BSM Searches at the Tevatron

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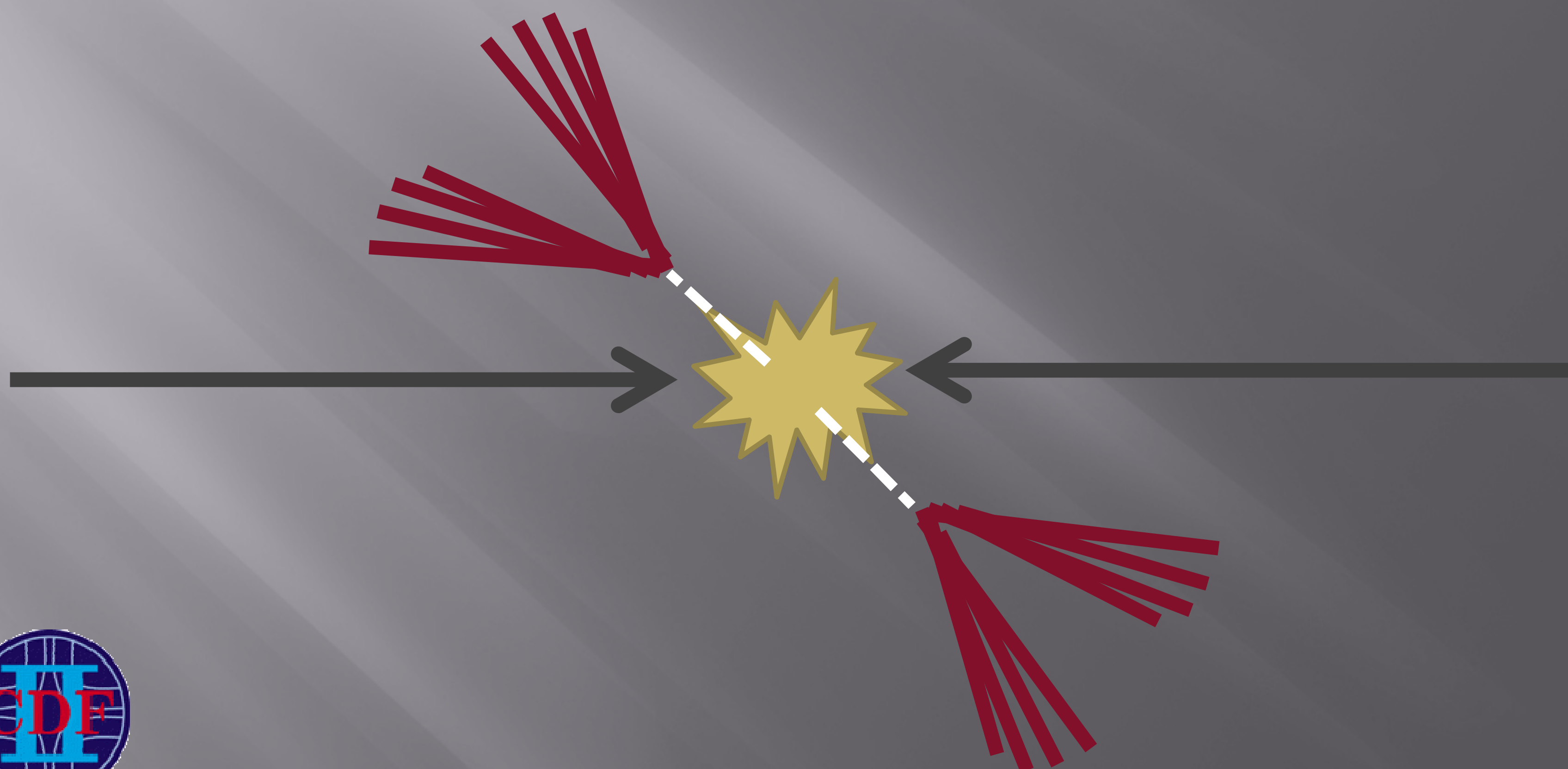
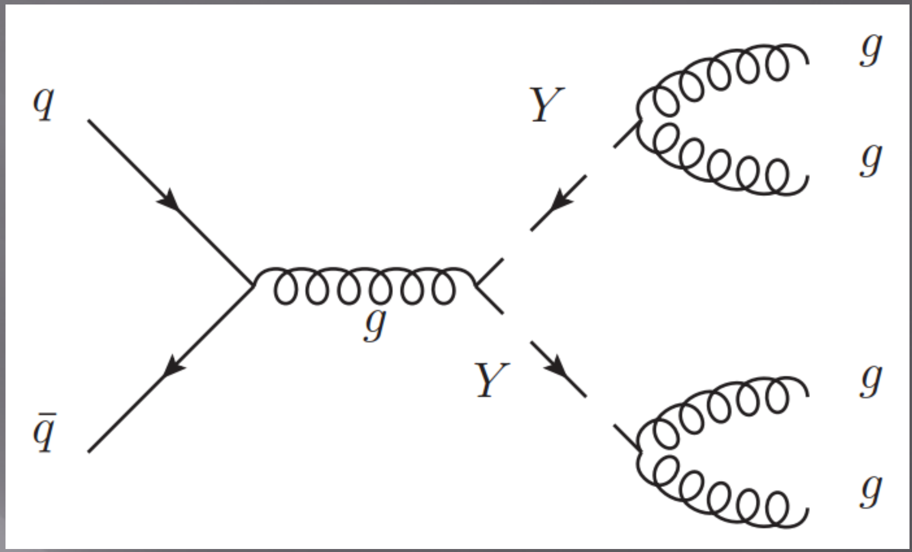
Search for Pair Production of Dijet Resonances



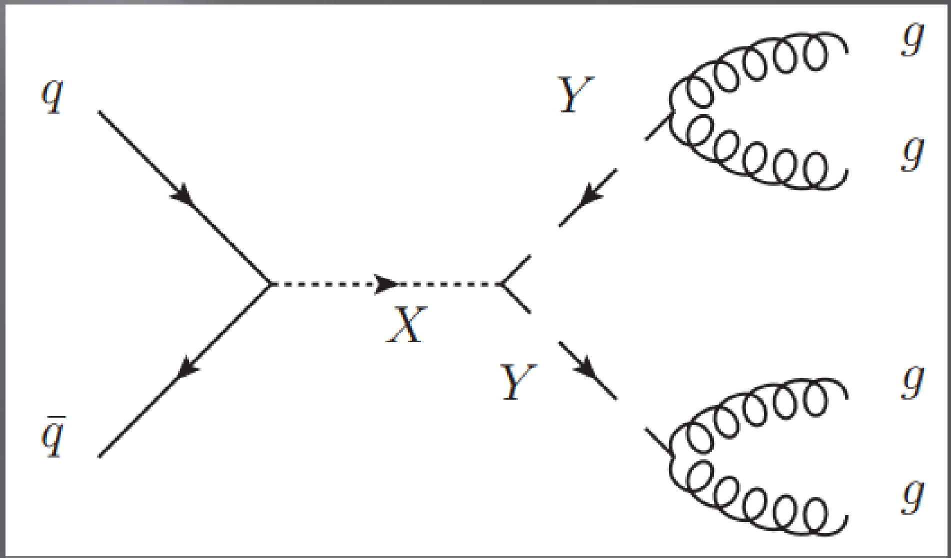
Phys Rev. Lett. 111, 031802 (2013)

(non) Resonant Production

- 6.6 fb^{-1}
- non-resonant production
  - Coloron pairs
  - RPV stop →jj

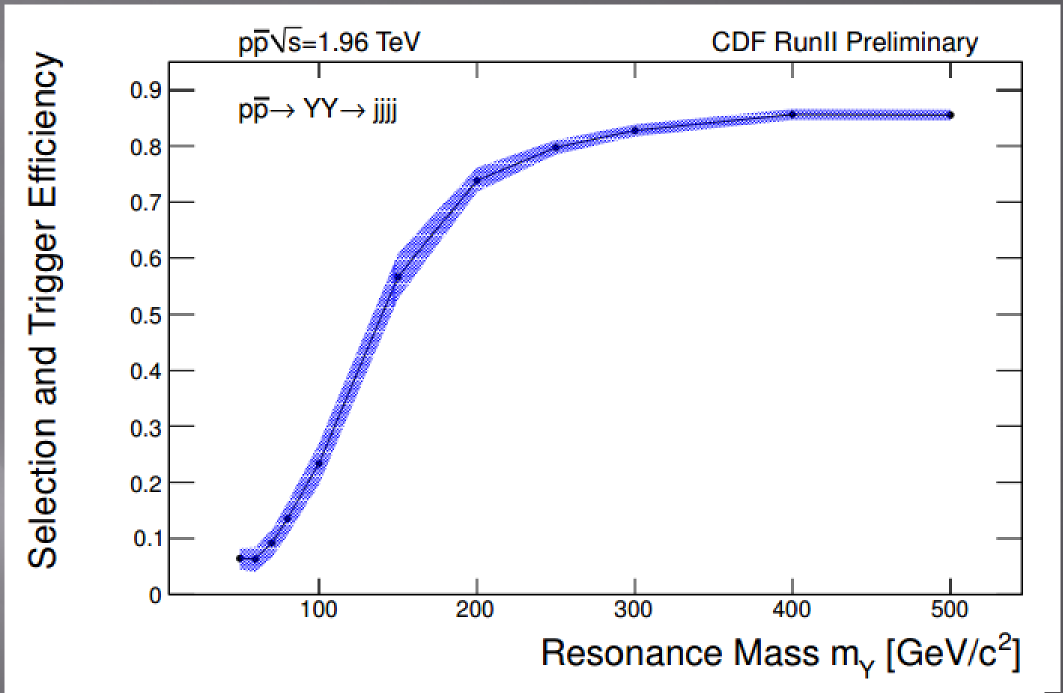


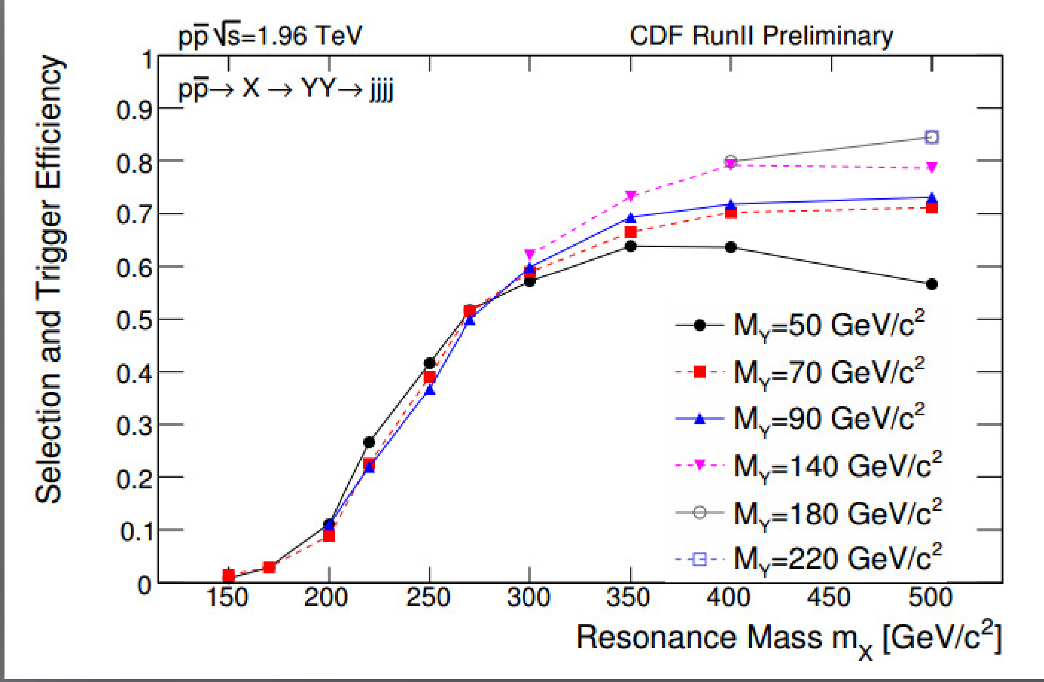
- resonant production
  - axi-gluon - consistent with Tevatron tt A_{FB} asymmetry excess



Selection

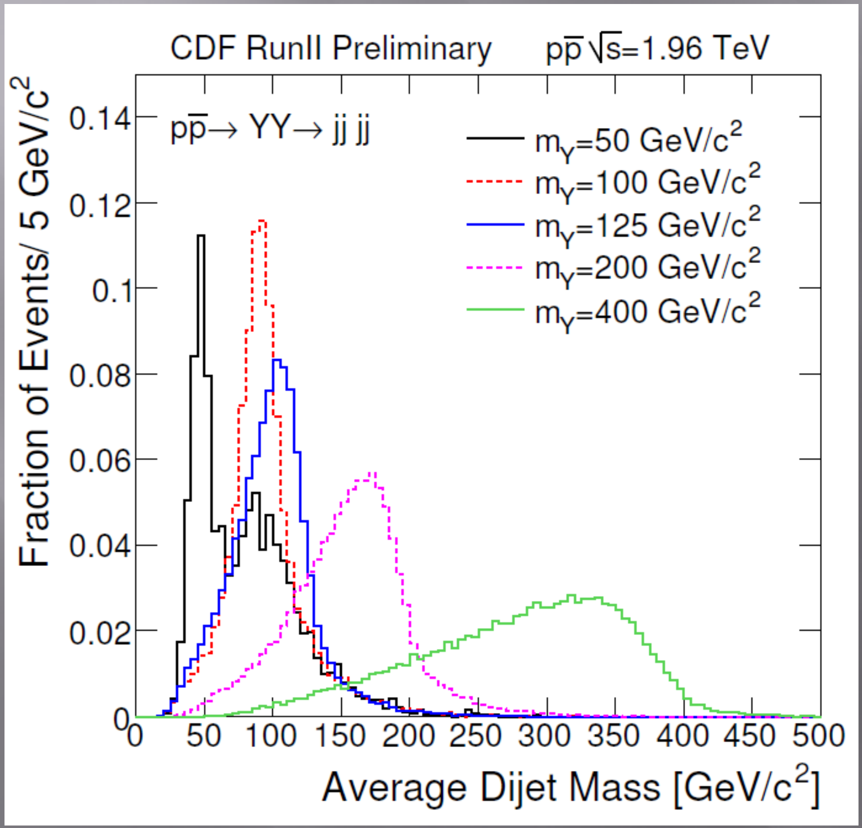
- Trigger
  - 3 jets, $E_T > 20$ GeV
  - Σ Et>130 GeV
- Selection
  - JETCLU, cone 0.4
  - 4 jets, $E_T > 15$ GeV
  - $|\eta| < 2.4$
- Efficiencies
  - PYTHIA + GEANT



