Perspectives for early discoveries BSM non SUSY at LHC

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Outline

GF3

The Standard Model (SM) describes a all the accelerator based HEP data with great accuracy. On the other hand it is not fully theoretically satisfactory and there are hints for it to be the low energy limit of a more fundamental theory, e.g.

- the hierarchy problem: no symmetry preventing the scalar masses (Higgs) from getting quadratic divergent radiative corrections at all perturbative orders
- it does not include a quantum description of the gravity
- it does not have a viable candidate for cold DM and cannot explain cosmological issues like baryon asymmetry and Λ_{cosm}
- it does not take into account massive neutrinos
- no exact unification of the gauge couplings through RG

Slide 2

GF3

- about 19 free unpredicted parameters (in molti modelli BSM tale numero di parametri viene ridotto usando il solito trucco di simmetrie originarie che poi vengono rotte)
- has coupling constants that are not asymptotically free (lo si puo' anche omettere...ma per completezza andrebbe detto)
- it does not explain the existence of the 3 fermion families nor the strong hierarchical values of fermion masses (importante se si vuole accennare alle fenomenologie che estendono il numero di famiglie fermioniche)
- does not take into account massive neutrinos (fondamentale se vuoi parlare poi di neutrini di Majorana pesanti o simili)
- cannot explai cosmological issues (baryon asymmetry, cosmological constant...)

Giovanni Franzoni, 10/11/2005

Outline

The LHC will have an interesting potential already at the beginning:

- $\sqrt{s}$: from 12 to 14 TeV before first shutdown
- luminosity: from 10^{26} to 10^{33} in 1st phase. Then 10^{34} cm^{-2} s^{-1}
- fraction of fb^{-1} collected in the first year

even compared to the latest Tevatron

- $\sqrt{s}$: 1.8 TeV
- luminosity: latest peaks at 1.2×10^{32}

Here we present the physics potential of ATLAS and CMS at start-up.

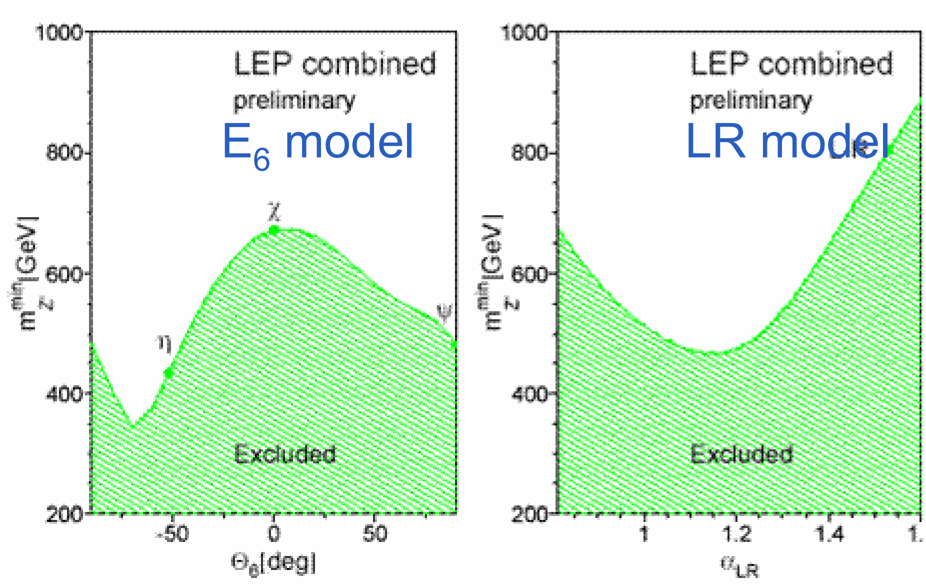
Among the *several* on going analysis in the two collaborations, in this talk we chose to report on:

- Z' searches
- Extra dimensions:
  - ADD
    - γ+G
    - $G\rightarrow\gamma\gamma$ $G\rightarrow l^+l^-$
  - Randal Sundrum:
    - graviton decay
    - radion decay

[Z' heavy neutral gauge bosons]

- Several models (GUT SO(10) and E_6, SSM) predict an additional heavy neutral gauge boson, referred to as Z'. No prediction on $m_{Z'}$
- Z & Z': assuming they have the same coupling to fermions, they do not mix significantly (electroweak LEPI)
- Most recent lower bounds from combined LEP data,
  - $m_{Z'} > 400\text{-}900\ \mathrm{GeV}/c^2$, depending on the model
  - Tevatron RunII: expected to explore up to 800 GeV, depending on scenario

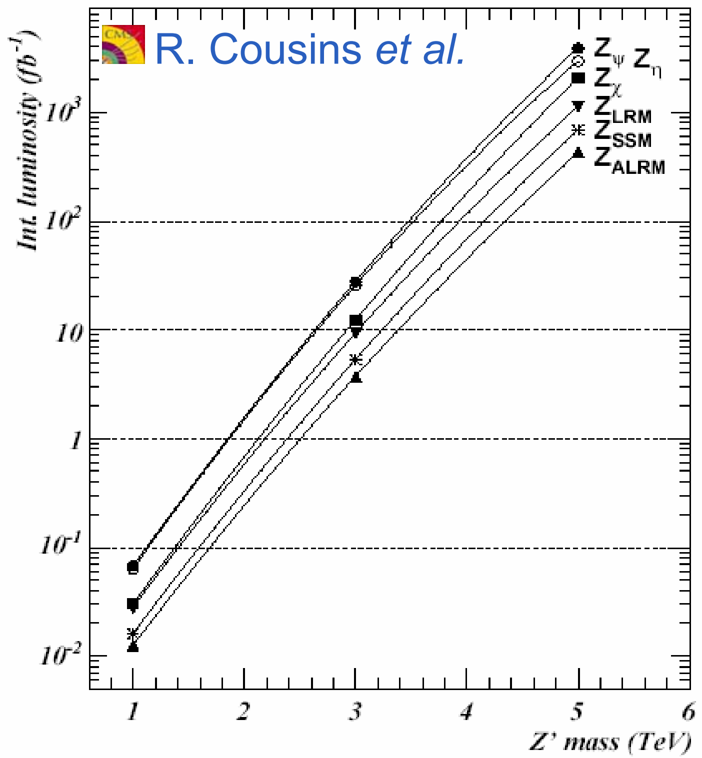
- LEPII combined analysis: Exclusion based on different scenarios leading to Z'

