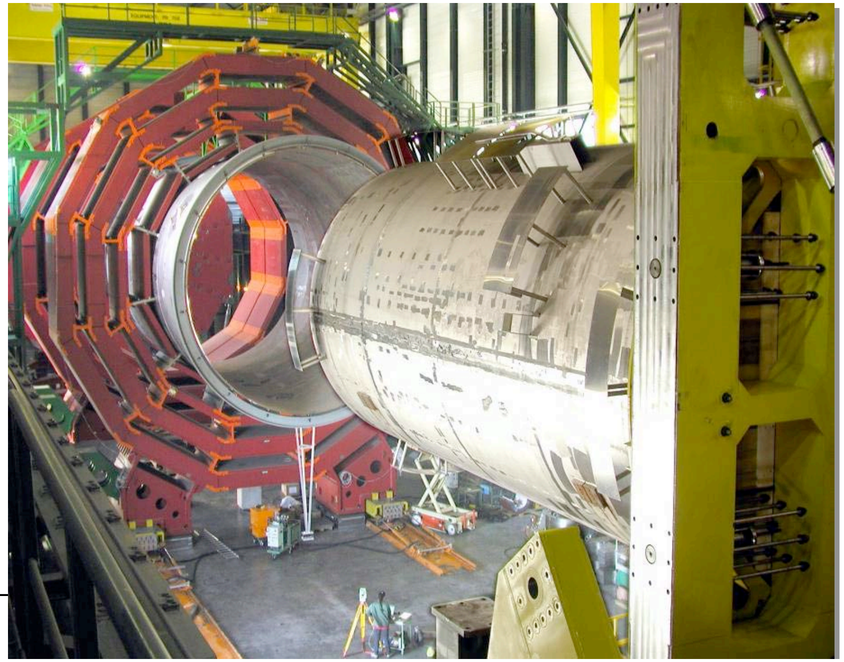
(New) Physics at the LHC

Fabiola Gianotti (CERN)

- ❶ Status of machine and experiments, experimental challenges
- ❷ The first year(s) of data taking
- ❸ Longer-term physics potential (examples …)
- ❹ Constraining the underlying theory

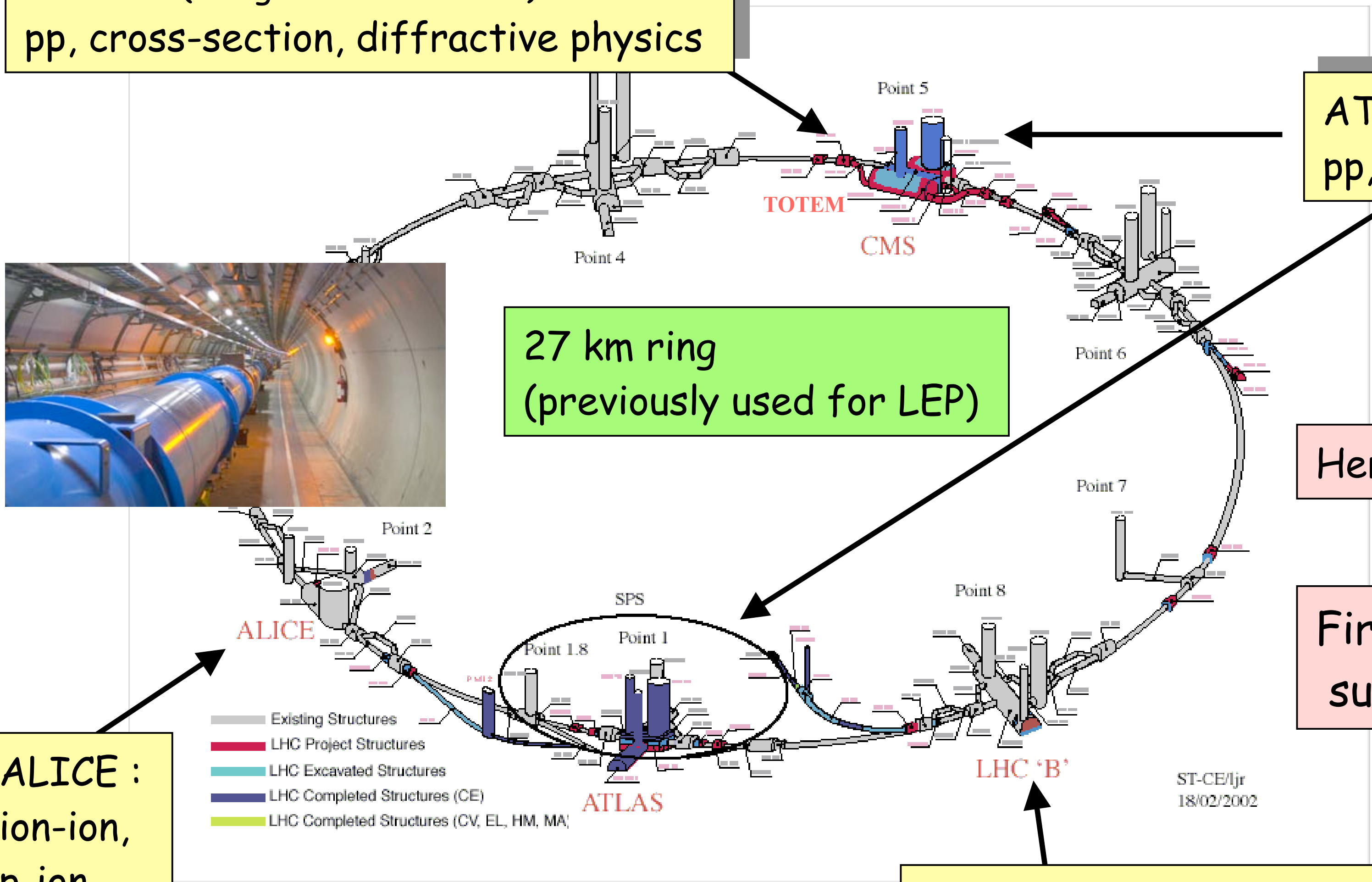


LHC

- pp $\sqrt{s}$ = 14 TeV $L_{design} = 10^{34}$ cm^{-2} s^{-1} (after 2009)
  $L_{initial} \leq 2 \times 10^{33}$ cm^{-2} s^{-1} (until 2009)
- Heavy ions (e.g. Pb-Pb at $\sqrt{s} \sim 1000$ TeV)

TOTEM (integrated with CMS):
pp, cross-section, diffractive physics

ATLAS and CMS :
pp, general purpose



27 km ring
(previously used for LEP)

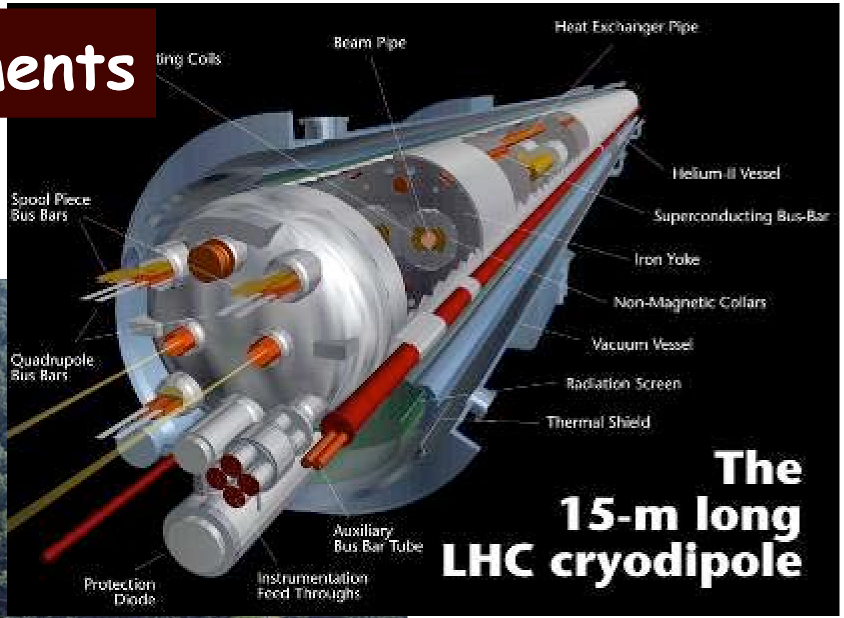
Here: ATLAS, CMS

First collisions :
summer 2007

ALICE :
ion-ion,
p-ion

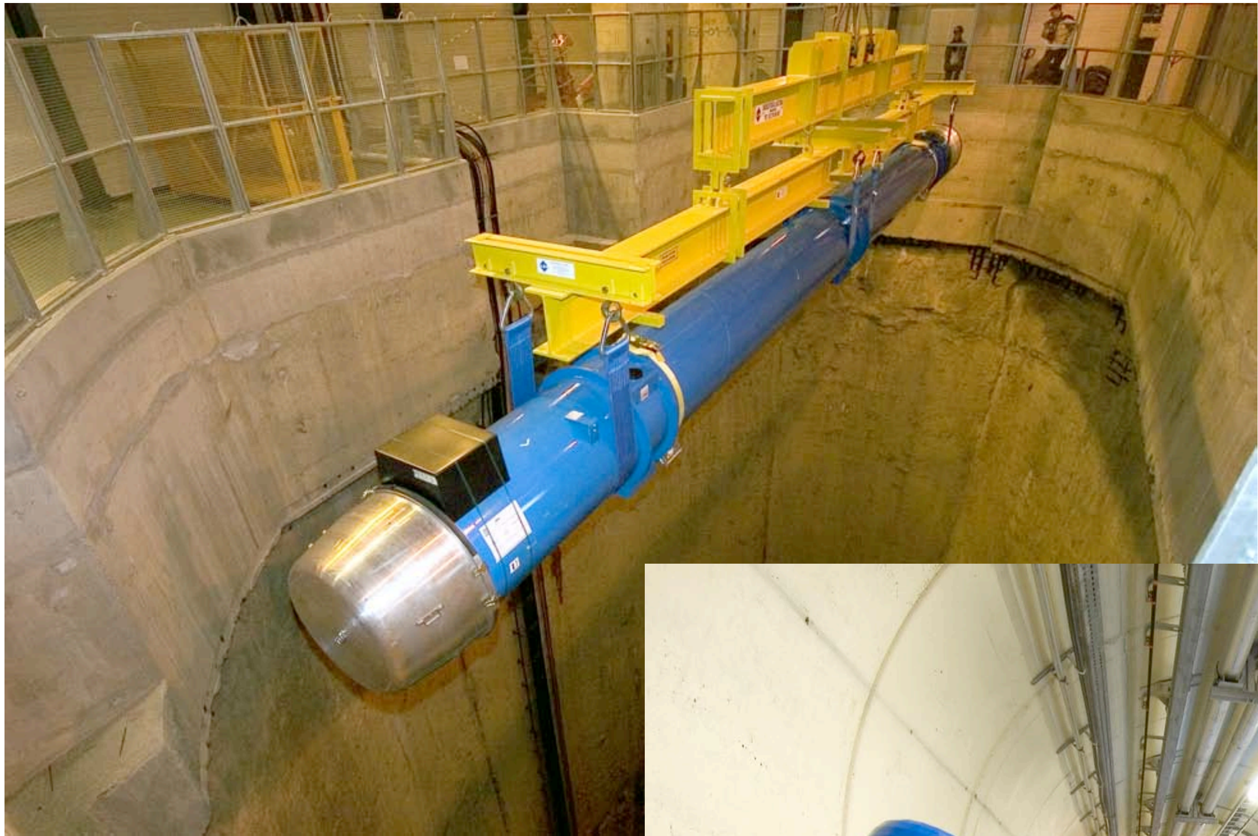
LHCb :
pp, B-physics, CP-violation

❶ Status of machine and experiments

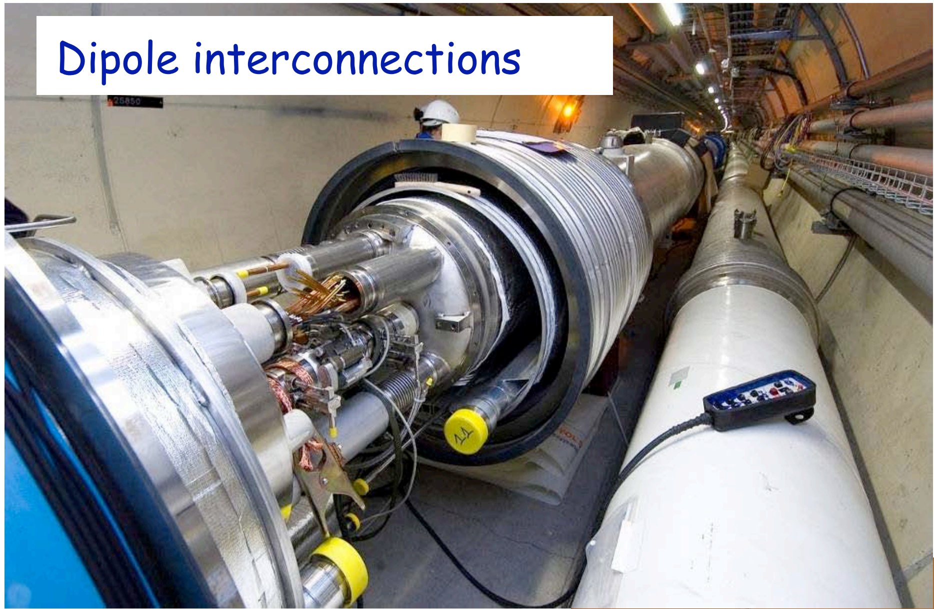


836 out of 1232 superconducting dipoles (B=8.3 T) produced as of last Friday

Magnet quality is very good



110 dipoles installed
in the underground tunnel
as of last Friday


Dipole interconnections

Cryoline successfully cooled down last week

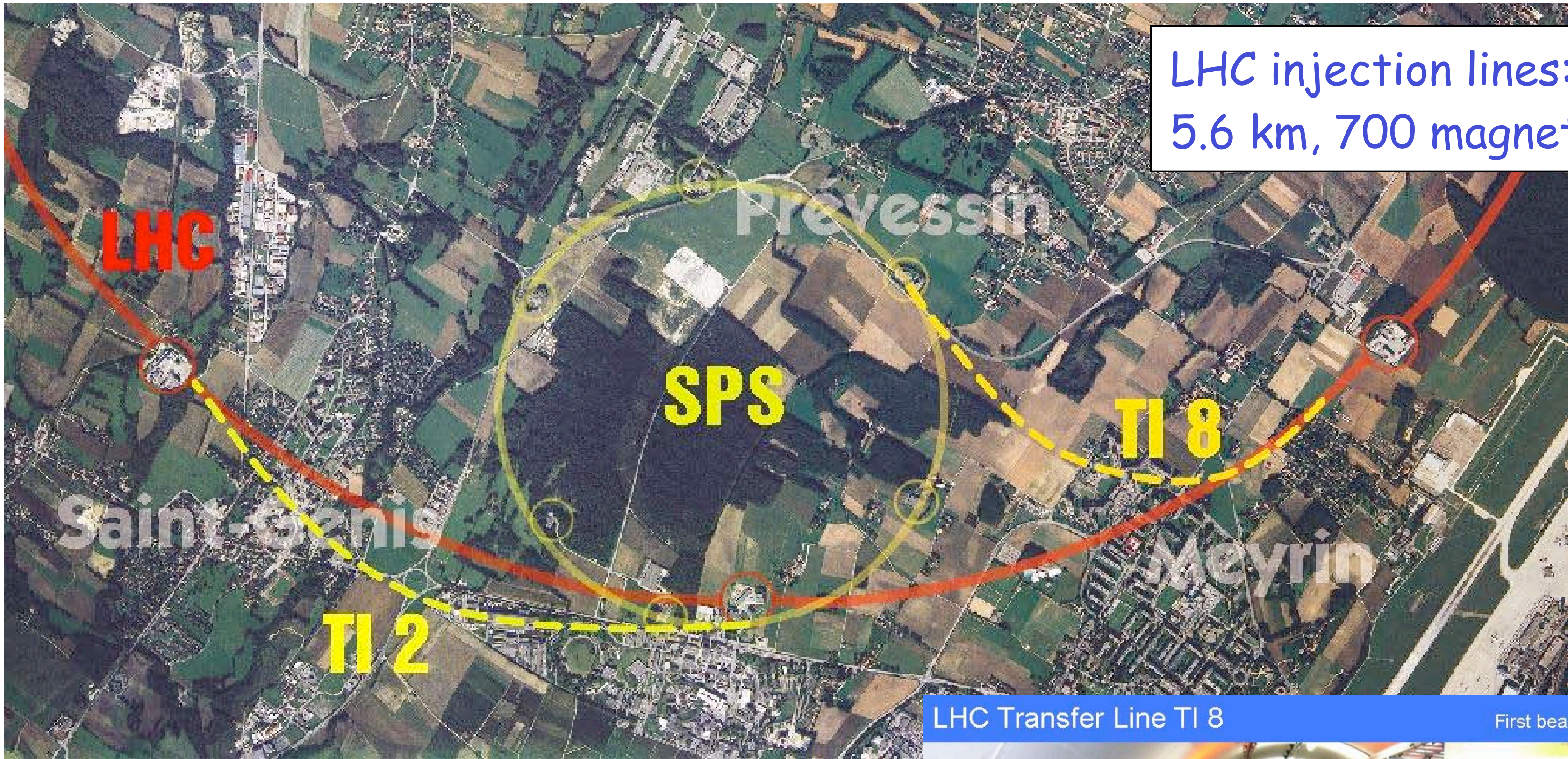
Such a high-tech machine requires sophisticated tests …

Not only dipoles ....

Dipoles	1232
Quadrupoles	400
Sextupoles	2464
Octupoles/decapoles	1568
Orbit correctors	642
Others	376
Total	~ 6700

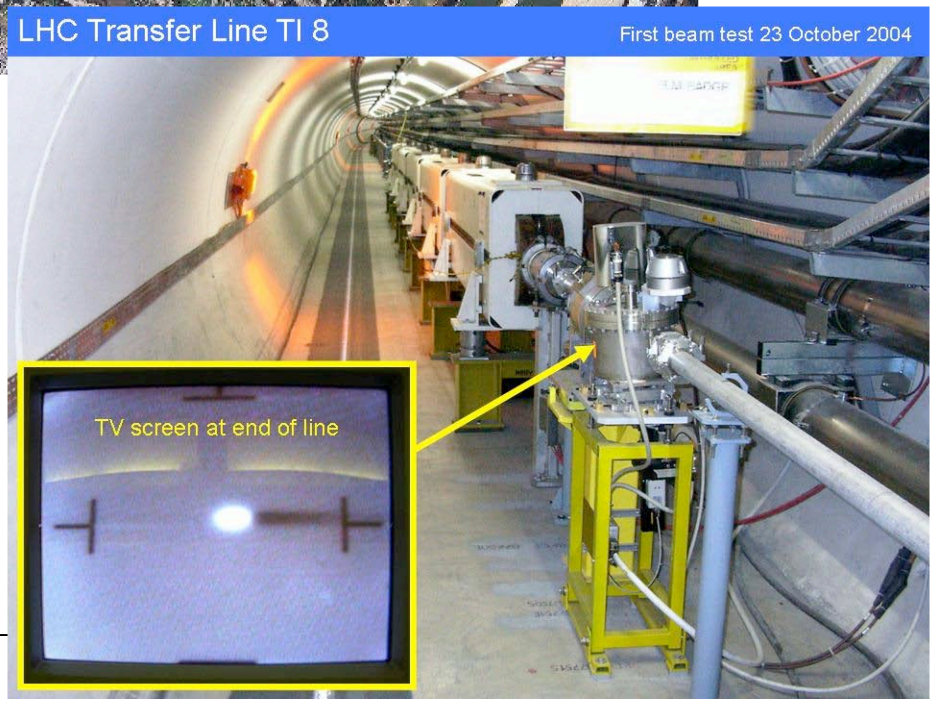

Assembly of Short Straight Session


Inner triplet quads assembly



LHC injection lines:
5.6 km, 700 magnets

23/10/2004: first beam injection
test from SPS to LHC
through TI8 transfer line



LHC physics goals

Search for the Standard Model Higgs boson over ~ $115 < m_H < 1000$ GeV.

Explore the highly-motivated TeV-scale, search for physics beyond the SM (Supersymmetry, Extra-dimensions, q/l compositness, leptoquarks, W'/Z', heavy q/l, etc.)

Precise measurements :

-- W mass

-- top mass, couplings and decay properties

-- Higgs mass, spin, couplings (if Higgs found)

-- B-physics (mainly LHCb): CP violation, rare decays, B^0 oscillations

-- QCD jet cross-section and α_s

-- etc. ....

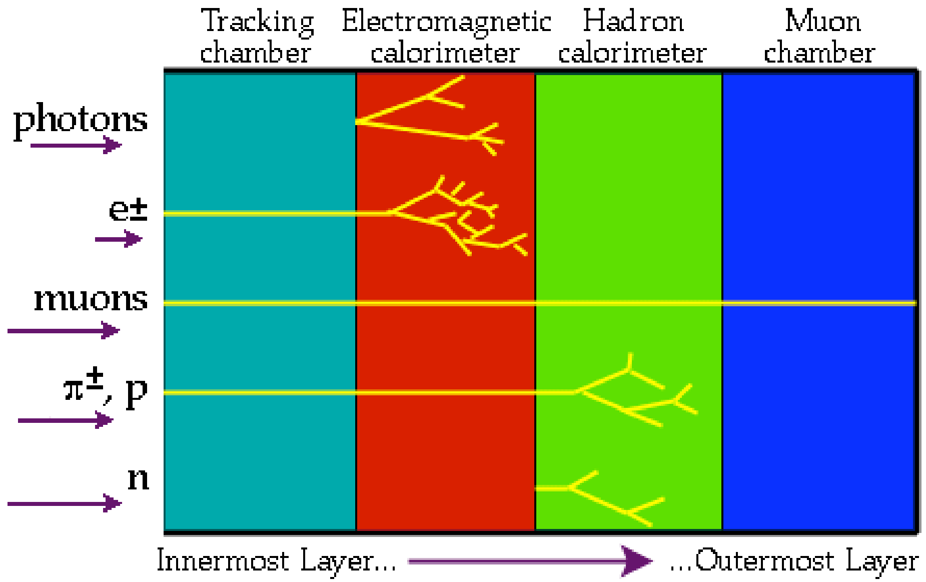
Study phase transition at high density from hadronic matter to quark-gluon plasma (mainly ALICE).

