Study of the hadronization of charged pions

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Abstract

Hadronization is the process by which energetic quarks transform into colorless hadrons. The process is non-perturbative, therefore, only a qualitative understanding based on phenomenological models can be achieved. By comparing hadron production on different nuclei, one can measure the most sensitive variables to the hadronization phases, the transverse momentum broadening, that is believed to be tightly connected to the quark energy loss, and the multiplicity ratio, which is a measure of the hadron attenuation in the nuclear medium.

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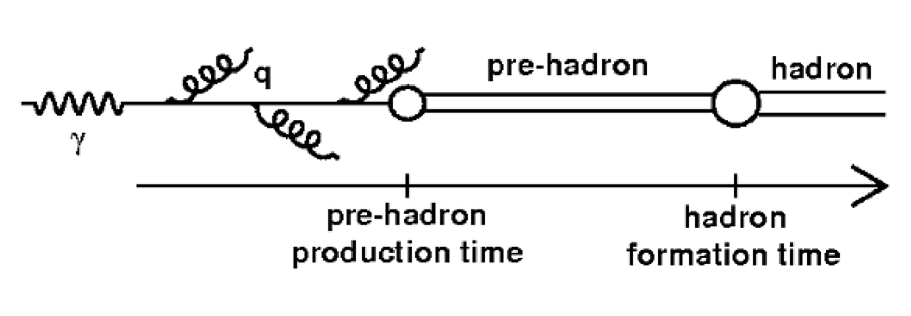
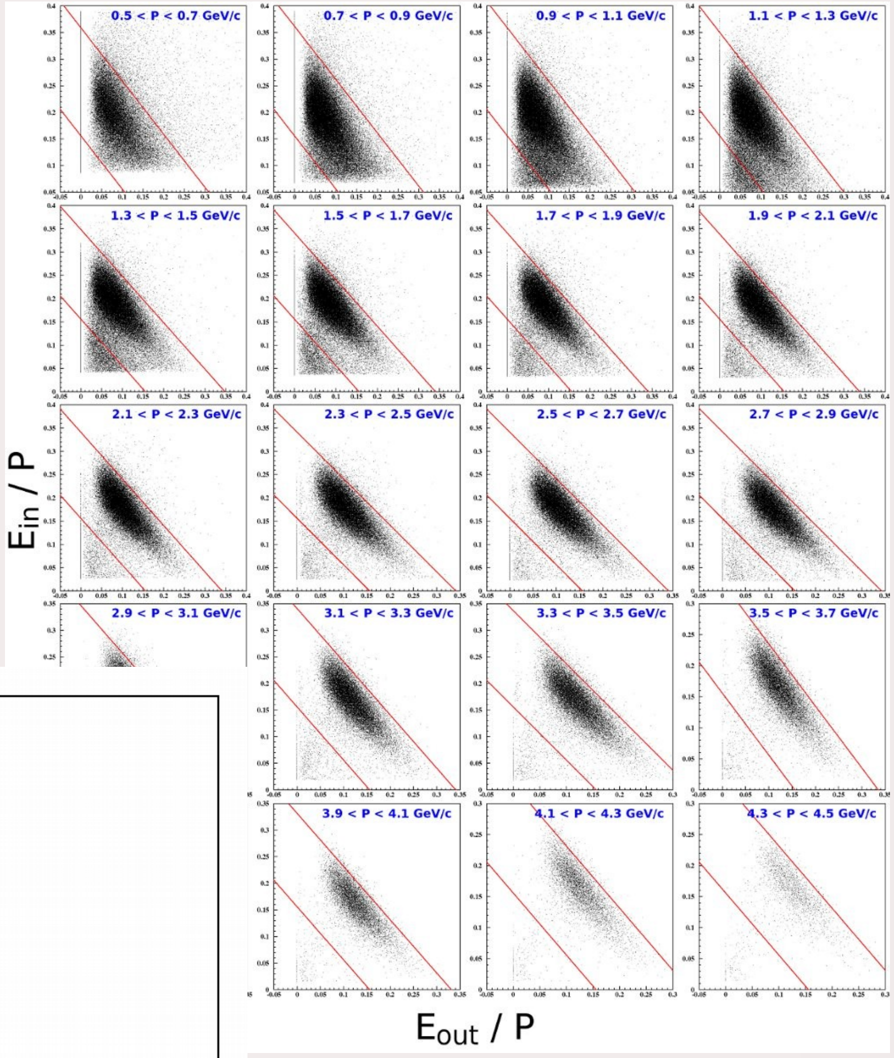
Introduction