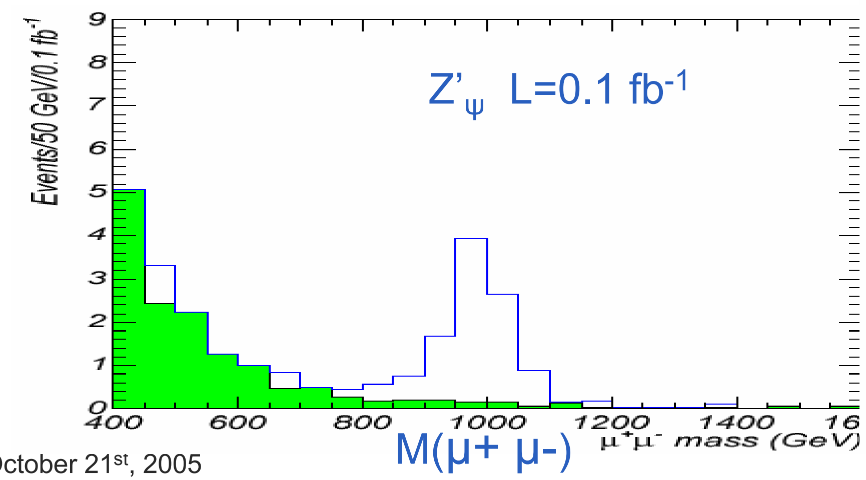


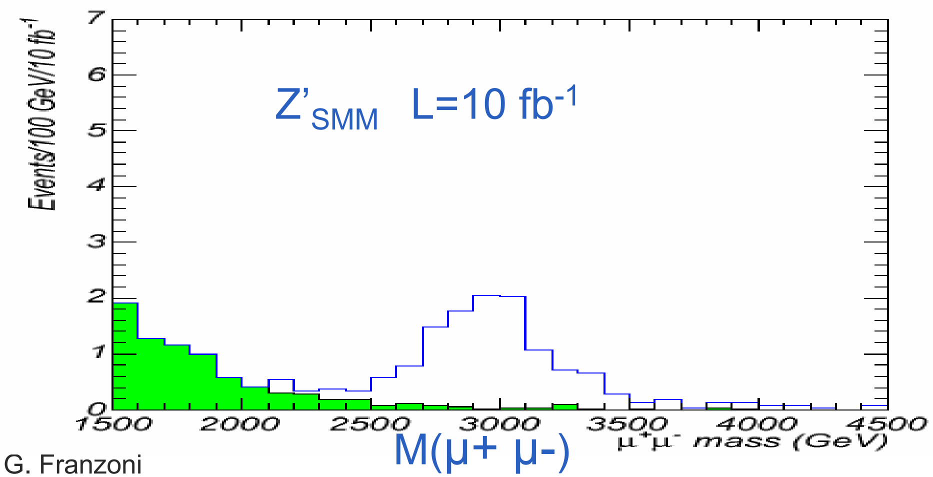
(Figure 8.10: The 95% confidence level limits on $M_{Z'}$ as a function of the model parameter θ_6 for E_6 models and α_{LR} for left-right models. The Z-Z' mixing is fixed, $\Theta_{ZZ'} = 0$.

$Z' \rightarrow \mu^+ \mu^-$

- CMS
  - $pp \rightarrow Z' \rightarrow \mu^+ \mu^-$
    - full simulation
    - dominant irreducible background DY: $pp \rightarrow \gamma/Z^0 \rightarrow \mu^+ \mu$
    - selection on single-μ OR double-μ L1 and HLT: μ μ tra originate from same vertex
    - cuts to suppress reducible background could give sma improvement (μ isolation, jet veto, μ's be back to back)
  - no study of systematic errors yet, nor pile up
  - discovery potential starting from 1 fb^{-1}
    - after discovery: how to determine the theoretical frame Z' belongs to? Forward-backward asymmetry, study o going

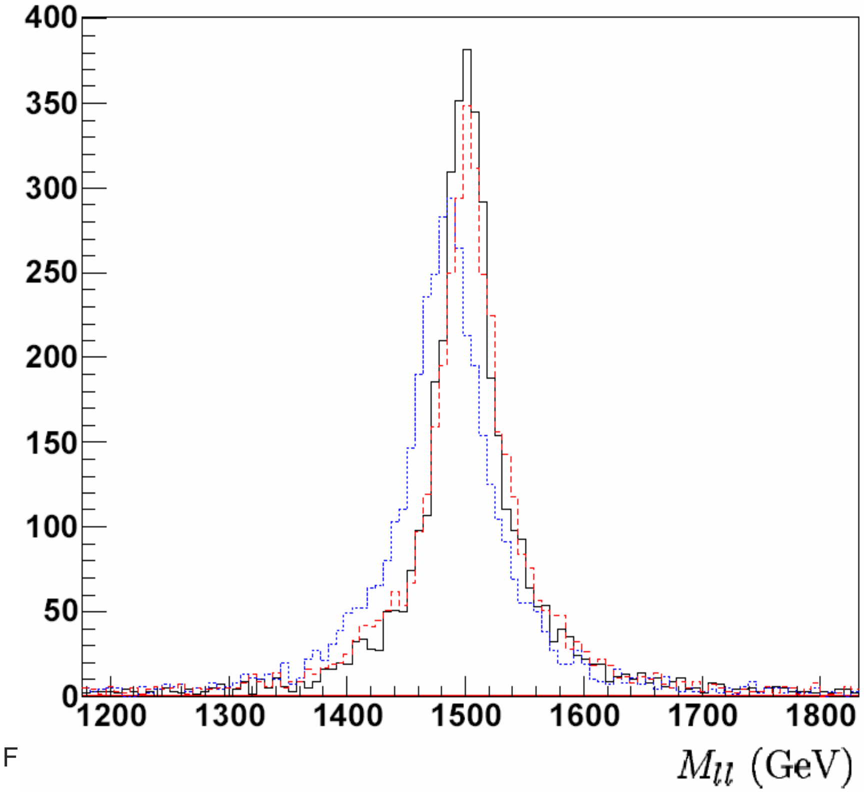






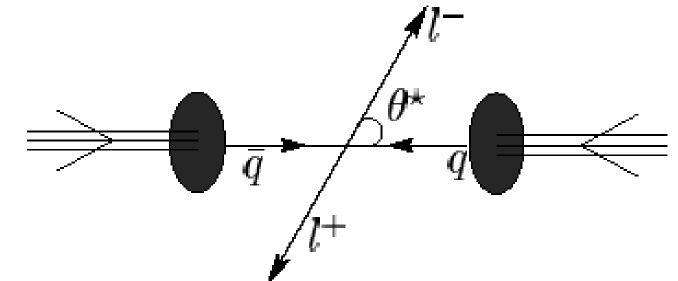
$Z' \rightarrow e^+e^-$

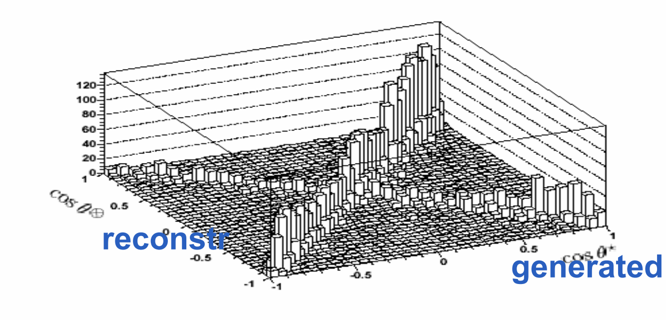
- ATLAS
  - $pp \rightarrow Z' \rightarrow e^+e^-$ ($M_{Z'}$ = 1.5 TeV) full simulation
  - selection:
    - electron ID based on: shower shape (bkg from mis-ID jets) and charge track reconstructed. Only events with 2 identified electrons are kept.
    - on e e: opposite charge + track isolation e^+e^- back to back in transverse plane
    - only electrons in the ECAL barrel considered
  - re-calibration for electrons (instead of the usual γ calibration) removes the bias in measurement of $M_{Z'}$
  - observables needed for the discrimination among different Z' models
    - Z' rapidity distributions
    - forward-backward asymmetry as function of the Z' rapidity



