Status of Beyond the SM Searches

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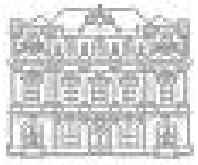
Vienna, July 16, 2004

thanks to organizers and BSM group conveners (especially G. Polesselo,D.Denegri,G. Azuelos,J-F.Grivaz,S.Lammel)



[...] @ Colliders and Mostly with Data

There is also "towards BSM" implications/results from

- Neutrinos
- Astrophysical Observations, UHECR, CMB
- B-Factories
- Macroscopic Gravity Experiments
- &tc

that we will not discuss here

The High Energy Data We Have

- Tevatron
  - $p\bar{p}$, ~120 pb$^{-}1$ at $\sqrt{s} = 1.8$ TeV
  - $< 300\ pb^{-1}$ at $\sqrt{s} = 1.96$ TeV
- HERA
  - ep at $\sqrt{s} = 320$ GeV $\sim 120\ pb^{-1}$ (2001)
- LEP
  - ee at $\sqrt{s}$ up to 209 GeV ~ 1 fb$^{-}1$

Our High Energy Delinquencies Today

- Tevatron
  - top quark mass and $t\bar{t}$ cross section
  - "superjet" events vis à vis b-tagging
- HERA
  - H1 vs ZEUS - events with large missing E_T and a lepton
- LEP
  - A_{fb}^{0b}

other: neutrino masses, [cosmological constant & not yet Higgs]

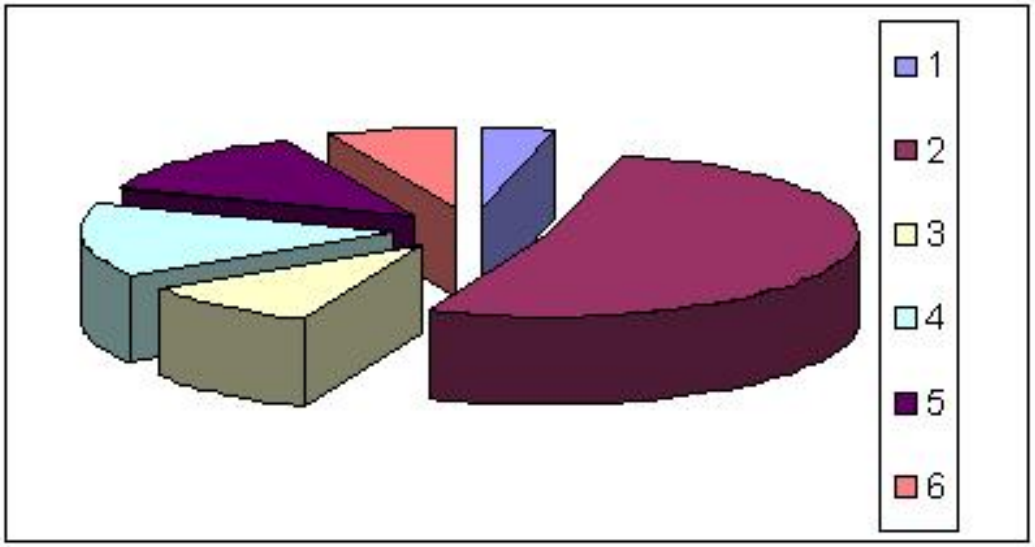
PDG the last 10 years on BSM Searches

- Free Quarks - discarded in 1996
- Magnetic Monopole
- SUSY
- Technicolor - included in 2000
- Quark and Lepton Compositeness
- Extra Dimensions - included in 2002
- Other Stable Particles - renamed WIMPS and Other Particles in 1997

* taken from online PDG editions.

PDG the last 10 years on BSM Searches

1=Monopoles, 2=SUSY, 3=Technicolor 4=Compositeness 5=EDs 6=WIMPS



J. Lykken's list for pheno BSM, BSUSY

- U(1)$'$
- little higgs
- EWSB or SUSY breaking from extra dimensional boundary effects
- KK modes
- black holes, string balls
- flavor and EDs
- leptoquarks

Initial Remarks

- **most all can be motivated from one kind or another of Extra Dimensions and/or SUSY**

- **there is loose or strict dualities between the BSM models $\rightarrow$ the final states/data signatures can be the same $\rightarrow$ the characterization of an excess or a deviation could be in the fine details $\rightarrow$ dig out all the information out of an event (there is millions of channels in the modern detectors giving you kinematics, topology, everything)**

- **From the "analysing the data" point of view, i think one needs to know the qualitative and quantitative differences in the predictions of the models and not exactly the models $\rightarrow$ this leads to the disentangling**

efforts today (is it UED or is it SUSY, is it a Z' or is it an RS graviton mode? is it a monopole or a light gluino? etc)

- **all data that we have today point to the fact that there is something more but that it is rather tricky to say what.**

- **in HEP today when we talk about Beyond the Standard Model (including SUSY) we talk about data at the edge or tails of the standard model (e.g large invariant masses, tails of distributions)**

- **the accurate and precise determination of the standard model physics is crucial: (i) as a background to direct exotic searches (ii) as an indirect probe of other physics**

example list of "Very Exotic" searches (CDF's)

- Dilepton Resonances
  - searching for Z', RS Extra Dimensions, Technicolor
  - using $ee,\ \mu\mu,\ \tau\tau$
  - results- YES
- Same-Sign Dilepton Resonances
  - searching for H^{++}
  - using $ee, \mu\mu, e\mu, \tau\tau$
  - results- YES
- Dilepton+Photon
  - searching for heavy leptons

- using $ee\gamma, \mu\mu\gamma, \tau\tau\gamma$
- results- YES

- Dilepton+Di-jet
  - searching for leptoquarks
  - using $ee jj, \mu\mu jj, \tau\tau jj, e\nu jj, \mu\nu jj, \tau\nu jj, \nu$
  - results- YES

- Photon+missing E_T
  - searching for ADD Graviton
  - using $\gamma + \mathrm{missing\ E_T}$
  - results- YES

- Photon+jet
  - searching for b'
  - using $\gamma + \mathrm{missing\ E_T}$

  - results- in progress

- Highly-ionizing (slow) track
  - searching for H^{++}, H^{--}, monopoles, UEDs stops and staus
  - results YES

Tevatron wisdom: e.g. Di-leptons

$p\bar{p} \to X \to \ell^+\ell^-$: Two energetic, isolated, same flavor, opposite sign leptons

- $p\bar{p} \to \ell^+\ell^-$ **Drell-Yan** irreducible, calculable, simulable, estimated to 10%.
- **"fake"** leptons, *i.e.* $b \to c\ell\nu$, conversions, $K^+ \to \mu\nu$. Not predicted. Estimated from data control samples to ∼30-50%. Not significantly contributing at high masses.
- **cosmics** in the muon channels always more of a problem than one might think. Estimated to ∼30-50%. Trouble.
- W**+jets, di-bosons, top** negligible at high mass

and in general Di-objects

what do you usually work with?

- cross section (especially at high P_T)
- invariant mass (especially tails)
- angular distributions (especially at high invariant mass)

example models for interpretation: ADD

direct G

$$e^+e^-, p\bar{p} \longrightarrow \gamma G,\ jG \text{ (Mirabelli et al., Giudice et al.)}$$
$$\longrightarrow ZG \text{ (Cheung, Keung)}$$
$$\longrightarrow WG \text{ (Balazs et al.)}$$
$$\longrightarrow f\bar{f}G \text{ (Balazs et al.;Atwood et al.)}$$

exchange G

$$e^+e^-, p\bar{p} \longrightarrow \gamma\gamma,\ WW,\ ZZ$$
$$q\bar{q} \longrightarrow \ell^+\ell^-$$
$$\ell^+\ell^- \longrightarrow q\bar{q}$$
$$ep \longrightarrow eX,\ \nu X$$
$$q\bar{q} \longrightarrow jj,\ t\bar{t}$$

Giudice,Han,Nussinov,Hewett,Rizzo,Agashe,Deshpande,Cheung,Lee, Mathews, Davoudiasl,Guptal, Atwood,Ghosh,Cheng,He et.al. &tc

But also asymmetrical ADD with flat TeV^{-1} EDs! e.g KK Z or KK γ or KK $gluon$ exchange affects dilepton, or di-gamma, or dijet cross section at high P_T

LEP widsdom vis à vis EDs (99)

- Higgs type analyses $\rightarrow$ direct G production in ADD

  e.g Visible mass analyses $e^+e^- \longrightarrow Z+$ Missing Energy

- GMSB type analyses $\rightarrow$ direct G production in ADD

  e.g $e^+e^- \longrightarrow \gamma+$ Missing Energy

- anomalous $Z\gamma\gamma$ couplings, WW, $Z\gamma$ analyses$\rightarrow$ virtual ADD effects

  e.g $e^+e^- \longrightarrow \gamma\gamma,\ VV$

- &tc with Bhabhas/other QED type of measurements

(+2004 branons)

summary reach ADD

	M_S (TeV)					
	$n=2$	$n=4$	$n=6$	$n=2$	$n=4$	$n=6$
		Run I				
Dilepton	1.2	1.1	0.93			
Diphoton	1.4	1.2	1.0			
Combined	1.5	1.3	1.1			
		2 fb^{-1}			20 fb^{-1}	
Dilepton	1.9	1.6	1.3	2.7	2.1	1.8
Diphoton	2.4	1.9	1.6	3.4	2.5	2.1
Combined	2.5	1.9	1.6	3.5	2.6	2.2
		LHC				
Dilepton	10	8.2	6.9			
Diphoton	12	9.5	8.0			
Combined	13	9.9	8.3			

summary reach for TeV^{-1}

Using

- Drell-yan production at Tevatron
- HERA NC and CC DIS
- LEPII hadronic, leptonic cross section, angular distributions
- dijet cross section and angular distribution,
- $t\bar{t}$ production.

Cheung & Landsberg Phys Rev D. **62** 076003

summary reach TeV^{-1}

	M_C^{95} (TeV)
LEP 2:	
hadronic cross section, ang. dist., $R_{b,c}$	5.3
μ, τ cross section & ang. dist.	2.8
ee cross section & ang. dist.	4.5
combined	6.6
HERA:	
NC	1.4
CC	1.2
HERA combined	1.6
TEVATRON I (120 pb^{-1}) :	
Drell-yan	1.3
Tevatron dijet	1.8
Tevatron top production	0.60
Tevatron combined	2.3
All combined	6.8

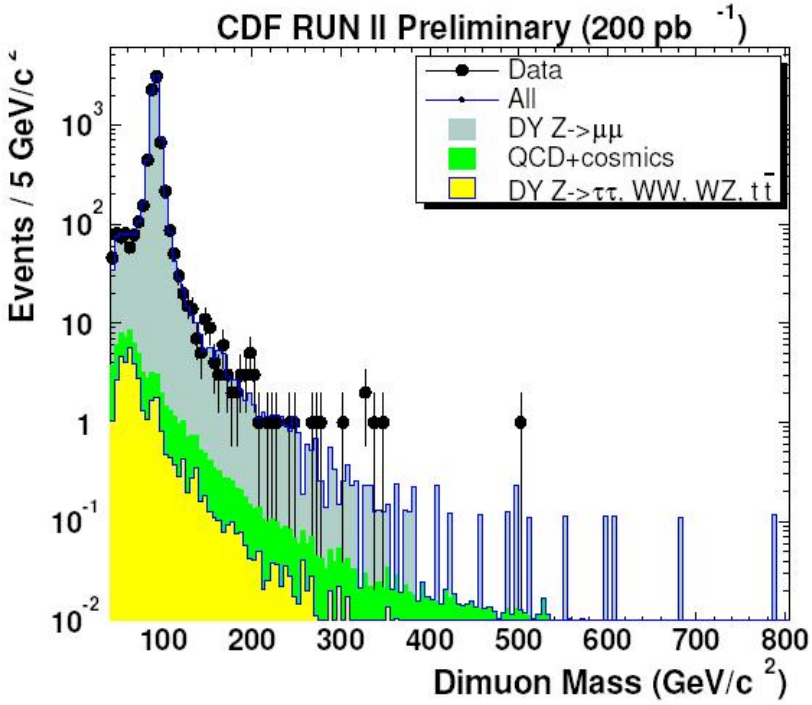
new results

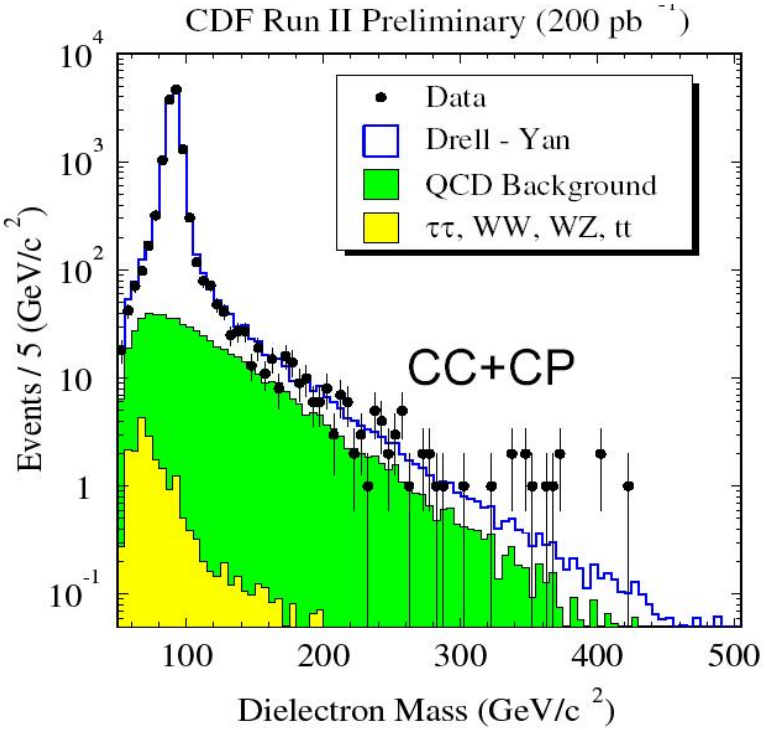
di-leptons/di-photons in virtual graviton exchange

