Coherent Diffraction of ρ^0 mesons off Au Nuclei

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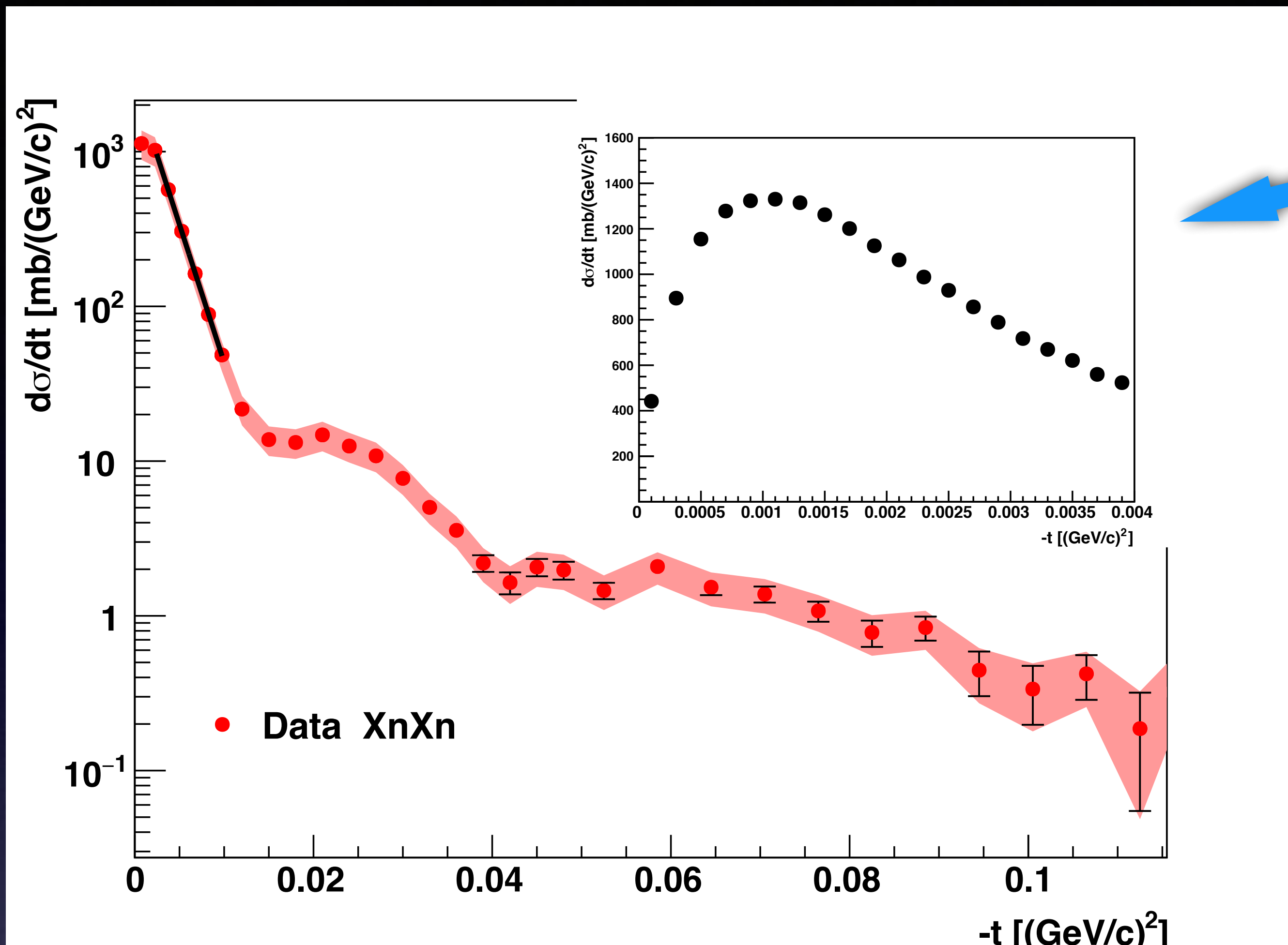
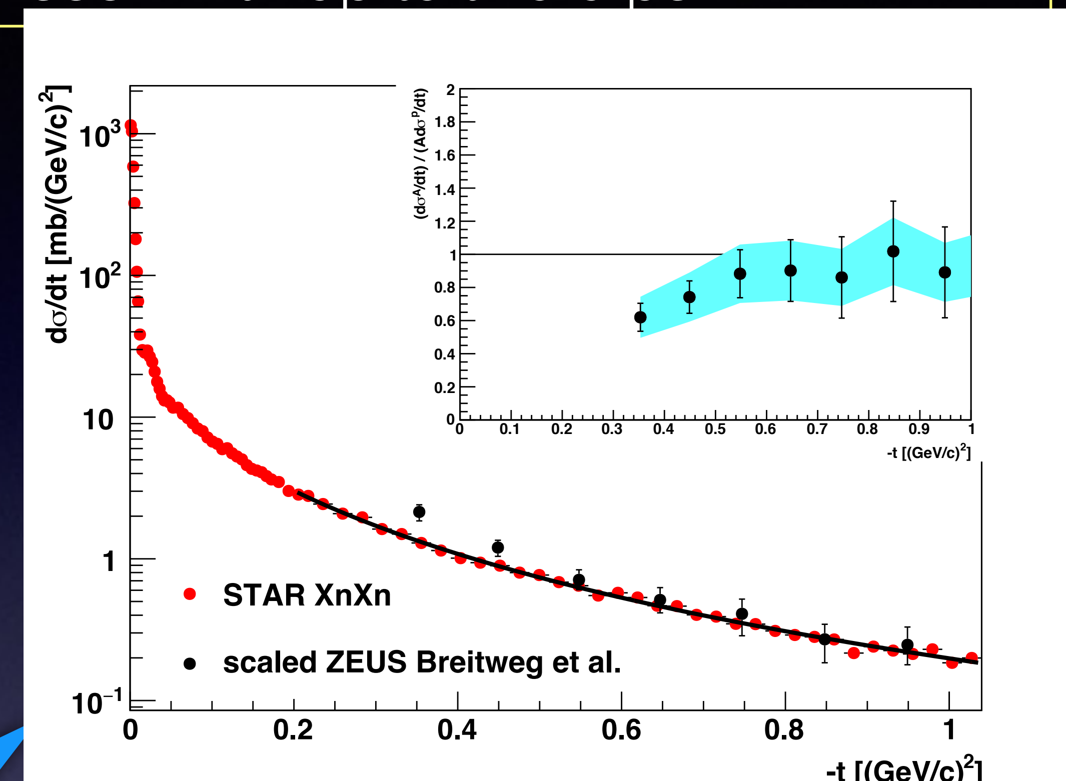
The STAR Collaboration reports on the photoproduction of $\pi^+\pi^-$ pairs in gold-gold collisions at a center of mass energy of 200 GeV/nucleon. These pairs are produced when a nearly-real photon emitted by one ion scatters from the other. The differential cross-section $d\sigma/dt$ clearly exhibits a diffraction pattern, compatible with scattering from a gold nucleus, with 2 dips visible. We fit the $\pi^+\pi^-$ mass spectrum to a combination of ρ^0 and ω resonances, plus a direct $\pi^+\pi^-$ continuum; the ratio of ρ^0 : direct $\pi^+\pi^-$ is consistent with previous measurements in lighter systems. The ω component is considerably larger than is expected from the measured ω photoproduction cross-section and $\omega \rightarrow \pi^+\pi^-$ branching ratio, in accord with previous studies. This may be due to ρ/ω mixing, since $\omega \rightarrow \pi^+\pi^-$ is disallowed by G-parity."

