

# A consideration of the search for graviton resonances in the diphoton decay mode at the ATLAS detector

---

---

Marco Almeida (Vassar College)  
Columbia University, Nevis Labs 2006 REU  
Advisor: Kamal Benslama, John Parsons

# Standard Model & Gravity

- In the Standard model, each force has an associated force mediator gauge boson (examples)
  - EM -> photon
  - Weak -> W, Z
  - Strong -> gluons
  - Gravity -> graviton?
- Particle physics has a tradition of unifying the fundamental forces: Maxwell's unification of electricity and magnetism into the electromagnetic force in the 1860's, and the unification of electromagnetism and the weak interaction into the electroweak interaction a century later.
- Convinced many that a unified field theory, combining general relativity and a grand unified theory of the electroweak and strong interactions, is in our future

# Randall-Sundrum Model

- Attempt to solve hierarchy problem (relative weakness of gravity)
- The 3-space+1-time dimensional world on the SM brane that exists within higher dimensional (5D) universe
- Extra dimension warped in a manner analogous to warping of spacetime near a massive object
- Graviton is the sole elementary particle capable of propagating in extra dimension; so-called 'warp factor' responsible for it's weak appearance in our 4D brane.
- Graviton Kaluza-Klein spectrum has a scale:  $\Lambda_{\pi} = M e^{-kr_c \pi}$

# RS Model (II)

- Distinct from other additional dimensional theories:
  - Hierarchy between fundamental 5D scale and compactification scale ( $=1/r_c$ ) is order 10 rather than  $(M_{\text{pl}}/\text{TeV})^{2/n}$
  - A single extra dimension rather than  $n \geq 2$
  - First KK modes are predicted at the TeV scale
  - Should be observable at colliders as spin-2 resonances capable of being reconstructed from their decay products
- Graviton has many decay modes, of which we will focus on  $G^* \rightarrow \gamma \gamma$

---

despite having a branching ratio of  $\sim 4\%$ .

---

# Simulation

- Pythia event generator to simulate proton-proton collision
- EM energy deposited in EM calorimeter used to reconstruct 4-vector information regarding particles associated with event using Geant4
- Signal: 500, 1000, 1500, 2000, 2500 GeV
- Background: 450,950 GeV
  - Two largest potential of background are the dijet and jet-photon, which although have a smaller probability of occurring is compensated by a cross section several orders of magnitude larger.

# Simulation Information

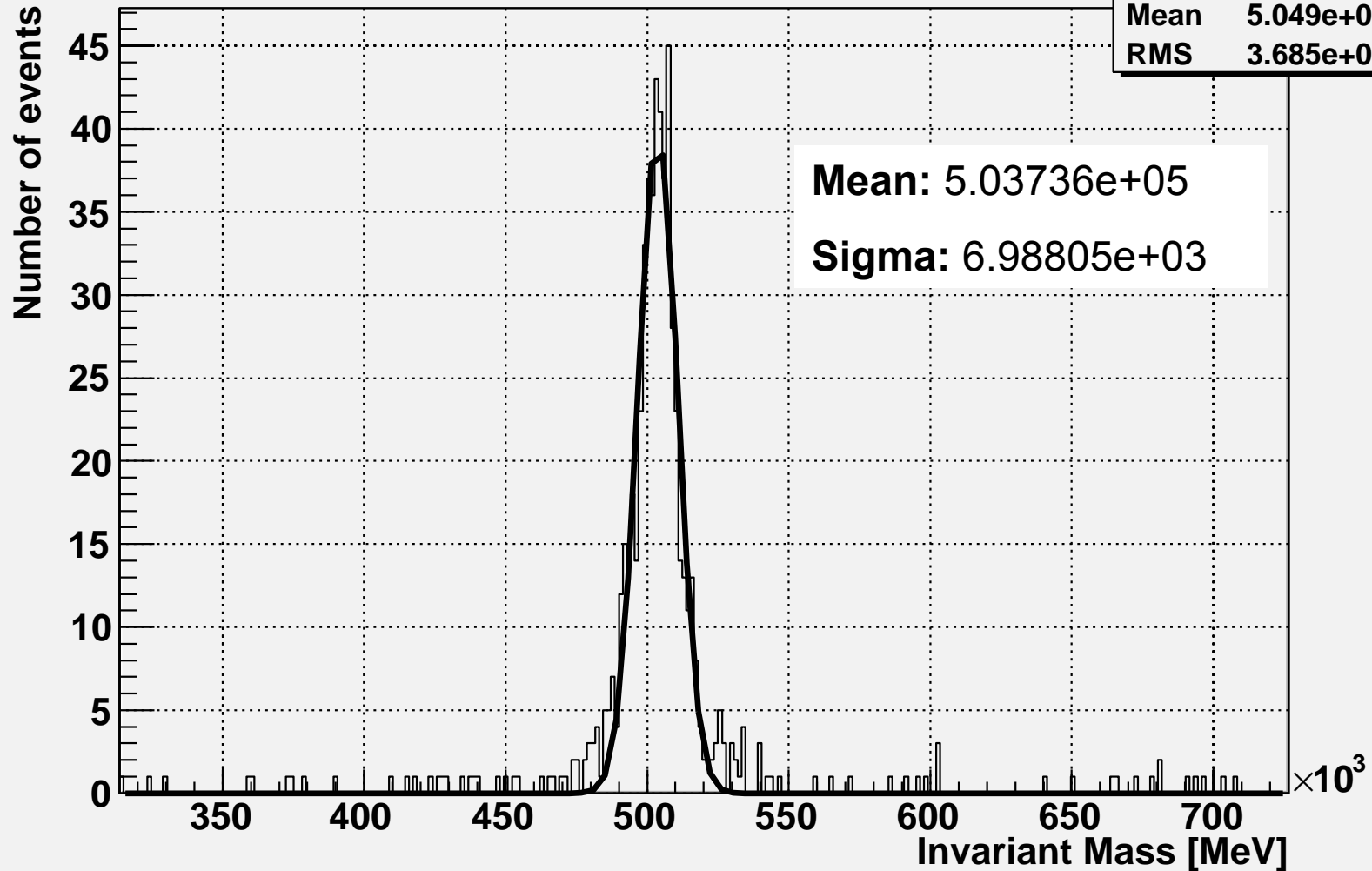
<i>Signal (GeV)</i>	$N_{events}$	$N_{matched \gamma}$	<i>Reconstruction efficiency, <math>\epsilon_R</math></i>
500	850	1367	85%
1000	1000	1877	86%
1500	991	2014	87%
2000	838	1845	87%
2500	498	1104	88%
<i>Background (GeV)</i>			
450	1000	768	71%
950	1000	846	68%

