 Leptons (same sign)*
  - *2 Leptons (opposite sign)*

Important SM Background:

- *ttbar*
- *W/Z + Jets*
- *QCD (multi-jets)*

[difficult to simulate]

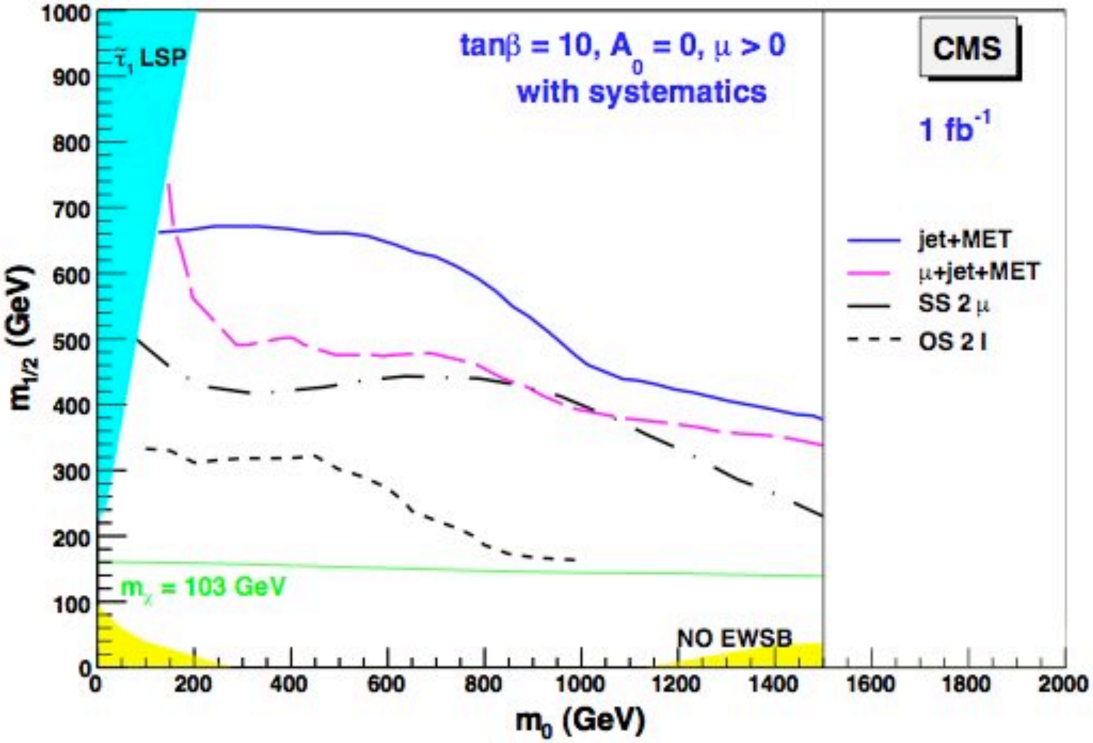
Background estimation:

- *use control samples and side-band region to "measure" the background and/or tune your Monte Carlo.*

→mainly "data-driven"

(complemented with Monte Carlo)

CMS Reach for 1fb^{-1} (ATLAS similar)



Other important signatures like di-taus, h→bb, Z and top production have also been studied but not covered in this talk!

“Preferred” SUSY Parameter Space

* BUCHMULLER, CAVANAUGH, DE ROECK,HEINEMEYER, ISIDORI, PARADISI, RONGA, WEBER, WEIGLEIN.

“Preferred” mSUGRA parameter space

Used indirect constraints from flavour, electroweak and cosmology physics to determine the mSUGRA parameter space compatible with these data.

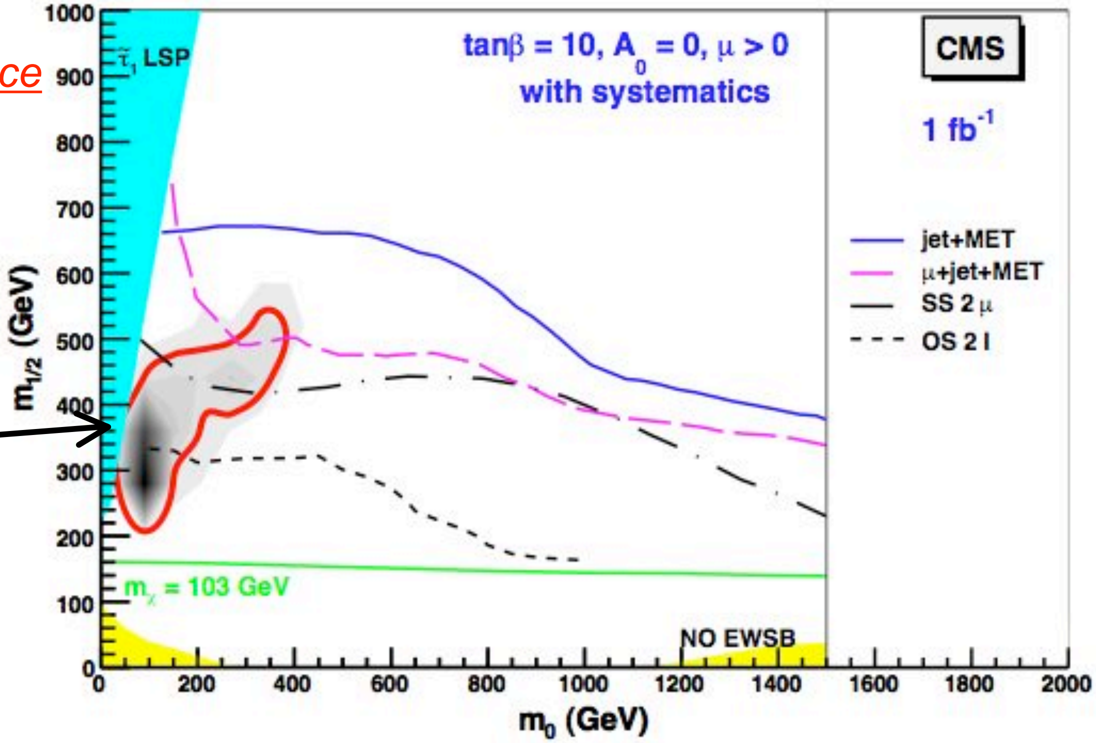
hep-ph/0707.3447*

95% contour obtained form a multi-parameter χ^2 fit to important indirect constraints.

χ^2/NDF = 17/14 - good fit

NOTE: All mSUGRA parameters are free in the fit!

CMS Reach for 1fb^{-1} (ATLAS similar)



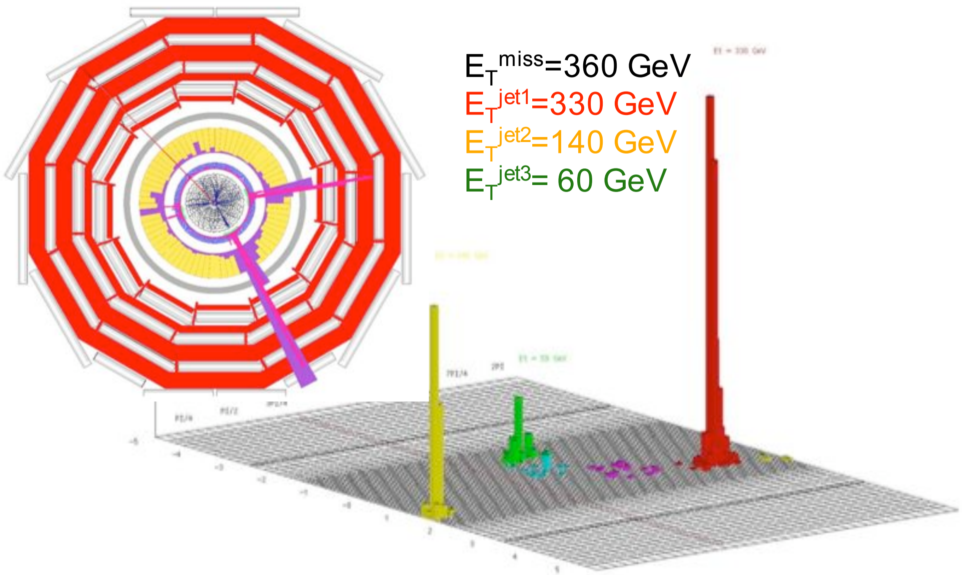
If these “LHC weather forecasts” are correct, SUSY will emerge very early!

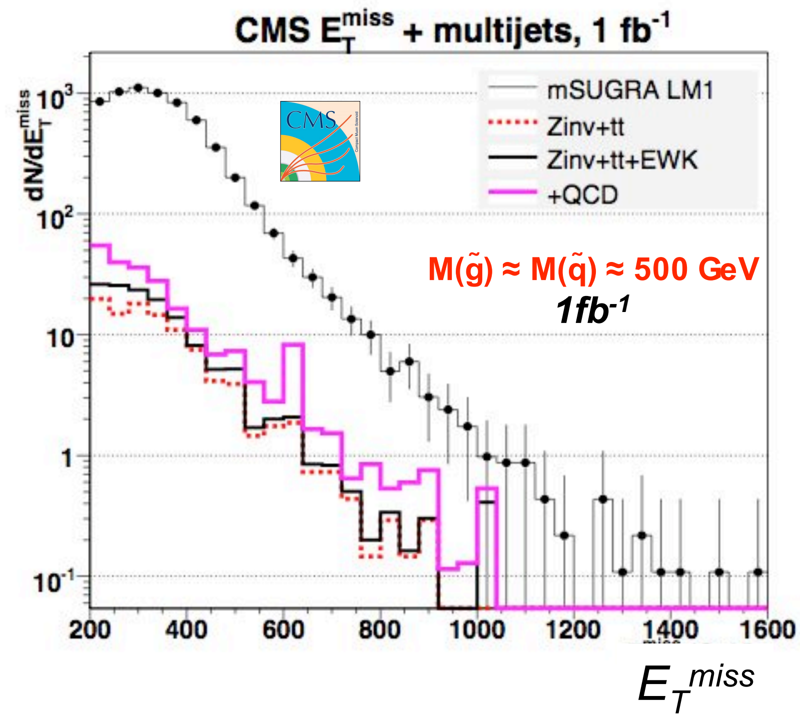
For sure these tools will be very useful to solve the “inverse problem”:
→Interpretation of discoveries

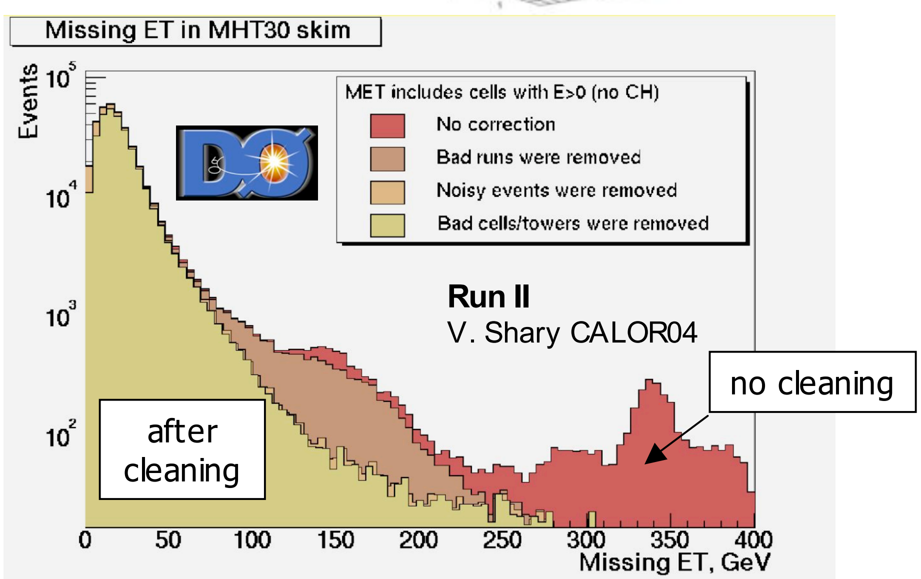
Example of similar analyses:

- Ellis, Heinemeyer, Olive, Weber, Weiglein - hep-ph/0706.0652
- Allanach, Lester, Weber - hep-ph/0705.0487
- Trotta, Austri, Roszkowski - hep-ph/0609126
- … there are more!

Jets + E_T^{miss} - Inclusive Search







Big discovery potential

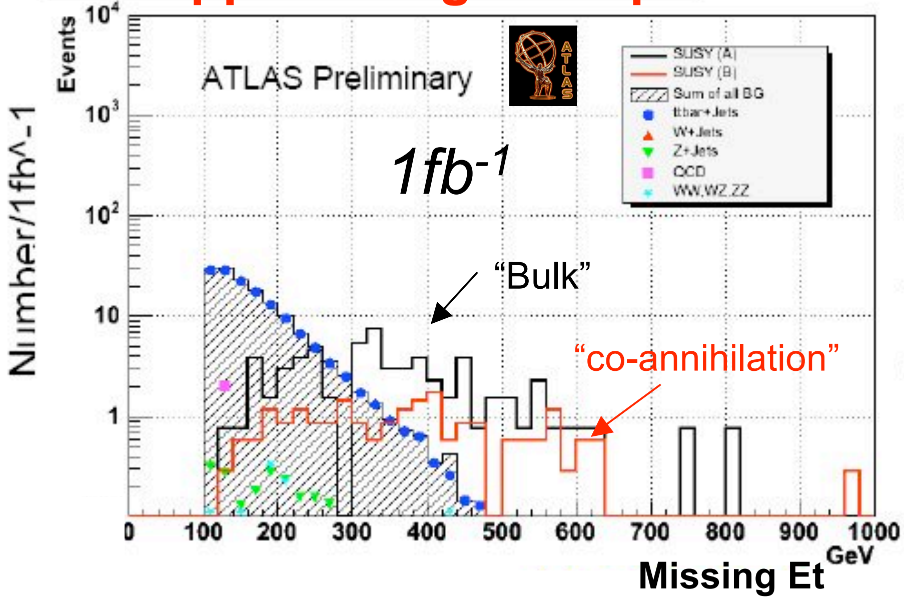
But requires a very good detector understanding:

Analysis Strategy:

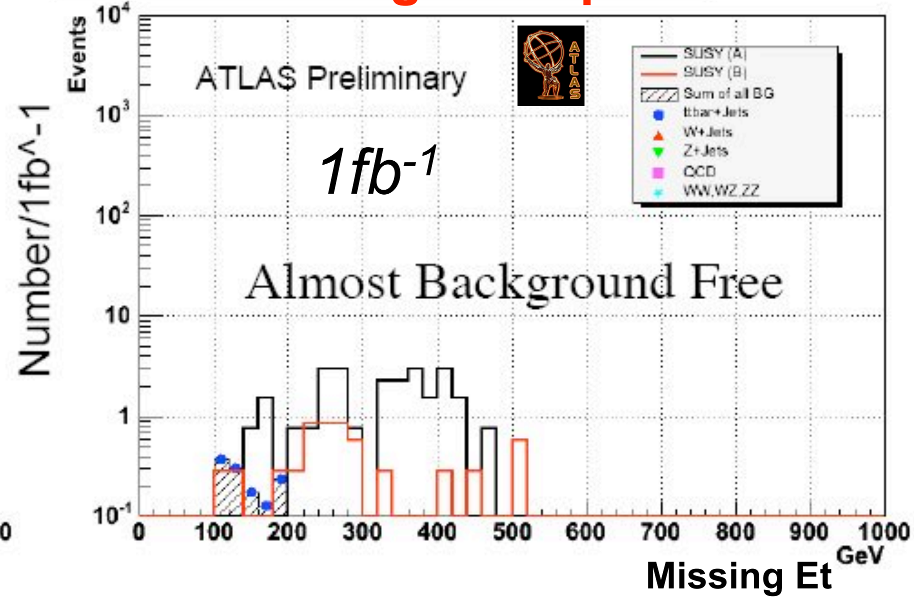
- Be brave
- Fight background and noise
- Use data control samples

Jets+E_t^{miss}+(1,2) l - Inclusive Search

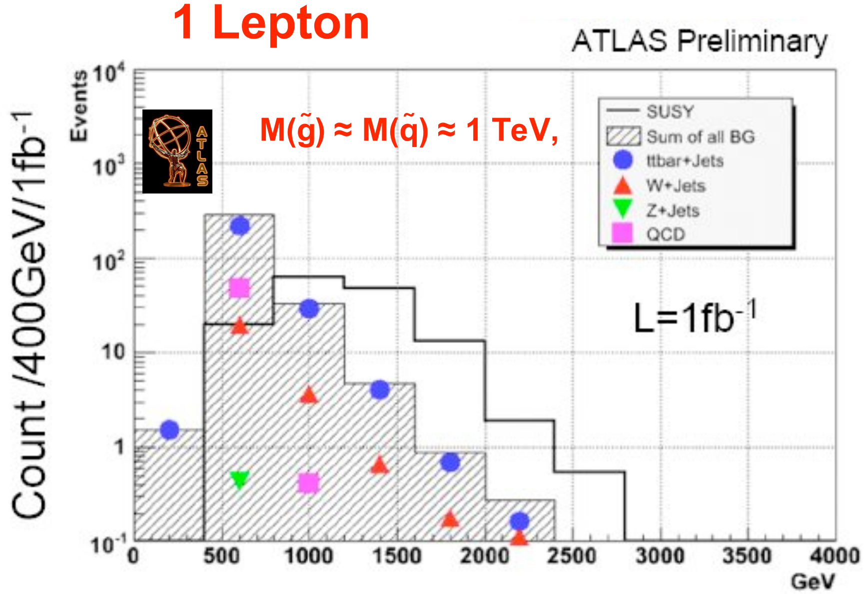
Opposite sign di-leptons



Same sign di-leptons



1 Lepton



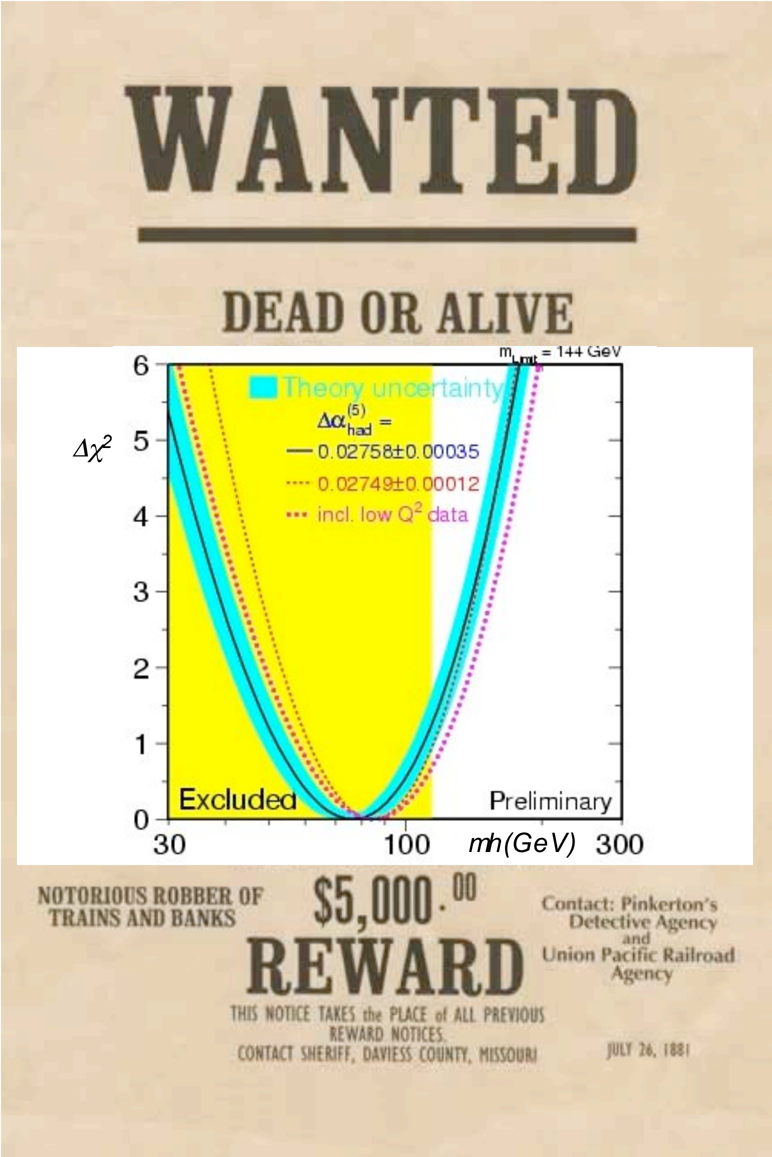
Good discovery potential

Lower statistic but cleaner than "0 lepton".

