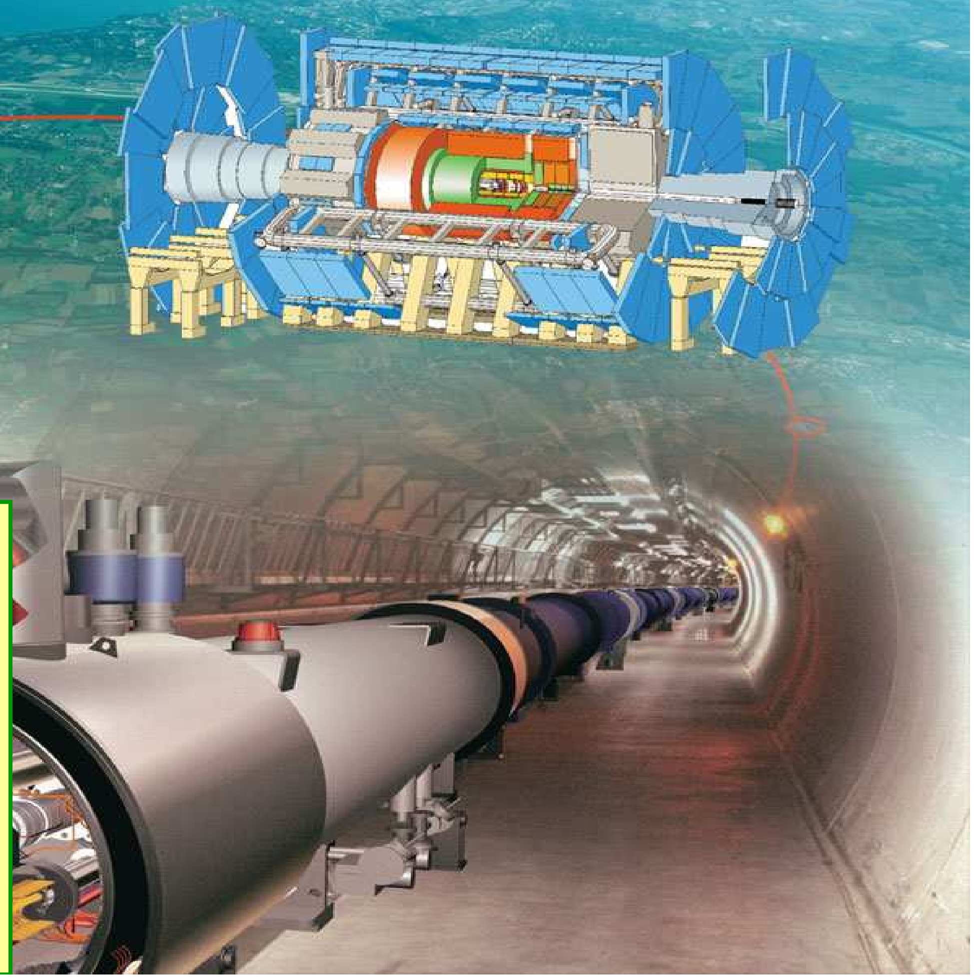
New Horizons in Particle Physics

- From the Higgs boson to Dark Matter at the LHC -

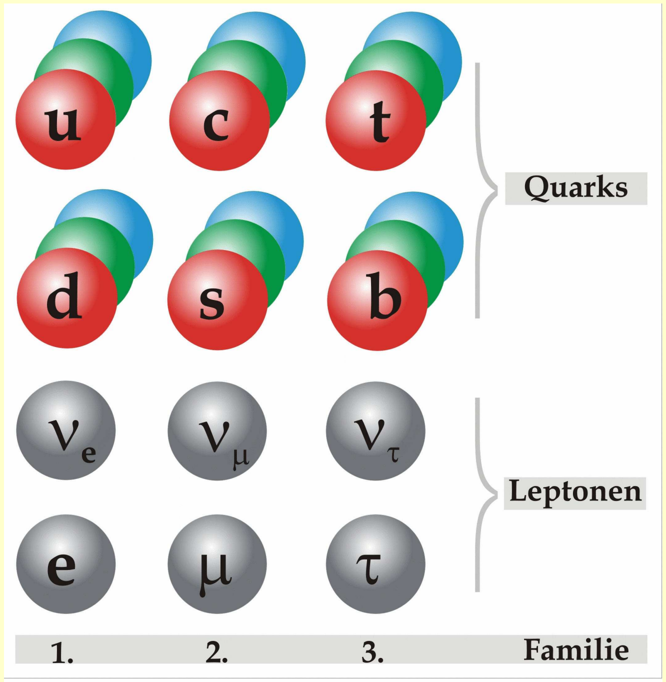


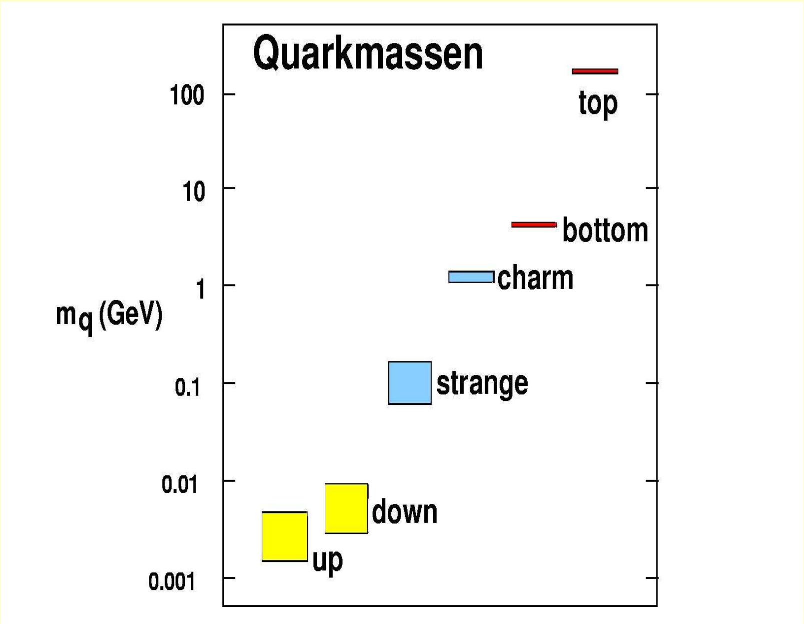
- **Introduction**

  Where do we stand today?
- **The open questions**
- **What answers can we expect from the *Large Hadron Collider (LHC)* ?**
- **Dark Matter at the LHC ?**

The Standard Model of Particle Physics

(i) Building blocks of matter: Quarks and Leptons





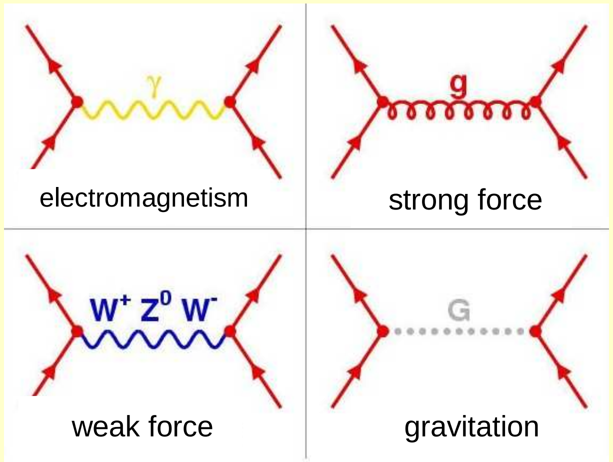
m (e) = 0.000511 GeV/c^2
m (τ) = 1.8 GeV/c^2

m (u) = 0.005 GeV/c^2
m (t) = 172.5 GeV/c^2

In comparison: m (p) = 0.938 GeV/c^2

(ii) Forces / Interactions:

mediated via the exchange of field quanta / bosons



$m_\gamma = 0$, $m_g = 0$

$m_W = 80.398 \pm 0.025$ GeV / c^2
$m_Z = 91.1875 \pm 0.0021$ GeV / c^2

(iii) Higgs sector

New (scalar) field is introduced;
Needed to break (hide) the electroweak symmetry

⇒ **Higgs particle**

Theoretical arguments: $m_H < \sim 1000$ GeV/c^2

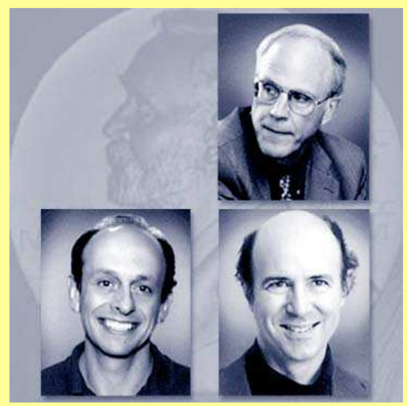
Theoretical description:

Gauge theories of electroweak and Strong interactions

(i) Electroweak theory

S. Glashow
A. Salam
S. Weinberg

(ii) Quantum Chromodynamics



D.J. Gross
H.D. Politzer
F.E. Wilcek

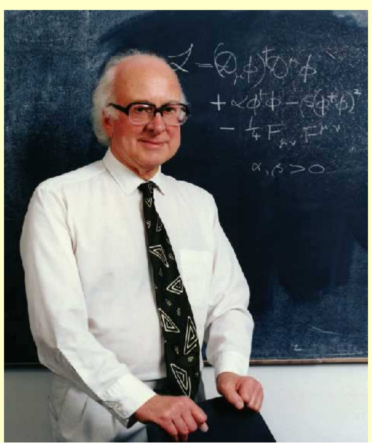
Problem: symmetry requires massless gauge bosons

Where do we stand today?

e^+e^- colliders LEP at CERN and SLC at SLAC + the Tevatron pp collider
+ HERA at DESY + many other experiments (fixed target…….)
have explored the energy range up to **~100 GeV** with incredible precision

- The Standard Model is consistent with all experimental data !
- No Physics Beyond the SM observed
  (except clear evidence for neutrino masses)
- No Higgs seen (yet)

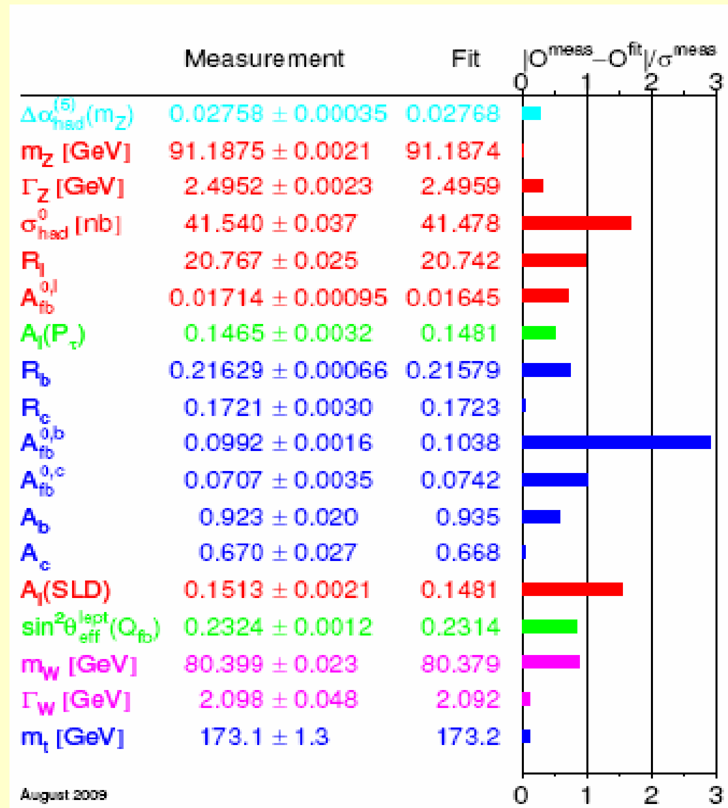
<u>Direct searches</u>: (95% CL limits)
$m_H > 114.4$ GeV/c^2
$m_H < 160$ GeV/c^2 or $m_H > 170$ GeV/c^2



Only unambiguous example of observed Higgs

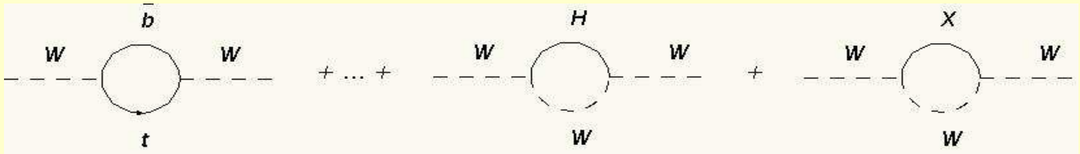
(P. Higgs, Univ. Edinburgh)

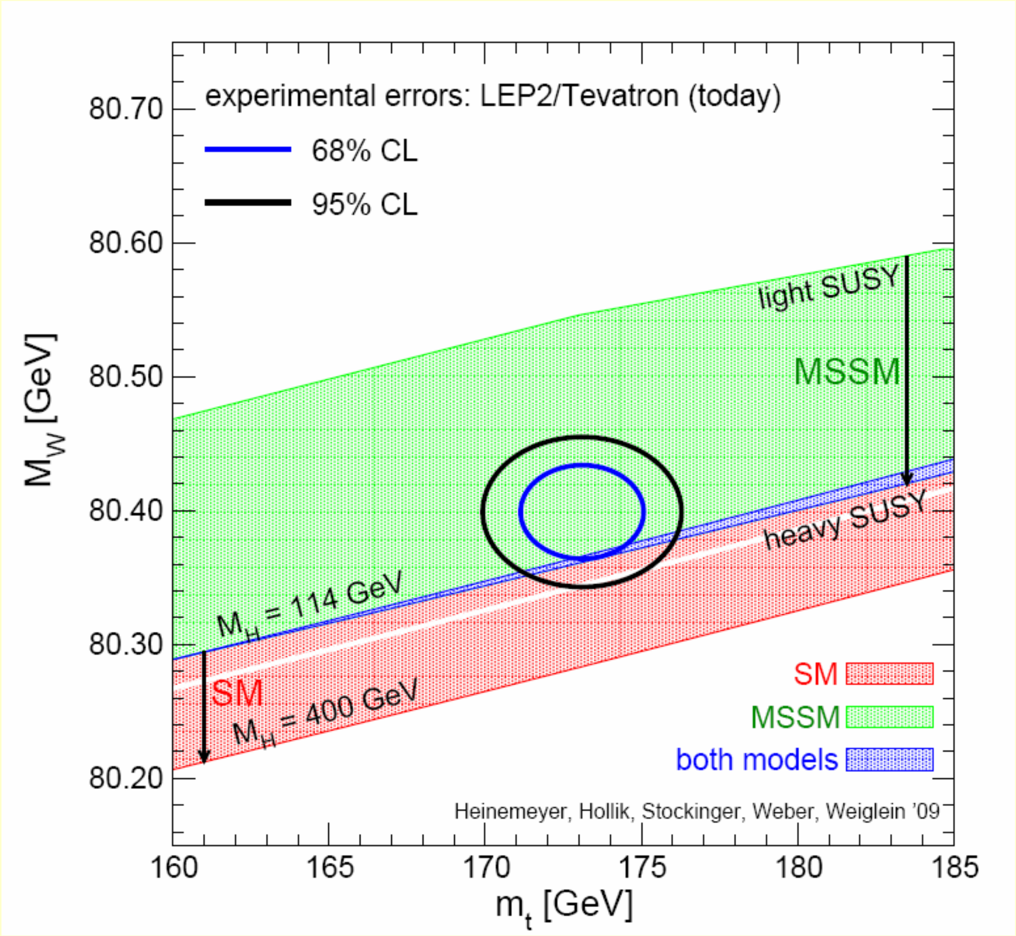
Summer 2009



Consistency with the Standard Model

Sensitivity to the Higgs boson and other new particles via quantum corrections:





The Open Questions

Key Questions of Particle Physics

1. Mass: What is the origin of mass?

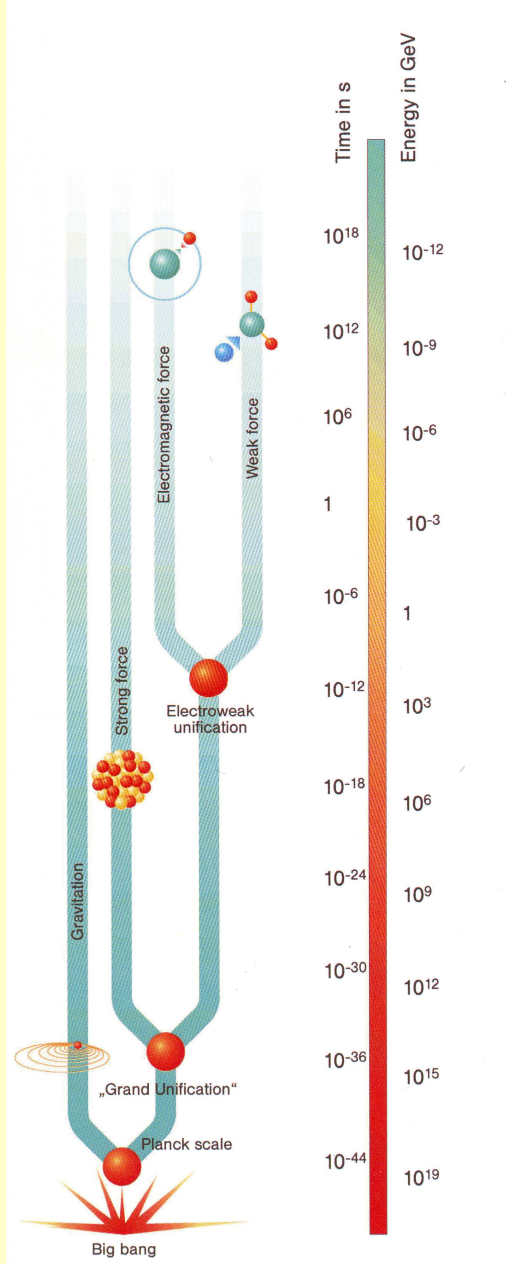
- How is the electroweak symmetry broken ?
- Does the Higgs boson exist ?

2. Unification: What is the underlying fundamental theory ?

- Can the interactions be unified at larger energy?
- How can gravity be incorporated ?
- Is our world supersymmetric ?
- ….

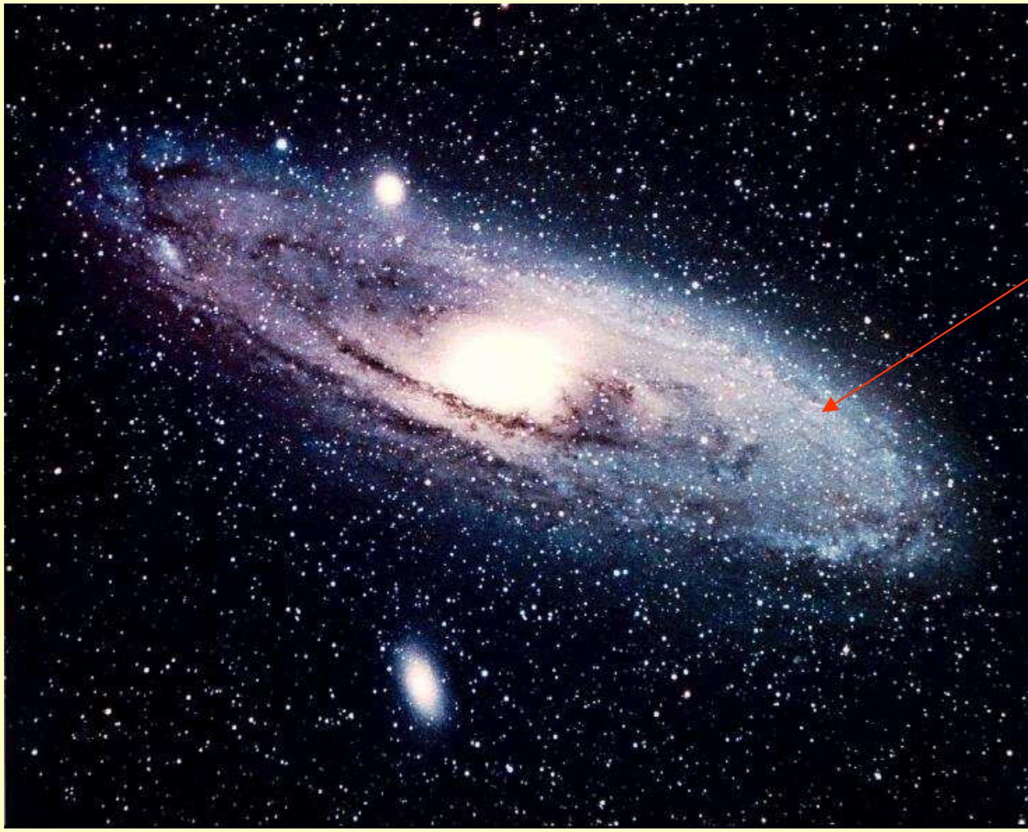
3. Flavour: or the generation problem

- Why are there three families of matter?
- Neutrino masses and mixing?
- What is the origin of CP violation?



