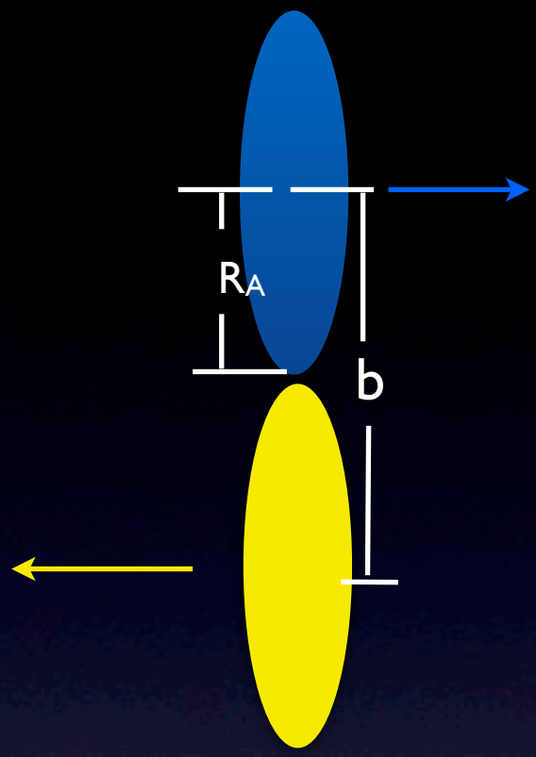
# Latest RHIC Results on UltraPeripheral Collisions

R. Debbe BNL

EDS Blois 2013 Saariselkä Finland 9-13th Sep.2013

# Brief Ultra Peripheral Physics formalism

Heavy Ions in colliders are a source of very strong EM fields ($Z\alpha = 0.58$) interesting physics accessible if hadronic interactions are excluded ($b > 2R_A$)




Strong fields and relativistic beams ($\gamma = 108$ at RHIC) amenable to good description of interaction via Weizsäcker-Williams formalism: Each ion sees a pulse of plane-polarized quasi-real photons that last $\Delta t \sim b/\gamma c$ with energies that reach $\hbar\omega_{max} = h/\Delta t = \gamma hc/b$

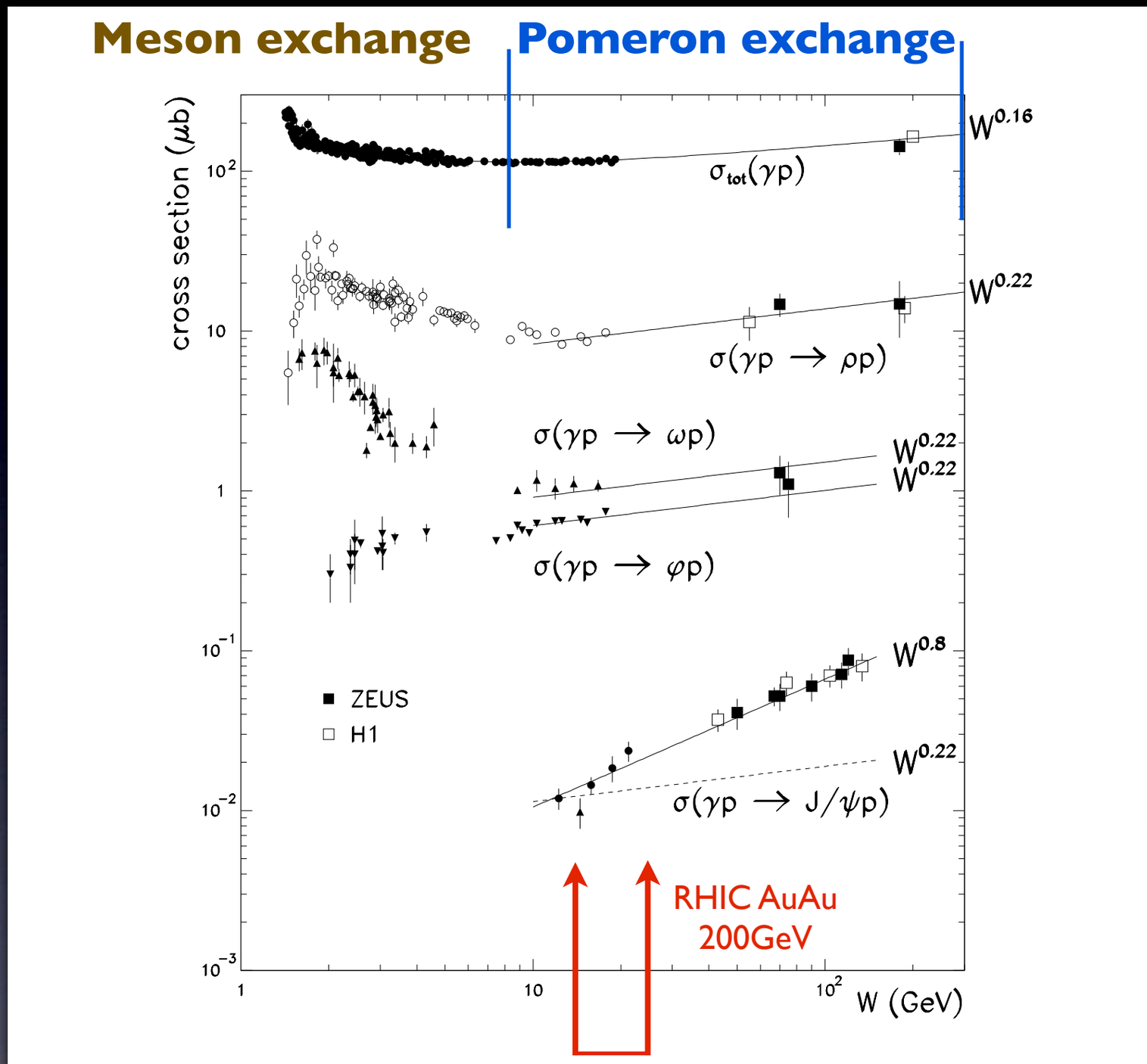
| Accelerator | Ions | Max. Energy per nucleon pair (CM) | Luminosity | Max. $\gamma p$ | Max. $\gamma\gamma$ energy |
|---|---|---|---|---|---|
| CERN SPS | Pb+Pb | 17 GeV | — | 3.1 GeV | 0.8 GeV |
| RHIC | Au+Au | 200 GeV | $4 \times 10^{26}$ cm$^{-2}$ s$^{-1}$ | 24 GeV | 6.0 GeV |
| RHIC | p+p | 500 GeV | $6 \times 10^{30}$ cm$^{-2}$ s$^{-1}$ | 79 GeV | 50 GeV |
| LHC | Pb+Pb | 5.6 TeV | $10^{27}$ cm$^{-2}$ s$^{-1}$ | 705 GeV | 178 GeV |
| LHC | p+p | 14 TeV | $10^{34}$ cm$^{-2}$ s$^{-1}$ | 3130 GeV | 1400 GeV |
| Tevatron | p+$\bar{p}$ | 20 TeV | $5 \times 10^{31}$ cm$^{-2}$ s$^{-1}$ | 320 GeV | 200 GeV |

Bertulani, Klein, Nystrand
Annu. Rev. Nucl. Part. Sci. 2005. 55:271–310

# RHIC kinematical reach

Minimum γ energy to produce a ρ at rest: 0.5GeV
$W_{min}$~14GeV

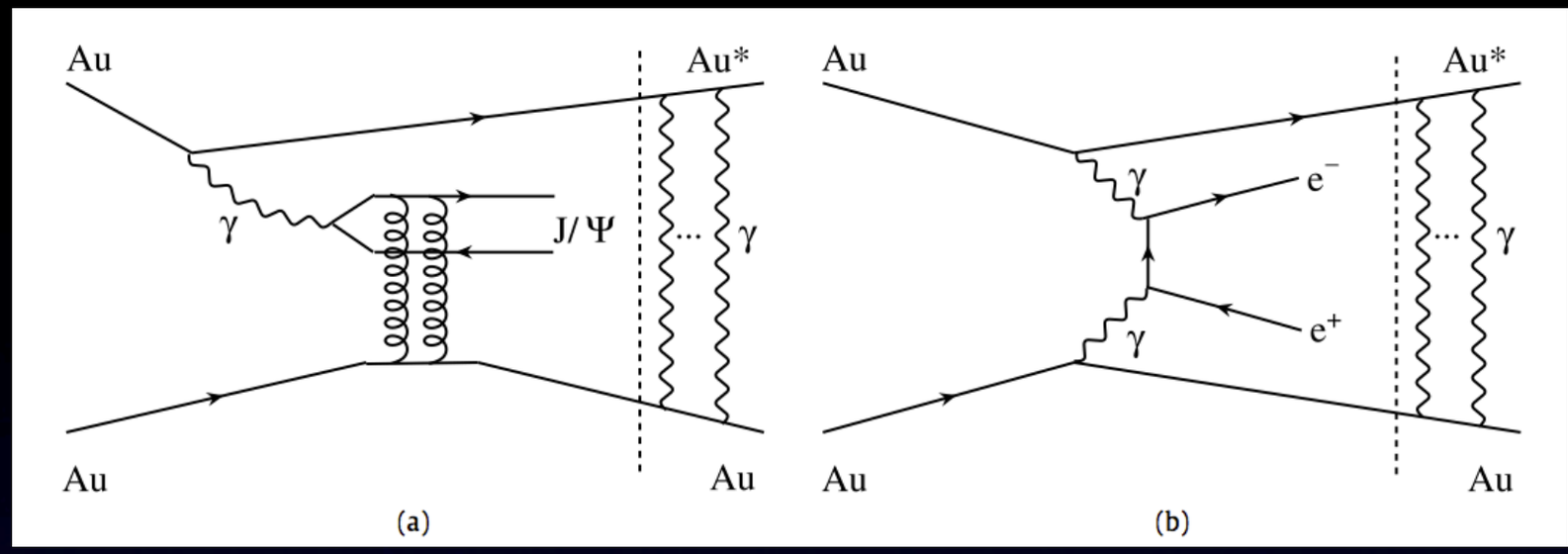
For the photon-nucleus events, the RHIC energies are in the Pomeron dominated region.
Only the J/ψ probe has a hard scale:
$Q^2$ ~2.5 $(GeV/c)^2$




J.A. Crittenden Springer Tracts in Modern Physics Volume 140 (Springer, Berlin, Heidelberg, 1997)

# UPC event types

The UPC events can be photon-nucleus (a) or photon-photon (b)




a) The photon-nucleus interaction is well described with di-quark fluctuations:

- u, d quark dipole $\rho^0$ ($u\bar{u}$-$d\bar{d}$) published STAR
- s quark dipole $\Phi$ ($s\,\bar{s}$) seen in STAR, study in progress.
- c quark dipole J/$\Psi$ ($c\,\bar{c}$) published by PHENIX, study in progress in STAR and PHENIX.

b) The high mass $\gamma+\gamma \rightarrow e^+ e^-$ has been published by PHENIX and the low mass region by STAR.

Additional $\gamma$ exchange produce nuclear excitations that help in trigger and event selection.

# Triggering on UPC events in collider mode

Avoid hadronic interactions  Reduce impact parameter

UPC events have most activity distributed around mid-rapidity with simple (2-4 tracks) topologies.

Triggers are based on the requirements:

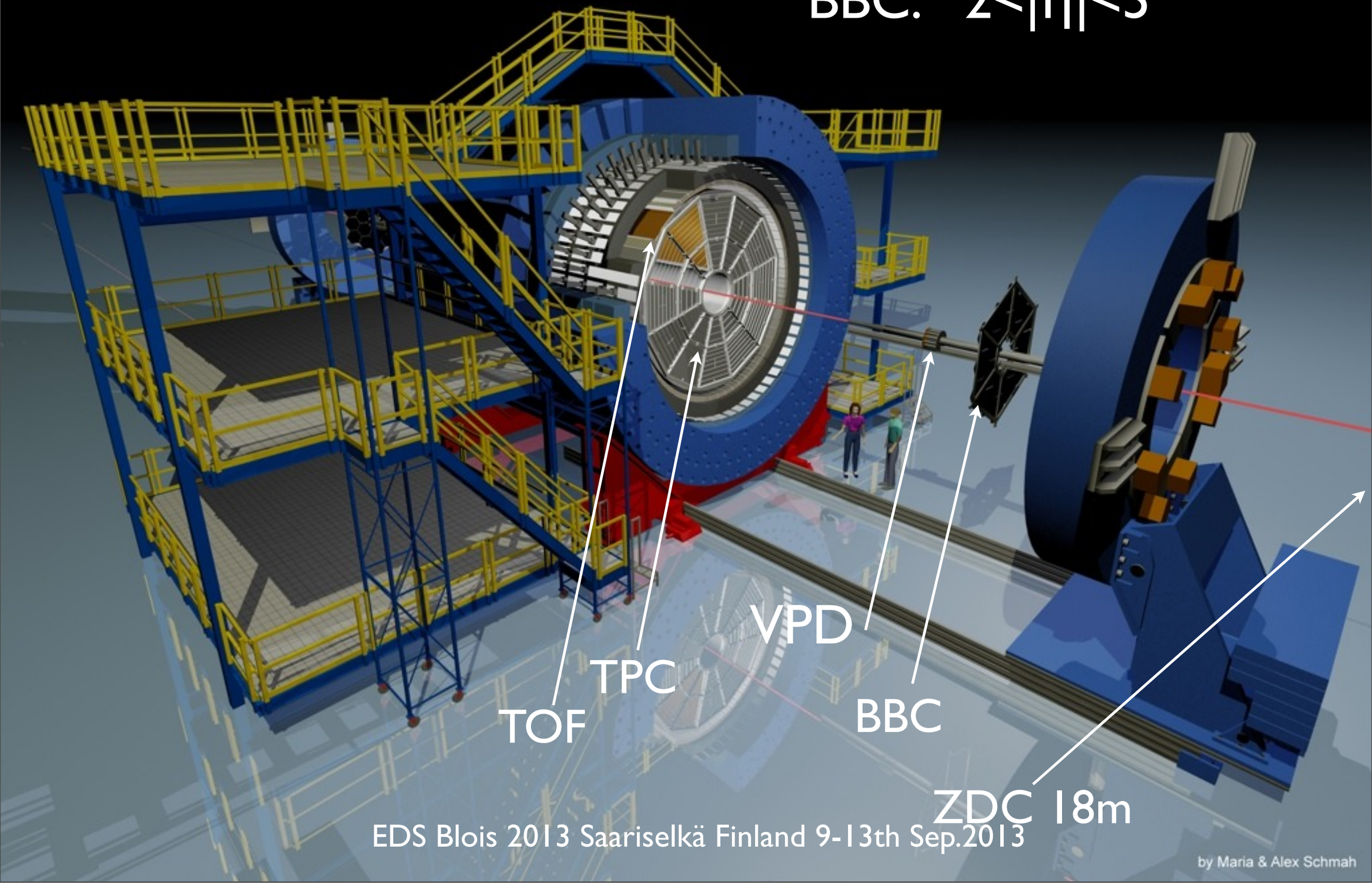
- No activity in a wide range of rapidity (symmetric).
- Low activity in a region of interest.

In high luminosity environments, these regions may get flooded with background and require additional constraints; beam momentum neutron counts at 0 degrees are good to clean-up the triggers

# Triggering UPC in STAR

TPC & TOF: $|\eta|<1.2$ $1<hits<7$

BBC: $2<|\eta|<5$

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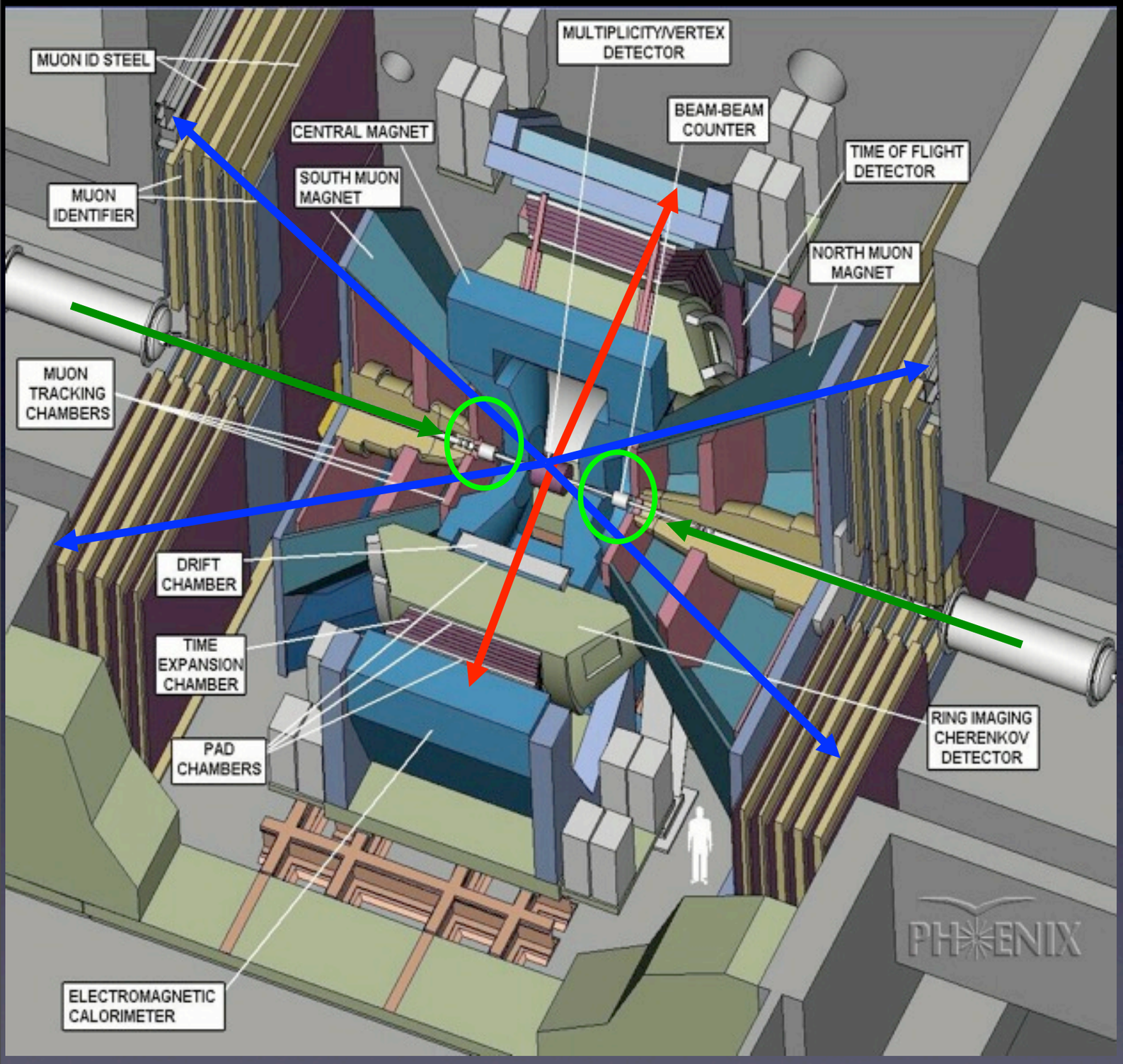
# Triggering UPC in PHENIX




2004 Central Arm $|y|<0.35$:
Veto on both BBC $3<|\eta|<3.9$,
EMCal trigger ERT 2X2 tile with signal above 0.8 GeV
At least 30 GeV in one or both ZDCs. (Xn)

2010 Forward Muon arm($1.2<|y|<2.2$)
same as 2007 but replace EMCal-trigger by requirement of a Muon track
both ZDCs are required XnYn

# 2004 PHENIX $e^+e^-$ events in Central Arm

8M events collected with the UPC trigger, 6.7M selected.

Integrated luminosity $\mathcal{L}_{int}$ = 141±12 $\mu b^{-1}$

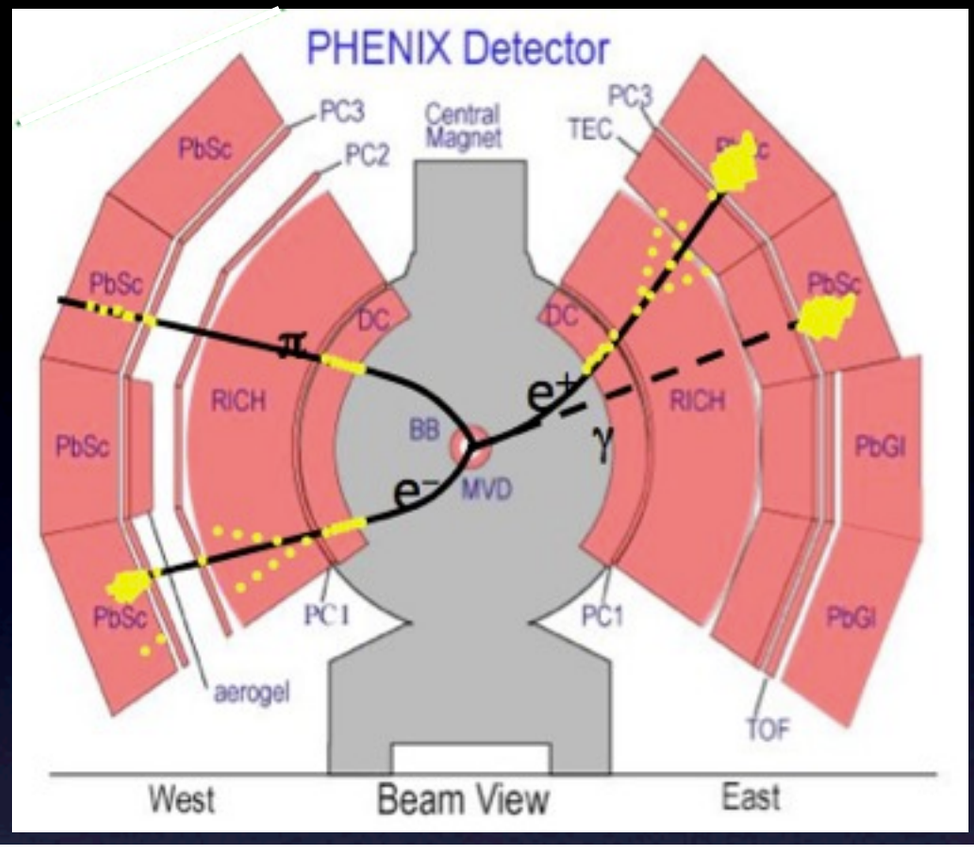
Vertex reconstructed in 2 tracks events

$\delta p/p \approx 0.7\% \oplus 1.0\% p[\mathrm{GeV}/c]$

Electron id in RICH and EMCal

Coherent production: one track in each central arm.

