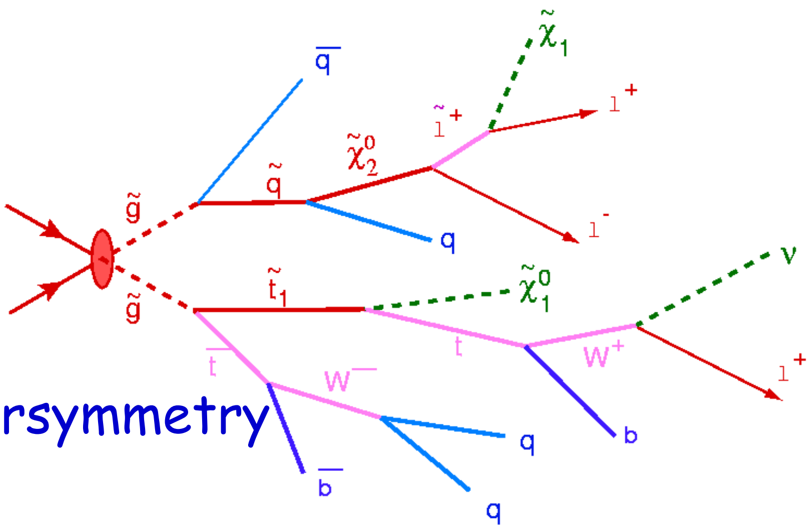
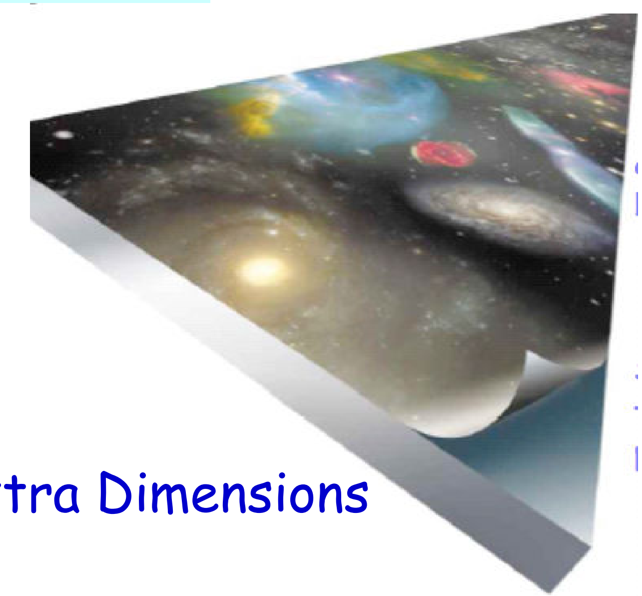
The Search for Physycs Beyond the Standard Model

CERN Summer Student Lecture I

Albert De Roeck
CERN
and University of Antwerp
and the IPPP Durham



Supersymmetry



Extra Dimensions

Contents

⇒ Lecture 1

- Introduction: Beyond the Standard Model
- Supersymmetry
- Extra Spatial Dimensions
- Black Holes
- Is the LHC dangerous place?

⇒ Lecture 2

- Other models for New Physics
- Special exotic signatures
- The task that lies ahead for the LHC
- Summary

See also lectures of G. Dvali

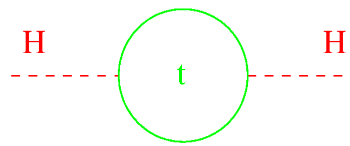
Why we believe the Standard Model is NOT the Ultimate Theory?

SM predictions confirmed by experiments (at LEP, Tevatron, SLAC, etc.) with precision $\approx 10^{-3}$ or better

So, what is wrong with it ?

- About 20 free parameters (masses of fermions and bosons, couplings
- Higgs: mass $m_H \approx 115$ GeV? Then New Physics for $\Lambda < 10^6$ GeV
- "Naturalness" problem :

  radiative corrections



  $\delta m_H^2 \sim \Lambda^2$ $\rightarrow$ diverge for large Λ

  $\rightarrow$ fine tuning!!

- "Hierarchy" problem: why $M_{EW}/M_{Planck} \sim 10^{-17}$?

\+ contribution of EW vacuum to cosmological constant ($\sim v^4$) is ~ 55 orders of magnitudes too large !

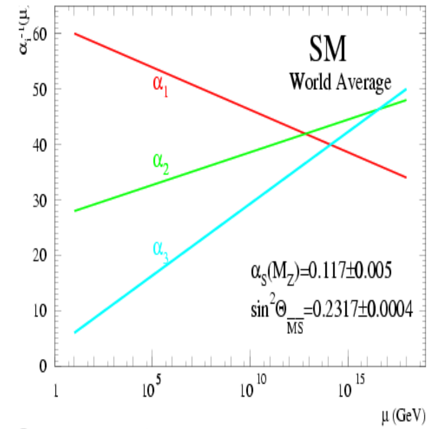
\+ flavour/family problem, coupling unification, gravity incorporation, ν masses/oscillations, … Dark Matter. Dark Energy?

Physics case for new High Energy Machines

Understand the mechanism Electroweak Symmetry Breaking

Discover physics beyond the Standard Model

Reminder: The Standard Model
- tells us how but not why
  3 flavour families? Mass spectra? Hierarchy?
- needs fine tuning of parameters to level of 10^{-30} !
- has no connection with gravity
- no unification of the forces at high energy

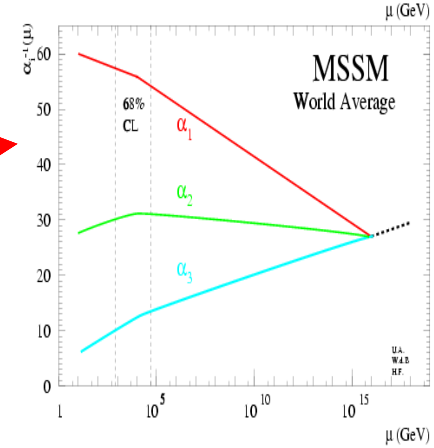


Most popular extensions these days

If a Higgs field exists:
- Supersymmetry
- Extra space dimensions

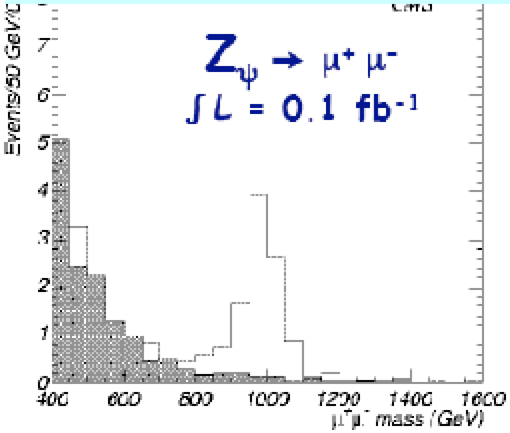
If there is no Higgs below ~ 700 GeV
- Strong electroweak symmetry breaking around 1 TeV

Other ideas: more gauge bosons/quark & lepton substructure,
Little Higgs models, Technicolor…

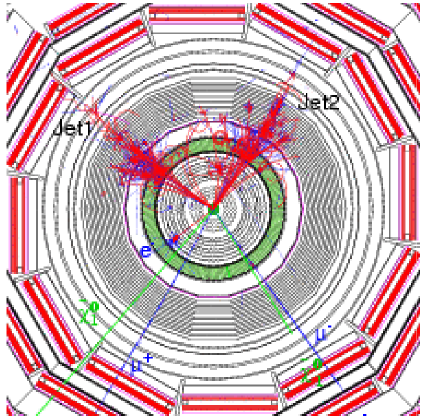


BSM Physics at the LHC: pp @ 14 TeV

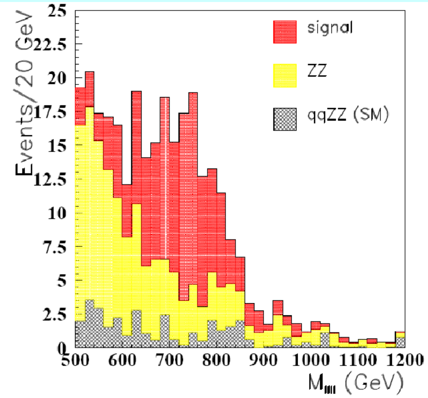
New Gauge Bosons?



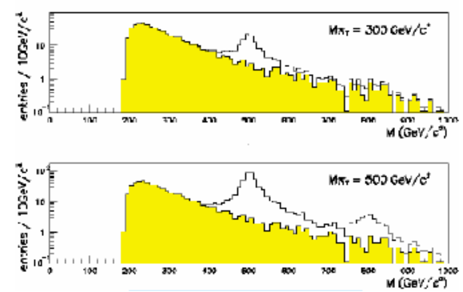
Supersymmetry



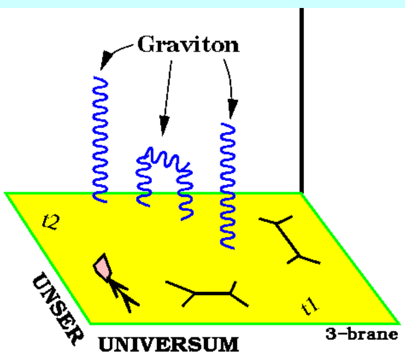
ZZ/WW resonances?



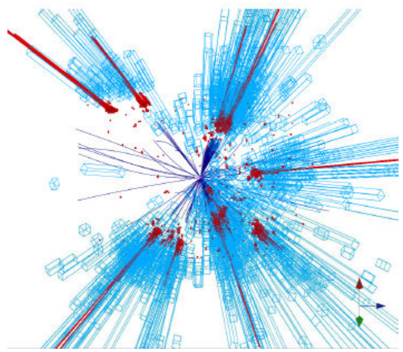
Technicolor?



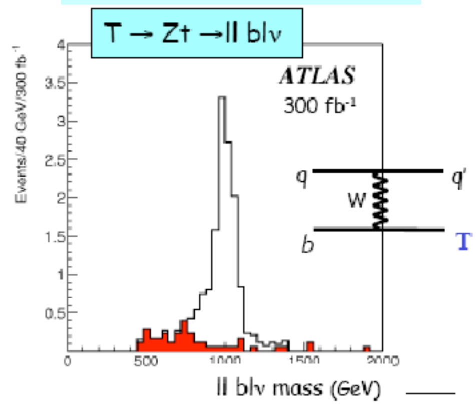
Extra Dimensions?



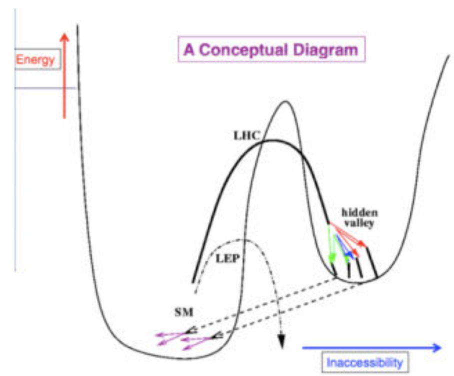
Black Holes???



Little Higgs?



Hidden Valleys?



We do not know what is out there for us…
A large variety of possible signals. We have to be ready for that

A Cellar of New Ideas

J. Hewett/Lishep09

'67	The Standard Model	a classic! aged to perfection
'77	Vin de Technicolor	better drink now
'70's	Supersymmetry: MSSM	mature, balanced, well developed - the Wino's choice
'90's	SUSY Beyond MSSM	svinters blend
'90's	CP Violating Higgs	all upfront, no finish lacks symmetry
'98	Extra Dimensions	bold, peppery, spicy uncertain terrior
'02	Little Higgs	complex structure
'03	Fat Higgs	young, still tannic needs to develop
'03	Higgsless	sleeper of the vintage what a surprise!
'04	Split Supersymmetry	finely-tuned
'05	Twin Higgs	double the taste

J. Hewett

We have a lot of signatures to look for…

Last Minute Model Building

Anything Goes!

- Non-Communtative Geometries
- Return of the 4th Generation
- Hidden Valleys
- Quirks - Macroscopic Strings
- Lee-Wick Field Theories
- Unparticle Physics
- .....

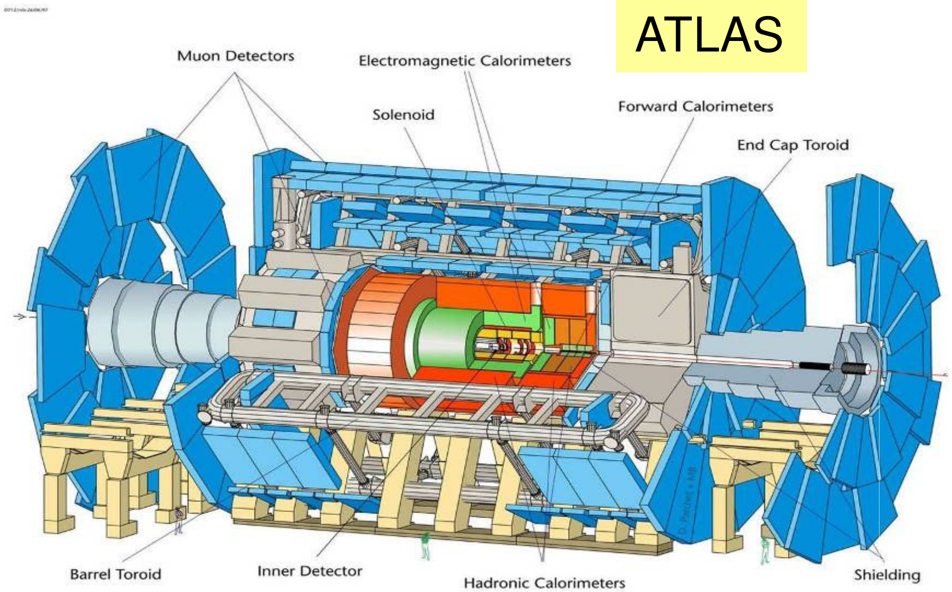
It is really high time we get the LHC data!

