Charge Symmetry Violation (CSV) in Quark Distributions Using Semi-Inclusive Deep Inelastic Scattering (SIDIS)

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MISSISSIPPI STATE UNIVERSITY

Jefferson Lab
EXPLORING THE NATURE OF MATTER

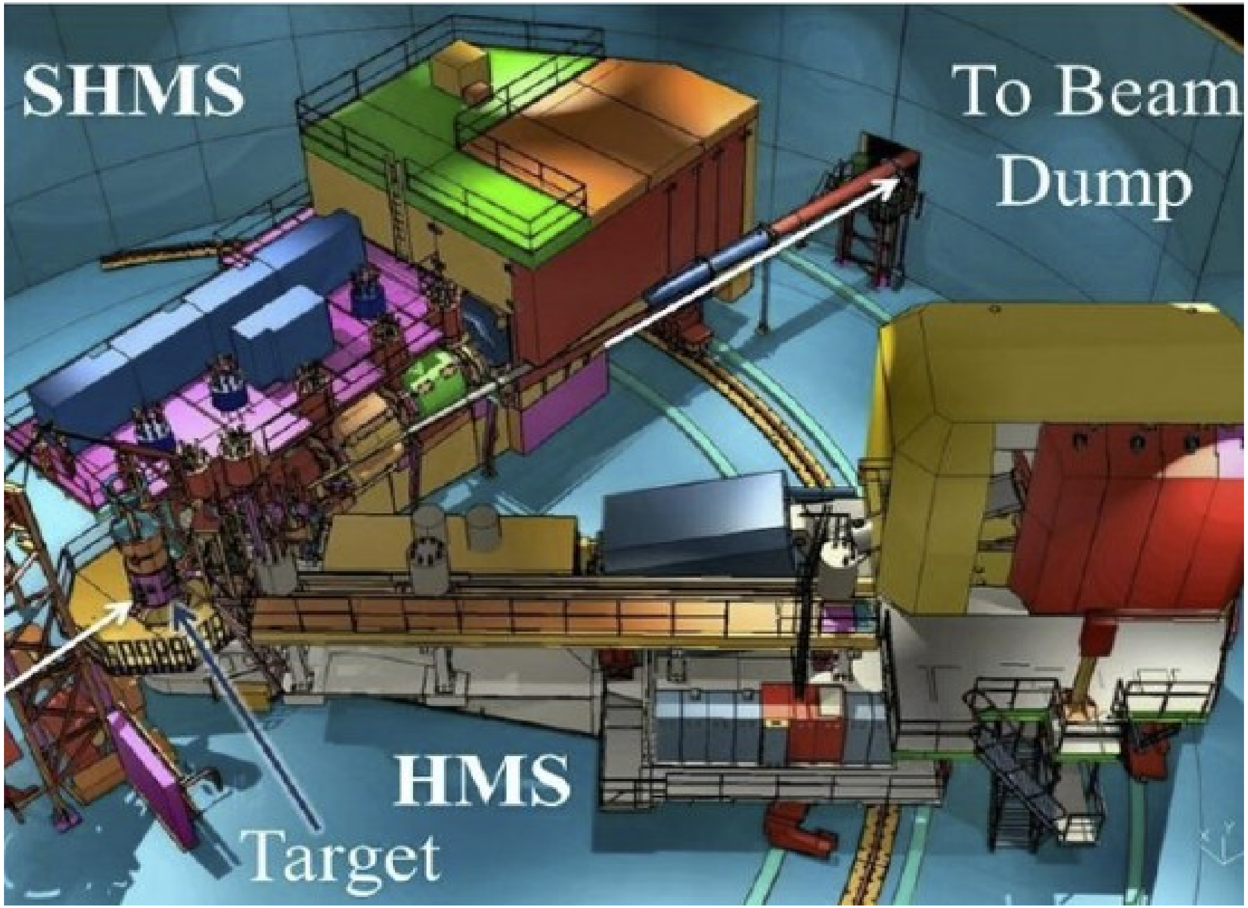
Outline

Physics Motivation

Measurement of CSV

Current Status of Data Analysis

Summary



Introduction

Charge Symmetry (CS):

Charge symmetry is a form of isospin symmetry which involves a rotation of 180° about the "2" axis in isospin space.

In Nuclei: protons and neutrons have similar properties:

nn = pp = np (identical interactions)

$M_p \approx M_n$ (1%)

After electromagnetic corrections, charge symmetry is valid to within 1%.

At the quark level: CS implies the invariance of a system under the interchange of up and down quarks while simultaneously interchanging protons and neutrons.

$$u^p(x,Q^2) = d^n(x,Q^2)$$
$$d^p(x,Q_2) = u^n(x,Q^2)$$

Charge Symmetry Violation (CSV):

CSV is due to:

(1) $\delta m = m_d - m_u$

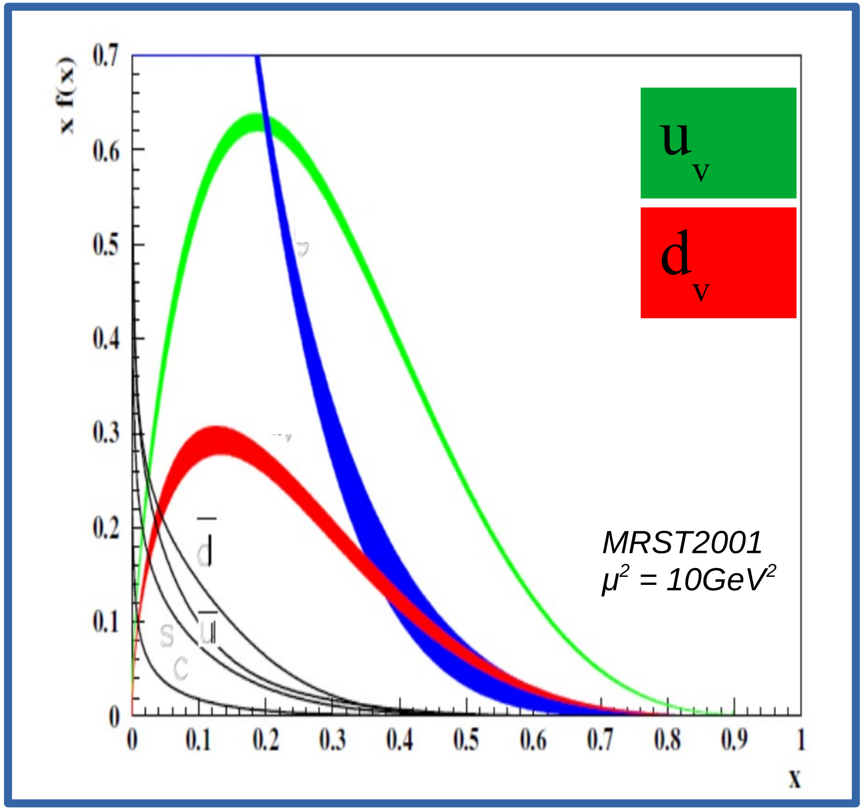
(2) Electromagnetic Interaction between the quarks

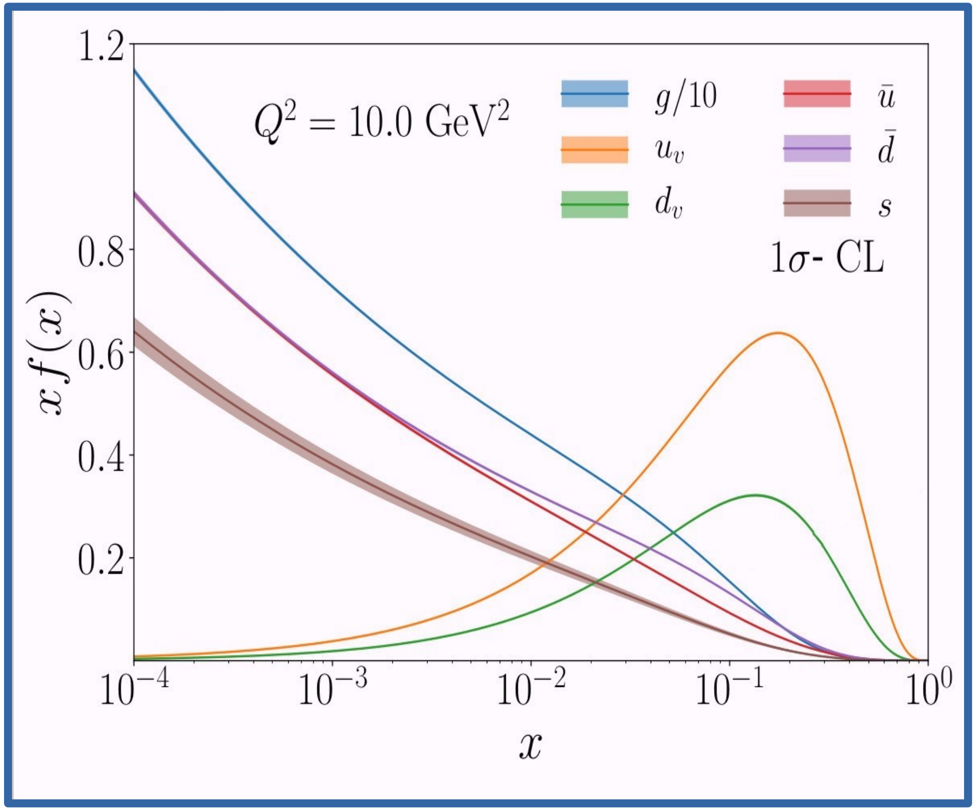
Of these two causes, the significant contribution to CSV is due the mass difference between the quarks.

For partonic systems, CSV = $\delta m / \langle M \rangle$ where, $\langle M \rangle$ = average expectation value of strong Hamiltonian, with a value roughly 0.5-1.0 GeV => CSV effect of about 1%.

PDFs extracted from fits of the global data

$x\,f(x)$





PDFs extracted from fits to DIS data

A.D. Martin, R.G. Roberts, W.J. Stirling and R.S. Thorne, Eur. Phys. J. C28 (2003) 455.

The uncertainty in the PDF distributions extracted from world data by the MRST group was used to obtain the limits on the CSV of the PDFs allowed by these uncertainties.

Unpolarized PDFs (preliminary)

Talk: Carlota A., JAM Colaboration-2018 Jlab Users Group Meeting

More recent PDF extraction, obtained from the world data

Theoretical Limits on CSV

The charge symmetry violating quark distributions are defined by:

$$\delta d_v(x) = d^p(x) - u^n(x) \text{ and}$$

$$\delta u_v(x) = u^p(x) - d^n(x)$$

$$C(x) = \delta d_v - \delta u_v \, (CSV)$$

Model by Sather:

$\delta d_v(x) \sim$ 2-3 % and

$\delta u_v(x) \sim 1\%$

Model by Rodionov, Thomas and Londergan

$\delta d_v(x)$ could reach upto 10% at high x

(including quark transverse momentum, which was neglected by Sather)

E. Sather, Phys. Lett. B274, 433 (1992)

E. N. Rodionov, A. W. Thomas and J. T. Londergan, Mod. Phys. Lett. A 9, 1799 (1994)

Phenomenological Limits on CSV

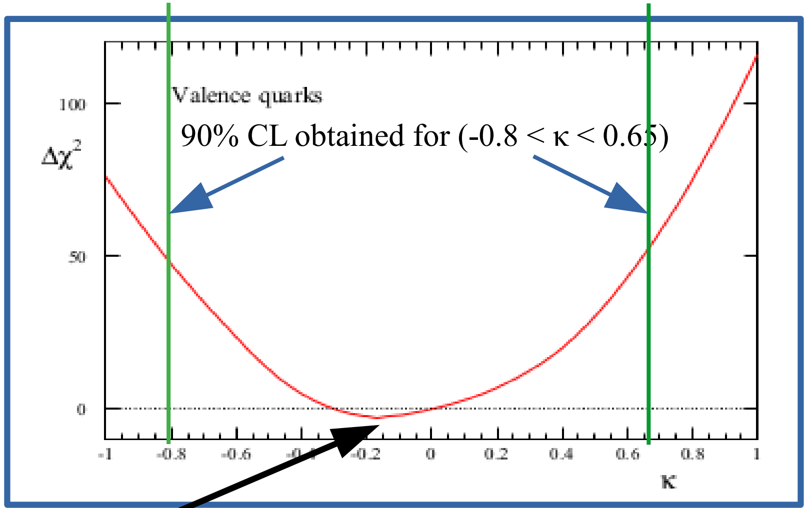
Using the uncertainties in PDFs studied by MRST Group, CSV was parameterized using the functional form:

$\delta u_v = -\delta d_v = \kappa(1-x)^4\, x^{-0.5}\,(x-0.0909)$, where $\delta d_v(x) = d^p(x) - u^n(x)$ and $\delta u_v(x) = u^p(x) - d^n(x)$

