Measuring Inclusive Cross Sections in Hall C

I. Methods for extracting cross sections from yields

   (a) Acceptance correction method
   (b) Monte Carlo ratio method

II. Eliminating backgrounds
III. Acceptance corrections
IV. θ bin centering
V. Radiative corrections
VI. Application of extraction methods

Cross Section Extraction Methods

For each bin in ΔE, $\Delta\Omega$, the number of detected electrons is:

$$N^- = L*(d\sigma/d\Omega dE')*(\Delta E'\ \Delta\Omega)*\varepsilon*A(E',\theta) + BG$$

with L: Integrated Luminosity (# *of beam electrons*targets/area*)

ε: Total efficiency for detection

$A(E',\theta)$: Acceptance for bin

BG: Background events.

The efficiency corrected electron yield is

$$Y = (N^- - BG)/\varepsilon \quad = \quad L*\sigma^{data}*(\Delta E\ \Delta\Omega)*A(E',\theta)$$

For known $A(E',\theta)$, $\sigma^{data} = Y/[(\Delta E\ \Delta\Omega)*A(E',\theta)*L]$

From previous slide:

$d\sigma/d\Omega dE' = Y(E',\theta) / [(\Delta E\ \Delta\Omega) * A(E',\theta) * L]$ (Acceptance correction method)

$A(E',\theta)$ is the probability that a particle will make it through the spectrometer and *must be measured or determined from simulation!*

$\Delta\Omega_{eff} = \Delta\Omega * A(E',\theta)$ is the *effective solid angle* or *solid angle acceptance*.

Conversely, we can simulate Monte Carlo data using a cross section model to obtain

$$Y_{MC}(E',\theta) = L * \sigma^{mod} * (\Delta E\ \Delta\Omega) * A_{MC}(E',\theta):$$

Taking ratio to data and assuming that $A_{MC} = A$, yields

$$d\sigma/d\Omega dE' = \sigma^{mod} * [Y(E',\theta)/Y_{MC}(E',\theta)]$$ (MC ratio method)

Notes on Acceptance

- **In general, whether a particle makes it to the detectors without hitting the collimator, beam pipe, or other stopping aperture depends on the full vertex coordinate and the momentum vector of the particle at the target, and *implicitly* on the spectrometer optics) i.e. A = A(E',x,y,z,X',Y').**

- **The acceptance above is purely deterministic. The trajectory through the spectrometer will either intersect with an aperture or not.**

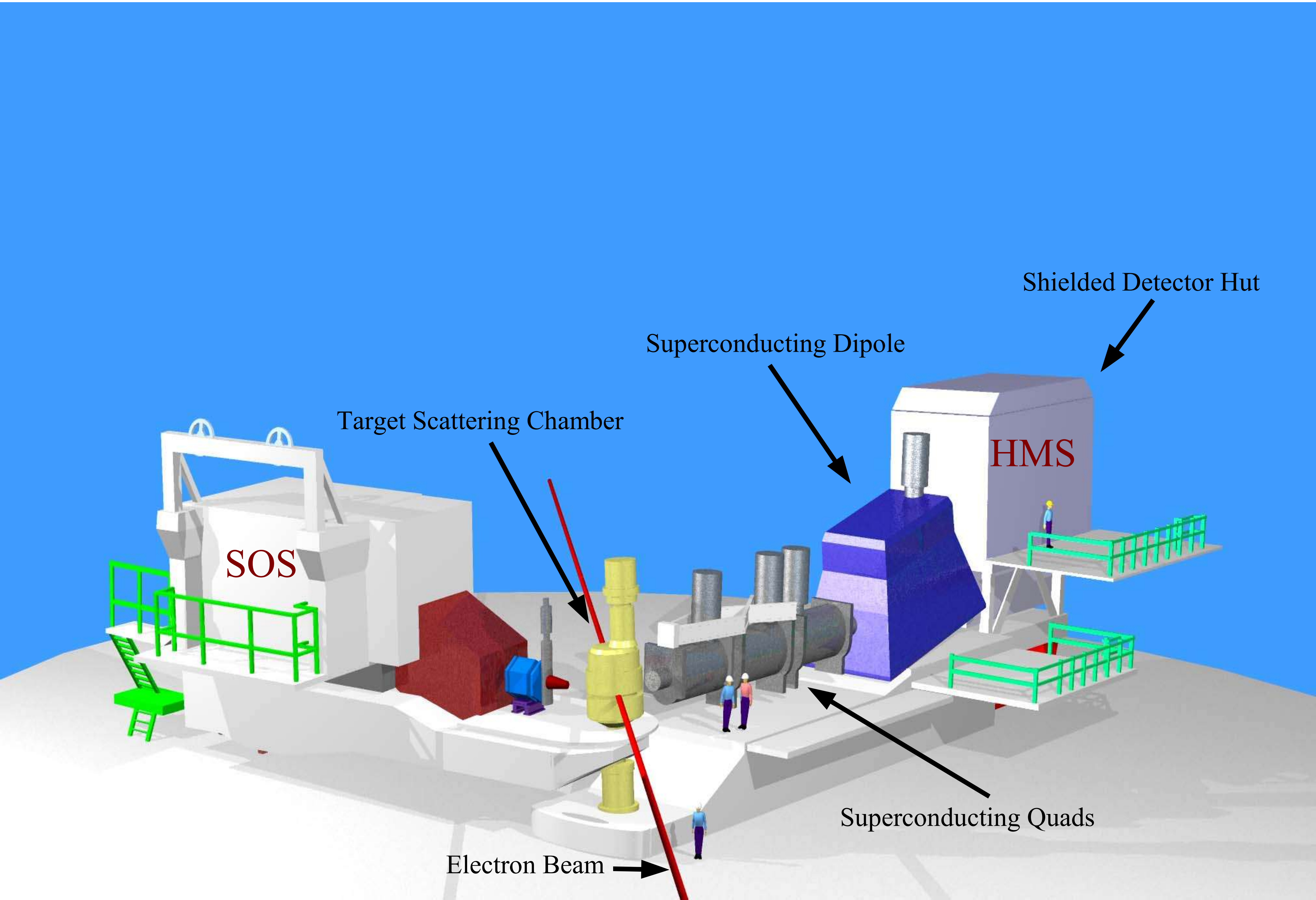
- **However, if we know the fraction of particles at each vertex location then we can properly average over x, y, and z and write A = A(E',X',Y')**

- **The physics only depends on θ (combination of X', Y') => A = A(E',θ)**

  (This has been checked!)

