Status of GMP experiment

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Outline

- Introduction to GMP Experiment: Proton Magnetic Form Factor:

  (I) Physics motivation

  (ii) Requirements on systematic uncertainties
- Hall A beamline and detector instrumentation
- Beam Position Measurement/Calibration
- Beam Charge Measurement/Calibration
- Status of GMP experiment
- Conclusion

Introduction to GMP Experiment: Proton Magnetic Form Factor

- Form factors encode electric and magnetic structure of the target

  → At low Q^2, form factors characterize the spatial distribution of electric charge and magnetization current in the nucleon

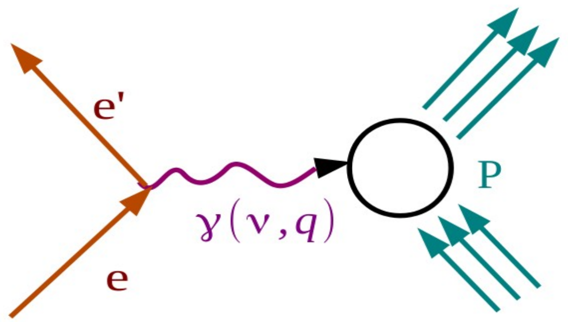
$$|\text{Form Factor}|^2 = \frac{\sigma(\text{Structured object})}{\sigma(\text{Point like object})}$$

$$\mathcal{J}_{\text{proton}} = e\bar{N}(p')\left[\gamma^\mu F_1(Q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2M}F_2(Q^2)\right]N(p)$$

$$G_E = F_1 - \tau F_2 \qquad G_M = F_1 + F_2$$

- In one photon exchange approximation the cross-section in *ep* scattering when written in terms of G_M^p and G_E^p takes the following form:

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott}\frac{\epsilon(G_E^p)^2 + \tau(G_M^p)^2}{\epsilon(1+\tau)}, \qquad \sigma_{Mott} = \frac{\alpha^2\cos^2\frac{\theta}{2}}{4E^2\sin^4\frac{\theta}{2}}\frac{E'}{E}$$



Where,

$$\tau = \frac{Q^2}{4M^2}, \qquad \epsilon = \left[1 + 2(1+\tau)\tan^2\left(\frac{\theta}{2}\right)\right]^{-1}$$

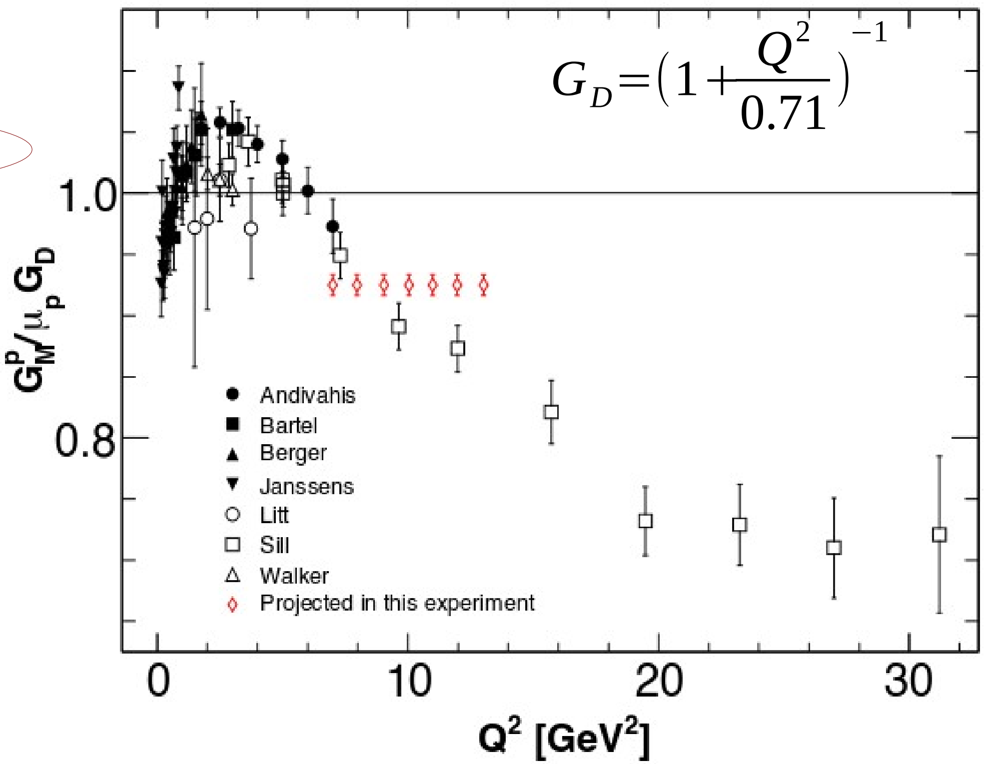
ϵ - Virtual photon polarization

GMP Experiment at Hall A JLab

- Accurate measurement of the elastic *ep* cross-section in the Q^2 range of 7-14 GeV^2 and extraction of proton magnetic form factors
  - To improve the precision of the previous experiment
  - To provide insight into scaling behavior of the form factors at high Q^2
  - To understand two photon exchange contribution in *ep* elastic scattering