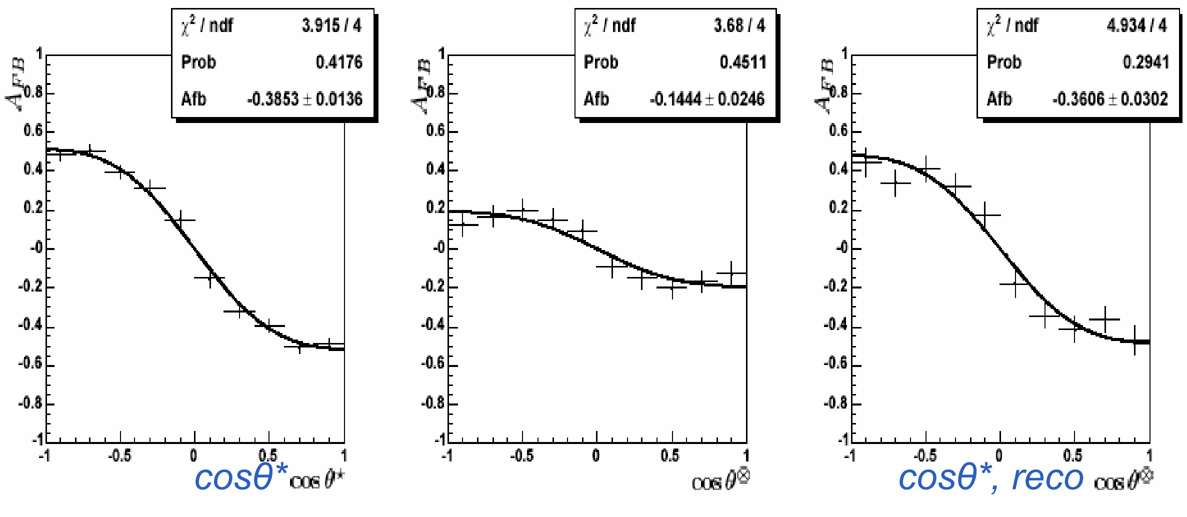
Z': A_{FB} model discrimination

- In all models, the Z' production cross section as a function of cosθ* has the typical spin 1 behaviour. Interesting handle to determined if and which Z' is being produced





- incoming quark direction unknown, estimated with the reconstructed Z' direction (see correlation)
- the probability, ***ε***, of wrong quark direction is energy dependent. Thus A_{FB} measured in bins of E around Z' peak.
- wrong **q** direction cos*θ**↔ -cos*θ** washes out asymmetry, which can be corrected for a-posteriori once is ***ε*** known



(a) *At generation level* (b) *Observed* (c) *Corrected*

in each bin of cos*θ**, from the observed A_{FB} the corrected A_{FB} is calculated using ***ε(***cos*θ**, E***)***

100 fb^{-1} used. Results from achiavable with smaller statistics being investigated

Extra dimensions

Extra Dimensions (ED) could appear at the TeV scale (not ruled out so far).
This is a possible way to

- turn the hierarchy problem into a topological one
- break EW, SUSY, GUT symmetries
- provide DM candidates and address different cosmological problems
- explaines weackness of gravity because it spreads also in ED’s
- explain fermion mass hierarchy and CP violation

- ED models can be classified as either having:
  - flat extra dimension (4D metric does not depend on position in the EDs)
  - or warped extra dimension, where the metric does not factorizes

- typically models with ED’s compactified on a scale R, so that boundary conditions (leading to KK towers) justify present lack of experimental evidence

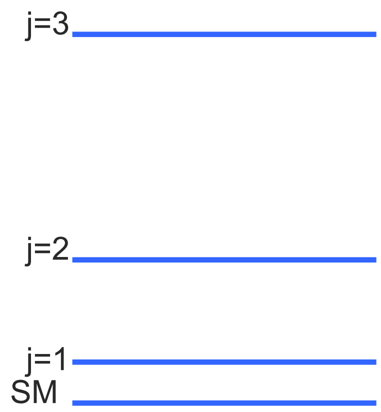
Three main fenomenologies are considered:

- Compact Large EDs (ADD)
- Warped EDs (Randall-Sundrum I&II)

Compact Large EDs

- Why $M_{Pl} >> M_W$? Model proposed by Arkani-Hamed, Dimopoulos and Dvali (ADD) as a low-energy effective theory
  - SM particles live in a 4D brane
  - gravity can propagate through a (4+n)-dim bulk with n compact EDs of radius r
  - then the real fundamental gravity scale is M*, defined by the compactification relation

$$M_{Pl}^2 = V_n M_*^{n+2}, \qquad V_n = (2\pi r)^n$$



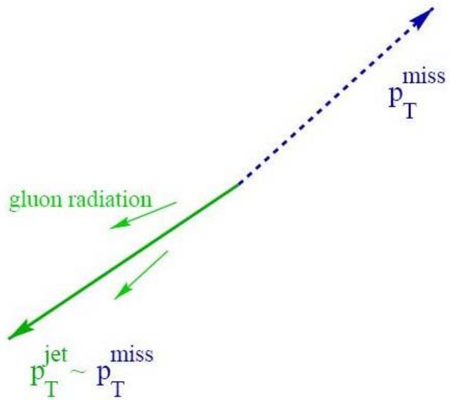
$$mj^2 = j^2/R + mj^2_{SM}$$

- What can we say about the number n on EDs?
  - n=1: the gravitational force should change its $1/r^2$ behaviour at a typical distance $R=10^8$m…EXCLUDED!
  - n=2: deviation from Newton at R=0.1mm…GREAT FOR LHC!
  - the bigger n, the smaller R…difficult to probe directly!
  - 4D phenomenology: Kaluza Klein (KK) states:

$$m_n^2 = n^2/R^2 + m_{SM}^2$$

Large EDs: jet+E_T

- A firts analysis (Hinchliffe&Vacavant): search for **jet+$\not{E}_T$ and γ+$\not{E}_T$** with n=2,3,4 and M*=M_{min},…,10 TeV
- main production: qg → qG
- Event generation with ISAJET + Fast simulation
- Different strategies to reject SM background
- Most relevant signal evidences at large $\not{E}_T$