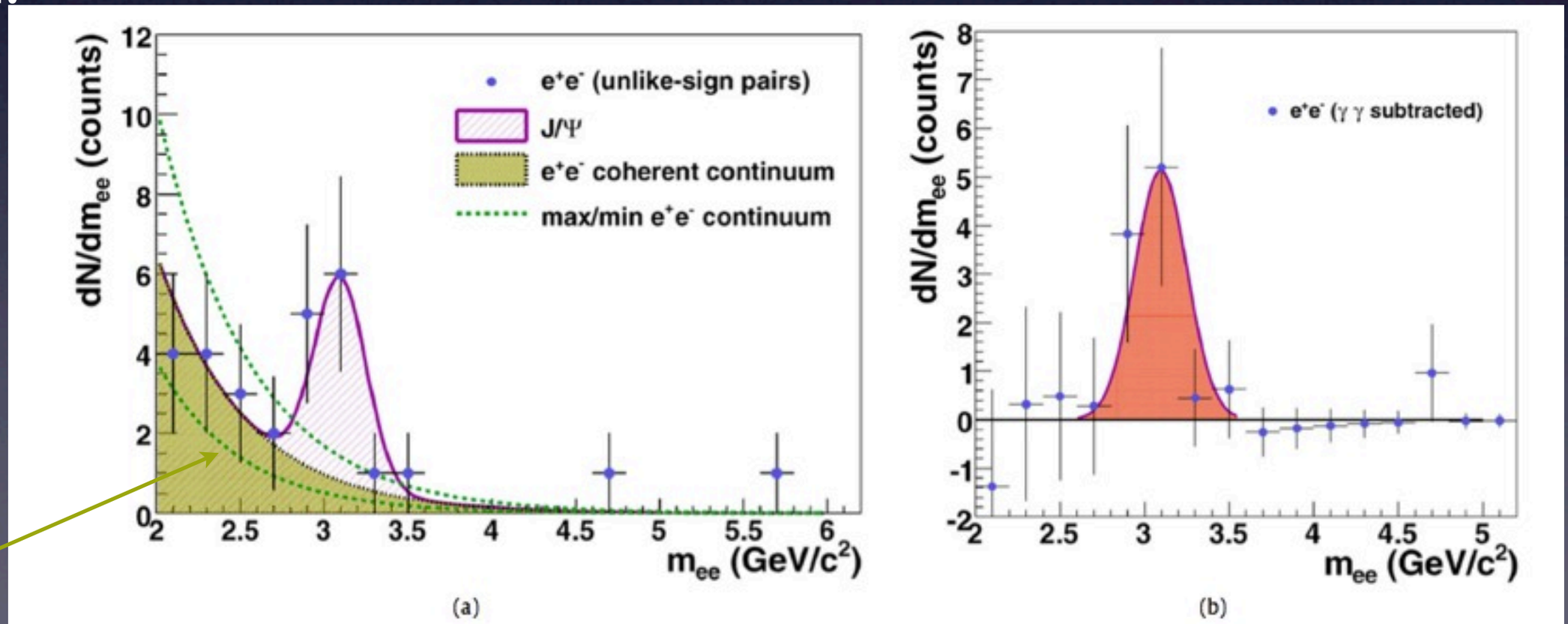
Physics Letters B 679, 321 (2009)




## J/ψ Xn

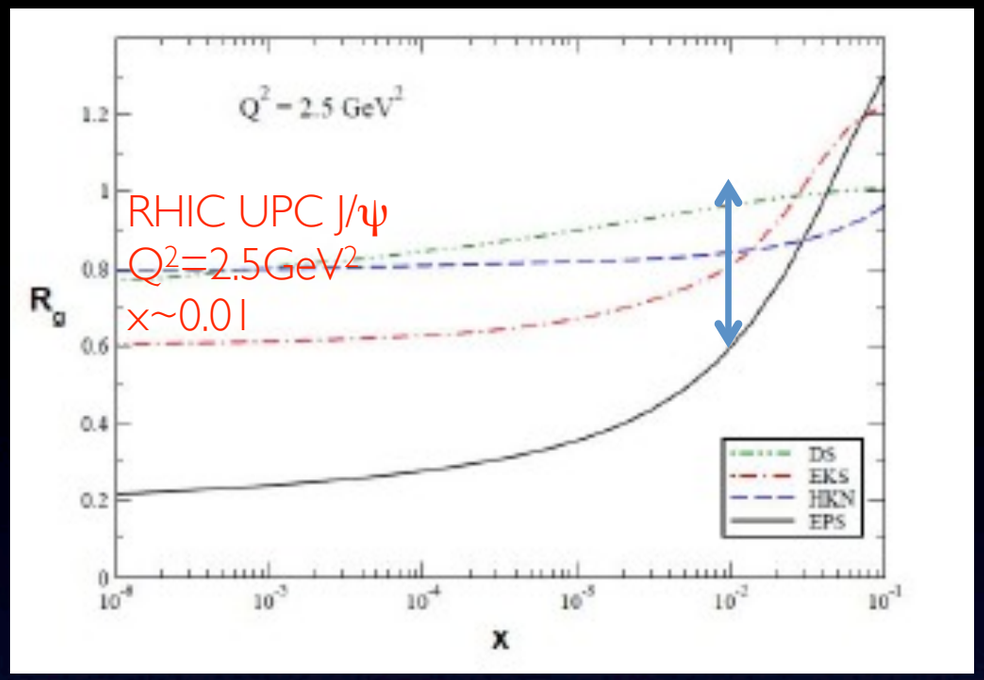
Background estimator: same sign pairs. No counts under above 2 GeV/$c^2$

Syst. uncert. on continuum



# 2004 PHENIX $e^+e^-$ events in Central Arm

The J/Psi + A interaction in UPC at y~0 has a scale $Q^2 \sim M_v^2/4$, it probes gluon PDFs that are, so far, unconstrained




From raw counts of

N(J/ψ)=9.9 ± 4.1 (stat) ± 1.0 (syst)

$$\frac{d^2\sigma_{e^+e^-+Xn}}{dy\, dm_{e^+e^-}} = \frac{N_{e^+e^-}}{Acc \cdot \varepsilon \cdot \varepsilon_{trigg} \cdot \mathcal{L}_{int}} \cdot \frac{1}{\Delta y} \cdot \frac{1}{\Delta m_{e^+e^-}}$$
$$= 86 \pm 23(\text{stat}) \pm 16(\text{syst})\ \mu\text{b}/(\text{GeV}/c^2)$$
for $m_{e^+e^-} \in [2.0, 2.8]$ GeV/$c^2$ and $|y| < 0.35$. (2)

For $J/\psi$ at midrapidity ($|y| < 0.35$) the differential cross section is:

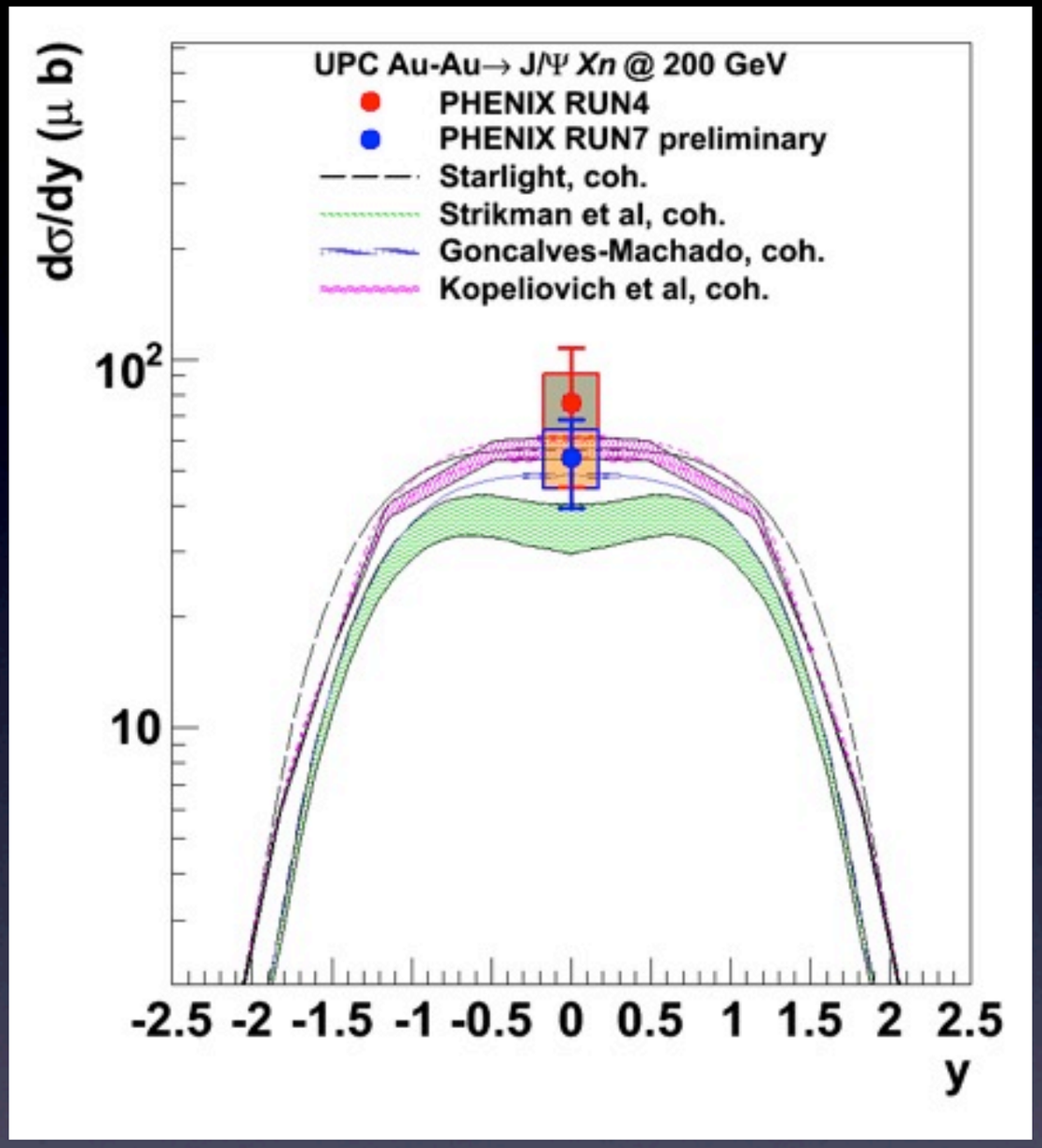
$$\frac{d\sigma_{J/\psi+Xn}}{dy} = \frac{1}{\text{BR}} \cdot \frac{N_{J/\psi}}{Acc \cdot \varepsilon \cdot \varepsilon_{trigg} \cdot \mathcal{L}_{int}} \cdot \frac{1}{\Delta y}$$
$$= 76 \pm 31(\text{stat}) \pm 15(\text{syst})\ \mu\text{b}. \quad (3)$$

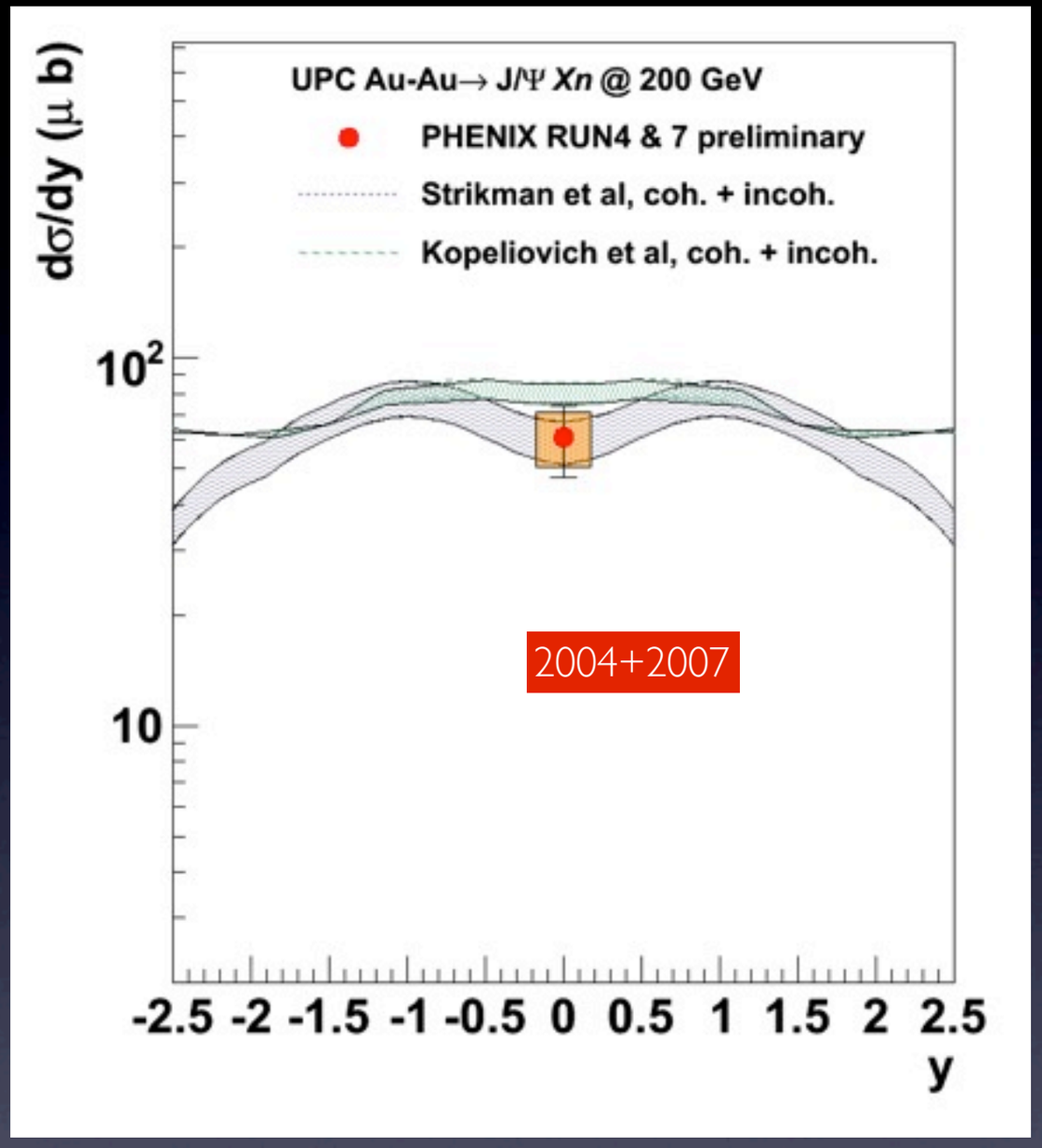
Cross sections for $e^+e^-$ and J/ψ at y~0

$e^+e^-$ pairs are coherent.

| $J/\psi$ | $d\sigma/dy\|_{y=0}$ [μb] $76 \pm 31(\text{stat}) \pm 15(\text{syst})$ | |
|---|---|---|
| $m_{e^+e^-}$ [GeV/$c^2$] | $d^2\sigma/dm_{e^+e^-}\, dy\|_{y=0}$ [μb/(GeV/$c^2$)] data | STARLIGHT |
| $e^+e^-$ continuum [2.0, 2.8] | $86 \pm 23(\text{stat}) \pm 16(\text{syst})$ | 90 |
| $e^+e^-$ continuum [2.0, 2.3] | $129 \pm 47(\text{stat}) \pm 28(\text{syst})$ | 138 |
| $e^+e^-$ continuum [2.3, 2.8] | $60 \pm 24(\text{stat}) \pm 14(\text{syst})$ | 61 |

# J/ψ +Xn Central 2004 & 2007




2004 PHENIX

76 ± 31 (stat) ±15 (syst) μb

2007 PHENIX

$61.8 \pm 17\,(\text{stat}) +^{+8.7}_{-8.8}\,(\text{sys})\ \mu\text{b}$

Combined result: $66.2 \pm 15.1\,(\text{stat}) +^{+9.41}_{-9.48}\,(\text{sys})\ \mu\text{b}$

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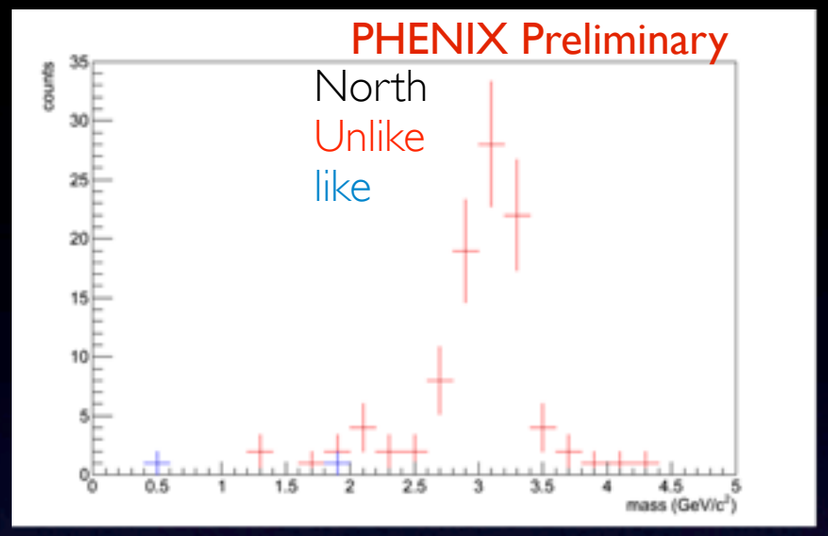
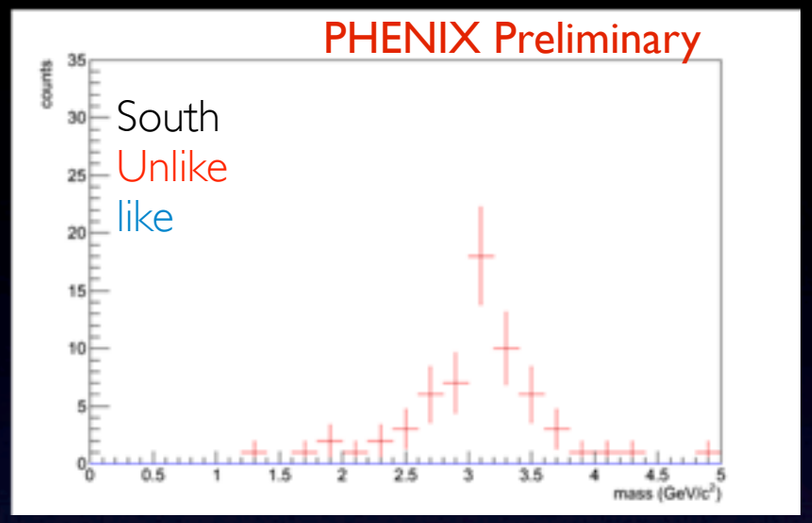
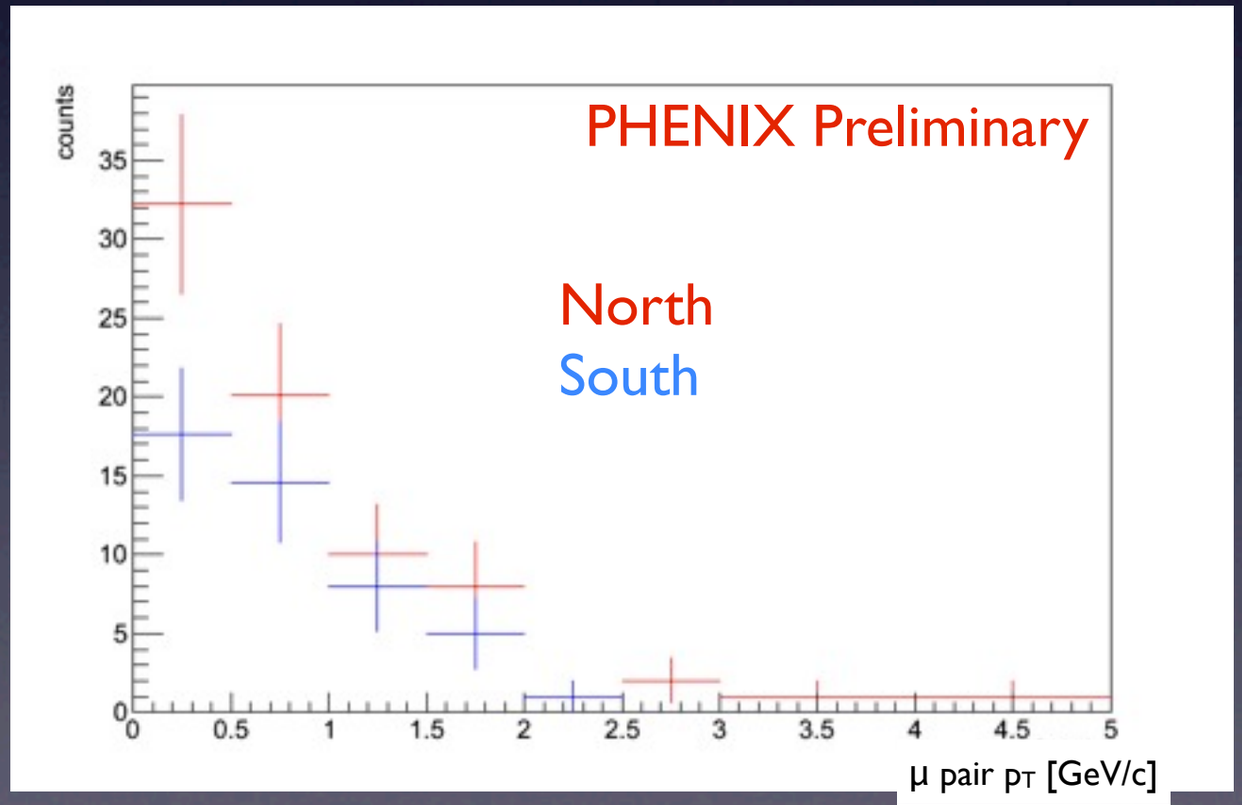
# 2010 PHENIX UPC with Muon Arms 1.2<|y|<2.2



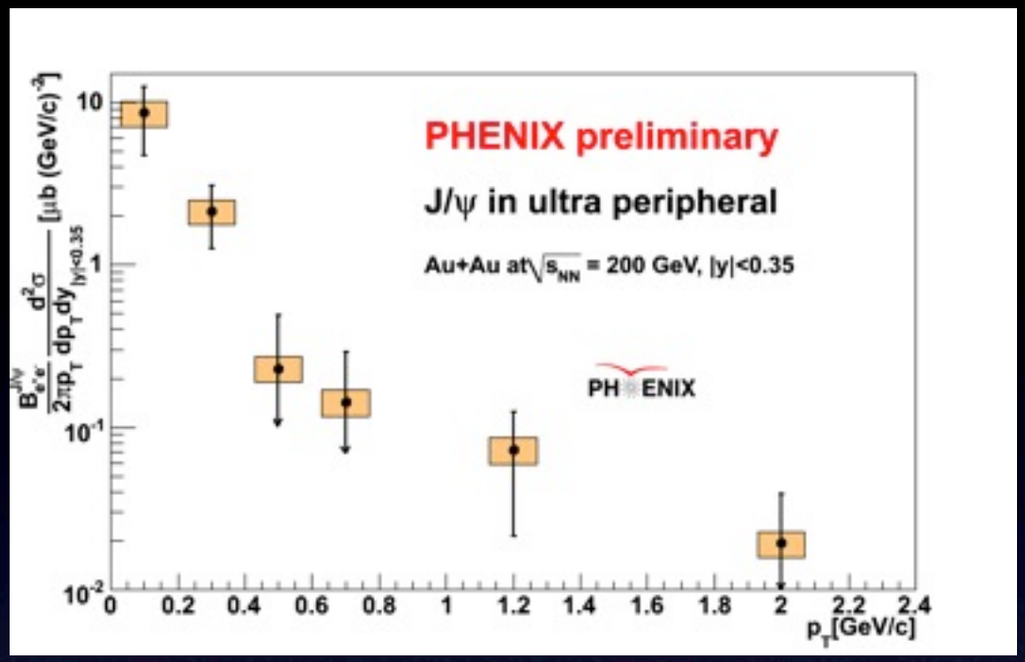



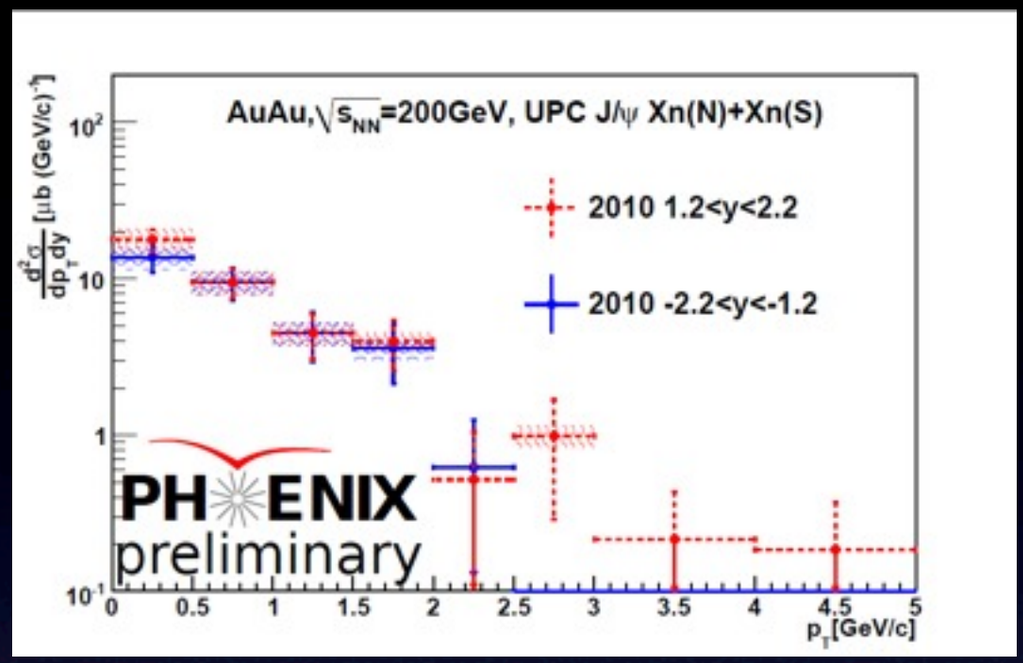

At least a neutron count in both ZDCs XnYn

Clear di-μ peak at J/ψ mass in both muon arms.
The $p_T$ distribution appears to be filled mainly from incoherent photo-production.