Goal: 2% or less total uncertainty

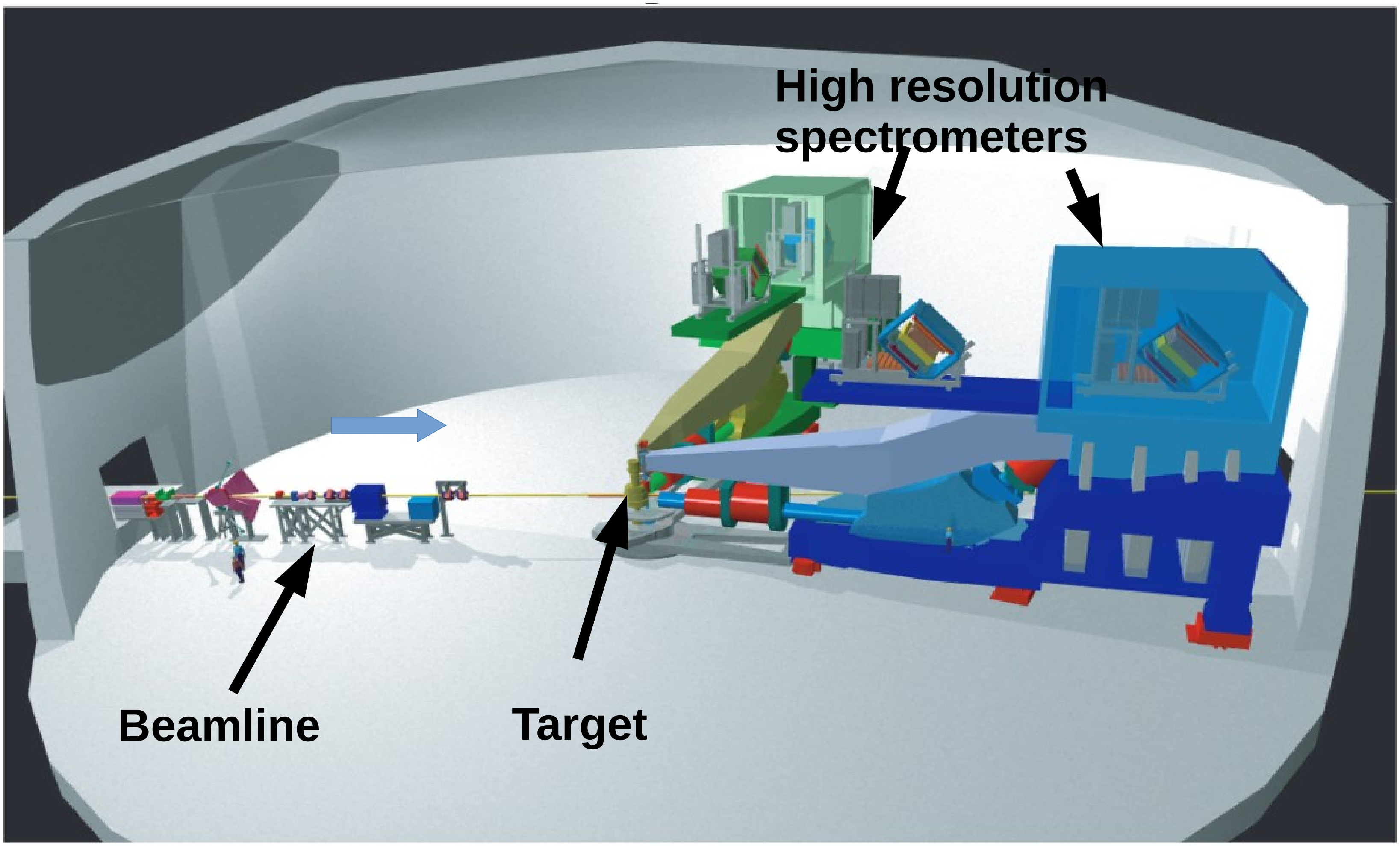
Syst: 0.5-0.8%
Point to point: 0.8-1.1%



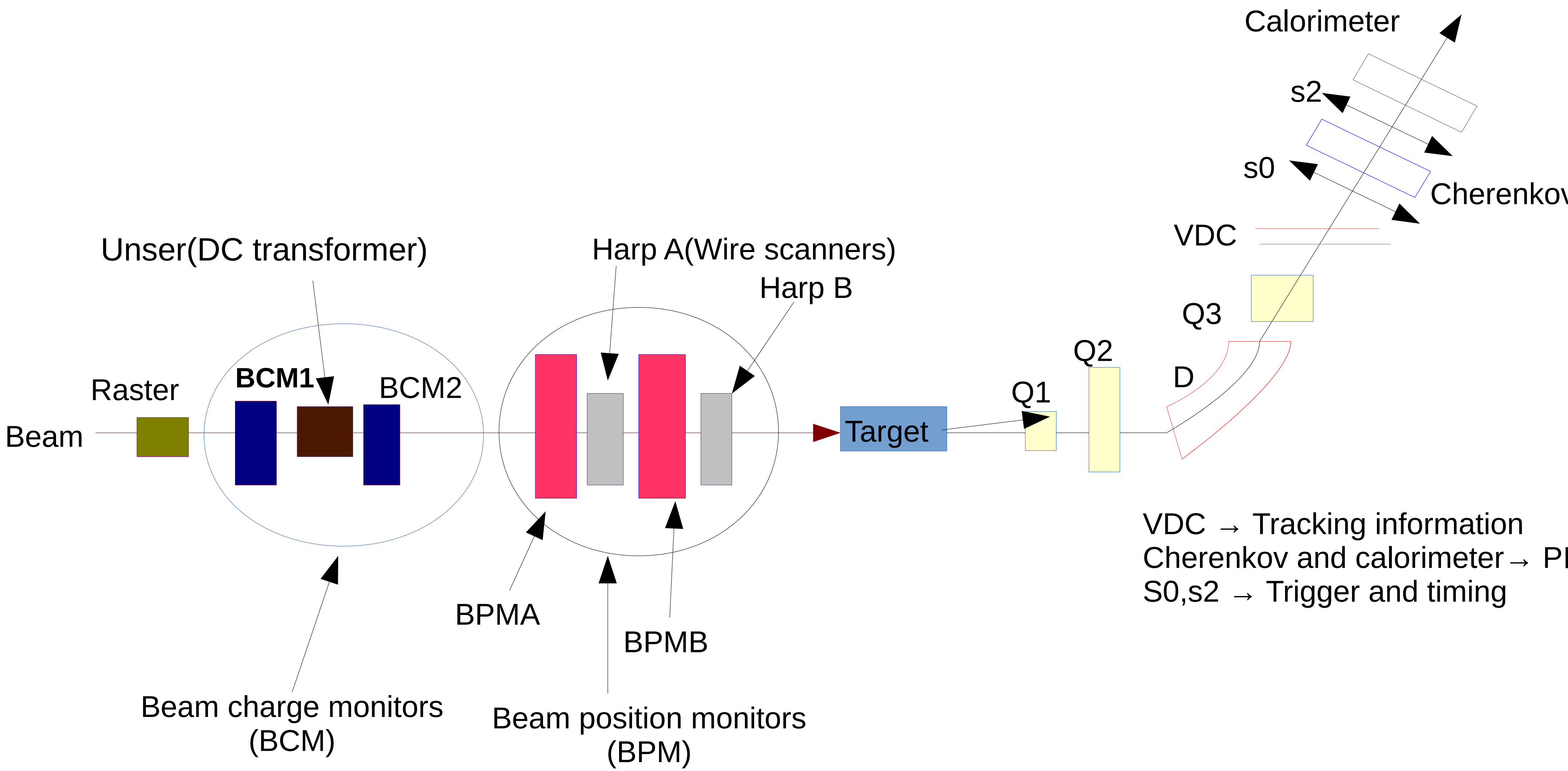
Need a good control on:

- Beam charge
- Beam position
- Scattering angle, target density, ...