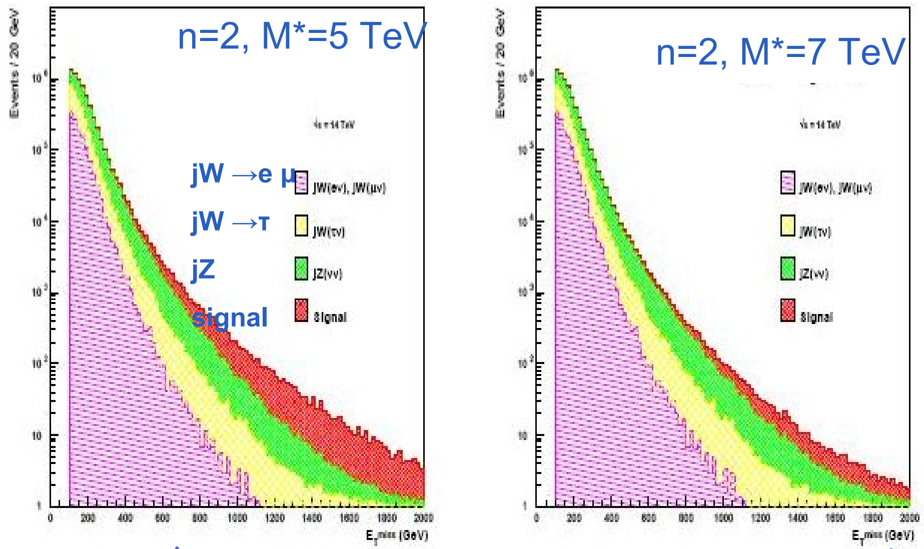


Typical jet+G event

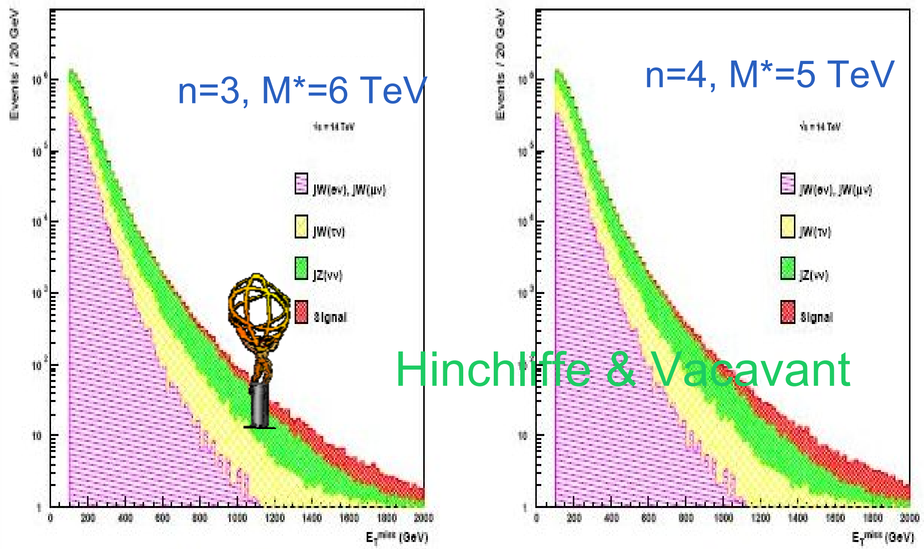
- Single **γ+G** signal has much lower rate at LHC and the region (n,M*) which can be probed is much more limited: a possible confirmation after the discovery in the jet channel (only γ+Z(→ $\nu\nu$) background)

Large EDs: jet+E_T

- jet+$\not{E}_T$ signals
  - Trigger: combination of $\not{E}_T$ and jet
  - Discrimination s/b: E_T & $\not{E}_T$ distributions
- Background from neutrinos:
  - jet+Z($\to\nu\nu$)
    - main irriducible bkg, controlled using Z in and μ
  - jet+W($\to\tau\nu$)
  - jet+W($\to\mu\nu$) *
  - jet+W($\to e\nu$) *
    - * Veto events with isolated lepton



$\not{E}_T$(GeV) distributions (jet), 100 fb^{-1}



- Significance from events $\not{E}_T$>1TeV

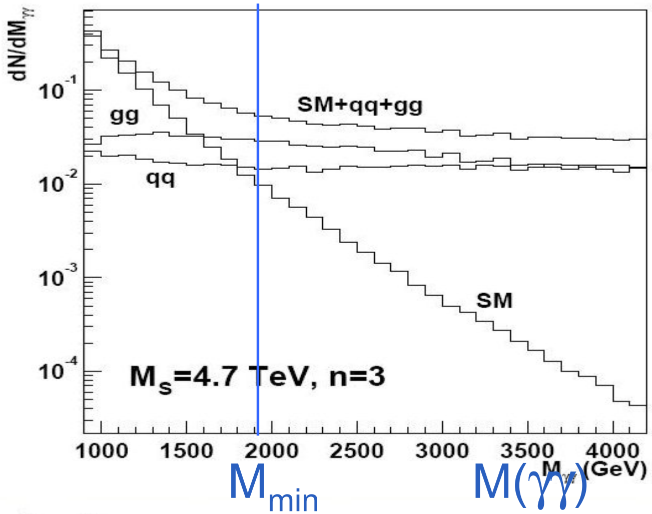
δ	M_D	Low luminosity, $30 fb^{-1}$ S	$S/\sqrt{B}$	$S/\sqrt{7B}$	High luminosity, $100 fb^{-1}$ S	$S/\sqrt{B}$	$S/\sqrt{7B}$
2	4	1036.4	81.6	30.8	3542.2	150.2	56.8
	5	417.0	32.9	12.4	1426.9	60.4	22.8
	6	205.9	16.3	6.2	700.6	29.6	11.2
	7	111.3	8.8	3.3	379.4	16.1	6.1
	8	65.3	5.2	2.0	222.5	9.4	3.5
3	4	641.8	50.6	19.1	2168.4	92.0	34.8
	5	211.5	16.6	6.3	706.0	30.0	11.3
	6	85.1	6.8	2.6	287.5	12.1	4.6
	7	39.3	3.1	1.2	134.0	5.7	2.2
4	4	436.2	34.3	13.0	1473.4	62.5	23.6
	5	113.0	8.8	3.3	383.4	16.3	6.2
	6	37.8	2.9	1.1	128.5	5.4	2.0

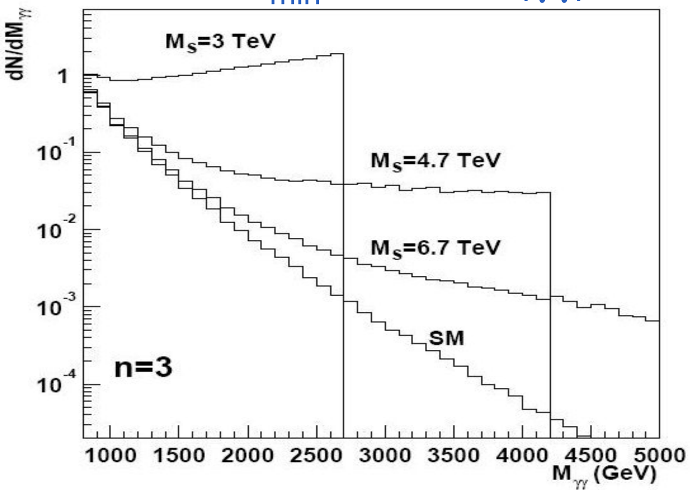
Large EDs: $G \rightarrow \gamma\gamma$ $G \rightarrow l^+l^-$