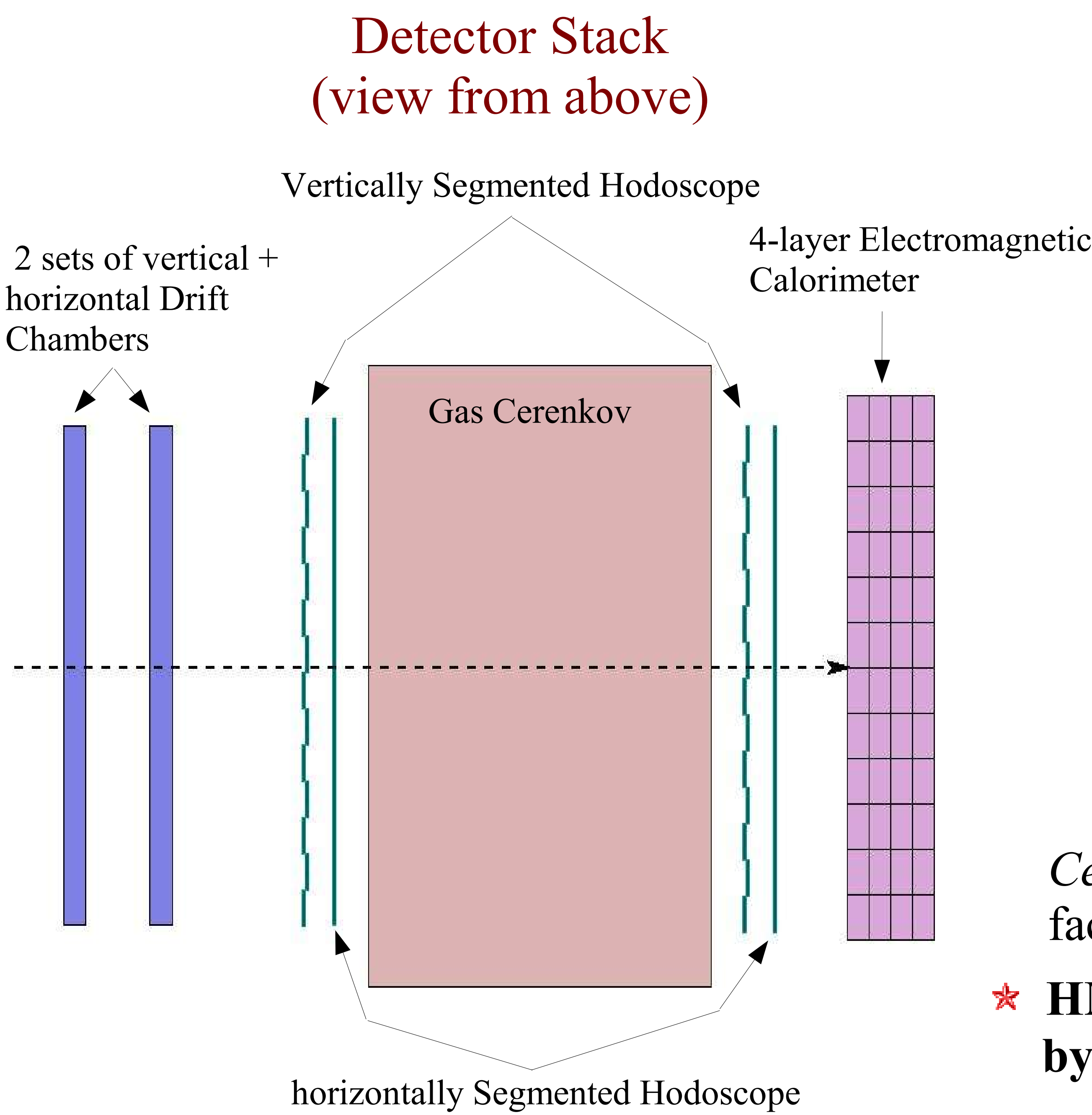
- **Multiple scattering and energy straggling enter only though bin migration and are accounted for in an approximate way.**

Jlab Hall C



Shielded Detector Hut
Superconducting Dipole
Target Scattering Chamber
HMS
SOS
Superconducting Quads
Electron Beam

HMS Spectrometer



HMS Properties (pt-pt tune)	
Kinematic Range:	
Momentum:	0.5 – 7.5 GeV/c
Angular:	10.5^{o} - 80^{o}
Acceptance:	
$\Delta\Omega$:	~6.5 msr
$\Delta p/p$:	+/-9%
Resolution:	
$\Delta p/p$:	< 0.1 %
Θ:	~ 1 mrad

Cer + *Cal* provide π rejection factor ~ 10000/1 At 1 GeV

☆ **HMS Acceptance is dominated by the octagonal collimator!**

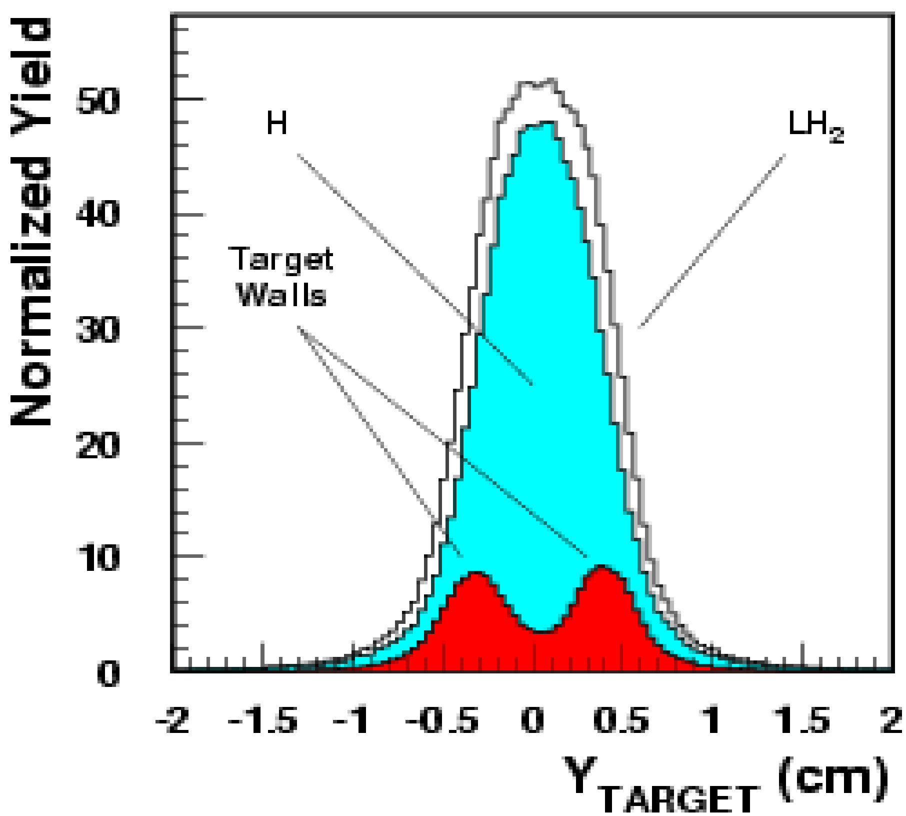
Dominant background for e^- Yields

Background	Eliminate by
1) e^- scattered from Al walls of cryogenic target cell.	1) Subtracting measured e^- from Al dummy target.
2) e^- from charge-symmetric π^0, γ production and decay.	2) Subtracting measured e^+ yields.
3) e^- from radiative events.	3) Applying radiative corrections.
4) π^-	4) Cerenkov and calorimeter cuts

Background from Cryo Cell Walls

Fraction of cell wall background in H_2 is

$$\frac{(\rho t)_{Al} * \sigma_{AL}}{(\rho t)_{H} * \sigma_{H}} \sim 18\% \text{ assuming } \frac{\sigma_{AL}}{\sigma_{H}} \sim 17$$

