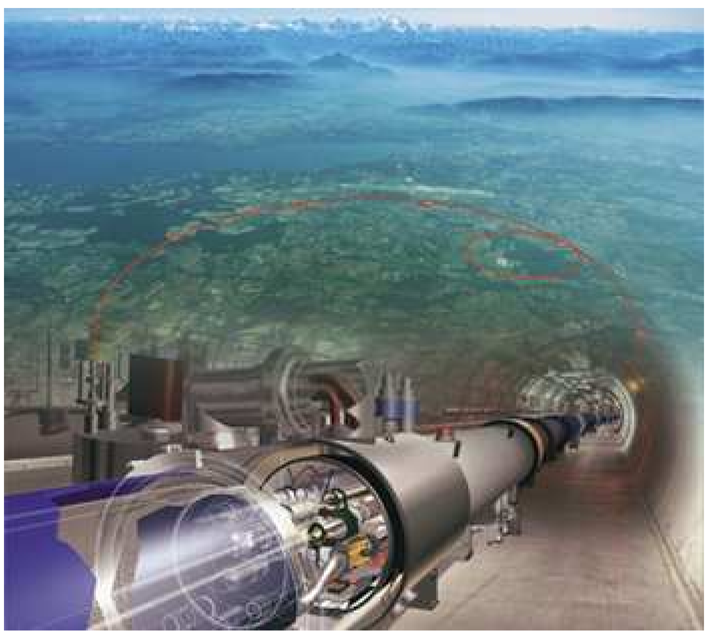
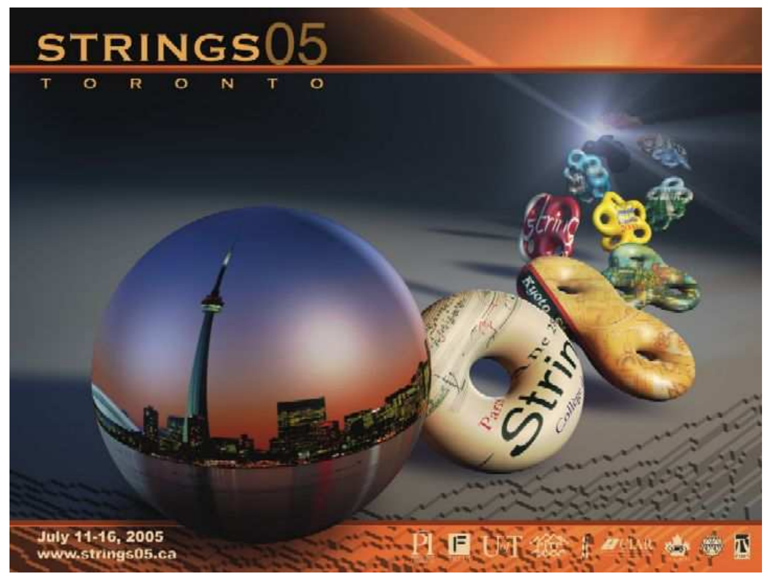
Physics Beyond the Standard Model at CERN's Large Hadron Collider
or
What could LHC tell us on strings?

Albert De Roeck / CERN

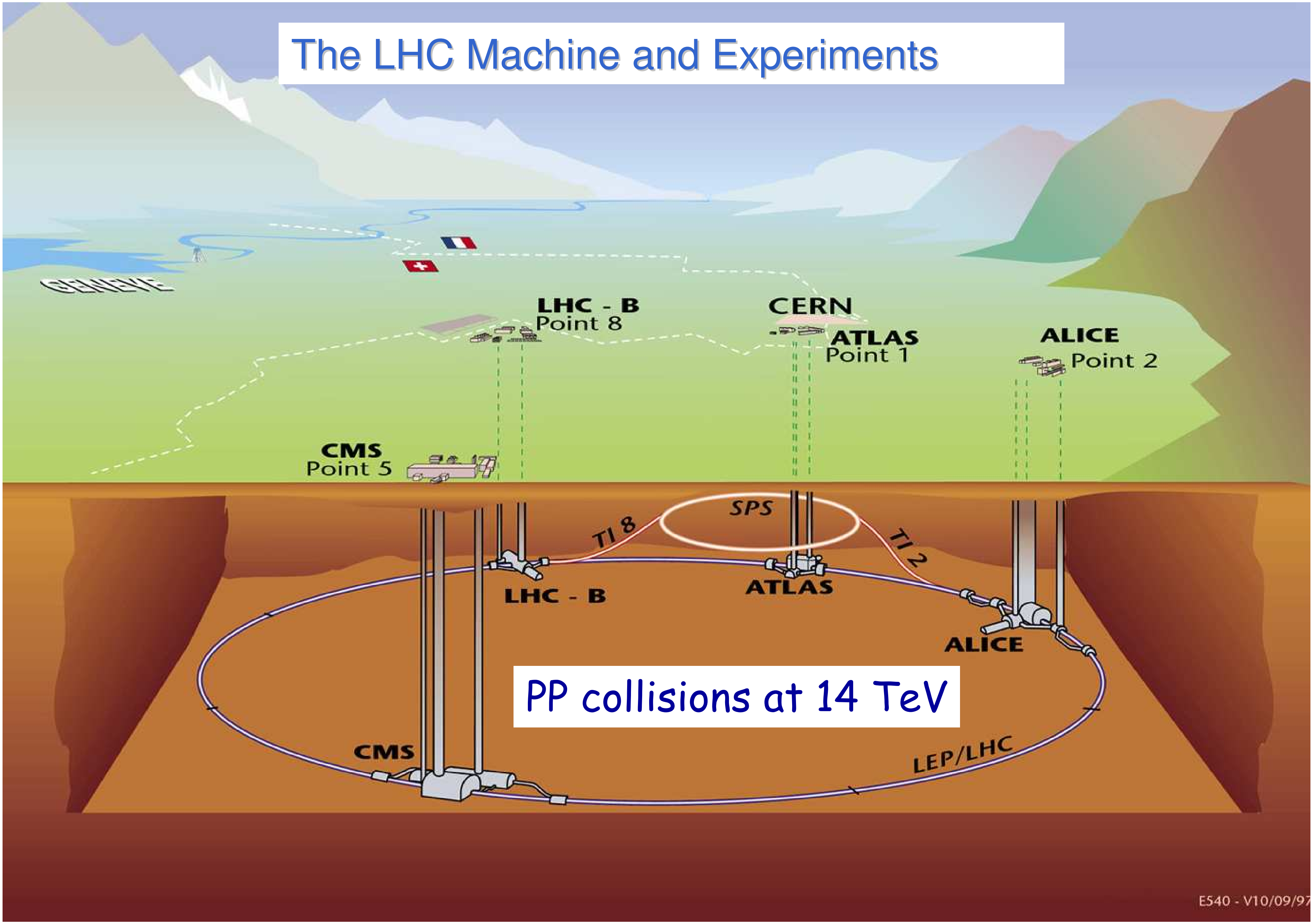




Contents

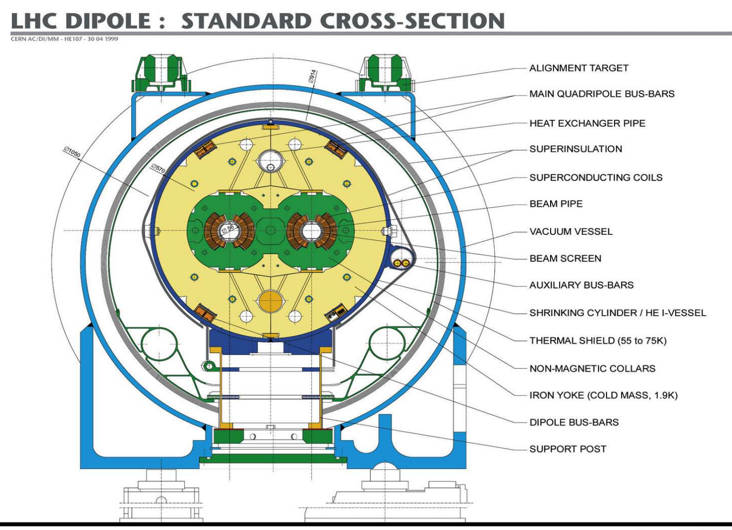
- The LHC
- The CMS and ATLAS Experiment
- Higgs
- Beyond the Standard Model signals: Supersymmetry, extra dimensions, others…
- Summary

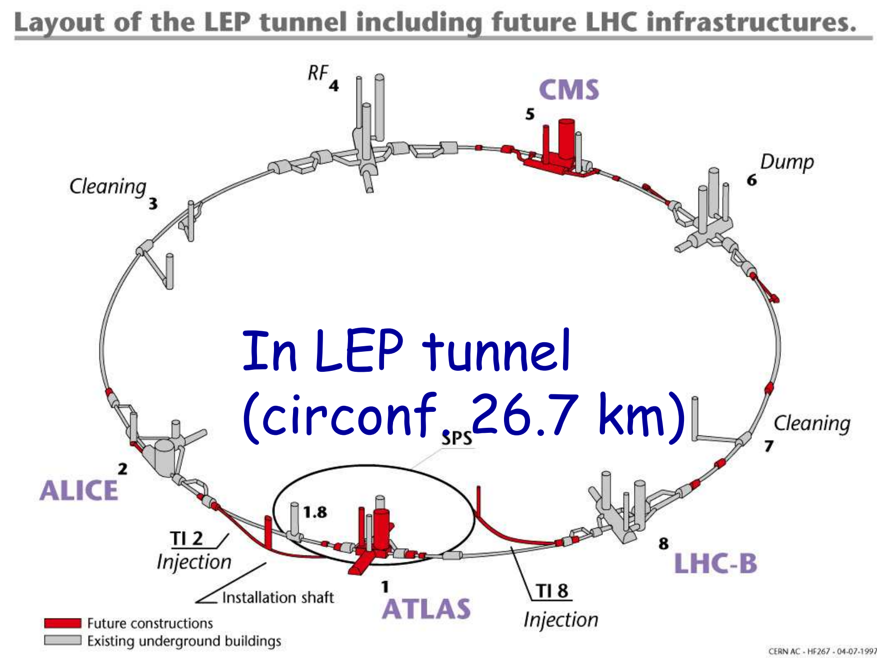
The LHC Machine and Experiments



PP collisions at 14 TeV

The Large Hadron Collider





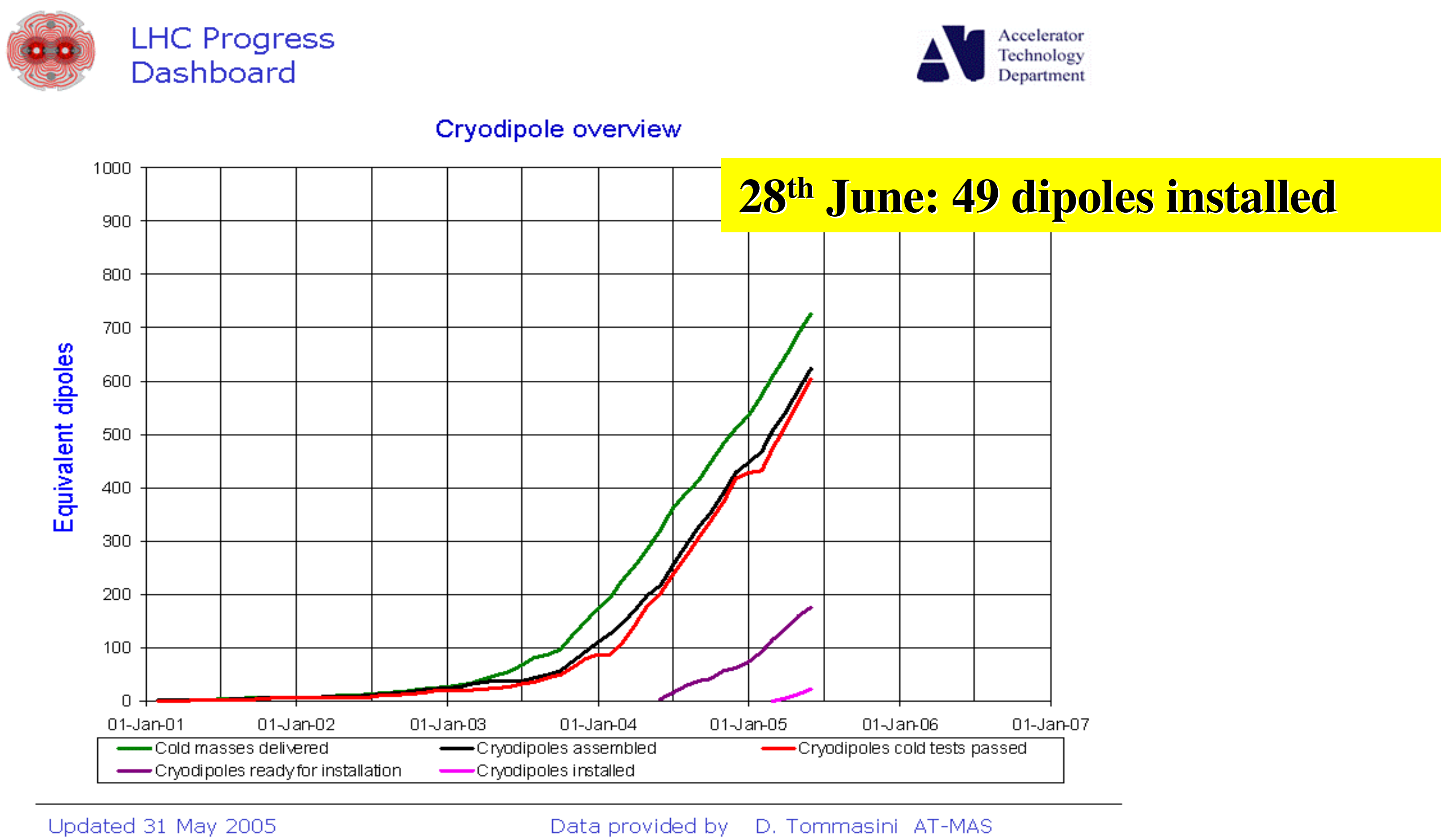
In LEP tunnel
(circonf. 26.7 km)

~1200 Super conducting dipoles needed
>600 dipoles delivered

25 ns bunch spacing ⇒ 2835 bunches with 10^{11} p/bunch

First years lumi
~2.10^{33} cm^{-2}s^{-1} ⇒ 20 fb^{-1}/year
Design Luminosity:
10^{34} cm^{-2}s^{-1} ⇒100 fb^{-1}/year

The LHC progress



Crucial part: 1200 superconducting dipoles (10m long each)
Can follow progress on the CERN web page (dashboard)
http://lhc-new-homepage.web.cern.ch/lhc-new-homepage/

LHC FAQs (Frequently Asked Questions)

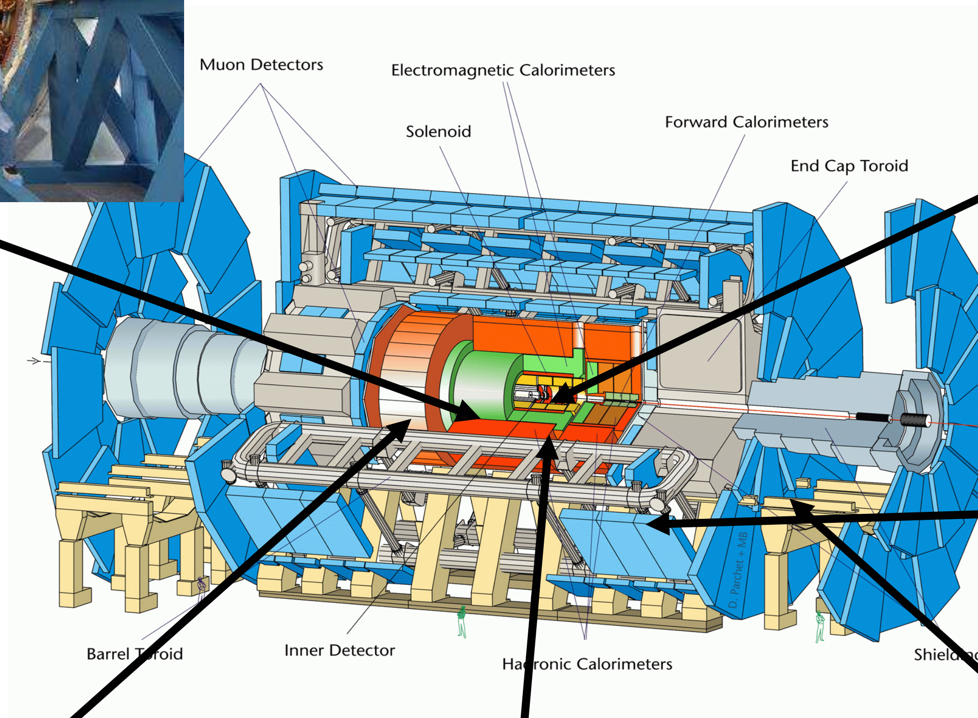
- When will they close the LHC/inject beams (Detector experimentalists)
- When will be first collisions in the LHC? (Analysis experimentalists)
- When will we have first physics results from the LHC? (Theorists)
- When will we have the new big discoveries at the LHC? (politicians thinking on whether to finance an International Linear Collider)

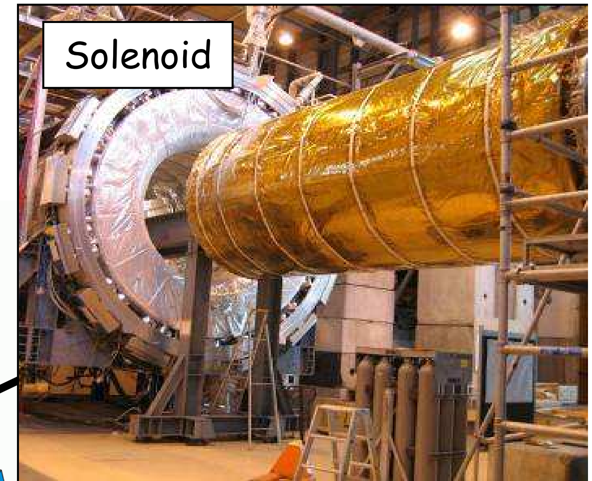
Picture becoming more clear now after the cryogenic line problem (and solution): according to the current plan (*)

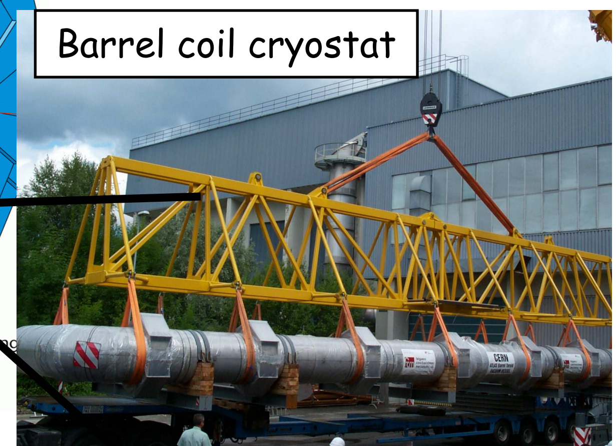
- LHC will be closed and set up for beam on 1 July 2007
- First beam in machine: August 2007
- LHC commissioning will take time!
- First collisions expected in November 2007
- Followed by a short pilot run
- First physics run in 2008 (starting April/May; one to a few fb^{-1}?)
- First big discovery ??

(*) M. Lamont at the TeV4LHC Workshop @CERN 30/4

ATLAS

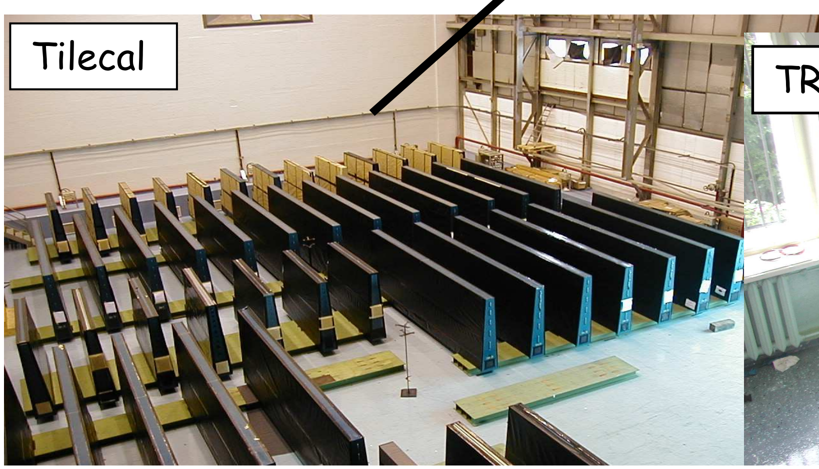


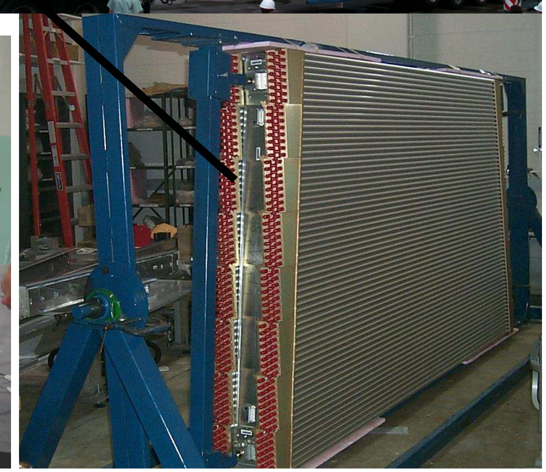




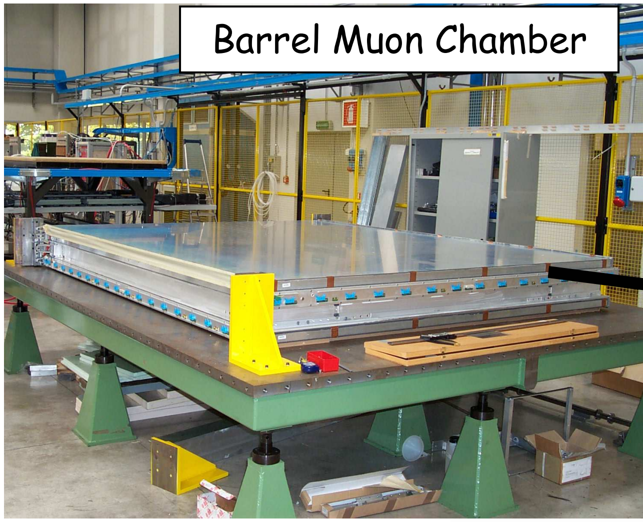
Barrel LAr ECAL

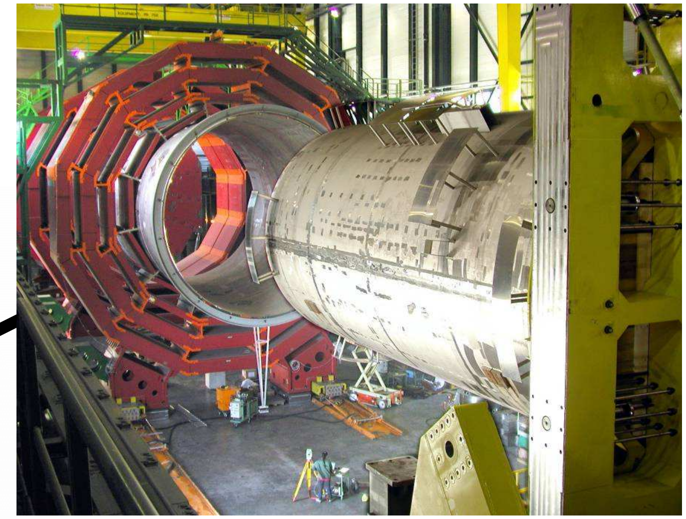
Length : ~40 m
Radius : ~10 m
Weight : ~ 7000 tons