Answers to some of these questions are expected on the TeV energy scale

Problems at a larger scale



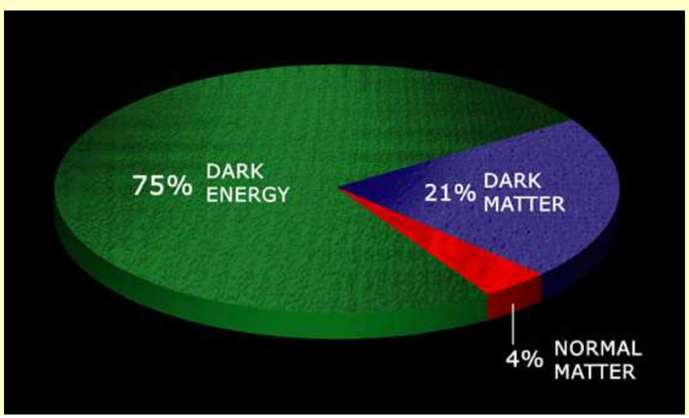
We are here

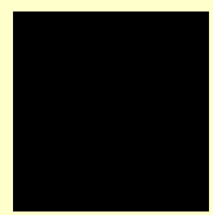
Surrounded by

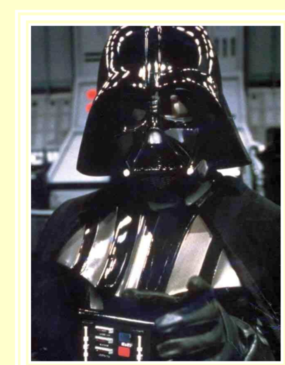
- Mass
  (planets, stars, ….,hydrogen gas)

- **Dark Matter**

- **Dark Energy**







The role of the LHC

1. Explore the TeV mass scale

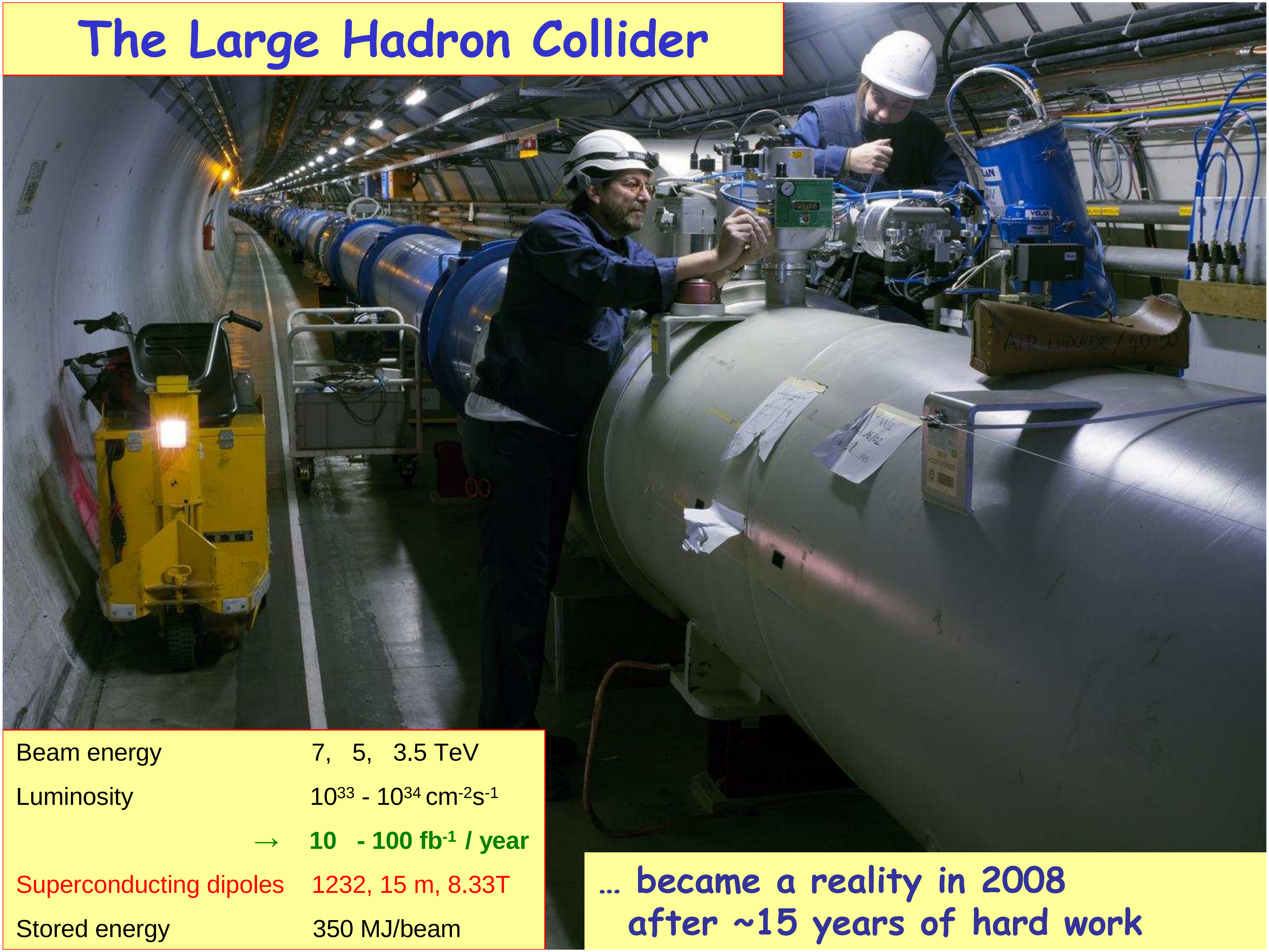
- What is the origin of the electroweak symmetry breaking ?
- The search for “low energy” supersymmetry
- Other scenarios beyond the Standard Model
- …….

Look for the “expected”, but we need to be open for surprises

2. Precise tests of the Standard Model

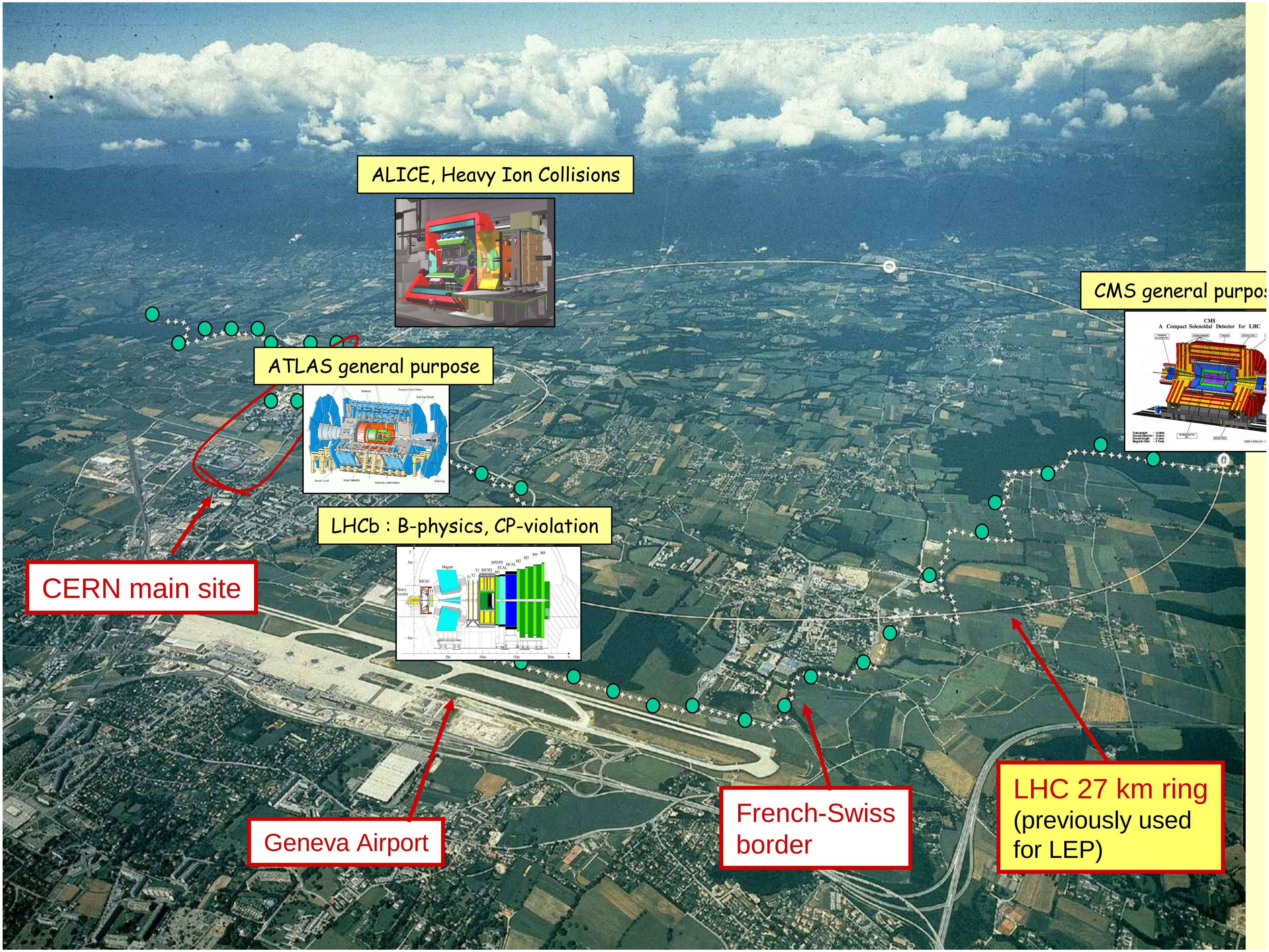
- There is much sensitivity to Physics Beyond the Standard Model in the precision area

The Large Hadron Collider

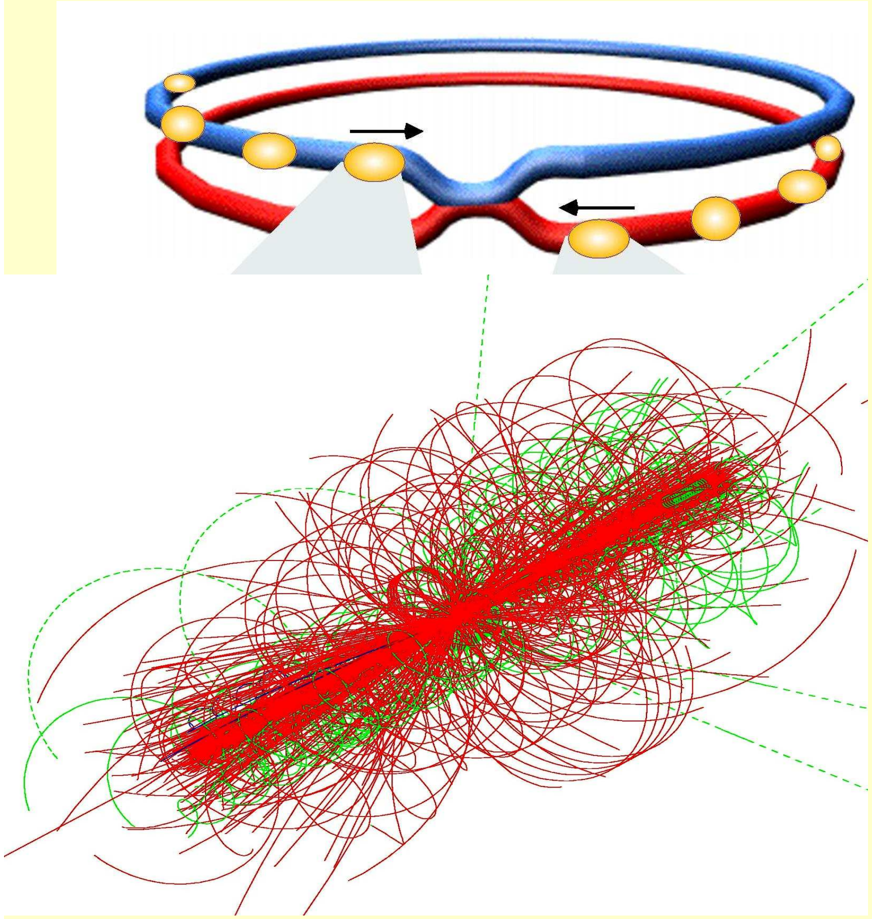


Beam energy	7, 5, 3.5 TeV
Luminosity	10^{33} - 10^{34} cm^{-2}s^{-1}
→	**10 - 100 fb^{-1} / year**
Superconducting dipoles	1232, 15 m, 8.33T
Stored energy	350 MJ/beam

… became a reality in 2008
after ~15 years of hard work


ALICE, Heavy Ion Collisions
CMS general purpos
ATLAS general purpose
LHCb : B-physics, CP-violation
CERN main site
Geneva Airport
French-Swiss border
LHC 27 km ring
(previously used for LEP)

Proton proton collisions at the LHC



Proton – proton:

2835 x 2835 bunches
Separation: 7.5 m (25 ns)

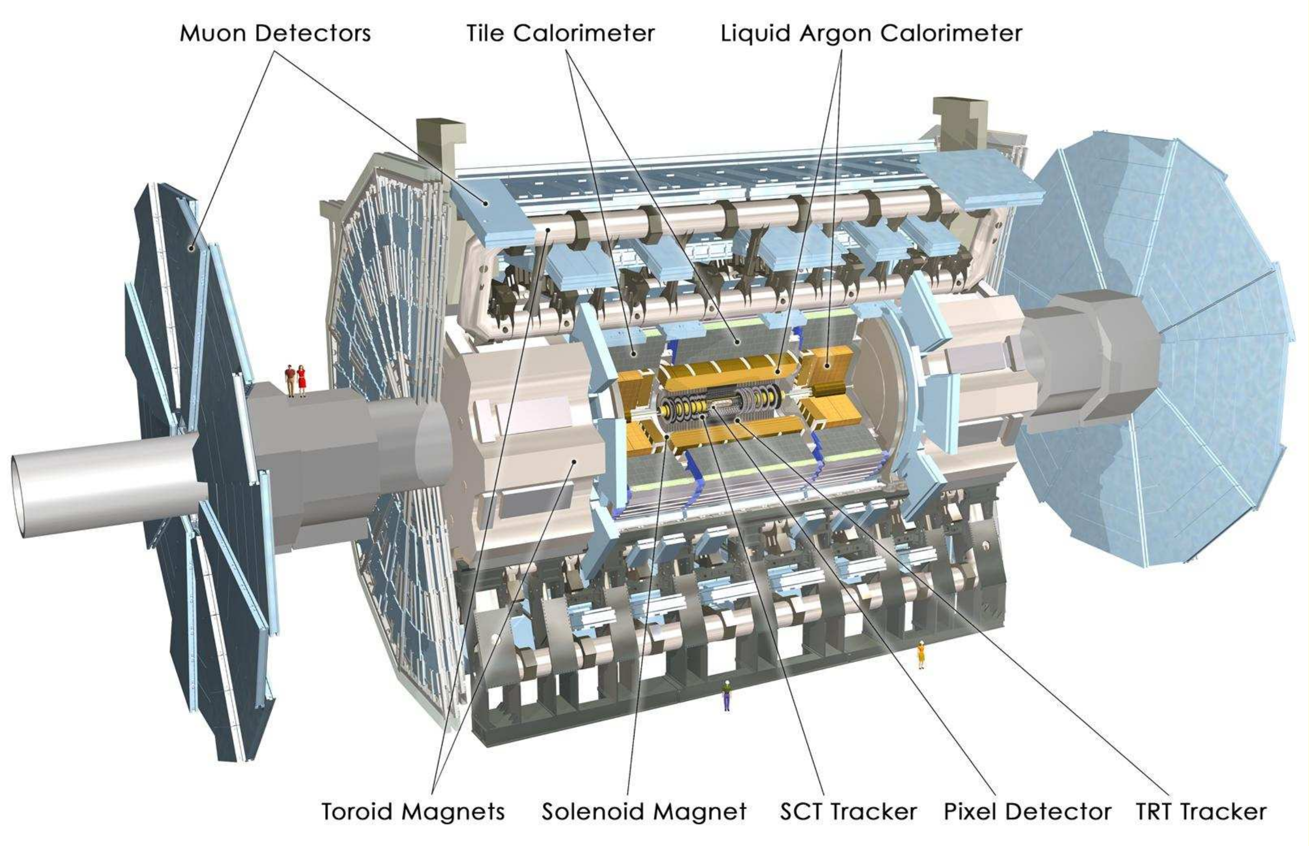
10^{11} protons / bunch
Crossing rate of p-bunches: 40 Mio. / s
Luminosity: $L = 10^{34}$ cm^{-2} s^{-1}

~10^9 pp collisions / s
(superposition of 23 pp-interactions
per bunch crossing: **pile-up**)

~1600 charges particles in the detector

⇒ high particle densities
high requirements for the detectors

The ATLAS experiment



- Solenoidal magnetic field (2T) in the central region (momentum measurement)

  High resolution silicon detectors:
  - 6 Mio. channels (80 μm x 12 cm)
  - 100 Mio. channels (50 μm x 400 μm)

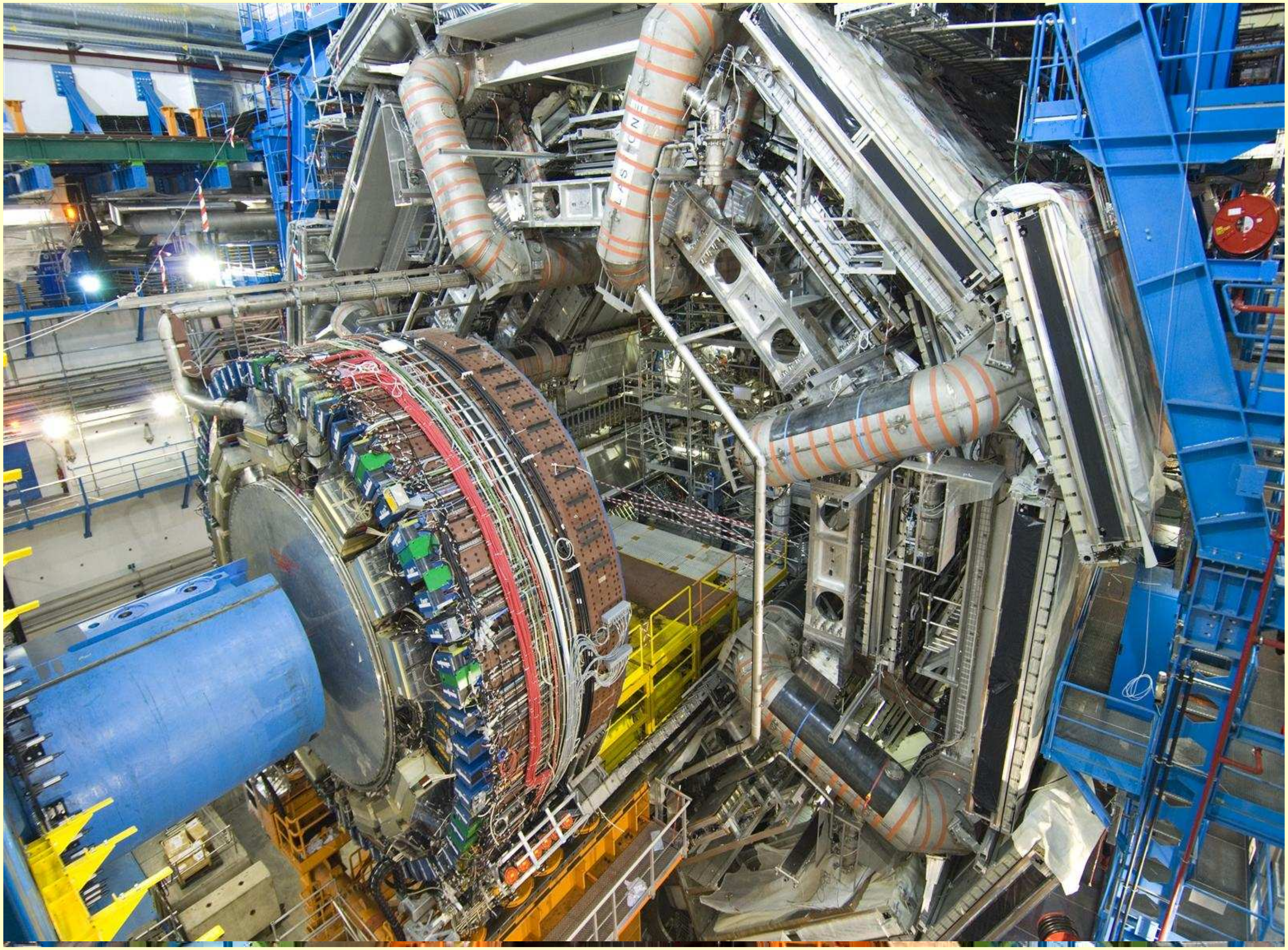
  space resolution: ~ 15 μm

- Energy measurement down to 1º to the beam line

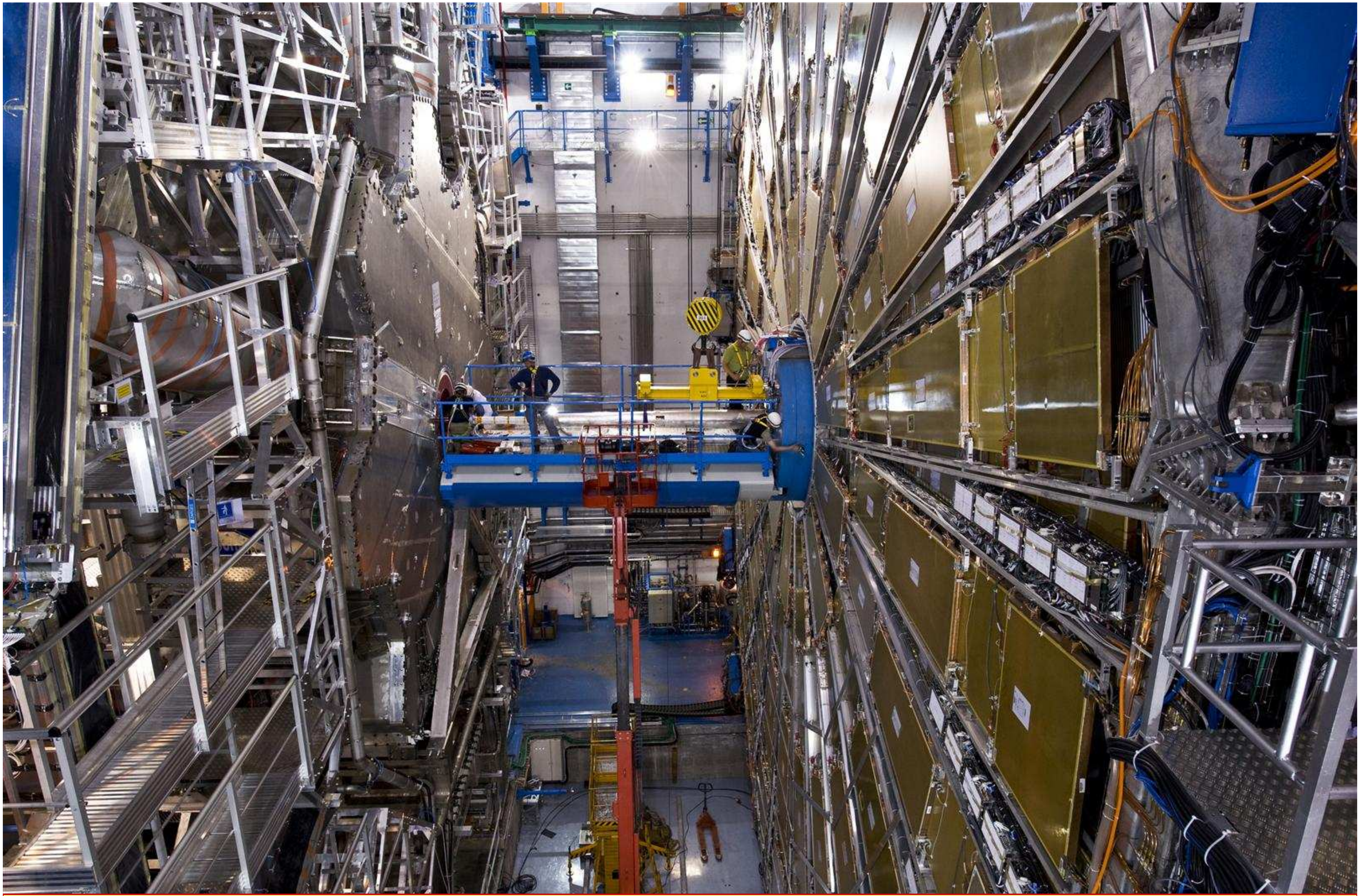
- Independent muon spectrometer (supercond. toroid system)

