Monte Carlo Work and Neural Networks

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Outline

- SBS Monte Carlo
- New Generators/Ported Fortran Code
- Neural Networks in ROOT
  - Overview/code
  - SBS resolution studies

Code Availability

- Be nice to put in a SVN repository if enough people need it
- I apologize for documentation! I've tried to make the headers, etc. commented well enough that you can use them. The full G4 MC is a bit more complicated, but yell at me if you have questions
- Put on my web space here:

  `http://www.jlab.org/~riordan/software/`

G_E^n, G_M^n, A_1^n, G_E^p Simulation

Basis:

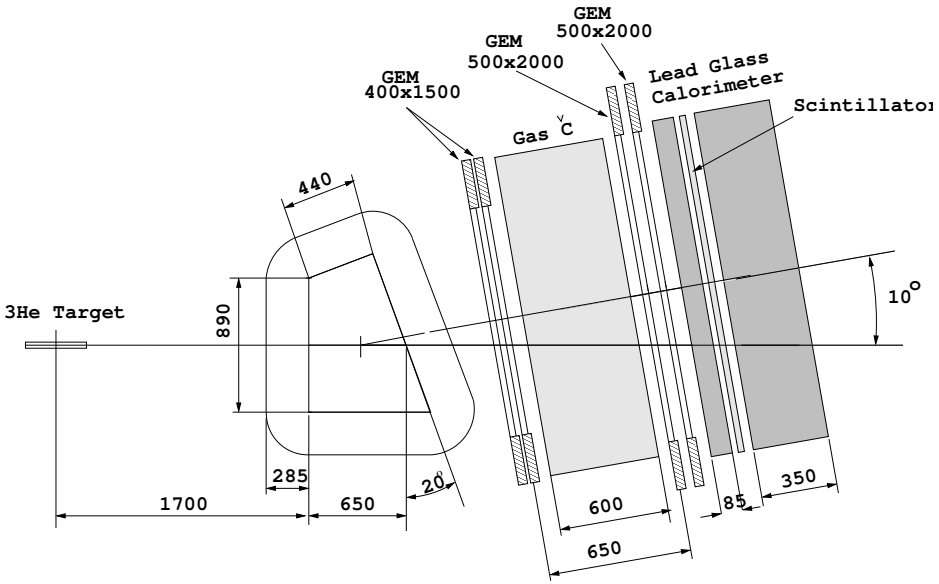
- Both G_E^n, G_M^n, A_1^n have similar hardware configurations
  - BigBite + GEMs + Cerenkov + shower/preshower
  - 48D48 and HCal
- FFs all use elastic or QE nucleon scattering - similar reconstruction needs

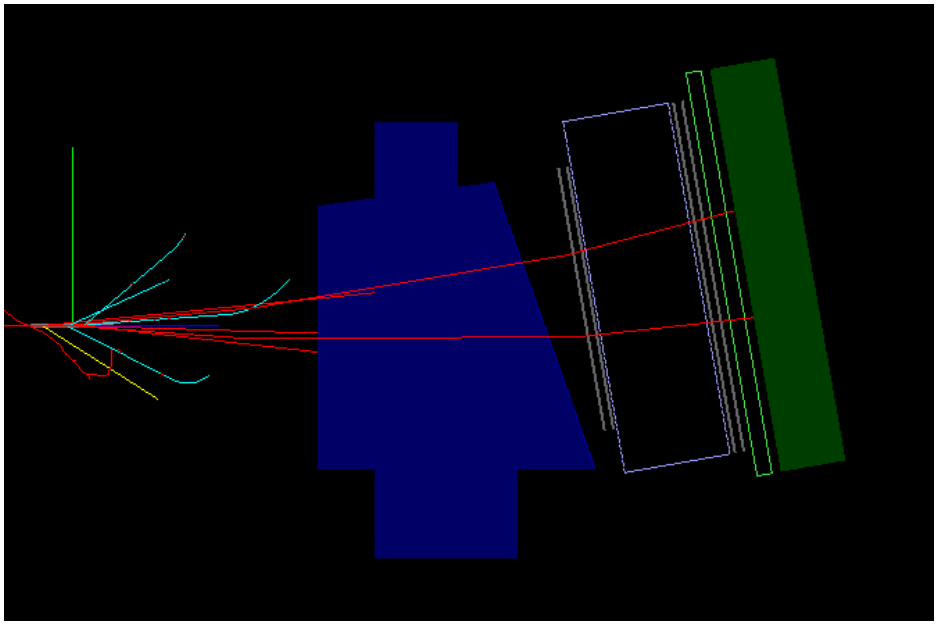
Needs:

- Given a realistic field map - what is the momentum resolution for various configurations?
  - High precision field propagation, multiple scattering effects in detailed geometry
- What is the acceptance given new placement of 48D48 for G_E^n, latest Cerenkov design?
- How do inelastic backgrounds contribute?

GEM Configurations I

G_E^n/G_M^n, G_M^n, A_1^n Proposal





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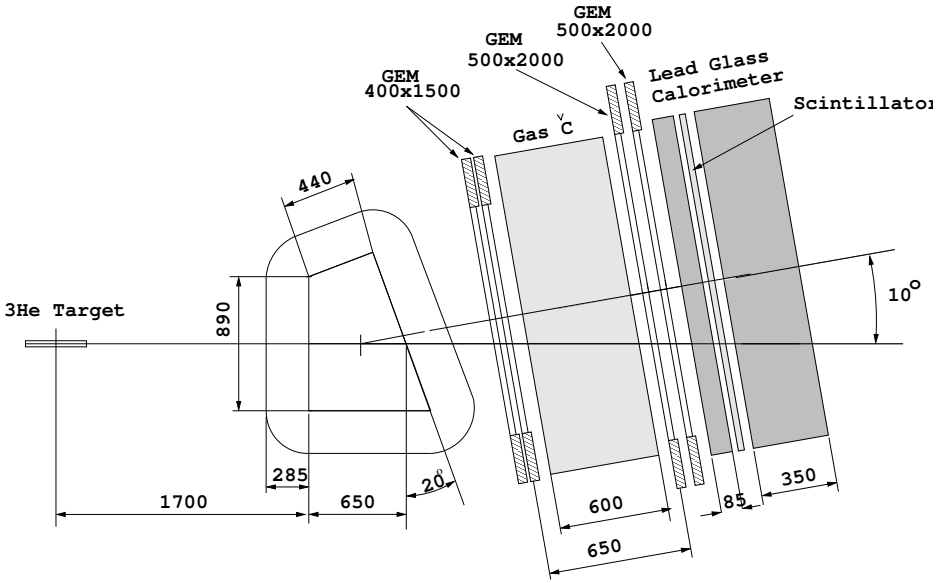
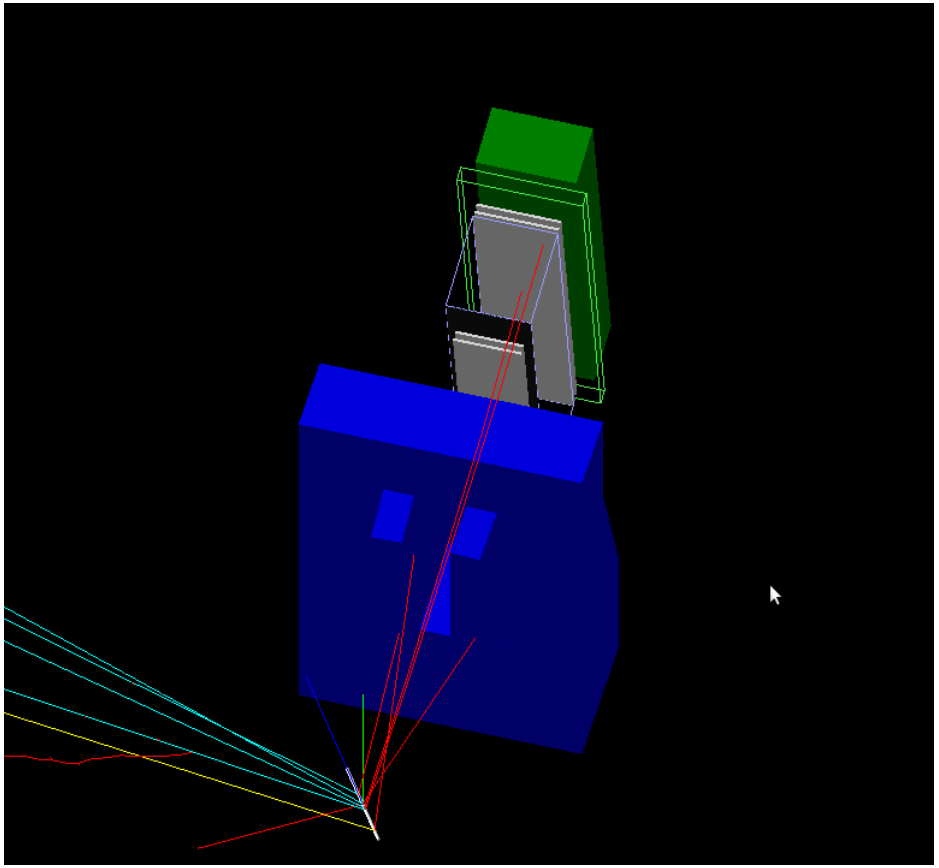
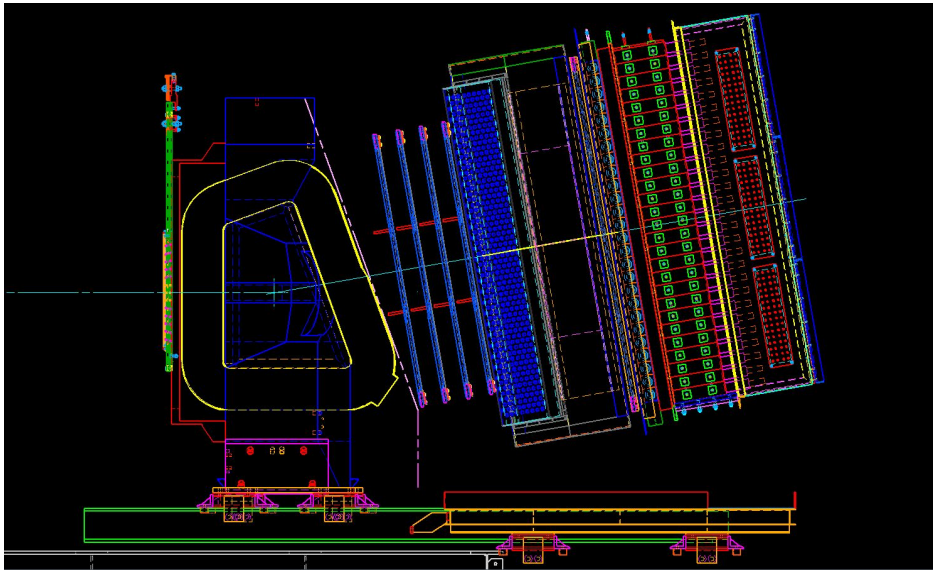
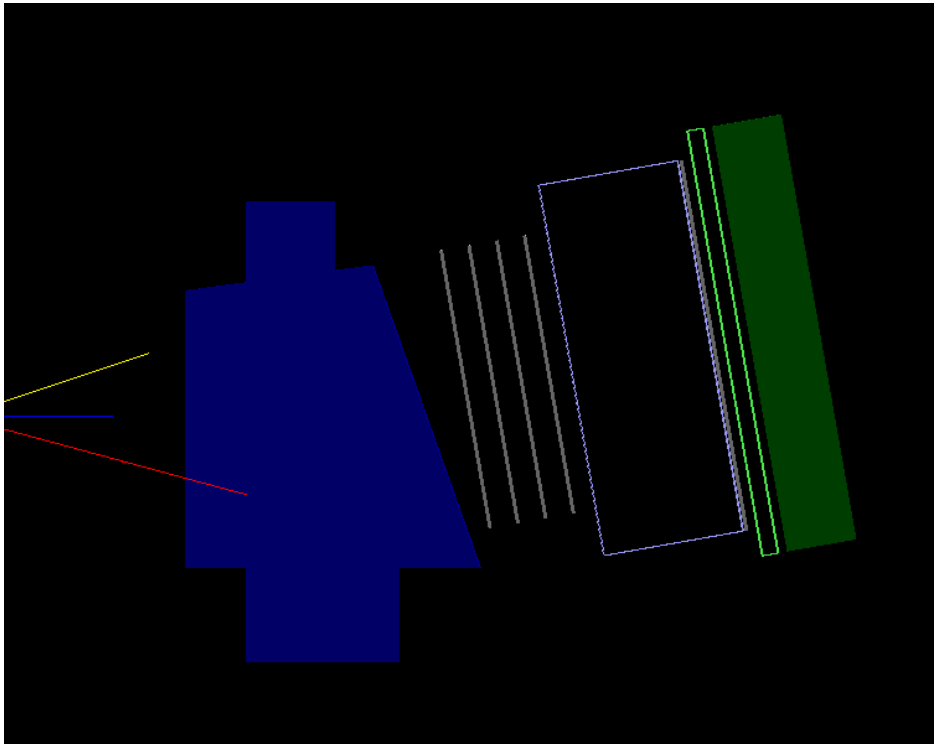




