Dipartimento di
Fisica Nucleare e Teorica

**Incontri di Fisica delle Alte Energie**
**IFAE 2006**

INFN
Istituto Nazionale
di Fisica Nucleare
Sezione di Pavia

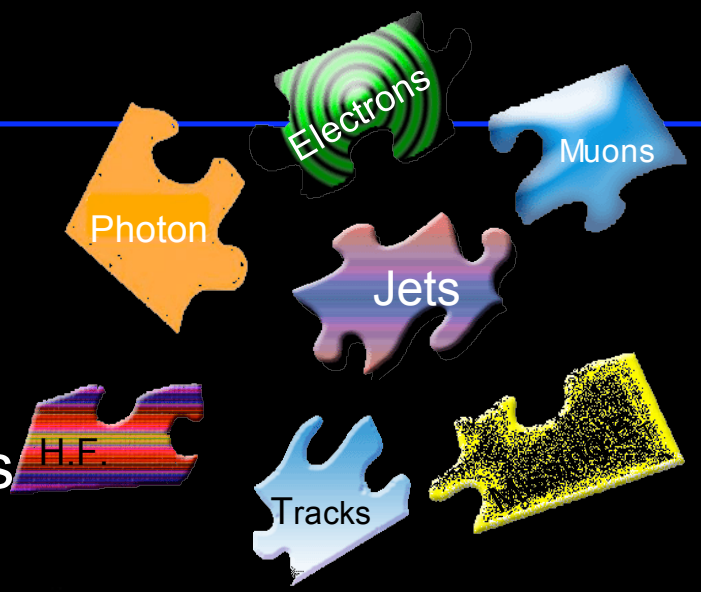
# Search for New Physics at the Tevatron

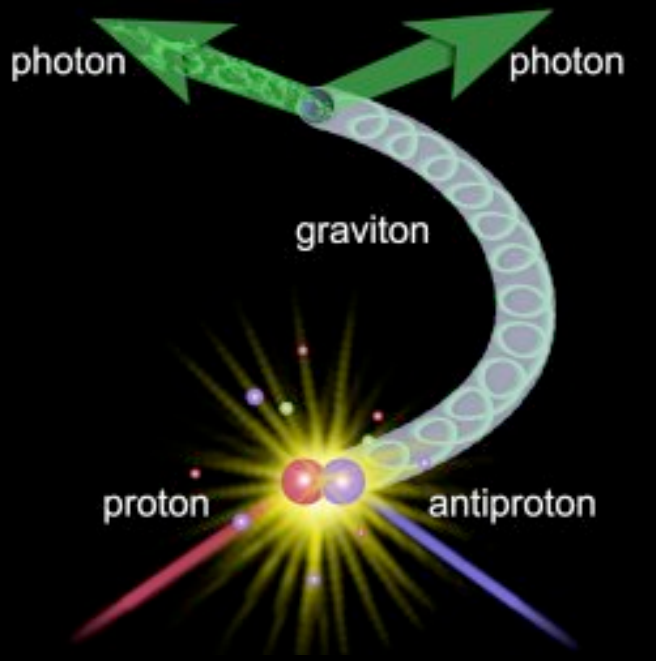
Simona Rolli
Tufts University

Simona Rolli - Tufts University

# Outline of the talk

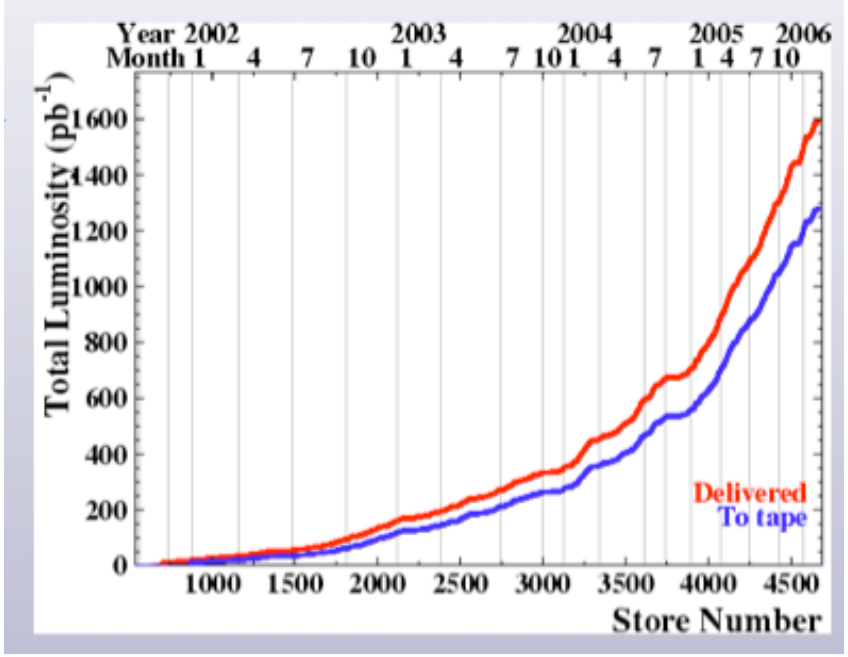
- TeVatron status
- Physics Processes and their signatures
  - from simple objects to complex final states
    - **leptons-only final states (and isolated tracks)**
    - **… + Missing Energy and Photons**
    - **… + Jets and heavy flavors**
- Final remarks and conclusions



# TeVatron Status

## Luminosity Profile

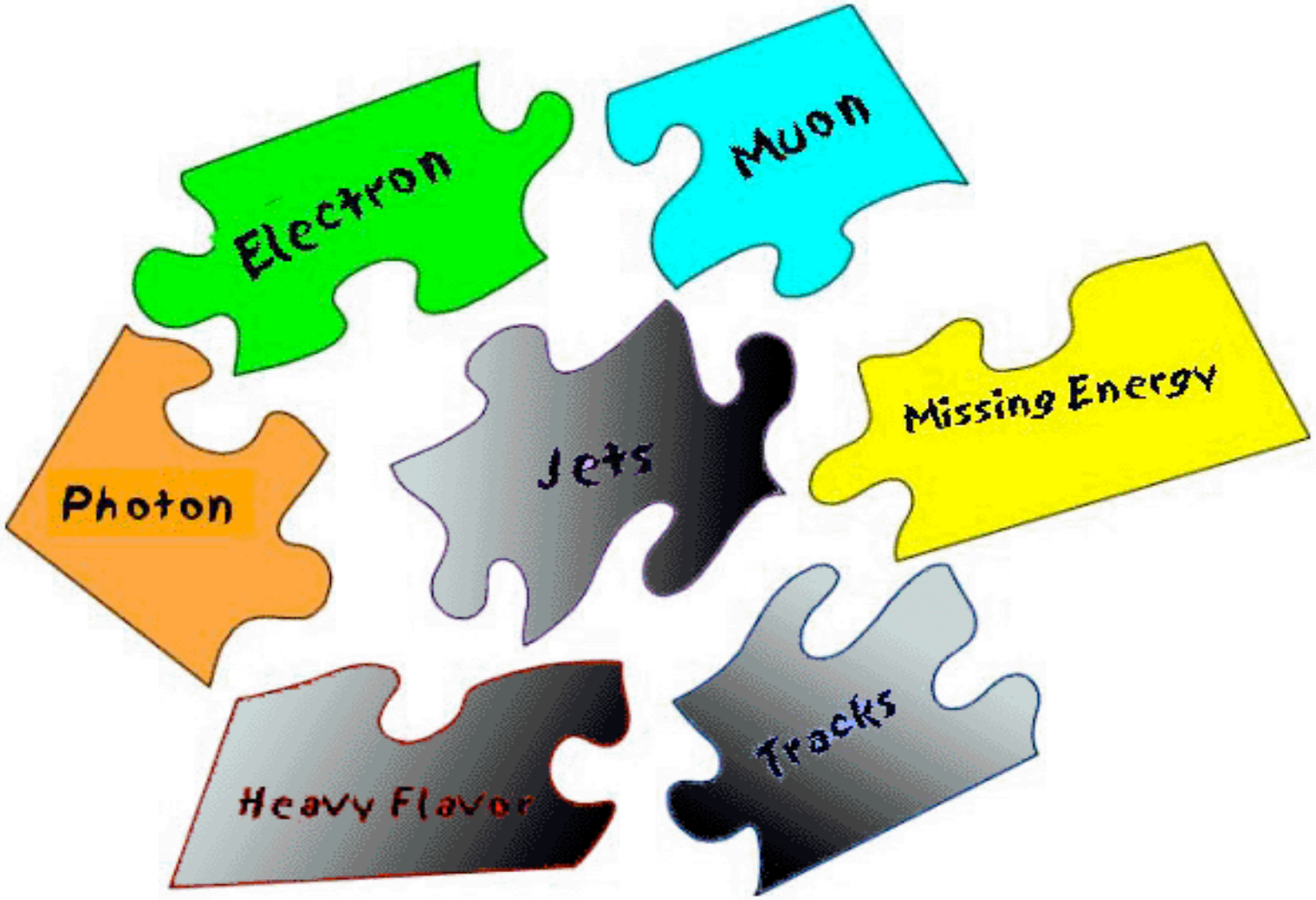



Highest Initial Luminosity
$1.8 \times 10^{32}$ cm$^{-2}$s$^{-1}$
Integrated lum. in a week
26 pb$^{-1}$

1.7 fb$^{-1}$ delivered to the experiments
1.2 fb$^{-1}$ on tape

Most of the analyses presented here use 0.2 to 1 fb$^{-1}$

# Leptons,Photons and MET



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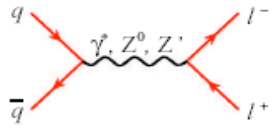
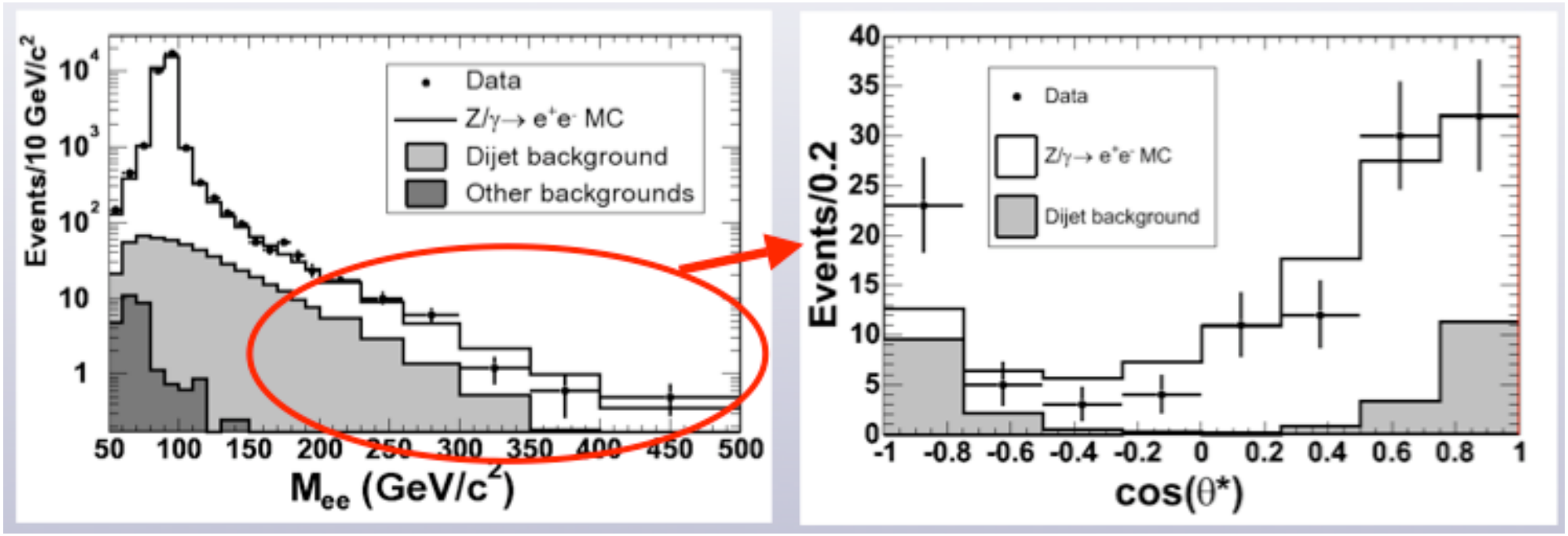
# Searches in dilepton final states

