Seeing Jets in Color

Sorting Events by Color Superstructure

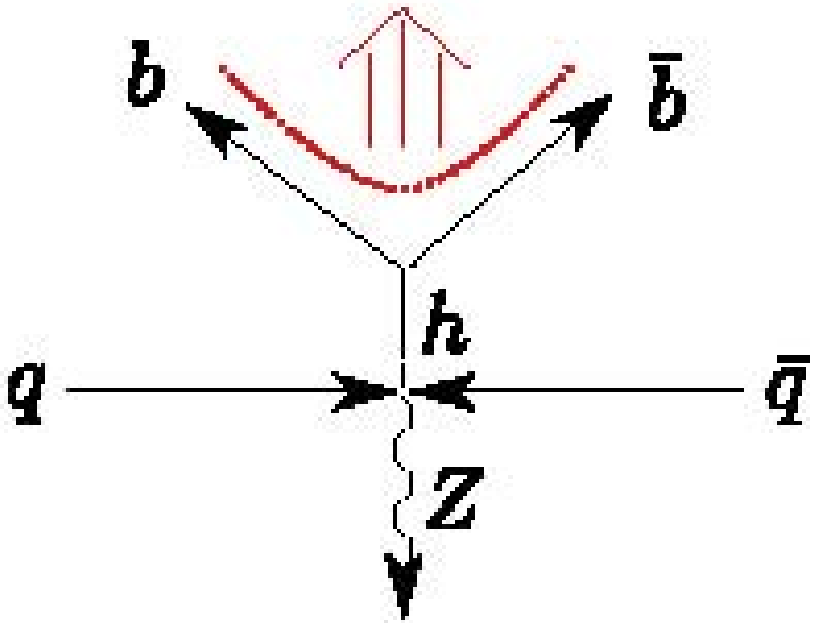
Jason Gallicchio

Harvard

Nov 13, 2009

Jumping Right In

Improve search for $H \to b\bar{b}$ associated with a Z for $m_H \approx 120$ GeV.

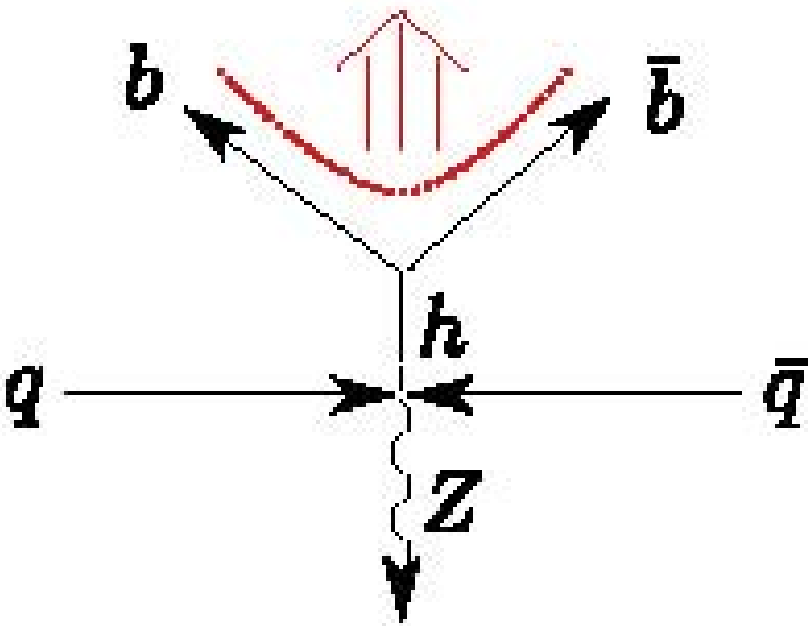


Higgs Signal

bs form color singlet

Jumping Right In

Improve search for $H \to b\bar{b}$ associated with a Z for $m_H \approx 120$ GeV.



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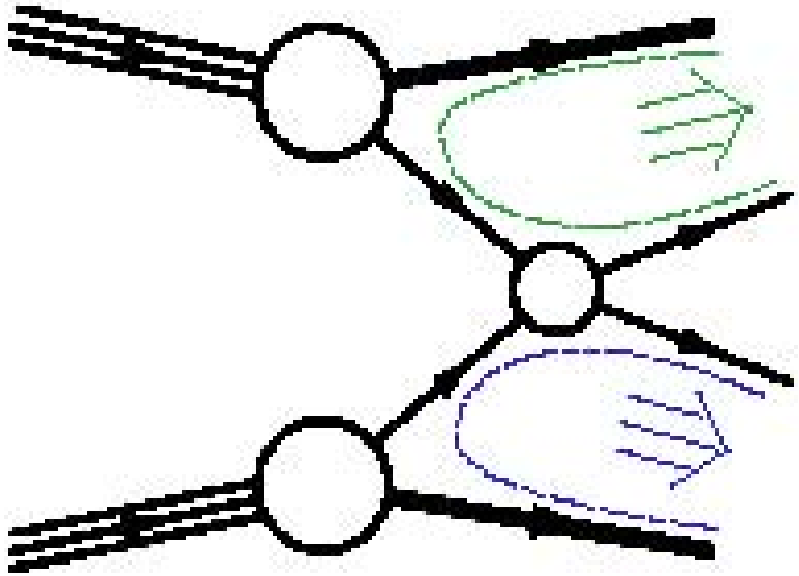


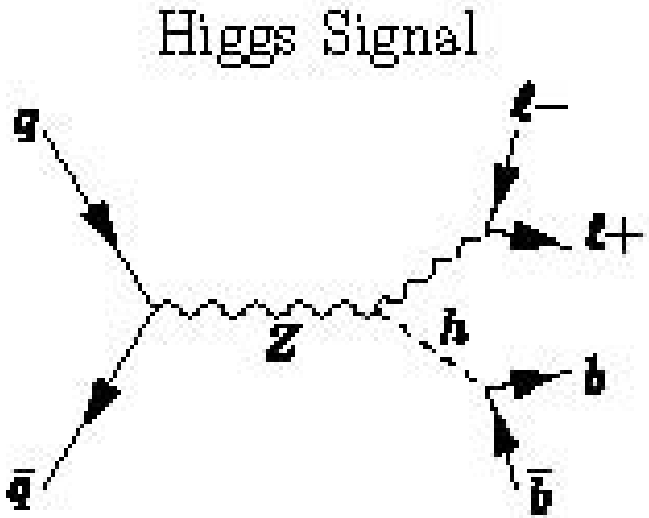
$Z + b\bar{b}$ Background

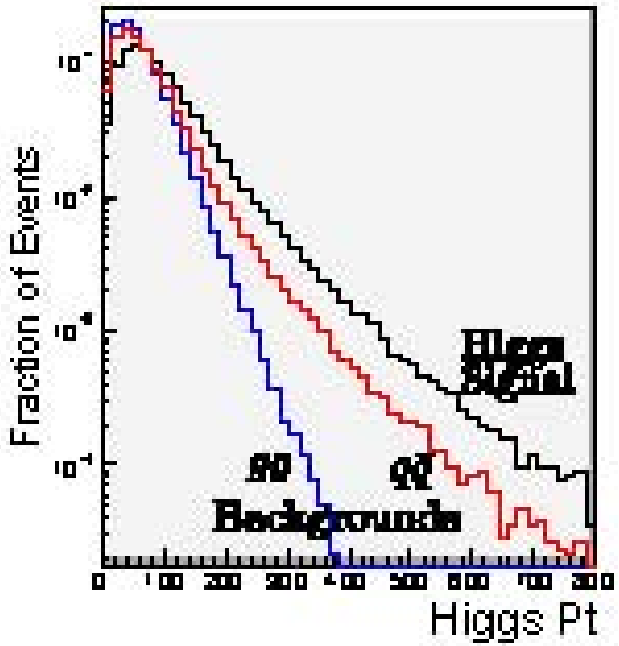
bs are color connected to beam

Higgs + Z

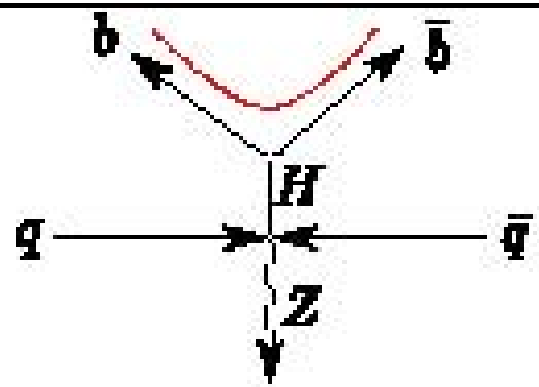
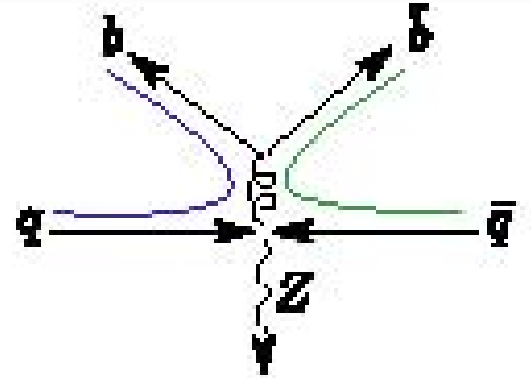
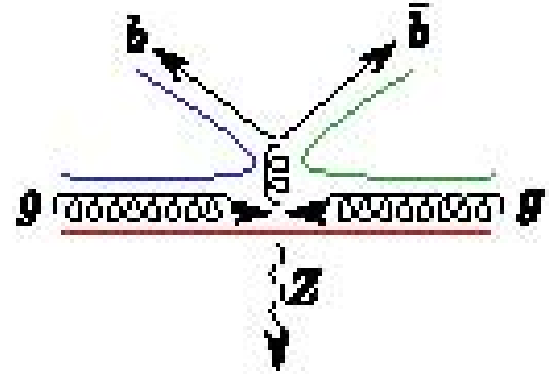
Kinematic variables to distinguish signal from background somewhat...

Good ones are P_T^H, P_T^Z, $\Delta\eta_{b\bar{b}}$, $\Delta\phi_{b\bar{b}}$

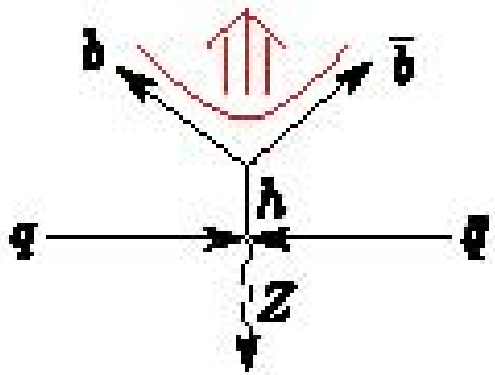




For *given* kinematics, *color* structure is different

Higgs	
$q\bar{q}$ Background	
gg Background	

Crossed and Uncrossed Color Kinematics



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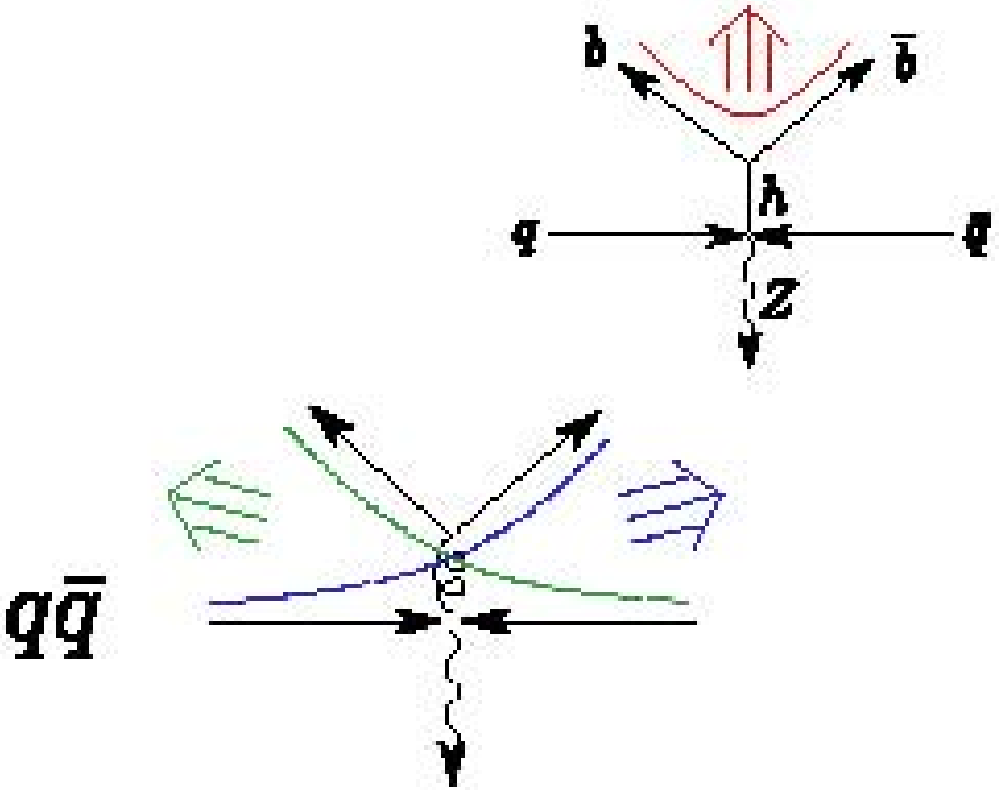

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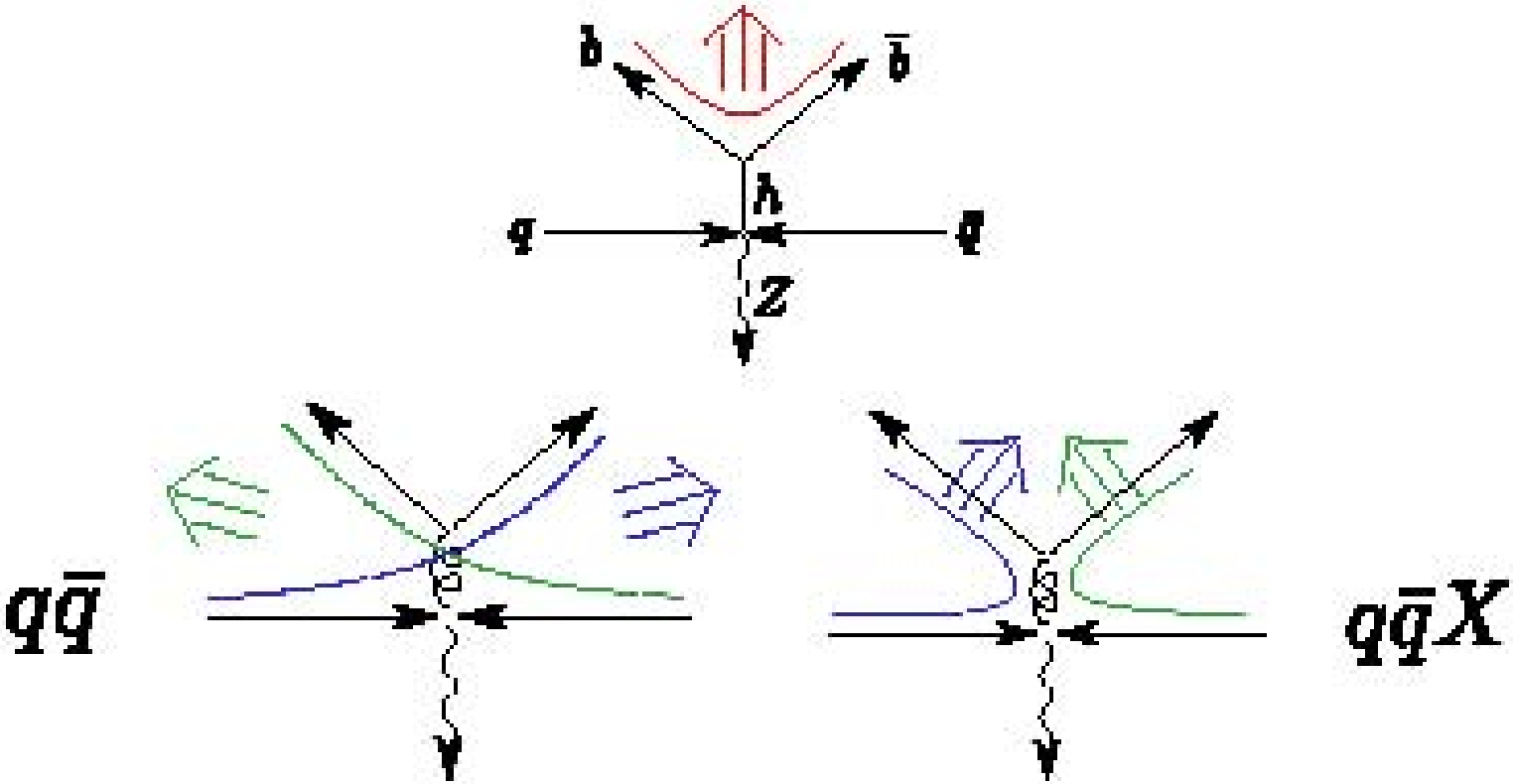