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

ATLAS Installation

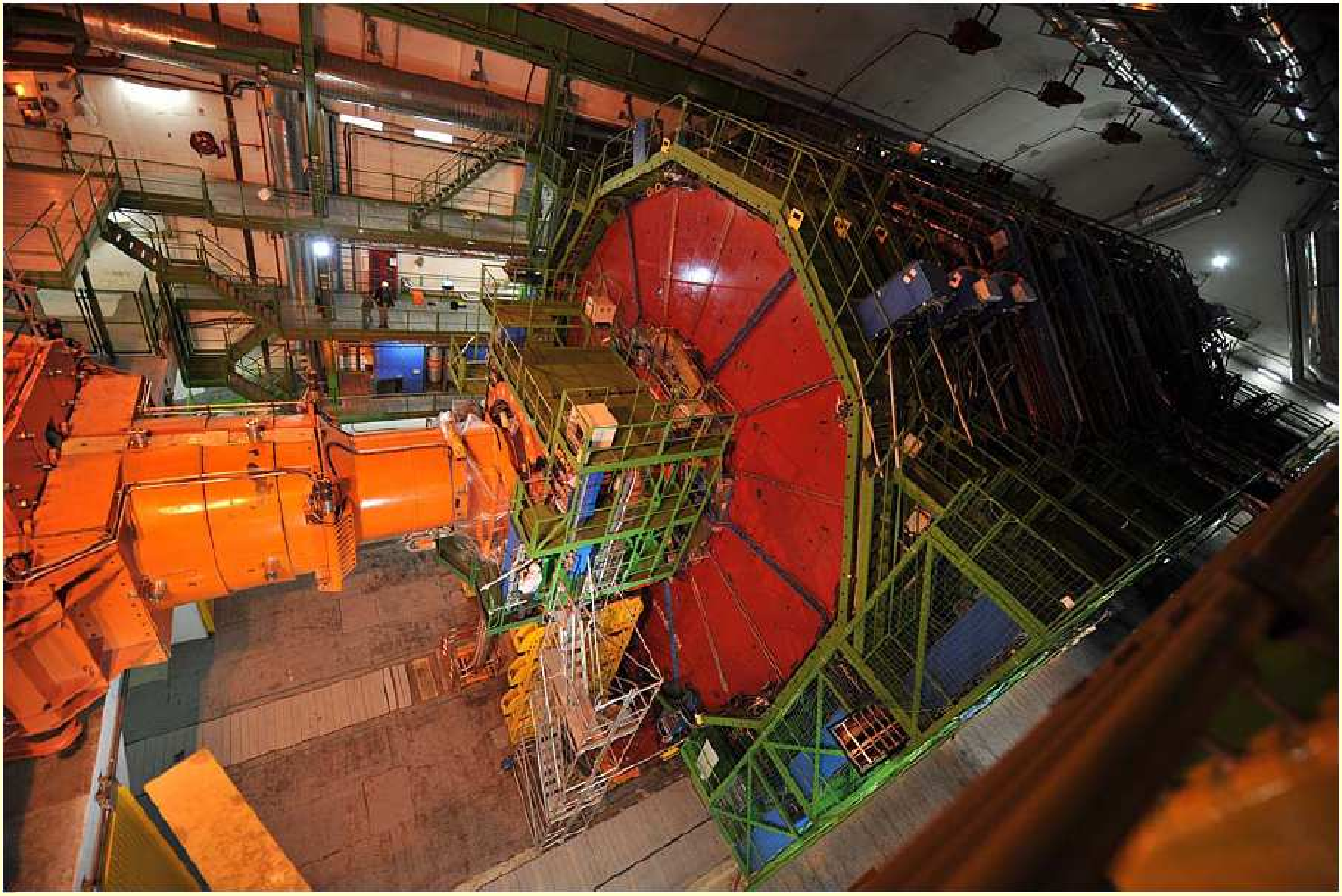


October 2006

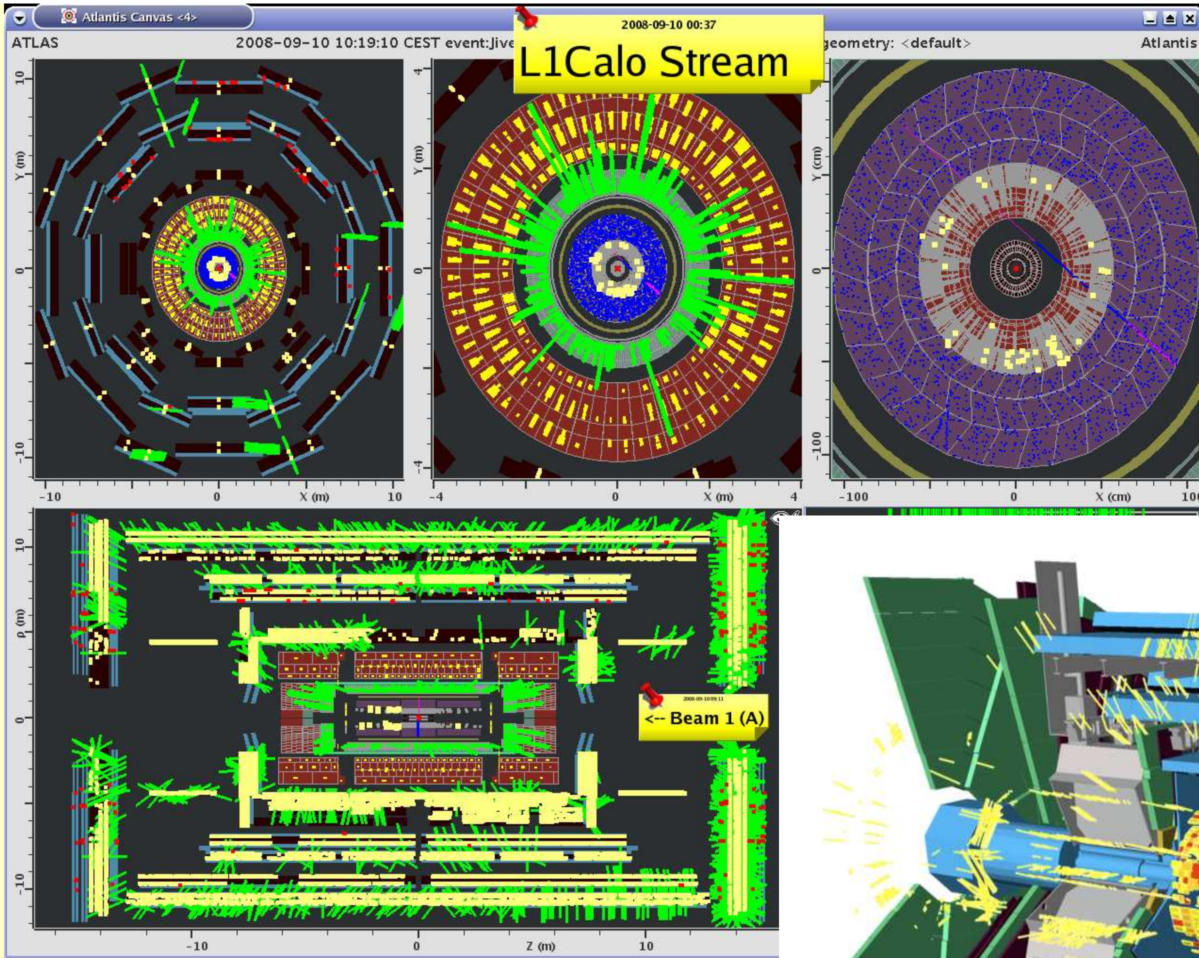


A historical moment:
Closure of the LHC beam pipe ring on 16th June 2008
ATLAS was ready for data taking in August 2008

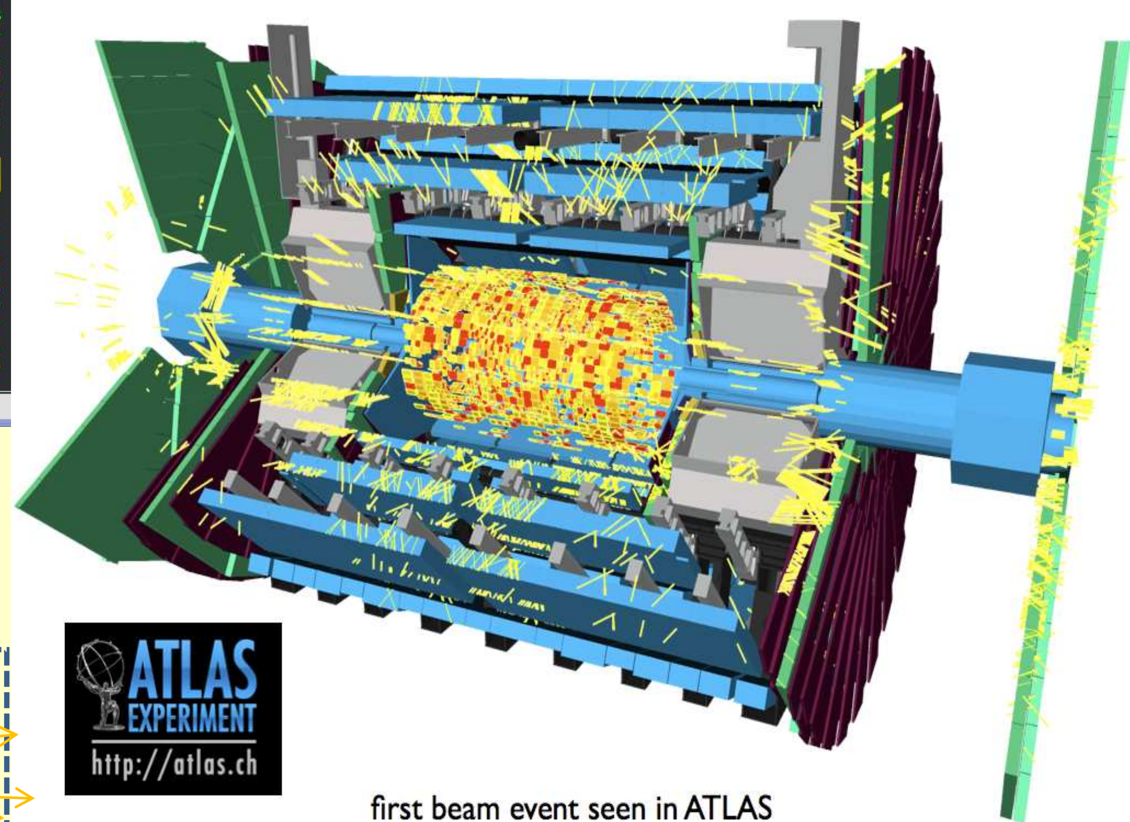
CMS Detector closed for 10th Sep. 2008



An excellent start: first beams – September 10, 2008

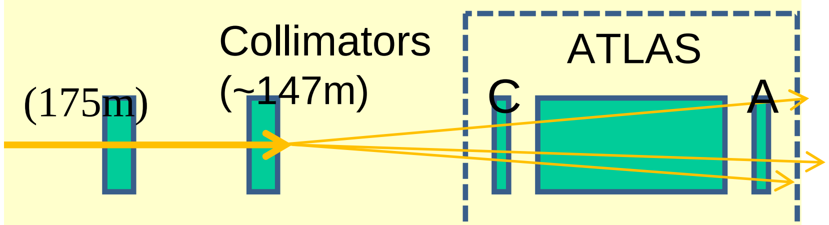


The very first beam-splash event from the LHC in ATLAS on 10th September 2008, 10:19



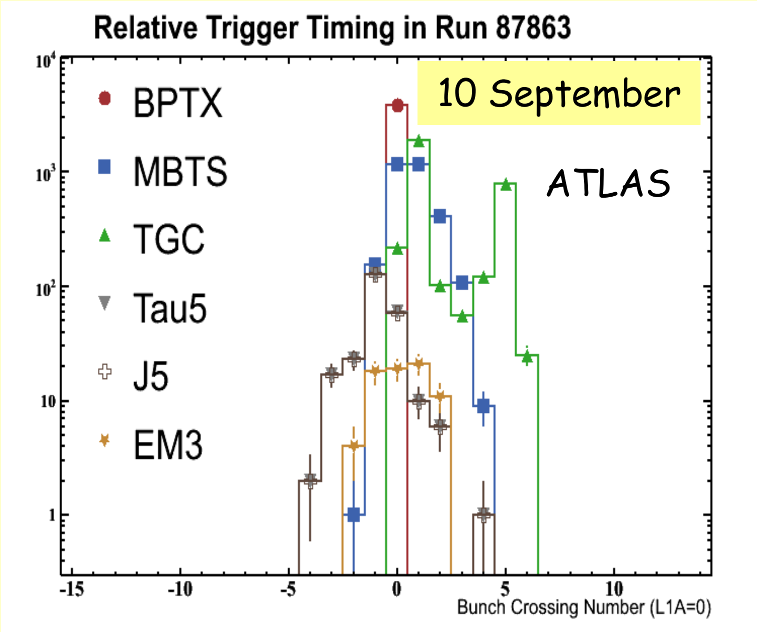
ATLAS EXPERIMENT
http://atlas.ch

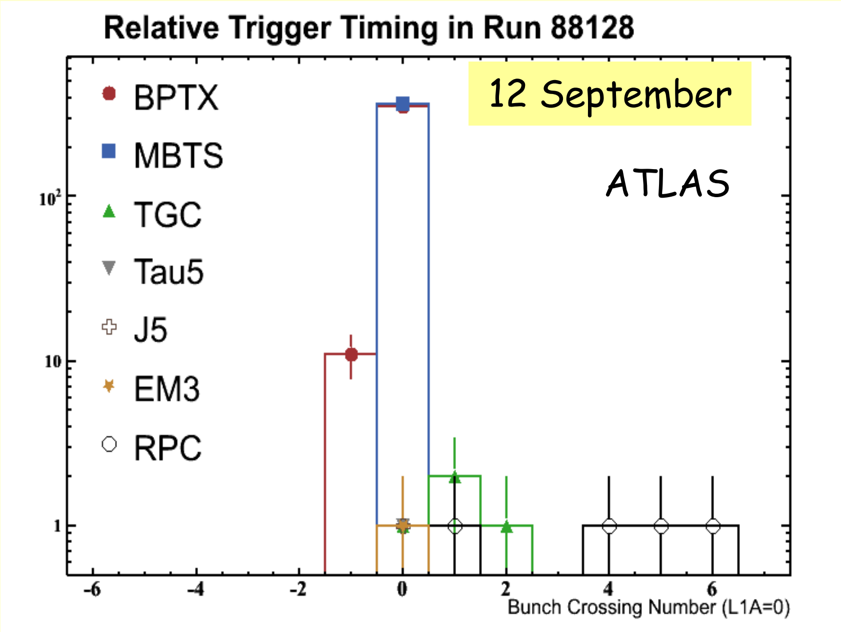
first beam event seen in ATLAS



Trigger timing with beam splash events

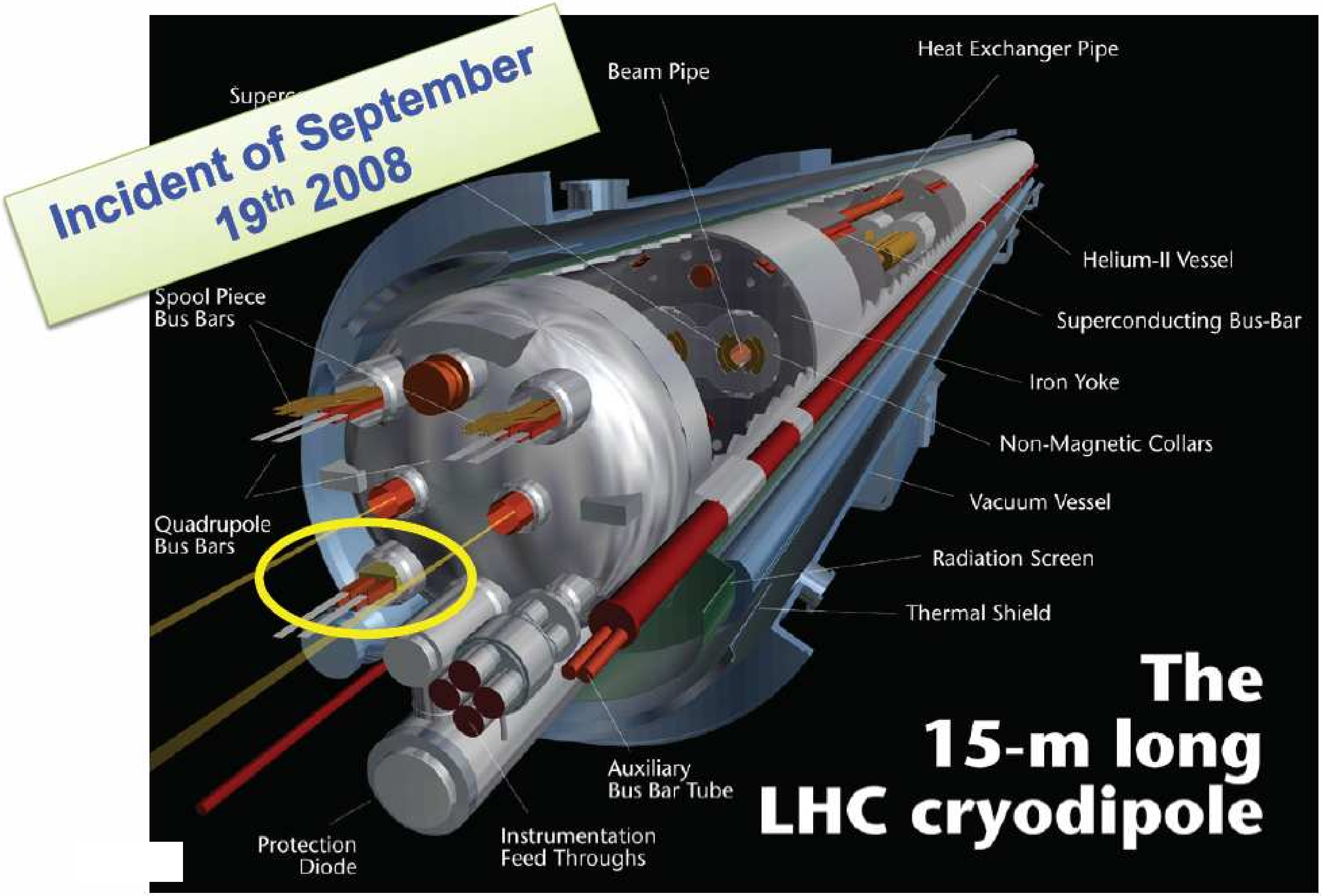
Few days of beam halo and splash events helped enormously to adjust timing of different triggers





1 bunch crossing number = 25 ns

Development of resistive zone in dipole bus bar splice



Diagnose, repair, comeback…..

- A resistive zone developed in an electrical bus bar connection
- Electrical arc → punctured the helium enclosure
- Helium release under high pressure
- Relief discs unable to maintain the pressure rise below 0.15 MPa

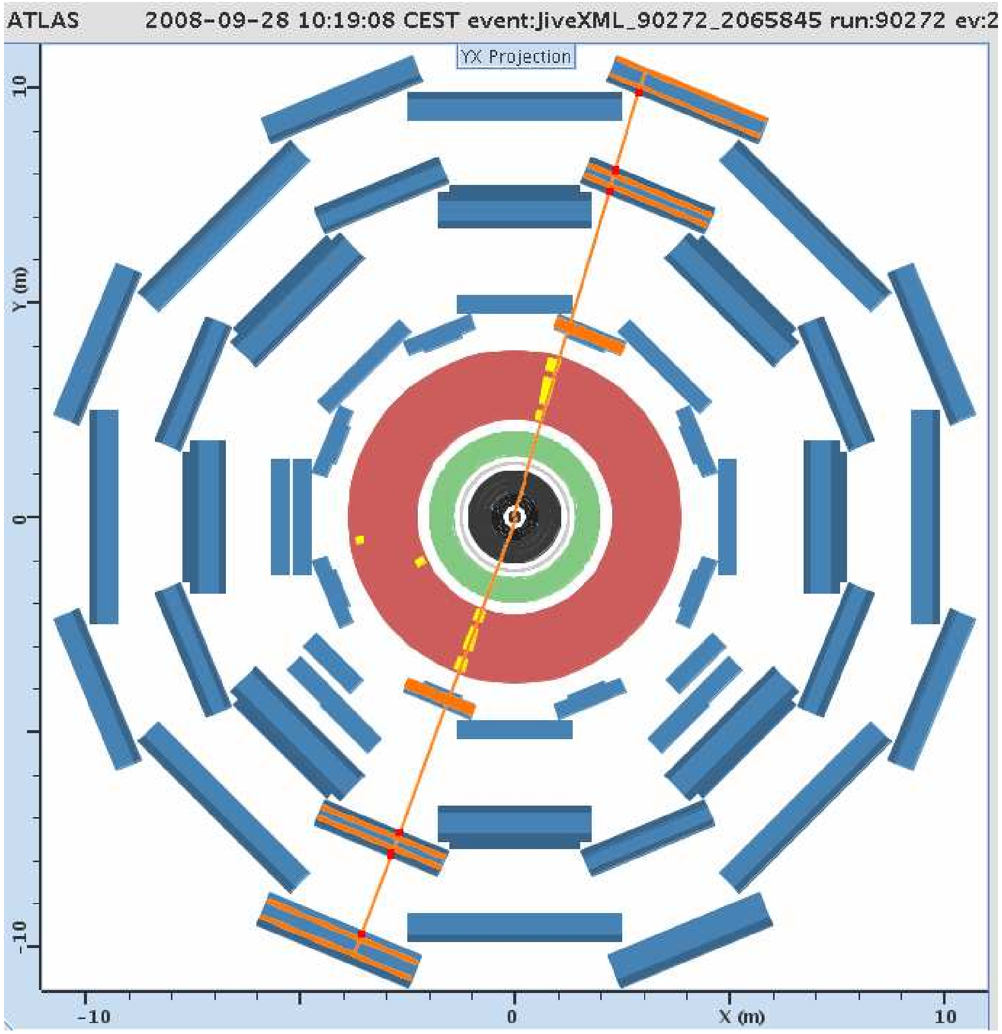
  → large pressure forces

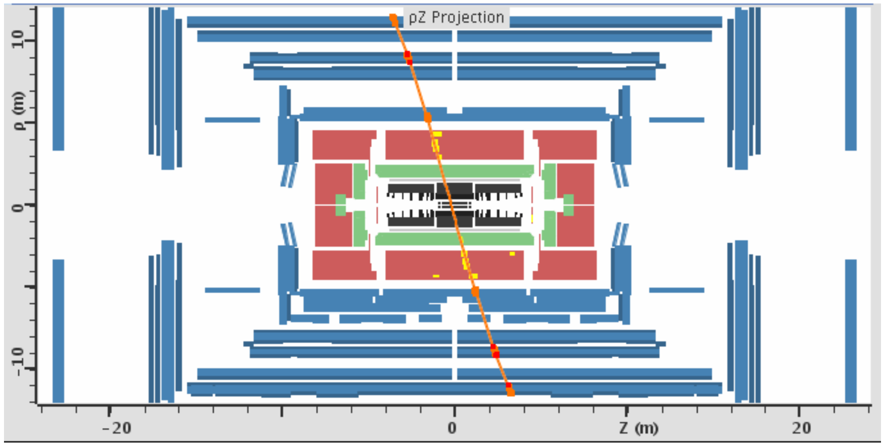
- Lot of repair work ongoing since then
  (14 quadrupole and 39 dipole magnets replaced, electrical interconnections repaired, larger helium pressure release ports installed,…..)

