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Geant Simulations of Electron Beam Side Injection through 2µm Diamond Windows.

PDPWA Meeting Lisbon

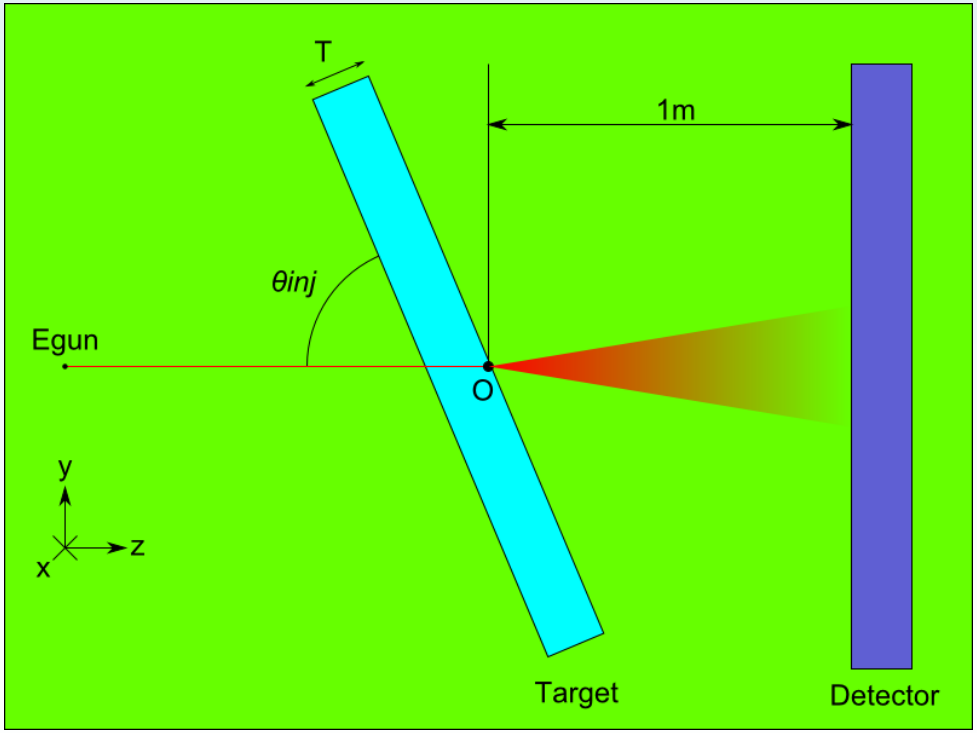
Thursday 21st June 2012

Scott Mandry

Outline

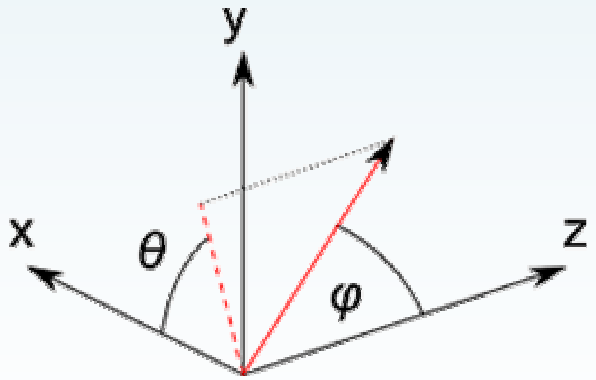
- Simulation Geometry
- Beam Injection
  - Perpendicular Injection
  - Large Angle Injection
  - Shallow Angle Injection
- Discussion
- Work in Progress
- Conclusions

Simulation Geometry



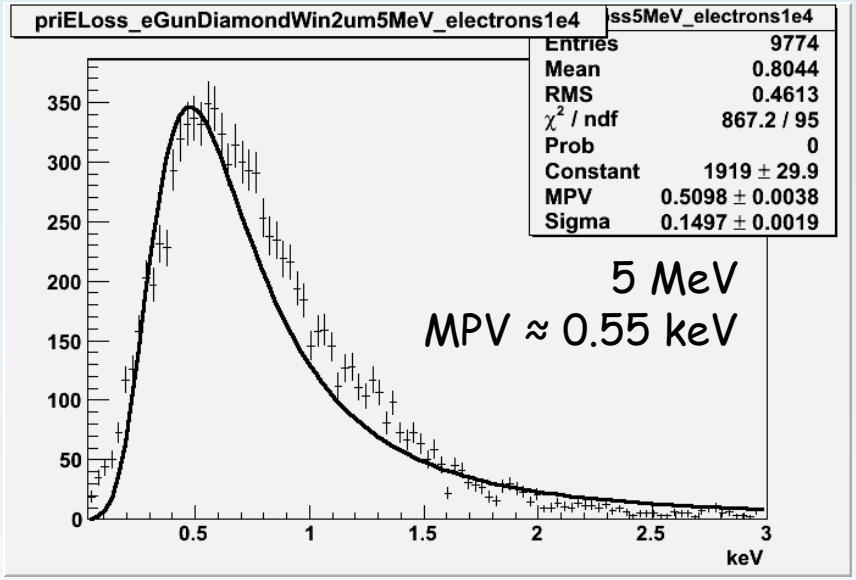
Beam Injection: Quantities Measured

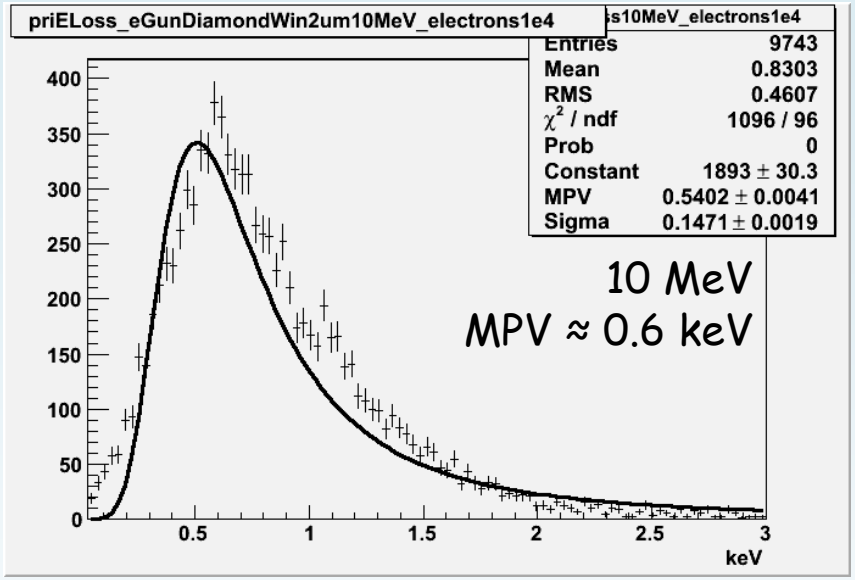
- All quantities simulated with 10,000 tracks at 5, 10, 15, 20 MeV
- Primary Energy Loss
- Scattering Angle φ
  - Angle between track and beam-axis z
- Perpendicular Scatter θ
  - Angle w.r.t. x axis in the xy plane, perpendicular to the beam-axis z.
- Beam Profile
- Beam Profile Projections in X and Y

