SoLID Collaboration Meeting July'25
Pre-R&D and Test Beam Plan

July-07-2025

Klaus Dehmelt - TJNAF

Pre-R&D Activities

SoLID FY'25-FY'26 Pre-R&D Plan

SoLID Collaboration

February 24, 2025

Contents

Pre-R&D Activities + MPGD ASIC White Paper → Submitted

Designing an Application-Specific Integrated Circuit for Gaseous Detector Applications—ASGAD

Alexandre Camsonne, Jian-ping Chen, Gianluigi De Geronimo, Klaus Dehmelt, Cynthia Keppel

March 2025

Contents

1

Pre-R&D Activities - Scope

- GEM readout → more general MPGD readout
- Tracking options
- MCP-PMT

→ to be combined with a Detector Beam Test in Hall C

Pre-R&D Activities – MPGD Readout

- MPGD readout

VMM tests

- Two test boards ordered
- Six SoLID prototype boards constructed
- Evaluation board developed → spy on data with small subset of detector data
    - Issue with external trigger, waiting for new firmware
    - Can check pedestal width
    - S/N of detector with source or cosmics
    - Monitor direct readout signals for 12 channels
- Prototype development for data performance; testing of direct output with detector and X-ray source

Pre-R&D Activities – MPGD Readout

- MPGD readout

    - Investigating the production of modified VMM
        - Drop the low gain
        - Add high gain setting
    - Inquiring design time + production costs

Pre-R&D Activities – MPGD Readout

- MPGD readout

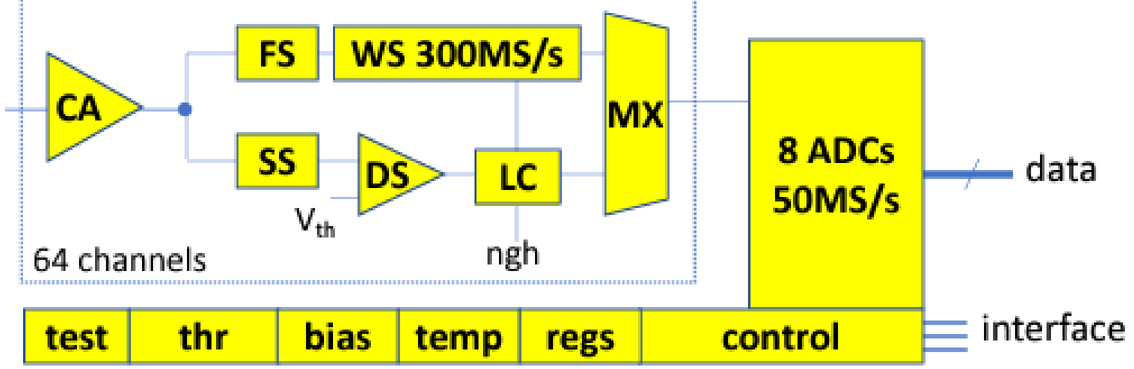
New potential dedicated ASIC

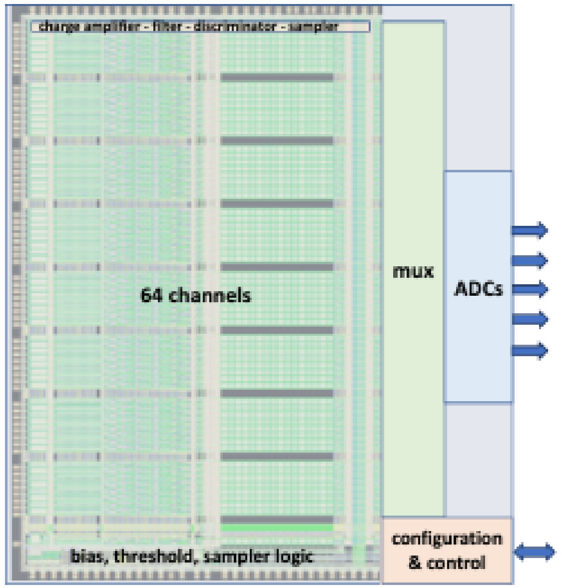
- High luminosity running
- Pile-up and deadtime can be significant

- Dedicated chip
  - Optmized gain and dynamic range
  - Optimize shaping time for high rate operation : from 50 ns to 25 ns or better
  - Zero dead time
  - High speed links to allow streaming

Pre-R&D Activities – MPGD Readout

Proposed Architecture





CA: charge amplifier
- optimized for 50-200pF
- programmable gain 25fC to 250fC

FS: fast shaper
- programmable 5-20ns

SS: slow shaper
- for discrimination (zero suppression)
- programmable 20-100ns

DS: discriminator
- trimmable per channel
- external trigger option

WS: waveform sampler
- 128 sampling cells (127 effective)
- continuous sampling until trigger
- 300MS/s → ~ 400ns waveform
- programmable pre-post trigger samples

LC: local control logic
- internal or external trigger
- neighbor (sub-threshold) logic

ADCs
- 8 operating at 10-bit 100MS/s
- waveform conversion time ~ 2.5µs

Data
- channel, trigger, 127 samples = 1,280 bits per waveform
- up to 8 waveforms with sub-threshold neighbors = 10,240 bits
- up to 8 SLVS outputs operating in DDR at ~ 500MS/s
- conversion/readout time (dead time) ~ 2.5µs per event
- maximum event rate ~ 330kHz
- maximum data rate ~ 4Gb/s

Architecture
- event-driven analog/digital with acquisition/readout
- SEU tolerant register and logic
- DSP-ready

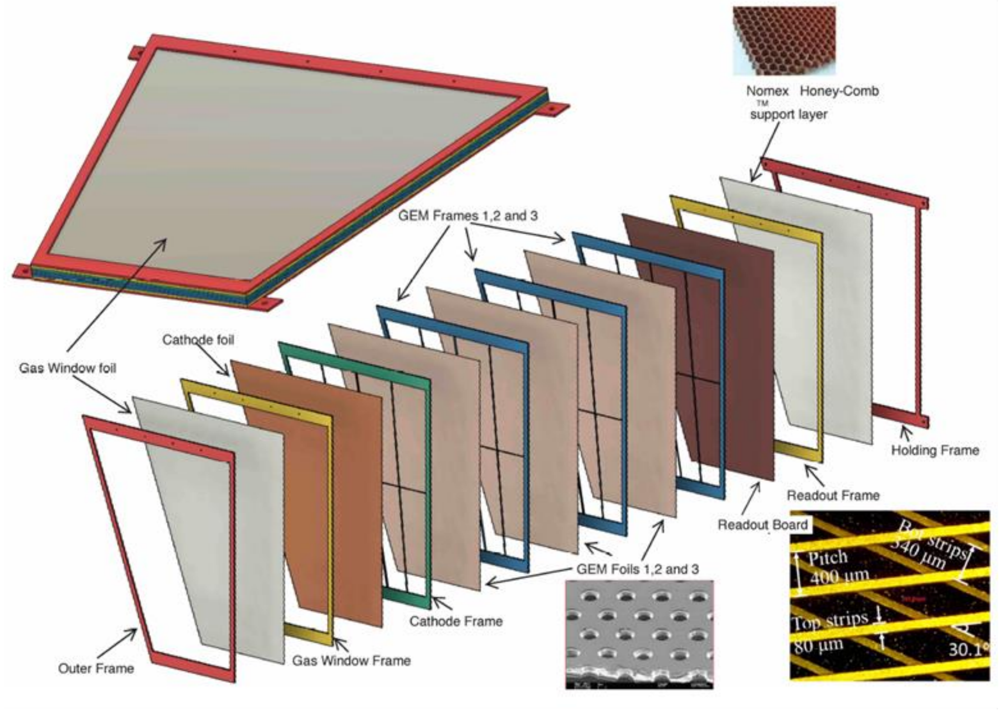
Power, Size, Technology, Schedule
- power consumption below 3mW/channel
- anticipated die size ~ 6x8 mm^2
- technology TSMC 65nm 1.2V
- development time ~ 24 months (1st proto in 12 months)

Design
- charge amplifier, shapers and samplers based on verified architectures
- ADCs from collaborative effort
- first prototype design time
  - ~ 12-13 months plus ADCs
  - ADC can be parallel effort
- second prototype design time
  - ~ 4-5 months

Key Features
- power-efficient analog zero-suppression
- efficient data generation and transfer
- highly flexible, highly programmable

Pre-R&D Activities – Tracking Options

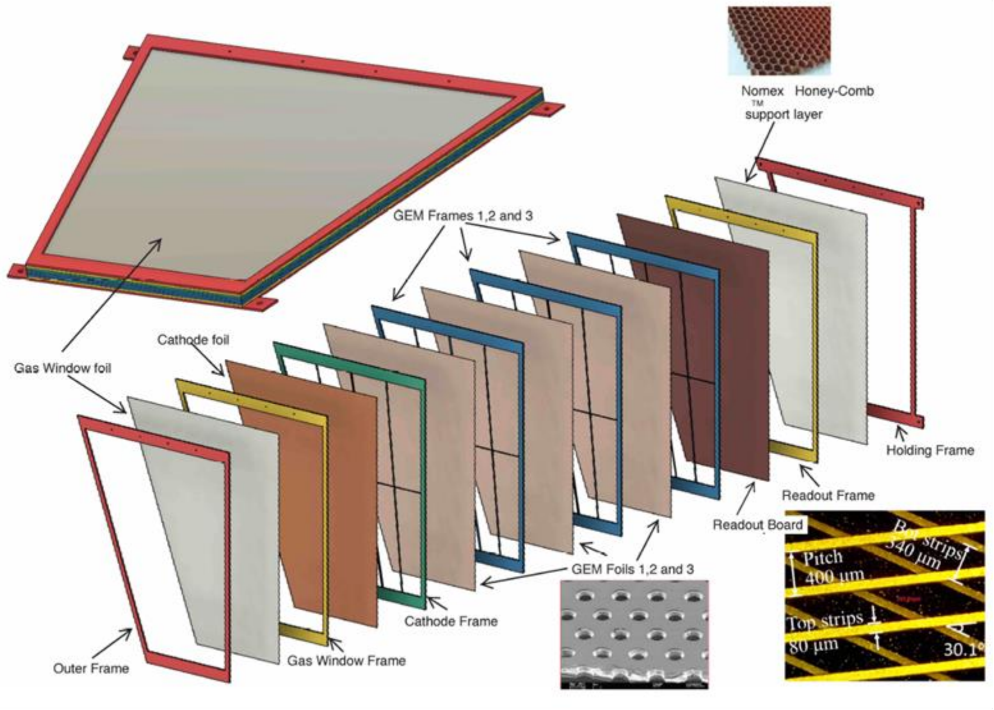
- Default configuration: Triple – GEM à la MOLLER