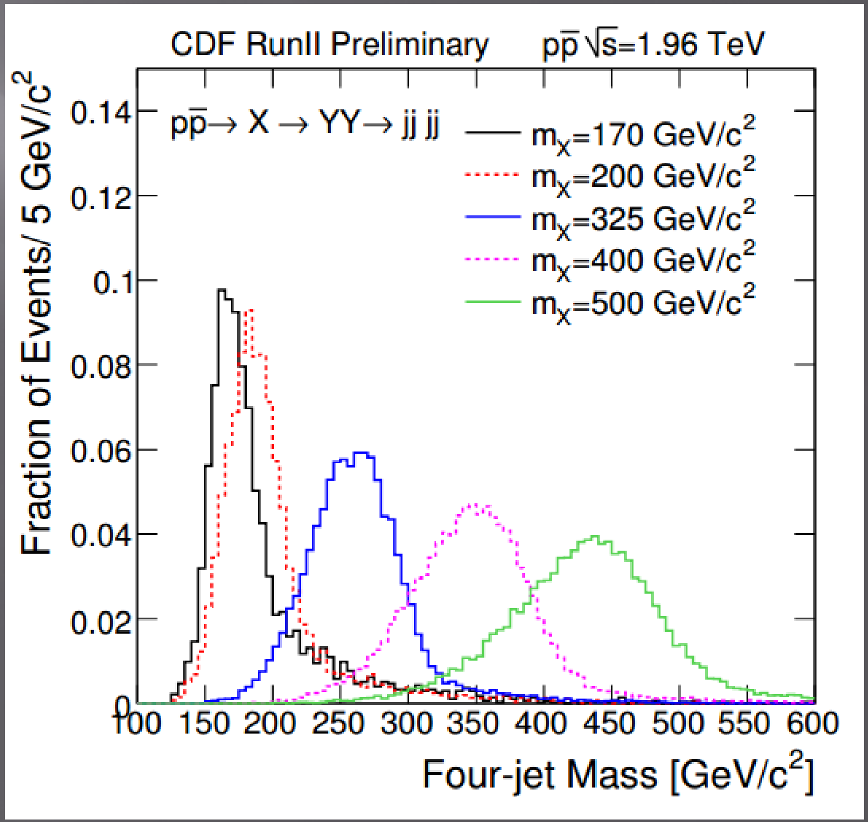


Mass Reconstruction

- Use 4 leading jets
- Select combinations with min $|M_{Y1}-M_{Y2}|$
- M_{Y1} and M_{Y2} must be within 50%, $\cos\theta^{*}<0.9$
- $YY\rightarrow(jj)(jj)$, use average of M_{Y1} and M_{Y2}
- $X\rightarrow YY\rightarrow(jj)(jj)$, use 4j mass

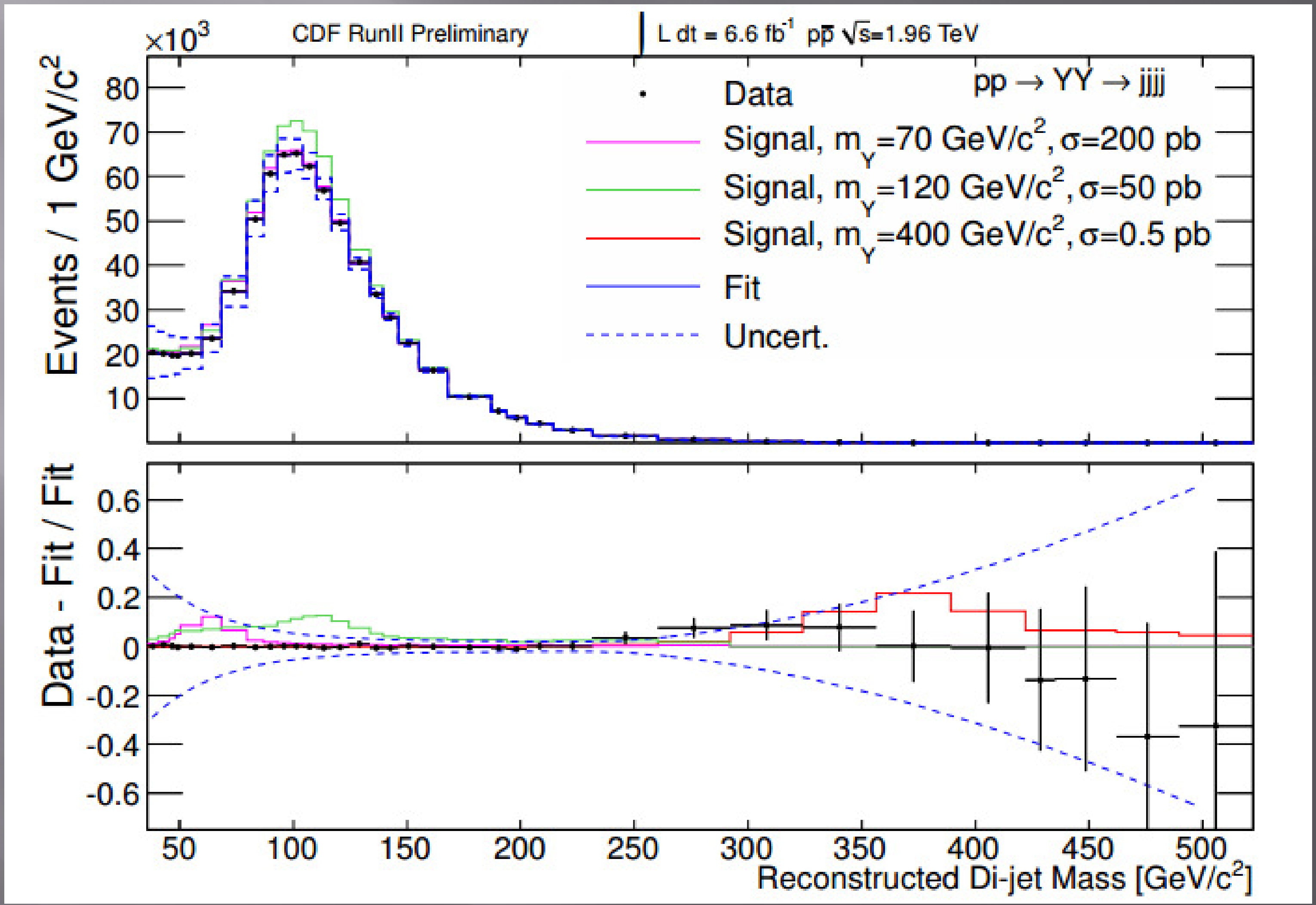


Models:



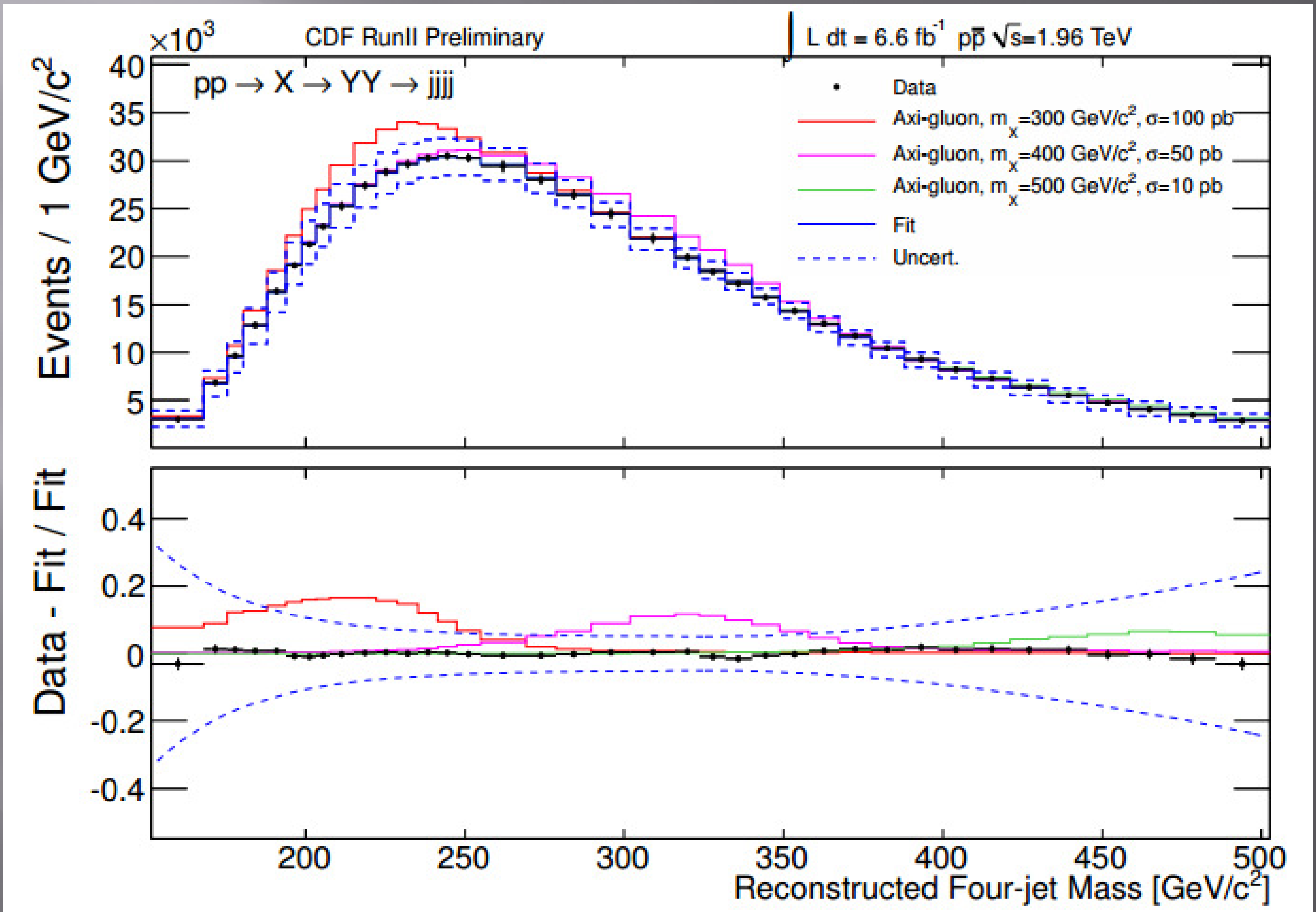
Background Mass Fits

- Fit mass spectra to nominal shapes, developed on MC
- 3 segments in 3 mass regions
- systematics from fitting residuals in control regions