What can we expect?
Ask an (un)baised theorist:

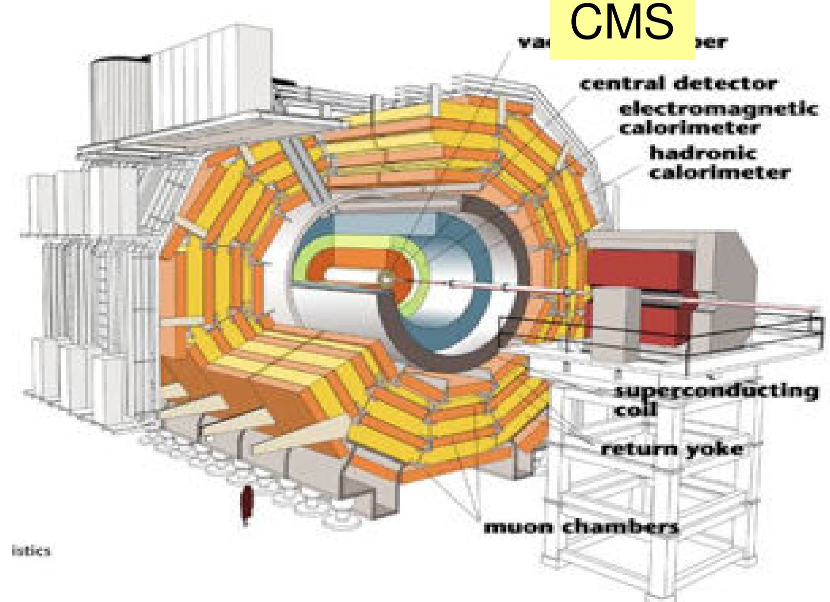
Murayama LP03

The Four Main LHC Experiments

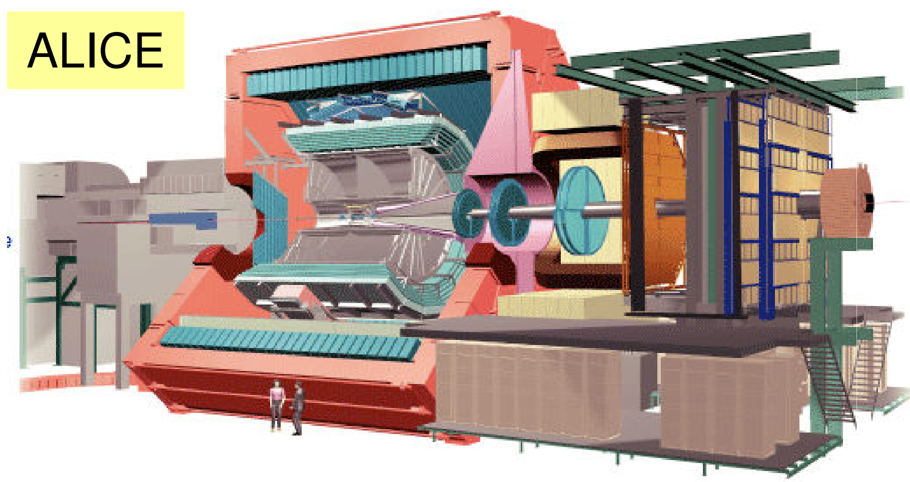
ATLAS



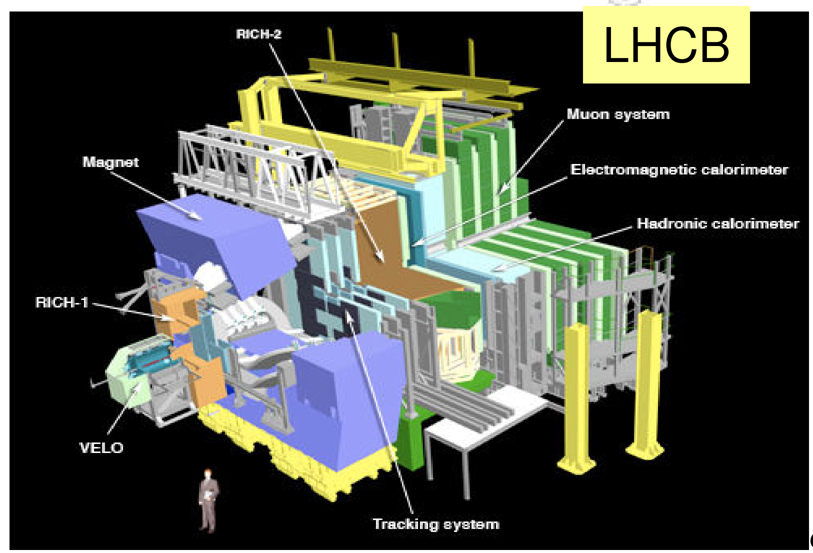
CMS



ALICE

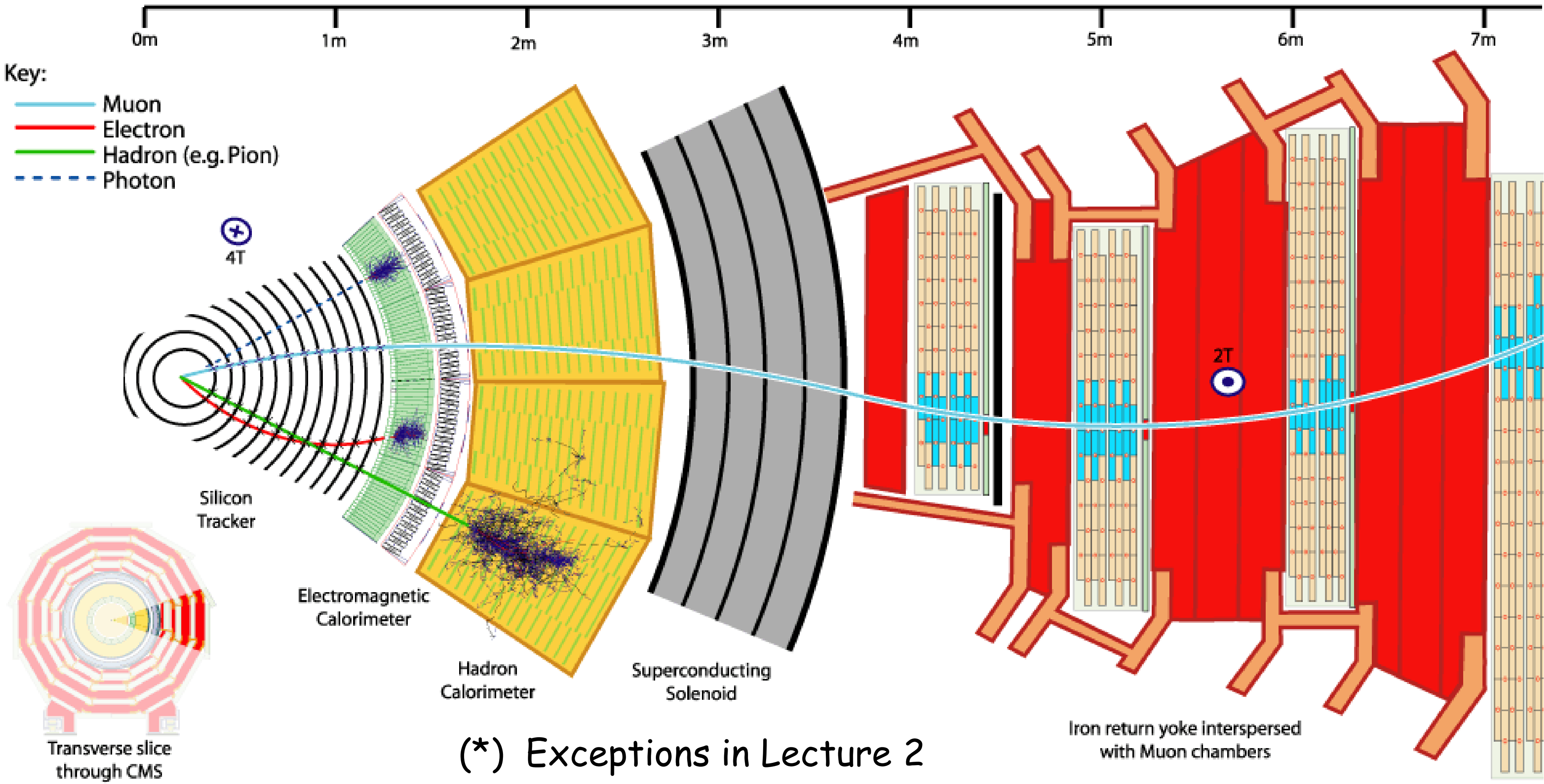


LHCB



Particles in the Detector

New physics particles will decay in 'known' particles (*)



(*) Exceptions in Lecture 2

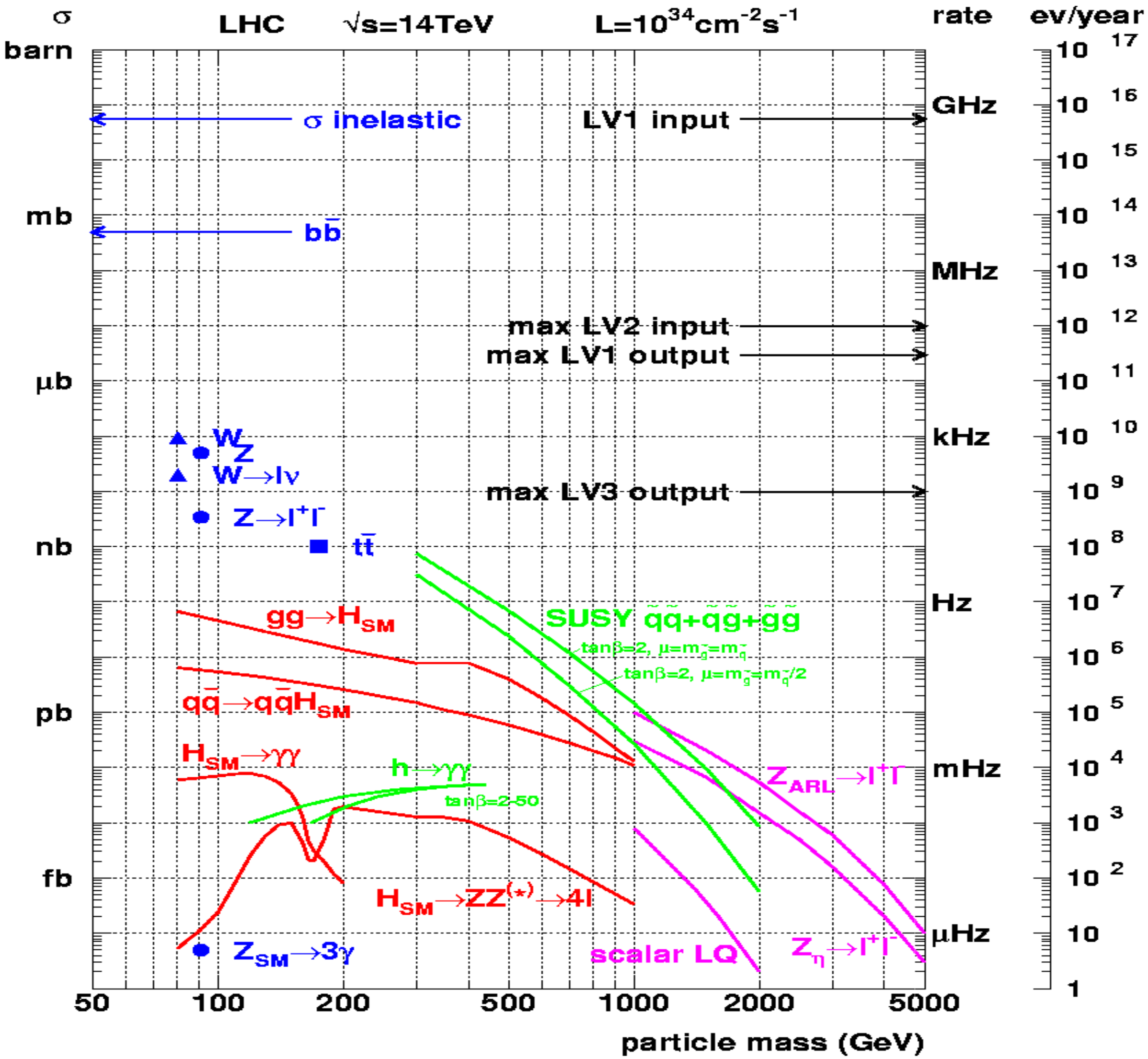
Experimental New Physics Signatures

- Many channels in New Physics : Typical signals
  - Di-leptons resonance/non-resonance, like sign/oposite sign
  - Leptons + MET (=Missing transverse momentum
  - Photons + MET
  - Multi-jets (2 $\rightarrow$ ~10)
  - Mono/Multi-jets +MET (few 10 $\rightarrow$ few 100 GeV)
  - Multi jets + leptons + MET…
  - B/τ final states…
- Also: new unusual signatures
  - Large displaced vertices
  - Heavy ionizing particles (heavy stable charged p
  - Non-pointing photons
  - Special showers in the calorimeters
  - Unexpected jet structures
  - Very short tracks (stubs)…

Lecture 1

Lecture 2

Cross Sections at the LHC

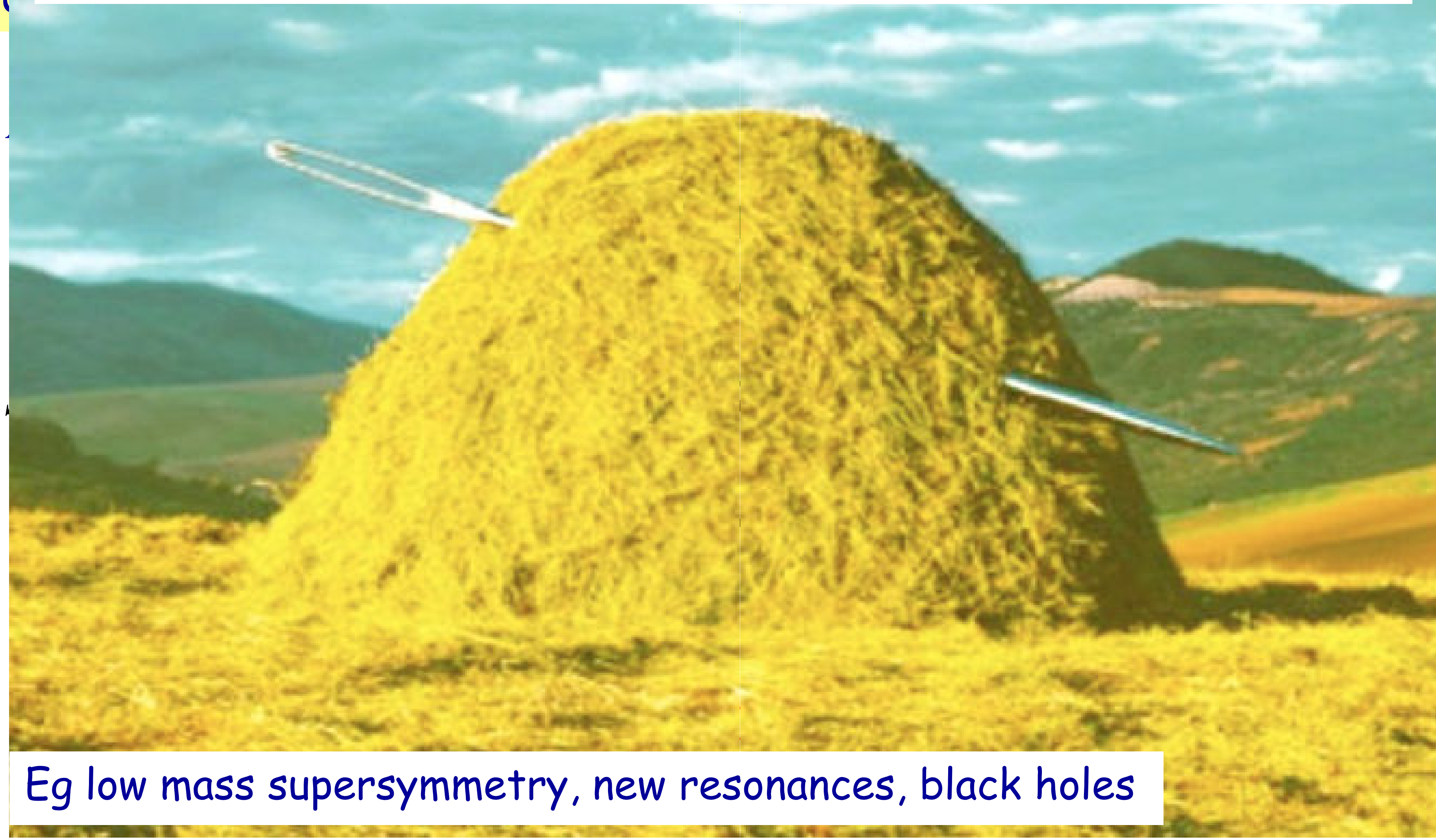


"Well known" processes, don't need to keep all of them …

New Physics!!
This we want to keep!!