Hall A arms and beamline transport



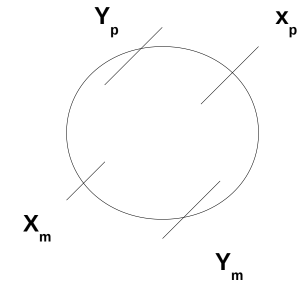
Hall A Beamline and detector schematics



VDC → Tracking information
Cherenkov and calorimeter → PID
S0,s2 → Trigger and timing

Beam Position Calibration

- The main components of beam position monitoring system are two BPMs and two Harps
- BPM is a cavity with four wire antennas whose signal is proportional to the distance from the beam and Harp is a system of three wires used to measure the beam profile
- Difference over sum technique is used to find relative beam position
- The relative position from BPM is calibrated to match the absolute beam position known from the Harp



BPM Relative coordinates(x',y')

Hall coordinates (x,y)

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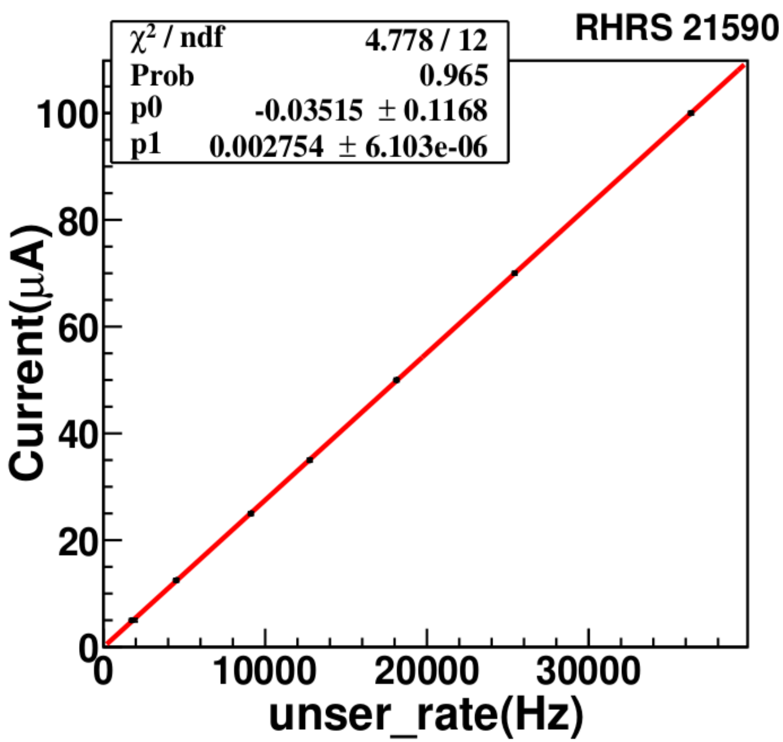
Creator:ROOT Version 5.34/17

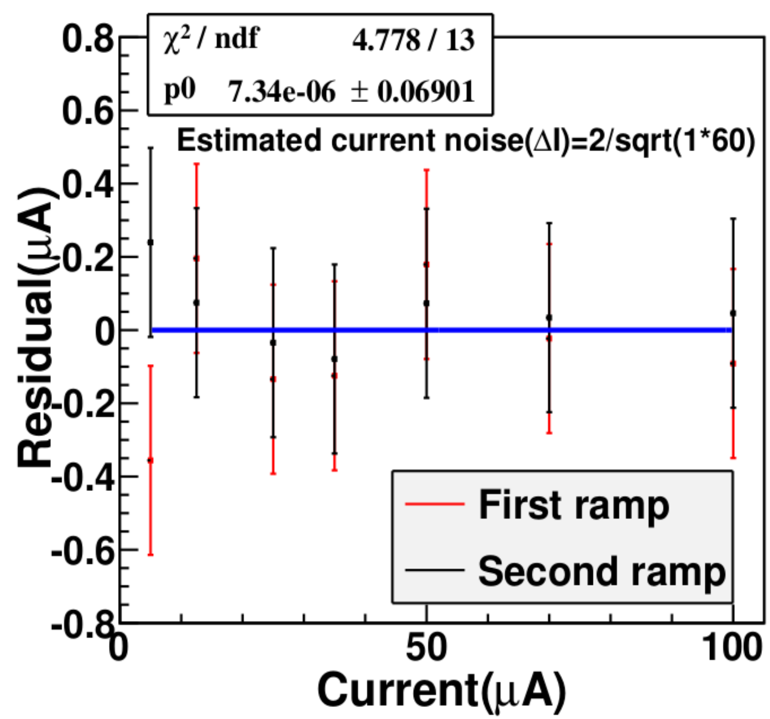
CreationDate:Wed Oct 21 08:30:09 2015

$$\begin{pmatrix} x \\ y \end{pmatrix}_{Abso} = \begin{pmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{pmatrix} \begin{pmatrix} x' \\ y' \end{pmatrix} + \begin{pmatrix} x_{of} \\ y_{of} \end{pmatrix}$$