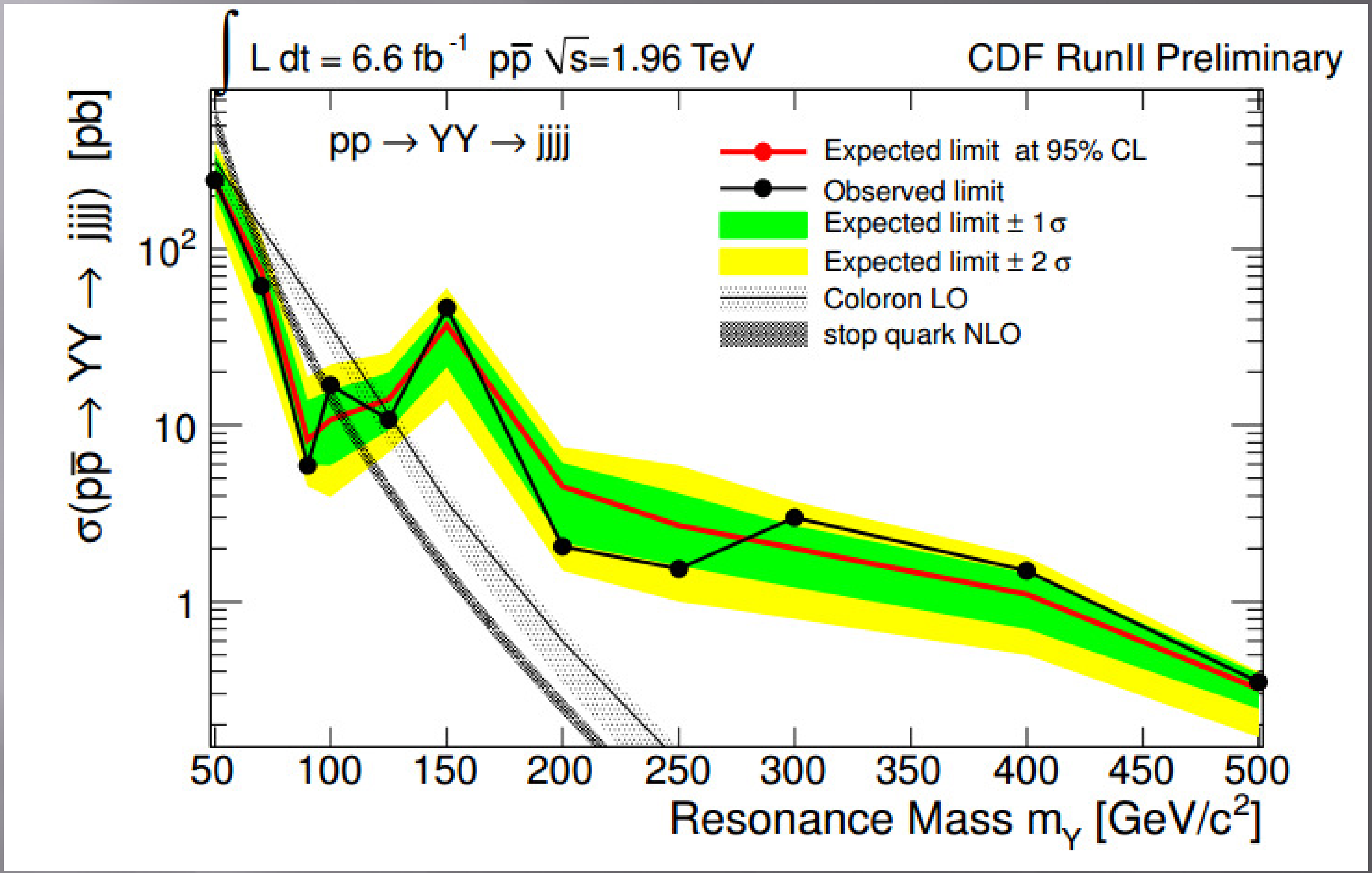


Background Mass Fits

- 4-jet mass in resonant production

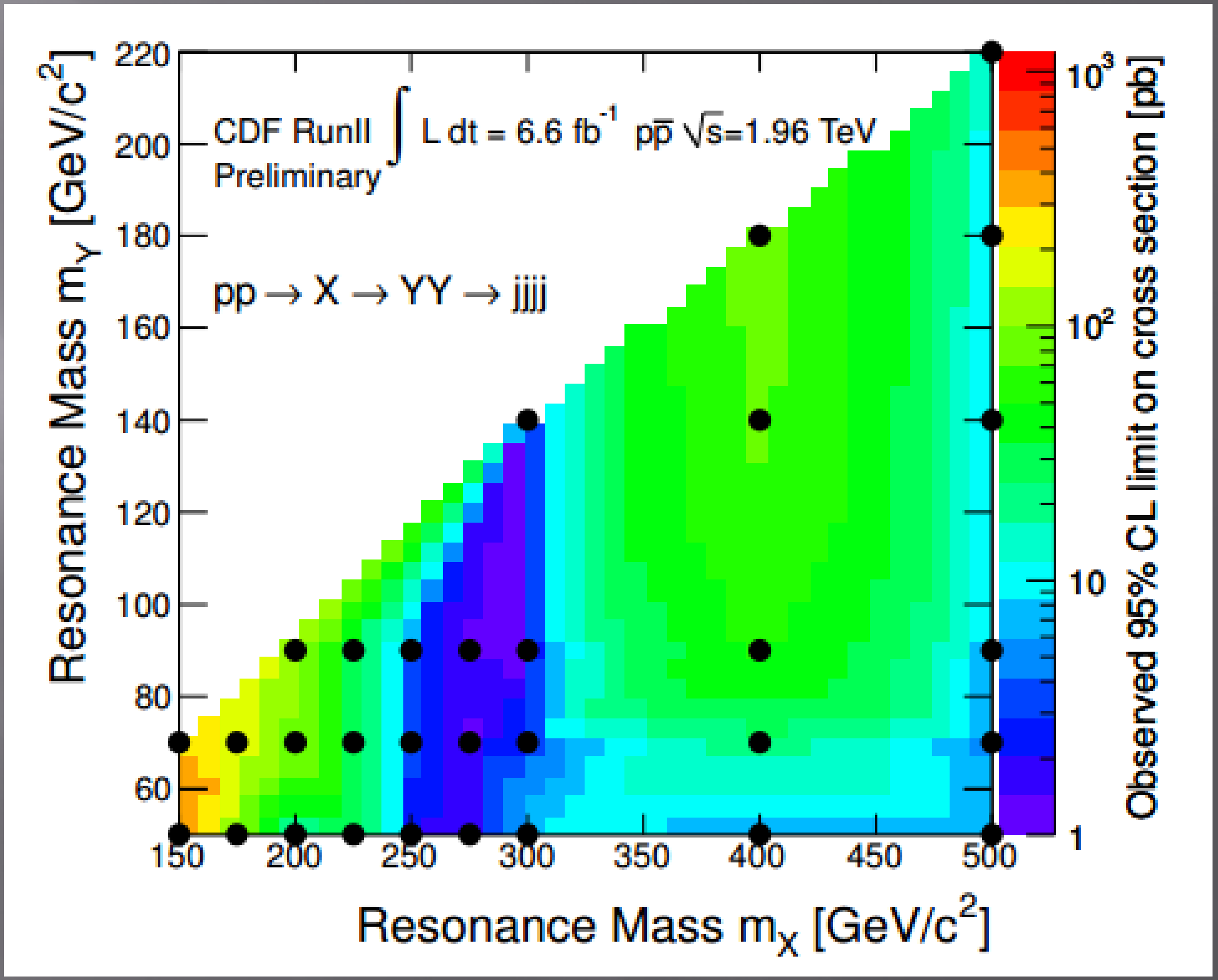


Non-resonant Limits



- Exclude 50<M(Y)<100 GeV for Coloron
  and 50<M(Y)< 125 GeV for RPV stop
- Low mass limits are unique to the Tevatron

Resonant Limits

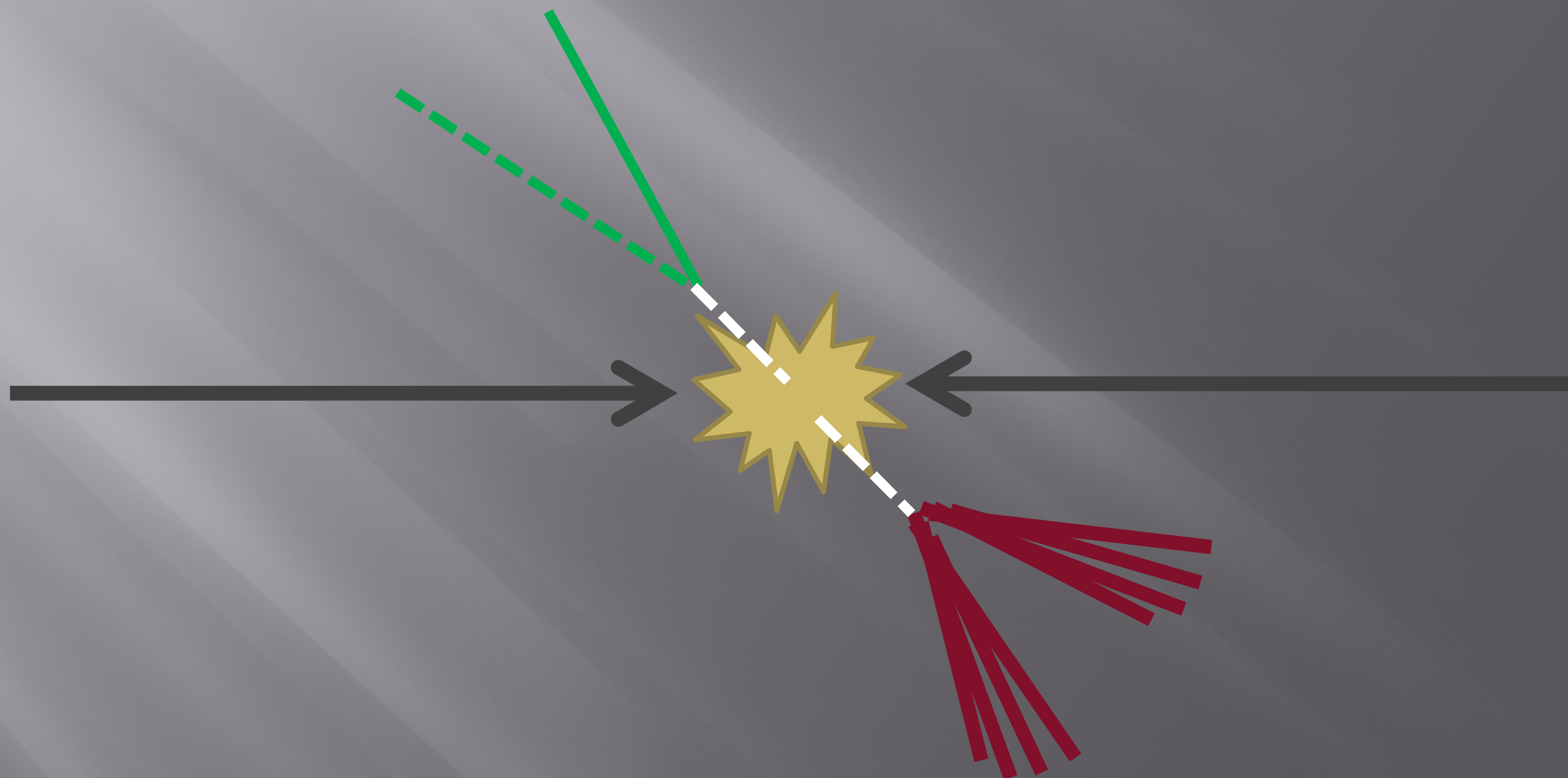


- Generic cross section limits

- Exclude axi-gluon [150,400] for M(σ) = [50, M(A)/2]

 - this is some space of interest for CDF tt A_{FB} excess, but can't exclude the axi-gluon as an explanation

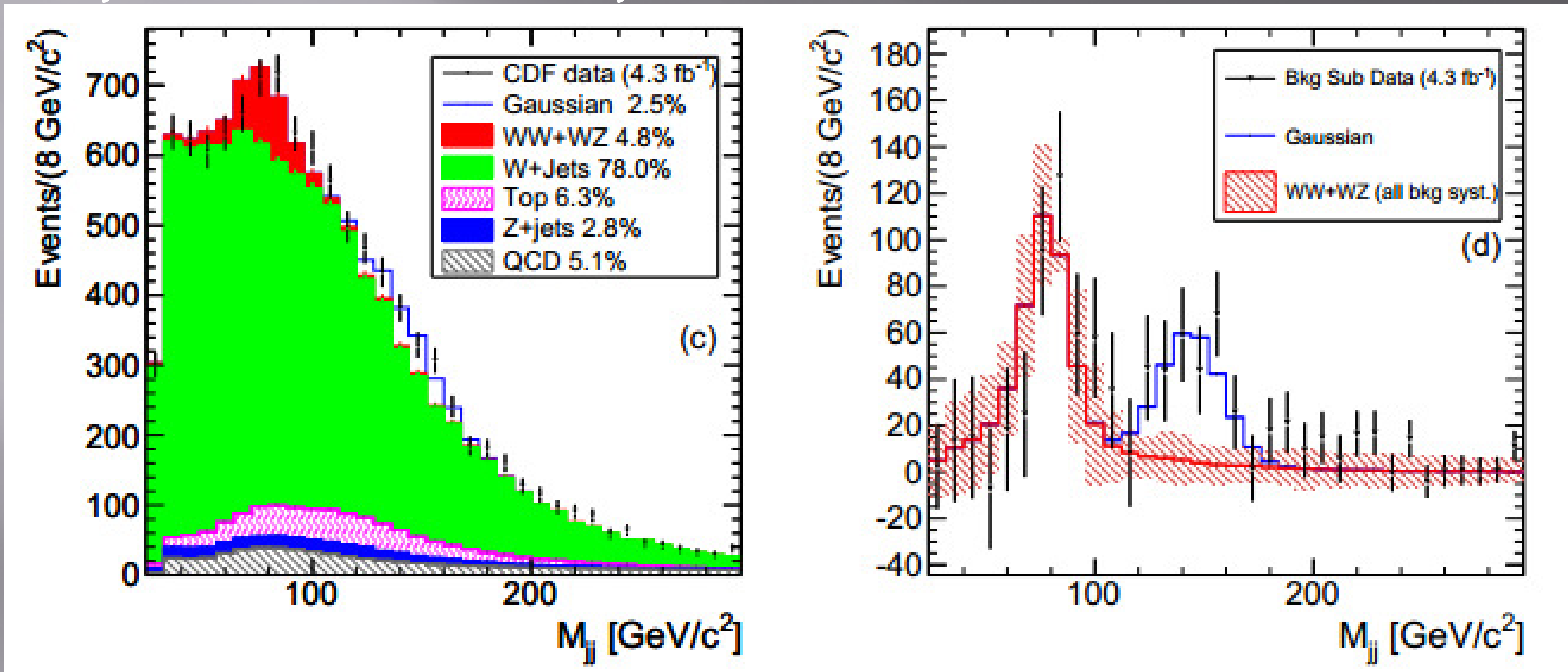
Update on Resonances in W+2 jets



Update of Phys. Rev. Lett. 106, 171801 (2011)

Anomalous mass peak?

