A Very Radiation Hard Upgrade to the ATLAS and CMS Zero Degree Calorimeters

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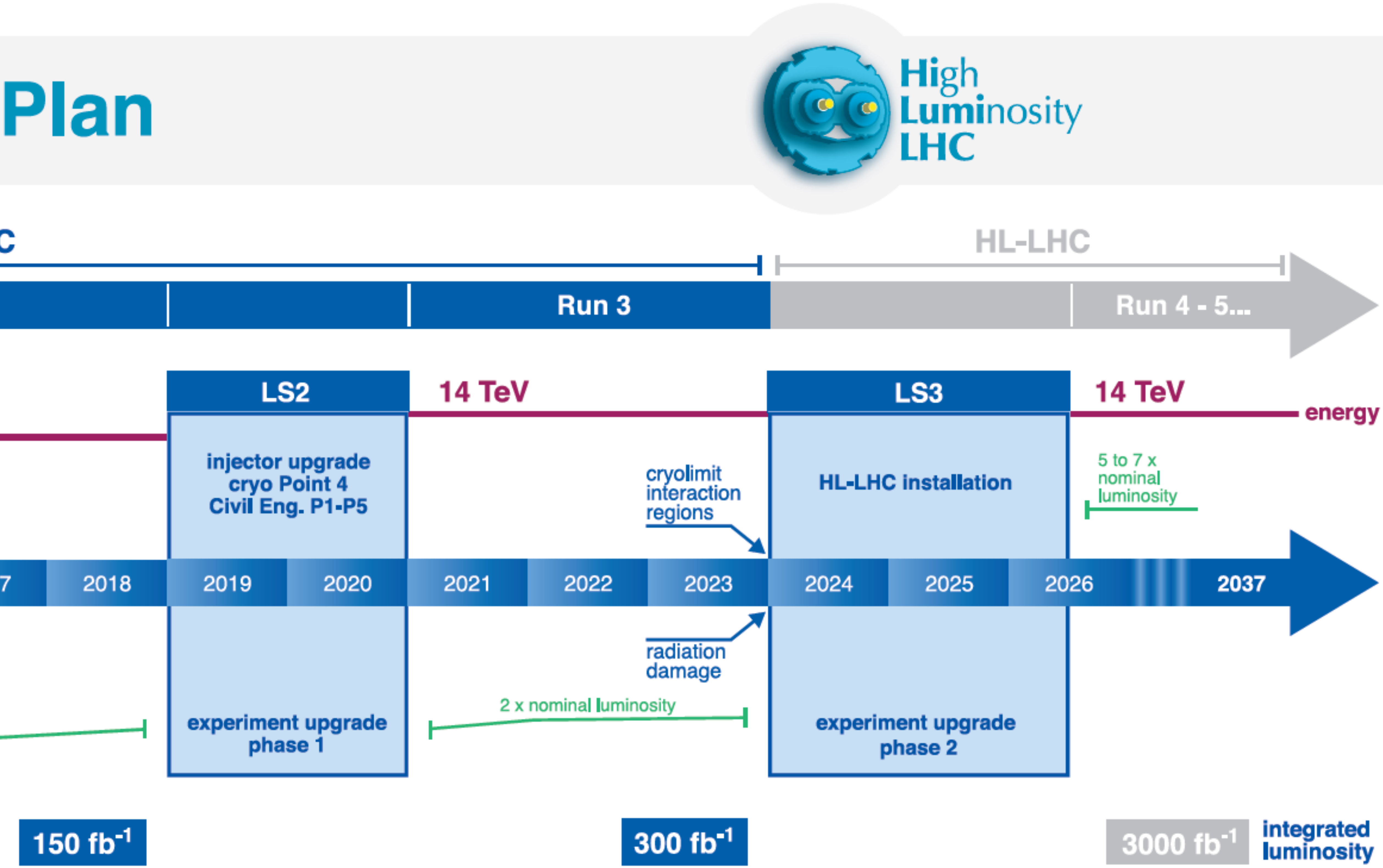
Goal: produce a radiation hard ZDC that will fit in the new TAN for both CMS and ATLAS and have the capability to measure the forward EM/HAD production for BOTH pp and HI collisions to address the interesting Physics just presented by Peter

LHC Plan


Plan
High Luminosity LHC
C
HL-LHC
Run 3
Run 4 - 5...
LS2
14 TeV
LS3
14 TeV
energy
injector upgrade
cryo Point 4
Civil Eng. P1-P5
cryolimit interaction regions
HL-LHC installation
5 to 7 x nominal luminosity
7
2018
2019
2020
2021
2022
2023
2024
2025
2026
2037
radiation damage
2 x nominal luminosity
experiment upgrade phase 1
experiment upgrade phase 2
150 fb-1
300 fb-1
3000 fb-1
integrated luminosity

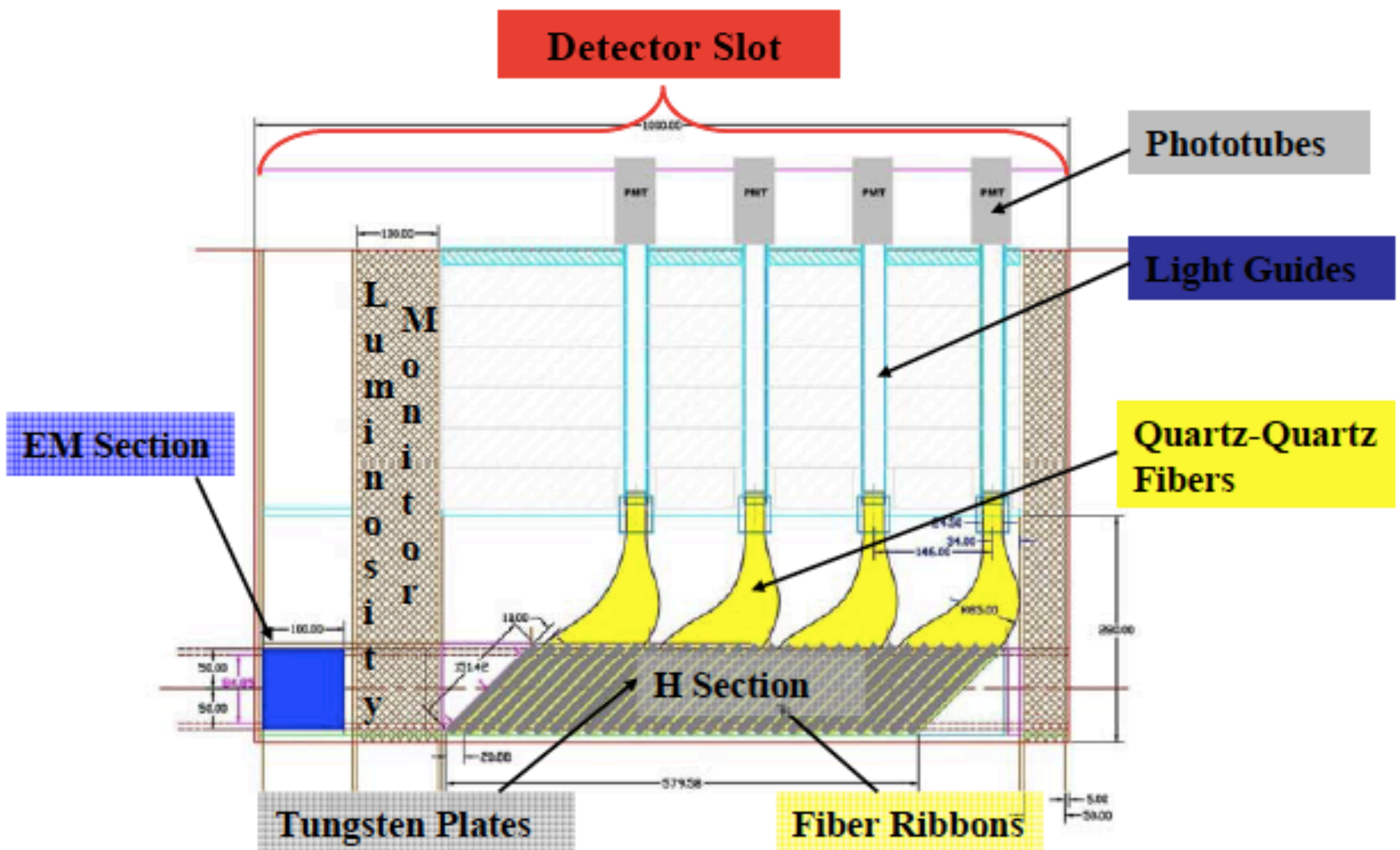
New Parameters

- *pp* luminosity (10^{34} cm^{-2} s^{-1})
  - Run 3: Increases by 2 x
  - Run 4: Increases by 5-7 x
- Heavy ion luminosity increases similarly:pp luminosity (10^{34} cm^{-2} s
  - Run 3: Increases by 2 x
  - Run 4: Increases by 5-7 x
- Heavy ion luminosity increases similarly:
  - Nominal *p*+Pb: 10^{31} cm^{-2} s^{-1}
  - Nominal Pb+Pb: 10^{28} cm^{-2} s^{-1}
- Crossing angle change during Run 4 (HL-LHC) causes:
  - ZDC to move closer to the IP (141 m to 126 m)
  - ZDC transverse width to shrink from 100 mm to 60 mm
  - Nominal *p*+Pb: 10^{31} cm^{-2} s^{-1}
  - Nominal Pb+Pb: 10^{28} cm^{-2} s^{-1}

