Radiation Hard Zero Degree Calorimeters for ATLAS and CMS in the HL-LHC era

Quan Wang
(Univ. of Kansas)

U.S. DEPARTMENT OF ENERGY | Office of Science

JZCaP

CPAD Instrumentation Frontier Workshop 2021

KU

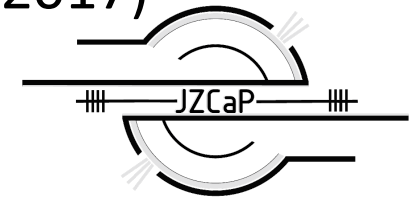
Introduction

- High Luminosity LHC (HL-LHC)
  - Run 2 [2015-2018] peak luminosity: $2x10^{34}$ $cm^{-2}s^{-1}$ (2 X designed)
  - Run 4 [2027-2030] HL-LHC: $5x10^{34}$ $cm^{-2}s^{-1}$
- Heavy Ion program at the LHC
  - Pb+Pb at Run 4: $7x10^{27}$ $cm^{-2}s^{-1}$ (20% increase from Run 2)
  - p+Pb, low PU pp, Xe+Xe, possible O+O, p+O

ATLAS ZDC fused quartz rods irradiated in Run 1 [2011] pp and PbPb by ~1 Grad

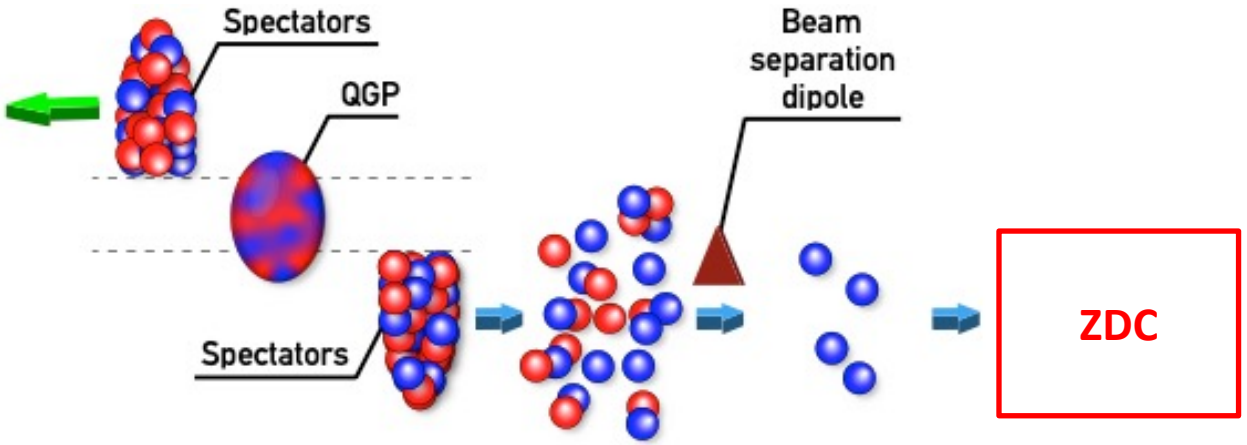
Introduction

- High Luminosity LHC (HL-LHC)
  - Run 2 [2015-2018] peak luminosity: $2x10^{34}$ $cm^{-2}s^{-1}$ (2 X designed)
  - Run 4 [2027-2030] HL-LHC: $5x10^{34}$ $cm^{-2}s^{-1}$
- Heavy Ion program at the LHC
  - Pb+Pb at Run 4: $7x10^{27}$ $cm^{-2}s^{-1}$ (20% increase from Run 2)
  - p+Pb, low PU pp, Xe+Xe, possible O+O, p+O
- HL-LHC leads to beam optics upgrade, TAXN
- A Joint Zero Degree Calorimeter Project (JZCaP since 2017)
  - **Ben-Gurion, Columbia, Maryland, UIUC, KU, BNL,**
  - CMS/ATLAS [LHCb]