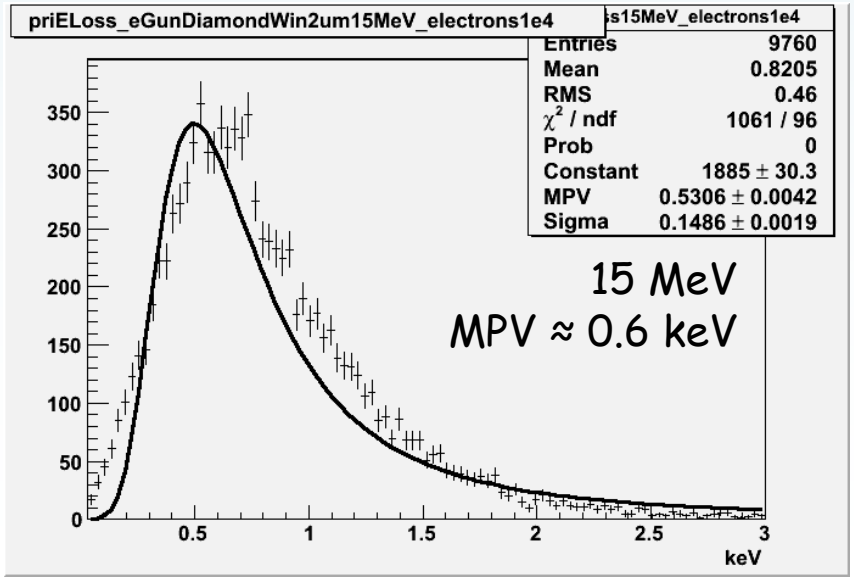


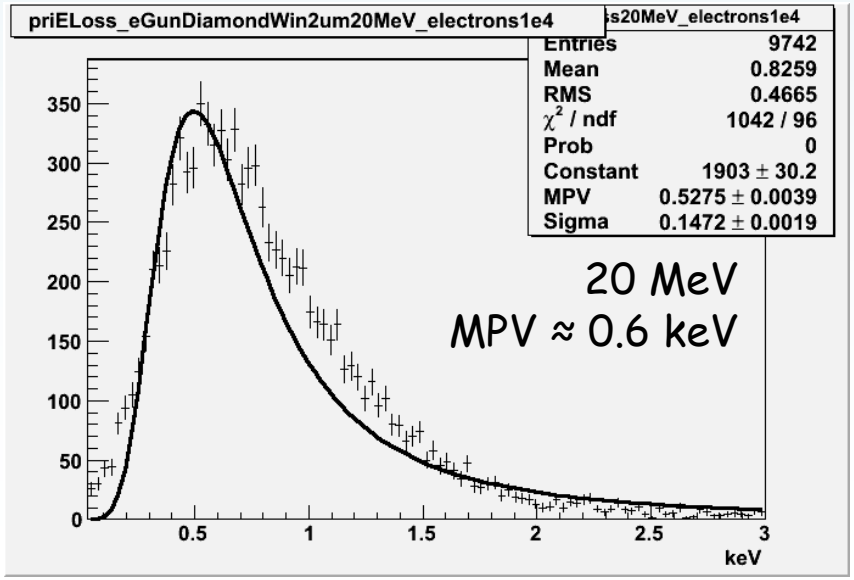
Beam Injection: Perpendicular Injection

Perpendicular Injection: Energy Loss

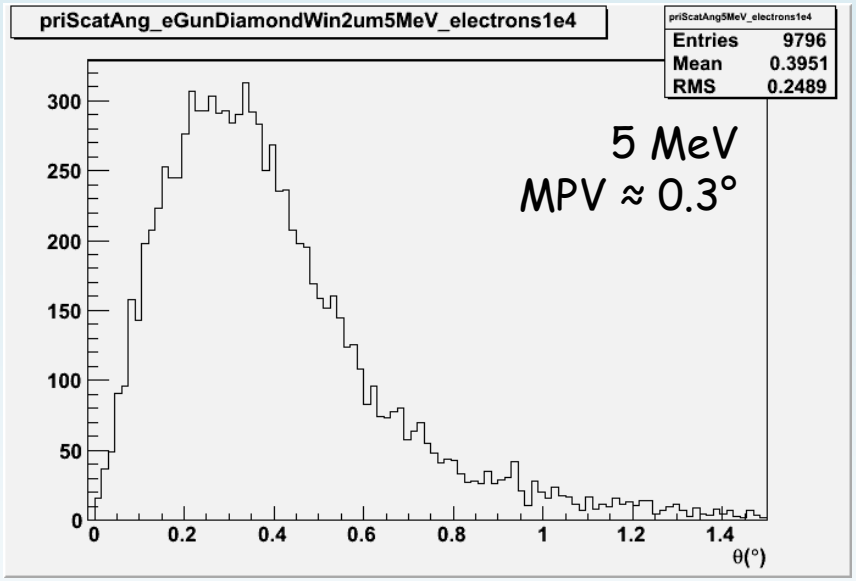


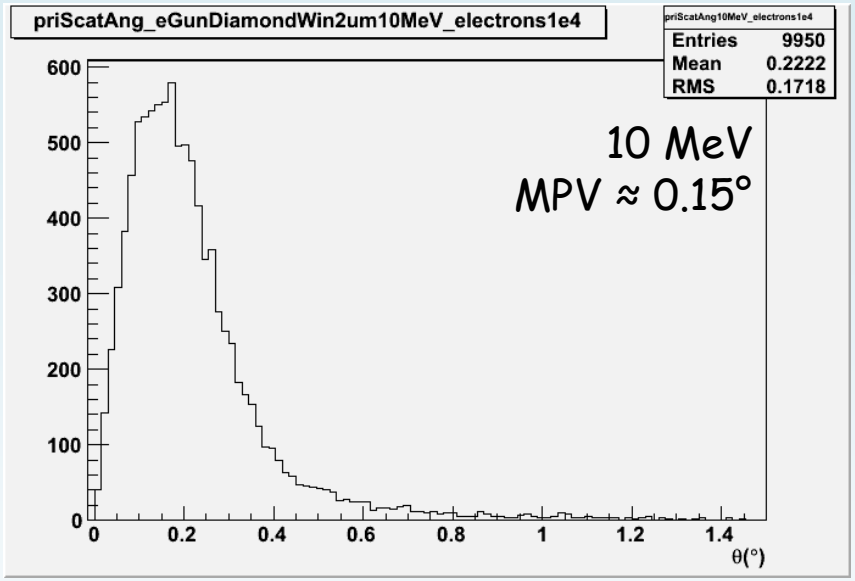


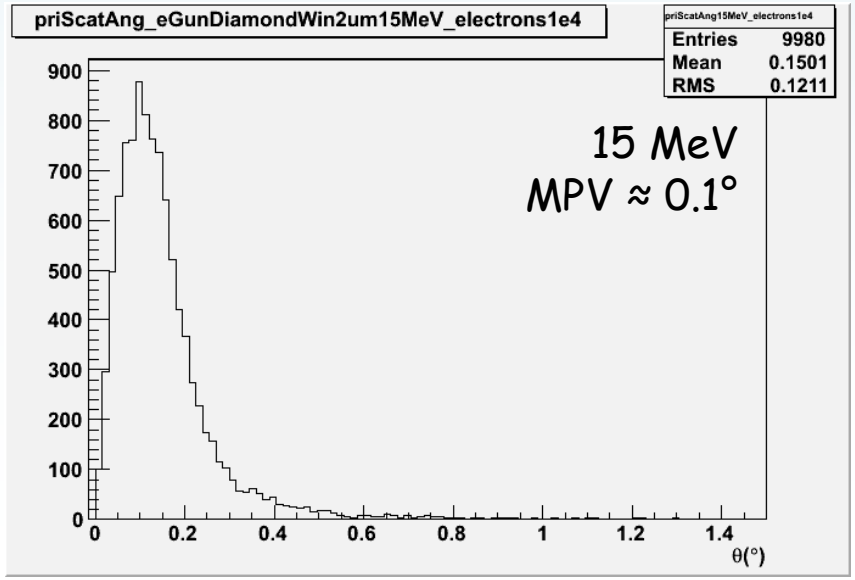


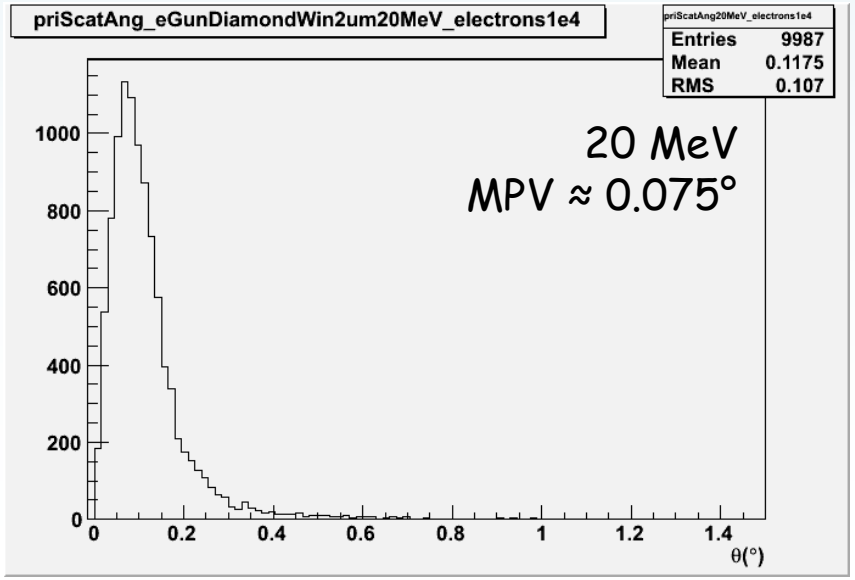


Perpendicular Injection: Scattering Angle

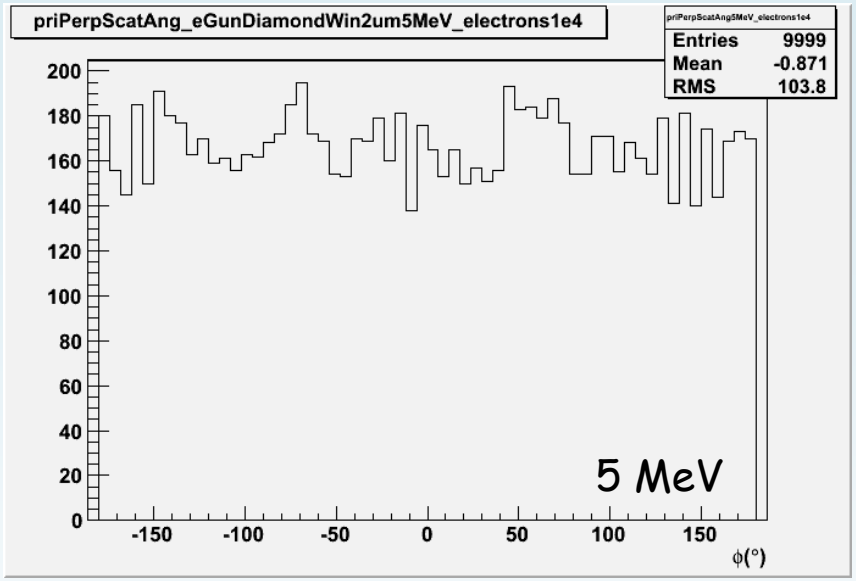


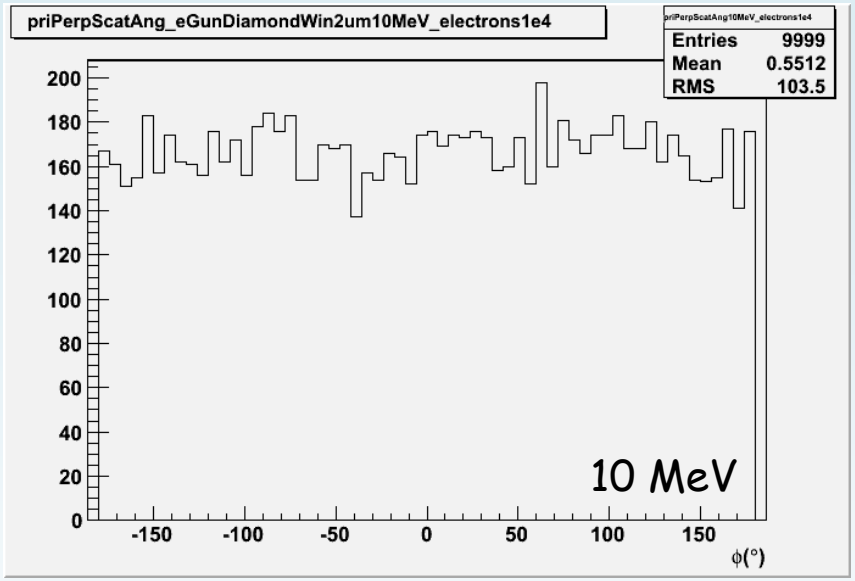


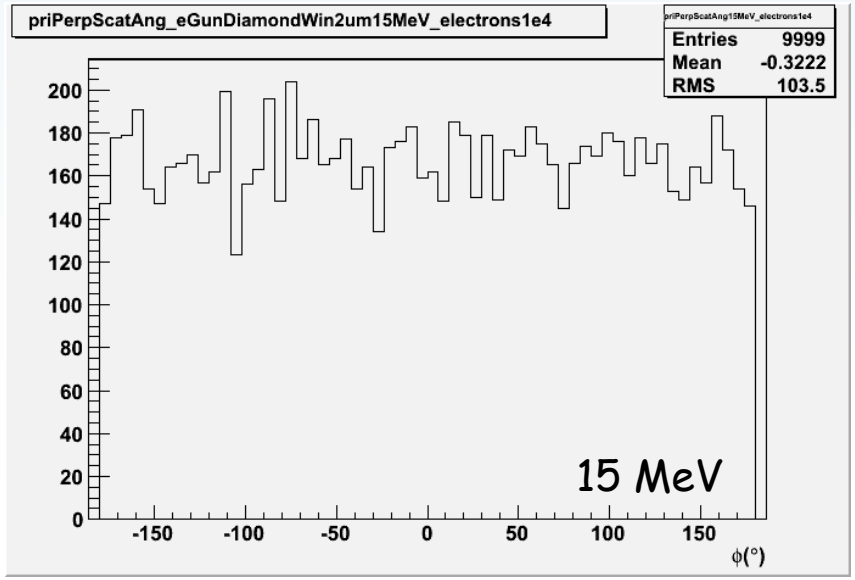


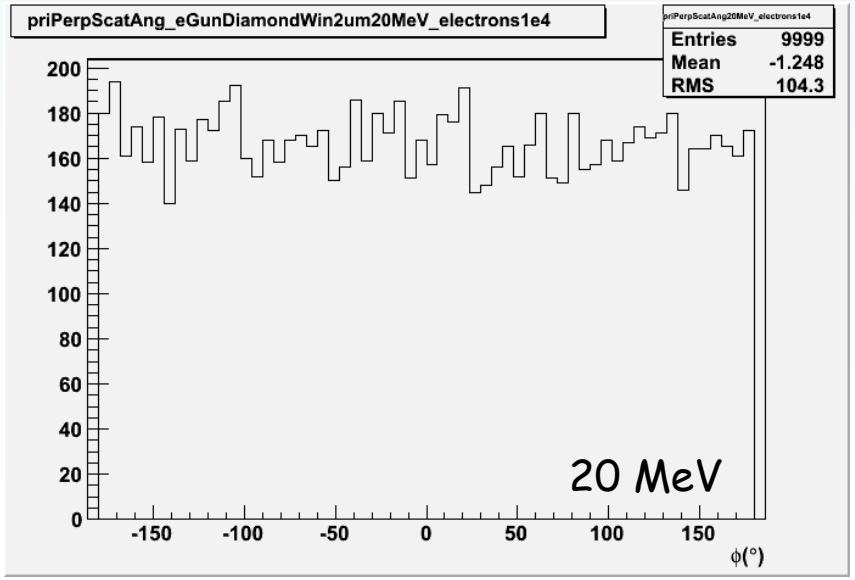


Perpendicular Injection: Perpendicular Scatter

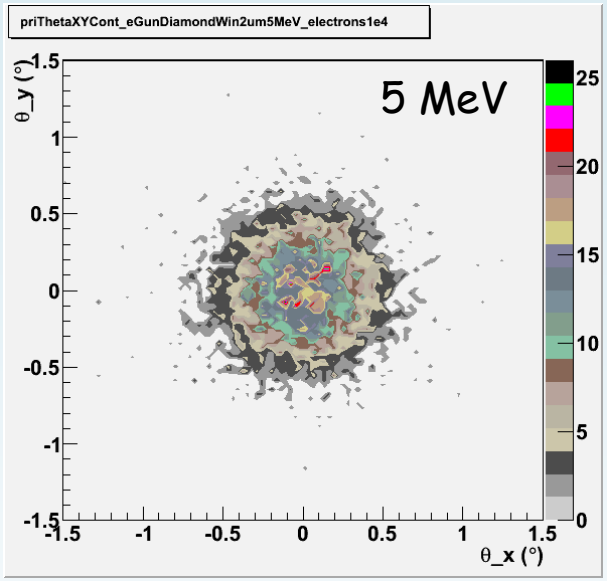


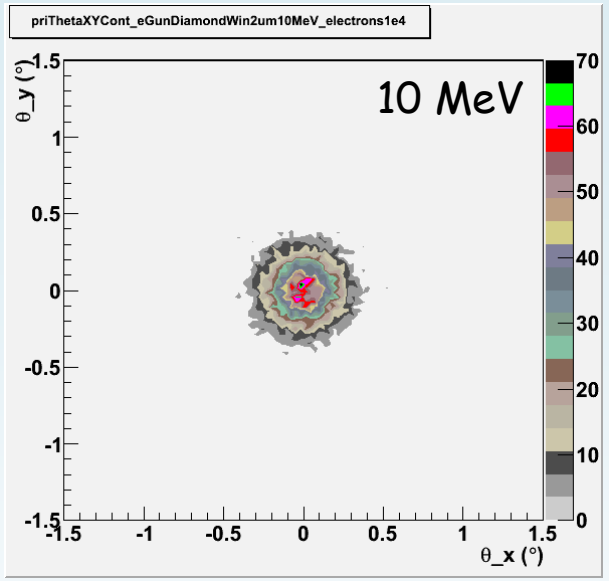


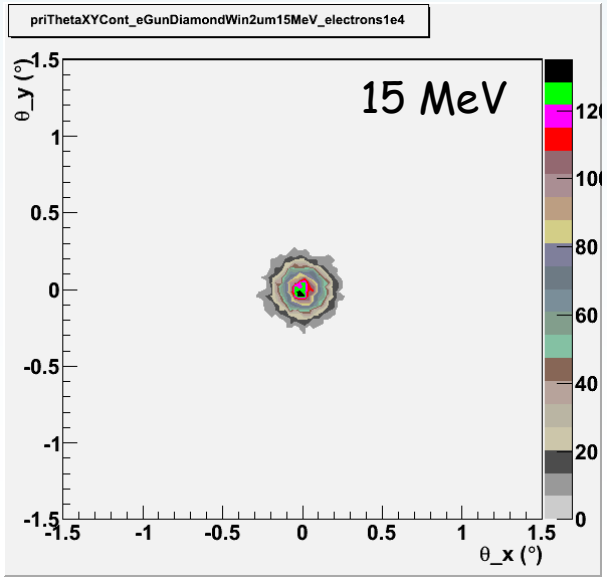


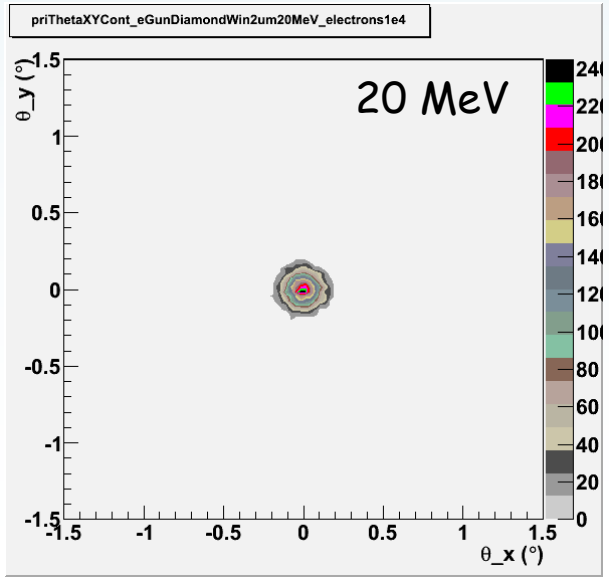


Perpendicular Injection (1m): Beam Profile (°)

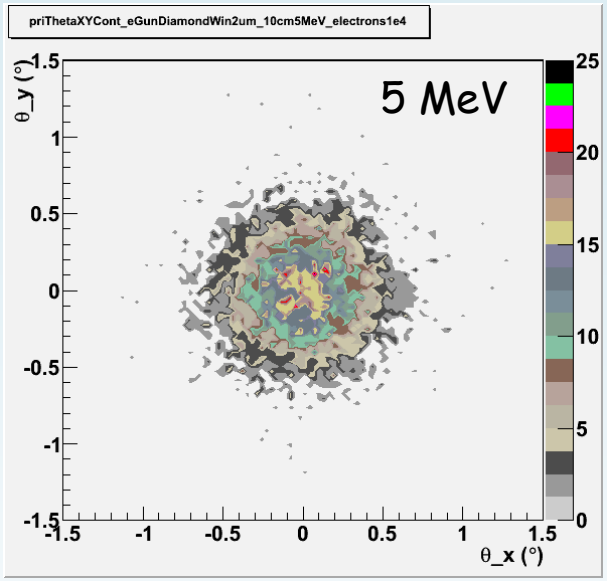


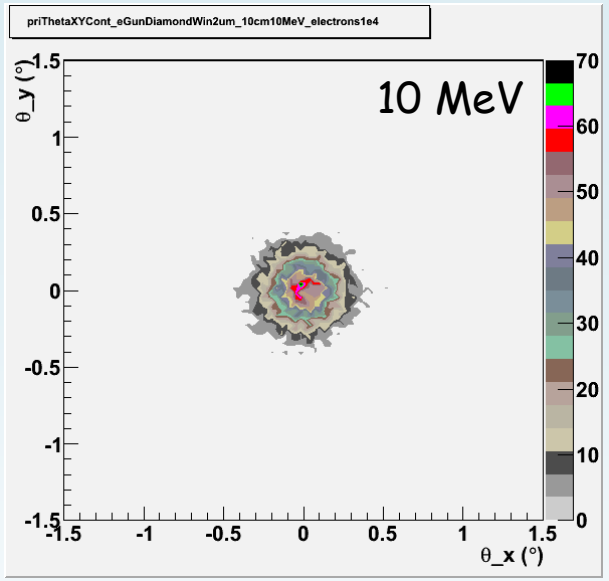


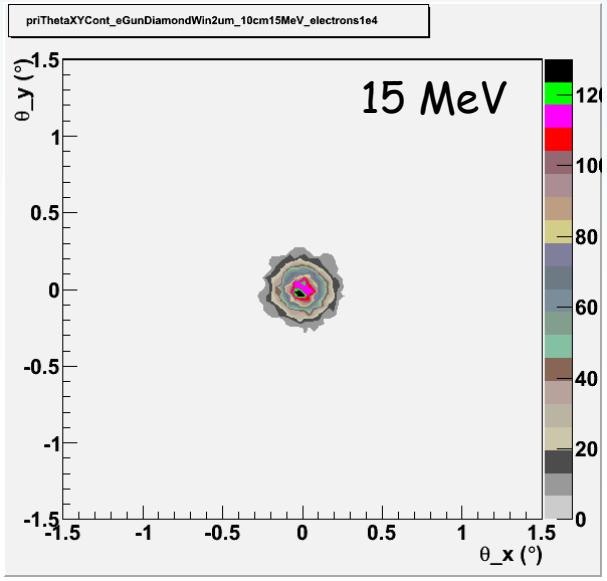


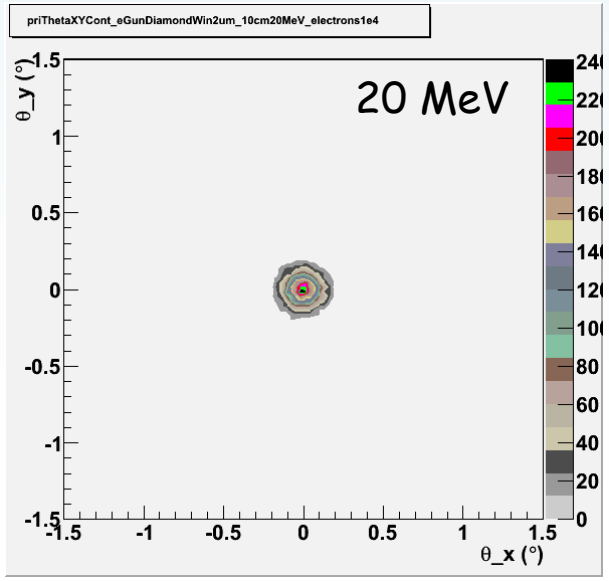


Perpendicular Injection (10cm): Beam Profile (°)

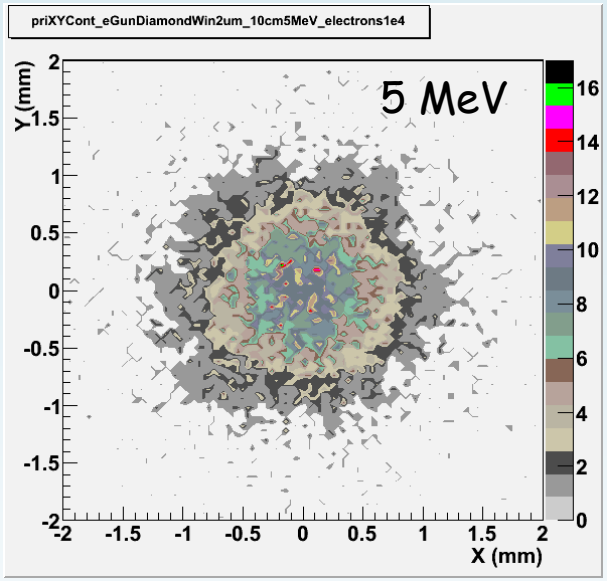


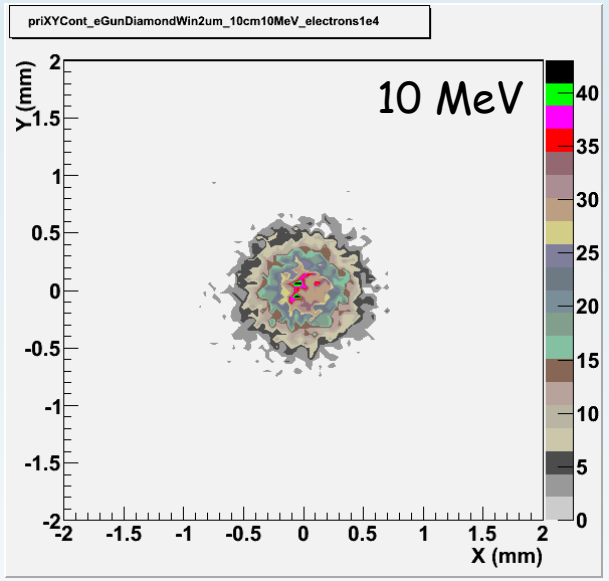


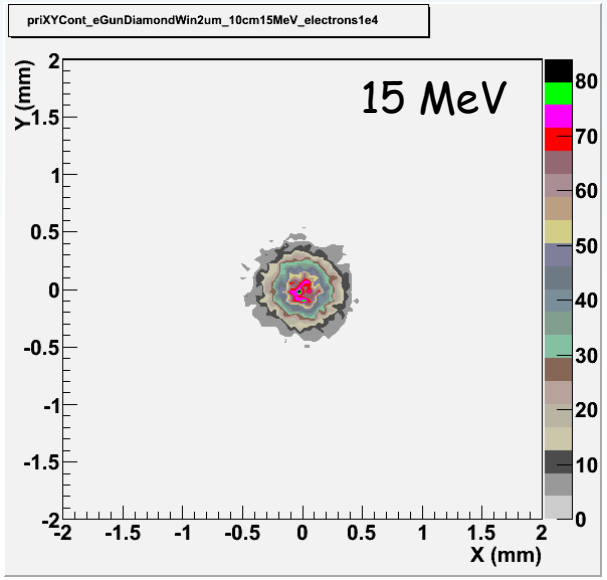


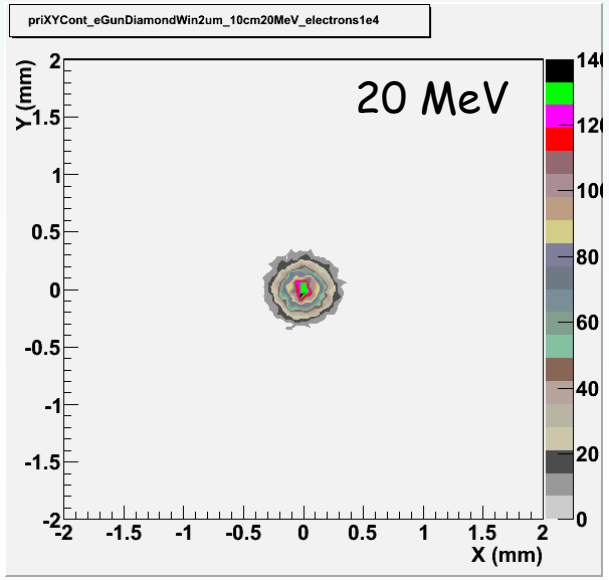


Perpendicular Injection (10cm): Beam Profile (mm)

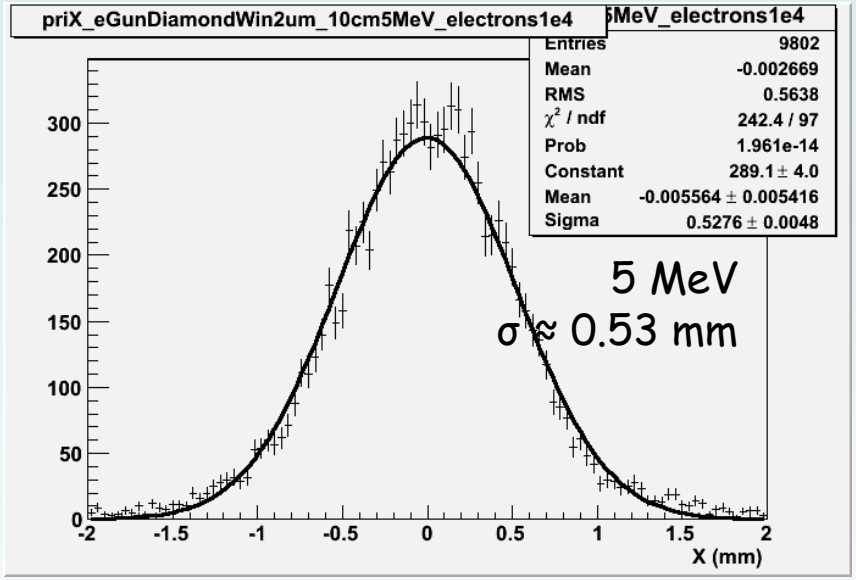


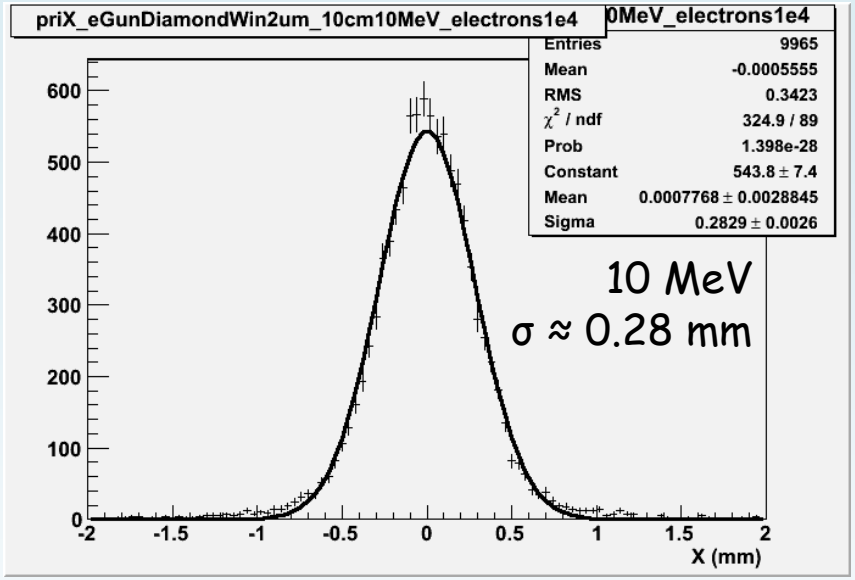


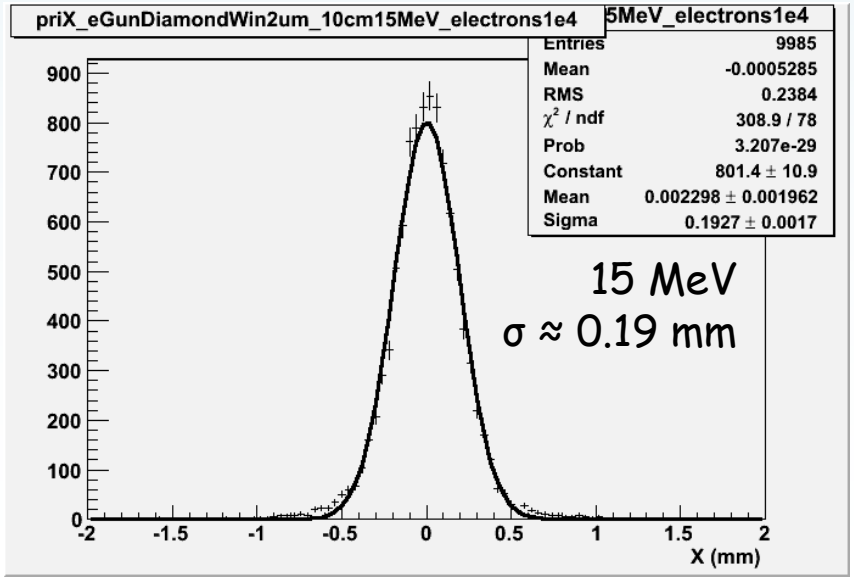


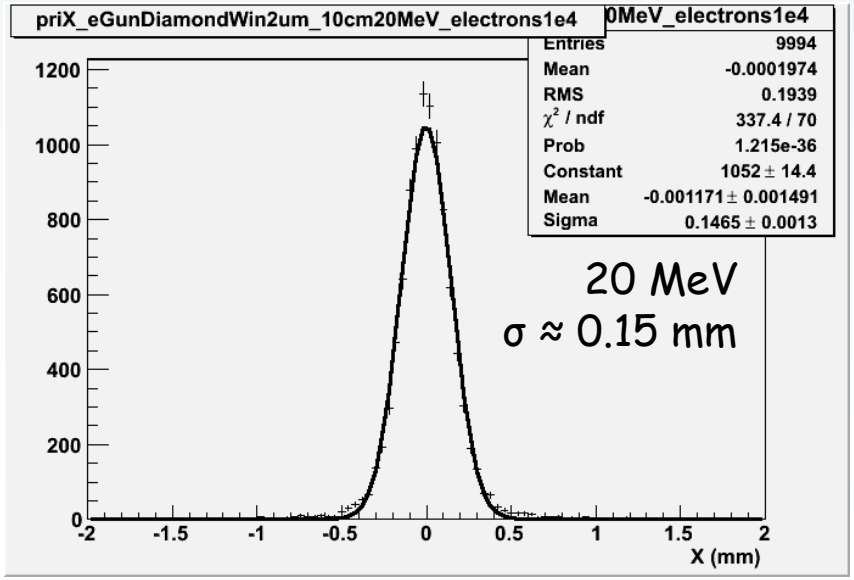


Perpendicular Injection (10cm): Beam Profile (X projection mm)