Paper proposal: https://drupal.star.bnl.gov/STAR/blog/ramdebbe/coherent-diffraction-rho-mesons-au-nuclei-star-detector-rhic

Paper outline:

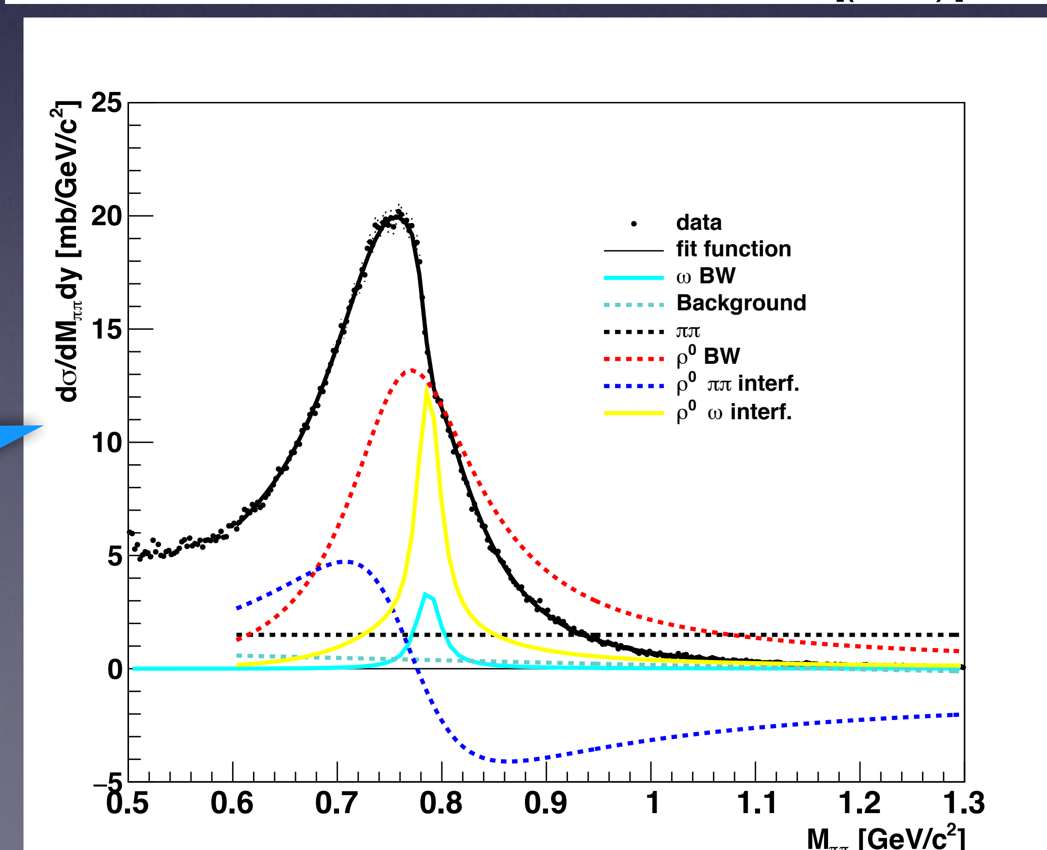
UPC events seen as high flux of q-qbar dipoles we focus on detection of ρ^0 mesons. Found clear coherent diffraction off an object as big as Au nuclei. First time seen with up to two dips.



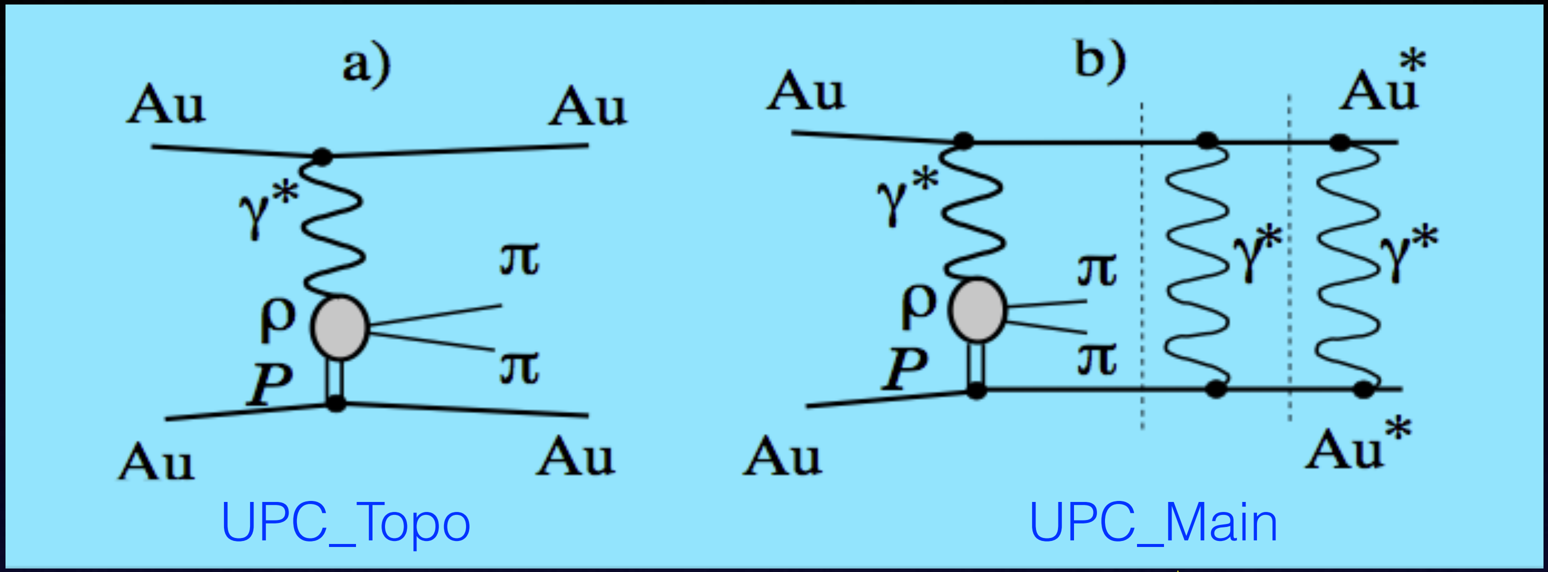


We can compare of incoherent scattering on A and p may be used to study nucleon fluctuations in target.

High statistic and good resolution permits a study of the interaction of non-resonant pion pairs, ρ^0 and ω mesons decaying into pion pairs.



The UPC physics



Ions exchange high flux of mostly real photons (which do fluctuate onto vector mesons and scatter elastically off the target)

