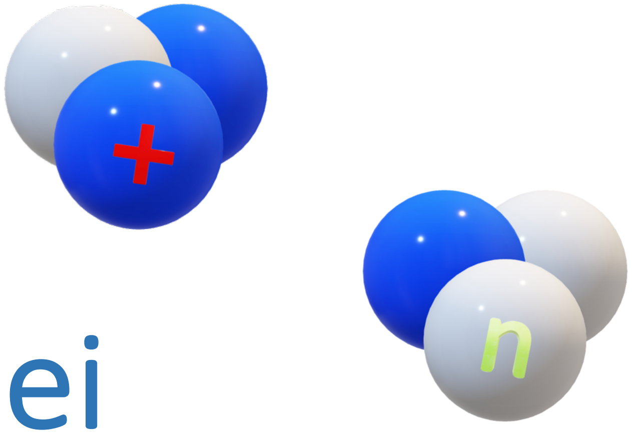
Elastic Electron Scattering From ^{3}He and ^{3}H Mirror Nuclei



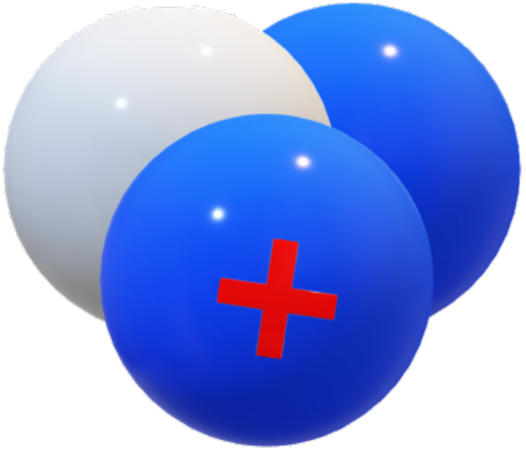
Leiqaa Kurbany

On behalf of the E12-11-112 collaboration

Hall A Winter Collaboration Meeting
January 22, 2021

University of New Hampshire

Jefferson Lab
Exploring the Nature of Matter

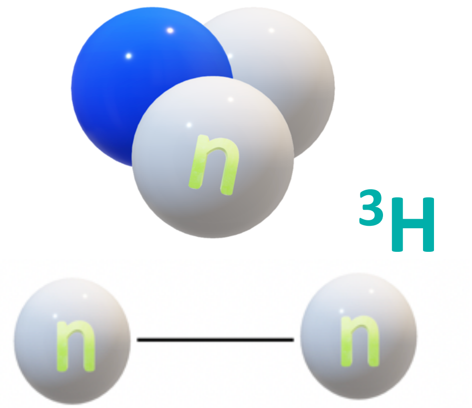


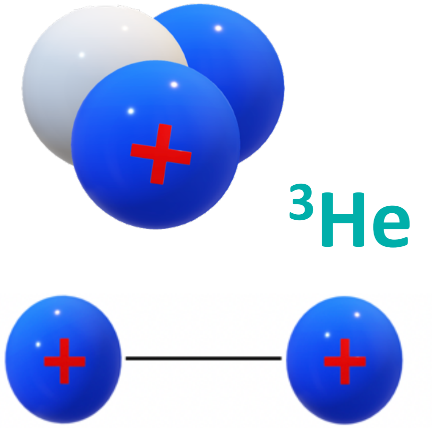
Talk Outline

- Physics motivation.
- Experimental setup.
- Data analysis.
- Future work.

Motivation and Mirror Nuclei

Mirror nuclei are pairs of nuclei in which the proton number in one equals the neutron number in the other and vice versa.



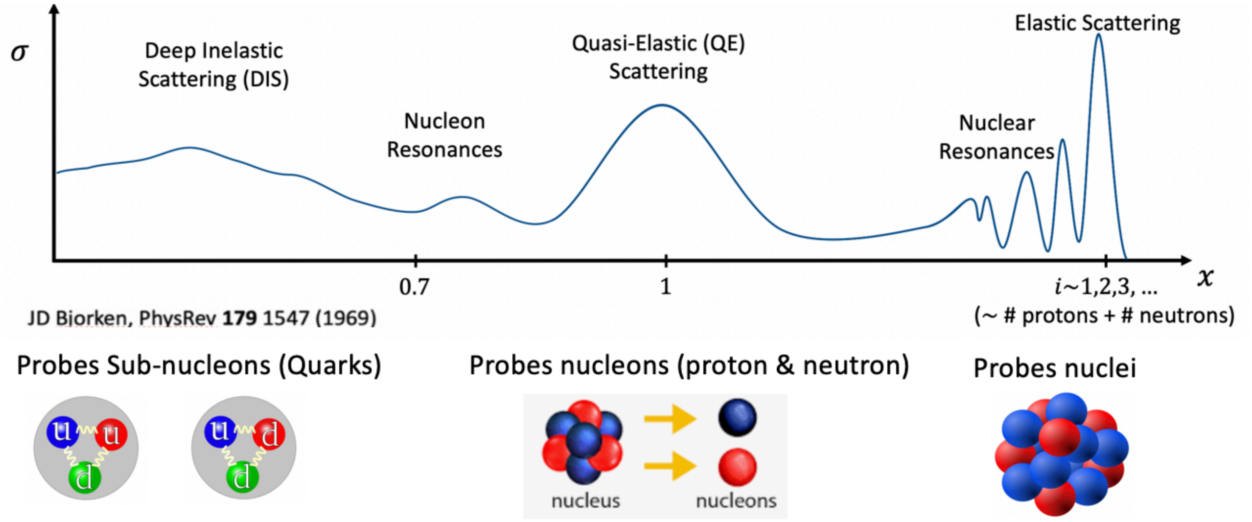


^{3}H and ^{3}He nuclei is the simplest pair of mirror nuclei.

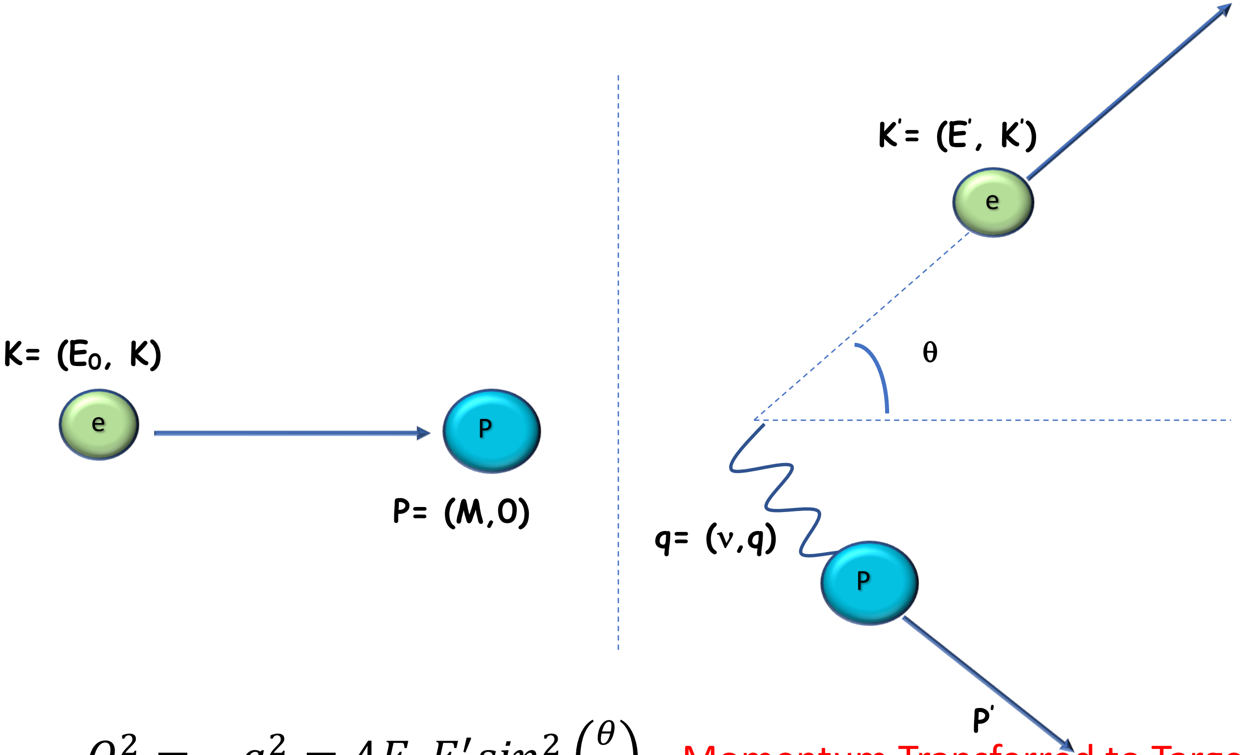
Comparison of ^{3}H and ^{3}He mainly sensitive to difference in contributions from protons and neutrons.