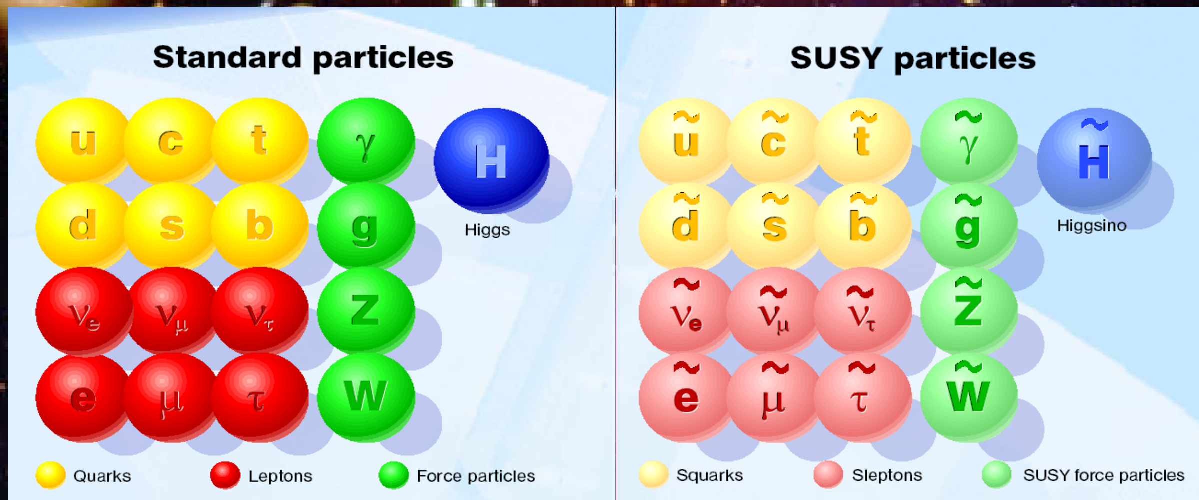
Finding New Physics at the LHC

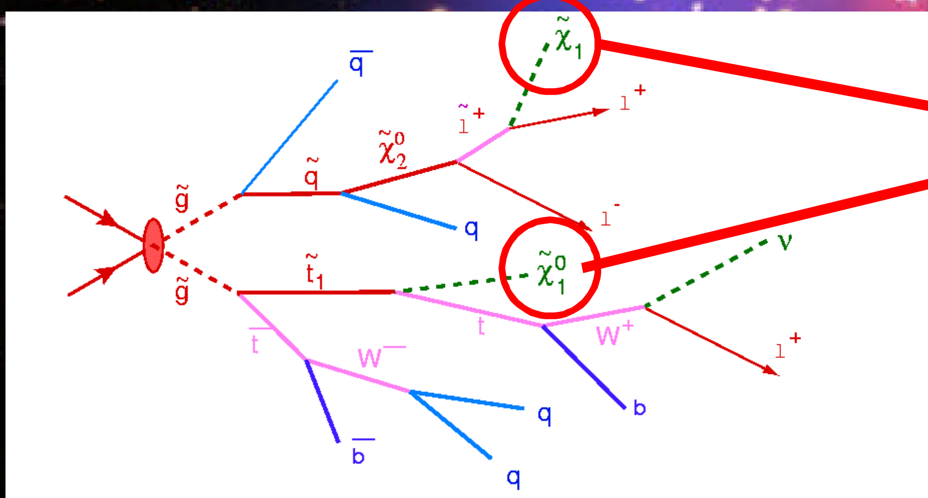
However: sometimes the expected signal is more like this



Eg low mass supersymmetry, new resonances, black holes

Supersymmetry: a new symmetry in Nature

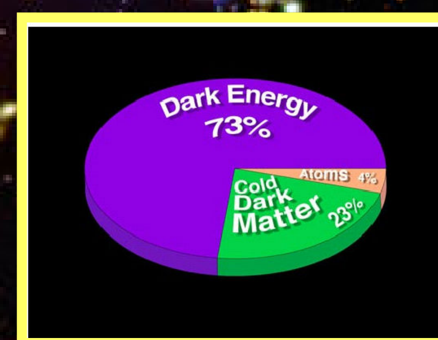




Candidate particles for Dark Matter

⇒ Produce Dark Matter in the lab

SUSY particle production at the LHC



Why weak-scale SUSY ?

- stabilises the EW scale: $|m_F - m_B| < O(1\ \text{TeV})$
- predicts a light Higgs $m_h < 130$ GeV
- predicts gauge unification
- accomodates heavy top quark
- dark matter candidate: neutralino, sneutrino, gravitino, ...
- consistent with Electro-Weak precision data

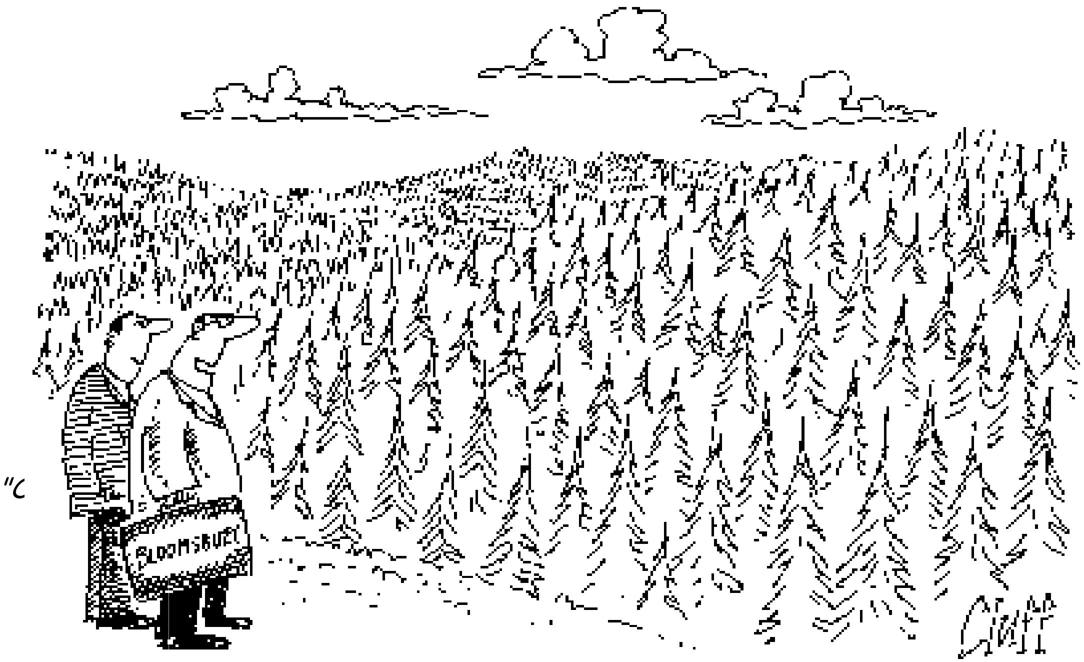
Discovering SUSY – A revolution in particle physics!!

- the outcome of LHC is far more important than any other in the past
- all future projects: ILC, superB, super..., depend on LHC discoveries
- huge responsibility to provide quick and reliable answers

Supersymmetry

A VERY popular benchmark…

More than 8000 papers since 1990 (Kosower)



"One day all these trees will be SUSY phenomenology papers"

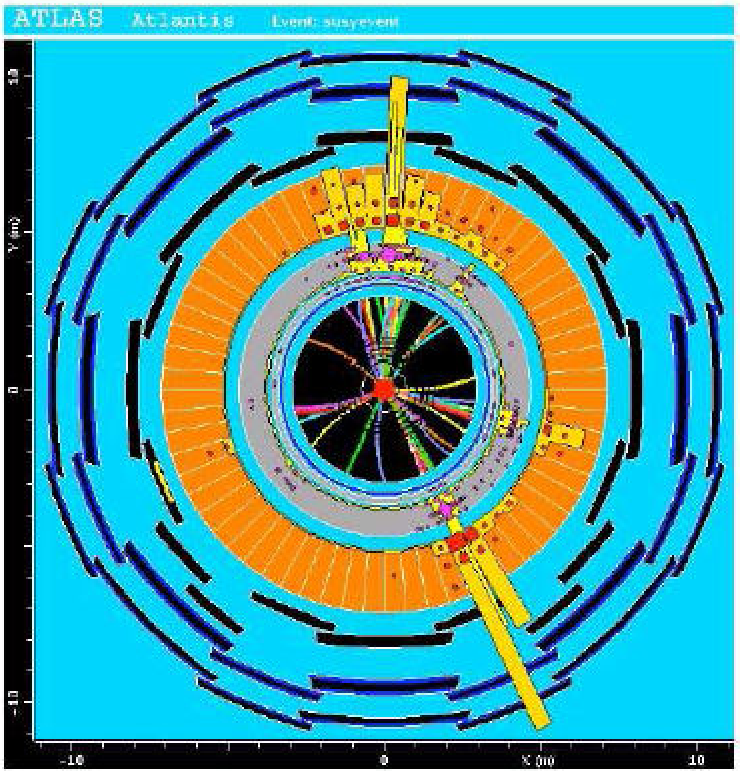
Considered as a benchmark for a large class of new physics models

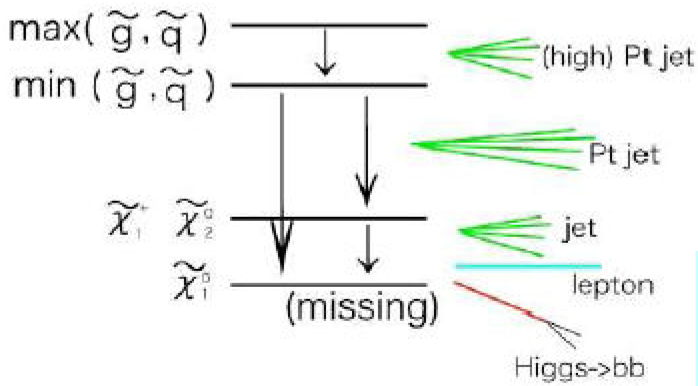
Early Supersymmetry?

SUSY could be at the rendez-vous very early on!

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

$10 fb^{-1}$





event topologies of SUSY

$\not{E}_T$ + High P_T jets + multi leptons / b-jets / τ-jets

For low mass SUSY we get O(10,000) events/year even at startup

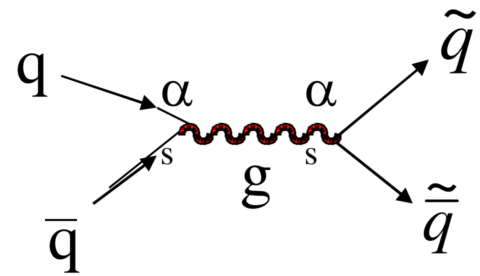
Main signal: lots of activity (jets, leptons, taus, missing E_T)

Needs an excellent understanding of the detector and SM backgrounds

Note: establishing that the new signal is SUSY will be more difficult!

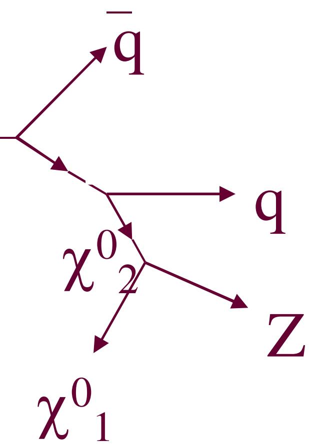
Supersymmetric Particles

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



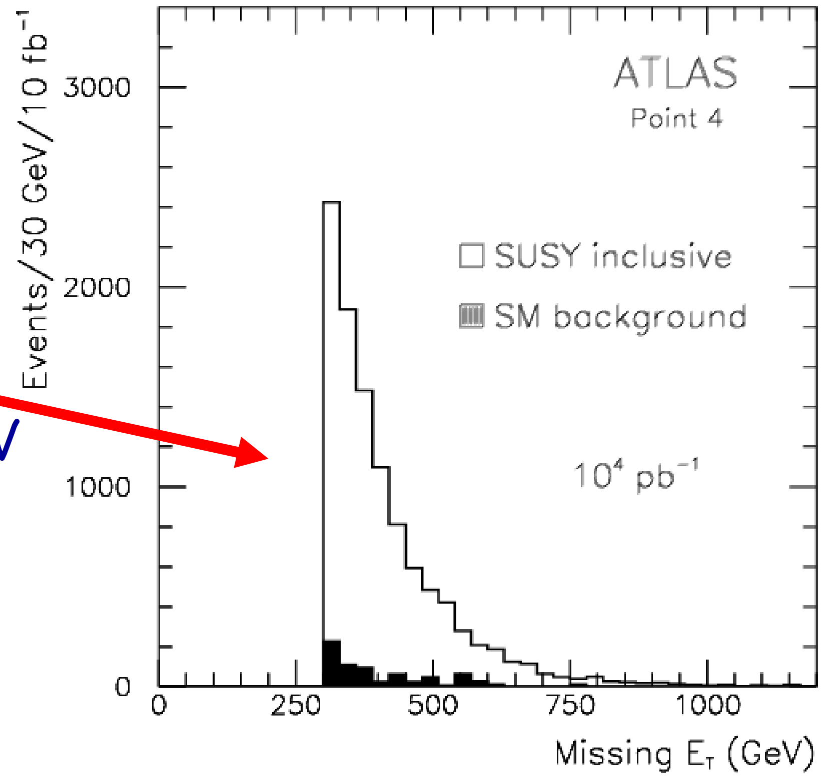
Will be easy (in most cases) to detect: many jets and missing energy from the lightest stable SUSY particle (LSP)

gluino



LSP

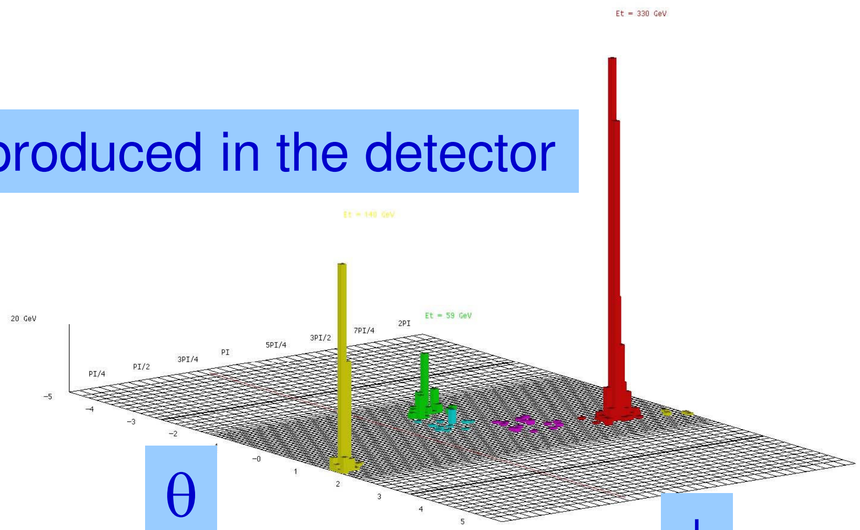
E.G. 900 GeV squarks
E_t^{miss} > 300 GeV
+ 4 jets