Etc. etc. .....

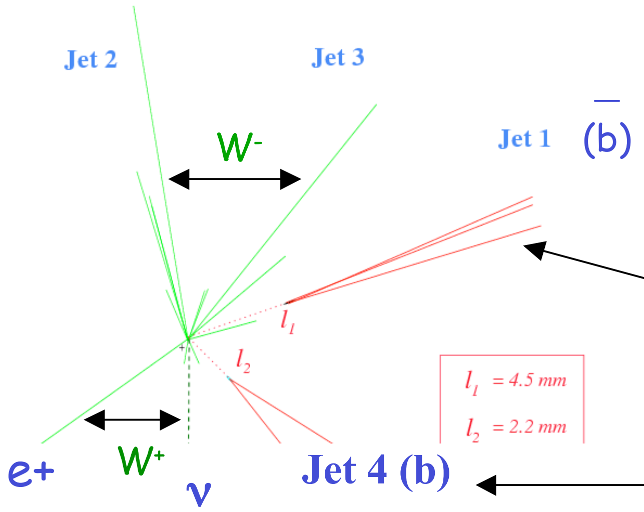
The environment and the experimental challenges

❶ Don' t know how New Physics will manifest → detectors must be able to detect as many particles and signatures as possible: e, μ, τ, ν, γ, jets, b-quarks, ….
→ ATLAS and CMS are general-purpose experiments.

Excellent performance over unprecedented energy range :
few GeV → few TeV

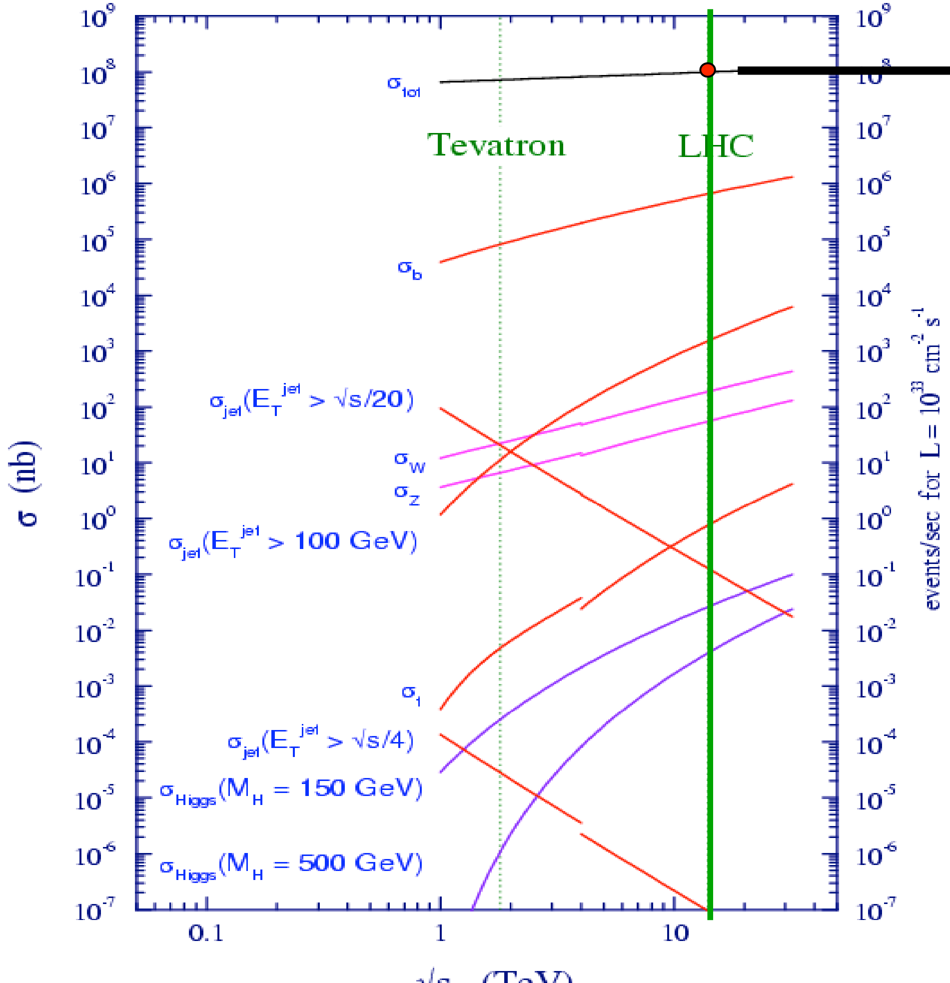


$t\bar{t} \to bW\,\bar{b}W \to bl\nu\,\bar{b}jj$ event from CDF data



b-tagging (secondary vetices)
τ(b-hadrons) ~ 1.5 ps
→ decay at few mm from primary vertex → detected with high-granularity Si detectors

❷ Event rate and pile-up (consequence of high luminosity …)



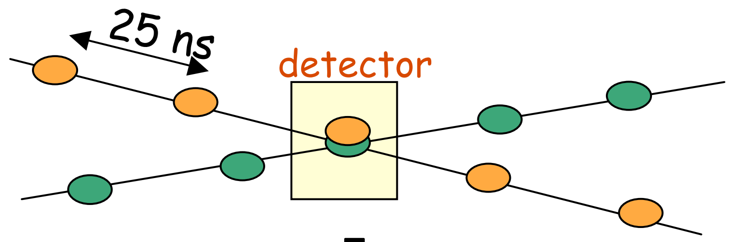
Event rate in ATLAS, CMS :

$N = L \times \sigma_{inelastic}(pp) \approx 10^{34}\ cm^{-2}\ s^{-1} \times 70\ mb$

$\approx 10^9$ interactions/s

Proton bunch spacing : 25 ns

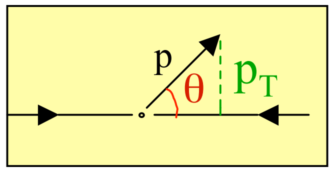
Protons per bunch : 10^{11}



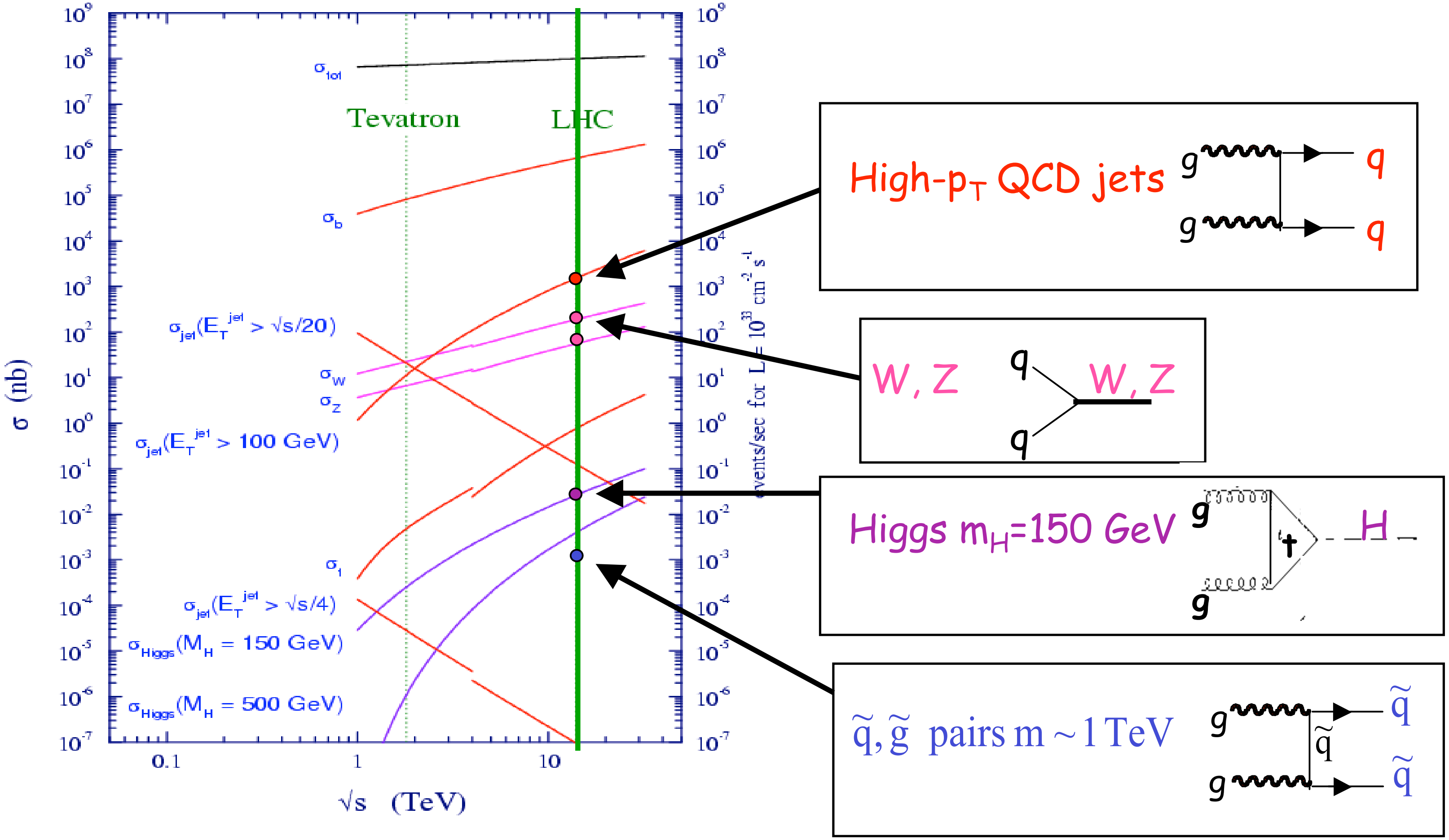
~ 20 inelastic (low-p_T) events ("minimum bias") produced simultaneously in the detectors at each bunch crossing → pile-up

Impact of pile-up on detector requirements and performance:

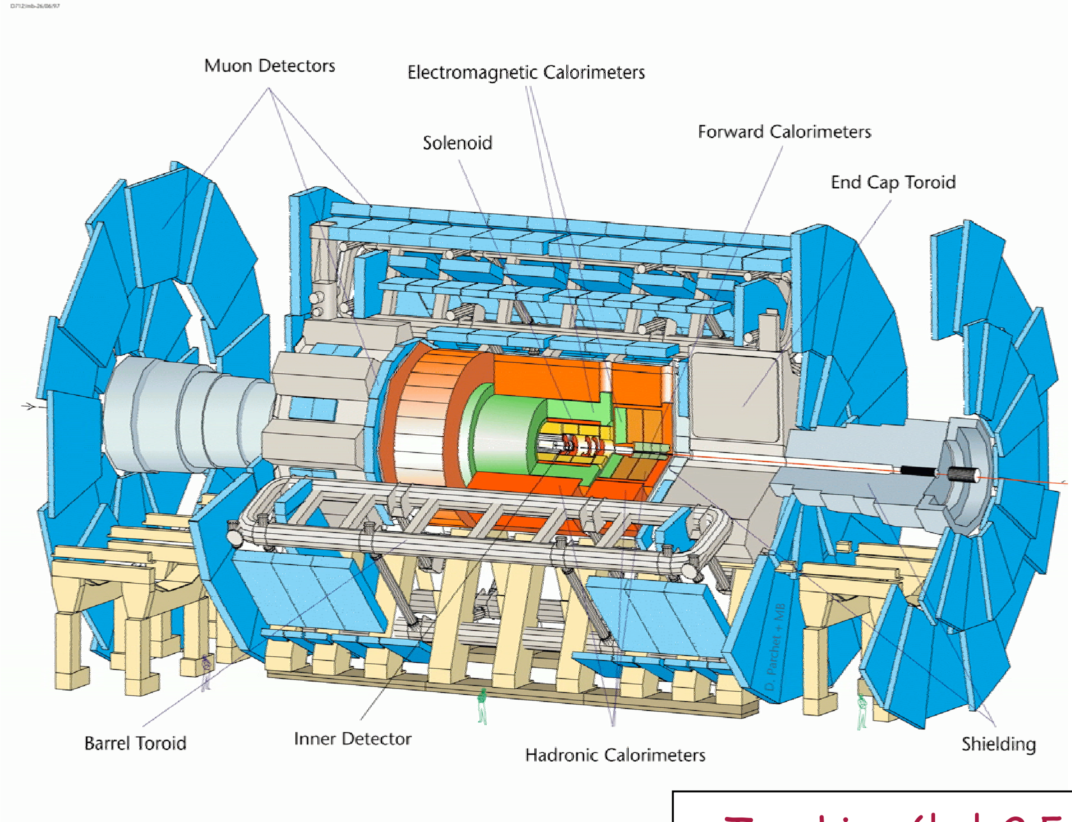
- -- fast response : ~ 50 ns
- -- granularity : > 10^8 channels
- -- radiation resistance (up to 10^{16} n/cm²/year in forward calorimeters)
- -- event reconstruction much more challenging than at previous colliders



❸ Huge (QCD) backgrounds (consequence of high energy …)



- No hope to observe light objects (W, Z, H ?) in fully-hadronic final states → rely on l, γ
- Fully-hadronic final states (e.g. q* → qg) can be extracted from backgrounds only with hard O(100 GeV) p_T cuts → works only for heavy objects
- Mass resolutions of ~ 1% (10%) needed for l, γ (jets) to extract tiny signals from backgrounds
- Excellent particle identification: e.g. e/jet separation



ATLAS

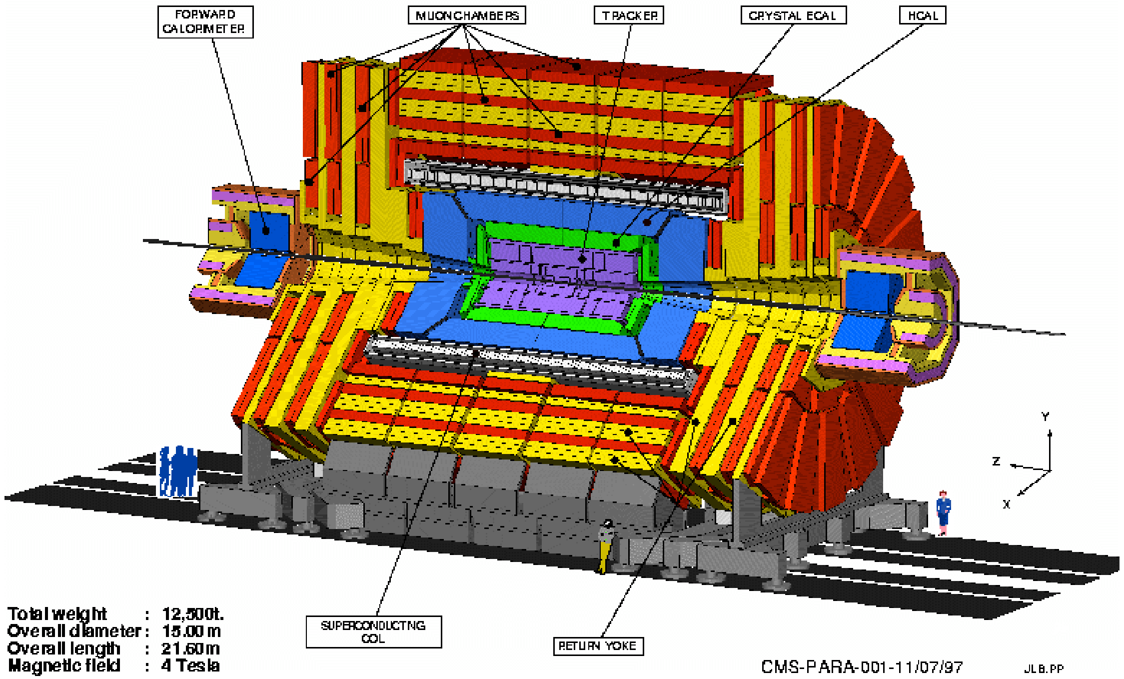
Length : ~45 m
Radius : ~12 m
Weight : ~ 7000 tons
Electronic channels : ~ 10^8

… and 3000 km of cables …

- Tracking ($|\eta|<2.5$, B=2T) :
  -- Si pixels and strips
  -- Transition Radiation Detector (e/π separation)

- Calorimetry ($|\eta|<5$) :
  -- EM : Pb-LAr
  -- HAD: Fe/scintillator (central), Cu/W-LAr (fwd)

- Muon Spectrometer ($|\eta|<2.7$) :
  air-core toroids with muon chambers



CMS

Length : ~22 m
Radius : ~7 m
Weight : ~ 12500 tons

- 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

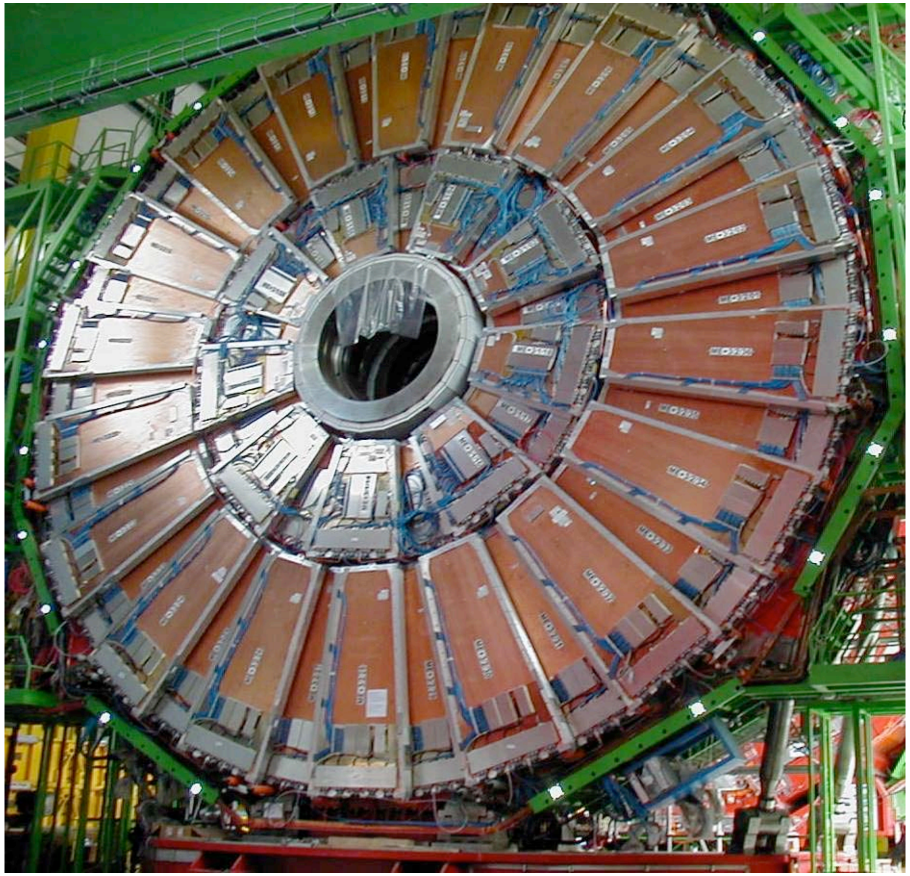
August 25 2005:
an historical day
at Point 1 and Point 5

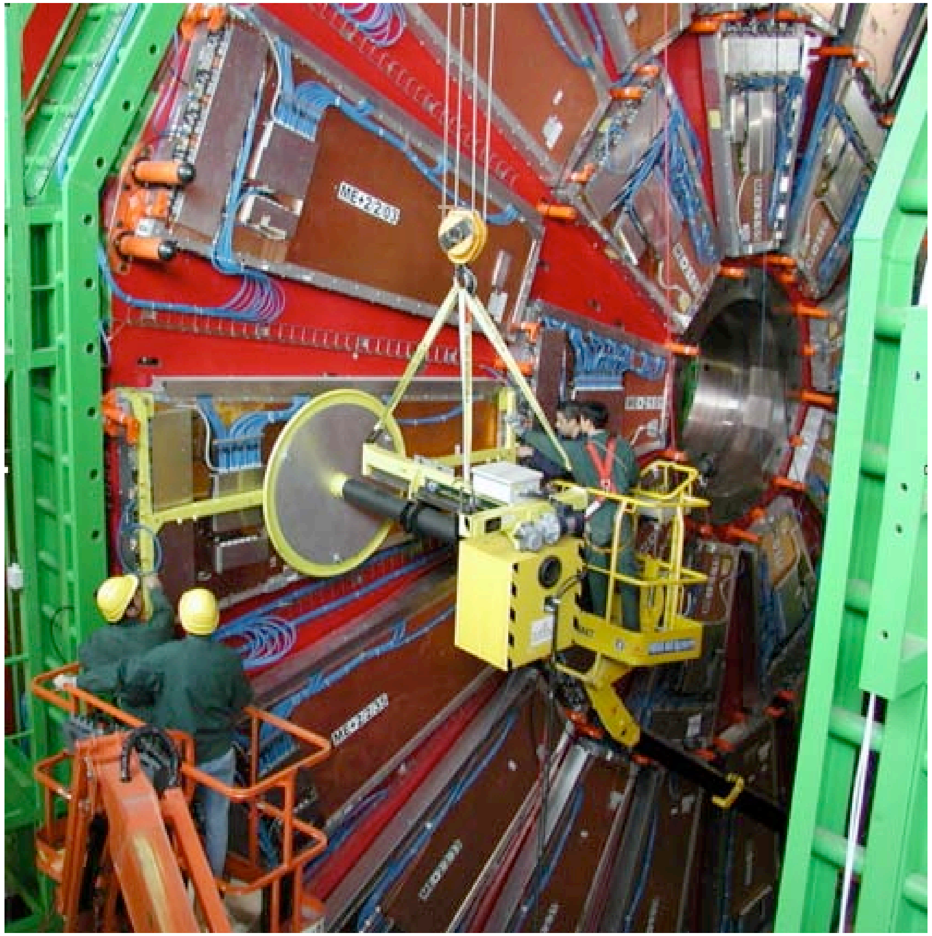
Point 1:
8^{th} (and last) ATLAS barrel toroid installed
in the underground cavern

