Search for New Particles Decaying to Dijets in Dijet Mass

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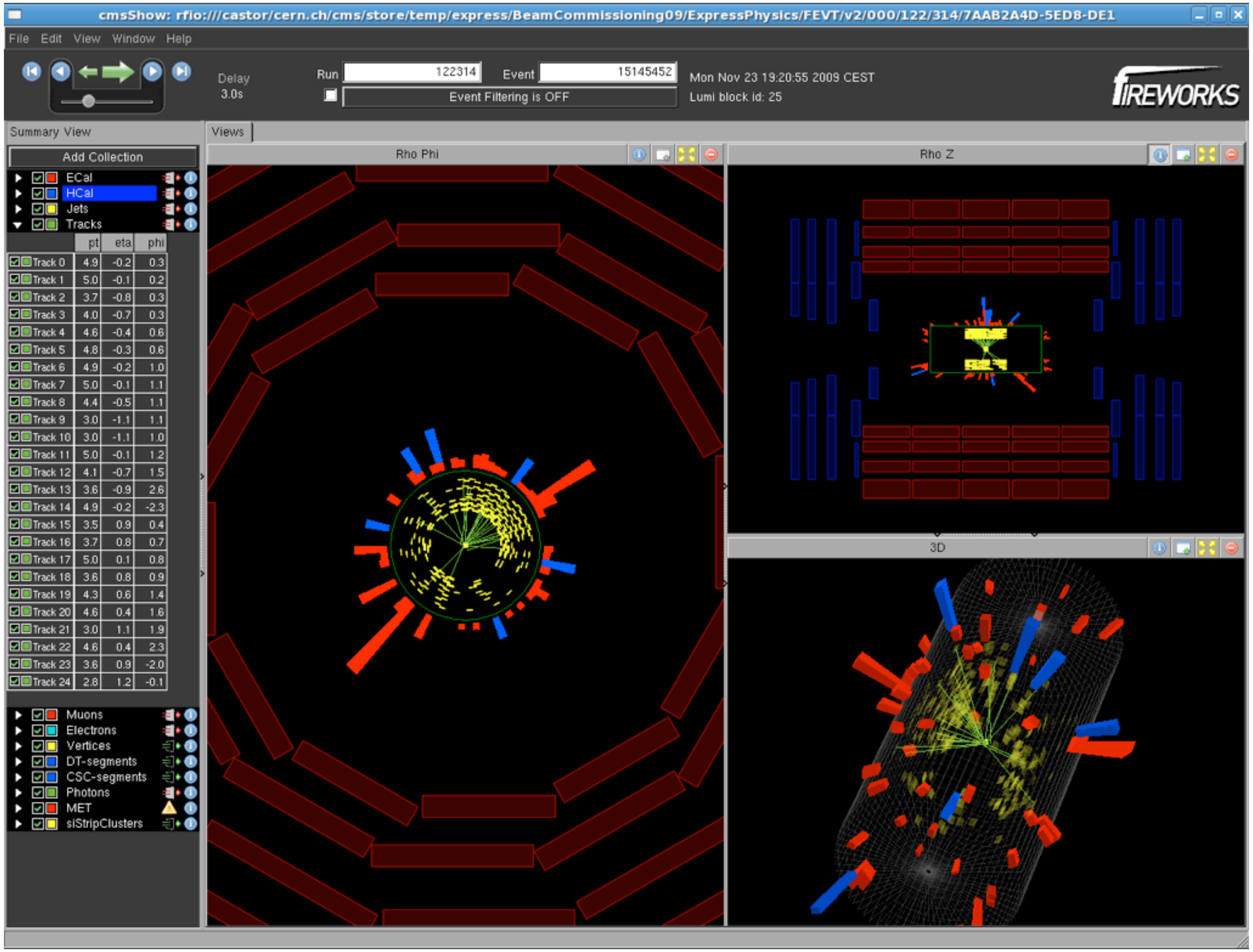
Dreams Come True!



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Delay 3.0s

Run 122314

Event 15145452

☐ Event Filtering is OFF

Mon Nov 23 19:20:55 2009 CEST

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☑ 🟩 Track 24	2.8	1.2	-0.1

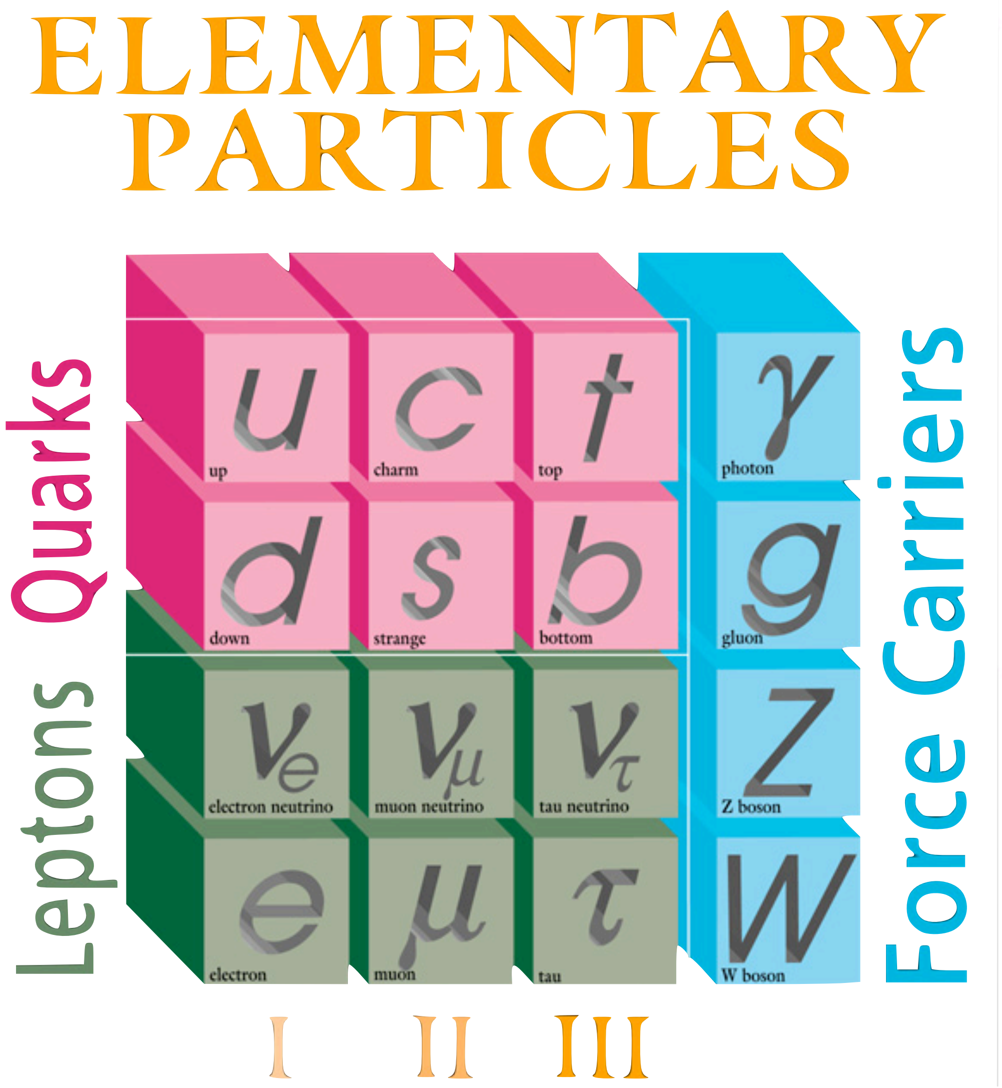
First Collision in CMS

Outline

- Motivation
- Jets at CMS
- Search for Dijet Resonances
- First Look at Dijets in Real Data
- Conclusion

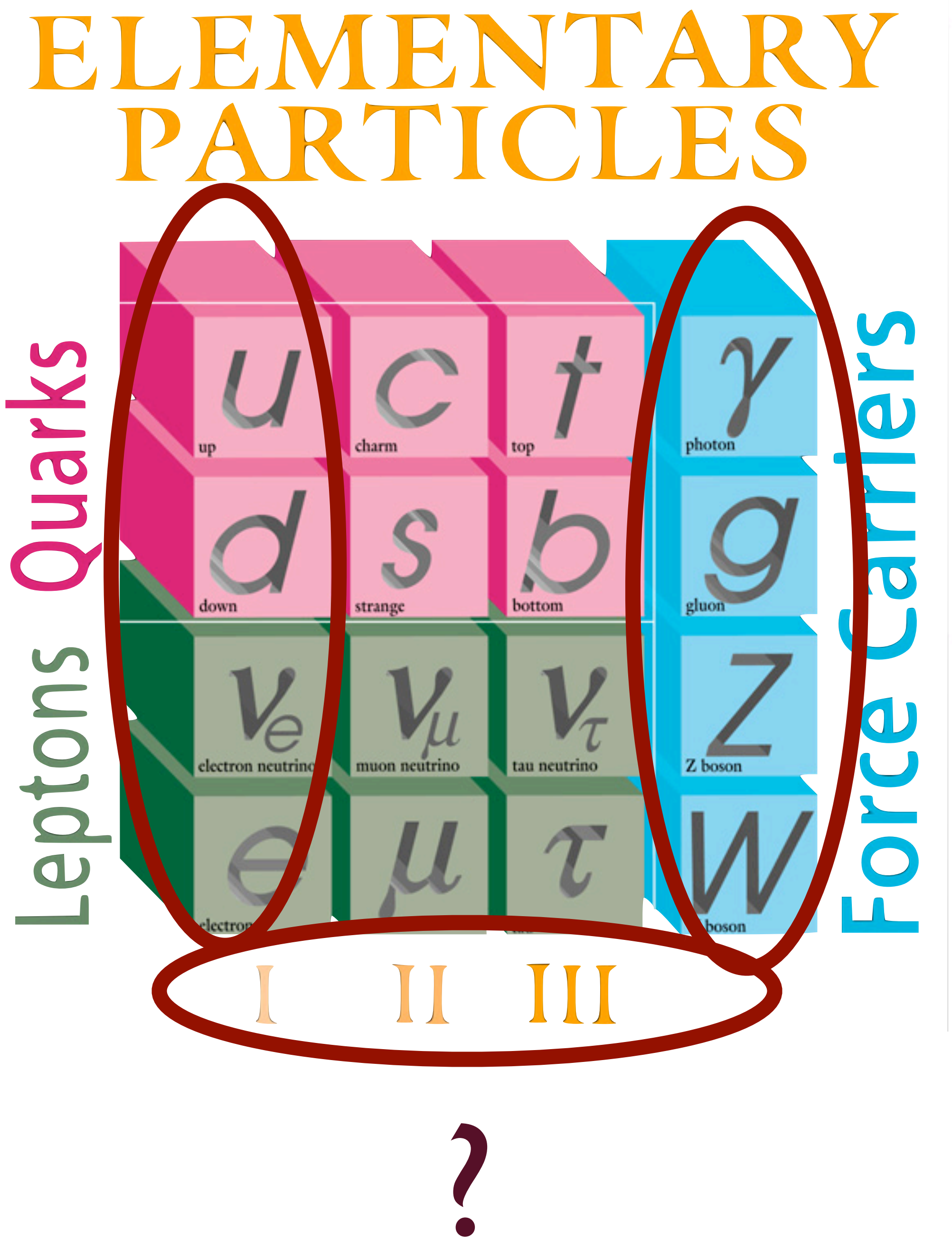
Standard Model

- In terms of Standard Model,
  - ✓ 6 quarks & 6 leptons
    - u and d quarks and electron make matter
  - ✓ 4 force carrying particles
    - ϒ: Electromagnetism
    - W & Z: Weak Interaction
    - g: Color (Nuclear) Interaction
  - ✓ Higgs particle to give mass
    - Higgs not discovered



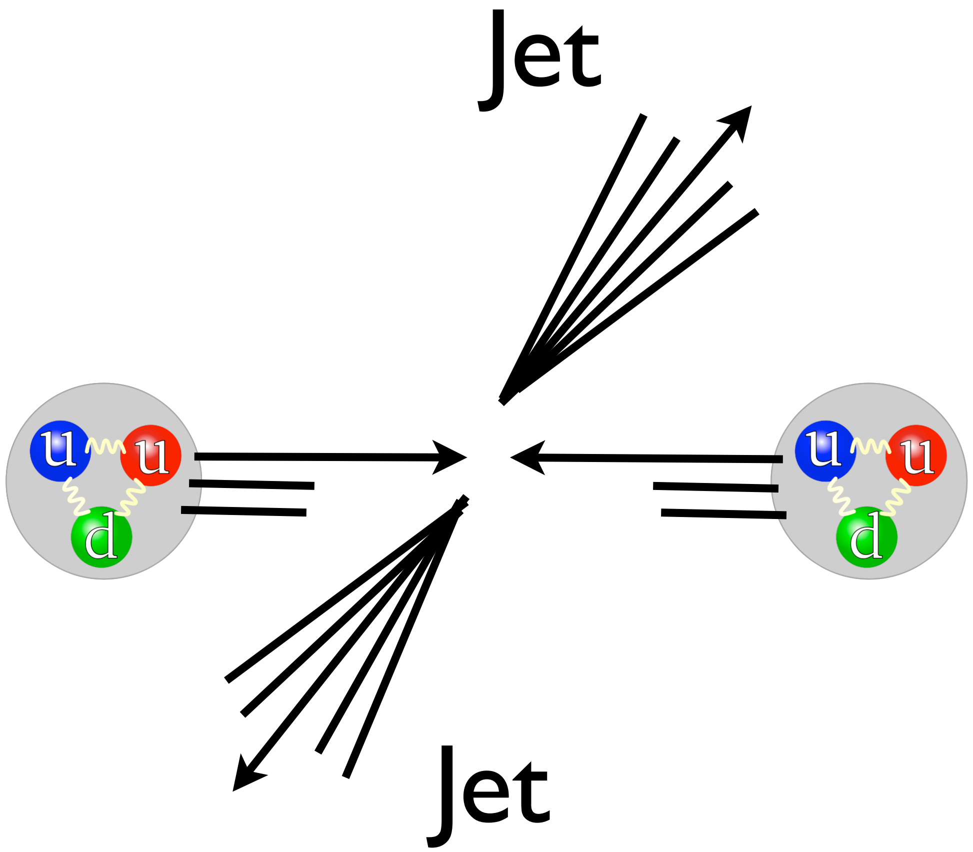
Beyond Standard Model

- The Standard Model raises questions.
- Why three nearly identical generations of quarks and leptons.
  - Like the periodic table of the elements, does this suggest an underlying physics?
- What causes the flavor differences within a generation?
  - Or mass difference between generations?
- How do we unify the forces?
  - Υ, Z and W are unified already.
  - Can we include gluons?
  - Can we include gravity?
- These questions suggest there will be new physics beyond the Standard Model.
  - We will search for new physics with Dijets.



Dijets in Standard Model

- What is a dijet?
- Parton Level
  - ✓ Dijet results from simple 2→2 scattering of “partons”
  - ✓ quarks, anti-quarks and gluons
- Particles Level
  - ✓ Partons come from colliding protons
  - ✓ The final state partons become jets of observable particles via the following chain of events
    - The partons radiate gluons.
    - Gluons splits into quarks and antiquarks
    - All colored object “hadronize” into color neutral particles
    - Jet made of π, k, p, n, etc
- Dijets are events which primarily consist of two jets in the final state.

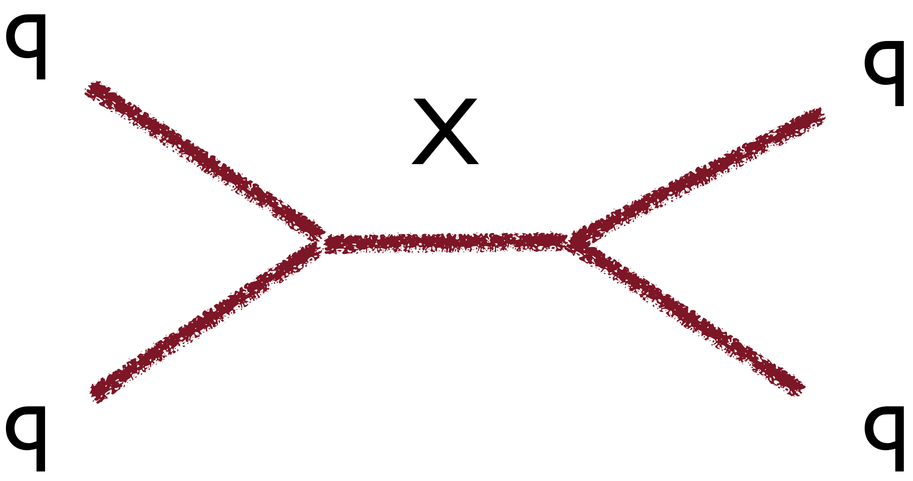


Particle Level

Dijet Resonances Model

- Theoretical Motivation
- Dijet Resonances found in **many models** that address fundamental questions.
- Why Generations ? → Compositeness → Excited Quarks
- Why So Many Forces ? → Grand Unified Theory → W ' & Z '
- Can we include Gravity ? → Superstrings & GUT → E6 Diquarks
- Why is Gravity Weak ? → Extra Dimensions → RS Gravitons
- Why Symmetry Broken ? → Technicolor → Color Octet Technirho
- More Symmetries ? → Extra Color → Colorons & Axigluons

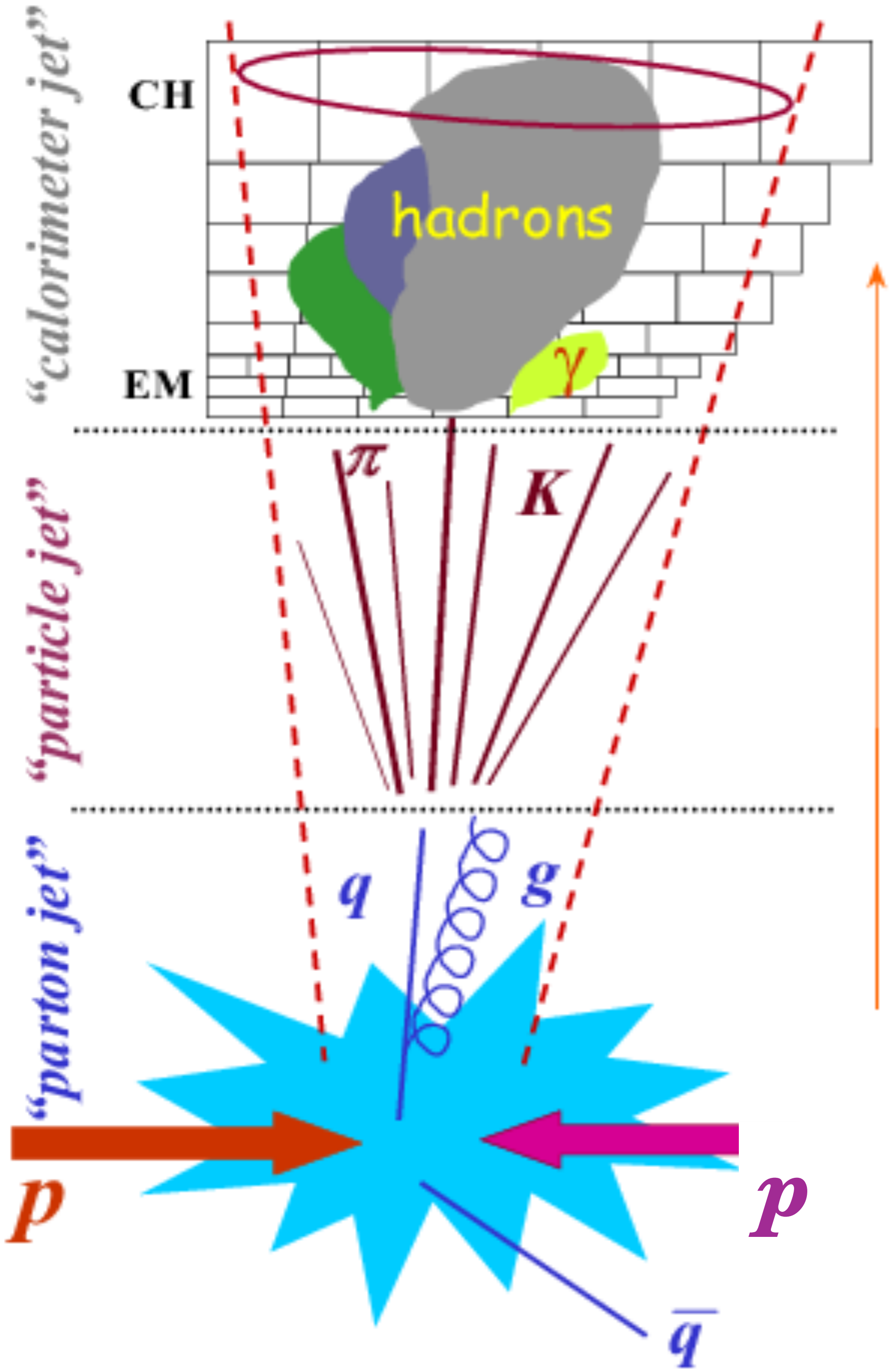
Model Name	X	Color	J^P	$\Gamma / (2M)$	Chan
E_6 Diquark	D	Triplet	0^+	0.004	ud
Excited Quark	q*	Triplet	$\frac{1}{2}^+$	0.02	qg
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
Octet Technirho	ρ_{T8}	Octet	1^-	0.01	$q\bar{q}$,gg
R S Graviton	G	Singlet	2^-	0.01	$q\bar{q}$,gg
Heavy W	W '	Singlet	1^-	0.01	$q_1\bar{q}_2$
Heavy Z	Z '	Singlet	1^-	0.01	$q\bar{q}$



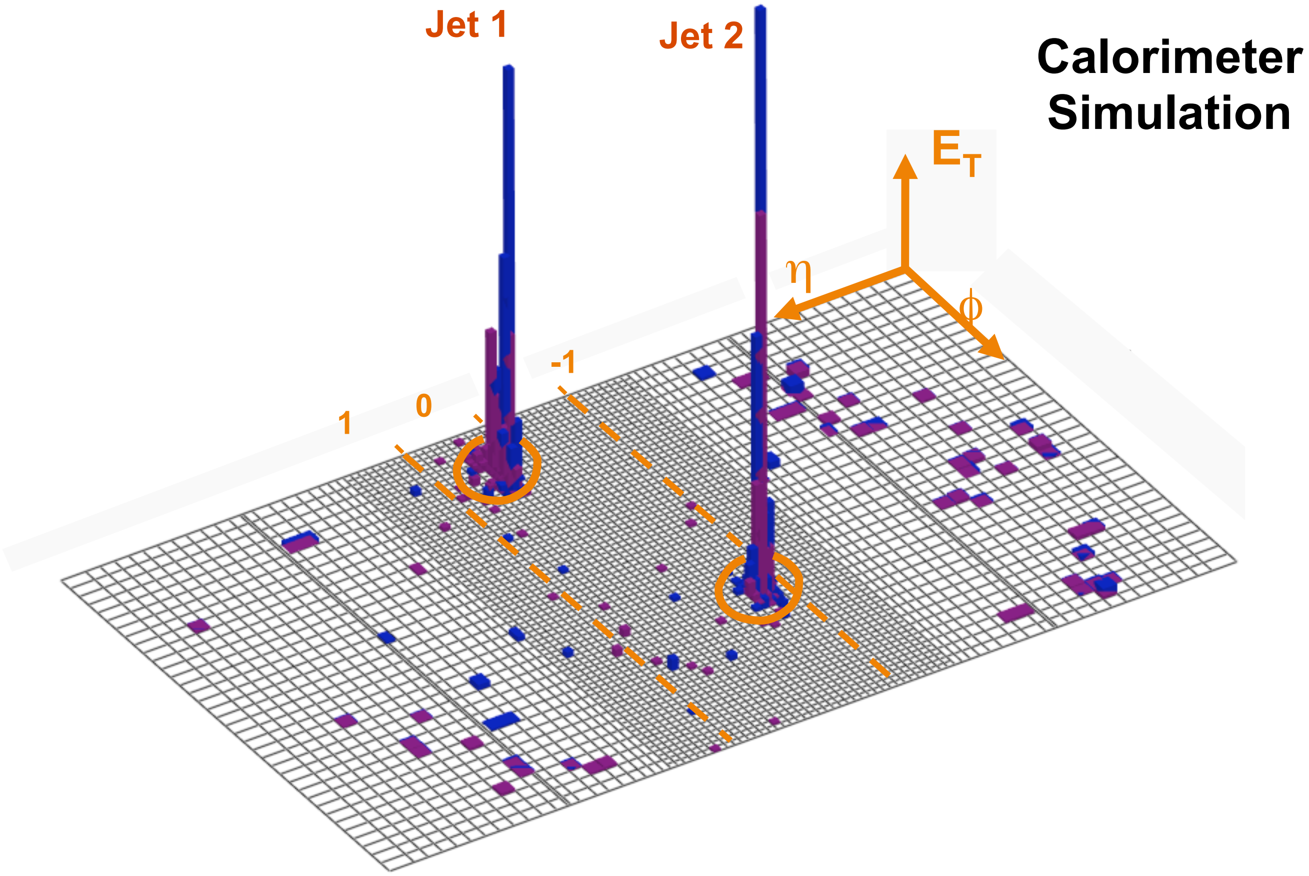
s-channel

Jets at CMS

What is a Jet?