Physics Motivation

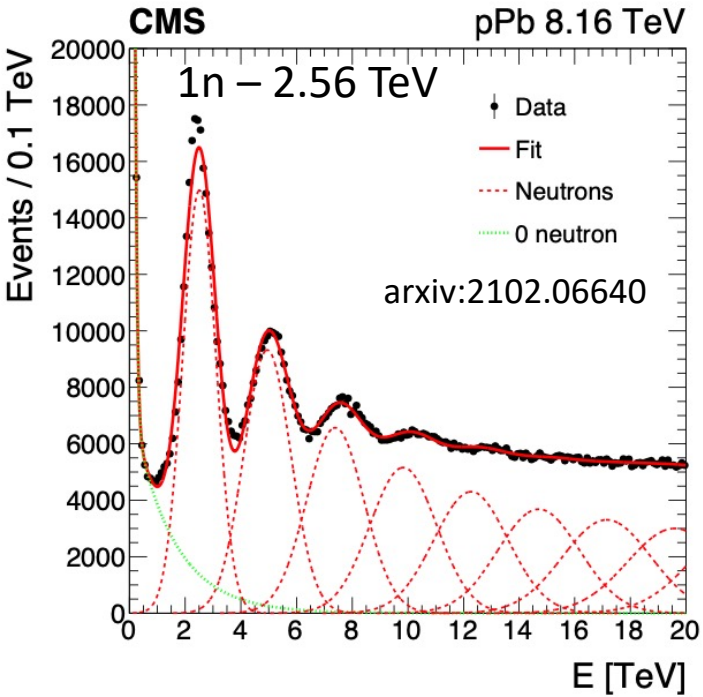
- Measure neutral particles in HI collisions
- Large dynamic range <1n, to ~100n



Up to ~ 55 neutrons

Physics Motivation

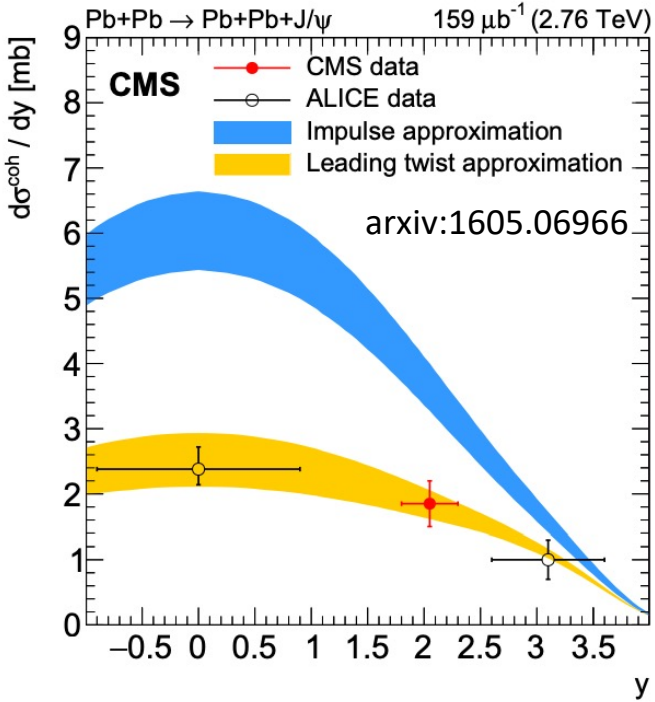
- Measure neutral particles in HI collisions
- Large dynamic range <1n, to ~100n
- 1n peak crucial for energy calibration
  - Beam energy neutron