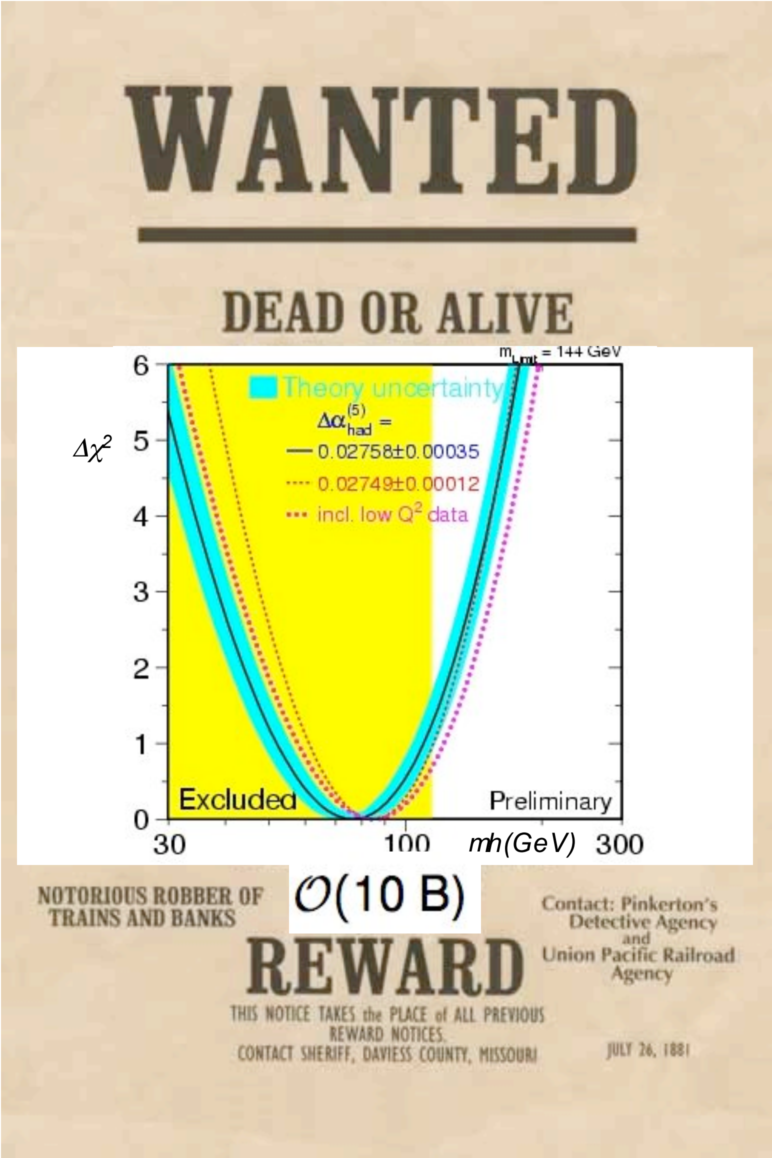
Analysis Strategy:

- Still worry about ttbar, W/Z jets and QCD
- Use data control samples
- get lepton reconstruction/selection under control

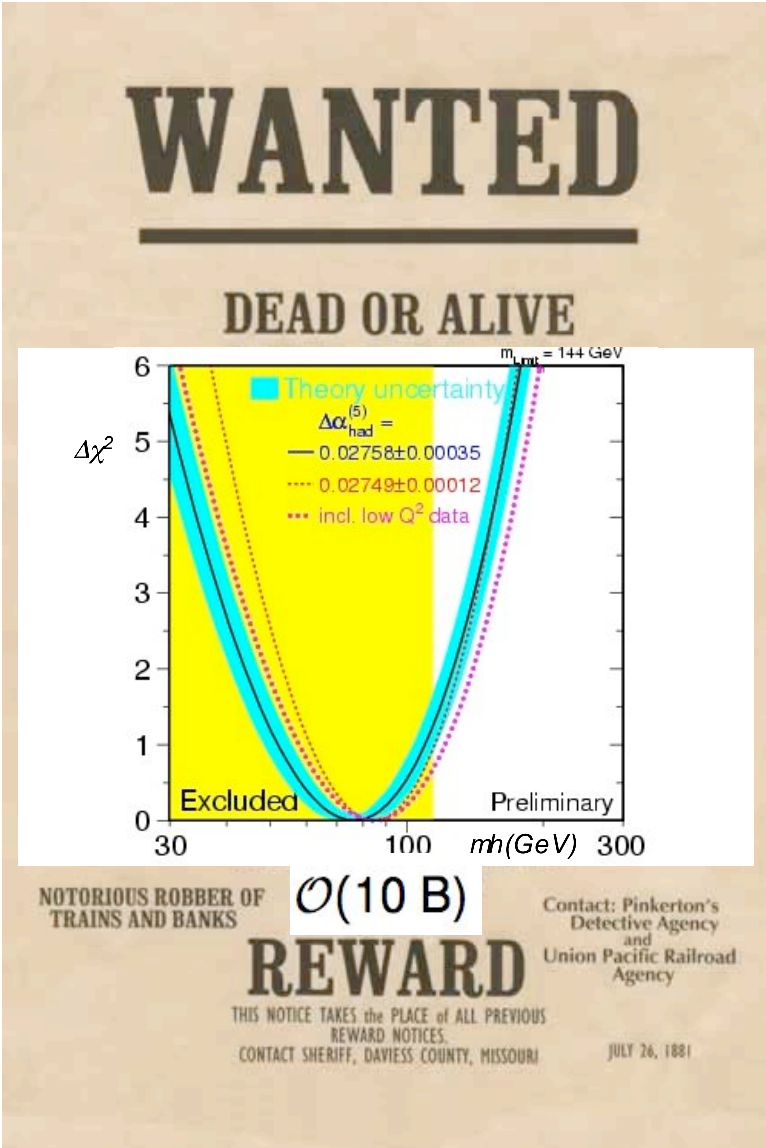
SM-like Higgs Boson



SM-like Higgs Boson



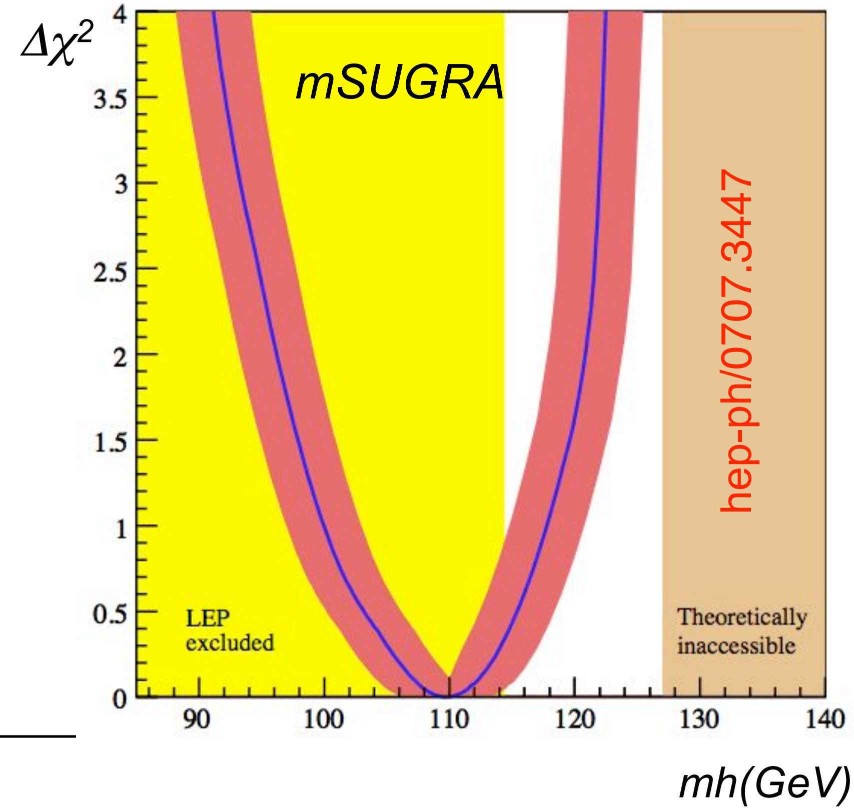
SM-like Higgs Boson



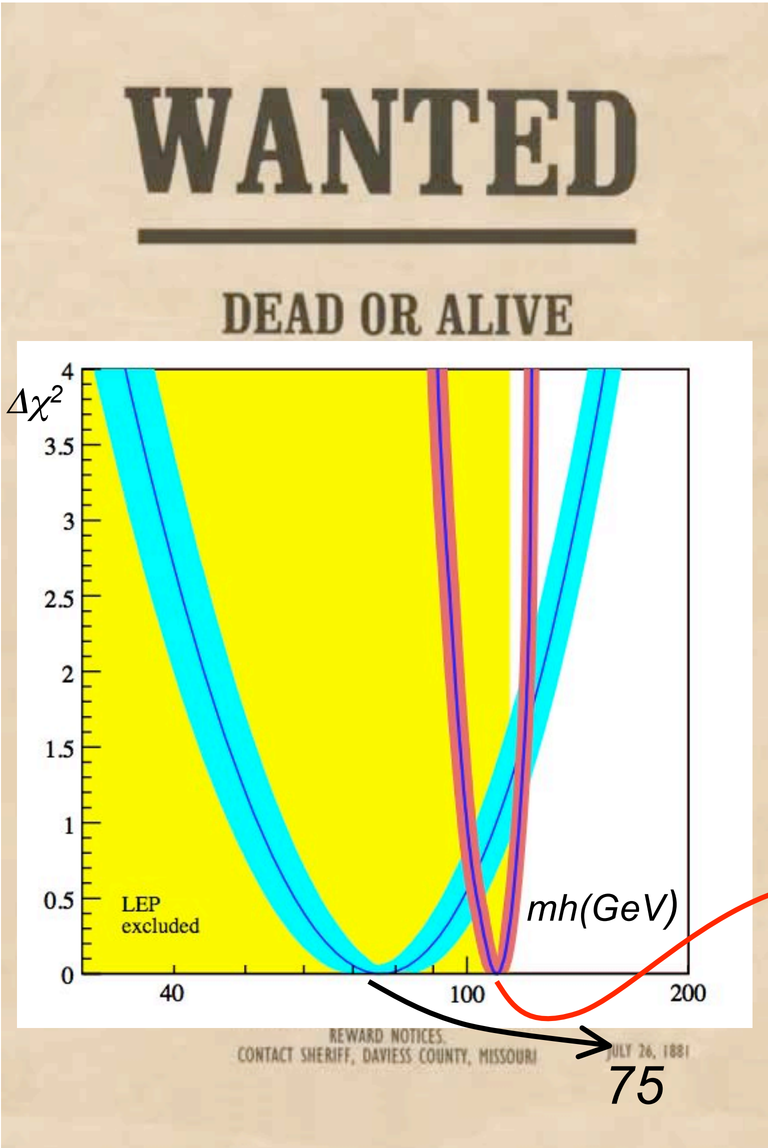
Precision electroweak data tightly constrain the allowed region of m_h in the SM.
Yet, also other important models like mSUGRA are constrained by these data:

mSUGRA fit to flavour, electroweak and cosmology data:

mh(mSUGRA)=110$^{+8}_{-10}$ (exp)±3(theo) GeV



SM-like Higgs Boson

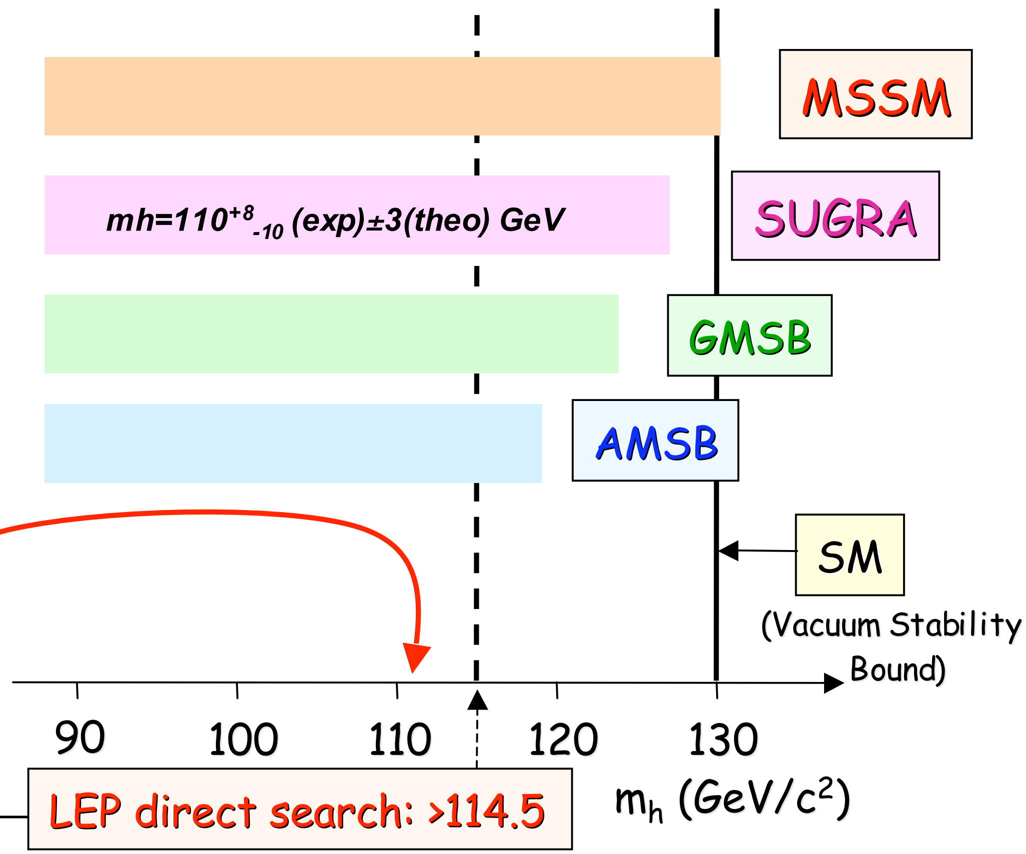


SM: Constrained Phase Space

$m_h(SM)=76^{+33}_{-24}$ GeV

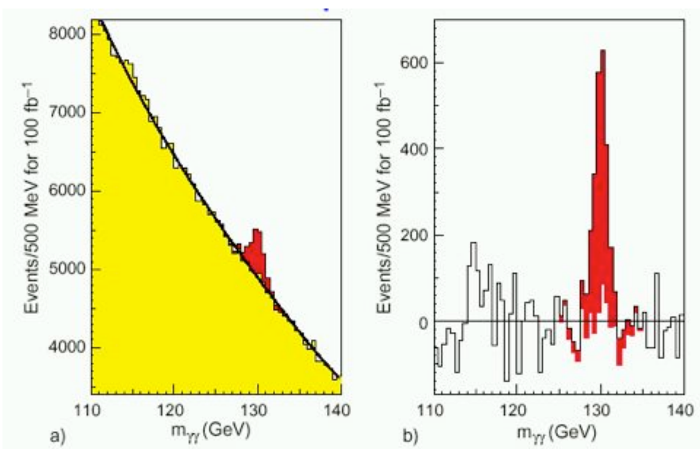
$m_h(SM)<144$ GeV @ 95% CL

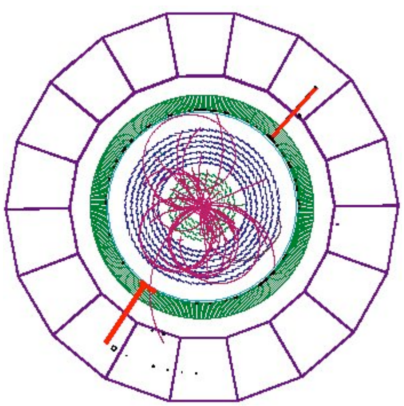
SUSY: Accessible Phase Space

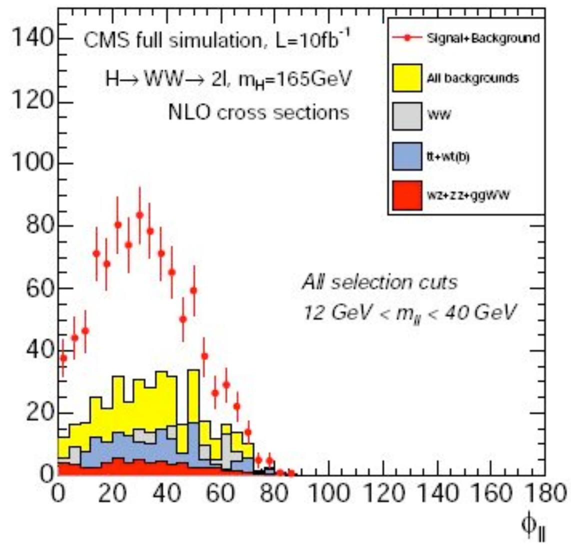


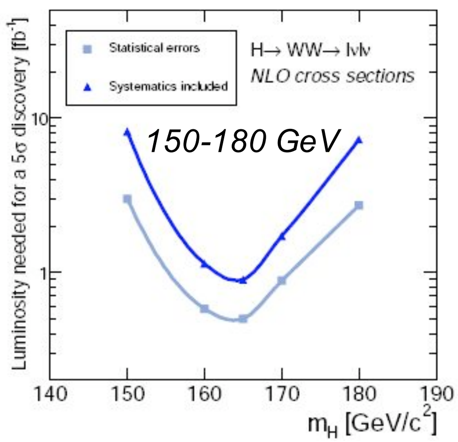
Higgs Mass below 200 GeV

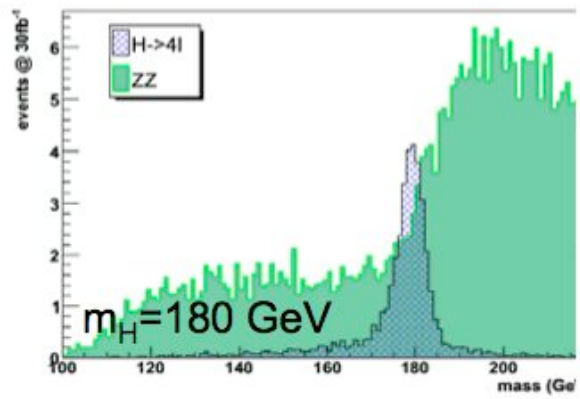
Low $M_H < 140$ GeV	$2M_W < M_h < 2M_Z$	$130 < M_H < \sim 600$ GeV
$H \to \gamma\gamma$	$H \to WW^{(*)} \to 2l$	$H \to ZZ^{(*)} \to 4l$

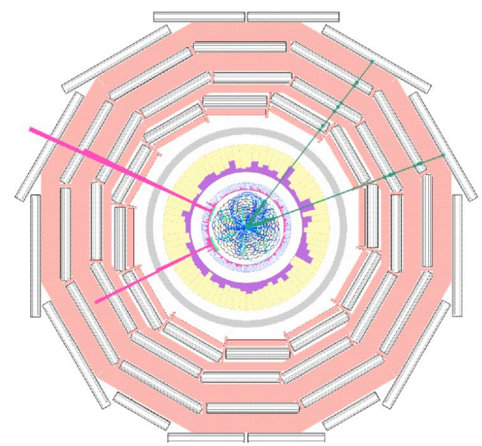






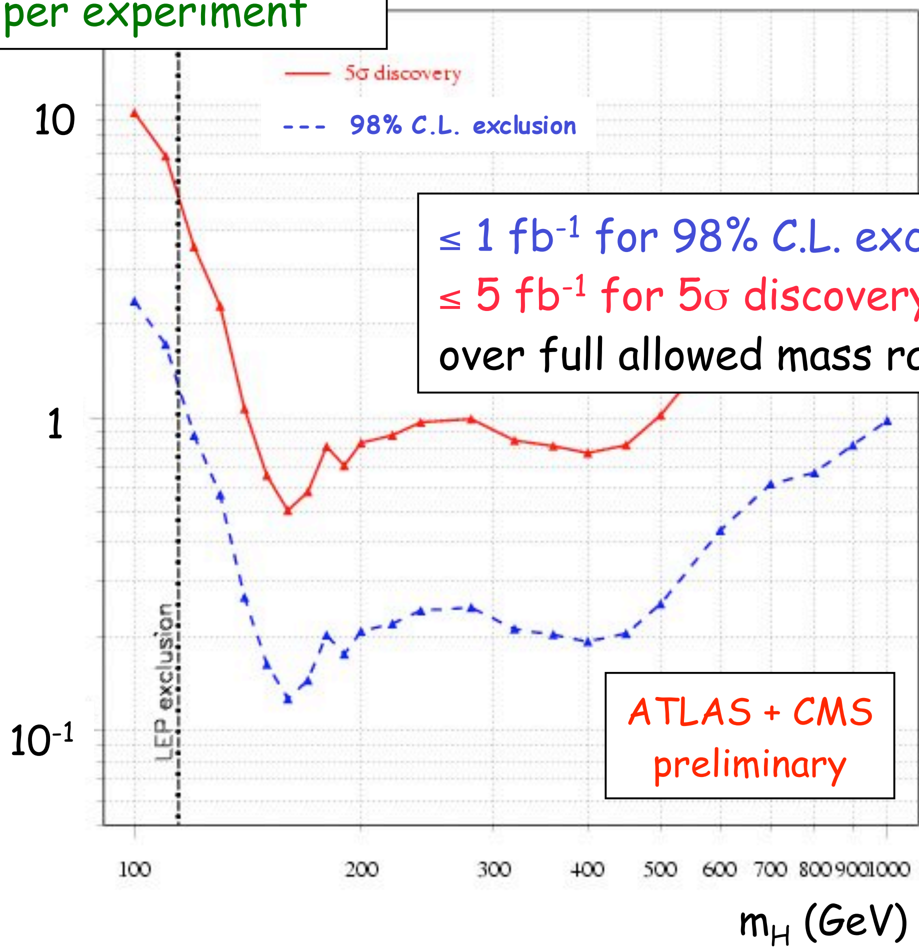






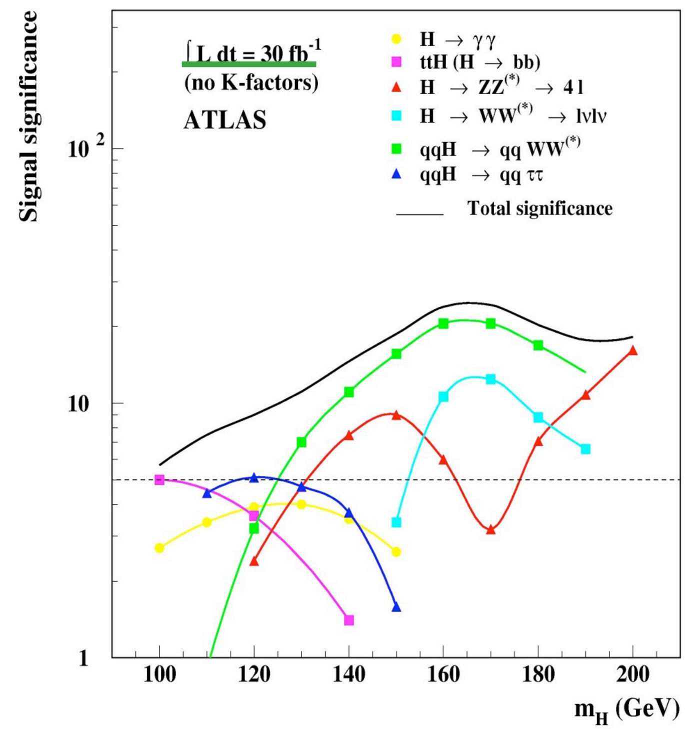
SM Higgs Reach

Needed ∫Ldt (fb^{-1}) per experiment



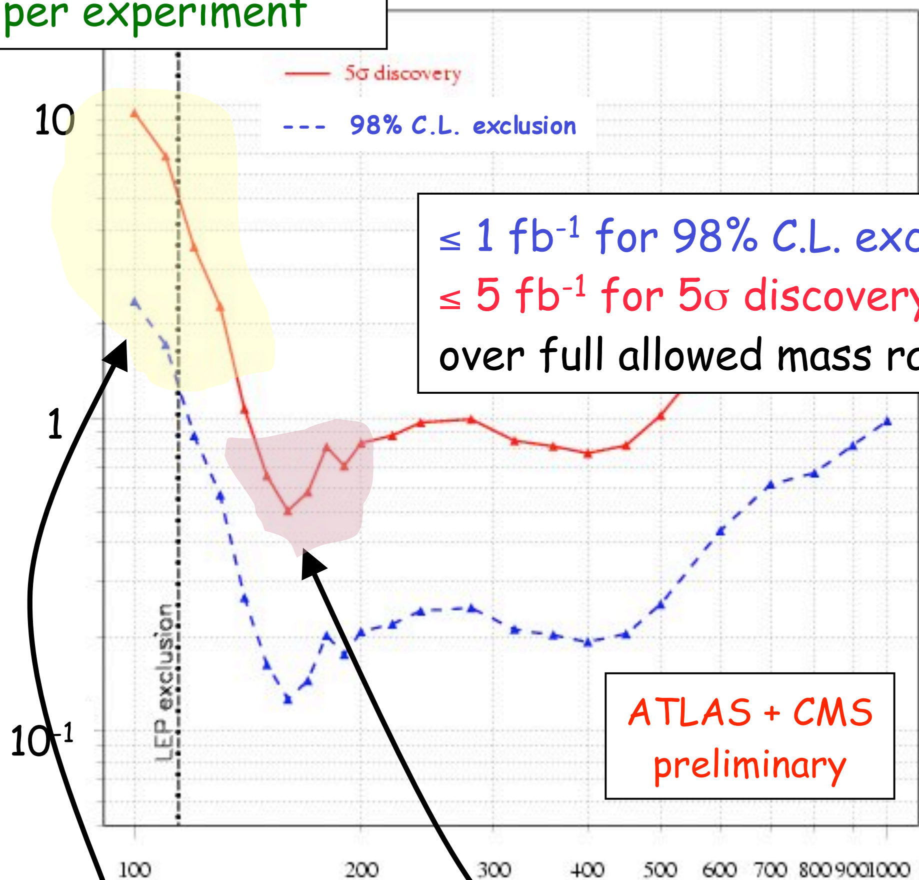
≤ 1 fb^{-1} for 98% C.L. exclusion
≤ 5 fb^{-1} for 5σ discovery
over full allowed mass range