- Jet is the experimental signature of a parton, materialized as a spray of highly collimated hadrons.



Jet Types in CMS

The jet algorithms take as input sets of 4-vectors:

1. GenJets

Stable simulated particles (after hadronization and before interaction with the detector).

2. CaloJets

Calorimeter energy depositions grouped in CaloTowers.

3. JetPlusTrack

Calorimeter jets whose energy has been corrected with jet-track association.

4. PFJets

Individually reconstructed particles by combination of multiple detector inputs (particle flow objects).

5. TrackJets

Tracks

Particles, CaloTowers, PF, Tracks → **Jet Algorithm** → GenJets, CaloJets, PFJets, TrackJets, JetPlusTrack

Jet Reconstruction Algorithms in CMS

1. Iterative Cone R = 0.5

Simple and fast cone algorithm. Used by HLT. Not recommended for analysis !!!!

2. Anti-k_T D = 0.5, 0.7

Belong to the k_T family. For all practical purposes it behaves as a cone algorithm. Infrared & collinear safe. Recommended by JetMET for startup (D = 0.5) !!!

3. k_T D = 0.4, 0.6

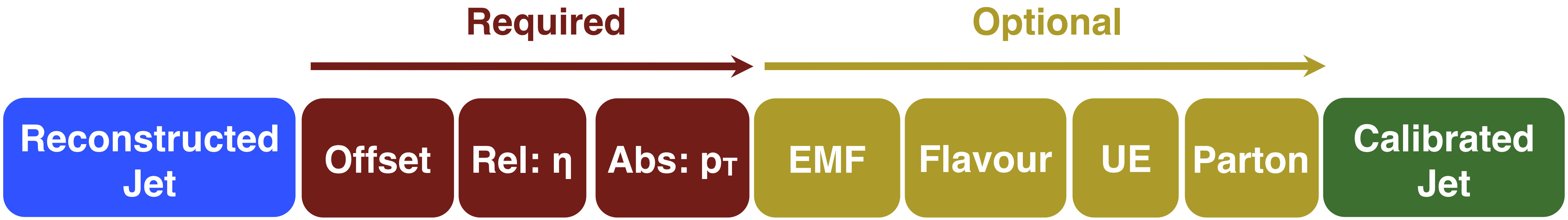
Infrared & collinear safe.

4. Seedless Infrared Safe Cone (SISCone) R = 0.5, 0.7

Infrared & collinear safe but CPU intensive in a “busy” environment. Will be eventually dropped in favor of anti-k_T.

Algorithm	Size	GenJets	CaloJets	PFJets
anti-k_T	**0.5**	**ak5GenJets**	**ak5CaloJets**	**ak5PFJets**
anti-k_T	0.7	ak7GenJets	ak7CaloJets	ak7PFJets
k_T	0.4	kt4GenJets	kt4CaloJets	kt4PFJets
k_T	0.6	kt6GenJets	kt6CaloJets	kt6PFJets
SISCone	0.5	sisCone5GenJets	sisCone5CaloJets	sisCone5PFJets
SISCone	0.7	sisCone7GenJets	sisCone7CaloJets	sisCone7PFJets
iterativeCone	0.5	iterativeCone5GenJets	iterativeCone5CaloJets	iterativeCone5PFJets

Jet Energy Calibration



Required → Offset, Rel: η, Abs: p_T

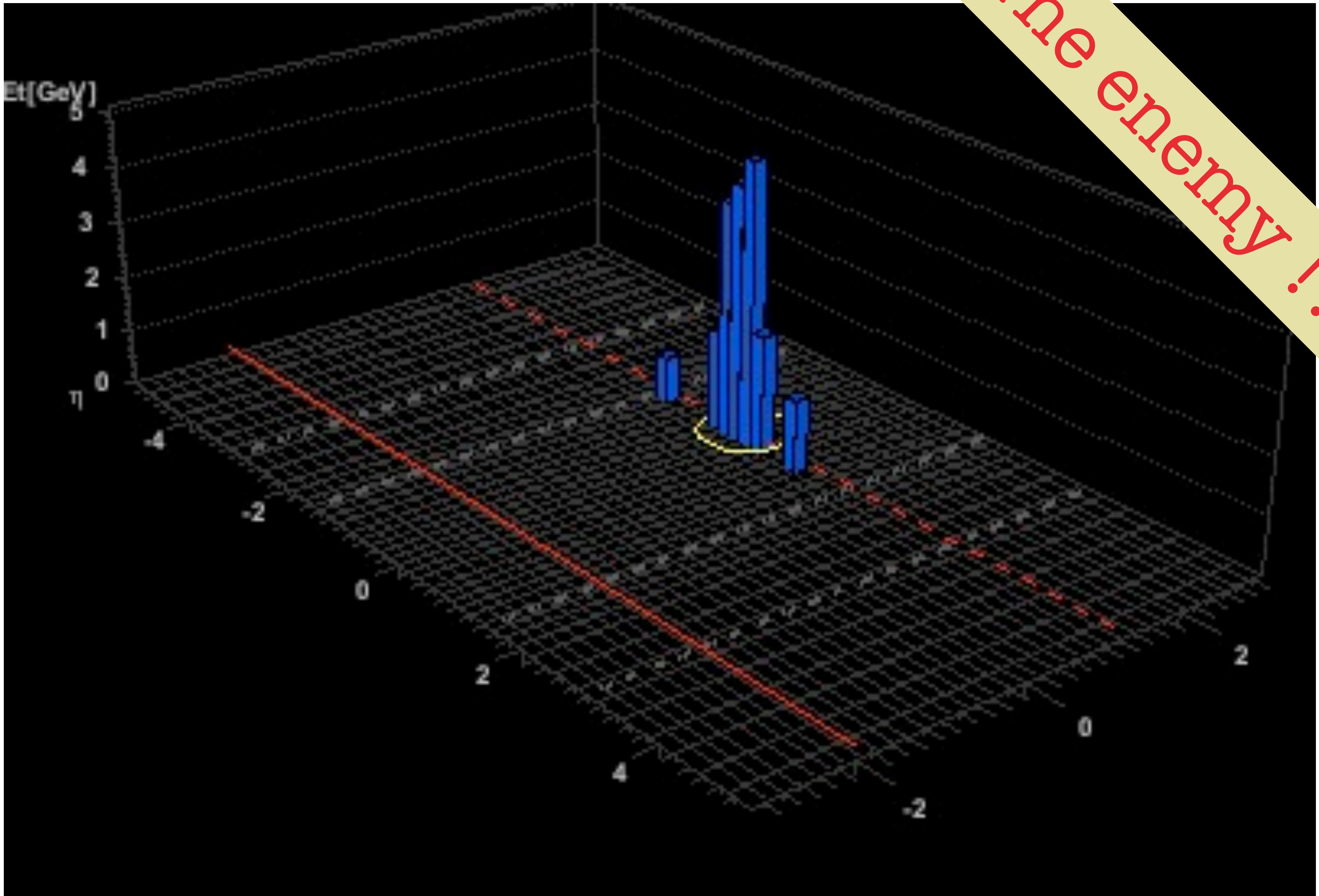
Optional → EMF, Flavour, UE, Parton

Reconstructed Jet → Offset → Rel: η → Abs: p_T → EMF → Flavour → UE → Parton → Calibrated Jet

- We need to calibrate jets because the calorimeter response is non-linear in pt and non-uniform across the detector.
- The jet energy scale is the most important uncertainty related to jets.
- ECAL calibrated with Z→ee , π→ΥΥ
- HCAL calibrated with isolated track.

JetID for CaloJets in CMS

- Electromagnetic energy fraction (EMF). A low cut defends against HCAL noise. A high cut defends again ECAL noise. (dangerous a low jets pt)
- n90. Number of calotowers carrying 90% of the jet energy.
- n90Hits. Number of rechits in the calotowers which carry 90% of the jet energy.
- fHPD. Fraction of the energy contributed by the hottest HPD.
- fRBX. Fraction of the energy contributed by the hottest RBX.
- NTrackCalo & NVertexCalo. Number of associated tracks at the calorimeter phase and vertex.



The enemy !!!

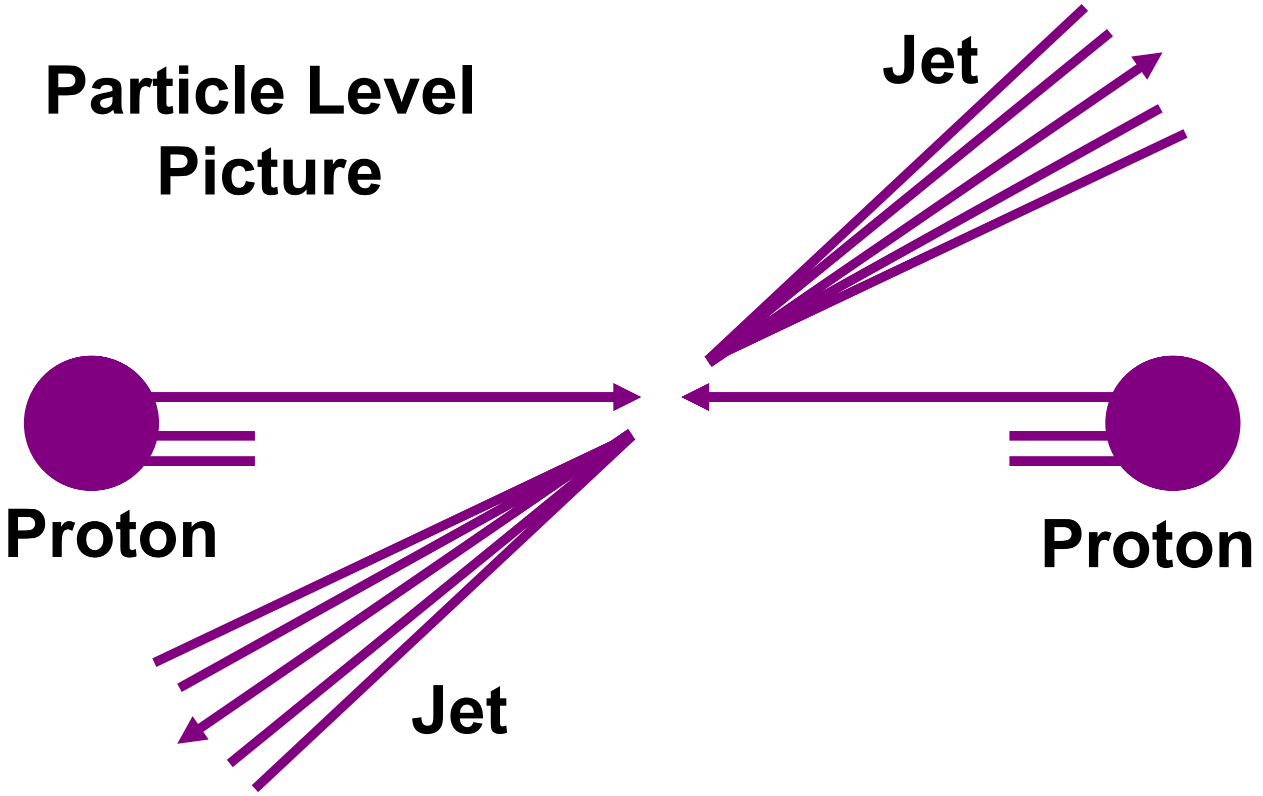
Example of HPD noise

Search For Dijet Resonances

Analysis Strategy

- Background
  - ✓ Pseudo-data from QCD Dijet Sample
- Signal
  - ✓ G→qq, q*→qg, and G→gg resonances at 0.7 TeV, 2 TeV and 5 TeV.
- Analysis
  - ✓ Jets from SisCone algorithm with R=0.7
  - ✓ |Jet η|<1.3
  - ✓ Dijet mass plots use variable dijet mass bins
    - The bins is equal to dijet mass resolutions
  - ✓ Unprescaled jet trigger (HLT_Jet110)
- Bump hunting in dijet mass distribution.
  - ✓ Fitting dijet mass data with BG param + Signal
  - ✓ Calculating of Likelihood vs resonance cross section
  - ✓ Finding 95% C.L. cross section upper limit and comparing with model cross section for mass limits

Dijet Mass



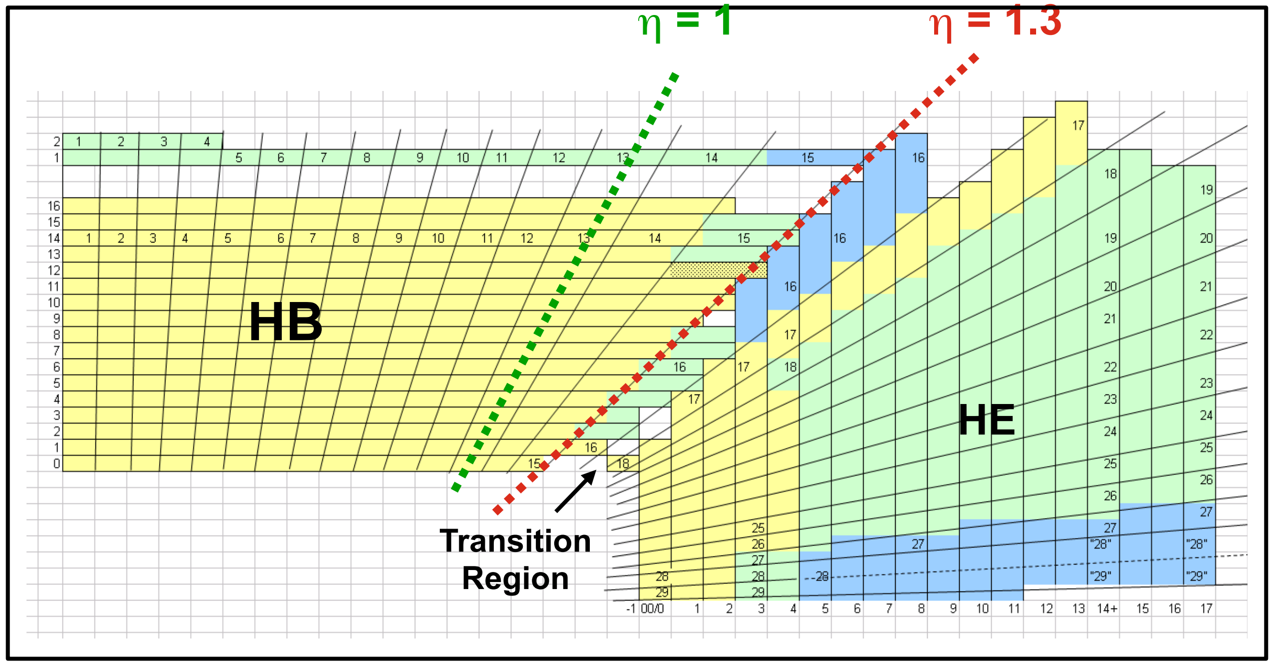
- Dijet Mass from final state

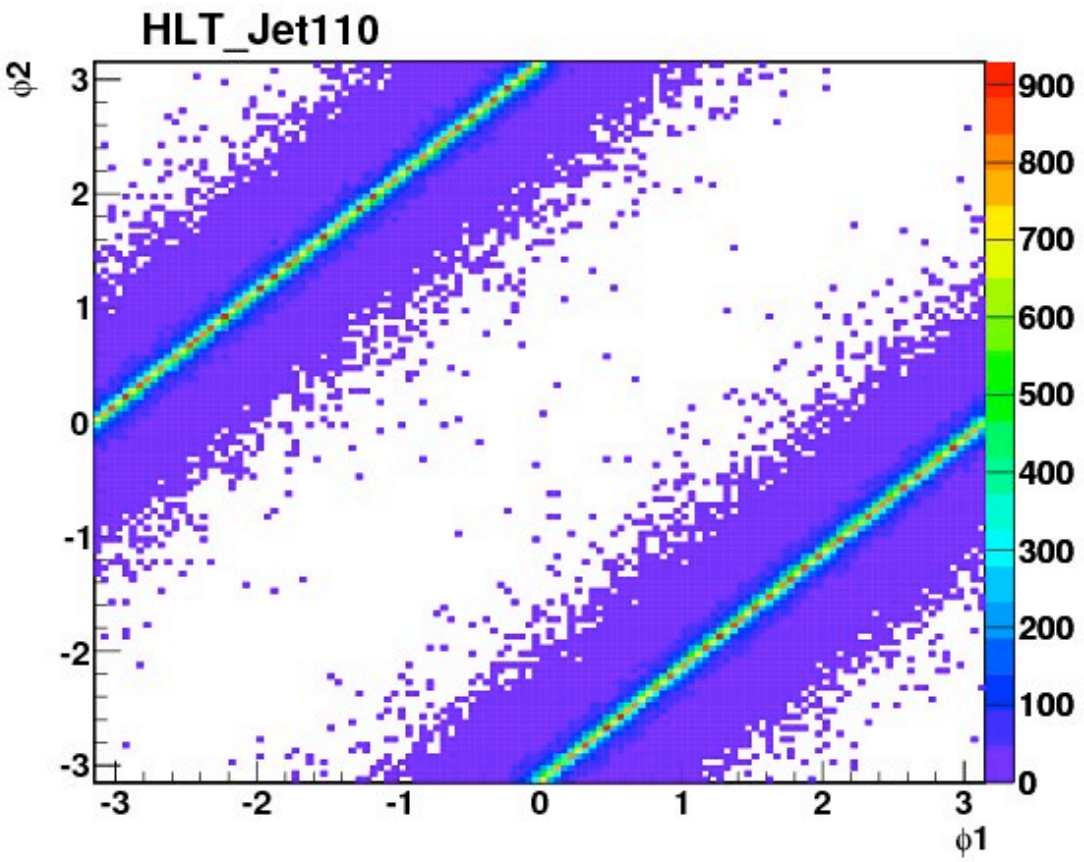
$$m_{jj} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2} = 2p_{t_1}p_{t_2}(cos\Delta\eta - cos\Delta\phi)$$

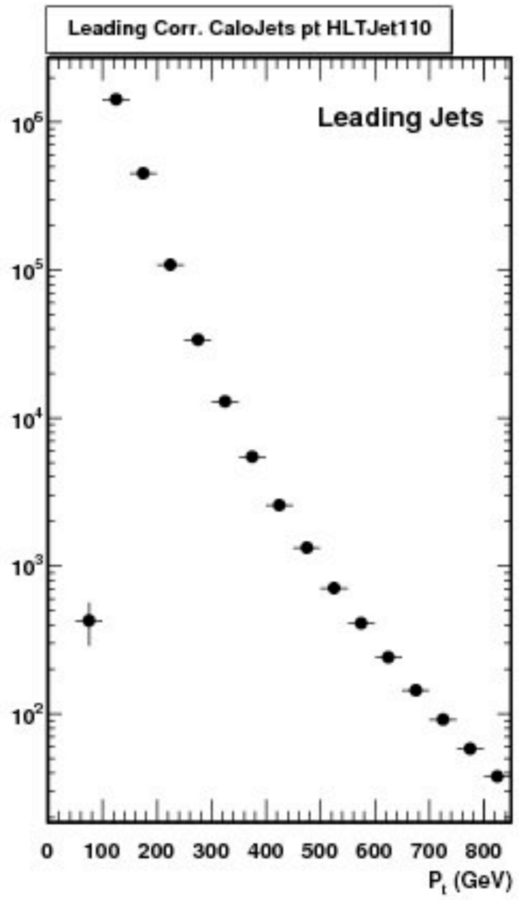
Kinematic Cut

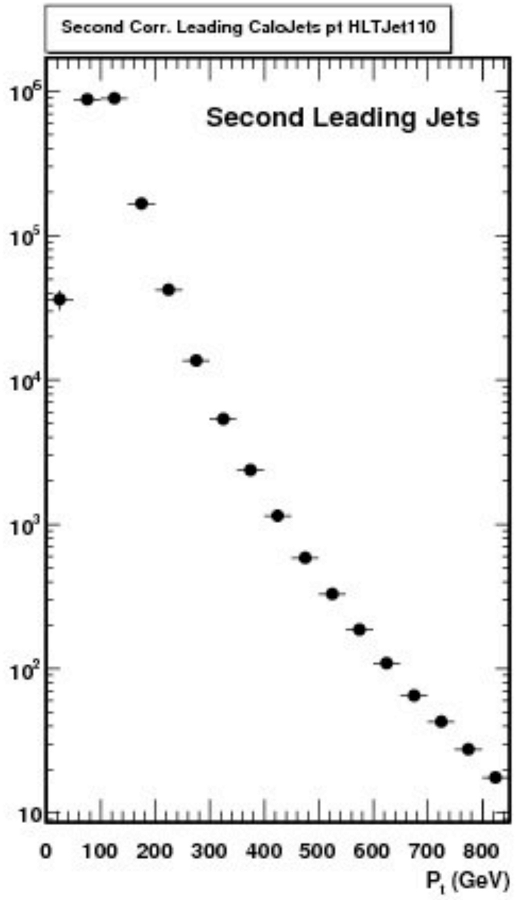
- Two leading jets required to have |η|<1.3
  - ✓ Uniform acceptance
  - ✓ Higher pt reach
  - ✓ Higher sensitivity to new physics