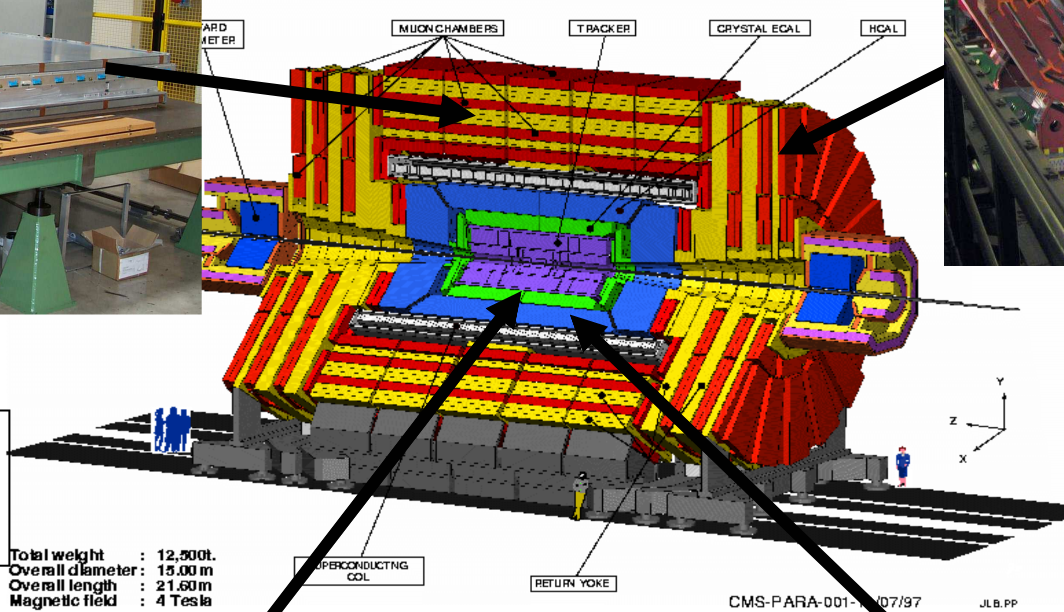




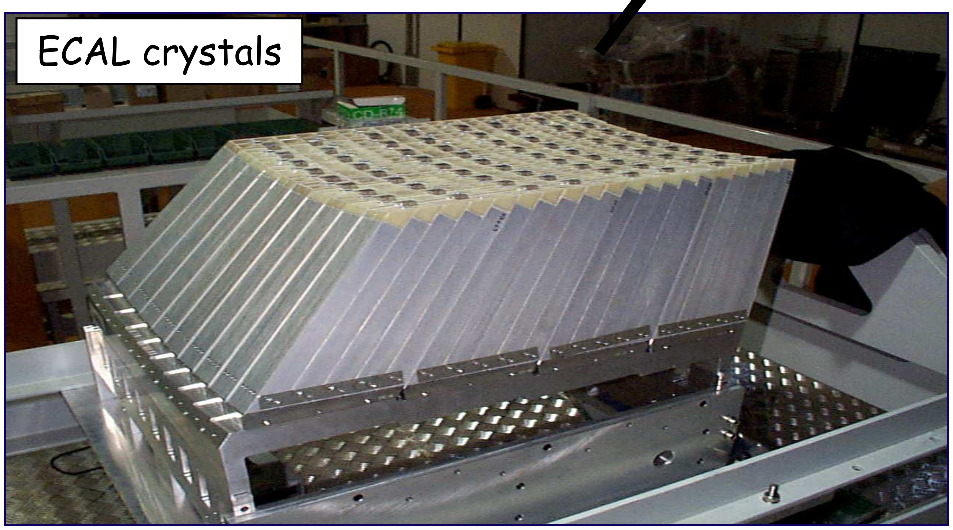
CMS

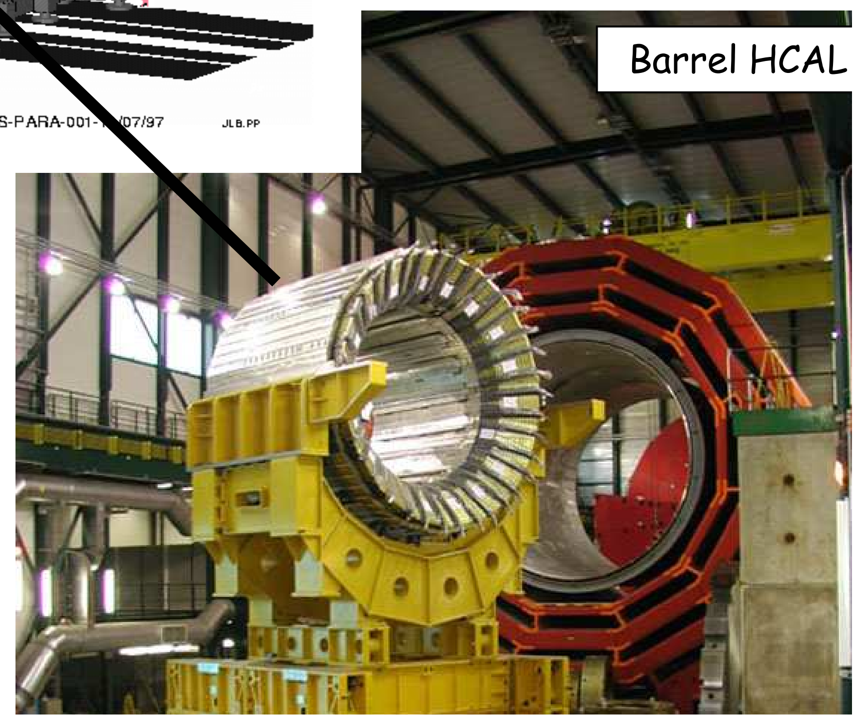






Length : ~20 m
Radius : ~7 m
Weight : ~ 13000 tons

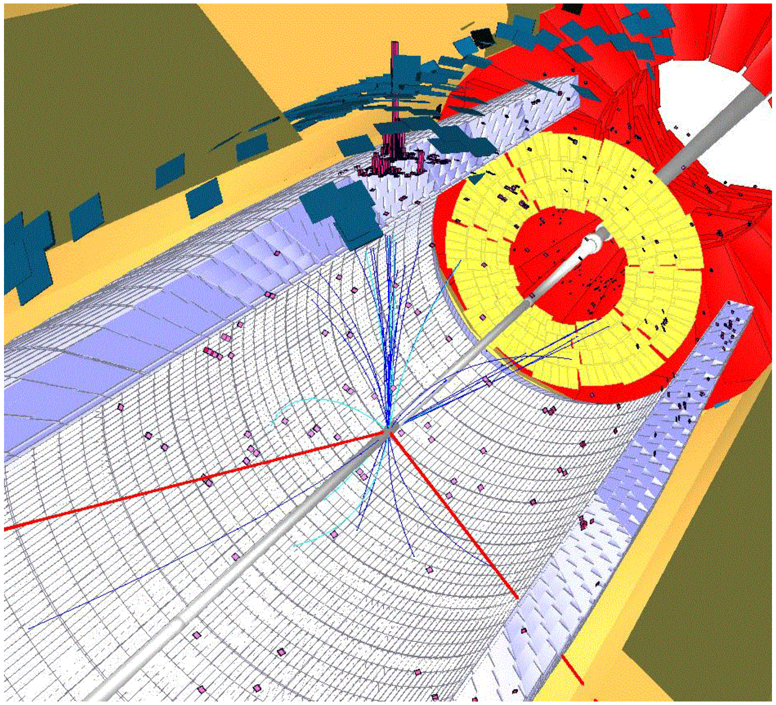




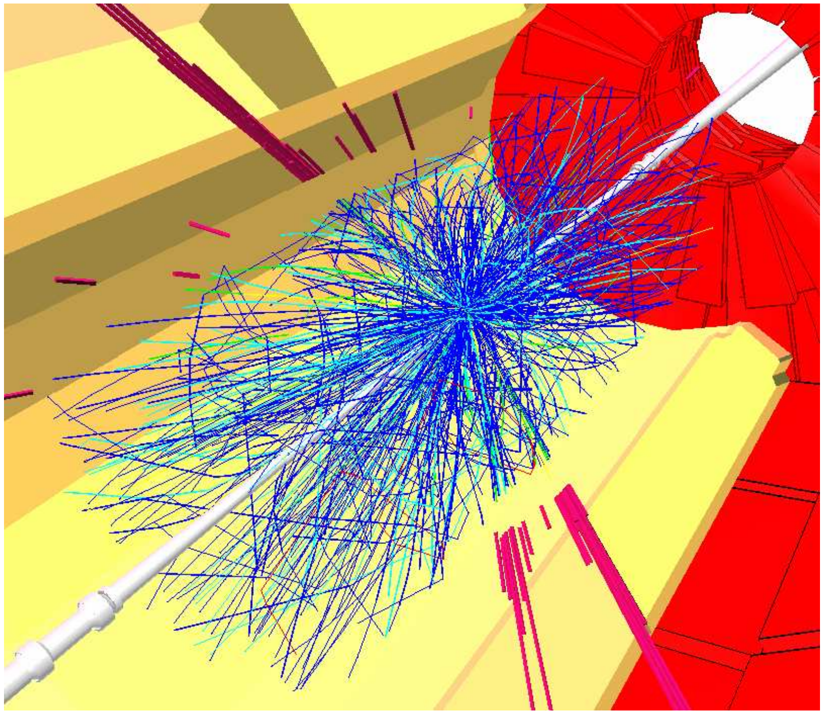

μ
6.920 m
5.635 m
4.645 m
3.850 m
2.950 m
2.864 m
1.840 m
1.320 m
Towards
Center of LHC
Transverse View
Will size matter?

Pile-up at the LHC

Pile-up ⇒ additional -mostly soft- interactions per bunch crossing
Startup luminosity $2 \bullet 10^{33} cm^{-2} s^{-1}$ ⇒ 4 events per bunch crossing
High luminosity $10^{34} cm^{-2} s^{-1}$ ⇒ 20 events per bunch crossing
Luminosity upgrade $10^{35} cm^{-2} s^{-1}$ ⇒ 200 events per bunch crossing



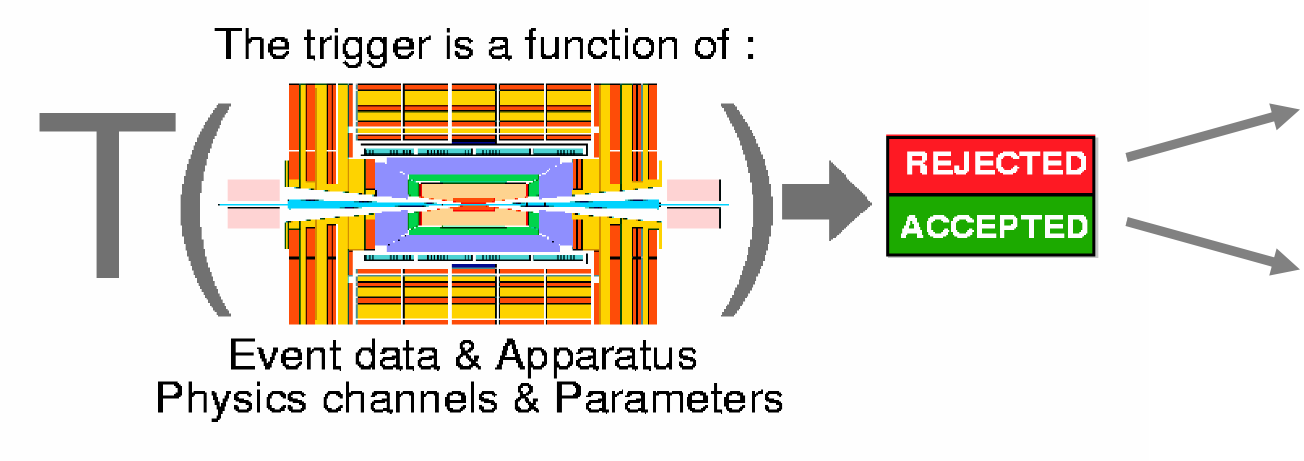
SUSY event (no pileup)



SUSY event ($10^{34} cm^{-2} s^{-1}$)

Event filtering: the trigger system

Collision rate is 40 MHz   Event size ~1 Mbyte
2007 technology (and budget) allows only to write 100 Hz of events to tape → need a factor ~10^7 online filtering!!



lost forever!!

written to disk for offline analysis

The event trigger is one of the biggest challenges at the LHC
⇒ Based on hard scattering signatures: jets, leptons, photons, missing Et,...

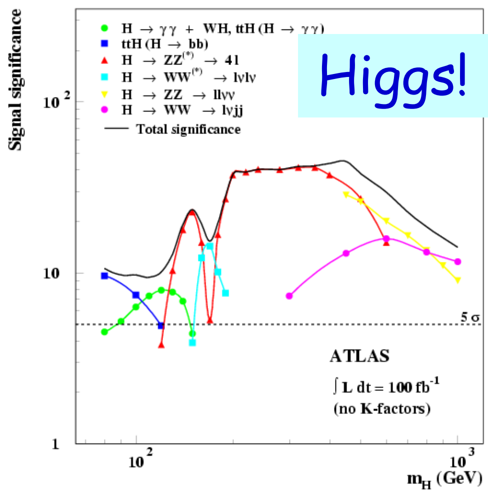
A few numbers…

- Rate of pp interactions at 10^{34} : 10^9 events per second
- Energy of pp is about 7 times higher than that of the Tevatron at FNAL
- Weight of the CMS experiment: ~ 13000 tons (30% more than the Tour Eiffel)
- Amount of cables used in ATLAS : ~ 3000 km
- Data volume collected by CMS in 1 second corresponds to 10,000 Encyclopedia Britannica
- Machine temperature : 1.9 K (largest cryogenic system in the world)
- Total cost of machine + experiments : ~ 5000 MCHF
- Total number of involved physicists : ~ 5000
- Etc. etc.

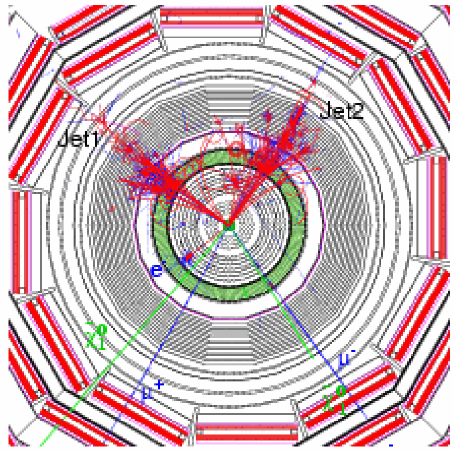
WHY ???

To explore in detail and directly the highly-motivated TeV-scale and say the final word about the SM Higgs mechanism and various TeV-scale predictions

Physics at the LHC: pp @ 14 TeV

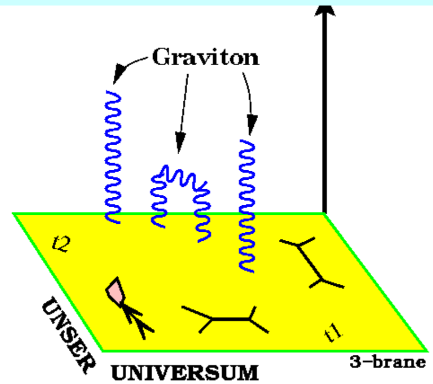


Higgs!

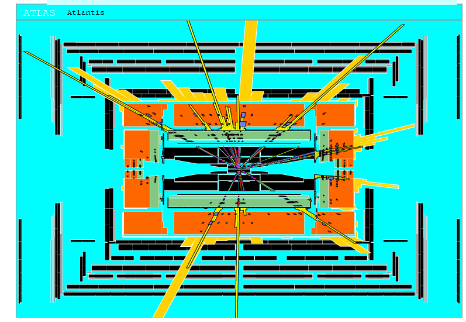


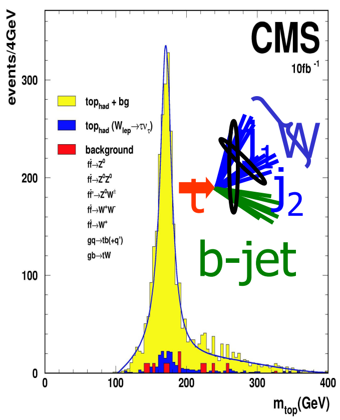
Supersymmetry?

Extra Dimensions?



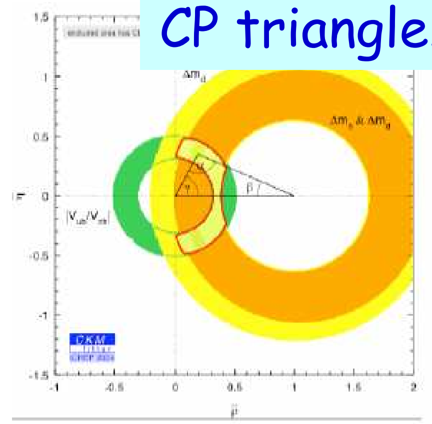
Black Holes???



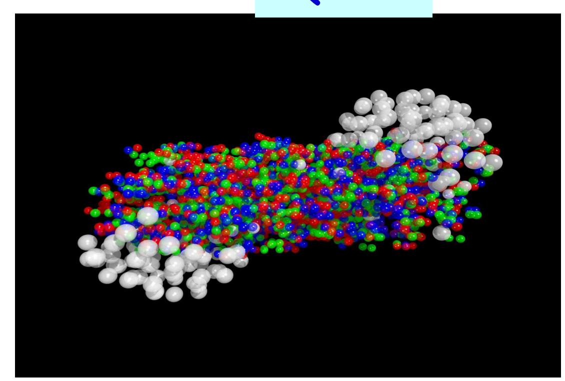


Precision measurements e.g top!

CP triangle!



QGP?



But also Other models with strong interactions, technicolor, compositness, new gauge bosons, etc. etc.

Event Rates at pp at $\sqrt{s}$=14 TeV

Process	Events/s	Events/year	Other machines
$W \to e\nu$	15	10^8	10^4 LEP / 10^7 Tev
$Z \to ee$	1.5	10^7	10^7 LEP
$t\bar{t}$	0.8	10^7	10^4 Tevatron
$b\bar{b}$	10^5	10^{12}	10^8 Belle/BaBar
$\tilde{g}\tilde{g}$ (m=1 TeV)	0.001	10^4	—
H (m=0.8 TeV)	0.001	10^4	—
Black Holes M_D=3 TeV n=4	0.0001	10^3	

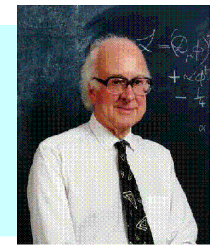
Huge event rates:
($10^{33}cm^{-2}\ s^{-1}$)

The LHC will be a W-factory, a Z-factory, a top factory, a Higgs factory etc..

Precision EW physics will be limited by systematics

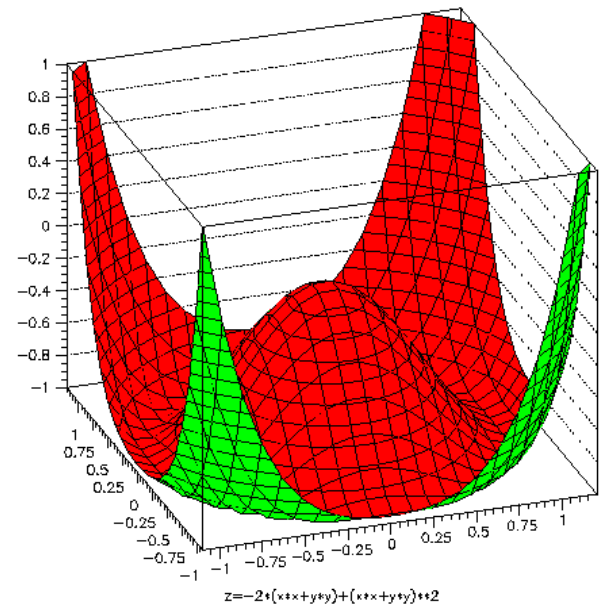
Higgs Physics

⇒ What is the origin of Electro-weak Symmetry Breaking?
⇒ If Higgs field at least one new scalar particle should exist: The Higgs
One of the main missions of CMS: discover the Higgs for m_H< 1 TeV



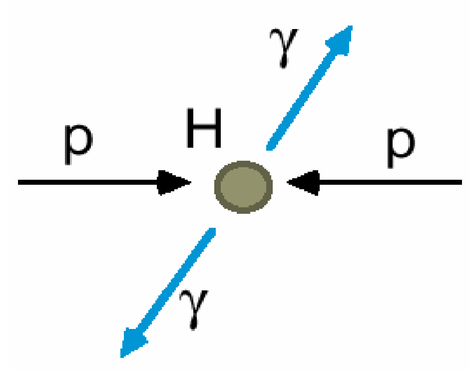
$$\phi = \phi_1 + i\phi_2$$

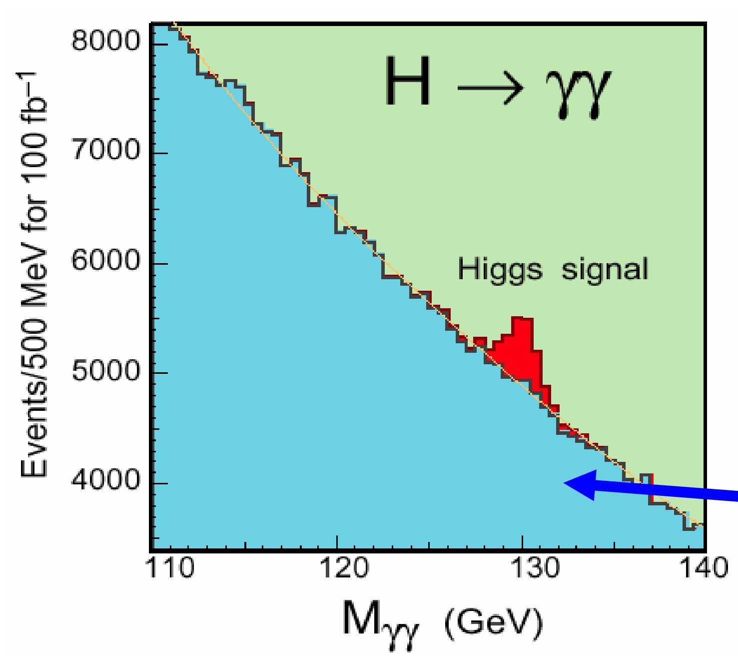
$$\mathcal{L} = (\partial^\mu \phi^\dagger)(\partial_\mu \phi) - \mu^2 \mid \phi \mid^2 - \lambda \mid \phi \mid^4$$



