p+A Physics with the PHENIX MPC-EX Detector

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Iowa State University
RHIC/AGS Users Meeting

The MPC-EX Physics Program

- **The Gluon Distribution in Cold Nuclear Matter at Low-x:**
  - Single π^0 production
  - π^0 pairs
  - Prompt Photons

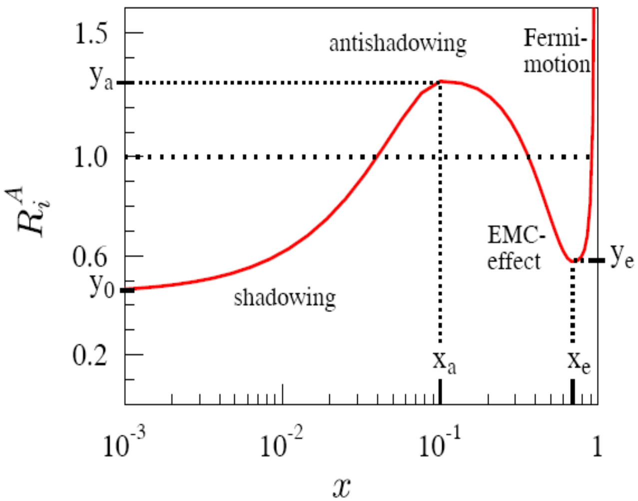
  Extended kinematic range for existing measurements (p_T>1 GeV/c, E>20GeV)

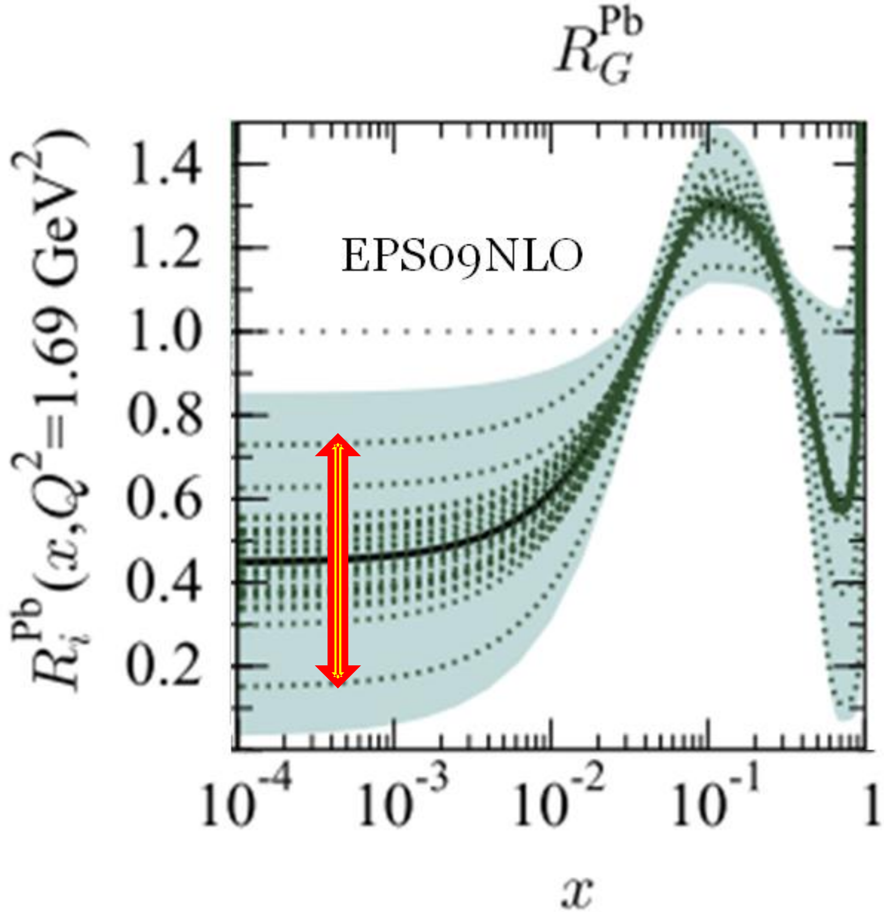
- **Source of A_N in p↑+p Collisions:**
  - Prompt Photon A_N
  - π^0 correlations with jet-like clusters
    - "pioneering" measurement
  - Jet A_N

Gluons in Nuclei

Eskola , Paukkunen, Salgado, JHP04 (2009)065

shadowing/saturation in nuclei



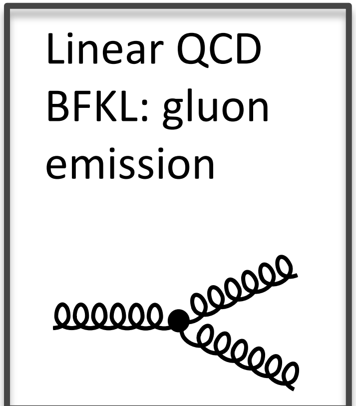


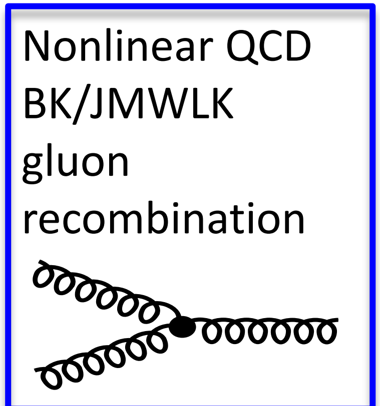
$$R_G{}^{Pb}(x,Q^2) = \frac{xG_A(x,Q^2)}{AxG_p(x,Q^2)}$$

- Lack of data means large uncertainties at low-x
- Additional complications
  - Saturation, energy loss, shadowing, anti-shadowing

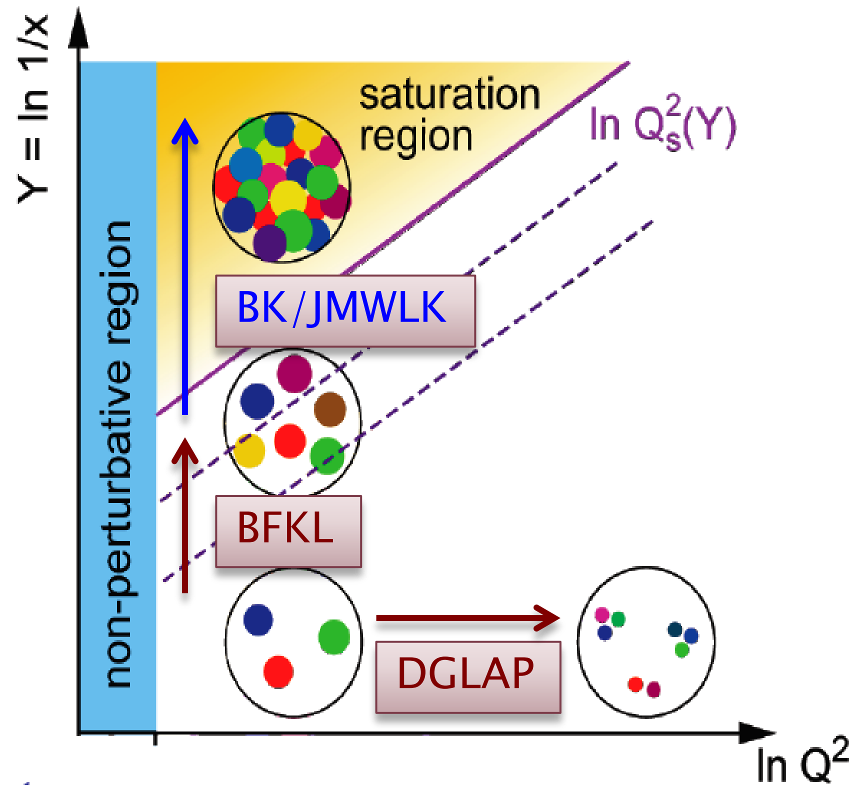
Structure deep inside nuclei?

- High gluon density, small coupling at low x (p_g/p_N)
  - More in nuclei than nucleons





(McLerran, Venugopalan)

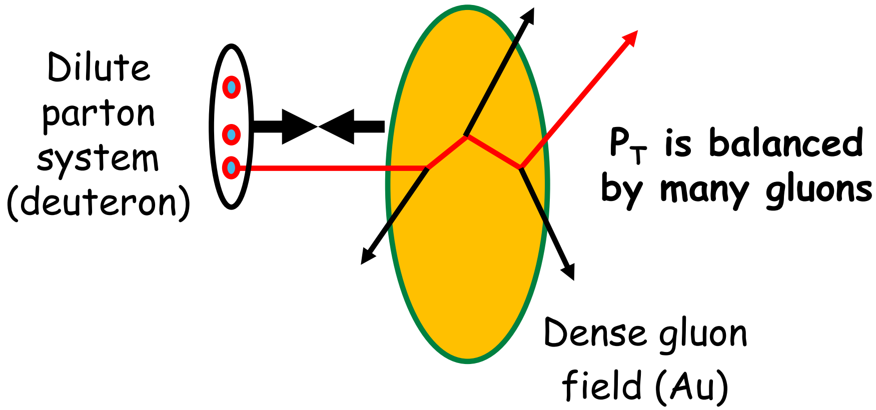


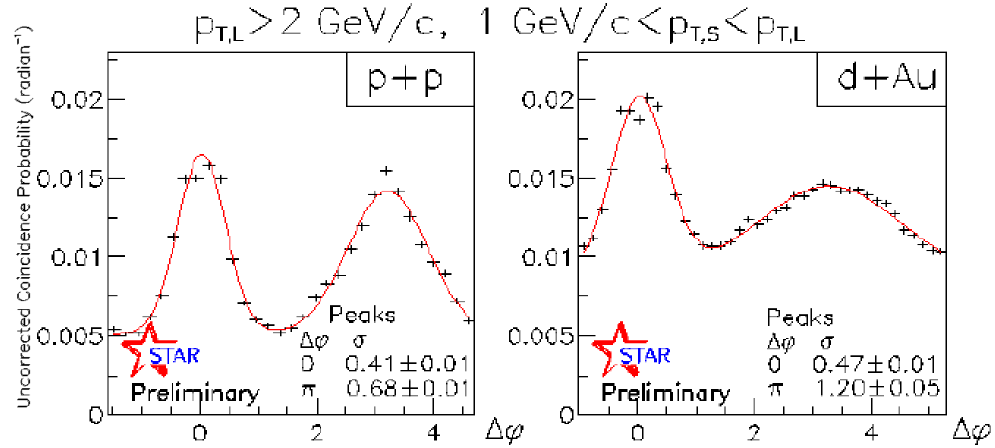
- Can describe saturated gluon distribution as a field

What effects of incoming parton dynamics?