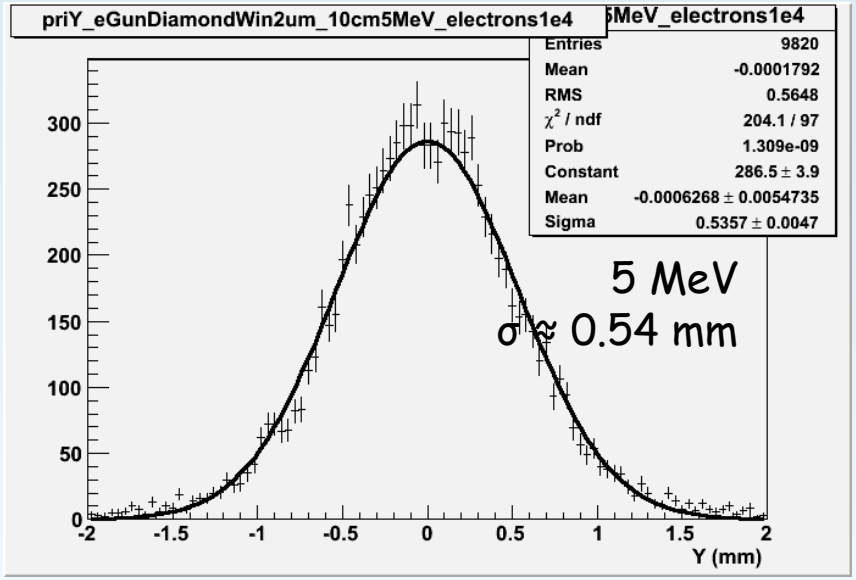


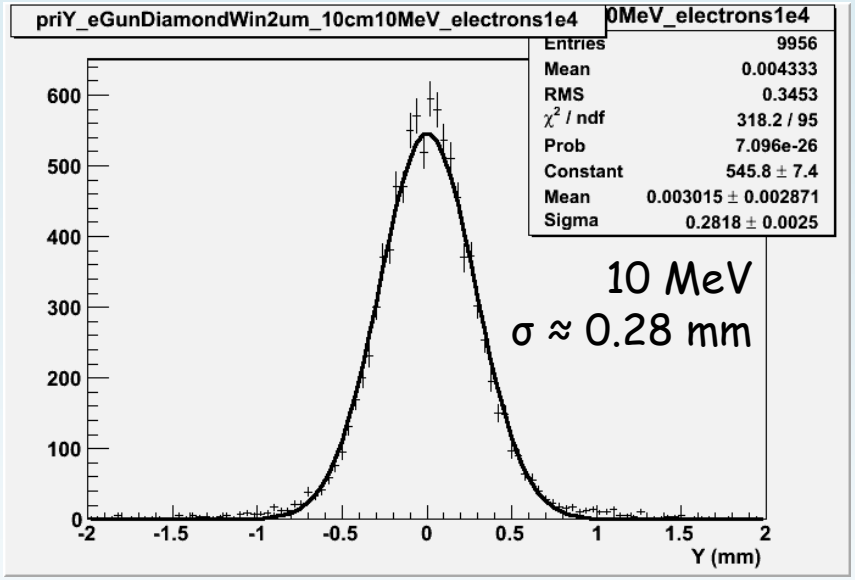


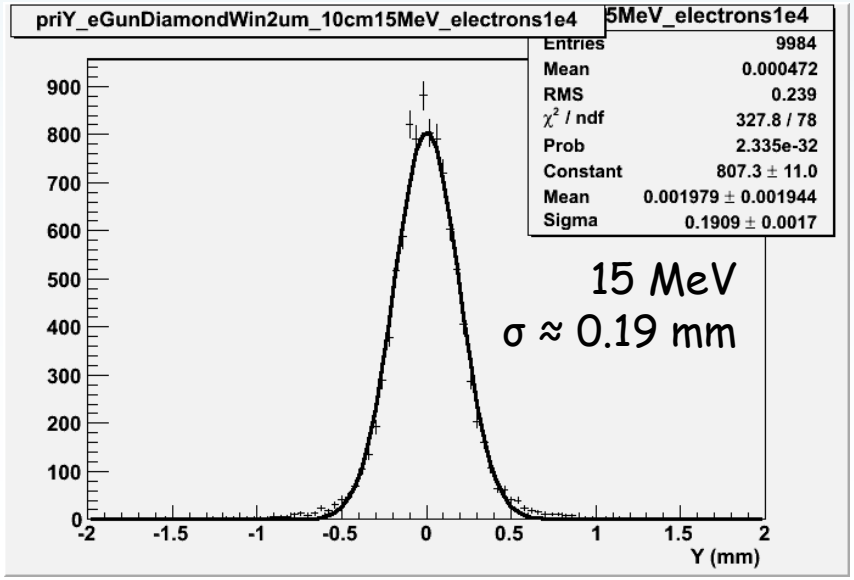


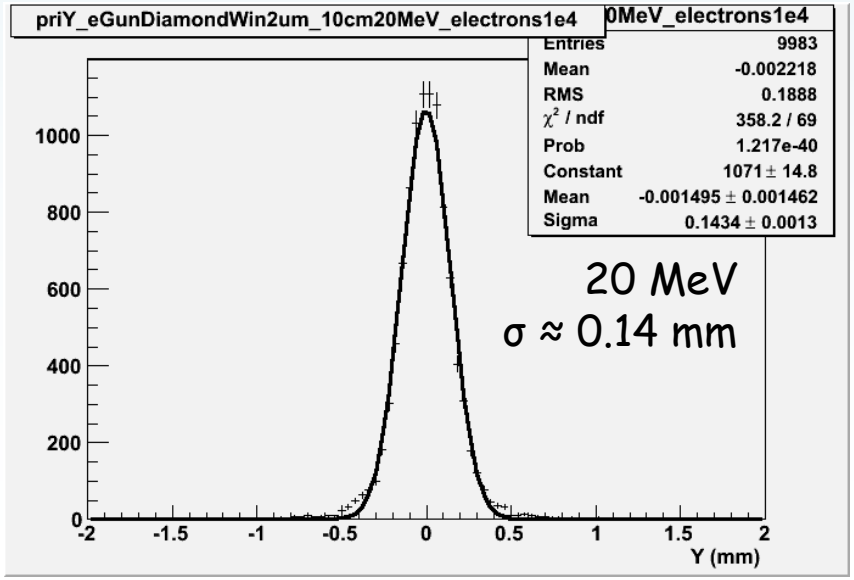


Perpendicular Injection (10cm): Beam Profile (Y projection mm)









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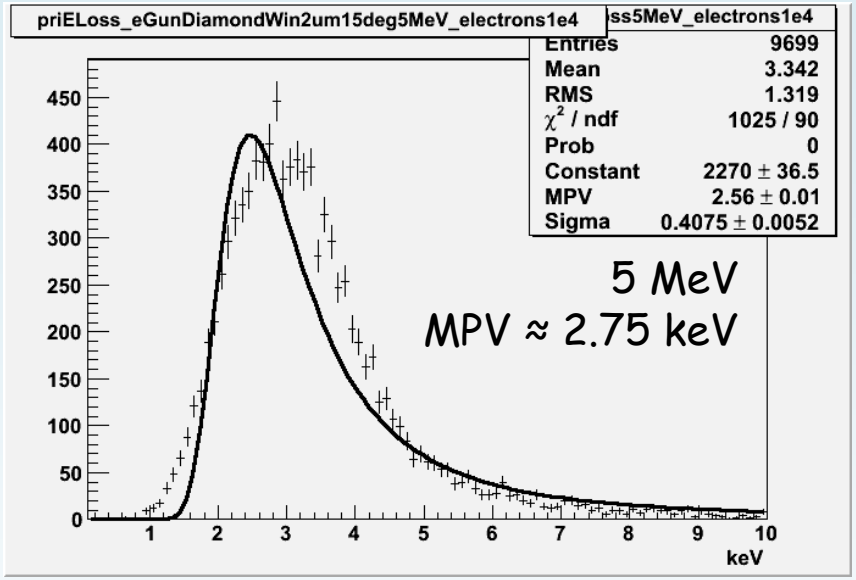
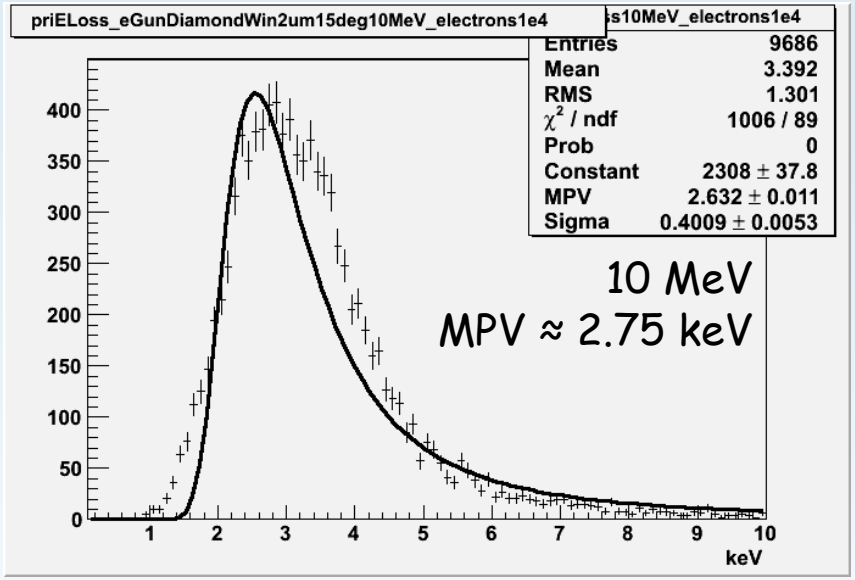
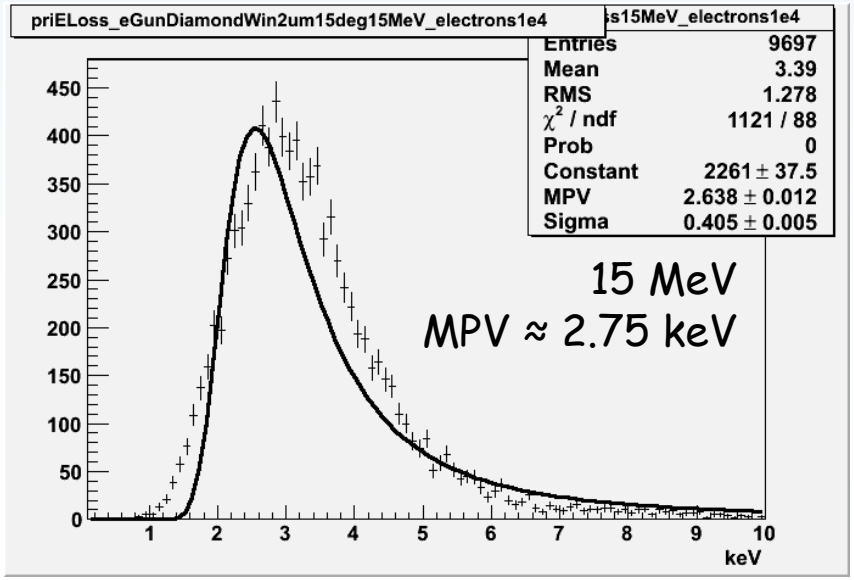
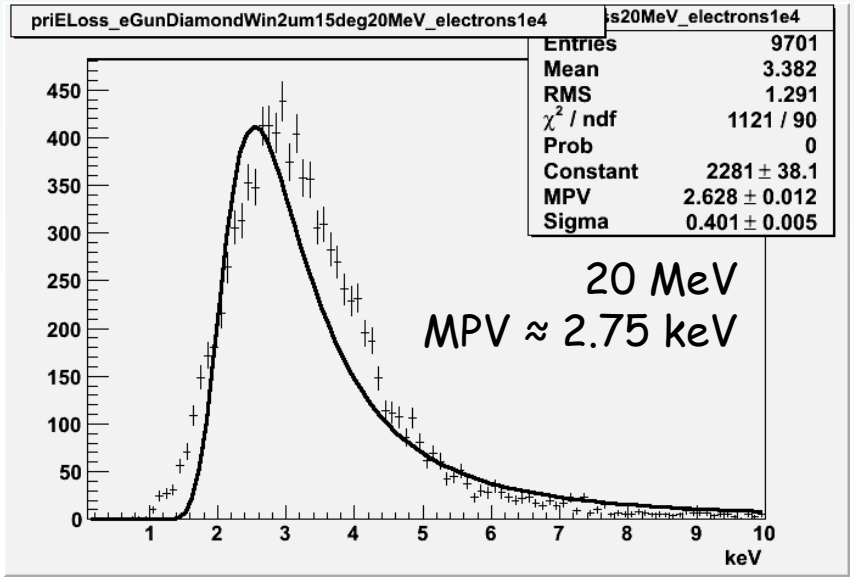
Beam Injection: Large-Angle Injection