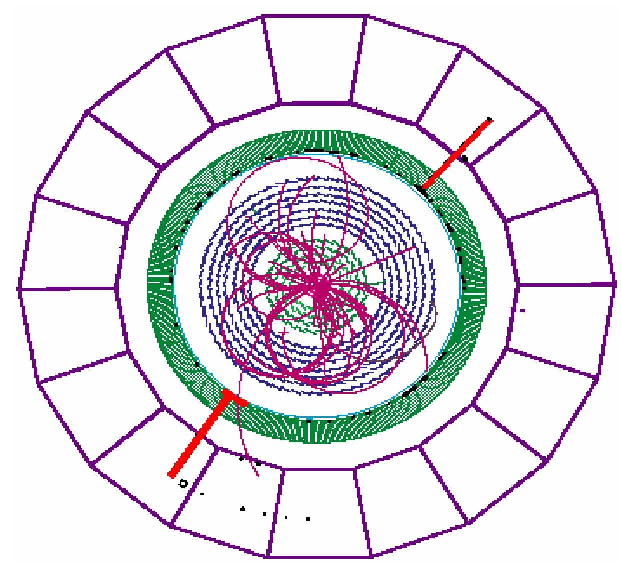
Example: Low Mass Higgs (M_H<140 GeV/c^2)

- $H \to \gamma\gamma$: decay is rare ($B \sim 10^{-3}$)
  - But with good resolution, one gets a mass peak
  - Motivation for LAr/$PbWO_4$ calorimeters
  - CMS example: at 100 GeV, $\sigma \approx$1GeV
    - S/B $\approx$ 1:20



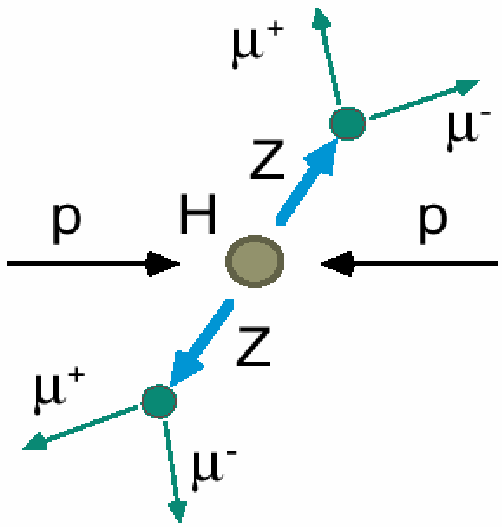


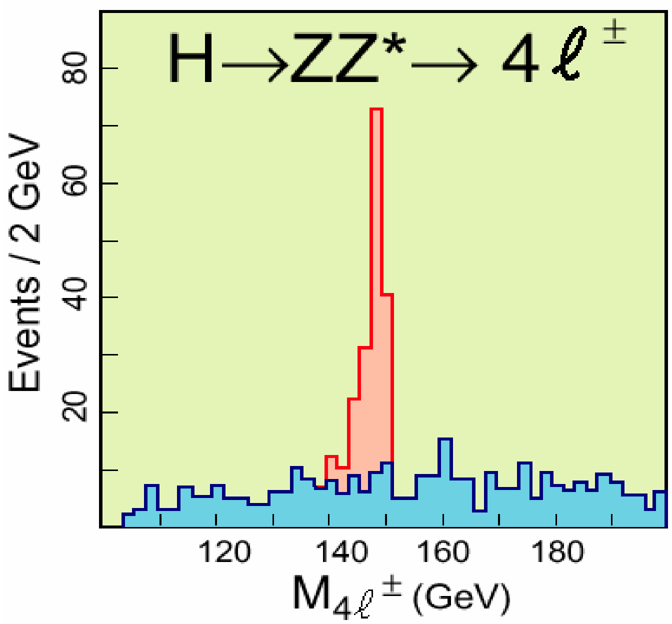
gg→γγ
qq→γγ

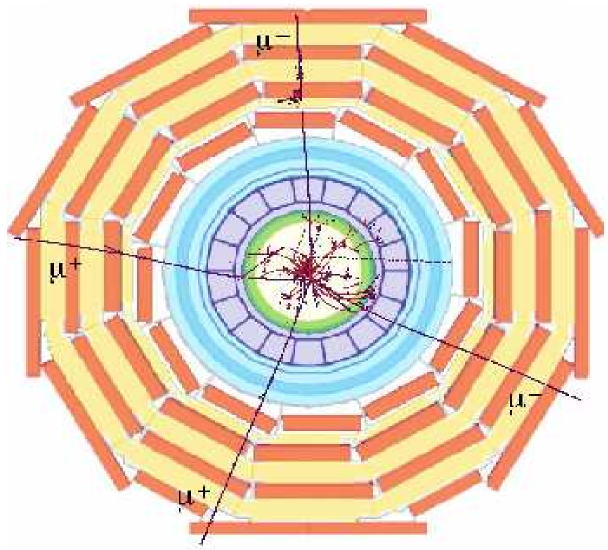


Example: Intermediate Mass Higgs: $ZZ^{(*)}$

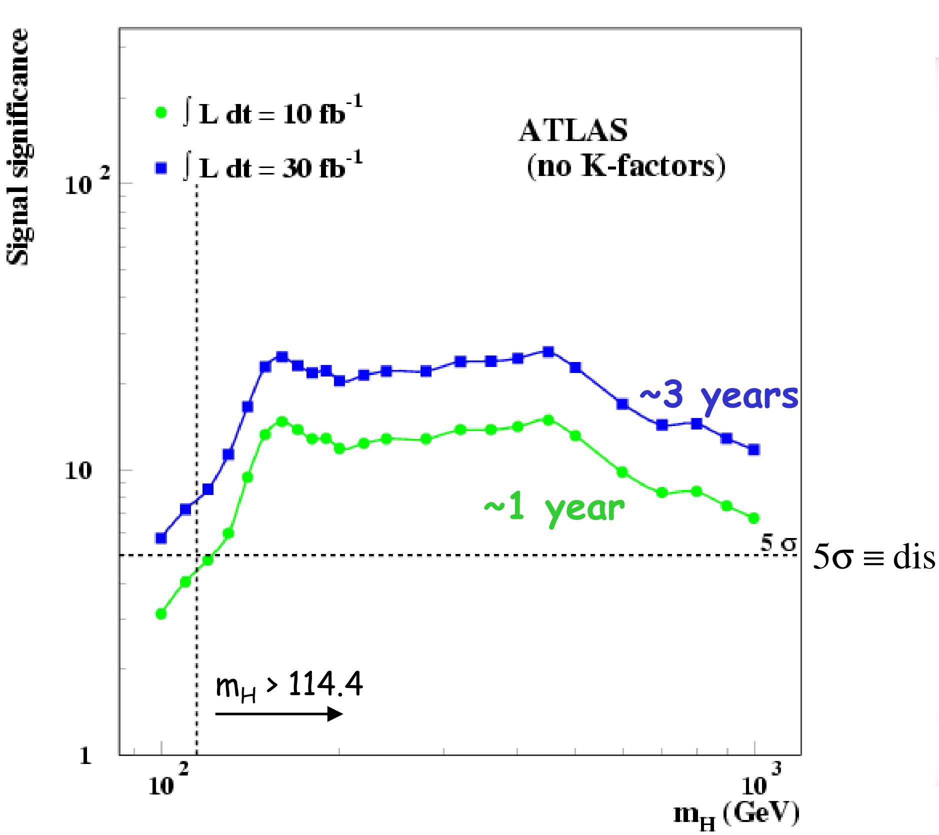
- $H \to ZZ \to \ell^+\ell^- \ell^+\ell^-$ (ℓ =e,μ)
  - Very clean
    - Resolution: around 1 GeV (around 100 GeV mass)
  - Valid for the mass range $130 < M_H < 500\ GeV/c^2$

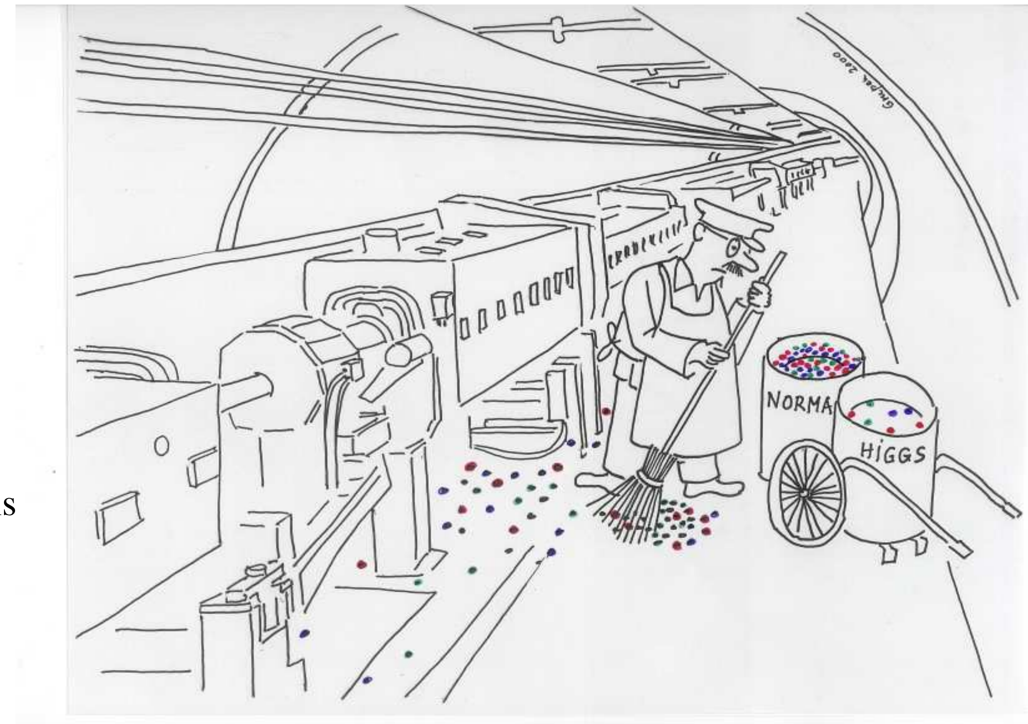






Expected Higgs signal significance (S/√B) at the LHC





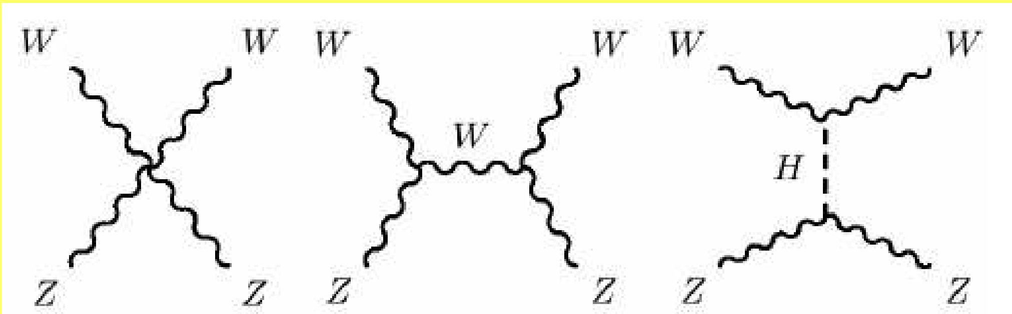
- Higgs can be discovered over full allowed mass range in 1 year of good LHC operation
  → <u>final word about SM Higgs mechanism by 2009 or so</u>
- However: it will take time to understand and calibrate ATLAS and CMS …
- In most difficult region m_H < 130 GeV ≥3 different channels observable → robustness

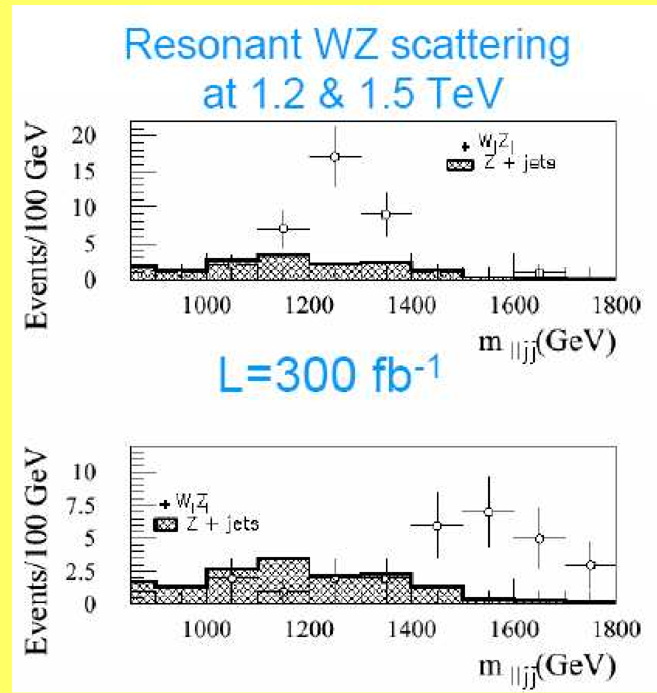
- If Higgs found, mass can be measured to 0.1% up to m_H~ 500 GeV

EWSB: If no Higgs exists

Vector Boson scattering amplitudes violate unitarity for s~ 1TeV

New physics must enter to cure this problem





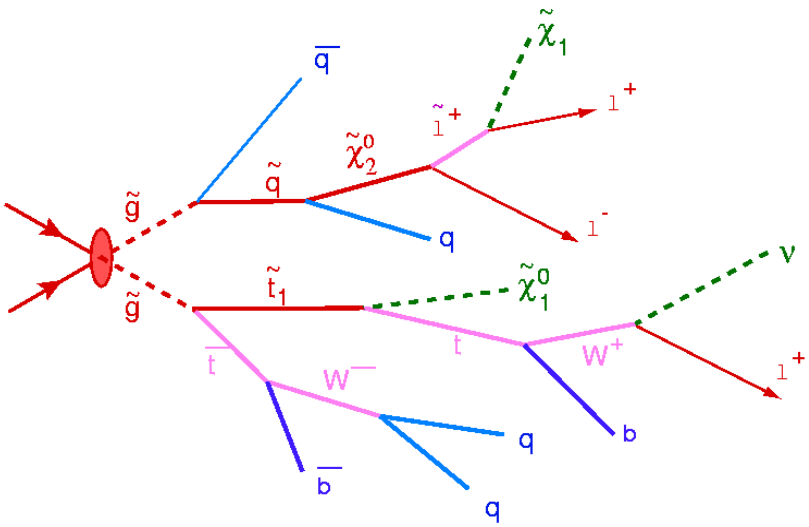
- Examples
  - Strongly interacting vector bosons
    - Study WW,WZ,ZZ scattering
  - Technicolor
    - New particles (techni-ρ, techni-π,…)

Mantra: LHC will either discover Higgs or find new dynamics ~ 1 TeV

Beyond the SM

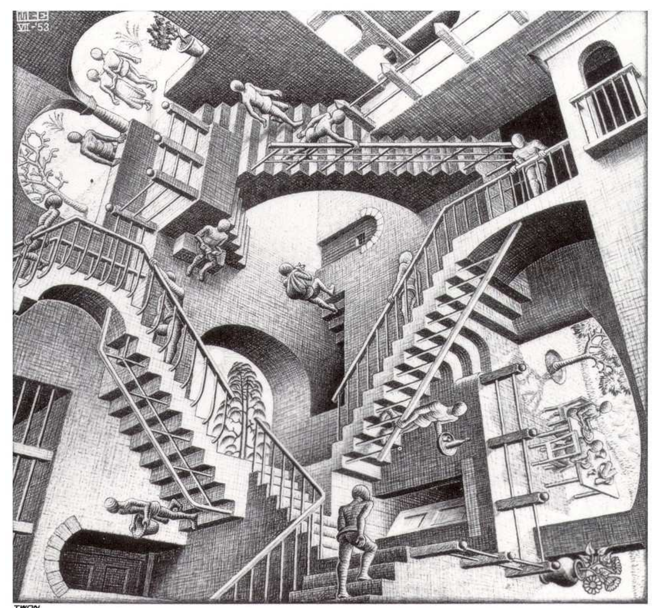
New physics expected around the TeV scale ⇒
Stabelize Higgs mass, Hierarchy problem, Unification of gauge couplings, CDM,…

Supersymmetry



3 isolated leptons
+ 2 b-jets
+ 4 jets
+ E_t^{miss}

Extra dimensions

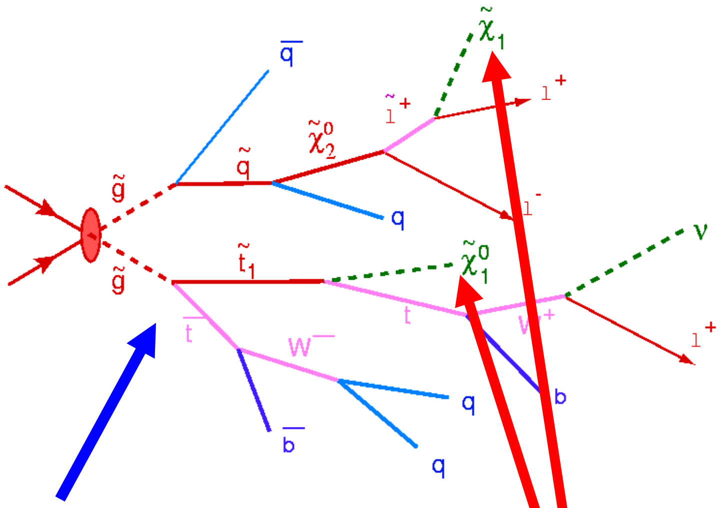


+…

Supersymmetry

Supersymmetry (SUSY) → assumes a new hidden symmetry between the bosons (particles with integer spin) and fermions (particles with half integer spin) to stabelize the Higgs mass up to the Planck scale

⇒Lots of new particles (squarks, sleptons,….) predicted with masses in the range from 10's of GeV's up to several TeV range



3 isolated leptons
+ 2 b-jets
+ 4 jets
+ E_t^{miss}

Lightest SUSY particle stable: dark matter candidate ?

Supersymmetry is broken
We don't see the superpartners

E.g. Minimal Supersymmetric Model

⇒ O(100) new parameters! masses, mixing angles…

SUSY breaking mechanisms: reduces # of param.

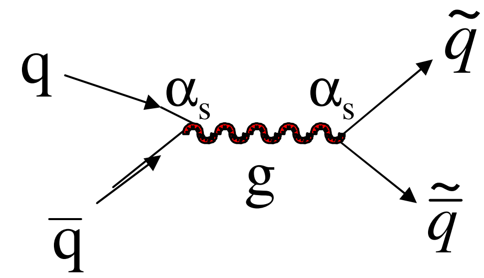
- Minimal SUSY Gravity (msugra)
- Gauge mediated SUSY breaking
- Anomaly mediated SUSY breaking
- Gravitino mediated SUSY breaking… etc.

More than 7000 papers since 1990

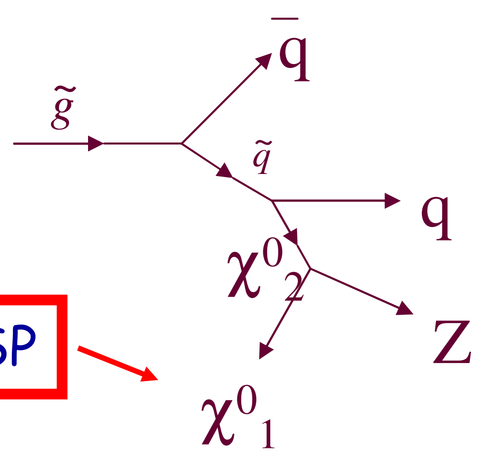
Supersymmetric particles

Squarks and gluinos are produced via strong processes:
!Large cross sections!

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

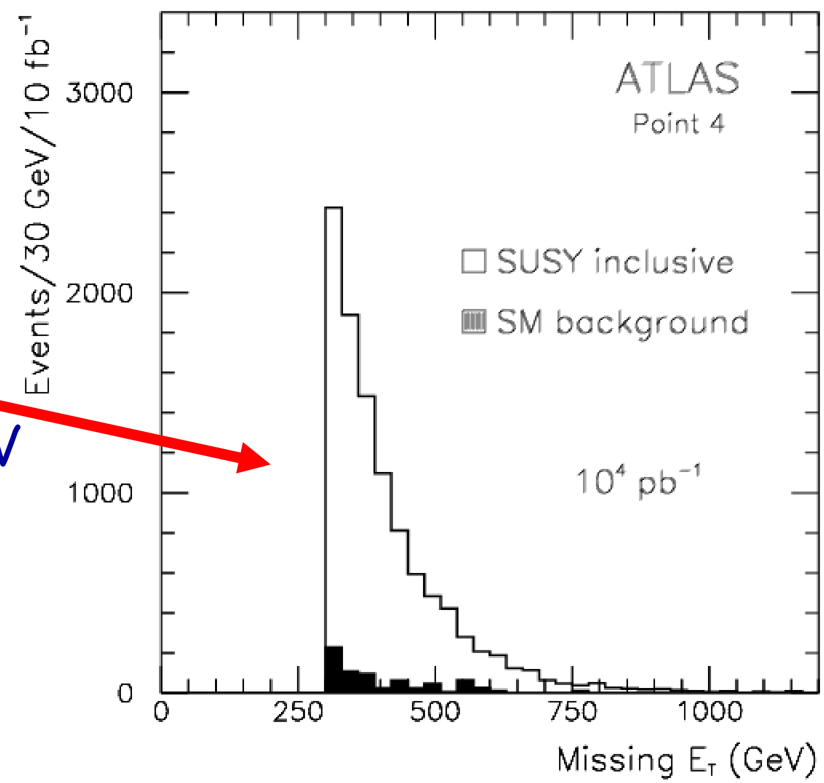


Will be easy (in most cases) to detect: many jets and missing energy from the lightest stable SUSY particle (LPS)

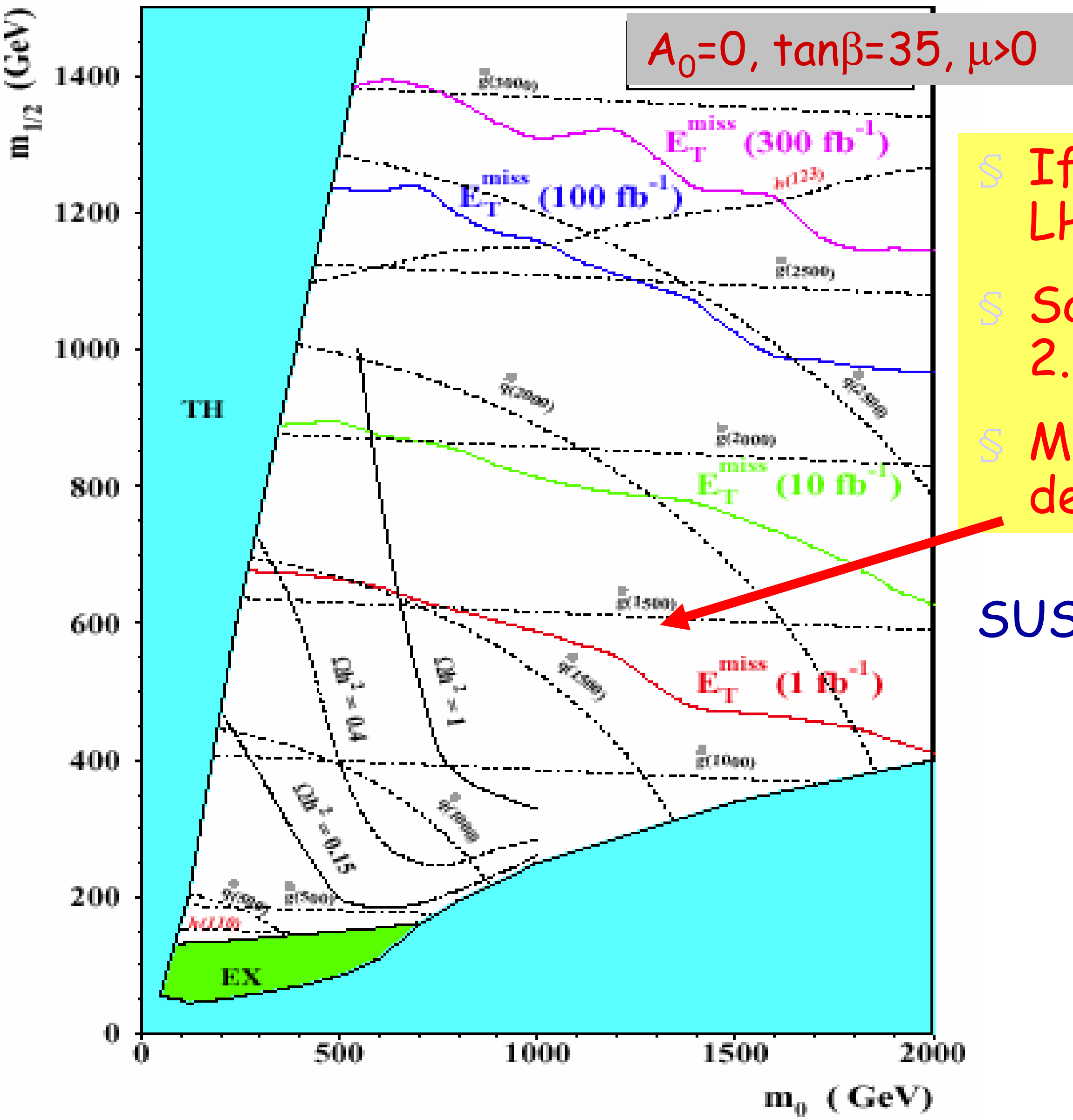


LSP

E.G. 900 GeV squarks
E_t^{miss} > 300 GeV
+ 4 jets



Reach vs integrated luminosity



- If low energy Supersymmetry exists, LHC will almost certainly observe it
- Squarks and Gluinos detectable up to 2.5-3 TeV mass with 300 fb^{-1}
- Masses up to 1 TeV already detectable with 1 fb^{-1}

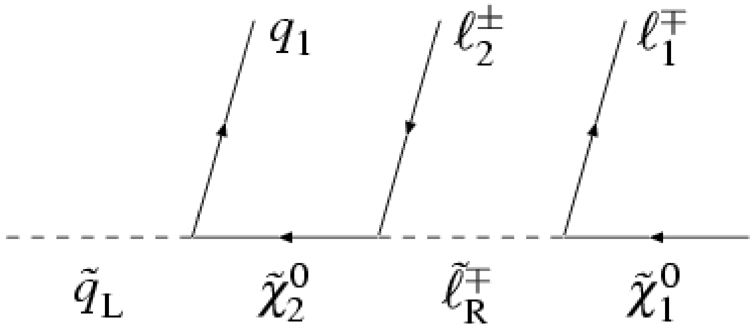
SUSY could be early at the rendez vous!