## Dilepton mass and cosθ* distributions



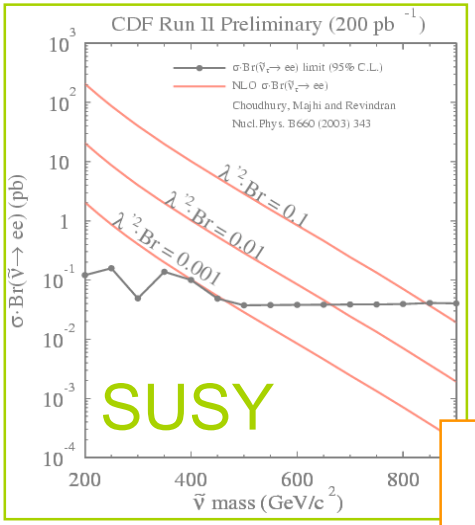



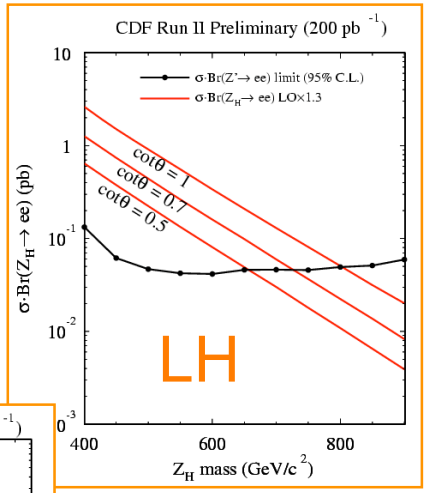

Search for Z' using the $m_{ee}$ > 200 GeV/$c^2$ region (448 pb$^{-1}$)

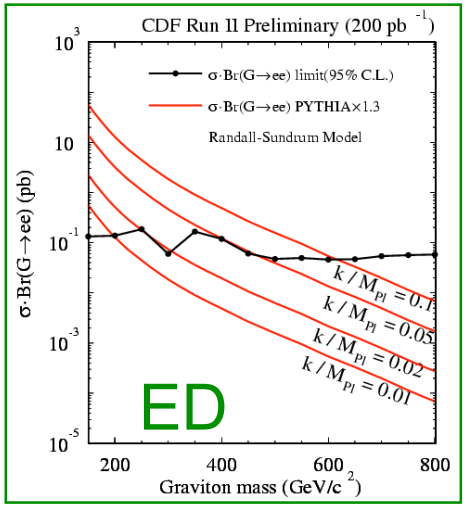
| Source | $Z/\gamma^* \rightarrow e^+e^-$ | Dijet | Diboson | Total SM | Observed |
|---|---|---|---|---|---|
| Events | $80.0 \pm 8.0$ | $28^{+14}_{-17}$ | $6.8 \pm 1.4$ | $115^{+16}_{-19}$ | 120 |

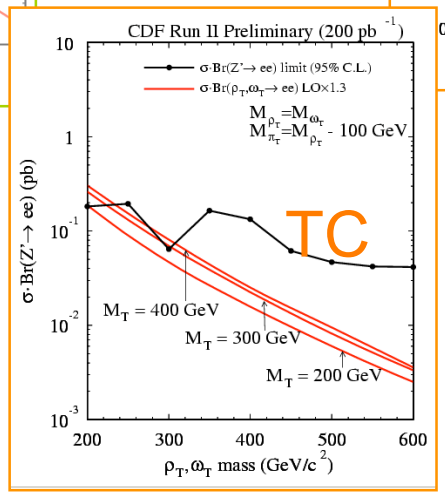
# Testing different models

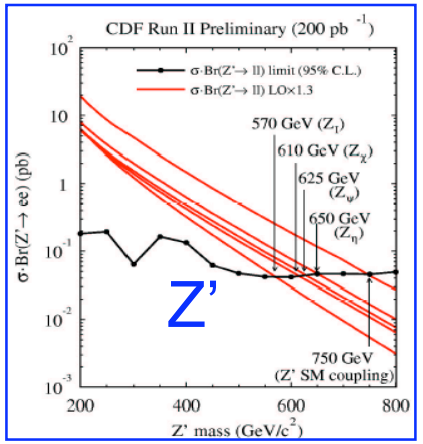
Calculate the acceptances for resonant states for 3 different spin assumption (0,1,2)




200 pb$^{-1}$

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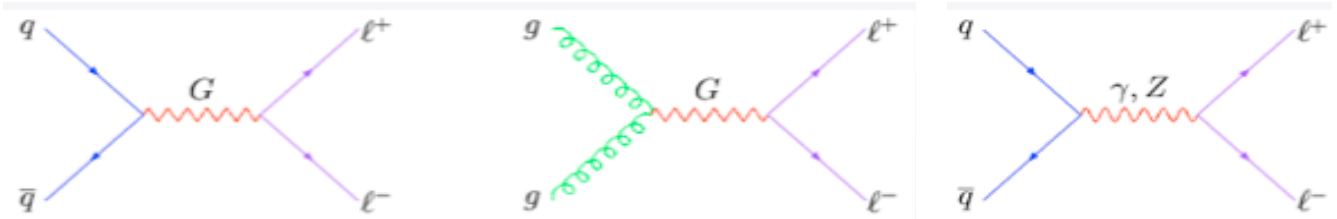
# Search for LED Graviton exchange




$$\sigma_{TOT} = \sigma_{SM} + \eta\sigma_{INT} + \eta^2\sigma_{GRV} \quad (\eta = F/M_S^4)$$

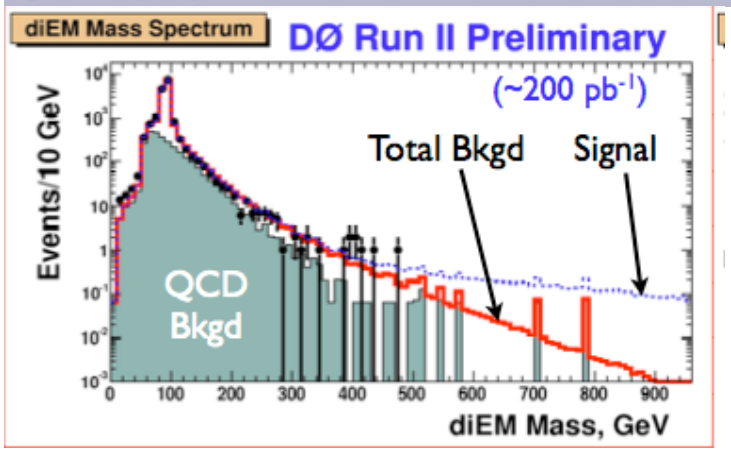
## Analysis strategy

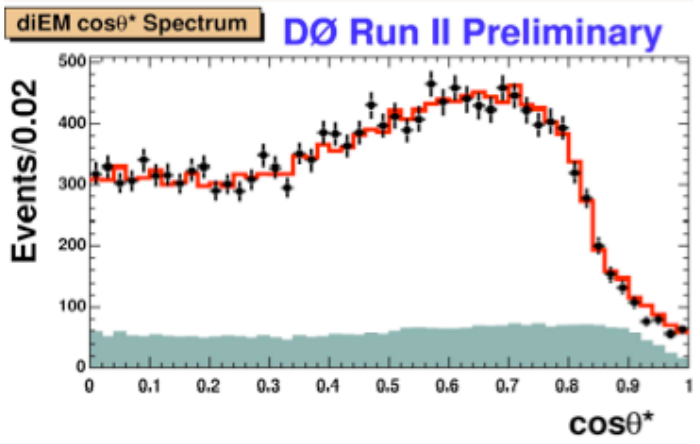
Use di-EM objects (ee+γγ)

2D Fit to M and cosθ*

Set Limits on η and convert to limits on model

| Conventions for *F* | |
|---|---|
| GRW | 1 |
| HLZ (n=2) | $\log(M_S^2/M)$ |
| HLZ (n>2) | $2/(n-2)$ |
| Hewett | $2\lambda/\pi$ |




| $M_S$ Limit(TeV) | D0 (RunII) | D0(RunI+II) | CDF | LEP |
|---|---|---|---|---|
| λ=+1 | 1.22 | 1.28 | 0.96 | 1.1 |
| λ=−1 | 1.10 | 1.16 | 0.99 | 1.2 |

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# Search for BSM in dilepton + X

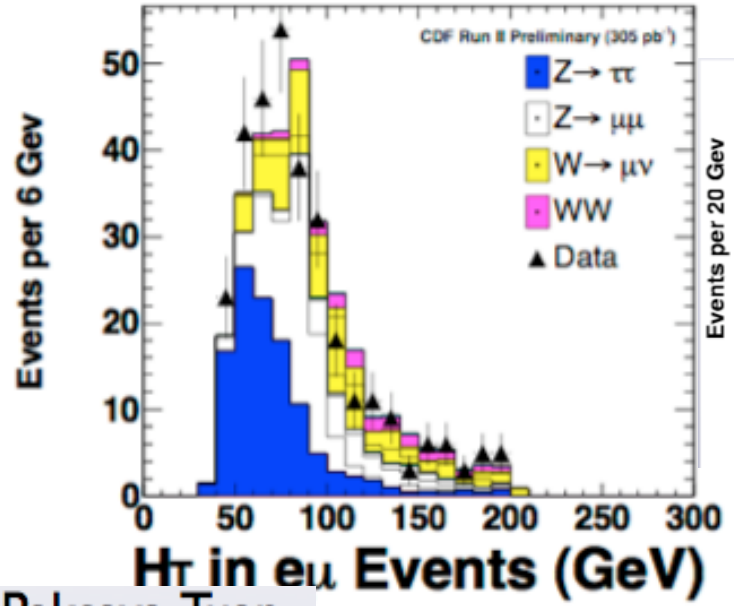
Looking for anomalous dilepton +X events.
X = large $H_T$, large MET, b tags, high $E_T$ jets, 3rd lepton