Large-Angle Injection (15°): Energy Loss

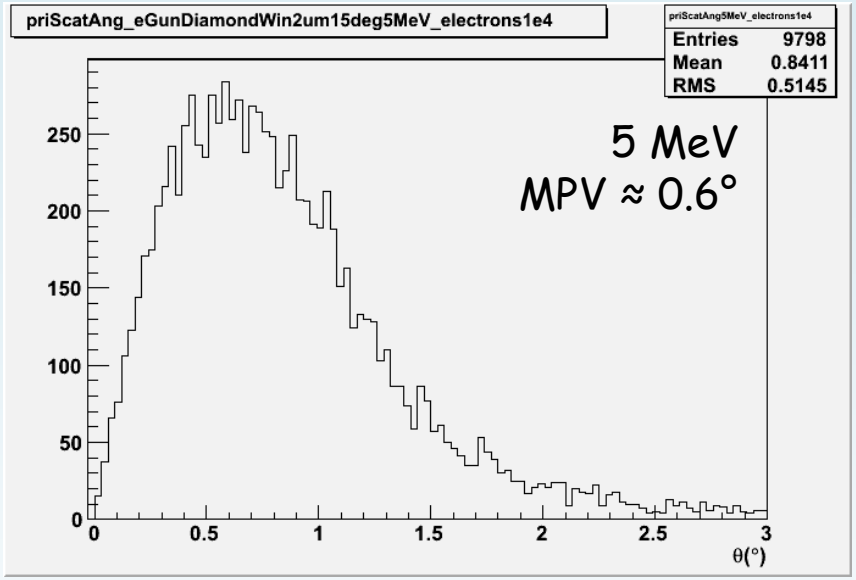


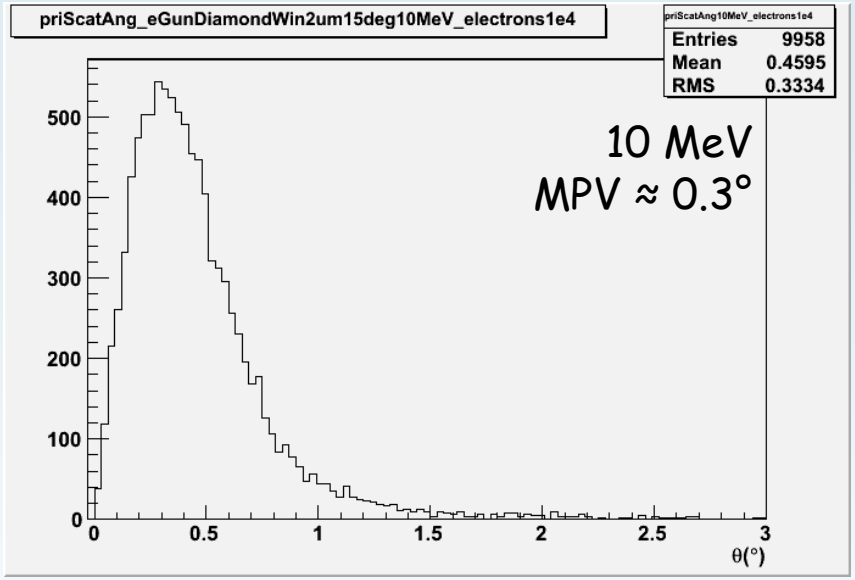


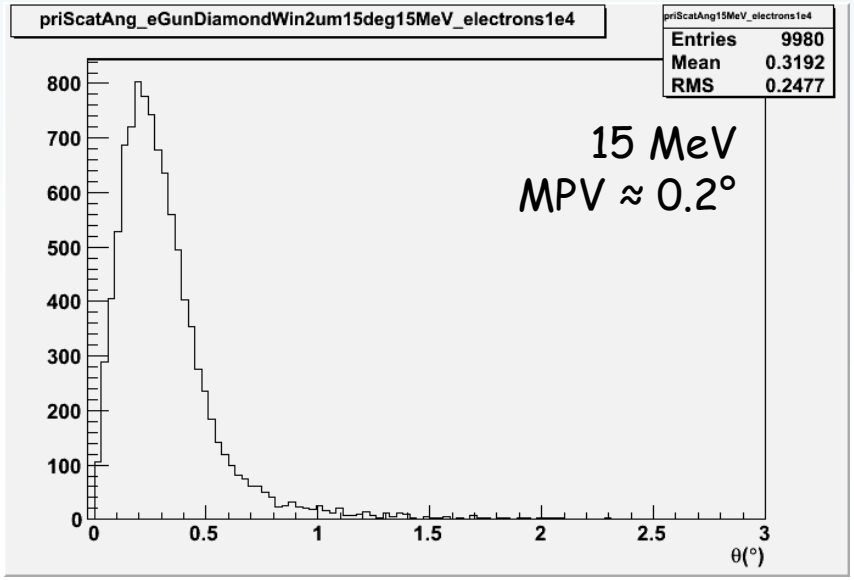


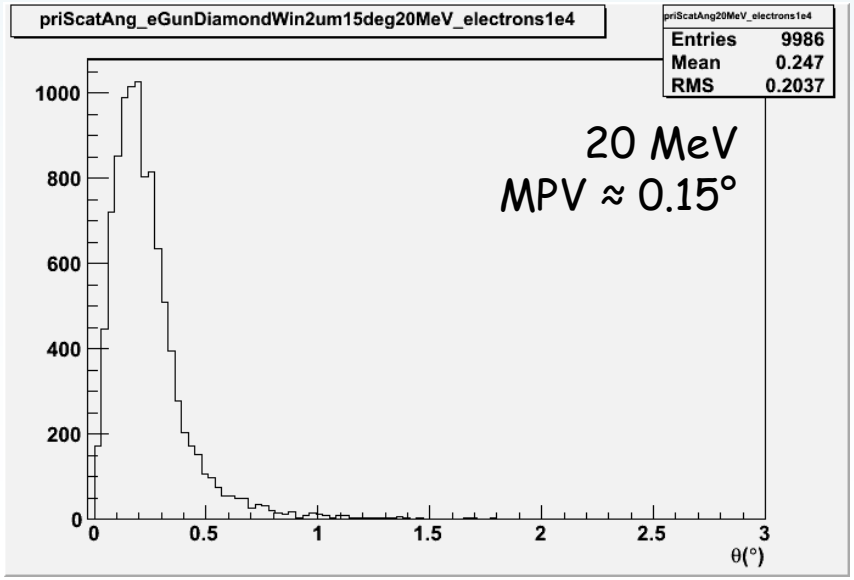


Large-Angle Injection (15°): Scattering Angle

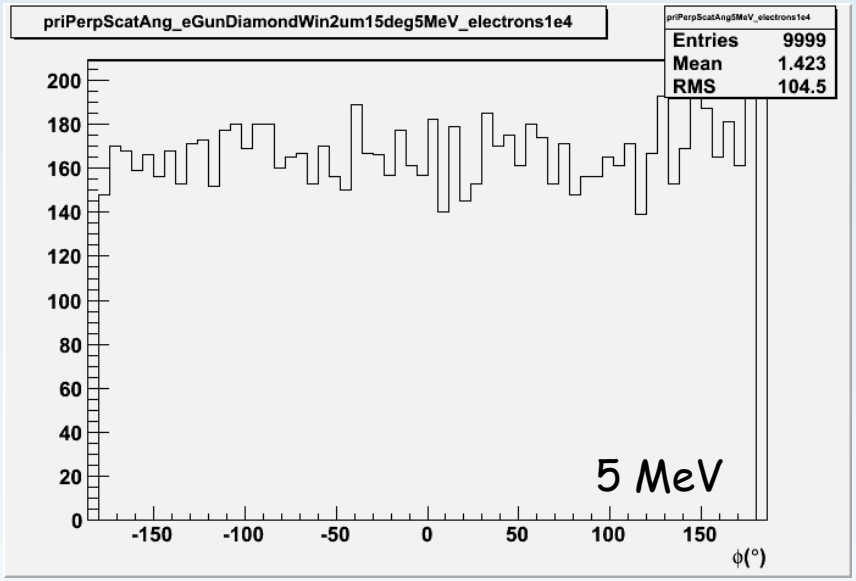


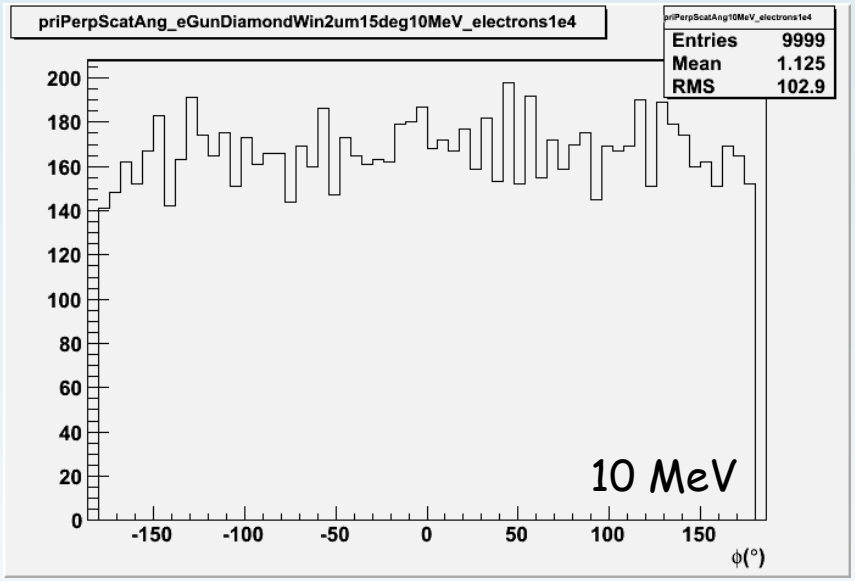


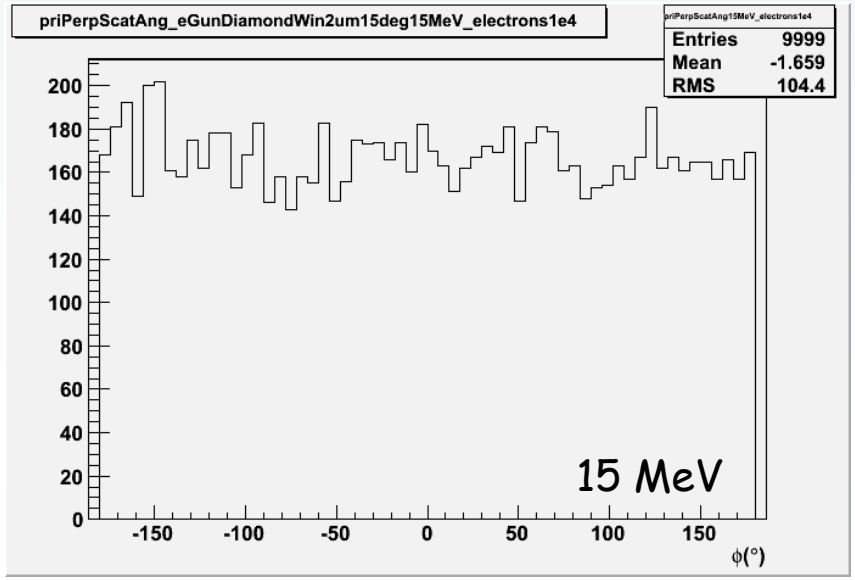


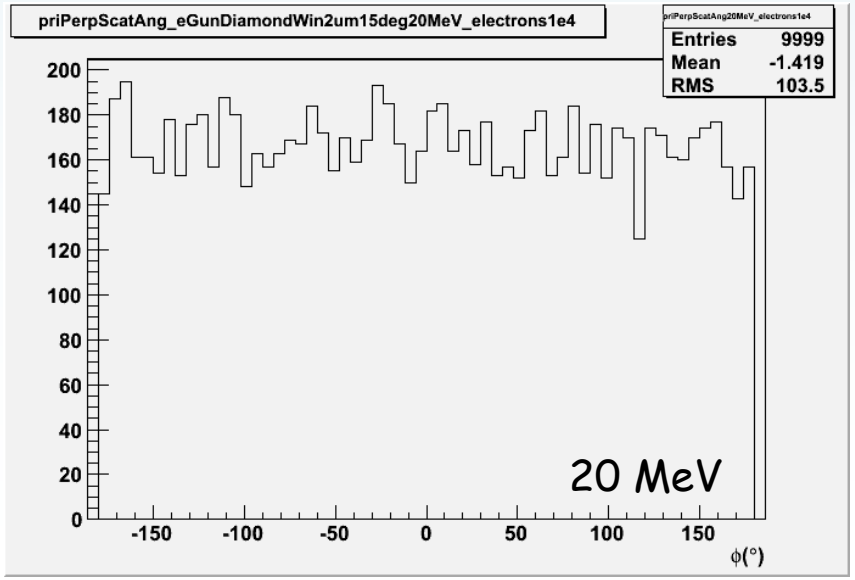


Large-Angle Injection (15°): Perpendicular Scatter

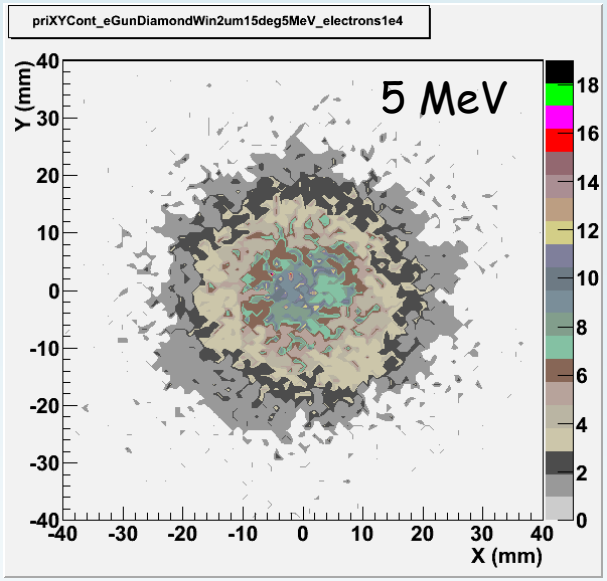


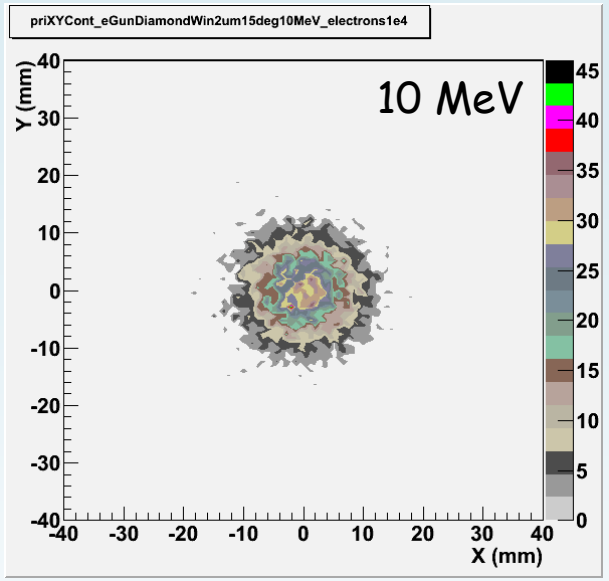


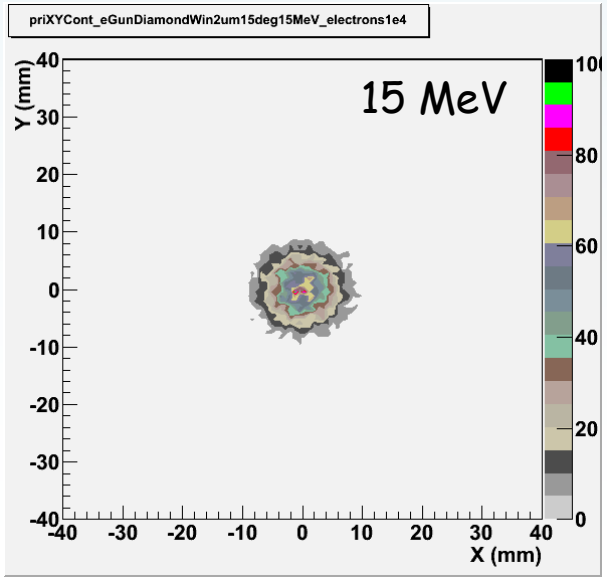


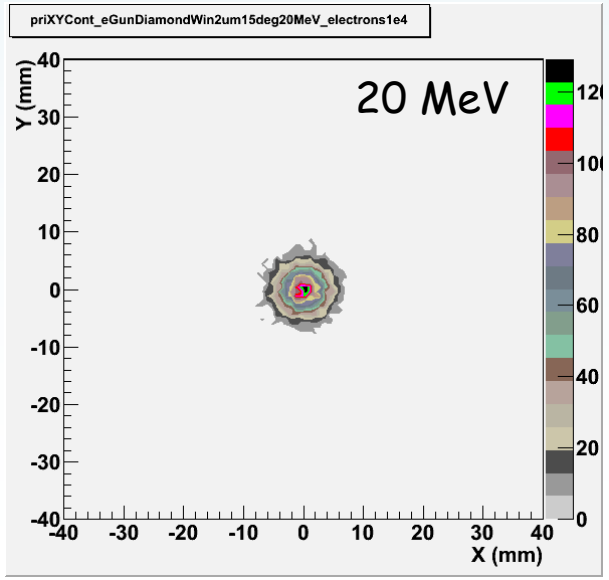


Large-Angle Injection (15°): Beam Profile @ 1m

