Scattered Electron Detection in HPS Experiment

$e + Z \rightarrow e' + Z' + A'$

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HPS Meeting

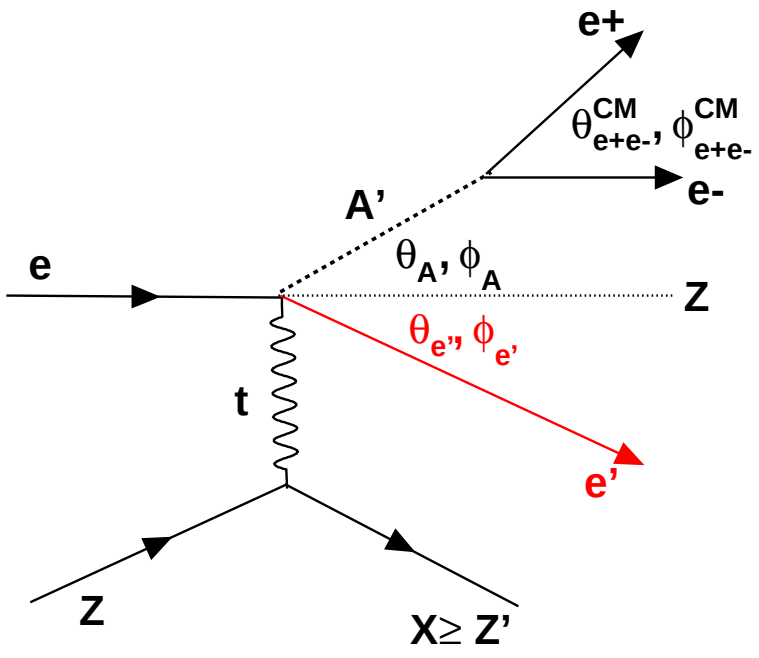
Reaction of Interest

$$e(p) + Z(P_i) \rightarrow e'(p') + Z'(P_f) + A(k)$$
$$t = P_i - P_f$$
$$A(k) \rightarrow e^+(l_+) + e^-(l_-)$$

Approximations:

- Coherent: $X = Z'$
- Diffractive: $t^0 \simeq 0$ and $|\vec{t}| \simeq \frac{E_0}{E'} E_A(1 - cos\theta_A)$
- Weizsacker-Williams[1]:

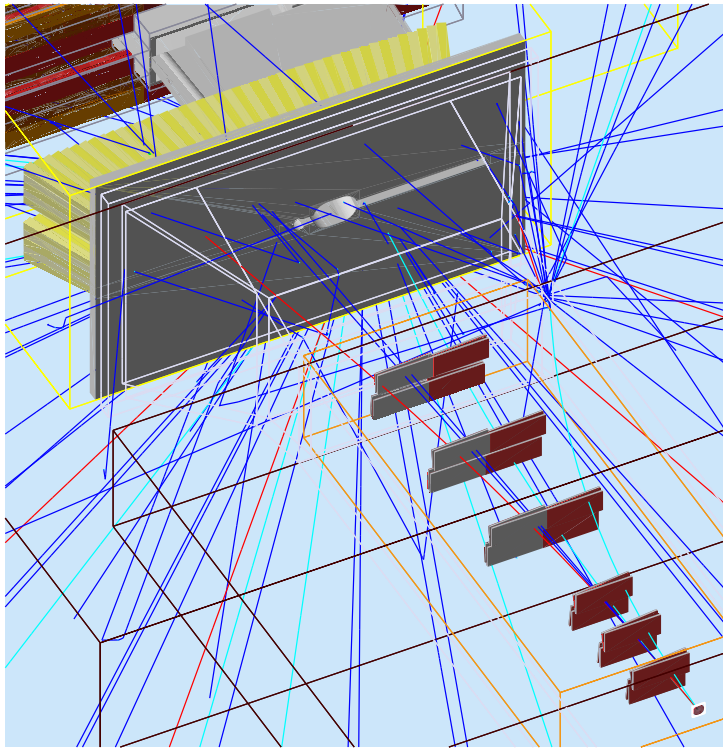
  $\sigma_{e+Z \rightarrow e'+Z'+A} \simeq$
  $\Gamma_{\gamma^*}(t) \times \sigma_{e+\gamma_r \rightarrow e'+A}$



[1] J.D. Bjorken, R. Essig, P. Schuster, N. Toro, Phys. Rev. **D80**, 075018 (2009).

Detector Simulations with GEMC

- MadGraph event generators for A' production and background[1]
- Geant4 based detector simulation and reconstruction package[2]
- Events generated ($E_0 = 1.1, 2.2, 6.6$ GeV): $E_{+\wedge(-\vee e')} > 0.05, 0.2, 0.6$ GeV, $E_+ + E_{(-\vee e')} > 0.1, 0.4, 1.2$ GeV and $\theta_Y^{+\wedge(-\vee e')} > 0.01$ rad.
- Events satisfying Trigger conditions[3] were analyzed.