Dijet mass for W+2jets, 2011, 4.3fb^{-1}



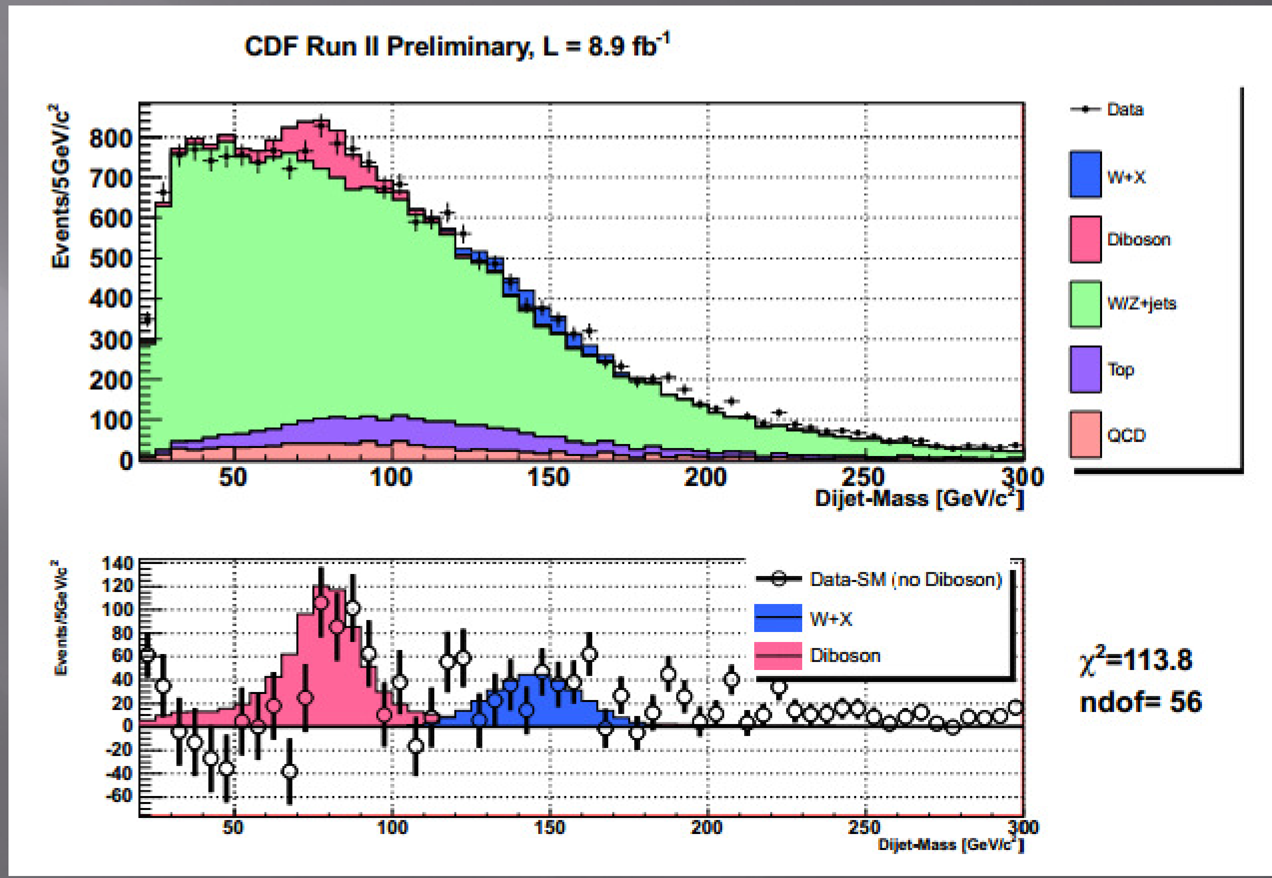
3.6σ

"not described by current theoretical predictions within the statistical and systematic uncertainties"

DØ and LHC did not confirm…

Reproduced in the Full Dataset

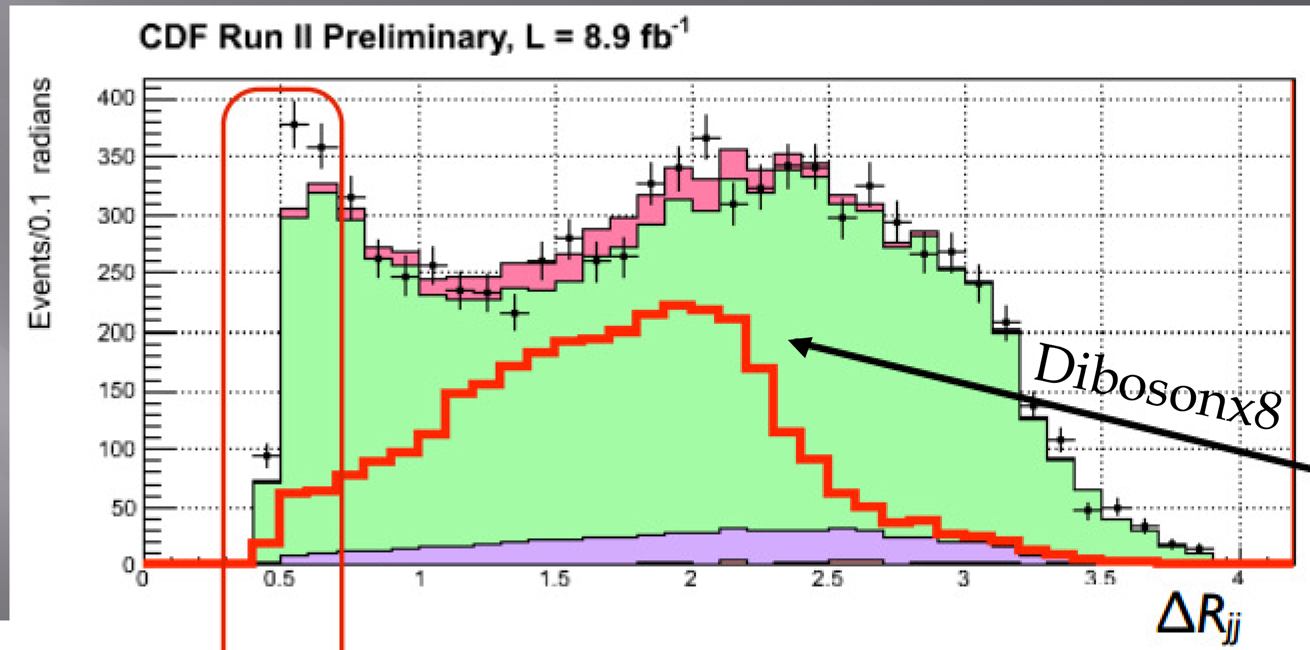
- Full Dataset
- e's and μ's
  - P_T> 20 GeV
  - |η| < 1 (central)
  - MET>25,
  - M_T>30 GeV
- 2 jets
  - E_T> 30 GeV
  - |η| < 2.4
- Additional selection
  - P_T(j1+j2)>40 GeV
  - |Δη (j1,j2)| < 2.5
  - Δφ(MET,j1)>0.4