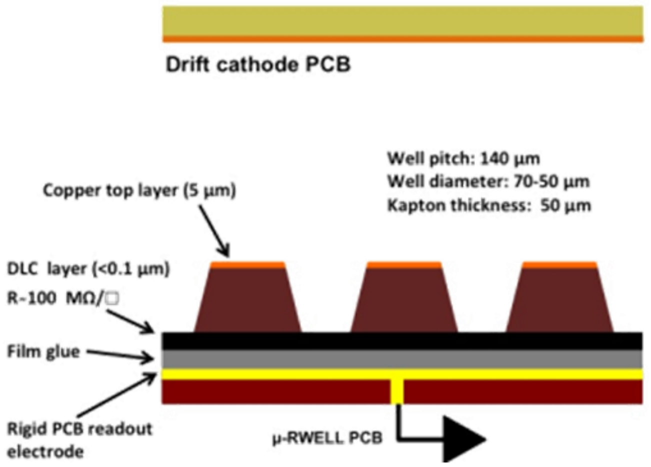


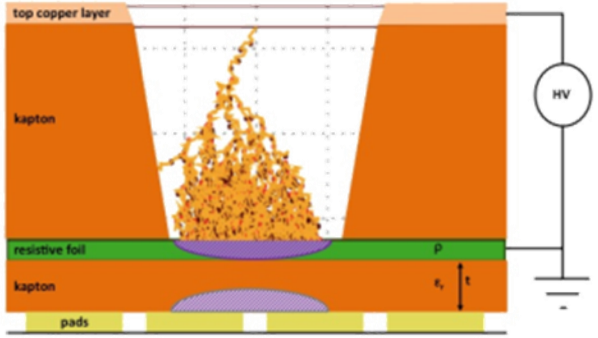
Jefferson Lab

Pre-R&D Activities – Tracking Options

- Default configuration: Triple – GEM à la MOLLER
- Alternative configuration: μRWell and derivatives

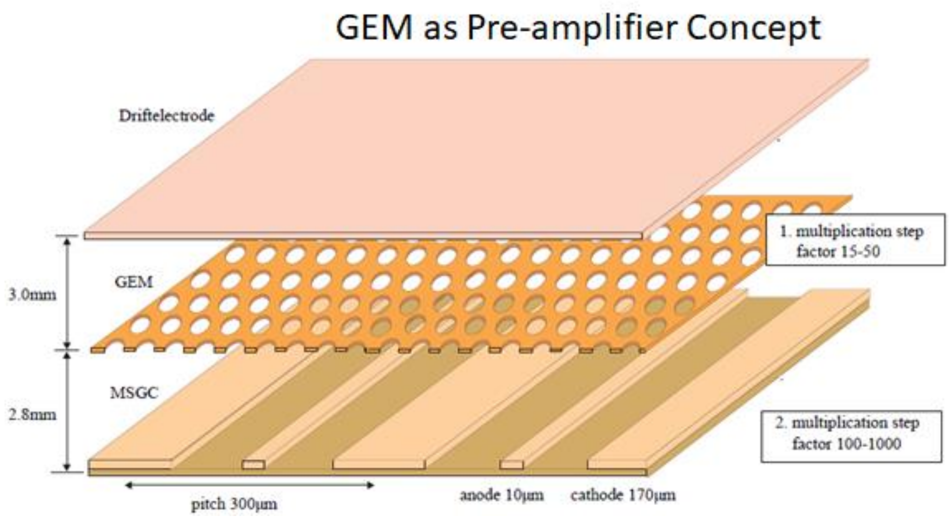


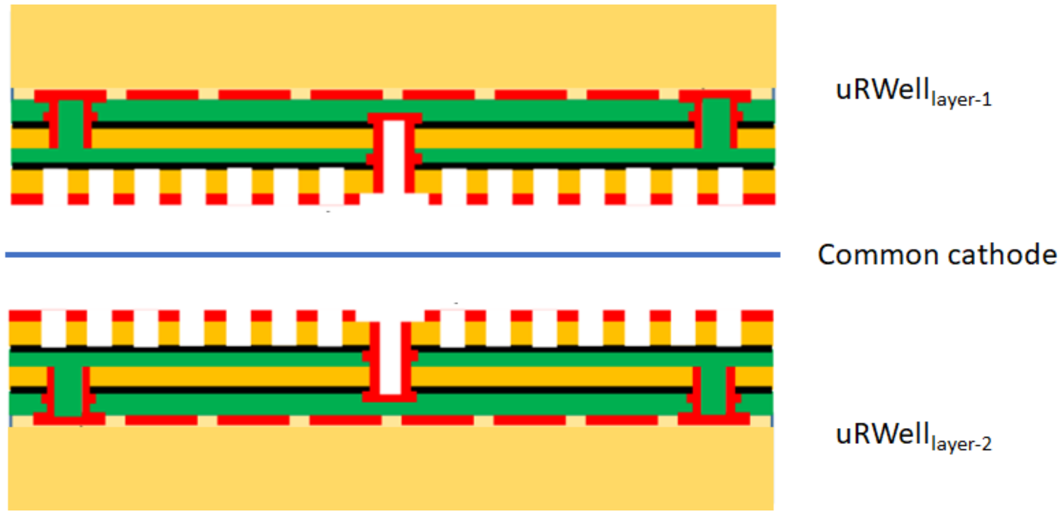




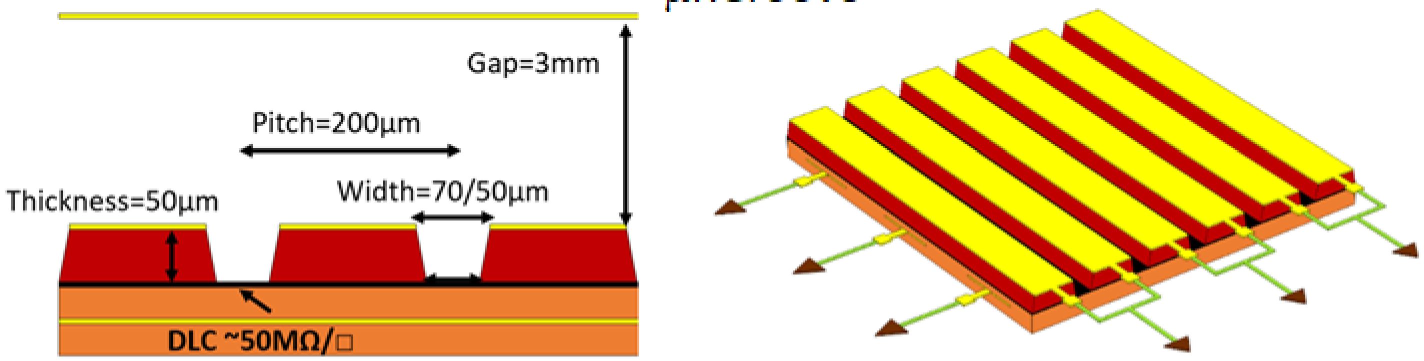
Pre-R&D Activities – Tracking Options

- Alternative configuration: μRWell and <u>derivatives</u>





μRGroove



Pre-R&D Activities

- MPGD readout
- Tracking options

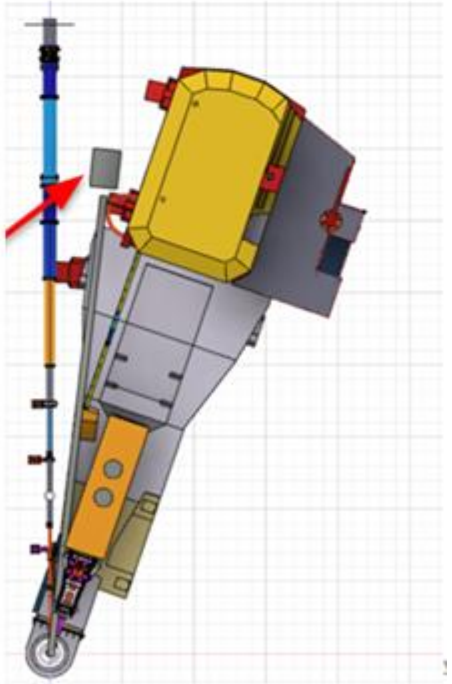
SoLID_preRD_Fall2024 $\rightarrow$ Proposed Milestones and Budget

Budget uncertainties postponed this endeavor

Pre-R&D Activities – Past Activities

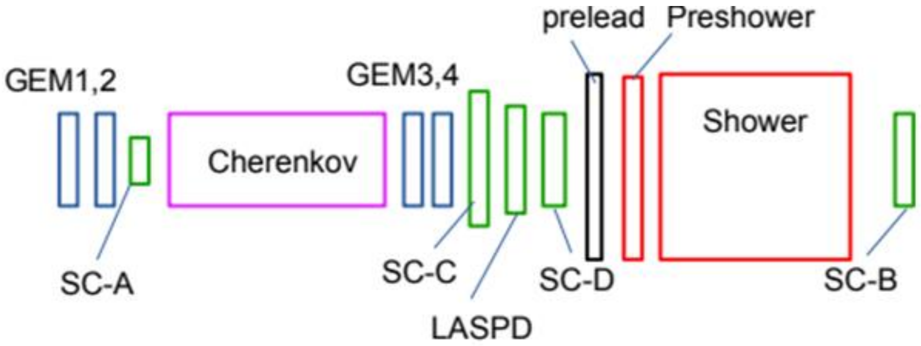
FY22 Hall C Beam Test Overview

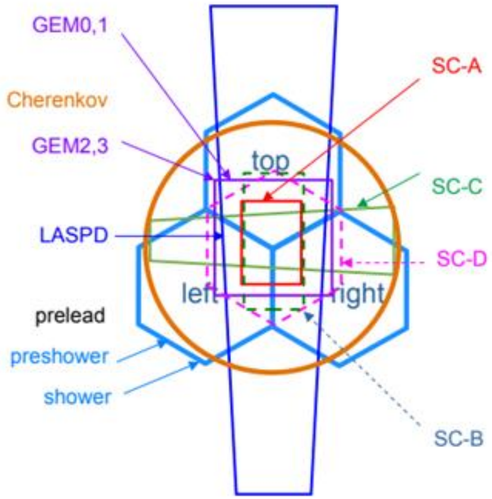
1. Goal was to study ECal and SPD performance under high rate, high radiation
2. Installed in Hall C in summer – fall 2022
3. Three stages:
   - 80 deg beam-left in Fall 2022, low rate "commissioning"
   - 7 deg beam-right in Jan 2023, high rate part 1
   - 18 deg beam-right in Feb-March 2023, high rate part 2
   - de-install in March 2023
4. Analysis was focused on:
   - Comparison of data with simulation
   - detector performance and stability from low to high rate
   - ECal and SPD PID performance
5. Report now ready for review by collaboration, is part of it publishable?