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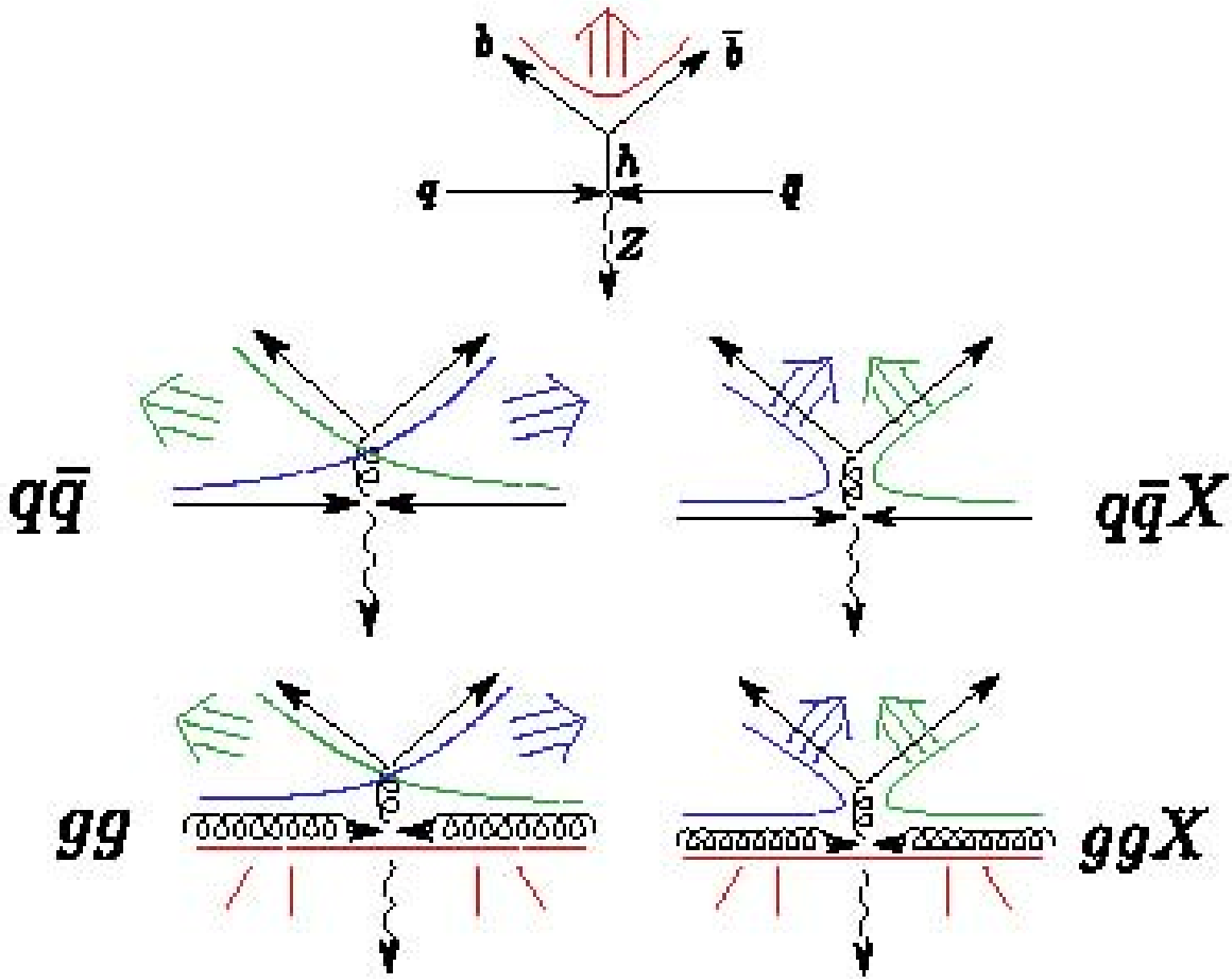
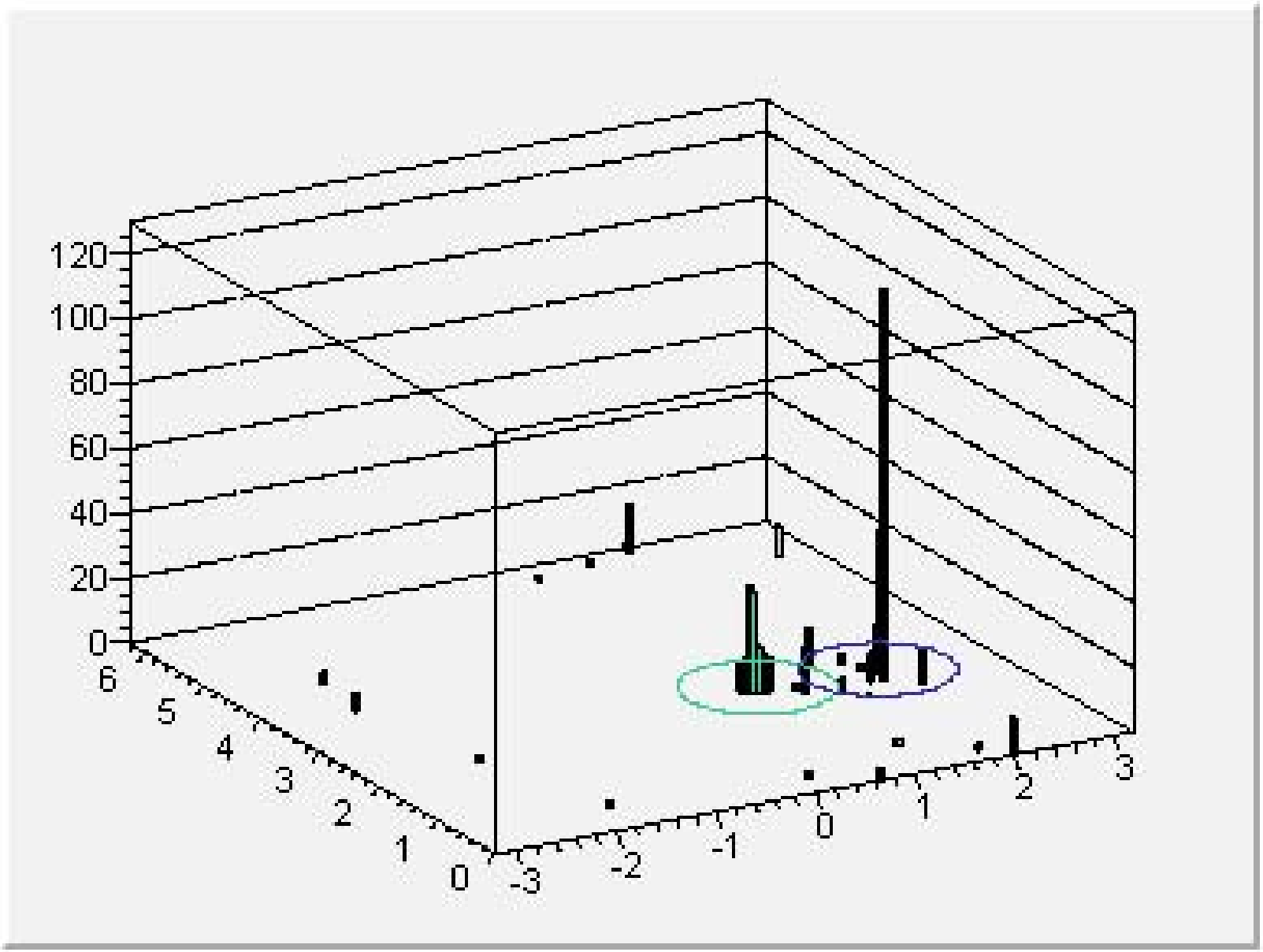
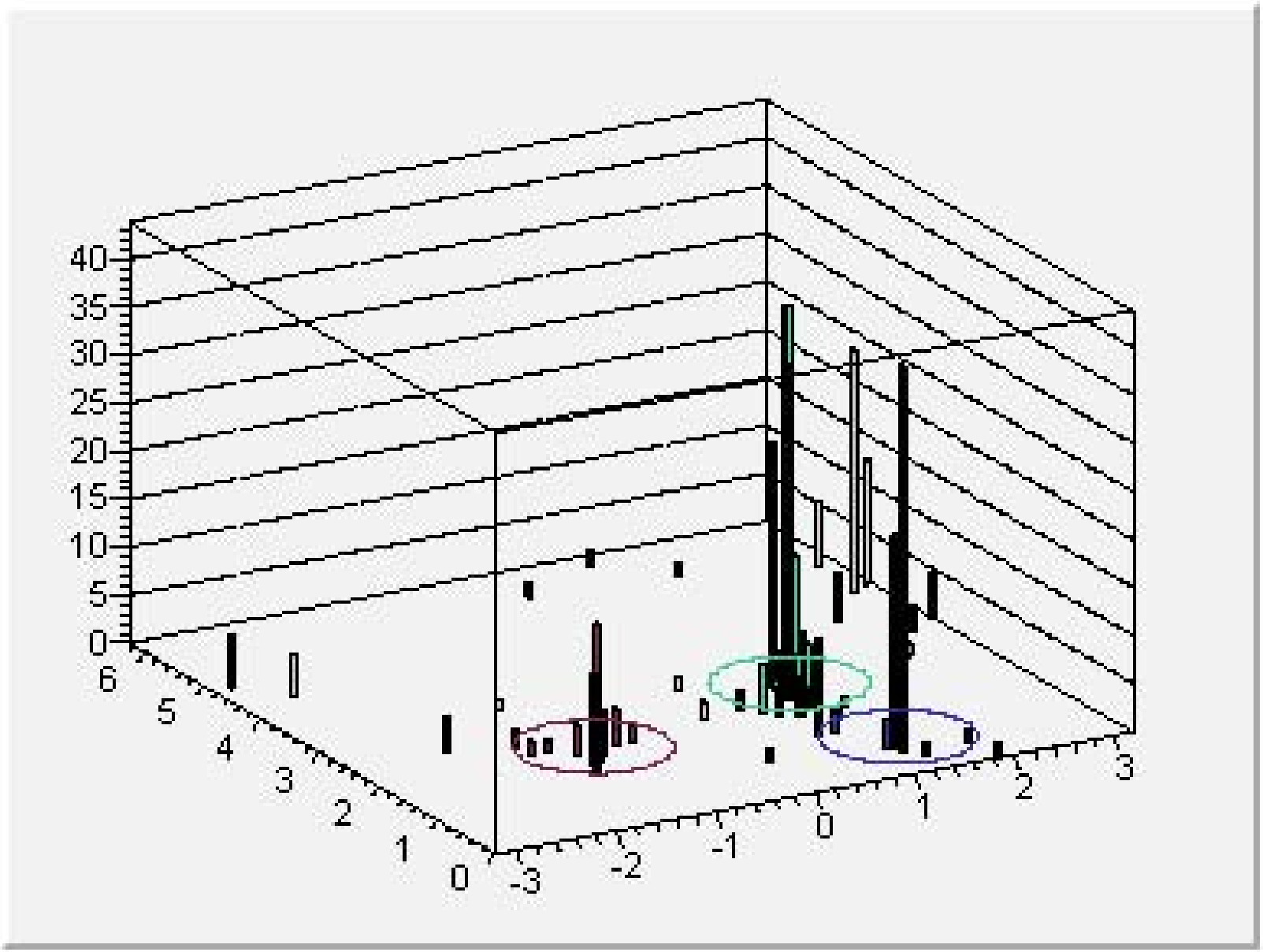