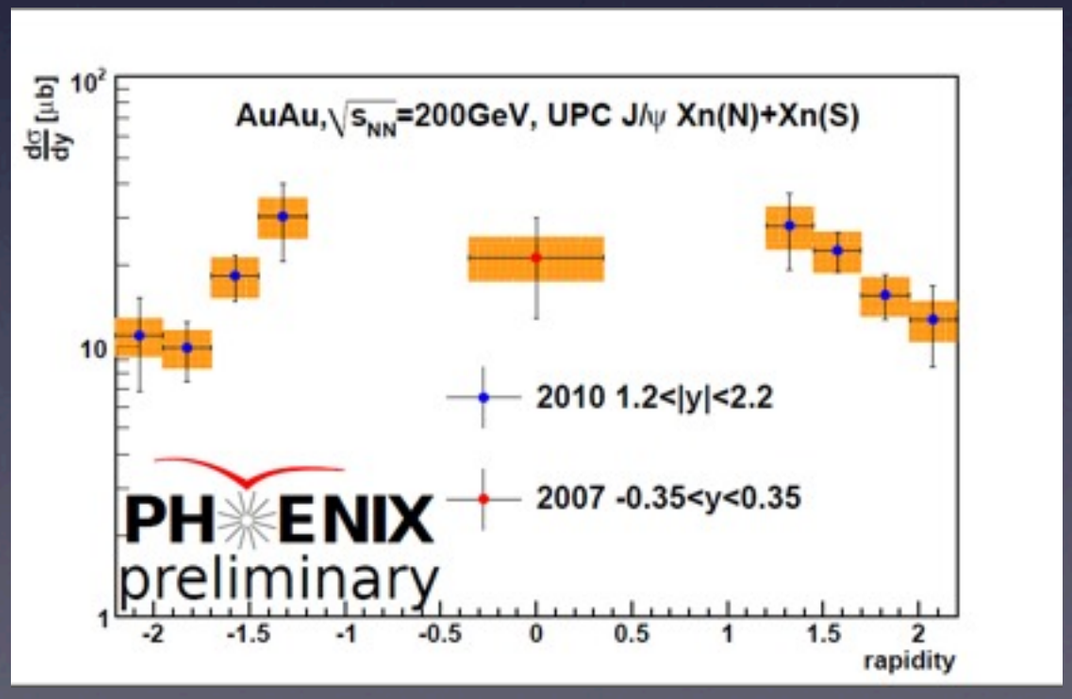
# PHENIX J/ψ at different rapidities




The 2007 higher statistics show clear presence of coherent and incoherent components at mid-rapidity. In the 2010 dataset one only finds incoherent photo-production at higher rapidity.

With the 2010 data set an almost complete rapidity distribution is possible.

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# The STAR UPC program

## Publications:

**$rho^{0}$ Photoproduction in AuAu Collisions at $\sqrt{s_{NN}}$=62.4 GeV with STAR**
*Submitted Jul. 22, 2011 , published Jan. 30, 2012*
Phys. Rev. C **85** (2012) 14910

**Observation of pi^+pi^-pi^+pi^- photoproduction in ultraperipheral heavy-ion collisions at sqrt(s_NN) = 200 GeV at the STAR detector**
*Submitted Dec. 4, 2009 , published Apr. 2, 2010*
Phys. Rev. C **81** (2010) 44901

**Observation of Two-source Interference in the Photoproduction Reaction $Au Au \rightarrow Au Au \rho^0$**
*Submitted Dec. 5, 2008 , published Mar. 16, 2009*
Phys. Rev. Lett. **102** (2009) 112301

**$\rho^0$ Photoproduction in Ultra-Peripheral Relativistic Heavy Ion Collisions with STAR**
*Submitted Dec. 21, 2007 , published Mar. 31, 2008*
Phys. Rev. C **77** (2008) 34910

**Coherent Rho-zero Production in Ultra-Peripheral Heavy Ion Collisions**
*Submitted Jun. 7, 2002 , published Dec. 20, 2002*
Phys. Rev. Lett. **89** (2002) 272302

Event selection and triggering
di electron from $\gamma$+$\gamma$ with low inv. mass
$\rho^0$ production
$\Phi$ production
J/$\psi$ production
$\rho^0$ diffraction
Future plans (include UU + pA)

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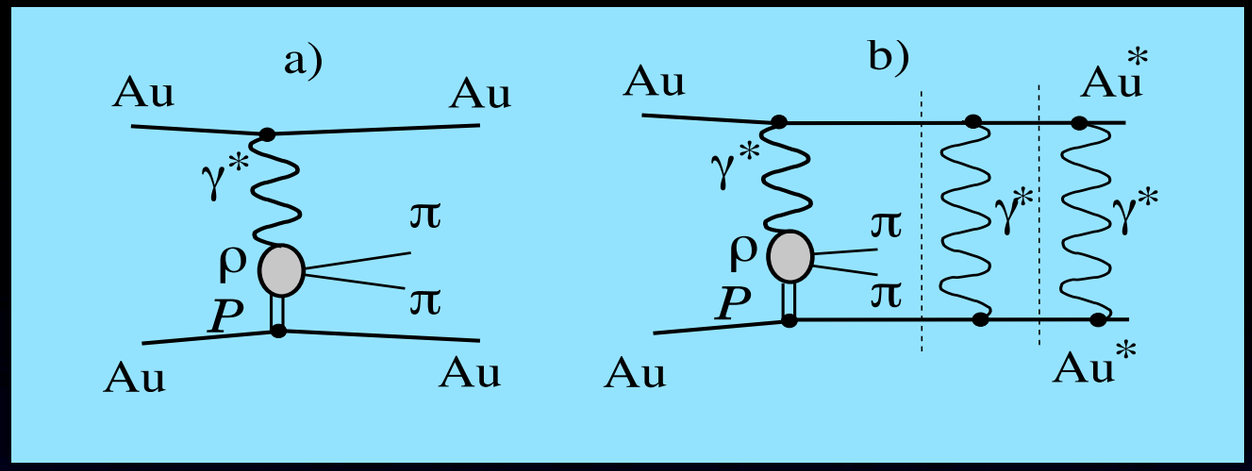
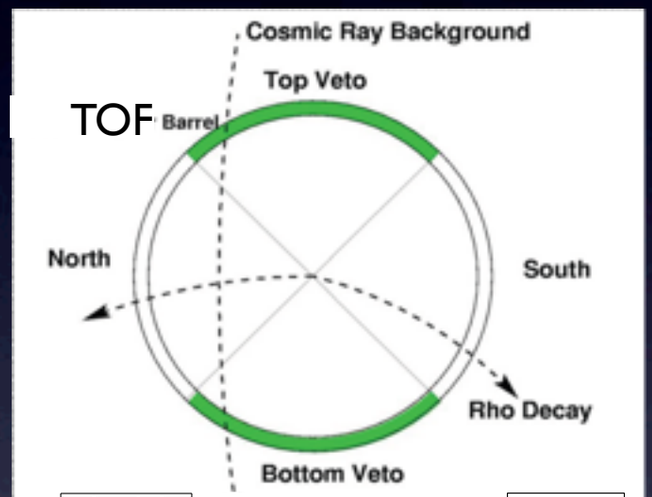
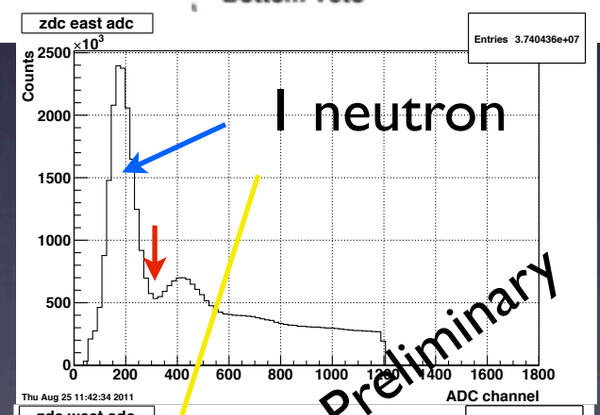
# STAR triggers

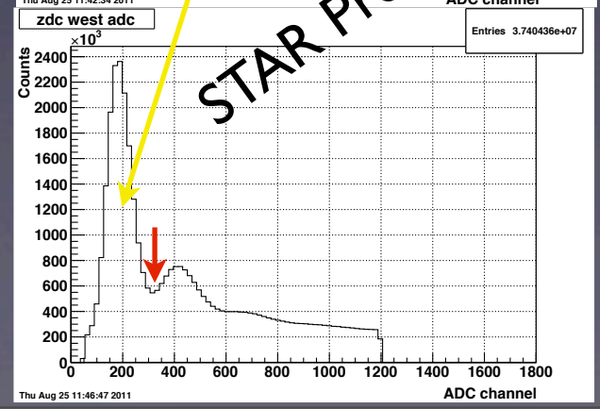



a) UPC_Topo: veto on all BBC tiles 2<|η|<5, TOF hits in two sectors and veto remaining ones (exclude cosmic rays.)

b) UPC_Main: veto on small BBC tiles 3<|η|<5, 2≤TOF hits ≤6, 1≤beam neutron≤6 in both ZDCs (may select smaller b)

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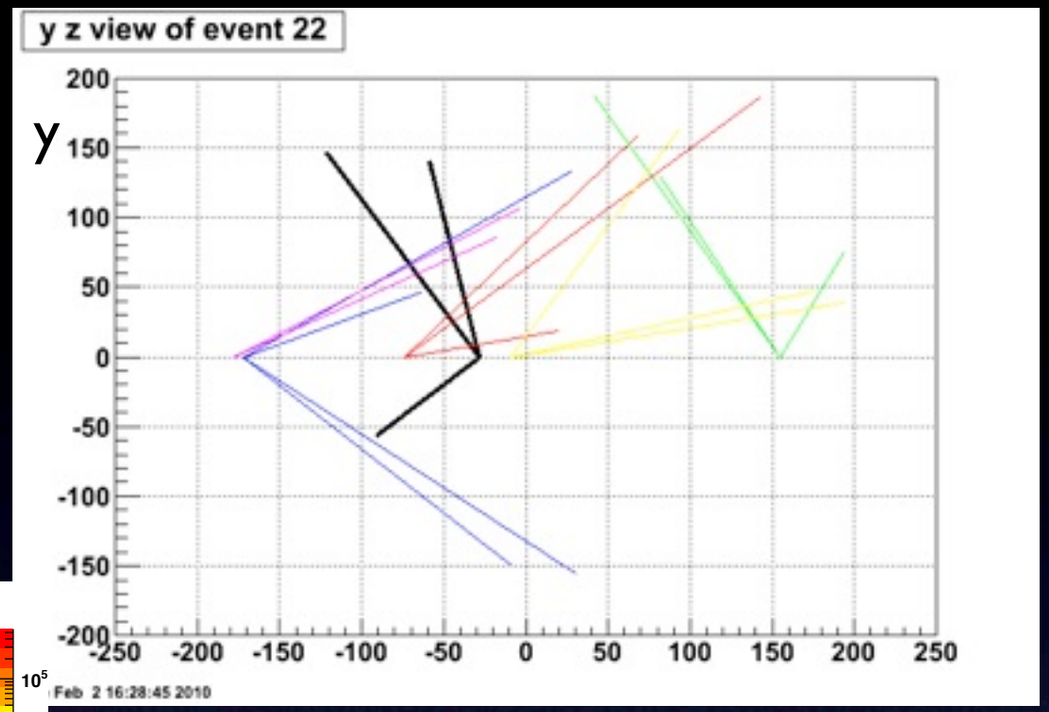
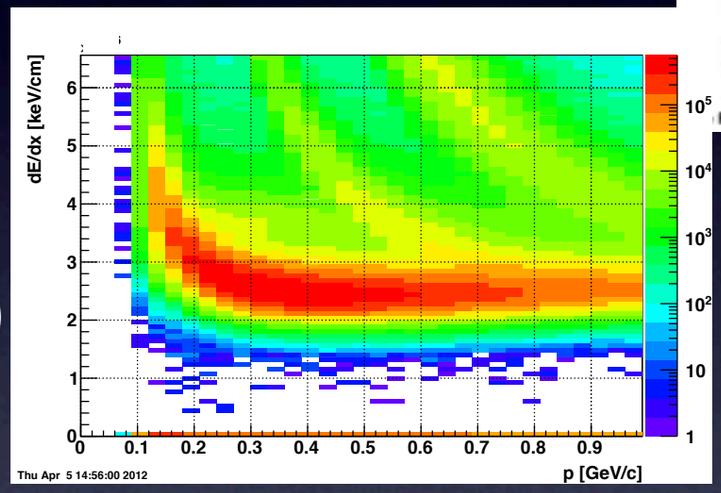
# The STAR UPC event selection

Low activity at y~0 use STAR TPC and trigger with TOF. Multiple events recorded in TPC. Use TOF to select the triggered events

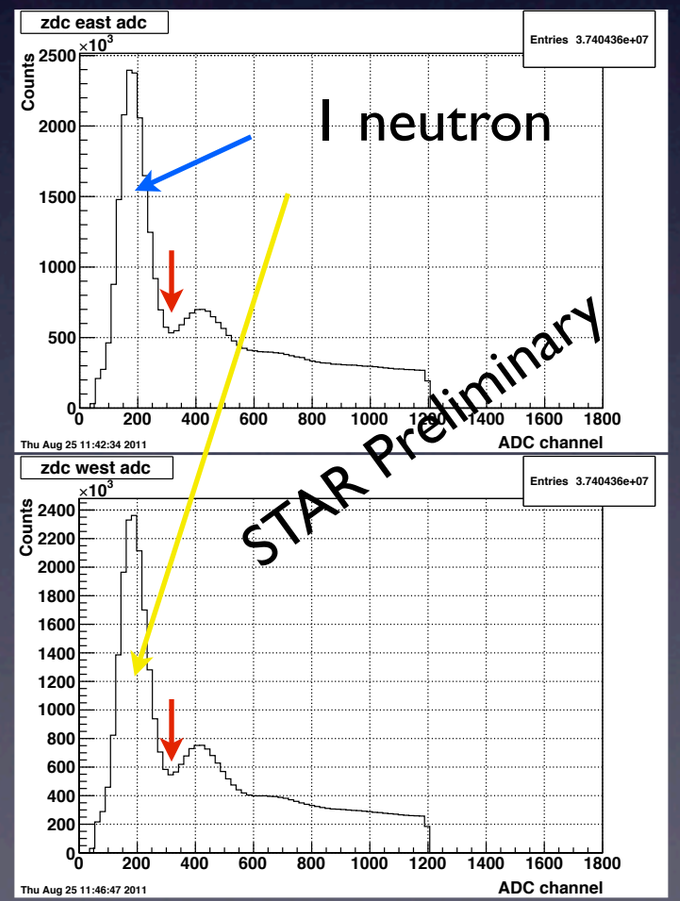



PID done with ionization in TPC (up to 47 samples)




Exclusive vector meson production by selecting events with only 2 tracks out of selected vertex.

Diffraction analysis requires 1n1n in ZDCs

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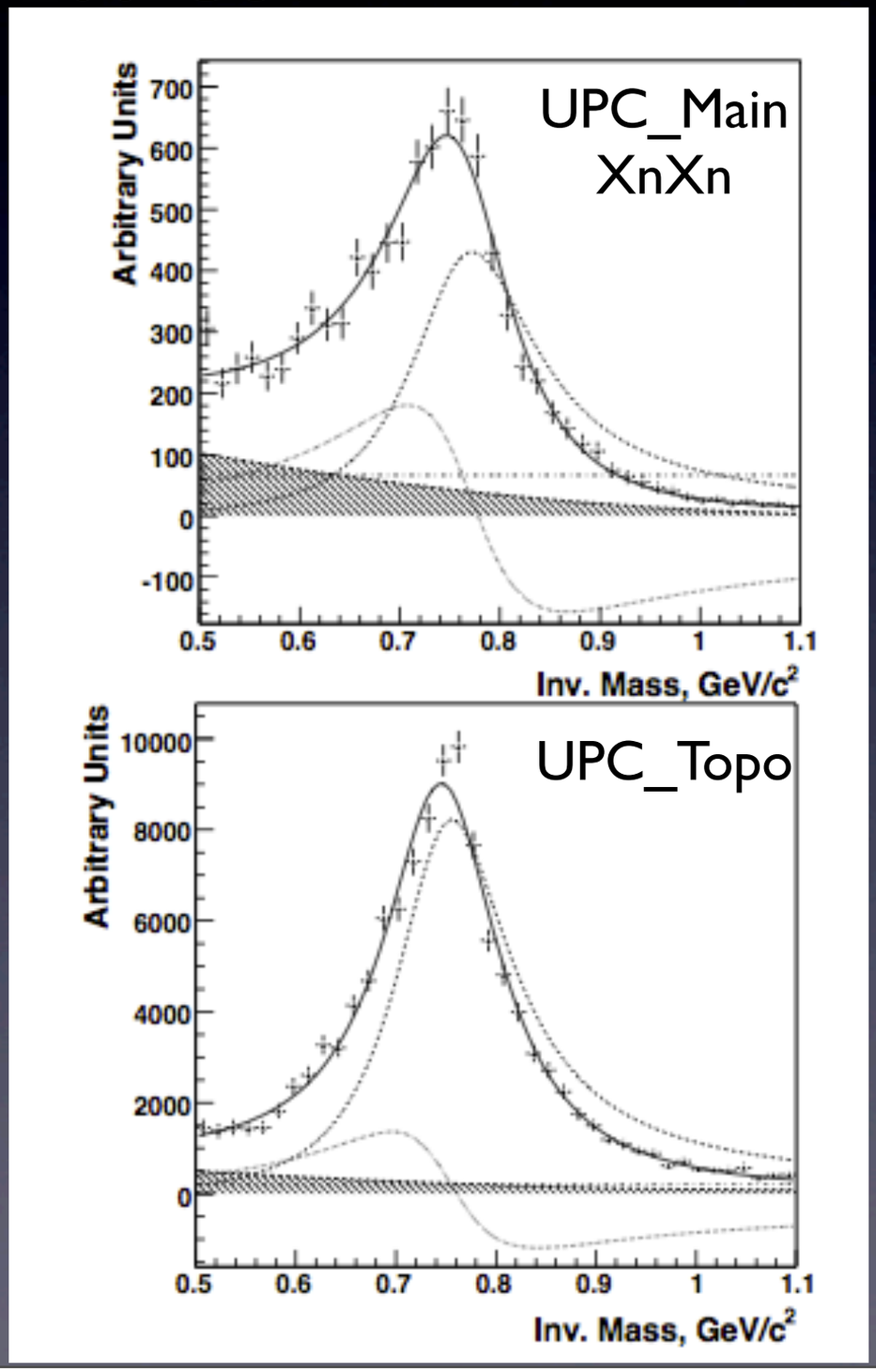
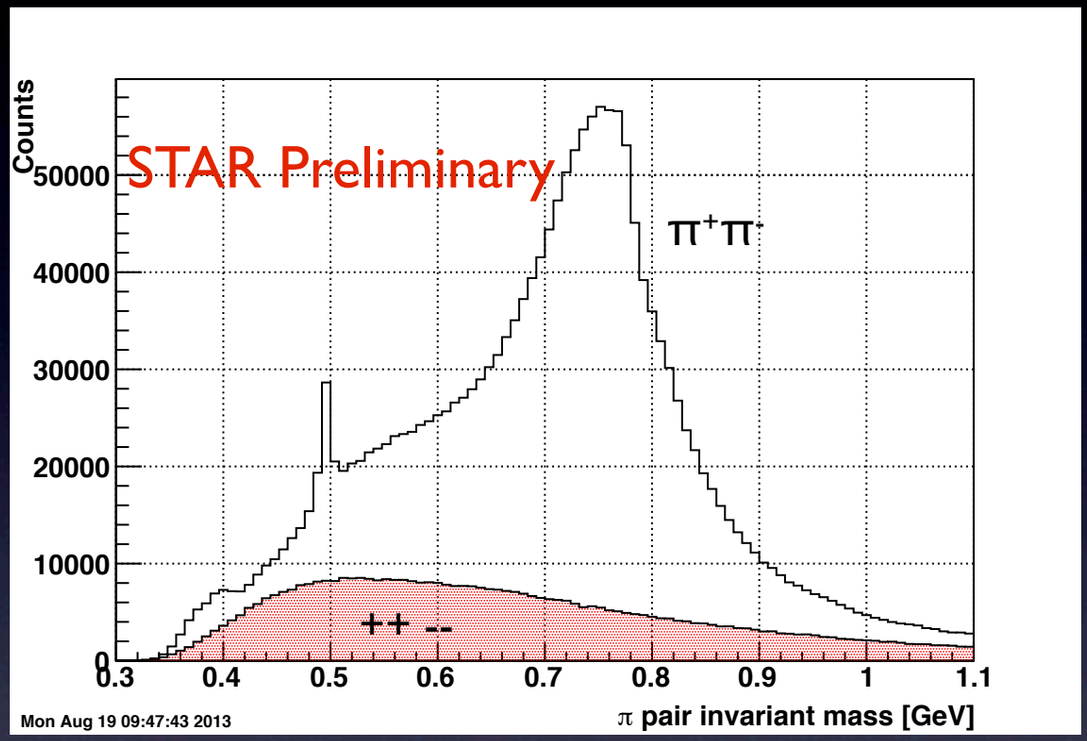
# STAR photo-production of $\rho^0$ Au+Au 200 GeV

Detailed publication with data from run 2001 Au+Au 200 GeV

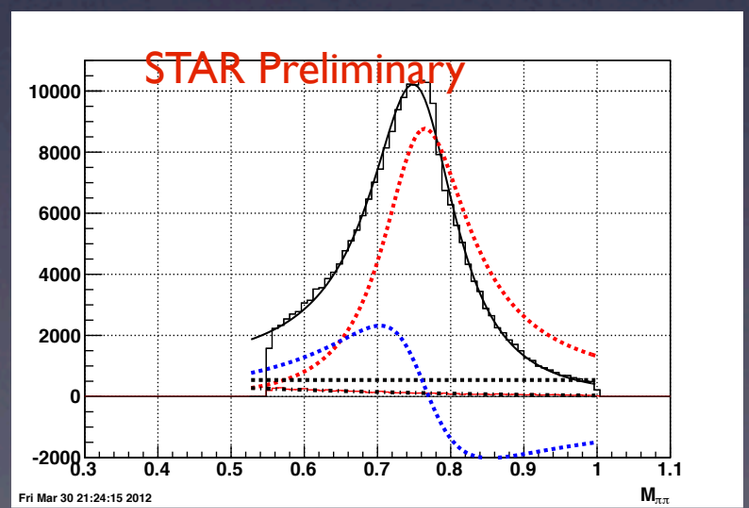
Phys. Rev. C77 034910




2M rho candidates from the high luminosity 2010 run




Reproduces old results with much higher statistics.

