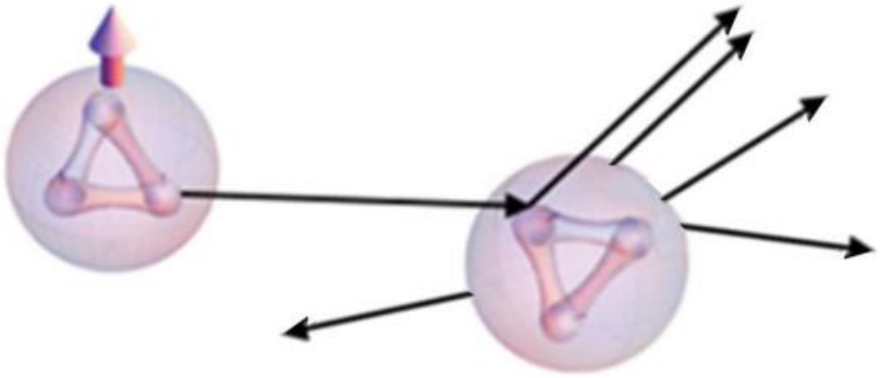

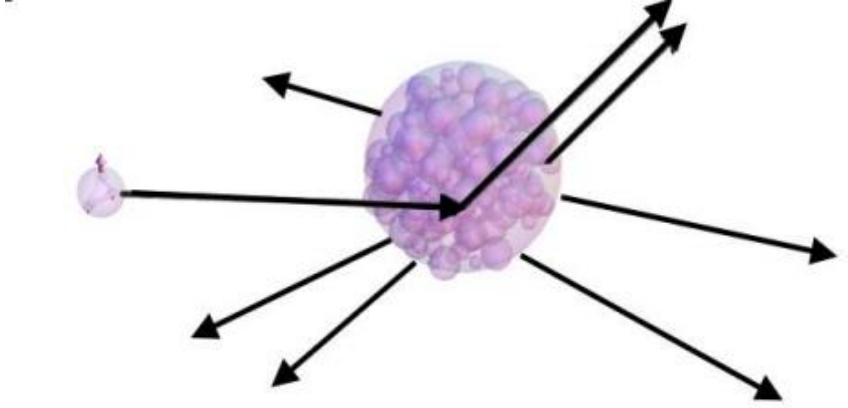

Comparisons between pp and pA at forward rapidity at STAR

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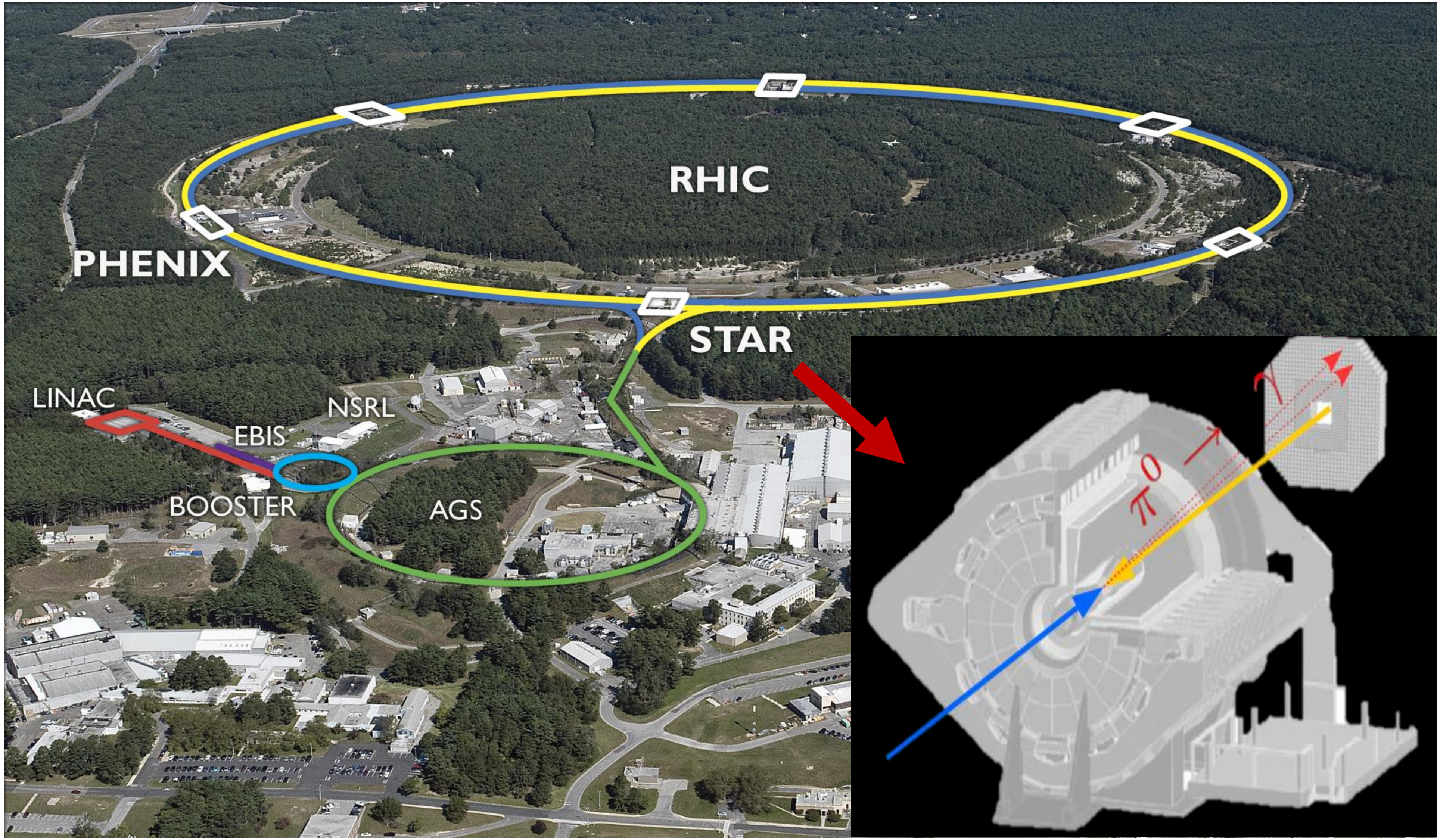
Outline