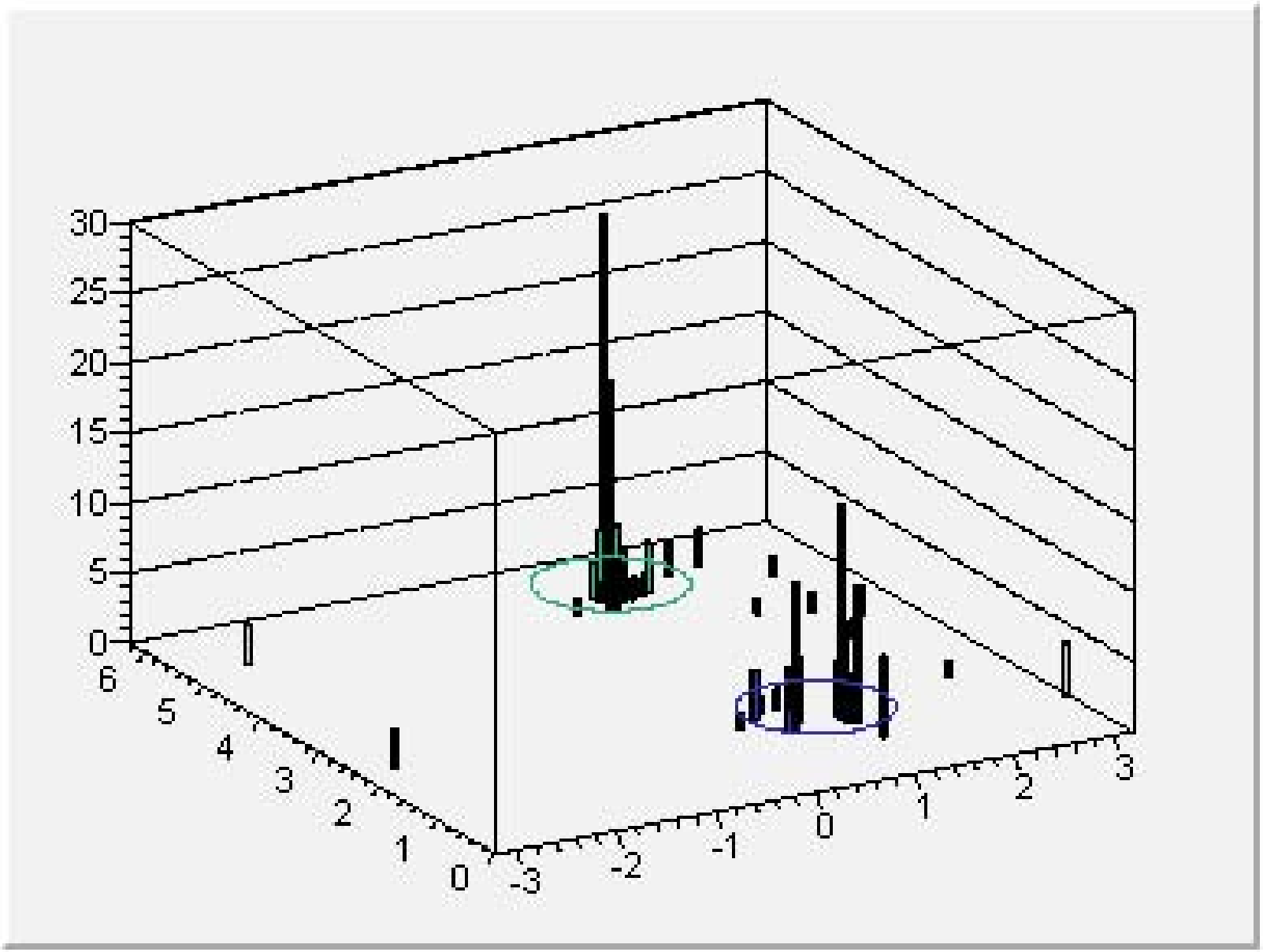
Higgs Event Example 1



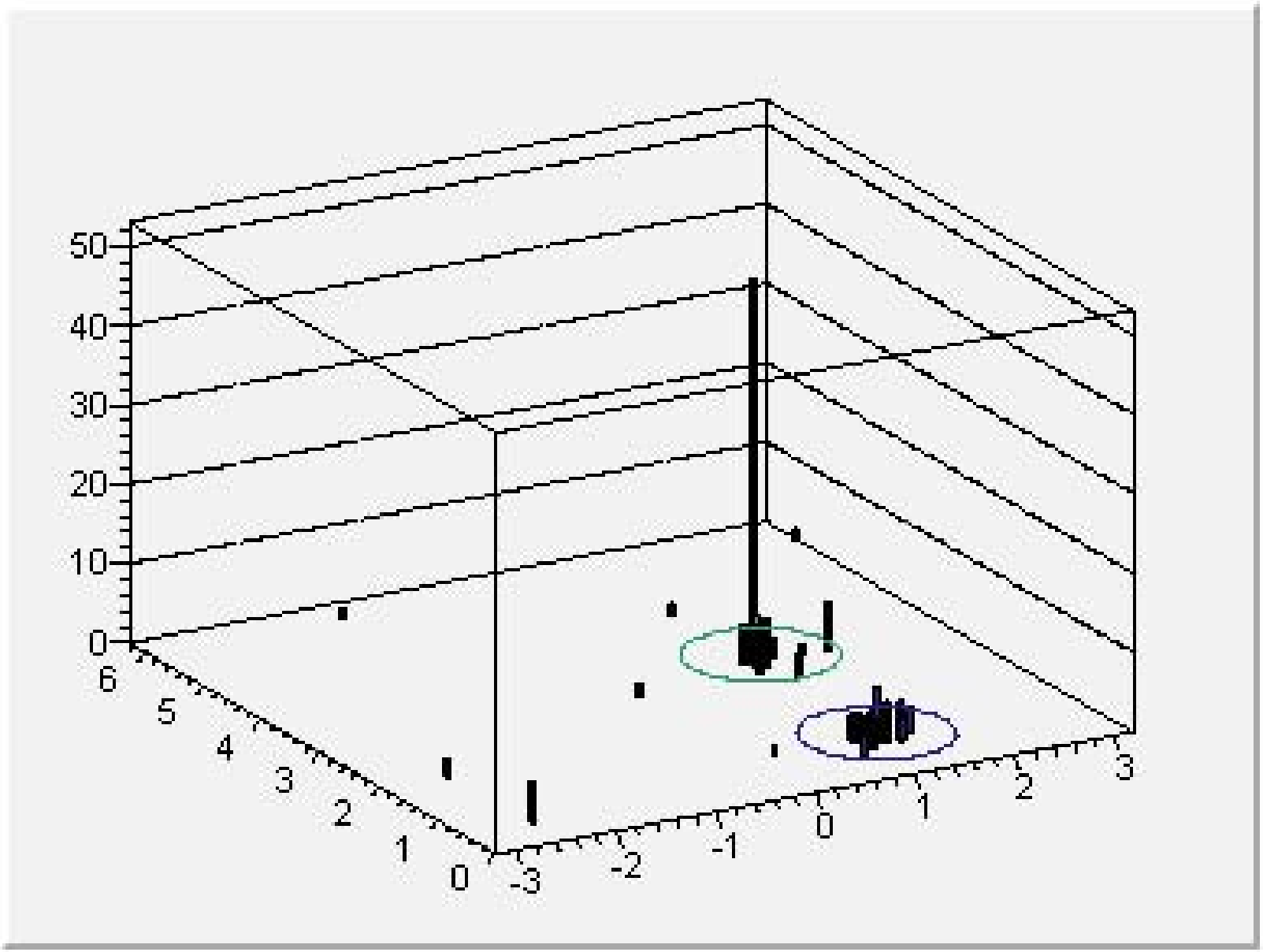
Higgs Event Example 2



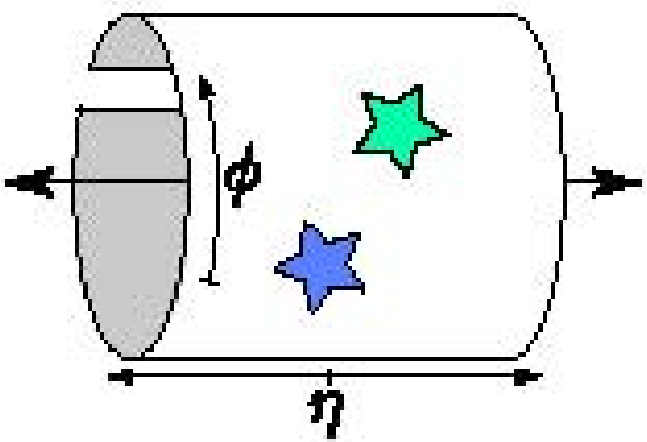
Background Event Example 1



Background Example 2



Showering Same Event Millions of Times



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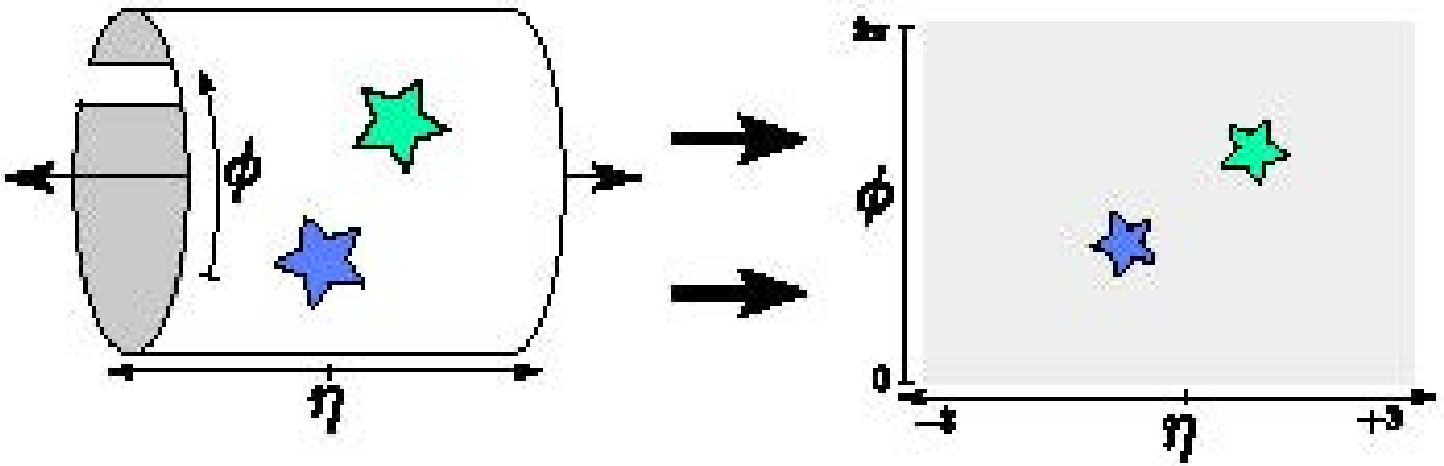

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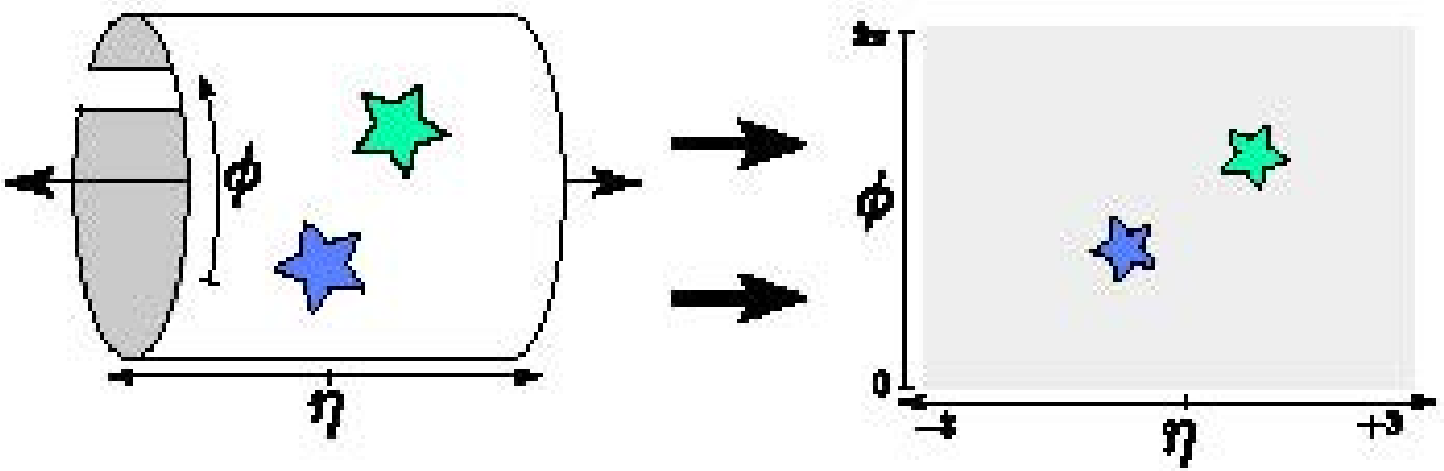
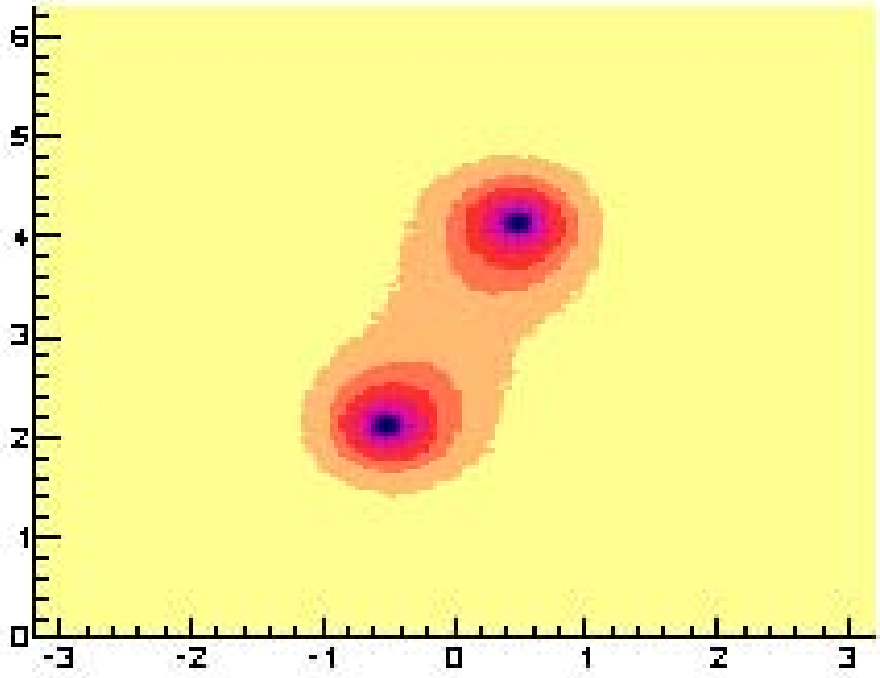


Higgs:

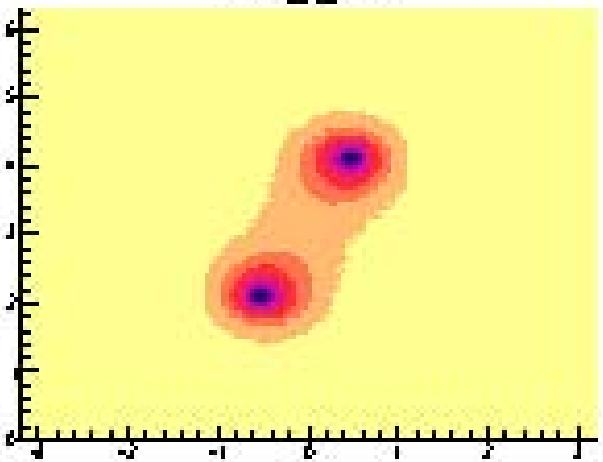
$\Delta\eta_{b\bar{b}} = 1$
$\Delta\phi_{b\bar{b}} = 2$

Add up E_T in each cell:

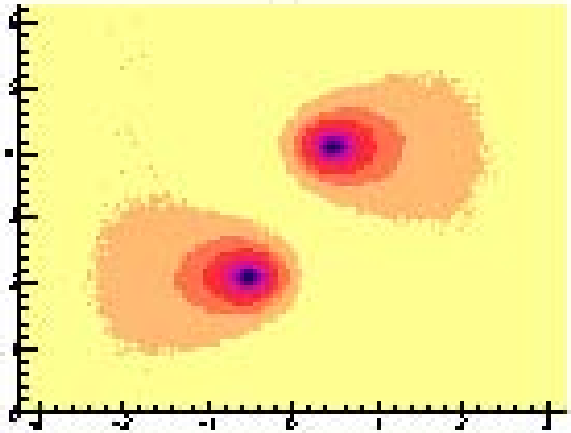


Signal vs Background Accumulated E_T

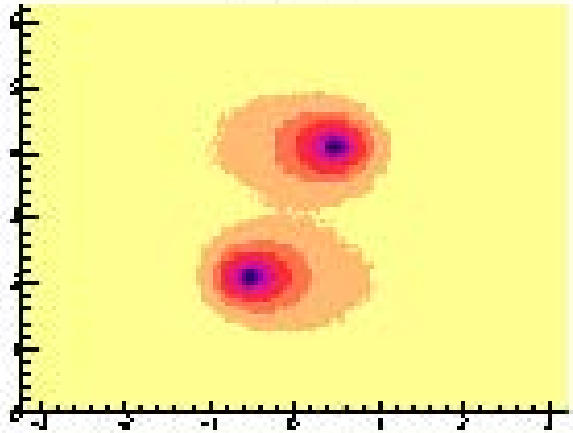
Higgs:



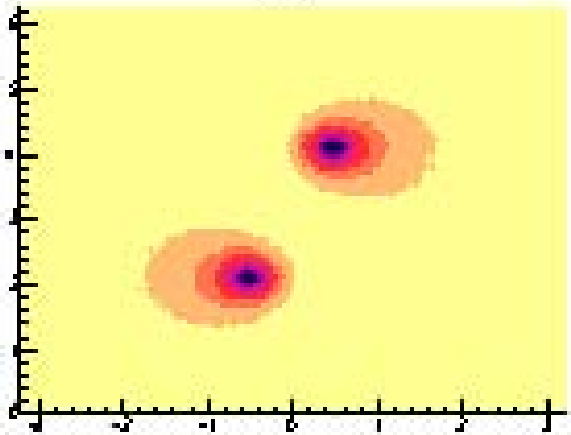
$q\bar{q}$



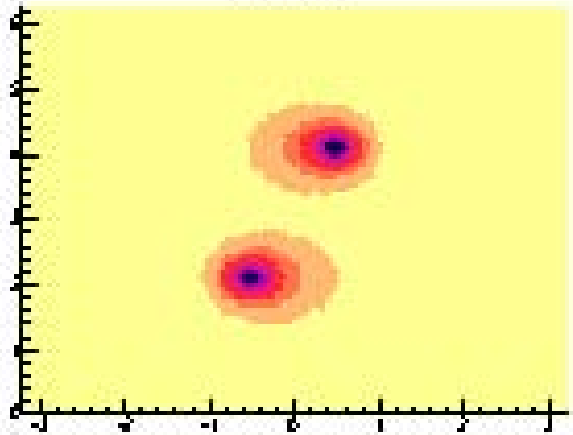
$q\bar{q}X$



gg

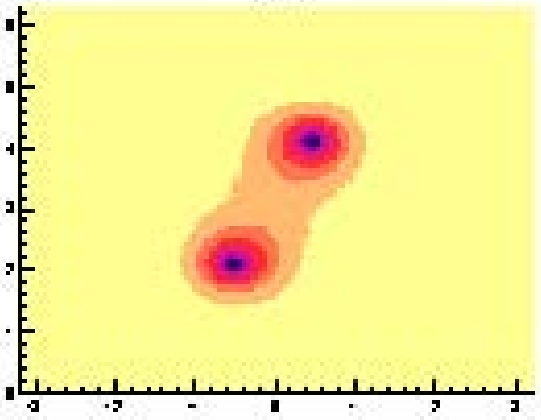


ggX



Probability that a GeV of E_T somewhere is from Higgs

Higgs:



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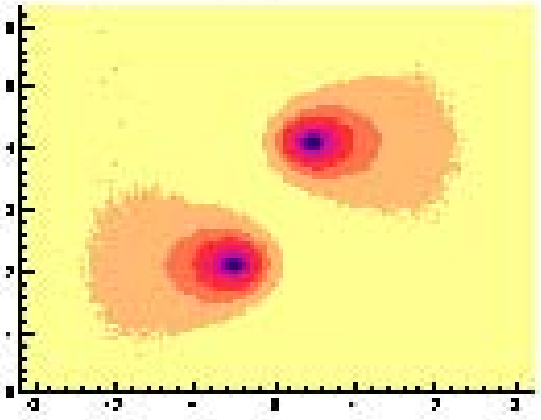
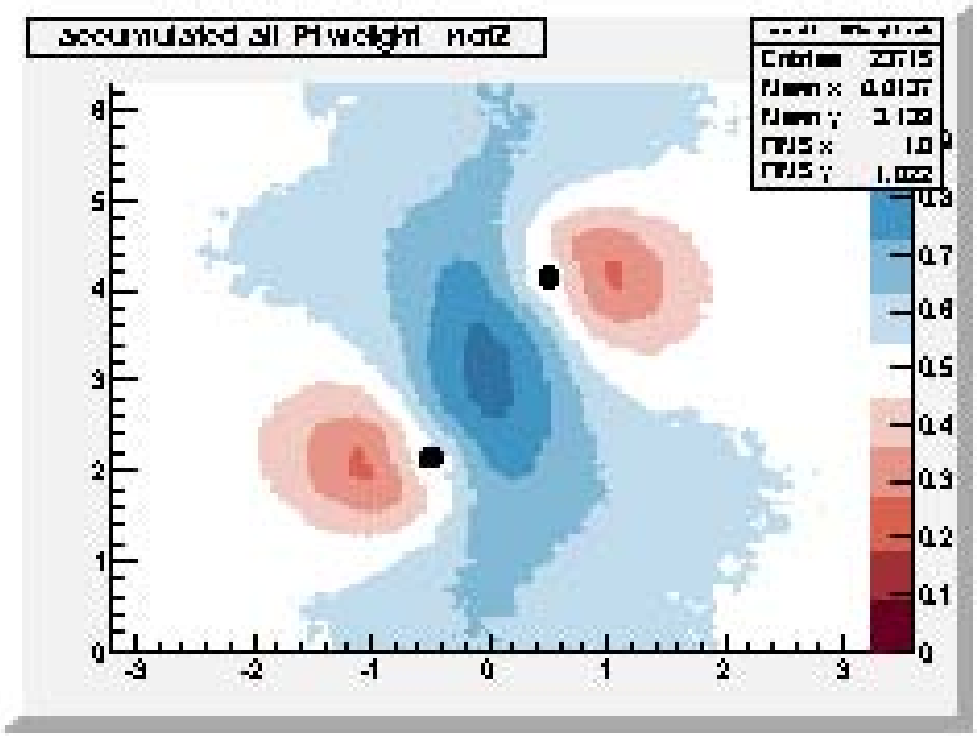


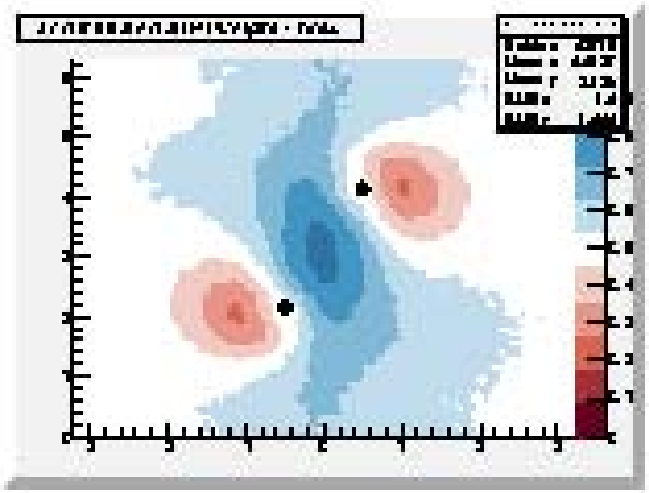
$\rightarrow$



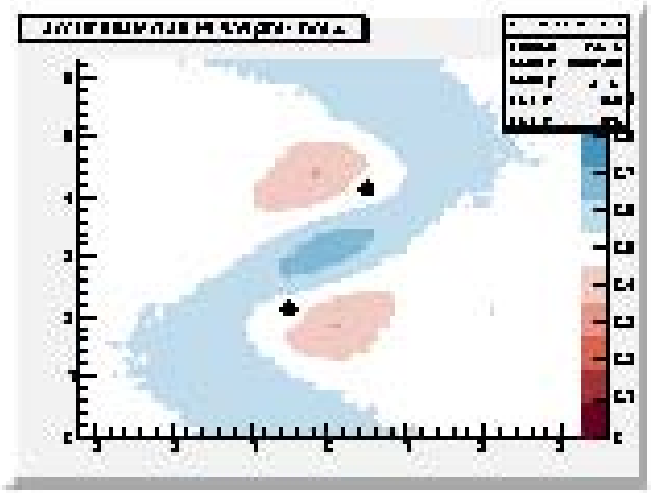
Important discrimination isn't at jet center — it's $\Delta R \approx 0.5 - 1.5$ away.

Probabilities for Pt Deposits

$q\bar{q}$



$q\bar{q}X$



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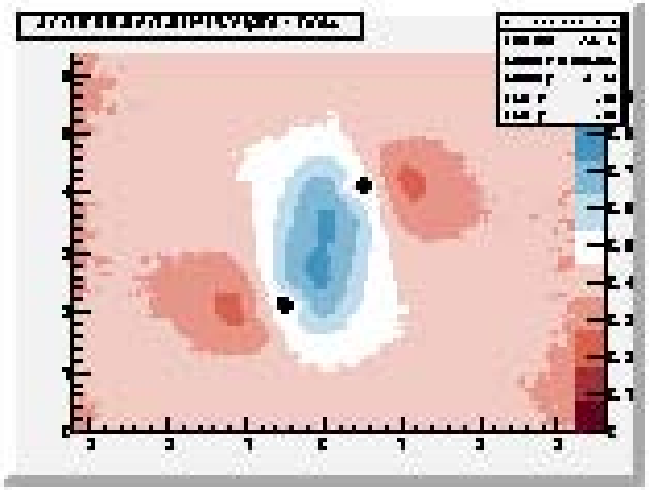
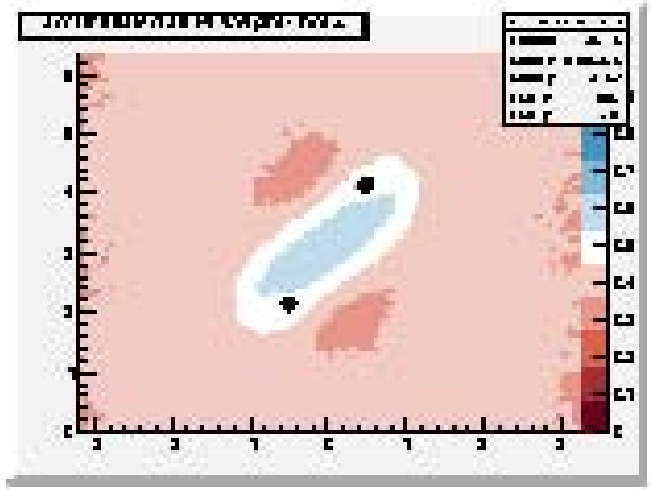
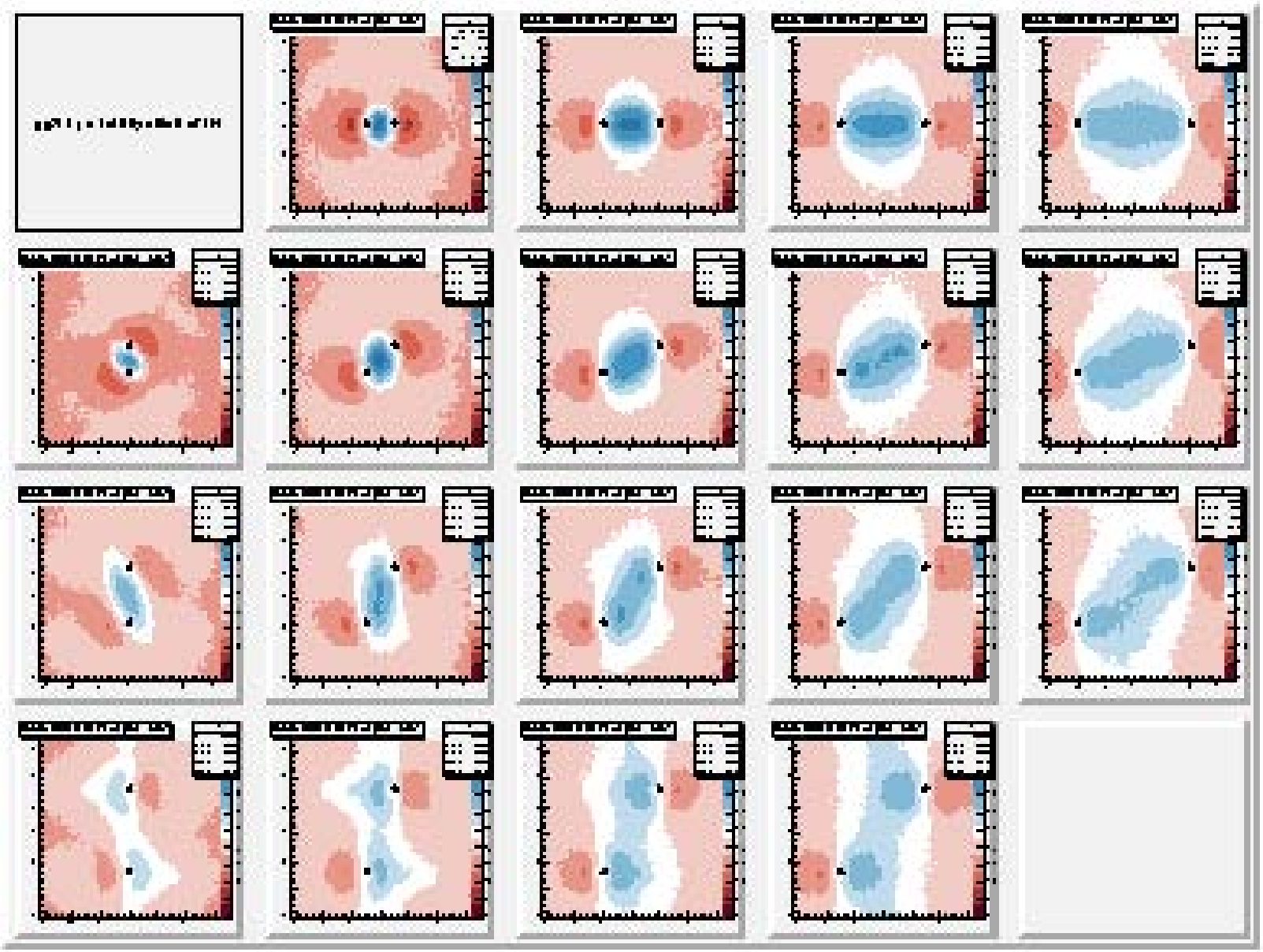


ggX



Different Jet Separations



Big Baysean Estimator

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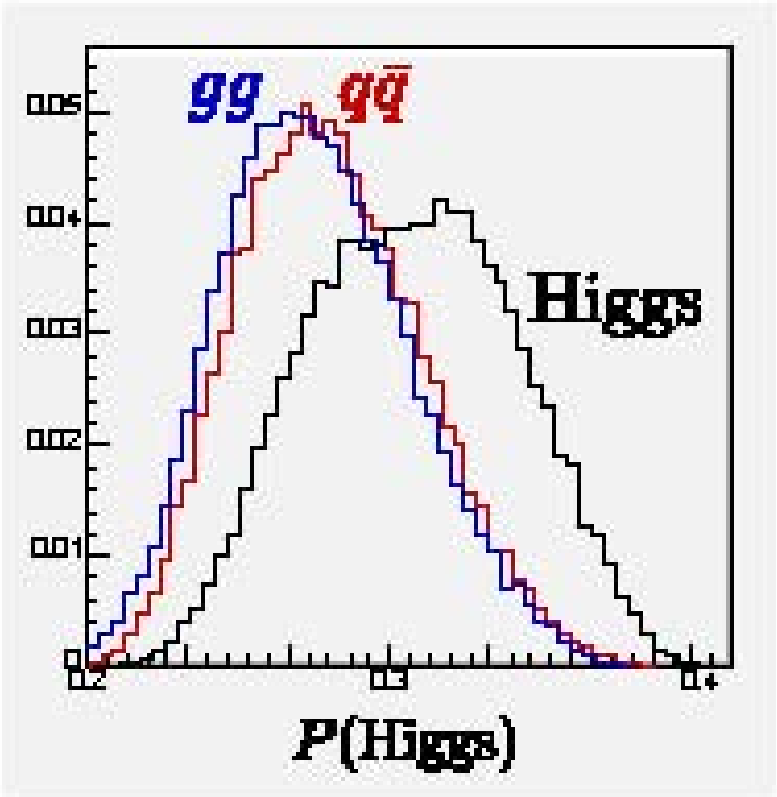
$$= \prod_i P_{higgs}(\eta_i,\phi_i)^{E_i/E_{event}}$$

Event-By-Event Estimate



(this plot includes only events with well-separated jets)

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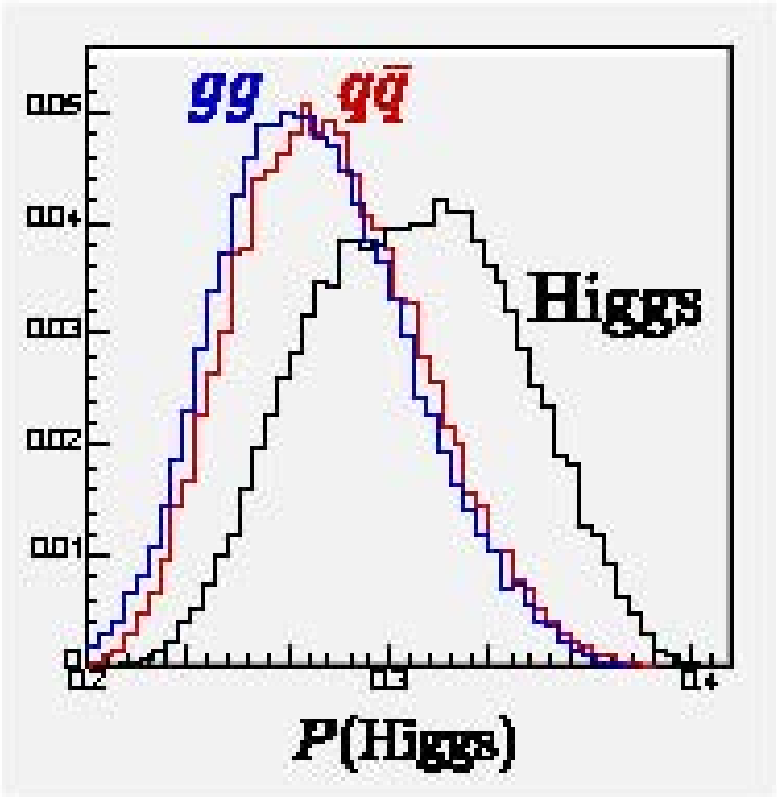