Point 5:
CMS magnet (230 tons, L=12.5 m, R=3m) rotated from vertical
to horizontal position before insertion into cryostat (operation at T=4.2 K)

25 August 2005

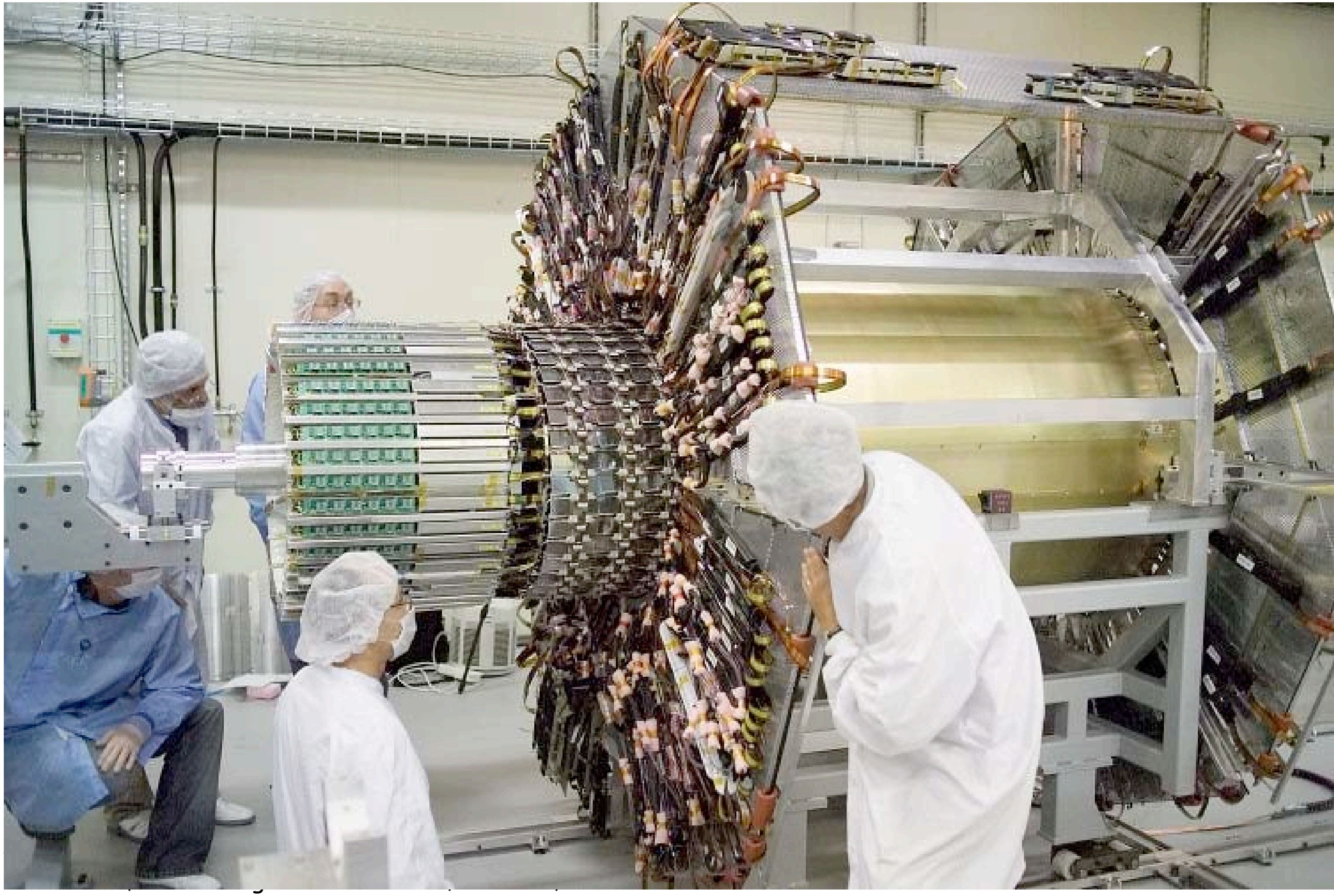
CMS end-cap Muon Spectrometer



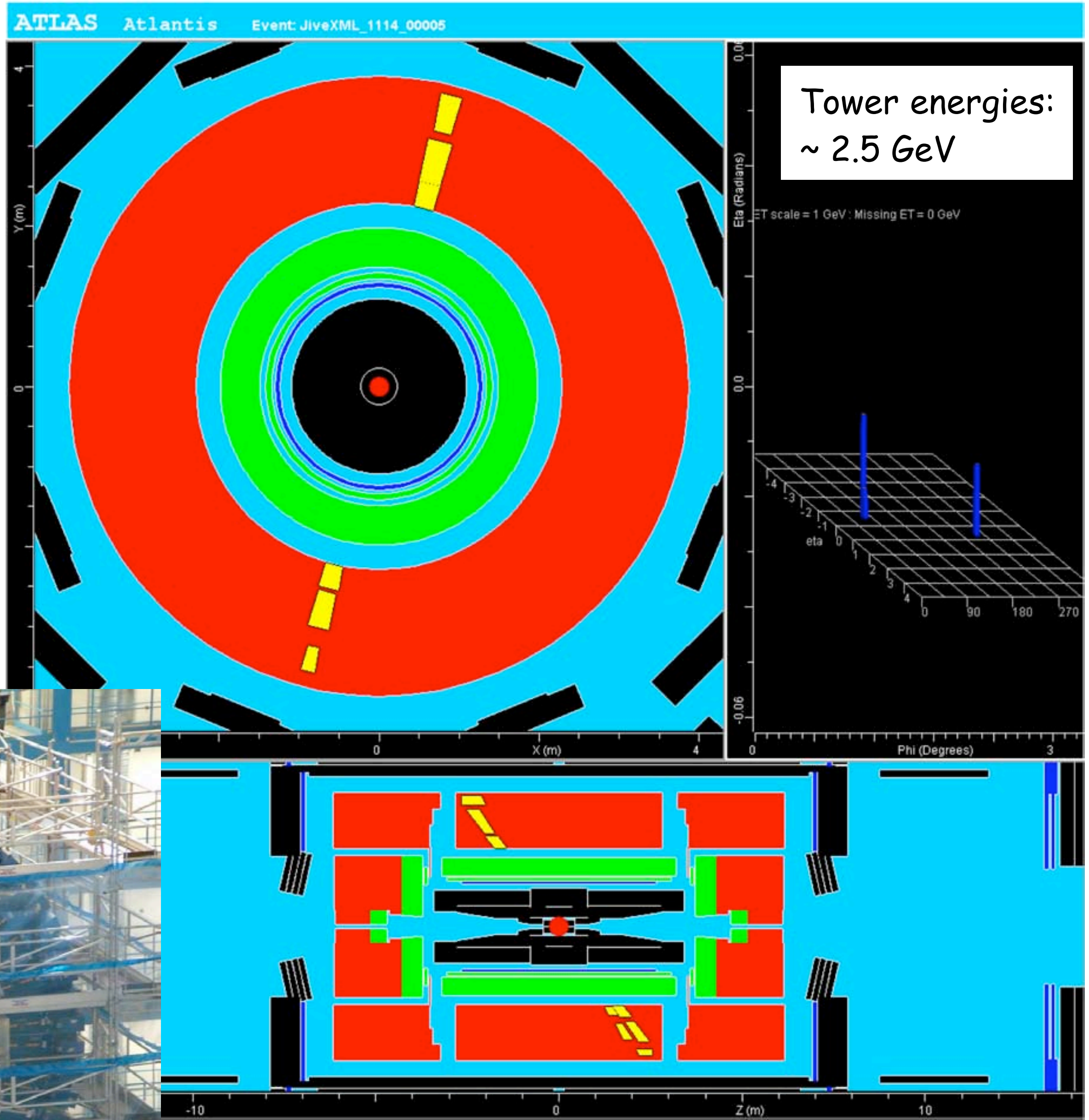


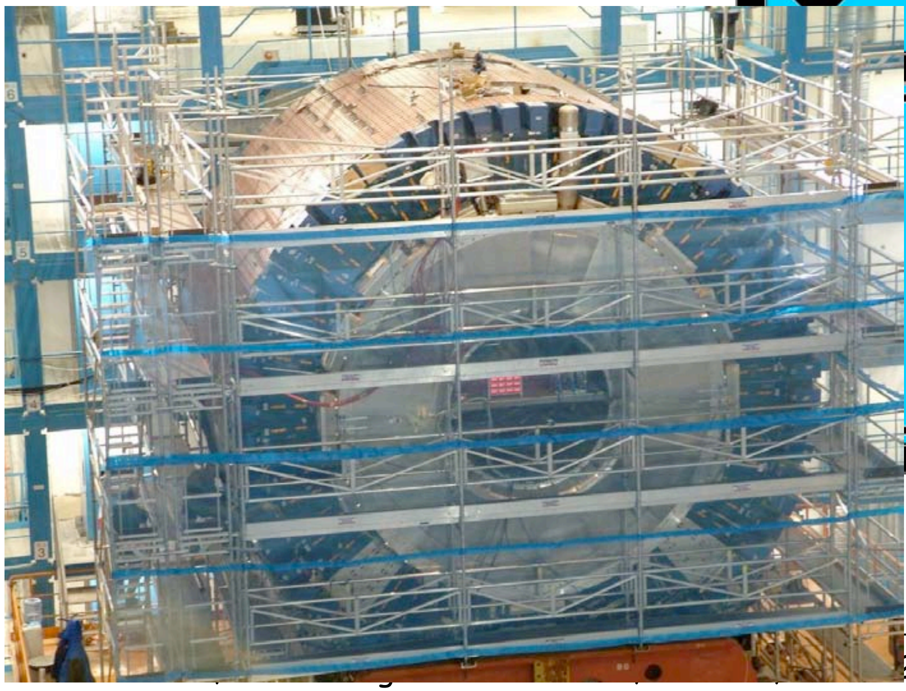
All 400 CSC chambers produced, > 60% installed

ATLAS inner tracker: insertion of the third Silicon layer (out of four) into the barrel cylinder



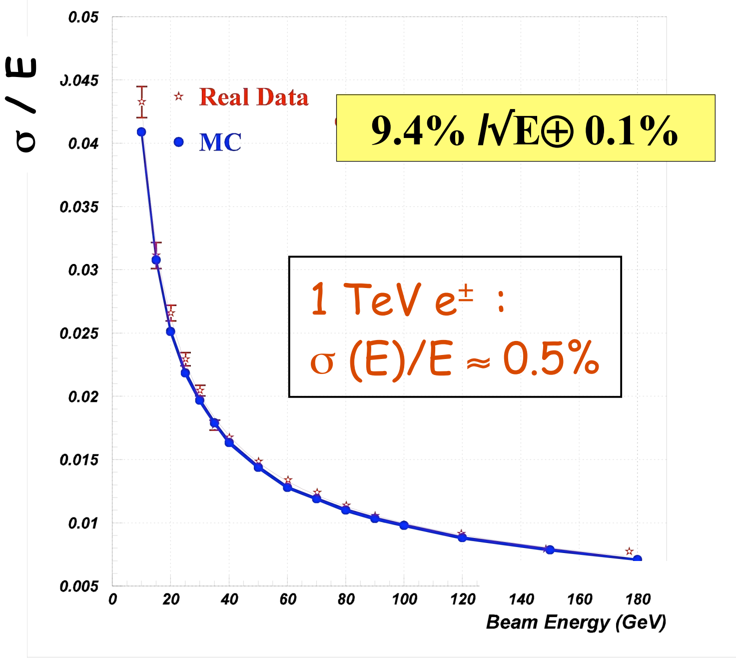
First cosmic muons observed by ATLAS in the underground cavern on June 20th (recorded by hadron Tilecal calorimeter)



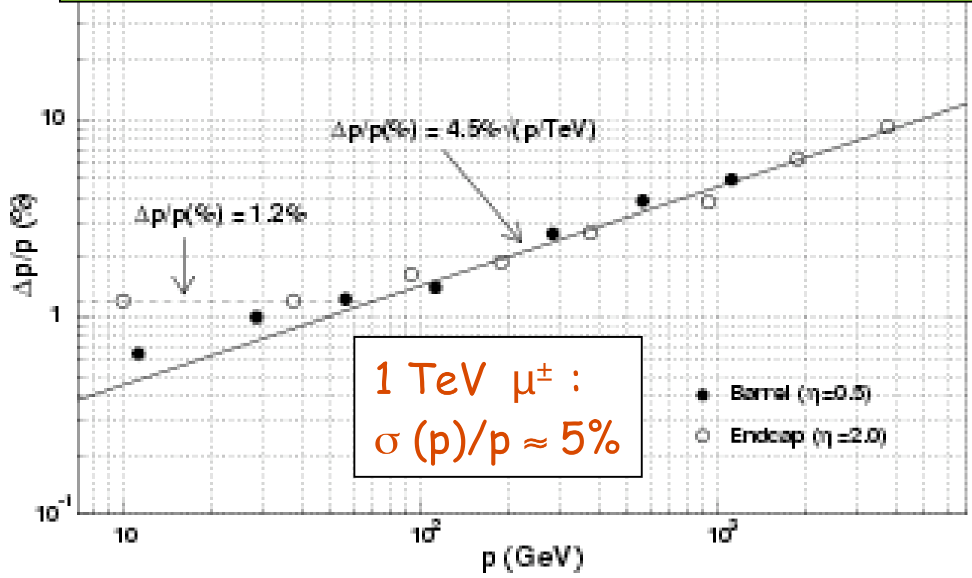


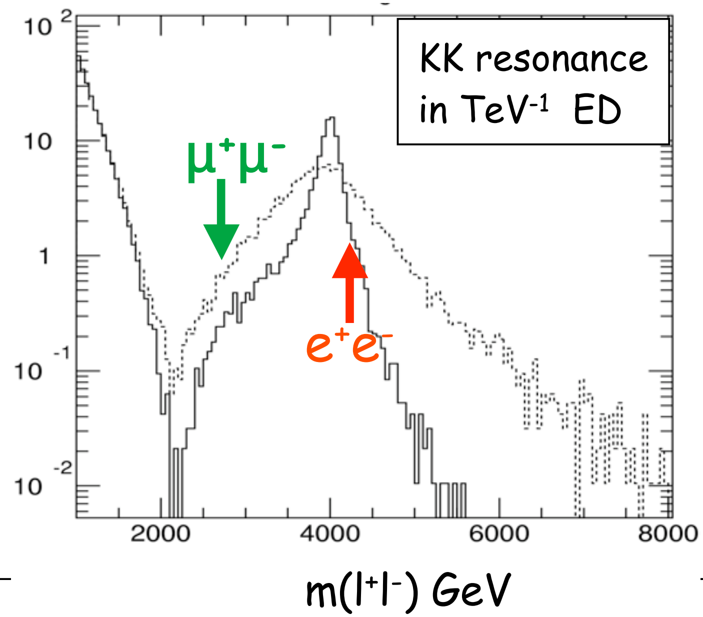
Examples of expected performance

Electron E-resolution measured in beam tests of ATLAS EM calorimeter



Muon momentum resolution expected in CMS





Heavy narrow resonances will likely be discovered in the X → ee channel
(muon decay useful for couplings, asymmetry, etc.)

❷ The first year(s) of data taking

First collisions (Summer 2007) : L ~ 5x 10^{28}
Plans to reach L ~ 10^{33} in/before 2009
Hope to collect few fb^{-1} per experiment by end 2008

Channels (examples …)	Events to tape for 1 fb^{-1} (per expt: ATLAS, CMS)	Total statistics from previous Colliders
$W \to \mu\nu$	7 x 10^6	~ 10^4 LEP, ~ 10^6 Tevatron
$Z \to \mu\mu$	~ 10^6	~ 10^6 LEP, ~ 10^5 Tevatron
$tt \to W b W b \to \mu\nu + X$	~ 10^5	~ 10^4 Tevatron
$\tilde{g}\tilde{g}$ m = 1 TeV	10^2 - 10^3	—

With these data:

- Understand and calibrate detectors in situ using well-known physics samples
  e.g. - $Z \to ee, \mu\mu$ tracker, ECAL, Muon chambers calibration and alignment, etc.
  - $tt \to bl\nu\, bjj$ jet scale from $W \to jj$, b-tag performance, etc.

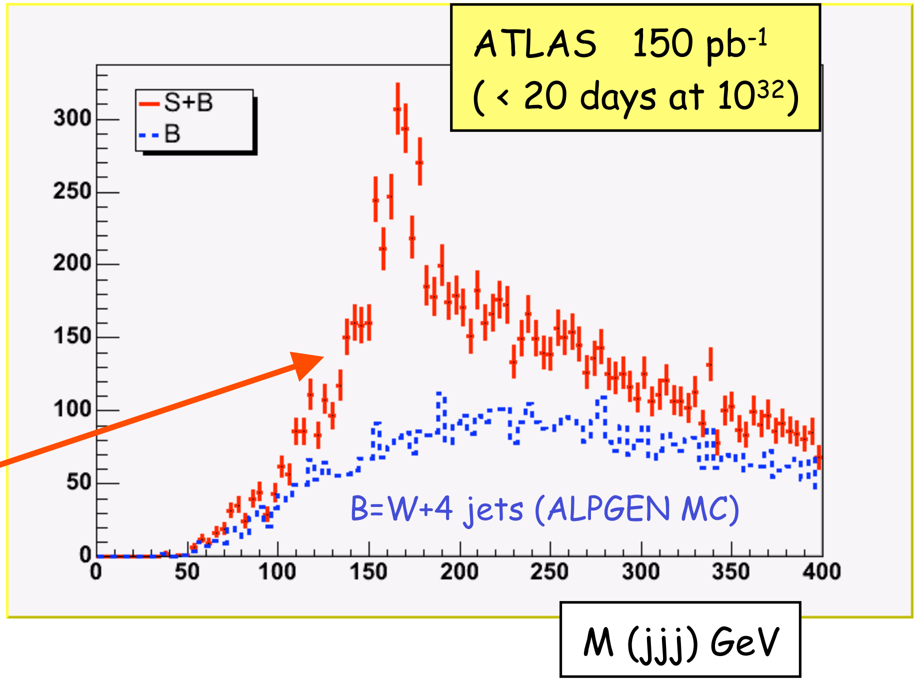
- Measure SM physics at $\sqrt{s}$ = 14 TeV : W, Z, tt, QCD jets … (omnipresent backgrounds to New Physics)

→ prepare the road to discovery ……. it will take a lot of time …

Example of initial SM measurement : top signal and top mass
(relevant to New Physics .....)

Bentvelsen et al.

- Use gold-plated tt → bW bW → blν bjj decay
- Very simple selection:
  - -- isolated lepton (e, μ) $p_T > 20$ GeV
  - -- exactly 4 jets $p_T > 40$ GeV
  - -- no kinematic fit
  - -- no b-tagging required (pessimistic, assumes trackers not yet understood)
- Plot invariant mass of 3 jets with highest p_T



Time	Events at 10^{33}	Stat. error δM_{top}(GeV)	Stat. error $\delta\sigma/\sigma$
1 year	3×10^5	0.1	0.2%
1 month	7×10^4	0.2	0.4%
1 week	2×10^3	0.4	2.5%

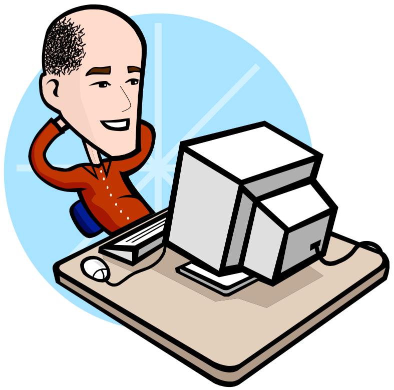
Ultimate LHC measurement precision:
m_{top} to ~ 1 GeV (and m_W to ~ 15 MeV)

- top signal visible pretty soon with simple selection cuts and no b-tagging
- cross-section to ~ 20%
- top mass to ~7 GeV
- get feedback on detector performance (jet E-scale, b-tag)
- tt is background to many searches

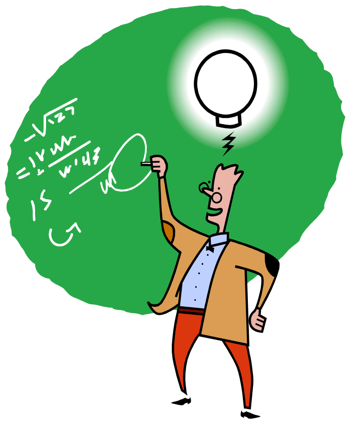
What about early discoveries ? Three examples ....