# Computing the invariant mass...

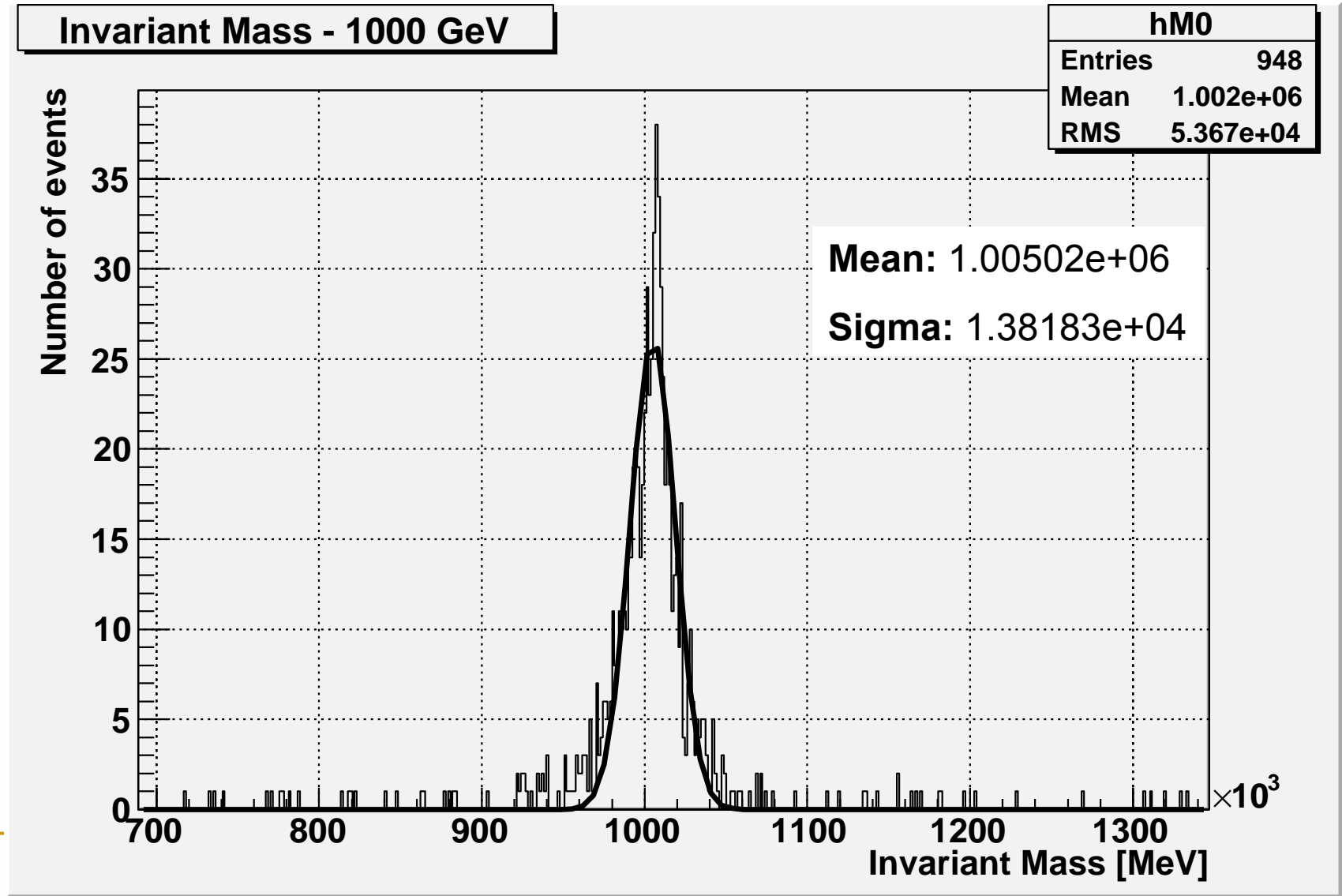
- For each collision event:
  - Define a 60 GeV  $P_T$  cut so as to disregard photons not energetic enough to have decayed from massive  $G^*$
  - All possible combinations of reconstructed photons, compute invariant mass from four-vectors of decay products, the photons
  - $W^2c^4 = (\sum E)^2 - (\sum \mathbf{pc})^2$ , for a system of 2 particles