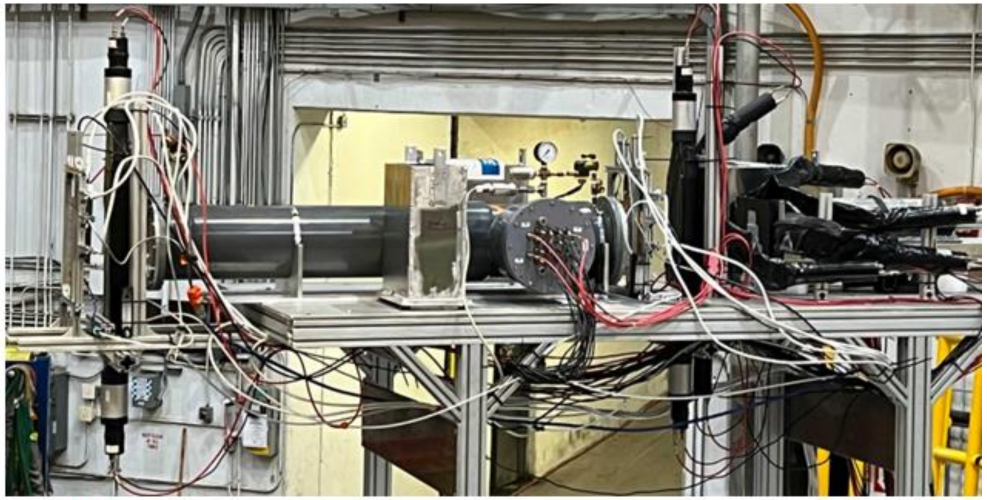


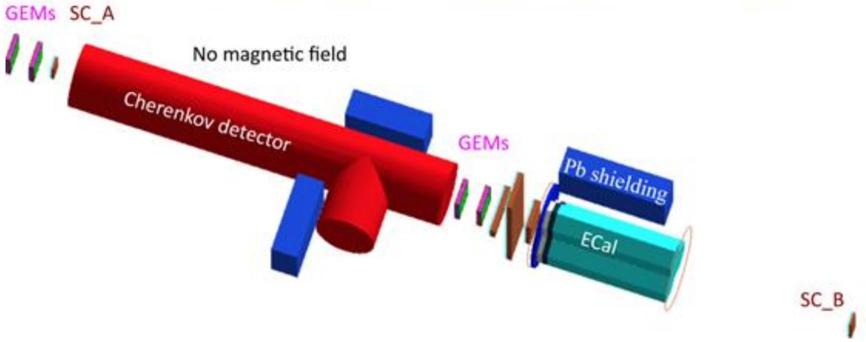
Pre-R&D Activities – Past Activities

Setup Overview







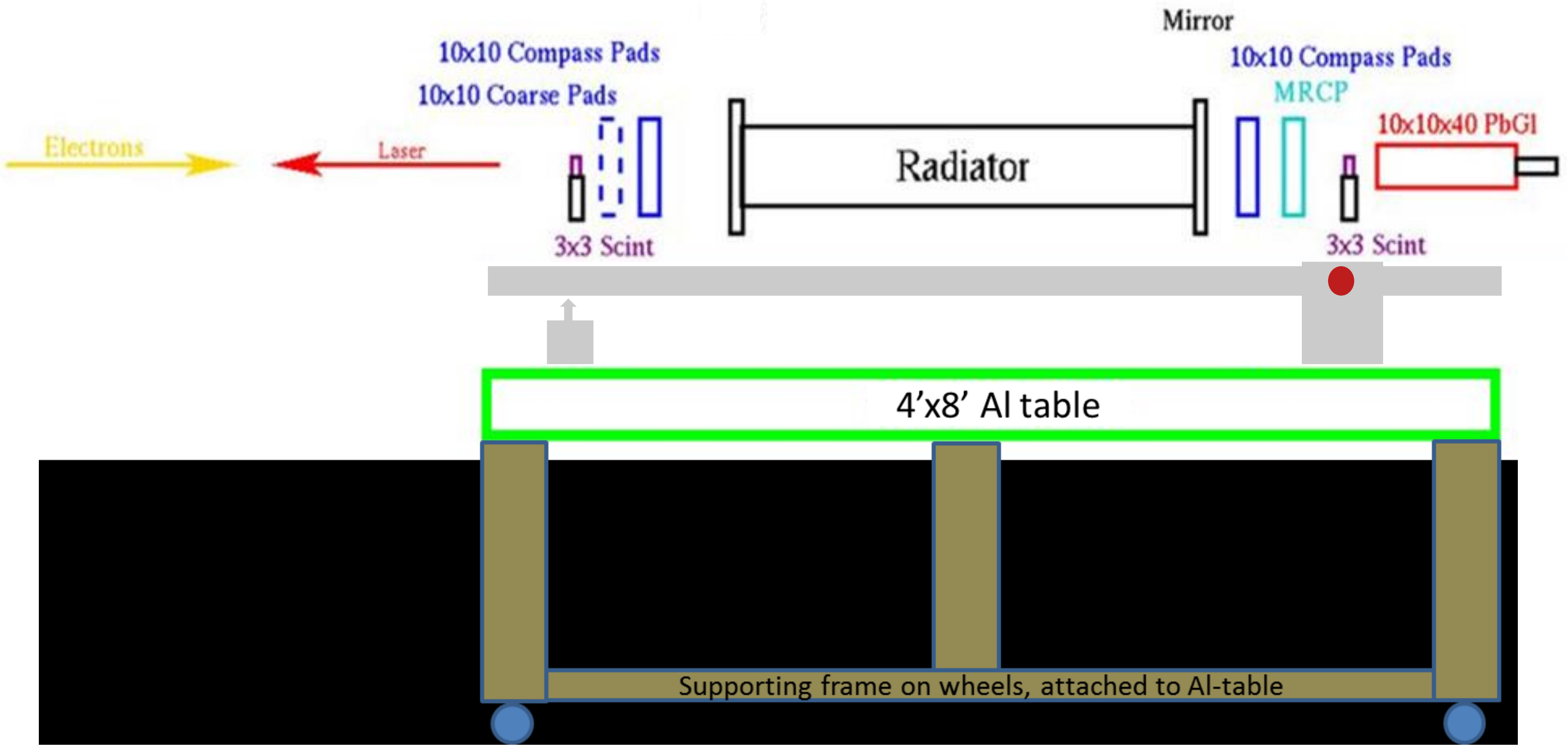


Jefferson Lab

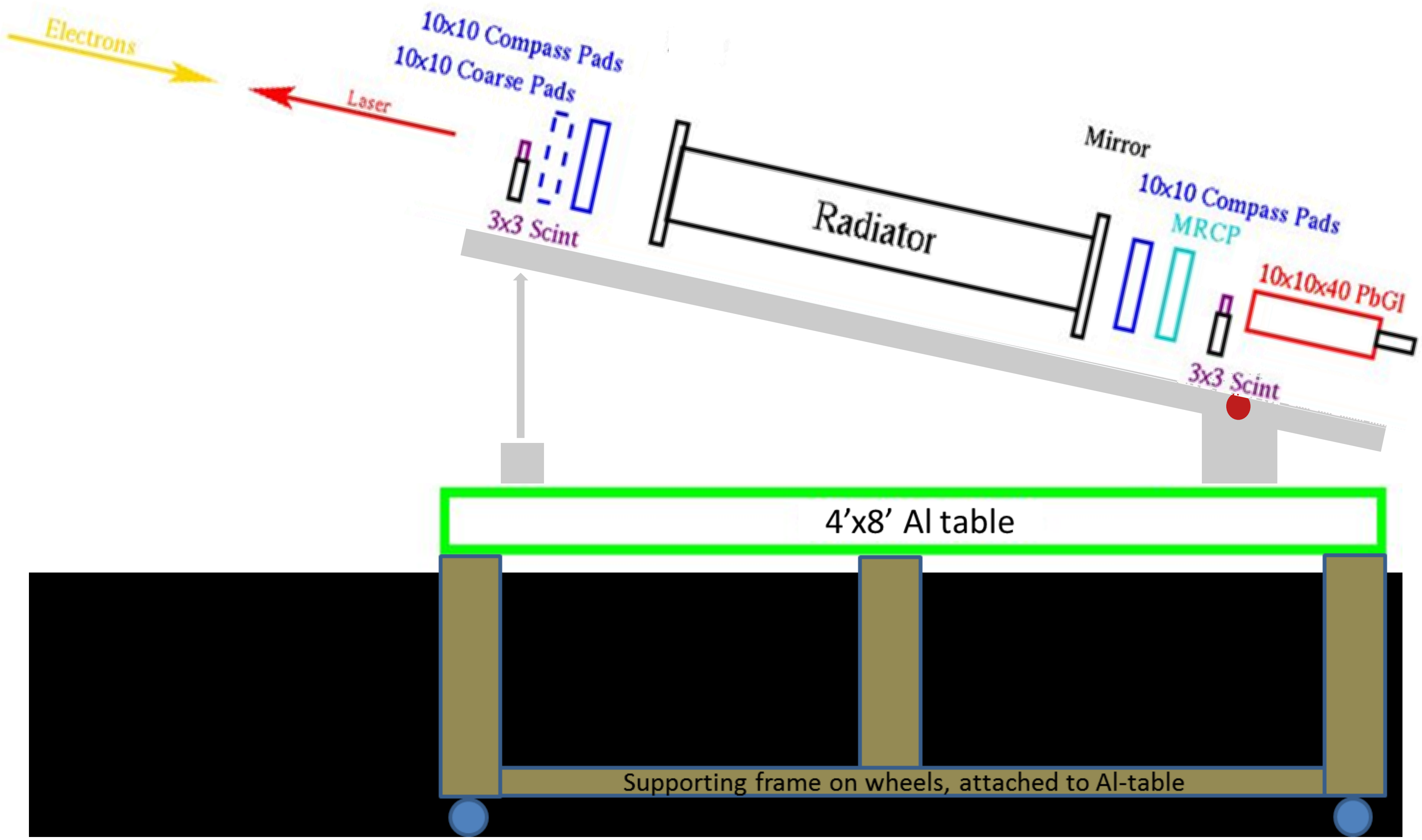
Pre-R&D Activities And Test Beam Plans – Hall C

- Perform a sector test with SoLID sub-detectors
- Focus on new MPGD technologies

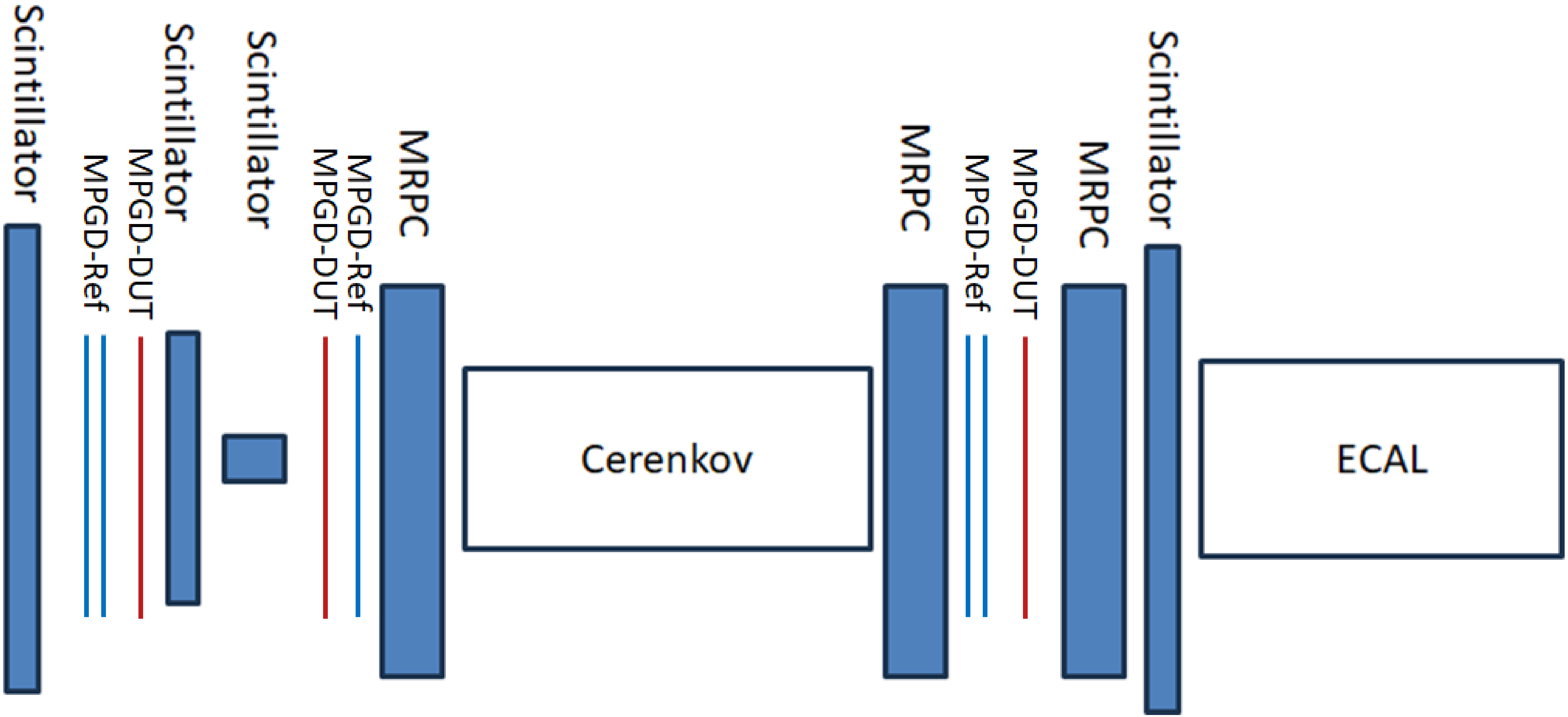
Pre-R&D Activities And Test Beam Plans – Hall C