Beam Current Calibration (I): Unser calibration

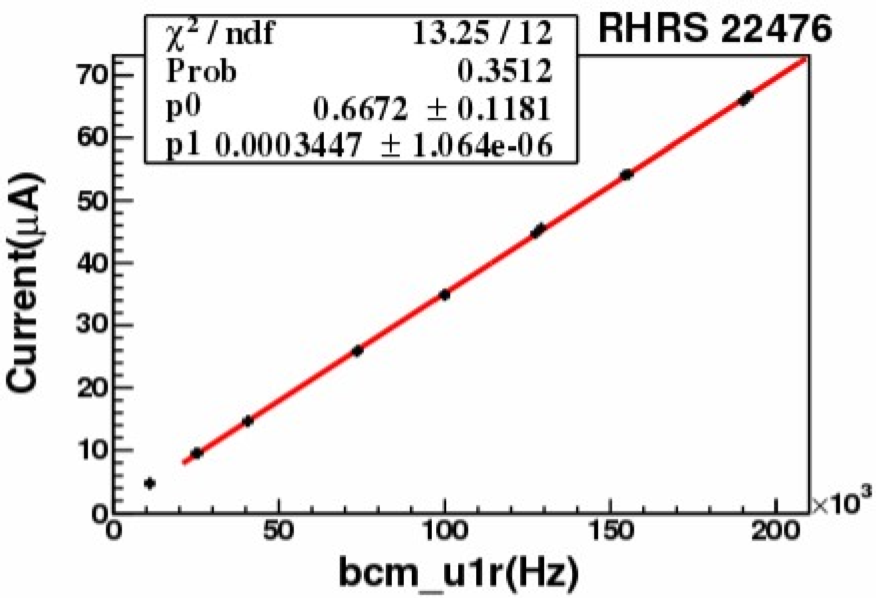
- The beam current measurement system consist of an unser monitor and two BCM cavities
- The unser monitor is a toroidal transformer sensitive to the DC currents passing through its cores
- Output signal of unser monitor drifts significantly on a time scale of several minutes and can't be used for long term beam current monitoring
- Unser is calibrated by passing high-precision current along a wire through the device
- Precise knowledge of the beam current from unser monitor is used for BCM calibration

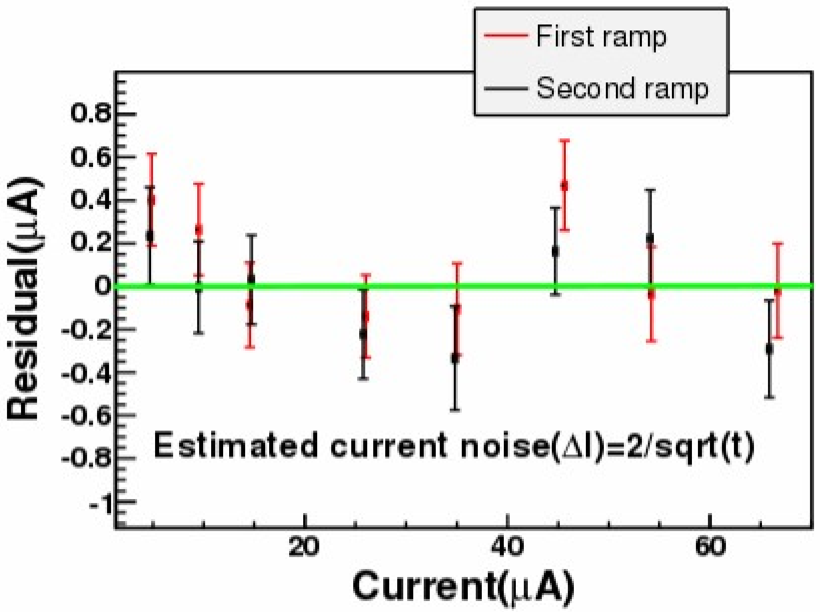




Beam Current Calibration (II): BCM Calibration

- A BCM is a cylindrical resonant cavity whose output voltage is proportional to the beam current
- The signal from the BCM cavity is send to a V-F converter and then fed to scalers
- BCM calibration obtains the parameters to convert the scaler counts into electron charge
  - Standard error of the residual in the range of 15 to 65 uA indicates a beam current precision of 0.39%





Production data collected in spring 2016

E(GeV)	P0(GeV)	θe(deg)	Q2(GeV2)	I(uA)
4.481	1.547	52.91		5.515uA
8.841	2.101	48.75		12.6510uA
11.021	2.204	48.75		16.5410uA
8.841	2.503	43		11.89*40uA
8.841	2.503	43		11.89*60uA
8.841	2.101	48.75		12.6560uA

*Complete (1%)statistics

Tracking efficiency Study

- Calculated 1 track efficiency for events passing electron PID cuts: Cut on no. Photoelectron in Cherenkov and total energy deposited in calorimeter

- Eff = (No. passing PID cuts and having 1 track)/(Number passing PID cuts)

Pass	set momentum (GeV/c)	efficiency (%)
1	1.254	99.432
2	1.547	95.340
4	2.101	60.281

Clearly there is some cosmic contamination passing these cuts, because the electron rate drops quickly at higher pass. To estimate the cosmic events we took a cosmic run taken over 3 days period and applied same cuts

pass	total time for pass (hrs)
cosmic	68.037
1	0.561
2	86.37
4	115.79

- Using the ratio of (Production)/(Cosmic time) we estimated the number of cosmic passing our cuts:

pass	total events passing pid	total events passing pid+1trk
1	274450	272891
2	110310	105169
4	11876	7159

pass	cosmics passing pid cuts (expected)	cosmics passing pid+1trk (expected)
1	39.56	6.359
2	5181	796.2
4	5555	856.0

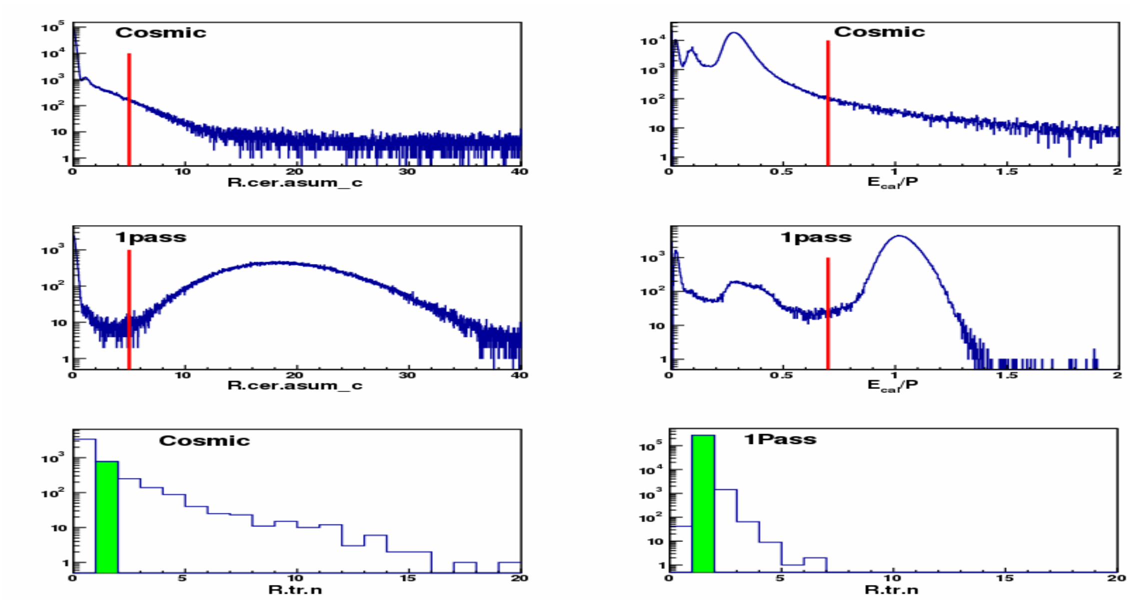
Tracking efficiency Study

- So, the corrected efficiency = (total events passing pid+1trk – cosmic passing pid+1trk)/
  (total events passing pid – cosmic passing pid)

pass	corrected efficiency(%)
1	99.44
2	99.28
4	99.71

- The top panel in the plot shows the cherenkov and calorimeter response for cosmic run. The middle shows the same for production and the bottom shows the no. of track for the events passing PID cuts.