ATLAS + CMS preliminary



SM Higgs Reach

Needed ∫Ldt (fb^{-1}) per experiment



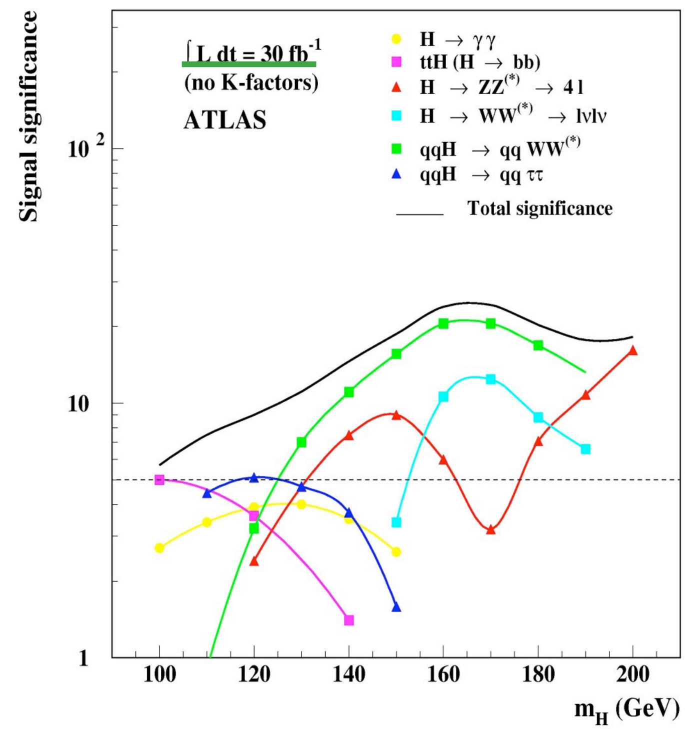
≤ 1 fb^{-1} for 98% C.L. exclusion
≤ 5 fb^{-1} for 5σ discovery
over full allowed mass range

ATLAS + CMS preliminary

m_H (GeV)

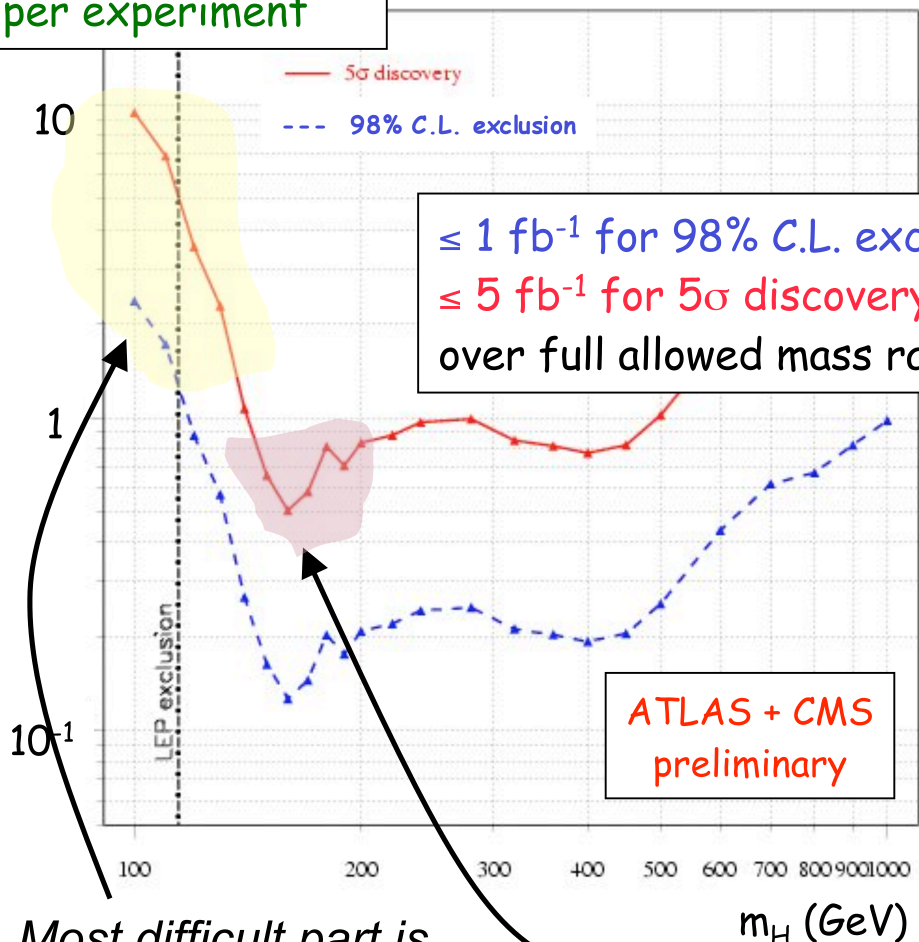
Most difficult part is M_h~115 GeV

Early discovery already Possible with $1fb^{-1}$ $H \rightarrow WW^{(*)} \rightarrow 2l$



SM Higgs Reach

Needed ∫Ldt (fb^{-1})
per experiment

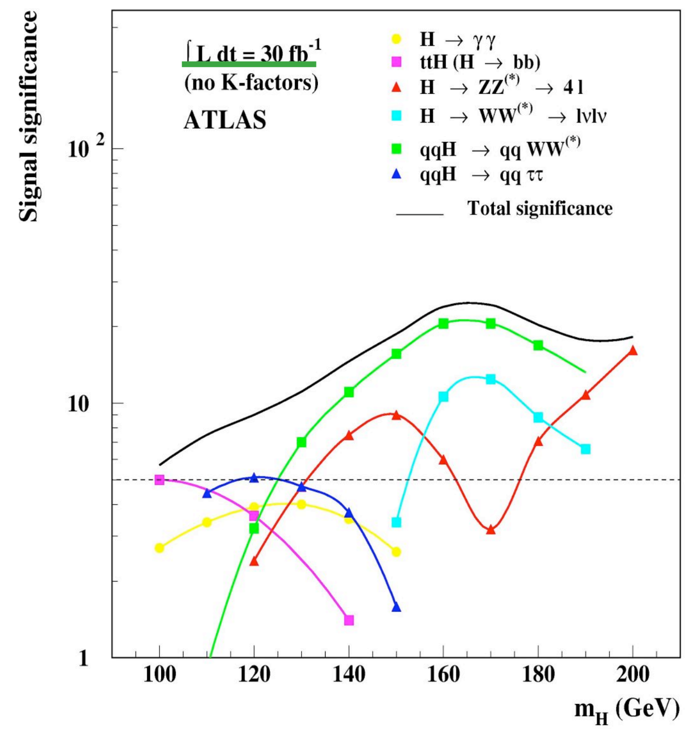


≤ 1 fb^{-1} for 98% C.L. exclusion
≤ 5 fb^{-1} for 5σ discovery
over full allowed mass range

ATLAS + CMS
preliminary

Most difficult part is M_h~115 GeV

Early discovery already Possible with 1fb^{-1} $H \rightarrow WW^{(*)} \rightarrow 2l$



With 1fb^{-1} of understood data:

- *potential to exclude almost all m_h values*
- *potential to discover higgs with m_h~165 GeV*

LHC will give us an answer!

Summary

- LHC&Experiments are on track for first collisions in 2008
  - Challenge: commissioning of machine and detectors of unprecedented complexity, technology and performance
- The LHC will discover (or exclude) the Higgs by ~2010
  - Electro Weak Symmetry Breaking
  - Large phase space can already be excluded with only ~1fb^{-1}
- The LHC will discover low energy SUSY (if it exists)
  - Could be easy; could also take more time and ingenuity before we can claim a discovery
  - First signals might emerge already in the first data
  - 1-2 TeV can be covered already with ~10fb^{-1}
- The LHC will cover a new physics scale of 1-3 TeV
  - Many new physics models; Black hole, Extra Dimensions,Little Higgs, Split Susy, New Bosons, Technicolour, etc …

In other words; the next five years will be an exciting time for particle physics . . .

Many Thanks to:

R. Cousins, A. De Roeck, F. Gianotti, J. Incandela, K.Jakobs, P. Jenni, J-P. Revol, G. Rolandi, F. Ronga, T.Ruf, K. Safarik, O. Schneider, P. Sphicas,

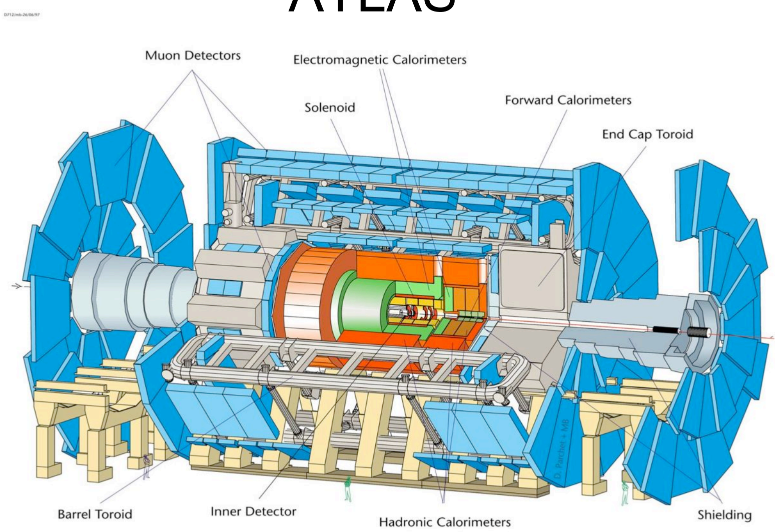
and many others …

Backup

Backup: Commissioning & Experiments

General Purpose Detectors

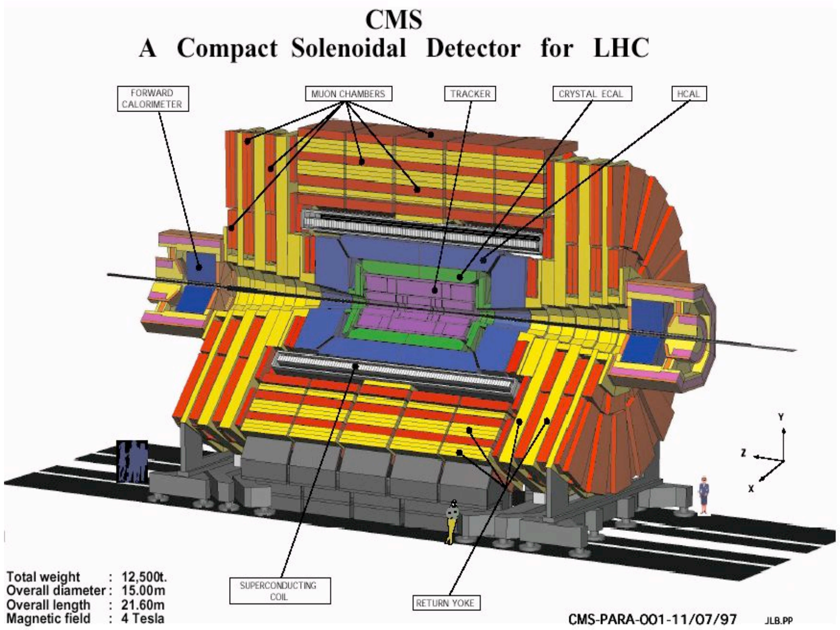
ATLAS

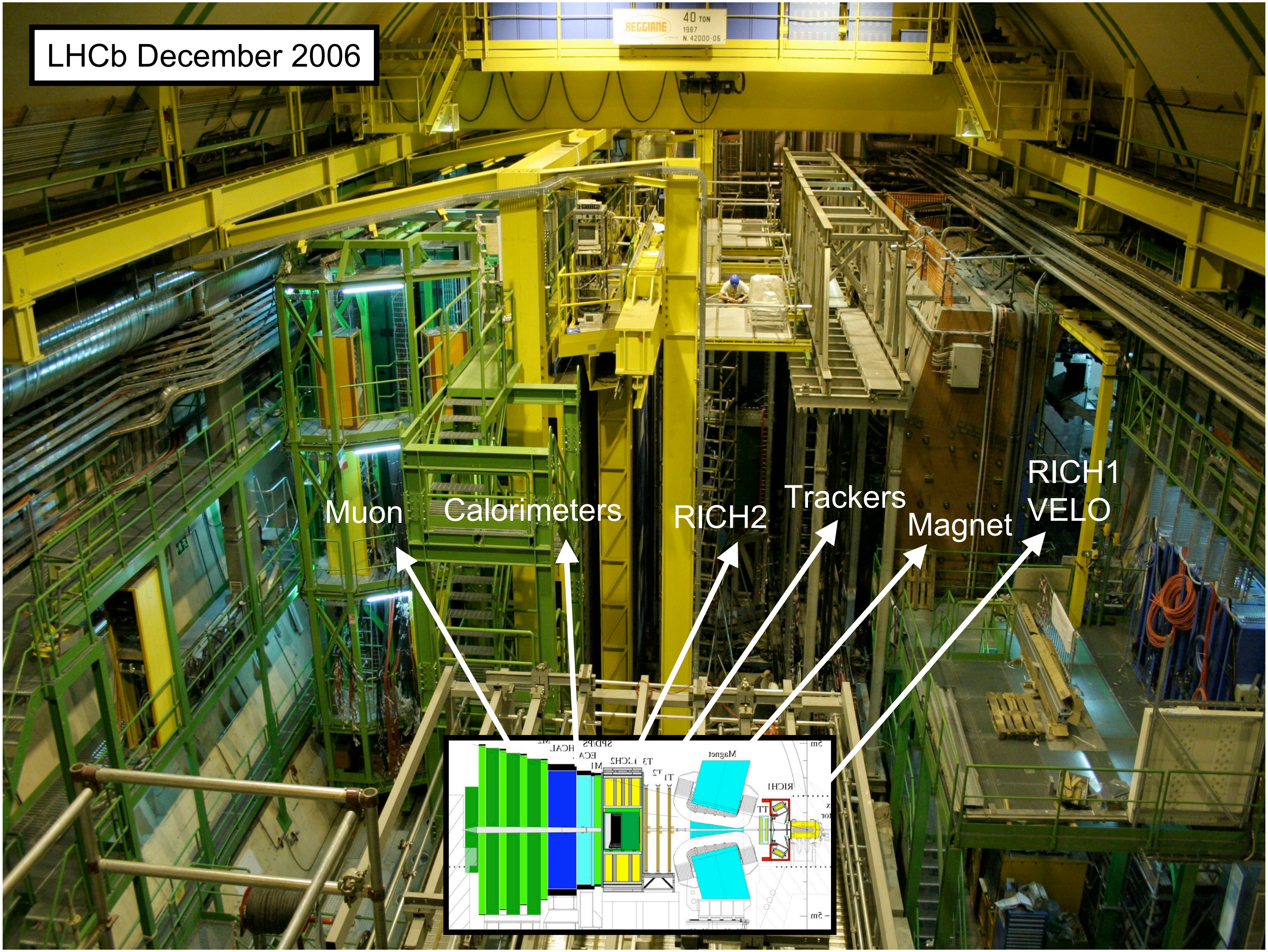


- Tracking (|η|<2.5, B=2T) :
  - Si pixels and strips
  - Transition Radiation Detector (e/π separation)
- Calorimetry (|η|<5) :
  - EM : Pb-LAr with Accordion shape
  - HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- Muon Spectrometer (|η|<2.7) :
  - air-core toroids with muon chambers

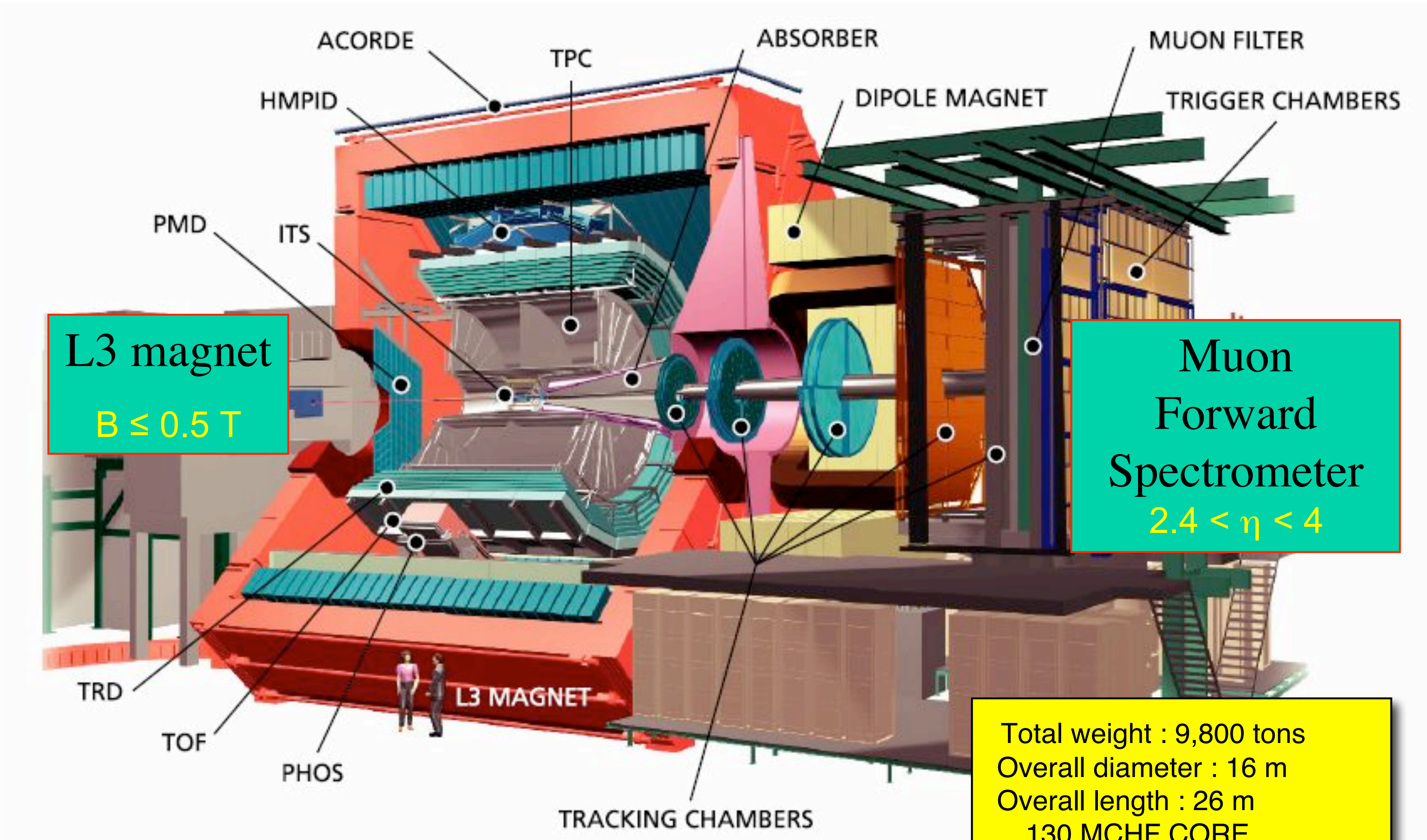
CMS

- Tracking (|η|<2.5, B=4T) :
  - Si pixels and strips
- Calorimetry (|η|<5) :
  - EM : $PbWO_4$ crystals
  - HAD: brass/scintillator (central+ end-cap), Fe/Quartz (fwd)
- Muon Spectrometer (|η|<2.5) :
  - return yoke of solenoid instrumented with muon chambers




