Physics Backgrounds at the Muon Collider

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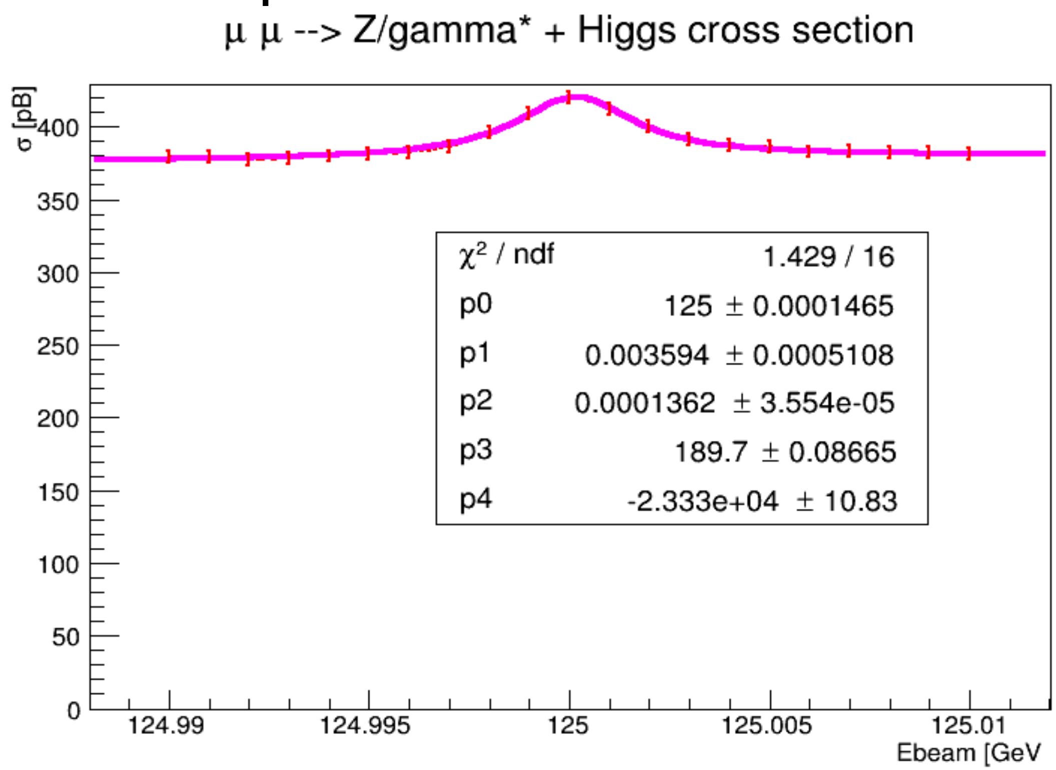
Physics Backgrounds at the Muon Collider

- Identify backgrounds
  - What can we eliminate?
  - Compare background event characteristics
    - Dijet momenta and opening angle
    - Thrust
  - Estimate Higgs signal to background ratio
    - Branching fractions
- Search strategy
  - Simple model using estimated parameters
  - Luminosity required to find Higgs

Physics Backgrounds

- The dominant physics background near Higgs mass is the production of Z bosons.
  - 9x Higgs peak cross section
  - Essentially flat around peak

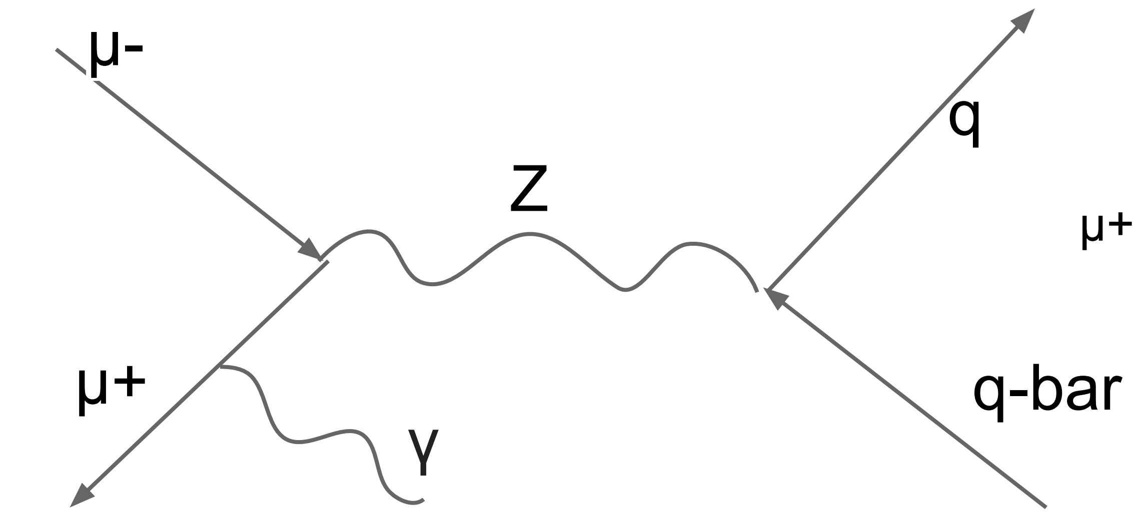
- This plot assumes background and Higgs events are indistinguishable.



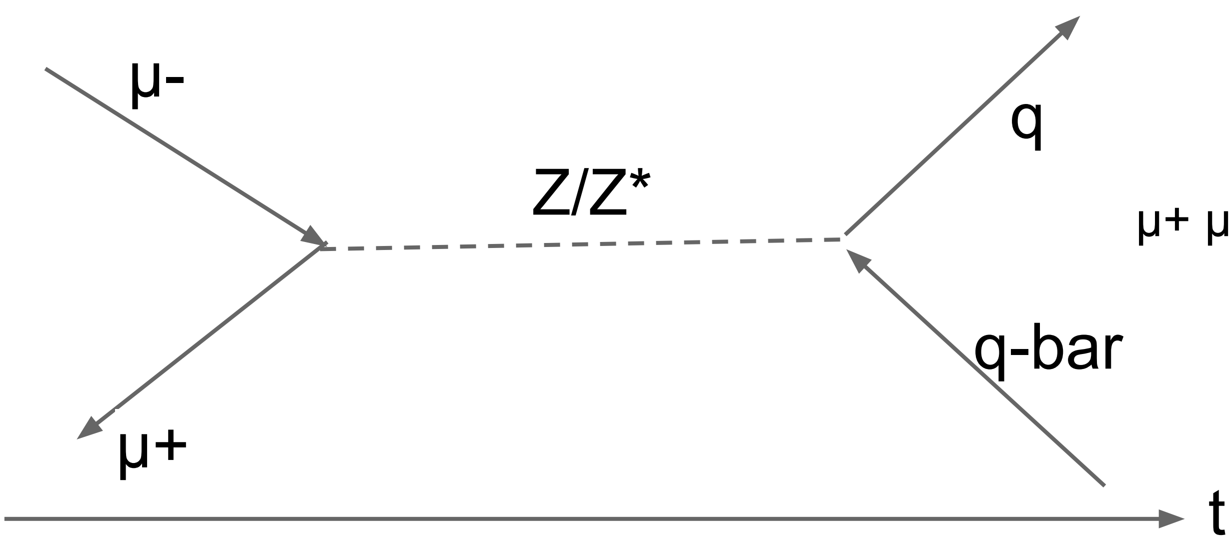
Physics Backgrounds

- Two Z production modes at MC
  - Real Z: 71%
    - mu+mu- --> Z/gamma*
  - Virtual Z: 29%
    - mu+mu- --> Z*
- Real Z produced with gamma has normal Z mass, high energy gamma
- Most virtual Z*'s have beam CoM
- Simple cut on presence of a single 20+GeV gamma distinguishes the two processes noticeably
  - gamma is colinear with beam, might avoid detection