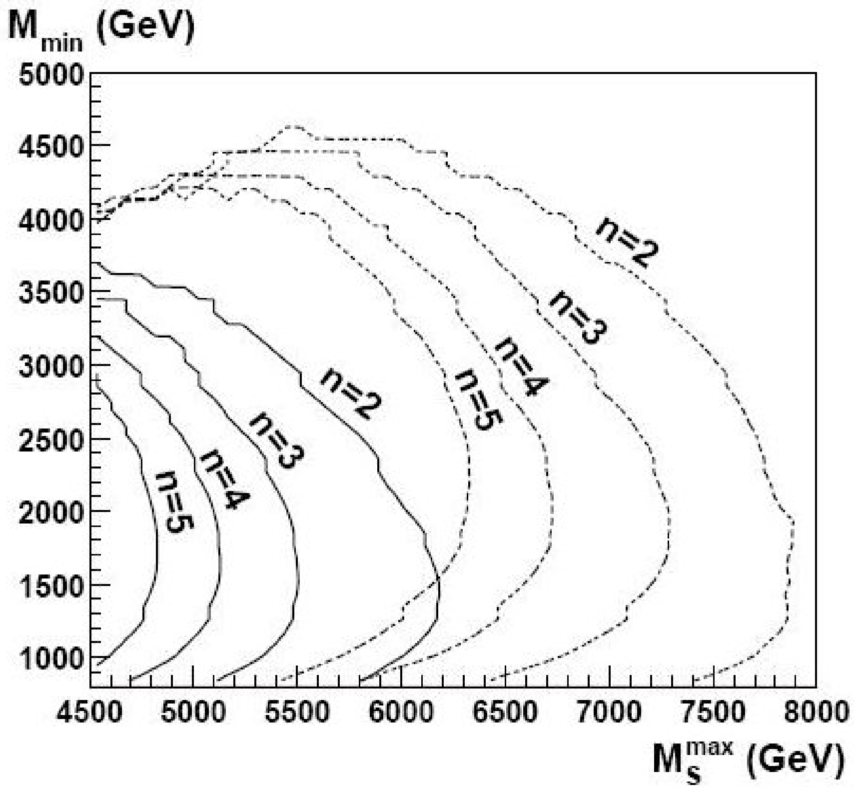
- Other possible signals of large EDs come from processes involving virtual G exchange (s-channel) with γ or lepton pair production
- γ pair production subprocesses:
  - $q\bar{q} \rightarrow G \rightarrow \gamma\gamma$
  - $gg \rightarrow G \rightarrow \gamma\gamma$
- lepton pair production subprocesses:
  - $q\bar{q} \rightarrow G \rightarrow l^+l^-$
  - $gg \rightarrow G \rightarrow l^+l^-$
- Fast simulation for both signal and background
- Irreducible SM background: t&u-channel → different rapidity distributions for signal and background
- SM background rapidly drops with invariant mass $M_{\gamma\gamma/ll}$: impose a lower cutoff M_{min}

Large EDs: $G \rightarrow \gamma\gamma$

- γ pair production



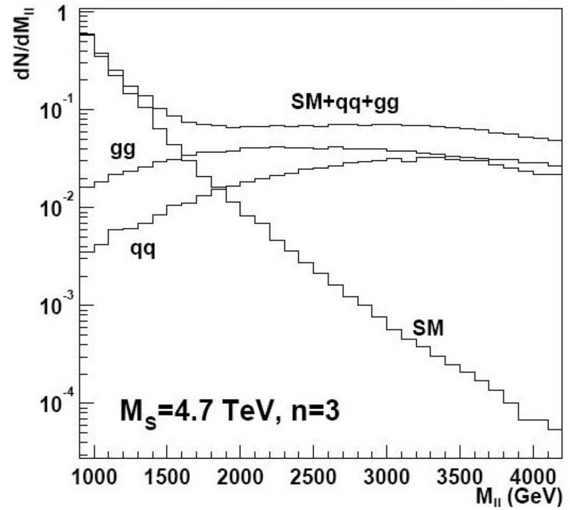


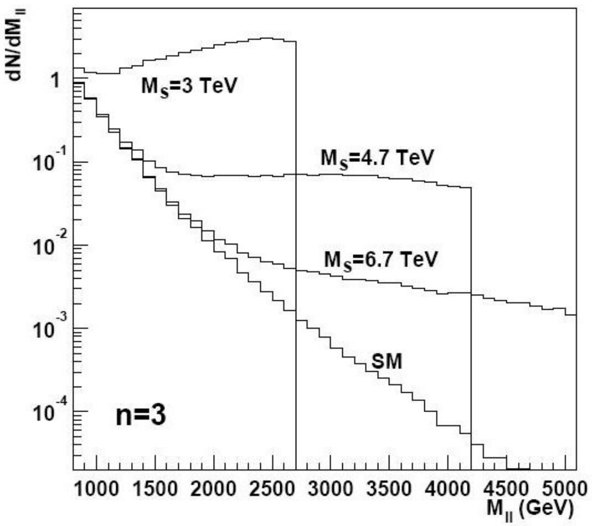


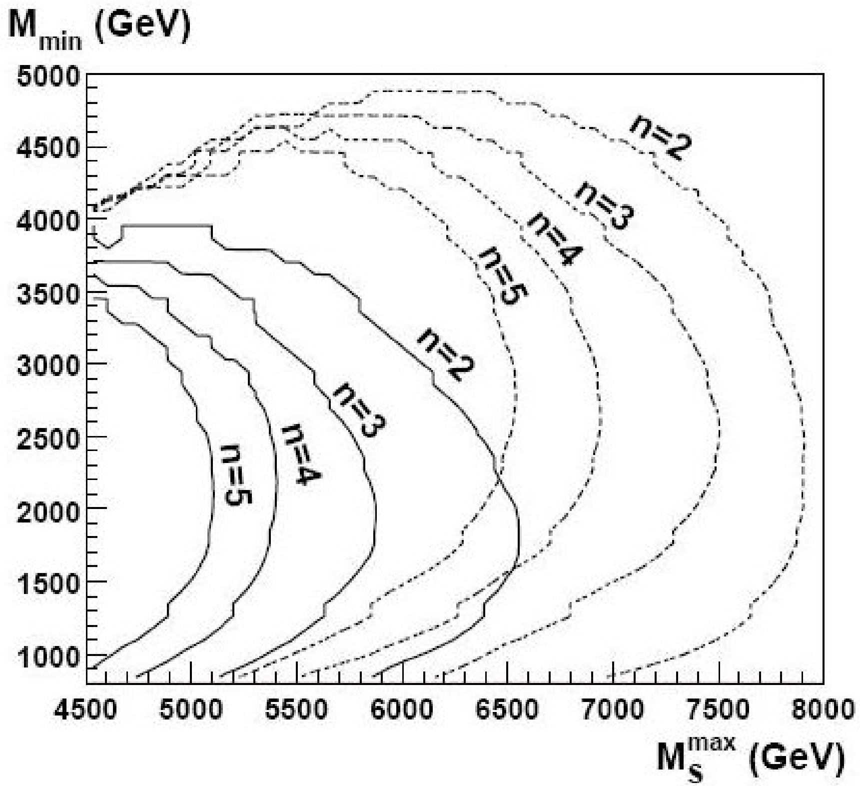
$\gamma\gamma$ production: 5σ contour plot as function of M* and M_{min} for n=2,3,4,5: solid lines are for **10 fb^{-1}**, dashed lines for **100 fb-1**

