Squark Mass Measurement from Dijet

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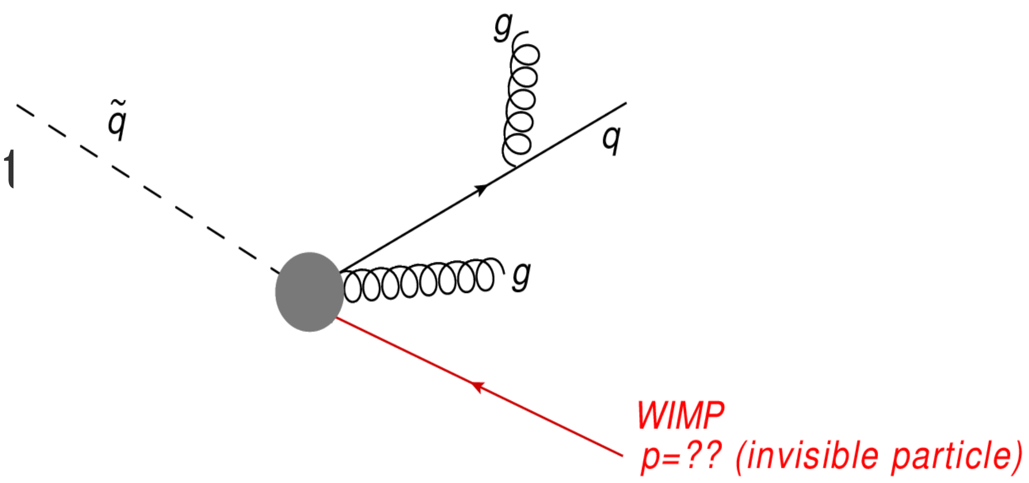
Determining the squark mass at the LHC,
V.Barger, Y. Gao, A. Lessa, X. Tata (arXiv:1103.0018, excepted by PRD)

How DM affects measuring new particle mass

- Without DM:
  Momenta of decay products sum up to parent momentum
  → invariant mass peaks at parent particle mass

With DM:

Insufficient information to
reconstruct parent moment
mass of visible jets does
no peak at parent mass



- **Arsenal to deal with invisible particles**

  m_{T2} & derivatives; matrix element method; cusps in angular distributions; multi-lepton channels; etc...

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Dijet mass + angular cuts

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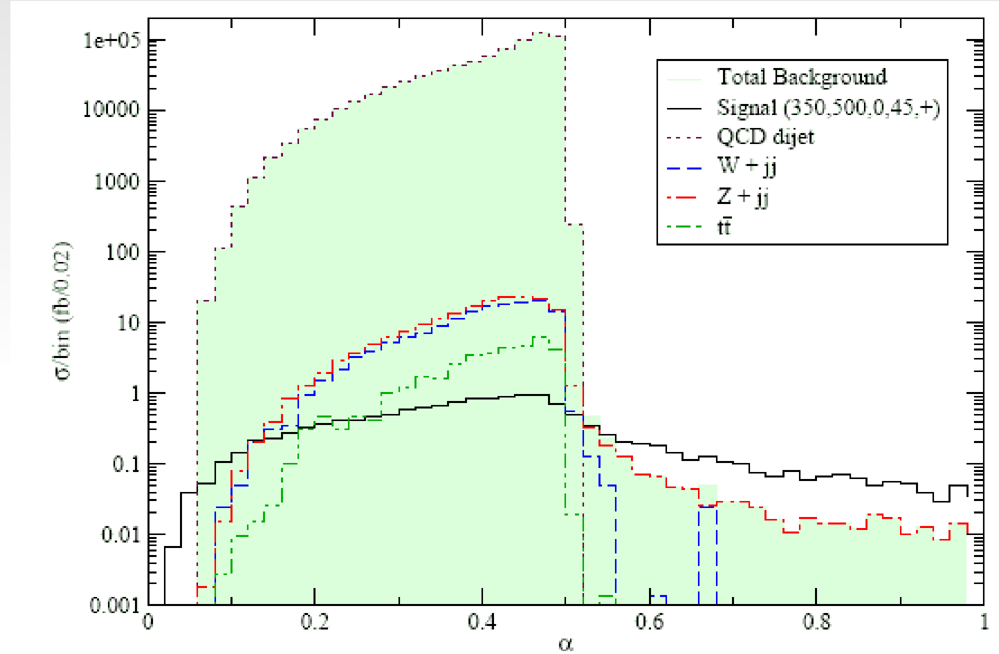
Powerful angular cuts

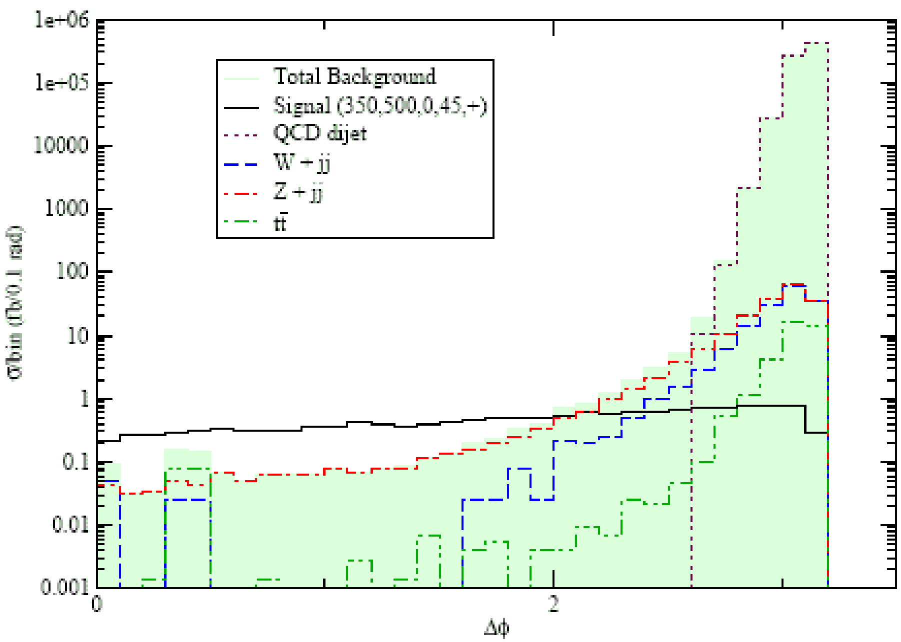
Theoy: mSUGRA
DM: neutralino as the LSP
signal channel: squark/gluino pair production

Cuts: **2-jet (jet $E_T > 50$ GeV)**
$\Sigma E_T > 700$ GeV
isolated leptons veto
$\Delta\Phi<1.5$, $\alpha > 0.5$

$\Delta\Phi$: suppresses W/Z+jets bkg
[$\Delta\Phi$= dijet azimuthal separation]



α: complete SM QCD dijet removal
[$\alpha = E_{T2} / m_{jj}$]