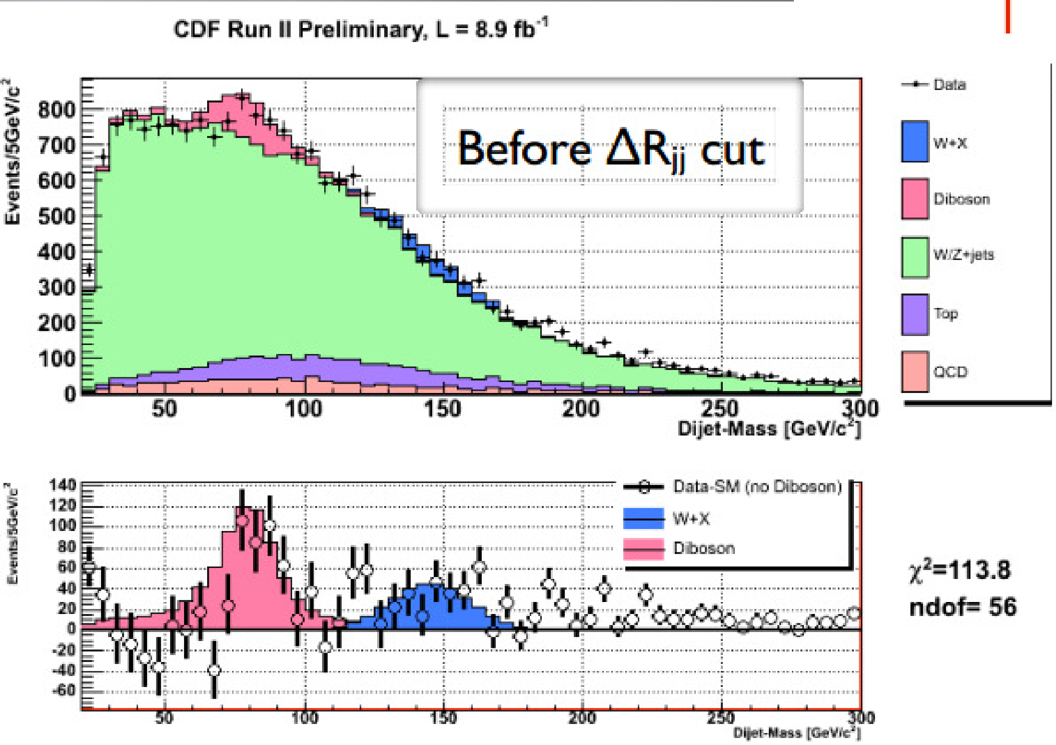


- Similar excess persists
- Recently,
  3 new effects discovered…

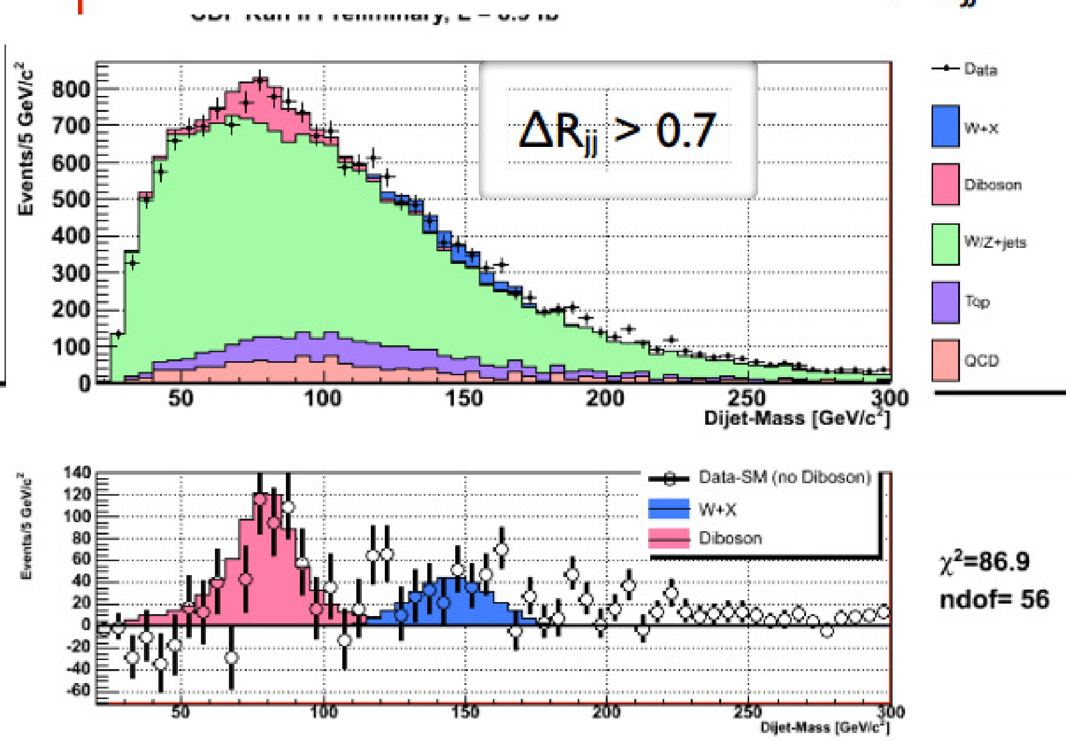
1) small ΔR

Small ΔR not modeled, but not needed, cut it out – small improvement





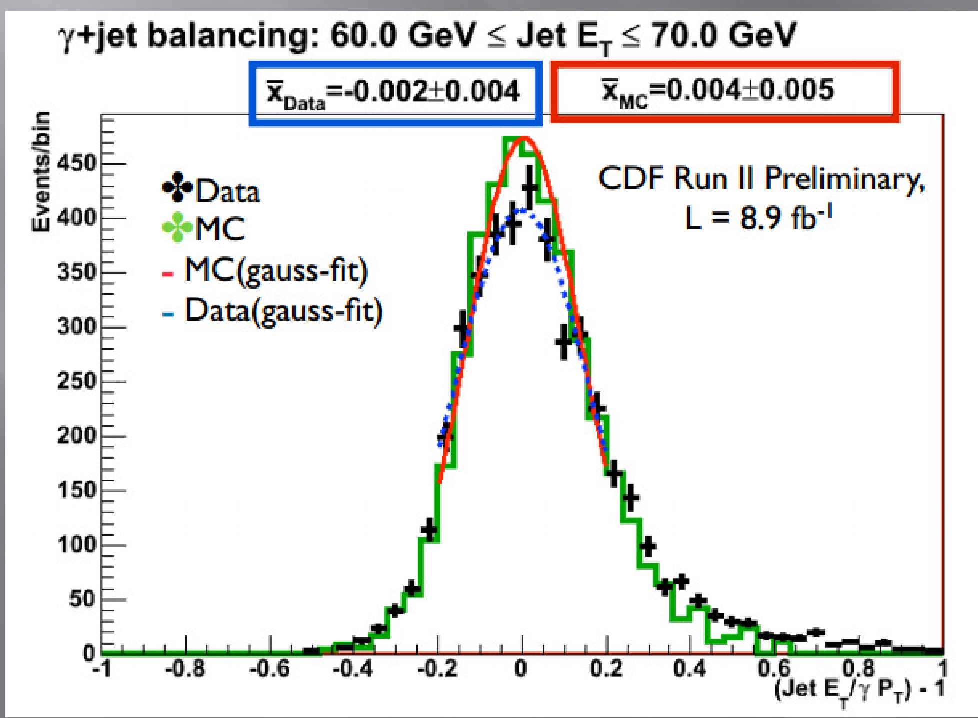
χ^2=113.8
ndof= 56

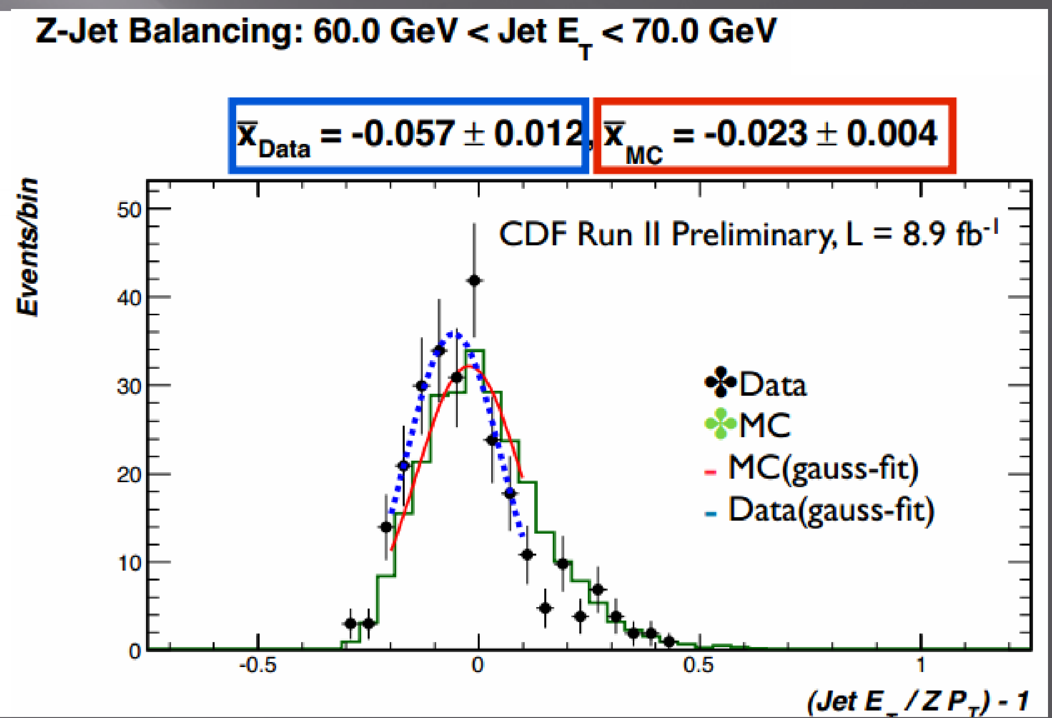


χ^2=86.9
ndof= 56

2) Jet Corrections for q/g

- Jet corrections convert observed tower energy to true hadron energy
- validated on photon-jet balancing, 80% quarks
- doesn't quite work for Z-jet balancing, 60% gluons

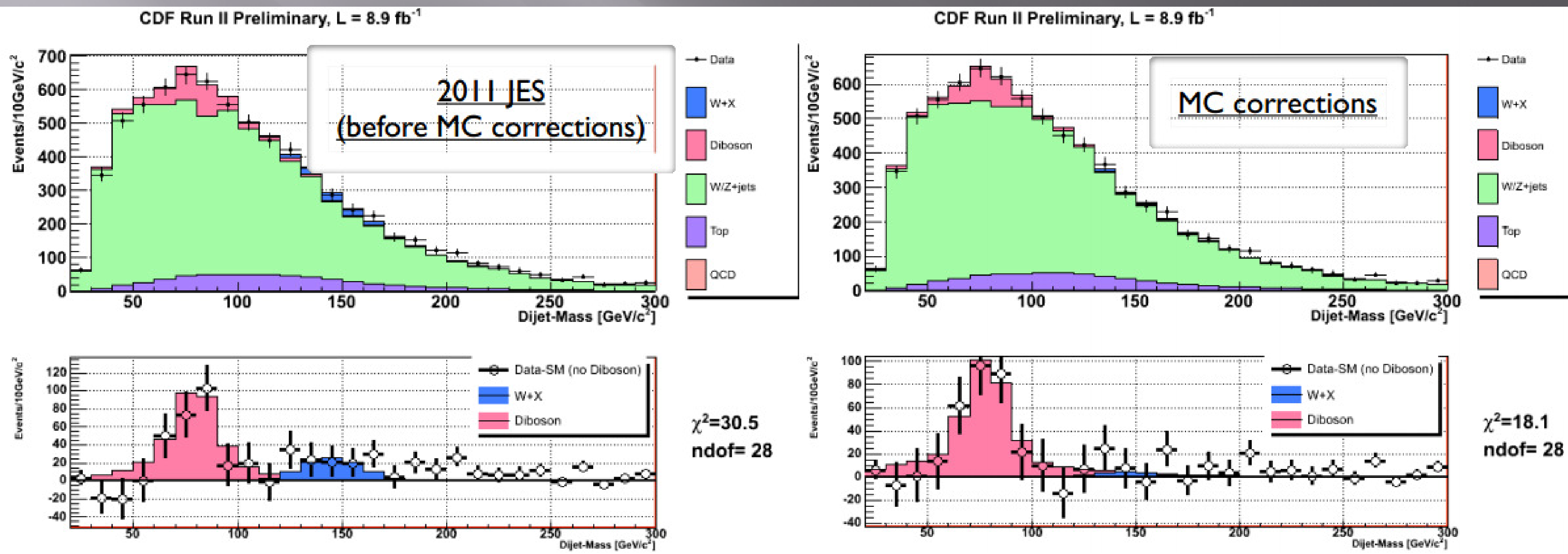




Effect of JES change

Corrections to MC samples jet energy, based on q/g truth:

- quark-jets: (+1.4 +/- 2.7)% gluon-jets: (-7.9 +/- 4.4)%



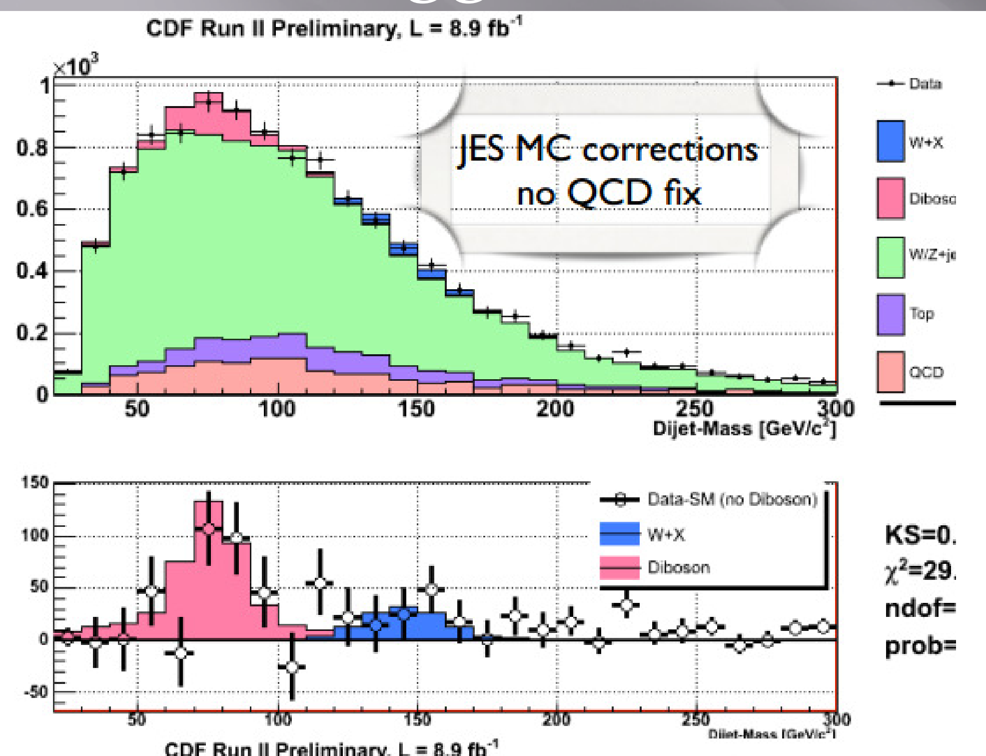
Muon sample now well described,

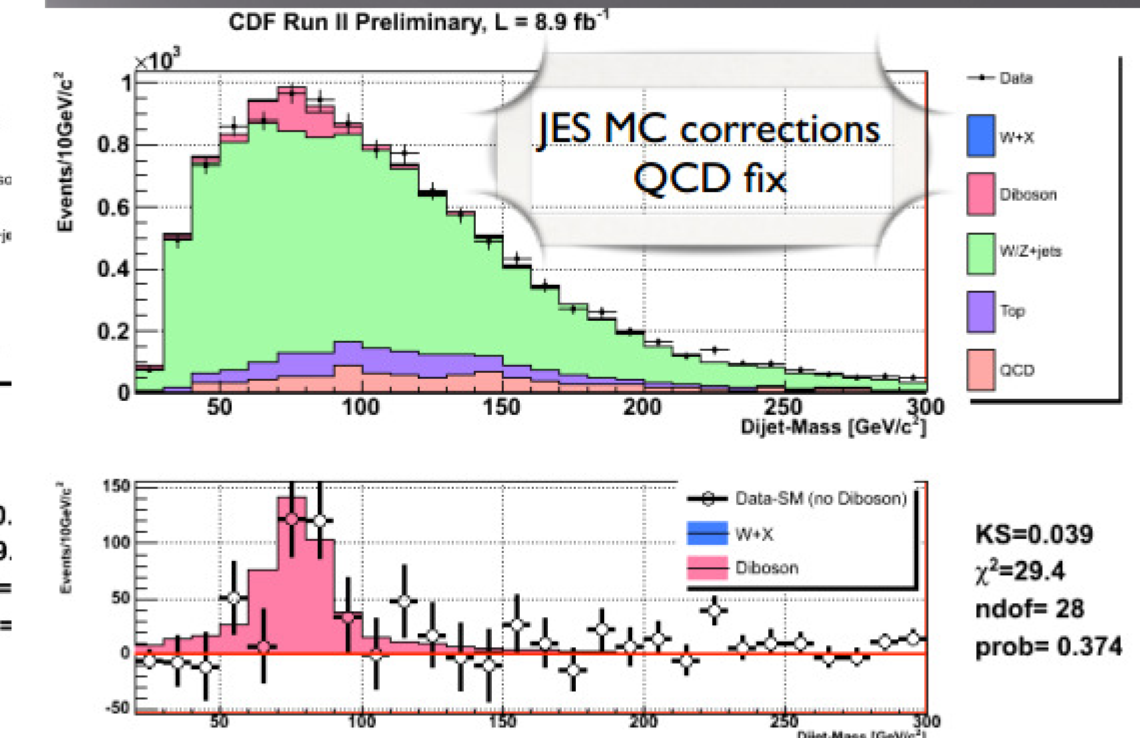
electron sample still not quite so well

3) Electron "QCD" Fakes Effect

Using data electron candidates with extra energy to represent jets that fake electrons had two problems

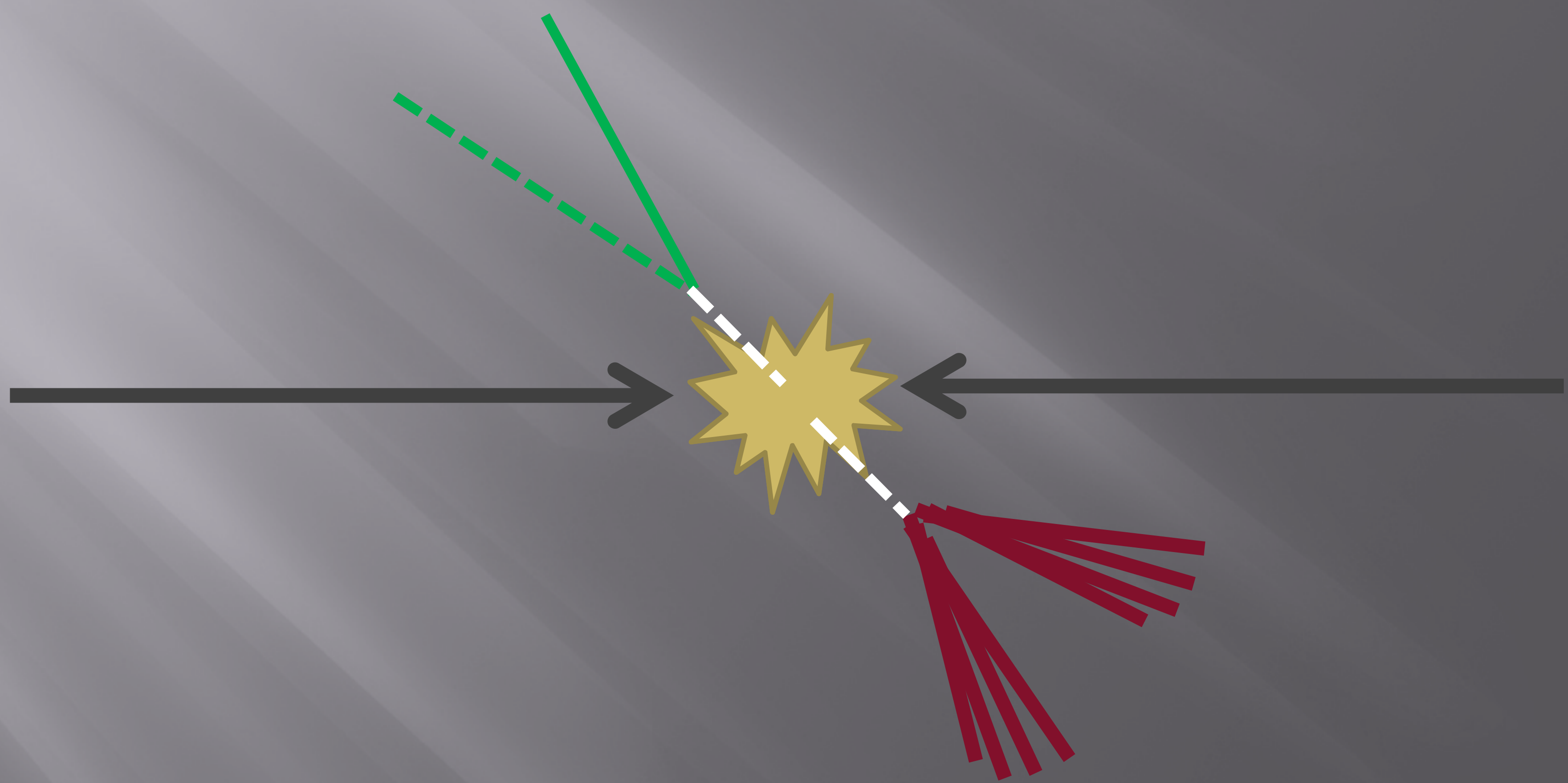
- extra/missing energy skews the kinematics
- the trigger also feels differences





- A small group of dedicated analysts figured it out – case closed!