Elastic Electron Scattering

$$E' = \frac{E_0}{1 + \frac{E_0}{M}(1 - \cos\theta)}$$ Scattered electron’s final energy.



JD Bjorken, PhysRev **179** 1547 (1969)



- The kinetic energy of the scattering is conserved.
- The same particles are presented both before and after the scattering.
- we can be described the scattering by two variables the scattering angle θ,and the initial energy E_0.

- $Q^2 = -q^2 = 4E_0E'sin^2\left(\frac{\theta}{2}\right)$ Momentum Transferred to Target.
- $x = \frac{Q^2}{2M\nu}$ Bjorken x (Normalizes 4-momentum-transfer to known masses).
- $\nu = E_0 - E'$ The energy lost by the incident electron during scattering.

Form Factor

$$(d\sigma/d\Omega)_{exp} = (d\sigma/d\Omega)_{Mott}\,|F(q^2)|^2$$

Experimentally

Electron Cross section from Point like particle

$$\left(\frac{d\sigma}{d\Omega}\right)_{exp.} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott}\left[\frac{F_{ch}^2+\tau F_M^2}{1+\tau}+2\tau F_M^2 \tan^2\left(\frac{\theta}{2}\right)\right].$$

$$\boldsymbol{\tau = Q^2/4M^2}$$

Rosenbluth Cross Section

F_{ch} : Electric form factor

F_M : Magnetic form factor

- $F_M(Q^2)$ describes the magnetic structure of the target and equals the magnetic moment of the target at $Q^2 = 0$ in units of the nuclear magneton.
- $F_{ch}(Q^2)$ describes the electric structure of the target and equals the electric charge of the target at $Q^2 = 0$ in units of elementary charge.

Charge Form Factor and Charge Radius

$$F(q^2) = \int e^{\frac{iq\cdot x}{\hbar}} \rho(x) d^3x \xrightarrow{x\longrightarrow r} 4\pi \int \rho(r) \frac{\sin\left(|q|r/\hbar\right)}{|q|r/\hbar} r^2 dr$$

- Recoil is negligible
- The validity of the Born approximation
- In non-relativistic limit

The charge distribution is spherically symmetric.

This procedure can be inverted to find the charge distribution of a target from its form factor.

$$\rho(r) = \frac{1}{(2\pi)^3} \int F(q^2) e^{\frac{-iq\cdot x}{\hbar}} d^3q$$

*Related to charge radius in infinite-momentum-frame
GA Miller, PRL **99** 112001 (2007)

$$F(q^2) = 1 - \frac{q^2}{6\hbar^2}\langle r^2\rangle$$

→

$$\langle r^2\rangle = -6\hbar^2 \frac{dF(q^2)}{dq^2}\Big|_{q^2=0}$$

Mean square root of charge radii

E12-11-112 Kinematics

P. Solvignon, J.Arrington, D.B.Day, D. Higinbotham, Z. Ye (Spokepeople)

Fall 2018

LHRS: Dedicated NN and 3N SRC study (1<xbj<3) with 4.3 GeV beam

RHRS: QE scan

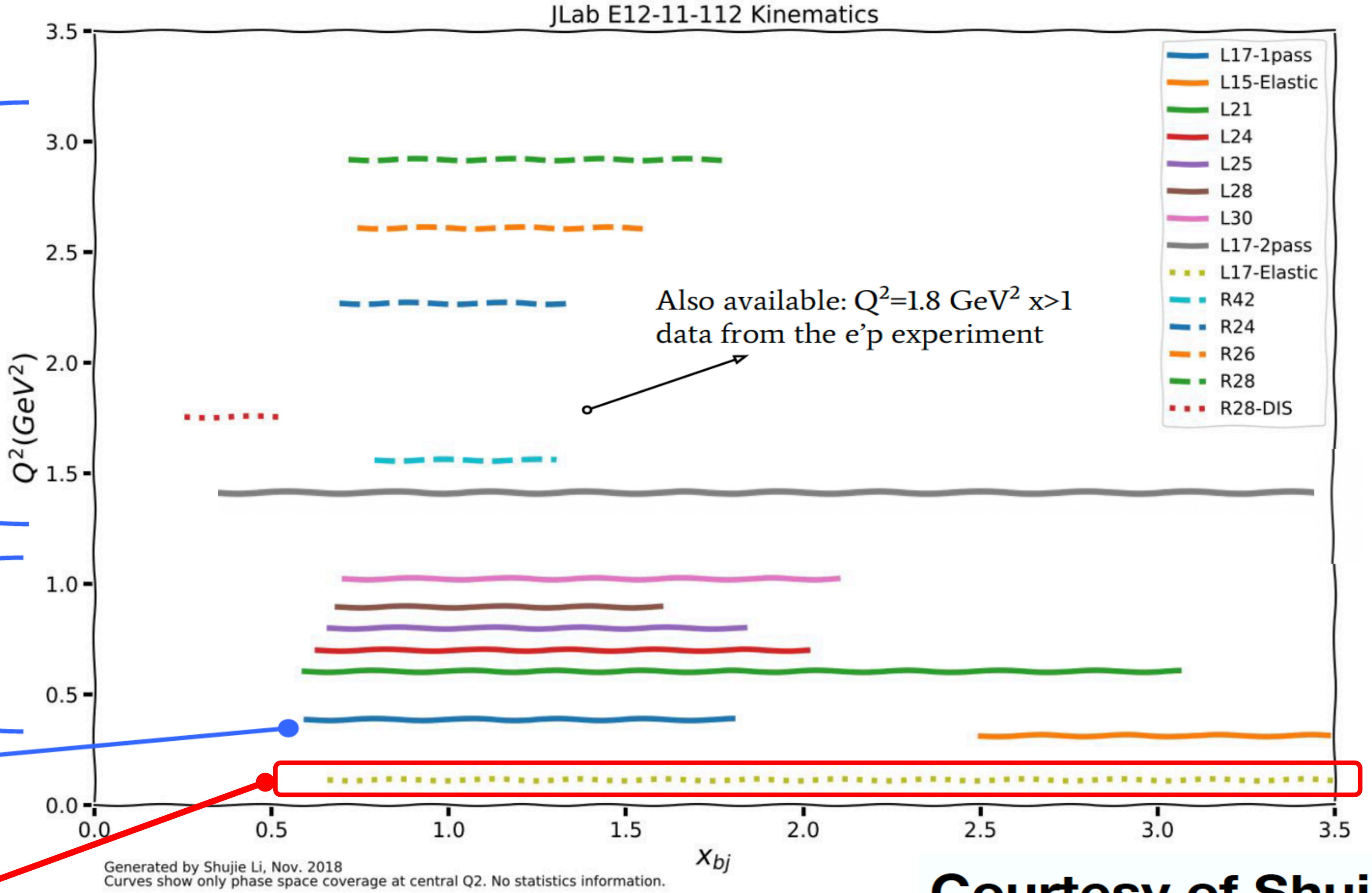
May 2018:

QE scan with 2.2 GeV beam

Dec 2017:

Commissioning

Target "boiling" study (also QE data at Q2=0.4 GeV2)



Also available: Q^2=1.8 GeV^2 x>1 data from the e'p experiment

Generated by Shujie Li, Nov. 2018
Curves show only phase space coverage at central Q2. No statistics information.