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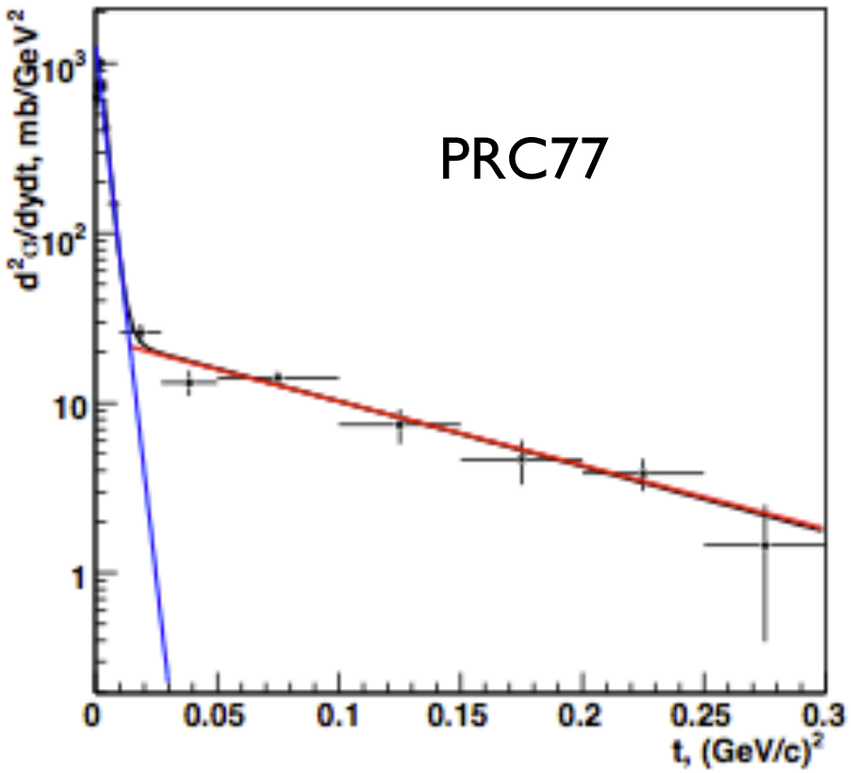
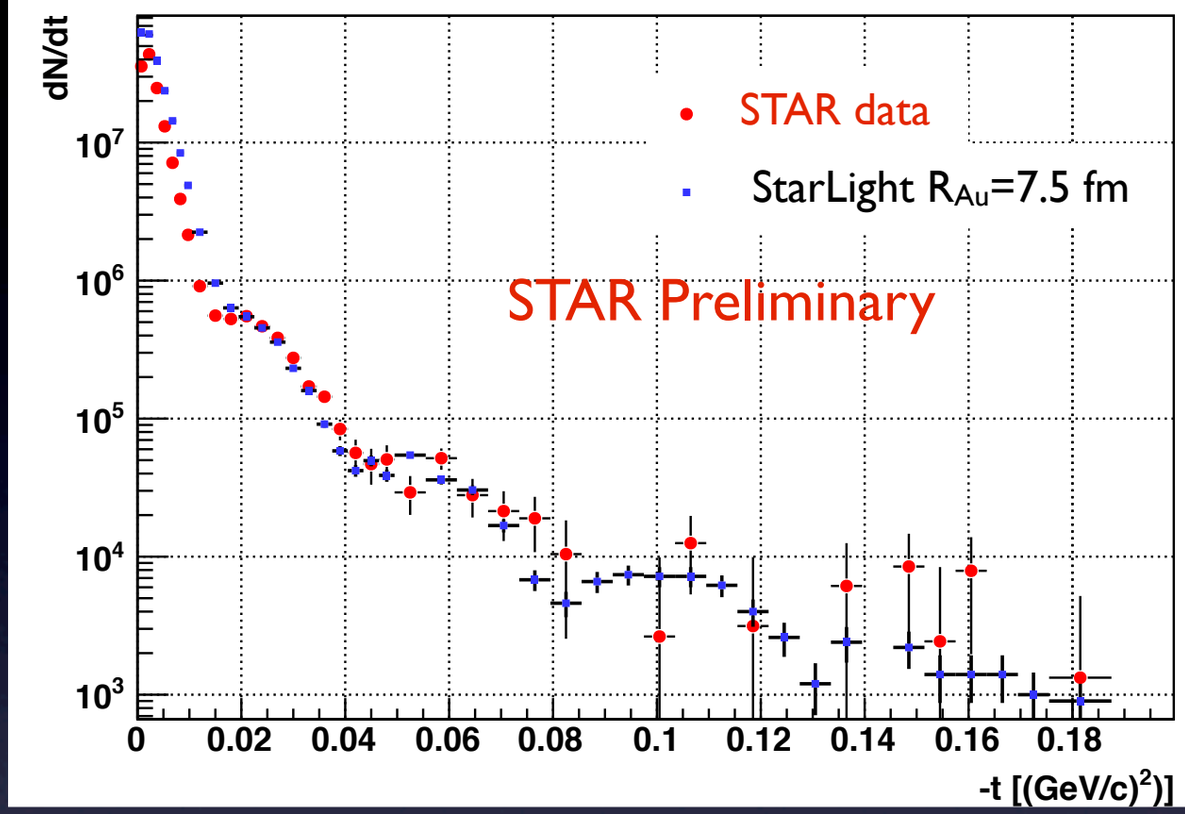
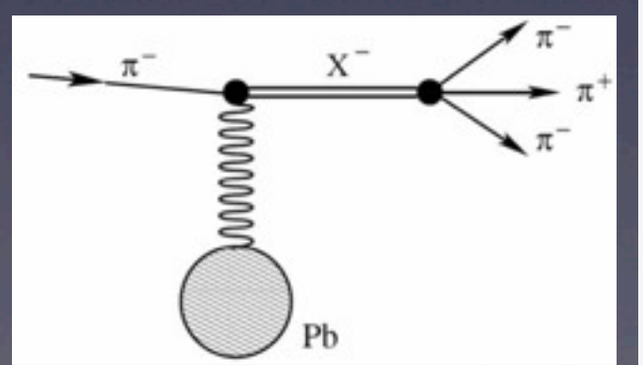
# $\rho^0$ meson diffraction

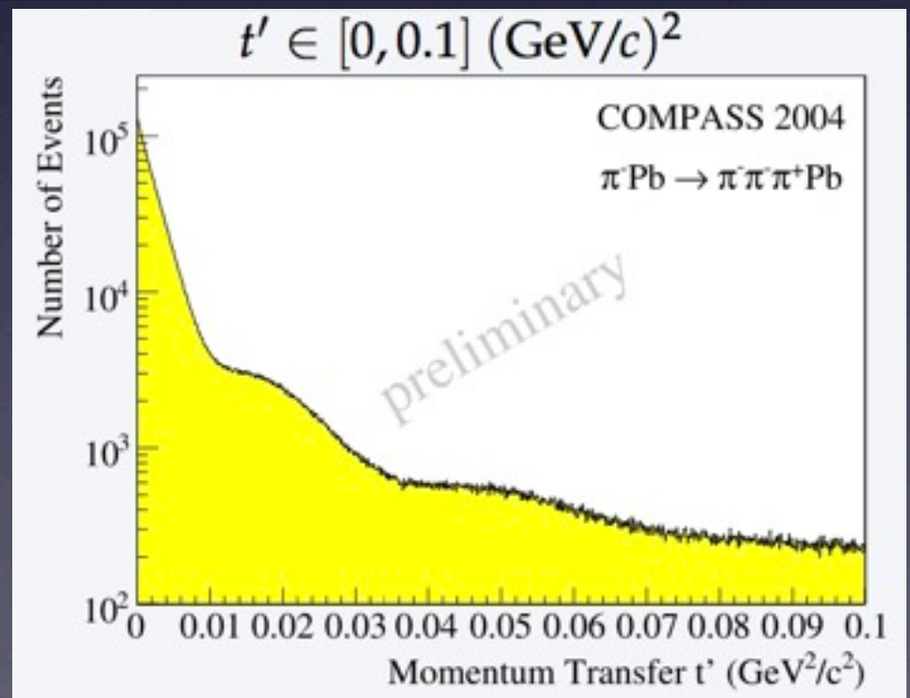



## Higher statistics permit to visualize a diffraction pattern off a Au target.

COMPASS has similar measurement in pion diffractive dissociation into three pion system $P_\pi$=190GeV/c

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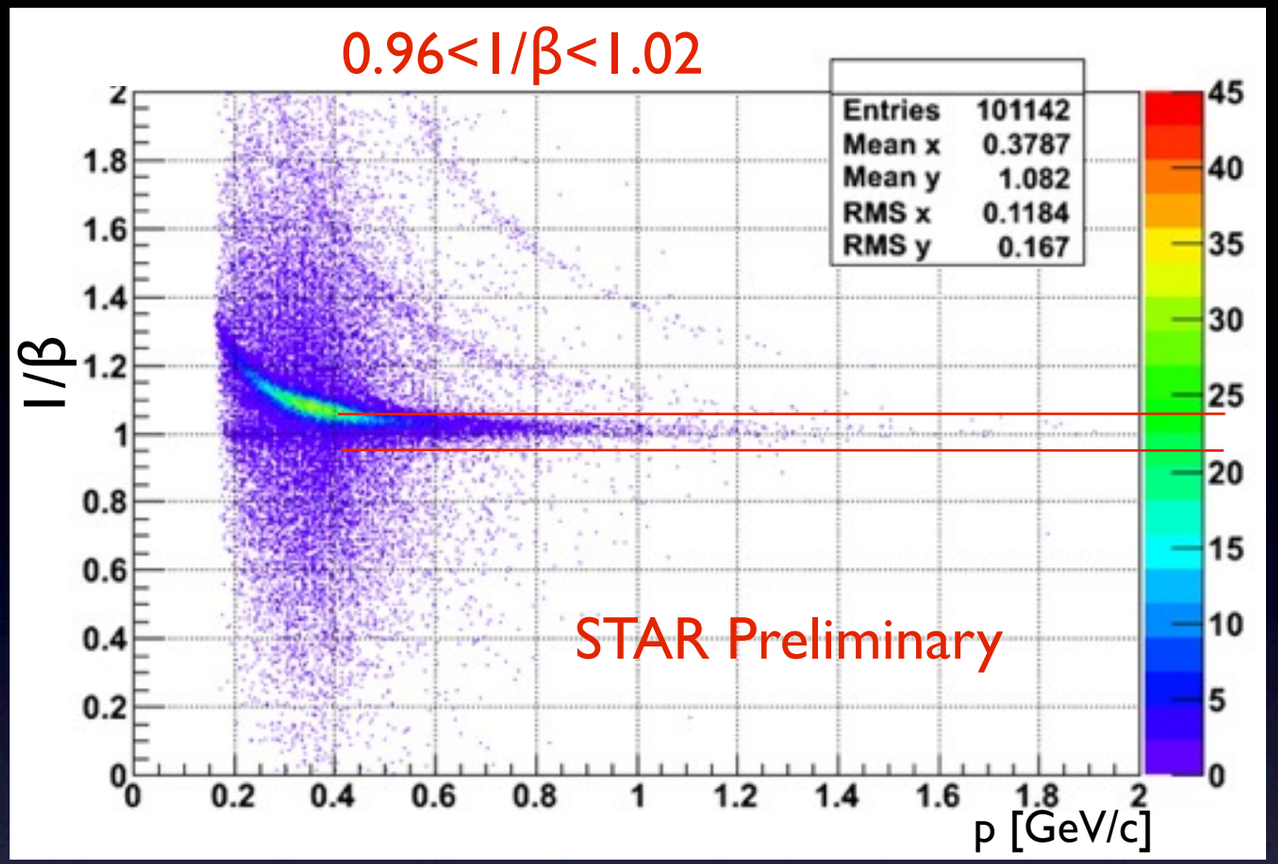
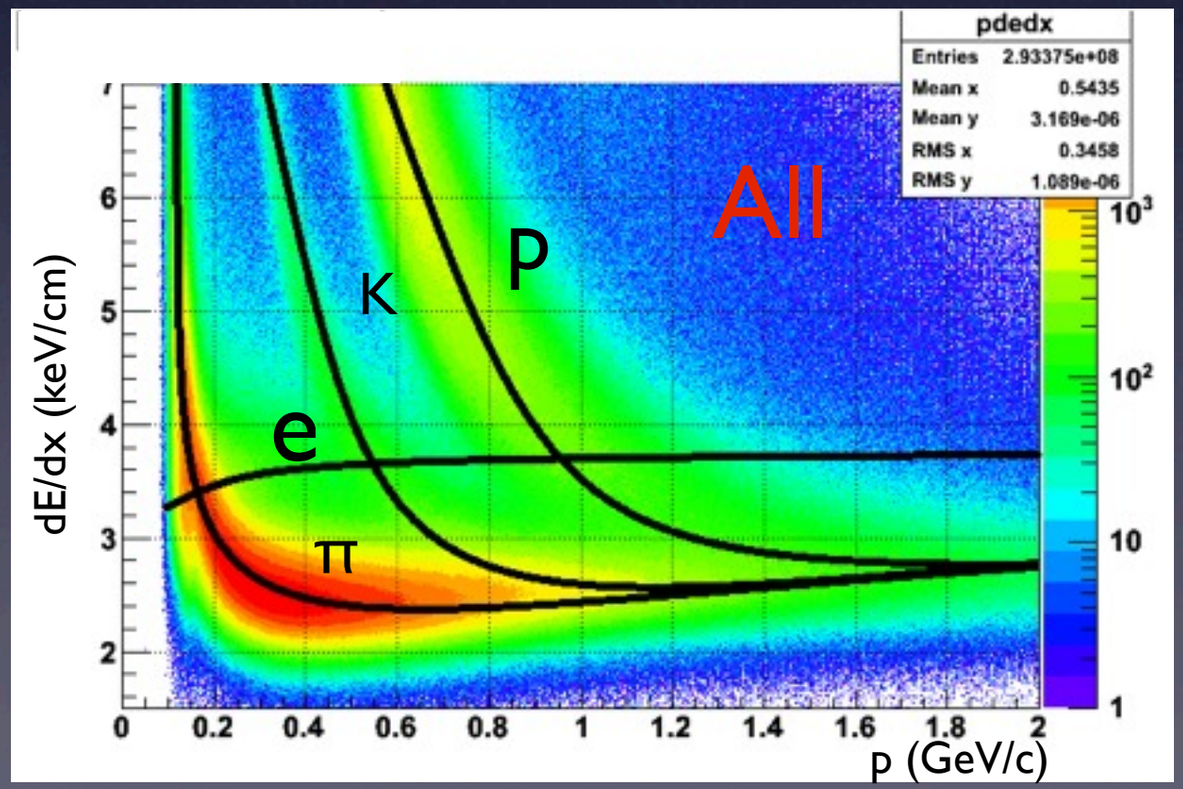
# STAR $e^+$ $e^-$ pair in $\gamma$-$\gamma$ events

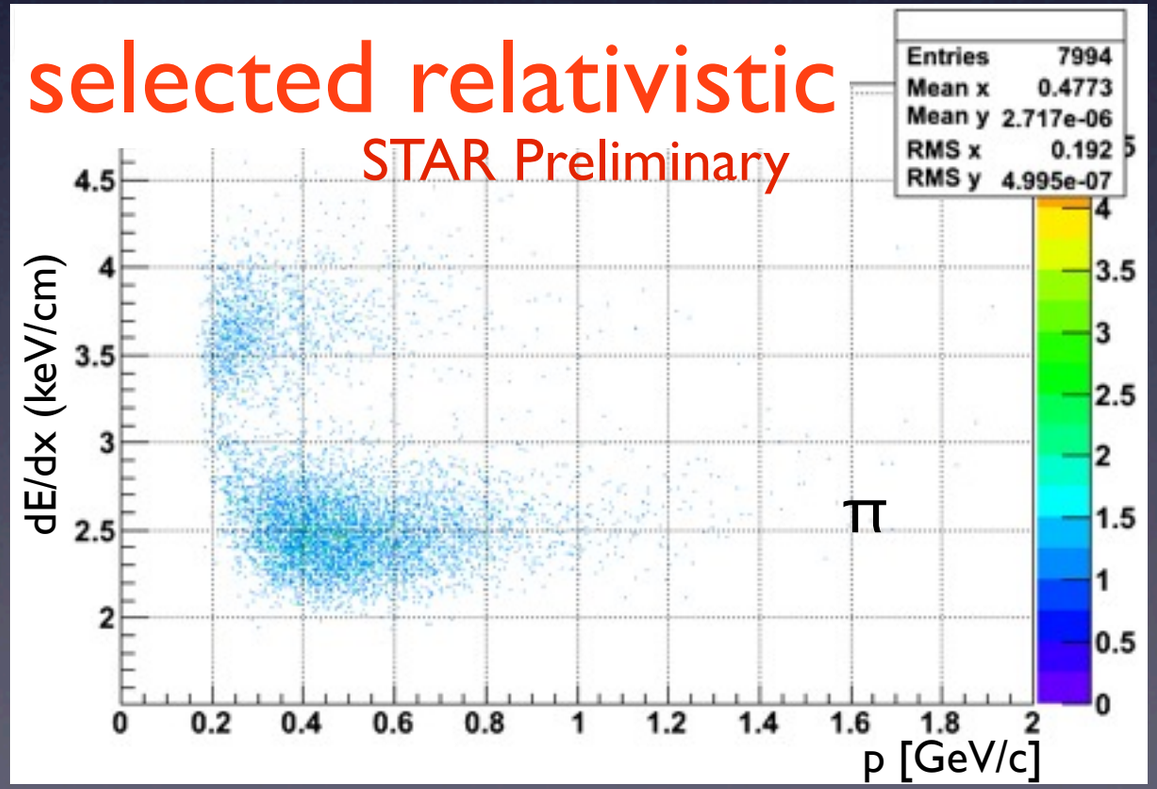
Using the big dataset from run 2010. Use TOF to select relativistic particles

Need to extract the efficiency of this cut




selected relativistic

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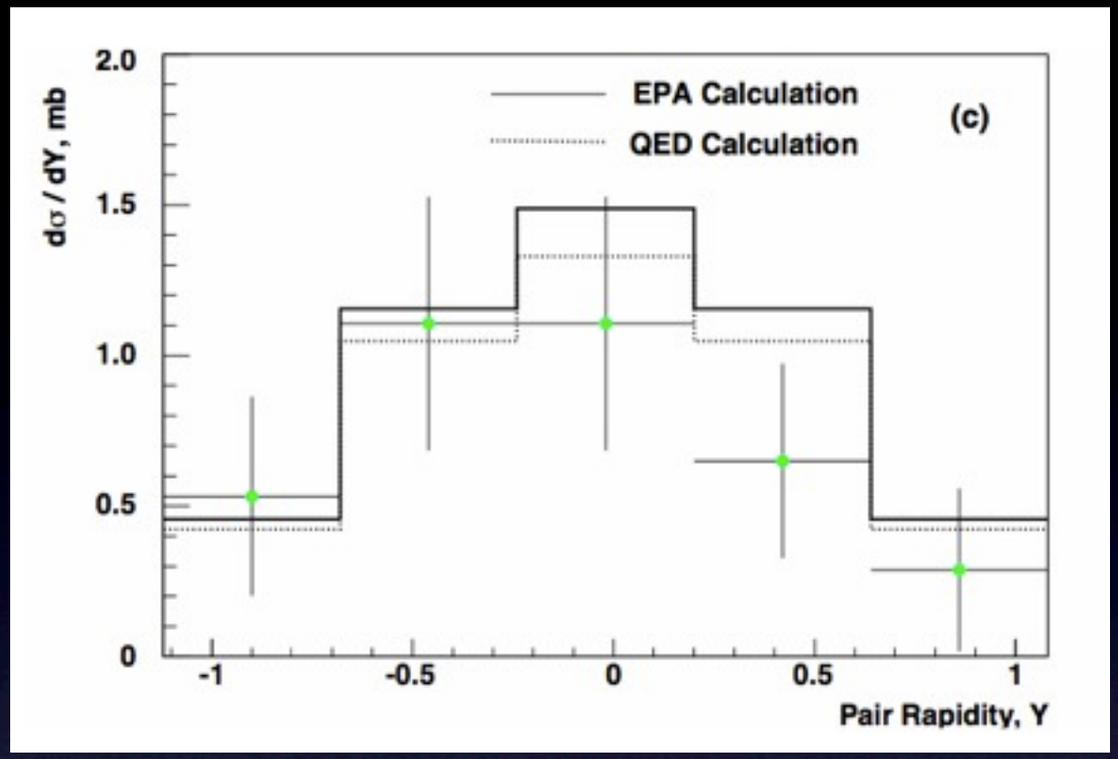
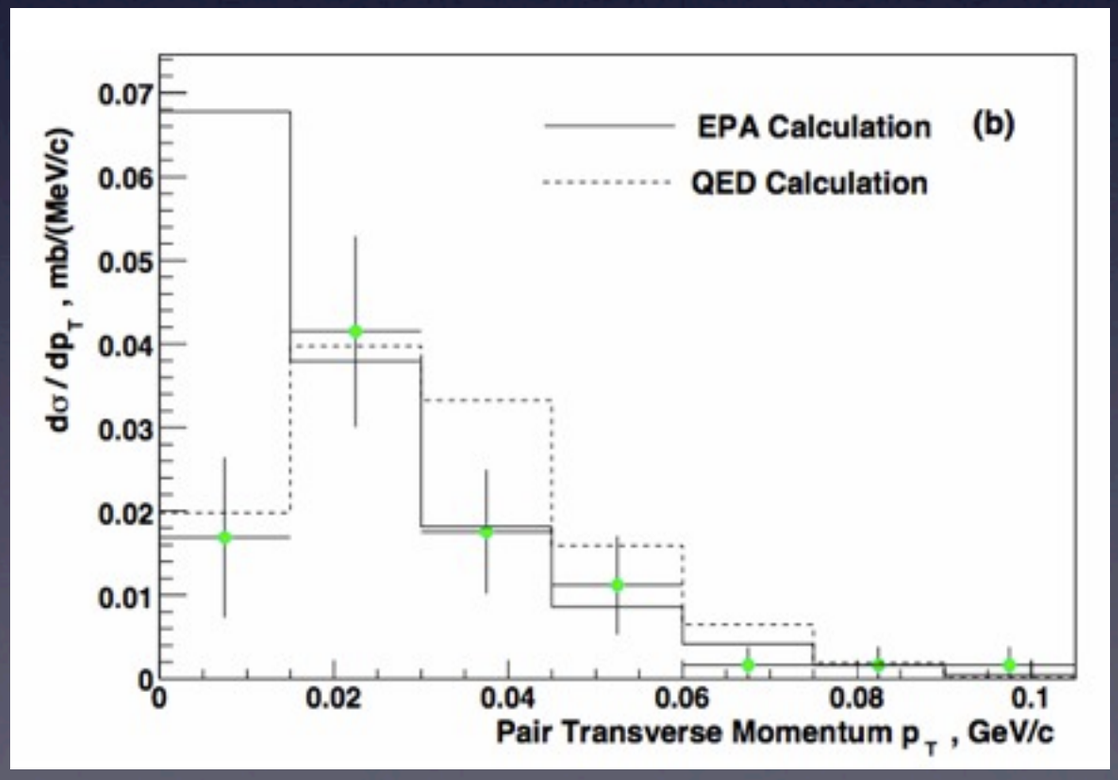
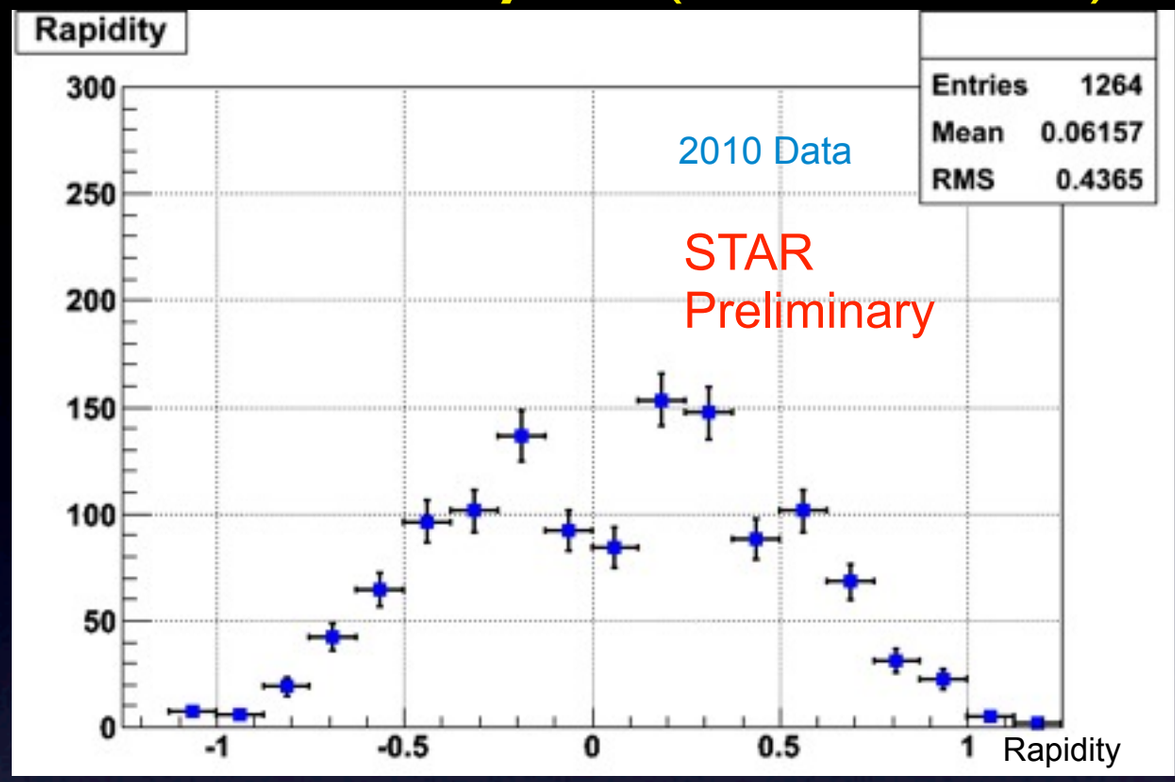
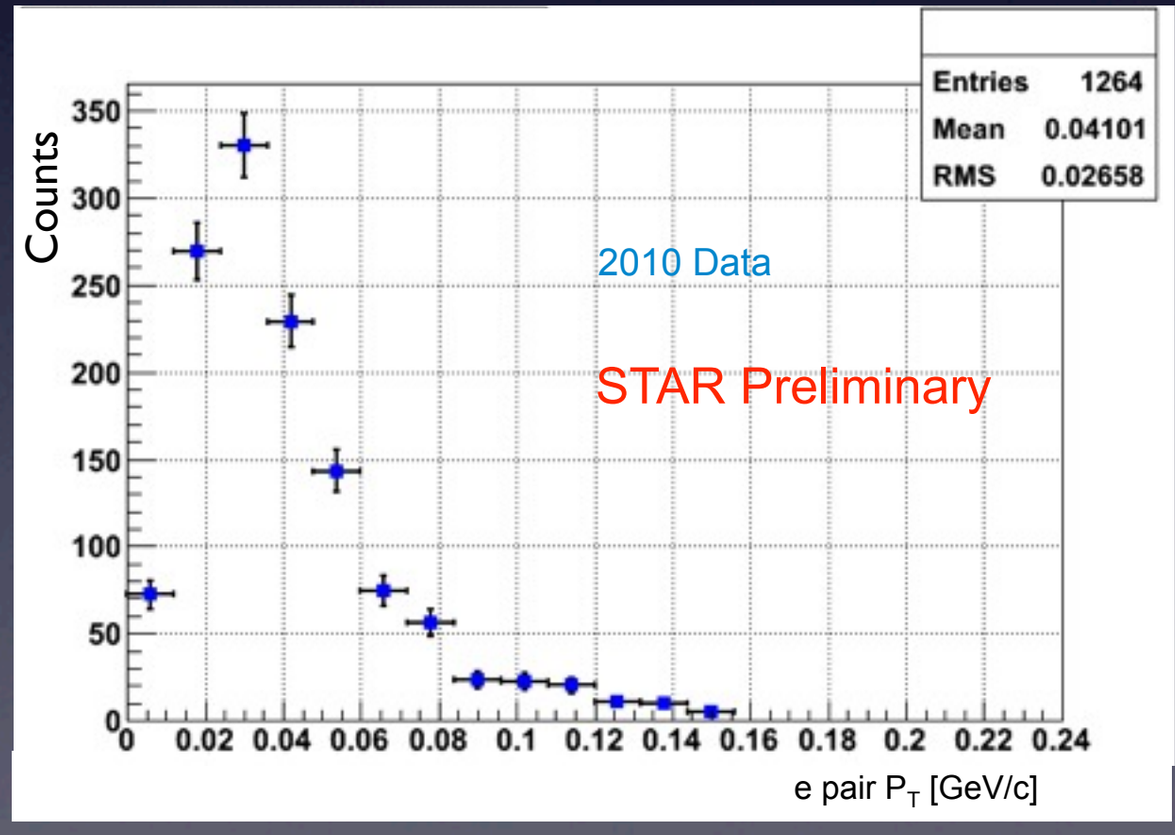
Phys. Rev. C 70 (2004) 031902(R)