LHCb December 2006
Muon
Calorimeters
RICH2
Trackers
Magnet
RICH1
VELO

ALICE



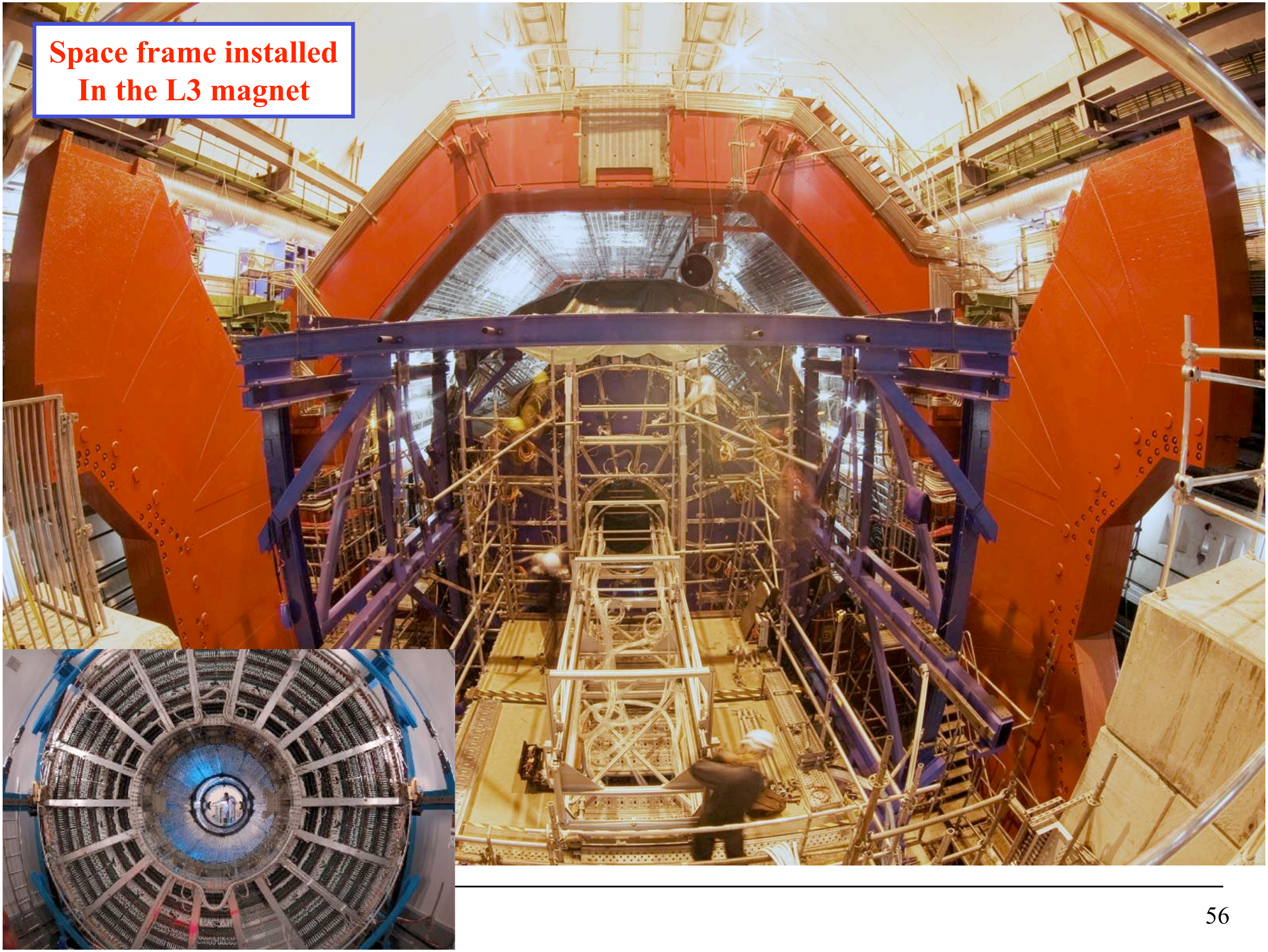
L3 magnet

B ≤ 0.5 T

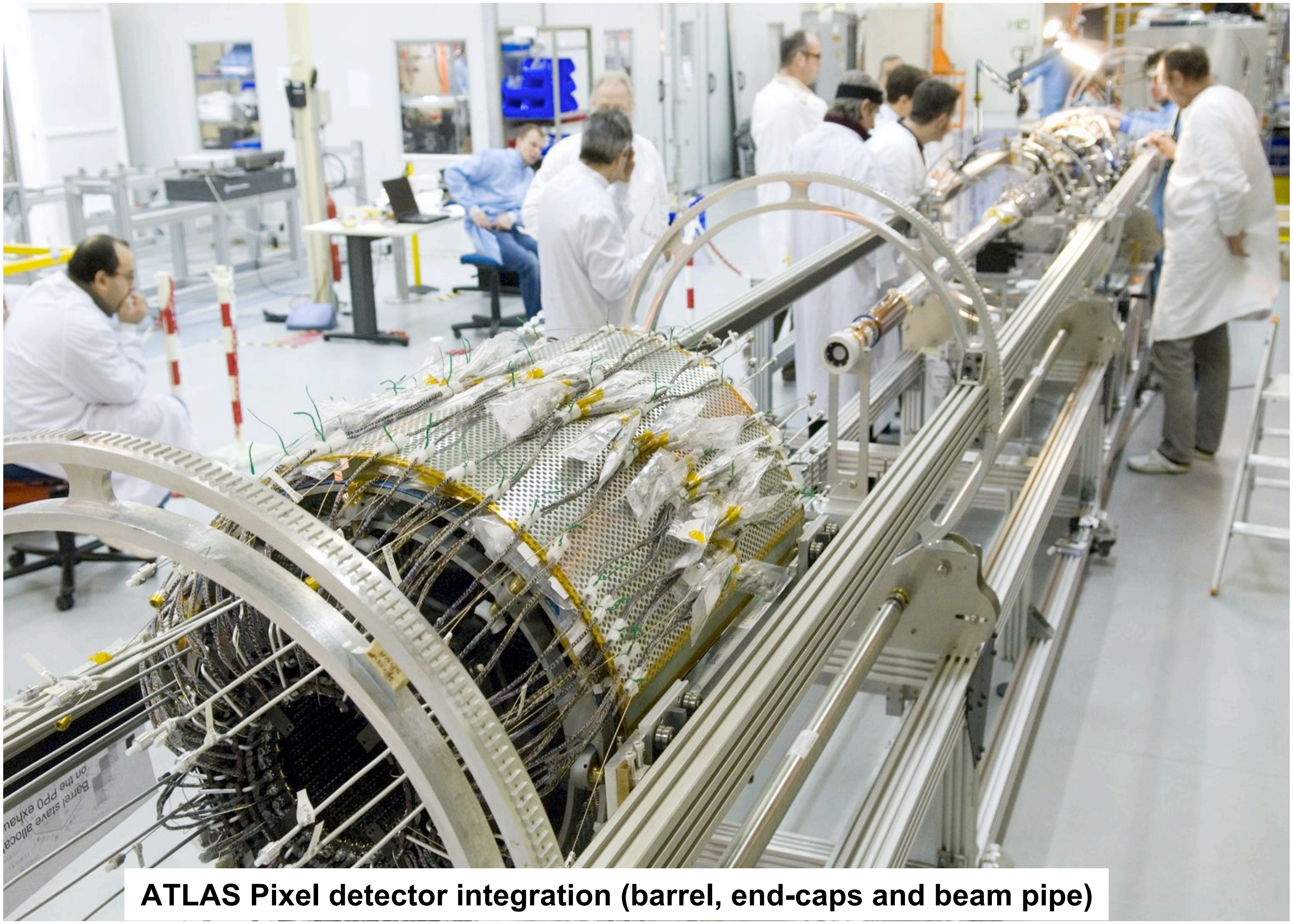
Muon Forward Spectrometer

$2.4 < \eta < 4$

Total weight : 9,800 tons
Overall diameter : 16 m
Overall length : 26 m
130 MCHF CORE

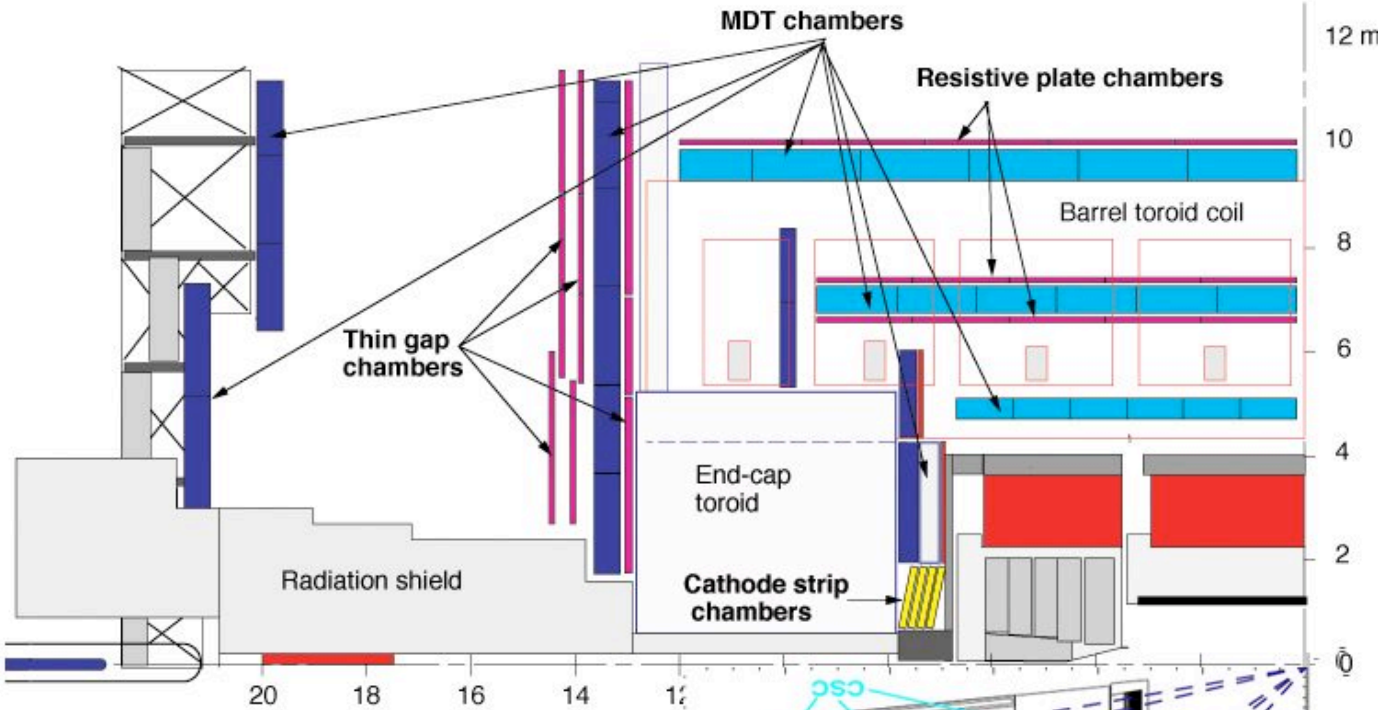

Space frame installed
In the L3 magnet

ATLAS Inner Detector

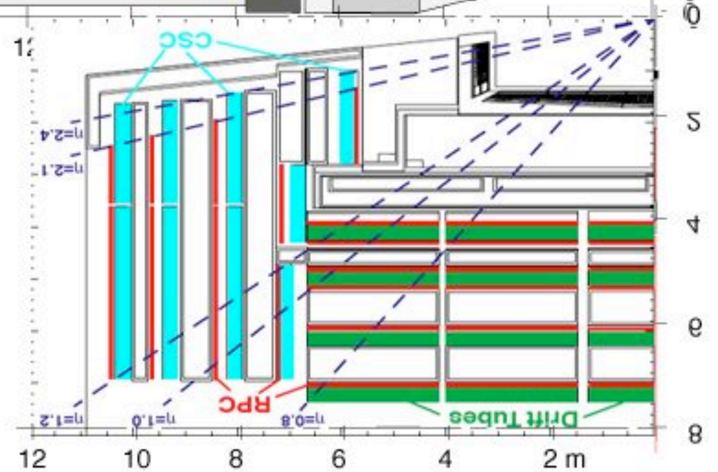


ATLAS Pixel detector integration (barrel, end-caps and beam pipe)

ATLAS & CMS



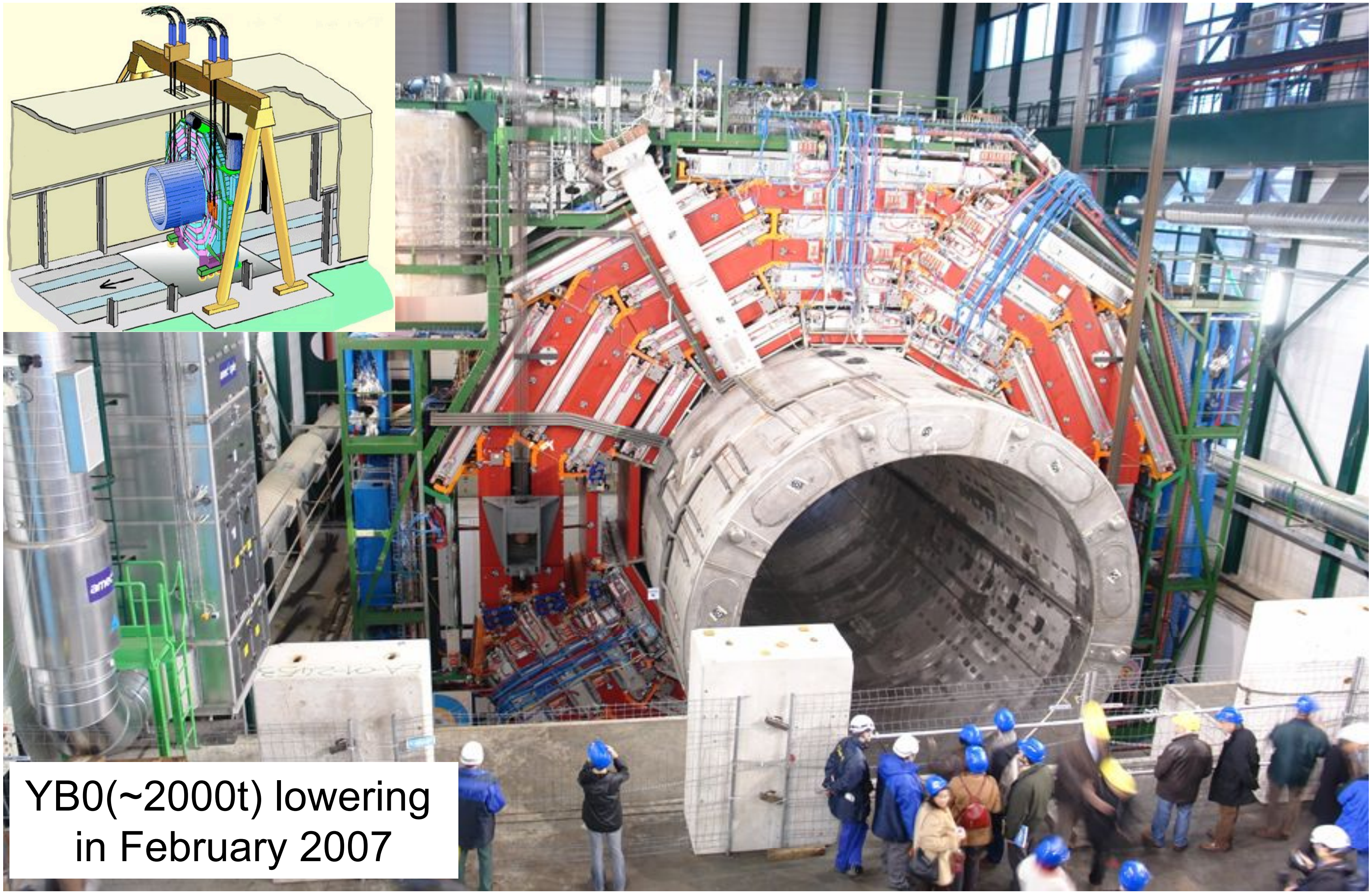
ATLAS:
Length: ~45m
Radius: ~12m
Weight: ~7000t



CMS:
Length: ~22m
Radius: ~7m
Weight: ~12500t

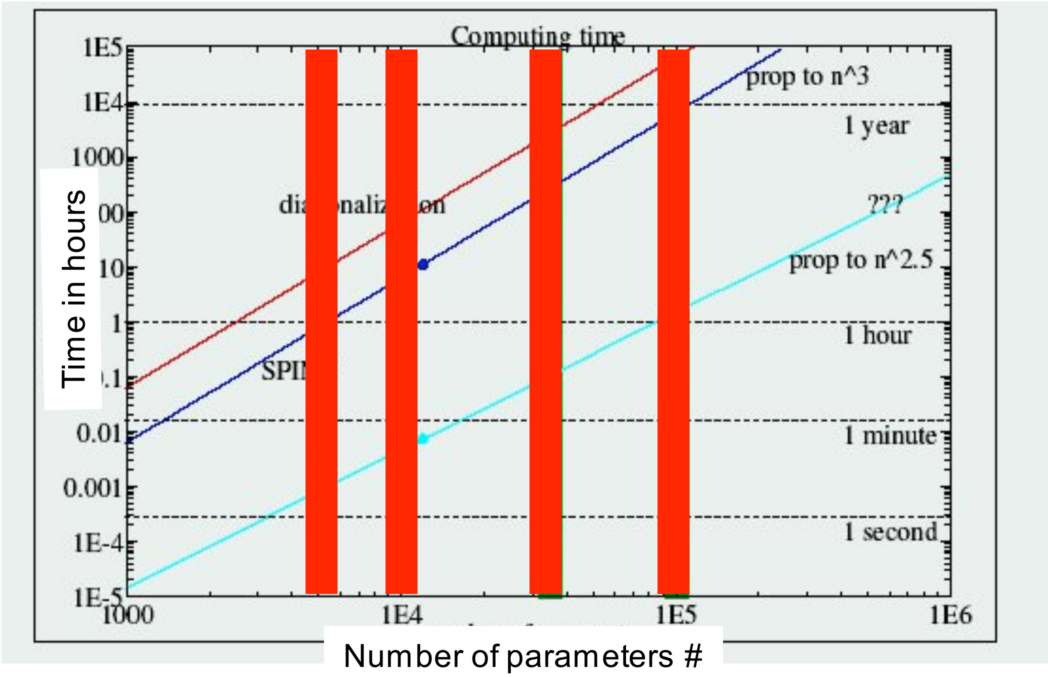
General Purpose Detectors:
Main Tasks:
Search for new physics
and the Higgs.

…CMS Installation

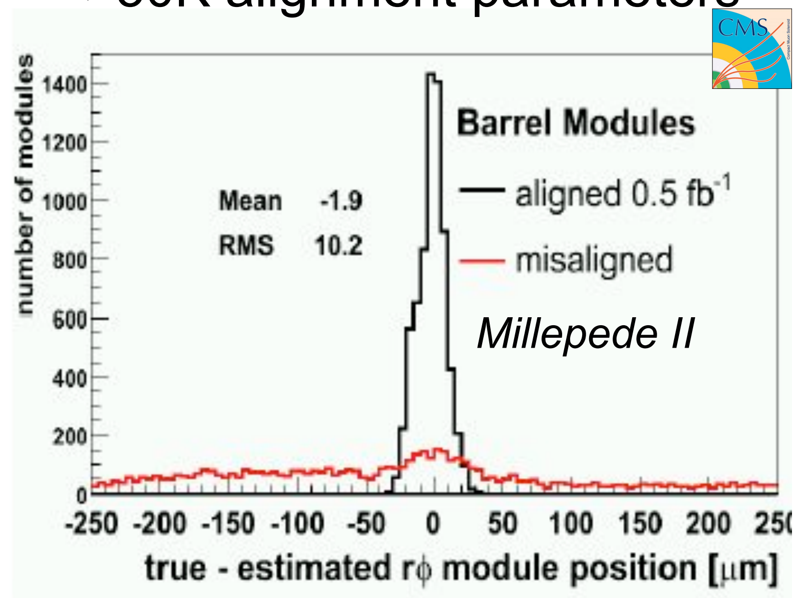


YB0(~2000t) lowering in February 2007

Commissioning Challenge: Alignment



>50K alignment parameters



Complexity Problem

	LHCb	ALICE	ATLAS	CMS
#	~6000	~10000	~35000	~100000
CPU*	~1h	~5h	~200h	~1year

New territory of complexity
- especially true for ATLAS and CMS

* CPU time required to invert a NxN Matrix on one CPU

New Alignment Algorithms

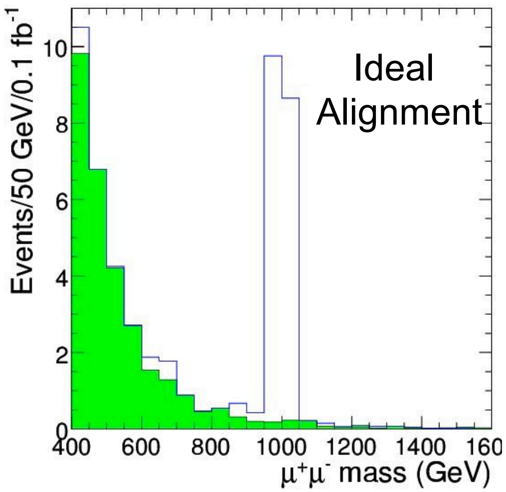
Develop new statistical methods able to deal with alignment complexity problems >50k parameters!

Example: Millepede II (V.Blobel)

- *applied to full CMS tracker*
- *1h 40min CPU time only for ~50K*
- *all correlations considered*

(Mis)Alignment & Physics

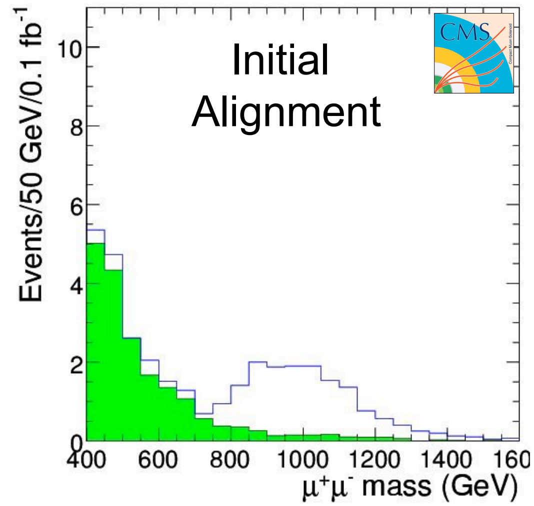
A speedy alignment of the tracking devices is crucial; *just two examples*



High mass di-lepton pairs

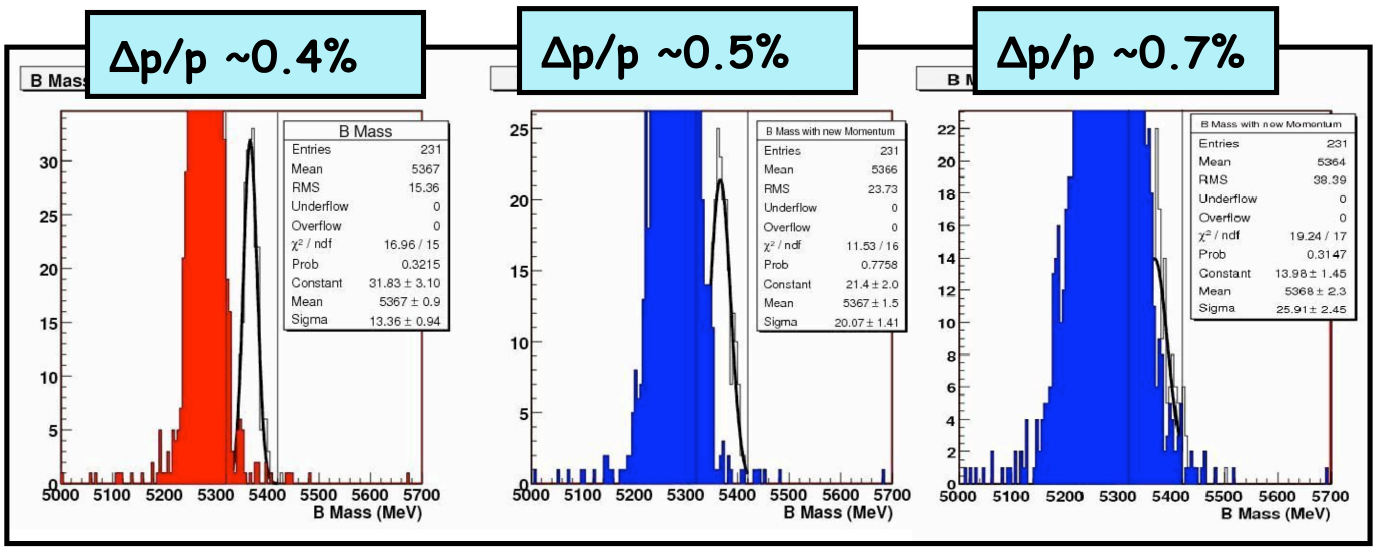
Example:
$Z' \to \mu\mu$; $M_{Z'}$=1TeV

Significant Impact!