# Invariant Mass (500 GeV)

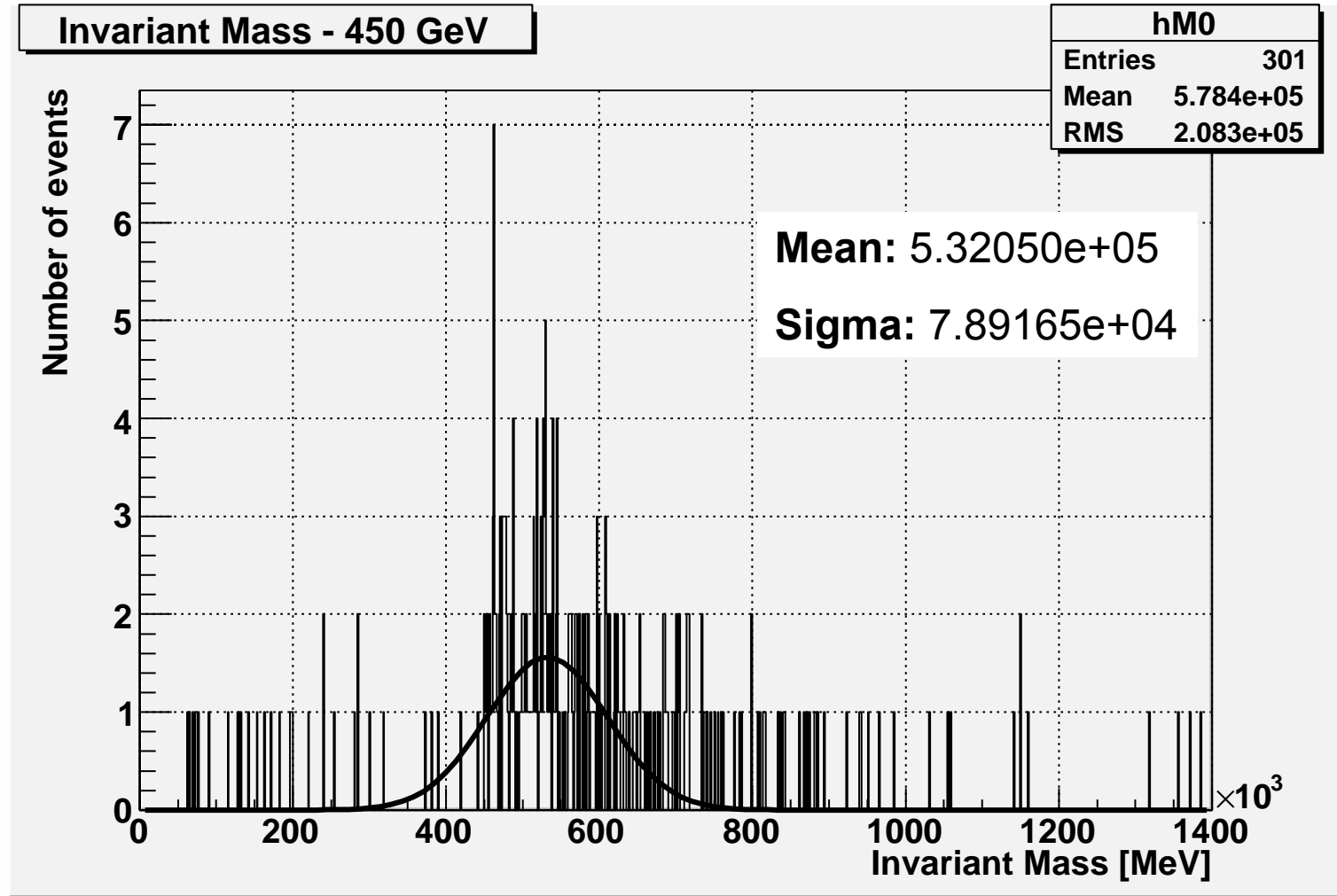
Invariant Mass - 500 GeV



# Invariant Mass (1000 GeV)



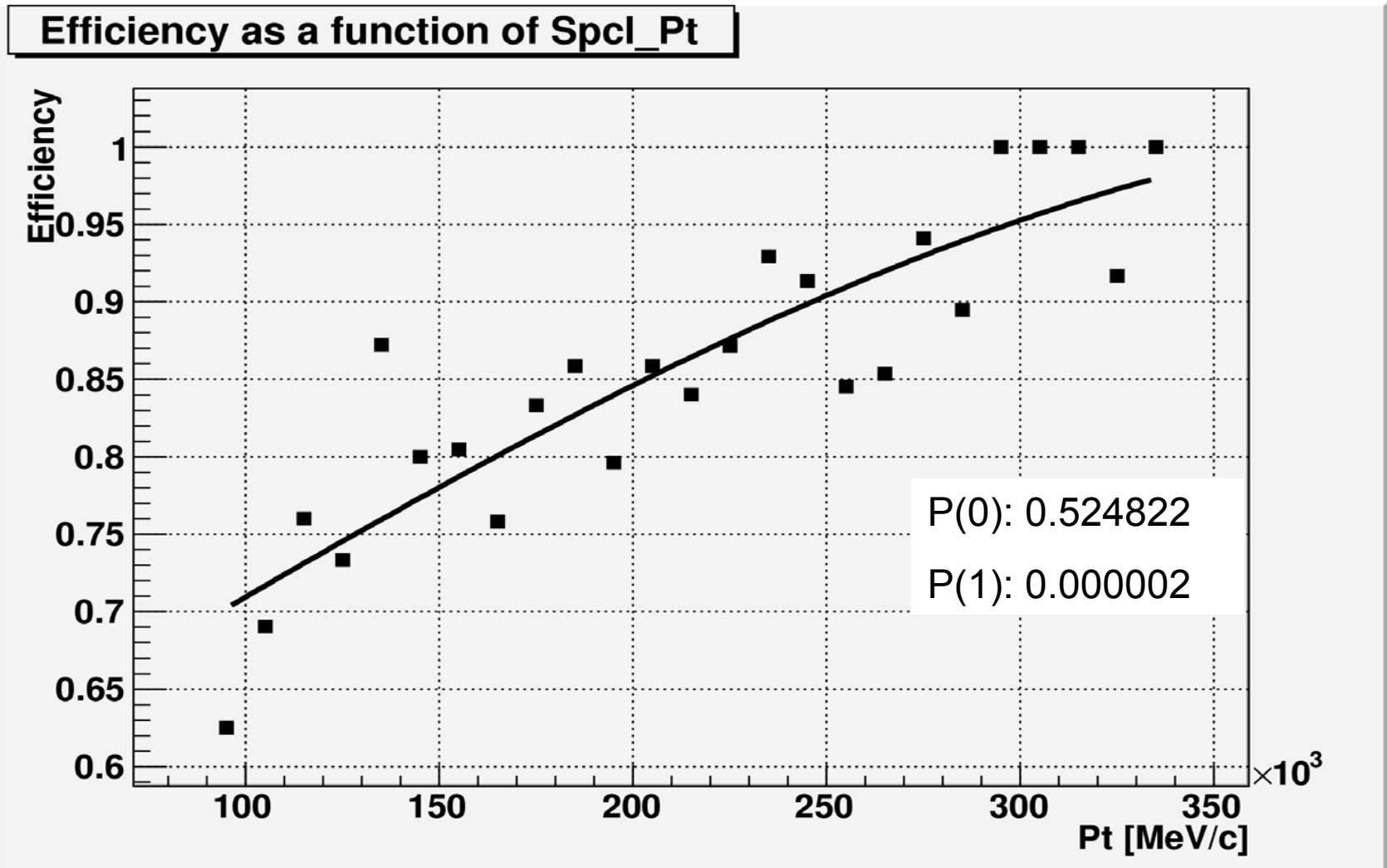
# Invariant Mass (450 GeV)