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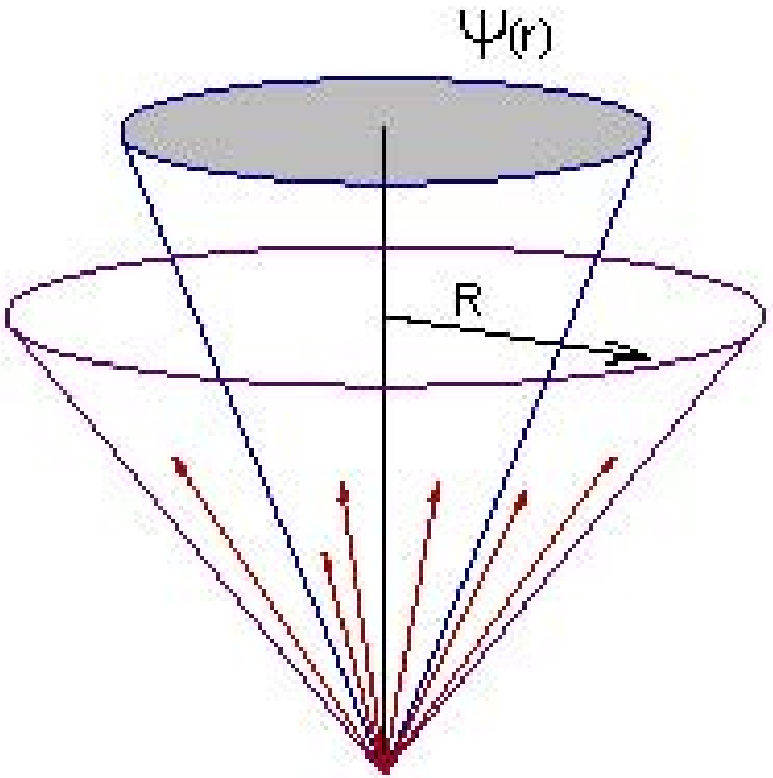
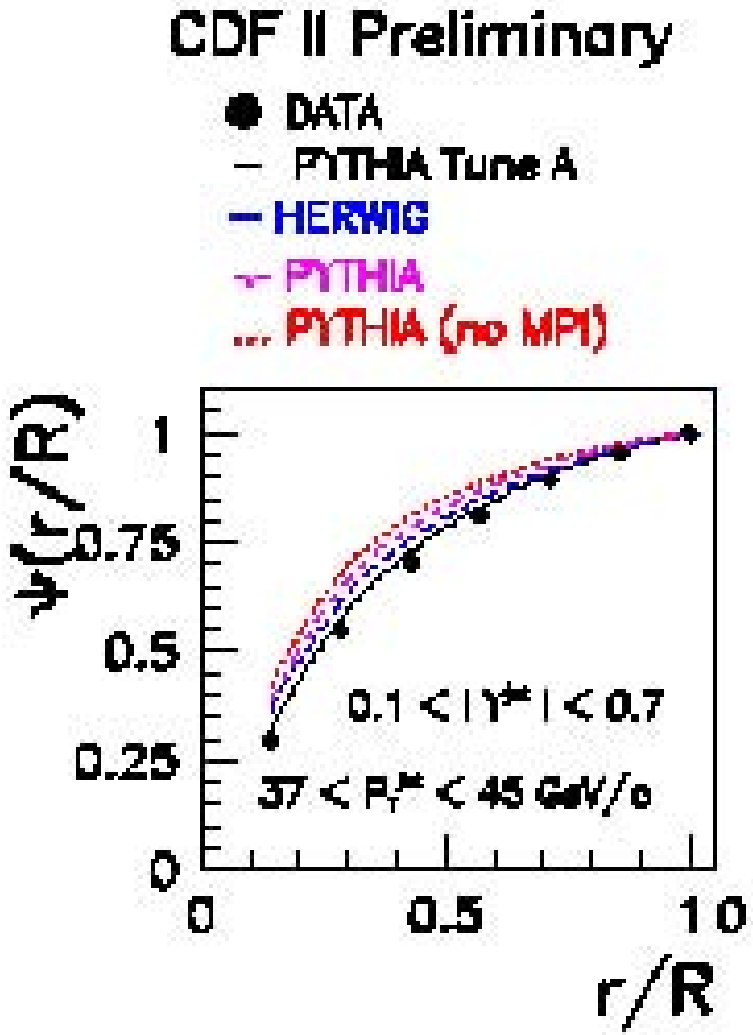
Switching to more general technique looking more locally at each jet...

Traditional Jet Shapes

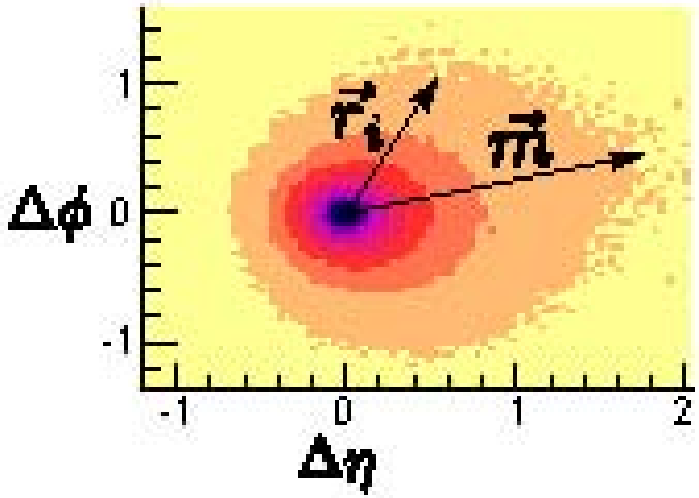




... but our jet "shapes" seem to have angular information ...

Jet Moment or "pull"

Add up particles or calorimeter energy deposits *within* a jet:



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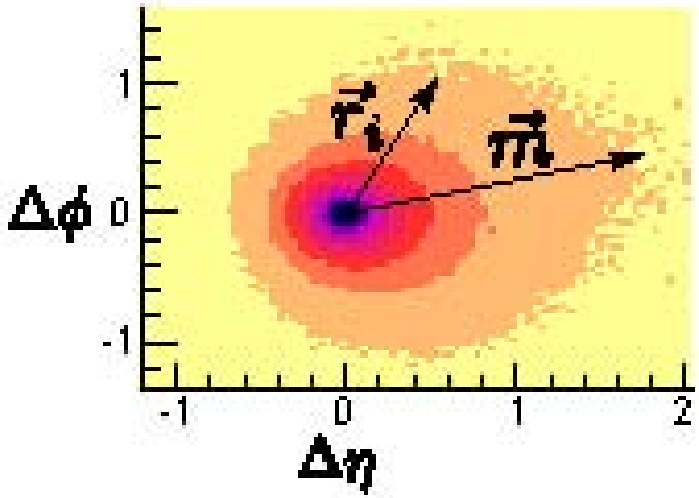

$$\vec{m} = \sum_i \frac{E_T^i \, |r_i| \, \vec{r}_i}{E_T^{jet}} \qquad \text{where} \qquad \vec{r}_i = (\eta_i - \eta_{jet}, \phi_i - \phi_{jet})$$

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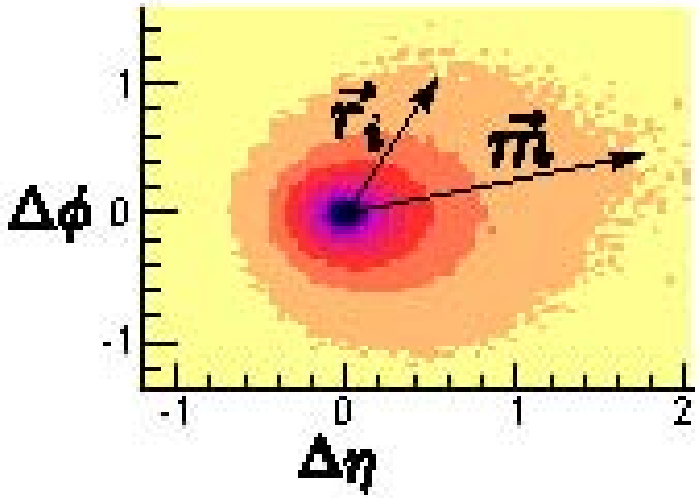

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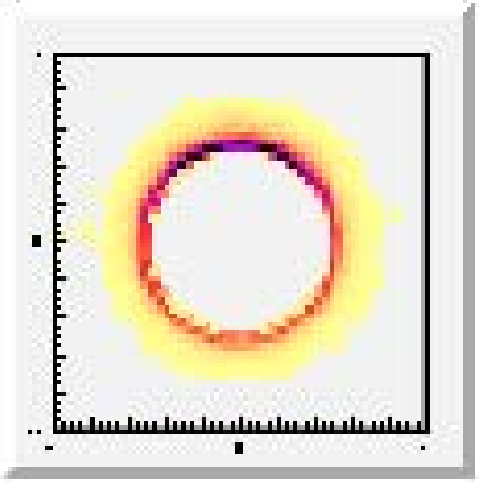
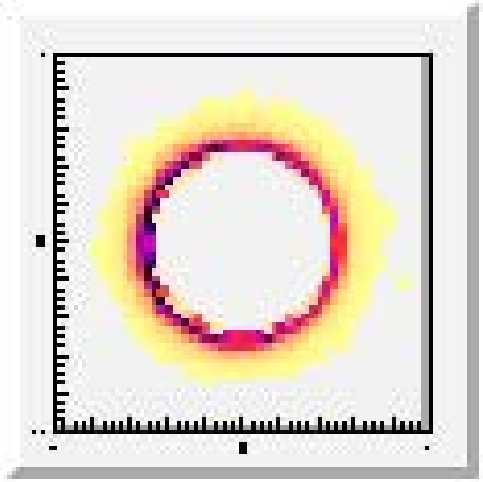
- Angle of moment gives "pointing" direction of teardrop
- Length of moment gives measure of confidence
  - not used today... didn't find it helped much

Jet Moments for one b for $\Delta\eta_{jj} = 0$ and $\Delta\phi_{jj} = 1$

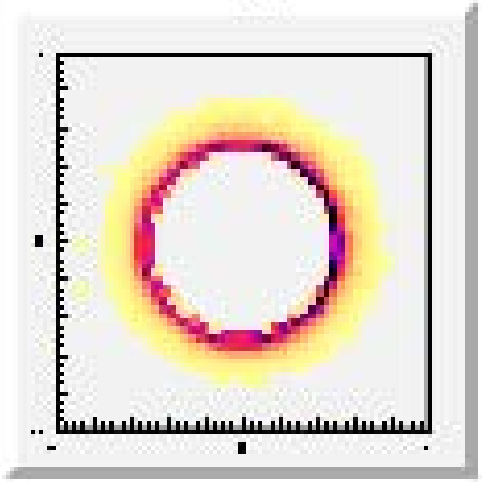
Higgs Signal
(Toward Other Jet)



Uncrossed Background
(Toward Left Beam)



Crossed Background
(Toward Right Beam)



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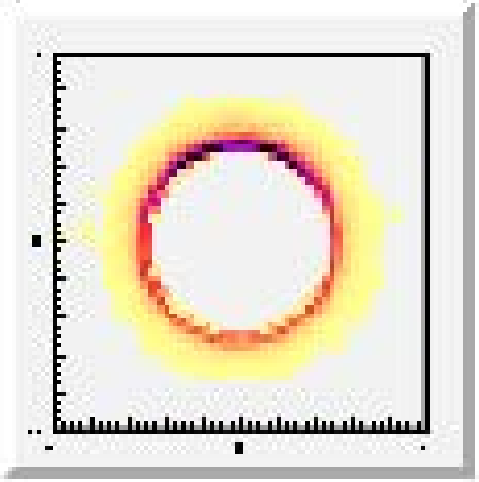

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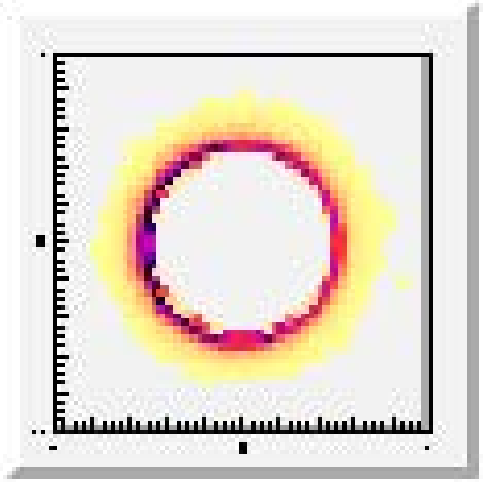
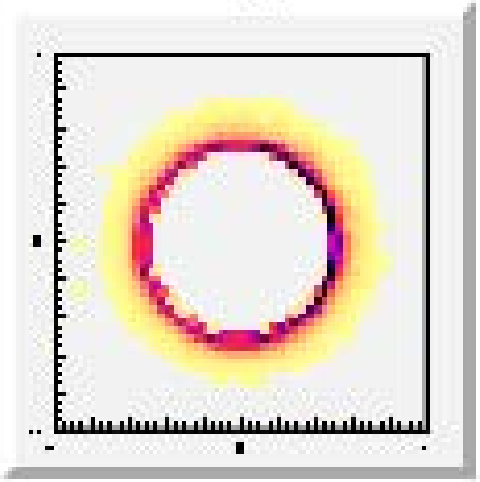
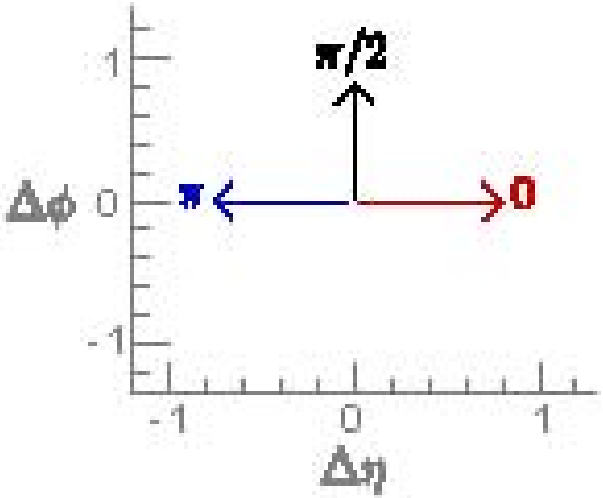
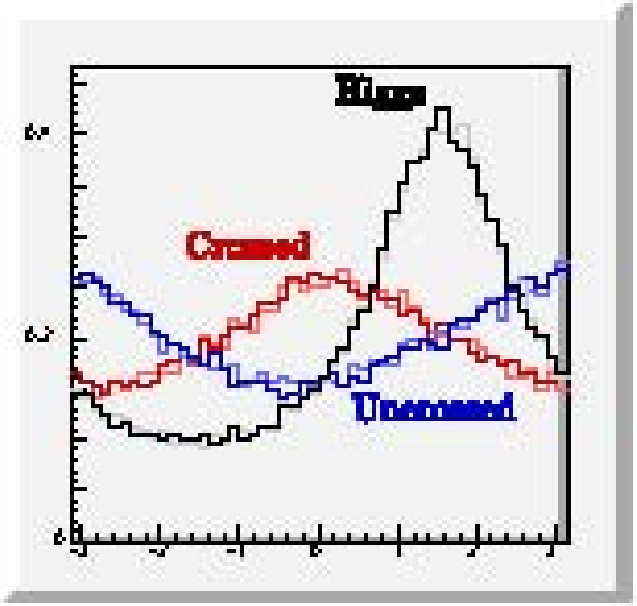