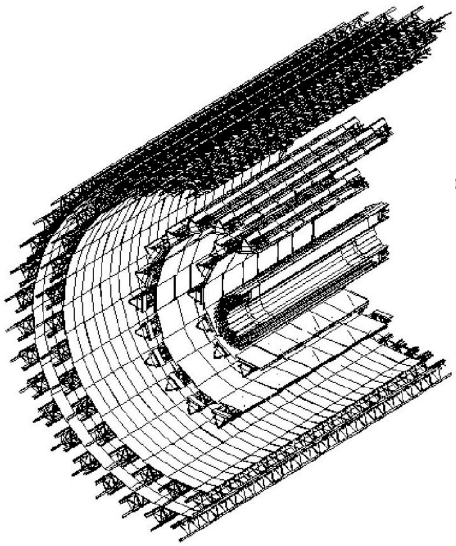


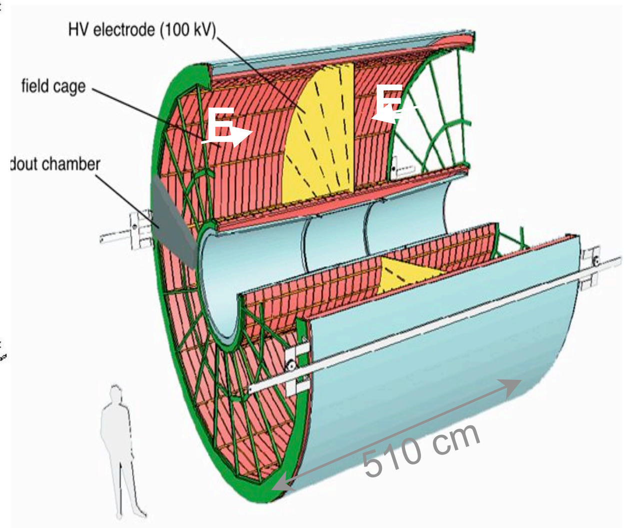
$B_s \to \pi^+ K^-$

Mass separation of Bs and Bd for different levels of misalignment



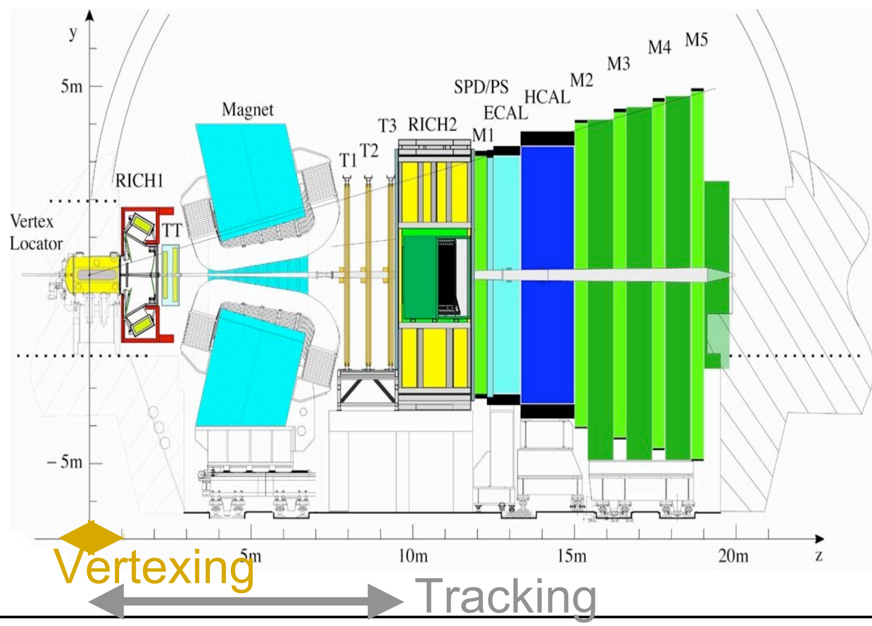
Tracker ALICE & LHCb





ALICE tracker:

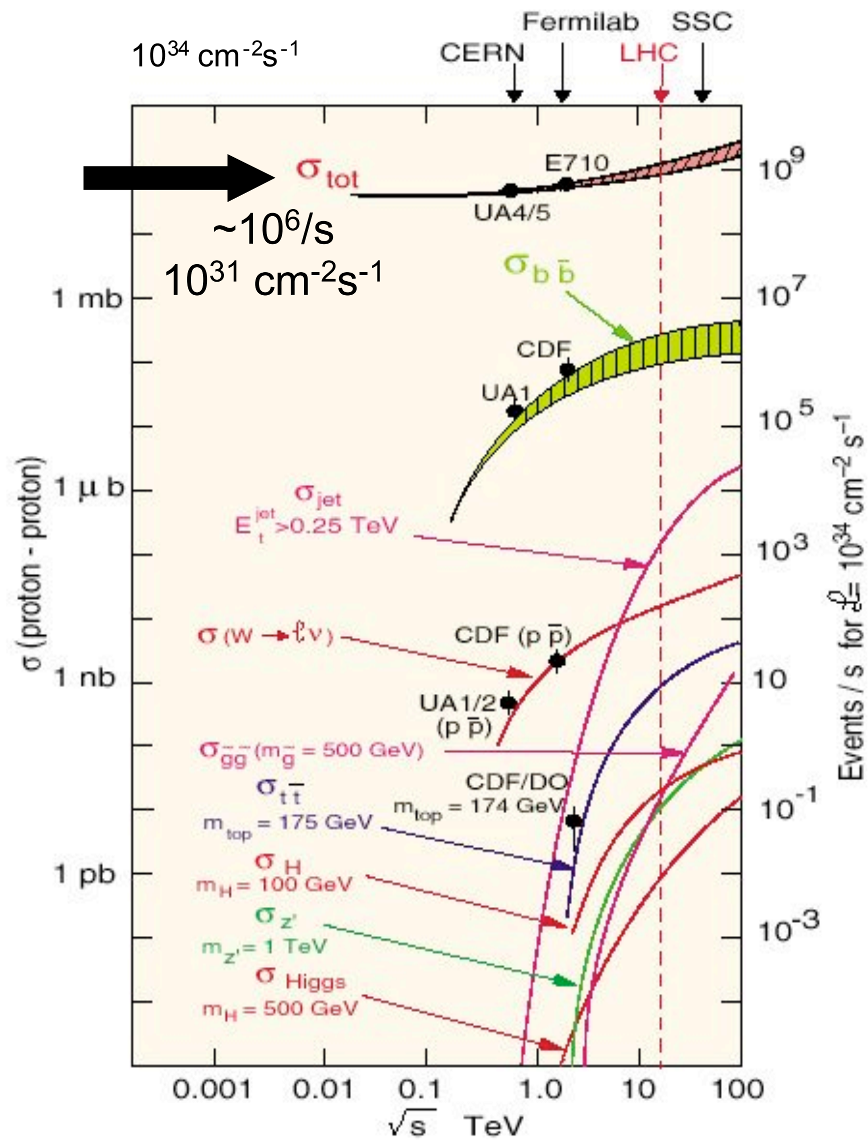
- Si pixels, strips and TPC
- Pixel FAST-OR (unique at LHC) and provides a high multiplicity trigger → Study MB events
- p_T cutoff ~100 MeV



LHCb tracker:

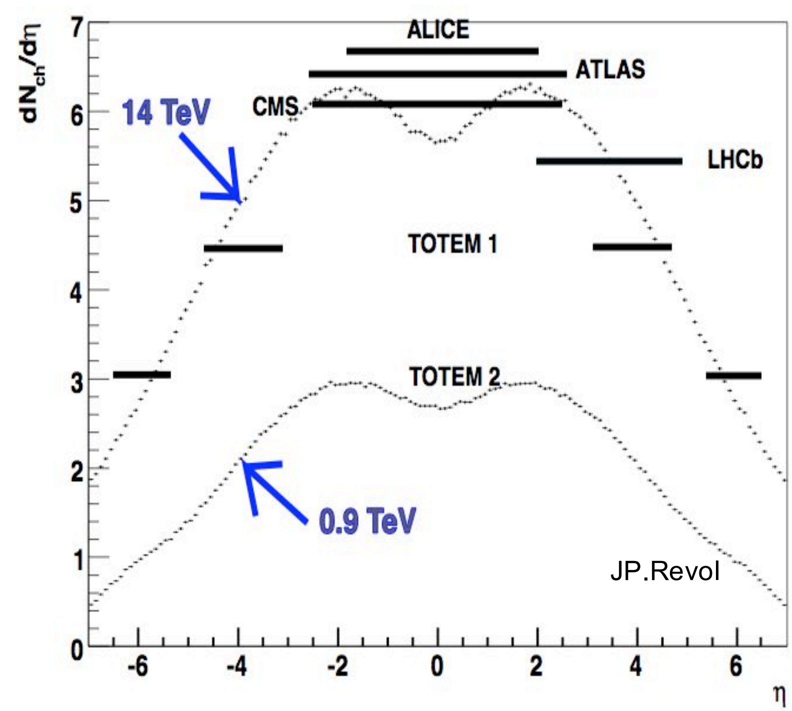
- Vertex Locator, Si trigger tracker tracker station (T1,T2&T3)
- Tracking efficiency > 95% for long tracks from B decays
- Average B-decay track resolutions:
  Impact parameter: ~30 µm
  Momentum: ~0.4%

First Phase at 14 TeV

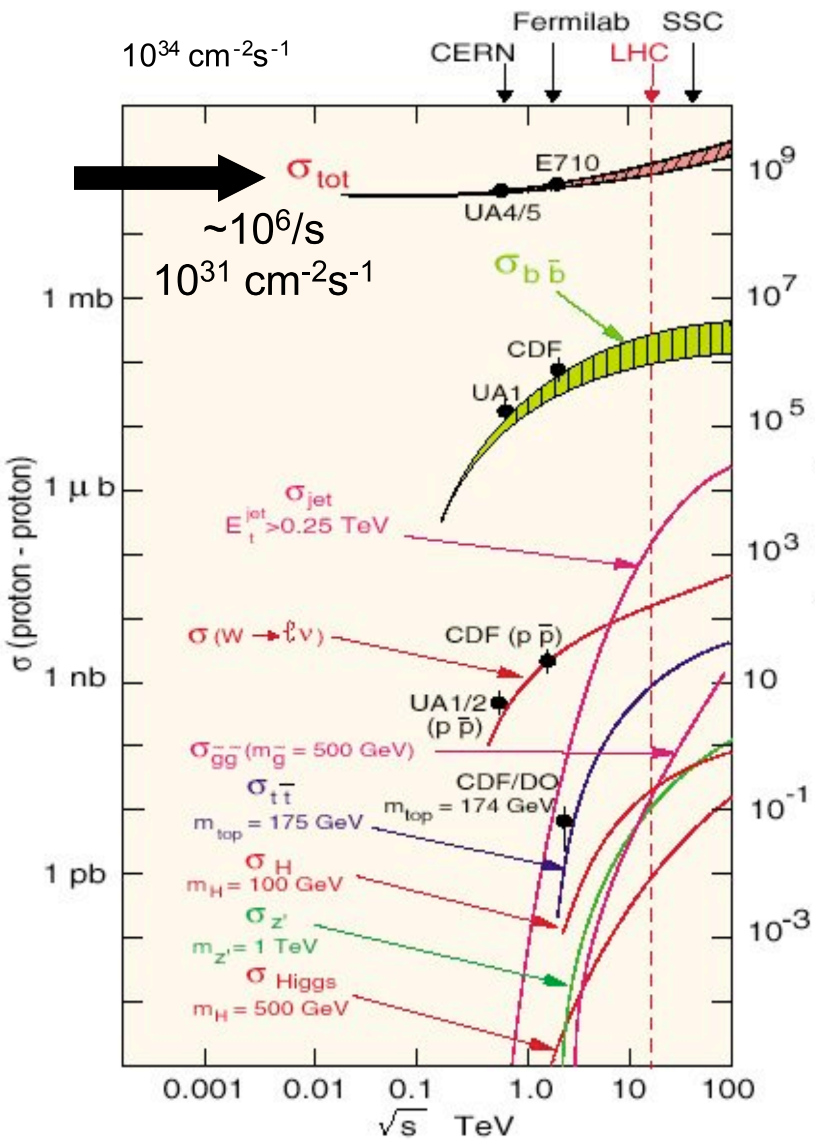


“How”: Measure
Charged Particle Density

- Huge cross section: ~10^5 events needed (15min)
- Can already be done with first (imperfect) tracking
- ALICE, ATLAS&CMS, LHCb and TOTEM are complementary and cover entire η range

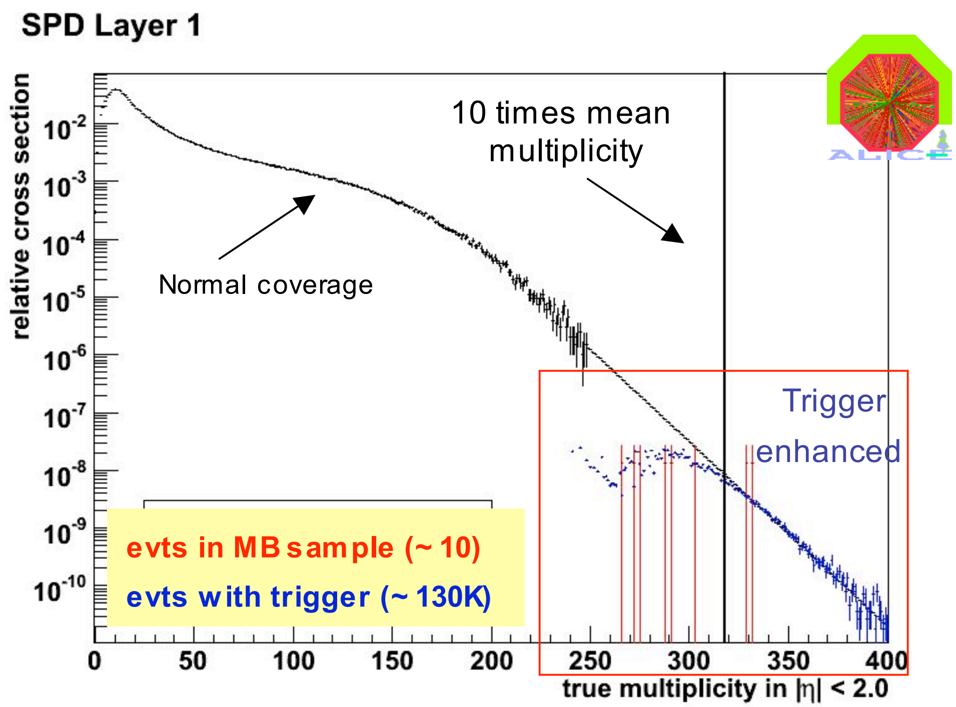


First Phase at 14 TeV

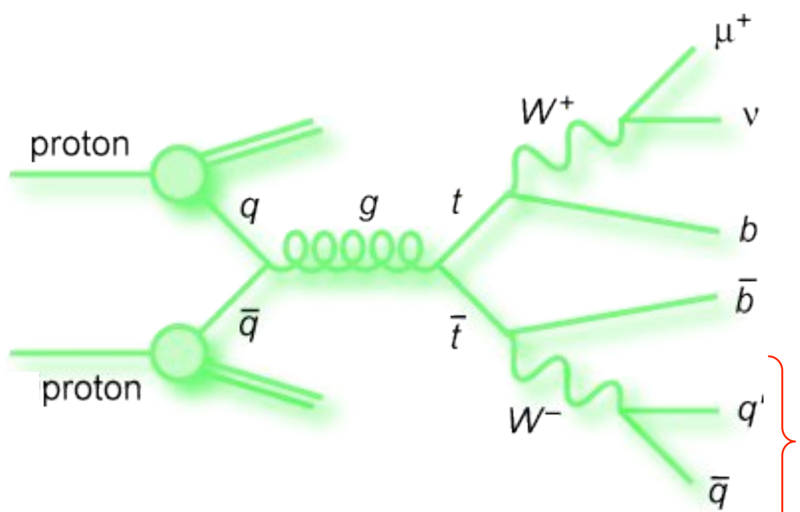


"Unique": Measure Charged Particle Density

- High Multiplicity Trigger from ALICE to study tail of charged density distribution
- For Nch>300 trigger enhancement factor: 130K/10



Example: Top Events as a Tool



Tag and Lepton study tool

Missing E_T study tool

B tag study tool

Light quark jet energy scale from M_W constraint

b quark jet energy scale from M_{top} constraint

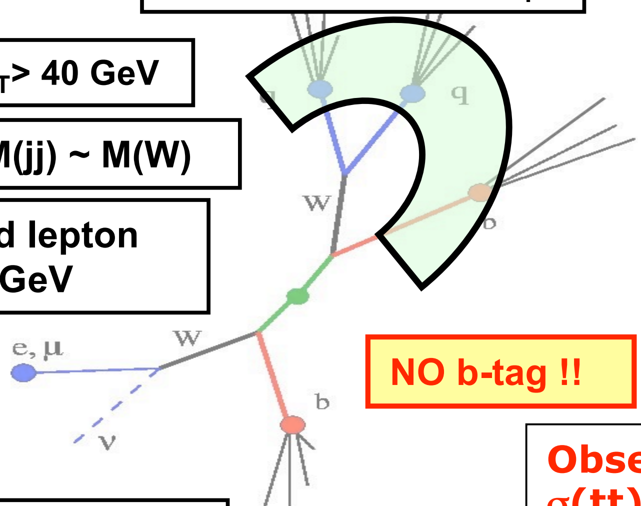
3 jets with largest $\sum p_T$

4 jets p_T> 40 GeV

2 jets M(jj) ~ M(W)

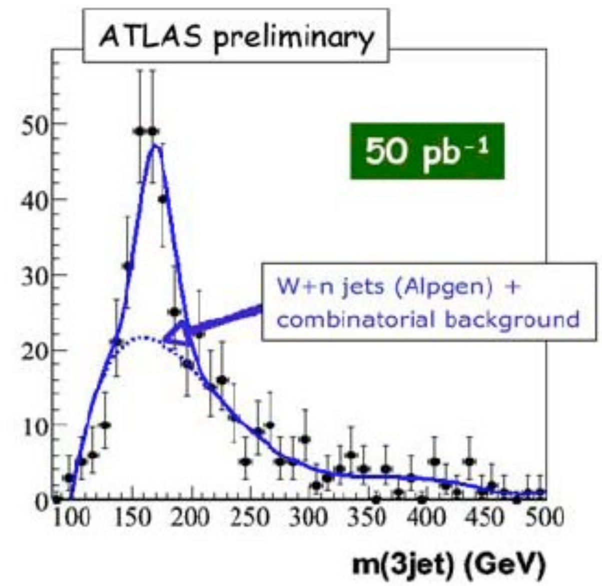
Isolated lepton p_T> 20 GeV

E_T^{miss} > 20 GeV



NO b-tag !!

Observe with 30 pb^{-1}
σ(tt) to 20%: 100 pb^{-1}
M(t) to 7-10 GeV



Backup: CMSSM Fits

"Preferred" Parameter Space

Pulls from mSUGRA fit:

$\chi^2/NDF = 17/14$; $P(\chi^2)=20\%$

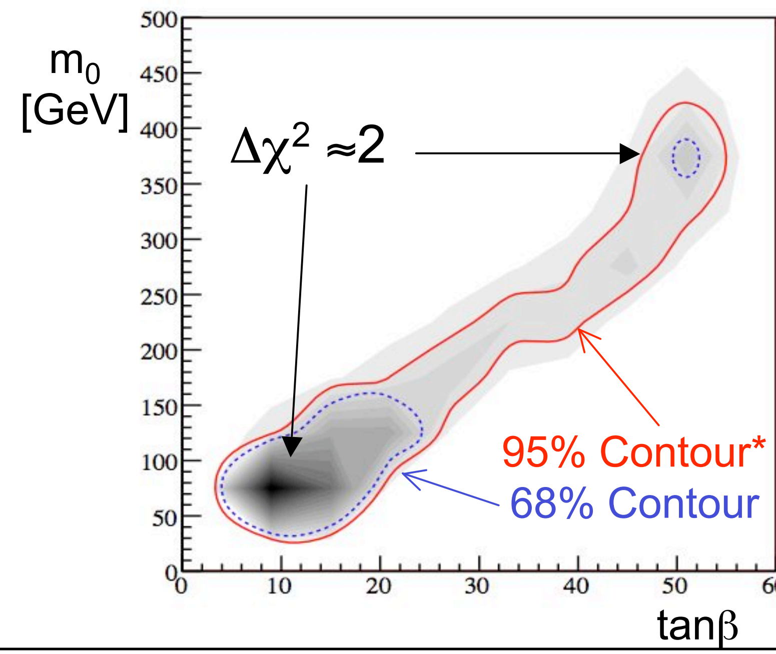
Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774	
m_Z [GeV]	91.1875 ± 0.0021	91.1873	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952	
σ^0_{had} [nb]	41.540 ± 0.037	41.486	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479	
R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b\rightarrow s\gamma)$	1.13 ± 0.12	1.12	
$B_s\rightarrow\mu\mu$ [$\times 10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times 10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

Collaboration of experimentalists and theorists:
hep-ph/0707.3447

BUCHMULLER, CAVANAUGH, DE ROECK, HEINEMEYER, ISIDORI, PARADISI, RONGA, WEBER, WEIGLEIN.

$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_i^M \frac{(f^{\rm obs}_{{\rm SM}_i} - f^{\rm fit}_{{\rm SM}_i})^2}{\sigma(f_{{\rm SM}_i})^2}$$

Multi-parameter fit using all mSUGRA parameters. Relevant SM uncertainties like Δm_{top} are also considered



"Preferred" Parameter Space

Pulls from mSUGRA fit:

χ^2/NDF = 17/14 ; P(χ^2)=20%

Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774	
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R_b	0.21629 ± 0.00066	0.21613	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1479	
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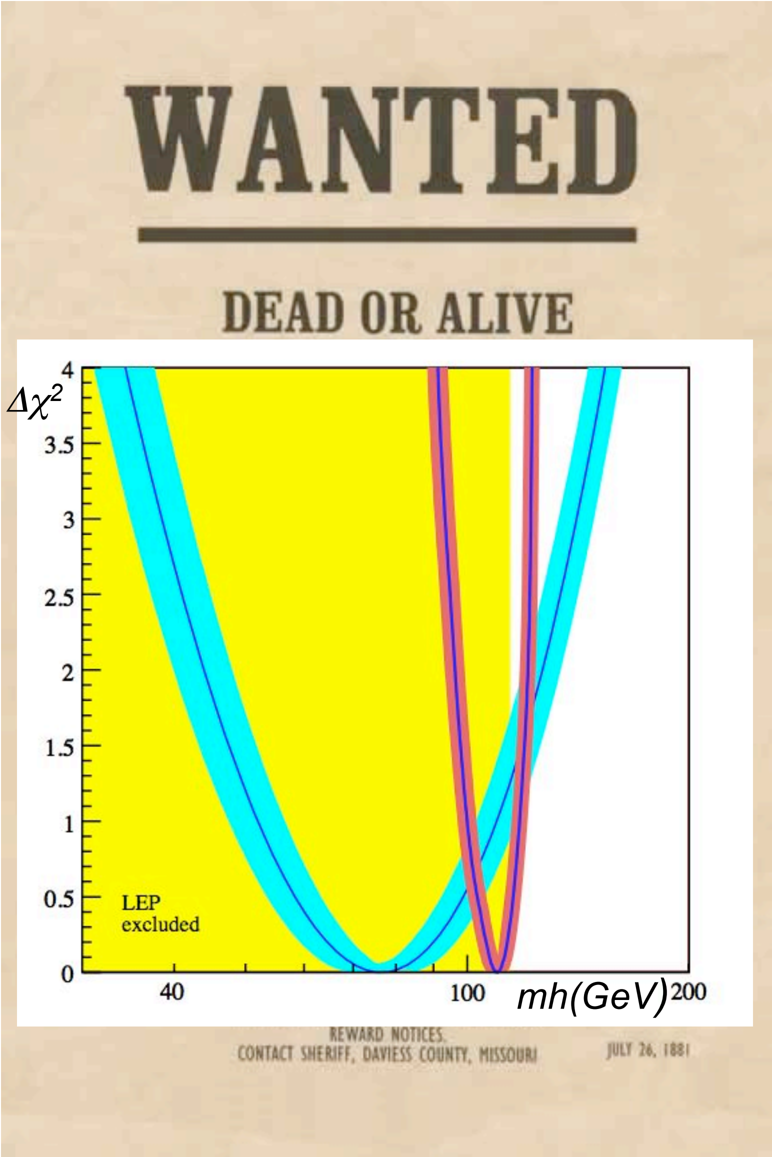
$R(b\to s\gamma)$	1.13 ± 0.12	1.12	
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

Pulls from official EW fit:

χ^2/NDF = 18/13 ; P(χ^2)=15%

Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768	
m_Z [GeV]	91.1875 ± 0.0021	91.1875	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957	
σ^0_{had} [nb]	41.540 ± 0.037	41.477	
R_l	20.767 ± 0.025	20.744	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21586	
R_c	0.1721 ± 0.0030	0.1722	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1481	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.374	
m_t [GeV]	170.9 ± 1.8	171.3	
Γ_W [GeV]	2.140 ± 0.060	2.091	

SM-like Higgs Boson



Many of the popular models (e.g SM or MSSM) require the lightest higgs boson mass to be significantly below 200 GeV.

If the higgs boson really exist, it is probably just around the corner!

