# A New Proposal to Measure the Nucleon Axial Vector Form Factor at Jefferson Lab

Proposal PR12-25-009 to JLab PAC 53 (July 2025)

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$$\vec{e}^- + p \rightarrow \nu_e + n$$

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Marciana 2025 - Lepton Interactions with Nucleons and Nuclei

Sunday, June 22, 2025 - Friday, June 27, 2025

# What is the Axial Vector Form Factor?

## Charged Weak Current Analog of the Electromagnetic FF's

Vector Interaction

$$\langle p+q\,|\,J_V^\mu\,|\,p\rangle = \bar{u}(p+q)\left[F_1(q^2)\gamma^\mu + \frac{\kappa}{2m}F_2(q^2)i\sigma^{\mu\nu}q_\nu\right]u(p)$$

You are very familiar with these form factors.

Axial-Vector Interaction

$$\langle p+q\,|\,J_A^\mu\,|\,p\rangle = \bar{u}(p+q)\left[F_A(q^2)\gamma^\mu\gamma^5 + F_{PS}(q^2)q^\mu\gamma^5\right]u(p)$$

Well measured at zero momentum transfer (beta decay).

Our goal is to measure $F_A(q^2)$ at finite momentum transfer.

*The only existing measurements use pion production with PCAC or neutrino reactions, but each have issues with precision of interpretation!*

# Why Do We Want to Measure It?

(Besides being another fundamental QCD observable!)

- New constraints on Generalized Parton Distributions

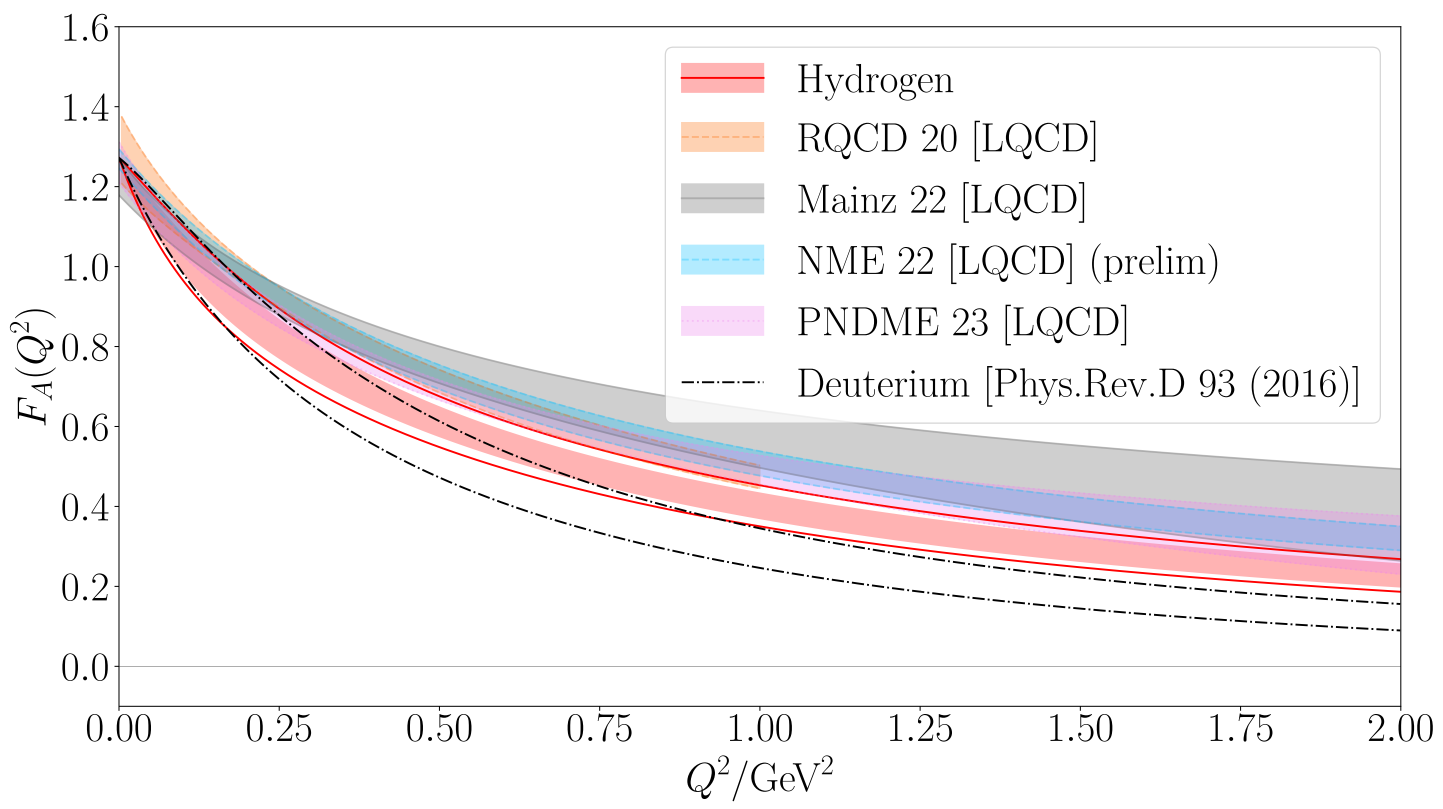
(Peter Kroll)

$$F_A^{(3)}(t) = \int_0^1 \left[\widetilde{H}_v^u(x,\xi,t) - \widetilde{H}_v^d(x,\xi,t)\right] dx \quad \text{Valence quarks}$$

$$+ \; 2\int_0^1 \left[\widetilde{H}^{\bar{u}}(x,\xi,t) - \widetilde{H}^{\bar{d}}(x,\xi,t)\right] dx \quad \text{Sea quarks (small)}$$

- Important input for DUNE and other high energy neutrino experiments

(Aaron Meyer)




Important constraints on LQCD calculations needed to untangle neutrino oscillations in DUNE.

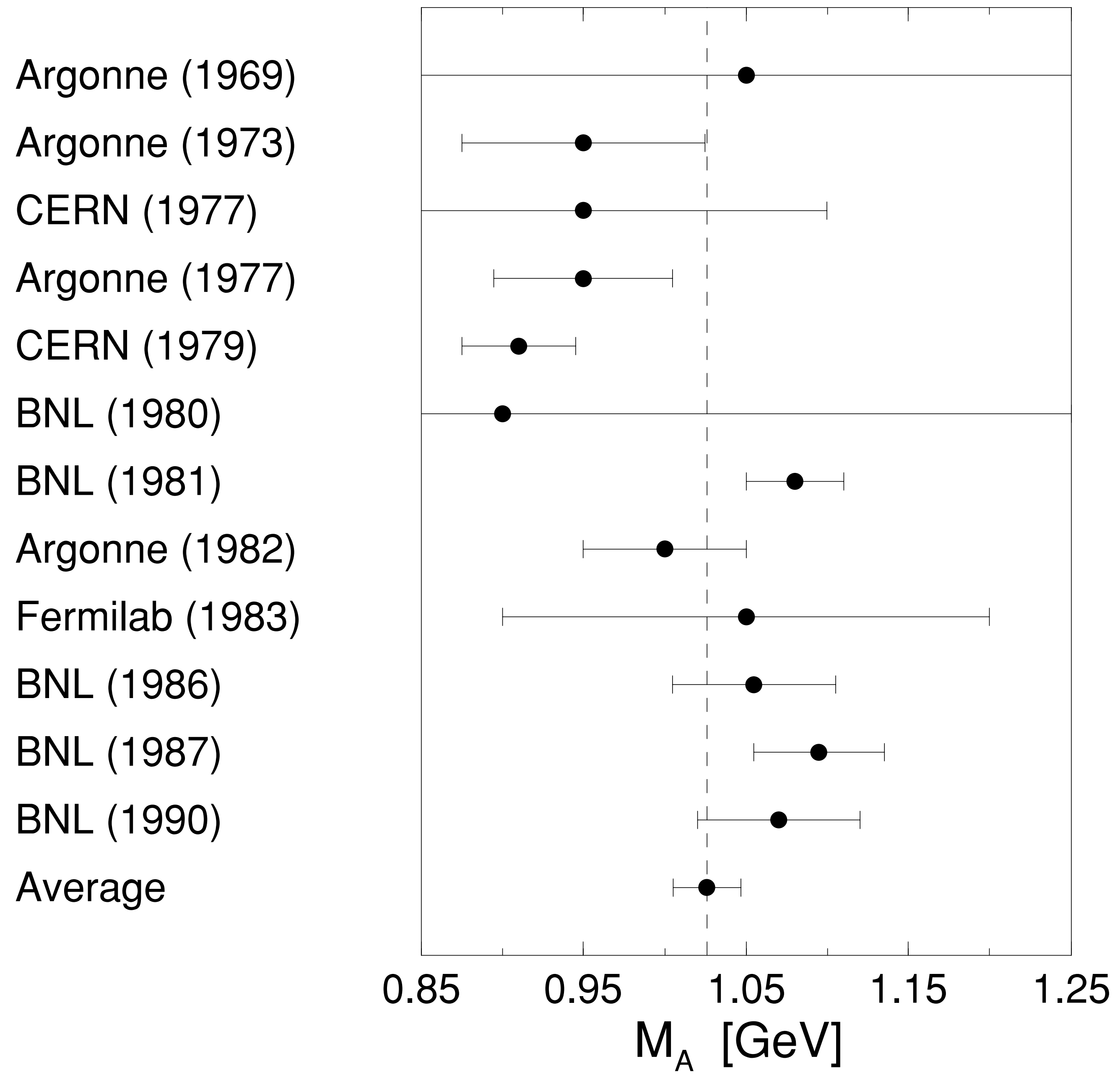
(Even a 25% measurement helps a lot.)

