New Physics in the First Years of LHC

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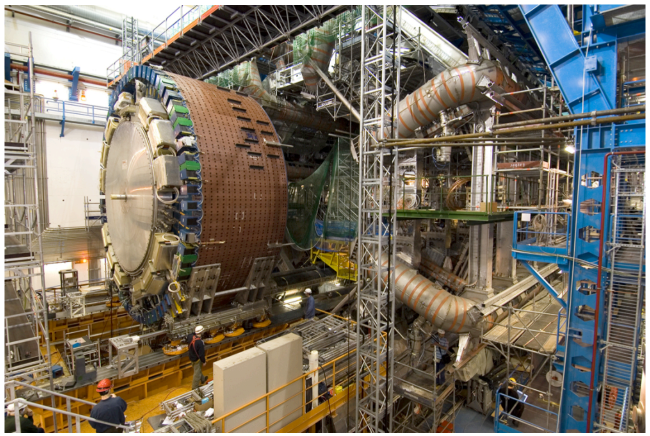
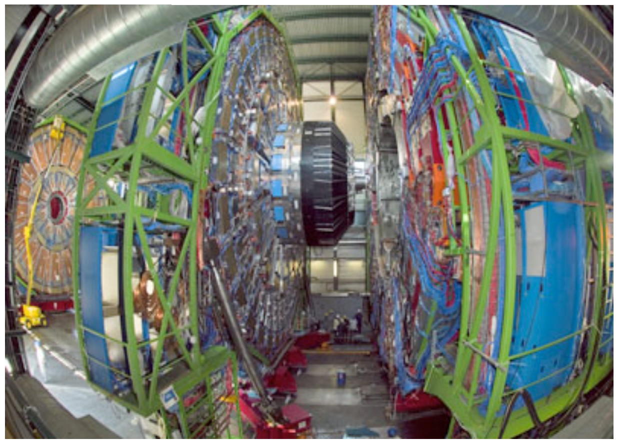
CERN
and University of Antwerp
and the IPPP Durham

CRACOW EPIPHANY CONFERENCE
ON HADRON INTERACTIONS
AT THE DAWN OF THE LHC

Dedicated to the memory of Jan Kwieciński

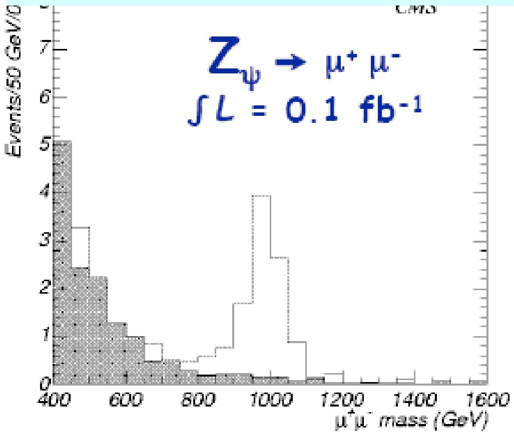
5-7 January 2009, Cracow, Poland



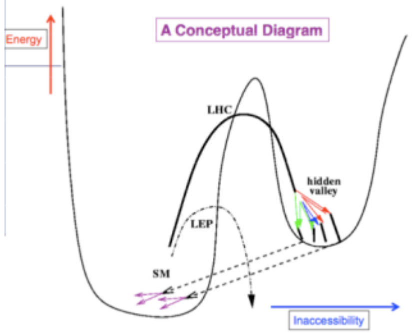


BSM Physics at the LHC: pp @ 14 TeV

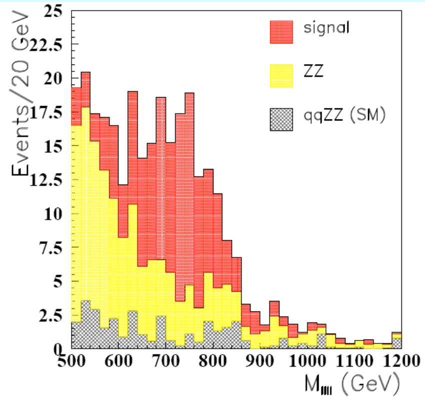
New Gauge Bosons?



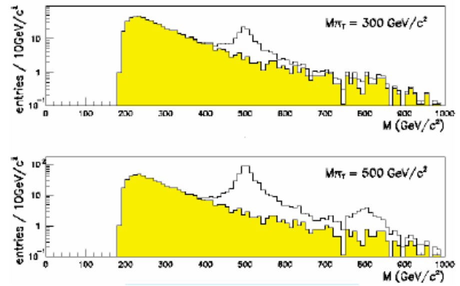
Hidden Valleys?



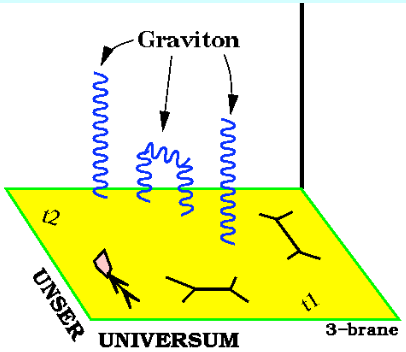
ZZ/WW resonances?



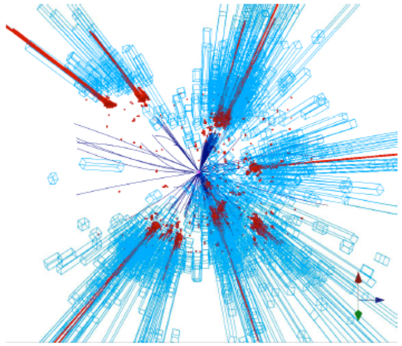
Technicolor?



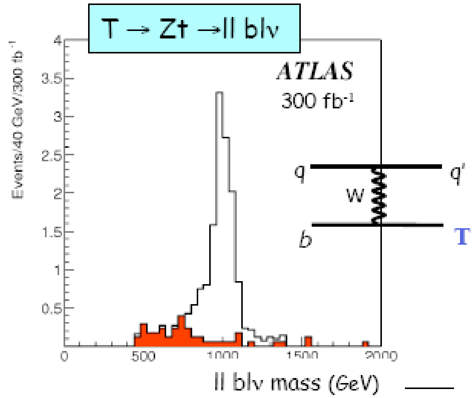
Extra Dimensions?



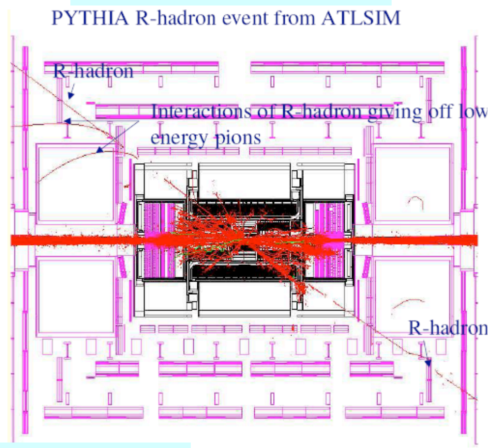
Black Holes???



Little Higgs?



Split Susy?



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

LHC Status

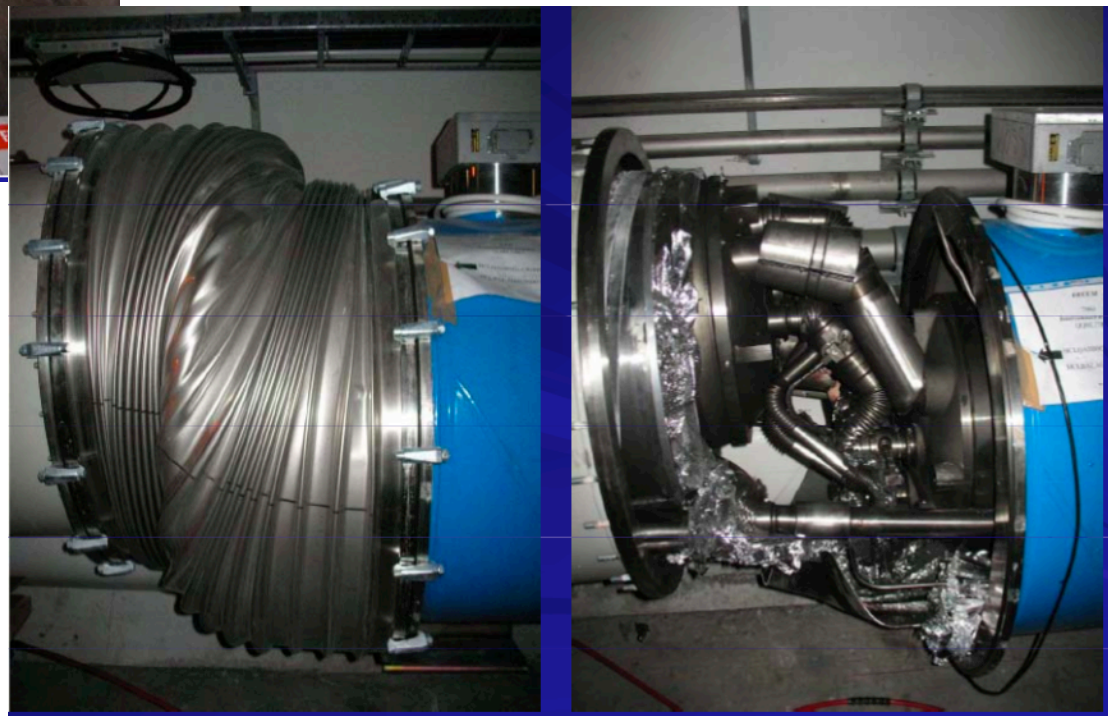
- The LHC has been completed in 2008.
- Start-up of the LHC on 10/9 was really good
  - Beam circulating for 30 minutes within days.
- However on 19/9 an unfortunate incident happened
  - An electrical resistive zone built up and led to an electric arc in the cryogenics part in one of the 8 arcs of the LHC
  - This created a rupture in the helium enclosure of the magnets
- This created considerable damage that needs to be repaired
  - 53 dipoles and 14 quadrupoles (SSS) moved to surface
  - Safety margin increased (8-40 fold) on Helium relief devices
- As of 5/12 a new schedule has been announced
  - Aggressive schedule: Full cooldown of LHC by end of June 2009.
  - Multi-TeV collisions fall 2009?
  - Luminosity? 10 pb^{-1}? 100 pb^{-1}? More? (Energy?)

Collateral Damage

Some objects moved by
50 cm (longitudinally)

R. Aymar PECFA
28/11/08

Cryostat pedestals



Damaged
quadrupole-dipole
connection

The detectors are ready for collisions

2008: First Higgs observed also in CMS

New Physics Signatures

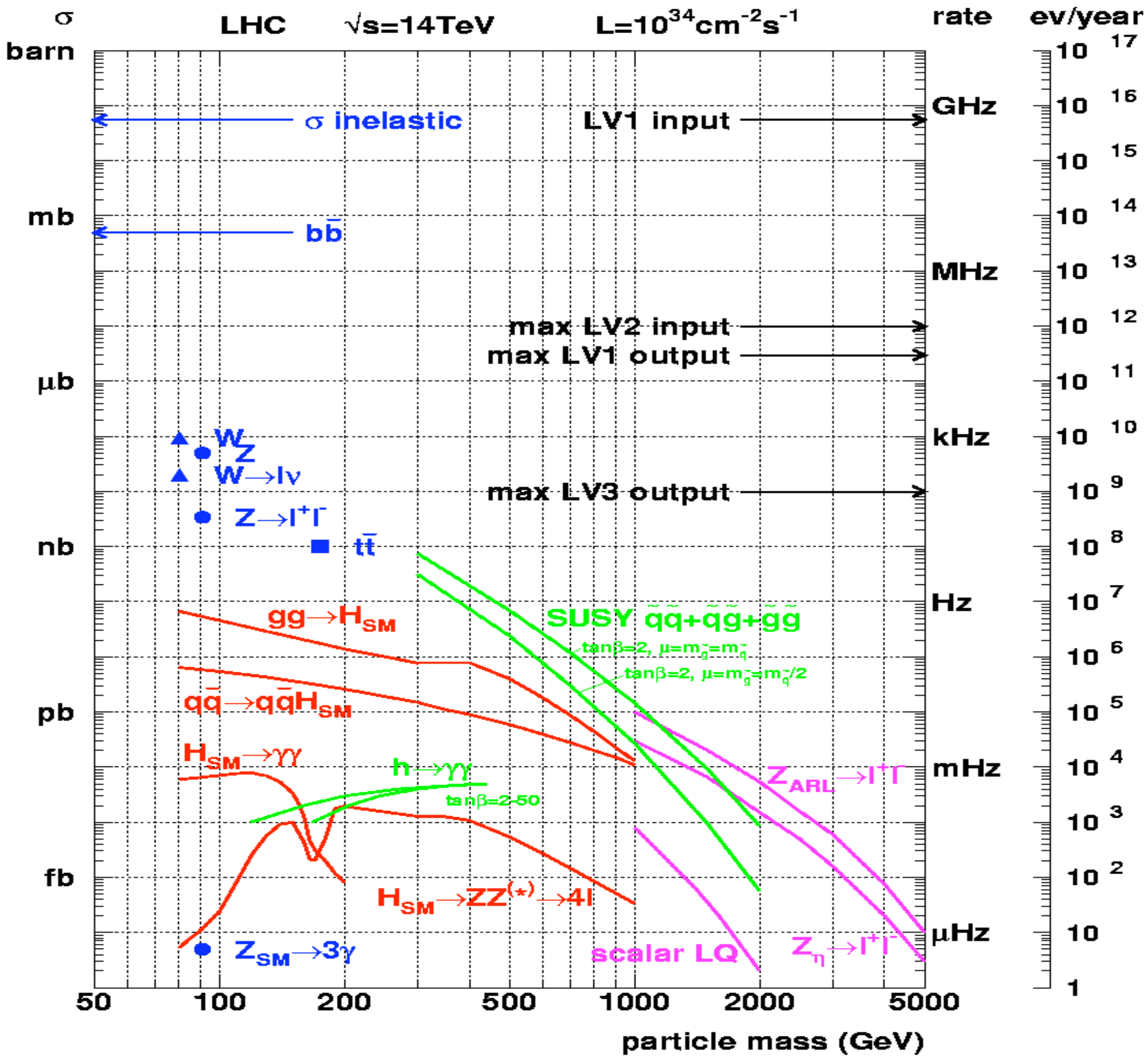
- Many channels in New Physics :Typical signals
  - Di-leptons (like sign/same sign)
  - Leptons + MET (Missing E_T)
  - Photons + MET
  - Multi-jets (2 → ~10)
  - Mono/Multi-jets +MET (few 10 → few 100 GeV)
  - Multi jets + leptons + MET…
  - B/τ final states…
- Also: new unusual signatures
  - Large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

Progress over the last years

- Full simulation/Closer to the real experimental set-up
- Improved signal & backgrounds (More complex MCs, NLO (QCD/EW) corrections)
- Studies for first luminosities (10-100 pb^{-1})
- Studies for detectors with start-up conditions (energy calibration, misalignment of the detectors)
- Special attention to the trigger
- Data driven methods to estimate backgrounds for discoveries.
- In a few cases, real in situ background estimates (cosmics, beam halo)

Sources: CMS Physics TDR Vol II, J. Phys. G34 (2007) 995
ATLAS CERN-OPEN-2008-20 (December 2008)

Cross sections at the LHC



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

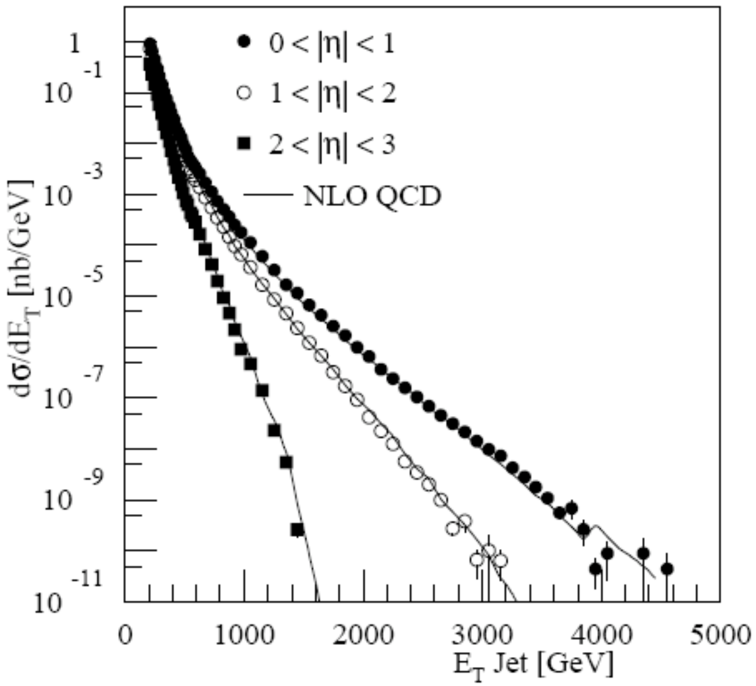
New Physics!!

This we want to keep!!

In the beginning "there will be QCD"

E.g. Jet Physics

Huge cross sections:
Eg for 1 fb^{-1} ~ 10000 events with E_T> 1 TeV
100 events with E_T> 2 TeV



- PDFs
- Jet shape
- Underlying event
- α_s?
- Diffraction
- BFKL studies
- low-x
- New physics?

1938-2003

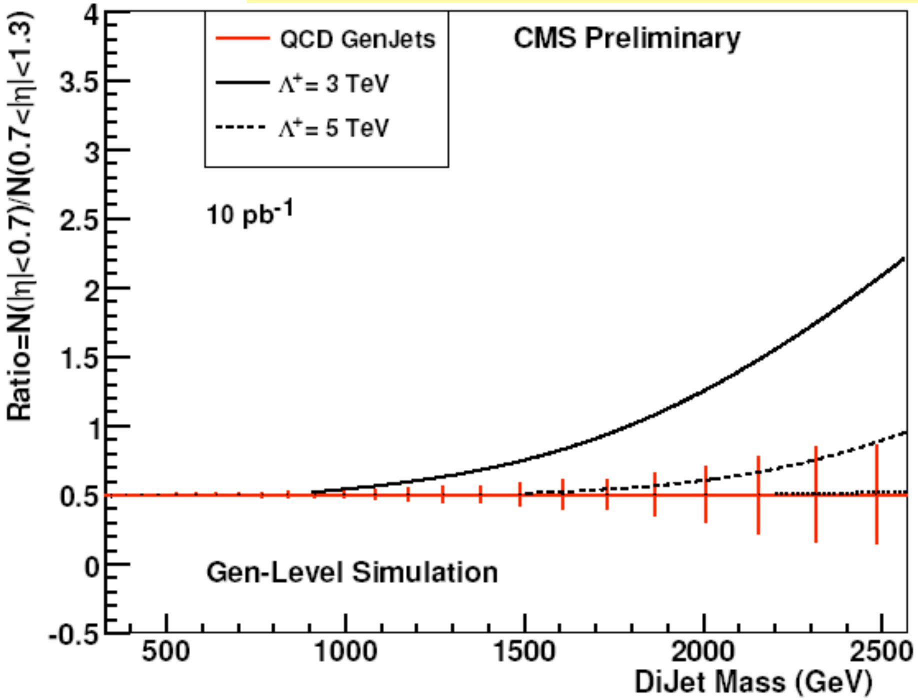
•Understanding QCD at 14 TeV will be one of the first topics at the LHC

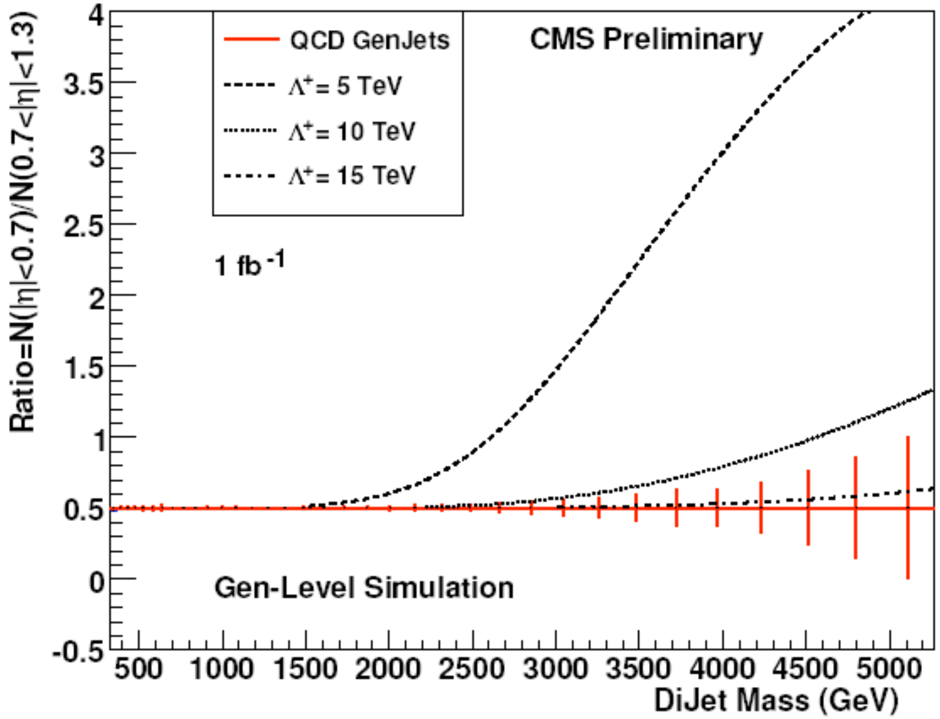
…and a whole b-physics and top-physics program