E_t^{miss} = missing transverse energy

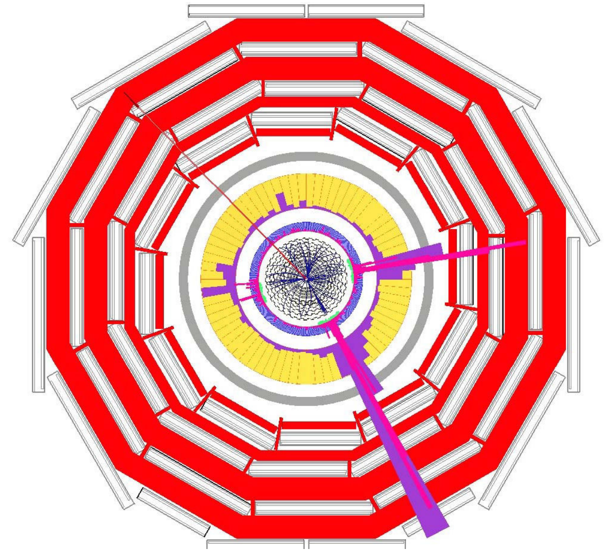
Hunting for SUSY

Energy produced in the detector



θ

φ

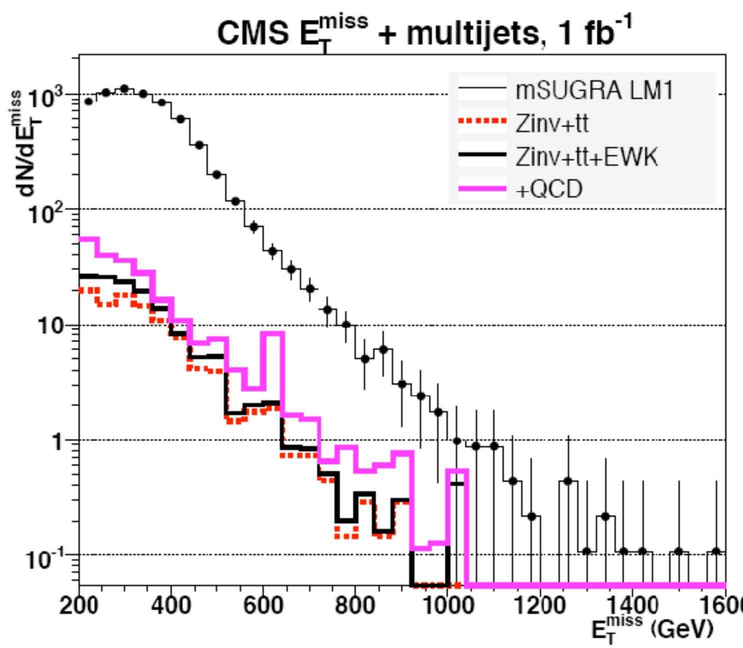


Missing E_T is a difficult measurement for the experiments

Distribution of the "Missing Transverse Momentum (Energy) "⇒

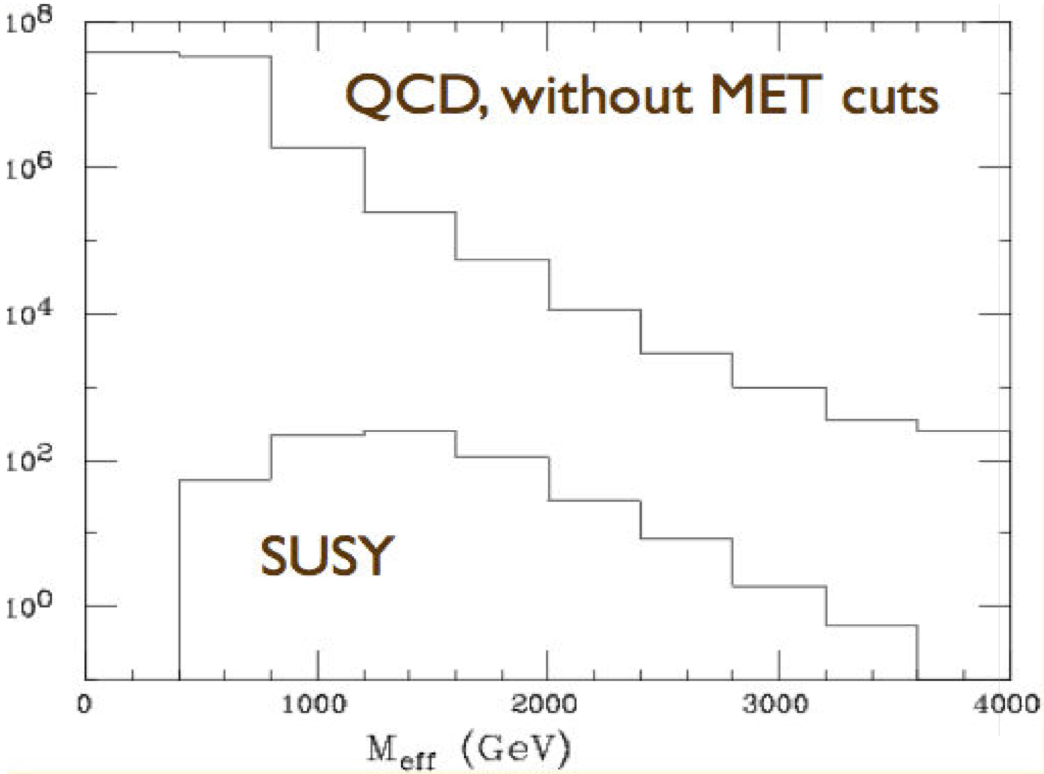
Large signal over background in E_T^{miss} for the a chosen "easy" SUSY point (LM1)

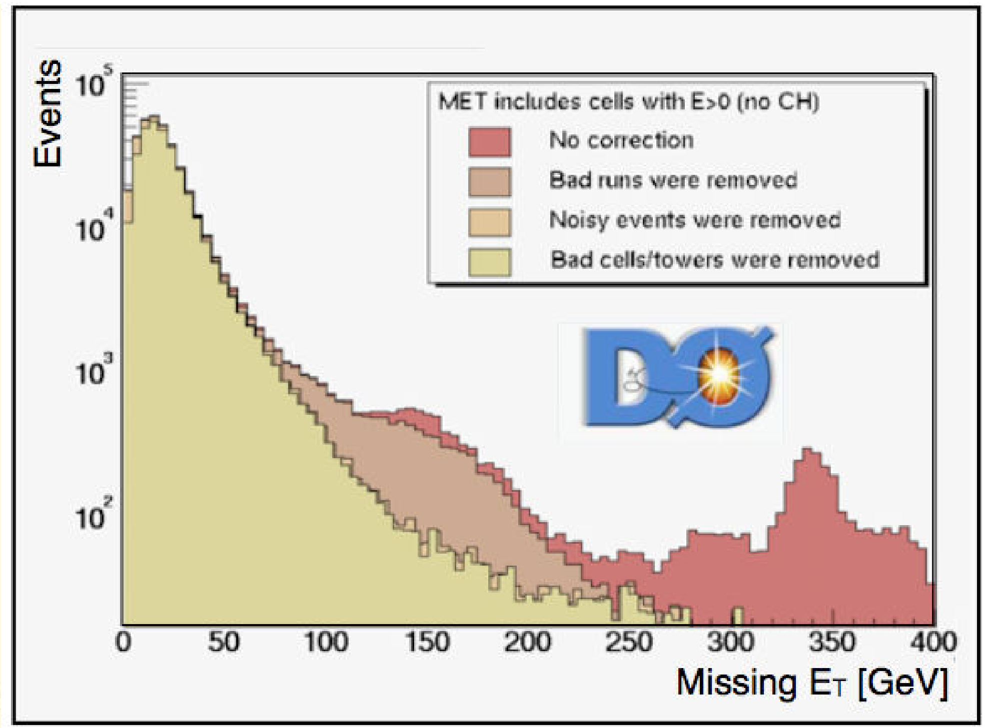
Can we thrust our background estimate?



Missing Transverse Energy

A difficult quantity to measure!

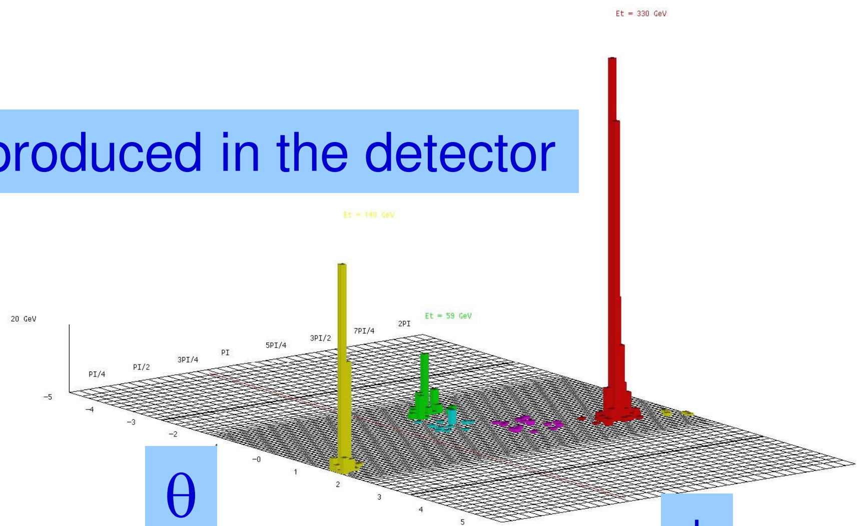




Tevatron experience!
Clean up cuts: cosmics, beam halo, dead channels, QCD background

Hunting for SUSY

Energy produced in the detector



θ

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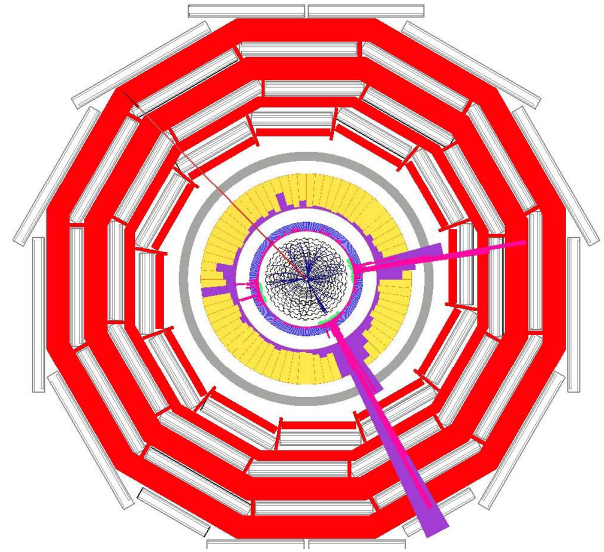
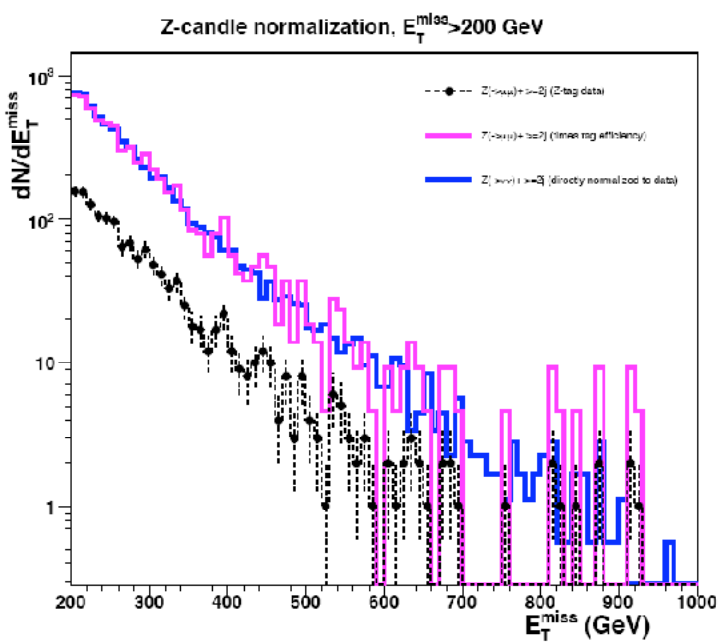


Missing E_T is a difficult measurement for the experiments

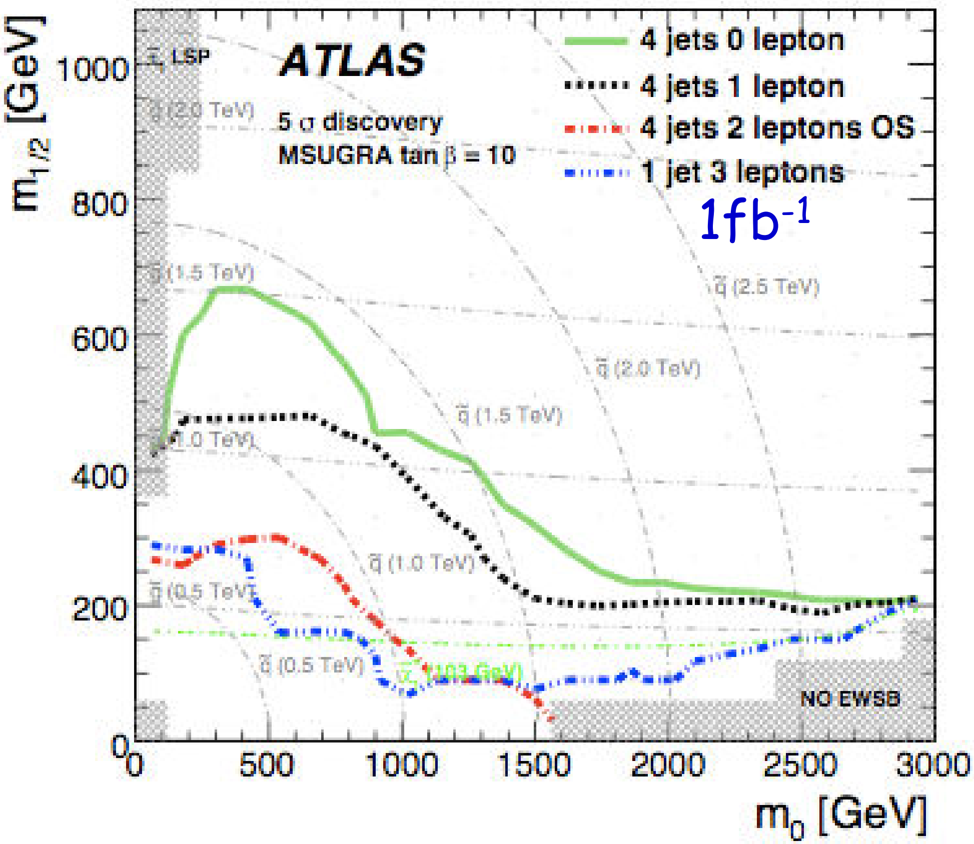


⇒ Missing E_T from the process $Z \to \nu\nu$ (+jets)

- Determine this background by the measurable process $Z \to \mu\mu$ (+ jets)
- Calculate the expected $Z \to \nu\nu$ (+jets)

  Still see more events in data? You are in business!!
- More checks $W \to \mu\nu$, $e\nu$, photon + jets, kinematic variables etc etc…

Early SUSY Reach



minimal Supergravity (mSUGRA)

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

Low mass SUSY(m_{gluino}~500 GeV) will show an excess for O(100) pb^{-1}
⇒ Time for discovery will be determined by:
- Time needed to understand the detector performance, Etmiss tails,
- Time needed collect SM control samples such as W+jets, Z+jets, top..

Where do we expect SUSY?

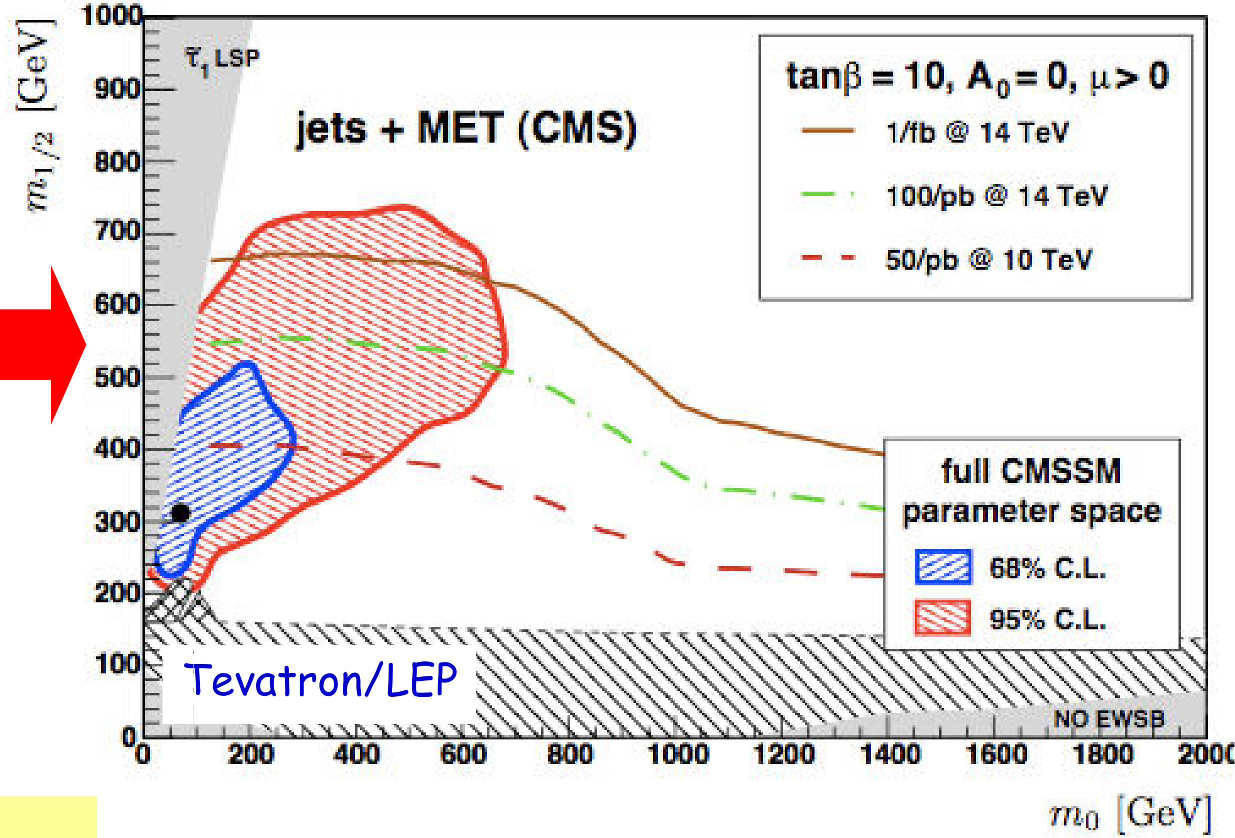
O. Buchmuller et al
arXiv:0808.4128

OB, R.Cavanaugh, A.De Roeck,
J.R.Ellis, H.~Flaecher, S.~Heineme
G.Isidori, K.A.Olive, P.Paradisi,
F.J.Ronga, G.Weiglein