Current CMS ZDC

1 EM section with 5 horizontal divisions:
33 2-mm thick tungsten with 0.7 mm quartz fibers vertical geometry

4 Hadronic sections:
24 15.5-mm thick tungsten plates with 0.7 mm quartz fibers

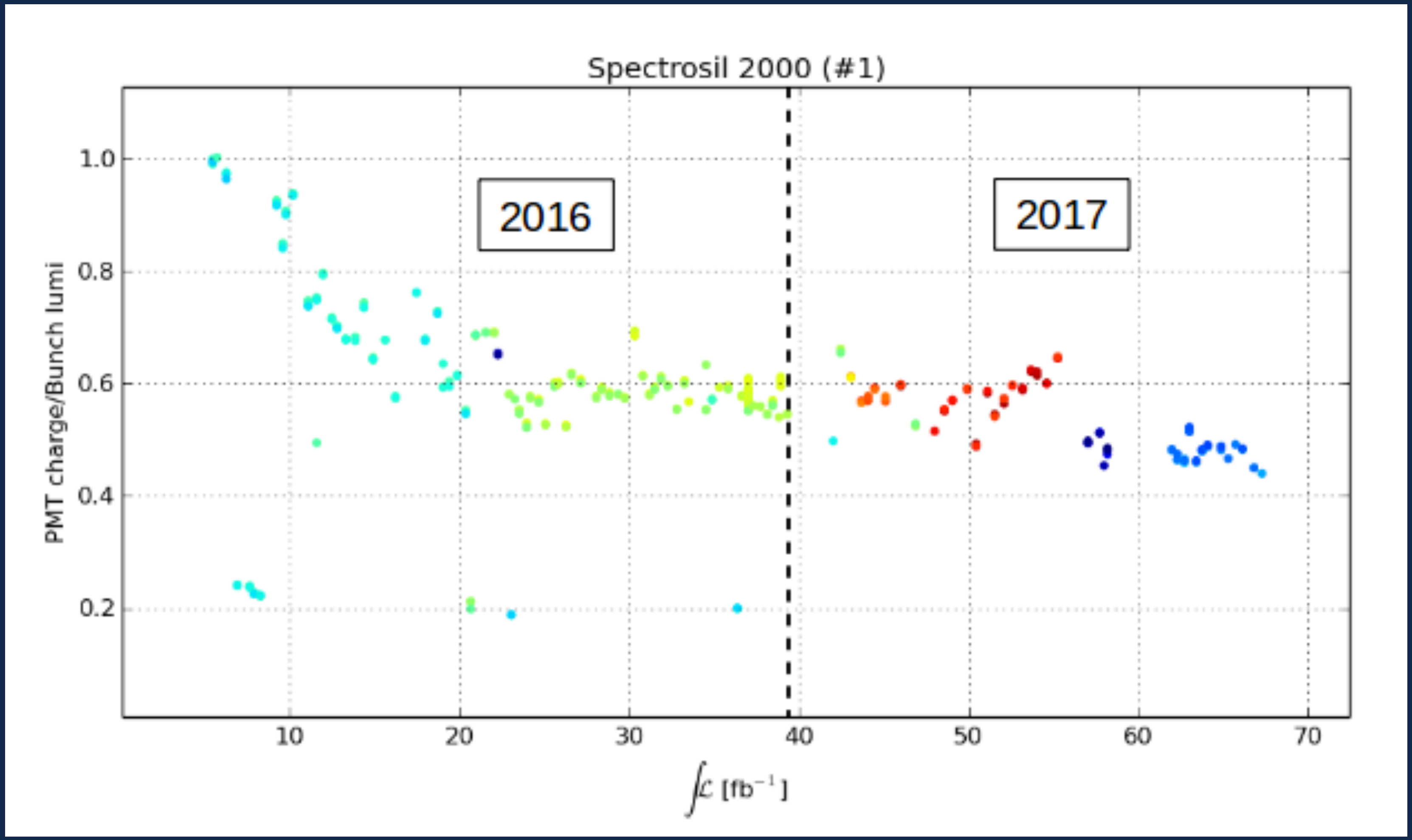


Our Constraints within the Existing ATLAS and CMS ZDC:

- The active area of the current ZDC is ~ 10x10 cm^2
- All signals must travel to the top of the TAN ~ 50 cm from the top of the SRPD - electronics must avoid the EM section PMT's
- Only a 1-cm space available between the EM and BRAN - HAD sections of the ZDC

Reaction Plane Detector Proposed:
Current one is
4x4 array of 2.0-cm square quartz - each 1-cm thick

Heraeus Spectrosil 2000: Initial losses then stable signal amplitude for two years of irradiation in LHC tunnel



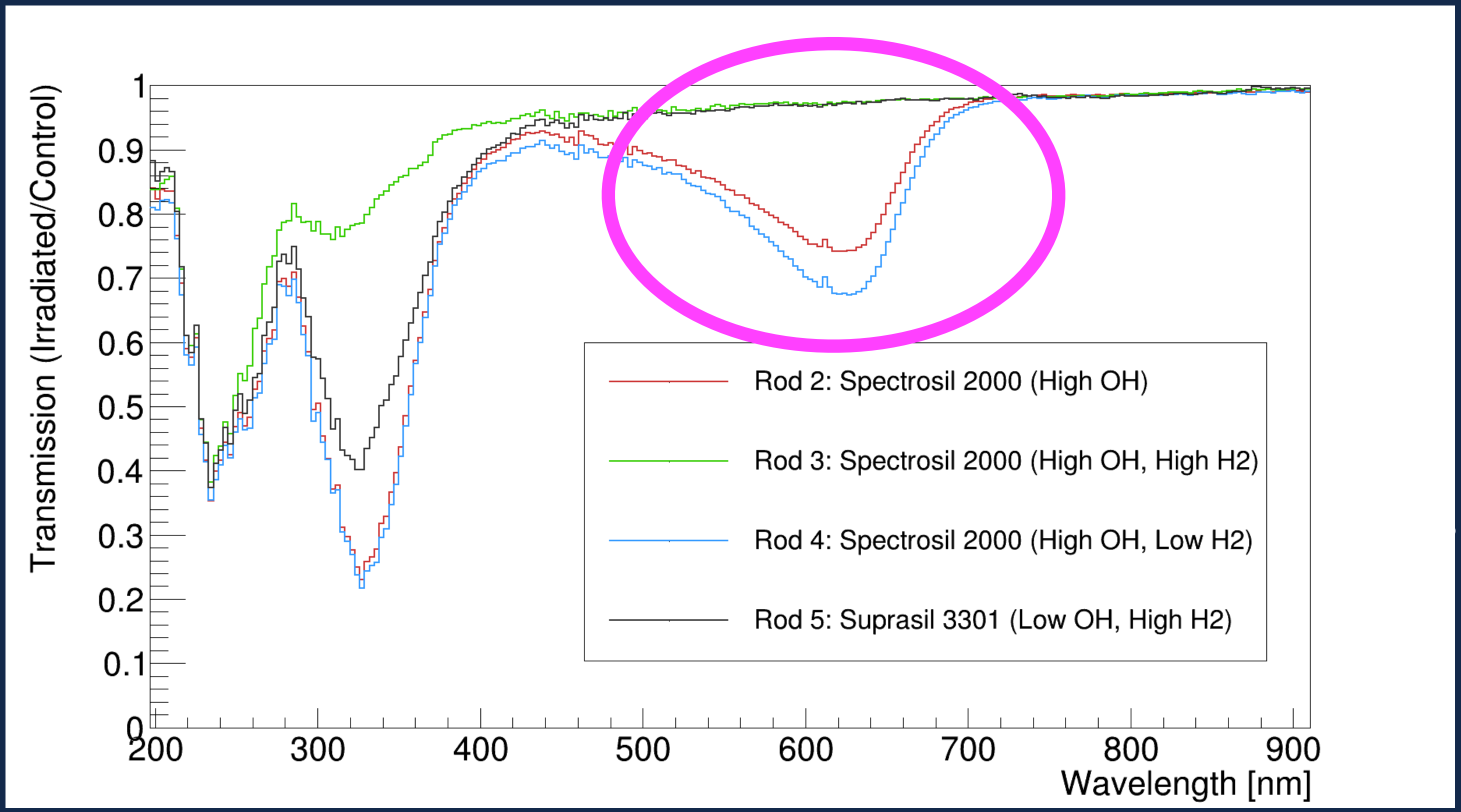
- After initial transmission loss BRAN sees flat signal size over two years of LHC running!
- Transmission loss occurs early in radiation history of fused silica rods
- Rods sent to University of Illinois for spectrometry analysis
- For more details see:

https://indico.cern.ch/event/647714/contributions/2651509/attachments/1557659/2450420/Palm_HL-LHC_2017_BRAN.pdf

Result provided courtesy of Marcus Palm and BRAN Luminosity Monitor

BRAN Luminosity Monitor: Performance of Spectrosil 2000 for 2 years of Irradiation

Radiation Induced Transmission Loss (Irradiated / Control)



1 Year of LHC Running: Rod 3 (2015)
2 Years of LHC Running: Rods 2, 4, and 5 (2015 - 2016)

BRAN Fused Silica Rods: Optical spectrometry results

- 230 nm absorption center:
  - Possibly an E' center
    - ≡Si• (oxygen deficiency)
  - Rods irradiated for 2 years show same los as rod irradiated for 1 year
    - Suggests saturation of the absorption site!?
    - Saturation of transmission loss might explain the observed early light losse followed by stable light yields at ever higher doses.
- 325 nm absorption center:
  - Specific defect unknown
  - Rod 3 appears to have annealed
  - Unclear if saturation occurs
- 629 nm absorption center:
  - Non-bridging oxygen hole center (NBOHC
    - ≡Si-O• (silicon deficiency)
  - Only shows up in OH-rich rods
  - Low OH rods show little visible radiation damage!