# What Measurements Currently Exist?

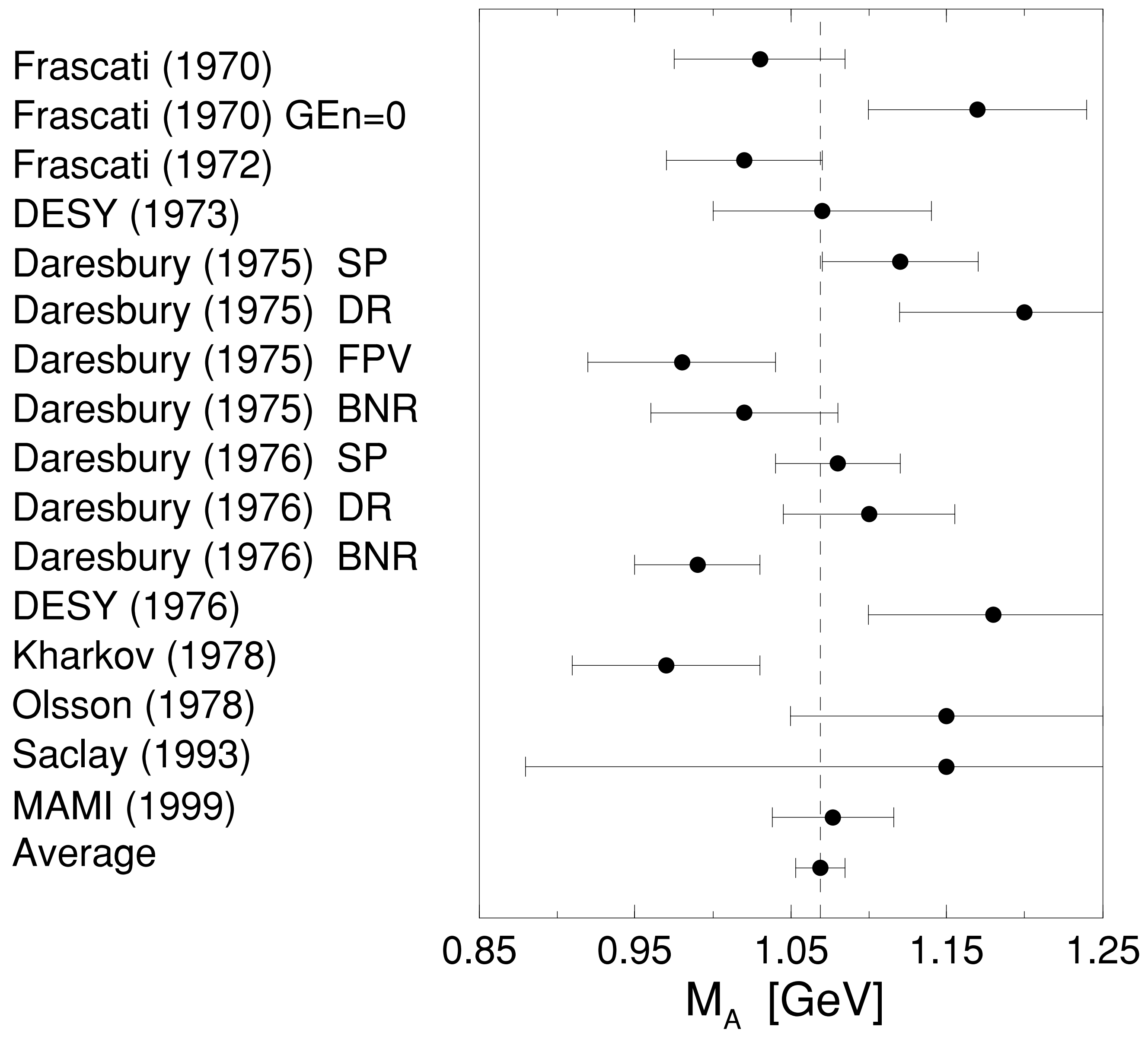
No direct measurements with constrained kinematics → **Dipole fit**