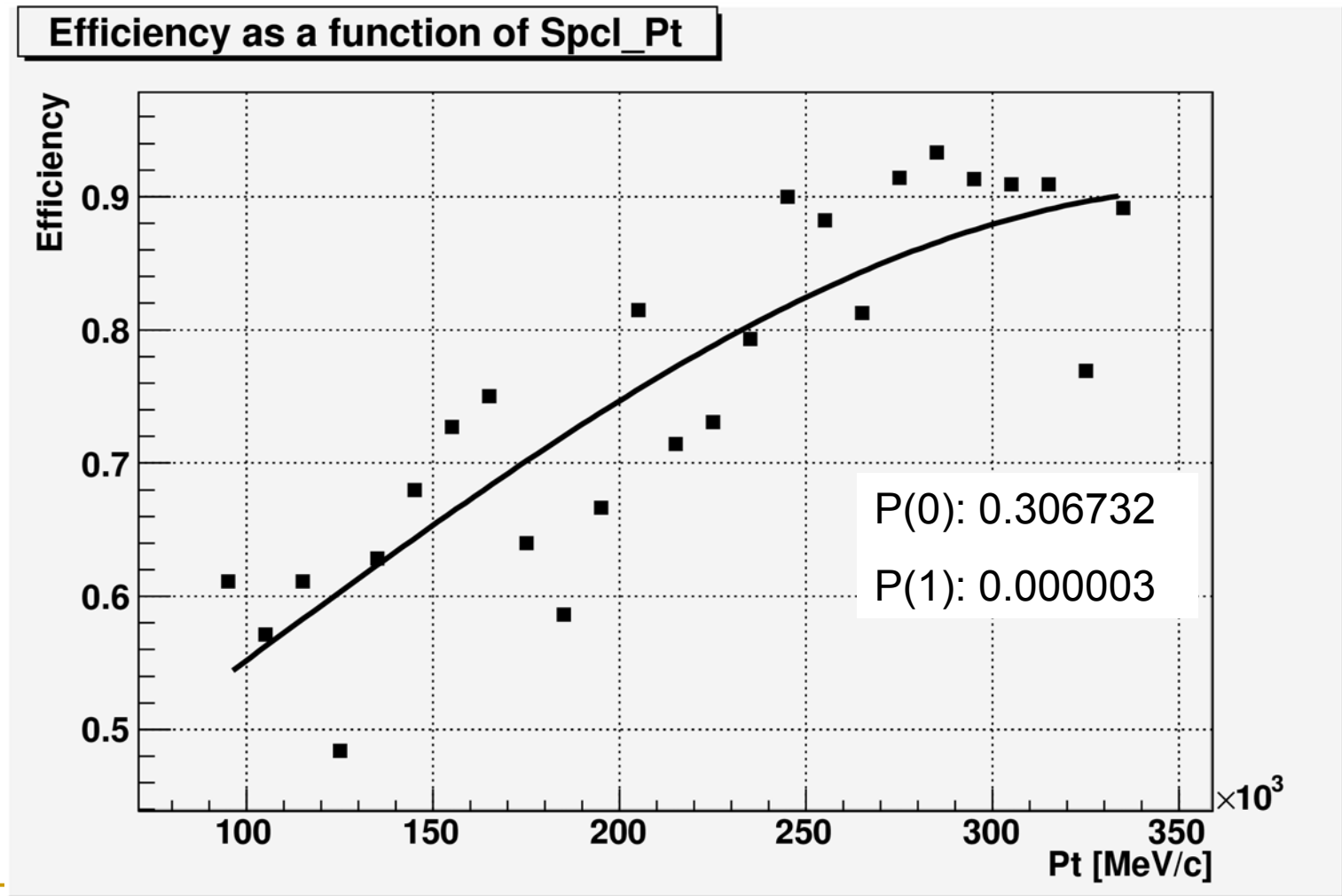
# Reconstruction Efficiency

- Why is this important?
  - Limitations are inherently imposed by the success of detectors in being able to accumulate data regarding an event.
  - Simulations represent the single arena where we have access to the “truth”, that is we know how