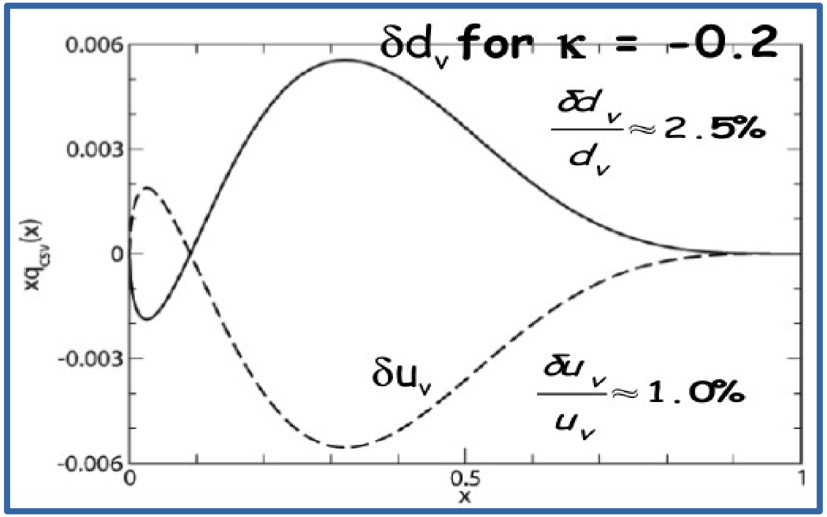
The functional form must also satisfy the normalization conditions:

$$\int_0^1 dx\,\delta d_v(x) = \int_0^1 dx\,\delta u_v(x) = 0$$

The global fit of the PDF data including CSV while varying κ



Best fit obtained for κ = -0.2



$\delta d_v(x)$ and $\delta u_v(x)$ distributions for the best fit including CSV

(Eur. Phys. J.35(2004)325)

However, considering the uncertainty in the existing PDF data, at the 2- sigma level, allows upto 9% of CSV.

NuTeV anomaly and CSV

In 2001 NuTeV collaboration, using ν DIS, measured:

$\sin^2\theta_W = 0.2277 \pm 0.0013(\text{stat}) \pm 0.0009(\text{syst})$

G. P. Zeller et al. Phys. Rev. Lett. 88, 09. 02)

World average (not including NuTeV):

$\sin^2\theta_W = 0.2227 \pm 0.0037$

D. Abbaneo et al., , CERN Report CERN-EP/2001-098, arXiv:hep-ex/0112021.

3 σ discrepancy!!! ⇒ "NuTeV anomaly"

CSV corrections reduces anomaly by about ∼30% (1σ)

J.T.Londergan, Possible Explanations for The NuTeV Weinberg Angle Measurement

https://arxiv.org/pdf/hep-ph/0408243.pdf

Talk: Ian C. : INT Program: Low Energy Precision Electroweak Physics in the LHC Era, 4th Nov, 2008

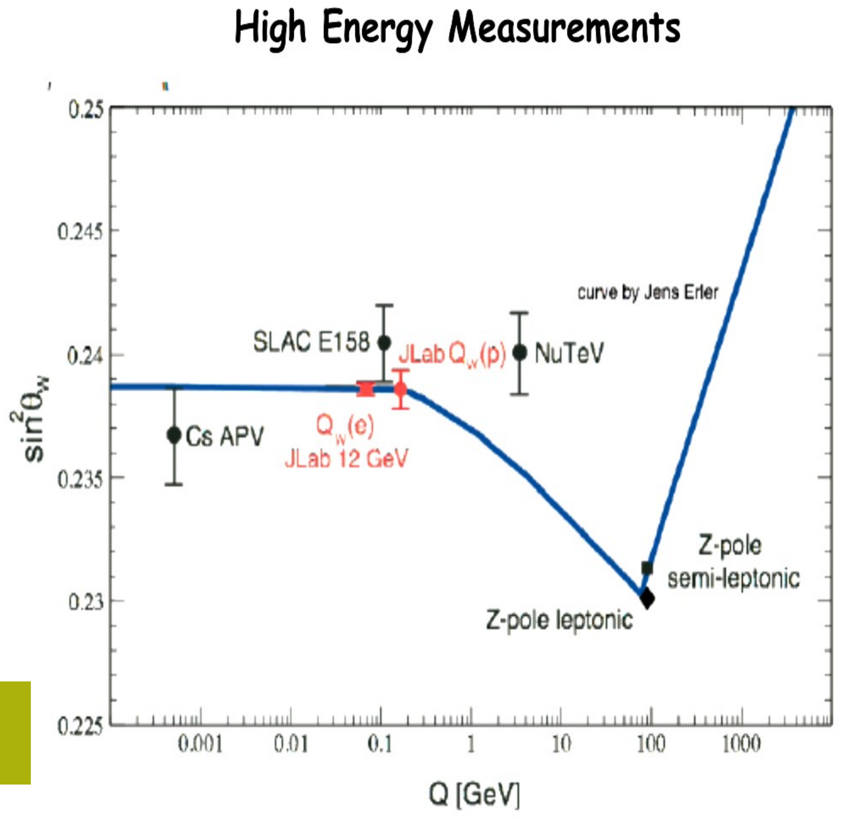


Fig: $\sin^2\theta_W$ vs Q

Motivations for Direct Measurement of CSV

- Charge symmetry has been universally assumed in extracting PDFs but never been tested experimentally. So, we want to test it experimentally.

- CSV measurements are important on their own as a further step in studying the inner structure of the nucleon.

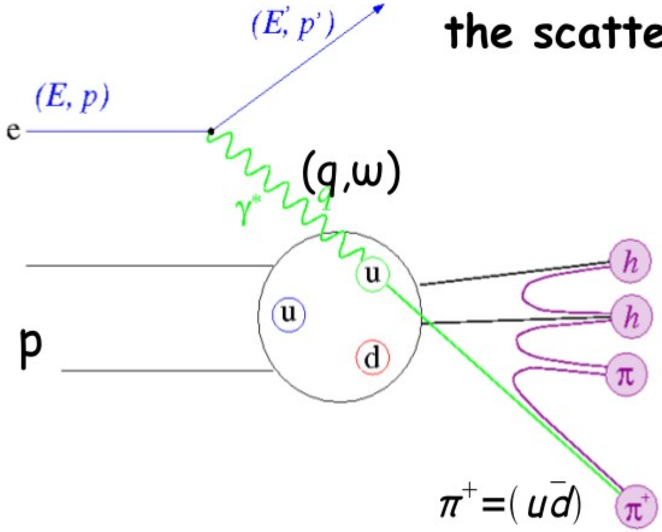
- CSV could be an explanation for the anomalous value of the Weinberg angle extracted by NuTeV experiment.

- Extraction of Flavor symmetry violation [$\bar{u}^p(x) \neq \bar{d}^p(x)$] is based on the assumptions of charge symmetry in sea quarks.

Semi-Inclusive Deep Inelastic Scattering

Semi-inclusive DIS

the scattered electron is detected



Tags the struck quark (flavor tagging)

When u quark is struck:	π^+ is favored
When d quark is struck:	π^- is favored

at least one hadron is detected in coincidence

Few kinematic Quantities :

x = $Q^2 / 2M_p\nu$: Fraction of proton's momentum carried by the quark

M_p = mass of proton

ν = energy Transfer in lab frame

Q^2 = 4 momentum transfer squared

z = fraction of energy transfer carried by outgoing hadron (pion)

Formalism by Londergan, Pang and Thomas PRD54, 3154 (1996)

Get this ratio :

$R_Y(x,z)$ = Yield ratio = $Y_{\pi+}(x,z) / Y_{\pi -}(x,z)$: from the data

$$R^D_{Meas}(x,z) = (4 - R_Y(x,z)) / (R_Y(x,z)-1)$$

$$R(x,z) = (5/2) + R^D_{Meas}(x, z)$$

$$\mathbf{D(z)\, R(x,z) + A(x)\, C(x) = B(x,z)}$$

Goal: By using the measured yield ratio of Pi+ over Pi- for different Q^2 at various x and z, we will extract **C(x)** and **D(z).**

D(z) = Function of ratio of fragmentation function

$R(x,z) = (5/2) + R^D_{Meas}(x, z)$: from Experiment

A(x) = Function of Valence quark PDFs (known)

C(x) = CSV parameter = $\delta d_v - \delta u_v$

B(x,z) = Function of sea quark PDFs (known from the Global Fit)

Formalism by Londergan, Pang and Thomas PRD54, 3154 (1996)

$$\Delta(z) = D_u^{\pi^-} / D_u^{\pi^+}$$

$$D(z) = \frac{1 - \Delta(z)}{1 + \Delta(z)}$$

where Δ(z) is the ratio of the unfavored to the favored quark fragmentation functions;

$$A(x) = \left[\frac{-4}{3(u_v(x) + d_v(x))}\right]$$

$$B(x,z) = \frac{5}{2} + \frac{5\left[\bar{u}(x) + \bar{d}(x)\right]}{u_v(x) + d_v(x)} + \frac{\Delta_s(z)\left[s(x) + \bar{s}(x)\right] / \left[1 + \Delta(z)\right]}{u_v(x) + d_v(x)}$$

$$R(x,z) = (5/2) + R^D_{Meas}(x, z)$$

$$C(x) = \text{CSV parameter} = \delta d_v - \delta u_v$$

$$\boxed{D(z)\, R(x,z) + A(x)\, C(x) = B(x,z)}$$

10.6 GeV Jefferson Lab Hallc- Experiment: E12-09-002

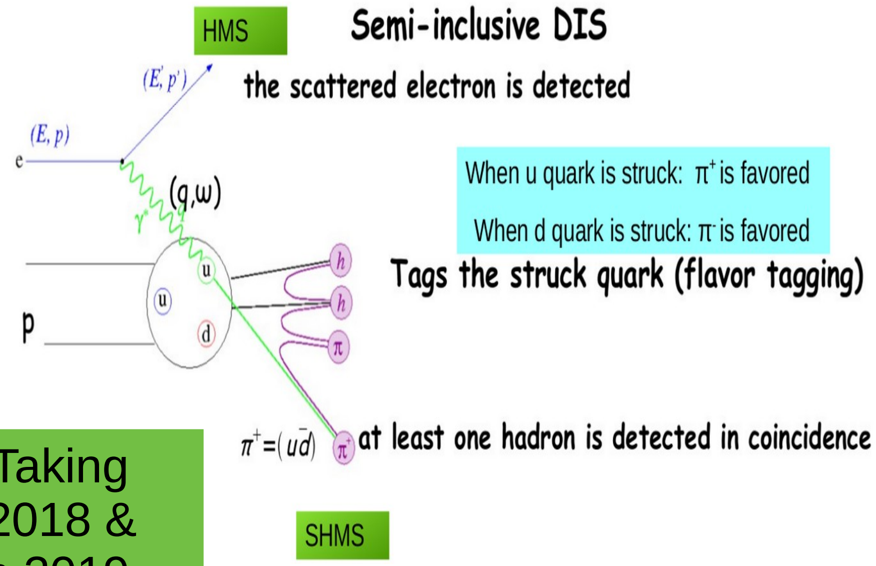
Precise Measurement of pi+/pi- Ratios in Semi-inclusive Deep Inelastic Scattering

Kinematics :

Q^2	x	z
3.9 – 4.0	0.35 – 0.5	0.4 – 0.7
4.75 – 5.0	0.45 – 0.6	0.4 – 0.7
5.50	0.5 – 0.65	0.4 – 0.7

- Target : LH2, LD2 and Al Dummy
- HMS Angle = 13 - 21 Degrees
- SHMS Angle = 11 - 21 Degrees
- HMS P = 4.4 - 6.4 GeV/c (electrons)
- SHMS P = 1.7 - 4.5 GeV/c (pi + and pi -)

Data Taking Nov. 2018 & March 2019.



We used the isoscalar target (LD2) to extract CSV distribution, LH2 target for cross-section measurement and factorization test and Al dummy target to subtract the contribution from the target walls.