An easy case : a new (narrow) resonance of mass ~ 1 TeV decaying into e^+e^-,

e.g. a Z' or a Graviton → e^+e^- of mass ~ 1 TeV



An intermediate case : SUSY



A difficult case : a light Higgs (m_H ~ 115 GeV)

An "easy case" : G → e+e- resonance with m ~ 1 TeV

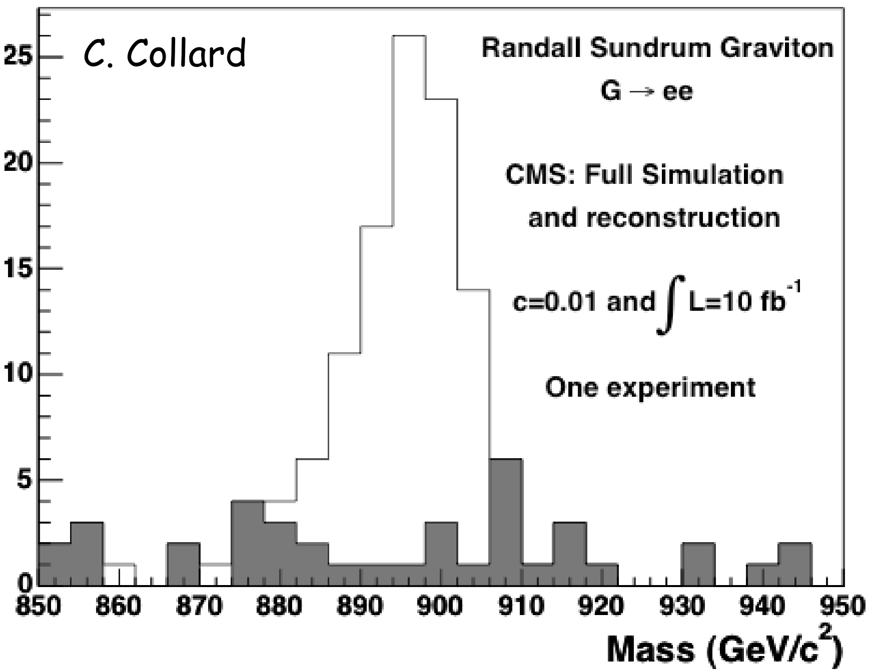
predicted in Randall-Sundrum Extra-dimensions

BR ($G \to ee \approx 2\%$), c = 0.01 (small/conservative coupling to SM particles)

Mass (TeV)	Events for 10 fb^{-1} (after all cuts)	$\int L\, dt$ for discovery ($\geq$ 10 observed events)
0.9	~ 80	~ 1.2 fb^{-1}
1.1	~ 25	~ 4 fb^{-1}
1.25	~ 13	~ 8 fb^{-1}

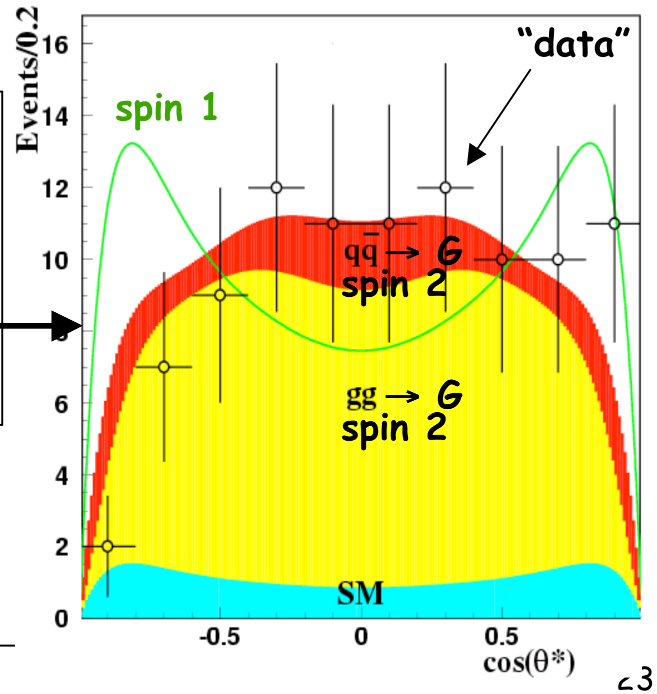
CMS

- large enough signal for discovery with ~ 1 fb^{-1} for m → 1 TeV
- dominant Drell-Yan background small
- signal is mass peak above background



Graviton (s=2) or Z′ (s=1) ?
→ look at $e^{\pm}$ angular distributions

ATLAS, 100 fb^{-1}, m_G=1.5 TeV

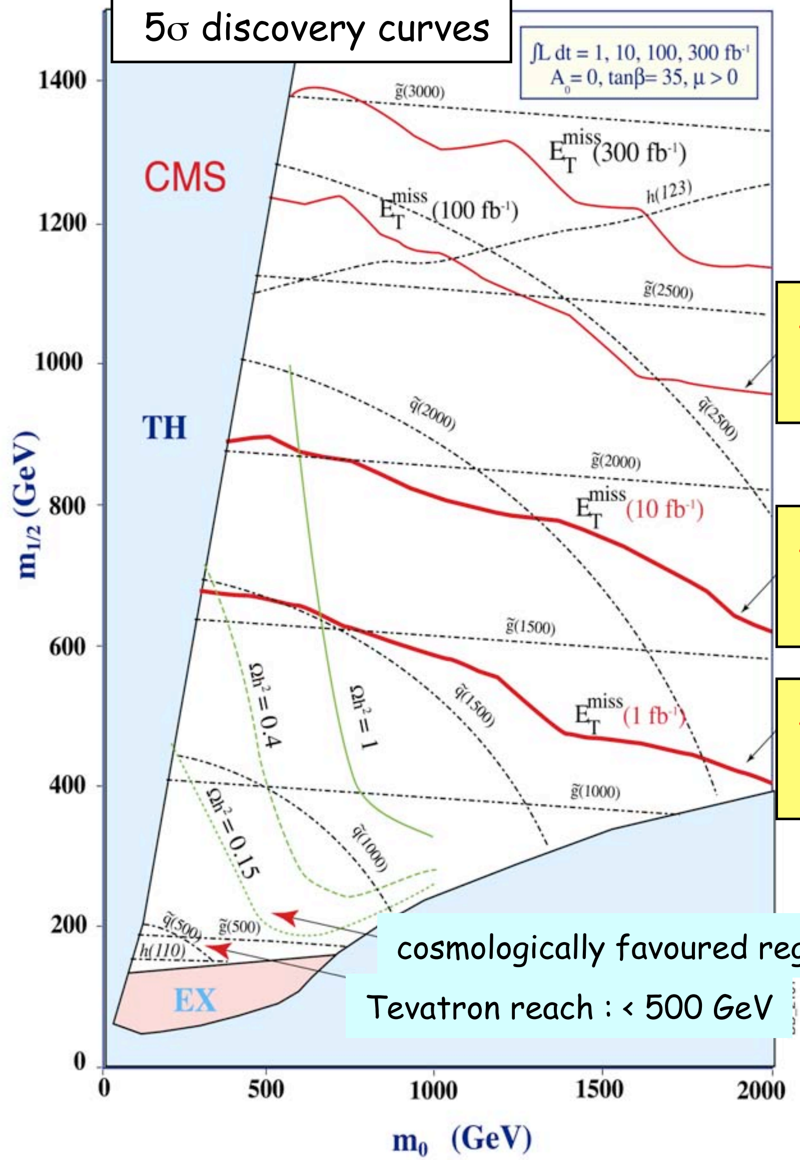


An "intermediate case" : SUPERSYMMETRY

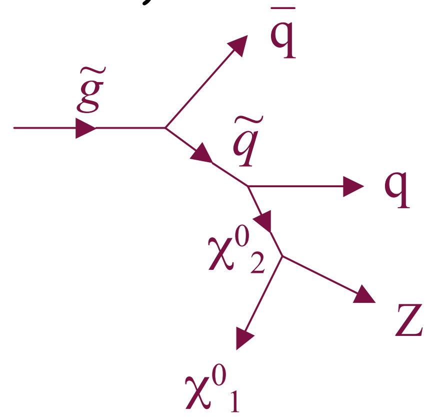
If SUSY stabilizes m_H → at TeV scale → could be found quickly .... thanks to:

- large $\tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g}$ cross-section → ≈ 100 events/day at 10^{33} for $m(\tilde{q}, \tilde{g}) \sim 1$ TeV
- spectacular signatures from cascade decays of heavy objects

5σ discovery curves



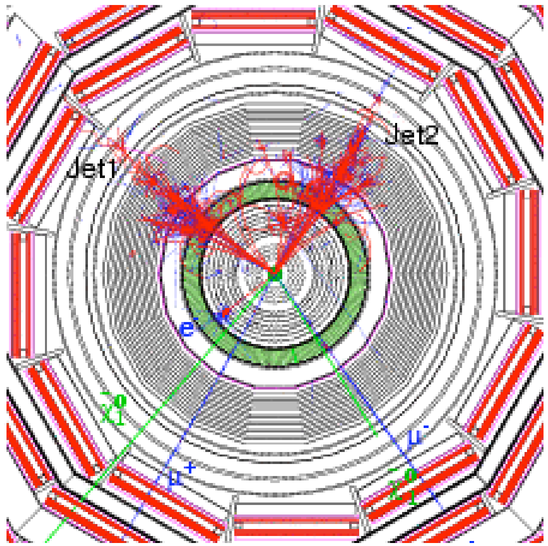
Using multijet + E_T^{miss} (most model-independent signature if R-parity conserved)



~ one year at 10^{34}: up to ~2.5 TeV

~ one year at 10^{33} : up to ~2 TeV

~ one month at 10^{33} : up to ~1.5 TeV



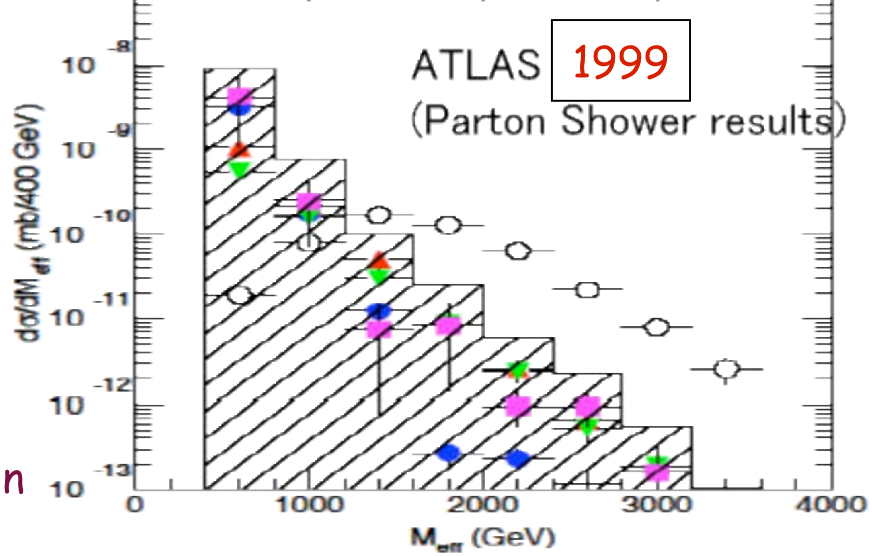
Why is SUSY more difficult than the previous case ?

Because of larger (and less well known) detector-related and physics backgrounds

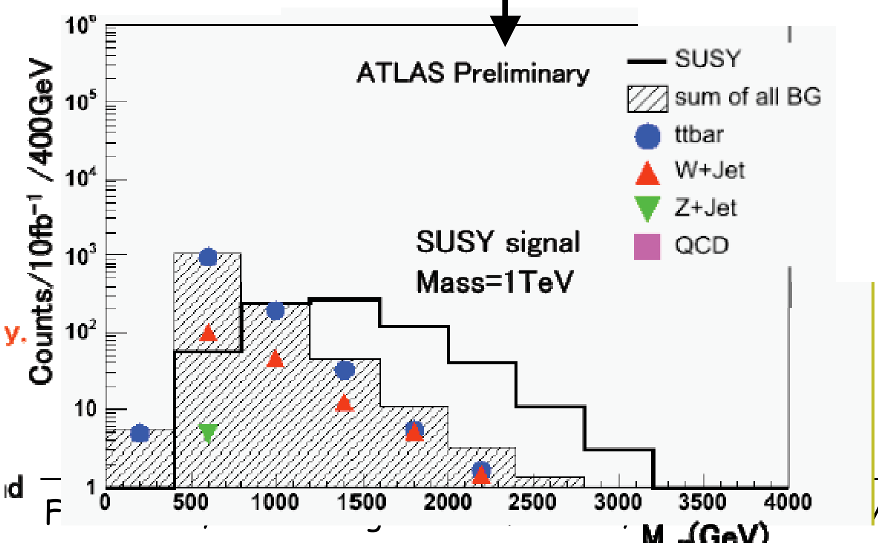
Example:
Parton shower MC underestimate high-p_T region, signal less clear today with Matrix Element → importance of adequate MC tools to describe backgrounds

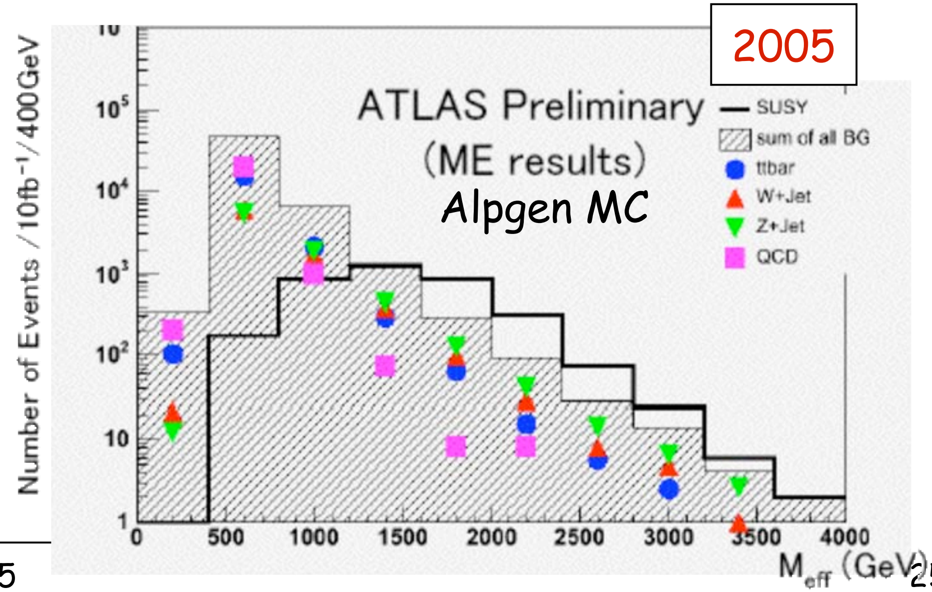
At LHC will use a combination of MC and data : e.g. $Z \to ee$ + jets events to measure $Z \to \nu\nu$ + jets (dominant) background

$M_{eff} = \Sigma_{i=1,5} E_{Ti}$ (jets) + E_T^{miss}

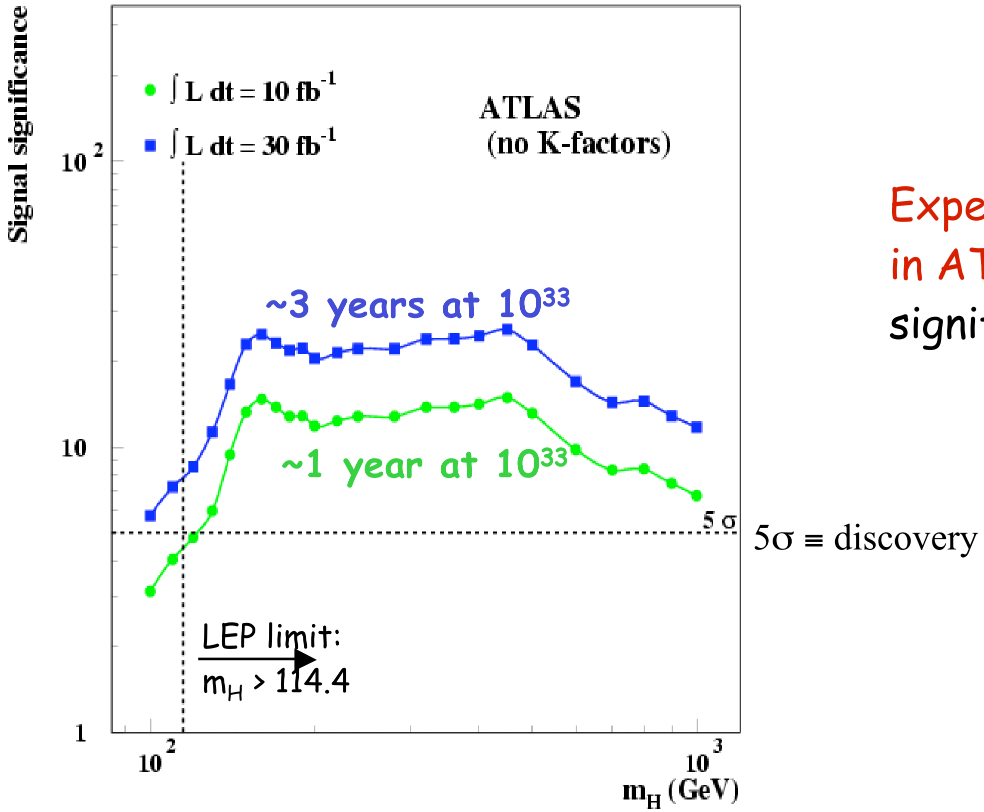


Will also look for SUSY events with ≥ 1 lepton (cleaner signature)





A difficult case: a light Higgs (m_H ~ 115 GeV) …



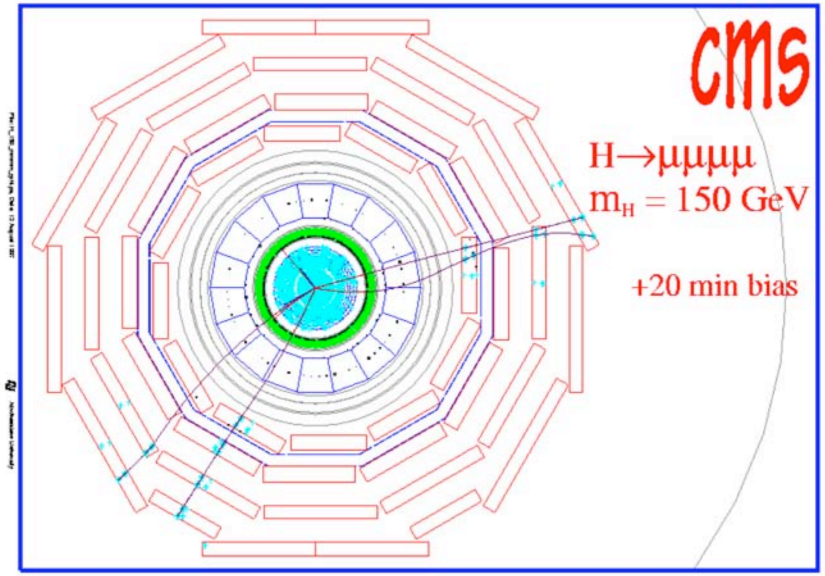
Expected Higgs signal significance ($S/\sqrt{B}$) in ATLAS (combining both experiments significance increases by ~ $\sqrt{2}$)

- Higgs can be discovered over full allowed mass range
  → LHC will say final word about SM Higgs mechanism
- Most difficult region (especially at the beginnning) : m_H ~ 115 GeV
  - close-to-optimal detector performance needed
    to detect $H \to \gamma\gamma$, $ttH \to bb$, $qqH \to \tau\tau$
  - knowledge of (huge) backgrounds to few percent required

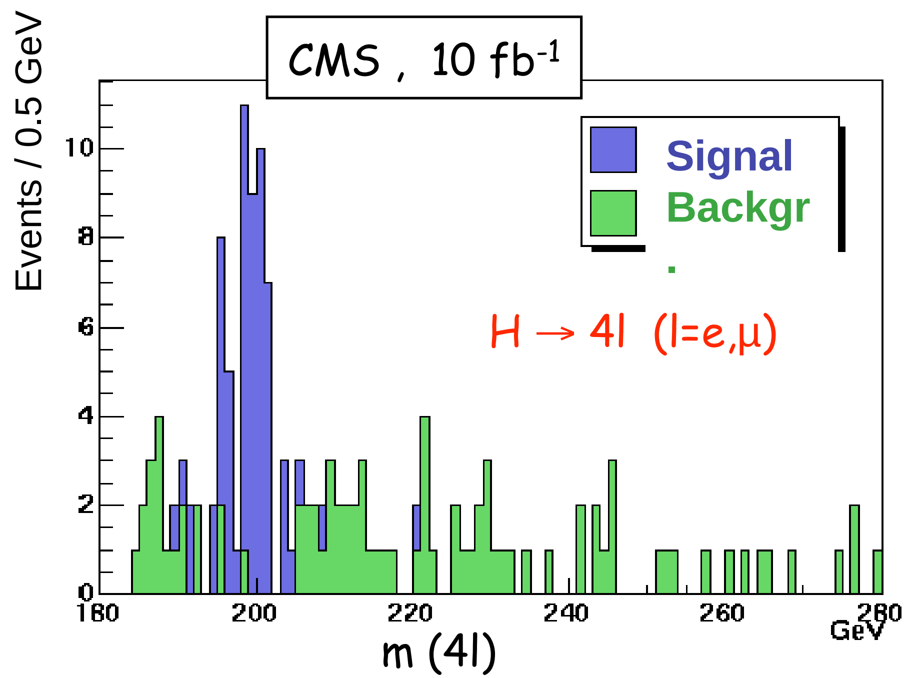
→ it will take a lot of time …

If m_H > 180 GeV : early discovery easier with gold-plated $H \to 4l$ channel

$H \to 4l$: low-rate but very clean (narrow mass peak, small background)

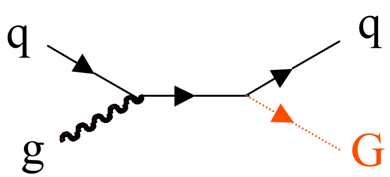


May be observed with 3-4 fb^{-1}
(end 2008 ?)