# 2010 run analysis (raw counts)

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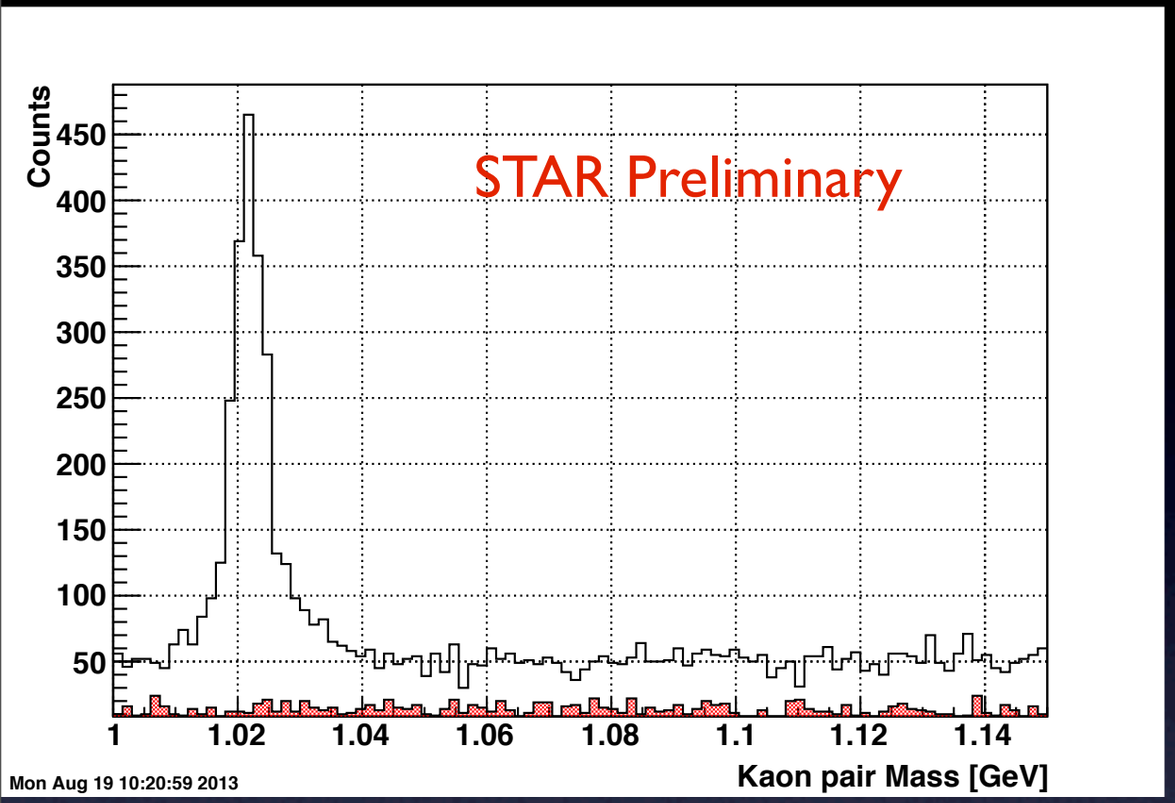
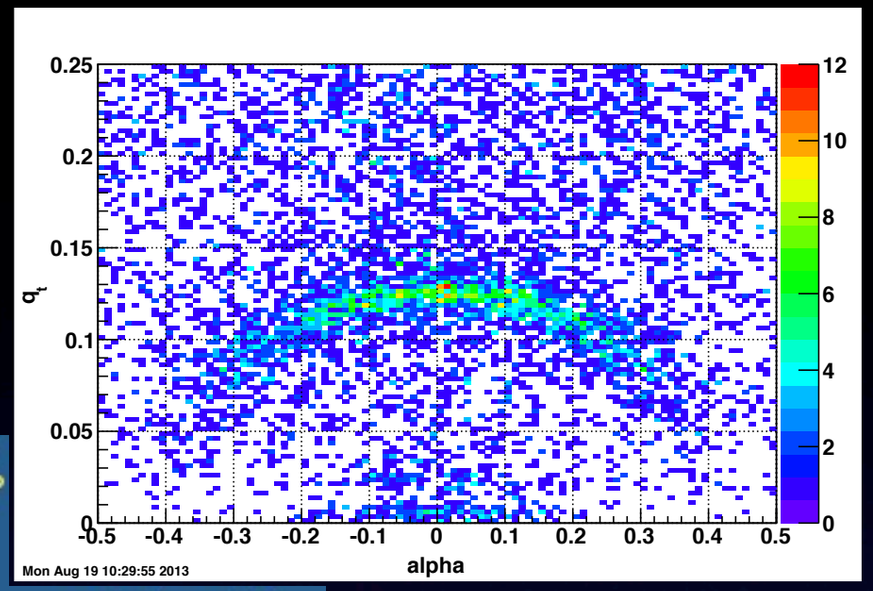
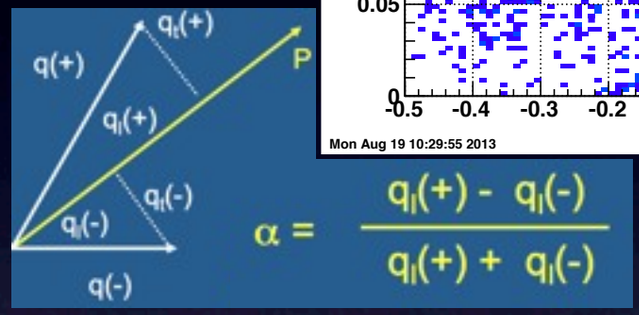
# STAR Φ production in UPC_Main events

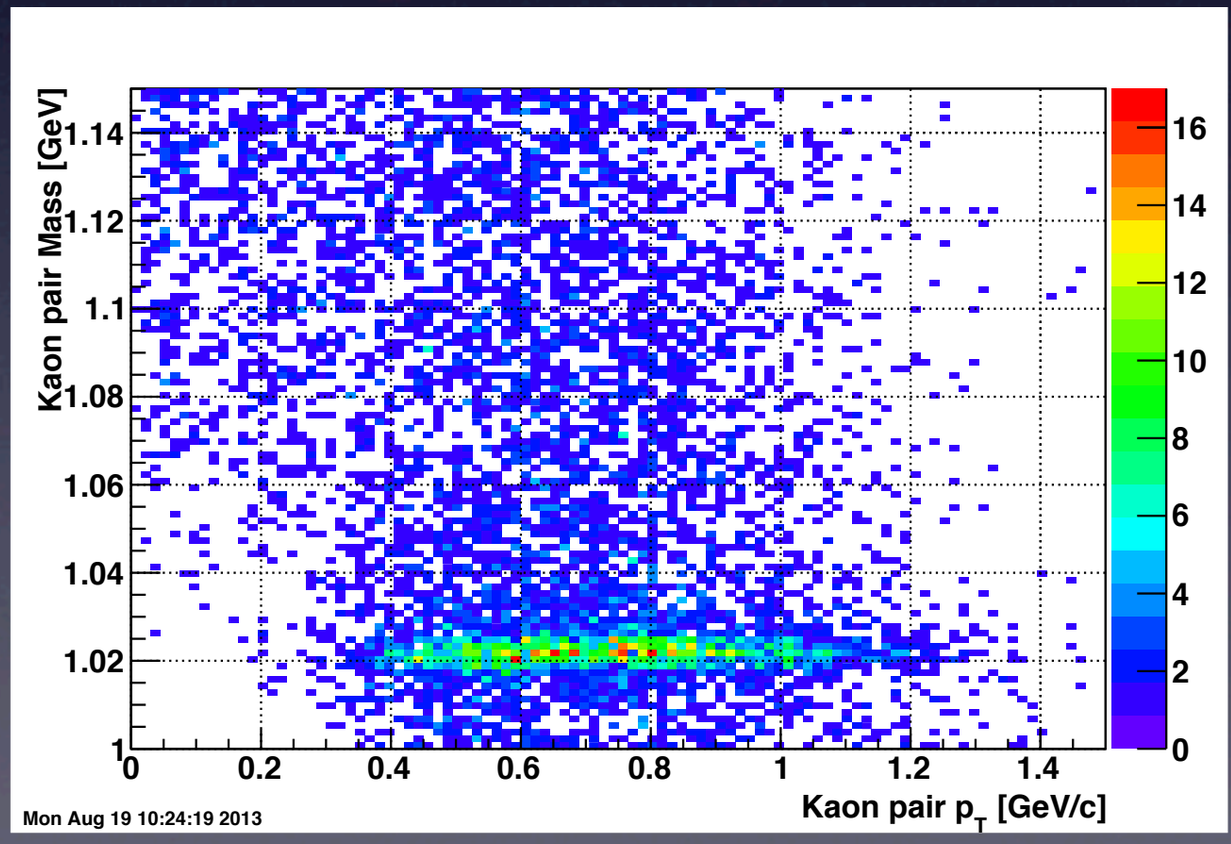



Two kaon events in XnYn UPC_Main events with dEdx PID.




Cannot access coherent production but may be able to study incoherent prod.

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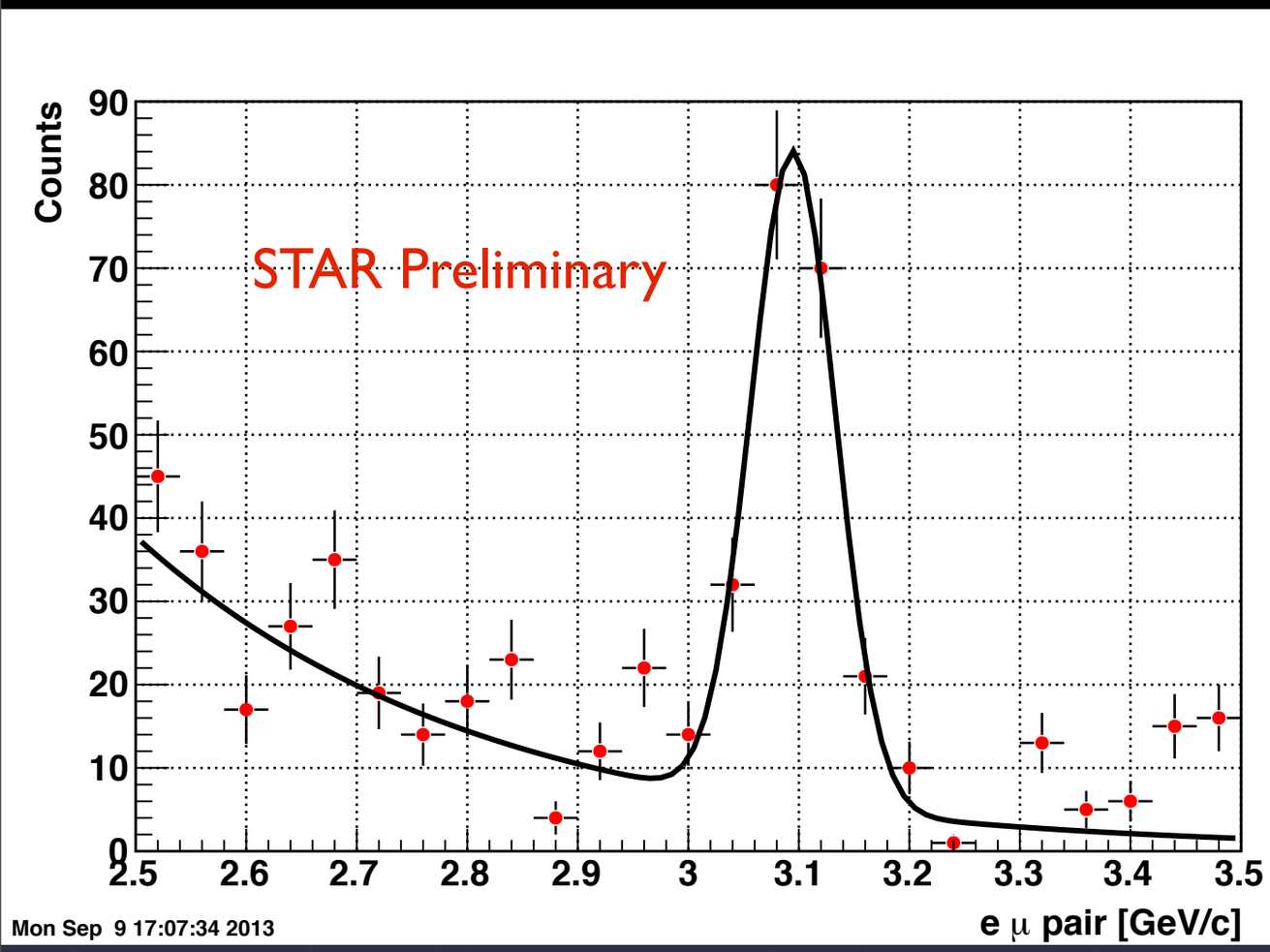
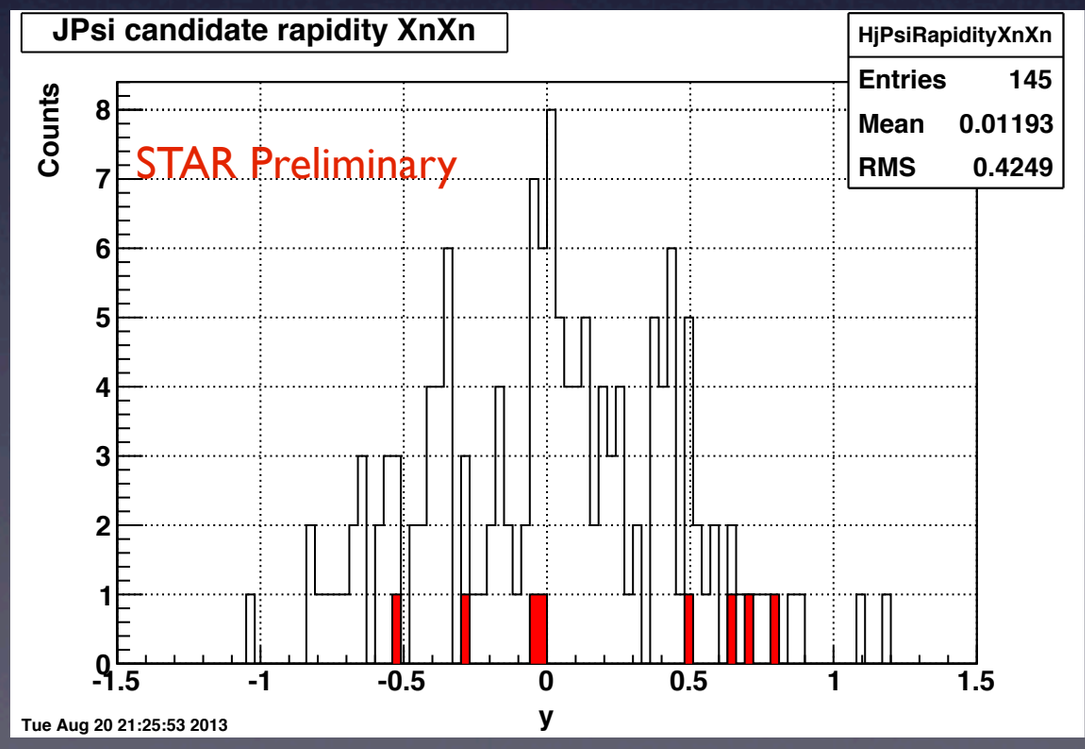
# STAR J/ψ XnYn photo-production Au+Au 200 GeV




Same sign background subtracted. Remaining e +e- continuum fit with polynomial + Gauss.
~230 counts in peak




Identification done solely by invariant mass. Includes electron and muon pairs. Work in progress to extract efficiencies from data and MC.

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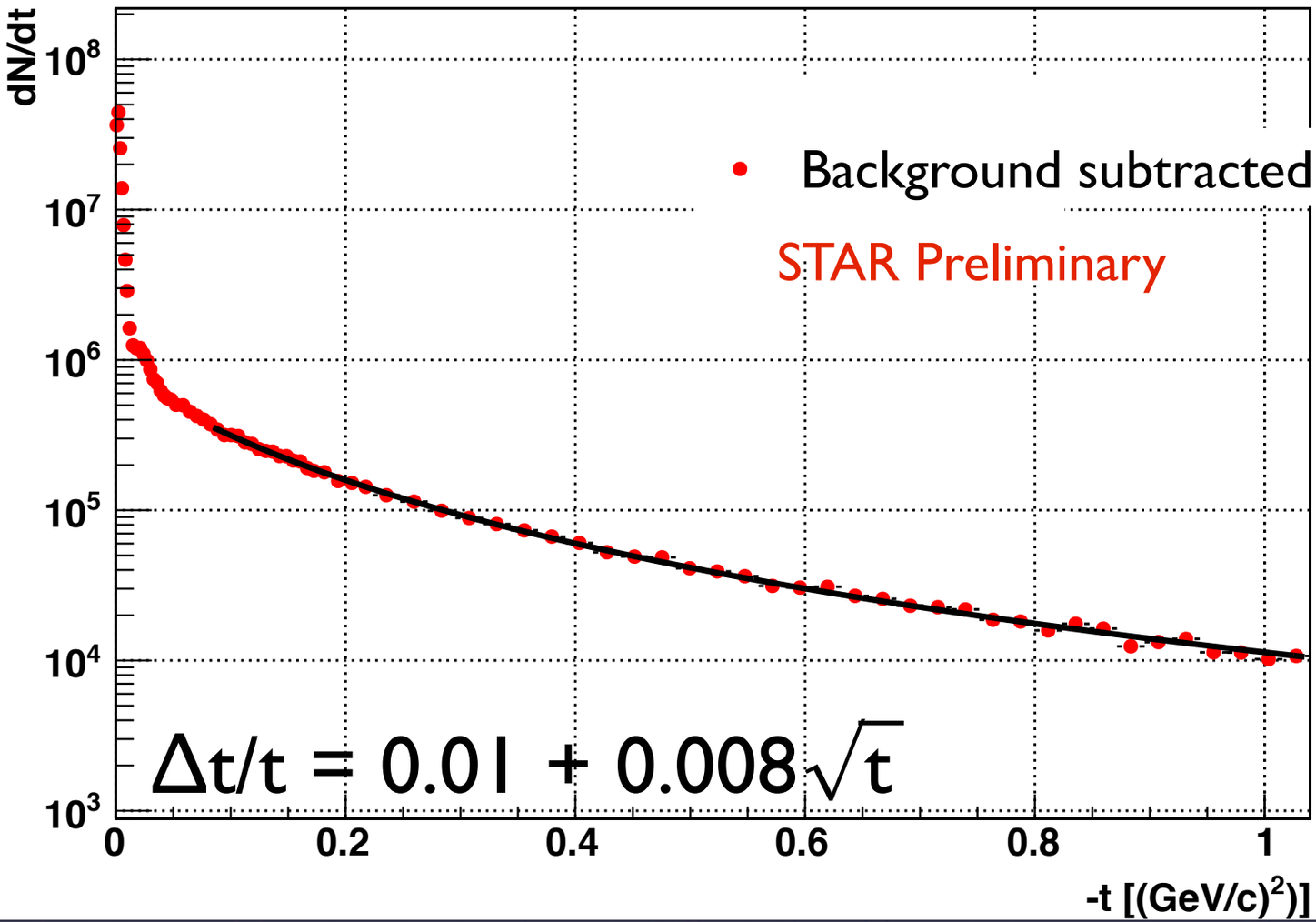
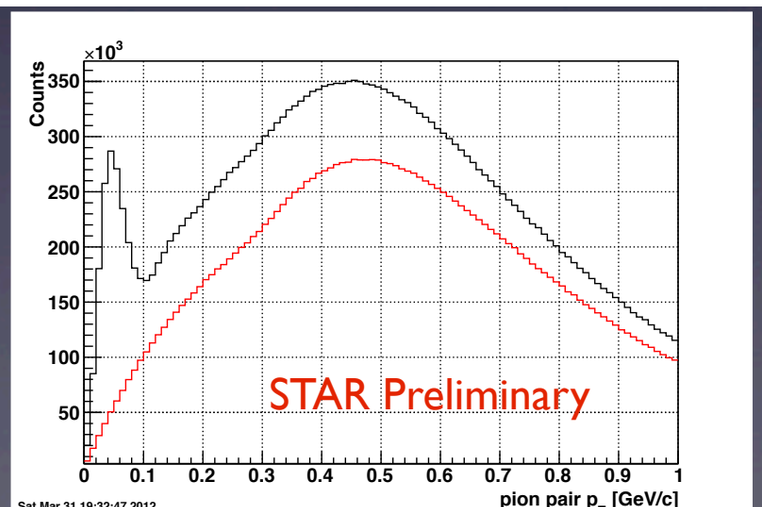
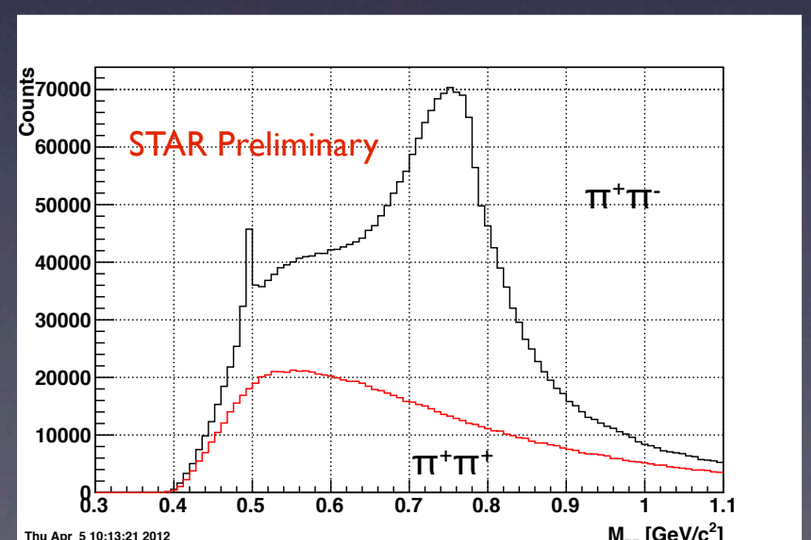
# $\rho^0$ diffraction off Au nuclei in UPC events




The main background to the exclusive $\rho^0$ production must be contributions from peripheral hadronic events that elude our vetoes in the trigger.