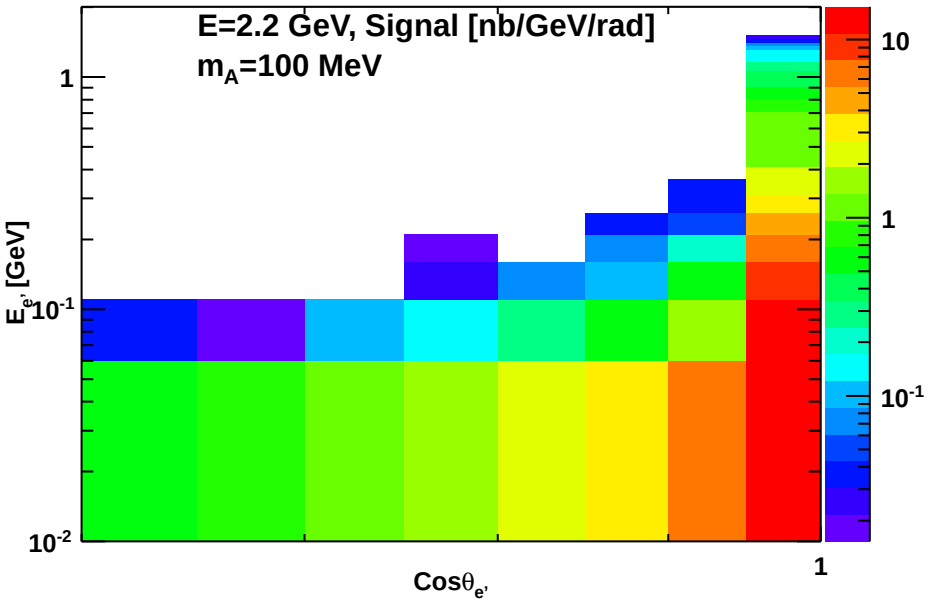


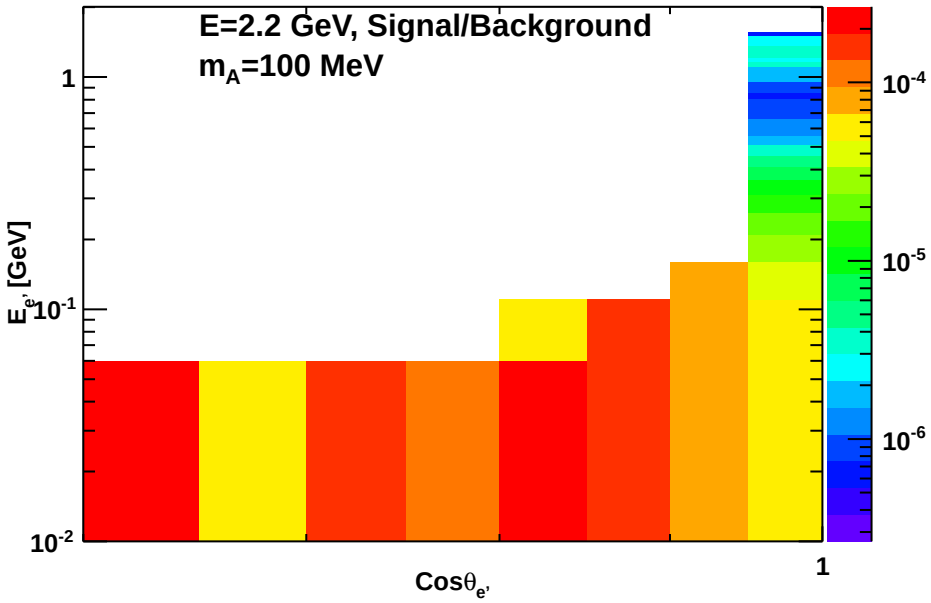
[1] courtesy of Mathew Graham, SLAC National Accelerator Laboratory
[2] courtesy of Maurik Holtrop, University of New Hampshire and Maurizio Ungaro, JLab

[3] see backup slides

Scattered Electron Kinematics

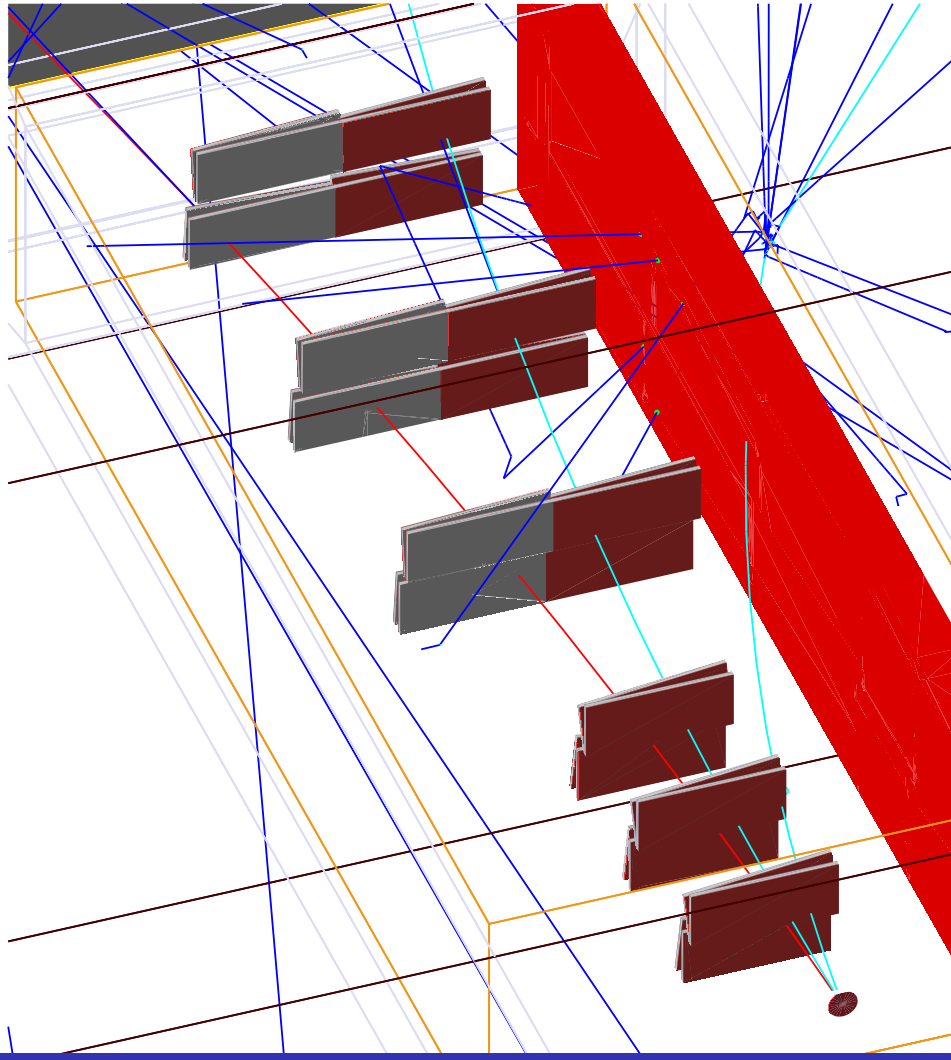
- Scattered electron goes at 0° and carries < 200 MeV.
- Signal/background ratio is maximized:
  at $> 20°$ and < 50 MeV.
- Detection at $Z_{det.} \sim \sqrt{X_{det.}(666cm\frac{P_{e'}/1GeV}{B/1T} - X_{det.})}$
  e.g. for $X_{det.} = 20$ cm, $Z_{det.} < 70$ cm.