Hcal towers and η cuts



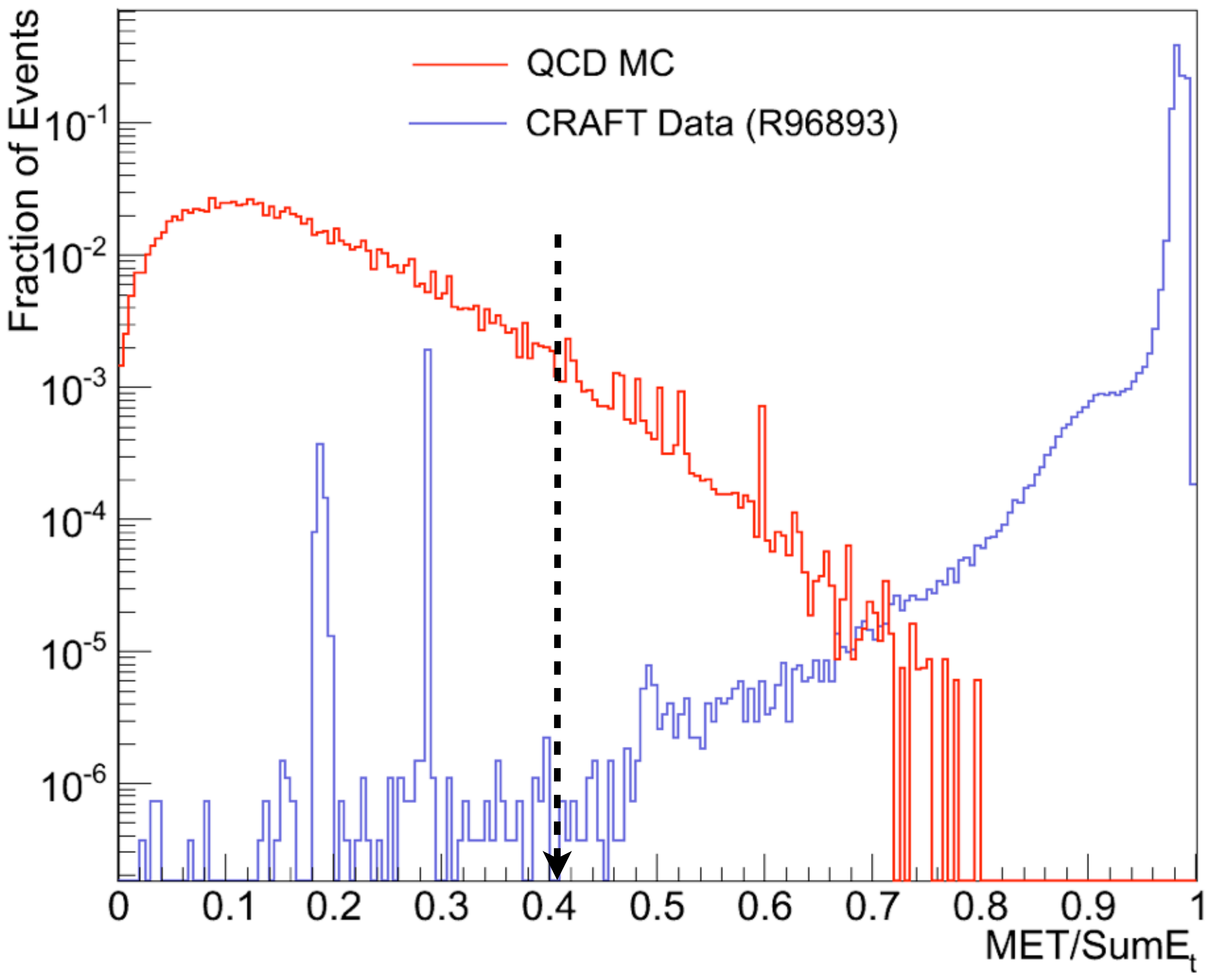






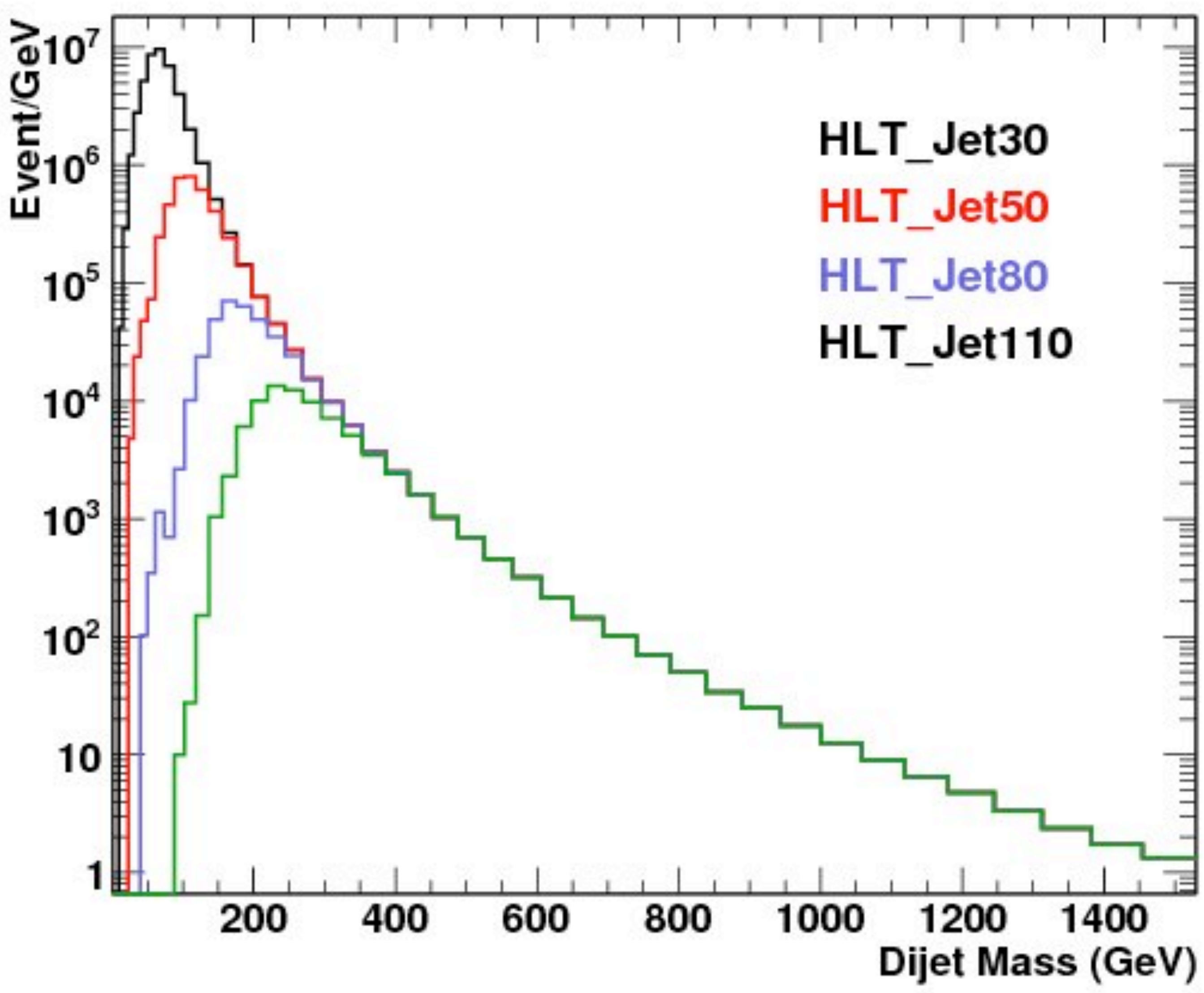
MET/SumET Cut

- MET/SumEt<0.4 to cleanup noise, beam halo, cosmic background .



Trigger Efficiency

- HLT_Jet100 trigger used.
  - ✓ Full efficiency after 420 GeV.



99% Efficiency point

Trigger	Mjj (GeV)
HLT_Jet30	136
HLT_Jet50	204
HLT_Jet80	318
HLT_Jet110	420

Dijet Mass Cross Section

Event counting in bins of dijet mass.

unsmearing correction

$$\frac{d\sigma}{dM} = \frac{C_{uns}}{\mathcal{L}\cdot\epsilon}\cdot\frac{N_{dijets}}{\Delta M}$$

differential cross section

integrated luminosity

jetID & event cleanup efficiency

Dijet Mass Cross Section

Event counting in bins of dijet mass.

~~unsmearing correction~~

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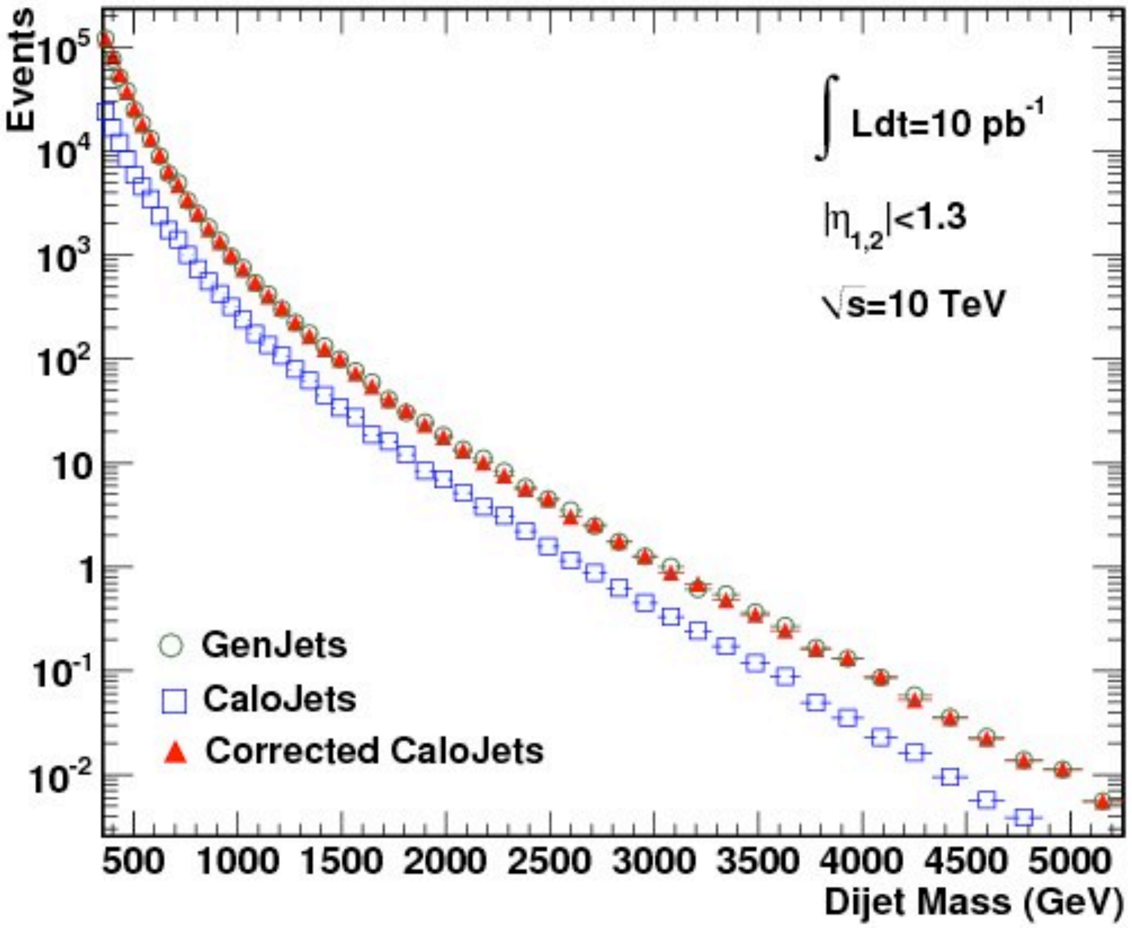
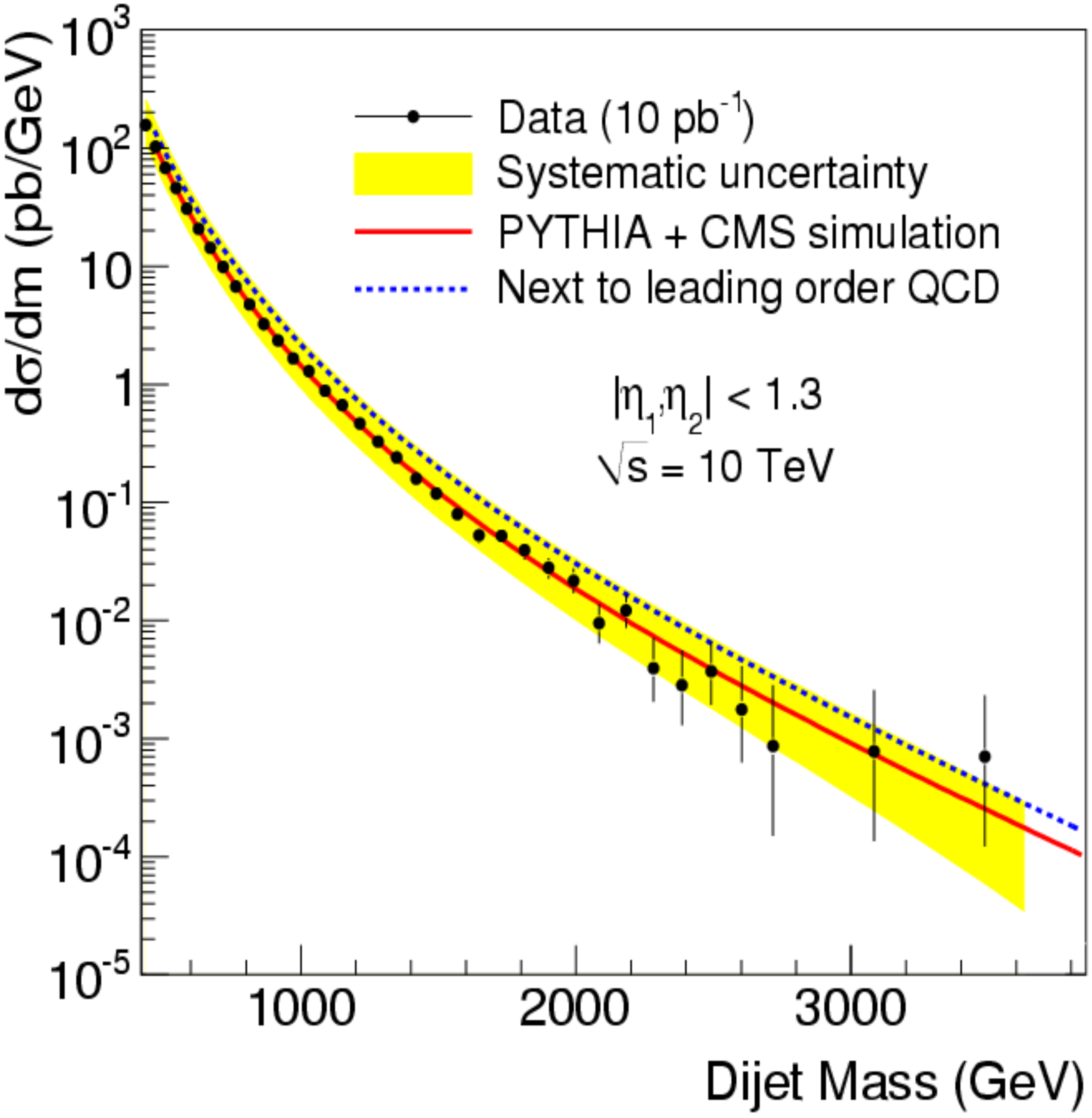
QCD Dijet



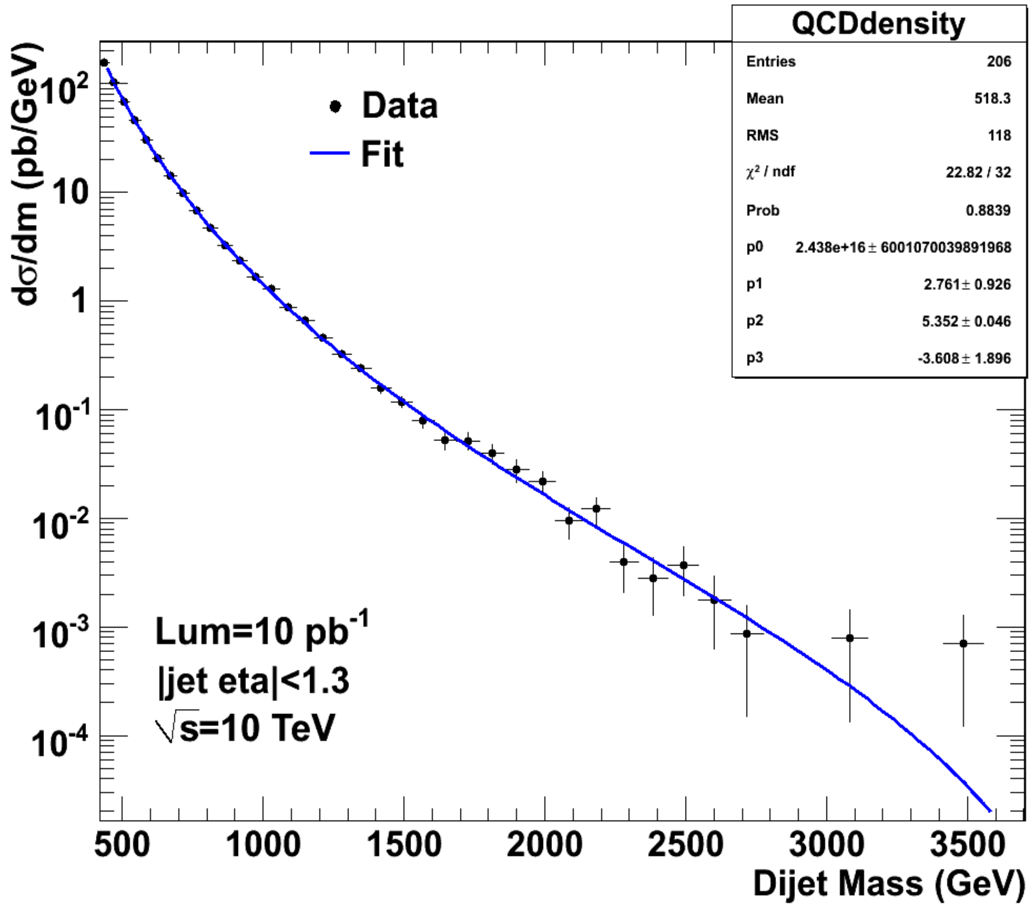
- We have produced a pseudo-data sample for our research.
  - ✓ Cross section from QCD samples was smoothed by fitting.
  - ✓ A toy generator was written to produce random statistical fluctuation in smooth QCD curve.
    - Poisson distribution where n<25.
    - Gaussian distribution where n>25.
- It gives pseudo-data sample with realistic fluctuation.

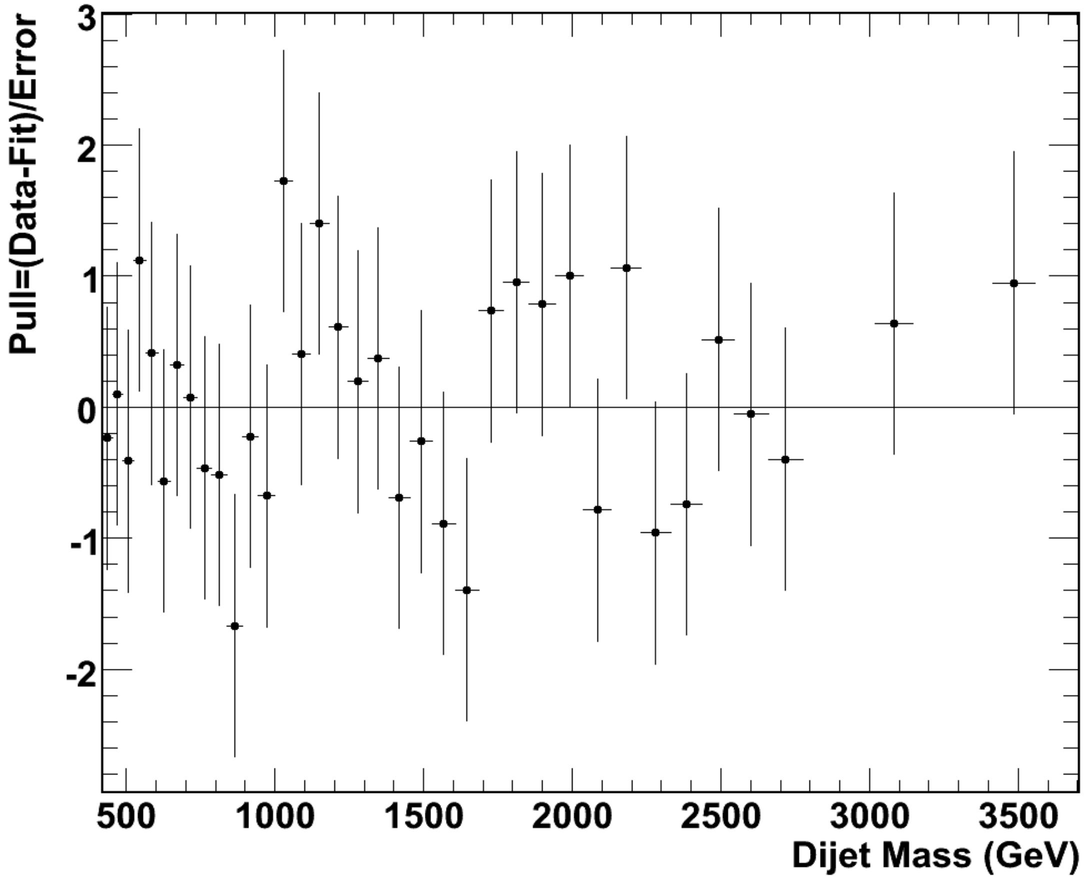
QCD and Pseudo-data



- Pseudo-data set is compared to PYHTIA simulation and NLO QCD.
  - ✓ It is like real data
  - ✓ no evidence for dijet resonance.
- We would proceed to set upper limit

Data and Fit

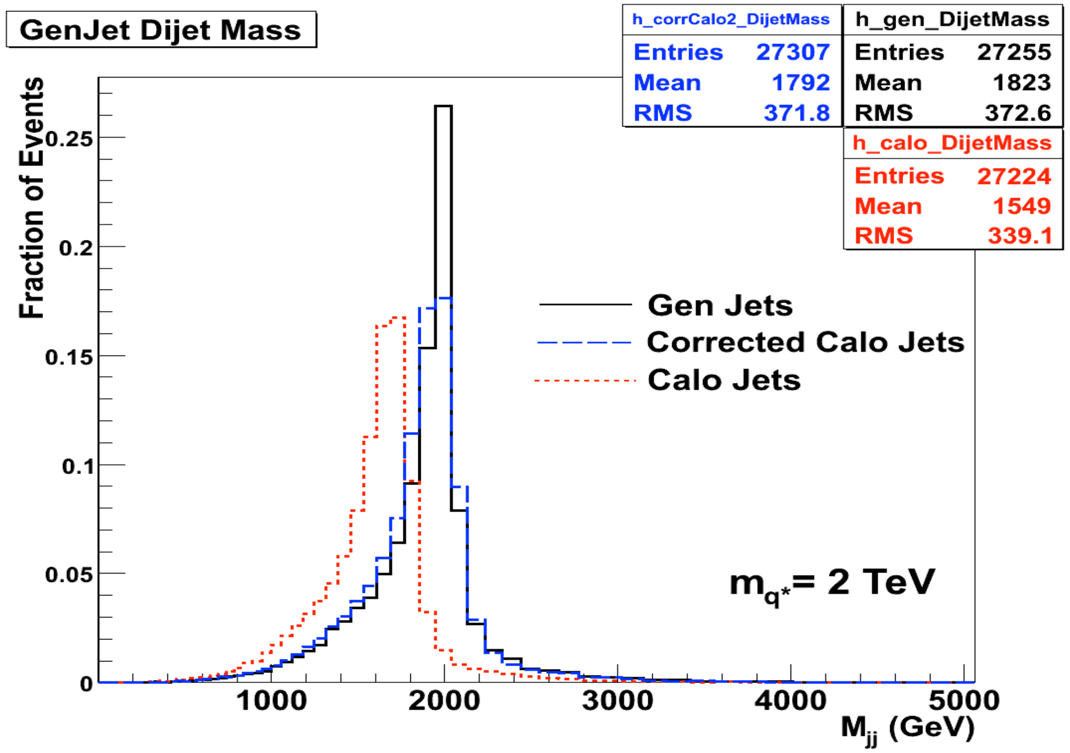


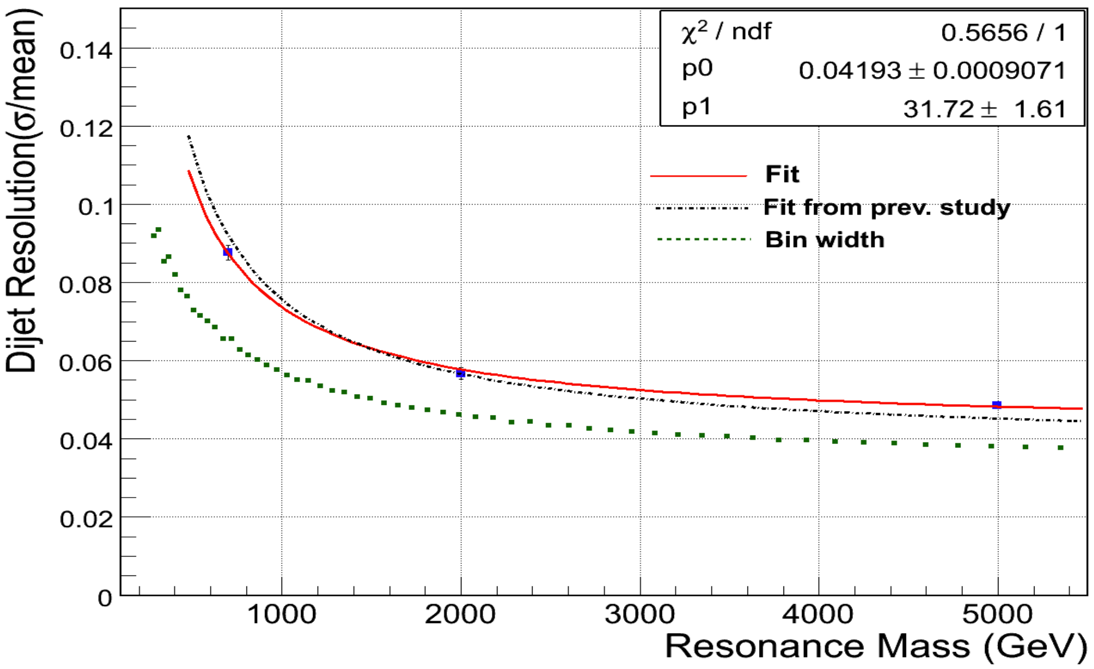


$$\frac{d\sigma}{dm} = p_0 \frac{(1-\frac{m}{\sqrt{s}}+p_3(\frac{m}{\sqrt{s}})^2)^{p_1}}{(m)^{p_2}}$$

- The pulls are consistent with statistical fluctuation.