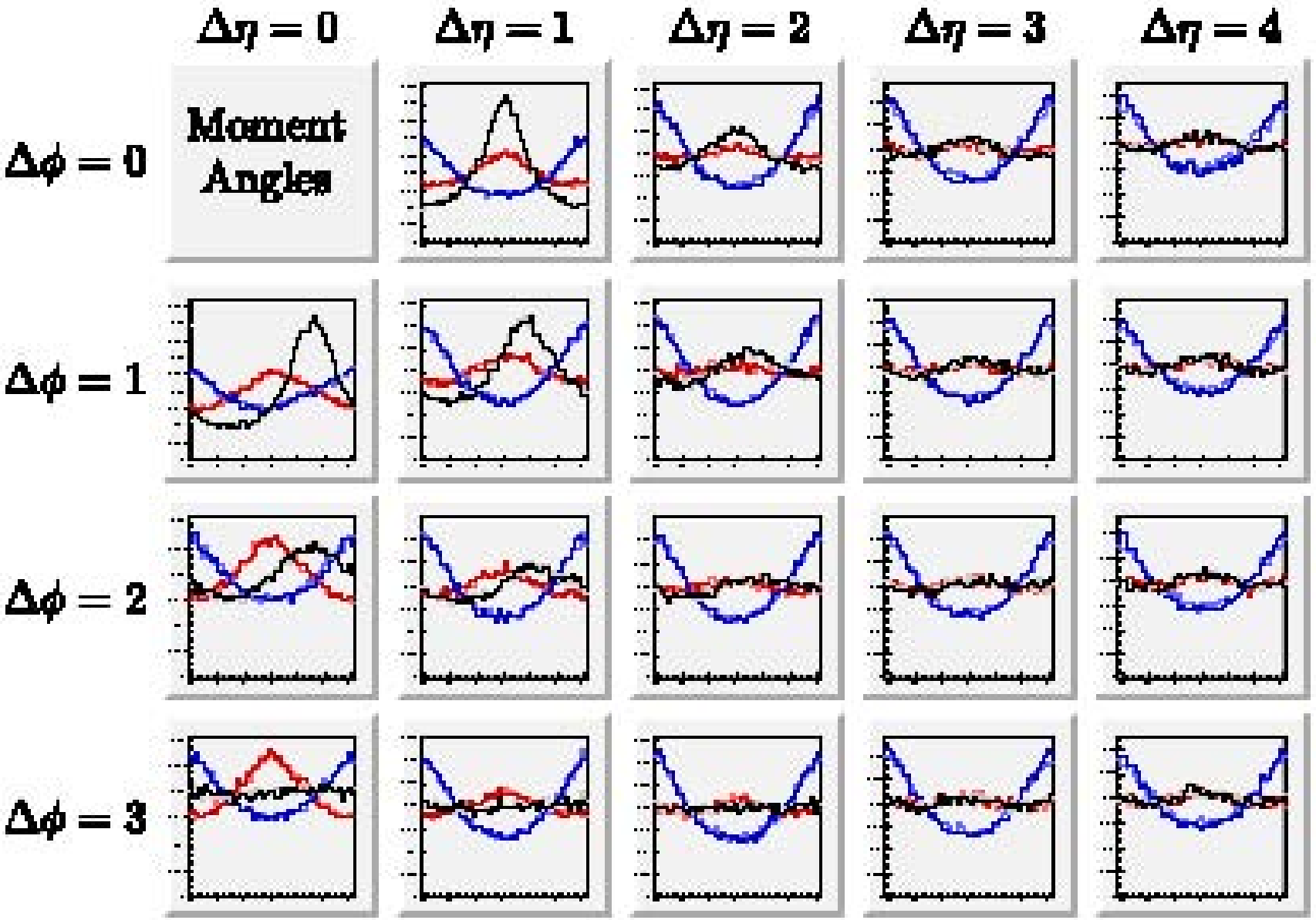
Crossed Background
(Toward Right Beam)







Moment Angles for Higgs and Background

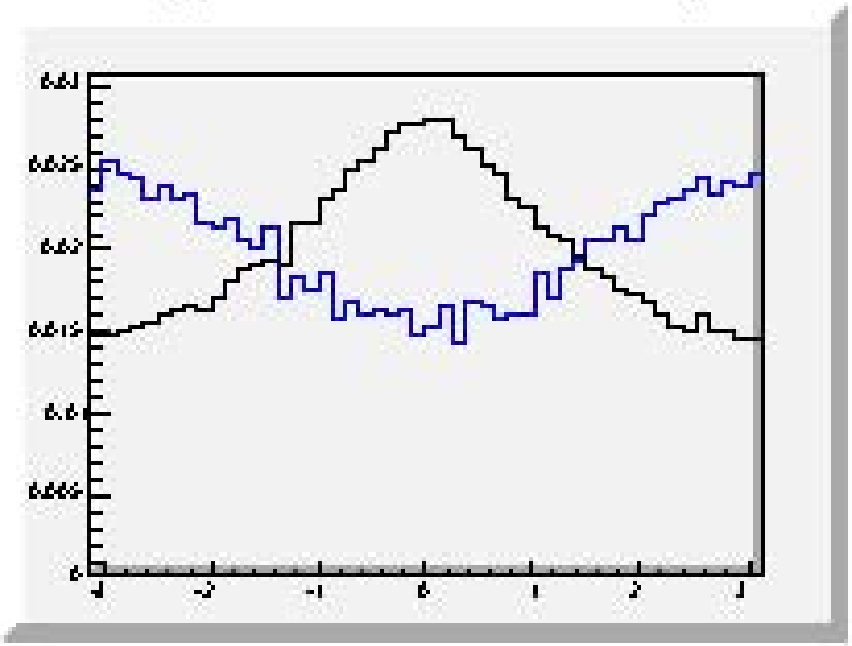


Back-to-back Higgs bs (and glue) are elliptical, not teardrop shaped.

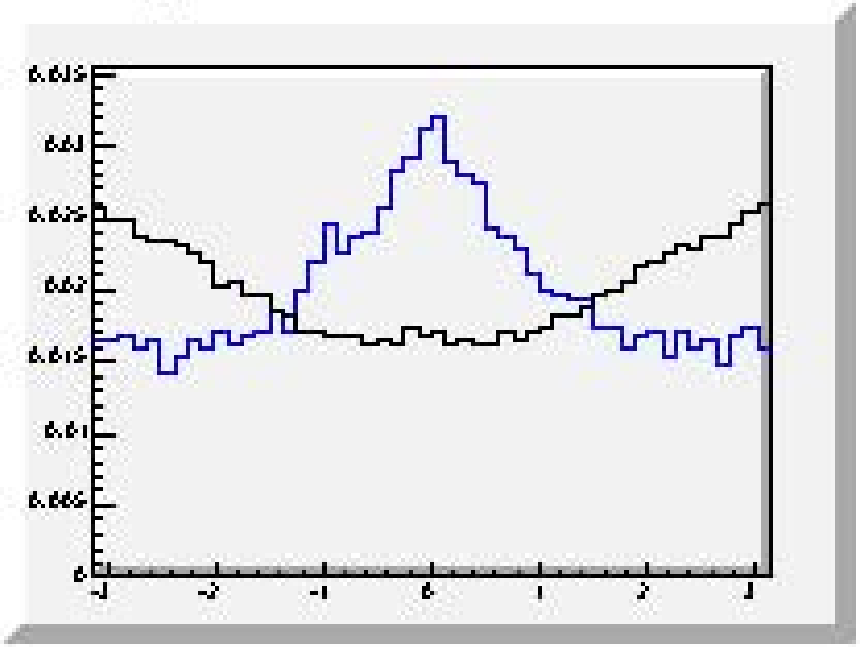
Moment Angles for Higgs and Background

Moment Angles for *full* **Higgs signal** / $Z + b\bar{b}$ **background** :

Angle toward other b-jet:



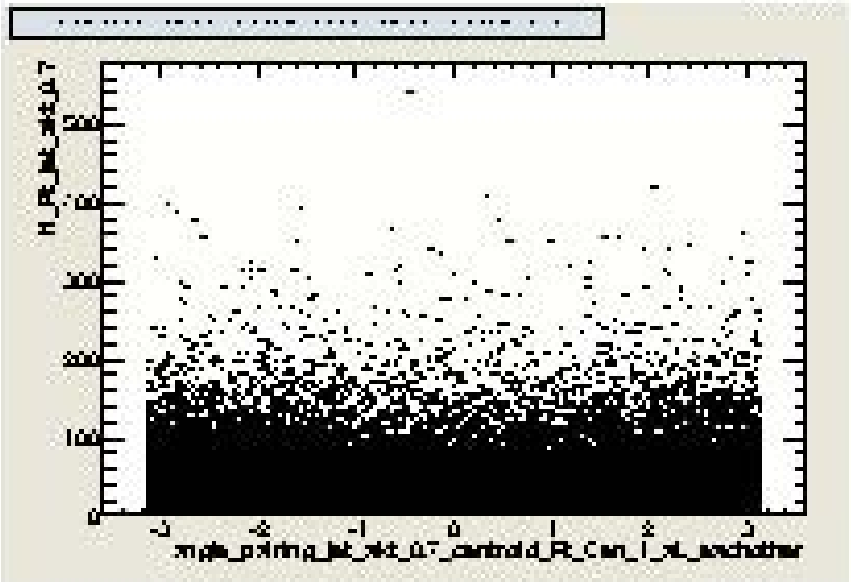
Angle toward closest beam:



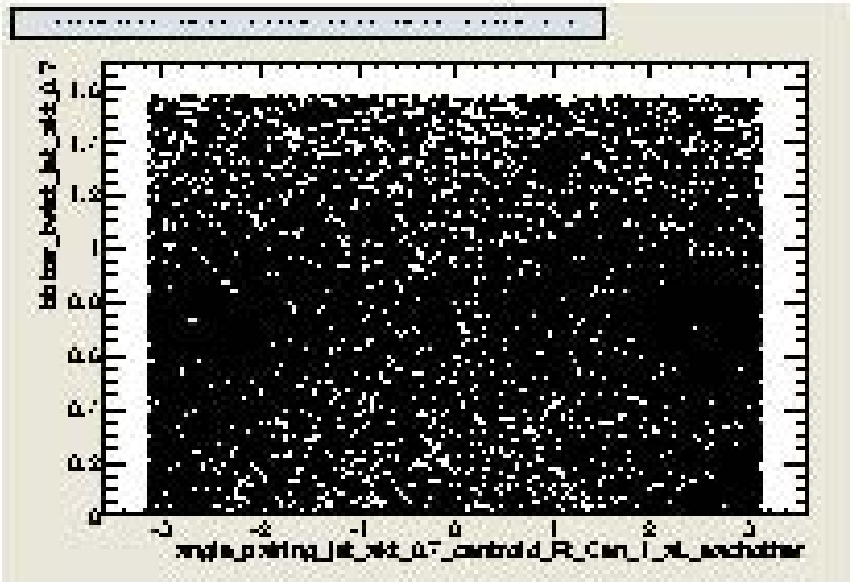
Correlations of Moment Angle with Kinematic Variables

Angle toward other b-jet is nicely independent of kinematics:

No correlation with P_T of Higgs

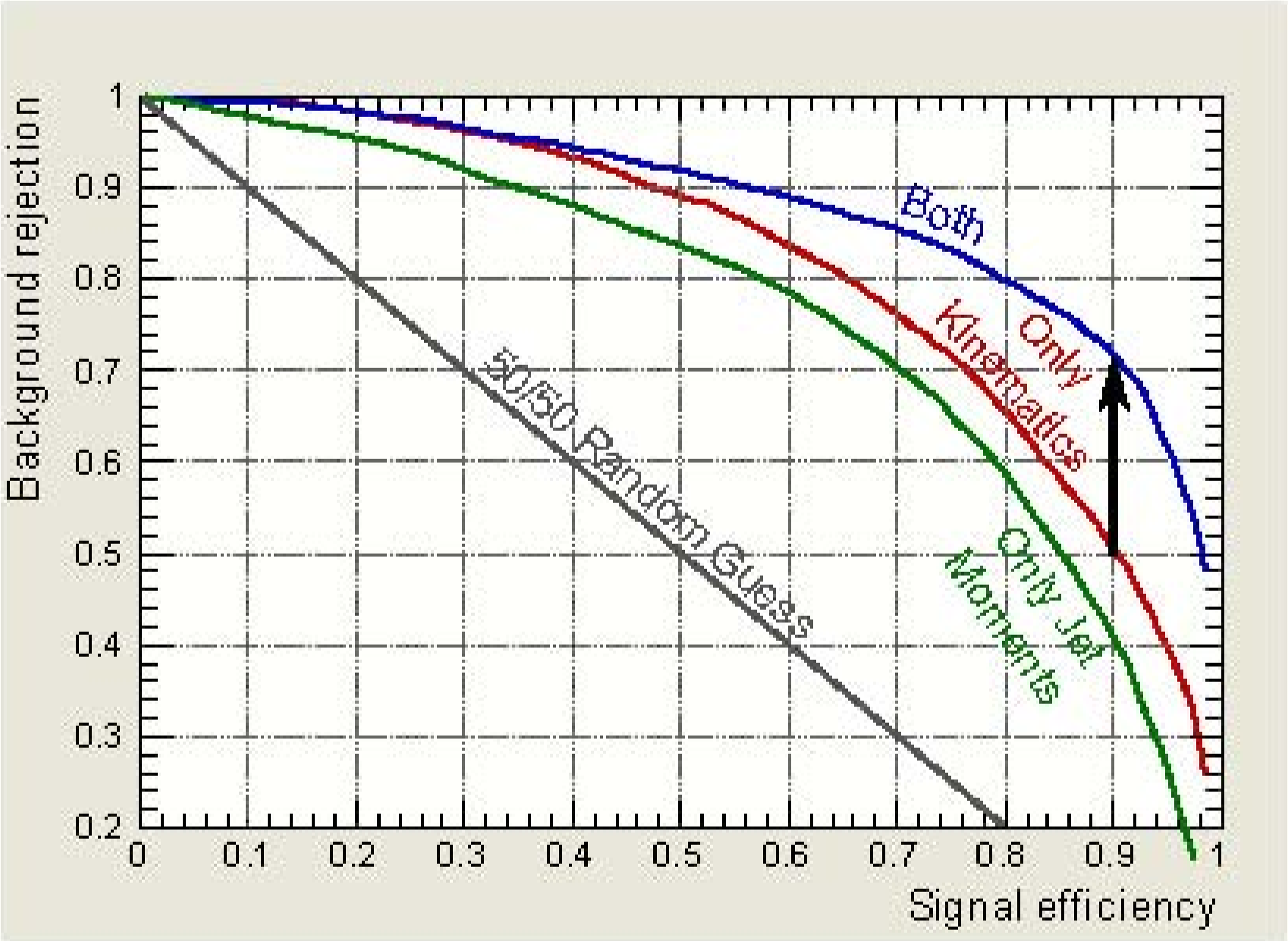


No correlation with jet orientation



etc

How Much Does This Help?



DØ Data from hep-ex/9908017

Found relatively more radiation in jet *toward* and *away* from beam as compared to "control" sample $W \to \ell\nu$.

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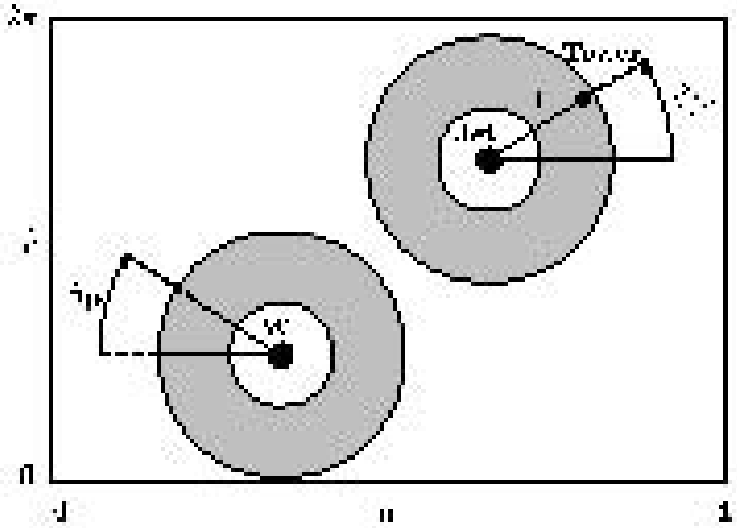
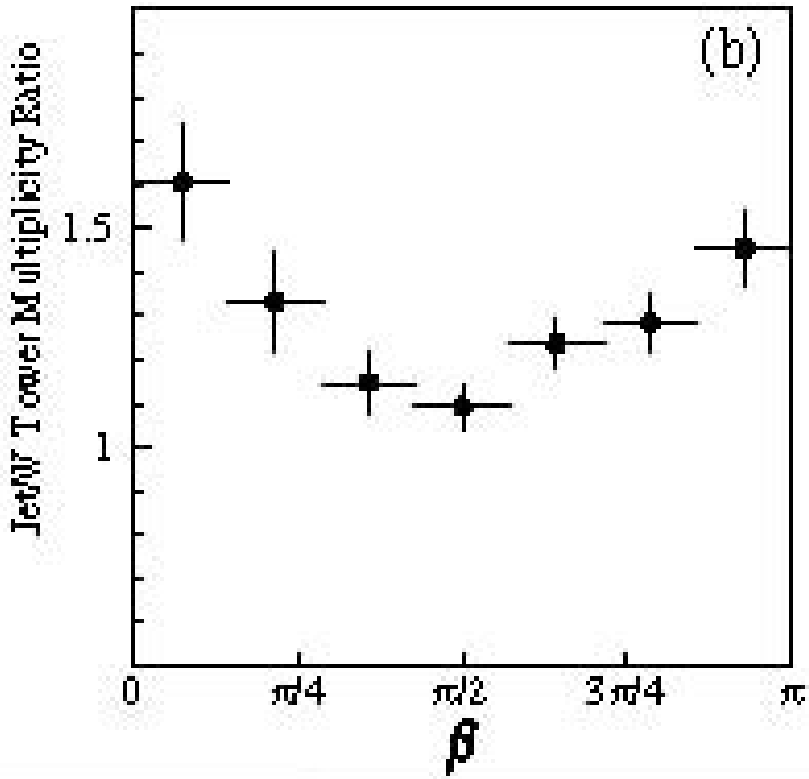
Found relatively more radiation in jet *toward* and *away* from beam as compared to "control" sample $W \to \ell\nu$.