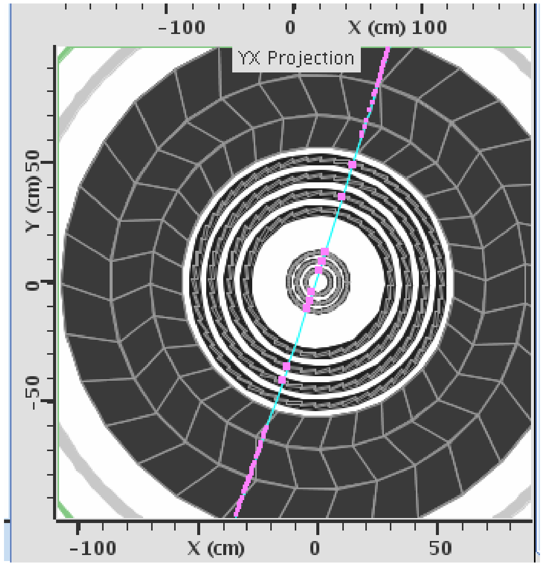
- **Startup plans (2009/10):**

  - Machine will restart in Nov. 2009
  - First collisions at injection energy at 900 GeV
  - Increase energy up to 3.5 TeV (→ 5 TeV)
  - Collect data corresponding to ~200 pb^{-1}

ATLAS Commissioning



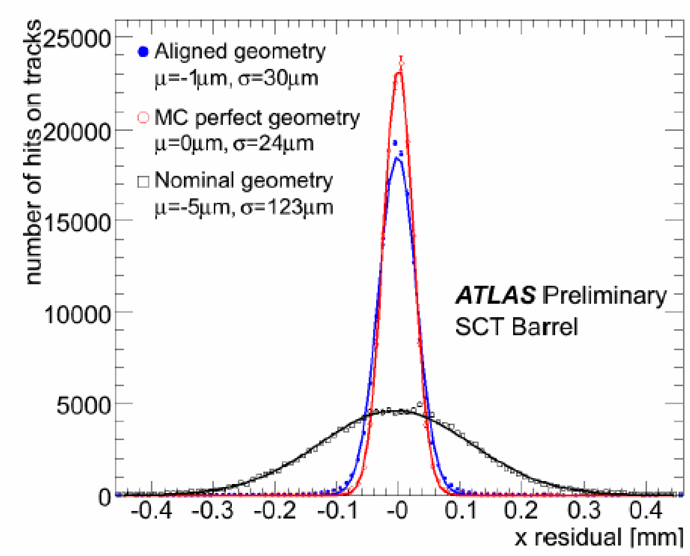


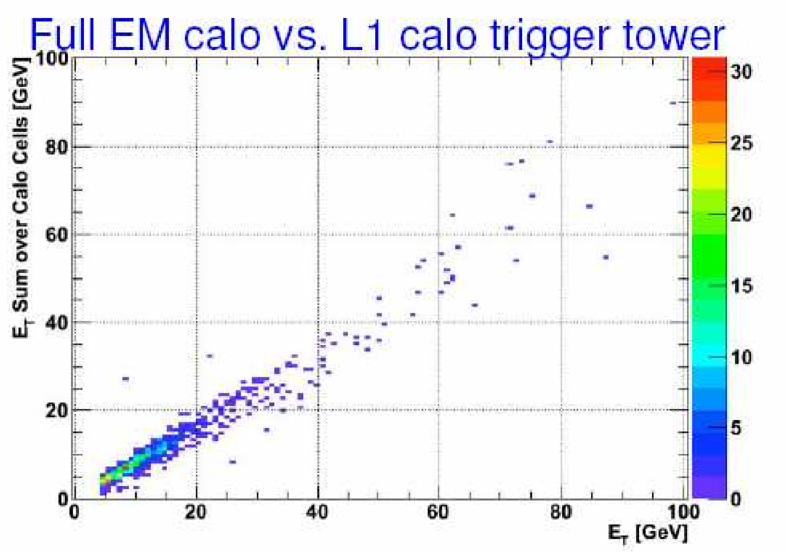


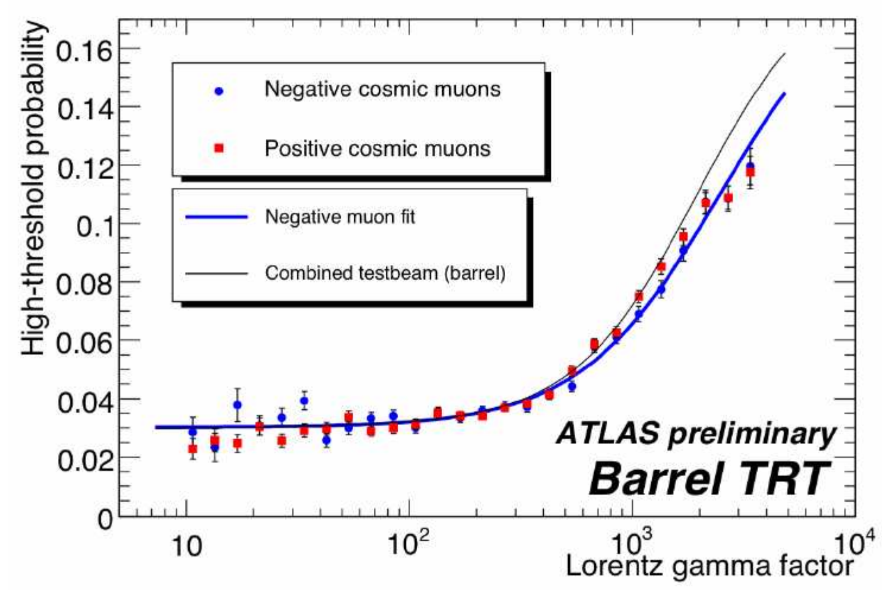
with cosmic rays....

ATLAS Commissioning (cont.)

- About 216 Mio. cosmic ray events recorded;
- Efficiencies and noise conditions of all sub-detectors are within specifications, and >99% of channels are working for most systems;
- Detectors have been aligned with high precision, better than expected for day one;
- Valuable experience gained on trigger and reconstruction algorithms....





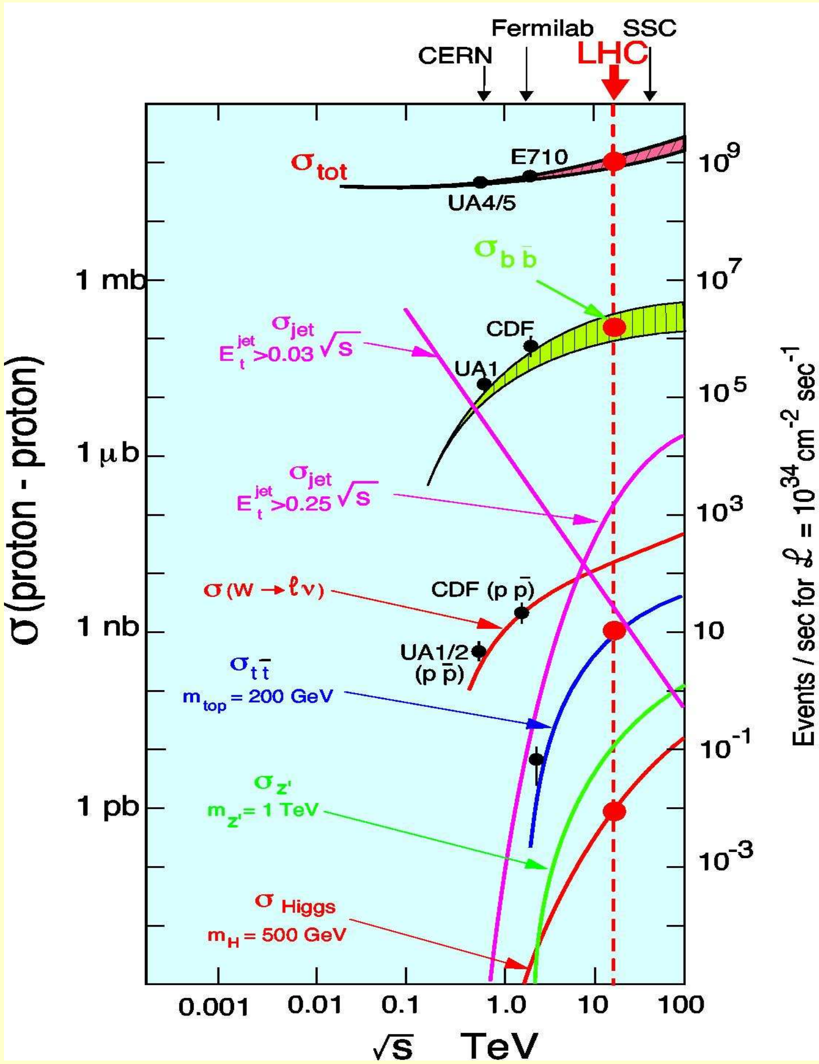


Towards First

Physics Results

in 2009/2010

Cross-sections and Production Rates, the first 10 pb^{-1}



Events for 10 pb^{-1}, $\sqrt{s}$ = 14 TeV

Inelastic pp (minimum bias events)	**large (prescaled)**
W → e ν **Z → ee**	**10^5** **10^4**
tt → eνb qqb	**10^3**
Higgs (130 GeV) **Gluinos (1 TeV)**	**10** **1**

Physics with 10 – 100 pb^{-1}:

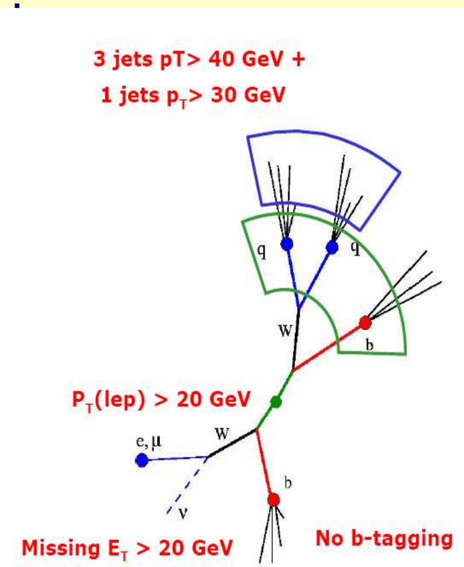
- Establish Standard Model signals
- Use them for calibration
  (tag and probe methods,….)
- Tune Monte Carlos

- Basic SM cross section measurements
- Look for surprises
  (e.g. high mass di-lepton resonances,…
  ….., black holes)

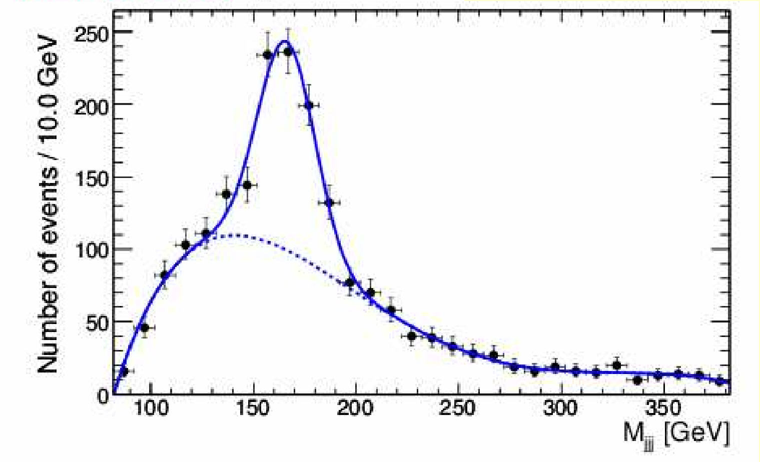
W/Z and top signals

Even with early data (10-50 pb^{-1}) at $\sqrt{s}$ = 7 TeV.
high statistics of W / Z and top samples

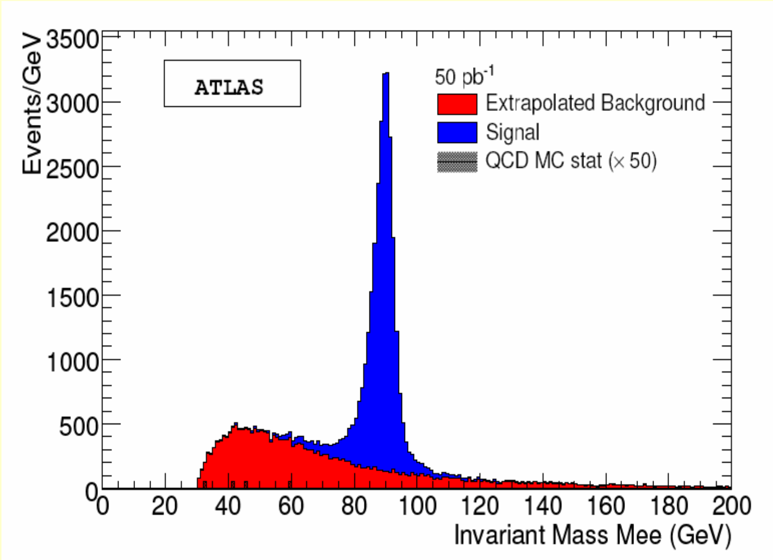
⇒ Establish performance for leptons, jets, missing transverse energy, ….., b-tagging



$t\bar{t} \rightarrow \ell\nu b\ qqb$



Z → ee



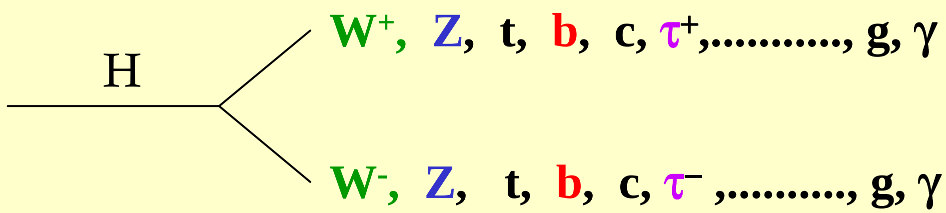
The Search for

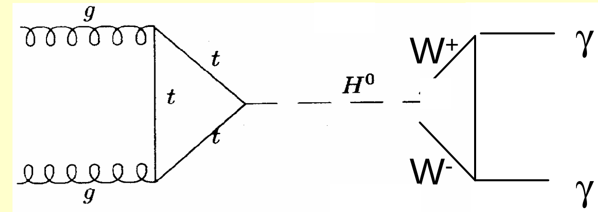
The first Higgs at ATLAS

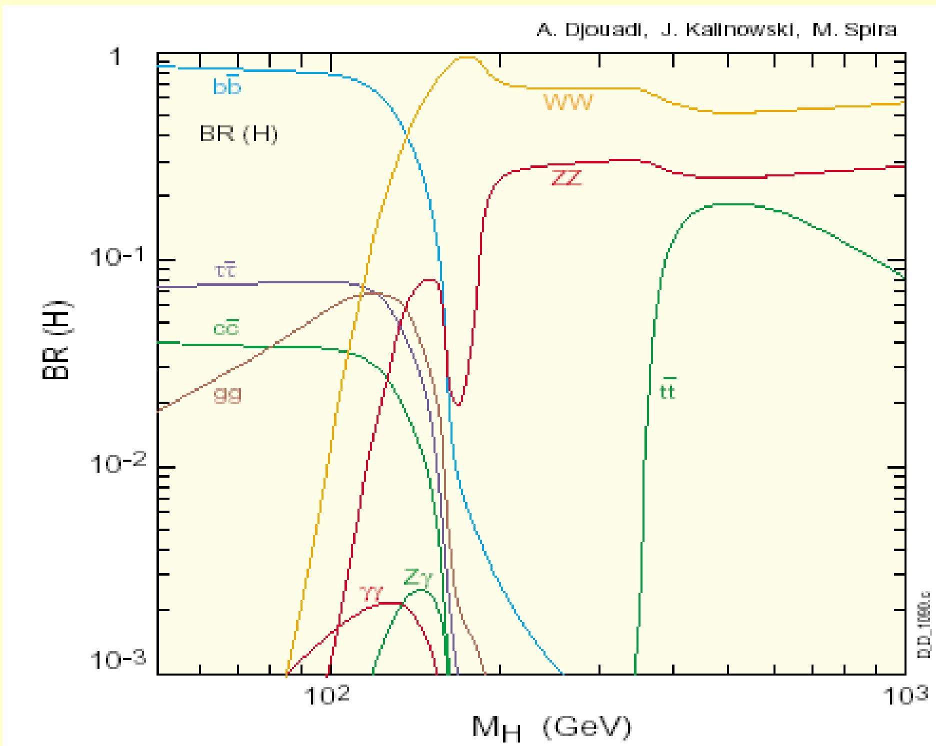
The Higgs boson

Decays of the Higgs Boson

Decay characteristics are known, as soon as the mass is known:





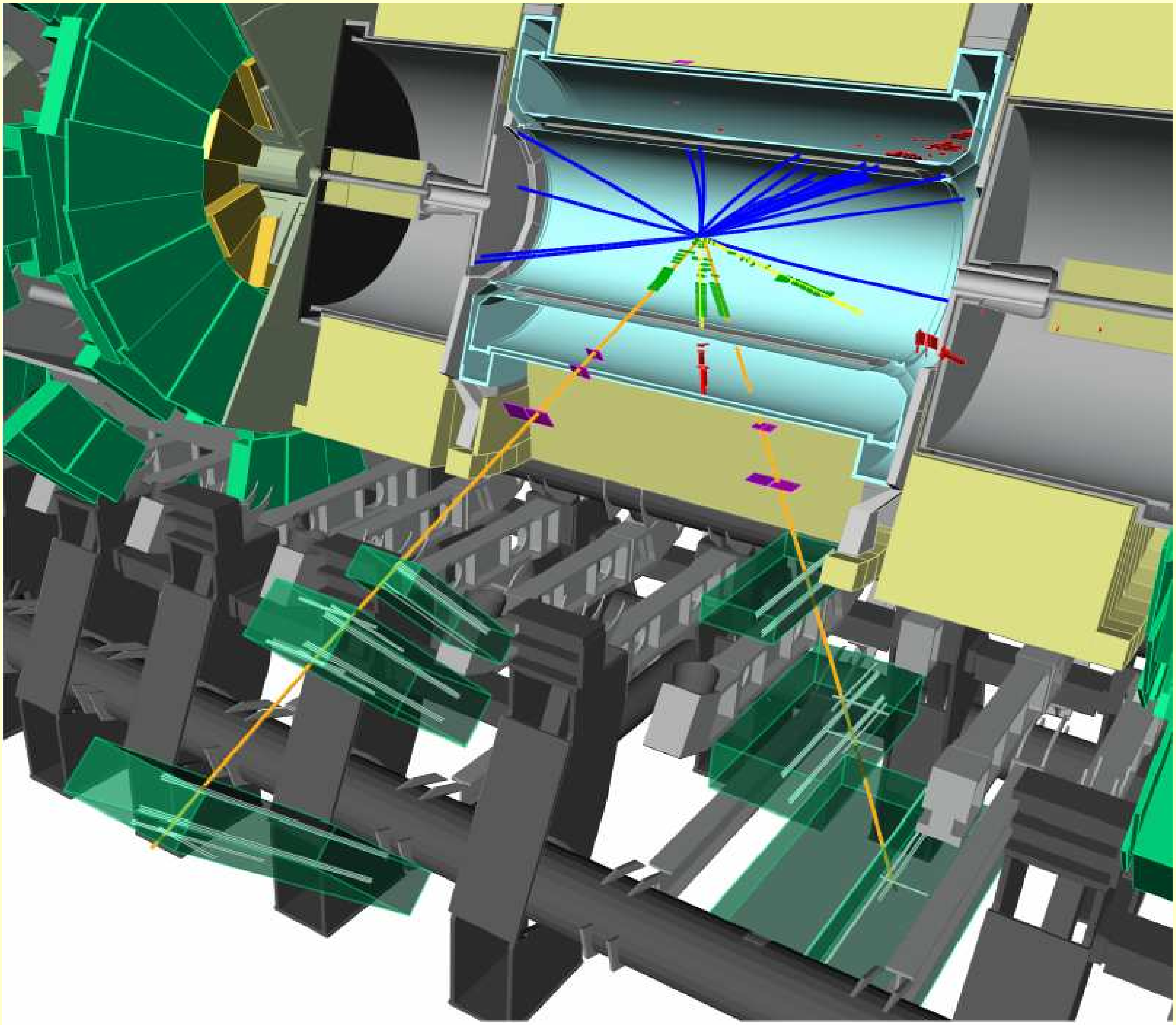


Important decays at hadron colliders:

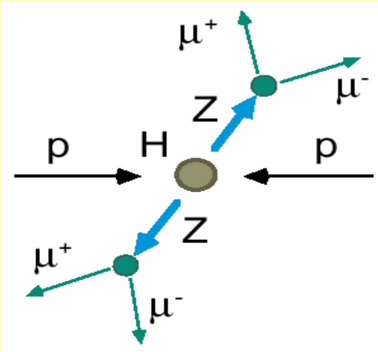
Final states with leptons or photons
(via $H \rightarrow WW$, ZZ or $H \rightarrow \gamma\gamma$)

The dominant **bb decays** in the low mass region are very difficult to detect
(due to the large background from jet production via QCD processes)

A simulated H → ZZ → ee μμ event



$H \rightarrow ZZ^{(*)} \rightarrow \ell\ell\ell\ell$



Signal: Decay via two Z bosons into four leptons

Background: Top production: $tt \rightarrow Wb\ Wb \rightarrow \ell\nu\ c\ell\nu\ \ell\nu\ c\ell\nu$

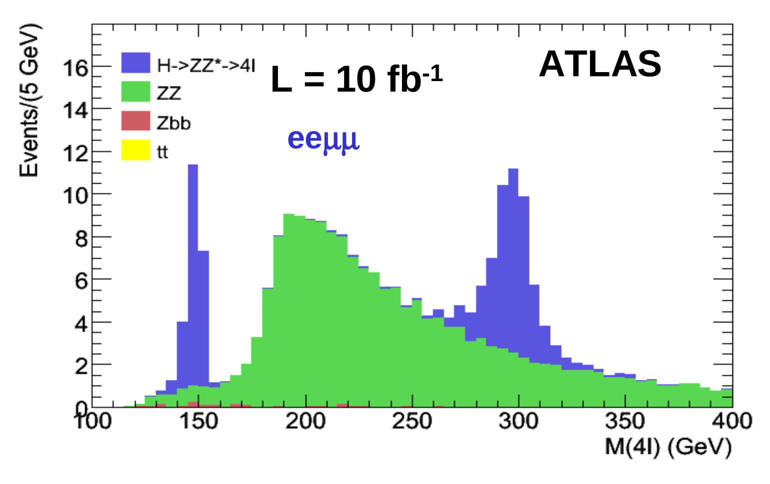
Associated Zbb production: $Z\ bb \rightarrow \ell\ell\ c\ell\nu\ c\ell\nu$

$P_T(1,2) > 20$ GeV
$P_T(3,4) > 7$ GeV
$|\eta| < 2.5$
Isolated leptons

Background rejection: Leptons from b-quark decays
→ non isolated
→ do not originate from primary vertex
(B-meson lifetime: ~ 1.5 ps)