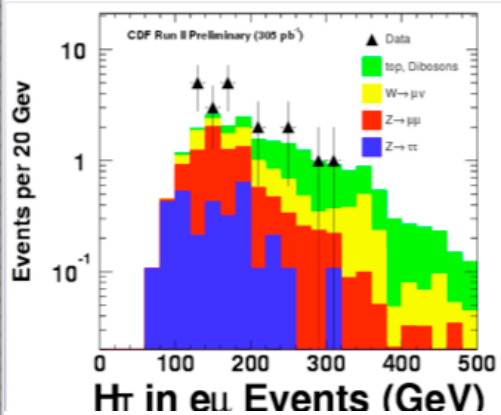
$H_T = E_T(e)+E_T(jet)+P_T(\mu)+MET$

Control Region: $H_T$<200 GeV

Signal Region: $H_T$>400 GeV

(S/√B !!) 2 jets $E_T$>50 GeV




heavy quark model of Bjorken, Paksava, Tuan

3 down-type quarks, $Q_i$ , decaying $Q \rightarrow Z/H+d$ or $Q \rightarrow W+u$

Expect:
0.802 ± 0.440 SM
0.526 ± 0.058 QQ
Observe: 0

$\sigma < 4.49*\sigma_Q$ (90%CL)
($\sigma_Q$=0.289pb $m_Q$=300 GeV)

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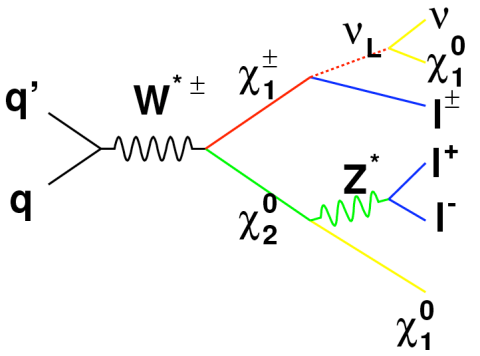
# SUSY in Trileptons

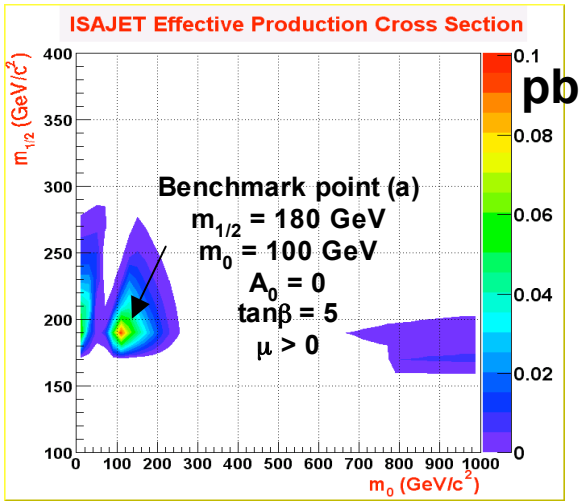


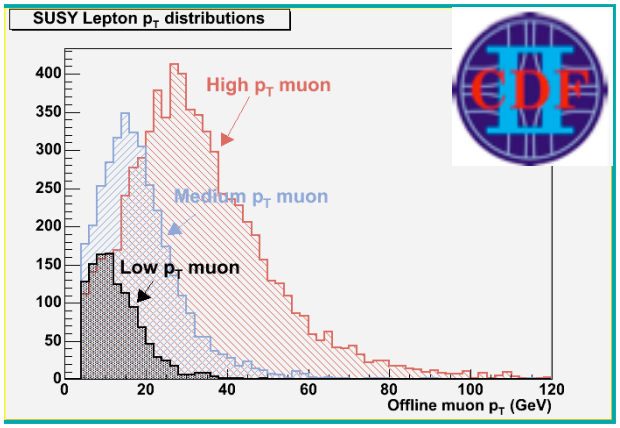

$$\sigma(qq' \to \chi_1^{\pm}\chi_2^0) \cdot BR(\chi_1^{\pm}, \chi_2^0 \to lll\ )$$

**Signature:**
**3 isolated leptons and large MET**

**Sensitivity study for trilepton channel in mSUGRA scenario**

**Detailed scan of the parameter space: $m_{1/2}$,$m_0$,$A_0$,tanβ,sign(μ)**




**4 independent analyses to maximize acceptance**
**High $p_t$ μμ + lepton & ee + lepton**
**Low $p_t$ μμ + lepton & ee + track**

| Channel | Benchmark signal | SM expected | Obs |
|---|---|---|---|
| μμ/e +l (0.7fb$^{-1}$) | 2.3±0.3 | 1.2±0.2 | 1 |
| ee+l (350pb$^{-1}$) | 0.5±0.06 | 0.2±0.05 | 0 |
| μμ+l (low pt) (320pb$^{-1}$) | 0.2±0.03 | 0.1±0.03 | 0 |
| ee+trk (600pb$^{-1}$) | 0.7±0.03 | 0.5±0.1 | 1 |

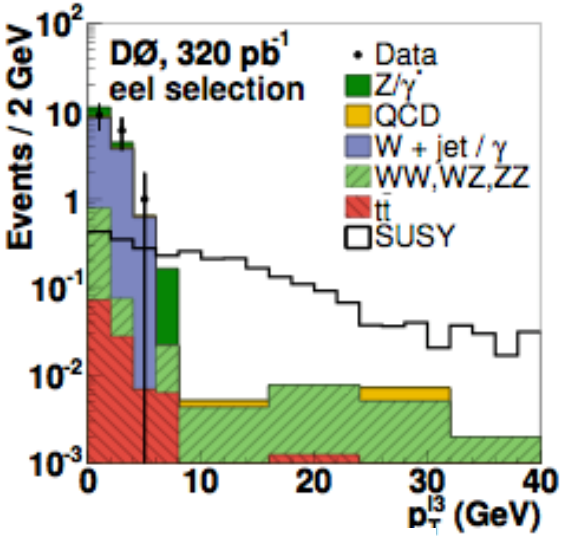
# SUSY in trileptons: results

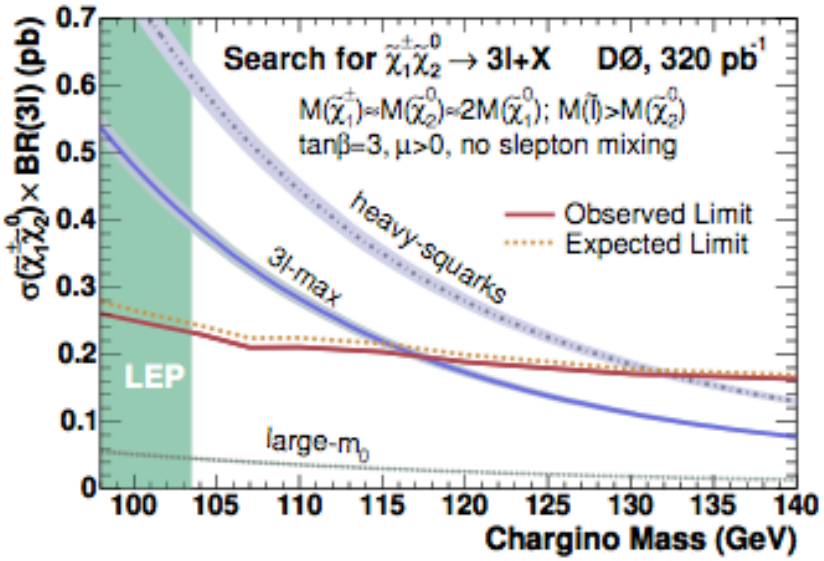
**Final state:**

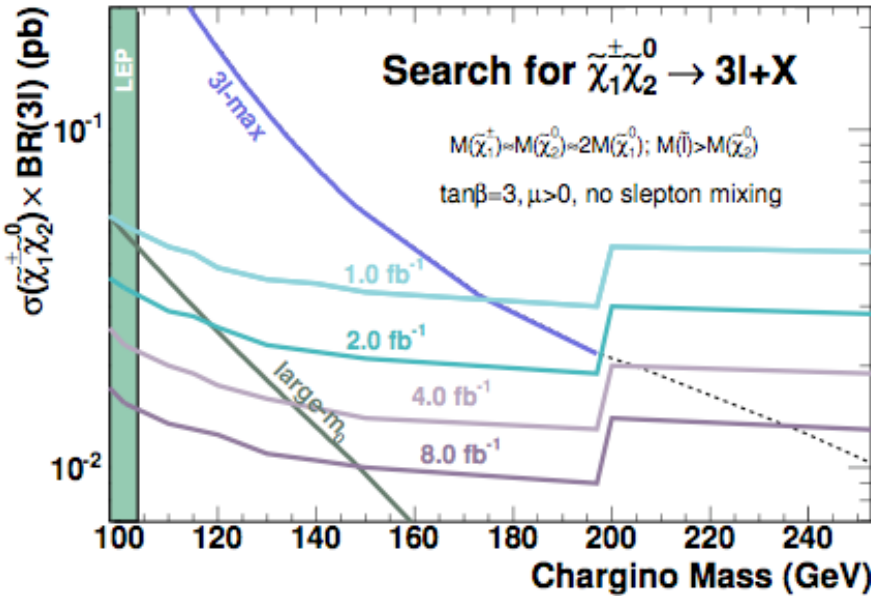
- consider only decays to leptons and LSP: 3-l + MET
- small $\sigma \times \mathrm{BR}$ but small SM background
- eel, $\mu\mu$l, $\mu^{\pm}\mu^{\pm}$, e$\mu$l (l=e/$\mu$/$\tau$) **PRL 95, 151805 (2005)**