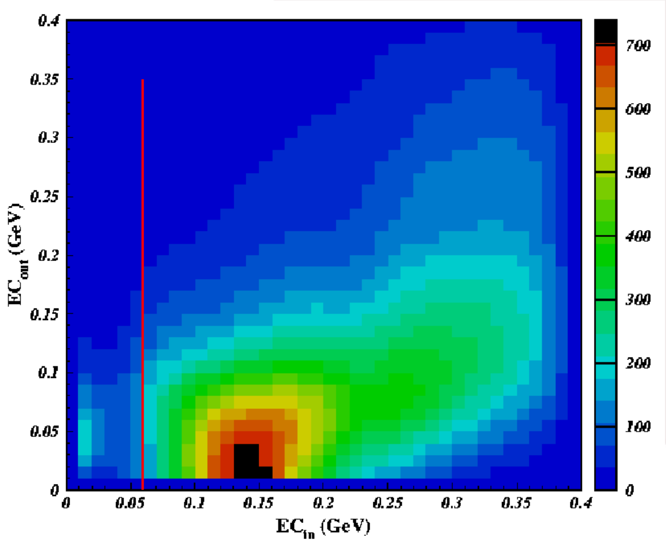


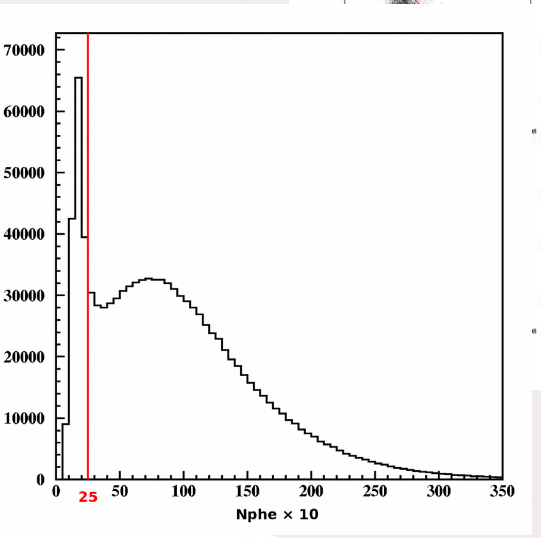
- **Measure charged pion production in nuclei**
  - Using the eg2 run data
  - Observables: attenuation and transverse momentum broadening
  - Targets: D, C, Al, Fe, Sn and Pb
- **Analysis review on going**
  - Analysis note submitted Oct 2016
  - 1st round of questions Dec 2016
  - Answer to first round coming soon
- **This talk is summarizing the analysis status**

PID: Electron

- **Copied from previously approved analysis of eg2**
  - Color transparency (L. El Fassi et al.)
- **Slight difference with vertex cuts**
  - Presented in a later slide