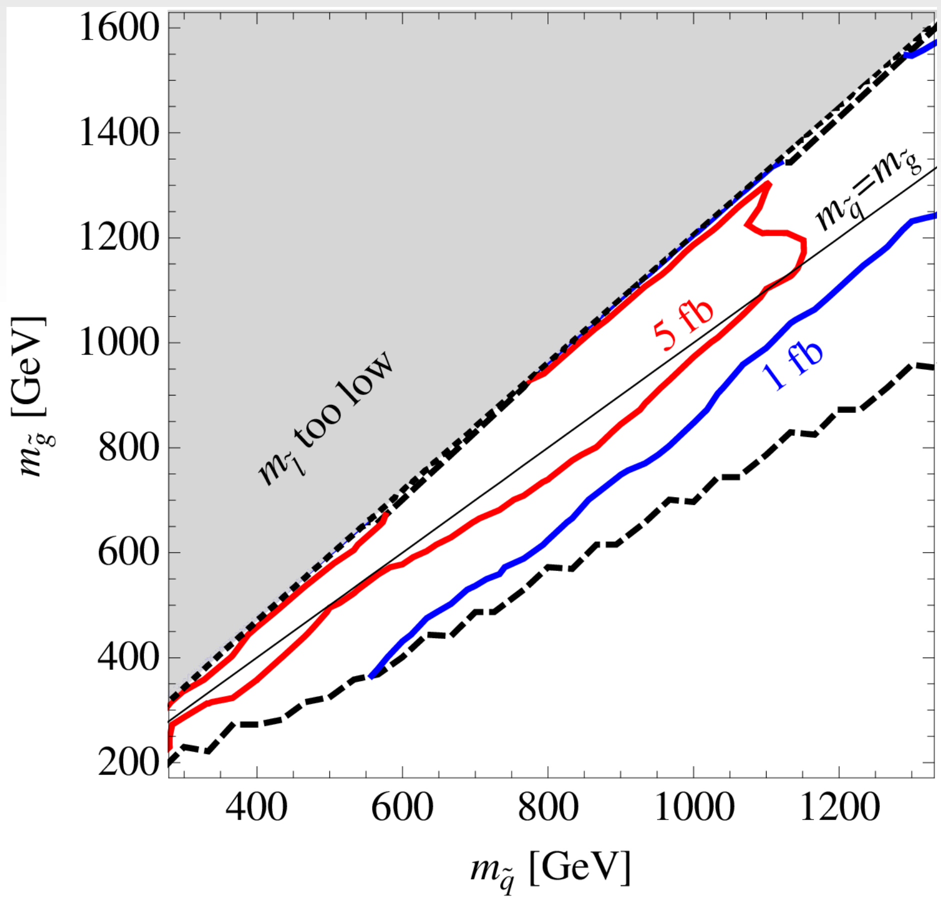


H. Baer, V. Barger, A. Lessa, X. Tata
JHEP 0909:063,2009.

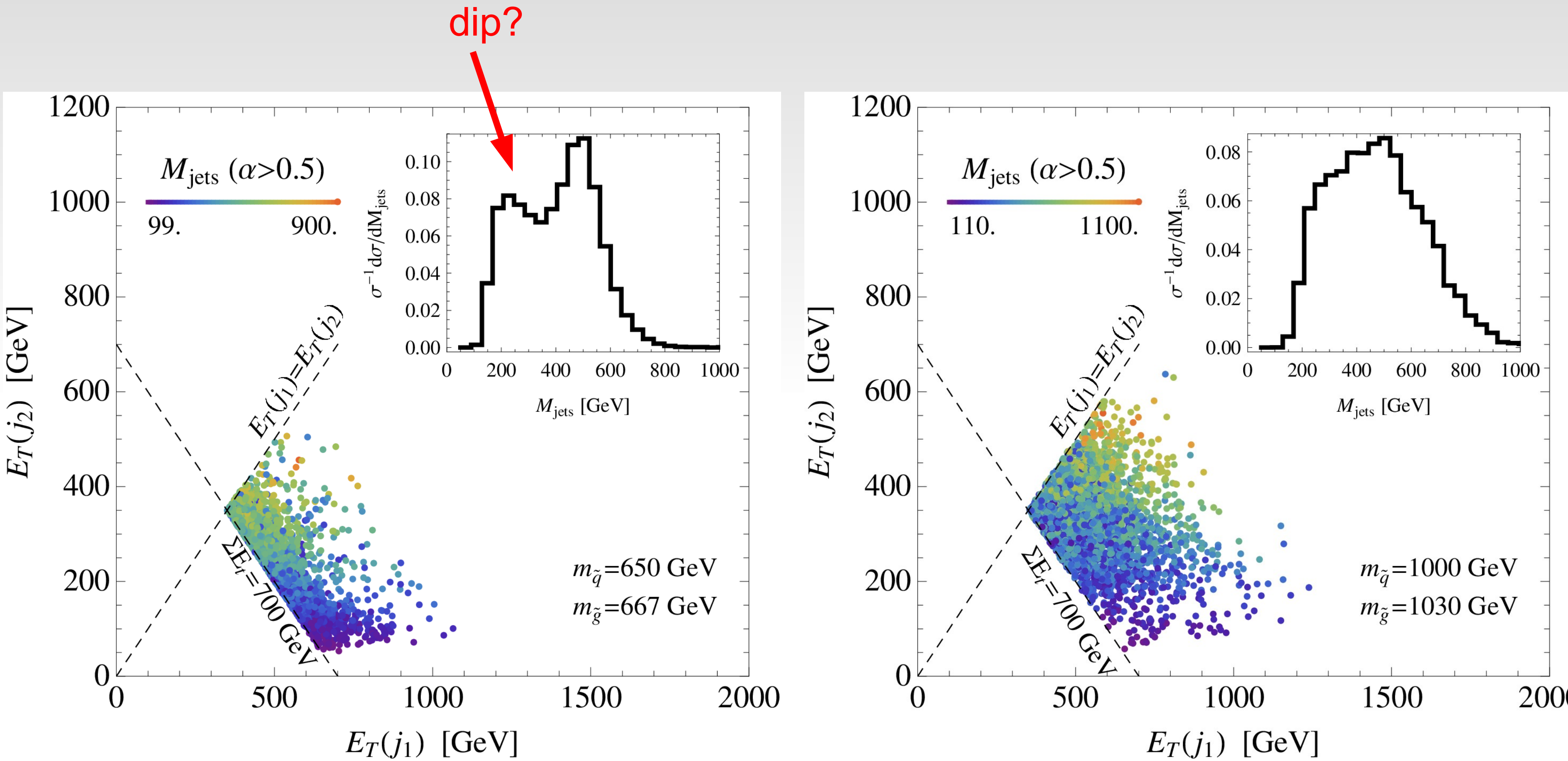
SUSY scenario

- A bino-like neutralino LSP, leading to a dominant quark-LSP decay mode of the right-handed squarks (our signal)
- Assumes mSUGRA and degenerate squark mass in this analysis
- Signal mostly from gluino/squark production
- Low LSP mass compared to squark/gluino