Large EDs: G→l^+l^-

- lepton pair production





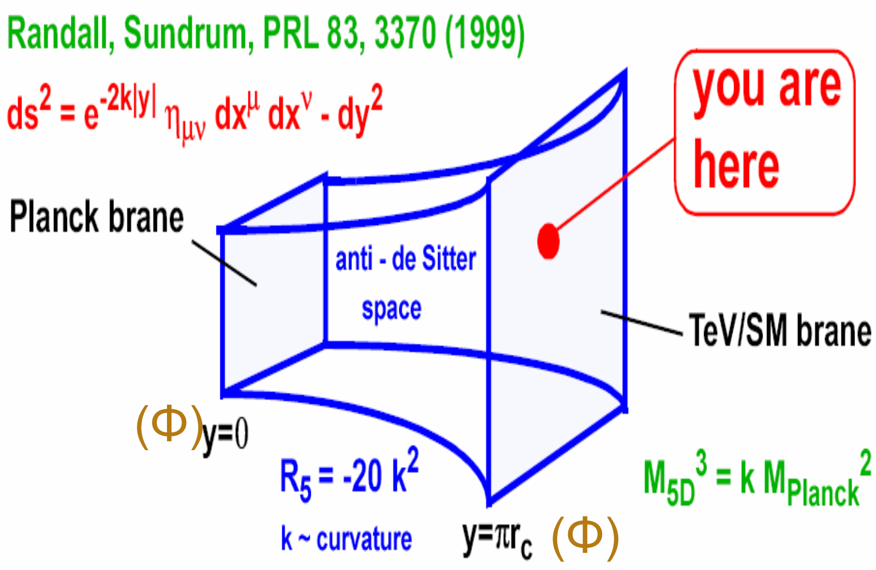


l^+l^- production: 5σ contour plot as function of M* and M_{min} for n=2,3,4,5: solid lines are for **10 fb^{-1}**, dashed lines for **100 fb-1**

Randall-Sundrum

- metric from Einstein equation with **only 1 warped** extra dimension
- $ds^2 = e^{-2 k r_c |\Phi|} \eta_{\mu\nu} dx^\mu dx^\nu + r_c^2 \, d\Phi^2$
  - $0 \leq \Phi \leq \pi$ is coordinate of E dimension
  - $k \sim M_{pl}$ is the curvature scale
  - gravity scale O(1TeV) given by
    - $\Lambda_\pi = M_{pl} e^{-k r_c \pi}$

    thus resolving problem if $kr_c \sim 11\text{-}12$
  - $r_c \sim 10^{-32}$m, thus no deviation from Newton law experimentally accessible within RS model

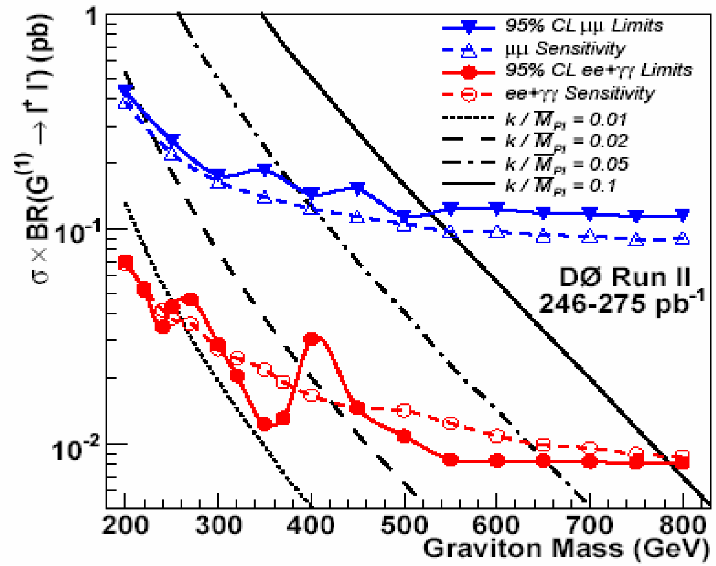


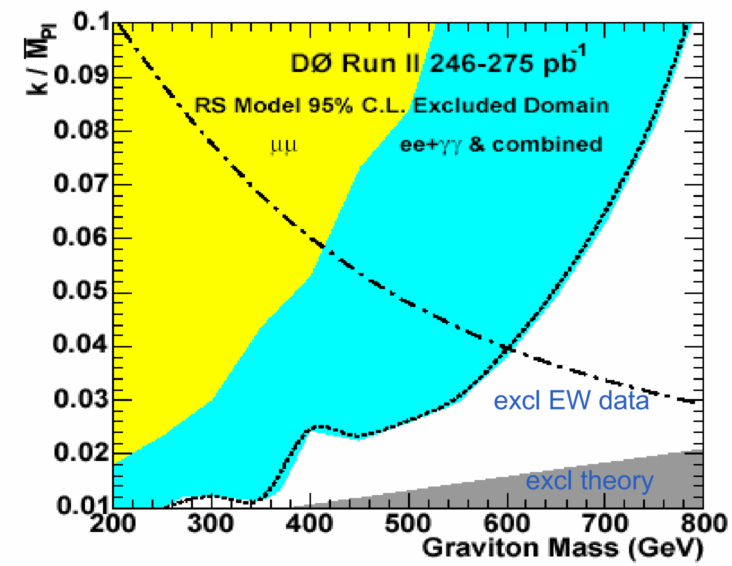
  - two 4D branes located at:
    - $\Phi = \pi$ Standard Model brane
    - $\Phi = 0$ hidden Planck brane
  - gravity originates at $\Phi = 0$ on the Planck brane and the graviton wave function is exponentially suppressed away from the brane along the ED
  - only gravitons propagate through the extra dimension, SM fields are confined to TeV brane
  - gravity scale O(1TeV) given by
    - $\Lambda_\pi = M_{pl} e^{-k r_c \pi}$

    thus resolving hierarchy problem if $kr_c \sim 11\text{-}12$

Randall-Sundrum

- KK excitations ≥1 of the graviton (G) couple not with just gravitational strength, but with $O(\Lambda_\pi)$, thus sizable production cross sections
  - KK tower: $M_n = k x_n e^{-krc\pi}$
- the RS phenomenology is parameterized by
  - mass M_1 of 1st excited G state (0.1-1TeV)
  - dimensionless coupling to the SM fields: k/M_{pl} (0.01-0.1)
- Most recent limits on RS, from D0:
  - $G \rightarrow \mu\mu$ $G \rightarrow \gamma\gamma$ and $G \rightarrow e^+e^-$
  - M_1 excluded up to 785 (250) GeV/c^2 for k/M_{pl} 0.1(0.01)