Analysis Workflow

Reference time and timing window
Detector Calibration

- **Calorimeter**
- **Drift Chamber**
- **Cherenkov**
- **Hodoscope**
- **BCM**

Efficiency Studies

- **Tracking Efficiency**
- **Trigger Efficiency**
- **Computer Dead Time**
- **Calorimeter and Cherenkov Efficiency**
- **Yield Ratio of Pi+ and Pi- with accidental subtraction, dummy subtraction and efficiency correction**

Comparison of extracted Yield with simulation

Acceptance study

Correction/Uncertainty from Diffractive ρ^0 production

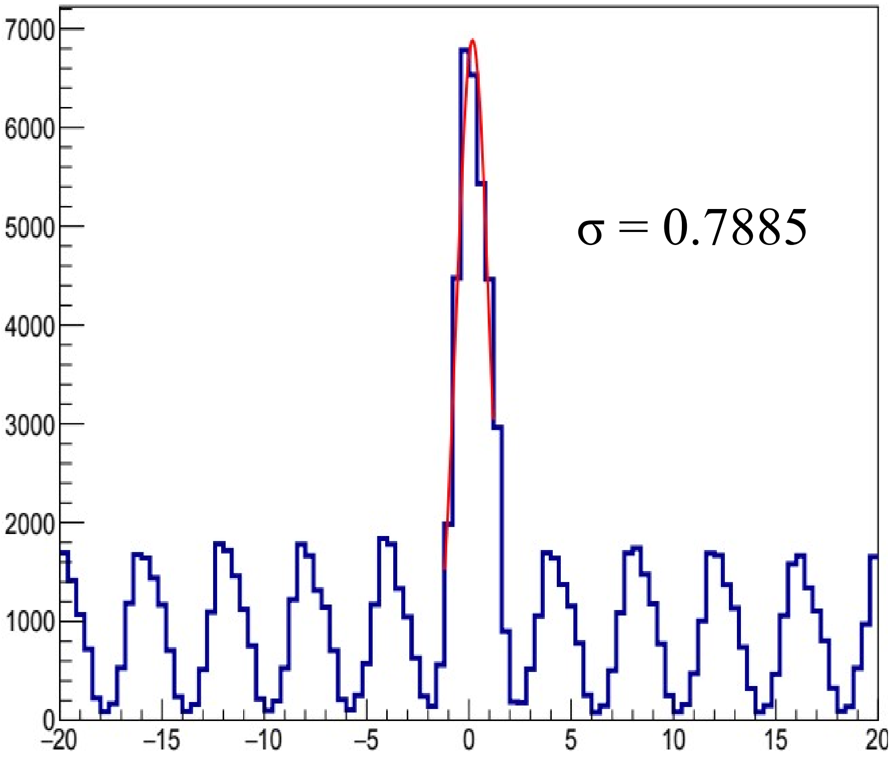
Uncertainty from radiative correction

Extraction of **C(x)** and **D(z)** using the yield **ratio** from the full grid of x, z for various Q^2 (x,z).

Factorization Test [H2 data]
Cross-section extraction

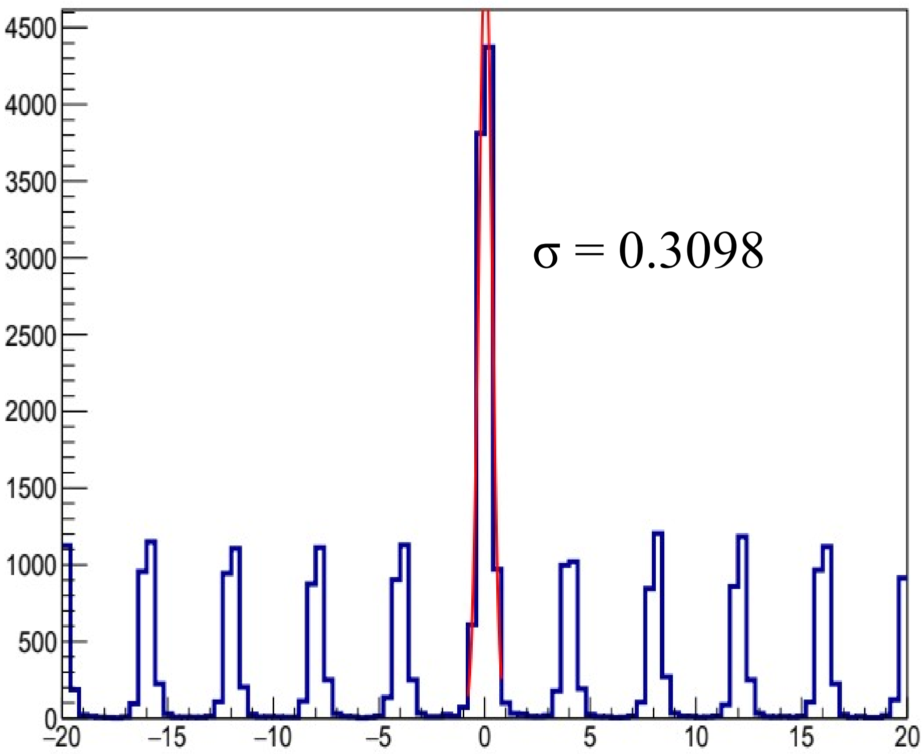
We detect charged pions in SHMS in coincidence with electrons in HMS

Fall 2018



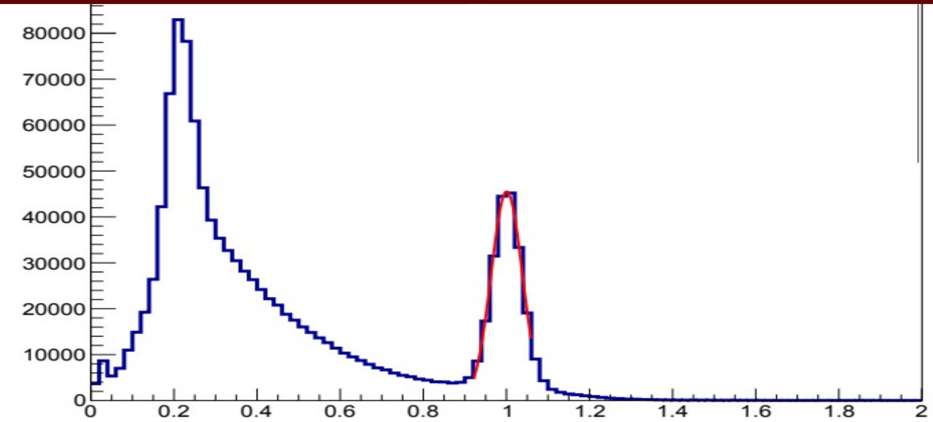
Coincidence time (ns)

Spring 2019

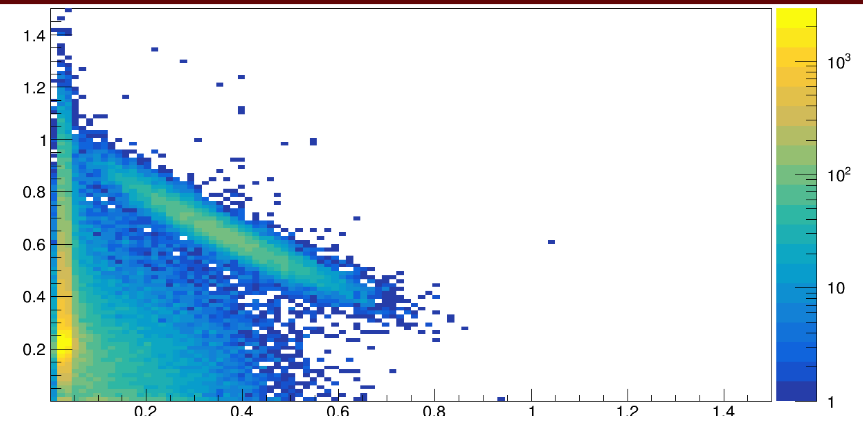


Coincidence time (ns)

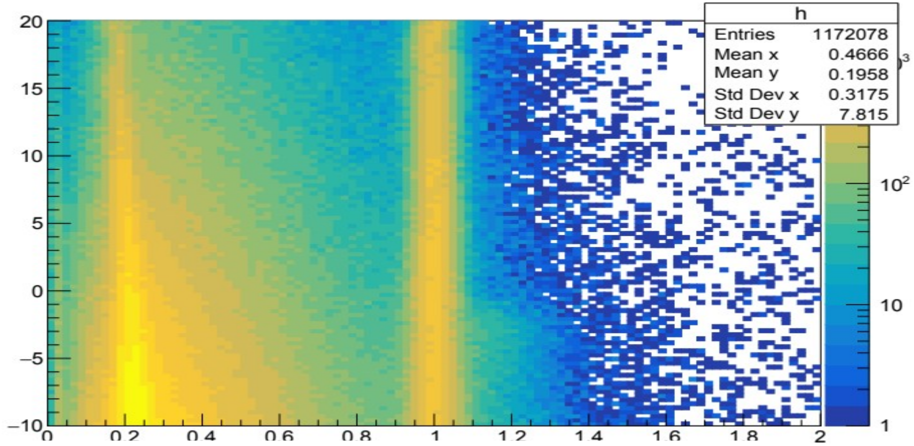
SHMS Calorimeter Calibration



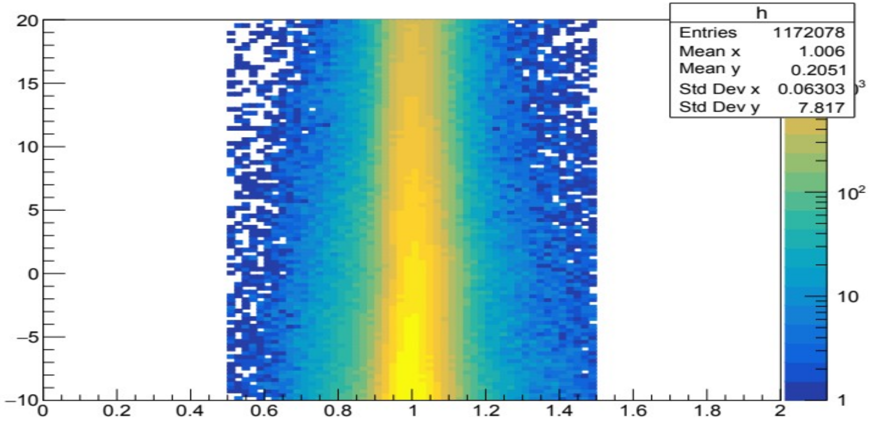
E/P



Shower vs preshower



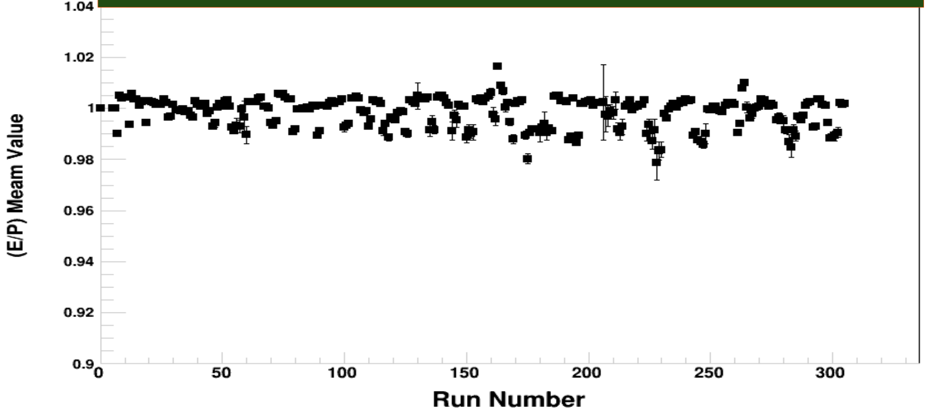
SHMS Delta vs E/P



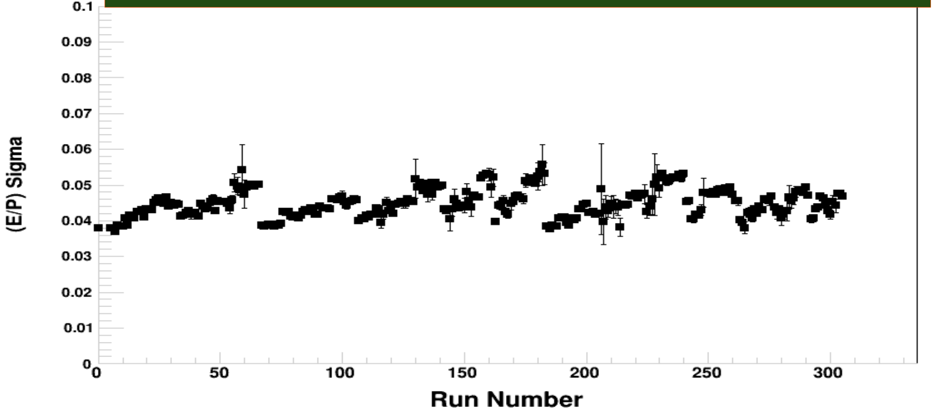
SHMS Delta vs Beta

Calorimeter Calibration Results

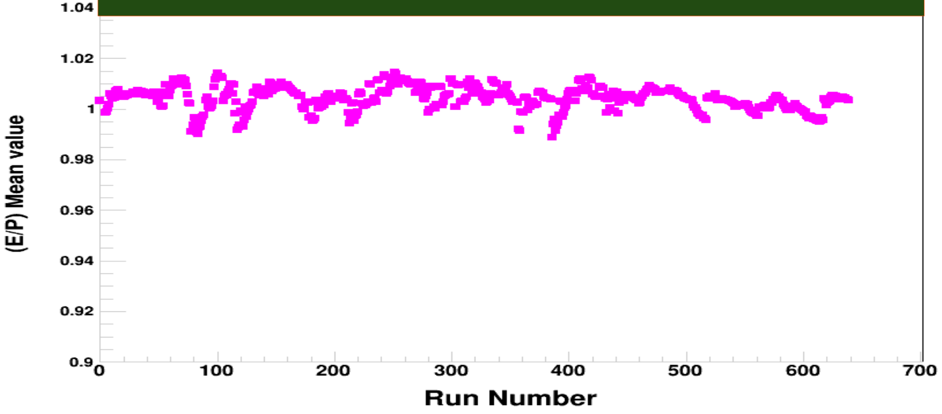
SHMS CAL E/P, Mean vs Run Num.