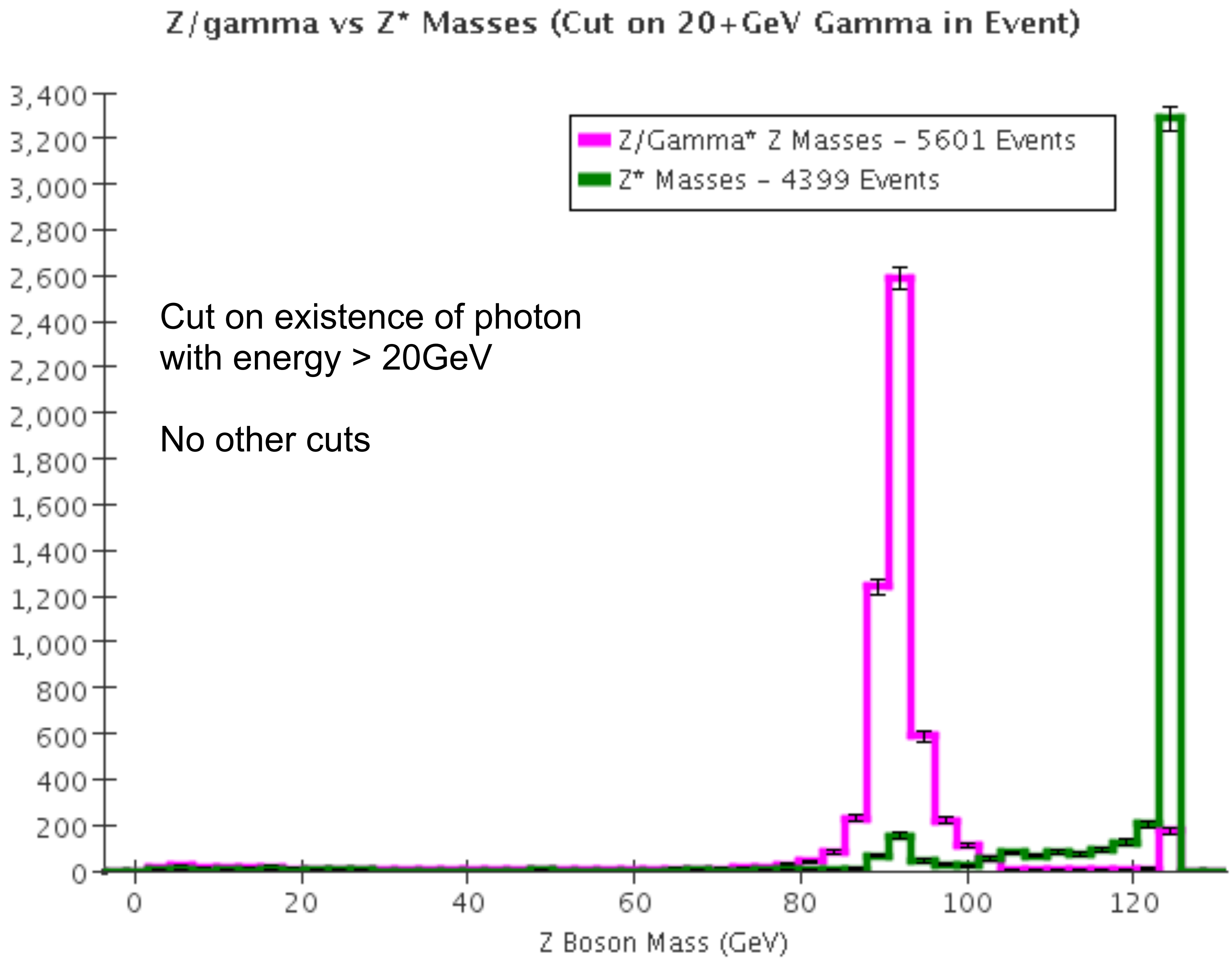
Physics Backgrounds



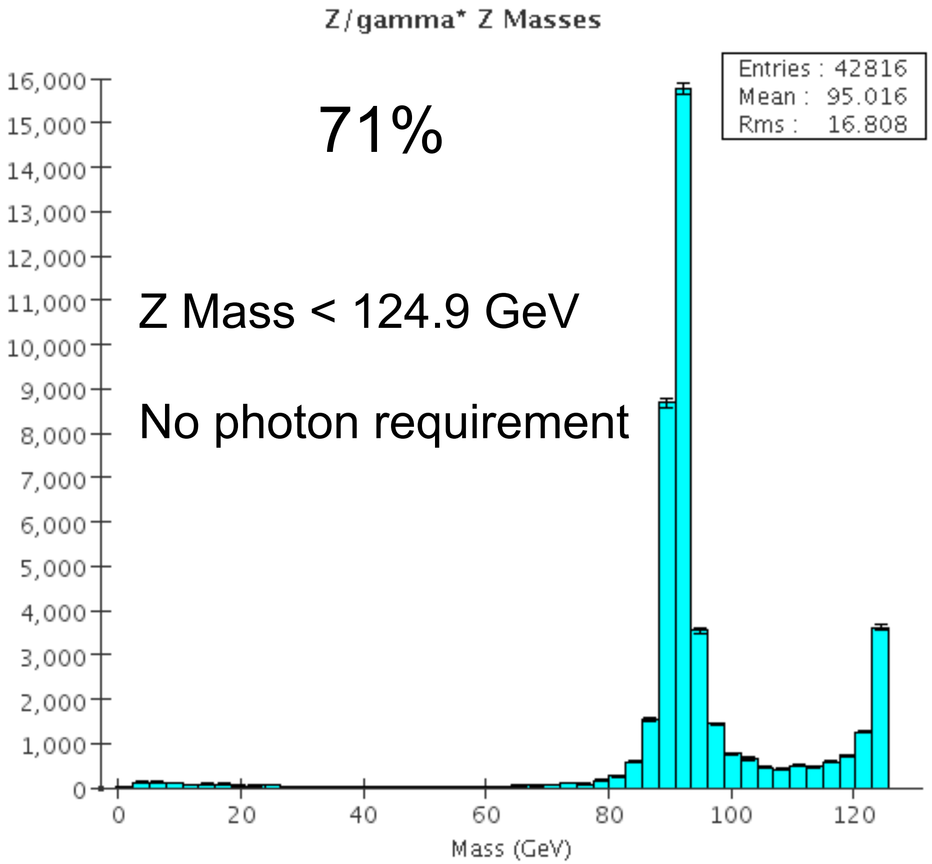
μ+ μ- -> Z/gamma* -> q-qbar

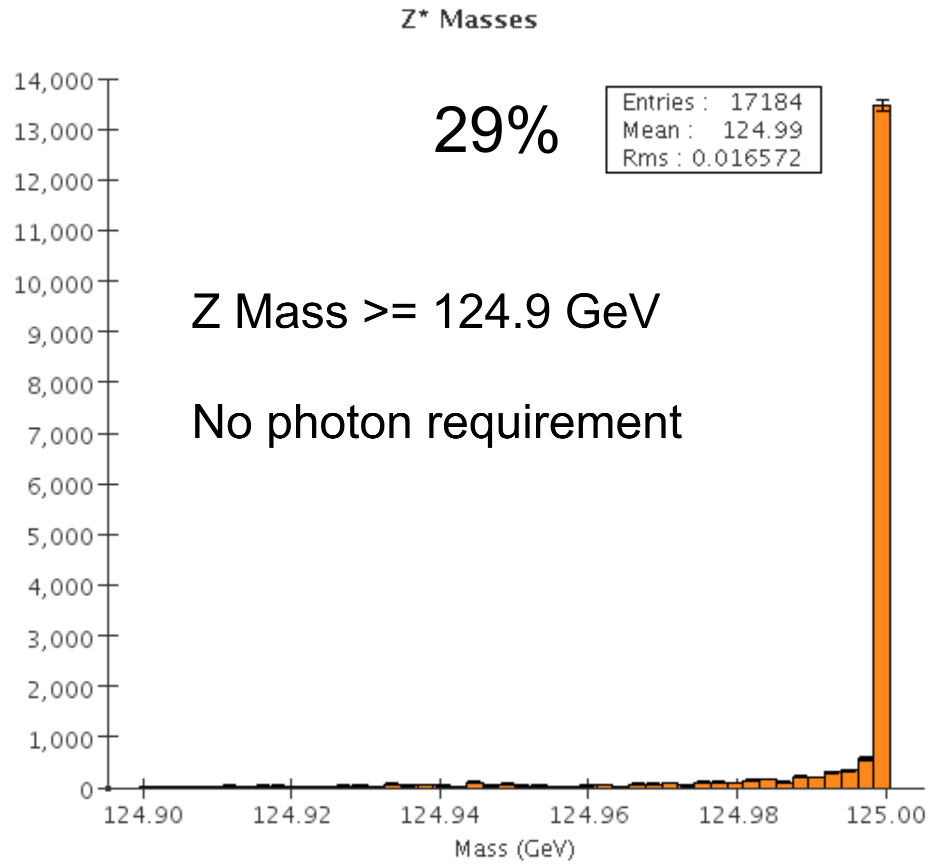


μ+ μ- -> Z/Z* -> q-qbar


Z/gamma vs Z* Masses (Cut on 20+GeV Gamma in Event)
Z/Gamma* Z Masses - 5601 Events
Z* Masses - 4399 Events
Cut on existence of photon
with energy > 20GeV
No other cuts
3,400
3,200
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
0
20
40
60
80
100
120
Z Boson Mass (GeV)