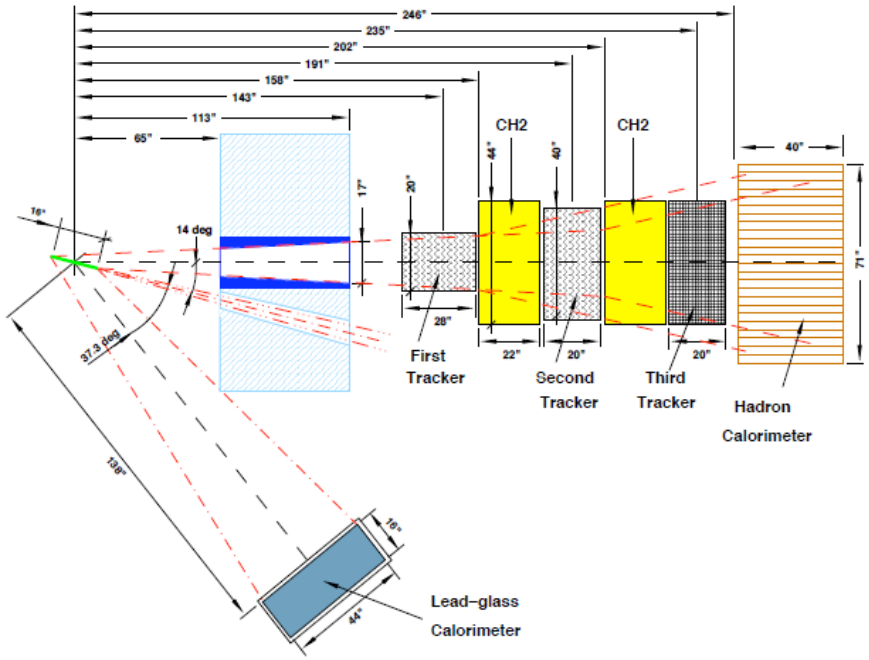
GEM Configurations II

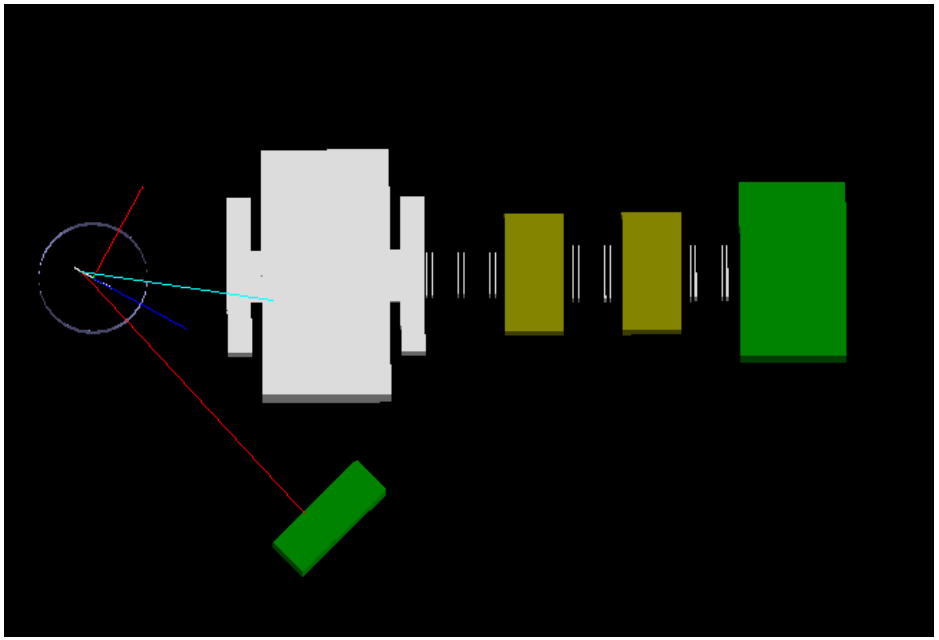
G_E^n / G_M^n New Frame





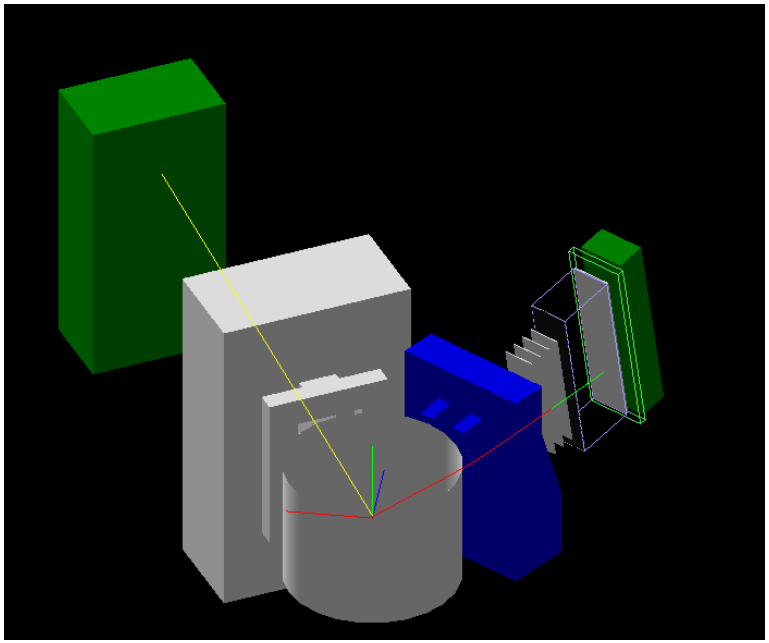
GEp-V Configuration

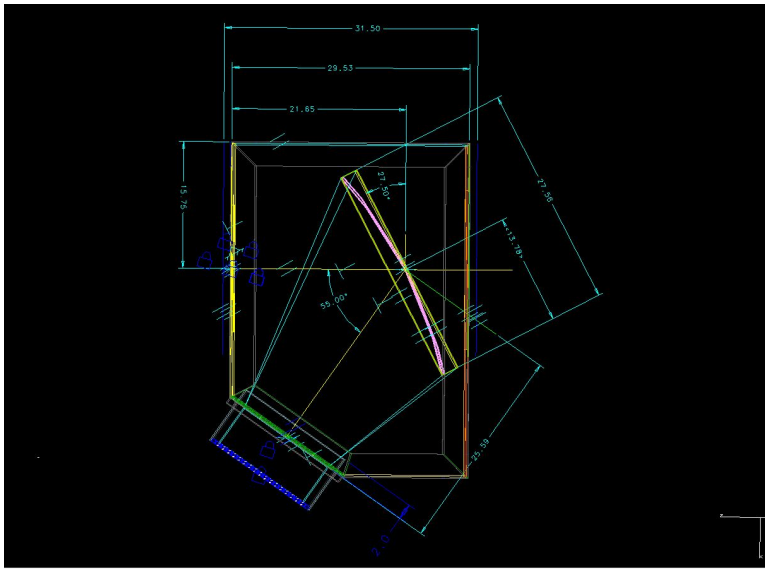




Components Included

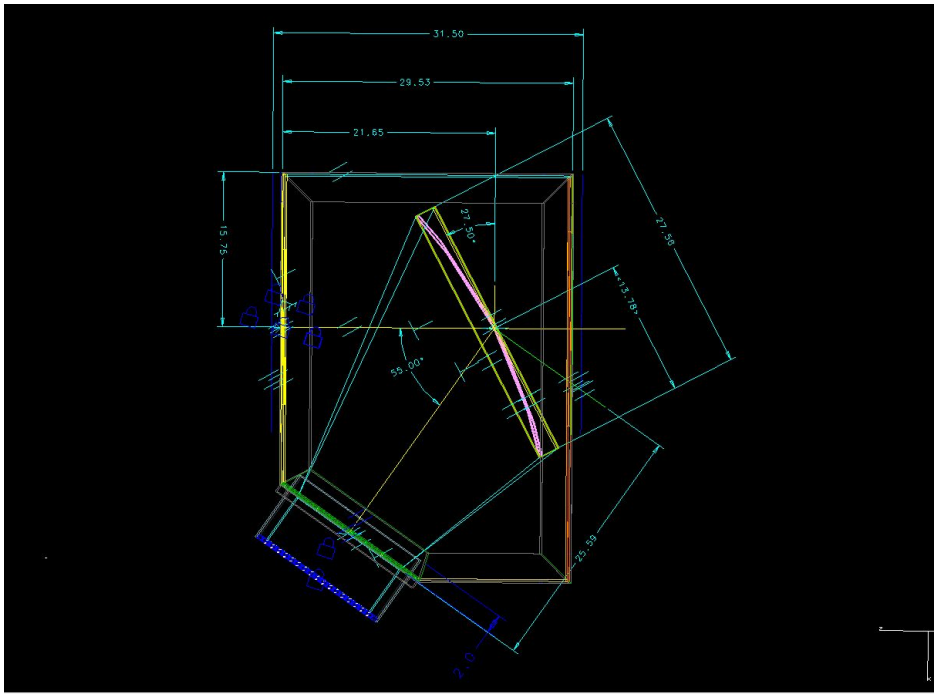
- BigBite and 48D48 Magnet
- Realistic BigBite field
- LH_2/LD_2 cryotargets, ^3He glass cells
- Vacuum scattering chamber
- GEMs
- Calorimeters
- Cerenkov