After-cut cross-section



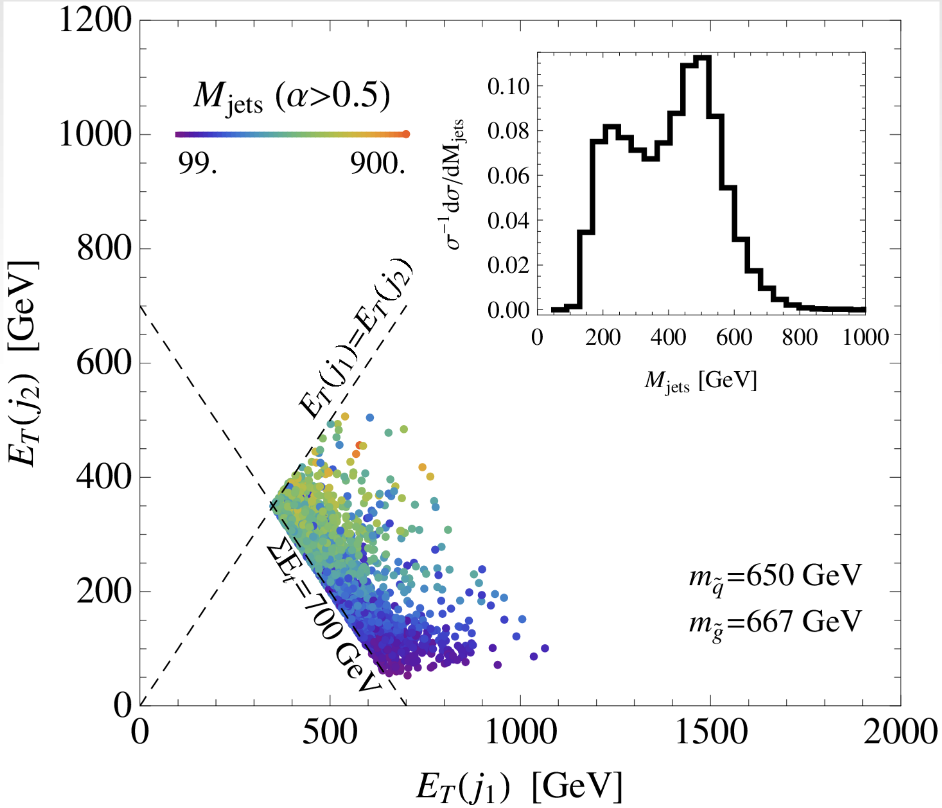
m_{jj} spectrum shape can be sensitive

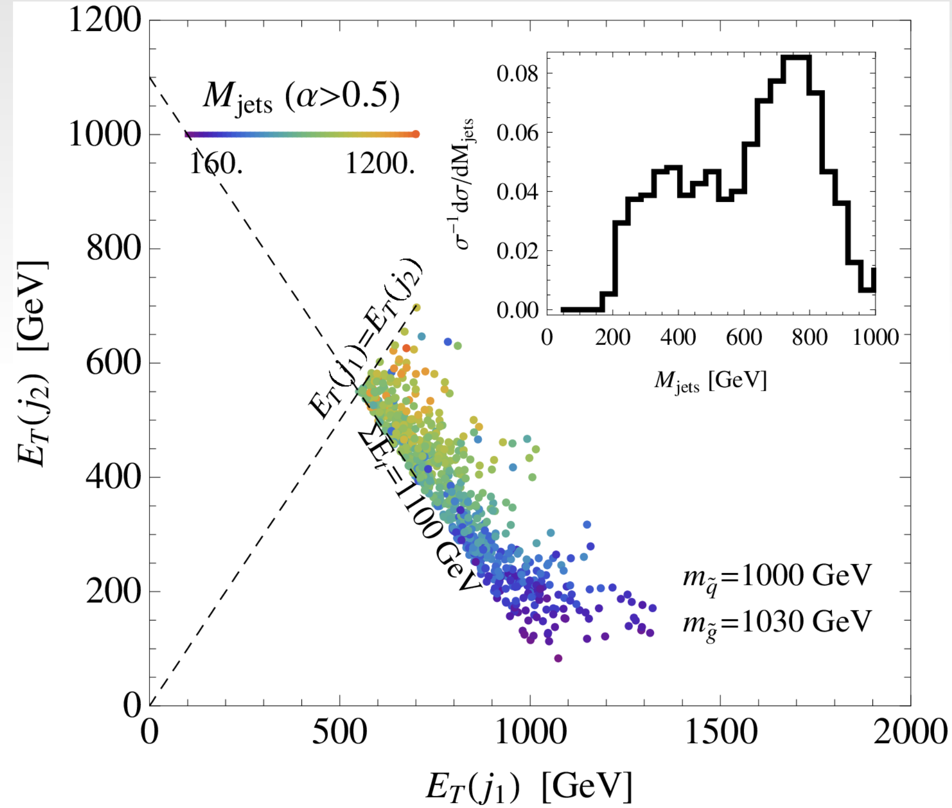


SUSY signal only

m_{jj} spectrum shape can be sensitive

ΣE_T raised from 700 GeV to 1.1 TeV

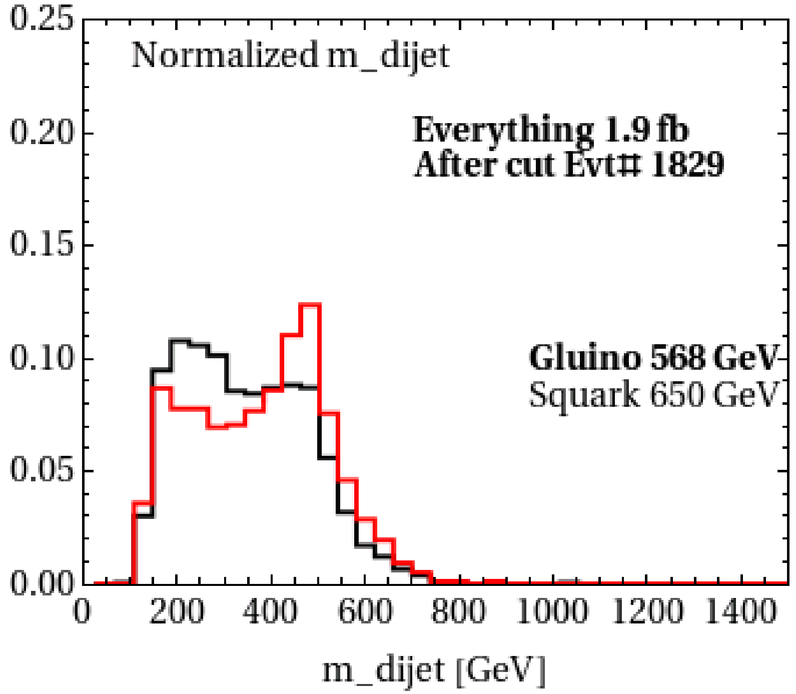




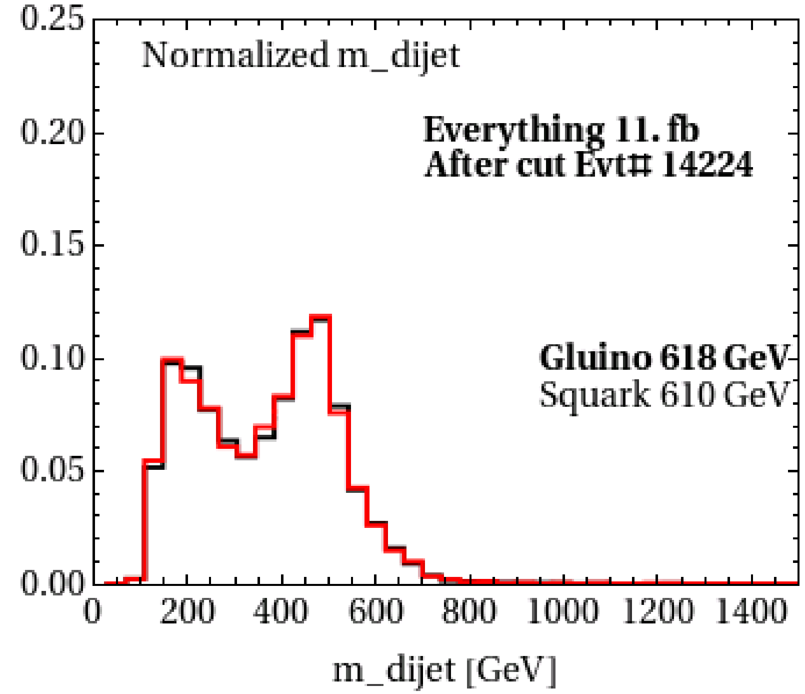
SUSY signal only

Dependence on squark & gluino mass

Black: Susy inclusive
Red: squark pair production only



m_{squark} fixed at 650 GeV



$m_{squark} \approx m_{gluino}$

Dijet mass spectrum develops a `dip' structure under E_T and angular cuts. The shape is sensitive to E_T and squark mass.