October 2018: Elastic scattering with 1.171 GeV beam

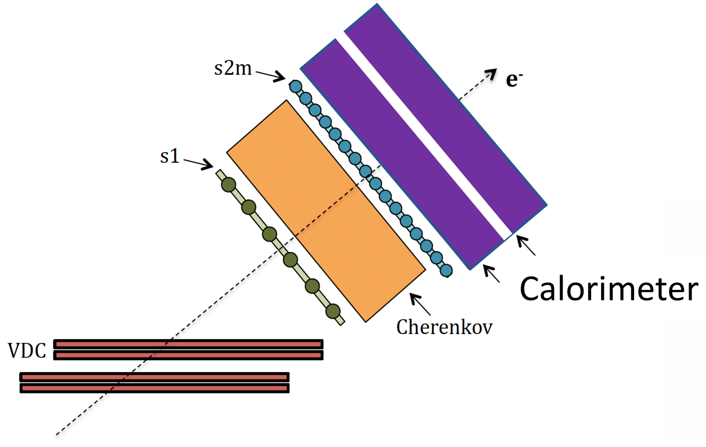
Courtesy of Shujie Li

- Vertical Drift Chamber

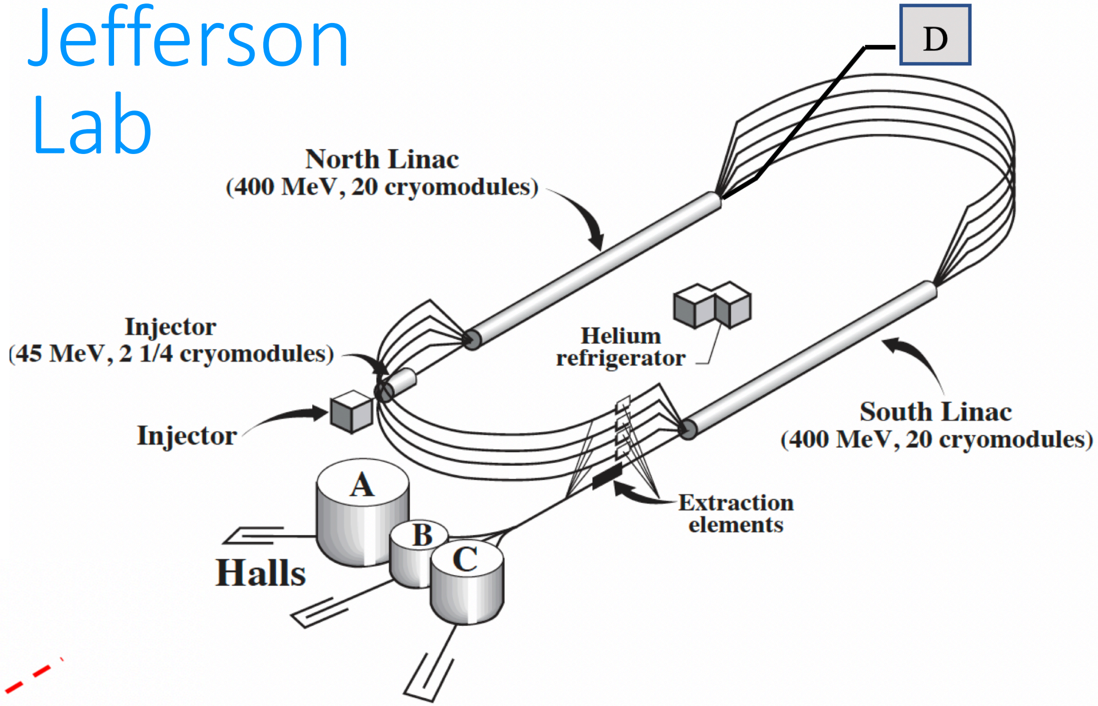
  Position and angle of the electrons.
- Scintillator

  Measure the electrons.
- Cherenkov & calorimeters

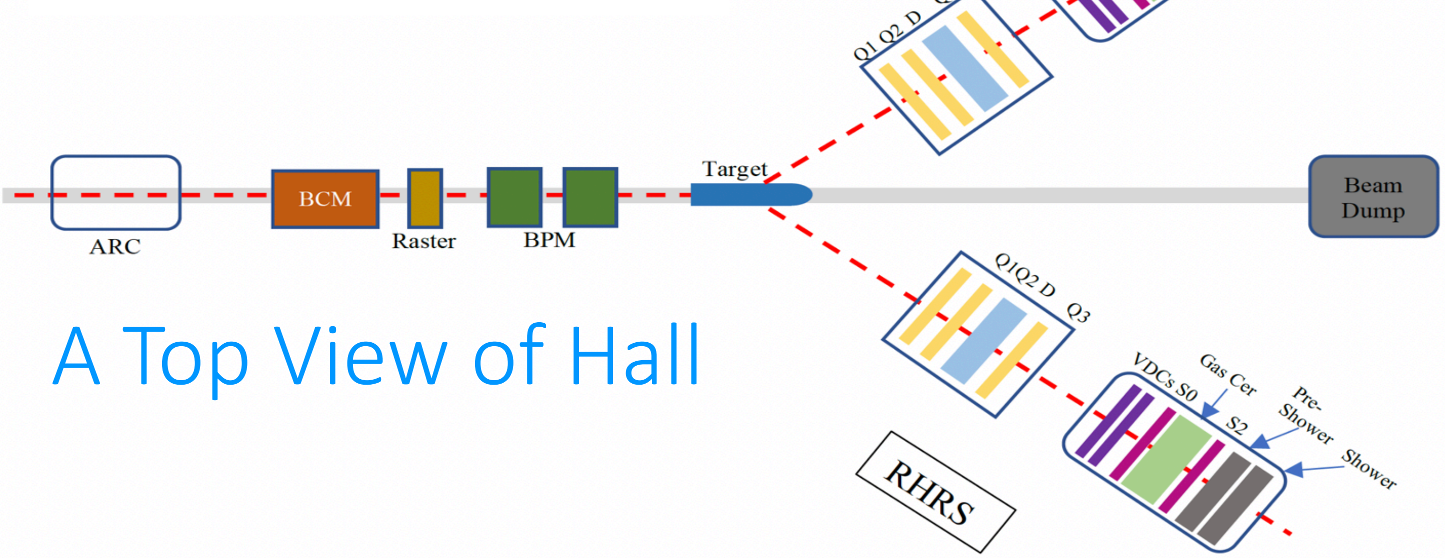
  Pion rejecter



Jefferson Lab



.Alcorn *et al.*, Nucl. Instr. Meth. **A,** 522 (2004).