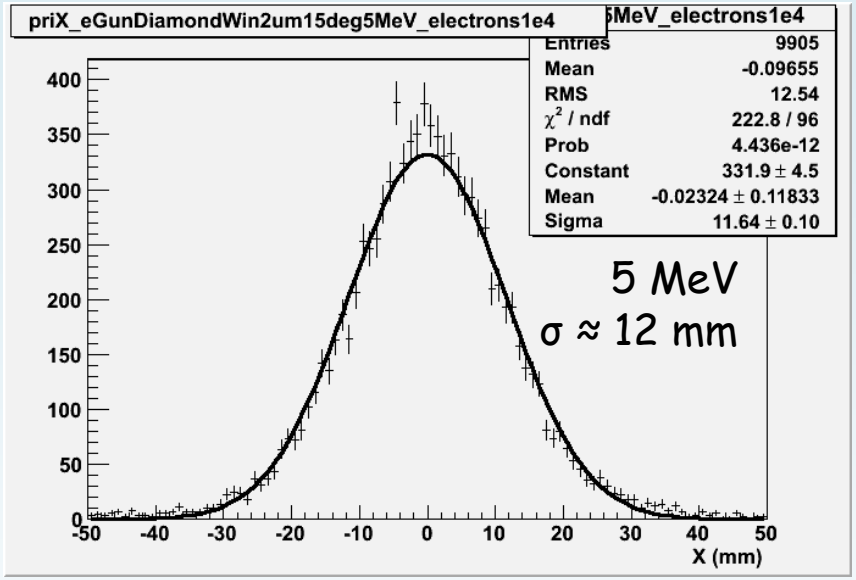


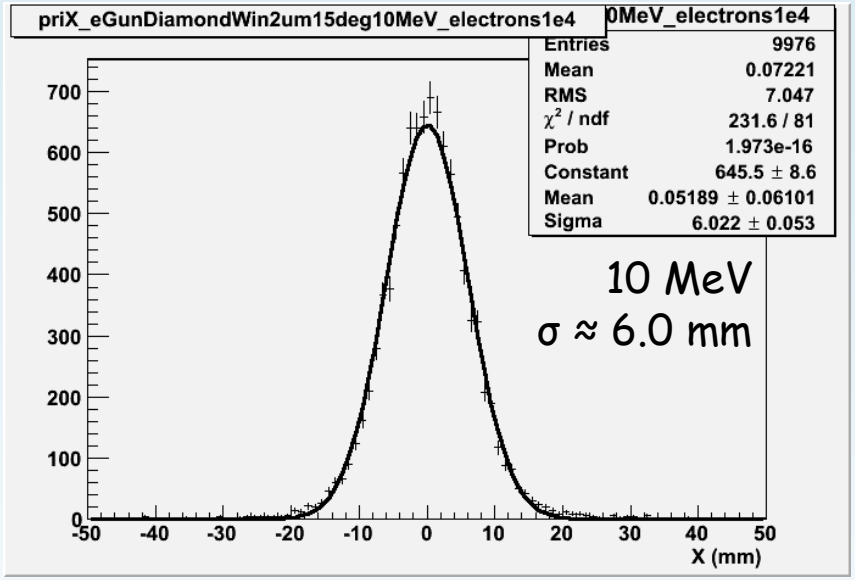


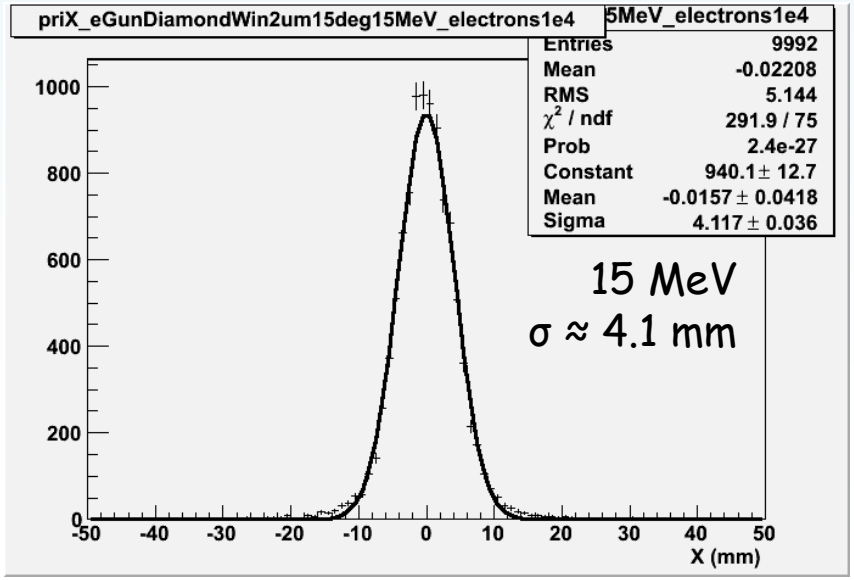


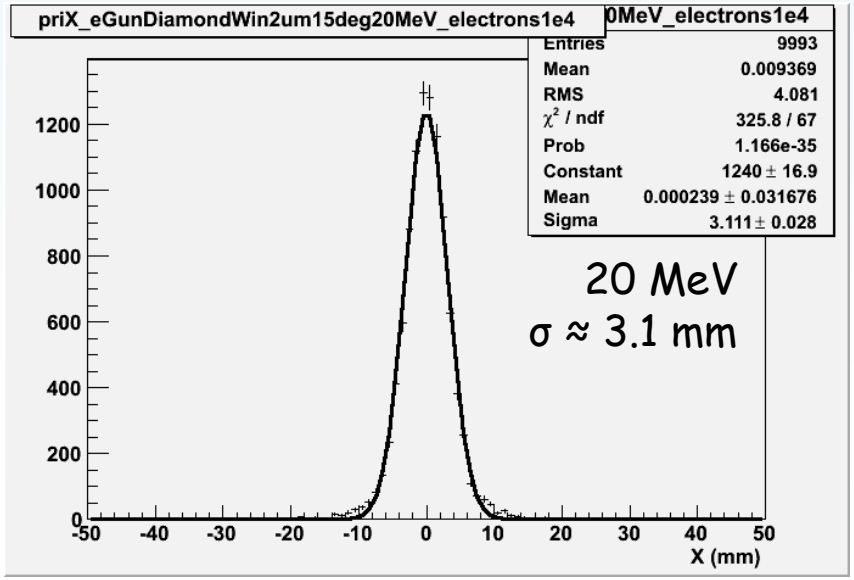


Large-Angle Injection (15°): Beam Profile (X projection) @ 1m

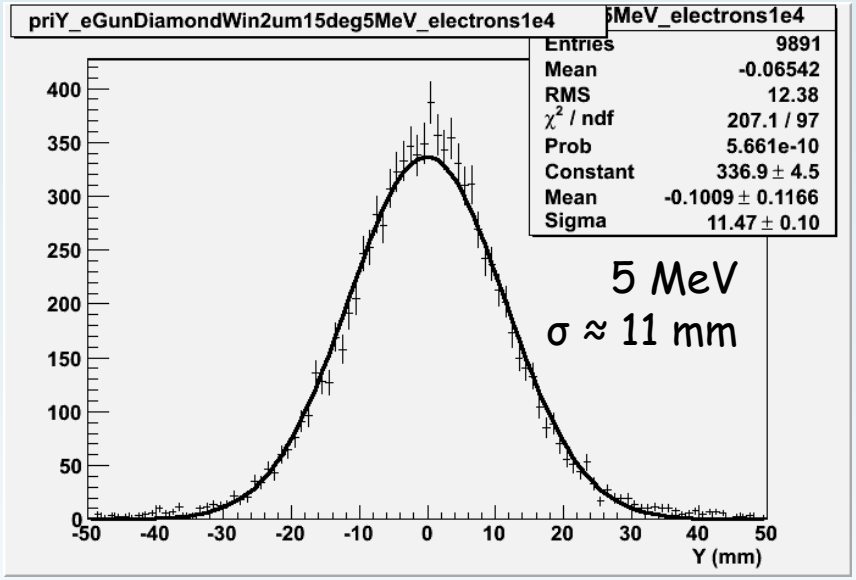


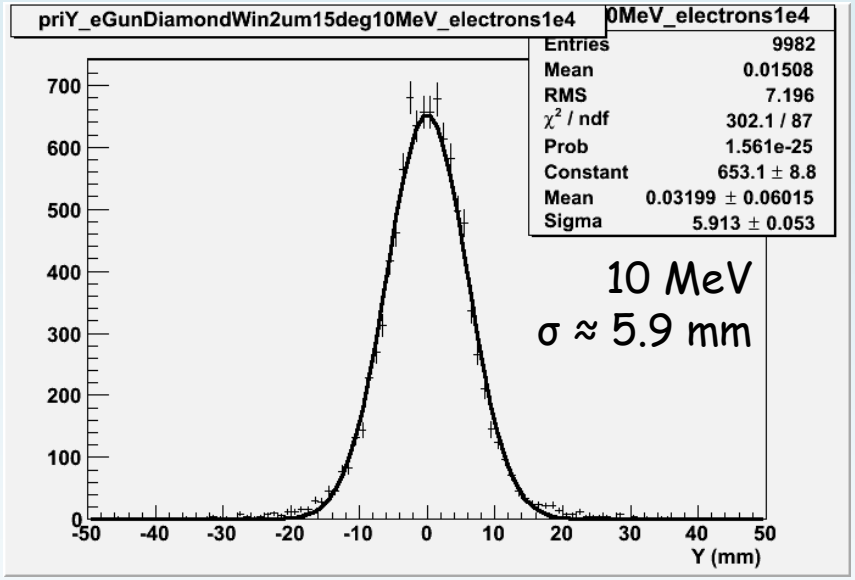


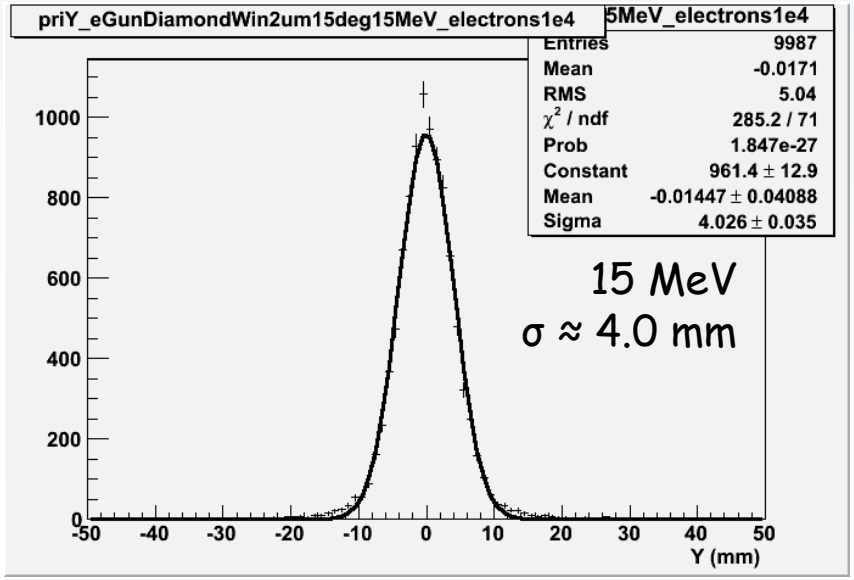


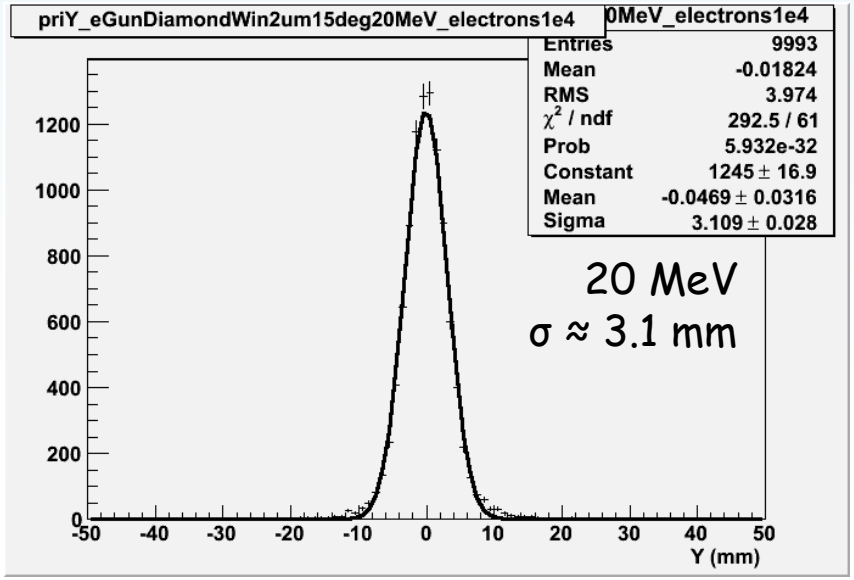


Large-Angle Injection (15°): Beam Profile (Y projection) @ 1m









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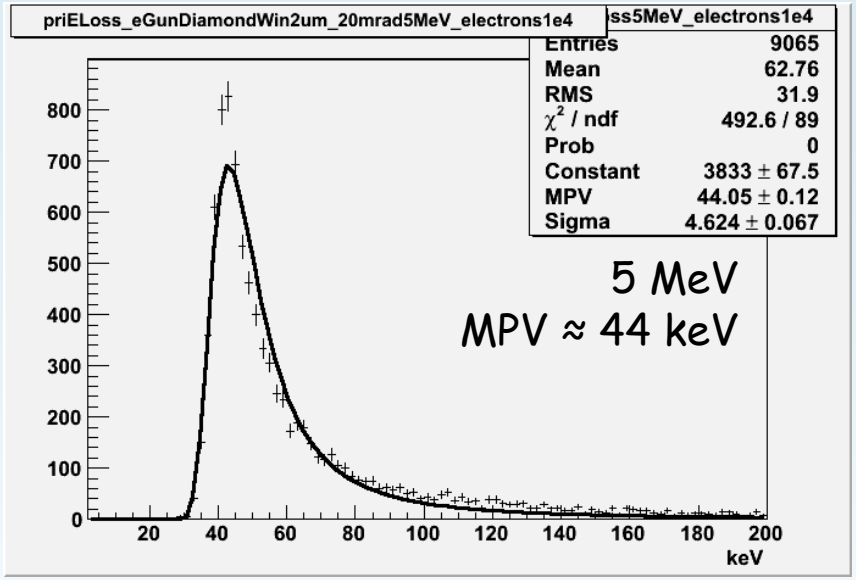
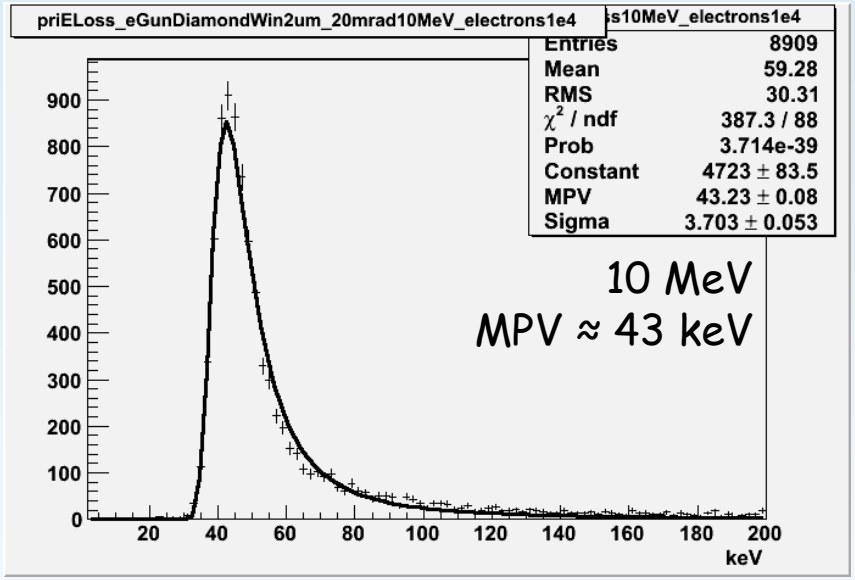
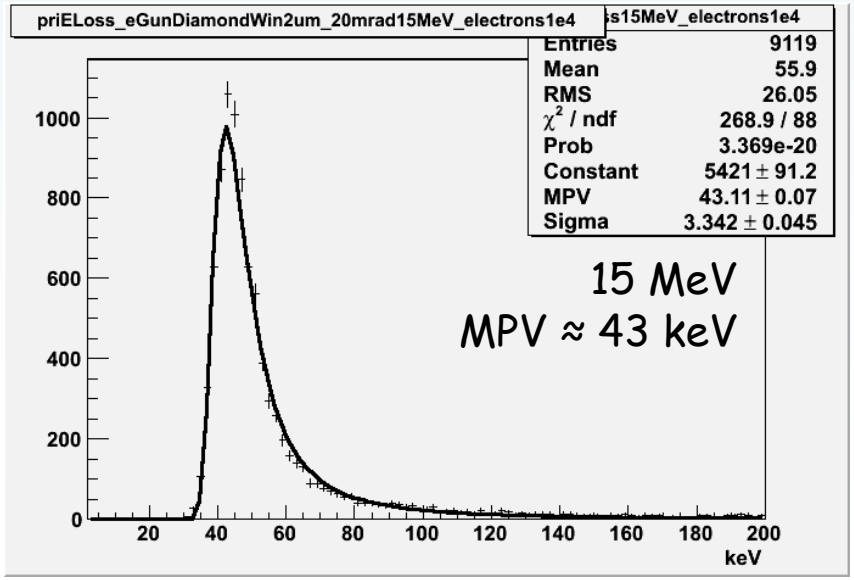
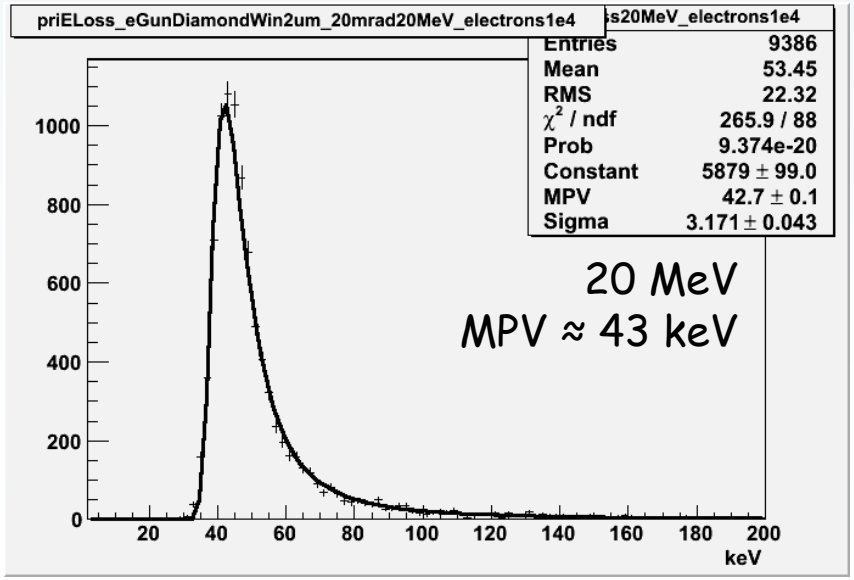
Beam Injection: Shallow-Angle Injection

