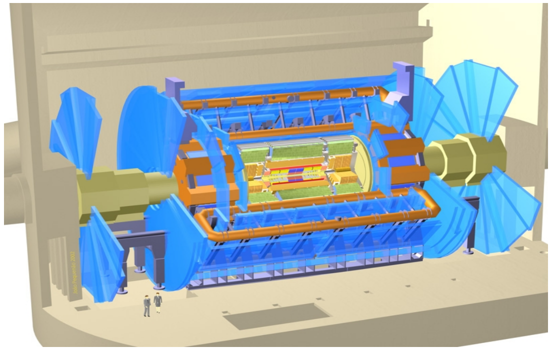
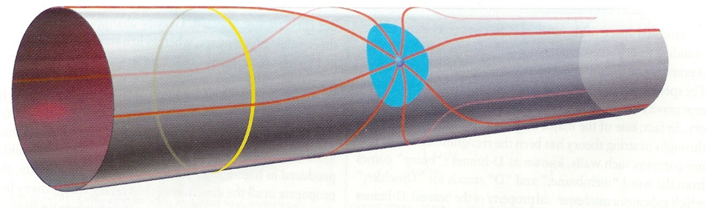
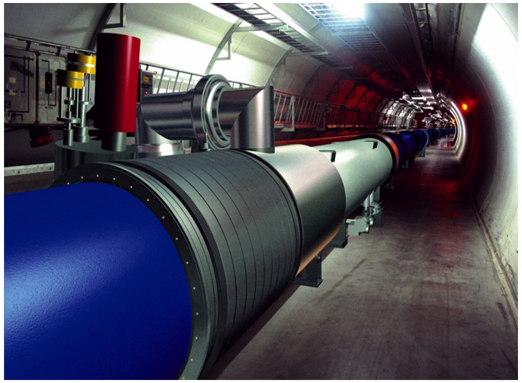
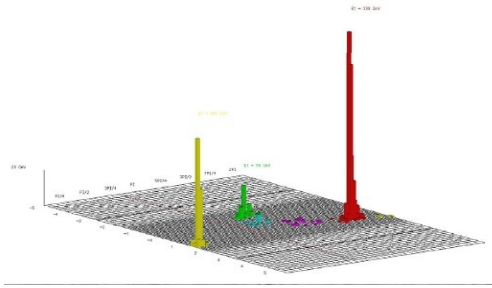


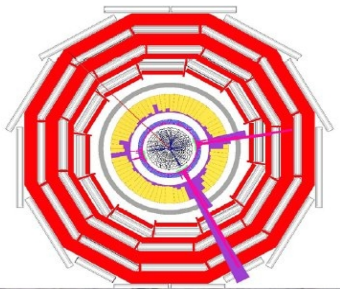


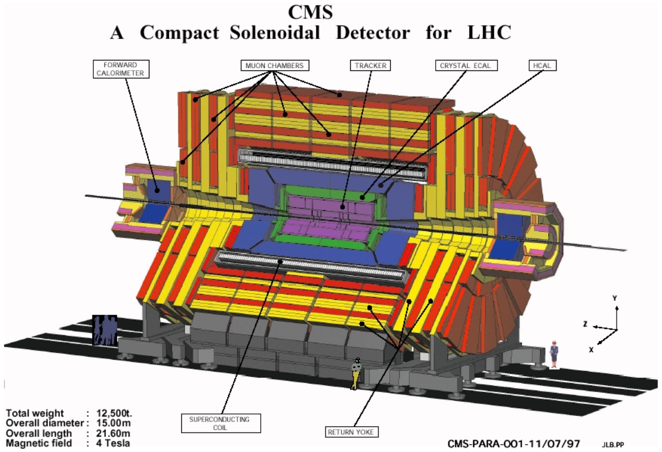


SUSY and Extra Dimension searches at the LHC

Barbara Clerbaux
ULB, Brussels







Plan:

- The LHC: ATLAS and CMS:
  The CMS detector status

- ATLAS and CMS results:
  Few examples of physics commissioning with ~10 pb^{-1}

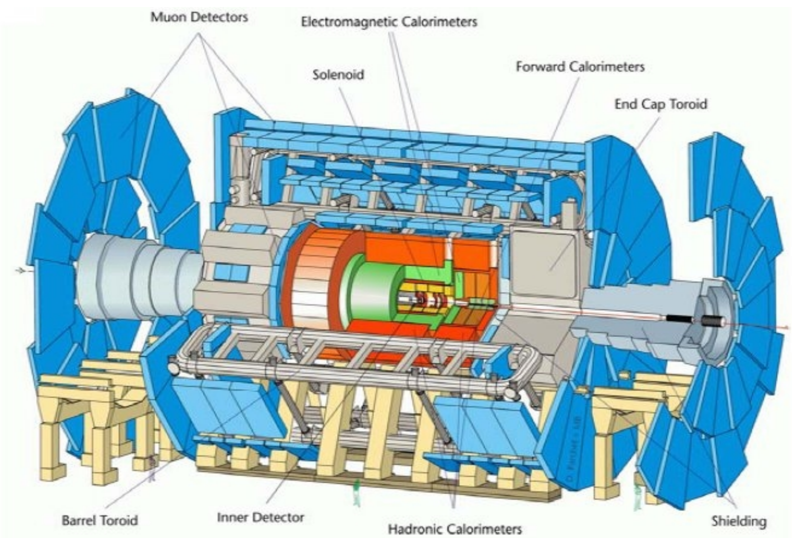
- Search for SUSY   FOCUS on early physics!

- Search for ED   FOCUS on early physics!

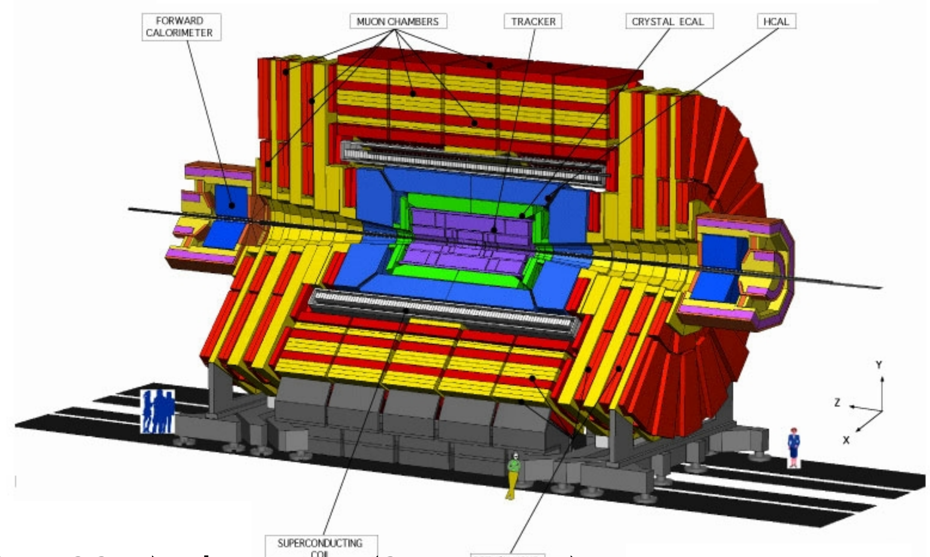
- Summary

LHC detectors are similar ... But not equal

A Large Toroidal LHC ApparatuS (ATLAS)



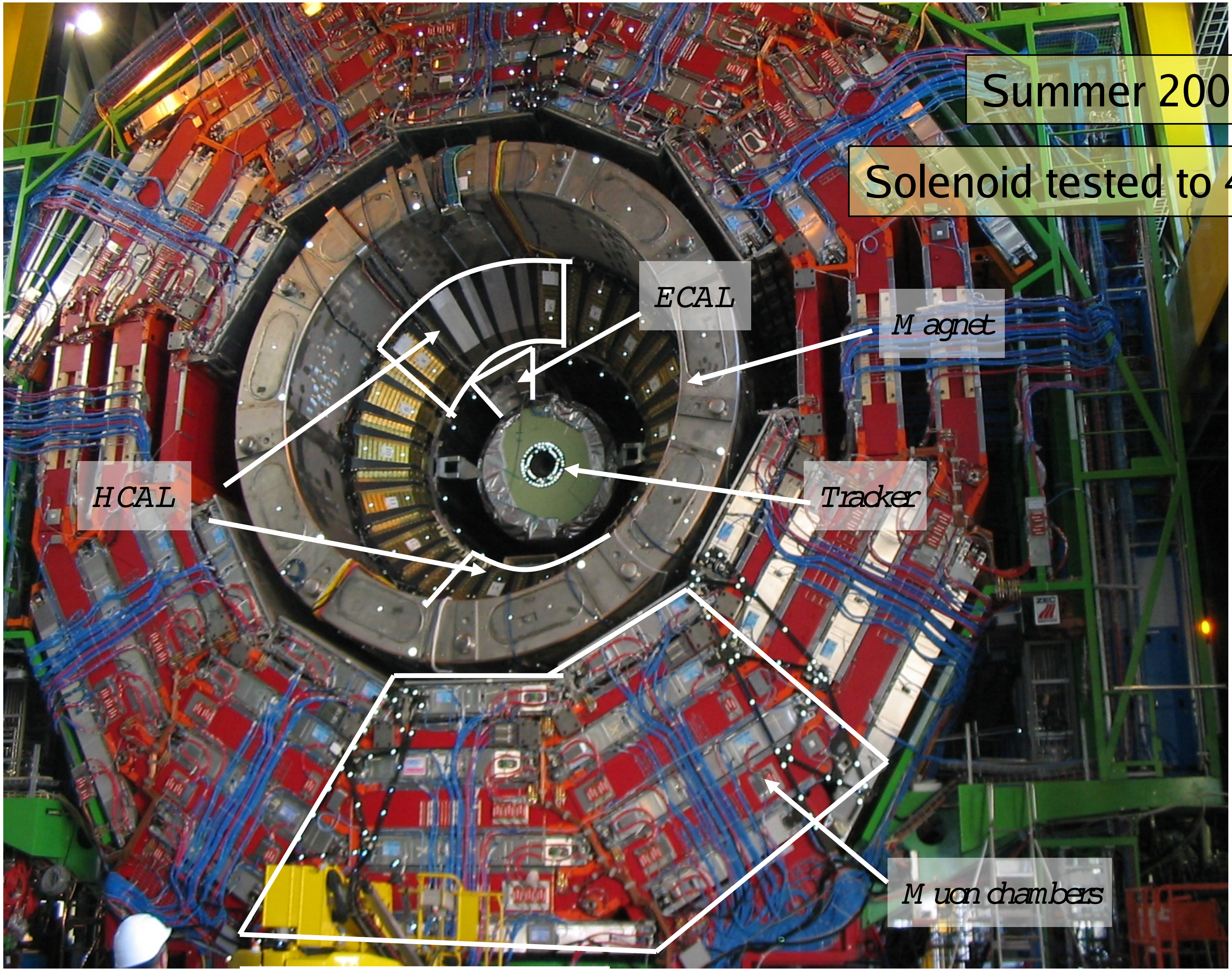
Compact Muon Solenoid (CMS)



- **Total weight**: (7 kT, 12.5 kT) and **Size**: length (46m, 22m), diameter (25m, 15m)
- **Magnetic field**: ATLAS: solenoid 2T + air-core toroids
  CMS: big solenoid 4T
- **Inner tracker**: ATLAS: silicon + Transition Radiation tracker (50% at 1 TeV)
  CMS: silicon (15% at 1 TeV)
- **ECAL:** ATLAS: Liquid argon (10% at 1 GeV) – but very good granularity and uniformity
  CMS: PbWO4 crystals – very good energy resolution (5% at 1 GeV)
- **HCAL:** ATLAS: $\sigma/E=50\%/\sqrt{E(\mathrm{GeV})} + 3\%$ - CMS: $\sigma/E=100\%/\sqrt{E(\mathrm{GeV})} + 5\%$
- **Muon detectors**: ATLAS: very good stand alone momentum resolution (7% at 1 TeV)
  CMS: redundant detector/trigger system (5% at 1 TeV from tracker)

CMS detector – Status

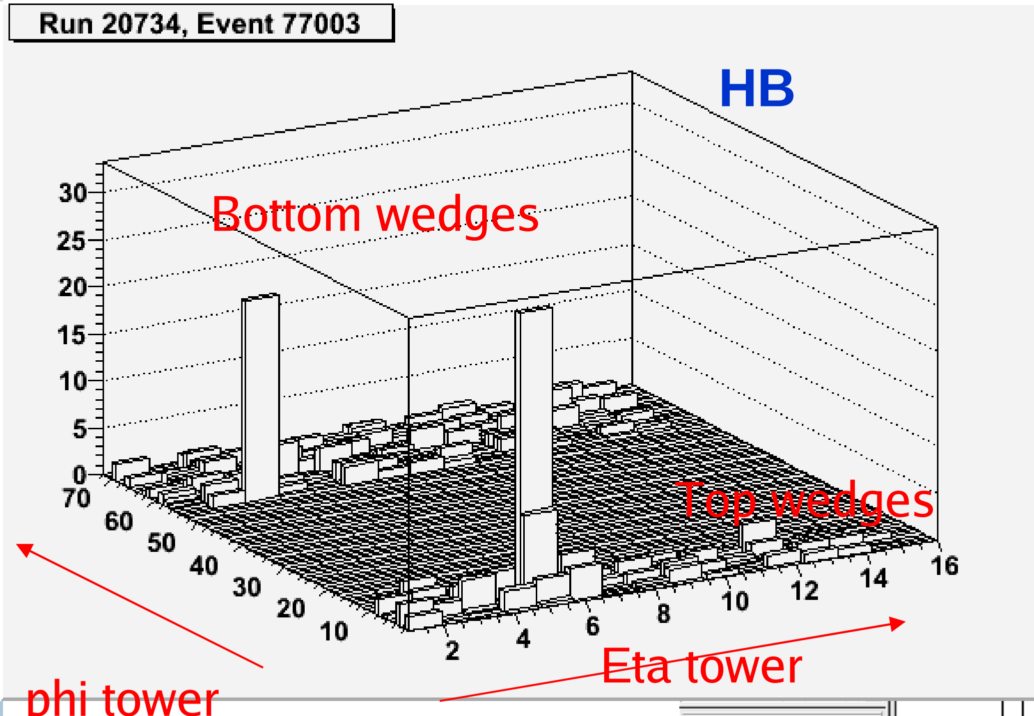
CMS "Vertical Slice Test" Magnet Test & Cosmic Challenge:

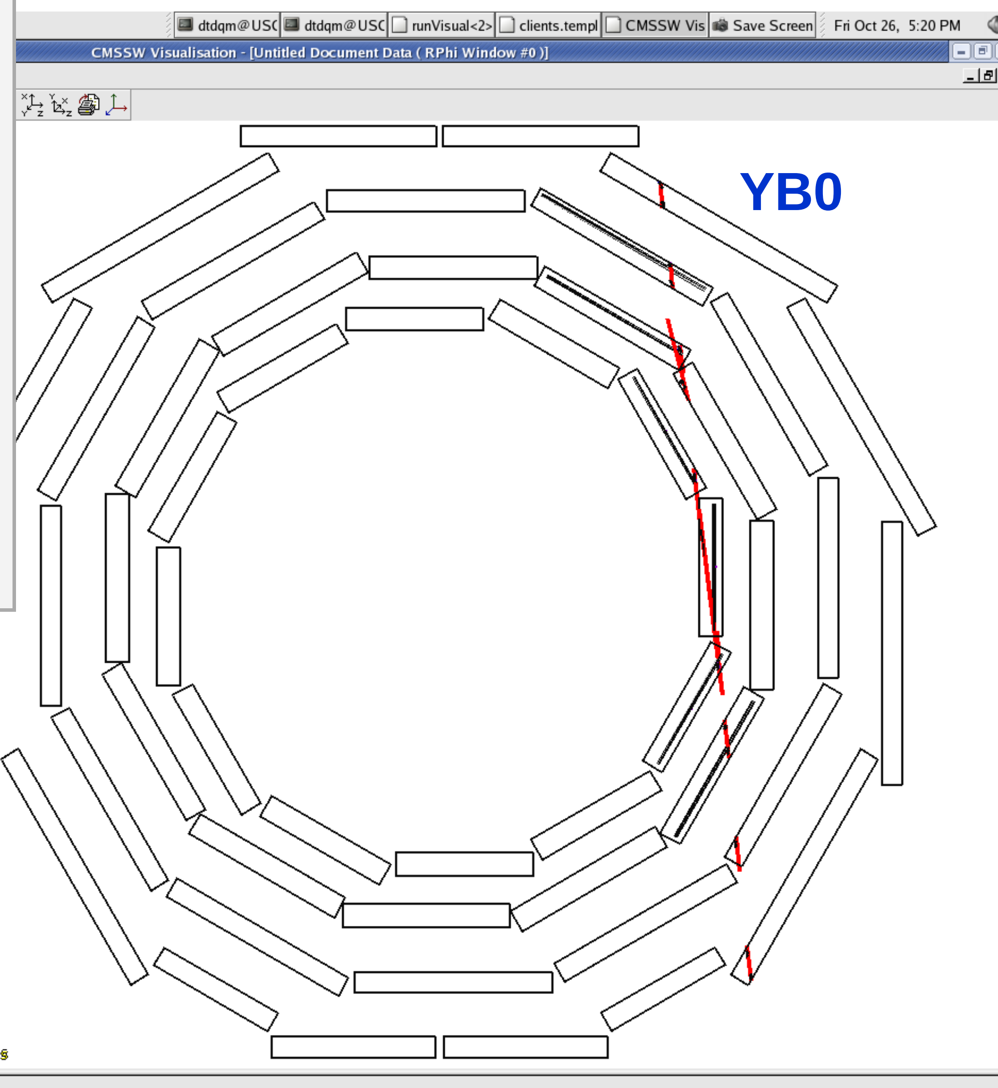


Cosmics in YB0 in UX5

Cosmics in UX5: Barrel ECAL and Muon Systems (Aug 2007)

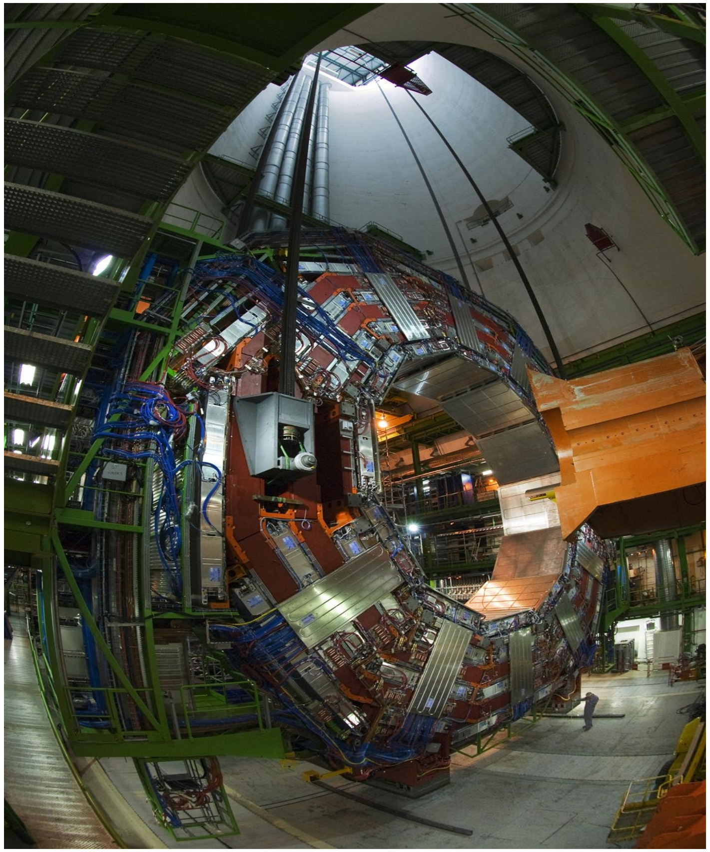
ECAL & DT readout with final central DAQ

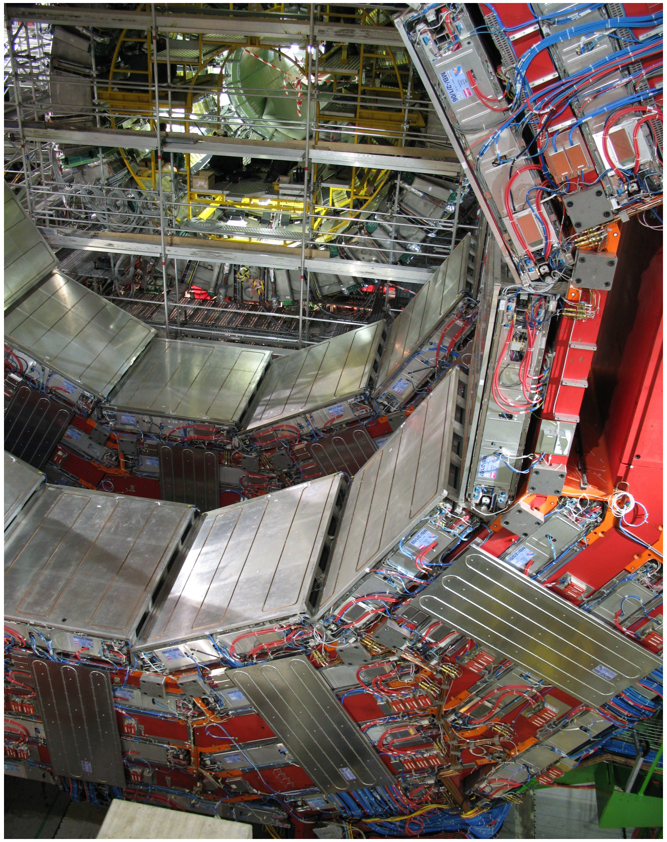




Lowering of YB-1 and YB-2

October 10th and 17th





Main Target: Apr'08: CMS* Closed & Field ON - Cosmics Run
* including one EE, and pixels.