Resolution: 19-22%

Physics Motivation

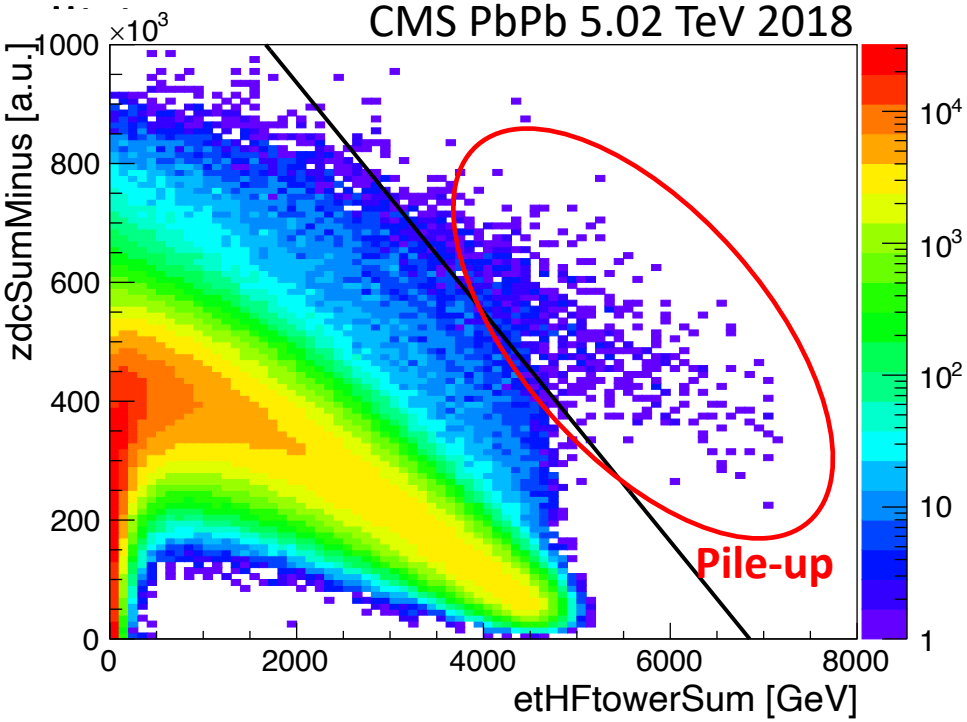
- Measure neutral particles in HI collisions
- Large dynamic range <1n, to ~100n
- 1n peak crucial for energy calibration
  - Beam energy neutron
- Clean separation between 0 and >=1n
  - UPC vs hadronic