**Dataset:**

- $\mathcal{L}_{int}$ ~320 pb$^{-1}$
- single and di-lepton triggers



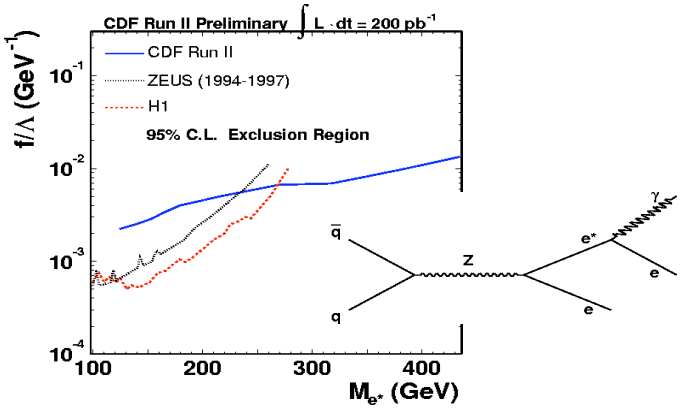



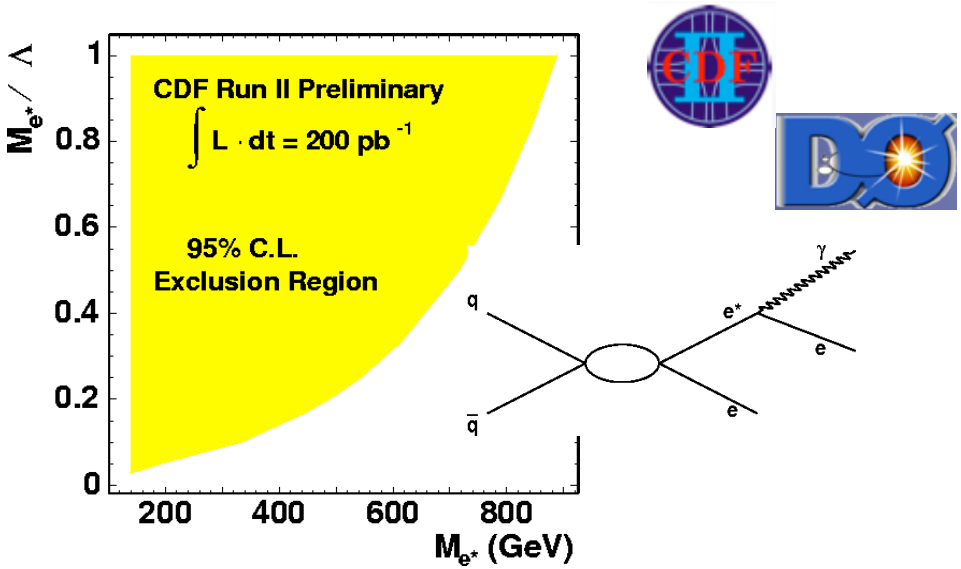
# Excited leptons

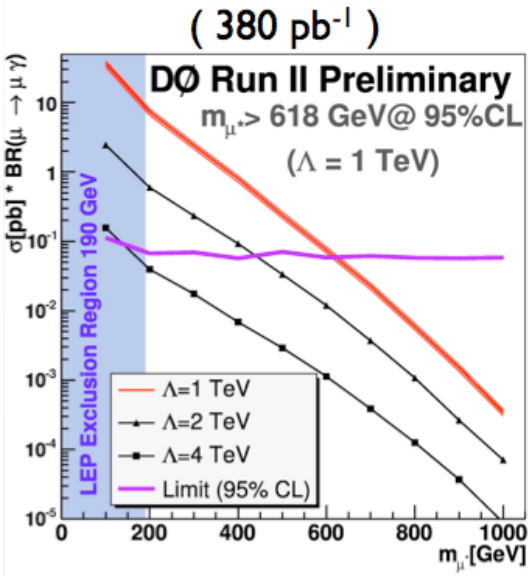
Observation of excited states of quarks and leptons might confirm the hypothesis that they are not elementary particles , but composite states

Select events with ee$\gamma$ ($\mu\mu\gamma$) in the final state and look for resonance in M($e\gamma$) or M($\mu\gamma$)




At Tevatron, $e^*$ /$\mu^*$ can be produced via contact interactions or gauge mediated interactions

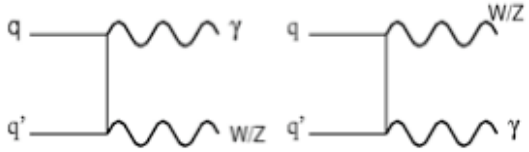


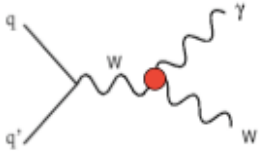
# Wγ and Zγ

Test of gauge couplings (as predicted by the SM) and a window on new physics

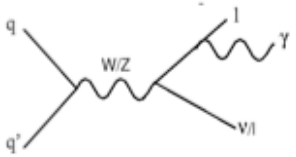
u- or t-channel

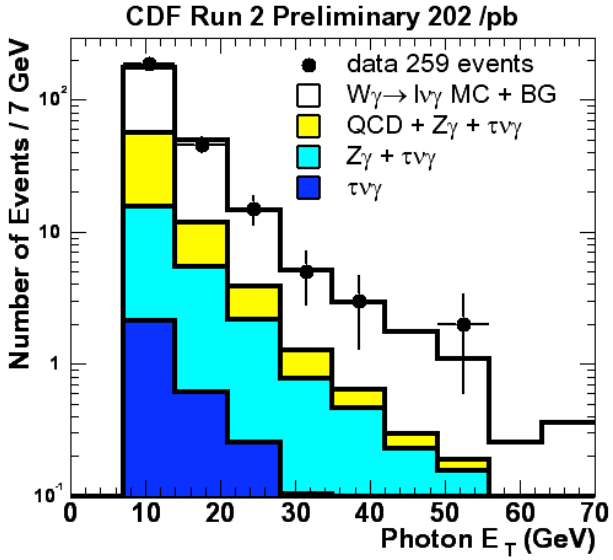


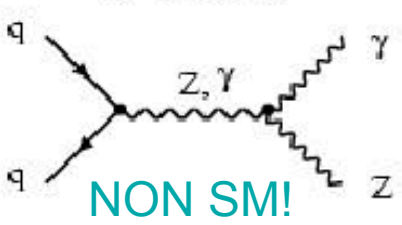

s-channel



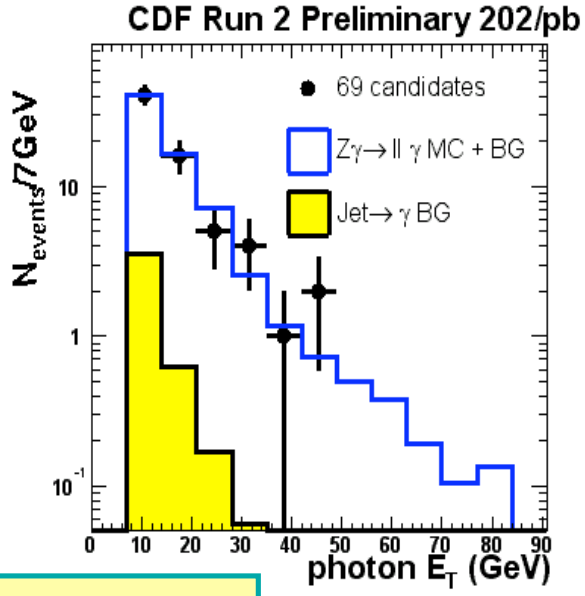

final-state radiation



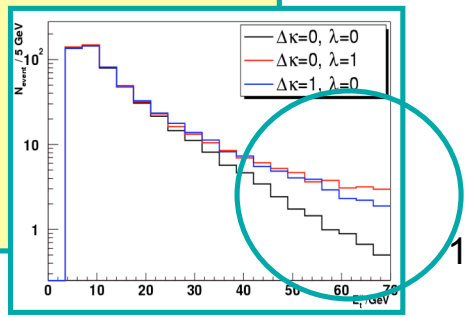




NON SM!




Now V+γ cross-sections well established, we are:

- optimizing sensitivity to anomalous coupling and new physics
- testing the Standard Model in ways unique to the TeVatron (e.g. observing RAZ in W γ production)



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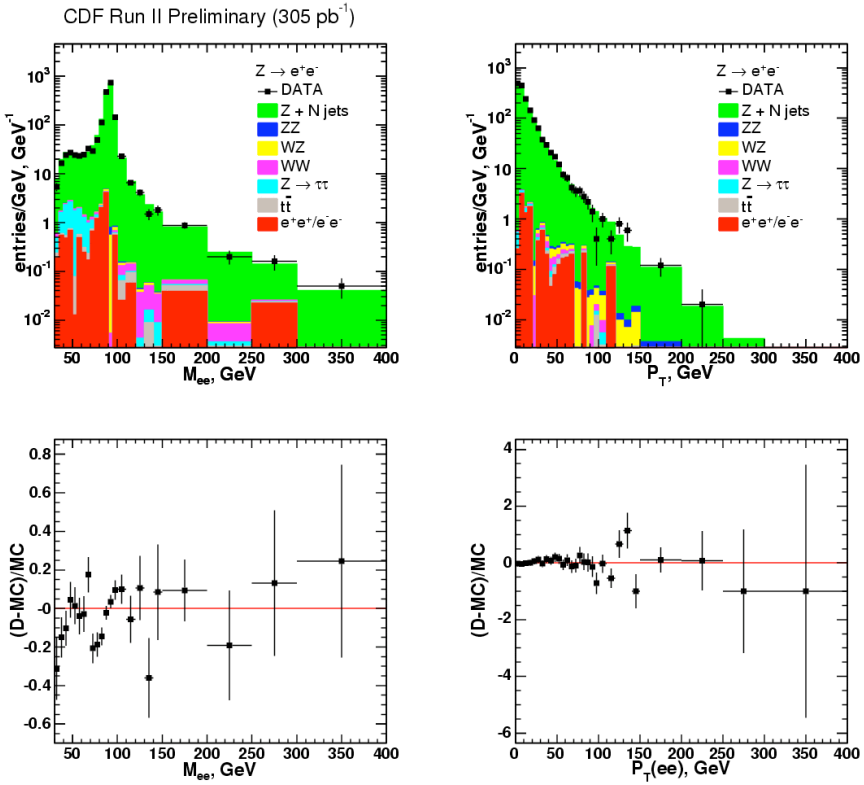
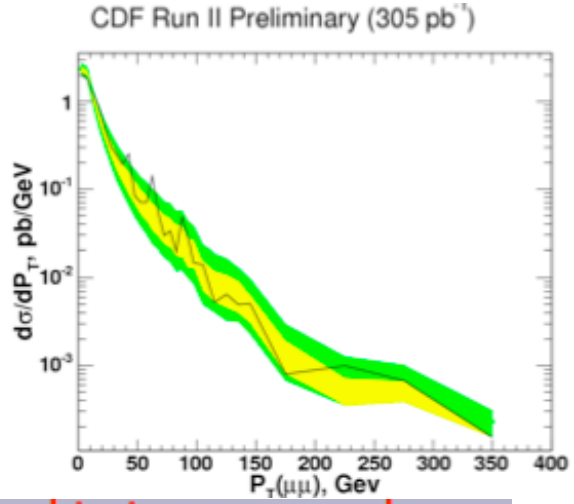
# Search for BSM in high $P_T$ Z

Look for Z decaying weakly from heavier particles
Open to different models (SUSY, ED, etc)




Set Limit on anomalous Z Production

To use this limit one needs to fold in the information relative to the process acceptance!