New Physics with Jets

Eg Contact Interactions

⇒ Using dijet event ratios in pseudorapidity η bins



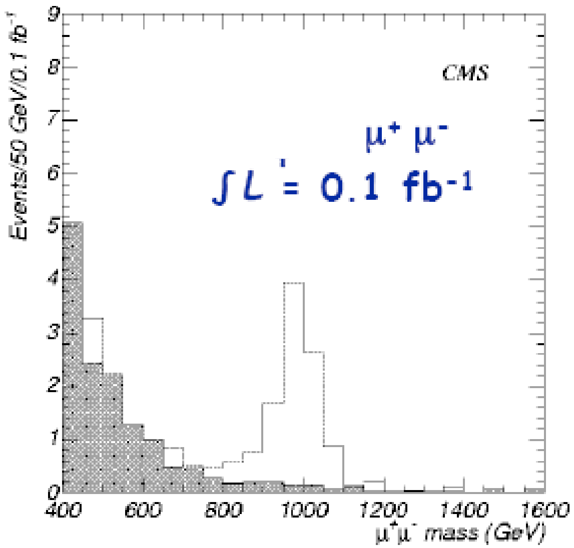


	Excluded Λ (TeV)			Discovered Λ (TeV)		
	$10\ pb^{-1}$	$100\ pb^{-1}$	$1\ fb^{-1}$	$10\ pb^{-1}$	$100\ pb^{-1}$	$1\ fb^{-1}$
DØ and PTDR η cuts	< 3.8	< 6.8	< 12.2	< 2.8	< 4.9	< 9.1
Optimized η cuts	< 5.3	< 8.3	< 12.5	< 4.1	< 6.8	< 9.9

Already sensitivity with $10\ pb^{-1}$

Early discoveries? E.g. Di-lepton Resonance

If we are lucky:
a signal could be
seen very early on



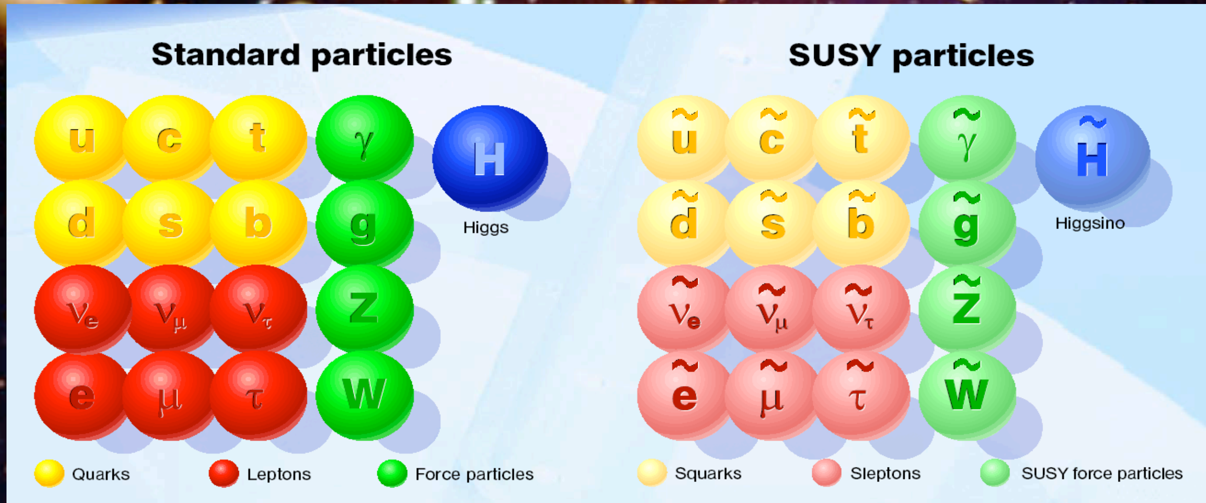
$pp \rightarrow \mu\mu + X$

First months of operation

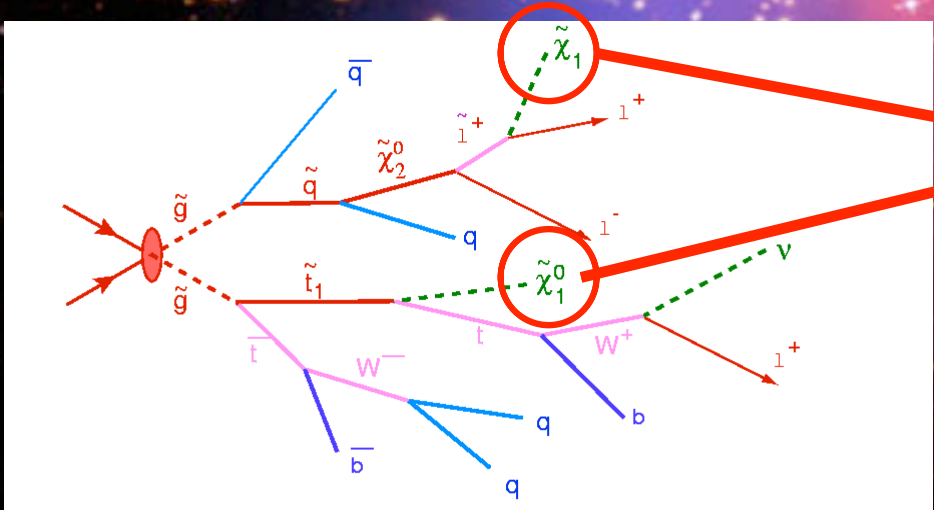
Example : The Di-lepton channel

- Z′ (New gauge bosons)
- A_H, Z_H (Little Higgs)
- $G^{(1)}$ (Randall-Sundrum)
- $\gamma^{(1)}/Z^{(1)}$ (TeV^{-1} Extra Dimensions)
- $G^{(KK)}$ (ADD)
- ...

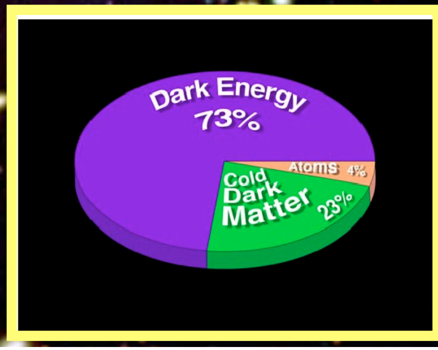
Supersymmetry: a new symmetry in Nature



Candidate particles for Dark Matter
⇒ Produce Dark Matter in the lab



SUSY particle production at the LHC

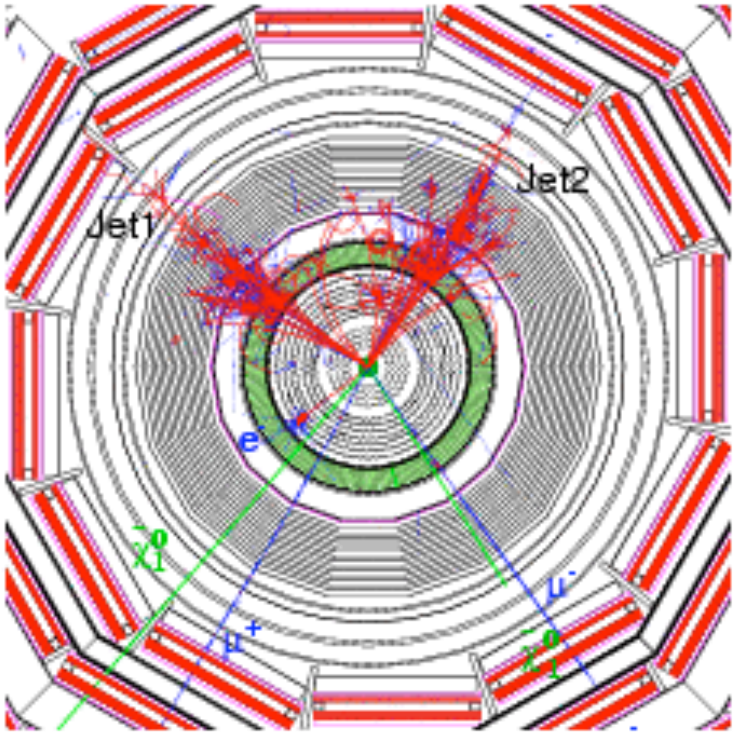


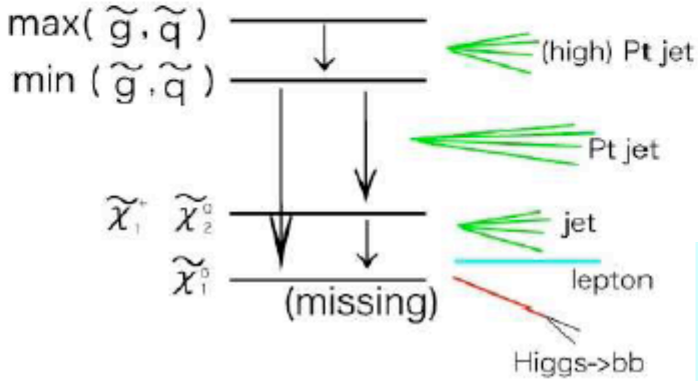
Supersymmetry

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

10fb^{-1}





event topologies of SUSY

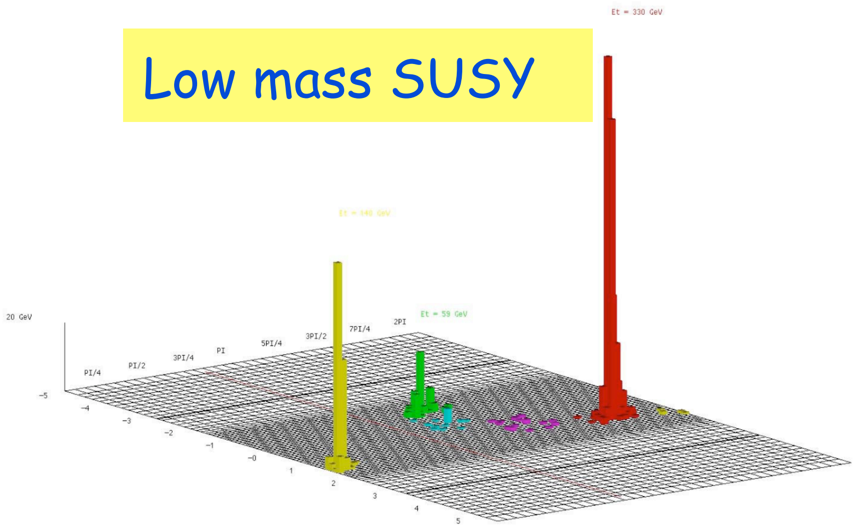
multi leptons
$\not{E}_T$ + High P_T jets + b-jets
τ-jets

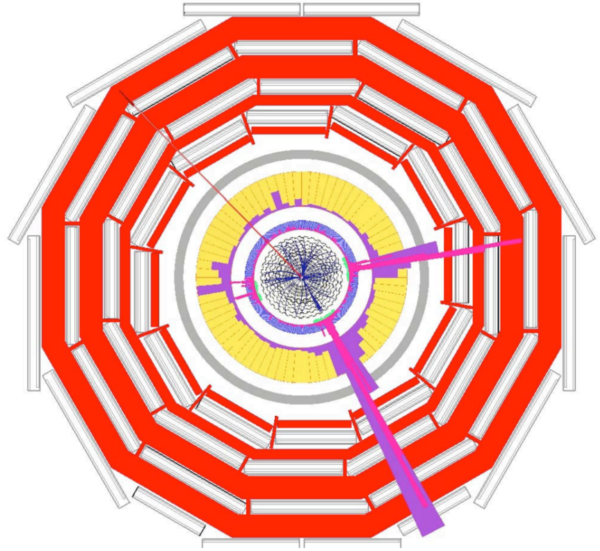
Therefore:
SUSY one of the priorities of the "search" program

Main signal: lots of activity (jets, leptons, taus, missing E_T)
Needs however good understanding of the detector & SM processes!!

Detailed Simulation: Missing E_T

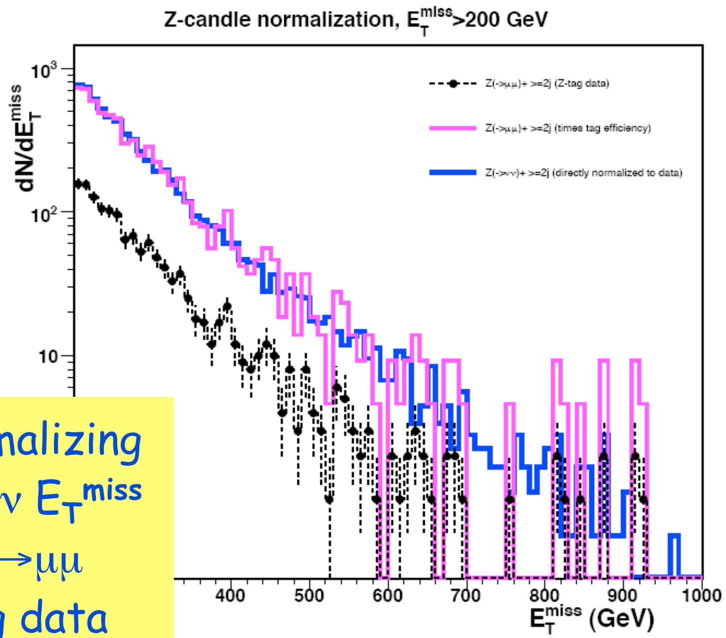
Low mass SUSY



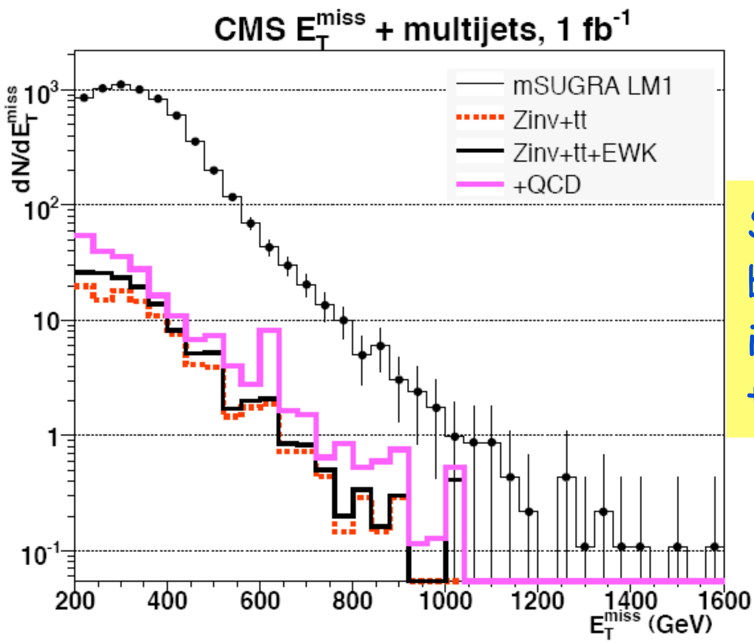


Missing E_T is a difficult measurement for the experiments

CMS PTDR



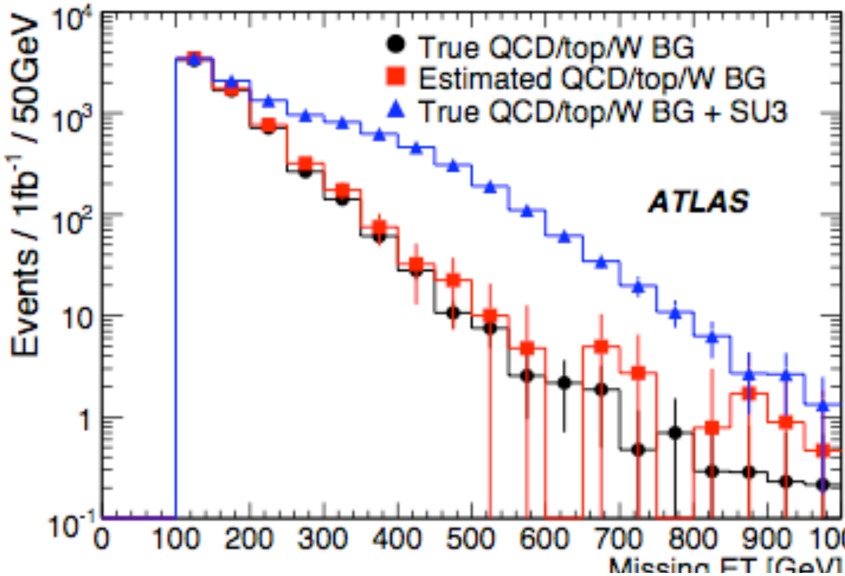
Normalizing $Z\rightarrow\nu\nu$ E_T^{miss} to $Z\rightarrow\mu\mu$ using data



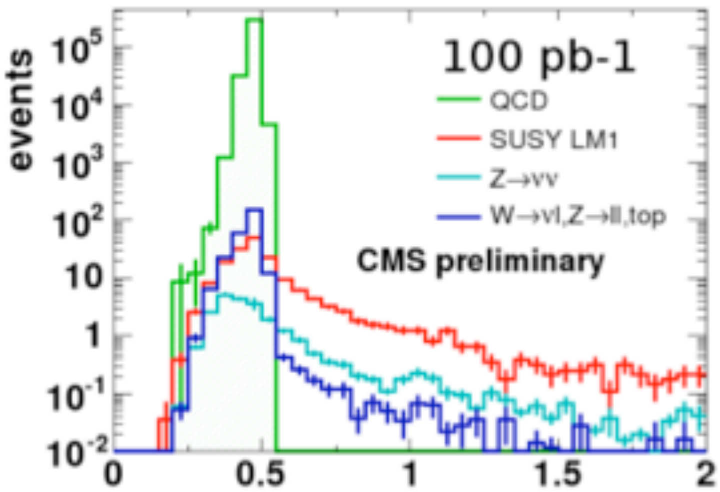
Signal over background in E_T^{miss} for the LM1 point

Preparing for SUSY Hunting

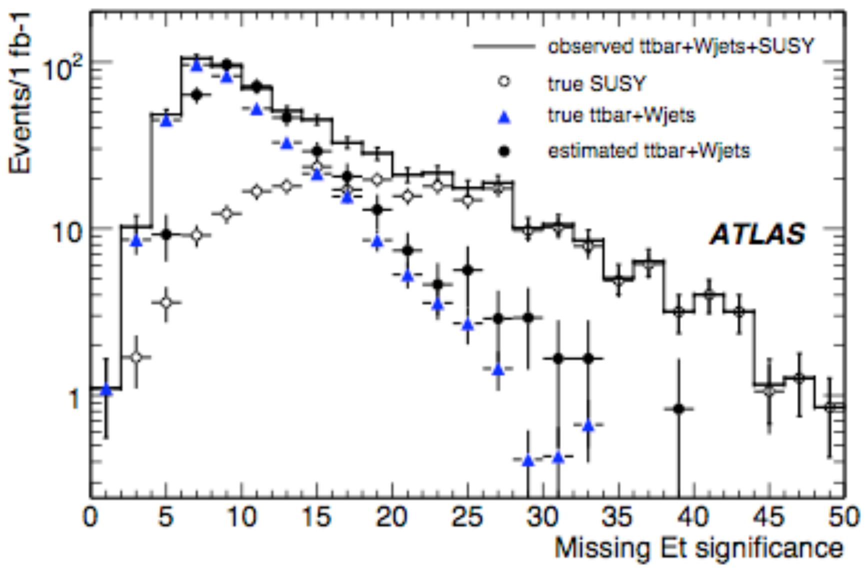
- Find new kinematic variables (α_T, MT2,…)
- Data driven methods to control the backgrounds



Angular correlation: direct-decay SUSY
e.g. $\tilde{q}\tilde{q} \rightarrow q\chi_1^0\, q\chi_1^0$