❸ Examples of longer-term potential

Look for a continuum of Graviton KK states :



→ topology is jet(s) + missing E_T

Cross-section $\approx \frac{1}{M_D^{\delta+2}}$

M_D = gravity scale

δ = number of extra-dimensions

ATLAS, 100 fb^{-1}

	δ = 2	δ = 3	δ = 4
M_D^{max}	9 TeV	7 TeV	6 TeV

Discriminating between models:

-- SUSY : multijets plus E_T^{miss} (+ leptons, ...)

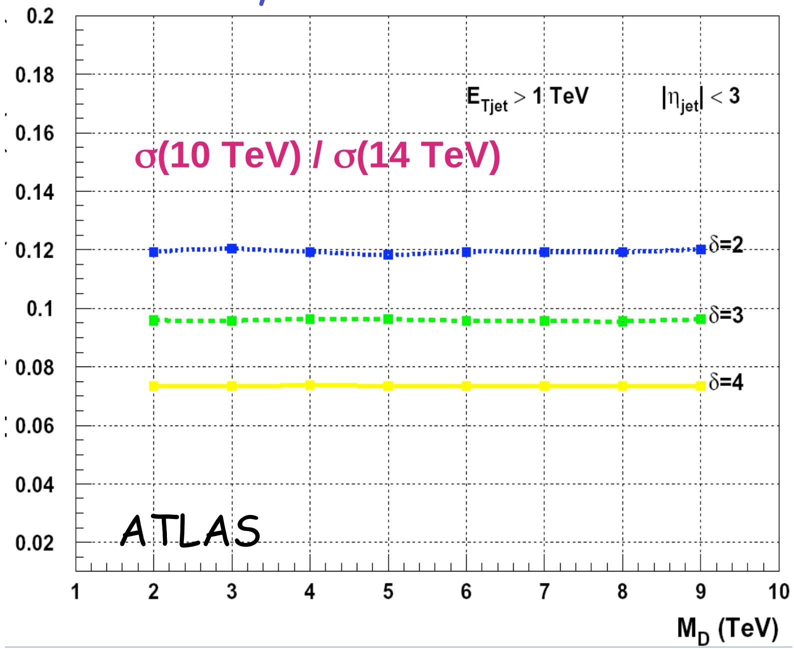
-- ADD : monojet plus E_T^{miss}

Extra-dimensions (ADD models)

To characterize the model need to measure M_D and δ

Measurement of cross-section gives ambiguous results: e.g. δ=2, M_D= 5 TeV very similar to δ=4, M_D= 4 TeV

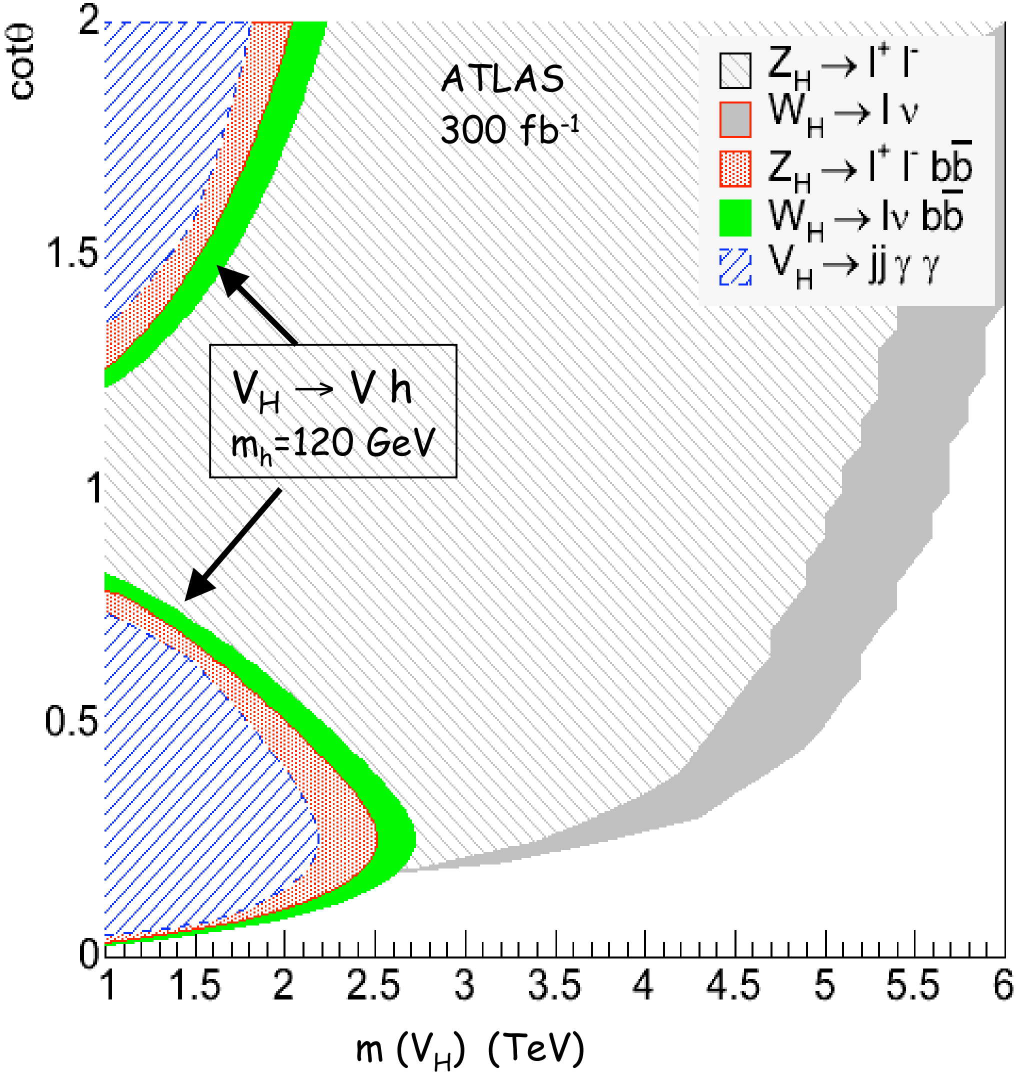
Solution may be to run at different $\sqrt{s}$:



Good discrimination between various solutions possible with expected <5% accuracy on $\sigma(10)/\sigma(14)$ for 50 fb^{-1}

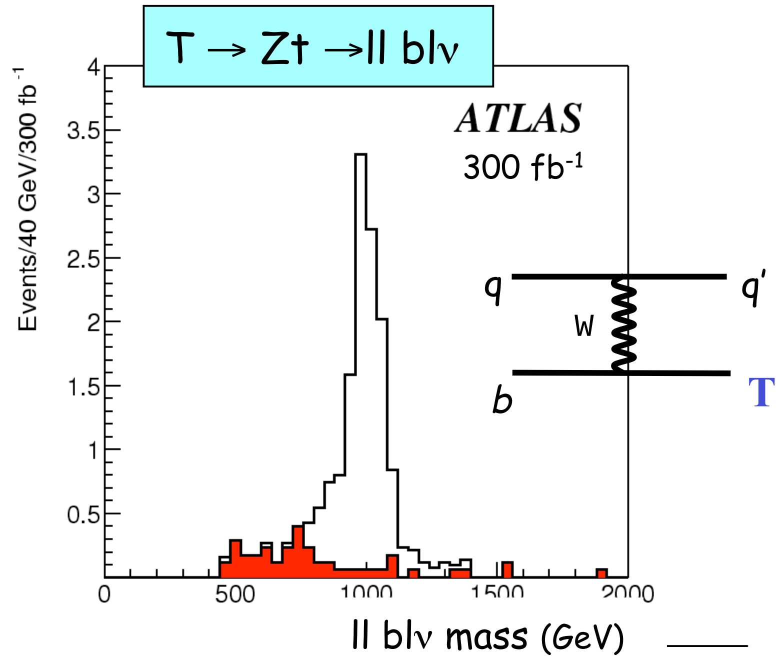
Little Higgs  models

Alternative approach to the hierarchy problem predicting heavy top T (EW singlet), new gauge bosons W_H, Z_H, A_H and Higgs triplet Φ^0, Φ^+, Φ^{++}



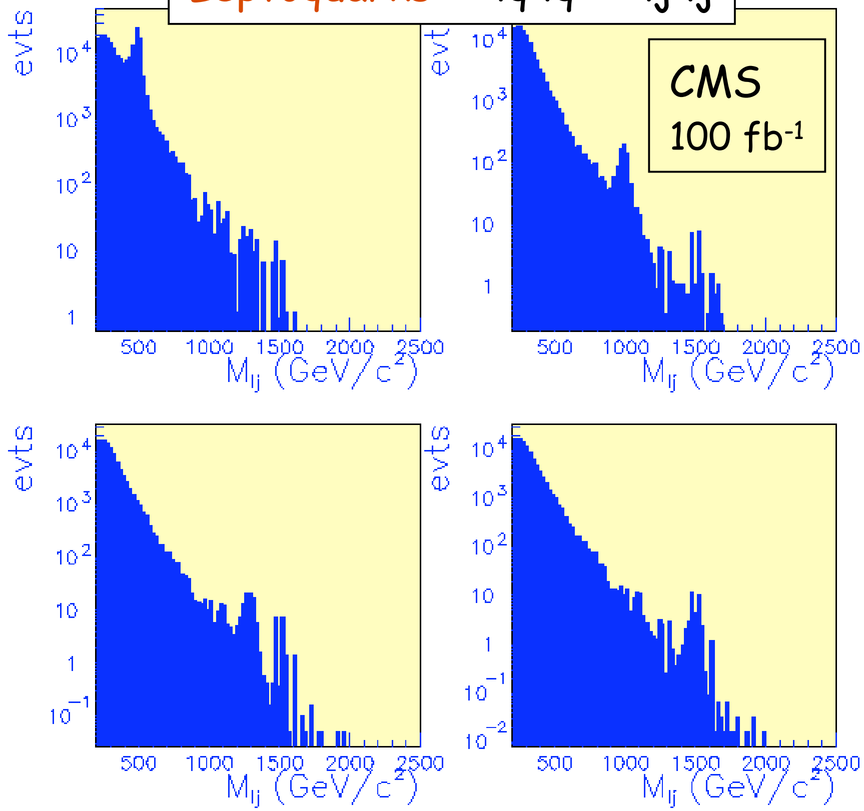
Observation of T → Zt, Wb discriminates from 4th family quarks

Observation of V_H → Vh discriminates from W′, Z′

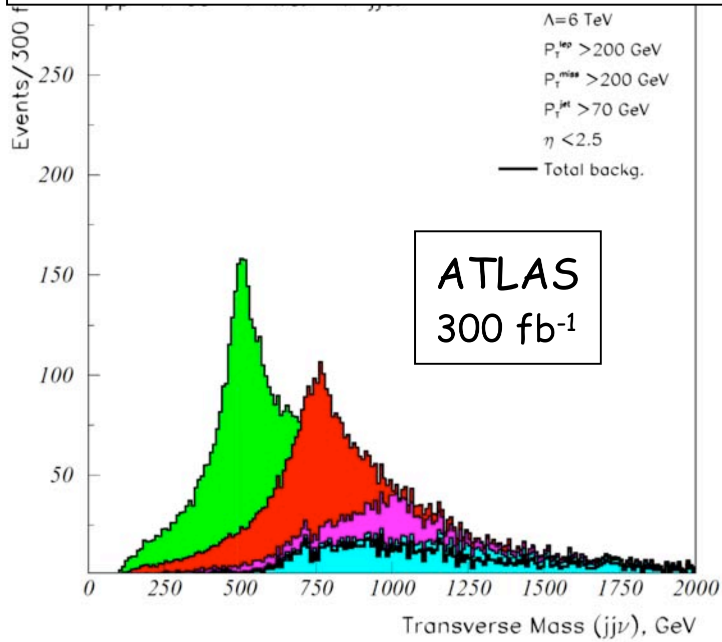


Other scenarios .....

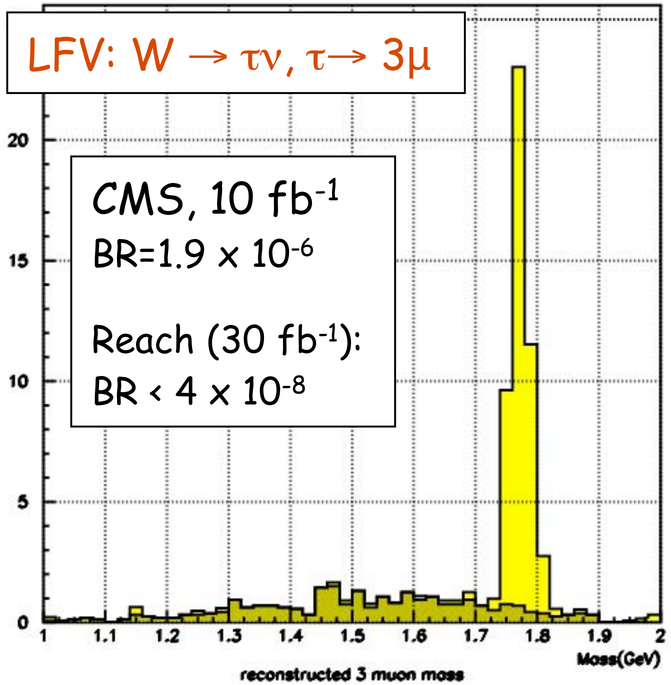
Leptoquarks : lq lq → lj lj



Excited leptons ; e*e, e* → Wν → jj ν



LFV: W → τν, τ→ 3μ



Large number of scenarios studied:

⇒ demonstrated detector sensitivity to many signatures

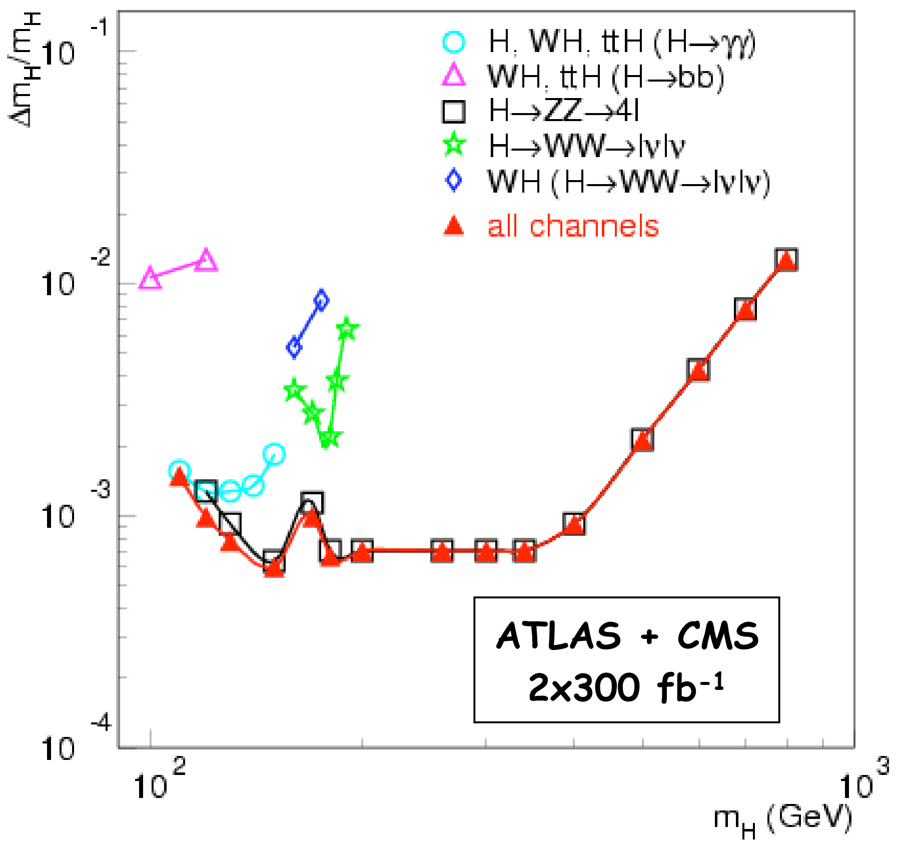
→ robustness, ability to cope with unexpected scenarios

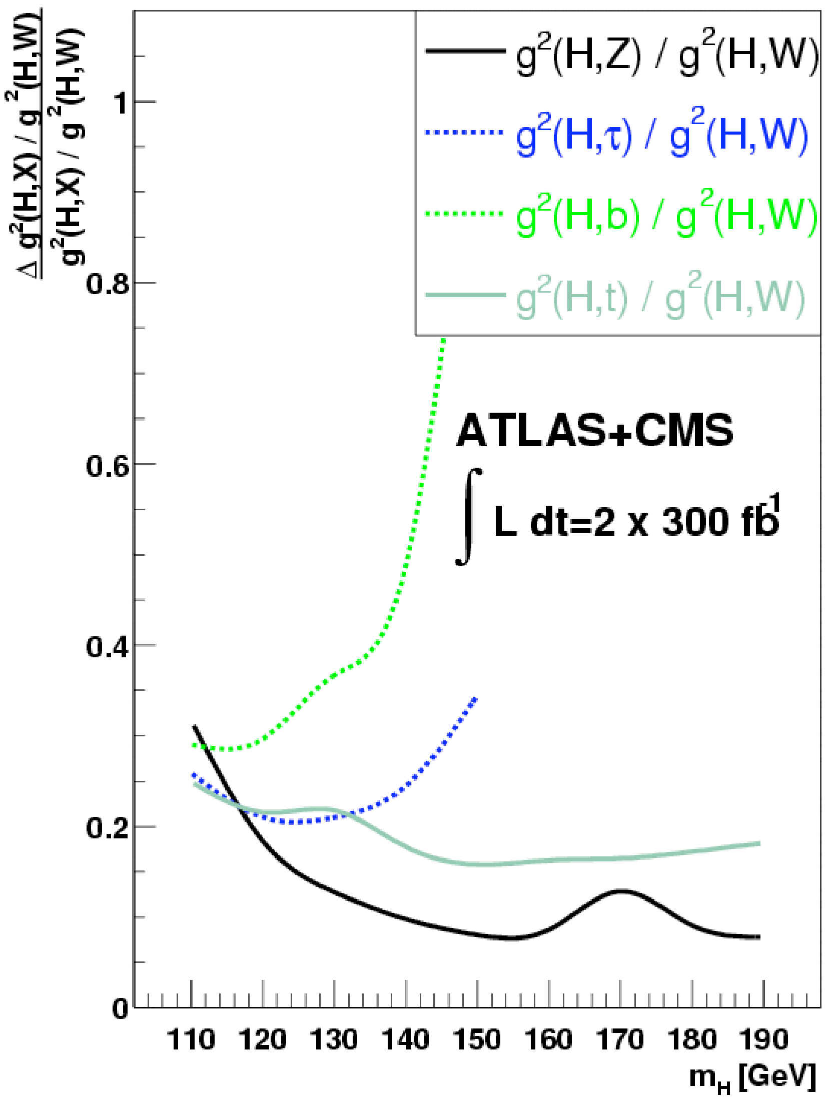
⇒ LHC direct discovery reach up to m ≈ 5-6 TeV

❹ Constraining the underlying theory …

Courtesy M. Duehrssen

Measurements of the SM Higgs parameters



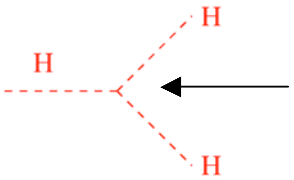


Lot of useful information to constrain the theory

(though not competitive with LC precision of e.g. ≈ % on couplings)

Higgs self-coupling λ

- not accessible at LHC
- may be constrained to ≈ 20% at Super-LHC ($L=10^{35}$)



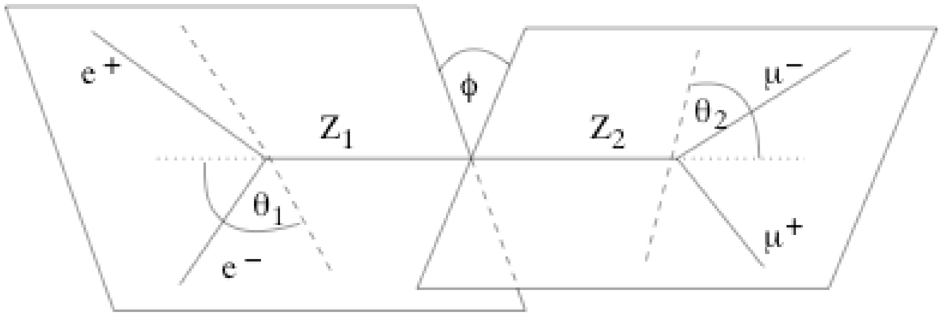
~ λv

$m_H^2 = 2 \lambda v^2$

Buszello et al. SN-ATLAS-2003-025

Higgs spin and CP

Promising for m_H > 180 GeV ($H \to ZZ \to 4l$), difficult at lower masses

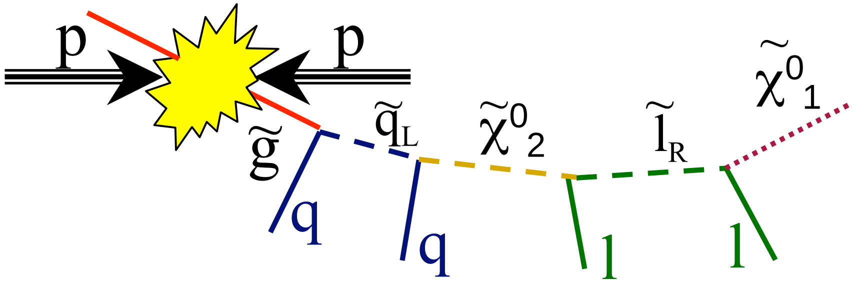


Significance for exclusion of $J^{CP}=0^+$

ATLAS + CMS, 2 x 300 fb^{-1}

m_H (GeV)	$J^{CP} = 1^+$	$J^{CP} = 1^-$	$J^{CP}=0^-$
200	6.5 σ	4.8 σ	40 σ
250	20 σ	19 σ	80 σ
300	23 σ	22 σ	70 σ