Bernard et al, J. Phys. G: Nucl. Part. Phys. 28(2002) R1

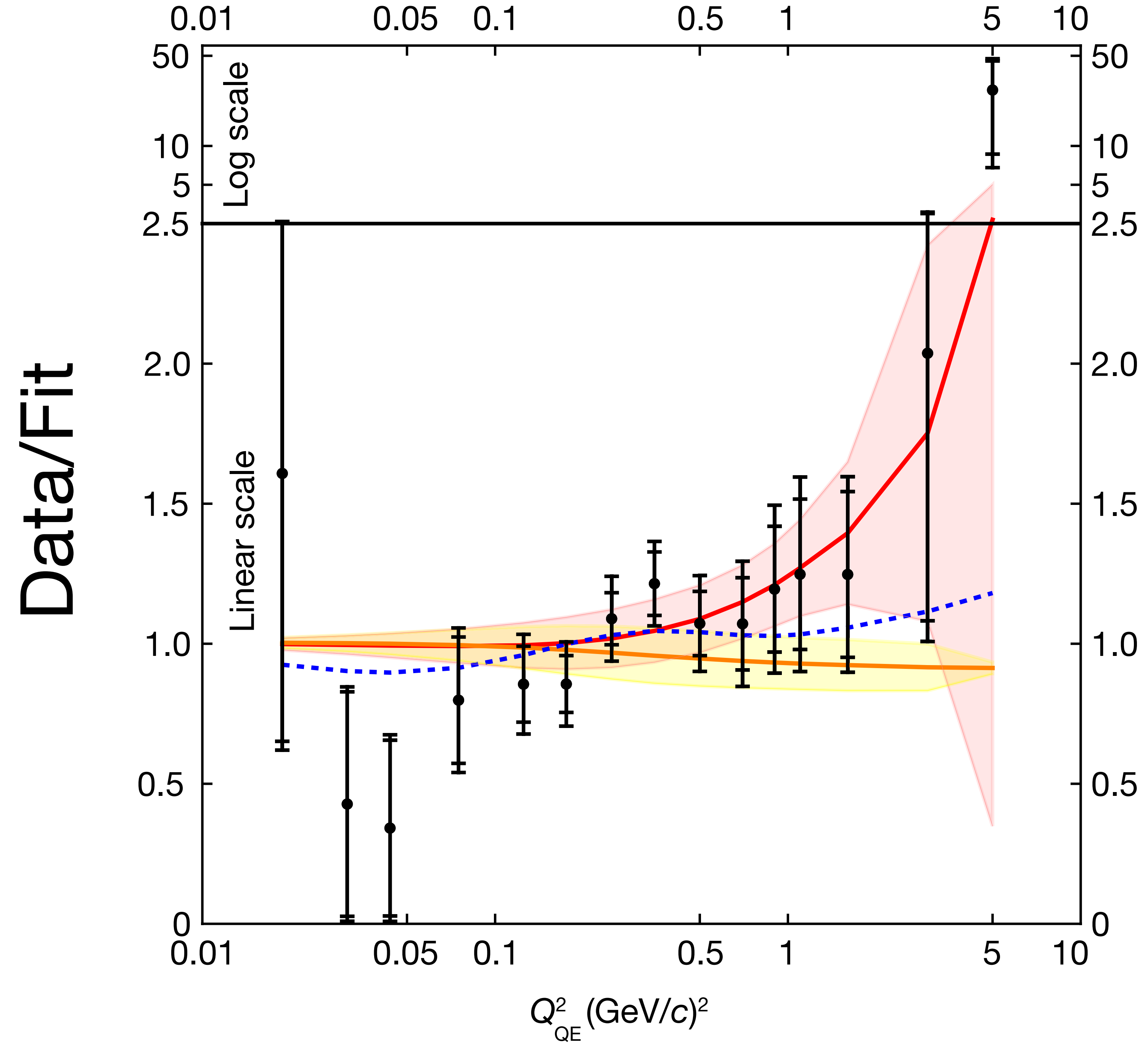
Neutrino




Pion electroproduction




MINERvA Nature 614 (2023)48

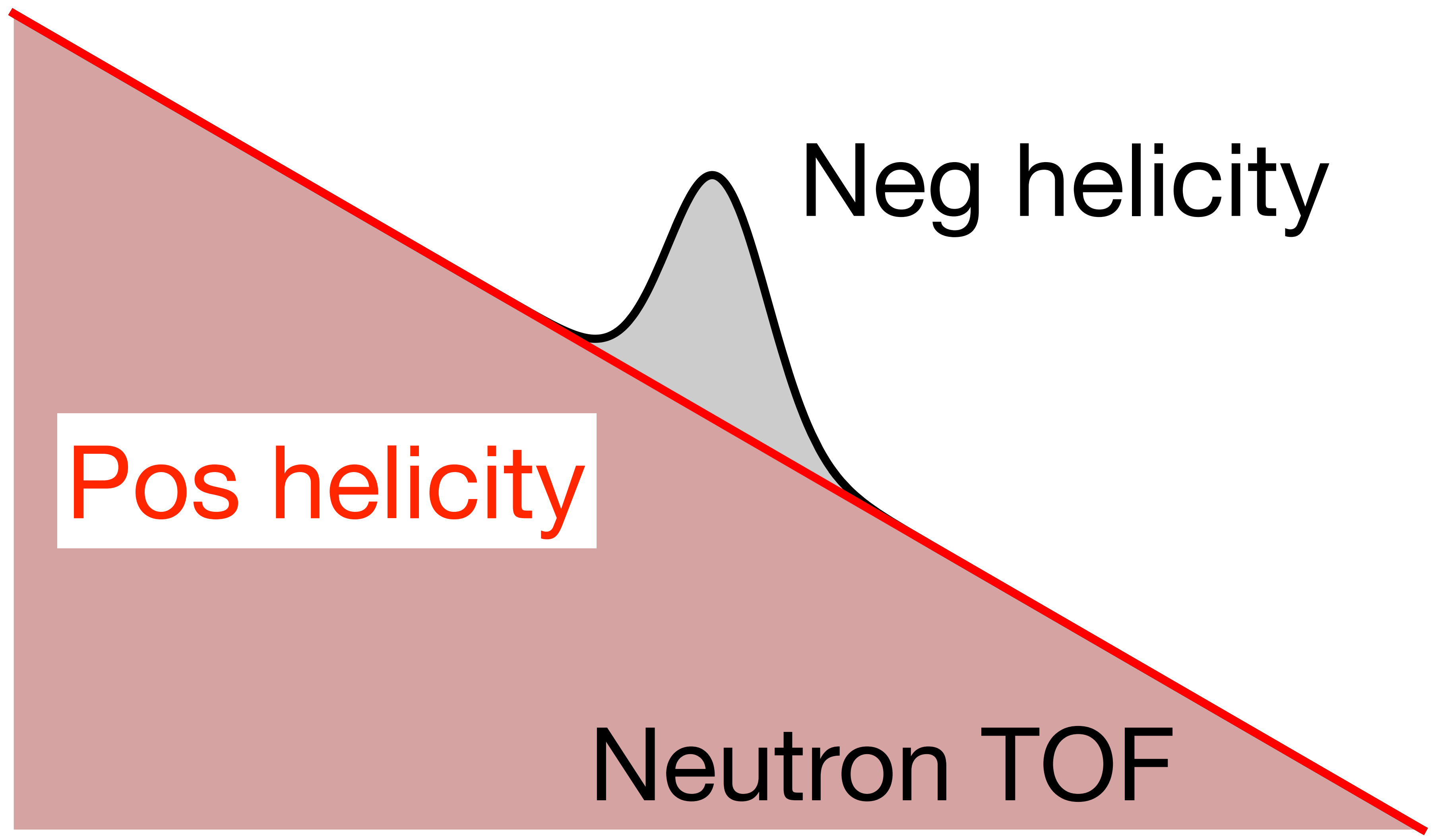



$M_A = \underline{1.026 \pm 0.021}$ $M_A = \underline{1.069 \pm 0.016}$ $M_A = 1.014$

***Inconsistent***

# How Are We Going To Do It?

- Detect the neutron from $\vec{e}^- p \to \nu_e n$
- Identify neutron using time-of-flight
- Minimize backgrounds from pion production, elastic $ep$, and other sources
- <u>Subtract remaining background using data from right handed electrons</u>

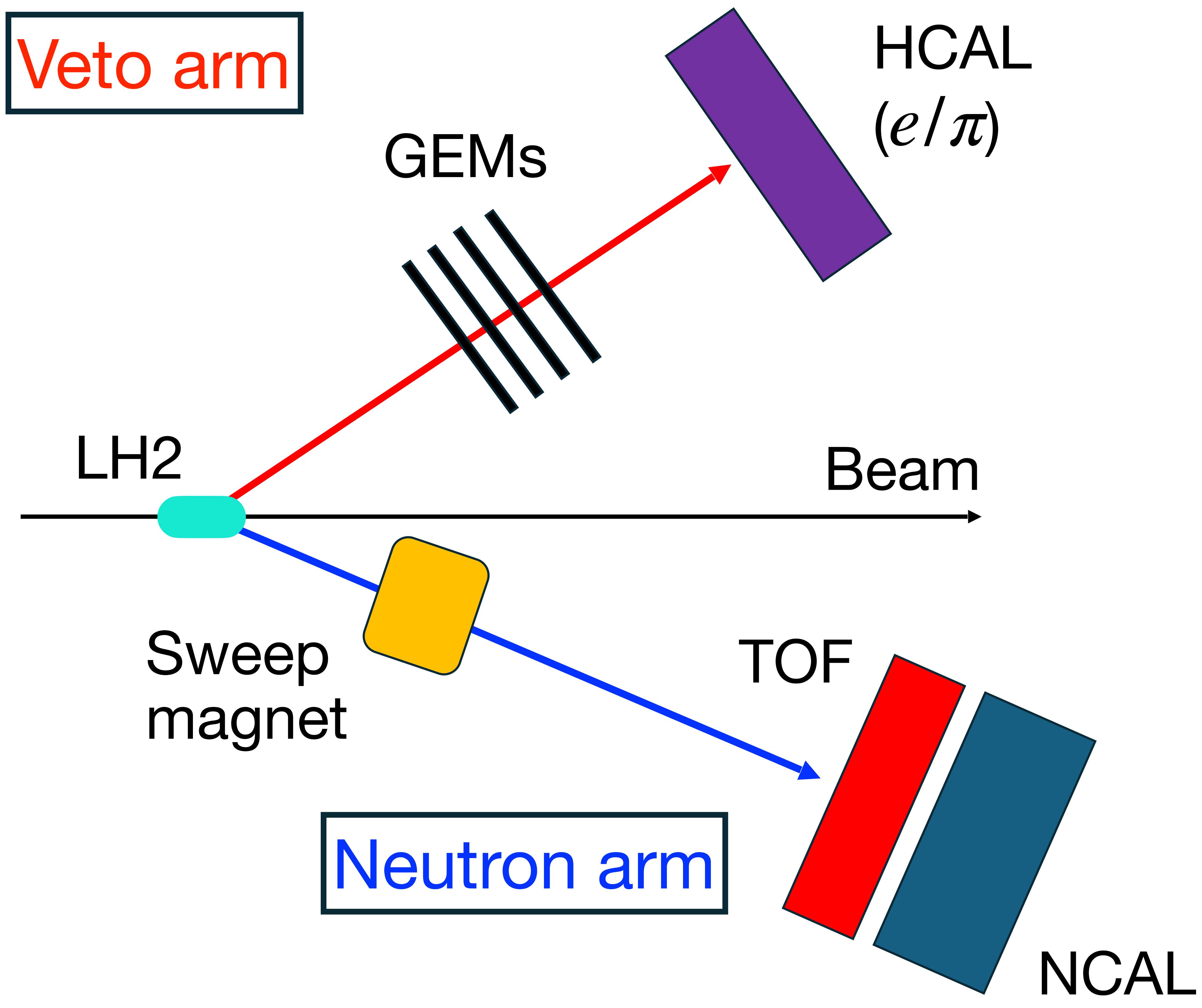



The primary challenge is to reduce the backgrounds from electromagnetic processes ($10^7$ larger than our signal) so that background subtraction yields a statistically useful signal.

The idea has been around a while!