- CDF using di-leptons (ee, $\mu\mu$) and 200 pb^{-1}
- D0 using diEM and 200 pb^{-1}
- D0 using diEM combining RUNI (120 pb^{-1}) with RUNII

	GRV	HLZ					Hewett
		$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$	$\lambda = +1/\text{-}1$
CDF	1.1		1.17	0.98	0.89	0.83	0.78	0.98/0.96
D0	1.36	1.56	1.61	1.36	1.23	1.14	1.08	1.22/1.10
D0 I+II	1.43	1.67	1.70	1.43	1.29	1.20	1.14	1.28/-

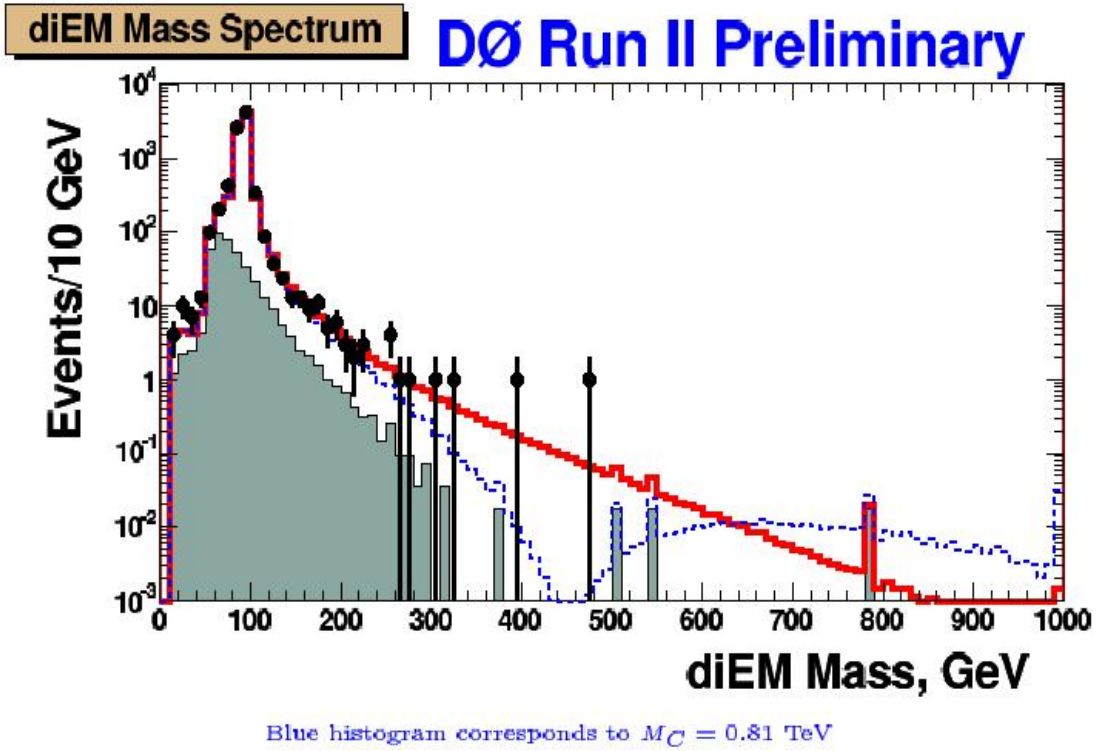
e.g. **Di-electron, Di-Muon invariant mass at the Tevatron**





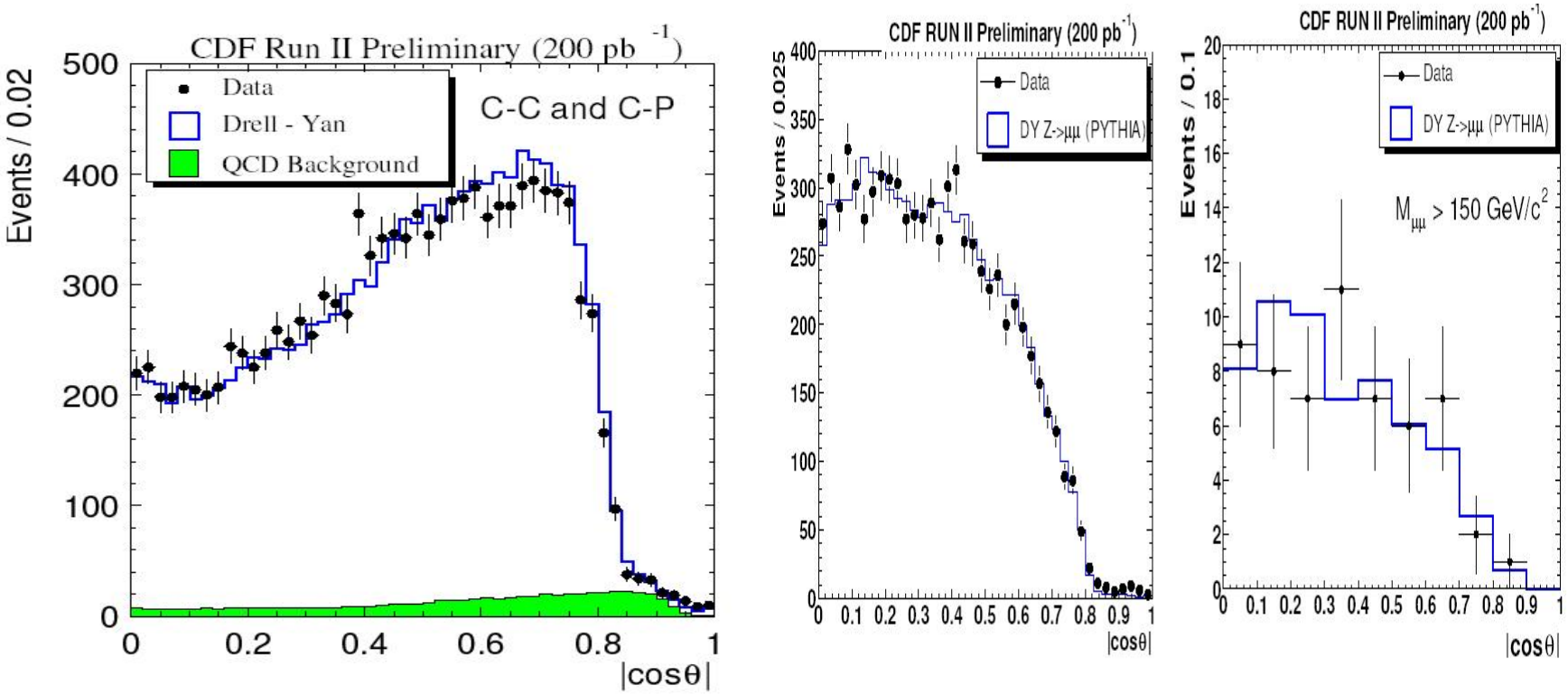
the uncertainty on total background estimate for $M_{\ell\ell} > 300$ is 40%for electrons, and 25%for muons. systematics come from luminosity, acceptance, energy/momentum scale/resolution, selection efficiency, background statistics/normalization.

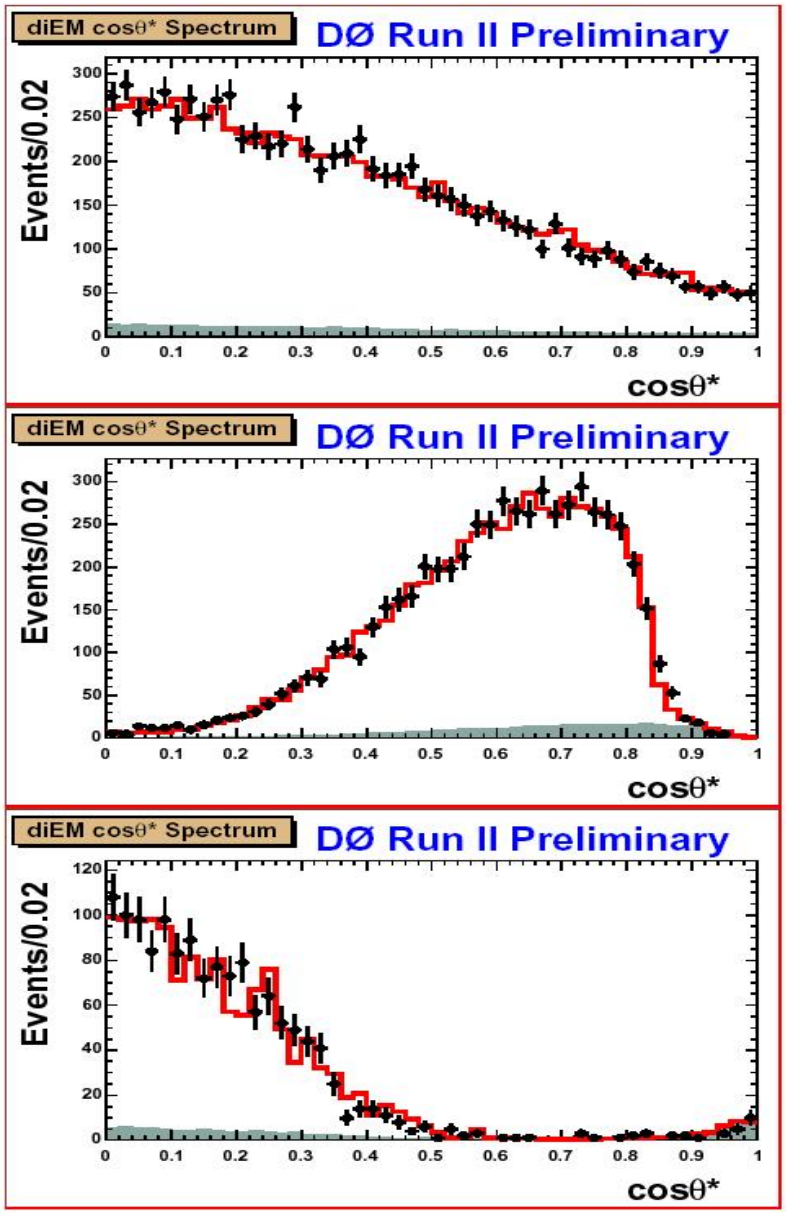
e.g. **Di-EM invariant mass at the Tevatron**



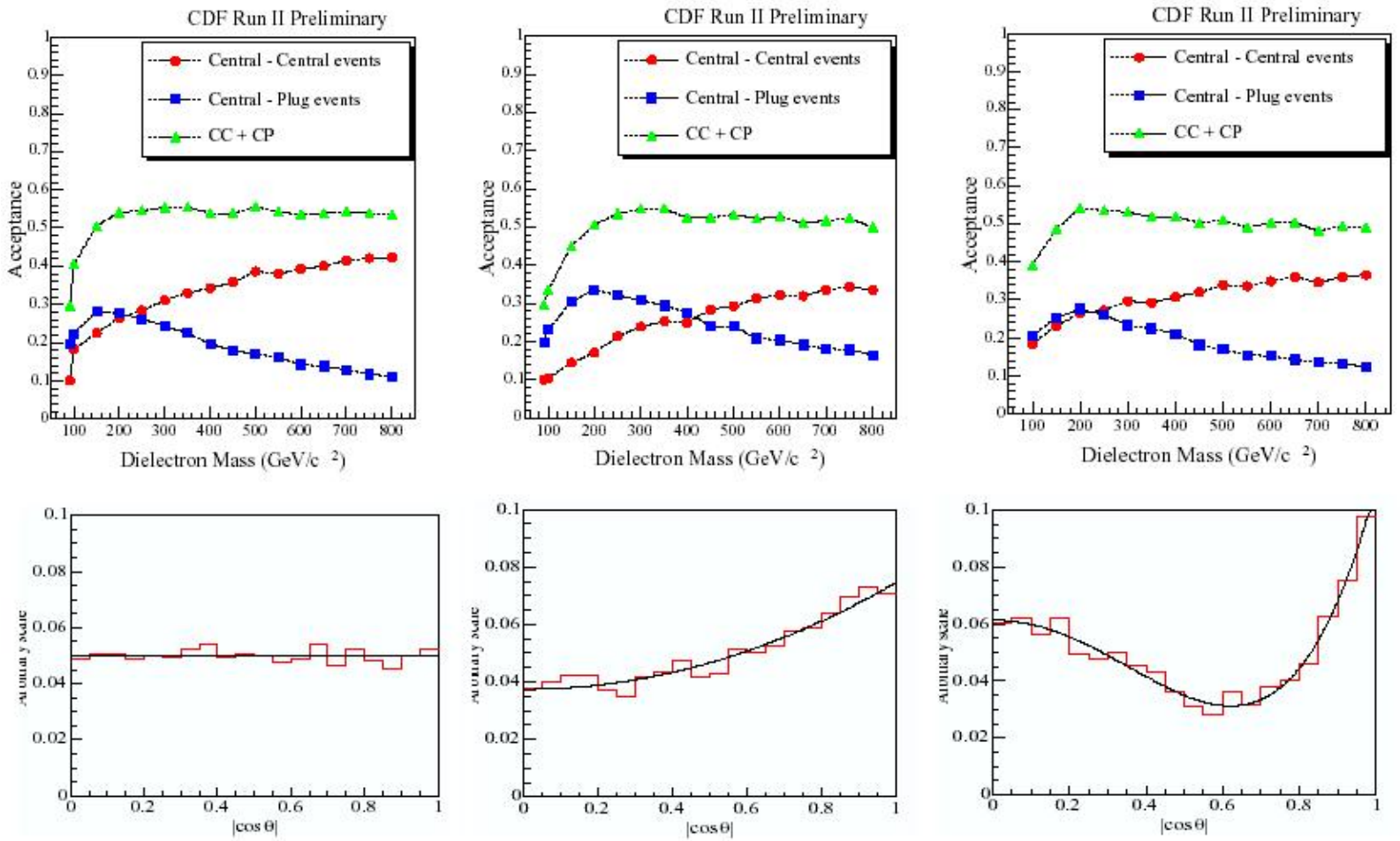
D0 di-EM search for TeV^{-1} extra dimensions (KK Z and γ virtual effects) $\longrightarrow M_C > 1.12$ TeV.
The sensitivity at the Tevatron for 2fb^{-1} using dileptons and both experiments is 2.3 TeV and for LHC(14TeV, 100 fb^{-1} 1-3% systematics) 13.5-15.5 TeV. (95% C.L., Cheung SUSY 2004)