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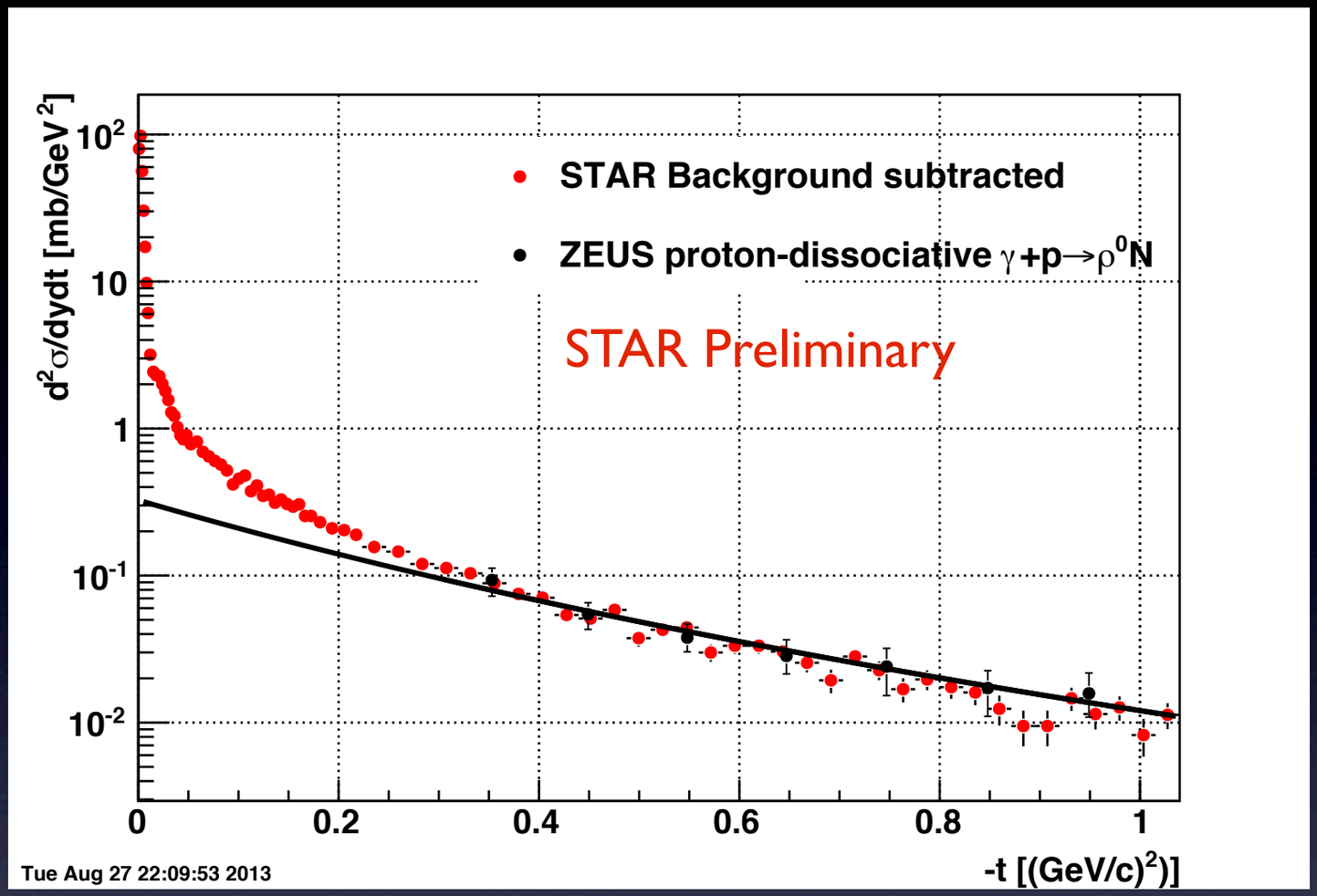
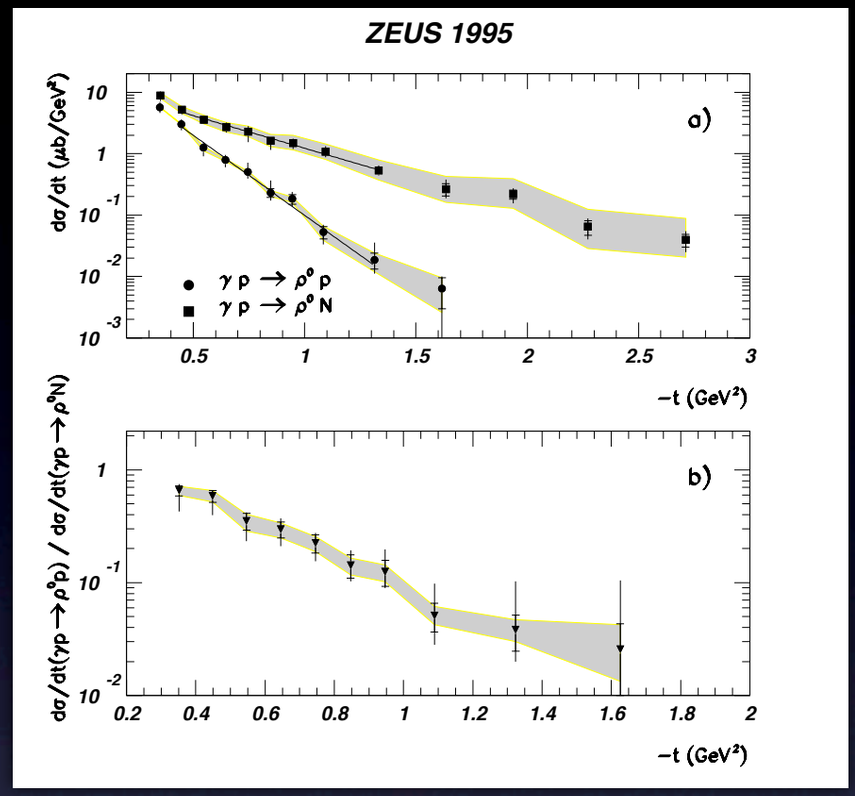
# The subtraction of the $\rho^0$ incoherent production




Eur. Phys. J. C 14, 213–238 (2000)

The tail of the -t distribution is mostly filled with events where the rho mesons interacts with individual nucleons. We fit the tail with a power law shape and subtract it to bring forward the underlying coherent distribution.

ZEUS results for $\gamma p \rightarrow \rho N$ scaled by 10.6 match the measured tail.

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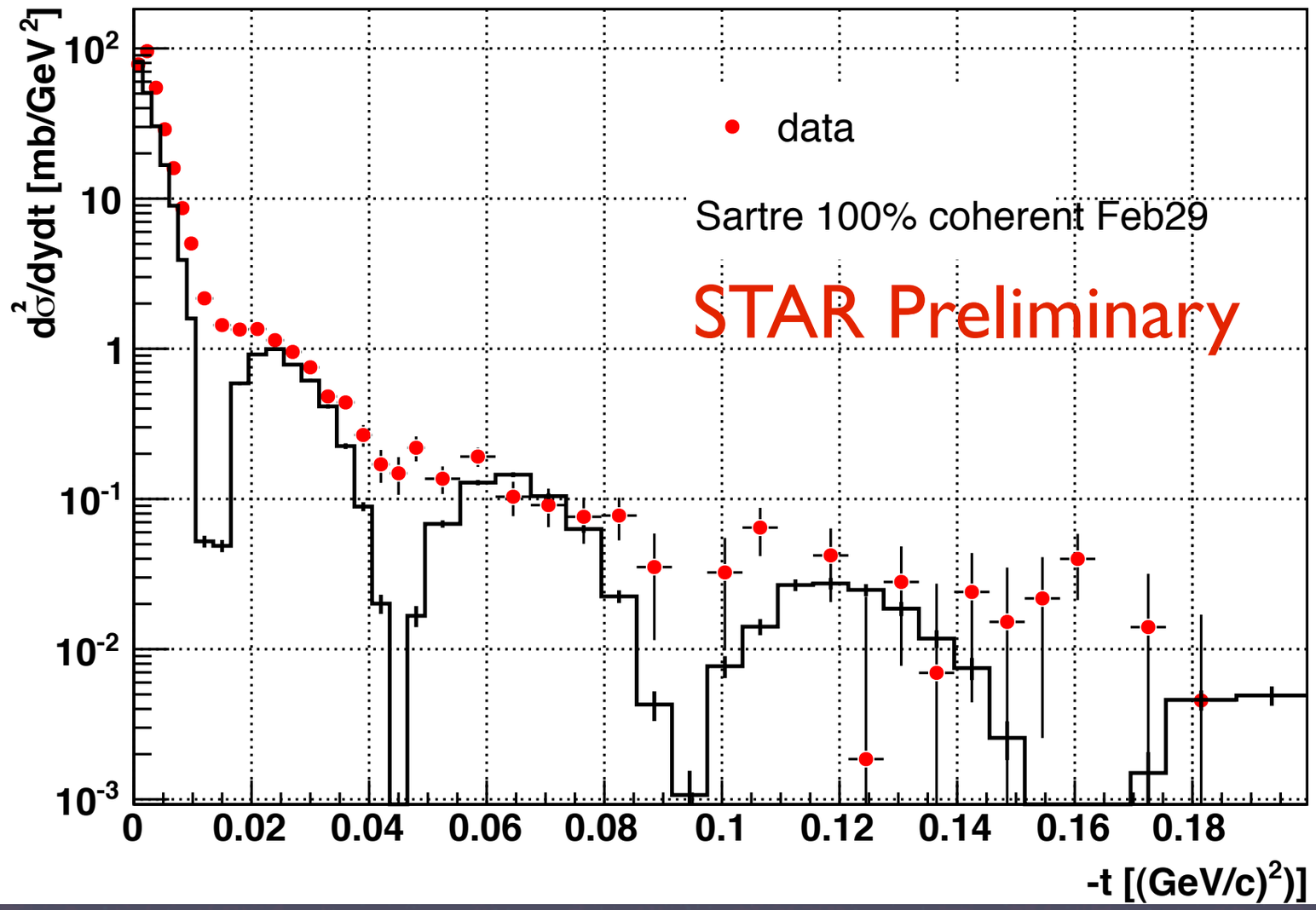
# Diffractive pattern produced by elastic $\rho^0$ scattering off Au nuclei




The diffraction pattern is evident up to its third peak, the slope of the first peak as well as the location of the peaks is consistent with the coherent interaction with an object with dimensions comparable to the Au nuclei.

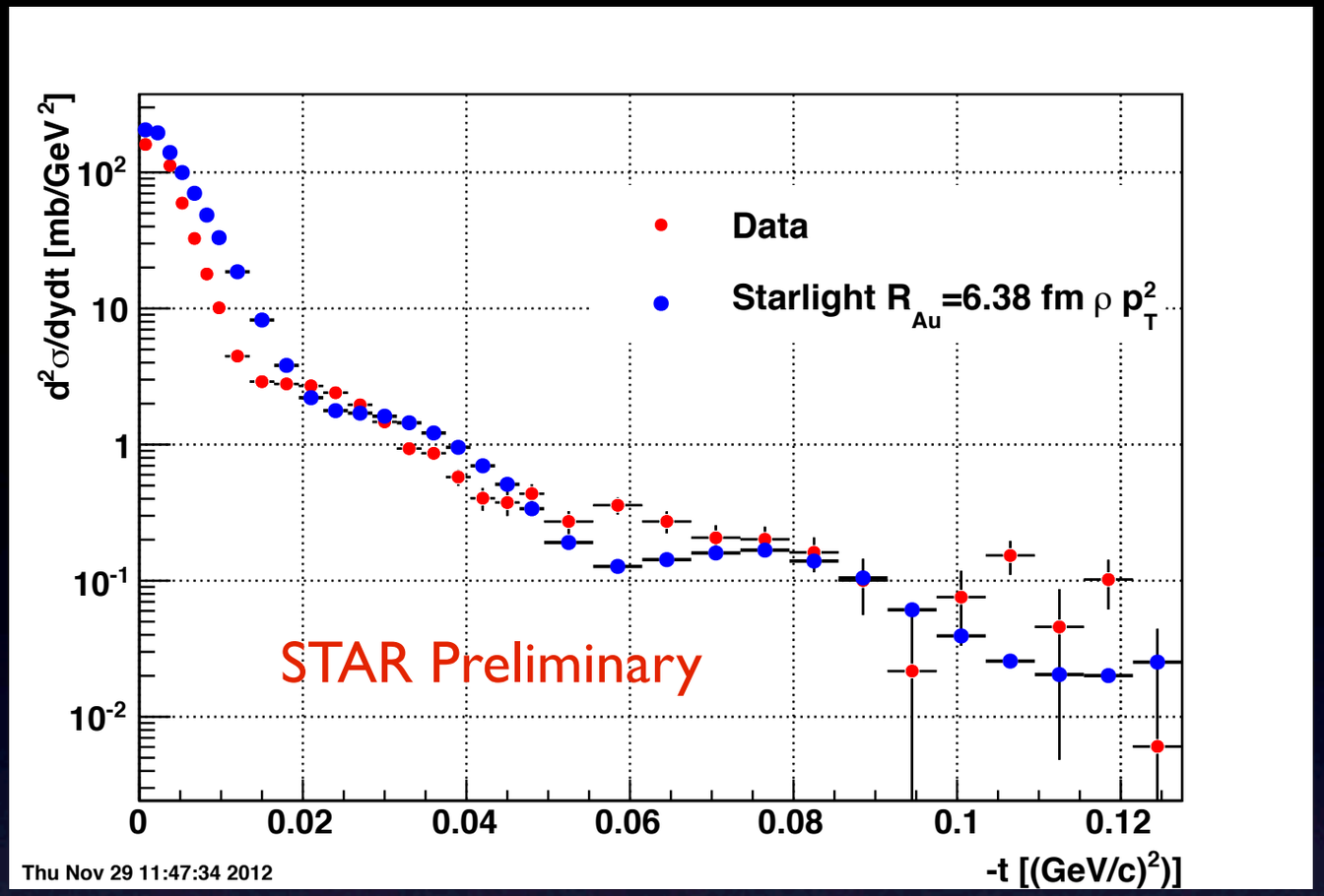
The Sartre histogram shows the -t distribution of the recoiling Au target. Phys.Rev. C87 (2013) 024913

Nuclei described with Wood-Saxon R=6.38 fm a=0.53 fm

# Comparison to StarLight

If we run Starlight with Wood-Saxon distribution from electron scattering measurements we get a distribution that is shifted systematically to higher $p_T$ values.

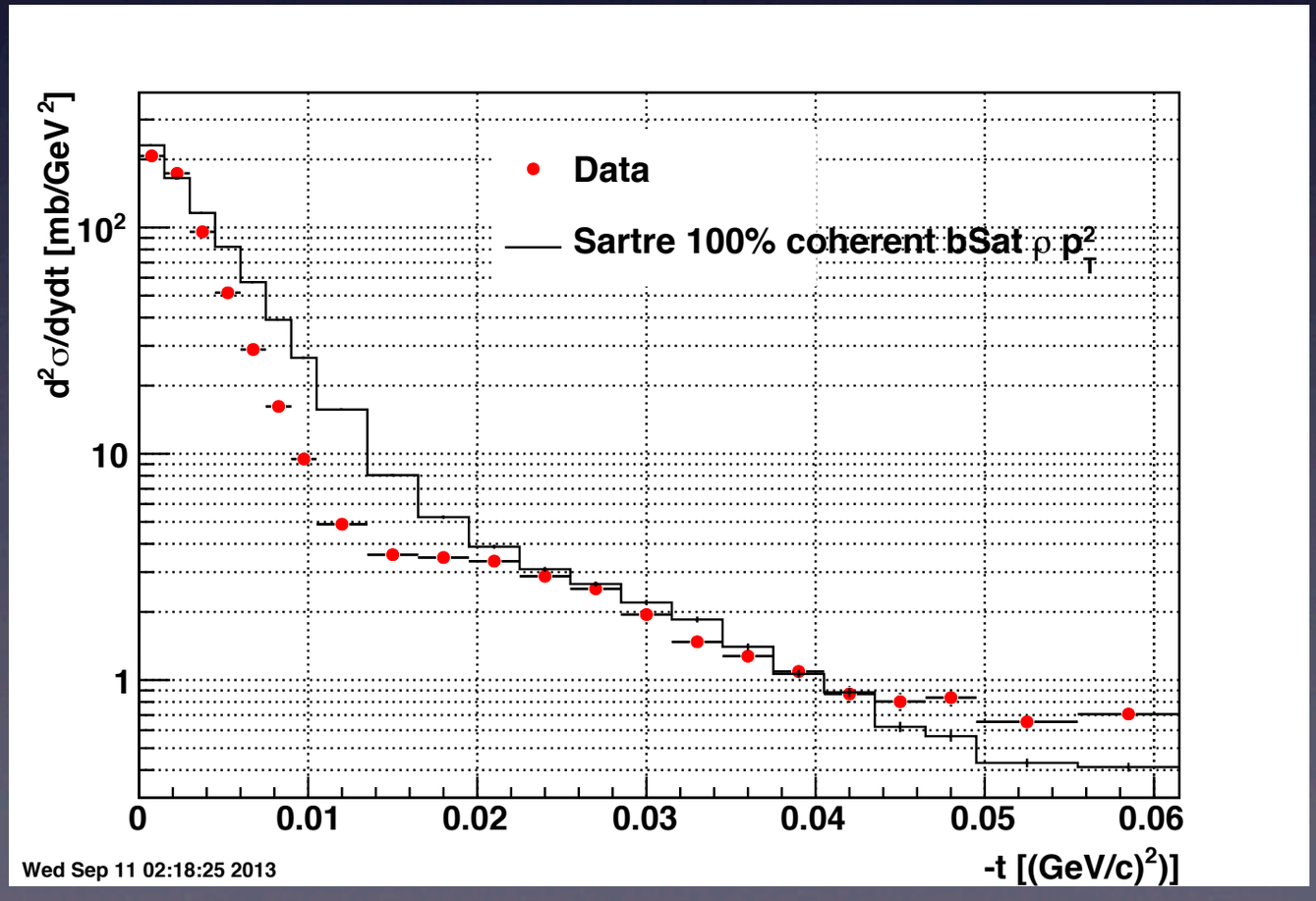
PHYSICAL REVIEW C, VOLUME 60, 014903




# Comparison to Sartre

Sartre photon flux is based on StarLight. We display the -t distribution of the Au recoils (best match to dip location). The rho -t minus the photon pT contribution (good match but below data). The distribution of rho which includes the photon pt (worst deviation from data).

Does this calls for a "tuning" of the Au charge form factor?



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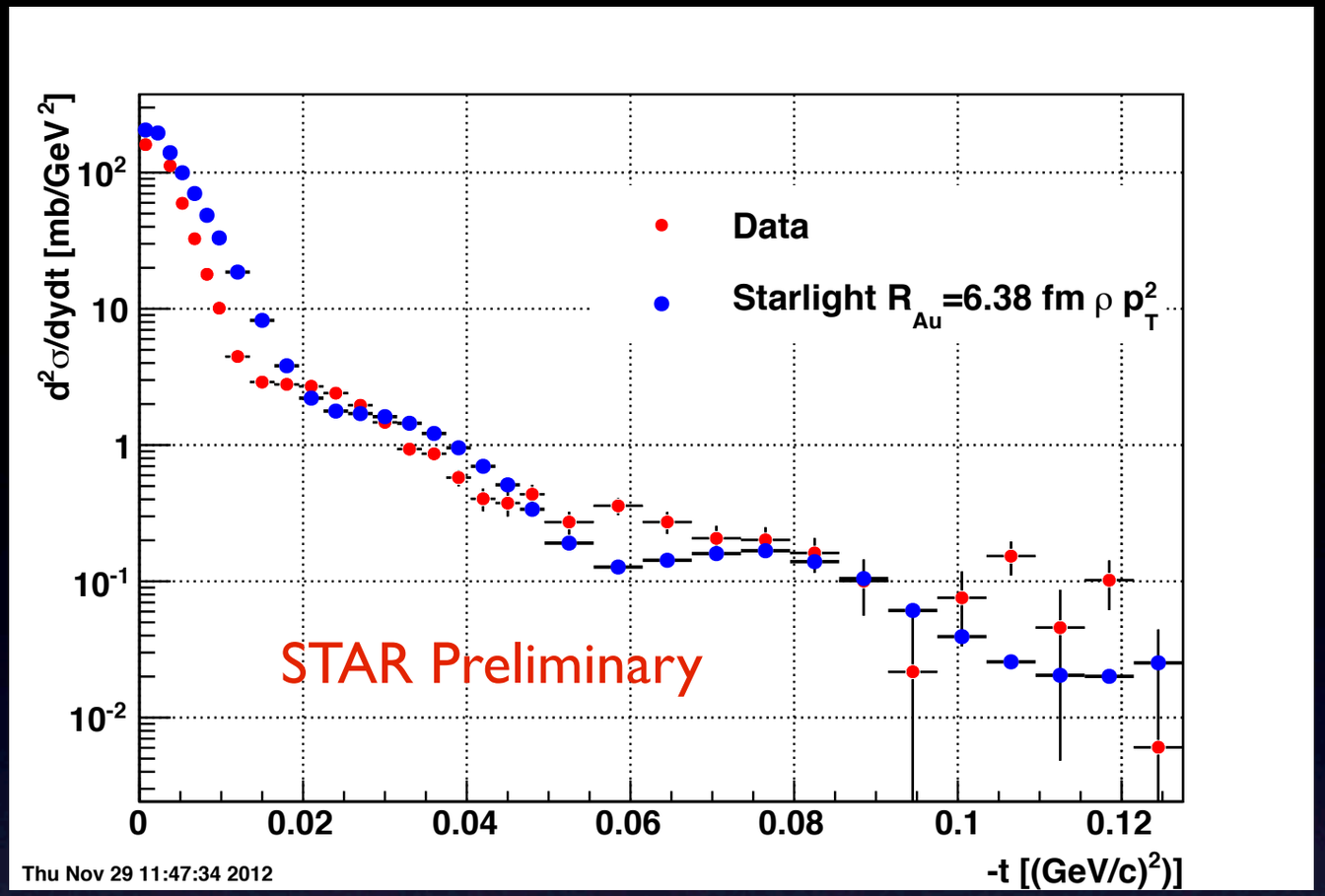


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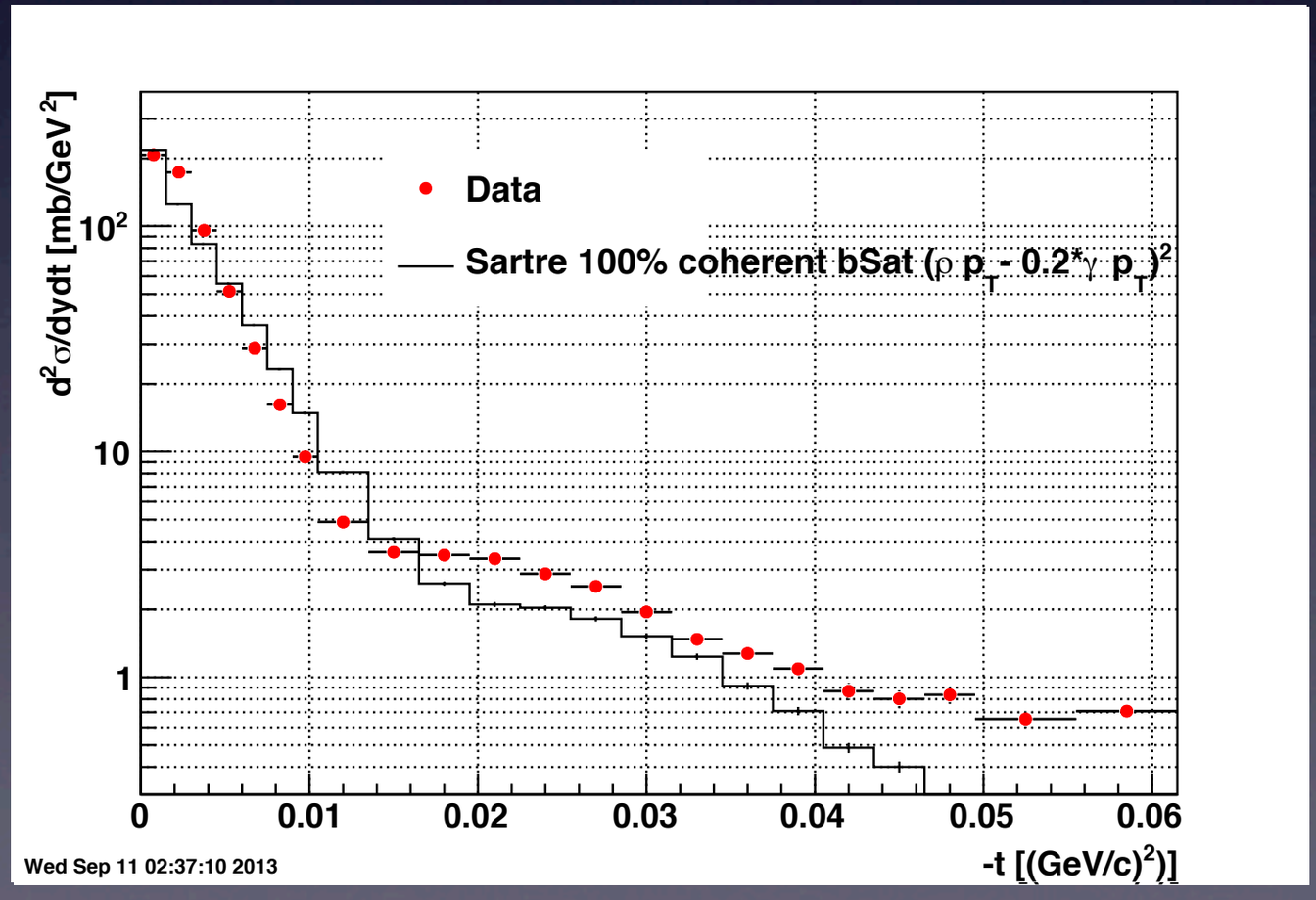