Z/Z* Boson Masses
124.9 GeV Cut

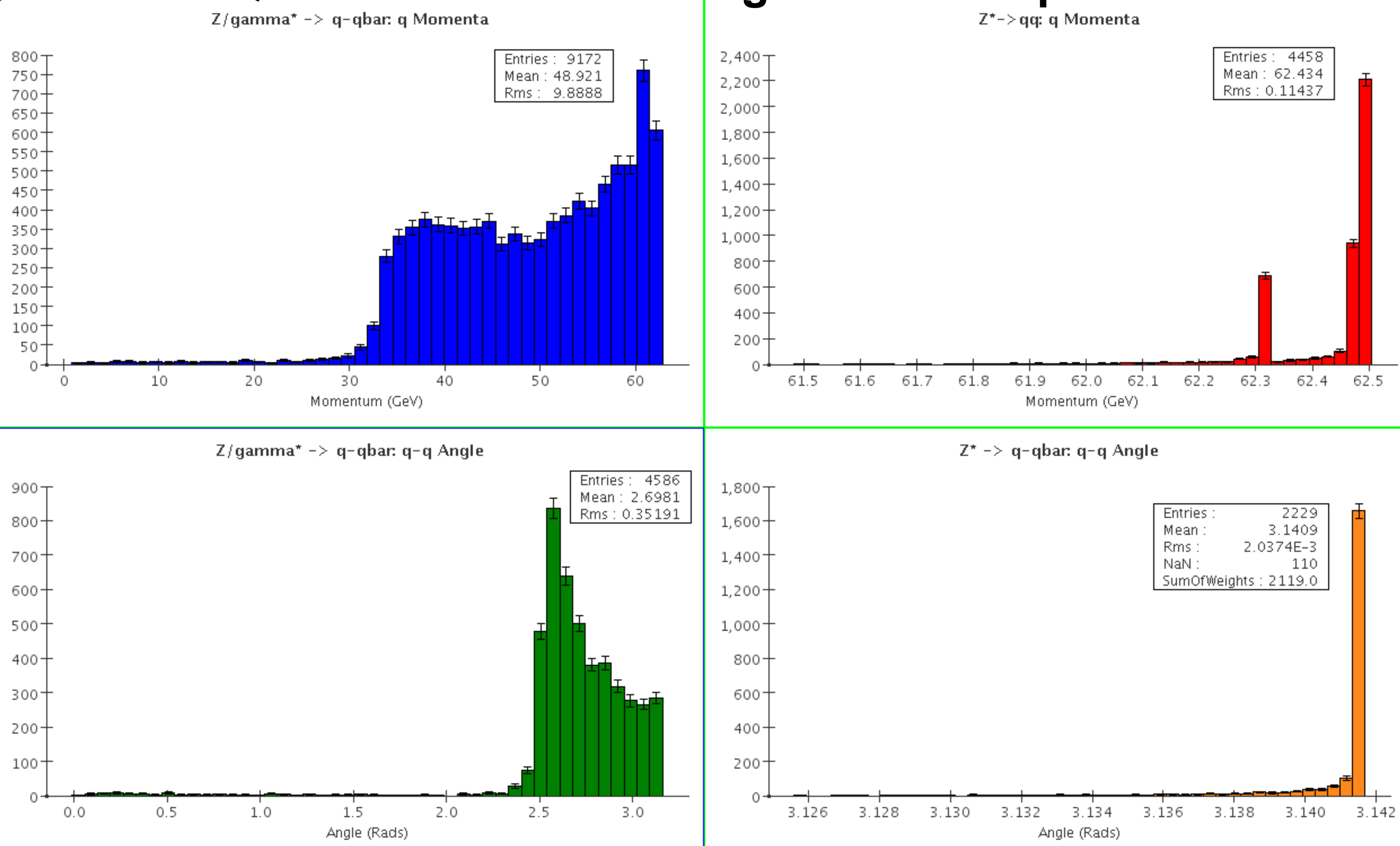




Physics Backgrounds

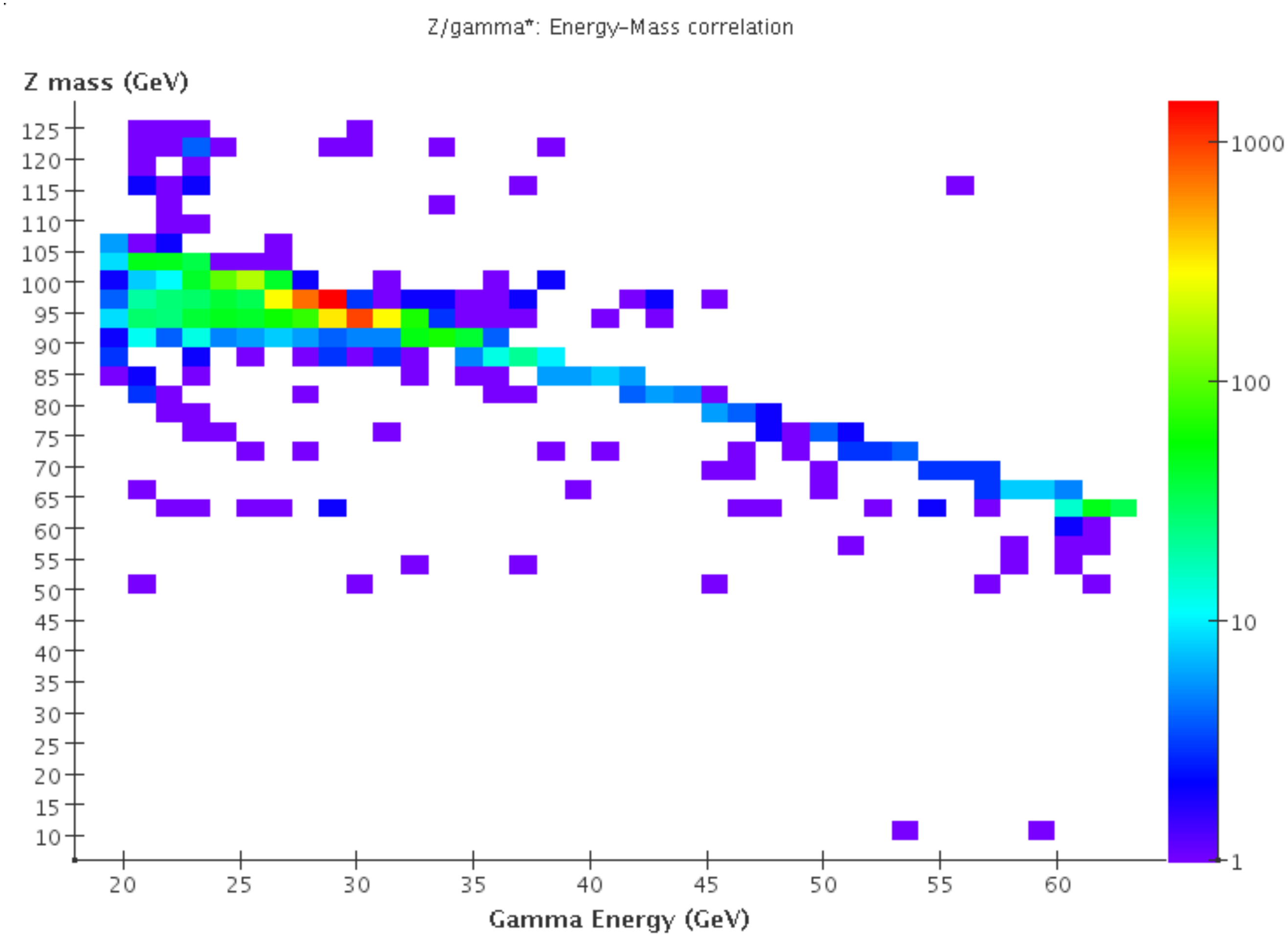
- 124.9GeV cut reveals
  - 71% - Z/gamma*
  - 29% - Z*
  - Using this cut from here on out
- How well can they be separated?
  - Gamma is colinear to beam
  - Z decay is boosted relative to Z* (Z* is at rest)
  - Z has lower mass
  - Compare dijet decays