$\alpha_T = E_T(\text{jet 2})/M_{\text{transverse inv}}(\text{jets 1\&2})$

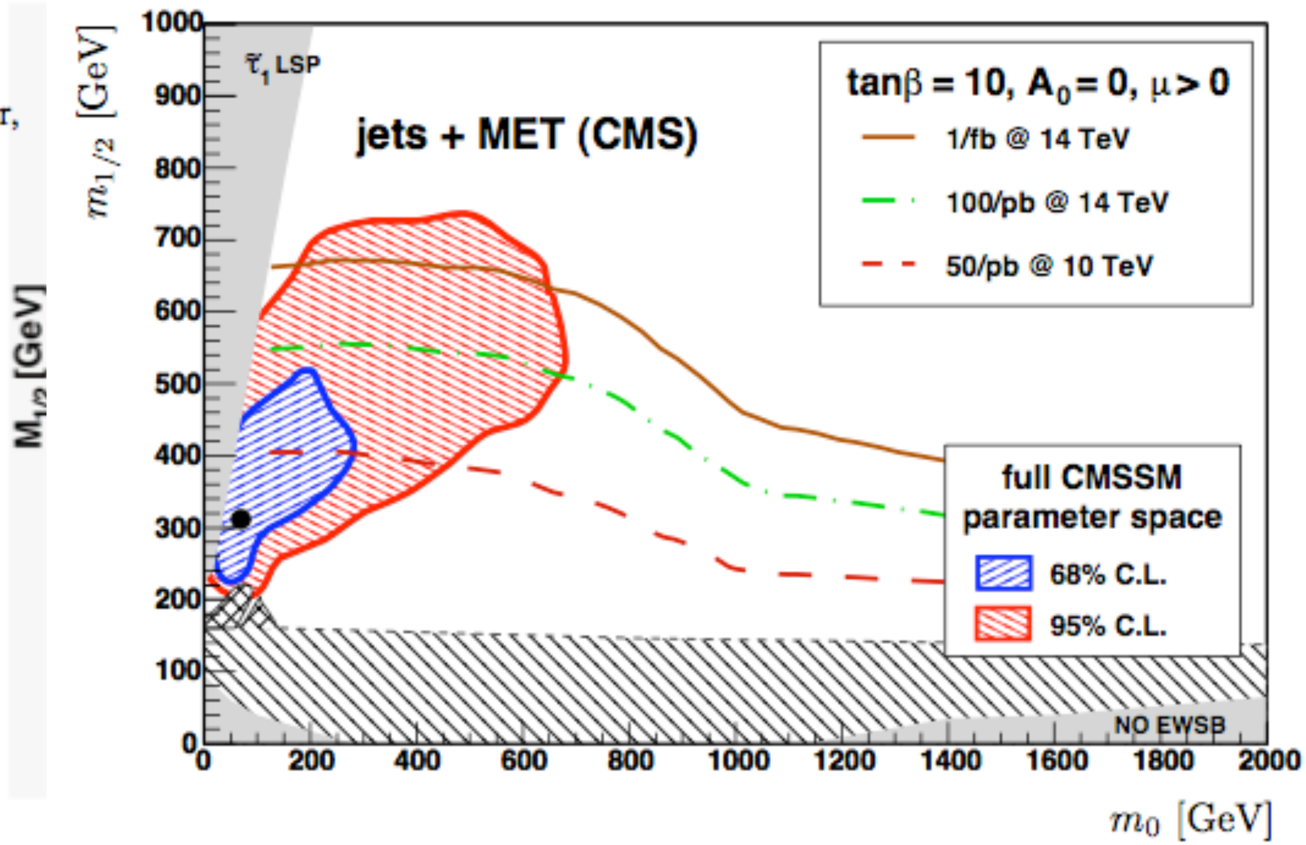


Where do we expect SUSY

"LHC Weather Forecast"

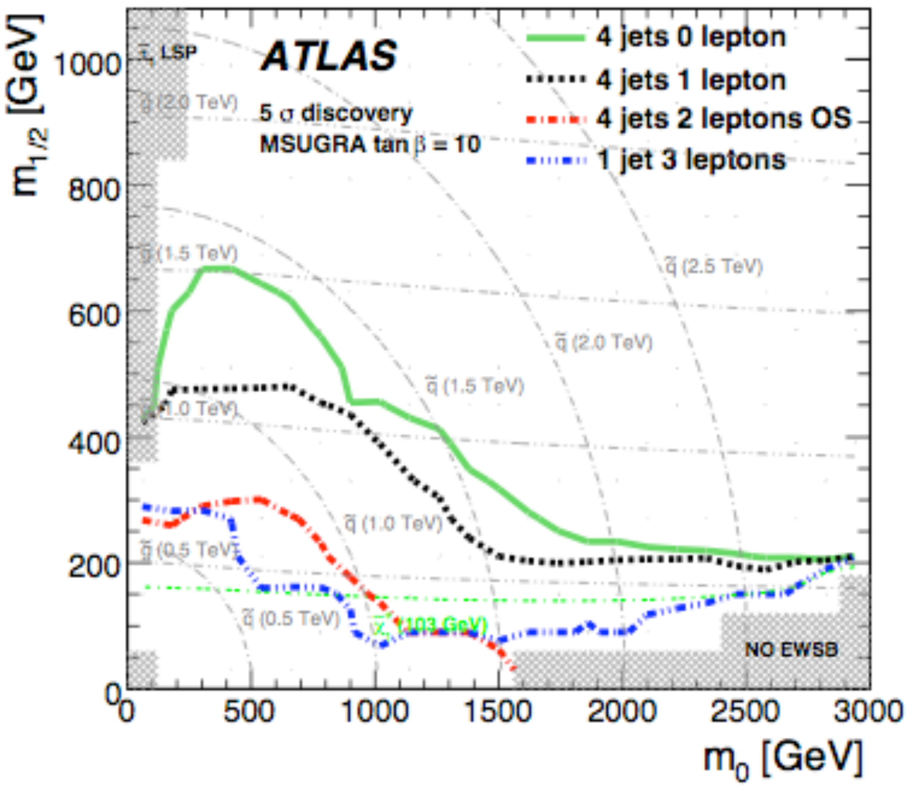
OB, R.Cavanaugh, A.De Roeck, J.R.Ellis, H.~Flaecher, S.~Heinemeyer, G.Isidor, K.A.Olive, P.Paradisi, F.J.Ronga, G.Weiglein

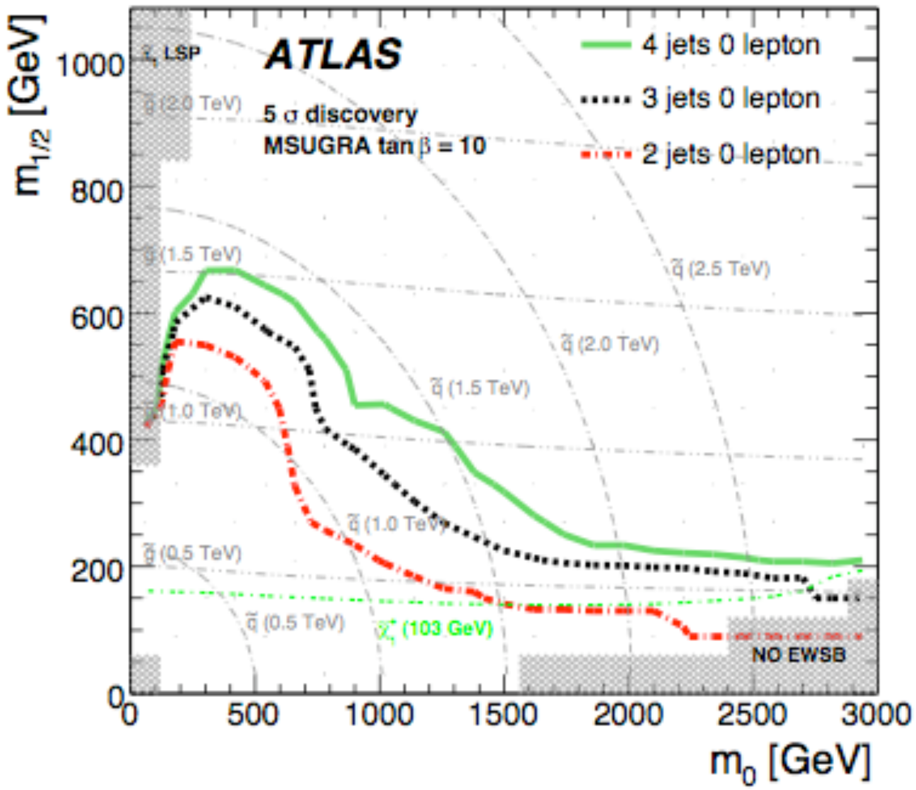
Simultaneous fit of CMSSM parameters m_0, $m_{1/2}$, A_0, $\tan\beta$ (μ>0) to more than 30 collider and cosmology data (e.g. M_W, M_{top}, g-2, BR($B \rightarrow X\gamma$), relic density)



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

SUSY Reach (updated)

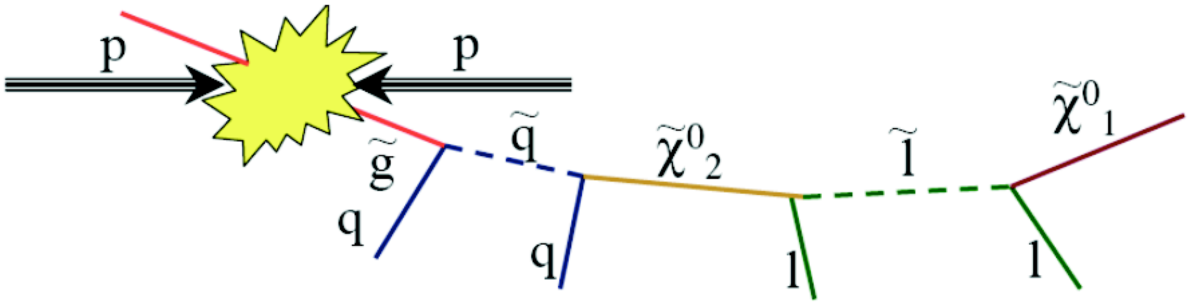


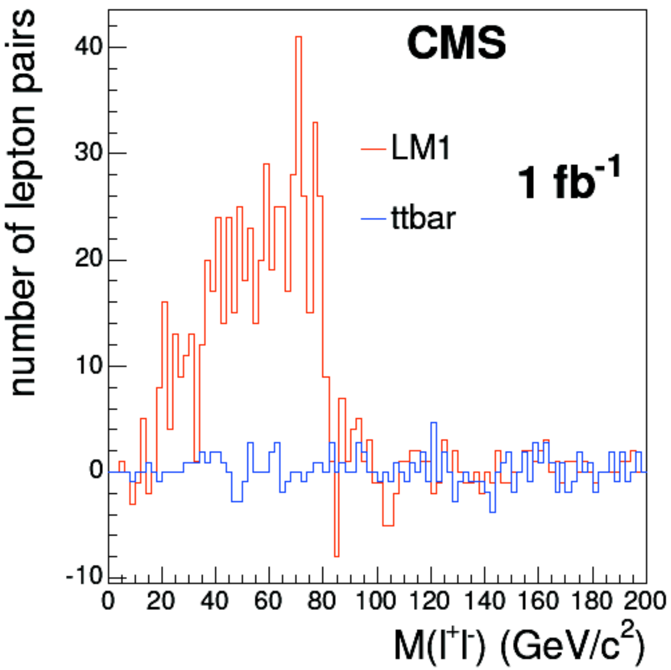


Latest from the ATLAS report…

Sparticle Mass Reconstruction

First Mass Clues (dileptons)





- $M_{\ell\ell}^{max} = M(\tilde{\chi}_2^0)\sqrt{1 - \frac{M^2(\tilde{\ell}_R)}{M^2(\tilde{\chi}_2^0)}}\sqrt{1 - \frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{\ell}_R)}}$
- $M_{\ell\ell}^{max}$(meas)= 80.42 $\pm$ 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]

D. Miller et al: Scot Thomas et al.
⇒ use also the shapes

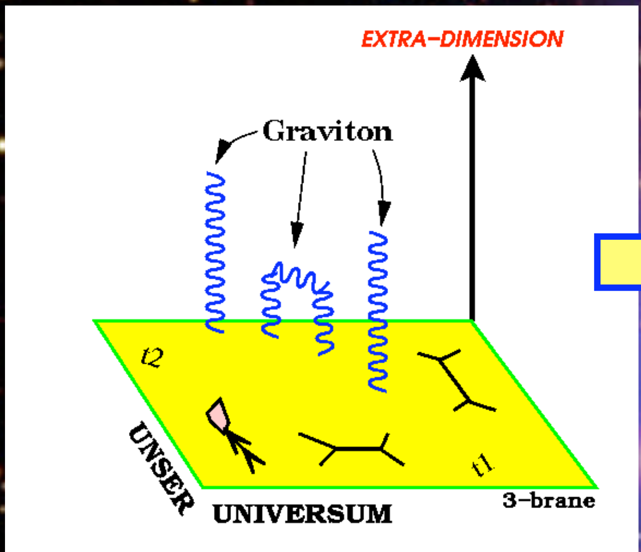
Determining SUSY Parameters with 1fb^{-1}

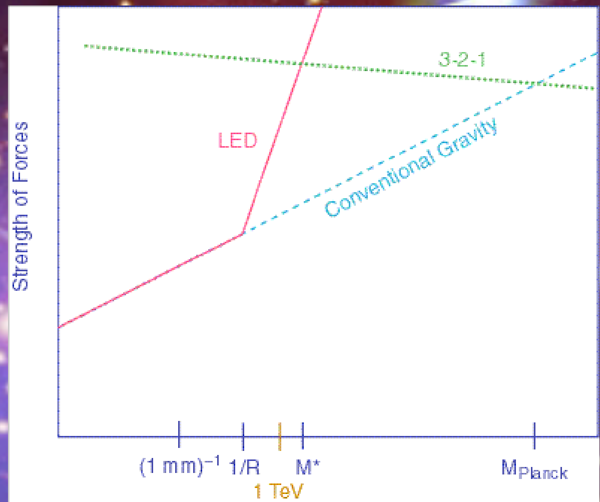
Observable	SU3 m_{meas} [GeV]	SU3 m_{MC} [GeV]	SU4 m_{meas} [GeV]	SU4 m_{MC} [GeV]
$m_{\tilde{\chi}_1^0}$	$88 \pm 60 \mp 2$	118	$62 \pm 126 \mp 0.4$	60
$m_{\tilde{\chi}_2^0}$	$189 \pm 60 \mp 2$	219	$115 \pm 126 \mp 0.4$	114
$m_{\tilde{q}}$	$614 \pm 91 \pm 11$	634	$406 \pm 180 \pm 9$	416
$m_{\tilde{\ell}}$	$122 \pm 61 \mp 2$	155		
Observable	SU3 Δm_{meas} [GeV]	SU3 Δm_{MC} [GeV]	SU4 Δm_{meas} [GeV]	SU4 Δm_{MC} [GeV]
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	$100.6 \pm 1.9 \mp 0.0$	100.7	$52.7 \pm 2.4 \mp 0.0$	53.6
$m_{\tilde{q}} - m_{\tilde{\chi}_1^0}$	$526 \pm 34 \pm 13$	516.0	$344 \pm 53 \pm 9$	356
$m_{\tilde{\ell}} - m_{\tilde{\chi}_1^0}$	$34.2 \pm 3.8 \mp 0.1$	37.6		

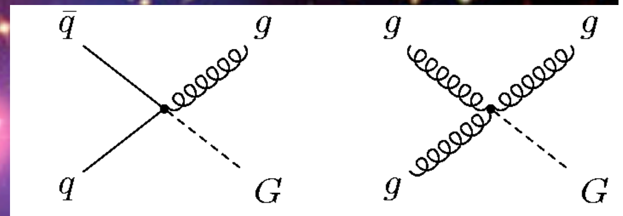
Parameter	SU3 value	fitted value	exp. unc.
	$\text{sign}(\mu) = +1$		
$\tan\beta$	6	7.4	4.6
M_0	100 GeV	98.5 GeV	$\pm$9.3 GeV
$M_{1/2}$	300 GeV	317.7 GeV	$\pm$6.9 GeV
A_0	$-$300 GeV	445 GeV	$\pm$408 GeV
	$\text{sign}(\mu) = -1$		
$\tan\beta$		13.9	$\pm$2.8
M_0		104 GeV	$\pm$18 GeV
$M_{1/2}$		309.6 GeV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

ATLAS Report

Extra space dimensions?







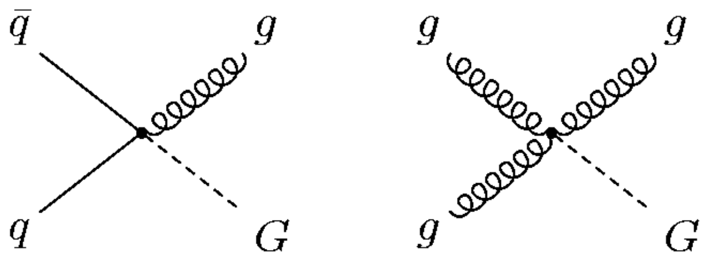
Signatures

Eg monojet events
monophoton events
Z' like resonances
KK excitations
…

The Gravity force becomes strong!

Extra Dimension Signals at the LHC: ADD

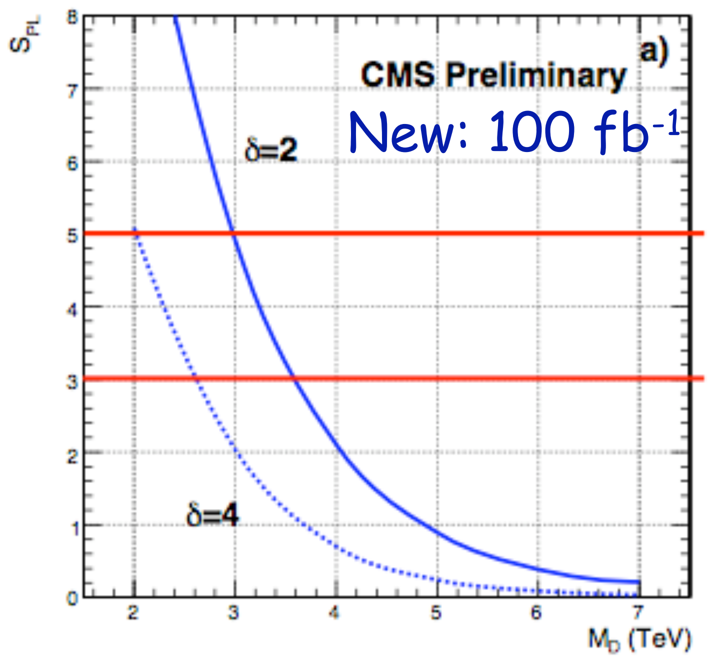
ADD: Arkani –Hamed, Dimopolous,Dvali



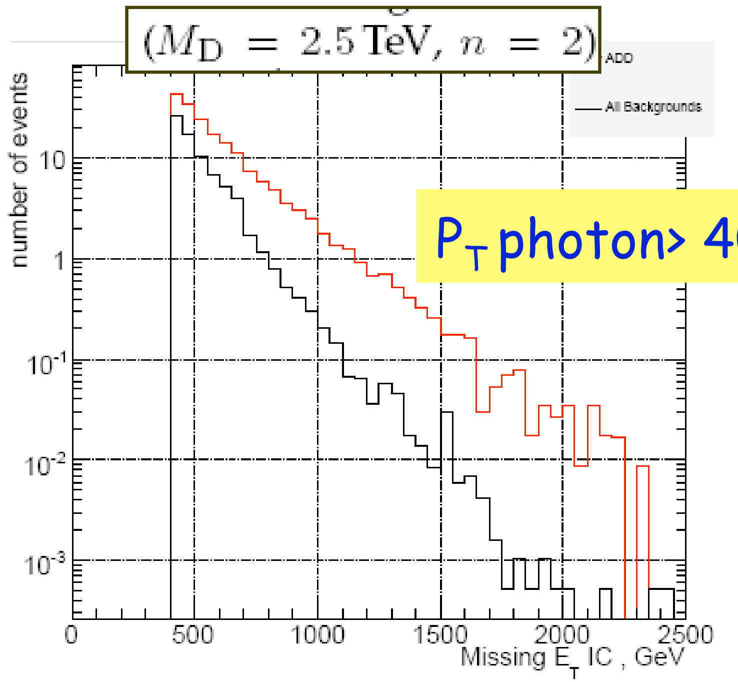
Graviton production!
Graviton escapes detection

Signal: single jet + large missing ET

Signal: single photon + large missing ET



New: 100 fb^{-1}



30fb^{-1}

P_T photon> 400 GeV

δ

CMS PTDR

Test M_D to 2-3 TeV for 100 pb^{-1}

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

Quantum Back Holes

- Schwarzschild radius

Landsberg, Dimopoulos
Giddings, Thomas, Rizzo…

4-dim., $M_{gravity} = M_{Planck}$

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

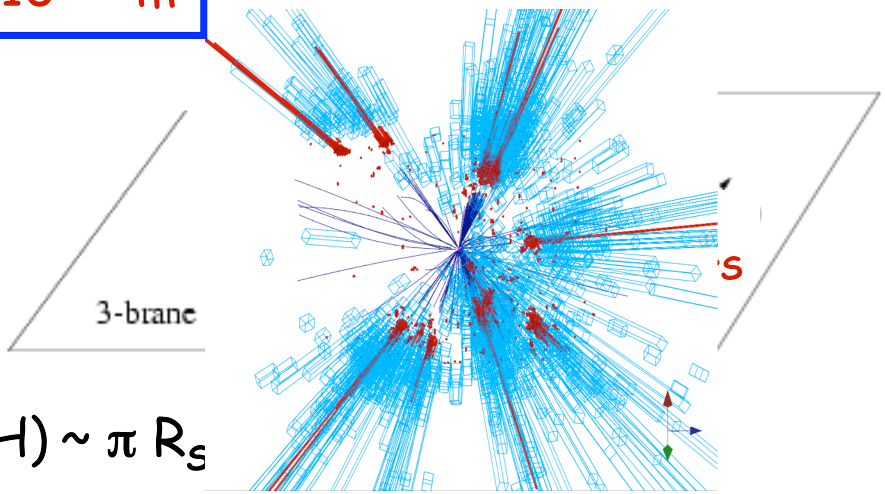
4 + n-dim., $M_{gravity} = M_D \sim$ TeV