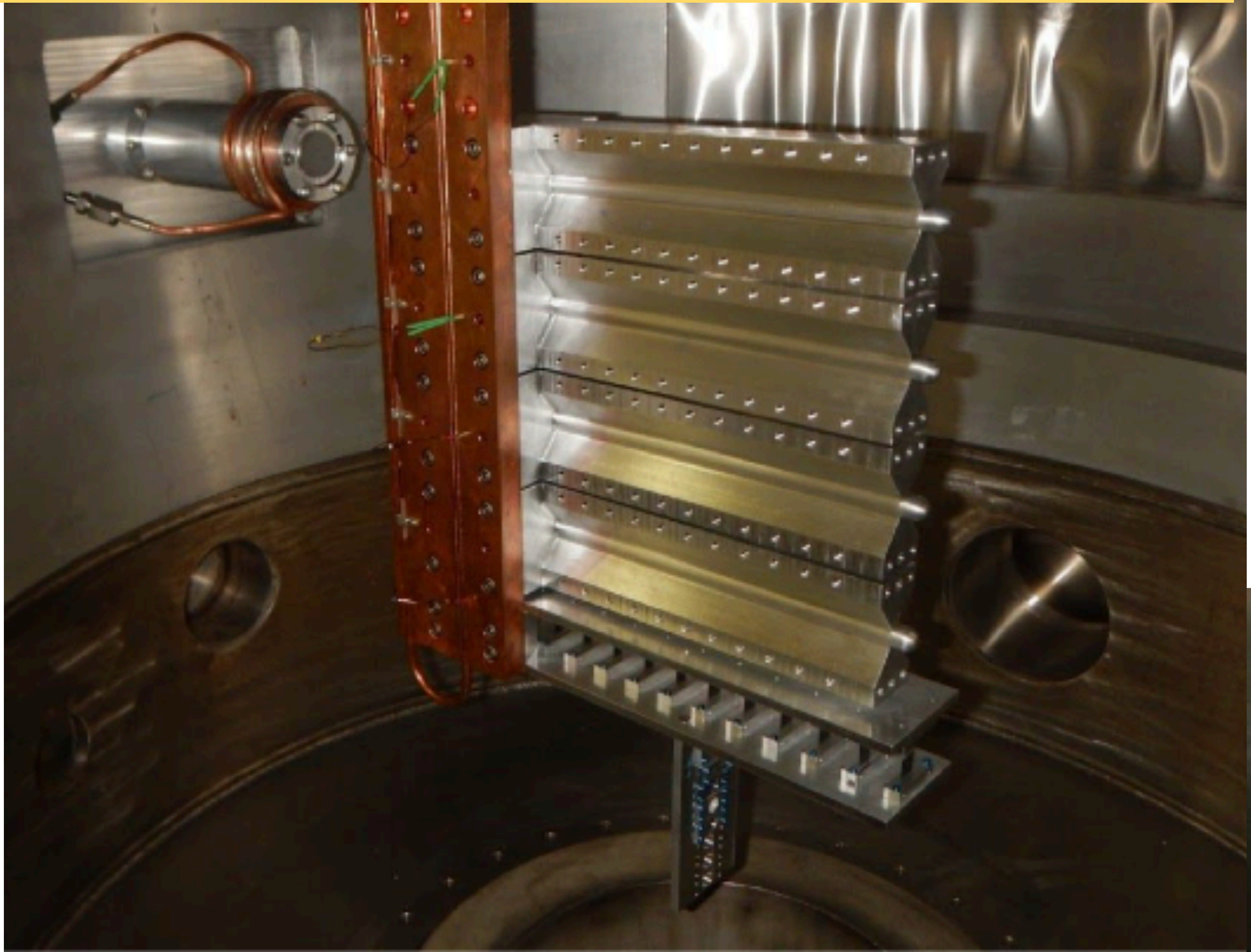


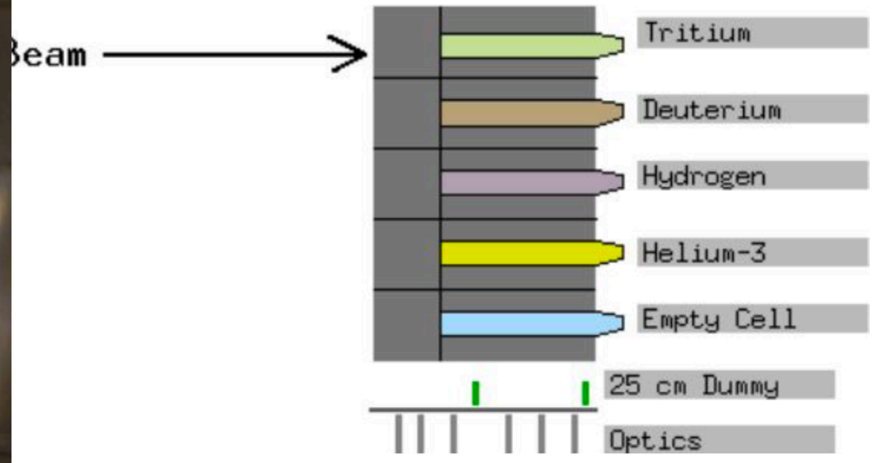
A Top View of Hall

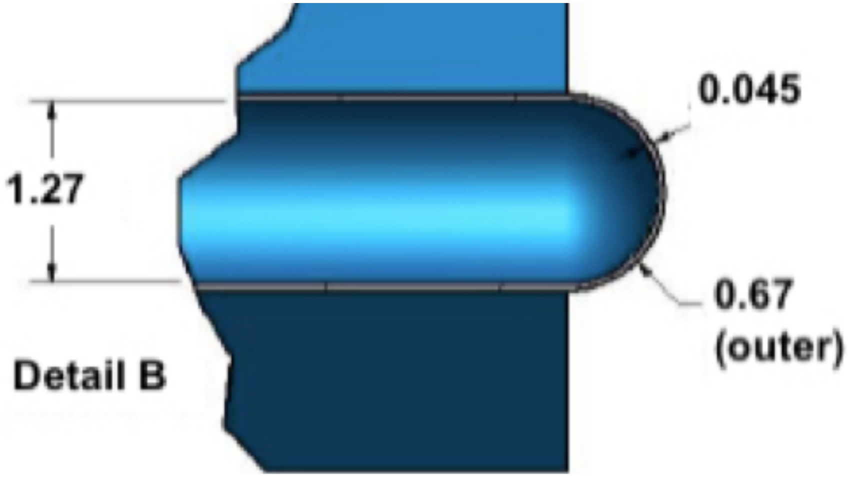
Experiment Configuration

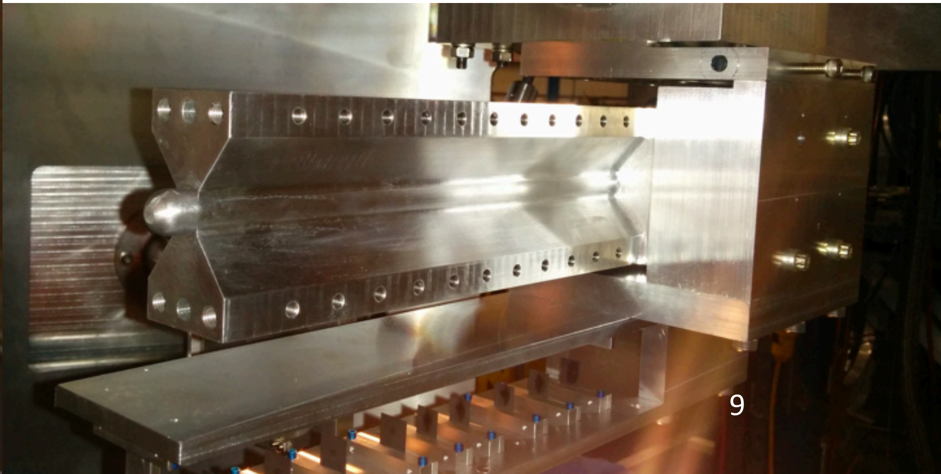
- Beam current: 5μA
- Beam energy: 1.171 GeV
- Momentum: 1.128 GeV
- Angle: 17 degree
- $Q^2 = 0.11\ \text{GeV}^2$

Nuclear Targets









From Yield to The Cross Section

$$Yield = \frac{Number\ of\ Good\ Scattered\ Electrons}{Effective\ Luminosity}$$

$Effective\ Luminosity$ is the product of the number of incoming beam particles per unit time , the target particle density in the scattering material , and the target's thickness. Its unit [(area x time)−1].

$$Normalized\ Yield = \frac{N_e\ .\ ps}{Q\ .\rho_a\ .\ Boiling.\ \epsilon_{tot}.\ LT}$$