- The next step is to apply additional cuts to better select the electron sample. We plan on using the scintillator timing to do this as well as requiring minimum energy deposition on both layer of calorimeter..



Scintillator timing calibration

$$\beta = \frac{v}{c} = \frac{Pathlength_{s_0 s_2}}{time_{s_0 s_2} \times c}$$

- Each paddle of the scintillator detectors has two PMTs
- To determine the particle beta we need to calibrate time offset for each PMT. These timing offsets are caused by varying cable lengths from PMT to the TDC.
- To obtain the time offsets we need to solve the following linear combinations:

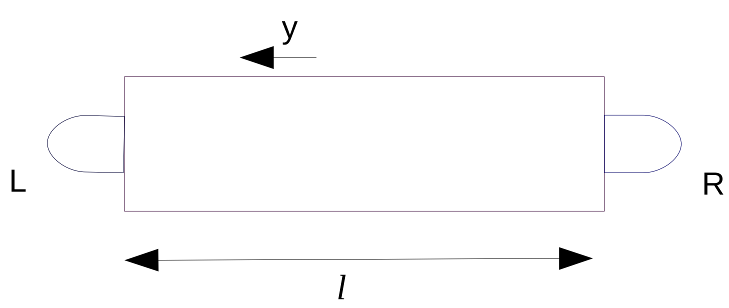
$$t_L = t_0 + \frac{l/2 - y}{c_n} + C_L \qquad (1)$$

$$t_R = t_0 + \frac{l/2 + y}{c_n} + C_R \qquad (2)$$

To get,

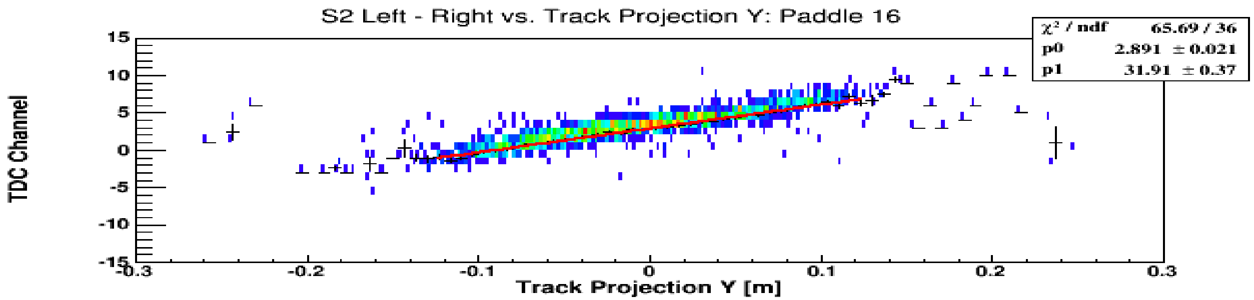
$$t_L - t_R = -2\frac{y}{c_n} + C_L - C_R \qquad (3)$$

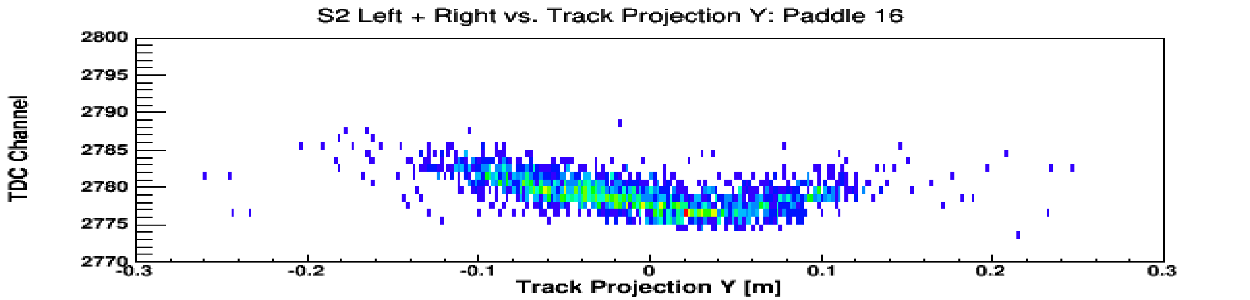
$$t_L + t_R = 2t_0 + \frac{l}{c_n} + C_L + C_R \qquad (4)$$