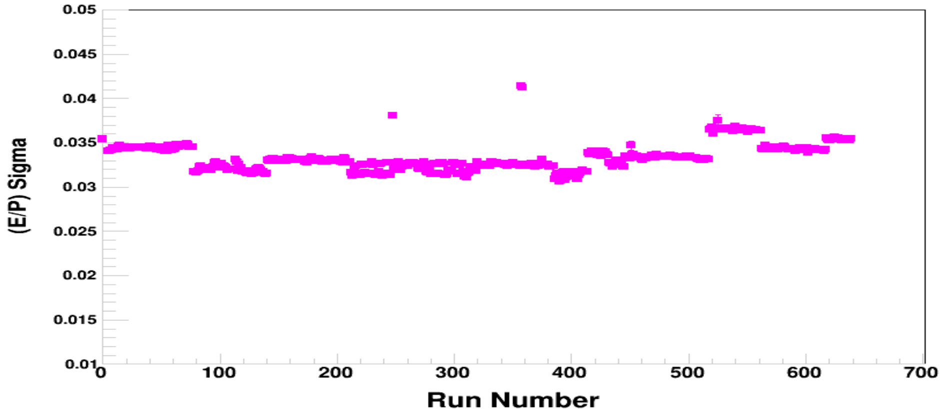
SHMS CAL E/P, sigma vs Run Num.



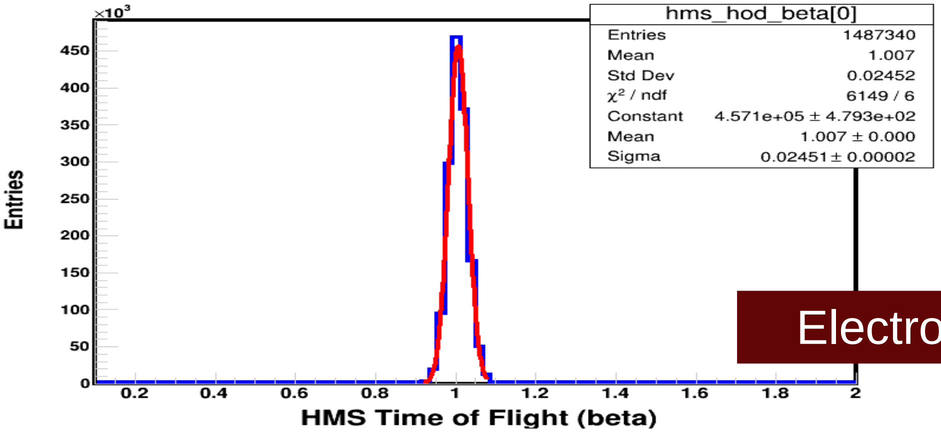
HMS CAL E/P, Mean vs Run Num.

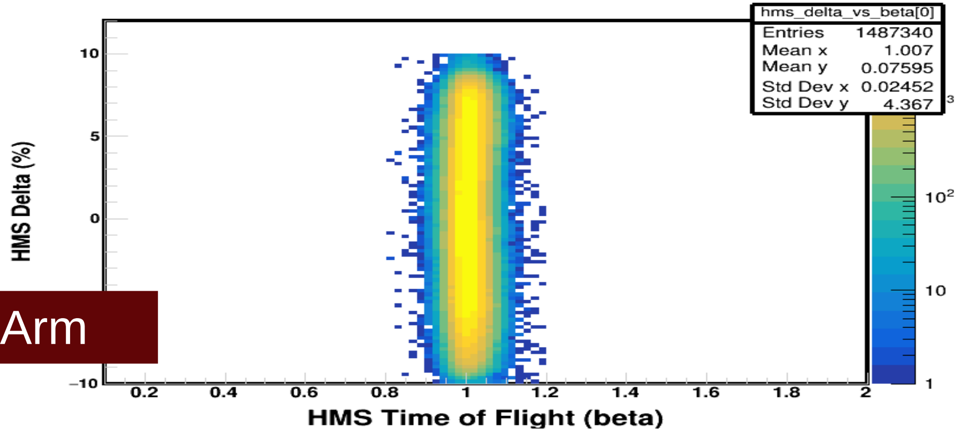


HMS CAL E/P, sigma vs Run Num.

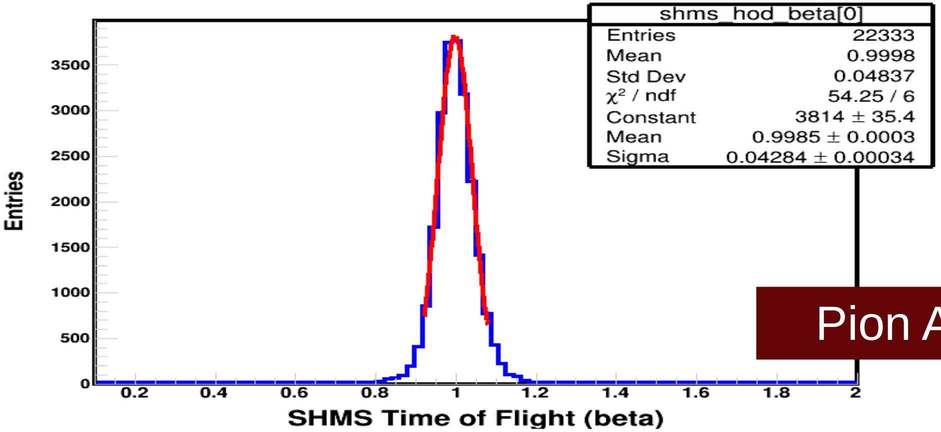


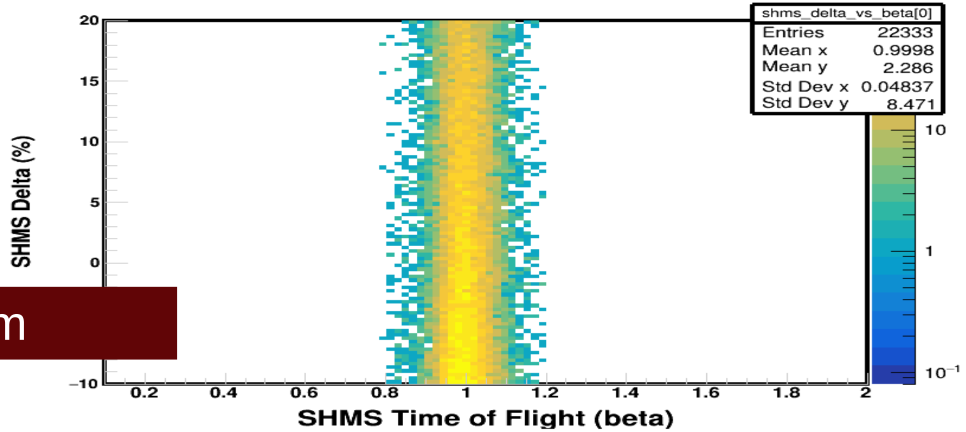
Time of Flight (Beta) Calibration Results