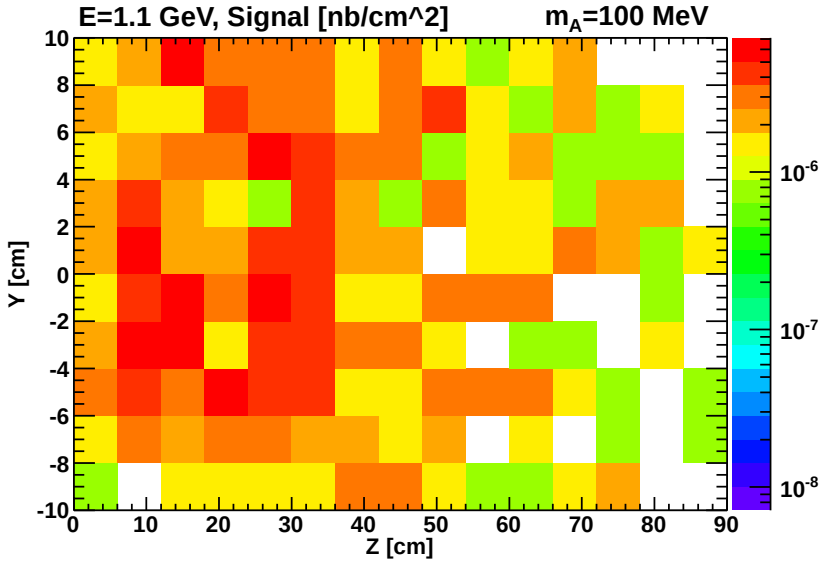
Detector Prototype

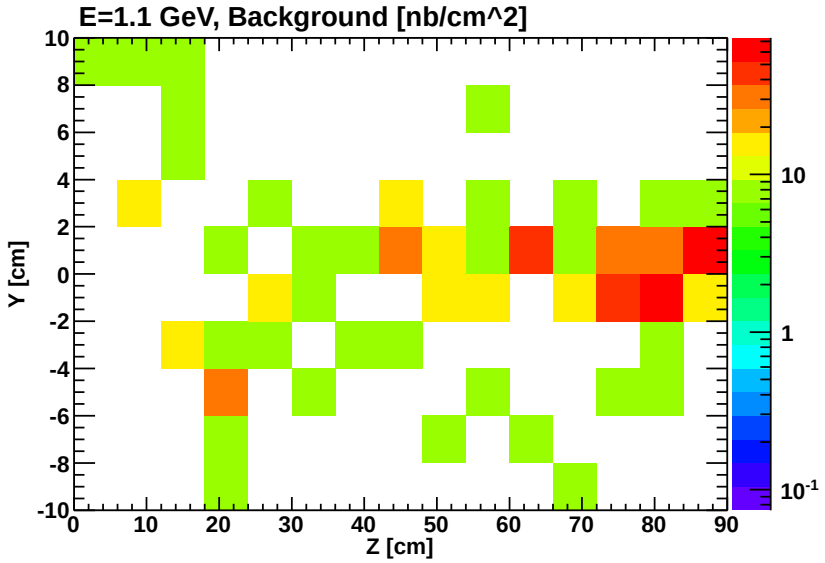
- No space for $> 10X_0$ scintillator crystals,
- cost of such calorimeter would be of the order of M$,
- magnetic spectrometer may be feasible.
- Flux detector at magnet wall on electron side.



Detector Acceptance I

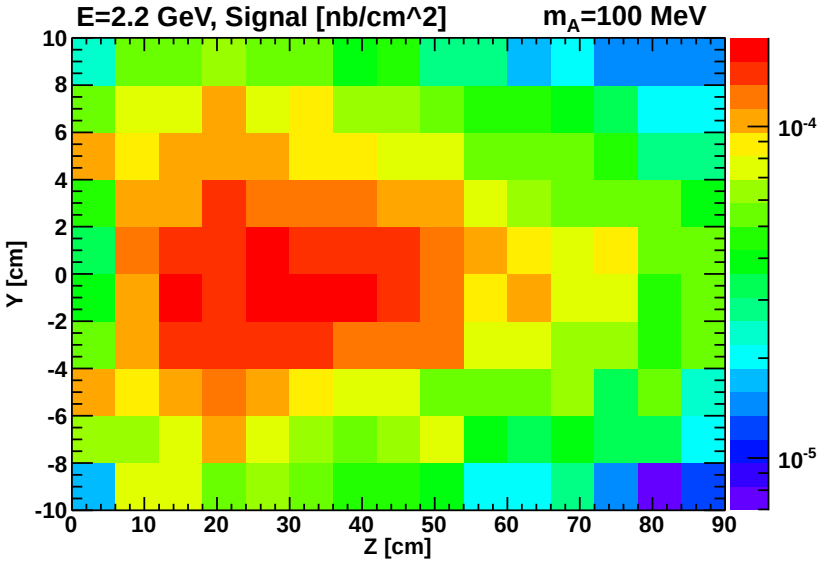
- acceptance of Flux detector - 0.37,
- acceptance of STR (two layers) - 0.19,
- acceptance of STR (one layer) + Flux detector - 0.24,