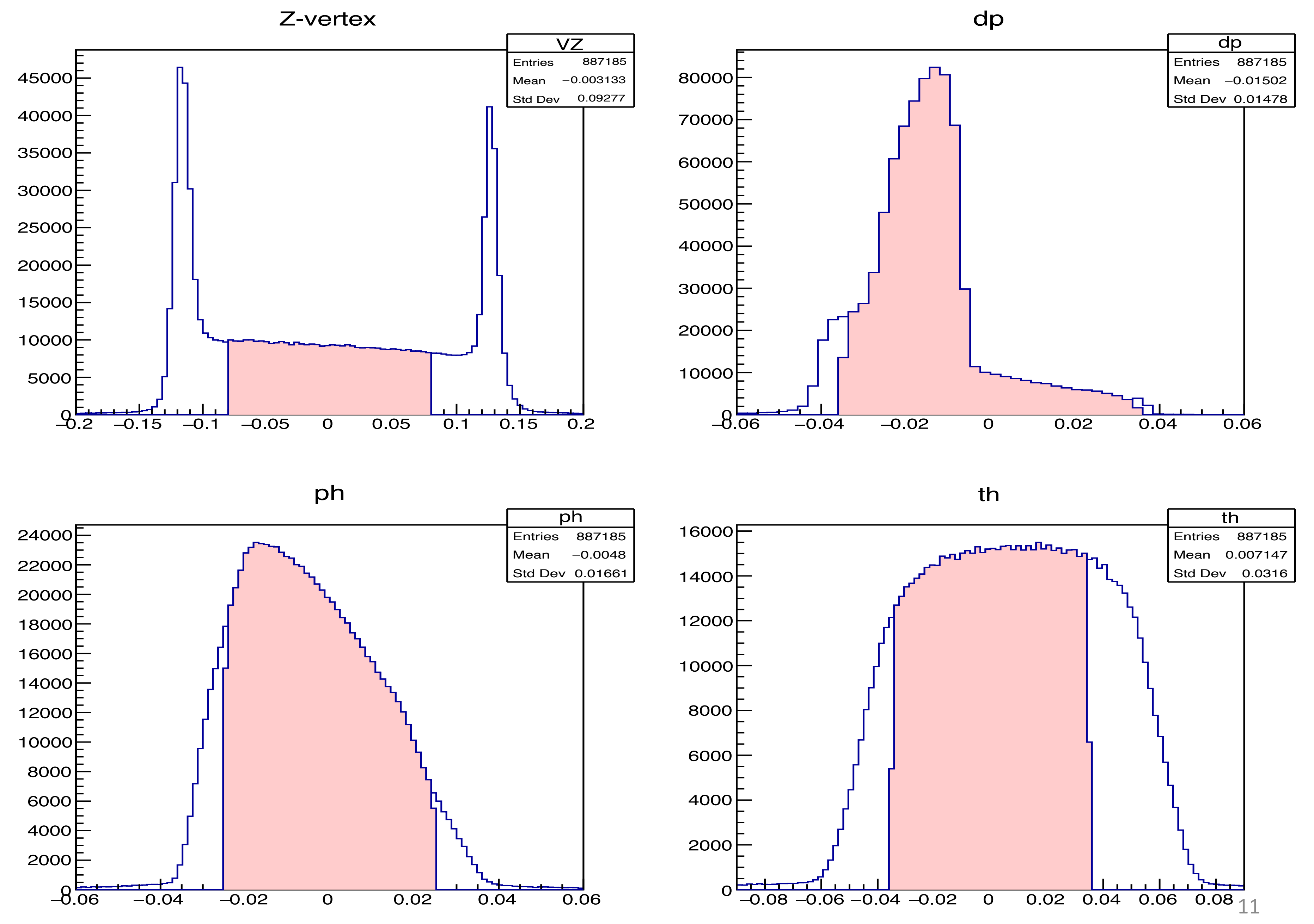
$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} = \frac{N_e\ .\ ps}{N_{in}.\ \rho\ .\ \Delta Z.\ LT.\ \epsilon_{tot}}\ \frac{1}{\Delta\Omega}$$

$$\boxed{\left(\frac{d\sigma}{d\Omega}\right)_{exp} = \frac{Yield}{\Delta\Omega}}$$

- N_e is the number of good events.
- ps is the prescale factor for the production trigger.
- Q is the charge with stable beam current.
- ρ_a is the effective area density of the target (g/cm^2).
- $Boiling$ is the ratio of the effective gas target density at given beam current comparing to no beam.
- ϵ_{tot} is the product of all efficiencies; trigger, tracking and cut efficiencies
- LT is the computer livetime.

Selection of Good Electrons

Hydrogen Target



Acceptance Cut

TCut vz =
"fabs(L.tr.vz)<0.08";

TCut dp =
"fabs(L.tr.tg_dp)<0.04";

TCut phi =
"fabs(L.tr.tg_ph)<0.025";

TCut theta =
"fabs(L.tr.tg_th)<0.04";

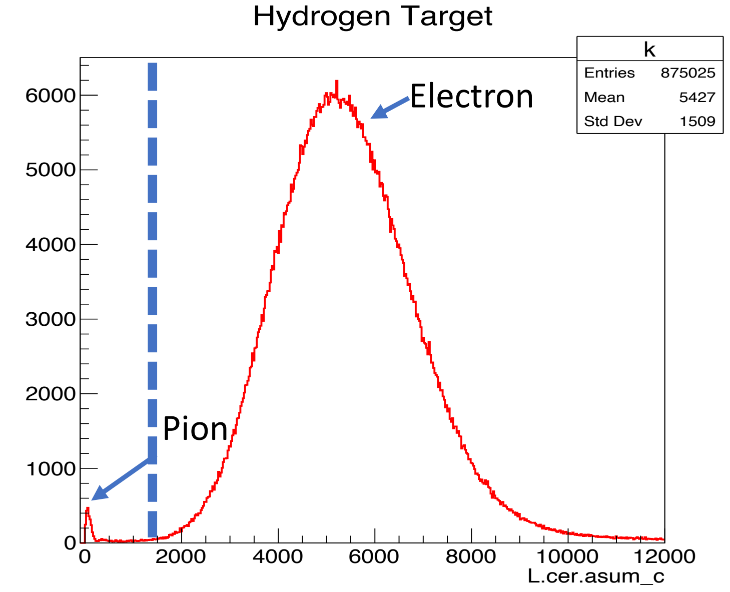
89.9075

PID Cut

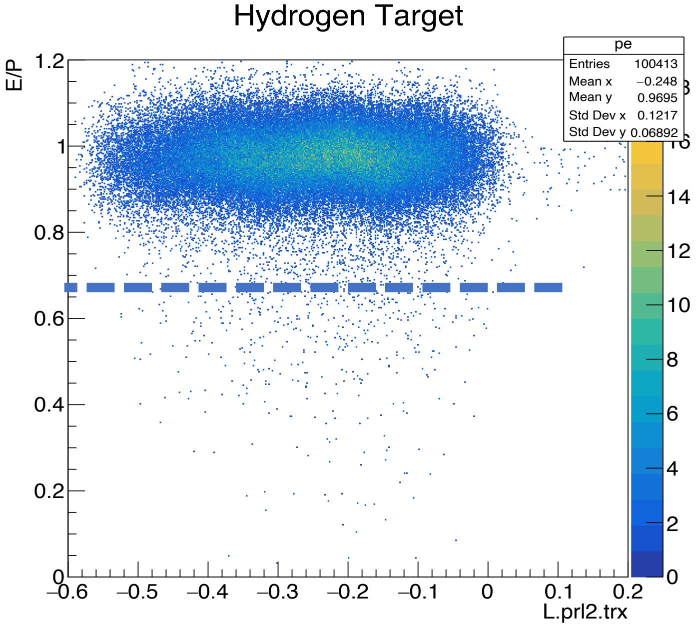
PID Cut

```
TCut cer = "L.cer.asum_c>1500”;
TCut Ep  = "(L.prl1.e+L.prl2.e)/(L.tr.p[0]*1000)>0.7";
```

Cherenkov



Calorimeter



Run #	Target	Cher eff.	Shower eff.	Pion Rejection eff.
3989	Hydrogen	99.94±0.007	99.45±0.03	99.75±0.02
3991	Tritium	99.9±0.01	99.45±0.03	99.95±0.015
3992	Helium-3	99.92±0.01	99.44 ±0.02	99.81±0.02
3993	Deuterium	99.92±0.006	99.43±0.01	99.59±0.02

Data Correction factors

- Live time: Ave. 89.9075
- Trigger1 Efficiency: Ave. 99.28
- VDC Efficiency: Ave. 97.06
- Cherenkov Cut Efficiency
- Shower/Pion Rejecters Cut Efficiency
- Pion Rejecters Cut Efficiency

Trigger 1= S_1 & S_2
Trigger 2= S_1 & S_2 & Cherenkov
Trigger 3= S_1 || S_2 & Cherenkov

Elastic Cross Section Monte Carlo

What is SIMC

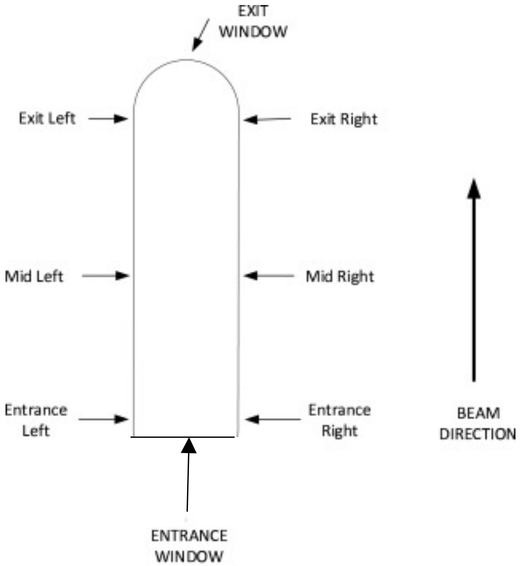
SIMC primarily used by JLab's Halls A and C to simulate electron scattering experiments.