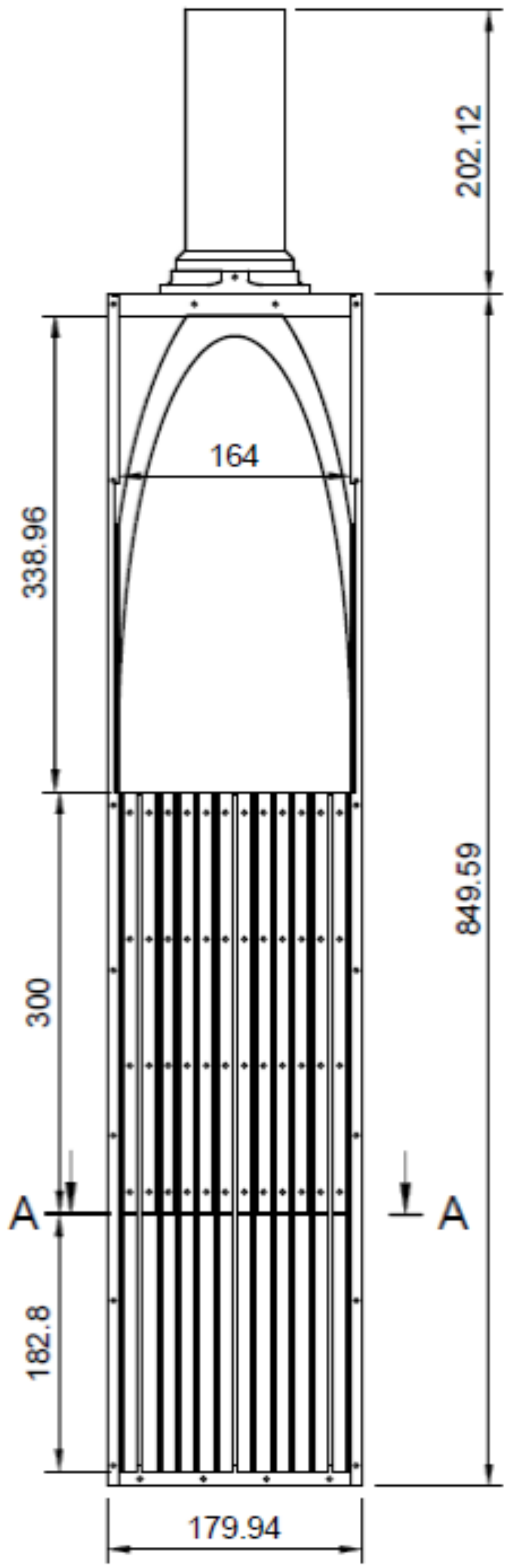
Courtesy of Michael Phipps

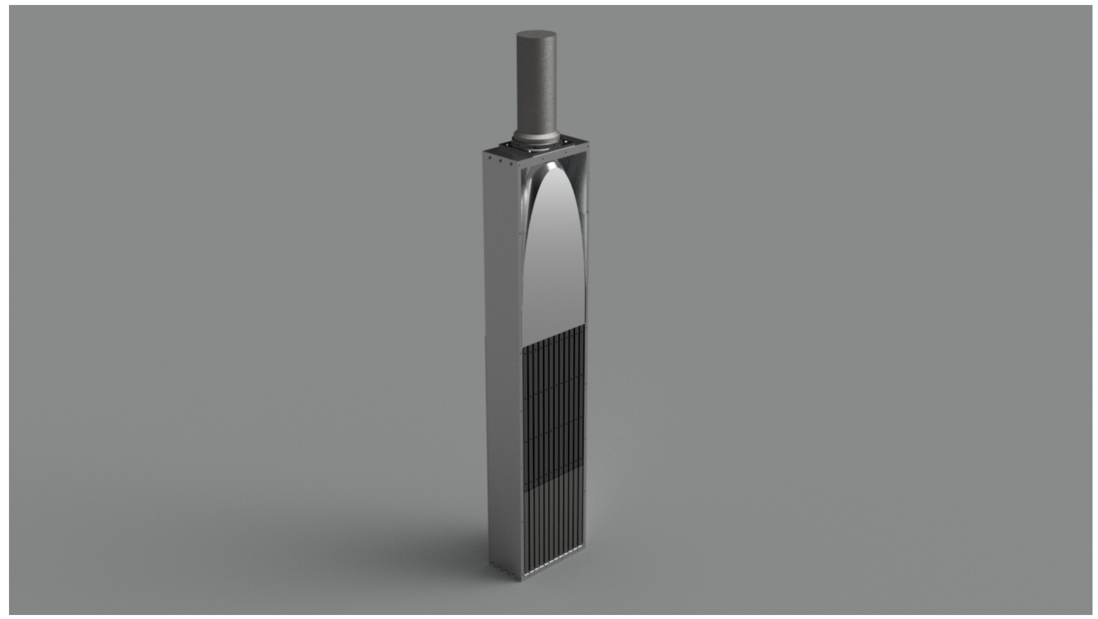
- *Fused quartz* not acceptable in extreme radiation environments
- *Fused silica*
    - After initial transmission loss, PMT signal stable for **2 full years of LHC pp running** in extreme radiation area!
    - Damage occurs early in radiation history
        - Possibly caused by UV absorption site saturation
        - Design possibility: **detector pre-irradiation** before physics running to reach broad-band stable operation
    - Low OH fused silica sees little transmission loss in visible region
        - Design possibility: use **long pass filter, fused silica prisms, etc** to filter UV light completely
- Other applications for radiation hard fused silica:
    - Fused silica tiles
    - Optical fibers (narrow core + doped cladding)
    - PMT windows