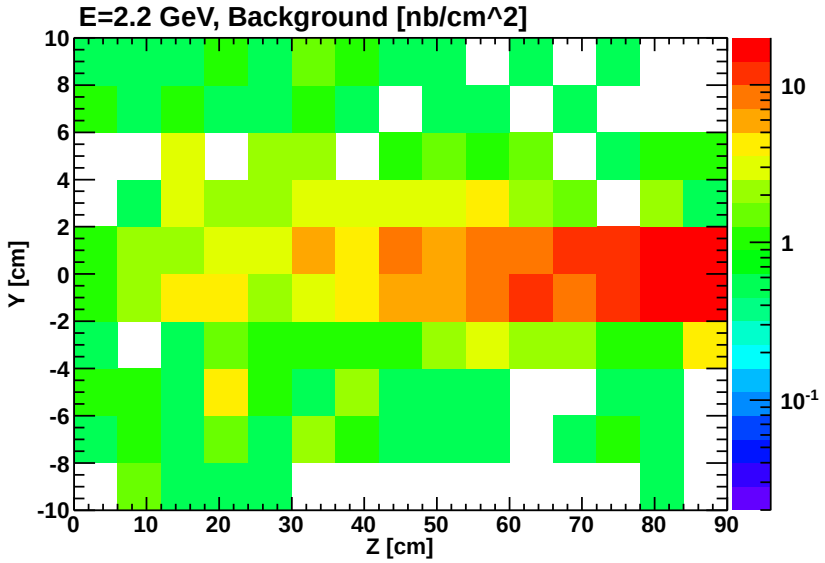




Detector Acceptance II

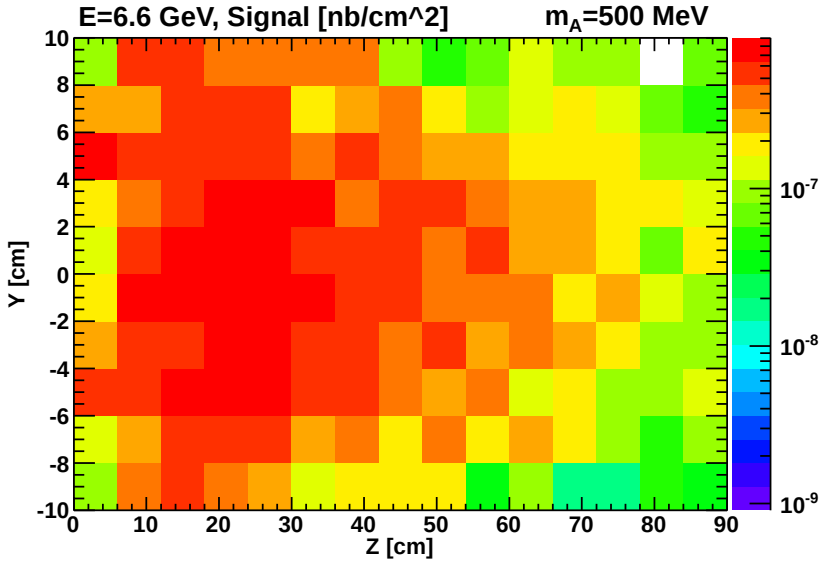
- acceptance of Flux detector - 0.45,
- acceptance of STR (two layers) - 0.19,
- acceptance of STR (one layer) + Flux detector - 0.26,