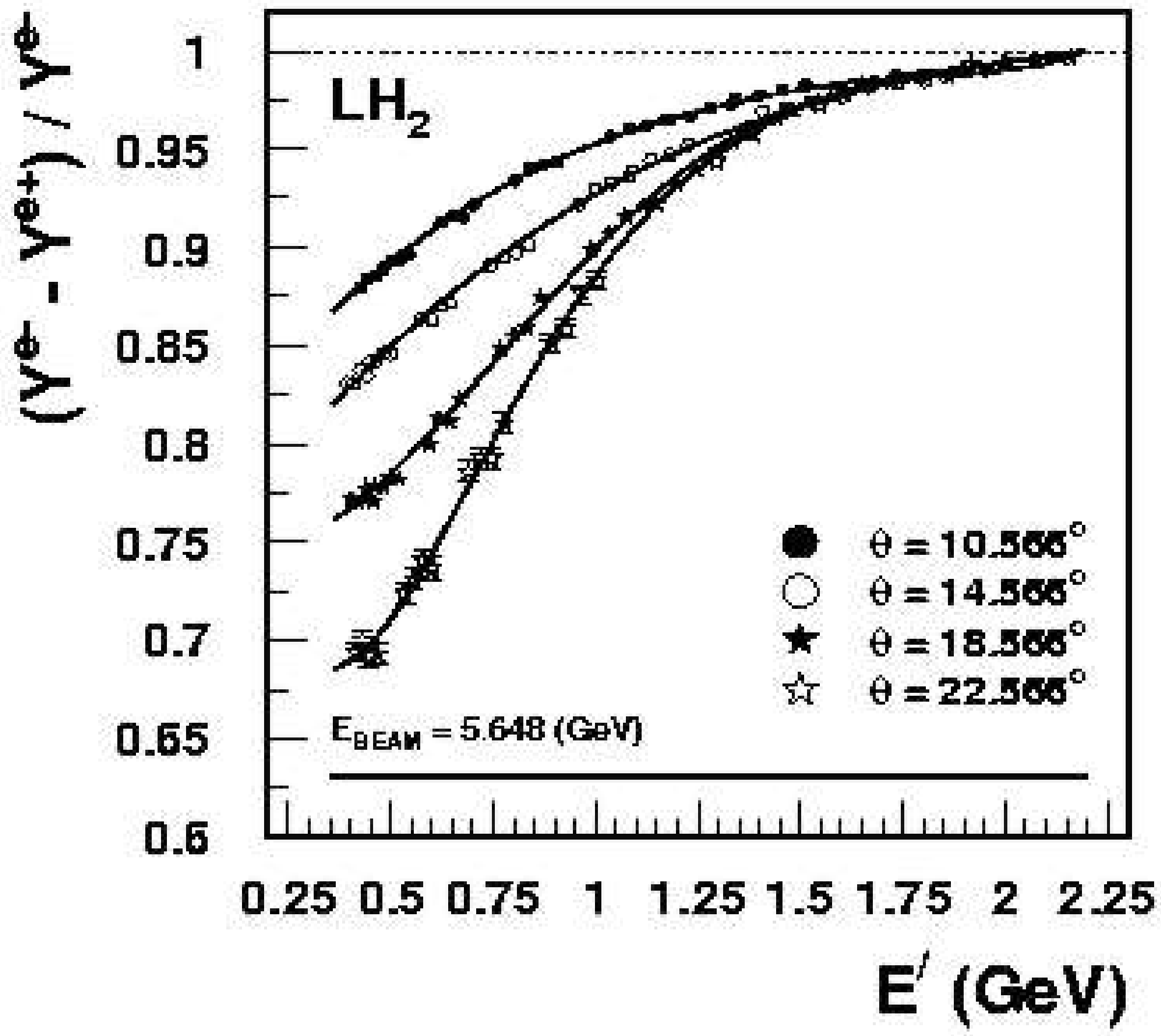


The efficiency corrected yield of hydrogen events can be calculated from

$$Y_H = Y_{cryo} - Y_{dummy} * \frac{L_{walls} * RC_{dummy}}{L_{dummy} * RC_{walls}}$$

Plot from Vladas Tvaskis' PhD Thesis

Charge Symmetric Background



If the CS background is not too large then a multiplicative correction factor can be applied to the electron yield, as