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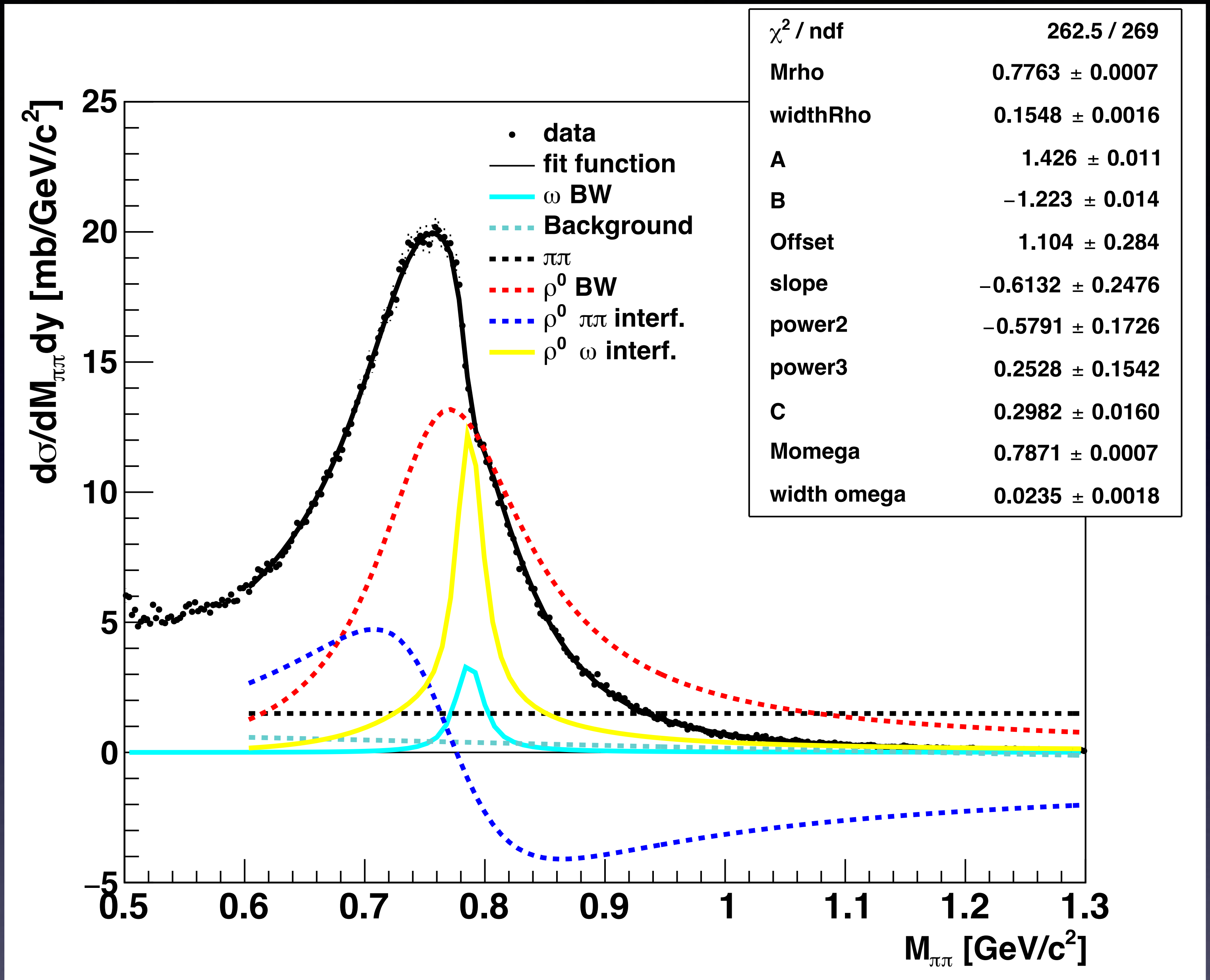
Needs to separate this events from copious hadronic interactions as ions overlap.

The data was collected during the 2010 Au+Au 200 GeV run. This analysis use UPC_Main which relies on 1-5 neutrons detected on both ZDC's (diagram b cleaner trigger), rapidity gaps based on BBC vetoes and no more
than 6 TOF hits.

Invariant mass fits

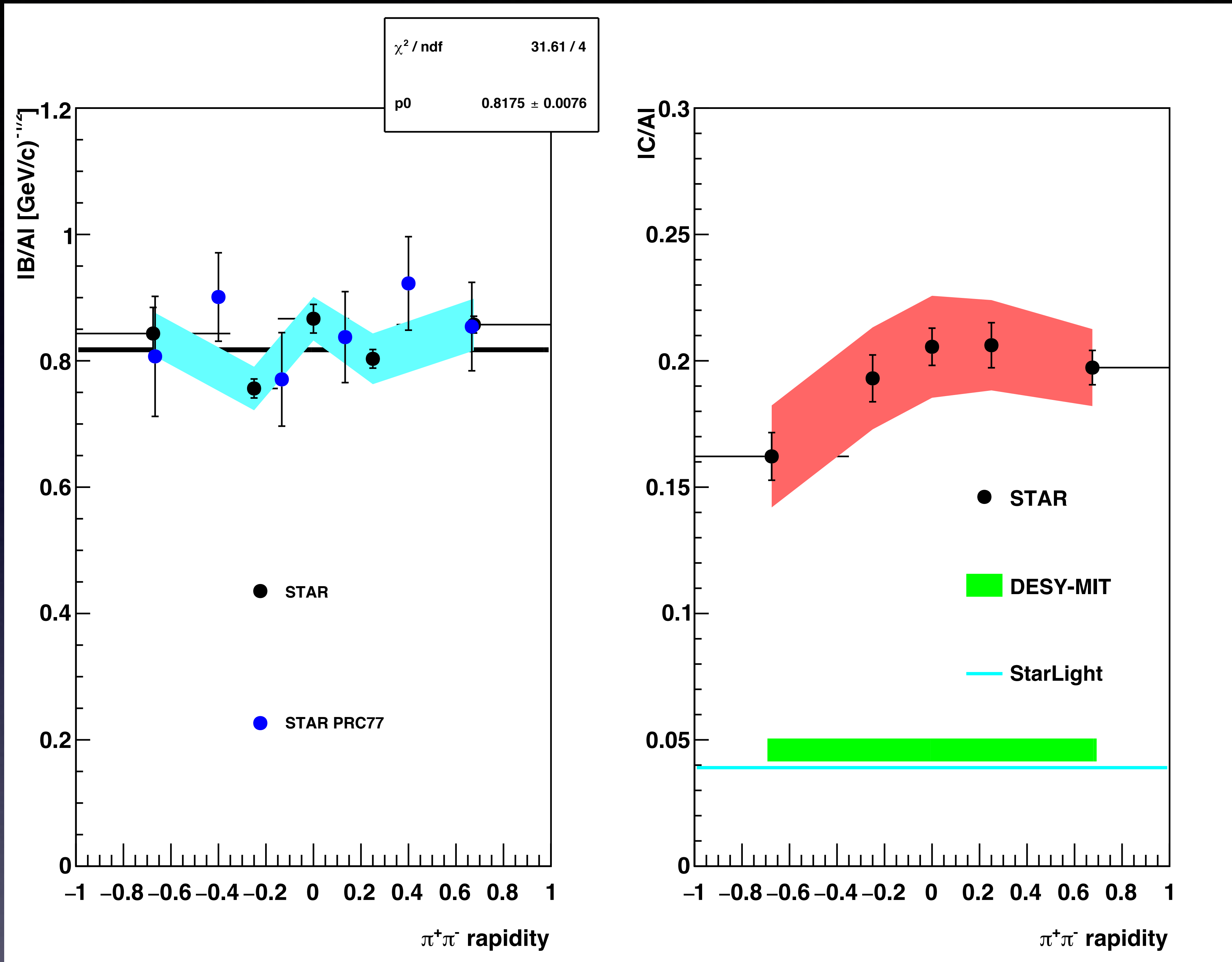


Focus on the interplay between ρ, ω and non-resonant ππ as hadronic components of photon

$$\frac{d\sigma}{dM_{\pi^+\pi^-}} = \left| A_\rho \frac{\sqrt{M_{\pi\pi}M_\rho\Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + iM_\rho\Gamma_\rho} + B_{\pi\pi} + C_\omega \frac{\sqrt{M_{\pi\pi}M_\omega\Gamma_\omega}}{M_{\pi\pi}^2 - M_\omega^2 + iM_\omega\Gamma_\omega} \right|^2 + f_p$$

With ~500K selected pairs our fits allow us to study the interplay between non-resonant pion pairs and ρ and ω mesons. This re-visits the hadronic structure of the photon but this time, at higher RHIC energies.