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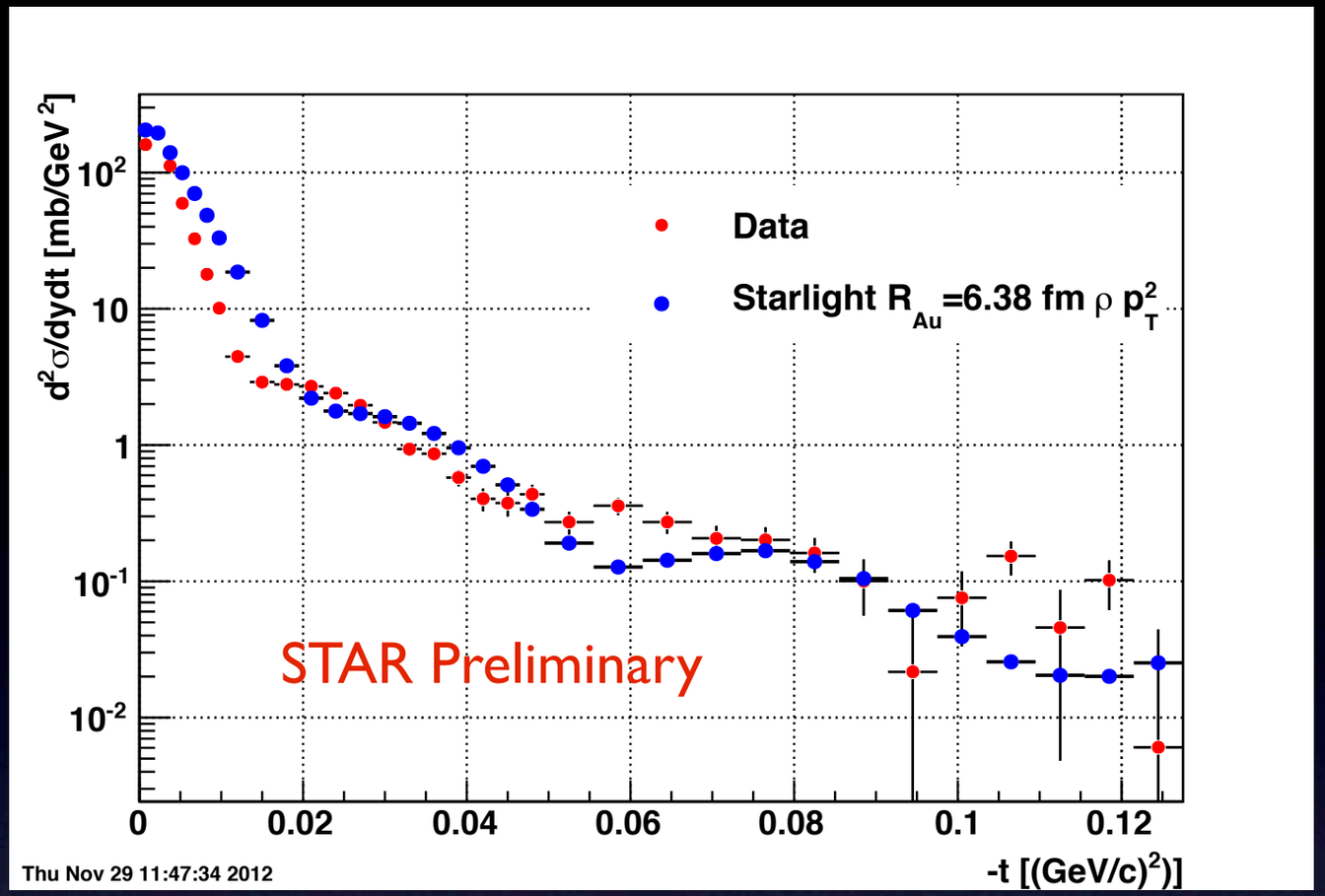


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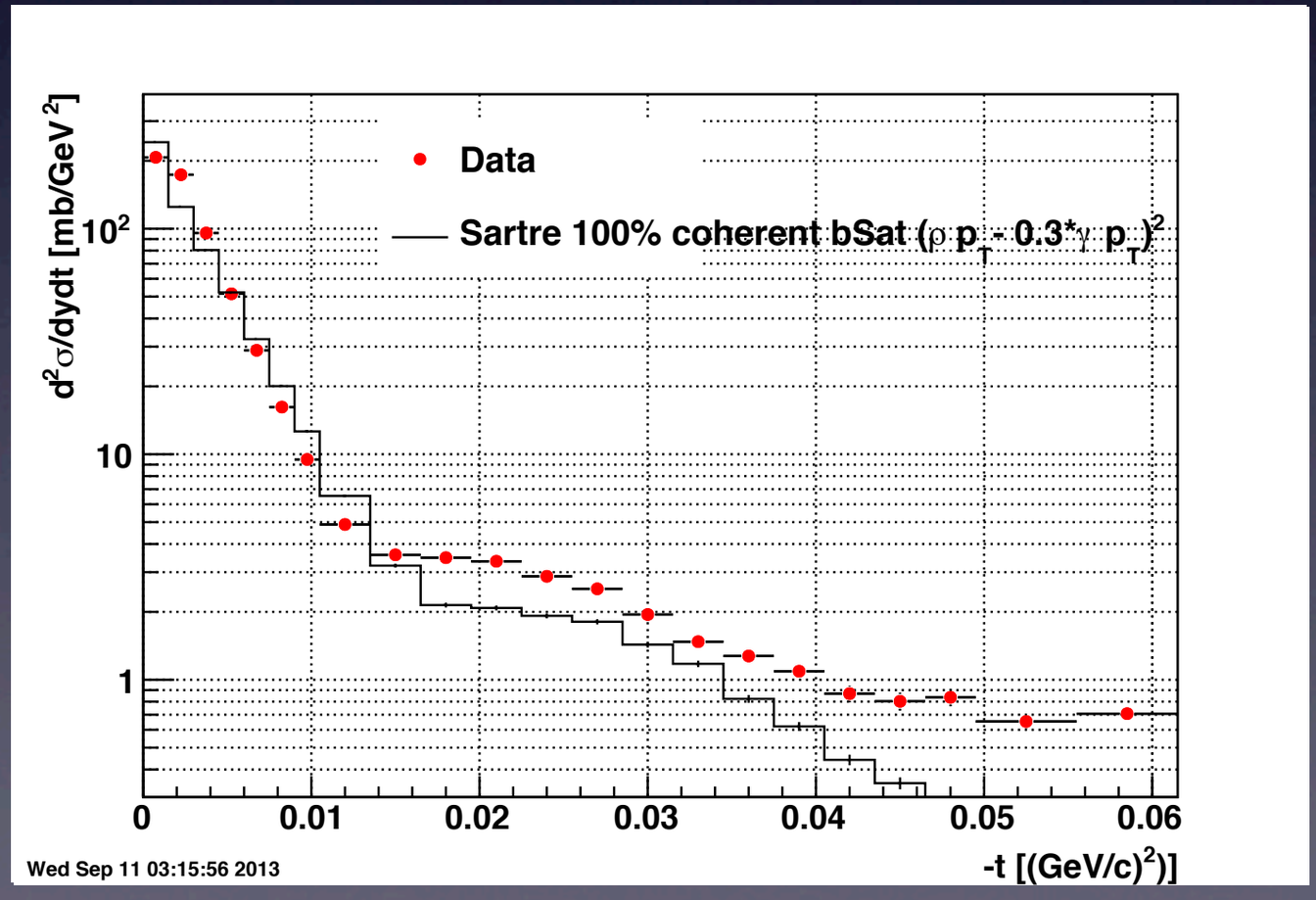

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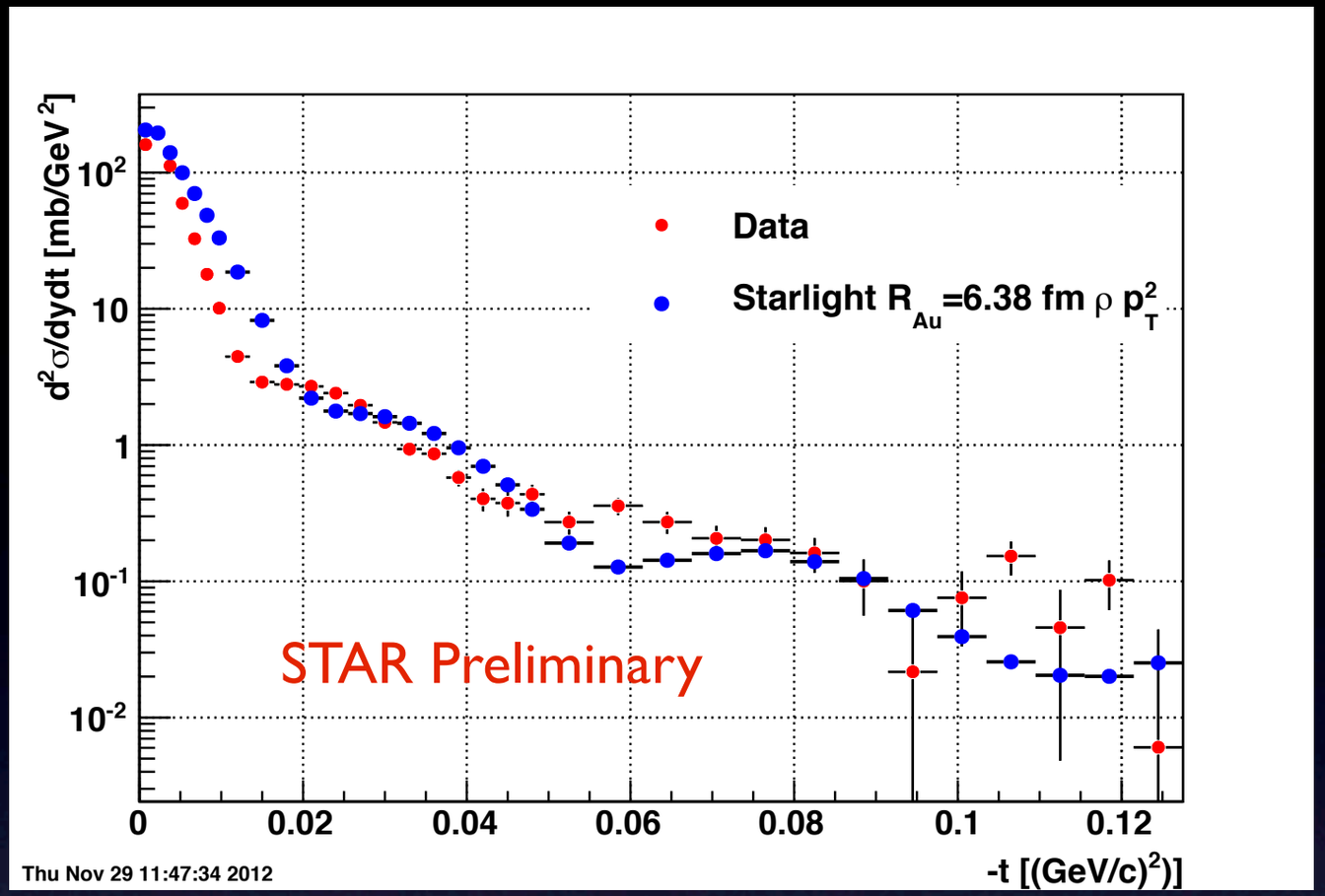


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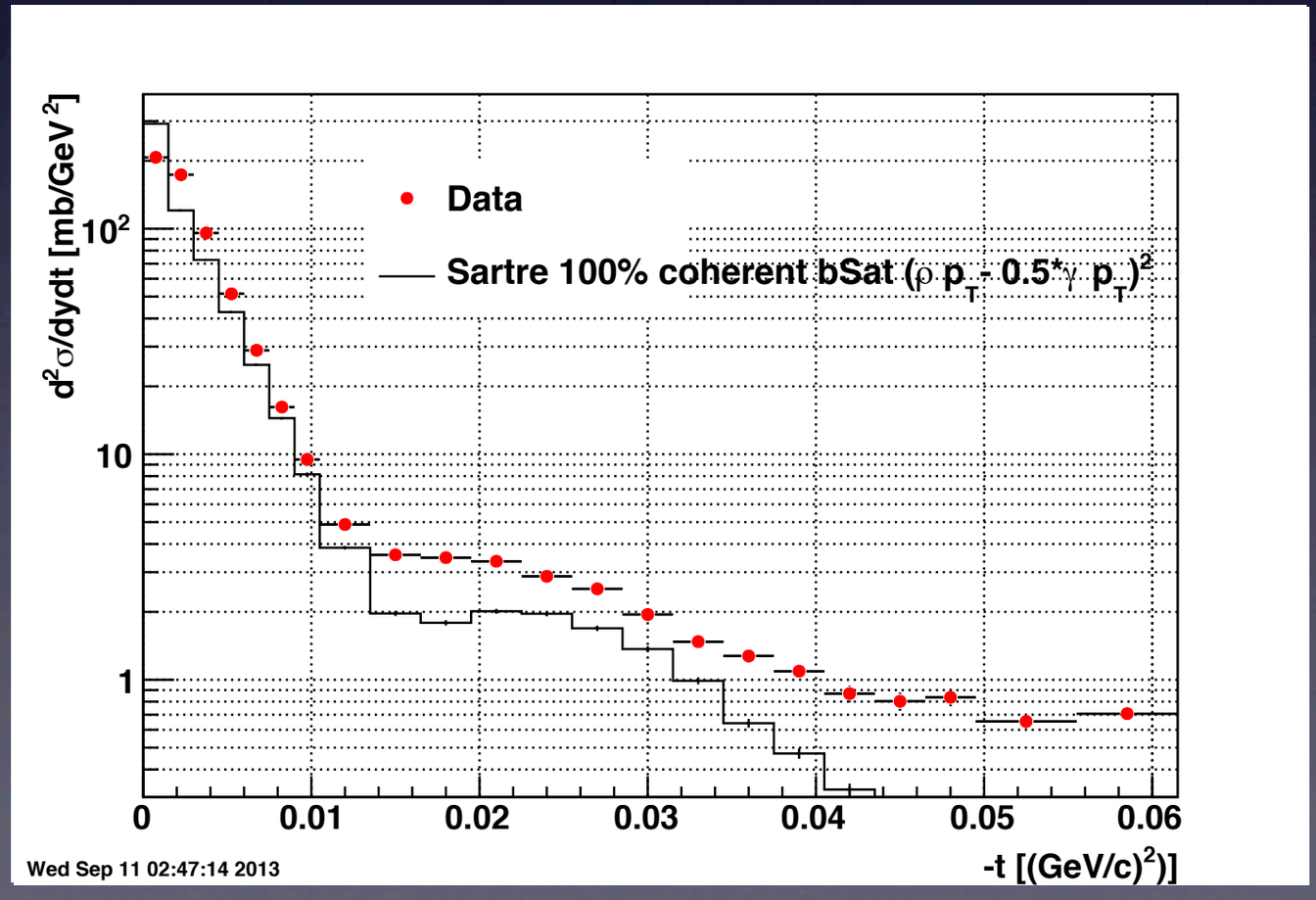

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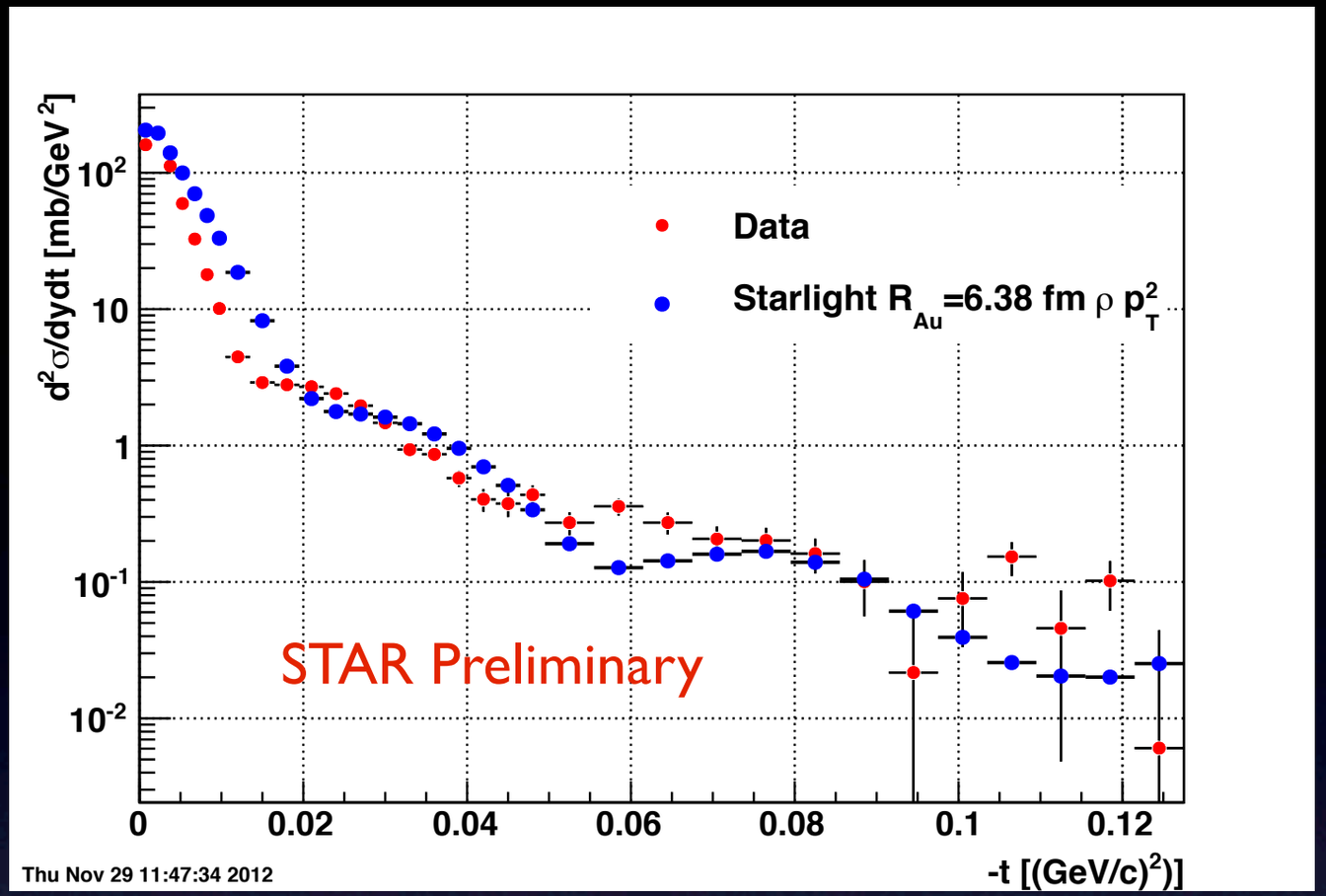


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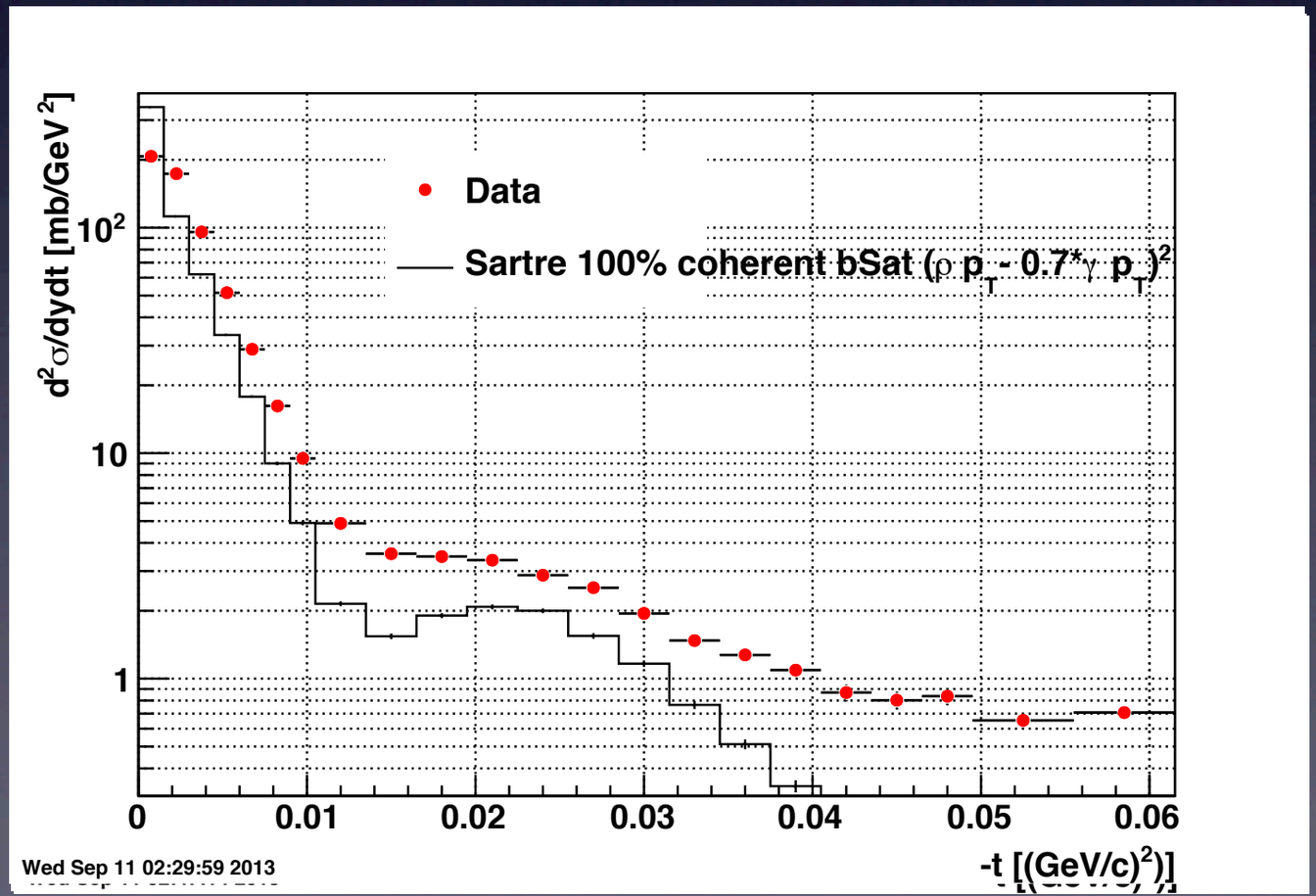