Precision measurements
Heavy flavour observables

Simultaneous fit of CMSSM parameters m_0, $m_{1/2}$, A_0, tan (μ>0) to more than 30 collide and cosmology data (e.g. M, M_{top}, g-2, BR(B→Xγ), relic density)

"LHC Weather Forecast"



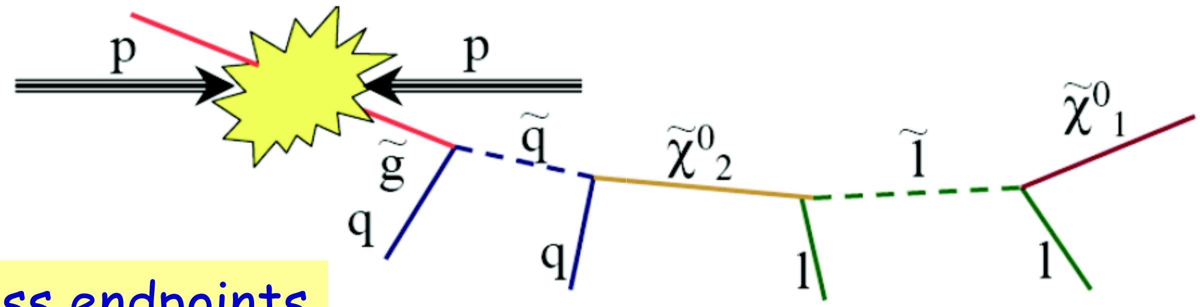
"CMSSM fit clearly favors low-mass SUSY - Evidence that a signal might show up very early?!"

"Predict" on the basis of present data what the preferred region for SUSY is (in constrained MSSM SUSY)

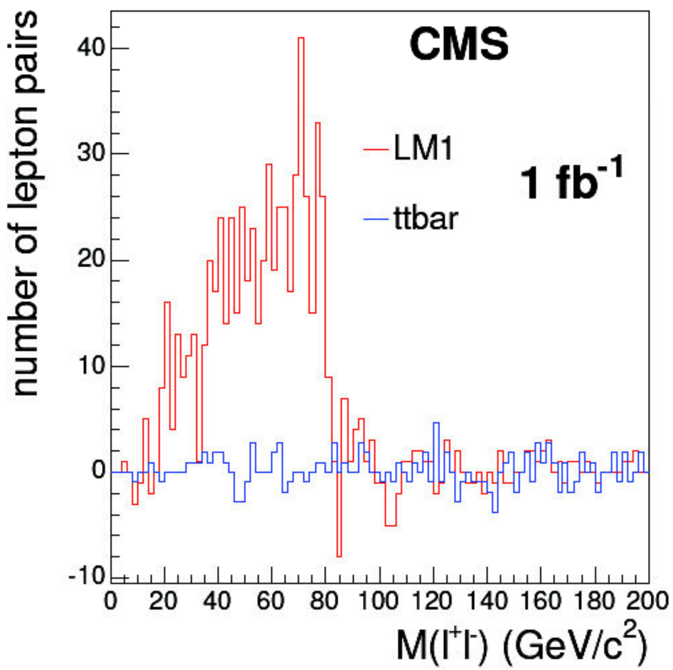
Many other groups attempt to make similar predictions

Sparticle Mass Reconstruction

First Mass Clues (dileptons)



Invariant mass endpoints

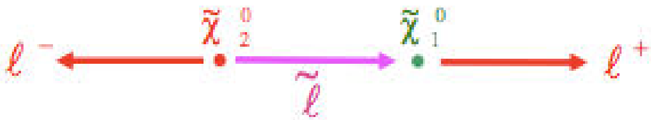


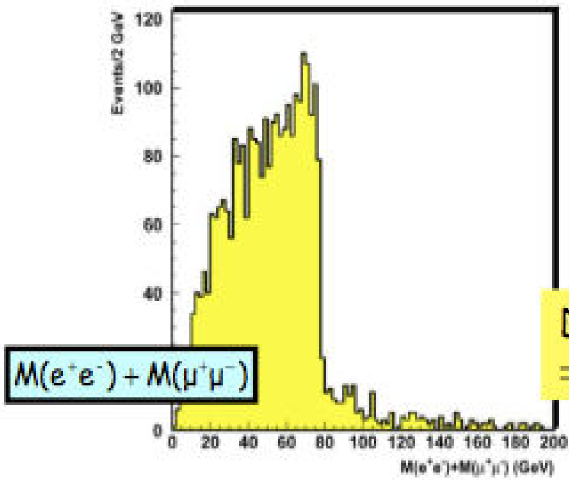
- $M_{\ell\ell}^{max} = M(\tilde{\chi}_2^0)\sqrt{1 - \frac{M^2(\tilde{\ell}_R)}{M^2(\tilde{\chi}_2^0)}}\sqrt{1 - \frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{\ell}_R)}}$
- $M_{\ell\ell}^{max}$(meas)= 80.42 ± 0.48 GeV/c^2, *cfr* with
- expected $M_{\ell\ell}^{max}$= 81 GeV/c^2 [given $M(\tilde{\chi}_1^0)$ = 95, $M(\tilde{\chi}_2^0)$= 180 and $M(\tilde{\ell}_R)$ = 119 GeV/c^2]

Sparticle Detection & Reconstruction

Mass precision for a favorable benchmark point at the LHC
LCC1~ SPS1a~ point B′ with 100 fb^{-1}

m_0=100 GeV
$m_{1/2}$= 250 GeV
A_0=-100
$\tan\beta$ = 10
sign(μ)=+



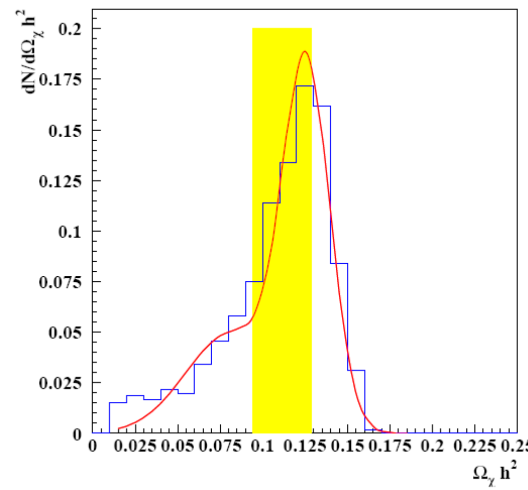


D. Miller et al
⇒Use shapes

hep-ph/0508198

GeV	LHC
$\Delta m_{\tilde{\chi}^0_1}$	4.8
$\Delta m_{\tilde{\chi}^0_2}$	4.7
$\Delta m_{\tilde{\chi}^0_4}$	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

Lightest neutralino → Dark Matter?
Fit SUSY model parameters to the measured SUSY particle masses to extract $\Omega_\chi h^2$ ⇒ O(10%) for LCC1



SUSY Program for an Experimentalist

- Understand the detector and the Standard Model Backgrounds
- Establish an excess ⇒ Discover a signal compatible with supersymmetry
- Measure sparticle masses
- Measure sparticle production cross sections, branching ratios, couplings
- Look for more difficult sparticle signatures hidden in the data
- Is it really SUSY? Check eg. the spin of the new particles. Compatible with present/future data on precision measurements (LHCb, B-fact…)
- Turn the pole mass measurements into MSSM Lagrangian parameters of the model
- Map the measurements to the SUSY space to select possible underlying theory at the high scale and SUSY breaking mechanism (Eg. Nature May06, "theorists try to guess what the theory is from pseudo-data")

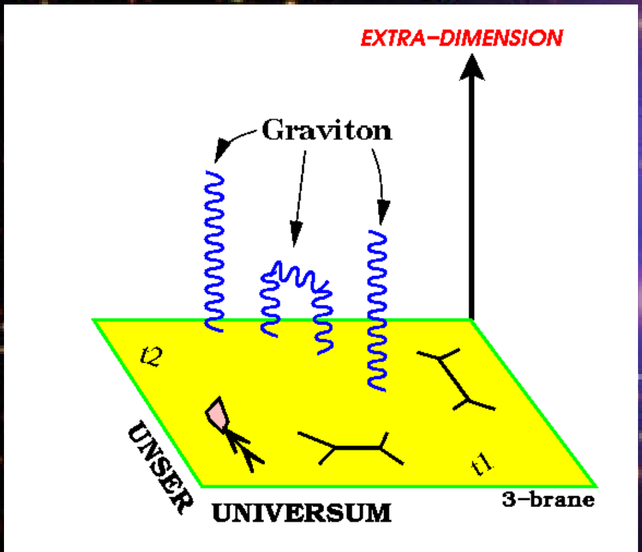
Even for an early discovery it will take years to complete such a program

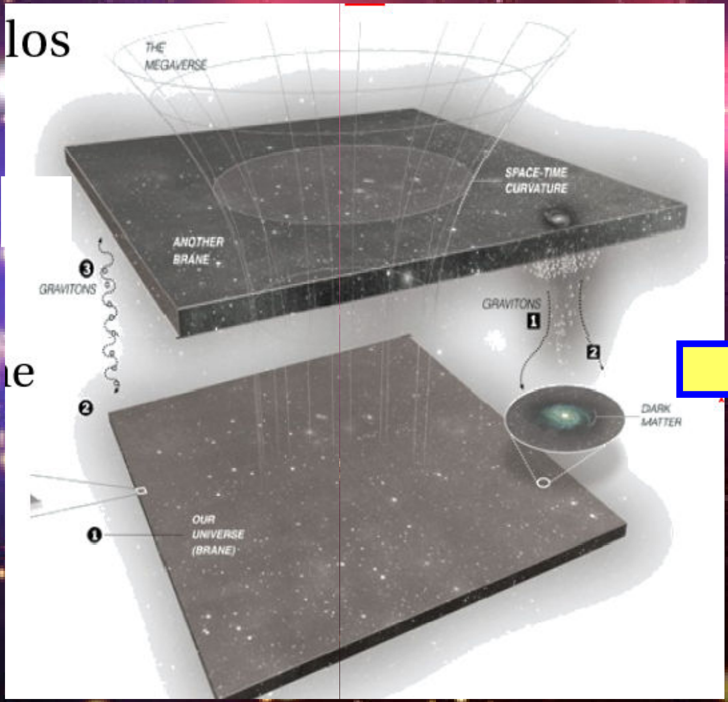
Extra Space Dimensions

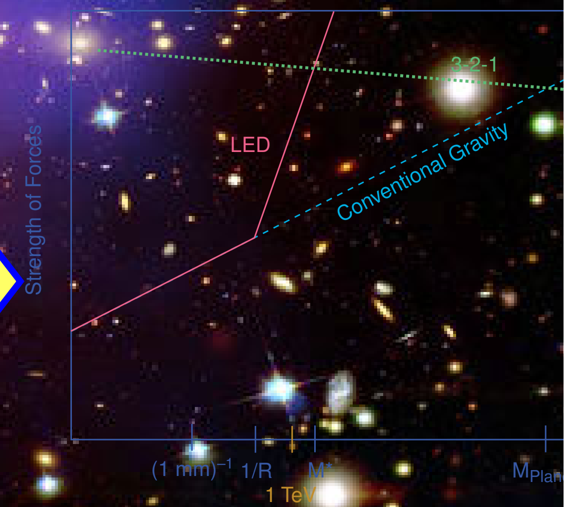
Problem:

$$m_{EW} = \frac{1}{(G_F \cdot \sqrt{2})^{\frac{1}{2}}} = 246\ \text{GeV}$$

$$M_{Pl} = \frac{1}{\sqrt{G_N}} = 1.2 \cdot 10^{19}\ \text{GeV}$$







The Gravity force becomes strong!

Models with Extra Dimensions

Large Extra Dimensions

Planck scale (M_D) ~ TeV

Size: » TeV^{-1}; SM-particles on brane; gravity in bulk

KK-towers (small spacing); KK-exchange; graviton prod.

Signature: e.g. x-section deviations; jet+$E_{T,miss}$ ....

Warped Extra Dimensions

5-dimensional spacetime with warped geometry

Graviton KK-modes (large spacing); graviton resonances

Signature: e.g. resonance in ee, μμ, γγ-mass distributions ...

TeV-Scale Extra Dimensions

look-like SUSY

SM particles allowed to propagate in ED of size TeV^{-1}

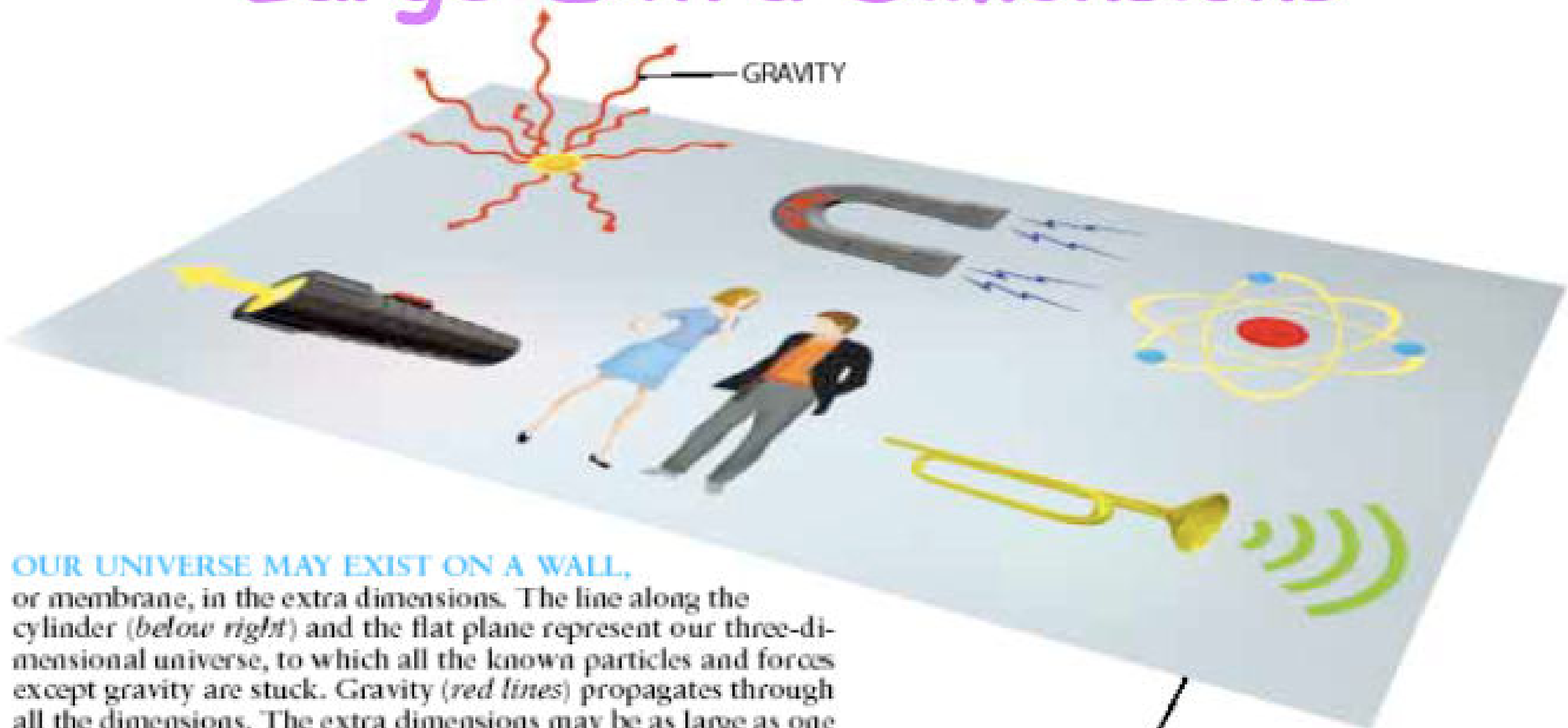
[scenarios: gauge fields only (nUED) or all SM particles (UED)]

nUED : KK excitations of gauge bosons

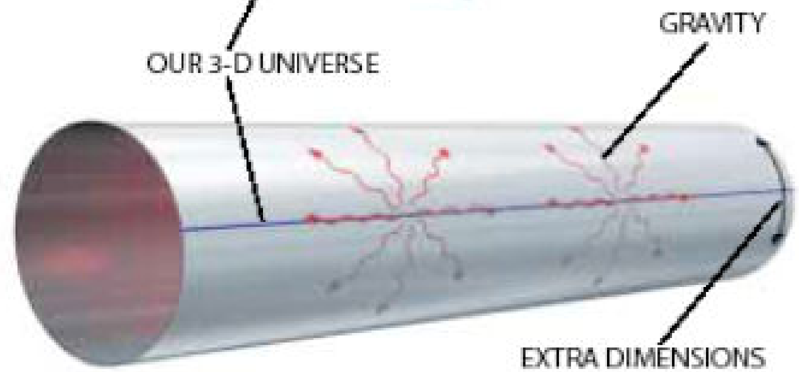
UED : KK number conservation; KK states pair produced (at tree-level) ...