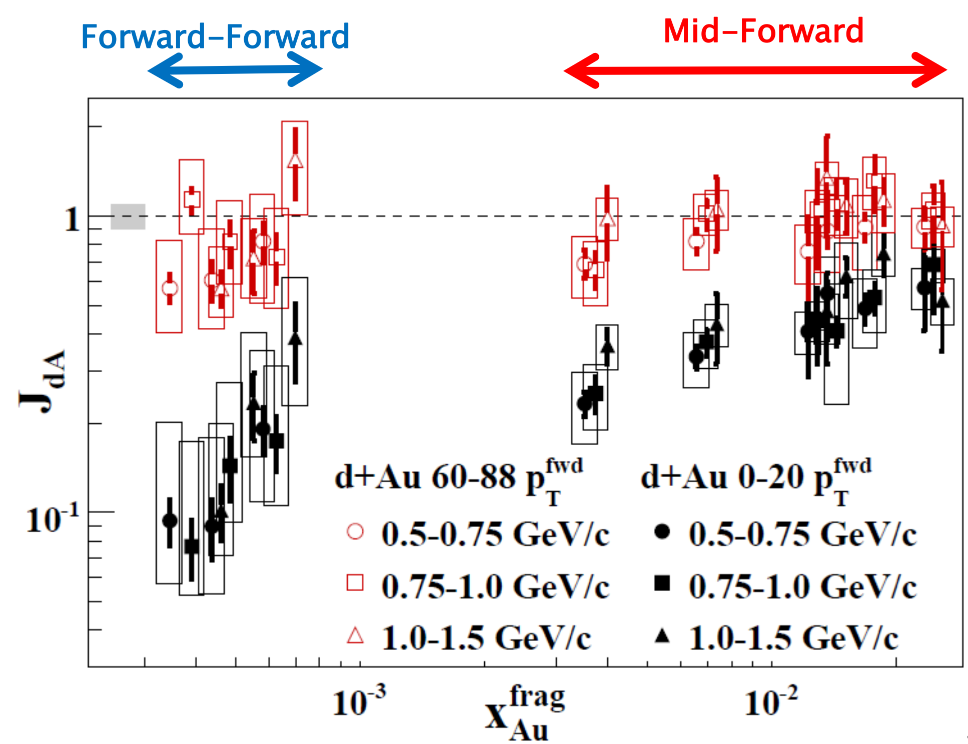
See Ann. Rev. Nucl Part (60) 2010 F. Gelis et al., , arXiv:1002.0333)

First hints at RHIC for saturation of gluons





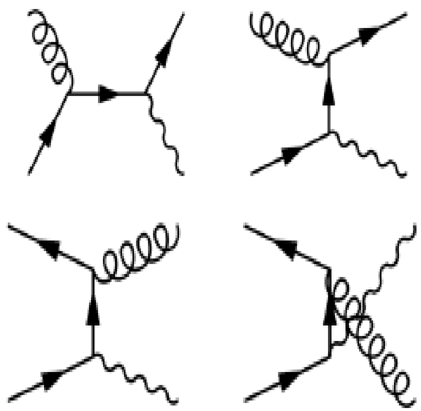
Saturation = dense gluon field



QCD Compton scattering to find out (q+g -> q+γ):
<u>no final state effects on γ!</u>
Forward rapidity to reach small x & high g density

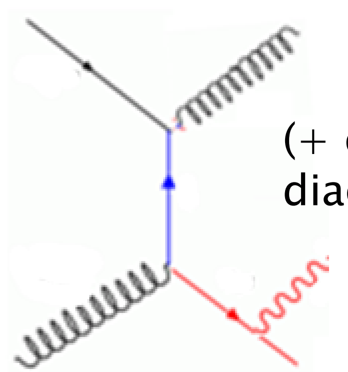
Prompt Photons at Forward Rapidity

Direct Photons
Dominated by gluon Compton at forward rapidites



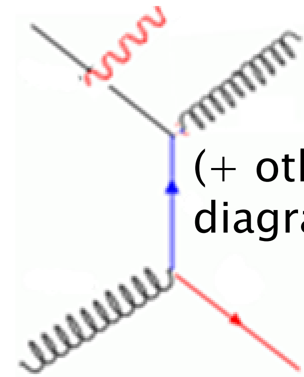
Same level of production in pythia and NLO calculations (within ~2x)

Fragmentation Photons
Comparable between pythia and NLO calculations



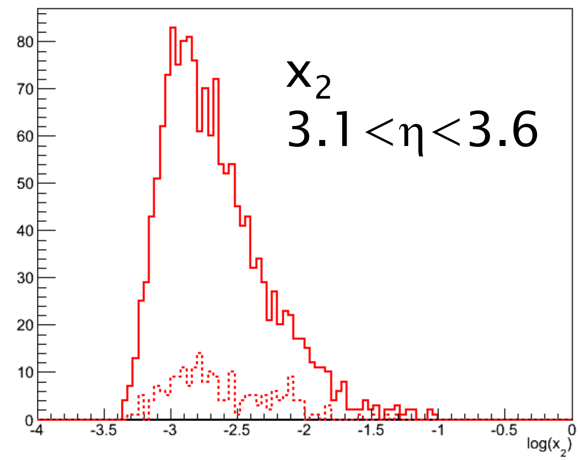
(+ other diagrams)

QED Radiation (initial state)
Production over-estimated in Pythia (Included in direct in NLO)

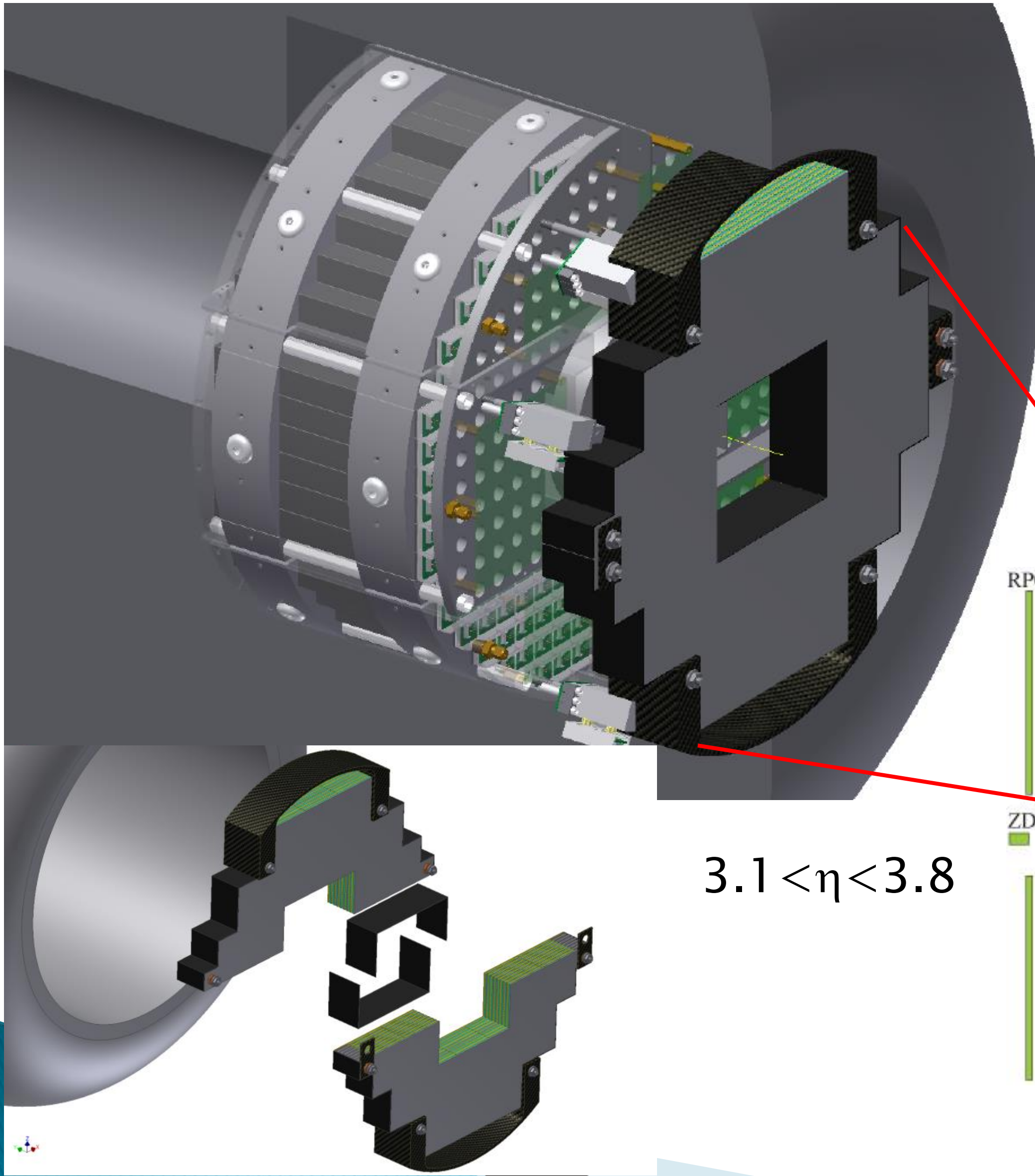


(+ other diagrams)

d(p)+A:
low-x gluons



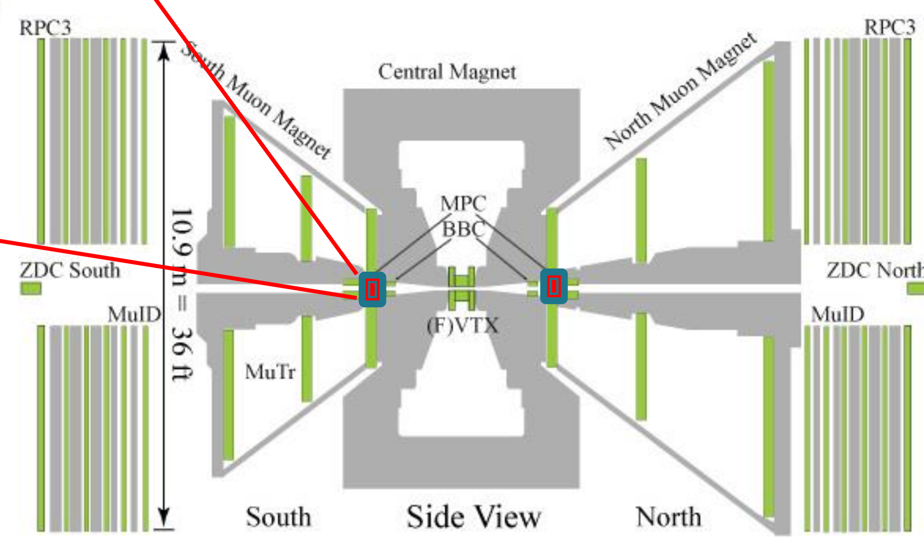
The MPC-EX Detector



A combined charged particle tracker and EM preshower detector – dual gain readout allows sensitivity to MIPs and full energy EM showers.

- π^0 rejection (direct photons)
- π^0 reconstruction out to >80GeV
- Charged track identification

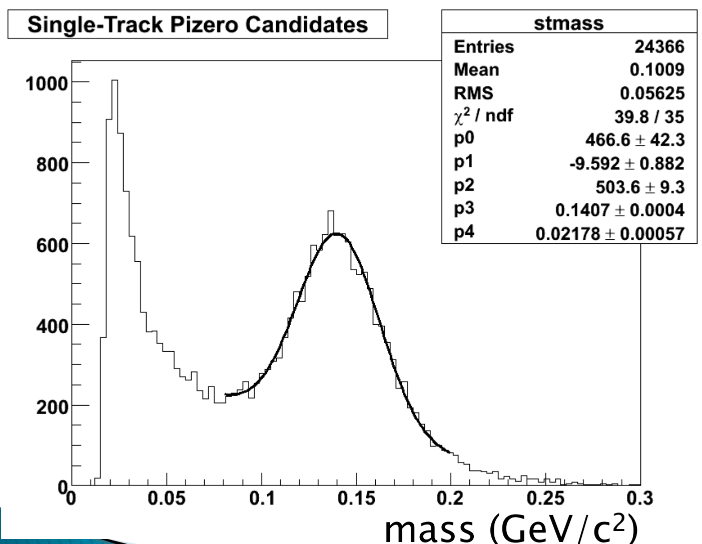
$3.1 < \eta < 3.8$



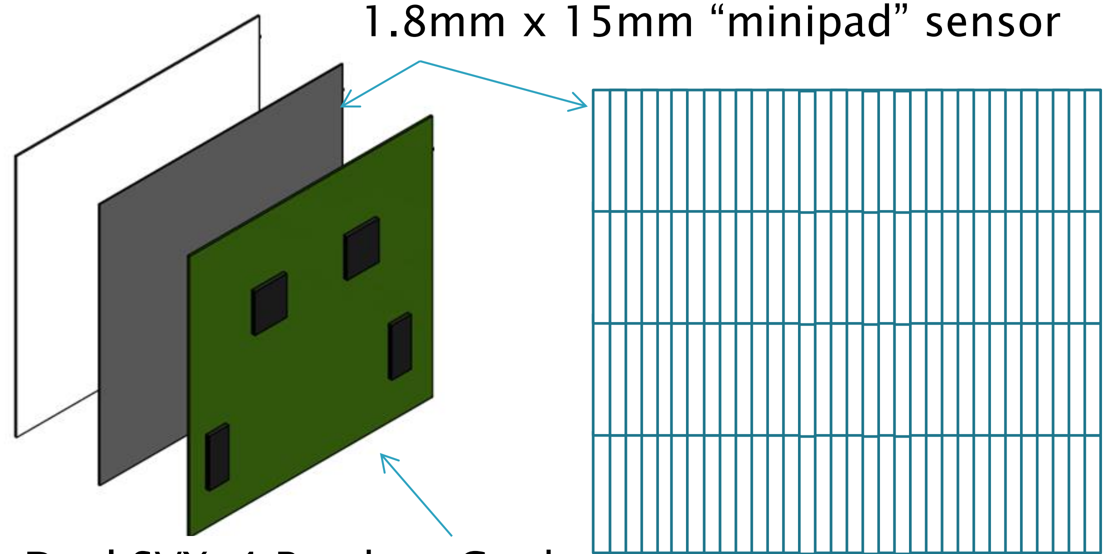
Minipad Sensors

Detector elements are Si "minipad" detectors, one layer per tungsten gap, oriented in X and Y (alternating layers).