SM Higgs Spin



Higgs Spin Possibilities

- SM predicts $J^P=0^+$
- Other options are:
  - 0^- pseudoscalar
  - 2^+ graviton - like
  - Spin 1 ruled out by LHC

observation in decay to dibosons (Landau Yang Theorem)

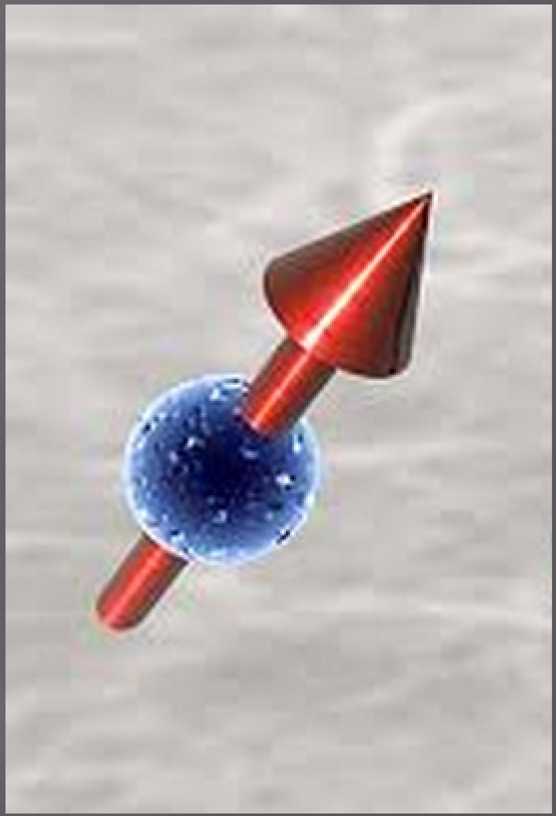
- LHC excludes

2^+ at 99.9% CL (Atlas)

0^- at 99.8% CL (CMS)

- But is the Tevatron data in $b\bar{b}$

consistent??



Spin Sensitivities

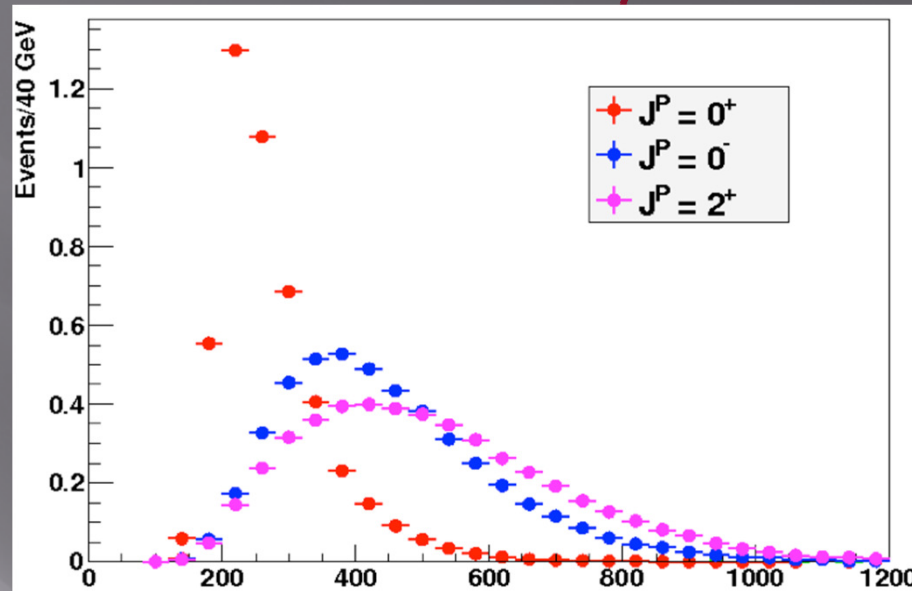
- LHC uses decay product and angular information in bosonic decays (mostly gg + VBF production modes)
- In associated production at Tevatron, production processes are different depending on J^P assignment
  - 0^+, S-wave; cross section ~β near threshold
  - 0^-, P-wave; cross section ~β^3 near threshold
  - 2^+, D-wave; cross section ~β^5
- So at the Tevatron the kinematic differences will come from different behaviors at the production threshold

$$\beta = 2p/\sqrt{s}$$

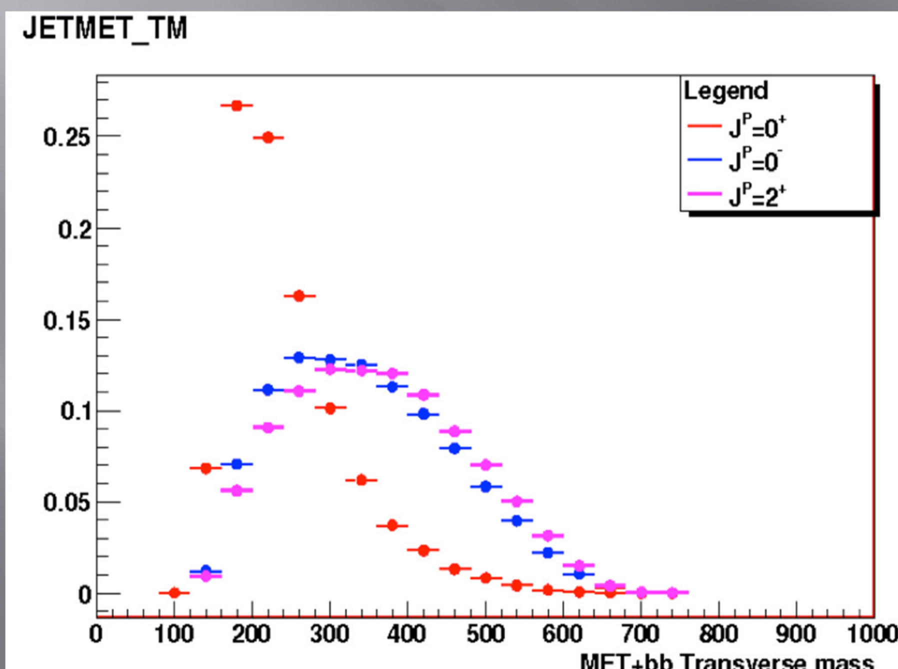
Miller, Choi, Eberle, Muhlleitner, and Zerwas, PLB **505**, 149 (2001)
Ellis, Hwang, Sanz, You, JHEP **1211**, 134 (2012)

Simulation of Sensitivity

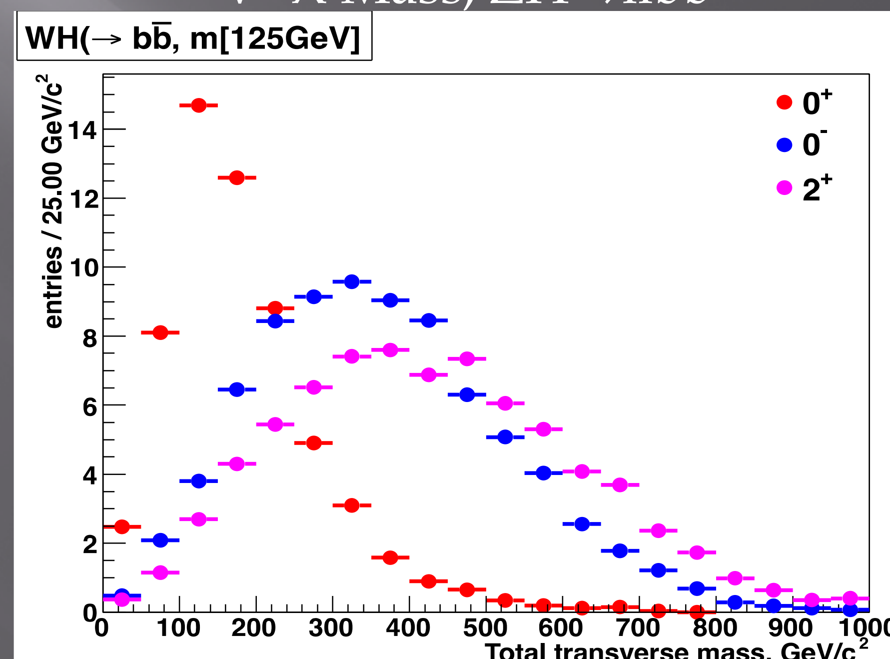
- MADGRAPH+PYTHIA
- Use Graviton for J=2
  - PYTHIA + GEANT,



V+X Mass, ZH→llbb



V+X M_T, ZH→vvbb

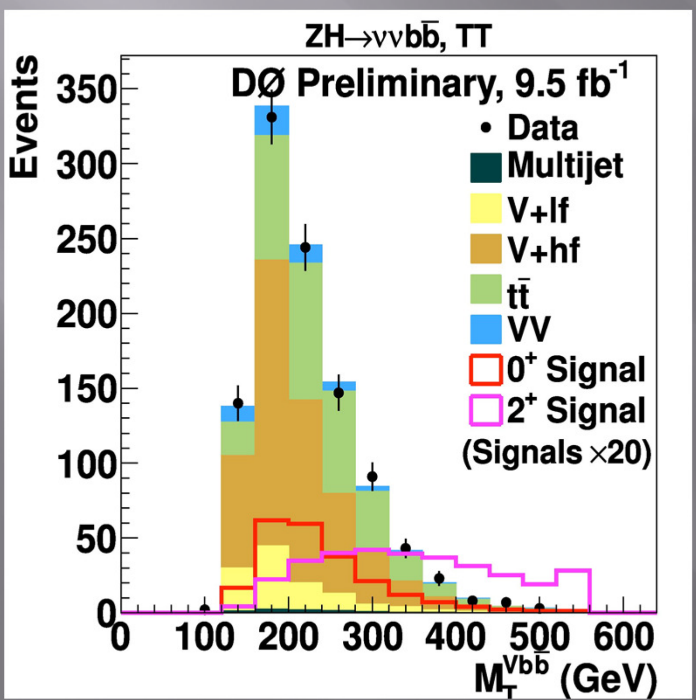


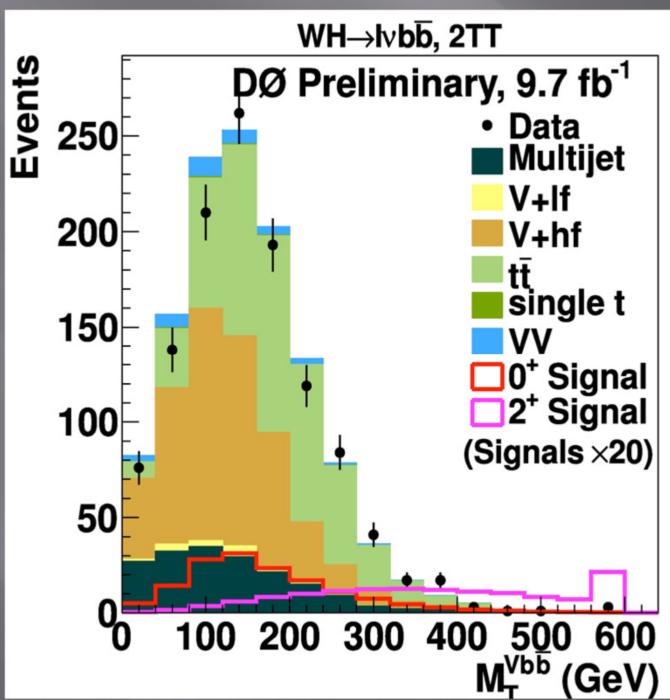
V+X M_T, WH→lvbb

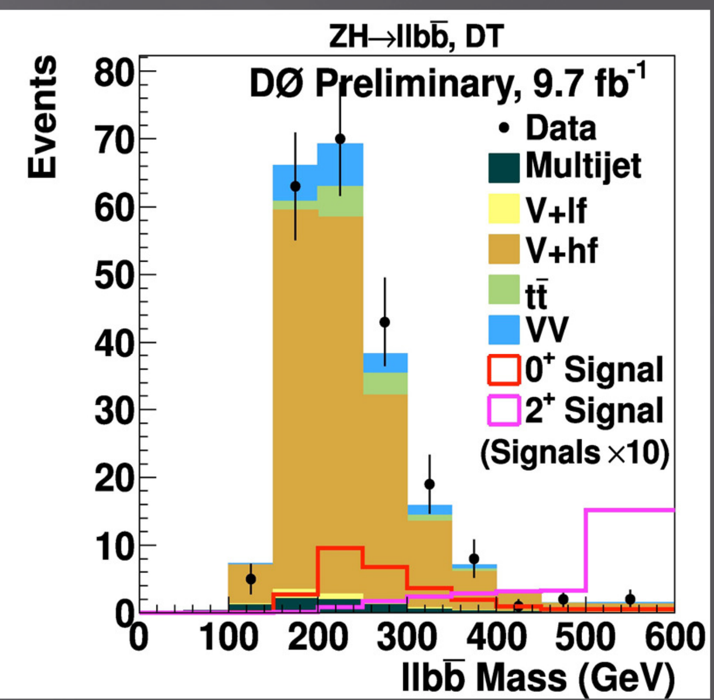
Signal Discriminants

- Use known mass to improve sensitivity
- Divide kinematic distributions into high and low S/N, sensitivity regions and treat them statistically separately