e.g. **Di-electron, Di-Muon** $|cos\theta|$




diEM cosθ* Spectrum
DØ Run II Preliminary
Events/0.02
cosθ*
diEM cosθ* Spectrum
DØ Run II Preliminary
Events/0.02
cosθ*
diEM cosθ* Spectrum
DØ Run II Preliminary
Events/0.02
cosθ*

e.g. **acceptance as a function of spin**



no BSM high mass same flavor dilepton pairs

- large extra dimensions $\sqrt{}$
- Randall-Sundrum gravitons
- so-called "sequential" Z'
- other Z' models (Z'_ψ,Z'_χ,Z'_η,Z'_I)
- Z_H from a little Higgs model
- technicolor particles ω_T and ρ_T
- R-parity violating sneutrinos

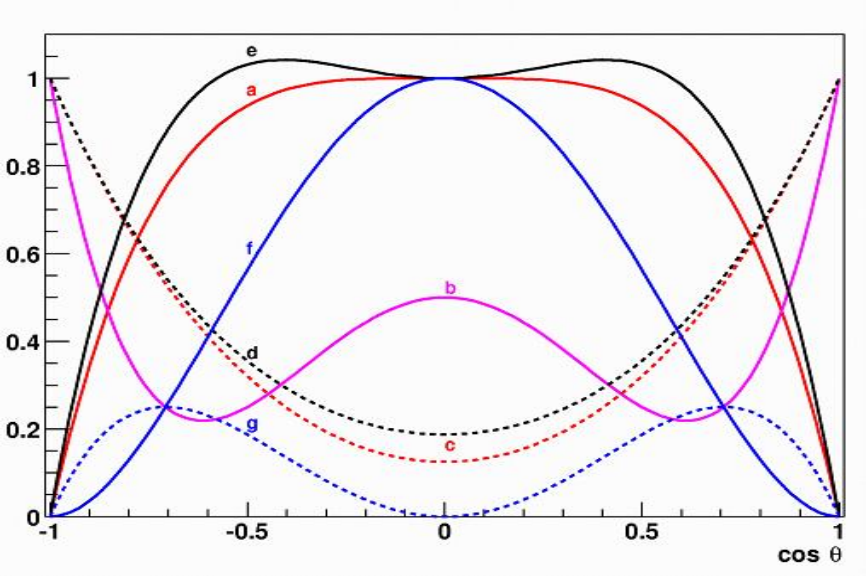
Example of Z′ reach

- 20 pb^{-1} $Z' > 505$ GeV/c^2
- 90 pb^{-1} $Z' > 640$ GeV/c^2
- 200 pb^{-1} $Z' > 750$ (D0 $>$780) GeV/c^{2*}

* CDF (750) fits $M_{\ell\ell}$, D0 (780) uses mass window cut and counting

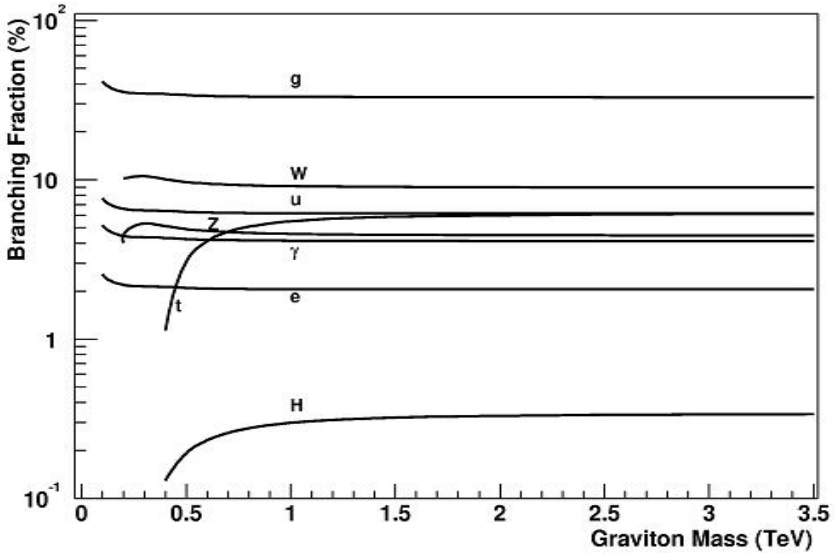
- N.B. factor of 10 in luminosity $\rightarrow$ factor of 1.5 in mass reach.
- CMS reach this afternoon in μ-pairs at the parallel (V. Valuev)

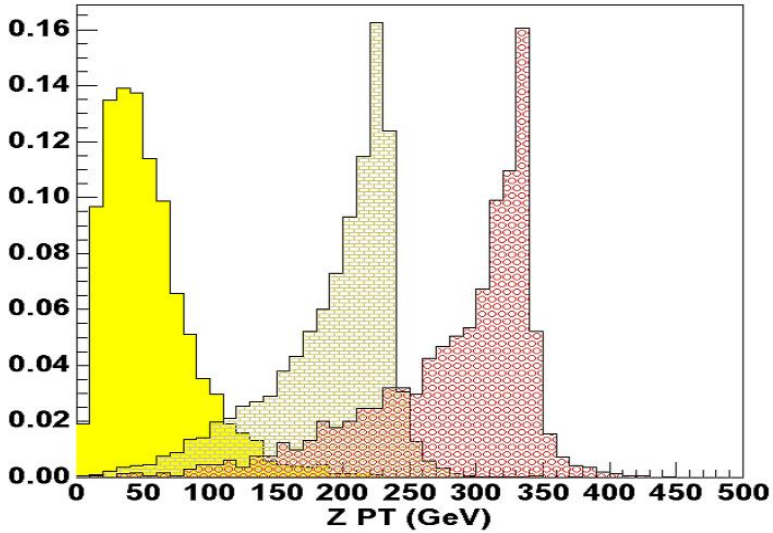
example RS final states



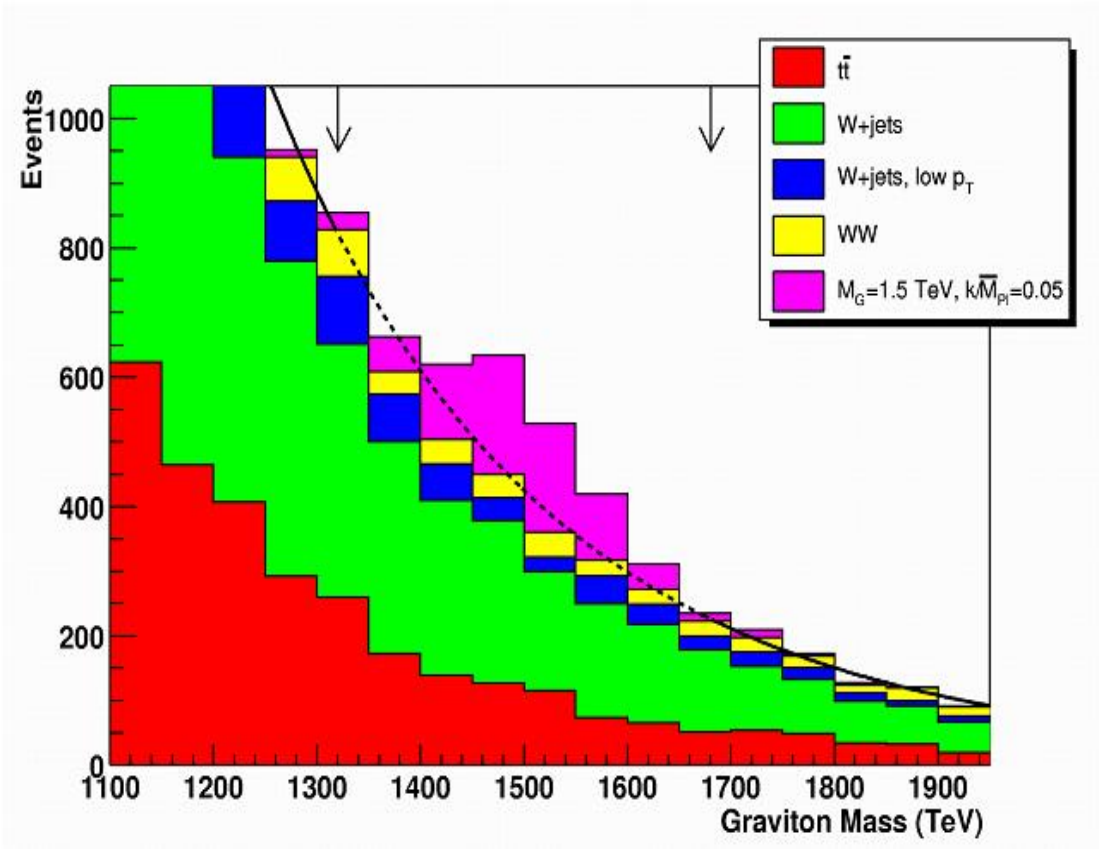
- (a) $gg \to G \to ff$ • (b) $qq \to G \to ff$
- (c) $gg \to G \to gg, \gamma\gamma$ • (d) $gg \to G \to WW, ZZ$
- (a) $qq \to G \to gg, \gamma\gamma$ • (e) $qq \to G \to WW, ZZ$
- (f) $gg \to G \to HH$ • (g) $qq \to G \to HH$