particles in simulations decay to form a particular collection of products
  - Thus, simulations are the ideal method to investigate the ability of detectors to reconstruct events with vastly different particle properties.

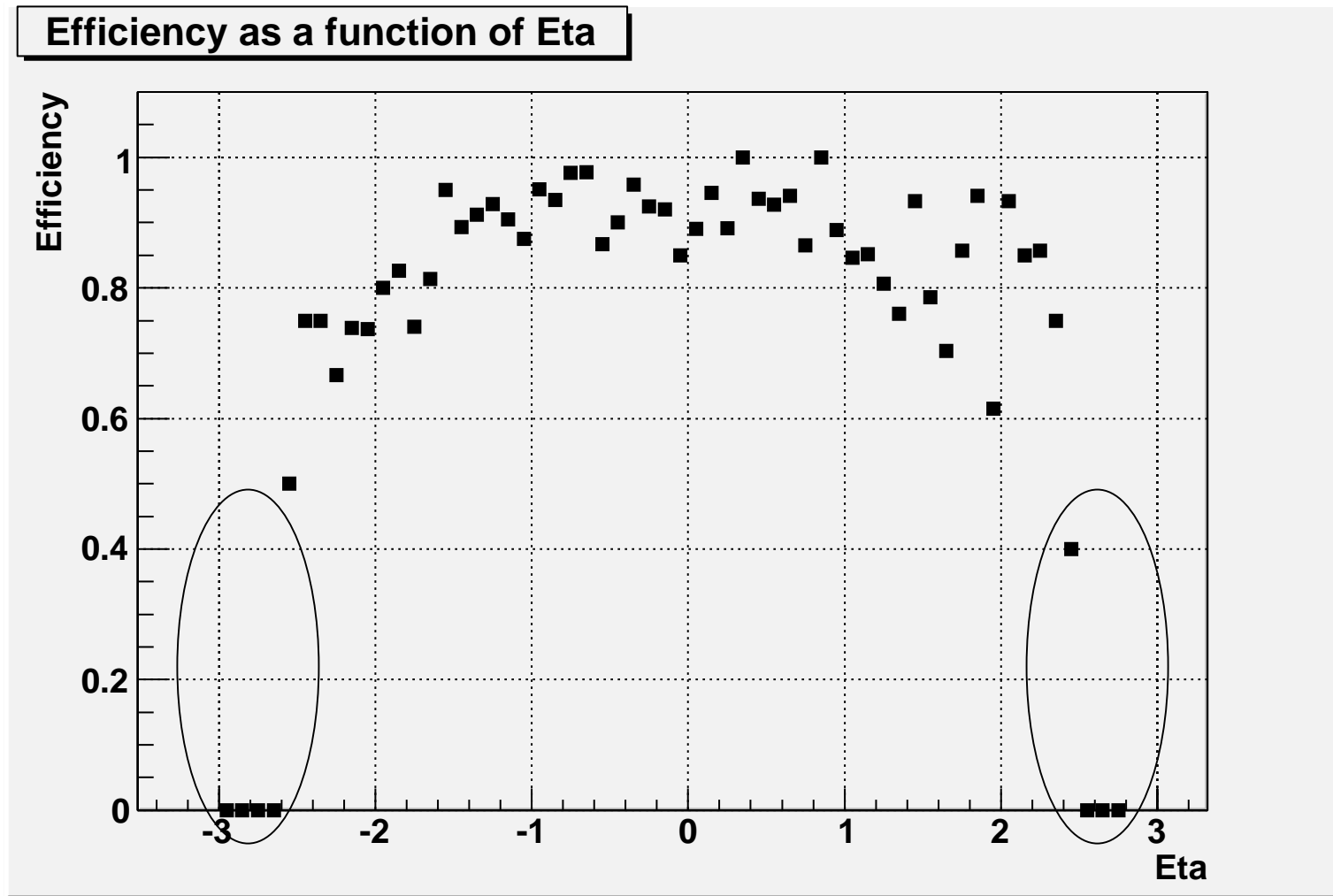
# Efficiency vs Photon Pt (500 GeV simulation data)