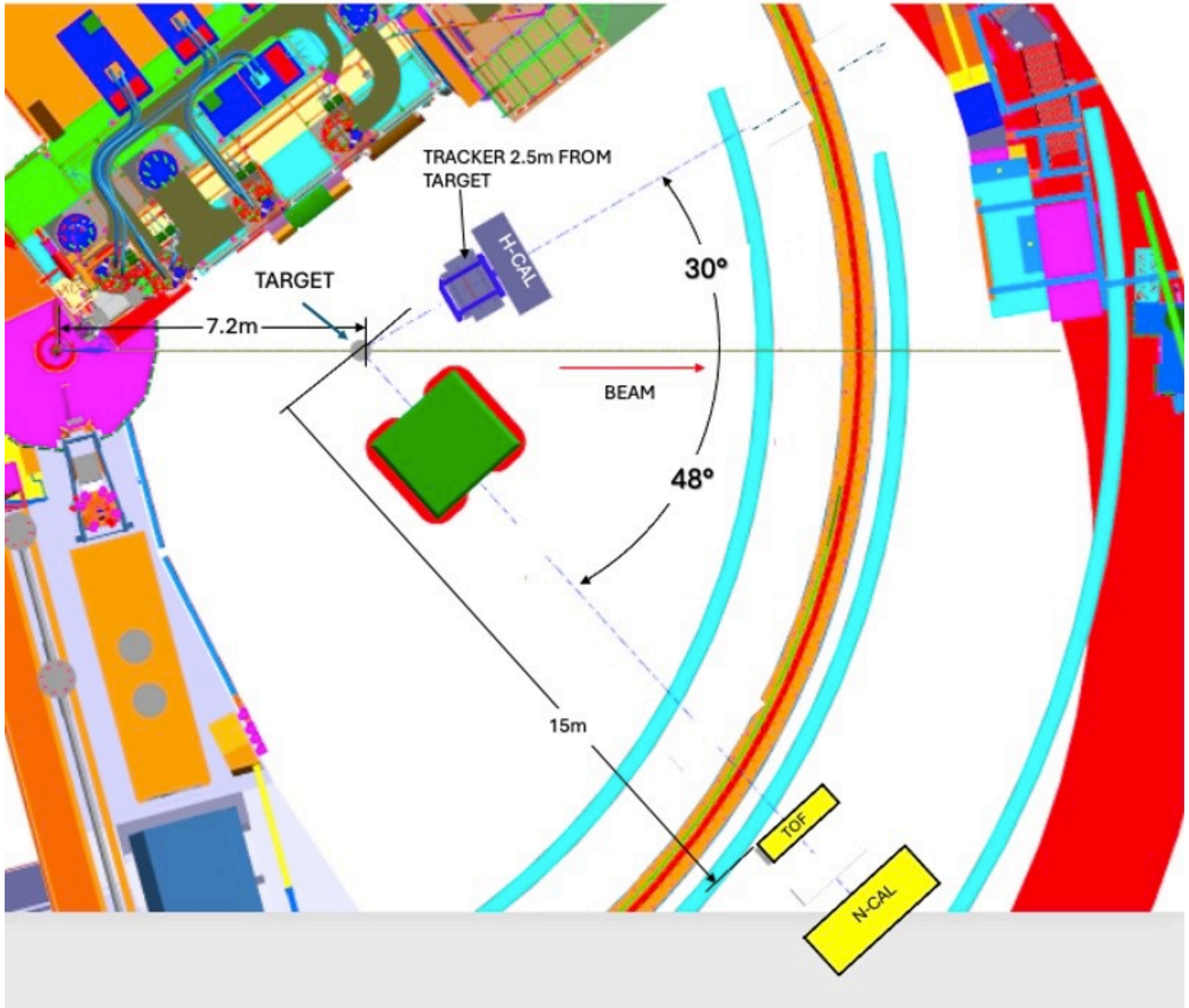
- LOI to PAC 1 (JN) *Not a typo!*
- LOI to PAC 25 (A Deur)
- LOI to PAC 52 (JN and BBW)

# Schematic of the Experiment




- Signal from neutron time-of-flight and calorimetry
- Sweep magnet removes low energy charged particle backgrounds
- Existing GEMs and HCAL reject $\gamma p \to \pi^+ n$ and $ep$ elastic
- (Investigating “wide angle veto” to deal with $\gamma p \to \pi^+ \pi^0 n$ background)
- GEMs used for calibrating system with $ep$ elastic events

# Proposed Realization in Hall C at CEBAF



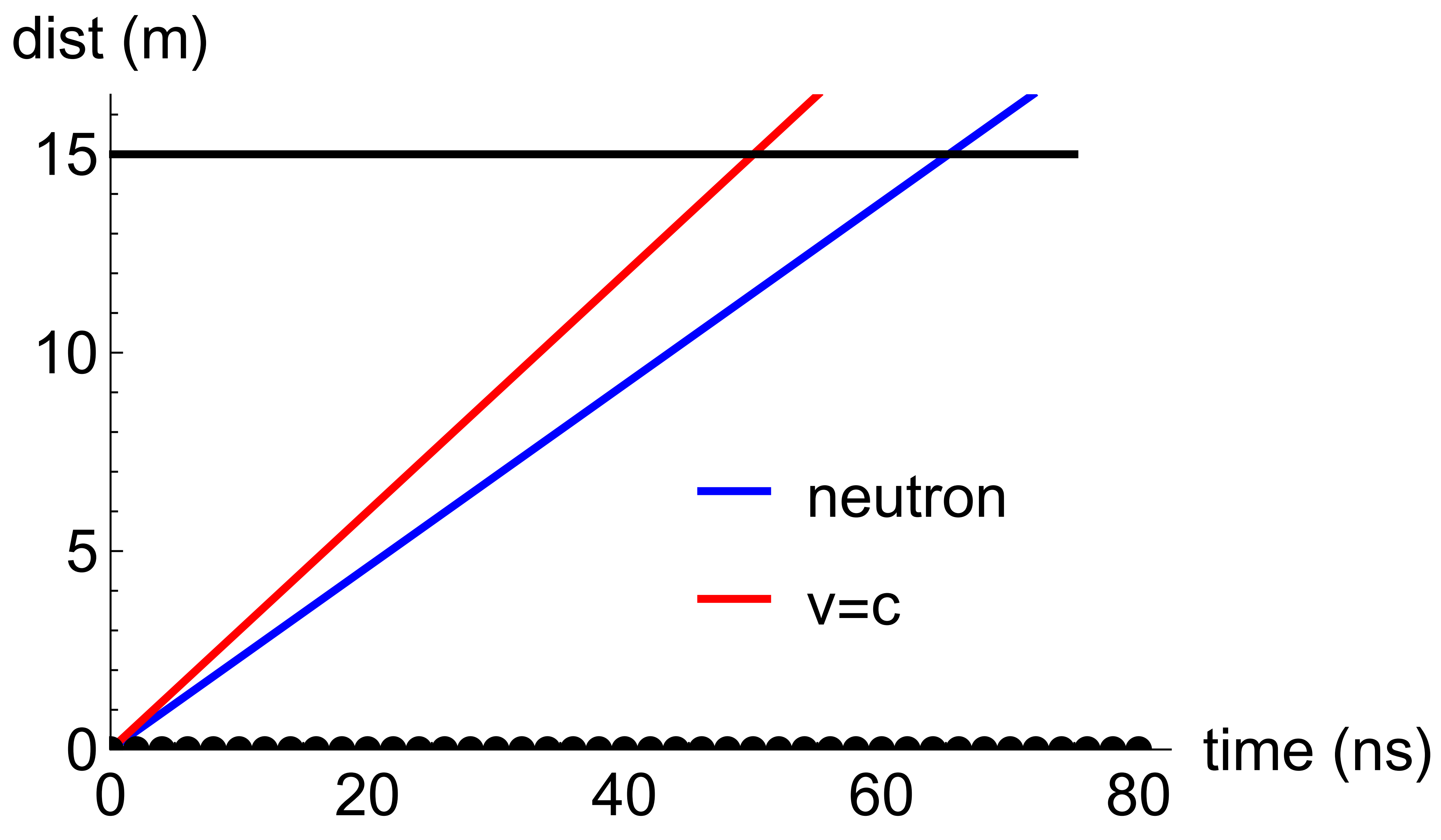

- E=2.2 GeV, 120$\mu$A, P=85%
- 10cm LH2 target (*pure; low D2)*

- $\theta_n$=48° so $Q^2 = 1 GeV^2$
- $T_n = 525$ MeV, v/c=0.77
- 15m to TOF, 65 ns, $\Delta\Omega$=75 msr
- Expect to get $\sigma_{TOF}$=100 ps