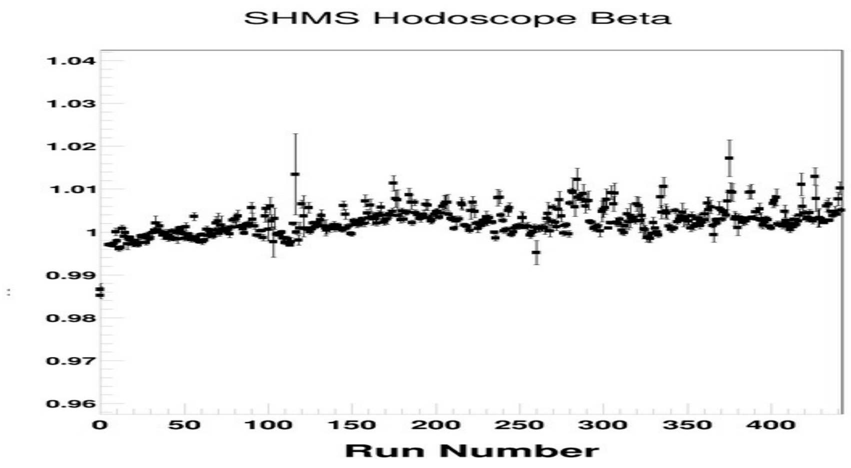
Electron Arm

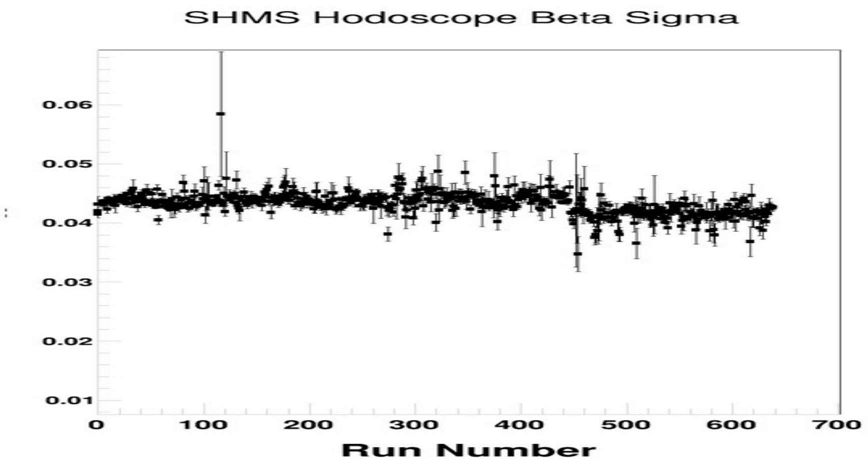


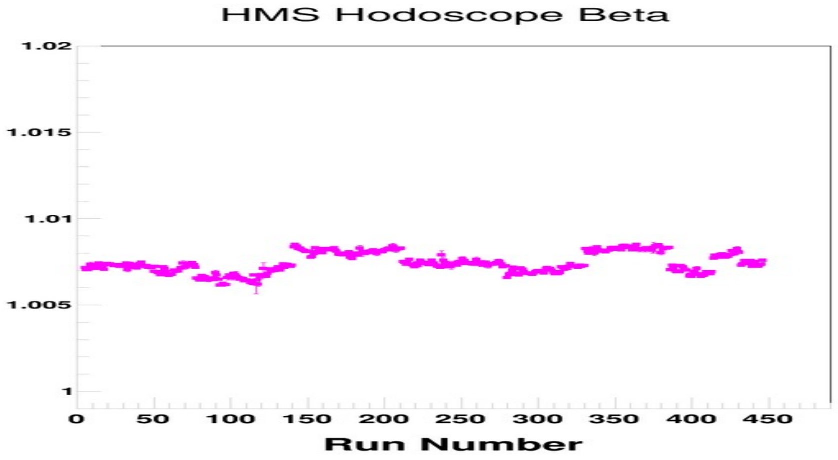


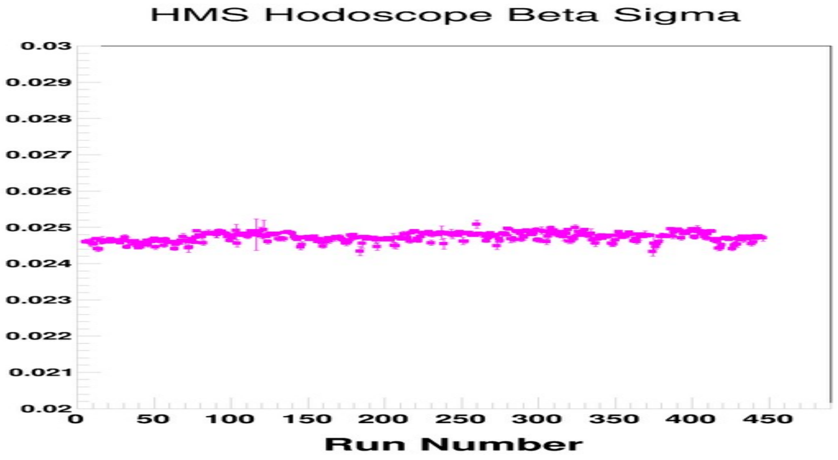
Pion Arm

Time of Flight (Beta) Calibration Results

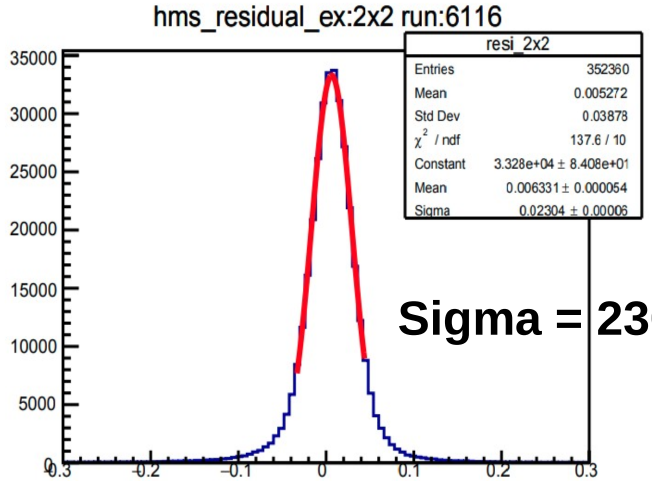




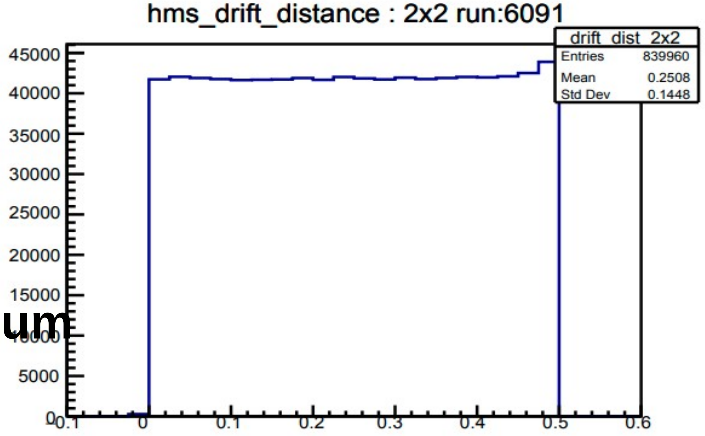


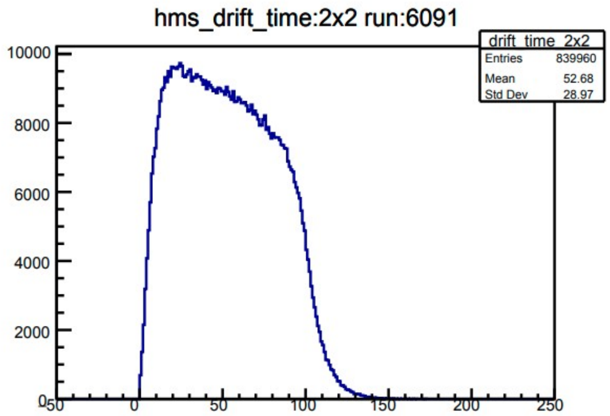


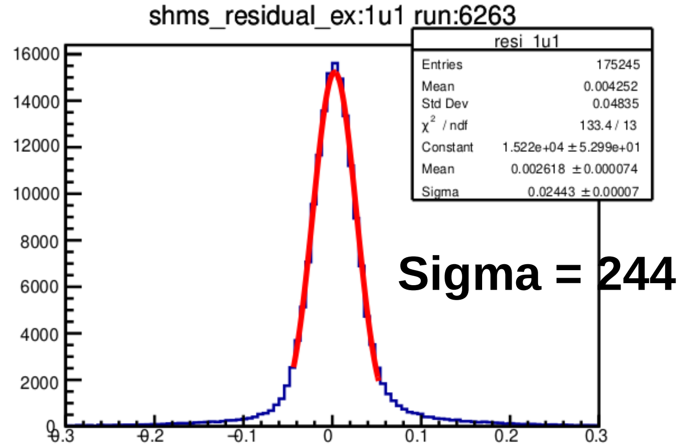
Drift Chamber Calibration



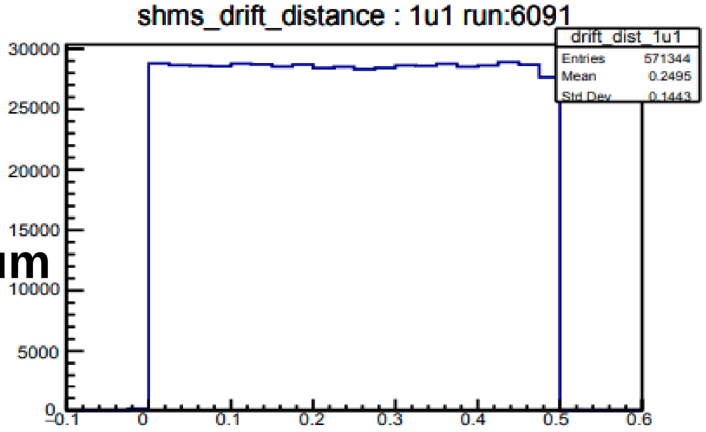
Sigma = 230 um

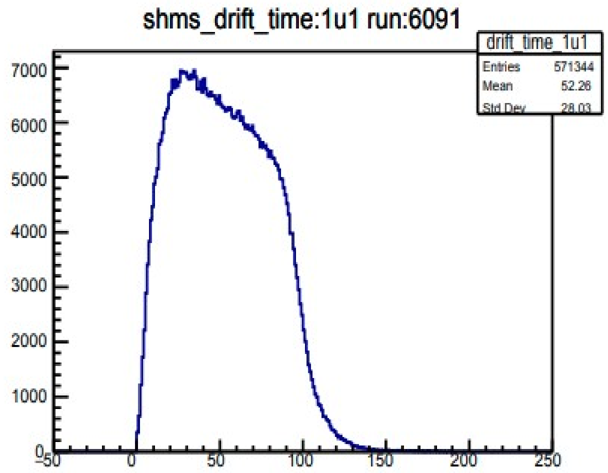




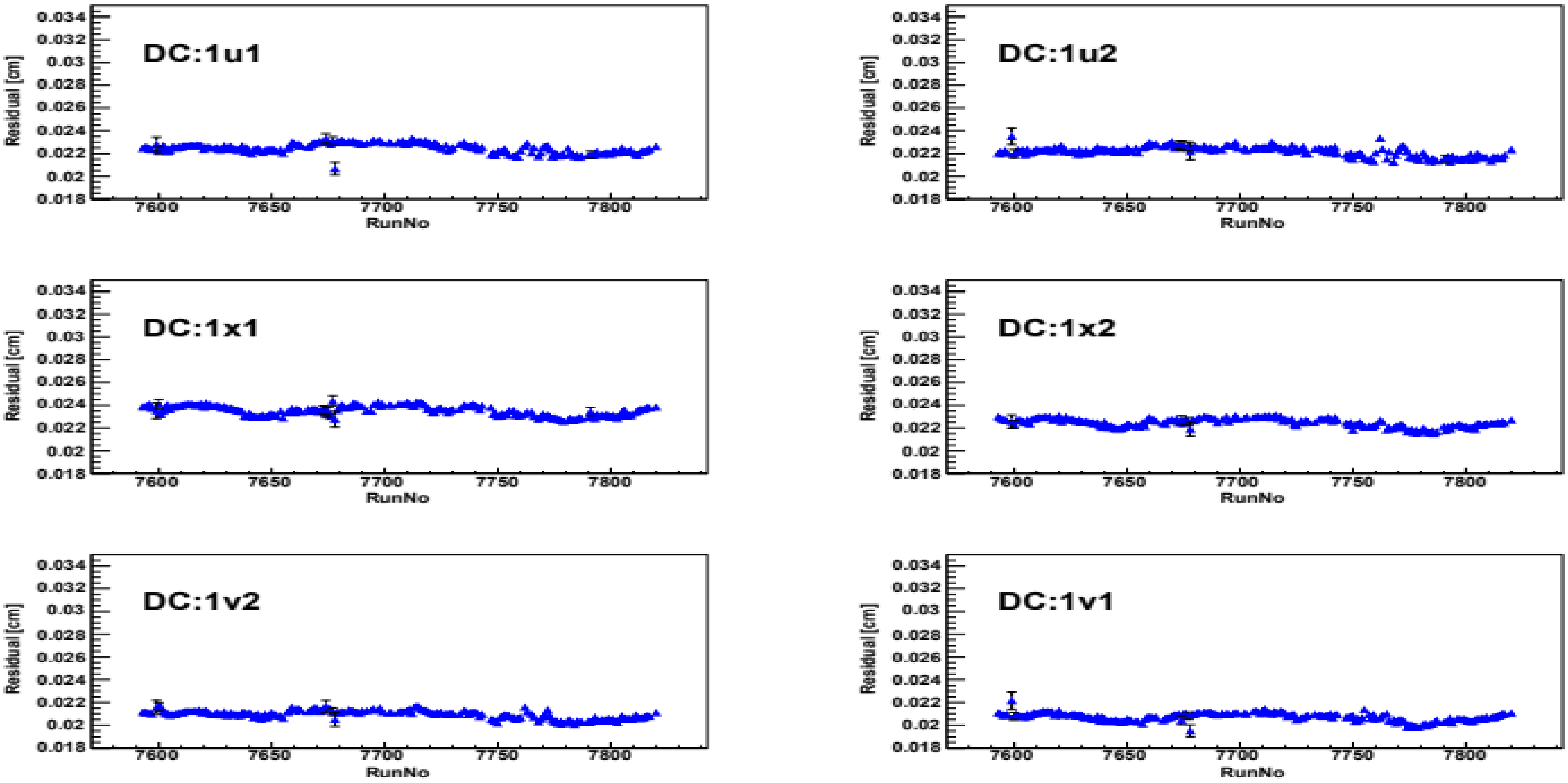


Sigma = 244 um



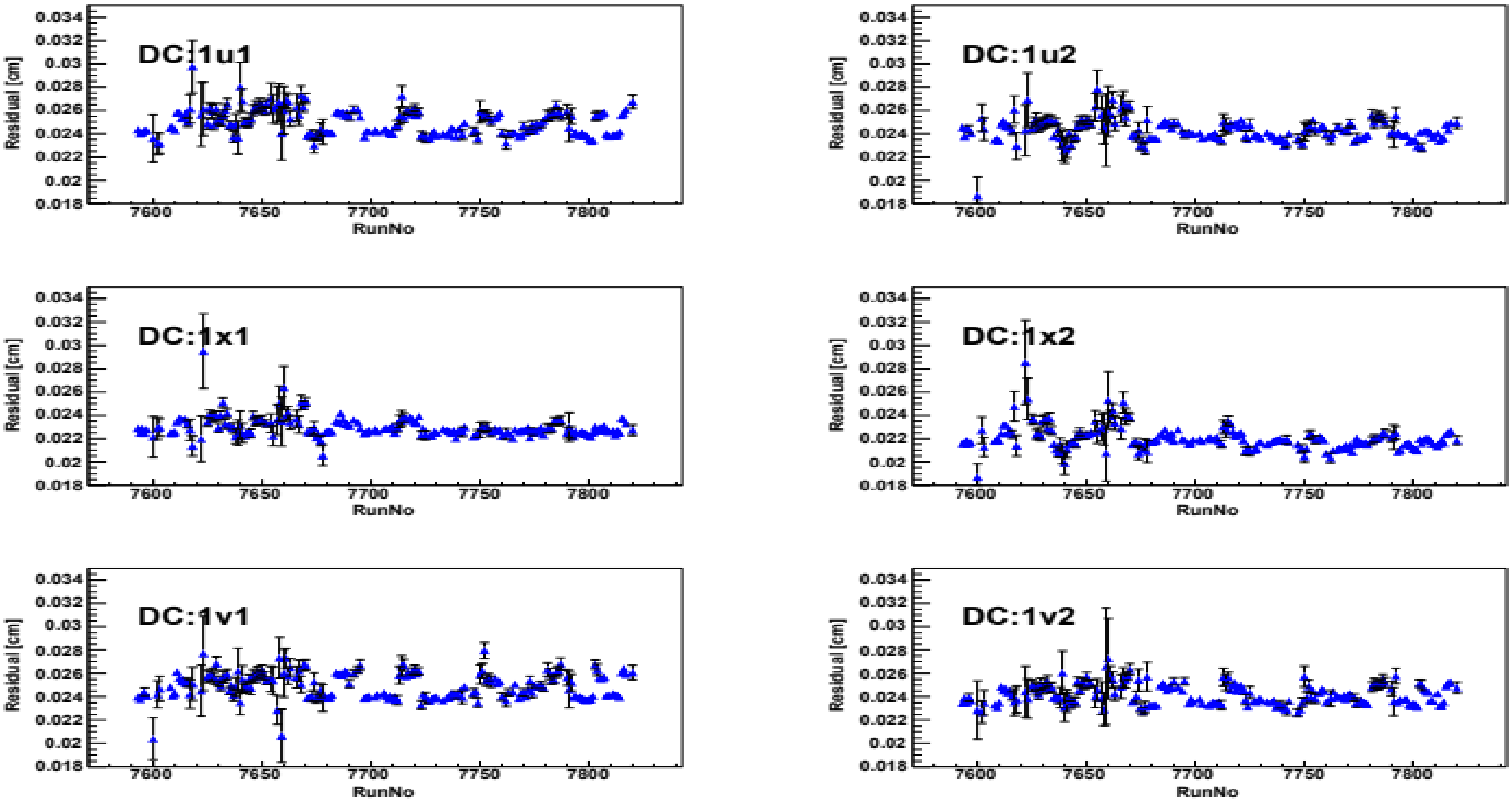


Drift Chamber Calibration: Residuals per plane HMS DC1



< 250 μm for all the HMS planes

Drift Chamber Calibration: Residuals per plane SHMS DC1