Design Conclusions

Courtesy of Michael Phipps, UIUC

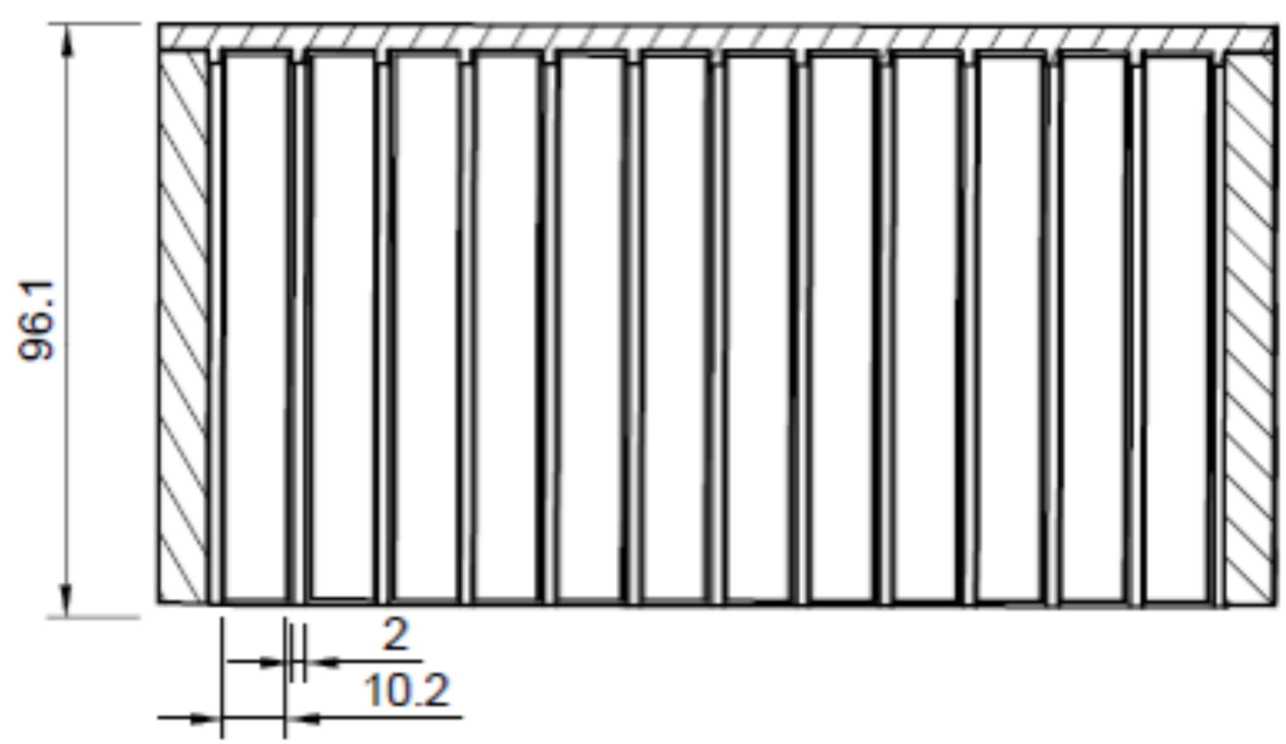
Prototype Design



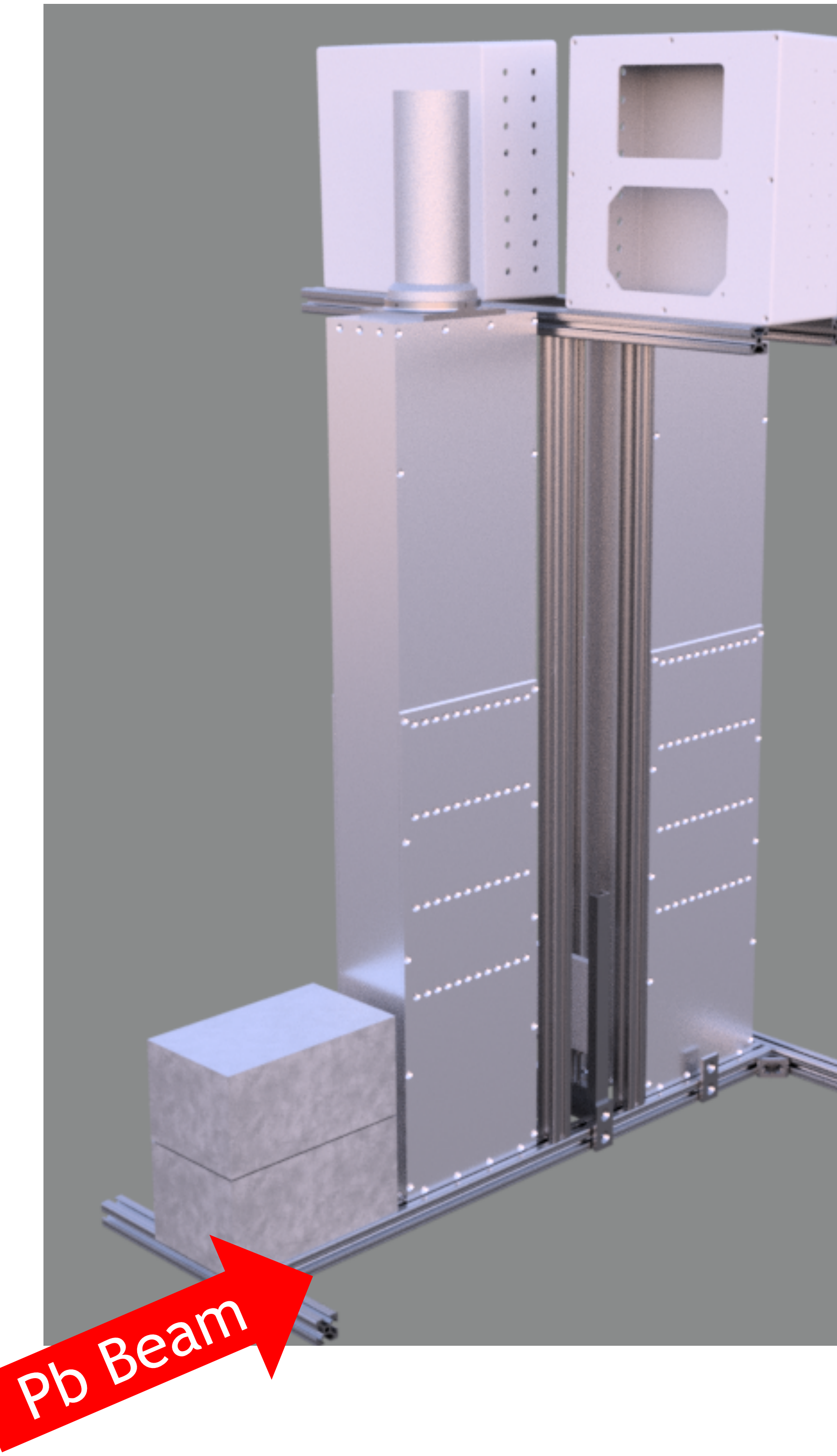


tungsten plate converters

Using the Spectrosil 2000 fused silica for the fibers



bottom view



SPS Test Beam, 11-2018
Pb at 150 GeV

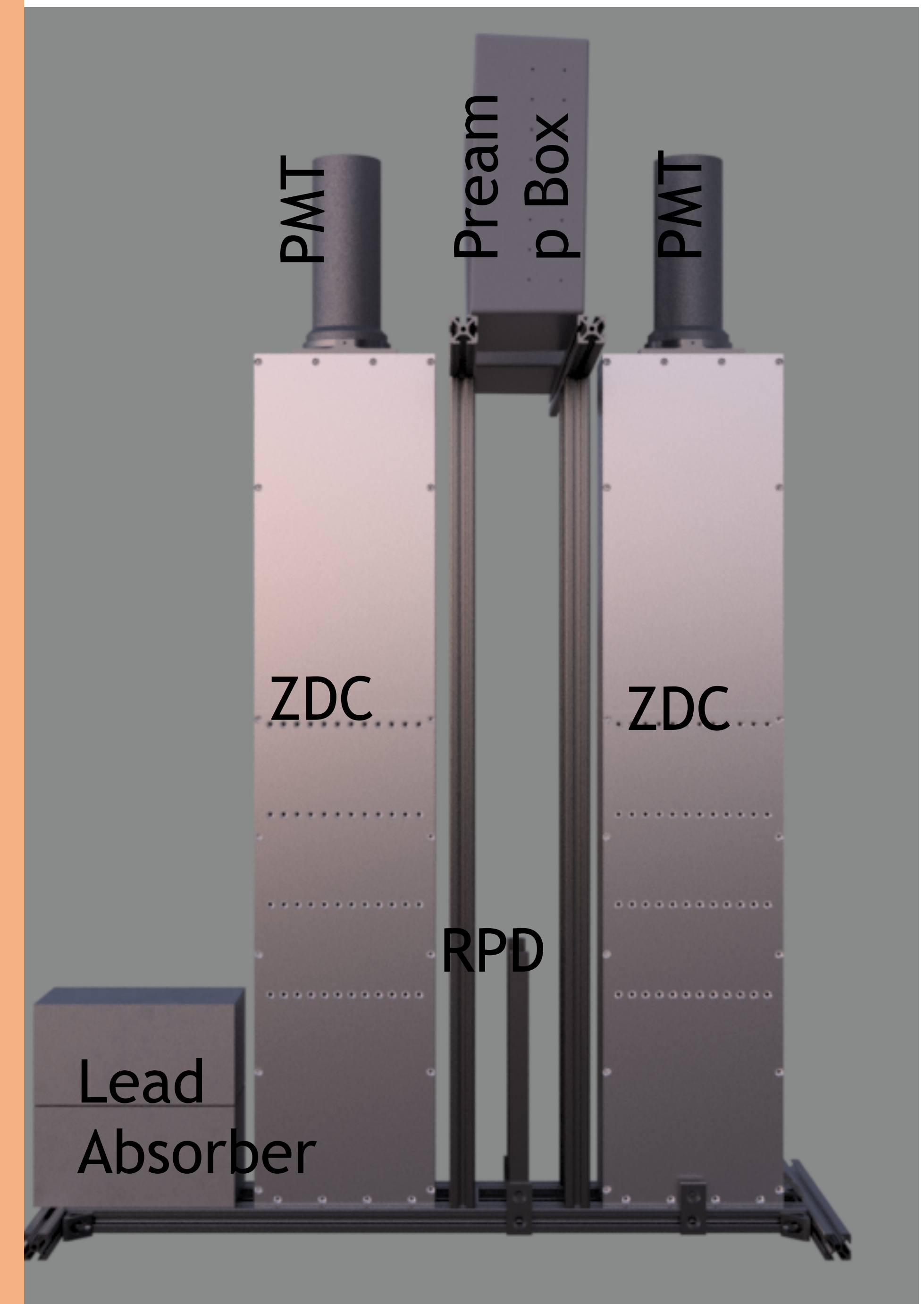
- o ZDC calibration
- o ZDC energy resolution
- o ZDC timing resolution
- o RPD timing resolution
- o Shower shape & containment
  at different longitudinal
  positions using RPD

Irradiation Tests (Maryland & Soreq)

- o RPD response vs dose
- o ZDC response vs dose

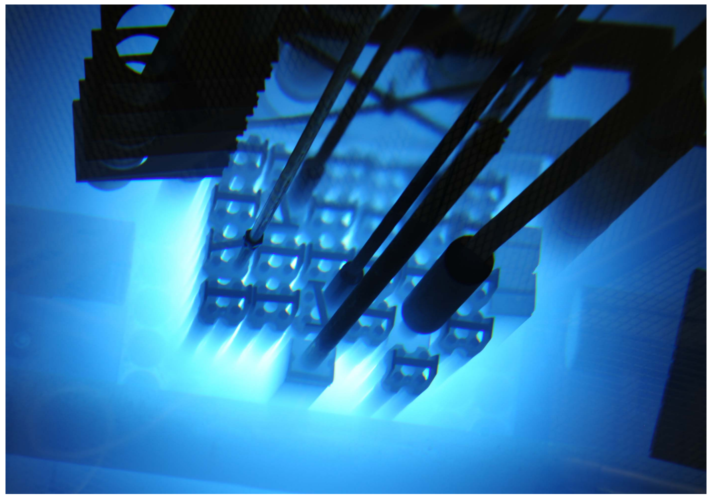
Material Tests (Ben Gurion & UIUC)

- o uniformity of light collection
- o optical properties vs dose
- o characterize color centers



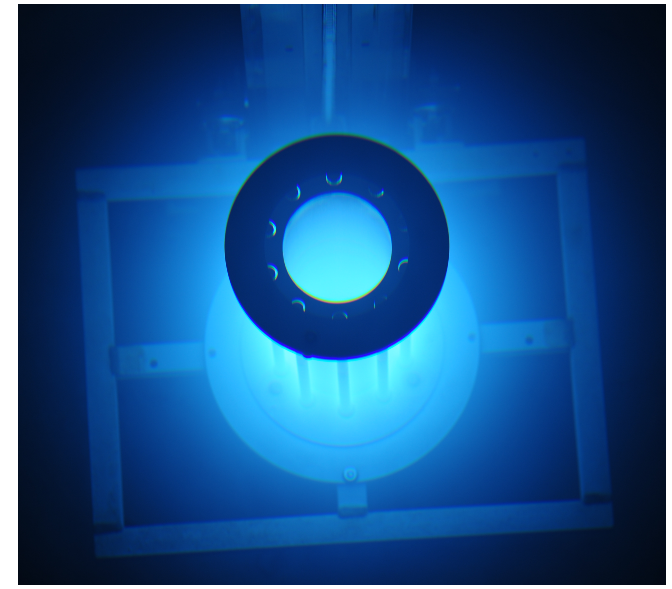
UMD Radiation Facilities

Neutrons: 250 kW TRIGA Reactor



5 experimental ports, most popular:
In-core irradiation "rabbit" : 2.5E10 n/cm^2/s/kW
Thermal column: 1E4 n/cm^2/s @250kW

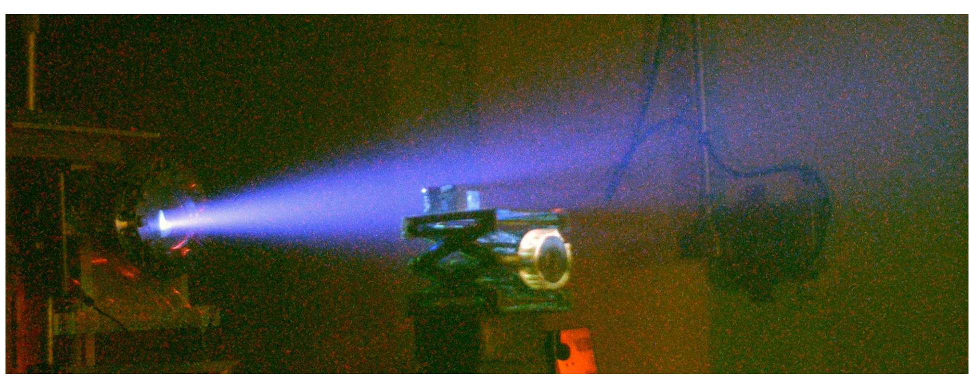
Gamma Rays: ^{60}Co Panoramic Irradiator



Up to 5 Mrad/hr

University of Maryland Radiation Facilities • Reactor • Co-60 • Linac

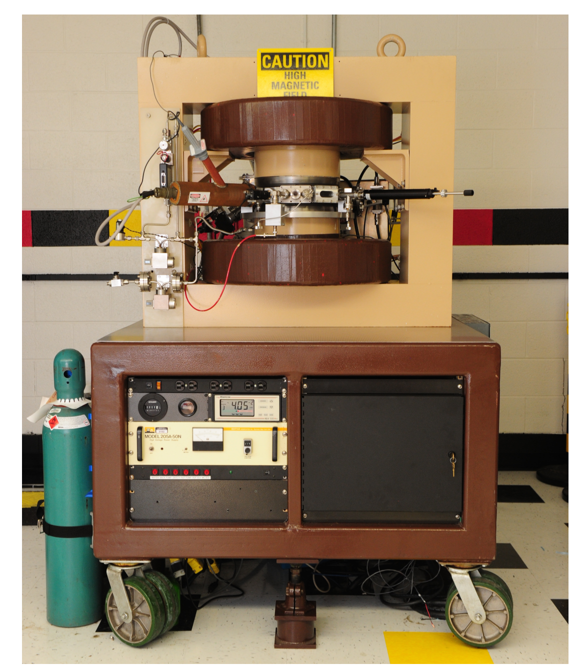
High Energy Electrons



- 2-10 MeV Electrons
- Up to 1 kW beam on target
- In-air or in-vacuum irradiation

Protons / Deuterons / Alphas

Small Research Cyclotron
- 1 MeV Protons
- 500 keV Deuterons
- Pulsed 2.2 MeV Neutron Productions