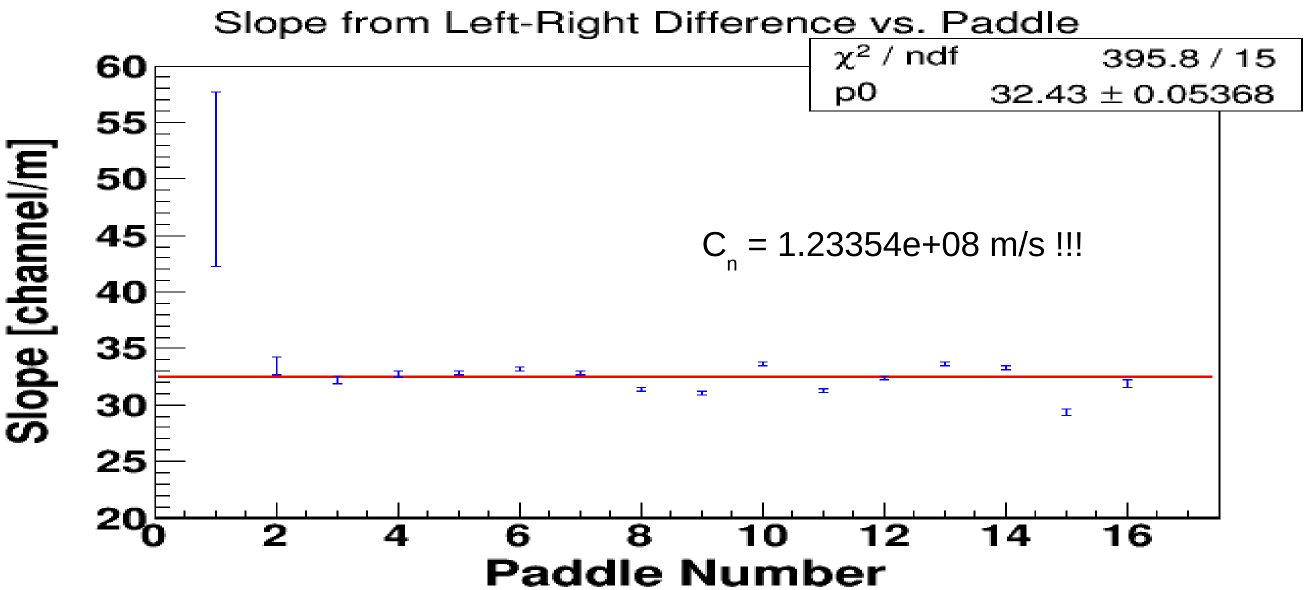


- By calculating mean channel from eq. (4) and intercept of fit of eq. (3) we get left and right corrected time whereas the slope of eq. (3) is use to calculate the velocity of the particle in scintillator.

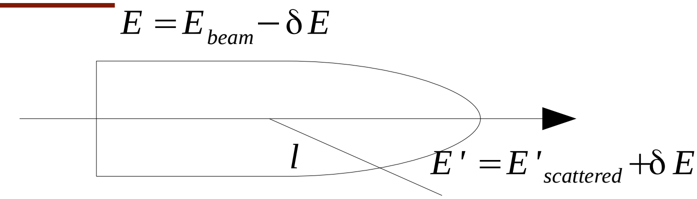
Scintillator timing calibration







Energy Loss correction

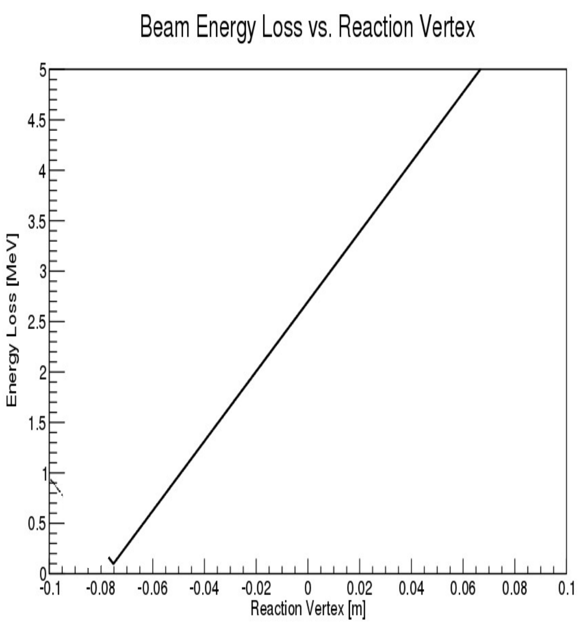


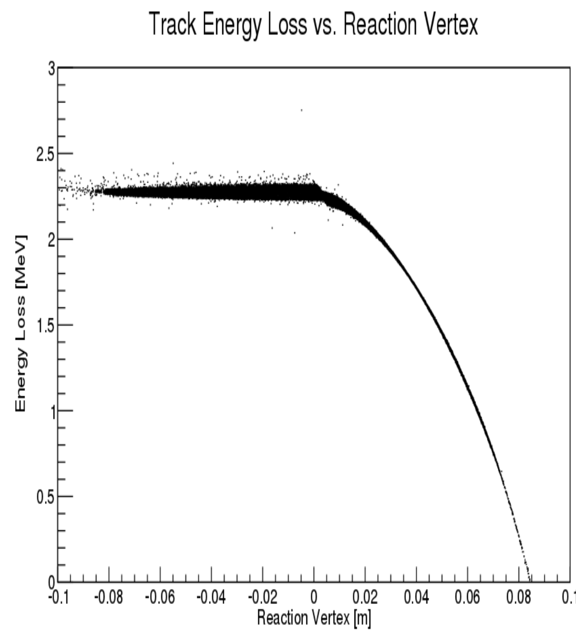
- Charge particle loses energy when it goes through a material.

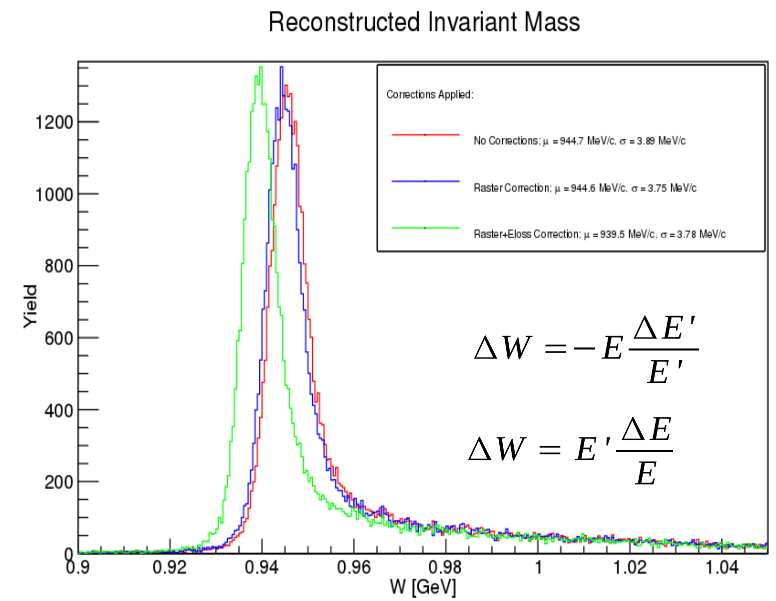
  -For incoming electron we corrected beam energy by calculating reaction vertex dependence of average energy loss using Beth-Bloch formula

  -For scattered electron the energy loss is both angle and reaction vertex dependence

- Clearly for incoming electron energy loss is linear with reaction vertex and for scattered electron energy loss is flat along the cylindrical part and decreasing along the tip.