Pre-R&D Activities And Test Beam Plans – Hall C



Pre-R&D Activities And Test Beam Plans – Hall C

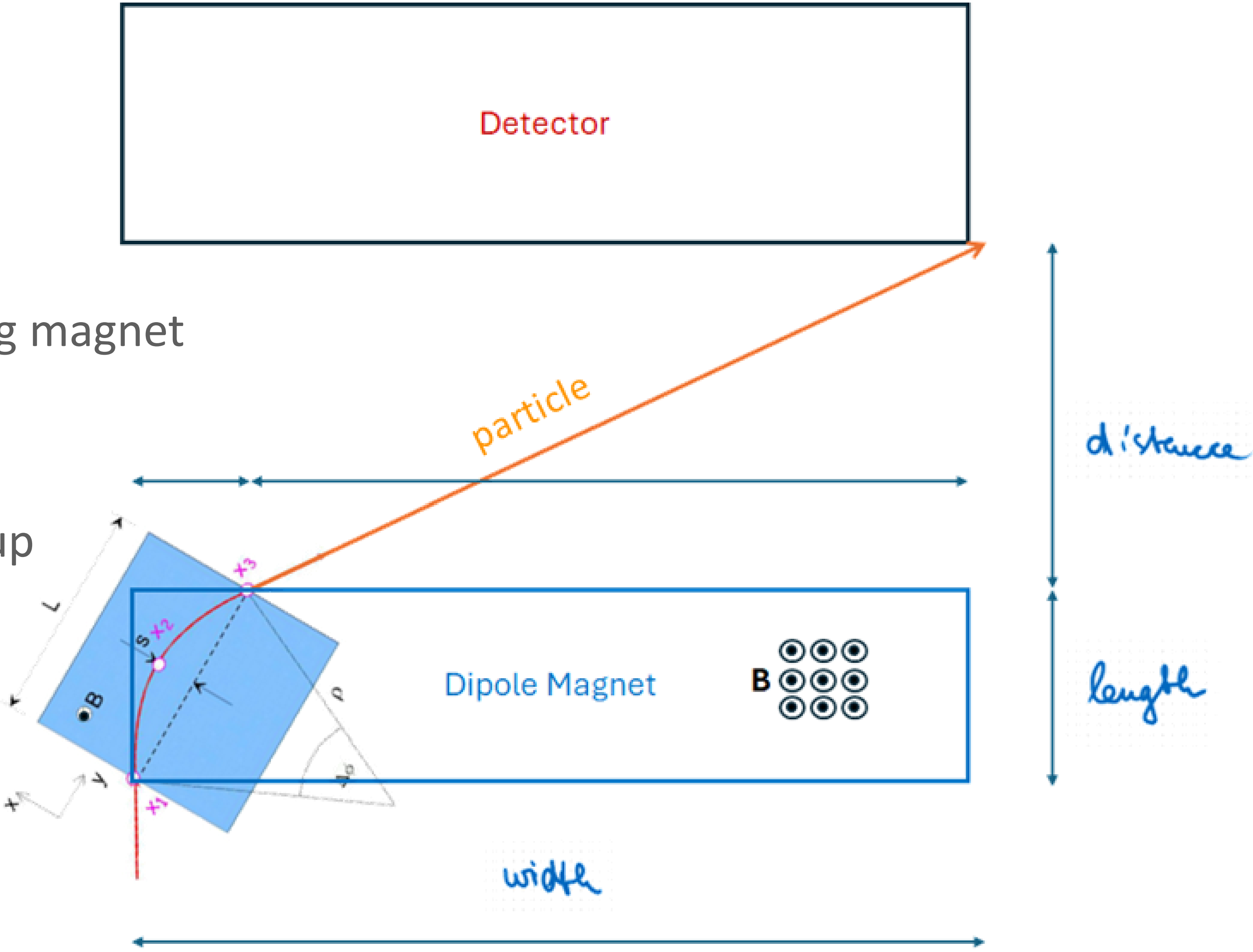


Pre-R&D Activities – Planned Future Activities – Hall C

- Detectors under Test (DUT)
  - Trackers
    - Hybrid μRWell – strips → status TBD
    - Hybrid μRWell – pads → status TBD
    - μRGroove → two prototype trackers in production – SBU
    - General reference trackers – GEMs → status TBD
    - RO electronics – VMM3/APV25 → appropriate?
  - MRPC – sealed → in HMS?
- Kinematics: Angle, distance from target
- What particle will we track?
  - Electrons: need high rates to get clean electrons
  - e^+/e^- from photons?
  - Minimum ionizing π: low energy → multiple scattering?
- Reducing soft background.
  - Soft Moller electrons in front: Absorber or magnetic field (sweep) → NPS magnet
  - Distance from target
- Anticipated beam current:
  - Need 100 nA for tune-up, 5 μA for low-rate tracking.
  - Will useful data be obtained at higher rates?
- Are there other tests beyond tracking that may interfere?

Pre-R&D Activities And Test Beam Plans – Hall C

- Background reduction
  - Remove Møller electrons → sweeping magnet
  - Dipole magnet
    - Aperture, gap, field strength
  - Accommodated around detector setup

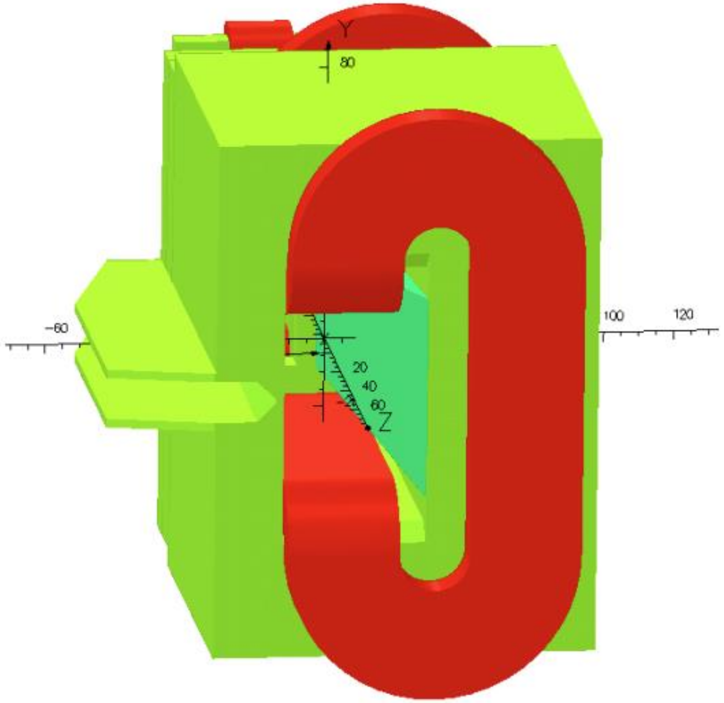


Pre-R&D Activities – Planned Future Activities – Hall C

- Possible use of sweeping magnet – NPS magnet
- Magnetic rigidity $B \cdot dl = 0.58\, T \cdot m$
- Documentation available, field-map integrated in GEANT4 (Ye Tian)

Pre-R&D Activities – Planned Future Activities – Hall C

- Possible use of sweeping magnet – NPS magnet
- Magnetic rigidity $B \cdot dl = 0.58\, T \cdot m$
- Documentation available, field-map integrated in GEANT4 (Ye Tian)