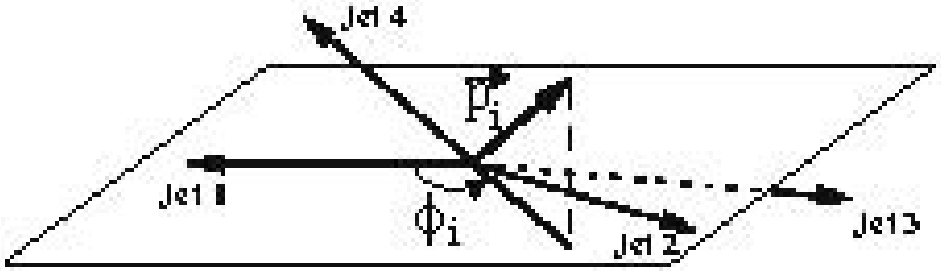
- Started with W + 1jet events with strict location cuts
- Counted particles in 7 anular wedges around the W and the jet
- Took the ratio of each wedge



Annulus: $0.7 < R < 1.5$



LEP L3 Data from mildly boosted Ws hep-ex/0303042



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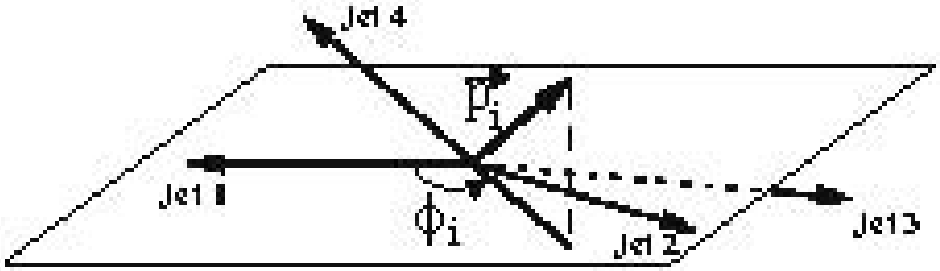
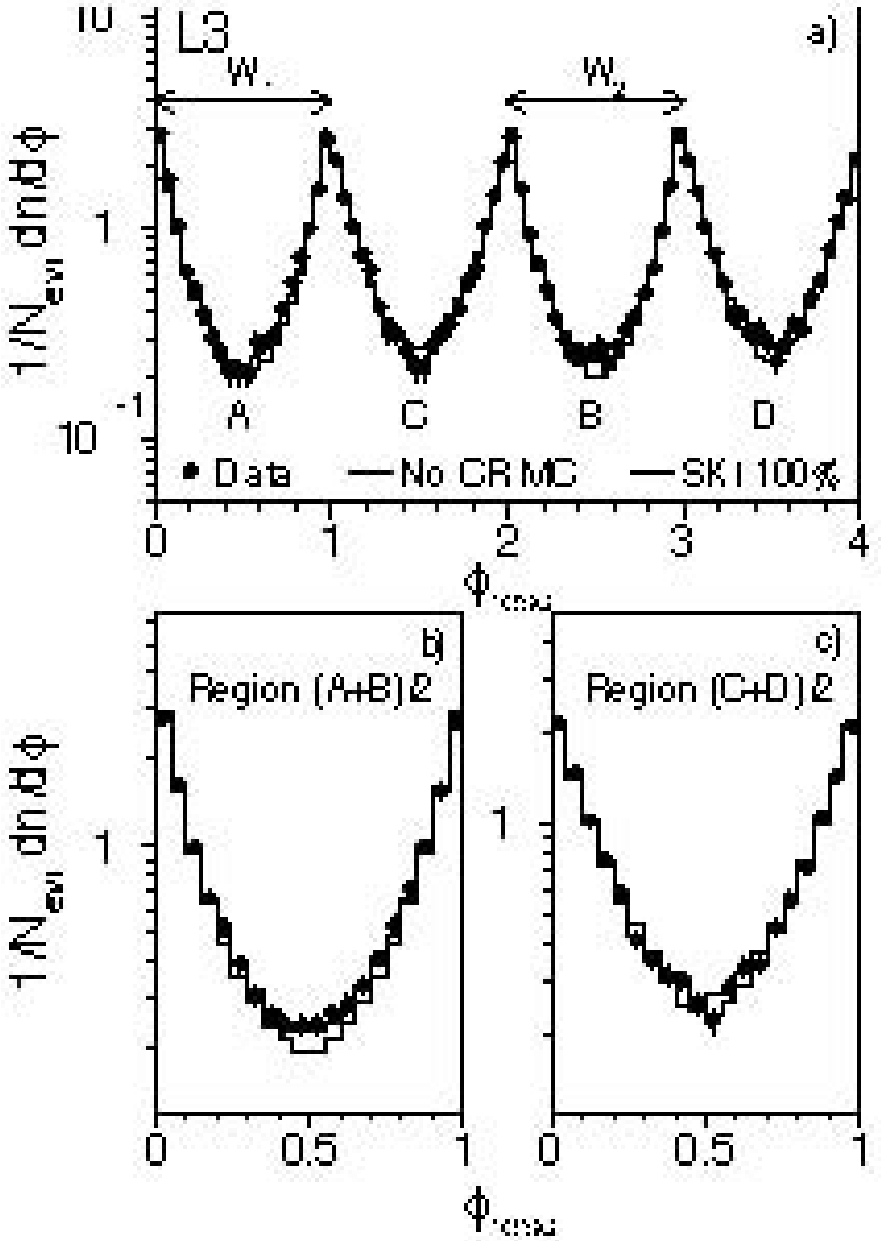


Particles as func. of *rescaled* angle.
b) same W c) btw. different Ws

Motivation: Bias in m_{qqW} as compared to $WW \to q\bar{q}\ell\nu$.

Result: No significant colour reconnection *between* Ws.

Same for DELPHI arXiv:0704.0597



Clean Sample at LHC to Test This?

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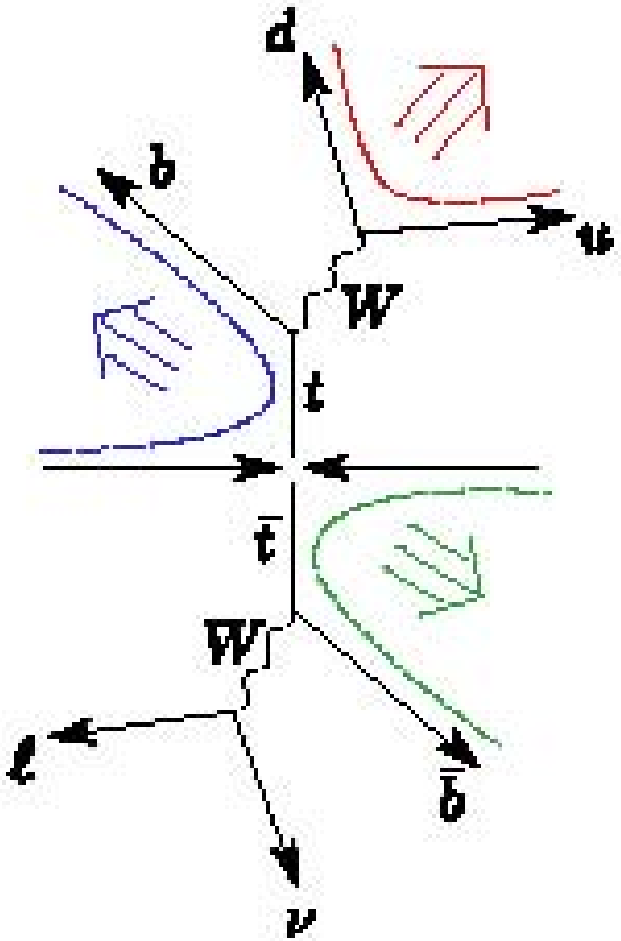
- B-Tagging gives heavy-quark jets
- Must *know* if it's a light q or g jet and *know* the color connection.
- Turn to $t\bar{t}$ semileptonic events

Semileptonic $t/\bar{t}$



- Look for W's lepton and missing E_T and two b tags that reconstruct $t\bar{t}$
- The two b jets are color-connected to the beam (like $Z + b\bar{b}$ background earlier)
- The two light quark jets from W are color-connected to each other

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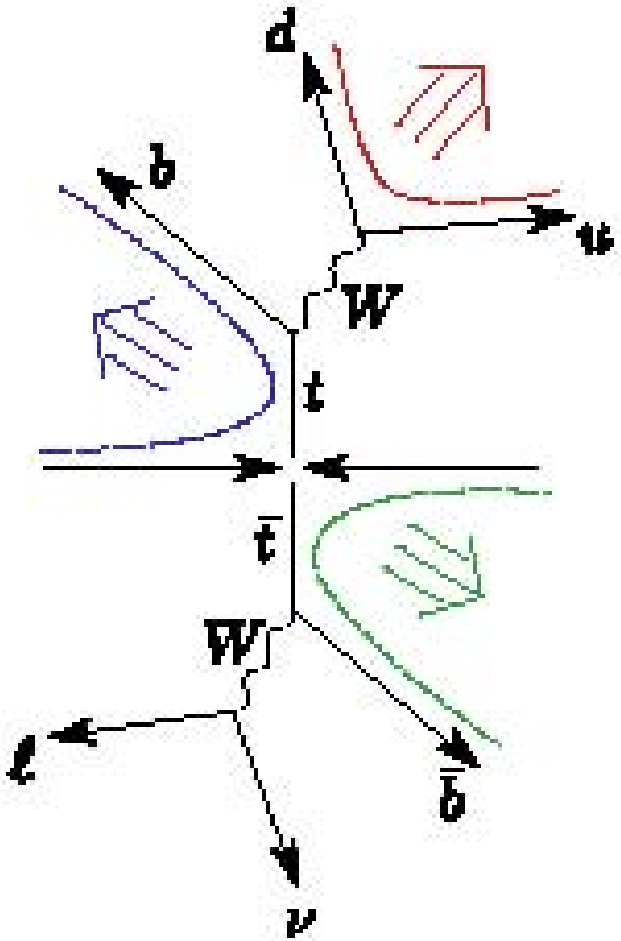

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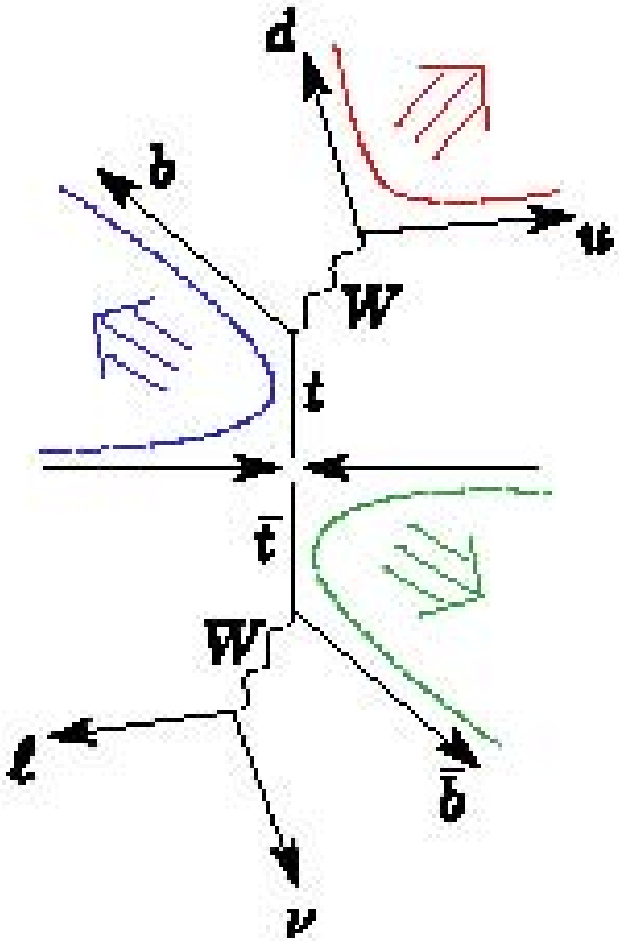
Test QCD and the Monte Carlos: Given b tags and *clean* top sample, what do the moments look like?