Dijet Resonances Signal

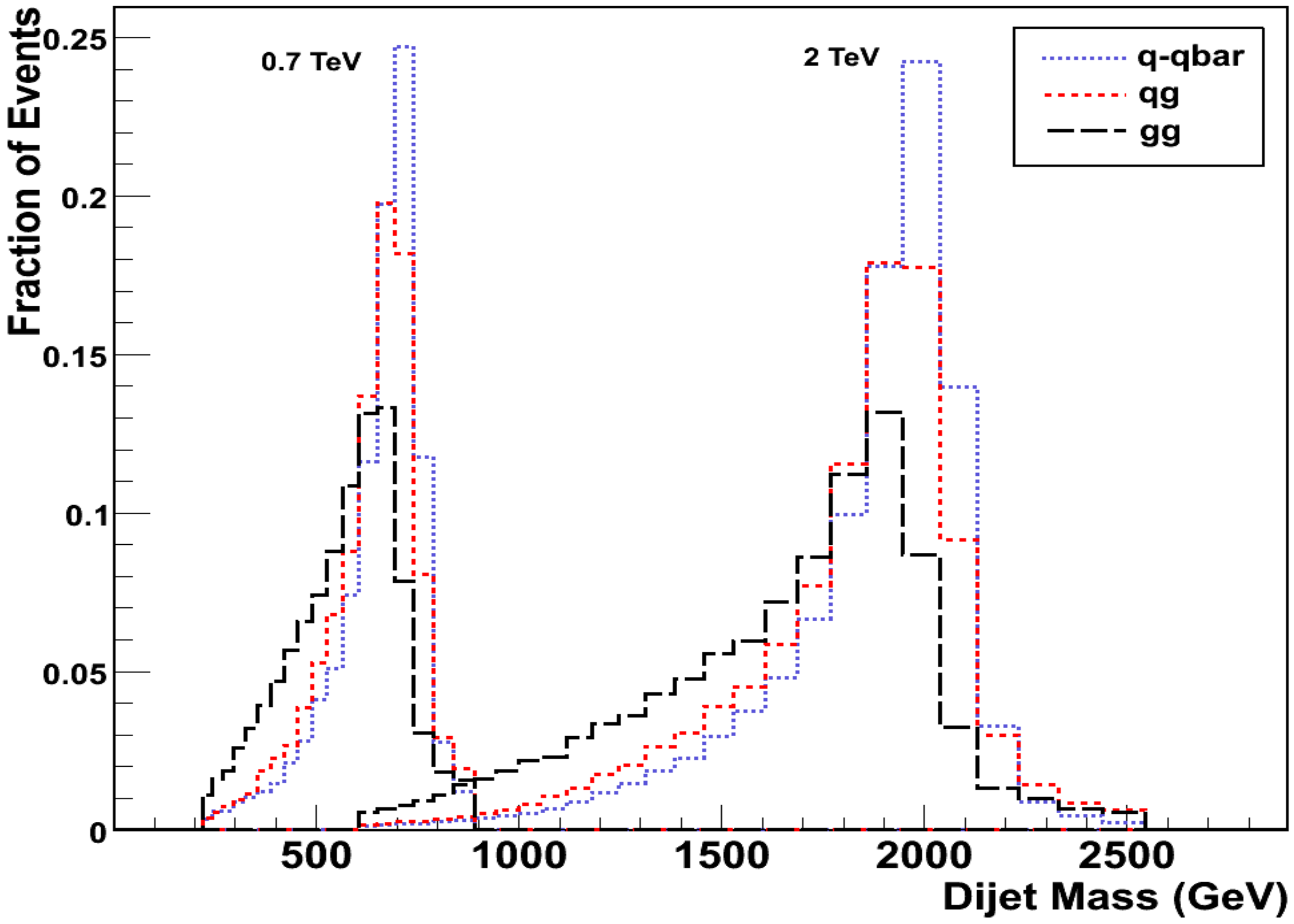


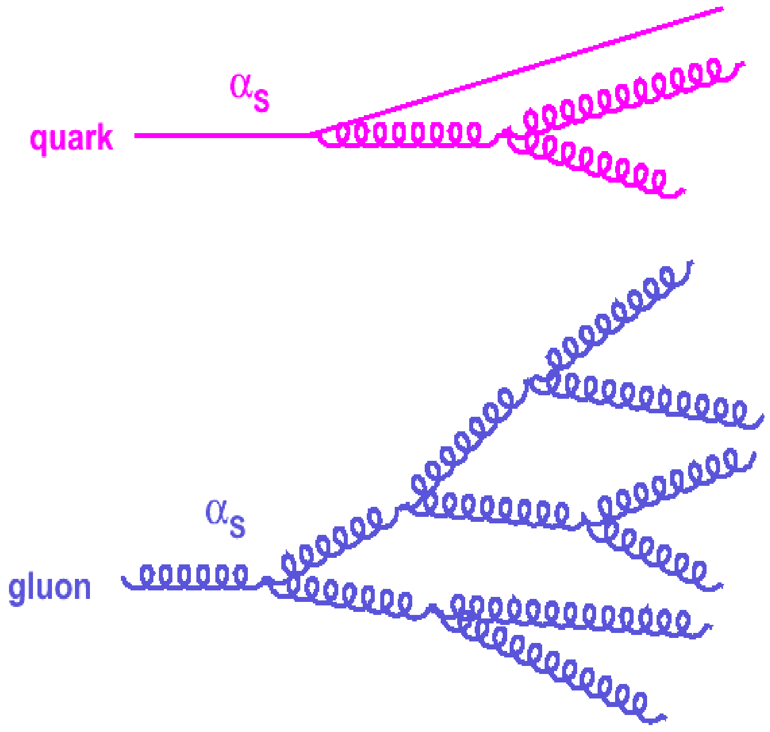


- Peaks are expected resonance mass.
- Resolution varies from 9% to 5%.
- Bin widths are about 75% of resolution.
- Resolution is similar to previous study.

Resonance Shapes

- Because of diffeent detector response, ISR and FSR, the resonance shapes are different
- The width of dijet resonance increase with number of gluon because gluons emit more radiation than quarks.

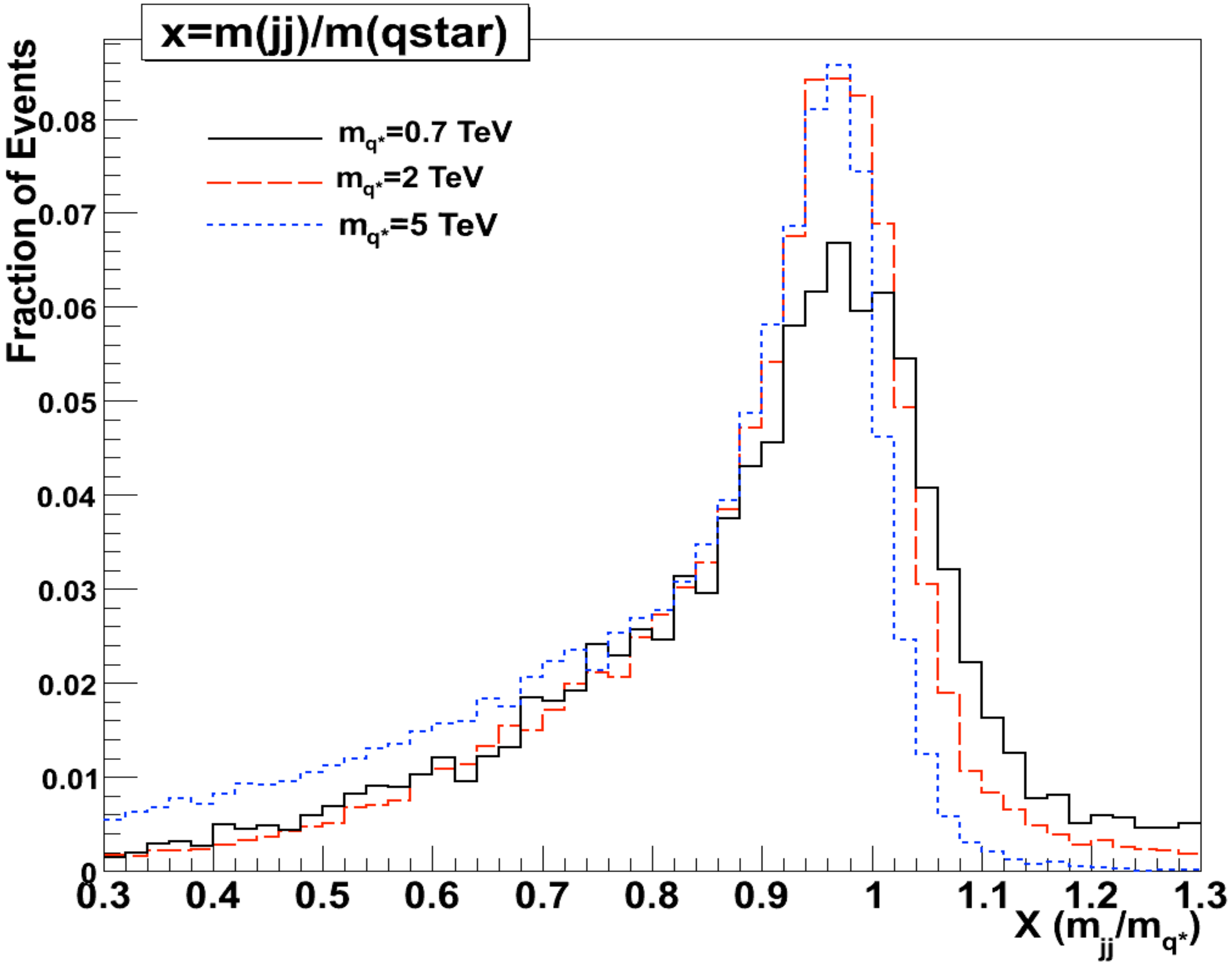




Generating Resonance Shape

- We wanted to get shape of Dijet Resonance for any qstar mass value from the MC samples we have at 0.7, 2, 5 TeV.
- A new parameter, *X*, is determined in terms of resonance mass value.

$$X = \frac{M_{jj}}{M_{Res}}$$

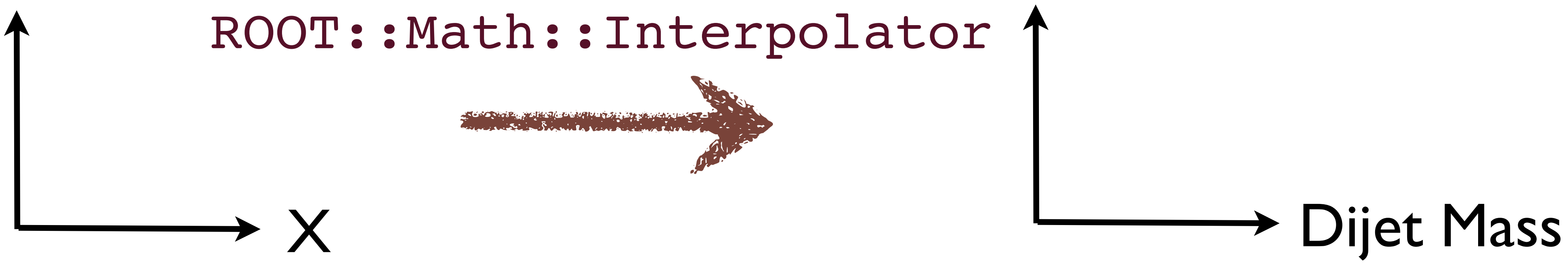


Interpolation

- Interpolation technique was used.
- The X distribution for resonances of mass *M* between generated samples for resonances of mass M_1 and M_2 is calculated as;

$$Prob_M(x) = Prob_{M_1}(x) + \left[Prob_{M_2}(x) - Prob_{M_1}(x)\right] \cdot \frac{M - M_1}{M_2 - M_1}$$

- The X distribution is converted to variable dijet mass bins using interpolation technique to get resonance shape at any resonance masses.



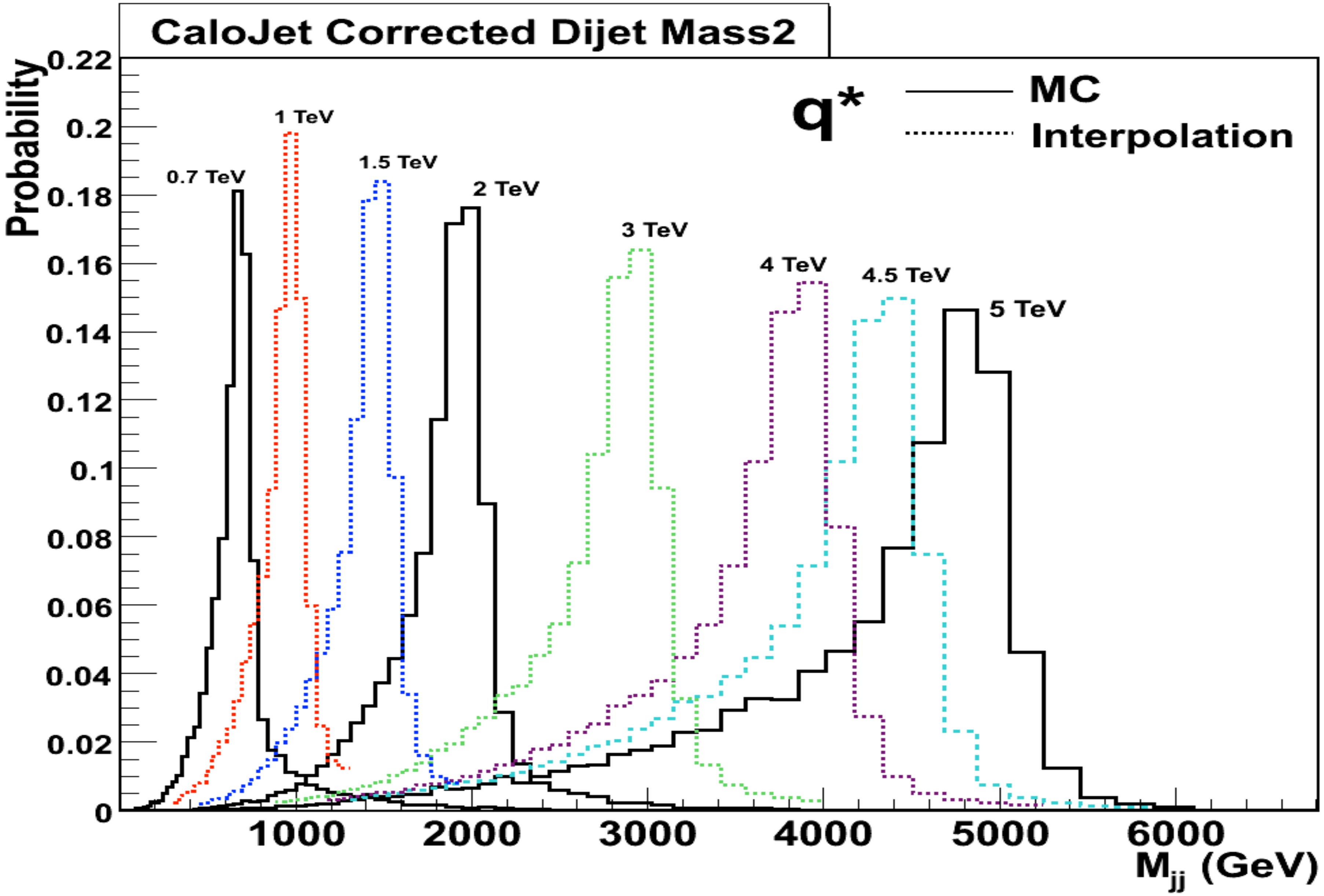
ROOT::Math::Interpolator

X

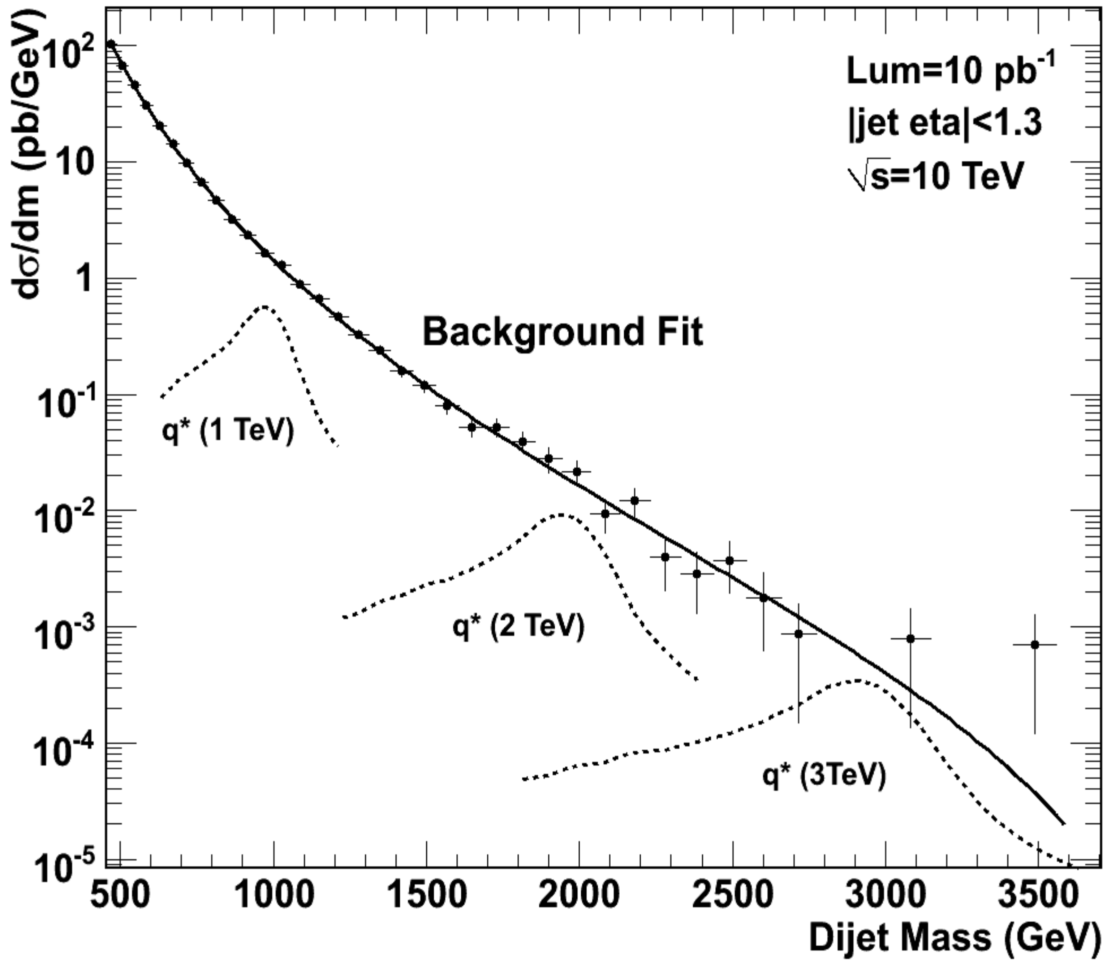
Dijet Mass

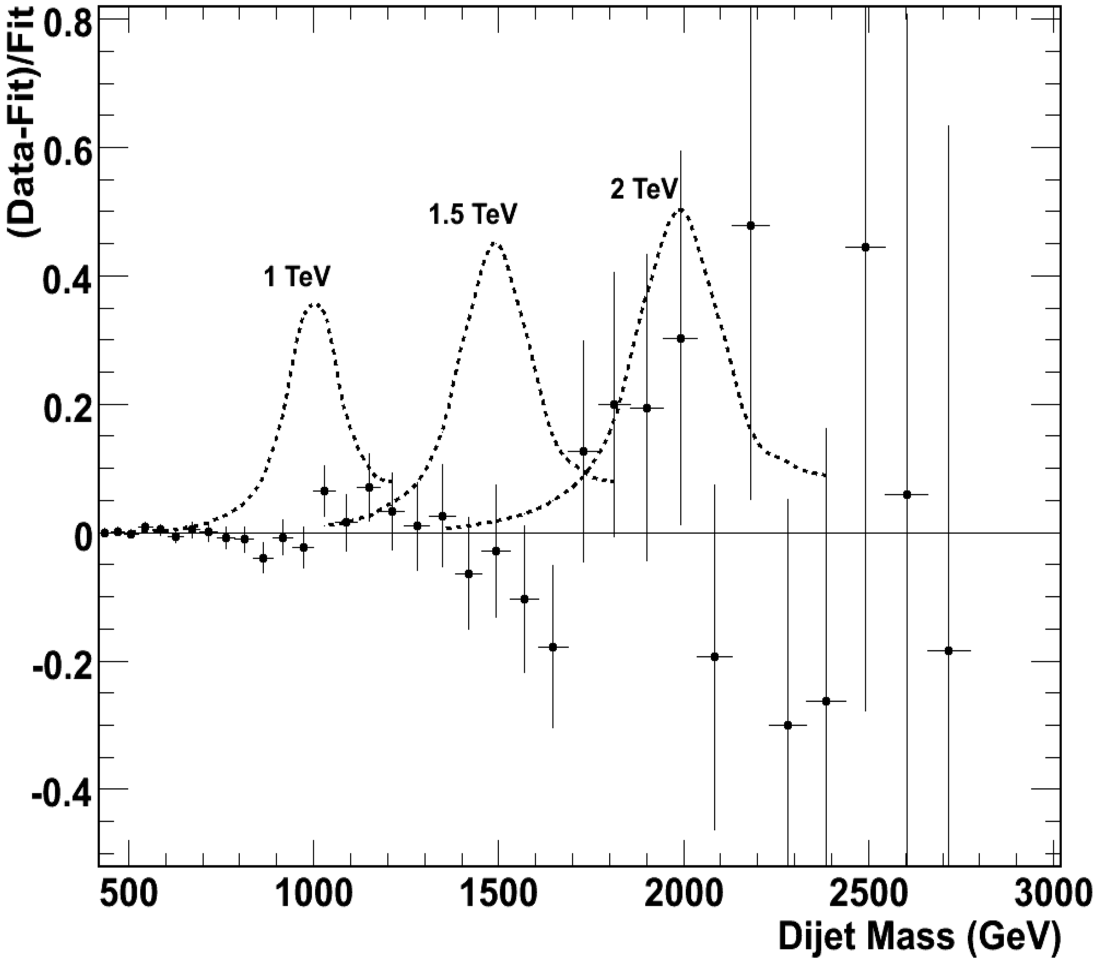
Resonance Shape at any Resonance Mass

- Shape.h and Shape.C can be found in CVS (UserCode/Sertac)



Background and Signal





- The pseudo-data is compared to background fit and resonance signal.
  - ✓ (Data-Fit)/Fit shows that q* signal with M<2 TeV could be seen or excluded.