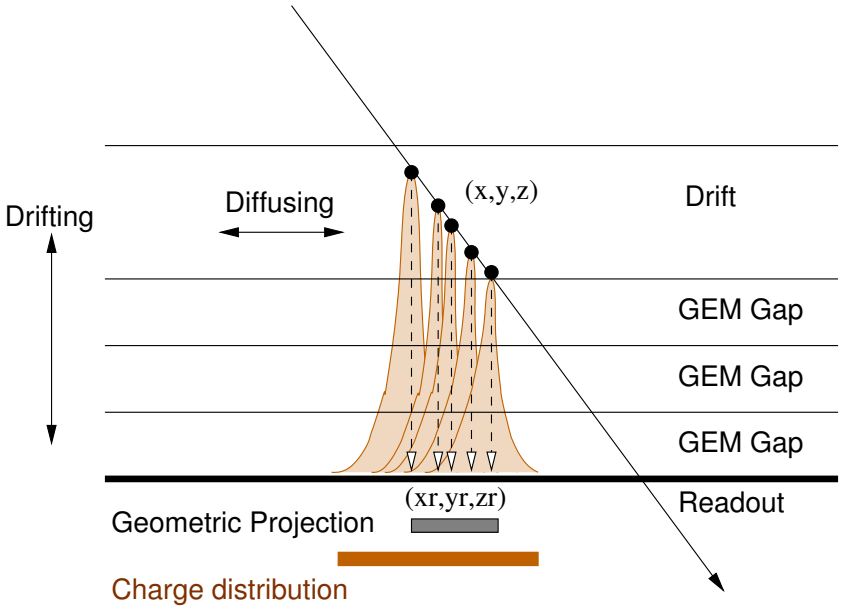
Cerenkov

- Cerenkov just a gas box with flat mirror - no light collection
- Mirror 1 mm acrylic
- Entrance (exit) windows 0.1 (0.2) mm Al
- Gas is C4F8O, 1 atm

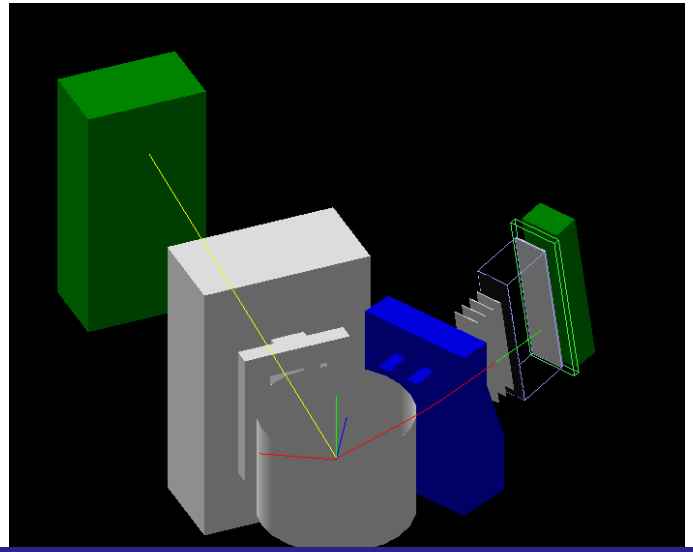


Sensitive Detector Elements

- GEM material/design from SBS GEM tracking sim
- Gas ionization layer sensitive detector for hits
- Hits taken as points - only from primary track, no background
- Assume 70 $\mu\mathrm{m}$ detector res.



- Calorimeters are dead absorbers, no showering, no smearing
- Acts as "trigger" for each arm



Implemented Generators

Wrote:

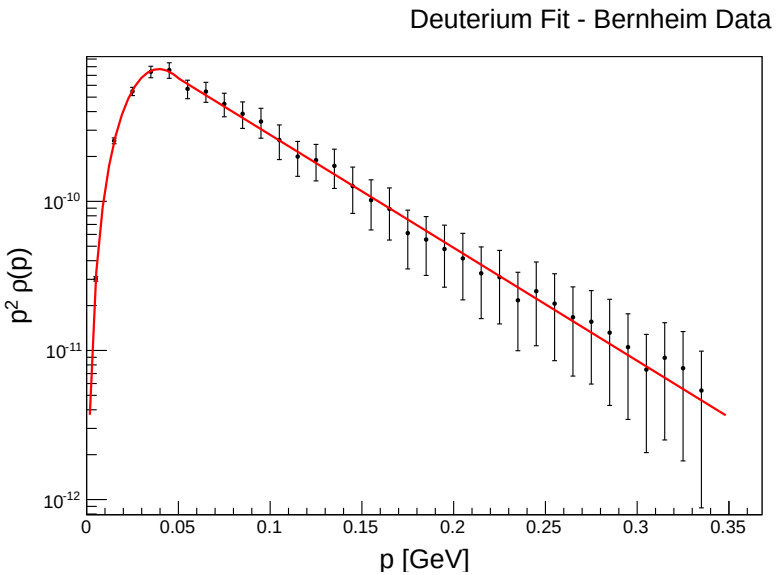
- eN elastic, quasielastic
- Parameterized eN inelastic
- DIS from CTEQ distributions

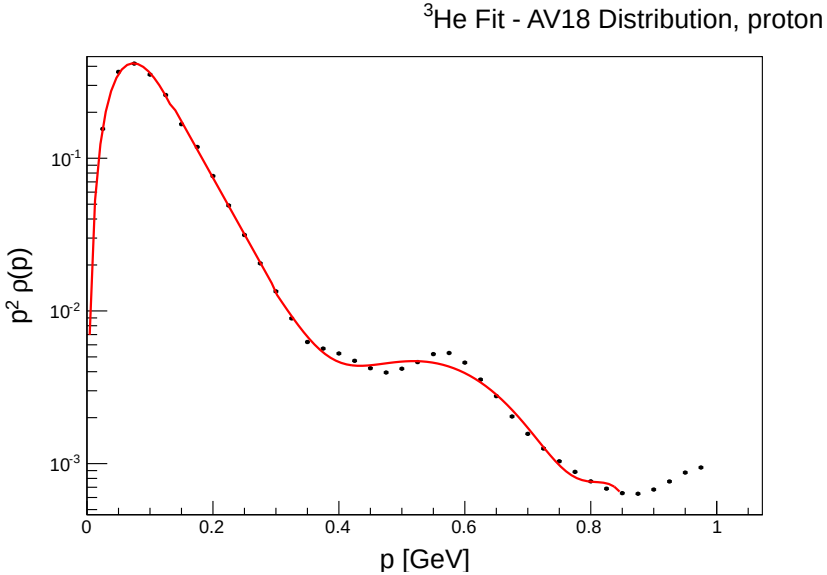
Nice to include someday:

- External radiative effects
- Wiser $\pi^{\pm,0}$ production
- Asymmetries
- Multiple scattering?

QE Generator

- QE rates given by
  - Nucleon momentum distributions - just use simple smearing
  - Kelly parameterization for G_E^p, G_M^p, G_M^n, E02-013 parameterization for G_E^n





- Dumbly sample these distributions
- No offshell effects, could implement DeForest PWIA

Rate Results - G_E^n

Kin	Cut factor	Quoted Rate [Hz]	Prop conf [Hz]
1.5 GeV^2	1.0	29.7	37.9
3.7 GeV^2	2.0	1.01	1.00
6.8 GeV^2	3.0	0.049	0.053
10.2 GeV^2	4.0	0.006	0.007

- Rates agree with outher caculations
- With plausible cuts on data, reproduce rates quoted in plots

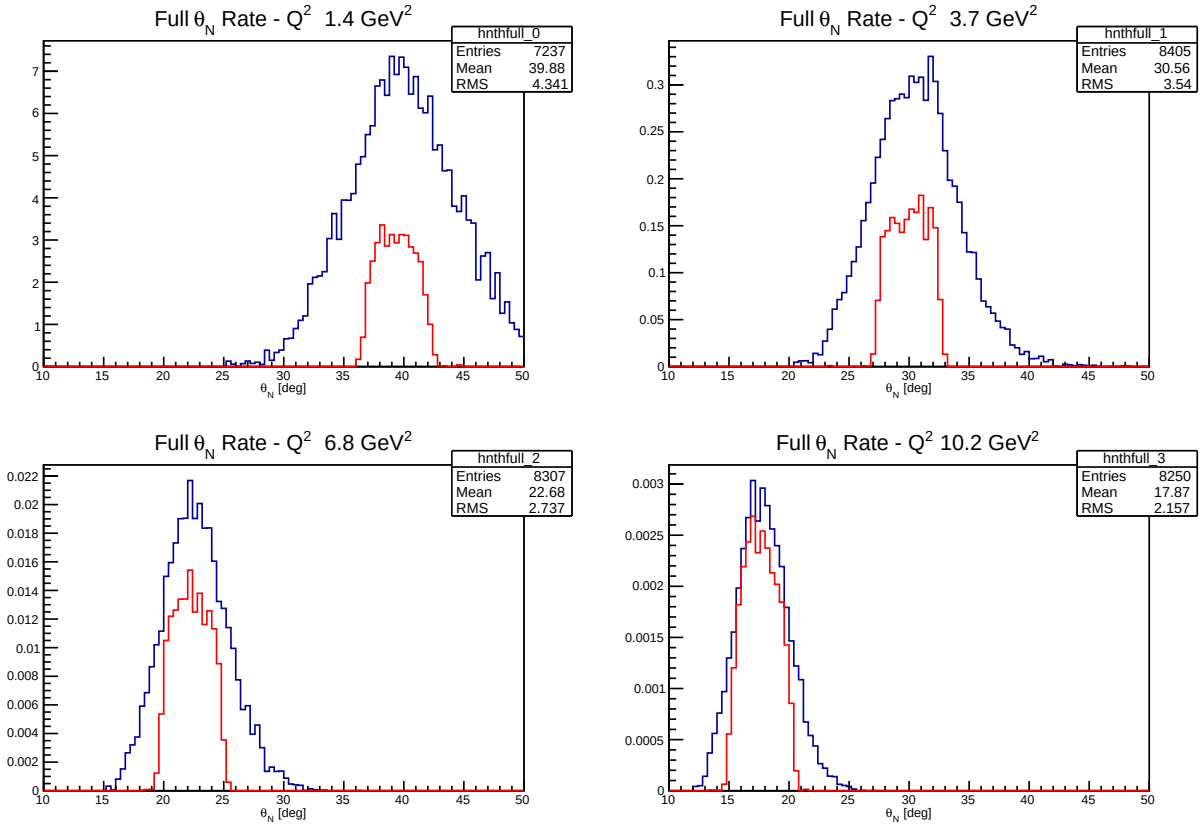
Rate Results - G_M^n

Kin	Quoted	MC New
Kin	Rate [Hz]	conf [Hz]
3.5 GeV^2	50.0	56.6
4.5 GeV^2	10.0	10.2
6.0 GeV^2	0.73	0.74
8.5 GeV^2	0.26	0.29
10.0 GeV^2	0.21	0.30
12.0 GeV^2	0.043	0.051
13.5 GeV^2	0.010	0.012
New 13.5 GeV^2	-	0.058

- Rates agree very well with Kelly param. and what was used for the G_M^n proposal

Rate Results - G_E^n Acceptance

- Black is QE neutron inclusive, red is coincidence
- Acceptance not matched well for G_E^n for θ and ϕ - was taken into account in rates
- Maybe some room for tuning?