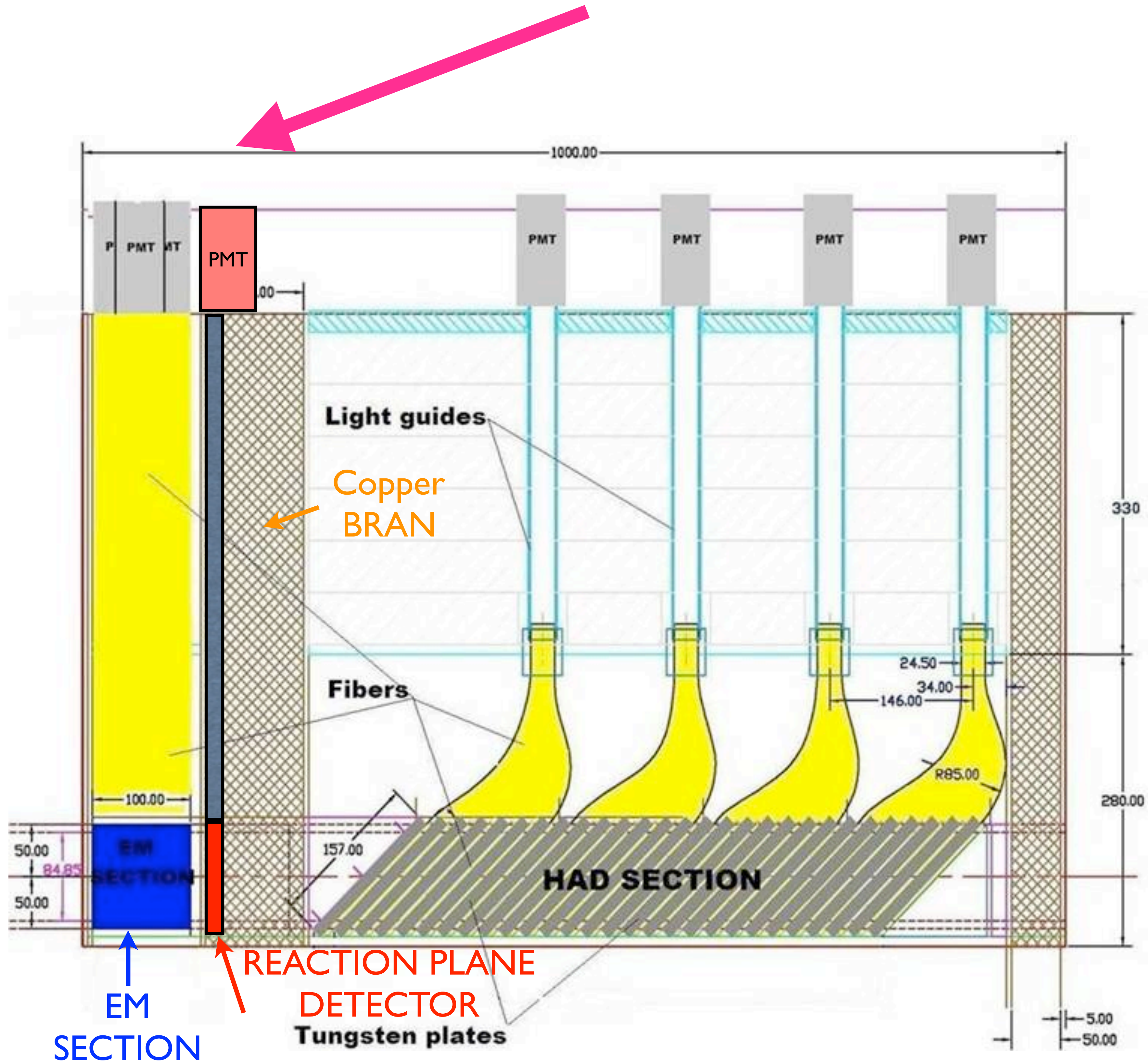


Studies at Soreq and Ben Gurion University - Zvi Citron

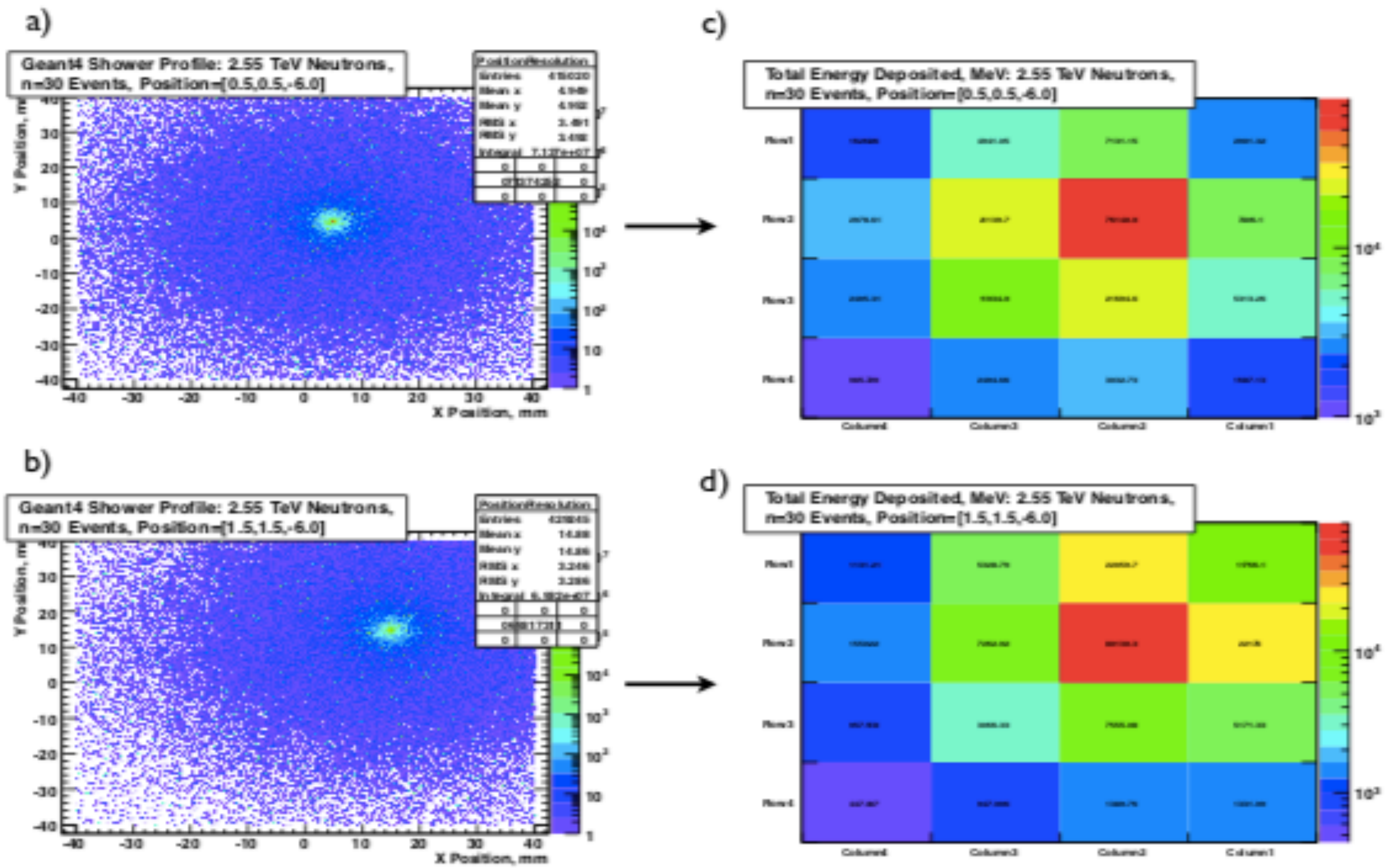
- Main focus has been on improving radiation hardness of detection elements
- Basic workflow is to irradiate samples and return to BGU for testing
- Irradiation at at Soreq Nuclear Research Center:
  - Research reactor operates two ~6 hour shifts a week; high flux of thermal neutrons
  - Saraf (Soreq Applied Research Accelerator Facility) accelerator, high energy somewhat lower flux of neutrons
- Group’s lab focuses on optical probing/bleaching of quartz
- Also utilize BGU Nano-Center resources: Raman spectroscopy, spectrafluoremetry, SEM+EDS, etc.