# Efficiency vs Photon Pt (1000 GeV simulation data)

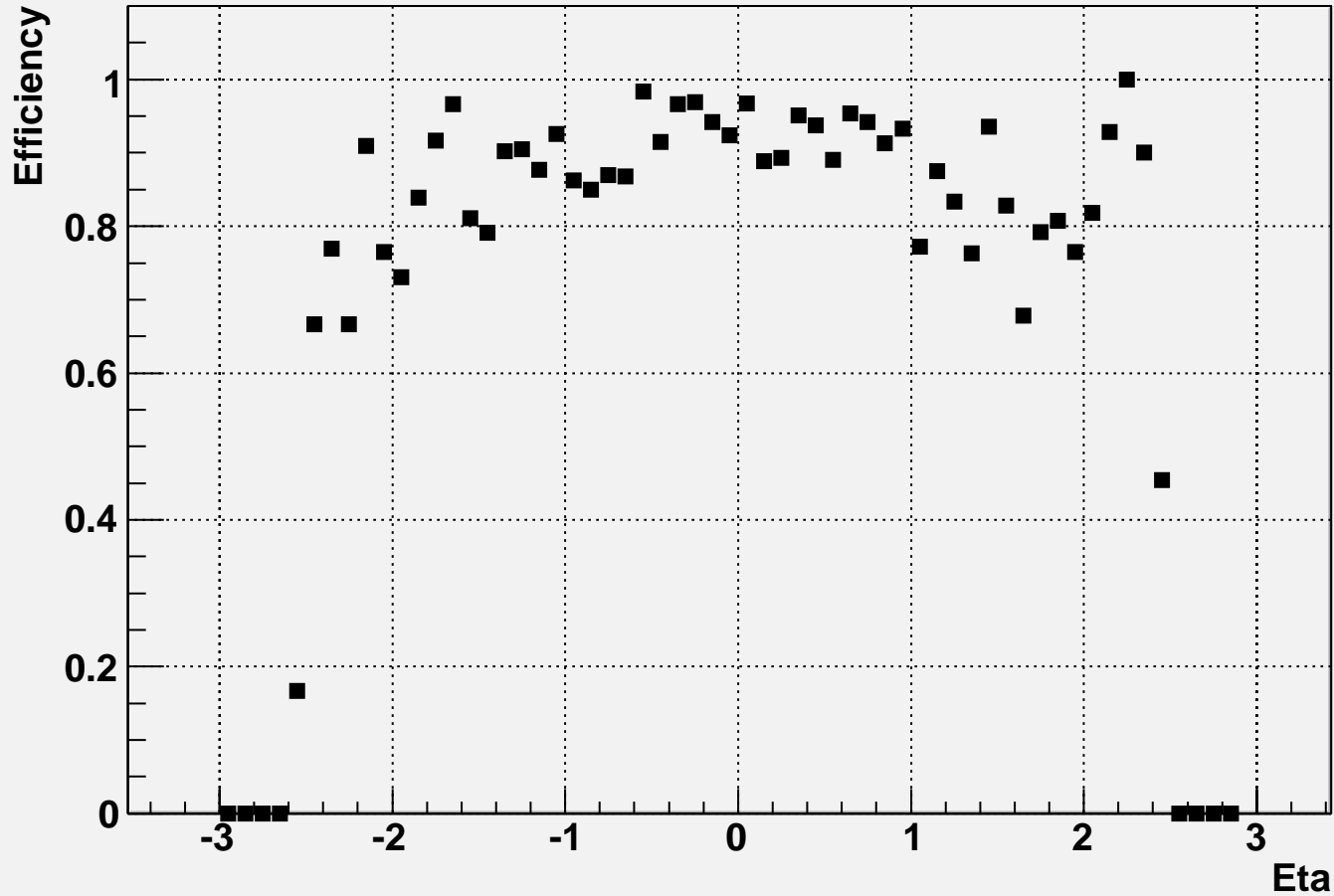


# Efficiency vs Pseudorapidity (500 GeV Simulation Data)



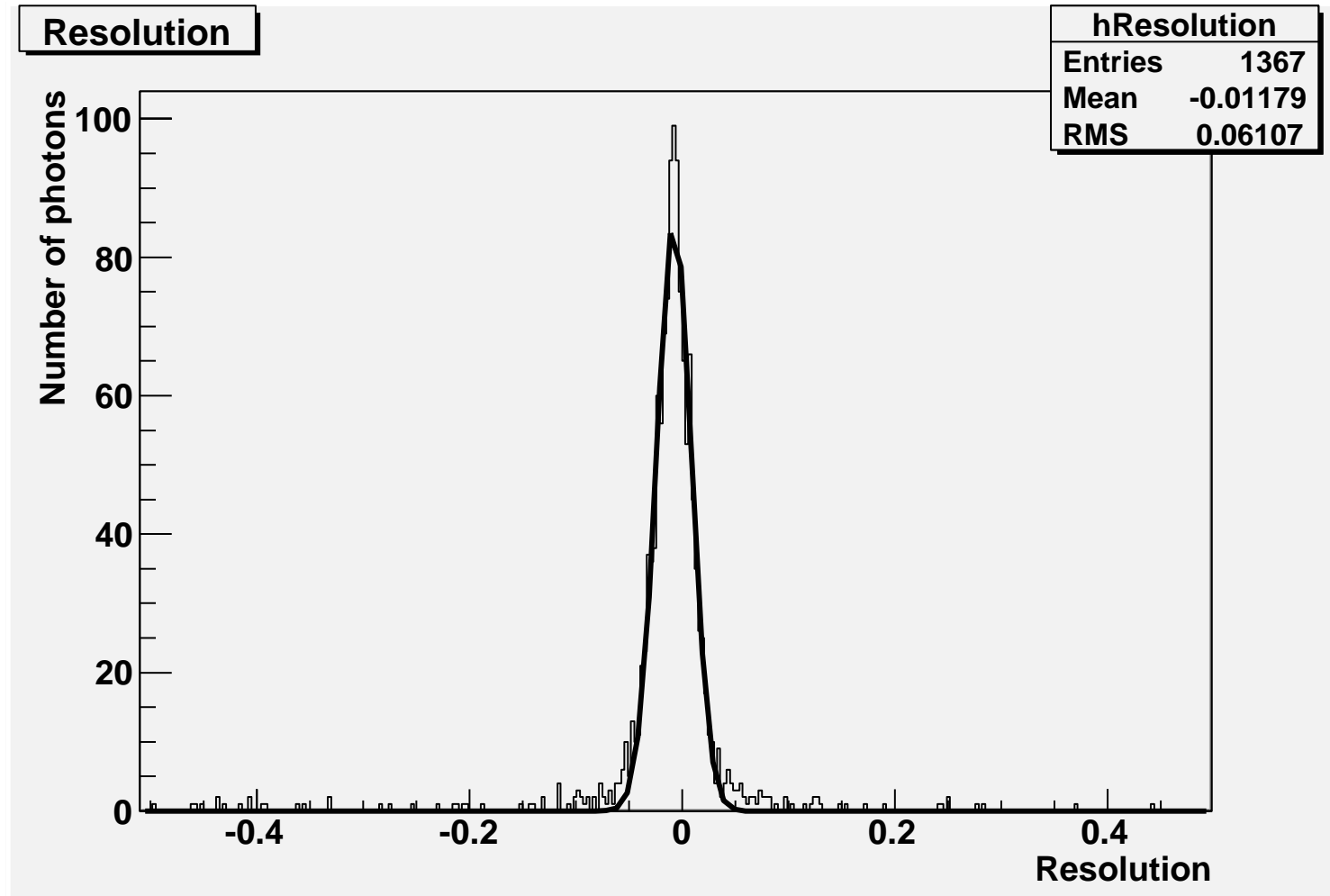
# Efficiency vs Pseudorapidity (1000 GeV simulation data)

Efficiency as a function of Eta

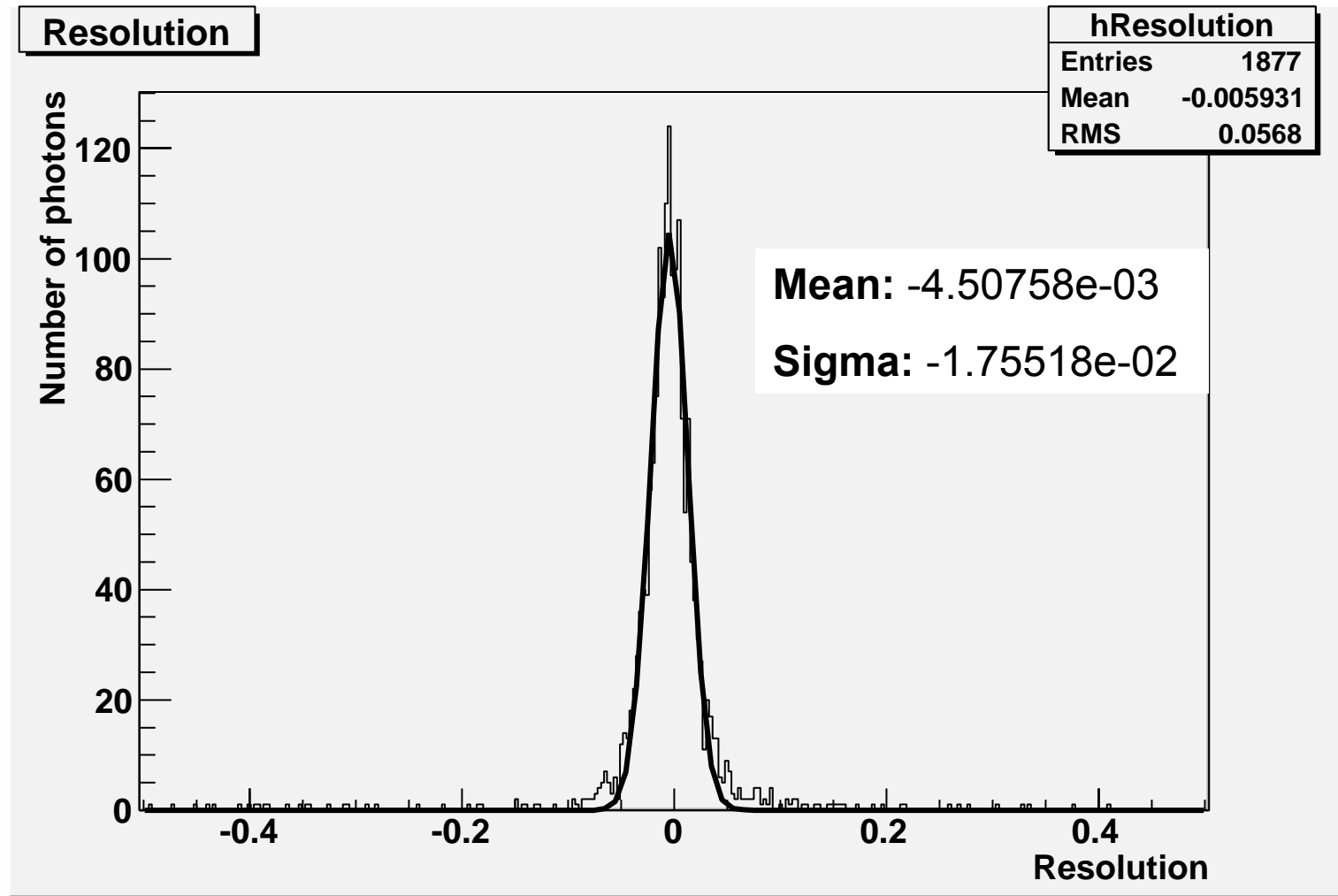


$$\text{Resolution} = (\text{Pt}_{\text{Gen}} - \text{Pt}_{\text{Recon}}) / \text{Pt}_{\text{Gen}}$$

(500 GeV simulation data)



# Resolution (1000 GeV simulation data)



# Determination of Min Luminosity (Process)

- Apply a Gaussian fit to invariant mass distribution, obtaining mean and standard deviation fit parameters
- Count the number of signal events in a 1, 2, or 3 sigma mass window.
- Applying same window invariant mass distribution of the SM background, count the number of background events
- Use the relation, Total Number of Events =  $\epsilon * (\sigma * Br) * L$ , where  $\epsilon$  represents the fraction of the entire distribution that is localized within the selected mass window,  $\sigma$  and  $Br$  are the cross section and branching ratio of the decay mode respectively, and  $L$  is the luminosity.
- Statistical error is minimized by maximizing the significance,  $S$ , where

$$S \equiv \frac{N_{signal}}{\sqrt{N_{background}}}$$

- Algebraic manipulation allows one to solve for the integrated luminosity as a function of the other variables, from which you can derive the minimum luminosity required to achieve a significance of 5 or larger.

# Determination of Min Luminosity (Results)

Sigma	$\sigma$	$2 \sigma$	$3 \sigma$
Min. Luminosity, 500 GeV	4.56 pb <sup>-1</sup>	4.07 pb <sup>-1</sup>	5.87 pb <sup>-1</sup>
Min. Luminosity, 1000 GeV	417.7 pb <sup>-1</sup>	385.8 pb <sup>-1</sup>	455.4 pb <sup>-1</sup>

# Future Work

- Angular distribution:
  - Important because by plotting the angular distribution of the signal and background, one can say with confidence that the signal is a fundamentally difference process and even claim a spin-2 resonance has been observed in the collider, consistent with RS(1) model
  - The fact that the anomalous decay products are photons, if indeed found, would be suggestive of a graviton because of the fact that the graviton is said to couple universally, to sheer energy, while this is not the case for alternative exotic particles such as the  $Z'$ , the heavy cousin of the Z boson which would not decay to a diphoton pair
- Modify code to prevent (rare) possibility of superfluous invariant masses by including a single photon in multiple diphoton pairs. Sufficient to just take most energetic photons in this case as the most likely to have decayed from a massive graviton
- Relatively few signal and background events simulated; would like to apply work to a larger project so as to achieve more

---

# Conclusions

- Able to study the effects of the detectors ability to reconstruct photons of varying energies and angles from the beam line
- Calculated the minimum required luminosity to achieve various degrees of significance
- Still exist other decay modes to examine, since  $G^* \rightarrow$  diphoton represents about 4% of the decays for given 1.5 TeV gravitons

---

# Acknowledgements

- John Parsons
- Kamal Benslama
- Andy Haas
- Nevis Labs & Columbia University
- NSF