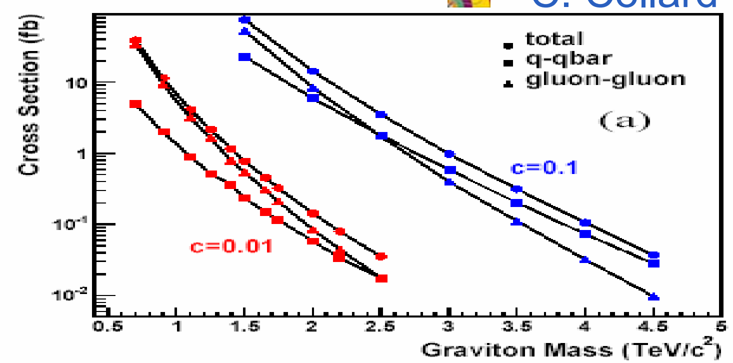


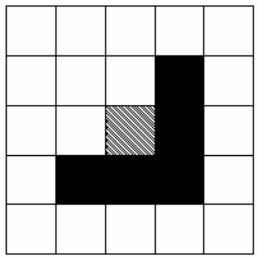


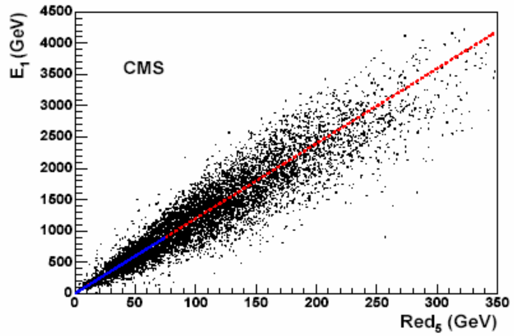
RS: graviton$\rightarrow e^+e^-$

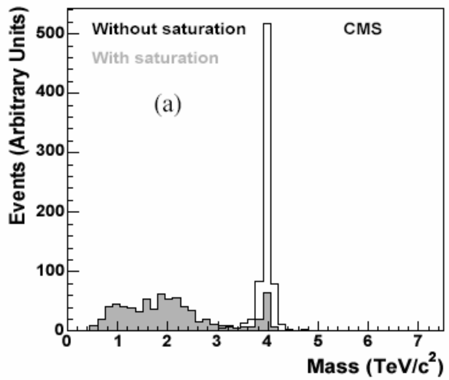
C. Collard

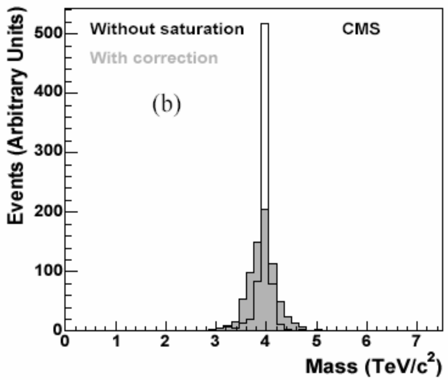
- RS discovery: 1st graviton excitations $\rightarrow e^+e^-$ and $\mu^+\mu^-$ μ
- background $pp \rightarrow Z/\gamma \rightarrow e^+e^-$ from 34 (2)fb @ 0.7 (5)TeV
- selection:
  - electron isolation
  - H/E < 0.1 (suppress hadrons)
- For high M_1: e^{+-} depositing more than 1.7 TeV in one ECAL crystal saturates ADC
- effect corrected for by means of correlaction with neighbours





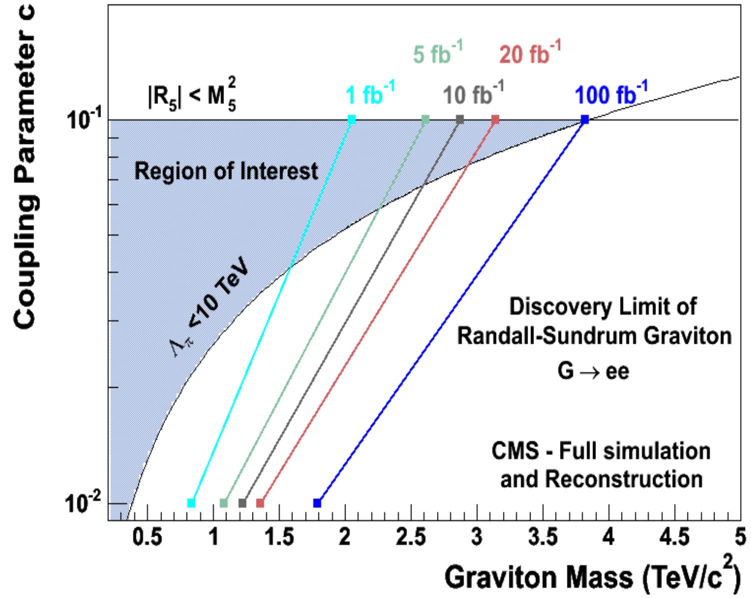


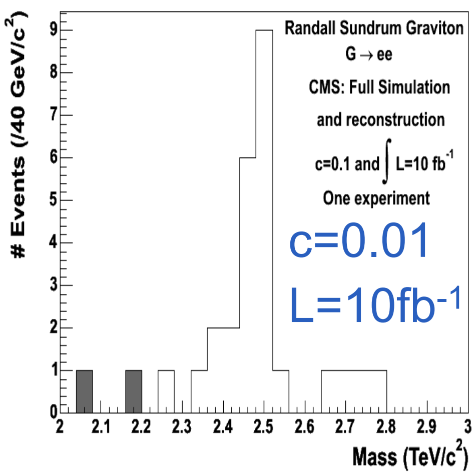


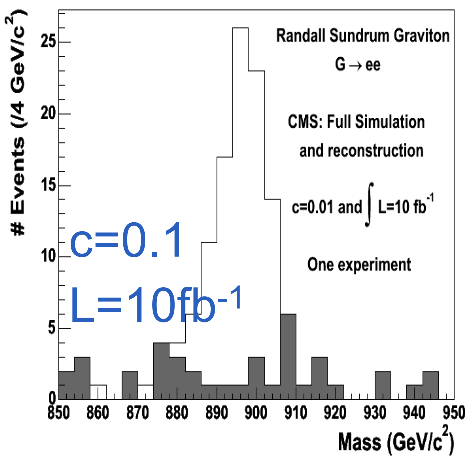


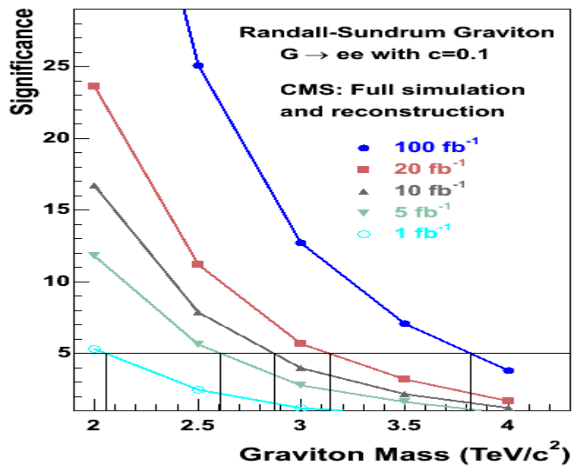
RS: graviton $\rightarrow e^+e^-$

- depending on k/M_{pl} significances estimated for differet integrated luminosity
- discovery reaches prove stable within 100 GeV/c^2 considering change in parton distribution functions
- 100fb^{-1} cover whole allowed region



