Probe extra dimension at D0

Presented by
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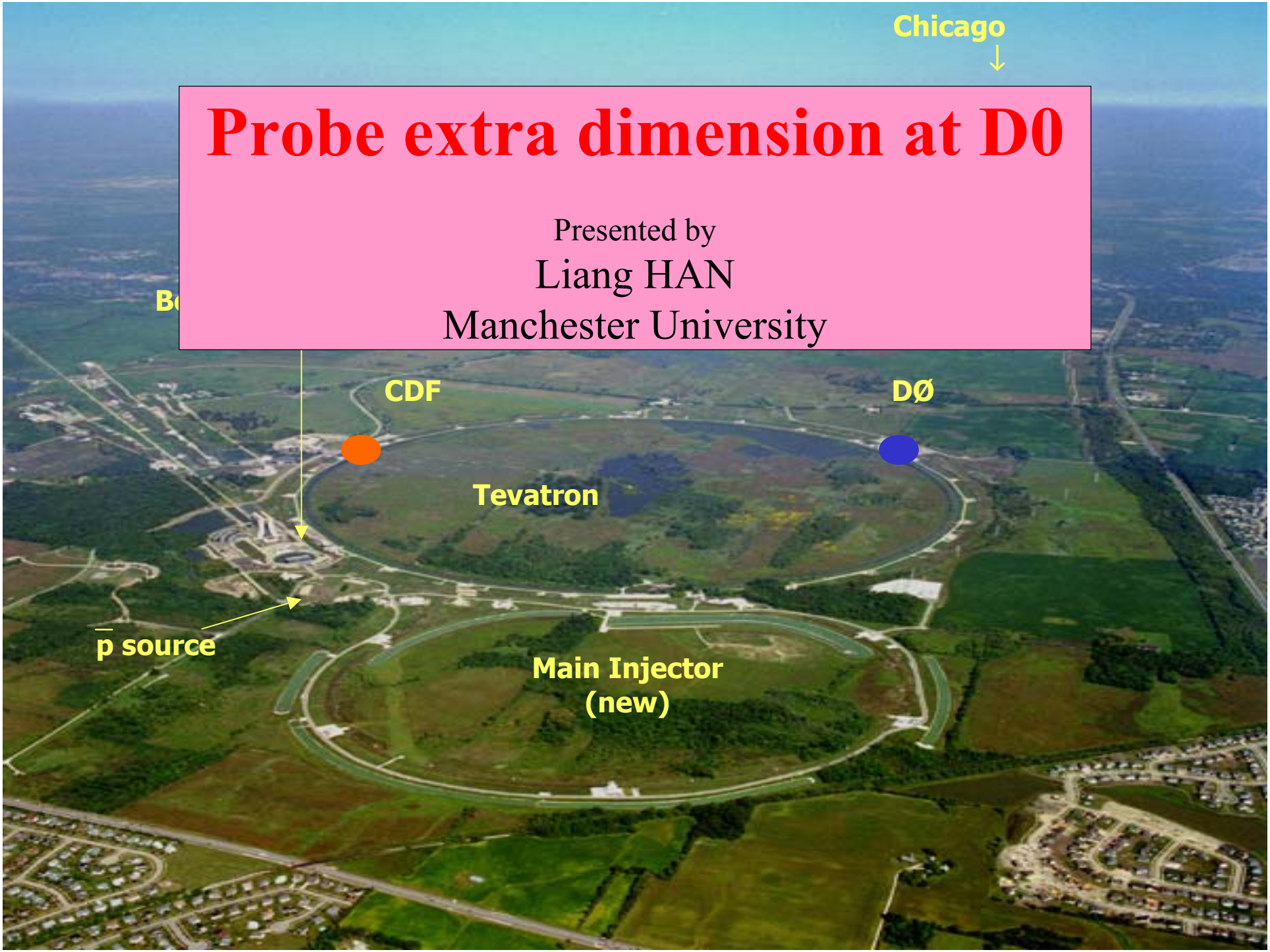
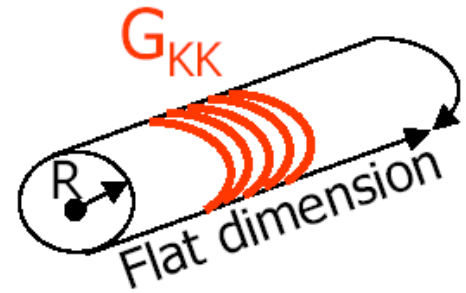


Review of extra-dimension(ED)

3d space a compactified n-torus with radius

(x,y,z) → R radius

$V_n=(2\pi R)^n$ volume



Gravitational potential

$$V(r) = \frac{1}{M_D^{n+2}} \frac{m_1 m_2}{r^{n+1}}$$ for r<<R

$$V(r) = \frac{1}{M_D^{n+2}} \frac{m_1 m_2}{R^n r} \propto \frac{1}{M_{Pl}^2} \frac{m_1 m_2}{r}$$ for r>>R

where

$M_D \sim 1$ TeV the fundamental Planck Scale

$M_{Pl}=1/\mathrm{sqrt}[G_N]\sim 10^{19}$GeV the apparent Planck Scale

How large or small ED?

$$\because M_{Pl}^2 \propto M_D^{n+2} R^n$$

$\therefore$ The radius

$$R \propto \frac{1}{M_D}\left(\frac{M_{Pl}}{M_D}\right)^{2/n} \sim 10^{\frac{32}{n}-16}\, mm,$$ if $M_D \sim 1\,TeV$

- n=1, R ~10^{19} km ! modify Newton gravity at solar scale
- n=1, R ~1 mm ? only testable on high energy collider
- n=3, R ~1 nm ?

…

Graviton

in extra (3+n)D: massless

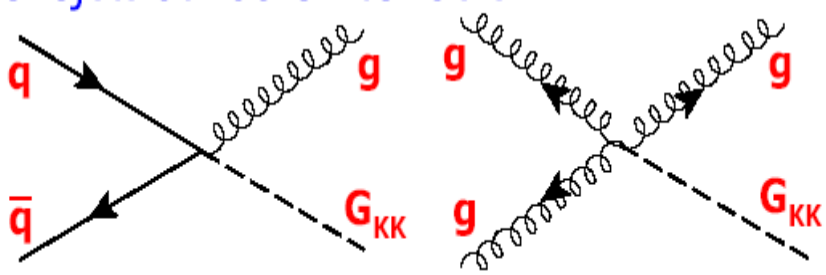
a large number of excitations

in ordinary 3D: massive Kaluza-Klein modes G_{kk}, couple to energy-momentum tensor

How to test?