Dominant background after isolation cuts: ZZ continuum

$M(\ell\ell) \sim M_Z$
$M(\ell'\ell') \sim < M_Z$

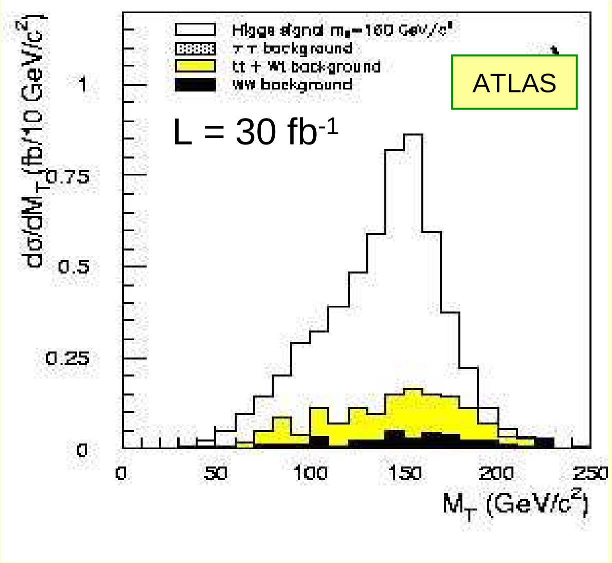


Discovery potential in mass range from ~130 to ~600 GeV/c^2

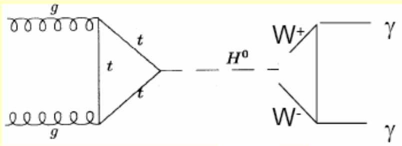
The Search for the Higgs Boson at the LHC

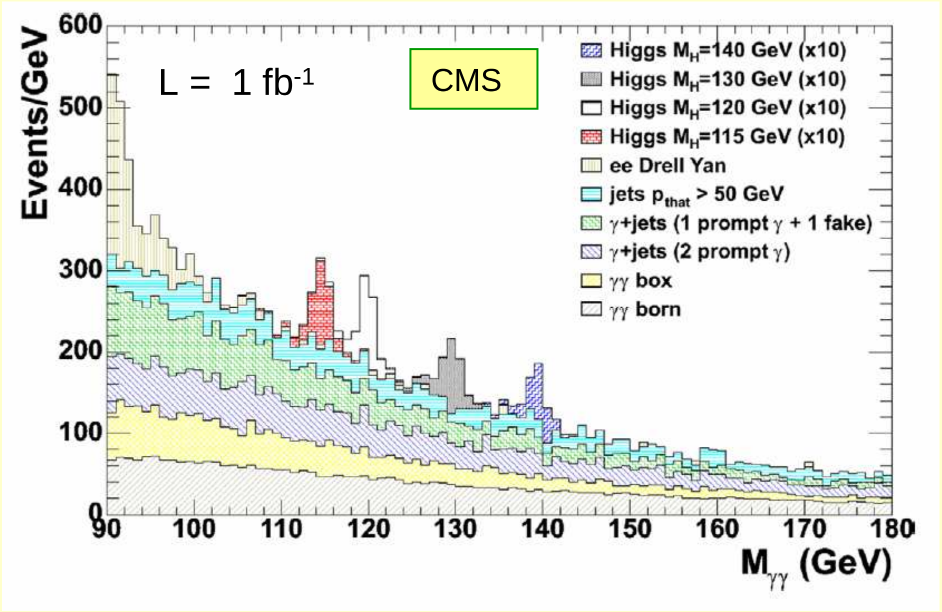
H → WW→ ℓν ℓν

$$M_T = \sqrt{(E_T^{ll} + E_T^{\nu\nu})^2 - (\vec{p}_T^{e\mu} + \vec{p}_T^{miss})^2}$$

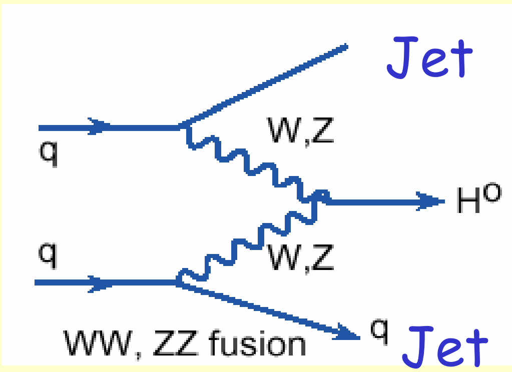


H → γγ

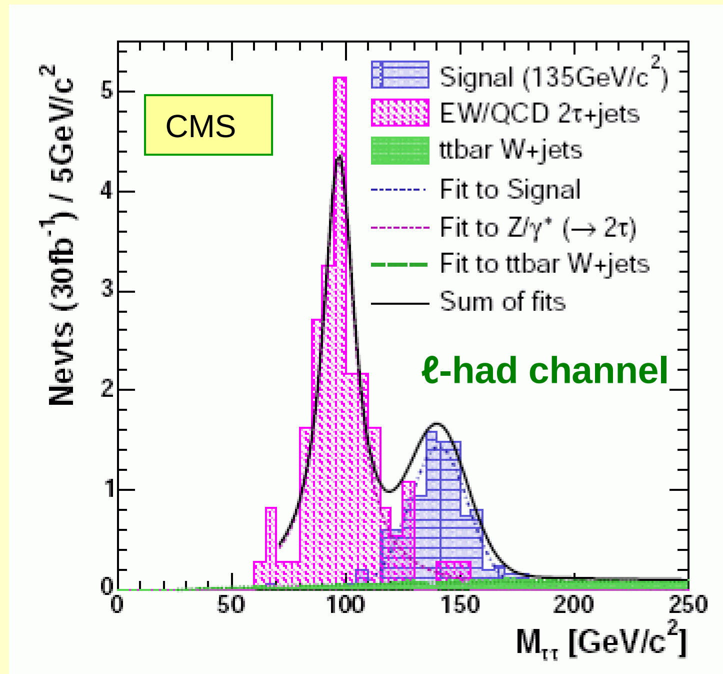




H → ττ exploiting the vector boson fusion



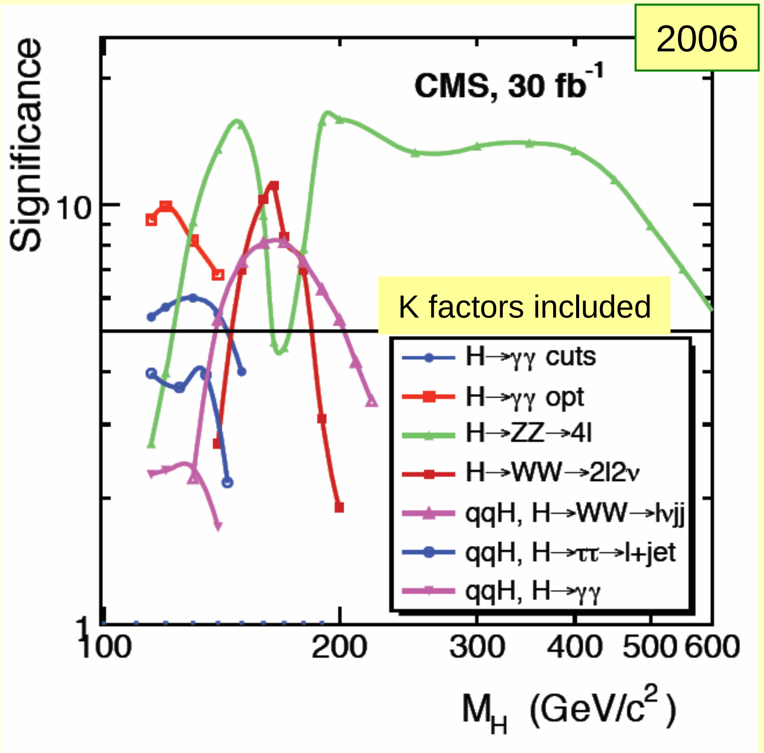
qq H → qq ττ → qq ℓνν had ν

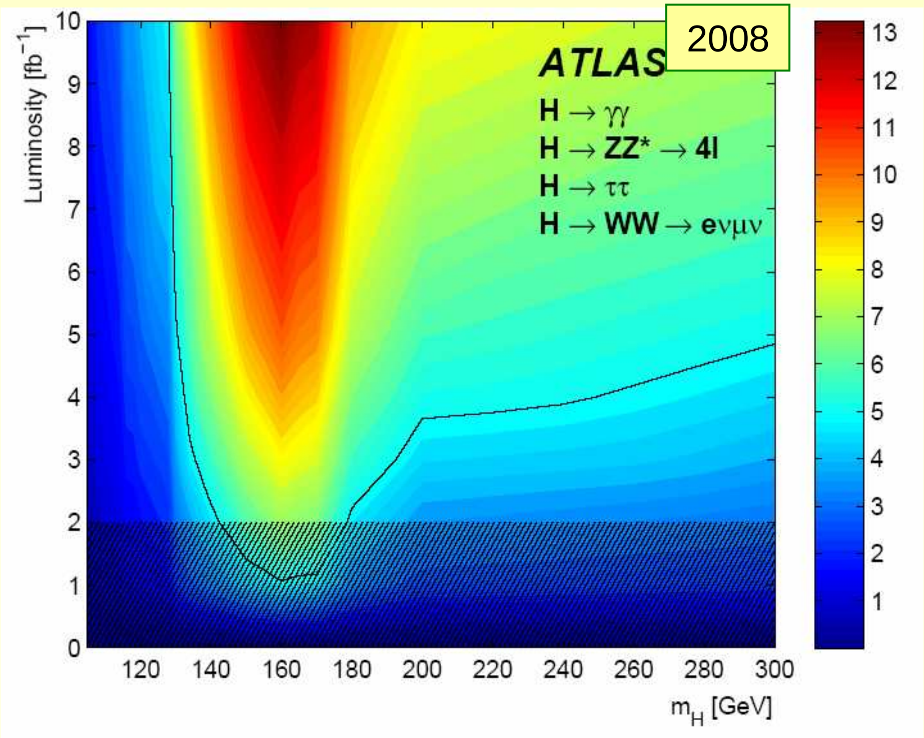


Experimental challenge:

- Identification of hadronic taus
- good E_T^{miss} resolution
  (ττ mass reconstruction in collinear approximation)
- control of the Z → ττ background shape
  in the high mass region

LHC Higgs boson discovery potential

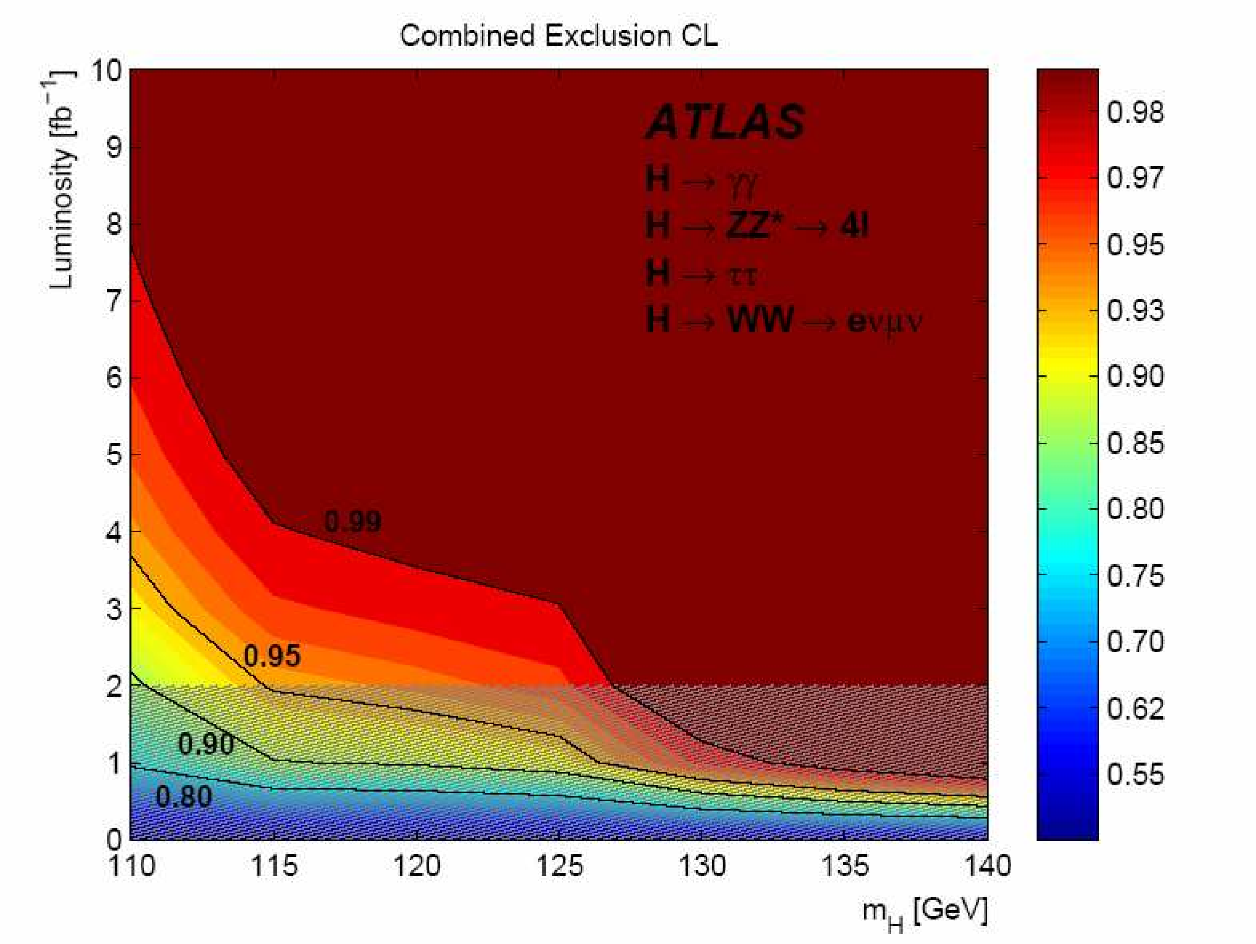




- Full mass range (up to ~ 1TeV) can be covered after a few years at low luminosity
- Several channels available over a large mass range
  [at high mass: more channels (in WW and ZZ decay modes) available than shown here]
- Comparable performance in the two experiments

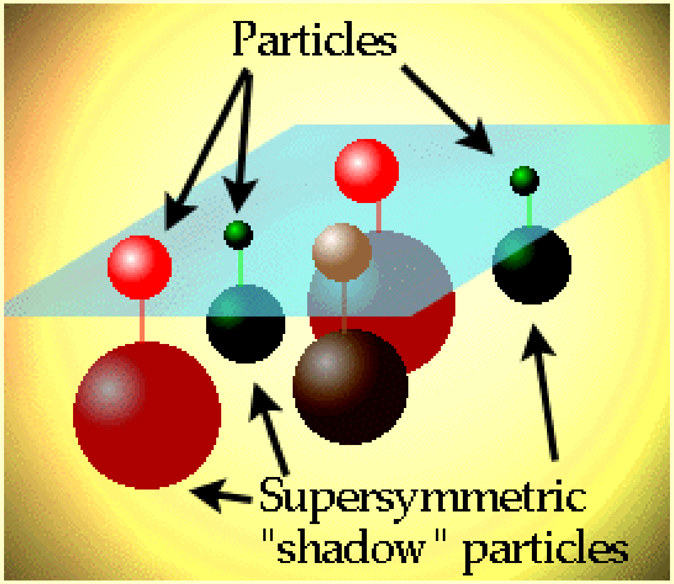
Important changes w.r.t. previous studies: **ttH → tt bb** disappeared in both ATLAS and CMS studies from the discovery plot; however, new sensitivity for bb-decay mode might be present in the associated WH → ℓν bb production, with highly boosted Higgs bosons

Luminosity required to exclude a Higgs boson with a mass m_H



Entire mass range, m_H > 115 GeV/c^2, can be covered (95% CL) by one experiment with data corresponding to an integrated luminosity of ~ 2 fb^{-1}

The Search for

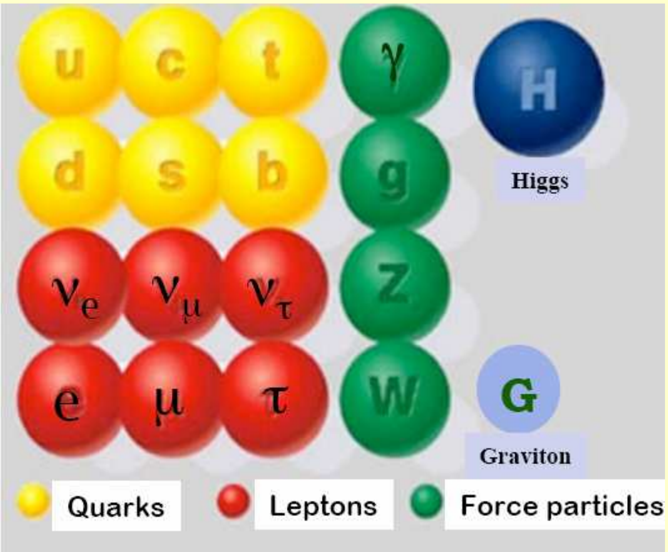


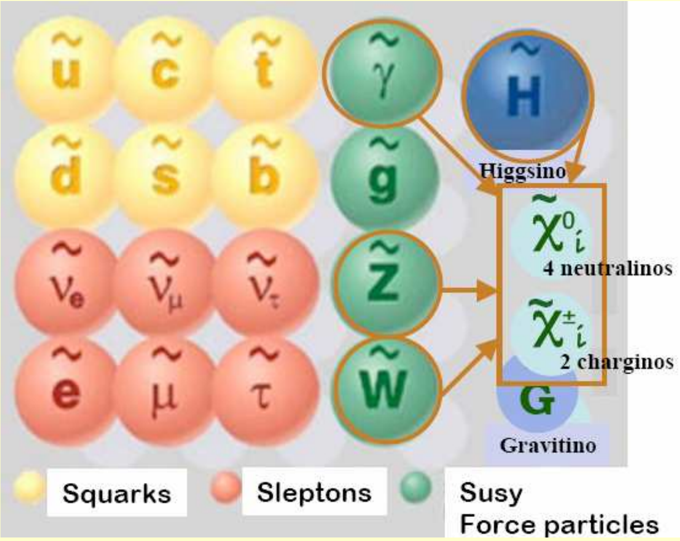
Supersymmetry

Supersymmetry

Extends the Standard Model by predicting a new symmetry
Spin ½ matter particles (fermions) ⇔ Spin 1 force carriers (bosons)

Standard Model particles | **SUSY particles**



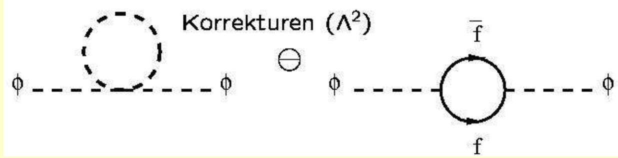


New quantum number: R-parity: $R_p = (-1)^{B+L+2s}$ = +1 SM particles
- 1 SUSY particles

R-parity conservation:
- SUSY particles are produced in pairs
- The lightest SUSY particle (LSP) is stable

Why do we like SUSY so much?

1. Quadratically divergent quantum corrections to the Higgs boson mass are avoided

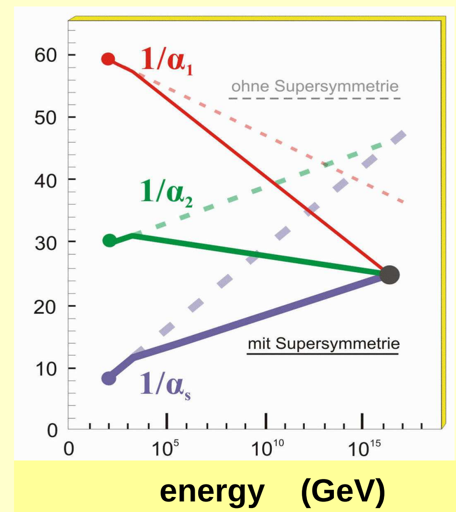


$$\Delta m_H = f(m_B^2 - m_f^2)$$

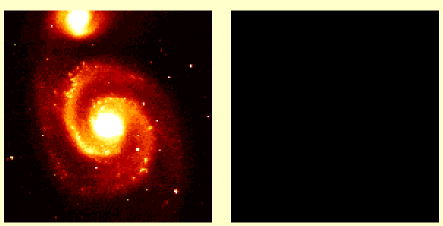
→ m_{SUSY} ~ 1 TeV

(Hierarchy or naturalness problem)

2. Unification of coupling constants of the three interactions seems possible



3. SUSY provides a candidate for dark matter,



The lightest SUSY particle (LSP)

4. A SUSY extension is a small perturbation, consistent with the electroweak precision data

Link to the Dark Matter in the Universe ?

Parameters of the SUSY model $\Rightarrow$ predictions for the relic density of dark matter

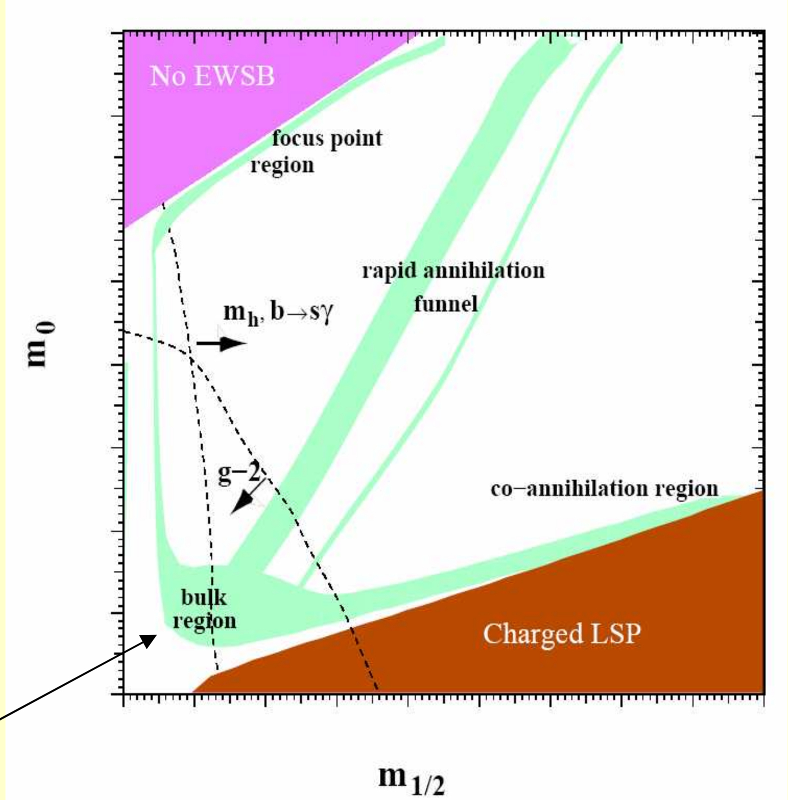
$$\rho_\chi \sim m_\chi n_\chi \,, \quad n_\chi \sim \frac{1}{\sigma_{ann}(\chi\chi \to \ldots)}$$

Interpretation in a simplified model

cMSSM
(constrained Minimal Supersymmetric
 Standard Model)

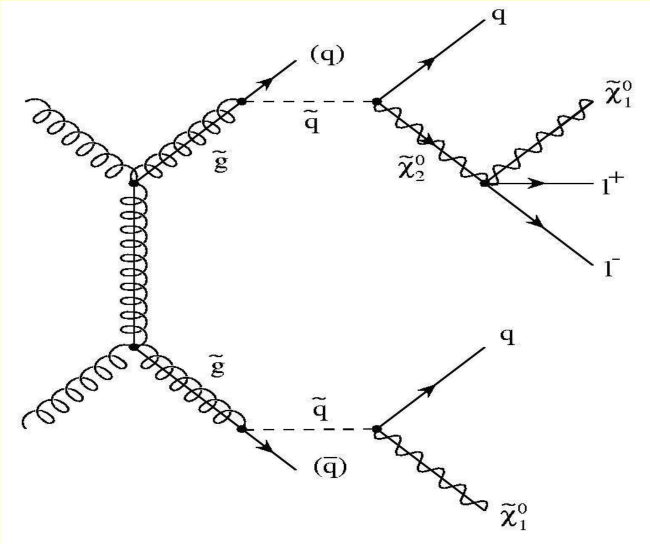
Five parameters:

m_0, $m_{1/2}$	particle masses at the GUT scale
A_0	common coupling term
tan β	ratio of vacuum expectation value of the two Higgs doublets
μ (sign μ)	Higgs mass term



regions of parameter space which are consistent with the measured relic density of dark matter (WMAP,…..)