Usually minimal Supergravity (mSUGRA) taken for studies ⇒5 parameters

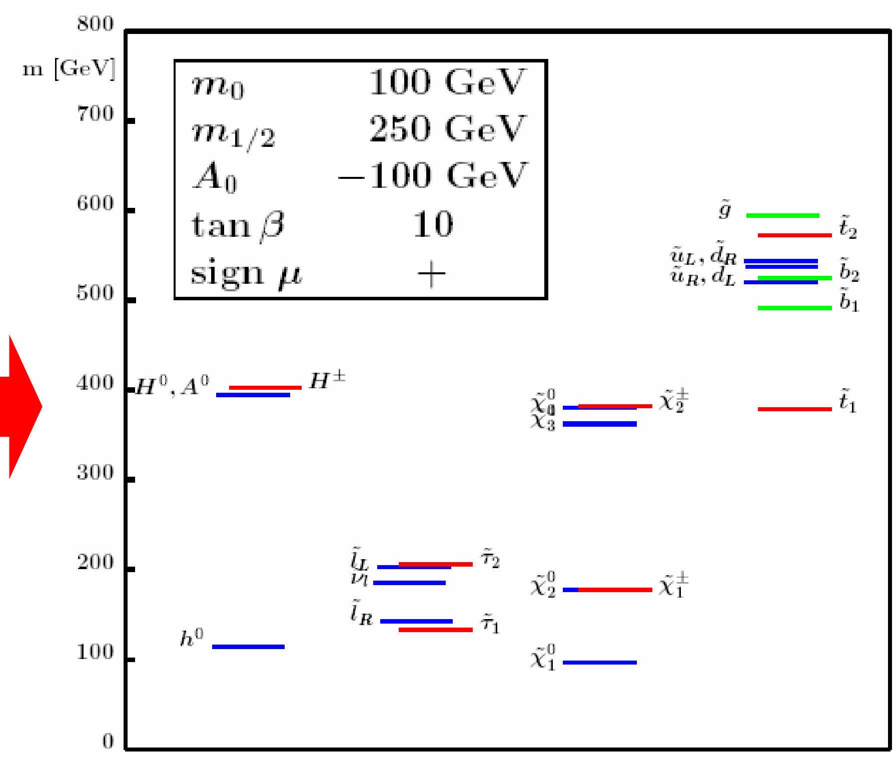
$m_{1/2}$: universal gaugino mass at GUT scale
m_0: universal scalar mass at GUT scale
tanβ: vev ratio for 2 Higgs doublets
sign(μ): sign of Higgs mixing parameter
A_0: trilinear coupling

SUSY studies: Benchmark points

LHC: complicated by decay chains for squarks and gluons



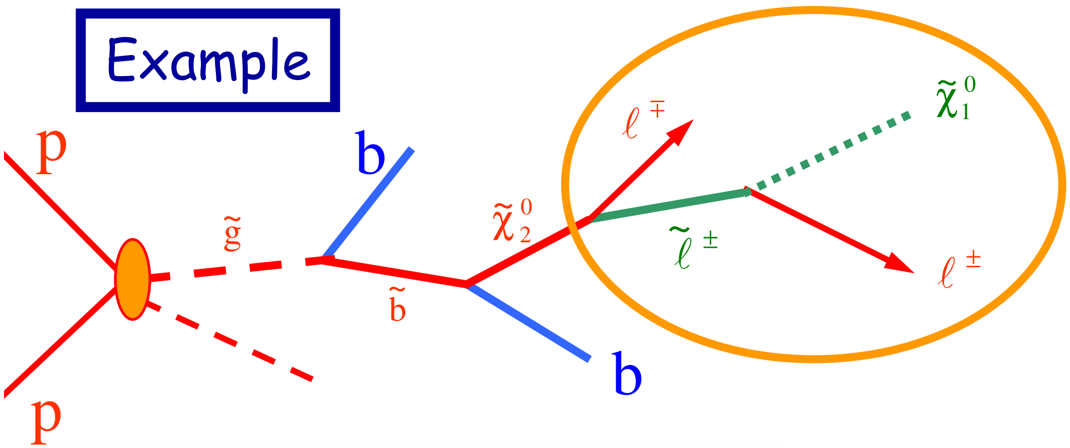
Examples worked out for SPS1a (point B) in ATLAS/CMS

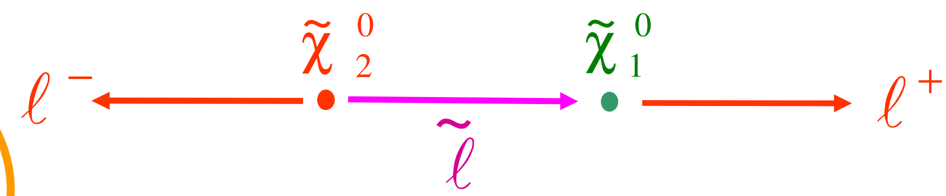


LHC will see all squarks, H,A and may see most gauginos

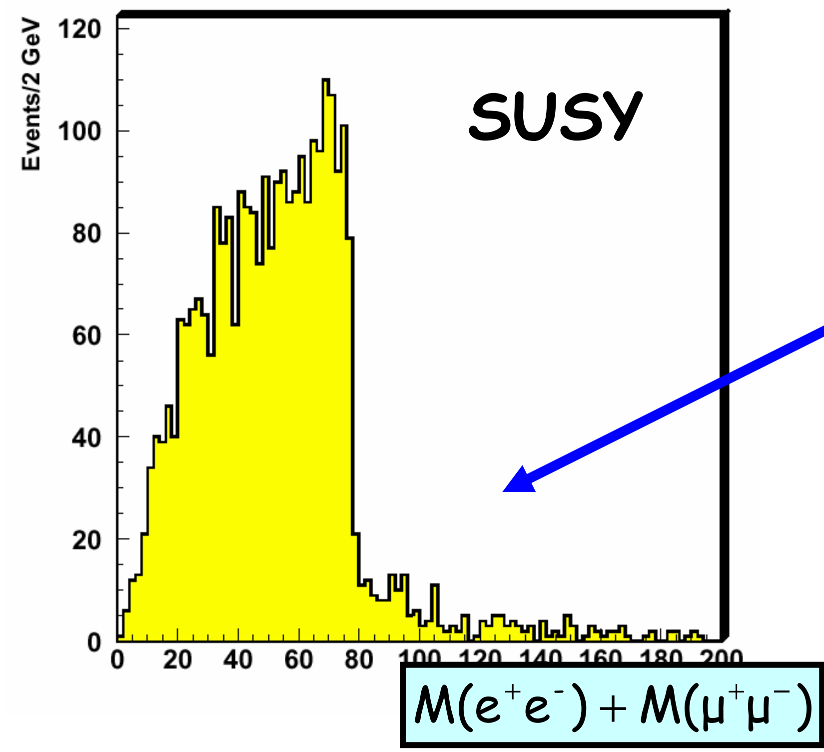
Sparticle Reconstruction

Example



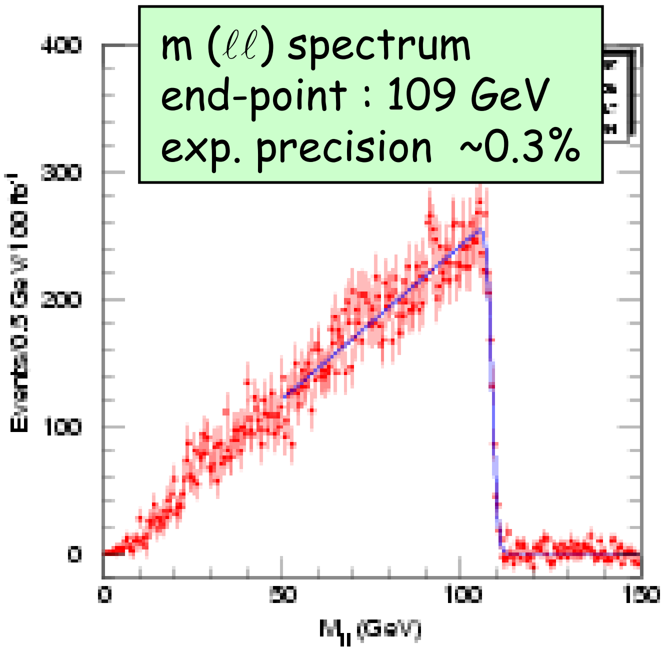


Problem χ_1^0 measurement!
It escapes detection like a neutrino!
Use kinematic formulae...

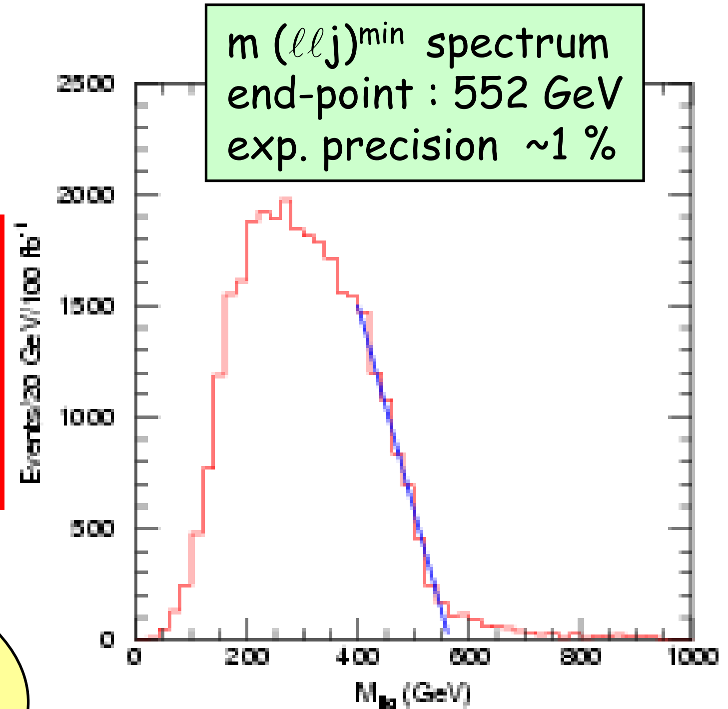


$$M^{max}_{\ell^+\ell^-} = \frac{\sqrt{(M^2_{\tilde{\chi}^0_2} - M^2_{\tilde{\ell}})(M^2_{\tilde{\ell}} - M^2_{\tilde{\chi}^0_1})}}{M_{\tilde{\ell}}}$$

Strategy:
- Study many decay modes & fit "kinematic end points"

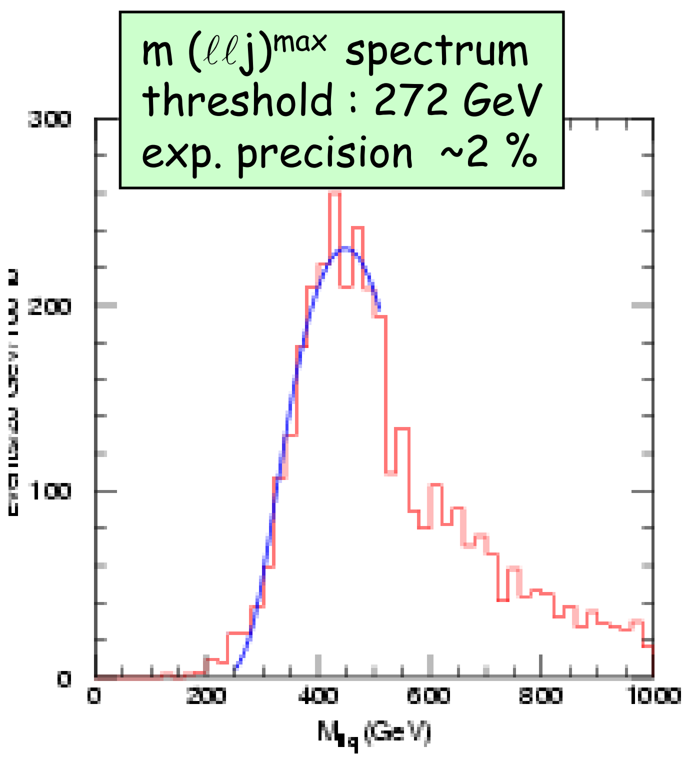


ATLAS
100 fb^{-1}

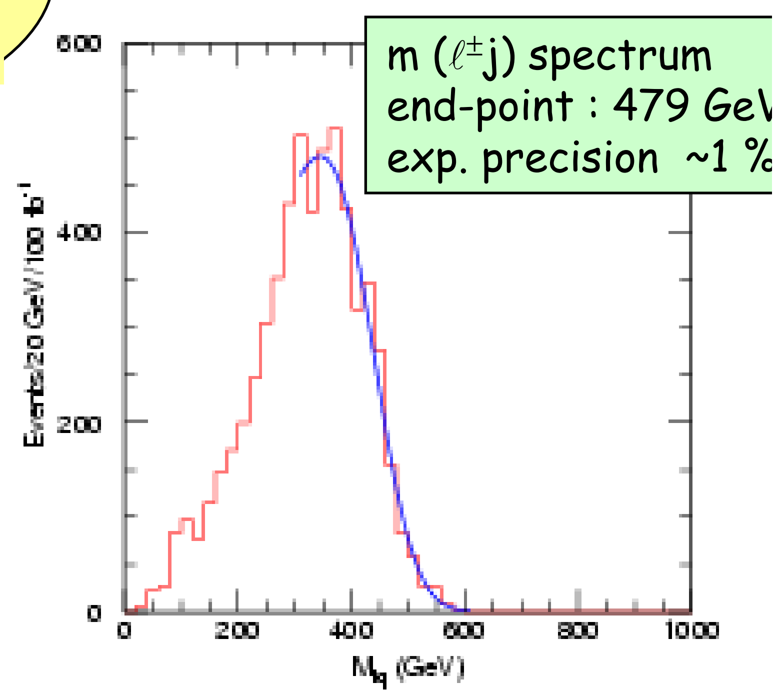


Idea: study as many kinematic endpoints as possible.
Relatively model indep.

$$\tilde{q}_L \to q\, \chi^0_2 \quad \chi^0_2 \to \tilde{\ell}_R\, \ell \quad \tilde{\ell}_R \to \ell\, \chi^0_1$$



Needs sufficient statistics & many different/long decay chains



Mass Measurements

300 fb^{-1}@LHC

Takes into account 1% energy scale uncertainties

ΔM values in GeV

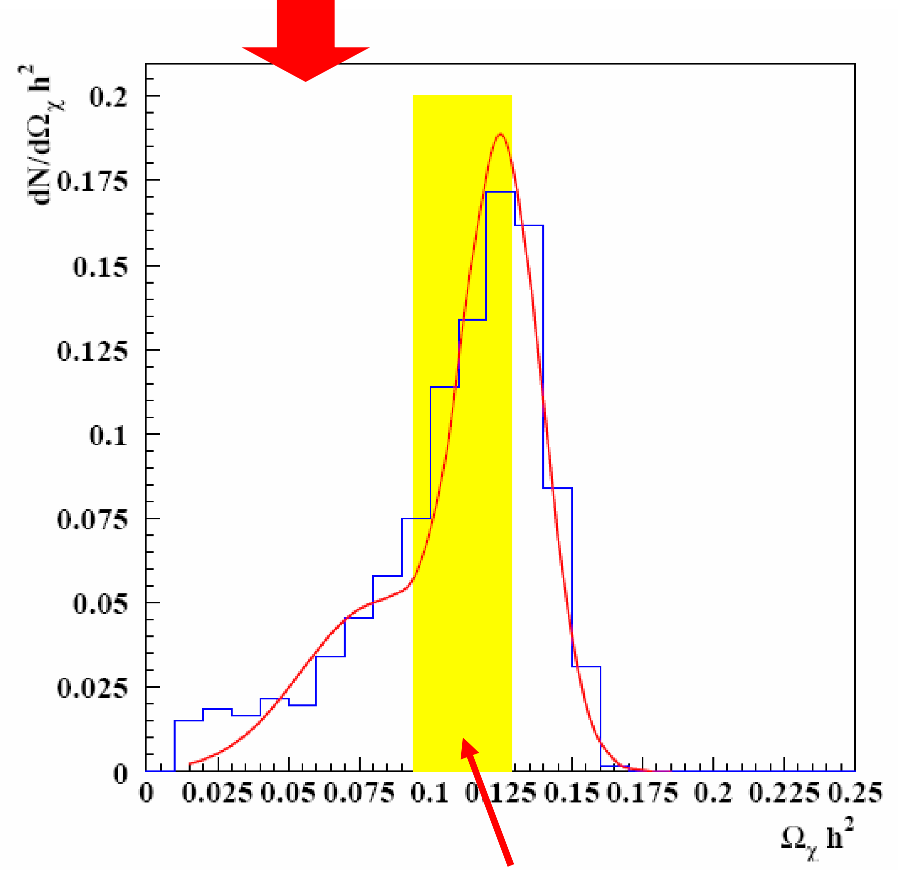
	LHC
$\Delta m_{\tilde{\chi}_1^0}$	4.8
$\Delta m_{\tilde{\chi}_2^0}$	4.7
$\Delta m_{\tilde{\chi}_4^0}$	5.1
$\Delta m_{\tilde{l}_R}$	4.8
$\Delta m_{\tilde{\ell}_L}$	5.0
Δm_{τ_1}	5-8
$\Delta m_{\tilde{q}_L}$	8.7
$\Delta m_{\tilde{q}_R}$	7-12
$\Delta m_{\tilde{b}_1}$	7.5
$\Delta m_{\tilde{b}_2}$	7.9
$\Delta m_{\tilde{g}}$	8.0

The LSP

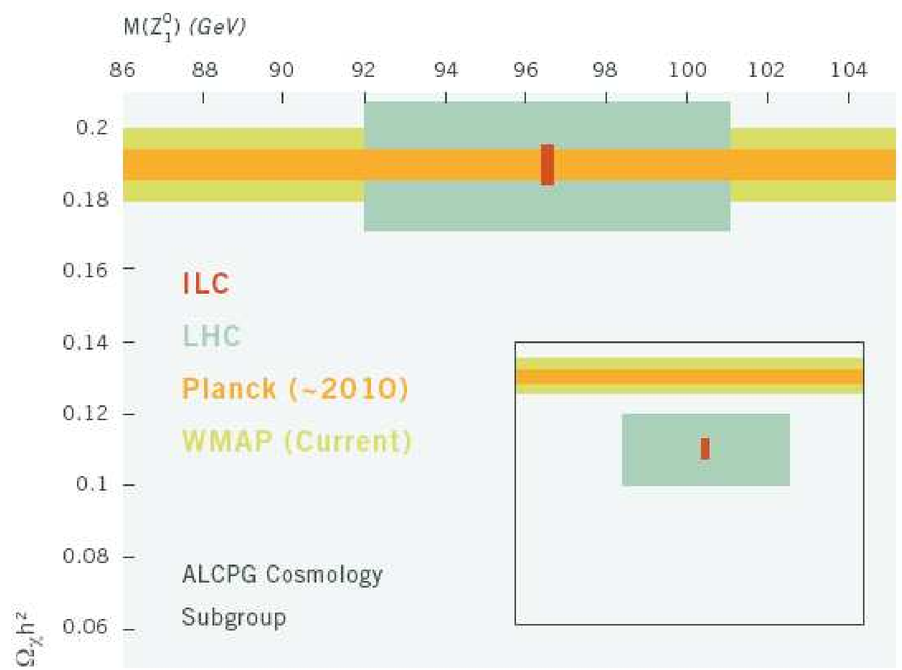
Can measure m(χ_1^0) to about 5-10%

Dark Matter

- Fit the model parameters of the assumed SUSY breaking model to the measured SUSY particle masses $\rightarrow \Omega_\chi h^2$
- Typical precision:



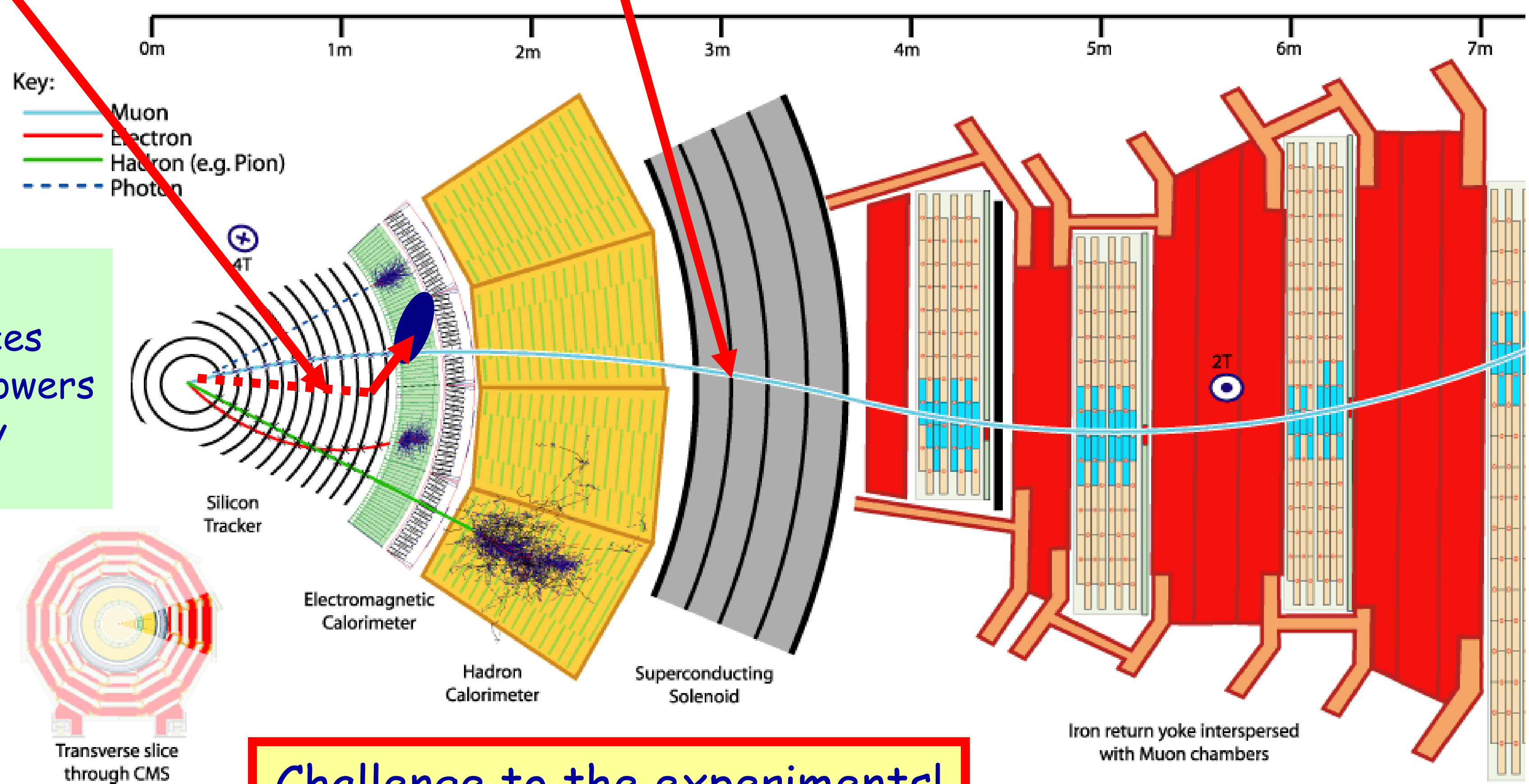
WMAP



ILC: international linear collider
e+e- collider @ 0.5-1 TeV

Recent concerns: Special signatures

In some models/phase space the gravitino is the LSP
Then the NLSP (neutralino, Stau lepton) can live 'long'
Eg. $\chi \rightarrow \gamma +$ gravitino or heavy (slow) stau slepton

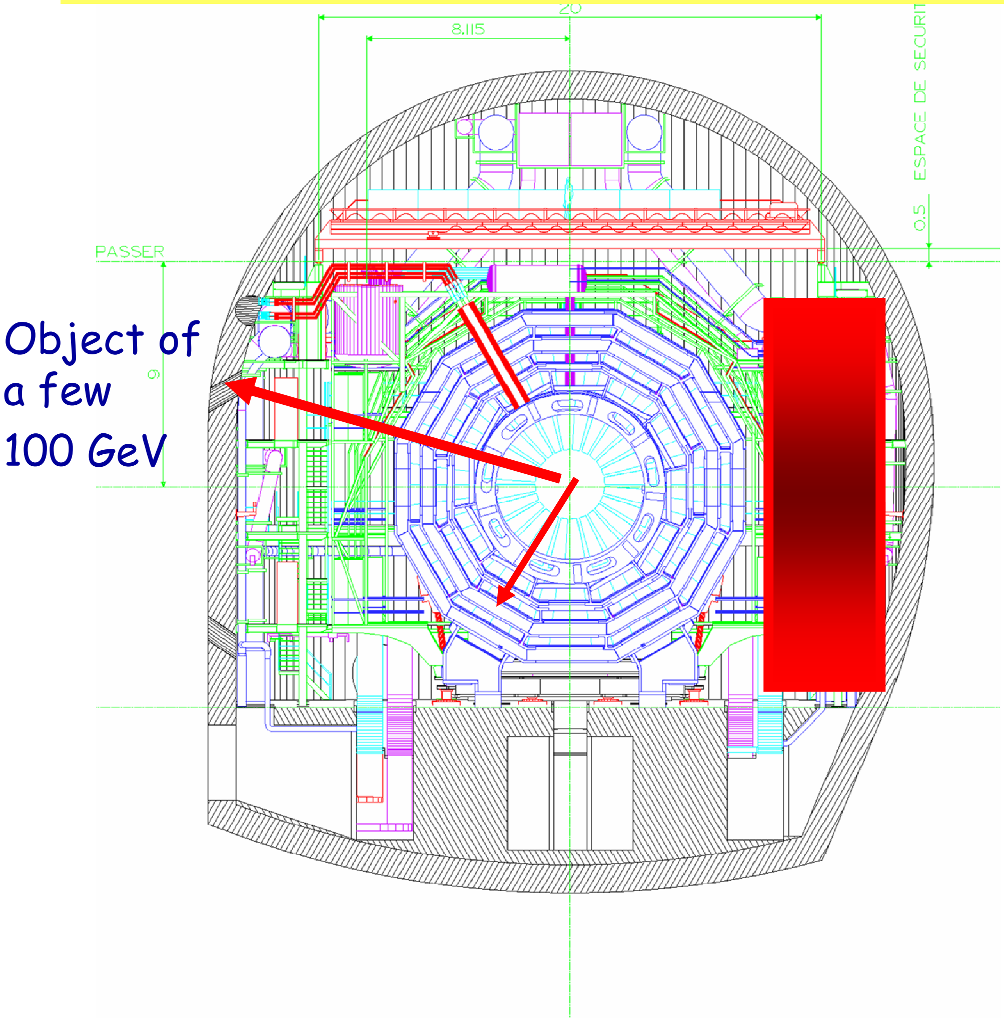


Signatures
- Displaced vertices
- Non-pointing showers
- Long lived 'heavy muons'

Challenge to the experiments!

Long lived sparticles

Some of these heavy long lived heavy sparticles will be stopped in the detector or walls around of the cavern. They will decay after some time: hours-days-weeks-months…



Some benchmark points with Lifetime of 10^4-10^6 sec are being studied:

M Nijori at al (to appear)

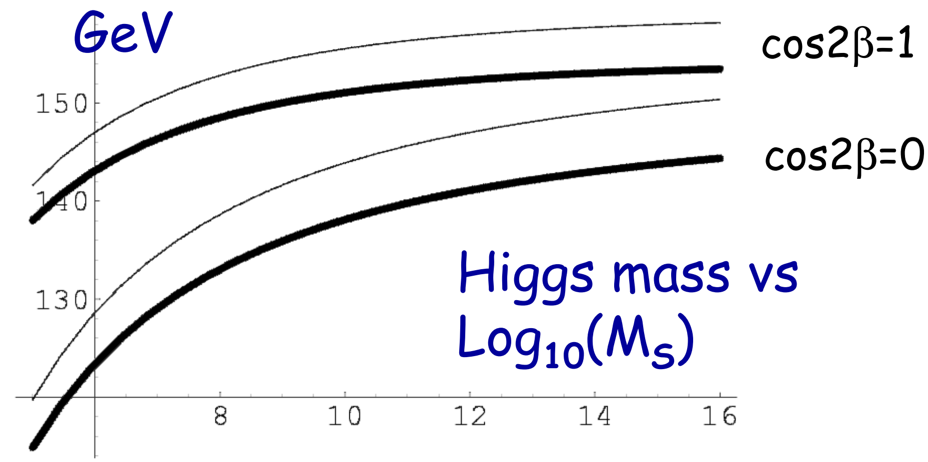
ADR, J. Ellis et al. (to appear)

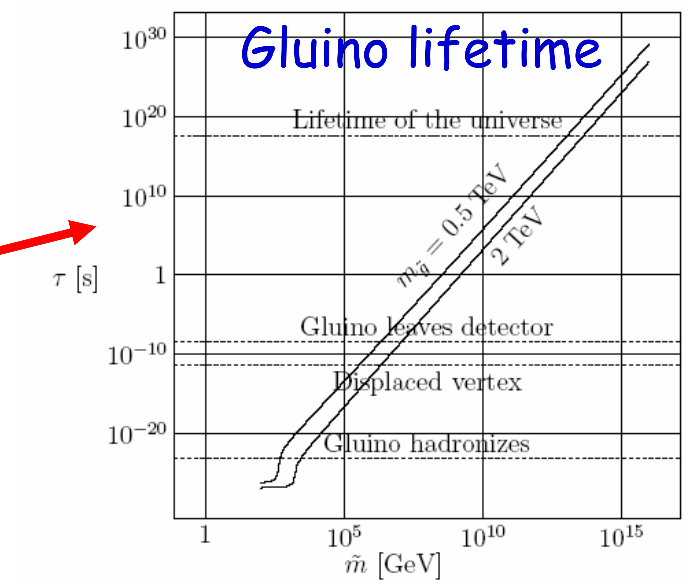
$\Rightarrow$Ideas: Use the cavern wall or addition of slepton stoppers in the cavern (multi-kton object)

Split Supersymmetry

Arkani-Hamed et al., Giudice et al.

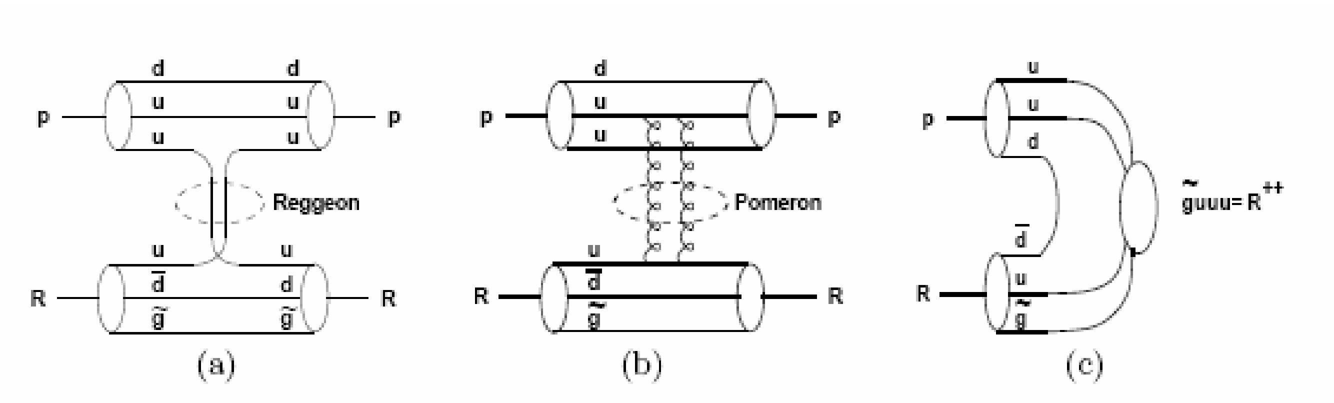
- Assumes nature is fine tuned and SUSY is broken at some high scale
- Motivated by cosmological constant problem and multitude of vacua in string theory (Landscape)
- The only light particles are the Higgs and the gauginos (several 100 GeV to several TeV)
- Interesting gluino phenomenology.
  - Gluino can live long: sec, min, years!
  - R-hadron formation: slow, heavy particles containing a heavy gluino –
  - special interactions with matter…





Can we detect these gluinos at LHC??…

How do these R-hadrons interact with matter?



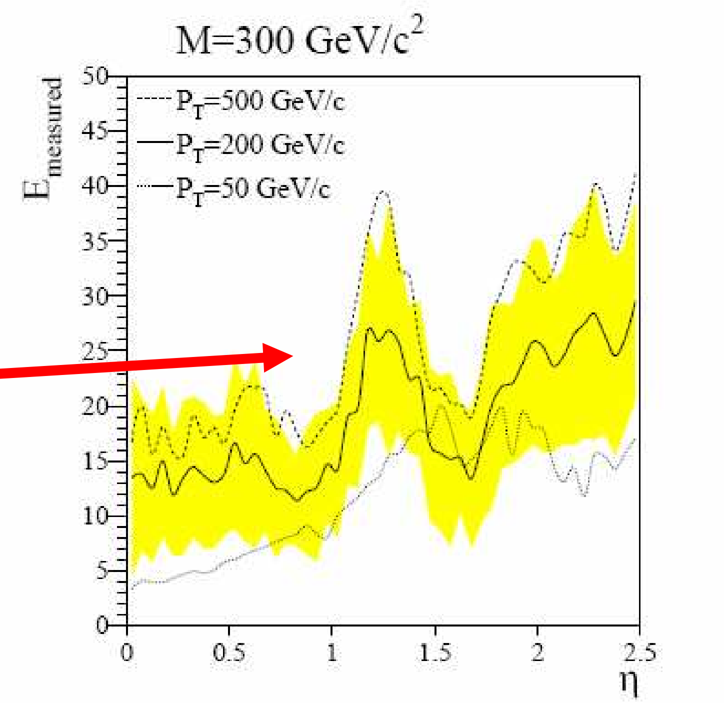
R-Hadrons

(e.g. A Kraan hep-ph/0404001)

- Gluino interactions suppressed as $1/M^2$
- u,d quarks interact but with a kinetic energy of order 1 GeV

$\Rightarrow$ Hence energy loss reduced while passing through e.g the ATLAS calorimeter only about 10-15% is deposited.

This will be a remarkable signature

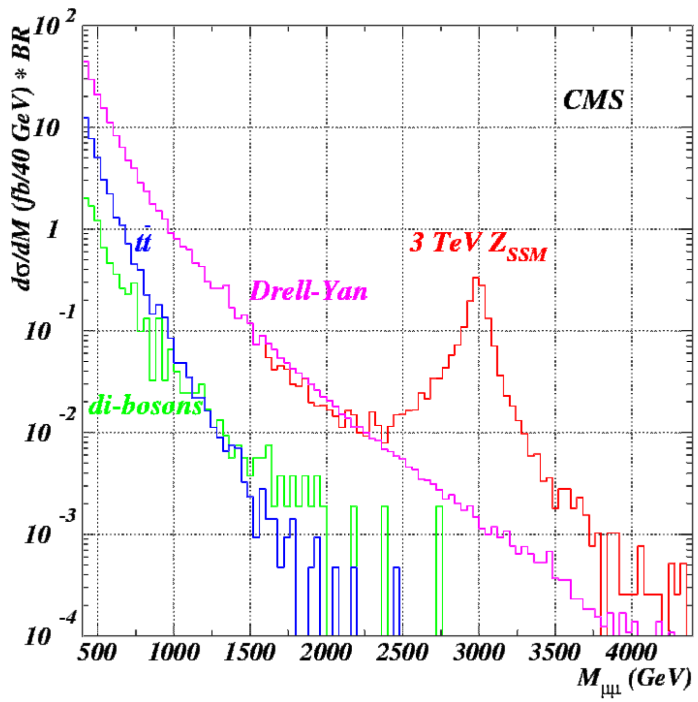


Also: charge flip while passing through matter

New Gauge Bosons

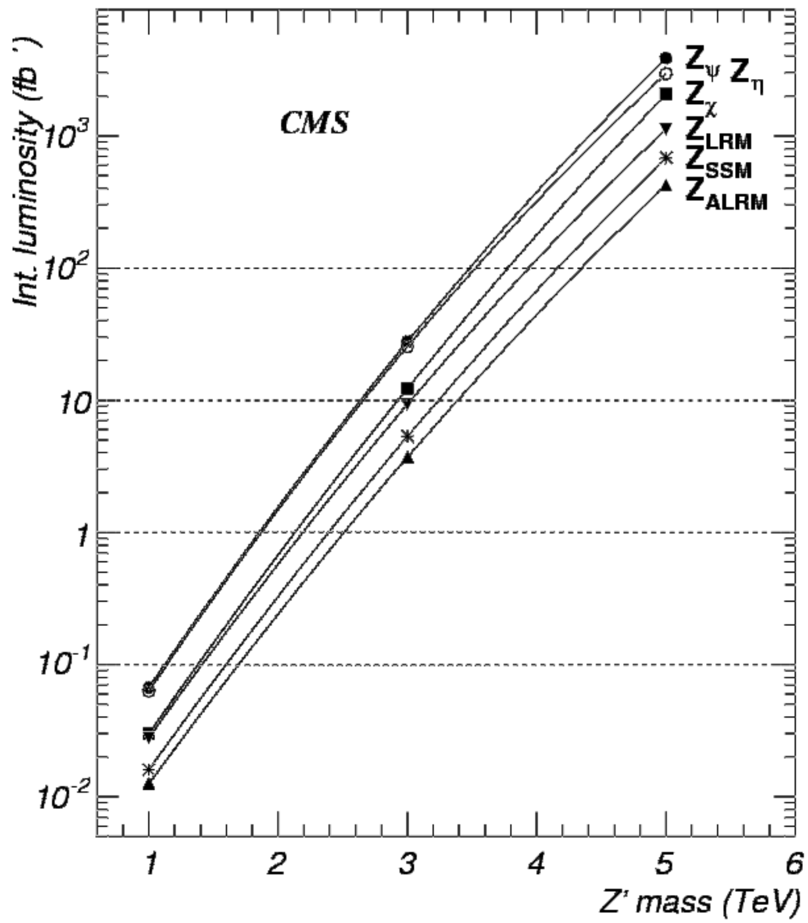
R. Cousins et al.

$Z' \to \mu\mu$ production



Note: Best possible theory knowledge on DY spectrum will be needed (tails!)

$Z' \to \mu^+\mu^-$: 5σ significance curves



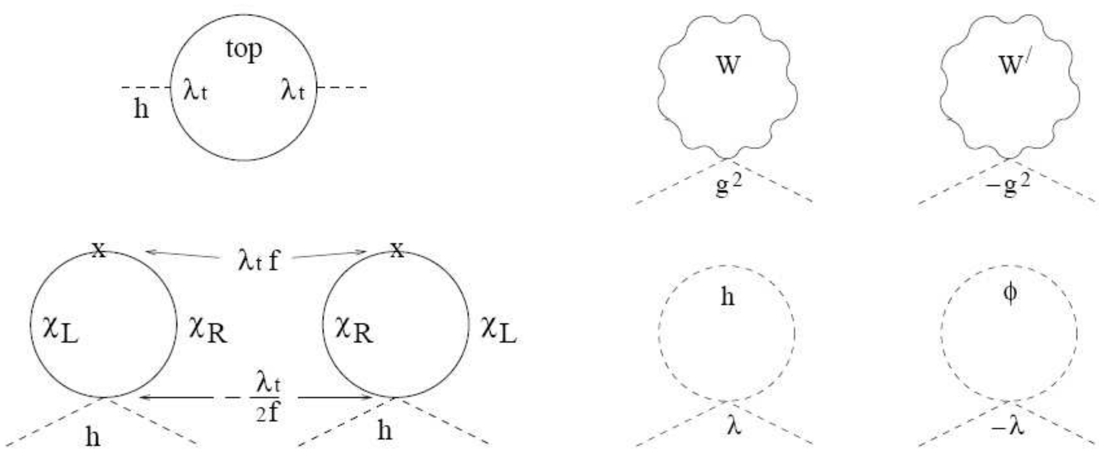
- Low lumi 0.1 fb^{-1} : discovery of 1-1.6 TeV possible, beyond Tevatron run-II
- High lumi 100 fb^{-1}: extend range to 3.4-4.3 TeV

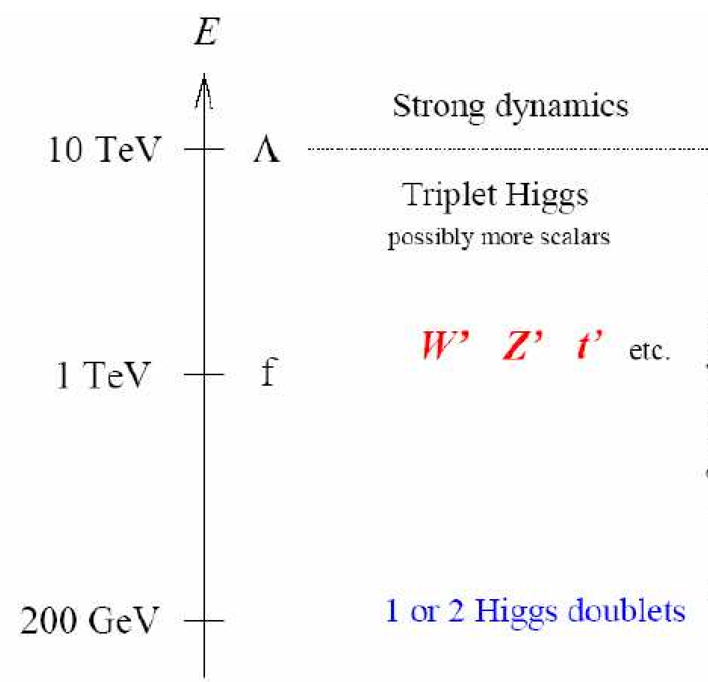
Little Higgs Models

Alternative to supersymmetry to protect the Higgs mass, via couplings of new particles

$W \leftrightarrow W_H \quad Z \leftrightarrow Z_H \quad B \leftrightarrow B_H \quad t \leftrightarrow T_H \quad H \leftrightarrow \Phi$

Arkani-Hamed et al.
Han et al.



