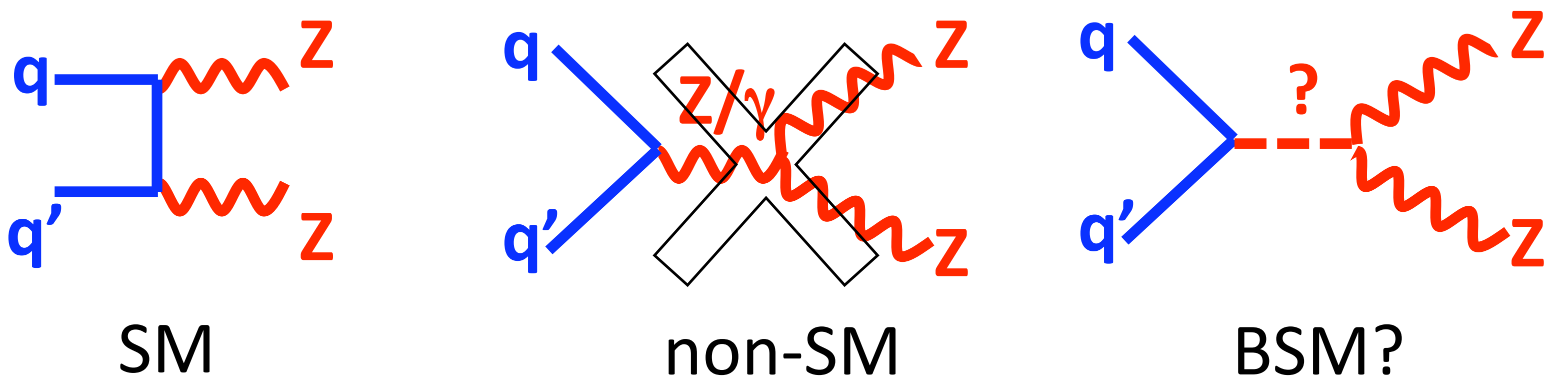
Search for high-mass ZZ resonances

Aidan Robson
University of Glasgow
for the CDF Collaboration
EPS, 21 July 2011

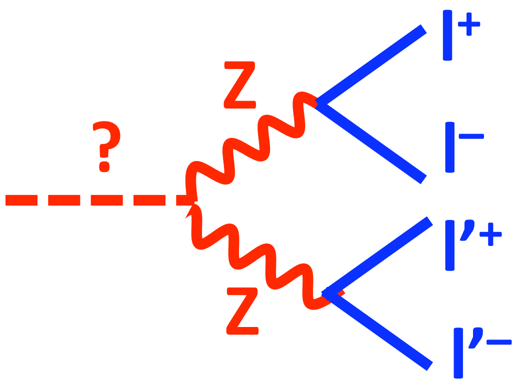
University of Glasgow | Experimental Particle Physics



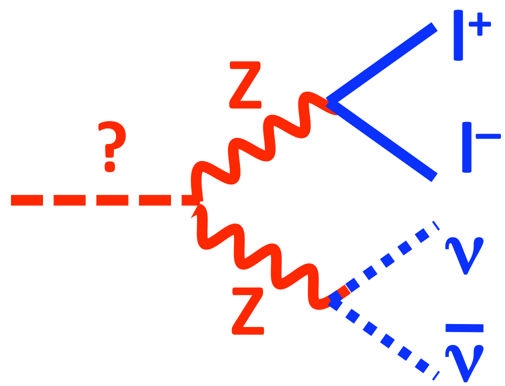
- Higgs?
- RS graviton?
- RS graviton in models with SM fields in bulk?

eg Fitzpatrick, Kaplan, Randall, Wang, JHEP 0709 (2007) 013

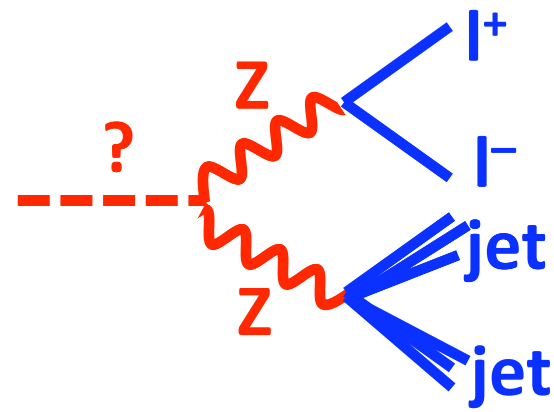
4ℓ



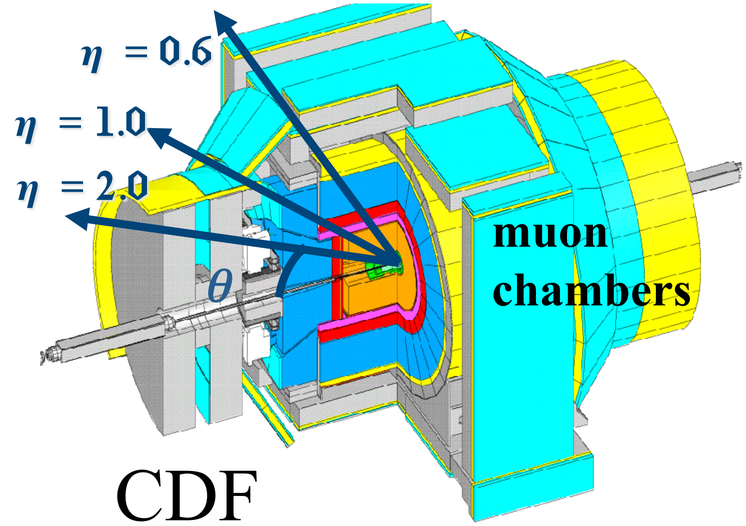
$\ell\ell + \not{E}_T$



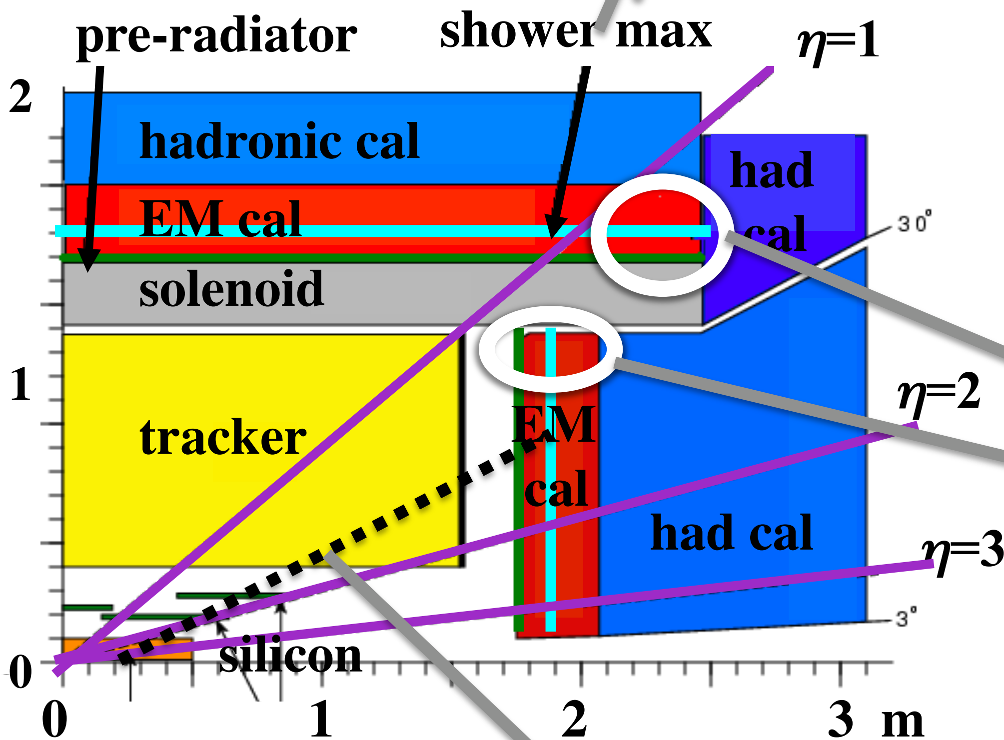
$\ell\ell jj$



Acceptance improvements for 4ℓ

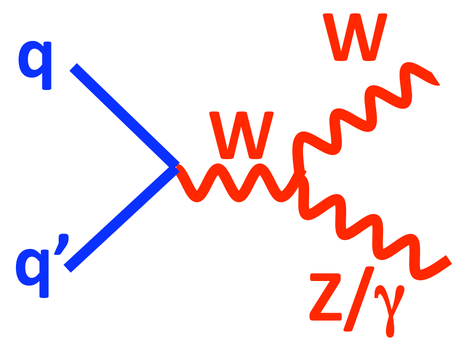


Improved shower max clustering
→ loosen cuts

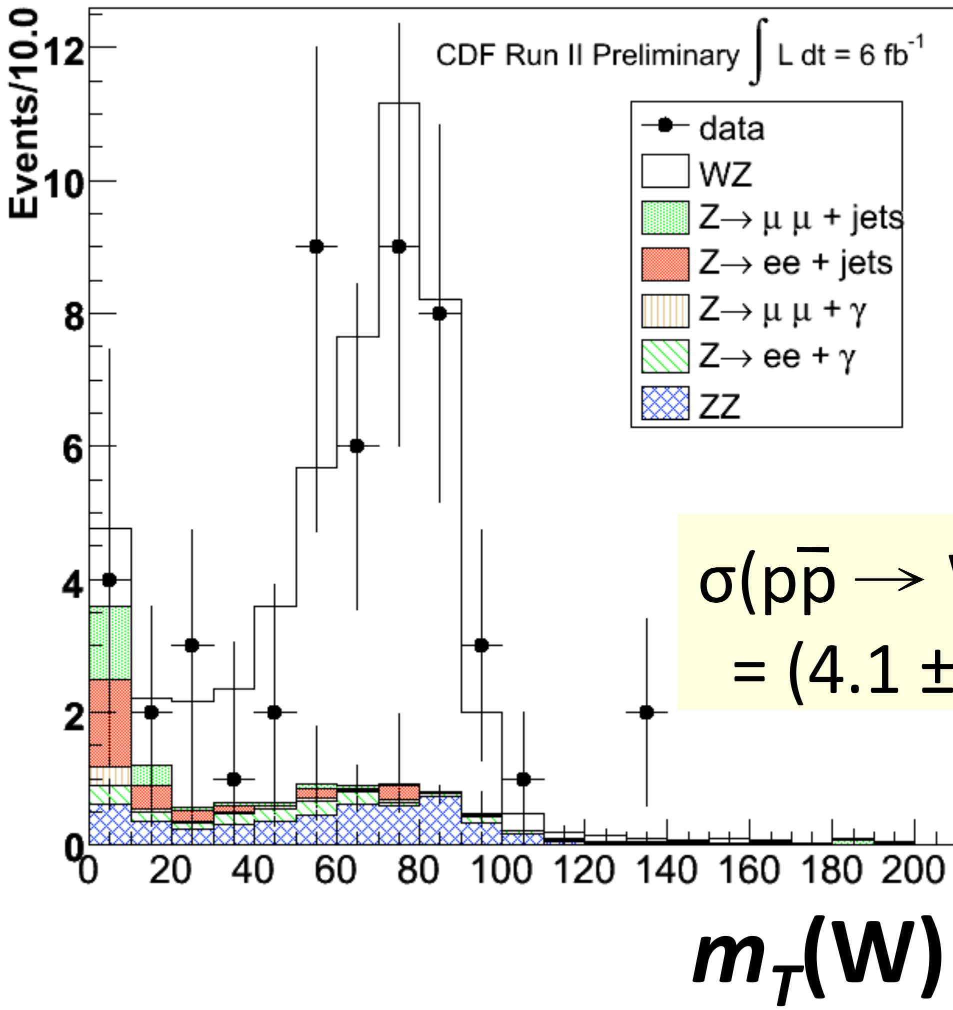


Include outer rings of calorimeters in electron ID

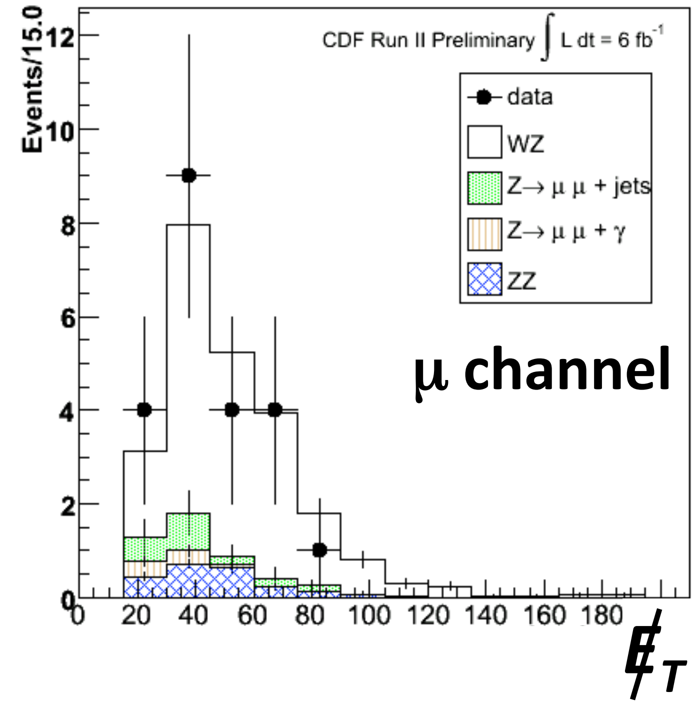
retrack for 4ℓ, and add central tracker hits to forward silicon tracks

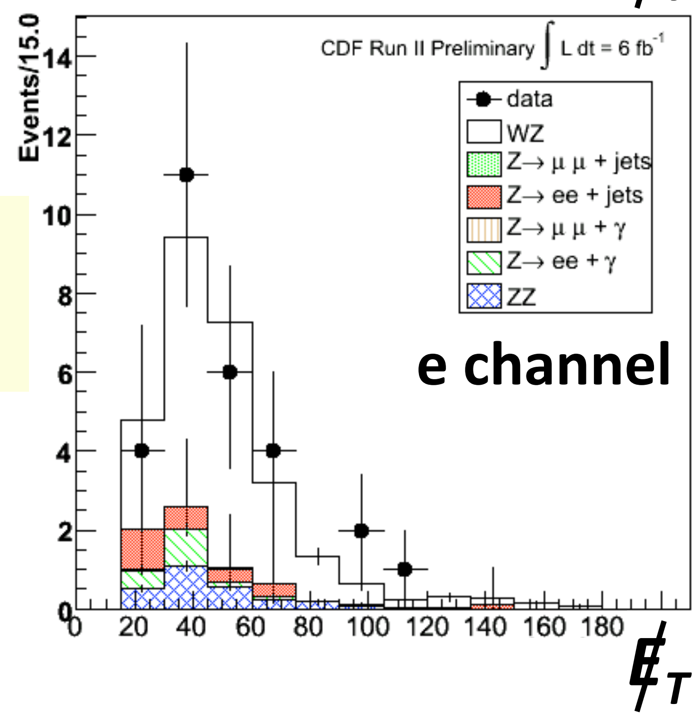


$WZ \rightarrow \ell\ell\ell + \not{E}_T$

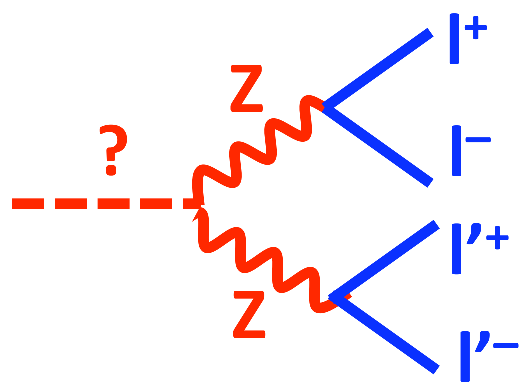


$\sigma(p\bar{p} \rightarrow WZ)$
$= (4.1 \pm 0.7)$ pb

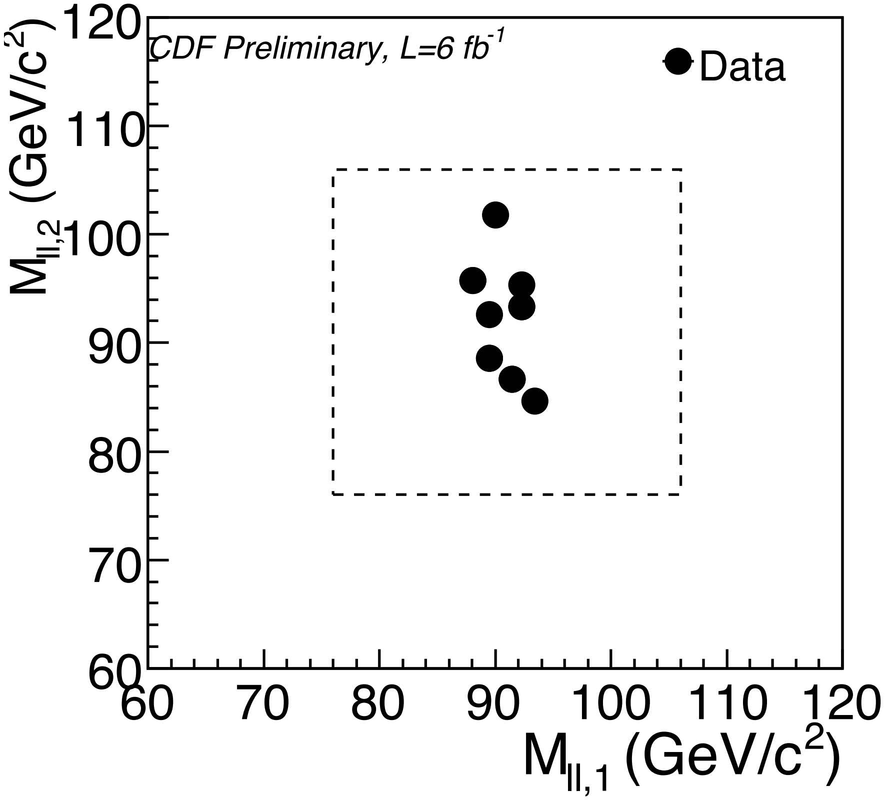




4ℓ



$ZZ \rightarrow 4\ell$



Select 4 leptons (e or μ)

p_T(lepton)>15 GeV/c

(one > 25 GeV/c)

10 candidates

$76 < m_{ll} < 106$ GeV/c^2; 8 remain

All same-flavour, opposite charge

Expected background < 0.01 event

Cross-section assuming standard model source:

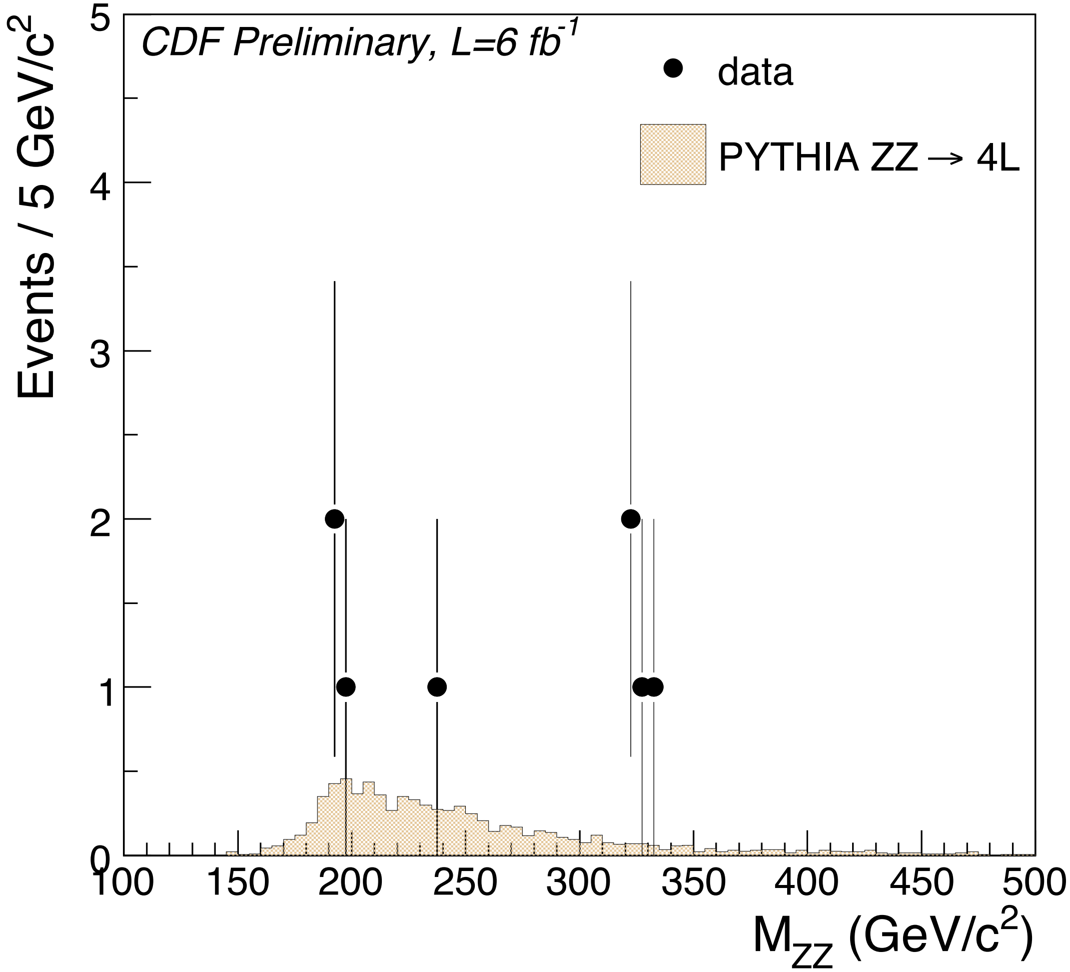
$$\sigma(p\bar{p} \rightarrow ZZ) = (2.8\ ^{+1.2}_{-0.9}\ (\text{stat}) \pm 0.3\ (\text{sys}))\ \text{pb}$$

NLO prediction (1.4± 0.1) pb

CDF other analysis cross-sec, $ZZ \rightarrow 4\ell + ZZ \rightarrow \ell\ell\nu\nu$

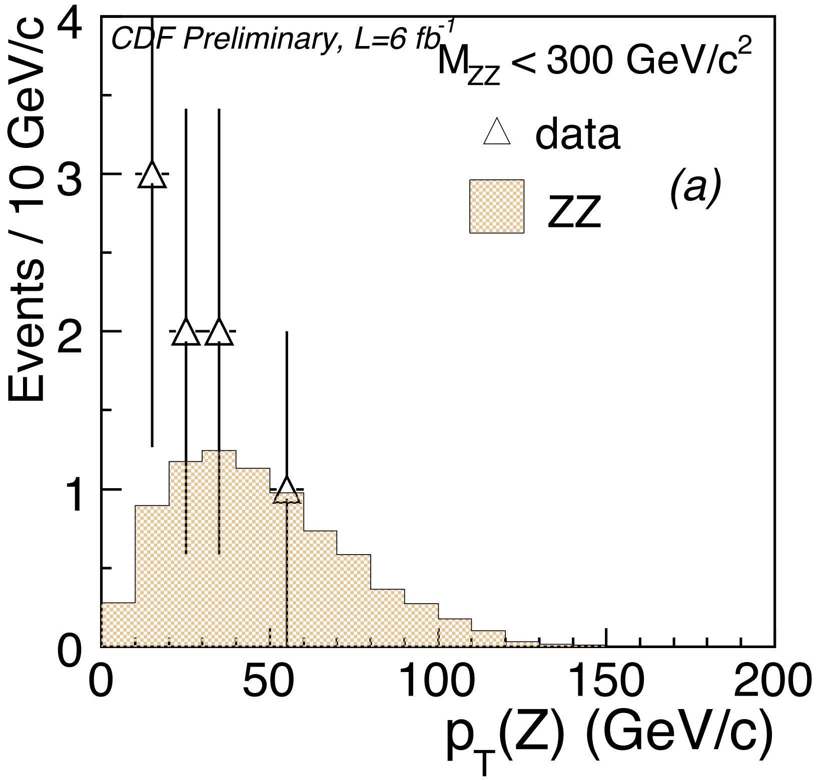
$\ell\ell\nu\nu$ dominates: $\sigma(p\bar{p} \rightarrow ZZ) = (1.6 \pm 0.3(\text{stat})^{+0.3}_{-0.2}(\text{sys}))$ pb

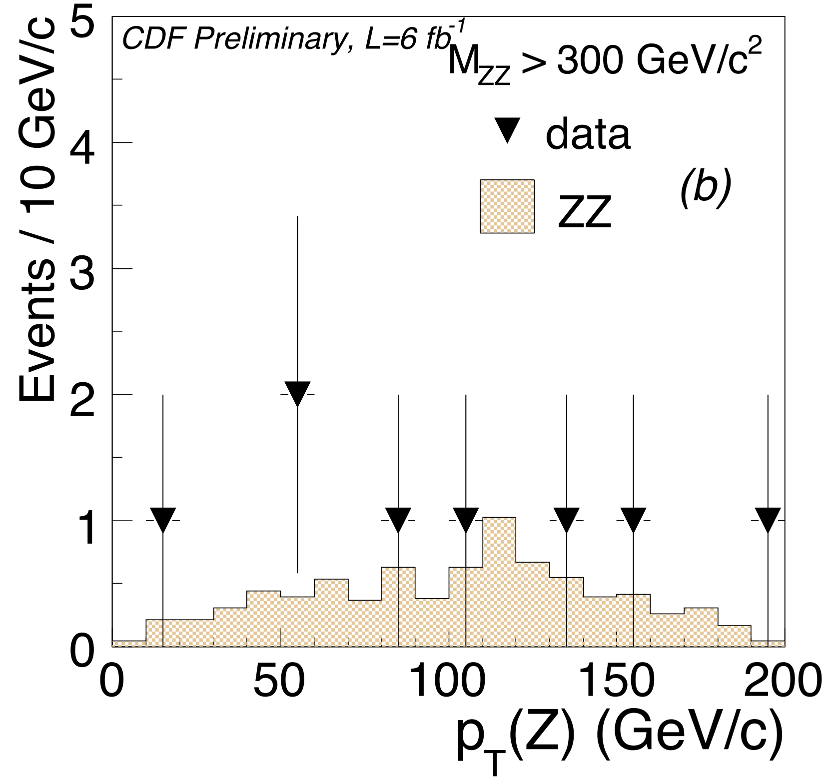
$ZZ \rightarrow 4\ell$



High mass:
eeee
eeμμ
μμμμ
μμμμ

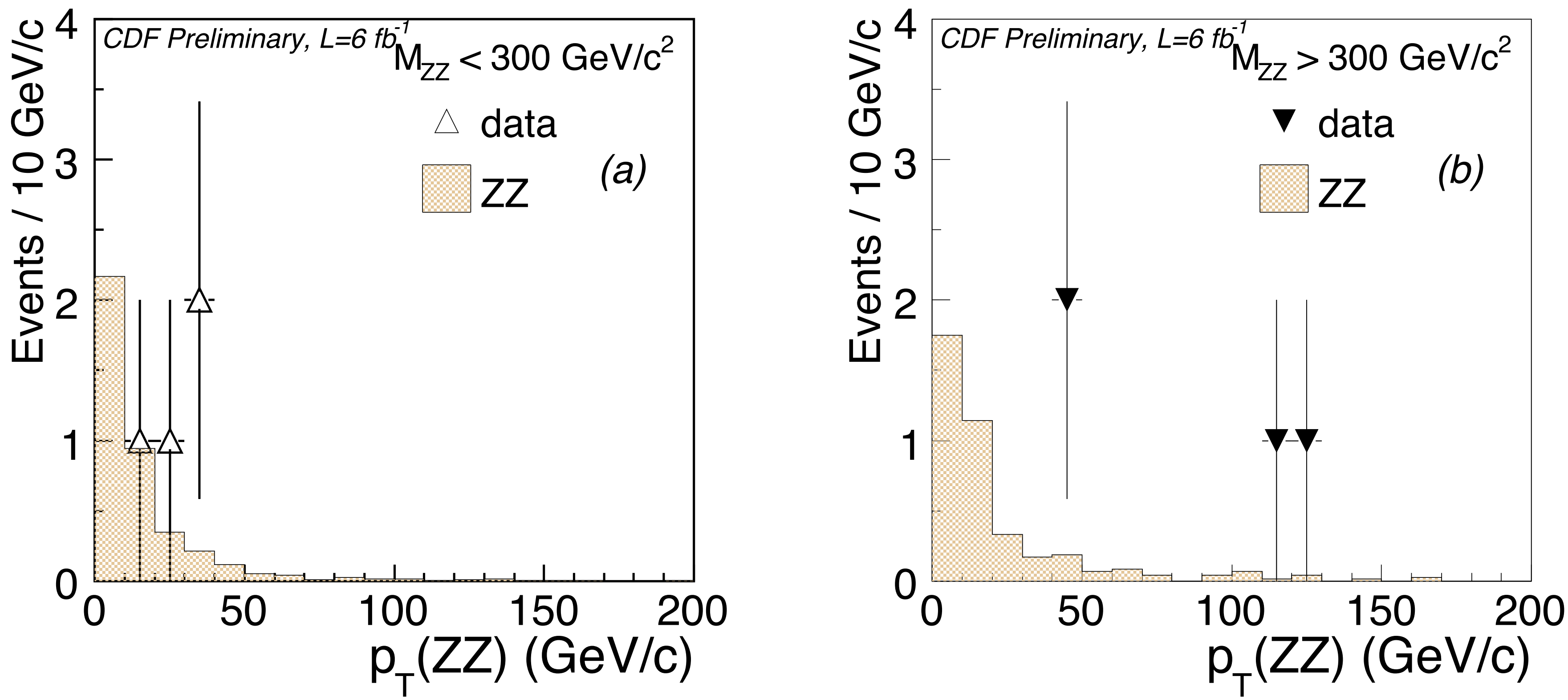
$ZZ \rightarrow 4\ell$





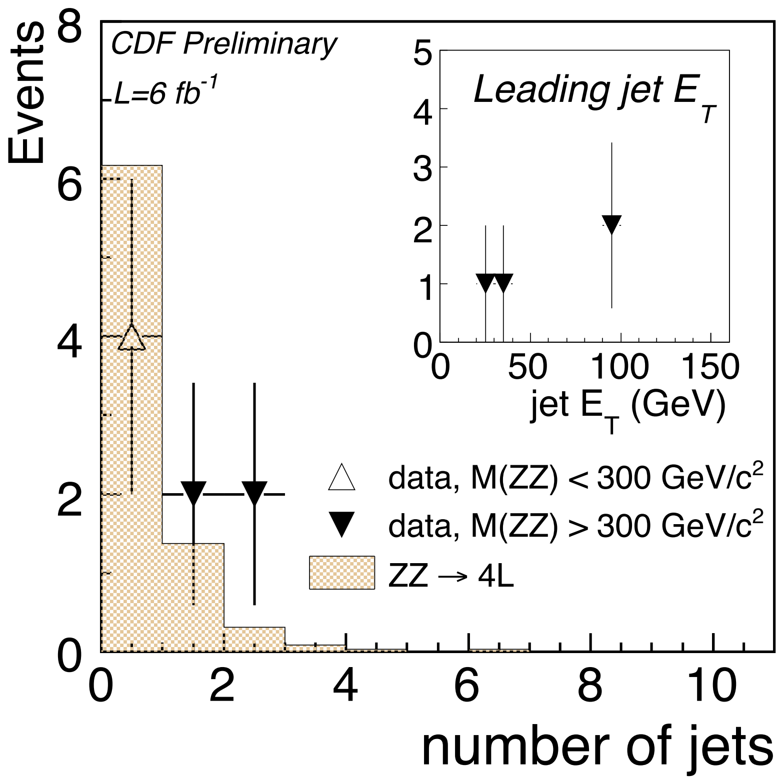
Most kinematic properties are as expected from SM prediction

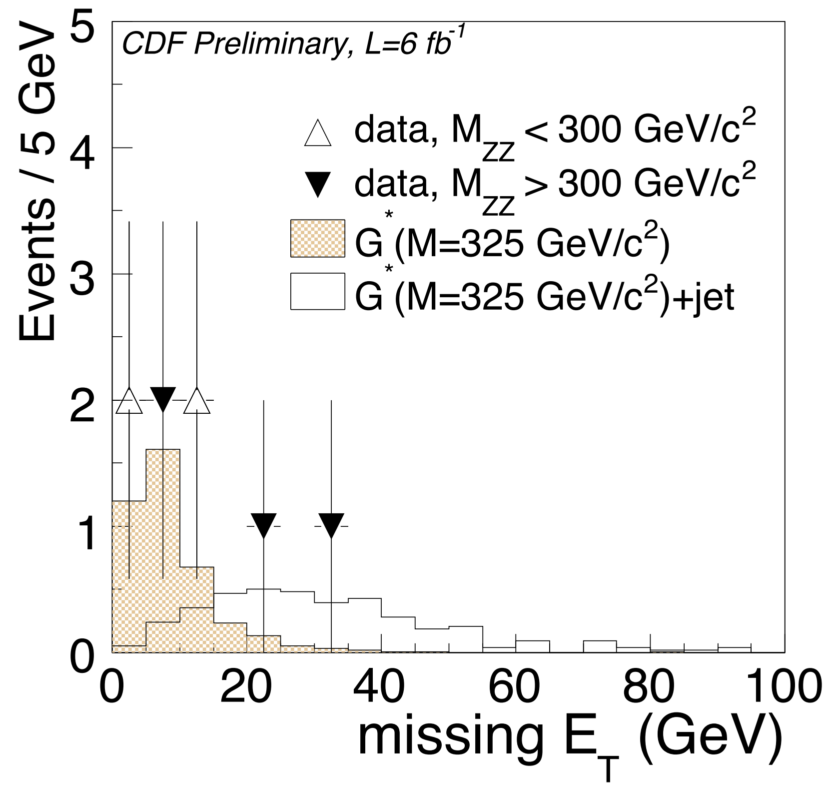
$ZZ \rightarrow 4\ell$



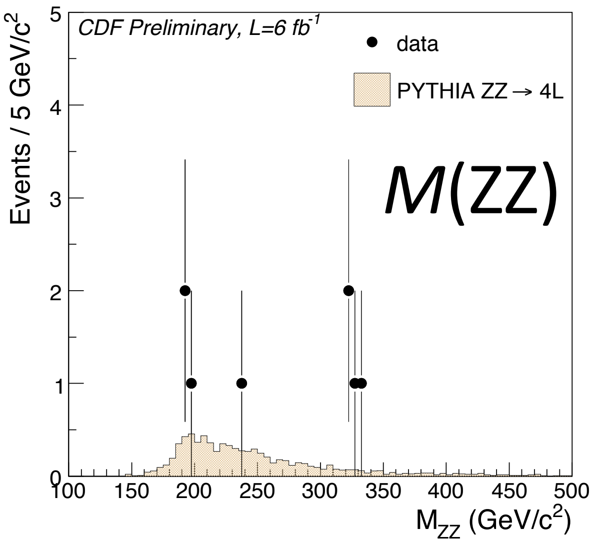
For the high-mass events p_T(ZZ) is not like SM prediction

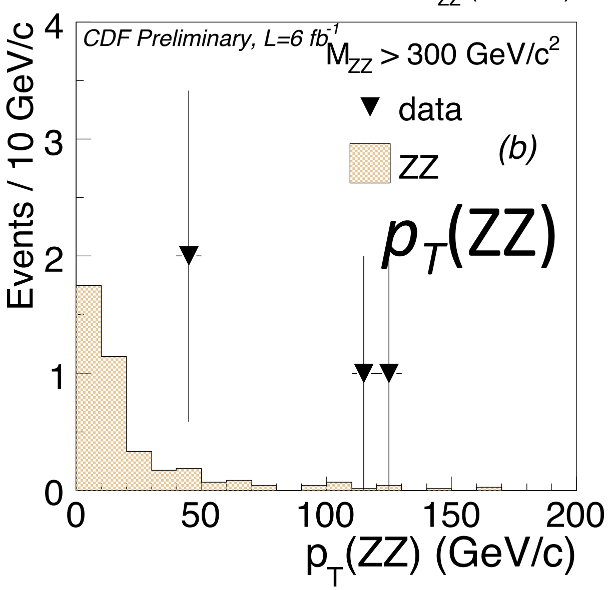
$ZZ \rightarrow 4\ell$





$ZZ \rightarrow 4\ell$



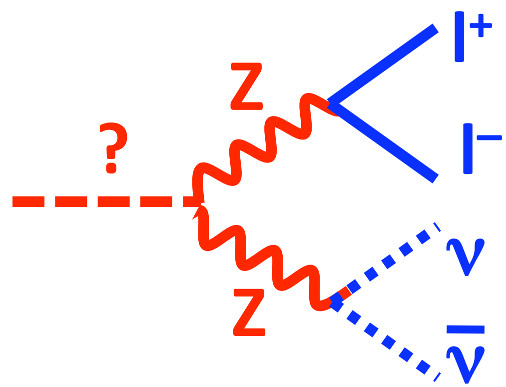


For mean expected events
prob. to observe ≥4 events with M_{ZZ}>300GeV/c^2
where M_{ZZ} of at least 4 within any 20GeV/c^2 window:
O(10^{-4}) (a range, depends Pythia/MC@NLO+Herwig)

Additionally include p_T(ZZ) in likelihood:
O(10^{-5})

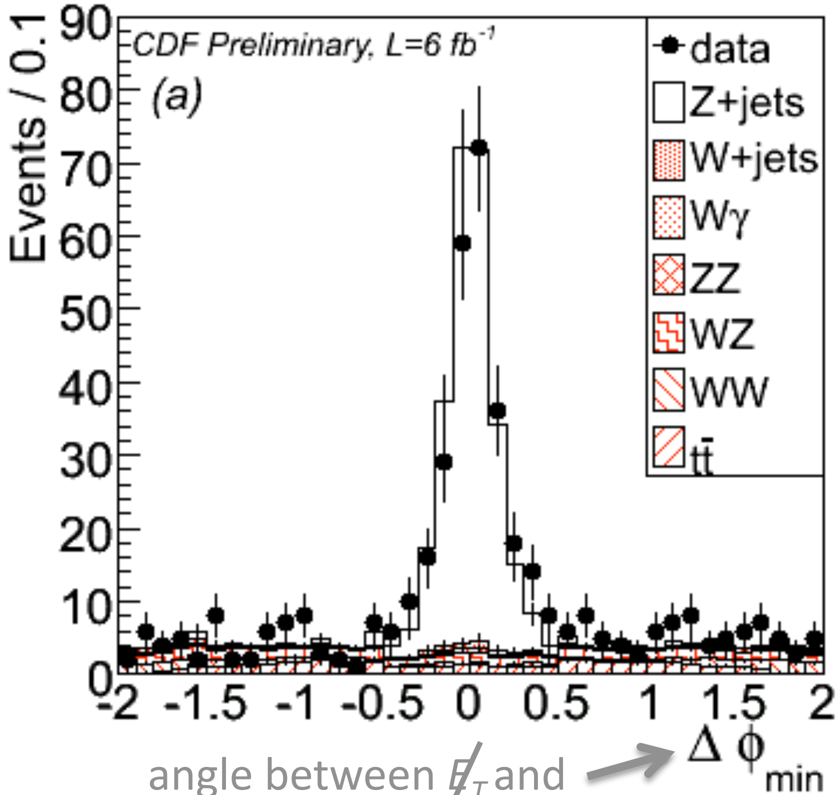
Prob. of likelihood of p_T(ZZ) distribution alone
being less than that of the data for high-mass events:
O(10^{-4})

$\ell\ell + \not{E}_T$

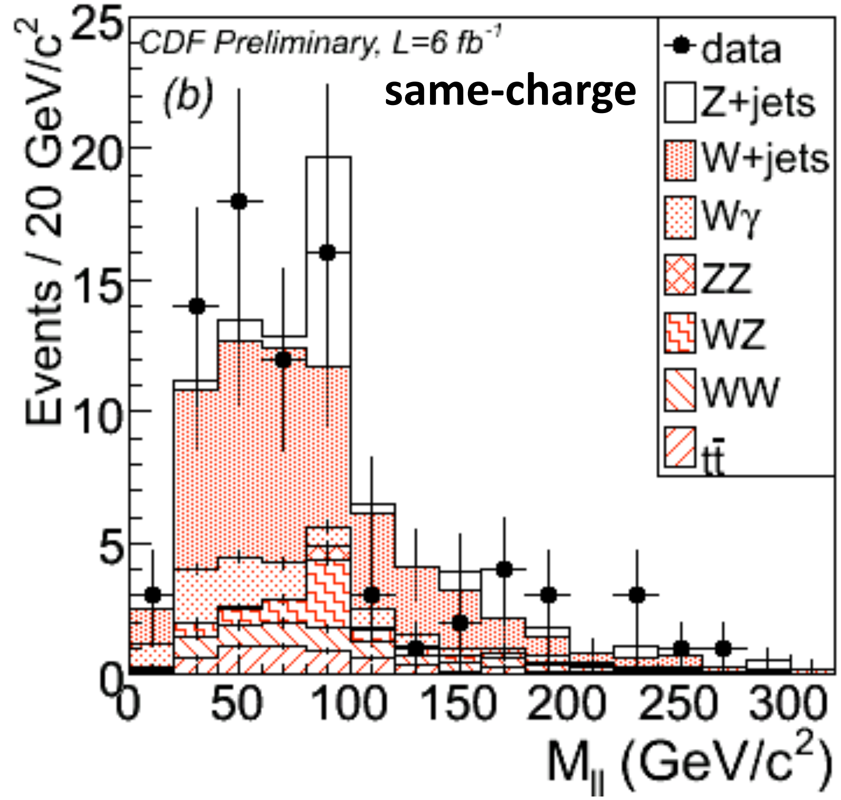


Expected yield: 10 x ZZ $\rightarrow 4\ell$

$\ell\ell+\not\!\!E_T$



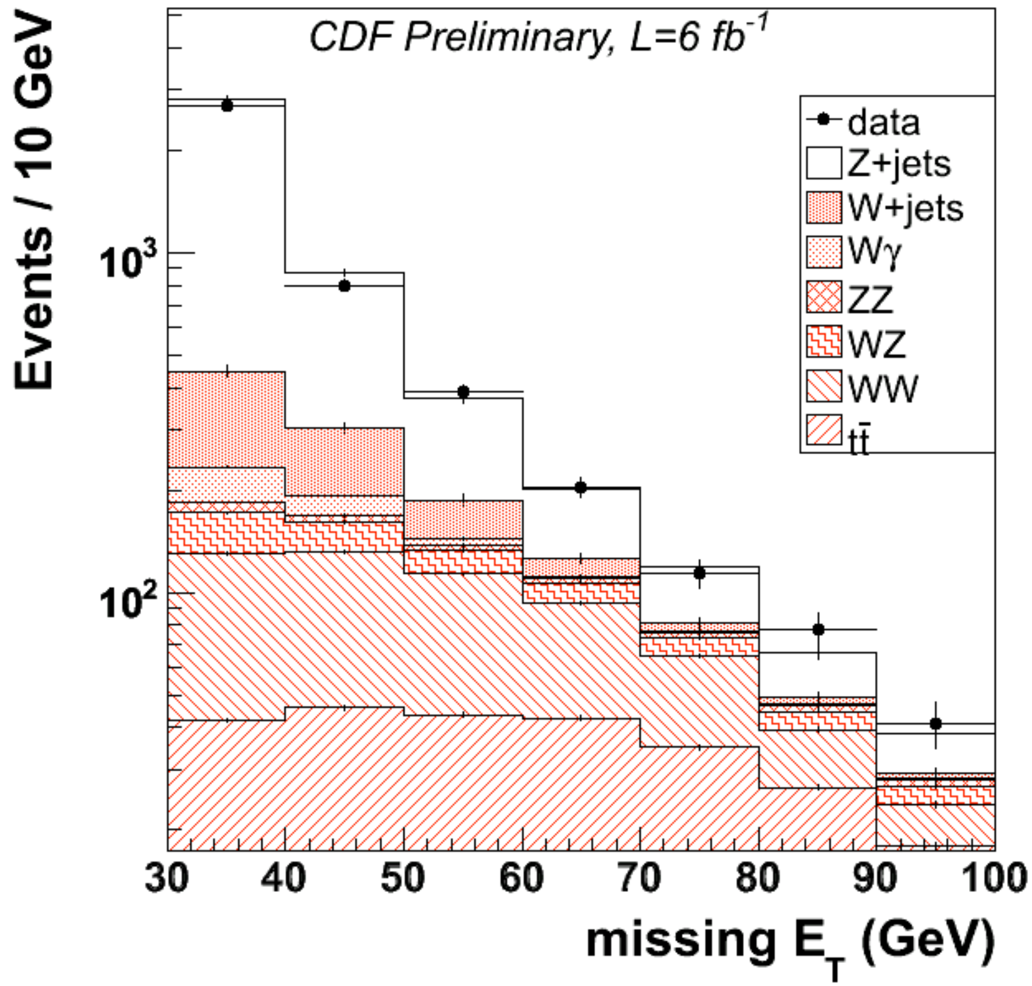
angle between $\not\!\!E_T$ and closest jet (or lepton)



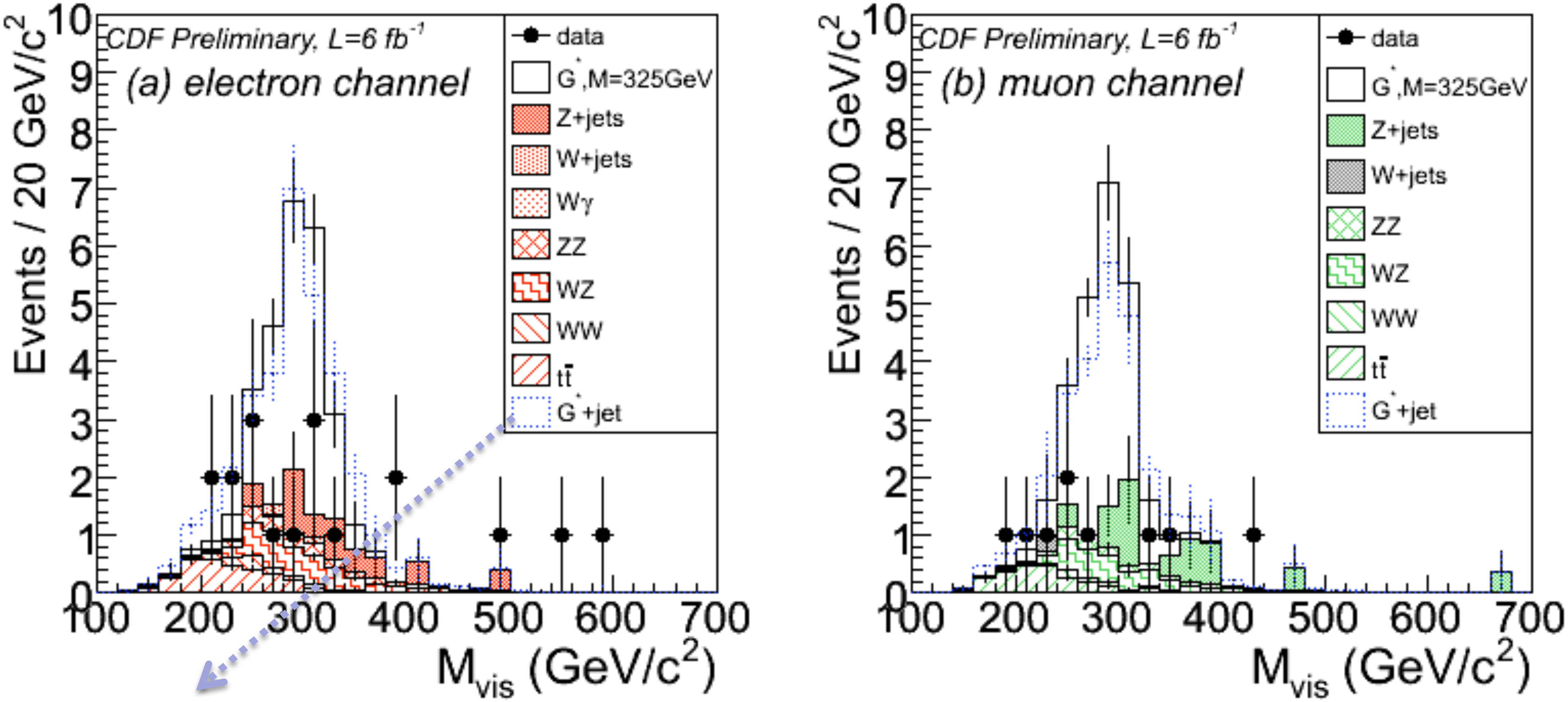
Select Z→ee & Z→μμ as for $\ell\ell\ell\ell$ channel
Signal region defined as $\not\!\!E_T$>100GeV
Here normalising Z+jets using:
50<$\not\!\!E_T$<100 GeV and $|\Delta\phi_{min}|$<0.5

Here cross-checking W+jets jet→lepton misidentification method using same-charge events with 50<$\not\!\!E_T$<100 GeV

$\ell\ell + \not{E}_T$



$\ell\ell+\not{E}_T$

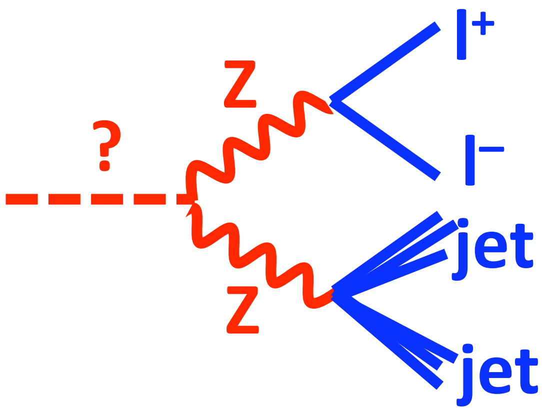


RS graviton, M(G*)=325 GeV/c^2, recoiling against a parton with E_T>100GeV

$$M_{vis} = |\, (E,\mathbf{p})_{lep\,1} + (E,\mathbf{p})_{lep\,2} + (|\not{E}_T|, \not{E}_x, \not{E}_y, 0)\, |$$

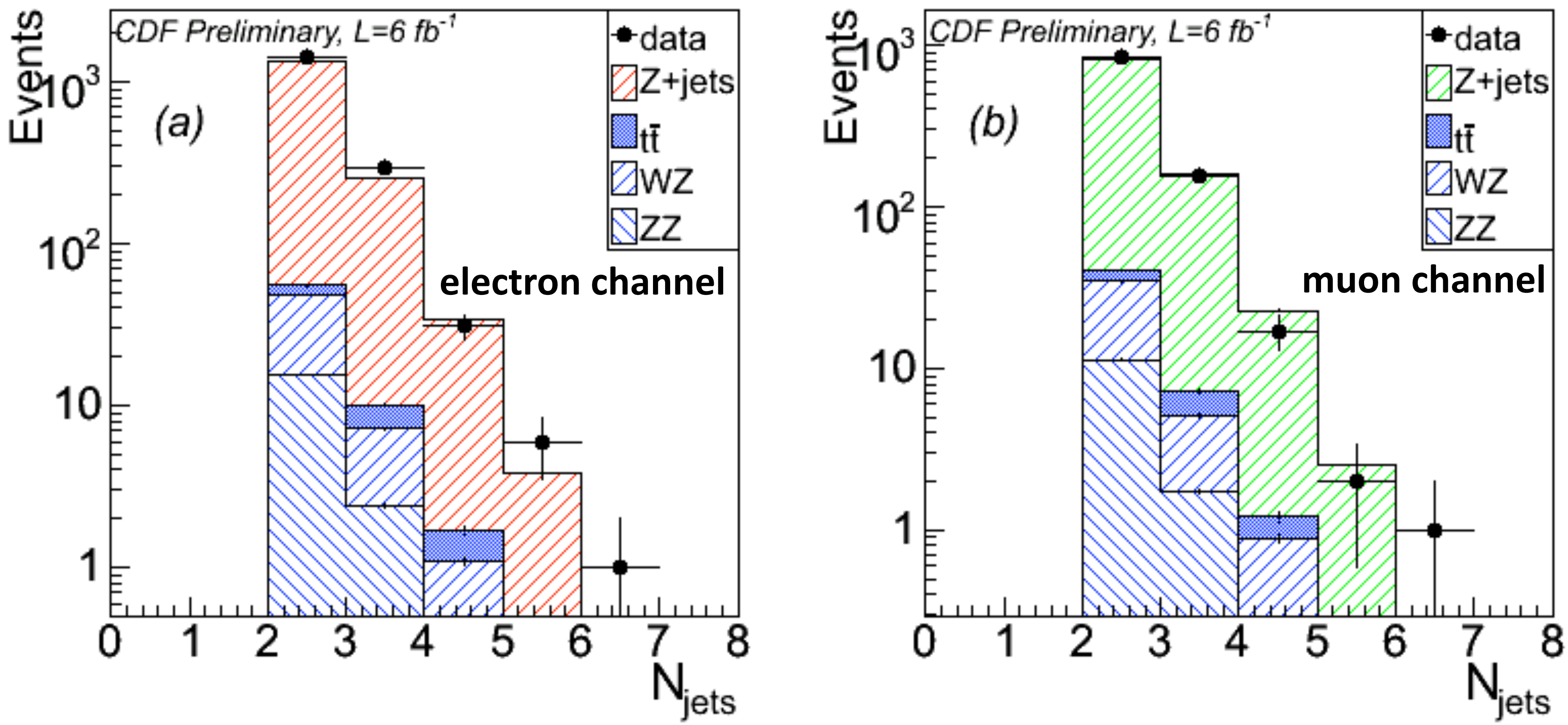
	electron channel	muon channel
standard model	13.6±1.8	12.4±1.8
data	18	9
expected M(G*)=325GeV/c^2, 1pb signal	17±1	18±1

ℓℓjj



Expected yield: 20 x ZZ →4ℓ

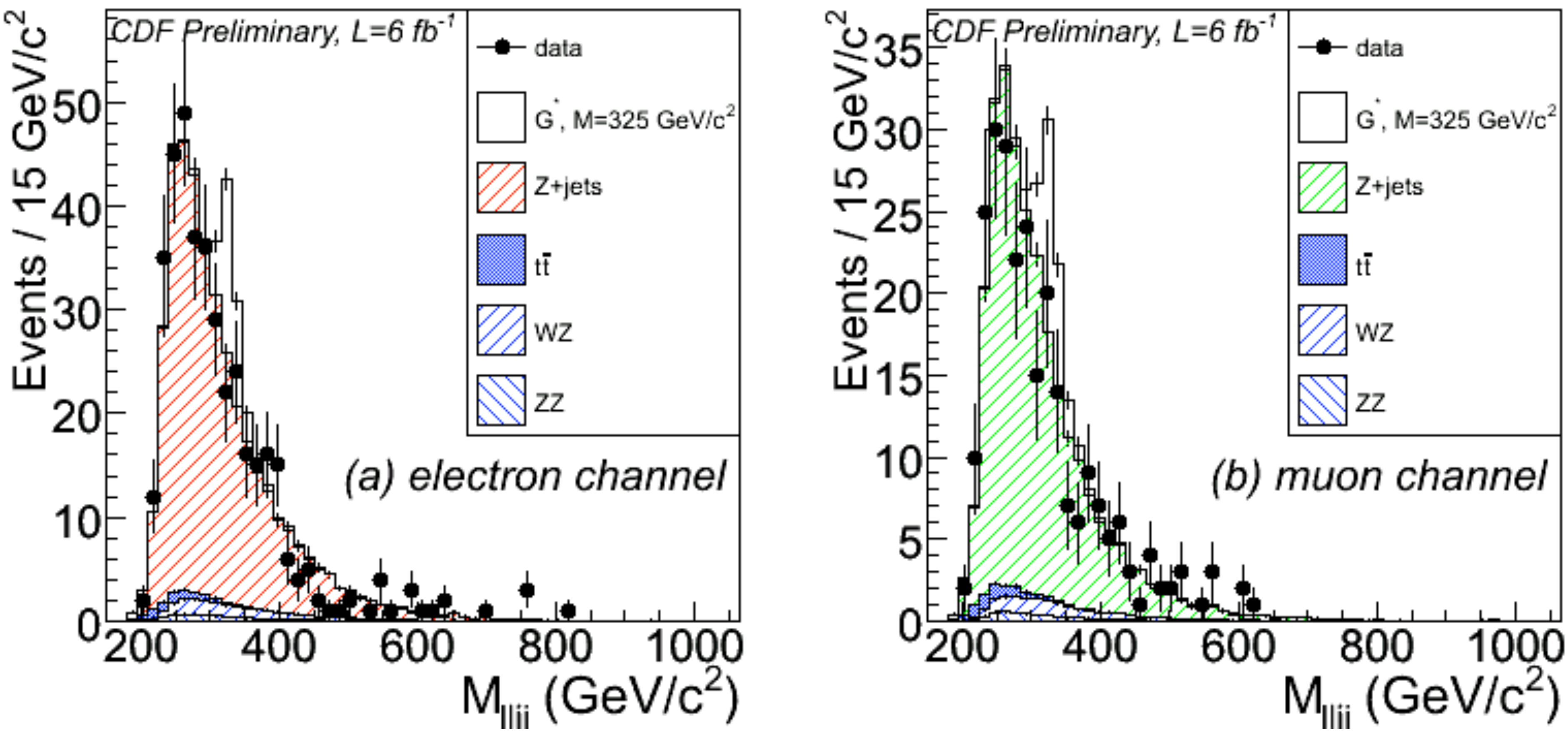
$\ell\ell jj$



Select Z→ee & Z→μμ as for $\ell\ell\ell\ell$ channel
Additionally, ≥2 jets E_T>25GeV
70<M_{jj}<110 accepted as a Z candidate

Here, M(lljj)<300GeV/c^2 defines control region for Alpgen Z+jets normalisation

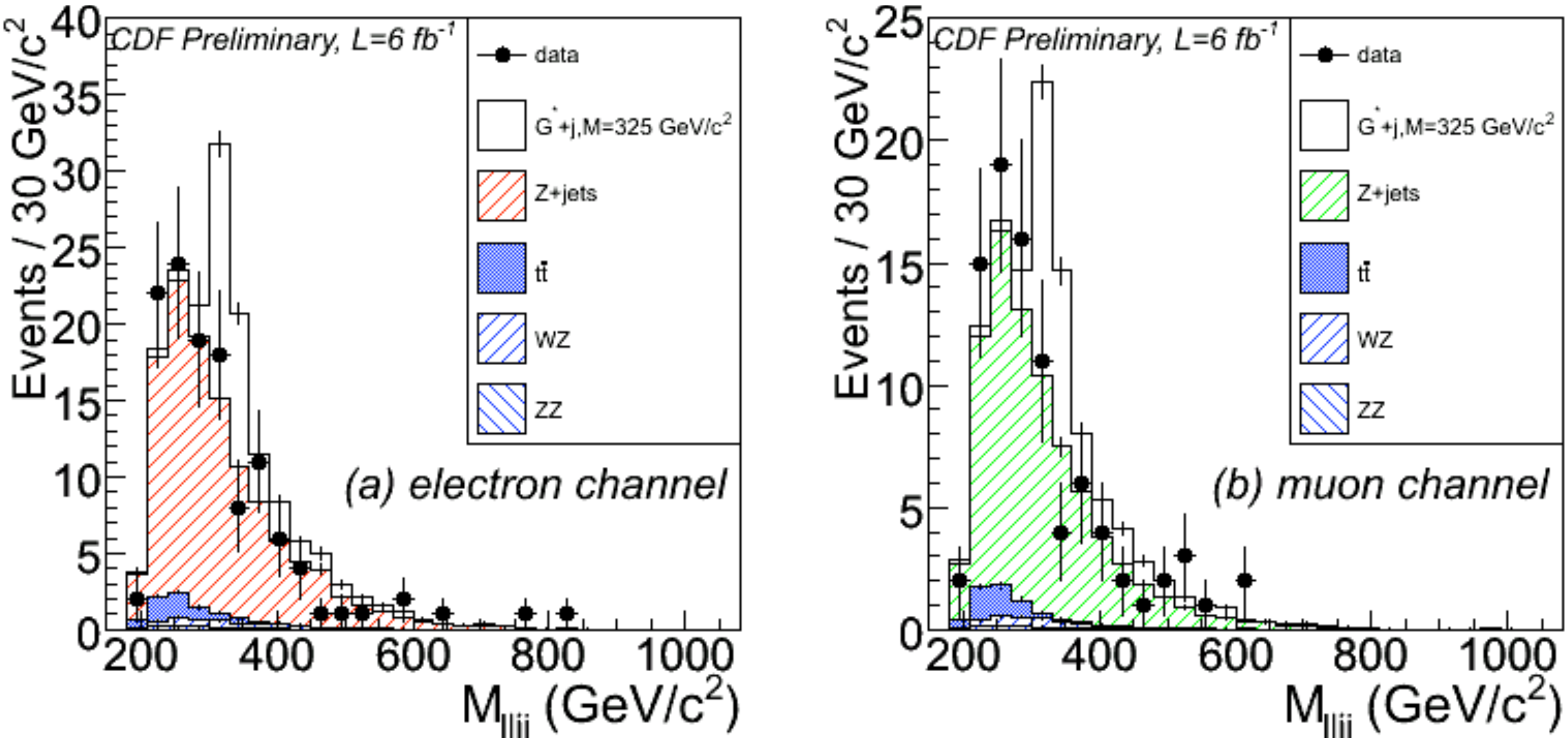
ℓℓjj



E_T(leading jet)>50GeV

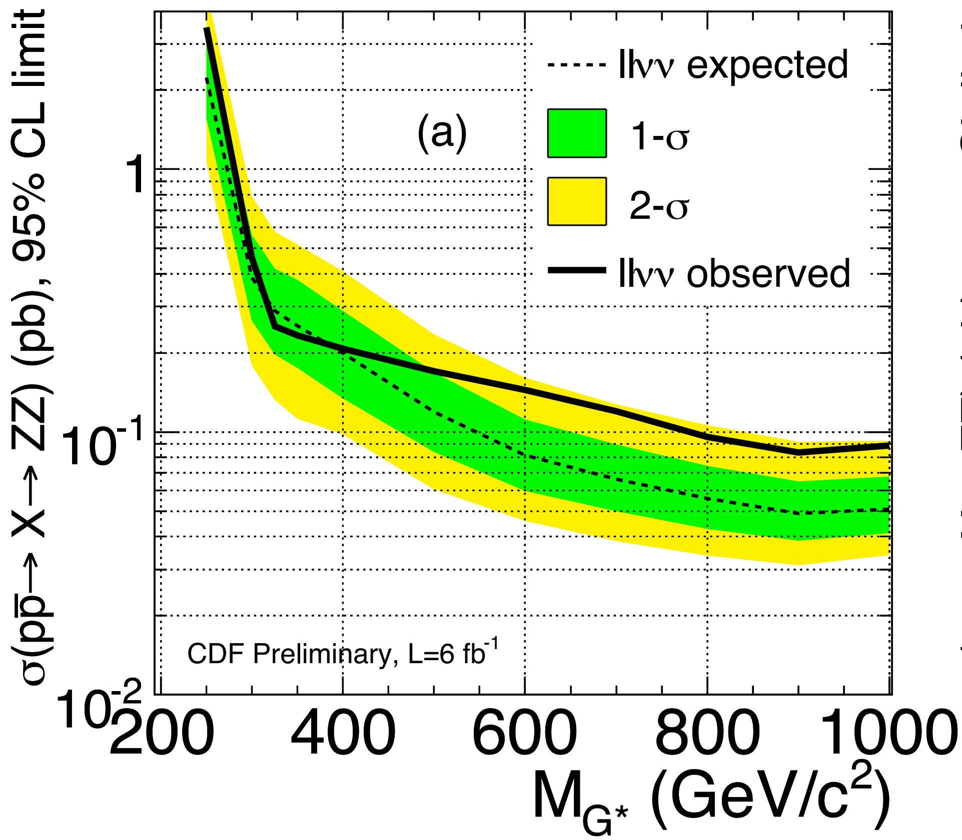
	electron channel	muon channel
standard model	424±40	266±24
data	392	253
expected M(G*)=325GeV/c^2, 1pb signal	41±1	32±1

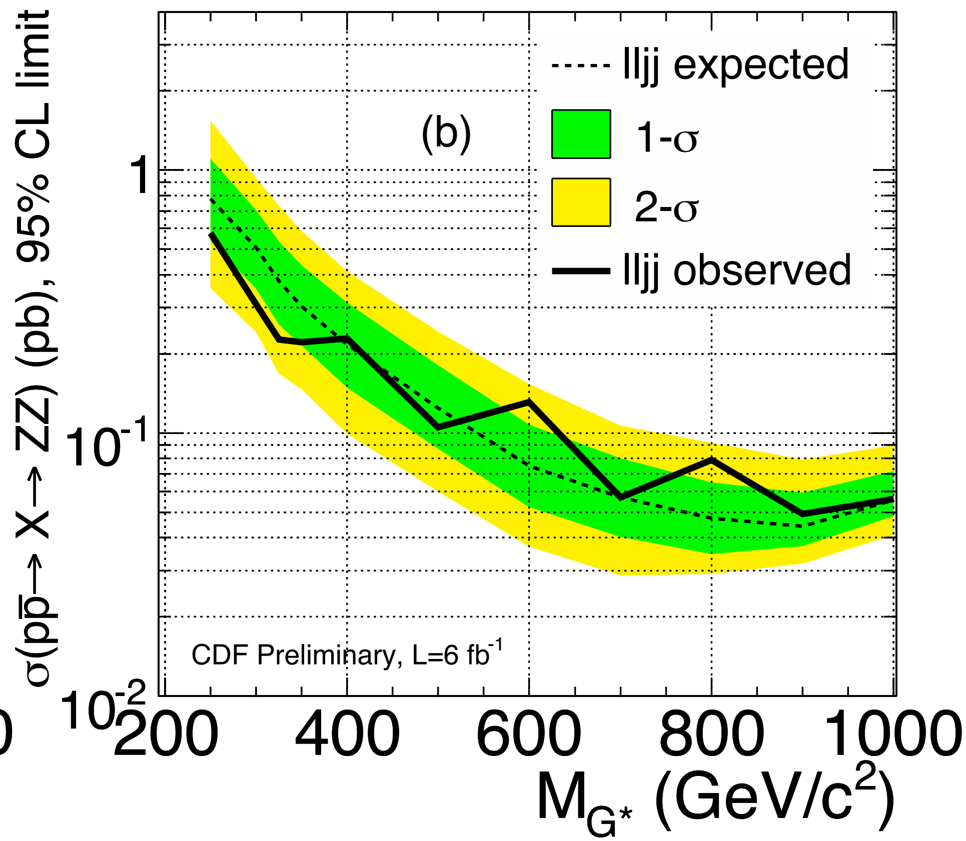
ℓℓjj



E_T(leading jet)>50GeV
and p_T(ll) or p_T (jj) > 40GeV/c

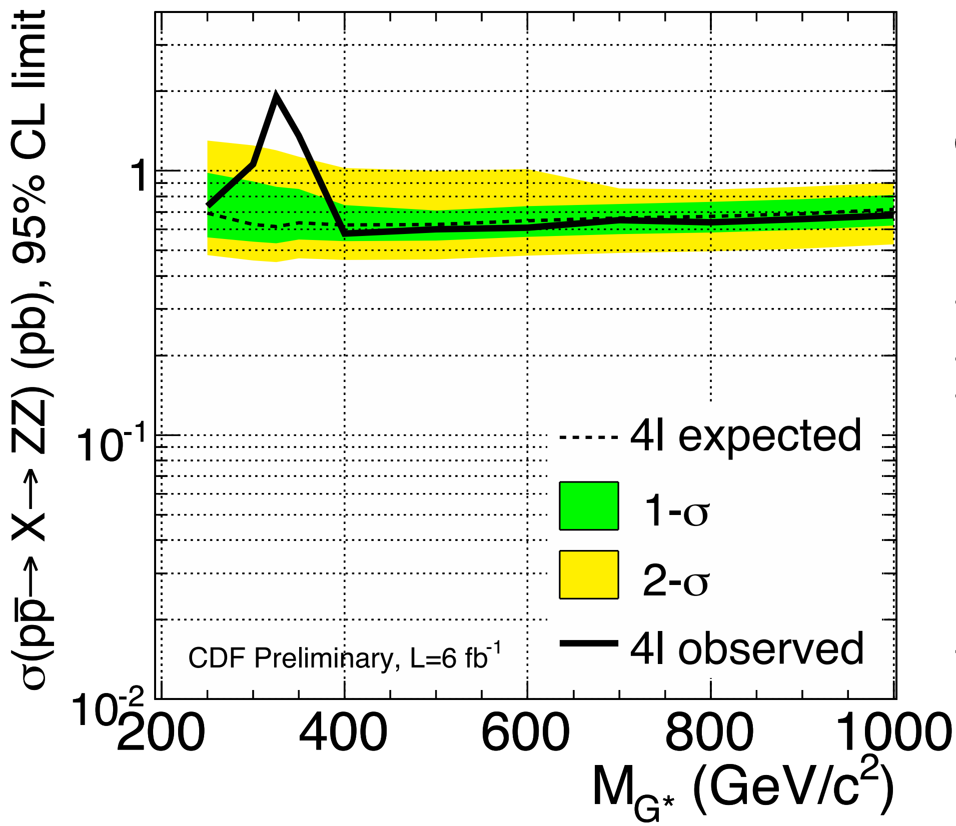
$\ell\ell + \not{E}_T$ $\ell\ell jj$

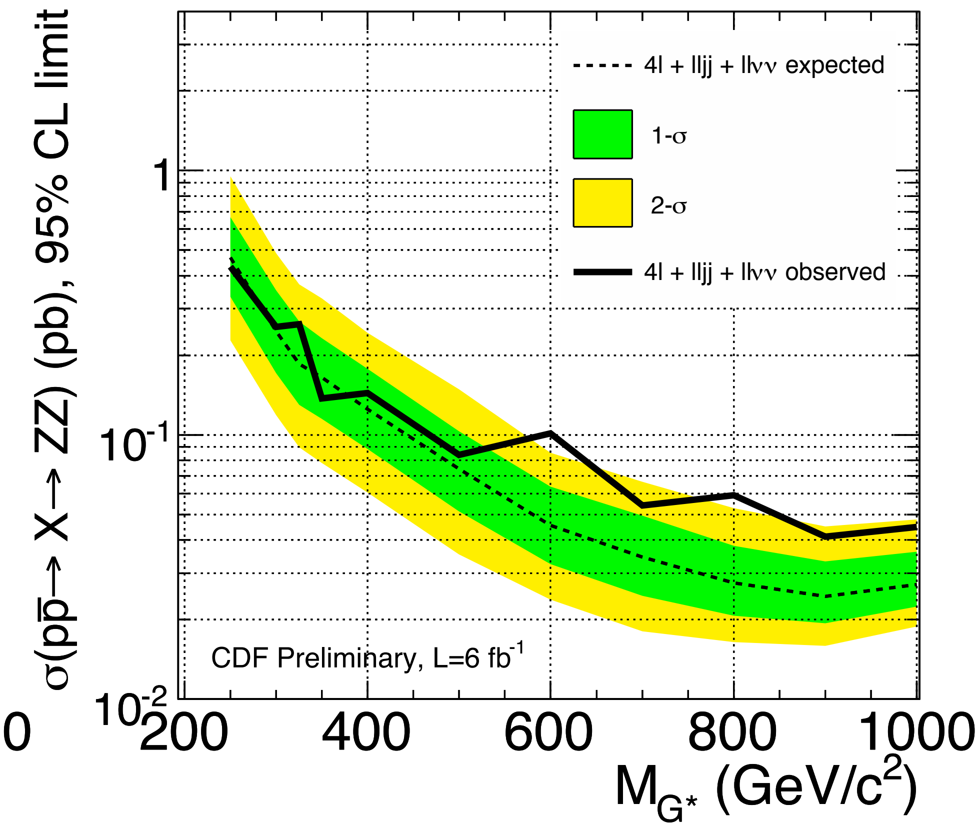




$M(G^*)=325 GeV/c^2$	expected	observed	expected	observed
RS:	0.29 pb	0.25 pb	0.38 pb	0.23 pb
Boosted RS:	0.30 pb	0.30 pb	0.27 pb	0.26 pb

$\ell\ell\ell\ell$ and $\ell\ell\ell\ell + \ell\ell + \not\!E_T + \ell\ell jj$

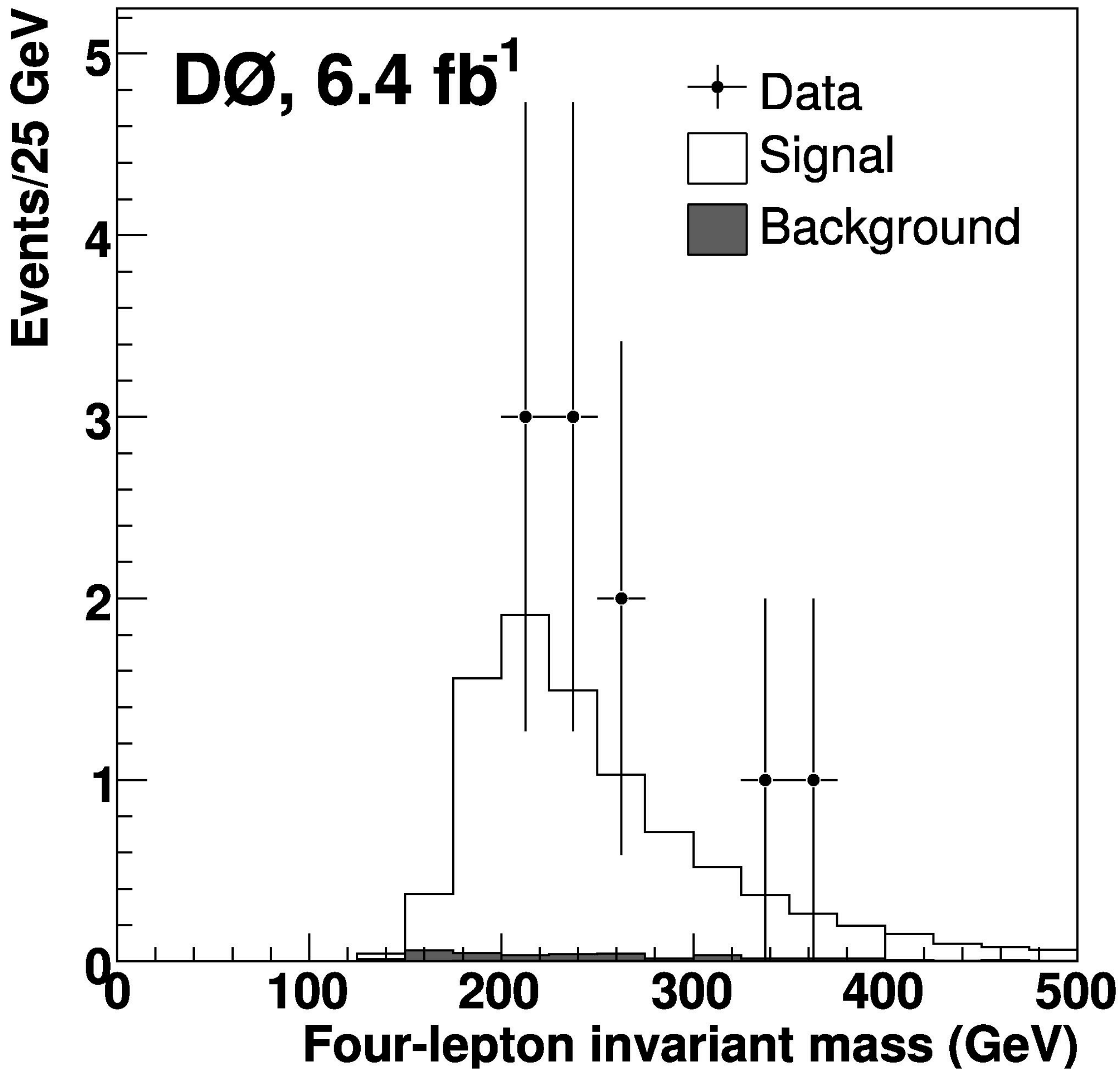




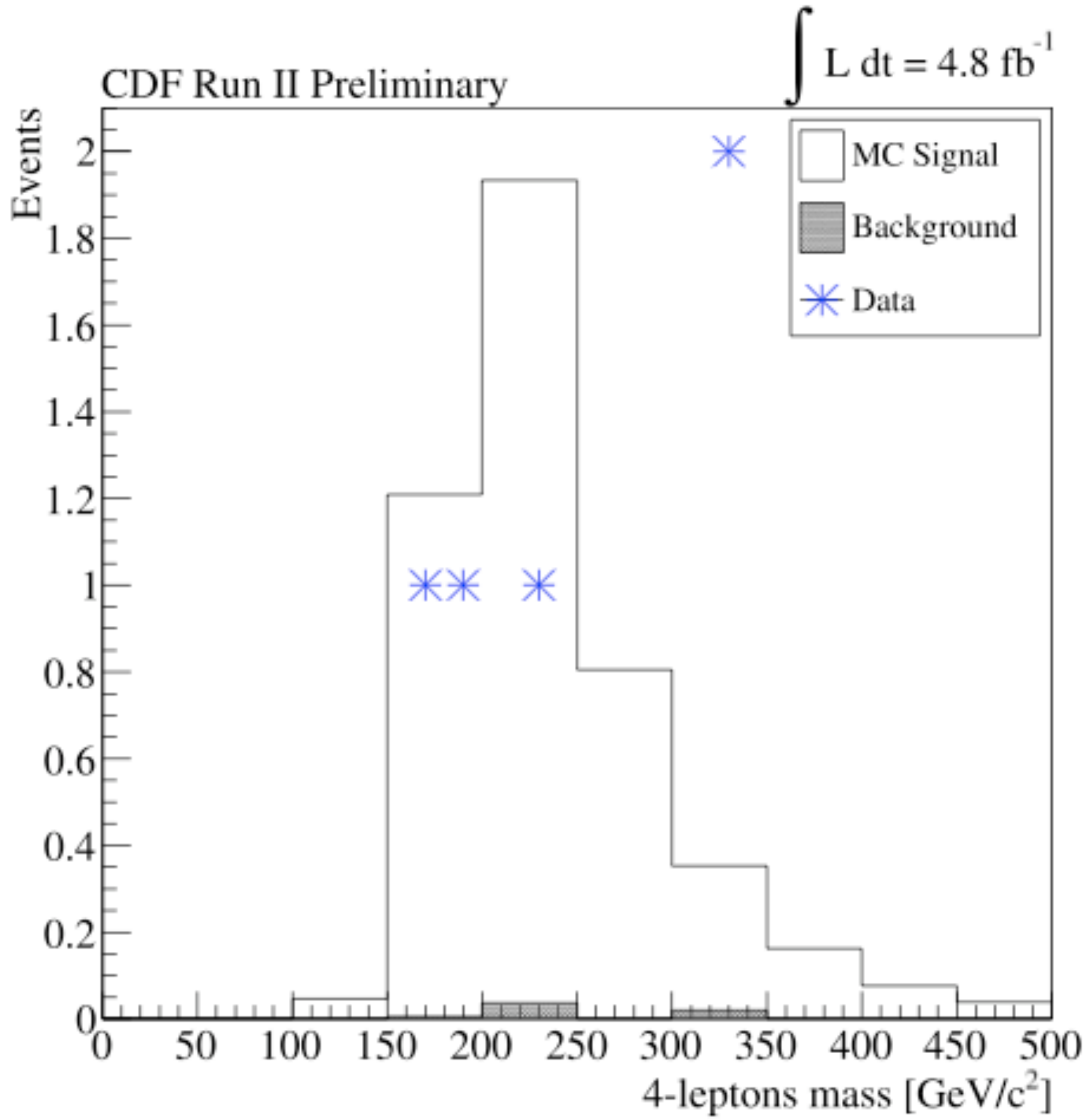
$M(G^*)=325\text{GeV}/c^2$	expected	observed	expected	observed
RS:	0.7 pb	1.9 pb	0.19 pb	0.26 pb
Boosted RS:			0.17 pb	0.28 pb

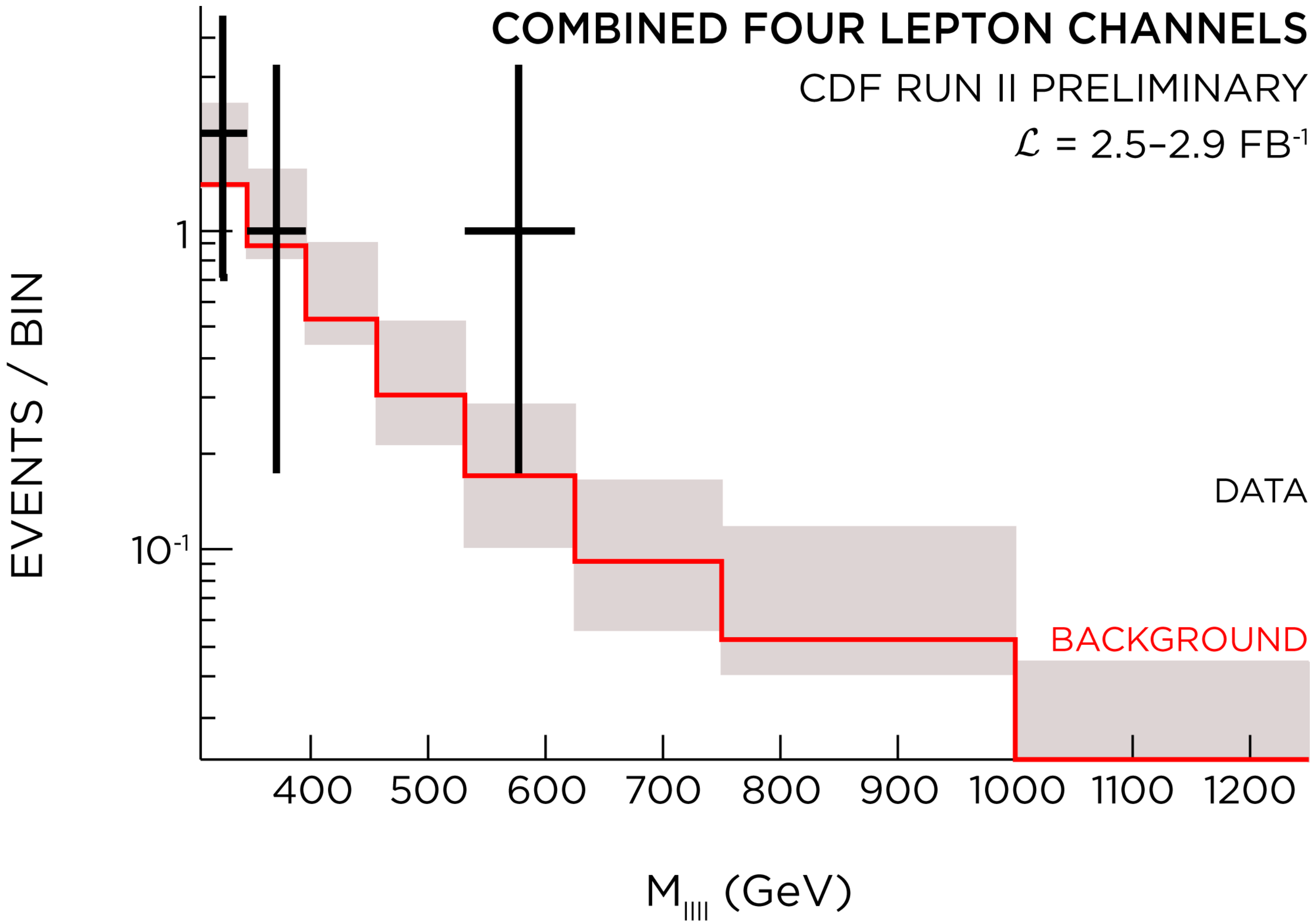
Searched for heavy resonances decaying to Z pairs

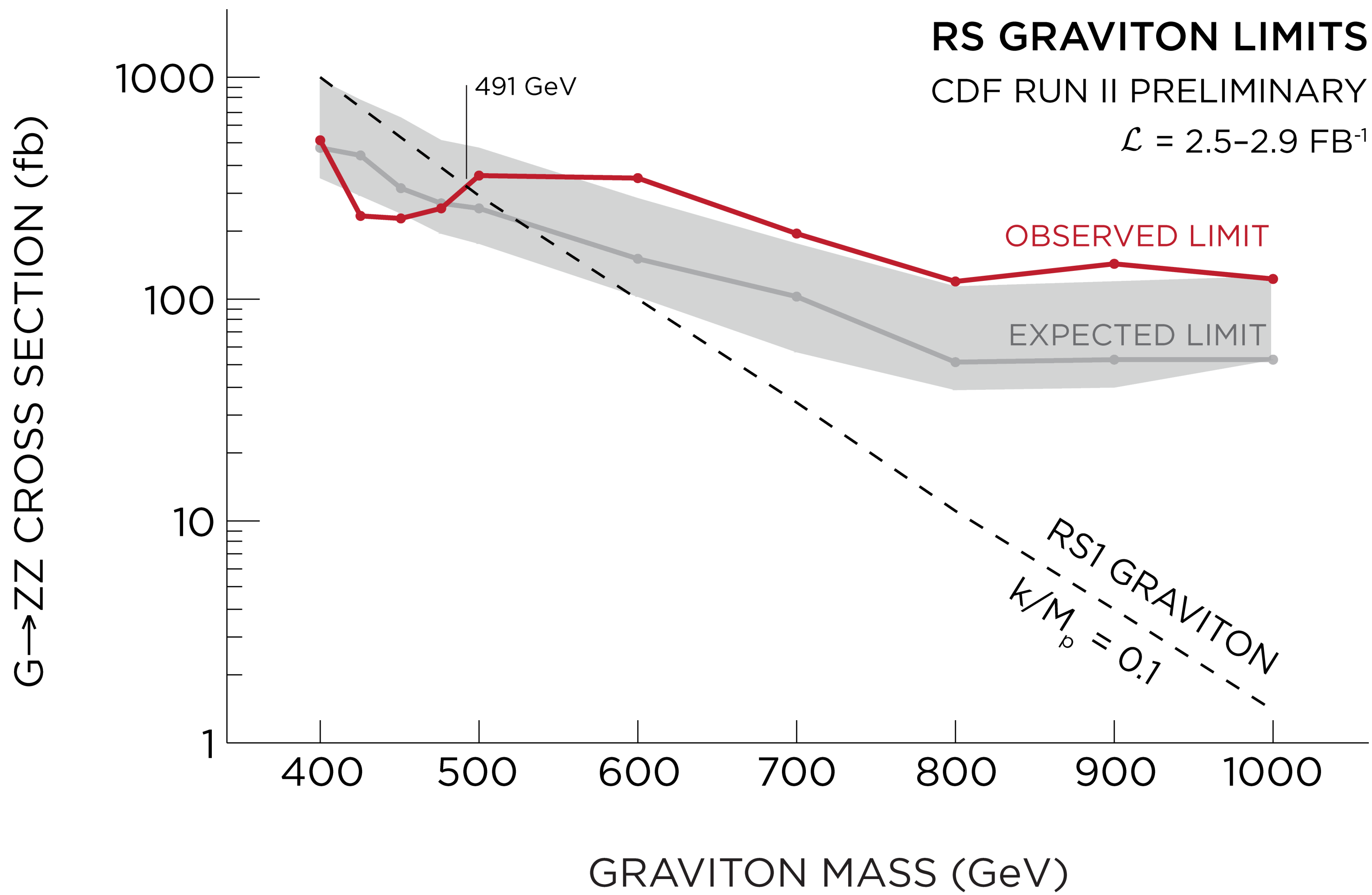
- M_{ZZ} and $p_T(ZZ)$ distributions in 4 lepton channel are different from those expected from standard model
- Four events have M_{ZZ} consistent with 327GeV/c^2
- $\ell\ell+E_T$ and $\ell\ell$jj channels do not confirm a new resonance
- limits set at level of 0.3pb in RS graviton models



DØ, 6.4 fb-1
Data
Signal
Background
Events/25 GeV
Four-lepton invariant mass (GeV)
0
1
2
3
4
5
0
100
200
300
400
500


CDF Run II Preliminary
$\int L\,dt = 4.8\ fb^{-1}$
Events
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
MC Signal
Background
Data
0
50
100
150
200
250
300
350
400
450
500
4-leptons mass [GeV/c^2]

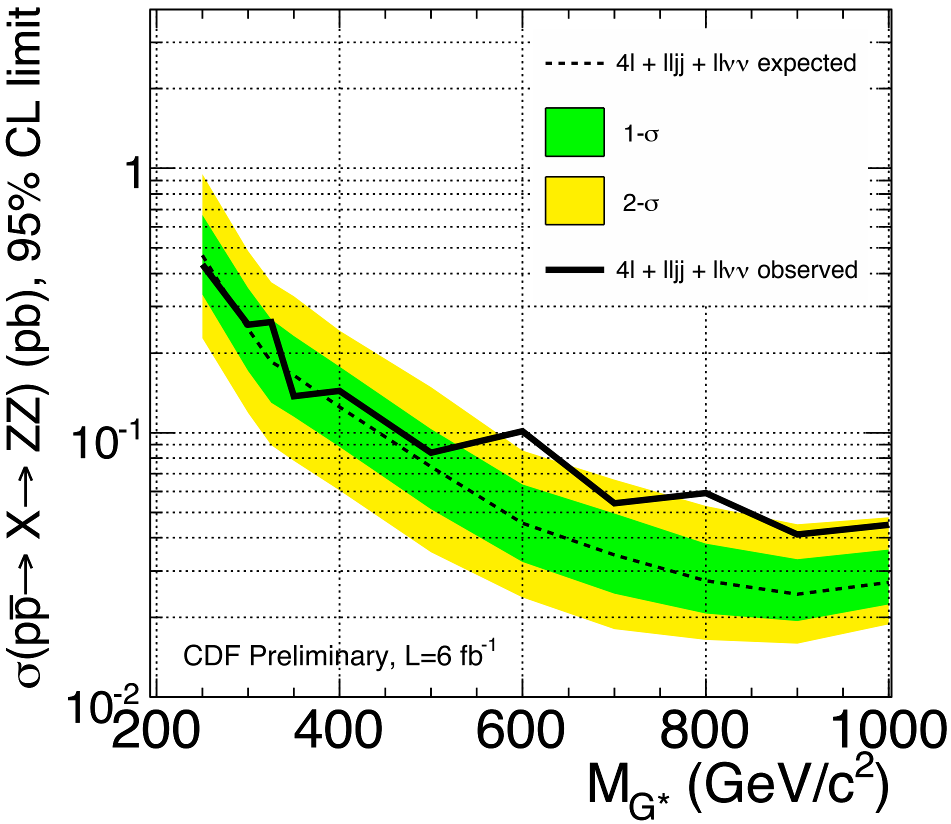

COMBINED FOUR LEPTON CHANNELS
CDF RUN II PRELIMINARY
$\mathcal{L}$ = 2.5–2.9 FB^{-1}
DATA
BACKGROUND
EVENTS / BIN
1
10^{-1}
400
500
600
700
800
900
1000
1100
1200
M_{llll} (GeV)

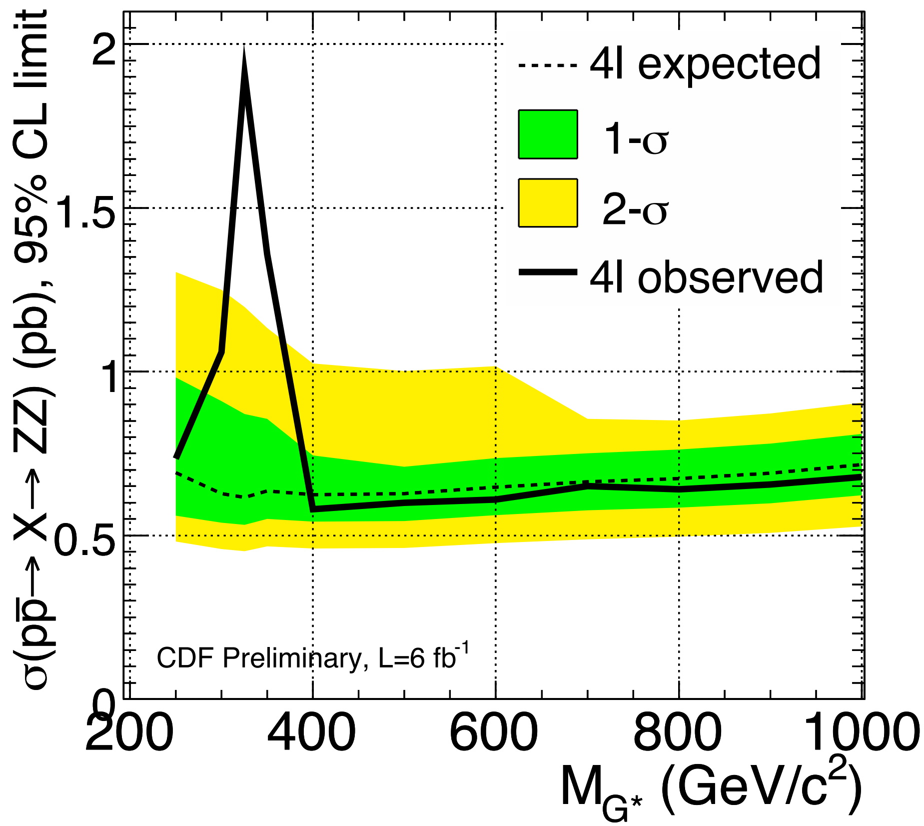


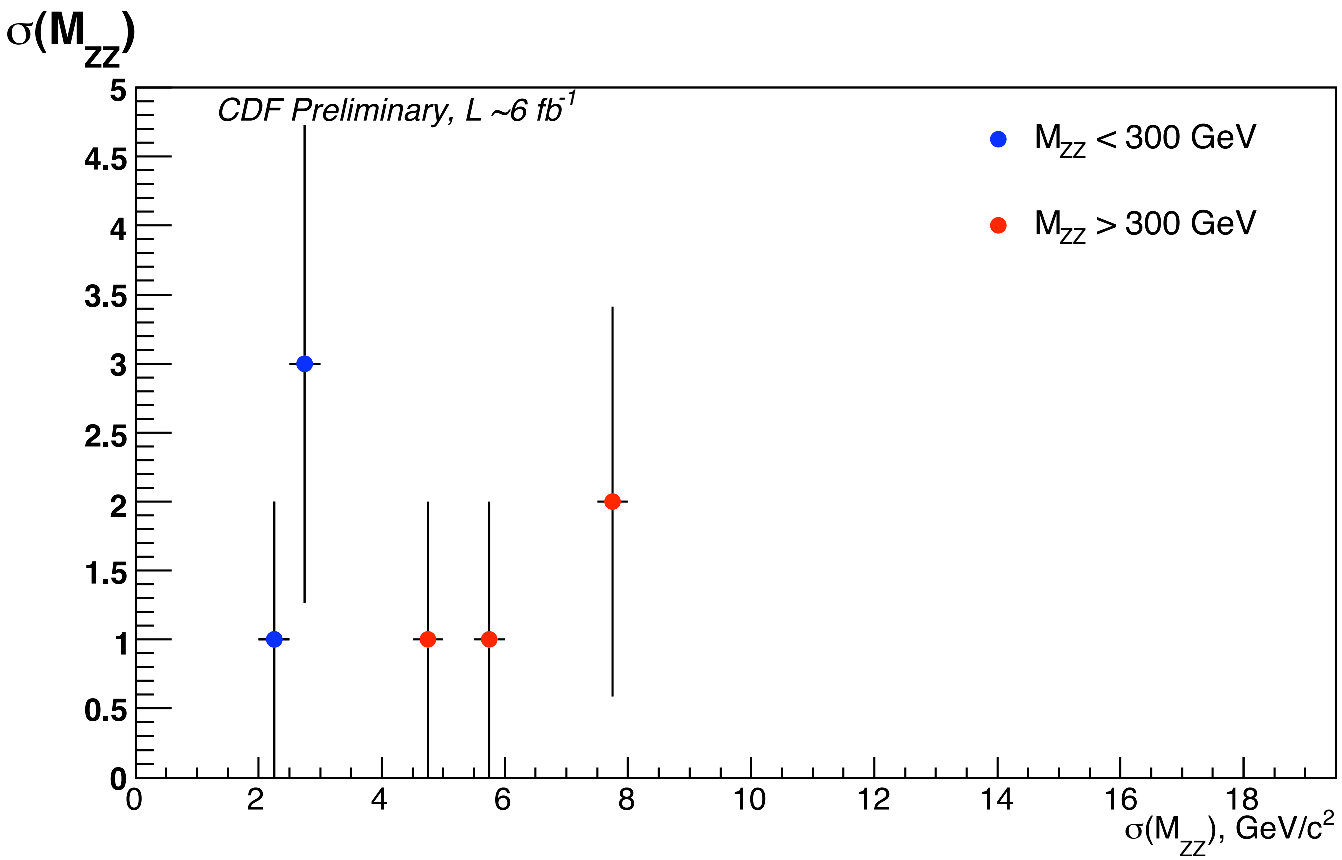
RS GRAVITON LIMITS
CDF RUN II PRELIMINARY
$\mathcal{L}$ = 2.5–2.9 FB^{-1}
491 GeV
OBSERVED LIMIT
EXPECTED LIMIT
RS1 GRAVITON
$k/M_P = 0.1$
G→ZZ CROSS SECTION (fb)
GRAVITON MASS (GeV)
1000
100
10
1
400
500
600
700
800
900
1000

RS1 graviton, k/M_P=0.1
M=600 GeV/c^2, σ(pp→G→ZZ) ≈ 1pb
M=700 GeV/c^2, σ(pp→G→ZZ) ≈ 0.1pb

Previous CDF limit 491 GeV/c^2.




4l expected
1-σ
2-σ
4l observed
CDF Preliminary, L=6 fb-1
σ(pp̄→ X→ ZZ) (pb), 95% CL limit
0
0.5
1
1.5
2
200
400
600
800
1000
MG* (GeV/c2)


σ(M_ZZ)
CDF Preliminary, L ~6 fb^-1
M_ZZ < 300 GeV
M_ZZ > 300 GeV
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
2
4
6
8
10
12
14
16
18
σ(M_ZZ), GeV/c^2

leptons	$M_{Z_1}, p_T(Z_1)$ (GeV/c^2), (GeV/c)	$M_{Z_2}, p_T(Z_2)$ (GeV/c^2), (GeV/c)	M_{ZZ} (GeV/c^2)	$p_T(ZZ)$ (GeV/c)	$\not\!\!E_T$ (GeV)	N_{jets}	Jet E_T (GeV)
$eeee$	93.3, 18.2	92.9, 17.4	196.6	35	14	0	
$\mu\mu\mu\mu$	85.9, 101.9	92.1, 54.8	321.1	47.4	8.4	1	36.7
$ee\mu\mu$	92.0, 156.0	89.9, 139.7	324.7	126.8	31	2	97.4, 40.0
$eeee$	101.3, 57.8	91.6, 13.2	334.4	44.7	9.9	1	22.7
$ee\mu\mu$	87.9, 17.7	91.8, 29.8	191.8	31	10.5	0	
$\mu\mu\mu\mu$	95.9, 197.9	92.0, 87.2	329.0	110.9	23.3	2	97.2, 24.7
$ee\mu\mu$	95.2, 36.7	89.7, 38.8	237.5	10.2	1.2	0	
$\mu\mu\mu\mu$	88.4, 51.0	89.8, 26.6	194.1	25.9	3.3	0	