Mass fits in rapidity

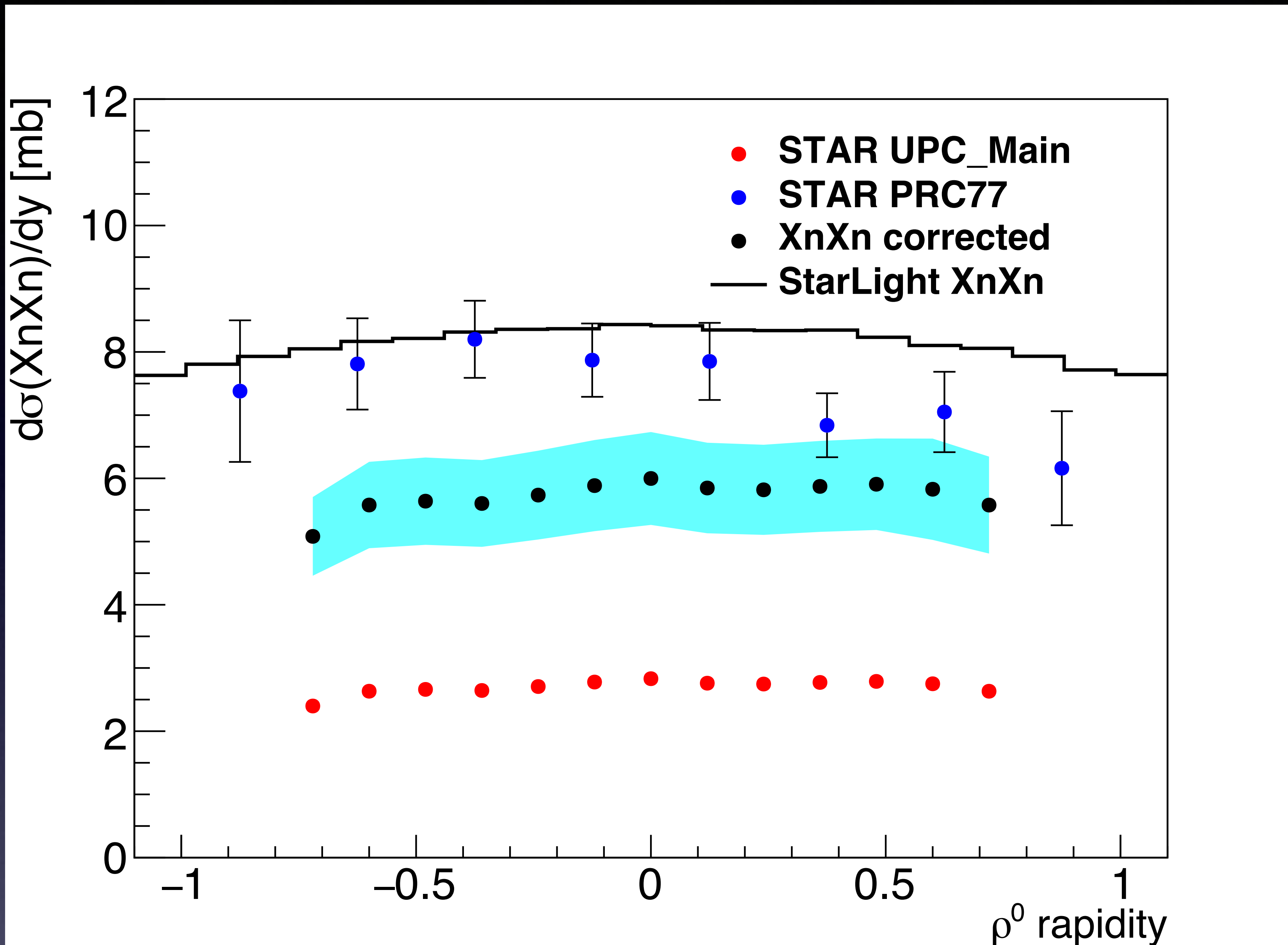


The C/A ratio measures the production amplitudes of of ρ and ω mesons. The value measured in the UPC environment at RHIC~0.2 (5 times higher than lower energy meas.) may be a hint of changing in the mixing between ω and ρ in the photon.

The B/A ratio compares the amplitude of the non-resonant pion pair (B) and the one of the rho Breit-Wigner component. This result confirms an already published STAR measurement (blue markers)

Colored bands show all systematic uncertainties identified so far, added in quadrature.

Rapidity distributions

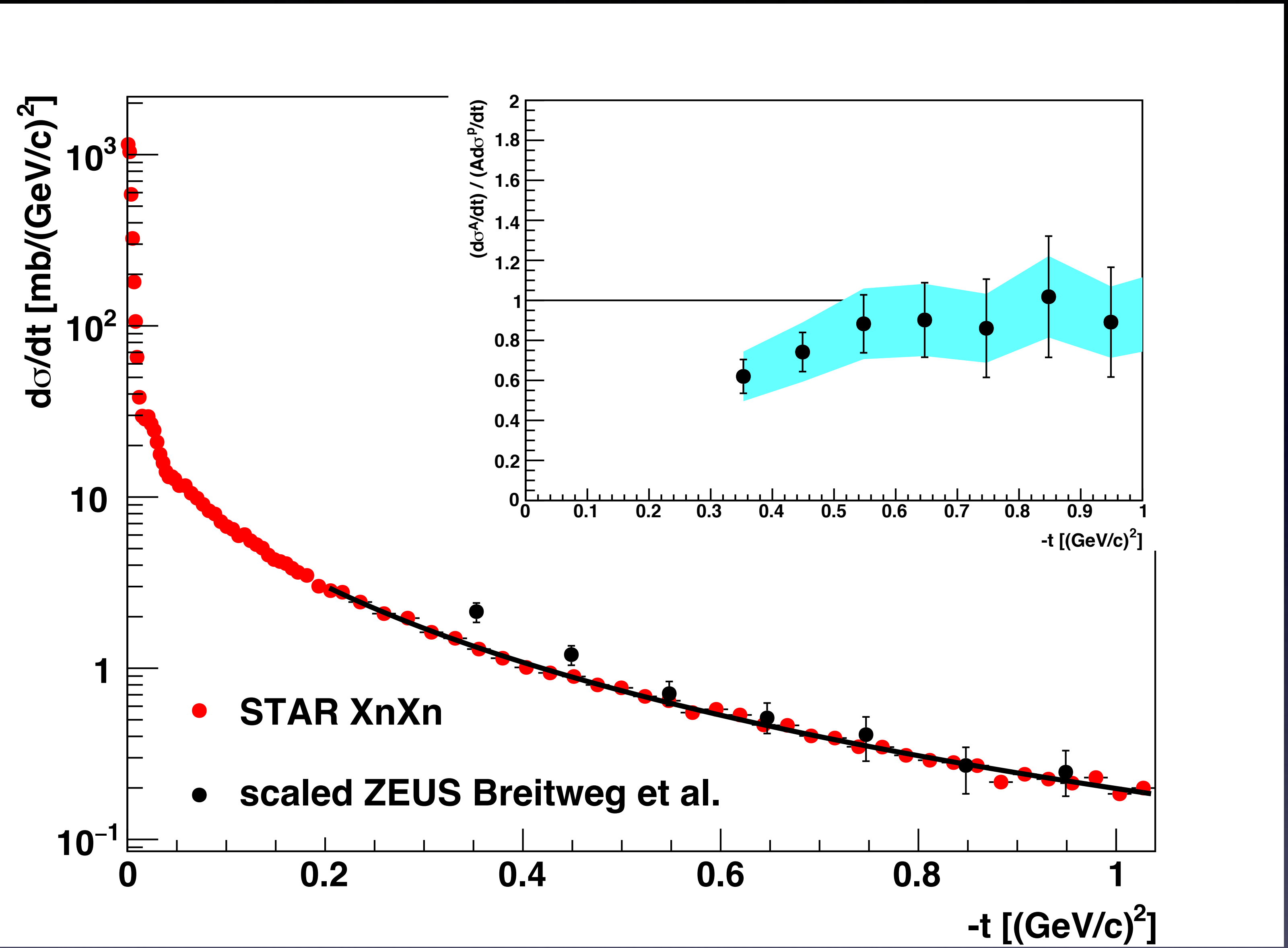


This distribution has been produced as a check for our analysis; it reproduces the published STAR publication (blue markers).

Blue band is sum in quad. of all systematic uncertainties identified in table below.

Red markers: fully corrected cross-section for UPC_Main triggered events (1-5 neutrons in ZDCs).
Black markers: Red markers scaled up by factor extracted from RELDIS to full XnXn mutual dissociation cross-section.