Continued...

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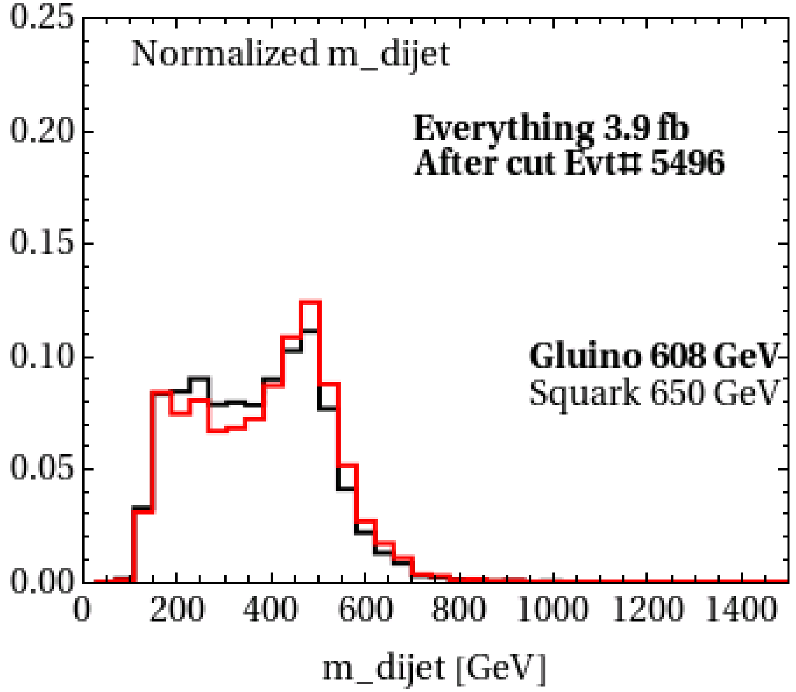
Red: squark pair production only



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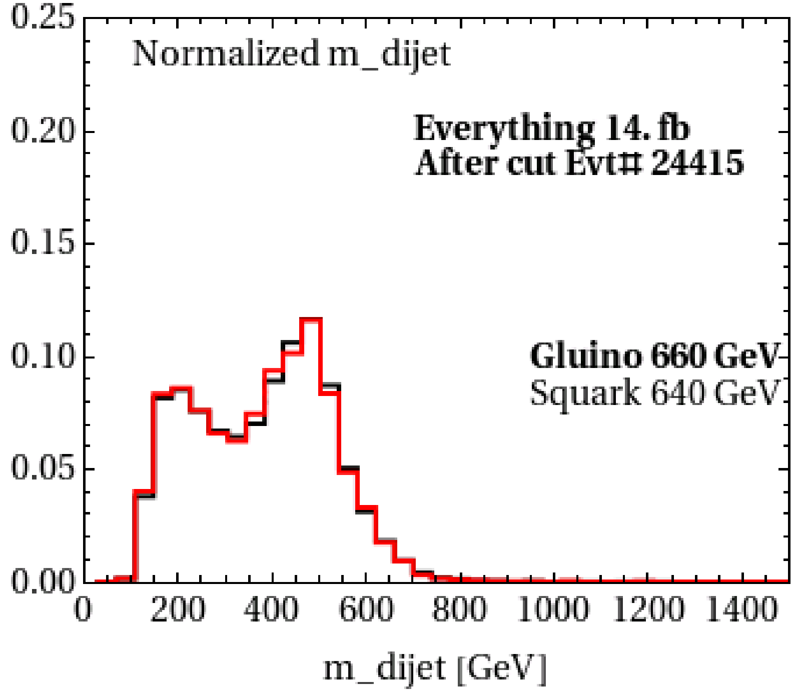

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Continued…

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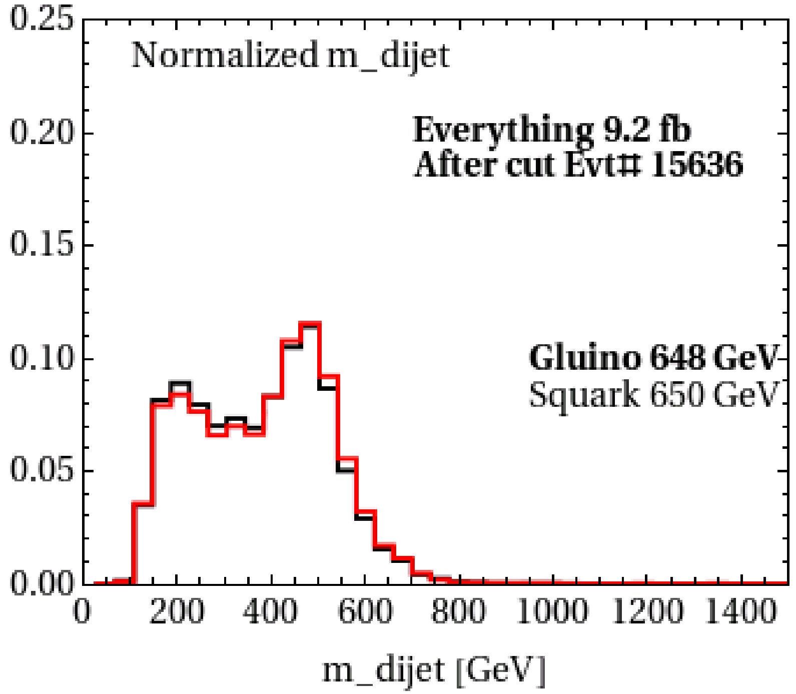

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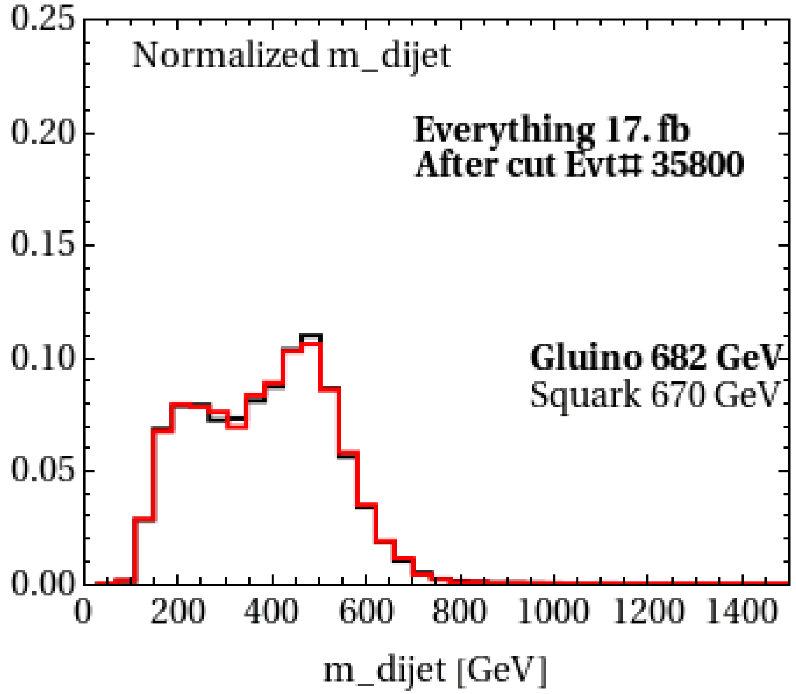