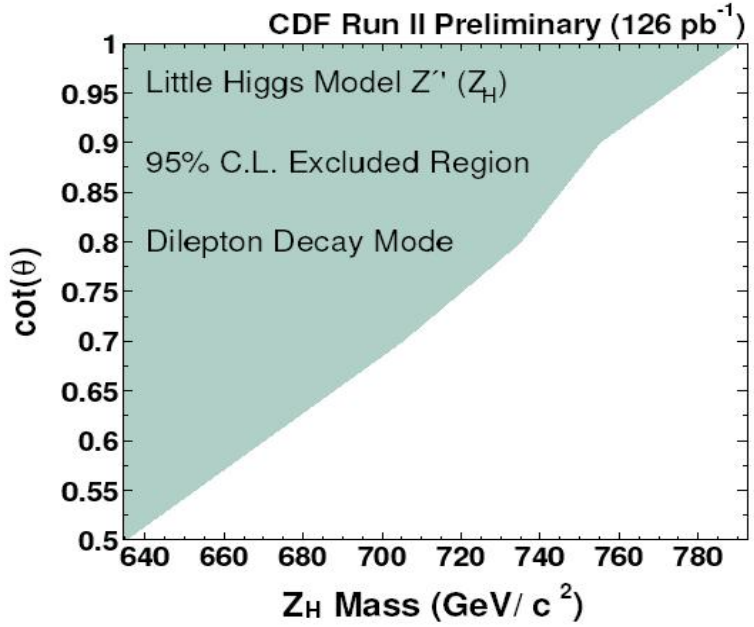
rates - backgrounds- efficiencies

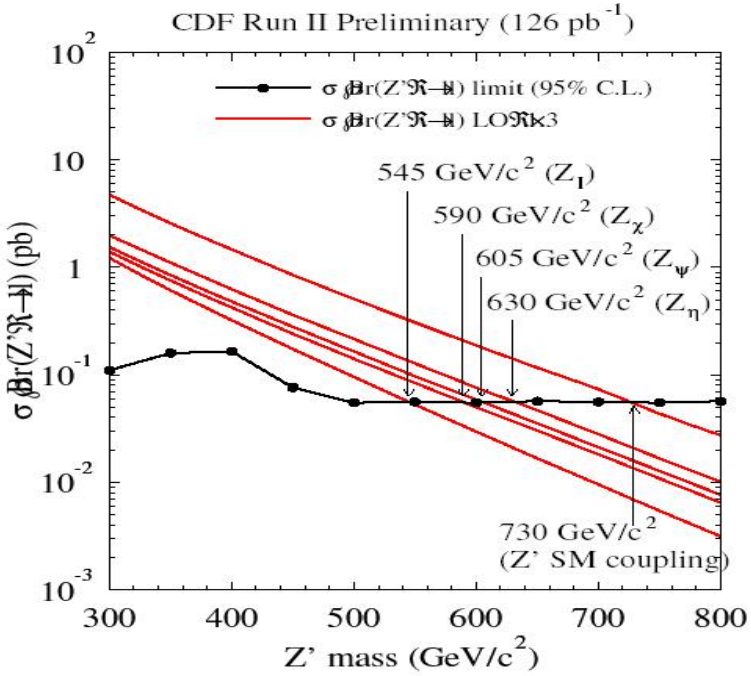


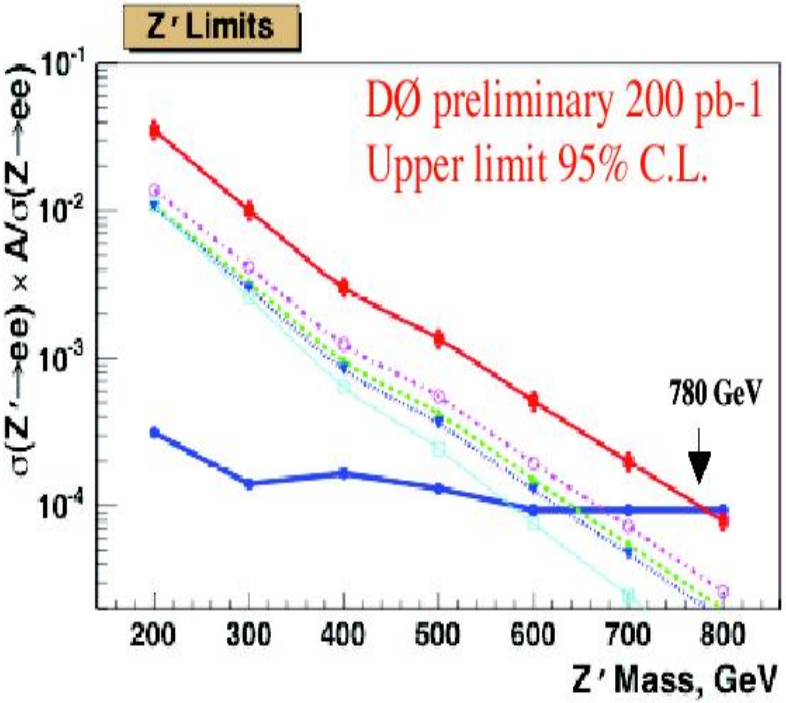


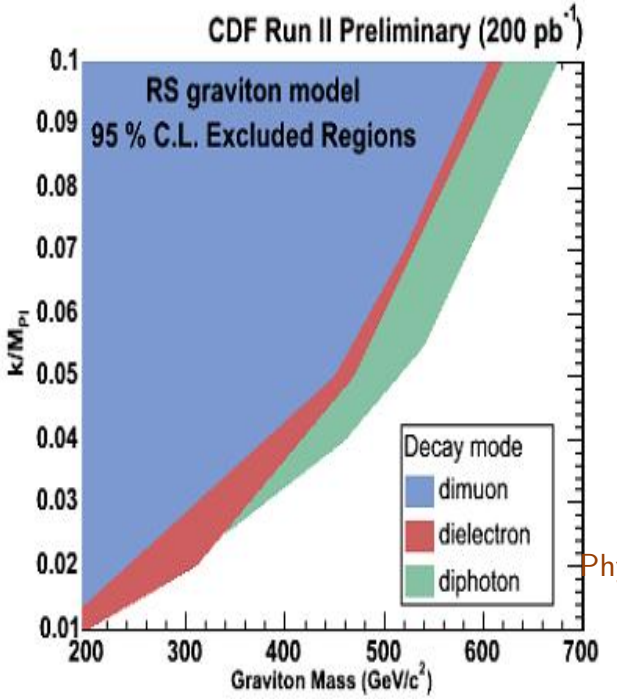
$G \to WW \to \ell\nu +$ jets reconstruction

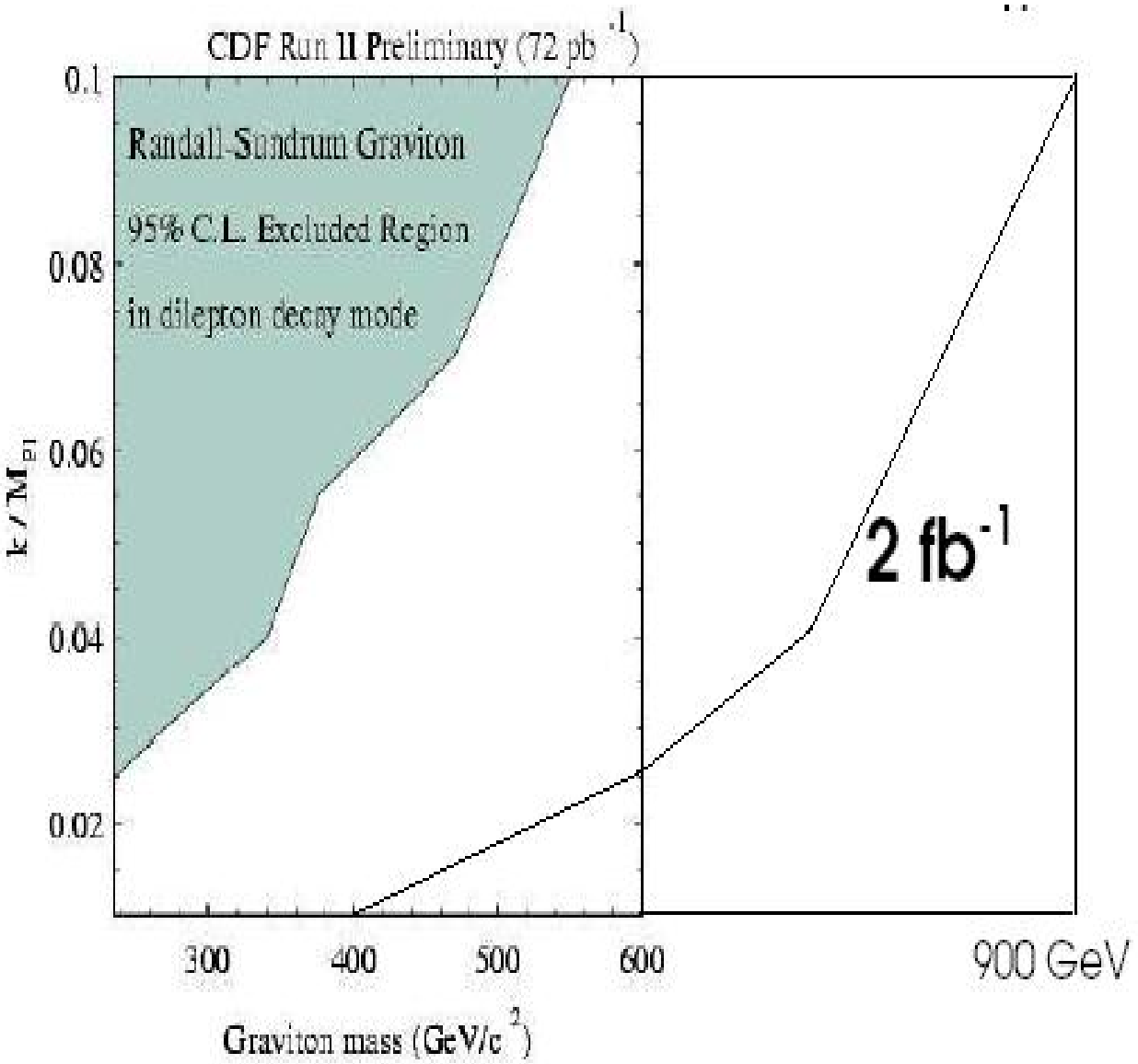


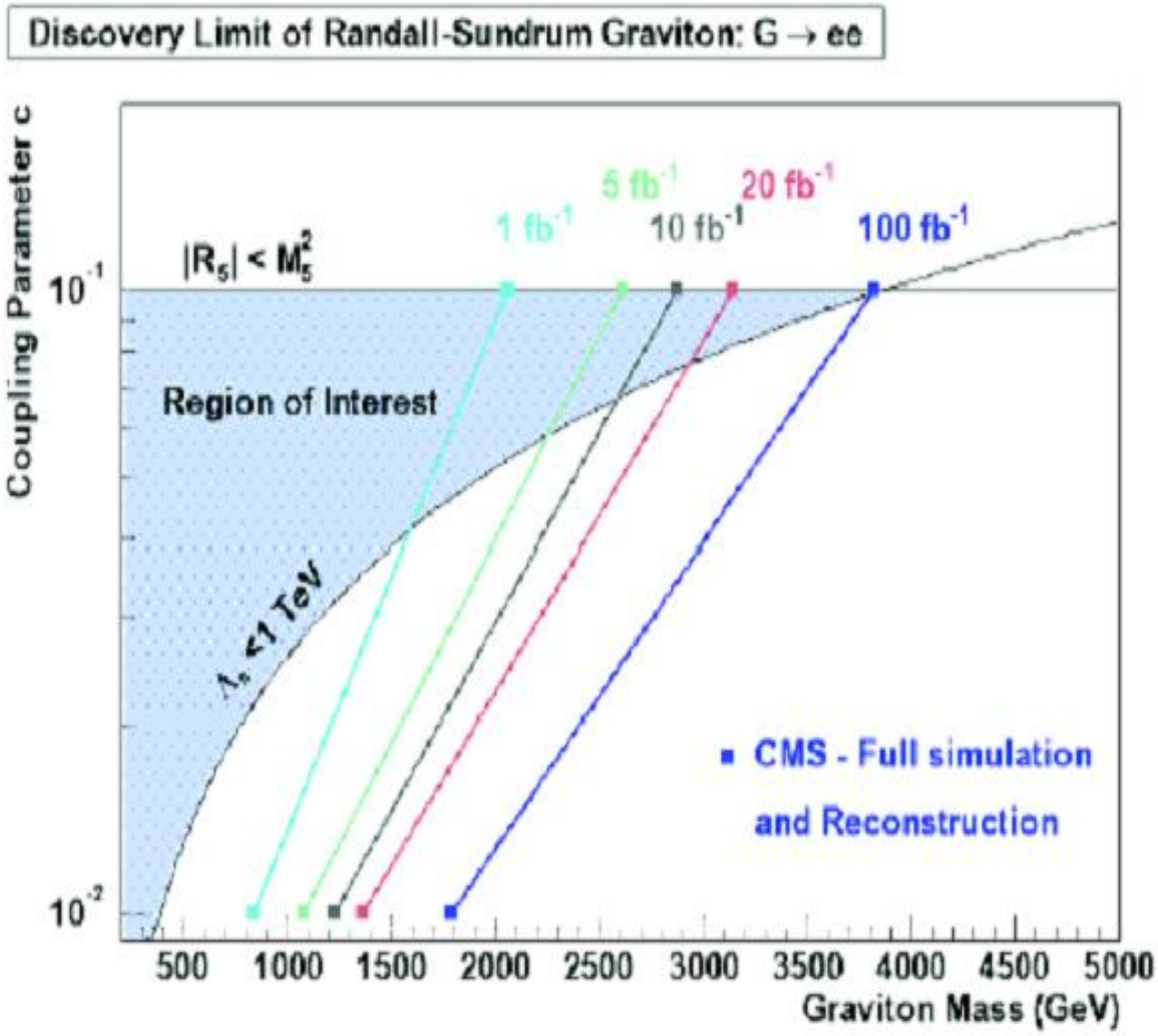

CDF Run II Preliminary (126 pb-1)
Little Higgs Model Z'' (ZH)
95% C.L. Excluded Region
Dilepton Decay Mode
cot(θ)
ZH Mass (GeV/ c2)


CDF Run II Preliminary (126 pb-1)
545 GeV/c2 (ZI)
590 GeV/c2 (Zχ)
605 GeV/c2 (Zψ)
630 GeV/c2 (Zη)
730 GeV/c2
(Z' SM coupling)
Z' mass (GeV/c2)


Z' Limits
DØ preliminary 200 pb-1
Upper limit 95% C.L.
780 GeV
σ(Z'→ee) × A/σ(Z→ee)
Z' Mass, GeV

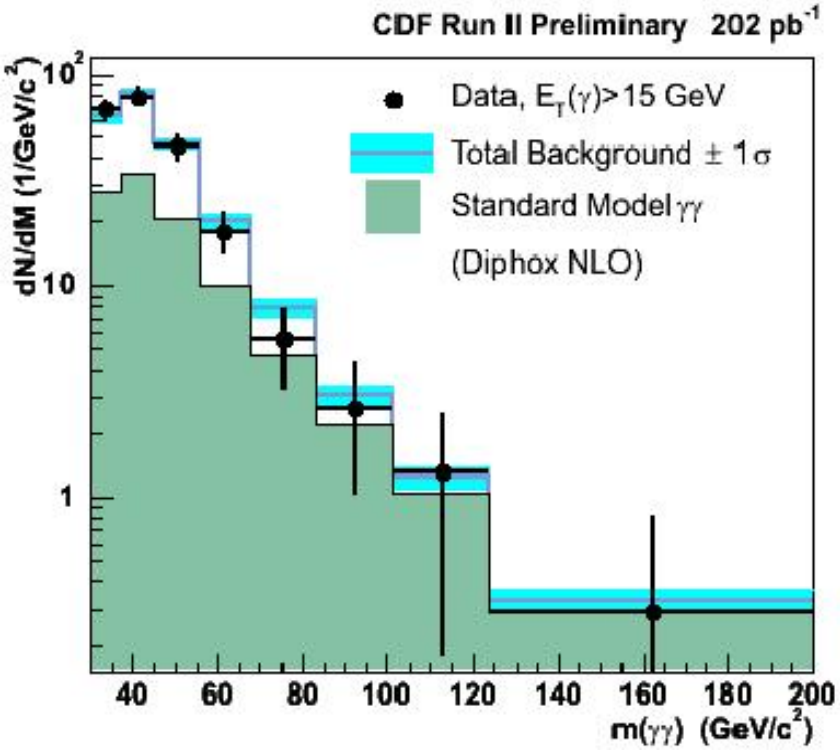

CDF Run II Preliminary (200 pb-1)
RS graviton model
95 % C.L. Excluded Regions
Decay mode
dimuon
dielectron
diphoton
k/MPl
Graviton Mass (GeV/c2)