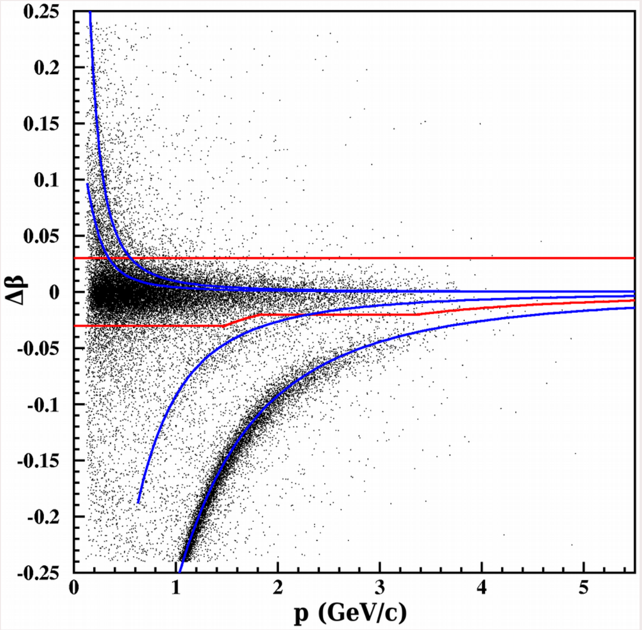


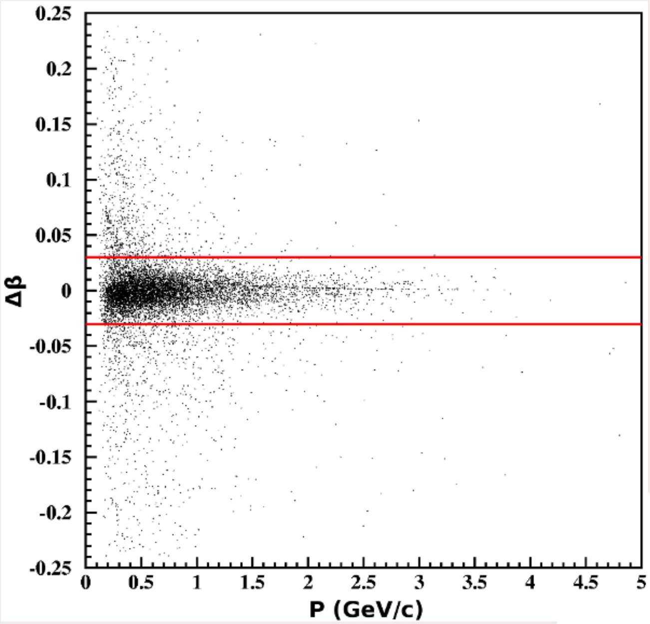




PID: Charged Pions

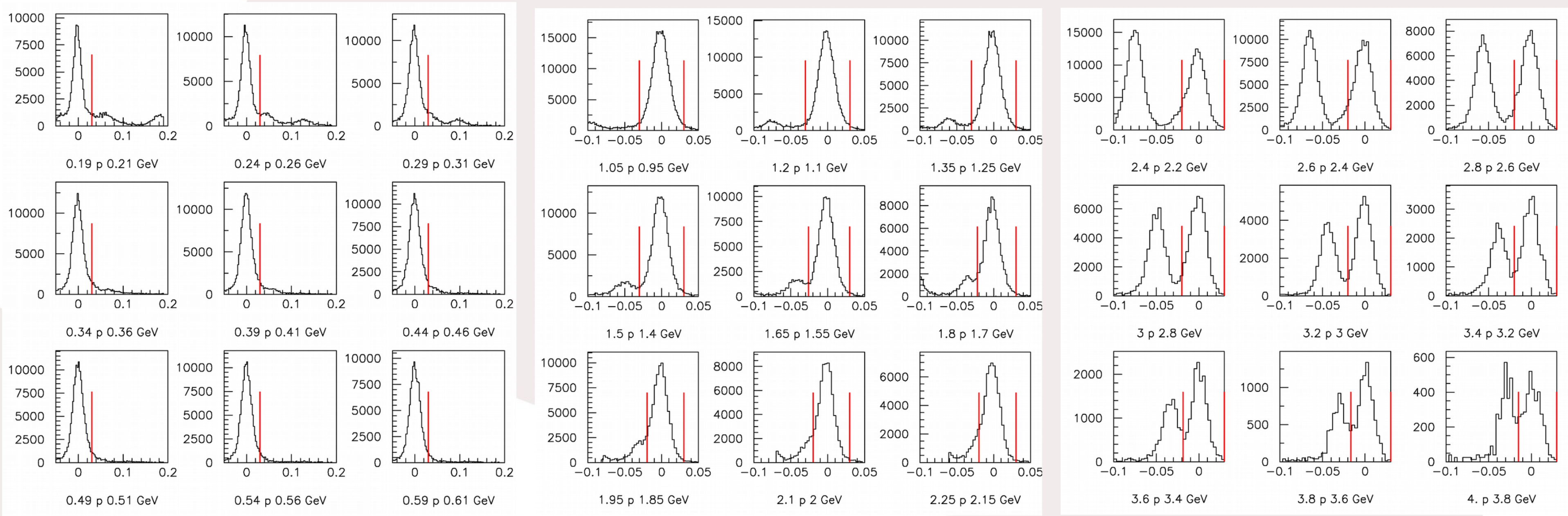
- **Tight cuts are used**
  - This is a semi-inclusive measurement with very little kinematic constraints
- **Positive pions**
  - Visible kaon and proton contamination
  - We tighten the TOF cut at high momentum to reduce their contribution
  - Kaon contamination is ~3% according to simulations
- **Negative pions**
  - No significant contamination noted (>1%)
  - we keep a constant cut (+/- 3%)





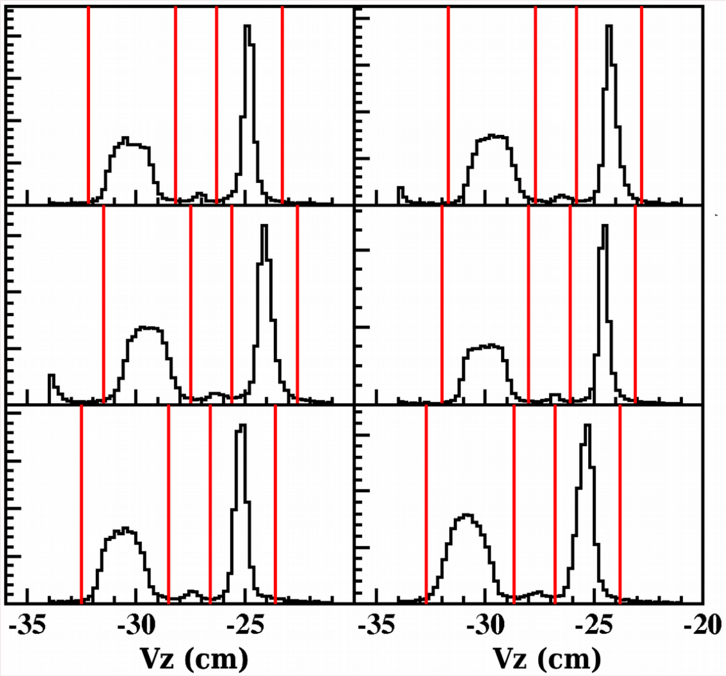
Question: TOF for Positive Pion

- **A question was raised about the choice of the TOF cut**
  - We can see here in more details these cuts
  - Muons and electrons are visible up to p = 0.5 GeV
  - Kaons can be separated up to p = 2.2 GeV
  - Protons can be separated up to p = 4 GeV
- **The proposed cuts allow to limit the contamination**
  - Included in systematic errors passed these limits

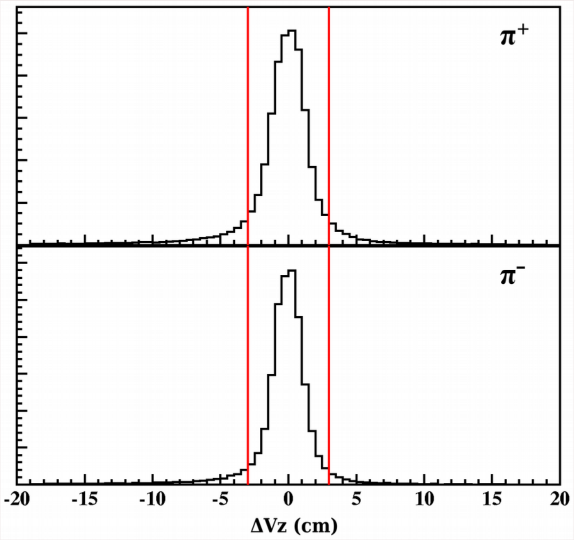


Vertex Cut

- **Vertex cuts have to be adapted for each sectors**
  - Extended liquid deuterium target and thin solid target
  - Warrants different cuts on electrons