Secondary Targets: All heavy lowering completed by end-07
Tracker installed and parts being readout by end-07
Dec'07-Mar'08: cosmics data in open configuration (+end, barrel, -end)

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CMS and ATLAS results

- Published results for ATLAS :
  http://cdsweb.cern.ch/collection/ATLAS
  updated the PTDR(1999) in spring 2008

- Published results for CMS :
  CMS Physics TDRII – summer 2006
  http://cmsdoc.cern.ch/cms/cpt/tdr/
  updated in spring 2008: early searches (10,100 pb^{-1})

In general: - CMS and ATLAS physics potential from 10/60 fb^{-1} to 100/300 fb^{-1}
- Full detector simulation (detailed material description)
- Complete bg study (K-factor, new generators (still in development...)
- Estimation of the systematics

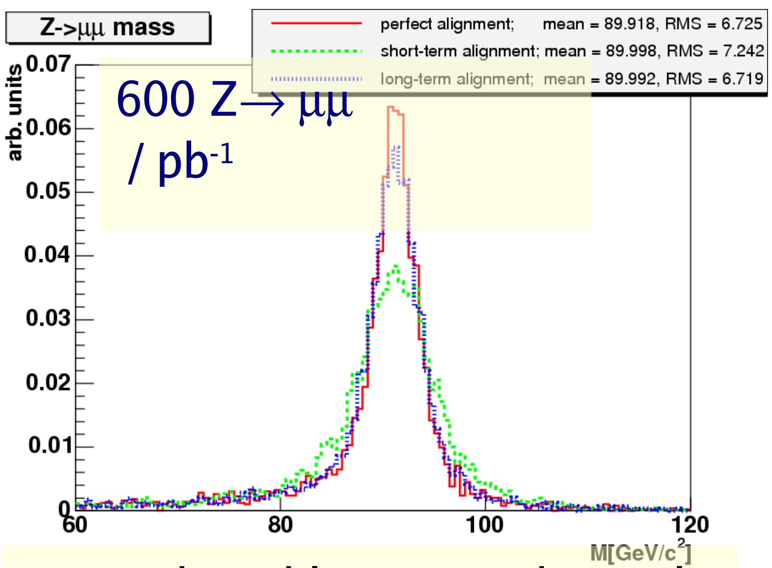
TODAY activities: Focus on **early searches** (2008 data) – 10,100 pb^{-1} (1 fb^{-1})
- Low statistic
- Not aligned/calibrated detector
- Rely as low as possible in MC
- Extract trigger and selection efficiency from data
- Extract bg from data

→ physics (objects) commissioning with first beams (L = 10 pb^{-1})

Few pb^{-1}: tracker & calorimeters

Tracker Alignment

	Expected Day 0	Goals for Physics
Tracker alignment	20-200 μm in Rϕ	o (10 μm)



600 Z→ μμ / pb^{-1}

Z peak visible even with initial (rough) alignment

Calorimeter calibration

	Expected Day 0	Ultimate goals
ECAL uniformity	~4%	< 1%
Lepton energy	0.5-2%	0.1%
HCAL uniformity	2-3%	< 1%
Jet energy	<10%	1%

ECAL, HCAL: intercalibration using azimuthal symmetry (min bias).

ECAL: π^0 calibration, then electrons

HCAL: di-jet balancing; check with photon+jets; Jet Energy Scale set by W→ jj in top events

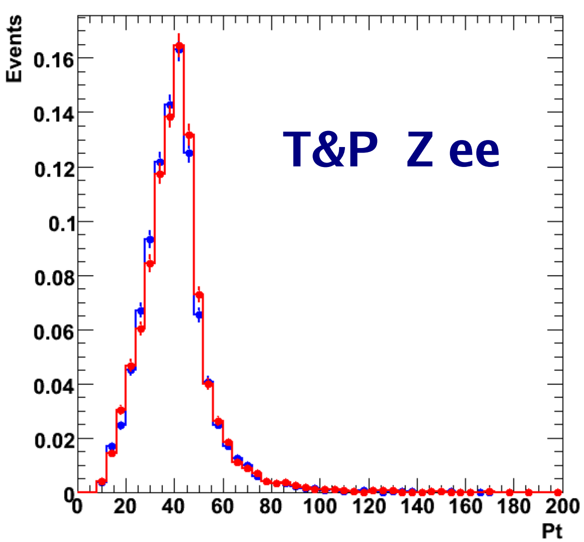
CMS NOTE 2006/017

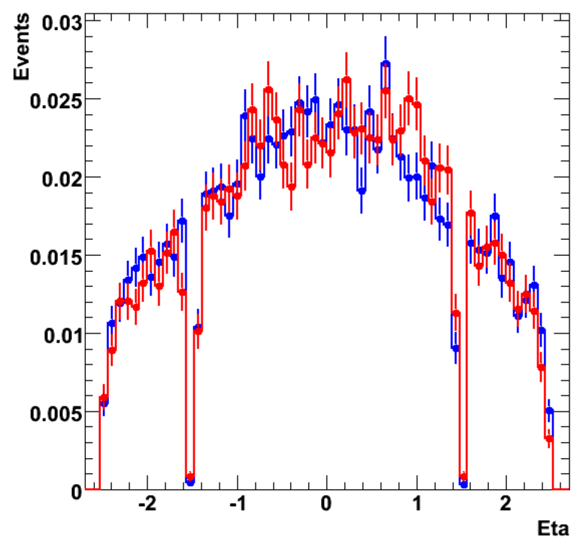
Object ID/efficiency: from data

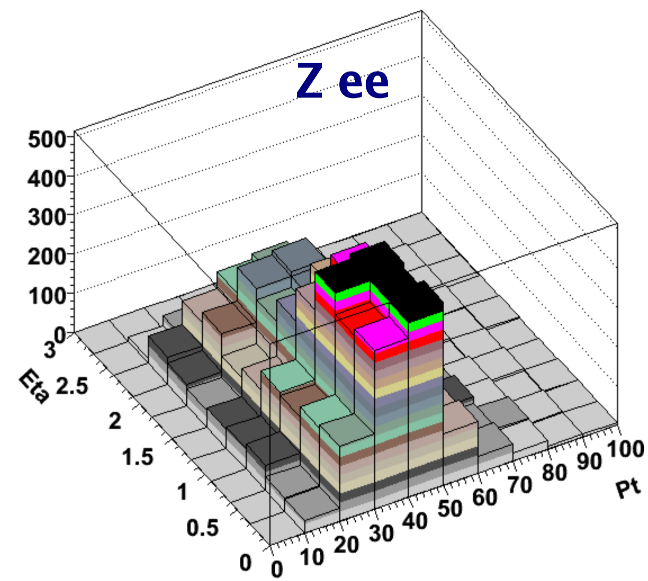
Tag and Probe (T&P): identify a physics object in an unbiased way in order to study efficiencies

One object (tag) has strict ID criteria imposed on it. Second object (probe) has looser ID criteria.

Z → ee events: one tight electron (tag); the other can be a probe, provided the invariant mass of the pair is ~ M_Z







Efficiency from T&P: 94.36±0.24 } (for 10 pb^{-1})
Efficiency from MC truth: 94.63±0.24

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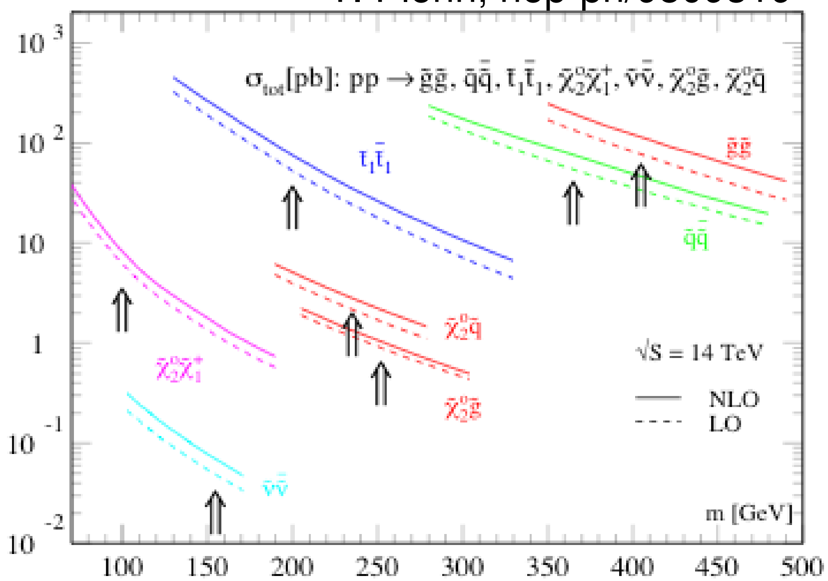
Production cross section at LHC – versus mass:

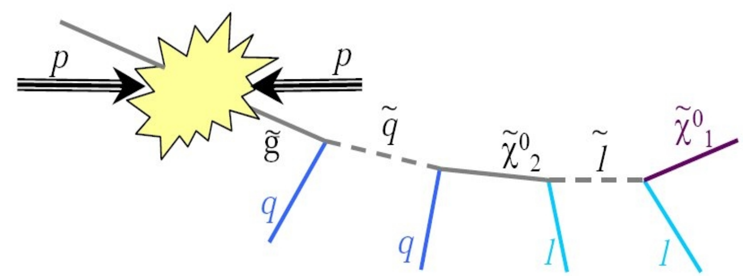
T. Plehn, hep-ph/9809319



For m(squark, gluino) ~ 400 GeV
σ ~ 100 pb -> 10 000 events expected for L=100 pb^{-1} !

Vertical arrow: mSUGRA point:
m_0=100 GeV, $m_{1/2}$=150 GeV,
A_0=300 GeV, tanβ=4, μ>0

Golden discovery channels: squark and gluino production:



Less model-dependent feature of SUSY:

- gluinos/squarks produced via strong interactions
- gluinos and quarks are heaviest
- Their decays give rise to high-pt jets
- Neutralinos/charginos decay via emission of leptons
- (assuming RPC) LSP is stable and neutral, escape from the detector

Experimental signatures

→ topologies: multi-jets + n-leptons + Etmiss

Try to cover broad range of experimental signatures, classified based on event topology

Main background: QCD, tt, W/Z + jets

Large E_T^{miss} +

Jet multiplicity	Additional signature	SUSY scenario	Backgrounds	
≥ 4	No lepton	mSUGRA, AMSB, split SUSY, heavy squark	QCD, ttbar, W/Z	<--
	One lepton (e,μ)	mSUGRA, AMSB, split SUSY, heavy squark	ttbar, W	<--
	di-lepton	mSUGRA, AMSB, GMSB	ttbar	<--
	di-tau	GMSB, large tan β	ttbar, W	
	γγ	GMSB	free	
~2		light squark	Z	

Baseline selection (to be optimised): typical selection for “low mass points”

- Jet multiplicity ⩾ 4, pt (jet1) > 100 GeV, pt (other) > 50 GeV
- Etmiss > Max(100 GeV, 0.2 Meff) Meff = Σi (pt(i) + Etmiss)
- Transverse sphericity > 0.2
- Additional cuts depending on signature (leptons)

Early SUSY studies:

Control of missing Et - and data-driven background estimation

Background from data

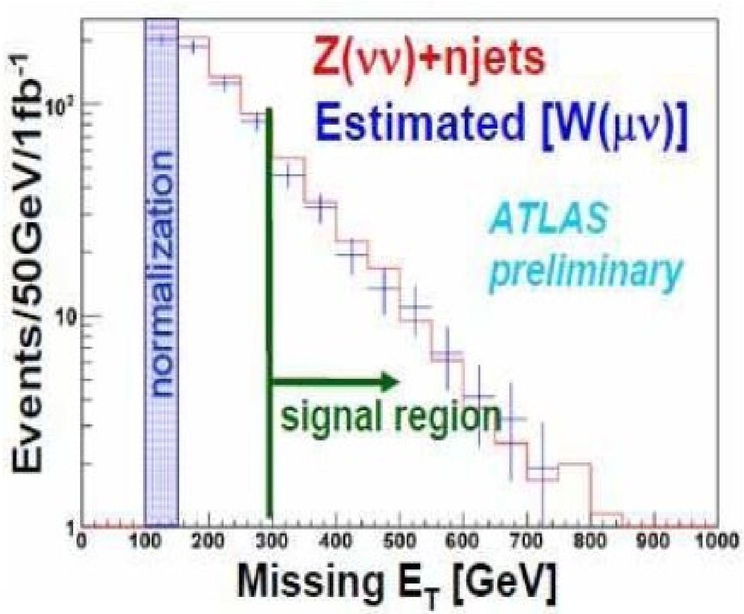
Background estimation using the data themselves:

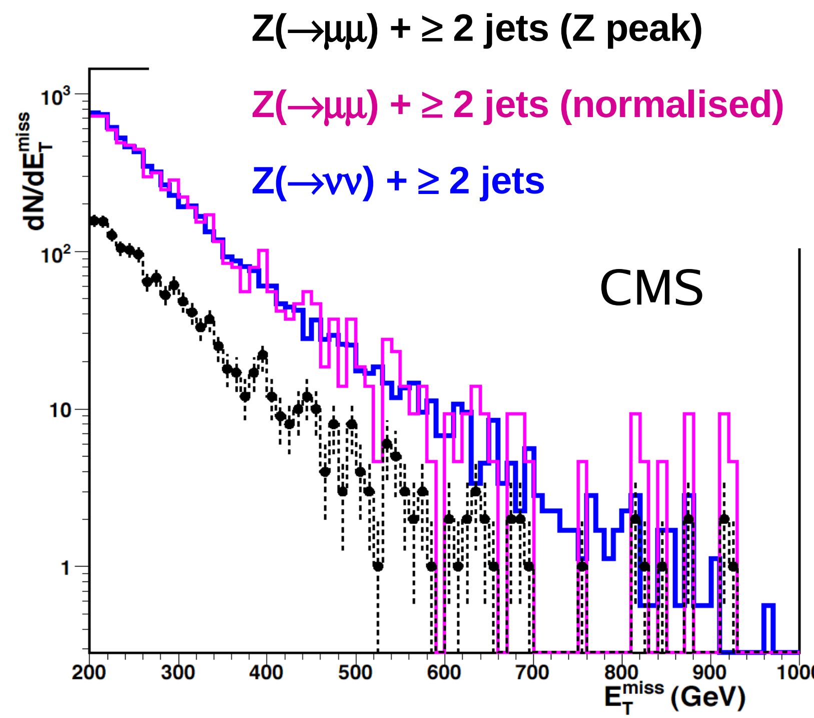
- QCD bg: shape de Etmiss extracted from data at lower Etmiss (Prescales)

- Z+njets with Z → νν bg: use “candle sample” :

  - Z + njets, Z→ μμ or ee, replace pt(ll) ↔ Etmiss

  - or W + njets, W-> lν, replace pt(lν) ↔ Etmiss

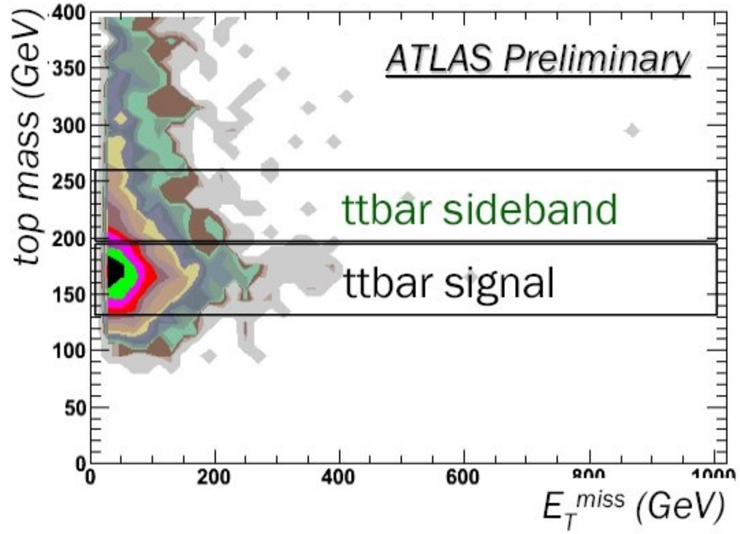


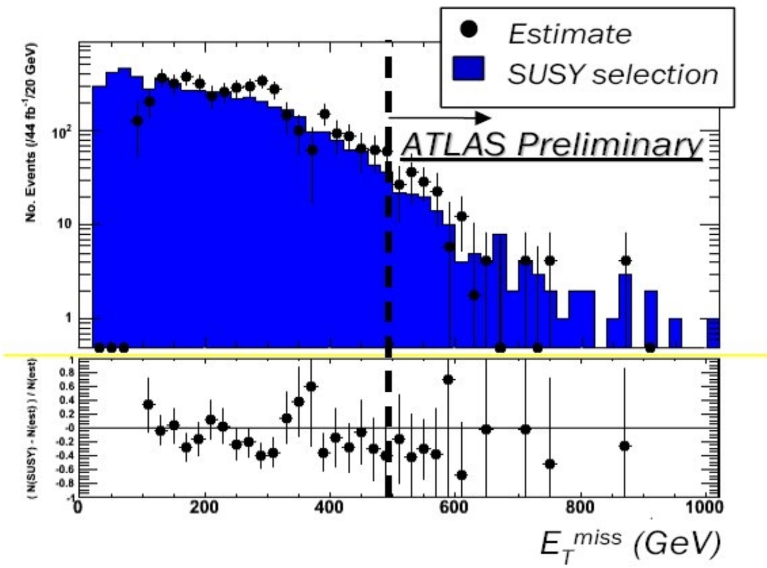


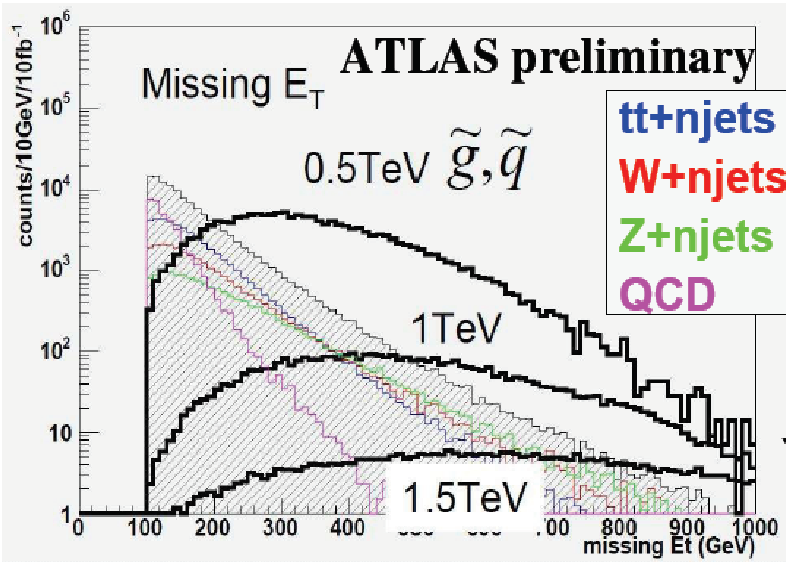
Background from data

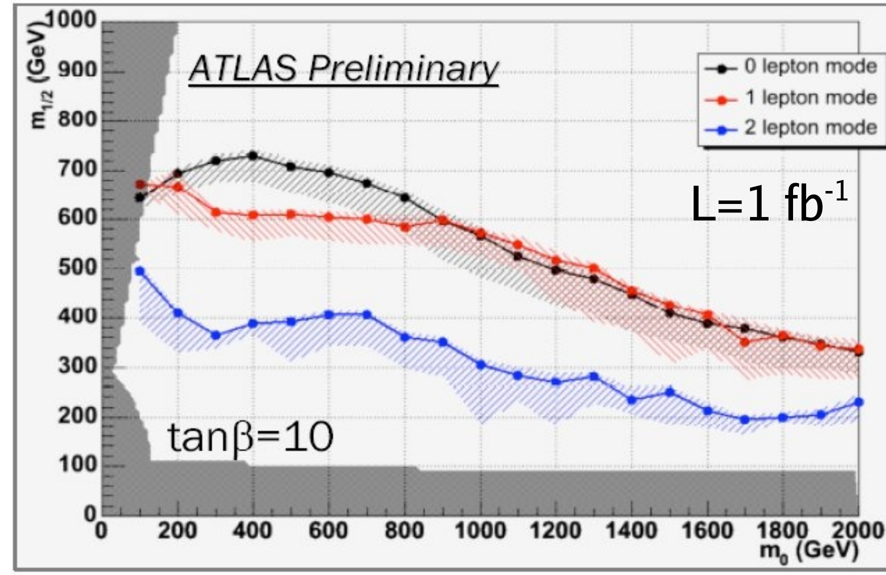
- ttar background estimation :

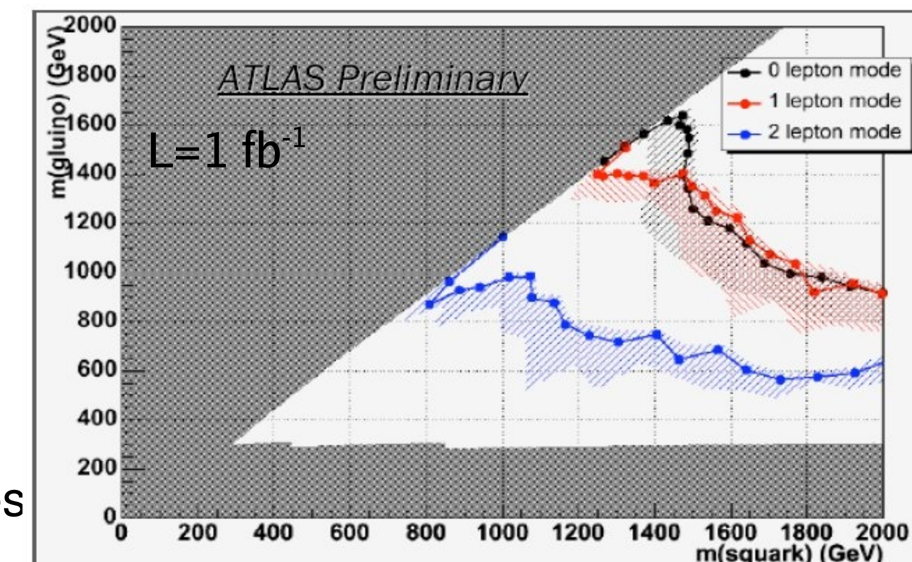
1. Top mass is largely uncorrelated with E_T^{miss}
   – used as a calibration variable
2. Select semi-leptonic top candidates
   – mass window: 140-200 GeV
3. Contributions of combinatorial BG to top mass are estimated from the side-band events ($200GeV<m_{top}<260GeV$)
4. Normalize the E_T^{miss} distribution in low E_T^{miss} region where SUSY signal contamination is small.
5. Extrapolate it to high E_T^{MISS} region and estimate the background with SUSY signal selection.