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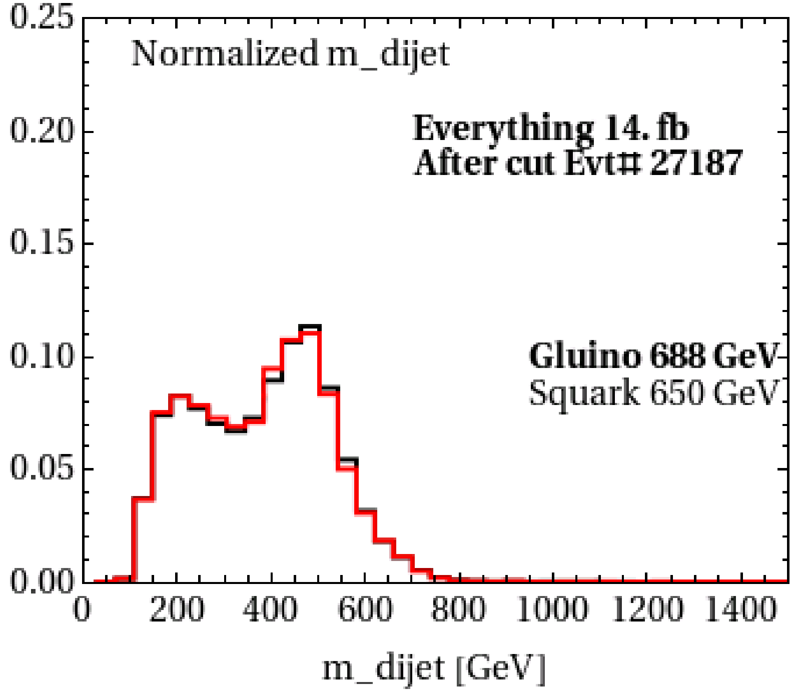

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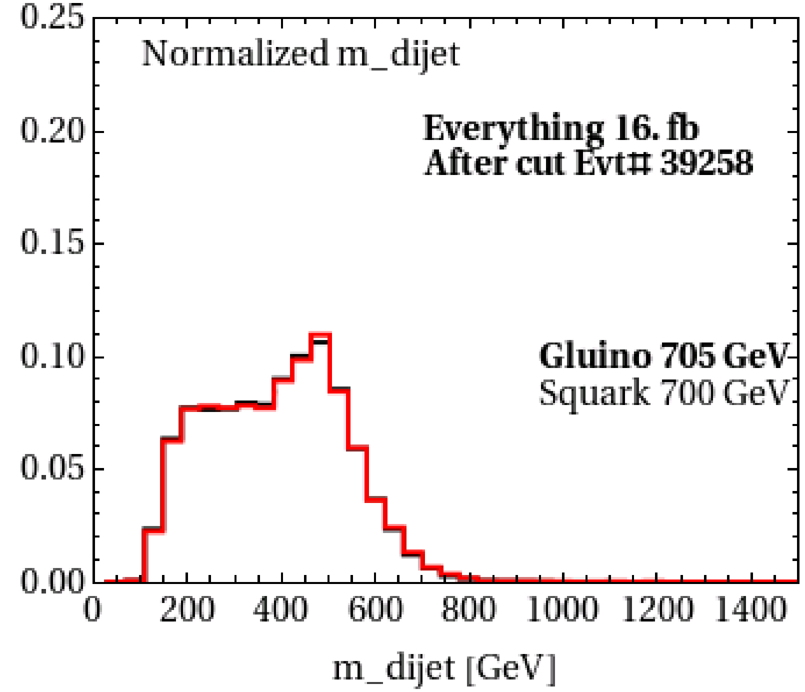

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Continued...

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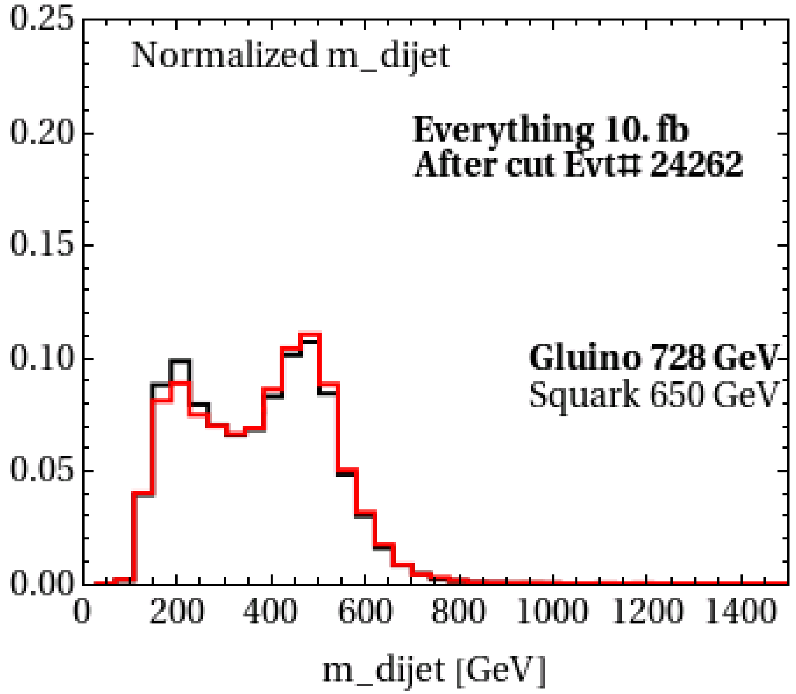

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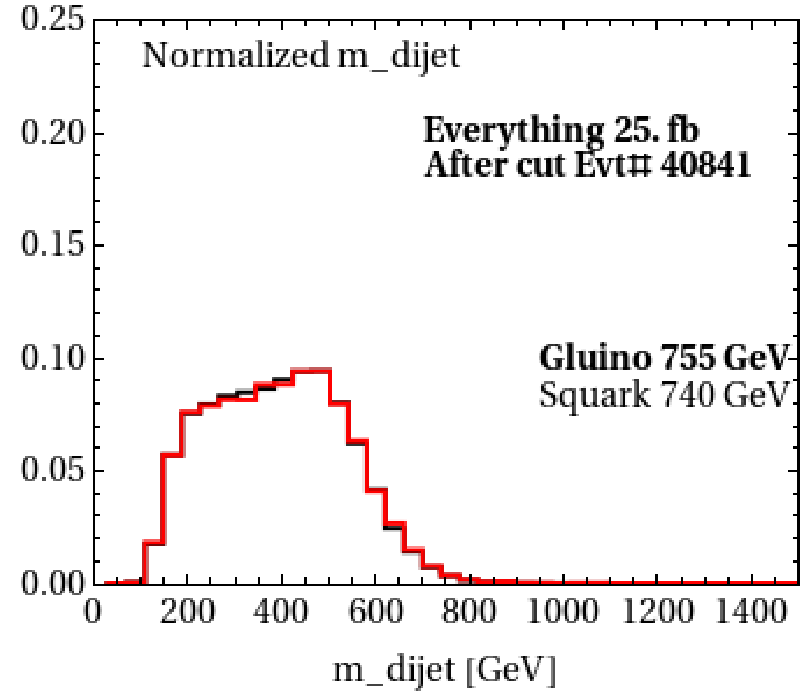


$m_{squark} \approx m_{gluino}$

Kinematics on the m_{jj} 'dip'