Tightest B-tag channels:

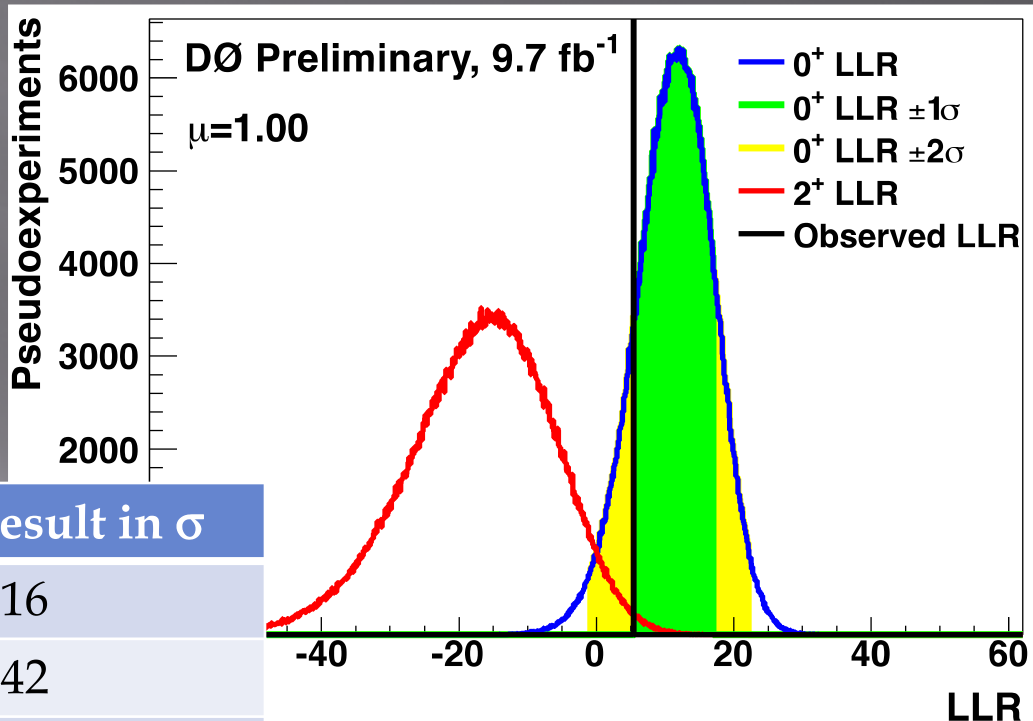






Spin Analysis Results

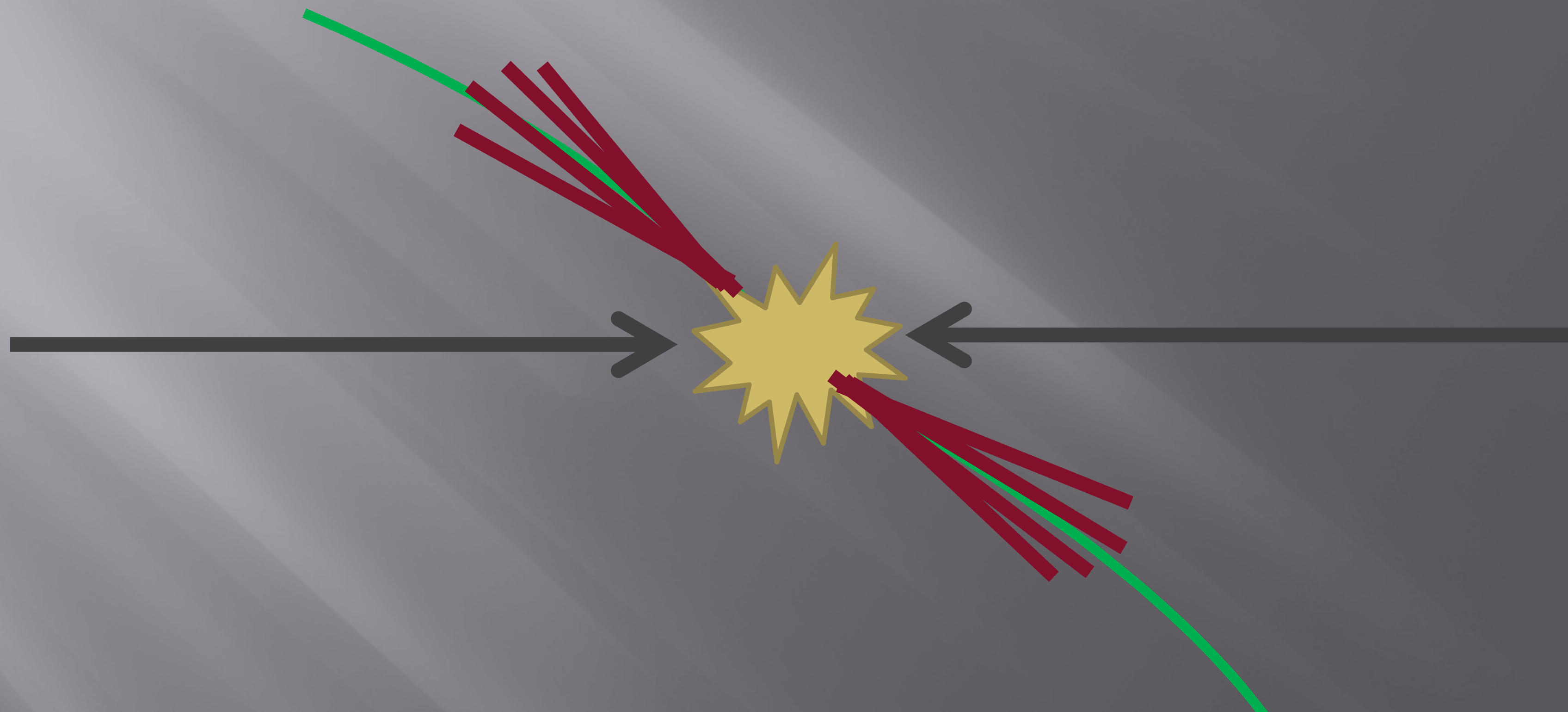
- Fix cross section to SM (1.0) or DØ observed rate (1.3)



Xsec scaling		1-CLs	Result in σ
1.0	Expected	0.9992	3.16
	Observed	0.9922	2.42
1.3	Expected	0.9999	3.72
	Observed	0.9988	3.04

- Sensitivity to 2^+ is similar to LHC single channel
- Results for 0^- will be available very soon!

Update of Dimuon Charge Asymmetry



Update of Phys Rev. D 84, 062007 (2013)

Dimuon Asymmetry

- Measures effects related to CP violation in B_d and B_s mixing
- published several times in Run II, current result using 9 fb^{-1} shows a 3.9σ anomaly
- Ongoing work:
  - bring data up to full dataset
  - update in methodology
  - preview of checks
  - preview of sensitivity

- Final 10 fb-1 results are in review, will be released in about two weeks!

The Idea

- Two samples,
  - inclusive low-P_T muons: (P_T>4.2 or P_z>5.2) and P_T<25GeV
  - inclusive low-P_T di-muons: M(μ μ) >2.8 GeV
- 2.2×10^9 μ; 22×10^6 $\mu^+\mu^-$; 6×10^6 $\mu^\pm \mu^\pm$
- Bin data in P_T, η, and impact parameter
- Examples:

◦ $b \rightarrow B^- \rightarrow \mu^- X$ "right-sign"

$\bar{b} \rightarrow \bar{B}^0 \rightarrow B^0 \rightarrow \mu^- X$ "wrong-sign

◦ $\bar{b} \rightarrow B^+ \rightarrow \mu^+ X$ "right-sign"

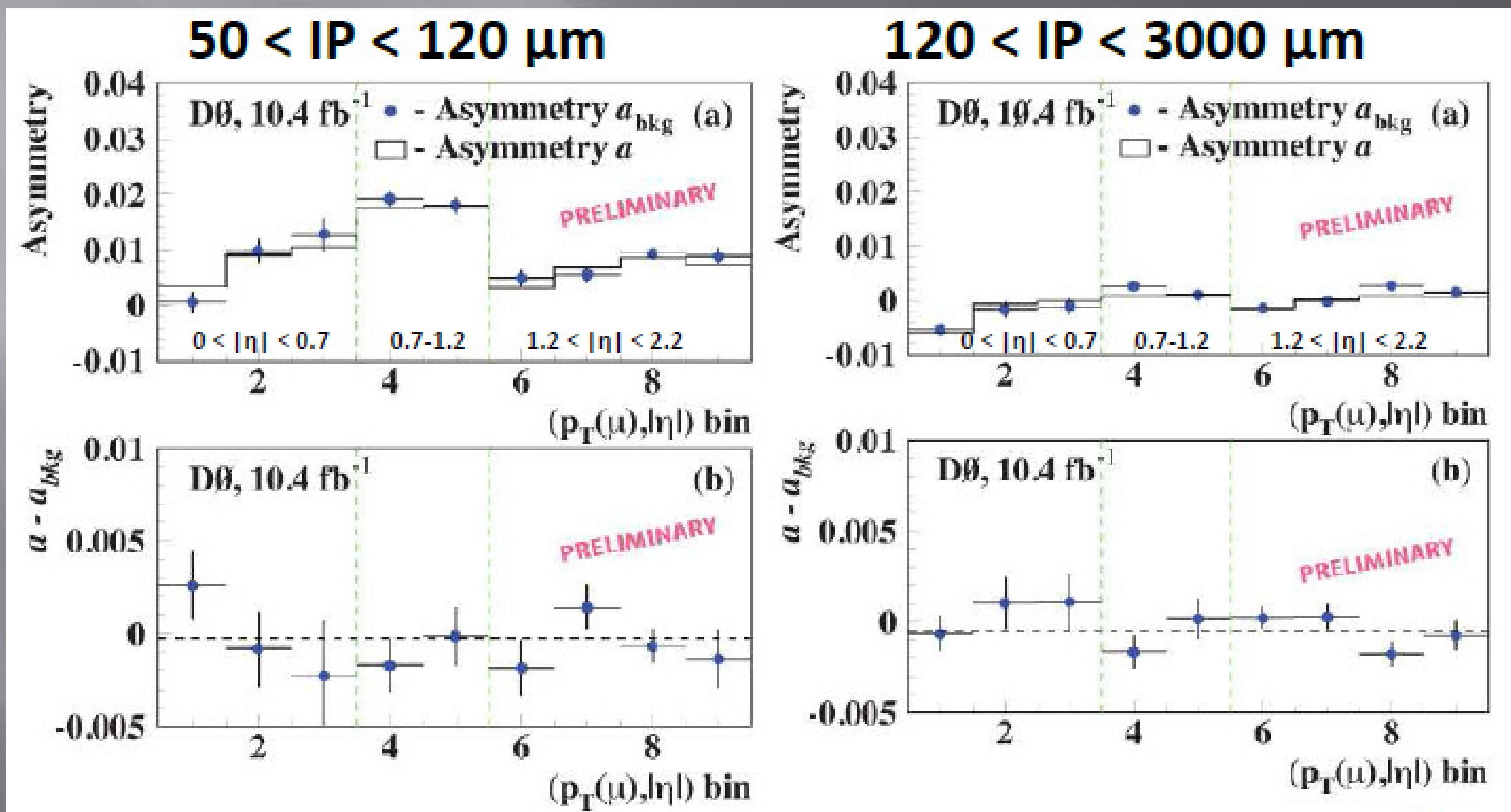
$b \rightarrow B^0 \rightarrow \bar{B}^0 \rightarrow \mu^+ X$ "wrong-sign"

◦ $b \rightarrow c \rightarrow \mu^+$ "wrong-sign"