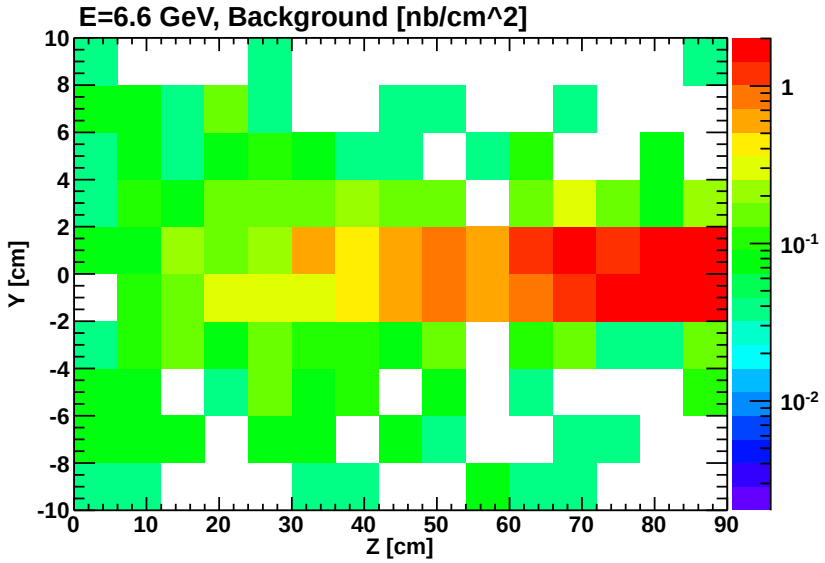




Detector Acceptance III

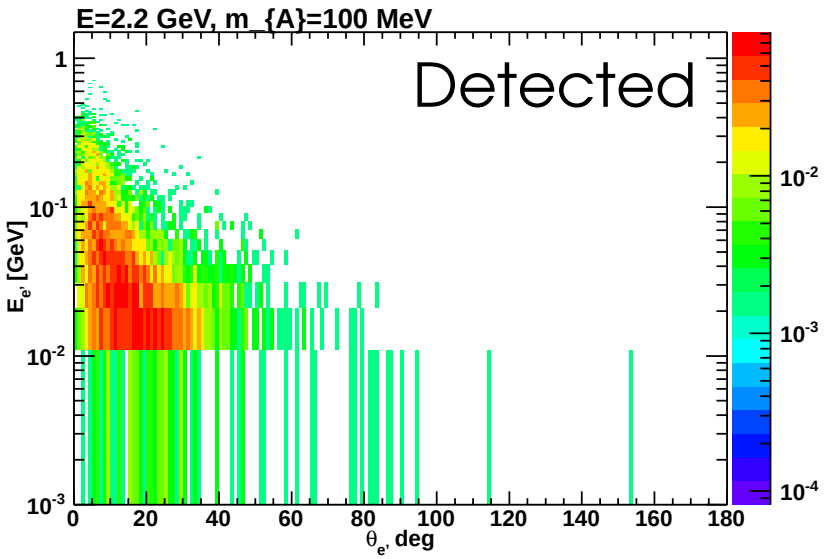
- acceptance of Flux detector - 0.48,
- acceptance of STR (two layers) - 0.15,
- acceptance of STR (one layer) + Flux detector - 0.28,

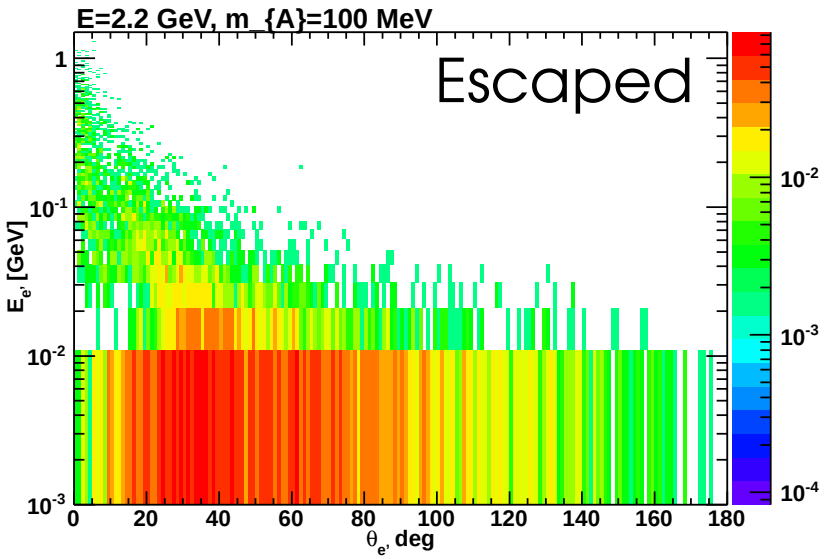




Detector Acceptance IV

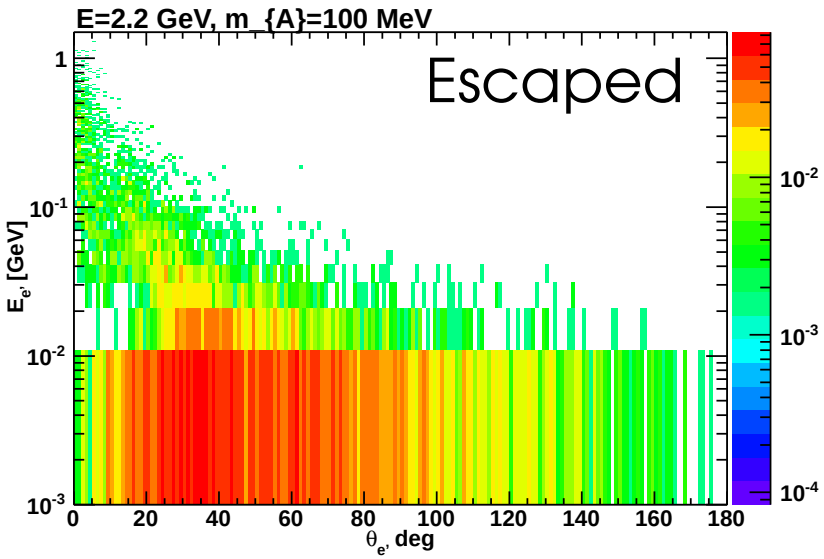
- most of events lie in the region $10 < Z_{det.} < 50$ cm and $-6 < Y_{det.} < 6$ cm,
- acceptance of STR alone (two layers) is about 1/6,
- acceptance of Flux detector alone is about 1/2,
- acceptance of STR (one layer) + Flux detector is only 50% better than STR alone.