For example, this limit translates into a limit on BPT models cross section: 0.35pb for m(Q) = 300 GeV/c$^2$

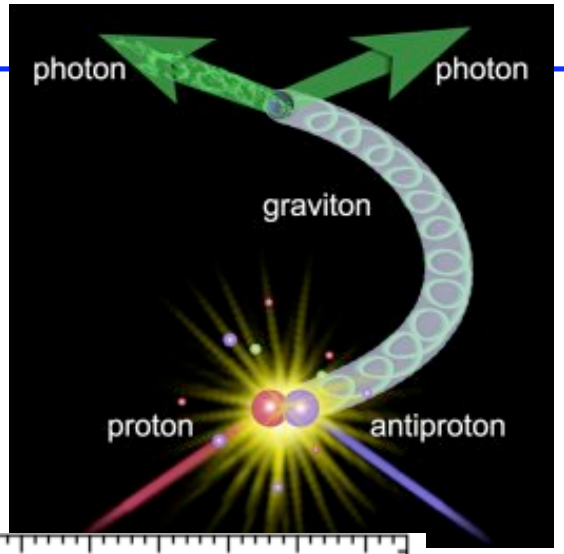
Study Kinematics for Inclusive, $P_T$(Z)>60, 120 GeV

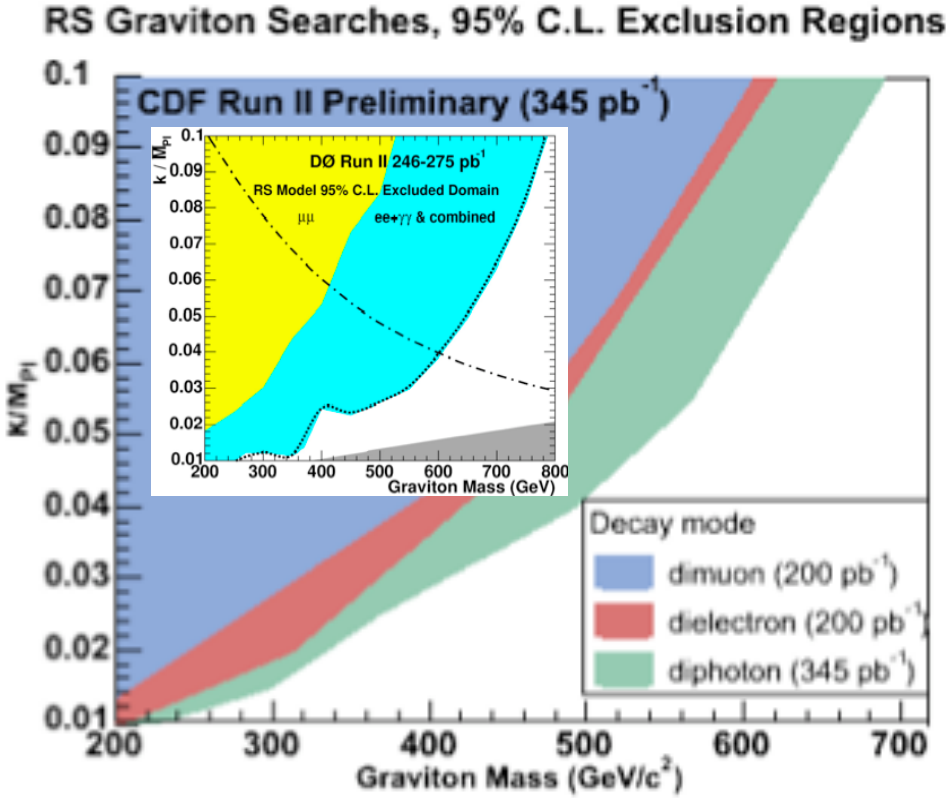
| Z + X | Inclusive | $P_T(Z) > 60$ GeV | $P_T(Z) > 120$ GeV |
|---|---|---|---|
| $Z \to ee$ | 8124 | 155 | 20 |
| $Z \to \mu\mu$ | 10732 | 233 | 18 |

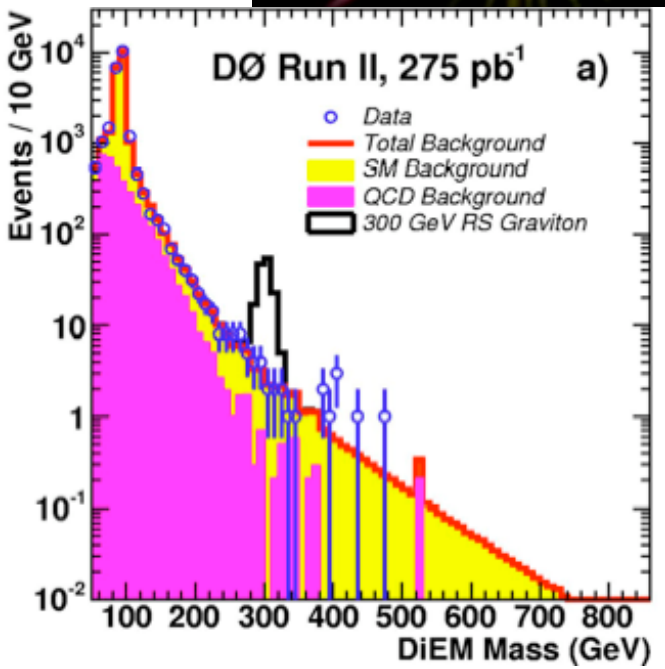
# LED in diphoton

- Randall-Sundrum graviton model
  4-dimensional metric multiplied by *warp* factor exponentially changing with the additional dimension
  Generating a large hierarchy does not require a large $r_c$

The coupling of individual KK states to matter is set by the weak scale (parameters : $M_G$ and $k/M_{P\ lanck}$)
KK states can be observed as spin 2 resonances

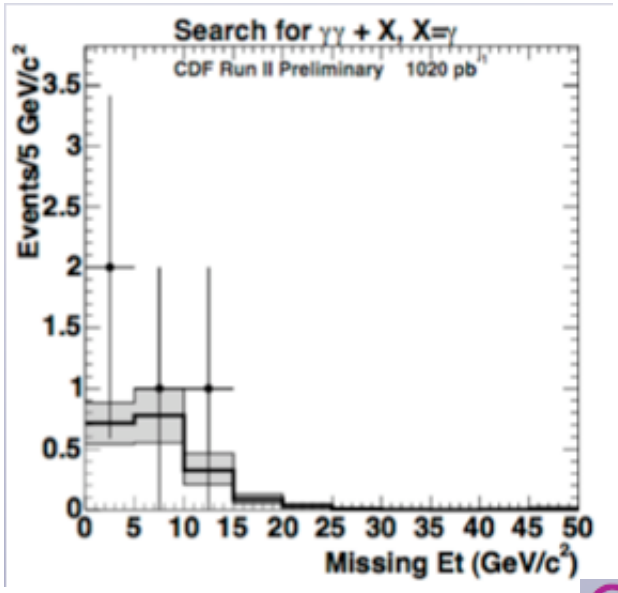


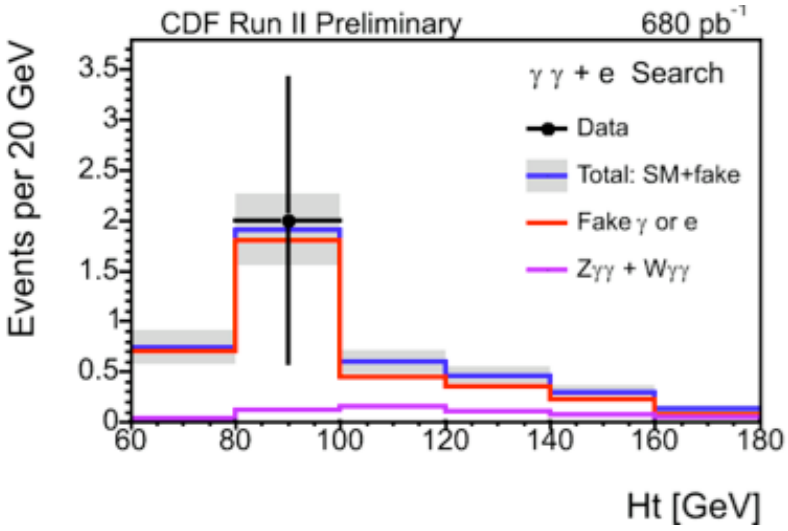



# Search for BSM in Diphoton

## Search for $\gamma\gamma$ + $\gamma$/e/$\mu$




Good agreement between data and SM predictions
- Continue to add objects in γγ+X Search

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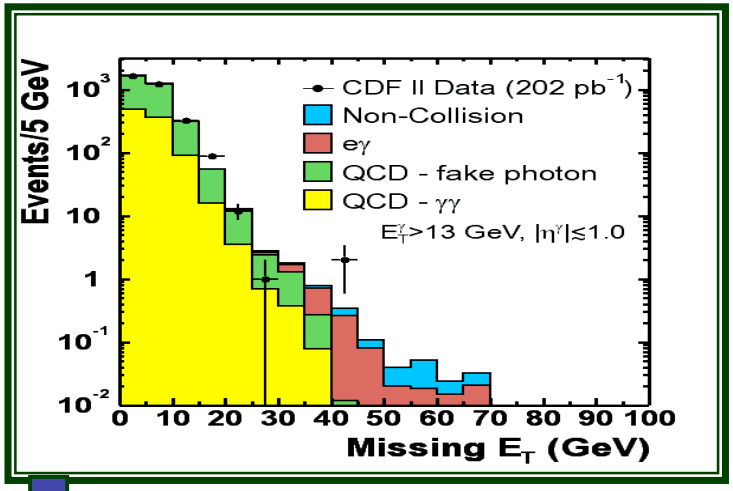
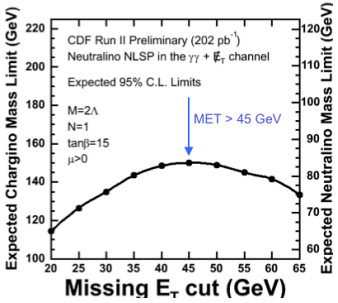
# SUSY searches in diphoton + $\not{E}_T$

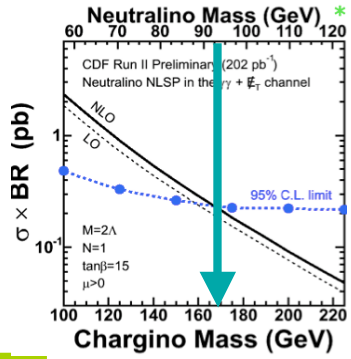
**GMSB scenario**
**NLSP = $\chi^0_1 \rightarrow \gamma \tilde{G}$**

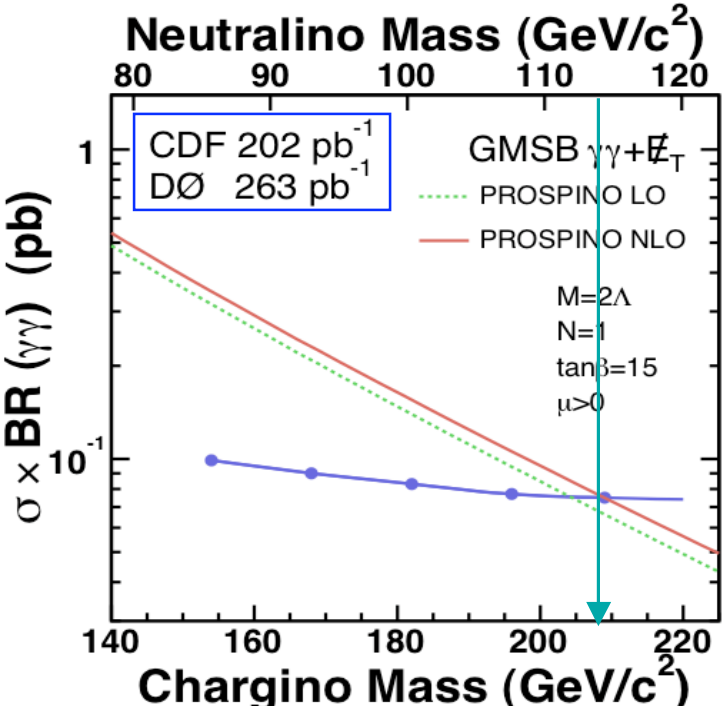
$p\bar{p} \rightarrow (X \rightarrow) \chi^0_1 \chi^0_1$ ⇒ $2\gamma + \not{E}_T$