< 300 µm for all the SHMS planes

Tracking Efficiency

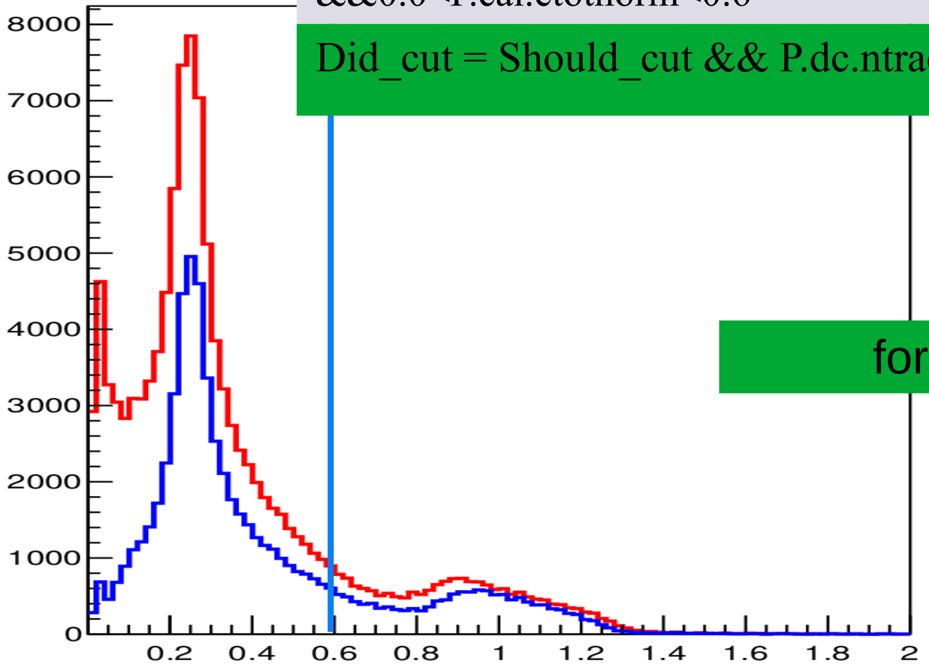
It is the ratio of number of tracked events to the number of events for which we expect to have a real track.

Tracking Efficiency = events passed through did cut / events passed through should cut

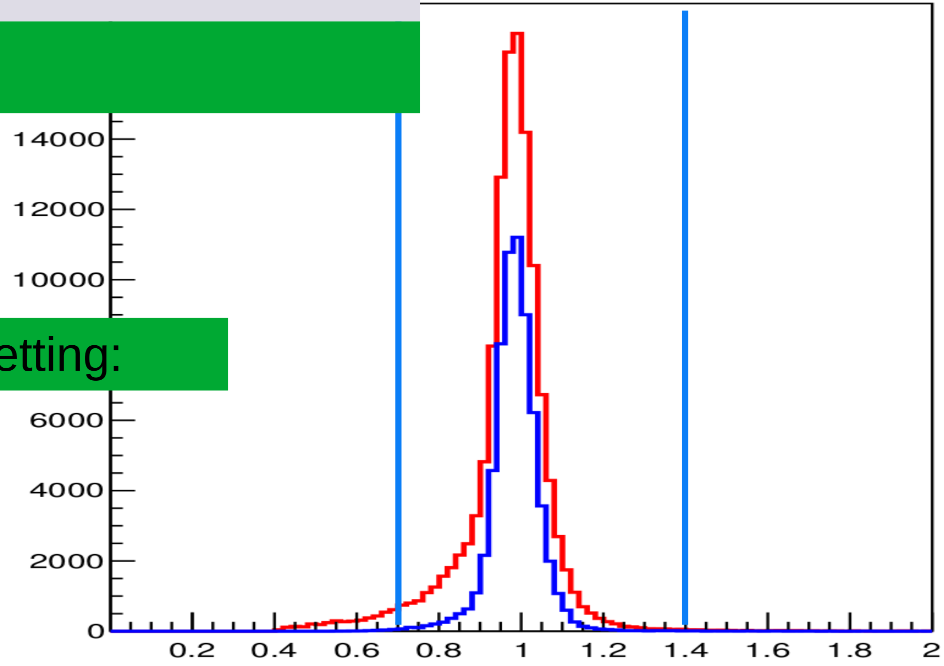
Should_cut =
P.hod.goodscinhit==1 && 0.7 < P.hod.betanotrack < 1.4
&&0.0<P.cal.etotnorm<0.6

Did_cut = Should_cut && P.dc.ntrack>0.0

for pi- Setting:



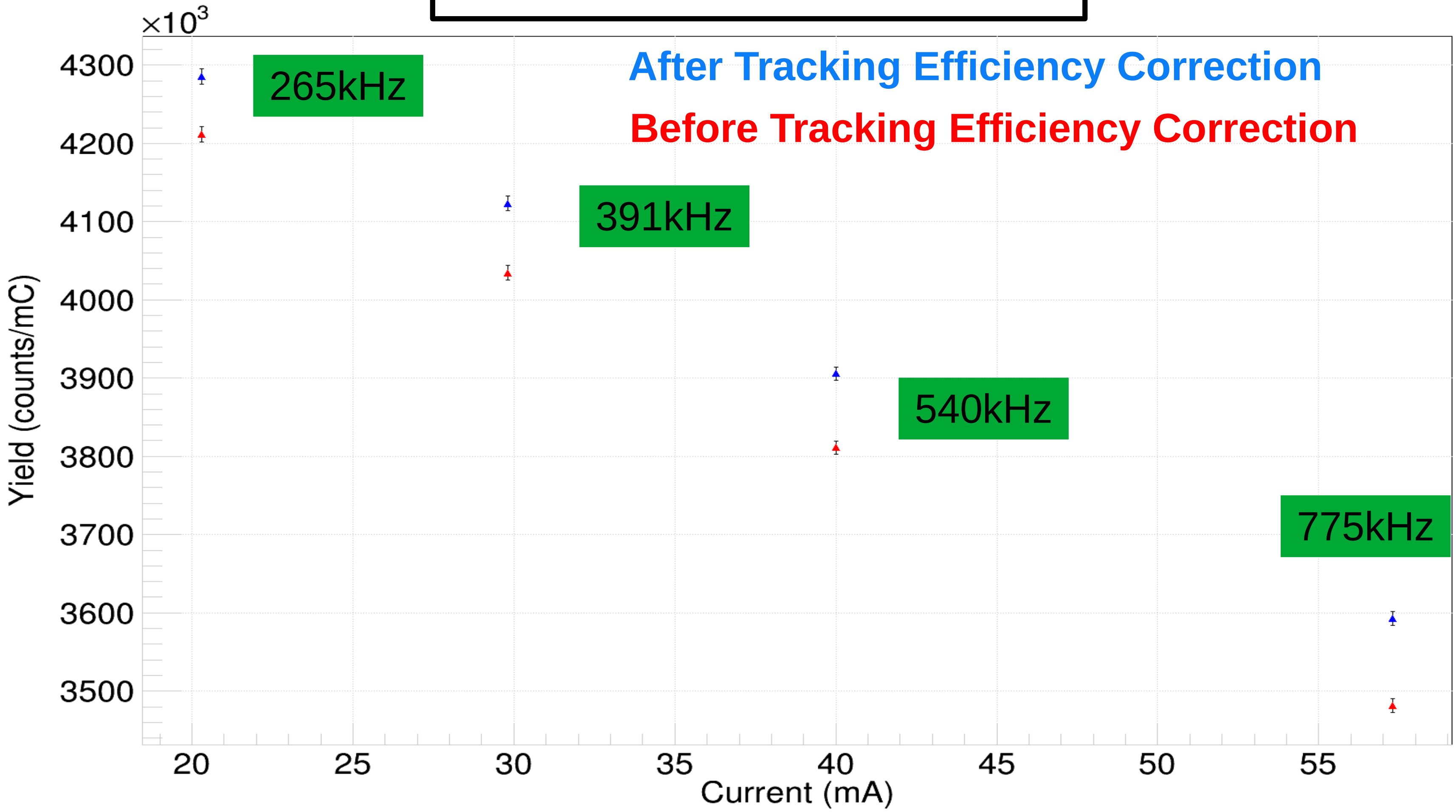
P.cal.etotnorm:
no cuts **P.hod.goodscinhit==1**



P.hod.betanotrack:
no cuts **P.hod.goodscinhit==1**

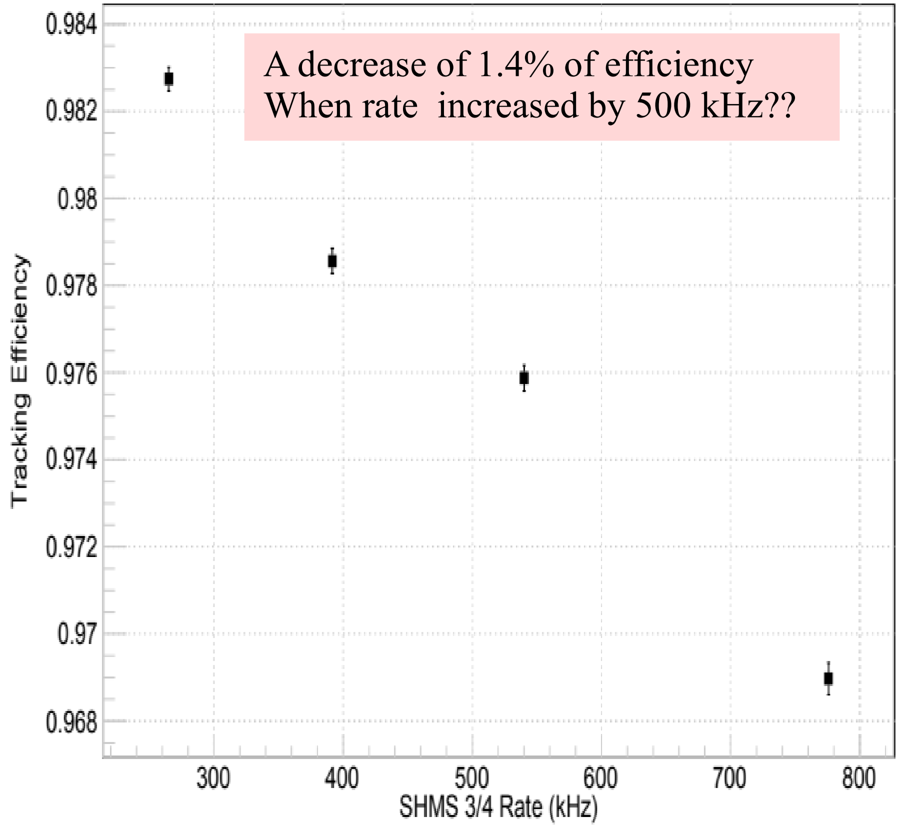
Charge Normalized Yield vs Current for Electron Singles Run