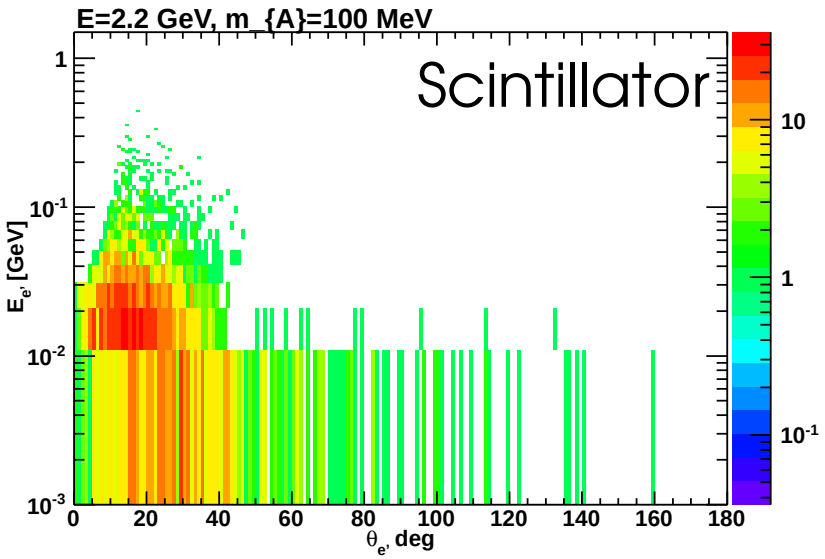




Detector Acceptance V

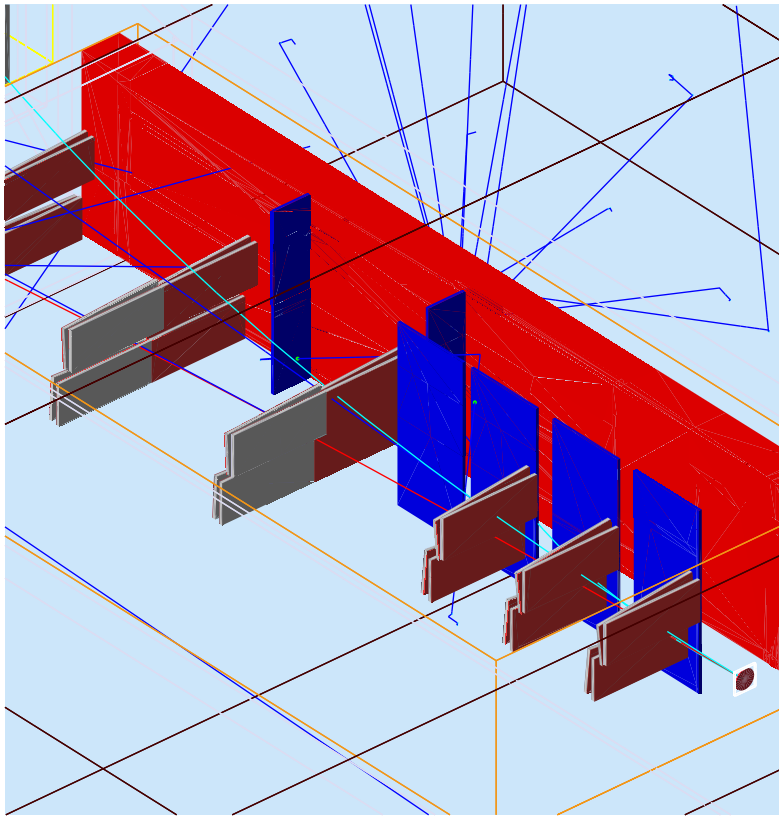
- added $5 \times 5 \times 1$ cm^3 LYSO scintillator nearby the target (electron side),
- recovered another 1/6 of acceptance for total of 50-60%,
- but the energy of scattered electron is too large to be contained.