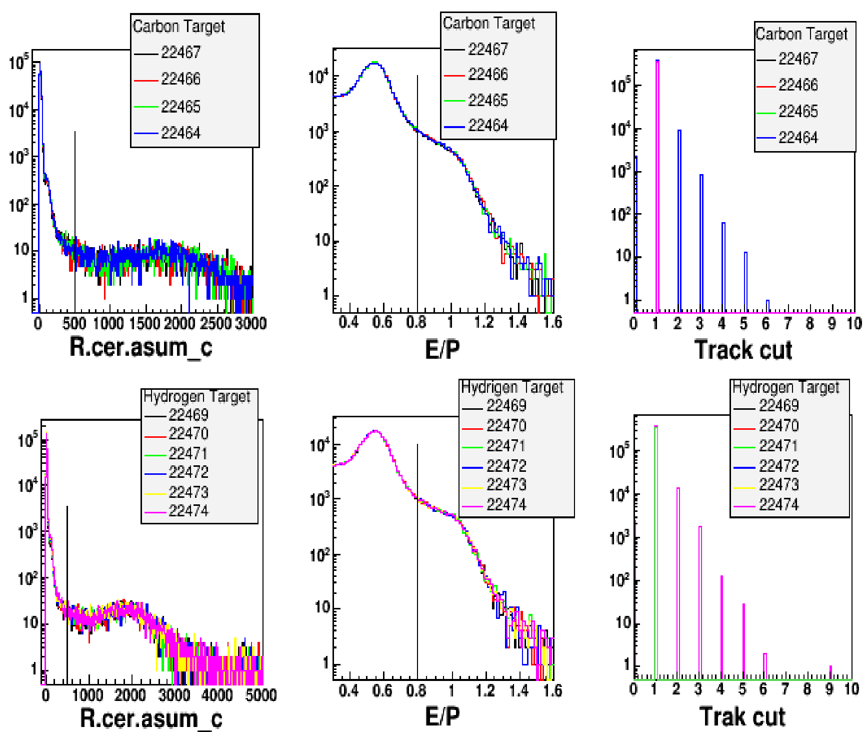


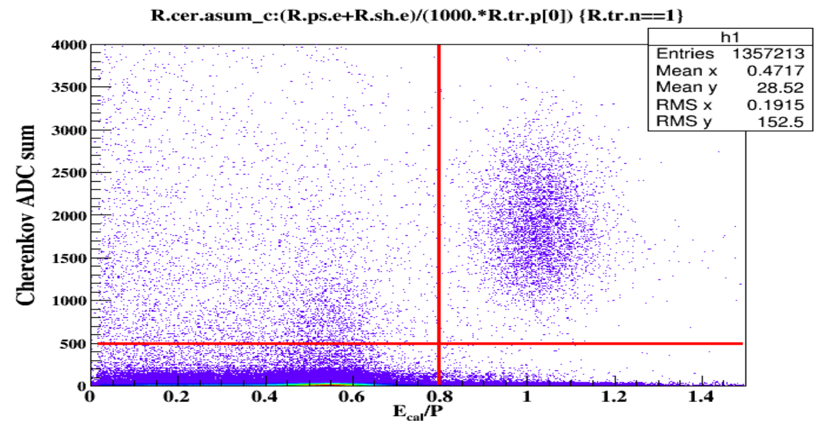


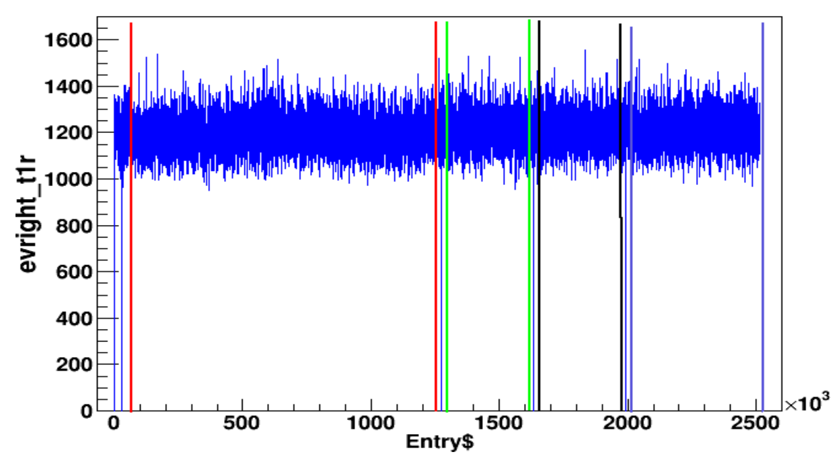
Target boiling study

- Localized boiling can cause the uncertainties in cryogenic target density.
- LH2 and carbon were used in this study. As carbon is a solid we should see no variation of yield with current.
- A range of 9-60uA beam current was used. The higher the current higher the risk of boiling, Whereas the smaller the raster size higher will be the boiling.
- Two types of analysis has been made:
  - Scalar analysis: Scalar rate was normalized to beam current plotted against current
  - Yield analysis: No. of good events determined by PID and one track cut are normalized by beam charge, tracking efficiency and live time plotted against beam current.

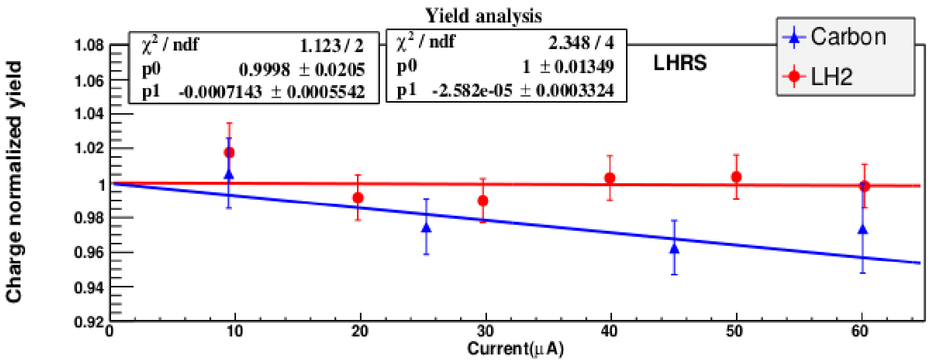
$$Yield = \frac{No.of\ events \times PS}{Charge \times efficiency \times Livetime}$$