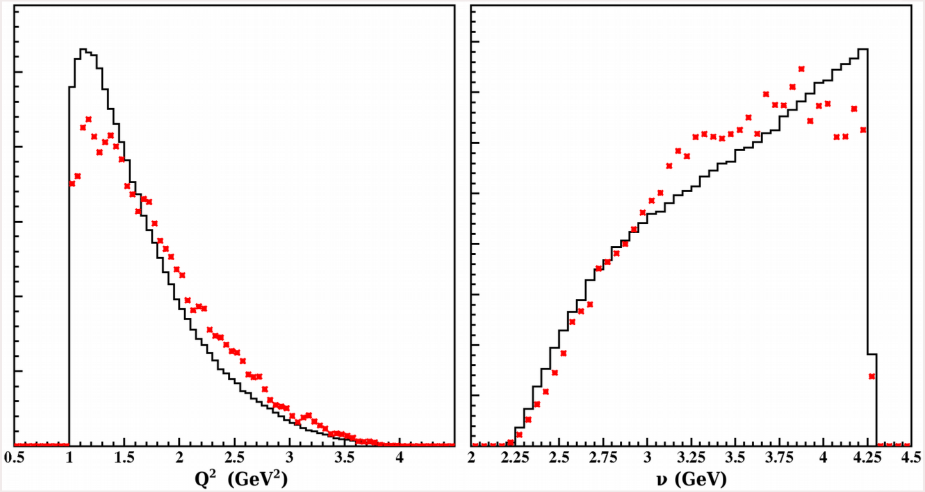


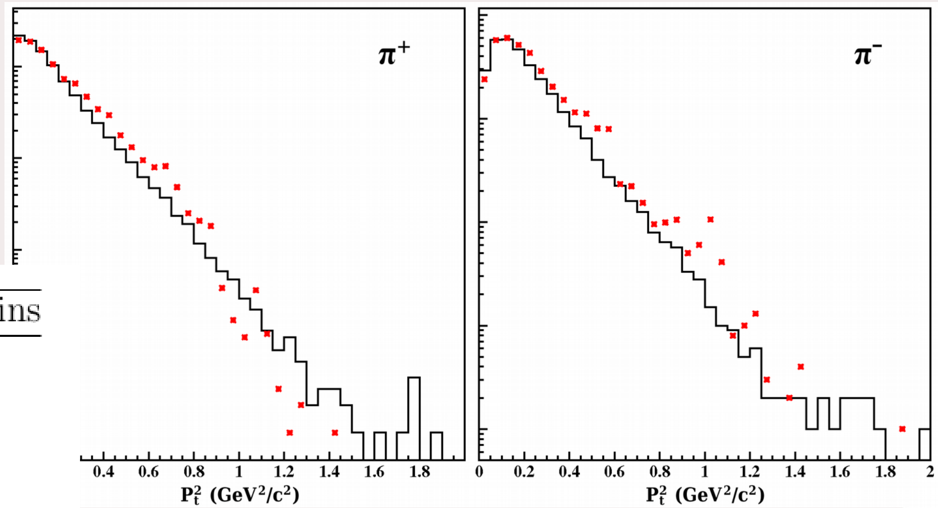
- **Pions are selected with respect to electron vertex position**
  - This avoid to use wider cuts for the liquid target



Acceptance (1)

- **Using the classic CLAS simulation chain**
  - GSIM, GPP, user_ana
- **Pythia event generator**
  - with addition of Fermi motion
  - Comparison with data is reasonable
- **Four dimensional binning**
  - A second binning is used to estimated the systematic error associated with the correction

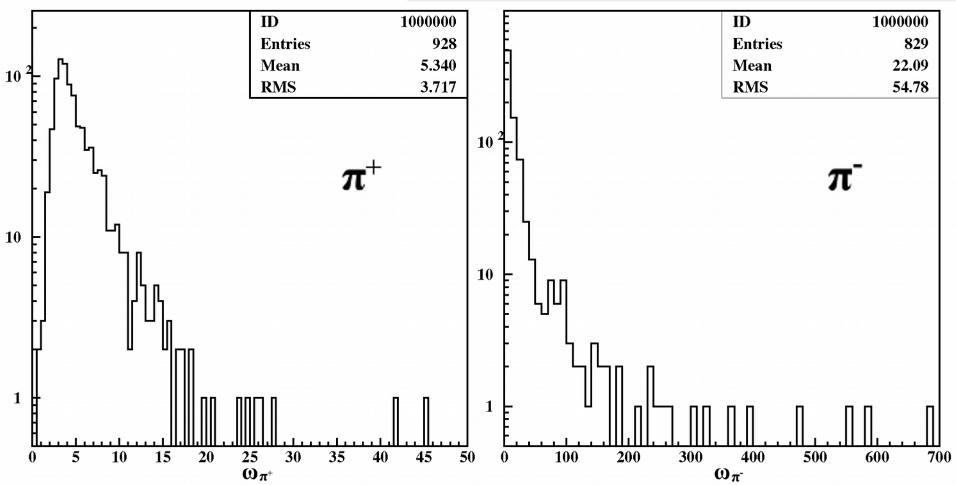




Variable	Number of bins
ν	5
x_{Bj}	5
p_h	7
t	7
Total	1225

Variable	Number of bins
Q^2	5
ν	5
z_h	7
t	7
Total	1225

Acceptance (2)