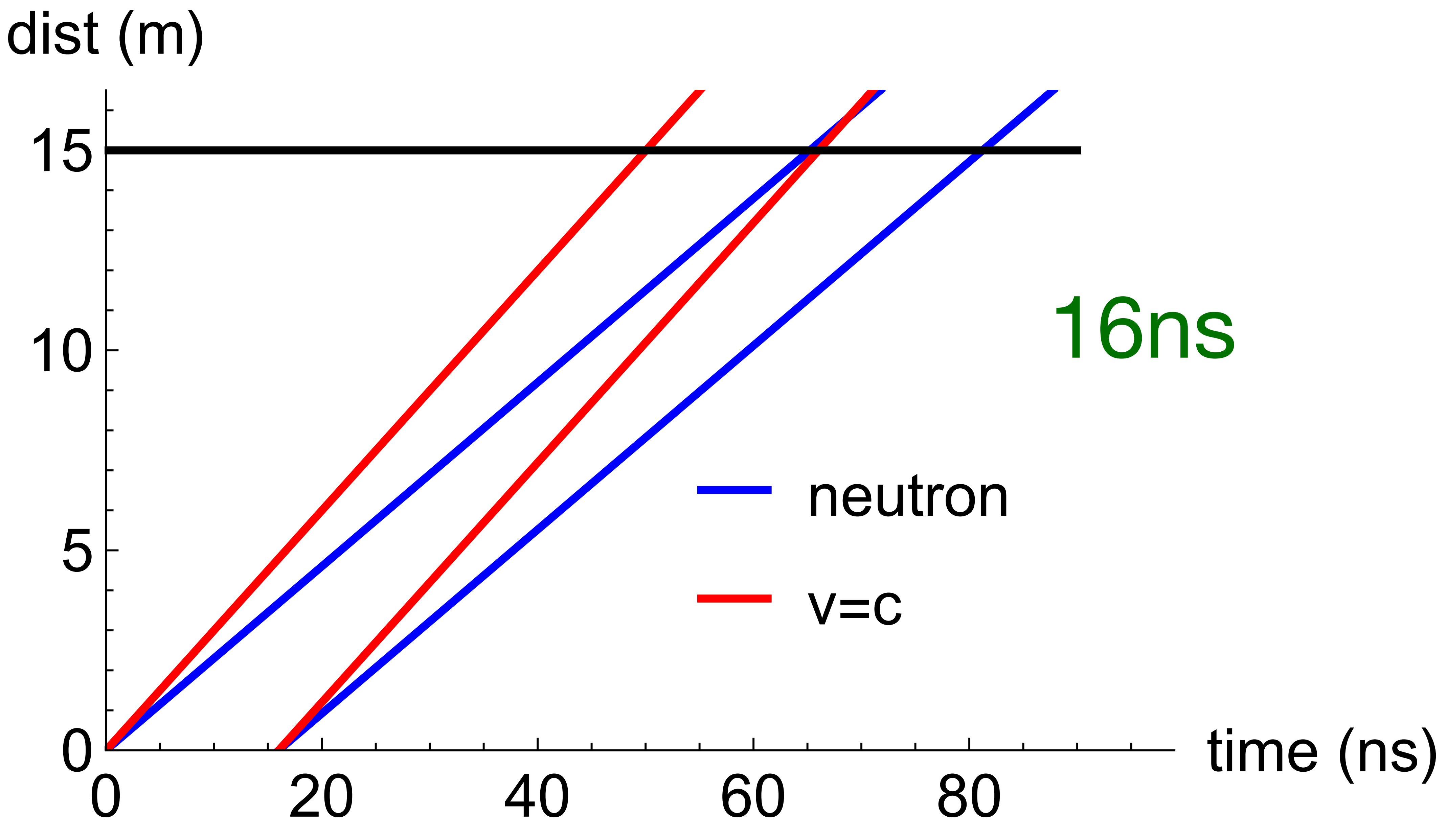
- $\theta_\nu = 30^\circ = \theta_e$
- $E_e = 1.67$ GeV