Sample selection
- 2 central photons $E_T > 13$ GeV
- cosmic rays and beam halo rejection




**For Missing Energy > 45 GeV**
**Expected: 0.60 ± 0.50**
**Observed : 0**

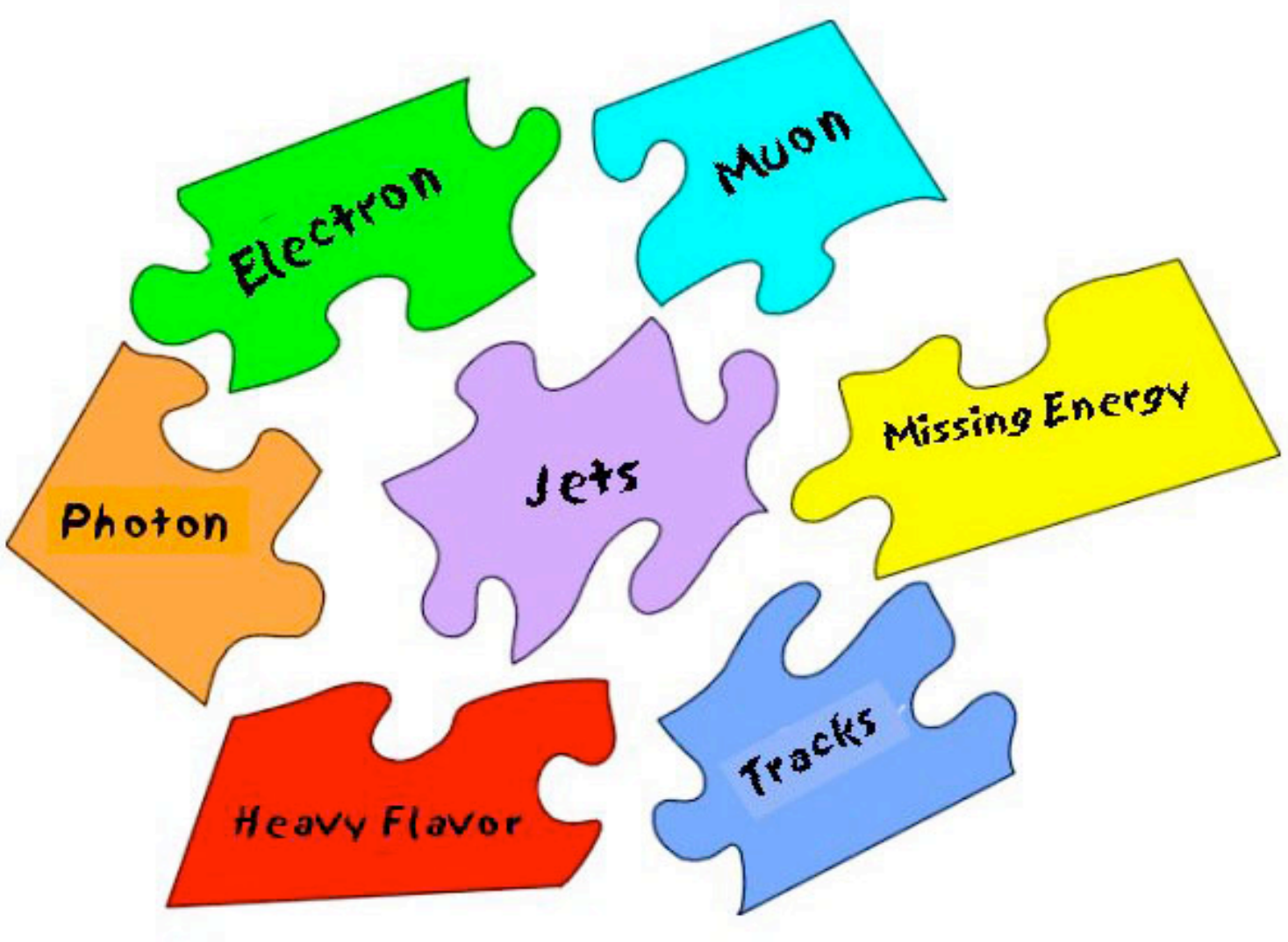
NLO Limit at 95% C.L.

$m(\tilde{\chi}_1^{\pm}) > 168$ GeV/c$^2$

$m(\tilde{\chi}_1^0) > 93$ GeV/c$^2$

(209)
(114)

# Adding jets and flavor tagging



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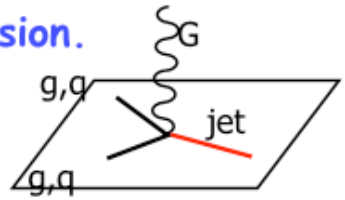
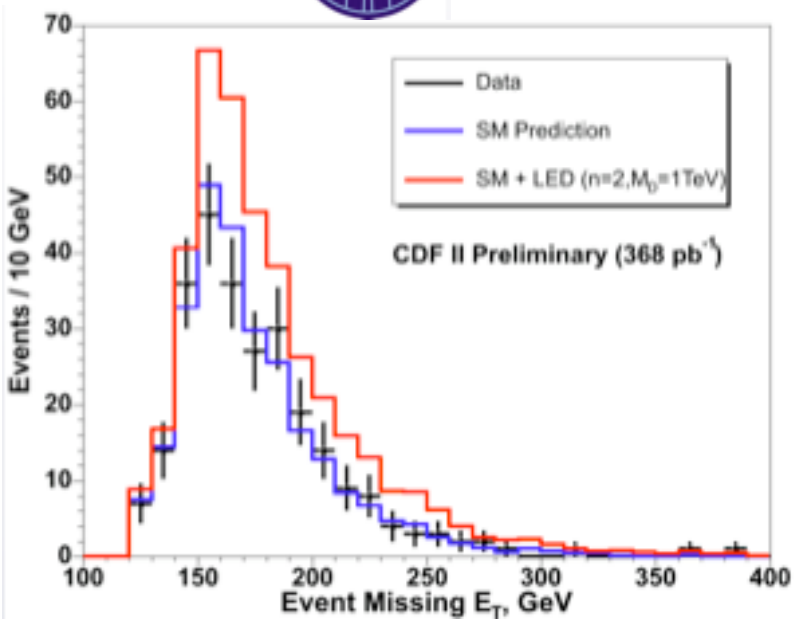
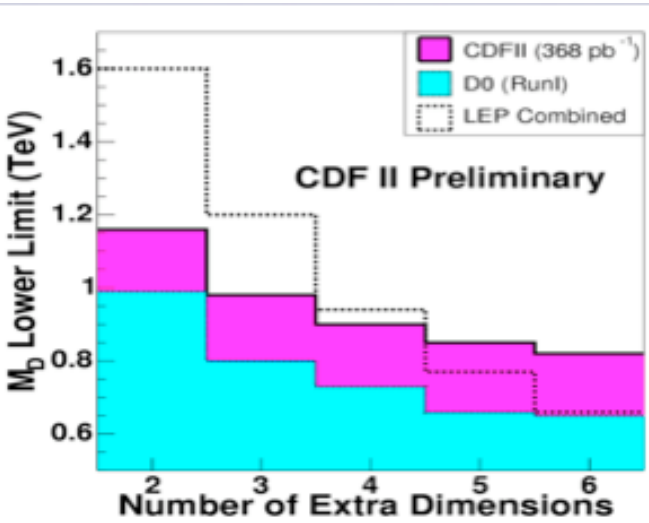
# LED in monojet + MET

Mono-jet channel where a jet recoils against the graviton which leaves the usual 3D dimension.




| n | $M_D$(TeV/c$^2$) | R(mm) |
|---|---|---|
| 2 | > 1.16 | < 3.6 × 10$^{-1}$ |
| 3 | > 0.98 | < 3.7 × 10$^{-6}$ |
| 4 | > 0.90 | < 1.1 × 10$^{-8}$ |
| 5 | > 0.85 | < 3.5 × 10$^{-10}$ |
| 6 | > 0.83 | < 3.4 × 10$^{-11}$ |



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# SUSY in MET + jets

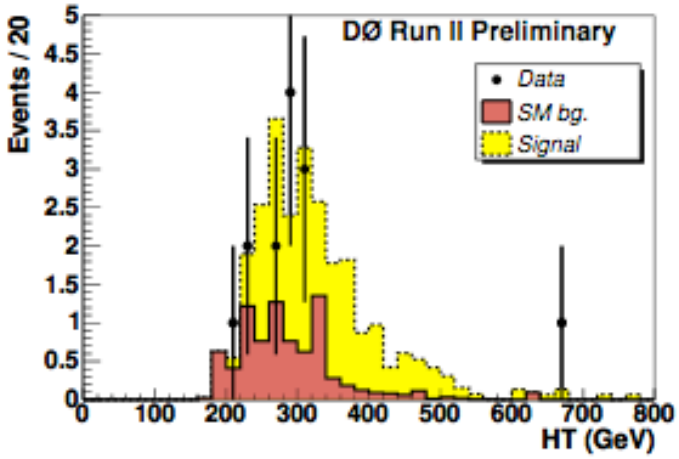
**Analysis:**

- [2j]: low $m_0$ ($m_{\tilde{g}} > m_{\tilde{q}}$), $\tilde{q}\tilde{q}^{\star} \rightarrow q\tilde{\chi}_1^0 + \bar{q}\tilde{\chi}_1^0$ dominates acoplanar di-jets events
- [4j]: large $m_0$ ($m_{\tilde{q}} > m_{\tilde{g}}$), $\tilde{g}\bar{\tilde{g}} \rightarrow q\bar{q}\tilde{\chi}_1^0 + \bar{q}q\tilde{\chi}_1^0$ dominates $\geq$4-jets events
- [3j]: intermediate $m_0$, all contributions ($\tilde{q}\tilde{q}^{\star}$, $\tilde{g}\bar{\tilde{g}}$, $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$) $\geq$3-jets events

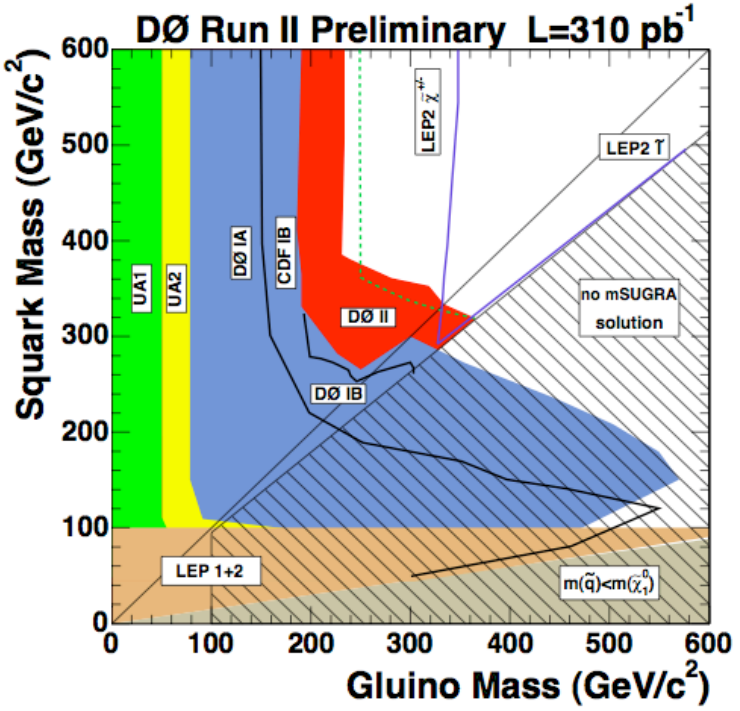
**Dataset:** jets + MET trigger ($\mathcal{L}_{int}$ ~310 pb$^{-1}$)