  - Compare event shapes
- How well can Z* be separated from Higgs?
  - Depends on how well we can eliminate Z*'s with mass < CoM Energy
  - Branching ratios
    - b-tagging
    - WW?

Z/gamma* vs. Z*
Dijet (Z->q-qbar) Decays
Quark Momenta and angle between quarks



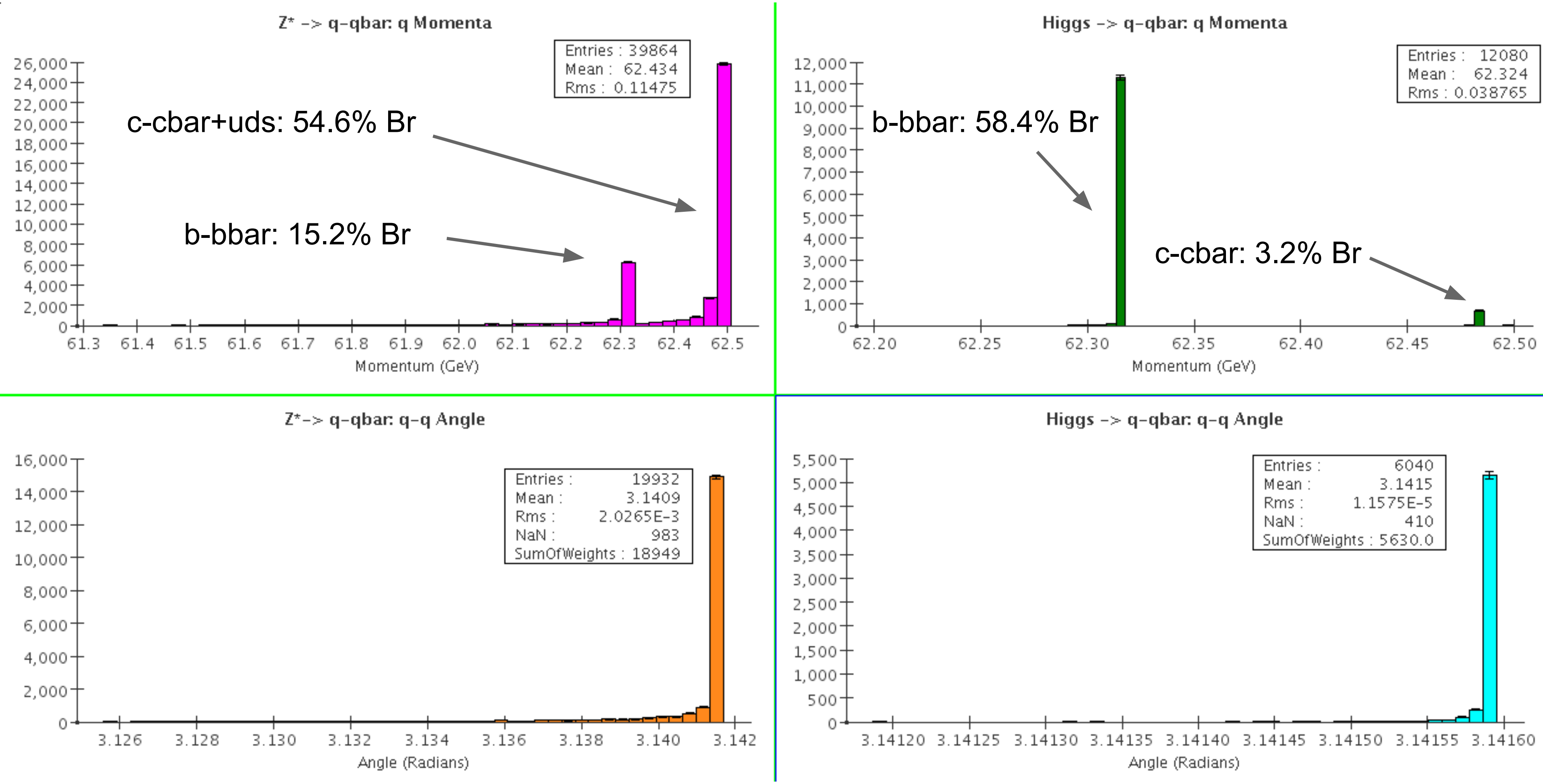
Z - gamma* Correlation

- High correlation between gamma energy and Z invariant mass in Z/gamma* events:



Z* vs. Higgs

Jet Momenta and Dijet Opening Angle



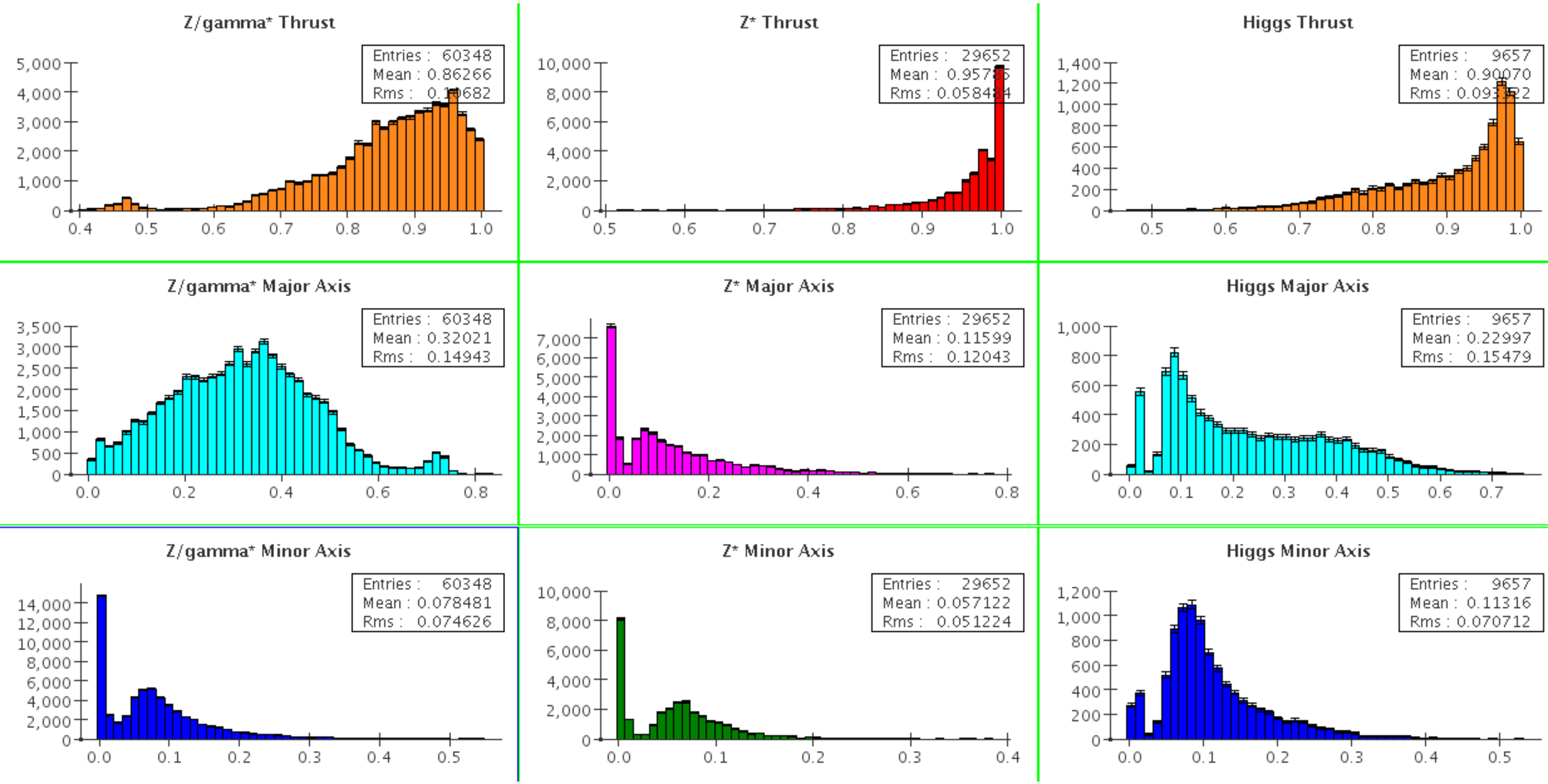
Essentially identical, except for branching ratios.

Event Shape - Thrust

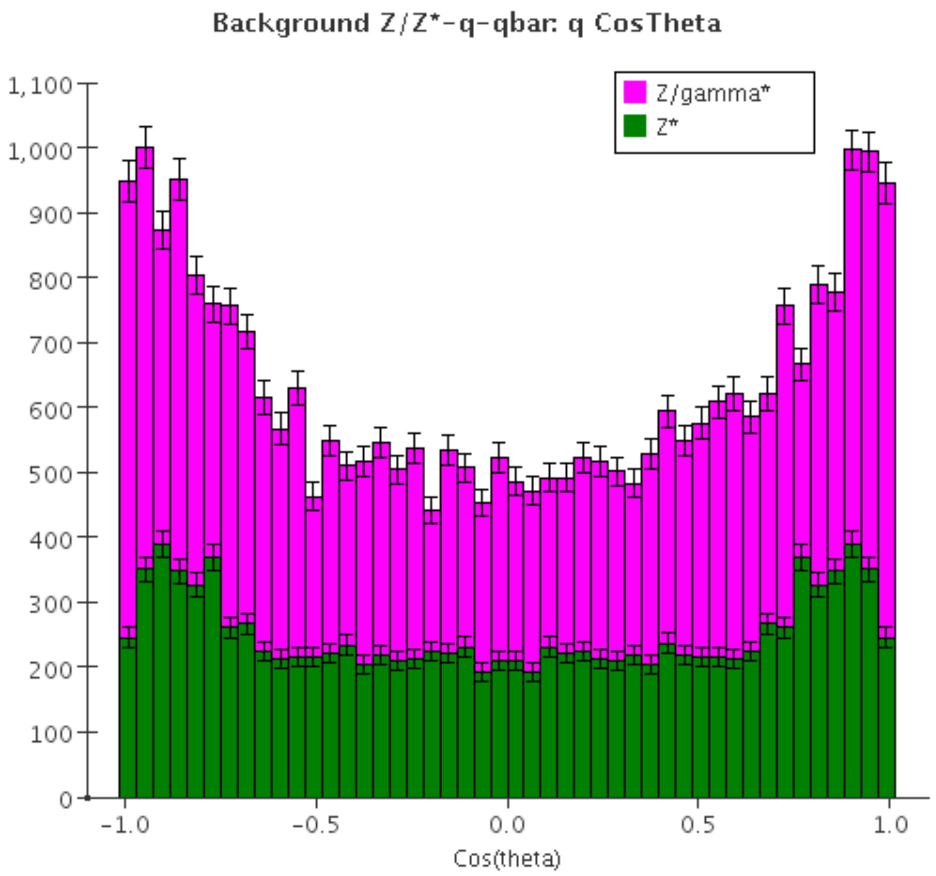
- The **Thrust Axis** is defined as the axis for which summing the projection of all final state particle momenta gives the greatest value.
  - **Thrust** is calculated as the normalized sum of particle momenta projected on the Thrust Axis
- The **Major Axis** is the axis perpendicular to the Thrust Axis with the highest projection of particle momenta
  - Major Axis magnitude is the normalized sum of particle momenta projected on the Major Axis
- The Minor Axis is perpendicular to the plane defined by the Thrust and Major Axes
- These parameters can show how **dijet** or **three-jet-like** an event is