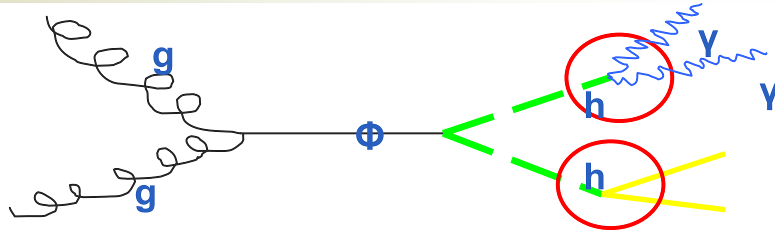




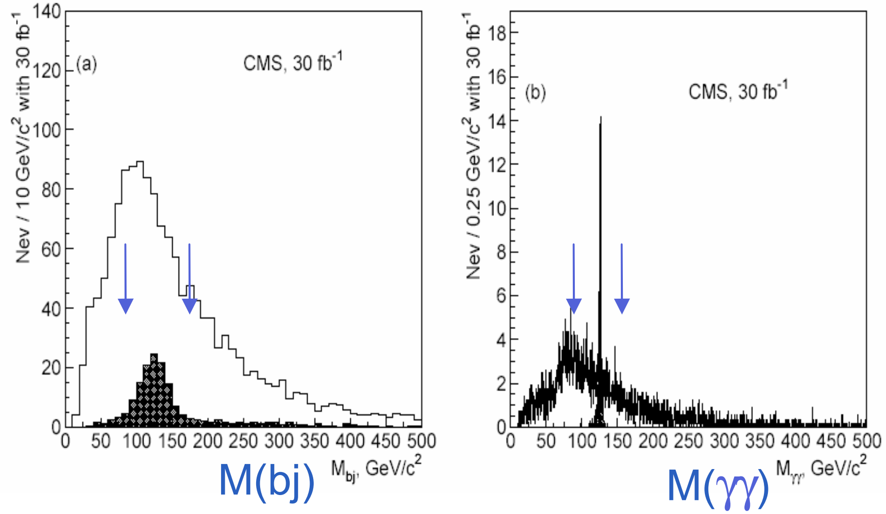


RS: Radion decay

- Radion Φ : GF5
  - likely to be lighter than any Kaluza-Klein tower, thus first signature of RS model
  - copiously produced at the LHC from gg fusion
- $\Phi \rightarrow hh$ with $30 fb^{-1}$ @low lumi:
  - choosing: $m_{\Phi}=300$ GeV/c^2 and $m_h=125$ GeV/c^2
  - $\Phi \rightarrow hh$ with selected final states
    - $\gamma\gamma$ +bb σ_{max} = 83 fb
    - $\tau^+ \tau^-$+bb σ_{max}= 960 fb



S. Gennai

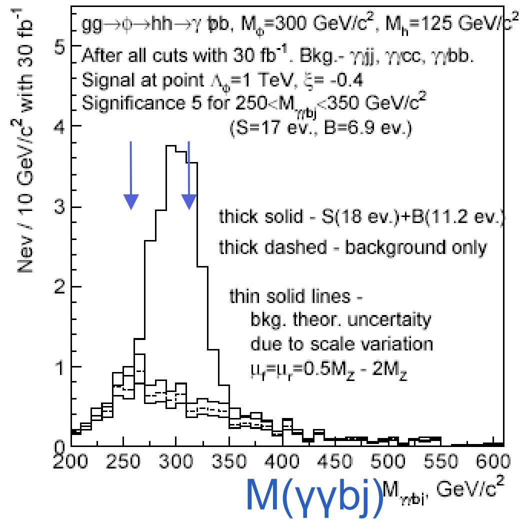


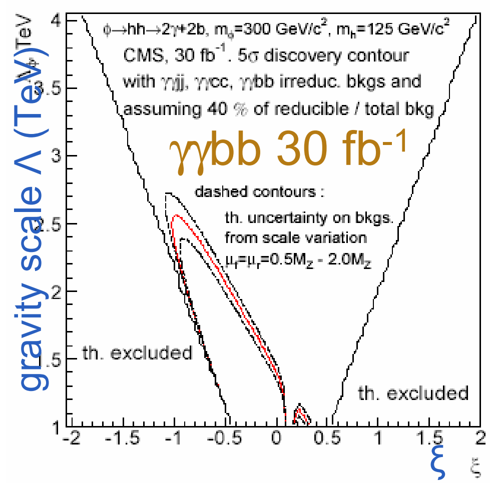
- background $\gamma\gamma$jj:
- first selection:
  - photon isolation
  - one jet b-tagged
  - and combined cut on invariant mass of (bj) and ($\gamma\gamma$) around Higgs peak

GF5 fluctuation of the compactification volume
Giovanni Franzoni, 10/13/2005

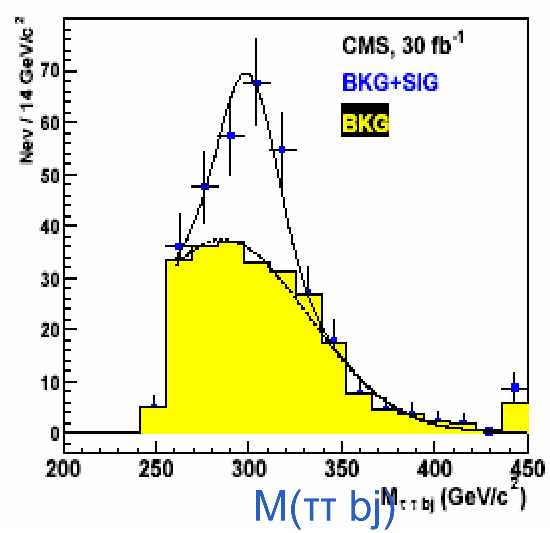
RS: Radion decay

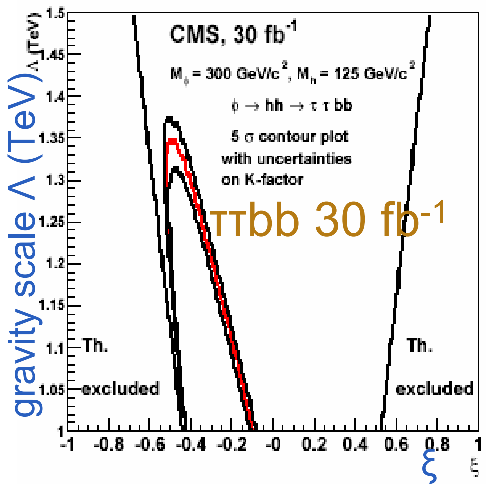
- Ultimately cut on a window of 50 GeV/c^2 around fitted peak of radion mass M(γγbb) is used to evaluate the 5σ significance
- best discovery potential





- Final state ττbb:
  - assuming radion and Higgs discovered already from γγ+bb
  - τ jet isolation essential to suppress bakcgoround (tt, Z+jets,W+jets ~30nb)





Conclusions

- We presented (only) some scenarios of physics BSM which can have results already with low integrated luminosity
- Z': discovery potential starting already from first year ($<1fb^{-1}$), model characterization with $100fb^{-1}$
- Large extra dimensions ADD: for num of ED =2,3,4,5 discovery with $10fb^{-1}$
- RS graviton: discovery possible starting from $1fb^{-1}$ full parameter space up to MG=4TeV explored with $100fb^{-1}$
- RS radion discovery ($\gamma\gamma bb$) and confirmation ($\tau\tau bb$) with $30fb^{-1}$

References

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