Shallow-Angle Injection (20mrad): Energy Loss

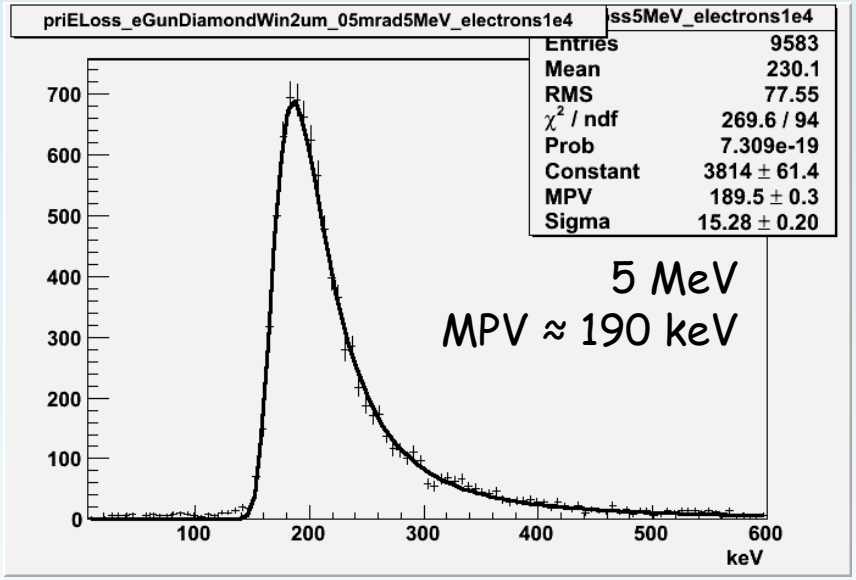


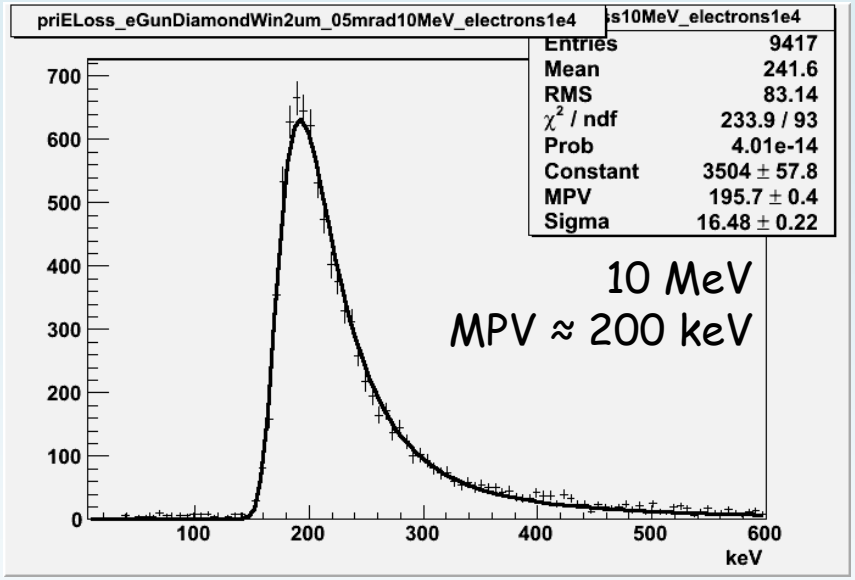


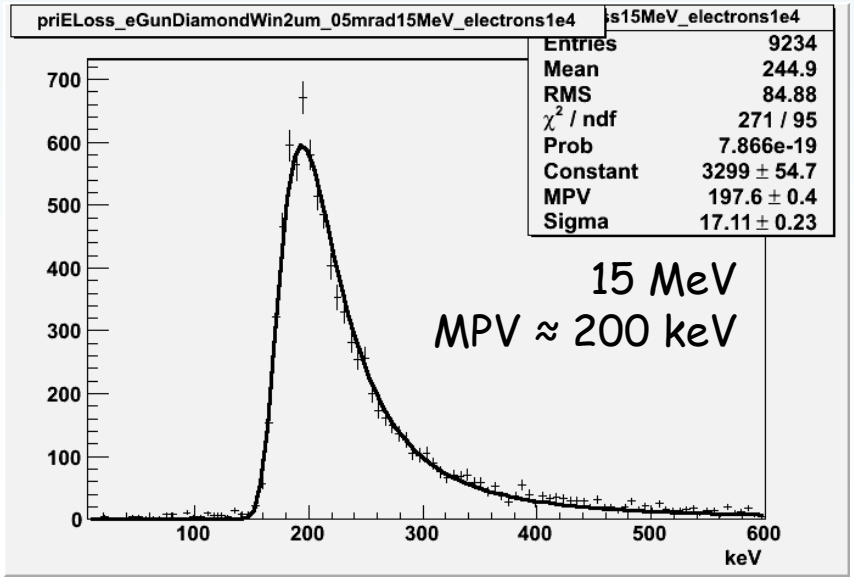


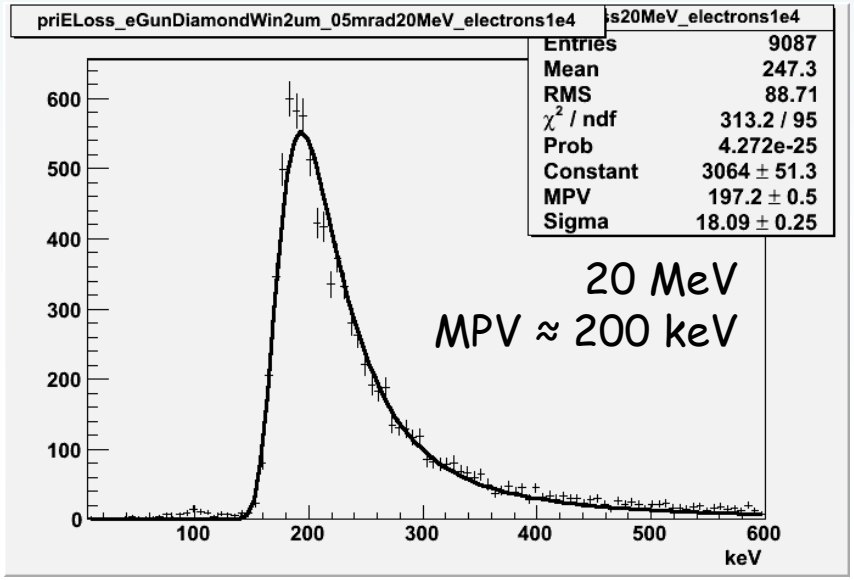


Shallow-Angle Injection (5mrad): Energy Loss

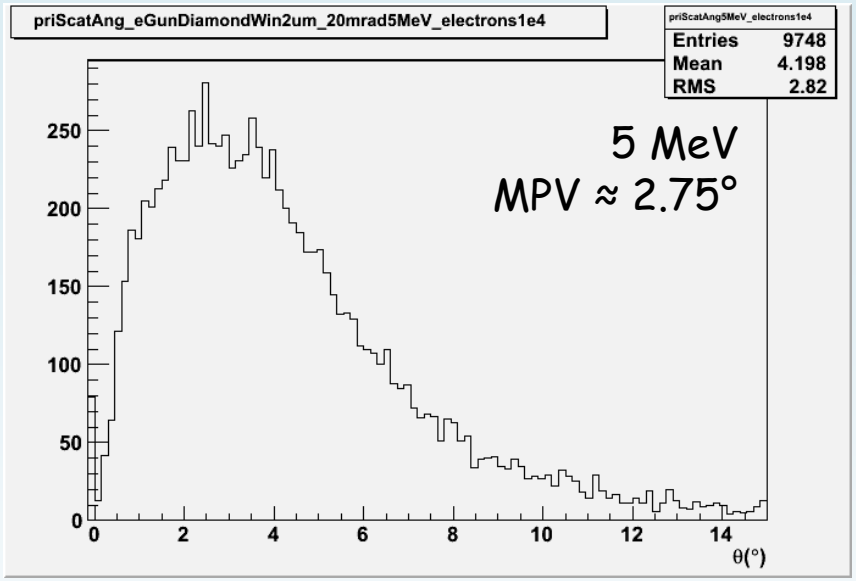


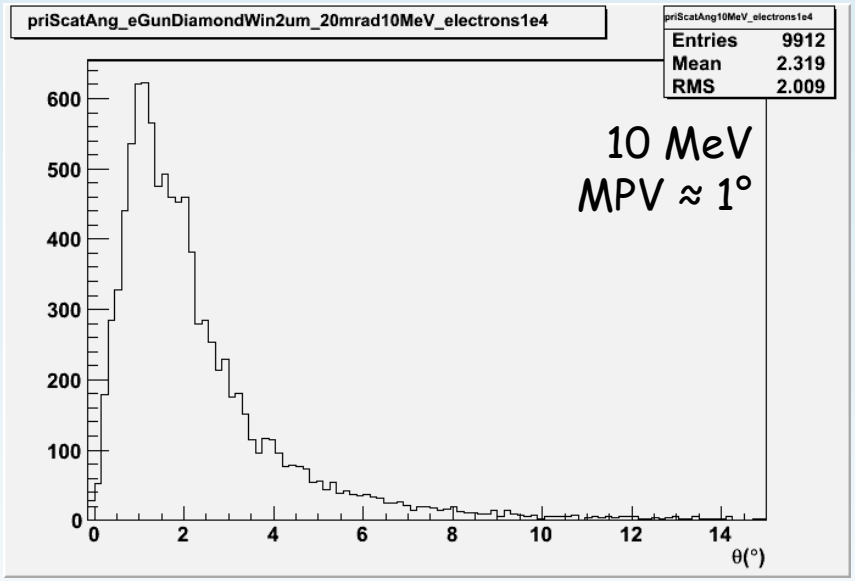


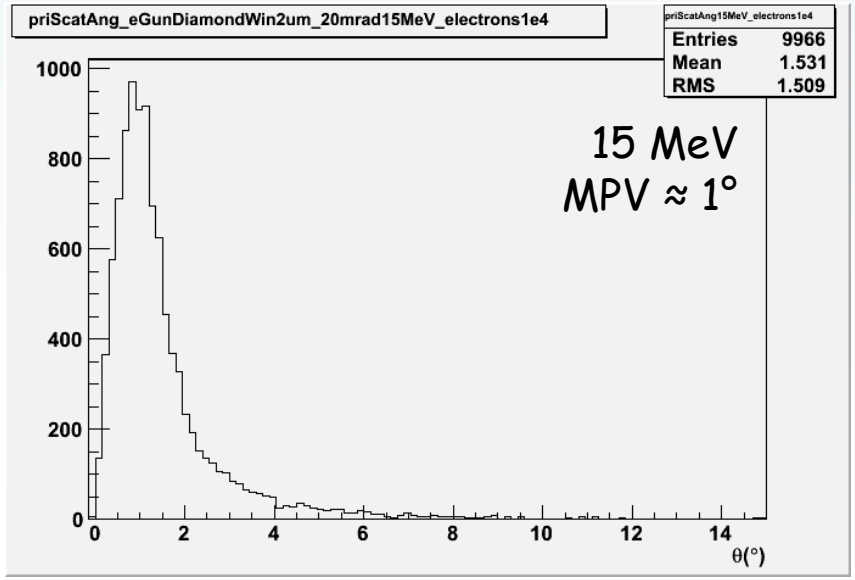


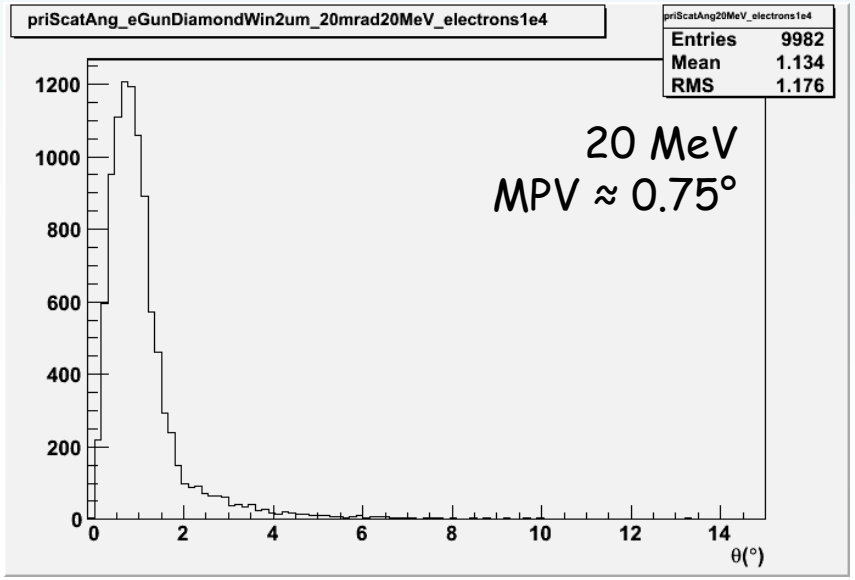


Shallow-Angle Injection (20mrad): Scattering Angle

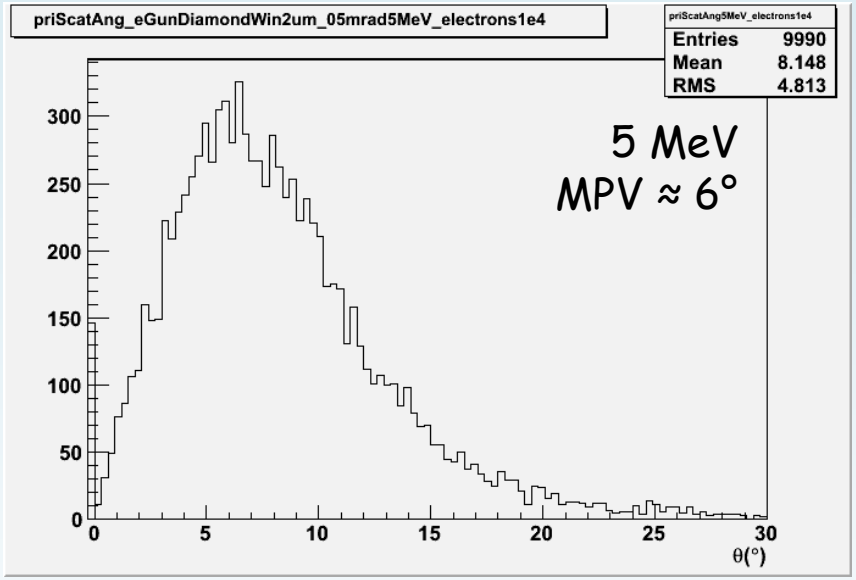


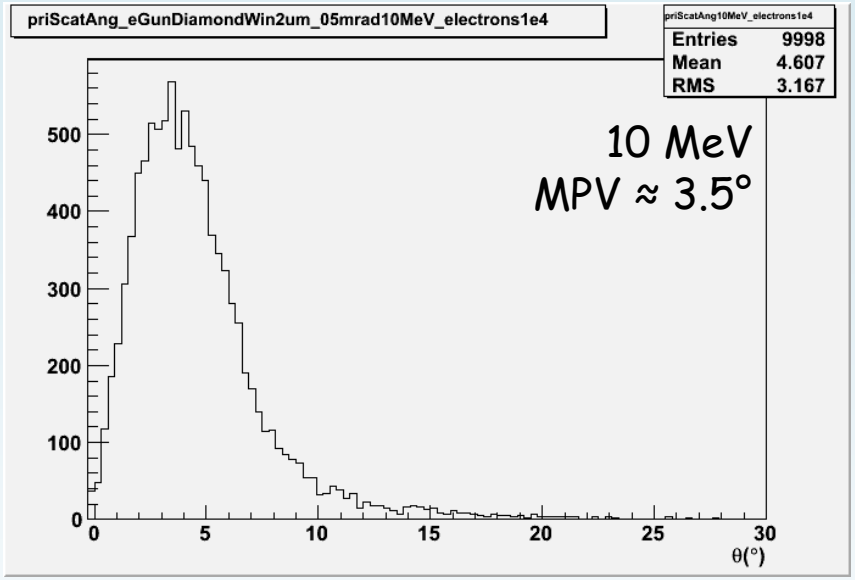


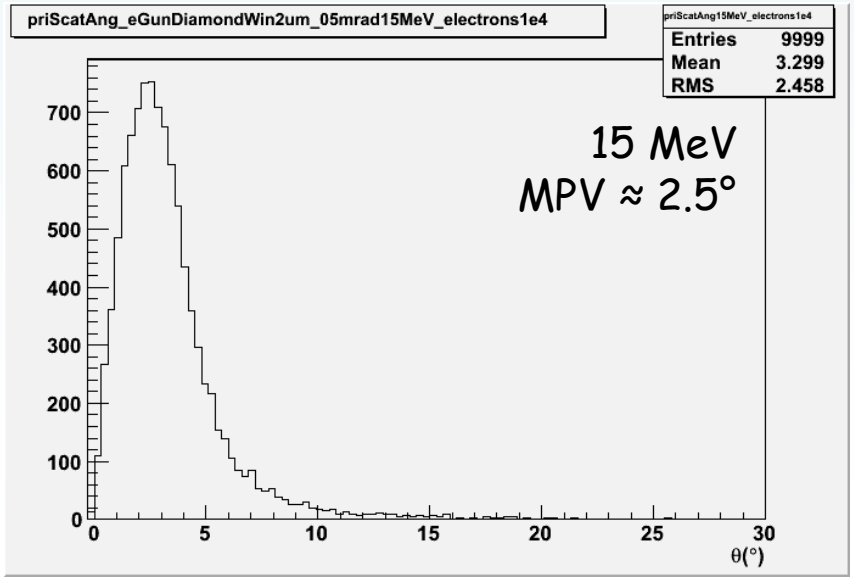


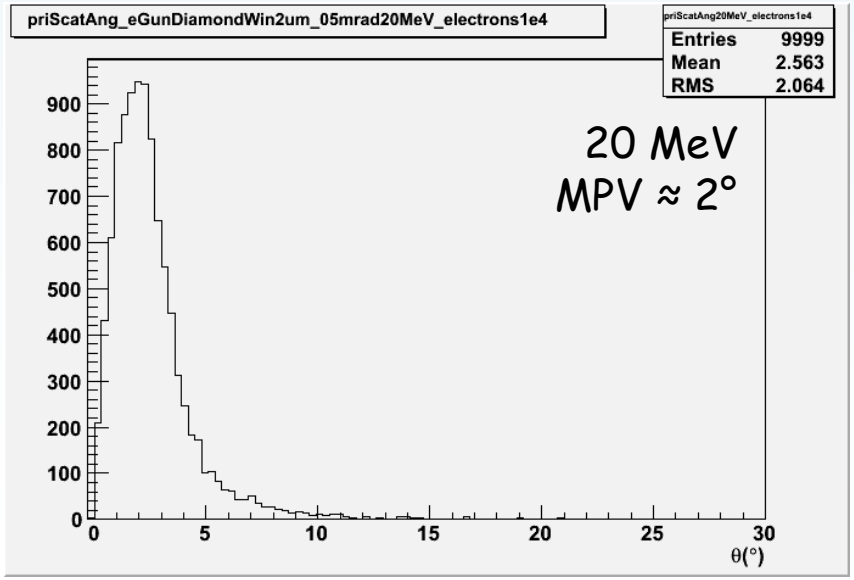


Shallow-Angle Injection (5mrad): Scattering Angle

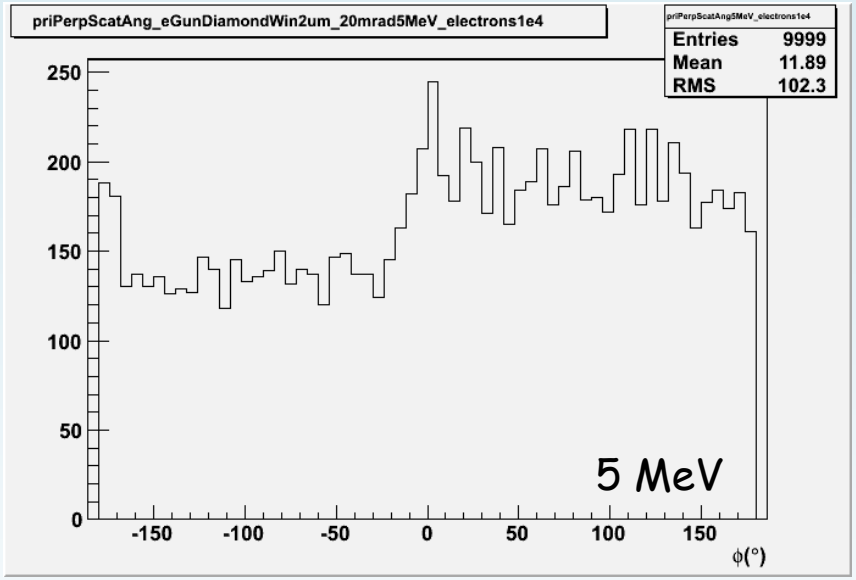


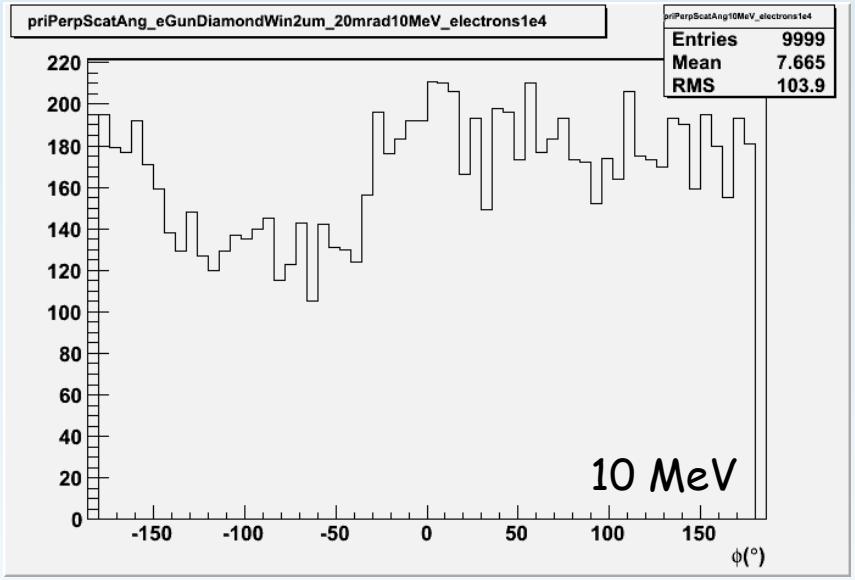


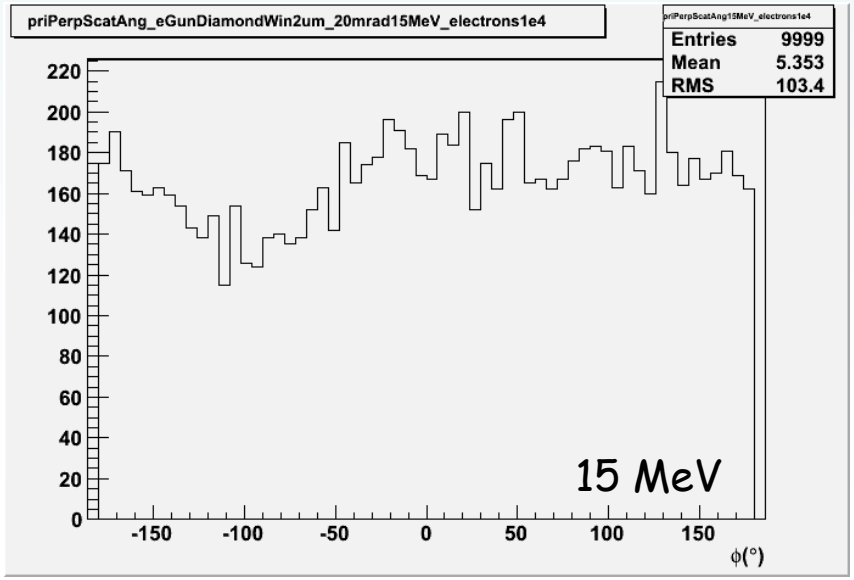


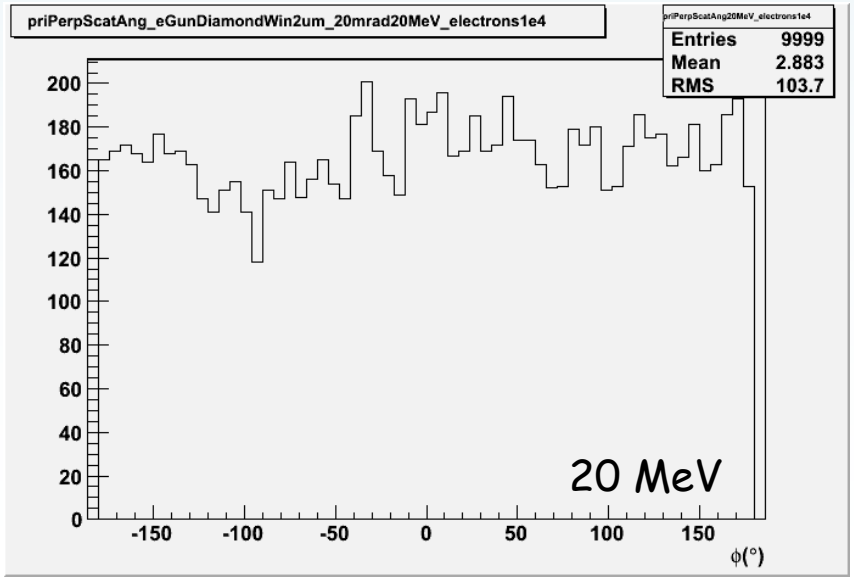


Shallow-Angle Injection (20mrad): Perpendicular Scatter

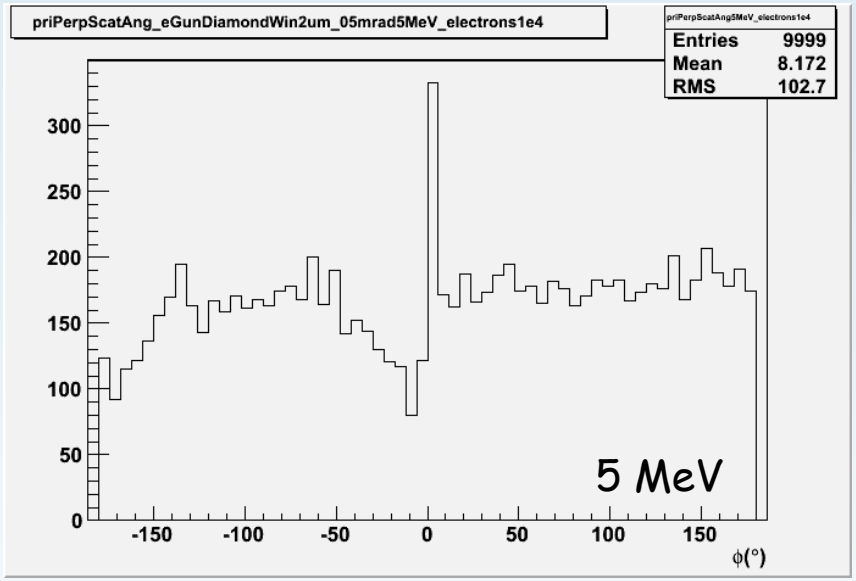


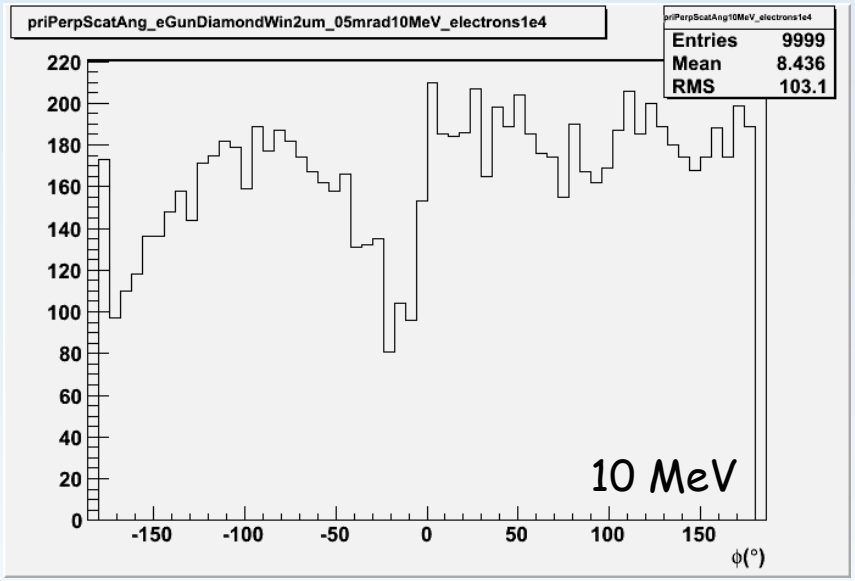


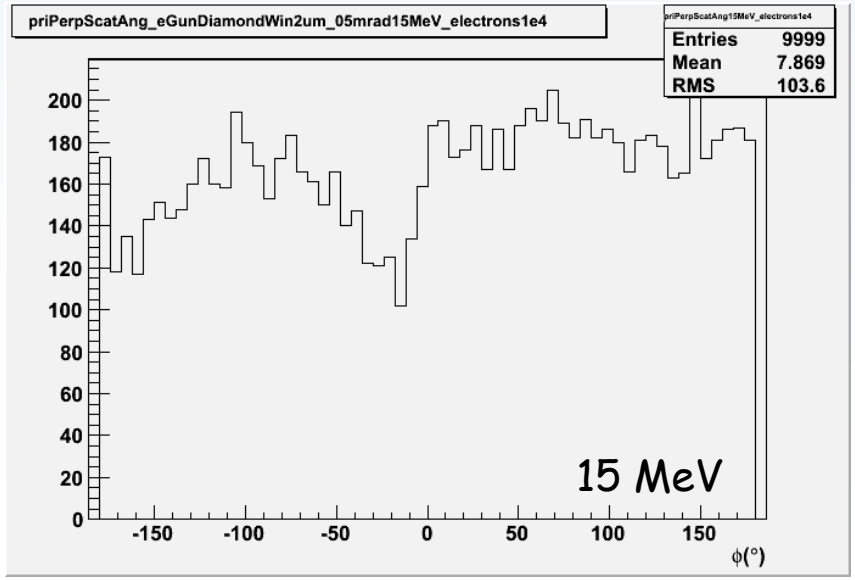


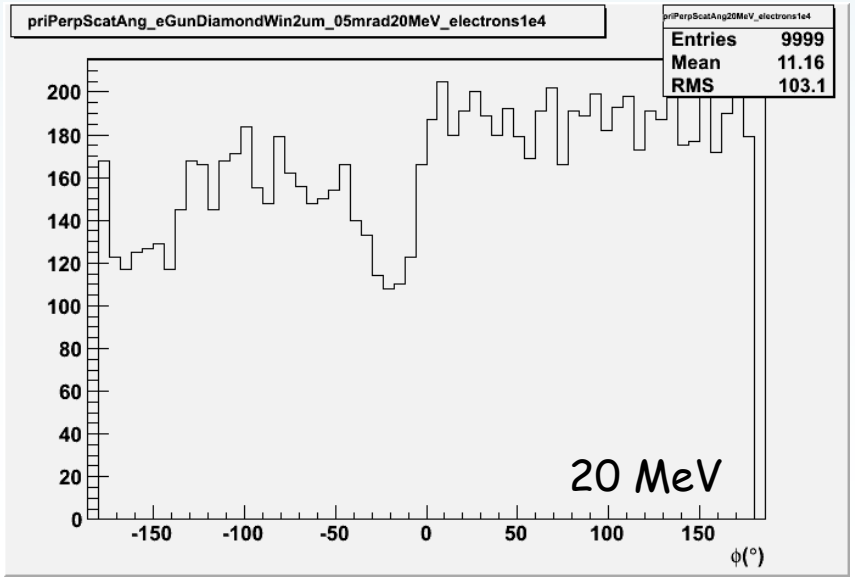


Shallow-Angle Injection (5mrad): Perpendicular Scatter

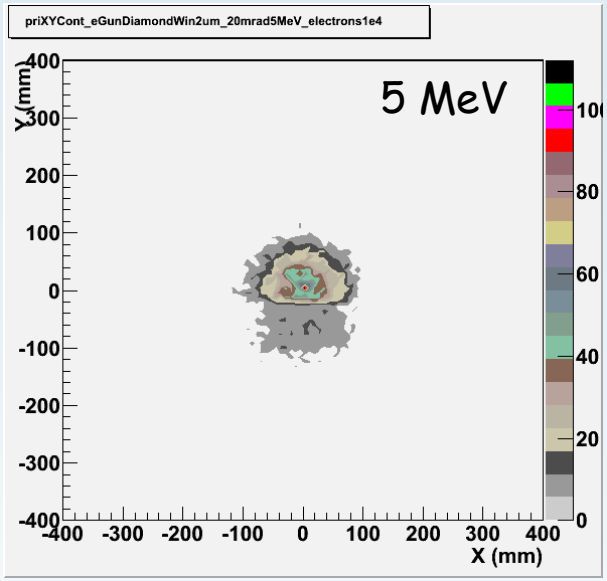


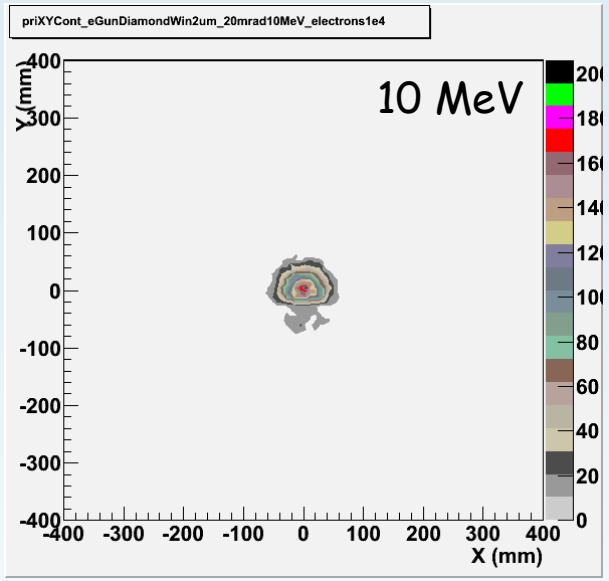


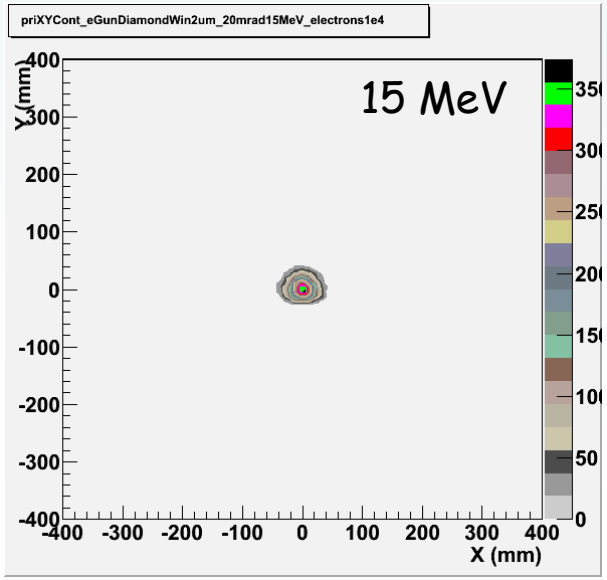


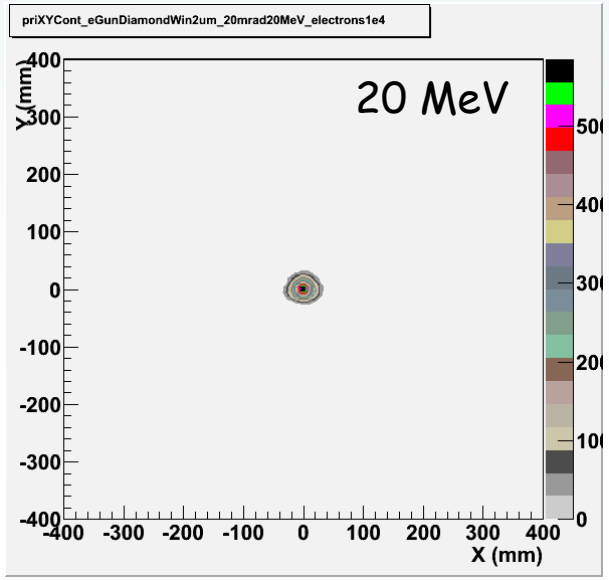


Shallow-Angle Injection (20mrad): Beam Profile @ 1m

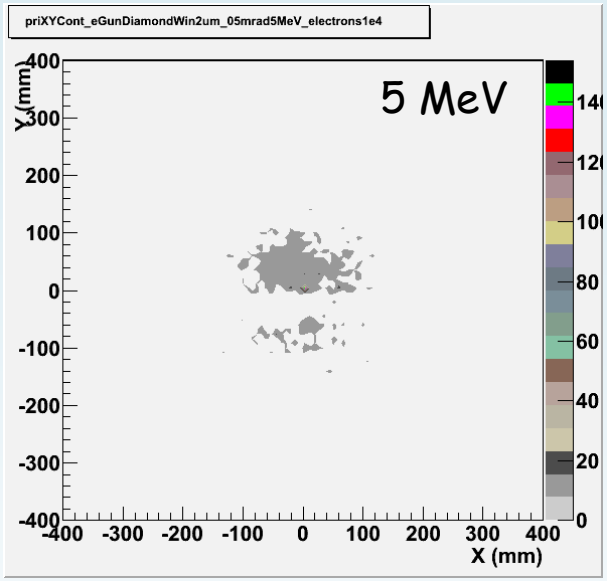


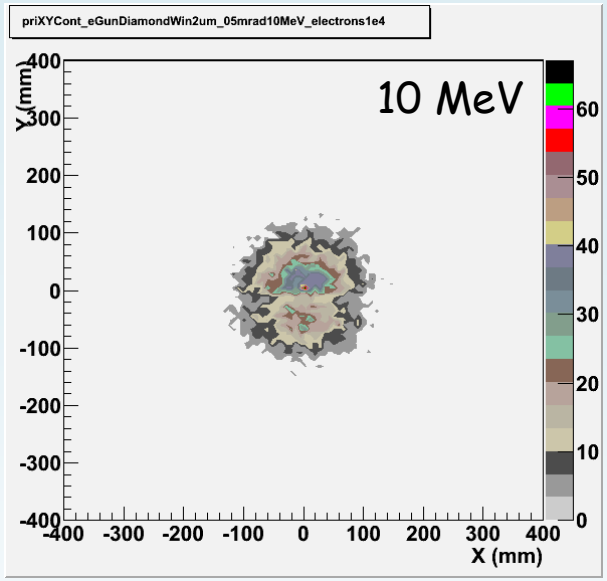


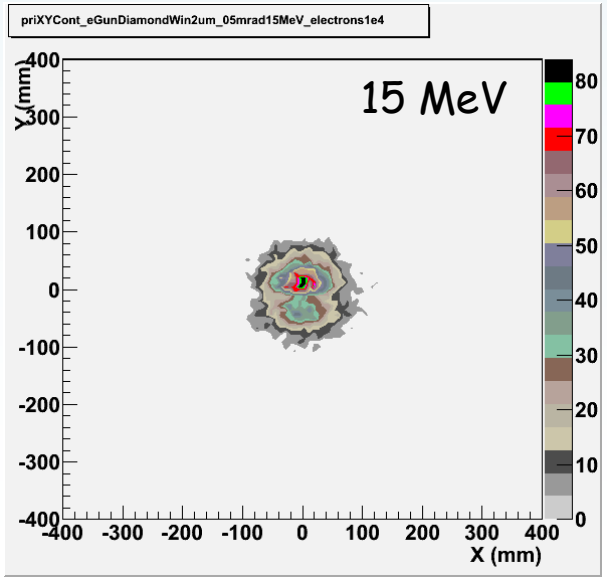


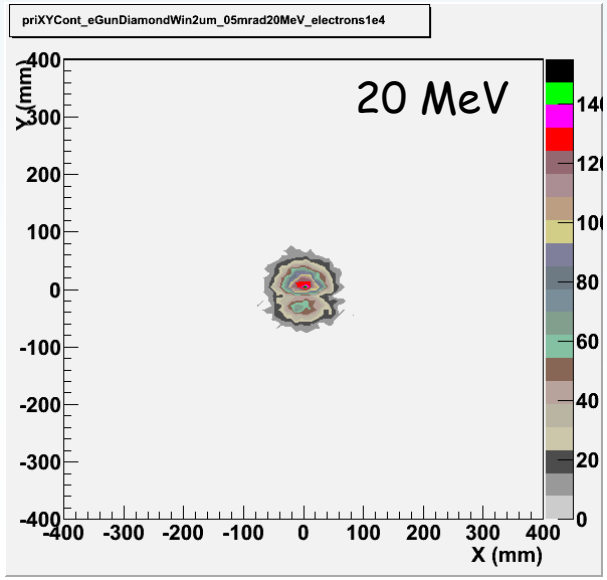


Shallow-Angle Injection (5mrad): Beam Profile @ 1m

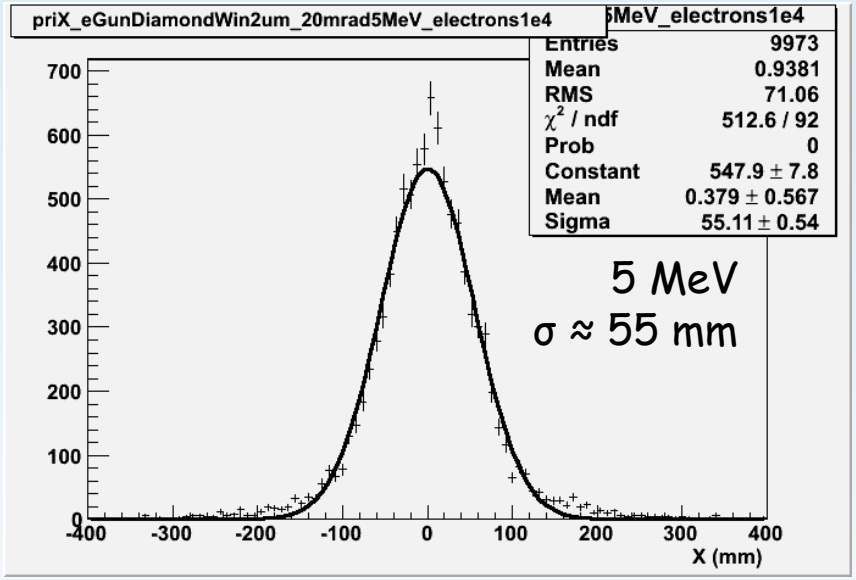


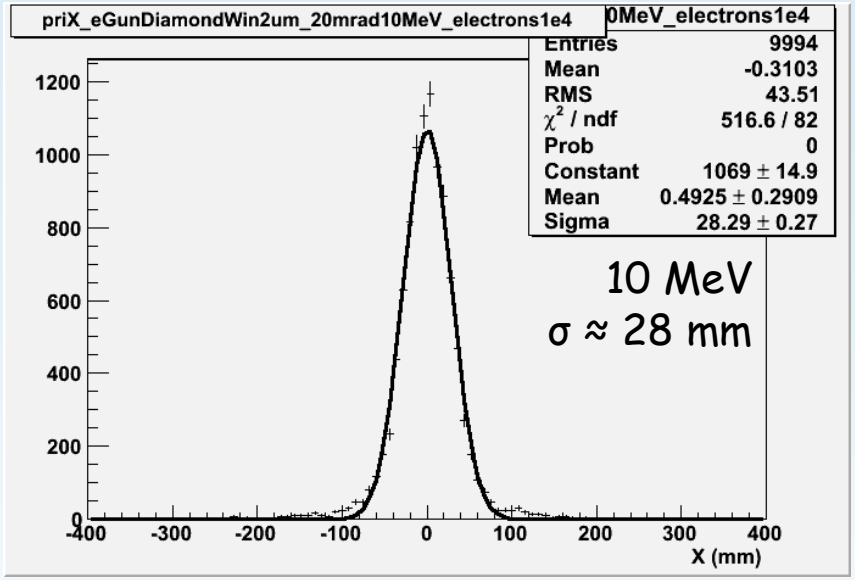


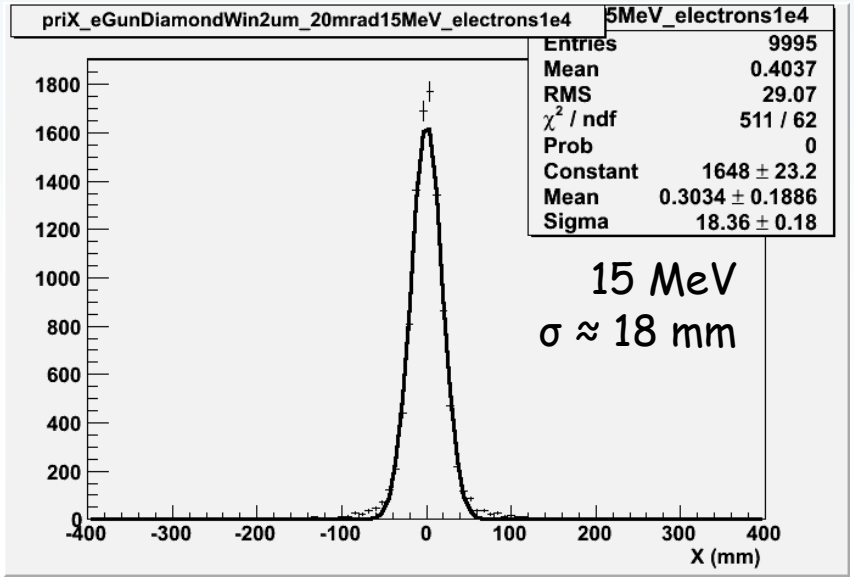


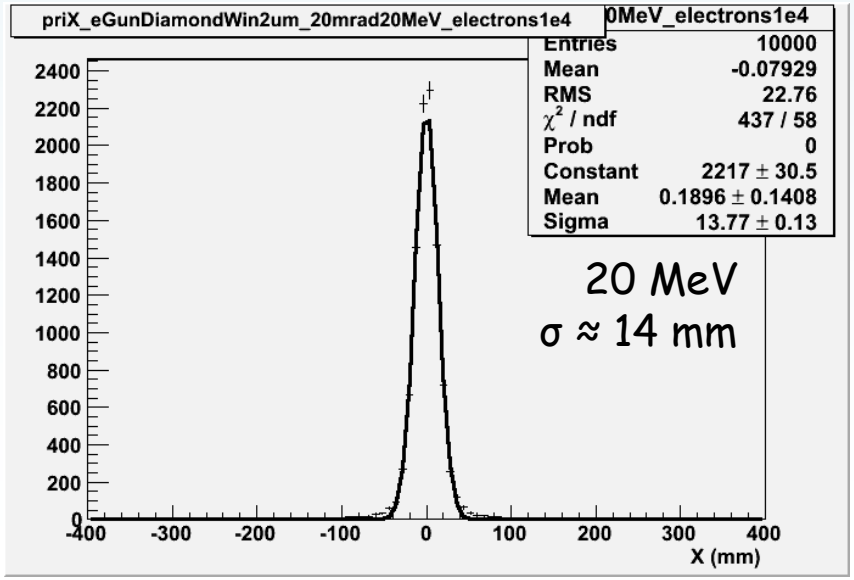