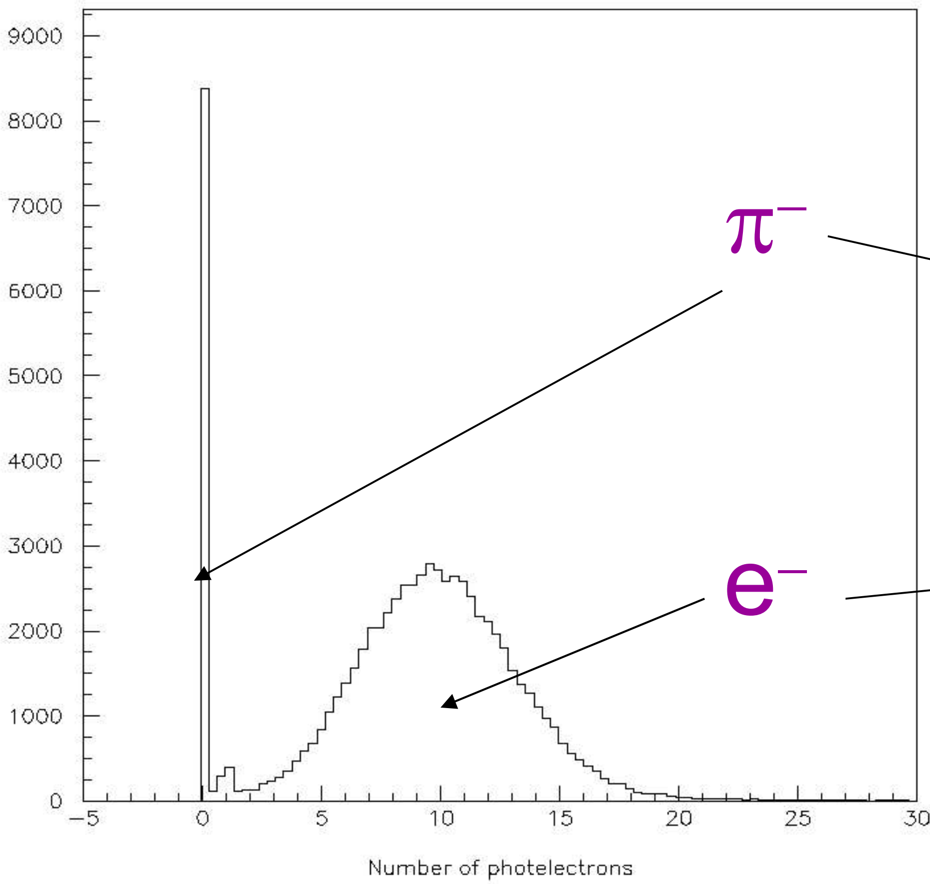
$$CScor = (Y^{e-} - Y^{e+})/Y^{e-}$$

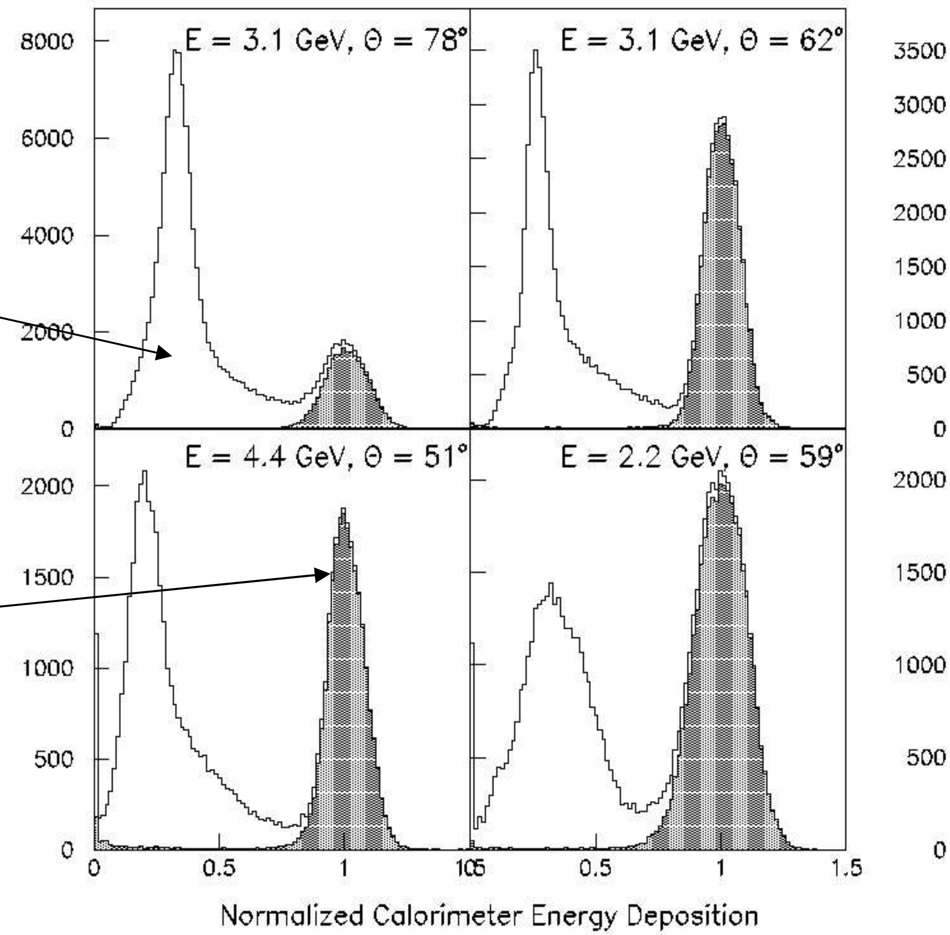
Plot from Vladas Tvaskis' PhD Thesis

PID Detectors and π^- elimination

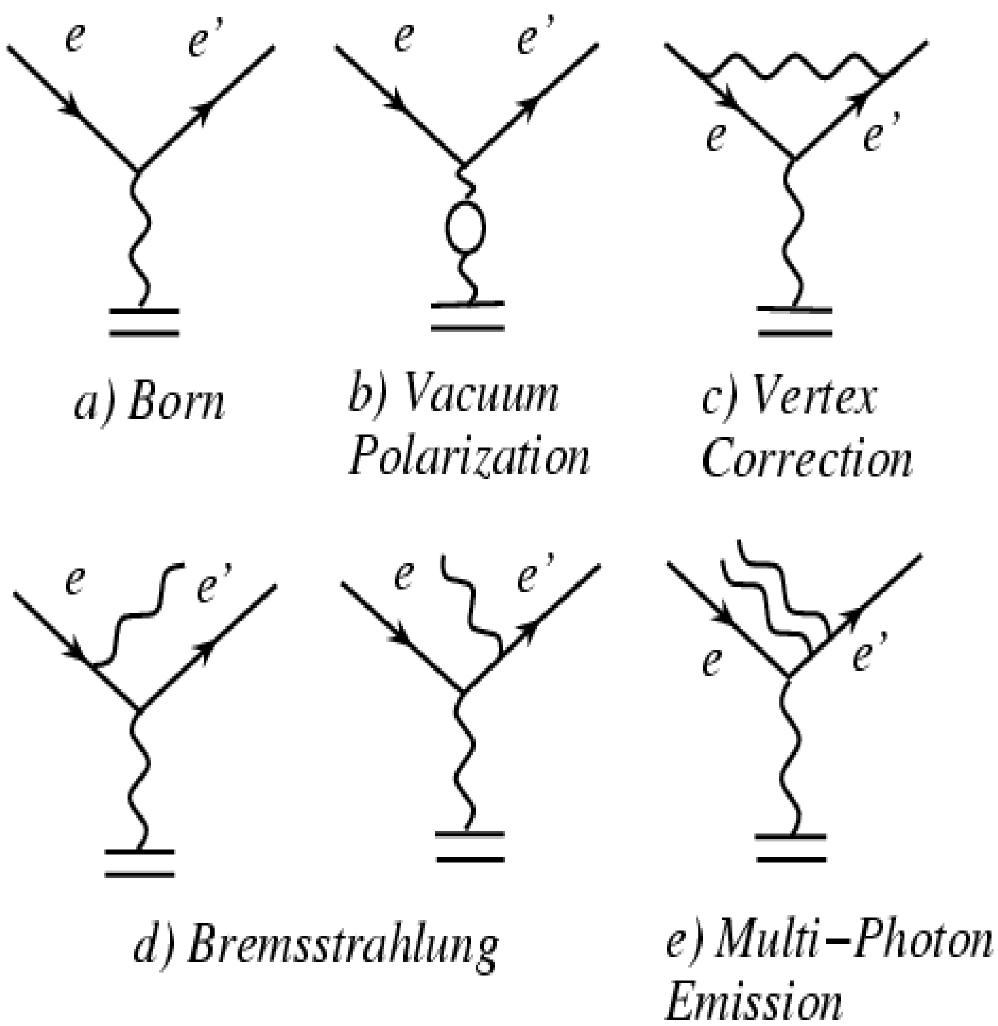
Cerenkov # photo-electrons

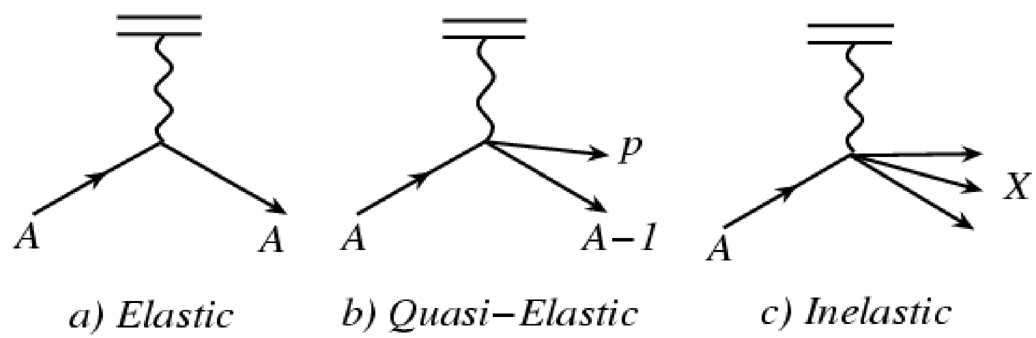
Calorimeter energy deposition





Radiative Corrections For Inelastic Processes





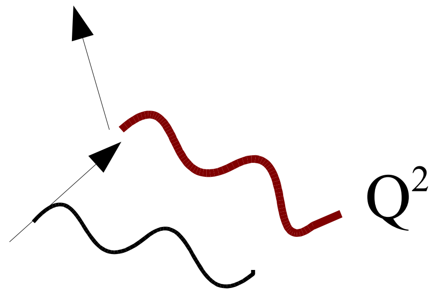
$$\sigma_{\text{Meas}} = \sigma_{\text{Born}} + \sigma_{\text{Elastic}} + \sigma_{\text{Q-Elastic}} + \sigma^{\text{Rad}}_{\text{Inelastic}}$$

$$\sigma^{Born} = (\sigma^{rad}_{\exp} - \sigma_{el} - \sigma_{qel}) \,\Big|\, \frac{\sigma^{Born}_{Inel}}{\sigma^{rad}_{Inel}} \rightarrow$$