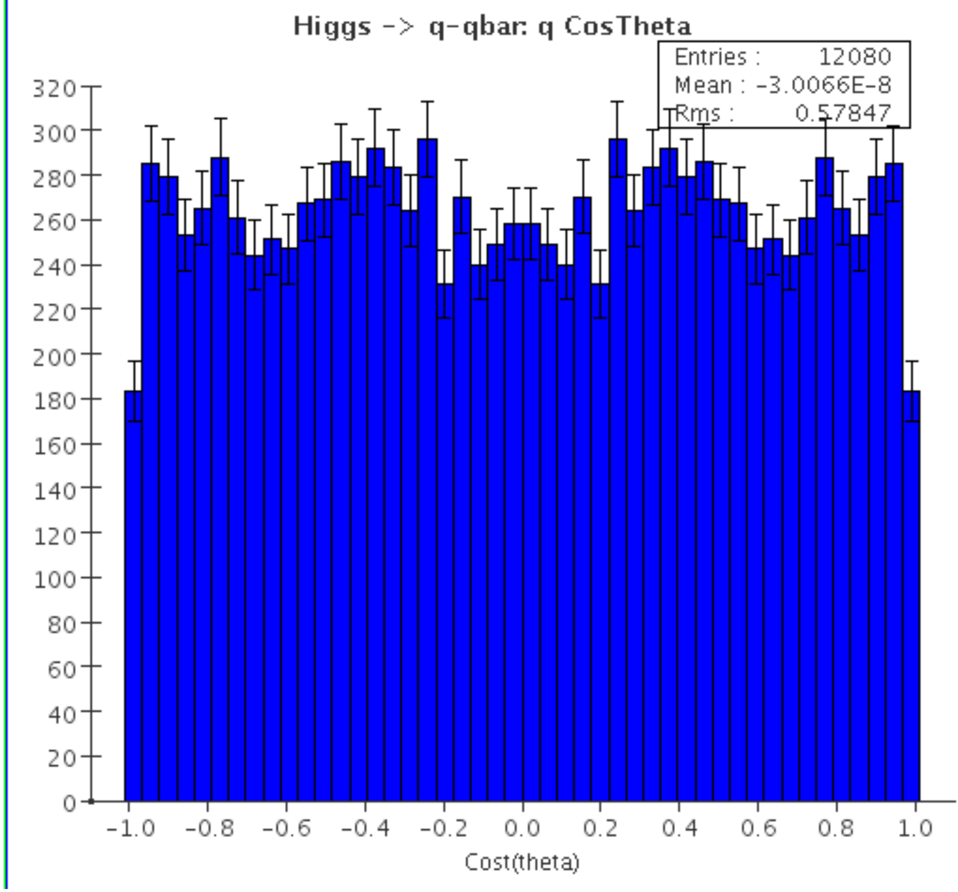
Event Shape - Thrust

| Z+gamma* | Z* | Higgs |



Background vs. Higgs Cos(theta)





Large cone will affect background more than signal

Z/gamma* vs. Z*
Dijet (Z->q-qbar) Decays

- Thrust distribution appears to differ between Higgs and Z*
    - Due to differing branching ratios.
- Need jet reconstruction for better estimation of realistic separation.
    - 124.9GeV cut on boson gives 29% Z* to 71% Z/gamma*
- Cutting on Dijet momentum and opening angle between jets can be very effective.
- Higgs and Z* events mostly differ in branching ratios.
    - b-tagging will be important.
    - W+W-

PYTHIA 6.4 Branching Fractions

Decay Channel	**Z* Branching Fraction**	**Higgs Branching Fraction**
Light quarks (uds)	0.427	0.0003
c-cbar	0.119	0.032
b-bbar	**0.152**	**0.584**
e-e+	0.034	---
mu-mu+	0.034	---
tau-tau+	0.034	0.071
gamma gamma	---	0.003
W+W-	**---**	**0.226**

Physics Backgrounds: b-tagging (preliminary)

- s/b is 0.11 when just counting events.
- Perfectly removing Z/gamma* events removes 71% of background, no signal.
- Perfect b-tagging retains 58% of signal, 15% of background.

	Background (pb)	**Higgs signal at peak (pb)**	**s/b**
Basic counting:	376	42.5	0.11
Z/gamma* tag:	113	42.5	0.38
b-tagging:	56.4	24.8	0.44
Combined:	16.9	24.8	1.47

Search Strategy Implications

- Find α, probability of not seeing a signal with significance p-value p when on peak
  - Find N s.t. p < cl confidence level given background rate b times integrated luminosity

$$p = \int_N^\infty Pr(X = n | \mathcal{L} \times b)\, dn$$

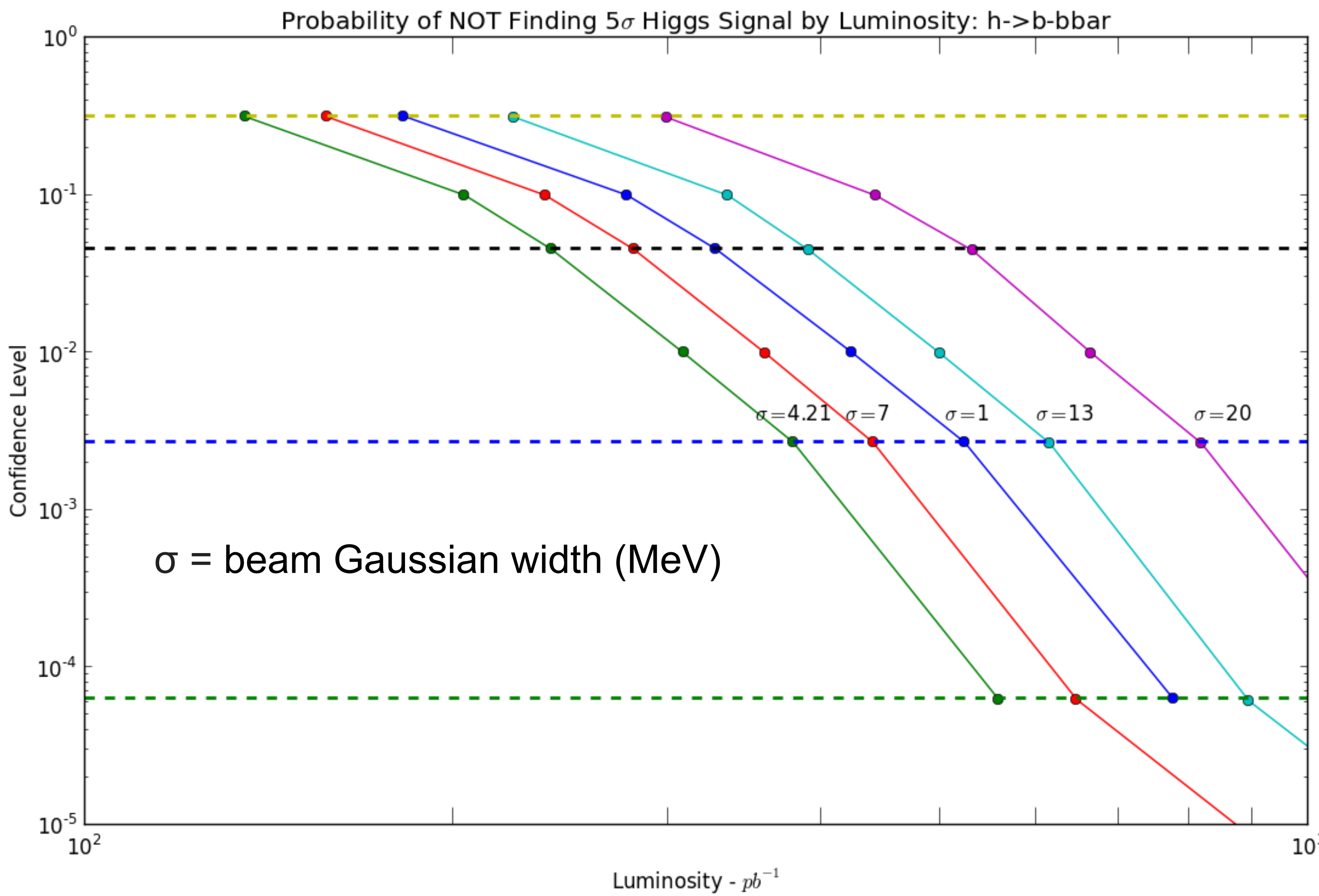
  - α is the probability of not seeing more than N given background + signal rate times integrate luminosity