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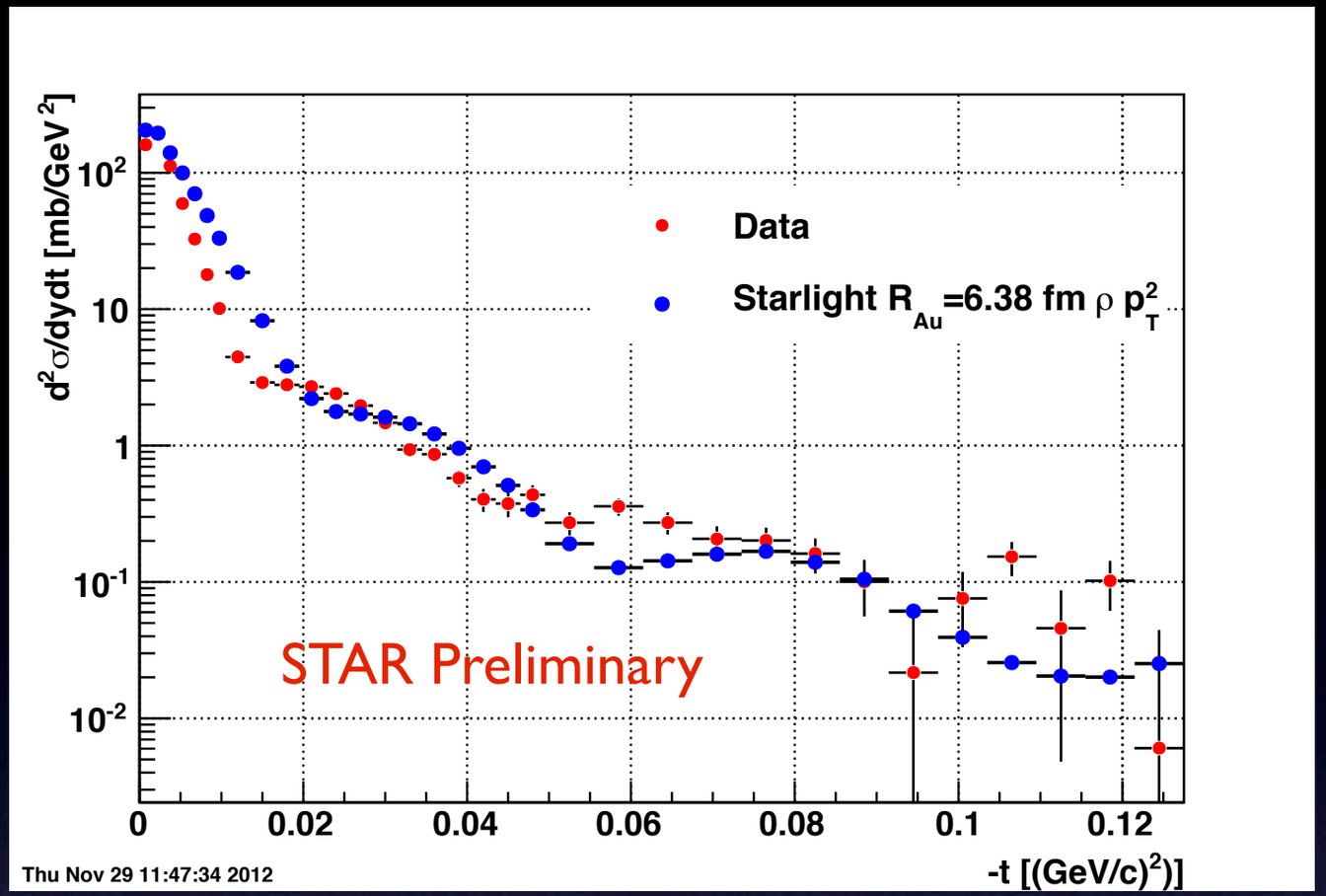


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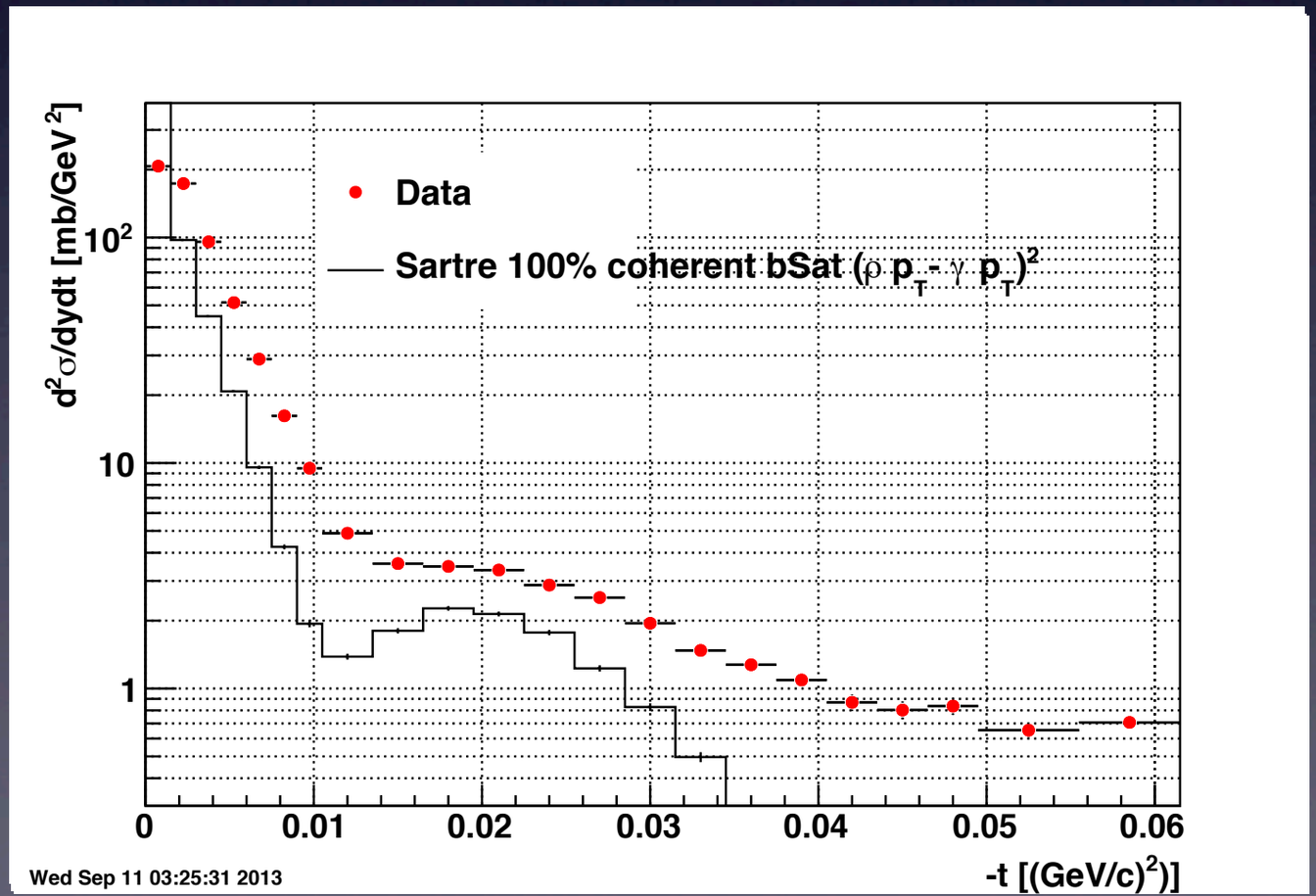
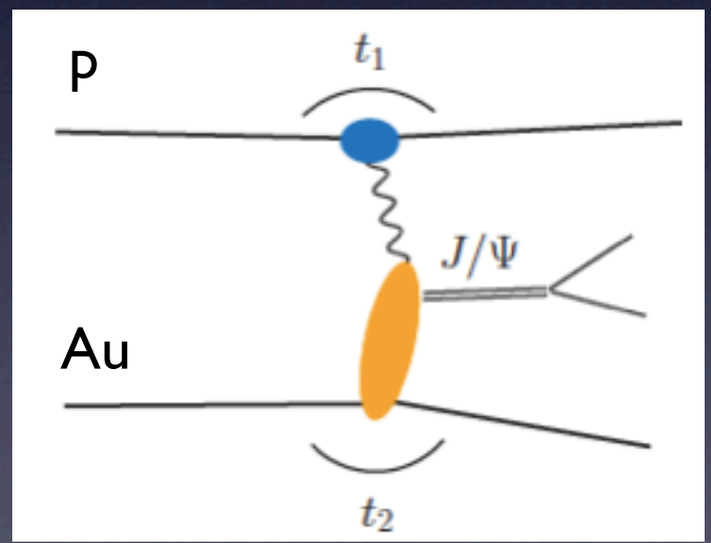


# STAR Future plans

Get the different analyses into publications.
Proceed with the analysis of the U+U at 193 GeV data.

Planned p+A run in 2015 run. STAR will add Roman Pots. UPC program will gain the control of the $t_1$ recoil of the proton.



# Summary

PHENIX measured J/ Ψ photo-production cross-sections and their $p_T$ dependence in a broad rapidity region.

J/ψ +Xn result at mid-rapidity is consistent with calculations suggesting strong gluon shadowing.

Important contribution from incoherent processes in J/ψ Xn(y<0)Yn(y>0) at forward rapidity.

New vertex detectors will help to further study UPC events at RHIC.

STAR has measured $\rho^0$ photo-production in A+A at several energies and systems. The high statistics obtained in recent runs permit the study of a diffraction pattern off the Au nucleus.

STAR is also embarked in the study of J/ψ photo-production in two units of rapidity at mid-rapidity. We are analyzing the U+U at 193 GeV and preparing for the 2015 p+Au run with the Roman Pots.

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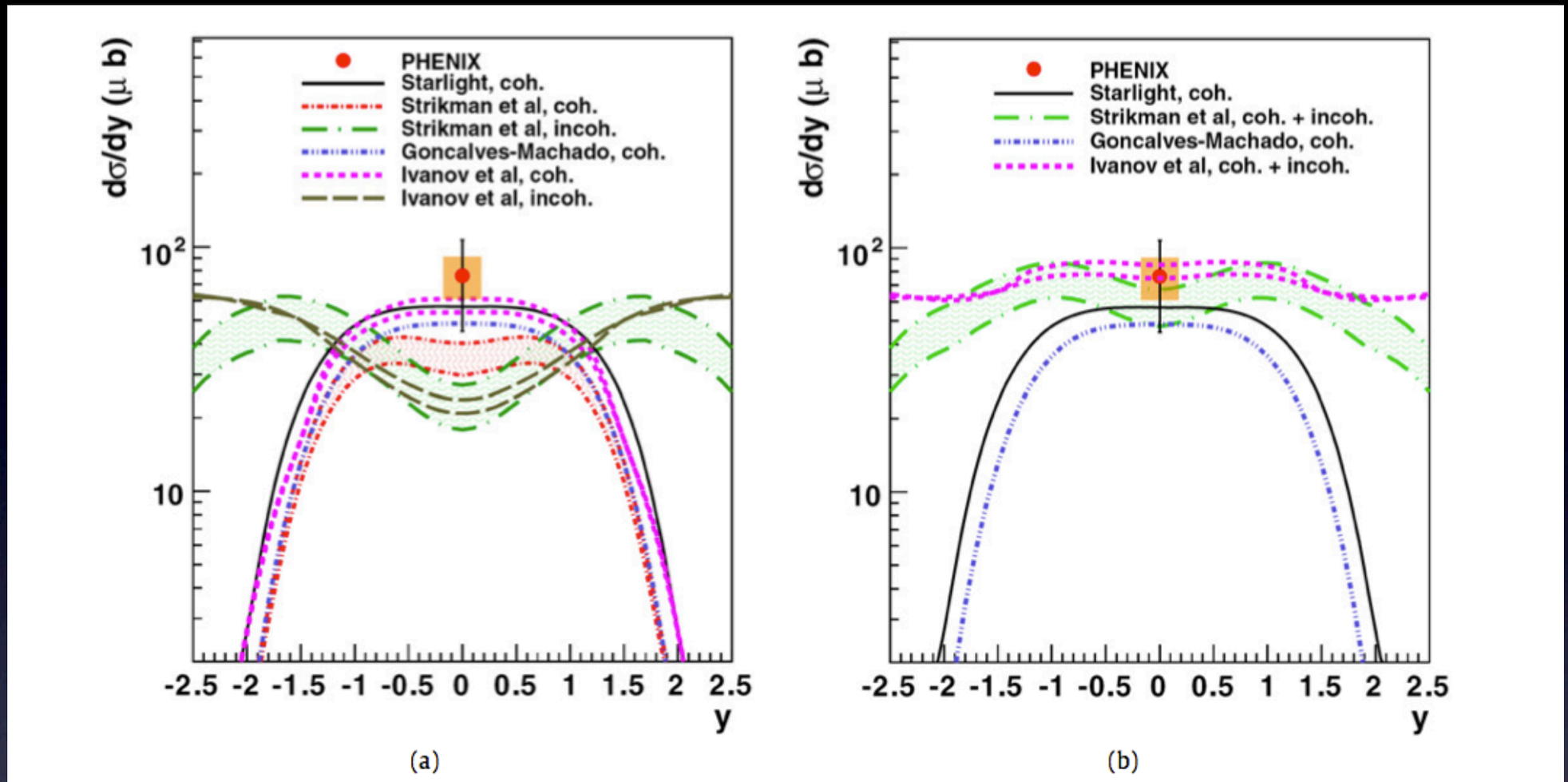
# Backups

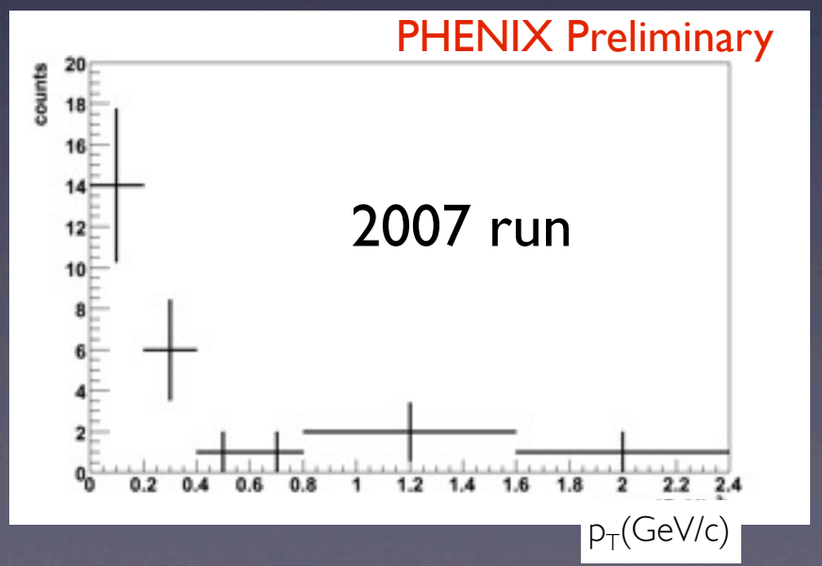
# J/ψ Xn  PHENIX y~0 cont.

Several calculations tend to agree with the 2004 result.




$d\sigma/dy\,|_{y=0} = 76 \pm 31\ (stat) \pm 15\ (syst)\ \mu b$

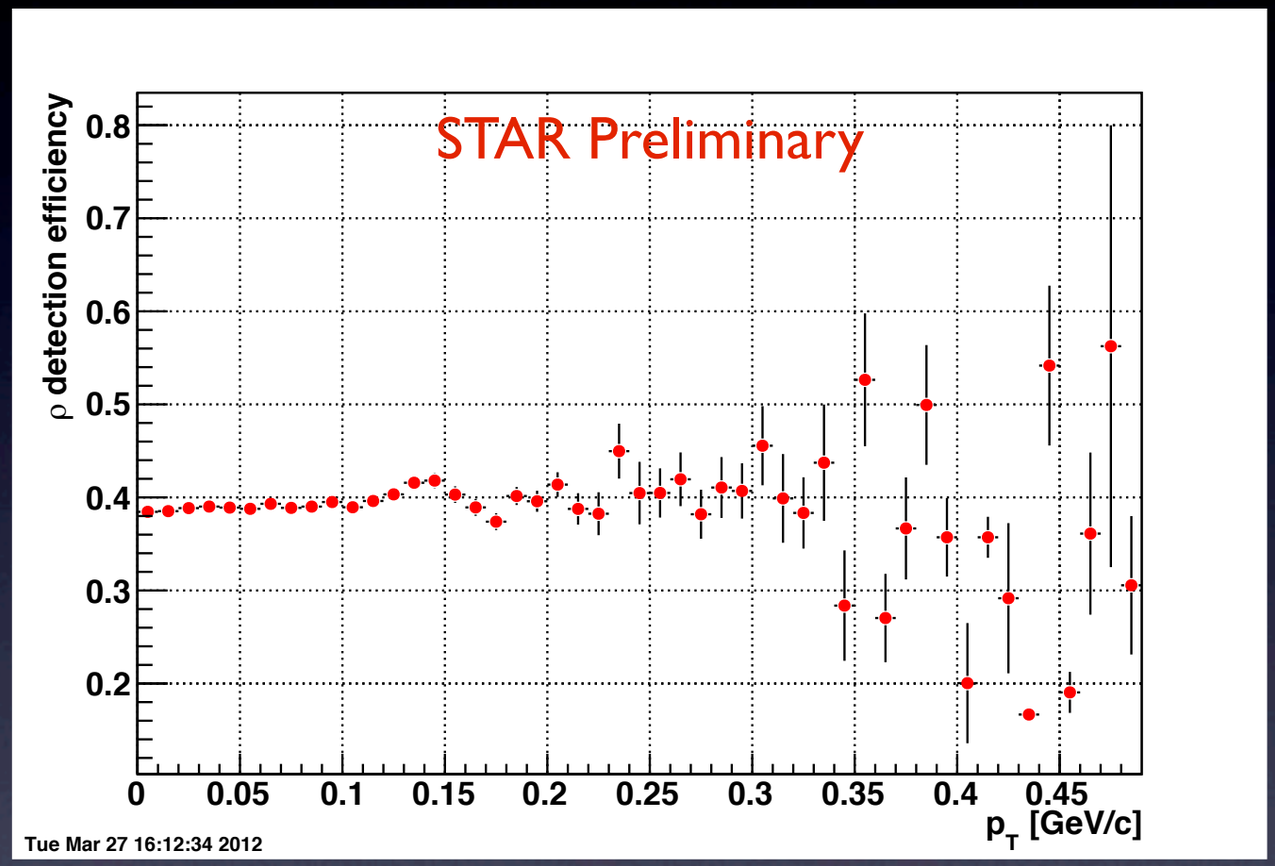
Higher statistics 2007 analysis applies same conditions: (Xn)



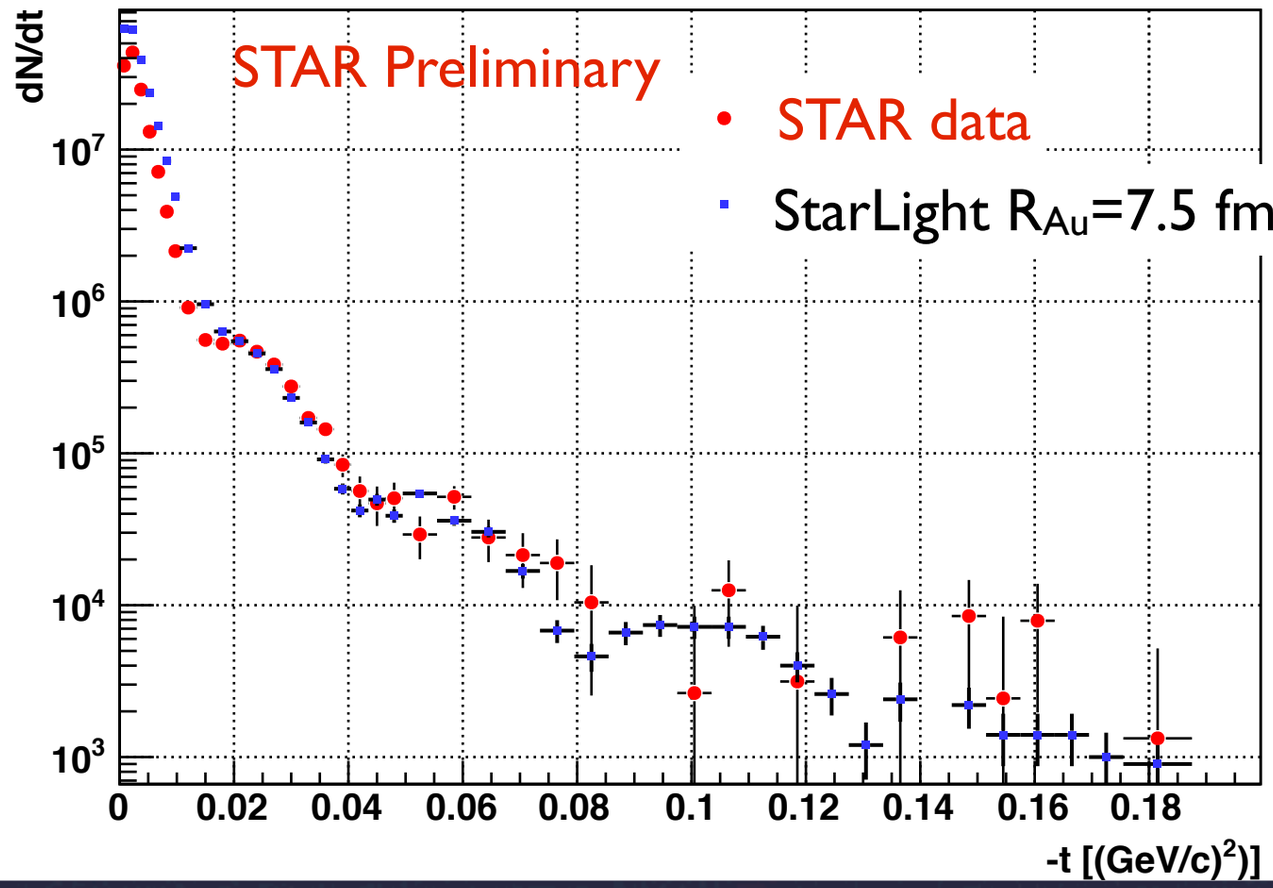
# Normalization

Luminosity from min_bias : 0.679 $nb^{-1}$ Scaler counts from the "minbias_monitor" trigger uses VPD and assumes 6 b cross section.

ρ meson detection efficiency obtained from embedding of Starlight pion pairs from ρ into zero-bias events: averaged over -1<η<1



# Comparison to StarLight




StarLight: Object-oriented simulator of $\gamma\gamma$ or $\gamma p$ interaction in UPC events.

From our presentation at the last DNP:
StarLight required $R_{Au}$=7.5 fm to match the data. The authors are working on an improved version to bring the radius back to ~6 fm

StarLight doesn't have deep valleys between diffraction peaks because it allows for a transverse component in the photon momentum.

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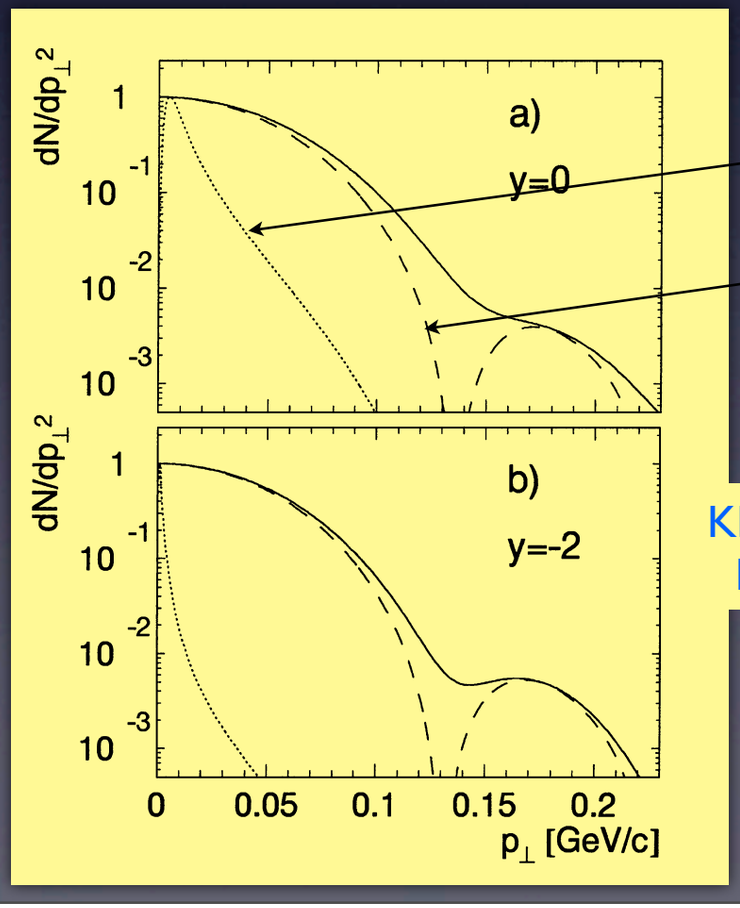


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