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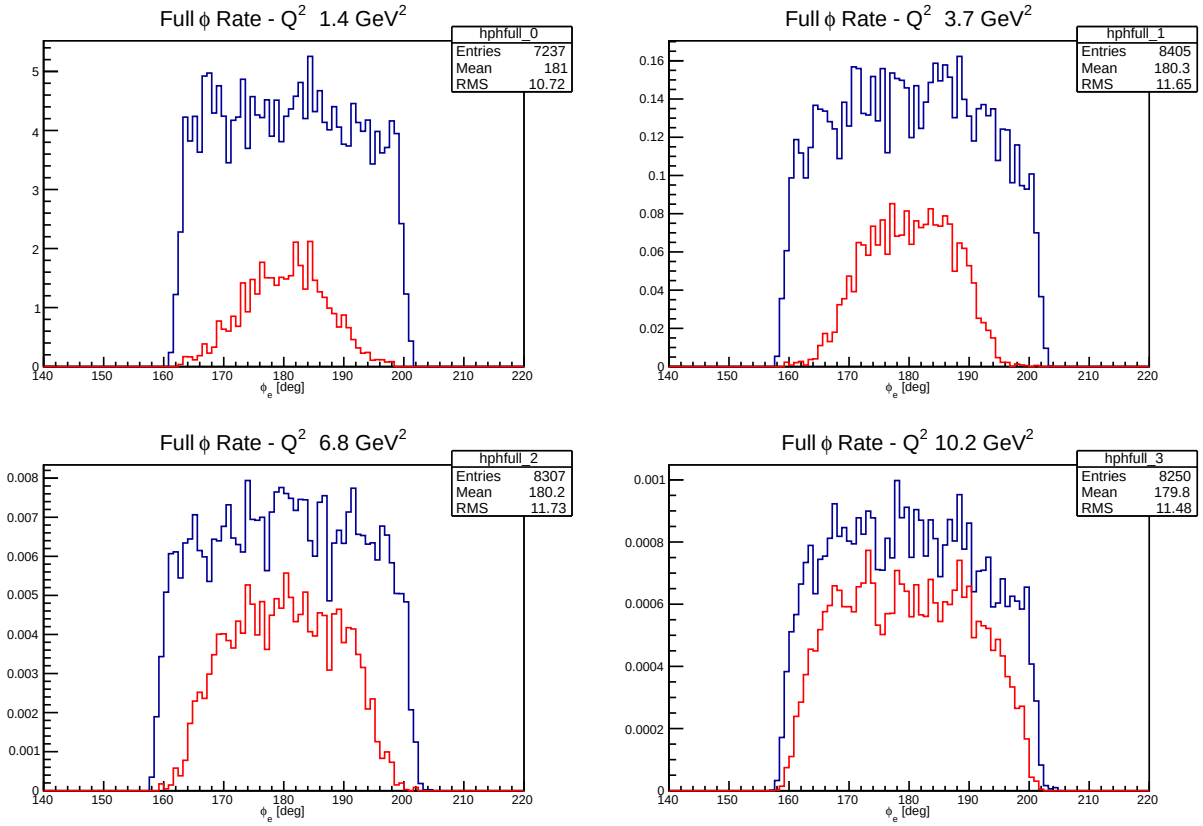
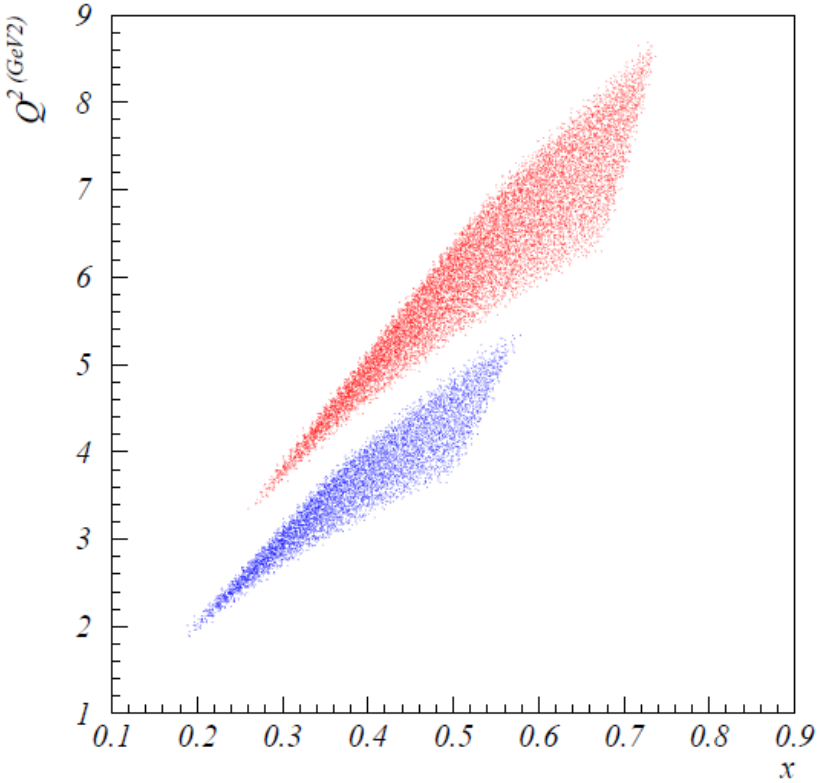


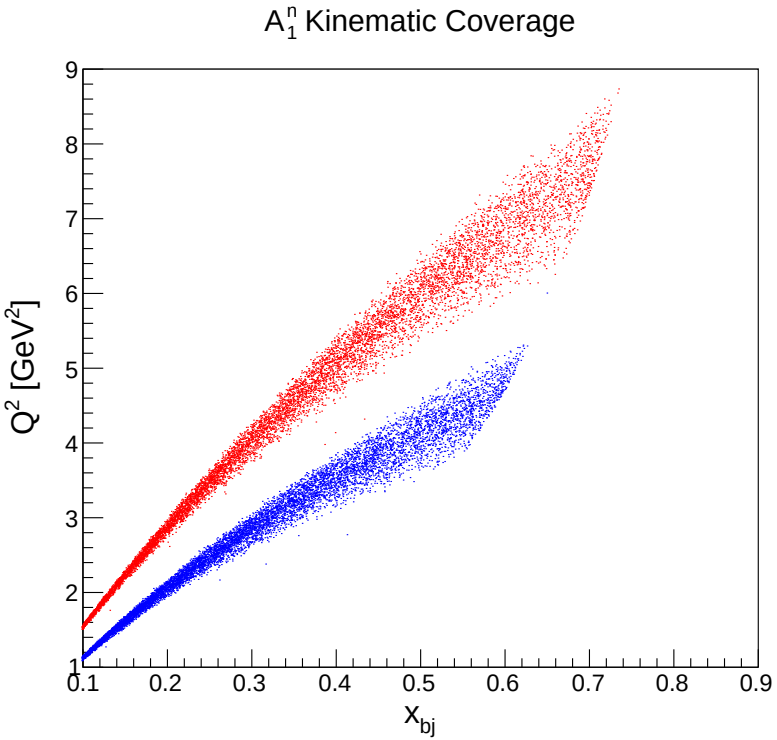
Acceptance for A_1^n

- Just used 1-arm neutron FF setup

Proposal



New MC



Rate Results - A_1^n

$E = 6.6$ GeV

x	Prop [Hz]	CTEQ [Hz]	B/C [Hz]
0.60	1.3	5.9	8.2
0.56	8.0	7.2	9.3
0.52	12.0	10.2	12.3
0.48	17.0	12.8	15.4
0.44	23.0	20.5	19.0
0.40	30.0	24.9	24.4
0.36	30.0	34.3	30.8
0.32	17.0	46.0	35.3

$E = 8.8$ GeV

x	Prop [Hz]	CTEQ [Hz]	B/C [Hz]
0.71	0.5	1.0	1.7
0.67	1.7	1.4	2.2
0.63	2.9	2.2	2.9
0.58	4.1	3.3	4.5
0.54	6.4	5.5	5.9
0.49	8.2	6.8	8.7
0.45	8.8	10.8	11.3
0.40	6.2	15.4	14.3

Pion Rates in Mollersim

Pion rate evaluation:

- Used "Wiser code", based on $\gamma N \rightarrow \pi^{\pm}$ cross section fits from SLAC, written in FORTRAN
- (Also have $K^{\pm}$ rates useful for hyperon evaluation)
- Brehmstralung from target for photoproduction, Weizsacker-Williams for electroproduction
- Implemented generator into **mollersim**
- Have not included any asymmetries

Pion Calculation

Photoproduction:

$$\sigma_\pi^{\text{photo}} = \int dk \rho_\gamma(k) \frac{d\sigma_\pi(\gamma(k)N \to \pi)}{dk}$$

$$\rho_\gamma(k) = \frac{t}{X_0} \frac{\frac{4}{3} - \frac{4}{3}x + x^2}{E_{\text{beam}} x}, x = k/E_{\text{beam}}$$

Electroproduction:

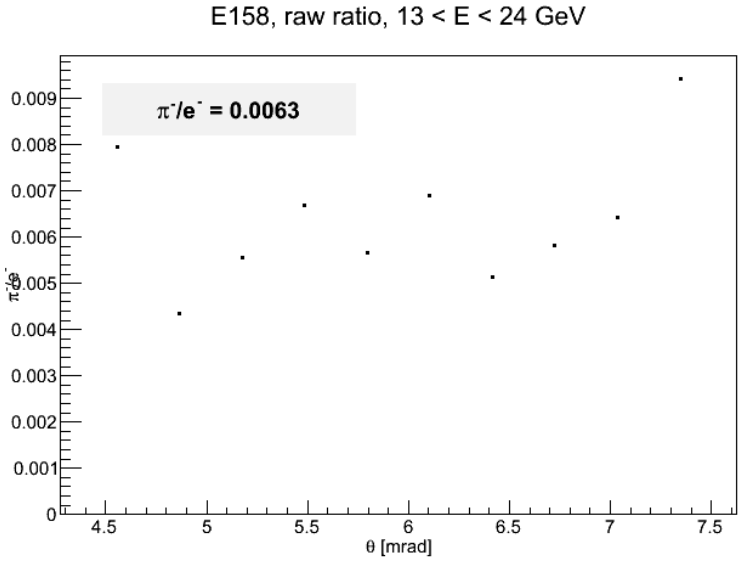
$$\sigma_\pi^{\text{electro}} = \int dx N_{\text{eff}}(E_{\text{beam}}, x) \frac{d\sigma_\pi(\gamma(xE_{\text{beam}})N \to \pi)}{dx}$$