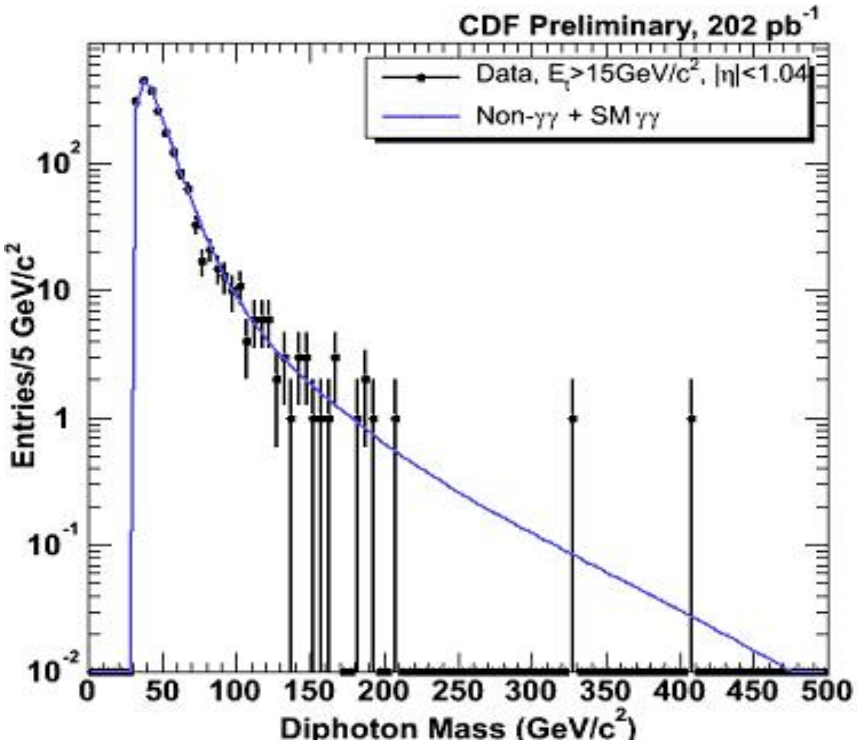

CDF Run II Preliminary (72 pb-1)
Randall-Sundrum Graviton
95% C.L. Excluded Region
in dilepton decay mode
2 fb-1
900 GeV
k / MPl
0.1
0.08
0.06
0.04
0.02
300
400
500
600
Graviton mass (GeV/c2)



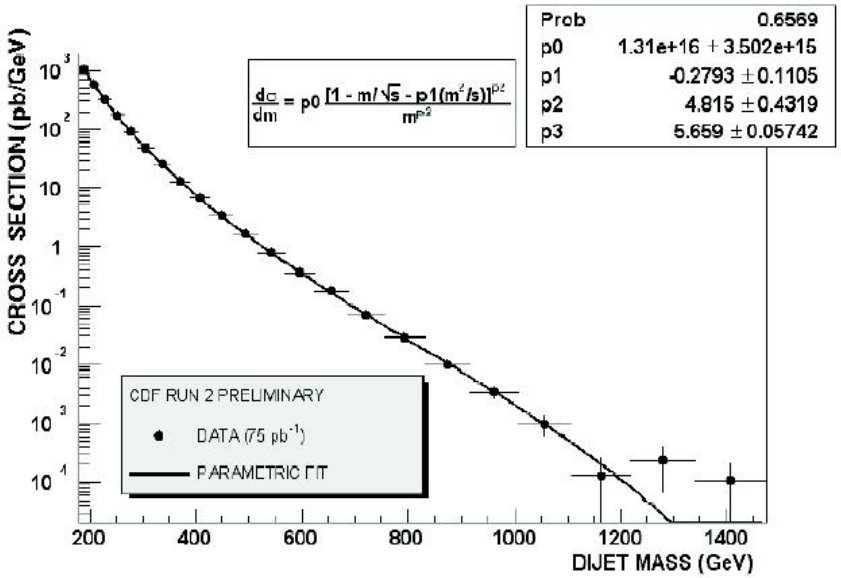
CMS, Collard *et al.* (16:45 BSM parallel today)

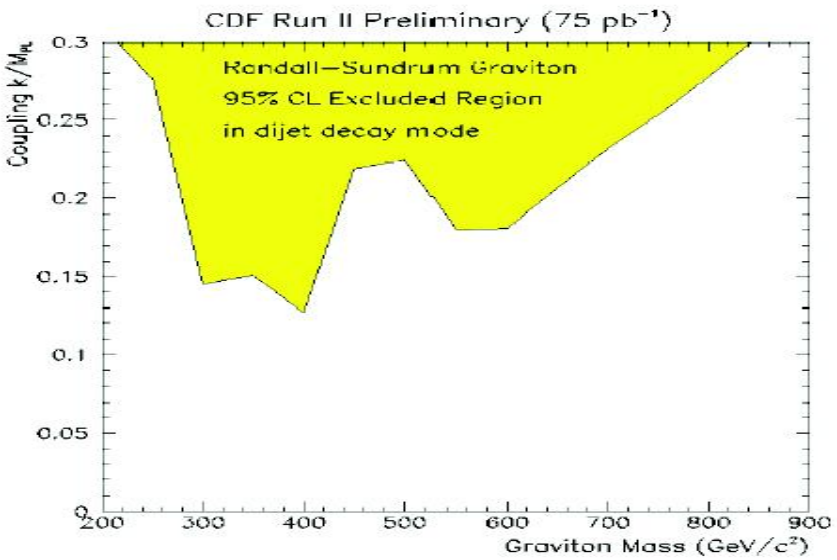
e.g. **Di-gamma**

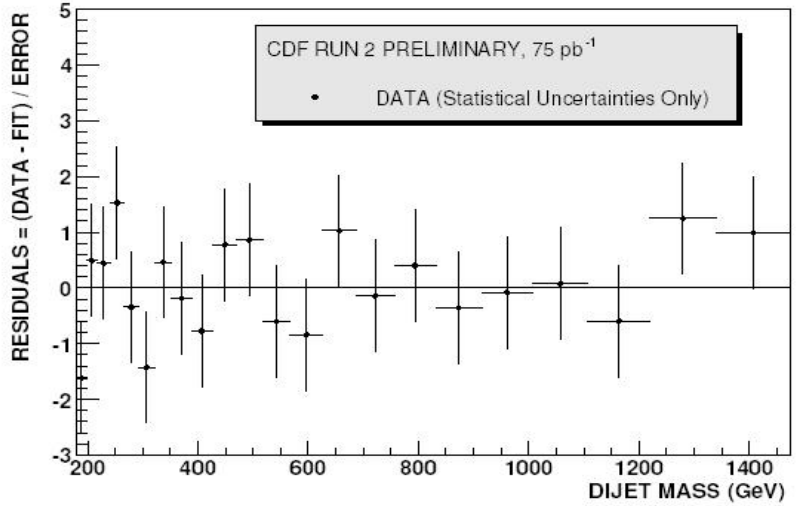


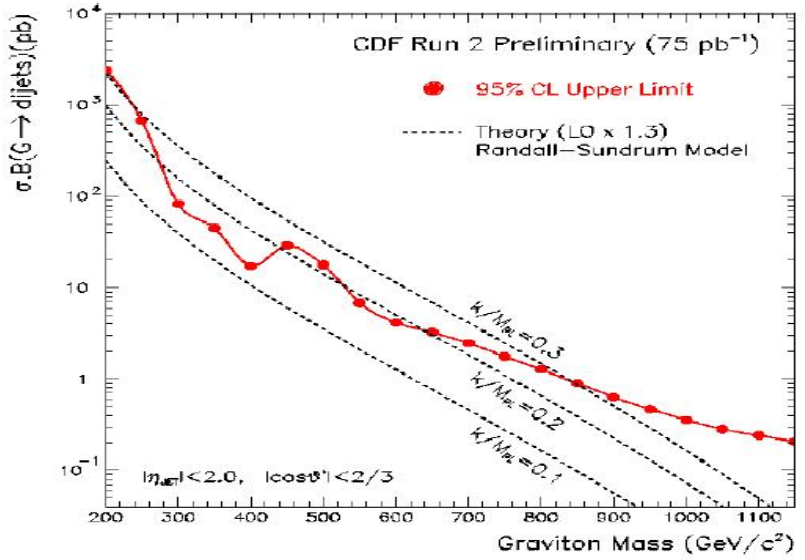


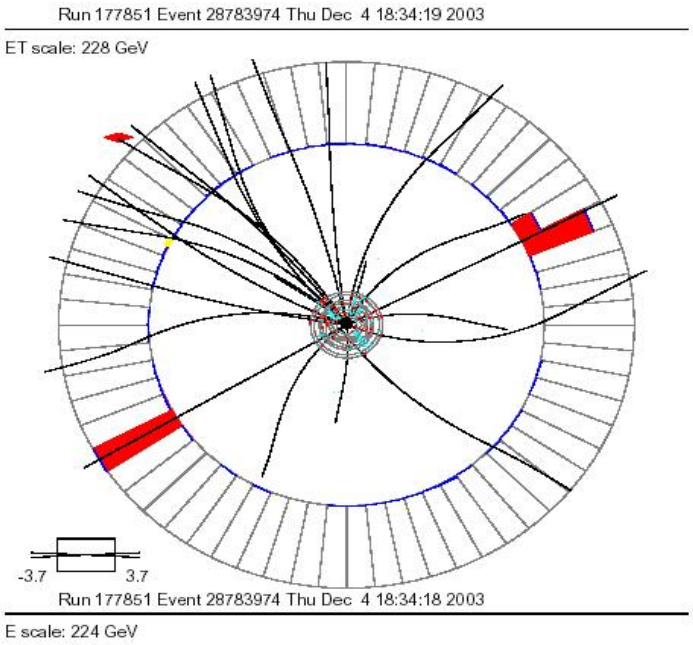
and **Di-jets** $\rightarrow$


Prob 0.6569
p0 1.31e+16 ± 3.502e+15
p1 -0.2793 ± 0.1105
p2 4.815 ± 0.4319
p3 5.659 ± 0.05742
CDF RUN 2 PRELIMINARY
DATA (75 pb⁻¹)
PARAMETRIC FIT
CROSS SECTION (pb/GeV)
DIJET MASS (GeV)


CDF Run II Preliminary (75 pb⁻¹)
Randall–Sundrum Graviton
95% CL Excluded Region
in dijet decay mode
Coupling k/M_Pl
Graviton Mass (GeV/c²)

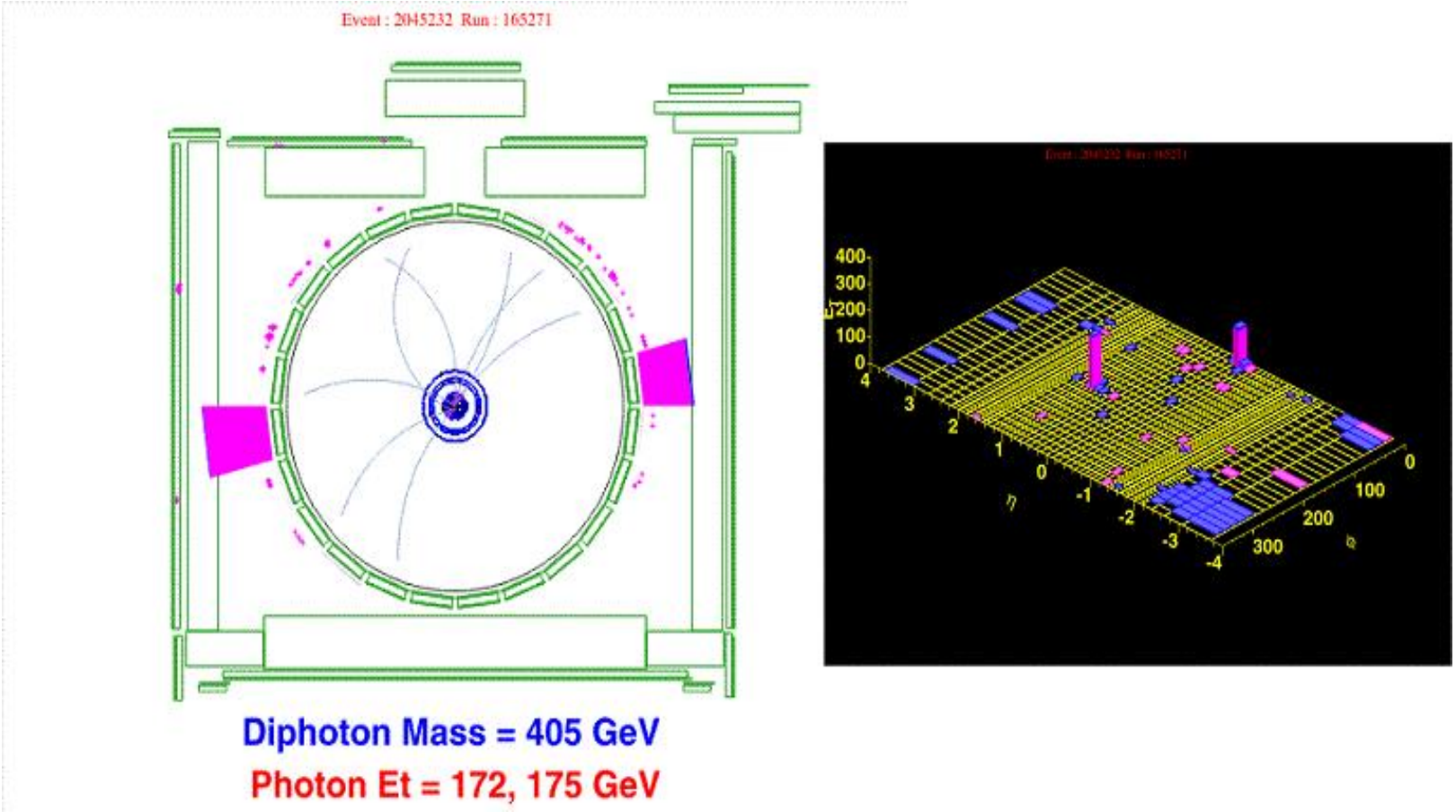

CDF RUN 2 PRELIMINARY, 75 pb⁻¹
DATA (Statistical Uncertainties Only)
RESIDUALS = (DATA - FIT) / ERROR
DIJET MASS (GeV)