.

5σ discovery potential is shown:

S>10 and S/√B>5

→ potential to discover:

~1.5 TeV scale SUSY for L=1 fb^{-1}

(~1 TeV scale SUSY in the three topologies

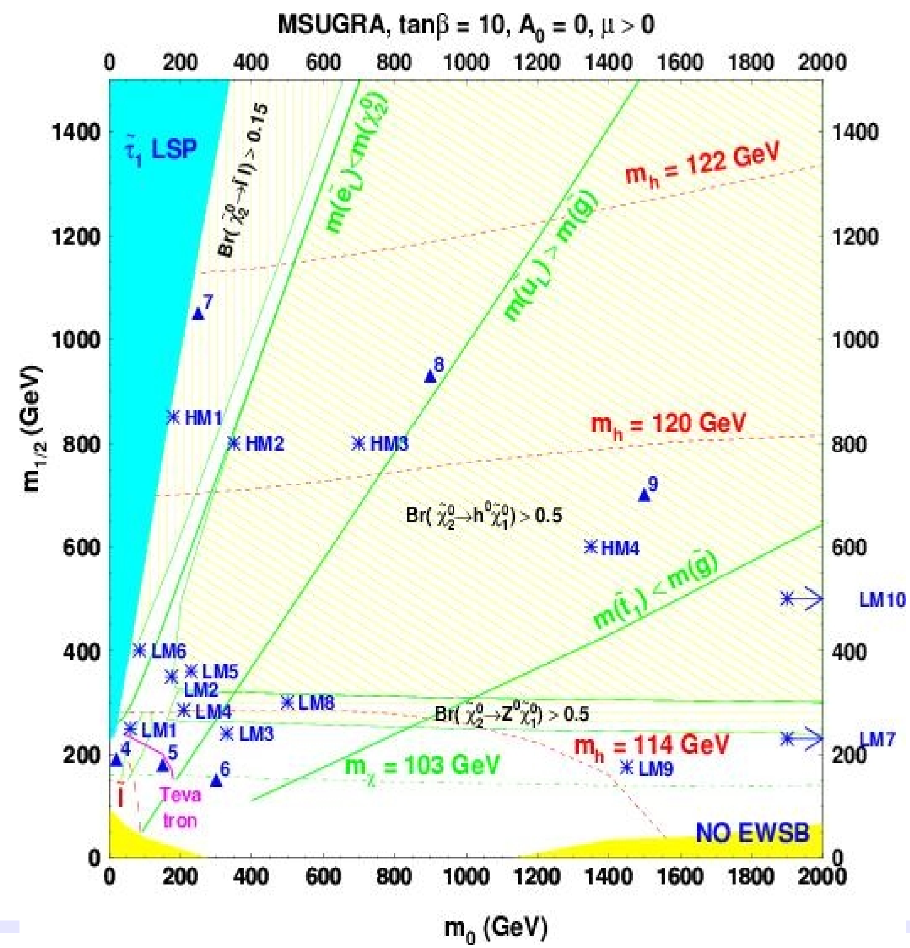
~1.1 TeV scale SUSY for L=100 pb^{-1}

mSUGRA points:

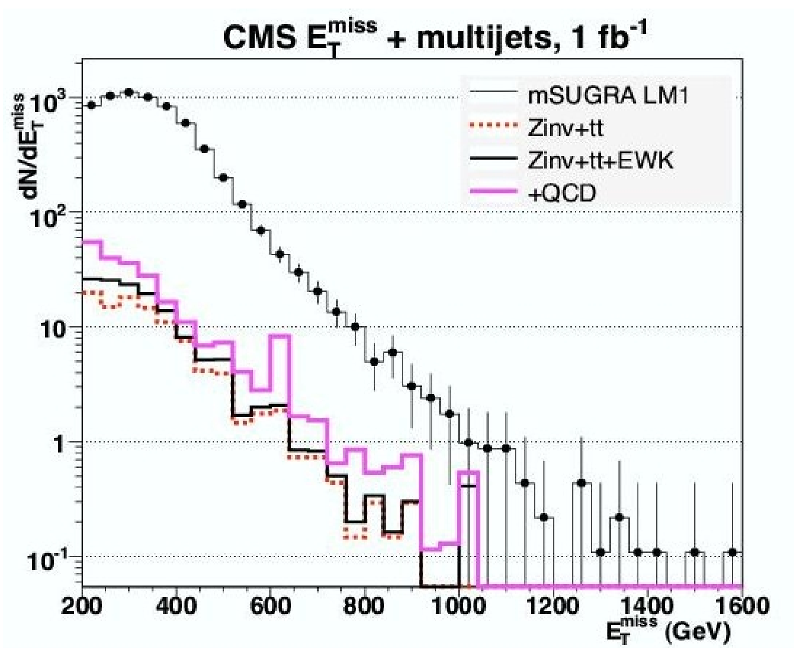
MSUGRA test points:
to cover different experimental signatures:
low mass points (LM1-LM9) above Tevatron limit and sensitivity to early LHC running
high mass points (HM1-HM4): ultimate reach of the LHC

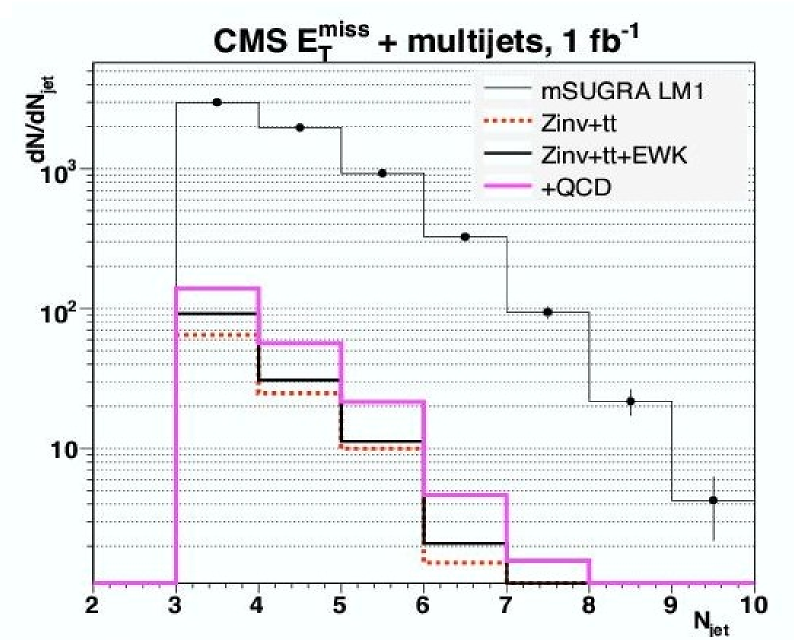
LM1,2,and 6 : compatible with WMAP CDM in mSUGRA
other points: compatible in NUHM

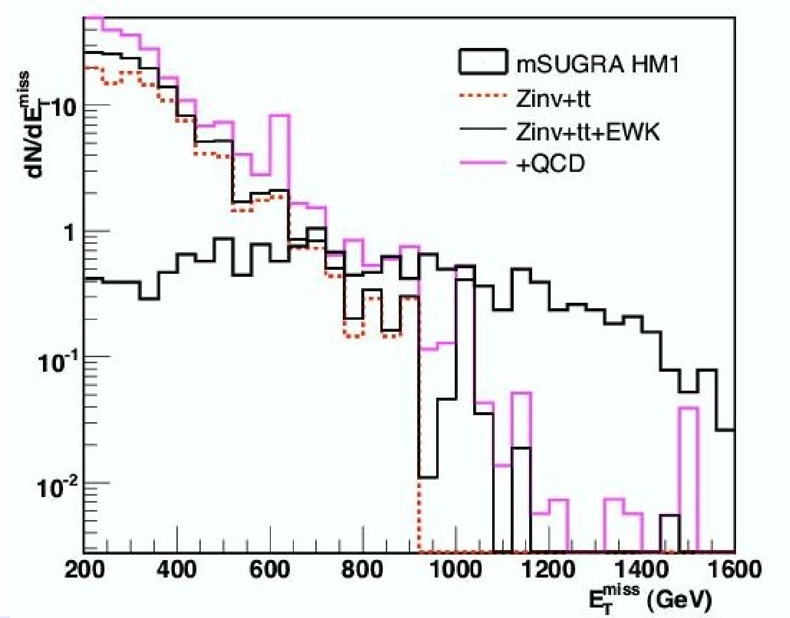
Point	m_0	$m_{1/2}$	$\tan\beta$	$\mathrm{sgn}(\mu)$	A_0
LM1	60	250	10	+	0
LM2	185	350	35	+	0
LM3	330	240	20	+	0
LM4	210	285	10	+	0
LM5	230	360	10	+	0
LM6	85	400	10	+	0
LM7	3000	230	10	+	0
LM8	500	300	10	+	-300
LM9	1450	175	50	+	0
LM10	3000	500	10	+	0
HM1	180	850	10	+	0
HM2	350	800	35	+	0
HM3	700	800	10	+	0
HM4	1350	600	10	+	0



CMS: multijets + Etmiss





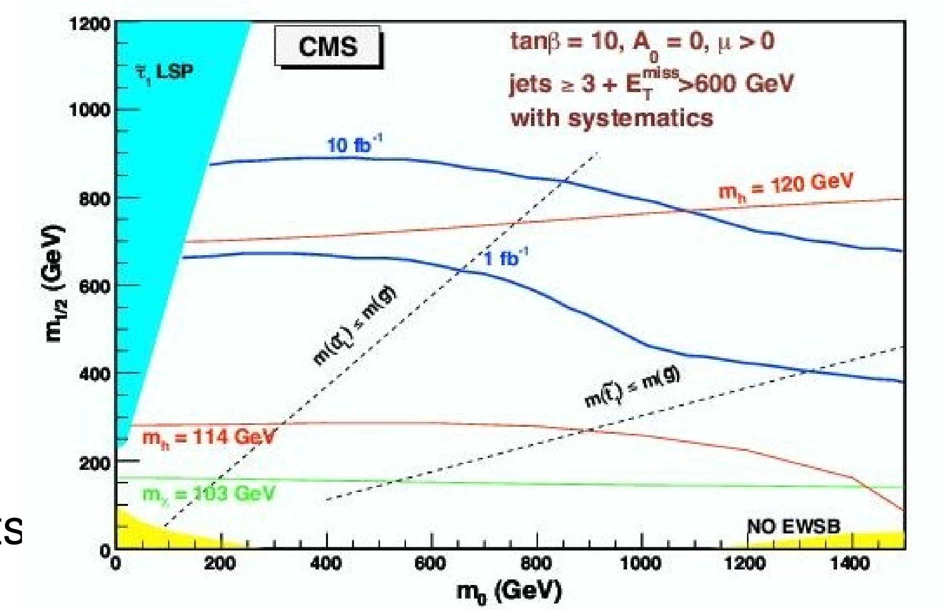


LM1: m(gluino, squark) ~ 600 GeV
HM1: m(gluino, squark) ~ 1800 GeV

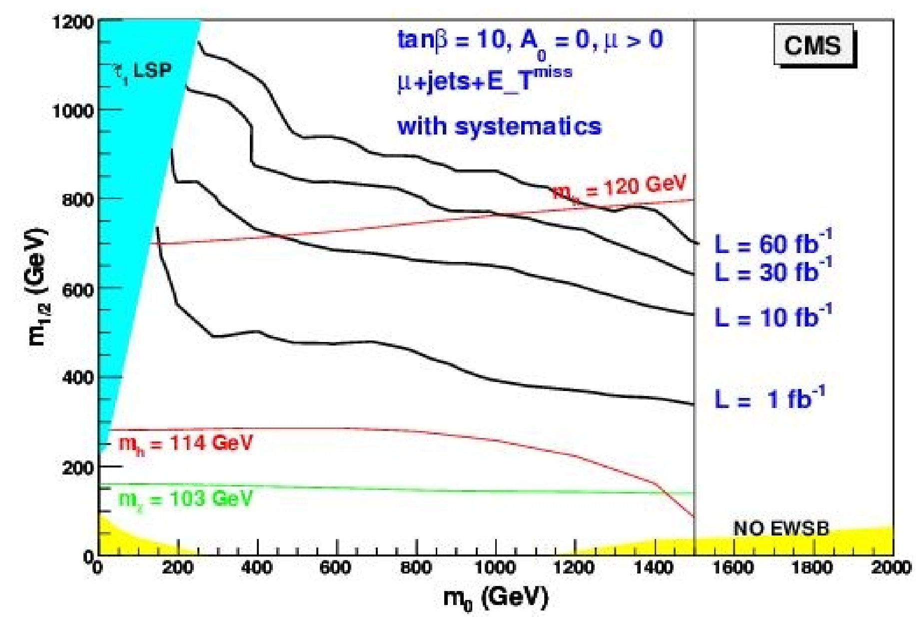
CMS Discovery potential

CMS : 5 σ reach scan in mSUGRA

Multi-jets + Etmiss:
HM1 test point is used as optimisation signal efficiency: ~ 12%
SM bg ~ 4.4 events (1fb^{-1})
(60% Z->νν, 20% QCD jets, 10% W/Z+jets



Multi-jets + μ+ Etmiss:
LM1 (HM1) test point is used as optimisation for L=1 and 10 fb^{-1}
(>10 fb^{-1})

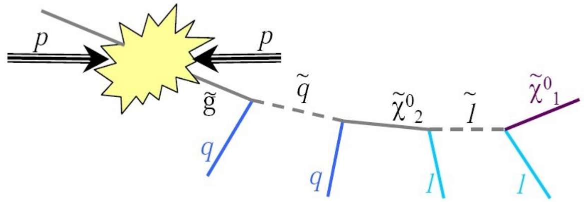


Exclusive analyses

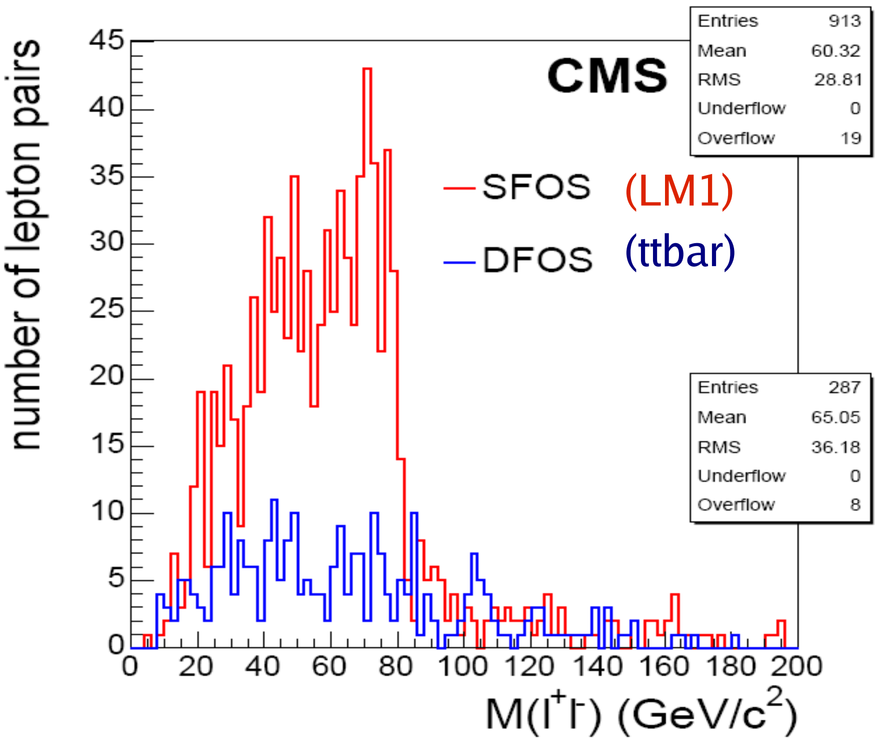
A particular decay channel to measure masses

Example: $\chi_0^{\,2} \rightarrow l_R\, l \rightarrow \chi_0^{\,1}\, l^+\, l^-$:

-> dilepton (opposite sign) + jets + Etmiss



CMS analysis on LM1: 2 OS SF isolated leptons (e,μ) with pt > 10 GeV,
Etmiss > 200 GeV
2 jets: Et(1)>100 GeV, Et(2) > 60 GeV, |η| < 3



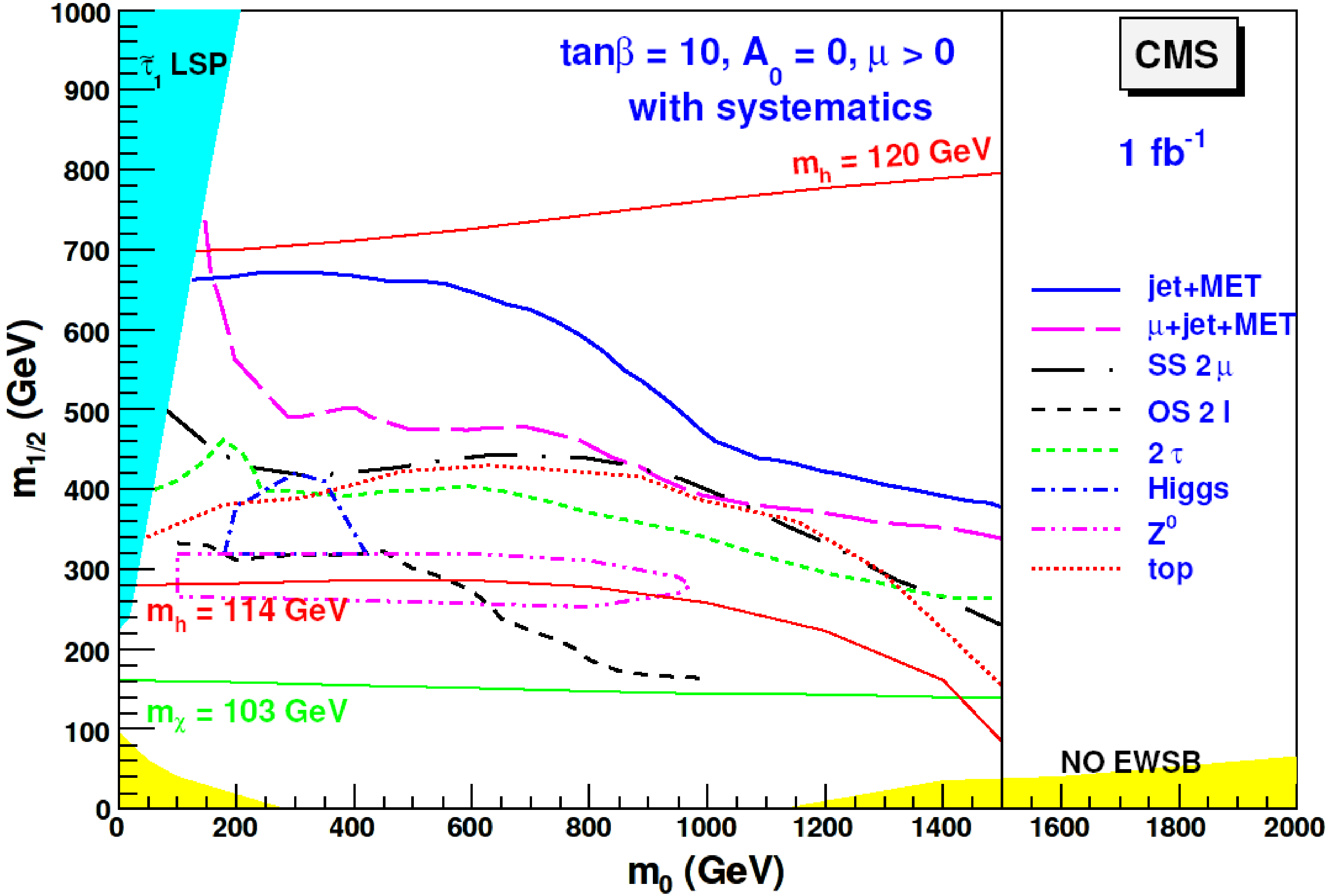
Pour 1 fb^{-1} : N_S = 850, N_B = 200 (150 de tt)