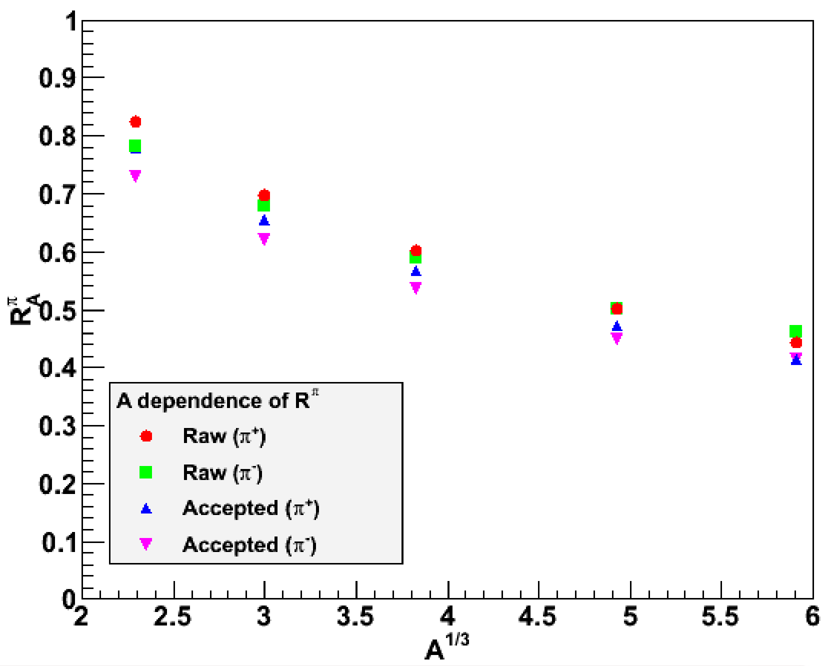


$$\left(\frac{\delta\omega}{\omega}\right)^2 \times R_c \times \omega < 2,$$

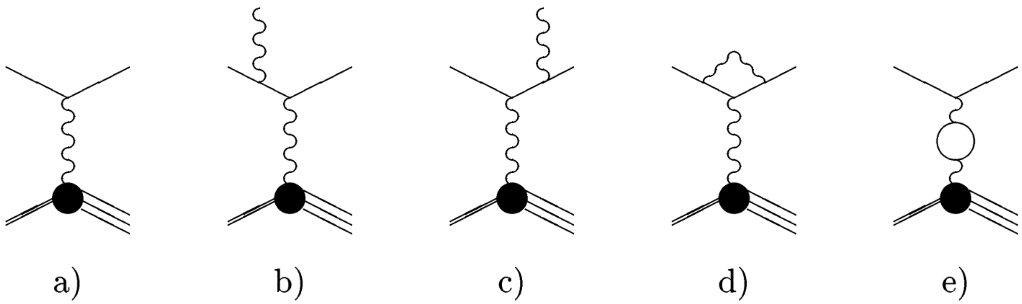
$$N_{rec} > 4,$$

$$\mathrm{Acc}_2(\nu, p_h) = \frac{\sum_{rec} \omega(\nu, x_{Bj}, p_h, t)}{N_{gen}(\nu, p_h)}.$$

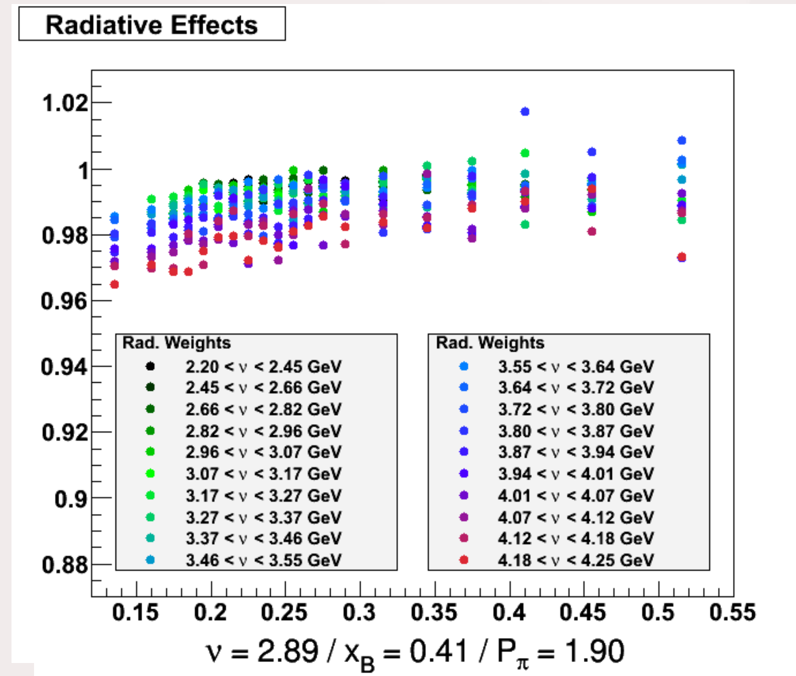
- **We cut problematic bins**
  - Very low acceptance, large errors or important contamination from other bins
  - A combined cut was found to be preferable to several 1d cuts
  - This is due to the critical low Pt bins
    - The have small acceptance but high statistics and no contamination problem
- **Important effect of acceptance**
  - Takes most points down by ~10%
  - Due to the small position difference between targets
    - Most events are concentrated at low angle
    - Even a small vertex shift (3 cm) has a strong impact