CDF Run 2 Preliminary (75 pb⁻¹)
95% CL Upper Limit
Theory (LO x 1.3)
Randall–Sundrum Model
σ.B(G → dijets)(pb)
k/M_Pl=0.3
k/M_Pl=0.2
k/M_Pl=0.1
|η_jet|<2.0, |cosθ*|<2/3
Graviton Mass (GeV/c²)



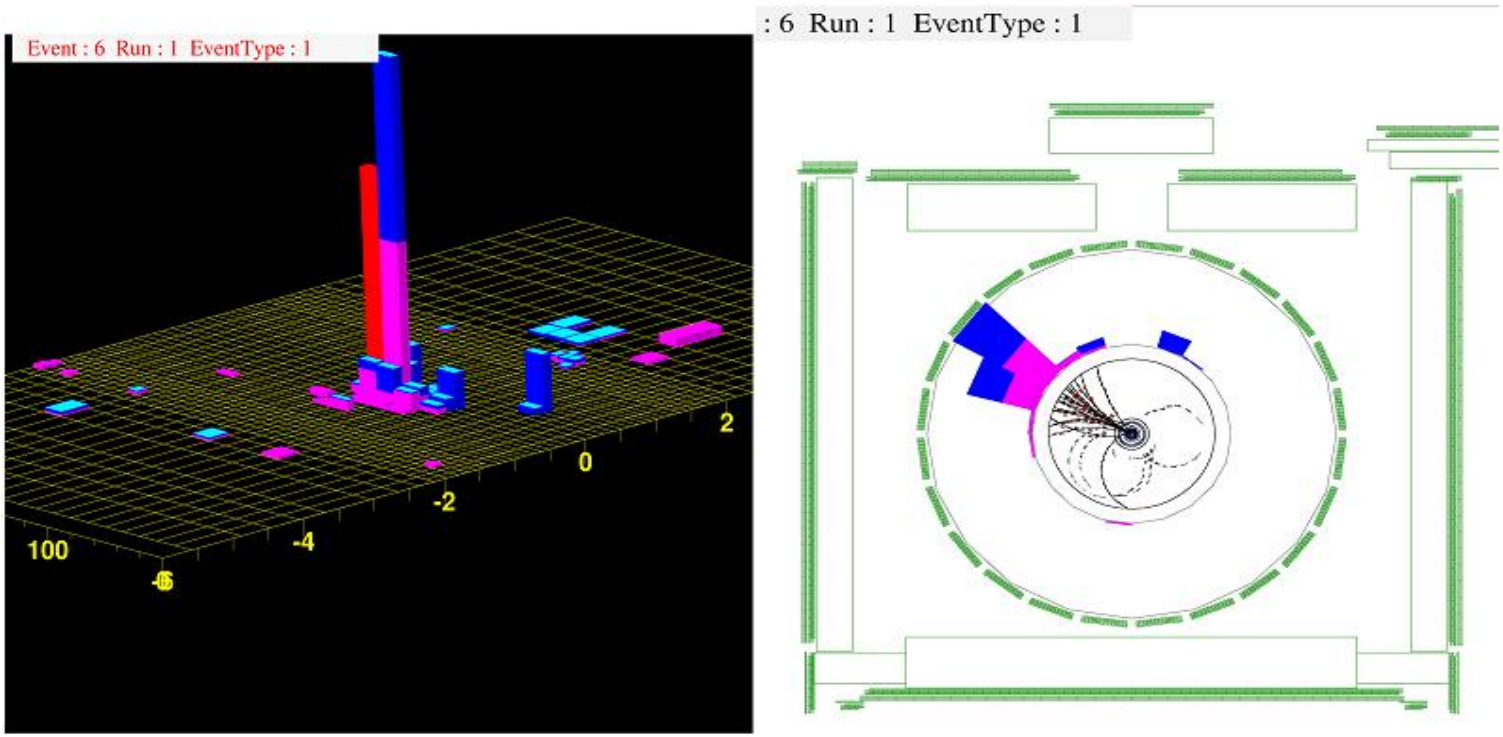
"Callas" highest D0 di-ele event

Highest mass di-photon Event CDF

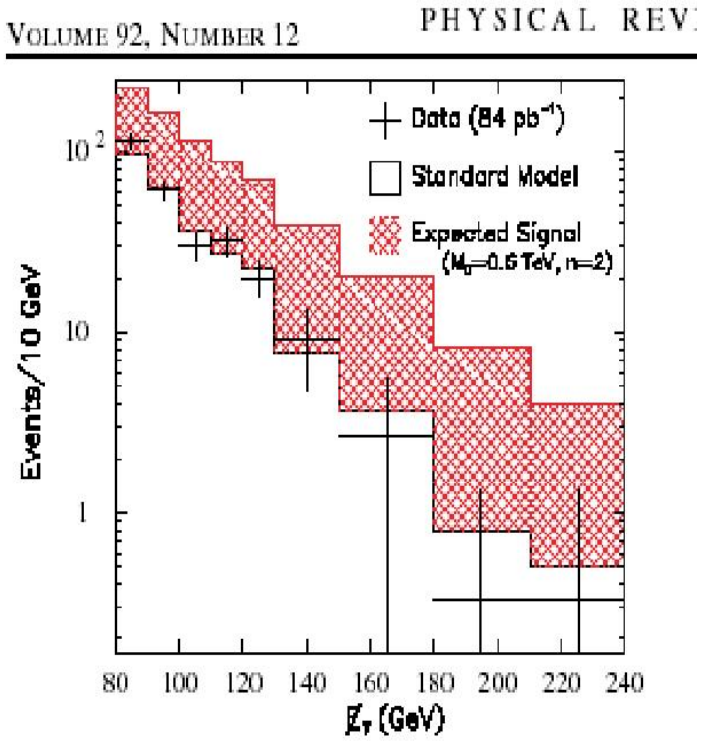


Direct Graviton Emission w/ Monojets

- example graviton emission → spectacular monojet+missing energy signature

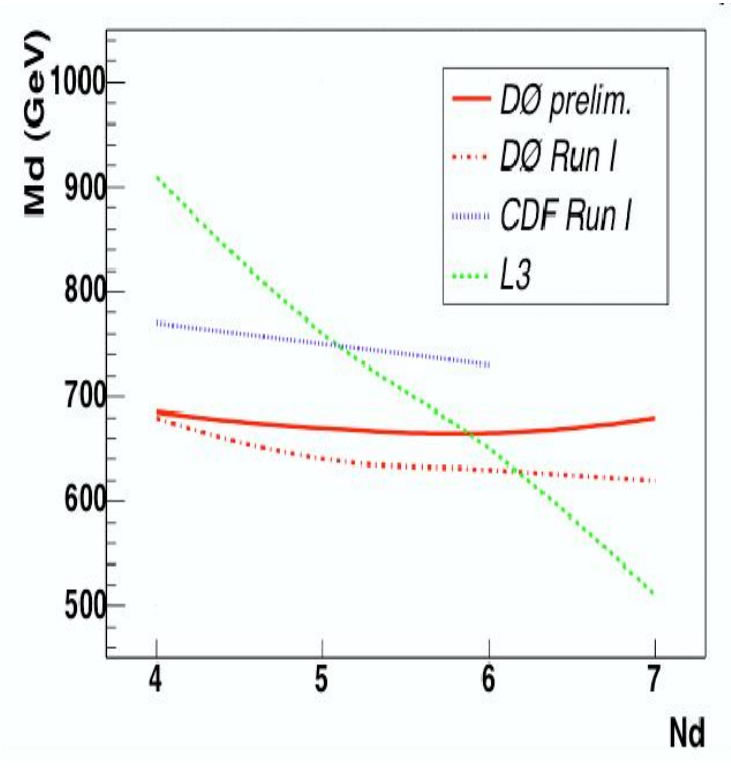


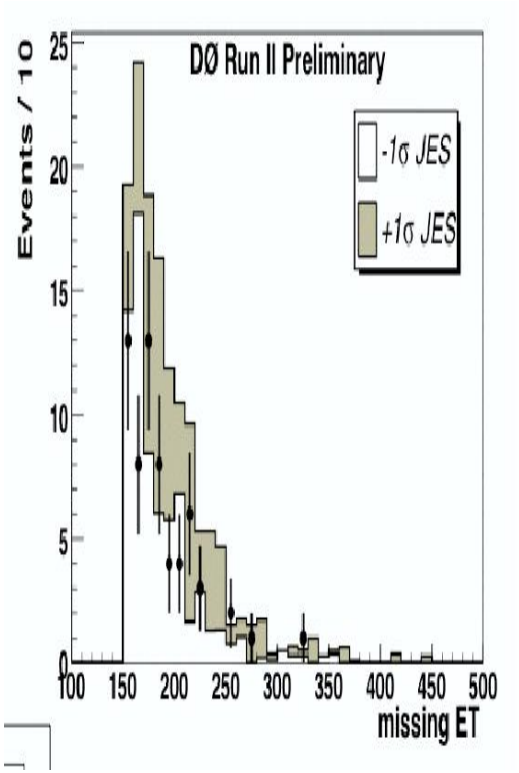
smooth excess over Standard Model

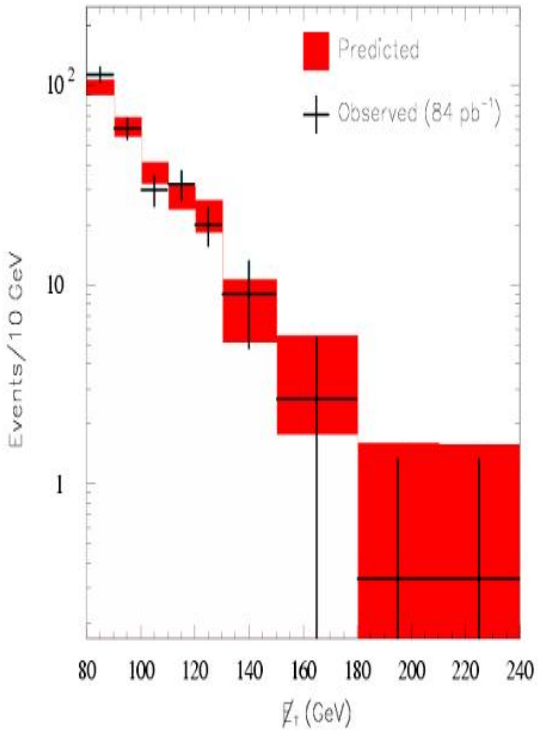


- On shell production of KK gravitons produces smooth missing energy distribution after convolution of closely spaced KK spectrum with PDFs (JL talk).