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

Harmless: they will decay within less than 10^{-27} seconds

⬇

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

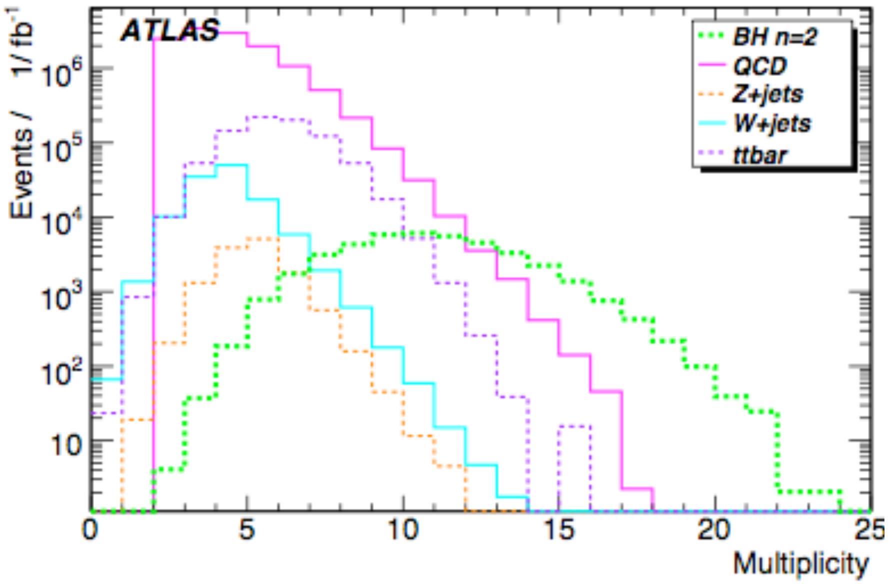
e.g. For M_D ~1 TeV and n=3, produce 1 event/second at the LHC

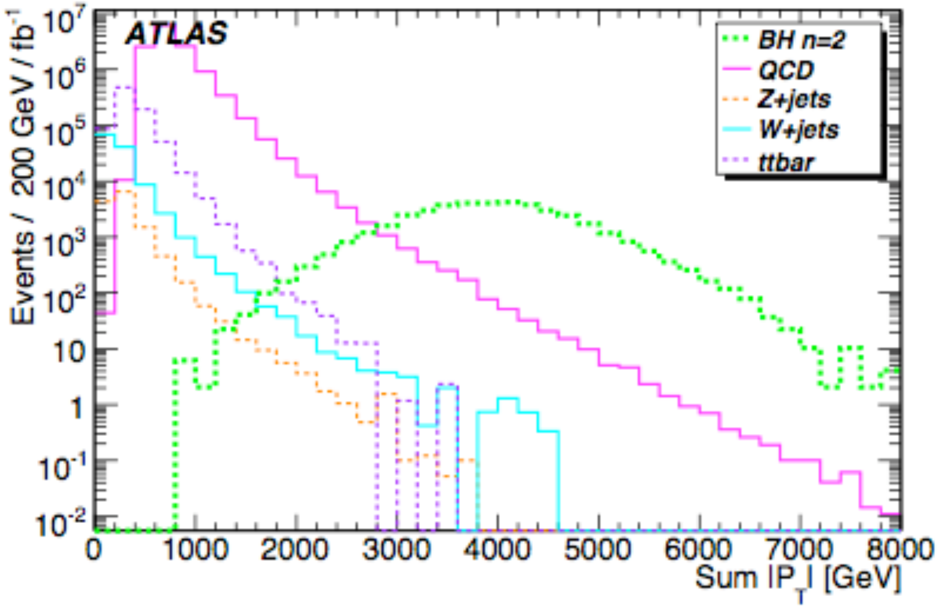
- Black holes decay immediately by Hawking radiation (democratic evaporation) :

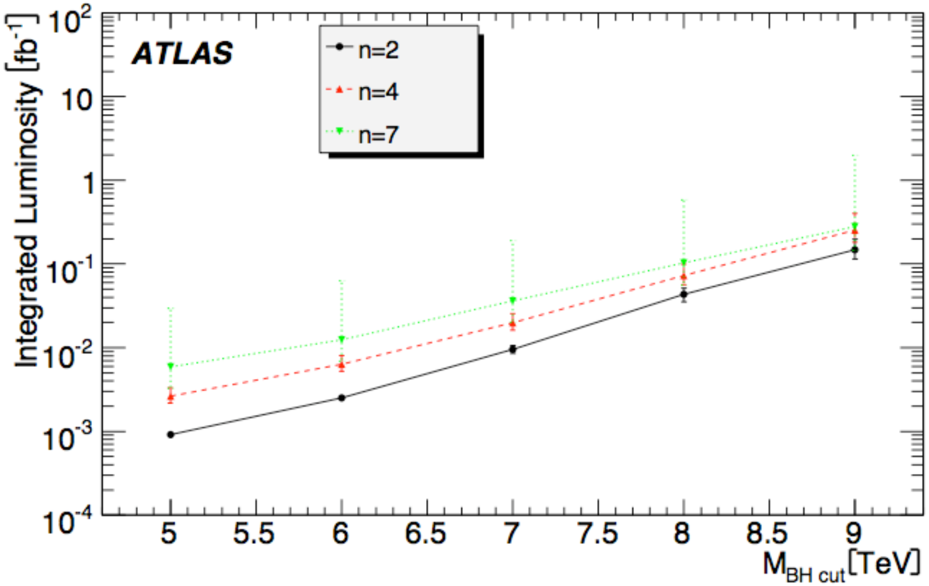
-- large multiplicity
-- small missing E
-- jets/leptons ~ 5

} expected signature (quite spectacular …)

Black Holes







Already sensitive with 1 pb^{-1}!!!

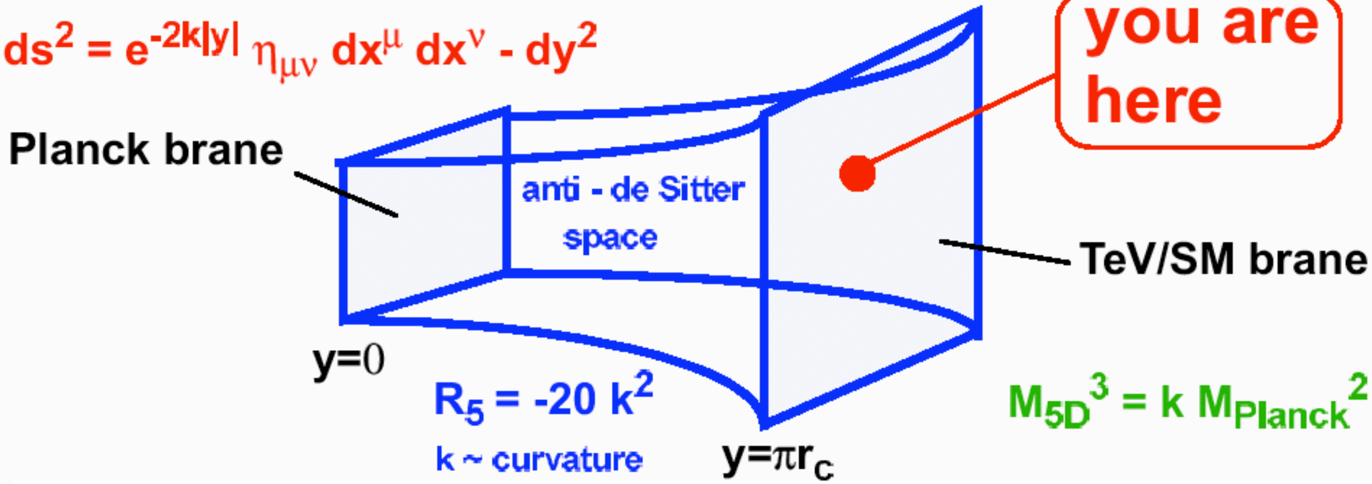
However cross sections largely unknown (and challenged)

Black Holes Hunters at the LHC…

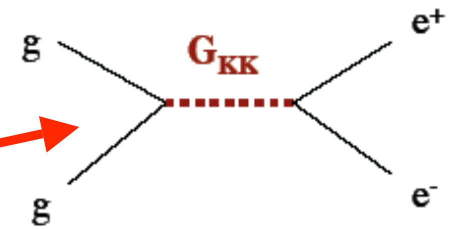
Curved Space: RS Extra Dimensions

Randall, Sundrum, PRL 83, 3370 (1999)

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

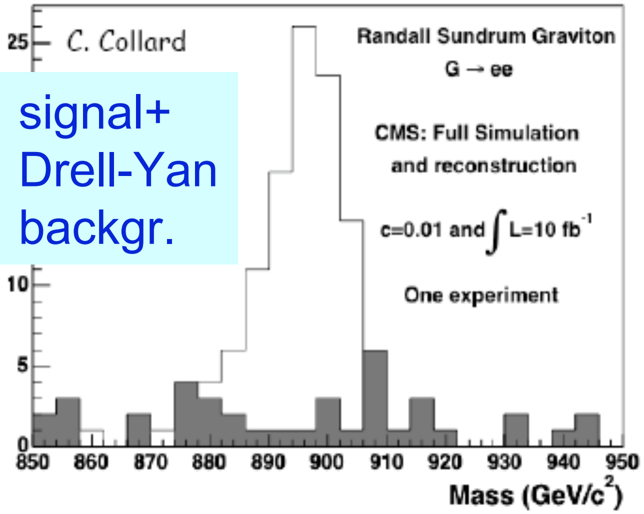


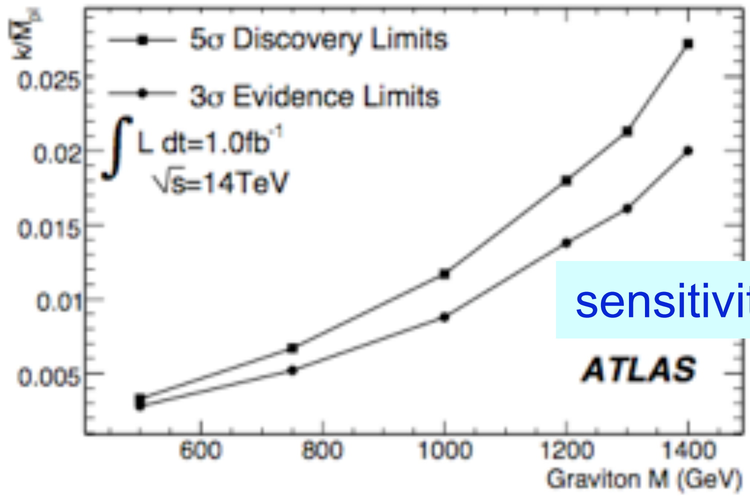
phenomenology



Graviton→ e+e-

signal+ Drell-Yan backgr.





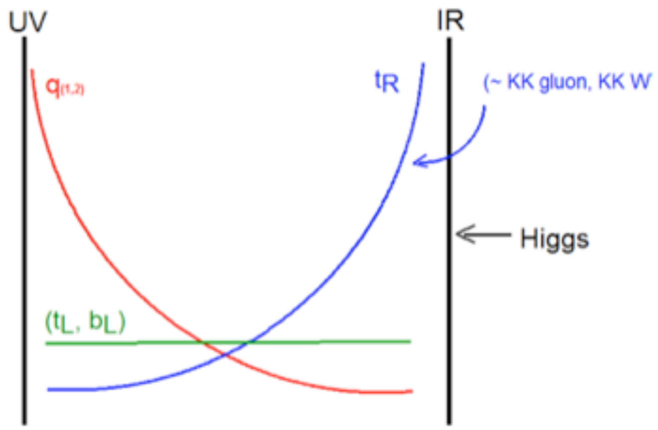
sensitivity

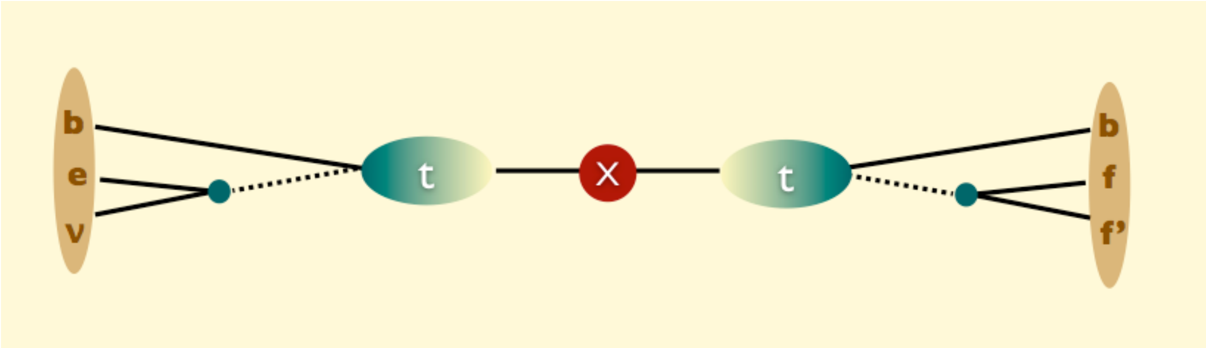
Highly boosted top

Recent developments in models: the prominent role of top production
Top co-anihilation SUSY, top resonances, RS→top top etc.
Often this leads to 'boosted top' ie the hadronic decay jets merge

- Eg RS → t tbar

T. Han et al.



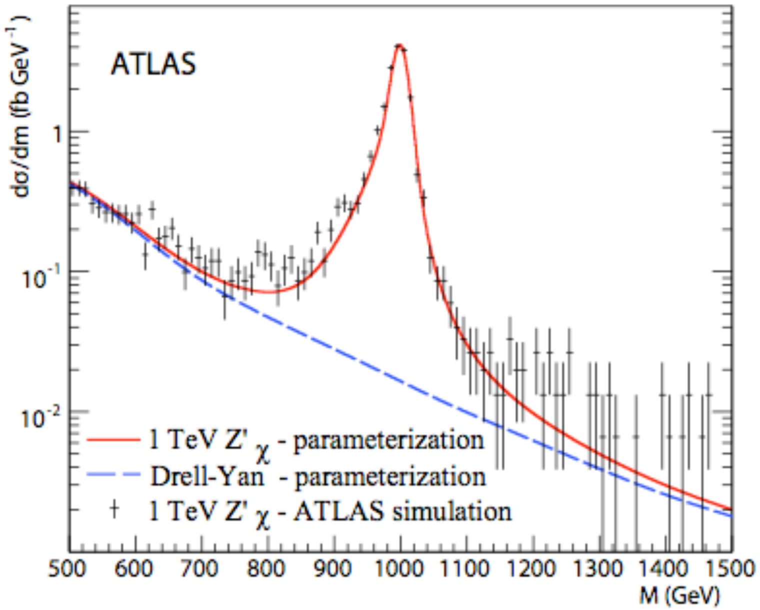


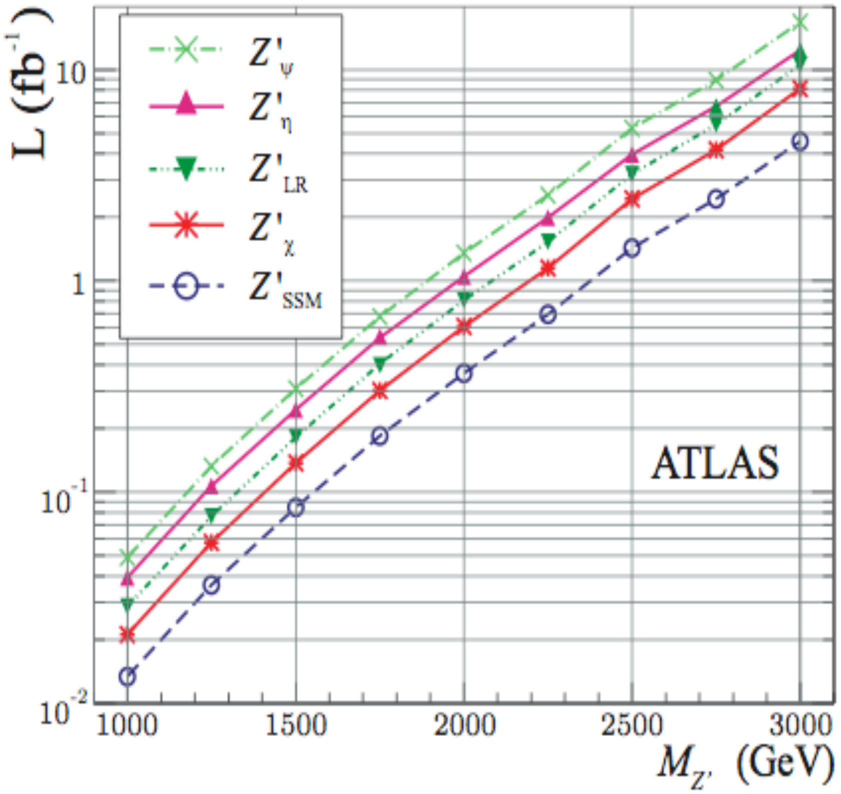
⇒High P_T tops

The jets typically appear as 'fat' jets
with internal structure
⇒ Can be studied with SM top production
→ Tool development
⇒ Needs input for SM 'jet structure' studies

New Gauge Bosons

Z′→ee production





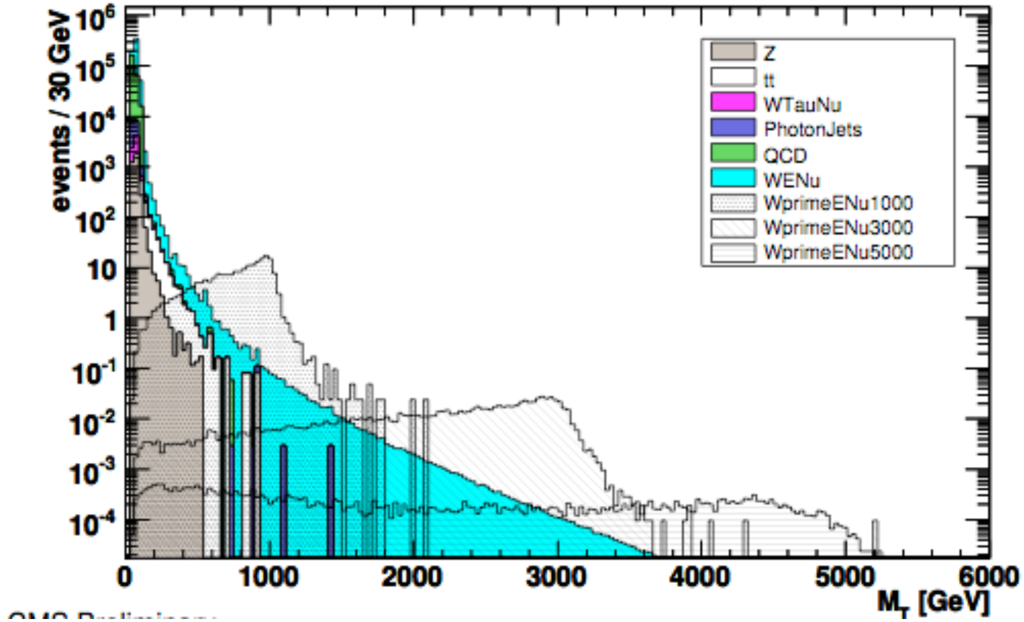
Note: Best possible theory knowledge on Drell Yan spectrum will be needed (tails!)