Incoherent component



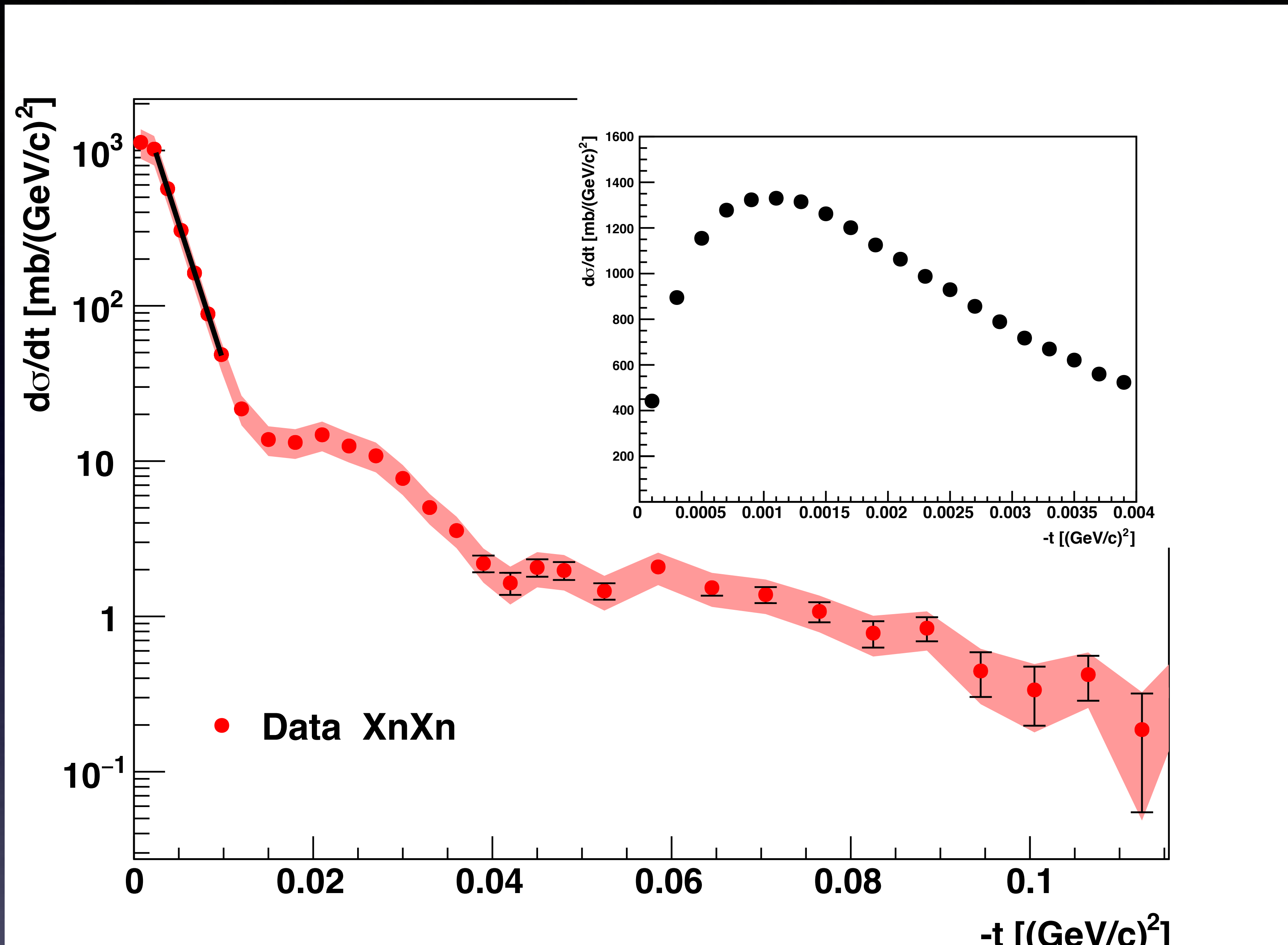
Background subtracted -t distribution with power law fit for -t>0.2 $(GeV/c)^2$

Black markers are diffractive measurements (ZEUS: γ+p) scaled from $W_{\gamma p}$=78GeV to RHIC value ($W_{\gamma p}$=12.5 GeV) and multiplied by A.

Insert: nuclear "transparency" factor $(d\sigma^A/dt)/(Ad\sigma^p/dt)$

This comparison may be used to shed light on the difference between incoherent scattering off nuclear and nucleon targets. In an extreme setting known as the "black disc" regime (smooth objects without fluctuations), incoherent cross sections in nuclear targets are "suppressed" the ratio is small. Very dilute system would produce a ratio ~1.

Diffraction pattern



Insert shows -t~0 with finer binning.
Displays destructive interference from two sources of ρ^0 mesons.

Coherent component of the -t ~p_T^2 distribution after subtraction of the fit to the high -t tail (incoherent component for -t>0.2 $(GeV/c)^2$

Slope of first peak: 386.6+-59.8 $(GeV/c)^{-2}$ f~$e^{-b|t|}$
b~10.8$A^{2/3}$ $(GeV/c)^{-2}$ (~366)
location of first dip at -t = 0.018± 0.005 (GeV/c)
location of second dip at -t = 0.043± 0.01(GeV/c)
FWHM of the two-dimensional Fourier transform ~6 fm. Consistent with charge radius of Au

Physics conclusions

- For the first time, in UPC environment, we see a clear coherent diffractive pattern (2 dips) with ρ^0 mesons off a target as big as the Au nuclei.

- We have been able to compare the incoherent scattering on Au to scaled γ+p and find small absorption.

- Fits to the coherent ρ^0 invariant mass show clear presence of ω meson. The high value of the ω/ρ^0 ratio of production amplitudes may be due to ω - ρ^0 mixing in the photon in possible conjunction with Pomeron exchange at RHIC energies.

Systematic uncertainties

Systematic Uncert. in the rapidity distribution:

rapidity	PID cut	Fit to efficiency	number of track hits	*normalization*	RELDIS (XnXn only)
-1., -0.5	8.%	0.25%	0.2%	10%	5%
-0.5 0.	5.%	0.25%	0.05%	10%	5%
0., 0.5	5.%	0.25%	0.05%	10%	5%
0.5, 1.	8.%	0.25%	0.2%	10%	5%

The “PID cut” and “number of track hits” uncertainties are correlated. The sum in quadrature of all uncertainties is chosen.

Systematic uncert. in the B/A and C/A ratios:

rapidity	B/A Lower limit of fit	C/A Lower limit of fit	B/A fullChain fit	C/A fullChain fit
-1., -0.35	3.2%	6.3%	1.9%	4.9%
-0.35 -0.15	2.%	2.5%	3.4%	21.8%
-0.15, 0.15	3.%	8.1%	1.7 %	6.5%
0.15, 0.35	3.8%	8. %	1.3%	0.6%
0.35, 1.	3.7%	6.3%	1.8%	0.4%

Systematic Uncert. in the -t distributions:

$-trange[(GeV/c)^2]$	track sel.	pion PID	Bkg sub.	Incoherent comp. sub.	Integrated luminosity	RELDIS
0 - 0.02	0.2%	8%	1.5	0.5%	10%	5%
0.02 - 0.04	0.2%	8%	1.5	1.0%	10%	5%
0.04 - 0.1	0.2%	8%	1.5	0.5%	10%	5%

Documents

First presentation DNP: http://www.star.bnl.gov/protected/pcoll/ramdebbe/RhoDiffractionDNP2011.pdf

Winter Workshop proceeding: arXiv:1209.0743 [nucl-ex]

EDSBlois proceedings: arXiv:1310.7044 [hep-ex]

Paper proposal: https://drupal.star.bnl.gov/STAR/blog/ramdebbe/coherent-diffraction-rho-mesons-au-nuclei-star-detector-rhic

Paper draft: http://www.star.bnl.gov/protected/pcoll/ramdebbe/rhoDiffraction.pdf

Supporting Analysis note: http://www.star.bnl.gov/protected/pcoll/ramdebbe/Main_analysisNote_RhoDiffraction.pdf

Backup

Data analysis

Collected 38.2 M events and processed them with the UPC StPeCMaker which was modified to handle several vertices produced by the VFPPVnoCTB vertex finder.