e.g. **missing energy/monojet type of analyses**

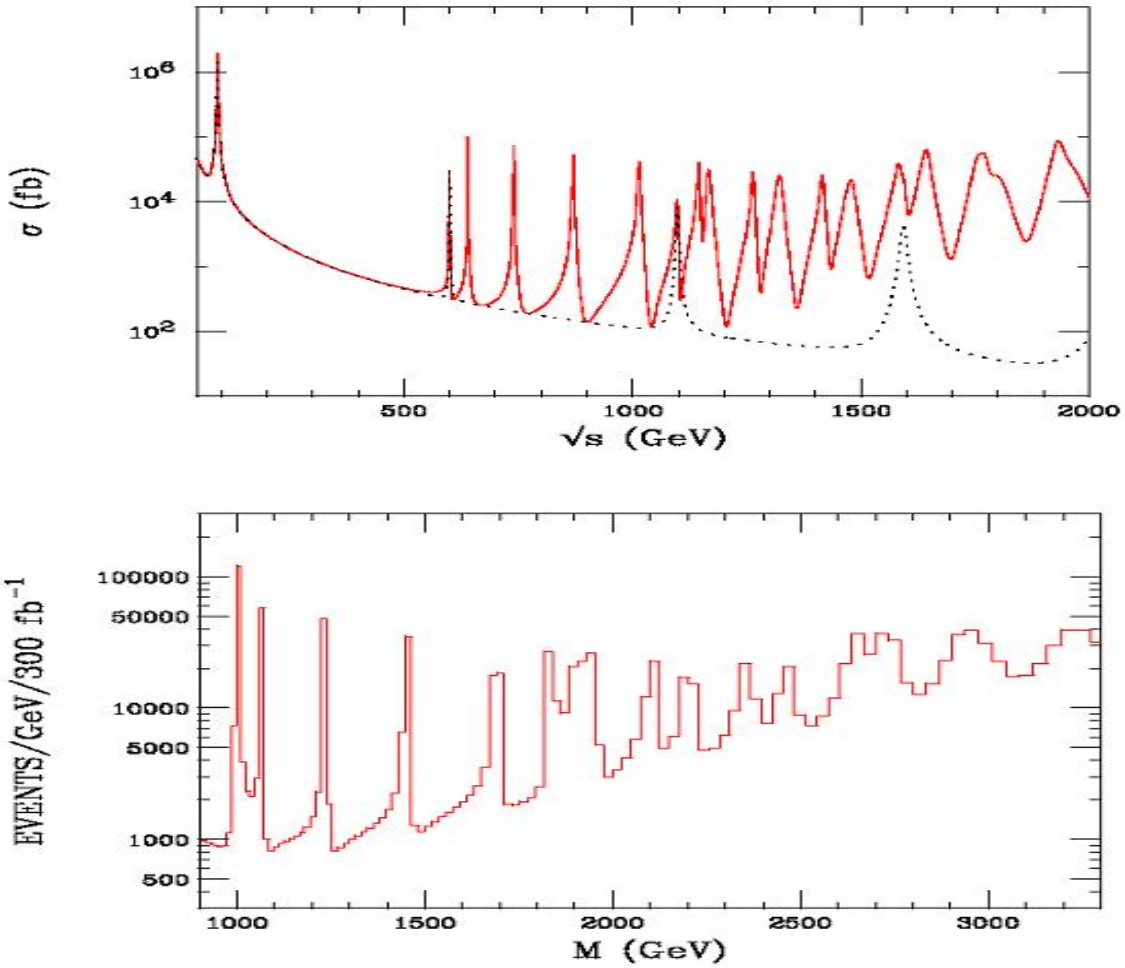




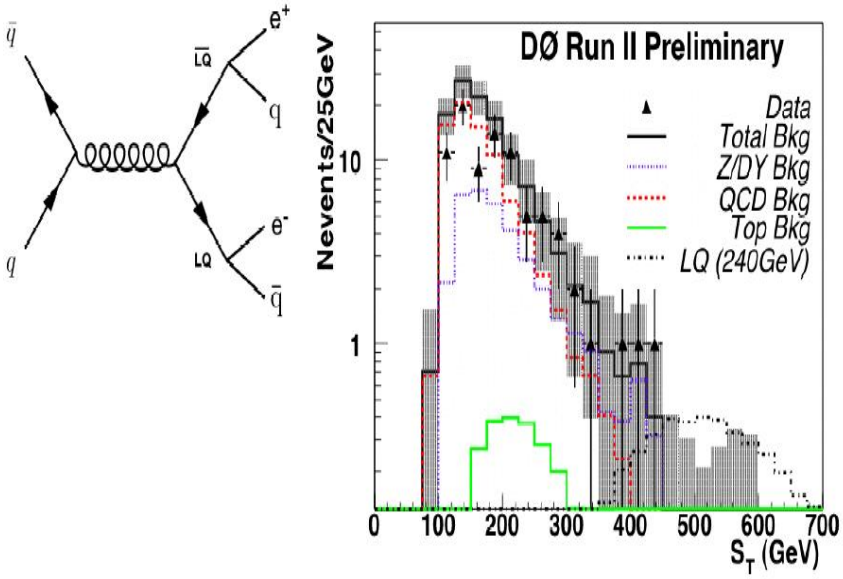


- Run-I Monojet (CDF-D0), Run-II Monojet (D0 85 pb^{-1}), L3

Hybrid Cases e.g One flat compact ED and one RS type ED (Davoudiasl, Hewett, Rizzo). Interesting mapping of the extra space geometry.

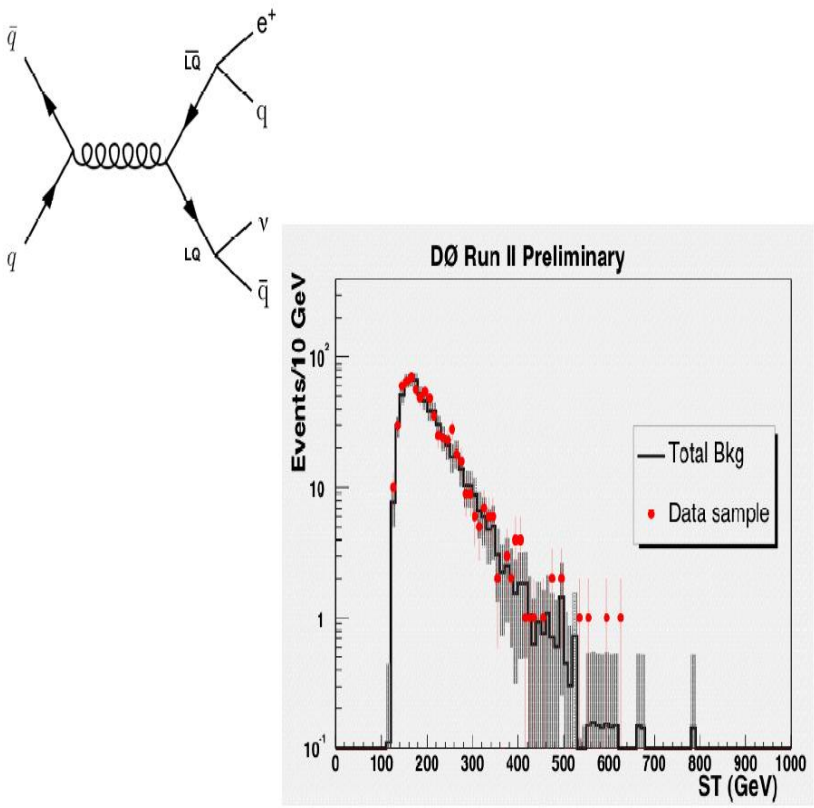


example leptoquark searches

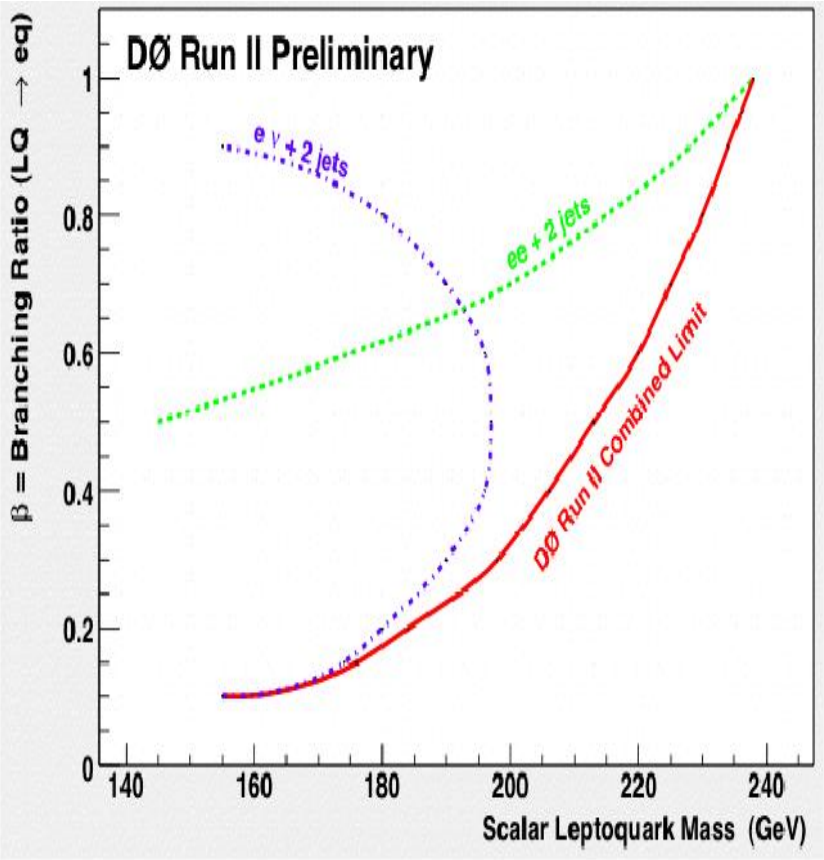


Require Scalar Sum of eejj E_T > 450 GeV

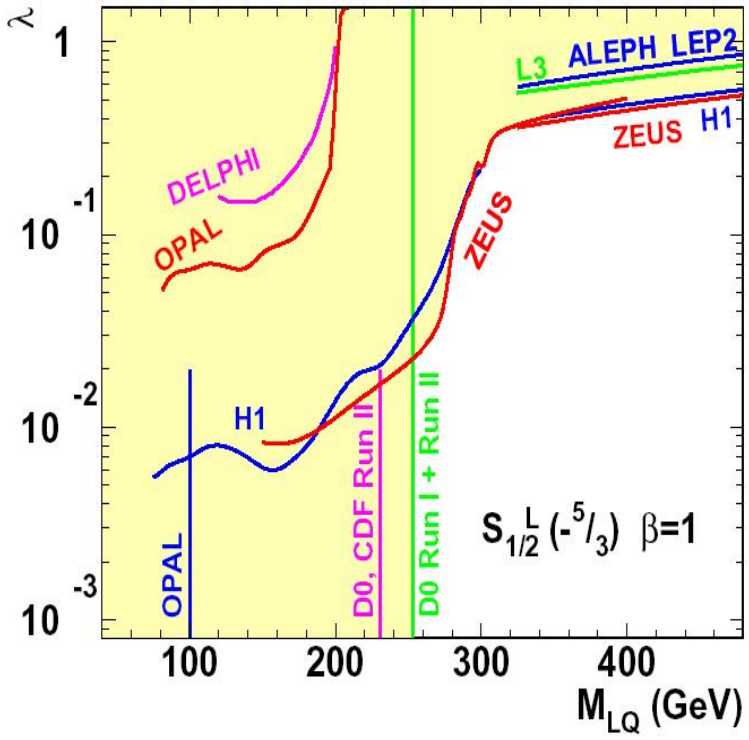
$\sigma \cdot Br < 60$ fb $\Rightarrow M > 238$ GeV/c^2 if Br(LQ→eq)=1

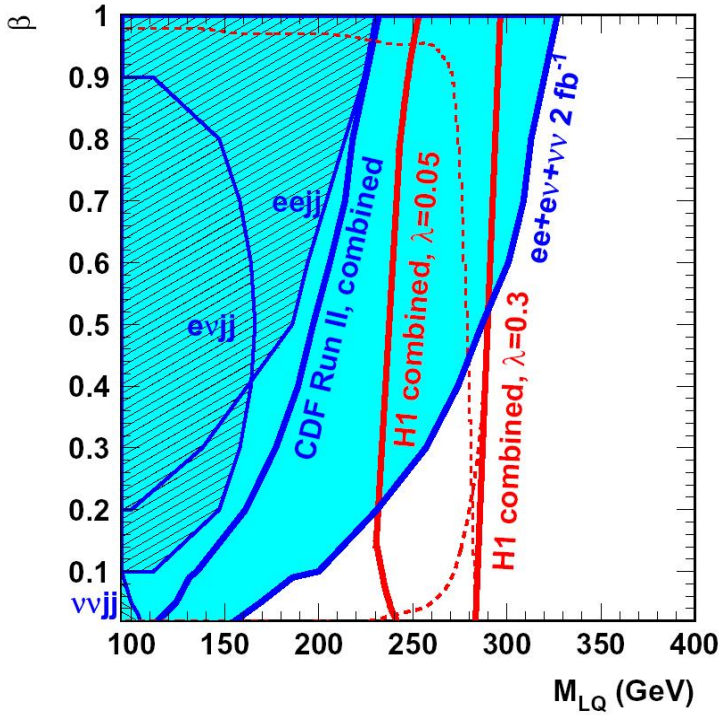


example leptoquark searches



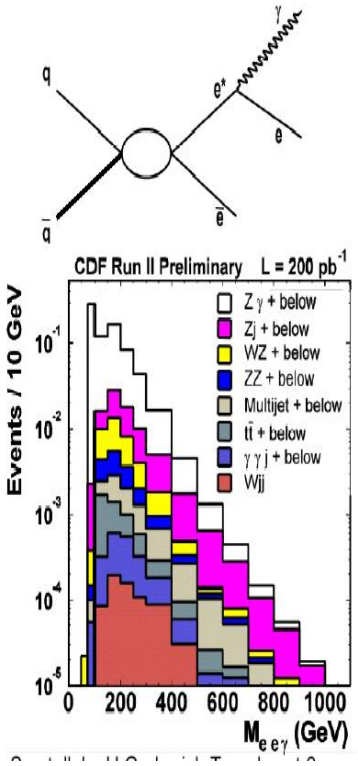
summary leptoquark searches

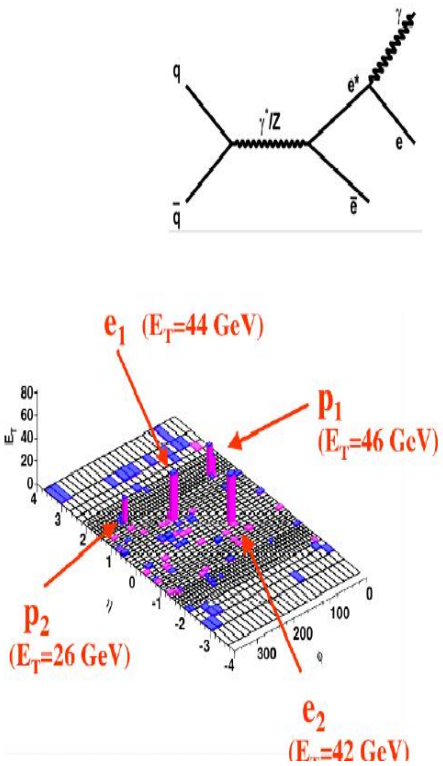


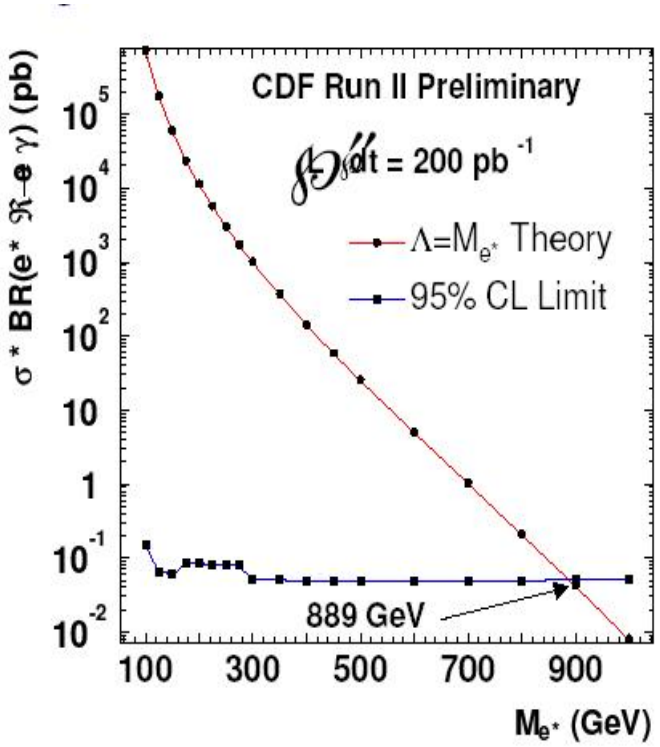


also BSM parallel today Search for Leptoquarks in ATLAS at the LHC (V. Mitsou)