Semileptonic $t/\bar{t}$



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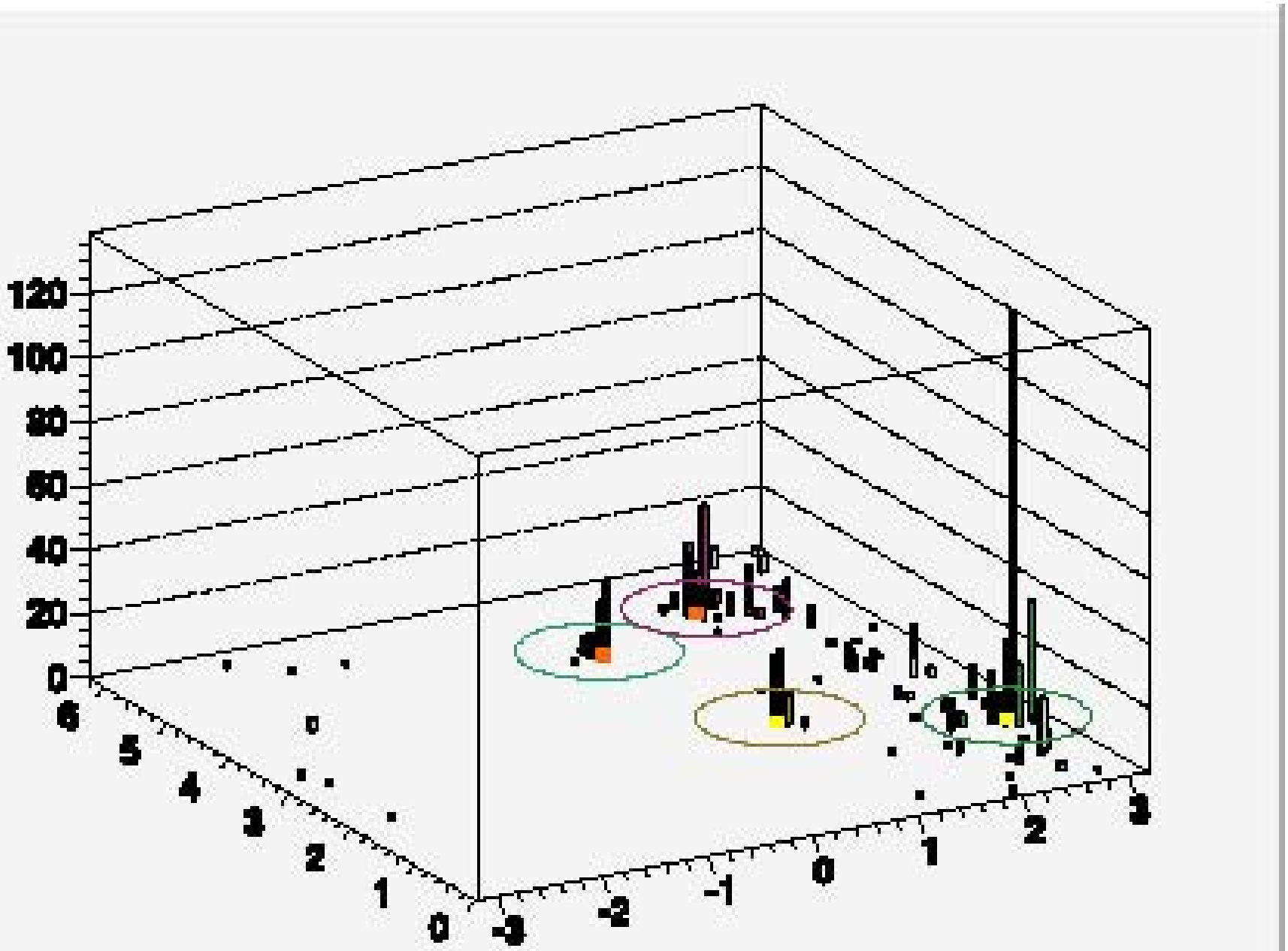
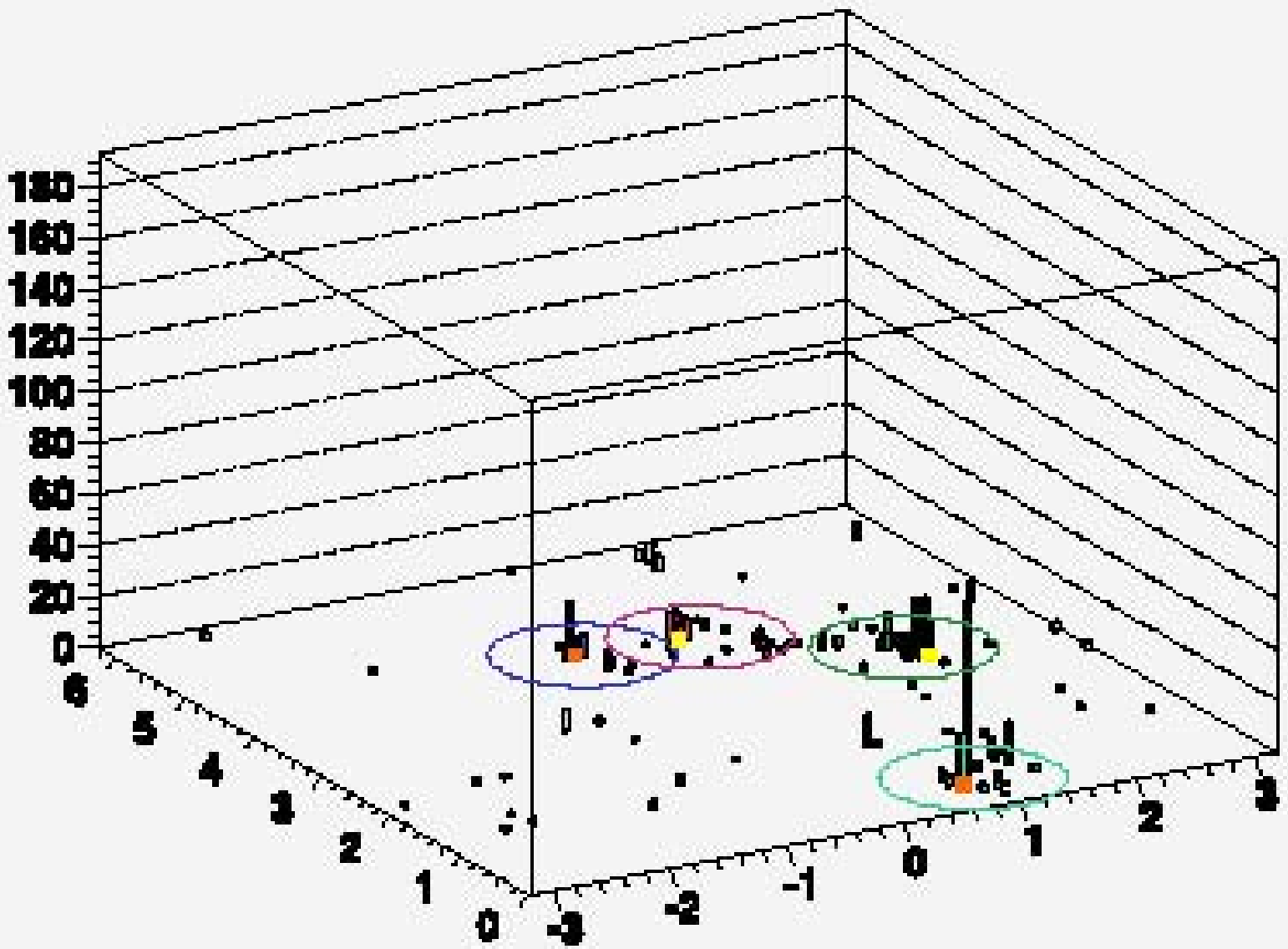
Test QCD and the Monte Carlos:
Given b tags and *clean* top sample, what do the moments look like?

Test the pairing technique:
Given the four jet moments, how well can we find the W color-singlet pair?

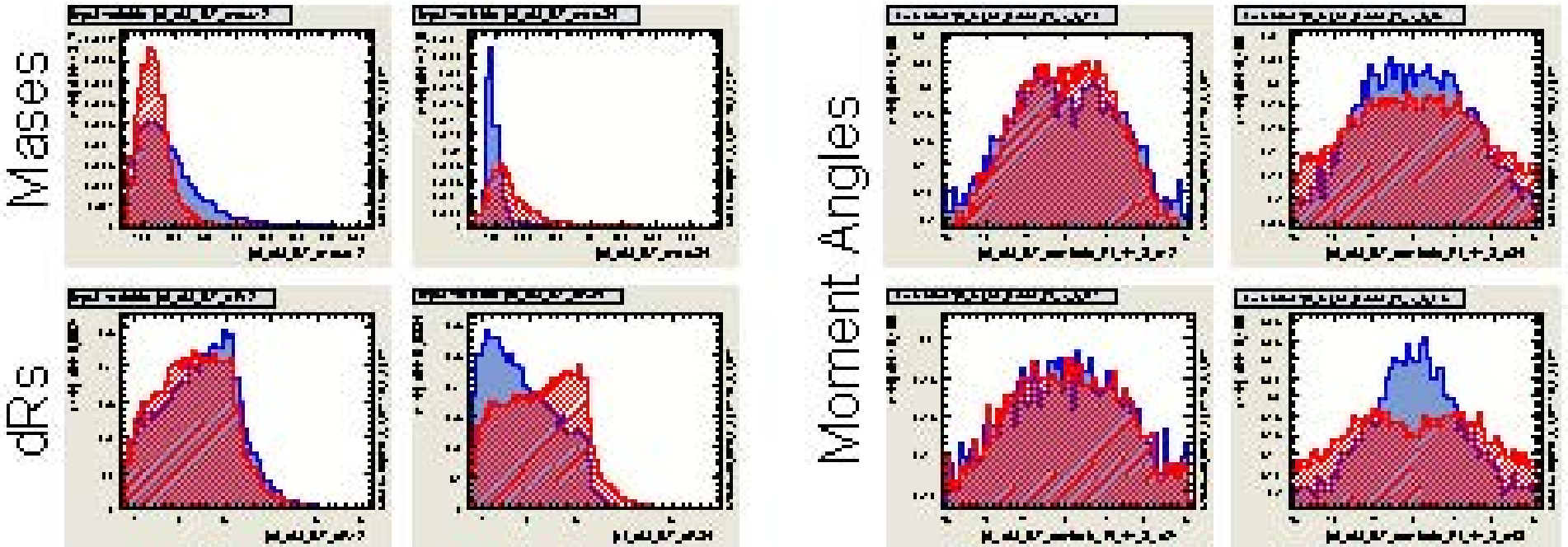
$t\bar{t}$ Event Example 1



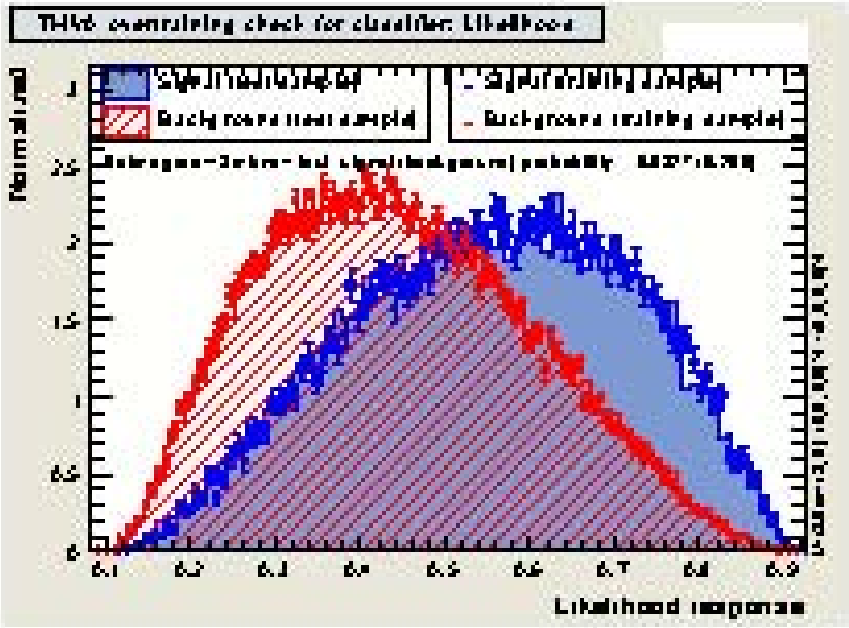
$t\bar{t}$ Event Example 2



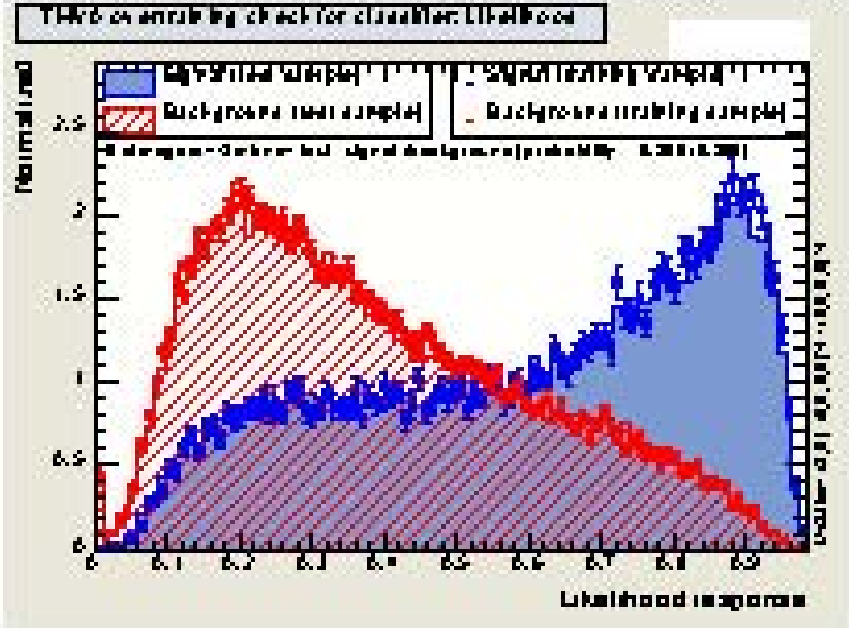
Pairing the 4 $t\bar{t}$ Jets in 3 Ways: 2 Wrong, 1 Right



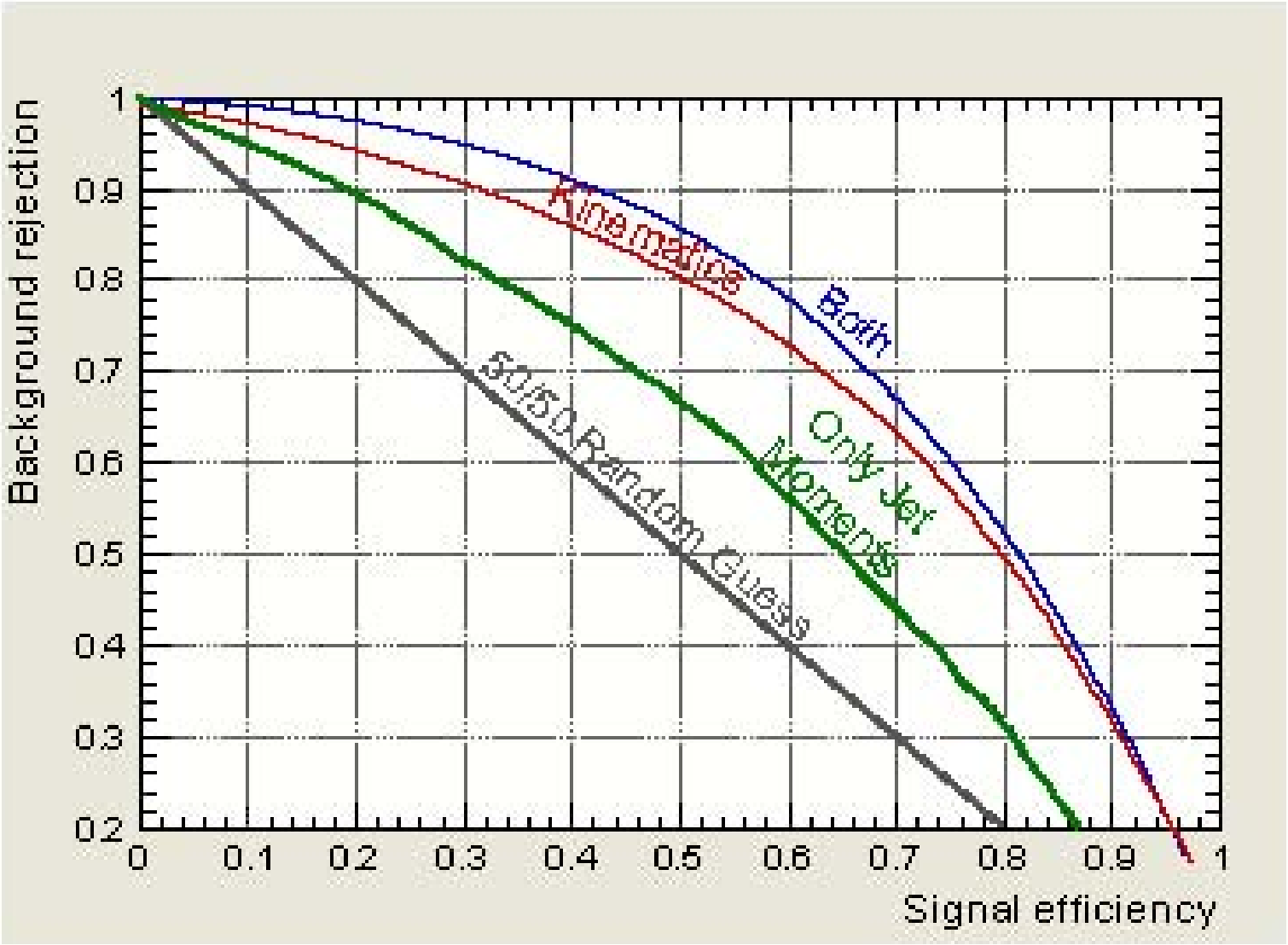
Likelihood for Angles Only



Likelihood for Angles, $\Delta\eta_{jj}$, $\Delta\phi_{jj}$



$t\bar{t}$ Improvements



meh ... but I didn't look to see if jets point toward the beam jet ...

Conclusions

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  - Global energy deposits / track momenta / particle counts in event
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  - How much is 1st hard emission vs soft spray?
- Only quark jets
  - Gluon jets have two "pulls,"
  - Will examine ellipse eccentricity and rotation...
  - ...which is also useful for back-to-back color-singlet quark jets