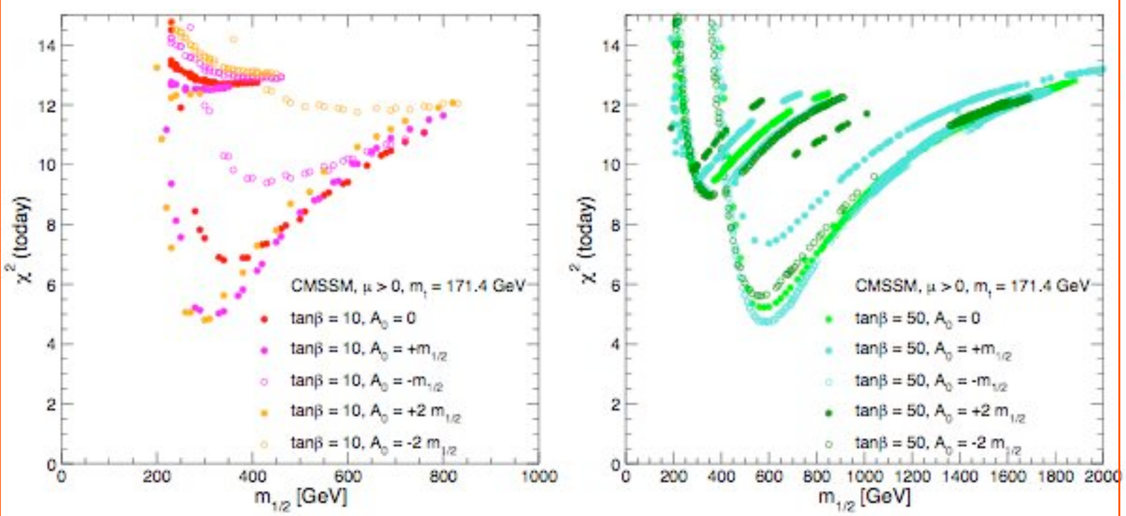
Concentrate on SM-like higgs search for mh<200 GeV but the LHC covers full phase space up to 1 TeV.

⇒ We will get an answer!

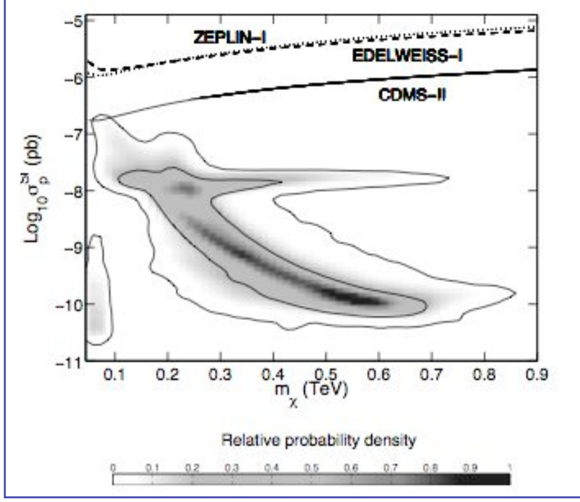
Not covered in this talk:
Search for heavy higgs (e.g. MSSM)

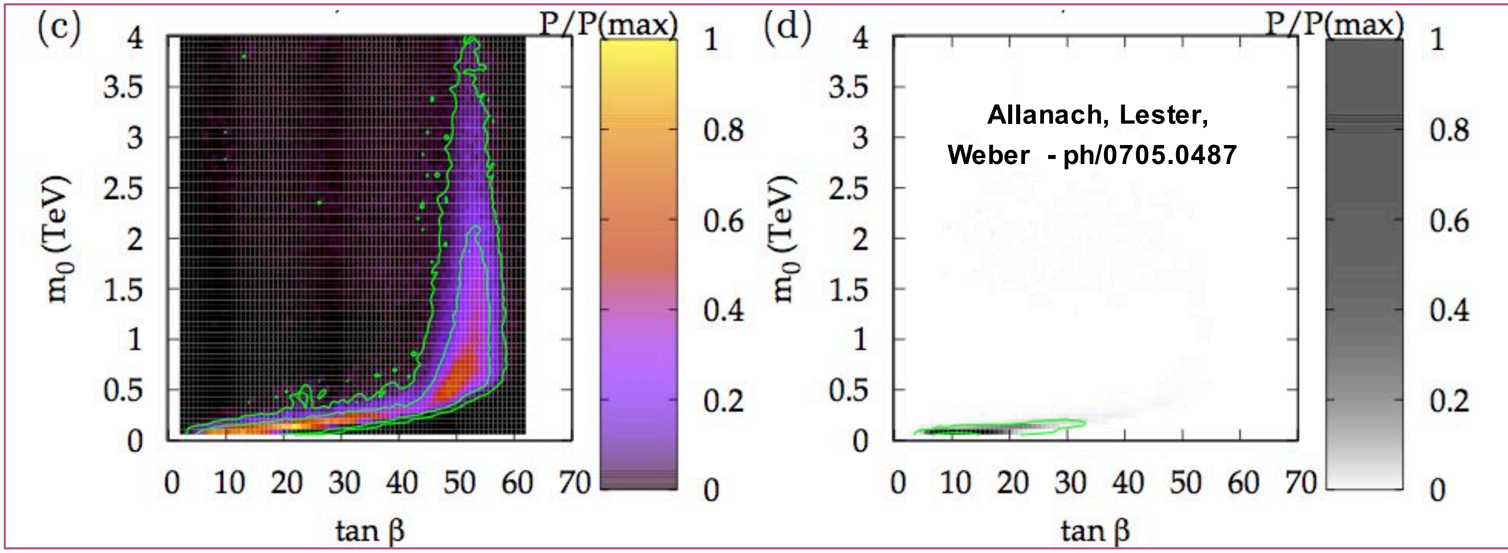
Recent mSUGRA Fits/Scans (Examples)

Ellis, Heinemeyer, Olive, Weber, Weiglein - ph/0706.0652



Trotta, Austri, Roszkowski - ph/0609126





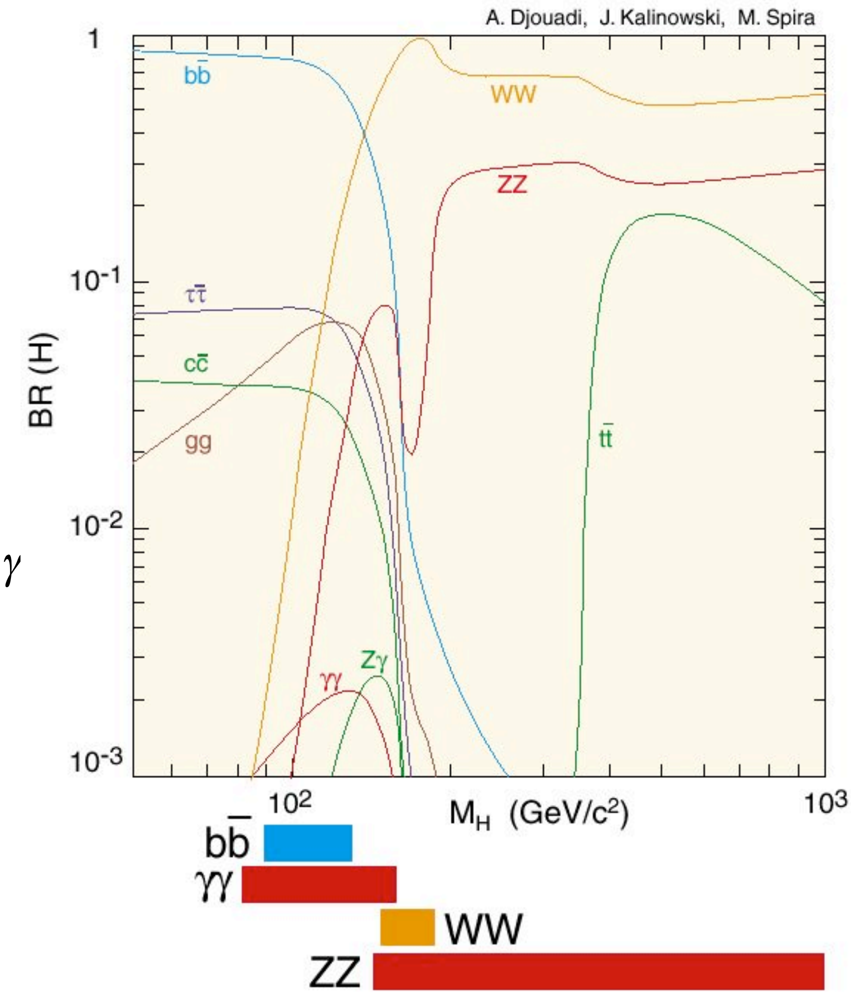
Allanach, Lester, Weber - ph/0705.0487

Backup - SM-like Higgs

SM Higgs (or lightest Higgs)

Higgs Decay channels

- Higgs couples to m_f^2
  - *Heaviest available fermion (b quark) always dominates*
  - *Until WW, ZZ thresholds open*
- Low mass: b quarks→ jets; resolution ~ 15%
  - *Only chance is EM energy (use γ decay mode)*
- Once $M_H > 2M_Z$, use this
  - *W decays to jets or lepton+neutrino (E_T^{miss})*

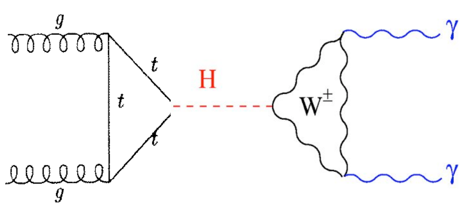


Light SM-like Higgs

$m_H \sim 115$ GeV 10 fb^{-1} : $S/\sqrt{B} \approx 4$ ATLAS

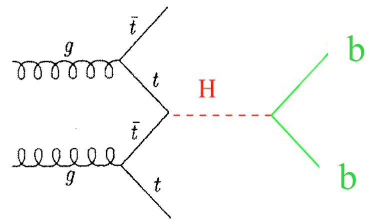
3 (complementary) channels with similar relative (small) significances:

$H \to \gamma\gamma$



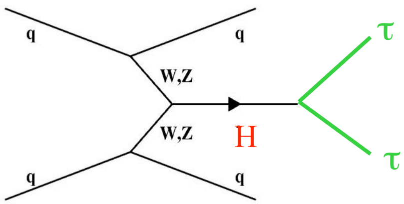
CMS: S=130 B=4300 S/√B=2

$ttH \to ttbb \to bl\nu bjjbb$



ATLAS S=15, B=45, S/√B=2.2

$qqH \to qq\tau\tau$



ATLAS: S=10, B=10, S/√B=2.7

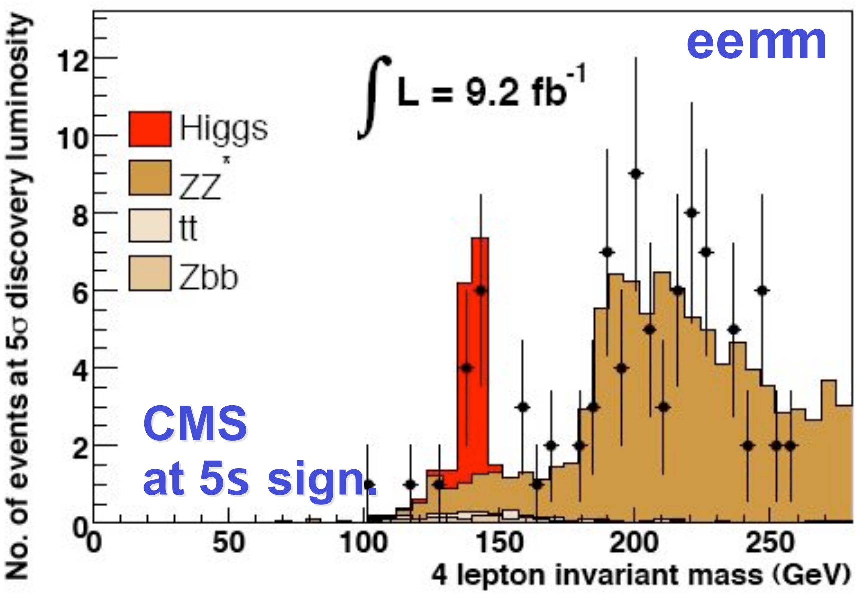
K-factors $\equiv \sigma(NLO)/\sigma(LO) \approx 2$
for $H \to \gamma\gamma$ NOT included (conservative)

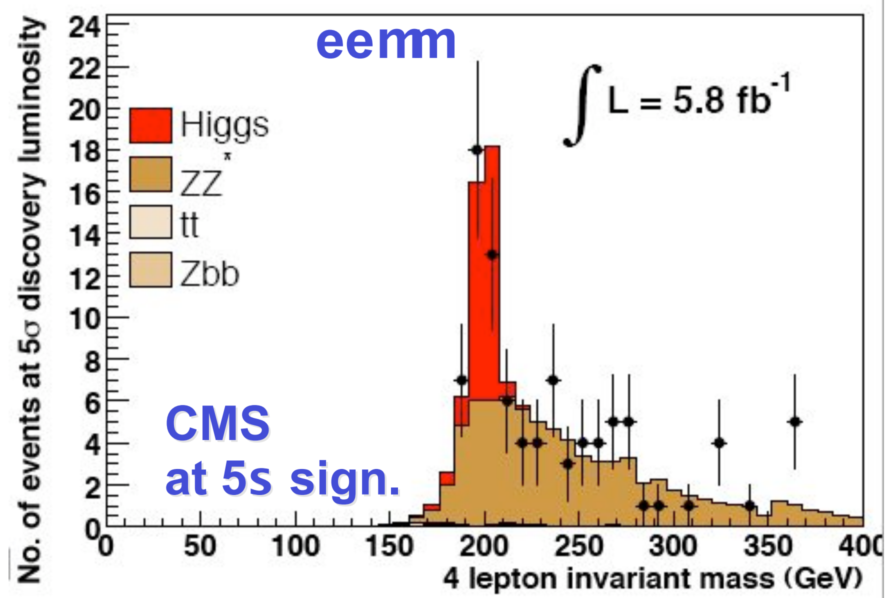
All three channels require very good understanding of detector performance and background control to 1-10% → convincing evidence likely to come later than 2008 …

H->ZZ->4l

- **New elements of analysis:**
  - **ZZ background: NLO k factor depends on m_{4l}**
  - **background from side bands or from ZZ/Z; (gg->ZZ is added as 20% of LO qq->ZZ, no good generator yet)**

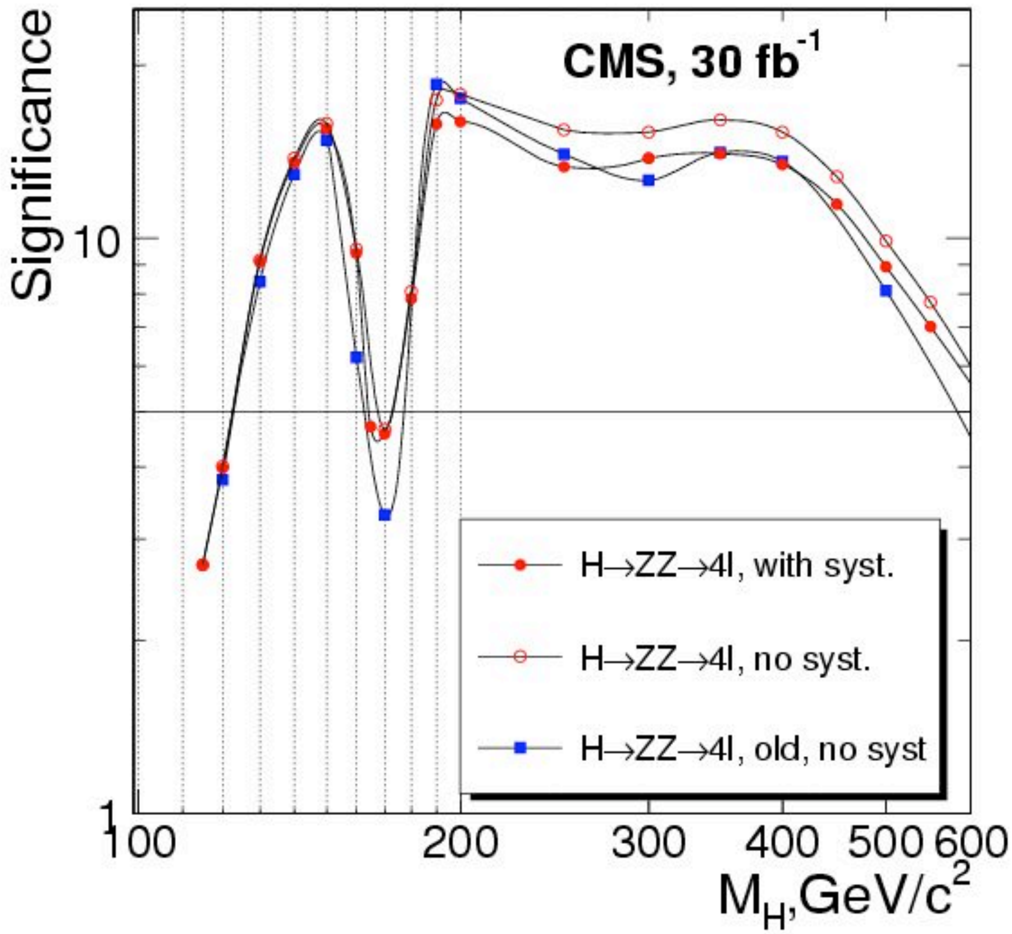
Signal and background at 5 sigma discovery





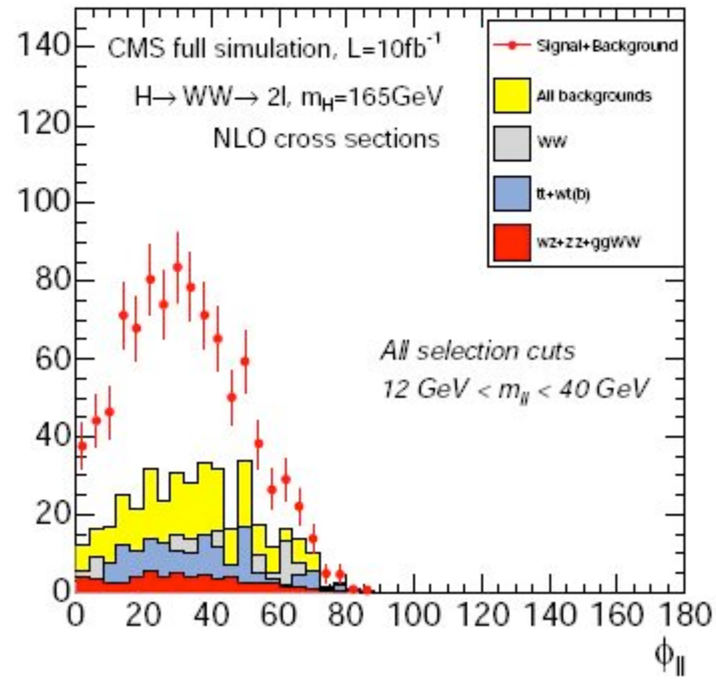
H->ZZ->4l

Signal significance: new vs old results; no big change



Early discovery with H->WW->2l2n

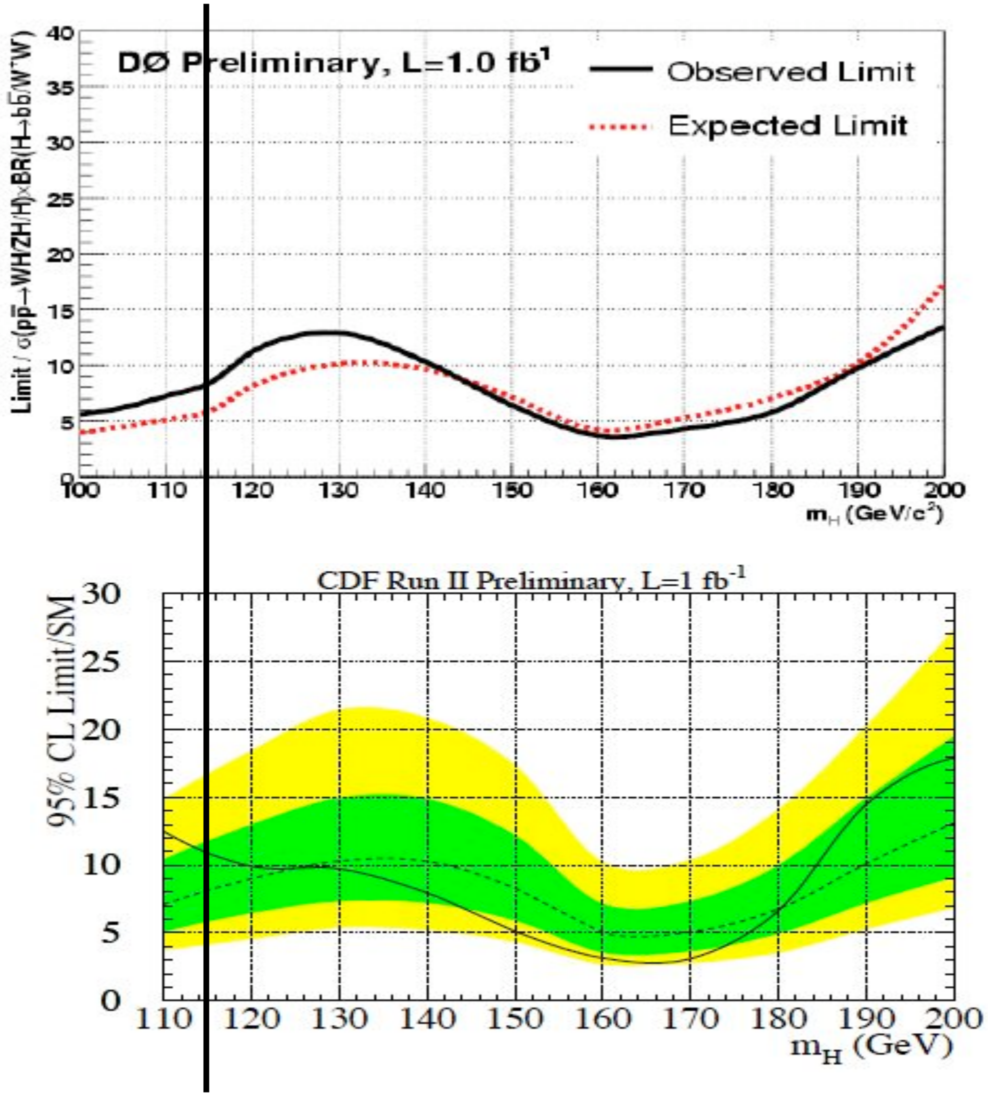
- **New elements of analysis**
  - **P_T Higgs and WW bkg. as at NLO (re-weighted in PYTHIA)**
  - **include box gg->WW bkg.**
  - **NLO Wt cross section after jet veto**
- **Backgrounds from the data (and theory)**
  - **tt from the data; uncertainty 16% at 5 fb^{-1}**
  - **WW from the data; uncertainty 17% at 5 fb^{-1}**
  - **Wt and gg->WW bkg from theor. uncertainty 22% and 30%**



after cuts:

- E_T^{miss} > 50 GeV
- jet veto in h < 2.4
- 30 <$p_T^{l\,max}$<55 GeV
- $p_T^{l\,min}$ > 25 GeV
- 12 < m_{ll} < 40 GeV

SM Higgs Search at Tevatron



Backup: SUSY

Probing the SUSY Parameters Space

The unconstraint MSSM with >100 free parameters is too complex for a comprehensive scan of its parameter space

need to reduce parameters (i.e. complexity).