Signature: e.g. Z'/W' resonances, dijets+$E_{T,miss}$, heavy stable quarks/gluons...

Large Extra Dimensions



OUR UNIVERSE MAY EXIST ON A WALL, or membrane, in the extra dimensions. The line along the cylinder (*below right*) and the flat plane represent our three-dimensional universe, to which all the known particles and forces except gravity are stuck. Gravity (*red lines*) propagates through all the dimensions. The extra dimensions may be as large as one millimeter without violating any existing observations.

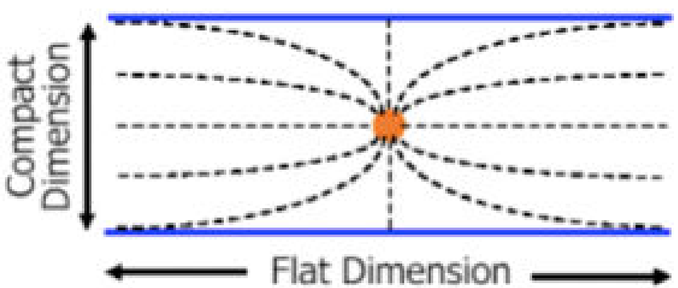


Model of Arkani-Hamed, Dvali, Dimopoulos: Standard Model particles are localized on a 3-D brane. Gravity propagates inside the bulk (a more dimensional space)

Large Extra Dimensions

- Model of Arkani-Hamed, Dvali, Dimopoulos:
  - World at 4 + n dimensions. Only the gravitons may propagate in extra dimensions. Gravity appears to be diluted.

$$V(r) = \frac{1}{M_{Pl}^2}\frac{m_1 m_2}{r} \rightarrow \frac{1}{\left(M_{Pl}^{[3+n]}\right)^{n+2}}\frac{m_1 m_2}{r^{n+1}}$$



$$V(r) \propto \frac{1}{\left(M_{Pl}^{[3+n]}\right)^{n+2}}\frac{m_1 m_2}{R^n r} \text{ for } r >> R$$

The Newton's Law is verified up to distances ~0.2 mm. Extra dimensions must be smaller than 0.2 mm and compactified.

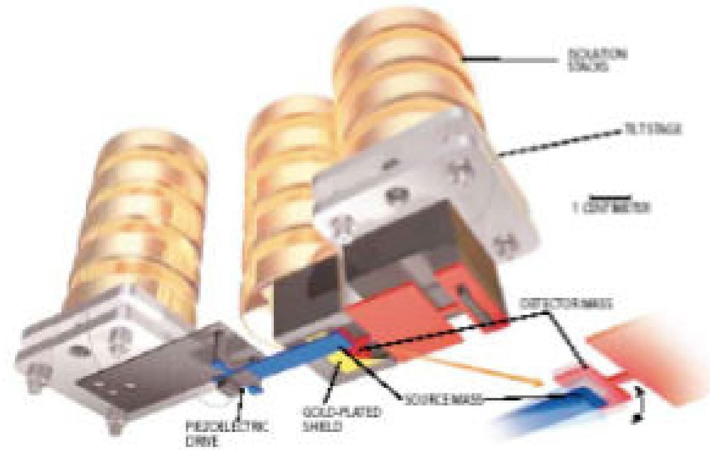
The real Planck mass $M_D = M_{PL}^{[n+4]}$:

$$(M_D)^{(2+n)} = (M_{PL}^{[4]})^2 R^n$$

If M_D ~ 1 TeV (= no more hierarchy problem):

$$R = \frac{1}{2\sqrt{\pi} M_D}\left(\frac{M_{Pl}}{M_D}\right)^{2/n} \propto \begin{cases} 8\times 10^{12} m, & n=1 \\ 0.7\, mm, & n=2 \\ 3\, nm, & n=3 \\ 6\times 10^{-12} m, & n=4 \end{cases}$$

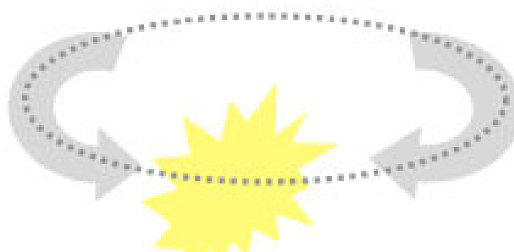
How to detect these extra dimensions?



Astrophysics : Study of the sky activity

Gravitation :Test of the Newton's Law

Particle Physics : Search for their effects on reactions produced in colliders



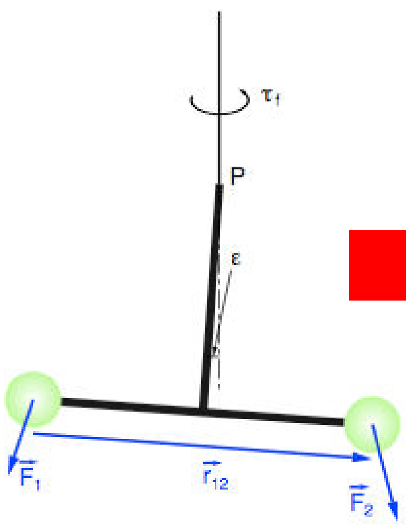
LHC!

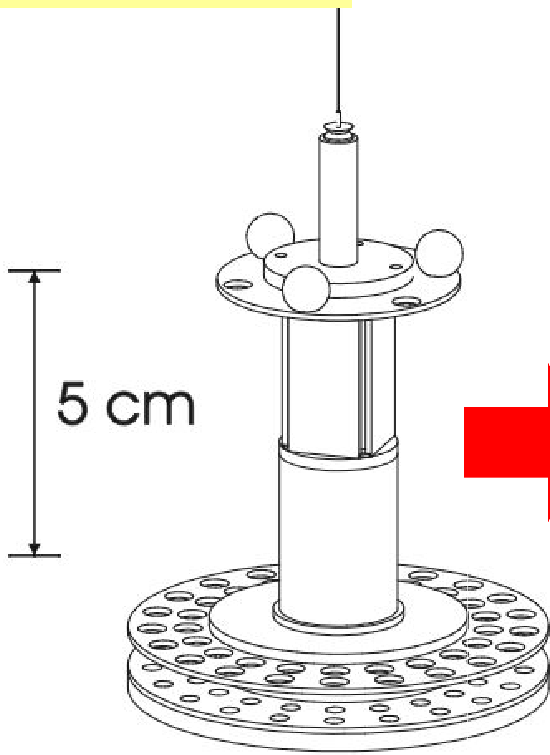
Gravity Experiments

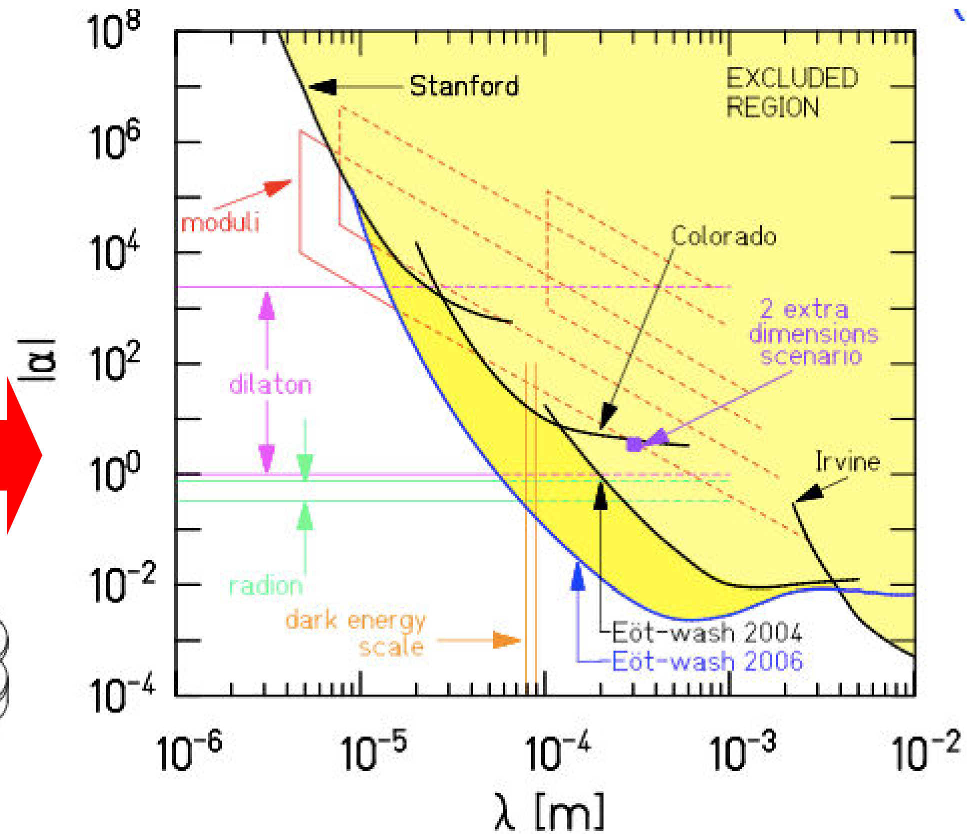
Measure the force of gravity at sub-milimeter distances with sophisticated torsion experiment

$$V(r) = -G\,\frac{m_1 m_2}{r}\left(1+\alpha e^{-r/\lambda}\right)$$

Adelberger et al. '06







$R_\perp \lesssim 45\ \mu m$ at 95% CL

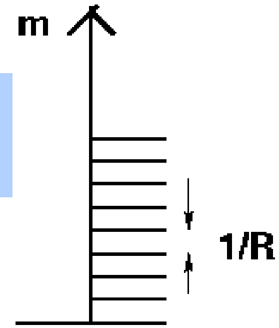
- dark-energy length scale $\approx 85\mu m$ [3] [18]

⇒ Newtonian law works down to ~ 45 μm

Large Extra Dimension Signatures at LHC

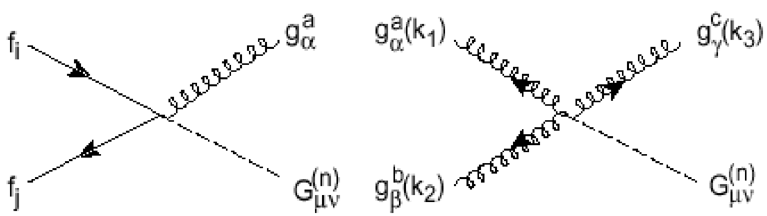
Particles in compact extra dimensions ($2\pi R$)
$\Rightarrow$ Towers of momentum eigenstates
Eg. graviton excitations (Δm=400 eV for δ =3)