Two step vertex selection; select vertices with less than 6 tracks during StPeCMaker pass. Then select triggered vertex by matching at least one track from vertex to a TOF hit while reading pico-dst.

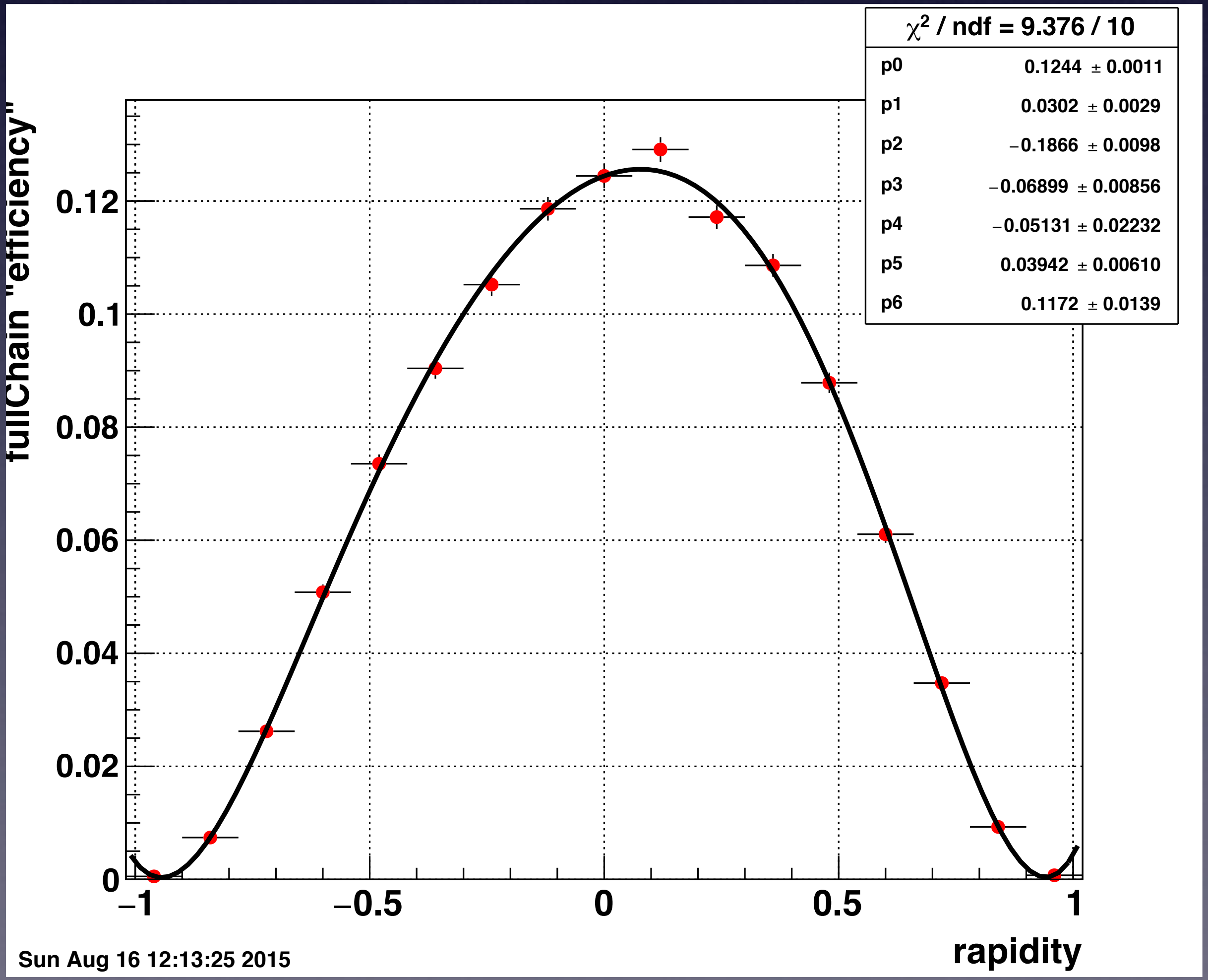
Our cleanest sample of ρ^0 mesons exclusively produced in $|Vz|<50$ cm has ~500K events.

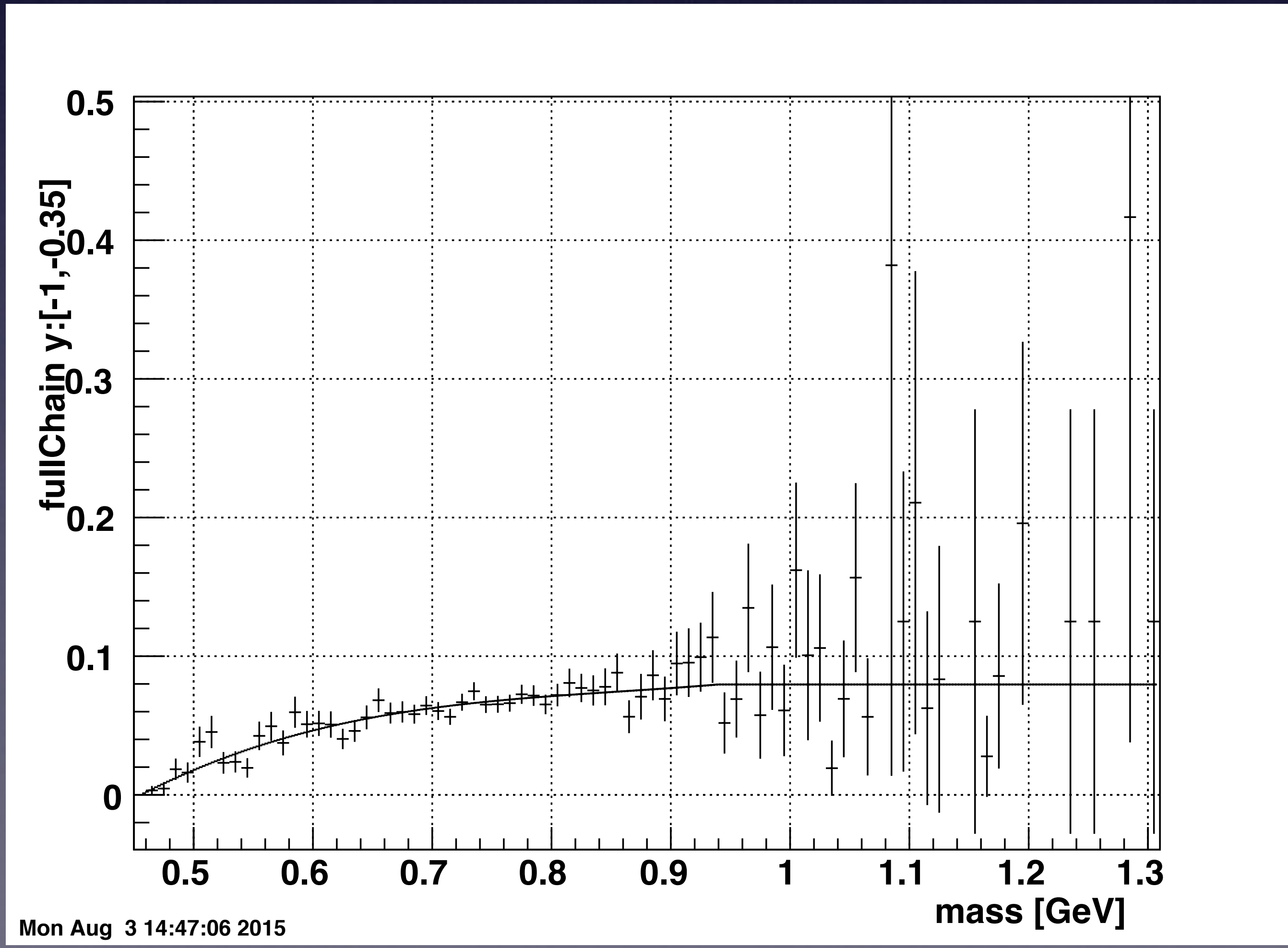
Extracted an overall correction “fullChain efficiency” with StarLight pion pairs embedded in zerobias events. Includes vertex reconstruction, full TPC mixing and TOF acceptance with updated geometry (no mixing). It also simulates the UPC_Main trigger. Includes all steps of the analysis.