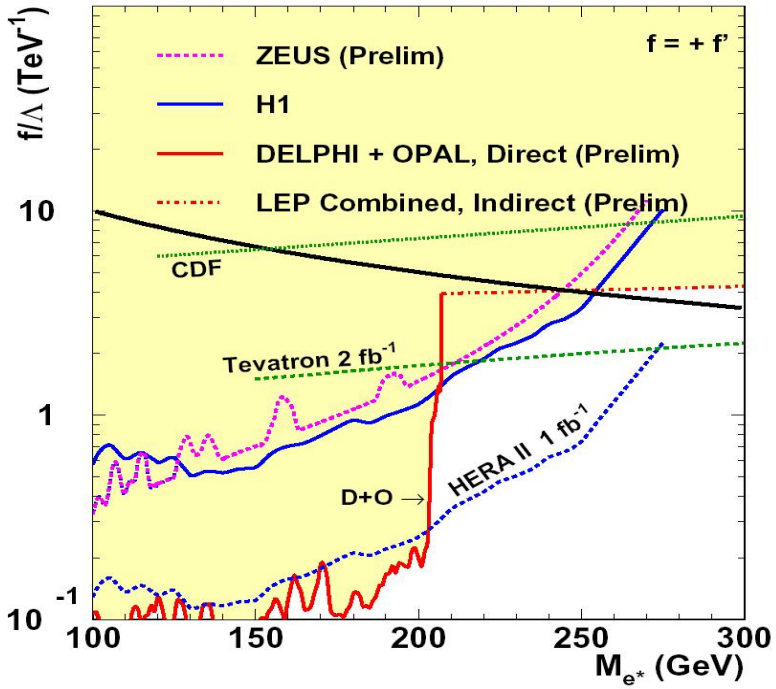
example heavy lepton searches (excited leptons)

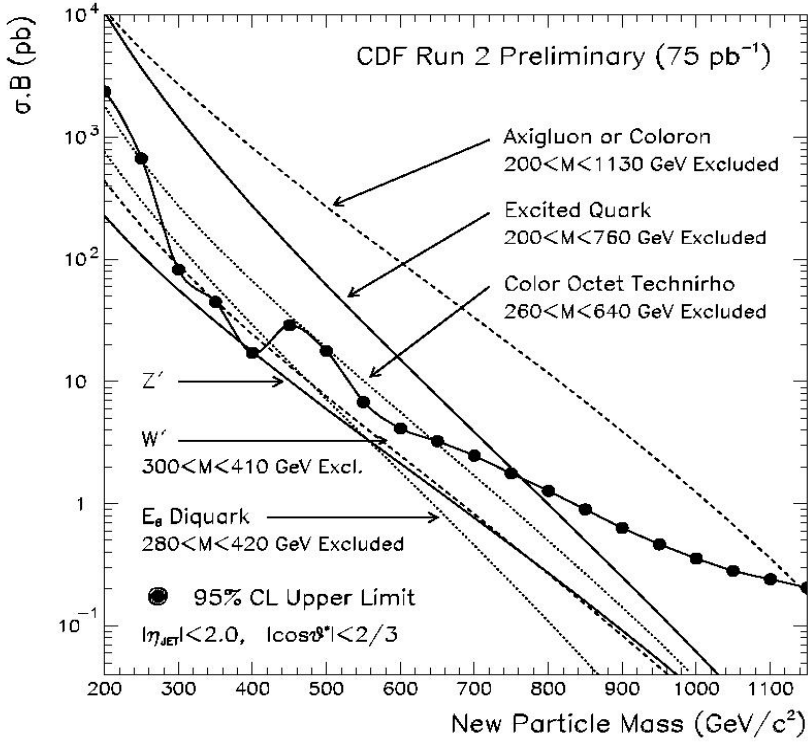






example heavy leptons/quark searches

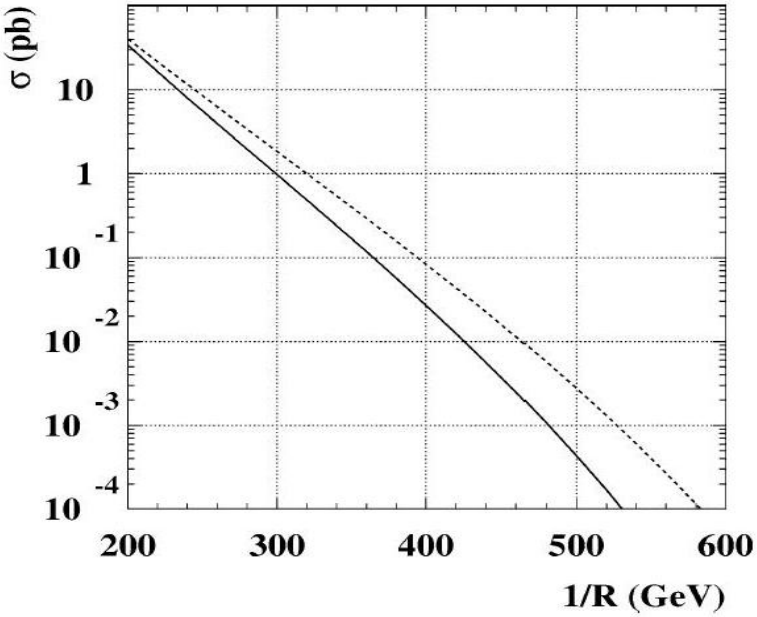


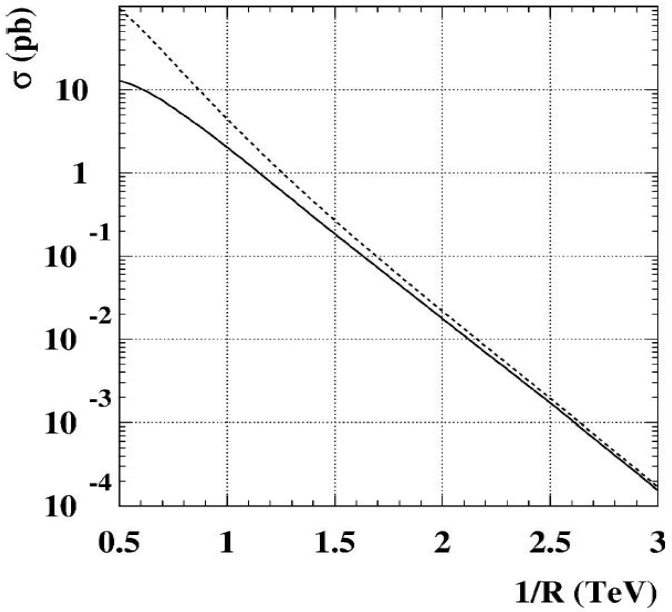


also BSM parallel today Heavy Lepton Physics in ATLAS (C. Alexa)

example universal extra dimensions

one compactified extra dimension/everybody lives in the bulk/(weird) signatures like di-photons + missing energy





Physics Letters B 546 (2002) 253. Macesanu,McMullen and S. Nandi w/ CDF cuts (R. Culbertson)- fat brane N=6 scenario– 2 photons $E_T >$ 20 GeV, $E_T^{miss} >$ 50 GeV. The estimated SM background is 0.6 $\pm$ 0.12 fb. (510-540) reach with (2-15) fb^{-1}

Other Recent Inspir(ed)ing BSM searches

- Test of non-commutative QED in the process $e^+e^- \to \gamma\gamma$ at LEP (OPAL, hep-ex/0303035)
- Search for Branons at LEP (L3 hep-ex/0407017) (in $Z(\gamma)$+missing energy events)
-
- Search for Black Holes (see parallel session, ATLAS, (F. Brochu))

example LHC list of "Very Exotic" Searches (ATLAS's)

- Jets and Missing ET :
  - L. Vacavant and I. Hinchliffe: Signals of Models with Large Extra Dimensions in ATLAS
  - P-H Beauchemin, G. Azuelos and C. Burgess Graviscalars in ATLAS
- Narrow Graviton Resonances
  - B.C. Allanach, K. Odagiri, M.A. Parker and B.R. Webber :Narrow Graviton Resonances with the ATLAS Detector at the Large Hadron Collider
- Virtual Graviton Exchange
  - V. Kabachenko, A. Miagkov, A. Zenin: di-photon and di-lepton, $t\bar{t}$ production from virtual graviton exchange graviton exchange on dijet production
- Radion and other scalars
  - G. Azuelos, D. Cavalli, H. Przysiezniak and L. Vacavant: Search for the Randall Sundrum Radion using the ATLAS detector
  - PH Beauchemin, G. Azuelos, C. Burgess: Graviscalar in ATLAS
- Gauge Excitations

  - G. Polesello and G. Azuelos : Gauge excitations in TeV-1 scale extra dimensions
  - M. Petra and G. Polesello : KK excitation of the W boson
  - S. Ferrag and G. Polesello : KK excitations of gluons
- Black Holes
  - A. Parker: Black hole production and Decay
  - A. Sabetfakhri: Search for Black Holes at the LHC
  - T. Yamamura and J. Tanaka: Search for Black Holes
  - J. Grain: Search for Gauss-Bonnet Black Holes
- TransPlanckian Elastic Collisions
  - G. Azuelos: First look at TransPlanckian elastic collisions in ATLAS, Oct. 2002 meeting
- Singlet Neutrino
  - K. Assamagan and A. Deandrea: The hadronic tau decay of a heavy charged Higgs in models with singlet neutrino in large extra dimensions
- Dark energy
  - K. Baker Dark Energy Signals Cosmological Constant Signatures in ATLAS
- Universal Extra Dimensions
  - PH Beauchemin: Dijets in a scenario of Universal Extra Dimensions

BSM parallel this afternoon

- Higgless electroweak symmetry breaking (C. Csaki)
- Baryon number violation (S. Bass)
- Higgs production at the LHC in the ADD model (D. Dominici)
- Search for Randall-Sundrum Gravitons in CMS (C. Collard)
- ATLAS: Extra dimensions (F. Brochu)
- Detection of Z' gauge bosons in the di-muon decay mode in CMS (V. Valuev)
- Search for Leptoquarks in ATLAS at the LHC (V. Mitsou)
- Heavy Lepton Physics in ATLAS (C. Alexa)

JDJ

Magnetic Monopoles

"At the present time [1975] there is no experimental evidence for the existence of magnetic charges or monopoles, but chiefly because of an early, brilliant theoretical argument by Dirac, **the search for monopoles is renewed whenever a new energy region is opened up in high energy physics or a new source of matter, such as rocks from the moon, becomes available.**"

J. D. Jackson, Classical Electrodynamics, 2nd edition (John Wiley & Sons, New York, 1975).

Monopole Production Cross Section

X-SECT (cm^2)	MASS (GeV)	ENERGY(TeV)	BEAMS
	KALBFLEISCH 04		
$<$ 0.6E-36	$>$265	1.8	$p\bar{p}$
$<$ 0.2E-36	$>$355	1.8	$p\bar{p}$
$<$ 0.07E-36	$>$410	1.8	$p\bar{p}$
$<$ 0.2E-36	$>$375	1.8	$p\bar{p}$
	KALBFLEISCH 00		
$<$ 0.7E-36	$>$295	1.8	$p\bar{p}$
$<$ 7.8E-36	$>$260	1.8	$p\bar{p}$
$<$ 2.3E-36	$>$325	1.8	$p\bar{p}$
$<$ 0.11E-36	$>$420	1.8	$p\bar{p}$

KALBFLEISCH 04 reports searches for stopped magnetic monopoles in Be, Al, and Pb samples obtained from discarded material from the upgrading of D0 and CDF. A large- aperture warm-bore cryogenic detector was used. Results are model dependent. KALBFLEISCH 00 used an induction method to search for stopped monopoles in pieces of the D0 (FNAL) beryllium beam pipe and in extensions to the drift chamber aluminum support cylinder. Results are model dependent.

The Detectors