Precise SUSY measurements

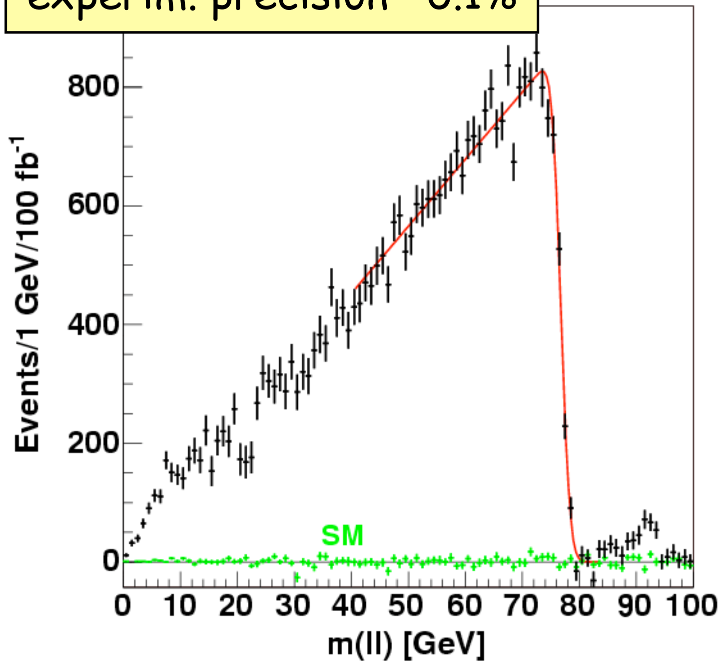


Mass peaks cannot be directly reconstructed (χ^0_1 undetectable) → measure invariant mass spectra (end-points, edges,..) of visible particles
→ deduce constraints on combinations of sparticle masses

m (l^+l^-) spectrum
end-point : 77 GeV
experim. precision ~0.1%

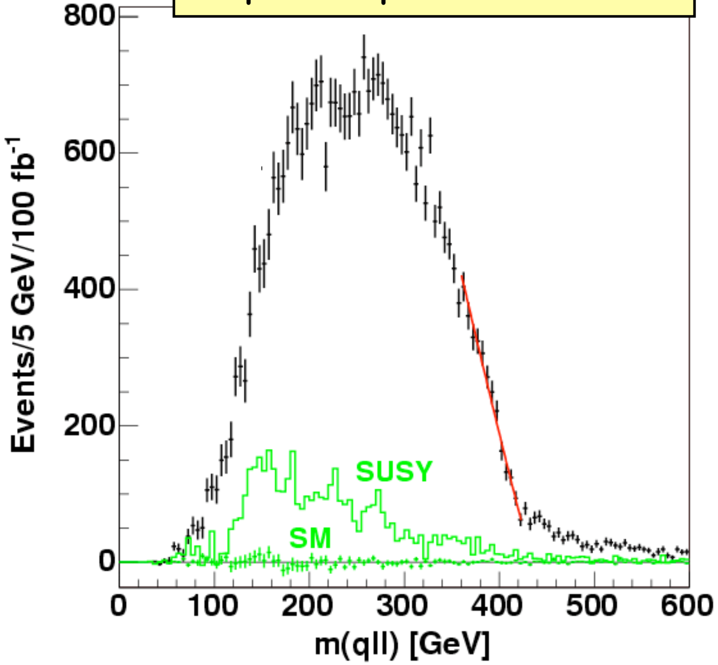
$m(\tilde{q}_L\ \chi^0_2\ \tilde{l}_R\ \chi^0_1) =$ 540, 177,143,96 GeV

m (llj)^{min} spectrum
end-point: 431 GeV
experim. precision ~1 %



ATLAS, 100 fb^{-1}

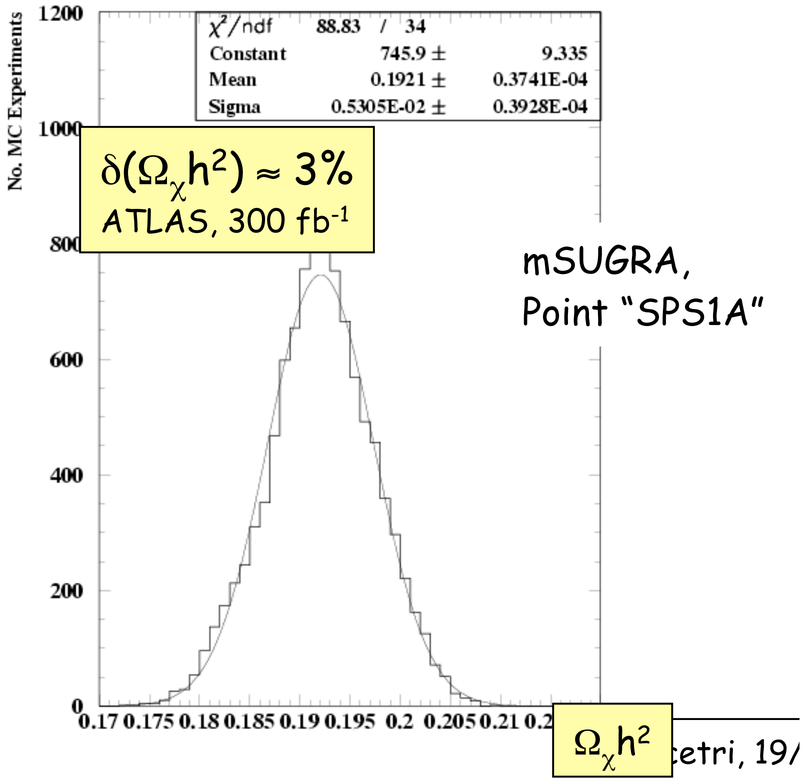
mSUGRA Point "SPS1A"
Courtesy B. Gjelsten



Putting all measurements together:

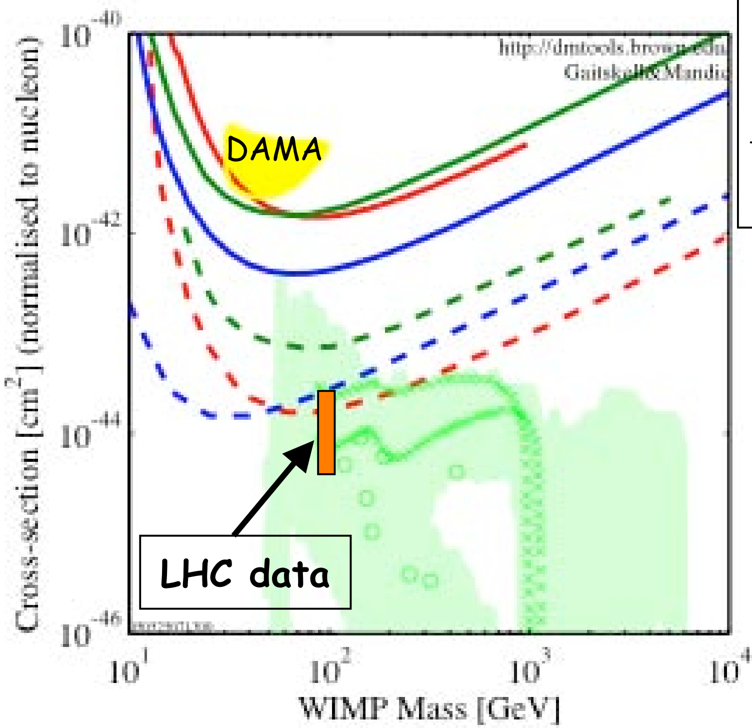
- deduce several sparticle masses: typical precision 1%-20%
  Model-indep. (just kinematics), but interpretation is model-dep.
- from fit of model to all experimental measurements derive
  -- sparticle masses with higher accuracy
  -- fundamental parameters of theory to 1-30%
  -- dark matter (χ^0_1) relic density and σ (χ^0_1 - nucleon)

demonstrated so far in mSUGRA (5 param.) and in more general MSSM (14 param.)



mSUGRA,
Point "SPS1A"

Direct Dark Matter searches



Zepelin, CDMS, Edelweiss
— present limit
--- projected

General strategy toward understanding the underlying theory

(SUSY as an example …)

Discovery phase: inclusive searches … as model-independent as possible

First characterization of model: from general features: Large E_T^{miss} ? Many leptons ? Exotic signatures (heavy stable charged particles, many γ's, etc.) ? Excess of b-jets or τ's ? …

Interpretation phase:

- reconstruct/look for semi-inclusive topologies, eg.:
  - -- h → bb peaks (can be abundantly produced in sparticle decays)
  - -- di-lepton edges
  - -- Higgs sector: e.g. A/H → $\mu\mu$, $\tau\tau$ ⇒ indication about tanβ, measure masses
  - -- tt pairs and their spectra ⇒ stop or sbottom production, gluino → stop-top
- determine (combinations of) masses from kinematic measurements (e.g. edges …)
- measure observables sensitive to parameters of theory (e.g. mass hierarchy)

At each step narrow landscape of possible models and get guidance to go on:

- lot of information from LHC data (masses, cross-sections, topologies, etc.)
- consistency with other data (astrophysics, rare decays, etc.)
- joint effort theorists/experimentalists will be crucial

Conclusions

Past year achievements in the LHC machine construction are impressive, giving robustness to the schedule (CERN fully committed to it !).

Main objectives: -- complete installation by end of 2006

-- deliver first collisions by summer 2007

The experiments are generally on track for ready-for-beam in middle 2007

Emphasis is now on integration, installation, commissioning of machine and detectors of unprecedented complexity, technology and performance

so, hopefully …

In ~ 2 years from now, particle physics will enter a new epoch, hopefully the most glorious and fruitful of its history.

The LHC will explore in detail the highly-motivated TeV-scale with a direct discovery potential up to m ≈ 5-6 TeV

→ if New Physics is there, the LHC will find it (*)
→ it will say the final word about the SM Higgs mechanism and many TeV-scale predictions
→ it may add crucial pieces to our knowledge of fundamental physics → impact also on astroparticle physics and cosmology
→ most importantly: it will likely tell us which are the right questions to ask, and how to go on

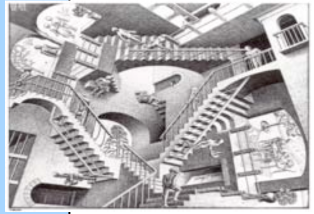
(*) Early determination of scale of New Physics would be crucial for the future of our discipline and for the planning of future facilities
(ILC ? CLIC ? Underground Dark Matter searches ? ….)

Spare slides

SUSY

New particles at TeV scale stabilize m_H

Extra-dimensions



Additional dimensions

$\rightarrow M_{gravity} \sim M_{EW}$

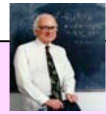
New states at TeV scale

$M_{EW} / M_{Planck} \sim 10^{-17}$

$\delta m_H \sim \Lambda$ (scale up to which SM is valid)

$\Rightarrow$ New Physics at TeV scale to stabilize m_H

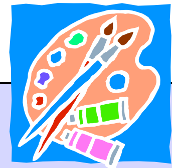
Little Higgs



SM embedded in larger gauge group

New particles at TeV scale, stable m_H

Technicolour

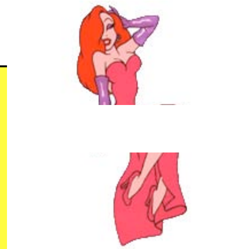


New strong interactions break EW symmetry

$\rightarrow$ Higgs (elementary scalar) removed

New particles at TeV scale

Split SUSY



Accept fine-tuning of m_H

(and of cosm. constant)

by anthropic arguments

Part of SUSY spectrum at TeV scale

(for couplings unification and dark matter)

LHC potential for ~all these scenarios demonstrated since long time. Here:

❶ What can be done at the beginning ?

❷ Signal interpretation and constraints of underlying theory ?

LHC start-up scenario

Stage 1
Initial commissioning
43x43 to 156x156, N=$3x10^{10}$
Zero to partial squeeze

L=$3x10^{28}$ - $2x10^{31}$

Stage 2
75 ns operation
936x936, N=$3\text{-}4x10^{10}$
partial squeeze

L=10^{32} - $4x10^{32}$

Stage 3
25 ns operation
2808x2808, N=$3\text{-}5x10^{10}$
partial to near full squeeze

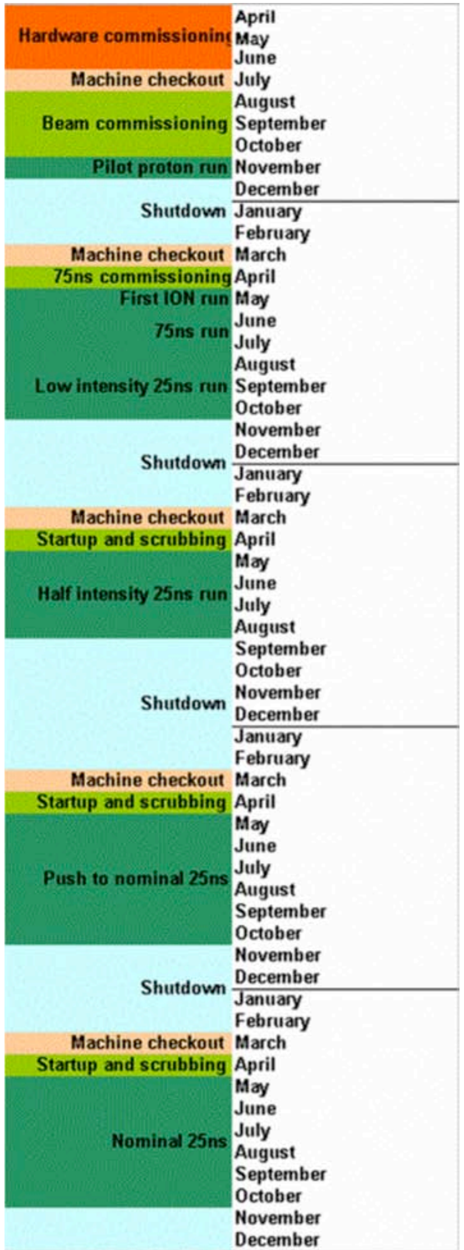
L=$7x10^{32}$ - $2x10^{33}$

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

L=10^{34}

" Difficult to speculate further on what the performance might be in the first year.
As always, CERN accelerators departments will do their best !"

Lyn Evans, LHC Project Leader



CMS Commissioning

- **Now :** detectors being commissioned with cosmic rays also in large chunks, addressing system issues.
- **Q1 06, cosmic challenge:** slice test of CMS during the Magnet Test
- Test with cosmic rays will continue in the pit after installation and re-cabling
- **Pilot run:** Assume that we get a reasonable amount of collision data which are completed by Beam Gas/Beam Halo Muon datasets
  - LVL1/HLT/DAQ: Timing-in, data coherence, sub-system synchronization, calibration, debug algorithms, …
  - ECAL and HCAL calibration :Intercalibrate barrel crystals - "Phi Symmetry Method" ~2% and Cross check and complete source calibration for HCAL channels ~2%
  - Tracker and Muon alignment : Align the tracker strip detector significantly below the 100 μm level, Align the muon chambers at the 100 μm level

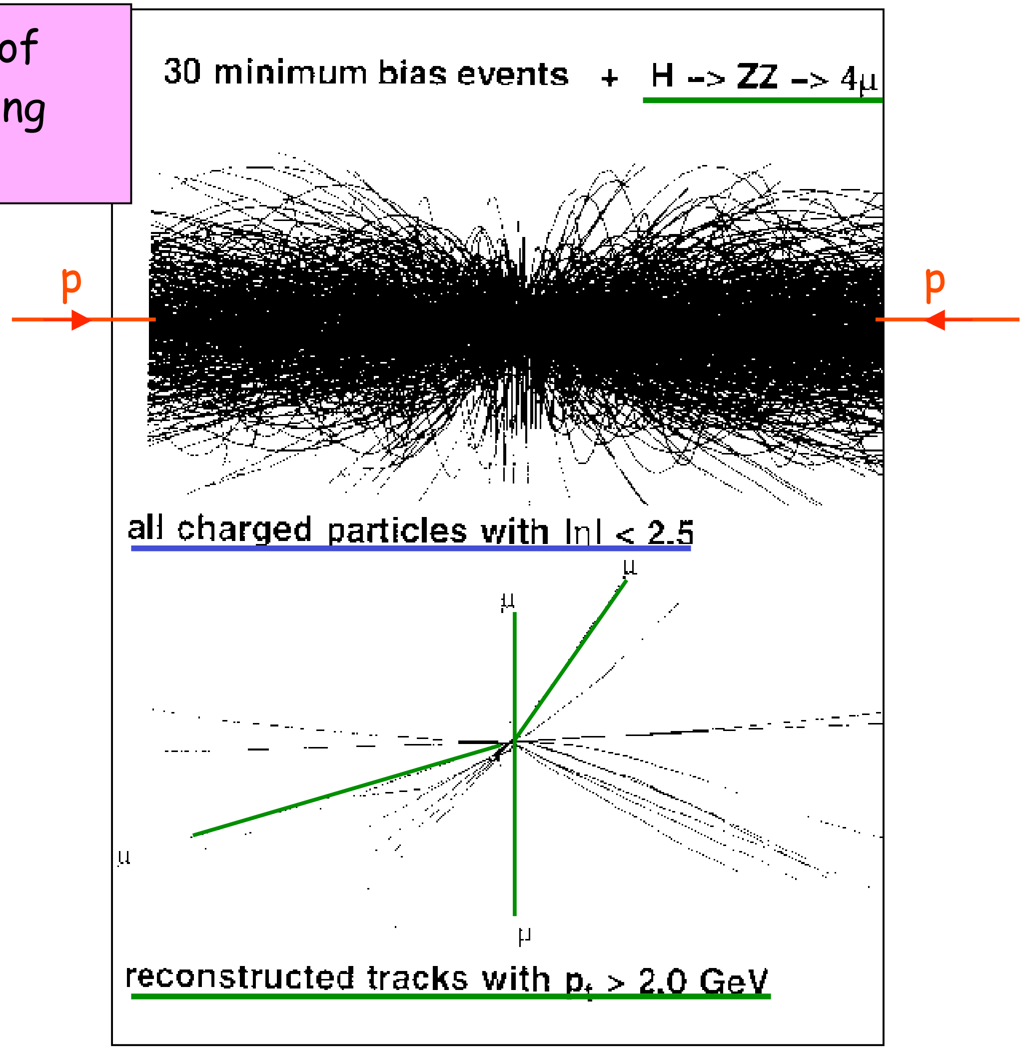
CMS Status

- Civil Engineering **is off the Critical Path**
- Magnet: **Coil connected. Start swivelling preparations in June 2005. Q1-06 end magnet test and cosmic challenge & start heavy lowering April 06**
- HCAL, Muons **: construction on schedule and well advanced.**
- TO WATCH:
- ECAL: **Crystals production, new contracts signed with two vendors.**
- TRACKER**: Hybrid production and tracker integration at CERN.**

Initial CMS* detector will be ready and closed for beam on 30 June 2007.