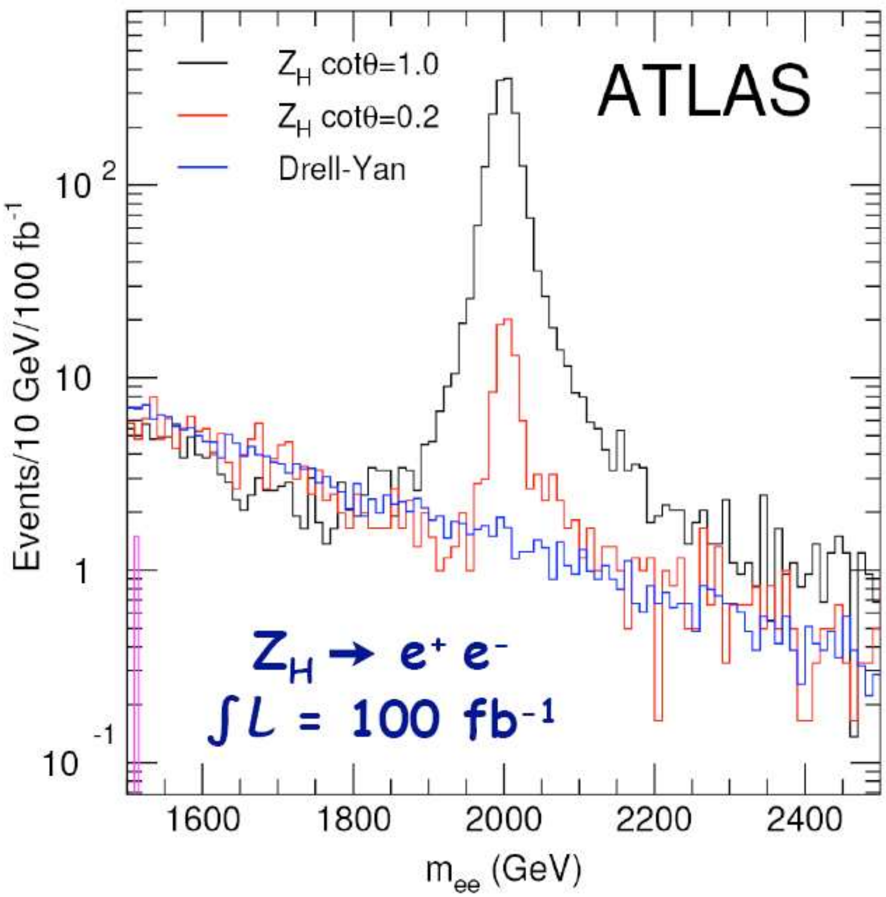


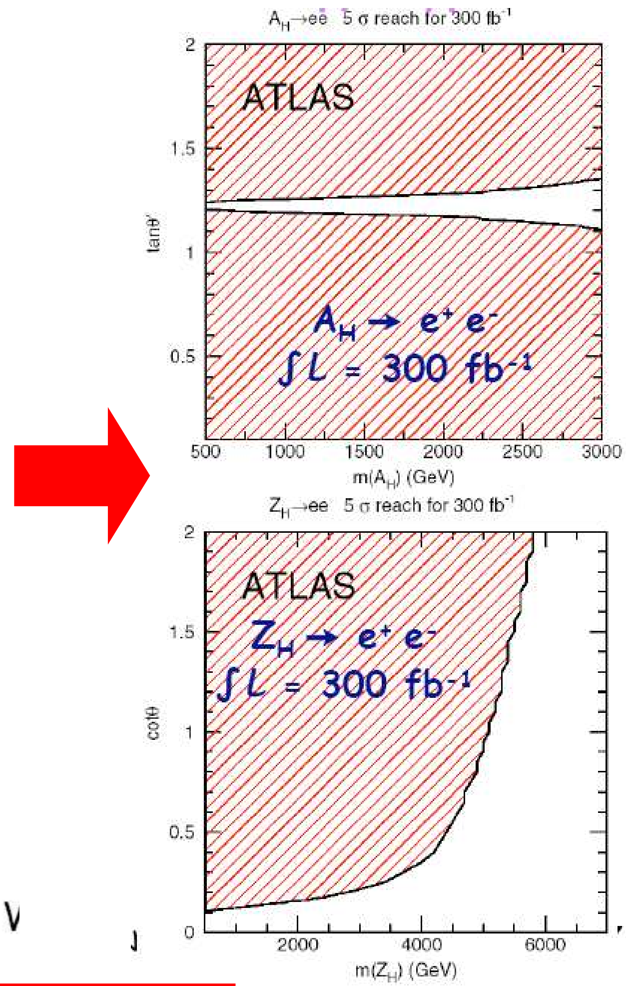
$[SU(2)\otimes U(1)]_A \otimes [SU(2)\otimes U(1)]_B$

$\Rightarrow$ Expect new particles in the TeV range

Little Higgs Model A_H and Z_H

Signal : di-lepton resonance





Reach up to 5.7 TeV depending on the θ angle

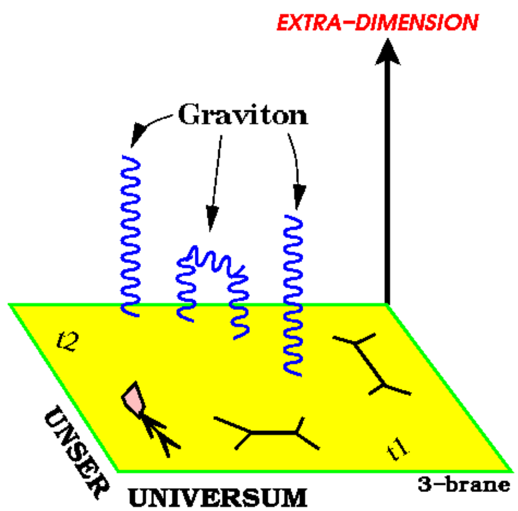
Large Extra Dimensions

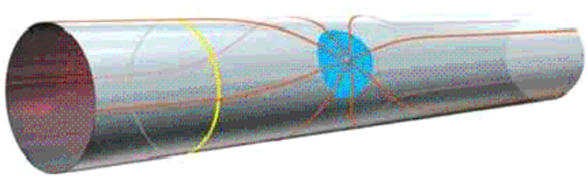
ADD: Arkani -Ahmed, Dimopolous,Dvali

Problem: $m_{EW} = \frac{1}{(G_F \cdot \sqrt{2})^{\frac{1}{2}}} = 246\ \text{GeV}$ $\Longleftrightarrow$ $M_{Pl} = \frac{1}{\sqrt{G_N}} = 1.2 \cdot 10^{19}\ \text{GeV}$

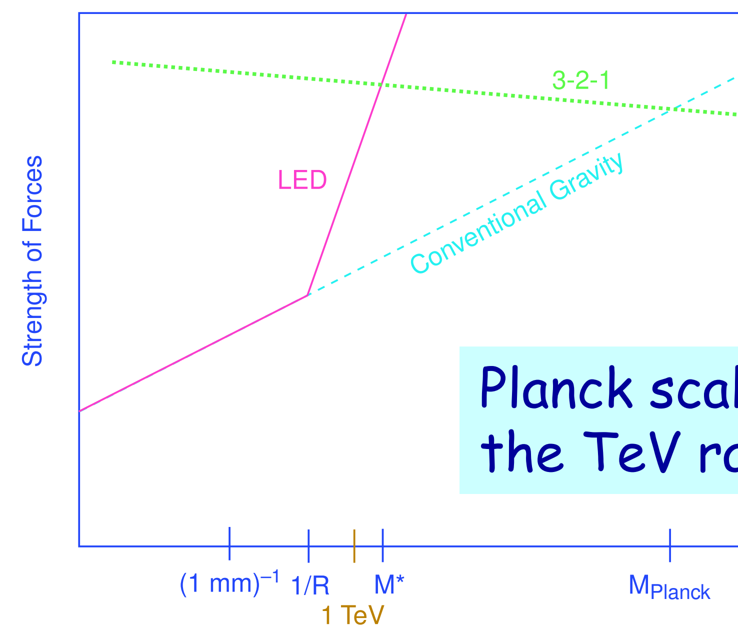
String Theory Inspired

Assume the world we see is in 4 dimensions but that gravity can expand in 4+δ dimensions. Extra dimensions have size R (mm to fm)



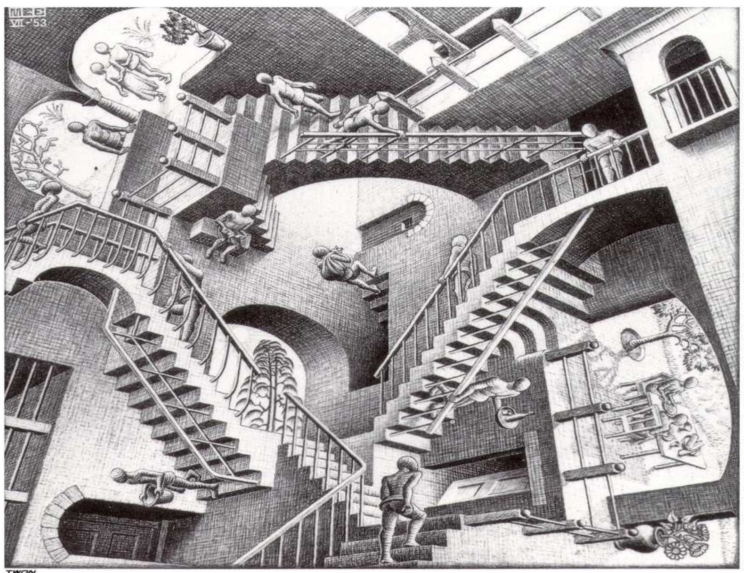


Curled up...



Planck scale in the TeV range?

Extra Dimensions



Large Extra dimensions (ADD)
Gravity in bulk / flat space
Missing energy/interference/black holes

$$ds^2 = G_{IJ}dx^I dx^J = \eta_{\mu\nu}dx^\mu dx^\nu + h_{ij}(y)dy^i dy^j \ ,$$

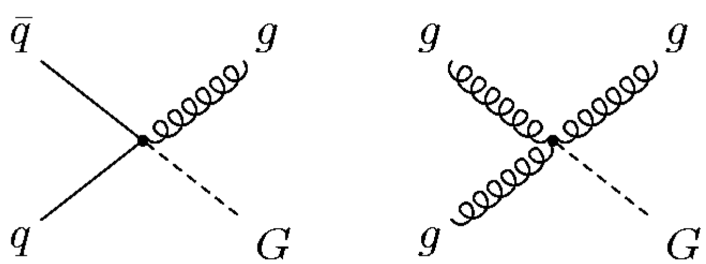
Warped Extra Dimensions (RS)
Gravity in bulk / curved space
Spin 2 resonances > TeV range/black holes

$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2 \ ,$$ k = warp factor

TeV Scale Extra Dimensions
Gauge bosons/Higgs in the bulk
Spin 1 resonances > TeV range
Interference with Drell-Yan

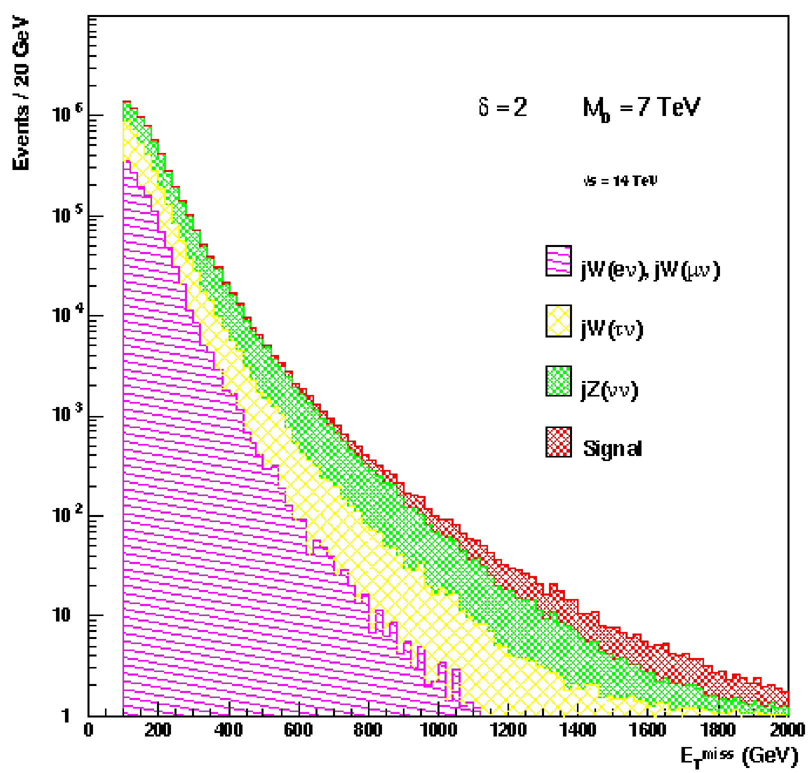
Special case: Universal Extra Dimensions UED
Everybody in the bulk!
Fake SUSY spectrum of KK states
+ many combinations/variations

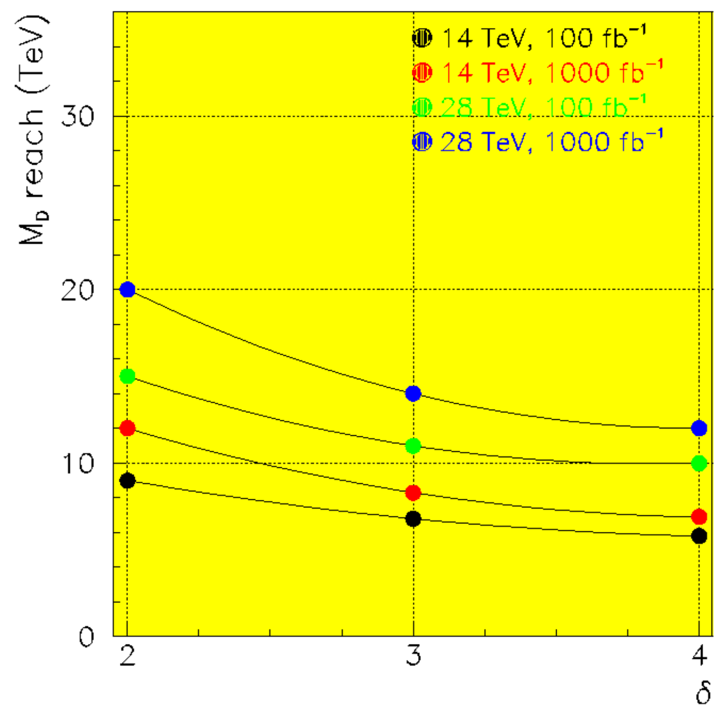
Extra Dimension signals at the LHC



Graviton production!
Graviton escapes detection

Signal: single jet + large missing ET



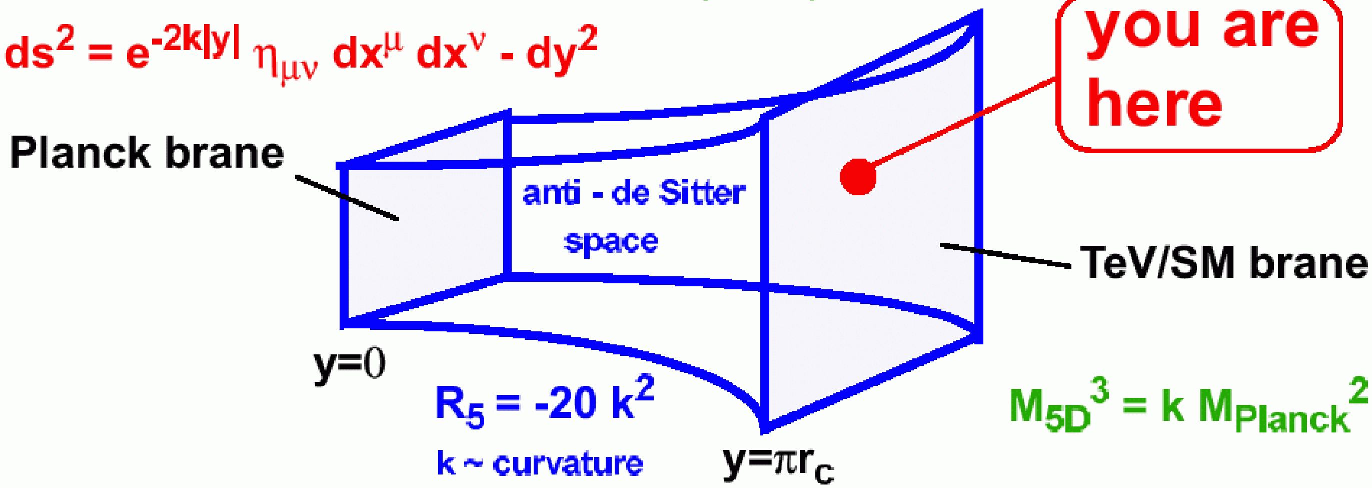


Test M_D to 7-9 TeV for 100 fb^{-1}

Curved Space: RS Extra Dimensions

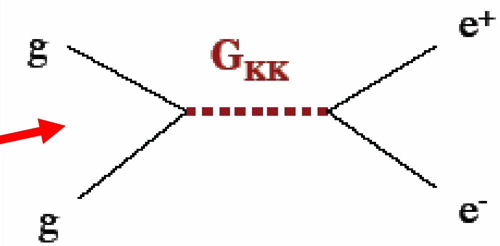
Randall, Sundrum, PRL 83, 3370 (1999)

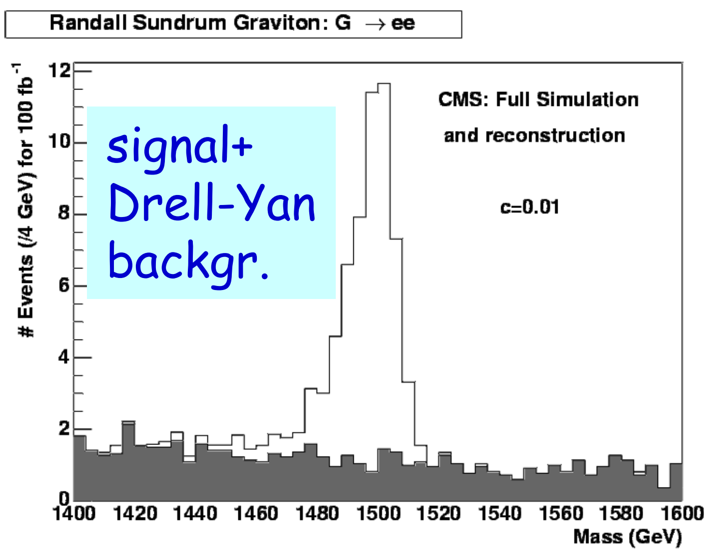
$ds^2 = e^{-2k|y|}\,\eta_{\mu\nu}\,dx^\mu\,dx^\nu - dy^2$



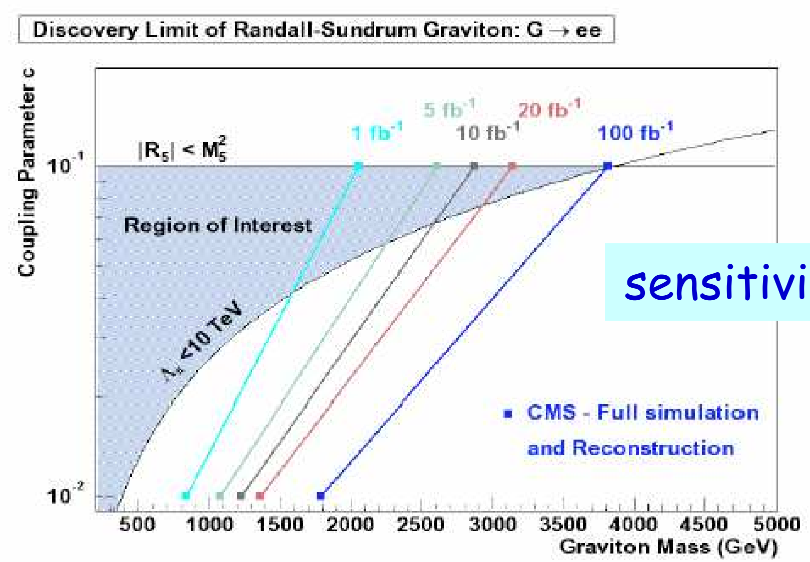
phenomenology

Study the channel pp→Graviton→ e+e-





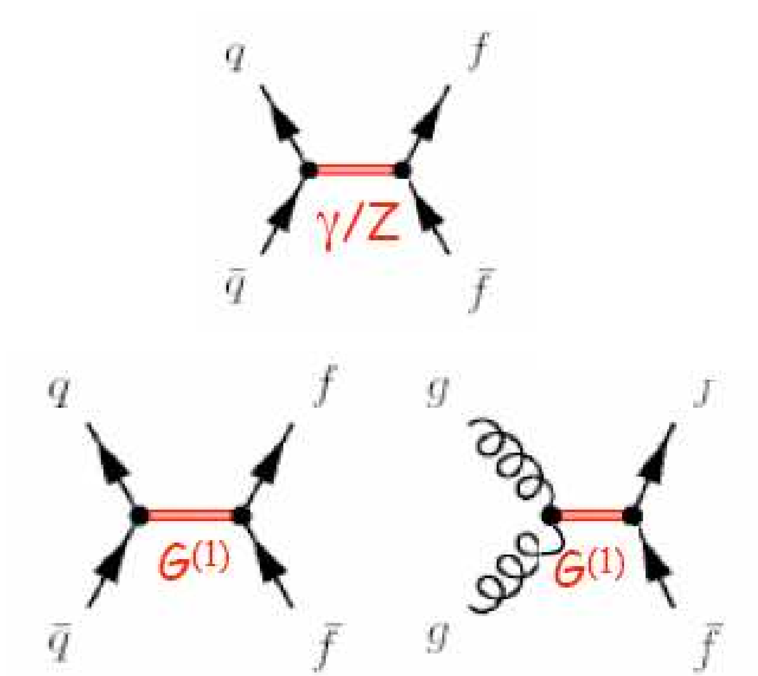
signal+ Drell-Yan backgr.