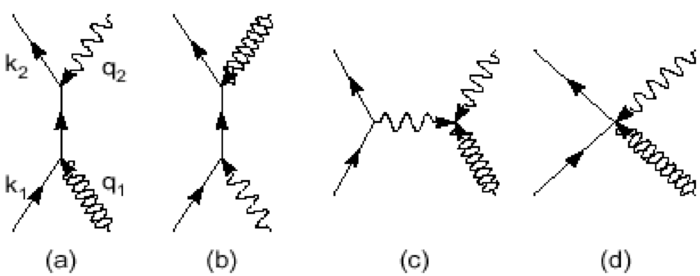
$$\Delta m_{G_{KK}} \sim \frac{1}{R}$$



$\Rightarrow$ Strong increase of graviton exchange at high energies

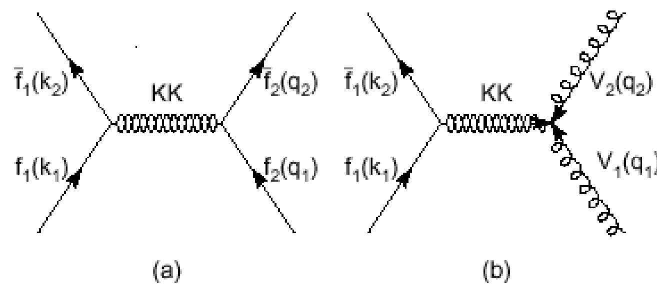
Direct Graviton Emission





- Jets + Missing E_T
- Photon + Missing E_T

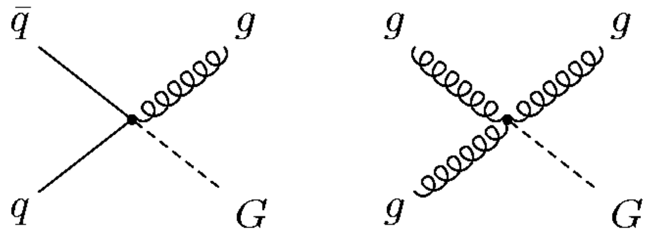
Virtual Graviton Exchange



- Dileptons
- Diphotons

Large Extra Dimension signals at the LHC

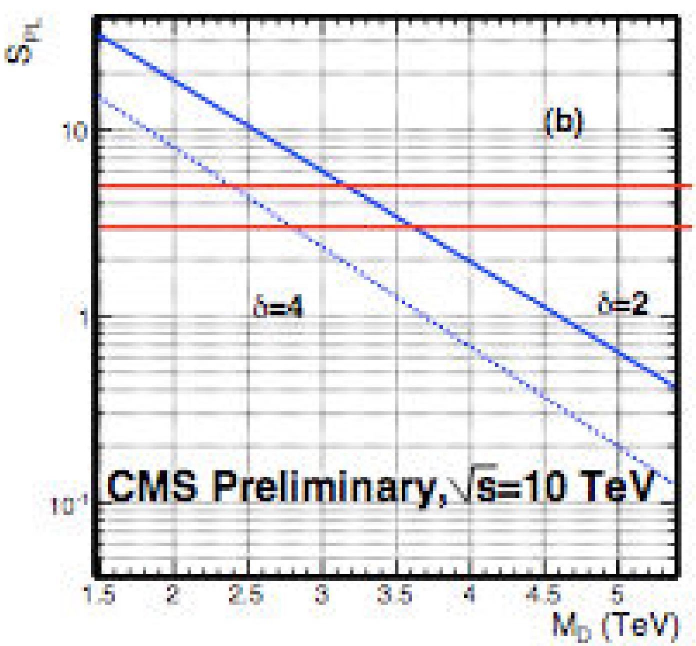
ADD: Arkani –Hamed, Dimopolous,Dvali

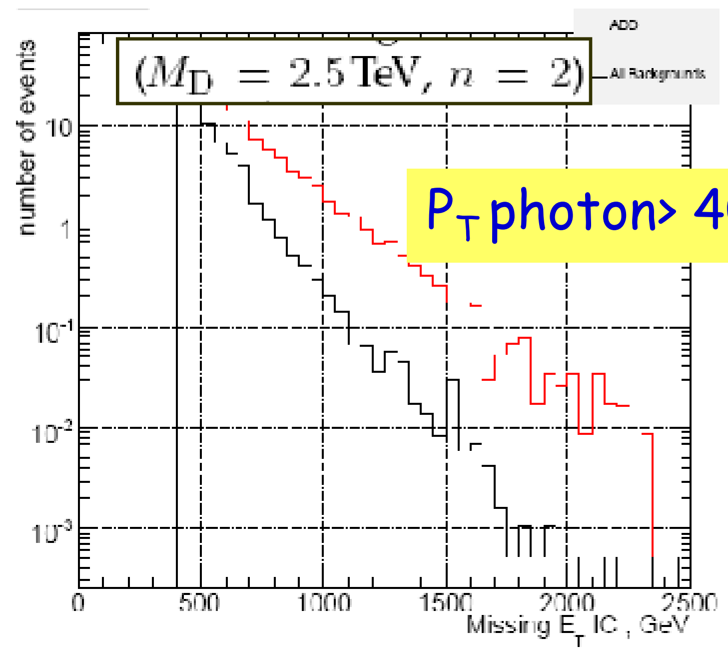


Graviton production!
Graviton escapes detection

Signal: single jet + large missing ET

Signal: single photon + large missing ET





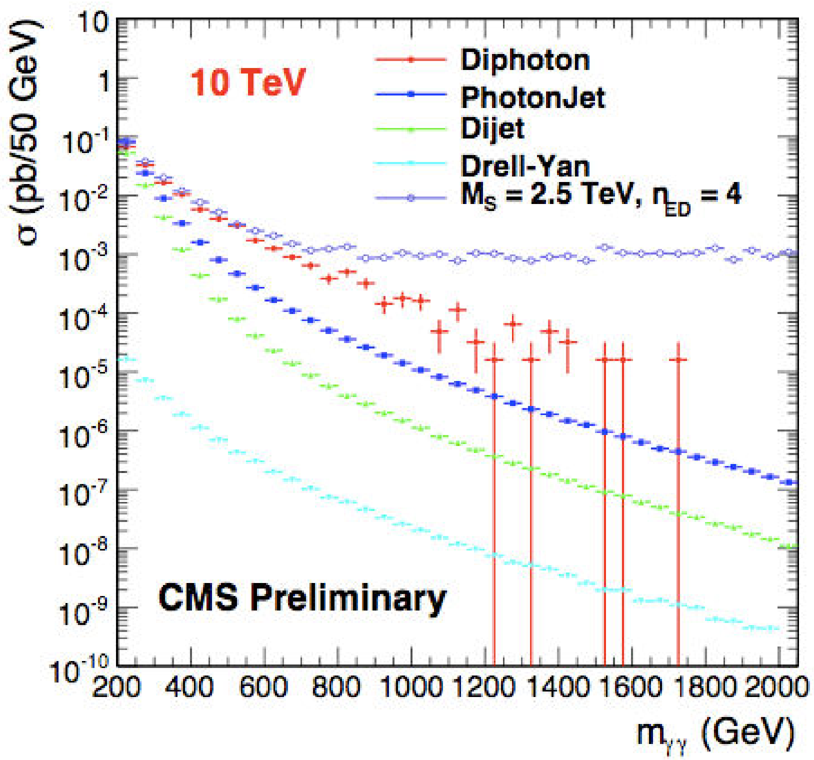
$30 fb^{-1}$

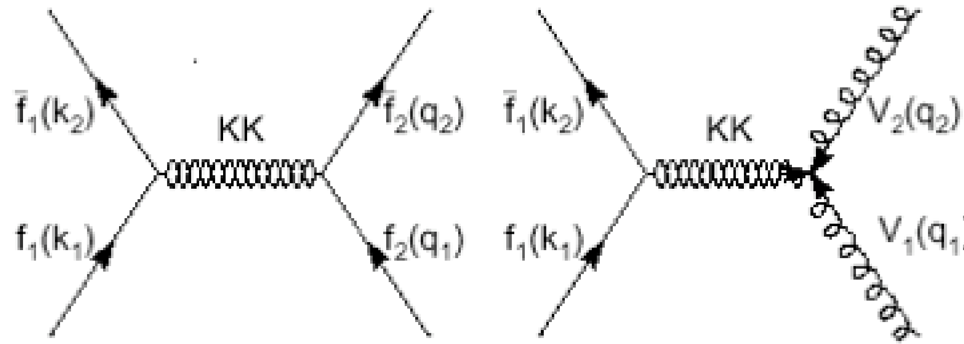
P_T photon> 400 GeV

Test M_D to 2.5-3 TeV for 100 pb^{-1}
Test M_D to 7-9 TeV for 100 fb^{-1}

Test M_D to ~ 2 TeV for O(300) pb^{-1}
Test M_D to ~ 4 TeV for 100 fb^{-1}

Large Extra Dimensions: Diphotons





n_{ED}	95% CL Limit on M_S		
	50 pb^{-1}	100 pb^{-1}	200 pb^{-1}
2	2.5 TeV	2.7 TeV	2.9 TeV
3	3.0 TeV	3.3 TeV	3.5 TeV
4	2.6 TeV	2.8 TeV	3.0 TeV
5	2.3 TeV	2.5 TeV	2.7 TeV
6	2.1 TeV	2.3 TeV	2.5 TeV
7	2.0 TeV	2.2 TeV	2.4 TeV

100 pb^{-1} ⇒ exclude M_S in range of 2.2-3.3 TeV

Probe M_S = 2-2.5 TeV
with O(100) pb^{-1}

Present Limits for Large Extra Dimensions

Experiment	$R_\perp(n=2)$	$R_\perp(n=4)$	$R_\perp(n=6)$
Collider bounds			
LEP 2	4.8×10^{-1}	1.9×10^{-8}	6.8×10^{-11}
Tevatron	5.5×10^{-1}	1.4×10^{-8}	4.1×10^{-11}
LHC	4.5×10^{-3}	5.6×10^{-10}	2.7×10^{-12}
NLC	1.2×10^{-2}	1.2×10^{-9}	6.5×10^{-12}
Astrophysics/cosmology bounds			
SN1987A	3×10^{-4}	1×10^{-8}	6×10^{-10}
COMPTEL	5×10^{-5}	-	-

Limits on the size of the extra dimensions (2001)

Limits on the Planck Scale M_D

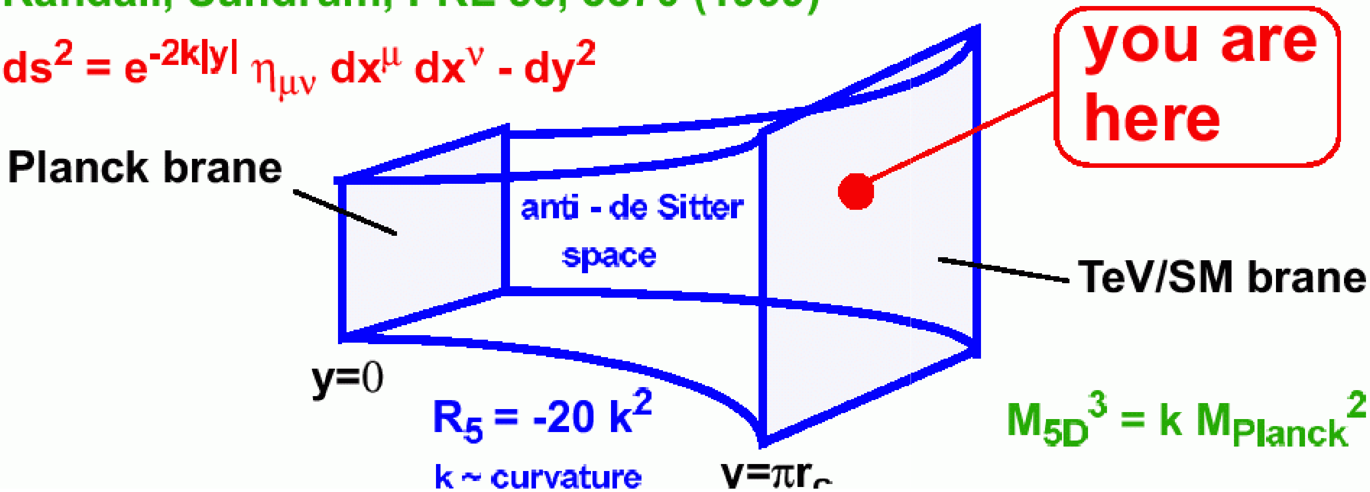
	LEP	DØ		CDF		
δ	$\gamma + E_T^{miss}$	jet+E_T^{miss}	$\gamma + E_T^{miss}$	jet+E_T^{miss}	$\gamma + E_T^{miss}$	combined
2	1.600	0.99	0.921	1.310	1.080	1.400
3	1.200	0.80	0.877	1.080	1.000	1.150
4	0.940	0.73	0.848	0.980	0.970	1.040
5	0.770	0.66	0.821	0.910	0.930	0.980
6	0.660	0.65	0.810	0.880	0.900	0.940

D0: PPRL 90, 251802 (2003); PRL 101, 011601 (2008)
CDF: 0807.3132v1[hep-ex]

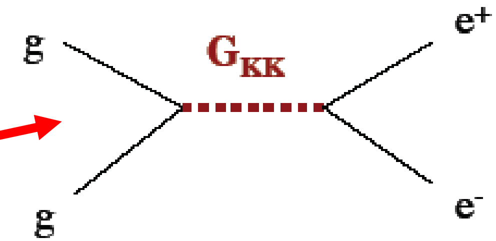
Curved Space: RS Extra Dimensions

Randall, Sundrum, PRL 83, 3370 (1999)

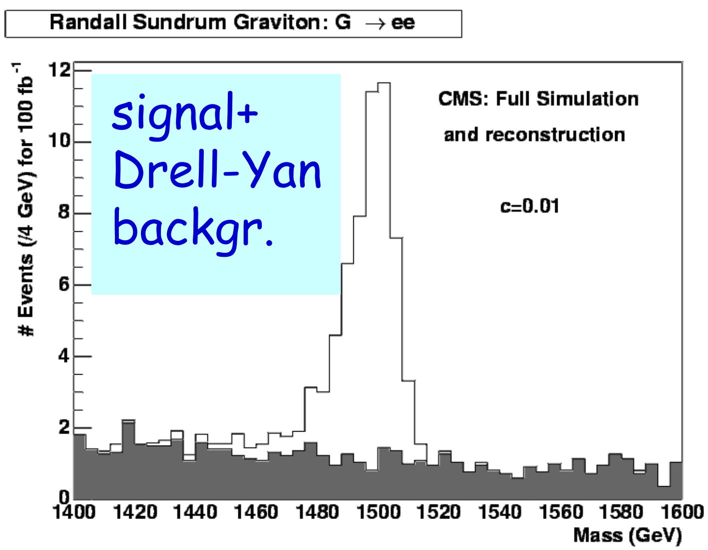
$ds^2 = e^{-2k|y|} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$



phenomenology



Study the channel pp→Graviton→ e+e-

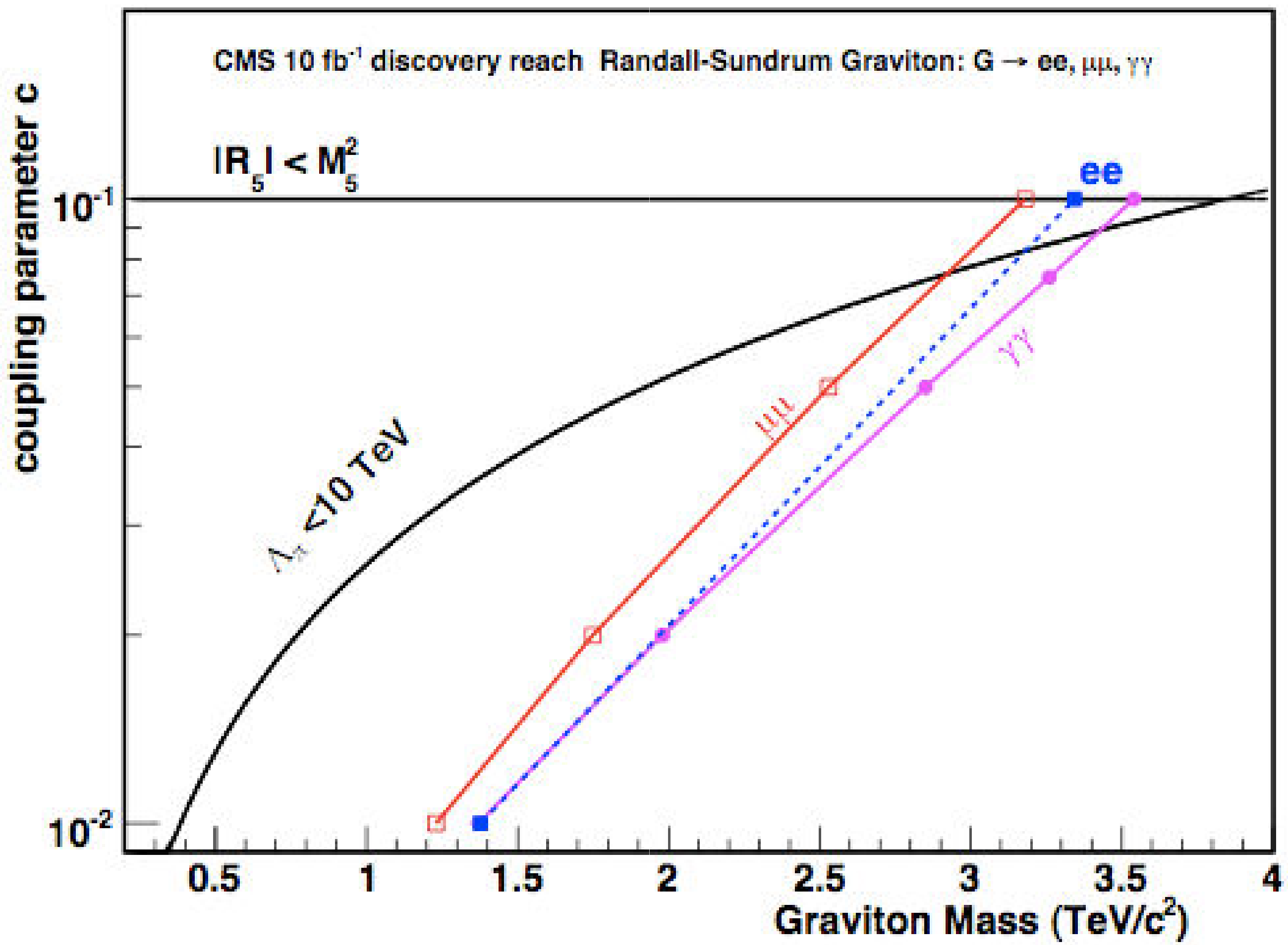


Signature: a resonance in the di-electron or di-muon final state
a priori easy for the experiments

Caveat: new developments suggest that G_{KK} would couple dominantly to top anti-top…