$$\alpha = \int_0^N Pr(X = n | \mathcal{L} \times (s + b))\, dn$$

Search Strategy Implications

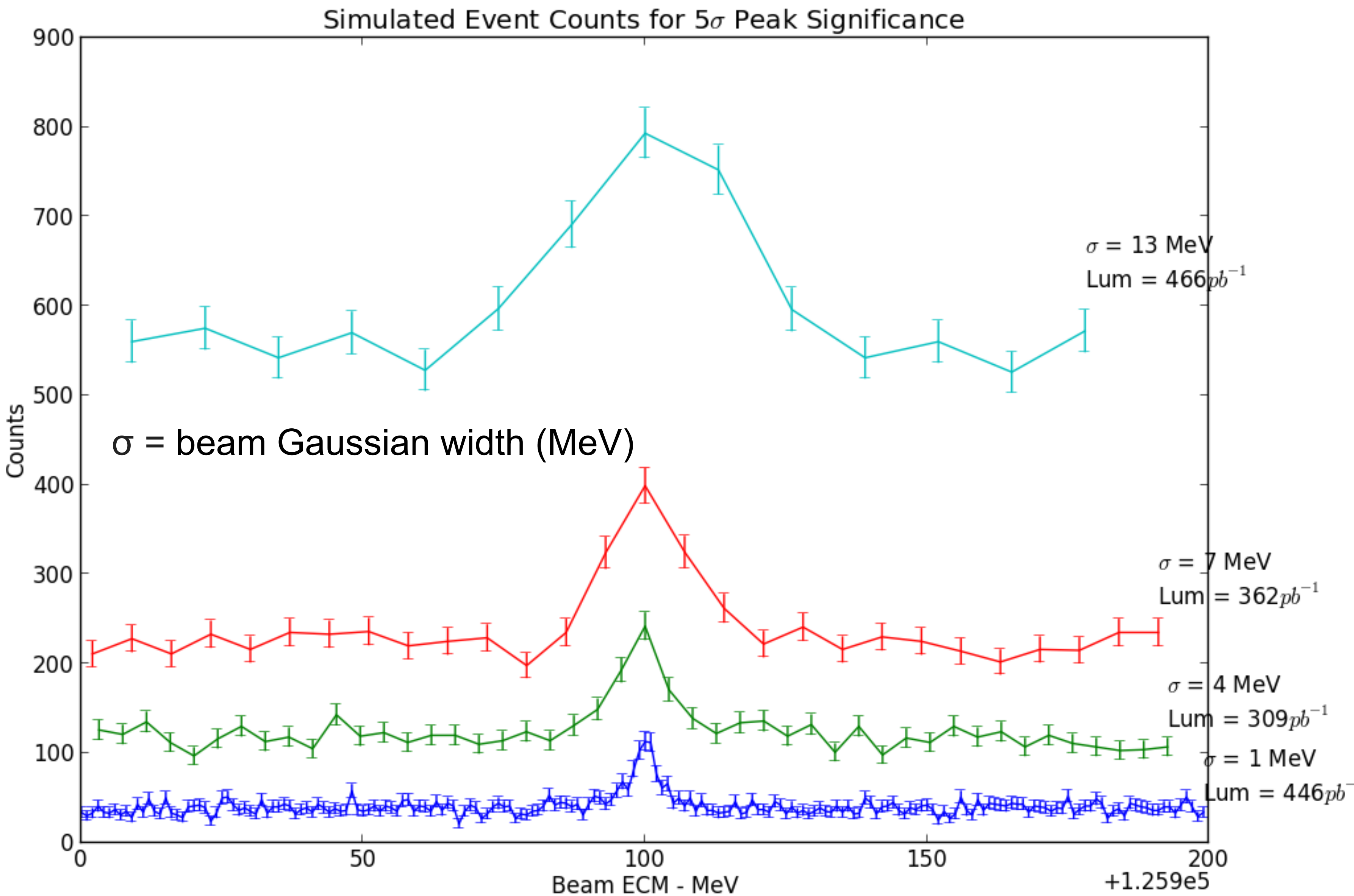
- Use Poisson distribution to calculate probabilities with L*s and L*(s+b) as mean.
- Use confidence level = 5σ = 5.7e-7
- Use b = background cross section
  - For b-bbar, b = 16.9pb
  - For WW*, b = 0.1pb
- Use s = Integral of Higgs peak times branching fraction times on-peak beam gaussian
  - beam width = σ
- Calculate α as a function of luminosity
- Conduct search for Higgs using hypothetical *a priori* info from LHC as guide.
  - M=126.0GeV, Γ=0.1GeV