Bg from the decay of the 2 W de tt: substracted using different flavor opposite sign selection

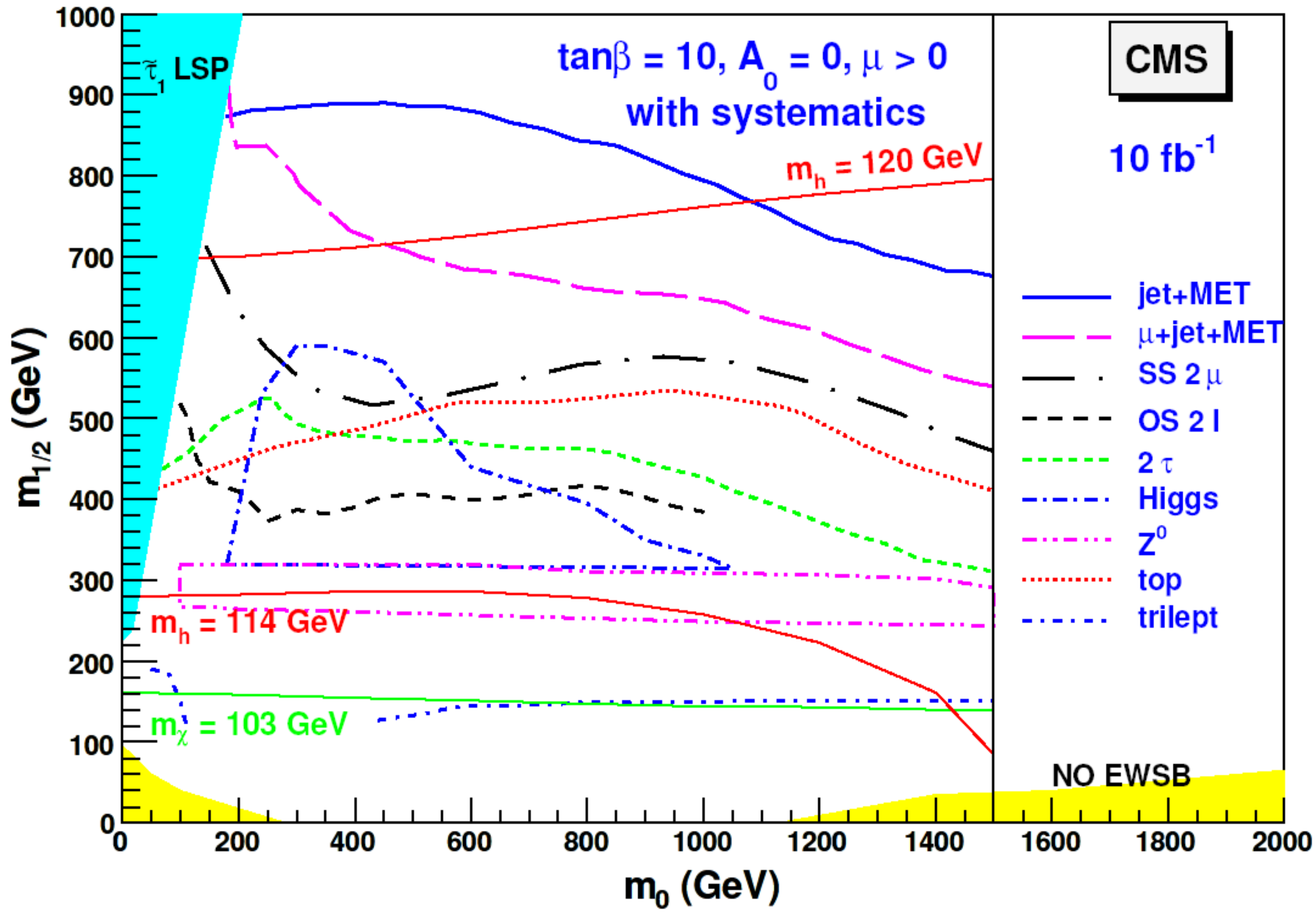
$$M_{\ell\ell}^{\max} = m(\tilde{\chi}_2^0)\sqrt{1-\left(\frac{m(\tilde{\ell}_R^{\pm})}{m(\tilde{\chi}_2^0)}\right)^2}\sqrt{1-\left(\frac{m(\tilde{\chi}_1^0)}{m(\tilde{\ell}_R^{\pm})}\right)^2}$$

Measure end-points in several decays, to estimate masses ~ 10 % with 100 fb^{-1}

Expected sensitivity for 1 fb^{-1}



Expected sensitivity for 10 fb^{-1}



With L = 10 fb^{-1} : Discover m(sq), m(g) up to ~ 2.1 TeV and m($\chi^{\pm}$) up to ~ 700 GeV

Tevatron limit: (tanβ=3, A_0=0): m(sq)>390 GeV, m(g)>310 GeV, m($\chi^{\pm}$)>140 GeV (L~1fb^{-1})

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Basic concepts:

3brane: matter and gauge forces are confined to our 3D subspace - mechanisme to hide the ∃ of ED for the observer localized on the brane

bulk: D=(3+1)+δ (δ dim to our 3B) where gravity propagates

ED compact., KK tower of massive states for **graviton**,
equal space mas: $M^2_{(n)} = (n^2/R^2)$ $(n=n_1, \dots n_\delta)$

Gravity - spin2 field in bulk: 3 classes of KK towers:
- 5-component tensor KK tower of massive gr. states couple to SM fields on brane via stress-energy tensor

[- (δ-1) gauge KK tower of massive vector]
[- $\delta(\delta-1)/2$ scalar towers]

4D effective theory: linearized quantum gravity:

$G_{AB} = \eta_{AB} + h_{AB}$

Compute interaction KK Graviton with SM fields:
all states couples with universal strength ~ $1/M_{Pl}$

Models considered

If $\sqrt{s} < M_D$: (1) Large flat Extra Dimension (ADD)

Extra dimensions are flat and could be as large as a few μm
SM particles restricted to 3D brane - bulk: only accessible to gravity
→ direct production of KKG
→ virtual effect of KKG

(2) TeV^{-1} size ED

if ED small enough R<= TeV^{-1}
SM fields are allowed to propagate in the bulk
→ KK excitation of gauge bosons

Size of the ED

(3) Randall, Sundrum (RS1 – two branes)

Small extra spatial dimensions
Curved bulk space (AdS5 - slice)
→ narrow resonance of KKG
free parameter: coupling c

In all cases: free parameter: m(1)

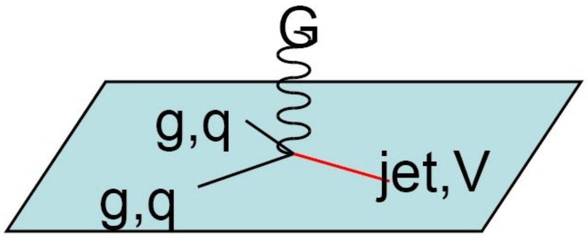
If $\sqrt{s} > M_D$: TransPlanckian physics

ADD: real graviton emission

Search for real graviton emission in ADD type of ED framework
(KK mode of G)

Model parameters are:
- δ = number of ED
- $M_{Pl}(4+\delta)$ = Planck mass in the 4+δ dimensions

$M_{Pl}^2 \sim R^{\delta} M_{Pl(4+\delta)}^{(2+\delta)}$

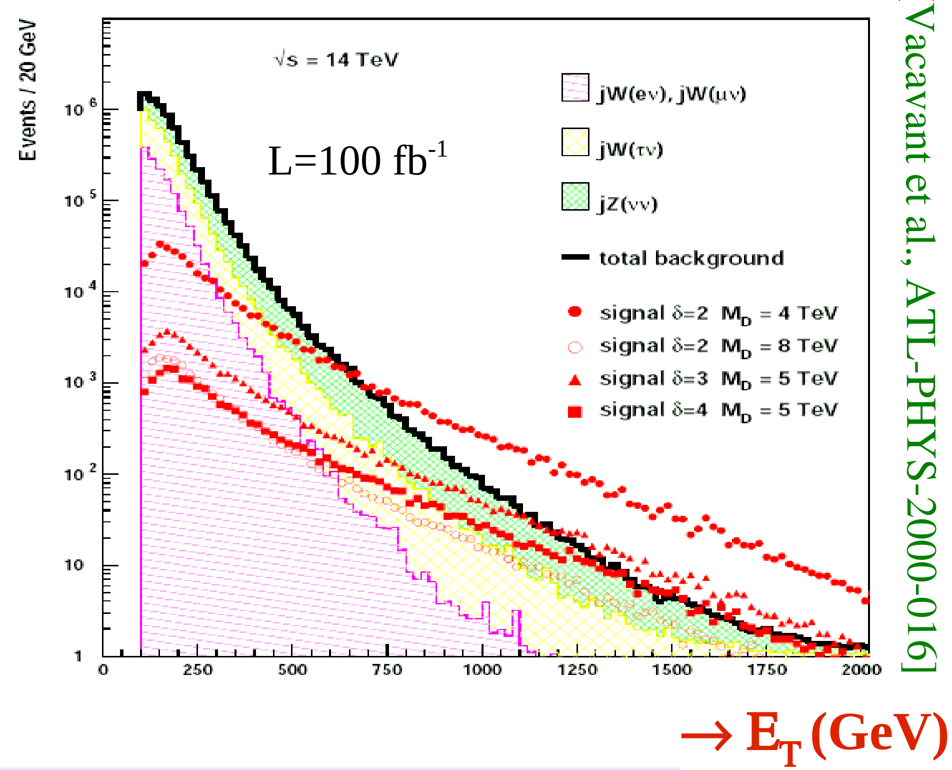


1. pp -> gamma + G
signature: high-pt photon + high missing E
bg: W->ev, gamma+jets, QCD, di-photon,

2. pp->jet+G
signature: high-pt jet + large missing Et
bg: irreducible: jet+W/Z -> jet + vv/ jet + l
lepton veto to reduce jet+W bg

Discovery limits:

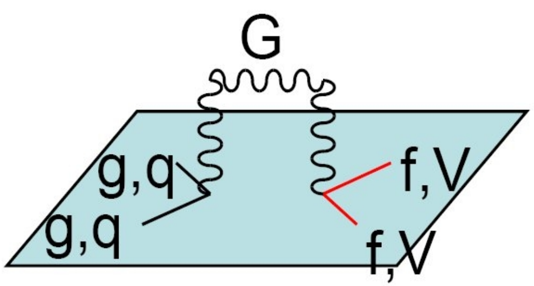
$M_{Pl(4+d)}^{MAX}$(TeV)	δ=2	δ=3	δ=4
LL 30fb^{-1}	7.7	6.2	5.2
HL 100fb^{-1}	9.1	7.0	6.0



[Vacavant et al., ATL-PHYS-2000-016]

ADD: virtual graviton exchange

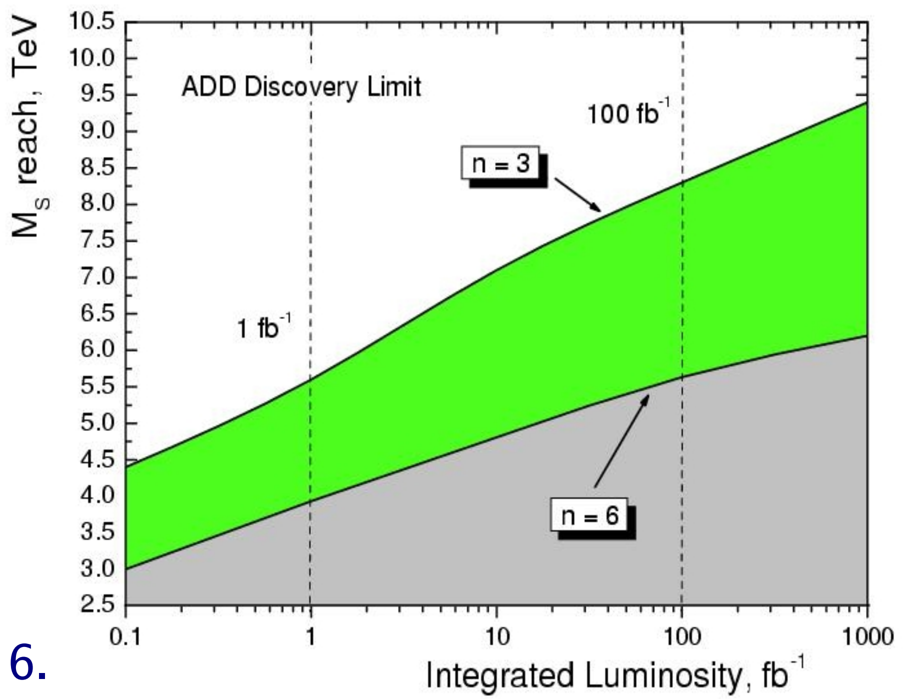
Search for deviation of the μμ DY spectrum due to virtual graviton exchange (KK mode of G) - in ADD ED framework



1. pp -> G -> mumu gamma
signature: 2 opposite sign muons and M>1 TeV
bg: irreducible Drell-Yan, ZZ, WW, tt

Discovery limits: includes systematics: misalignment, K factor (1.3 +-0.05), hard scale and PDF, trigger

1 fb^{-1}:	3.9-5.5 TeV for n=6..3
10 fb^{-1}:	4.8-7.2 TeV for n=6..3
100 fb^{-1}:	5.7-8.3 TeV for n=6..3
300 fb^{-1}:	5.9-8.8 TeV for n=6..3



-> Planck scale: $3.9 < M_S < 8.8$ TeV and n=3 to 6.

TeV^{-1} size extra dimensions

[Antoniadis, PLB246(1990)377; Lykken et al., PLB485(2000)224]

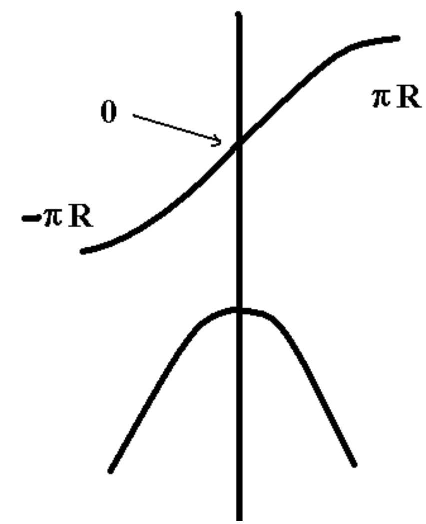
TeV^{-1} size ED:

p LED + δ-p 'small' ED

if ED small enough R <= TeV^{-1} SM field propagate in the bulk:

KK tower of states for gauge bosons:

$$m_k^2 = m_0^2 + k^2 M_C^2 \in k^2 M_C^2$$



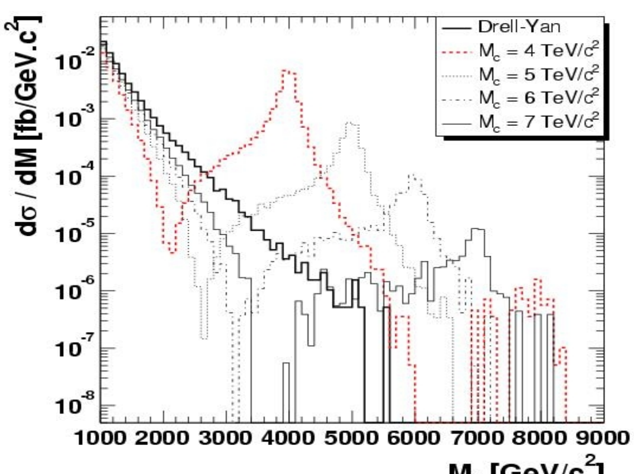
compactified on an orbifold S^1/Z^2

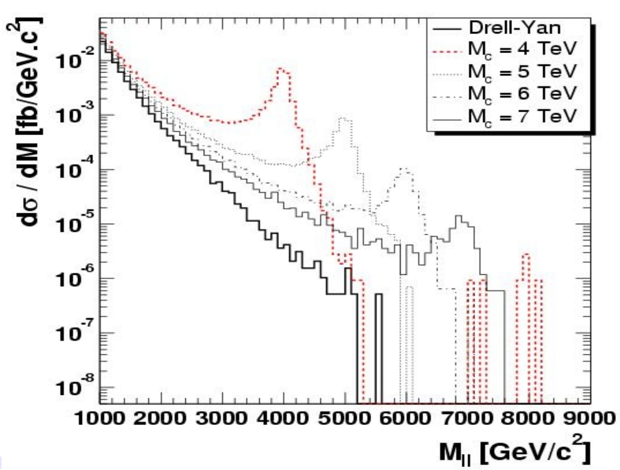
symmetry under the transformation y -> -y

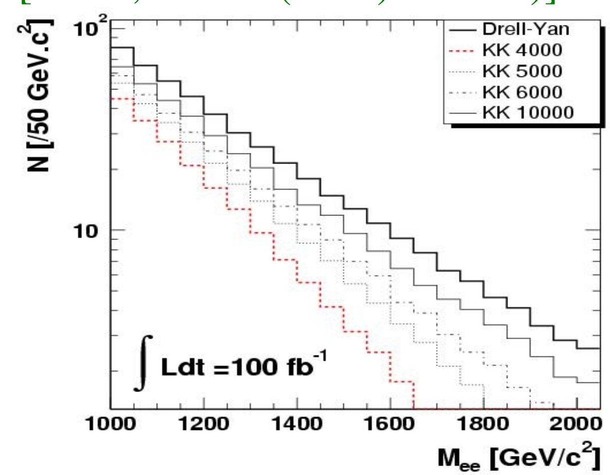
All the SM fermions are at the same fixed point y=0 (model M1)

or alternate at opposite points y=0 and y=r (model M2)

[Rizzo, PRD61(2000) 055005)]



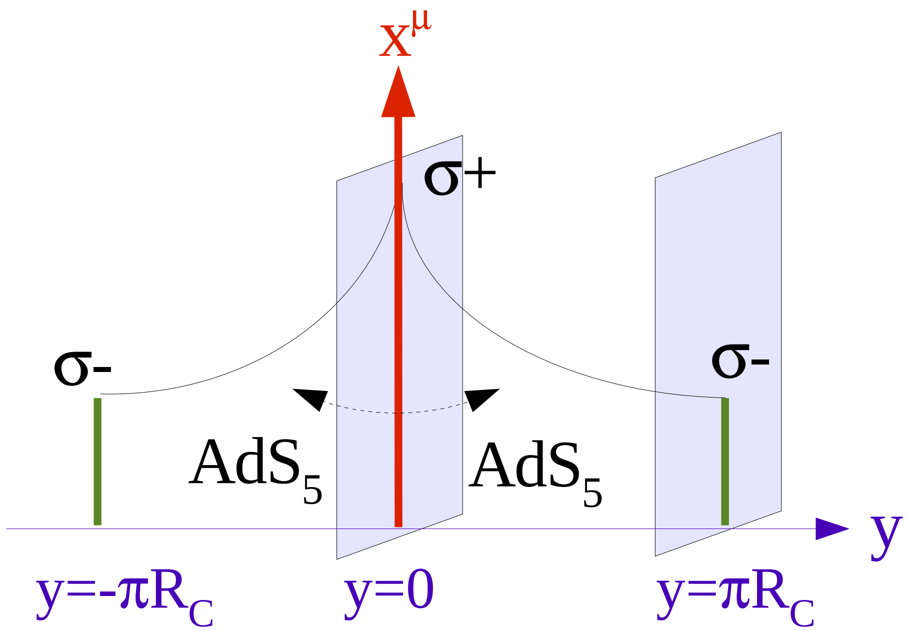




The Randall Sundrum (RS1) model

1 ED compactified, constant and negative curvature space (AdS_5):

bounded by 2 branes: Planck brane (y=0) and TeV or SM brane ($y=\pm\pi R_C$)



$$m \rightarrow m e^{-\pi k R_C}$$

metric: (non factorizable)

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

$R_5 = -20\ k^2$

Gauss law: relates M_D to M_{Pl} :

$$\overline{M}^2_{Pl} = \frac{M_D^3}{k}\left(1 - e^{-2\pi k R_C}\right)$$

The scale of phys. phen. as realized by 4D flat metric ⊥ to 5th dim:
~10^{18} GeV → 1 TeV need kR_C~11
R_C ~10^{-32} m (very small)