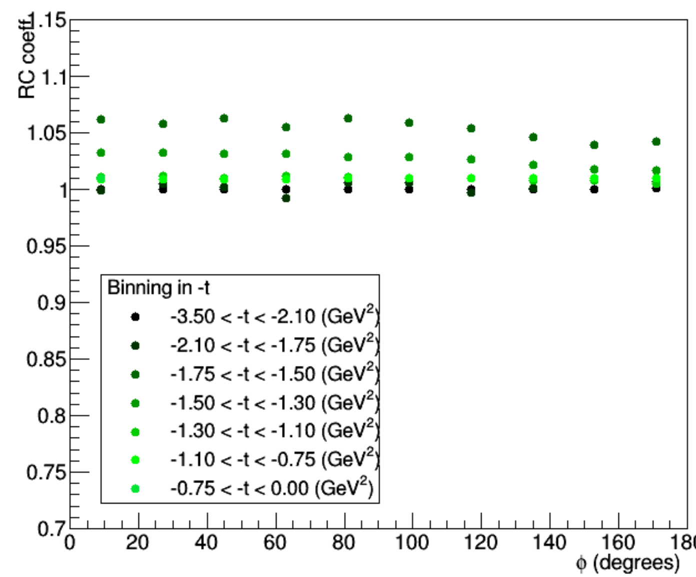


Radiative Corrections



- **RADGEN based for electrons**
- **HAPRAD 2 based for pions**
  - Both need adaptations for nuclear targets
  - Both are limited to 5% in most bins
- **Happen to be rather CPU consuming**
  - Found some missing bins recently → Main delay for the answer to the committee





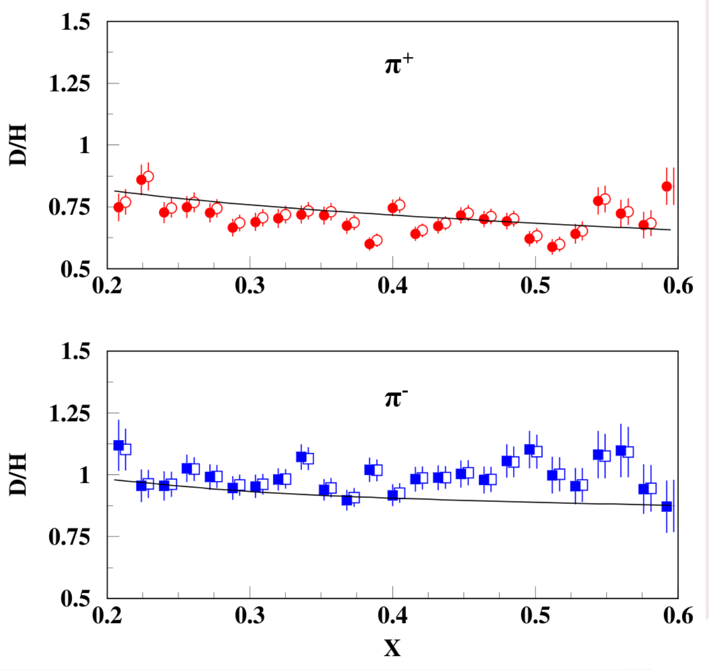
Coulomb and Isospin corrections

- **Coulomb correction**
  - To take the electric field of the nuclei into account
  - Use effective momentum prescription used for quasi-elastic
  - Shifts momentum of all particles depending on their charge
  - Has overall effect of few % for Pb

Nucleus	V_0 (MeV)	$\bar{V}$ (MeV)
^{2}H	-1	-1
C	-4	-3
Al	-7	-6
Fe	-11	-9
Sn	-17	-14
Pb	-23	-19

Target	Isospin correction
C	0
Al	1.5%
Fe	3%
Sn	8%
Pb	10%

- **Isospin correction**
  - Production yield of charged pions on proton and neutron target is not the same
  - This can lead to a modification of the multiplicity ratio completely unrelated to our physics focus
  - This can be corrected based on model but we preferred a simple correction based on data
    - Hall C has data in a very similar kinematic to us
    - Avoid to make any model assumptions
    - Using a simple scaling factor is crude but also make it easy for anyone to recover uncorrected results and apply a different correction



- **Effects are opposite and almost completely cancel each other**

Calculating Error Bars

$$\frac{\delta\left(R_A^h\right)}{R_A^h} = \sqrt{\left(\frac{\sum {\omega_A^h}^2}{\left(\sum \omega_A^h\right)^2}\right) + \left(\frac{\sum {\omega_A^e}^2}{\left(\sum \omega_A^e\right)^2}\right) + \left(\frac{\sum {\omega_D^h}^2}{\left(\sum \omega_D^h\right)^2}\right) + \left(\frac{\sum {\omega_D^e}^2}{\left(\sum \omega_D^e\right)^2}\right)}$$

$$\left(\delta\left(\Delta\langle P_\perp^2\rangle\right)\right)^2 = \left(\frac{\sum \omega_A^h P_\perp^4}{\sum \omega_A^h} - \left(\frac{\sum \omega_A^h P_\perp^2}{\sum \omega_A^h}\right)^2\right) \times \left(\frac{\sum \left({\omega_A^h}^2\right)}{\left(\sum \omega_A^h\right)^2}\right) + \left(\frac{\sum \omega_D^h P_\perp^4}{\sum \omega_D^h} - \left(\frac{\sum \omega_D^h P_\perp^2}{\sum \omega_D^h}\right)^2\right) \times \left(\frac{\sum \left({\omega_D^h}^2\right)}{\left(\sum \omega_D^h\right)^2}\right).$$