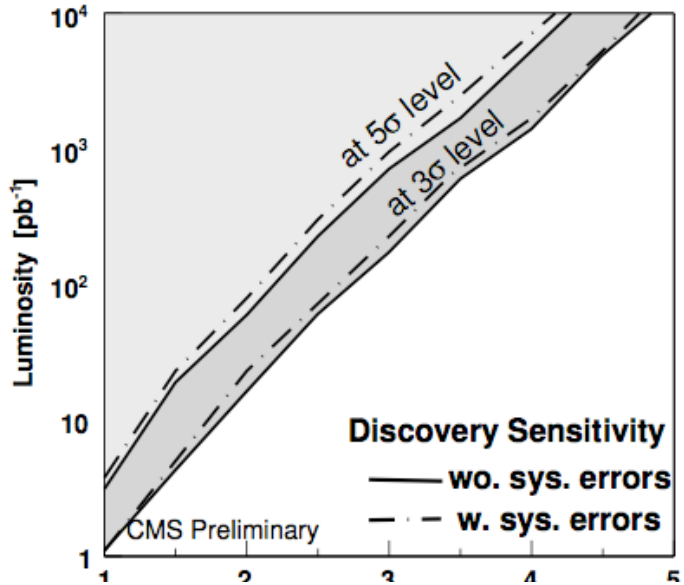
~ similar to CMS results

- 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

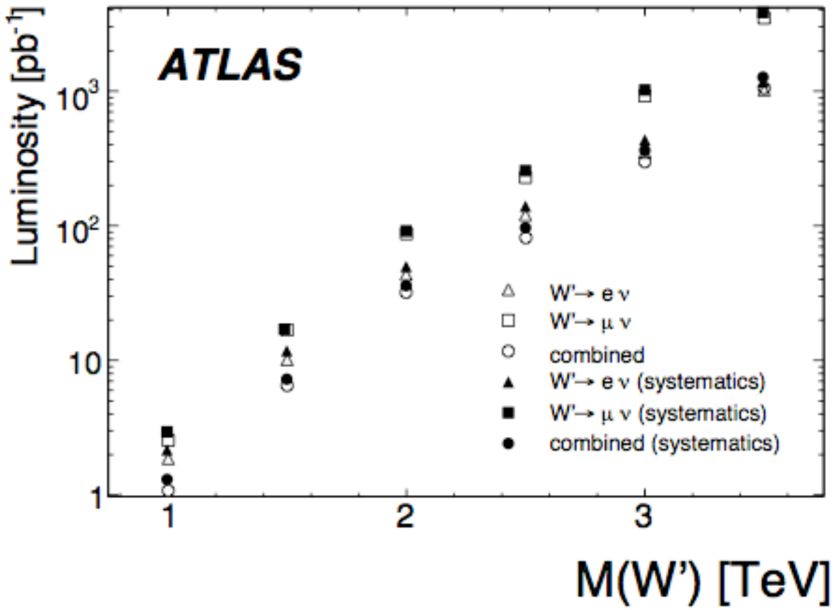
W' Searches

W→μν, eν channels





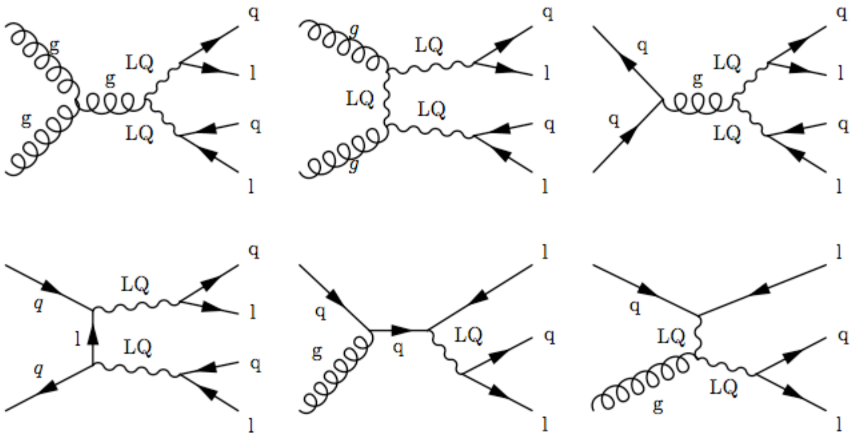
Tevatron > ~ 1 TeV



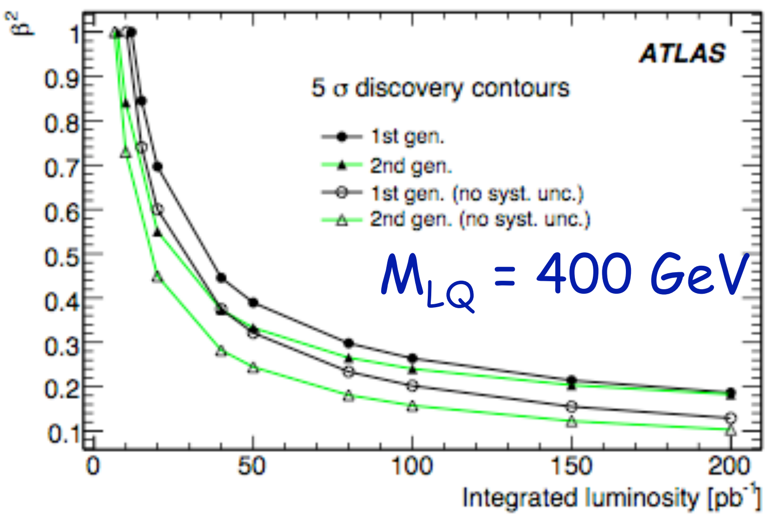
Sensitivity already for 10 pb^{-1}

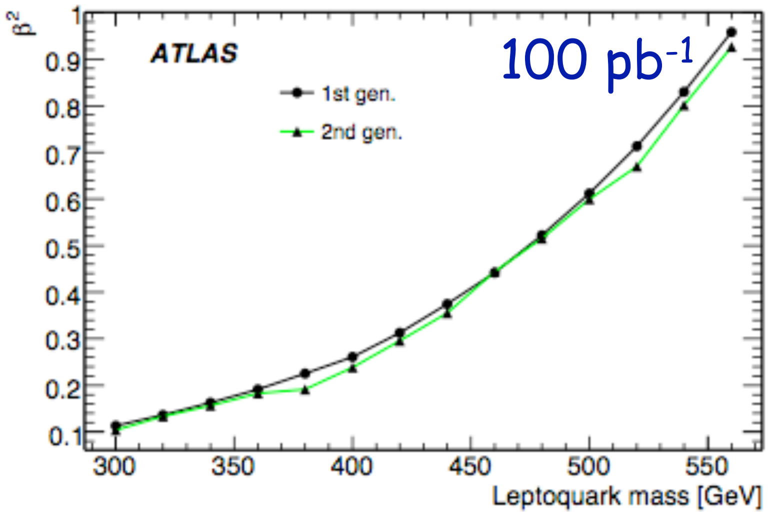
Leptoquark production

Tevatron limits ~ 300 GeV



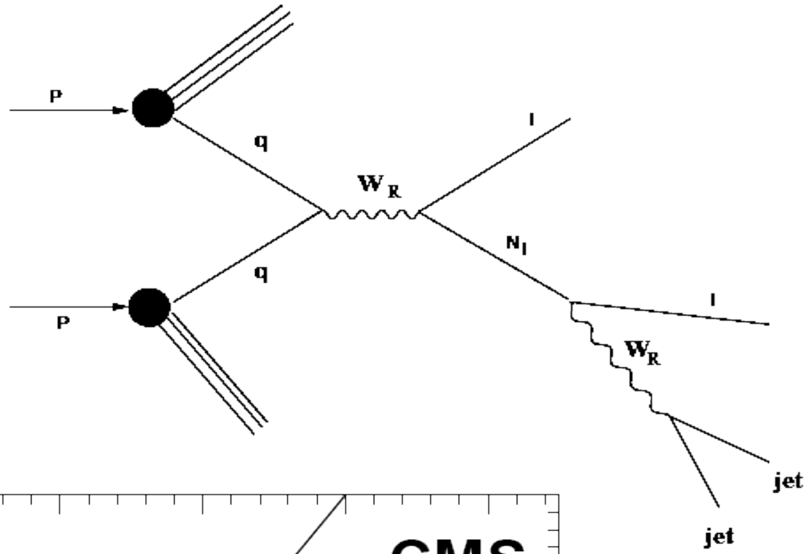
Leptoquark mass	Expected luminosity needed for a 5σ discovery	
	1st gen.	2nd gen.
300 GeV	2.8 pb^{-1}	1.6 pb^{-1}
400 GeV	11.8 pb^{-1}	7.7 pb^{-1}
600 GeV	123 pb^{-1}	103 pb^{-1}
800 GeV	1094 pb^{-1}	664 pb^{-1}

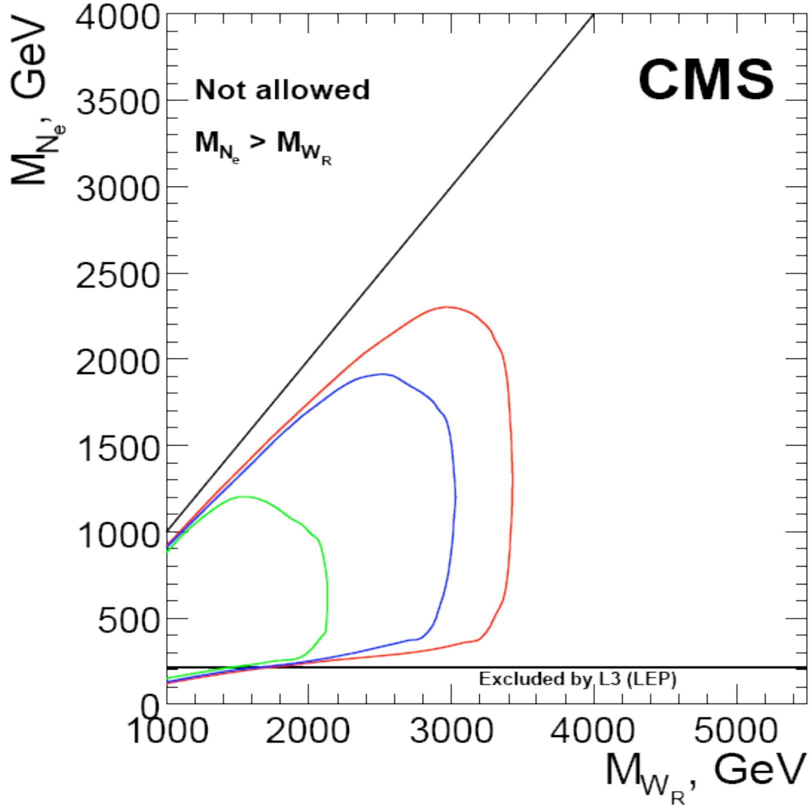




> 10 pb^{-1} to enter a new mass domain

Heavy Neutrinos





CMS discovery potential of the W_R boson and right-handed Majorana neutrino for luminosity 30 fb^{-1}, 10 fb^{-1}, 1 fb^{-1}.

$$S = 2(\sqrt{N_S + N_B} - \sqrt{N_B}) \geq 5$$

Tevatron limits
WR>0.7 TeV

N>0.3 TeV

M(WR) = 1.2 TeV, M(Nl) = 500 GeV can be discovered with 40 pb^{-1} @ 10 TeV

New Signatures

Recent Studies: New Signatures

Split Supersymmetry

- Assumes nature is fine tuned and SUSY is broken at some high scale
- The only light particles are the Higgs and the gauginos

  - Gluino can live long: sec, min, years!

  - R-hadron formation: slow, heavy particles containing a heavy gluino.

  Unusual interactions with material

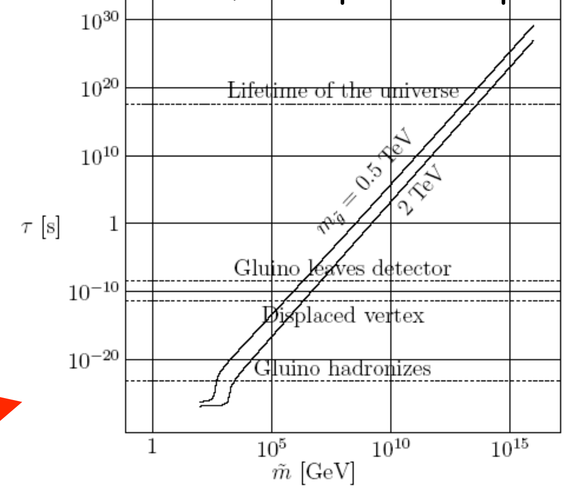
  eg. with the calorimeters of the experiments!

Gravitino Dark Matter and GMSB

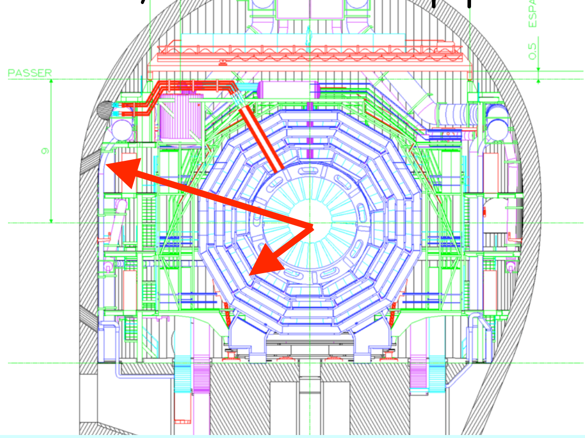
- In some models/phase space the gravitino is the LSP
- $\Rightarrow$ NLSP (neutralino, stau lepton) can live 'long'
- $\Rightarrow$ non-pointing photons

$\Rightarrow$Challenge to the experiments!

Arkani-Hamed, Dimopoulos hep-th/0405159



K. Hamaguchi,M Nijori,ADR hep-ph/0612060
ADR, J. Ellis et al. hep-ph/0508198



Sparticles stopped in the detector,walls of the cavern, or dense 'stopper' detector. They decay after hours---months...

New Stable Particles

Predicted by several models:

- lepton like
  - •GMSB staus
  - •Kaluza-Klein tau's in UED
- R-Hadrons
  - •long lived stop in SUSY
  - •long lived gluino in split-susy

Properties:

•O(100 GeV), β<1

•$c\tau$ few meters

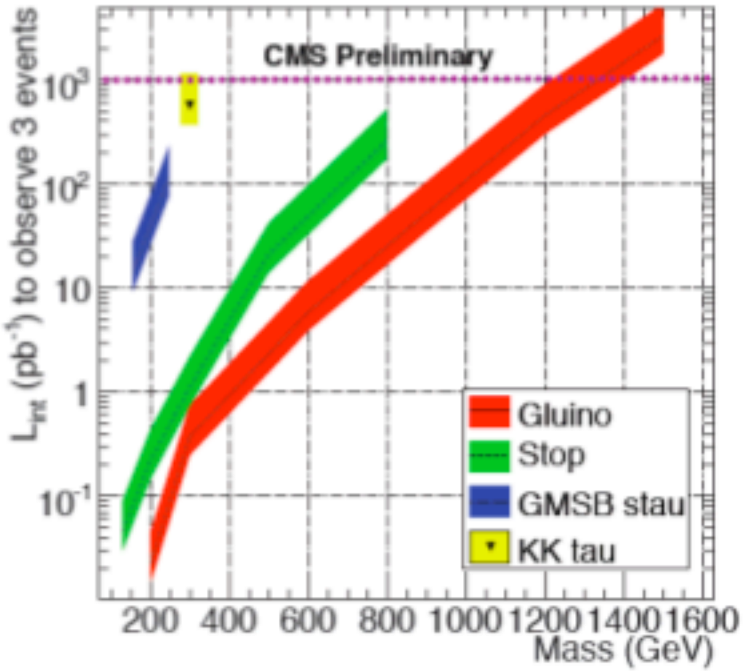
•electrical or colour charge

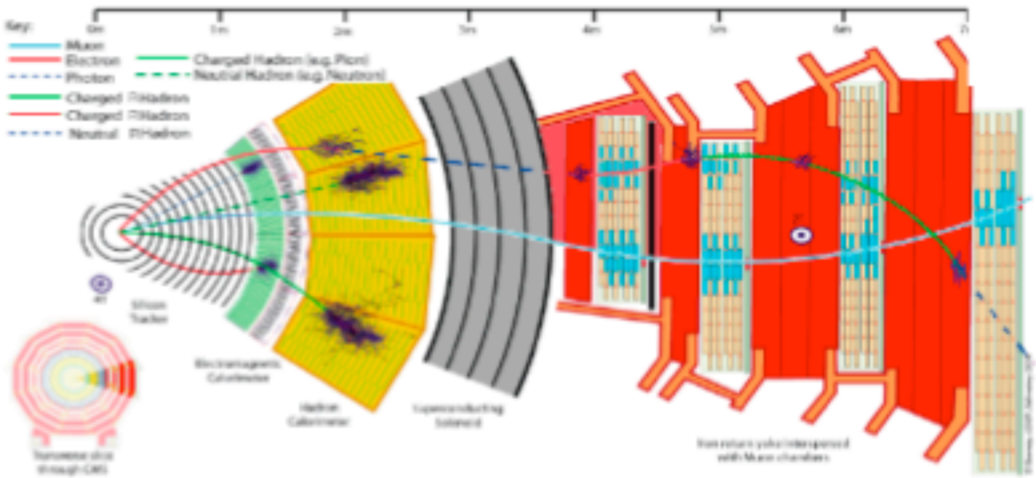
Measurement

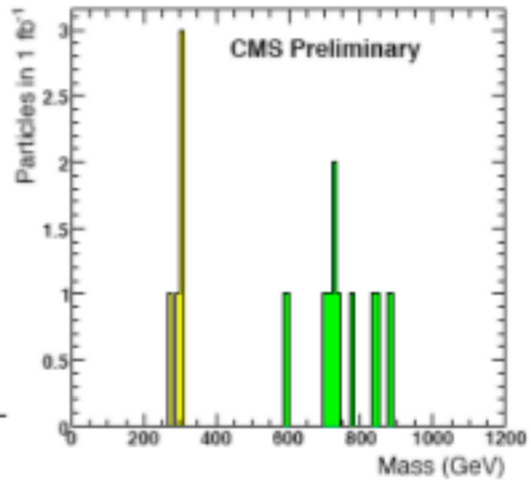
• momentum in Tracker&Muon

•β TOF in Muon DT & dE/dx in Tracker

ATLAS similar







Strings 2008 O. Buchmüller

Split SUSY

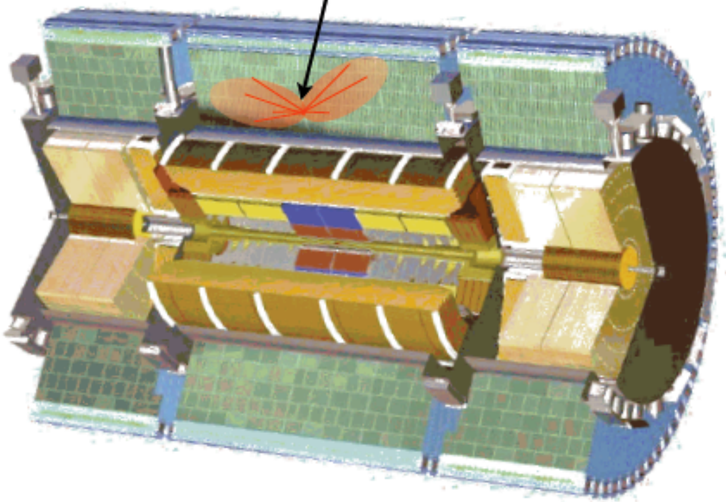
Arvanitaki et al.

Long Lived Gluinos

$\tau_{\tilde{g}} > 100$ ns

looking for stopped gluinos that later decay

100s GeV Unbalanced $= \not{E}_T$

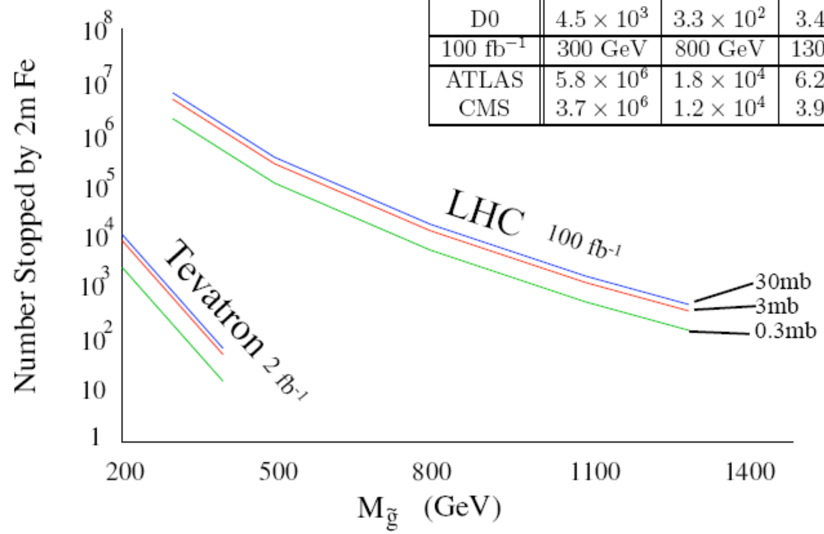


Uncorrelated with any beam crossing
No tracks going to or from activity

Total Number of Stopped Gluinos

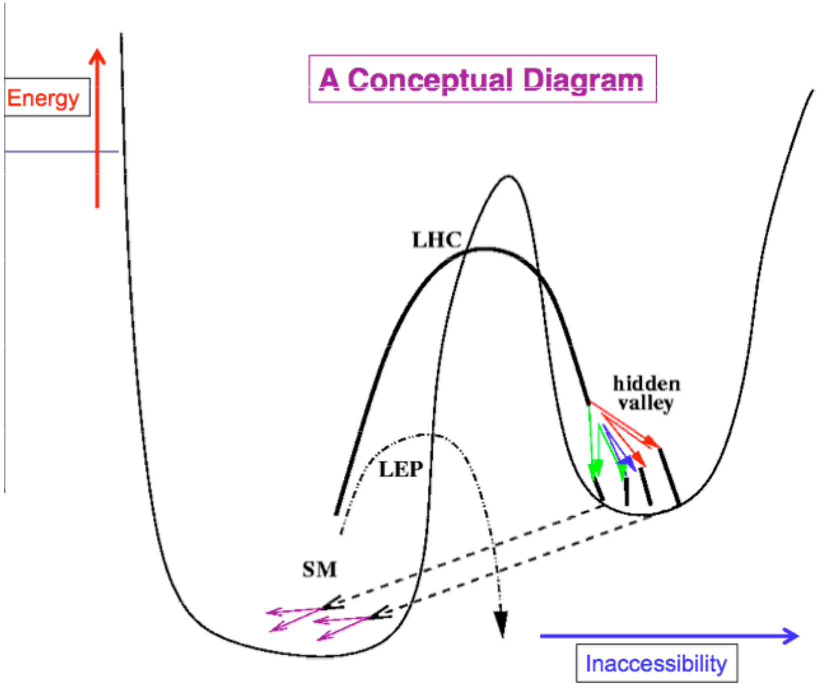
Arvanitaki, Dimopoulos, Pierce, Rajendran, JW hep-ph/0506242

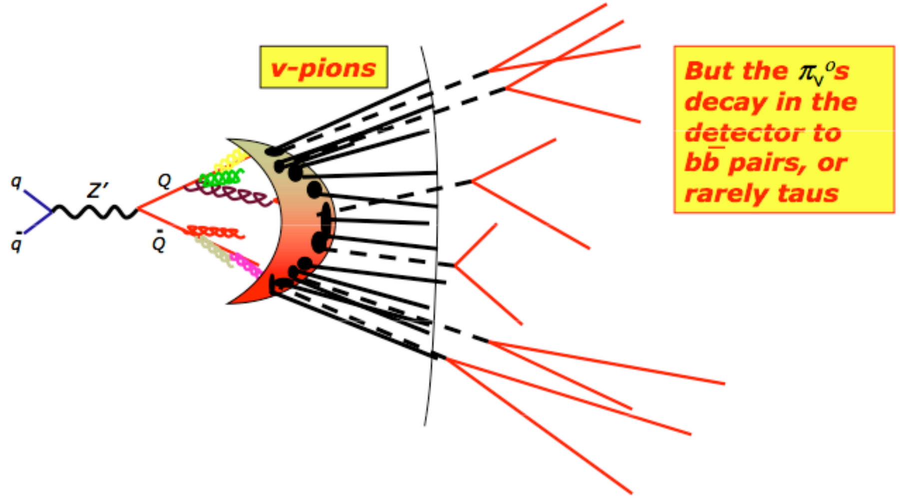
$2\ fb^{-1}$	200 GeV	300 GeV	400 GeV
CDF	4.1×10^3	3.1×10^2	3.3×10^1
D0	4.5×10^3	3.3×10^2	3.4×10^1
$100\ fb^{-1}$	300 GeV	800 GeV	1300 GeV
ATLAS	5.8×10^6	1.8×10^4	6.2×10^2
CMS	3.7×10^6	1.2×10^4	3.9×10^2