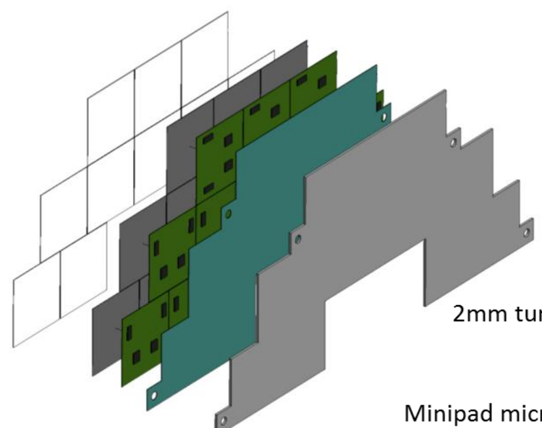
π^0 mesons reconstructed in p+p jet events (E>20GeV)



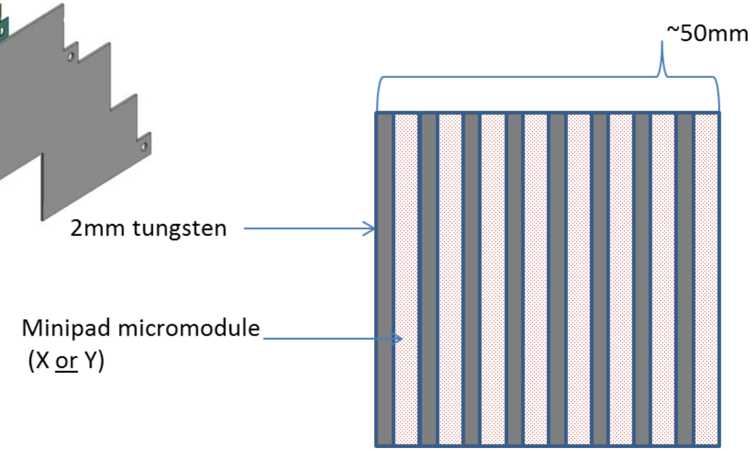
1.8mm x 15mm "minipad" sensor



Dual SVX-4 Readout Card

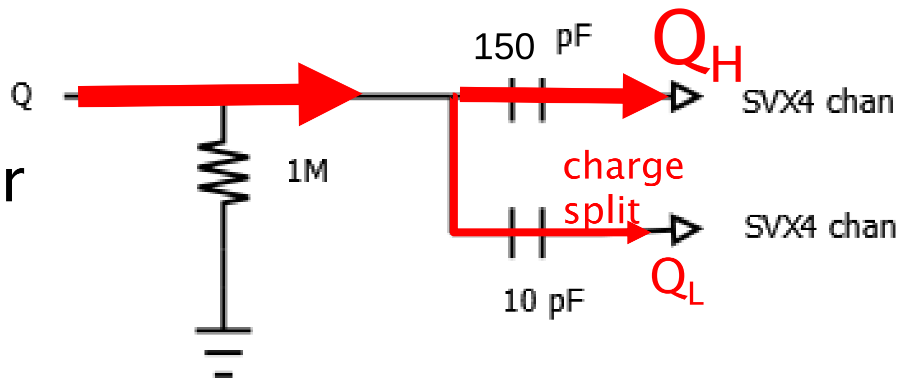


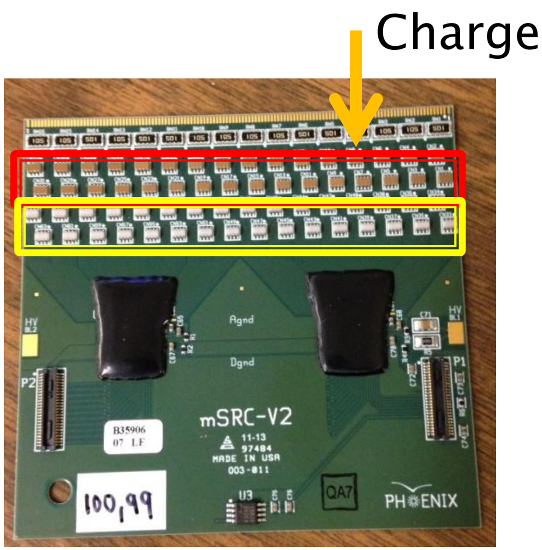
Cross-Section View:

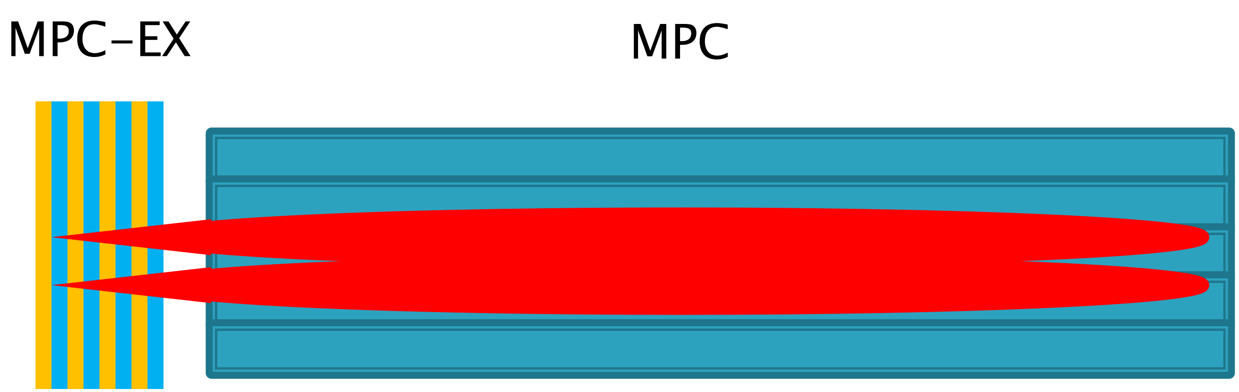


Tracking through the layers

- Need to be:
  - Sensitive to MIPs in first layer
  - Not saturated at last layer

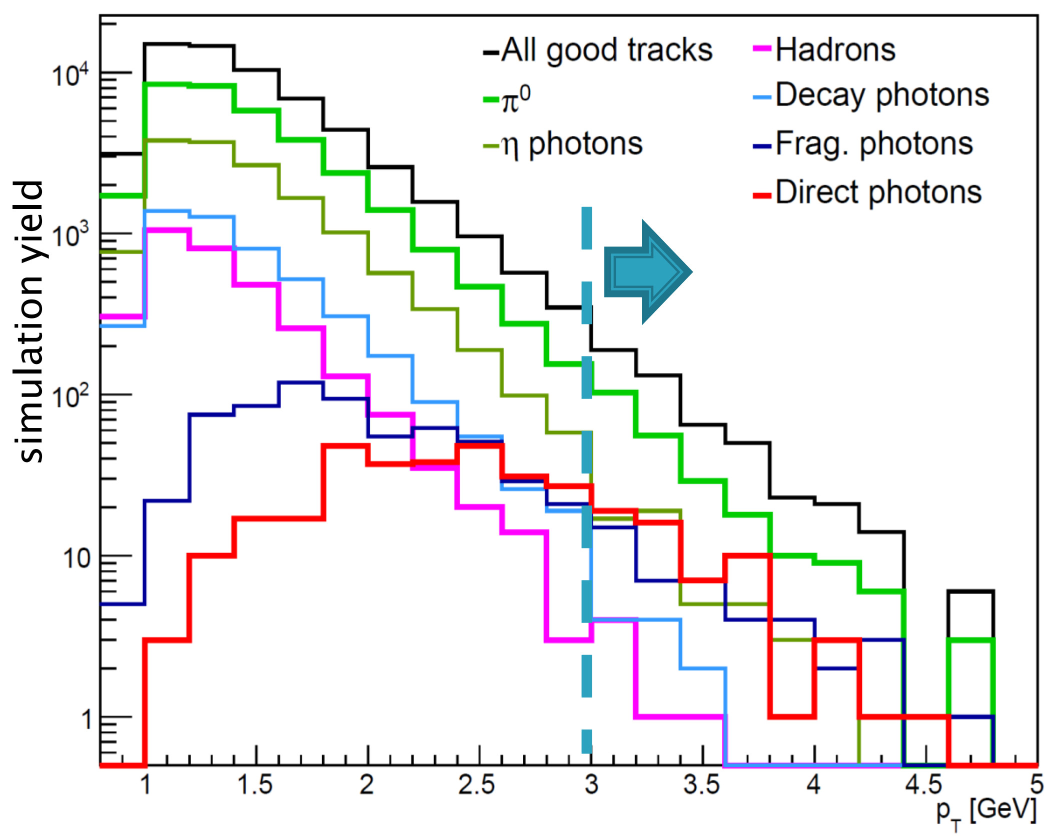




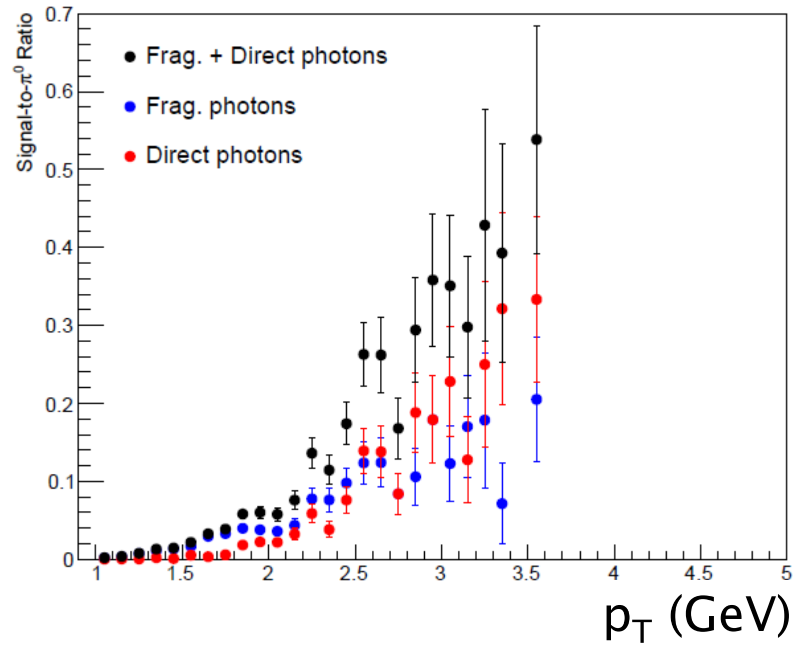


<u>128 minipads become 256 channels</u>

Prompt Photon Yields

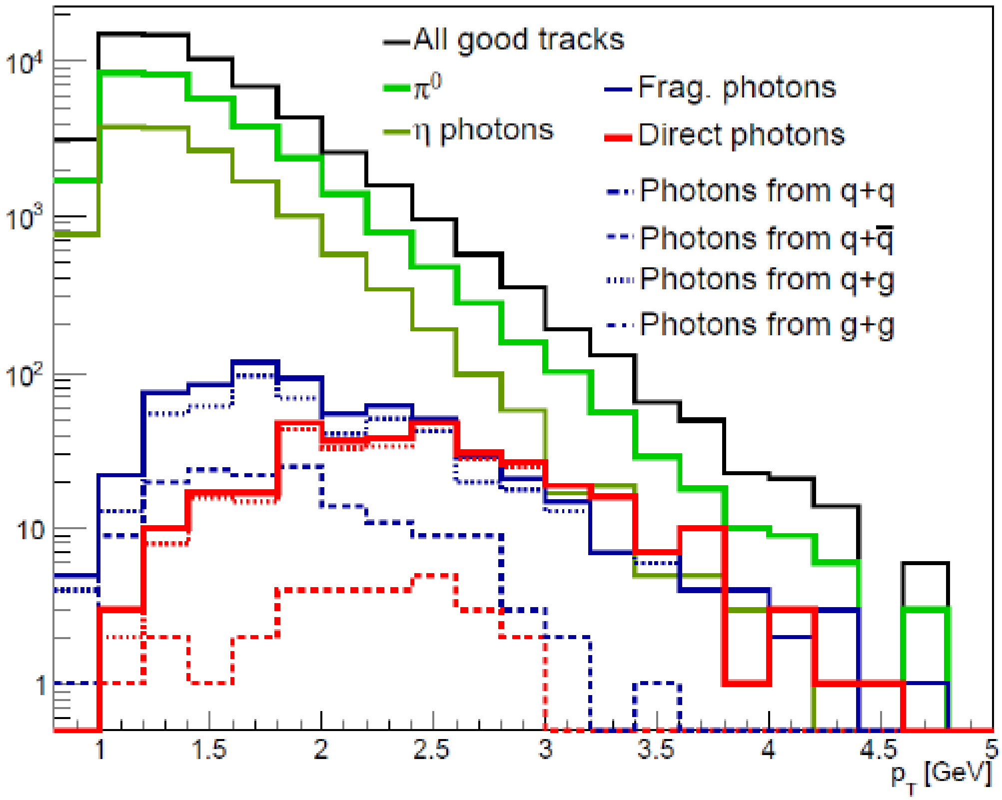


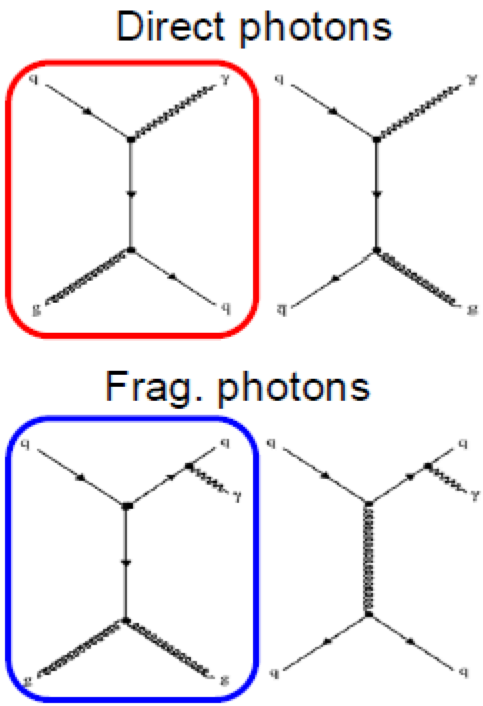
200GeV MB p+p



- <u>For $p_T > 3$GeV</u>
  - dir/(dir+frag) – 57.4%
  - signal/π^0 – 43%

Photon sources



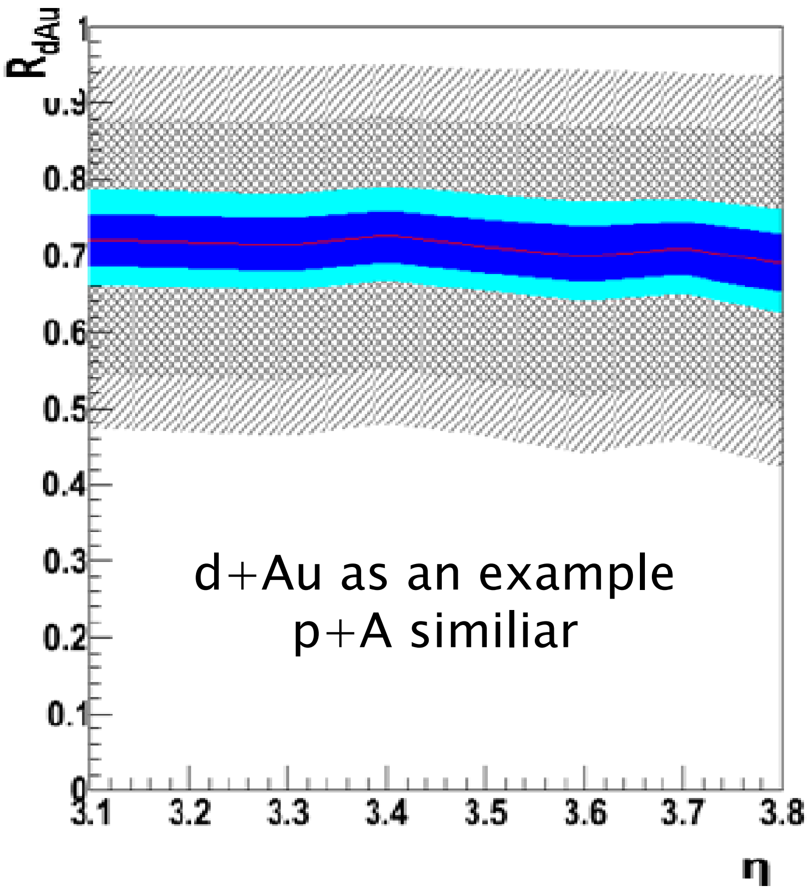


- pT >3GeV
  - 100% of direct photons from $q + g$
  - 93%(7%) of fragmentation photons from $q + g$ $(q + \bar{q})$

Calculating R_{pA}

$$\gamma_{signal} = \gamma_{Incl} * (1 - \frac{1}{R_\gamma})$$

$$R_\gamma = \frac{(\frac{\gamma_{Incl}}{\pi^0})_{Meas}}{(\frac{\gamma_{Incl}}{\pi^0})_{Sim}}$$



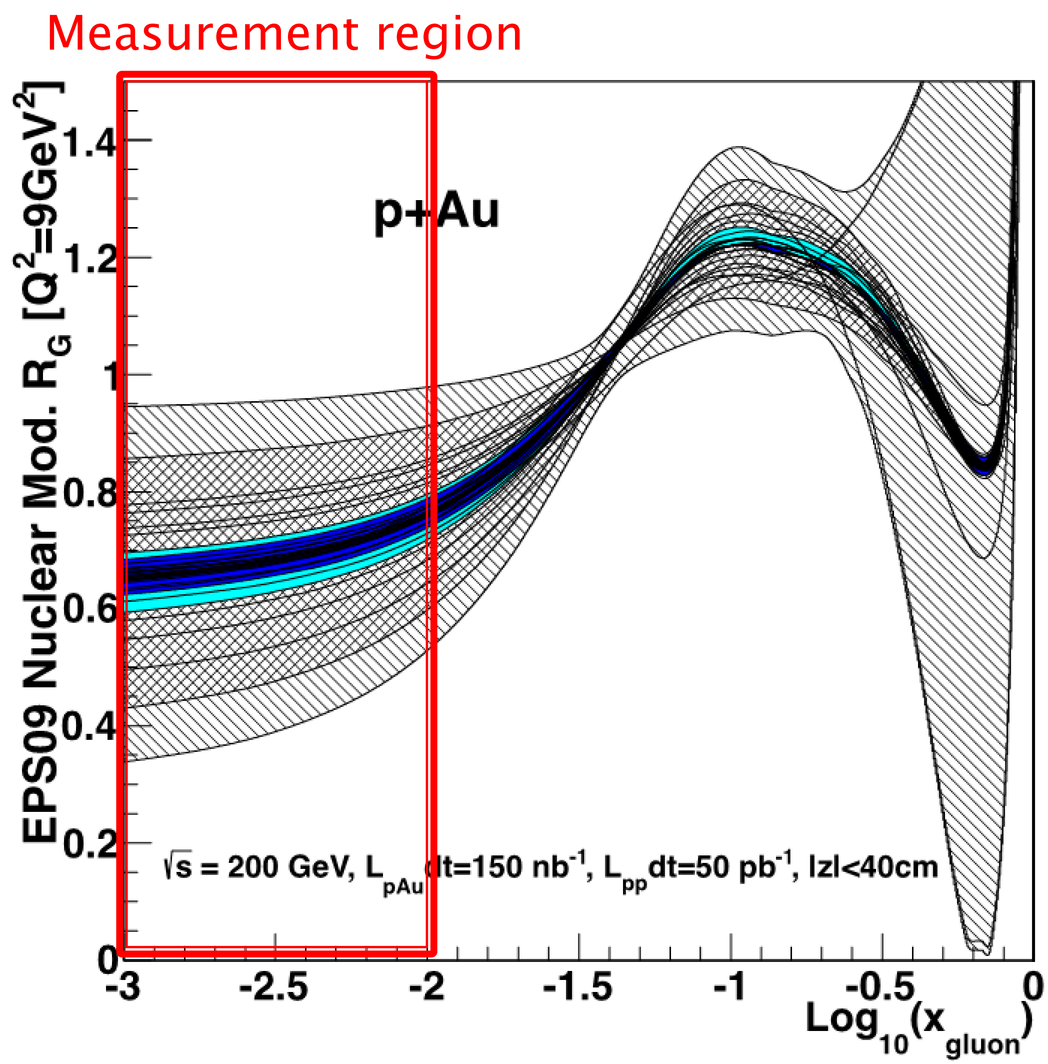
- γ_{Incl} = inclusive photon yield after hadron subtraction
- $(\frac{\gamma_{Incl}}{\pi^0})_{Sim}$ = simulated photon-to-pion ratio

$$R_{pA} = \frac{1}{\langle N_{coll} \rangle} \frac{\gamma_{Incl}{}^{pA} * \left(1 - 1/R_\gamma{}^{pA}\right)}{\gamma_{Incl}{}^{pp} * \left(1 - 1/R_\gamma{}^{pp}\right)}$$

EPS09 as a baseline

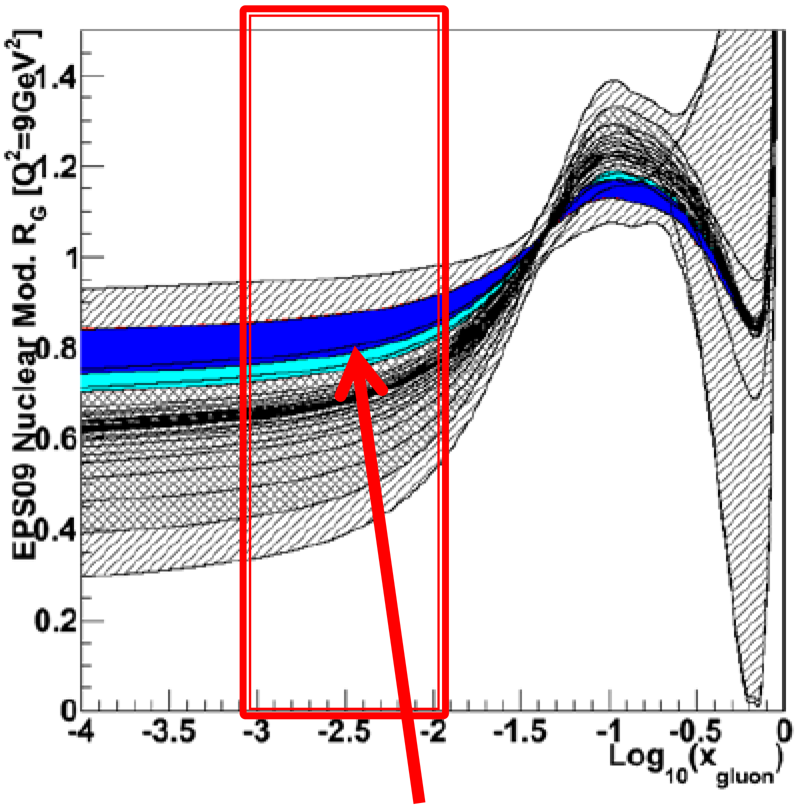
EPS09 Limits from Prompt Photons

- Weight events in x, Q^2 according to EPS09 to generate R_{pAu} for each curve
- Assume the R_{pAu} value we measure corresponds to the EPS09 baseline
- Vary R^{pp}_{γ}, R^{pAu}_{γ}, γ^{pAu}_{incl} and γ^{pp}_{incl} within 3-sigma systematic errors
- Evaluate EPS09 curves to see which are consistent within 90% C.L.

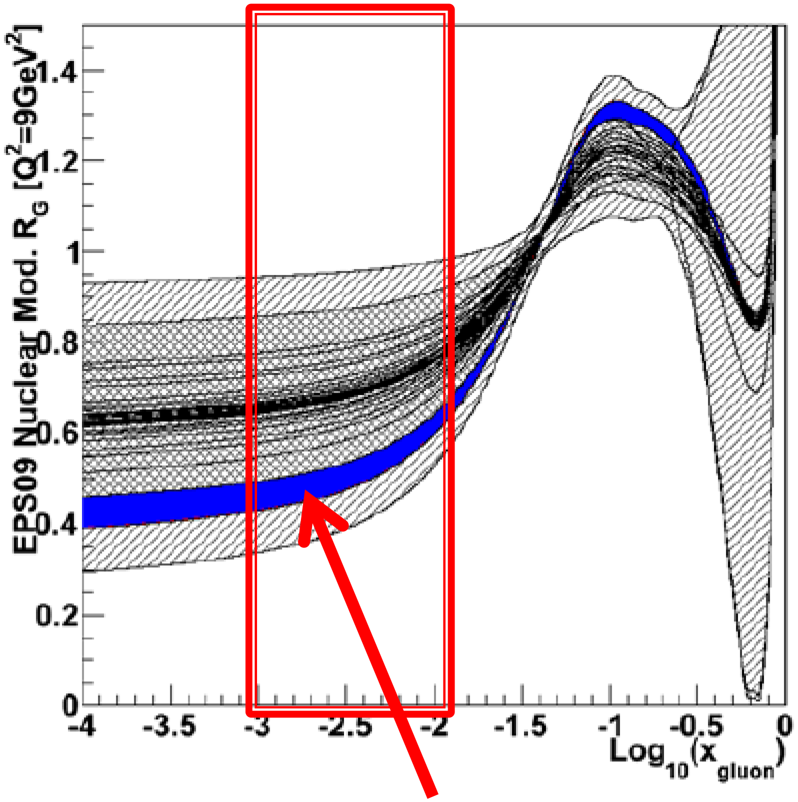


Prompt photons in MPC-EX -> Precise Measurement of Gluons at Low-x

Upper and Lower Limits from EPS09



assuming EPS09 upper curve



assuming EPS09 lower curve

Ultimate sensitivity depends on the measurement and a full NLO fit.

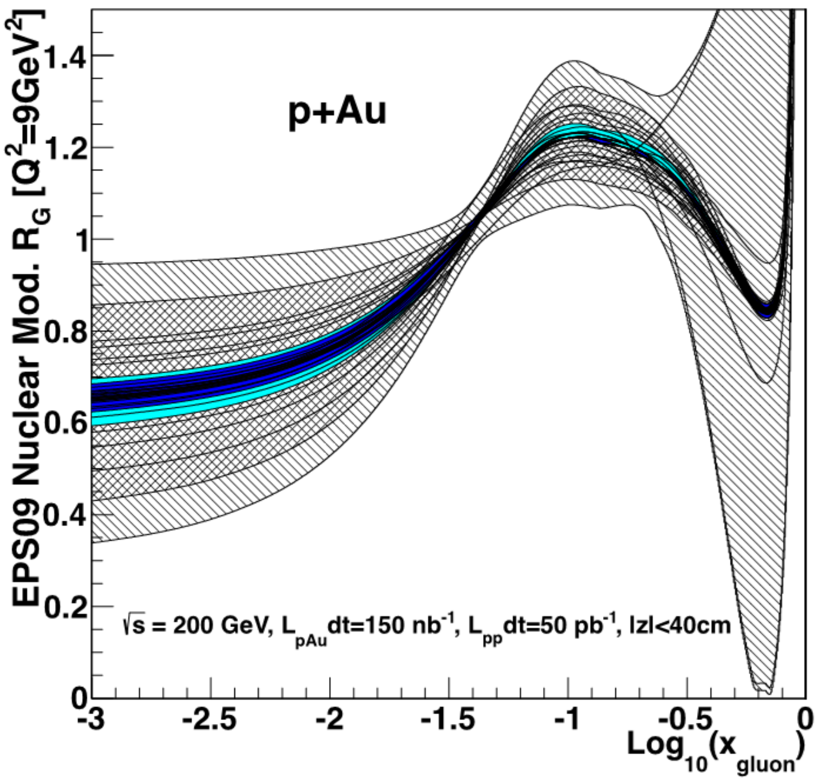
Why worry about "parton dynamics"?

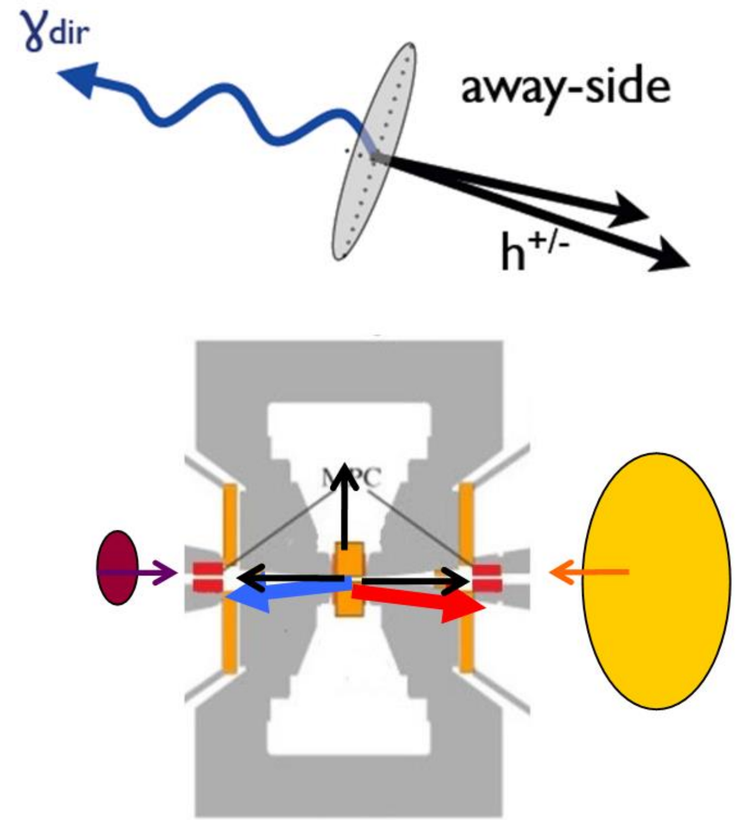
- Nuclear parton distribution functions (e.g. EPS09) aren't the whole story!

- In p/d+A you probe cold nuclear matter with a parton, not a photon.
  - It can lose energy before the hard scattering
  - It can lose energy after the hard scattering
  - It can experience multiple scattering

- Tool in the short run: γ–h correlations
  - γ will reflect only initial state effects
  - h will have both initial and final state scattering and energy loss
  - Measure the difference via p+A vs. p+p

To sort out parton dynamics

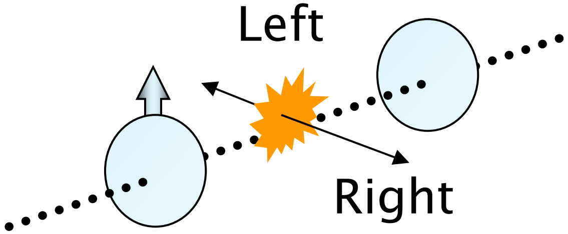




- Direct γ – Structure + initial state energy loss
- Correlations: γ vs. h – Final state parton dynamics
  - Probe as a function of y

Polarized p+A Collisions

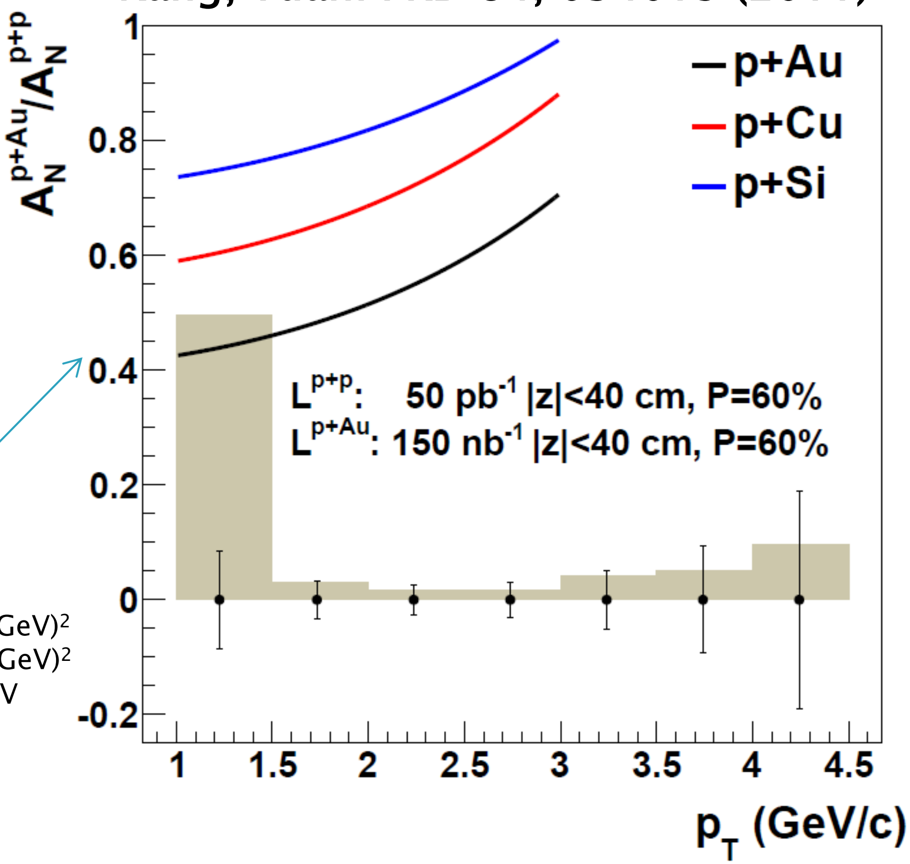
$$A_N = \frac{1}{P}\frac{\sigma_L^\pi - \sigma_R^\pi}{\sigma_L^\pi + \sigma_R^\pi}$$



$$\left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp}^2 << Q_{sA}^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{P_{h\perp}^2 \delta^2 / Q_{sp}^2}$$

$Q_{sp}^2 = (1.0\text{ GeV})^2$
$Q_{sA}^2 = (2.5\text{ GeV})^2$
$\delta = 0.16$ GeV

Kang, Yuan: PRD 84, 034019 (2011)



Single spin asymmetries can act as a probe of the saturation scale.

A unique capability of RHIC!

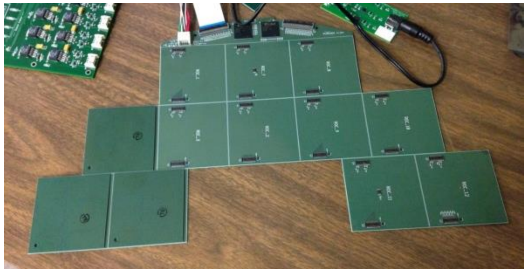
- Dependence of Q_{sA} on A
- Combined with other measurements this can estimate Q_{sp}

Systematic study of SSA's in p↑+A collisions will allow us to study Q_{Sat}

Actual Detector Performance

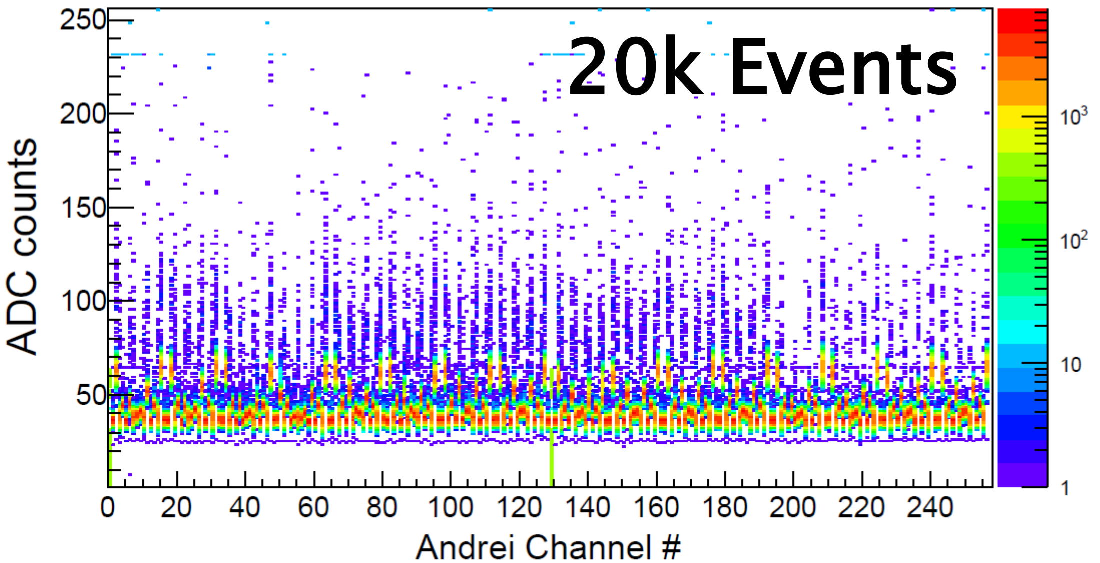
- Production testing on-going at SB
- All micromodules will undergo cosmic ray testing before installation

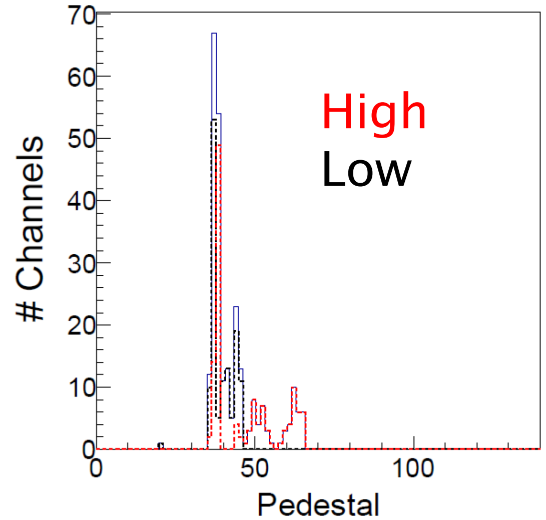
Measured Rate: 300/minipad/day (5Hz)
(will be slightly limited by readout)

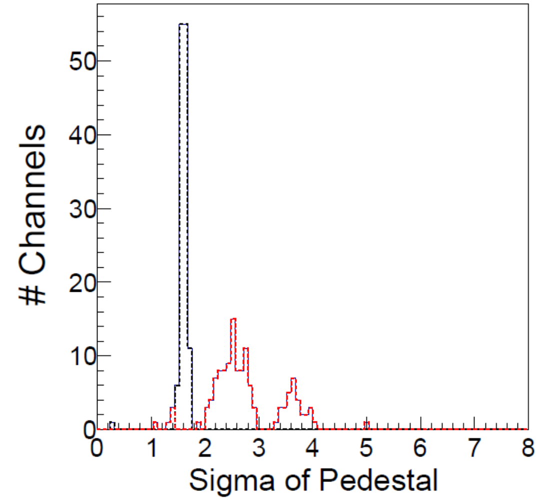


Scintillators about same size as one half layer

Cosmic Rays





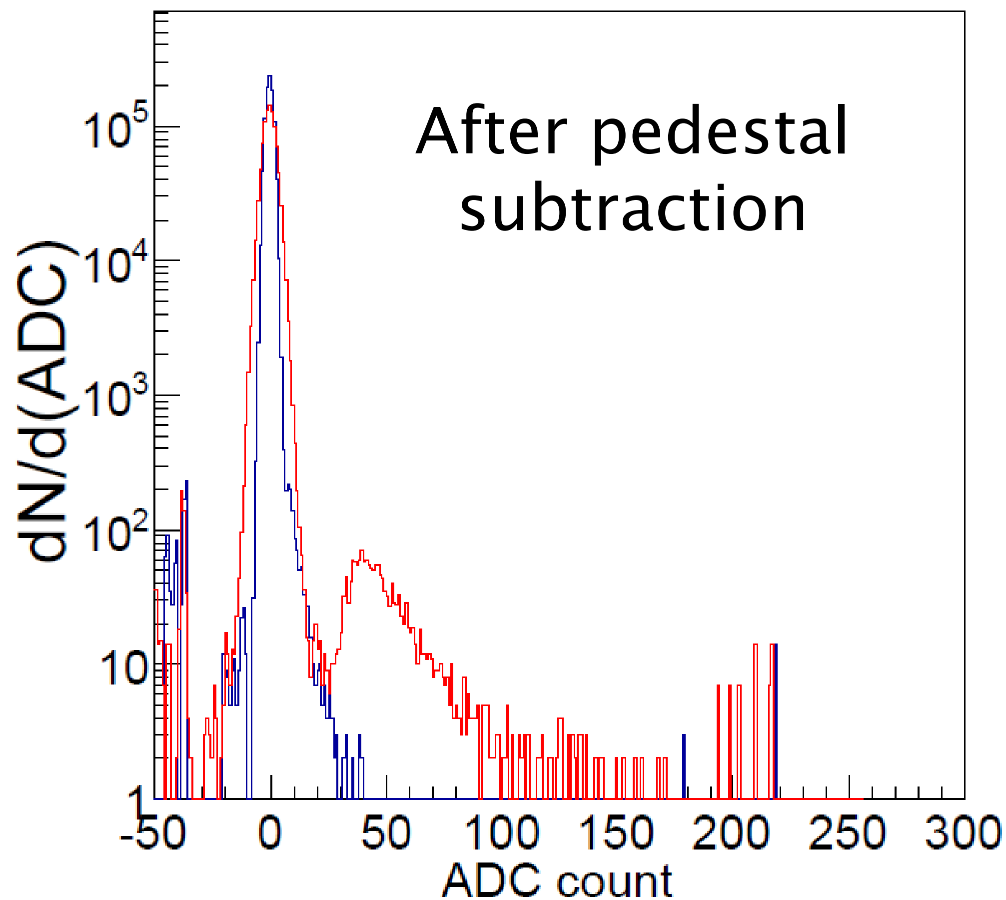


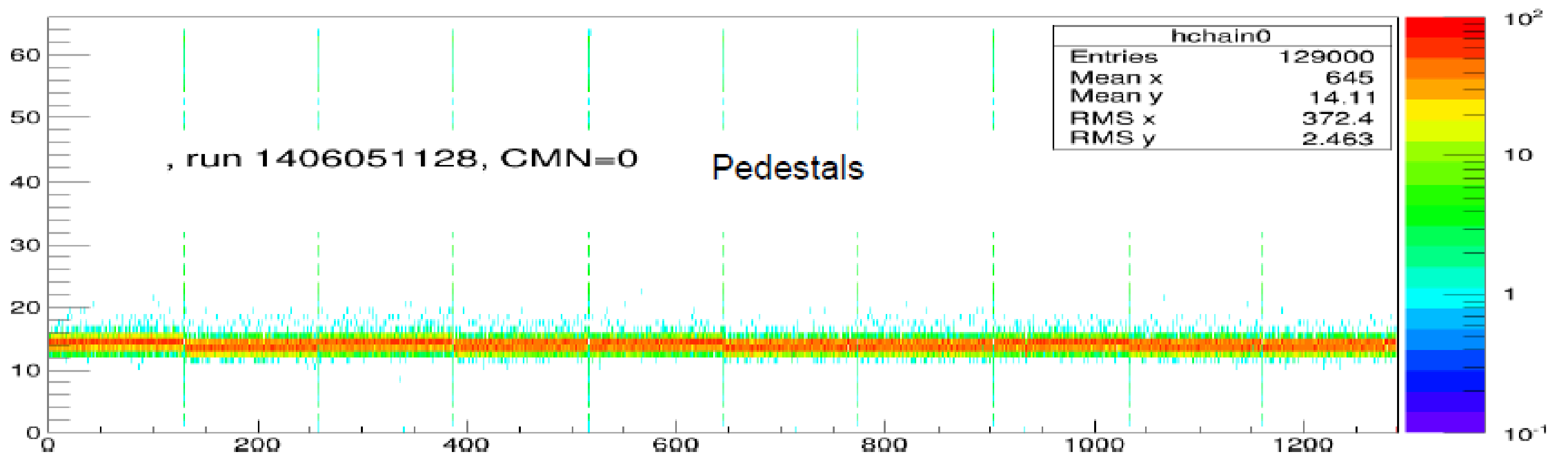
Pedestals are stable over the run:

- High sensitivity channels have broader pedestal fluctuations, higher average pedestals
- Low sensitivity channels have very stable pedestals

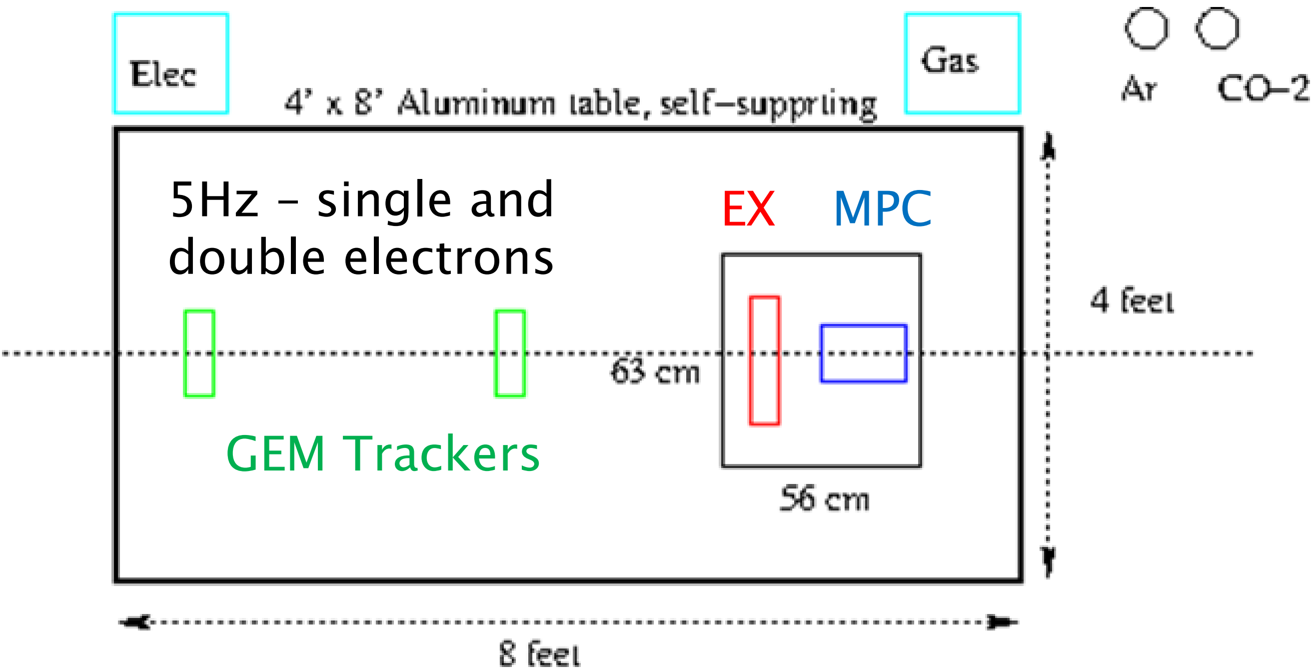
MIP signal

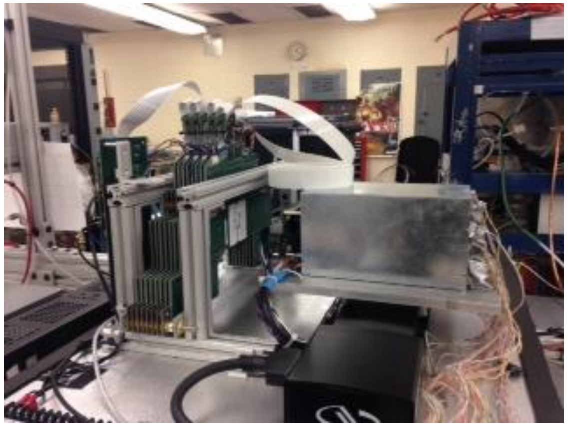
- Different modules
  - MIP peak consistent
  - Pedestals consistent





Next Step: SLAC Beam Test June 20–30





- GEM trackers will both count and vector in the electron(s)
- EX and MPC are on remote-controlled lift table.
- MPC is additionally on sliding table.
- Experiment begins w/o EX
  - MPC moves to center beam in each crystal → Energy Calibration.

Summary

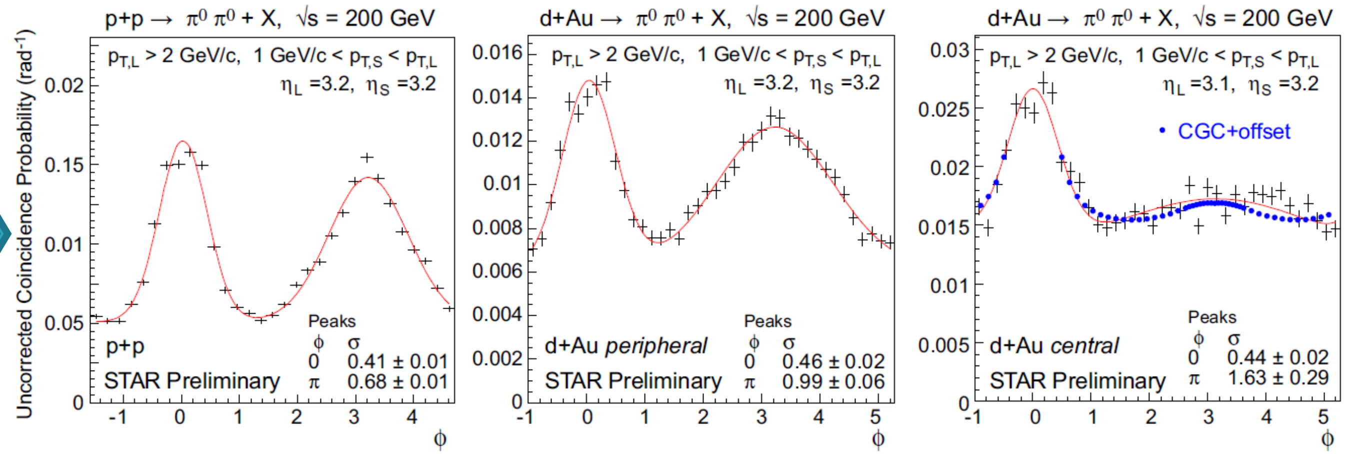
- MPC-EX detector will provide exciting physics opportunities
  - Low-x gluon nPDF
    - More understanding of CNM effects (saturation, shadowing, etc…)
    - Initial conditions for RHIC heavy ion collisions
  - Direct photons and γ-hadron correlations
- MPC-EX ready for Run 15 with minimal commissioning
  - Production testing on-going
  - Installation in the fall
  - Cosmic rays on the test bench
  - EM showers at SLAC

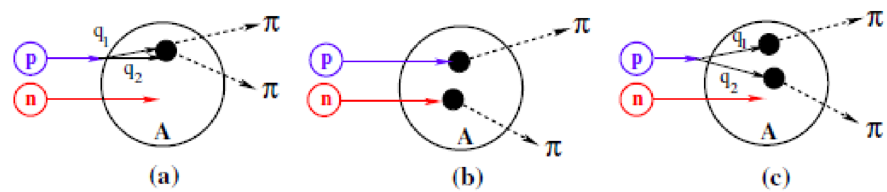
- Exciting future for p+A!

Backups

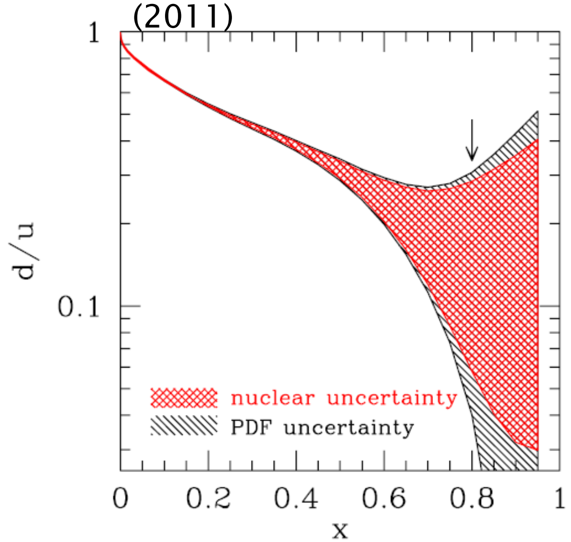
Why p+A instead of d+A?

Multi-parton interactions can contribute to the suppression of the away-side correlation strength.





Phys. Rev. D 84 014008 (2011)



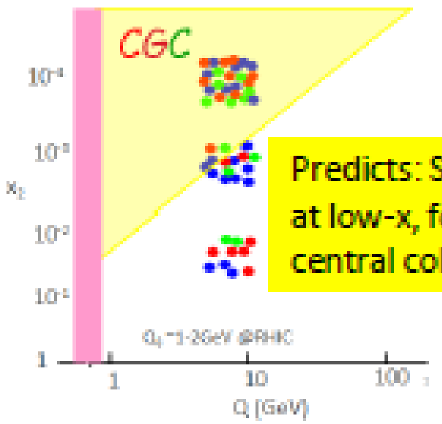
Forward rapidity corresponds to *high-x* in the projectile nucleon (d or p). Nuclear corrections at high-x are large for the deuteron, which may necessitate d+p running for proper comparison.

***…and you can't polarize the deuteron at** RHIC…*

Two pictures of p+Au

Color Glass Condensate

- High gluon density
  - Treat classically
- Saturation scale: Q_{sat}
- Assumes $\alpha_S(Q_{sat})$ small



Predicts: Suppression at low-x, forward η or central collisions

Equivalence

F Dominguez, C. Marquet, B-W. Xiao, F. Yuan PRD 83 (2011) 105005

???

Non-perturbative extensions to pQCD

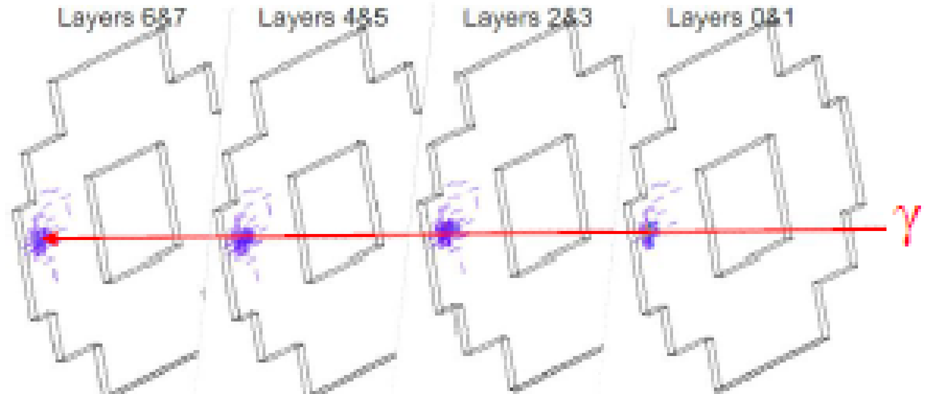
- Transverse momentum (k_T) dependent PDFs at low-x
  - G^1, G^2
- Higher twist shadowing effects
- Initial state energy loss
- Absorption
- Modified structure functions
- Coherent effects

Important:

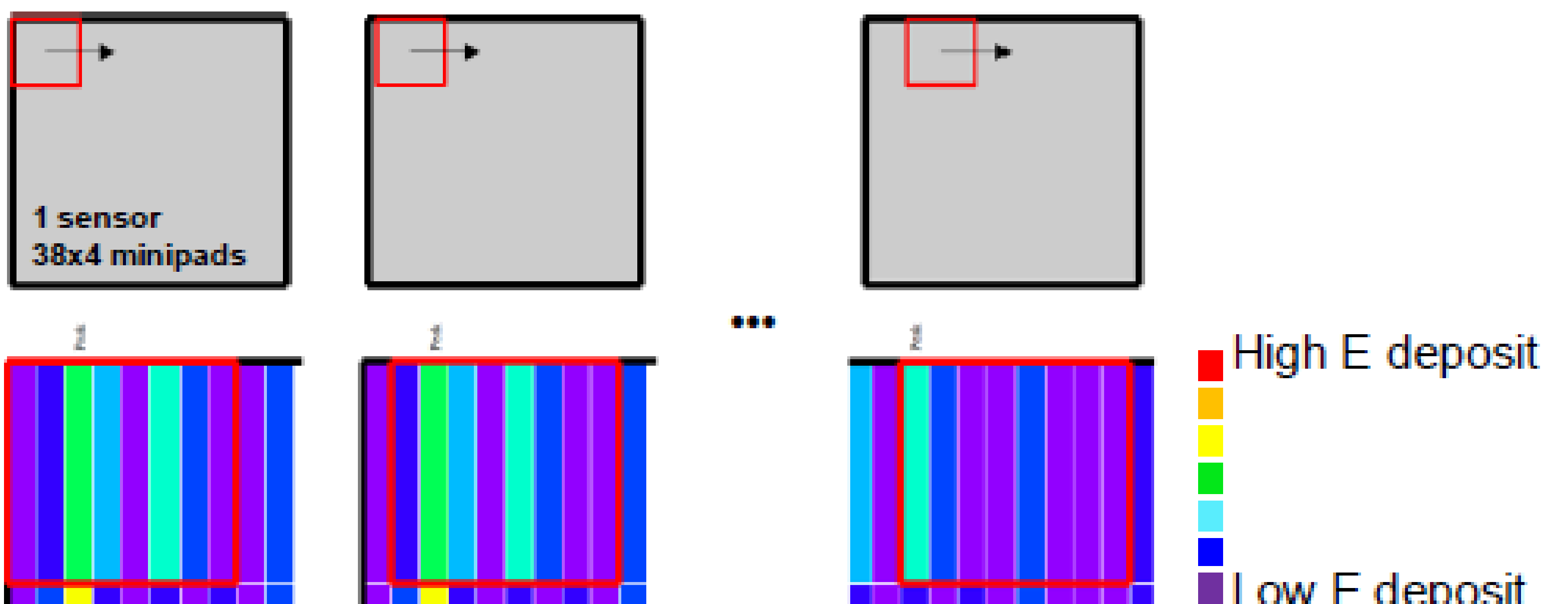
- Fundamental understanding of partonic processes in nuclei
- Initial conditions at RHIC and the LHC

Cluster reconstruction

- Separately sum energy in x and y towers



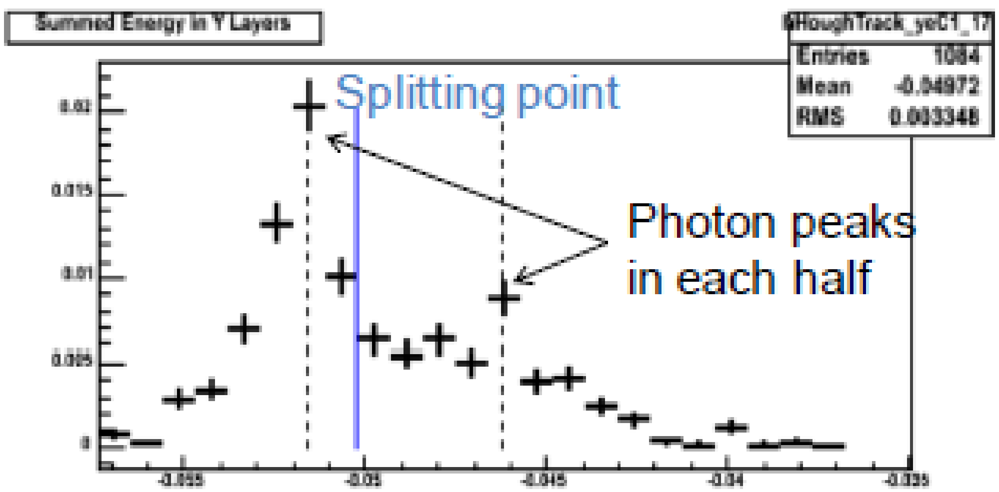
- Identifiy local maxima in scan of MPC-EX

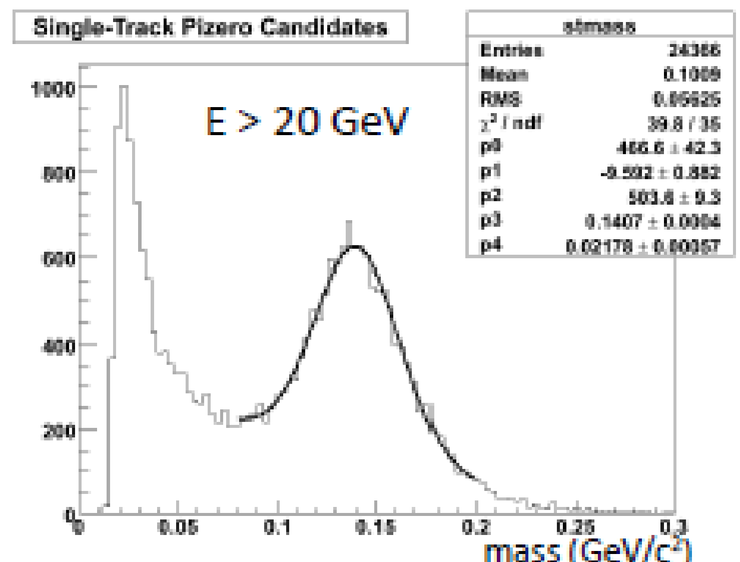


  - Energy and position of local maxima are found

π^0 rejection

- At E > 20 GeV, π^0s in one track in MPC-EX
- Split energy distributions into two parts
  - Iterate until find stable splitting point
  - Find energy of the halves
- Calculate mass from two halves