Shallow-Angle Injection (20mrad): Beam Profile (X projection) @ 1m

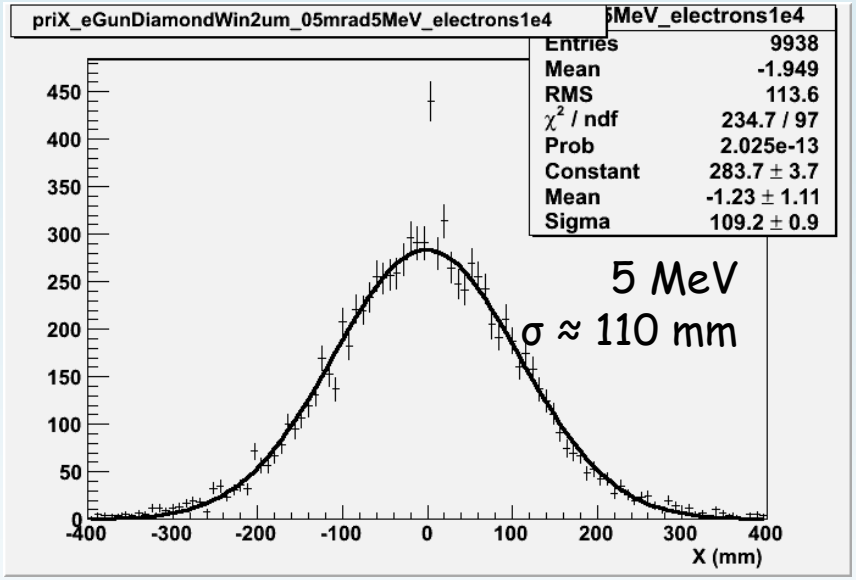


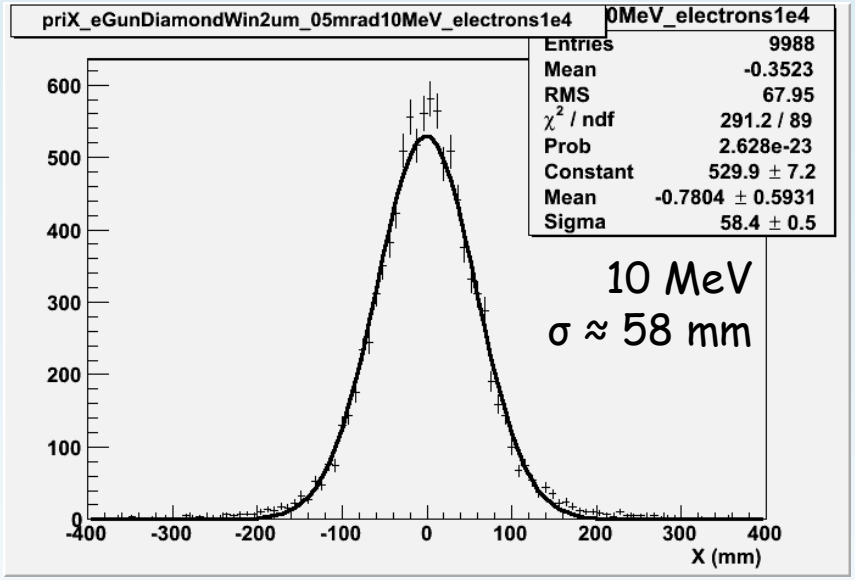


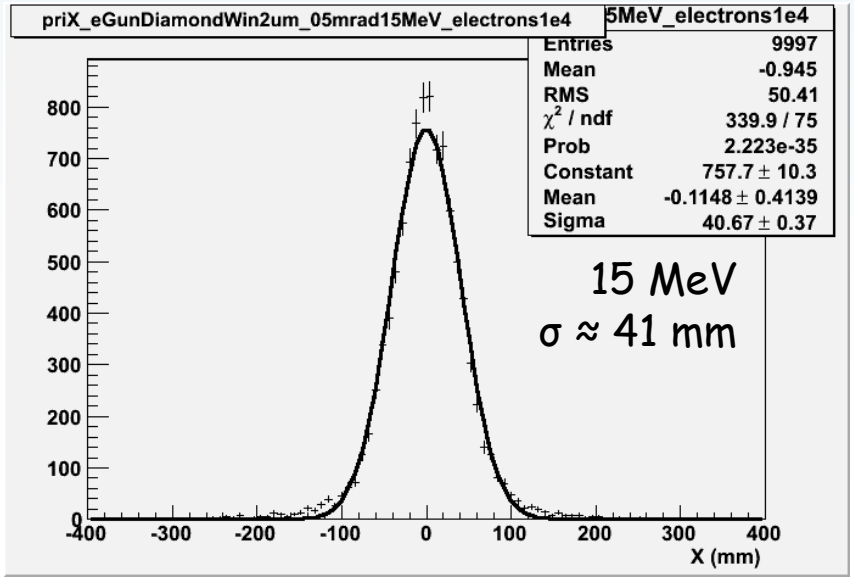


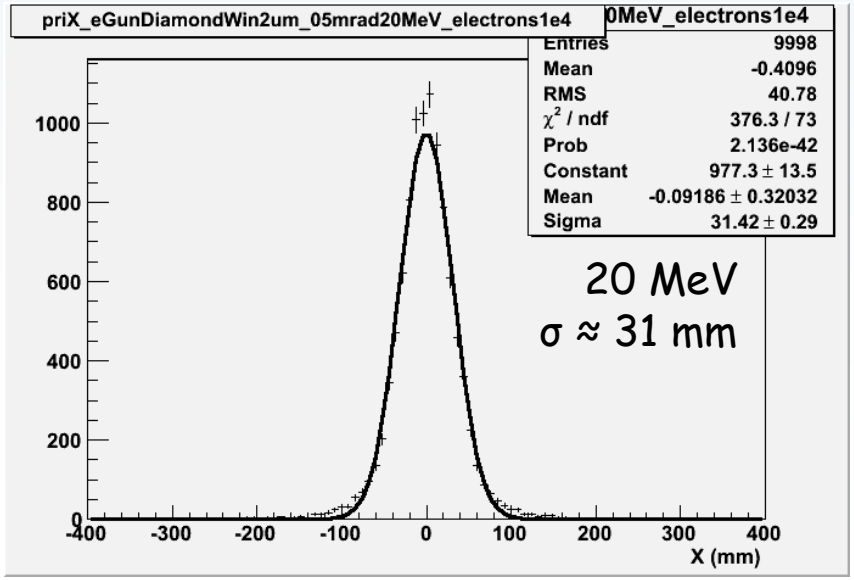


Shallow-Angle Injection (5mrad): Beam Profile (X projection) @ 1m

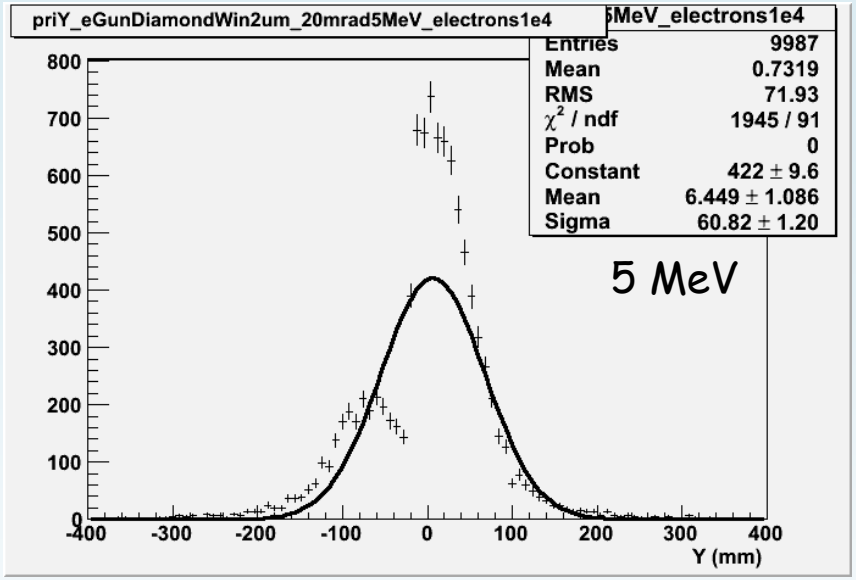


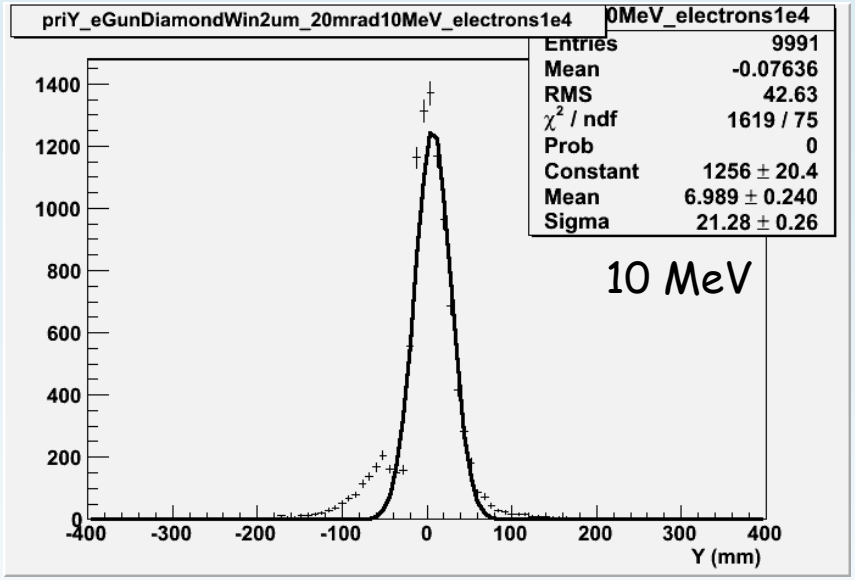


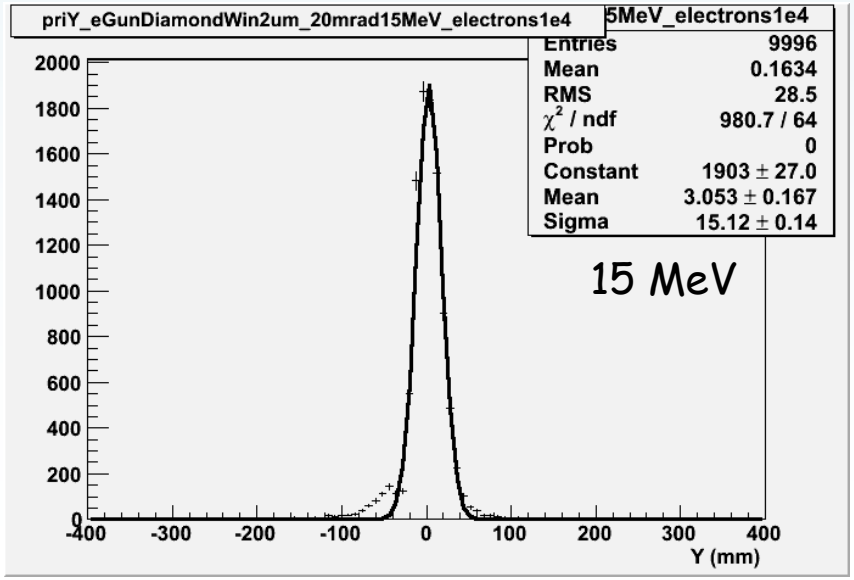


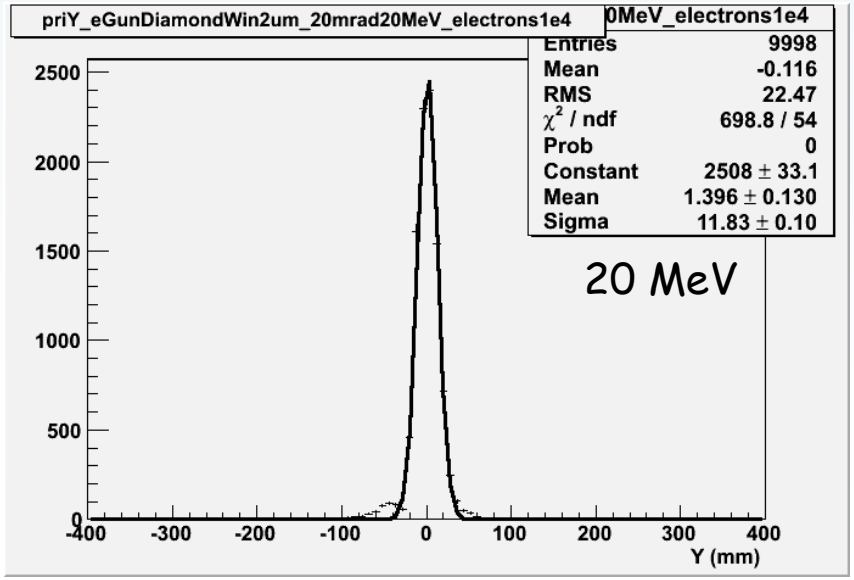


Shallow-Angle Injection (20mrad): Beam Profile (Y projection) @ 1m

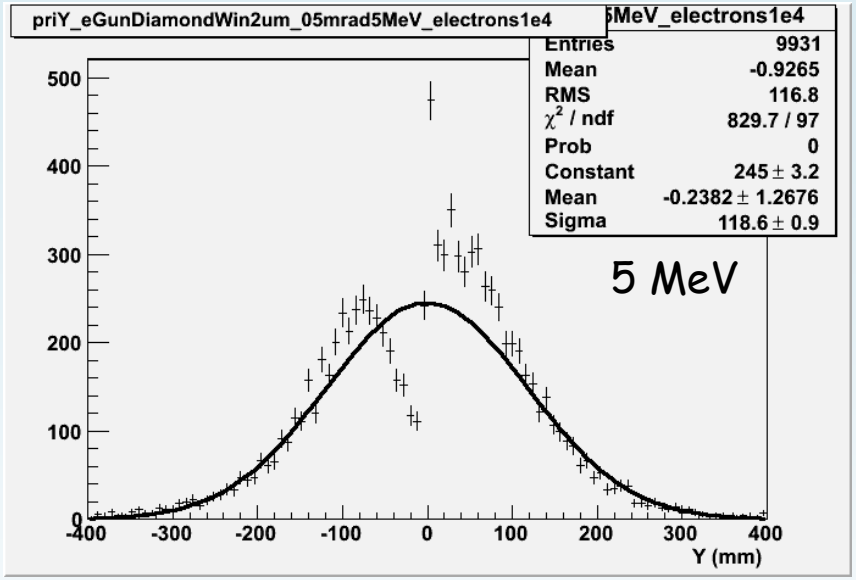


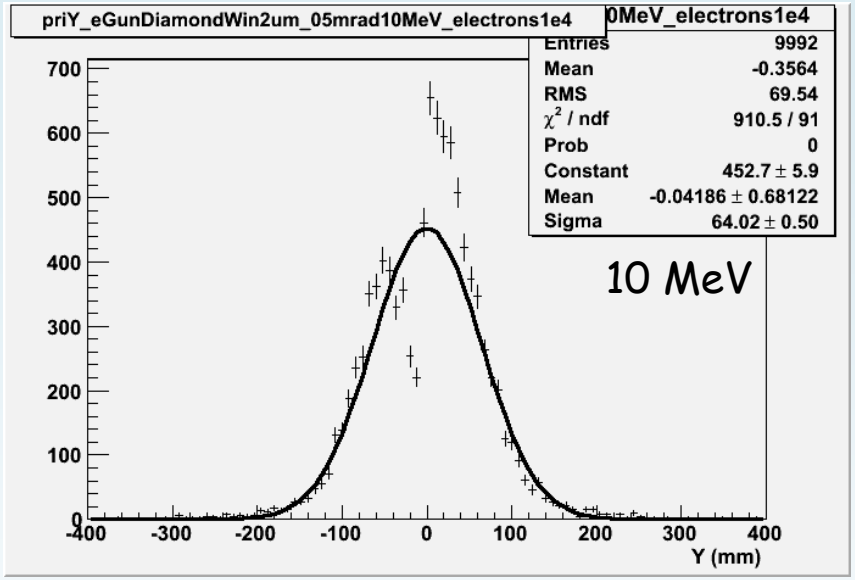


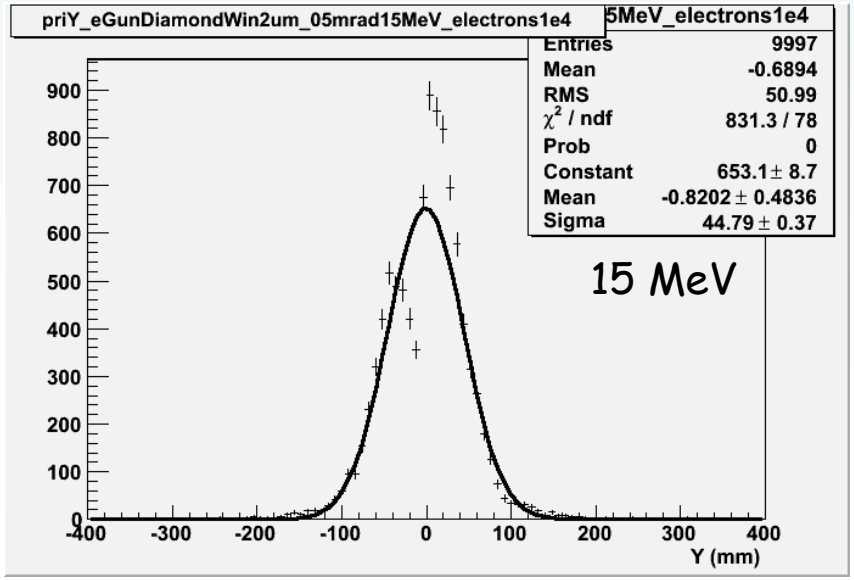


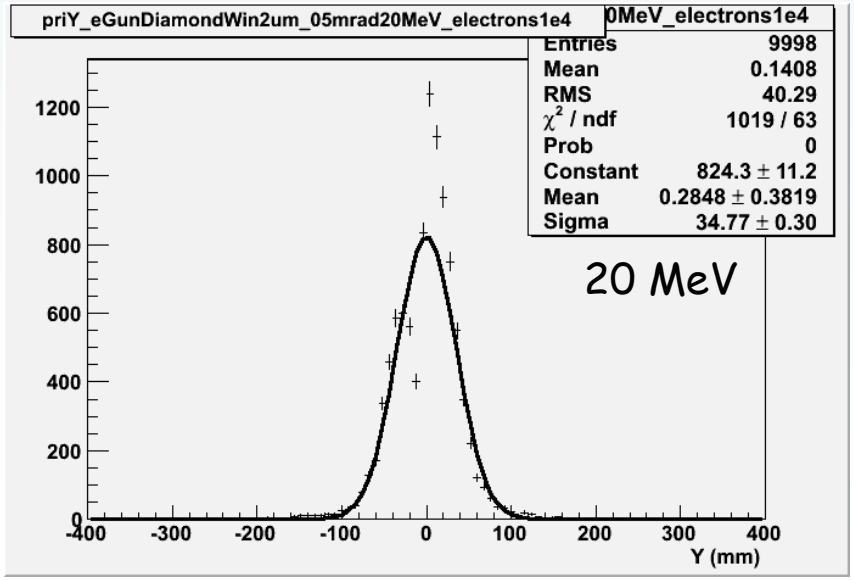


Shallow-Angle Injection (5mrad): Beam Profile (Y projection) @ 1m



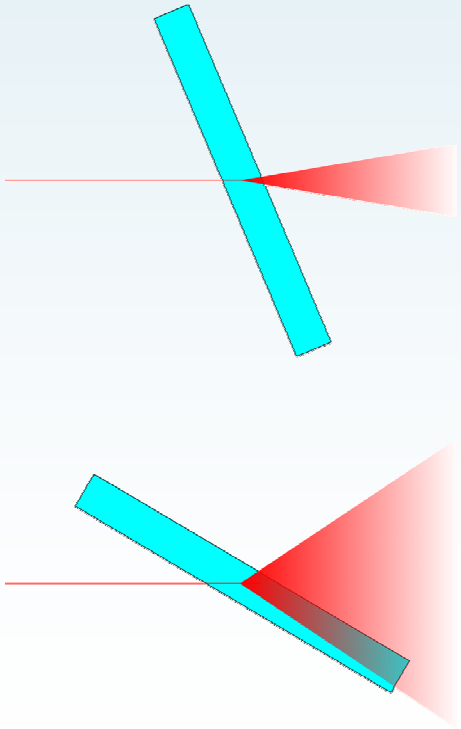






Discussion:
Explanation of Asymmetric Behaviour

Discussion: Explanation of Asymmetric Behaviour

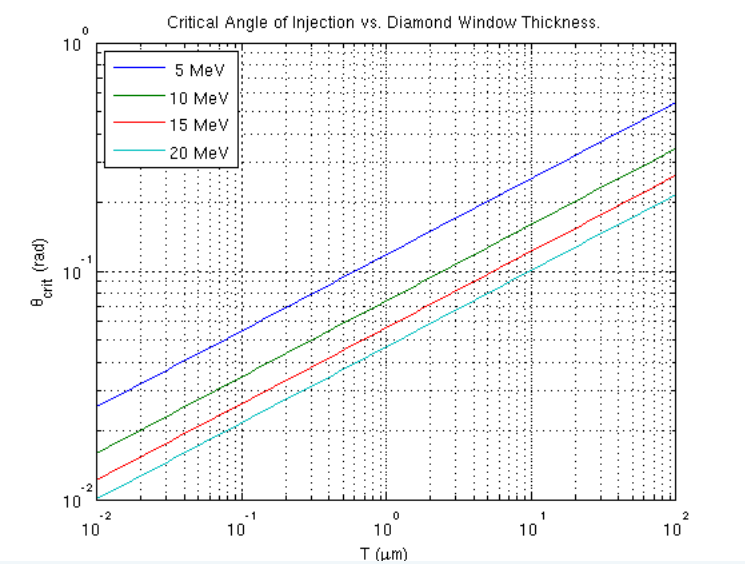


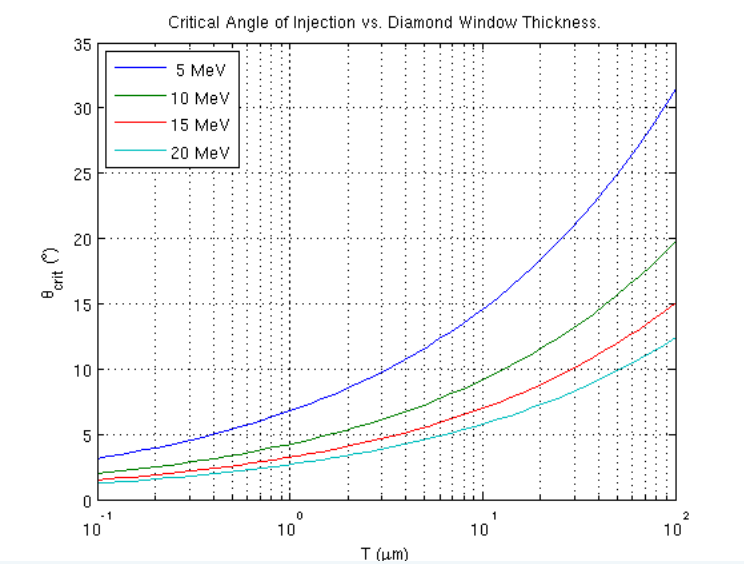
- Large angles only see scattering due to apparent thickness of window.
  => Gaussian Beams.

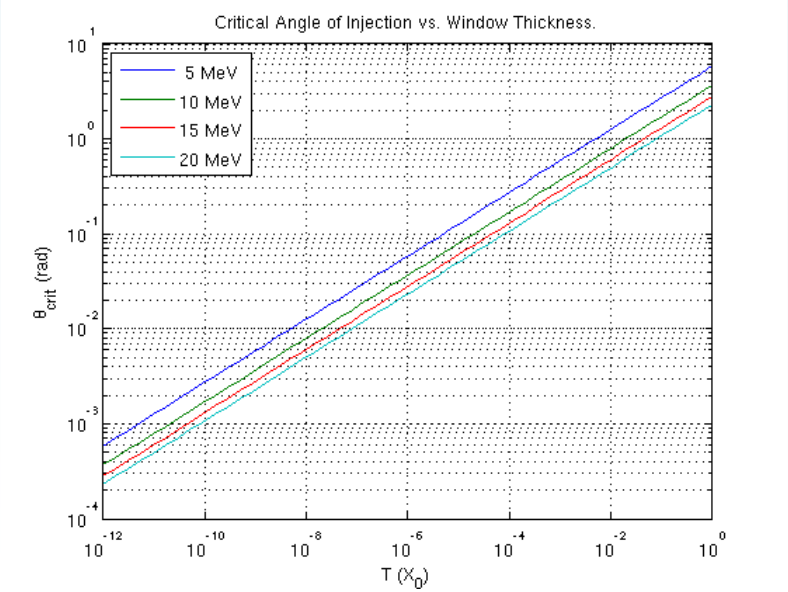
- Small angles see scattering greater than the window angle itself.
  => Horrible Beams…

Discussion:
Critical Angle of Symmetry Breaking

Critical Angle Vs. Thickness



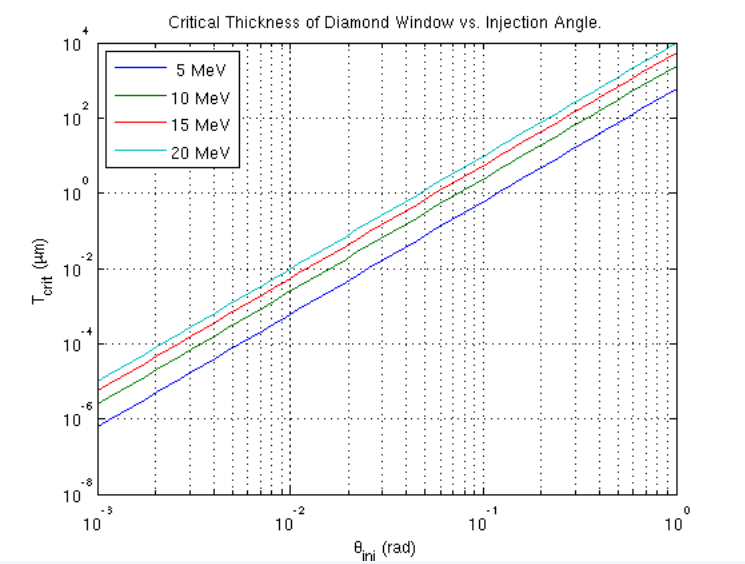


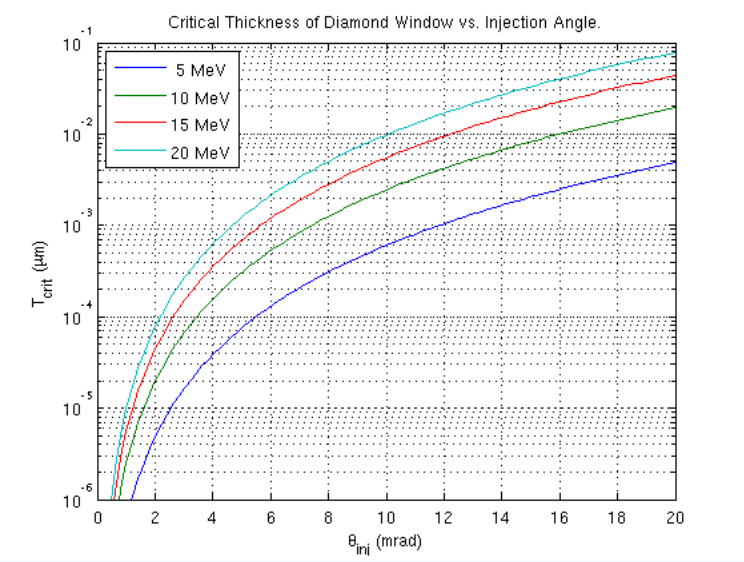


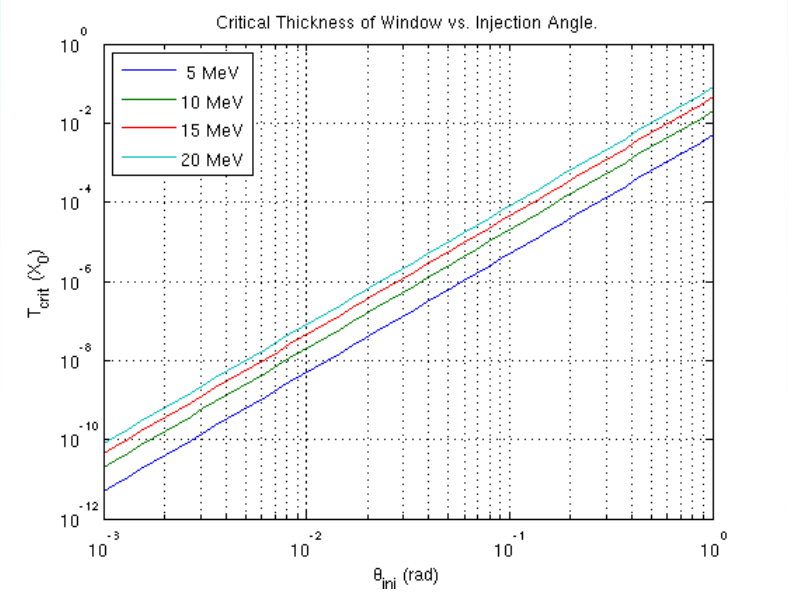
$$\theta_{\mathrm{crit}} = 3\sqrt[3]{\left(\frac{13.6\,\mathrm{MeV}}{\beta c p}\right)^2 \frac{T}{X_0}}$$

$$X_0 = 12.2\,\mathrm{cm}$$

Critical Thickness Vs. Angle







$$\frac{T_{\mathrm{crit}}}{X_0} = \left(\frac{\beta c p}{13.6\,\mathrm{MeV}}\right)^2 \left(\frac{\theta_{\mathrm{inj}}}{3}\right)^3$$

$$X_0 = 12.2\,\mathrm{cm}$$

Work in Progress