Electron Singles, p = -7GeV, angle 15.6, LD2,



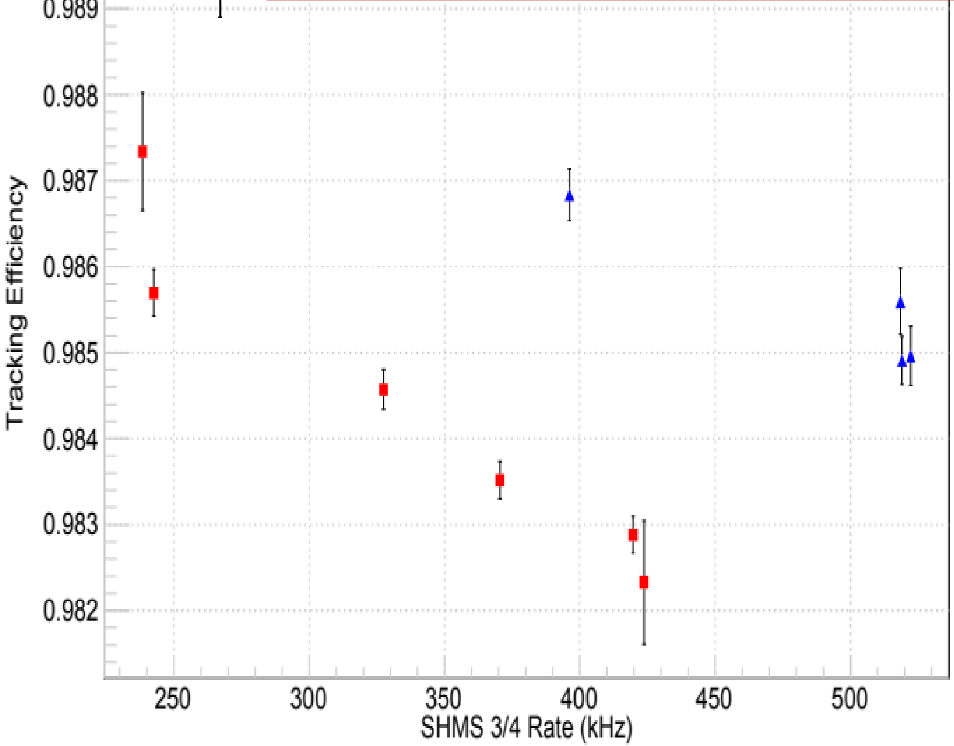
Tracking Efficiency (SHMS) vs ¾ Rate

Electron Singles, p = -7GeV, angle 15.6, LD2,



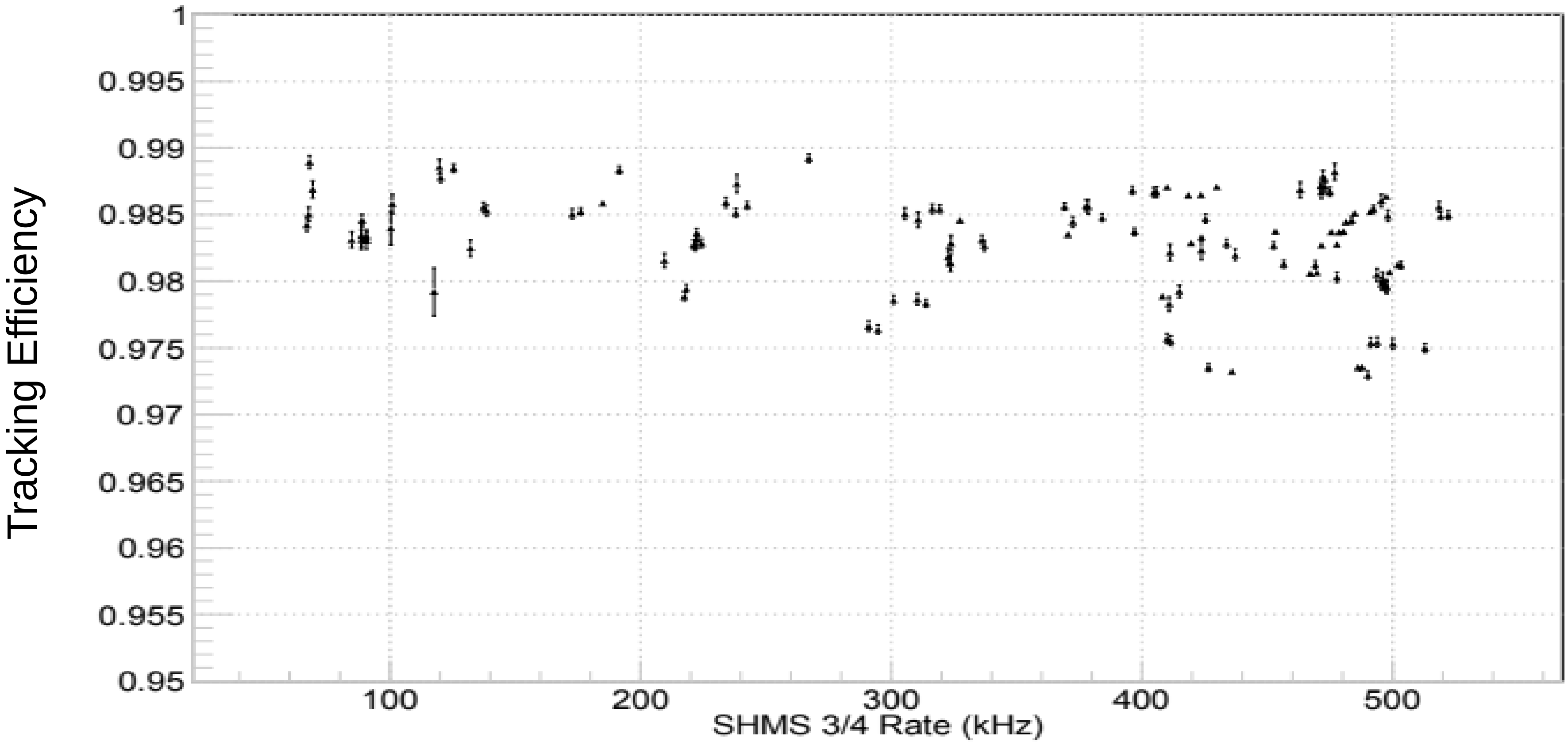
Pi+ , P = +3.1GeV, angle = 15.6 deg, LD2

Pi- , P = -3.1GeV, angle = 15.6 deg, LD2

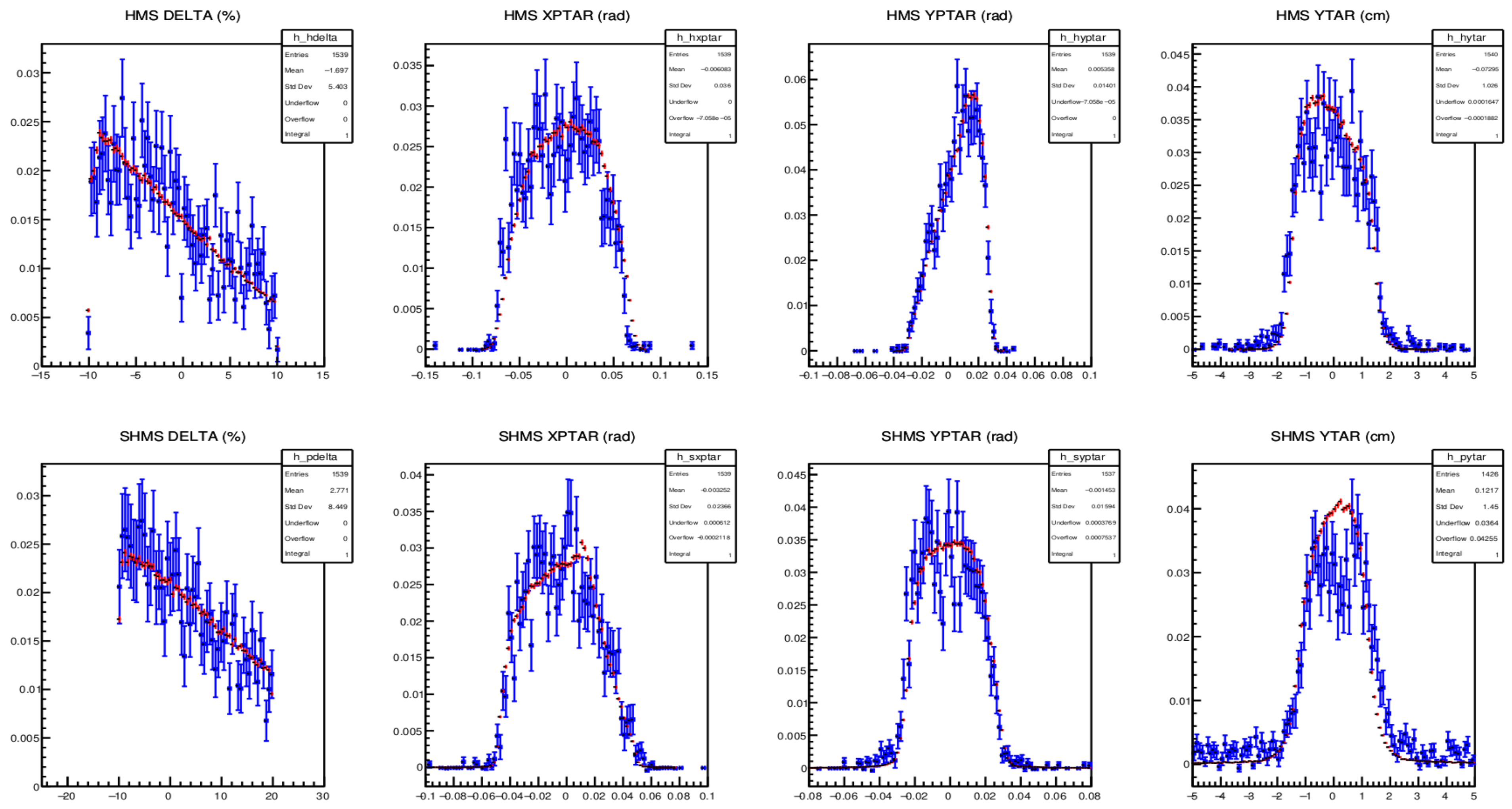


Rate dependence of the tracking efficiency is smaller than expected.

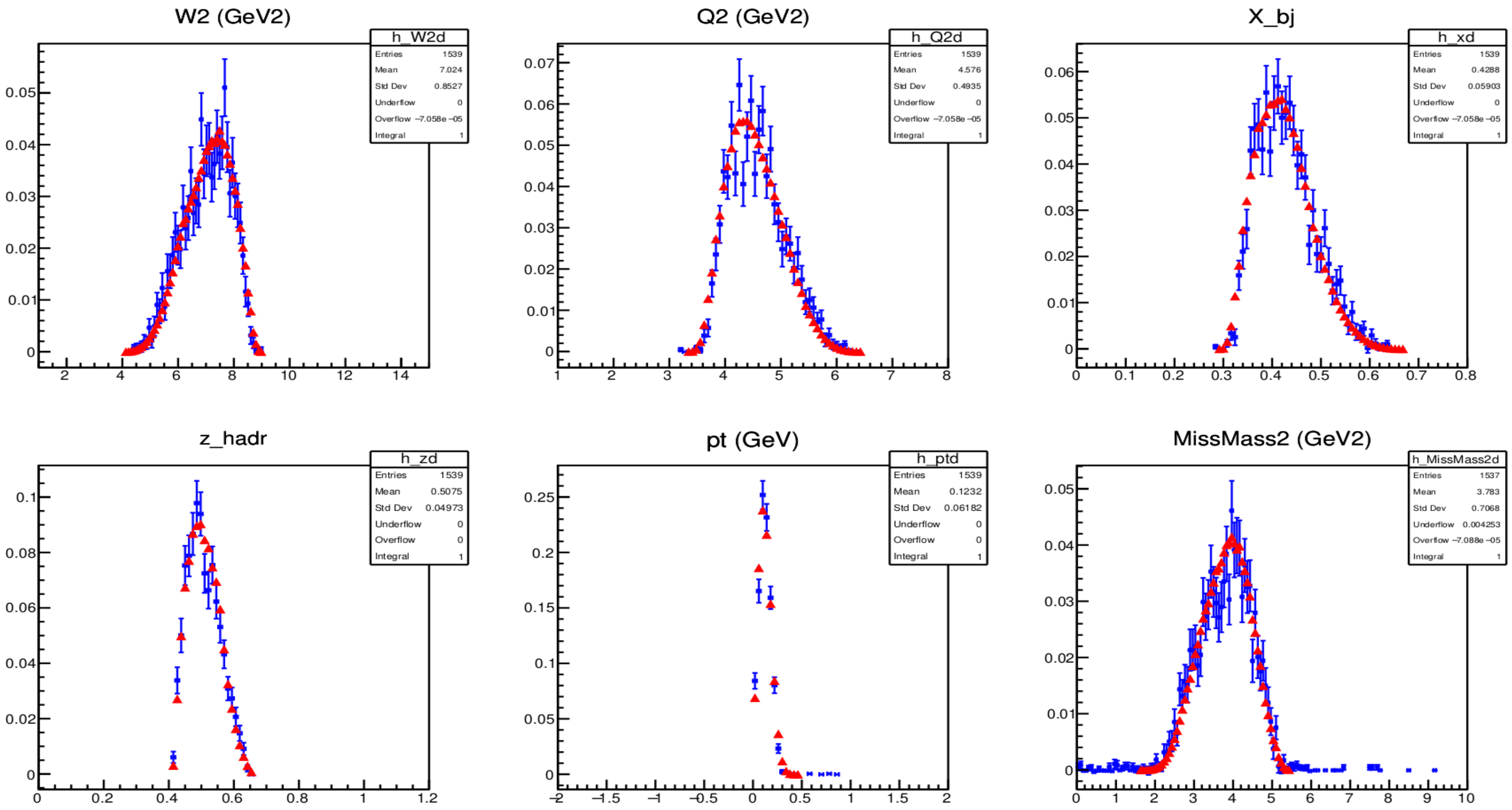
Tracking Efficiency vs ¾ Rate, LD2 Target (Pi+, Pi-)