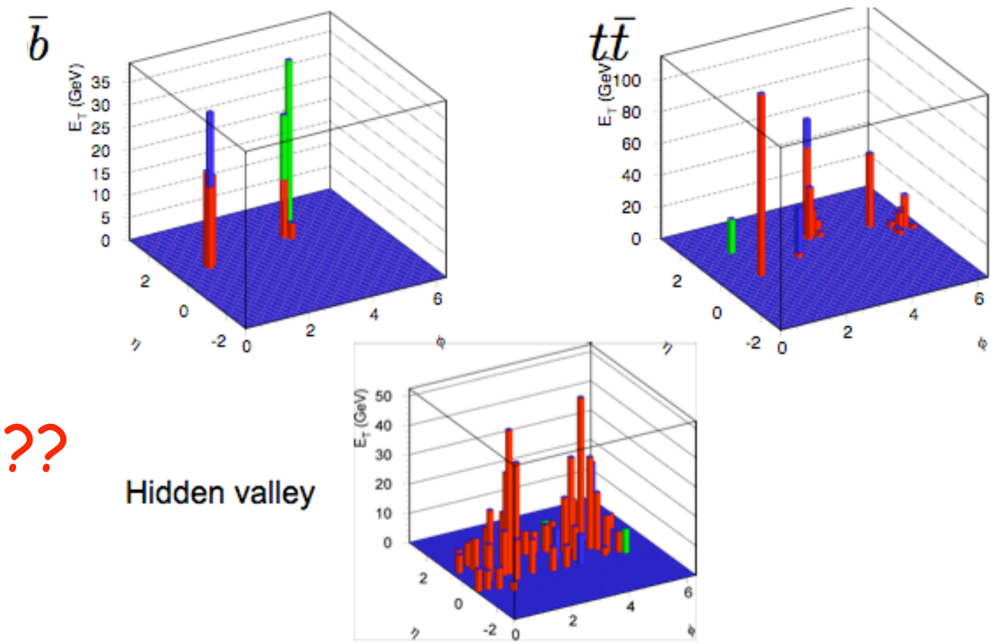
⇒ Special triggers needed, asynchronous with the bunch crossing

Hidden Valley Physics: New Signatures





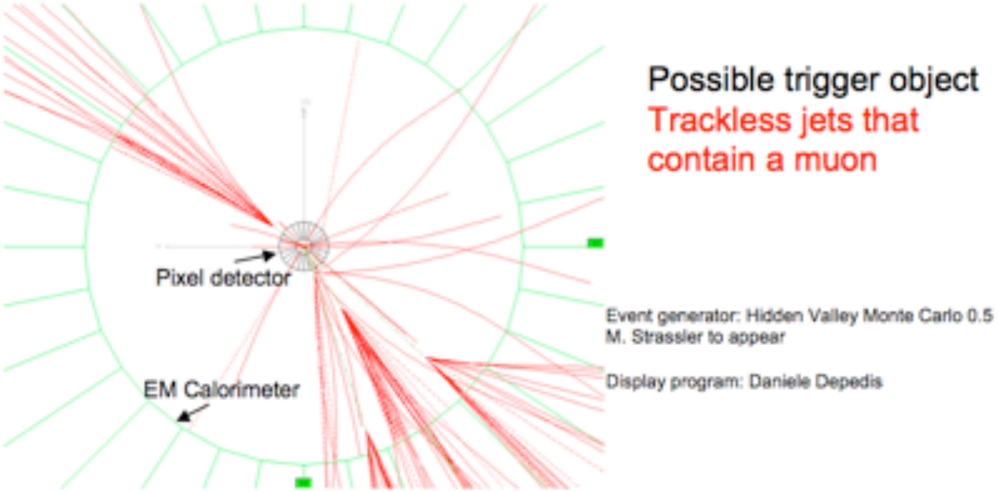
Will produce "Weird Jets" and a lot of secondary vertices



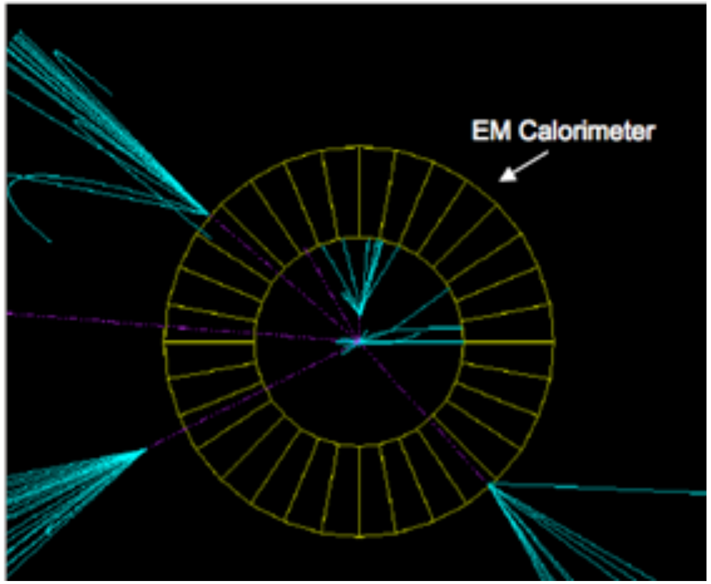
⇒ Difference with QCD jets??

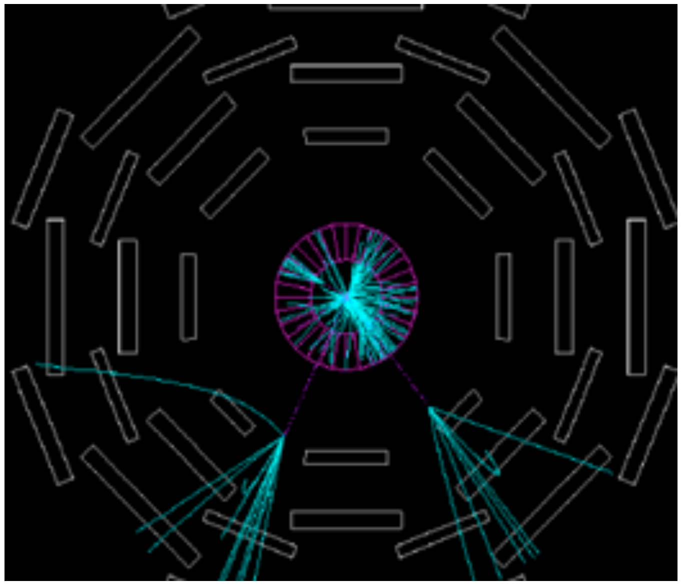
⇒ Study SM jet structure

Hidden Valley Events



ATLAS: Trigger issues for events with large displayed vertices

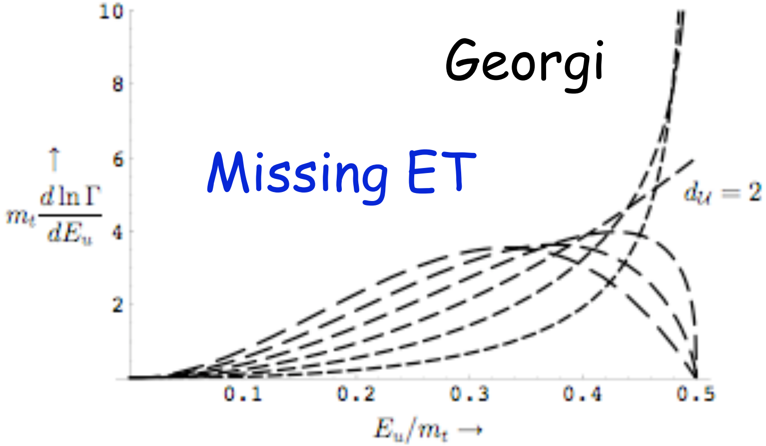




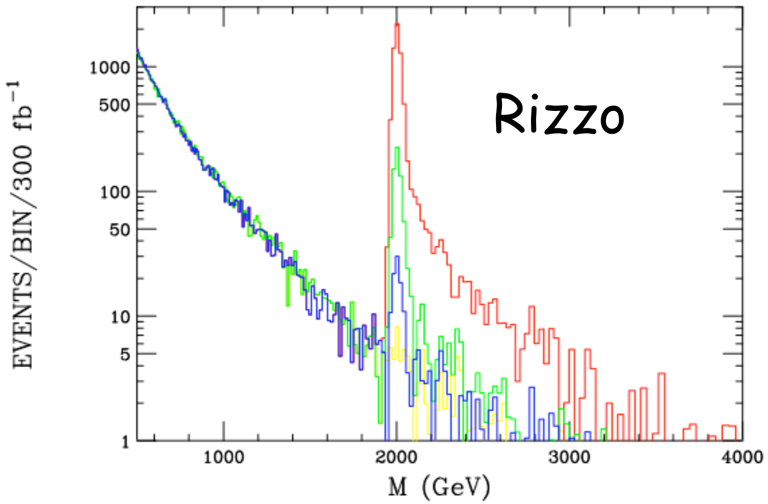
⇒Needs special triggers

Unparticles

Top decay $t \to u + \mathcal{U}$



Decaying unparticles



•QFT possibility: sector that is scale invariant leading to new physics weakly coupled to SM through heavy mediators

⇒Unparticle stuff (Georgi, '07 + >100 new papers)
arXiv:hep-ph/0703260

•Real unparticle production

–Monophotons at LEP: $e^+e^- \to \gamma$ U

–Monojets at Tevatron, LHC: g g → g U

•Virtual unparticle exchange

–Scalar unparticles: f f → U → $\mu^+\mu^-$, g g , ZZ,… [No interference with SM]

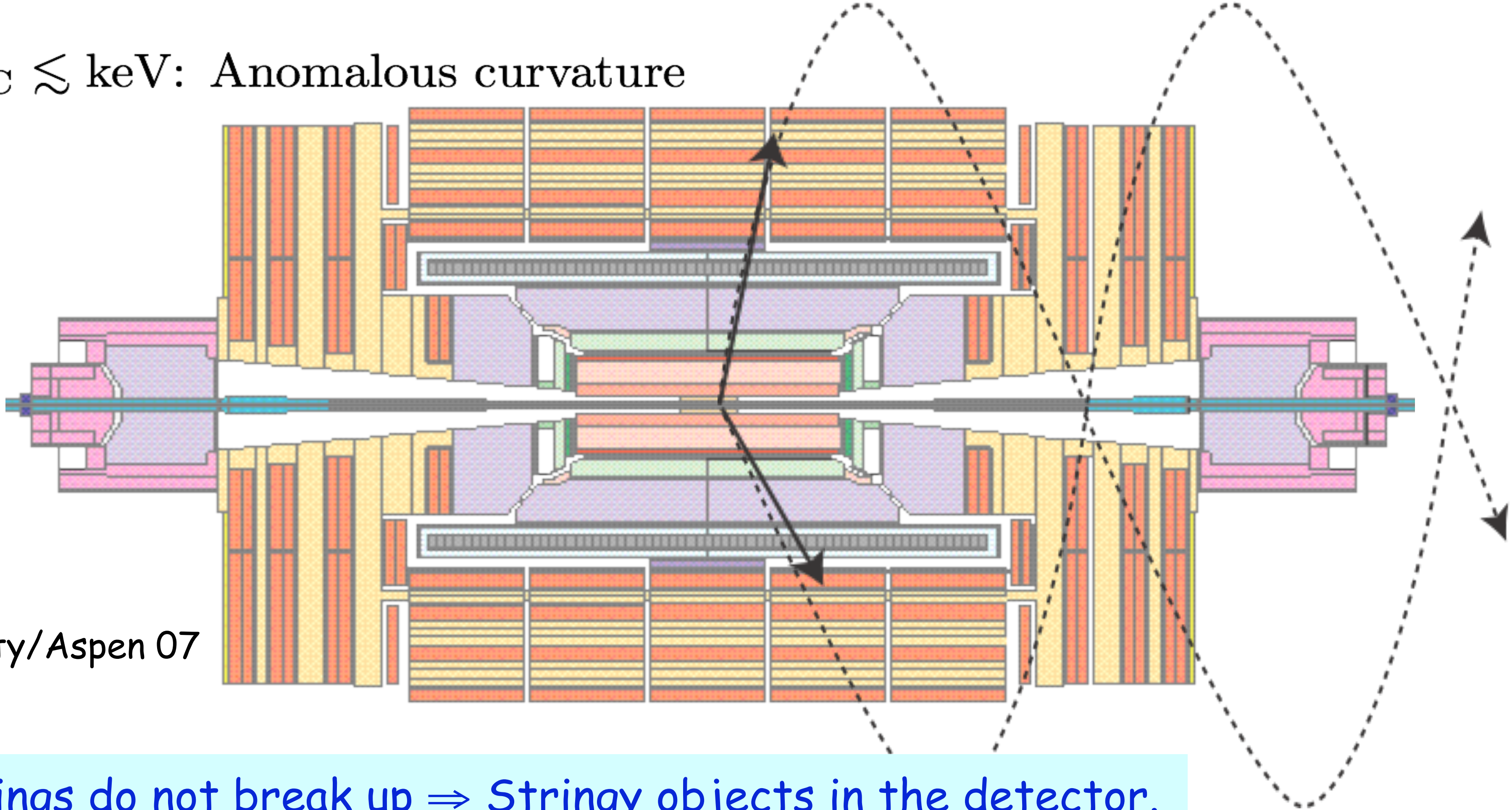
–Vector unparticles: e^+e^- → U^m → $\mu^+\mu^-$, qq, …

Other signatures: "funny jets"
high multiple photon rates

Macro-Strings at the LHC?

New strong interactions with small Λ & new quarks m_Q> several hundered GeV

$\Lambda_{IC} \lesssim \text{keV}$: Anomalous curvature

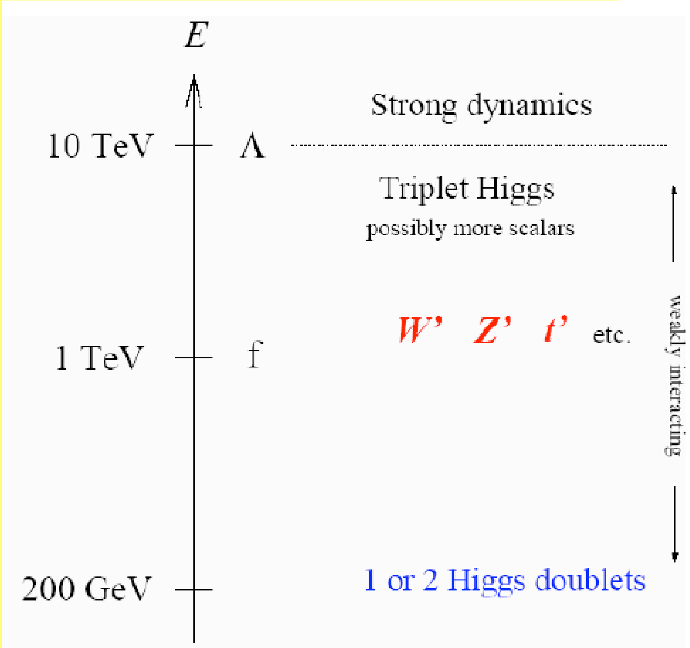


Markus Luty/Aspen 07

- Strings do not break up ⇒ Stringy objects in the detector.
- End points are massive quarks (quirks)
- The strings can oscillate⇒ strange signature in detectors

Other New Physics Ideas…

- Plenty!
  - Models with strong dynamics, eg. Little Higgs models
  - Technicolor
  - Lepton jets
  - Compositness
  - SUSY+ Extra dimensions
  - WW,WZ resonances
  - T-Balls
  - Bi-leptons
  - Monopoles
  - …

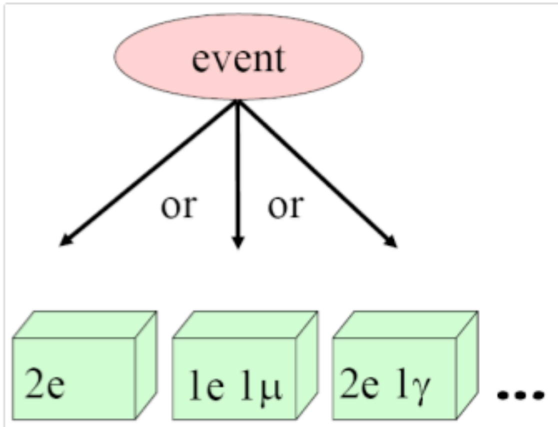


Have to keep our eyes open for all possibilities:
Food for many PhD theses!!

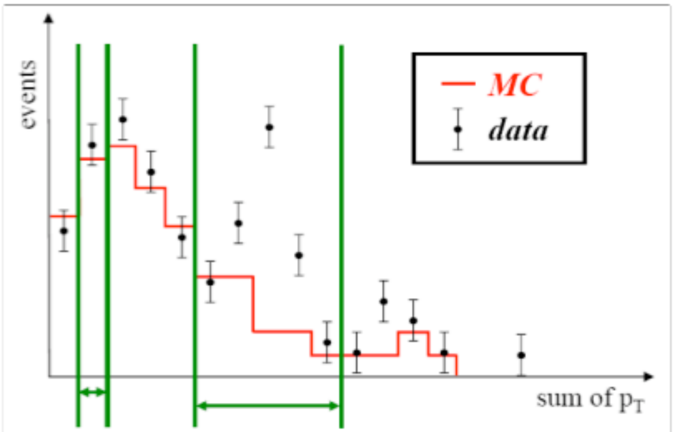
Generic Searches

Eg: MUSiC "Model Unspecified Search in CMS"

- Classify events by particle content
  - Single isolated lepton always required
    → easy trigger, less QCD
  - Exclusive & inclusive final states
    (~ 300 classes each)
  - e, μ, γ, jet, MET



- Scan distributions for statistically significant deviations
  - Presently $\sum p_T$, invariant (transverse) mass, MET
  - Dedicated algorithm searching biggest discrepancy
- Takes systematic uncertainties into account
- A priori sensitive to detector effects and new physics



Epilogue

…we do not know what is out there for us….

Nature.com

…so we will look at it from all angles….

Close interaction between Experiment and Theory will be important

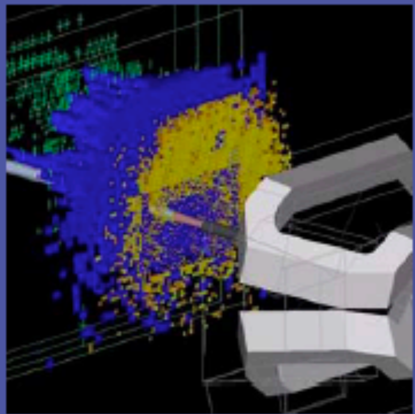
4th CERN-FERMILAB
HADRON COLLIDER PHYSICS SUMMER SCHOOL
CERN, 8-17 June 2009

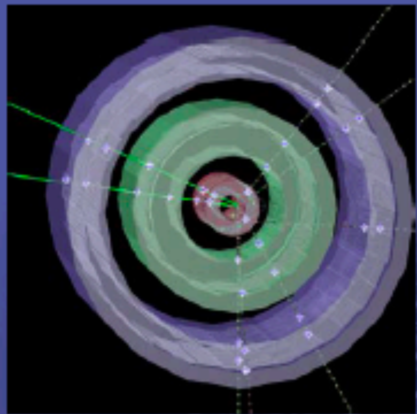
The CERN-Fermilab Hadron Collider Physics schools are targeted particularly at young postdocs and senior PhD students.