- Looking at incorporating Electron Gun beam parameters into these Geant simulations.
  - Requires phase-space transformations of Monte-Carlo random variables to yield tracks with correlated initial positions (x_0, y_0) and momenta (x'_0, y'_0) given σ_x, $\sigma_{x'}$ and ε_{RMS}.
  - Needs more complex geometry to allow measurement at 20 cm with a rotated target.
    - This distance would currently overlap the target and detector.

Monte-Carlo Phase Space Transformation

- Given the beam parameters σ_x, $\sigma_{x'}$ and ε_{RMS}, the ellipse in phase-space has semi-axes of:

$$a^4 = \frac{\gamma \tan^2\theta - \beta}{\beta \tan^2\theta - \gamma}\varepsilon_{\mathrm{RMS}}^2 \qquad b^4 = \frac{\beta \tan^2\theta - \gamma}{\gamma \tan^2\theta - \beta}\varepsilon_{\mathrm{RMS}}^2$$

where the variables are the Twiss parameters.

- Which can produce the appropriate random variables X & X' for x and x':

$$\begin{pmatrix} X \\ X' \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} G(0,a) \\ G(0,b) \end{pmatrix}$$

where G(μ, σ) is a random variable following a Gaussian distribution.

Conclusions

- Small-angle beam injection through non-perpendicular window very messy: hence possibly impractical?
  - Significant energy losses
  - Asymmetric beam scatter
- Perpendicular/large-angle injection through window solves asymmetry
  - This requiring more complex construction of plasma cell and electron gun interface.
  - Potentially causes problems for metal-vapour cell thermal uniformity & electrical discharge cell construction/operation.
- Scatter will clearly reduce beam flux captured by the wakefield.
- Current work will allow the simulation of realistic electron beam profiles for PIC side-injection.
  - Electron gun beam parameters needed! (σ_x, $\sigma_{x'}$, ε_{RMS})