Search Strategy Implications

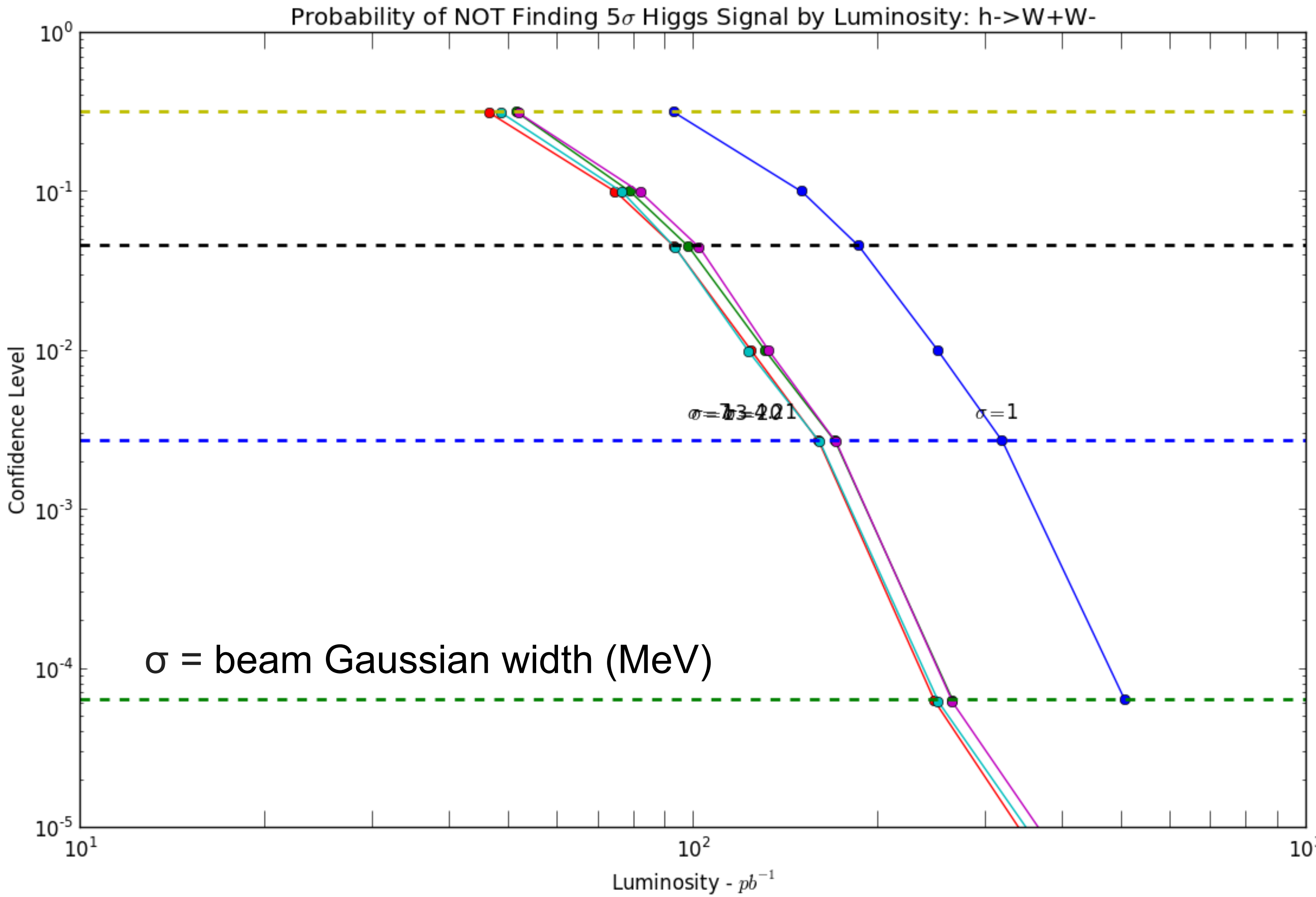


Simple b-tag + Z/gamma* Data Sim

Single Experiment

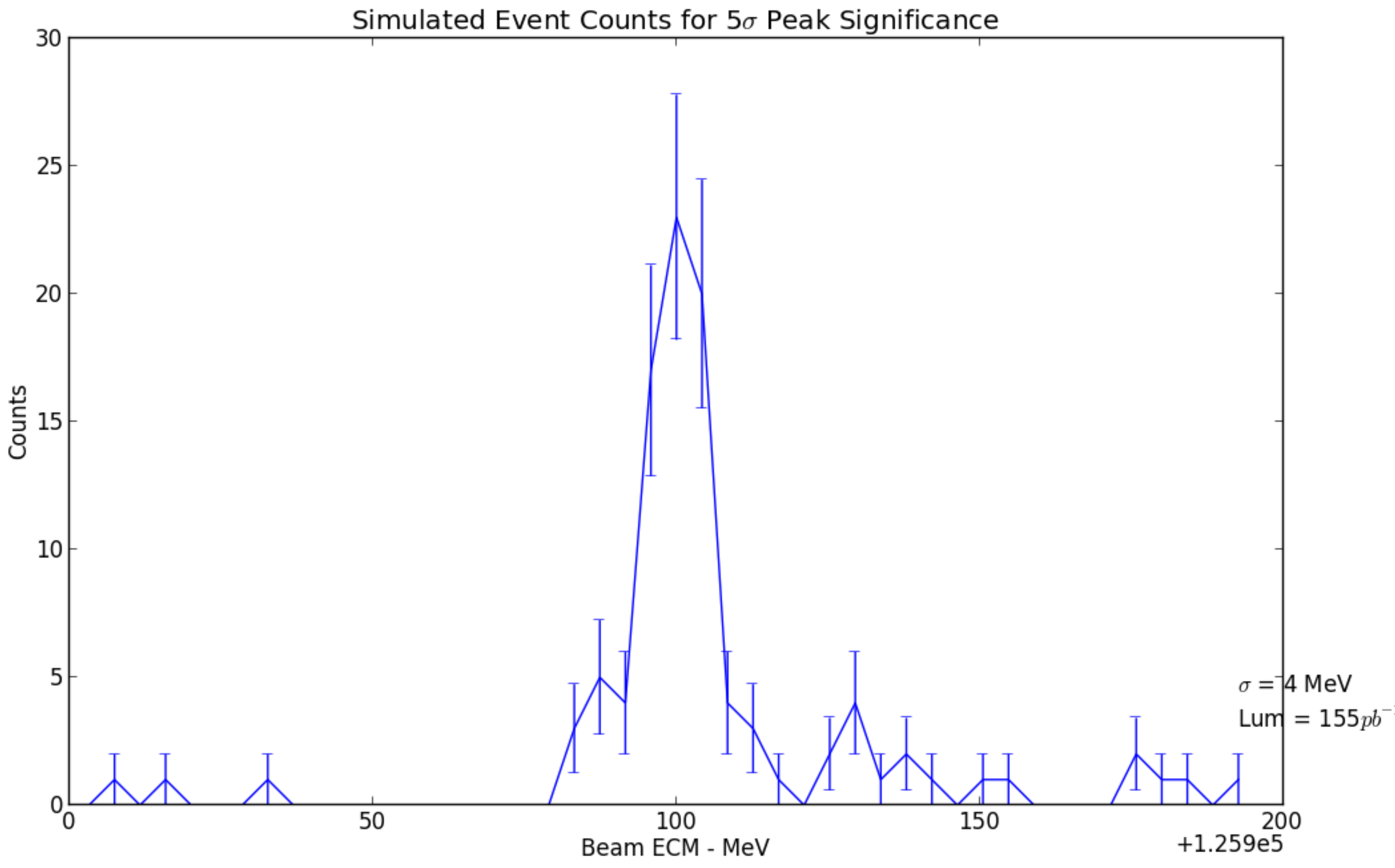


W+W- Assuming 0.1pb Background



- Low background reduces luminosity requirements.
- Beam width makes less difference.

WW* Assuming 0.1pb Background



Thoughts/Future

- Z* background events with beam CoM mass are indistinguishable from signal, but branching ratios reduce background dramatically in some channels
- Search and simulation:
  - Do fits on simulation data
  - Simulate search for randomly located peaks
  - Improve search with joint probabilities for b-bbar/WW*
- Do real b-tagging for better estimates on background
- Study WW* more closely
  - Tagging efficiency, possible backgrounds for each tag.