Use luminosity extracted with VPDMinBias trigger as “base scaler” to avoid the ringing in the ZDCs. The total integrated luminosity for the runs included in the analysis is 1074.6 μb^{-1}
Cross section accessed with VPDMinBias: 6b (with 10% syst. uncertainty.)

Embedding

One million ρ^0 mesons generated by Starlight are decayed into pion pairs. The pions are transported through a complete GEANT3 description of the STAR experiment and are embedded in ZeroBias data from runs that span the 2010 Au+Au run.
Mixing of tracking information is done at the level of cluster ADC.
TOF mixing is done by merging hit information.





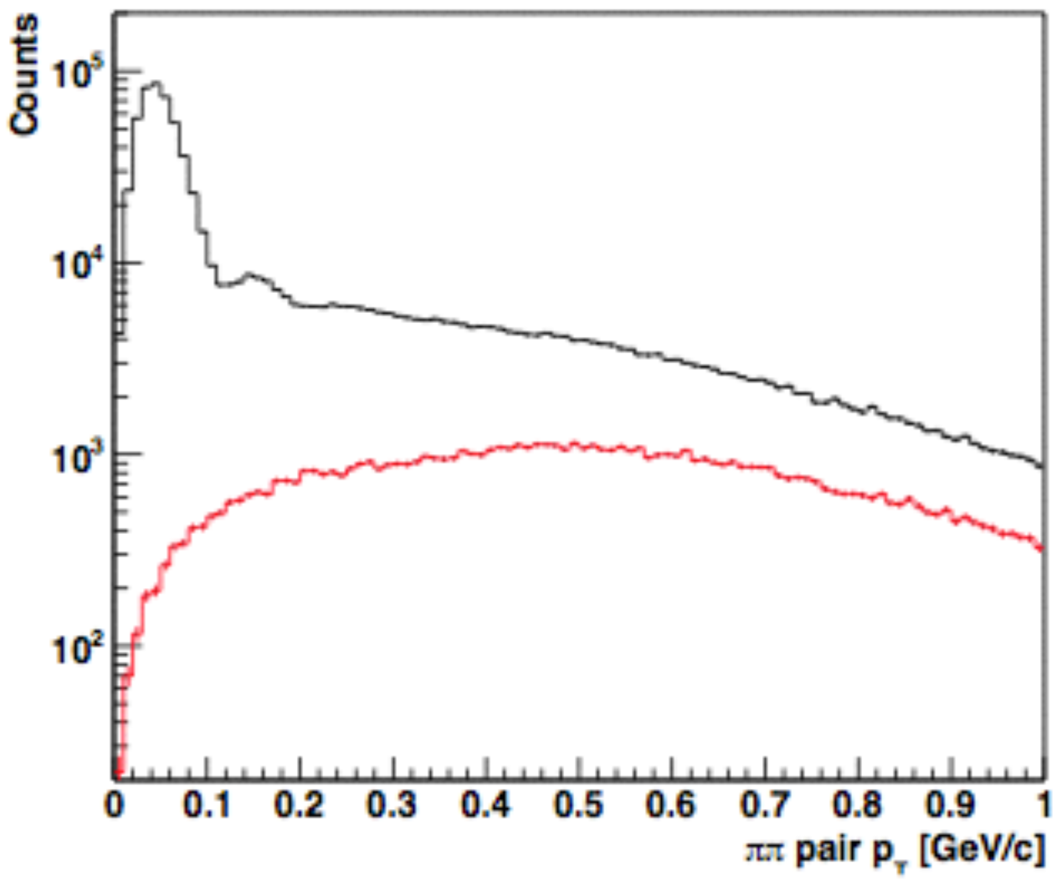


FIG. 1. The black histogram shows the distribution of the pion pair transverse momentum. The clear peak below 100 MeV/c is from the decay of coherently produced $\pi^+\pi^-$ pairs. The red histogram shows the distribution of the pair momentum for equal sign pion pairs. Both histograms are filled with selected pairs originating from vertices with only two tracks.

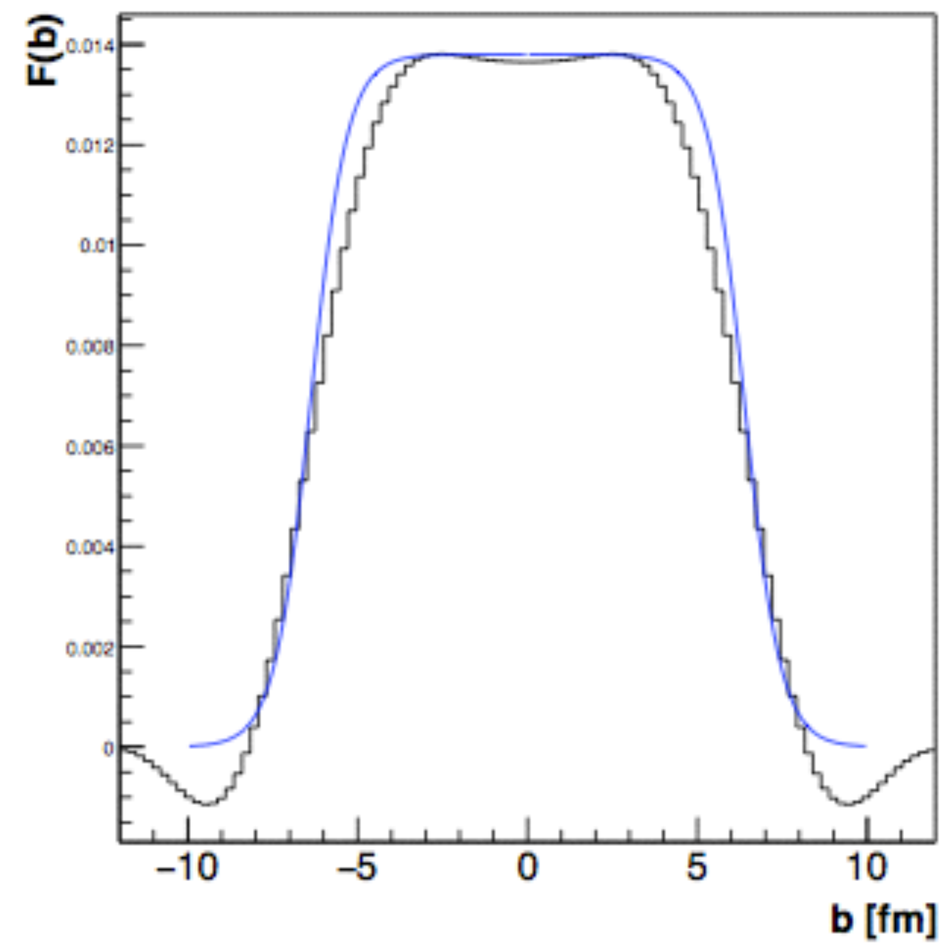
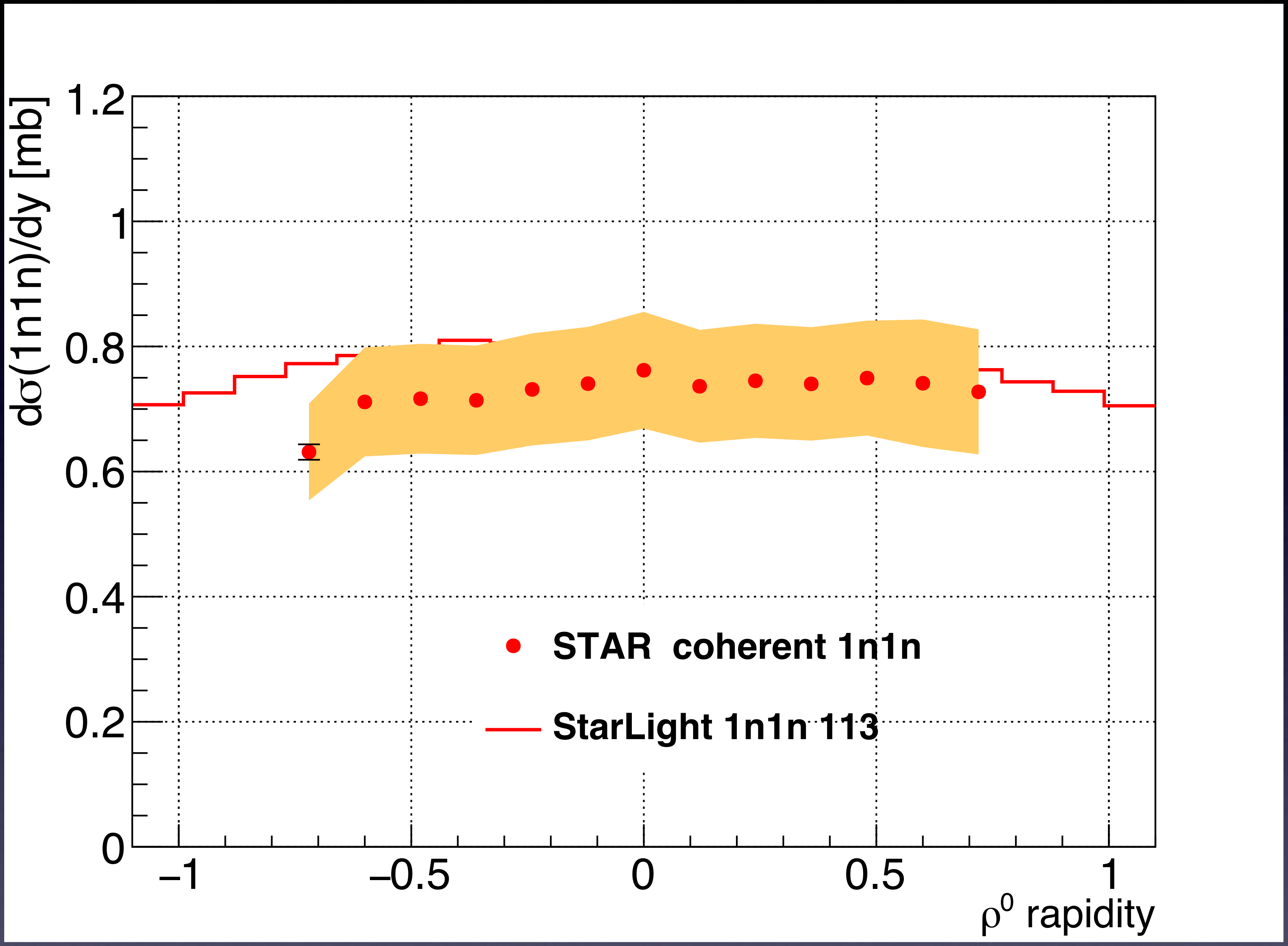