אוניברסיטת בן-גוריון בנגב
Ben-Gurion University of the Negev

A Reaction Plane Detector for the ZDC



Simulations in GEANT4



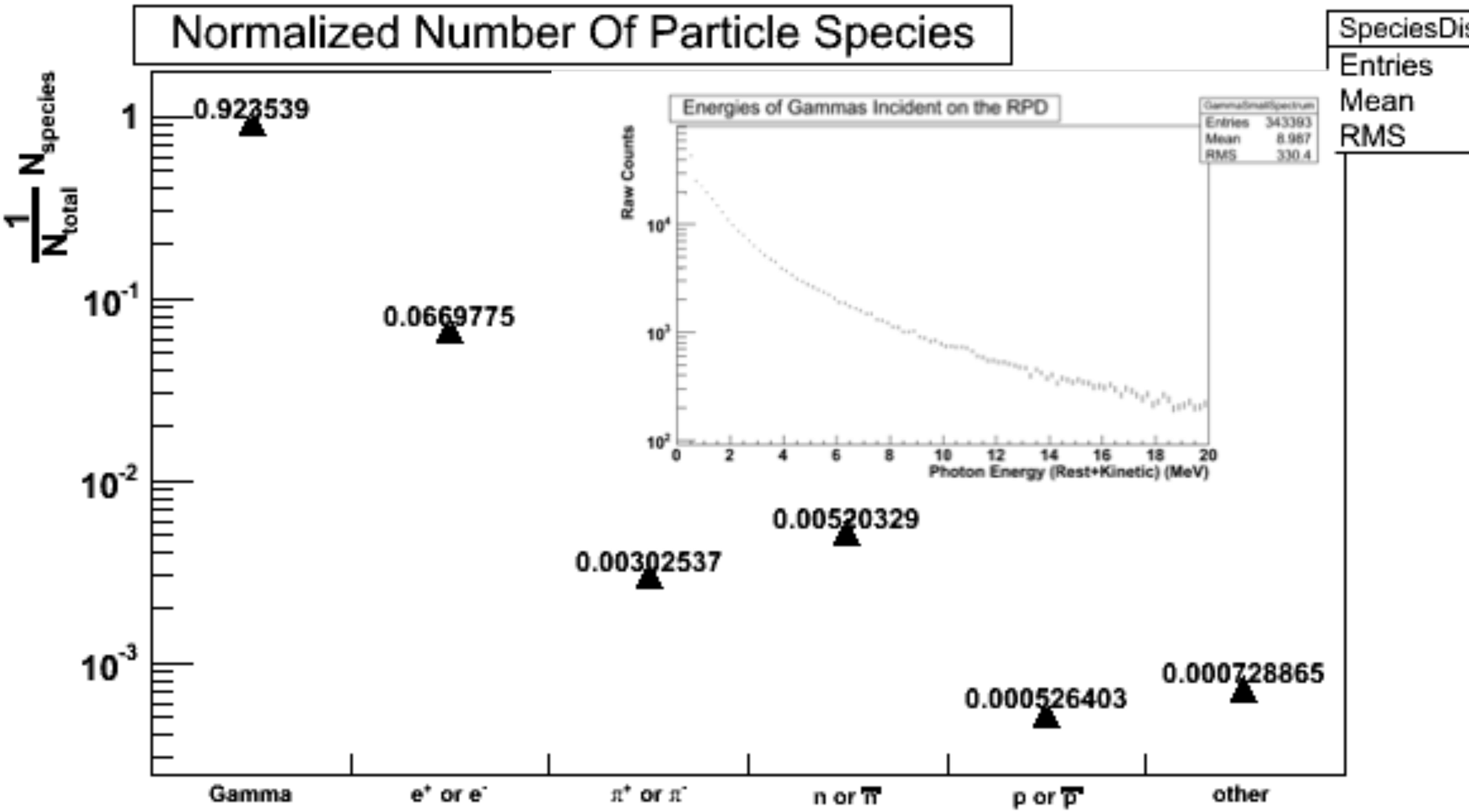
Center at 0.0,0.0

Neutrons at 0.5,0.5

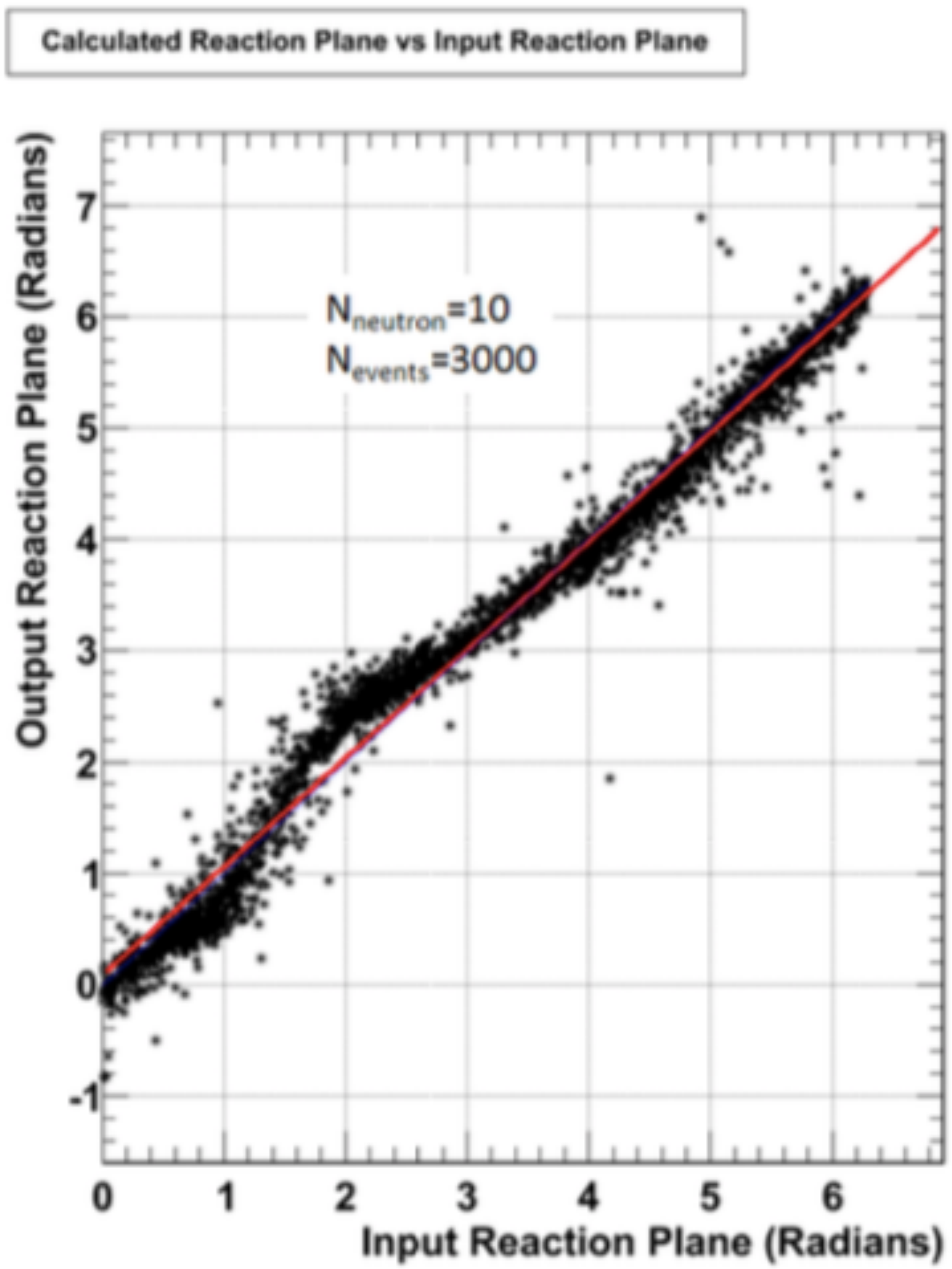
Neutrons at 1.5,1.5

30 neutrons of energy 2.55 TeV incident on the EM section of the ZDC producing showers that cause Cherenkov light in the quartz

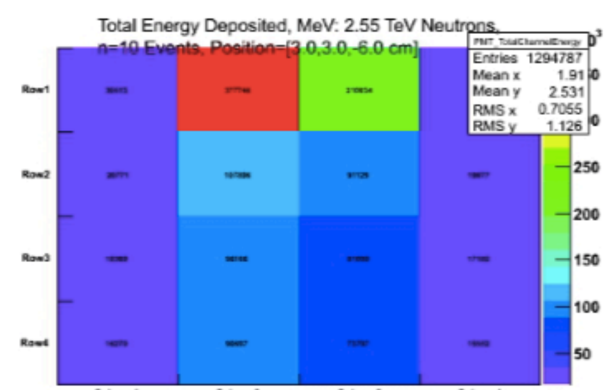
Composition of Shower



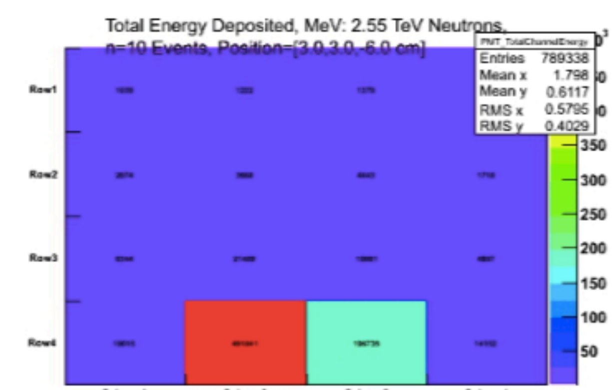
Reconstruction of Reaction Plane from Random Distributions of Neutrons



The "S" curve is due to the signals from the fibers that pass over the quartz blocks above- can be corrected by data.



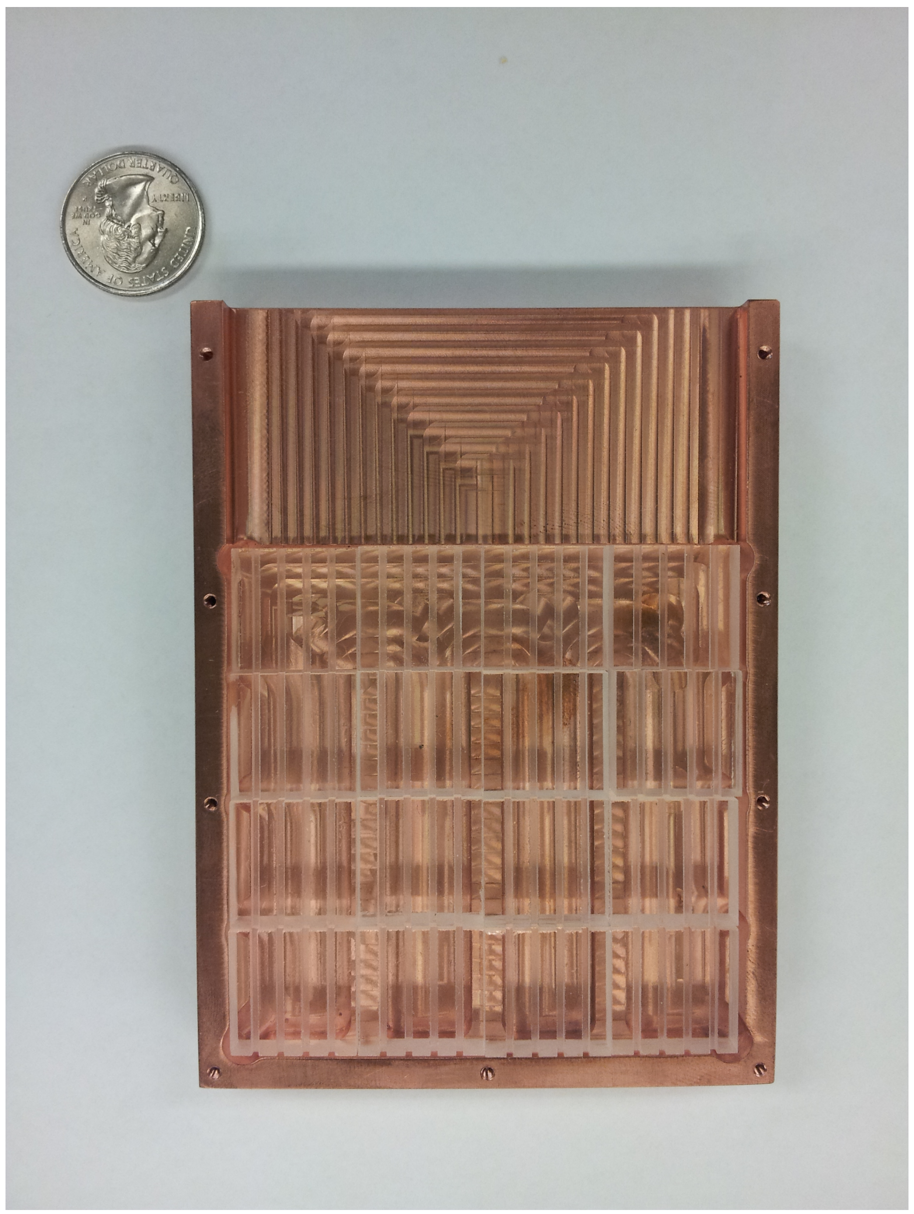
(a) Shows the result of a GEANT simulation, 100 neutrons were directed at the location (0,4).