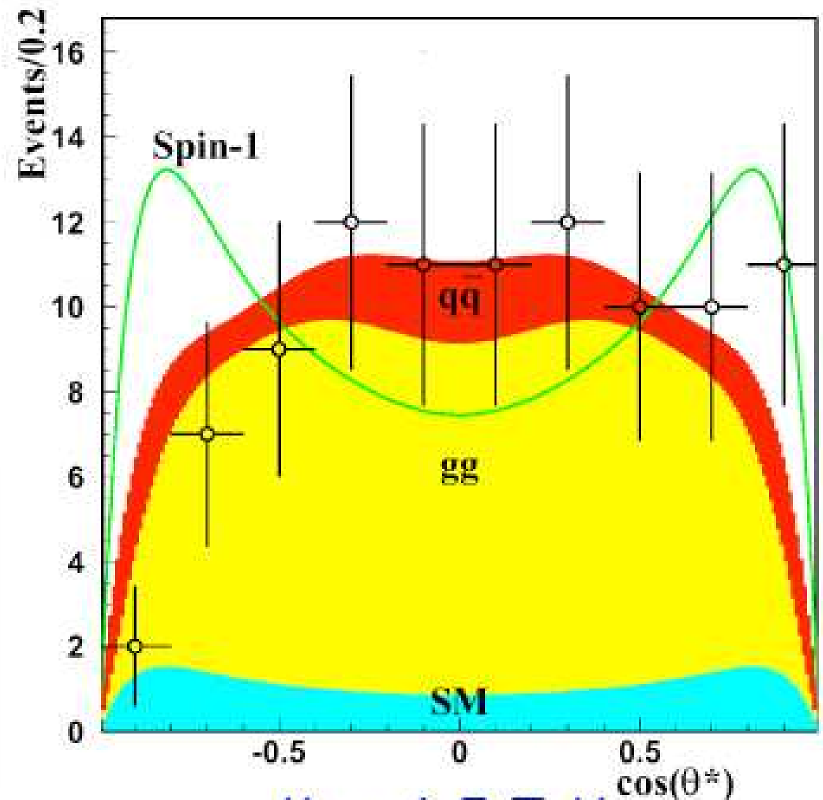


sensitivity

Randall-Sundrum EDs

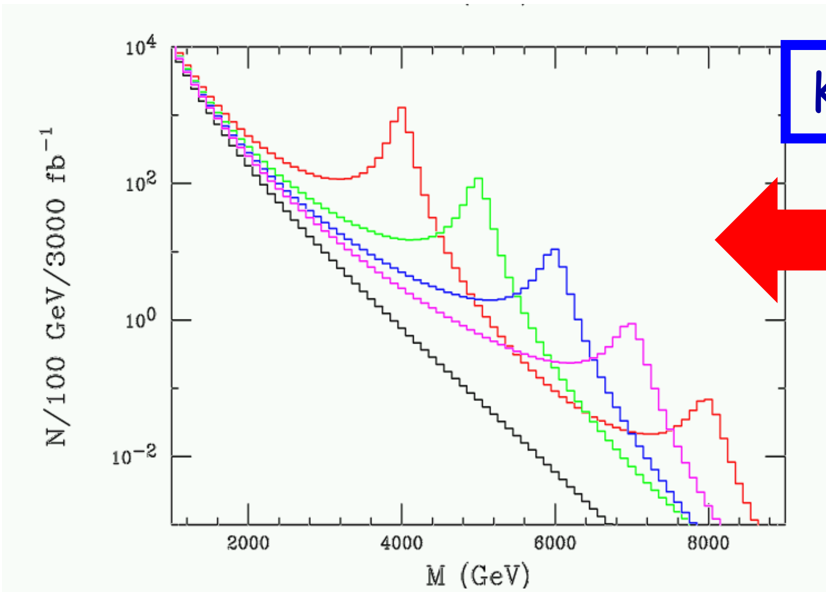
We observe a peak in di-lepton spectrum
Is it a new gauge boson or a RS KK excitation
$\Rightarrow$ Study the spin of the object: spin 1 versus spin 2



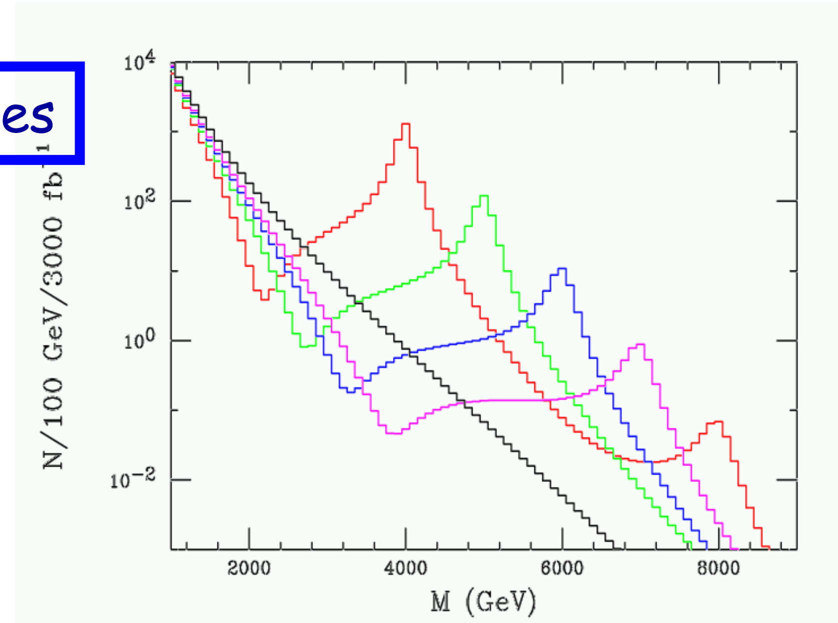


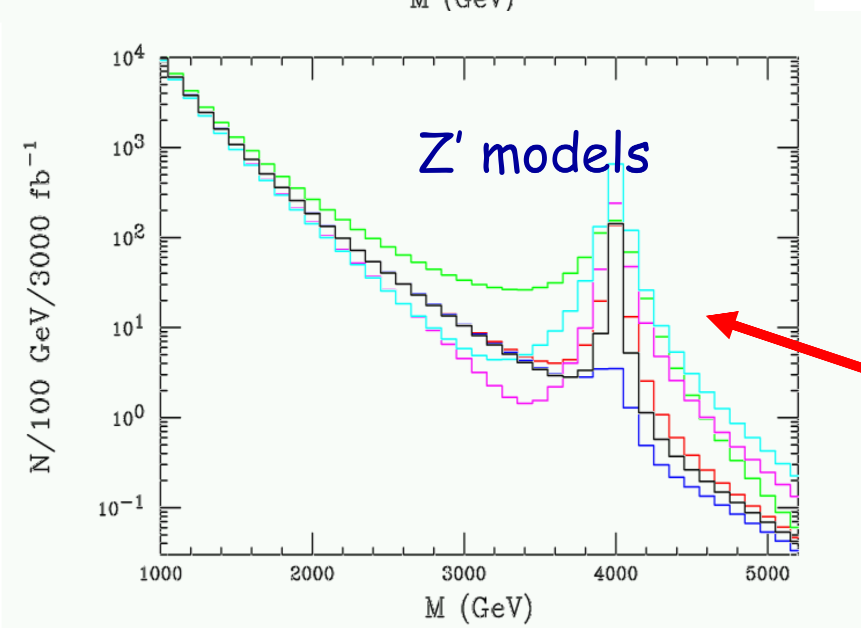
M_G = 1.5 TeV
$\int L$ = 100 fb^{-1}

TeV scale Extra Dimensions



KK states





LEP: M > 4 TeV (indirect)

Sensitivity of the LHC

- Direct up to 5.8 TeV for 300 fb^{-1}
- Indirect up to 13 TeV for 300 fb^{-1}

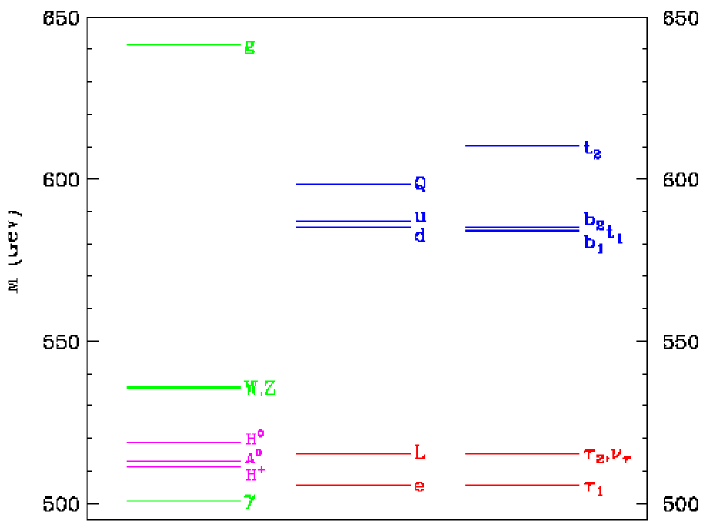
How to distinguish from a Z'?
E.g. use Forw-Backw assymetries
T. Rizzo (hep-ph/0305077)

Universal Extra Dimensions UED

e.g. Cheng, Matchev, Schmaltz hep-ph/0205314

UED⇒ all particles in the bulk
Phenomenology: a KK tower pattern from ED's which looks like supersymmetry:
Can the LHC tell distinguish?

Tools: spin of the "sparticles"/ No heavy higgses/mass splitting small/ pattern repeates at higher energies…



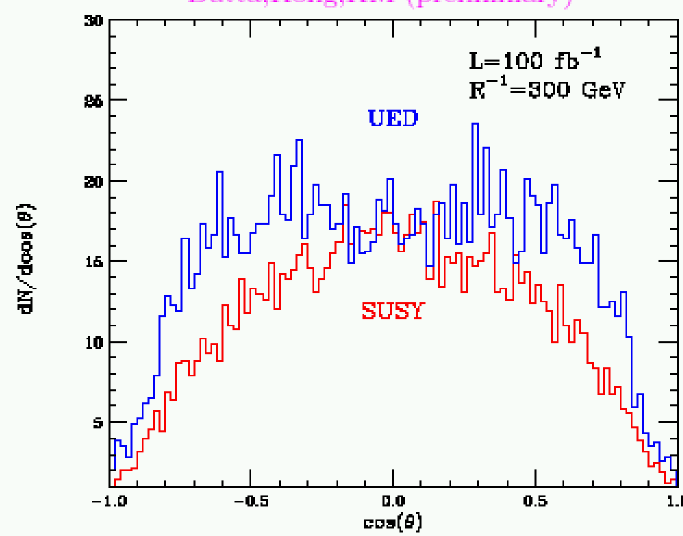
Study muon angular distribution in (approx.) smuon rest frame

First result looks encouraging
Also: A. Bar hep-ph/0405052 lepton charge asymmetry

SUSY versus UED at the LHC

- Cuts:
  - $E_{\mu^+} + E_{\mu^-} > 40$ GeV (similar with 60 and 80 GeV).
  - $|\eta(\mu)| < 2.5$.
- We can recover to some extent the difference in shapes!

Datta,Kong,KM (preliminary)



- Backgrounds? Other tricks? Strong KK production?

Studies of spin sensitive variables needed!

What if Planck Scale in TeV Range?

- Schwarzschild radius

Landsberg, Dimopoulos
Giddings, Thomas

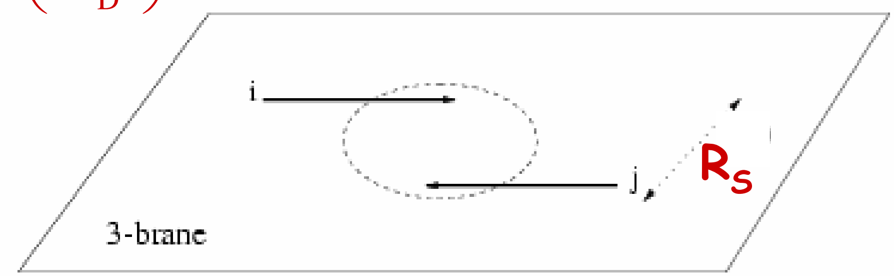
4-dim., $M_{gravity} = M_{Planck}$ $R_S \sim \frac{2}{M_{Pl}^2} \frac{M_{BH}}{c^2}$

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

$R_s \rightarrow \ll 10^{-35}$ m

$R_s \rightarrow \sim 10^{-19}$ m

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



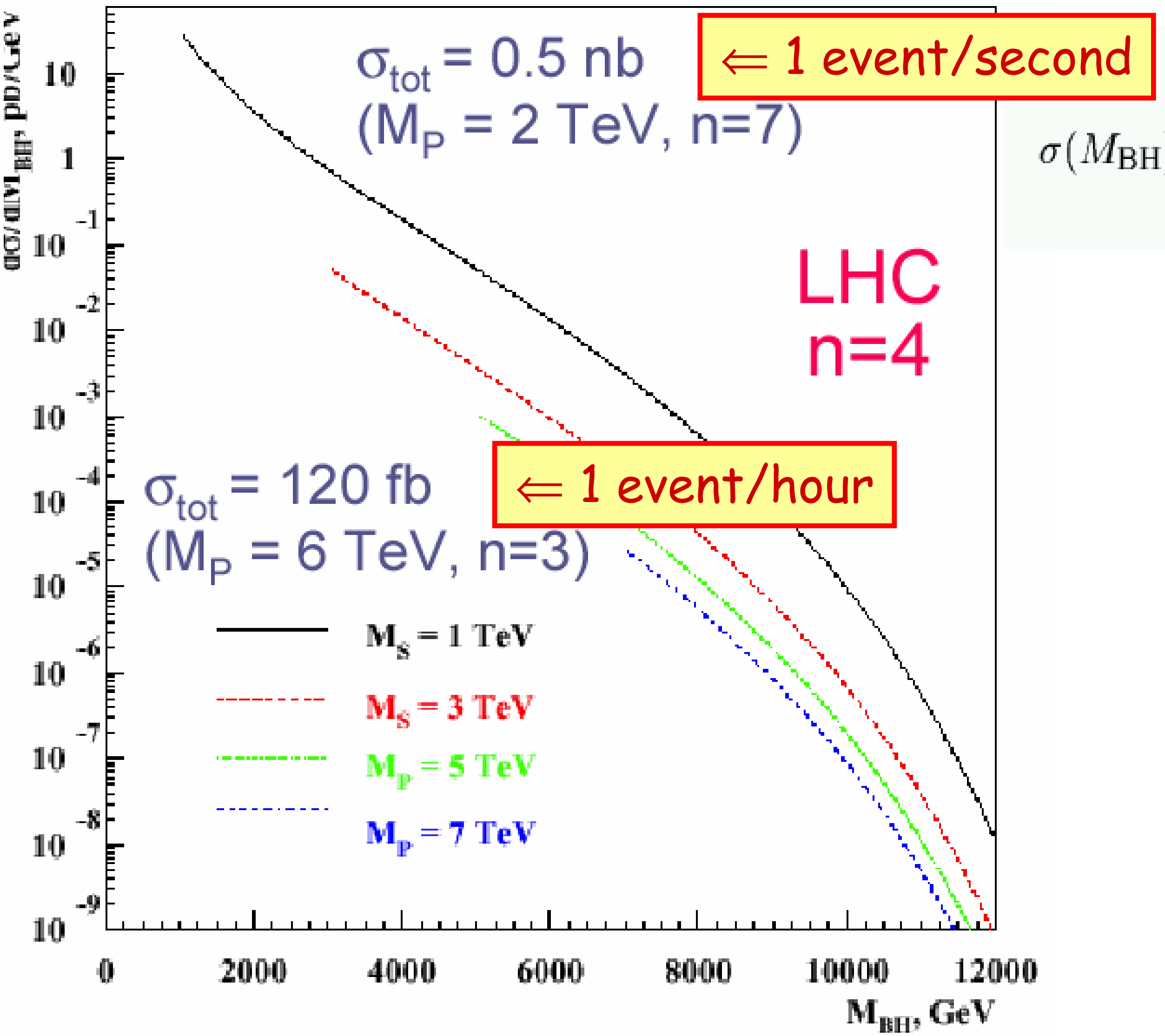
- Large partonic cross-section : $\sigma(ij \rightarrow BH) \sim \pi R_S^2$
- $\sigma(pp \rightarrow BH)$ is in the range of 1 nb – 1 fb

  e.g. For $M_D \sim 1$ TeV and n=3, produce 1 event/second at the LHC

- Black holes decay immediately by Hawking radiation (democratic evaporation) :
  - -- large multiplicity
  - -- small missing E
  - -- jets/leptons ~ 5

expected signature (quite spectacular …)

Black Holes



$$\sigma(M_{\rm BH}) \approx \pi R_S^2 = \frac{1}{M_P^2}\left[\frac{M_{\rm BH}}{M_P}\left(\frac{8\Gamma\left(\frac{n+3}{2}\right)}{n+2}\right)\right]^{\frac{2}{n+1}} .$$

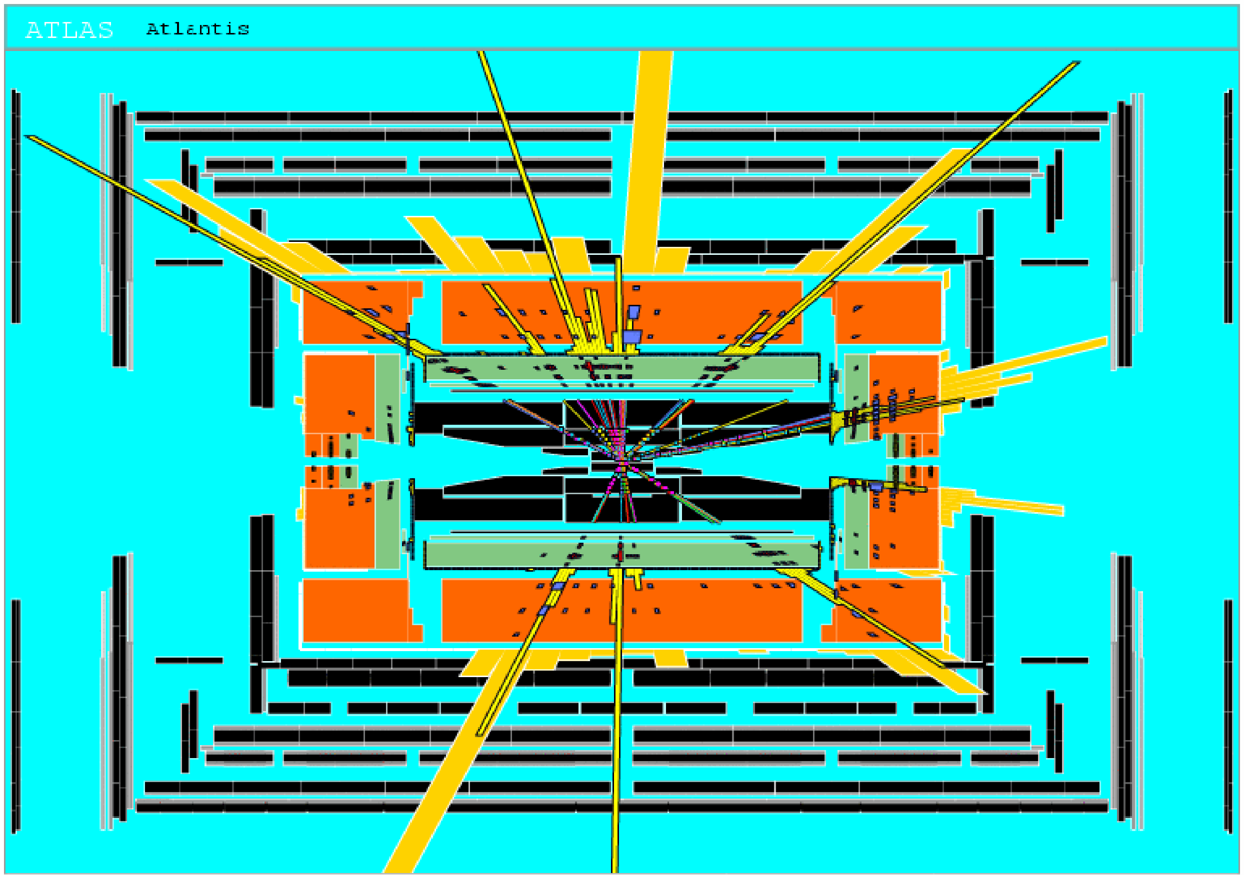
Cross sections for black holes be very large

May dominate the particle production at the LHC

Black Holes production

If the Planck scale in ~TeV region: can expect Black Hole production

Simulation of a black hole event with M_{BH} ~ 8 TeV in ATLAS M_D ~ 1 TeV n=6



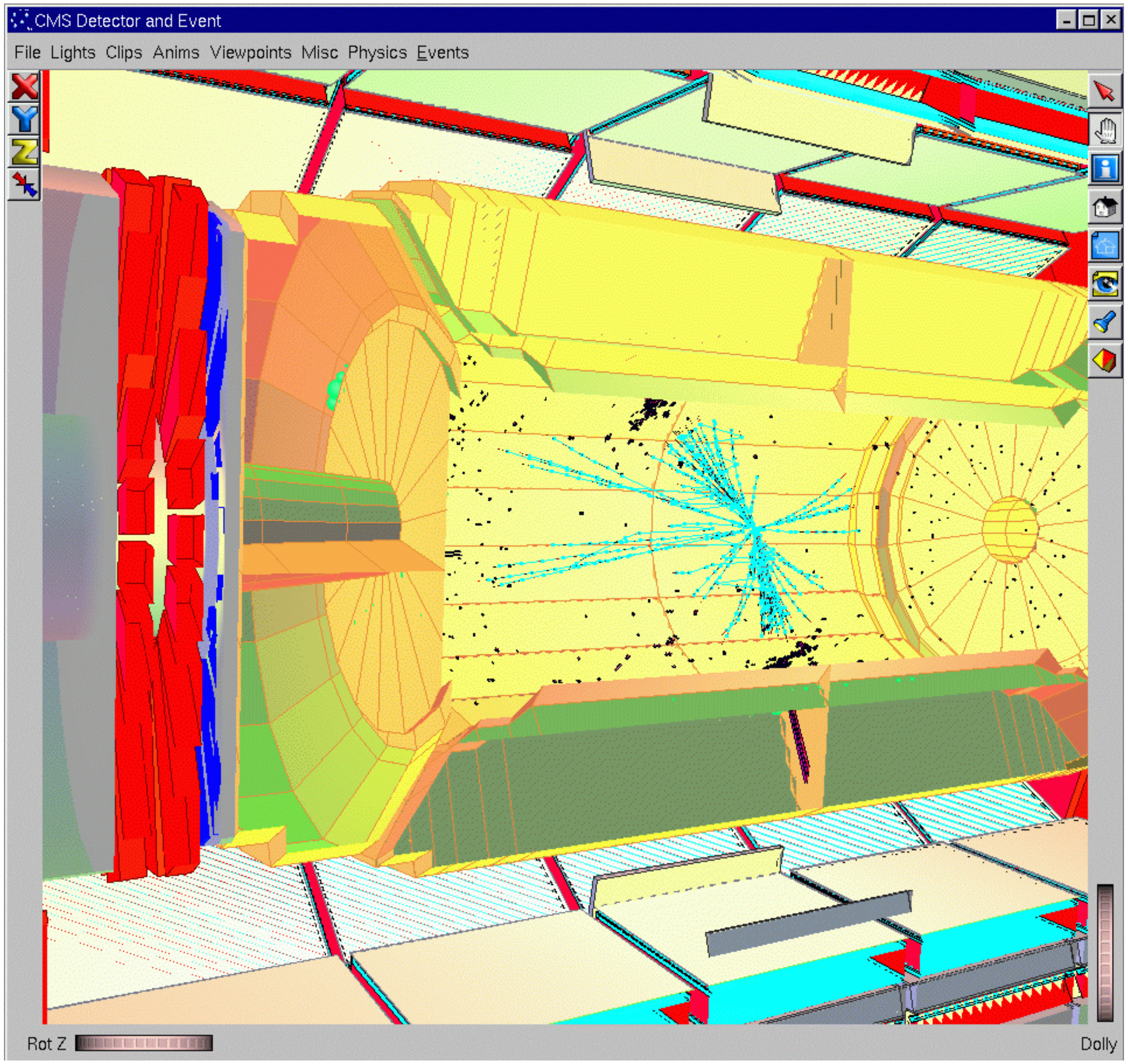
~ Spherical events
Many high energy jets leptons, photons etc.

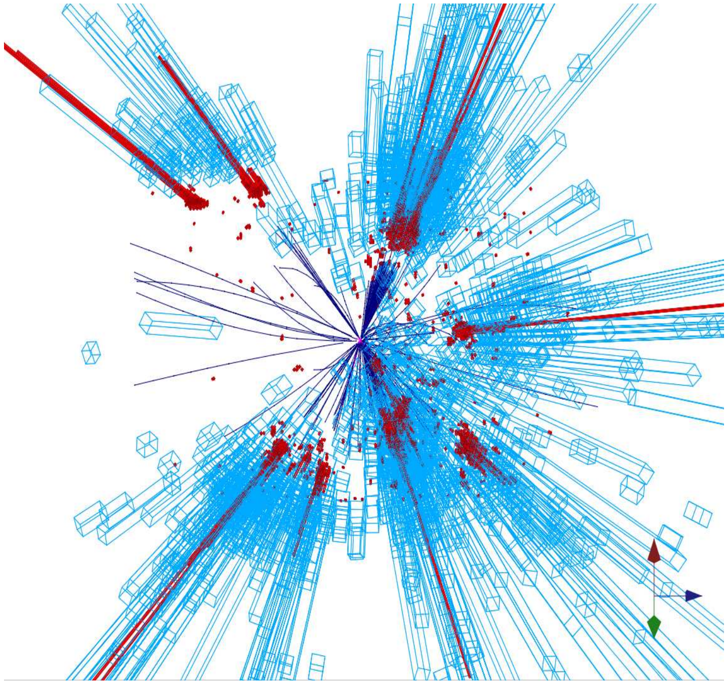
Ecological comment:
BH's will decay within 10^{-27} secs or so

Detectors, electronics (and rest of the world) are safe!!