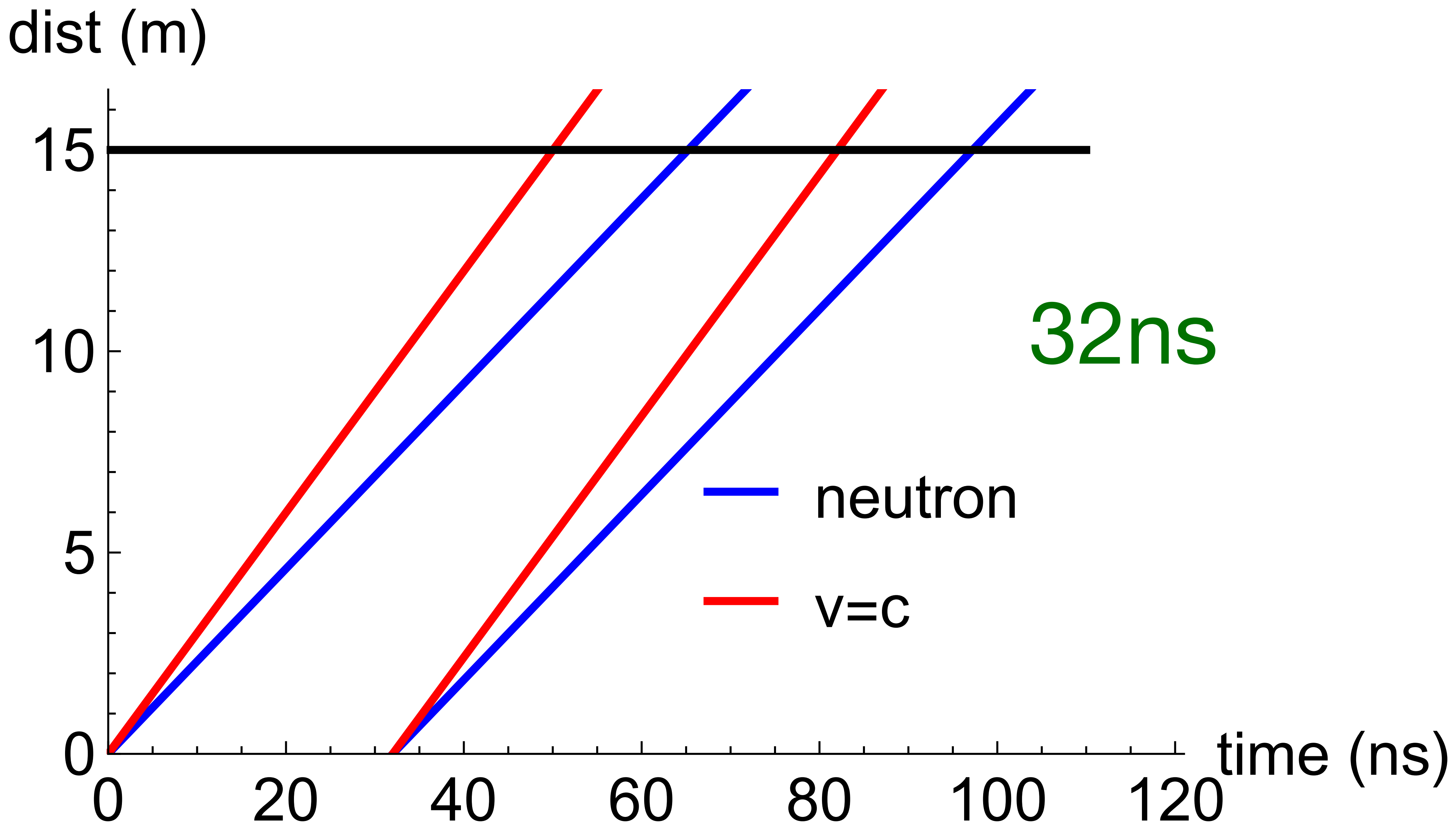
# Beam Structure

Pulses separated by 2ns will lead to background from overlaps

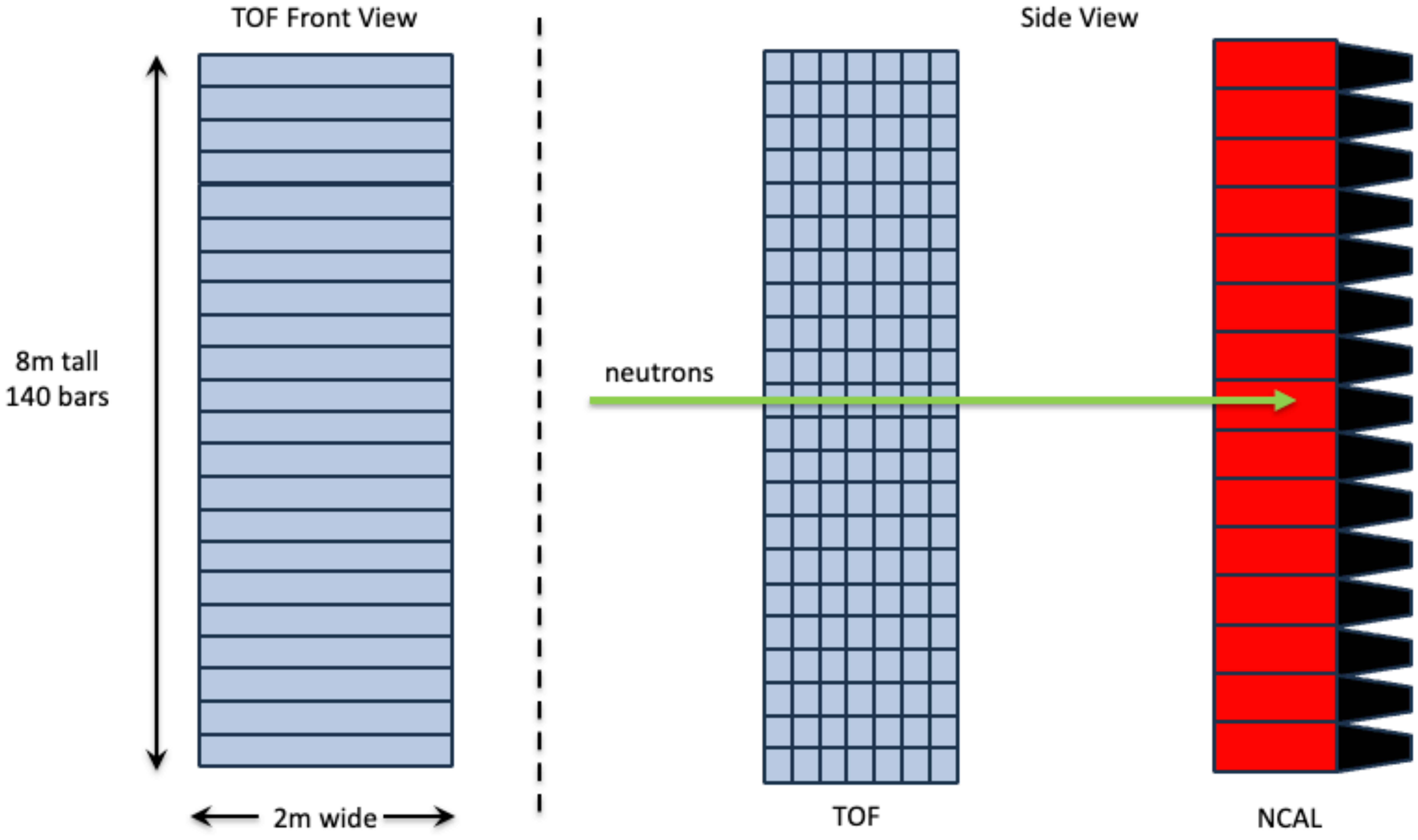



Discussions ongoing to achieve high current with large bunch spacing.



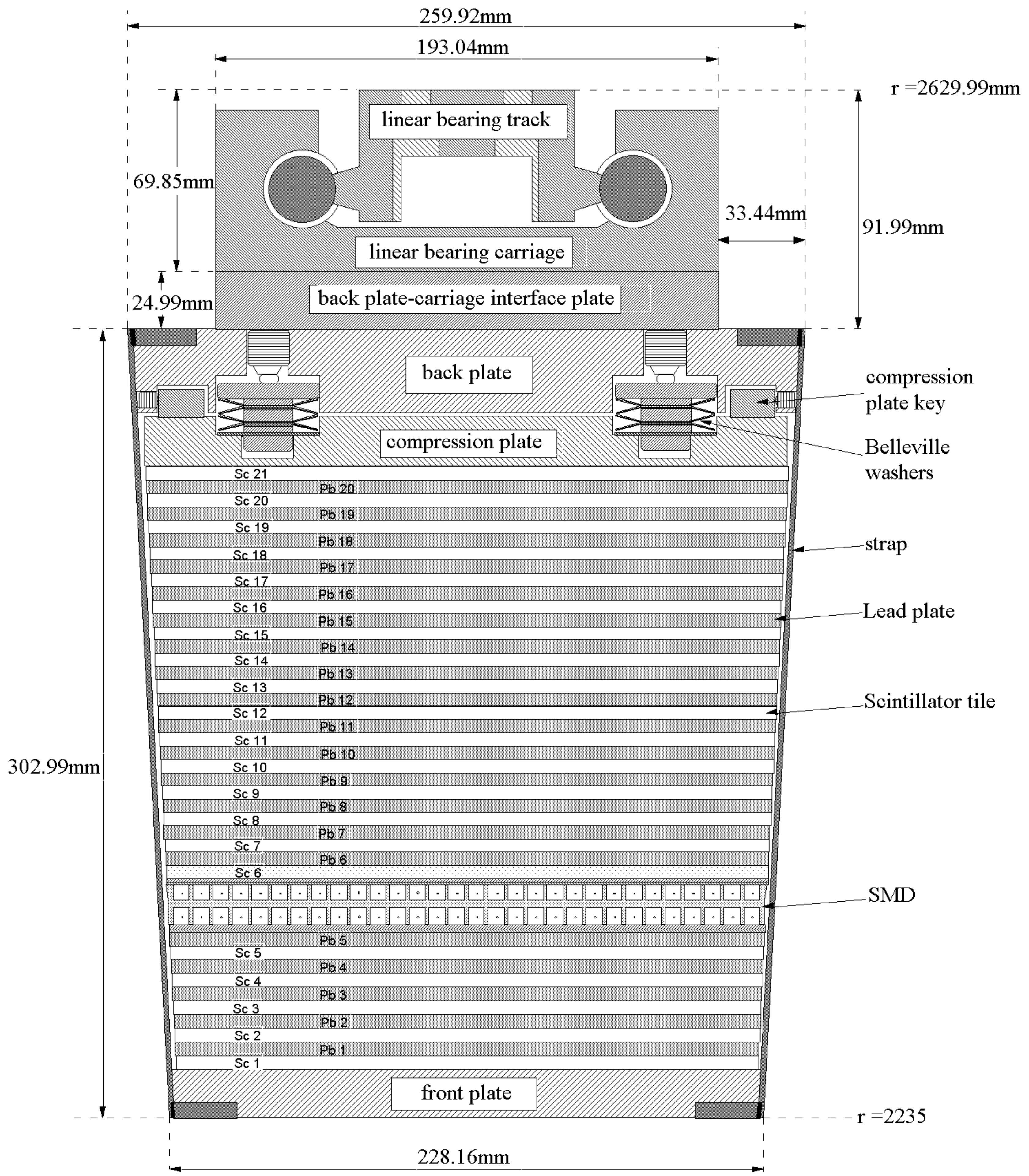
# The Neutron Arm (Schematic)




- New components to be constructed at JLab
- TOF based on CLAS12, 11 x 140 =1540 bars (Not all are shown!)
- Expect 110 ps resolution
- NCAL is 30m$^2$, currently looking for options from some decommissioned experiments.

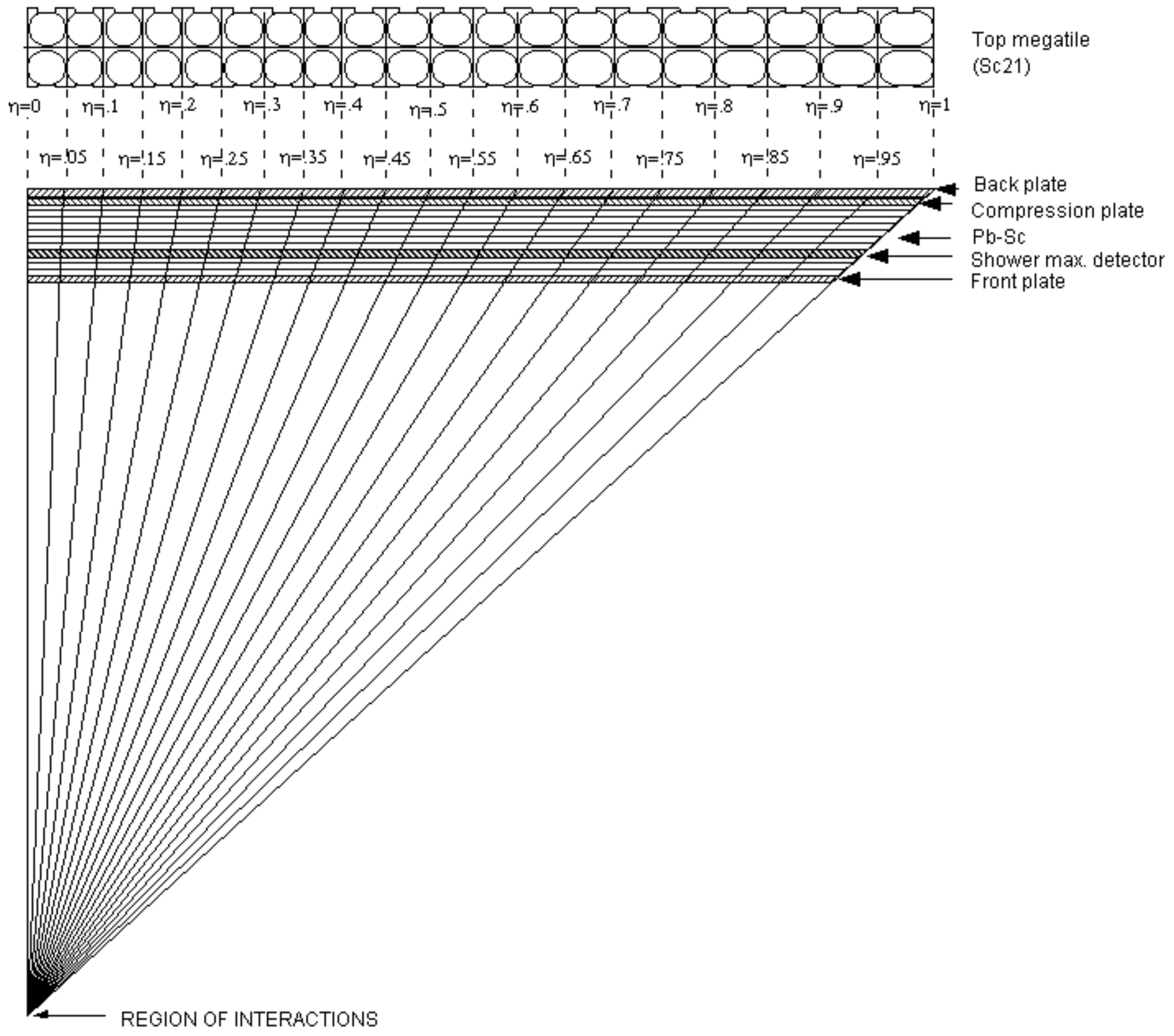
# Potential NCAL Option

## The STAR Barrel Electromagnetic Calorimeter




We would need to deal with the pointing geometry.

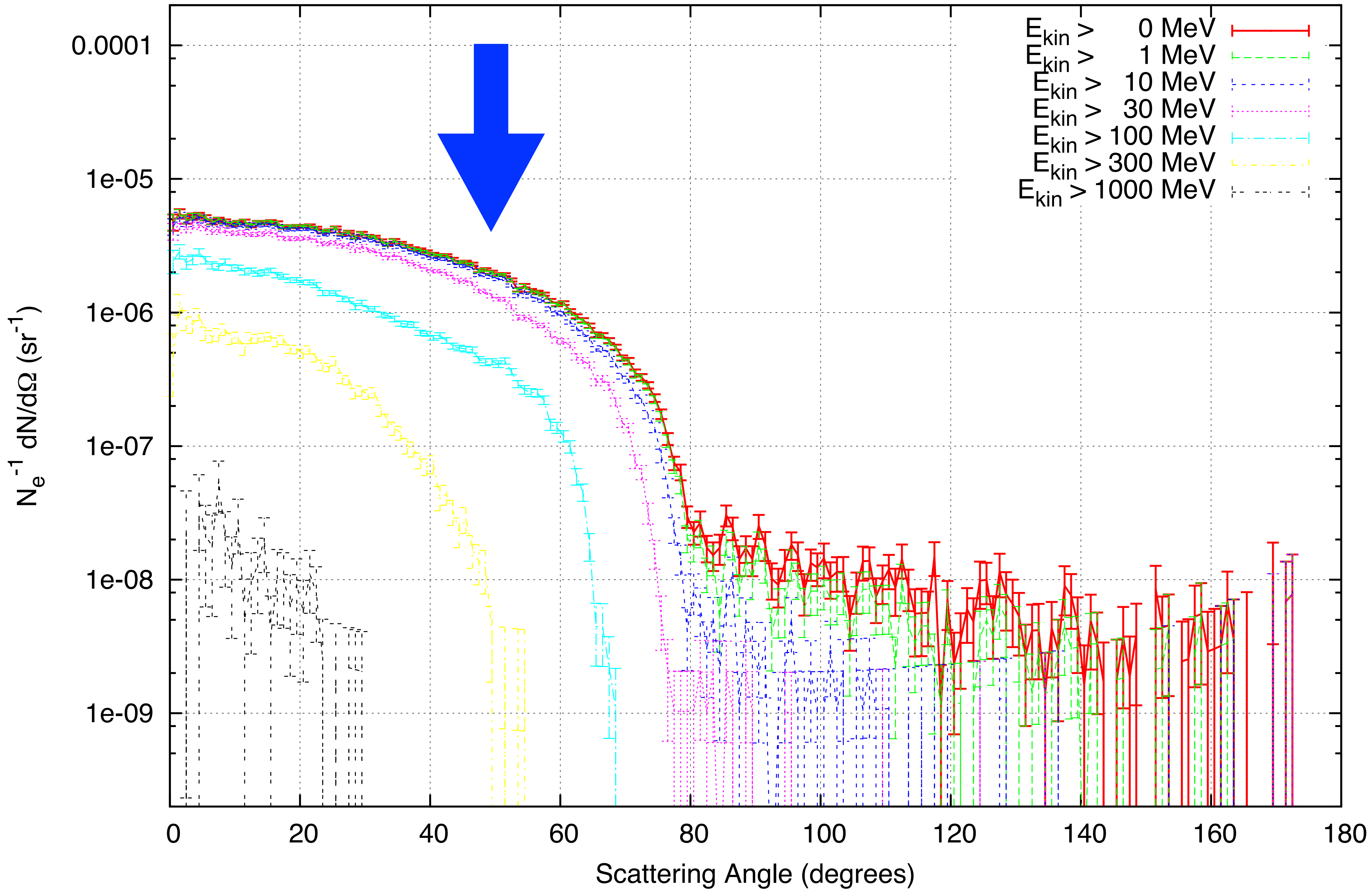
Alternating the modules can fix azimuthal, but we would need to live with rapidity segmentation.

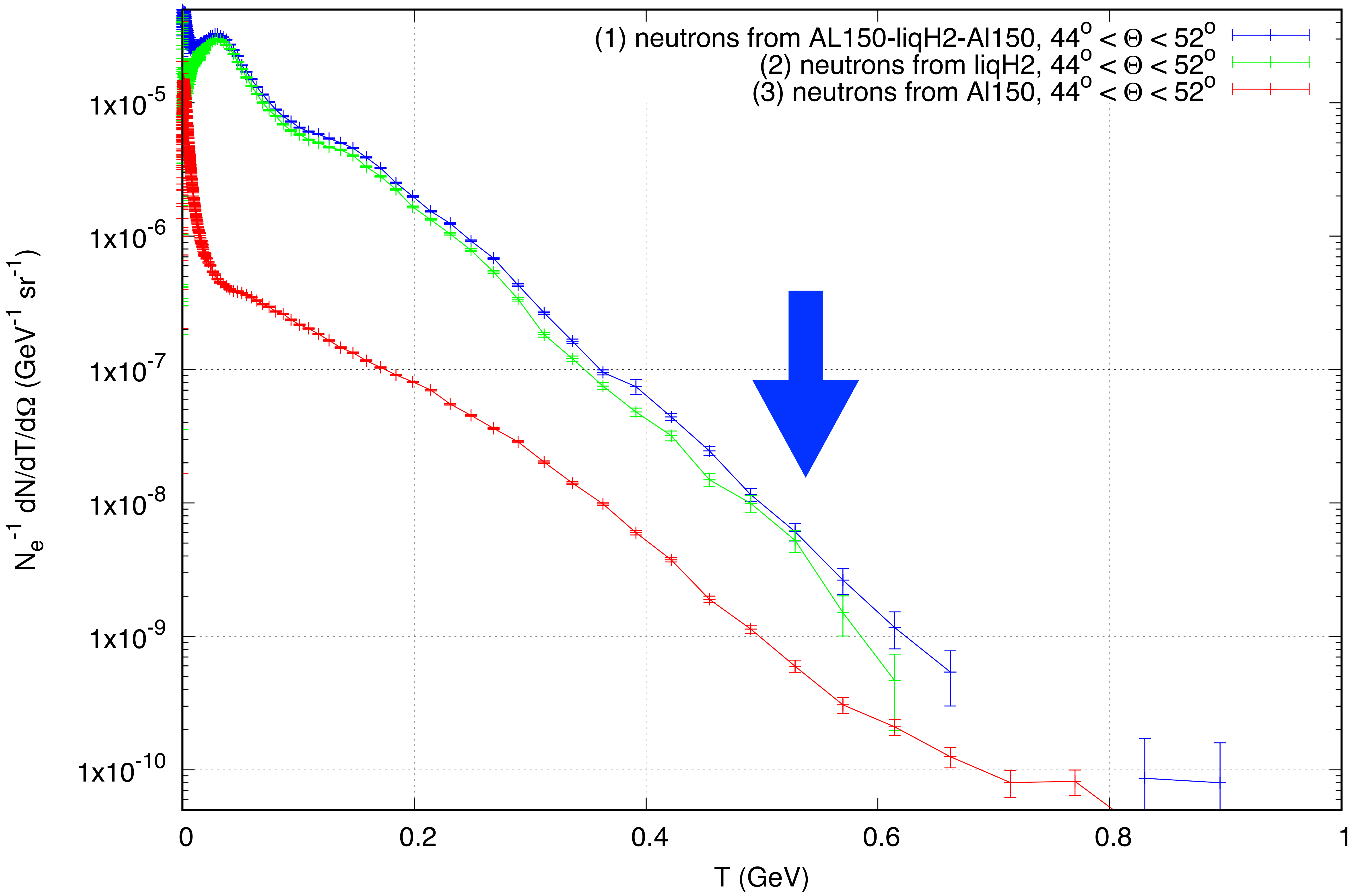


# Simulations: FLUKA for Raw Neutron Yield

## Remember: Reducing neutron backgrounds is the key to success

$$e + \text{liq.}H_2 \rightarrow n + X \quad \text{at} \quad E_{beam} = 2.2 \text{ GeV } (\varnothing 2\text{cm}\times 20\text{cm target})$$

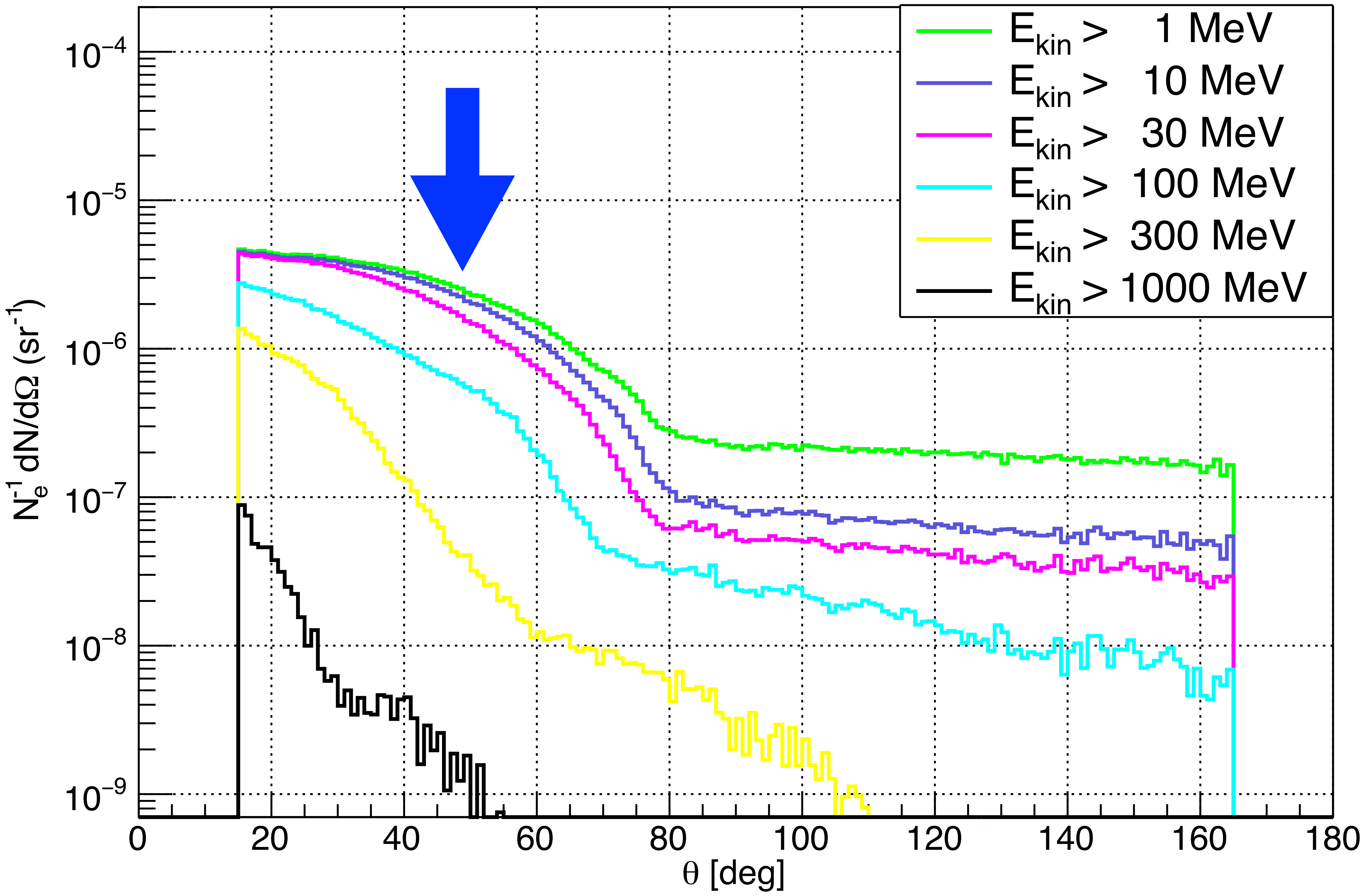


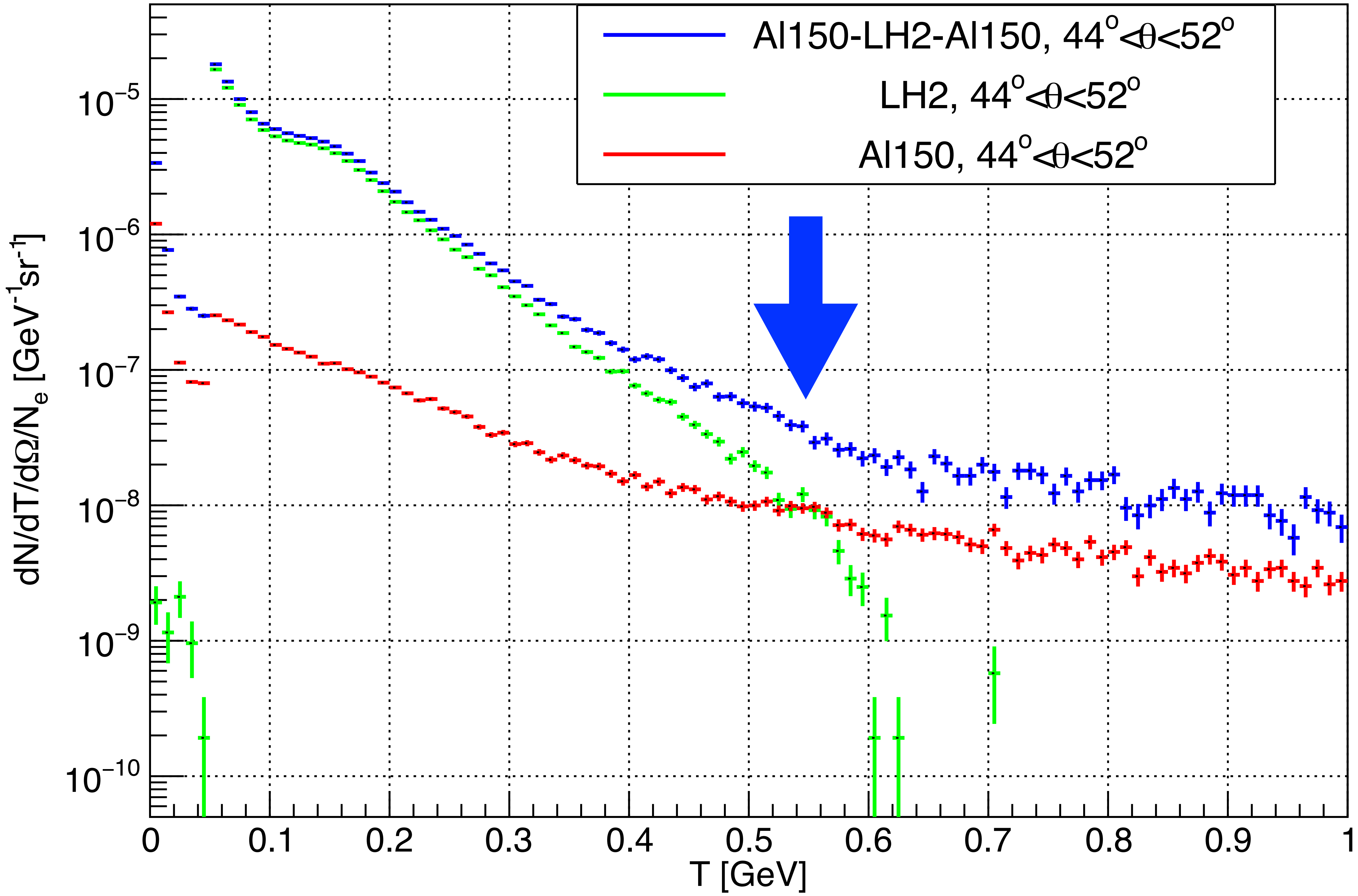



# Simulations: GEANT4 to Break it Down

## Lots of different processes to investigate

$e + \text{liq.}H_2 \rightarrow n + X$ at $E_{beam} = 2.2$ GeV (∅2cm×20cm target)



# Estimated Sensitivity

## Reaction cross section from calculation by Peter Kroll

- Recall E=2.2 GeV, 120$\mu$A, P=85%, 10cm (active length) LH2 target
- Best current estimate of neutron detection efficiency is 25%
- Rate for $p(e^-, \nu_e)n$ is 0.0022 Hz
- Best current estimate of background rate is 3.4 Hz. Dominant contribution is from $p(\gamma, \pi^+)n$ (after cuts), followed by Al$(e^-, n)X$ on target windows, but we still need to thoroughly research the double pion background.
- For a 50 day run, obtain 9.6K signal events and 14M background. This leads to a statistical uncertainty of 28% on $F_A(Q^2 = 1\ \mathrm{GeV}^2)$.

# Summary

- There is plenty of interest in determining the axial vector form factor free from model uncertainties at at least one $Q^2$ point.
- A direct, fully kinematically constrained measurement appears to be within reach at CEBAF, but it all hinges on beating down the background(s).
- We want to do a test run in Hall C with a prototype neutron detector to confirm background calculations, as well as neutron energy resolution and detector efficiency.
- The PAC 53 Meeting is coming up in July. We'll see what feedback we get.
- A complete experiment, at multiple momentum transfers, would follow our successful demonstration of this principle.

Thank you!