***ECAL endcaps and pixels (even though ready) will be installed during winter 2007 shutdown in time for physics run in 2008.**

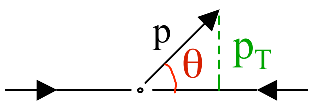
Simulation of CMS tracking detector



At each crossing : ~1000 charged particles produced over $|\eta| < 2.5$ $(10^0 < \theta < 170^0)$

However : $\langle p_T \rangle \approx 500$ MeV

→ applying p_T cut allows extraction of interesting events



$\eta = -\ln \mathrm{tg}\, \theta/2$

<u>Impact of pile-up on detector requirements and performance</u>:

-- fast response : ~ 50 ns

-- granularity : > 10^8 channels

-- radiation resistance (up to 10^{16} n/cm^2/year in forward calorimeters)

-- event reconstruction much more challenging than at previous colliders

❶ The first year(s) of data taling

The first LHC data : from Summer 2007…

1 fb^{-1} (10 fb^{-1}) ≡ 6 months at 10^{32} (10^{33}) $cm^{-2}s^{-1}$ at 50% efficiency → may collect few fb^{-1} per experiment by end 2008

Channels (examples …)	Events to tape for 1 fb^{-1} (per expt: ATLAS, CMS)	Total statistics from previous Colliders
$W \rightarrow \mu\nu$	7×10^6	~ 10^4 LEP, ~ 10^6 Tevatron
$Z \rightarrow \mu\mu$	~ 10^6	~ 10^6 LEP, ~ 10^5 Tevatron
$tt \rightarrow W b W b \rightarrow \mu\nu + X$	~ 10^5	~ 10^4 Tevatron
$\tilde{g}\tilde{g}$ m = 1 TeV	10^2 - 10^3	———

With these data:

- Understand and calibrate detectors in situ using well-known physics samples

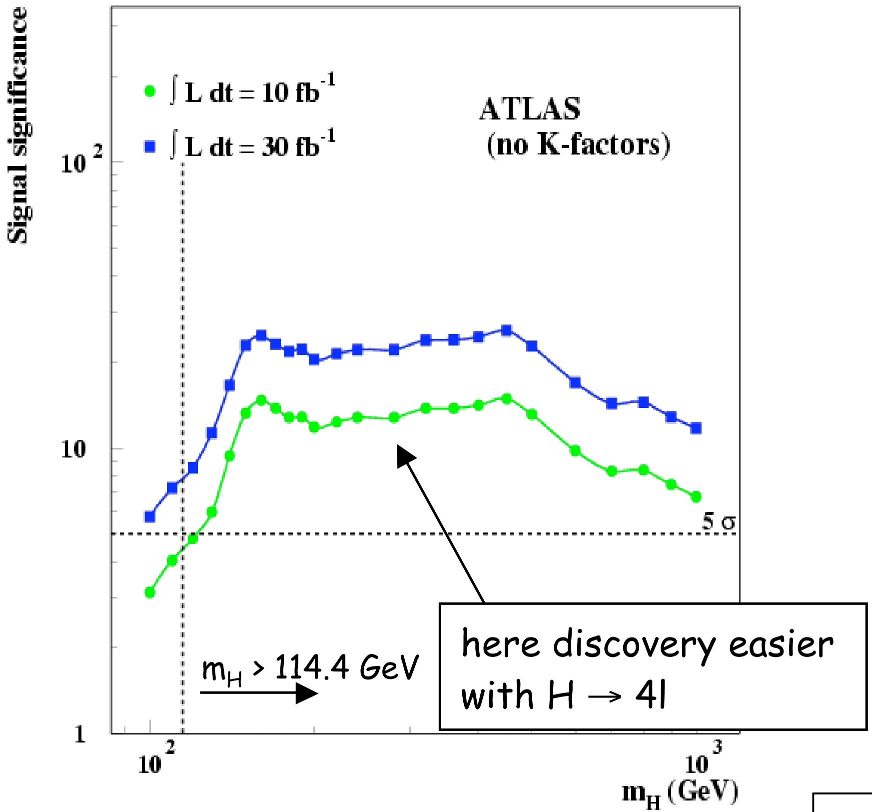
  e.g. - $Z \rightarrow ee, \mu\mu$ tracker, ECAL, Muon chambers calibration and alignment, etc.

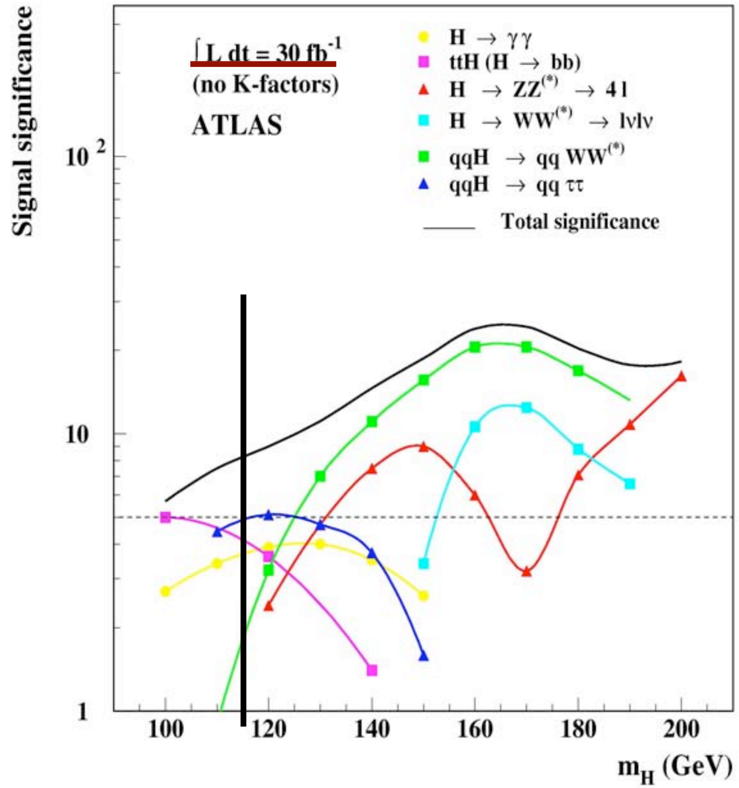
  - $tt \rightarrow bl\nu\, bjj$ jet scale from $W \rightarrow jj$, b-tag performance, etc.

- Measure SM physics at $\sqrt{s}$ = 14 TeV : W, Z, tt, QCD jets … (omnipresent backgrounds to New Physics)

→ prepare the road to discovery ……. it will take a lot of time …

A difficult case: a light Higgs (m_H ~ 115 GeV) …





m_H ~ 115 GeV   10 fb^{-1}

total $S/\sqrt{B} \approx 4^{+2.2}_{-1.3}$

ATLAS	$H \to \gamma\gamma$	$ttH \to ttbb$	$qqH \to qq\tau\tau$ (ll + l-had)
S	130	15	~ 10
B	4300	45	~ 10
$S/\sqrt{B}$	2.0	2.2	~ 2.7

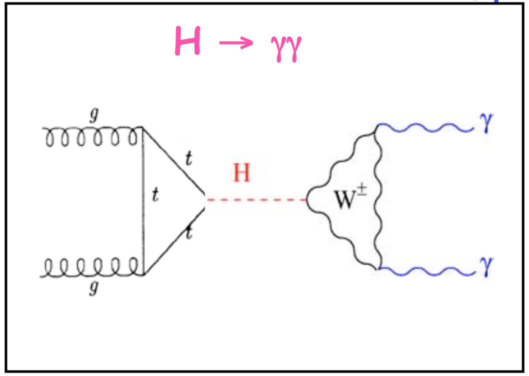
K-factors ≡ σ(NLO)/σ(LO) ≈ 2 not included

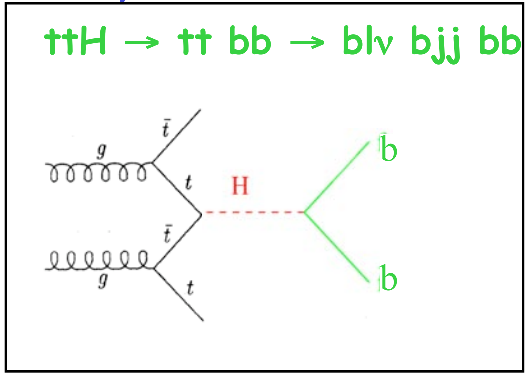
Full GEANT simulation, simple cut-based analyses

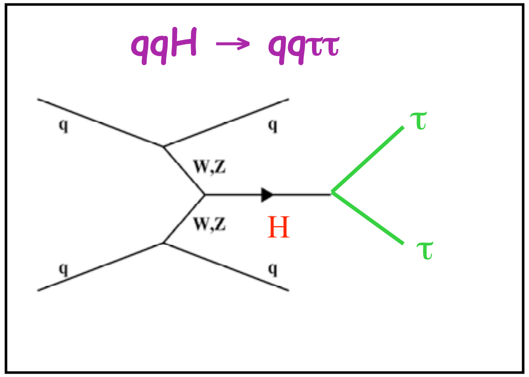
Remarks:

Each channel contributes ~ 2σ to total significance → observation of all channels important to extract convincing signal in first year(s)

The 3 channels are complementary → robustness:







- different production and decay modes
- different backgrounds
- different detector/performance requirements:
  - -- ECAL crucial for $H \to \gamma\gamma$ (in particular response uniformity) : $\sigma/m \sim 1\%$ needed
  - -- b-tagging crucial for ttH : 4 b-tagged jets needed to reduce combinatorics
  - -- efficient jet reconstruction over $|\eta| < 5$ crucial for $qqH \to qq\tau\tau$: forward jet tag and central jet veto needed against background

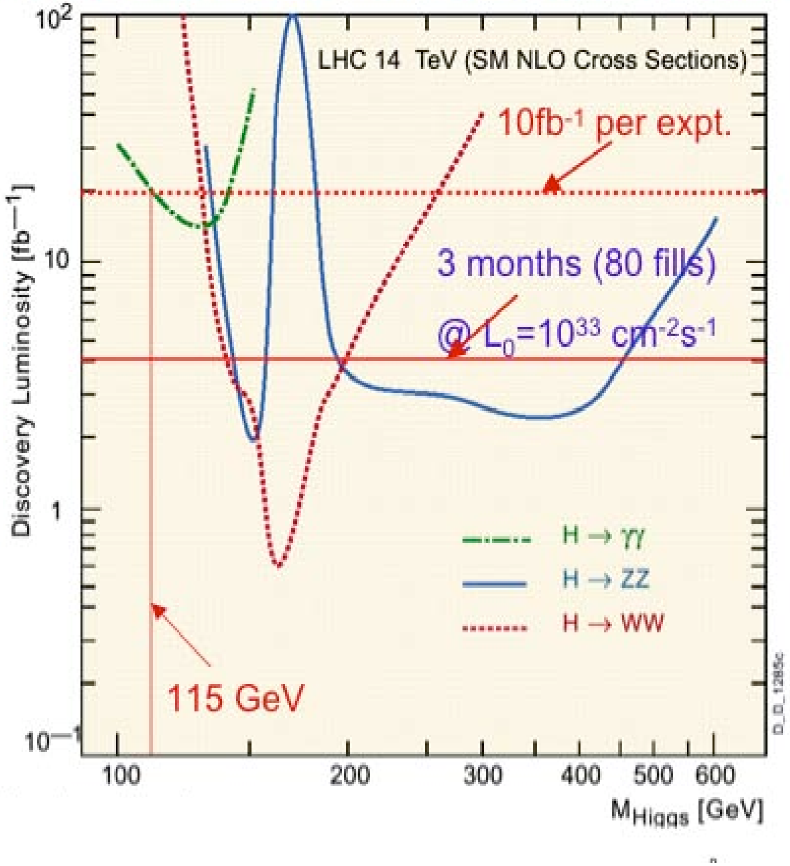
Note : -- all require "low" trigger thresholds

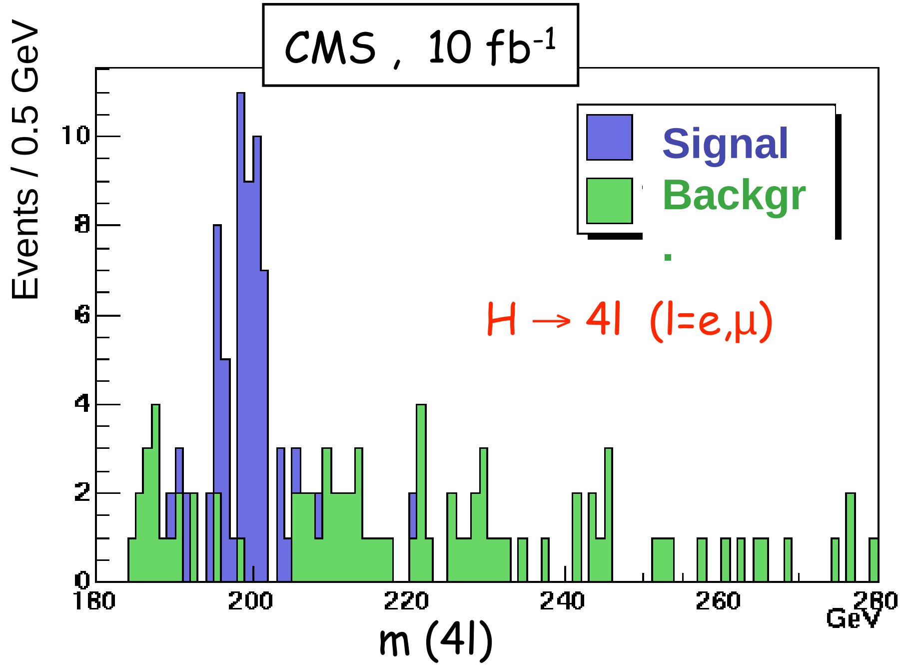
E.g. ttH analysis cuts : p_T (l) > 20 GeV, p_T (jets) > 15-30 GeV

-- all require very good understanding (1-10%) of backgrounds

If m_H > 180 GeV : early discovery may be easier with H → 4l channel

Luminosity needed for 5σ discovery (ATLAS+CMS)



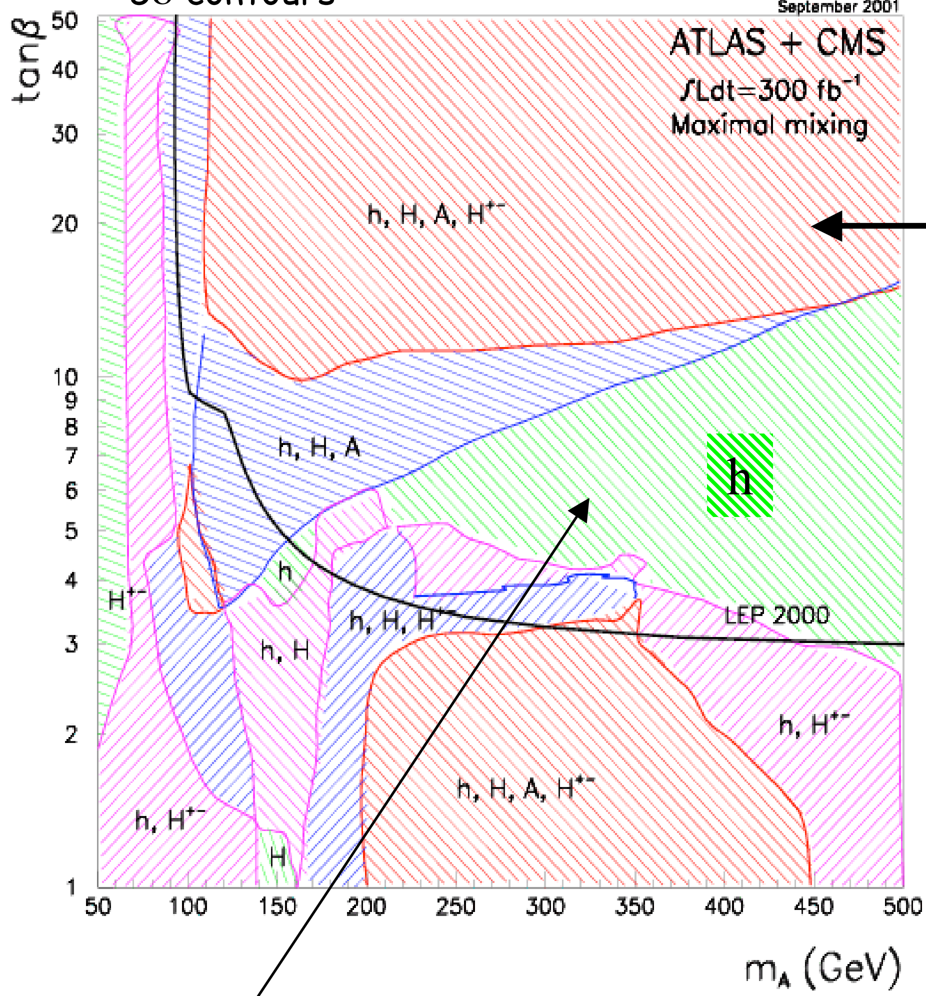


- H → WW → lν lν : high rate (~ 100 evts/expt) but no mass peak
  → not ideal for early discovery …
- H → 4l : low-rate but very clean : narrow mass peak, small background

SUSY Higgs sector : h, H, A, H$^{\pm}$

$m_h < 135$ GeV , $m_A \approx m_H \approx m_{H\pm}$

5σ contours



H, A → μμ, ττ
H$^{\pm}$ → τν , tb

- 4 Higgs observable
- 3 Higgs observable
- 2 Higgs observable
- 1 Higgs observable

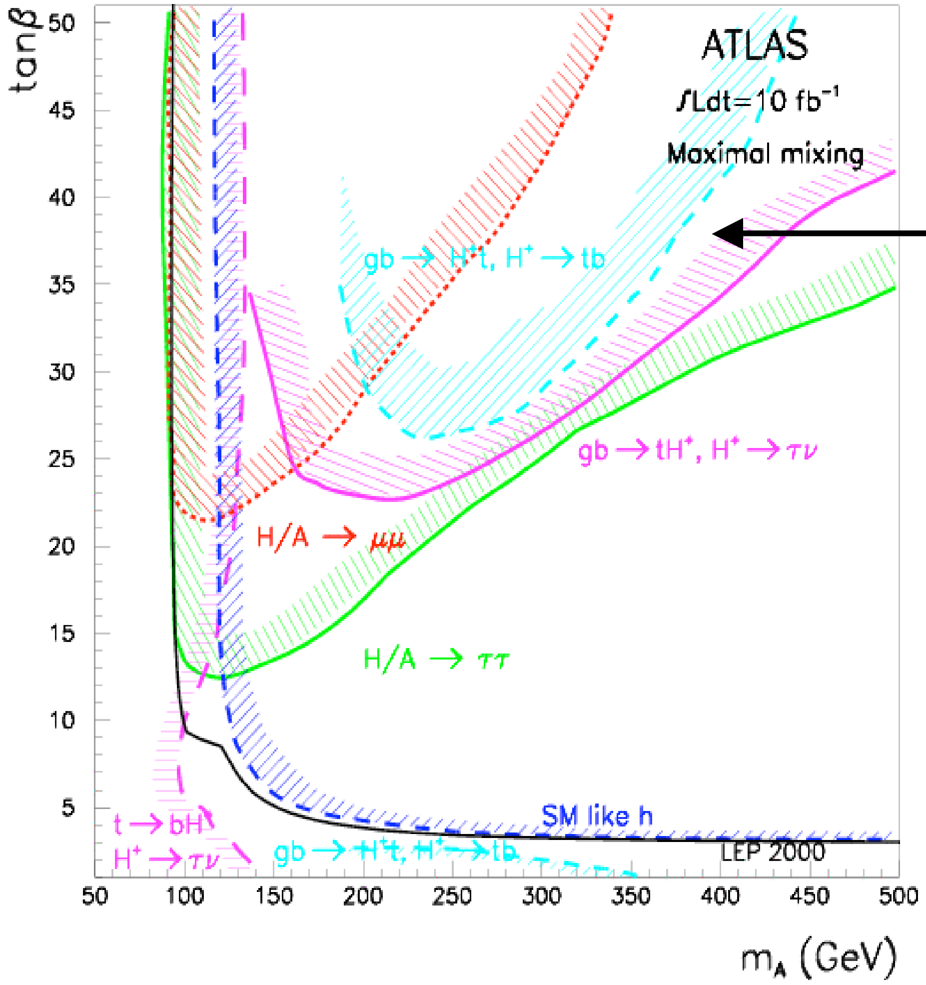
Assuming decays to SM particles only

Here only h (SM - like) observable at LHC, unless A, H, H$^{\pm}$ → SUSY

→ LHC may miss part of the MSSM Higgs spectrum

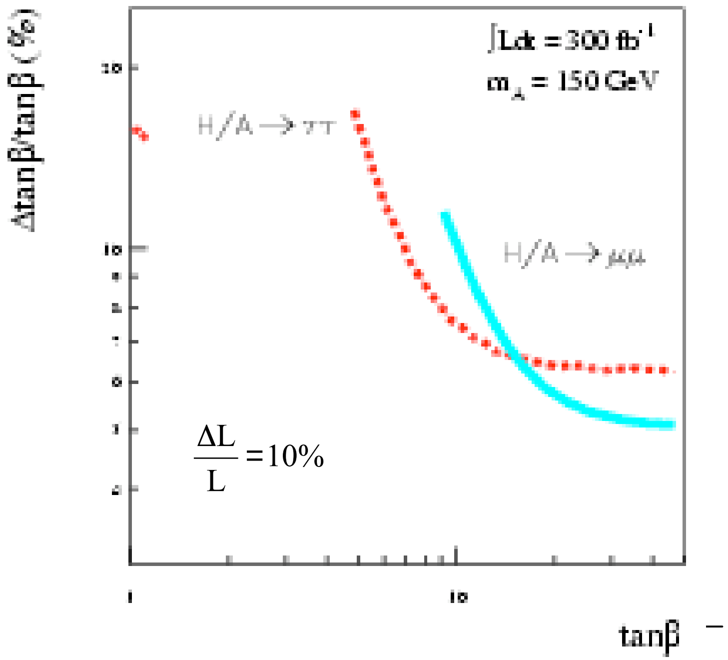
Observation of full spectrum may require high-E ($\sqrt{s} \approx 2$ TeV) Lepton Collider

Most of MSSM Higgs plane already covered after 1 year at L= 10^{33} …



A, H, H± cross-section ~ $tg^2\beta$

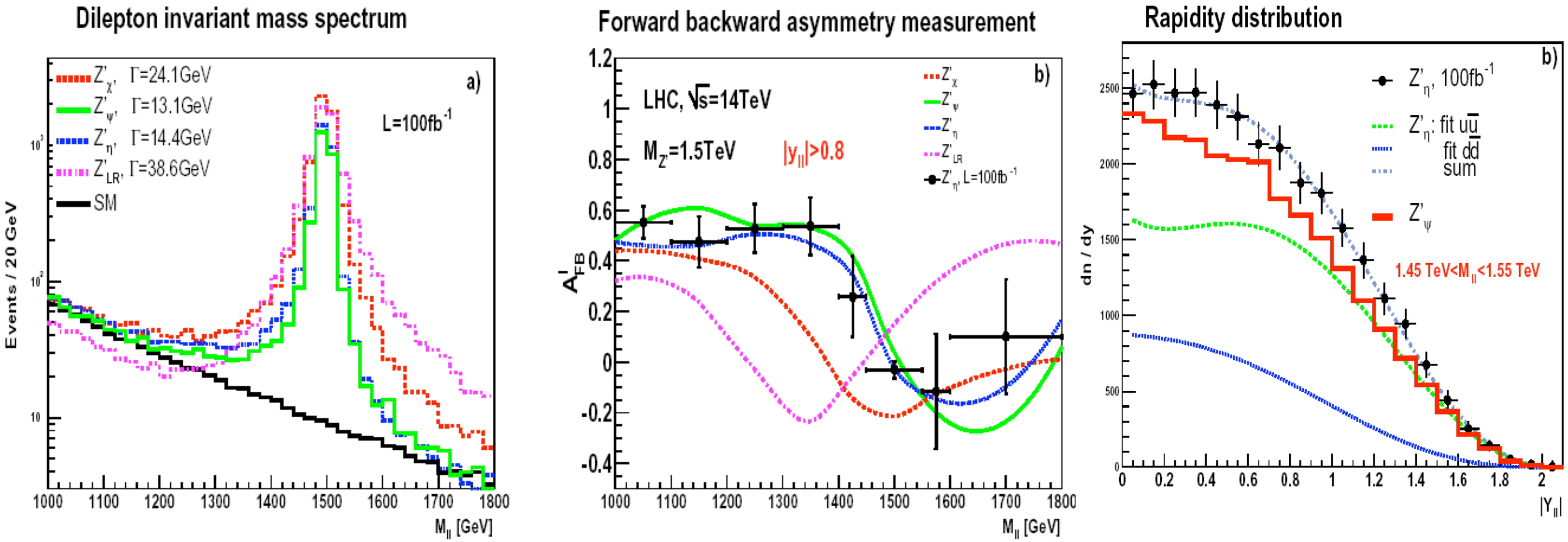
Measurement of tg β



Large variety of channels and signatures accessible

Extended gauge groups : $Z' \to l^+l^-$

CMS



- Reach in 1 year at 10^{34} : 4-5 TeV
- Discriminating between models possible up to m ~ 2.5 TeV by measuring:
  - -- $\sigma \times \Gamma$ of resonance
  - -- lepton F-B asymmetry
  - -- Z' rapidity

Mini black holes production at LHC ?

