Interference in Coherent Vector Meson Production in UPC Au+Au Collisions at $\sqrt{s} = 200GeV$

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Outline

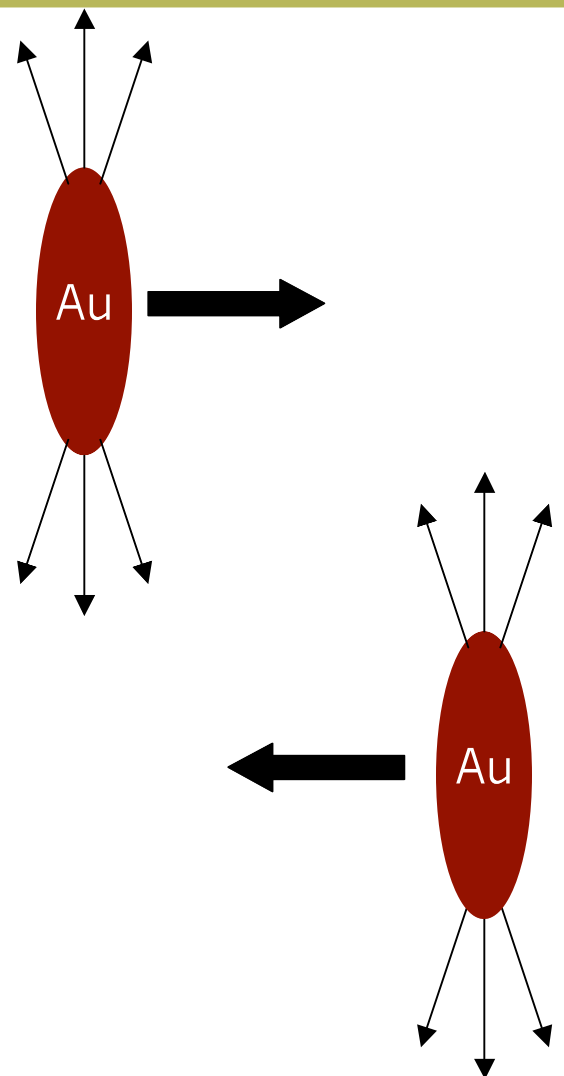
- Ultra Peripheral Heavy Ion Collisions (UPCs)
  - What is a UPC?
  - Vector Meson Production / Interference
  - STAR detectors / Triggers
- Analysis of UPC events
  - Fitting Scheme
  - Observation of interference effects in t spectrum
  - Systematic Errors and Outlook

Ultra Peripheral Collisions

- Photonuclear interaction
- Two nuclei “miss” each other ($b > 2R_A$), electromagnetic interaction dominates over strong interaction
- Photon flux ~ Z^2
  - Weizsäcker-Williams Equivalent Photon Approximation

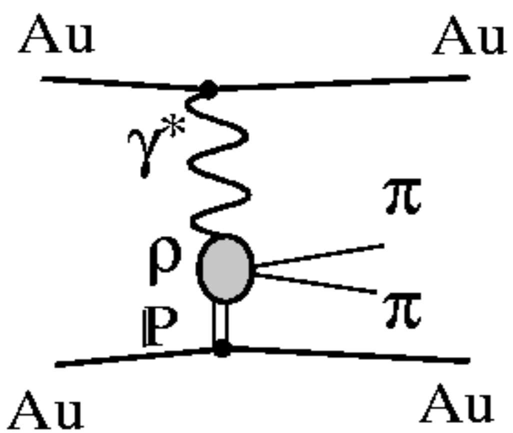
$$\frac{d^3N(k,r)}{dkd^2r} = \frac{Z^2\alpha x^2}{\pi^2 kr^2}K_1^2(x) \qquad x = \frac{kr}{\gamma}$$

- No hadronic interactions



Exclusive ρ^o Production

Au+Au → Au+Au+ρ^o



Courtesy of F. Meissner

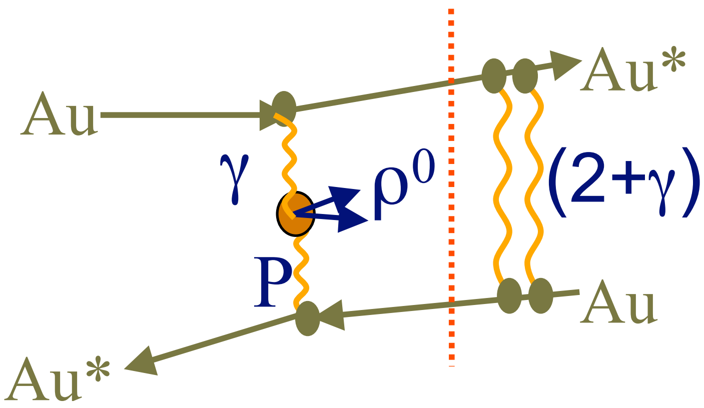
- Photon emitted by a nucleus fluctuates to virtual $q\bar{q}$ pair
- Virtual $q\bar{q}$ pair elastically scatters from other nucleus
- Real vector meson (i.e. J/ψ, ρ^o) emerges

- Photon and pomeron are emitted coherently
- Coherence condition limits transverse momentum of produced ρ

$$p_T < \frac{h}{2R_A}$$

ρ^o Production With Coulomb Excitation

Au+Au → Au*+Au*+ρ^o



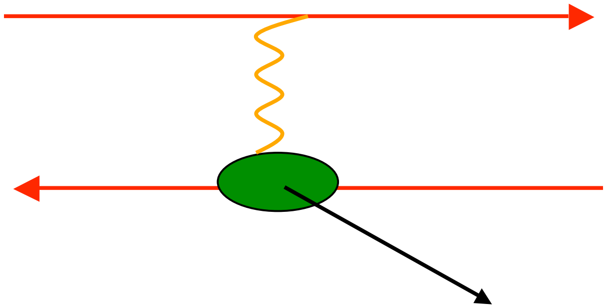
Courtesy of S. Klein

- Photons exchanged between ions give rise to excitation and subsequent neutron emission
- Process is independent of ρ^o production

$$\sigma(AuAu \rightarrow Au^* Au^* + \rho^o) = \int d^2b P_\rho(b) P_{XnXn}(b)$$

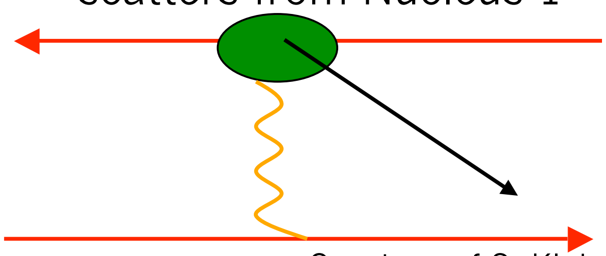
Interference

Nucleus 1 emits photon which scatters from Nucleus 2



-Or-

Nucleus 2 emits photon which scatters from Nucleus 1



Courtesy of S. Klein

- Amplitude for observing vector meson at a distant point is the convolution of two plane waves:

$$A_o(x_o,\vec{p},b) = A(p_\perp,y,b)e^{i[\phi(y)+\vec{p}\bullet(\vec{x}-\vec{x}_o)]} - A(p_\perp,-y,b)e^{i[\phi(-y)+\vec{p}\bullet(\vec{x}-\vec{x}_o)]}$$

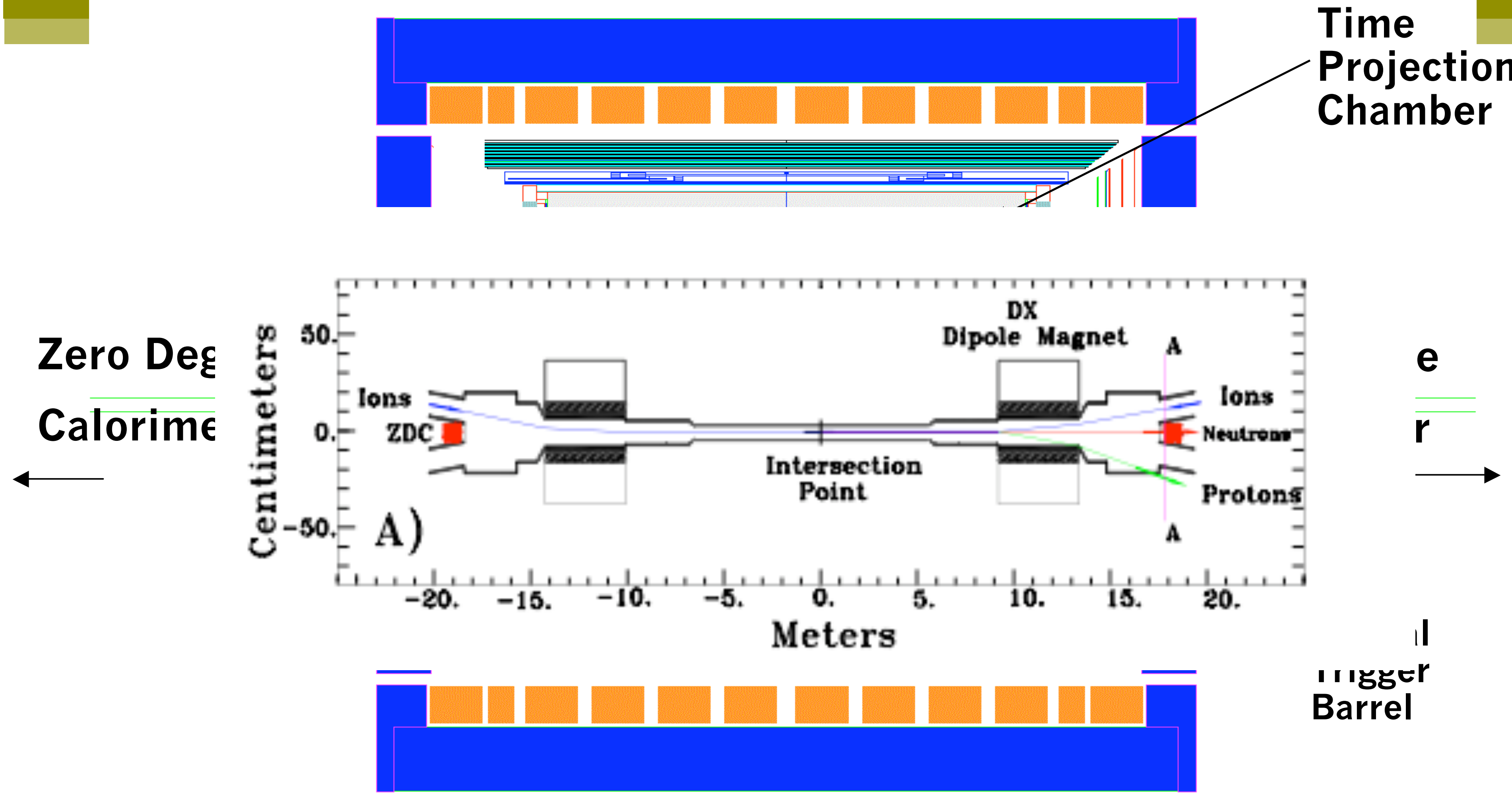
- Cross section comes from square of amplitude:

$$\sigma = A^2(p_\perp,y,b) + A^2(p_\perp,y,b) - 2A(p_\perp,y,b)A(p_\perp,-y,b)\times\cos[\phi(y)-\phi(-y)+\vec{p}\bullet\vec{b}]$$

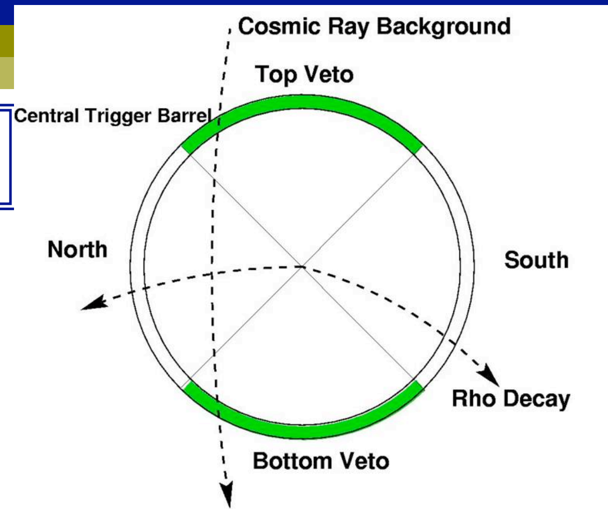
- We can simplify the expression if $y \to 0$:

$$\sigma = 2A^2(p_\perp,b)(1-\cos[\vec{p}\bullet\vec{b}])$$

STAR Analysis Detectors



Triggers



UPC Topology

Au+Au → Au+Au+ρ^{o}

- Central Trigger Barrel divided into four quadrants
- Verification of ρ decay candidate with hits in North/South quadrants
- Cosmic Ray Background vetoed in Top/Bottom quadrants

UPC Minbias

Au+Au → Au*+Au*+ρ^{o}

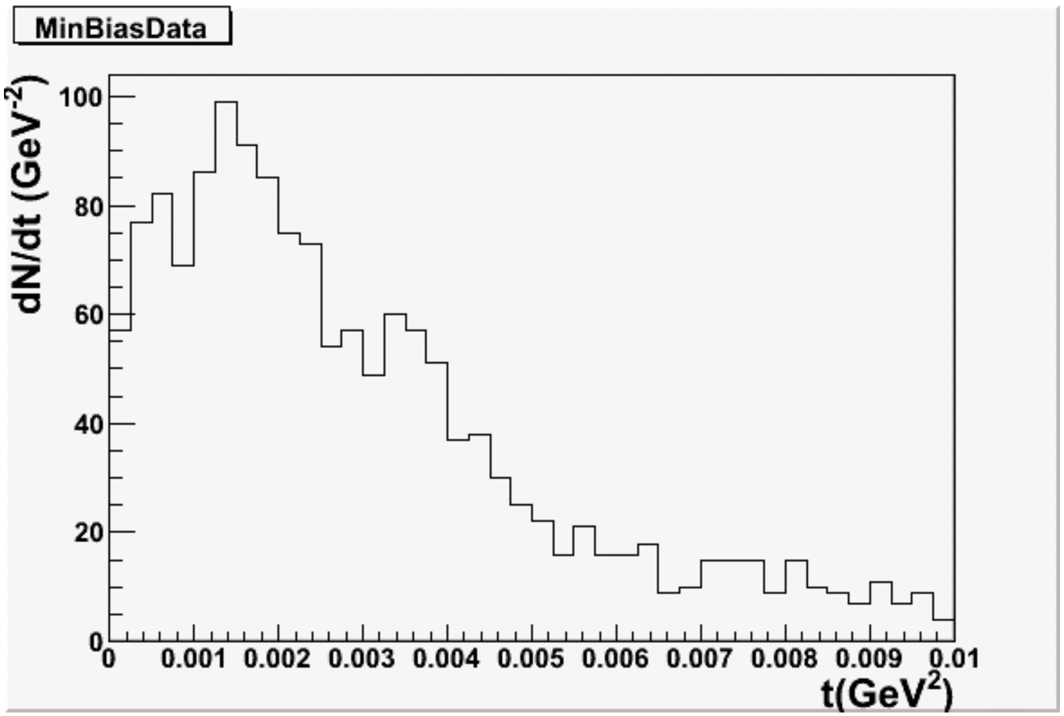
- Minimum one neutron in each Zero Degree Calorimeter required
- Low Multiplicity
- Not Hadronic Minbias!

Trigger Backgrounds

- Cosmic Rays
- Beam-Gas interactions
- Peripheral hadronic interactions
- Incoherent photonuclear interactions

Studying the Interference

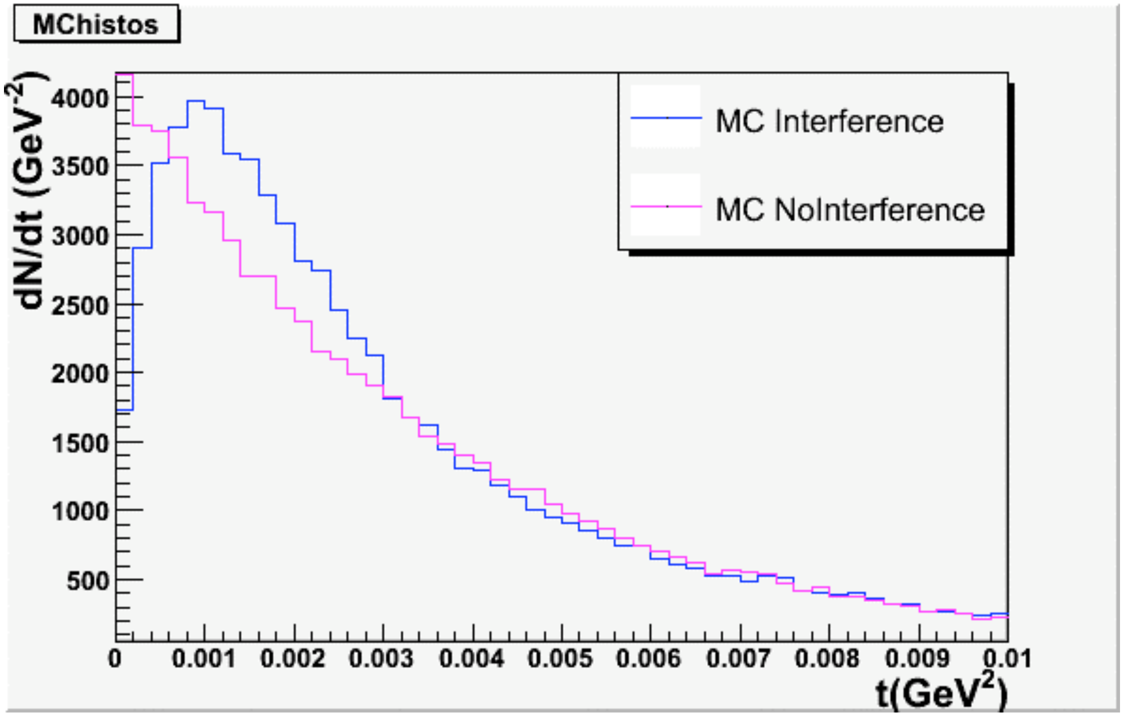
- *Determine ρ^o candidates by applying cuts to the data*



qTot	0
nTot	2
nPrim	2
|zVertex|	< 50 *cm*
|rVertex|	< 8 *cm*
rapidity	> 0.1 < 0.5
M_{Inv}	> 0.55 *GeV* < 0.92 *GeV*
p_T	> 0 *GeV* < 0.1 *GeV*

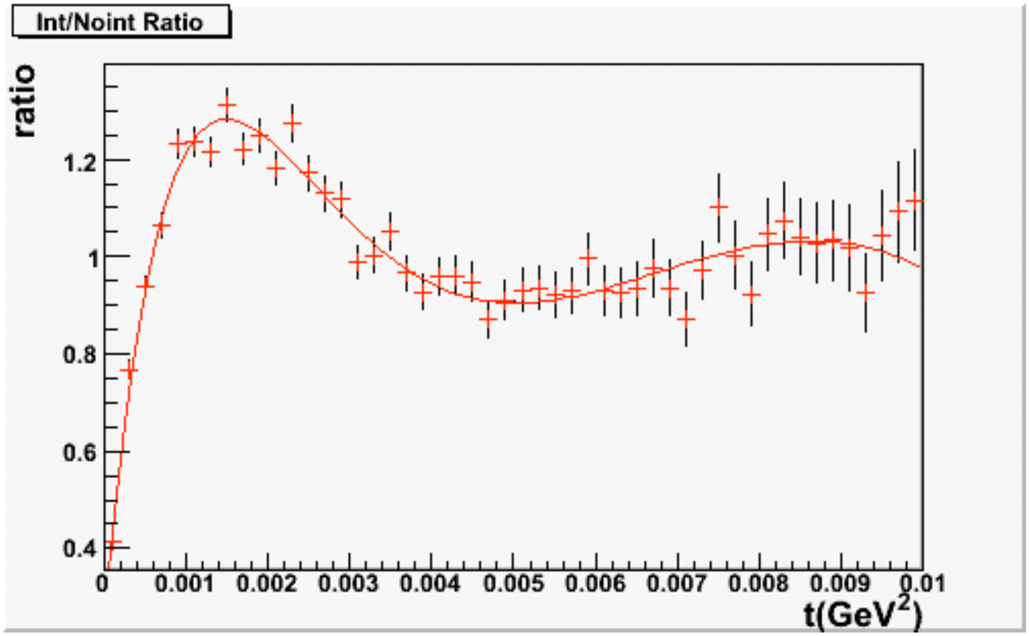
Studying the Interference

- *Generate similar MC histograms*



Studying the Interference

- *Generate MC ratio*
- *Fit MC ratio*



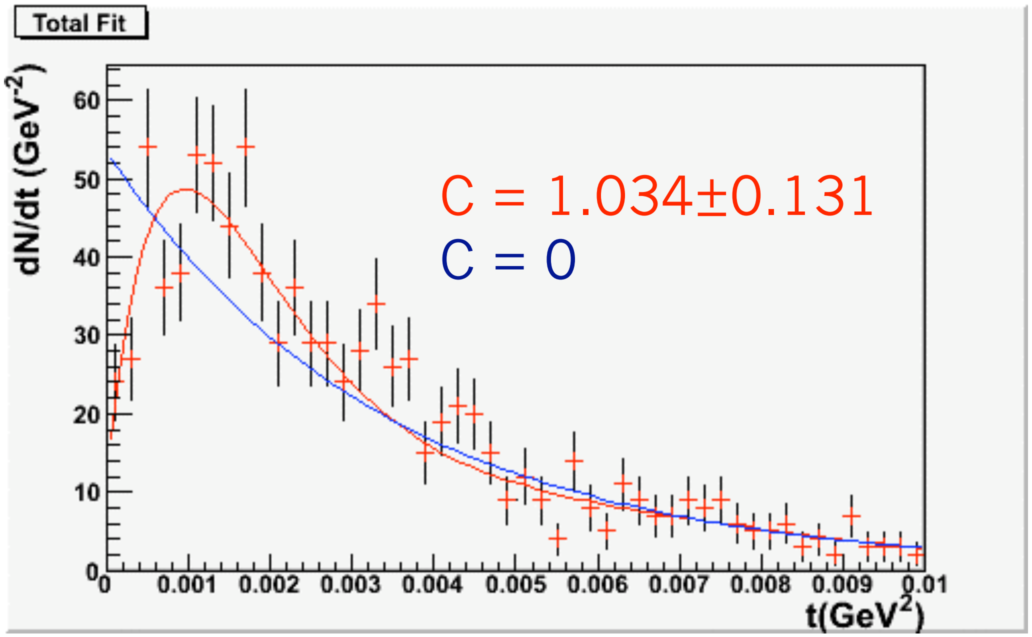
$$R(t) = a + \frac{b}{(t+0.012)} + \frac{c}{(t+0.012)^2} + \frac{d}{(t+0.012)^3} + \frac{e}{(t+0.012)^4}$$

Measuring the Interference

- *Apply overall fit*

$$\frac{dN}{dt} = Ae^{-kt}(1 - cR(t))$$

- A= overall normalization
- k = exponential slope
- c = degree of interference



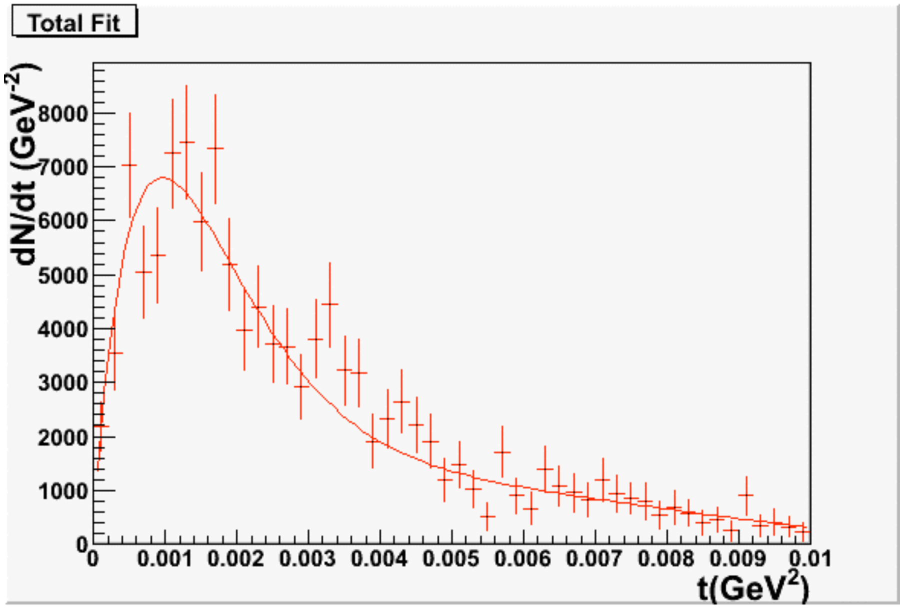
c = 1

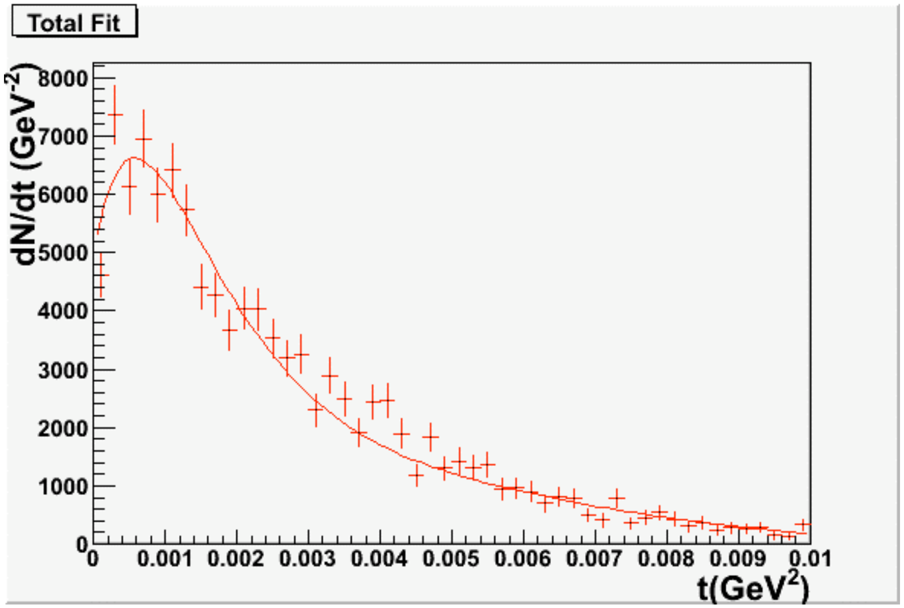
expected degree of interference

c = 0

no interference

Results





Minbias

Au+Au → Au*+Au*+ρ^o

C = 1.009±0.081

χ^2/DOF = 50.77/47

Topology

Au+Au → Au+Au+ρ^o

C = 0.8487±0.1192

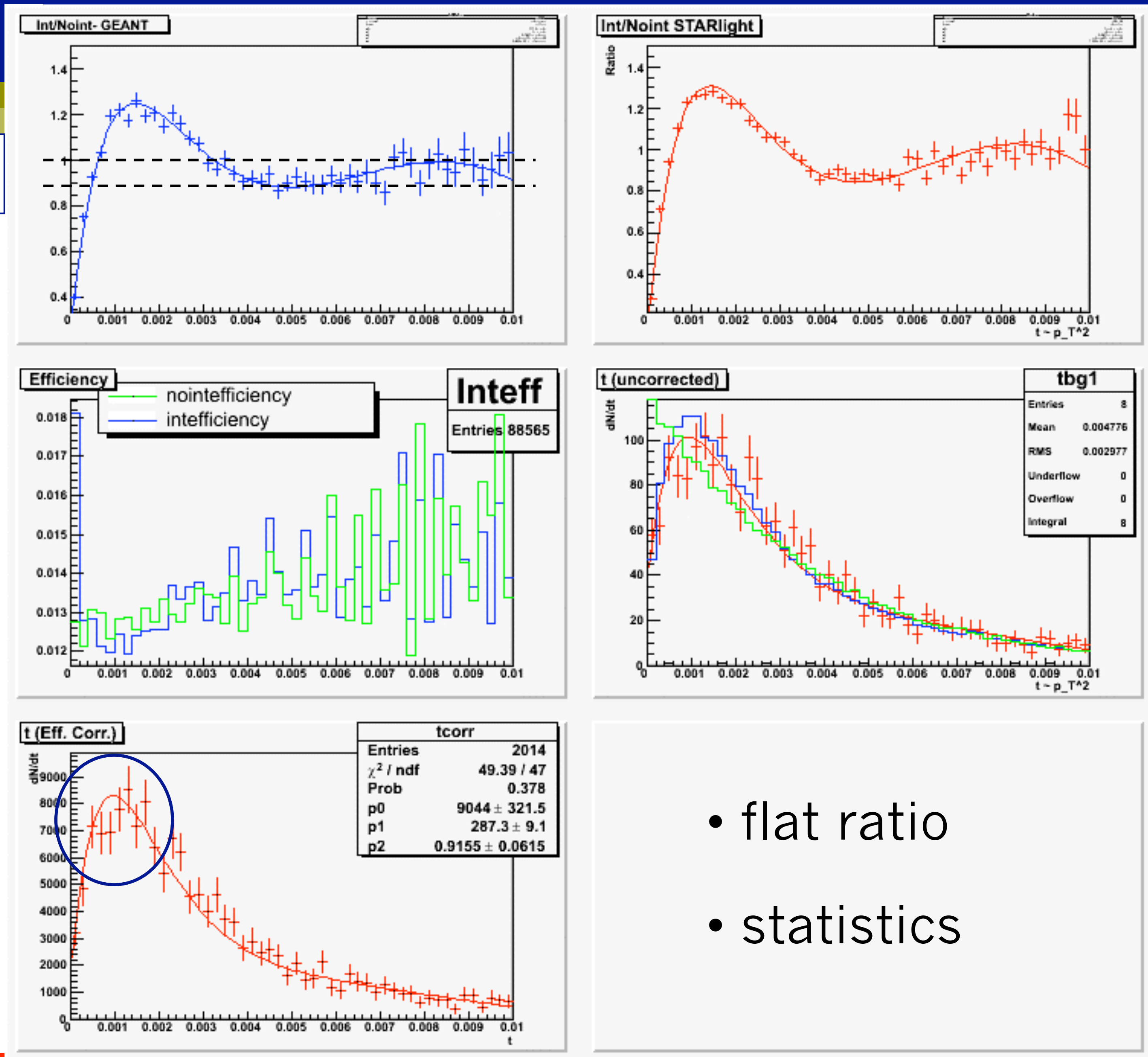
χ^2/DOF = 87.92/47

Results Summary

	c	χ^2/dof
Minbias		
0.1 < y < 0.5	1.009± 0.081	50.77/47
0.5 < y < 1.0	0.9275± 0.1095	80.18/47
Topology		
0.1 < y < 0.5	0.8487± 0.1192	87.92/47
0.5 < y < 1.0	1.059± 0.208	83.81/47

Interference routine for minbias 0 > y > 0.5

~10%



- flat ratio
- statistics

Systematic Error Study

	Standard Cut	Varied Cut	Data Set	Entries	Uncertainty
zVertex	$\lvert \text{zVertex} \rvert < 50$ $0.1 < y < 0.5$	zVertex > 0	minbias	811	0.0422
			topology	1989	0.1883
	$\lvert \text{zVertex} \rvert < 50$ $0.5 < y < 1.0$	zVertex > 0	minbias	637	0.1526
			topology	1100	-0.323
	$\lvert \text{zVertex} \rvert < 50$ $0.1 < y < 0.5$	zVertex < 0	minbias	826	0.1188
			topology	1844	0.0379
	$\lvert \text{zVertex} \rvert < 50$ $0.5 < y < 1.0$	zVertex < 0	minbias	628	0.0454
			topology	955	-0.414
rapidity	$0.1 < y < 0.5$	$0 < y < 0.5$	minbias	2014	0.0935

Systematic Error Study

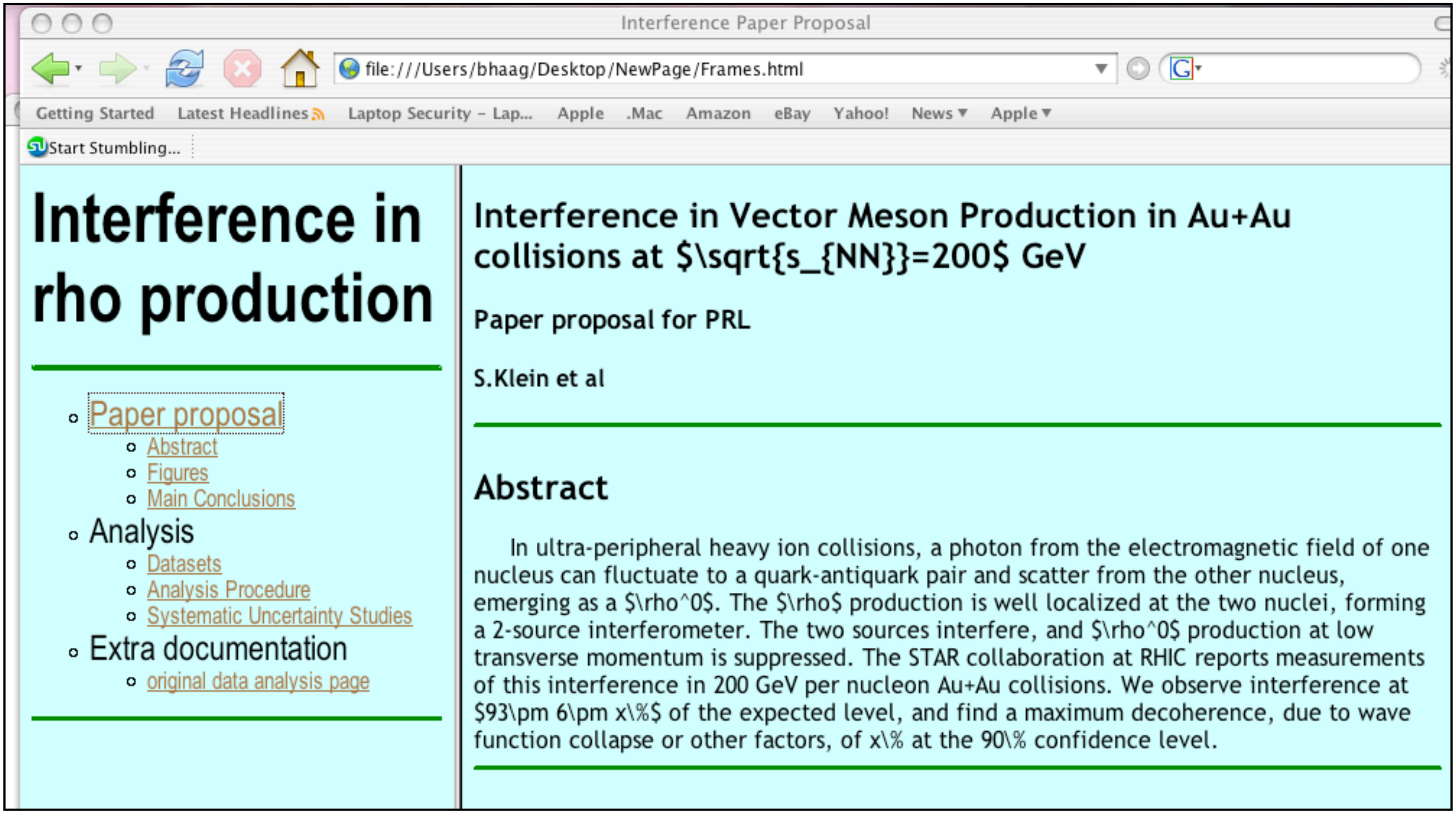
$$R(t) = a + \frac{b}{(t+0.012)} + \frac{c}{(t+0.012)^2} + \frac{d}{(t+0.012)^3} + \frac{e}{(t+0.012)^4}$$

$$R(t) = a + \frac{b}{(t+0.012)} + \frac{c}{(t+0.012)^2} + \frac{d}{(t+0.012)^3} + \frac{e}{(t+0.012)^4} + \frac{f}{(t+0.012)^5}$$

Fit	Data Set	Uncertainty	
6 parameter	minbias	0.013	1.3%
	topology	0.008	0.9%

The 5 parameter fit is sufficient -- adding another parameter doesn't improve the analysis.

Paper Proposal



Interference in rho production

- Paper proposal
  - Abstract
  - Figures
  - Main Conclusions
- Analysis
  - Datasets
  - Analysis Procedure
  - Systematic Uncertainty Studies
- Extra documentation
  - original data analysis page

Interference in Vector Meson Production in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV

Paper proposal for PRL

S.Klein et al

Abstract

In ultra-peripheral heavy ion collisions, a photon from the electromagnetic field of one nucleus can fluctuate to a quark-antiquark pair and scatter from the other nucleus, emerging as a ρ^0. The ρ production is well localized at the two nuclei, forming a 2-source interferometer. The two sources interfere, and ρ^0 production at low transverse momentum is suppressed. The STAR collaboration at RHIC reports measurements of this interference in 200 GeV per nucleon Au+Au collisions. We observe interference at $93\pm 6\pm x\%$ of the expected level, and find a maximum decoherence, due to wave function collapse or other factors, of x\% at the 90\% confidence level.

http://www.star.bnl.gov/protected/pcoll/bhaag/NewPage/Frames.html

Backup Slides

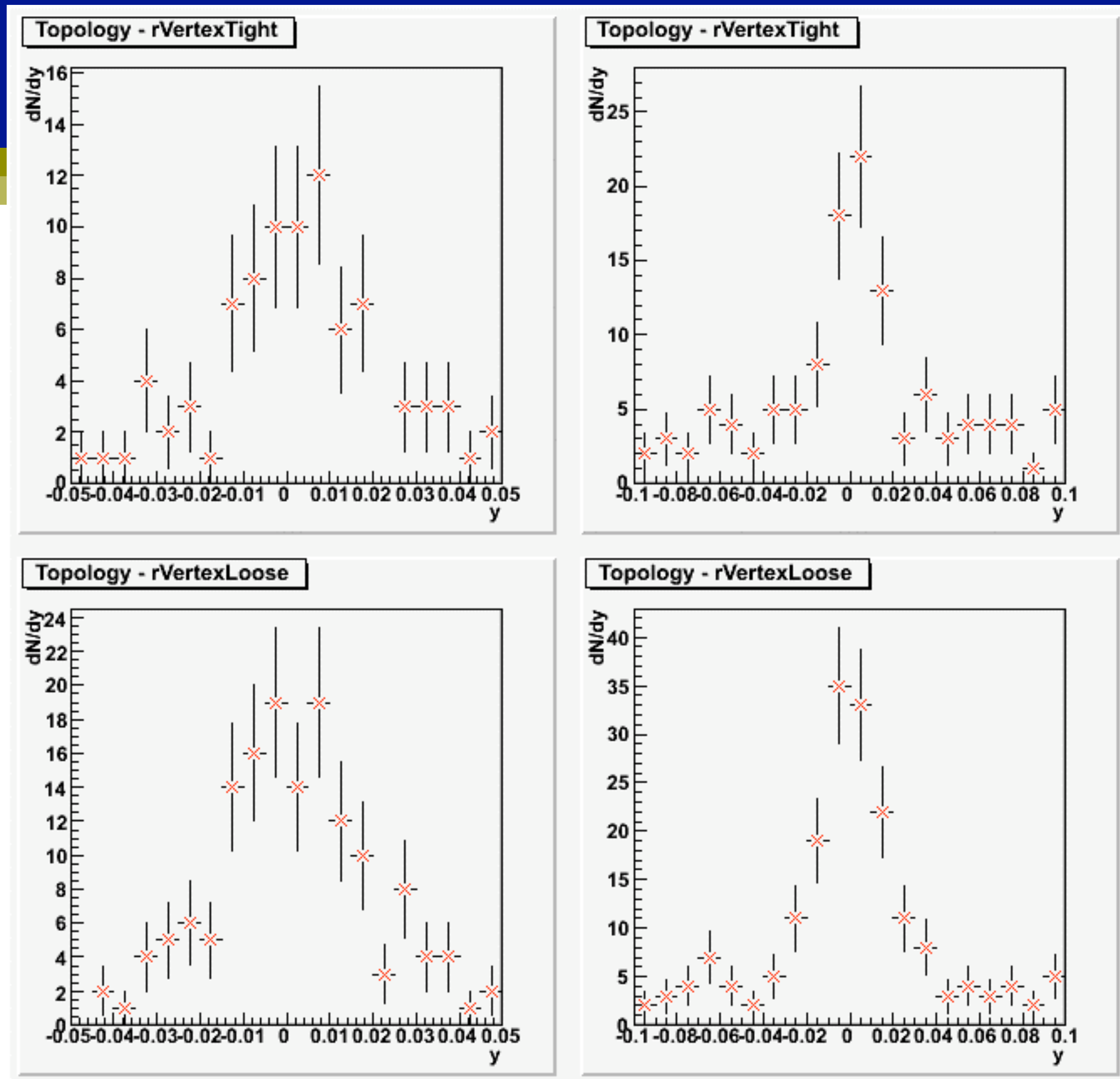
• two rapidity ranges

$|y| < 0.05$

$|y| < 0.1$

• **rVertex Tight** = rVertex < 8 cm

• **rVertex Loose** = rVertex < 16 cm



Topology rapidity study