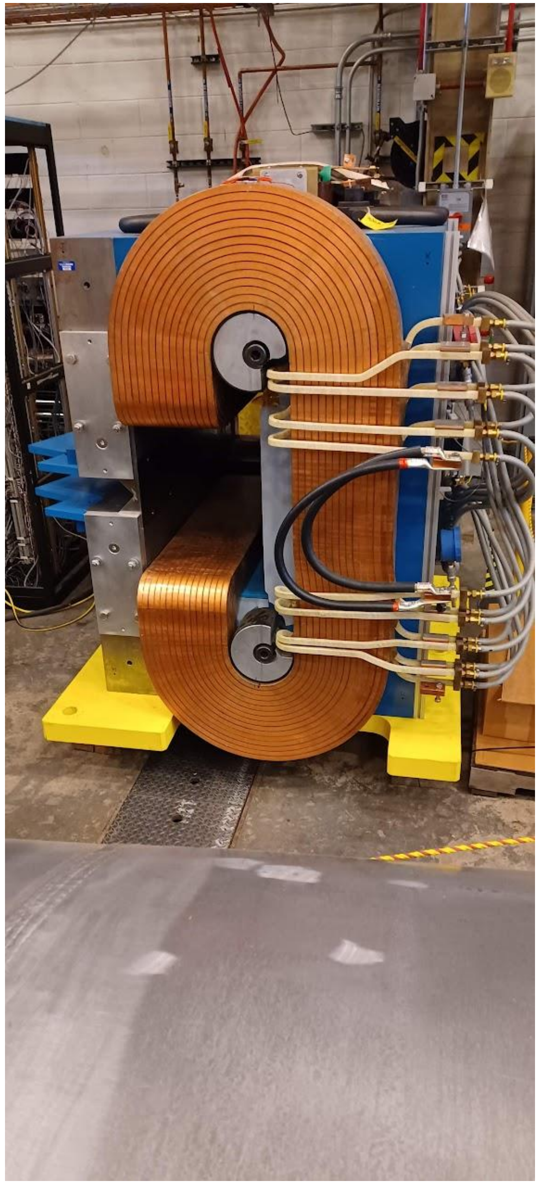


Non-uniform field but only

1-2% uniform integral Bdl

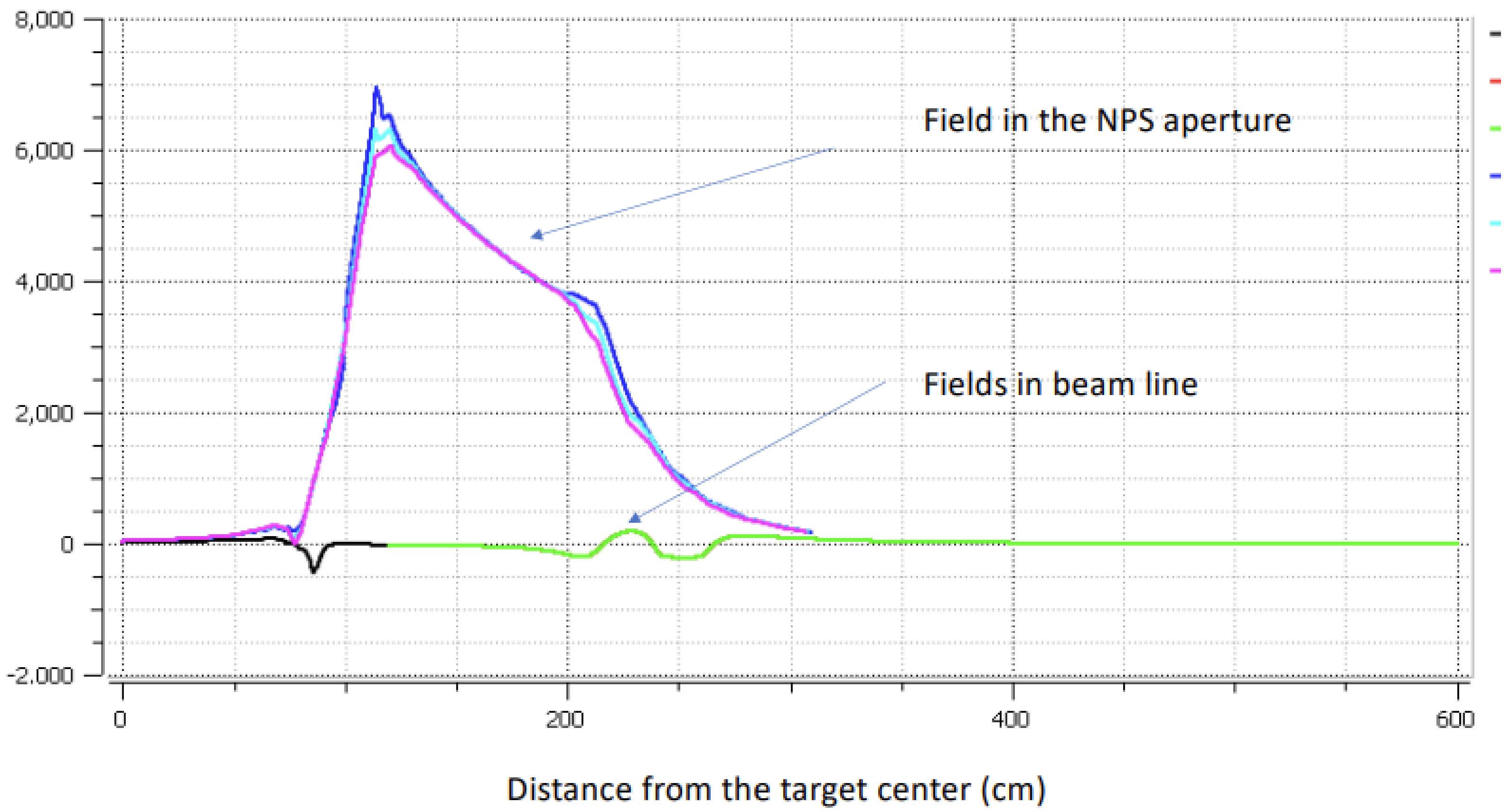
The same power and coil,

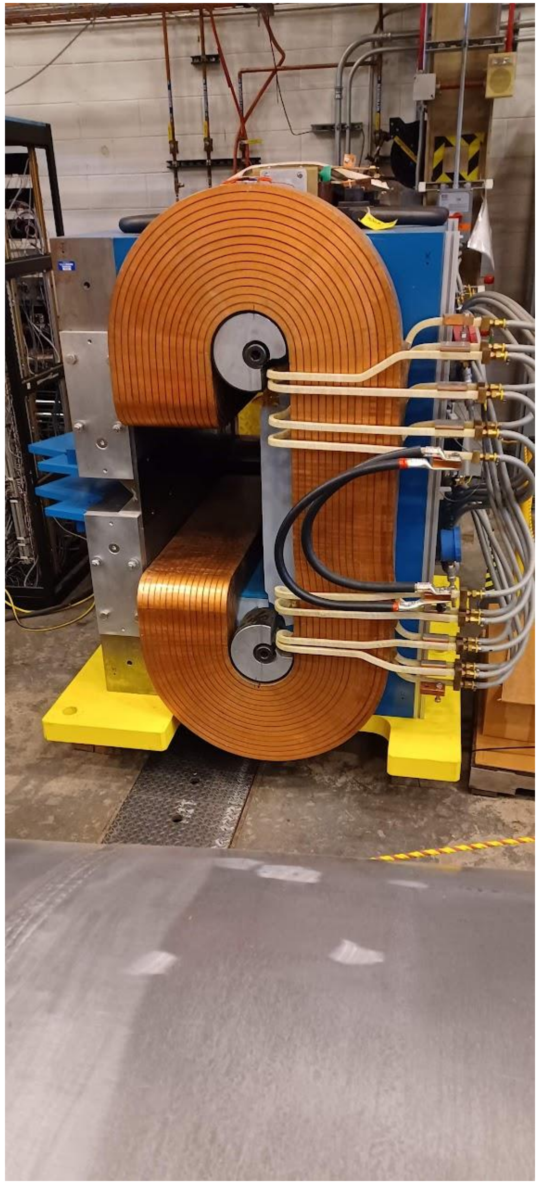
larger radius for the coil.



Pre-R&D Activities – Planned Future Activities – Hall C

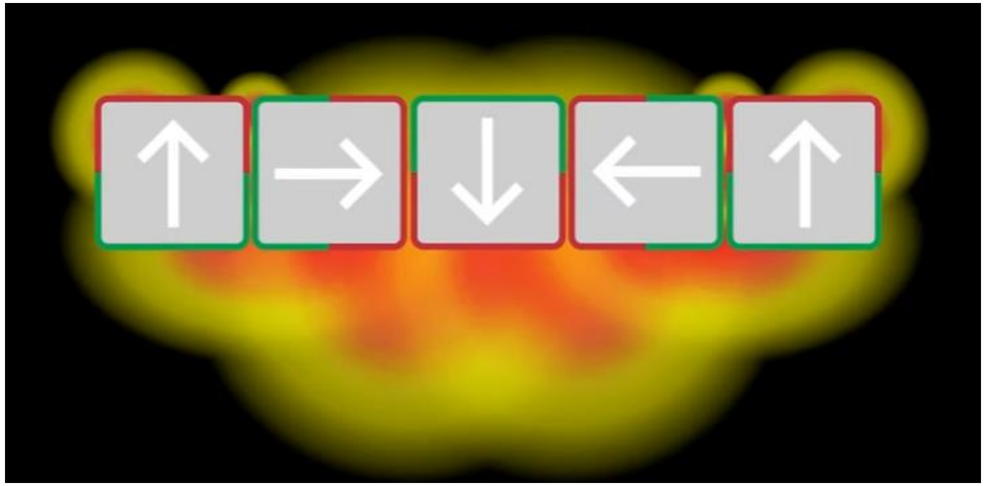
- Possible use of sweeping magnet – NPS magnet
- Magnetic rigidity $B \cdot dl = 0.58\, T \cdot m$
- Documentation available, field-map integrated in GEANT4 (Ye Tian)





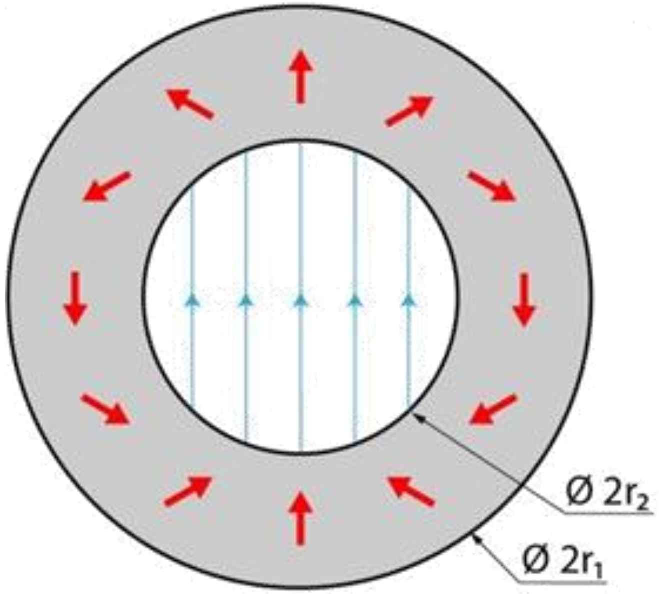
Pre-R&D Activities – Planned Future Activities – Hall C

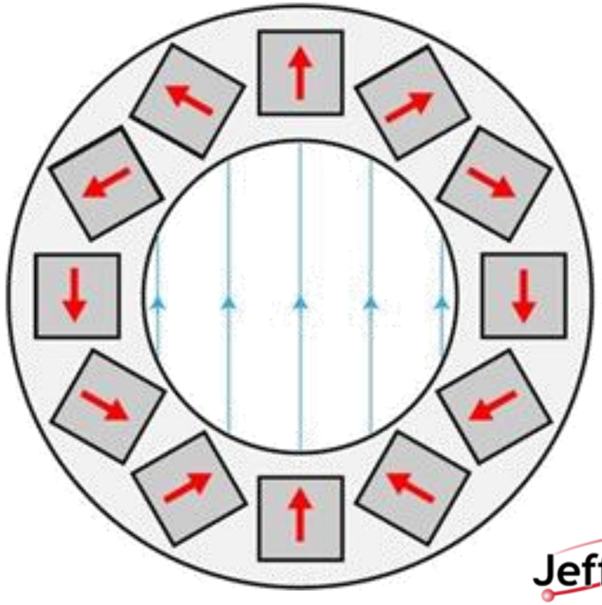
- Looking into alternative to NPS magnet → permanent magnet array
- Magnetic rigidity should be $B \cdot dl = 0.58\,T \cdot m$ as for NPS magnet
- Halbach Array
  - Magnetic array producing a high magnetic field utilizing permanent magnets
  - Magnets arranged with spatially rotating magnetic field vector → focusing and augmenting the magnetic field on one side, while cancelling it out on the other
- Non-trivial → needs investigations