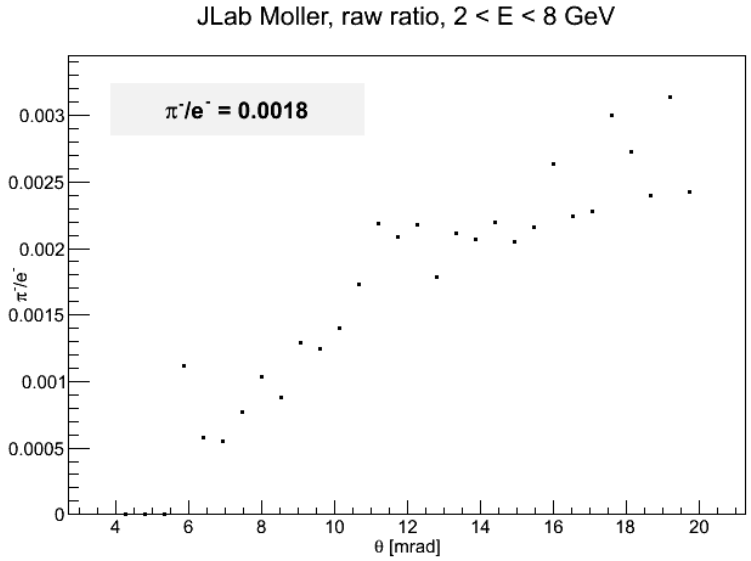
$$N_{\text{eff}}(E_{\text{beam}}, x) = \frac{\alpha}{\pi} \ln \frac{E_{\text{beam}}}{m_e} \frac{1 + (1-x)^2}{x}$$

- Add together to get pion rates - need radiation length of target traversed and internal radiation factor (typically 5%)
- Dominated by γ for Moller,

Results - Validation

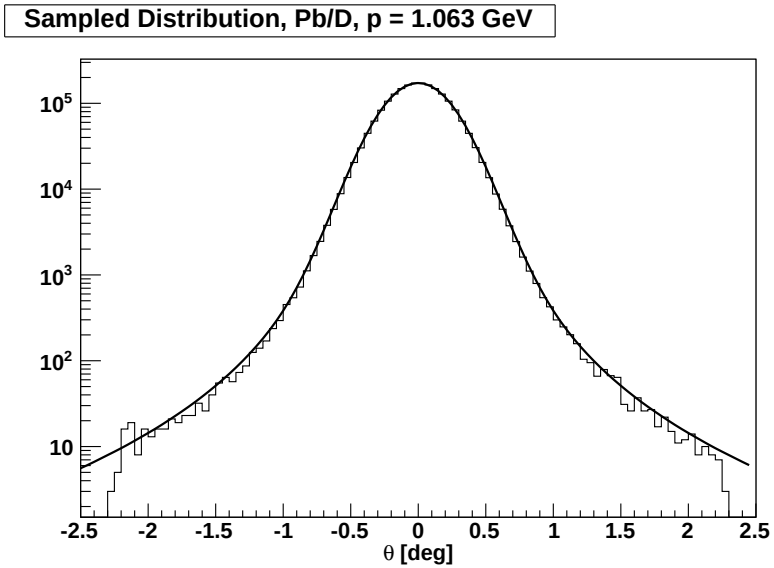
Ignoring optics and acceptance:

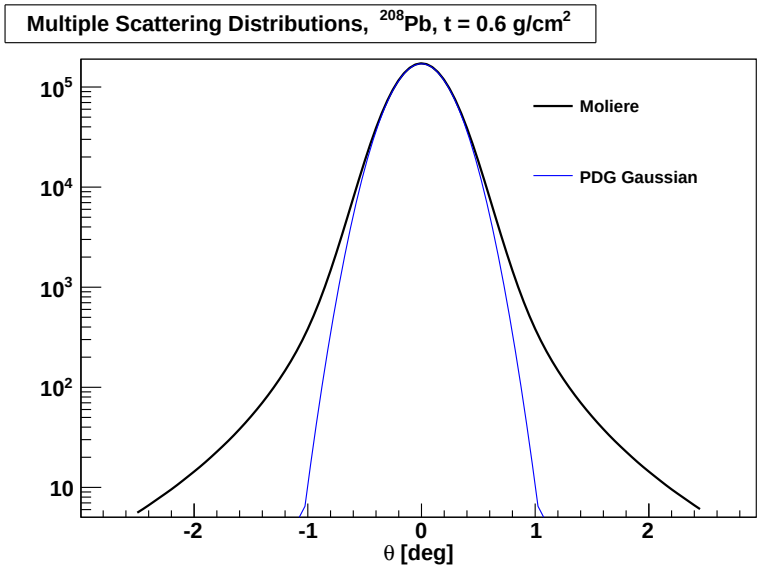




- E158 rates very close to what was measured
- Moller π^- rates scale down about as predicted in the proposal

Multiple Scattering





Multiple scattering given by gaussian of width:

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p} z \sqrt{x/X_0}\,[1 + 0.038 \ln(x/X_0)]$$

- Only good to about 98% of distribution, not good for low angle experiments (i.e. Moller)
- Wrote general code that handles multiple materials, can sample or plot widths relatively fast
- Should go in repository - email me in the meantime

Sampling Issues

PDG a great, free, practical resource!!!

http://pdg.lbl.gov/2012/reviews/rpp2012-rev-monte-carlo-techniques.pdf

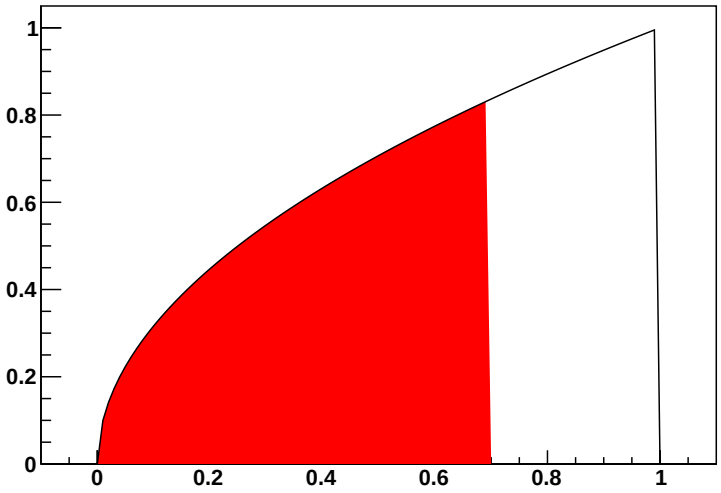
- Inverse transform method often neglected
- Useful if you have a distribution with known integral form that can be inverted or efficiently *contained* by envelope of that form (combined with accept-reject method or weights)

Solve:

$$z = \frac{\int_a^t f(t')dt'}{\int_a^b f(t')dt'}$$

Then invert to get:

$$F(z) = t$$



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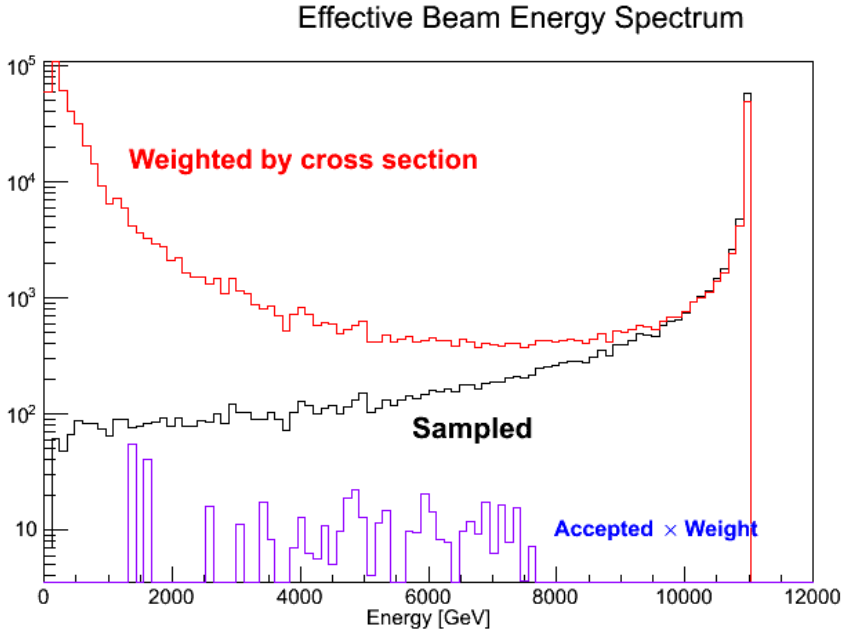
Shape	Range	sample uniform z
c	$0 < t < a$	az
Isotropic	$0 < \theta < \pi$	$\cos^{-1}(2z - 1)$
3D	$0 < \phi < 2\pi$	$2\pi z$
$e^{-t/\tau}$	$a < t < b$	$-\tau \ln \left[e^{-b/\tau} + z(e^{-a/\tau} - e^{-b/\tau})\right]$
e^{-t^2}	$-\infty < t < \infty$	$\sin(2\pi z_1)\sqrt{-2 \ln z_2}$

ep sampling

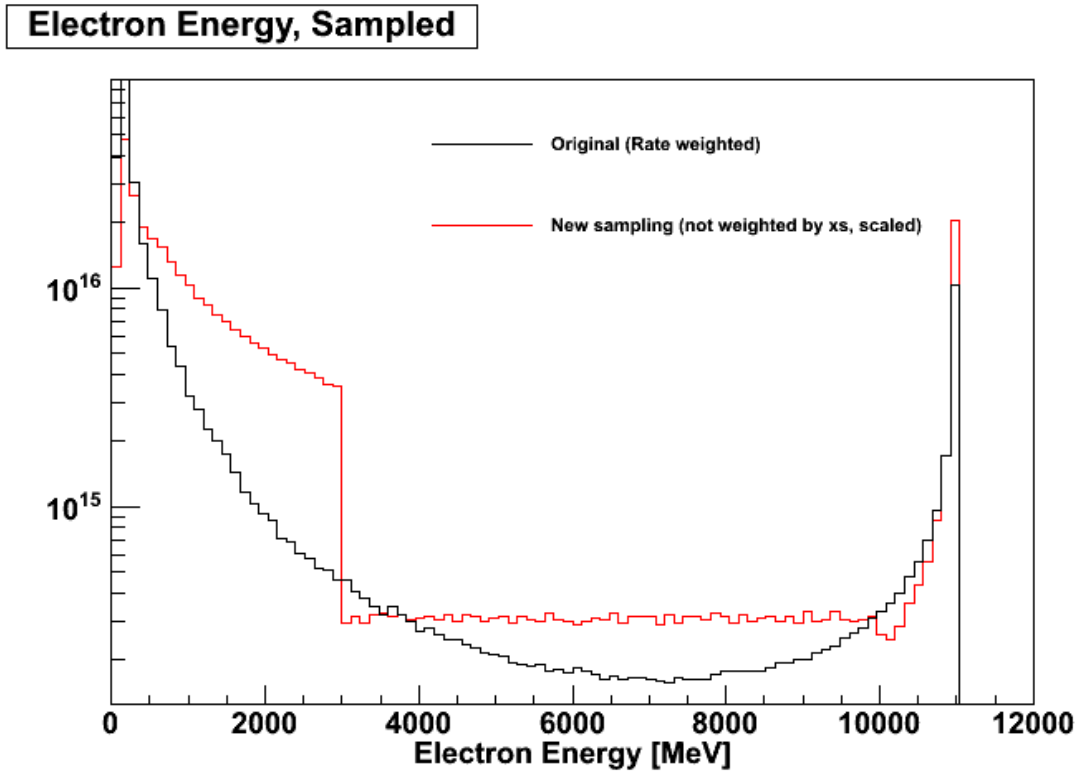
Previous *ep* sampling in **mollersim** neglected increase in cross section faster than energy falloff of e^- from bremstrahlung