**Selection:**

- kinematic and quality cuts ($p_T$, MET, HT, MET isolation and acoplanarity), lepton veto
- Major backgrounds:
  [2j] $Z \rightarrow \nu\nu + 2j$
  [4j] $t\bar{t}$, QCD
  [3j] $W \rightarrow \tau\nu + 2j$, $t\bar{t}$




$(m_0, m_{1/2})$=(500,80) GeV/C$^2$ [4j]




[2j] $m_0$= 25 GeV/C$^2$: $m(\tilde{q})$ >318 GeV/C$^2$
[4j] $m_0$=500 GeV/C$^2$: $m(\tilde{g})$ >233 GeV/C$^2$
[3j] $m(\tilde{q})$=$m(\tilde{g})$: $m(\tilde{q}), m(\tilde{g})$ >333 GeV/C$^2$

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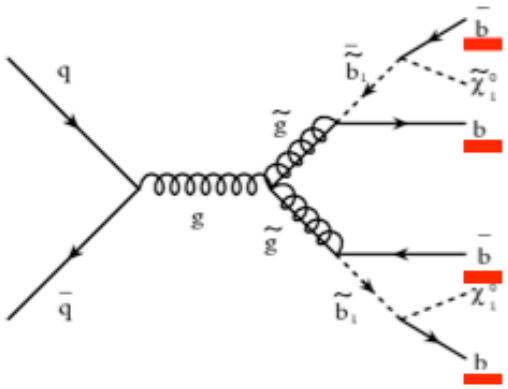
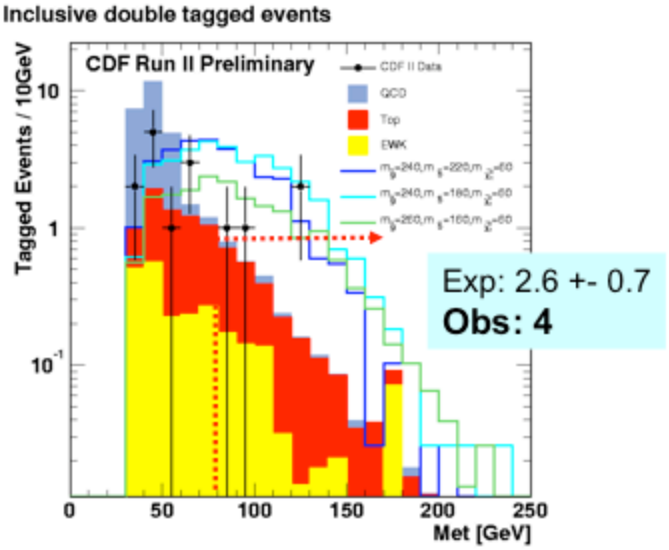
# SUSY: sbottom from gluinos

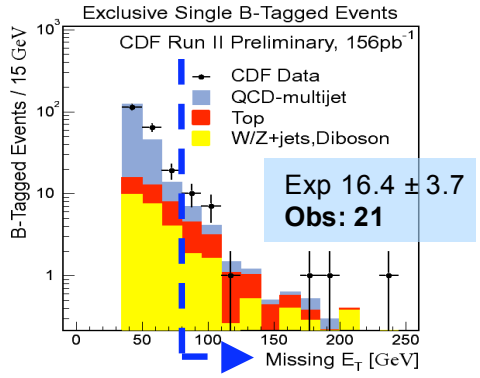
If the sbottom is significantly lighter than the other squarks, the two body decay of gluino into bottom/sbottom is kinematically allowed

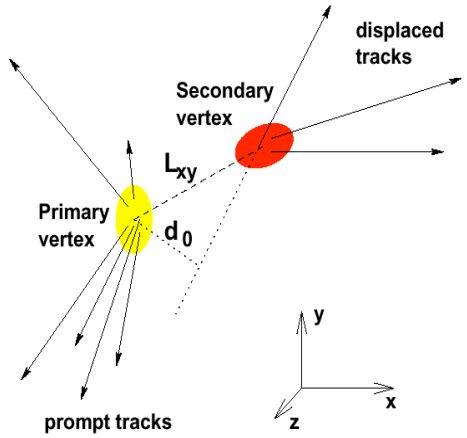


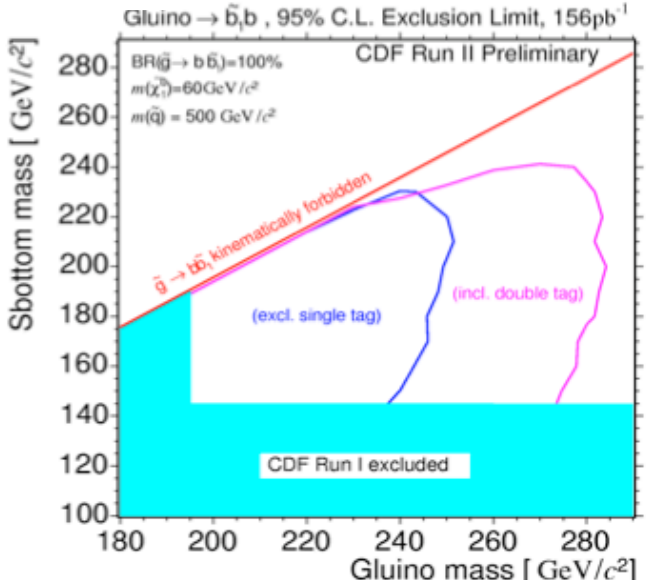

The sbottom decays into a bottom and LSP, giving rise to a final state with 4 b-jets and missing energy

b-tagging



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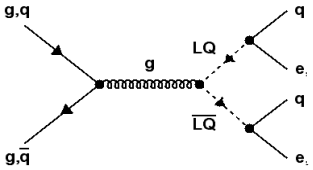
# Leptoquarks

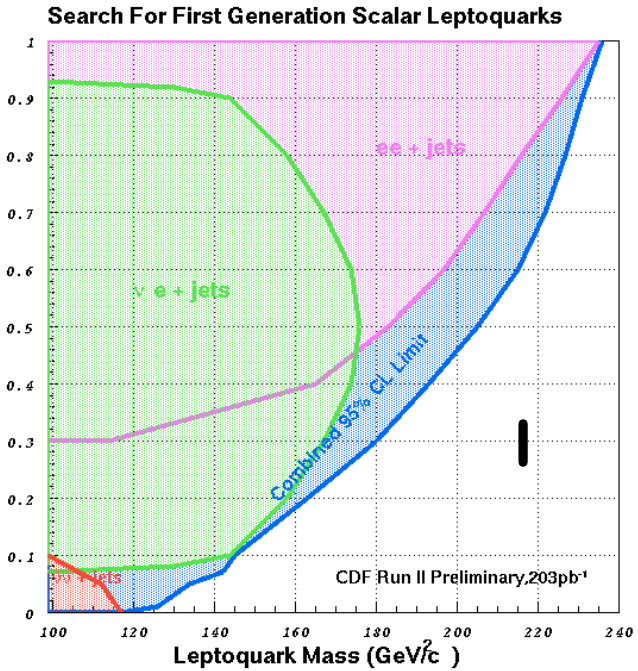
**Leptoquarks (LQ)** are hypothetical particles which appear in many SM extensions to explain **symmetry between leptons and quarks**

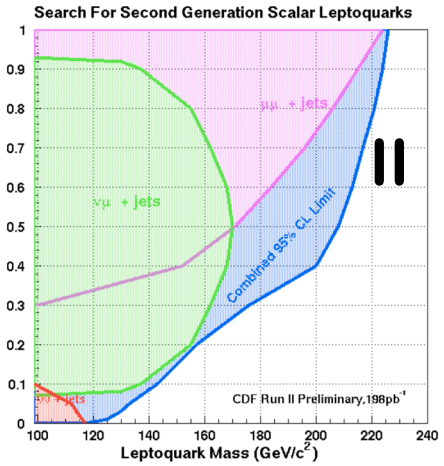
- SU(5) GUT model
- superstring-inspired models
- 'colour' SU(4) Pati-Salam model
- composite models
- technicolor

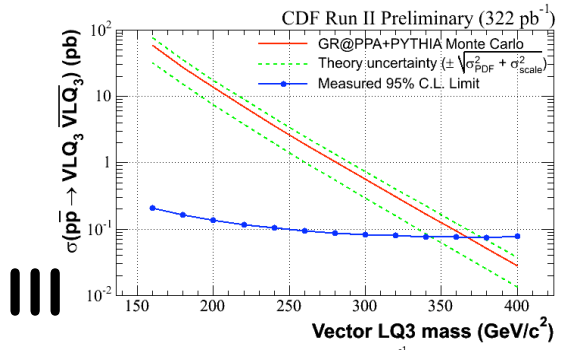


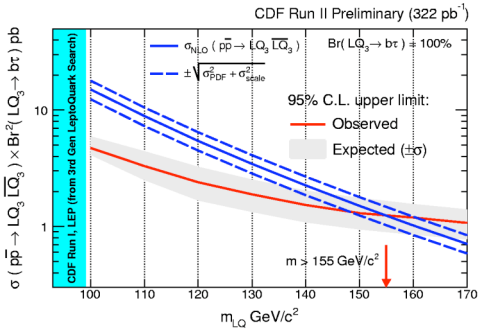

| 1st Generation | 2nd Generation | 3rd Generation |
|---|---|---|
| LQ $\overline{LQ}\rightarrow e^-e^+q\bar{q}$ | LQ $\overline{LQ}\rightarrow \mu^+\mu^-q\bar{q}$ | LQ $\overline{LQ}\rightarrow \tau^+\tau^-q\bar{q}$ |
| LQ $\overline{LQ}\rightarrow e^{\pm}\nu_e q_i q_j$ | LQ $\overline{LQ}\rightarrow \mu^{\pm}\nu_\mu q_i q_j$ | LQ $\overline{LQ}\rightarrow \tau^{\pm}\nu q_i q_j$ |
| LQ $\overline{LQ}\rightarrow \nu_e\nu_e q\bar{q}$ | LQ $\overline{LQ}\rightarrow \nu_\mu\nu_\mu q\bar{q}$ | LQ $\overline{LQ}\rightarrow \nu_\tau\nu_\tau q\bar{q}$ |

Signature: dilepton + jets, lepton + jets + MET, MET + jets
Analysis: counting experiment or signature based?