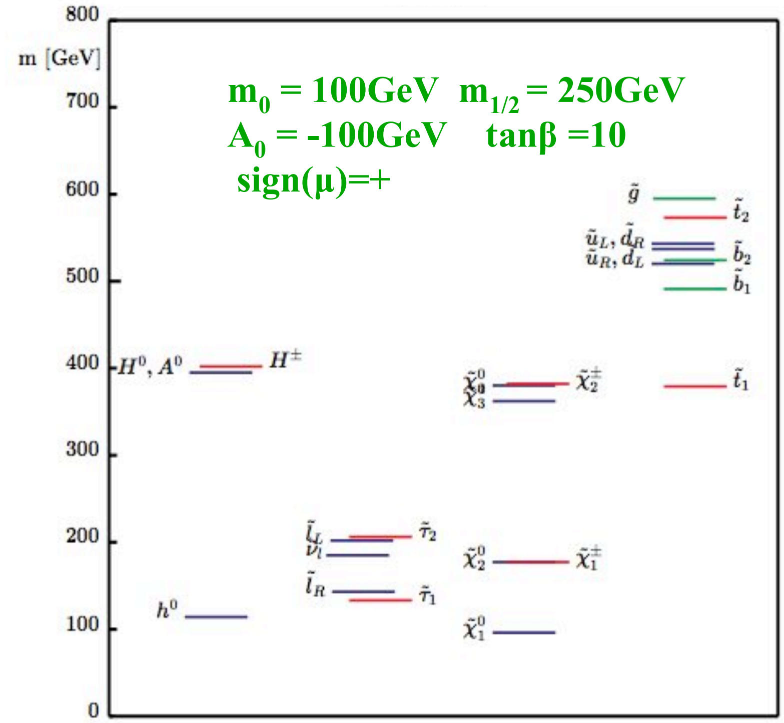
Most popular SUSY breaking model to constrain the MSSM is: minimal Super Gravity model mSUGRA: **4 parameters + one sign**

- **m_0 = one scalar mass parameter**
- **$m_{1/2}$ =one gaugino mass parameter**
- **A_0 = one trilinear coupling**
- **tanβ = ratio Higgs vacuum expectation values**
- **sign(μ) = sign of Higgs mixing parameter**

Define several of these benchmark points:

- *map different experimental signatures*
- *make sure that they are compatible with data*

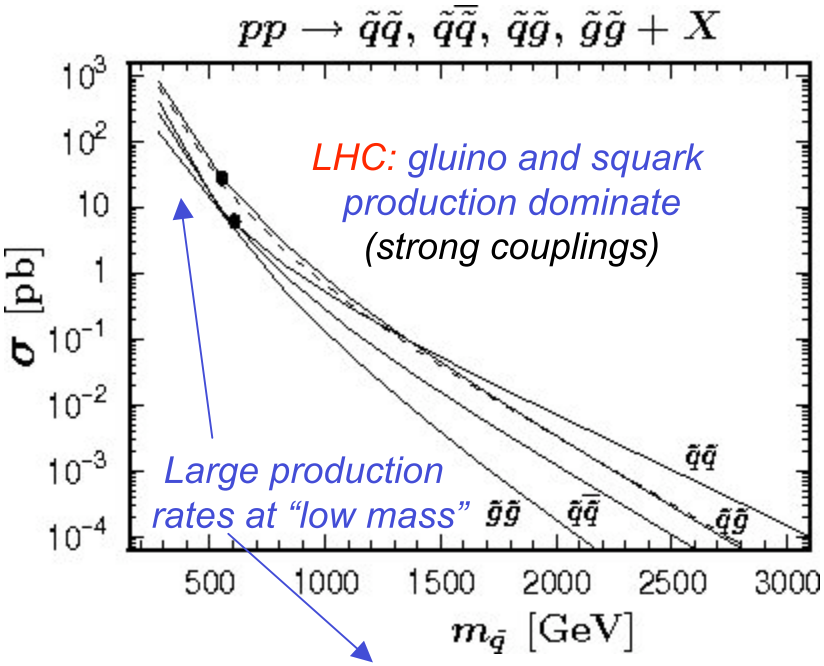
Example: SPS1a



Spectrum Characteristic

- "Heavy" gluinos and squarks
- "Heavy" and light gauginos
- Light sleptons
- lLghtest Higgs new LEP limit

SUSY Searches @ LHC

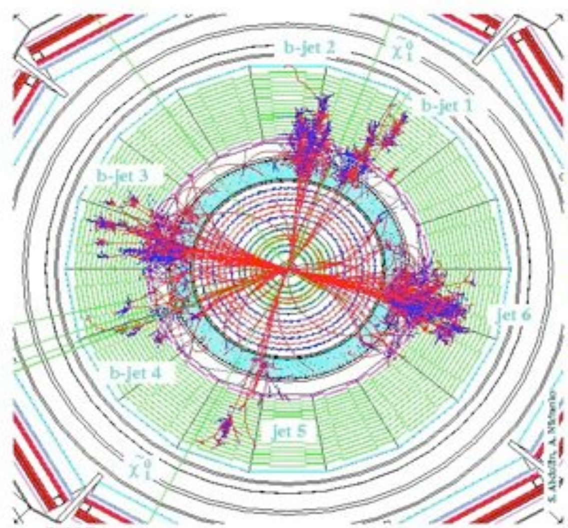


M_{sp}(GeV)	σ (pb)	Evts/yr
500	100	10^6-10^7
1000	1	10^4-10^5
2000	0.01	10^2-10^3

For low masses the LHC becomes a real ***SUSY factory***

Huge number of theoretical models

- Very complex analysis; MSSM >100 parameter
- To reduce complexity we have to choose some "reasonable", "typical" models; use a theory of dynamical SUSY breaking
  - mSUGRA (main model)
  - GMSB (studied in less detail)
  - AMSB (studied in less detail)
- Use models to study consistently different SUSY signatures in the detector.



Clear signatures of large missing energy, hard jets and many leptons!

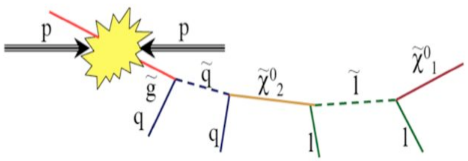
(assume R-Parity)

Could be very spectacular!

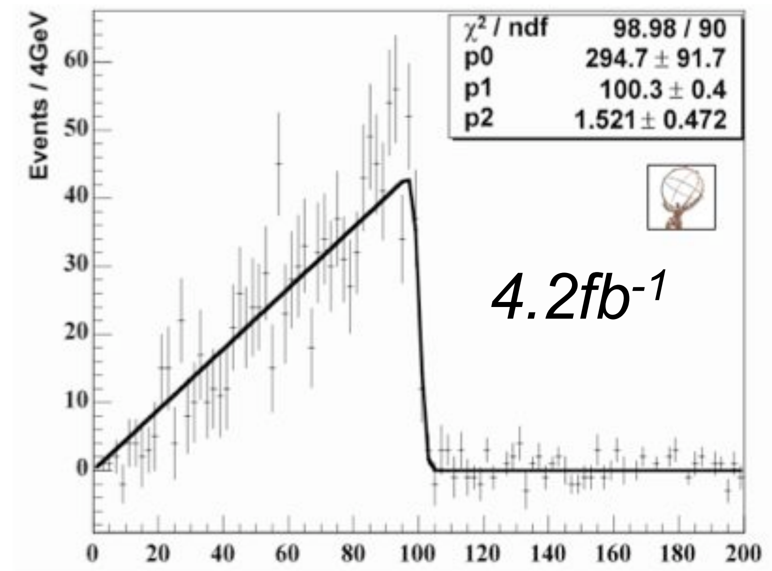
First Kinematic Measurements

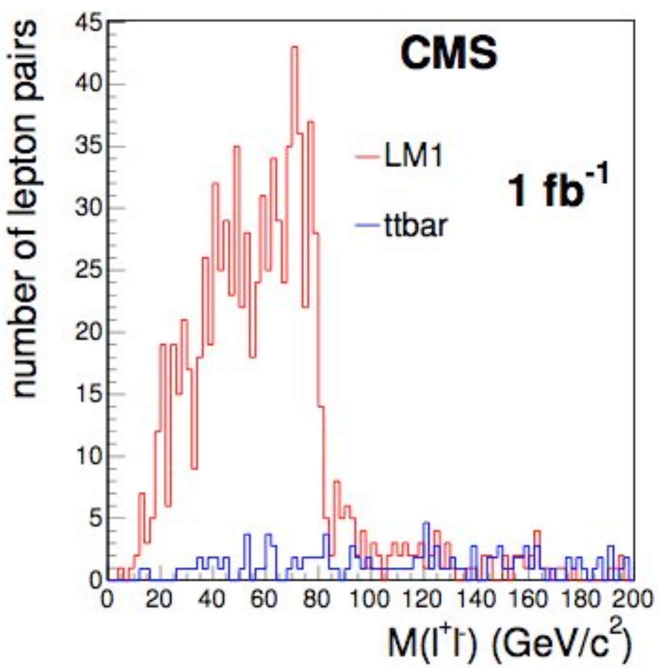
...and if we are a bit lucky we might see such spectacular signals already at the early days!

Look for generic signatures of cascade decays:



Jets + E_t^{miss} +SFOS di-leptons





Extract: $$M_{\ell\ell}^{max} = M(\tilde{\chi}_2^0)\sqrt{1-\frac{M^2(\tilde{\ell}_R)}{M^2(\tilde{\chi}_2^0)}}\sqrt{1-\frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{\ell}_R)}}$$

from a fit to the "edge distribution".

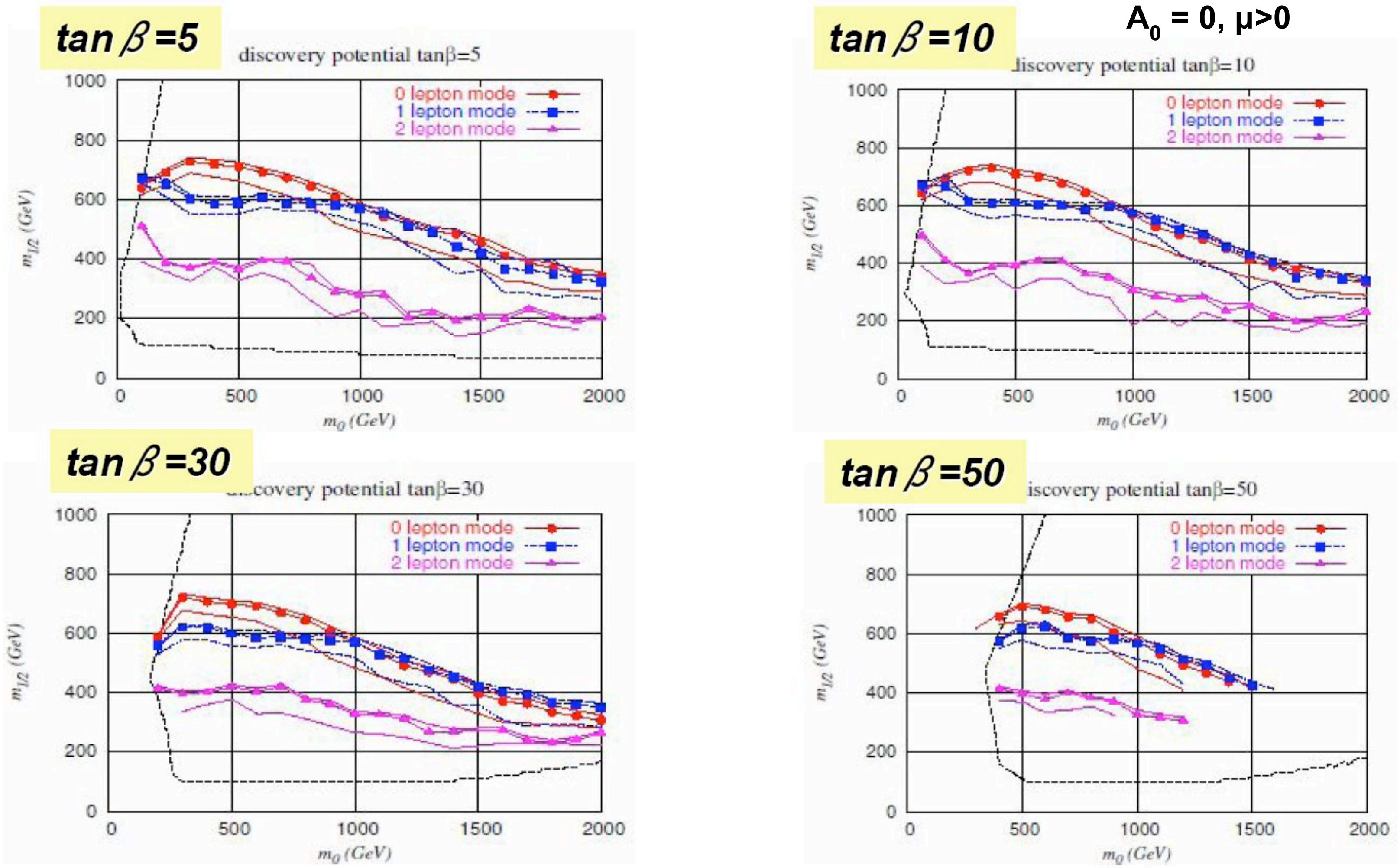
- M_{ll}^{max} =100.3±0.4 GeV (ATLAS no sys.).
- *Including systematic will worsen the error but a relative precise extraction of M_{ll}^{max} in the first few hundred pb^{-1} is still possible.*

Discovery Potential: tanβ dependence

Modest tanβ dependence ….

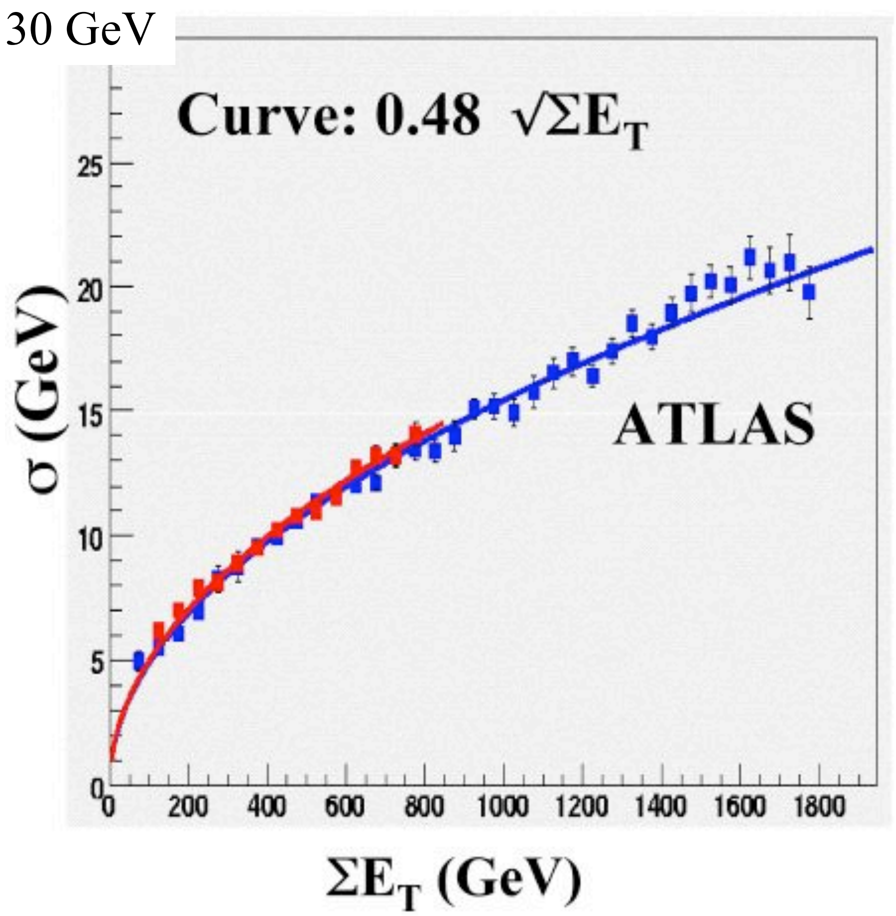
ATLAS preliminary ; 1 fb^{-1}

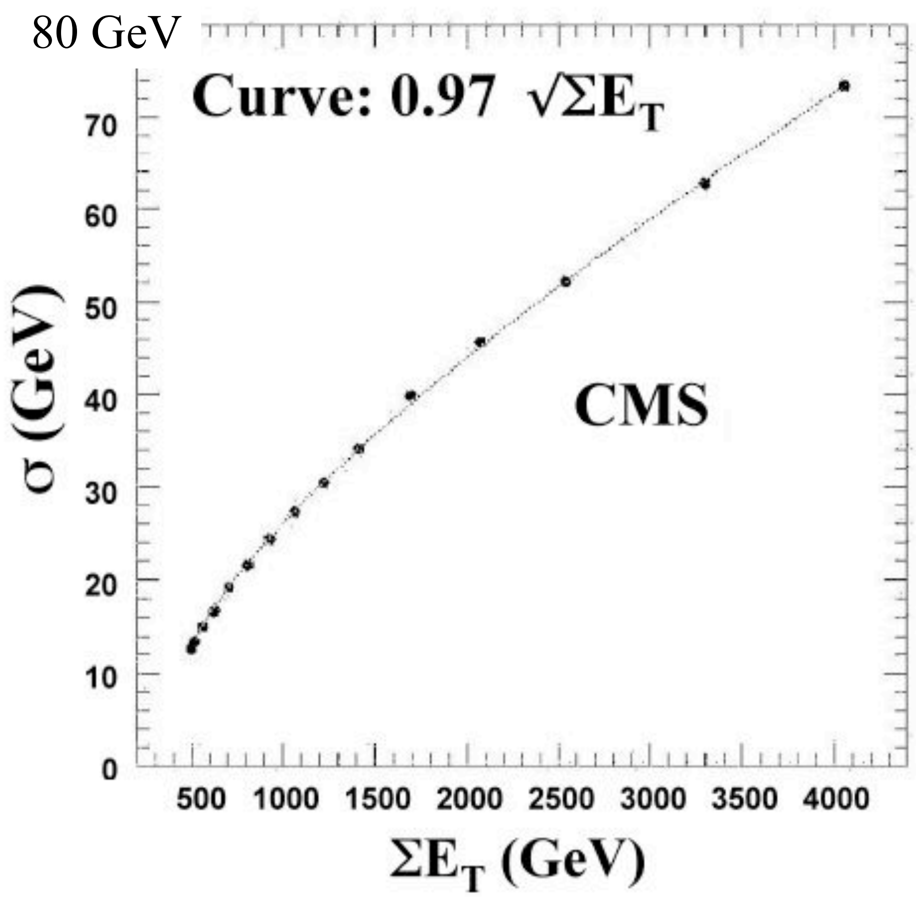
A_0 = 0, μ>0



Missing E_T

- Impact on supersymmetry, neutrino 2 or 3 momentum reconstruction
- ATLAS also better (also due to hadronic energy reconstruction)



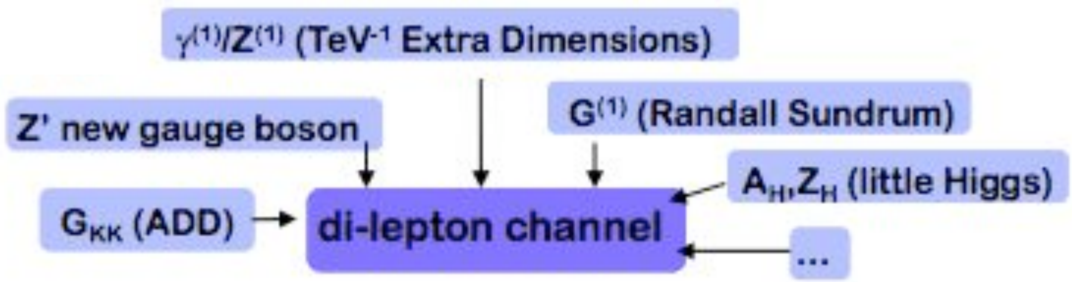


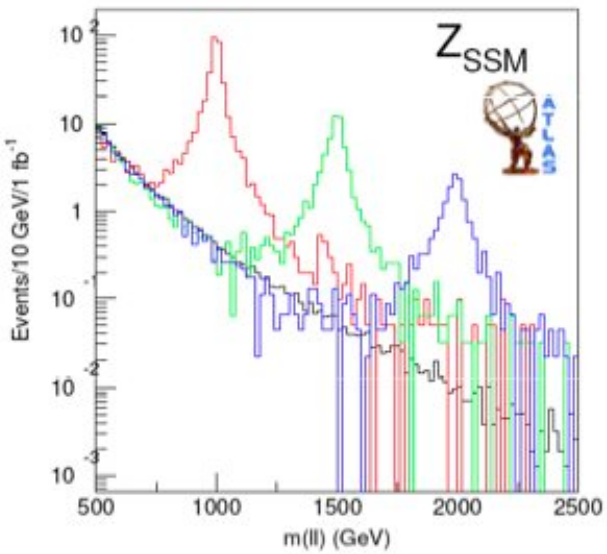
Backup: BSM

Di-lepton Resonances

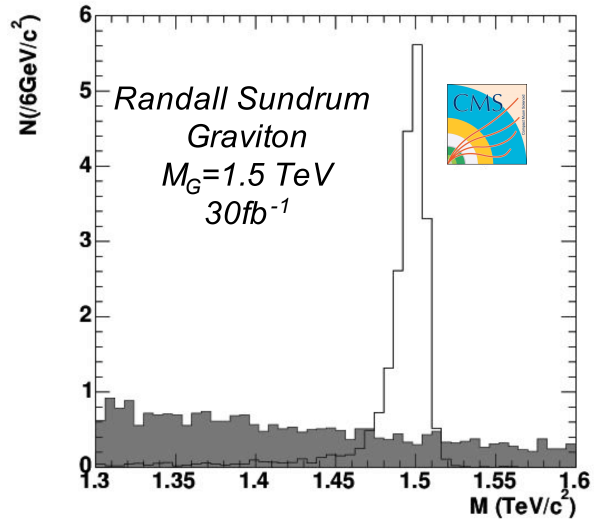
Because of their clear signature di-lepton resonances have always been subject of new physics searches.

At the LHC they are predicted to arise in many BSM models:



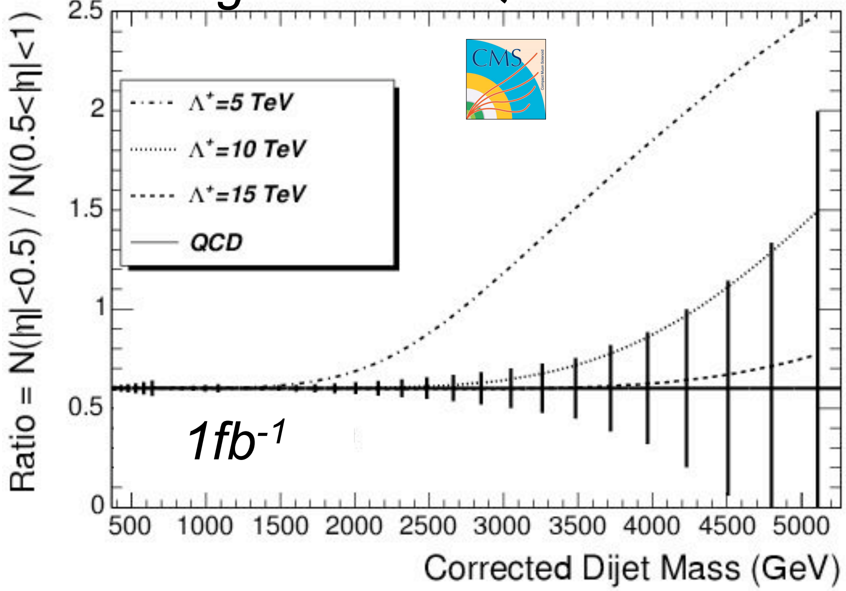


Clear signatures:
$\mu^+\mu^-$ and e^+e^- final state

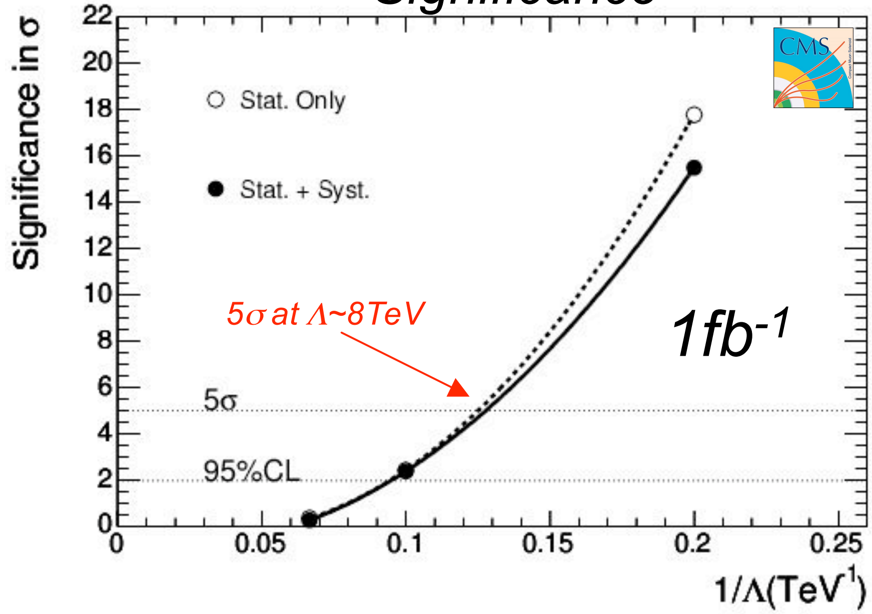


Contact Interactions with Di-jets

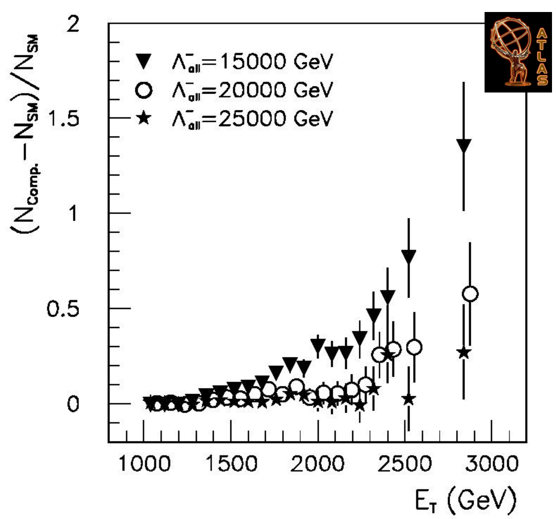
Signal “over QCD”



Significance



ATLAS:
Probe Λ>20 TeV
already
with 30fb^{-1}

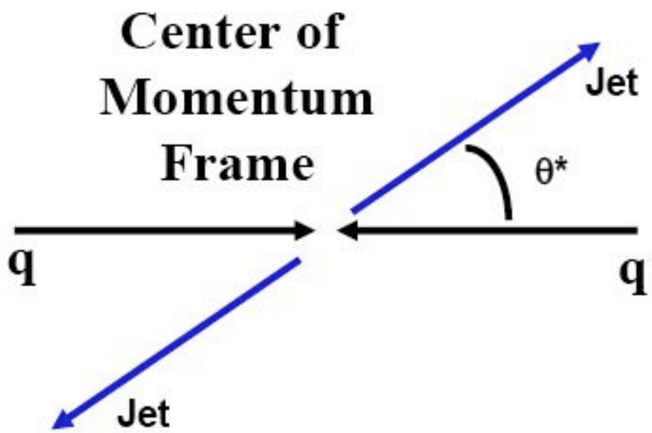


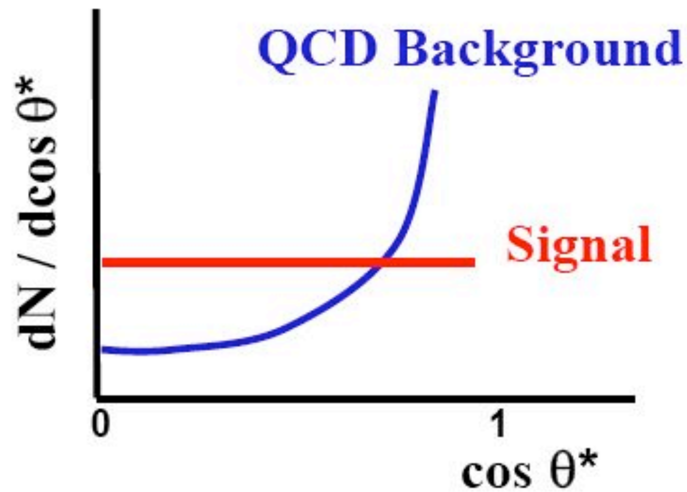
Small systematic due to use of ratio:
Di-jet Ratio = N(|η|<0.5) / N(0.5<|η|<1)

Discovery Sensitivity (CMS)

100pb^{-1} →Λ~5 TeV
1fb^{-1} →Λ~8 TeV
10fb^{-1} →Λ~12 TeV

Contact Interactions in Angular Distributions



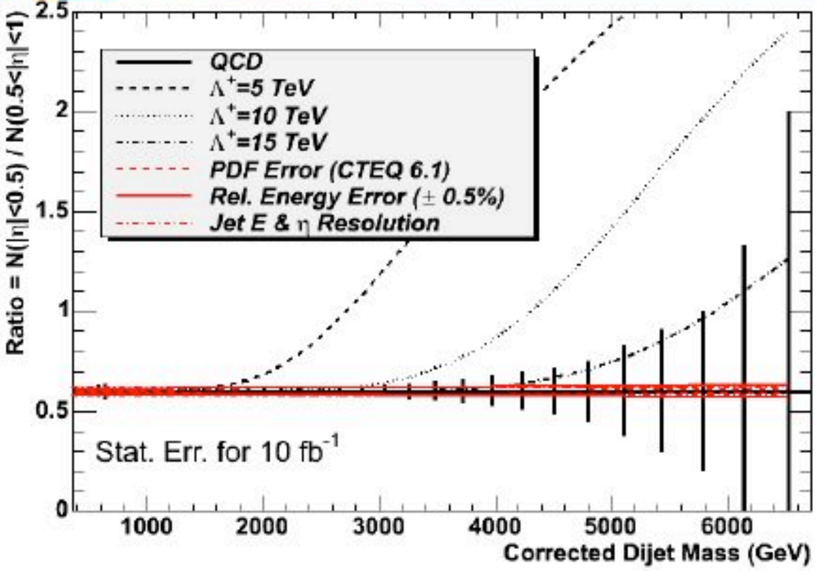


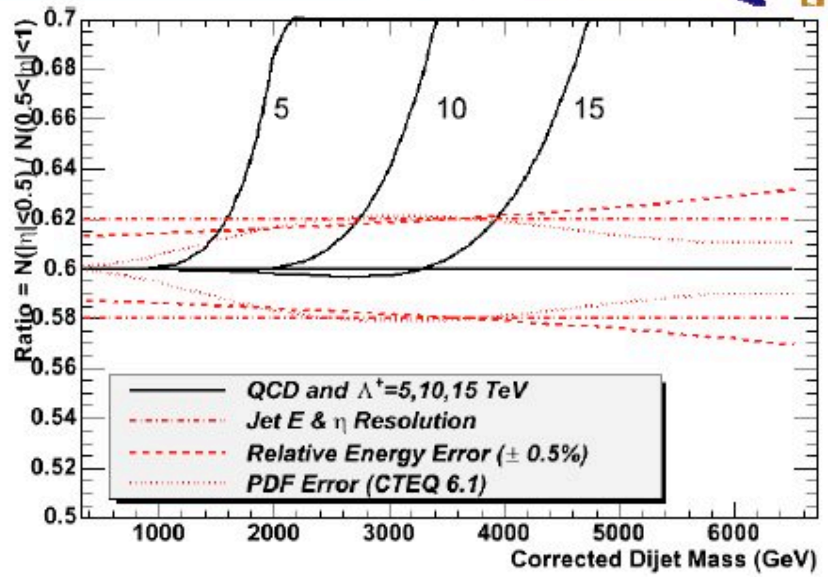
Contact interaction is often more isotropic than QCD

Angular distribution has much smaller systematic uncertainties than cross section vs. dijet mass

Effects emerge at high mass

CMS: Dijet Ratio Systematic Uncertainties





Absolute Jet Energy Scale

No effect on QCD dijet ratio: flat vs. dijet mass

Causes 5% uncertainty in Λ

Relative Energy Scale

Energy scale in $|\eta|<0.5$ vs. $0.5 < |\eta| < 1$

Estimate +/- 0.5 % is achievable in Barrel

Changes ratio between +/-.01 and +/-.03

Resolution

No change to the ratio when changing resolution

Systematics bounded by MC statistics: 0.02

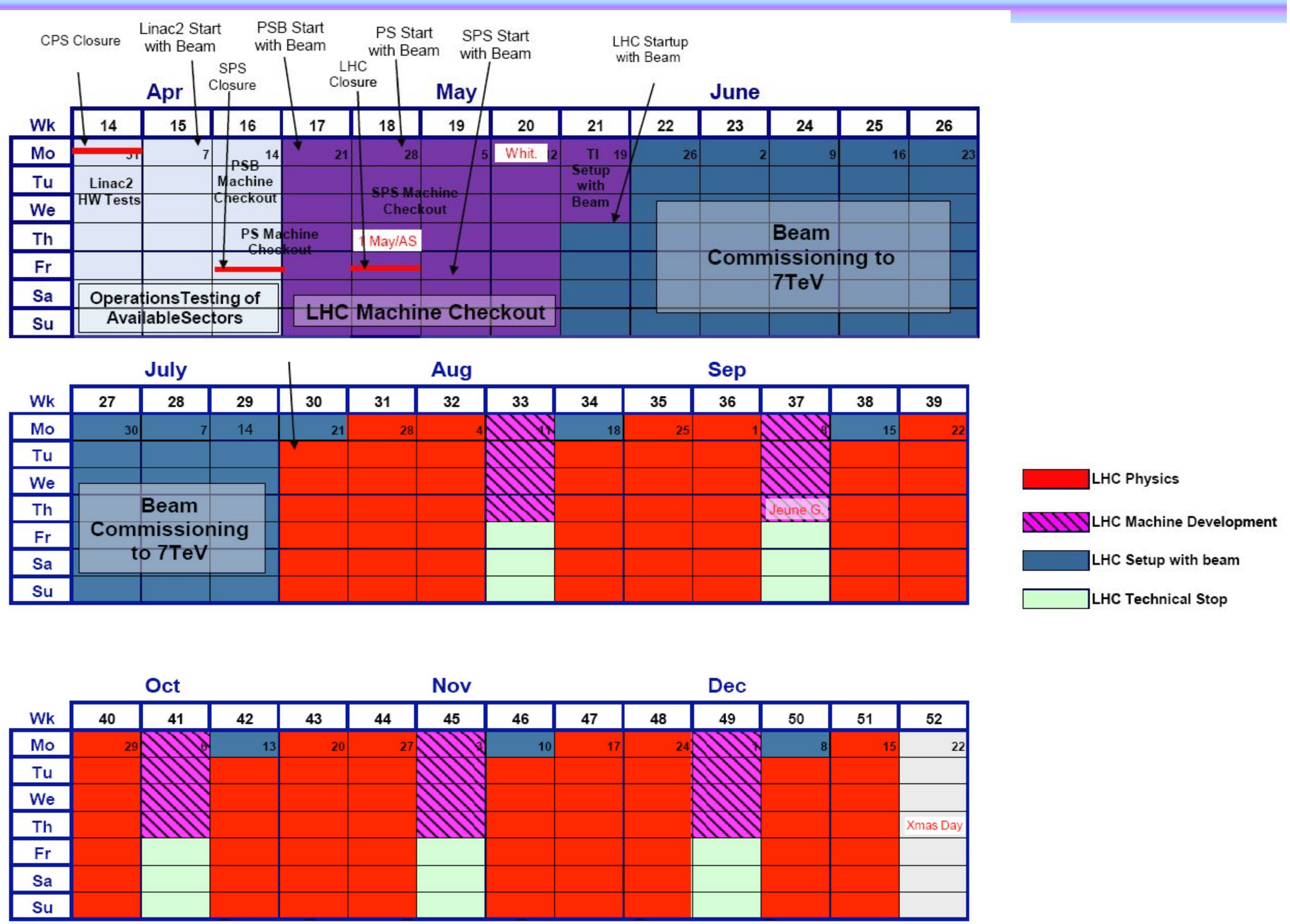
Parton Distributions

CTEQ6.1 uncertainties

Systematics on ratio less than 0.02

Backup:LHC Machine

LHC 2008 schedule



2008: Stage A Luminosity

- 1 to 43 to 156 bunches per beam
- Pushing gradually one or all of:
  - Bunches per beam
  - Squeeze
  - Bunch intensity

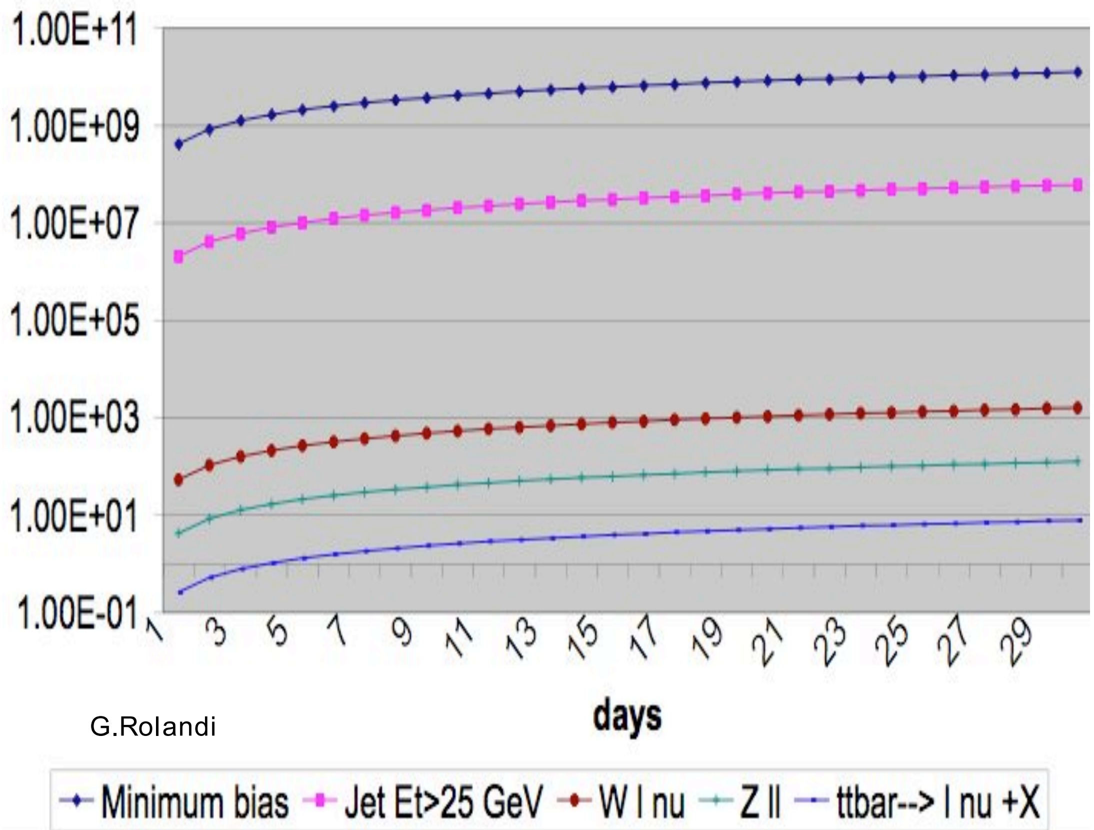
Assume ε= 20%

G.Rolandi

Bunches	β^*	I_b	Luminosity	pb^{-1}/month	Events X crossing
1 x 1	18	10^{10}	10^{27}	5×10^{-4}	Low
43 x 43	18	3×10^{10}	3.8×10^{29}	2×10^{-1}	0.05
43 x 43	4	3×10^{10}	1.7×10^{30}	9×10^{-1}	0.21
43 x 43	2	4×10^{10}	6.1×10^{30}	3×10^{0}	0.76
156 x 156	4	4×10^{10}	1.1×10^{31}	6×10^{0}	0.38
156 x 156	4	9×10^{10}	5.6×10^{31}	3×10^{1}	1.9
156 x 156	2	9×10^{10}	1.1×10^{32}	6×10^{1}	3.9

Produced Events in the First Days

30 days at 3×10^{29} with efficiency 20% =0 .15 pb^{-1}



Assumed Efficiencies

$\varepsilon(W)=0.3$ $\varepsilon(Z)=0.5$ $\varepsilon(ttbar)=0.02$

Events after one Month

Min Bias : $\sim 10^{10}$

$Jet_{Et>25}$: $\sim 10^{18}$

$W \rightarrow \ell\nu$: $\sim 10^{3}$

$Z \rightarrow \ell\ell$: $\sim 10^{2}$

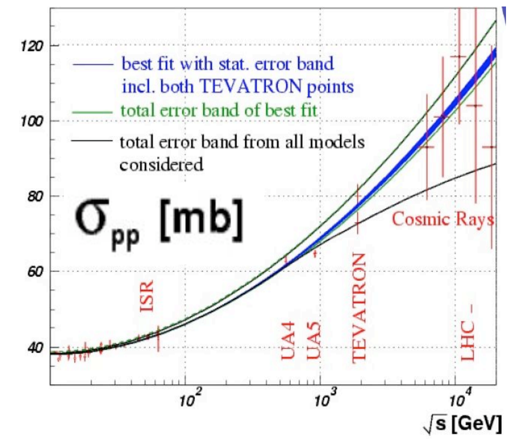
$tt \rightarrow \ell\nu + X$: $\sim 10^{1}$

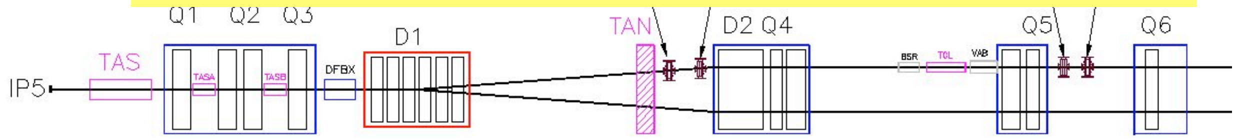
First mainly used for general commissioning and detector alignment & calibration.

Backup: Other LHC Experiments

Forward Coverage: TOTEM/LHCf

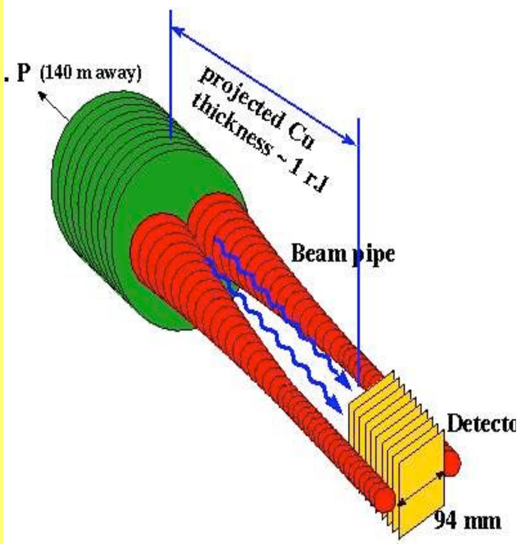
TOTEM: measuring the total, elastic and diffractive cross sections
Add Roman pots (and inelastic telescope) to CMS interaction regions.
Common runs with CMS planned

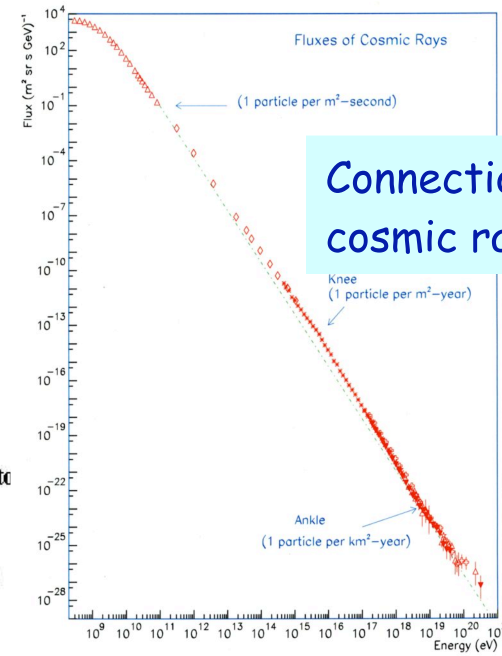




LHCf: measurement of photons and neutral pions in the very forward region of LHC

Add a EM calorimeter at 140 m from the Interaction Point (of ATLAS)

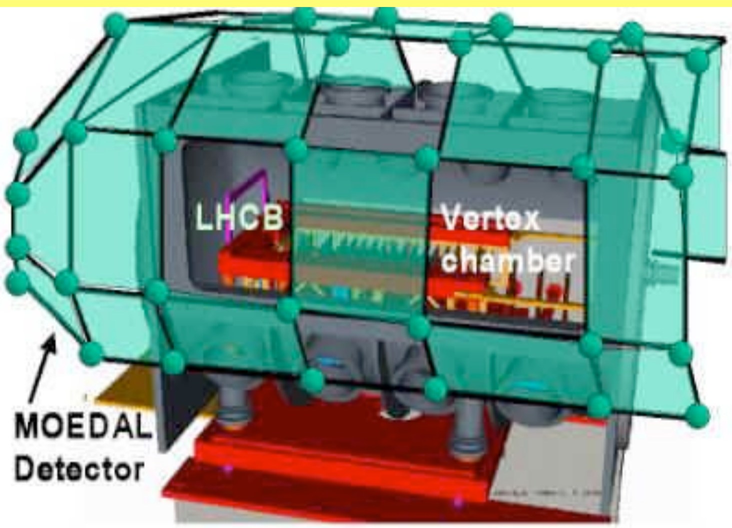


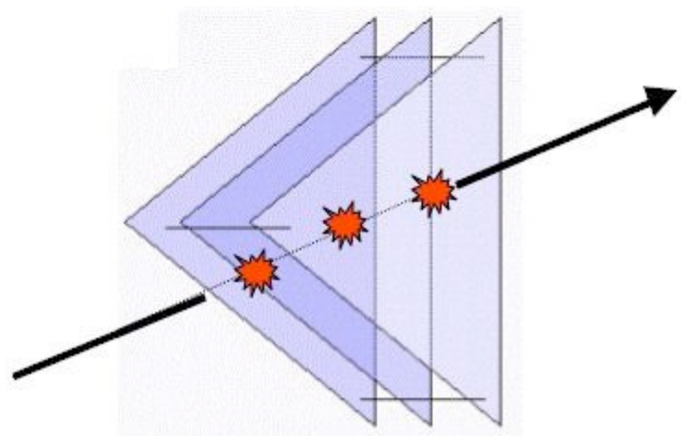


Connection wit
cosmic rays

MOEDAL: the 7^{th} experiment?

MOEDAL is an experiment so search for monopoles or other heavy ionizing particles
Detector: plastic track-etch sheets (50-70% of the solid angle)
Location: Around the LHC-b vertex chamber
Status: Proposal





Signal: set of collinear etch pits in the sheets

Remove the sheets after some running time and inspect for 'holes'