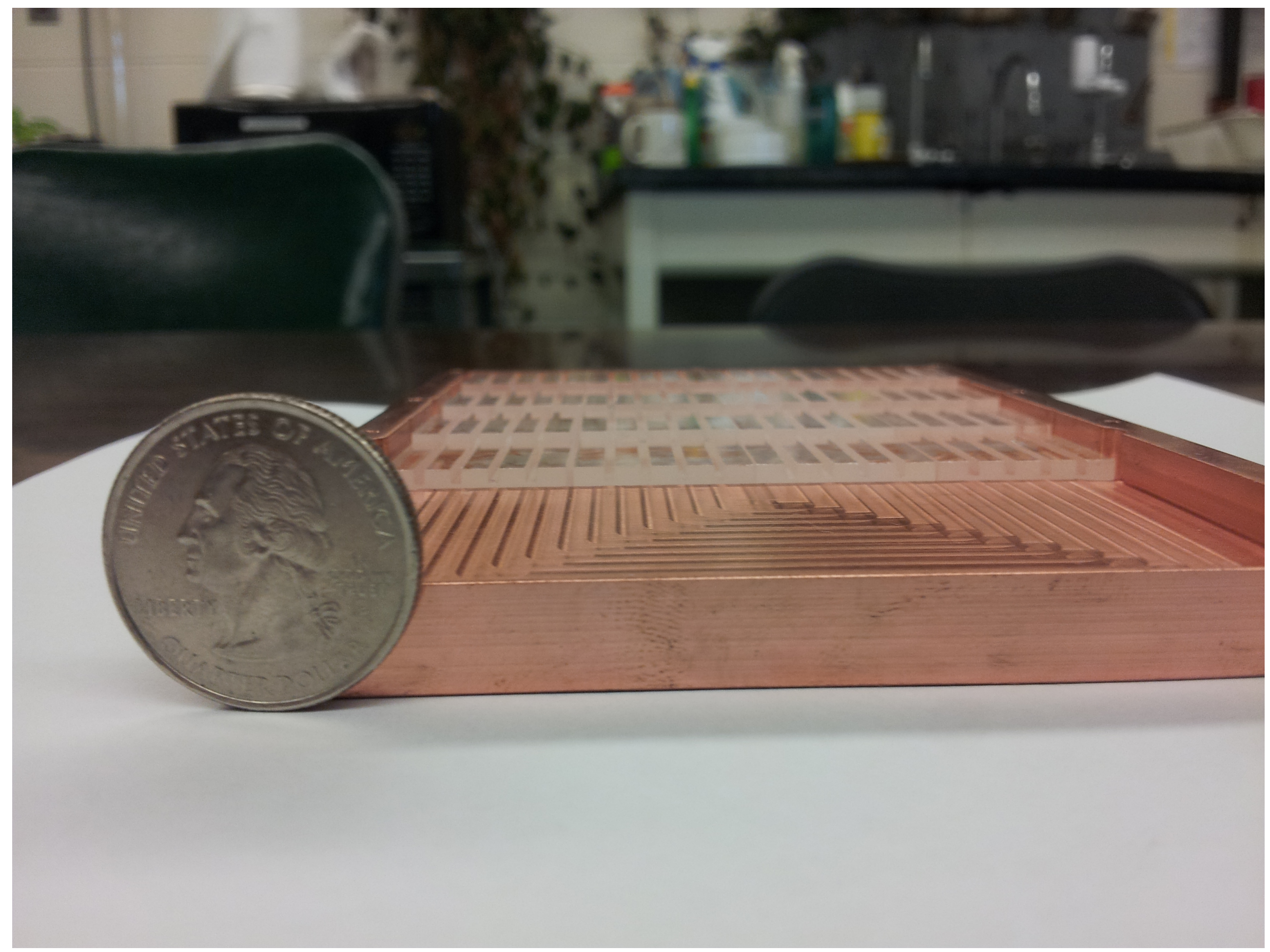


(b) Shows the result of a GEANT simulation, 100 neutrons were directed at the location (0,-4).

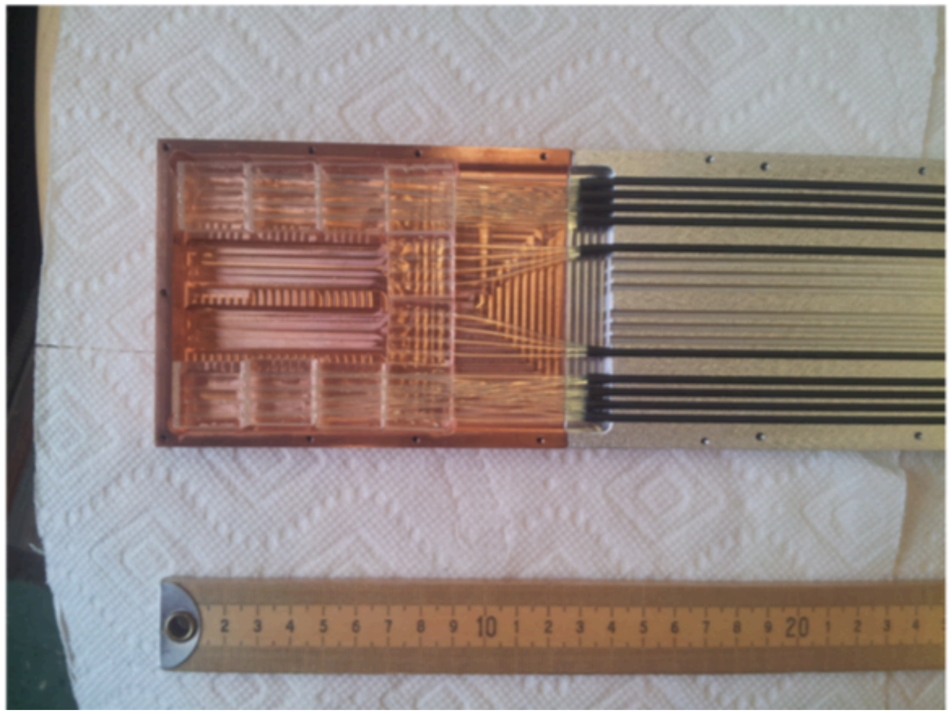
Detector Design 1

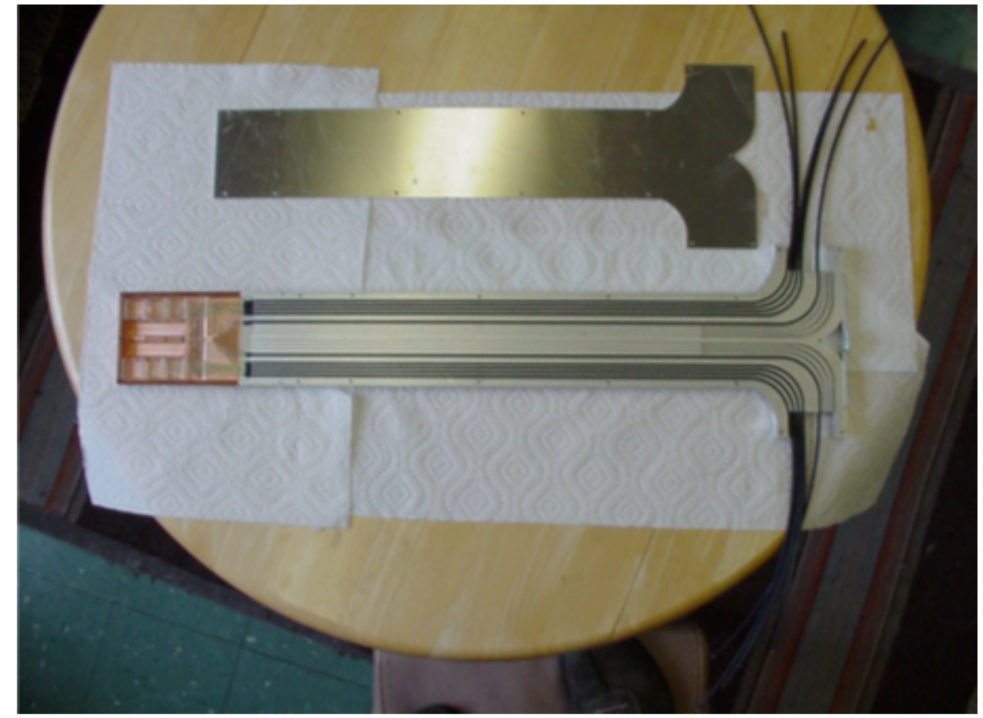
Blocks are offset to allow fibers to pass over the rows