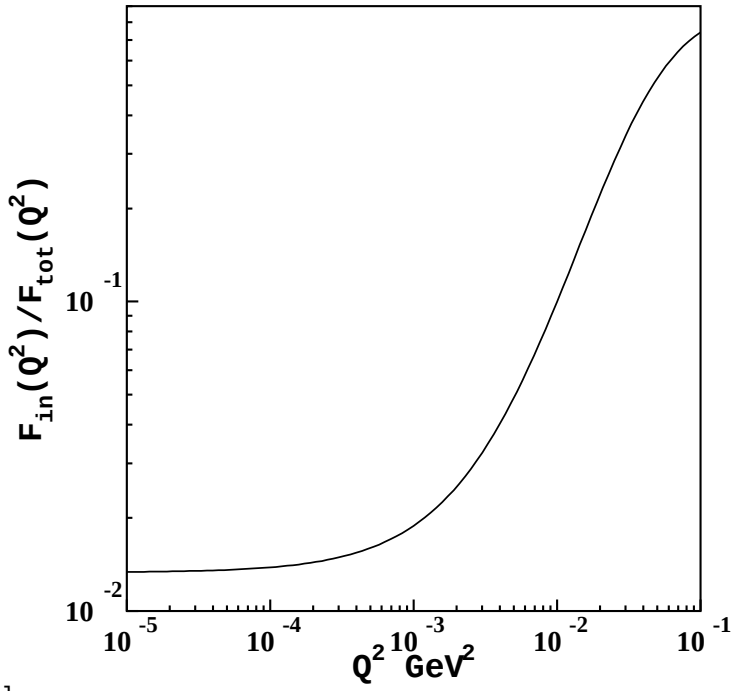
More Realistic Detector Geometry

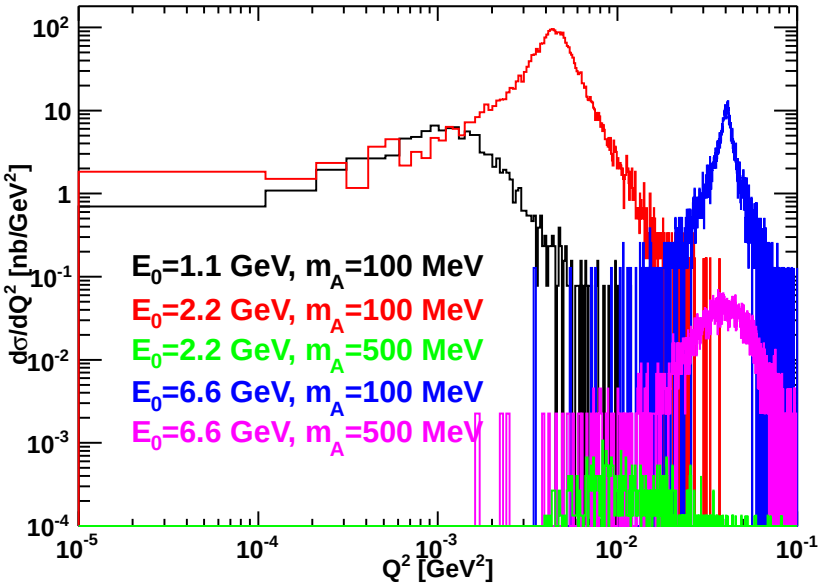
- Fill gaps between STR layers
- four modules of size similar to STR ones,
- assuming two point reconstruction, one STR layer + one Realistic detector layer, at 2.2 GeV and $m_A = 100$ MeV the acceptance is 1/2 of Flux detector acceptance,
- this value is marginally better than only STR (two layers) acceptance.



Identification of Coherent Process

- Contribution of incoherent production at large Q^2 is important[1],
- 6.6 GeV data lies at Q^2 values where incoherent production can reach 50%.





[1] J.D. Bjorken, R. Essig, P. Schuster, N. Toro, Phys. Rev. **D80**, 075018 (2009).

e^+e^- mass resolution I

- detector resolution on e^+e^- mass can be approximated:

$$\delta m_{A'}^2 \simeq m_{A'}^2 \sqrt{2\left(\frac{\delta p}{p}\right)^2 + 2(\delta\theta)^2}$$

- angular resolution gives order of magnitude smaller contribution[1]

E_0 [GeV]	B (T)	$\delta p/p$ (%)	$\delta\theta, \phi$ (mrad)	$\delta m_{A'}^2/m_{A'}^2$ (%)
1.1	0.25	7.7	2.7	11.6
2.2	0.5	4.4	1.4	6.9÷9.9
6.6	1.5	2.5	0.8	3.8÷4.8

[1] courtesy of Mathew Graham, SLAC National Accelerator Laboratory

e^+e^- mass resolution II

- substitute inaccurately measured lepton momenta with scattered electron energy:

$$m^2_{l^+l^-} \simeq \frac{(E_0 - E')^2}{2}(1 - \cos^2\theta_{CM})(1 - \cos\theta_\pm)$$

where only decay angle depends on them:

$$\cos\theta_{CM} = \frac{E_+ - E_-}{E_+ + E_-}$$

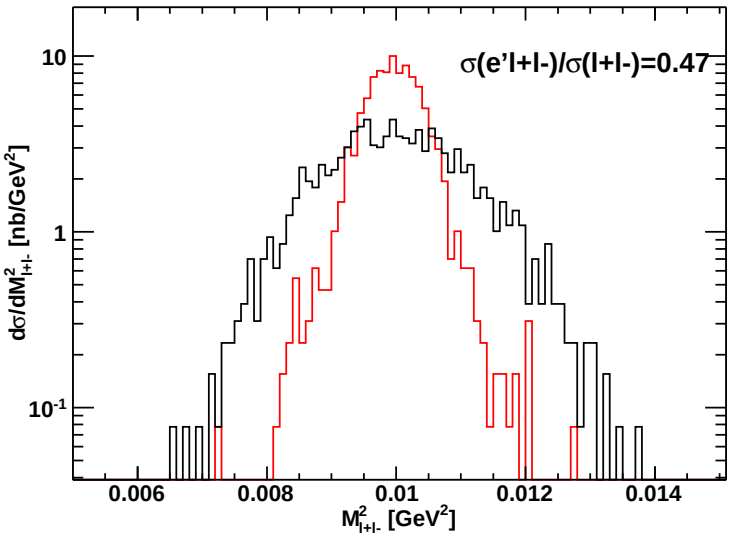
- this reduces dependence on E_+ and E_- energy resolution:

$$\delta m^2_{A'} \simeq m^2_{A'} \frac{2}{\frac{E_0}{E'} - 1} \frac{\delta E'}{E'}$$

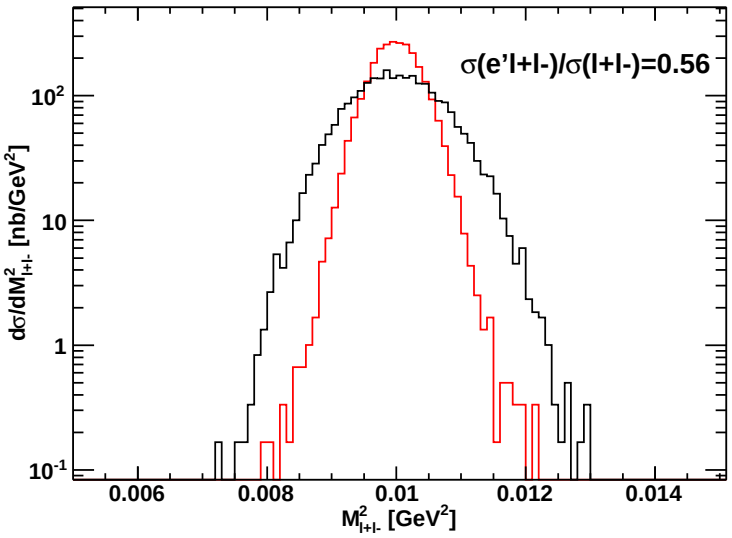
e^+e^- mass resolution III

- Scattered electron spectrometer resolution $\delta p/p = 2.5\%$ was assumed.
- Factor of 2 improvement in the mass reconstruction.