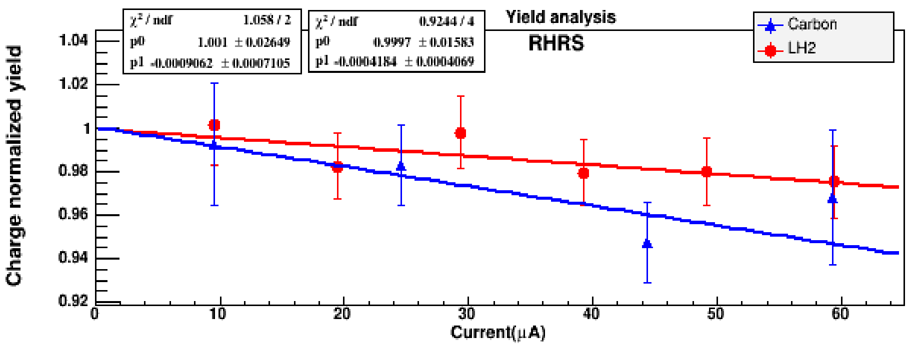


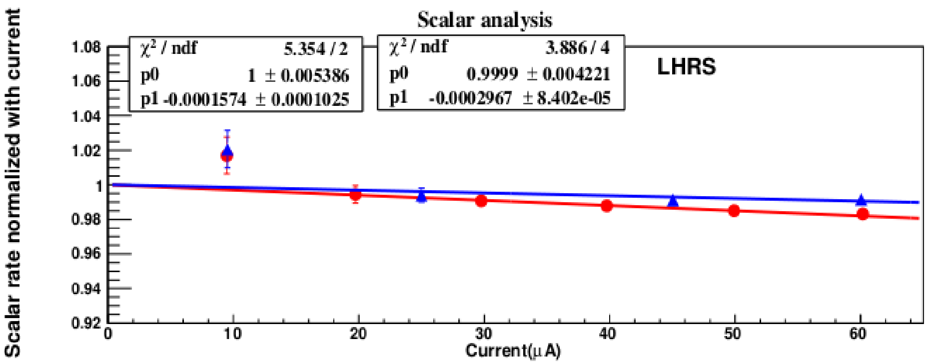


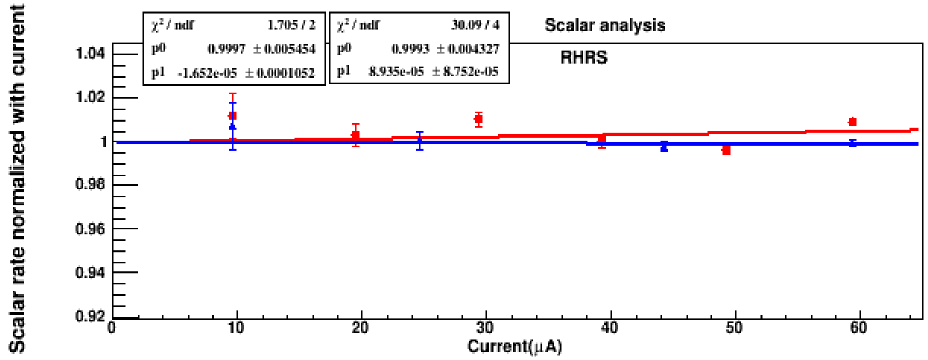


Target Boiling









Conclusion

- Took few production data from 12 GeV commissioning of GMP in spring 2016
- Beamline instruments were calibrated using the commissioning data
  - The BPMs are calibrated against harps up to 1.5%
  - The BCM is calibrated against unser to an accuracy of 0.39%
- In the study of tracking efficiency with simple PID selection we have seen some cosmic contamination at higher beam energies. We developing some timing cuts that can provide cleaner election selection.
- Target boiling study has done up to 60uA.
- Ionization energy loss correction has applied to both incoming and scattered electron.

Energy loss correction

Mean rate of energy loss (Stopping power)for an electron is:

$$\frac{-dE}{dx} = K\frac{Z}{\beta^2}[\ln\frac{\tau(\tau^2+2)}{2(I/m_ec^2)^2} - F(\tau) - \delta(\beta\gamma)],$$

Where,

$$F(\tau) = 1-\beta^2+\frac{\frac{\tau^2}{2}-(2\tau+1)\ln 2}{(\tau+1)^2}$$

τ: Kinetic energy of particle in the unit of m_ec^2

A: atomic mass of the absorber

$$\frac{K}{A} = 2\pi N_A r_e^2 m_e c^2/A$$

$$= 0.1535\ MeVg^{-1}cm^2,\ for\ A = 1\,g\,mol^{-1}$$

z: atomic number of incident particle

Z: atomic number of absorber

T_{max}: max. transferable energy

I: characterstic ionization constant material dependent

$\delta(\beta\gamma)$: density effect correction

$x = \rho s$, mass thicknes, where, s is the length

Maximum transferable kinetic energy: $T_{max} = \dfrac{2m_ec^2\beta^2\gamma^2}{1+2\gamma\frac{m_e}{m_o}+(\frac{m_e}{m_o})^2}$

Where,

$$\beta^2 = \frac{v^2}{c^2} = \frac{P^2}{E^2} = \frac{1}{1+\frac{m_e^2}{p^2}}$$

Since, $m_e \ll P$, $\beta \approx 1$.

For $m_e = m_o$

$m_ec^2 \approx 0.511$ MeV

For incoming electron $T_e \approx 2\times 2056.44\,$MeV, So, $\tau = 8048.88$

For scattered electron $T_e \approx 2\times 1224.49\,$MeV, So, $\tau = 4792.52$

For incoming electron

$$\gamma = \frac{E}{E_o}$$

$$\gamma = \frac{2.057\times10^9}{0.511\times10^6} = 4025.44$$

For scattered electron

$$\gamma = \frac{P}{E_o} = \frac{1.225\times10^9}{0.511\times10^6} = 2397.26$$

Ionization constant:

$$\frac{I}{Z} = (12+\frac{7}{Z})eV.$$

For Hydrogen Z = 1,

$So,\ I = 19\ eV.$

Average ionization energy loss $= \dfrac{dE}{dx}\dfrac{\Delta x}{2}$

$$= -0.896813\times7.5\times0.0723$$

$$= -0.486\,\text{MeV}$$

$X = \log_{10}(\gamma\beta) = 3.6048$

For H, $X_o = 0.4759$, $X_1 = 1.9215$,

-C = 3.2632

$\delta = 4.6052\ X + C$ As, $X > X_o$

$= 4.6052\times3.6048 - 3.2632$

$= 13.338$