Search for Supersymmetry at the LHC



$\Rightarrow$ combination of
jets, leptons,
missing transverse energy
(E_T^{miss})

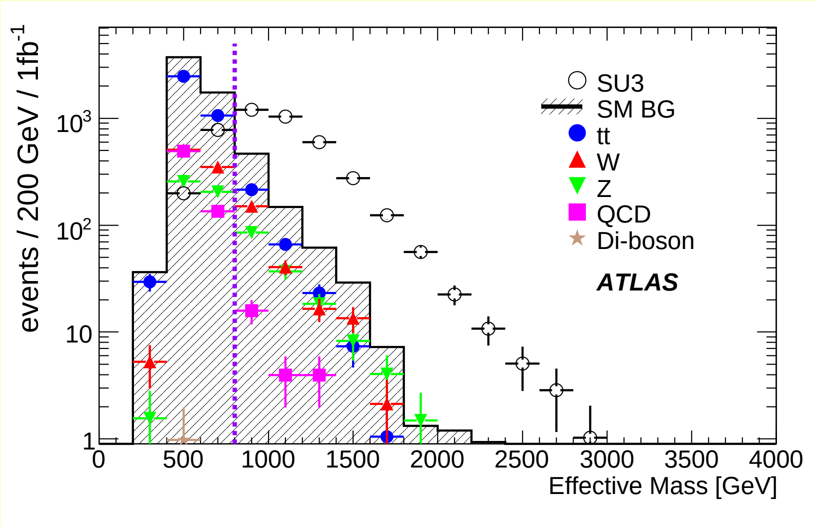
1. Step: search for deviations from the Standard Model

   Relatively easy: squarks and gluinos in TeV mass range are copiously produced (QCD production)

2. Step: can the parameter of the model be determined ?
   More difficult !

Squarks and Gluinos

- If R-parity conserved, cascade decays produce distinctive events: multiple jets, leptons, and E_T^{miss}
- Typical selection: $N_{jet} > 4$, $E_T > 100, 50, 50, 50$ GeV, $E_T^{miss} > 100$ GeV
- Define: $M_{eff} = E_T^{miss} + P_T^1 + P_T^2 + P_T^3 + P_T^4$ (effective mass)



example: mSUGRA, point SU3
m_0 = 100 GeV, $m_{1/2}$ = 300 GeV
$\tan\beta$ = 6, A_0 = -300, $\mu > 0$

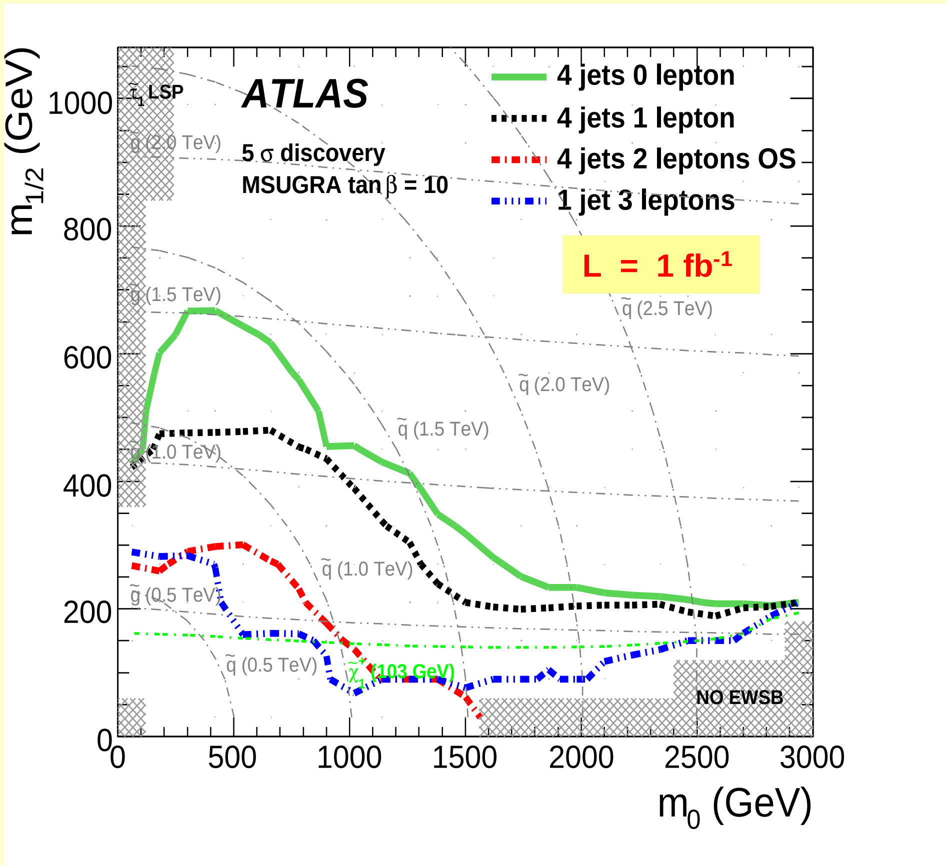
LHC reach for Squark- and Gluino masses:
($\sqrt{s}$ = 14 TeV)

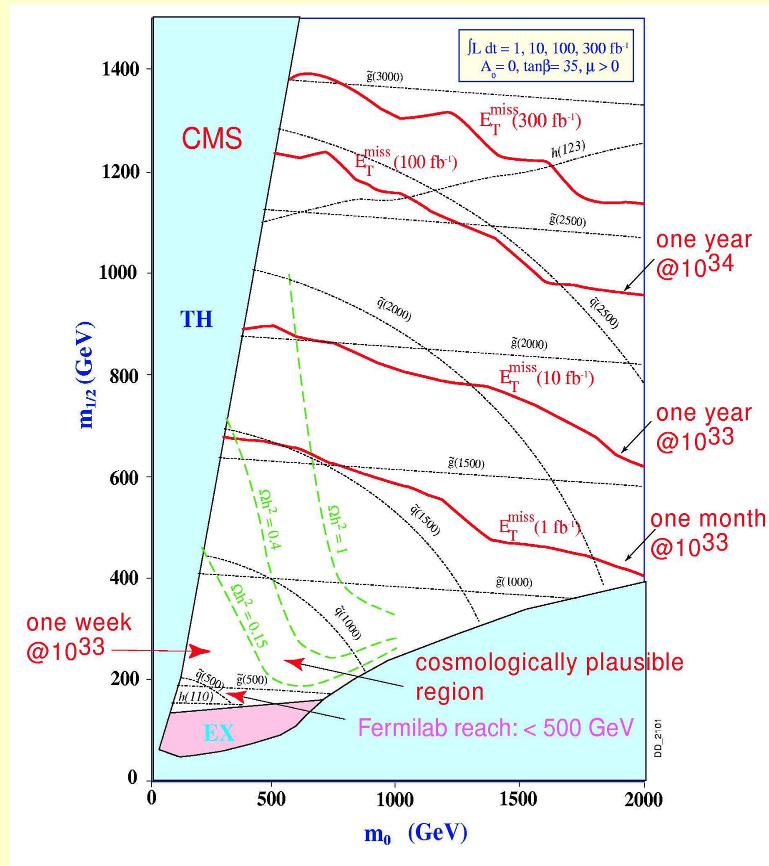
0.1 fb^{-1}	$\Rightarrow$	M ~ 750 GeV
1 fb^{-1}	$\Rightarrow$	M ~ 1350 GeV
10 fb^{-1}	$\Rightarrow$	M ~ 1800 GeV

Deviations from the Standard Model due to SUSY at the TeV scale can be detected fast !

LHC reach in the m_0 - $m_{1/2}$ mSUGRA plane:

Multijet + E_T^{miss} signature





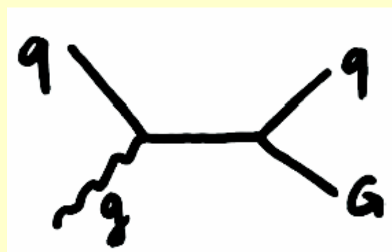
Expect multiple signatures for TeV-scale SUSY

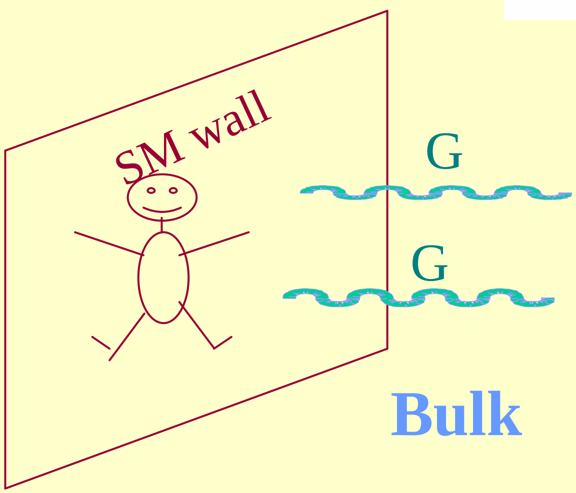
How can the underlying theoretical model be identified ?

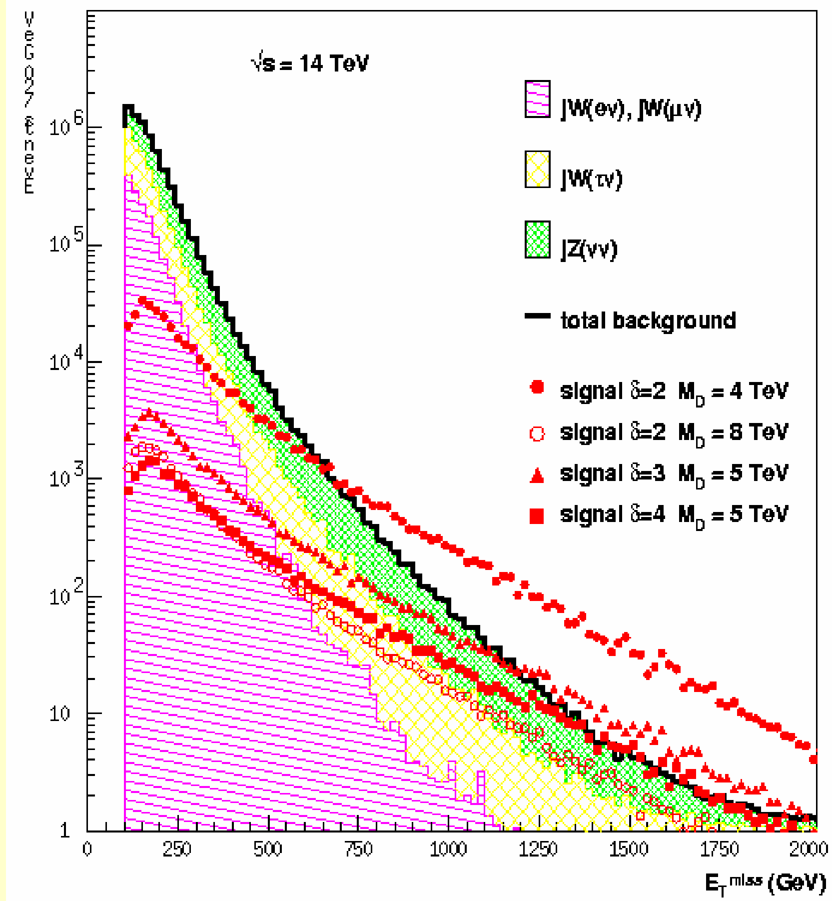
- Not easy !!
- Other possible scenarios for Physics Beyond the Standard Model could lead to similar final state signatures
  e.g. search for direct graviton production in extra dimension models

$gg \rightarrow gG$, $qg \rightarrow qG$, $q\bar{q} \rightarrow Gg$

$q\bar{q} \rightarrow G\gamma$

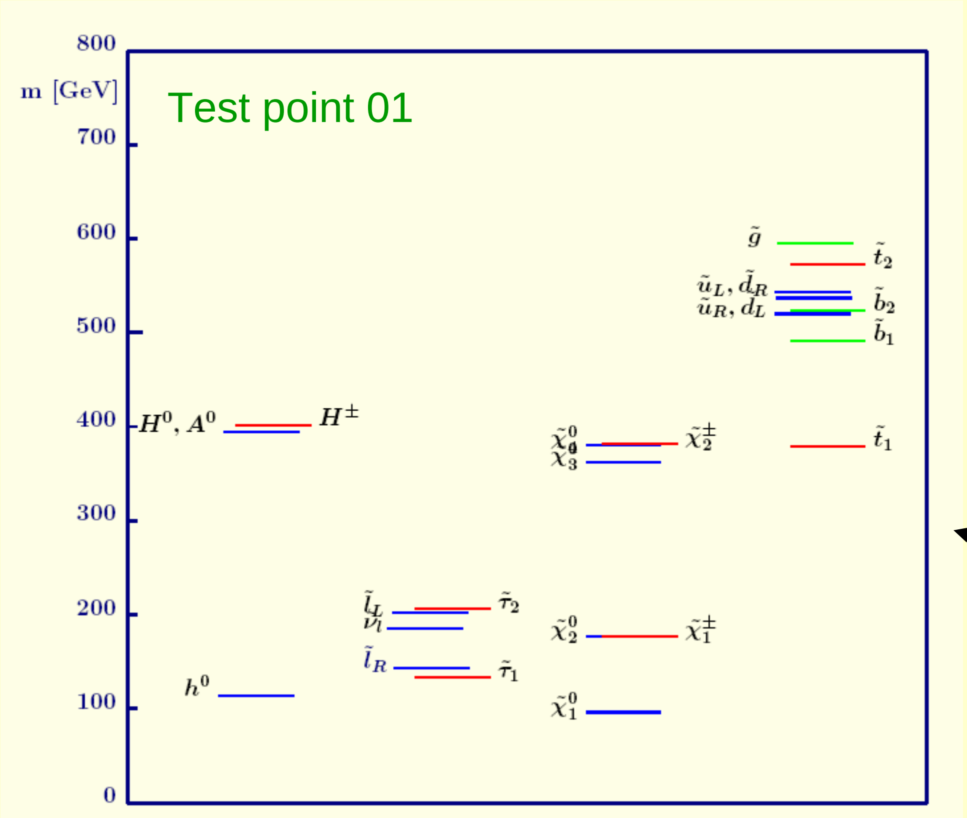


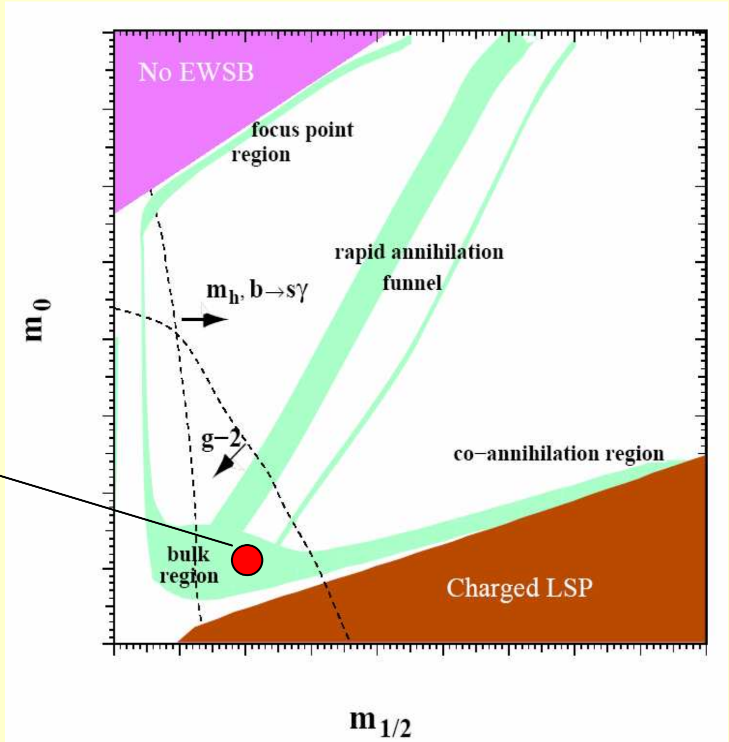




How can the underlying theoretical model be identified ?

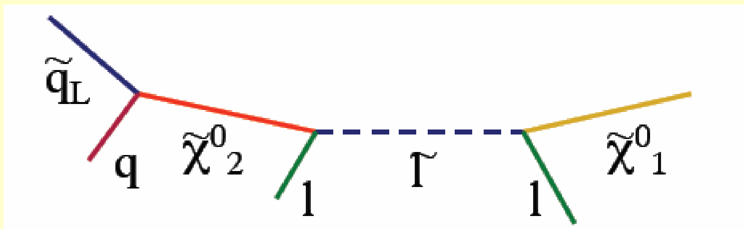
Measurement of the SUSY spectrum → Parameter of the theory





LHC Strategy: End point spectra of cascade decays

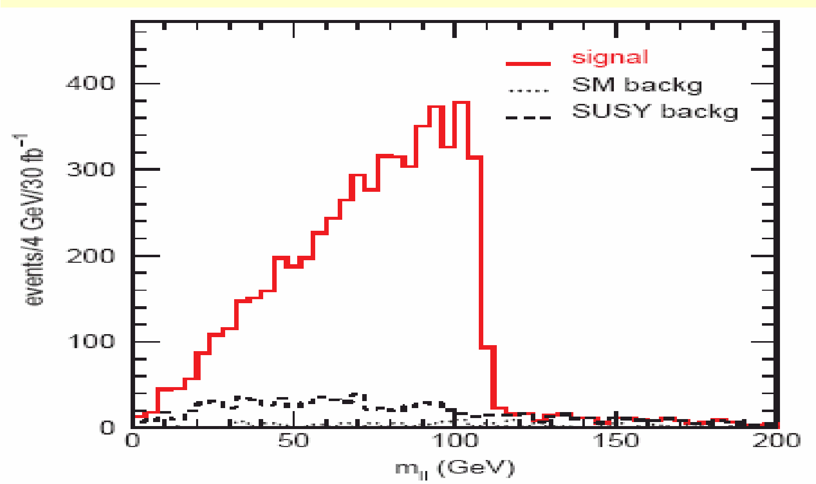
Example: $\tilde{q} \rightarrow q\tilde{\chi}_2^0 \rightarrow q\tilde{\ell}^{\pm}\ell^{\mp} \rightarrow q\ell^{\pm}\ell^{\mp}\tilde{\chi}_1^0$



$$M_{\ell^+\ell^-}^{max} = \frac{\sqrt{(m_{\chi_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{\ell}}^2 - m_{\chi_1^0}^2)}}{m_{\tilde{\ell}}}$$

$$M_{\ell_1 q}^{max} = \frac{\sqrt{(m_{\chi_2^0}^2 - m_{\tilde{\ell}}^2)(m_{\tilde{q}}^2 - m_{\chi_2^0}^2)}}{m_{\chi_2^0}}$$

ATLAS: expected precision for point 01 ($L = 1\ fb^{-1}$):



	Measured [GeV/c^2]	Monte Carlo [GeV/c^2]
$m_{\tilde{\chi}_1^0}$	$88 \pm 60 \mp 2$	118
$m_{\tilde{\chi}_2^0}$	$189 \pm 60 \mp 2$	219
$m_{\tilde{q}}$	$614 \pm 91 \pm 11$	634
$m_{\tilde{\ell}}$	$122 \pm 61 \mp 2$	155
Observable	[GeV/c^2]	[GeV/c^2]
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	$100.6 \pm 1.9 \mp 0.0$	100.7
$m_{\tilde{q}} - m_{\tilde{\chi}_1^0}$	$526 \pm 34 \pm 13$	516.0
$m_{\tilde{\ell}} - m_{\tilde{\chi}_1^0}$	$34.2 \pm 3.8 \mp 0.1$	37.6

LHC precision on SUSY model parameters:

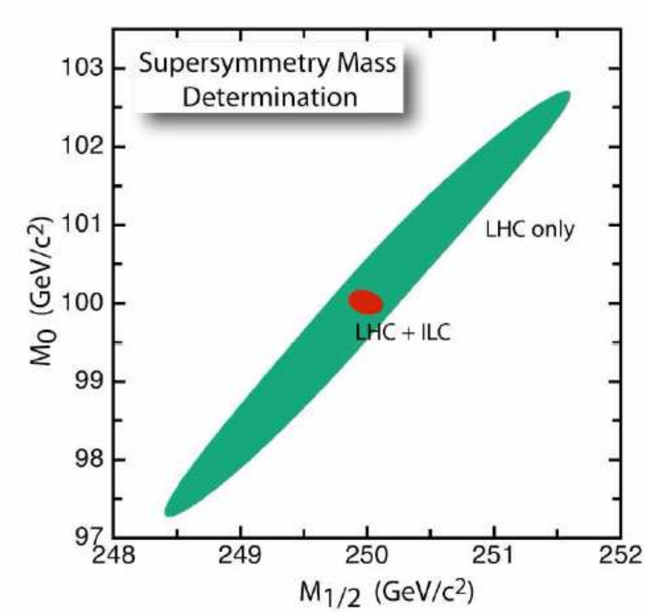
mSUGRA bulk region **1 fb^{-1}**

Parameter	SU3 value	fitted value	exp. unc.	theo. + exp. unc.
		sign$(\mu) = +1$		
$\tan\beta$	6	7.4	4.6	–
M_0	100 GeV	98.5 GeV	$\pm$9.3 GeV	$\pm$9.5 GeV
$M_{1/2}$	300 GeV	317.7 GeV	$\pm$6.9 GeV	$\pm$7.8 GeV
A_0	$-$300 GeV	445 GeV	$\pm$408 GeV	–
		sign$(\mu) = -1$		
$\tan\beta$		13.9	$\pm$2.8	–
M_0		104 GeV	$\pm$18 GeV	–
$M_{1/2}$		309.6 GeV	$\pm$5.9 GeV	–
A_0		489 GeV	$\pm$189 GeV	–