- m_{jj} and α are correlated

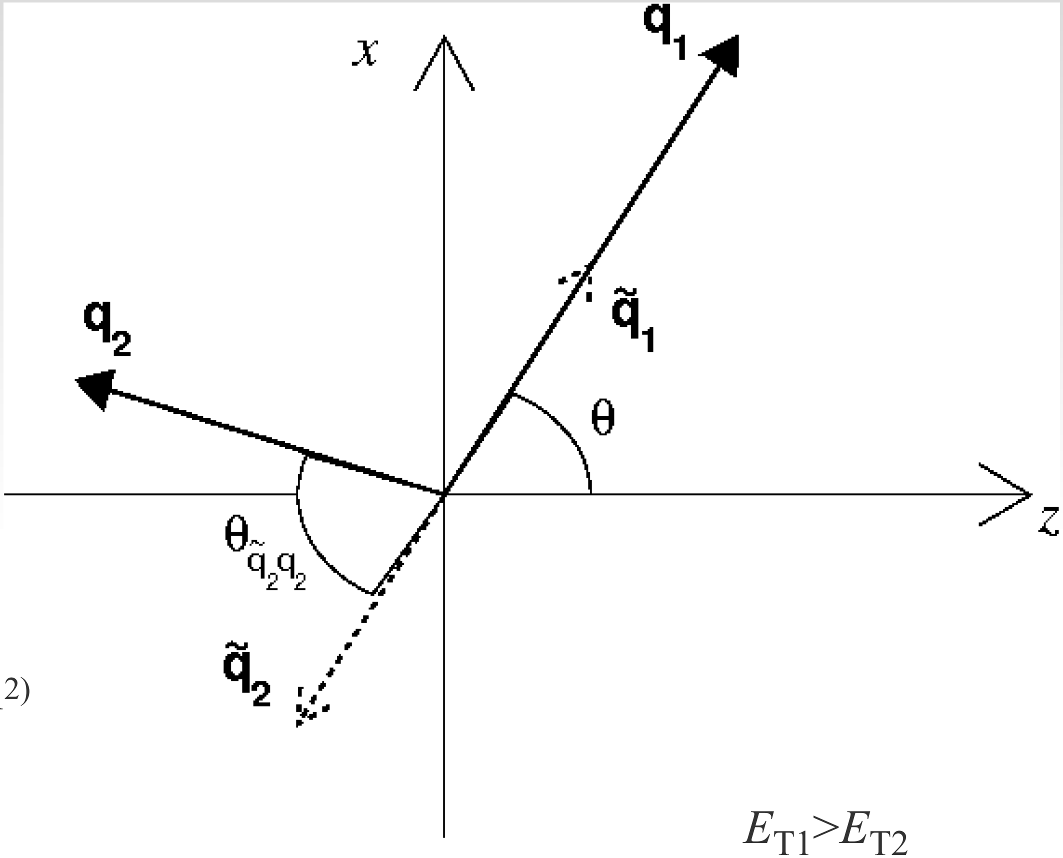
(with collinear approx. between j_1 and sq_1)

mjj depends on the opening angle between j_2 and sq_2

$$\cos\theta_{\tilde{q}_2 q_2} = \frac{\beta + \cos\theta_0}{1 + \beta\cos\theta_0}$$

(θ_0 is the jet polar angle in the rest frame of sq_2)

$$m_{jj} = \sqrt{2}\gamma E_0(1+\beta)\sqrt{1+\cos\theta_0}$$



$E_{T1} > E_{T2}$

- A) $\cos\theta_{\tilde{q}_2 q_2} \approx 1 \Leftrightarrow \cos\theta_0 \approx 1$, corresponding to high m_{jj} values,
- B) $\cos\theta_{\tilde{q}_2 q_2} = 0 \Leftrightarrow \cos\theta_0 = -\beta$, corresponding to intermediate m_{jj} values, and
- C) $\cos\theta_{\tilde{q}_2 q_2} \approx -1 \Leftrightarrow \cos\theta_0 \approx -1$, corresponding to low m_{jj} values.

Catergories of the (j_2, sq_2) angle

- **Case A**: j_2 (almost) parallel to sq_2
  Large m_{jj} & low α :
  (strictly back-to-back events will be removed by cuts)

- **Case B**: j_2 perpendicular to sq_2

$$E_T^{tot} = \sqrt{\frac{1+\beta}{1-\beta}} E_0[\sin\theta + (1-\beta)] \leq \sqrt{\frac{27}{4}} E_0 \approx 2.6 E_0$$

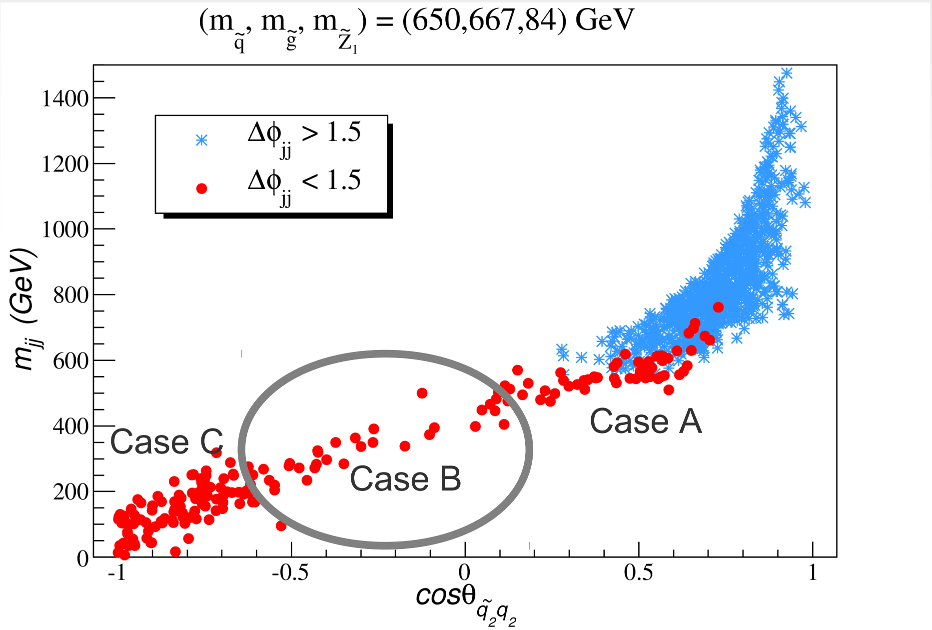
  Intermediate m_{jj} values, phase space is controled by total E_T
  For m_{sq}= 650 GeV, max total E_T= 830 GeV

- **Case C**: j_2 antiparallel to sq_2
  Low m_{jj}, requires a low boost β on the squark to pass the α cut

$$\alpha \approx \frac{\sin\theta(1-\beta)}{(1+\beta)\epsilon} \quad \text{and} \quad E_T^{tot} \approx 2E_0\gamma\sin\theta$$