Real Graviton Emission

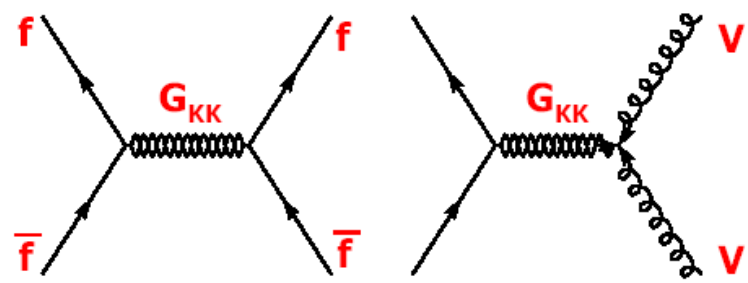
Monojets at hadron colliders



Signal: monojet+missing ET

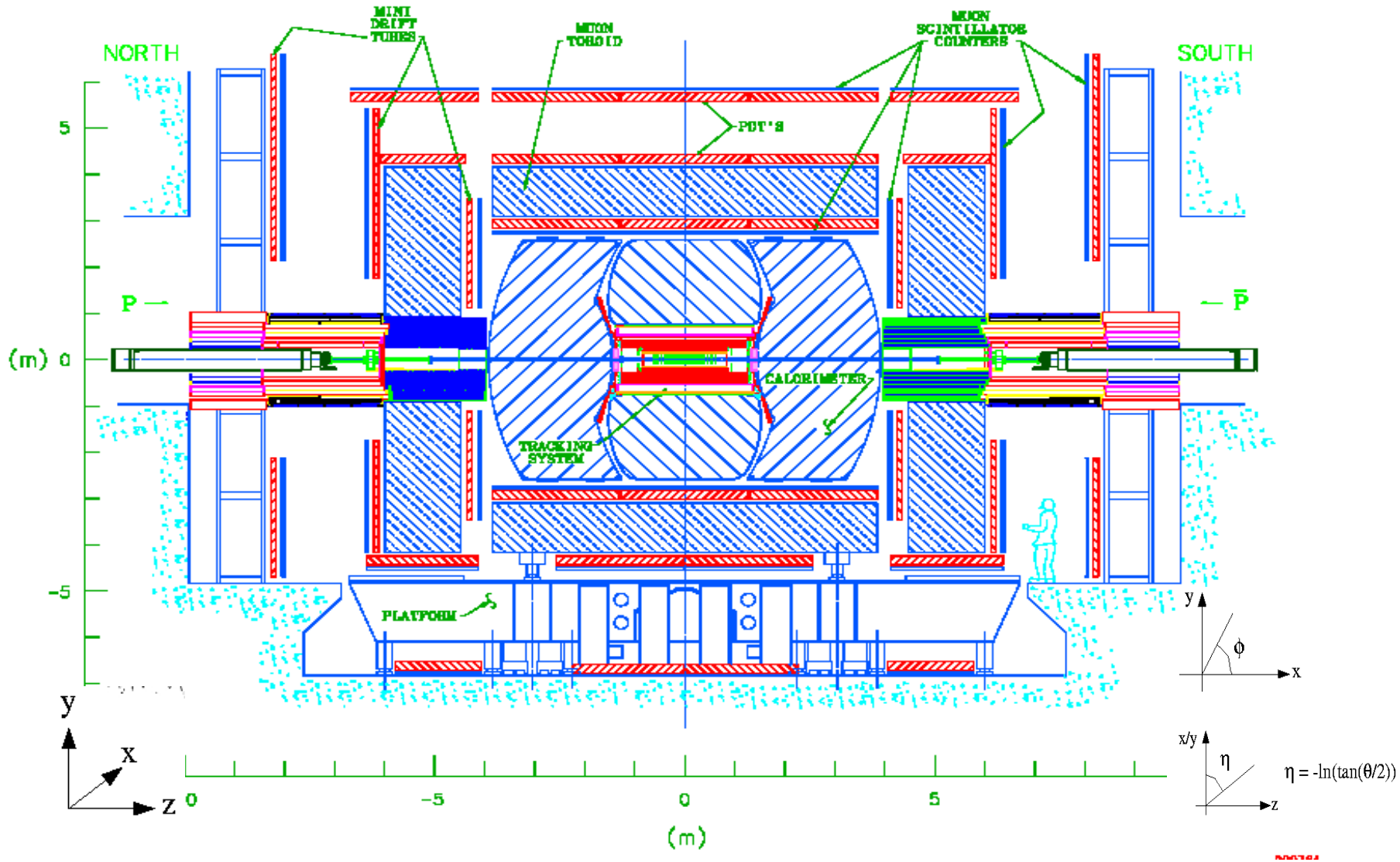
Virtual Graviton Emission

Fermion or VB pairs at hadron or e^+e^- colliders

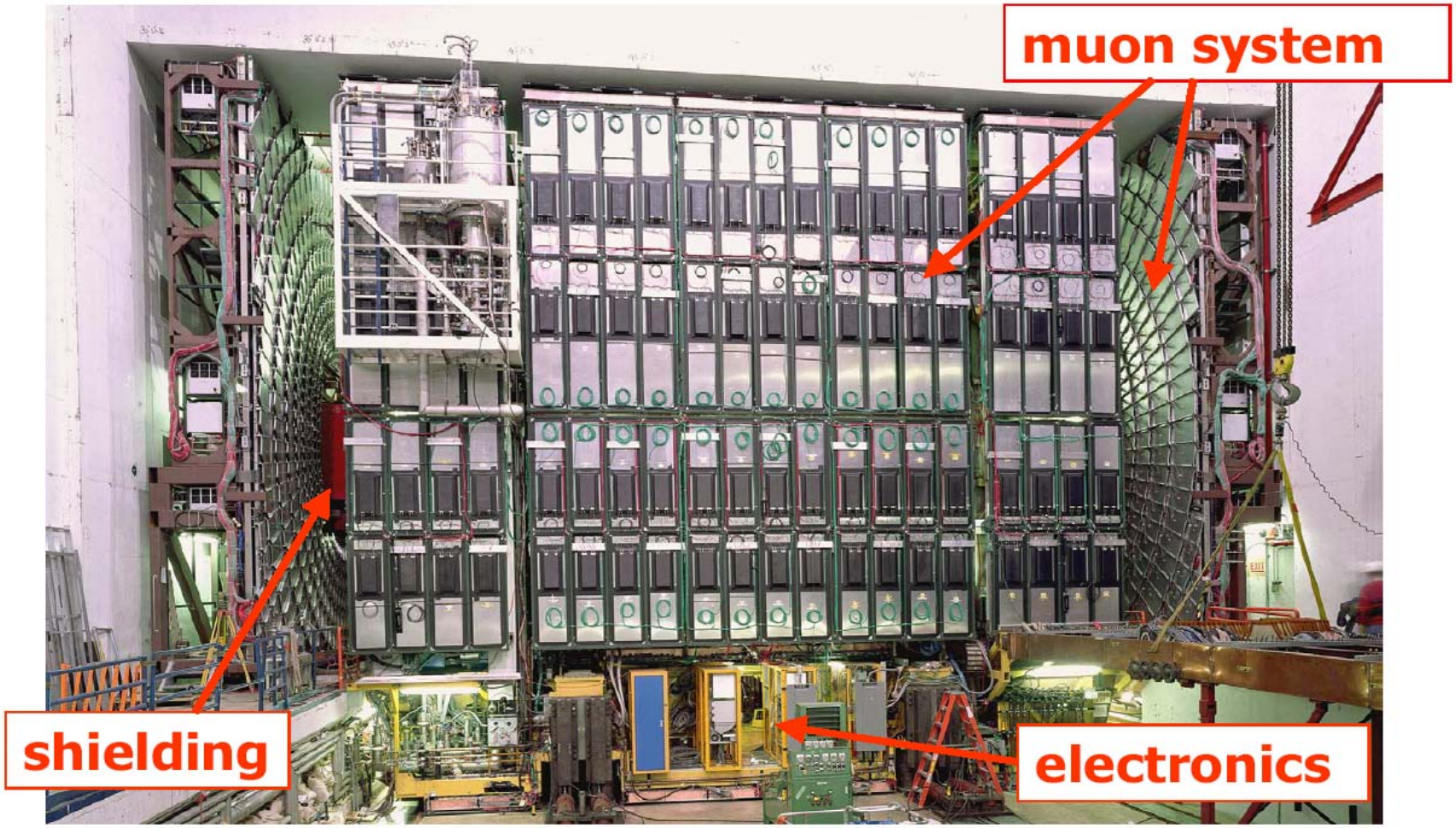


Signal: dif+diγ

The DØ Detector



DØ Detector



RunI: Monojet+MET channel

Data taken: com 1.8 TeV, int lumi 78.8+/-3.9pb^{-1} (MET trigger)

RunI D0:

1) Jet energy resolution

$$\sigma(E)/E=0.8/\mathrm{sqrt}[E(\mathrm{GeV})]$$

2) missing E_T resolution

$$\sigma(\mathrm{MET})=a+b*S_T+c*S_T^2$$

S_T scalar sum of all ET in CAL,

a~1.89GeV, b~6.7E-3, c~9.9E-6/GeV

Event selection:

1) central($|\eta|<1$) leading jet J1 with ET(J1)>150GeV
2) MET>150GeV
3) ISR/FSR J2 with ET(J2)<50GeV (di-j rejection)
4) no isolated μ in $\Delta R(J1,\mu)>0.5$ (W/Z/cosmic)
5) $\Delta\phi(J2,\mathrm{MET})>\pi/12$ (mis-measured jets in QCD)

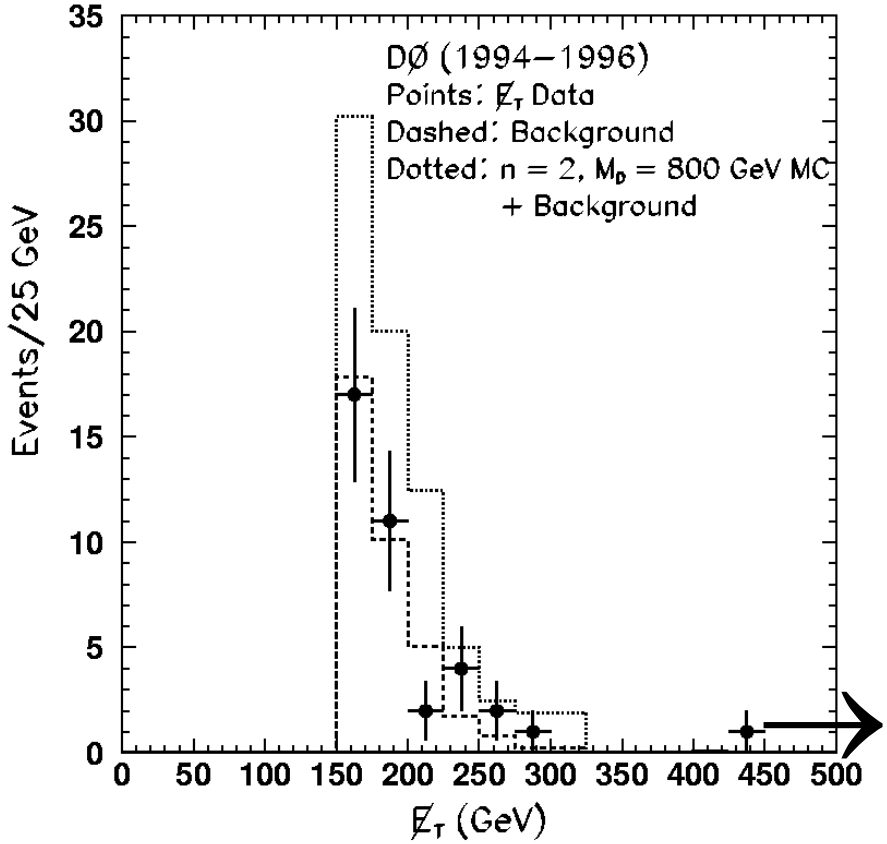
→ #38

MC generator:

- signal: qg→qG, qqbar→gG,gg→gG
- background: W/Z, normalized with eν/ee data

Data vs bgk:

Background	N
$Z(\nu\nu)$+ jets	21.0 ± 5.1
$Z(ee)$+ jets	< 0.01
$Z(\mu\mu)$+ jets	0.01 ± 0.01
$Z(\tau\tau)$ (+ jets)	< 0.09
$W(e\nu)$+ jets	3.1 ± 0.7
$W(\mu\nu)$+ jets	0.8 ± 0.3
$W(\tau\nu)$ (+ jets)	5.2 ± 2.3
QCD and cosmics	7.8 ± 7.1
Total background	38.0 ± 9.6
Data	38



Cosmic?

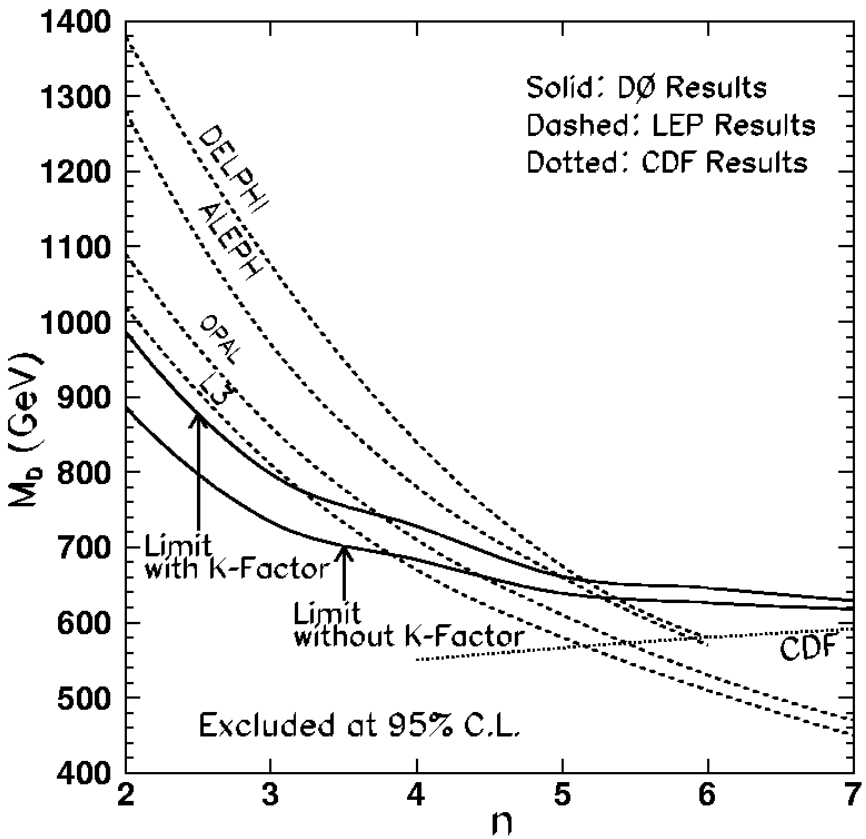
Limits on M_D:

- no evidence for large ED→upper limits on cross-section
- NLO effect: K=1.34
- Bayesian approach→95% CL exclusive limits on M_D

n	2	3	4	5	6	7
M_D limit without K-factor scaling (TeV)	0.89	0.73	0.68	0.64	0.63	0.62
M_D limit with K-factor scaling (TeV)	0.99	0.80	0.73	0.66	0.65	0.63

Compare to LEP & CDF:

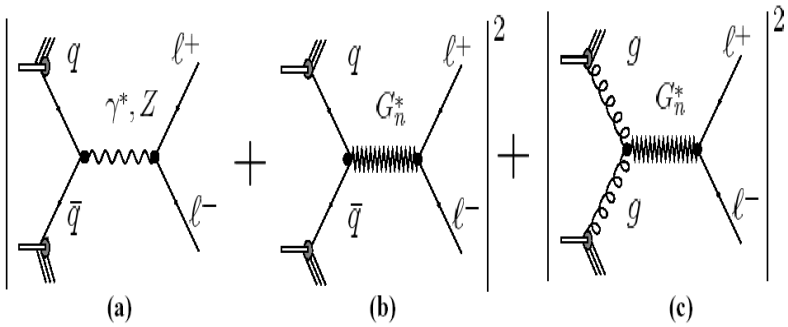
- D0: Jet+G
- LEP&CDF: γ+G



The sensitivity of monojet exceeds LEP at large n-ED, due to higher c.o.m energy at Tevatron

diEM channel: indirect search of ED

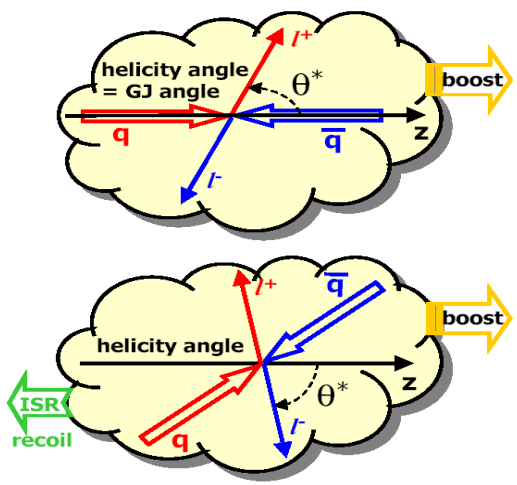
diEM: ee+γγ



= SM+ED

Two free parameters for 2→2:

- M : invariant mass of diEM system
- $\cos\theta^*$: cosine of the scattering angle in helicity frame



Cross-section:

$$\frac{d^2\sigma}{dM\,d\cos\theta^*} = f_{\rm SM} + f_{\rm int}\eta_G + f_{\rm KK}\eta_G^2,$$

with ED effects

$$\eta_G = \mathcal{F}/M_S^4,$$

where

$$\mathcal{F} = 1, \quad \text{GRW}$$

$$\mathcal{F} = \begin{cases} \log\left(\frac{M_S^2}{M^2}\right), & n = 2 \\ \frac{2}{n-2}, & n > 2 \end{cases}, \quad \text{HLZ}$$

$$\mathcal{F} = \frac{2\lambda}{\pi} = \pm\frac{2}{\pi}, \quad \text{Hewett}$$

RunII preliminary on diEM

Data taken: com 1.96 TeV, int lumi 51+/-5pb^{-1}

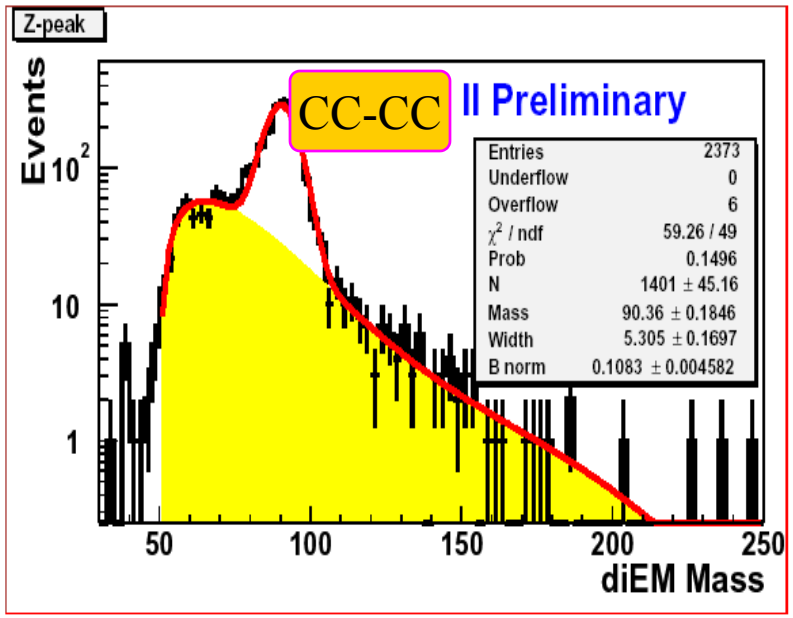
Selections: recalculate luminosity with Z data → "effective" 46+/-2 pb^{-1}

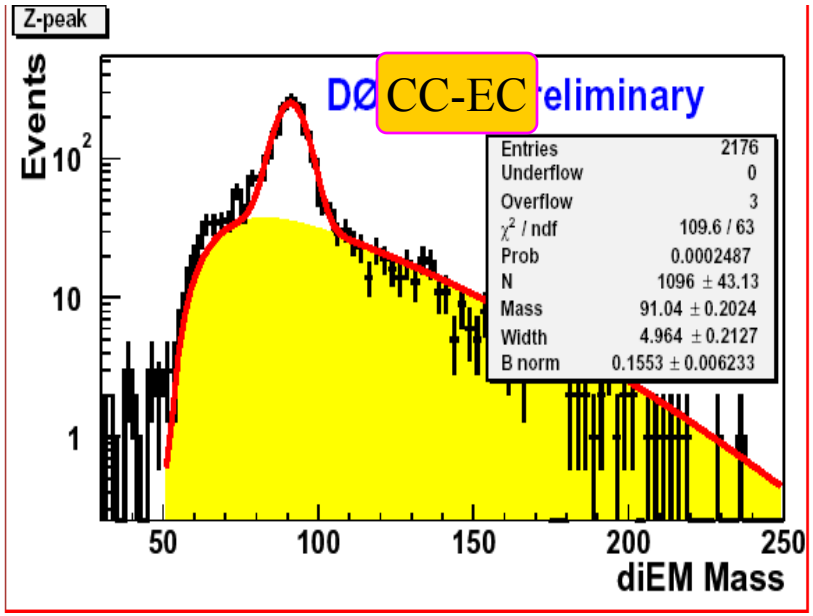
cut	No. of events
Reconstructed data	149.7 mln
diEM stream : di-EM with ET>7	2.8 mln
diEM with ET>20, in fiducial CAL, ISO<0.15,EMF>0.9	108,313
EM Trigger required; Bad Runs removed(→50+/-5pb^{-1})	95,378
diEM with ET>25 and χ^2<20; veto on >2EM(ET>5,ISO,EMF);	8,763
diEM with ET(EM)>25, MET<25 (**CC**:|η|<1.1, **EC**:1.5<|η|<2.4)	5,214=2,373 CC-CC + 2,176 CC-EC+765EC-EC

Background:

- SM : Drell-Yan + $\gamma\gamma$ included
- other phys bgk : $W\gamma, Z\gamma, WW, Z\rightarrow\tau\tau$, ttbar negligible(MET<25,=2EM)

- instrumental : misidentify in jj and γj, estimated by data passing all cuts but $\chi^2>20$, normalization by fitting diEM low-mass region to DY+instrumental





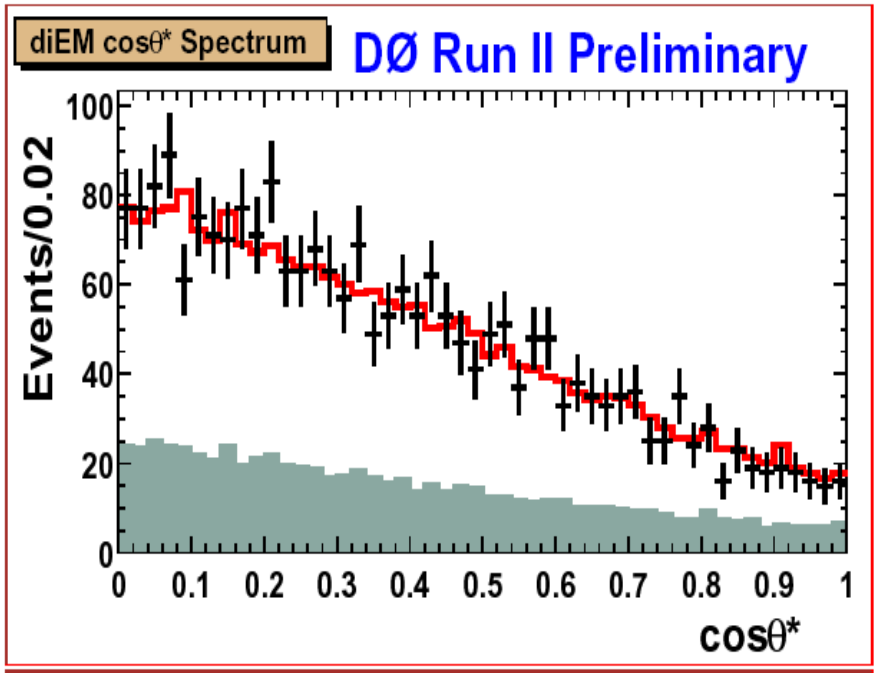
"fast" MC :

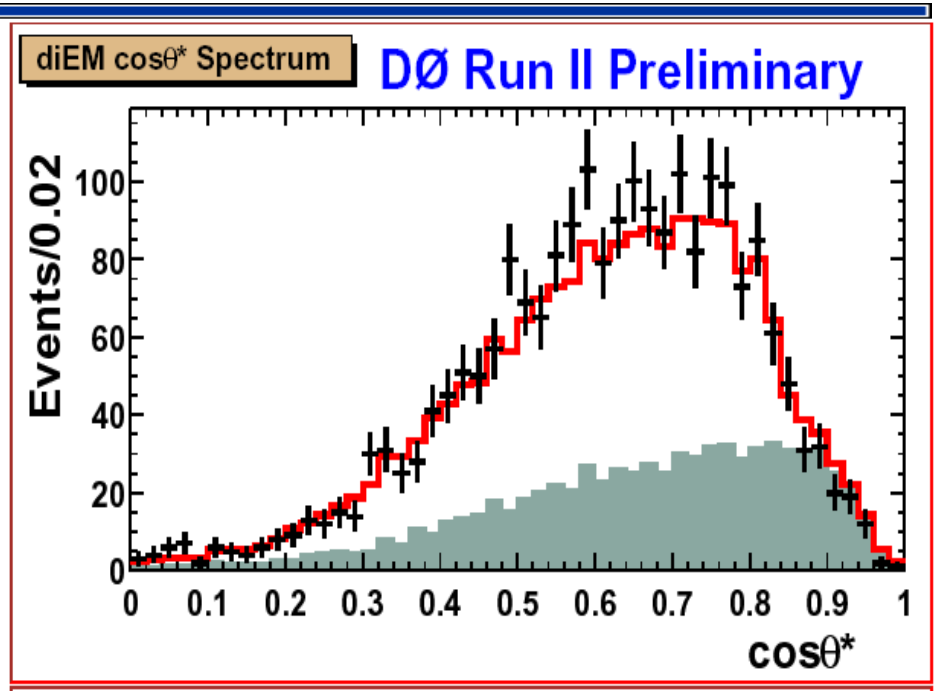
1. LO: $|SM+G_{kk}|^2$

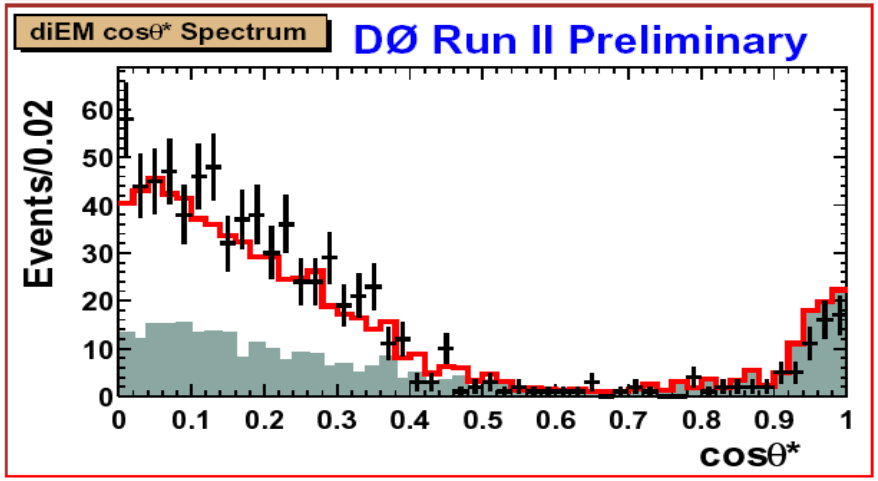
2. NLO effect: add a pT "kick" to diEM system for ISR,
   based on pT spectrum of diEM data;
   K=1.3 scaling the cross-section;
   pdf as CTEQ4LO

3. detector acceptance, ISR, efficiencies and EM resolution tuned by Z data

4. 5% primary vertex smearing





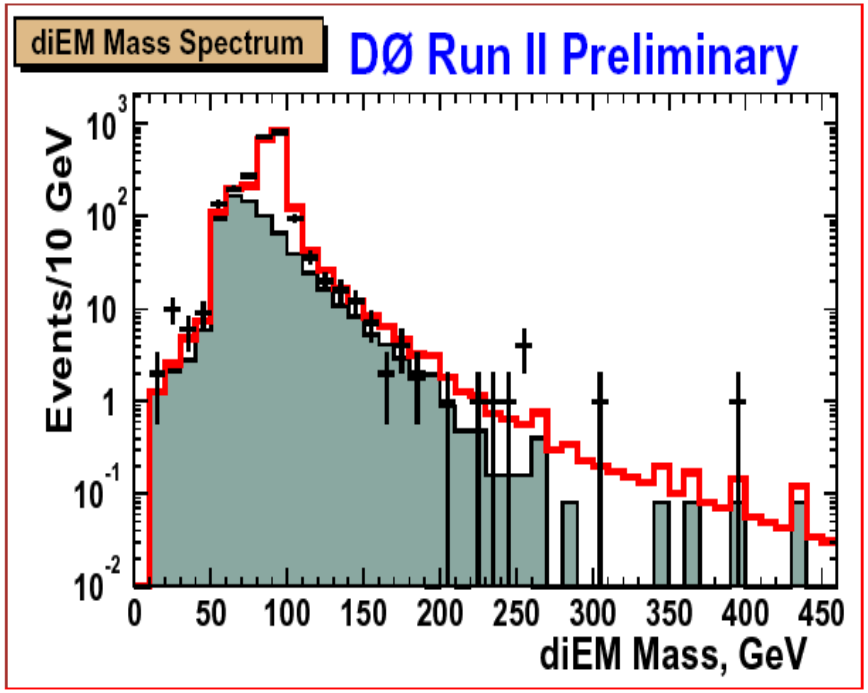


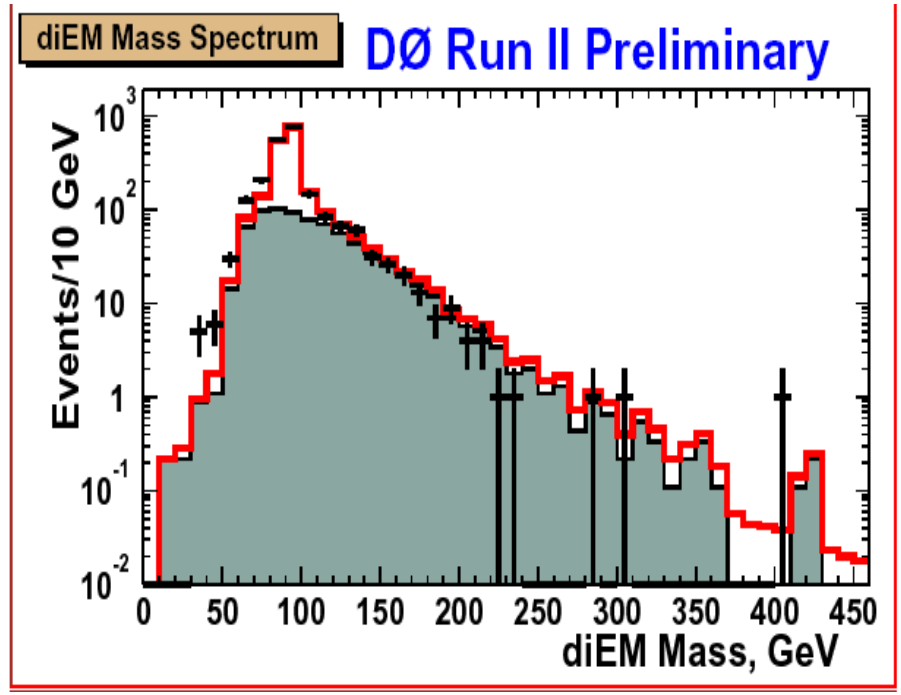
Data vs background

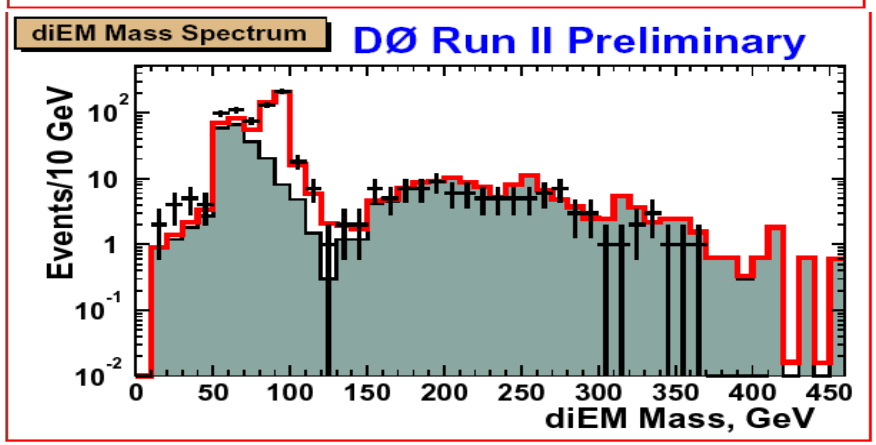
CC-CC

CC-EC

EC-EC







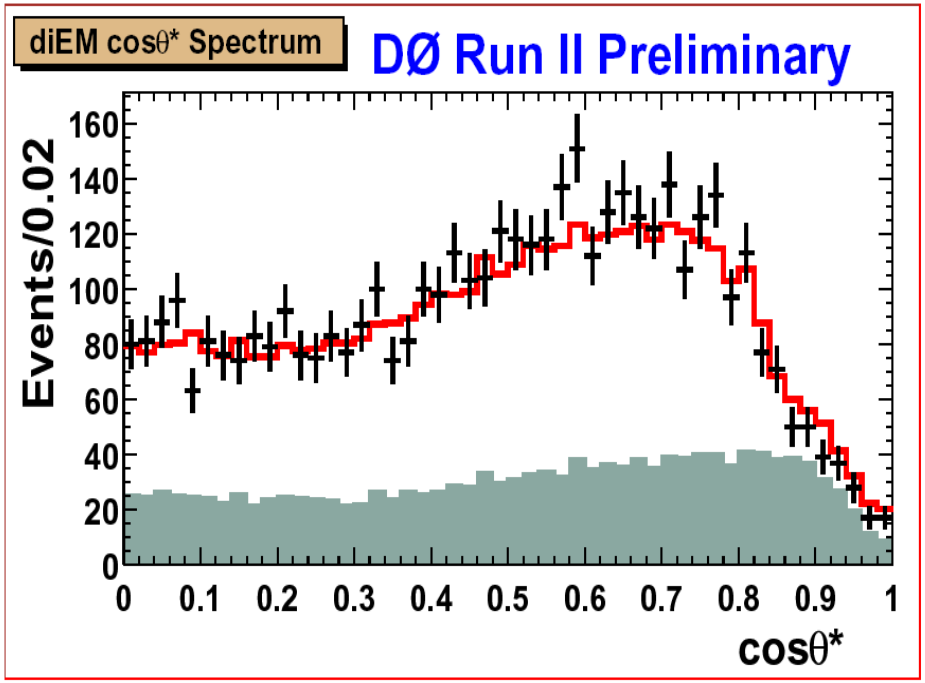
CC-CC

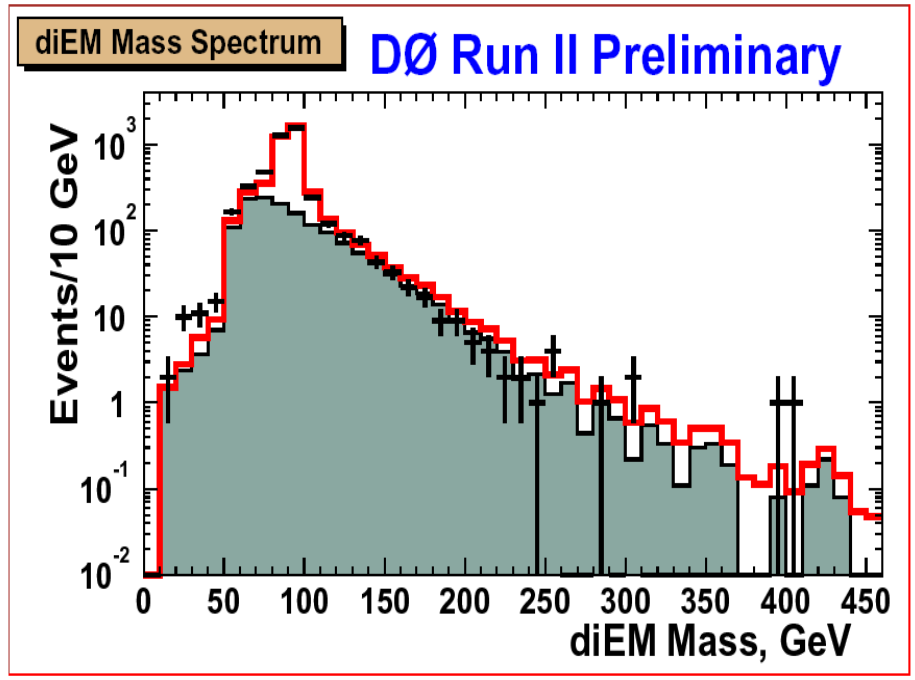
CC-EC

EC-EC

Samples in CC-CC + CC-EC:

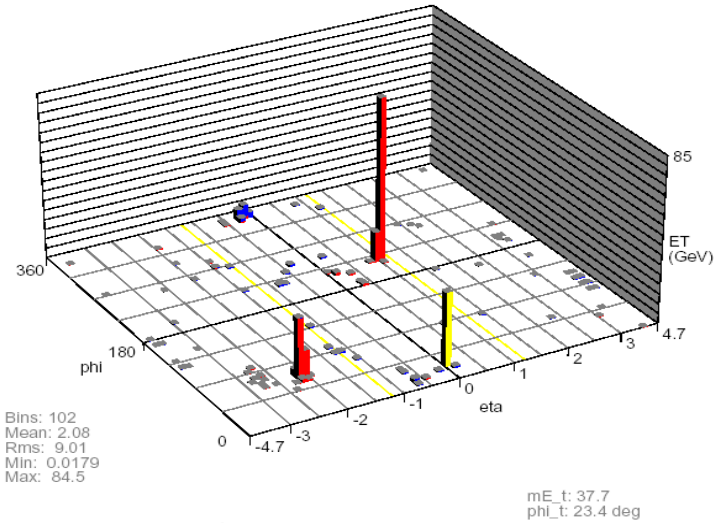
- EC-EC shows poor sensitivity
- combine CC-CC and CC-EC, as





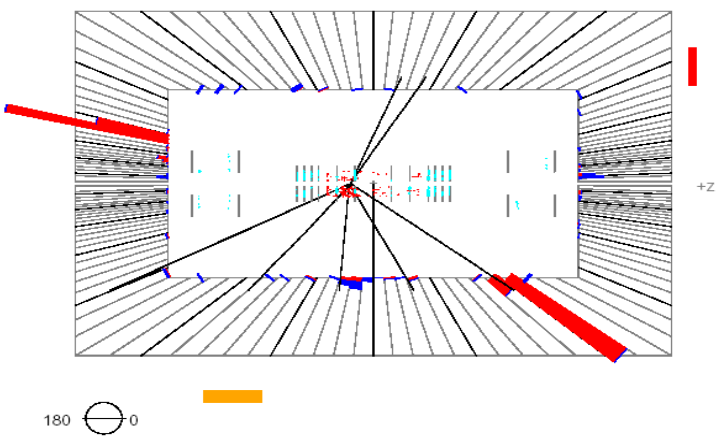
Run	Event	$\not{E}_T$	Type	E_T^1	E_T^2	η_1	η_2	ϕ_1	ϕ_2	M	$\cos\theta^*$	$N_{\rm jet}$
169521	3579842	9.8	$\gamma\gamma$ or $e\gamma$	105.2	63.5	1.02	-2.12	3.79	1.13	409	0.64	1
169736	23391029	1.2	ee	165.0	159.2	0.65	-0.65	1.63	4.74	394	0.49	0

Run 169521 Event 3579842 Thu Feb 6 13:08:46 2003

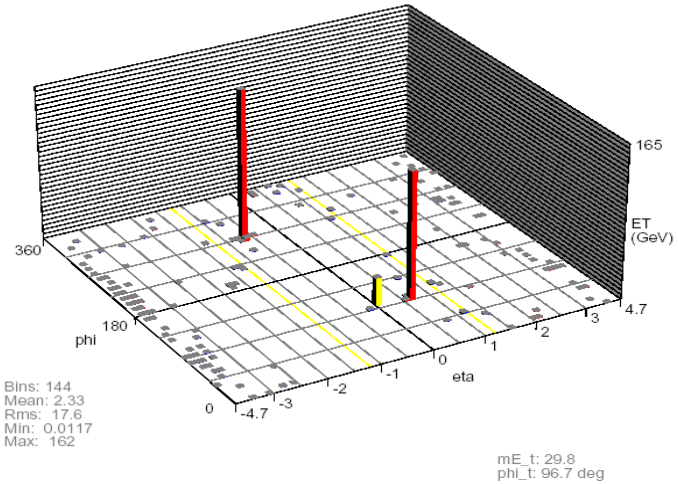


Run 169521 Event 3579842 Thu Feb 6 13:08:46 2003

E scale: 86 GeV

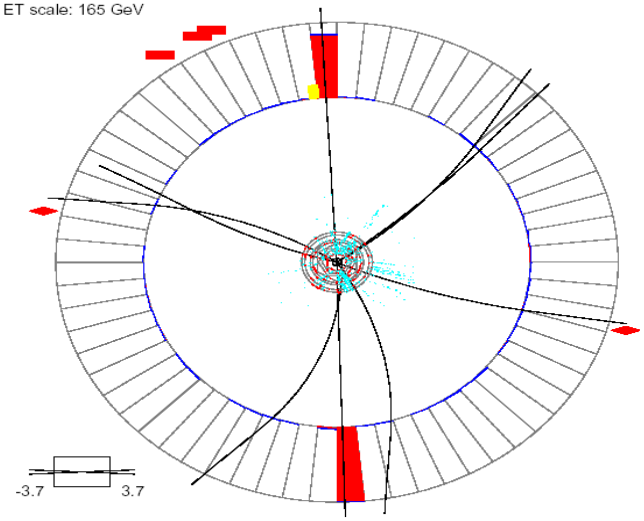


Run 169736 Event 23391029 Thu Feb 6 13:09:34 2003



Run 169736 Event 23391029 Thu Feb 6 13:09:34 2003

ET scale: 165 GeV

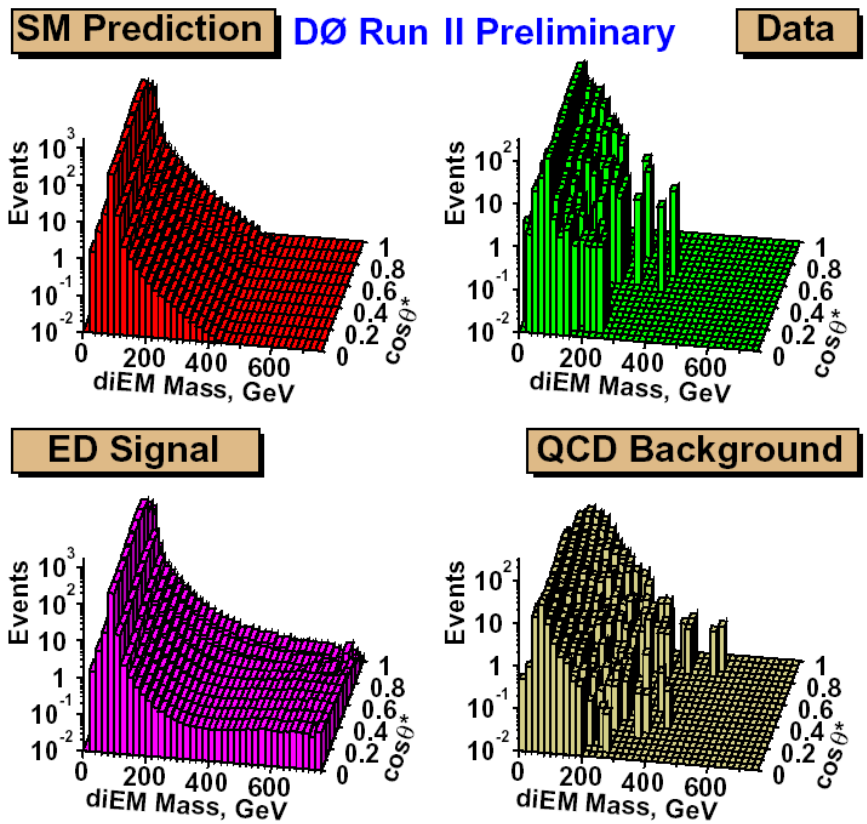


Set Limits on ED:

- MC templets: f_{SM},f_{int} and $f_{KK}(M,\cos\theta^*)$
- two-dimensional distribution:

(CC-CC + EC-CC):

$|M*\cos\theta^*|=50*5$



The diEM mass vs. $\cos\theta^*$ distribution for the combined CC-CC and CC-EC candidate samples.

- Method: Bayesian and likelihood, only η_d as free parameter

- signal uncertainty:

Source of systematics	Uncertainty
K-factor	10%
Choice of p.d.f.	5%
Luminosity times efficiency	4%
E_T dependence of the efficiency	10%
Total	15%

QCD(instrumental) background ~ 7-20%

Combined fit gives: $\eta_G = 0.00 + 0.27\ \mathrm{TeV}^{-4}$

The 95% upper CL limit:

$$\eta_G^{95\%} = \begin{cases} 0.618\ \mathrm{TeV}^{-4} & \text{Likelihood} \\ 0.628\ \mathrm{TeV}^{-4} & \text{Bayesian} \end{cases}$$

Lower limits at 95% CL on the fundamental Planck scale (in TeV):

GRW [7]	HLZ [8]						Hewett [9]
	n=2	n=3	n=4	n=5	n=6	n=7	$\lambda = +1$
1.12	1.16	1.34	1.12	1.02	0.94	0.89	1.00

RunI Results on diEM

Data taken: com 1.8 TeV, int lumi 126.8+/-5.6pb^{-1}

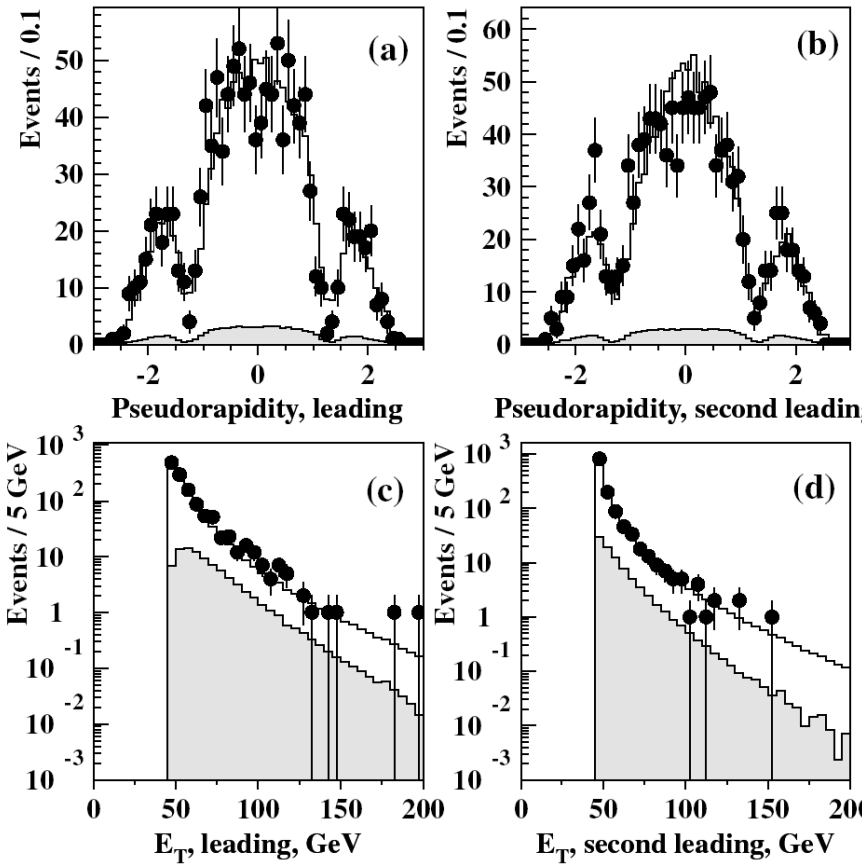
Selections:

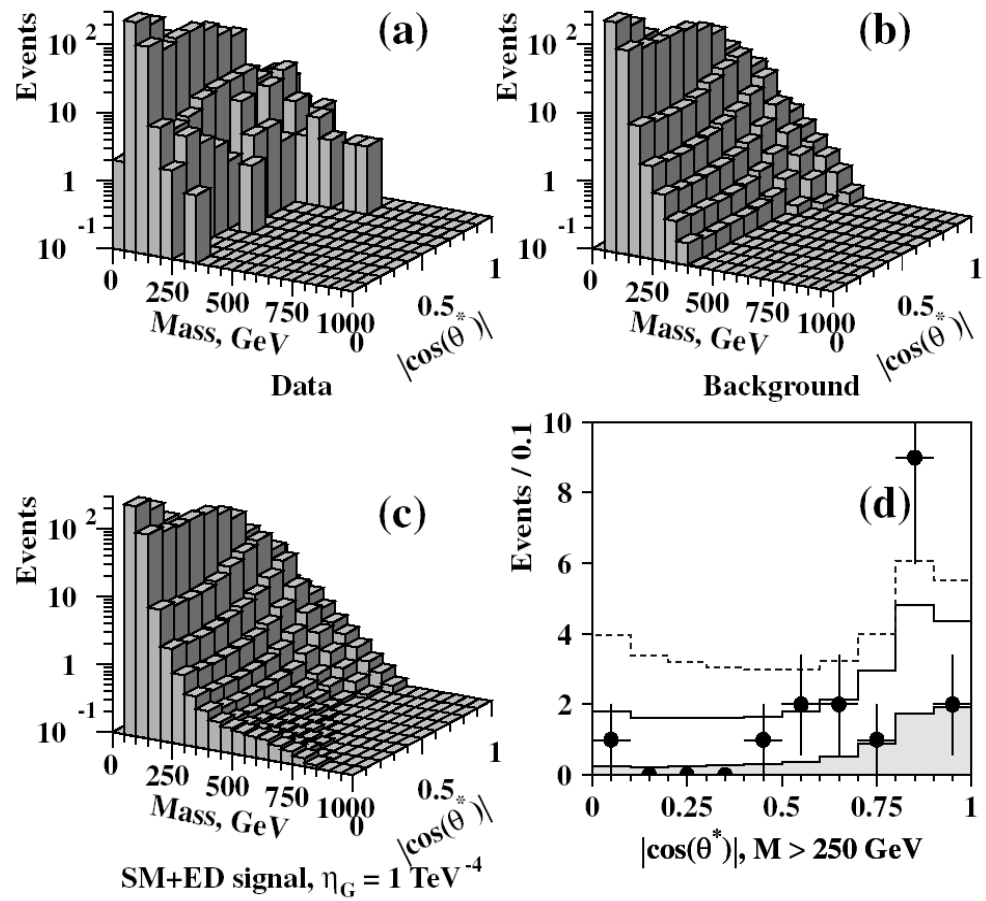
Cut	# of events
Starting sample	87,542
Quality cuts	82,947
≥2 EM	82.927
=2 EM	82,425
E_T > 25 GeV	36,409
Acceptance	30,585
EM ID	10,711
ET > 45 GeV	1,250

Cut	Efficiency
EM ID	(87 ± 2)%
MET < 25 GeV	(98 ± 1)%
Event quality	(99.8 ± 0.1)%
Overall, per event	(79 ± 2)%

→ #1282

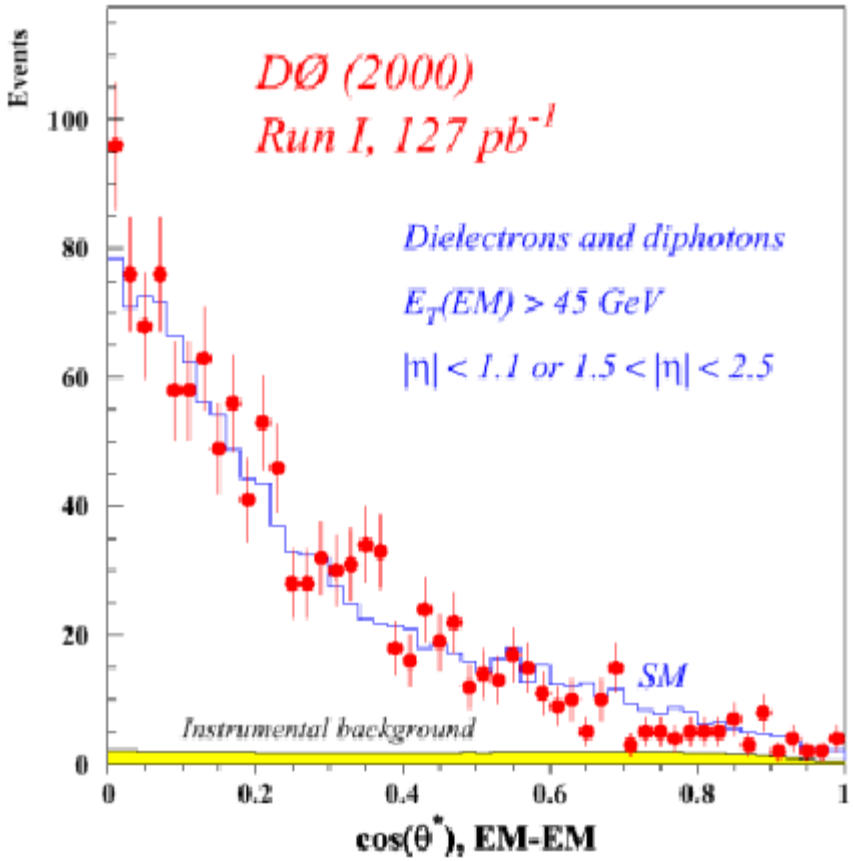
Data vs background:





Data agree well with background, no evidence for LED

Comparison of the data with the SM predictions



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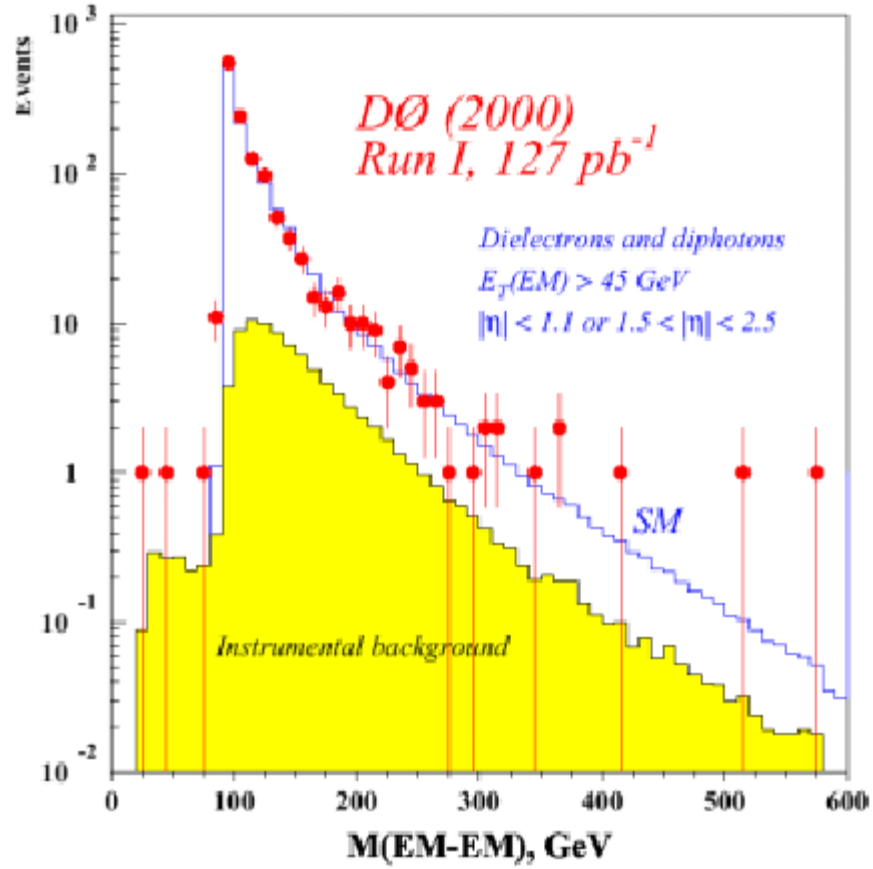


Note zero-events bins at high masses!

Systematic uncertainty:

- signal:

Source	Uncertainty
K-factor	10%
p.d.f. choice	5%
$\int Ldt$	4%
Efficiency	3%
Overall	12%

- instrumental QCD ~ 25%

The 95% upper CL limit:

$$\eta_G < 0.46 \text{ TeV}^{-4}$$

Lower limits at 95% CL on the fundamental Planck scale (in TeV):

	HLZ [8]						Hewett [10]	
GRW [7]	$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$	$\lambda = +1$	$\lambda = -1$
1.2	1.4	1.4	1.2	1.1	1.0	1.0	1.1	1.0

RunI & II diEM cross-check

	Int lumi (pb^{-1})	c.o.m (TeV)	$\eta_G^{95\%}$ (TeV^{-4})
Run I	127	1.8	0.46
Run II	46	1.96	~0.62

- due to luminosity, RunII limit should be sqrt[127/46]~1.6 times worse than RunI
- 10% increased c.o.m in RunII gives about 50% boost on the virtual graviton exchange cross-section, especially at high mass region

→ 1. RunII approaching RunI
2. reached LEP sensitivity

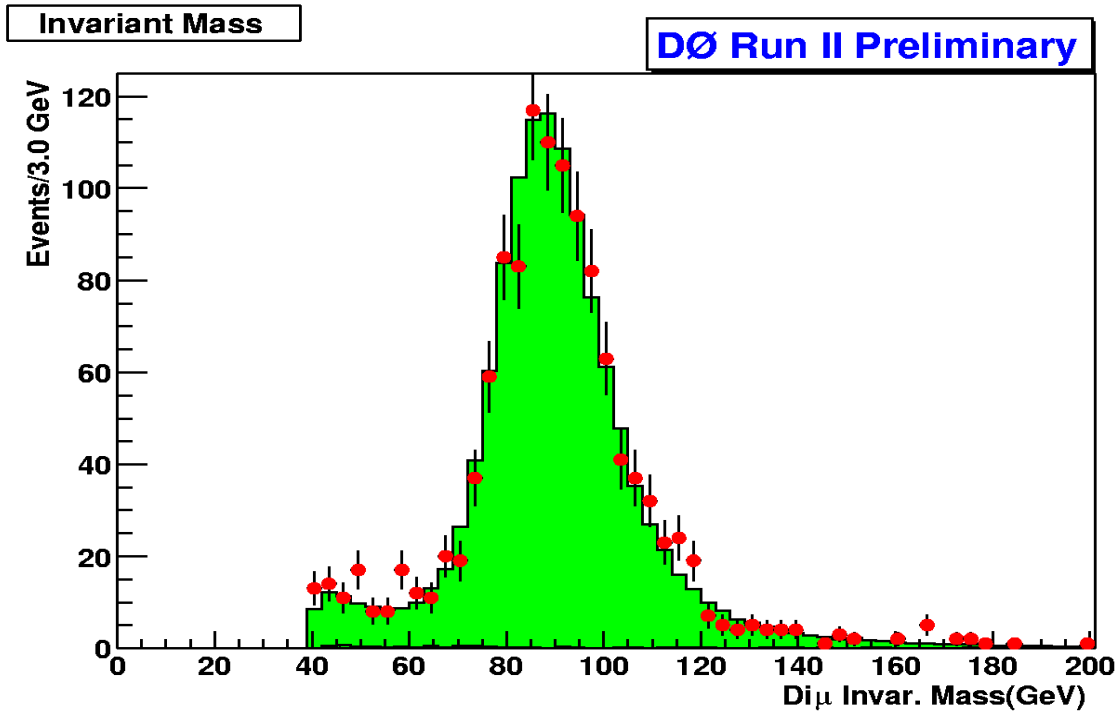
RunII preliminary on diMuon

Data : com 1.96 TeV, int lumi 30 pb^{-1}

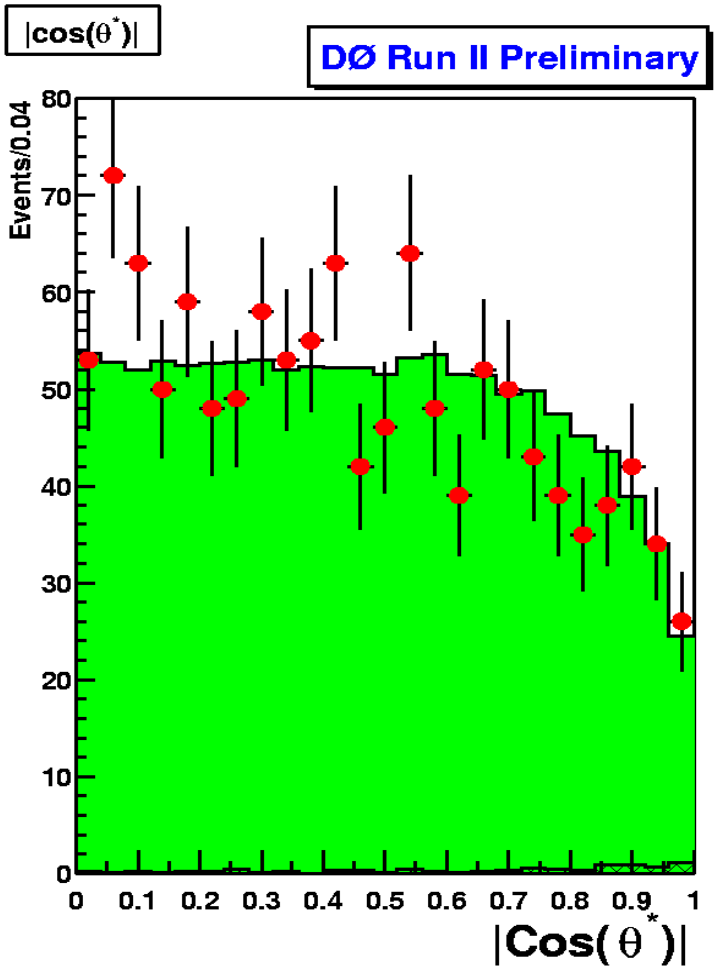
Cut	Number of events
Starting tmb_tree sample	1,233,225
Nseg=3 Requirement	1,091,040
Both Muons $p_T > 15$ GeV	2,056
$\mu\mu$ Invariant Mass > 40 GeV	1,840
Halo(0.4,0.1) < 2.5 GeV	1,312
Track Halo(0.5) < 2.5 GeV	1,242
Fired `2MU_A_L2M0` trigger	1,242

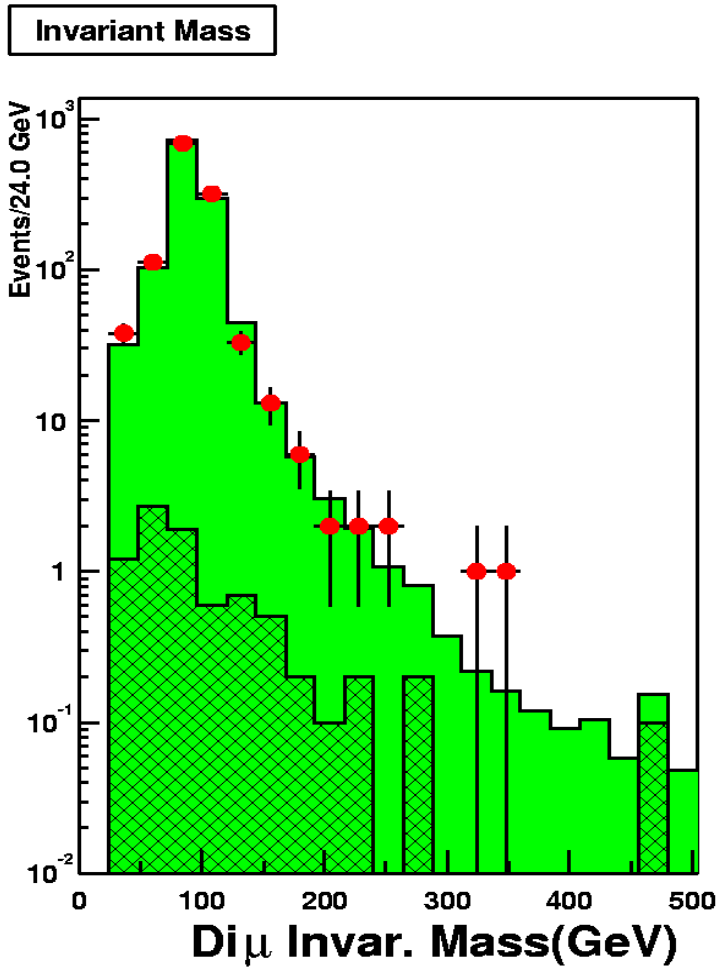
Background:

- SM : Drell-Yan included
- instrumental : charge mis-measurment and high pT muon from heavy quark, estimated by like-signed di-muon events in data which fail isolation cut, normalization by fitting diMuonu low-mass region to DY+like-signed

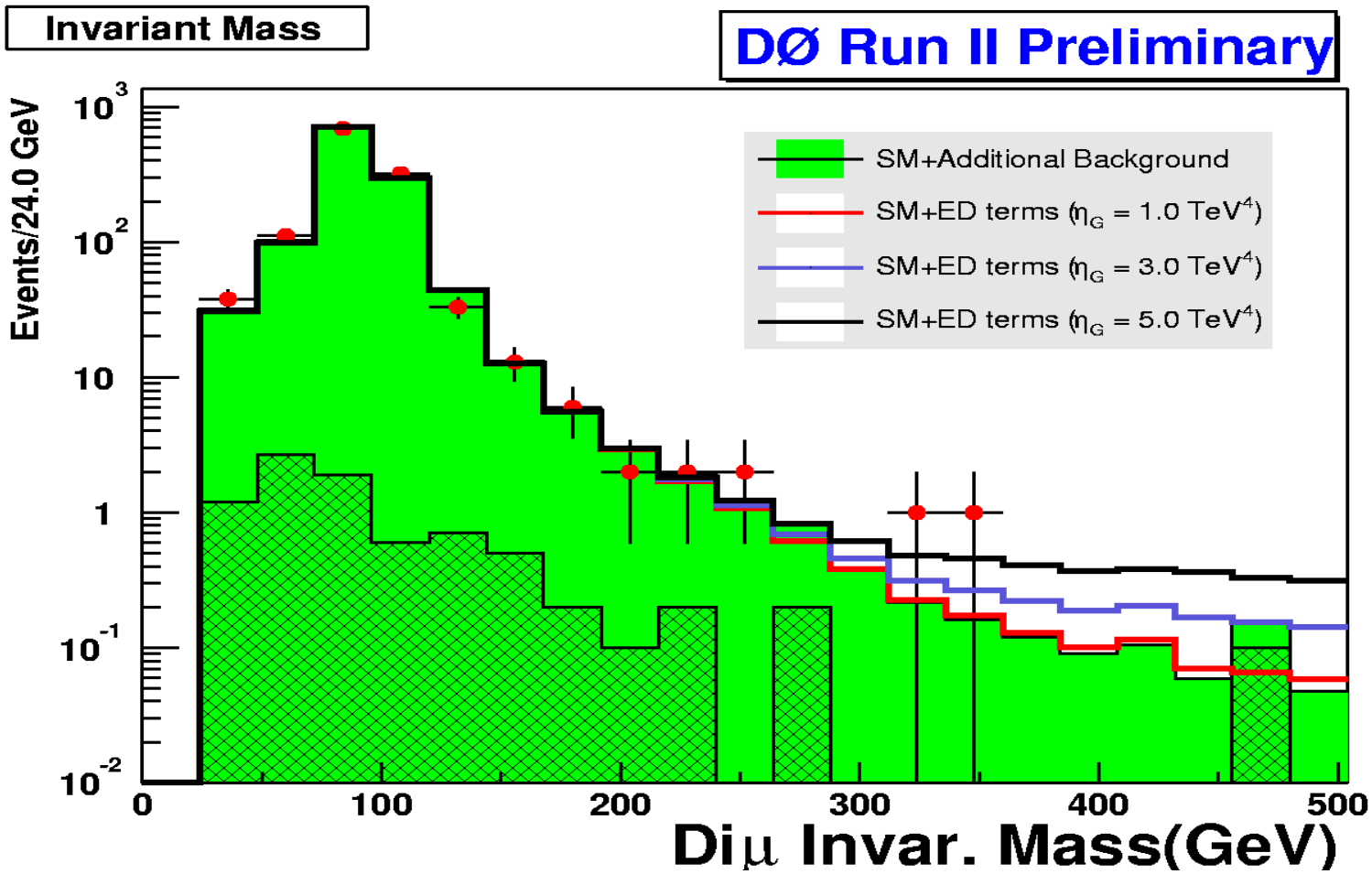


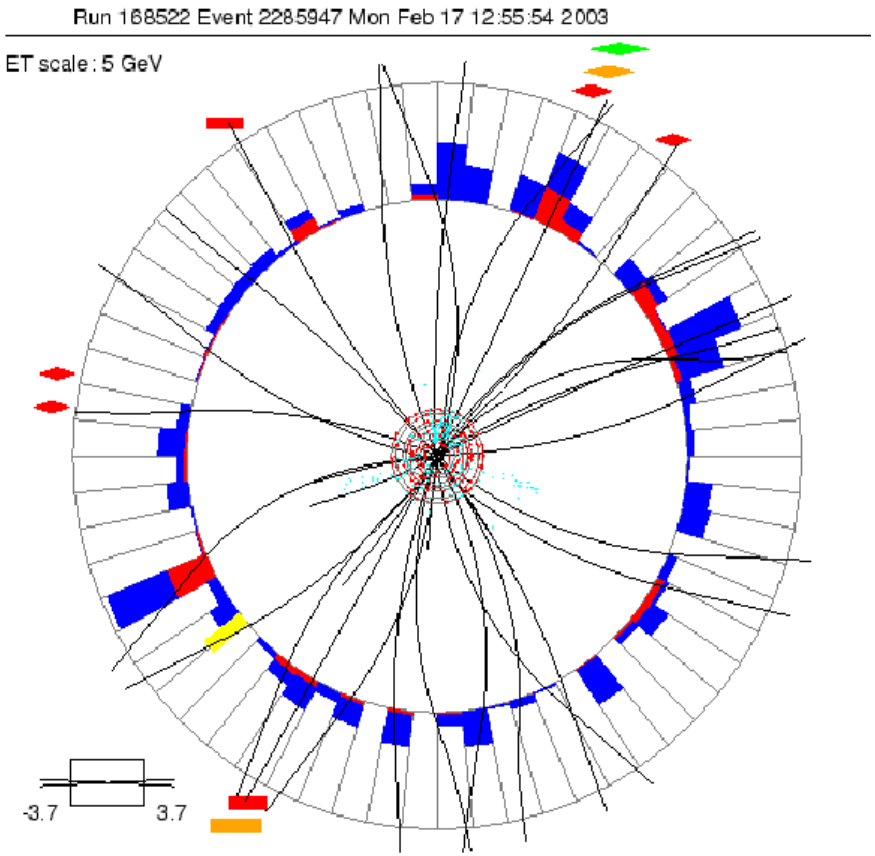
Data vs background:



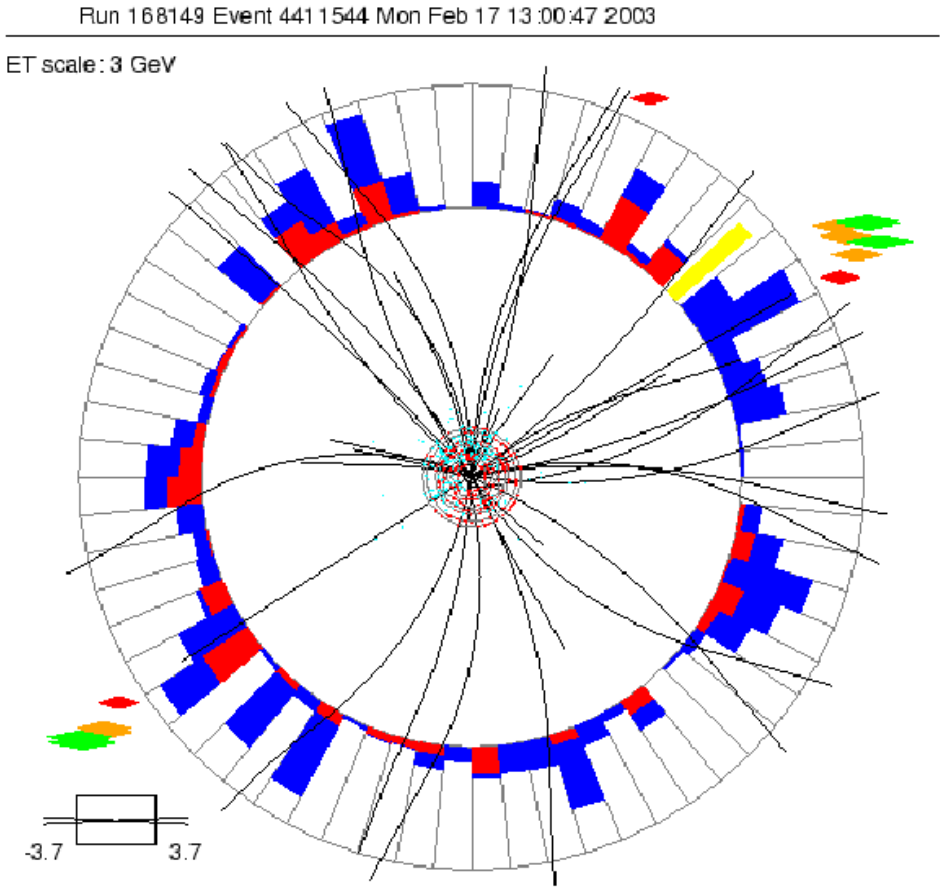


2 leading events:



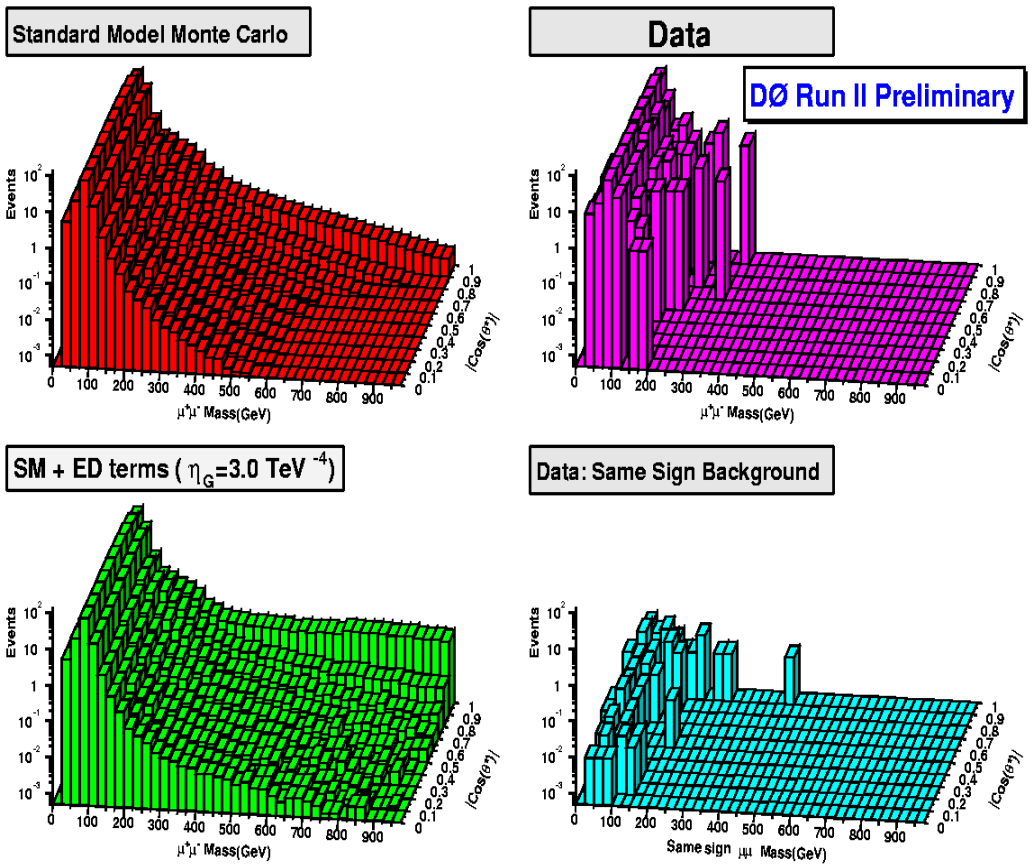


unlike-signed



like-signed

Two dimensional fit:



Signal uncertainty:

Source of systematics	Uncertainty
K-factor	10%
Choice of p.d.f.	5%
Luminosity times efficiency	3%
p_T dependence on efficiency	10%
Total	15%

The 95% upper CL limit:

$$\eta_G^{95\%} = \begin{cases} 2.5\ \mathrm{TeV}^{-4} & \text{Likelihood} \\ 2.5\ \mathrm{TeV}^{-4} & \text{Bayesian} \end{cases}$$

Lower limits at 95% CL on the fundamental Planck scale (in TeV):

GRW [13]	HLZ [14]						Hewett [15]
	n=2	n=3	n=4	n=5	n=6	n=7	$\lambda = +1$
0.79	0.68	0.95	0.79	0.72	0.67	0.63	0.71

Summary on D0 LED search

I. Jet+MET analysis(hep-ex/0302014):

- first research in the monojet channel at a hadron collider,
- sensitivity exceeds LEP at large ED

II. diEM analysis:

- RunII limits(D0 Note 4102) are approaching RunI(PRL V86, No7, 1156)
- already reached LEP sensitivity

III. diMuon analysis(D0 Note 4106):

- first research at a hadron collider
- improved over LEP results in the channel