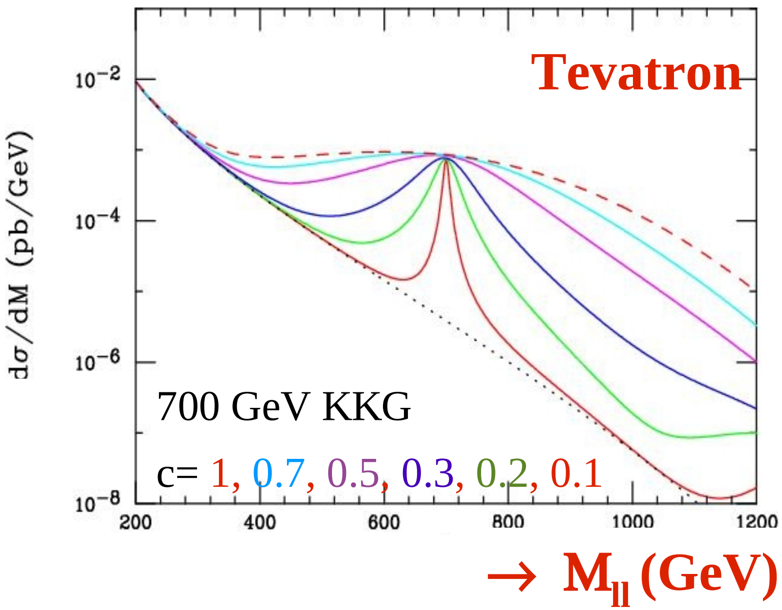
$$\Lambda_{\pi} = \overline{M}_{Pl} e^{-k\pi R_C}$$

No hierarchy: $k \sim M_D \sim M_{Pl}$

consistency SM:
$k < M_D$ ($k <= 0.1 M_D$)
$k < 0.1 M_{Pl}$

The Randall Sundrum (RS1) model

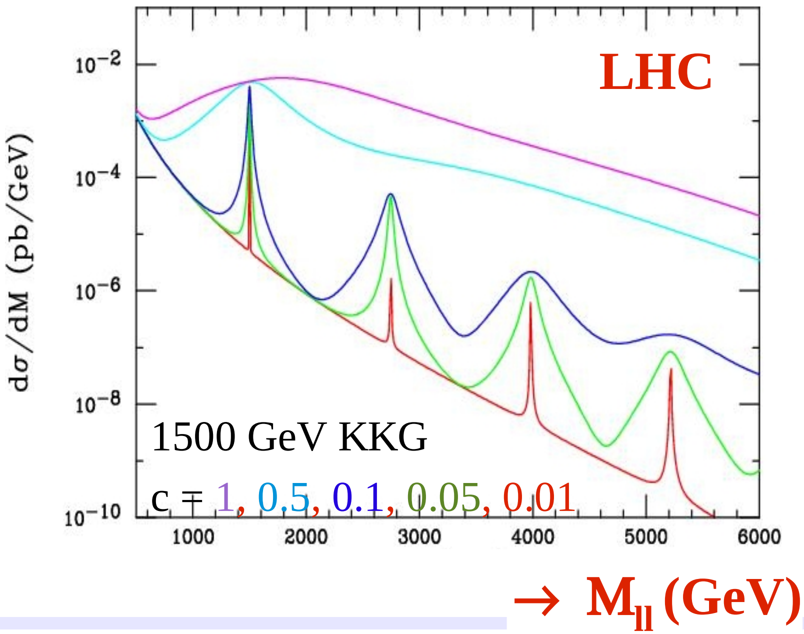
Davoudias et al, PRD63 (2001) 075004 hep-ph/0006041]

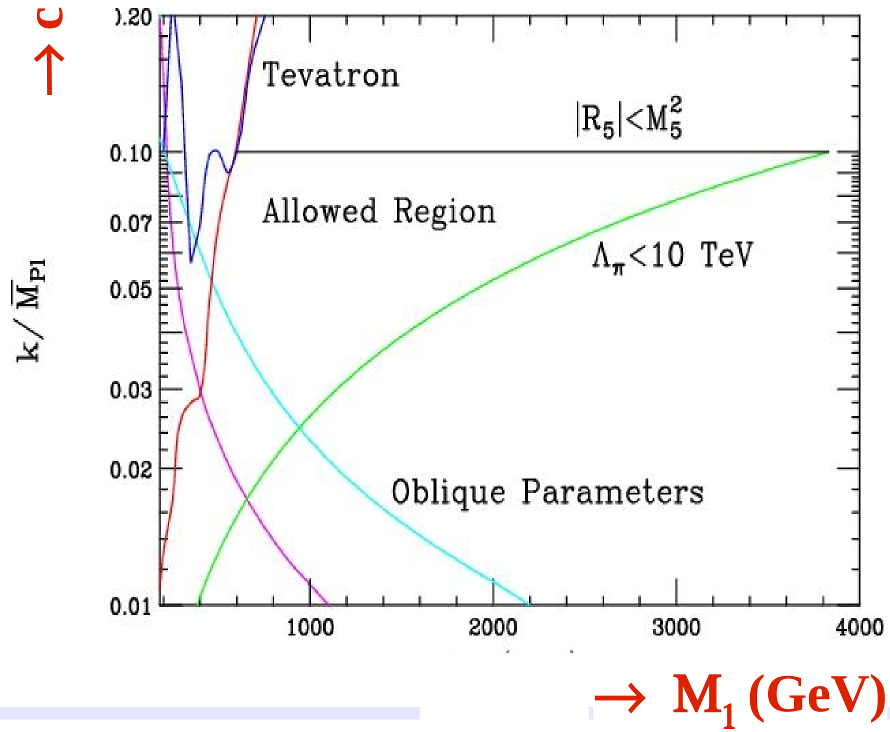


2 free parameters: m_1 or Λ_π and $k/M_{Pl} = c$

width: $\sim (k/M_{Pl})^2$

$\sim m_n^3$





The Z' (GUT) models

Additional heavy neutral gauge boson are predicted in many models BSM:
superstring-inspired and GUT theories - L-R models - little Higgs
No reliable prediction on the Z' mass scale (free parameter)

Consider 6 Z' models, representative of a broad class of models:
- Sequential Standard Model (SSM): same coupling as SM Z
- $Z(\psi)$, $Z(\eta)$ and $Z(\chi)$, arising from E6 and SO(10) GUT groups
  differ from couplings to quark and leptons
- Z_LRM and ZALRM, arising from the framework of the so-called “left-right” and “alternative left-right” models.

Current limits on Z' mass: from 600-900 GeV depending on models
Tevatron: expected to cover up to masses ~1 TeV

Search for heavy resonances

- **Search for a (narrow) resonance at the TeV scale in the following topologies:**

Di-electron, di-photon, di-muon and di-jets resonance states
from GUT models (Z'), RS1-model (G) and TeV^{-1} extra dimension model (KKZ)

- **How to distinguish between models ?**

B. Clerbaux et al. CMS NOTE 2006/083

pp → HR → ee

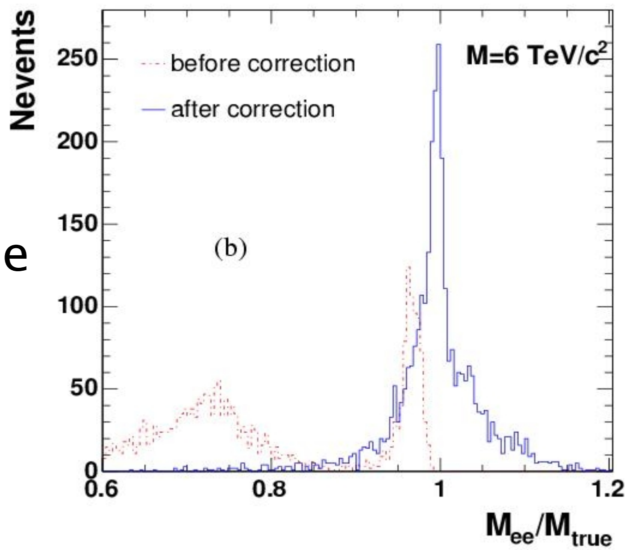
Heavy Resonance: from TeV^{-1} ED (KKZ), GUT (Z') and RS(G)

Dominant and irreducible bg: DY: pp → γ/Z → ee

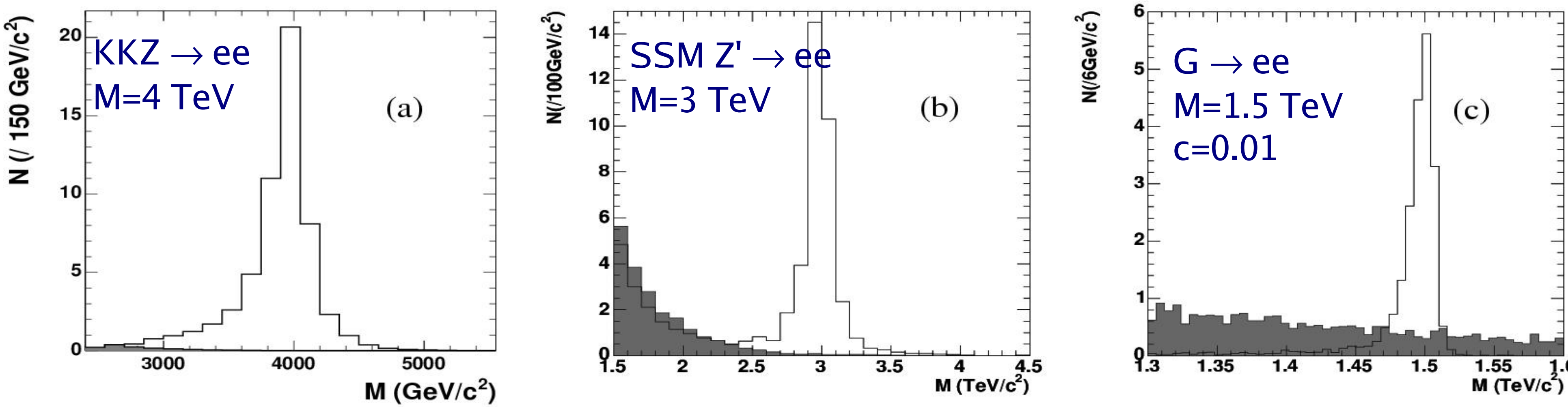
Selection: 2 electrons: Et>100 GeV in ECAL + track, + FSR recovery, H/E, isolation

Reconstruction: saturation of ECAL readout electronic because of limited dynamical range of the Multi-Gain- Pre-Amplifier: if E1>1.7 TeV (in barrel) and 3.0 TeV in Endcap

Mass resolution: ~0.6 % for non saturated events and ~7% for saturated events



For L=30 pb^{-1}:



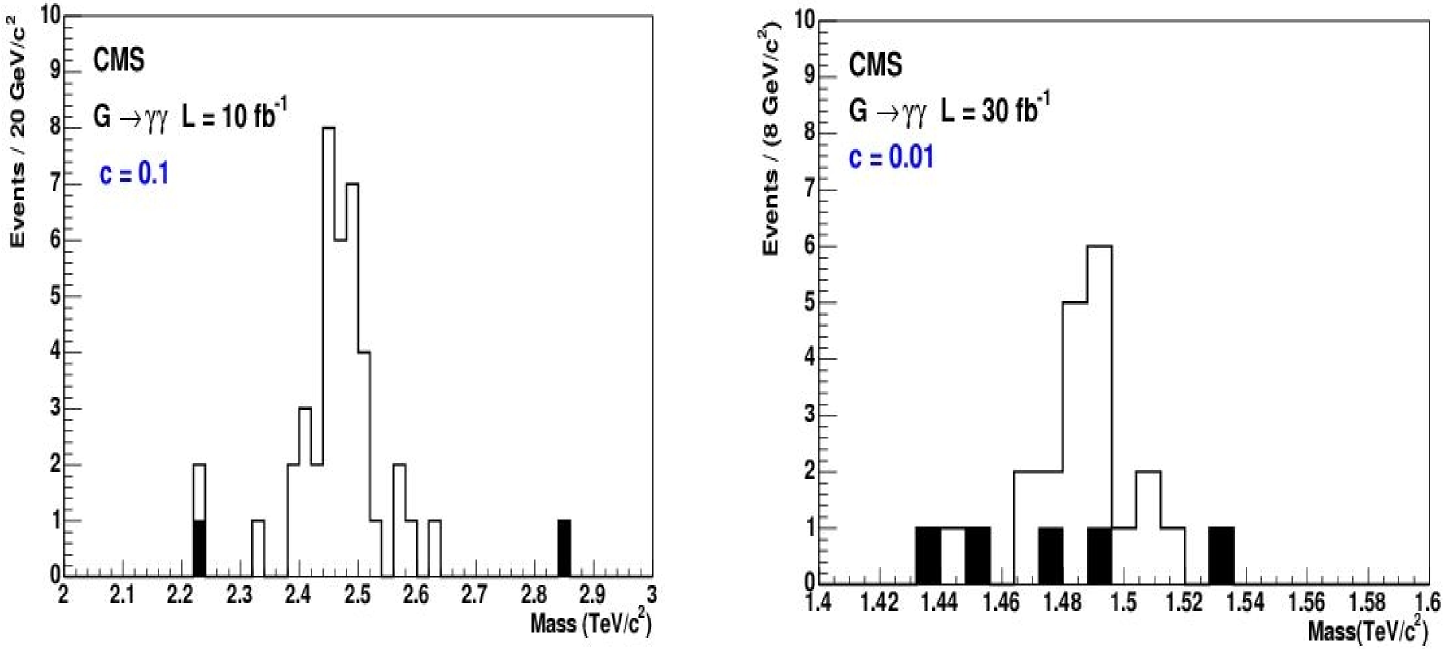
M.-C. Lemaire et al. CMS NOTE 2006/051

$pp \rightarrow G \rightarrow \gamma\gamma$

Important channel: Identify a graviton: $G\rightarrow \gamma\gamma$, distinguish to Z'

Main bg: prompt diphoton (irreducible)
(γ+ jets, QCD jets, DY(ee))

Selection: 2 electrons Et>150 GeV in ECAL, H/E, isolated in ECAL/tracker
Reconstruction: saturation correction



High mass di-muons

R. Cousins et al. CMS NOTE 2005/002
CMS NOTE 2006/062

$pp \to HR \to \mu\mu$
Heavy Z from GUT (Z') and RS(G)

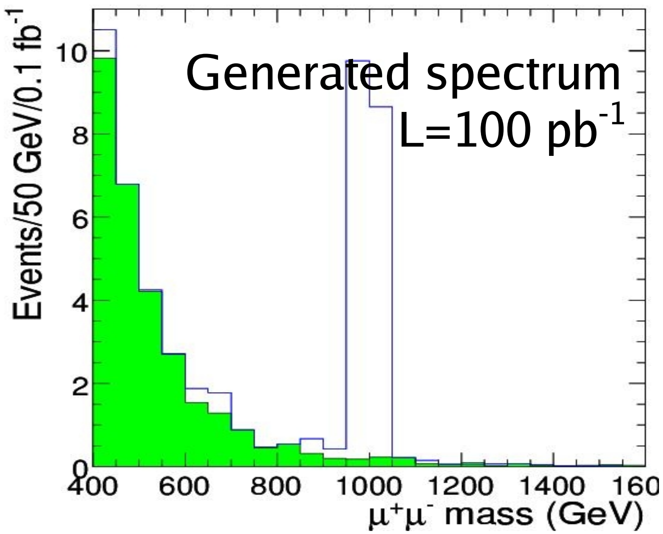
Dominant and irreducible bg: DY: $pp \to \gamma/Z \to \mu\mu$
others: ZZ,ZW,WW tt: few % of DY bg

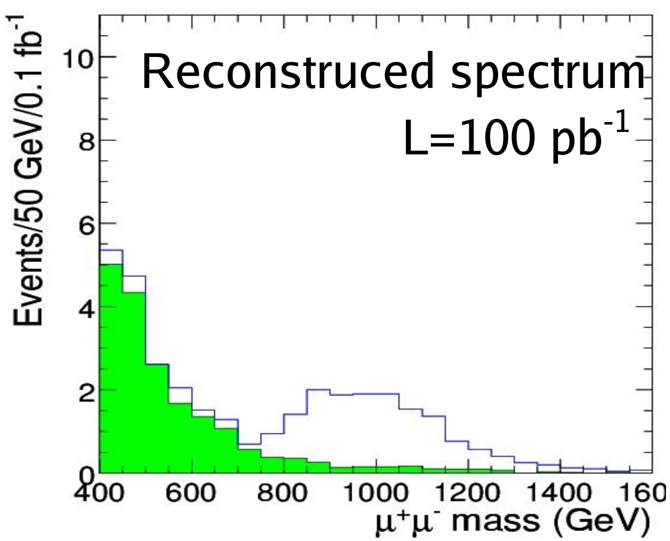
Selection:
- muon acceptance |eta| <2.4
- at least 2 muons of opposite charge + FSR recovery
- overall acceptance ~75-85 %

Reconstruction: misalignment of tracker + muon system: "first data" (0.1 fb^{-1}) and "long term" (1 fb^{-1}) scenarios

Mass resolution: 4.2 (1TeV) to 9% (5TeV) - long term
12.5 % (1 TeV) first data

Example: mass spectrum for 1TeV Z'(η) signal and DY bg ($L=100\ pb^{-1}$, and using "first data" misalignment).

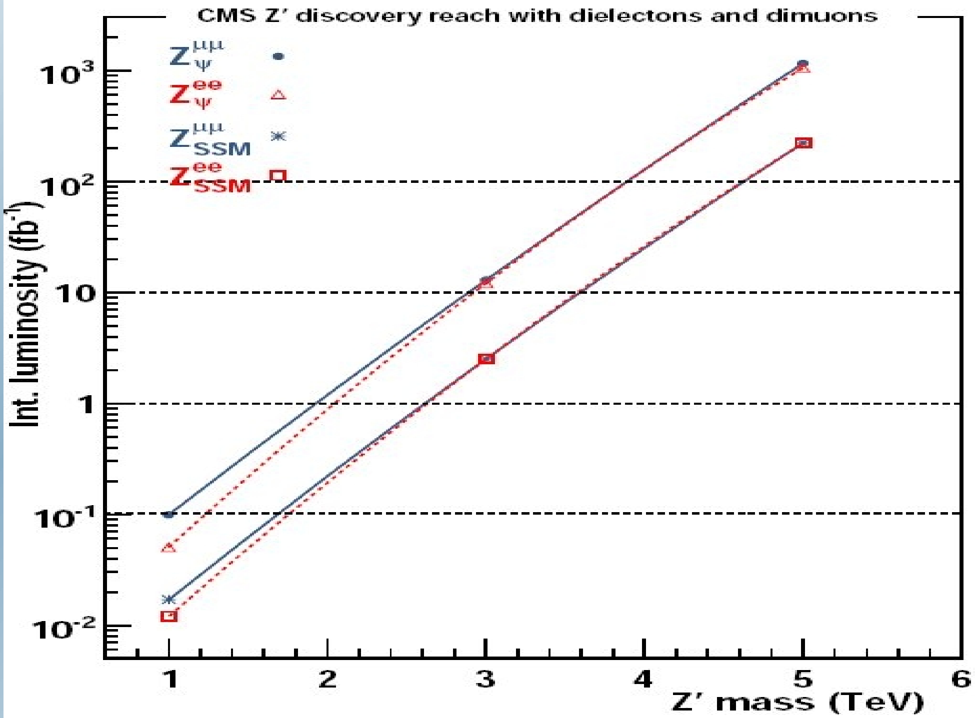




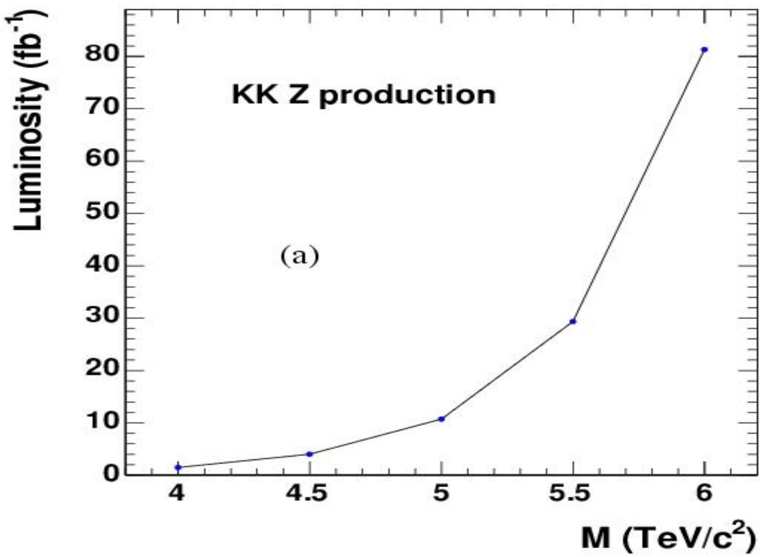
Discovery limits

CMS PTDR(volII) CERN/LHCC 2006-021

For Z' production:



For KKZ production:



Reach: Z' mass up to 1 (3) (5) TeV with L<~ 0.1 (10) (1000) fb^{-1}

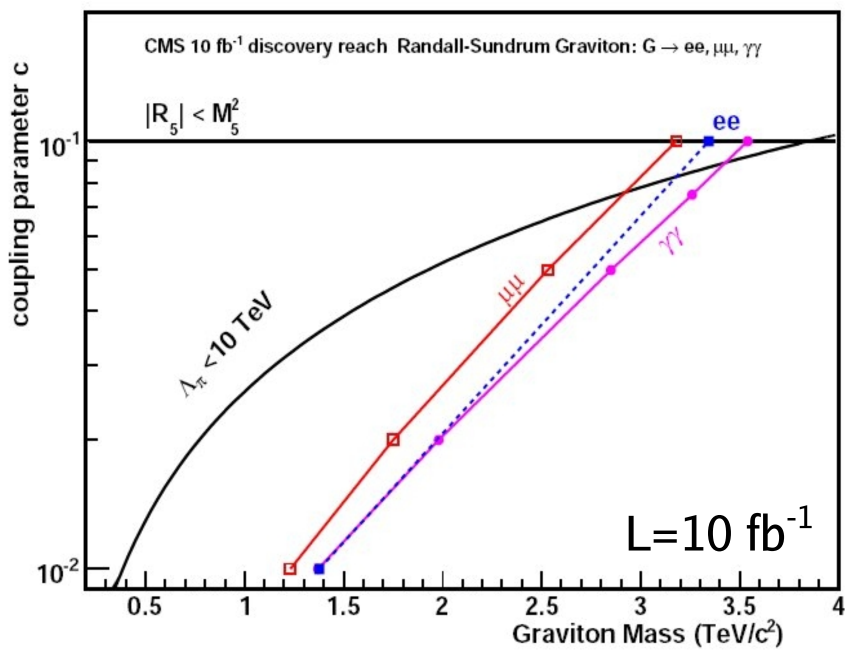
Reach: KKZ mass up to 5 (5.5) (5.9) TeV with L=10 (30) (60) fb^{-1}

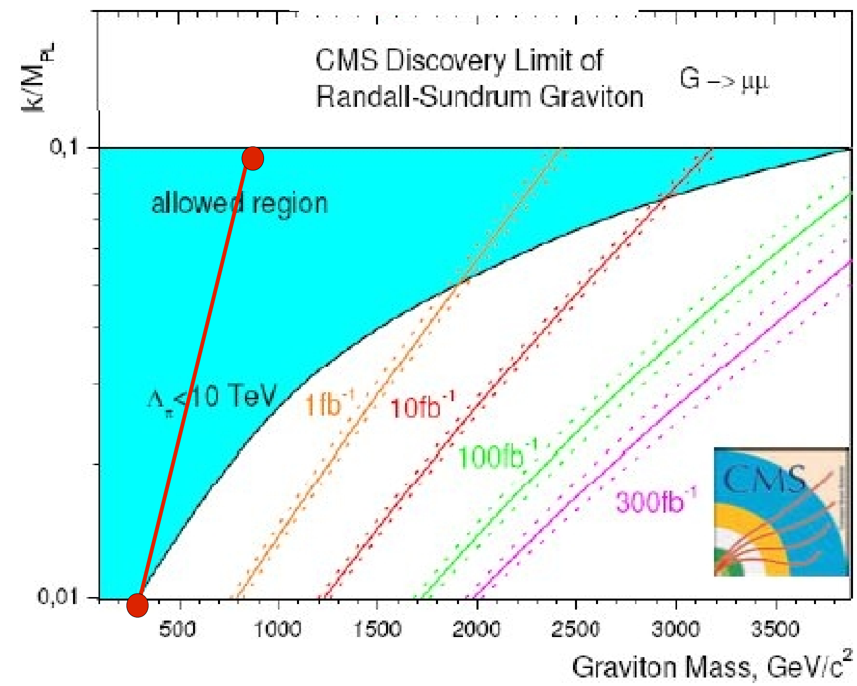
μμ: low Land low mass: suffers from misalignment effects (recover for L>10 fb^{-1})
ee: high mass: suffers from ECAL electronic saturation, degrade the mass resolution

Discovery limits

CMS PTDR(volII) CERN/LHCC 2006-021

For G production:





- BR for G $\rightarrow \gamma\gamma$ is ~twice the one for ee or $\mu\mu$
- Low c and mass: $\gamma\gamma$ channel suffers from QCD and prompt photon bg

Tevatron limit: (G->ee and gg)
L~1 fb-1 (D0) and 1.3 (CDF)

Reach: Most of the interesting plane in (M, c) for L < few fb^{-1}

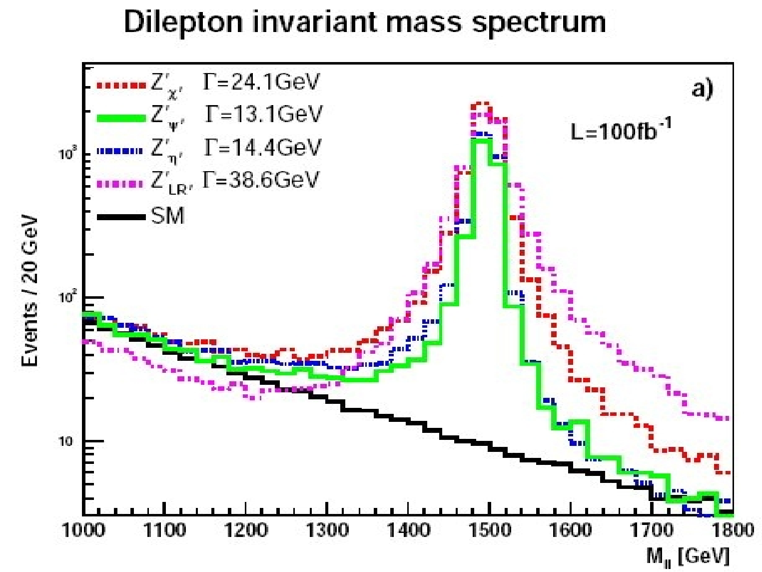
Distinguishing among heavy Z models

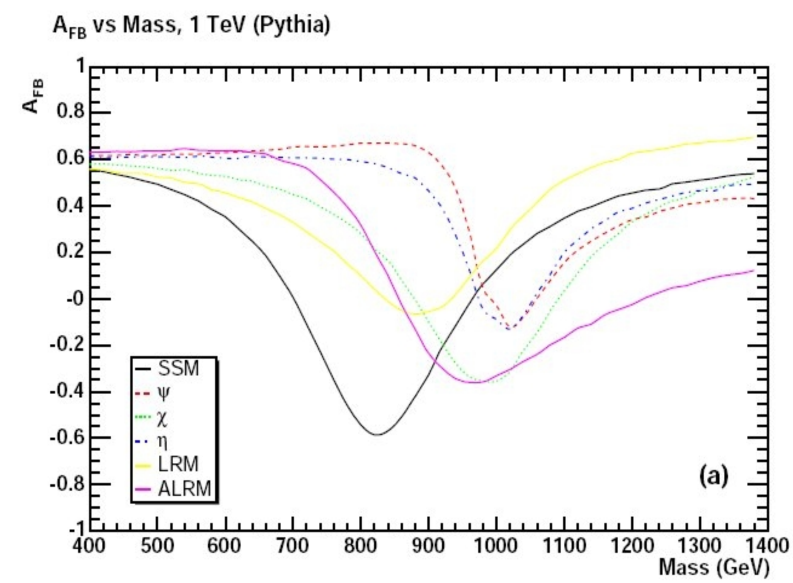
R. Cousins et al. CMS NOTE 2005/022

If new heavy Z resonance is discovered

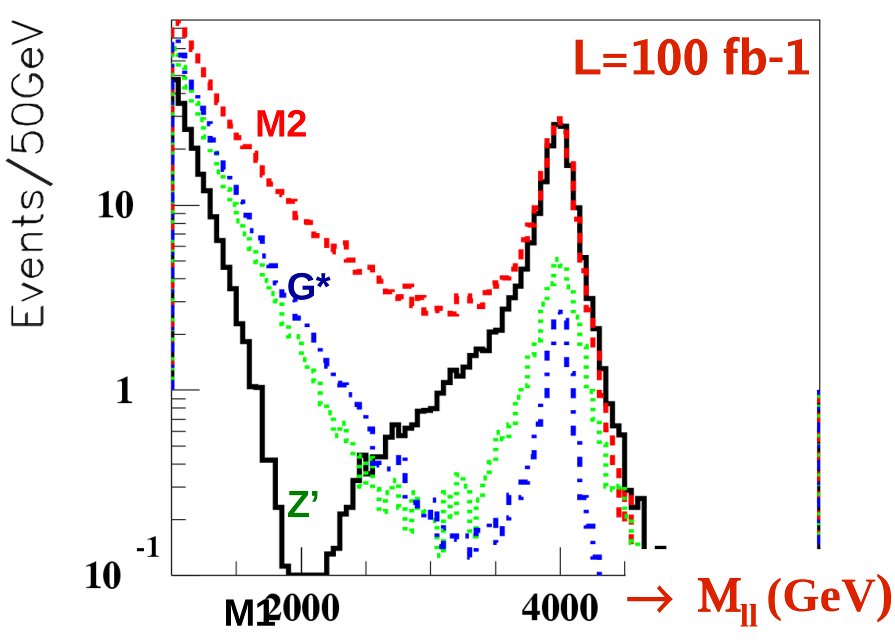
characterisation of its coupling using:
- production and decay distributions
- measurement of forward-backward asymmetries of leptonic decay product at the resonance peak and off-peak

(uncertainty in the sign of cosθ∗ in pp collision!)





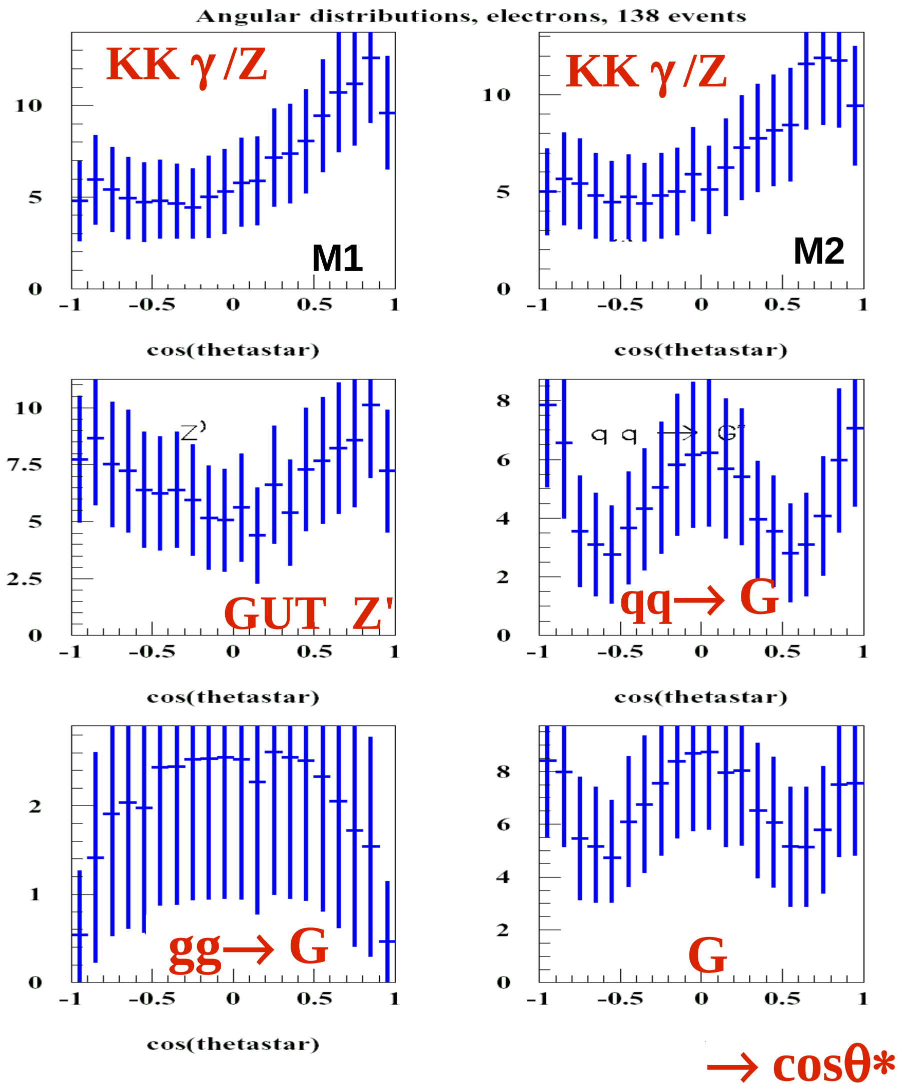
4 TeV resonances



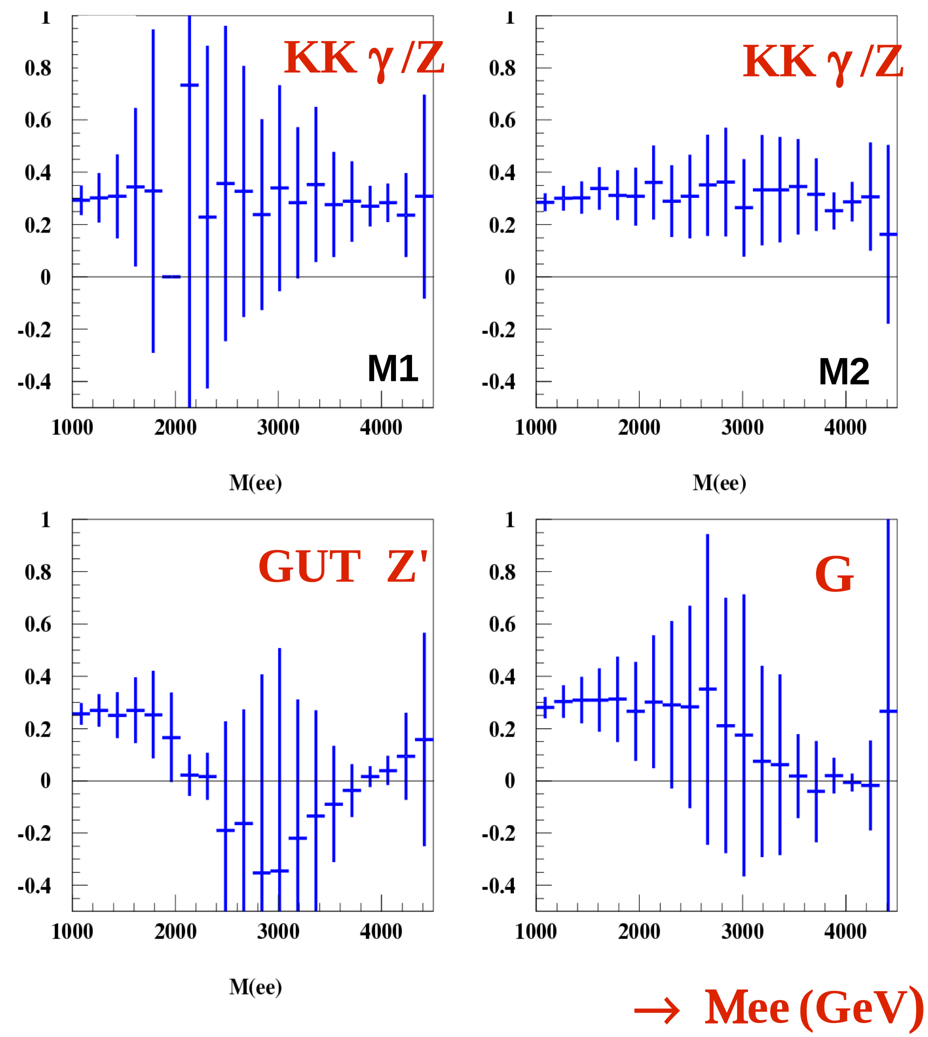
Distinguishing among heavy Z models

M=4 TeV resonance, L=100 fb^{-1}

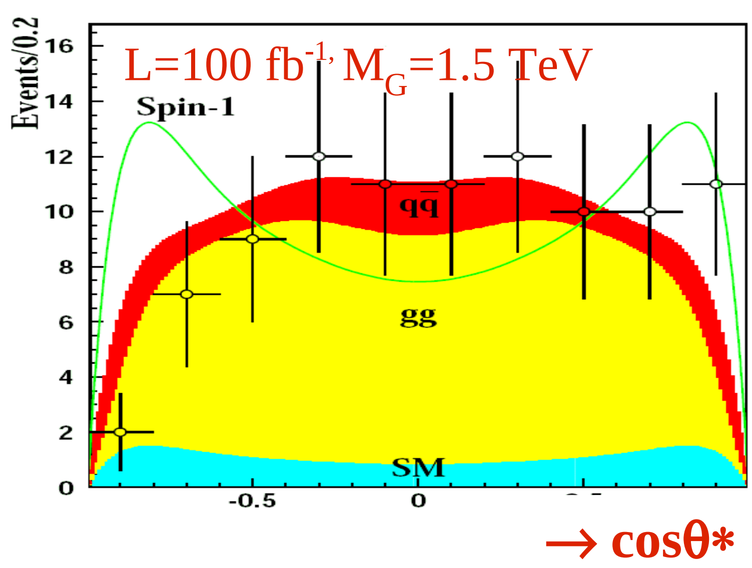
cos * distribution:

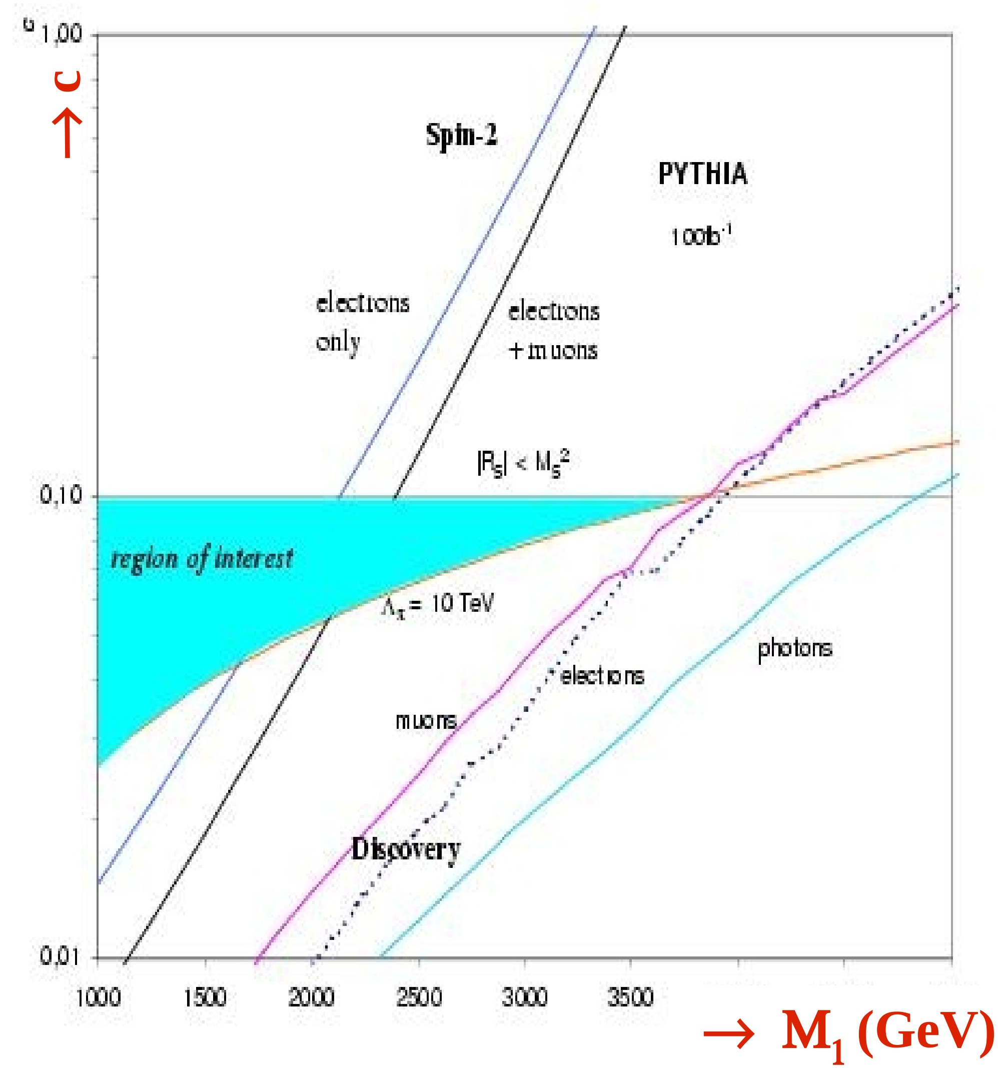


A_{FB} asymmetry:



Distinguishing among heavy Z models





Spin-2 (versus spin 1) could be determined up to G mass of ~ 1700 GeV

High energy single lepton

C. Hof et al. CMS NOTE 2006/117

Search for heavy W' : W' $\rightarrow \mu\nu$

(L-R models , composite models, little Higgs model)

Use reference model W' (same coupling as W, except opening ttbar for M(W')>180 GeV)

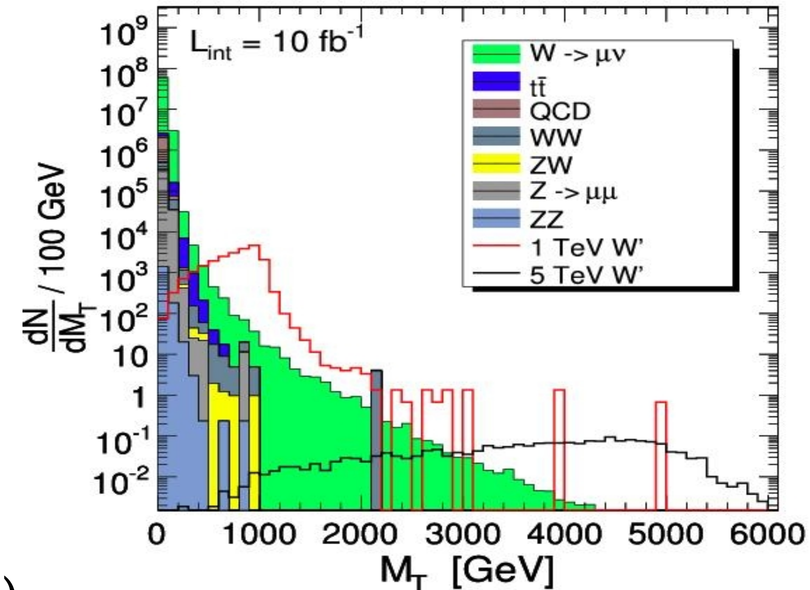
Topology: μ + missing Et

bg:W$\rightarrow\mu\nu$, Z$\rightarrow\mu\mu$, WW incl., ZZ incl., ZW incl., tt.