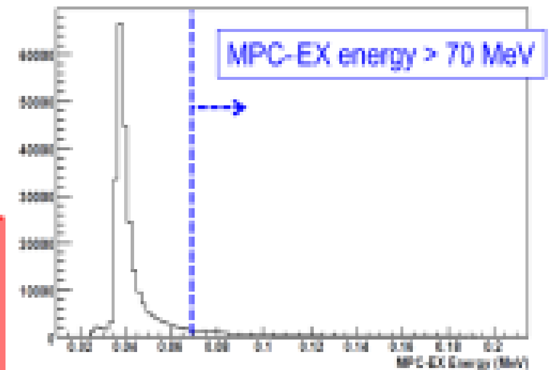




- Able to separate π^0 and γ out to E > 80 GeV

Finding prompt photons

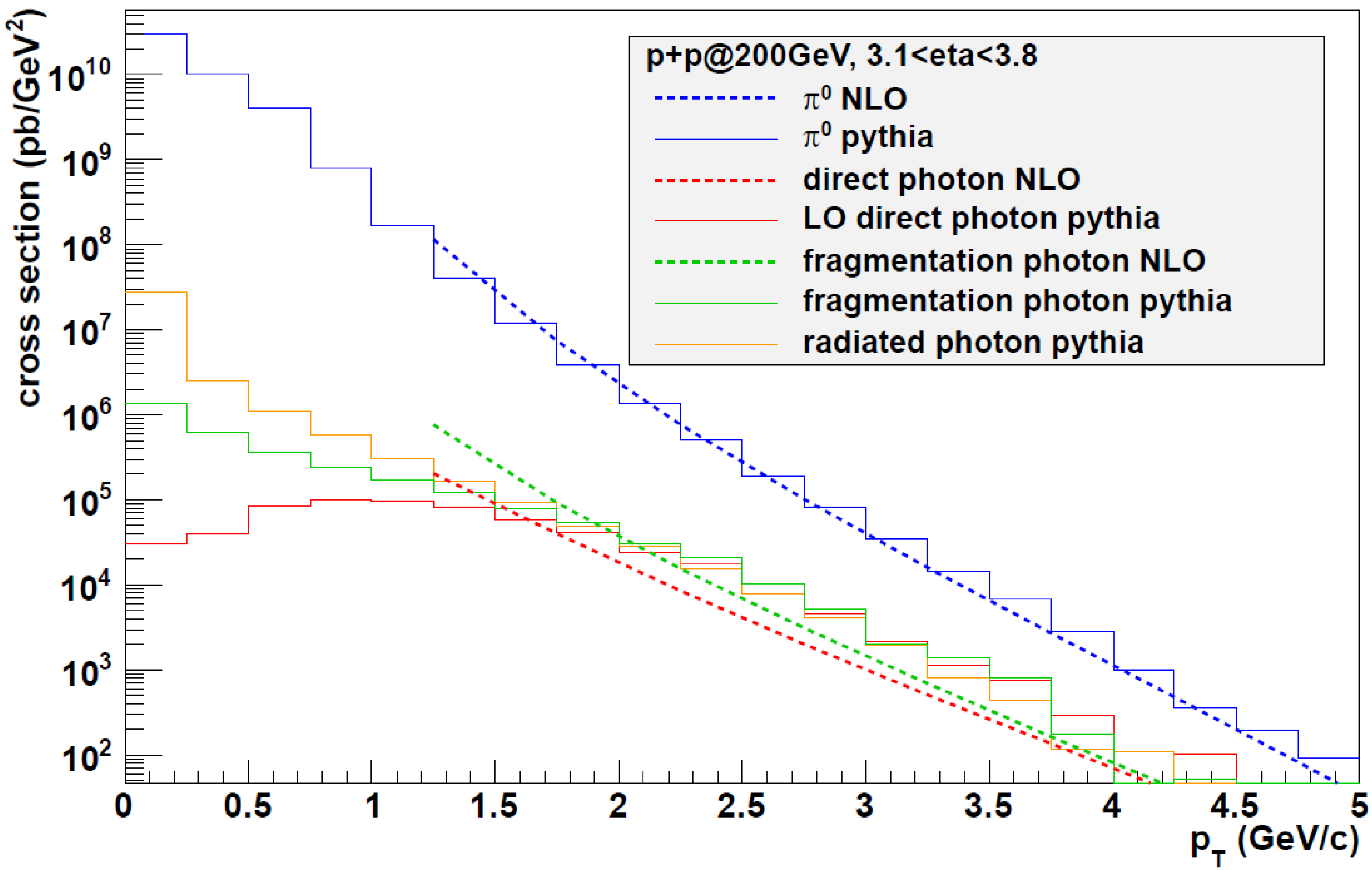
- 868 million MB p+p Pythia events
  - 16.5 GeV MPC trigger, +/- 50 cm vertex cut
- Remove hadrons
  - MPC-EX energy deposition



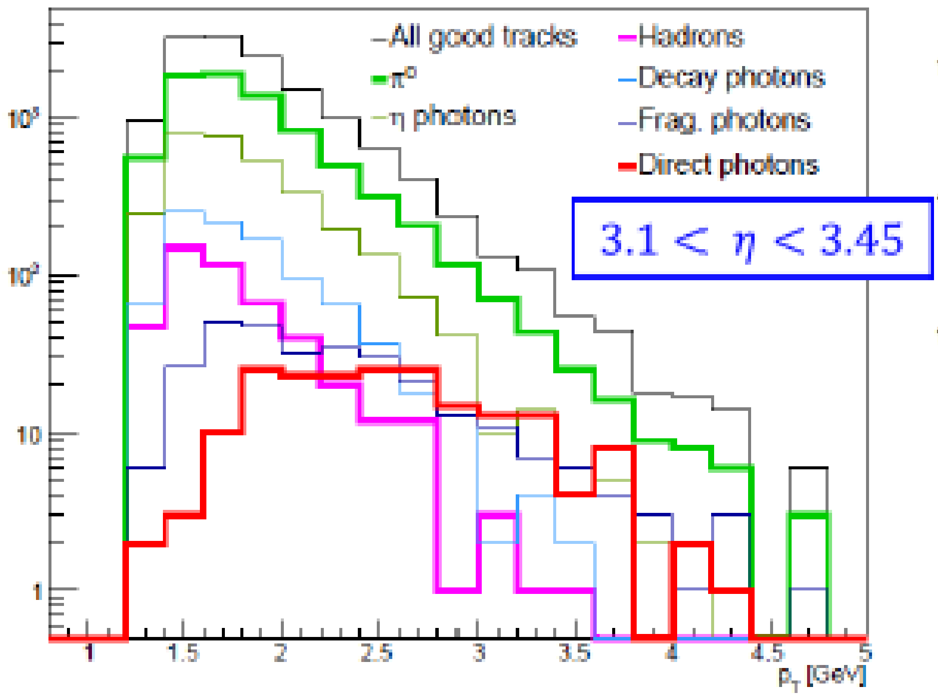
  - Shower shape in MPC, MPC-EX
  - $p_T > 3$ GeV
- Remove π^0s
  - MPC-EX energy distribution i.e. mass
  - Shower shape in MPC, MPC-EX
  - $p_T > 3$ GeV
- Reduce frag. photons
  - Track isolation cuts

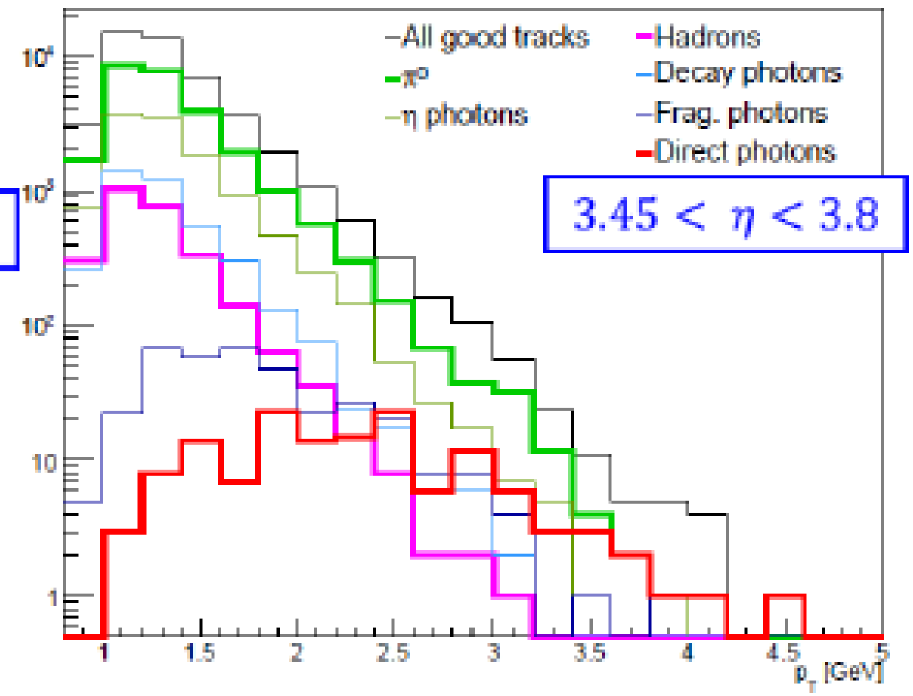
Cuts optimized using multivariate analysis

Direct Photons in Pythia



In η ranges





	$3.1 < \eta < 3.8$	$3.1 < \eta < 3.45$	$3.45 < \eta < 3.8$
Direct-to-signal ratio	57.4%	58.3%	56.6%
R_γ	1.34	1.34	1.35
Signal-to-π^0 ratio	43 ± 5 %	42 ± 6 %	46 ±11 %
Signal yield p_T > 3 GeV	101	77	24

Systematic errors

$$\Delta R_\gamma = \frac{\delta R_\gamma}{\delta \gamma_{Incl}} \Delta \gamma_{Incl} \oplus \frac{\delta R_\gamma}{\delta \pi^0} \Delta \pi^0 \oplus \frac{\delta R_\gamma}{\delta MC_{sim}} \Delta MC_{sim}$$

- 6% error in π^0 cross section
- 4% error in MC simulation
- 20% error in hadron subtraction

direct-to-signal ratio	57.4%
$\Delta\gamma_{Incl}/\gamma_{Incl}$	0.65%
R_γ	1.34
$\Delta R_\gamma / R_\gamma$	7.22%

- Correlated and uncorrelated components of sys. error between p+Au and p+p

Quantity	Sys. Error
Sys. error $\Delta R_\gamma/R_\gamma$ correlated	7.2%
Sys. error $\Delta R_\gamma/R_\gamma$ uncorrelated	1%
Sys. error $\Delta\gamma_{Incl}/\gamma_{Incl}$ uncorrelated	2%
Relative sys. error on <N_{coll}>	3%

SSA's in p↑+A Collisions

$$\left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp}^2 << Q_{sA}^2} \approx \frac{Q_{sp}^2}{Q_{sA}^2} e^{P_{h\perp}^2 \delta^2 / Q_{sp}^4} \Longleftrightarrow \left.\frac{A_N^{pA\to h}}{A_N^{pp\to h}}\right|_{P_{h\perp} \gg Q_s^2} \approx 1$$

δ = 0.16 GeV

Kang and Yuan PRD 84 034019 (2011)

- π^0 A_N in p+p, p+Au, and p+Cu ⟹ $Q_{sA}^2 \propto A^{1/3} Q_{sp}^2$
- Intermediate p_T dependence being developed by Zhongbo Kang ⟹ Fit p_T dependence to get Q_{sp}^2 and Q_{sA}^2
- Prompt photon A_N ⟹ Change proportion of Sivers to Collins

Systematic study of SSA's in p↑+A collisions will allow us to study Q_{Sat}

SSA's in polarized p+A Collisions

- Kang and Yuan, PRD 84, 034019

$$\left.\frac{A_N^{p+A\to h}}{A_N^{p+p\to h}}\right|_{P_{h\perp}^2 << Q_s^2} \approx \frac{Q_{s,p}^2}{Q_{s,A}^2} \cdot e^{\frac{P_{h\perp}^2 \cdot d^2}{Q_{s,p}^4}}, \quad \left.\frac{A_N^{p+A\to h}}{A_N^{p+p\to h}}\right|_{P_{h\perp}^2 >> Q_s^2} \approx 1$$

A systematic study of SSA's in spin-polarized p+A collisions would allow us to study the gluon saturation scale.

In terms of energy

- 500k single e – half in each arm for 50GeV & 100GeV
- 5.8fC per MIP in 500u silicon
- MIP ~ 200keV
- So 1000fC corresponds to 34000keV