Sensitivity for Randall Sundrum Gravitons

Different Channels 30 fb^{-1}

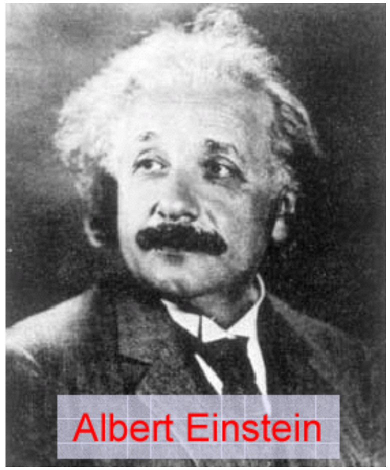


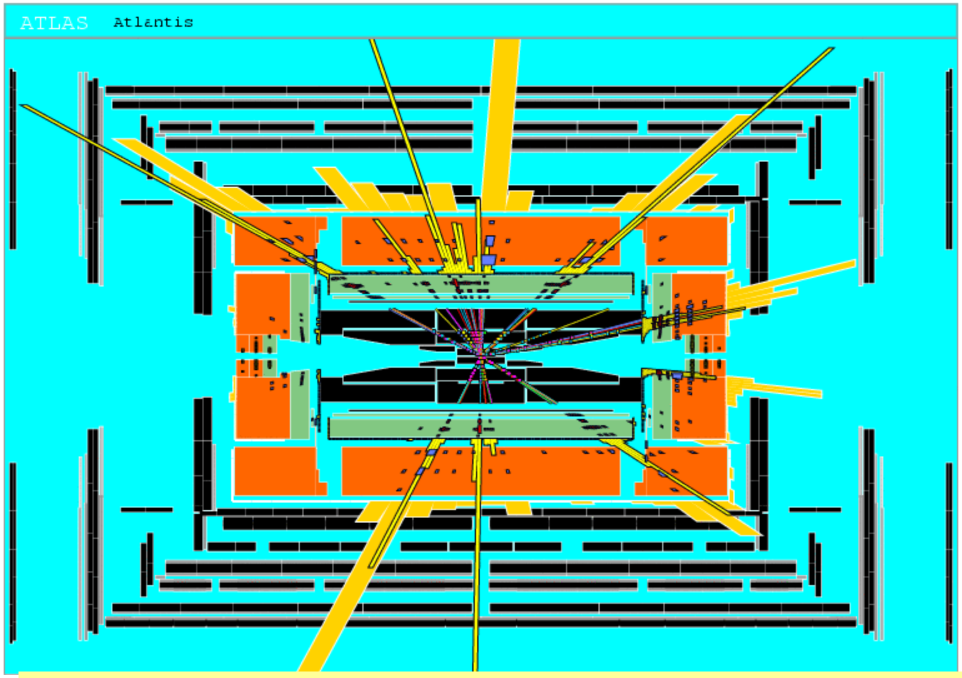
Covers essentially the full range of interest

Quantum Black Holes at the LHC?

Black Holes are a direct prediction of Einstein's general theory on relativity

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





Simulation of a Quantum Black Hole event

Quantum Black Holes are harmless for the environment: they will decay within less than 10^{-27} seconds

Quantum Black Holes open the exciting perspective to study Quantum Gravity in the lab!

Quantum Back Holes

- Schwarzschild radius

Landsberg, Dimopoulos
Giddings, Thomas, Rizzo…

4-dim., $M_{gravity} = M_{Planck}$ (:10^{19}GeV)

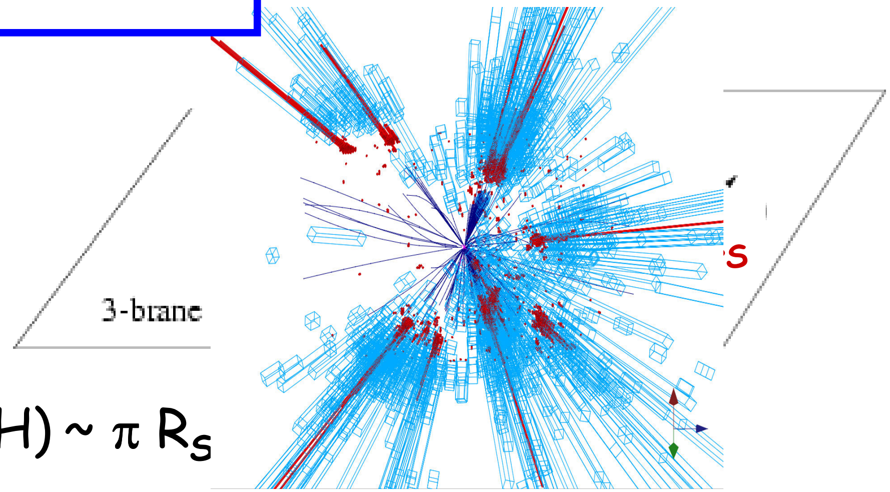
4 + n-dim., $M_{gravity} = M_D \sim$ TeV

$R_s \rightarrow \ll 10^{-35}$ 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 : $\sigma(ij \rightarrow BH) \sim \pi R_S$
- $\sigma(pp \rightarrow BH)$ is in the range of 1 nb – 1 fb

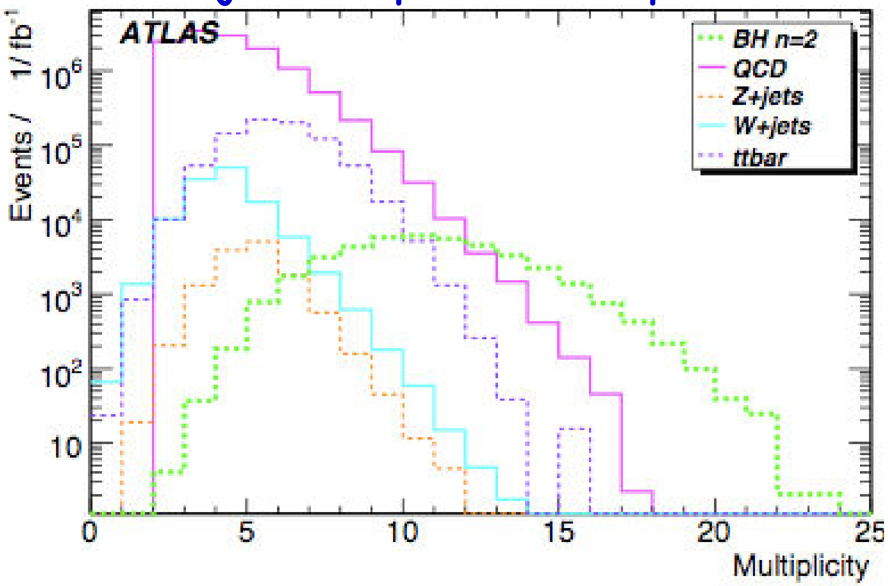
e.g. For $M_D \sim 1$ TeV and n=3, produce 1 event/second at the LHC

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

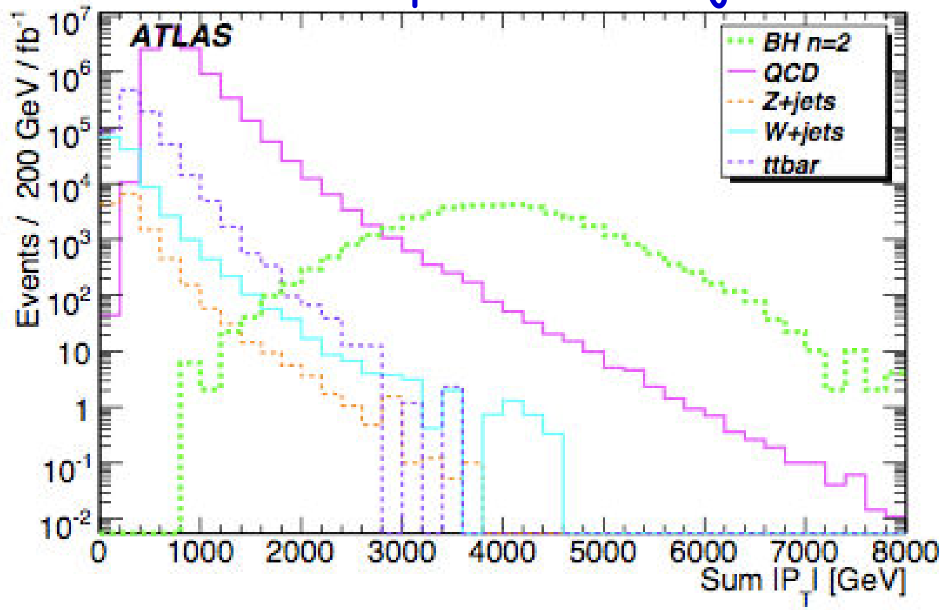
} expected signature (quite spectacular …)

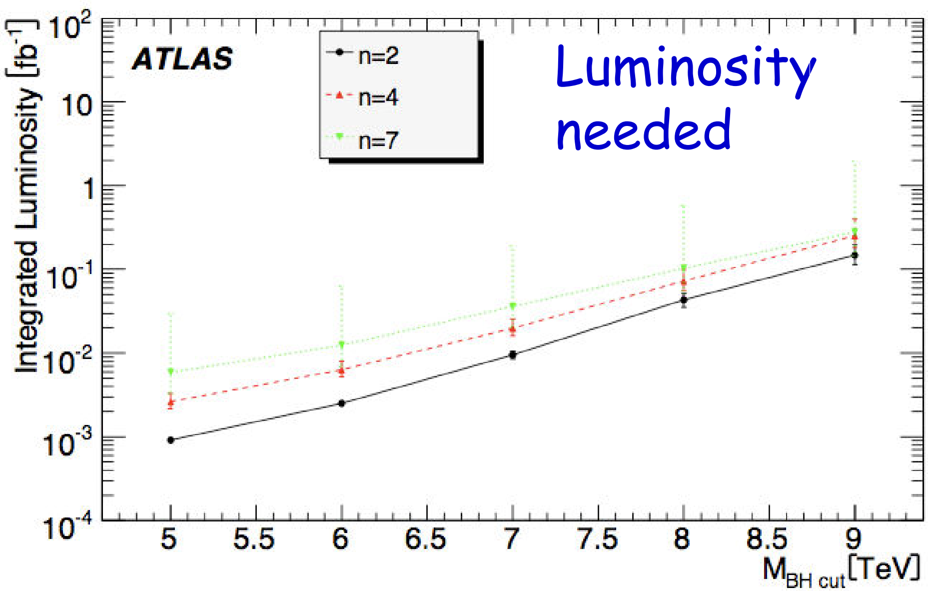
Black Hole Studies

of jets, leptons and photons



Sum of all pt of the objects

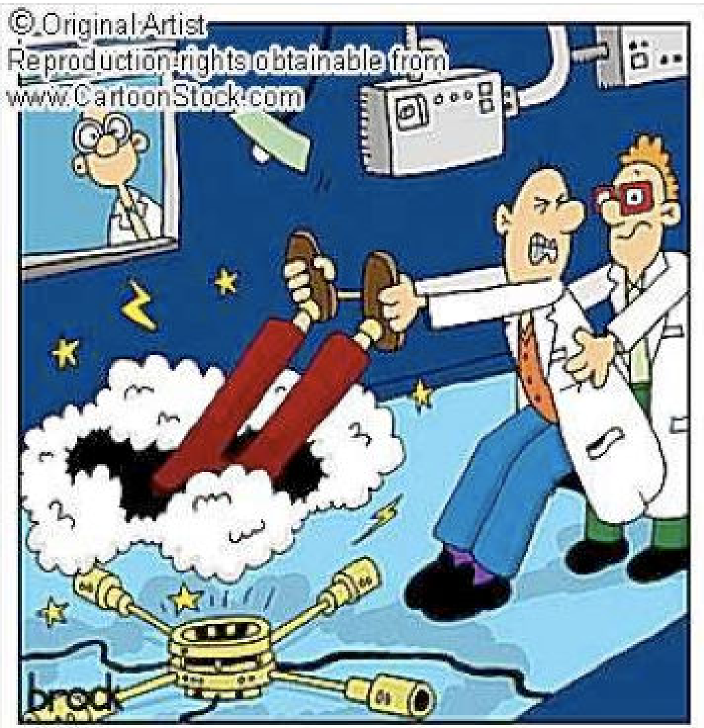




Already possible to discover with 1 pb^{-1}!!!

However cross sections largely unknown (and challenged)

Quantum Black Holes



Professor Landsberg was fast regretting becoming the first man to successfully create a mini black hole in the laboratory.

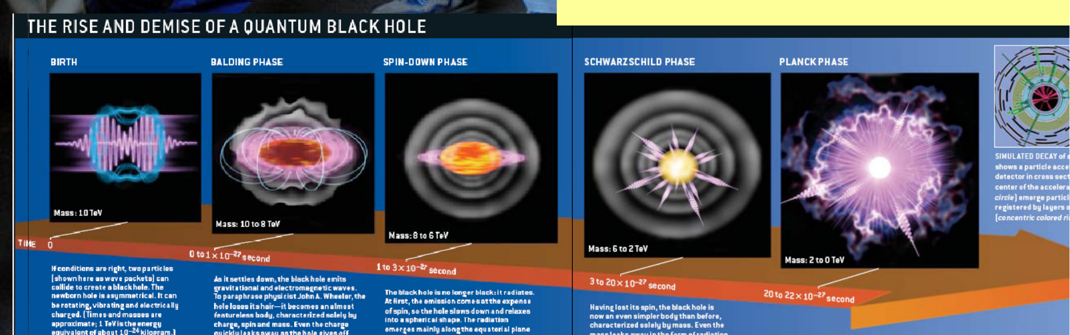
- Can LHC destroy the planet?

  ⇒ No!

- See the report of the LHC Safety assesment group (LSAG) *http://arXiv.org/pdf/0806.3414*
- More information on
  - S.B. Giddings and M. Mangano, *http://arXiv.org/pdf/0806.3381* LSAG, *http://arXiv.org/pdf/0806.3414*
  - Scientific Policy Committee Review, *http://indico.cern.ch/getFile.py/access?contribId=20&resId=0&materialId=0&confId=35065*
  - CERN public web page, *http://public.web.cern.ch/public/en/LHC/Safety-en.html*

Black Holes Hunters at the LHC...

Scientific American



End of Lecture I

- New Physics Beyond the Standard Model is highly anticipated in the TeV range (but not guaranteed)
- The LHC will enter a new region: the TeV Scale
- If either low mass Supersymmetry or Extra Dimensions in the TeV range exist the LHC can make an early discovery (first year to first few years)
- To understand WHAT exactly we will have discovered will take some more time as many models may give similar 'first signatures'
- But the exciting journey in the unknown is about to begin

Tomorrow's lecture

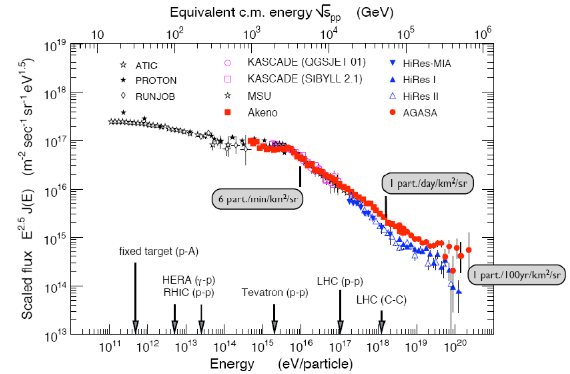
- Special and very exotic/weird possible signatures!

Is the LHC safe? Dangerous Exotica?

- NOTE: Cosmic rays with energies > LHC energies (10^8 GeV) hit Earth 10^4/s
  - Or the sun 10^8 /s . Or ANY sun 10^{30}/sec!!

    The full experimental LHC program is done

    10^{13} time per sec in the whole Universe



- ⇒ Micro black holes
  - Can a micro black hole be stable and eat earth?
  - No! black holes from CRs. Slow neutral black holes? (from neutron stars and white dwarf
- ⇒ Strangelets or strange matter (in heavy ion collisions)
  - Problem: UDS baryonic matter lower energy? Destroy all matter?
  - Chance to produce strange matter at LHC < chance at RHIC (LHC hotter and baryon density is less. Also the moon is still there!
- ⇒ Vacuum bubbles
  - Do we live in a false vacuum? Limits from CRs
- ⇒ Magnetic Monopoles
  - Monopoles could catalyze baryon desintegration. Limits from CRs