- **Using acceptance and radiative correction weights impacts statistical error bars**
  - The 1/sqrt(N) formula does not apply for weighted event counts
  - However there are also correlations in these weights that might affect the error bars
- **Committee question**
  - Part of these errors might also be already included in acceptance correction
  - This is true and we are now trying to figure out what is the best way to evaluate the error bars and separate statistical from systematics
- **There was a bug in the implementation of the Delta Pt errors**
  - These are reduced by a factor ~3

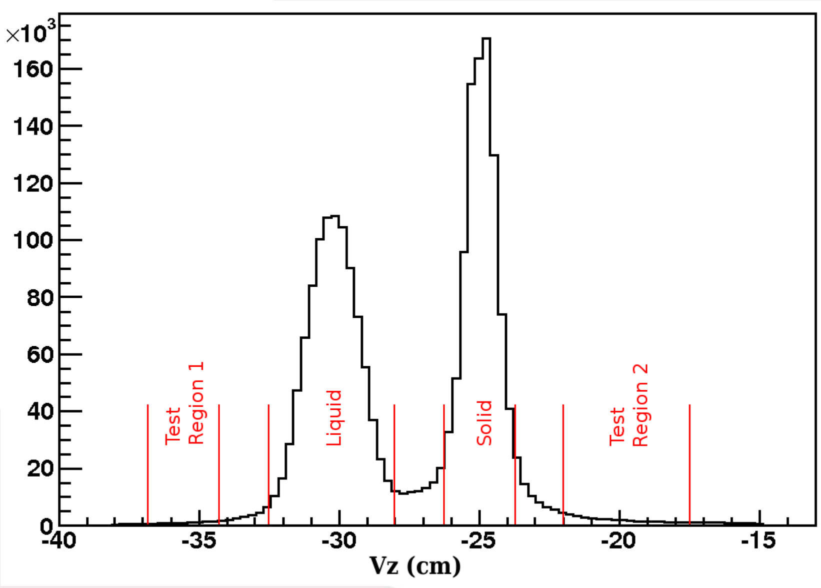
Systematic Error Bars

Acceptance Errors

Variable	Normalization errors	Point to point errors
$R_A^{\pi^+}$	1.2%	1.5%
$R_A^{\pi^-}$	2.5%	2.6%
$\langle \Delta P_\perp^2 \rangle_A^{\pi^+}$	5%	11%
$\langle \Delta P_\perp^2 \rangle_A^{\pi^-}$	5%	21%

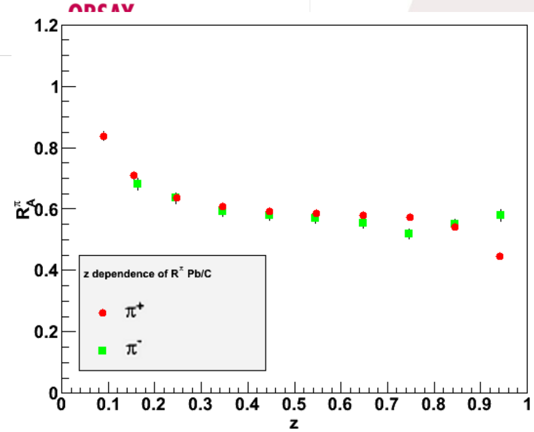
	$R_A^{\pi^+}$	$R_A^{\pi^-}$	$\Delta\langle p_\perp^2 \rangle^{\pi^+}$	$\Delta\langle p_\perp^2 \rangle^{\pi^-}$
Acceptance	1.2%	2.5%	5%	5%
Target id.	1%	1%	1%	1%
Isospin (Pb)	1%	1%	1%	1%
Total	1.9%	2.9%	5.2%	5.2%

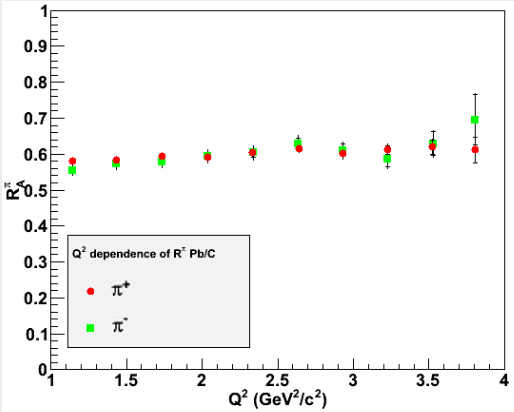
Table 10: Total normalization uncertainties for both charged pions.

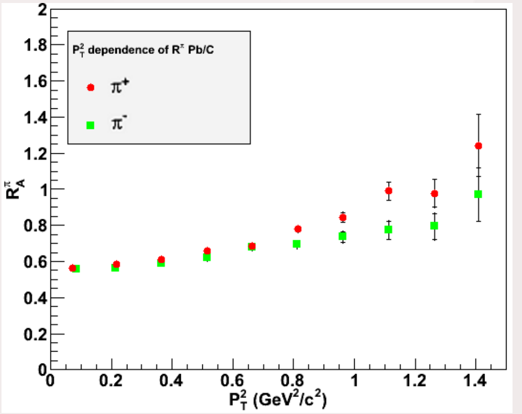


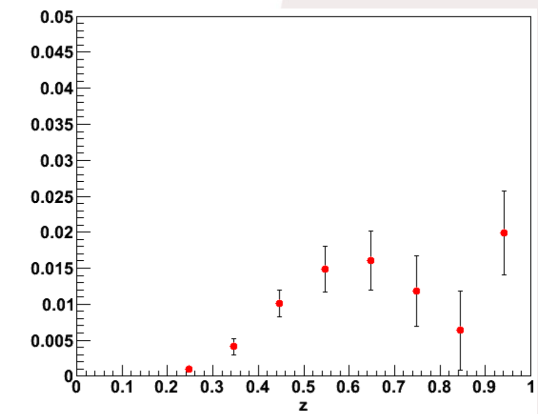
- **Normalization**
  - Acceptance error has been spread between normalization and pt to pt
  - Misidentification of target will affect the normalization
  - Isospin correction is associated with an error as well
- **Point to point**
  - Acceptance correction (lead to large errors on transverse momentum broadening)
  - Contaminations from other hadrons
- **Still a question to settle for stat error on acceptance**

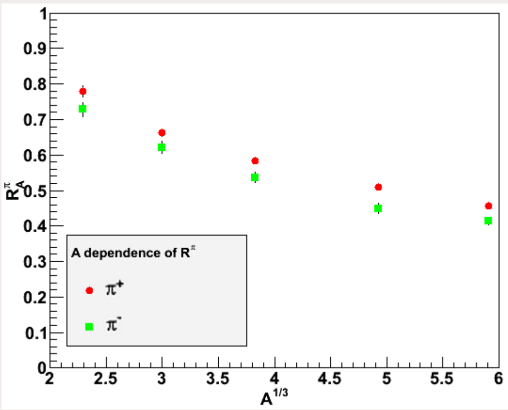
Many Results to Come (Soon)

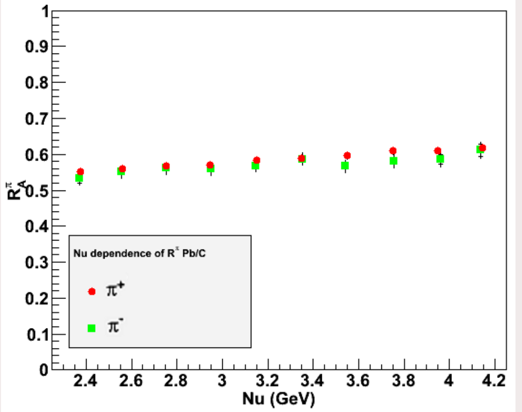


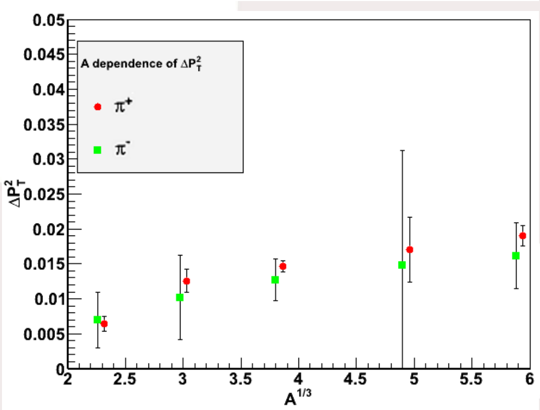


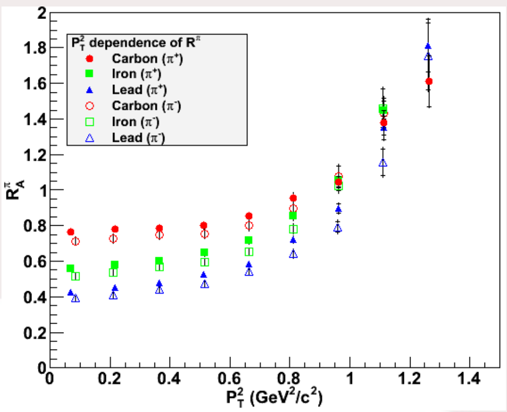


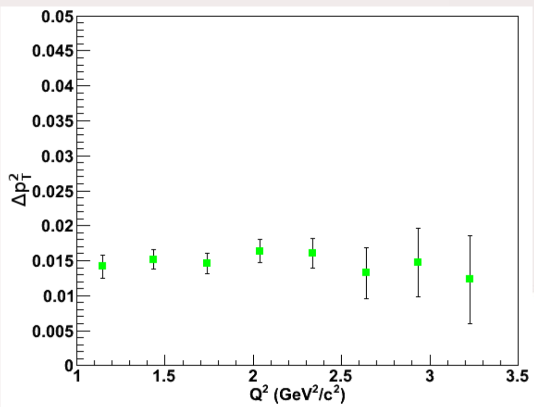












Summary

- **Analysis is complete and under review**
  - Review committee would like more details on radiative and acceptance corrections
  - We found a couple of minor bugs
    - Most importantly error bars got smaller
- **Parallel analysis of Hayk**
  - Several issues to be addressed (See next talk)
  - Comparison to Hall C is possible in a specific bin for aluminum
    - This analysis is 4% off, which is acceptable within our error bars (2% normalization and ~2% point to point in this bin)
    - This comparison will be added to the analysis note
- **End of round 1 in the coming month**