- Sampled distribution becomes sparse despite large cross section at low E
- *ep* events are accepted even below 2 GeV into detector
- Statistical accuracy becomes a concern

Reweighting

- Sample based on something closer to final cross section distribution



- Use combination of flat and $1/x$ sampling

Reweighting

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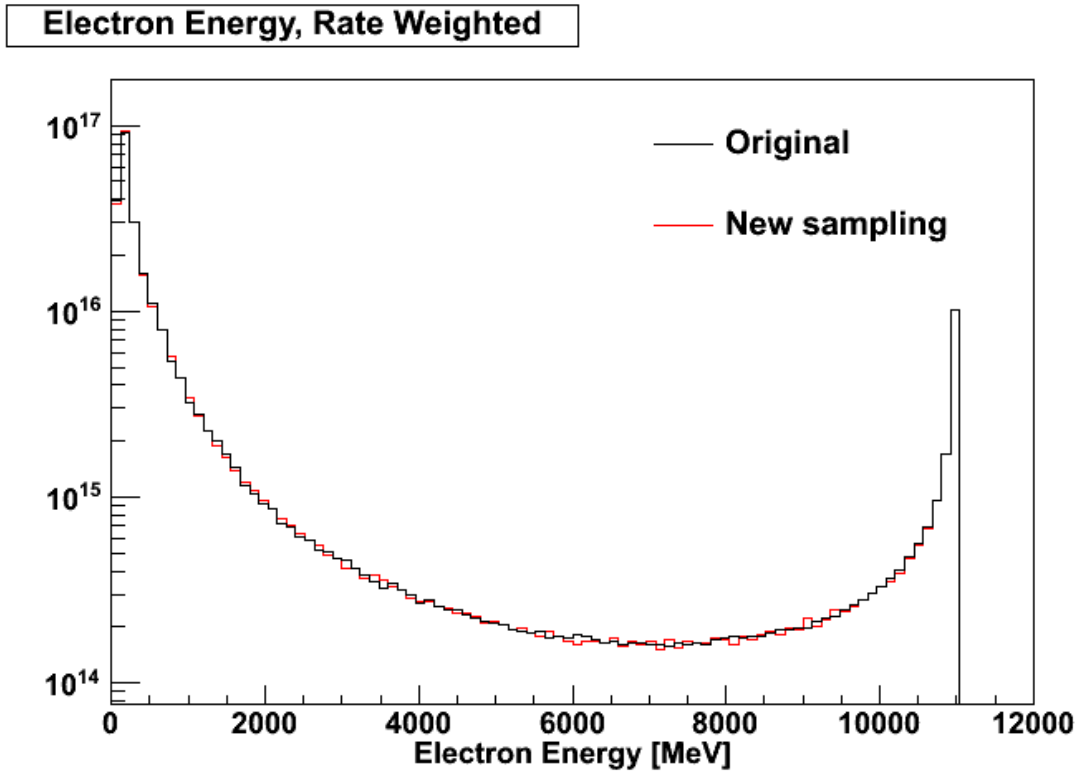

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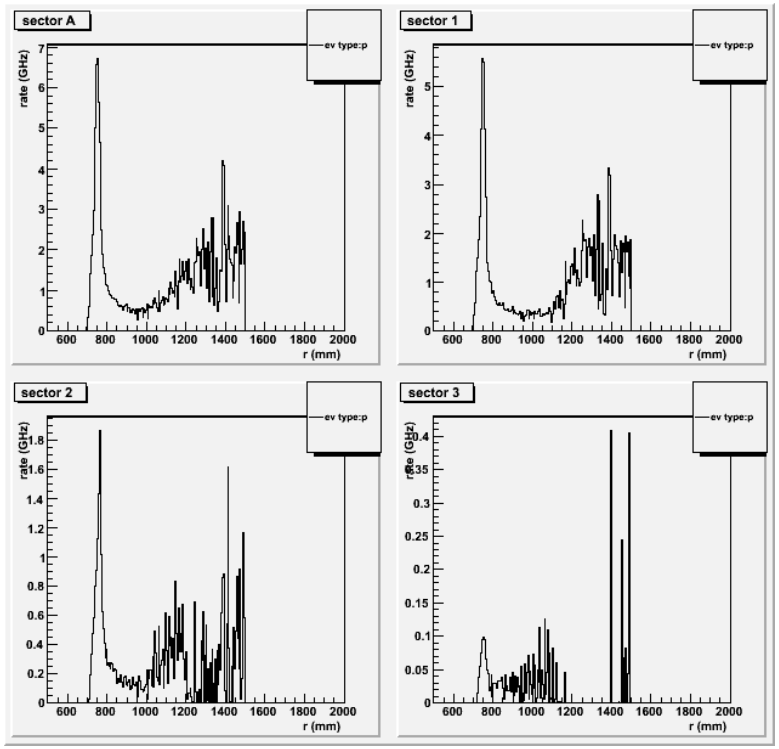

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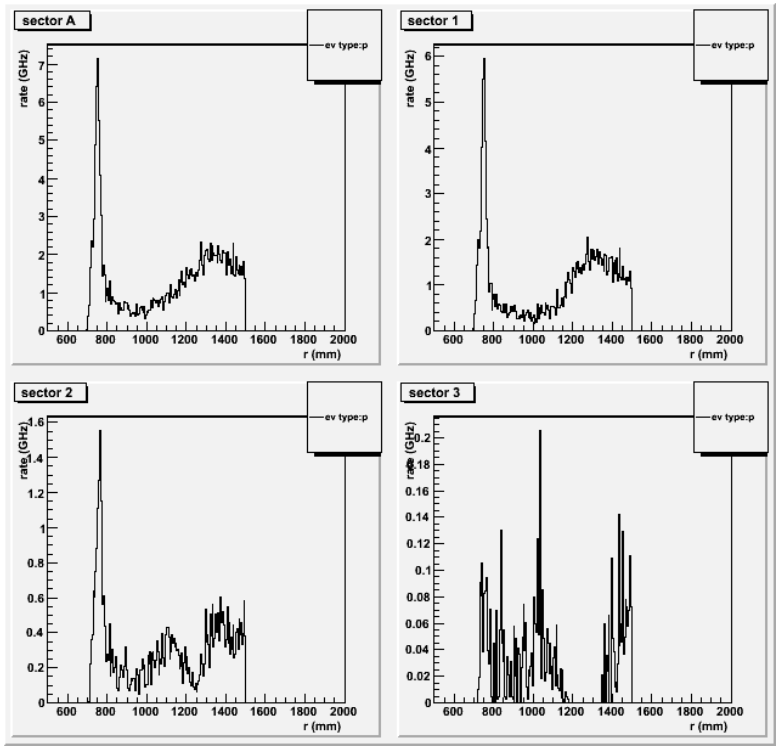


- End up with more evenly weighted distribution

Resolution Studies - Overview

Determine resolution given BigBite field map (from V. Nelyubin)

- G_E^n and G_M^n configurations (different multiple scattering)
- Both GEM configurations
- Effects of Cerenkov, scattering chamber, target

To speed up analysis, maps determined from neural network

- ROOT now contains multi-layer models which use ntuples
- Very little effort in producing mapping of tracks $\rightarrow$ momentum (or any event variable)
- Don't have to consider implementing specific forms
- Little control how map is produced - use no angular/momentum correlation in training events

Neural Network Overview

- Enormous field of study with lots of practical applications
- Good place to start:
  `ftp://ftp.sas.com/pub/neural/FAQ.html`
- Useful physics applications:
  - Function approximation (esp. multi-dimensional)
  - Classification problems (PID, signal vs. noise, etc.)

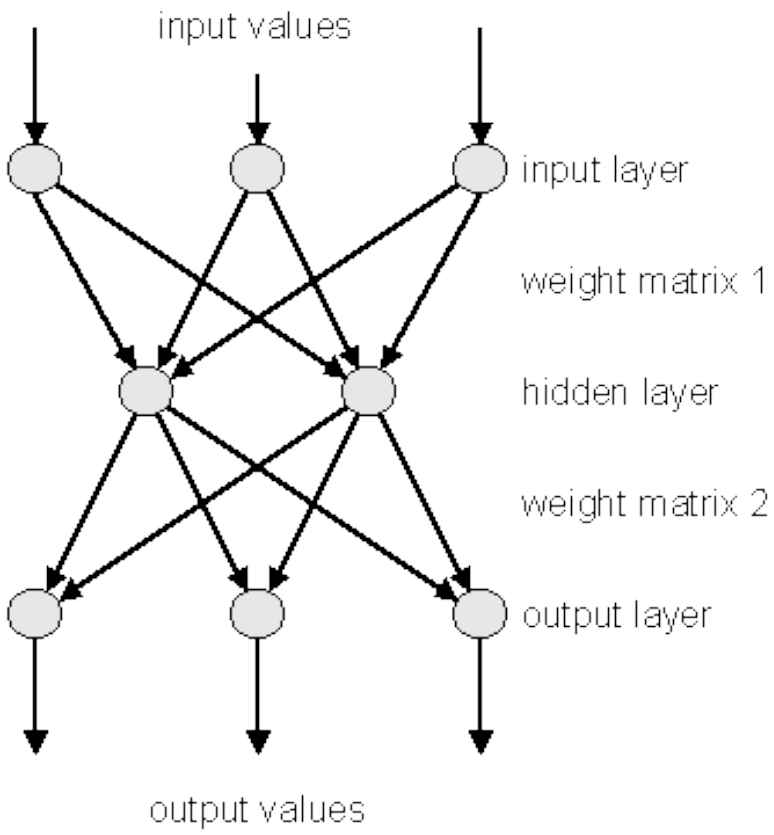
Today we'll focus on

- Feed forward, multi-layer perceptron
- Supervised learning (backpropagation)
- Included in ROOT in VERY easy way involving trees - see examples:

`$ROOTSYS/tutorials/mlp/`

Multi-layer Perceptron

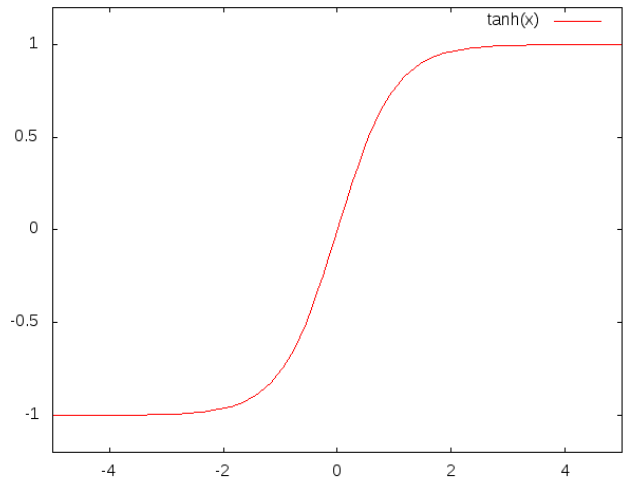
Multi-layer Perceptron model allows for arbitrary mapping from set of input values to output values



- Sigmoid function for output y_i of each node i:

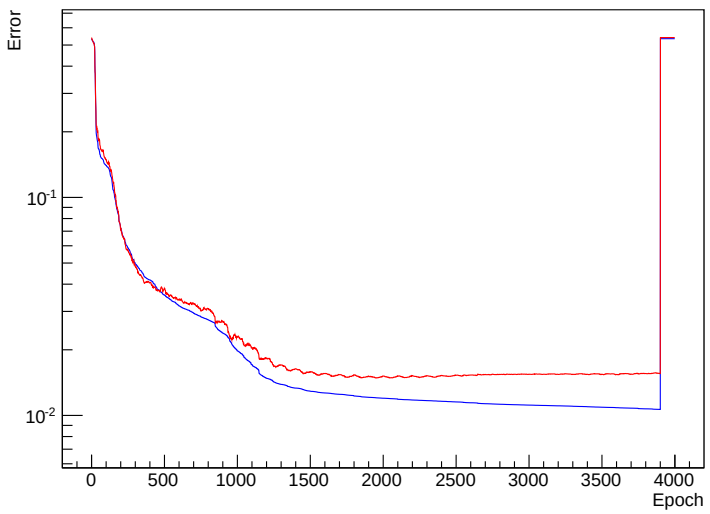
$$y_i = \tanh(v_i)$$

$$v_i = \sum_j w_j y_j^{\text{prev lay}}$$



Multi-layer Perceptron Training

Typical training sessions



- Use default fitting with "BGFS" method - "quasi-Hessian" finder effective for large number of dimensions (read: weights)
- Uses concept of "cross entropy" rather than min χ^2

- Run until training residuals much smaller than expected uncertainty contributed by GEM resolution
- Overfitting very easy - must be carefule!
- Need sufficient statistics to keep test and train samples close

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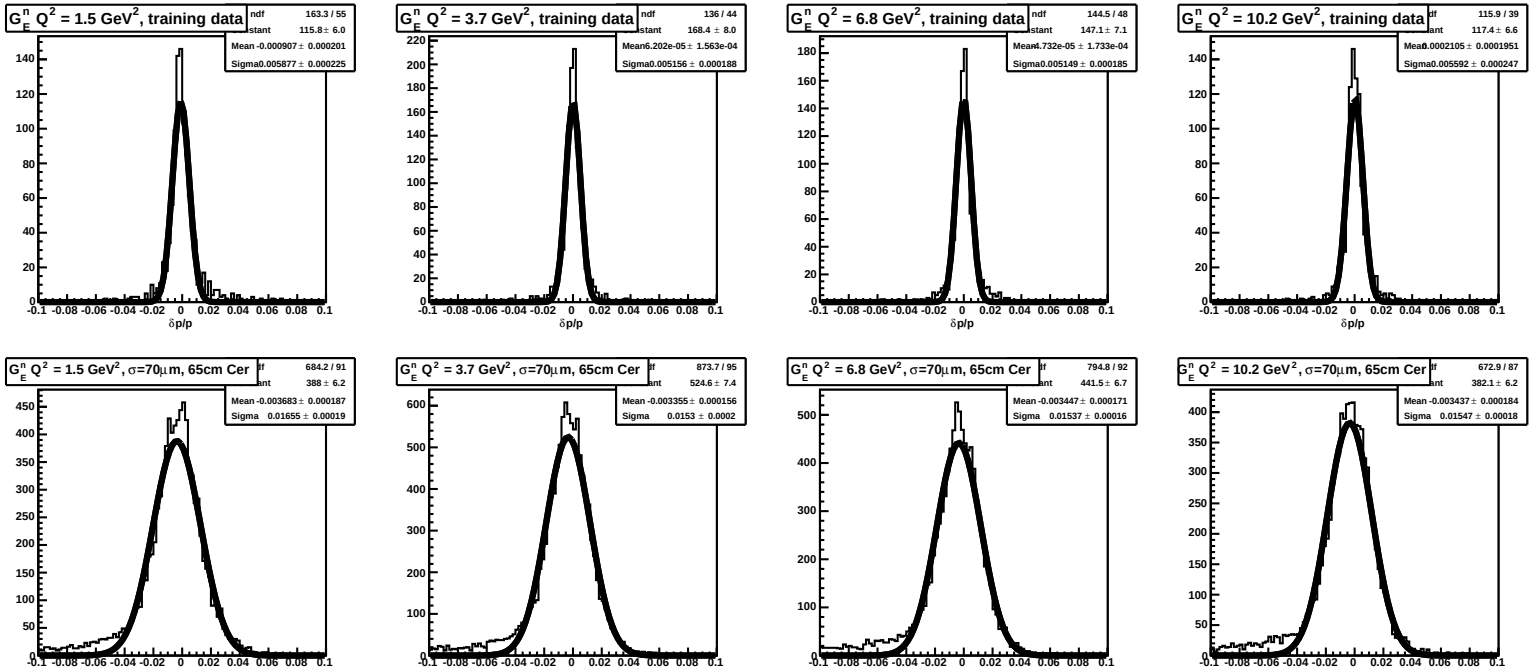

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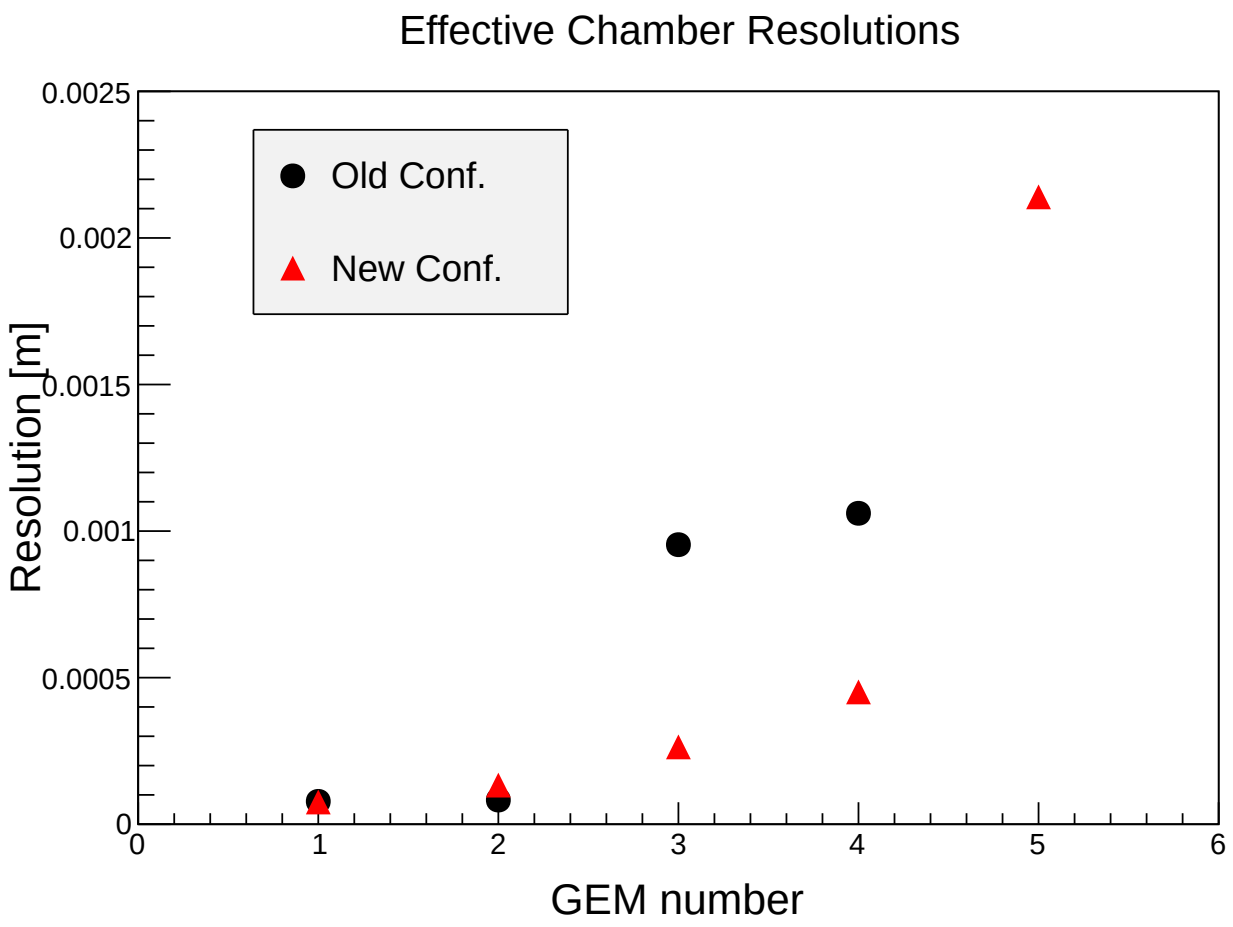
Fitting Method

Considerations

- Can use reconstructed track variables (straight-line χ^2 fits or hits themselves), but be careful of weighting!
- Train on QE data with no resolution, maybe try flat in $\theta - p$
- Also give information on θ_{BB} (target moves, so map moves)

- Used 2 layers of 20 nodes each
  - Number of layers: try two for generalizability with several inputs
  - Number of nodes to use not clear - some literature suggests start with inputs $\times 2$
- Limit $0.6\ \mathrm{GeV} < p < 1.1 E_{\mathrm{elas}}$ (events of QE interest)