- RHIC and the FMS
- Non-linear response and radiation damage
- A_N and atomic mass

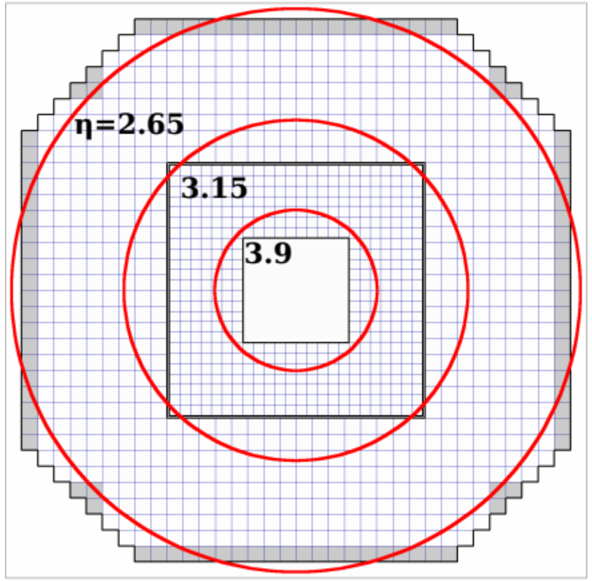
RHIC and STAR

- World's only spin polarized proton collider, located at Brookhaven National Lab on Long Island, NY
- Capable of colliding multiple species of nuclei including
  - proton-proton
  - proton-gold
  - proton-aluminum
- Focusing here on data from 2015 run, which had all the above species with $\sqrt{s_{NN}} \approx 200$ GeV

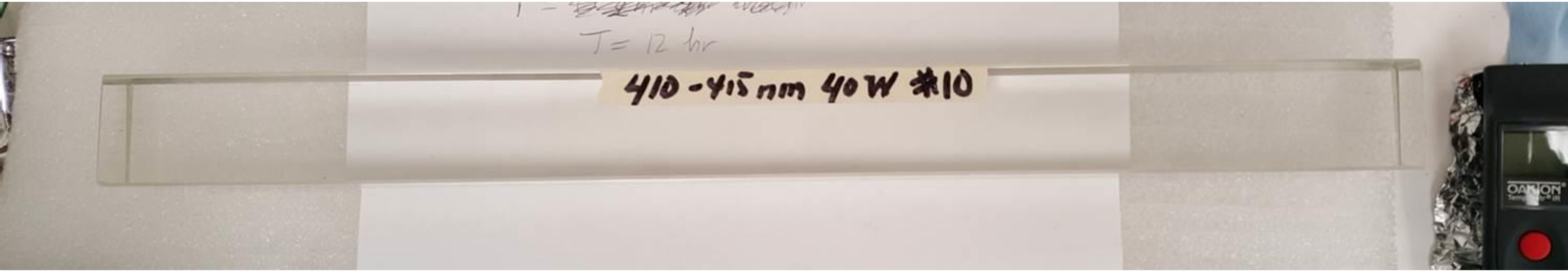


Forward Meson Spectrometer (FMS)

- Electromagnetic calorimeter at $2.5 \leq \eta \leq 4$
- Composed of 1264 lead glass cells, with smaller cells at larger η
  - Large cells: 5.8 x 5.8 x 60 cm^3
  - Small cells: 3.8 x 3.8 x 45 cm^3
  - Cells are approximately 18-19 radiation lengths long, with PMTs coupled to the end to record optical photons generated by the shower
- Calibrated using, and primarily observes $\pi^0 \rightarrow \gamma\gamma$ (with additional calibration checks from $\eta \rightarrow \gamma\gamma$ for some kinematics)
  - Calibration for large cells with $\approx$ 25 GeV π^0
  - Calibration for small cells with $\approx$ 40 GeV π^0