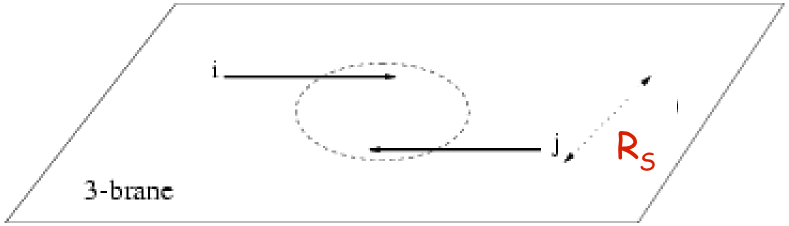
... quite speculative for the time being ... many big theoretical uncertainties

- Schwarzschild radius (i.e. within which nothing escapes gravitational force):

4-dim., $M_{gravity} = M_{Planck}$: $R_S \sim \frac{2}{M_{Pl}^2} \frac{M_{BH}}{c^2}$

4 + δ-dim., $M_{gravity} = M_D \sim$ TeV : $R_S \sim \frac{1}{M_D} \left(\frac{M_{BH}}{M_D} \right)^{\frac{1}{\delta+1}}$

Since M_D is low, tiny black holes of M_{BH} ~ TeV can be produced if partons ij with $\sqrt{s_{ij}} = M_{BH}$ pass at a distance smaller than R_S

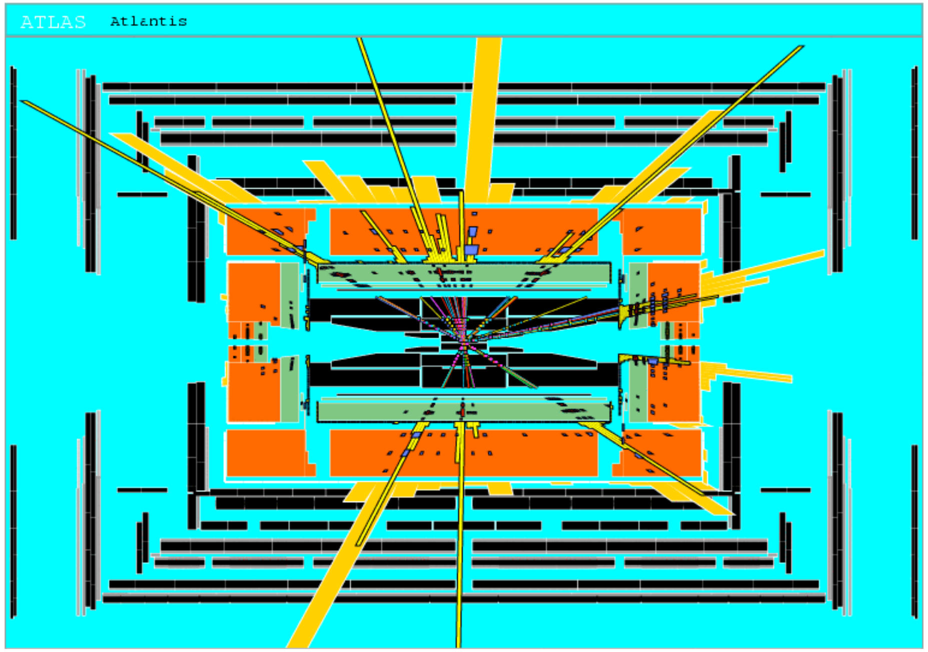


- Large partonic cross-section : $\sigma(ij \to BH) \sim \pi R_S^2$

e.g. For M_D ~3 TeV and $\delta = 4$, $\sigma(pp \to BH) \sim 100$ fb → 1000 events in 1 year at low L

- Black holes decay immediately ($\tau \sim 10^{-26}$ s) by Hawking radiation (democratic evaporation) :
  - -- large multiplicity
  - -- small missing E
  - -- jets/leptons ~ 5

  } expected signature (quite spectacular ...)



A black hole event with M_{BH} ~ 8 TeV in ATLAS

From preliminary studies : reach is M_D ~ 6 TeV for any δ in one year at low luminosity.

By testing Hawking formula → proof that it is BH + measurement of M_D, δ

$$\log T_H = -\frac{1}{\delta + 1} \log M_{BH} + f\,(M_D, \delta)$$

precise measurements of M_{BH} and T_H needed (T_H from lepton and photon spectra)

Note: mini-BH should also be produced by ultra-high-energy cosmic neutrinos and observed by Auger

Other examples of reach for Physics beyond SM …

Excited quarks $q^* \to \gamma q$: up to $m \approx 6$ TeV

Leptoquarks: up to $m \approx 1.5$ TeV

Monopoles $pp \to \gamma\gamma pp$: up to $m \approx 20$ TeV

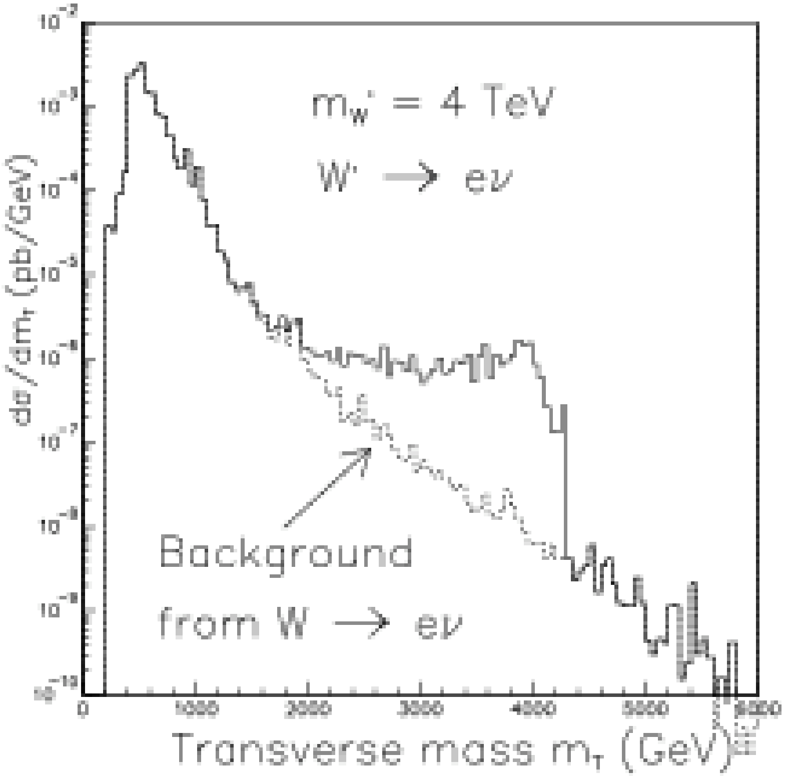
Compositeness: up to $\Lambda \approx 40$ TeV

$Z' \to \lambda\lambda$, jj: up to $m \approx 5$ TeV

$W' \to \lambda\nu$: up to $m \approx 6$ TeV

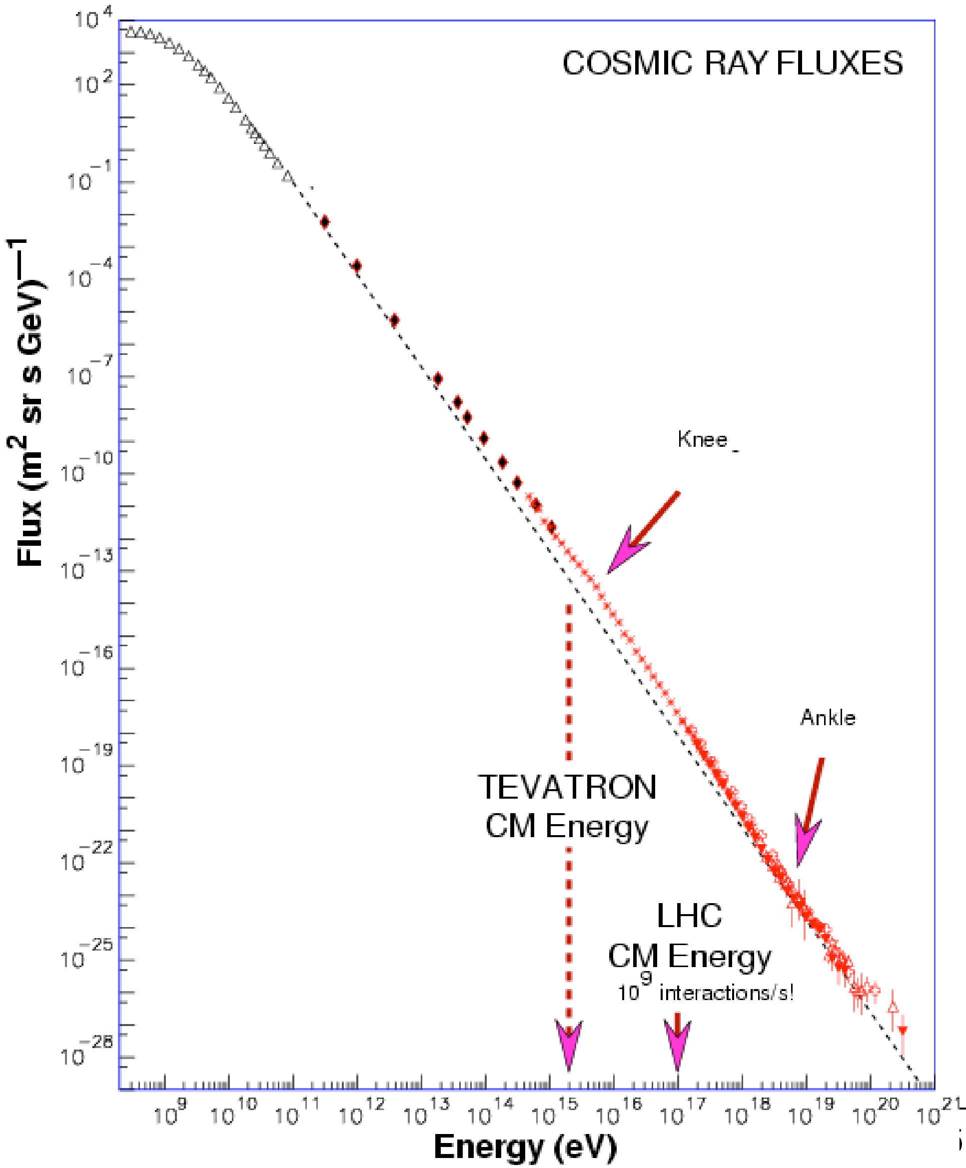
etc…. etc….

ATLAS
100 fb^{-1}



Links with astrophysics and cosmology ?

√s = 14 TeV → corresponds to E ~ 100 PeV fixed target proton beam



The LHC will be the first machine able to explore the high-E part of the cosmic ray spectrum

LHC studies most relevant to HECR:

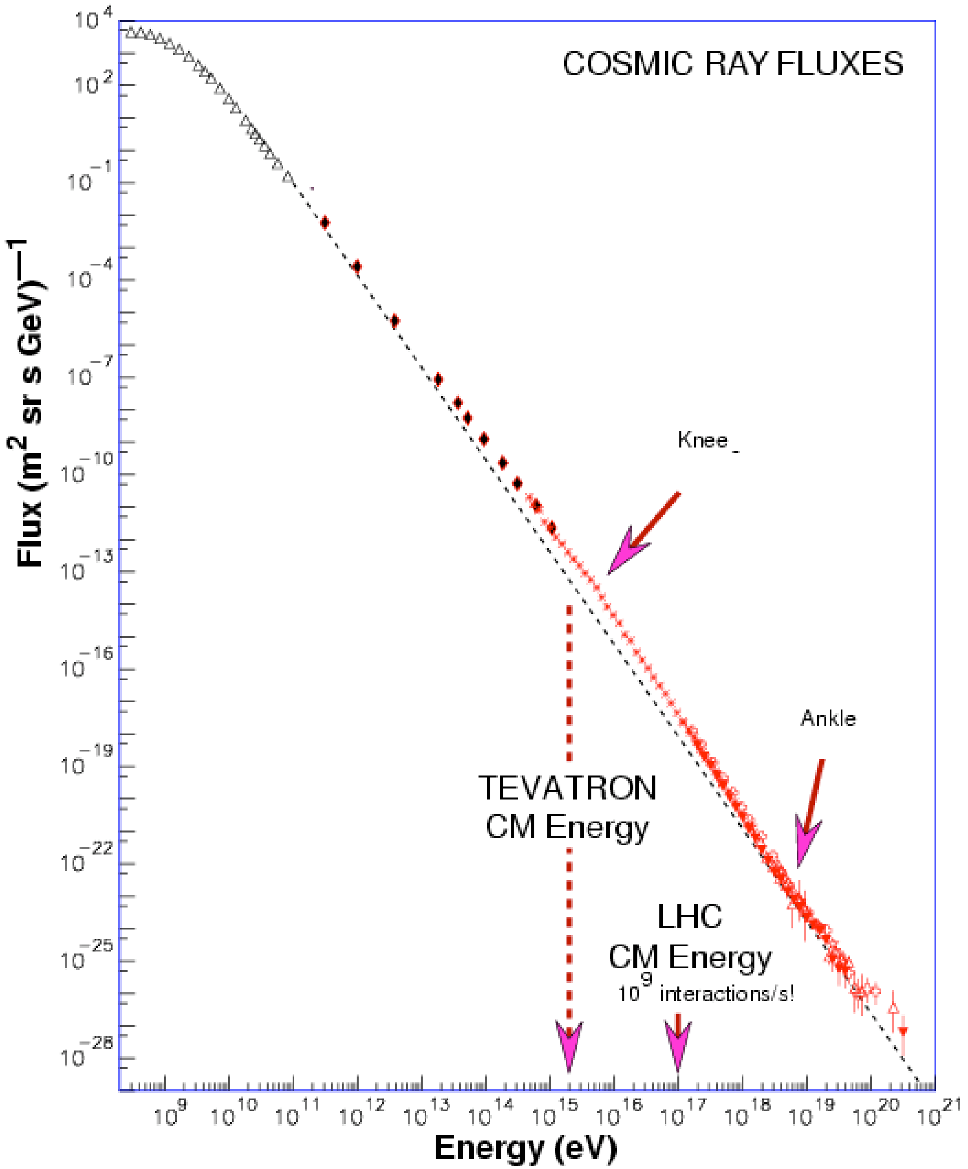
-- most energetic particles from pp collisions

-- pp (and pA, AA) cross-sections

both require detection in the forward region

LHC and high-energy cosmic rays

√s = 14 TeV → corresponds to E ~ 100 PeV fixed target proton beam



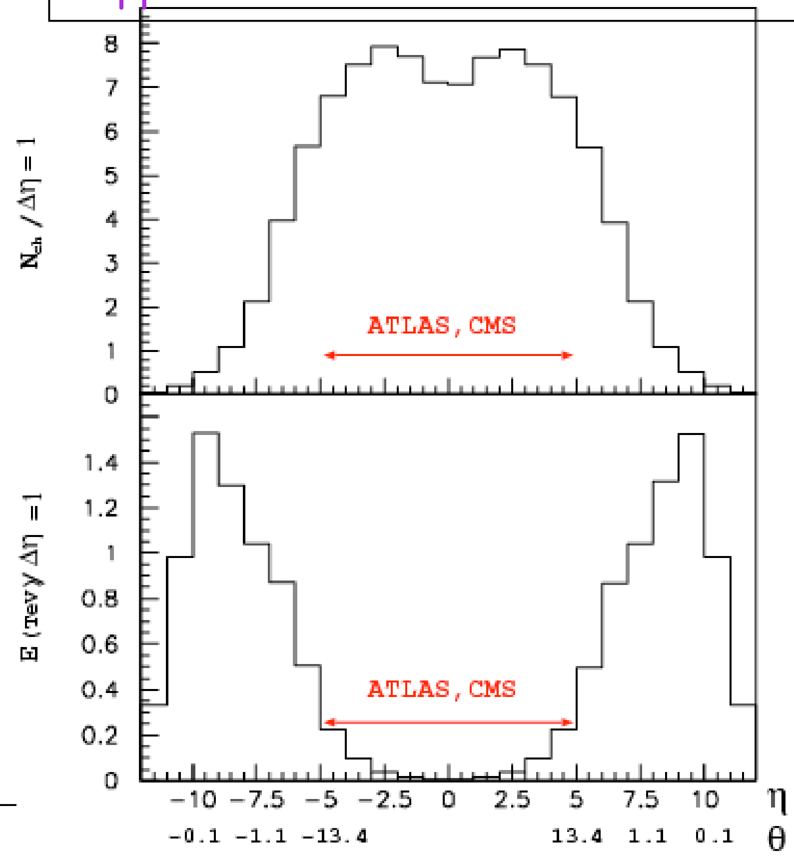
LHC studies most relevant to HECR:

-- most energetic particles from the collisions

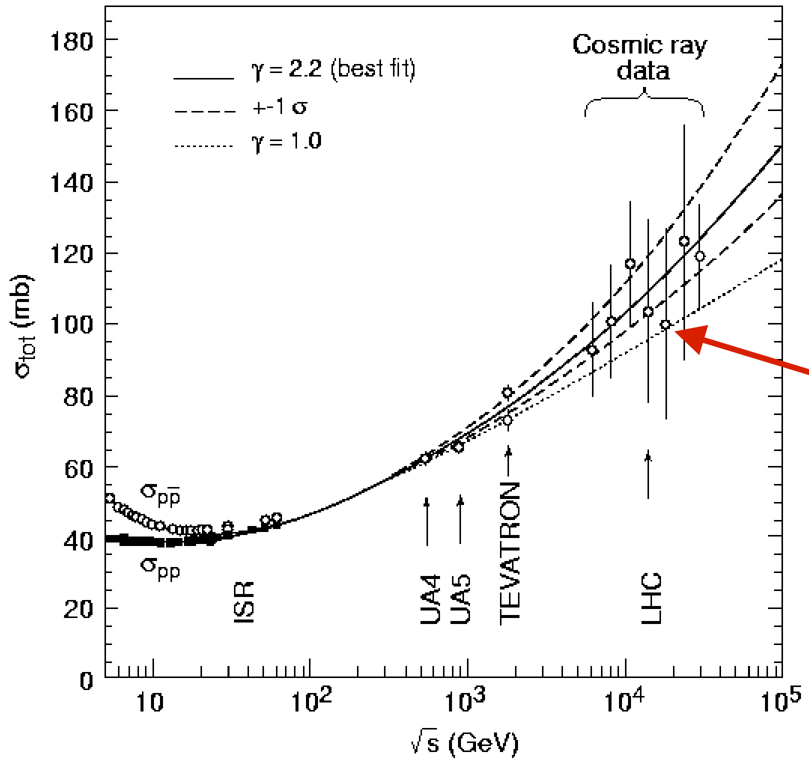
-- pp (and pA, AA) cross-sections

both require detection in the forward region

Charged particle multiplicity and energy in pp inelastic events at √s = 14 TeV



Measurement of σ_{tot} (pp)



Curves are ~ $(\log s)^\gamma$

Goal of TOTEM:
~ 1 % precision

TOTEM : 3 stations of detectors ("Roman Pots" RP1, RP2, RP3) at both sides of IP5 (integrated with beam pipe) to measure scattered proton in elastic interactions down

to $\theta_{scat} \approx 20$ μrad