Features

- ✓ SIMC contains the geometry of the Hall A spectrometers including their various apertures and the materials that comprise them.
- ✓ Our version of SIMC works with ^{1}H, ^{3}H, ^{3}He and any given nuclei.
- ✓ SIMC uses an event generator to create electrons which scatter from a given target and records their final states as they were viewed by a detector.
- ✓ SIMC Includes radiative effects, multiple scattering, ionization energy loss and particle decay.

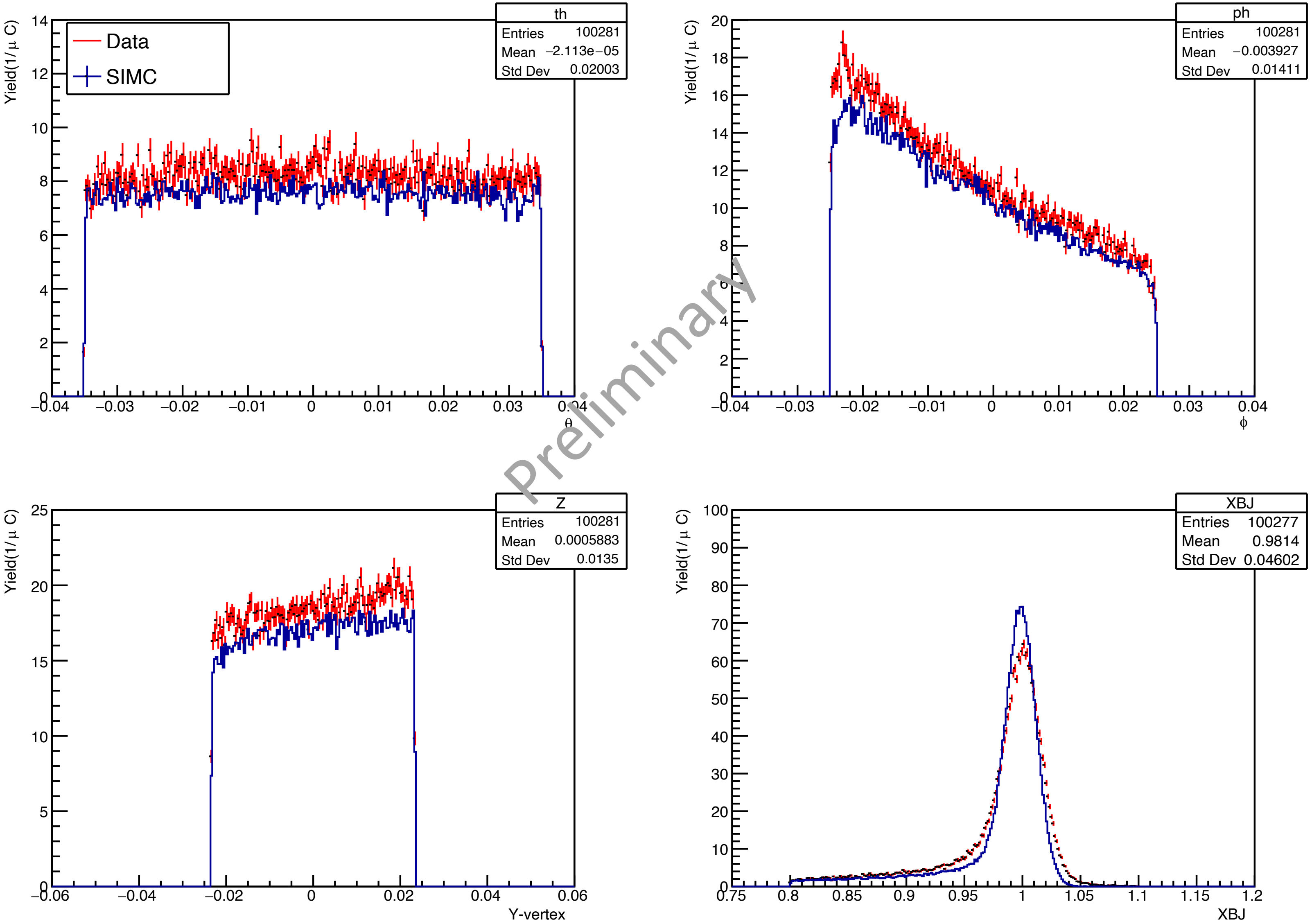
SIMC/Data Comparison

- No. of events 500K
- Spectrometer resolution 0.275 mm.
- Tight cut.
- Inter window 0.311mm.
- Exit window 0.330mm.
- Air distance 552.3mm.
- Cell Radius 6.35mm
- Mid exit left 0.374 mm