1.1 GeV, $m_A = 100$ MeV



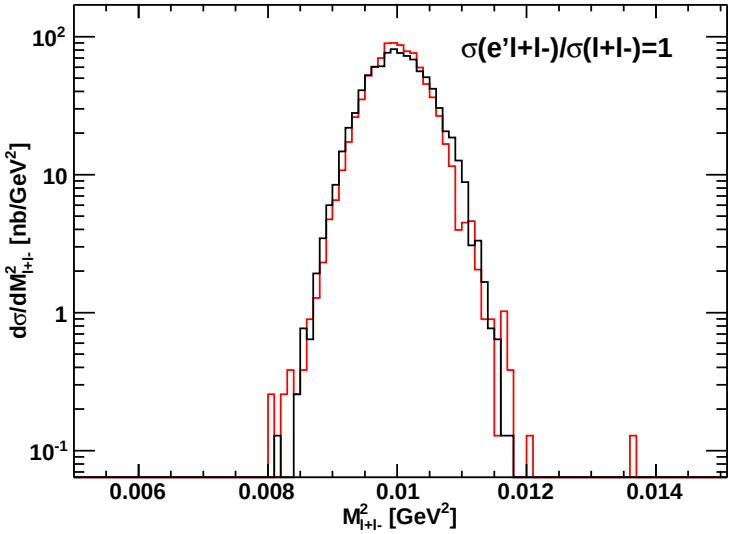
2.2 GeV, $m_A = 100$ MeV



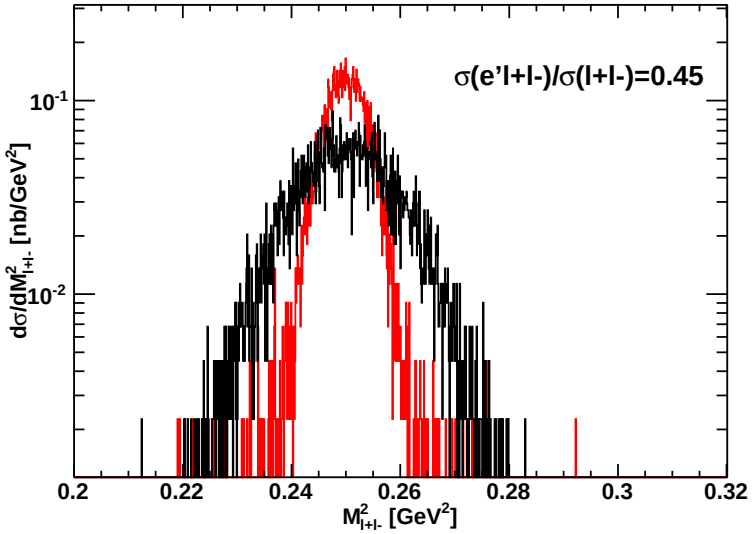
e^+e^- mass resolution IV

- No improvement when A' mass is negligible with respect to beam energy.

6.6 GeV, $m_A = 100$ MeV



6.6 GeV, $m_A = 500$ MeV



Summary

Development of scattered electron detector:

- does not improve physical background rejection. The scattered electron energy can be reconstructed from A' decay lepton pair;
- does not allow to extend detector acceptance because the reconstruction of A' mass from only scattered electron or from scattered electron and positron is problematic;
- allows for separation of the incoherent A' production channel. For low beam energies this contribution is negligible;
- allows to improve A' mass resolution by a factor of 2, except for 6.6 GeV and small masses.
- Acceptance of proposed FLUX detector (fully instrumented electron side magnet wall) ranges from 30 to 50%. However, the combined acceptance of STR and FLUX detectors drops by a factor of 2 and becomes comparable with acceptance of STR detector alone (assuming 2 double layer reconstruction).

Backup Slides

Trigger Conditions

The HPS trigger conditions were imposed to the simulated events. These conditions are listed below:

1. threshold on single crystal: 30 MeV,
2. number of crystals in cluster $>=1$,
3. cluster lower energy threshold: 200 MeV (1.1 GeV), 400 MeV (2.2 GeV), 1200 MeV (6.6 GeV),
4. cluster upper energy threshold: 0.9 E_0,
5. sum of clusters lower energy threshold: 500 MeV (1.1 GeV), 1000 MeV (2.2 GeV), 3000 MeV (6.6 GeV),
6. sum of clusters upper energy threshold: E_0,
7. maximum difference of clusters energies: 1500 MeV,
8. maximum deviation of the polar angle between two clusters from 180 deg.: 35 deg.

Acceptance

Table: Acceptances for the scattered electron detection in A' production with respect to the calorimeter trigger acceptance/efficiency: A_{STR} - for STR detector (at least 2 double layers), A_{Flux} - for Flux detector (impact point with $0 < Z < 90$ cm and $-10 < Y < 10$ cm), $A_{STR+Flux}$ - for STR and Flux detectors (at least 1 STR double layer and Flux impact point with $0 < Z < 90$ cm and $-10 < Y < 10$ cm).

E_0 [GeV]	$m_{A'}$ (MeV)	A_{STR}	A_{Flux}	$A_{STR+Flux}$
1.1	100	0.19	0.37	0.24
2.2	100	0.19	0.45	0.26
2.2	500	0.11	0.21	0.07
6.6	100	0.48	0.31	0.14
6.6	500	0.15	0.48	0.28