Slide from Vladas Tvaskis

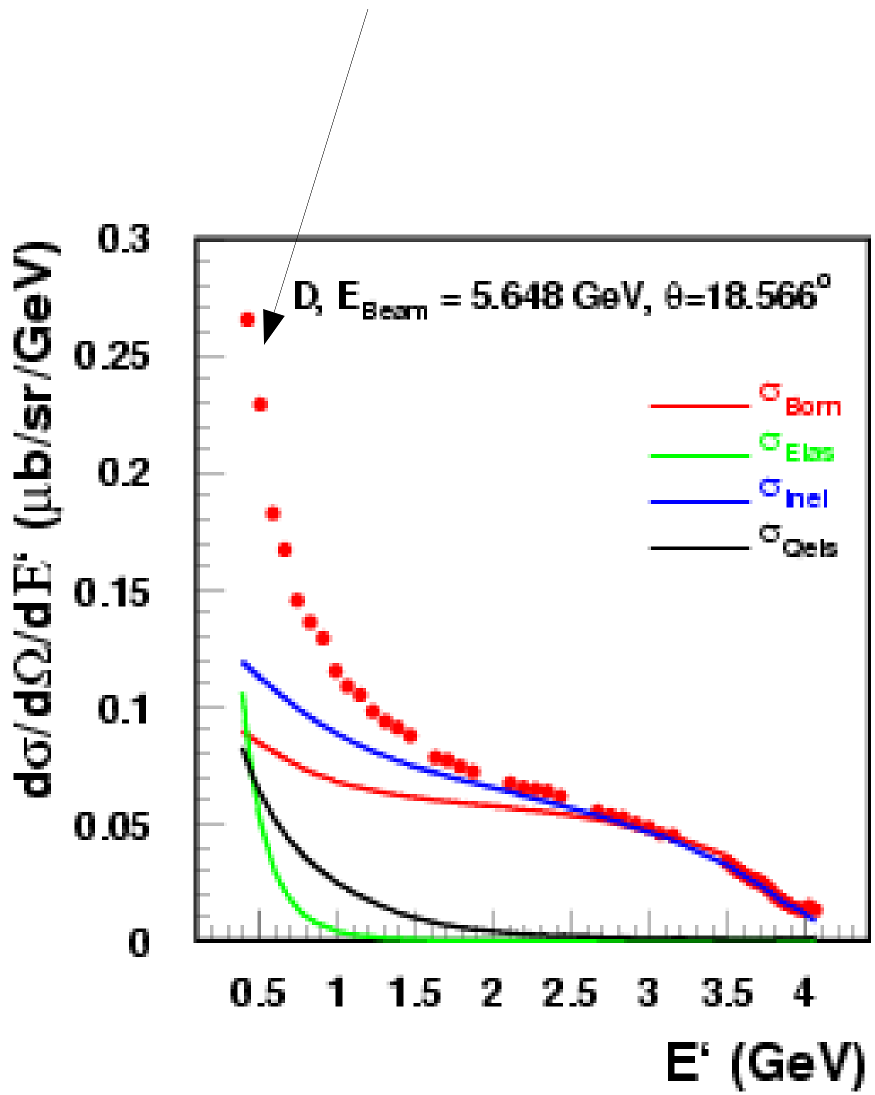
Radiative Corrections (2): Bremsstrahlung

Bremsstrahlung from beam electron

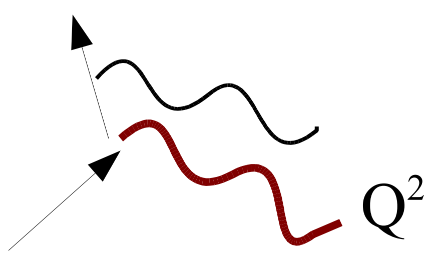


- E_{vertex} is *smaller* than E_{beam}
- Q^2_{vertex} is *smaller* than calculated
- W^2_{vertex} *typically smaller* than calculated.

Elastic events at lower Q^2, W^2 radiate to higher Q^2, W^2.

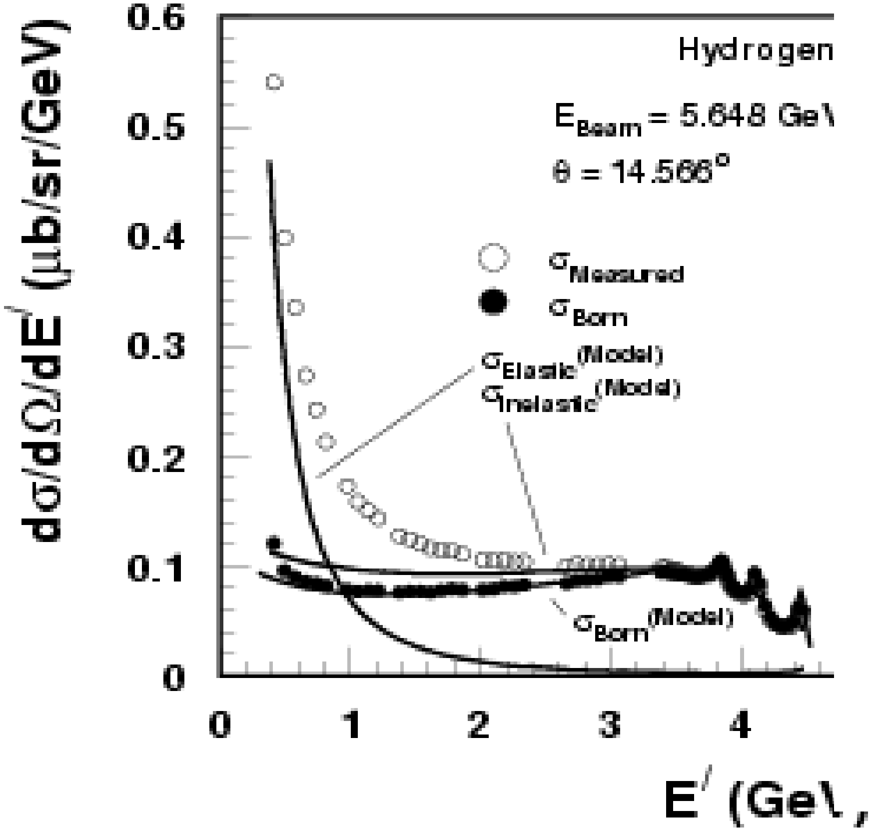


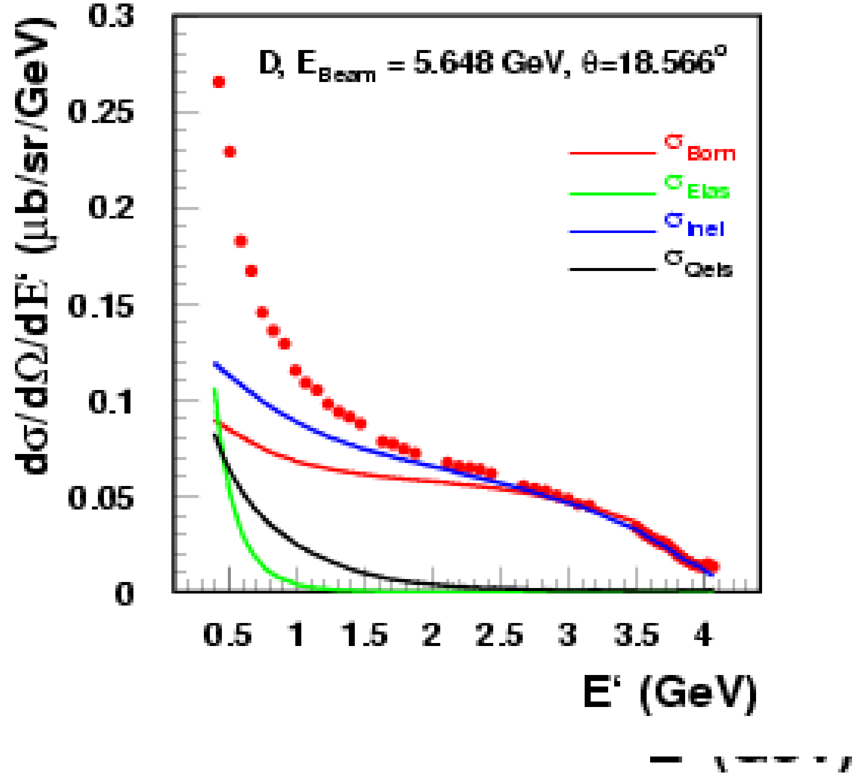
Bremsstrahlung from scattered electron



- E'_{vertex} is *larger* than E'_{HMS}
- Q^2_{vertex} is *larger* than calculated
- W^2_{vertex} is smaller than calculated.

Radiative Corrections (3): Application





$$\sigma_{\exp}^{Born} = (\sigma_{\exp}^{rad} - \sigma_{el} - \sigma_{qel}) \mid \frac{\sigma_{Inel}^{Born}}{\sigma_{Inel}^{rad}} \rightarrow$$

Slide from Vladas Tvaskis

Calculating Acceptance Corrections

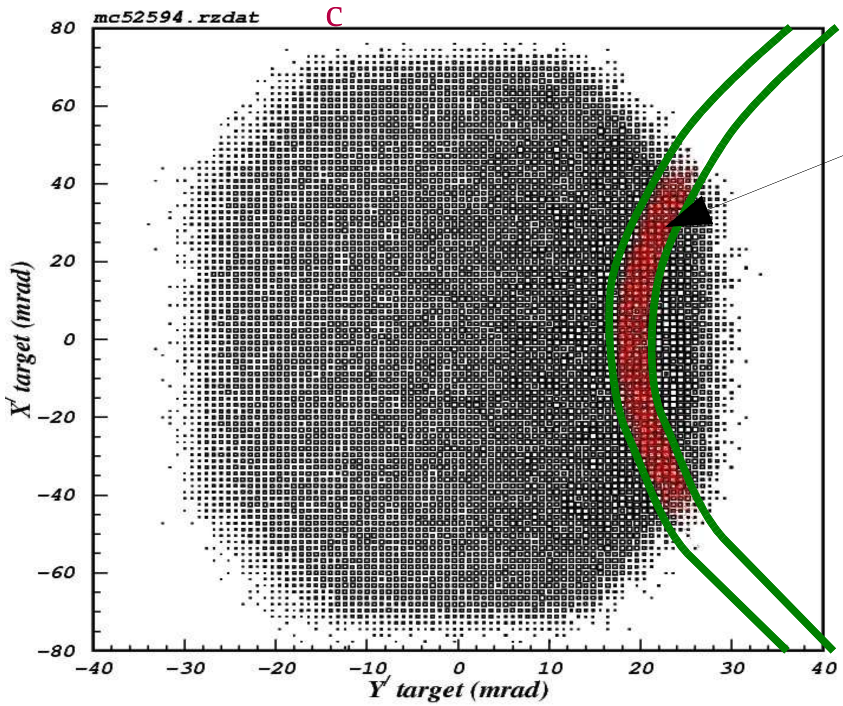
1st we generate MC with the same E', θ_c, target, raster, etc... as the data.

Then, for each bin: $\Delta\Omega_{eff}(\delta,\theta) \equiv$ $\mathbf{A(\delta,\theta)} * \Delta\Omega_{gen}(\delta,\theta)$,

where $\mathbf{A(\delta,\theta)} = \mathbf{N_{rec}(\delta,\theta) / N_{gen}(\delta,\theta)}$

Note that $\Delta\Omega_{gen}(\delta,\theta)$ is the solid angle generated into for that bin and *depends on generation limits in* **Y'** (in-plane angle) and **X'** (out-of-plane angle).

$\theta_c = 10.65^o$



$\Delta\theta$ = -20 +/- 1.75 mrad

If the only aperture were the collimator then the solid angle of this slice would be

$\Delta\Omega_{gen}$ (Green band for $|X'_{gen}| < 80$ mrad)

$\Delta\Omega_{eff}$ (Red area)

However, $\Delta\Omega_{eff}$ does **not** depend on the generation limits.

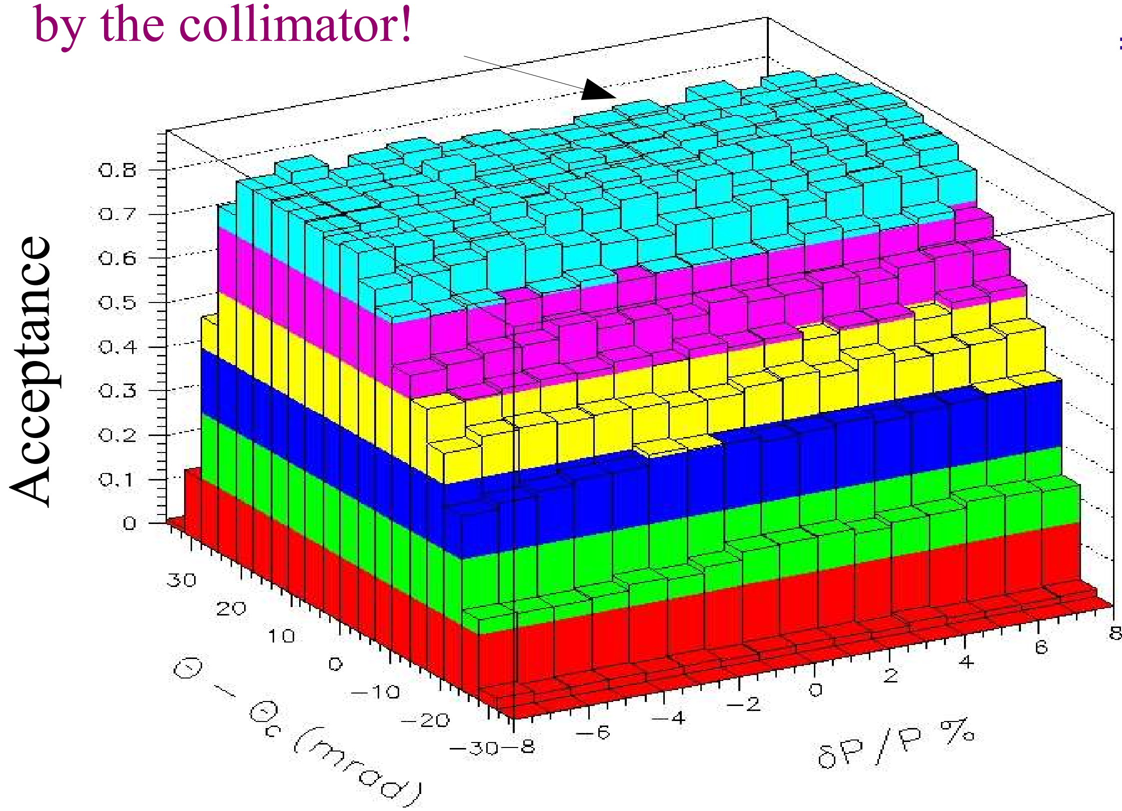
For uniform generation,

$$\Delta\Omega_{eff}(\delta,\theta) \equiv \frac{N_{rec}(\delta,\theta) * \Delta\Omega^{tot}_{gen}(\delta)}{N^{tot}_{gen}}$$

$$= \frac{N_{rec}(\delta,\theta)}{N_{gen}(\delta,\theta)} * \frac{N_{gen}(\delta,\theta)}{N^{tot}_{gen}(\delta)} \Delta\Omega^{tot}_{gen}(\delta)$$

$$= A(\delta,\theta) * \Delta\Omega_{gen}(\delta,\theta)$$

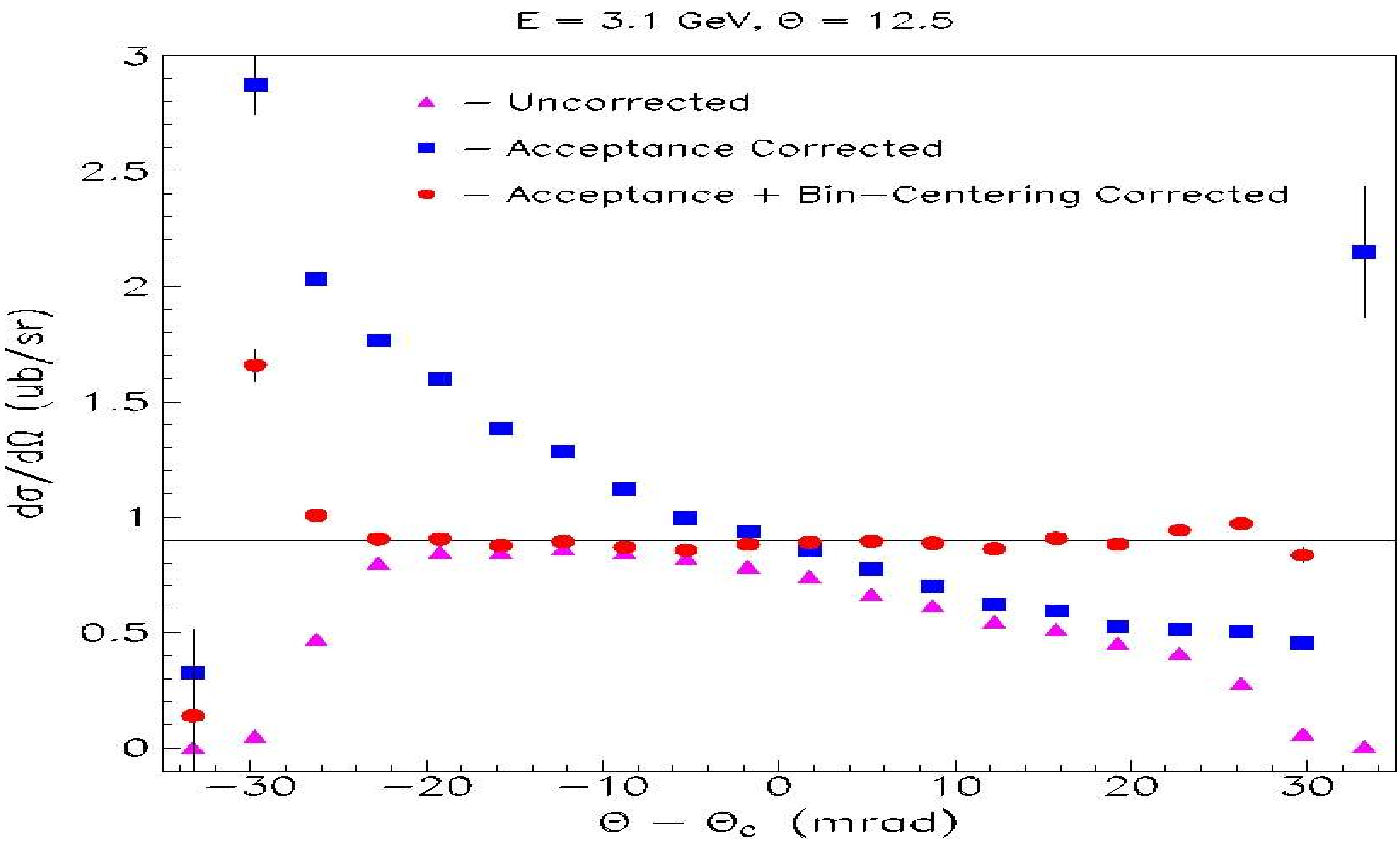
Shape in θ is dominated by the collimator!



Applying Acceptance and θ - BC Corrections

- *For Each E' bin, we want the cross section at fixed* θ *(or Q^2).*
- *Use model to correct d*σ *to central angle,*

$$d\sigma(\theta_c) = d\sigma(\theta) * \sigma^{mod}(\theta_c)/\sigma^{mod}(\theta)$$



Can now average over θ for each bin in δp/p (E')

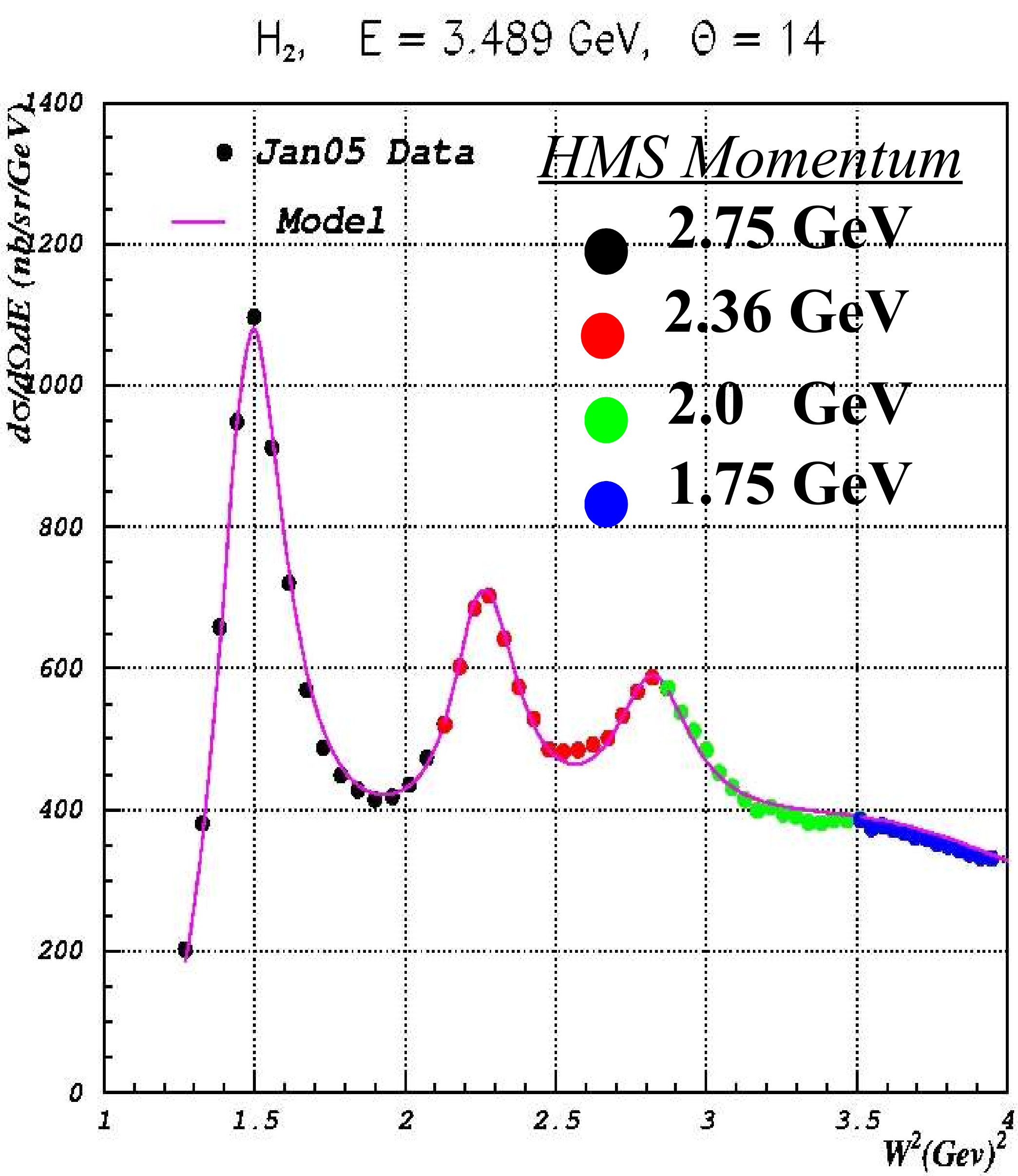
Notes on Bin-Centering

- **A bin-centering correction must be applied to any binned variable for which the yield varies significantly across a bin width.**

- **The bin-centering correction for a linear function = 1.**

- **For θ bin-centering, the full radiated cross section model must be used.**

Acceptance Correction Method



(1) Bin efficiency corrected e^- yield in $\delta p/p$ - θ.
($\delta p/p$ = +/- 8%, $\Delta\theta$ = +/- 35 mrad)

(2) Subtract scaled dummy yield bin-by-bin to remove e^- Al background.

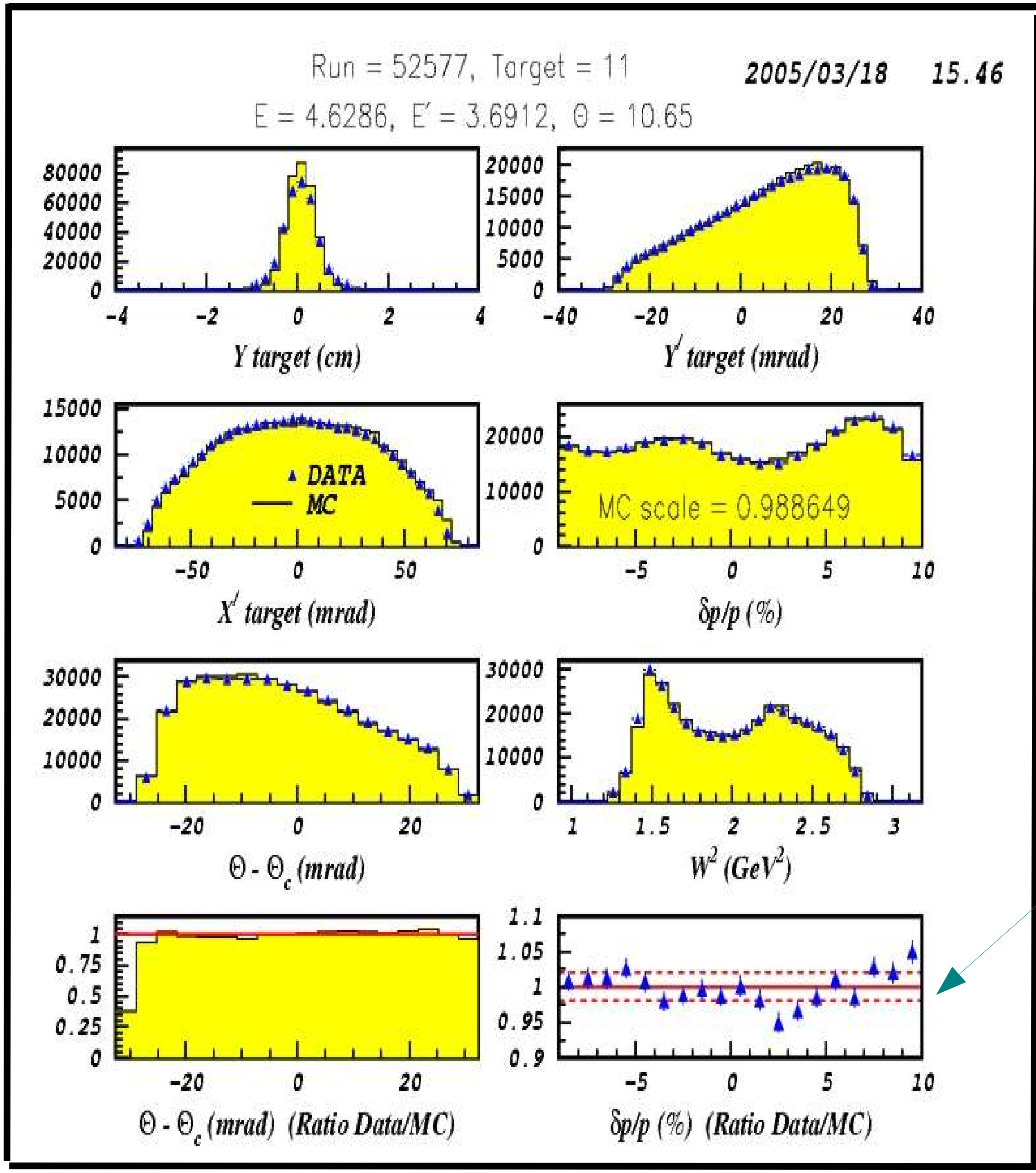
(3) Subtract charge symmetric e^- yield bin-by-bin.

(4) Apply acceptance correction for each δ-θ bin.

(5) Apply radiative corrections bin-by-bin.

(6) Apply θ bin-centering correction and average over θ => for each δ bin.

Monte Carlo Ratio Method



(1) Generate MC events with σ model weighting and radiative contributions included.

(2) Scale the MC yield by L_{data}/L_{MC}, where L_{MC} is that needed to produce N_{gen} for the given σ_{mod} and phase space generated into.

(3) Add background contributions to MC or subtract from data.

(4) $d\sigma(\delta, \theta_c) = d\sigma^{mod}(\delta,\theta_c) * Y(\delta)/Y_{MC}$

(δ) *Where Y(δ) is the yield for events with any value of θ, i.e. this integrates over θ.*

Warning: For inclusive data, radiative events can come from kinematically far away.

★ Comparison of January '05 proton data to MC using E94-110 resonance region model and externally calculated radiative corrections.