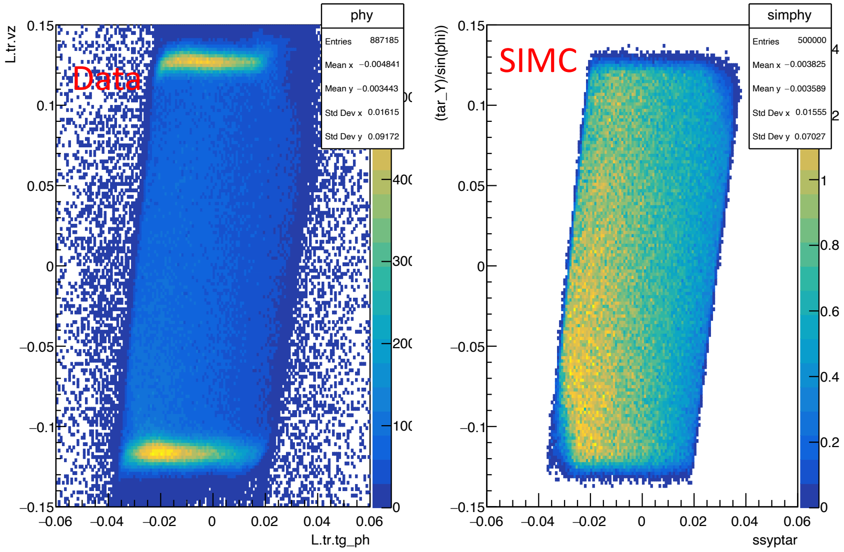
TOP VIEW OF CELL

Hydrogen Target

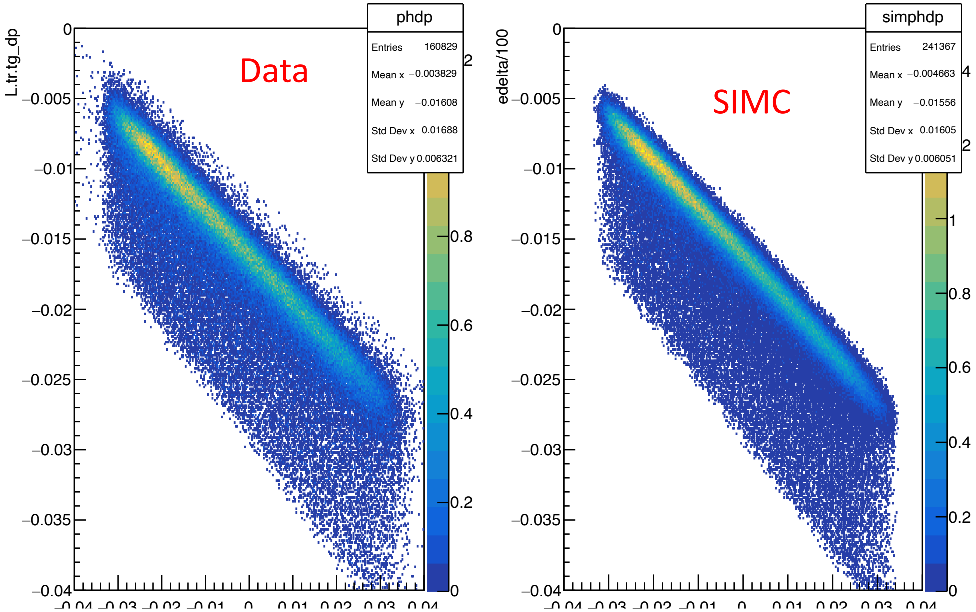


SIMC/Data Comparison

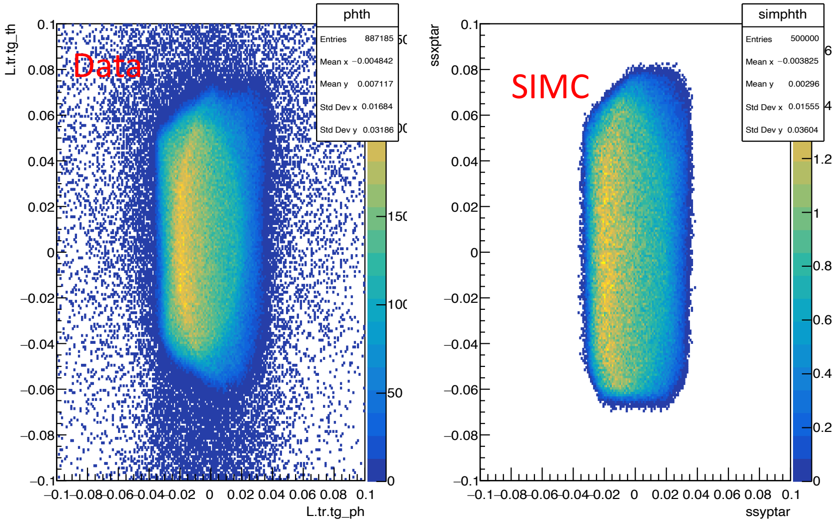
Hydrogen Target



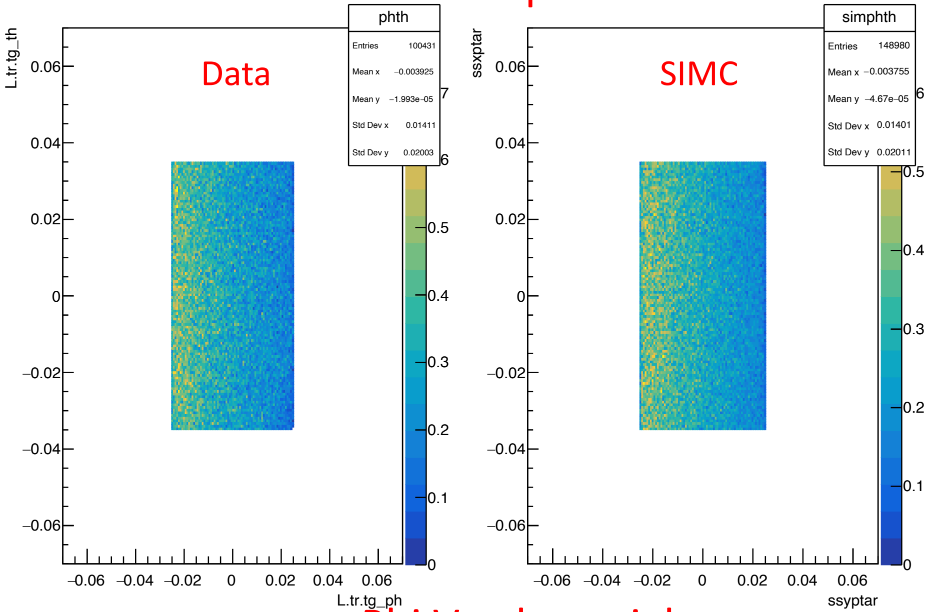
Phi Vs. Z-vertex no cut



Phi Vs. dp



Phi Vs. theta loose cut



Phi Vs. theta tight cut

SIMC Simulation

^{3}He Target

- No. of events 500K
- Spectrometer resolution 0.0275.
- Tight cut.
- Inter window 0.215mm.
- Exit window 0.294mm.
- Air distance 552.3mm.
- Cell Radius 6.35mm
- Mid exit left 0.487 mm

$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} = \boxed{\frac{Yield_{exp}}{Yield_{SIMC}}} \left(\frac{d\sigma}{d\Omega}\right)_{SIMC}$$

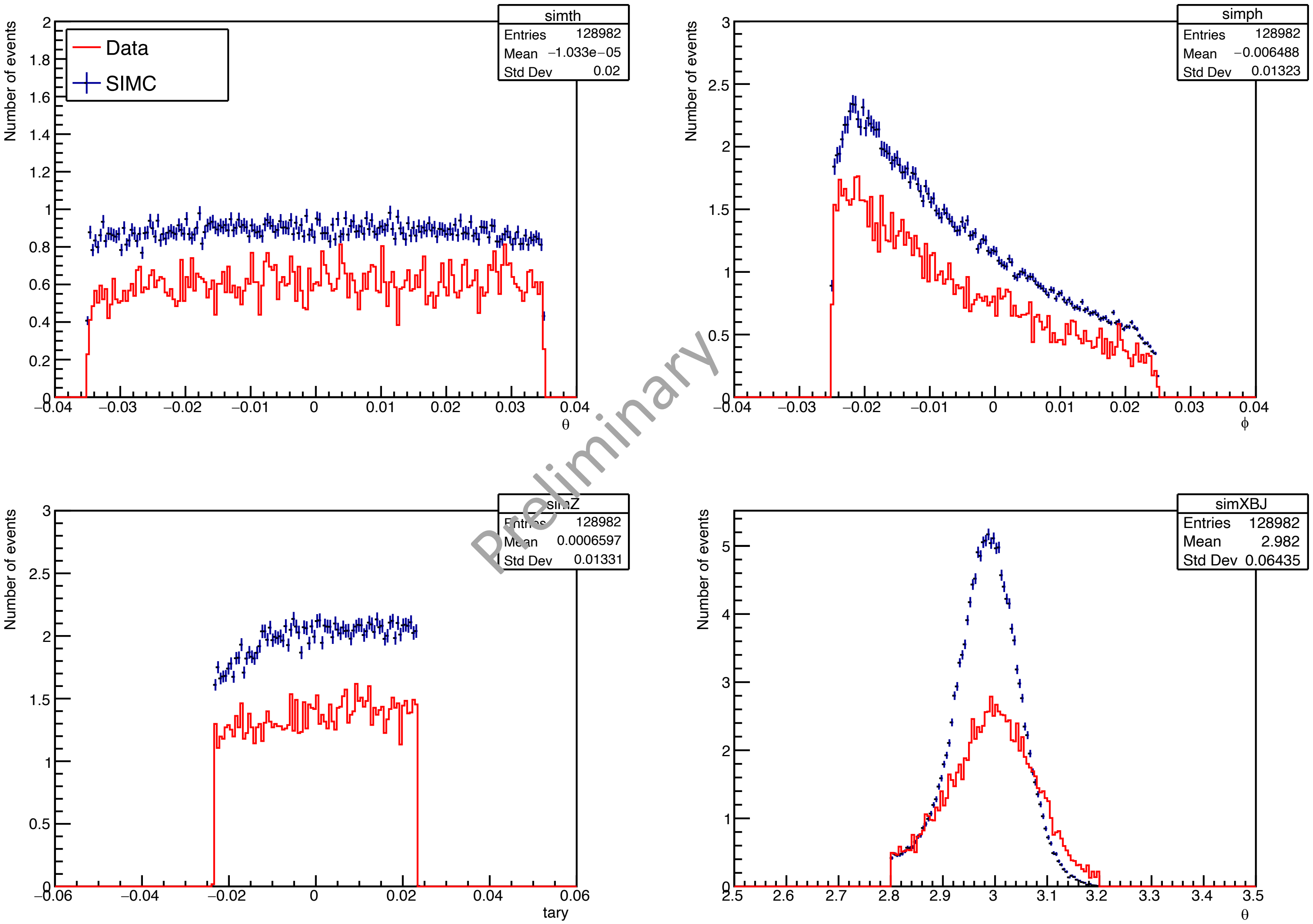
Correction Factor

- The simulation does

Acceptance.