Pre-R&D Activities – Planned Future Activities – Hall C

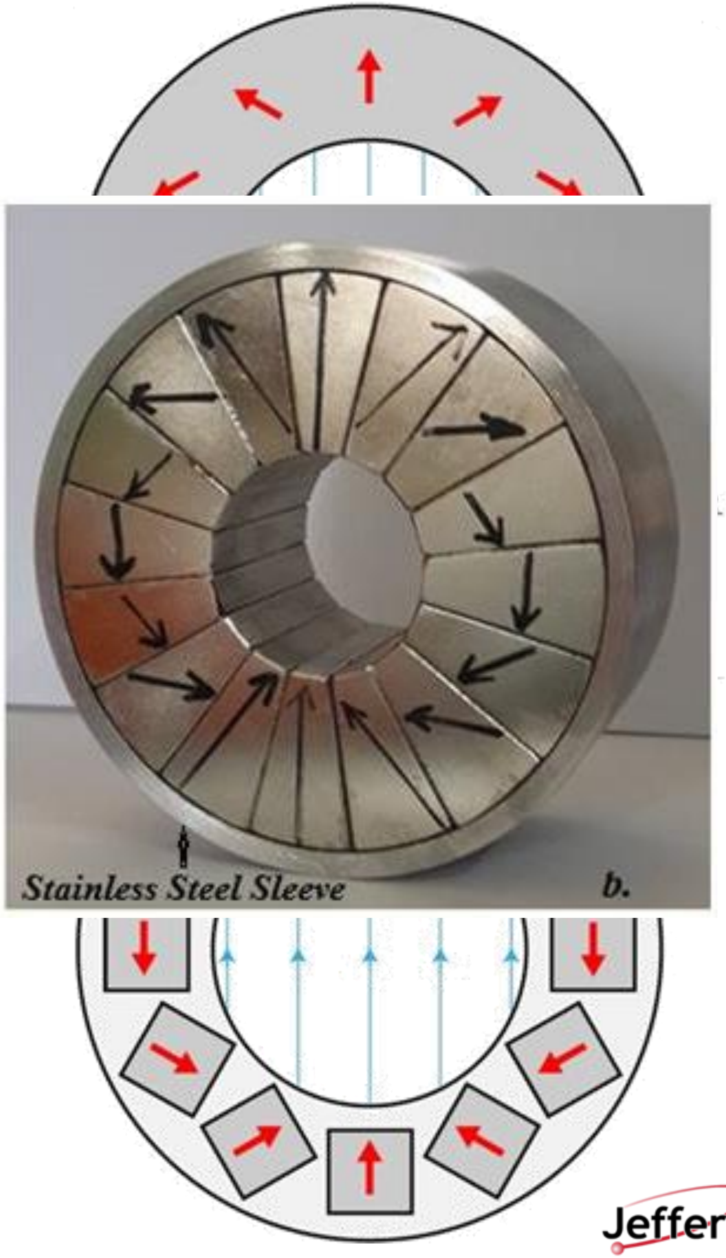
- Looking into alternative to NPS magnet → permanent magnet array
- Magnetic rigidity should be $B \cdot dl = 0.58\, T \cdot m$ as for NPS magnet
- Halbach Array
  - Magnetic array producing a high magnetic field utilizing permanent magnets
  - Magnets arranged with spatially rotating magnetic field vector → focusing and augmenting the magnetic field on one side, while cancelling it out on the other
- Non-trivial → needs investigations





Pre-R&D Activities – Planned Future Activities – Hall C

- Looking into alternative to NPS magnet → permanent magnet array
- Magnetic rigidity should be $B \cdot dl = 0.58\,T \cdot m$ as for NPS magnet
- Halbach Array
  - Magnetic array producing a high magnetic field utilizing permanent magnets
  - Magnets arranged with spatially rotating magnetic field vector → focusing and augmenting the magnetic field on one side, while cancelling it out on the other
- Non-trivial → needs investigations



Pre-R&D Activities – Planned Future Activities – Hall C

- Looking into alternative to NPS magnet → permanent magnet array
- Magnetic rigidity should be $B \cdot dl = 0.58\, T \cdot m$ as for NPS magnet
- Halbach Array
  - Magnetic array producing a high magnetic field utilizing permanent magnets
  - Magnets arranged with spatially rotating magnetic field vector → focusing and augmenting the magnetic field on one side, while cancelling it out on the other
- Non-trivial → needs investigations

APS/123-QED

arXiv:2502.18262v2 [cond-mat.mtrl-sci] 30 May 2025

Analytic approach to creating homogeneous fields with finite-size magnets

Ingo Rehberg*
Institute of Physics, University of Bayreuth, 95440 Bayreuth, Germany

Peter Blümler†
Institute of Physics, University of Mainz, 55128 Mainz, Germany

(Dated: June 12, 2025)

Homogeneous magnetic fields can be generated through the strategic arrangement of permanent magnets. The Halbach array serves as a prominent example of an effective design following this principle. However, it is a two-dimensional approach because it is optimal when placing infinitely long magnets – line dipoles– on a circle. If shorter, more realistic magnets are to be used, the optimal arrangement of magnetic moments diverges from the classical Halbach geometry. This paper presents optimal solutions for three-dimensional arrangements calculated for point dipoles, including optimized orientations for single rings and stacks of two rings. They are superior to the original Halbach arrangement and a modification described in the literature, both in terms of the strength and the homogeneity of the magnetic field. Analytic formulae are provided for both cases and tested by experimental realizations.

I. INTRODUCTION

The generation of homogeneous magnetic fields by permanent magnets is of interest for both laboratory measurements and various technical applications [1–7]. Applying the concept of one-sided fluxes [8], Klaus Halbach [9] has presented a perfect solution to this challenge which is illustrated in Fig. 1.

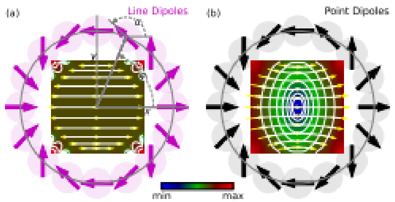


FIG. 1. Comparison of line and point dipoles. (a) Halbach arrangement of line dipoles (pink circles) with the direction of magnetization m' (magenta arrows) given by $\alpha_i = 2\varphi_i$. The central square shows B_x (color bar). It is very homogeneous with all field vectors (yellow lines and arrows) pointing in the x-direction. (b) The same orientation of point dipoles (gray circles with black arrows) leads to an inhomogeneous field with a local minimum B_c in the center. The white contour lines indicate 2^i%, i= 0...6, deviation from B_c.

Halbach considered two-dimensional magnets, aka line dipoles (see Appendix A), which can be approximately realized by very long circular rods magnetized perpendicular to their axis [1, 3]. The Halbach ring is formed by placing the cylinders in a circle with radius R, their cross section is shown in light magenta in Fig. 1(a). Setting the orientation angle α of the magnetic moments indicated by the arrows to twice the location angle φ, a very homogeneous field ensues [10], as shown in the inset of Fig. 1(a).

Using the same arrangement with finite-size magnets introduces a problem. To illustrate this, we consider the field of homogeneously magnetized spheres, which can be perfectly modeled as point dipoles [11]. The result is illustrated in Fig. 1(b), where the circles indicate the cross section of the spheres. The field now has a local minimum in the center, and the lines of equal field strength are roughly ellipsoidal, with the long axis of the ellipse oriented perpendicular to the magnetic field direction.

Tewari et al. [12] successfully addressed this issue. They numerically optimized the orientation angles α of the point dipoles to achieve the best homogeneity within a finite region of interest. That region was chosen as the area inside a circle of half the diameter of the dipole ring.

Here we present an analytical calculation for the orientation with the primary goal of maximizing the field strength in the center of the ring. The resulting configuration is shown to lead to a stronger field compared to both the circular Halbach [9] and the homogeneity optimized arrangement [12]. Moreover, it is also the most homogeneous one of these three arrangements, where homogeneity is quantified by the curvature of the magnetic field strength at the center of the arrangement.

This analytical approach is further refined by introducing an additional degree of freedom – allowing the magnets to twist along the third dimension. This shifts the maximum of the homogeneous field out of the magnet plane and facilitates the construction of stacked ring assemblies (limited here to two) with improved field strength and homogeneity. Moreover, rotating the rings within such a stack further enhances the uniformity of the magnetic field (magnitude) within the magnet plane.

* Ingo.Rehberg@uni-bayreuth.de
† bluemler@uni-mainz.de

Pre-R&D Activities – Planned Future Activities – Hall C

Table 6: Reference cube magnet used in all stacking calculations.

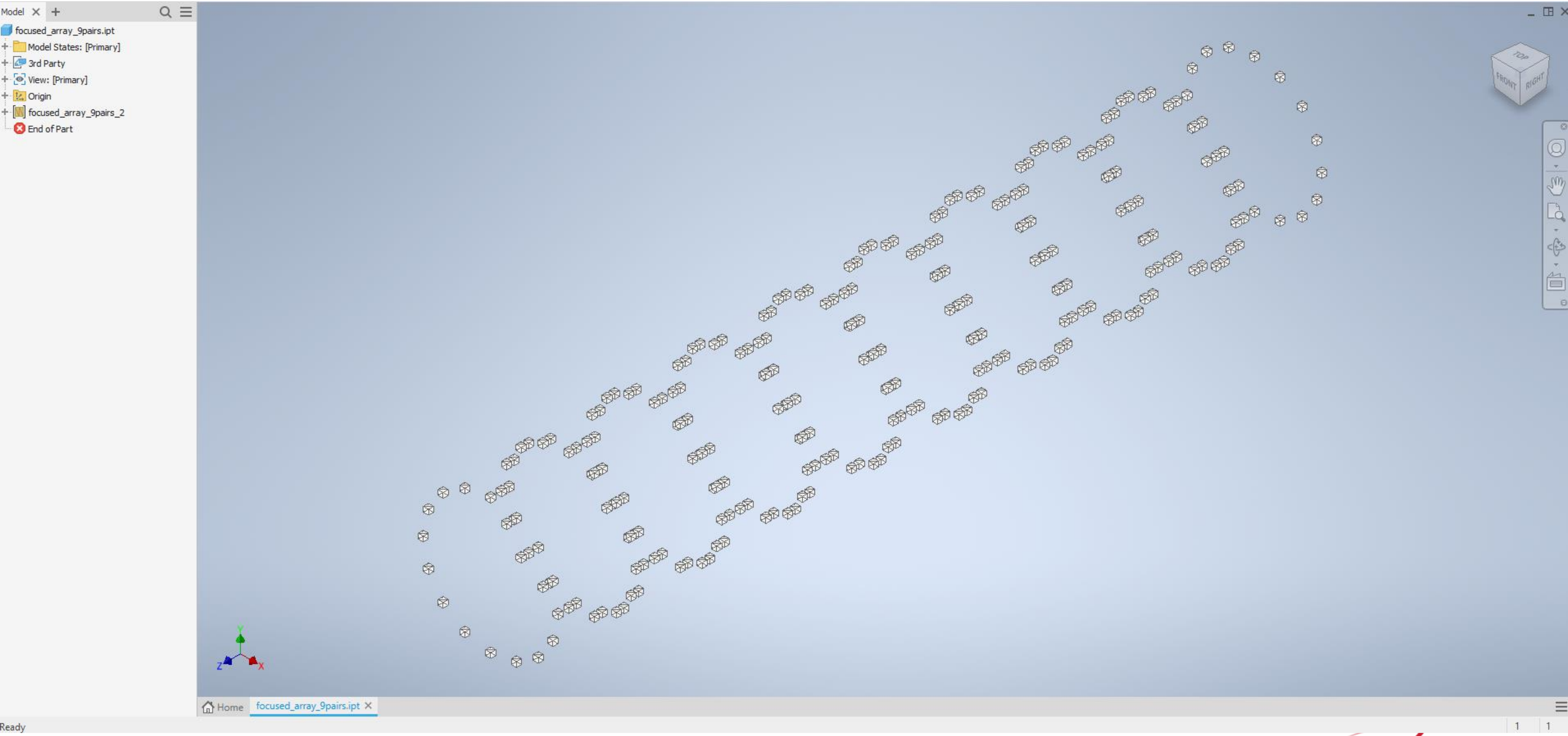
Parameter	**Value**	**Note**
Geometry	20 mm × 20 mm × 20 mm cube	Edges parallel/perpendicular to the ring plane
Material grade	NdFeB **N52**	Nominal remanence $B_r \approx 1.45\,\mathrm{T}$ at 20°C
Magnetic moment (magnitude)	$m \approx 5.2\,\mathrm{A\,m^2}$	Chosen so that one ring of radius $R = 0.265\,\mathrm{m}$ produces $B_c \simeq 0.095\,\mathrm{T}$ at the center[1]
Magnets per ring	$N = 16$	Placed at azimuths $\phi_k = 2\pi k/N,\ k = 0,\ldots,N-1$

Unit magnet assumed throughout The revised magnet counts (288–320 cubes for 9–10 focused pairs) therefore use the *same* 20 mm N52 cubes as the earlier 480-cube "roomy-margin" example; only the number of stacked rings has been reduced.