Detector Design 2





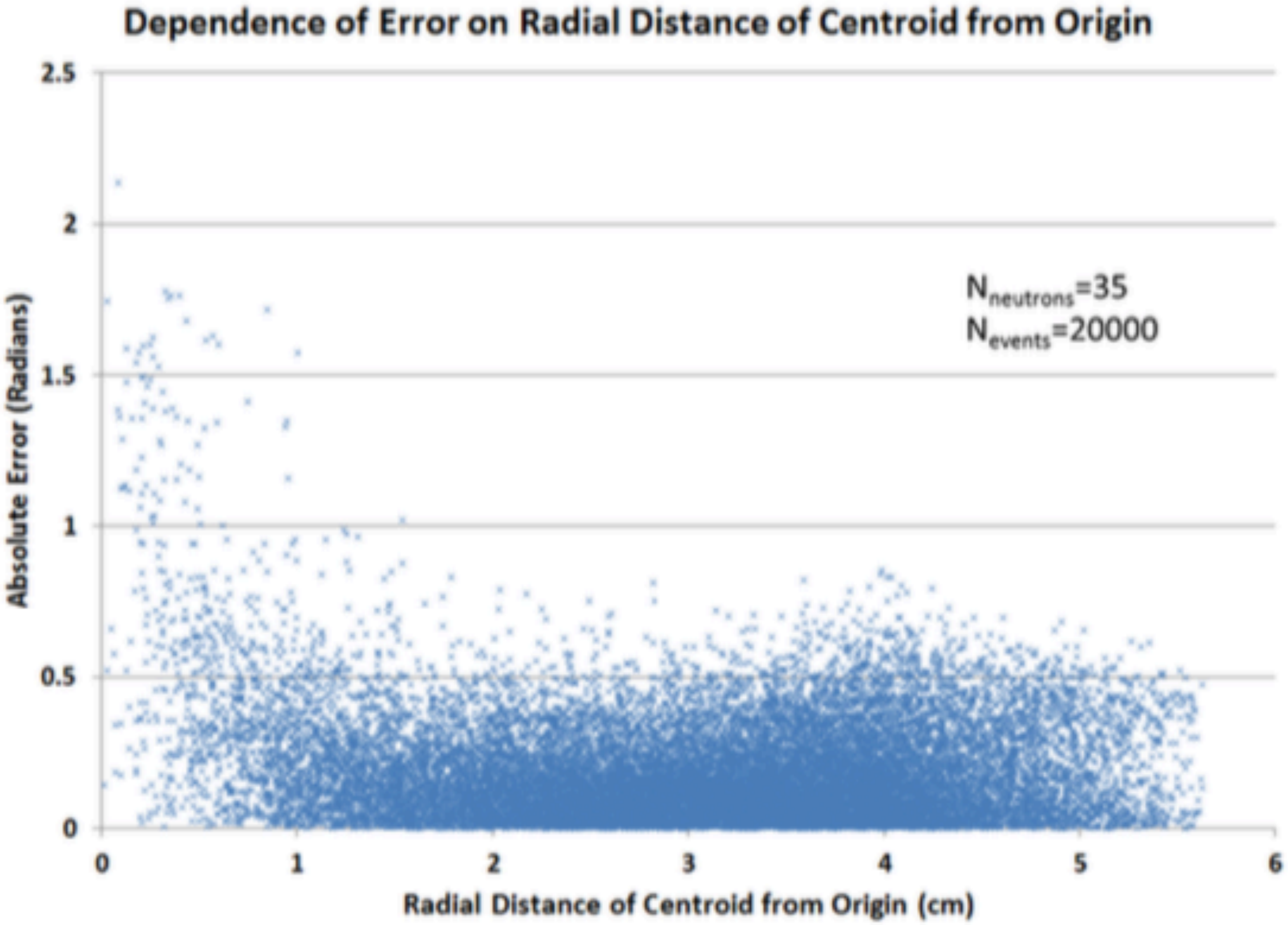
Full Detector
ready for installation

Upgrade Path for RPD

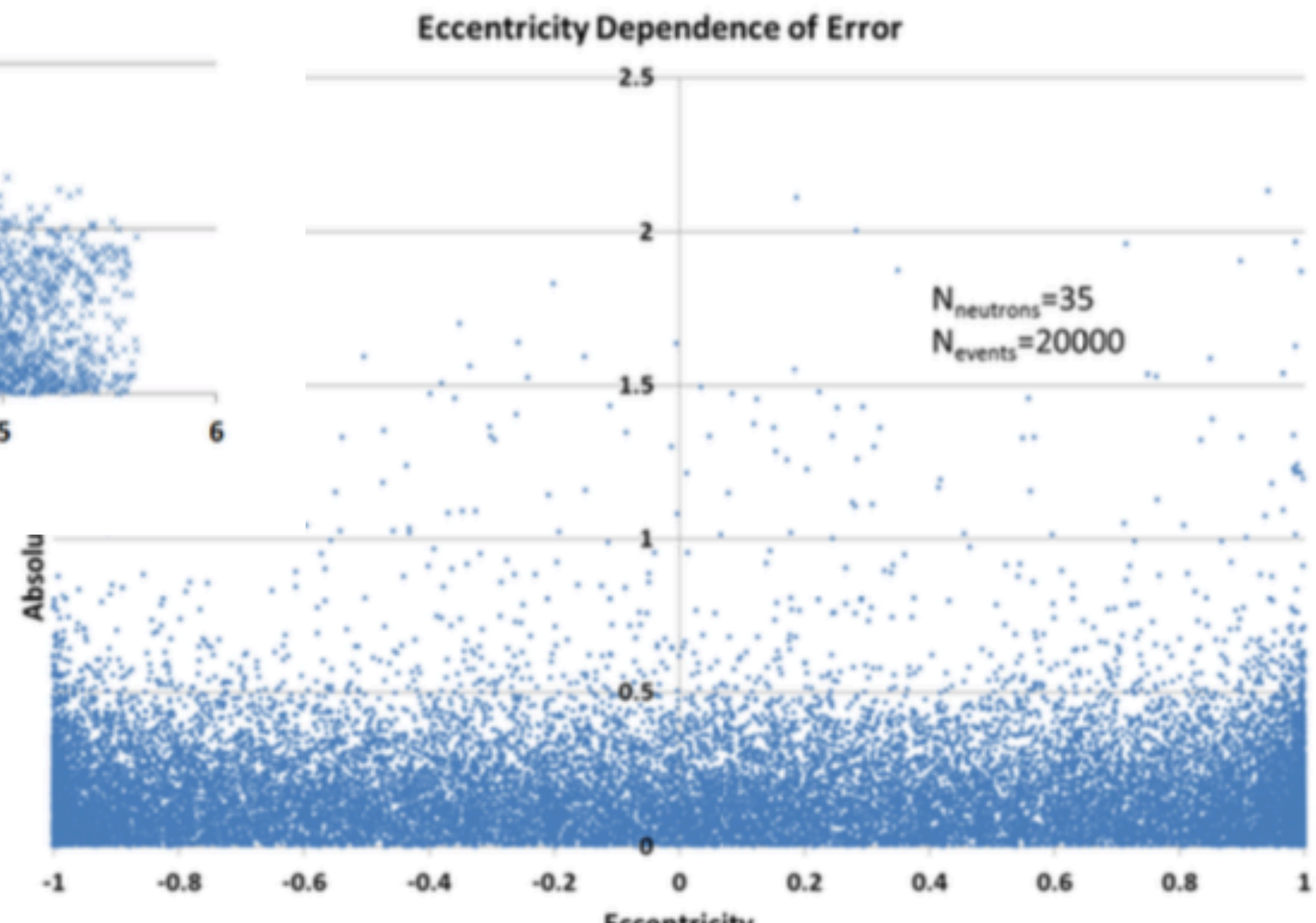
- Test the radiation hardness of light guides - currently WLS fibers and current quartz blocks
- Rerun the GEANT simulations to identify the segmentation needed to obtain a reaction plane
- Consider switching to fused silica for the actual elements
- Test the use of SiPM instead of the Hamamatsu PMT's being used now

Back-up Slides

Studies of Errors from Position

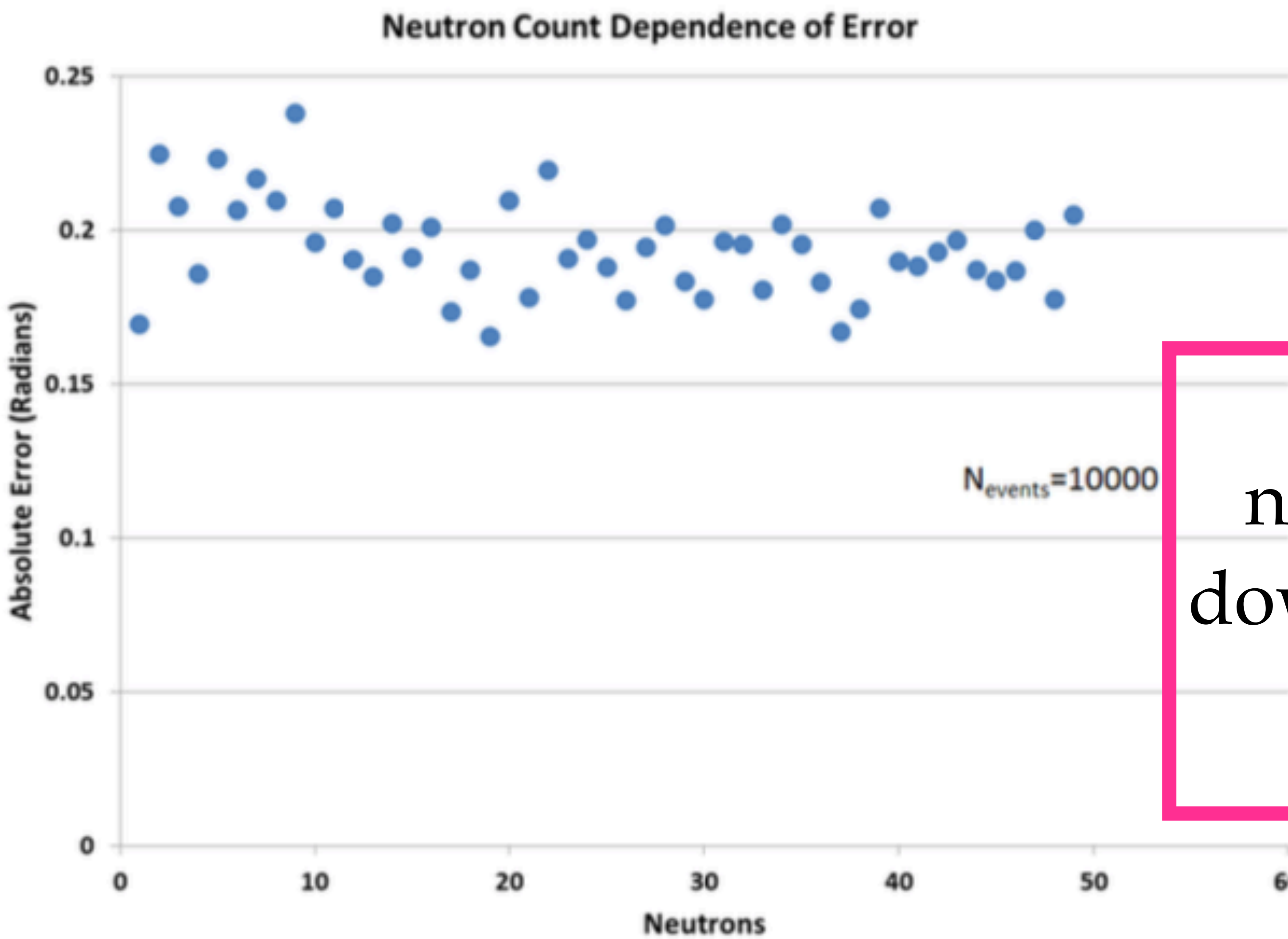


Radial Distance of Centroid from the Origin



Eccentricity of the distribution

Errors from Neutron Distribution



Absolute Error in radians ~0.2

Best results for n > ~ 10 neutrons, but can measure down to ~ 5 so should be able to measure O-O

Number of neutrons