Likelihood

- To calculate limit on new particle cross section we use a binned likelihood.

$$L = \prod_i \frac{e^{-\mu_i} \mu_i^{n_i}}{n_i!} \qquad \mu_i = \alpha N_i(S) + N_i(B)$$

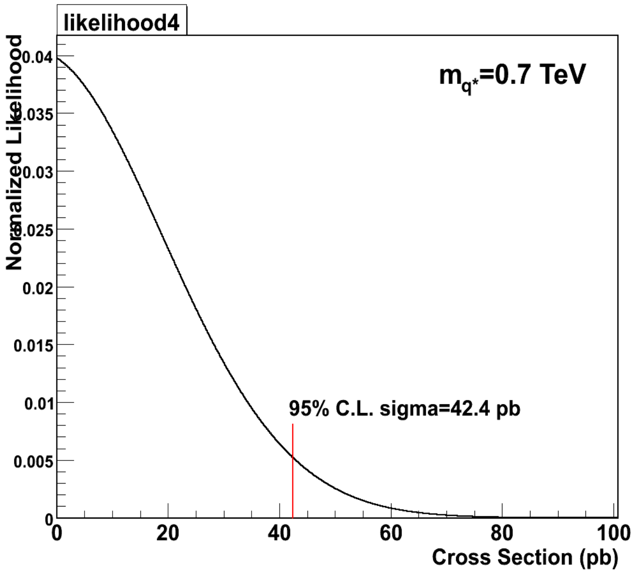
measured # of events in data

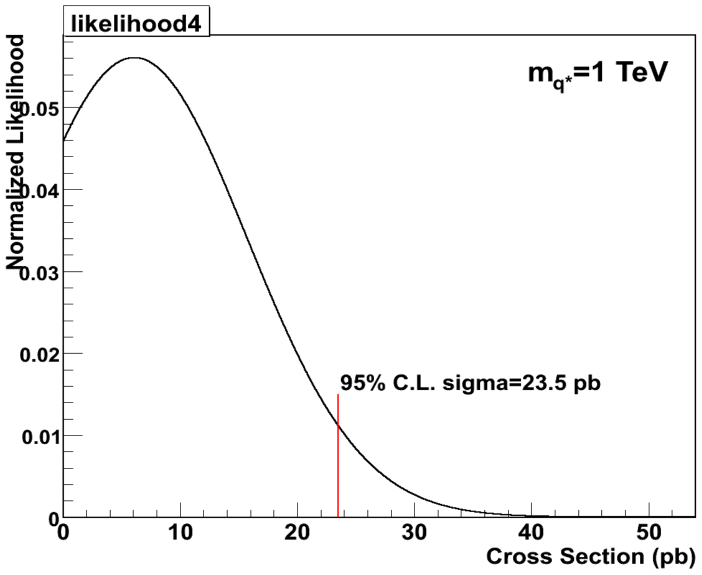
# of events from signal

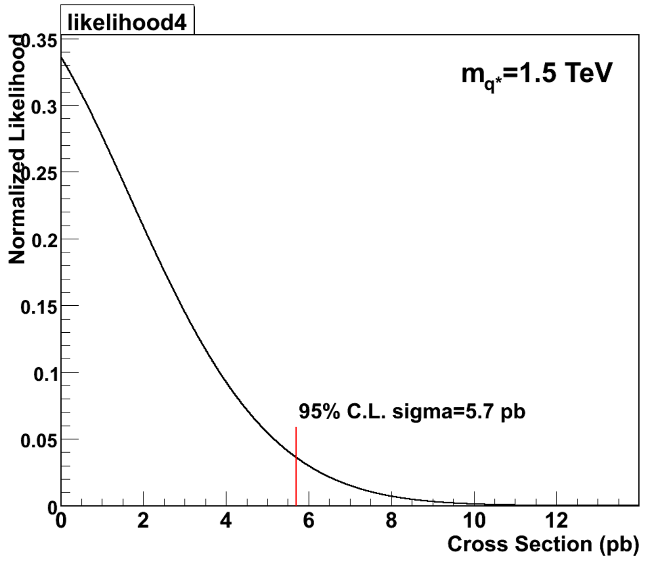
expected # of events from background

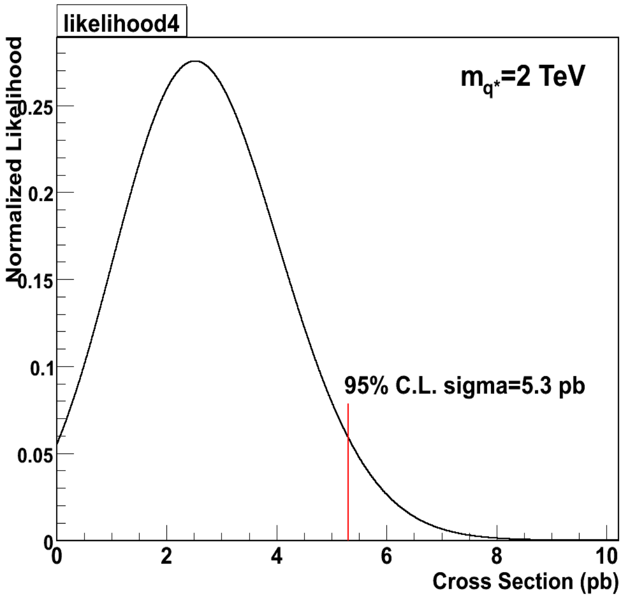
- The signal comes from our extrapolated resonance shapes.
  - ✓ QstarBinnedProb(M_{jj},M_{Res}) function in QstarBinned.h (UserCode/Sertac)
  - ✓ Returns probability in our dijet mass bins for any resonance mass
- Background comes from fit.
- We calculate likelihood as a function of signal cross section for resonances mass with mass from 0.7 TeV to 3.5 TeV in 0.1 TeV steps.

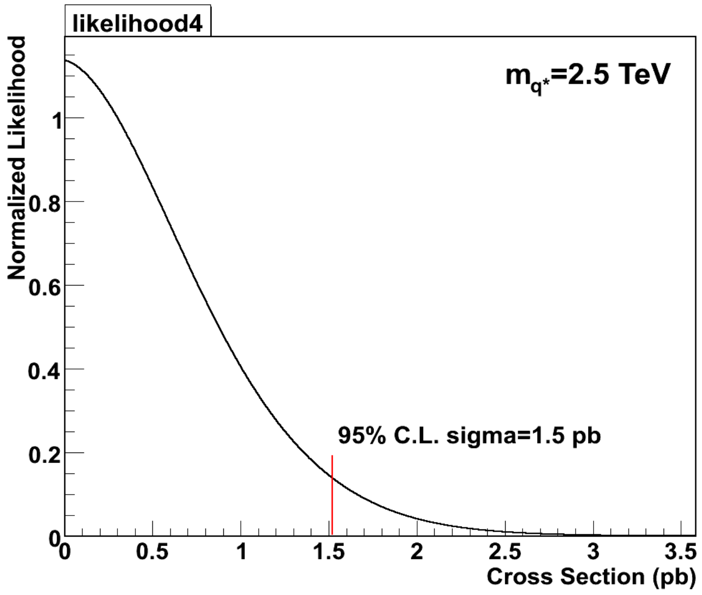
Likelihood Distribution

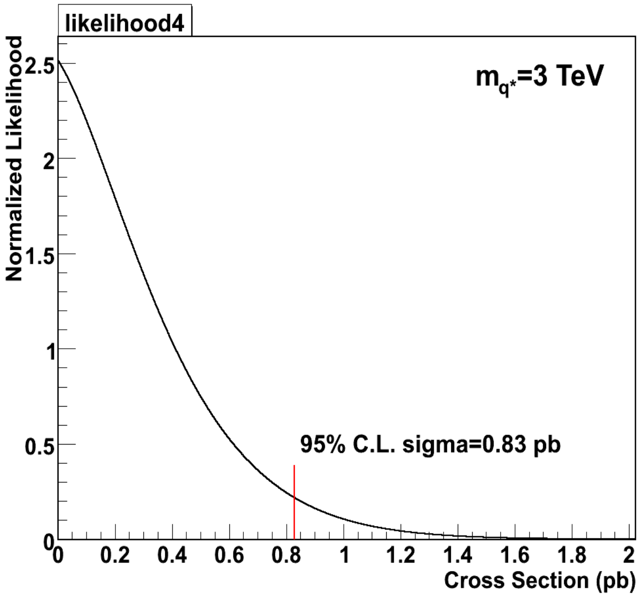








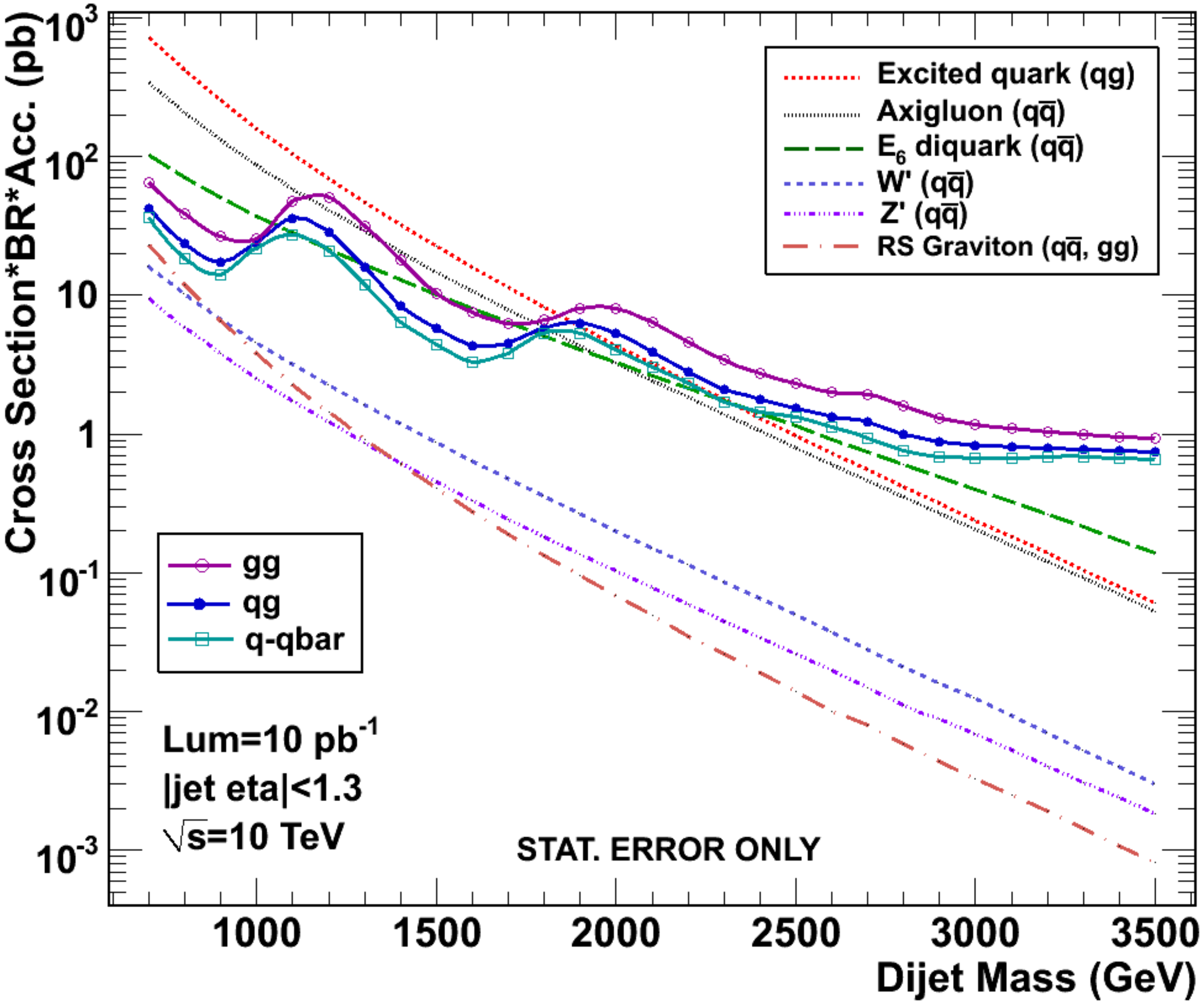




$$\frac{\int_0^{\sigma_{95}} L(\sigma)d\sigma}{\int_0^{\infty} L(\sigma)d\sigma} = 0.95$$

Dijet Resonance Limits with Only Statistical Erros

- 95% C.L. upper limit compared to cross section for various model.
  - ✓ Shown *qq*, *qg*, *gg* resonances separately.

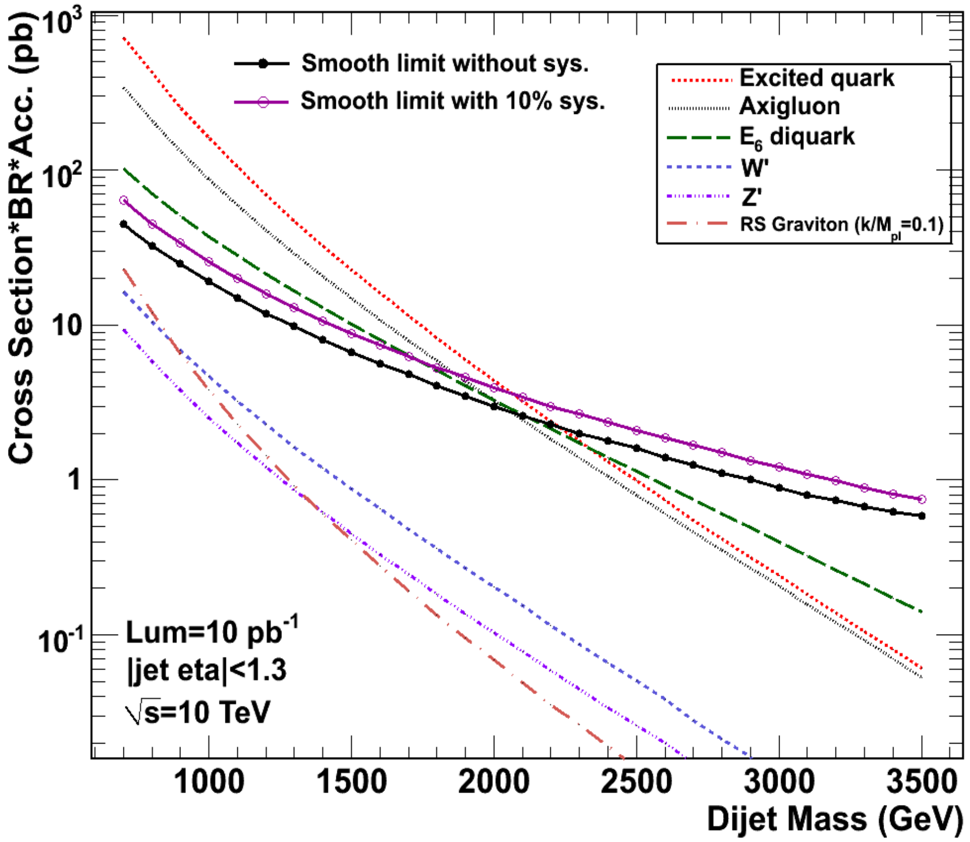


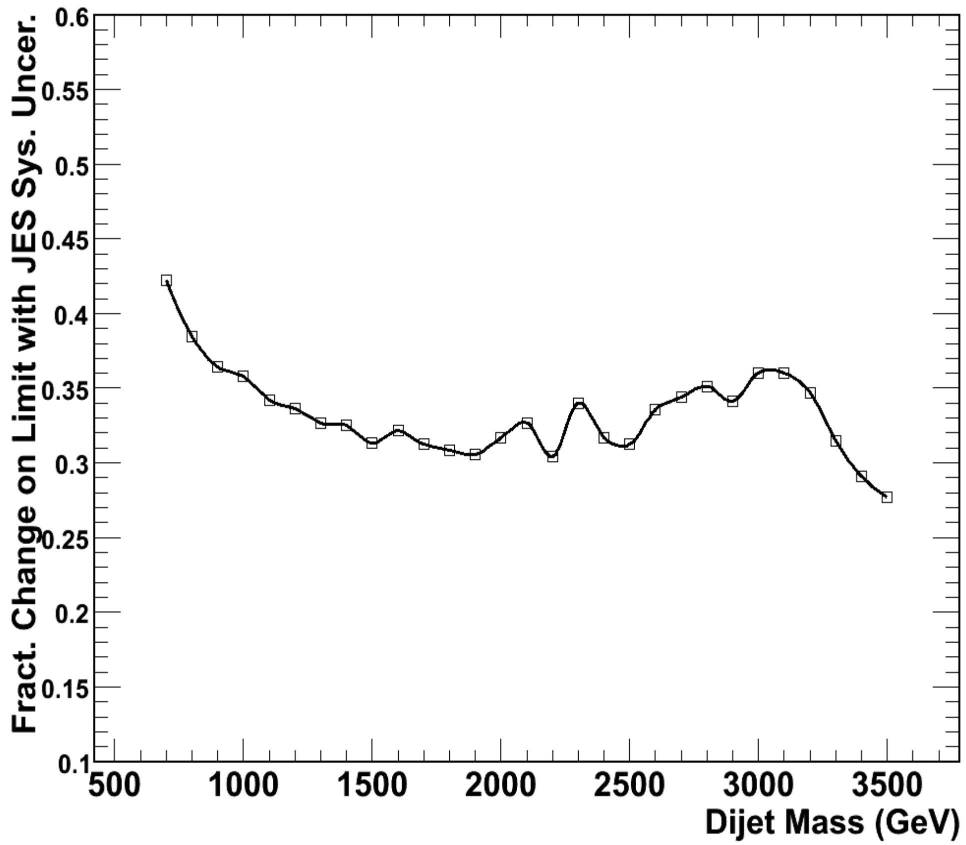
Systematics

- The found the uncertainty in dijet resonance cross section from following sources.
  - ✓ Jet Energy Scale (JES)
  - ✓ Choice of Background Parametrization
  - ✓ Luminosity

Jet Energy Systematic

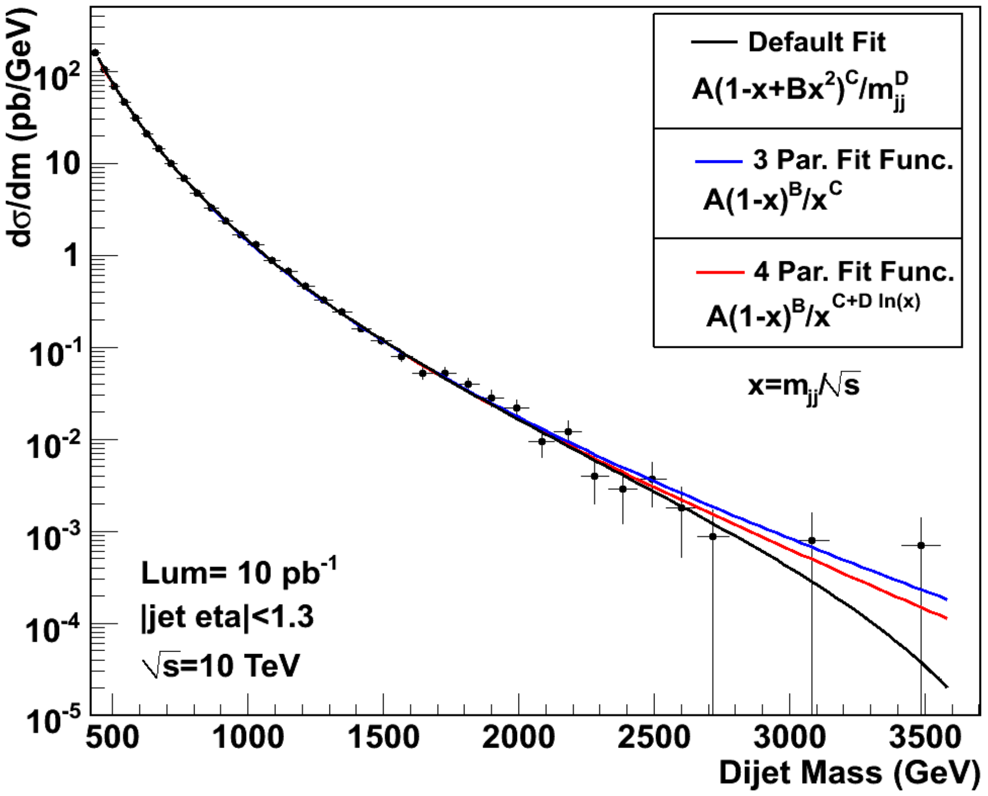
- Systematic uncertainty in jet energy is roughly 10% startup
  - ✓ We have decreased the mass of dijet resonance by 10%
  - ✓ This increases the pseuda-data in the region of the resonance, giving a worse limit
  - ✓ Use a soothed sample of pseudo-data reduce statistical fluctuations in systematic.
  - ✓ Systematic uncertainty varies from 45% at m-0.7 TeV to 30% at m=3.5 TeV