Radiative .

Energy loss .

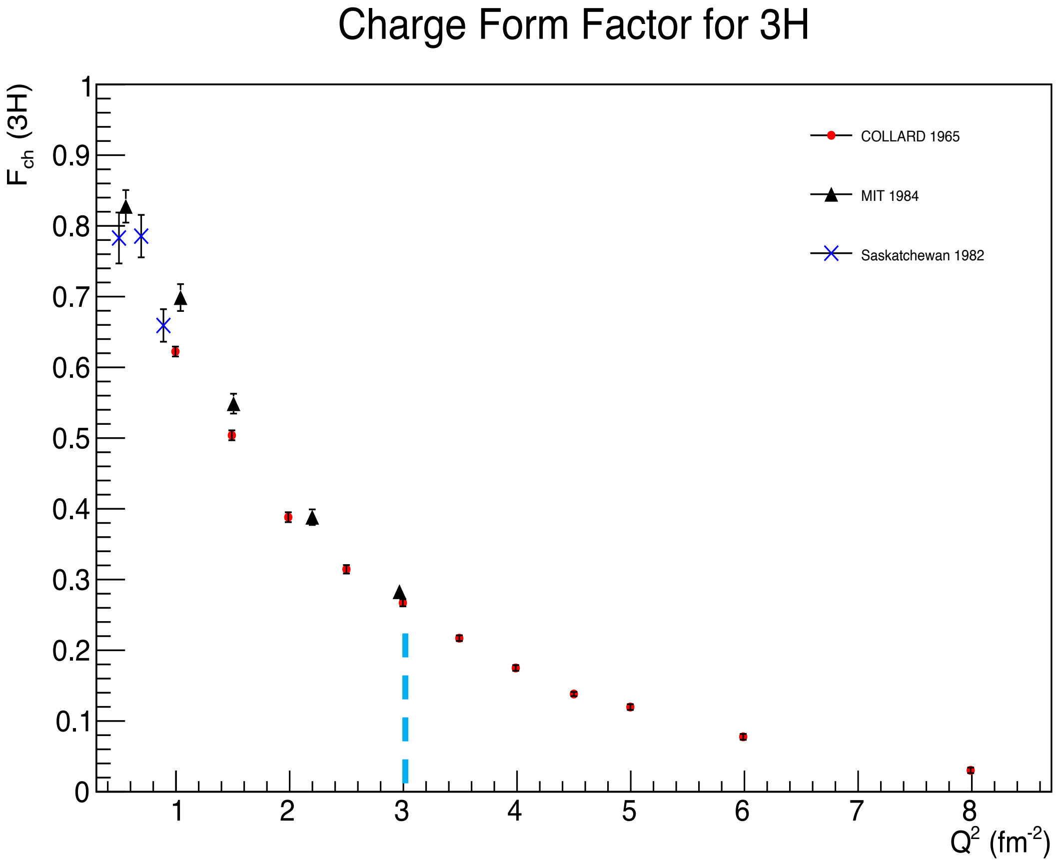


Expected Results

One data point at

- Beam energy: 1.171 GeV
- Momentum: 1.128 GeV
- Angle: 17 degree

$$\frac{\sigma\,{}^3H}{\sigma\,{}^3He} \rightarrow \frac{F_{ch}\,{}^3H}{F_{ch}\,{}^3He} \rightarrow$$

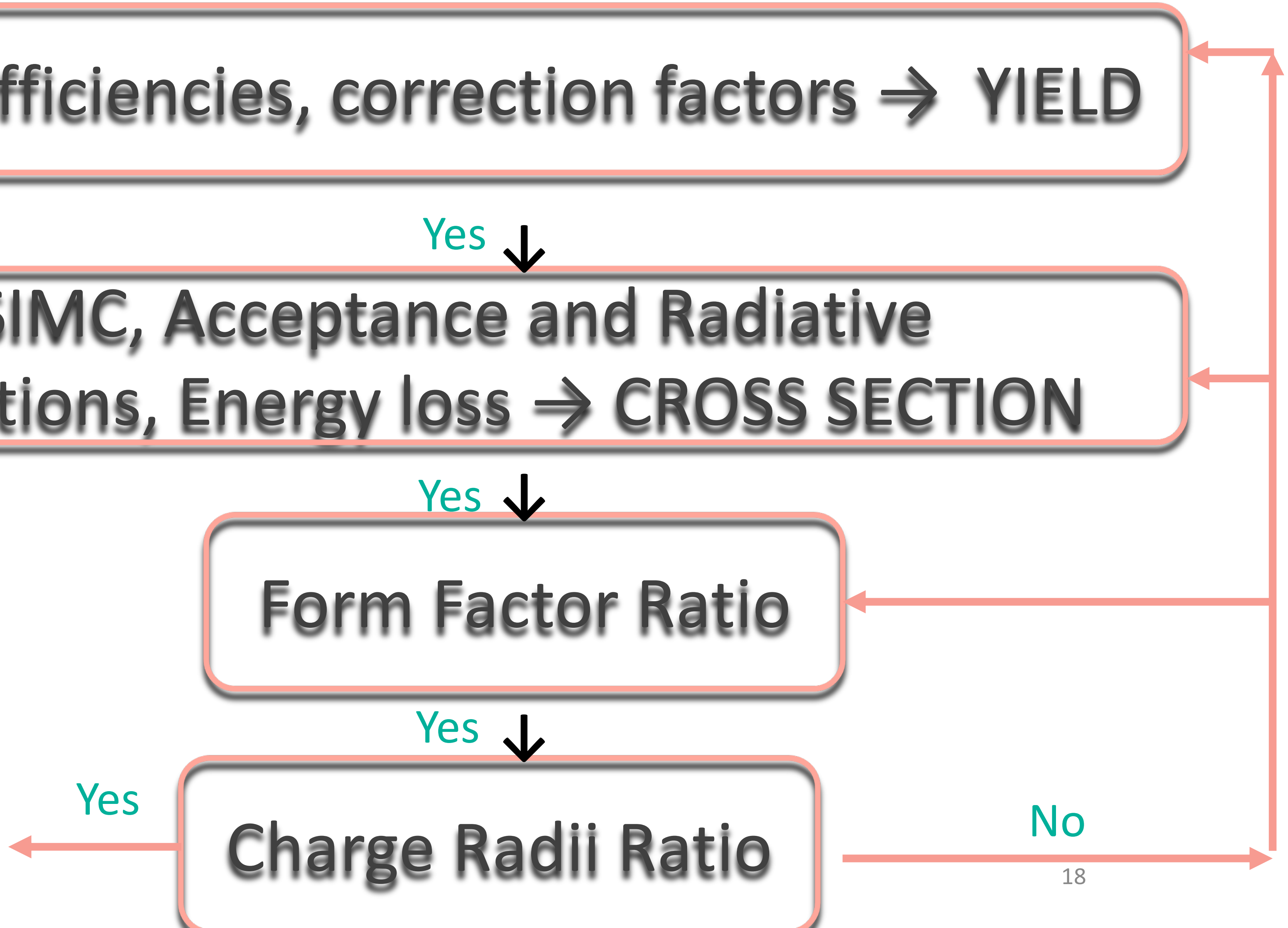


$$At\ low\ Q^2 \approx 3\ fm^{-2}$$

Why Ratio

- Minimize systematic uncertainties in the comparison of the ^3H and ^3He charge radii.
- This new data point will improve global fits and can be compared to the 3H/3He ratio for the experiments that have tried extracting the charge radii of 3H and give inconsistent results.

Analysis Path



✓

Cut, Efficiencies, correction factors → YIELD

Yes ↓

Now

Data/SIMC, Acceptance and Radiative corrections, Energy loss → CROSS SECTION

Yes ↓

Form Factor Ratio

Yes ↓

Charge Radii Ratio

No

Yes

&

2022-2023

Thank you !