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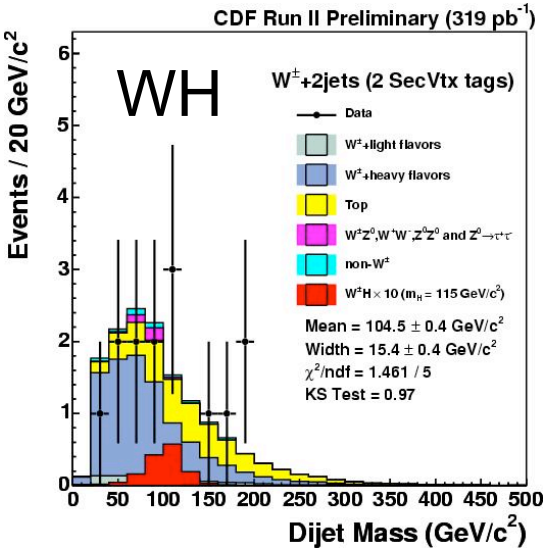
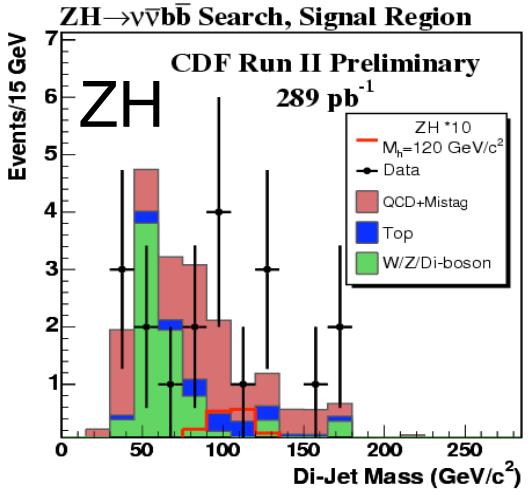
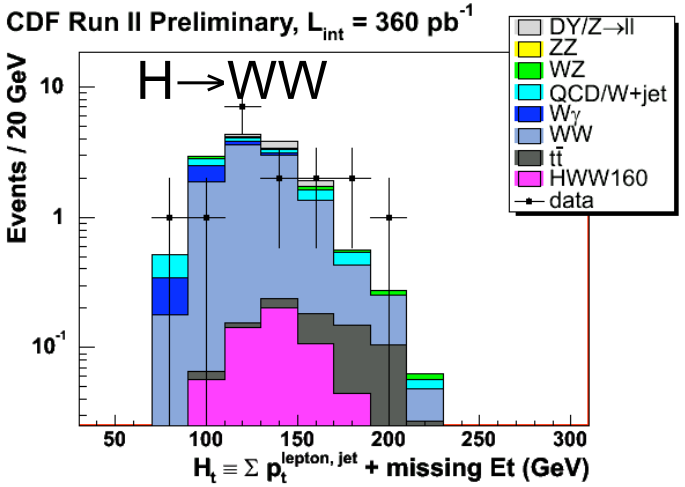
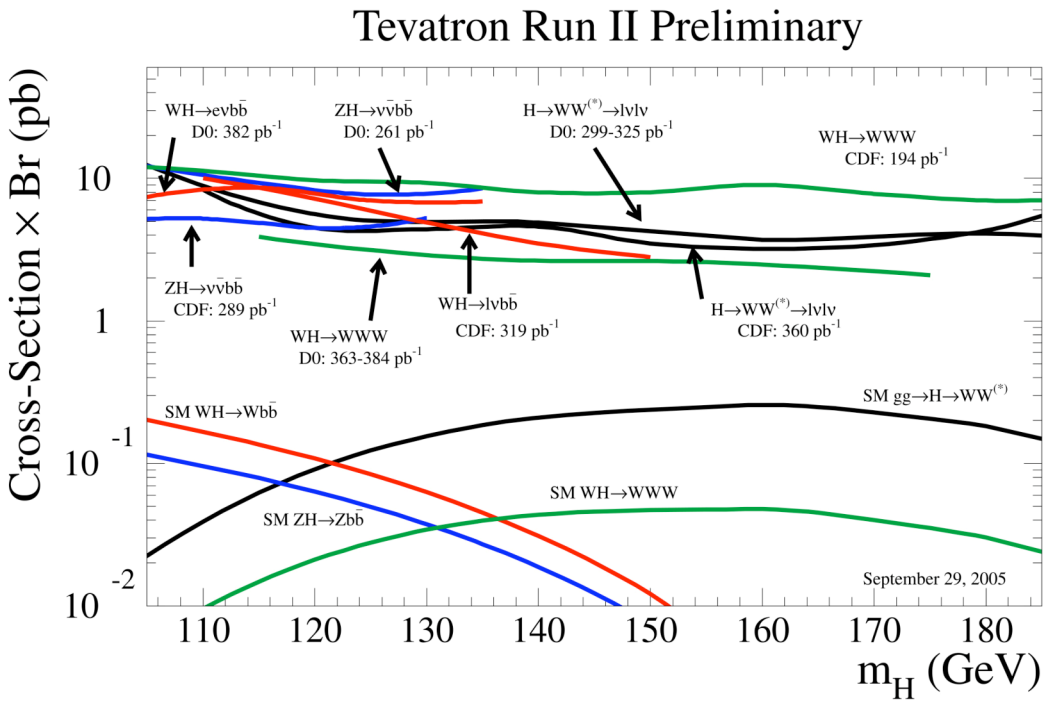
# SM Higgs search

Many analyses ongoing both for light and heavy Higgs
Golden channels and new strategies



# Final Remarks

- The results presented are by far not exhaustive
- Even when a signature-based approach is advocated, results are presented in the end as a function of specific models (typical case dilepton searches, high $P_T$ Z's etc)
- And when the result is presented as a testing of a model, there is always a check on control regions, defined by their signature…(see next transparency)
- So, what is all this fuss about model-based and signature-based approaches ?
- I believe that *both are to be pursued in a balanced way: both have their pros and cons:*
  - **A) Traditional model driven analyses**
    - pick a favorite theoretical model ☹ **might become soon outdated!**
    - pick a process, choose the best signature(s): optimize selection acceptances based on signal MC
    - calculate the background ☺ **best optimization!**
    - evaluate the limit or discovery your signal ☺ **in timely fashion allows theory testing!**
  - **B) Signature based approach**
    - pick a specific signature ( i.e. diphoton+X) ☺ **open to a whole lot of models!**
    - define your sample in terms of known processes ☹ **Not the best optmization !**
    - publish estimates of acceptances & cross section information useful for theorists ..but how much?? Detector effects are detector specific or we would all be using PGS! ;-)
    - see an excess? Inconsistency with SM? Test one or more models later …(but the experiments will never release a controversial results for theorists to interpret, this is just sociology 101)
    - Quero-like access to the data? Is the astrophysical model suitable for HEP?

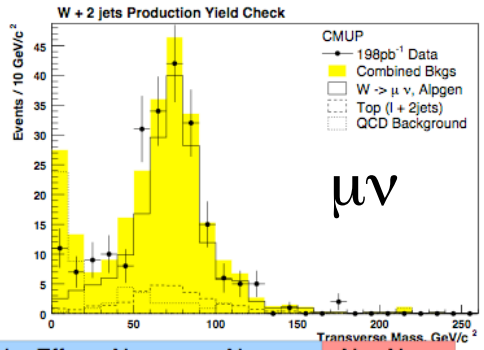
# LQ searches: W/Z+ 2 jets control regions (also good for Higgs, single top, etc..)

$\beta = 0.5$

**W+2jet Check**

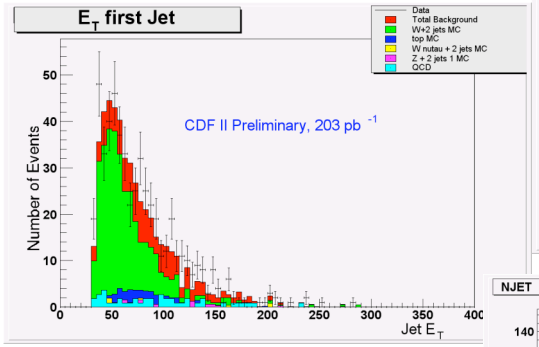
$N(W) = \sigma \times BR(W \to \mu\nu jj) \times A(W) \times \varepsilon \times L$

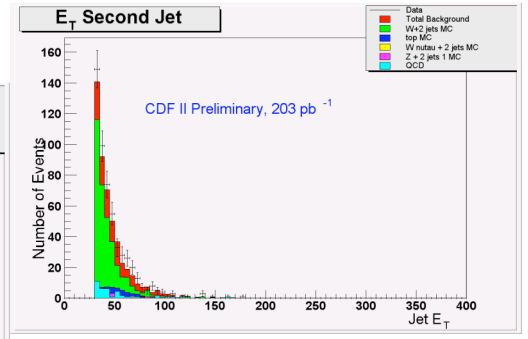
Theory = 295 pb
$\not{E}_T > 20$,
Muon $P_T > 25$
2 Tight Jets,
Jet Topology Cuts



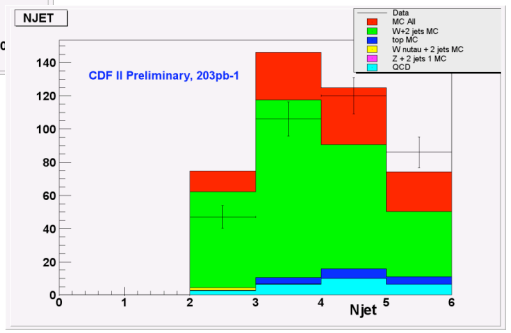

μν

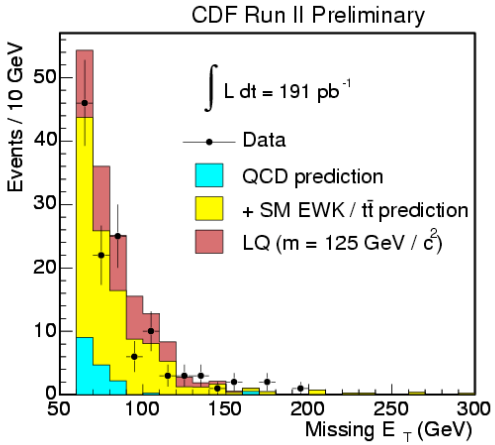
| TYPE | A(W) | Lumi | Eff | $N_{bkg}$ | $N_{W+2j}$ | $N_{obs}$-$N_{bkg}$ |
|---|---|---|---|---|---|---|
| CMUP | 0.37 | 197.9 | 0.695 | 84 ± 12 | 152 ± 10 | 133 ± 27 |
| CMX | 0.16 | 179.2 | 0.835 | 42 ± 7 | 69 ± 5 | 70 ± 16 |




eν




Checks on Z + jets for the $\beta = 1.0$

Checks on the MET distribution for $\beta = 0$

# Conclusions

Many exciting results are currently produced at the Tevatron!
So far a fraction of 1.2 $fb^{-1}$ delivered has been analyzed (Run IIa).

Many of the results interplay nicely :
from testing the SM processes to searches for Exotica
same signature, different physics

A long shutdown is underway: detectors upgrades are almost finished
and the luminosity integrated will increase by a factor 3-6 (Run IIb).
A bump can be around the corner before the LHC turns on….