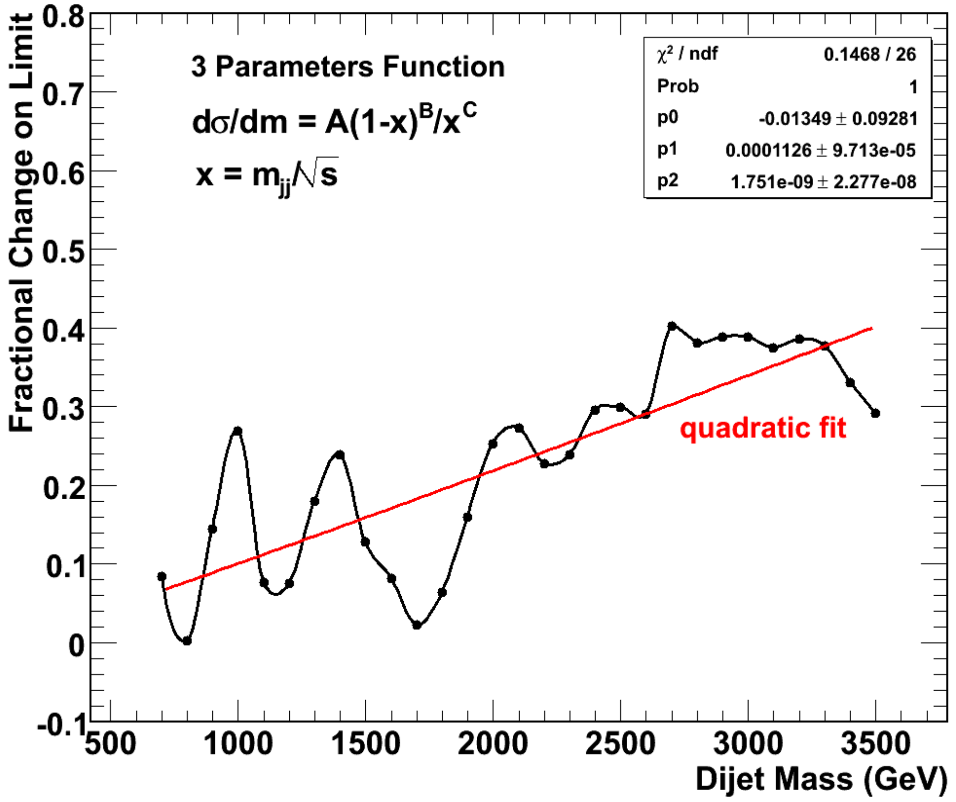




Background Parametrization Systematic

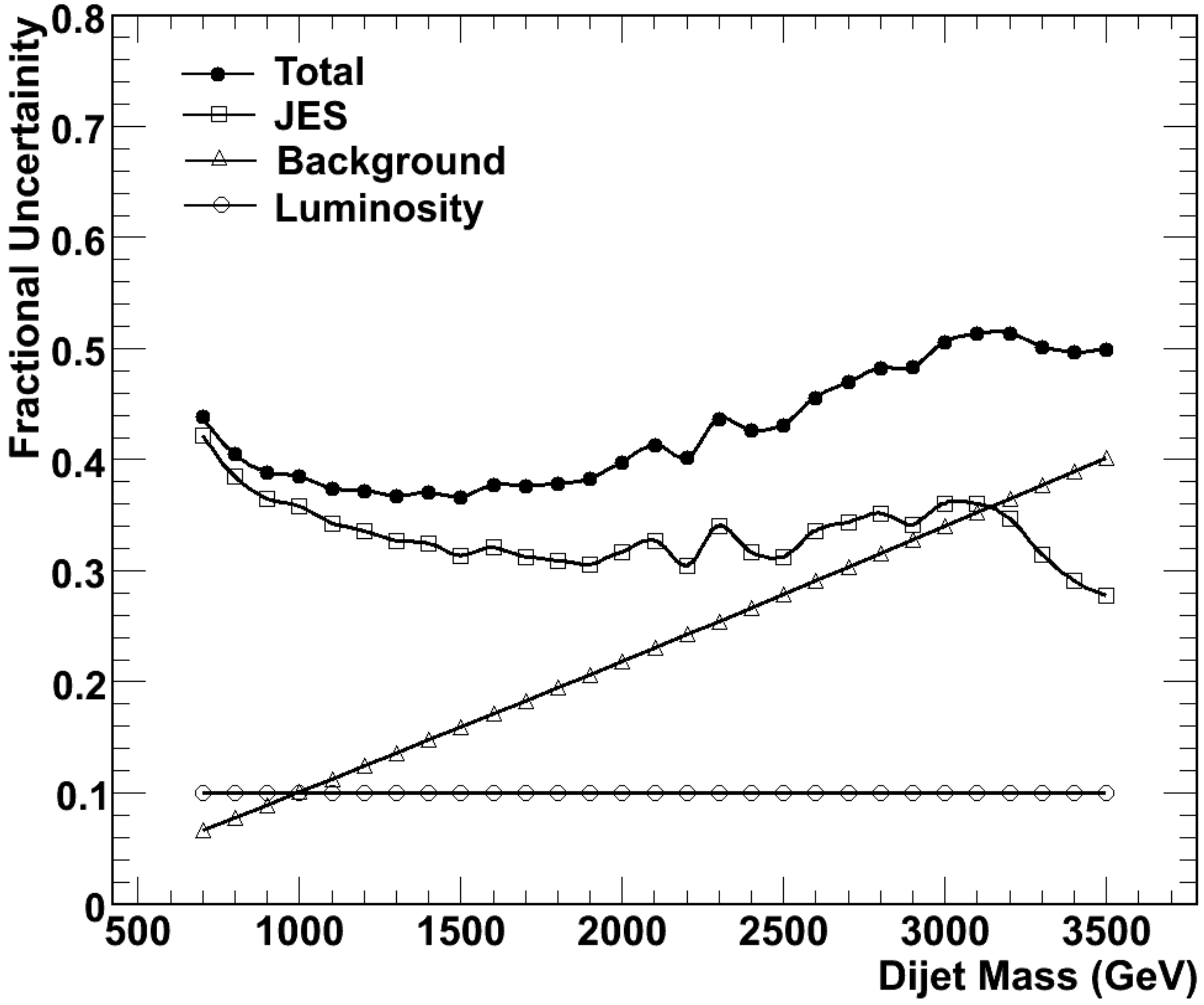
- We have varied the choice of background parametrization
  - ✓ A simpler functional form with 3 parameters and another with 4 parameters.
  - ✓ Both functional forms were used by CDF.
  - ✓ We found the 3 parameters form gave the largest change.
- We smoothed the statistical variations in the absolute change in the limit.
- Systematic uncertainty varies from 8% at m-0.7 TeV to 40% at m=3.5 TeV





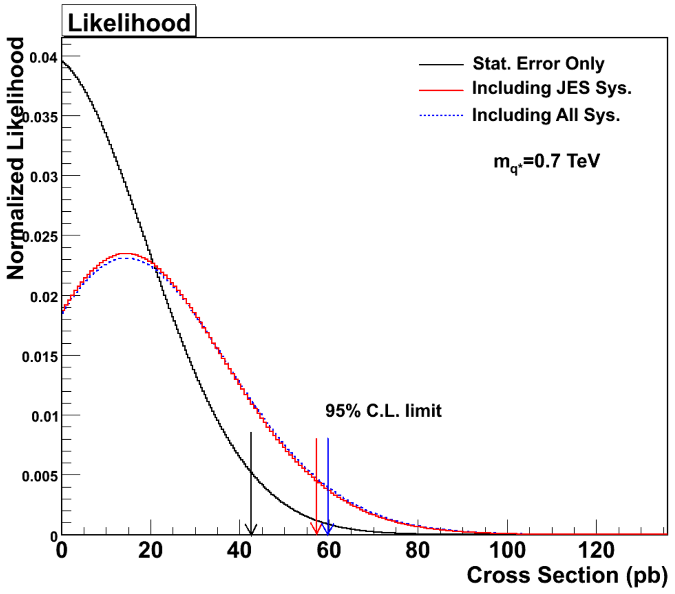
Total Systematic Uncertanity

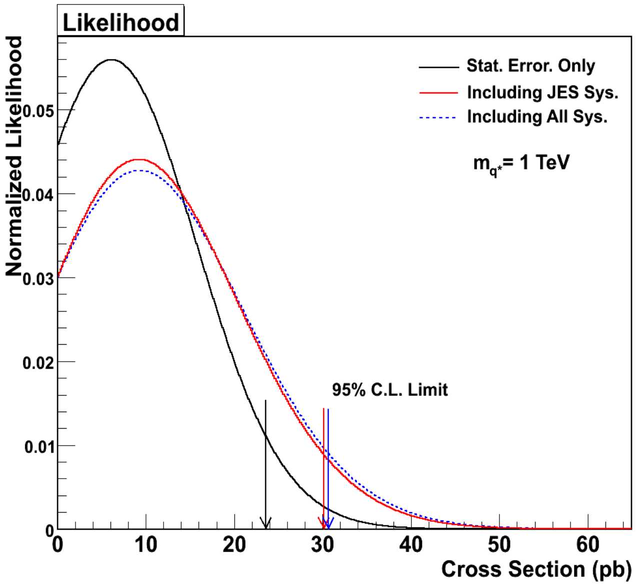
- We add in quadrature the individual systematic uncertainties
  - ✓ JES, background parametrization and luminosity
  - ✓ Total systematic uncertanity varies from 45% at m=0.7 TeV to 50% at m=3.5 TeV.

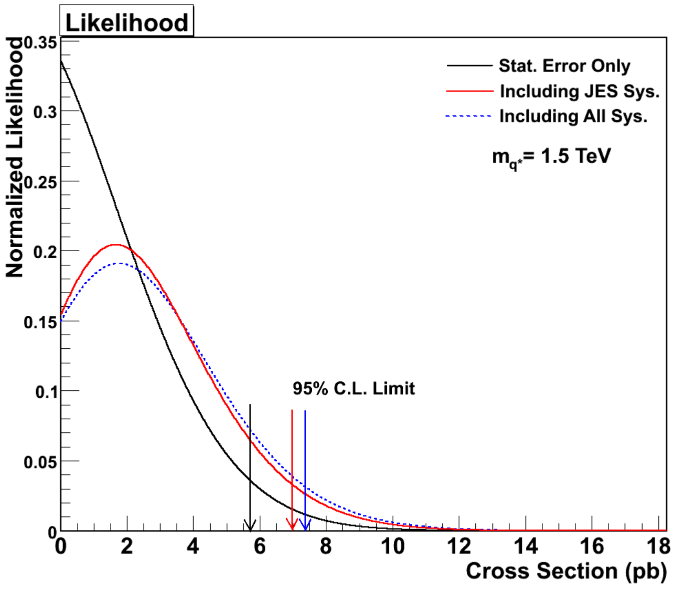


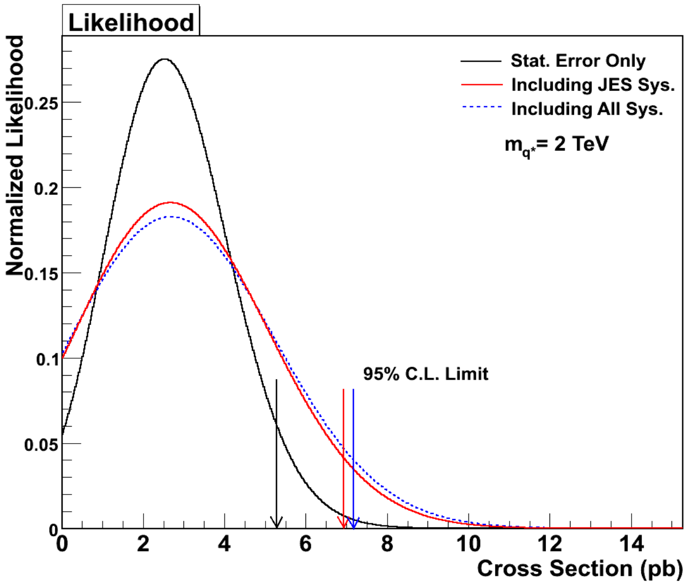
Likelihoods with Systematics

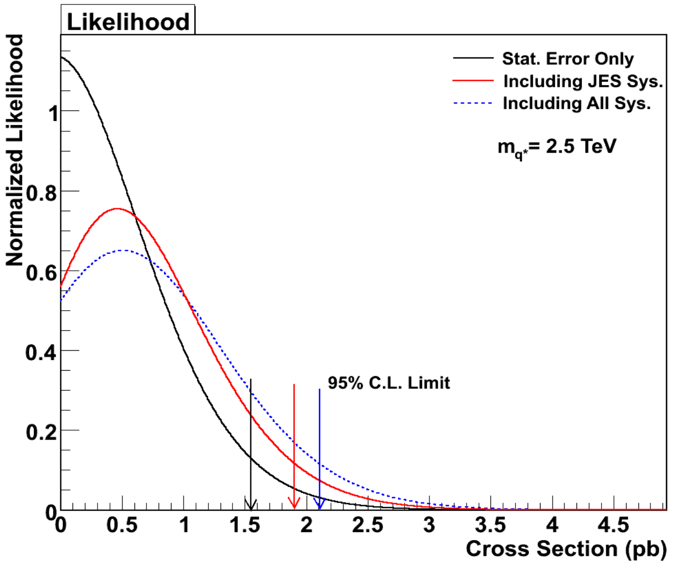
- We convolute Poisson likelihoods with Gaussian systematics uncertainties
  - ✓ Total likelihood including systematics in broader and gives higher upper limit

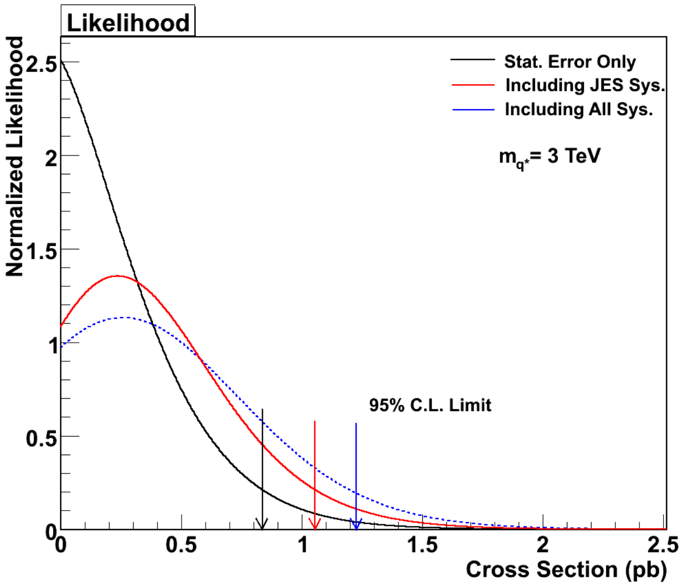






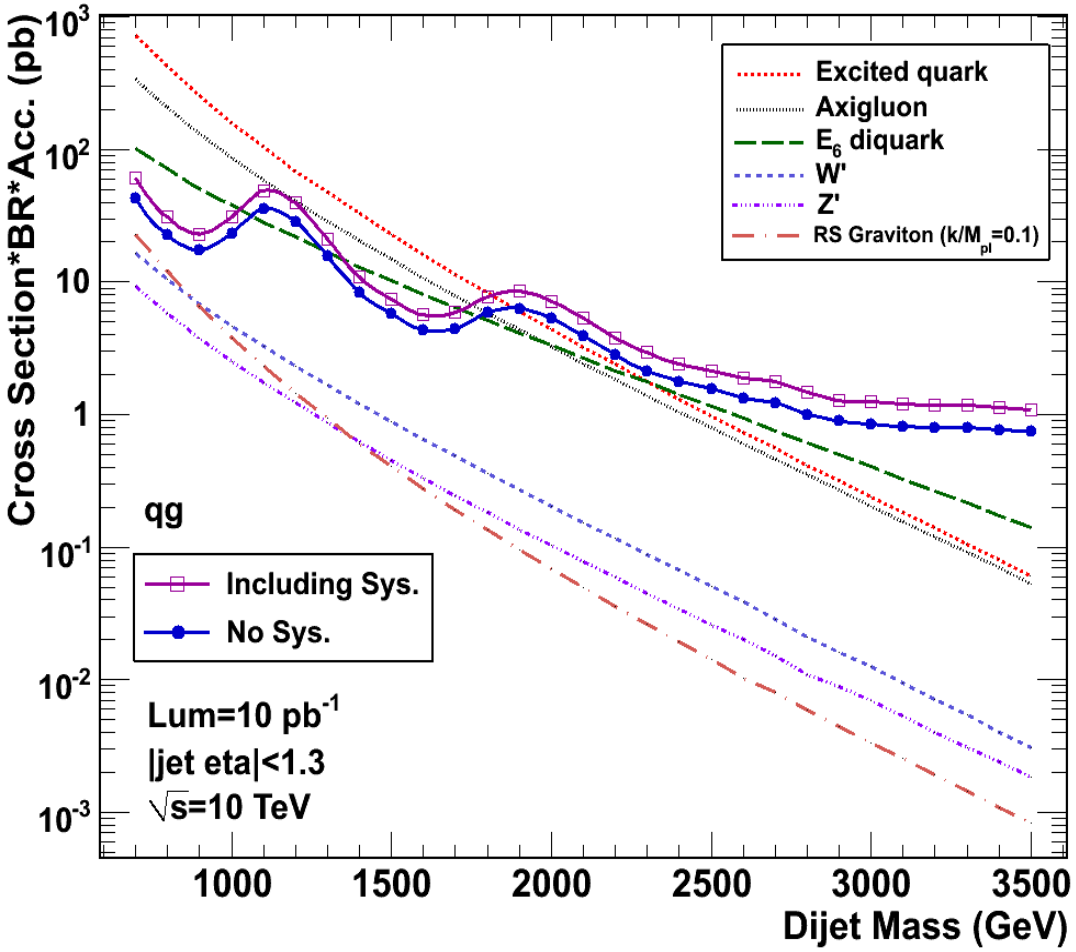


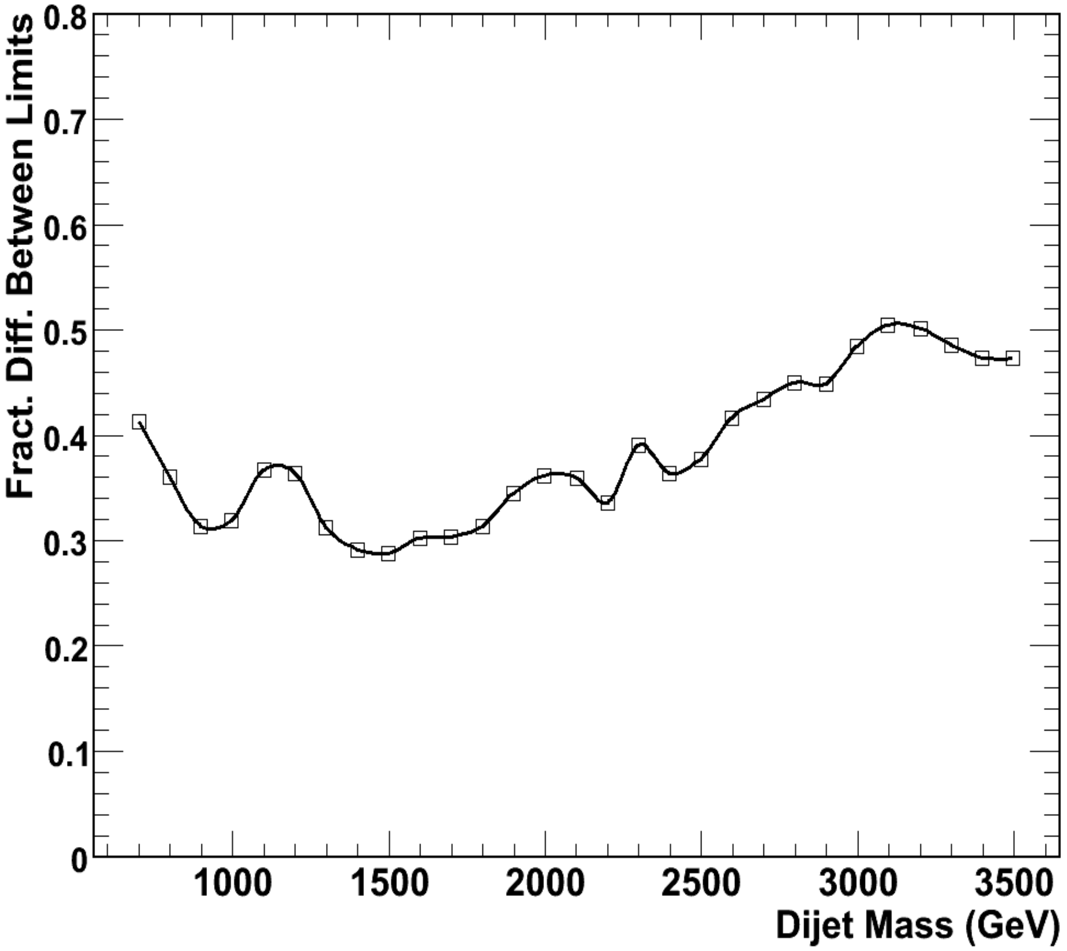




Effect of Systematics on Limit

- Cross section limit increase by about 30%-50% with systematic uncertanity.
  - ✓ q* mass limits decrease by about 100 GeV with systematic uncertainties.
  - ✓ Similar changes for qq and gg.

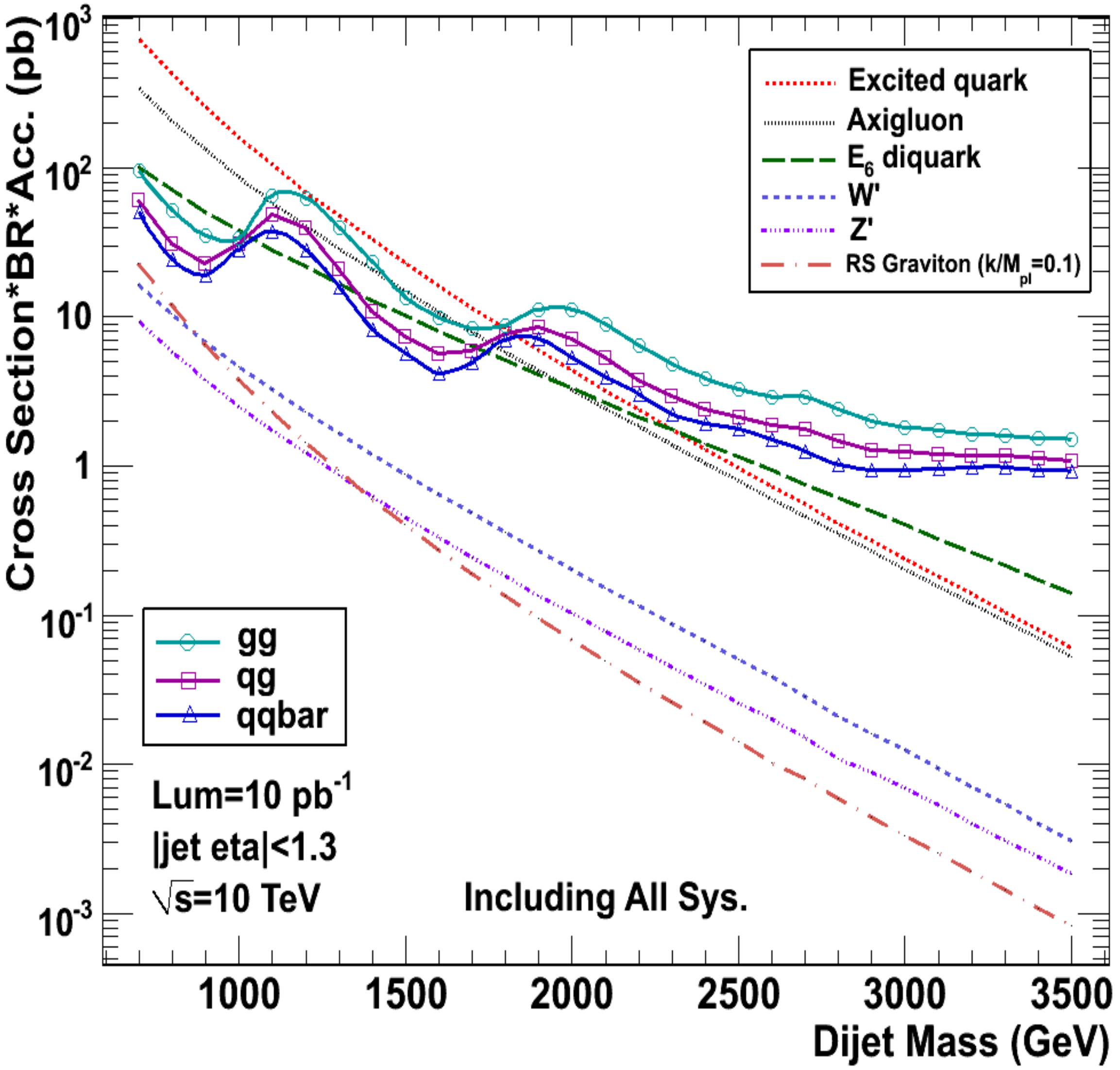




Results

- Final limits for qq, qg and gg resonances compared to models.
  - ✓ For excited quarks qg resonances was used.
  - ✓ For axigluon, coloron and E_6 diquarks qq resonance was used.

95% C.L. Excluded Mass (TeV)		
	CMS (10 TeV & 10 pb^{-1})	CDF (1.96 TeV & 1 fb^{-1})
Excited quark	M<1.8	M<0.87
Axigluon, Coloron	M<1.8	M<1.25
E_6 diquark	M<1.1 , 1.3<M<1.7	M<0.63

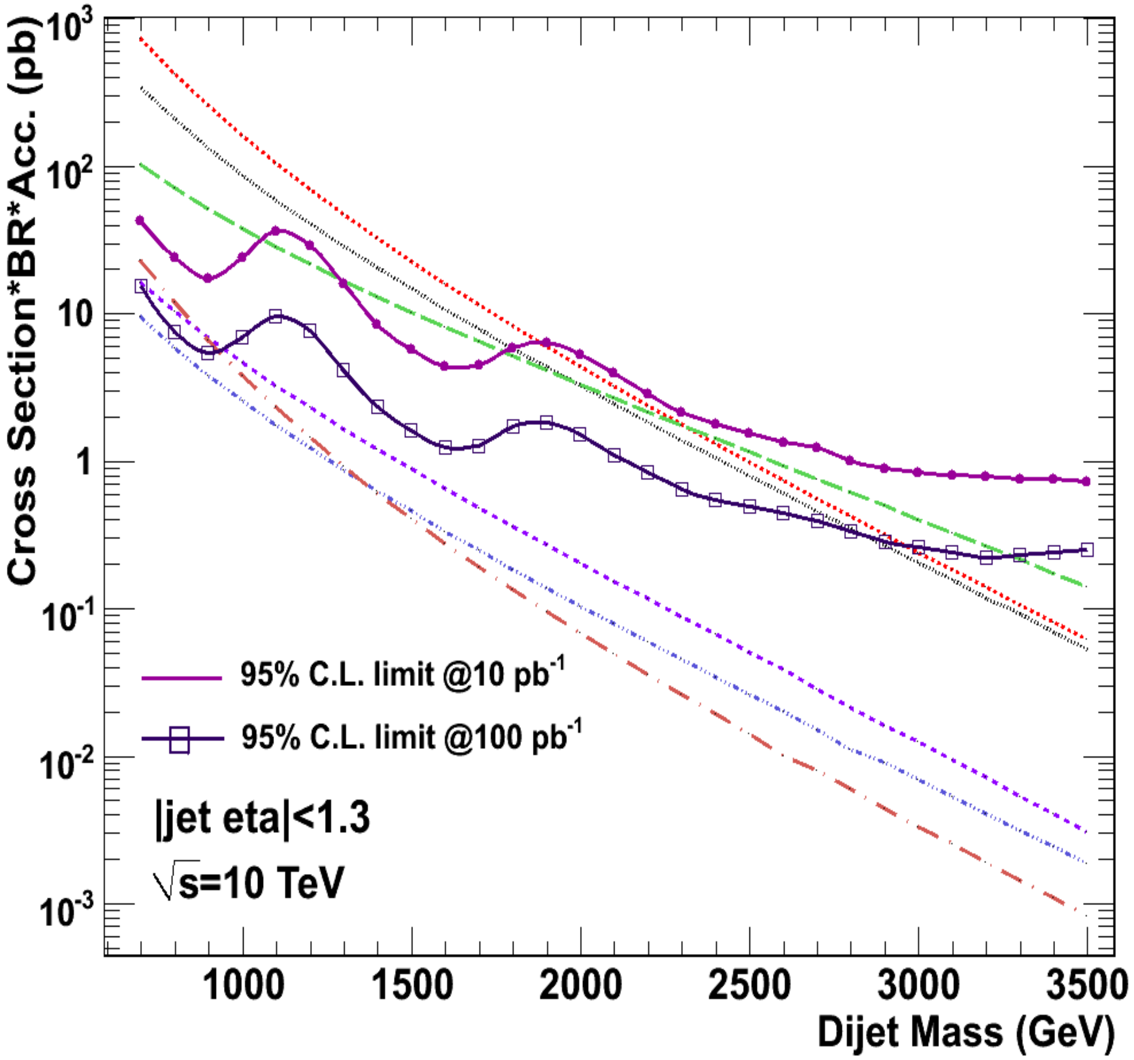


Luminosity Effects on Limit

- Shown cross section limit at 10 pb^{-1} and 100 pb^{-1}
- Cross section limit increase about 3 times.
- Consistent with theoretic expectation.

Resonance Model	95% C.L. Excluded Mass (TeV)	
	10 pb^{-1}	100 pb^{-1}
Excited quark	1.9	2.9
Axigluon	1.8	2.8
E_6 diquark	1.0	3.3
W’	N/A	0.9
Z’	N/A	N/A
RS graviton	N/A	0.9

STATISTICAL UNCERTAINTIES ONLY



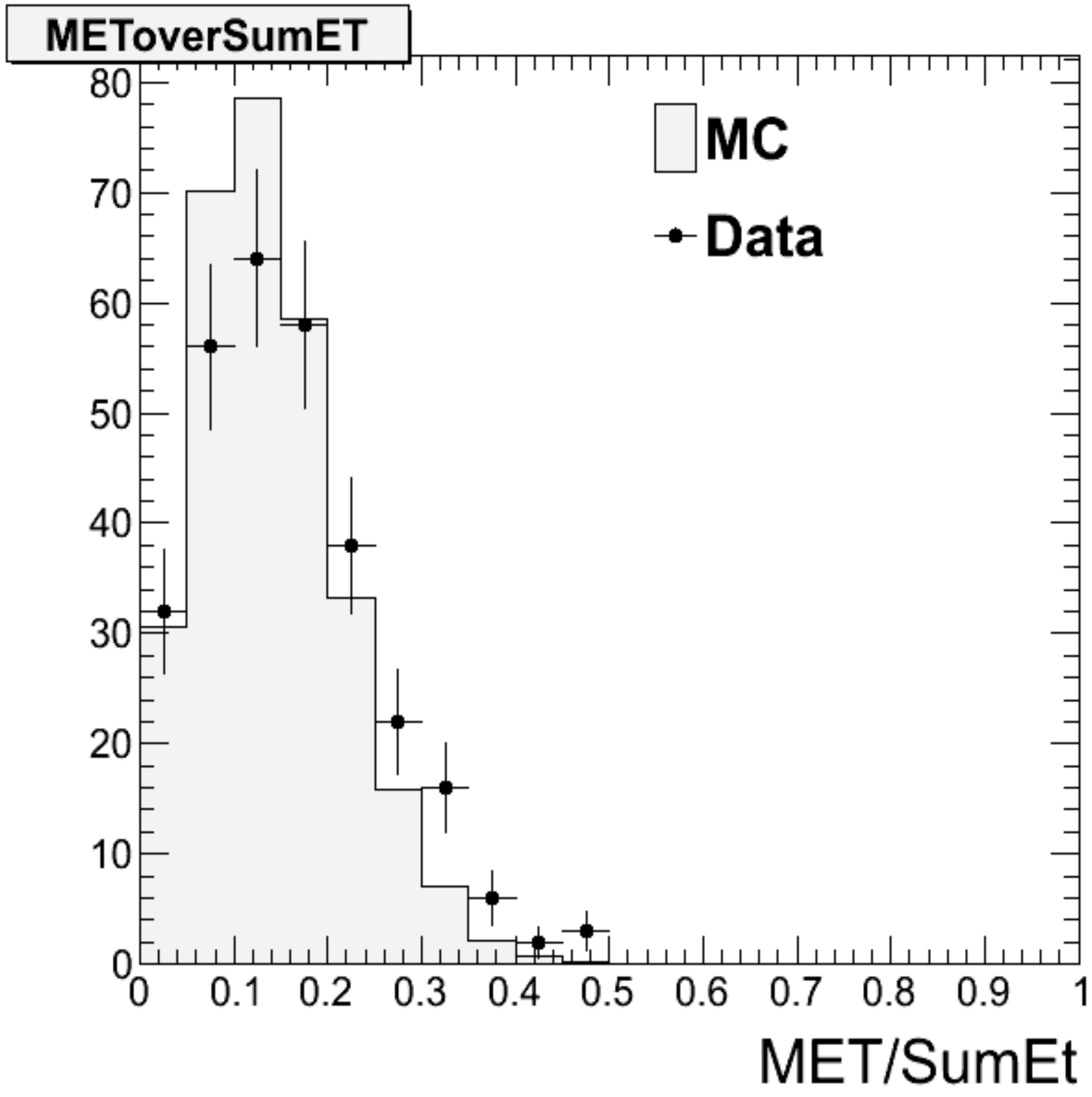
That's enough for MC. We have real data.

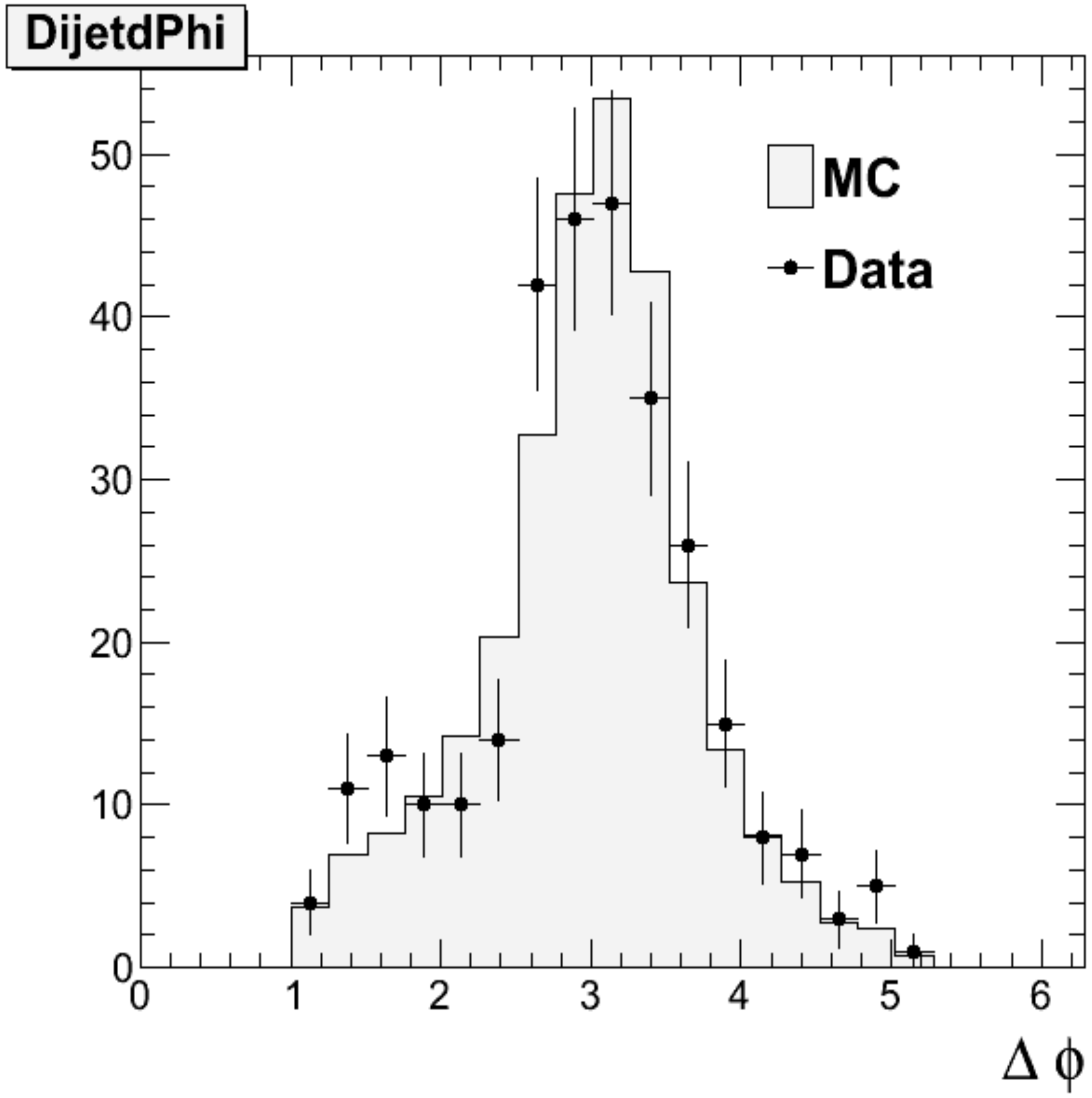
Let's have a look DiJet in Real Data.

Event Selection

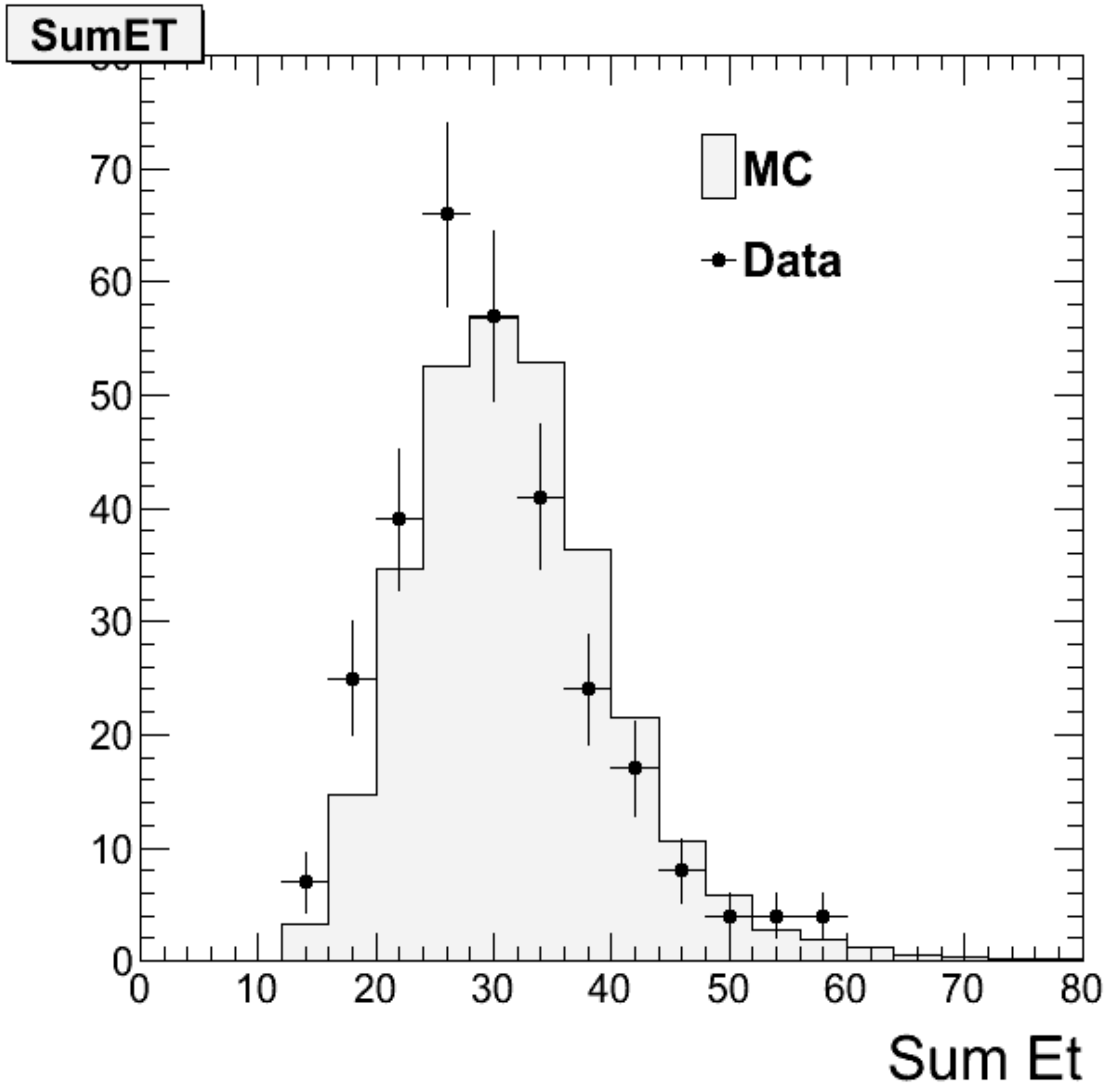
- Promt Reconstruction
- CMSSW_3_3_4
- /MinBias/Summer09-Startup3X_V8I_900GeV-v2/GEN-SIM-RECO
- Anti-kt R=0.5 Calo Jets
- 900GeV_L2L3_AK5Calo Jet Correction
- HLT_MinBiasBSC
- |PVz|<20
- MET/SumEt<0.5
- NJets>1
- Both Jets Corrected Pt>10 GeV
- Both Jets |eta|<2.6
- Both Jets EMF>0.01
- Both Jets fRBX<0.98 & fHPD<0.98
- |Delta Phi - 3.1416|<2.
- Total : 294 Dijet events

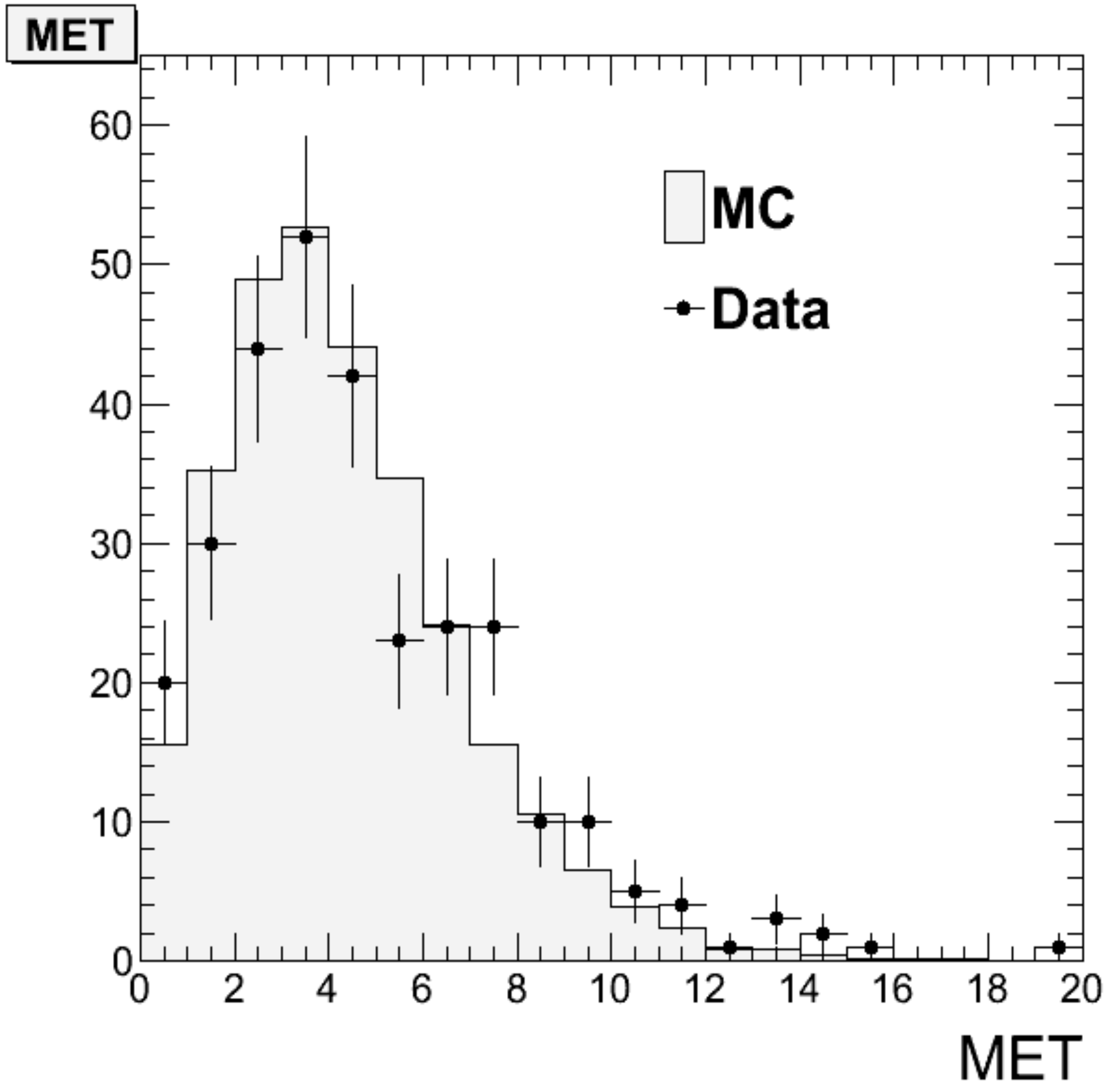
Event Selection Cut



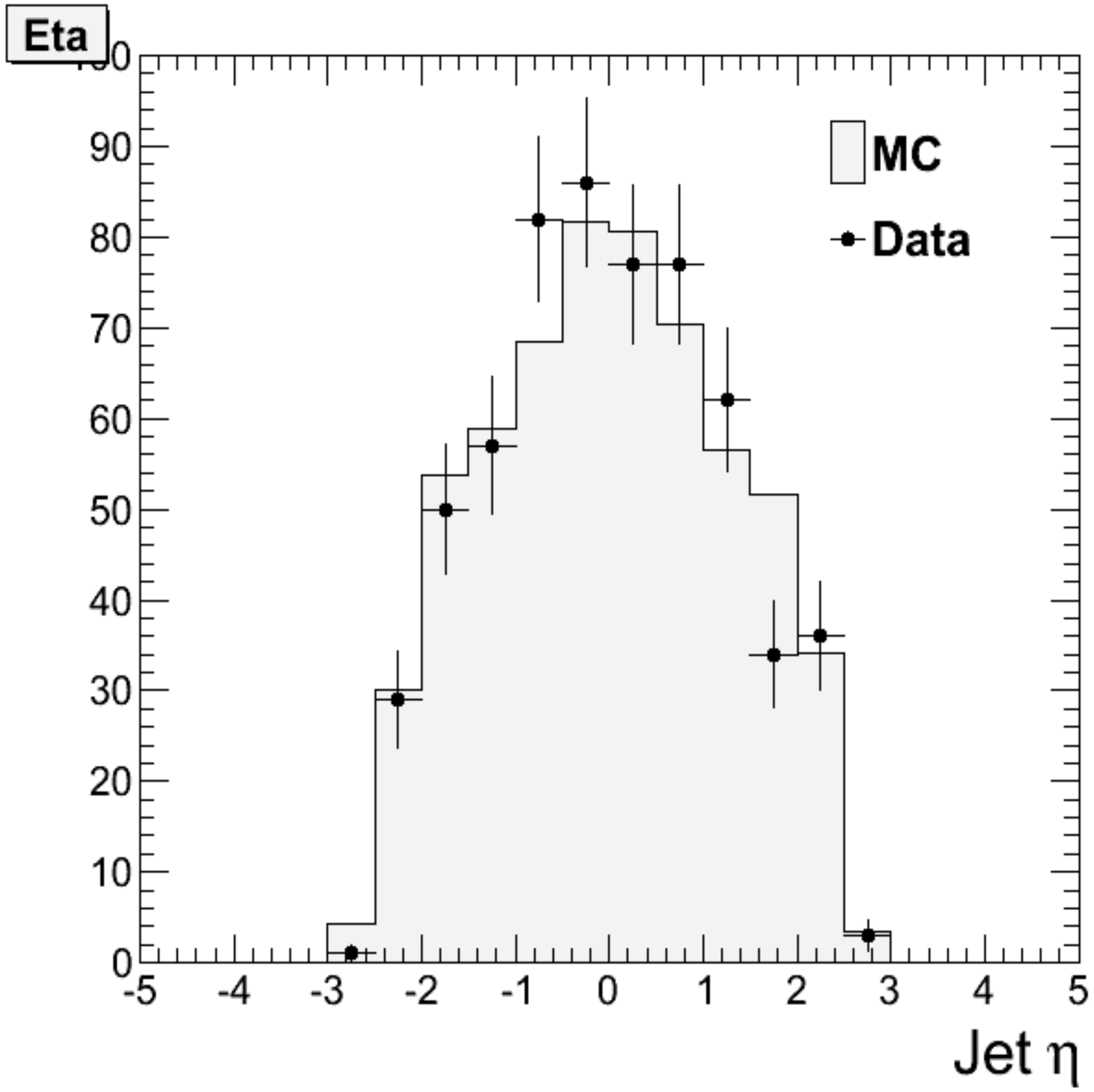


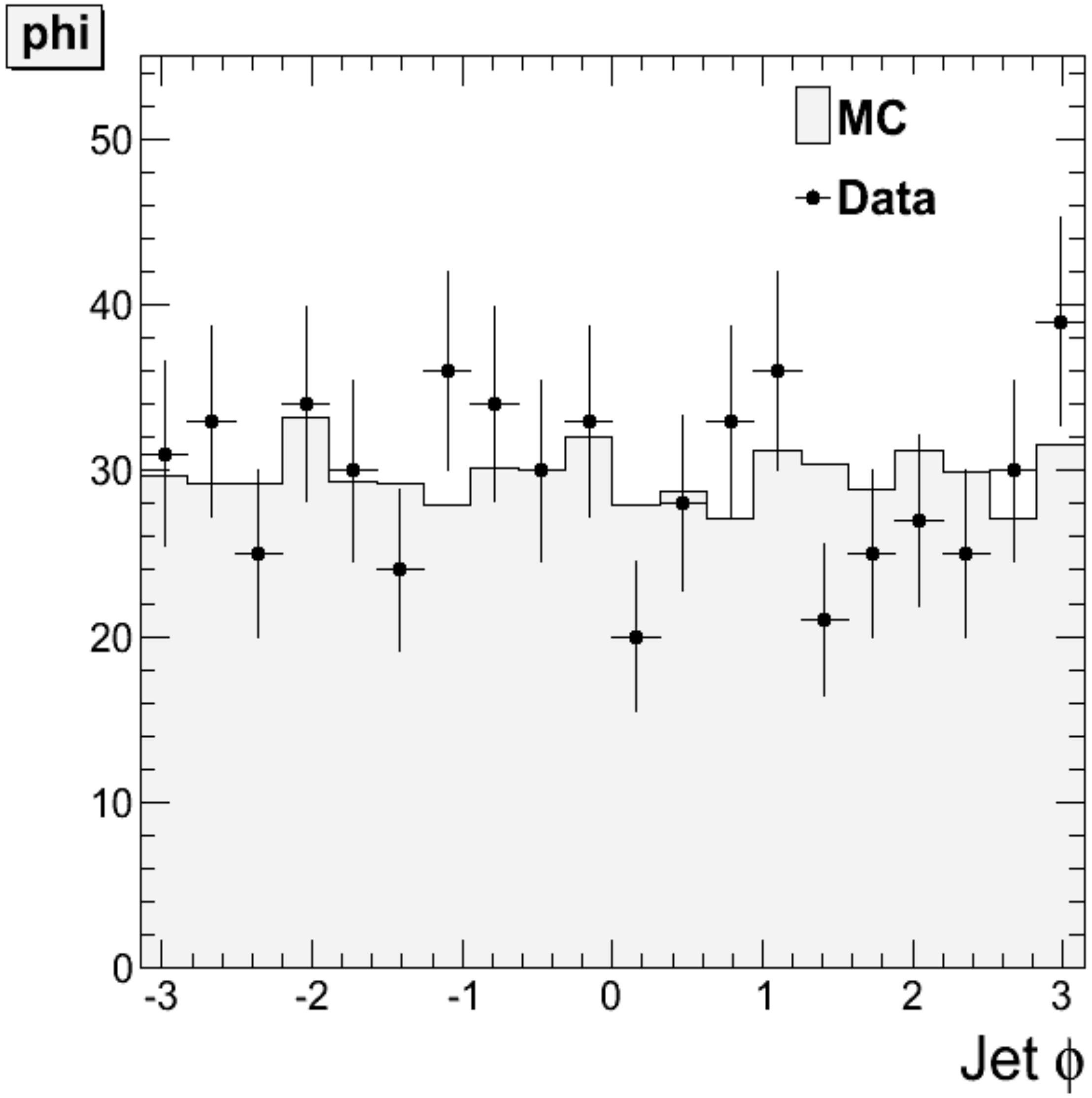
MET & SumEt


SumET
MC
Data
0
10
20
30
40
50
60
70
0
10
20
30
40
50
60
70
80
Sum Et

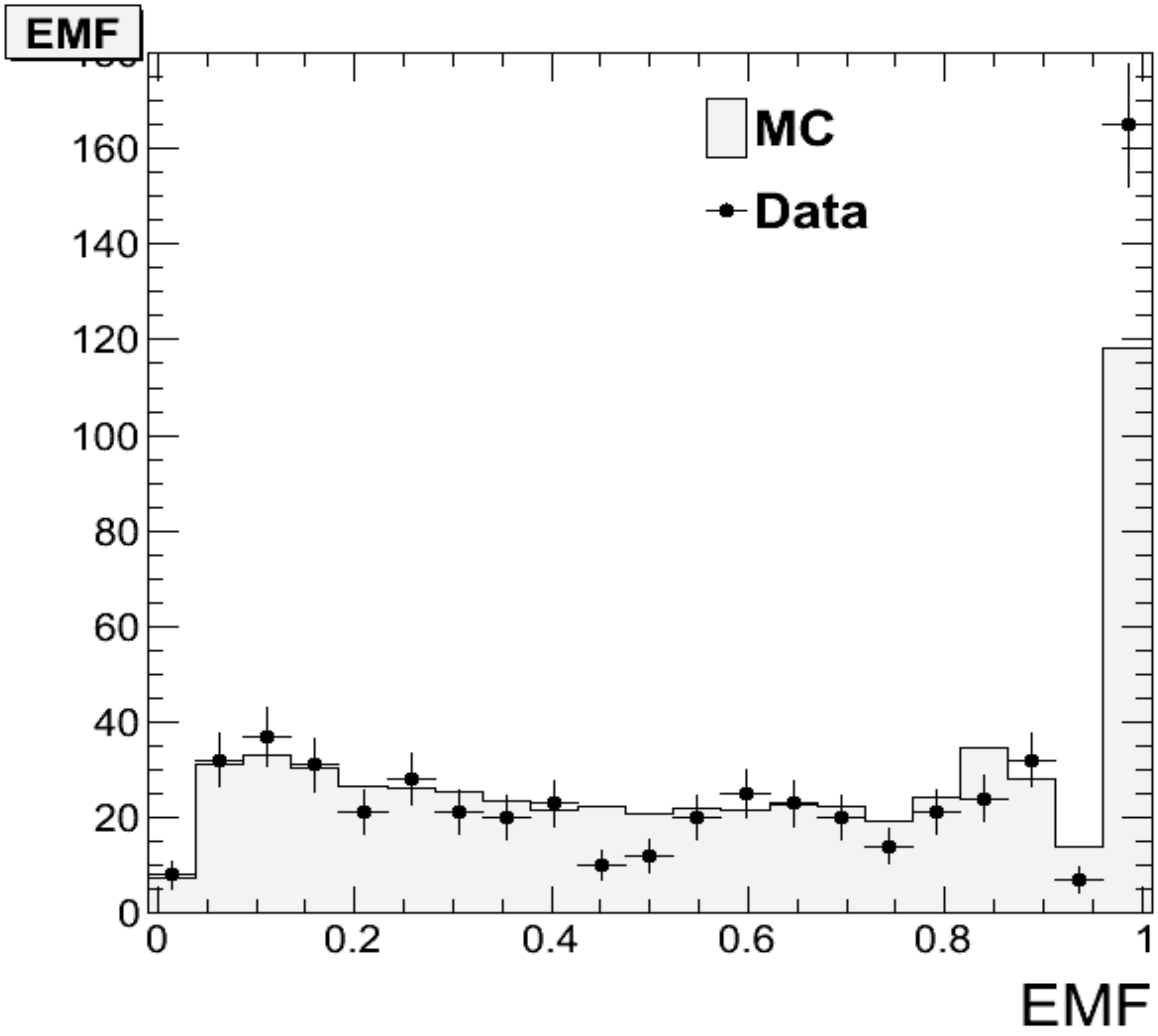

MET
MC
Data
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
16
18
20
MET

Eta & Phi

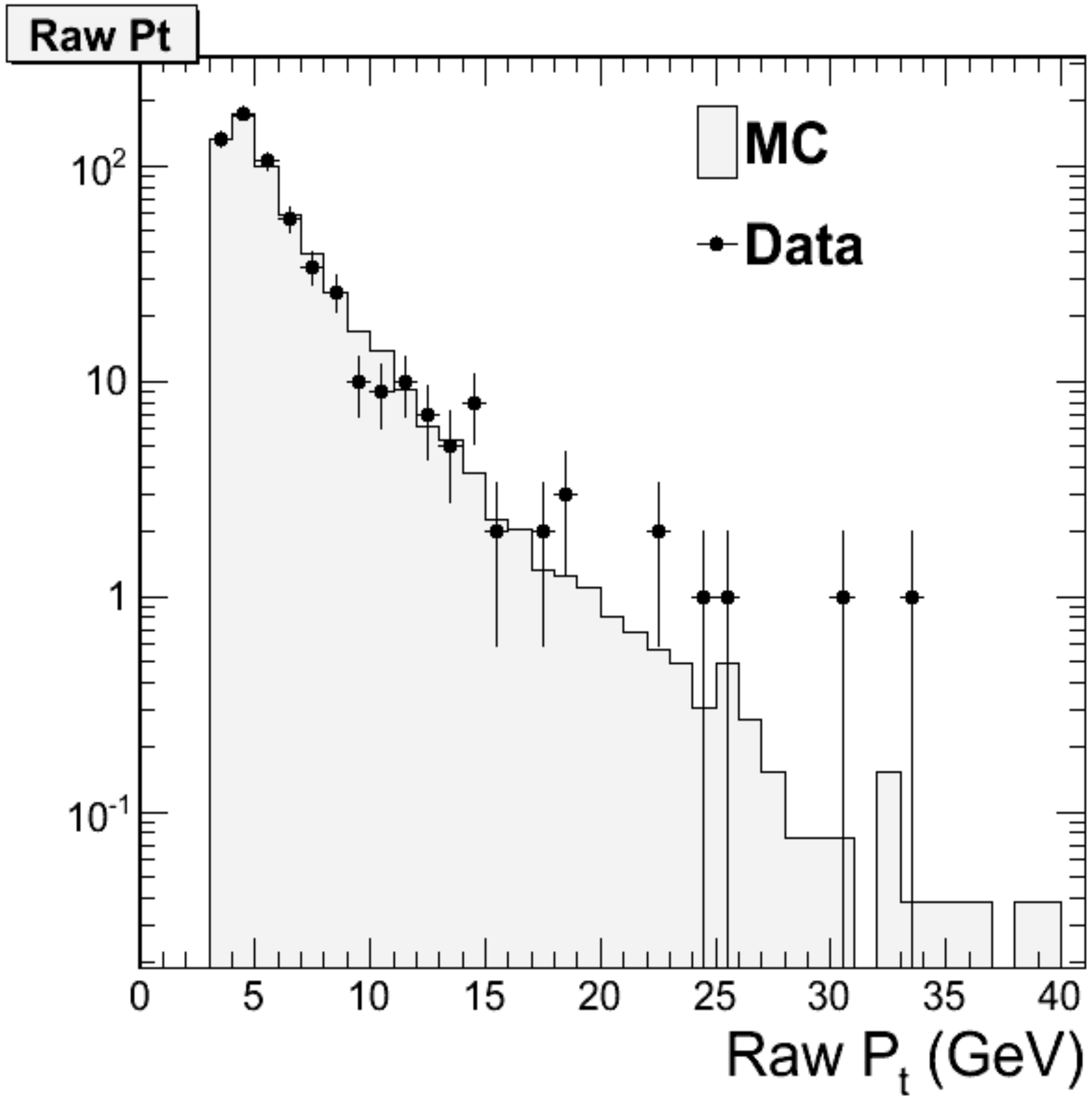

Eta
MC
Data
0
10
20
30
40
50
60
70
80
90
-5
-4
-3
-2
-1
0
1
2
3
4
5
Jet η

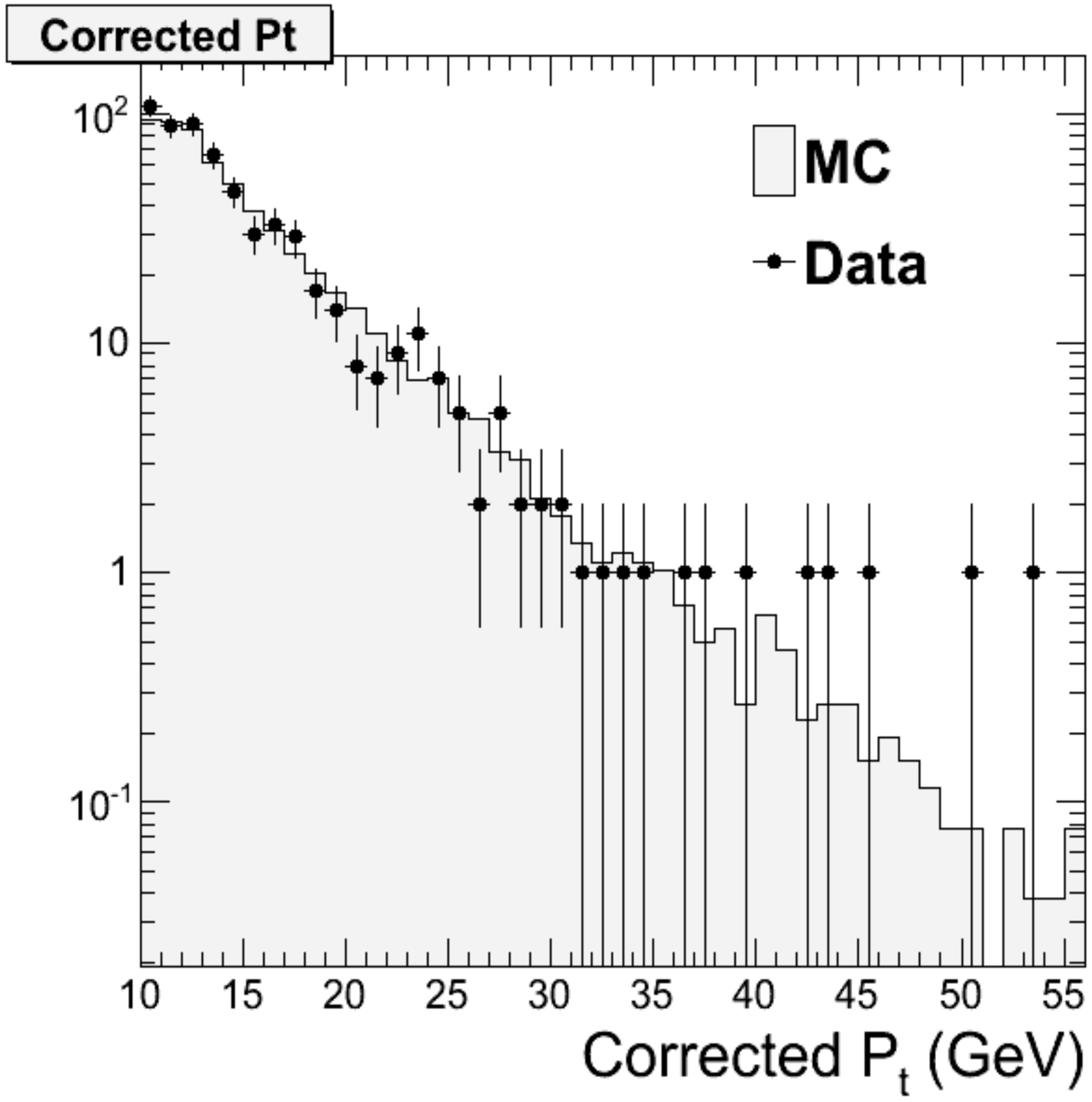

phi
MC
Data
0
10
20
30
40
50
-3
-2
-1
0
1
2
3
Jet ϕ

Electromagnetic Energy Fraction

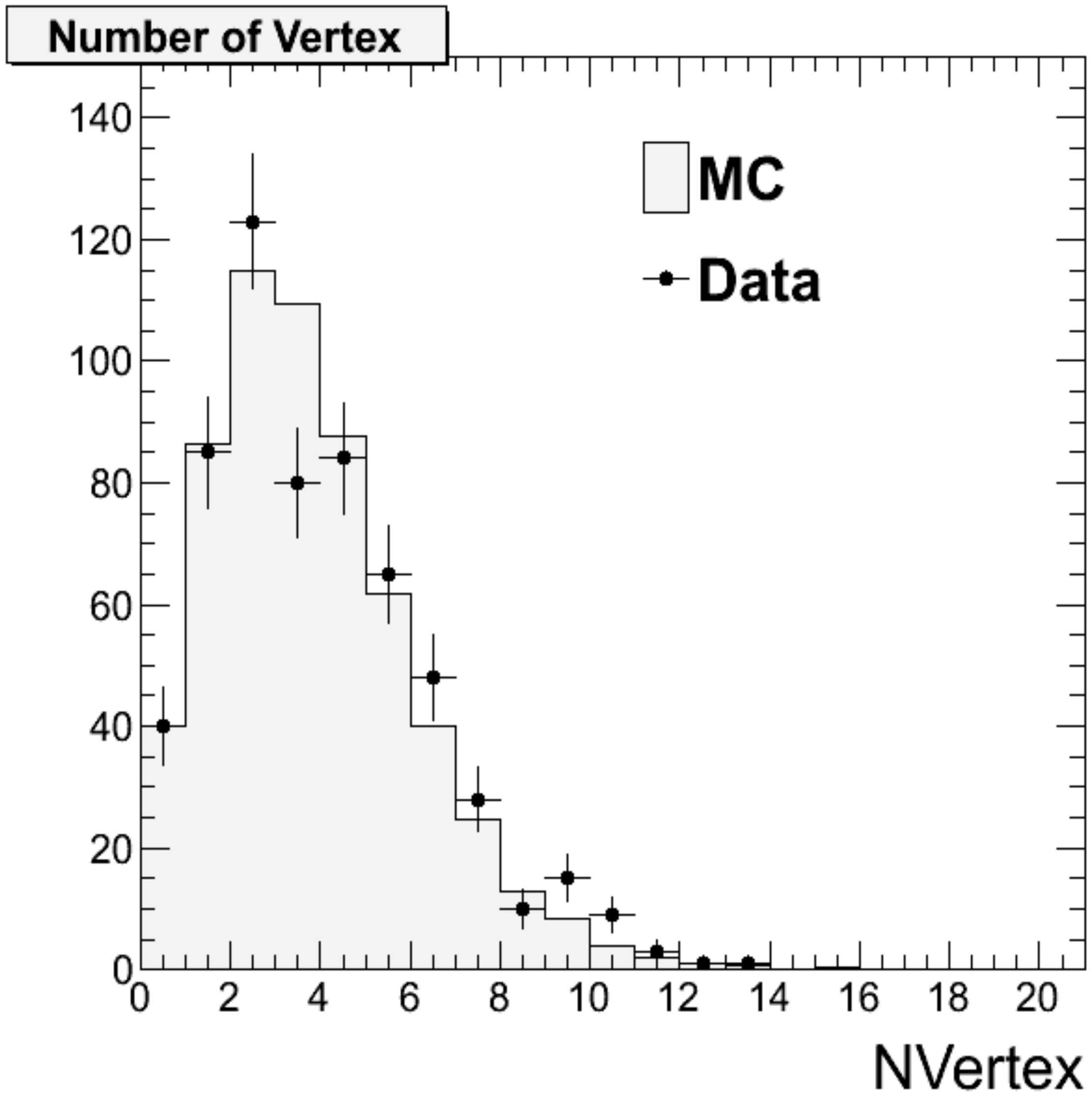


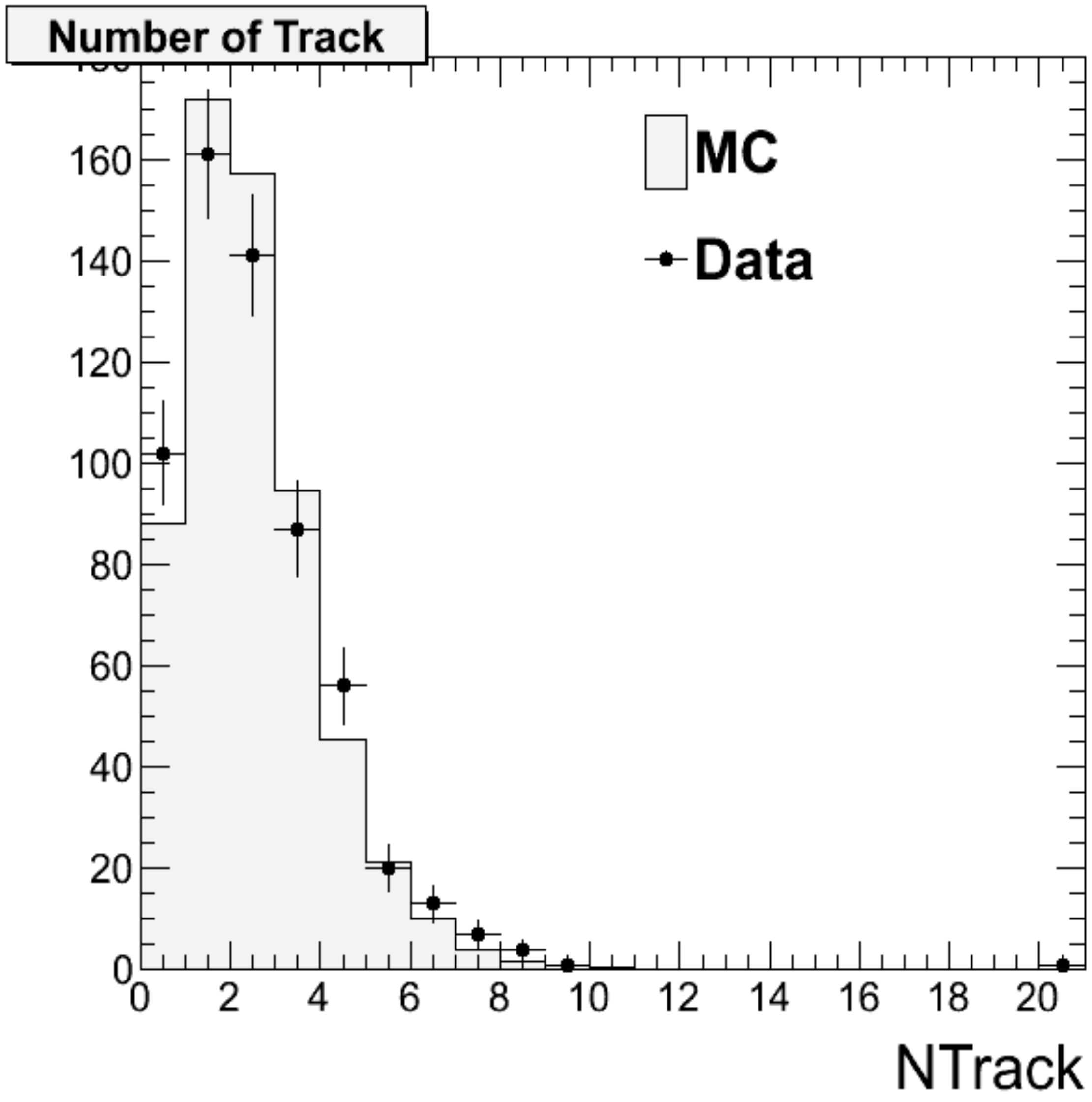
Pt Distribution





Number of Track & Vertex





Conclusion-I

- We are ready search for "Dijet Resonances" in Real Data.
- All study have been done for 10 TeV. The study for 7 TeV is almost done. (except systematics).
- We have improved a new technique to generate resonance shape in intermediate mass steps.
- CMS should be sensitive to excited quarks, axigluon/coloron, and E_6 diquarks up to ~2 TeV at 95% CL with 10 pb^{-1}.
- Even in early CMS data, new discoveries are highly possible.
- We have written three papers for dijet resonance study. CMS-AN 2009/070, CMS-AN 2009/145, QCD-PAS 2009-006. Will be present in APS April Meeting (13-16 February, Washington, USA).

Conclusion-II

- Finally, we have real data.
- There are about 8μb^{-1} MinBias data.
- We have a look Dijet and JetID variable efficiency in real data.
- The data is consistent with MC.
- Analysis note and PAS are under preparation for coming Winter conferences.