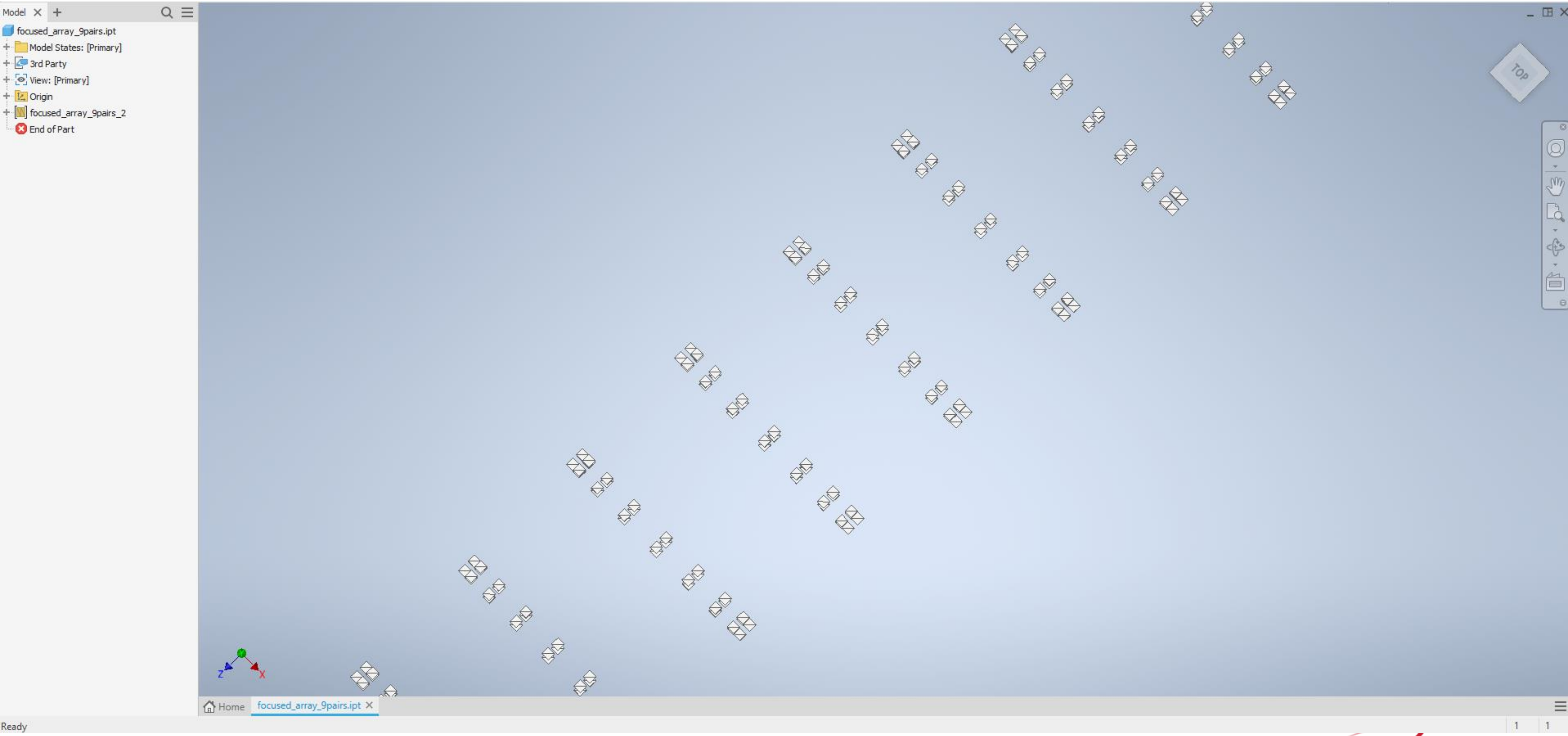
Table 7: U.S. sources for grade N52 cube magnets suitable for the focused-ring array (prices as of June 30 2025).

#	Vendor (HQ)	Example catalog item	Typical price[2]	Notes
1	Applied Magnets / Magnet4Less (TX)	1 in × 1 in × 1 in "N52 Rare-Earth Cube Magnet" [1]	\$14–16 each (1–9 pcs)	Ni–Cu–Ni coat; ∼ 148 lb pull; Houston fulfillment.
2	K&J Magnetics (PA)	BX0X0X0-N52 cube, 1 in³ [2]	\$41.71 each; \$37 ea. 10+	Same-day shipping (Mon–Fri); detailed data sheets.
3	totalElement (CO)	1 in Heavy-Duty Cube Magnet N52 [3]	\$29.79 each; \$23.83 ea. 10	Free U.S. shipping ≤\$10; 94.6 lb pull force.
4	Supreme Magnets (OH)	20 mm × 20 mm × 20 mm cube N52 [4]	≈ \$6.60 ea. (pack of 10)	True metric cube; 55 lb pull; triple-nickel plated.
5	CMS Magnetics (TX/MI)	Custom 20 mm cube N52 (in stock) [5]	RFQ (≈\$5–7 ea. small lot)	Two U.S. warehouses; RoHS/REACH certs available.

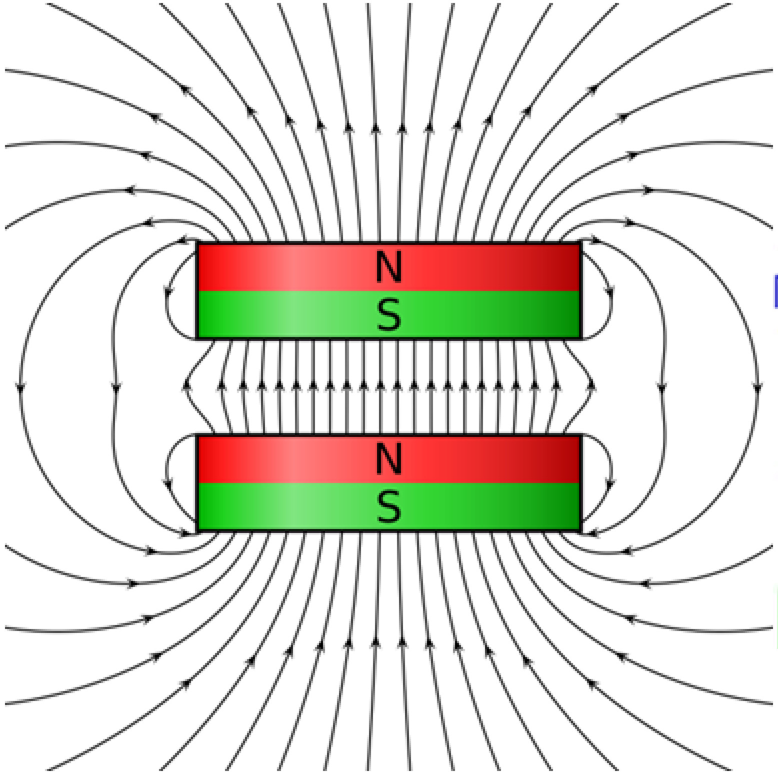
Pre-R&D Activities – Planned Future Activities – Hall C



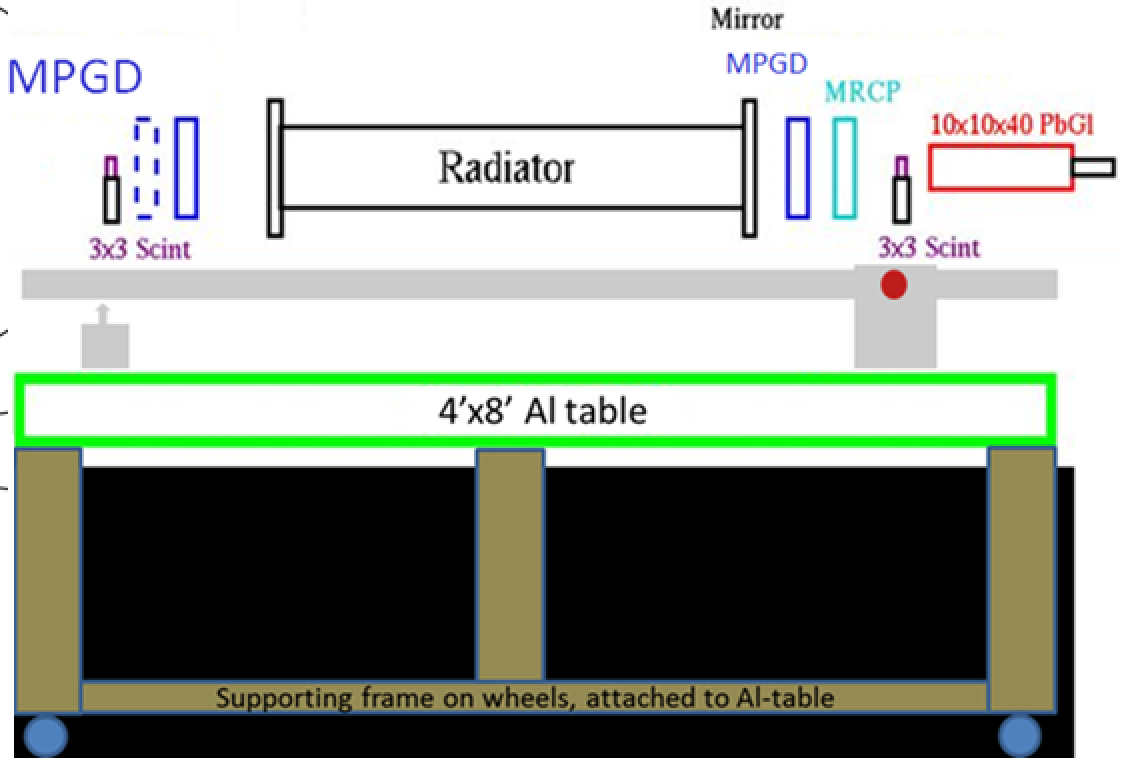
Pre-R&D Activities – Planned Future Activities – Hall C



Pre-R&D Activities And Test Beam Plans – Hall C

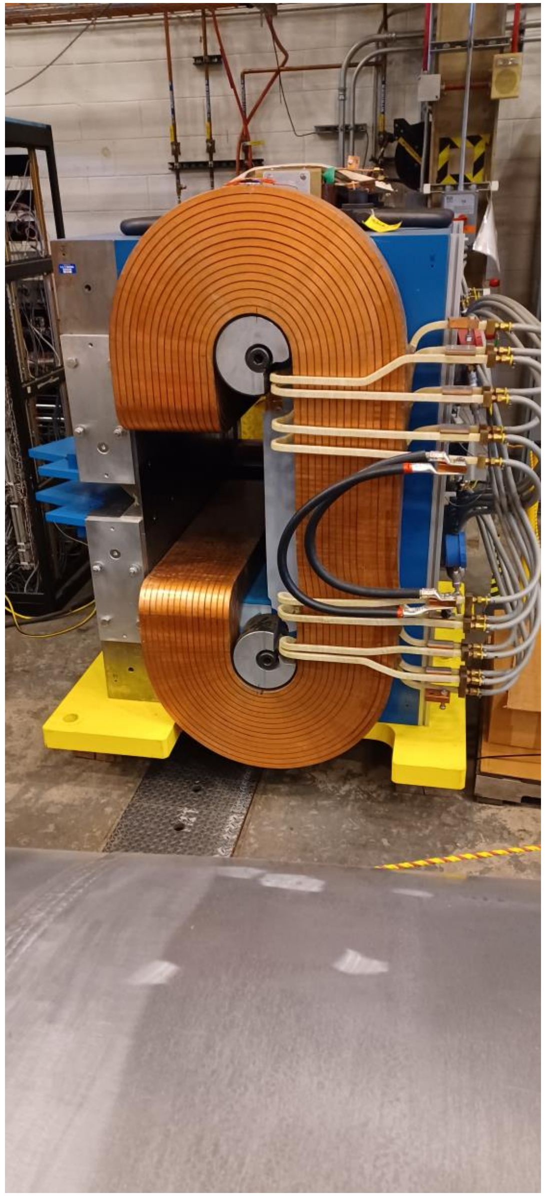


- NPS magnet or Halbach Array
  - Detailed information available
  - Need to investigate configuration

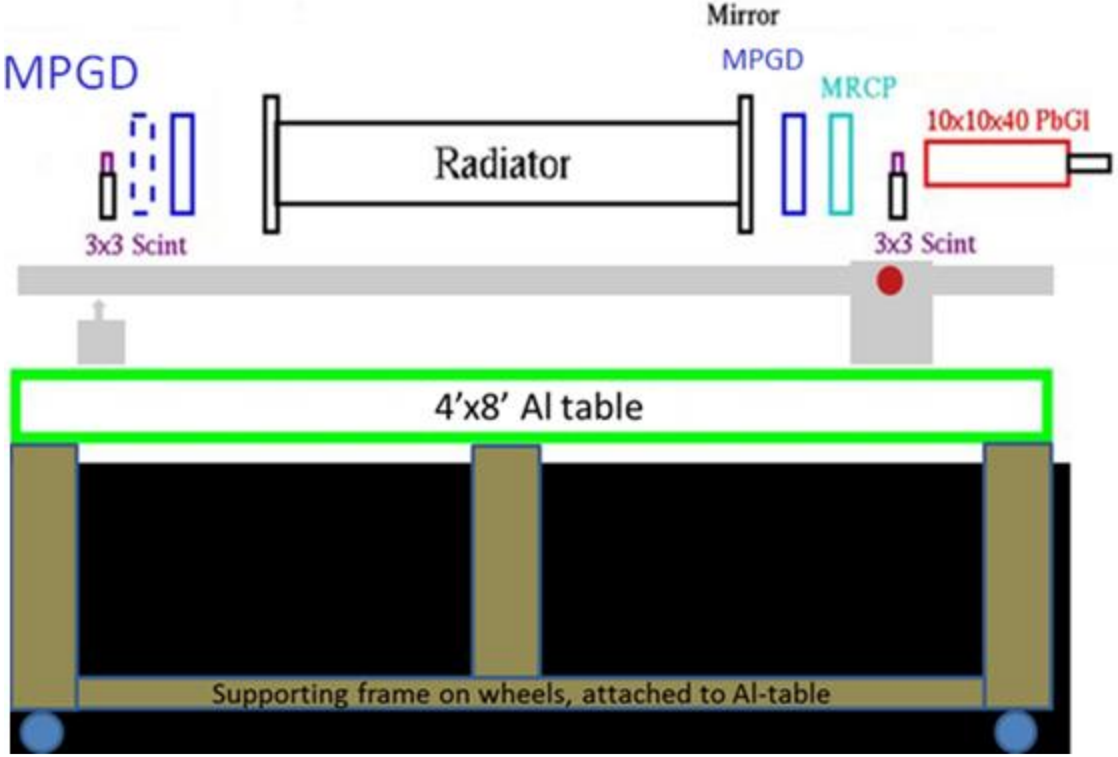


Jefferson Lab

Pre-R&D Activities And Test Beam Plans – Hall C

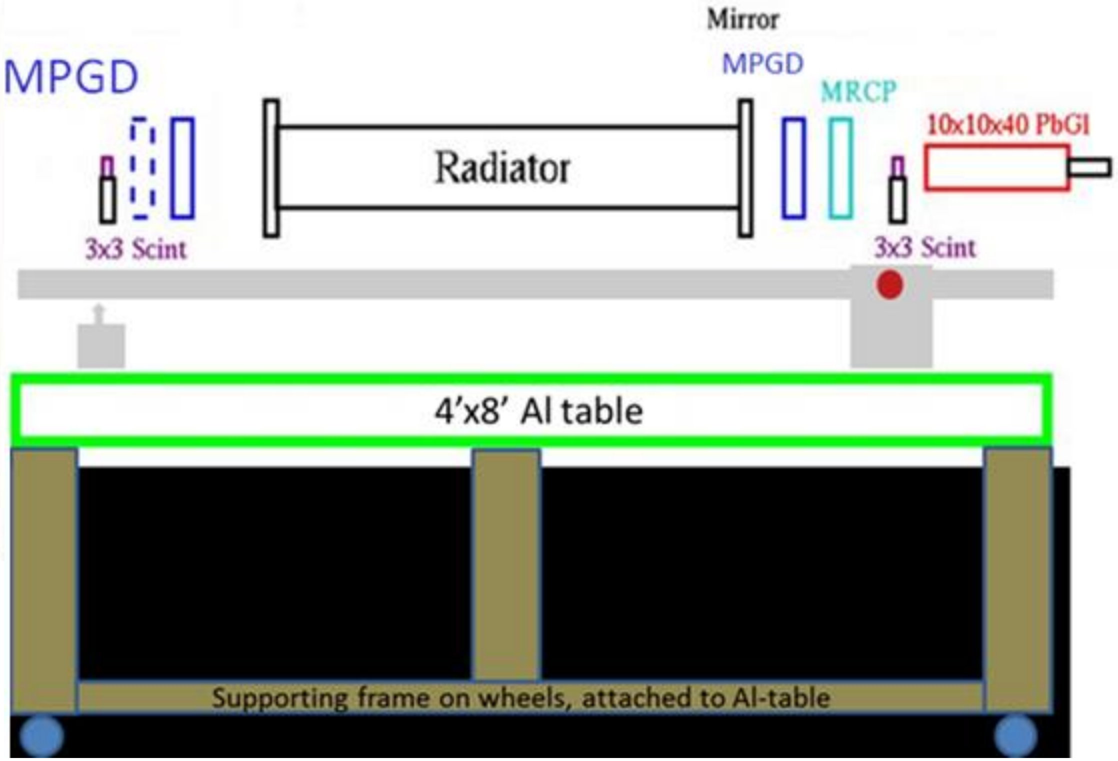


- NPS magnet or Halbach Array
  - Detailed information available
  - Need to investigate configuration



Pre-R&D Activities And Test Beam Plans – Hall C

- NPS magnet or Halbach Array
  - Detailed information available
  - Need to investigate configuration



Jefferson Lab

Pre-R&D Activities And Test Beam Plans – Hall C

#	Experiment	Topic	Start	End	Pass Change/Rescaling	Run Time/Days
1.	E12-22-001	Transverse structure of the hadrons (N to Delta)	1/28/2026	2/20/2026		24
2.	PR12-23-001	Transverse structure of the hadrons (Polarizability)	2/21/2026	3/22/2026	03/05 PC	28
3.	E12-06-107	Color Transparency	3/28/2026	5/03/2026	03/23 – 03/27 (5 days)	37
4.	E12-24-001 E12-06-104	Nuclear Dependence σ_L/σ_T in SIDIS	5/4/2026	6/21/2026	5/20 PC; 6/04 PC	45

Prospective

- Configurations for Hall C experiments to be specified for parasitic beam tests
  - Exact details will be worked out ~ August
- No funding from NP in FY’25 → what funding is available in FY’26
- What can we start with in FY’26?
- What is already now/then (Fall/Winter 2025) available?

Topic	Lead Group
New tracking	JLab, SBU, UVA-Liyanage
MAPMT and MCP-PMT	ANL, UVA-Zheng
MRPC	JLab, Tsinghua University


BACK UP

HMS/SHMS Configuration – PR12-22-001 (# 1.) – N to Delta

Setting	SHMS θ (deg)	SHMS P (MeV/c)	HMS θ (deg)	HMS P (MeV/c)
1a	7.29	952.26	18.77	532.53
2a			25.17	527.72
3a			33.70	506.61
4a			42.15	469.66
5a			50.44	418.56
6a			54.47	388.38
7a			12.37	527.72

Setting	SHMS θ (deg)	SHMS P (MeV/c)	HMS θ (deg)	HMS P (MeV/c)
1c	10.37	941.61	24.40	562.00
2c			30.47	556.95
3c			38.52	534.79
4c			46.47	496.06
5c			54.17	442.64
6c			57.85	411.16
7c			12.69	543.24

Setting	SHMS θ (deg)	SHMS P (MeV/c)	HMS θ (deg)	HMS P (MeV/c)
1b	8.95	946.93	22.01	547.54
2b			28.24	542.61
3b			36.52	520.95
4b			44.64	483.08
5b			52.68	430.78
6b			56.53	399.92
7b			12.46	535.98

Setting	SHMS θ (deg)	SHMS P (MeV/c)	HMS θ (deg)	HMS P (MeV/c)
1d	11.63	936.28	26.24	575.96
2d			32.16	570.80
3d			40.01	548.17
4d			47.73	508.64
5d			55.18	454.17
6d			58.71	422.13
7d			12.47	548.17

Run group a: 6 μA beam current
Run group b-d: 15 μA beam current

N. Sparveris

HMS/SHMS Configuration – PR12-23-001 (# 2.) – Polarizability

75 μA beam current
on 10 cm LH2

$$\mathcal{L} \approx 2.0 \times 10^{38}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$$

Kinematic Group	Spectrometer	Particle detected	Angles (°)	Momentum range (MeV/c)
General Runs	HMS	Protons	11.3° – 56.5°	494 – 993
	SHMS	Electrons	11.2° – 20.5°	736.3 – 1783
Elastic ep Calibration Runs	HMS	Protons	50° – 63°	495 – 994
	SHMS	Electrons	19° – 33°	924 – 1797

N. Sparveris

HMS/SHMS Configuration – PR12-06-107 (# 3.) – Color Transparency

D. Dutta

80 μA beam current

Target	Thickness (cm or %X_0)	Luminosity $\mathcal{L}$ [$cm^{-2}s^{-1}$]
Liquid Hydrogen	15 cm (2% X_0)	3.18×10^{38}
Liquid Deuterium	15 cm (2% X_0)	3.79×10^{38}
Carbon (solid)	6% X_0	6.40×10^{37}
Copper (solid)	6% X_0	3.66×10^{36}

Q^2 [$(GeV/c)^2$]	HMS Angle (electron)	SHMS Angle (hadron)
8.0	25.90°	22.73°
10.0	33.30°	17.86°
12.0	44.30°	13.32°
14.0	35.00°	14.00°
16.4	48.05°	10.00°

HMS/SHMS Configuration – PR12-14-002 (# 4.) – R-dependence

D. Gaskell

80 μA beam current

Target	Luminosity $\mathcal{L}$ [$cm^{-2}s^{-1}$]
Liquid Hydrogen (4 cm)	2.3×10^{38}
Liquid Deuterium (4 cm)	3.2×10^{38}
Carbon (2% X_0)	2.1×10^{37}
Copper (2% X_0)	1.2×10^{36}
Gold (2% X_0)	2.0×10^{35}

Spectrometer	Role	Angular Range (degrees)	Momentum Range (GeV/c)
HMS	Electron arm	50° – 63°	0.495 – 0.994
SHMS	Hadron arm	19° – 33°	0.924 – 1.797