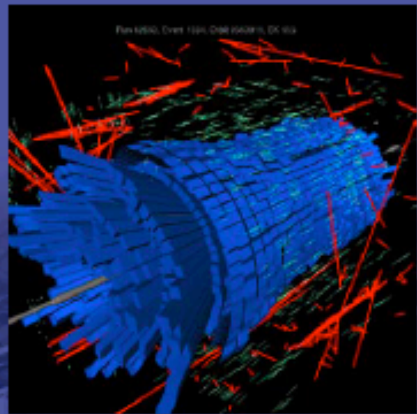
Application deadline
21 February 2009

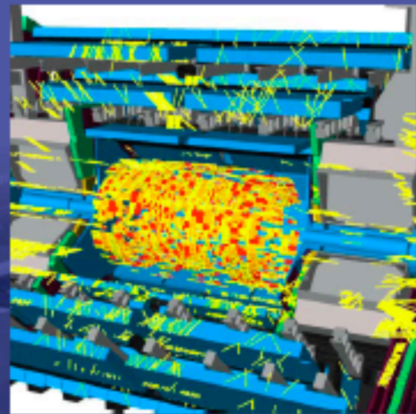
More information at : http://cern.ch/hcpss/
cern-fnal-school-sec@cern.ch

Main topics:
Electroweak and Higgs Physics
LHC Accelerator
Physics of heavy flavours
Statistics
Heavy flavours at LHC
QCD and MC tools
Particle detection and reconstruction
Beyond the SM
Trigger and data analysis
The road to discovery at the LHC
Heavy ion Physics









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Paris Sphicas , Athens and CERN, CMS
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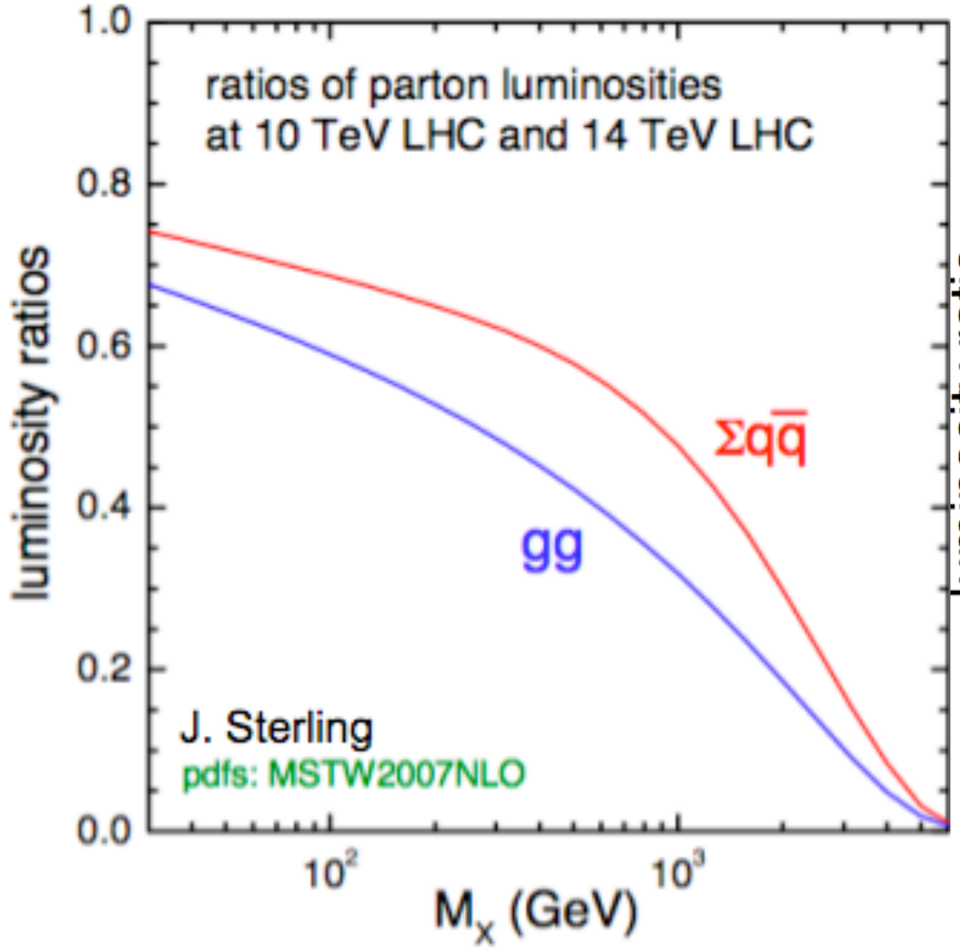
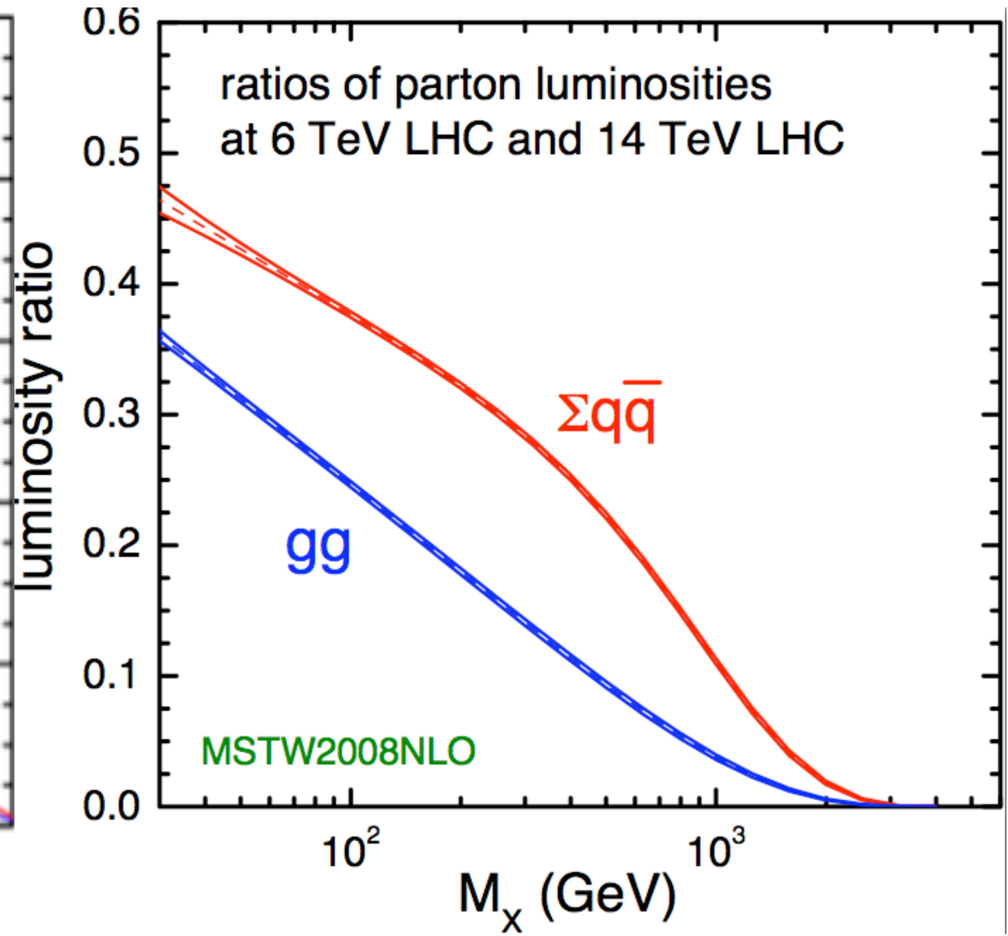
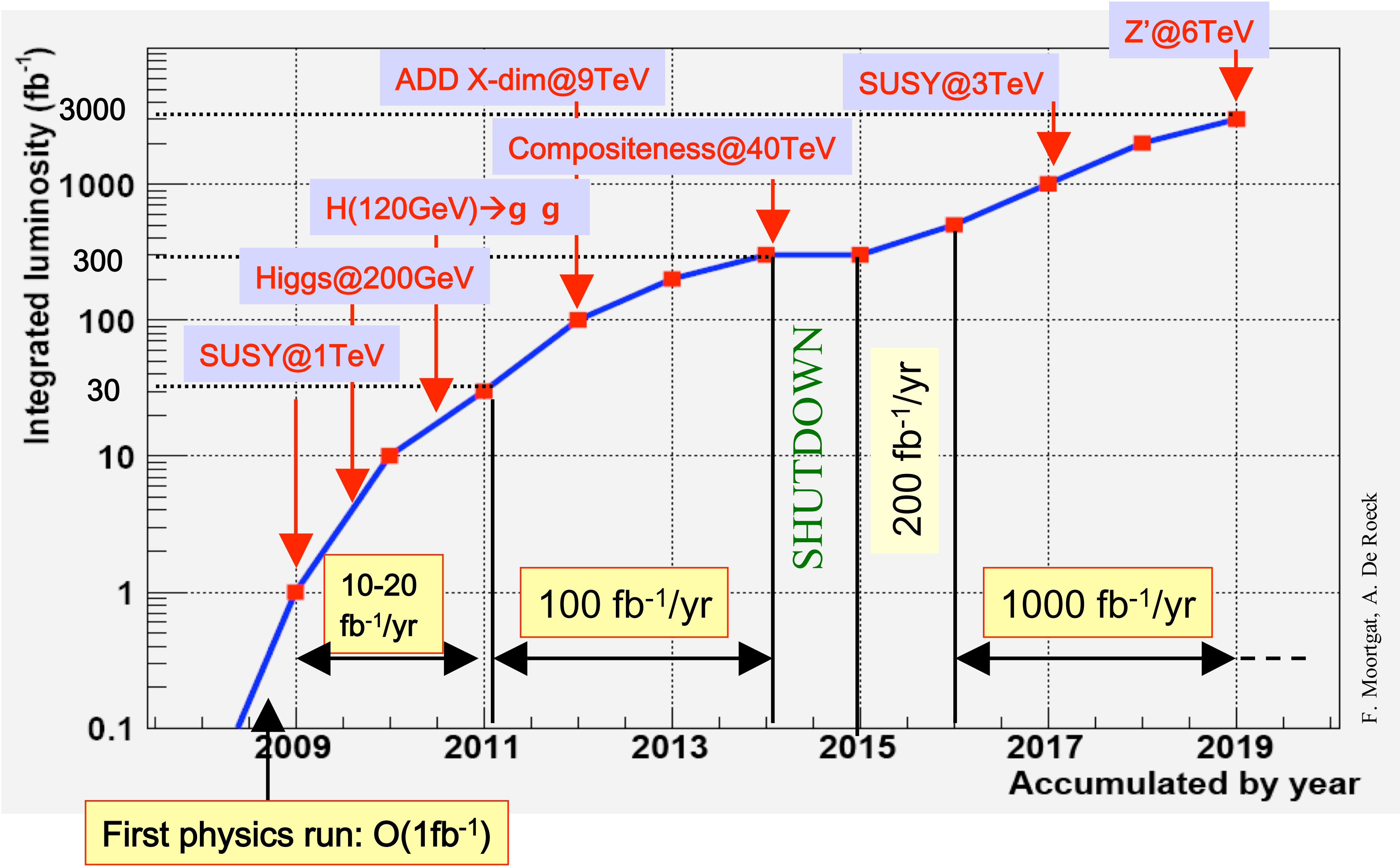
Backup

6 TeV ⇔ 10 TeV ⇔ 14 TeV





LHC Luminosity/Sensitivity with Time

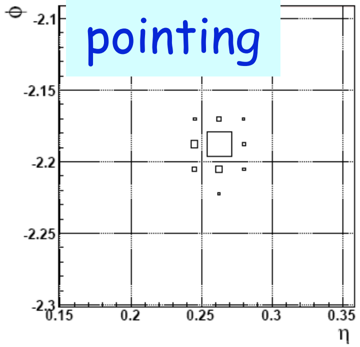


Recent CMS Analyses

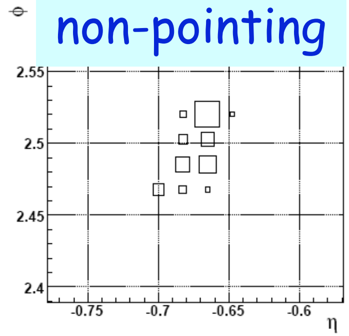
• GMSB: Non-pointing photons

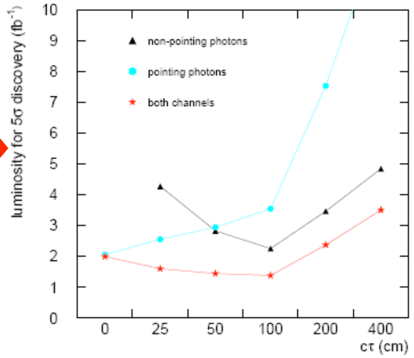
GMSB parameters $N = 1 \quad \tan\beta = 1 \quad \mathrm{sgn}\,\mu = 1 \quad M_m = 2\Lambda$

pointing



non-pointing

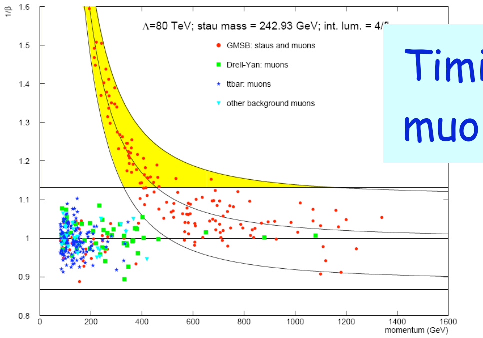




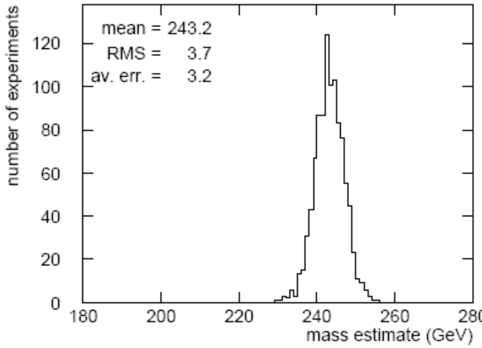
χ cτ lifetime extraction with ~20% precision

• GMSB: long living staus

GMSB parameters $N = 3 \quad \tan\beta = 3 \quad \mathrm{sgn}\,\mu = 1 \quad M_m = 2\Lambda$



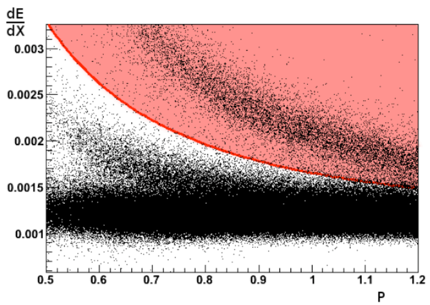
Timing (β) in muon detectors



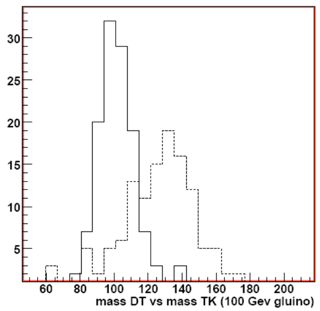
stau mass extraction with a few % precision

• R-hadrons

trigger/mass meas. for region β > 0.6

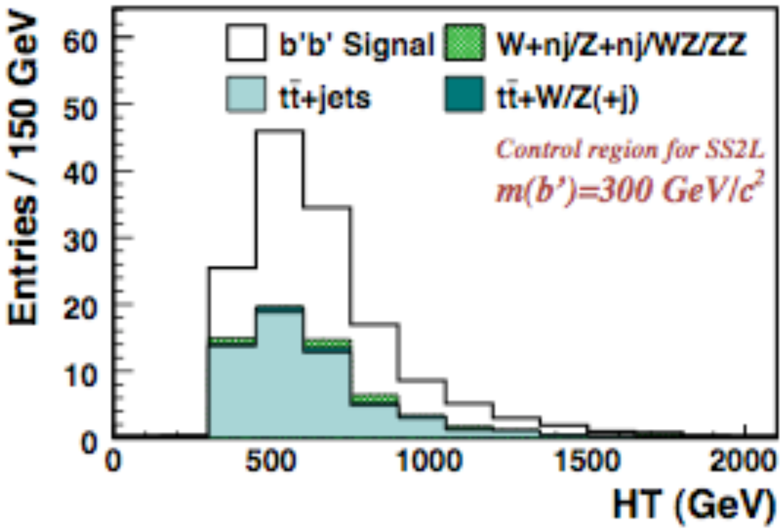


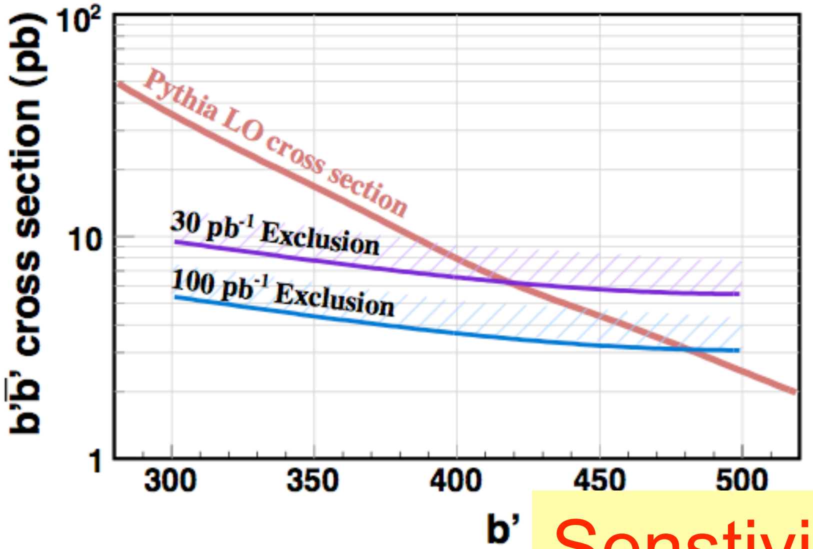
de/dx in the tracker



β-tracker
β-muons

b' production

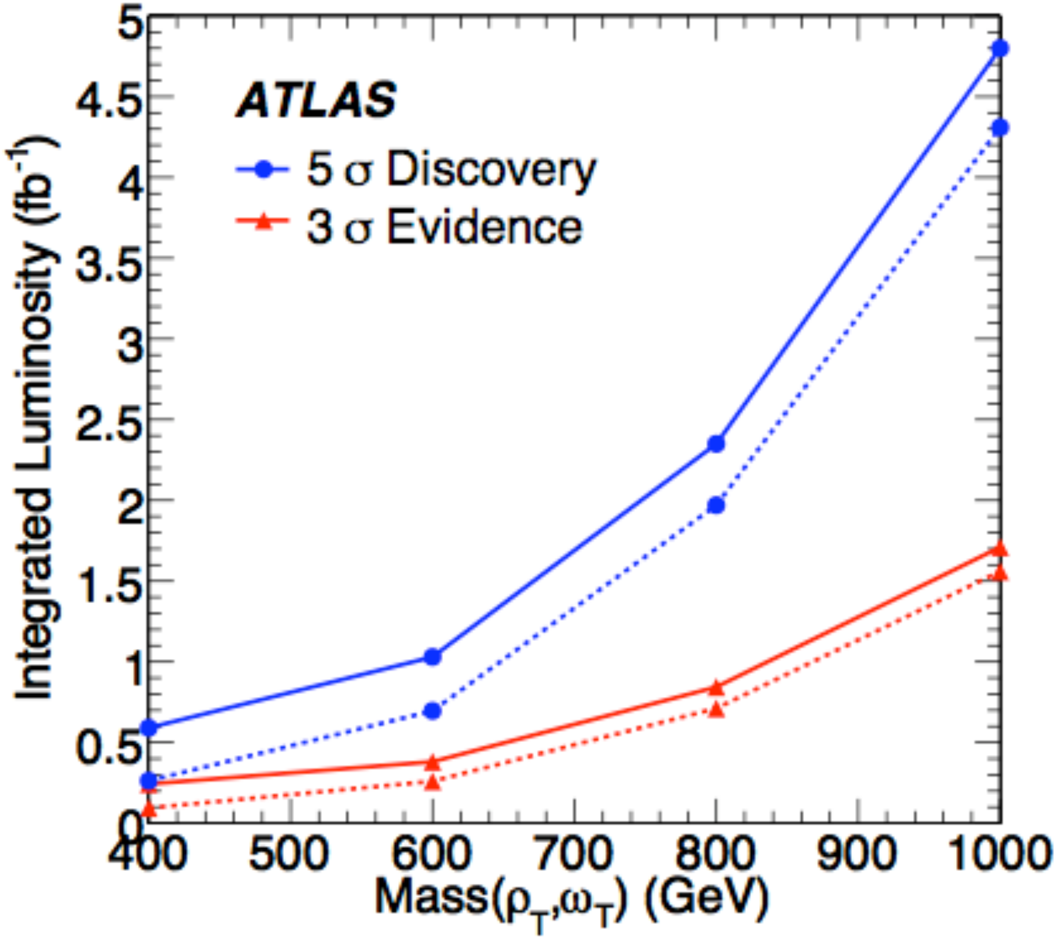




Senstivity ~400 GeV with 100 pb^{-1}

Technicolor

$\rho_T \rightarrow \mu^+\mu^-$ and $\omega_T \rightarrow \mu^+\mu^-$



Luminosoties of ~ 1 fb-1 pr more needed

Micro Black Holes

- Can LHC destroy the planet?