ATLAS

mSUGRA bulk region (SPS1a model) 300 fb^{-1}

Parameter	Expected % precision
m_0	± 2%
$m_{1/2}$	± 0.6%
$\tan(\beta)$	± 9%
A_0	± 16%

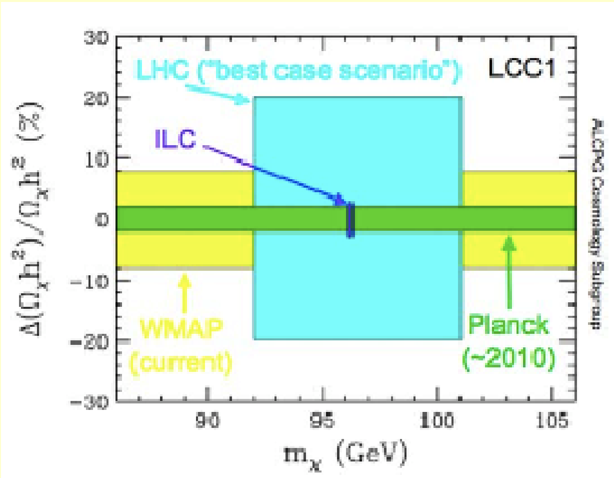


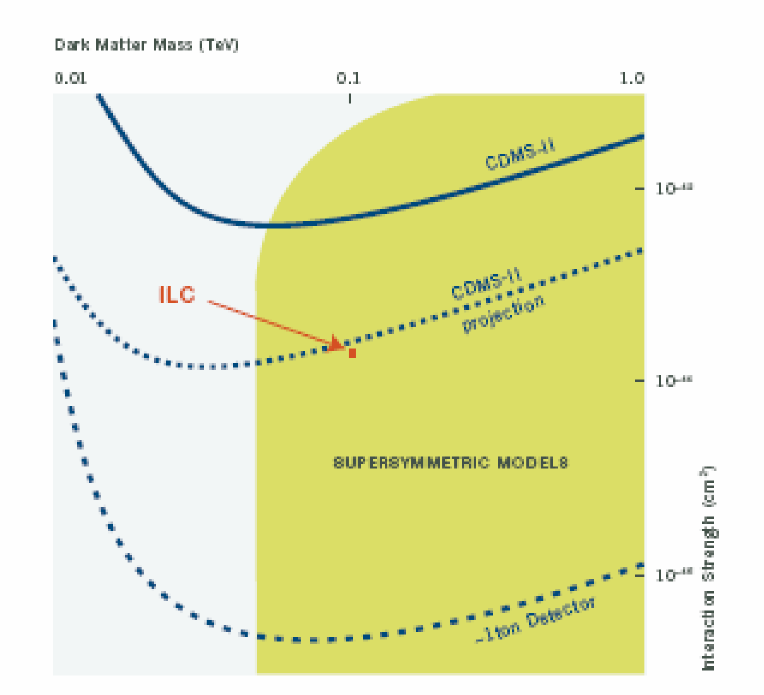
Complementarity of LHC and ILC in SUSY studies:

LHC: strongly interacting squarks and gluinos
ILC : precise investigation of electroweak SUSY partners

Importance for the interplay between direct and indirect Dark Matter searches

- Following a discovery of New Physics at the LHC (deviation from the Standard Model) the LHC will aim to test the Dark Matter hypothesis
- Estimation of relic density in a simple model-dependent scenario will be the first goal
- Less model-dependent scenarios will follow, detailed studies probably require the ILC
- Conclusive result is only possible in conjunction with astroparticle physics experiments
- Ultimate goal: observation of LSP at the LHC, confirmed by a signal in a direct dark matter experiment with predicted mass and cross-section





Summary / Conclusions

- The *Large Hadron Collider* is the largest and most ambitious project realized in particle physics so far
(technology, complexity, resources, collaboration, ..……..)

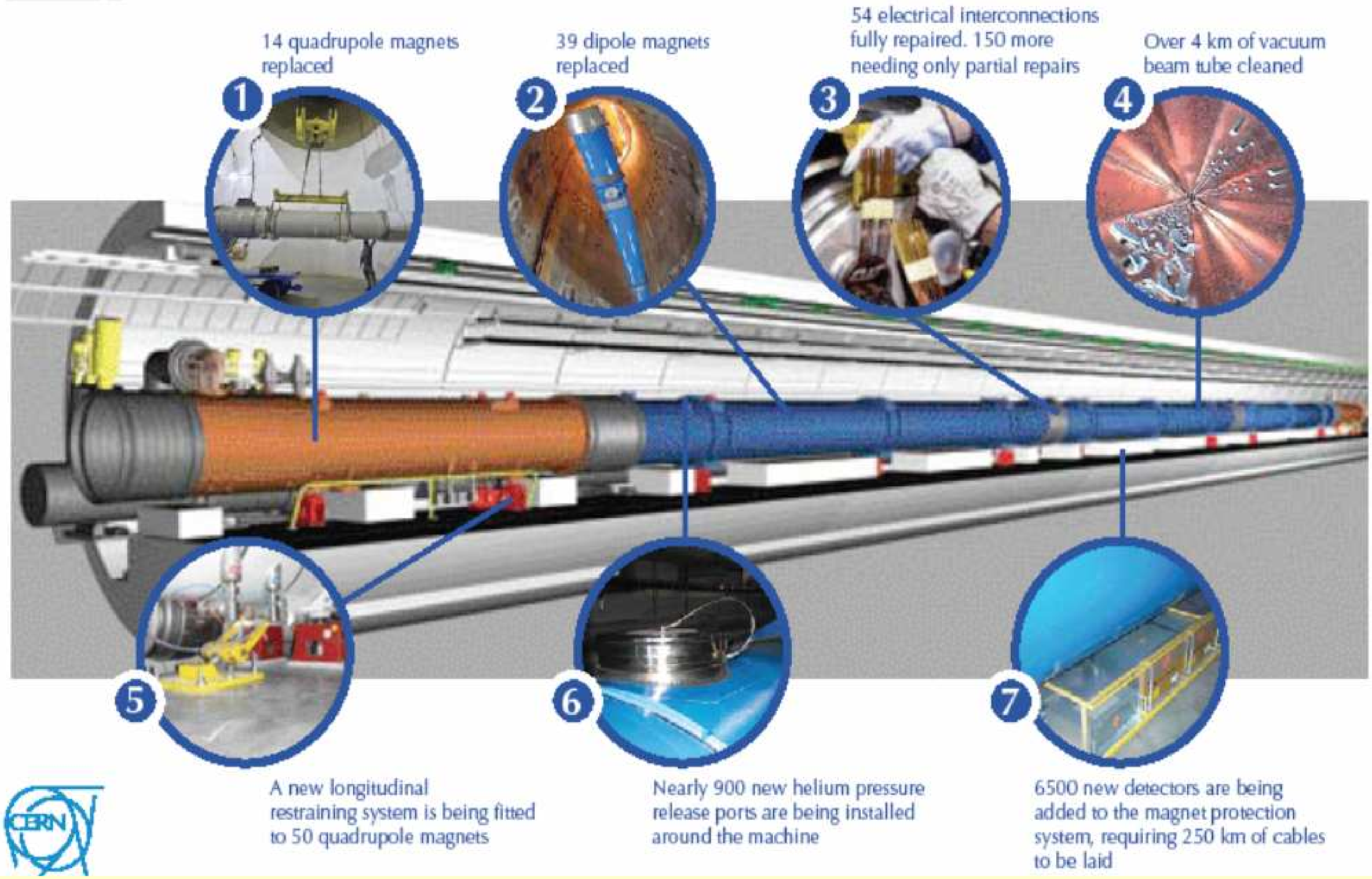
- With its startup in 2009, Particle Physics is about to enter a new era

- Questions of
  - Existence of Higgs particles,
  - Low energy supersymmetry or
  - many other phenomena beyond the Standard Model at the TeV scale

  can be answered.

The answers will most likely modify our understanding of Nature
…..
and give guidance to theory and future experiments

The LHC repairs in detail



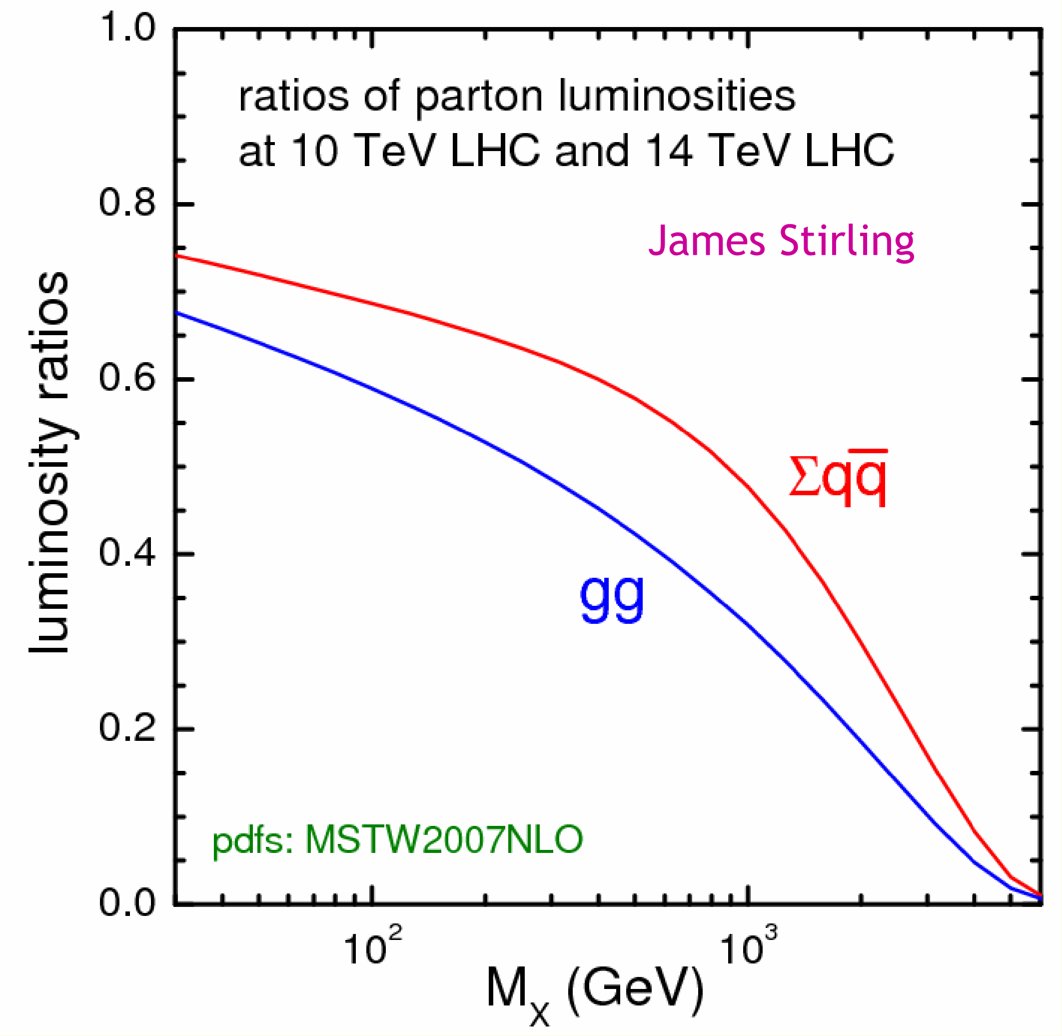
ATLAS Collaboration

(Status July 2008)

37 Countries
169 Institutions
2500 Scientific Authors
(1800 with a PhD)

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, UFRJ Rio de Janeiro, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, **Washington**, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

10 vs 14 TeV ?



At 10 TeV, more difficult to create high mass objects...

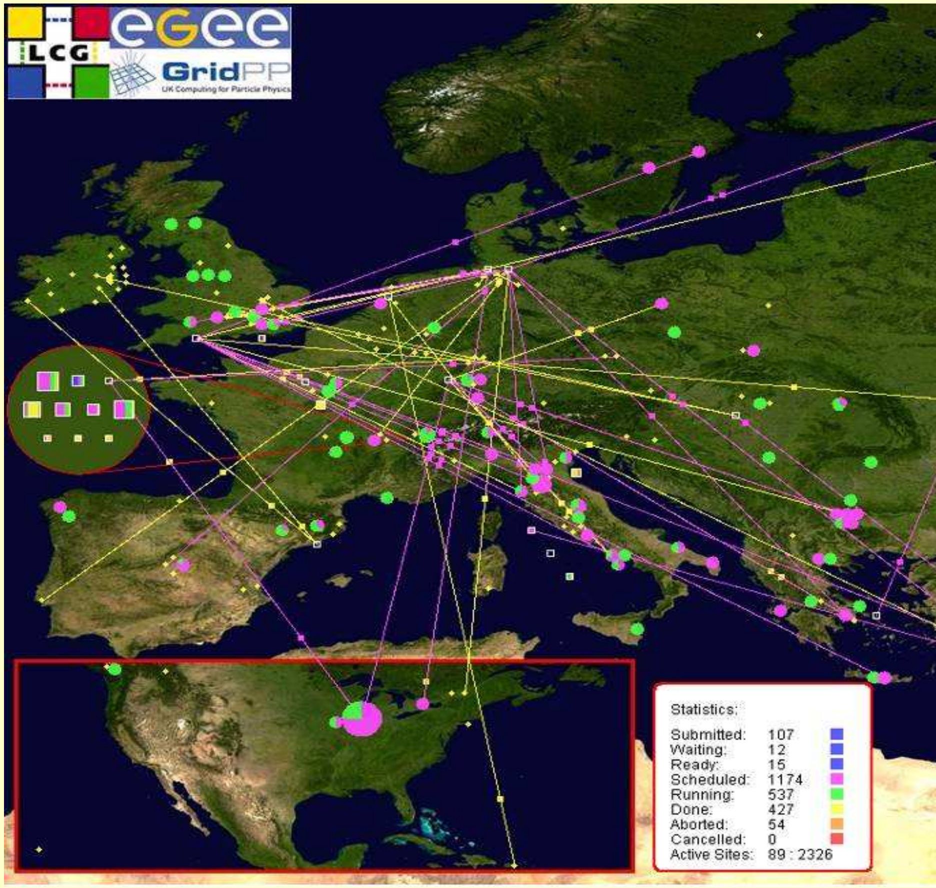
Below about 200 GeV, this suppression is <50% (process dependent)

e.g. tt ~ factor 2 lower cross-section

Above ~2-3 TeV the effect is more marked

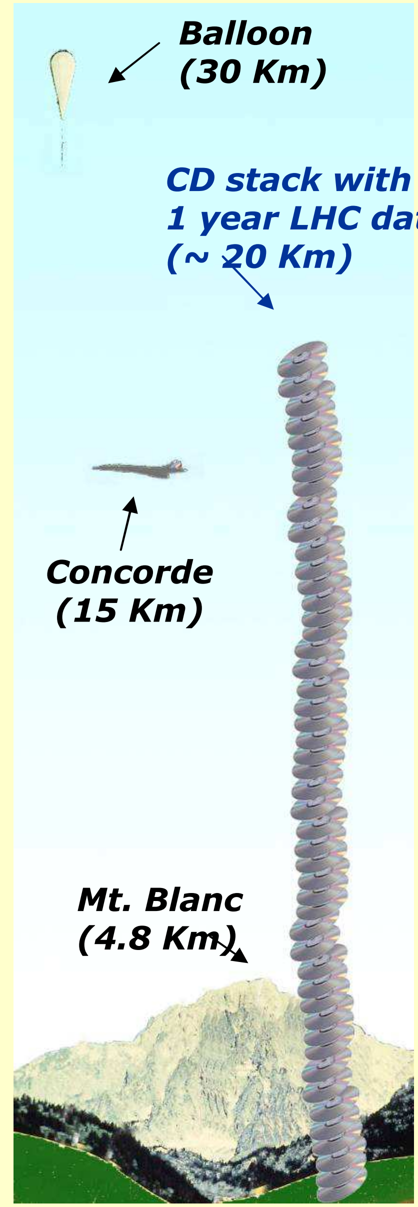
The rest of the talk discusses $\sqrt{s}$=14 TeV capabilities

LHC data handling, GRID computing



LCG/EGEE/OSG e-Science Grid is in production:

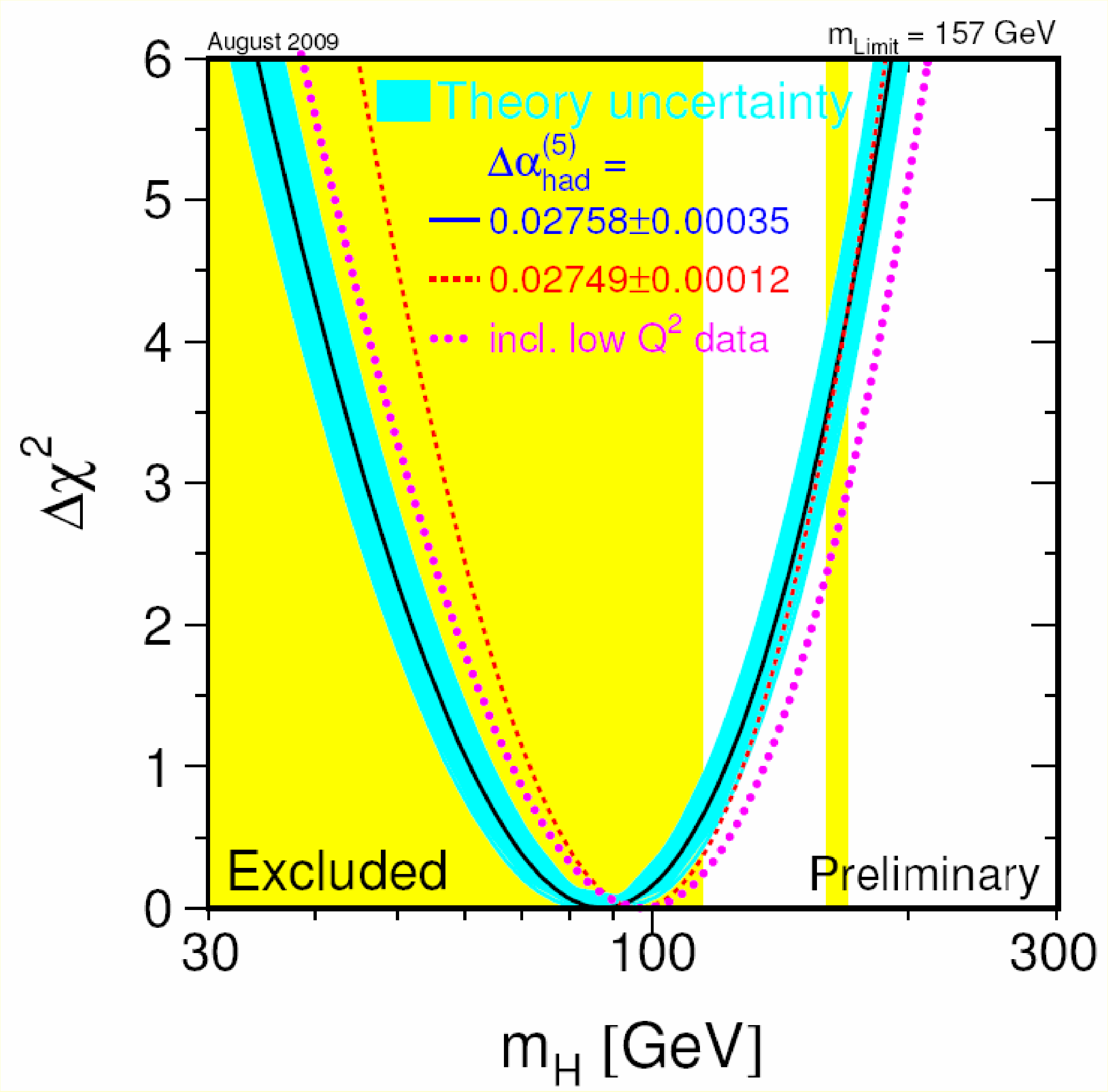
World-wide Coverage
Over 200 sites
20'000 CPUs
Multi-petabyte storage



Trigger system selects ~200 "collisions" per sec.

LHC data volume per year: 10-15 Petabytes

= 10-15 $\cdot 10^{15}$ Byte



August 2009
m_{Limit} = 157 GeV
Theory uncertainty
$\Delta\alpha_{had}^{(5)}$ =
0.02758±0.00035
0.02749±0.00012
incl. low Q^2 data
Excluded
Preliminary
$\Delta\chi^2$
m_H [GeV]
0
1
2
3
4
5
6
30
100
300

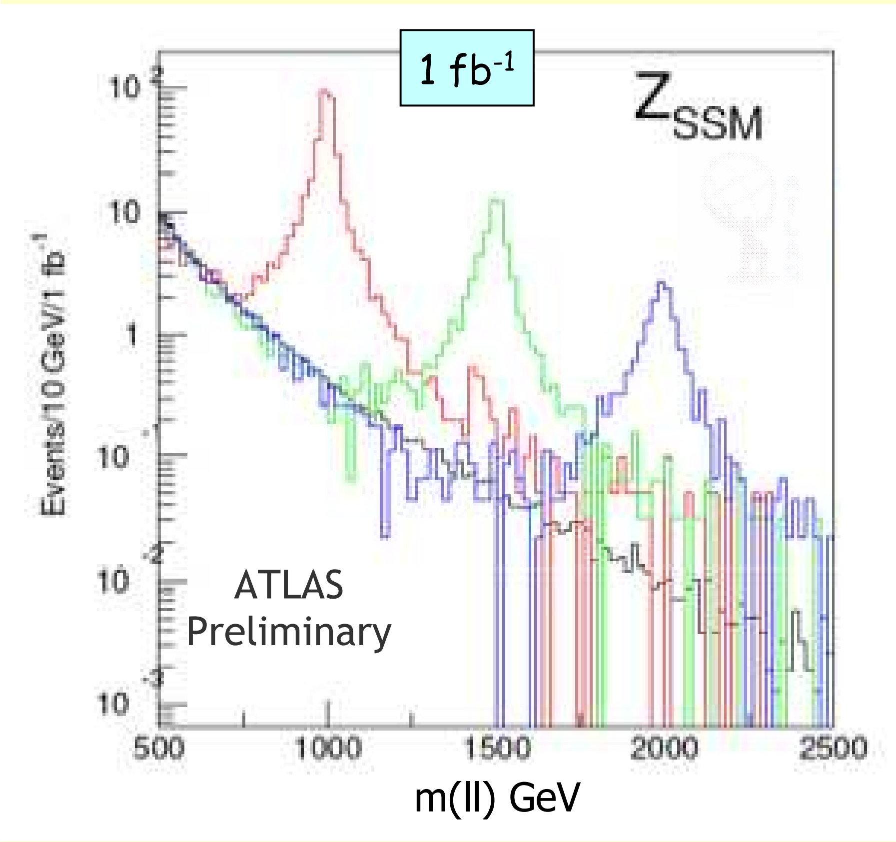
Early Surprises ??

- as already mentioned, the experiments must
  be open for surprises /
  unknowns /
  unexpected discoveries

- requires unbiased measurements of
  - inclusive lepton spectra
  - dilepton spectra……
  - Missing E_T spectrum…….
  - ……

One example of many….

$Z' \rightarrow e^+e^-$ with SM-like couplings (Z_{SSM})



Mass (TeV)	Events / fb^{-1} (after cuts)	Luminosity needed for a 5σ discovery + (10 obs. events)
1	~160	~70 pb^{-1}
1.5	~30	~300 pb^{-1}
2	~7	~1.5 fb^{-1}

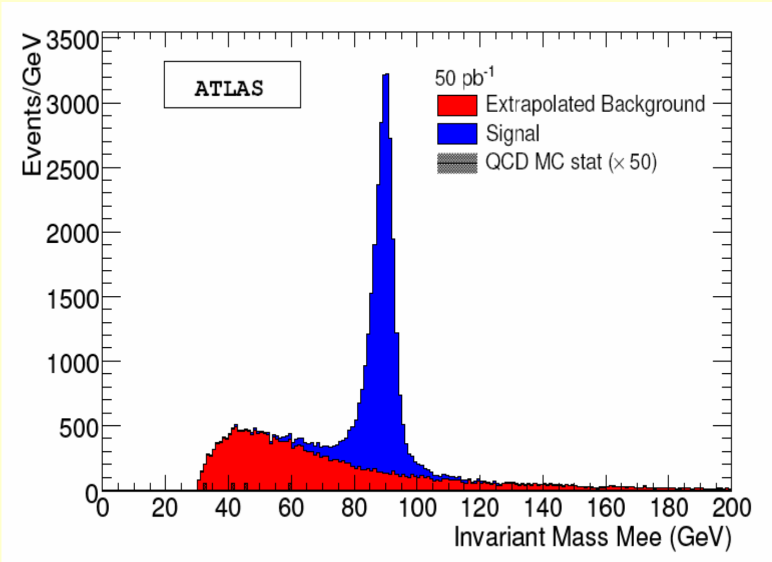
Discovery window above Tevatron limits
m ~ 1 TeV, perhaps even in 2009... (?)

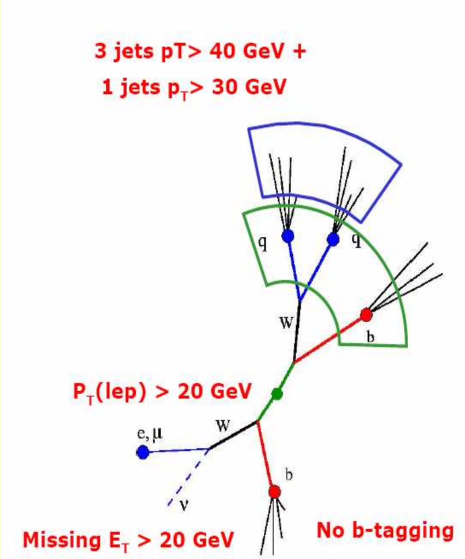
W/Z and top signals

Even with early data (10-50 pb^{-1}),
high statistics of W / Z and top samples

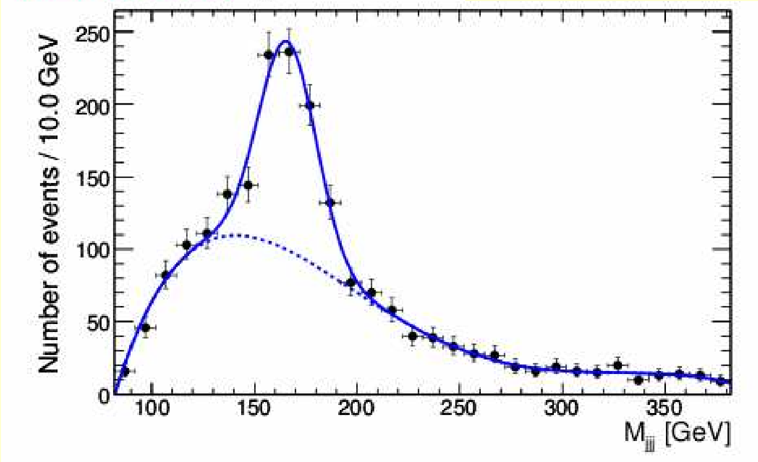
$\Rightarrow$ Establish performance for leptons,
jets, missing transverse energy, ….

Z $\rightarrow$ ee

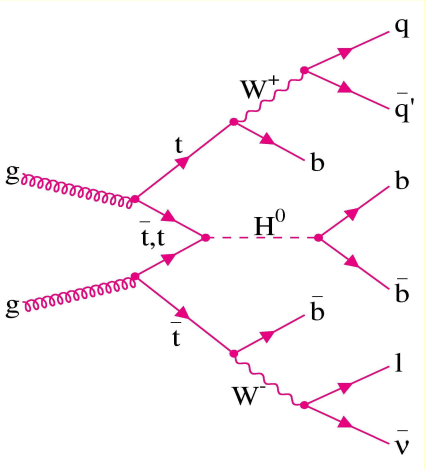




tt $\rightarrow$ ℓνb qqb

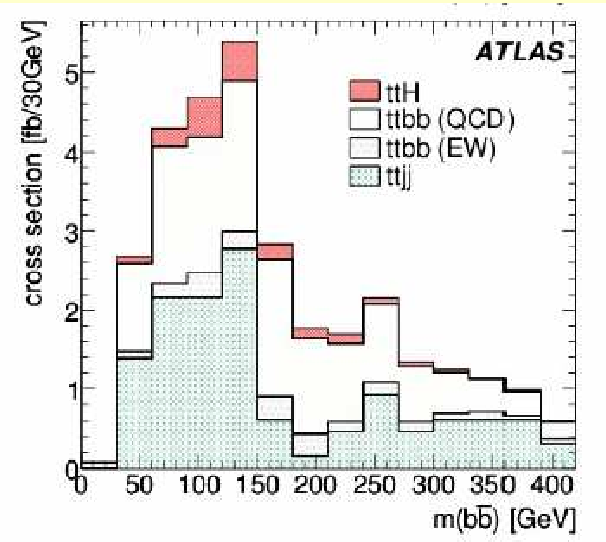


$t\bar{t}\,H \rightarrow t\bar{t}\,b\bar{b}$

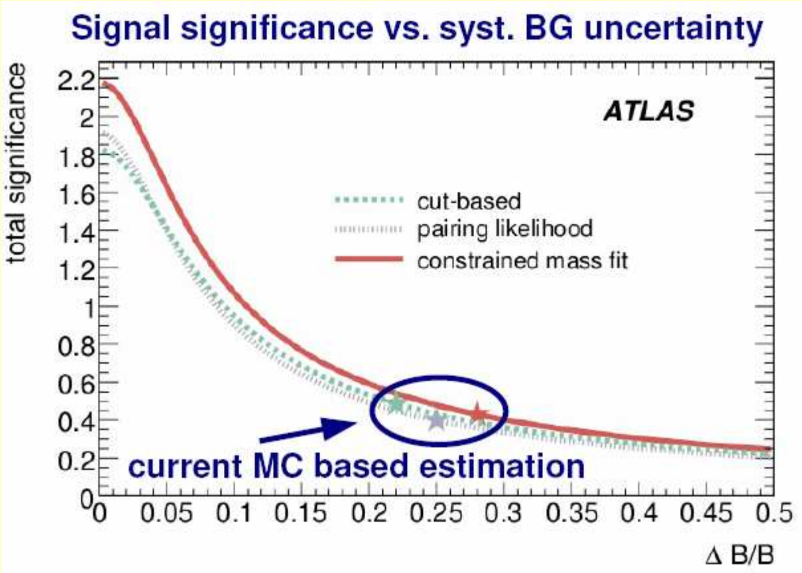


- Complex final states: H→ bb, t → bjj, t → bℓν
  t → bℓν, t → bℓν
  t → bjj, t → bjj
- Main backgrounds:
  - combinatorial background from signal (4b in final state)
  - ttjj, ttbb, ttZ,…
  - Wjjjjj, WWbbjj, etc. (excellent b-tag performance required)

- Updated ATLAS and CMS studies: matrix element calculations for backgrounds
  → larger backgrounds (ttjj and ttbb)



M (bb) after final cuts, 30 fb^{-1}



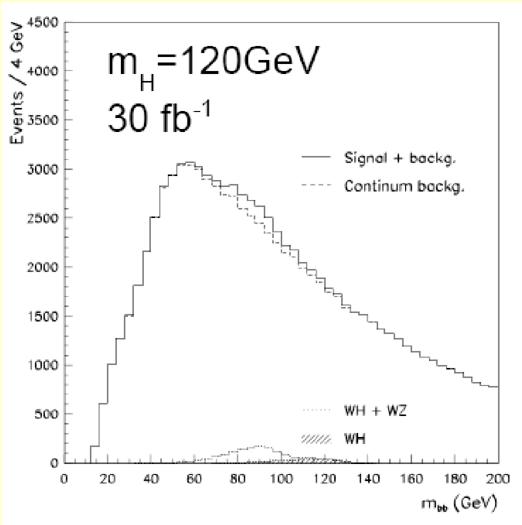
estimated uncertainty on the background: ± 25% (theory, + exp (b-tagging))
⇒ Normalization from data needed to reduce this (non trivial,…)

New hope for H→ bb decays at the LHC: W/Z H, H → bb

NEW!

The most important channels at the TEVATRON at low mass!

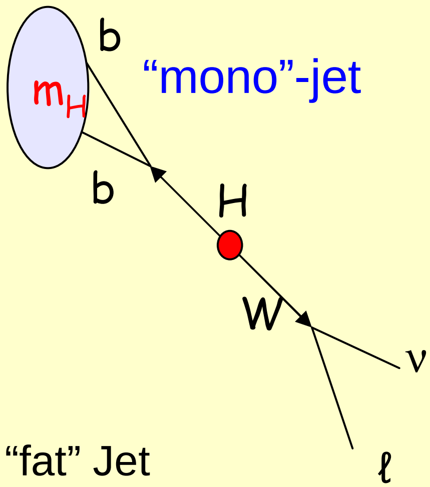
But: signal to background ratio less favourable at the LHC



$S/\sqrt{B}$	2.1
S/B	1.3%

Follow idea of J. Butterworth, et al.
[PRL 100 (2008) 242001]

Select events (≈5% of cross section), in which H und W bosons have large transverse momenta: p_T > 200 GeV



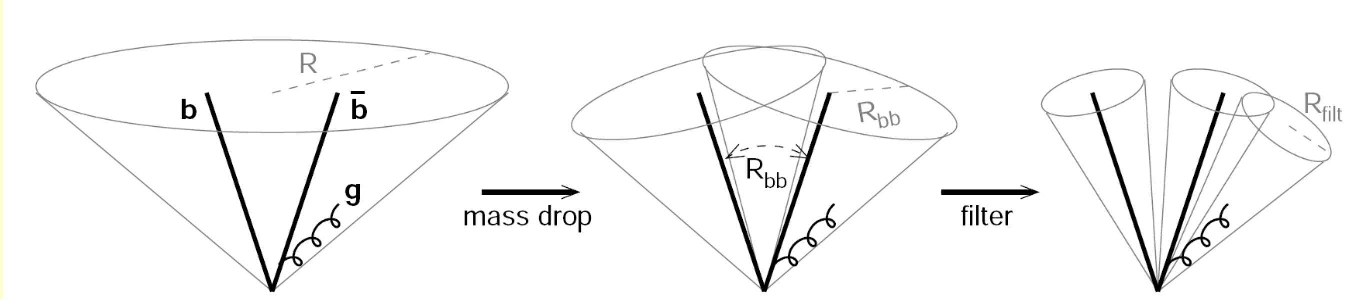
→ b-quarks in one "fat" Jet

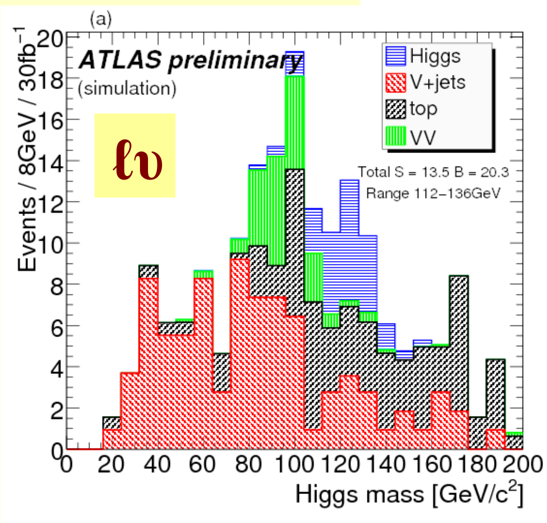
+ Acceptance (more central in detector)
+ Lepton identification, b-tagging

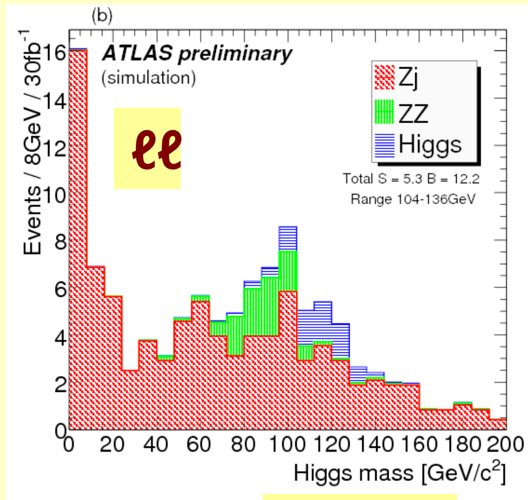
High p_T W/Z H, H → bb

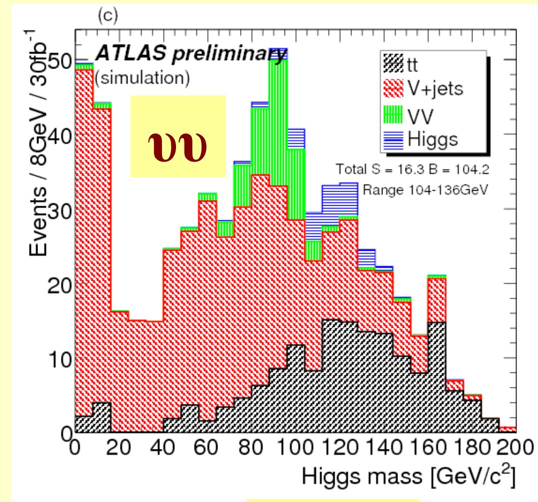
ATL-PHYS-PUB-2009-088

Analyze jet structure:









$L^{int.} = \mathbf{30}\ fb^{-1} : \frac{S}{\sqrt{B}} = \mathbf{3.0}$

M_H = 120 GeV

$\frac{S}{\sqrt{B}} = \mathbf{1.5}$

$\frac{S}{\sqrt{B}} = \mathbf{1.6}$

Combined: $\frac{S}{\sqrt{B}} = \mathbf{3.7}$

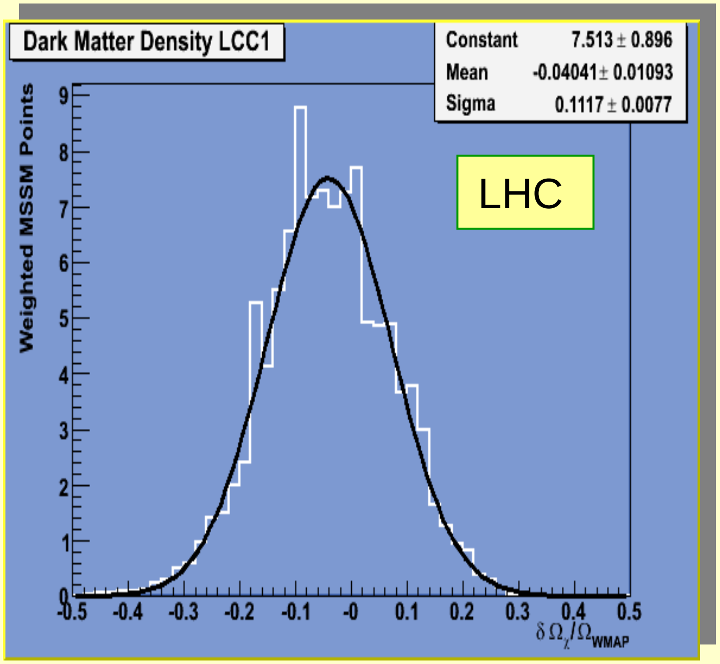
(Pileup not yet included)

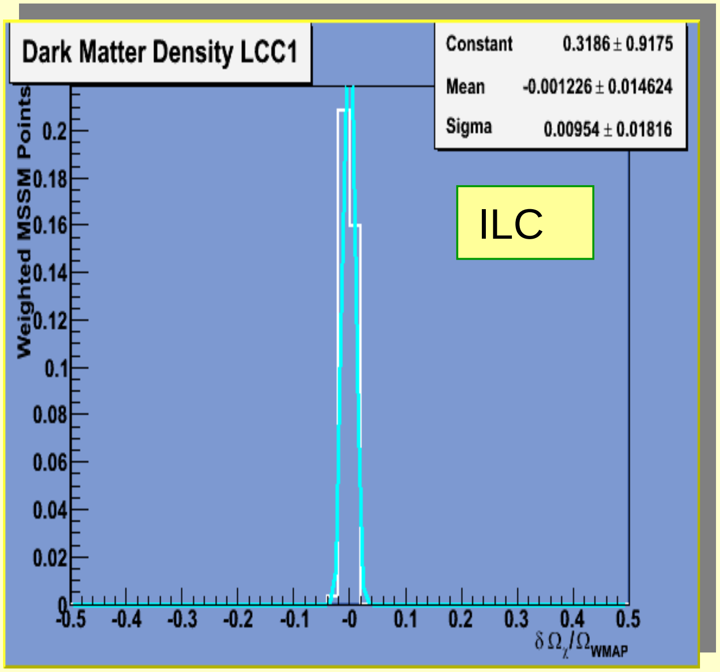
- S/B much better than for ttH
- Different backgrounds for different channels
- Still good sensitivity including systematics
  (e.g. S/√B = 3.0 for 15% uncertainty on all backgrounds)

Dark Matter at Accelerators ?

Parameter of the SUSY-Model $\Rightarrow$ Predictions for the relic density of Dark Matter

$$\rho_\chi \sim m_\chi n_\chi \,, \quad n_\chi \sim \frac{1}{\sigma_{ann}(\chi\chi \to \ldots)}$$



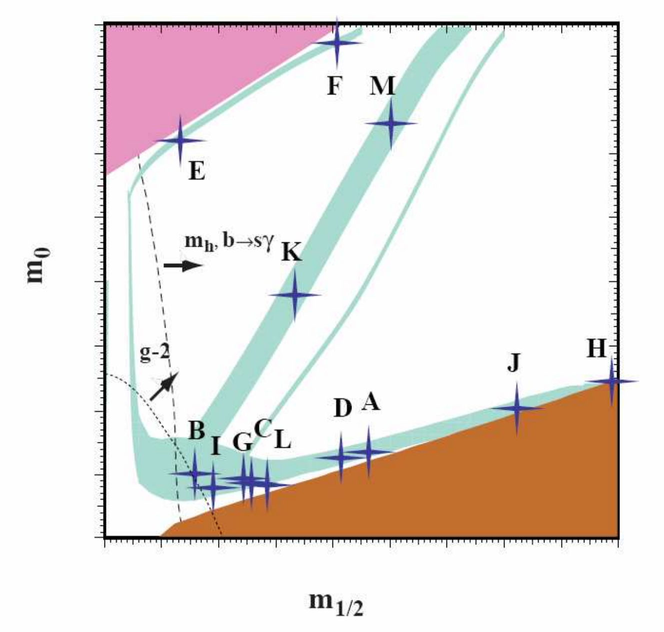


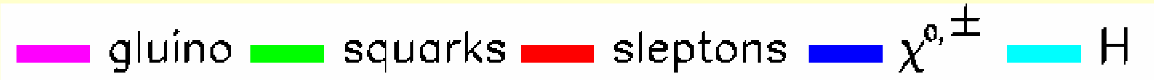
Battaglia et al.

L = 300 fb^{-1} $\delta\Omega / \Omega \sim 11\%$

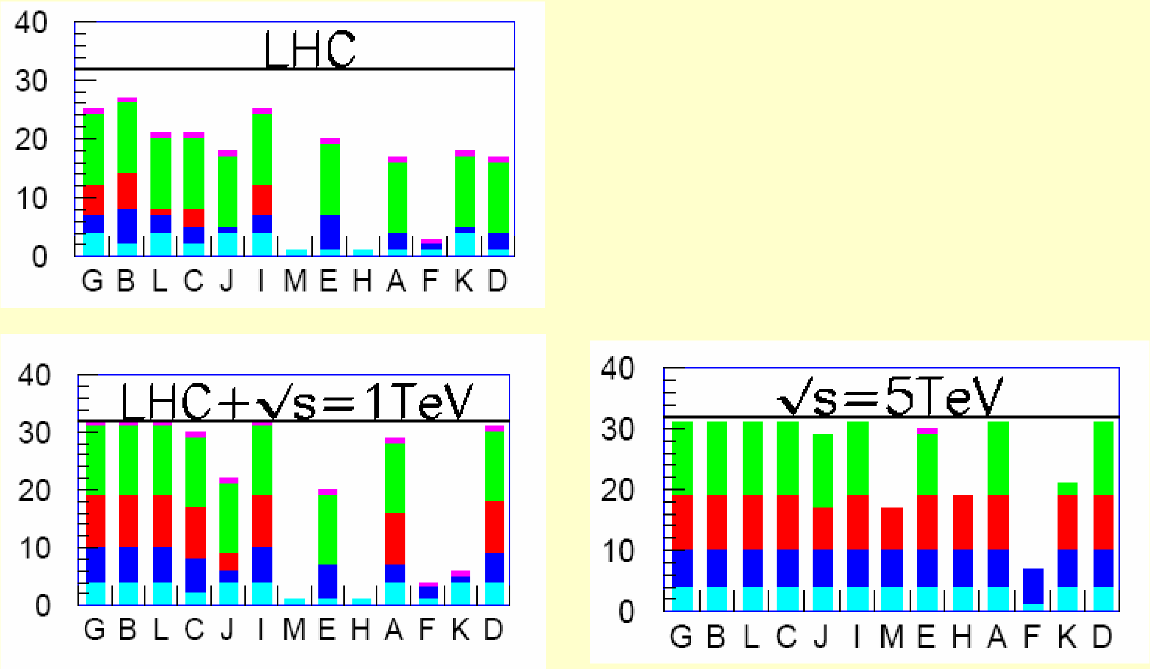
L = 1000 fb^{-1} $\delta\Omega / \Omega \sim 1\%$

The LHC and the ILC (International Linear Collider, in study/planning phase) are complementary in SUSY searches





Number of observable SUSY particles:



)* Study by J. Ellis et al., hep-ph/0202110