Preview of Checks

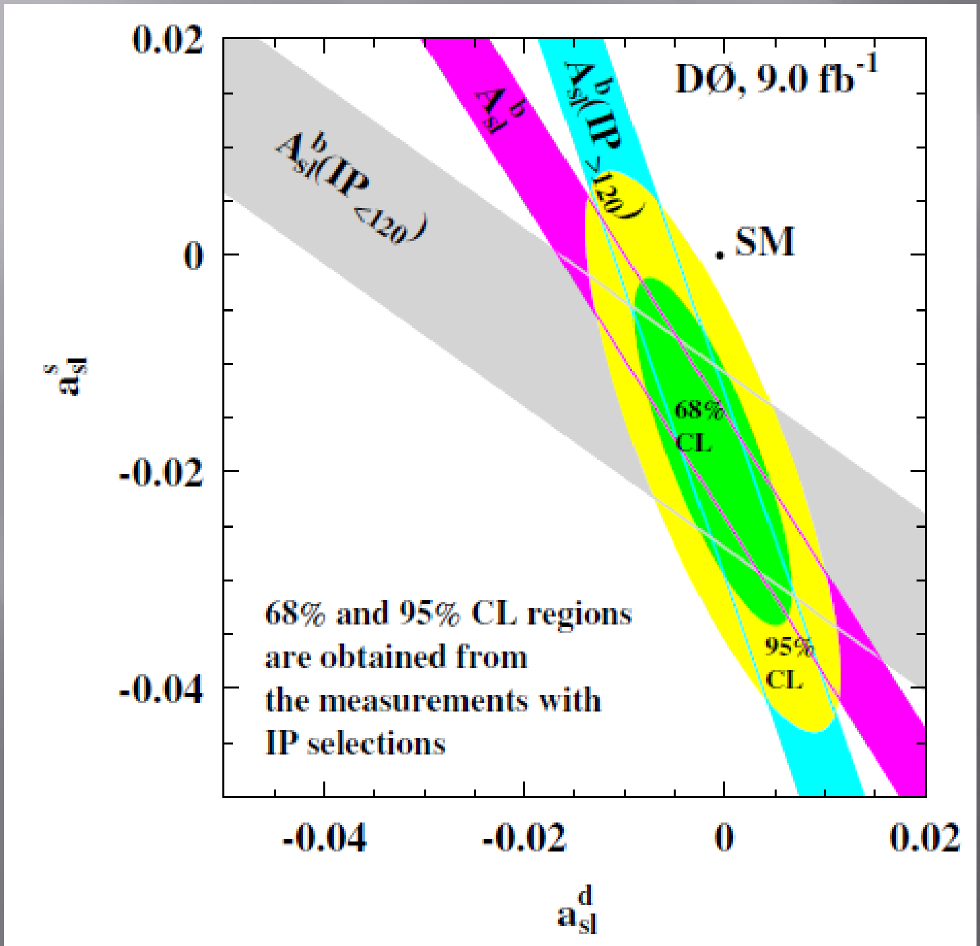
- inclusive muon sample should show little asymmetry over background – it checks background

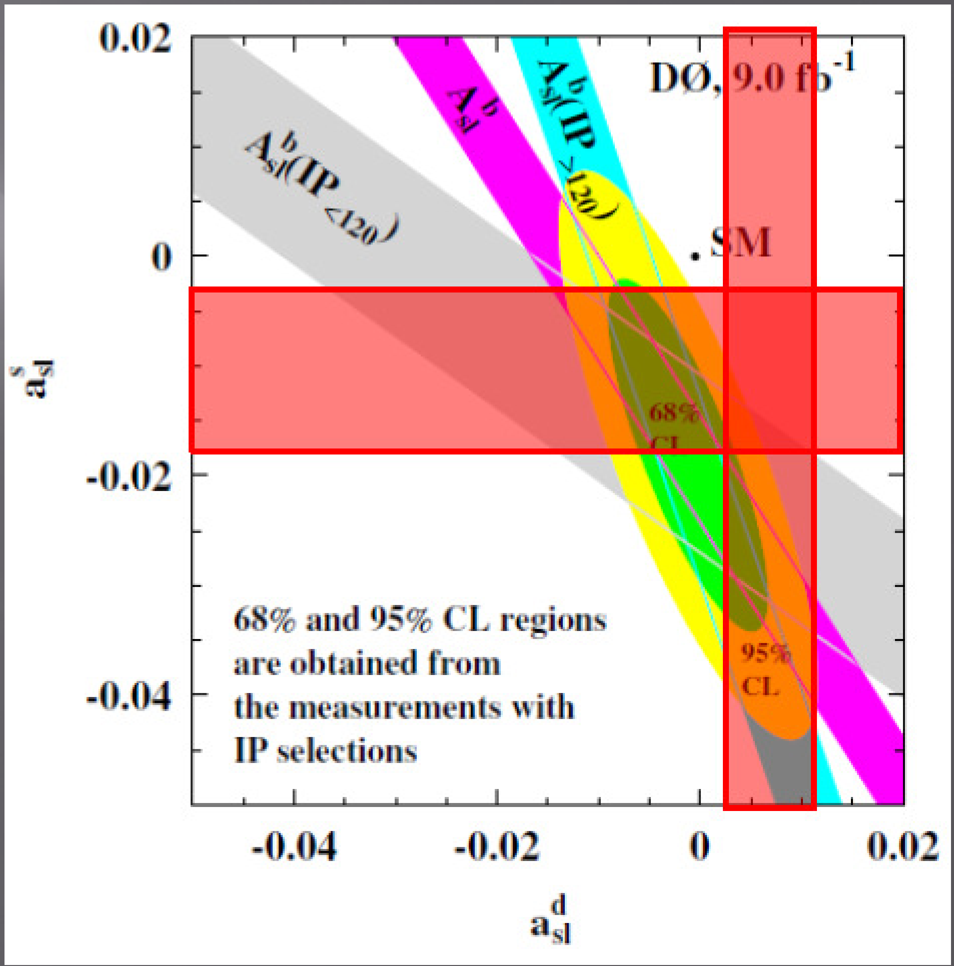
  $a = (n^+ - n^-)/(n^+ + n^-)$, with corrections



Previous and Projected Results

- Results from previous analysis, $9fb^{-1}$, 3.9σ from SM
  red bands from other work: $B_d \rightarrow D\mu$, $B_S \rightarrow D_S\, \mu$
- With $10fb^{-1}$ improvements, ellipse is 44% smaller!





A New Wrinkle!

G. Borissov & B. Hoeneisen Phys. Rev. D **87**, 074020 (2013)

- Previous analyses considered all the asymmetry above background to be from CP violation in mixing
- Recent work proposed that interference from mixing and non-mixing states can also contribute

$$b \rightarrow B^0 \rightarrow D^+D^- \qquad b \rightarrow B^0 \rightarrow \bar{B}^0 \rightarrow D^+D^-$$

CP-even states can Contribute to wrong –sign

- With the new binning, the 10fb^{-1} analysis can measure the contribution!

$$A^b_{CP}(\text{bins}) = C_d(\text{bins})\, \mathbf{a}^{\mathbf{d}}_{\mathbf{sl}} + C_s(\text{bins})\, \mathbf{a}^{\mathbf{s}}_{\mathbf{sl}} + C_\delta(\text{bins})\, \boldsymbol{\Delta\Gamma_d/\Gamma_d}$$

- Is the anomaly resolved? Will $\boldsymbol{\Delta\Gamma_d/\Gamma_d}$ be measured?

Stay Tuned - 2 weeks!?

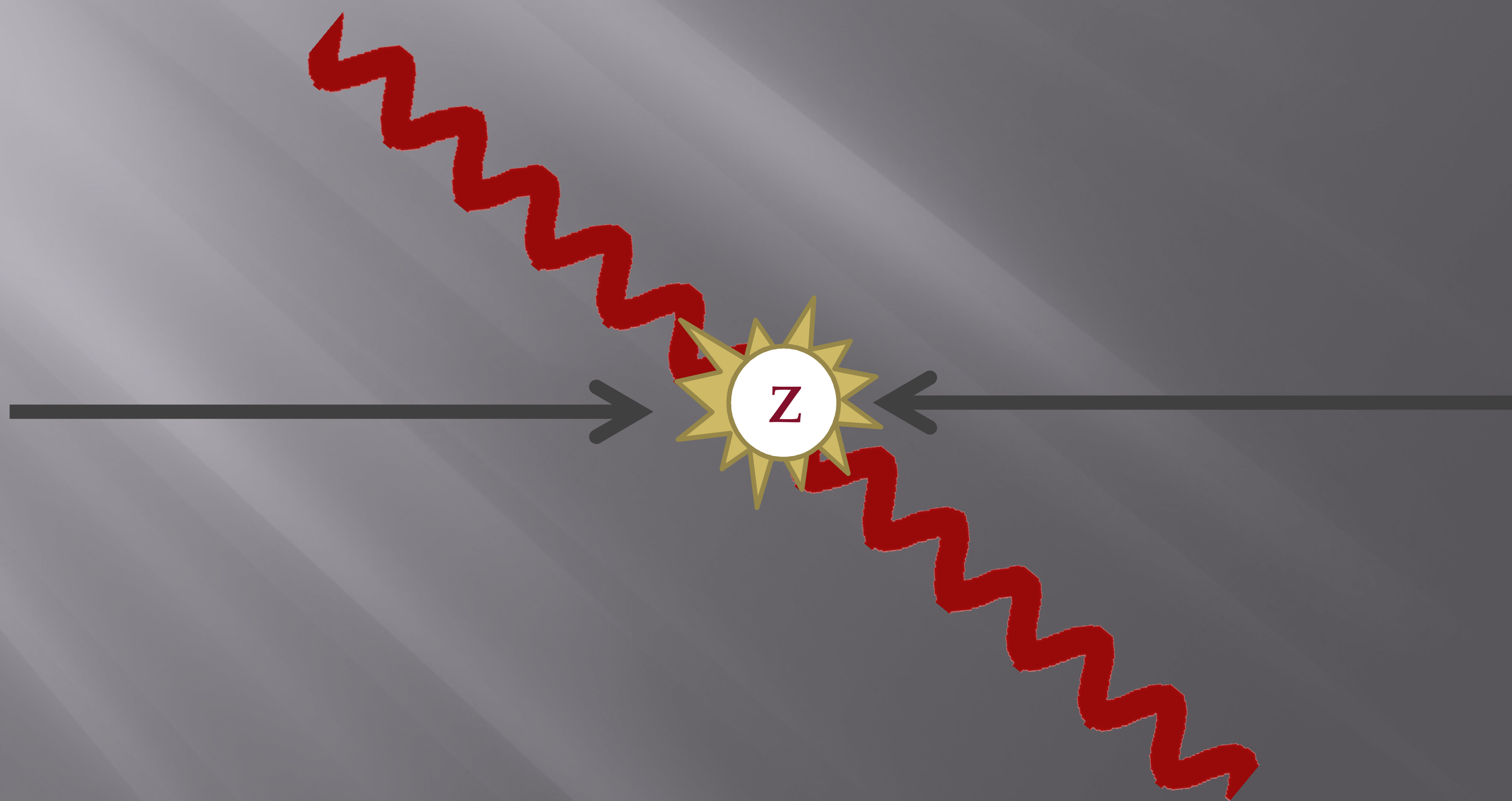
Last Slide

The LHC energy frontier is not the whole story - the Tevatron continues to make a significant contribution to BSM!

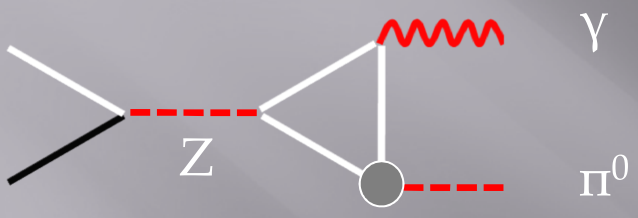
- phase space difficult to reach at LHC
- complementary to LHC
- finalizing unanswered questions
- topics not covered yet

And this doesn't count the many unique and valuable legacy measurements that can still be performed with the Tevatron data…

Z Decays to Photons and Neutral Pions



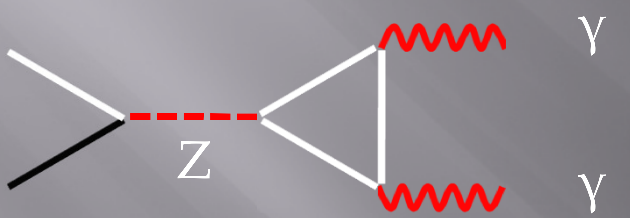
Rare and Forbidden Z decays



Small in the SM, Similar to $W^+ \rightarrow \pi^+ \gamma$

Tests:

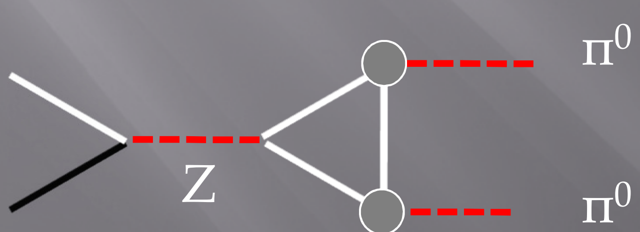
- Pion form factor
- Physics beyond the SM…



Not allowed in SM - Landau-Yang theorem, Bose-Einstein statistics

Tests:

- Commutativity of gauge theory
- Physics beyond the SM…



Limits

- Final result reported as BR

CDF Run II Preliminary						$\int \mathcal{L} = 10.0\ \text{fb}^{-1}$
	95% C.L. Limits					
Signal	Expected ($\times 10^{-5}$)					Observed
Process	-2σ	-1σ	Median	$+1\sigma$	$+2\sigma$	($\times 10^{-5}$)
$Br(Z \rightarrow \gamma\gamma)$	0.88	1.19	1.66	2.34	3.20	1.66
$Br(Z \rightarrow \pi^0\gamma)$	1.21	1.63	2.28	3.21	4.37	2.28
$Br(Z \rightarrow \pi^0\pi^0)$	0.93	1.23	1.72	2.41	3.29	1.73

- 3.1 times smaller than world's best
- 2.3 times smaller than world's best
- first reported

- SM expectations for $BR(Z \rightarrow \pi^0\gamma)$: $10^{-9} - 10^{-12}$