  $\Rightarrow$ 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*

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

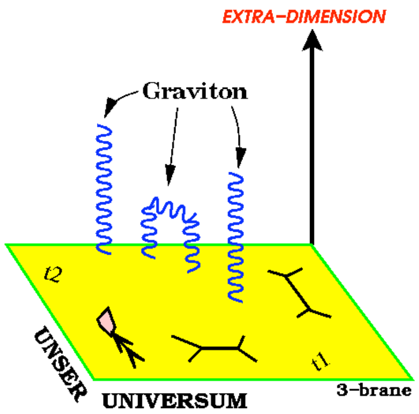
Large Extra Dimensions

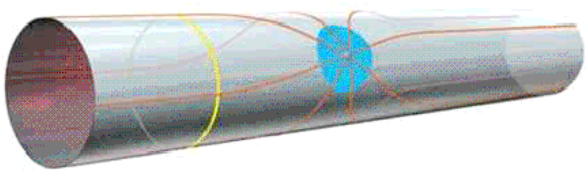
ADD: Arkani –Hamed, Dimopolous,Dvali

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

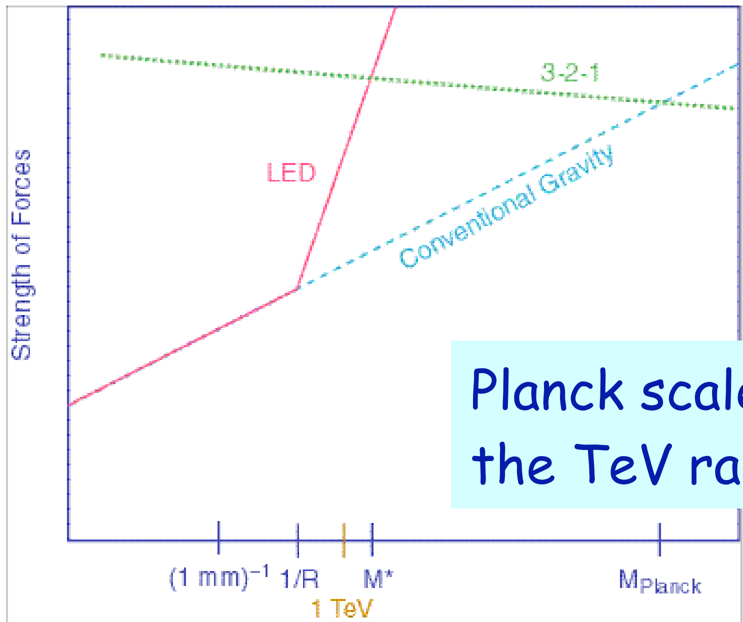
String Theory Inspired

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…



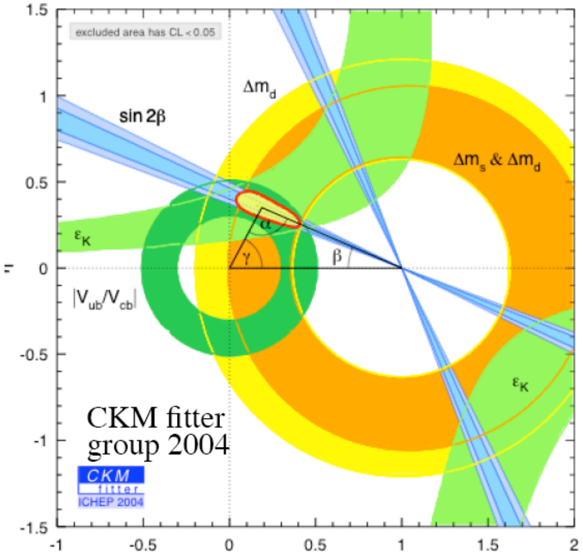
Planck scale in the TeV range?

LHCb: b-physics at the LHC

Examples

CKM triangle

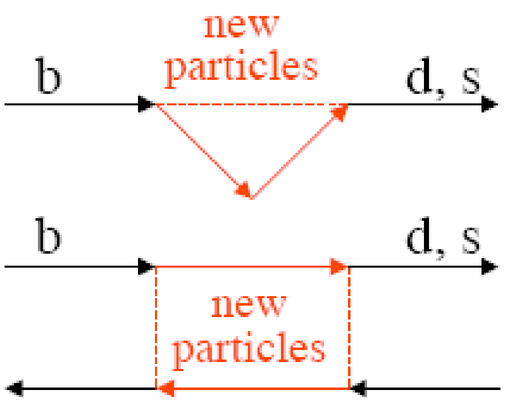
including $\not{C}\not{P}$ B and K



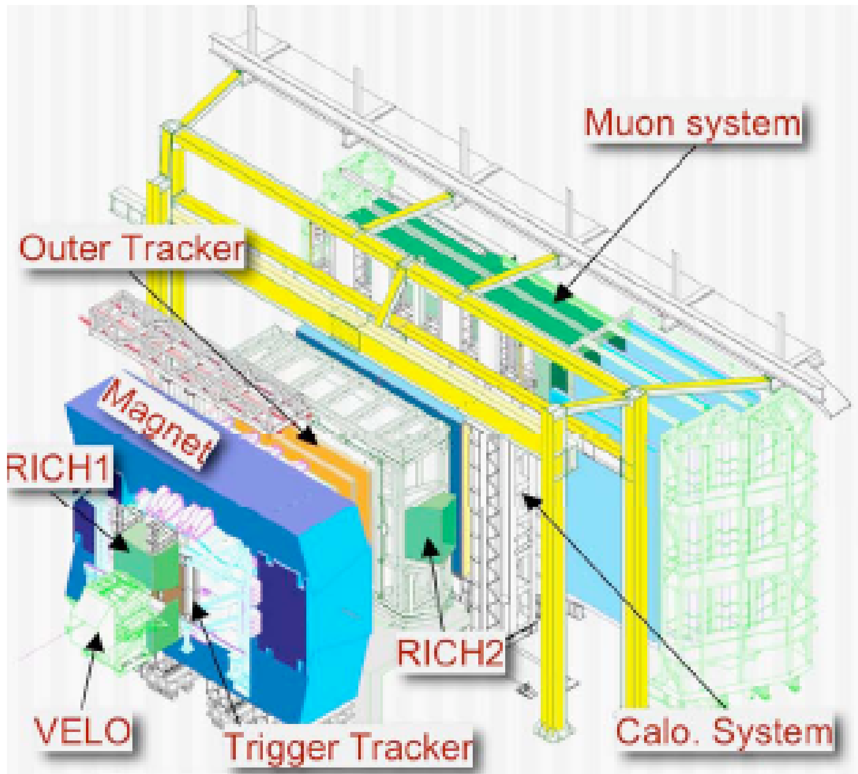
$B_s \rightarrow J/\psi\phi$ 120k signal events/year in LHCb

$\sigma(\sin\phi_s) \sim 0.06$, $\sigma(\Delta\Gamma_s/\Gamma_s) \sim 0.02$

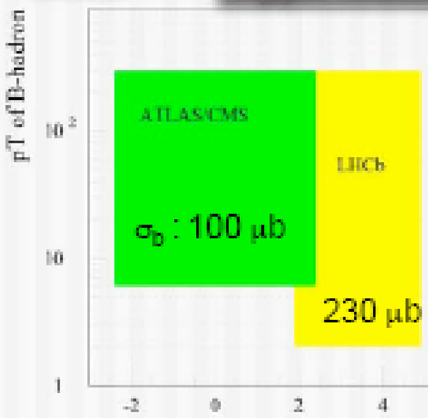
Measurement of B_s–$\bar{B}_s$ oscillation

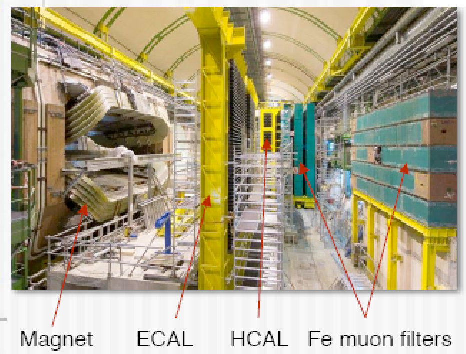


Sensitive to new physics complementary to ATLAS/CMS



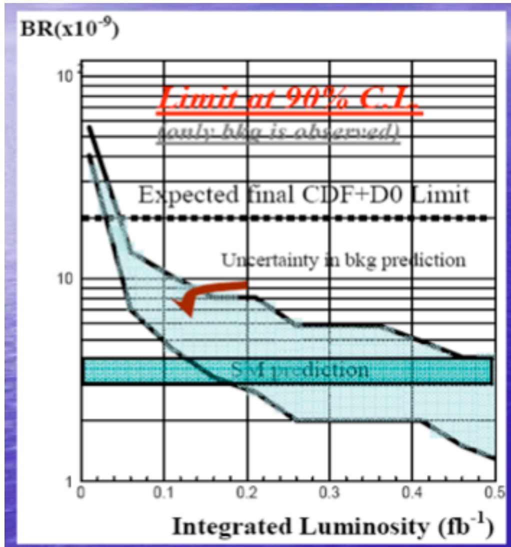
L ~ 2×10^{32} cm^{-2}s^{-1}

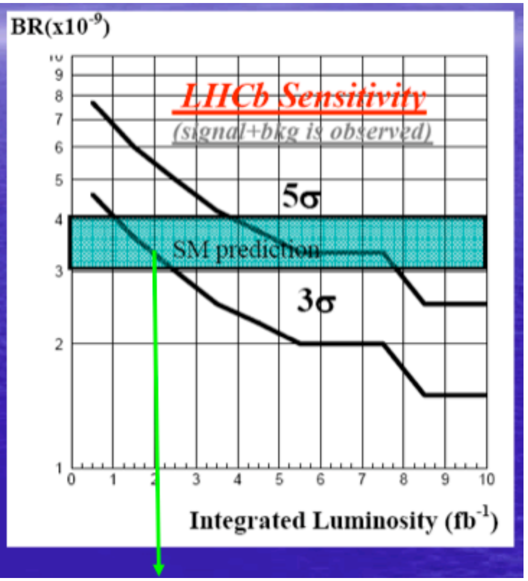




LHCb: Hunt New Physics

- B_s oscillations
  - Measurement of oscillation parameters with $b \to c$ cbar s
- Radiative and EW penguin decays (FCNC transitions)
  - $b \to s\gamma$
  - $b \to sll$
- Very rare decays: $B_s \to \mu\mu$





3σ observation possible with $2 fb^{-1}$, 5σ discovery with $5 fb^{-1}$

Limit at 90% CL already with $0.5\ fb^{-1}$

ϕ_s

Decay mode	Yield (/2 fb^{-1})	$\sigma(\phi_s)$
$J/\Psi\eta_{\gamma\gamma}$	8.5k	0.109
$J/\Psi\eta_{\pi\pi\pi 0}$	3k	0.142
$J/\Psi\eta'_{\pi\pi\eta}$	2.2k	0.154
$J/\Psi\eta'_{\rho\gamma}$	4.2k	0.08
$\eta_c\Phi$	3k	0.108
$D_s^+D_s^-$	4k	0.133
All CP eig.	-	0.046
$J/\Psi\Phi$	130k	0.023
All modes	-	0.021

Tools & Theoretical Estimates

The LHC will be a precision and hopefully discovery machine
But it needs strong collaboration with theorists

Examples

- Precision predictions of cross sections
- Estimates for backgrounds to new physics
- Monte Carlo programs (tuned) for SM processes: W,Z,t.. + njets and more..
- Monte Carlo programs for signals (ED's,...)
- Evaluation of systematics due to theory uncertainties
- Higher order calculations
- New phenomenology/signatures to look for
- Discriminating variables among different theories
- Getting spin information from particles
- Tools to interprete the new signals in an as model independent way as possible (MARMOSET, footprints?)
- ...

After the Champagne…

- WHEN new physics is discovered at the LHC, how well can we determine what it is? Does a specific experimental signature map back into a unique theory with a fixed set of parameters?

- Even within a very specific context, e.g., the MSSM, can one uniquely determine the values of, e.g., the weak scale Lagrangian parameters from LHC data alone?

Is it SUSY?

Example: Universal Extra Dimensions

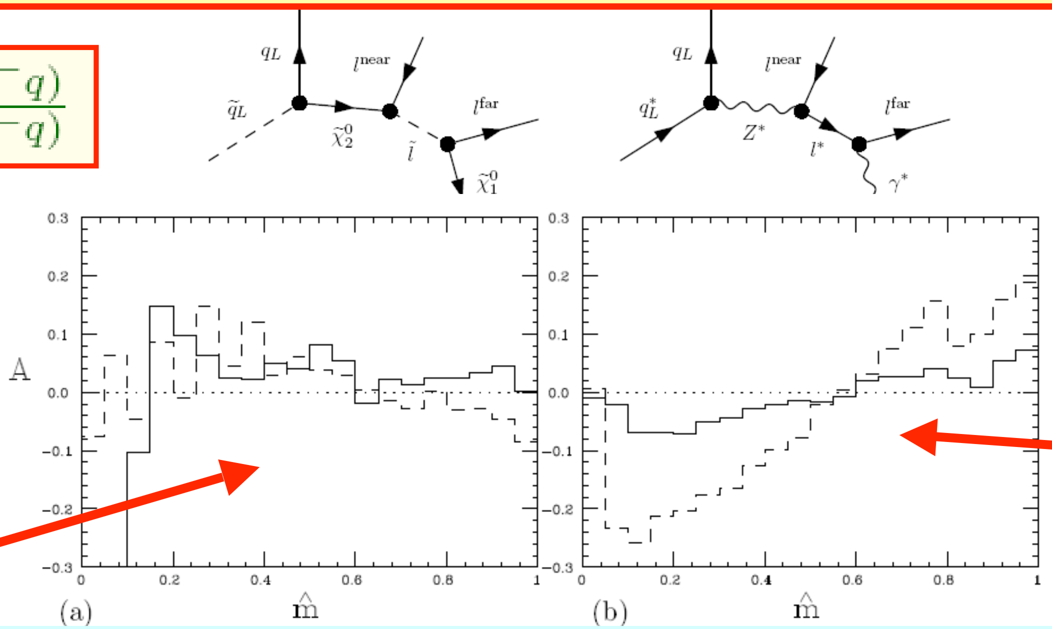
Phenomenology: a Kaluza Klein tower pattern like a SUSY mass spectrum:

Can the LHC distinguish?

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

Look for variables sensitive to the particle spin eg. lepton charge asymmetries in squark/KKquark decay chains Barr hep-ph/0405052; Smillie & Webber hep-ph/0507170

$$A = \frac{(l^+q)-(l^-q)}{(l^+q)+(l^-q)}$$



KK like spectrum (small mass splitting)

SPS1a benchmark type spectrum

Method works better or worse depending on (s)particles spectrum

More discriminating variables needed!!

Recents efforts to map data to BSM space

Dictionary of LHC signatures

A. Belyaev, I.A. Christidi, A. De Roeck, R.M. Godbole, B. Mellado, A. Nyffeler, C. Petridou, D.P. Roy

Table 1. Discriminating signatures between SUSY (MSSM), LHT and UED. See description in the text. "YES" or "NO" mean presence or absence of the particular signature respectively, "SS" stands for "like-sign leptons".

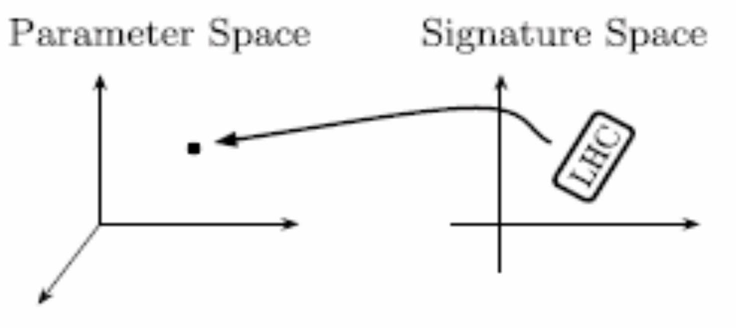
Variables	SUSY (MSSM)	LHT (littlest)	UED(MUED)
Spin	heavy partners are spin 1/2 different	heavy partners have the same spin, no heavy gluon	heavy partners have the same spin
Higher level modes	NO heavy partners	NO heavy partners	YES heavy partners
$N_{l^+l^+}/N_{l^-l^-}$	$< 4:1$	$4:1$	4:1
SS leptons rates	from several channels: SS heavy fermions, Majorana fermions	only from SS heavy fermions	only from SS heavy fermions
$R = \frac{N(\not{E}_T + jets)}{N(l's + \not{E}_T + \text{jets})}$	R_{SUSY}	$R_{\text{LHT}} < R_{\text{SUSY}}$	R_{UED} to be studied
b-jet multiplicity	enhanced (FP)	not enhanced	not enhanced
Single heavy top	NO NO	YES YES	YES via KK2 decay
polarization effects: $tt + \not{E}_T$	to be studied	to be studied	to be studied
polarization effects: $\tau\tau + \not{E}_T$	to be studied	to be studied	to be studied
Direct DM detection rate	high (FP) low (coann)	low (Bino-like LTP)	typically low for γ_1(5D) DM [20] typically high for γ_H(6D) DM [20]

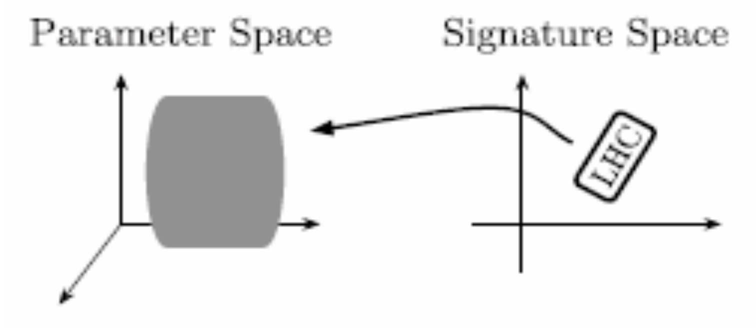
Also G. Kane et al.
N. Arkani-Hamed et al
…

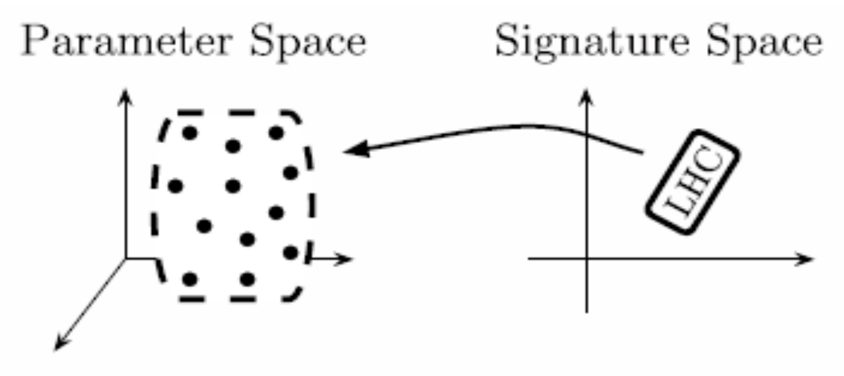
Missing energy look-alikes with 100 pb^{-1} at the LHC

Jay Hubisz[1a], Joseph Lykken[2b], Maurizio Pierini[3c], and Maria Spiropulu[3d]

The Inverse Mapping of Data: there are many possible outcomes….







Much of the time a specific set of data maps back into many distinct islands/points in the model parameter space… → model degeneracy

Arkani-Hamed, Kane, Thaler, Wang, hep-ph/0512190
Kane, Kumar and Shao, arXiv:0709.4259

The efforts to understand the problems and design strategies - even before data- are very important!

In any case:

The only place where you find success before work is in the dictionary

LHC: machine in place, now being commissioned… A big challenge
Experiments: Detectors have been completed!
Preparing for collisions in a few weeks!!

Theorists et al.: (please) be patient…

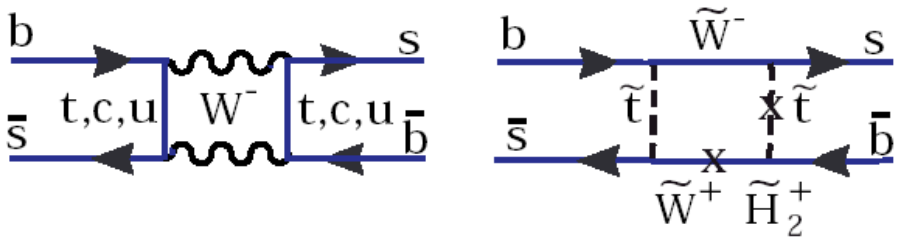
Summary Lecture 3

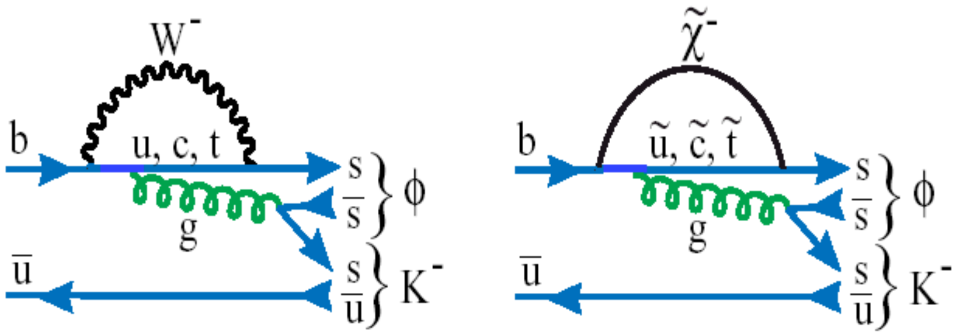
- The LHC will break new ground in exploring the TeV scale and hunt for the Higgs particle and new physics (SUSY?, EDs? Z'? Quirks? Hidden Valleys, Unparticles...)
  - Will it be easy and fast with the first luminosities as we all hope, or shall we have to sweat through years of data taking and hard work before we can claim a discovery ?
  - Watch out for weird signatures!
- How to interprete the new signatures to the underlying theory?
  - Strategies are being designed
  - Interaction with theory will be important
- In 2008(+) we will finally know!

New Physics in the B sector (LHCb)

Where would New Physics manifest itself?

- In box or penguin diagrams in which the intermediate particles could be New Physics particles in addition to SM particles.





L. Camilleri
Cairo March 07

- This could result in:
  - **unexpected** CP violation effects
  - or **affect properties** of rare decays where standard model contributions are small enough to allow potential small New Physics effects to emerge.

New Physics in the B sector (LHCb)

Example: constrained minimal SSM: CMSSM

Anomalous magnetic moment of muon:
Measured at BNL, disagrees with SM at **2.7 σ**.

$\Delta a_\mu = (25.2 \pm 9.2)\ 10^{-10}$.

To explain it with CMSSM:
for different A_0 and $\tan\beta$:
$250 < m_{1/2}$ (gaugino mass) < 650 GeV

CMSSM with this **same range** of gaugino mass
Predicts **BR ($B_s \to \mu^+\mu^-$)** could be ~ a few **10^{-9} to 10^{-7}**

much higher than SM: