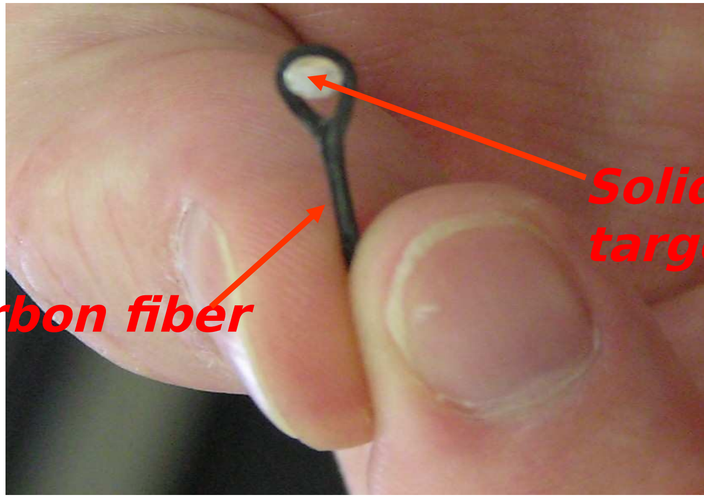
Quark propagation and hadron formation in the nucleus

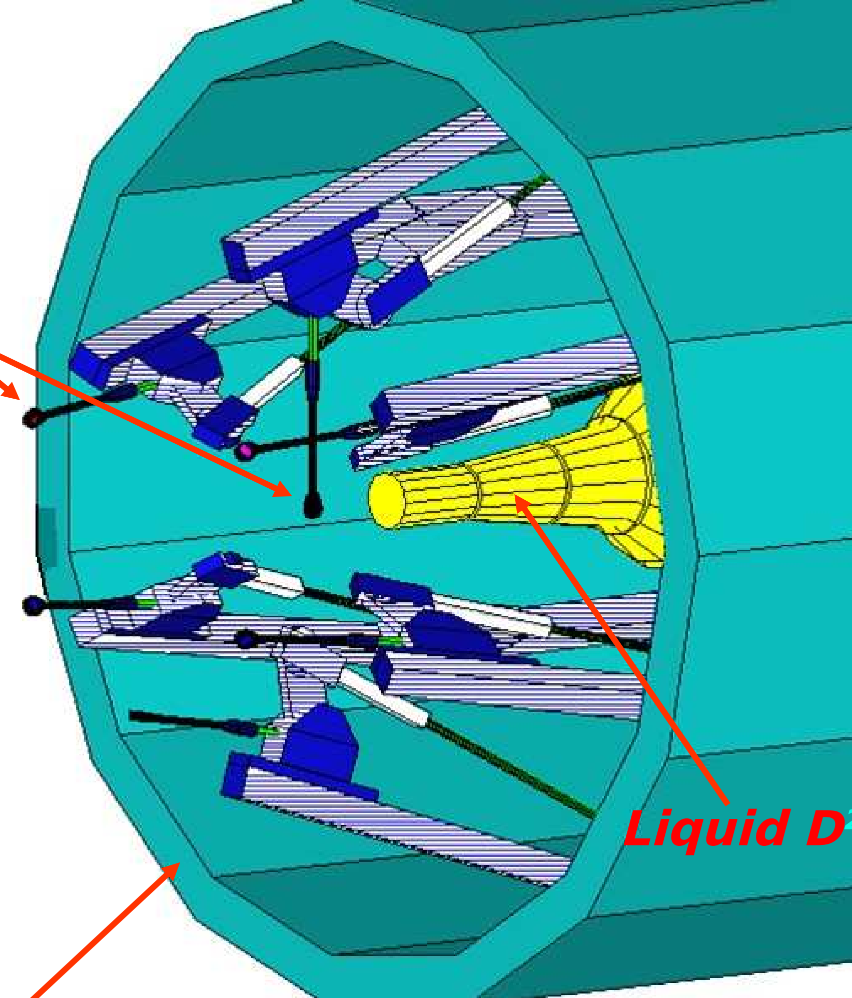
(progress in analysis of experimental data
of CLAS EG2 experiment)

Hayk Hakobyan for UTFSM group

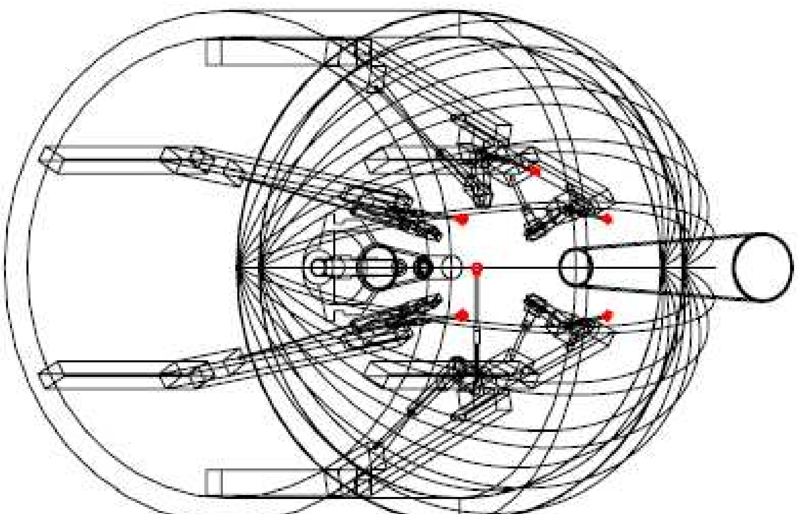
CLAS collaboration meeting
March, 2018

Experimental details



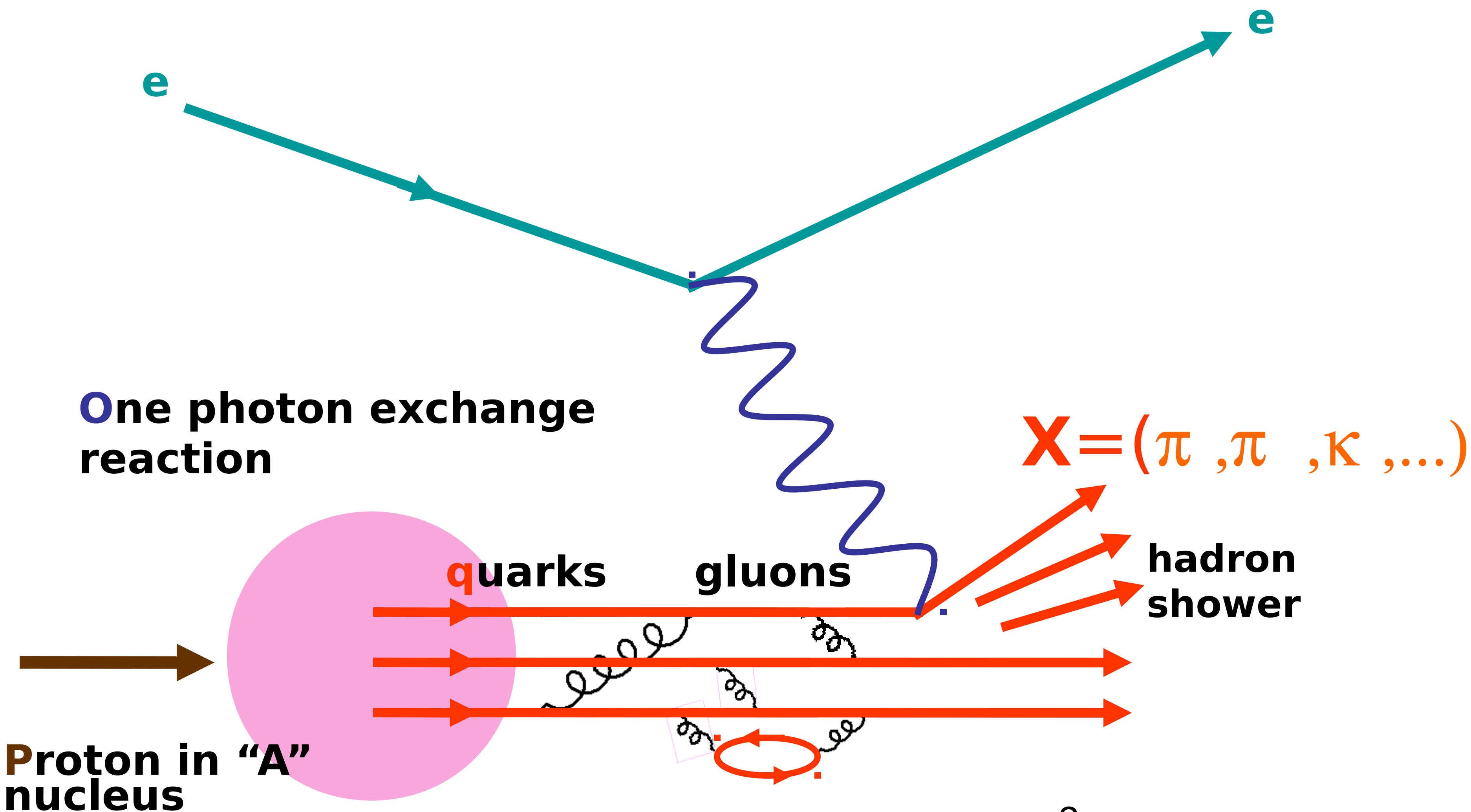


Rohacell foam scattering chamber



EG2 Experiment target in GEANT3
Solid (C, Al, Fe, Sn, Pb) target
simultaneously with deuterium target

Schematic diagram describing semi-inclusive Deep Inelastic Scattering of a lepton off a nucleon



Experimental Variables

ν – energy transferred by the electron, = initial energy of struck quark, (2 ~ 4.5) GeV here

Q^2 – probe, (1 ~ 4) GeV^2 here

z_h – energy fraction carried by hadron; $0<z_h<1$

p_T – hadron momentum transverse to virtual photon direction

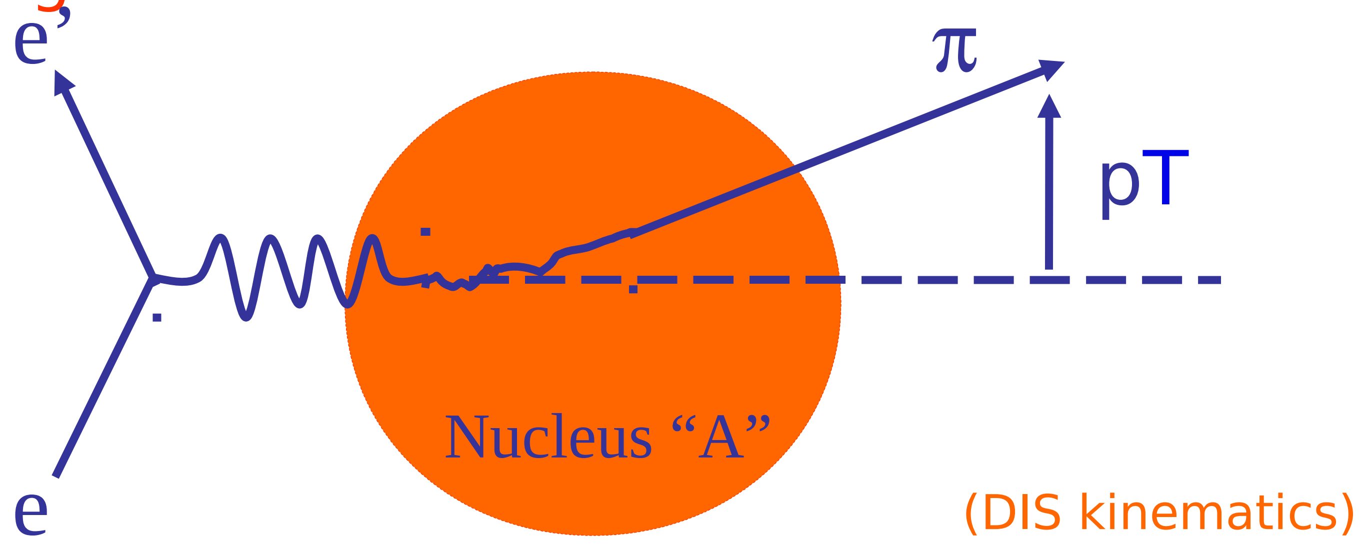
Φ – hadron azimuthal angle to virtual photon direction

E_{BEAM}=5 GeV (CLAS)

Experimental Observables

Transverse momentum broadening

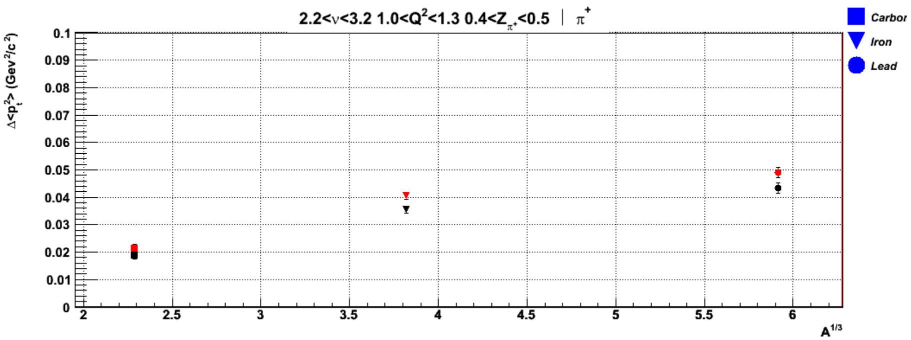
$$\Delta p_T^2 = p_T^2(A) - p_T^2(^2H)$$



Hadronic multiplicity ratio

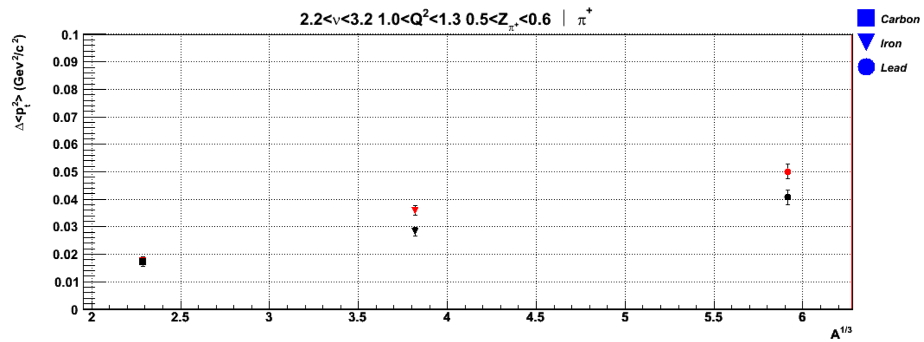
$$R_M^h(z,\nu,p_T^2,Q^2,\phi) = \frac{\left\{\dfrac{N_h^{DIS}(z,\nu,p_T^2,Q^2,\phi)}{N_e^{DIS}(\nu,Q^2)}\right\}_A}{\left\{\dfrac{N_h^{DIS}(z,\nu,p_T^2,Q^2,\phi)}{N_e^{DIS}(\nu,Q^2)}\right\}_D}$$

Transverse momentum dependence on 1/3 of nuclear mass number (all together in 24 kinematical region)



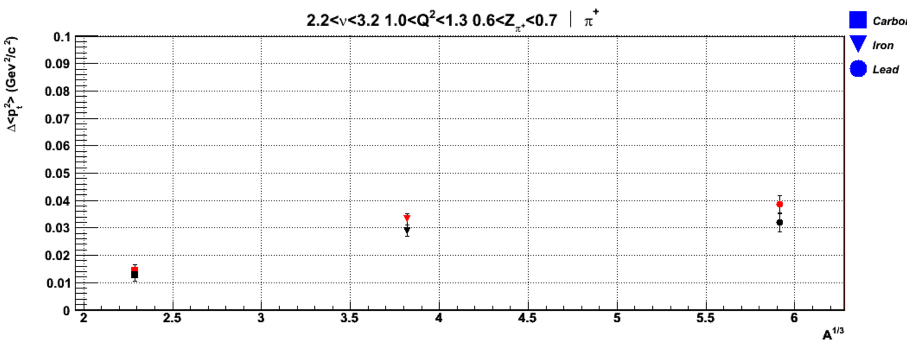
C_{mean}=0.0214 Fe_{mean}=0.0404 Pb_{mean}=0.0490
C_{err}=0.0013 Fe_{err}=0.0012 Pb_{err}=0.0019

Corrected data
C_{mean}=0.0189 Fe_{mean}=0.0355 Pb_{mean}=0.0434



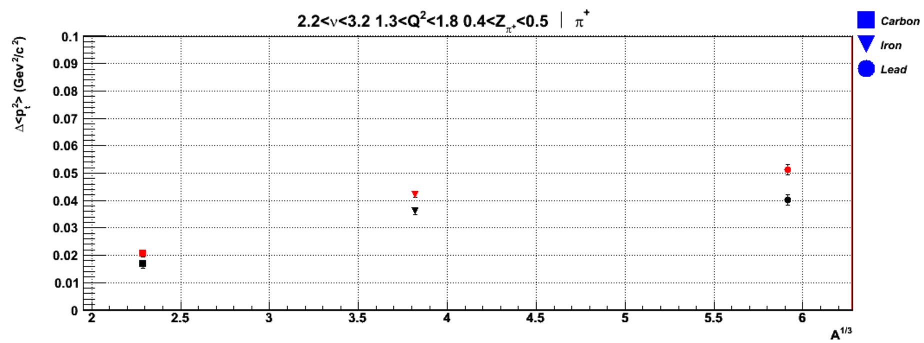
C_{mean}=0.0174 Fe_{mean}=0.0359 Pb_{mean}=0.0501
C_{err}=0.0018 Fe_{err}=0.0017 Pb_{err}=0.0027

Corrected data
C_{mean}=0.0173 Fe_{mean}=0.0282 Pb_{mean}=0.0407



C_{mean}=0.0144 Fe_{mean}=0.0333 Pb_{mean}=0.0385
C_{err}=0.0023 Fe_{err}=0.0021 Pb_{err}=0.0034

Corrected data
C_{mean}=0.0129 Fe_{mean}=0.0290 Pb_{mean}=0.0320

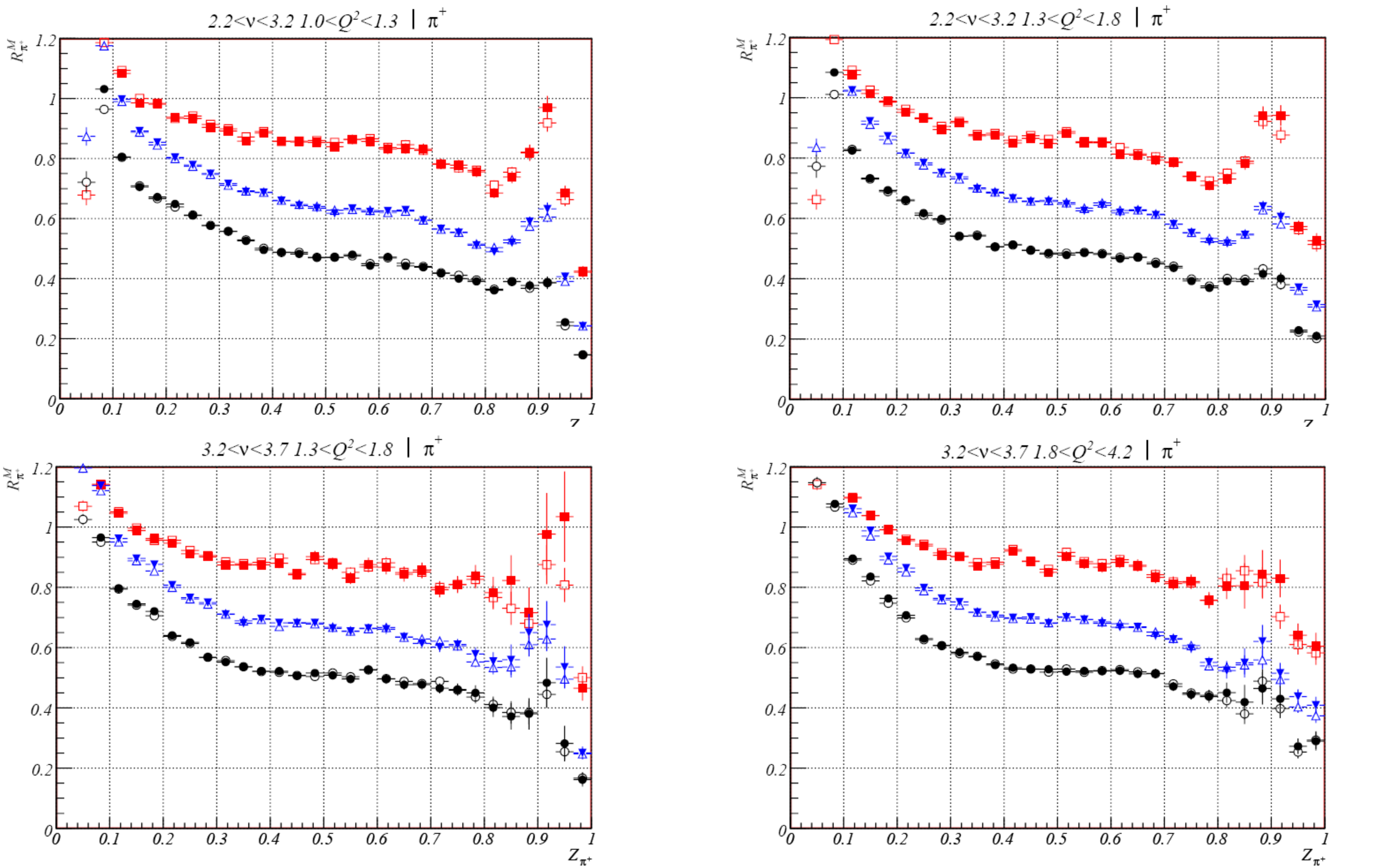


C_{mean}=0.0206 Fe_{mean}=0.0422 Pb_{mean}=0.0512
C_{err}=0.0013 Fe_{err}=0.0012 Pb_{err}=0.0019

Corrected data
C_{mean}=0.0167 Fe_{mean}=0.0360 Pb_{mean}=0.0403

Acceptance correcion less than 14 %

Multiplicity Ratio Dependence on Z_h in different Q^2 and ν bins



3 pions 1 dimensional Multiplicity Ratios distributions paper

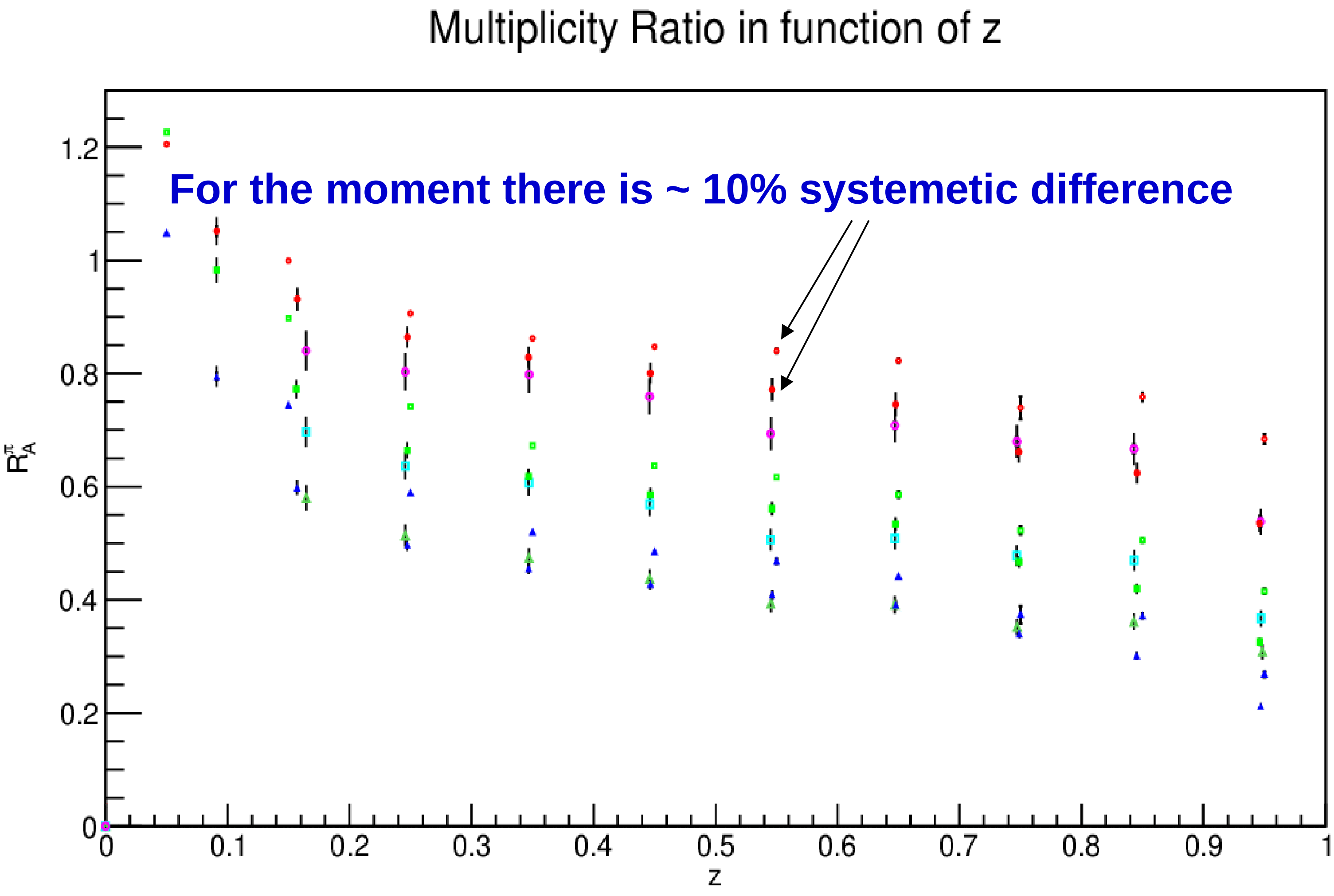
People currently involved in the analysis:

William Brooks (coordinator)
Raphael Dupre
Ahmed El Alaoui
Hayk Hakobyan
Taiysia Mineeva
Sebastian Moran
Orlando Soto

Several independent data analysis are performed

Two analysis notes are under review:
“Hadronization studies via pi0 electroproduction off D, C, Fe and Pb”
“Study of the hadronization of the charged pions”

Integrated distribution comparison between Raphael and Hayk analysis



Possible sources for uncertainty in the results

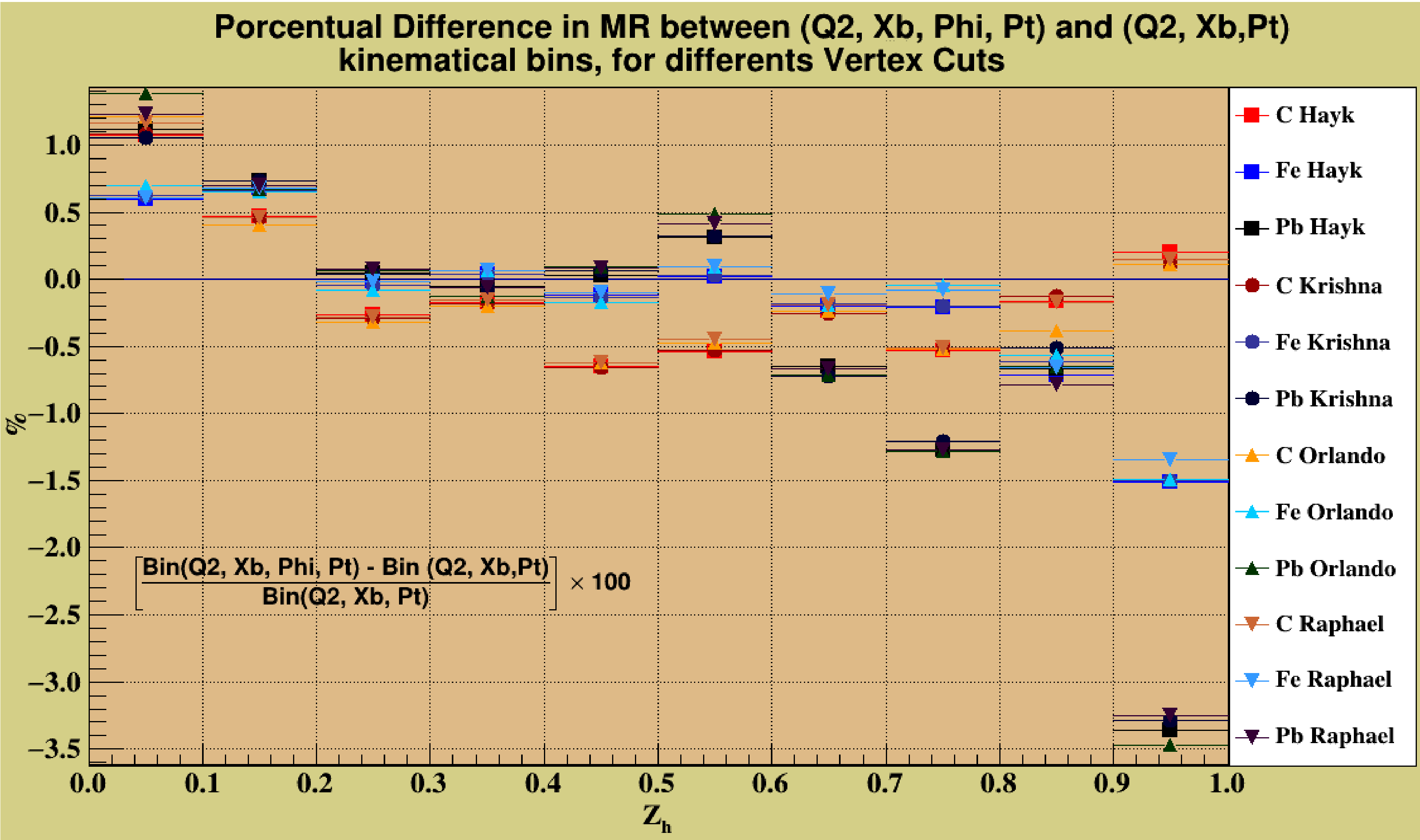
- Different dimensional binning in acceptance correction procedure (5 dim. - Hayk (up to 3% correction) & 4 dim. Raphael (10% correction))
- Tighter particle ID cuts in the case of Raphael's analysis for electrons and for pions.
- Vertex cut
- Different approaches in pion identification:

Δt – Hayk & $\Delta\beta$ – Raphael

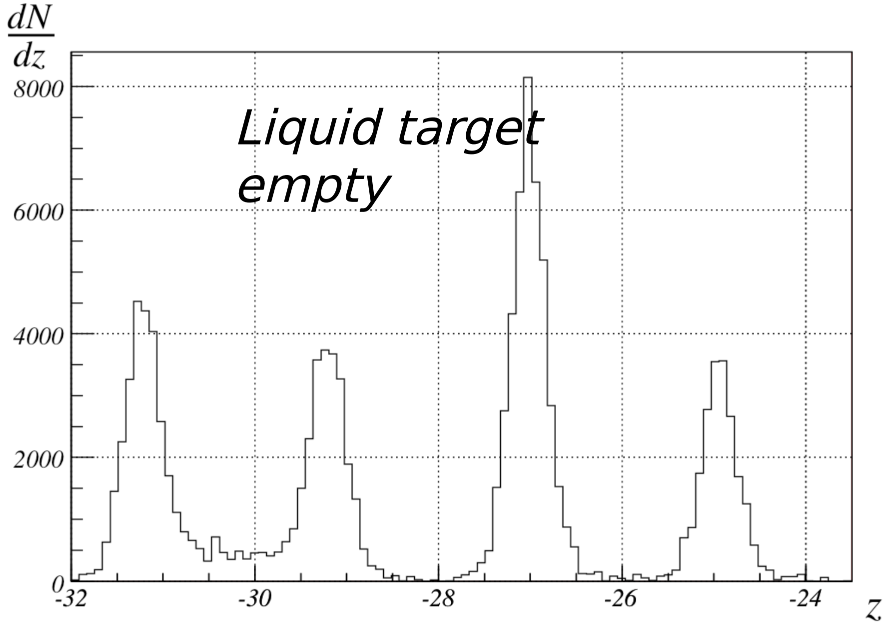
- Etc.

Acceptance correction method?

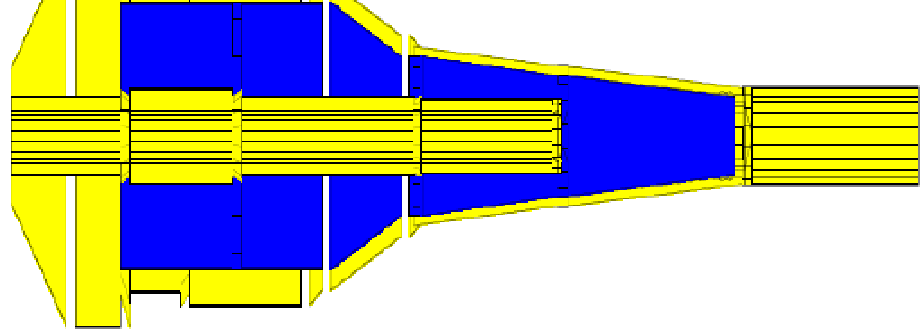
Comparison 5 dim. acceptance correction vs. 4 dim.

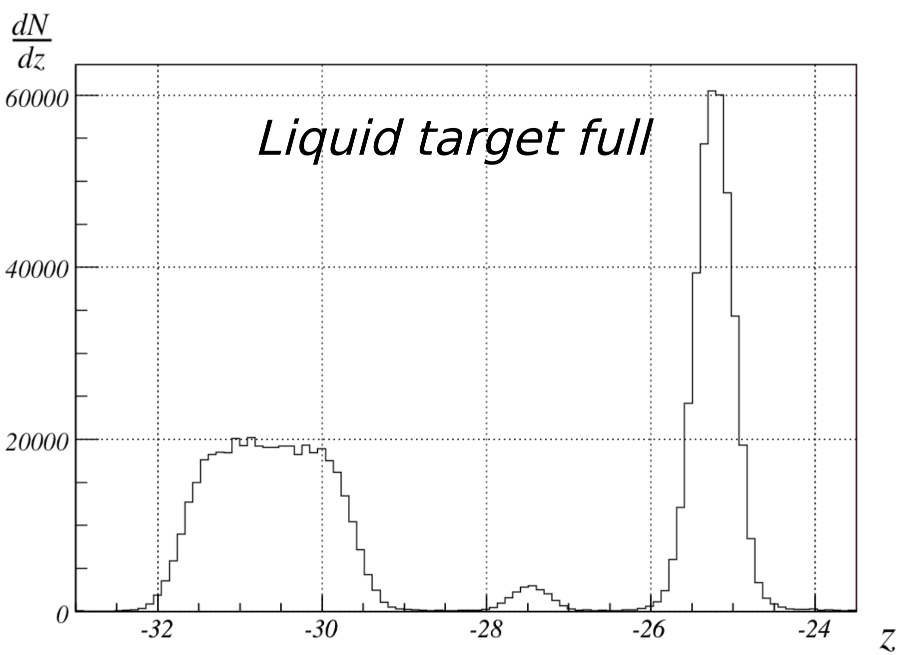


Vertex cut?

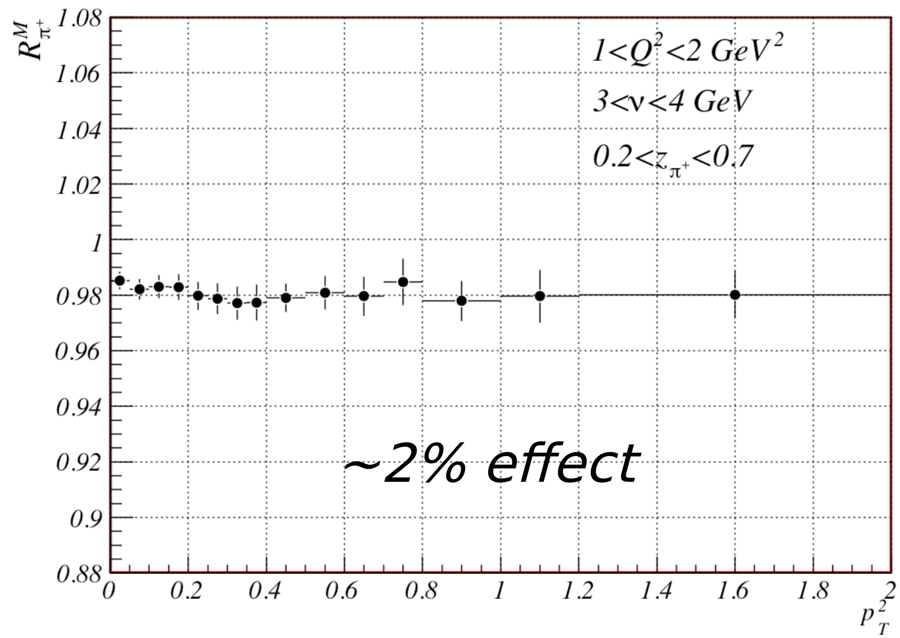


D^2 cell in GSIM

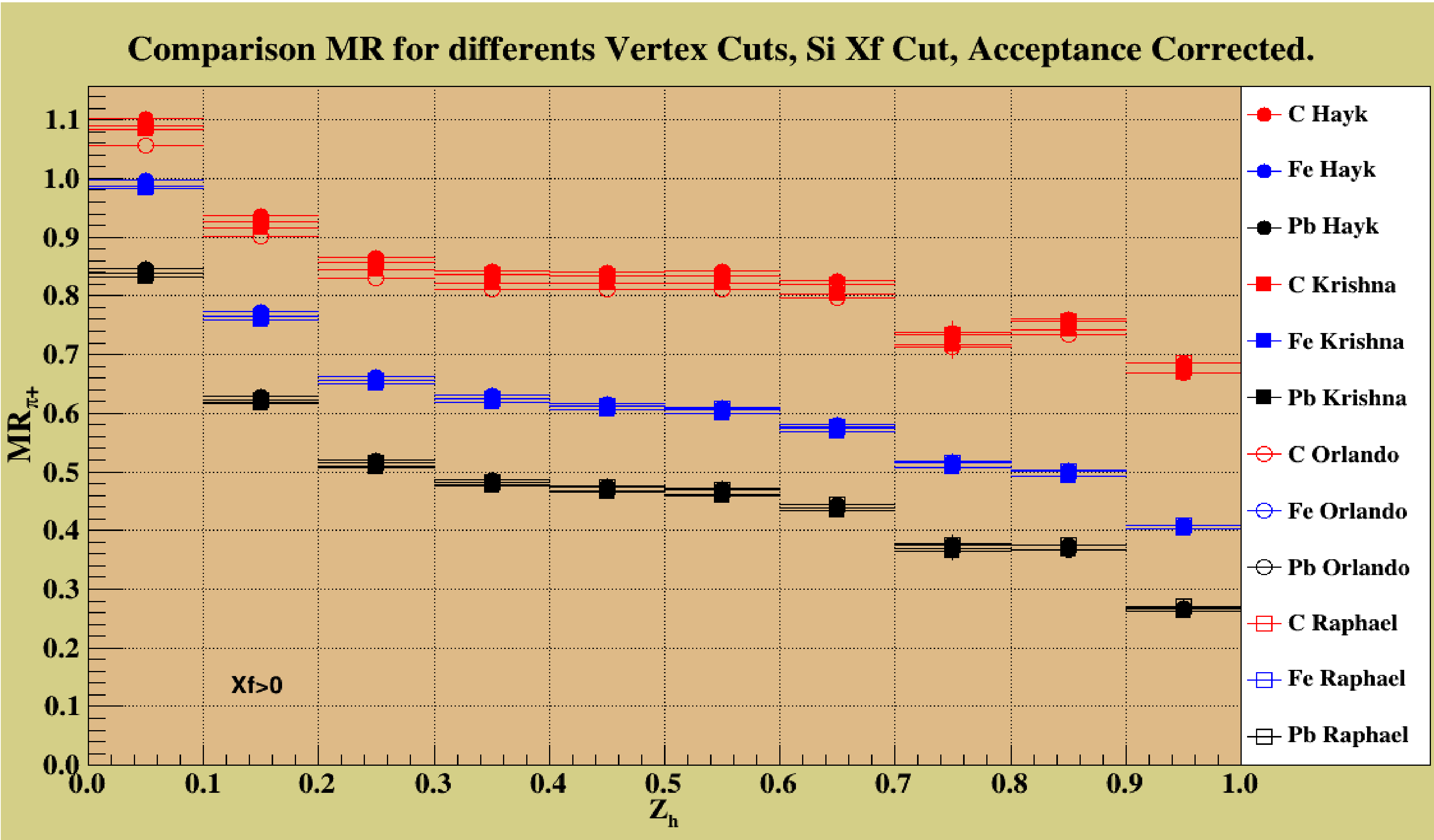




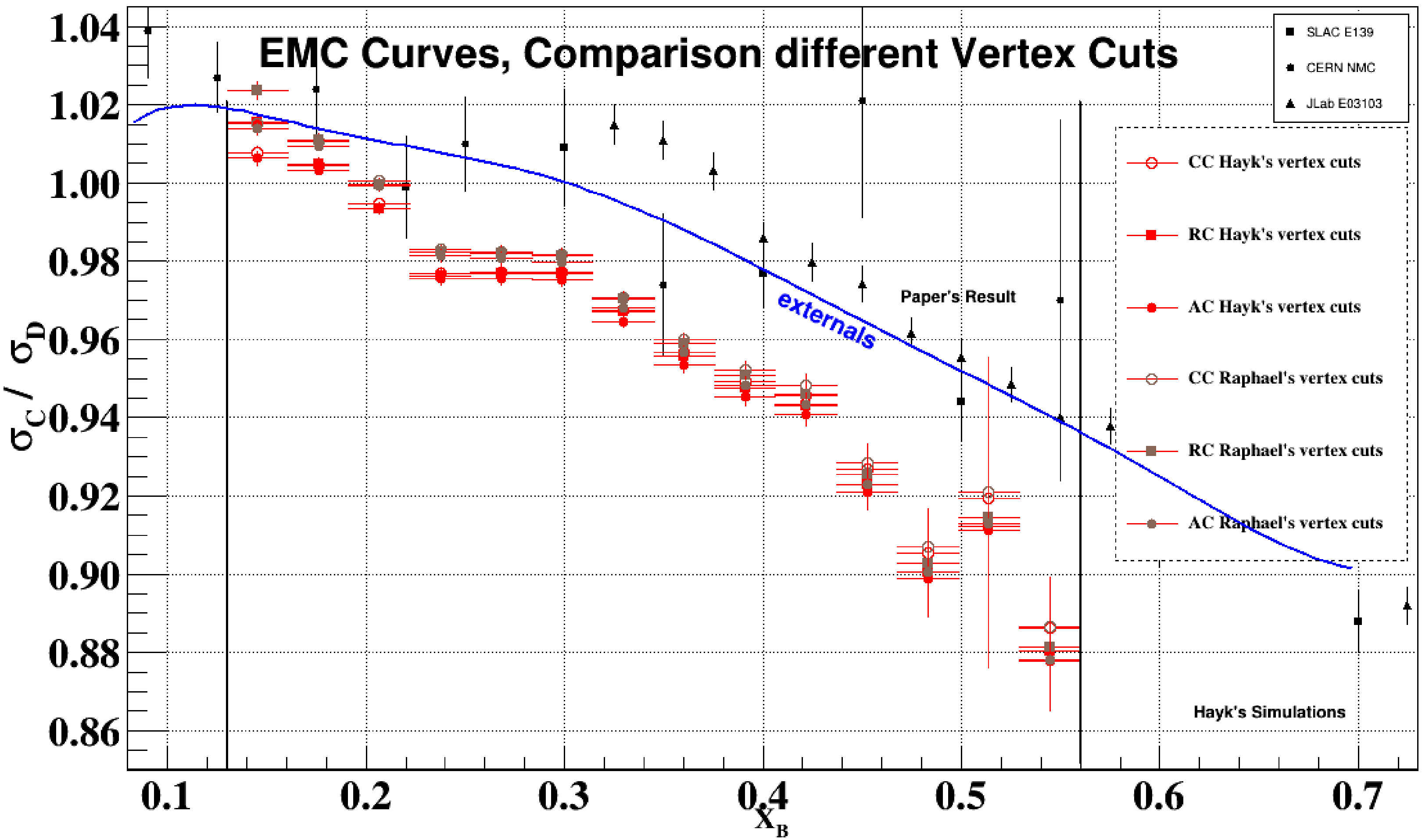
Ratio of acceptances for positive pions from the solid target to the liquid target



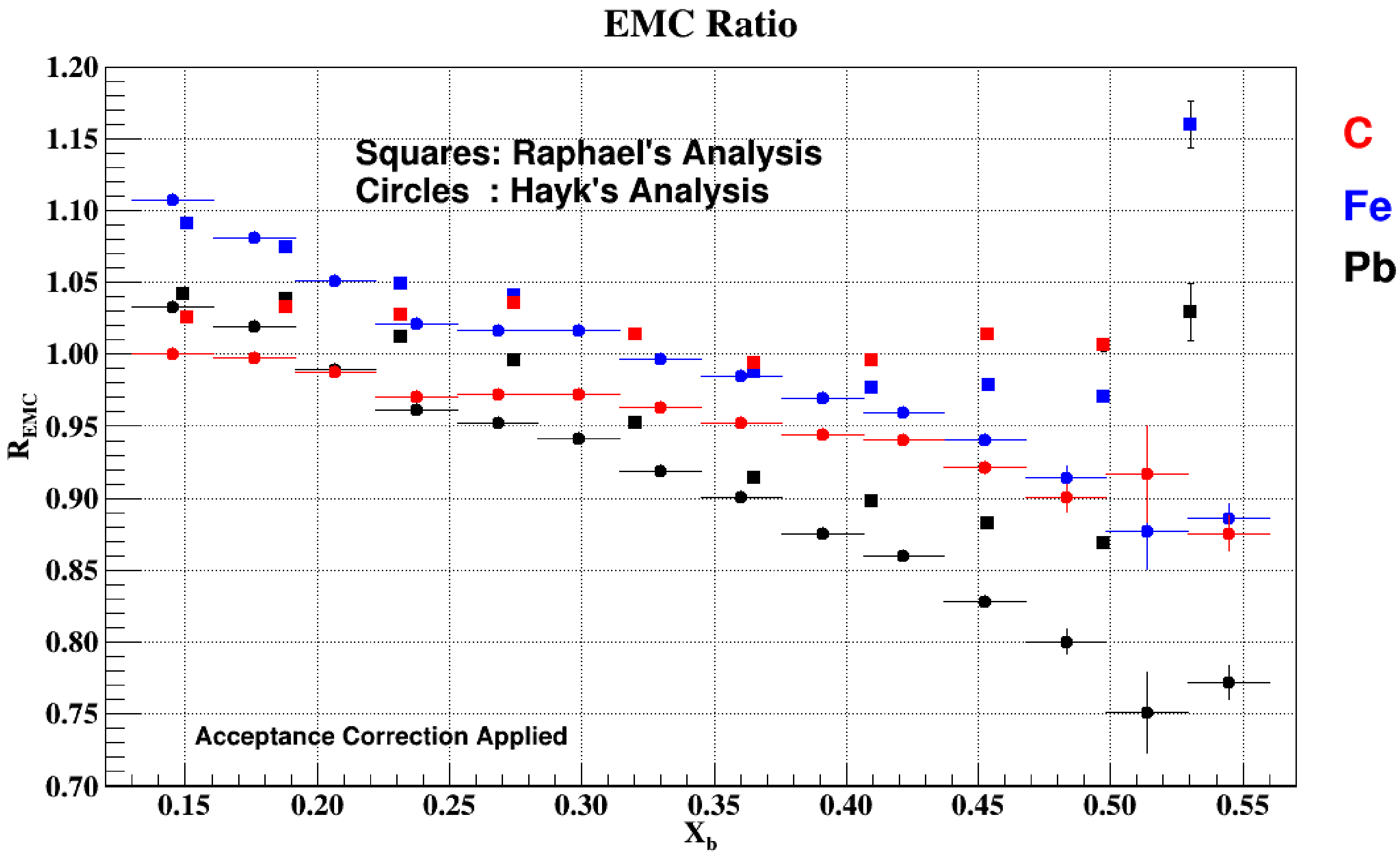
Comparison of different vertex cuts



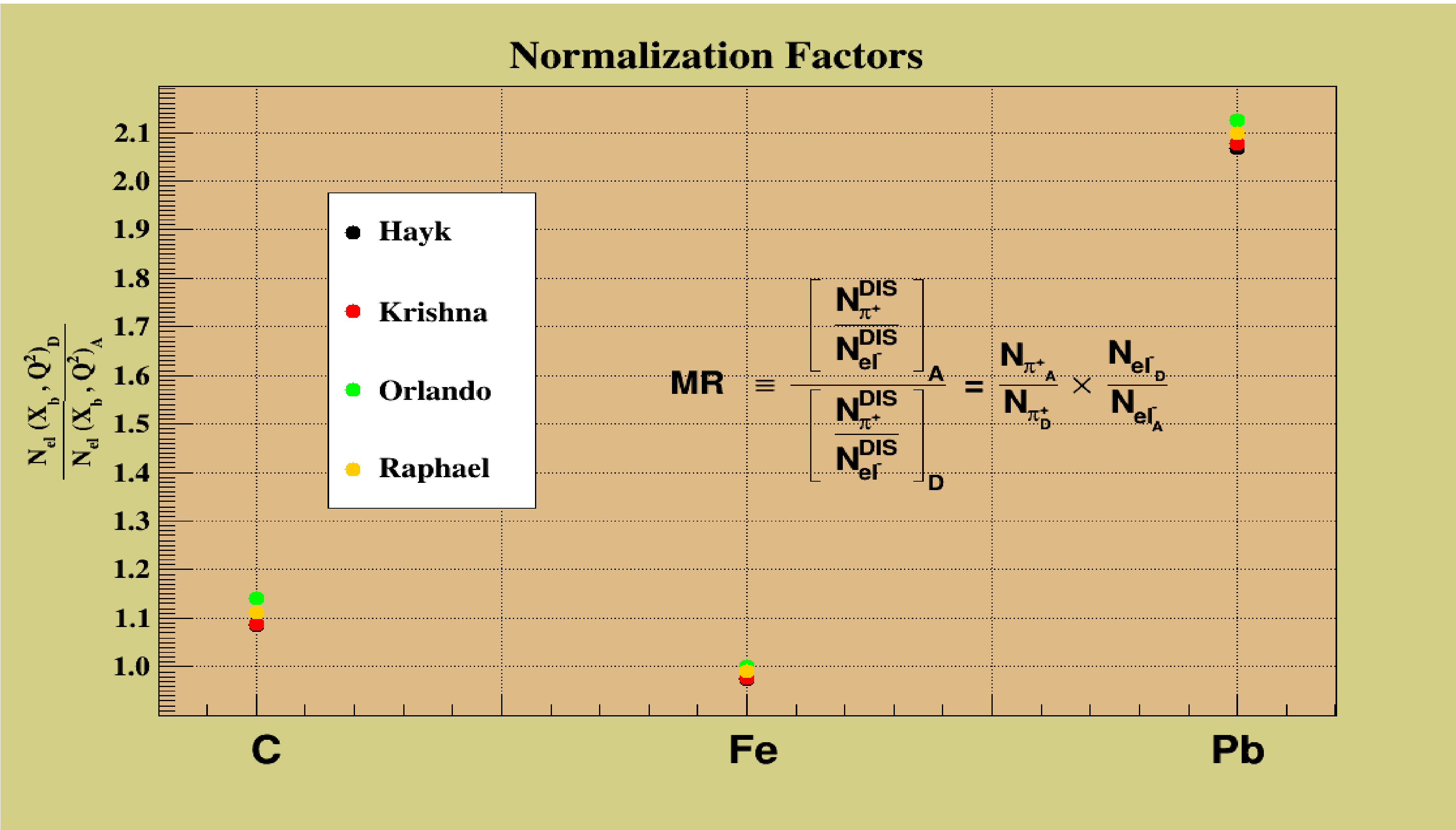
EMC curve with different vertex cuts



EMC curve from different analysis

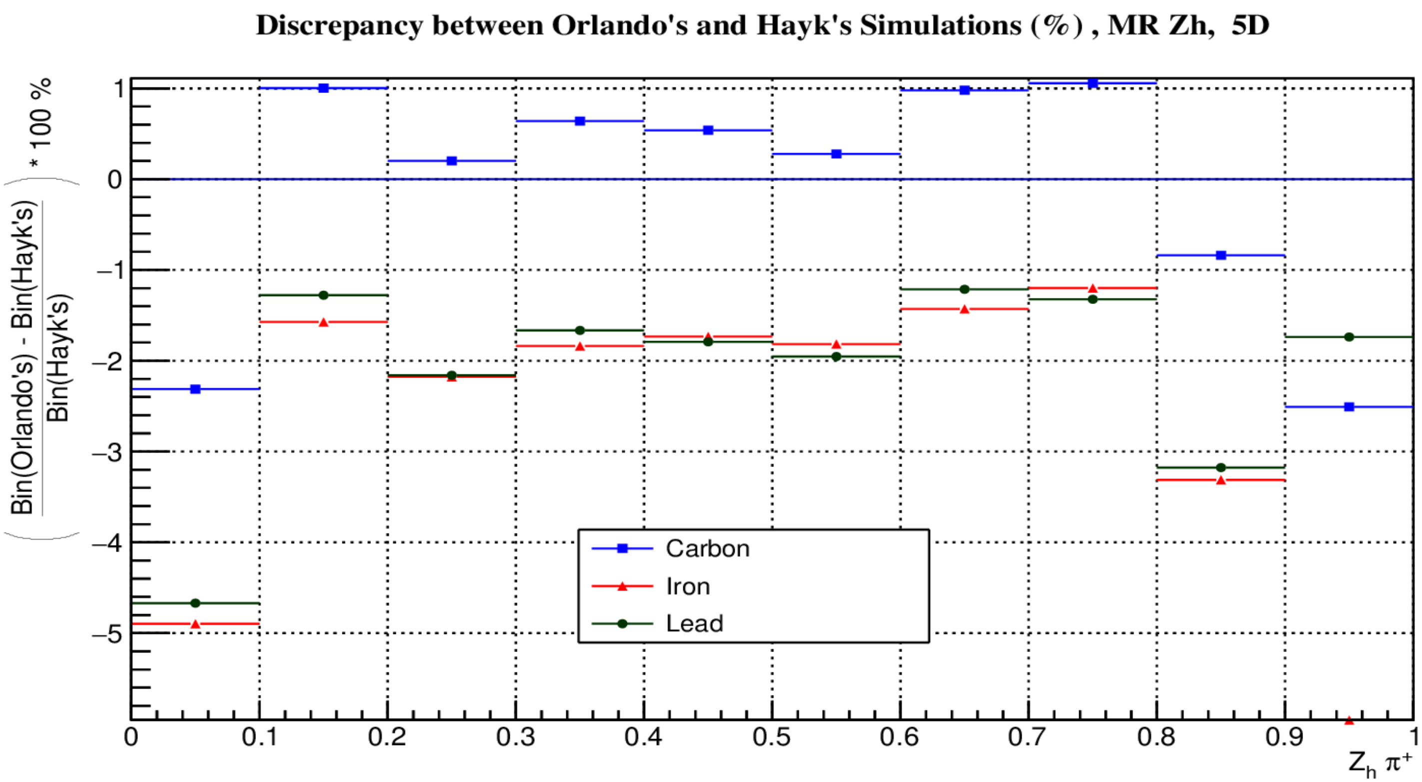


Normalization factors comparison



Physics generator code for simulations?

Comparison of different simulation codes



Conclusions!

- Acceptance correction method (5 dim vs 4 dim) doesn't reproduce the observe uncertainty between different analysis

- Vertex cut doesn't reproduce the observed uncertainty between different analysis

- Further studies are necessary (currently on progress)

π^0 analysis status update (1):

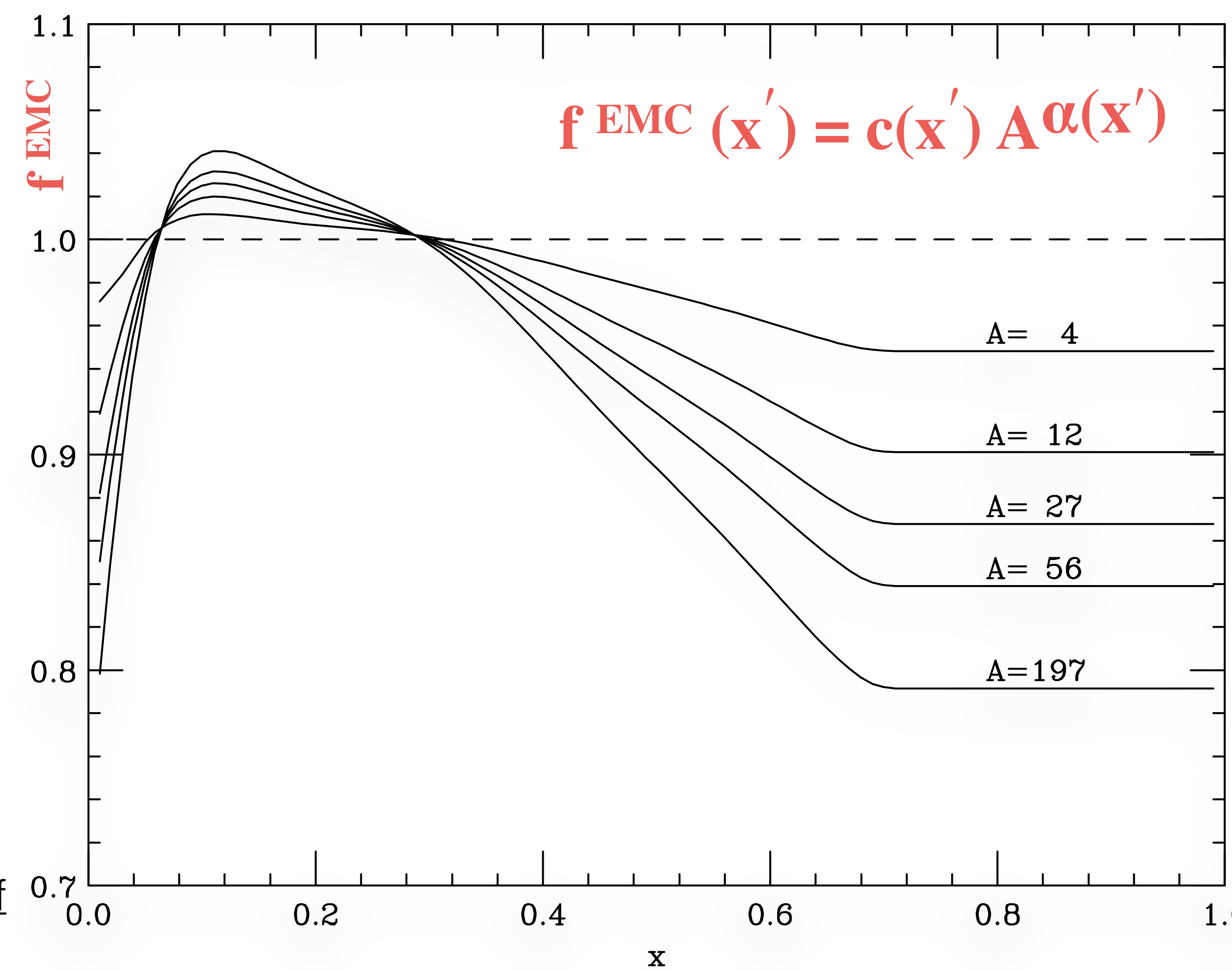
radiative correction for the electron off nuclear targets

Taisiya Mineeva

Inclusive electron radiative corrections in DIS

Code: EXTERNALS from D.Gaskell & al (based on the code originating in SLAC in 80s)

- First Born approximation + next-to leading order QED processes
- Mo & Tsai formalism for handling of IR divergencies: angular peaking approximation
  equivalent radiator method
- New: full 3D integration of radiative tails in elastic, quasielastic and dis regimes
- Nuclear dependencies are accounted via global parametrization to structure fnc *



* P.Bosted, V.Mamyan “Empirical fit to electron-nucleus scattering” arXiv:1203.2262v2

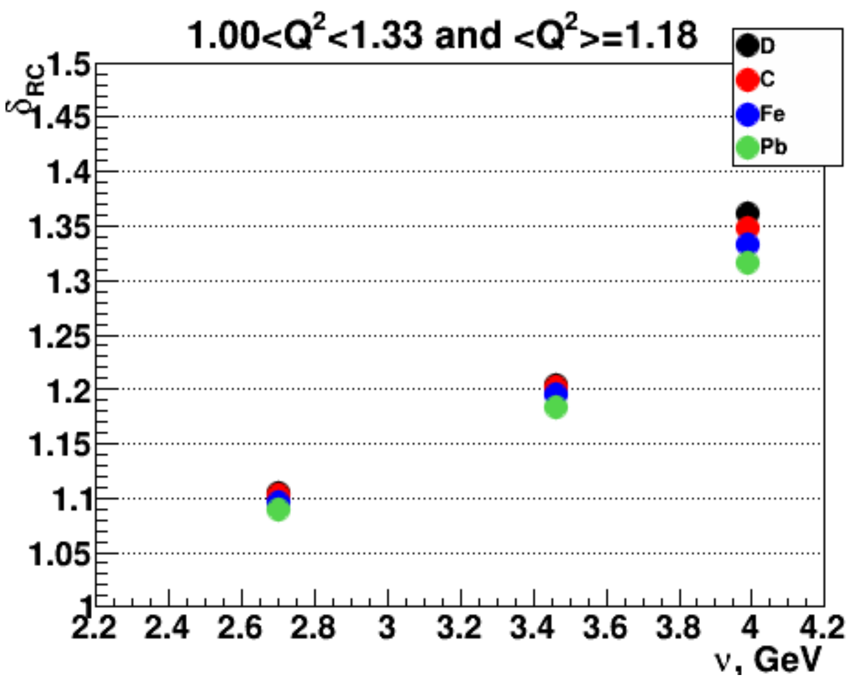
Mo&Tsai(1969):
https://journals.aps.org/rmp/pdf/10.1103/RevModPhys.41.205

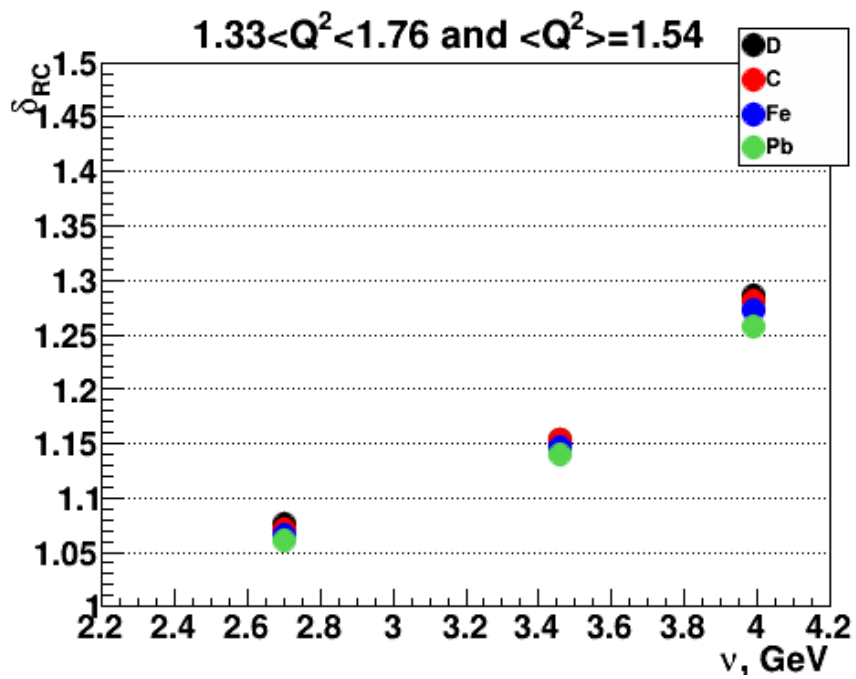
Y.S.Tsai (1971):
http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-0848.pdf

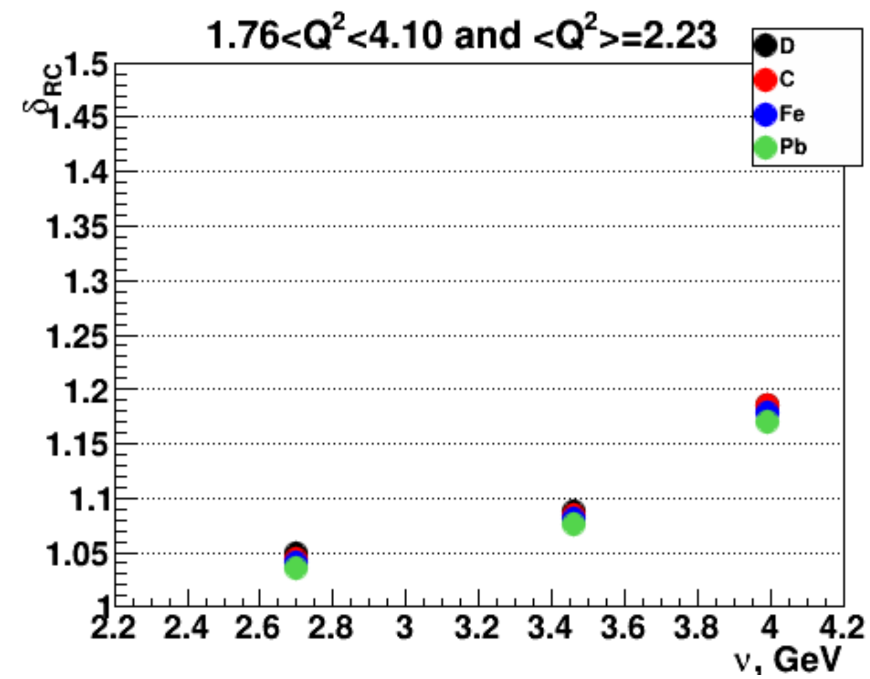
Radiative correction (RC) factors for D,C,Fe,Pb

$$\delta_{RC} = \sigma_{Rad} / \sigma_{Born}$$

$$N^e_{corr} = N^e_{meas} / \delta_{RC}$$

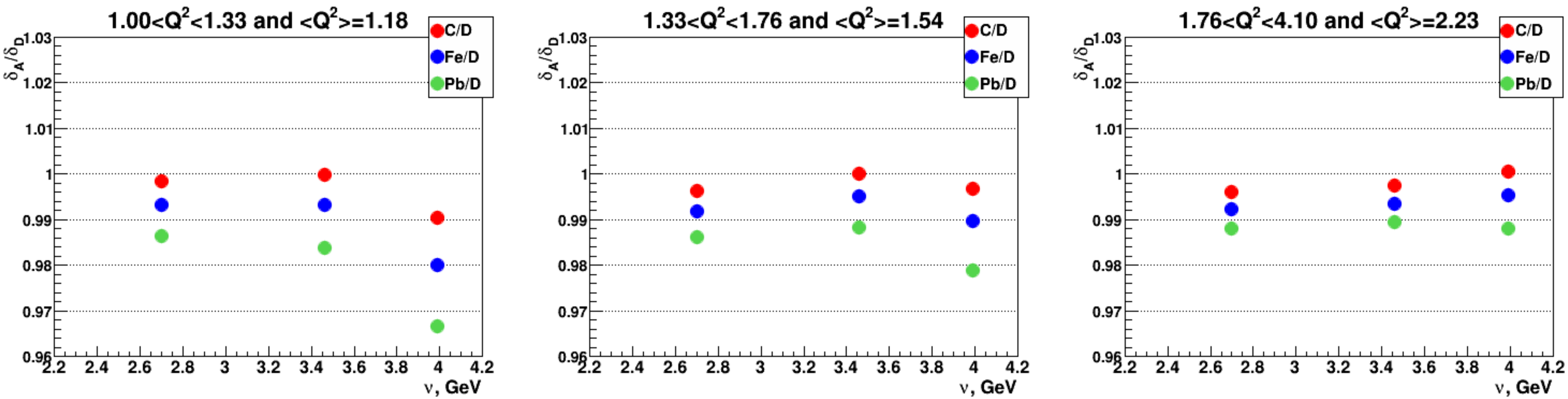






Radiative correction (RC) factors normalized to D

$$R^{e}_{corr} \sim \frac{(N^{e}_{meas}/\delta_{RC})_{\mathbf{D}}}{(N^{e}_{meas}/\delta_{RC})_{\mathbf{A}}} \sim N * \frac{(\delta_{RC})_{\mathbf{A}}}{(\delta_{RC})_{\mathbf{D}}}$$



Coulomb correction for C, Fe, Pb

Code: the same code EXTERNALS from D.Gaskell & *al*
Formalism: effective momentum approximation + focusing factor

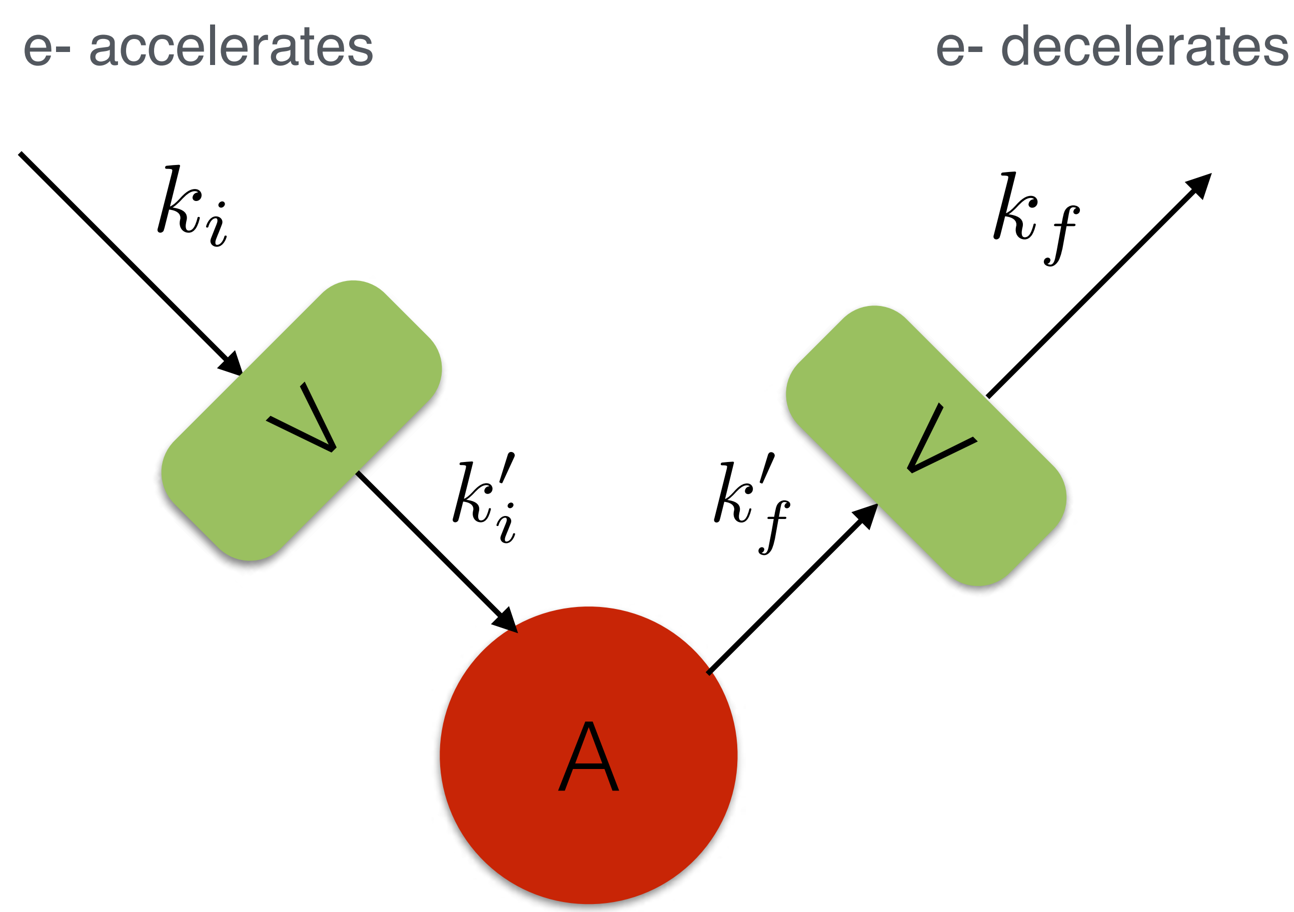
$$k'_i = k_i + \Delta k, \qquad k'_f = k_f + \Delta k,$$

$$k'_{i,f} = |\vec{k}'_{i,f}|, \qquad \Delta k = -V_0/c,$$

V_0 = (1.5)*(Z/R)*(hbar*c)*α*0.775

Coulomb correction factor is normalized by the square of focusing factor :

$$f(0) = \left(1 - \frac{\beta}{R}\right)^{-2} \sim \left(1 - \frac{V(0)}{E}\right)^2 \sim (k'_i/k_i)^2$$



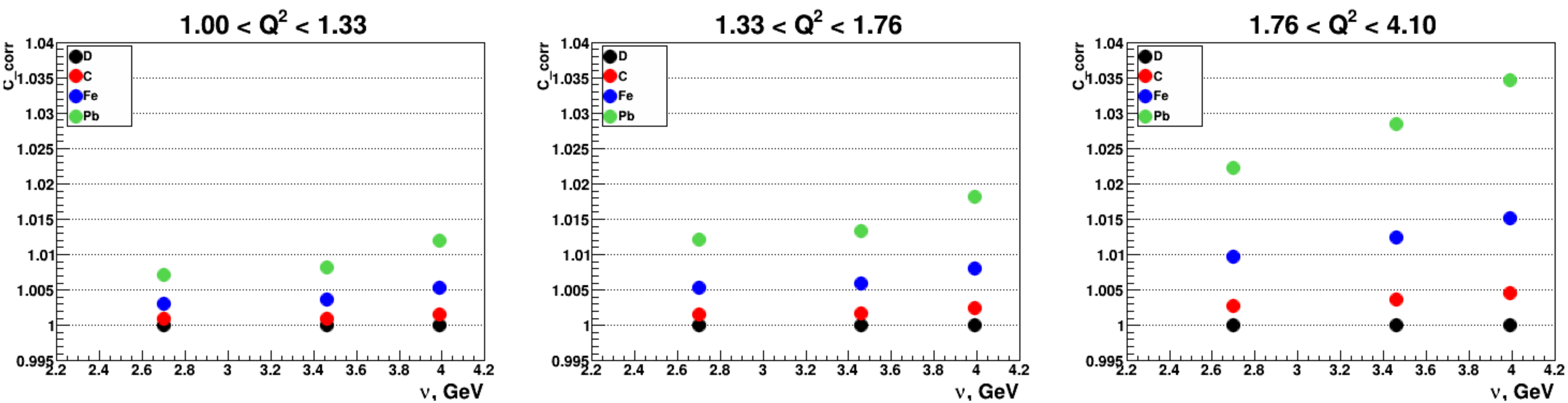
e- accelerates: $k_i' > k_i$
e- decelerates: $k_f' > k_f$

Aste et al., Eur. Phys. J. A 26, 167 (2005)
Aste et al. Nucl.Phys. A743 :259-282 (2004)

Coulomb correction (CC) for C, Fe, Pb

$$\delta_{CC} = \sigma_{QE} / \sigma_{Coul}$$

$$N^e_{corr} = N^e_{meas} * \delta_{CC}$$

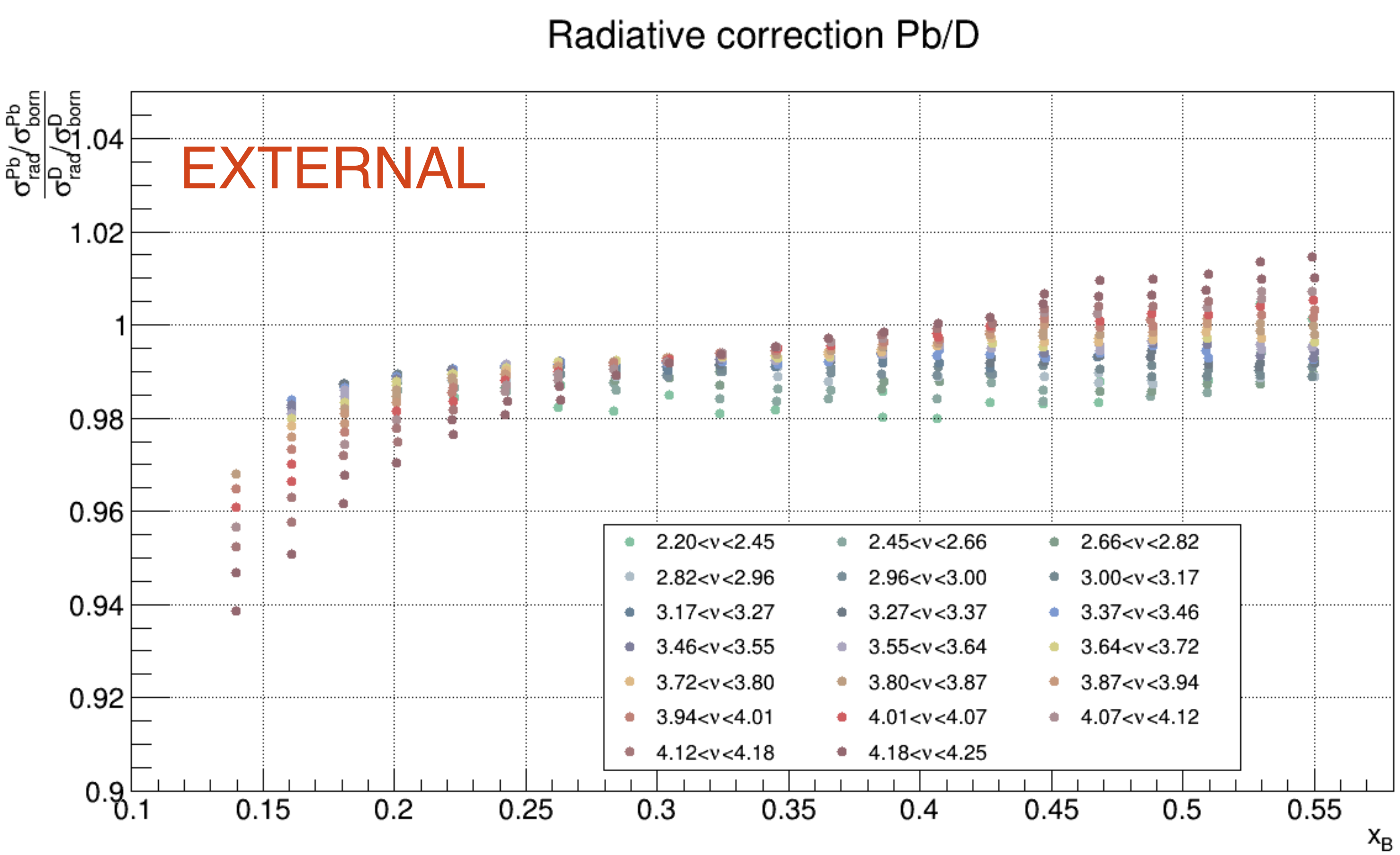


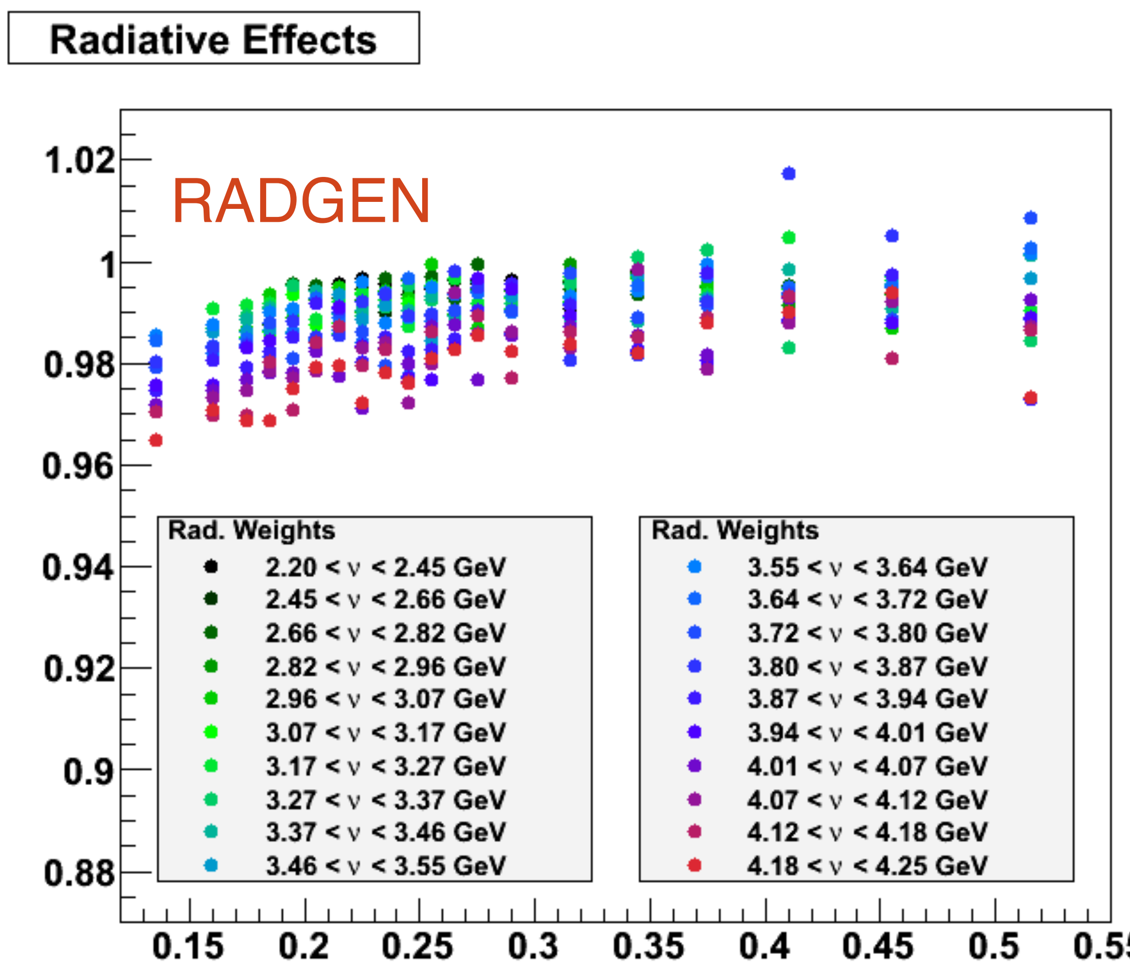
Consensus on electron radiative corrections

- Inclusive electron RC are now calculated with EXTERNAL code for all three pion analysis
- Charged pion analysis carried by Raphael Dupré previously used RADGEN

Comparison of $(\delta_{RC})_{Pb}/(\delta_{RC})_D$ between two codes, in bins of ν (color) vs x_B

Note: EXTERNALS does exact calculations, while RADGEN is based on MC and has statistical fluctuations





The average difference between EXTERNAL and RADGEN over all bins is 0.75%

π^0 analysis status update (2):

systematic uncertainties

Taisiya Mineeva

Summary table of the current status on systematic uncertainties

Systematic uncertainty	$\Delta^{C}_{RMS}(\%)$	Δ^{Fe}_{RMS} (%)	Δ^{Pb}_{RMS} (%)	
Normalization type				
Target vertex cut	0.5	0.5	0.5	MIGHT CHANGE
Target leakage	0.9	0.9	0.9	
Sampling fraction cut	0.4	0.4	0.4	
Photon energy cutoff	2.1	2.1	2.2	
EC time (beta) cut	0.6	0.6	0.6	NEW
DC fiducial cuts	1.3	1.3	1.3	
Electron radiative corrections	3.3	3.3	3.3	NEW
SIDIS radiative corrections				REMAINING
Bin-by-bin basis				
Background shape	0.6	0.5	0.8	
Signal shape	2.1	2.1	4.5	
Acceptance in finite bin width	2.8	2.8	2.8	
Total in (ν, z, p_T^2)	5.6	5.6	6.9	