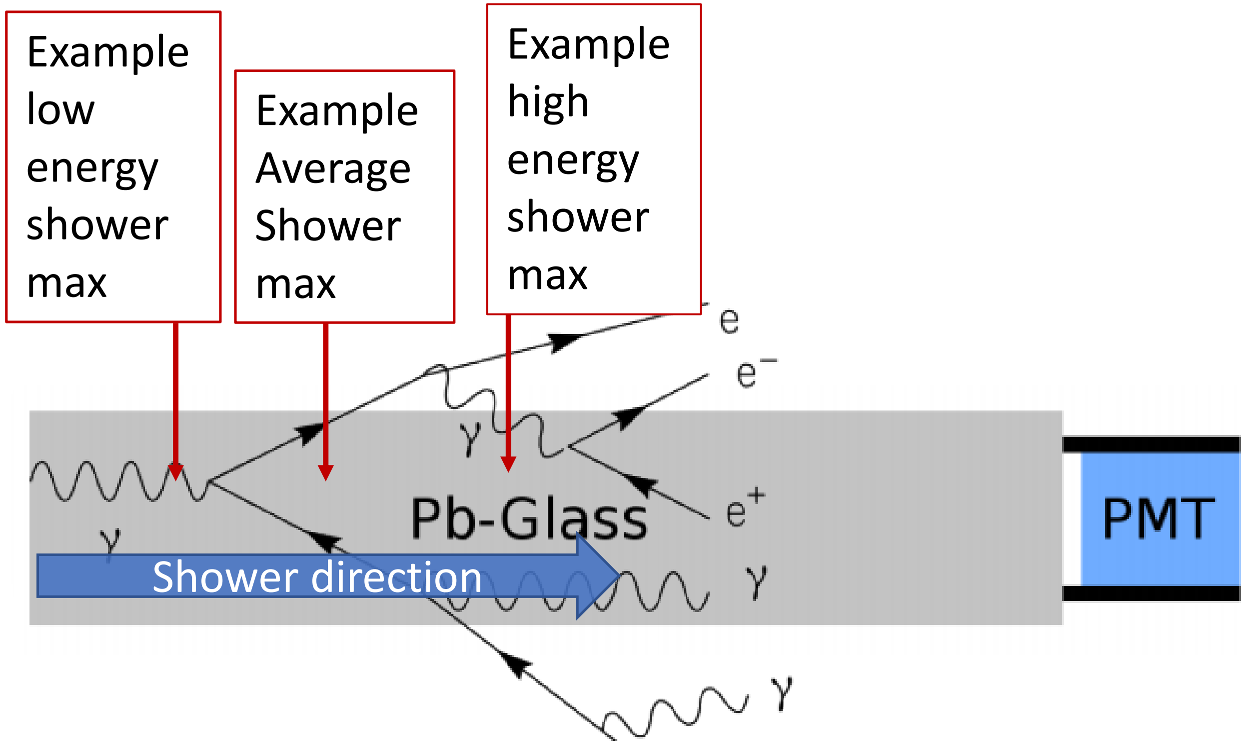


Example FMS lead glass cell



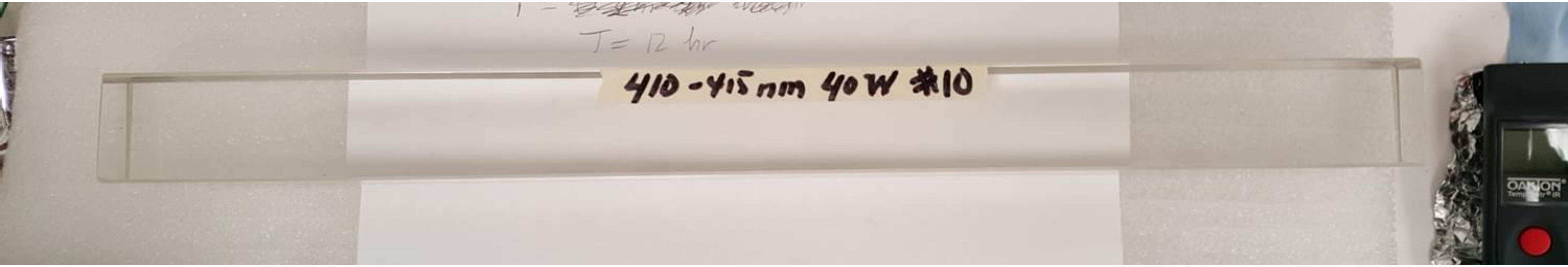
Energy Response Non-linearity

- Lead in the glass induces an electromagnetic shower.
- The depth that this shower penetrates into the glass before trailing off will depend on the energy of the incoming γ
  - Lower energy γ will peak at smaller depths, while higher energy γ will peak later (closer to PMT).
- Because a larger percentage of light is generated further / closer to the PMT at the end of the cell, a smaller / greater number of photons are detected per unit energy deposited



Radiation Damage

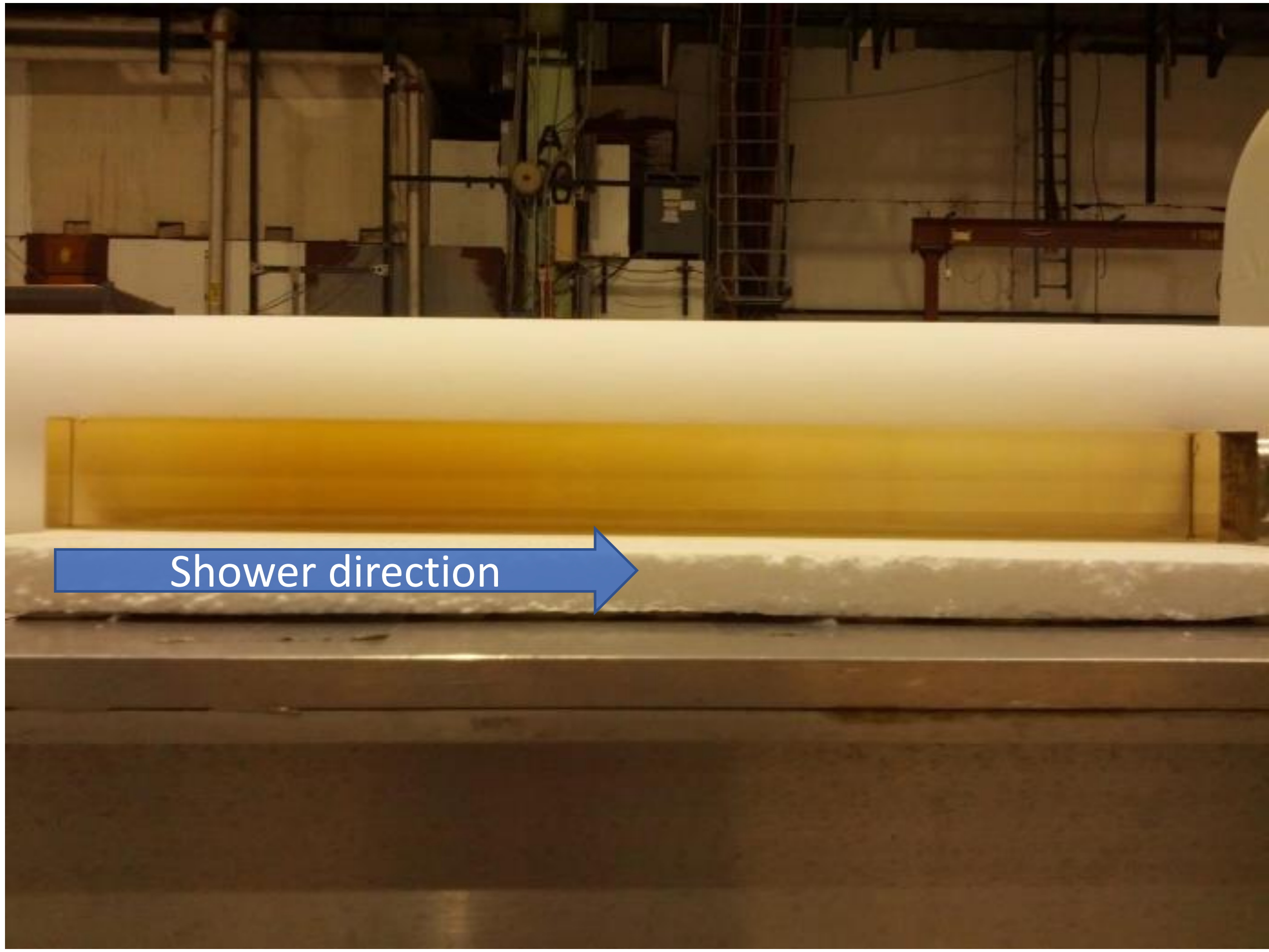
Lead glass cell before cleaning, showing radiation damage



Same cell after clearing with ultraviolet light

Effects of Radiation Damage

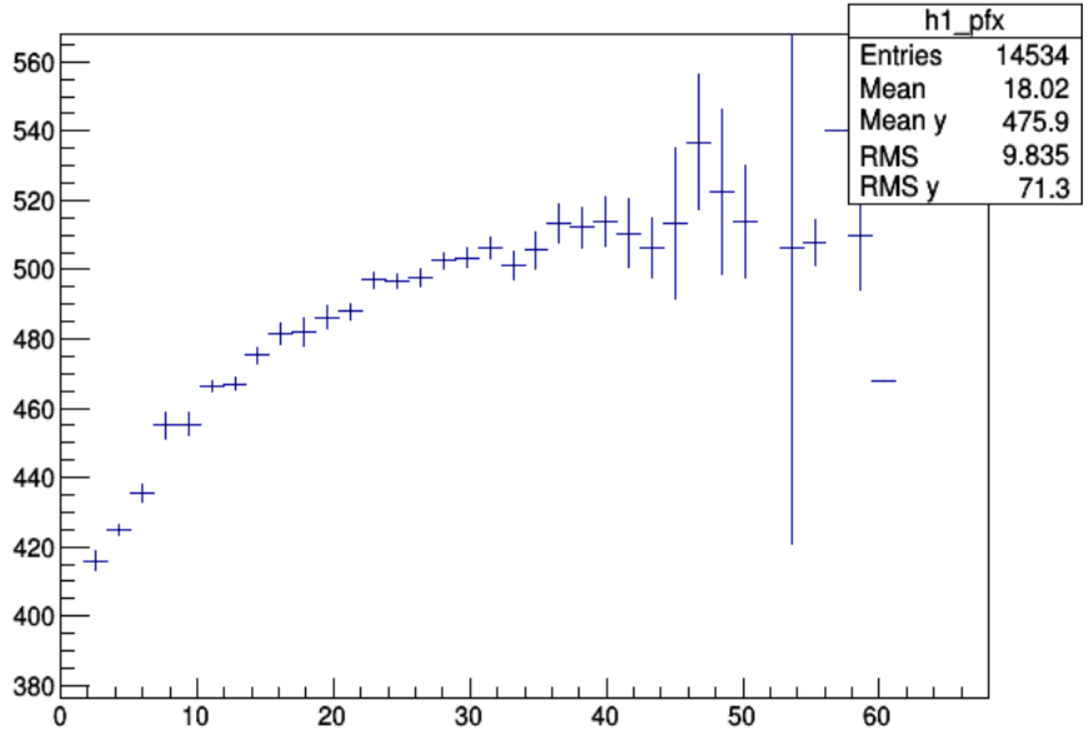
- Particles from the electromagnetic shower create impurities in the glass called f-centers. These cause the glass to darken and become less transparent.
- This causes two major problems
  1. Overall lower light yield at the PMT. This necessitates gain changes/calibrations over time
  2. Increased non-linear response to photon energy
     - Energy dependence of shower development combined with attenuation already causes the amount of light at the PMT (and thus energy) to be non-linear.
     - Adding in radiation damage causes additional z-dependence that evolves over time
- Prior to 2015 run, cells were cleared by bathing in sun. However, the cells darkened throughout the run.



Modeling Non-linearity

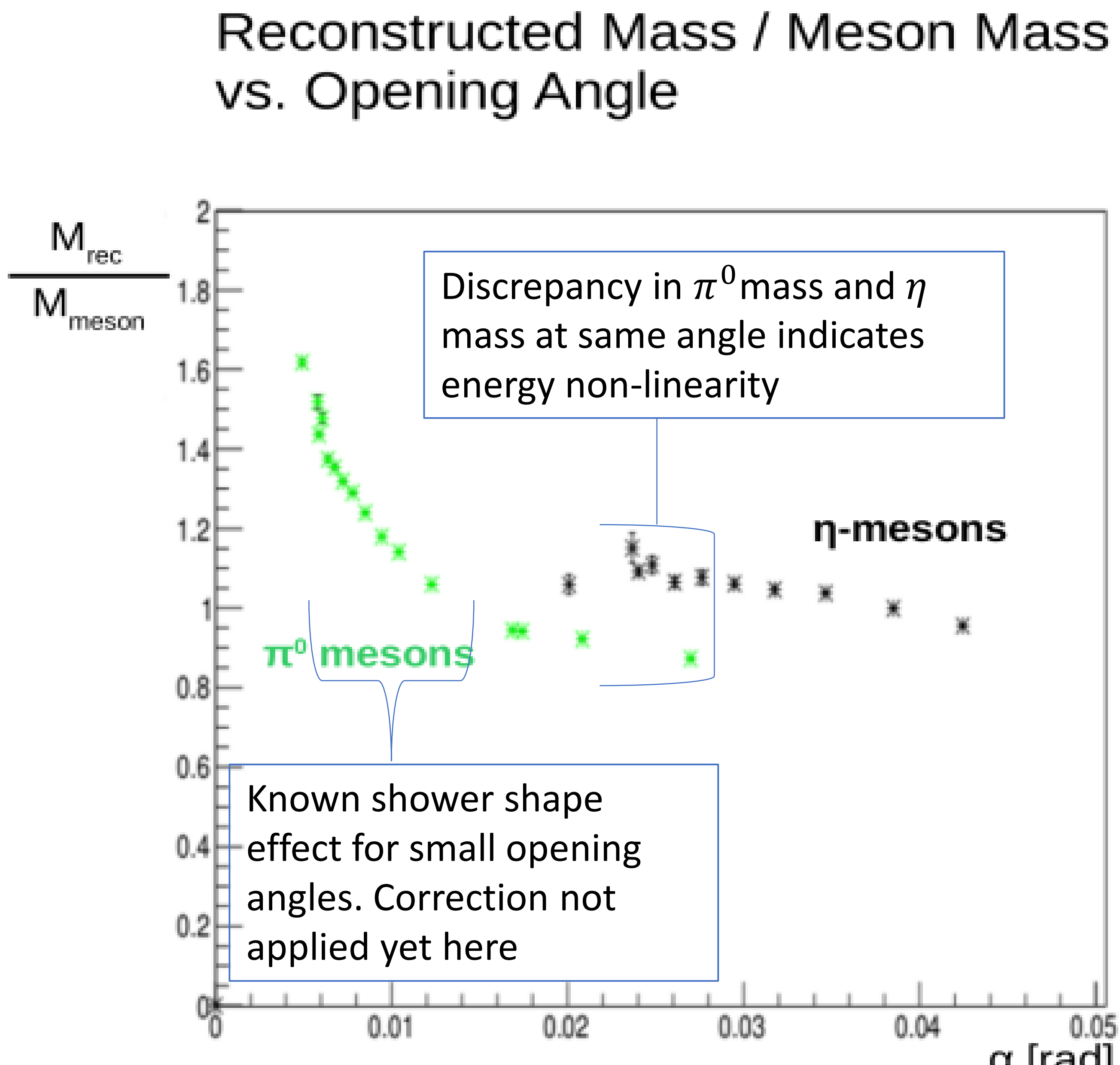
- Changing overall PMT gains can ensure that at some calibration point we reconstruct the correct energy
  - However, if the response of the detector is not linear (as in the amount of light collected by the PMT), then assuming linearity leads to systematic over/under estimation of the photon energy
- To model this effect, we turned to GEANT simulations of our detector
- For clean cells, all that was needed was to look at the how the number of photons measured by the PMT changed with energy
- Additional radiation damage effect was modeled as additions to the attenuation following shape of energy deposition (from min bias Pythia)
  - Additional feature to account for pseudo-rapidity and wavelength dependence of damage and it’s progression with time
  - By parameterizing the non-linear shape correction with time, can predict overall needed correction for arbitrary amounts of radiation damage

$\frac{N_{photons}}{E_{\{\gamma\}}}$ vs $E_{\{\gamma\}}$ (GeV)

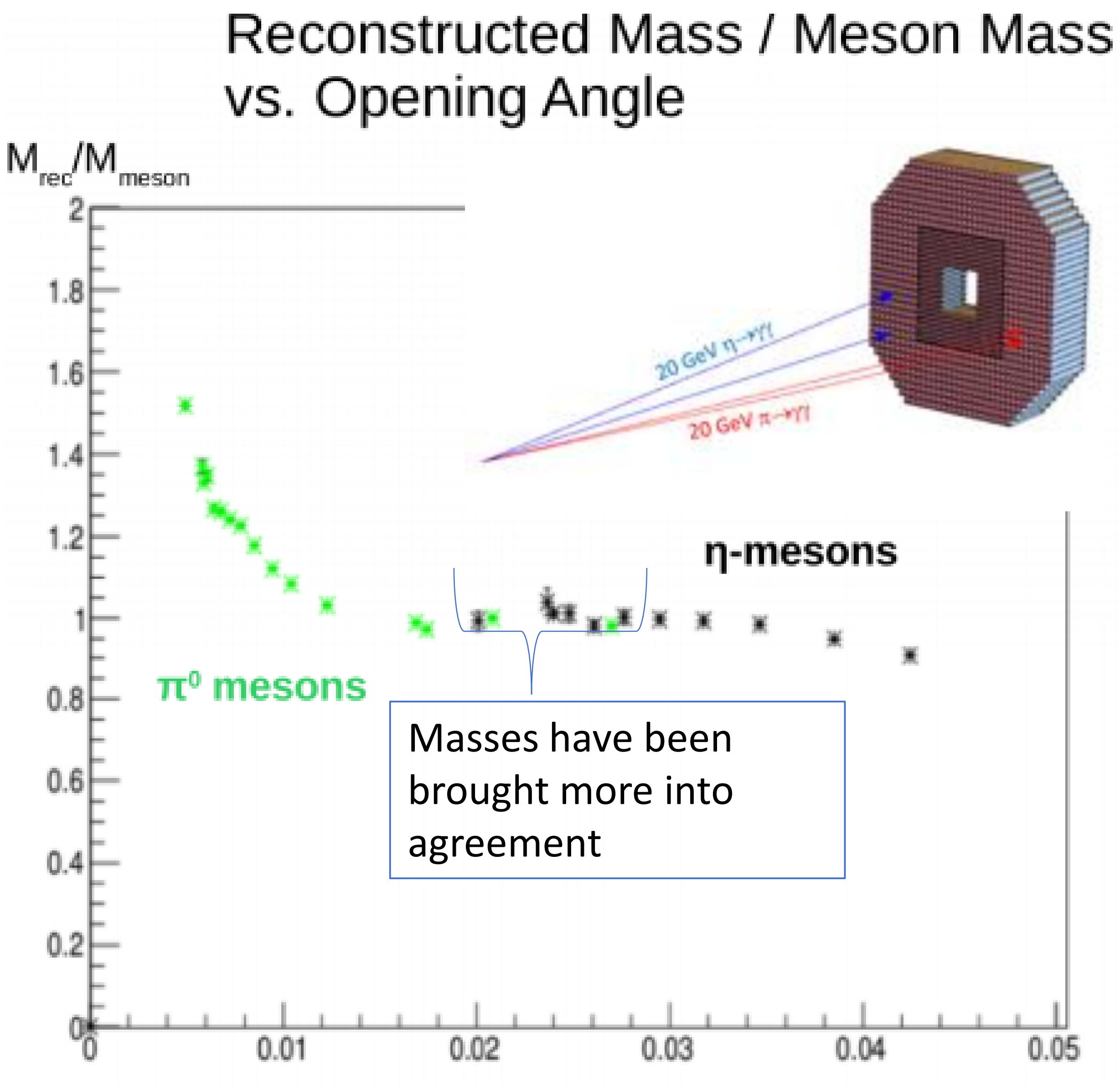


Results from GEANT simulation of clear large cells showing number of detected optical photons per unit energy vs γ energy
Deviations from flat line demonstrate non-linearity

Effect of a non-linear gain correction on reconstructed masses



Early 2015 data analysis, before non-linear correction

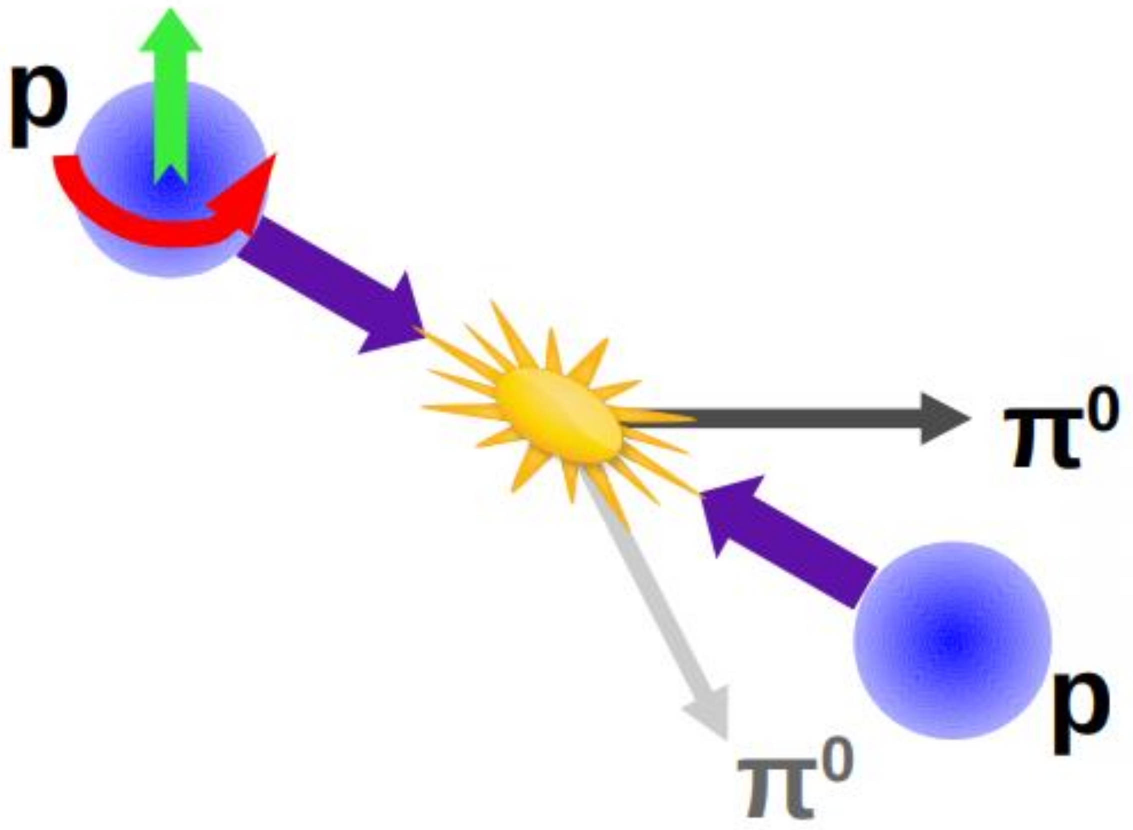


Same data, after early form of non-linear corrections

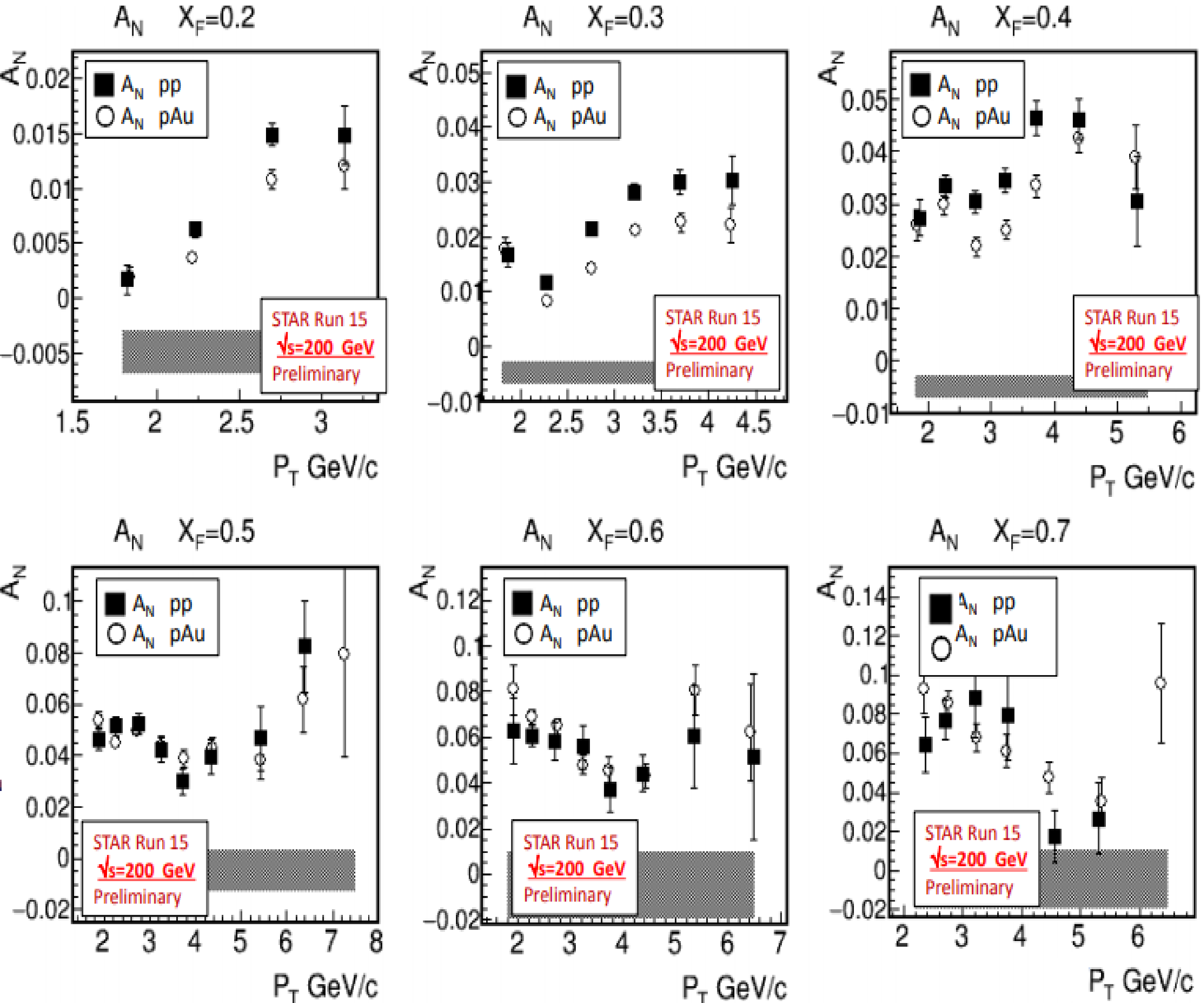
A_N and mass number

Transverse Single Spin Asymmetry (A_N)

- $A_N = \frac{d\sigma\uparrow - d\sigma\downarrow}{d\sigma\uparrow + d\sigma\downarrow}$
- Correlations between particle spin and transverse momentum can lead to favoring one direction over another
- Historically, unpredicted high A_N results gave key insights into internal proton structure such as the limitations of the collinear framework
- Dependence of A_N on mass number A provides a probe into internal nuclear structure
  - Some models of color glass condensate predict that A_N should decrease with increasing A
  - Various pQCD predictions indicate no dependence on A_N with A

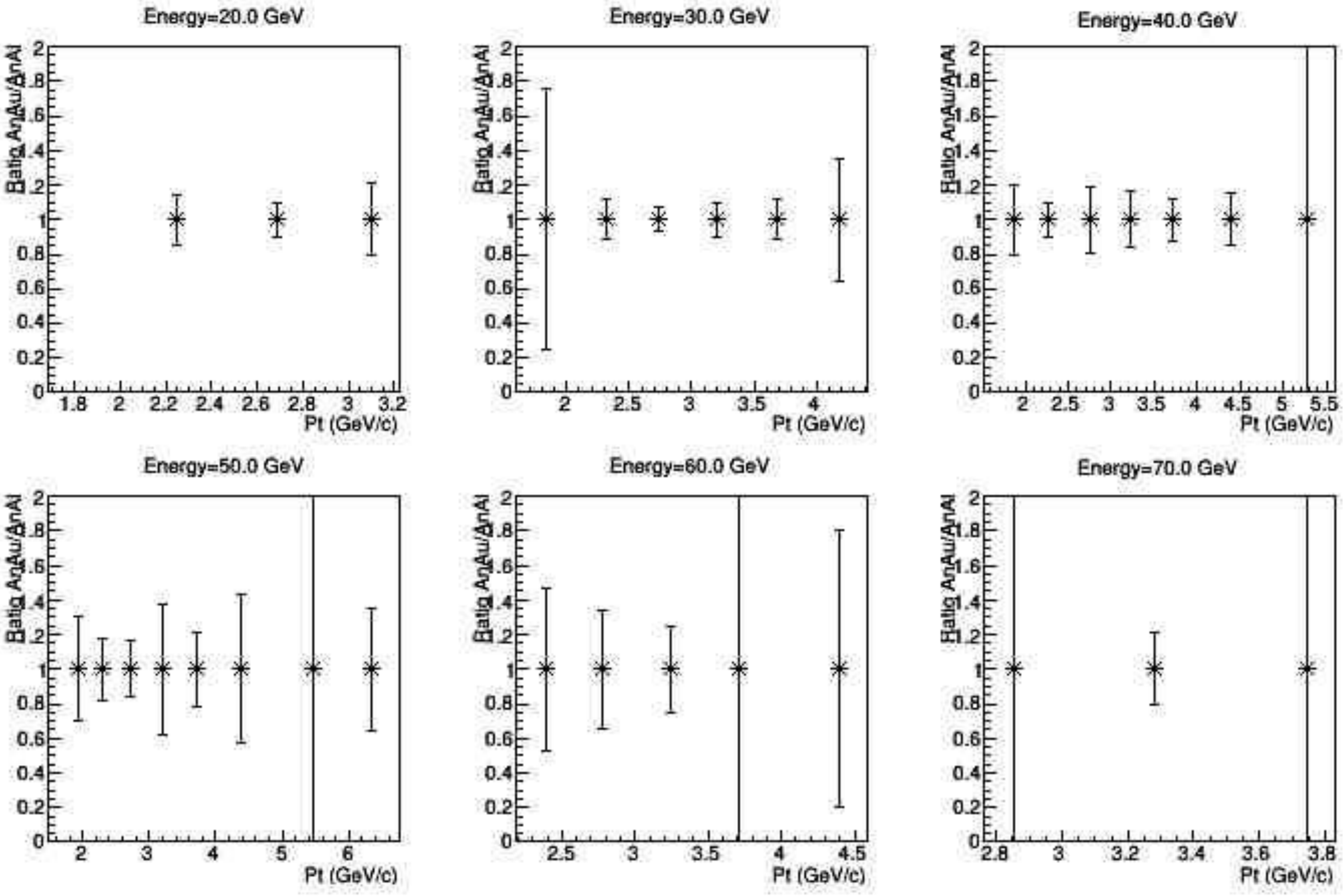


Previous released preliminary result for A_N. $X_F \approx \frac{Energy}{100} GeV$



- STAR has already released preliminary results for A_N for both the pp and pAu period
- Results show some evidence of a suppression of A_N in pAu as compared to pp
  - Largest suppression in preliminary release is on the order of 25%

Projected statistical errors on A_N for pAl compared to previous pAu $\frac{A_N(pAu)}{A_N(pAl)}$. Values have been set to 1



- Preliminary results for the pAl period have yet to be released
- Here we show projections of statistical errors on the ratio of A_N between pAu and pAl
  - Errors are a combination of trigger efficiencies, cross-sections, and from effects involving divisions of small numbers
  - We expect statistical errors to dominate for most bins

Conclusions

- The 2015 RHIC run, with pp, pAu, and pAl all in the same run year, presents a great opportunity to probe nuclear matter
- Preliminary results for transverse single spin asymmetry A_N have been shown previously for pp and pAu, but final results for these asymmetries as well as pAl are being worked on
  - Together these will give constraints on evolution of A_N with increasing atomic weight, which could give insights into nuclear structure
- Analysis of 2015 run should produce measurements of nuclear modification factor R_{pA} using these three species
  - Could give insight into nuclear suppression and multiple collision effects

Backup

Nuclear Modification Factor

- Provides a measure of how cross sections are altered by the presence of other nucleons
  - In the case where there were no other effects, $R_{pA} = 1$
  - $R_{pA} < 1$ indicates that the additional nucleons serve to suppress/screen observed cross sections
  - $R_{pA} > 1$ indicates that the additional nucleons increase observed cross section
- Full pp, pAl, pAu comparisons are underway, with a few run condition systematics needed to properly compare pp to pA periods

$$R_{pA} = \frac{dN^{pA}/dp_t}{< N_{coll} > dN^{pp}/dp_t}$$