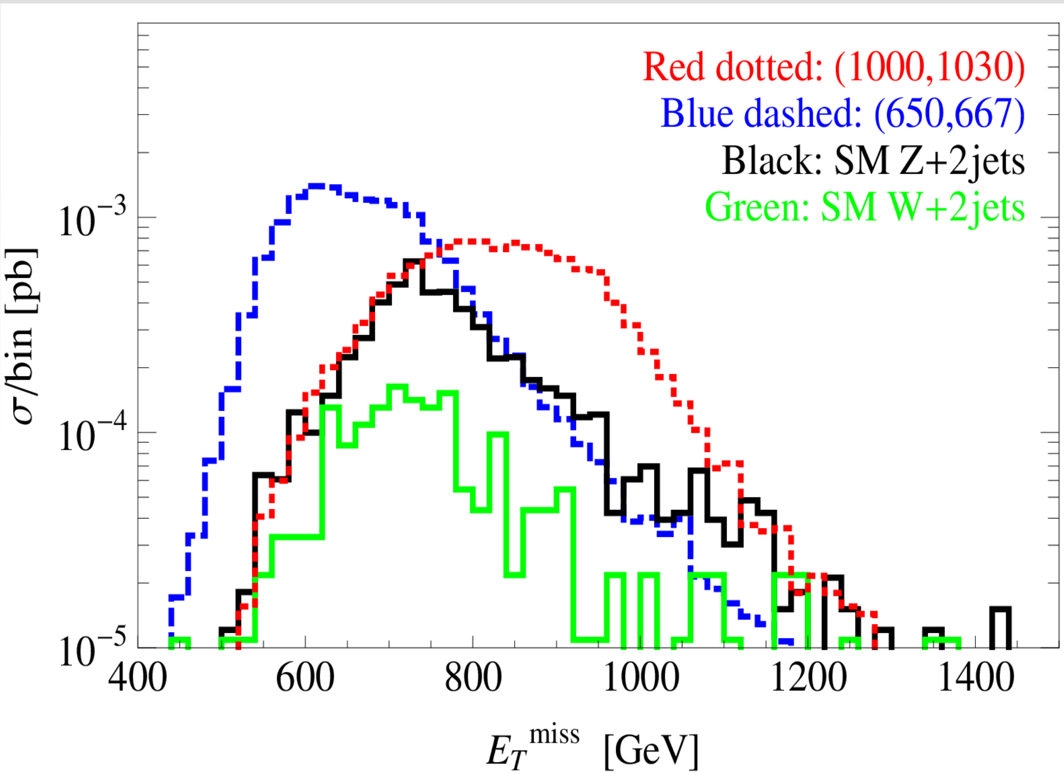
$$\theta_0 = \pi - \epsilon$$

  (a very hard E_T cut can also remove Case C, causing the low m_{jj} shoulder to disappear).



Intermediate m_{jj} range is less populated with high ΣE_T cut

SM backgrounds



- DM leads to large missing energy
- Cuts on missing energy increases s/b but lowers statistics
- No significant improvement from missing energy cuts

SM bkg generated by Alpgen & Pythia

After cut: zjj : 6.0 fb (LHC measureable as the zl^-l^+ channel)

wjj : 1.5 fb

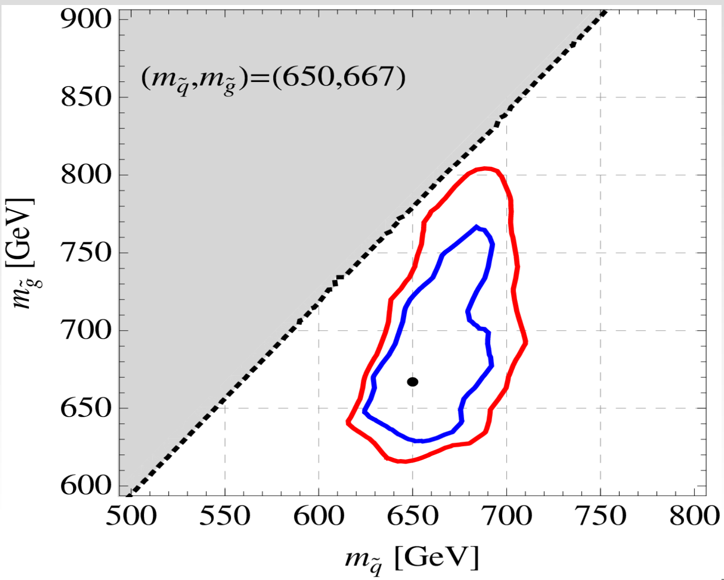
Jet cone size ΔR=0.4, |η|<4

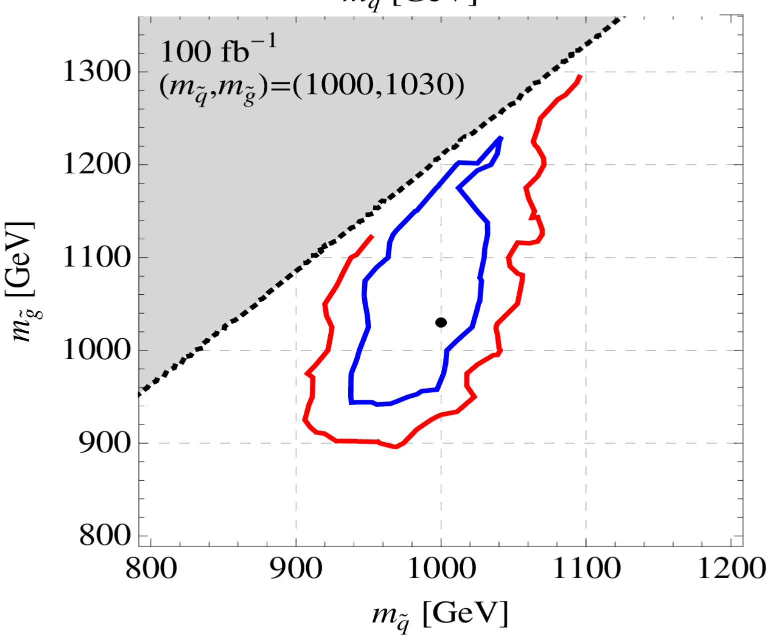
E_T smearing: HCAL 100%+√E*5% ECAL: 5%+√E*0.55%

Isolated lepton def. : p_T >5 GeV & HCAL < 5 GeV within ΔR=0.2

Good mass measurement for a good theory…

2, 3 σ contours @ LHC 14 TeV, 100 fb^{-1}





2σ squark mass constrants (95% C.L.)

m_{squark}	m_{gluino}	σ_{signal}	Δm_{sq} 2σ
650 GeV	667 GeV	16 fb	33 GeV
1 TeV	1.03 TeV	11 fb	53 GeV

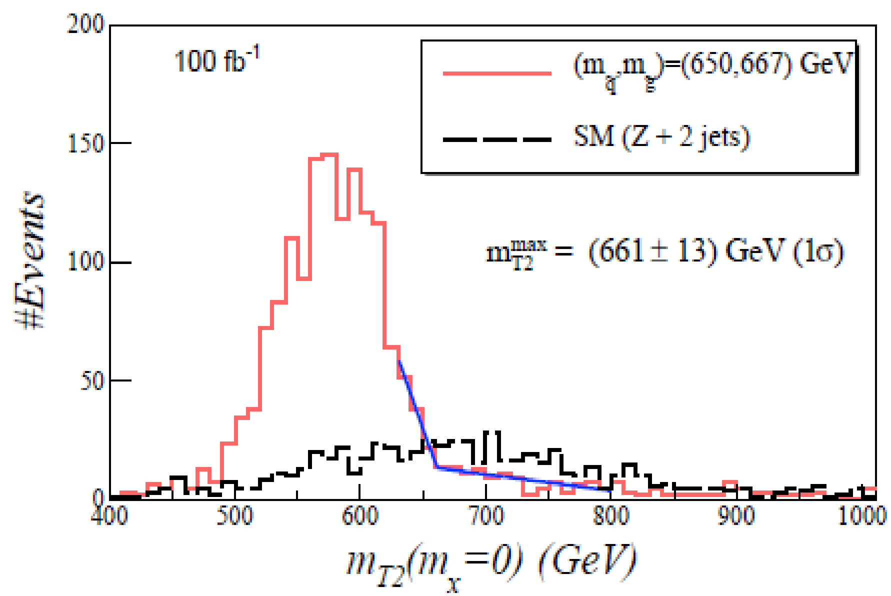
- (Isajet) Monte Carlo for 1000 fb^{-1} data
- Assume complete bkg subtraction
- Bkg statistical error from zjj assumes SM zl^+l^- event rate to mimic a `realistic' bkg.
- χ^2 fit to the shape of normalized signal dijet mass distribution, wih bin size Δm_{jj}=30 GeV, excluding bins with less than 5 events