Black Holes

...and in CMS



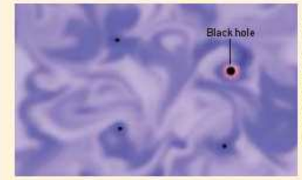


Scientific American (May 05)

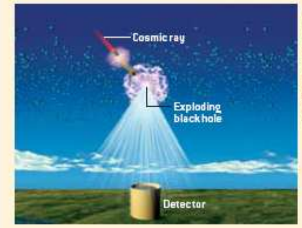
PHYSICISTS COULD SOON BE CREATING BLACK HOLES IN THE LABORATORY

QUANTUM BLACK HOLES

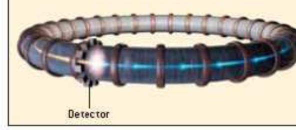
WAYS TO MAKE A MINI BLACK HOLE



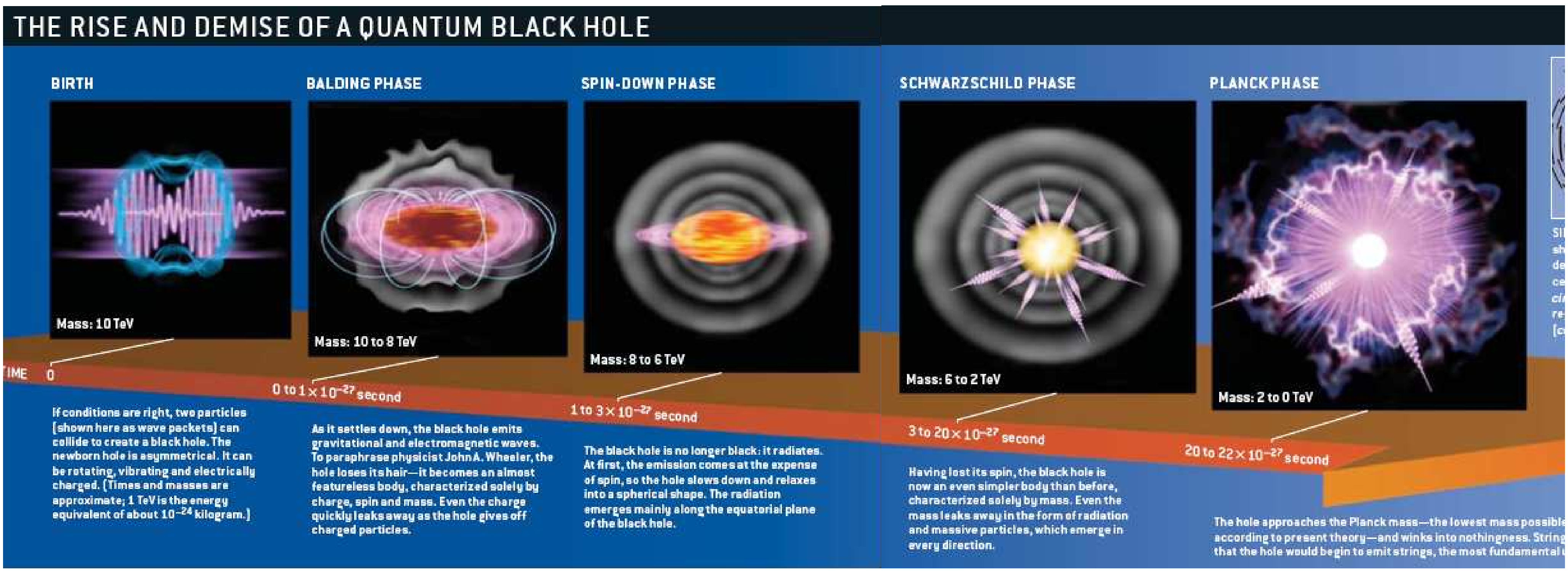
PRIMORDIAL DENSITY FLUCTUATIONS
Early in the history of our universe, space was filled with hot, dense plasma. The density varied from place to place, and in locations where the relative density was sufficiently high, the plasma could collapse into a black hole.



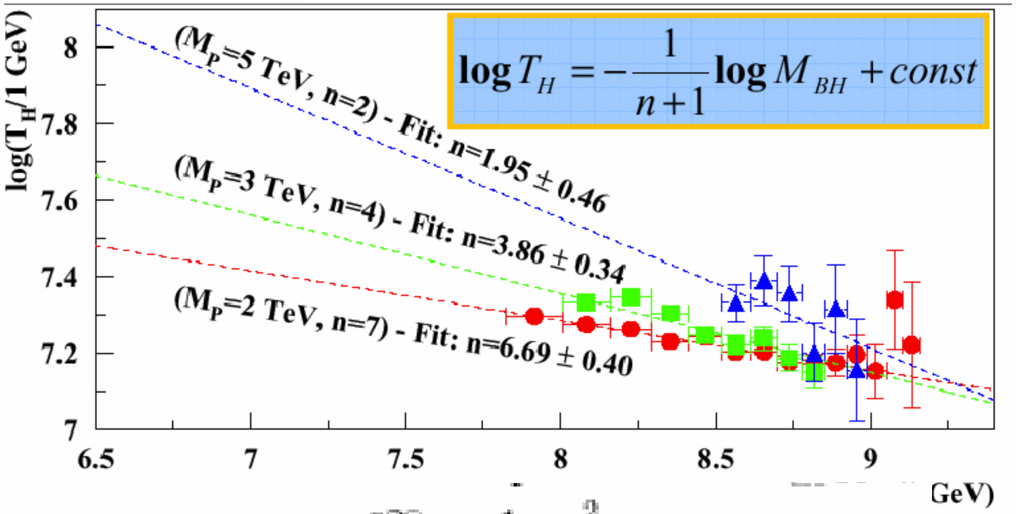
COSMIC-RAY COLLISIONS
Cosmic rays—highly energetic particles from celestial sources—could smack into Earth's atmosphere and form black holes. They would explode in a shower of radiation and secondary particles that could be detected on the ground.



PARTICLE ACCELERATOR
An accelerator such as the LHC could crash two particles together at such an energy that they would collapse into a black hole. Detectors would register the subsequent decay of the hole.



Study Black Holes at the LHC



$$\left\langle \frac{1}{E} \right\rangle = \frac{1}{T_H} \frac{\int_0^\infty dx \frac{1}{x} \frac{x^2}{e^x \pm c}}{\int_0^\infty dx \frac{x^2}{e^x \pm c}} = a/T_H,$$

- Measure the mass of the BH (reconstruct events with no missing transverse momentum)
- Measure T_H from number of Radiated jets & leptons

Determine the shape of Gravity
Extract number of EDs!

Reconstruct mass & Black body spectr. of Black Hole
⇒Direct test of the Hawking radiation law
⇒But dependence on BH decay modeling
Any clues from Quantum Gravity??

$$T_H = M_P \left[\frac{M_P}{M_{BH}} \frac{n+2}{8\Gamma\left(\frac{n+3}{2}\right)} \right]^{\frac{1}{n+1}} \frac{n+1}{4\sqrt{\pi}}$$

Producing micro-black holes will allow for the firsts tests of Quantum Gravity in the lab

LHC "Olympics"

Next thoughts:

- How can we go from the hadron collider data to the underlying theory?
- Can we map the measurements to theory phase space (e.g. SUSY)?
  Statistical techniques/Patterns? (talk of N. Arkani Ahmed last Tuesday)
- SUSY: measurements ⇔ parameters in the Langrangian
  Can we learn anything about underlying (string?) theory? Needs low scale predictions

Workshop @ CERN this summer:
Exercise discovery and how to interprete future data with pseudo data

Organising Comittee

- Ignatios Antoniadis (CERN)
- Nima Arkani-Hamed (Harvard)
- Savas Dimopoulos (Stanford)
- Gordy Kane (Michigan)
- Joe Lykken (Fermilab)
- Steve Mrenna (Fermilab)
- Gary Shiu (Wisconsin)
- Herman Verlinde (Princeton)

Summary

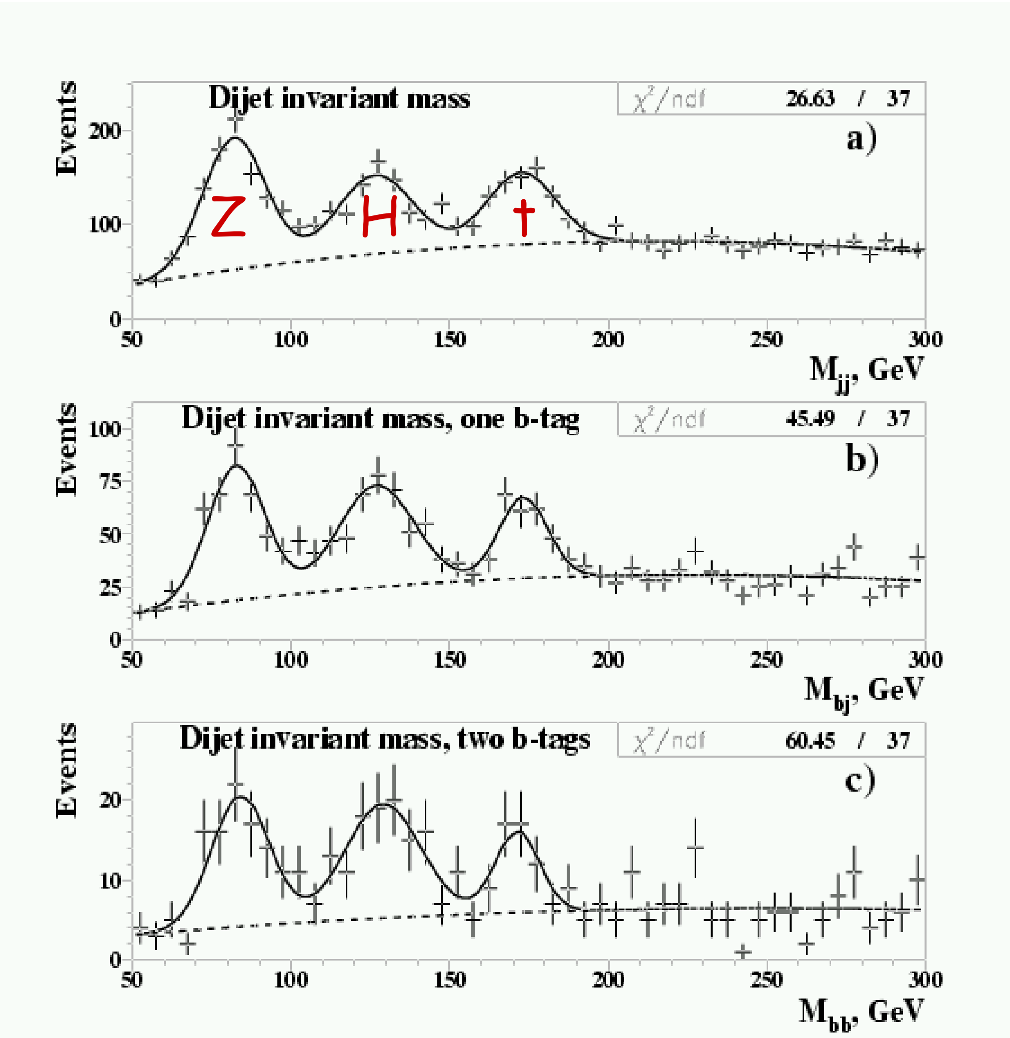
The LHC is coming!

- The LHC should be decisive on EWSB in the Standard Model
- Has Nature prepared a “pleasant” welcome to the TeV-scale

  (striking signals with limited luminosity and non-ultimate detector performance) or shall we have to sweat through years of data taking and hard work before we can claim a discovery ?
- Will the results have relevance for string theory?
  (Supersymmetry, extra dimensions, black holes, stringballs…)
- We will know more in 2008+

Next challenge: efficient and as-fast-as-possible commissioning of machine and detectors of unprecedented complexity, technology and performance

New Particle Production



Dijet inv. mass for evts w. hard γ or lepton tag

Hawking Radiation:
Democratic production of all particle quantum states

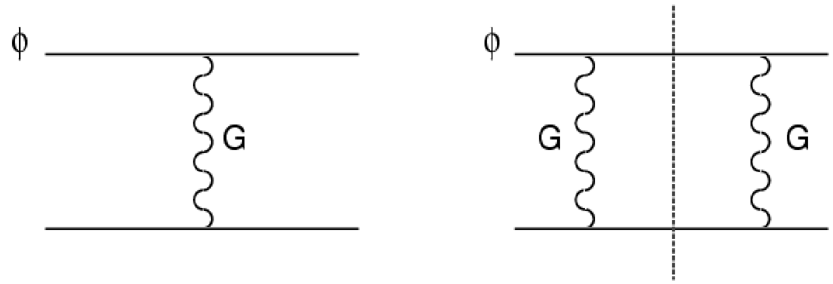
Eg. 1% of the time produce a Higgs with mass of 120 GeV
i.e. in 1 Black Hole out of 10
If 1 Black Hole produced/sec
$\Rightarrow$ 10^6 Higgses per year

Caveat:
Black Hole evaporation complicated:
- Balding phase (15-40% Energy loss)
- Hawking Radiation (50% lost)
- Planck Phase, Quantum Gravity

Will affect all these naïve estimates

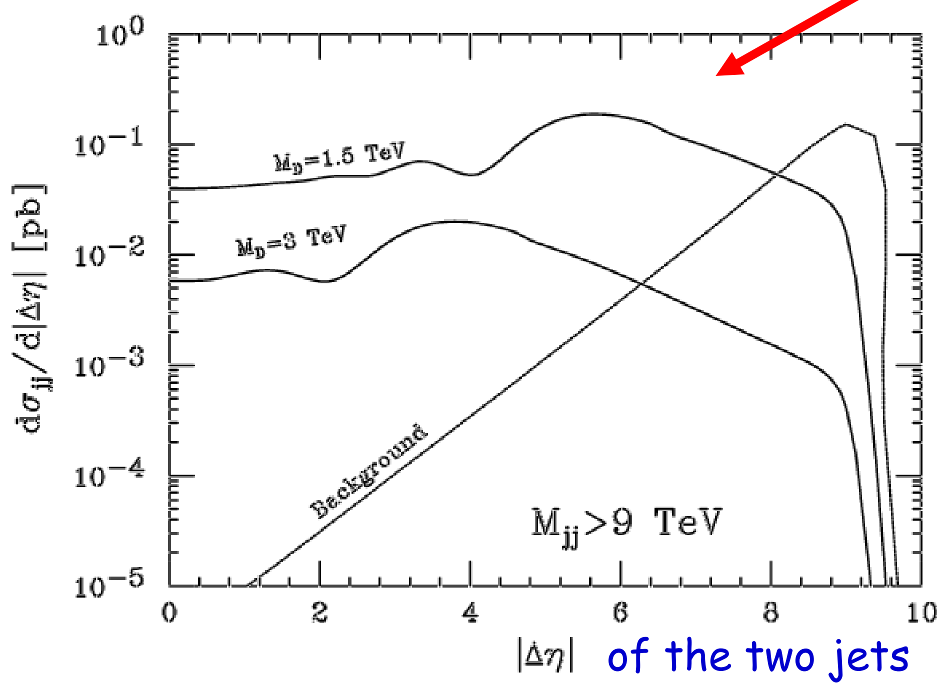
Transplanckian effects

Once you pass the Planck scale $\sqrt{s} \gg M_D$…

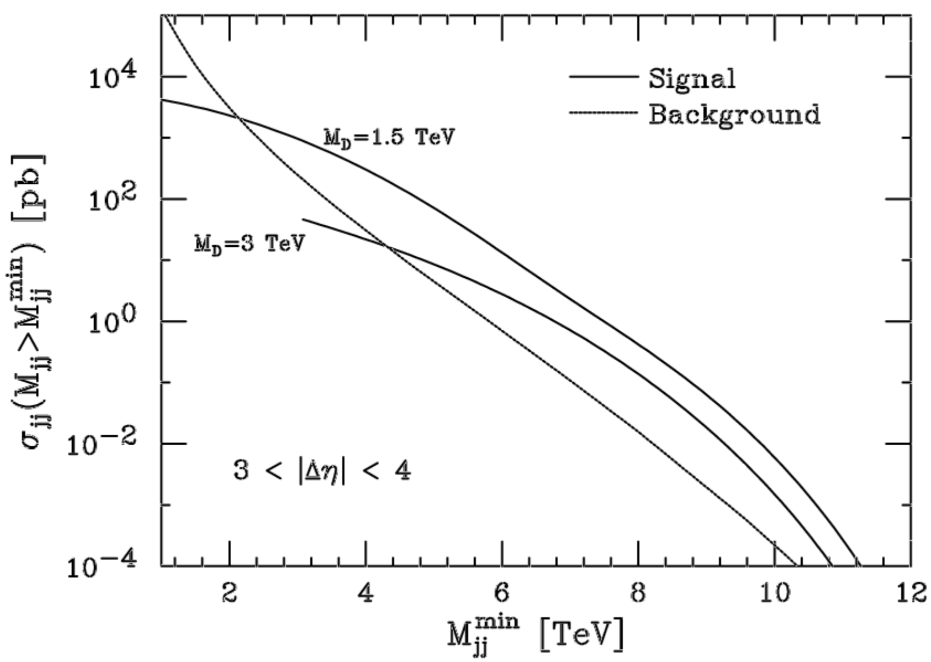


Processes with small momentum transfer e.g. :
Elastic transplanckian collisions:
Study gravity propagation in ED's
Signal: dijets with large M_{jj}

Guidice, Rattazzi, Wells



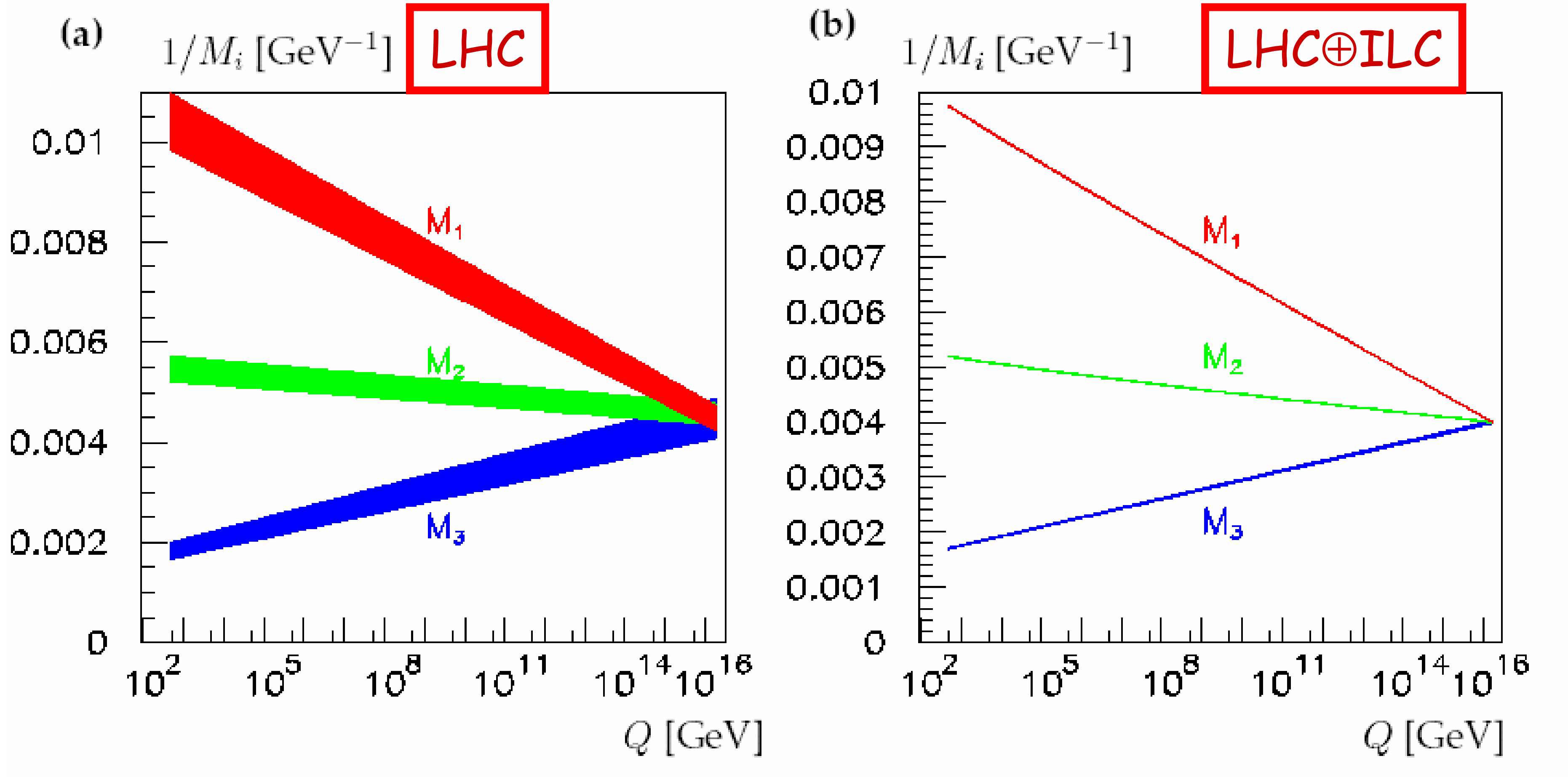
of the two jets



Extrapolation to physics at high scales

Blair, Martyn, Polesello, Porod, Zerwas

From a combination of LHC and ILC results, precise measurements of masses of SUSY particles, couplings: Evolution of gaugino mass parameters



Detectors at Start-up

❷ Which detectors the first year ?

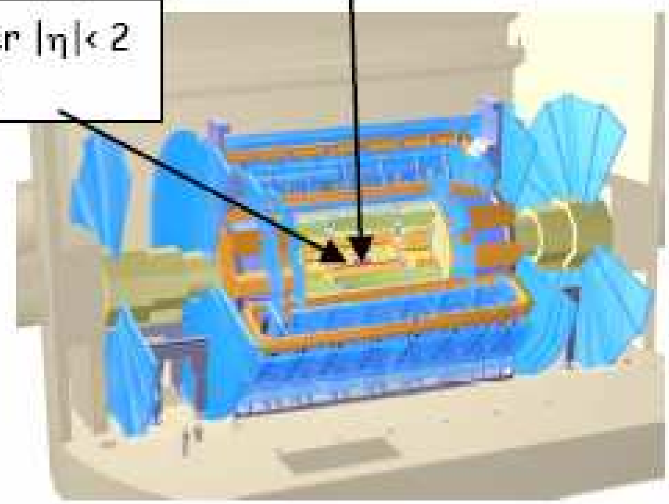
RPC over $|\eta|<1.6$ (instead of $|\eta|<2.1$)
4th layer of end-cap chambers missing

Pixels and end-cap ECAL
installed during first shut-down

2 pixel layers/disks instead of 3 ?

Detectors will be fairly complete at start-up

TRT acceptance over $|\eta|<2$ (instead of $|\eta|<2.4$)



Both experiments:
deferrals of high-level Trigger/DAQ processors
→ LVL1 output rate limited to
~ 50 kHz CMS (instead of 100 kHz)
~ 40 kHz ATLAS (instead of 75 kHz)

Impact on physics visible but acceptable
Main loss : B-physics programme strongly reduced (single μ threshold $p_T>$ 14-20 GeV)

LHC New Physics Reach Summary

Measurements at LHC (14 TeV / 100 fb^{-1})

Higgs (SM)	$\rightarrow$ 1 TeV
Higgs (Heavy/MSSM)	Problems in medium $\tan\beta$ range
squarks	2.5 TeV
sleptons	0.3-0.35 TeV
Z' (direct)	5.4 TeV
q^*	6.5 TeV
l^*	3.4 TeV
TGC (λ 95%)	0.0014
Λ compos.	35-40 TeV
ED (ADD)	9 TeV
ED (RS)	2.6/4.7 TeV (c=0.01/0.1)
ED (TeV^{-1})	6.5-8 TeV
Black Holes	$\sim$ 6-10 TeV
Transplanckian effects	$\sim$ 10 TeV

Exciting prospects!!

Compiled in 2001: Time to update for the physics TDR
New scenarios since then: little Higgs models, split SUSY, stable sleptons