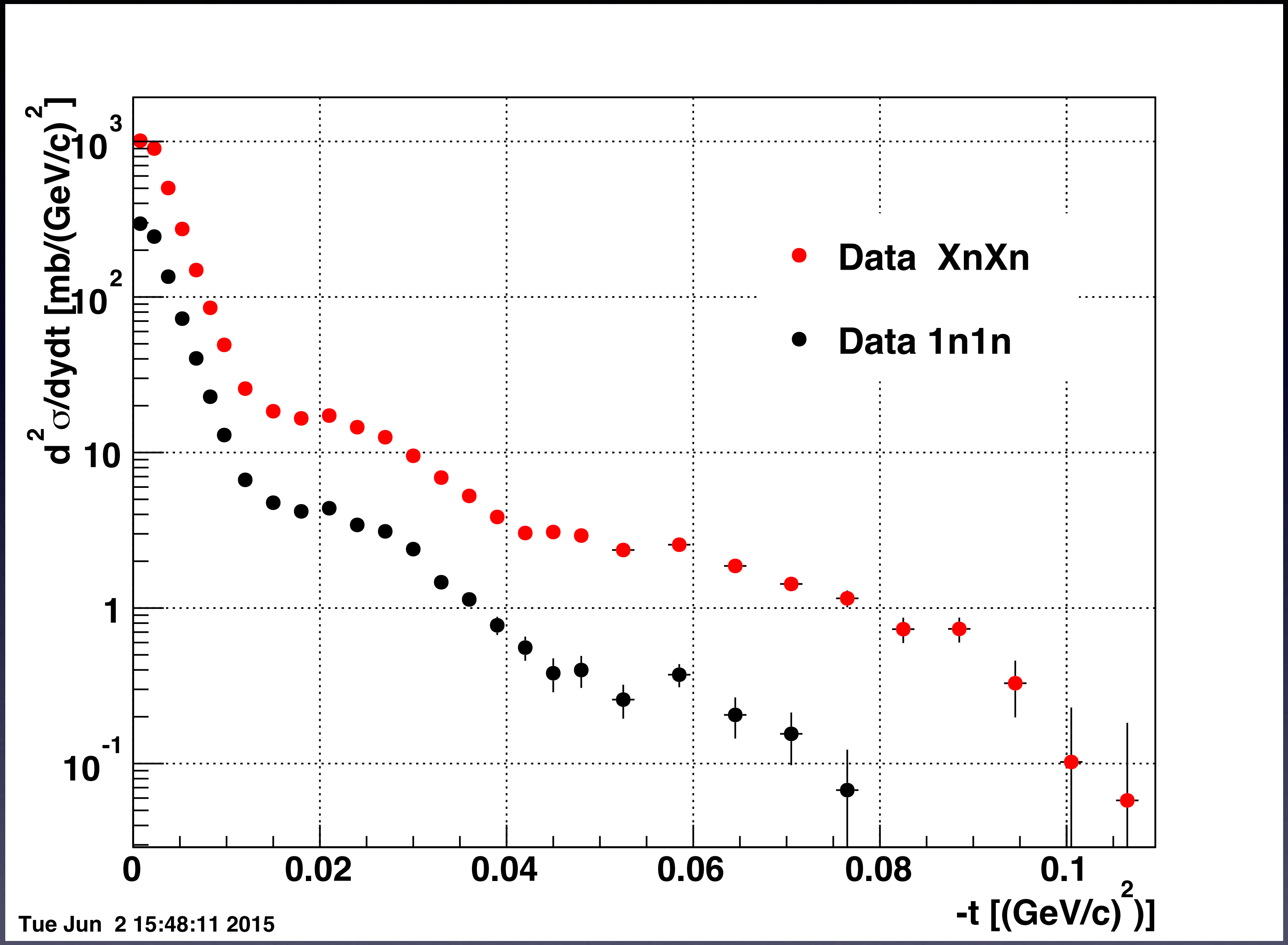
FIG. 7. The black histogram shows the Fourier transfom of the diffraction pattern shwon in Fig. 6 (integrated over azimuth angle and the finite rapidity window of this measurement). A Wood-Saxon distribution with Au nuclei parameters extracted from electron scattering experiments, scaled to the match the histogram, is displayed with the blue curve. The FWHM of both distributions agrees well and confirms the coherent diffraction of ρ^0 mesons off an object as big as the Au nuclei.

Another comparison to StarLight



By selecting only 1 neutron in both ZDCs we can avoid the RELDIS scaling and make the comparison directly to starlight.

Number of neutrons in ZDcs selects impact parameters



First dip is well defined, second dip is also clear.
No visible dependence with the number of neutrons in ZDC (impact parameter)