Effective GEM Resolutions

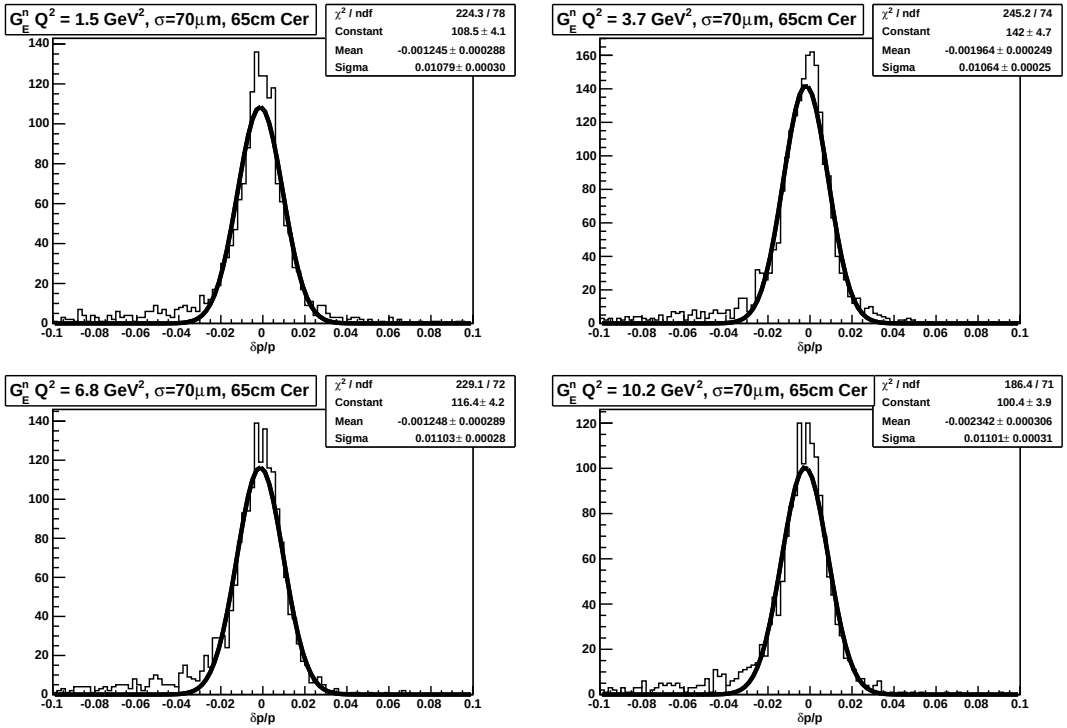


- With high resolution, multiple scattering contributes and must be accounted for
- Weight chambers with effective resolutions

Resolution Results - G_E^n momentum

- Training data results for various configurations

G_E^n Conf	$\delta p/p$ for Q^2 [%]			
	1.5 GeV^2	3.7 GeV^2	6.8 GeV^2	10.2 GeV^2
proposal	1.3	1.4	1.4	1.3
new conf	1.2	1.1	1.1	1.2



Resolution Results - G_E^n, in plane

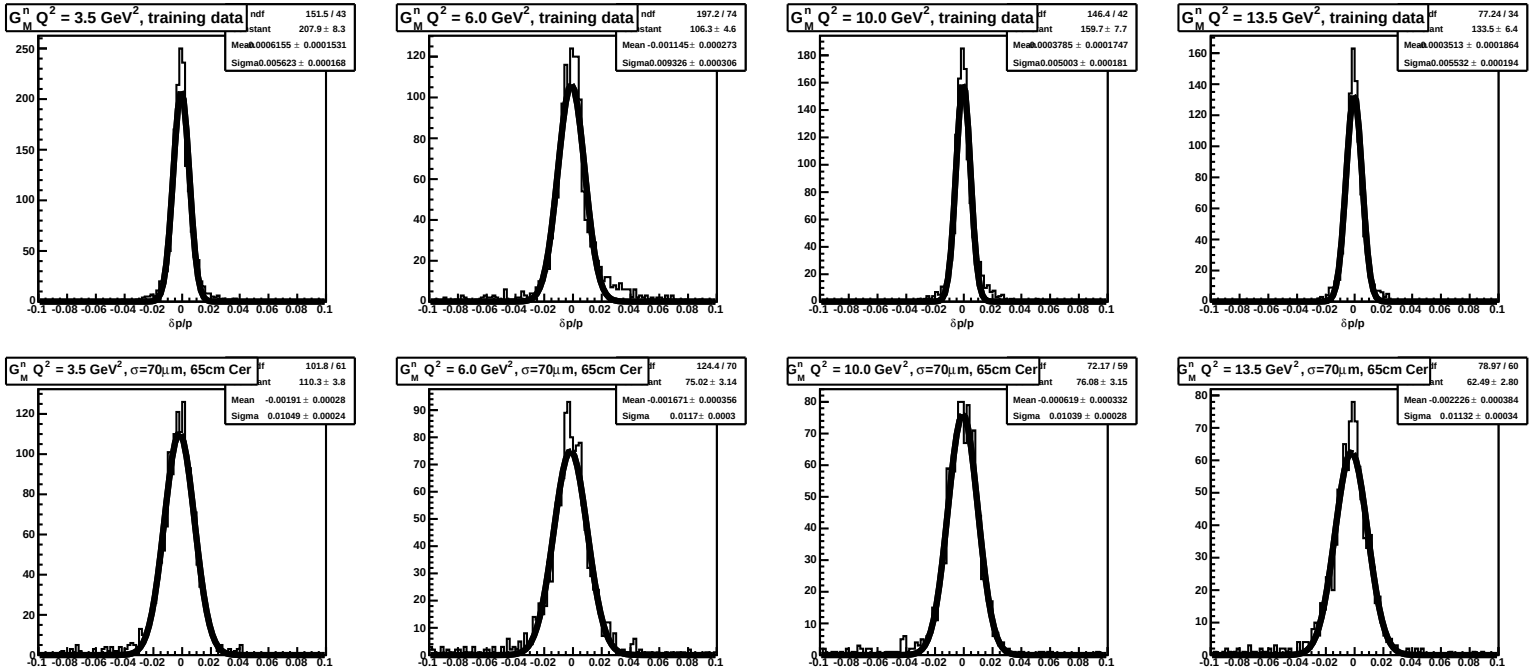
- Training data results for various configurations

G_E^n *Conf*	$\delta\theta$ for Q^2 [mrad]			
	1.5 GeV^2	3.7 GeV^2	6.8 GeV^2	10.2 GeV^2
Proposal	4.5	3.8	3.5	3.4
New conf	4.4	3.5	3.5	3.5
G_E^n *Conf*	δv_z for Q^2 [cm]			
	1.5 GeV^2	3.7 GeV^2	6.8 GeV^2	10.2 GeV^2
Proposal	0.9	0.9	0.8	0.7
New conf	0.8	0.7	0.6	0.7

- θ and v_z training data was roughly half width of full resolution data

Resolution Results - G_M^n

G_M^n *Conf*	$\delta p/p$ for Q^2 [%]			
	3.5 GeV^2	6.0 GeV^2	10.0 GeV^2	13.5 GeV^{2*}
New conf	1.1	1.2	1.2	1.1
No cer	1.0	1.0	1.0	1.1
No cer, no targ	0.9	0.8	1.0	1.0

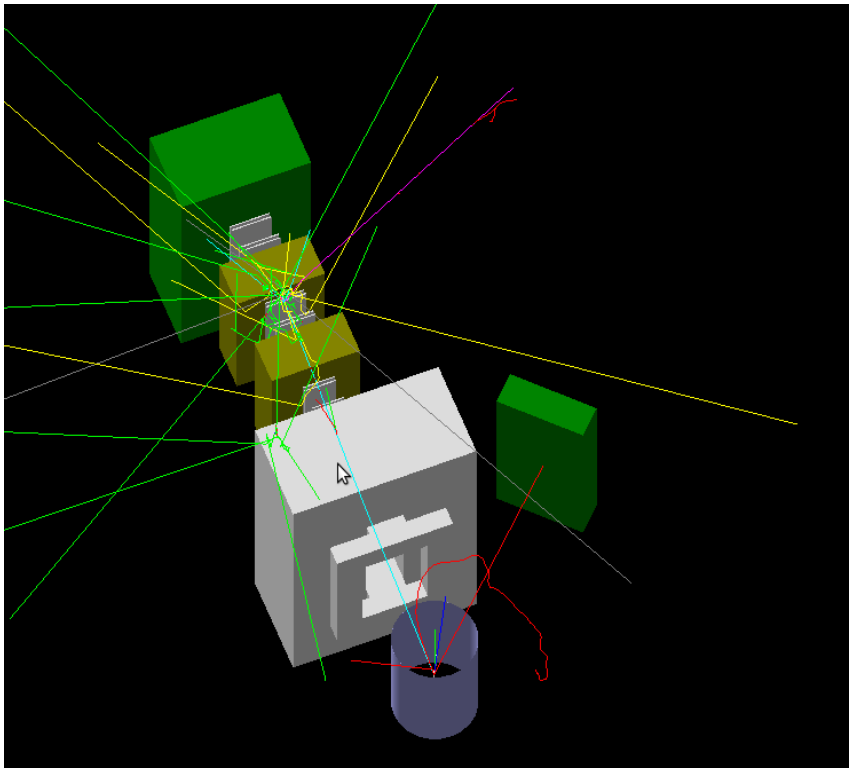


* Updated G_M^n, $Q^2 = 13.5\ \mathrm{GeV}^2$ point

Rate Results - G_E^p-V

Q^2 [GeV^2]	Rate [Hz]
5	1060
8	485
12	65

- Resolutions are with constant dipole field
- Training data and realistic data comparable - not sure how accurate these are



Q^2	5 GeV^2	8 GeV^2	12 GeV^2
δp (%)	0.4	0.3	0.3
$\delta\theta$ (mrad)	2.3	1.5	0.9
δv_z (cm)	0.5	0.2	0.2

Further Work

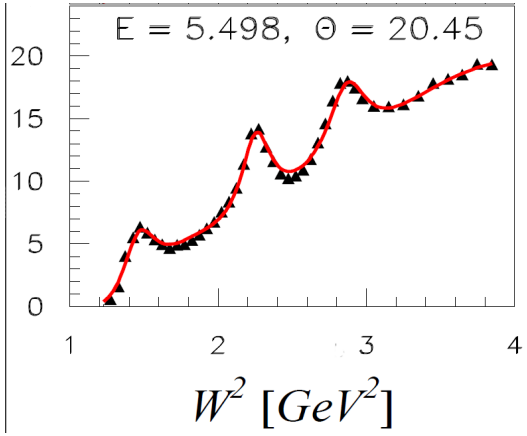
- Momentum resolution into reconstructed variables
- Radiative effects
- Add in Wiser code to SBS
- Shower responses
- Cerenkov responses

Summary

- Resolution studies for GEMs show resolutions compatible with proposals
- Rates are near proposal expectations
- G_E^n kinematics might use some tuning to improve acceptance matching
- Inelastic studies are underway

Inelastic Generators

- Previous inelastic rates were given by MAID parameterization - got both σ and A, but limited in Q^2
- Worked in Christy/Bosted inclusive parameterization of *ep* and *en* data
- Use simple single pion decay model, assume Δ contributes for $\pi^{+/-}$,π^0 rates



- Reproduce plots in the papers well