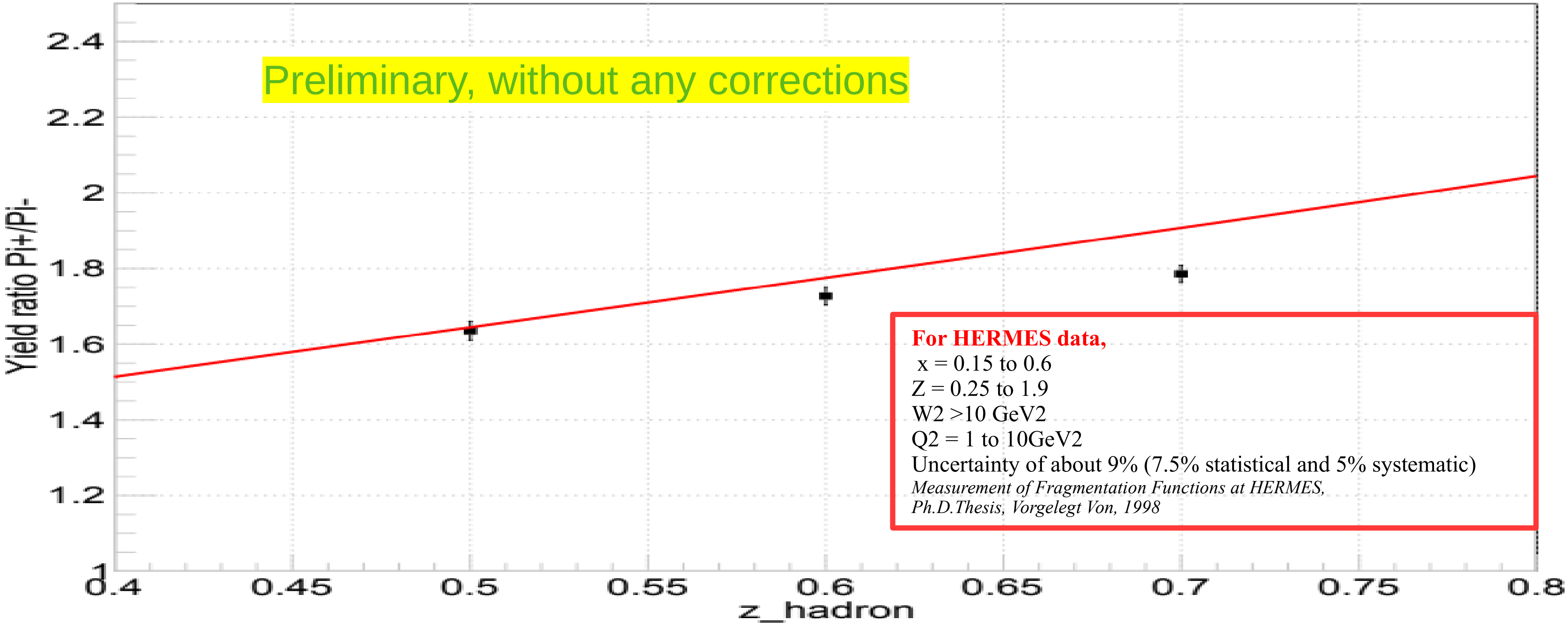
Data and simulation comparison of some spectrometer quantities



Data and simulation comparison of some physics quantities

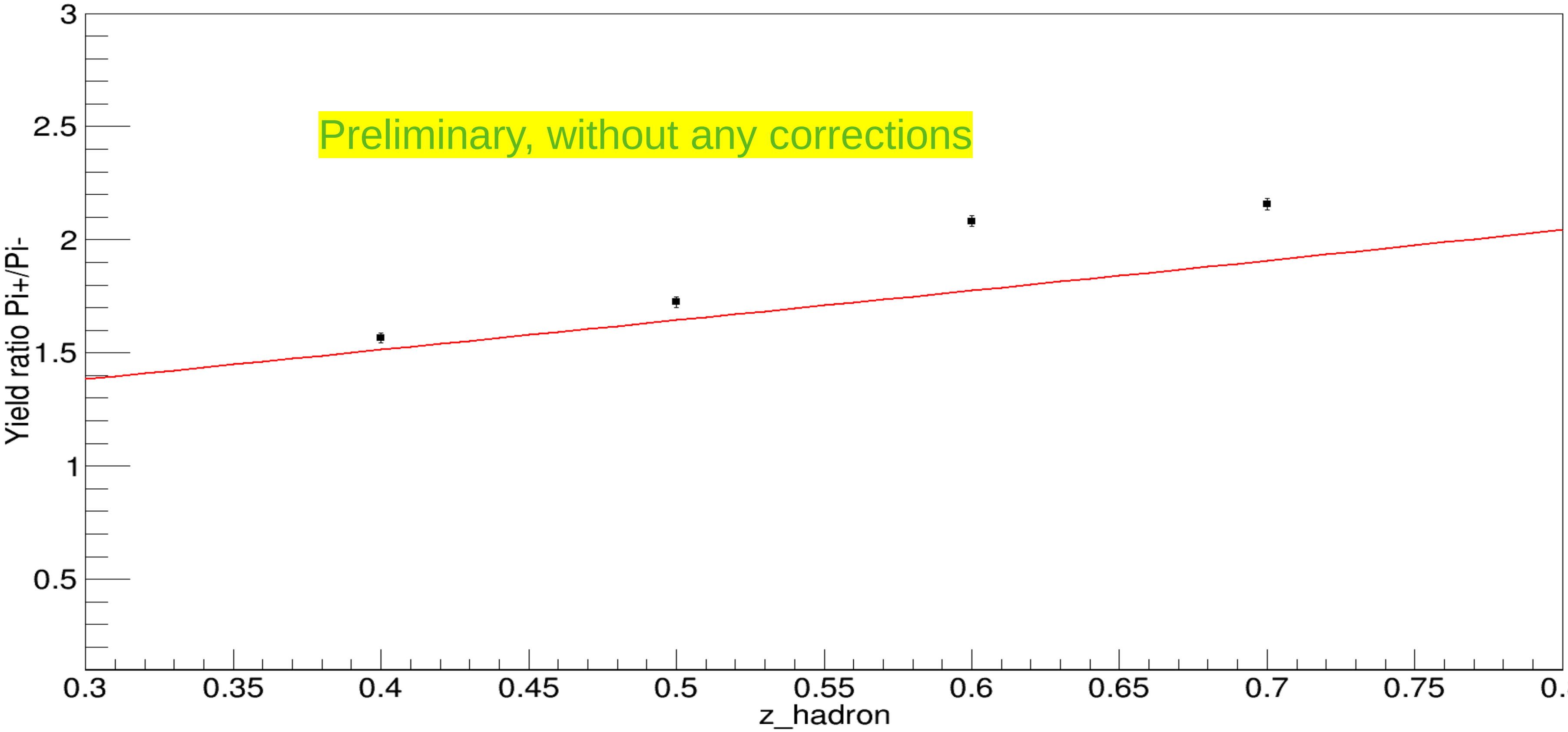


Yield Ratio vs z_hadron, $Q^2 = 4.0$ GeV^2, z_hadron = 0.7, 0.6, 0.5, x =0.4



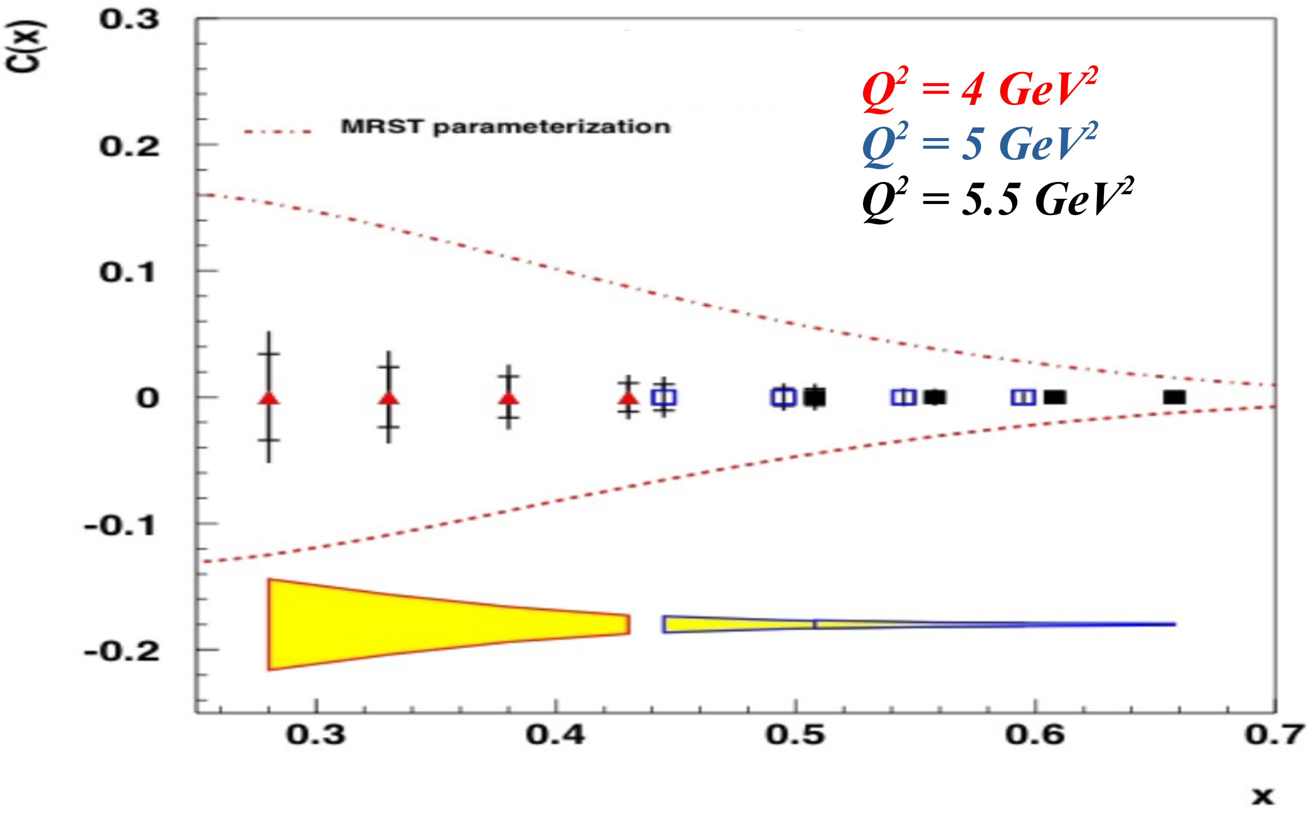
Red Graph: parameterization from HERMES DATA

Yield Ratio vs z_hadron, $Q^2 = 4.0\ GeV^2$, z_hadron = 0.7, 0.6, 0.5, 0.4 x =0.35



Red Graph: parameterization from HERMES DATA

Projected uncertainties from the original proposal



Predicted uncertainties for the charge symmetry violating quark distributions. The inner error bar represents the statistical uncertainties, whereas the external error bar are the quadrature sum of the statistical and experimental systematic uncertainties.Two red curves gives the range of CSV contribution from MRST parameterization. The Yellow band represents the systematic error related to the uncertainties in the PDFs.

Summary

This Experiment will:

- Extract the precise ratio of charged pion electro production using semi-Inclusive deep inelastic scattering from Deuterium.
- Constrain the strength of charge symmetry violation in valence PDFs for the first time.
- Constrain the x-dependence of charge symmetry violating valence PDFs.

The detector calibration is completed and we are currently working on PID study, detector efficiency study, data and simulation comparison of physics quantities and yield ratio measurement.

Thank You

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