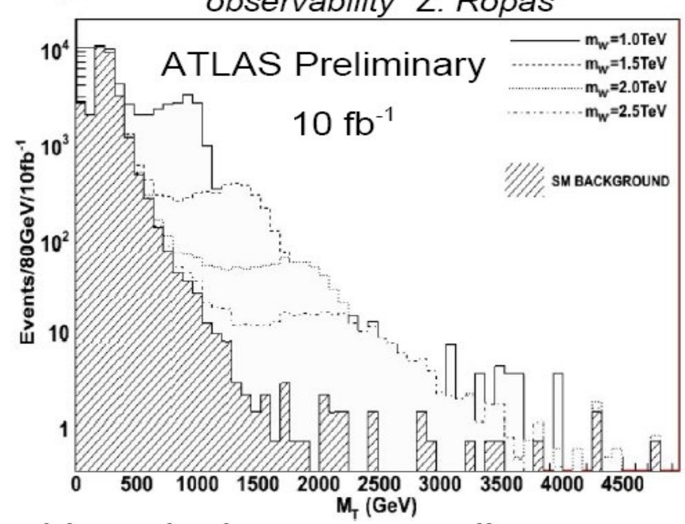
Selection: single muon (good quality fit) + isolation

Transverse mass: $M_T = \sqrt{(2pt(\mu)\ Et(miss)\ (1-\cos\Delta\Phi))}$

Peak is spread at large M_T due to detector resolution



"Recent results on W' observability" Z. Ropas



5 sigma discovery:

W' mass (TeV)	Luminosity (pb^{-1})
1	3.0 ± 0.3
1.5	14.6 ± 1.4
2	84 ± 9
2.5	283 ± 31

. ~3.5 (4.5) TeV for 1 (10) fb-1

ED reach summary

Model	Mass reach	Integrated Luminosity (fb-1)
ADD: direct G	M_D~ 1.5 – 1.0 TeV, n= 3 – 6	1
ADD: virtual G	M_D~ 4.3 – 3.0 TeV, n= 3 – 6 M_D~ 5.5 – 3.9 TeV, n= 3 – 6	0.1 1
RS1 di-electrons di-photons di-muons di-muons	 M_{G1}~ 1.3 – 3.3 TeV, c= 0.01-0.1 M_{G1}~ 1.3 – 3.5 TeV, c= 0.01-0.1 M_{G1}~ 1.2 – 3.2 TeV, c= 0.01-0.1 M_{G1}~ 0.8 – 2.3 TeV, c= 0.01-0.1	 10 10 10 1
TeV-1 : KK Z (1)	M_Z < 5 TeV	1
SSM Z'	M_Z < 3 TeV M_Z < 2 TeV	10 1
SSM W'	M_Z < 4.5 TeV M_Z < 3.5 TeV	10 1

→ **Rich potential at the LHC**
in particular *already* at the LHC start up: luminosity < few fb^{-1}

Summary

CMS and ATLAS from now to 1fb^{-1}:

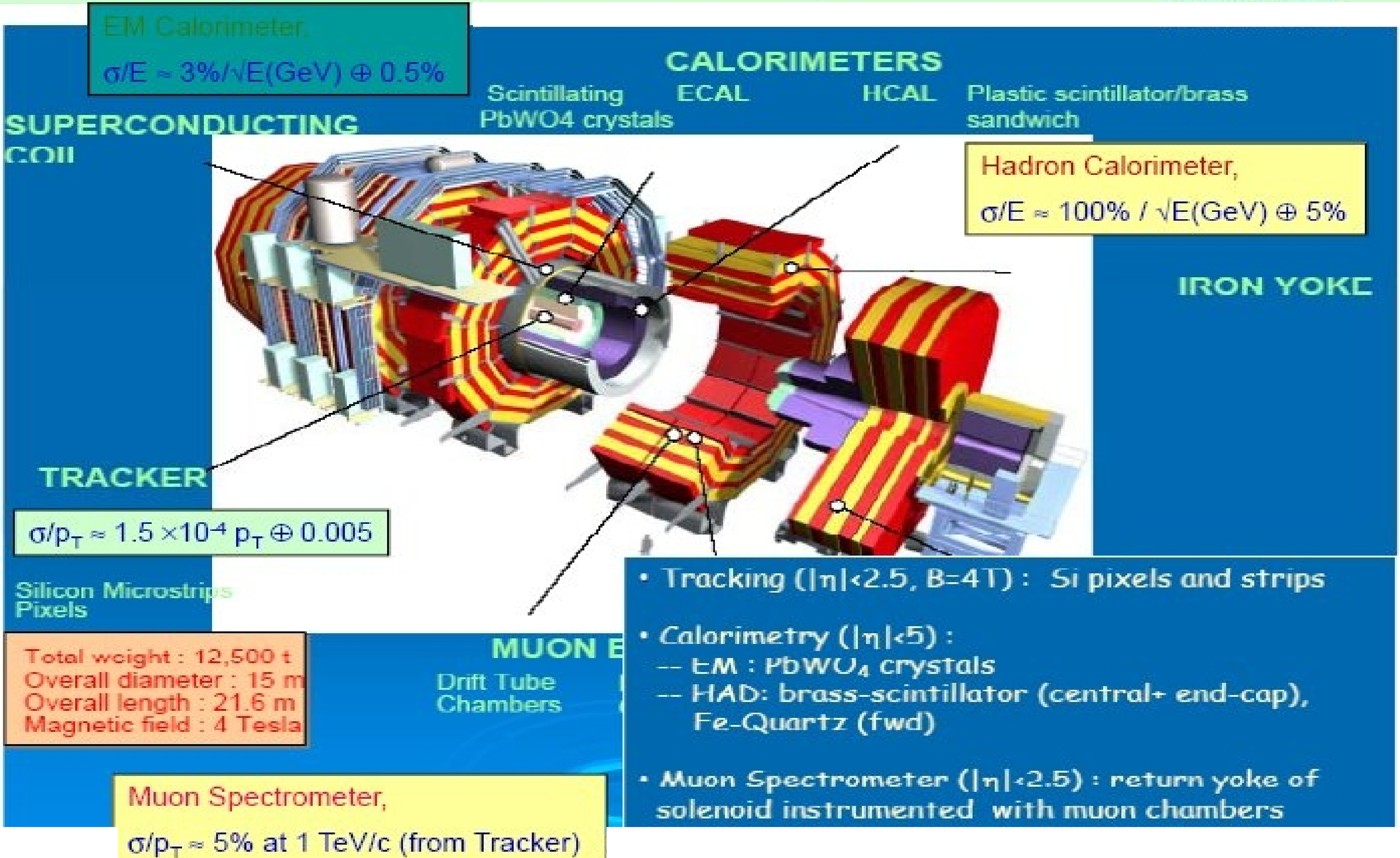
- **Early beam, up to 10 pb^{-1}: physics objet commisioning**
  - Detector synchronization, alignment with beam-halo events, minimum bias events
  - First alignment and calibration using physics events
  - Measure physics objetcs: jet and lepton rates: observe W, Z, top
  - Look at BSM signature ! ...

- **Physics collisions up to 100 pb^{-1}: measure SM and start searches**
  - 10^6 W->lν (l=e,μ) 2×10^5 Z->ll and 10^4 ttbar->μX
  - improved understanding of physics objects: JES from W->jj', b tagging
  - measure background to SUSY and HIGGS searches
  - initial MSSM (and some SM) Higgs sensitivity
  - early look for excesses from SUSY and Z' resonances.

- **Physics collisions up to 1 fb^{-1}: enter Higgs discovery era**
  and explore large part of SUSY and resonances at ~ few TeV

Back up slides

Compact Muon Solenoid (CMS) DETECTOR



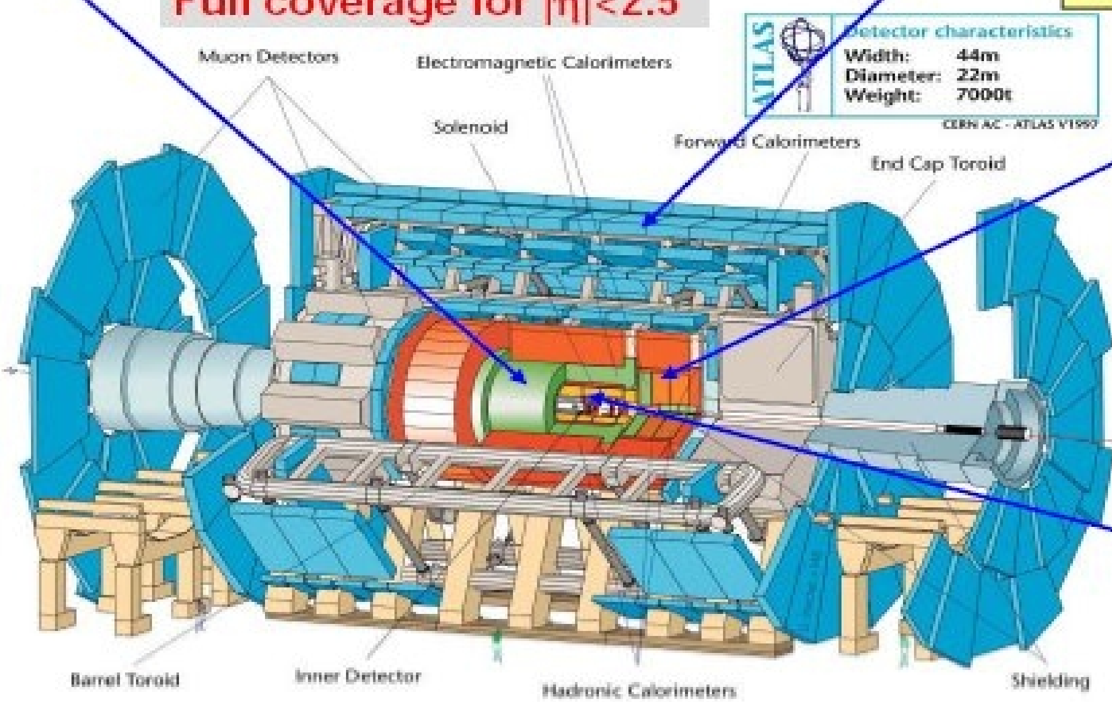
- Tracking ($|\eta|<2.5$, B=4T) : Si pixels and strips
- *Calorimetry* ($|\eta|<5$) :
  - -- EM : $PbWO_4$ crystals
  - -- HAD: brass-scintillator (central+ end-cap), Fe-Quartz (fwd)
- Muon Spectrometer ($|\eta|<2.5$) : return yoke of solenoid instrumented with muon chambers

A Toroidal LHC AppartuS (ATLAS) DETECTOR

Precision Muon Spectrometer,
$\sigma/p_T \approx 10\%$ at 1 TeV/c
Fast response for trigger
Good *p* resolution
(e.g., $A/Z' \rightarrow \mu\mu$, $H \rightarrow 4\mu$)

EM Calorimeters, $\sigma/E \approx 10\%/\sqrt{E(GeV)} \oplus 0.7\%$
excellent electron/photon identification
Good *E* resolution (e.g., $H \rightarrow \gamma\gamma$)

Full coverage for $|\eta|<2.5$



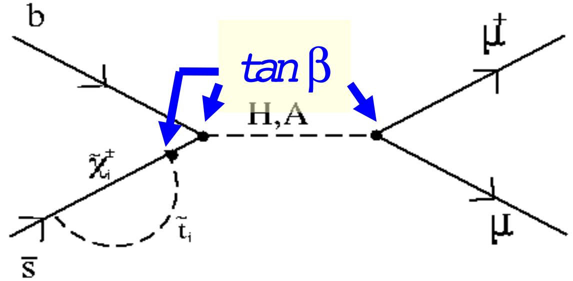
Hadron Calorimeters,
$\sigma/E \approx 50\% / \sqrt{E(GeV)} \oplus 3\%$
Good jet and E_T miss performance
(e.g., $H \rightarrow \tau\tau$)

Inner Detector:
Si Pixel and strips (SCT) &
Transition radiation tracker (TRT)
$\sigma/p_T \approx 5 \times 10^{-4}\, p_T \oplus 0.001$
Good impact parameter res.
$\sigma(d_0)$=15μm@20GeV (e.g. $H \rightarrow bb$)

Magnets: solenoid (Inner Detector) 2T, air-core toroids (Muon Spectrometer) ~0.5T

Bs → μμ

BR(SM) = $(3.4\ \ 0.5) \times 10^{-9}$



SUSY : ~ $(\tan\beta)^6$ → can be as high as 10^{-6} !

Results (limits at 95% C.L.):

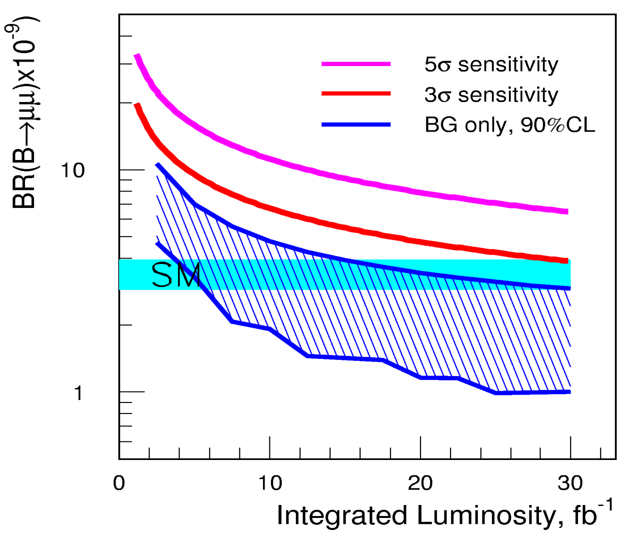
DØ (2 fb^{-1}): 2.3±0.5 expected, 3 observed → $BR(B_s \to \mu^+\mu^-) < 9.3\times10^{-8}$
CDF (2 fb^{-1}): 3.7±1.0 expected, 3 observed → $BR(B_s \to \mu^+\mu^-) < 5.8\times10^{-8}$

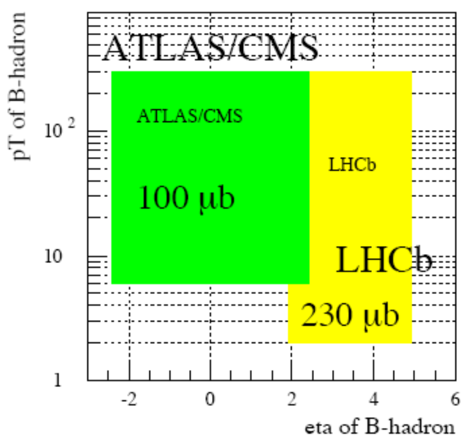
Projection for Run IIb: sensitivity will approach 10^{-8}

ATLAS & CMS, keys :

- Trigger on diμ at low pt
- tracking, PID, resolution M

J.Berryhill, Flavor Workshop 07

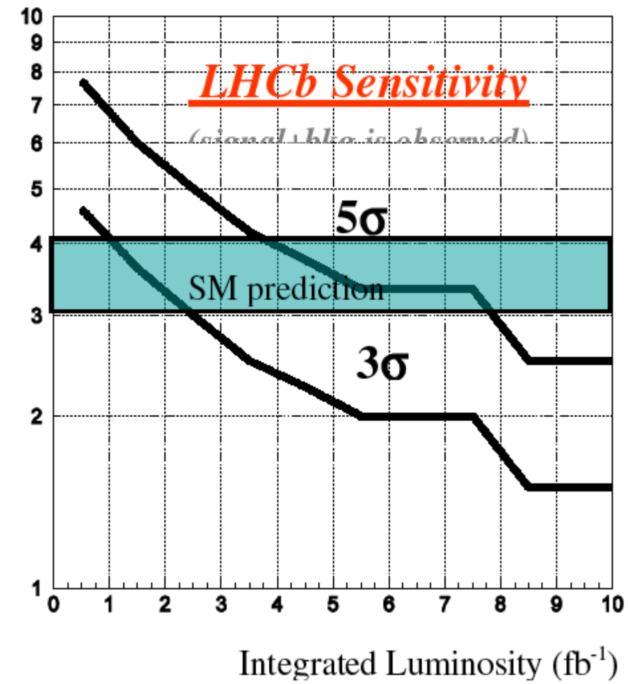




S/B similaire ~ 0.4
30 fb^{-1} : ~ 20 evts
signal (SM), B ~ 40 evts
i.e. 3σ possible with
L = 30 fb^{-1}, for BR = BR(SM)

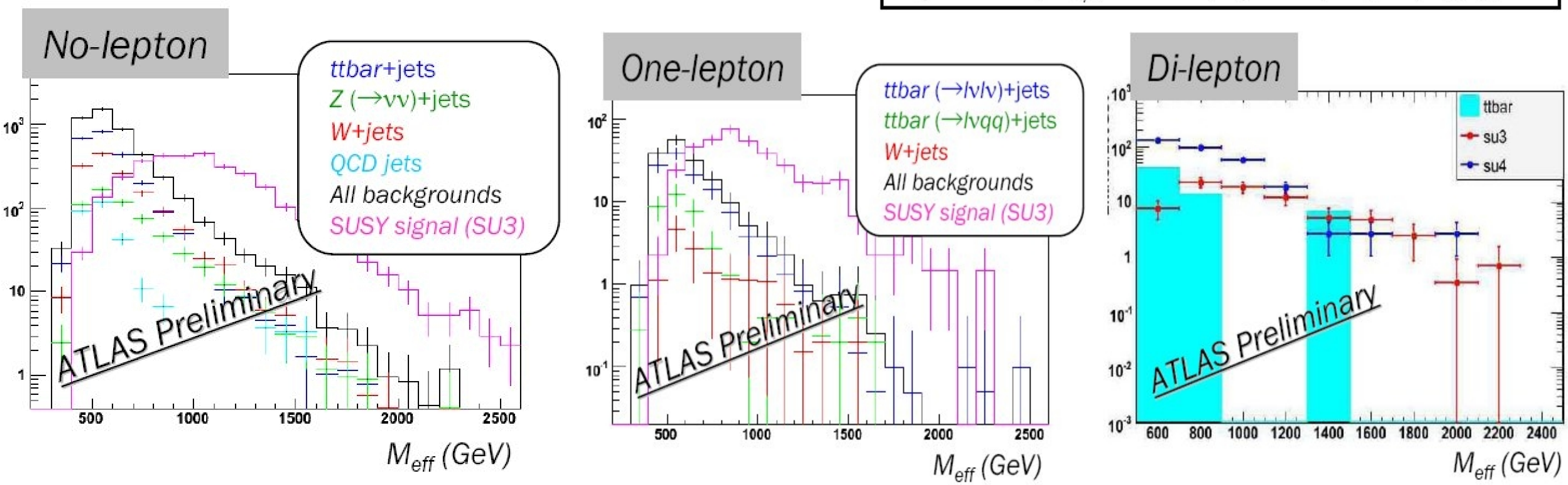
CMS : AN-2006-097
ATLAS : J. Nucl. Phys. B156 (2006) 119

LHCb : e.g. resolution
~ 20 MeV (40 CMS, 80 Atlas)



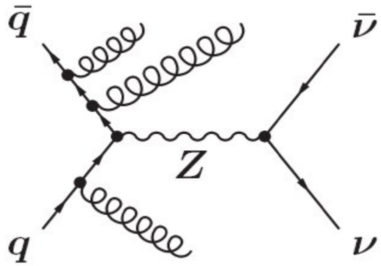
Effective Mass:
Meff = Si (pt(i) + Etmiss) discriminates between SUSY and SM background
look for excess at high Meff:

Benchmark point SU3:
m_0=100GeV, $m_{1/2}$=300GeV, A_0=-300, tanβ=6, sign(μ)=+

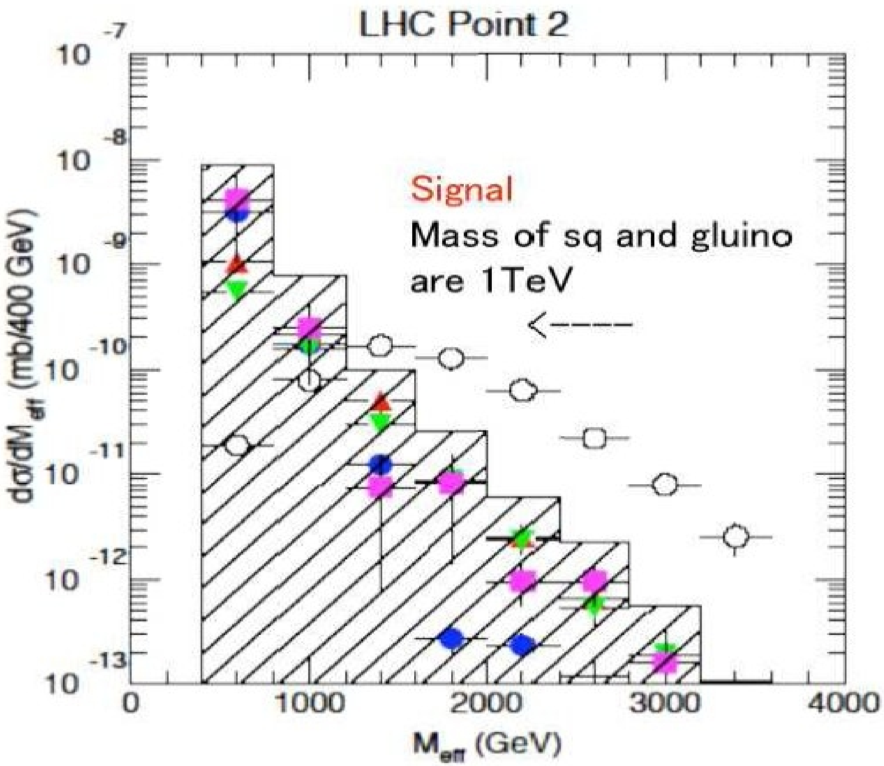


(full detector simulation, 1fb^{-1})

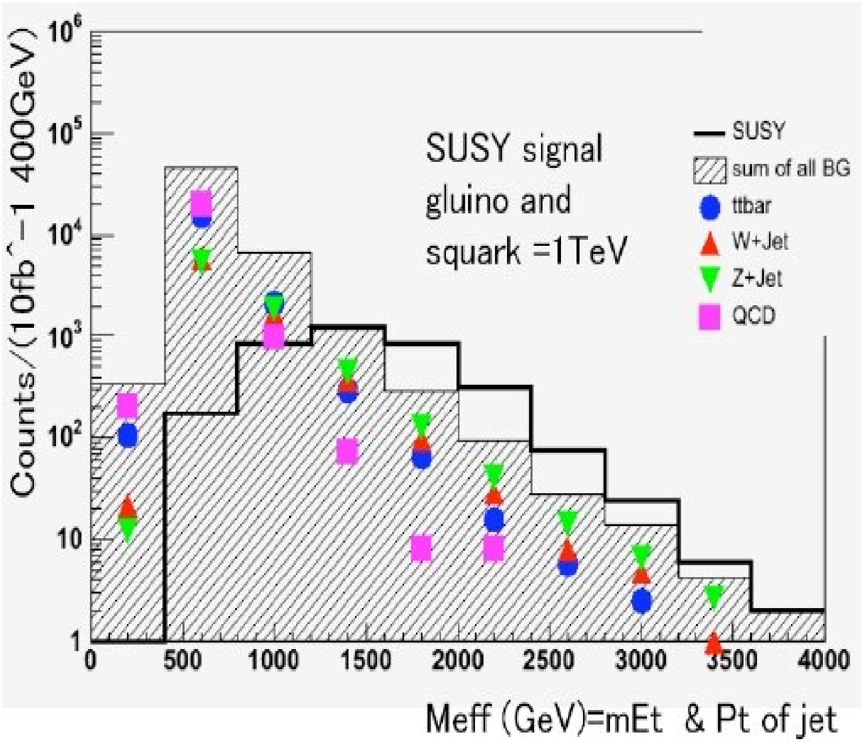
ATLAS: multijets + Etmiss



ATLAS TDR study (1999)
using PYTHIA (Parton Shower)



New analysis
with updated MC
(matrix element)



(S. Asai et al.)

Introduction

1916: Einstein: General relativity

1920: T. Kaluza and O. Klein: Tentative of unification of gravity+em in a (4+1)D space

Introduced important concepts still used in many models:

(1) - Presence of the gravity field in the bulk, which reflect the existence of a unify theory in 4+1

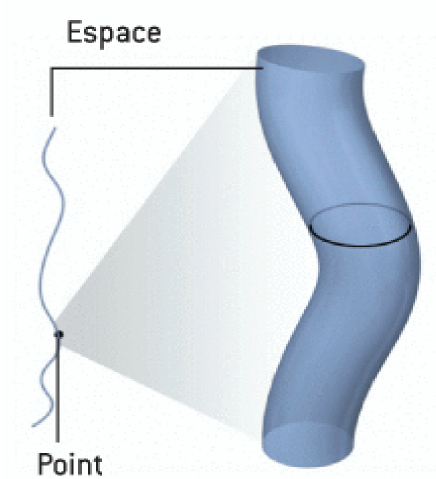
(2) - Factorization: bulk = M_4 + compact variety

(3) - Compactification of the ED
re-interpretation of field in 5D
in term of KK massif states in 4D

Suppose a massless scalar field

5D space-time. 5th dim: y, finite and compactification on a circle of radius R

$$S=\int d^4x \int_{y1}^{y2} dy \, \frac{1}{2}[\partial_A\phi \, \partial^A\phi]=\int d^4x \int_{y1}^{y2} dy \, \frac{1}{2}[\partial_\mu\phi \, \partial^\mu\phi-\partial_y\phi \, \partial^y\phi]$$

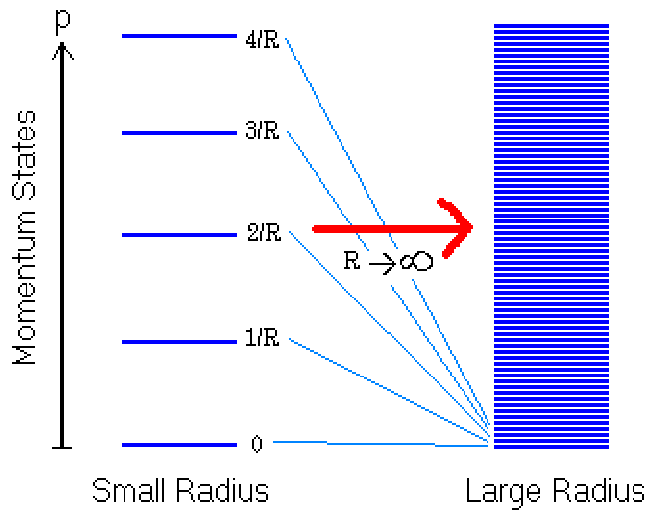


$$\phi=\sum_n \phi_n(x^\mu)\chi_n(y)$$

$$\phi=\sum_{n=-\infty}^{n=\infty}\left(\frac{1}{\sqrt{2\pi R}}\right)\phi_n(x^\mu)e^{i\frac{n}{R}y}$$

$$S=\int d^4x \int_0^{2\pi R} dy \frac{1}{2\pi R}\,\frac{1}{2}\sum_{n=-\infty}^{\infty}\sum_{m=-\infty}^{\infty}[\chi_n\chi_m\partial_\mu\phi_n\partial^\mu\phi_m-\phi_n\phi_m\partial_y\chi_n\partial^y\chi_m]$$

$$S=\int d^4x \, \frac{1}{2}\sum_{n=-\infty}^{\infty}[\partial_\mu\phi_n\partial^\mu\phi_n-m_n^2\phi_n^2] \qquad m_n=\frac{n}{R}$$



→ equation of a massive field

A observer in 4D space sees a field propagating in 5D space asa tower of massif states (called KK tower), equidistant in mass

Distinguishing among Z' models

- The forward-backward asymmetry:

qq → μ+μ−

$$A_{\rm FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

$$\sigma_F \equiv \int_0^1 \frac{d\sigma(q\overline{q} \to \mu^+\mu^-)}{d\cos\theta^*} d\cos\theta^*$$

θ∗: angle between quark direction and μ− in μ−μ+ CM

$$\sigma_B \equiv \int_{-1}^0 \frac{d\sigma(q\overline{q} \to \mu^+\mu^-)}{d\cos\theta^*} d\cos\theta^*$$

For spin 1 (γ/Z/Z') propagators:

$$P(\cos\theta^*; A_{\rm FB}, b) = \frac{3}{2(3+b)}(1 + b\cos^2\theta^*) + A_{\rm FB}\cos\theta^*$$

A_{FB}: depends on left- and right- handed couplings of γ/Z/Z' to u and d quarks and charged leptons.

- Uncertainty in the sign of cosθ∗ in pp collision:

quark direction is ambiguous experimentally since the quark can come from either p

assume: longitudinal motion of the dimuon system gives the quark direction

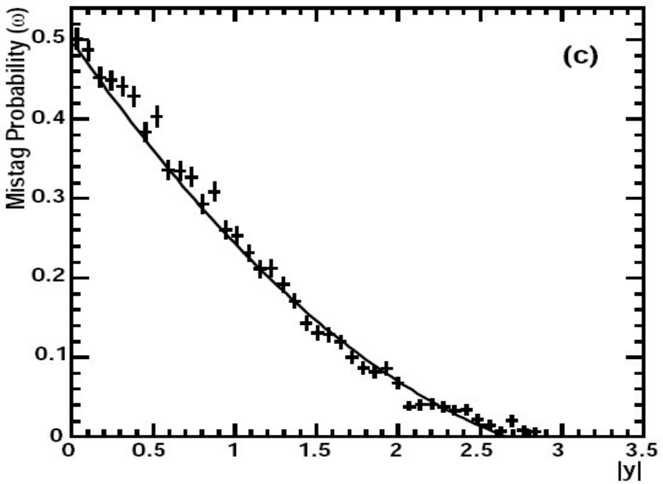
→ exist "mistagging probability" - high at low y value – low at high y value

→ dilute the A_{FB} if not corrected for

Use the Collins-Soper reference frame (pt effect)

To correct for mistag: y cut, A_{FB} in y bin or mistagging probability on an event by event basis (using all event)

Define a mistagging probability function: W(y, M)
unbinned likelihood fit on P(cosθ∗) after mistag correction
→ nominal uncertainty on A_{FB}
= 0.09 in a fit of 400 events for 1 TeV Z'
0.08 400 3



Significance level (in term of sigma's)
for pairwise comparisons of Z' models:

Model	Z_{ALRM}	Z_χ	Z_η	Z_ψ	Z_{SSM}	Z_{LRM}
Z_{ALRM}	–	0.0	5.3	6.6	7.6	9.4
Z_χ	0.0	–	3.7	4.6	5.3	6.6
Z_η	2.7	2.6	–	0.7	1.2	2.1
Z_ψ	3.3	3.3	0.7	–	0.5	1.4
Z_{SSM}	6.8	6.8	2.1	0.9	–	1.6
Z_{LRM}	6.8	6.8	3.0	2.1	1.3	–

at M=1 TeV, L=10 fb^{-1}

Model	Z_{ALRM}	Z_χ	Z_η	Z_ψ	Z_{SSM}	Z_{LRM}
Z_{ALRM}	–	0.3	2.5	3.0	3.2	4.2
Z_χ	0.2	–	1.4	1.7	1.8	2.4
Z_η	1.2	1.0	–	0.3	0.4	0.8
Z_ψ	1.4	1.3	0.3	–	0.1	0.5
Z_{SSM}	2.7	2.5	0.6	0.2	–	0.8
Z_{LRM}	2.8	2.6	1.1	0.8	0.6	–

at M=3 TeV, L=400 fb^{-1}

Spin discrimination

I. Belotelov et al. CMS NOTE 2005/104

If new resonance is discovered

Characterisation of its spin and coupling using:

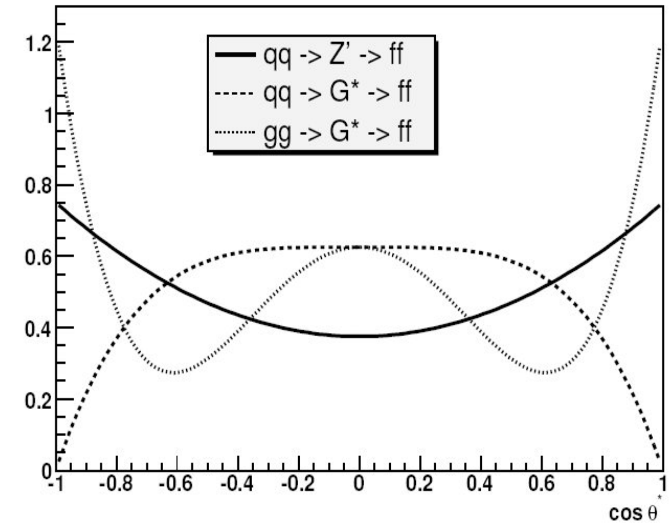
- Production and decay probabilities and distributions: for example $G \to \gamma\gamma$
- Angular distribution of the decay product : useful for spin discrimination

Spin-1 States: Z from extended gauge models, ZKK

Spin-2 States: RS1-graviton

Method: unbinned likelihood ratio statistics incorporating the angles in of the decay products the Collins-Soper frame consider only the even term in $\cos\theta*$ (sign of $\cos\theta*$ is random)

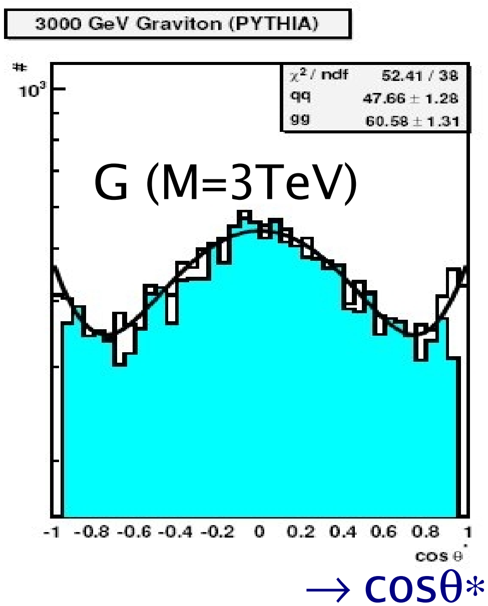
subprocess	angular distribution
$q\bar{q} \to \gamma/Z^0/Z' \to f\bar{f}$	$\frac{3}{8}(1 + \cos\theta*^2)$
$q\bar{q} \to G^* \to f\bar{f}$	$\frac{5}{8}(1 - 3\cos\theta*^2 + 4\cos\theta*^4)$
$gg \to G^* \to f\bar{f}$	$\frac{5}{8}(1 - \cos\theta*^4)$

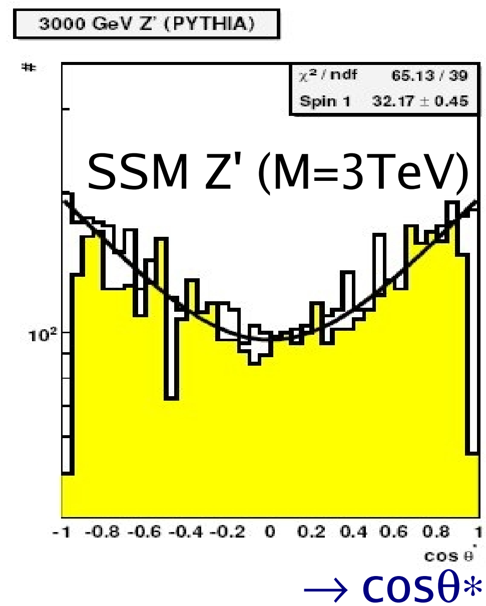


$\to \cos\theta*$

Spin discrimination

The statistical technique has been applied to fully simu/reco events:



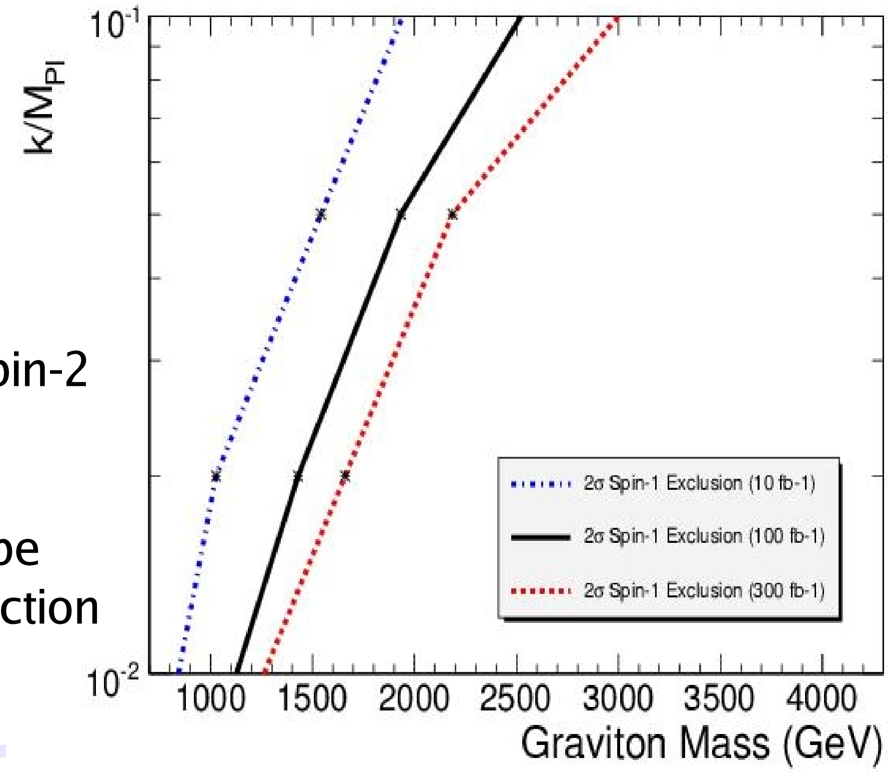


$\sqrt{s}$, TeV	c	$\int \mathcal{L}dt$, fb^{-1}	N_s	N_b
1.0	0.01	50	200	87
1.0	0.02	10	146	16
1.5	0.02	90	174	41
3.0	0.05	1200	154	22
3.0	0.10	290	148	6

Table: Integrated luminosity and numbers of signal and bg events required to distinguish spin-1 and spin-2 hypothesis (2σ)

Region in the (M, c) plane where RS graviton can be distinguisg from Z' (2σ) – having an equal cross section

Z' vs RS-graviton



High mass dijets

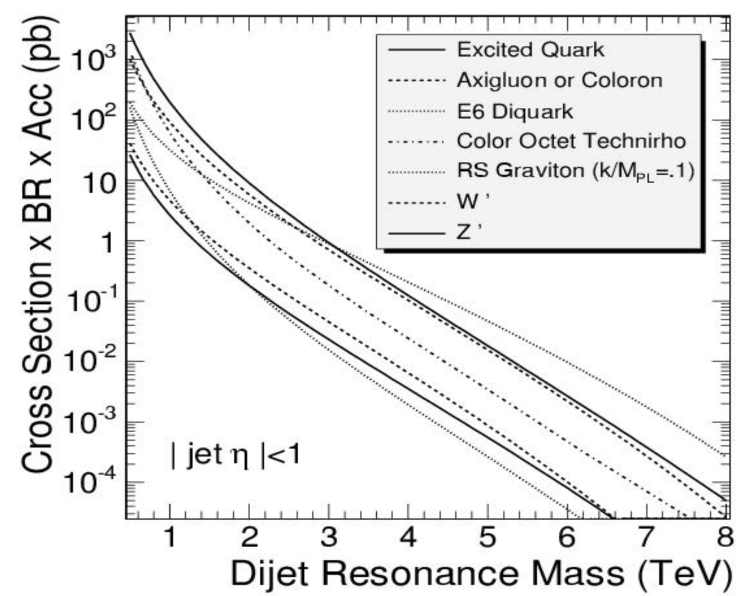
K. Gumus et al. CMS NOTE 2006/070

Search for dijet resonance (pp → X → jet+jet)

Sensitivity to observing narrow resonance signal on a high QCD bg - Challenging channel: large QCD bg and often limited dijet mass resolution

Goal: as generic an analysis as possible

Give the CMS cross section sensibility for 95% CL and 5 σ discovery



Compare to 8 benchmark models:

First five: produced via strong interactions

last three:electro-weak coupling – lower cross-section

no 5σ discovery potential

but exclusion at 95%CL

|η|(jet)<1

Resonance Model	95% CL Excluded Mass (TeV/c^2)			5σ Discovered Mass (TeV/c^2)		
	100 pb^{-1}	1 fb^{-1}	10 fb^{-1}	100 pb^{-1}	1 fb^{-1}	10 fb^{-1}
Excited Quark	0.7 - 3.8	0.7 - 4.8	0.7 - 5.8	0.7 - 2.9	0.7 - 3.9	0.7 - 5.0
Axigluon or Coloron	0.7 - 3.6	0.7 - 4.6	0.7 - 5.6	0.7 - 2.6	0.7 - 3.8	0.7 - 4.8
E_6 diquark	0.7 - 4.1	0.7 - 5.6	0.7 - 7.0	0.7 - 2.8	0.7 - 4.5	0.7 - 6.0
Color Octet Technirho	0.7 - 2.4	0.7 - 3.4	0.7 - 4.5	0.7 - 1.8	0.7 - 2.6	0.7 - 3.6
Randall-Sundrum Graviton	0.7 - 1.1	0.7 - 1.7	0.7 - 1.7 1.9 - 2.4	0.7 - 0.8	0.7 - 0.8	0.7 - 0.8
W′	0.7 - 1.0	0.7 - 1.0 1.2 - 2.1	0.7 - 1.0 1.2 - 3.4	N/A	N/A	2.0 - 2.3
Z′	N/A	1.2 - 1.5	1.3 - 1.5 1.9 - 2.6	N/A	N/A	N/A