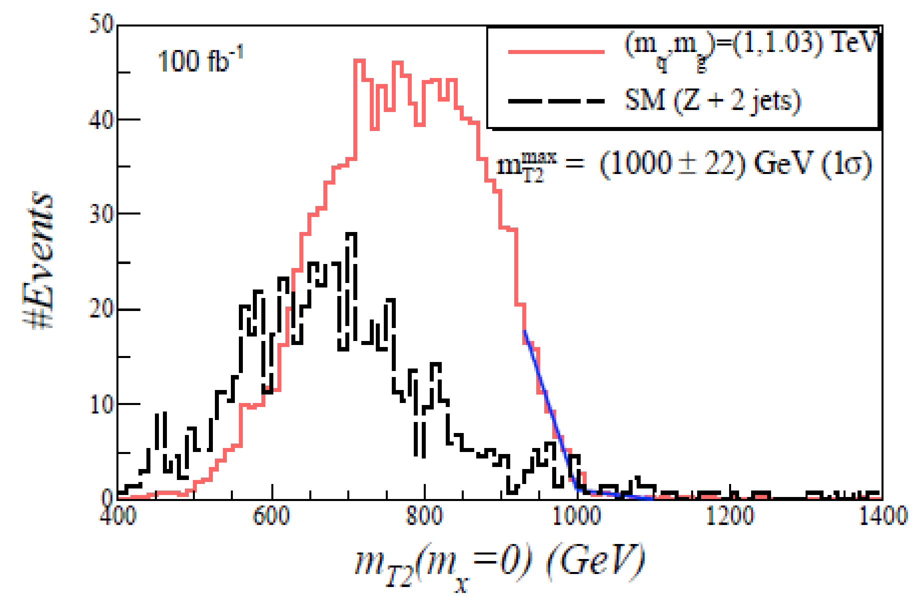
Comparison to m_{T2}

- linear kink fit (straight line)
- Same angular and E_T cuts
- Assume zero LSP mass correction ~ $(m_{lsp}/m_{sq})^2$

2σ constrants from m_{T2}

m_{squark}	m_{gluino}	Δm_{sq} 2σ
650 GeV	667 GeV	21 GeV
1 TeV	1.03 TeV	30 GeV





Gluino contamination tends to increase constructed m_{sq}

Pros & Caveats

- m_{jj} analysis gives averge squark mass if mass splitting exists among squarks; m_{T2} gives the larger of the squark masses.
- m_{sq} constraint is comparable to m_{T2} if the dip in m_{jj} can be used with good event rate
- Possible gluon-partner mass determination to compare with independent (multi-jets, etc) measurements
- Mass constraint is independent of missing E_T (and its uncertainties)

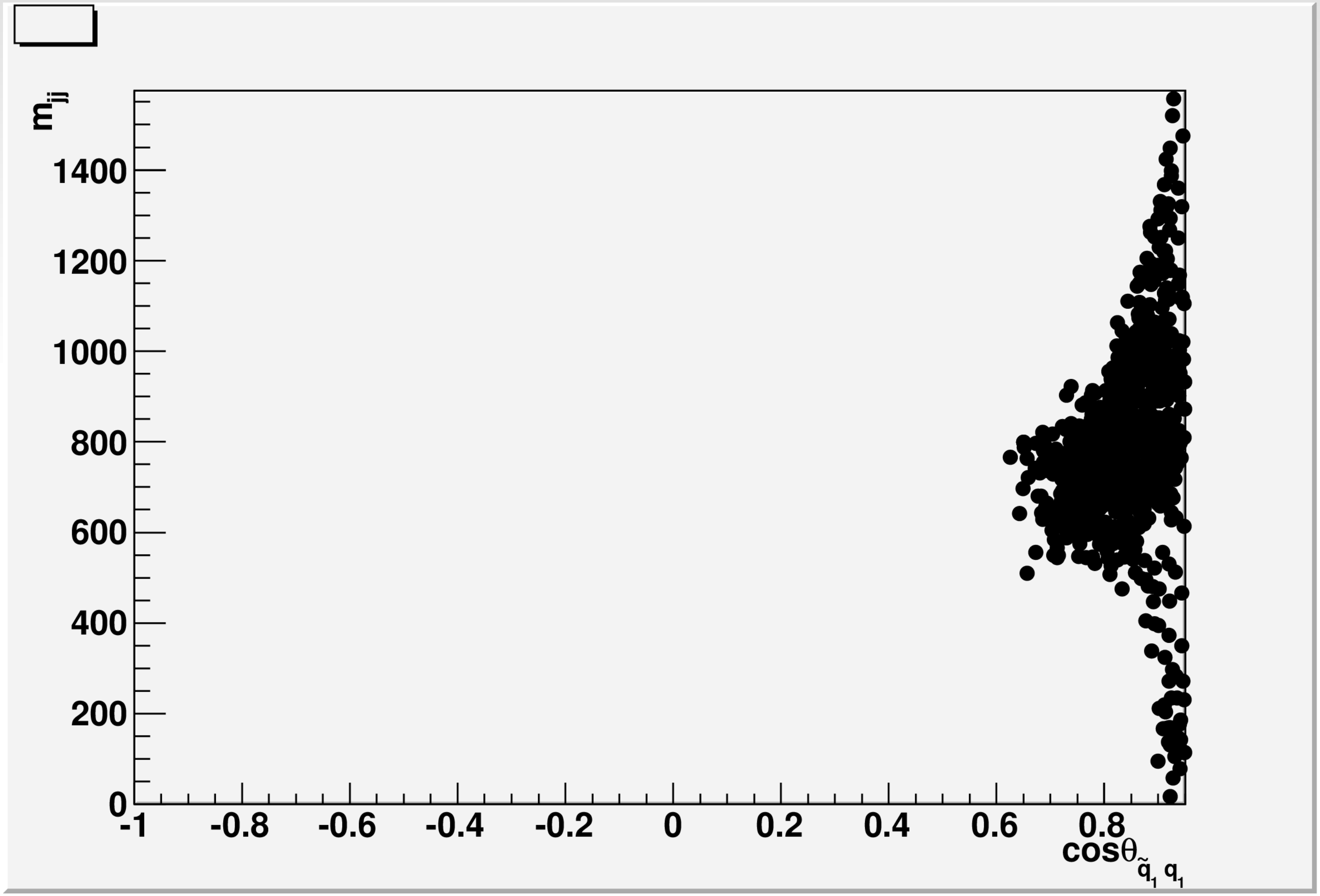
- Inapplicable if the squark is much heavier than the gluino
- Raising E_T cut too high (in order to develop mjj dip for large squark masses) may cause significant loss in statistics

Summary

- Kinematics-only approach (dijet mass + angular cuts)
- Requires low DM mass
- No dependence on missing E_T.
- Experimentally measureable bkg
- Competitive ~6% squark mass constraint (95% C.L. One year LHC running at 14 TeV)

Thanks !

How good is the colinear approximation?



(unavailable as pdf) mjj gif animation