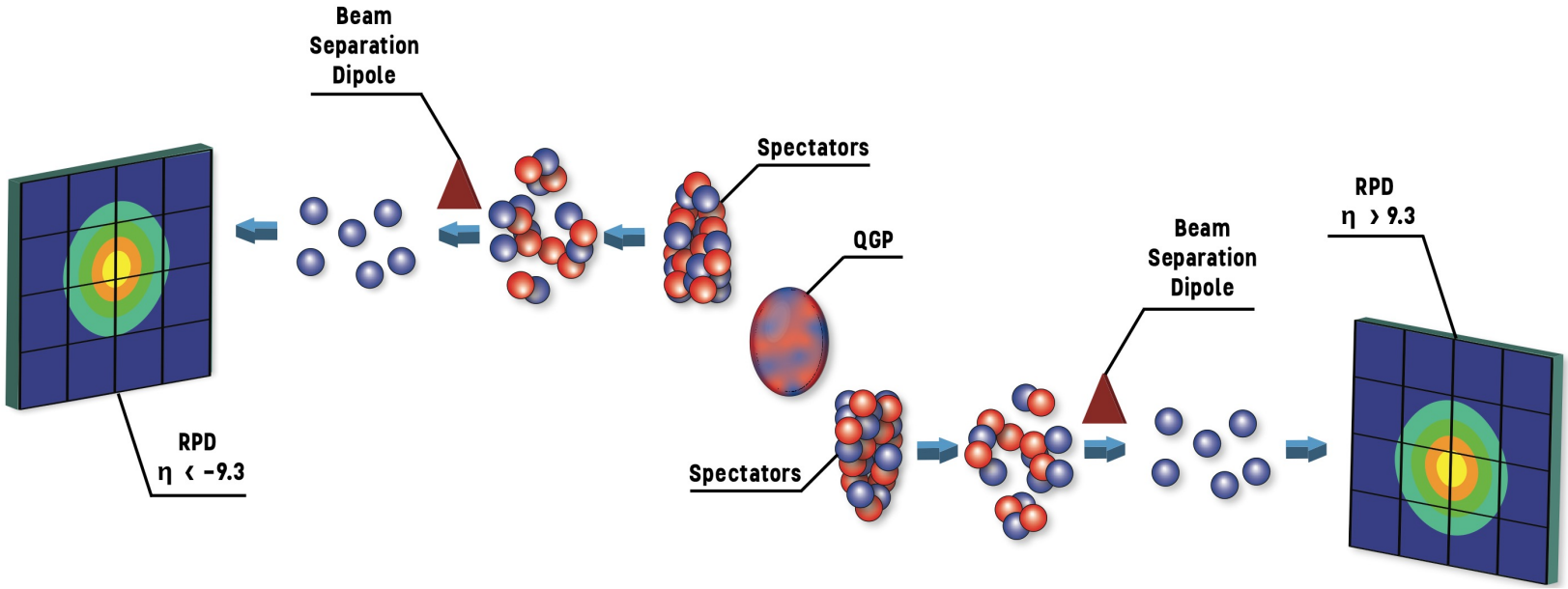
Pb+Pb→ Pb+Pb+J/ψ
Gluon saturation in Pb

Physics Motivation

- Measure neutral particles in HI
- Large dynamic range <1n, to ~1
- 1n peak crucial for energy calibr
  - Beam energy neutron
- Clean separation between 0 and
  - UPC vs hadronic
- In-time pile-up rejection



Physics Motivation



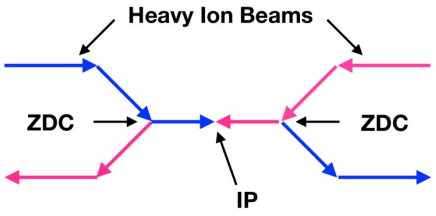
- Measure spectator event plane angle
  - Neutron orientation, collision geometry

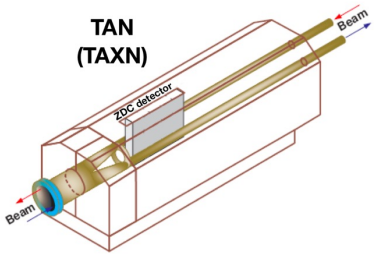
Physics Motivation

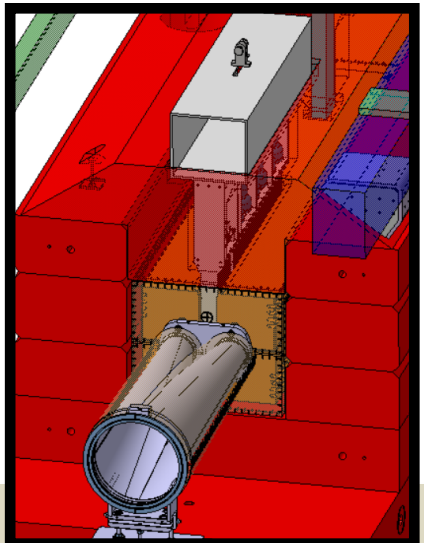
- Measure neutral particles in HI collisions
- Large dynamic range <1n, to ~100n
- 1n peak crucial for energy calibration
  - Beam energy neutron
- Clean separation between 0 and >=1n
  - UPC vs hadronic
- In-time pile-up rejection
- Measure spectator event plane angle
  - Neutron orientation, collision geometry
- Provide trigger decisions

ZDC Key Design Criteria

- Physics requirement
  - Clearly resolve 0n~1n~2n~3n
  - Good γ/n separation
- Performance requirement
  - Highly radiation hard
  - Stable over Run 4

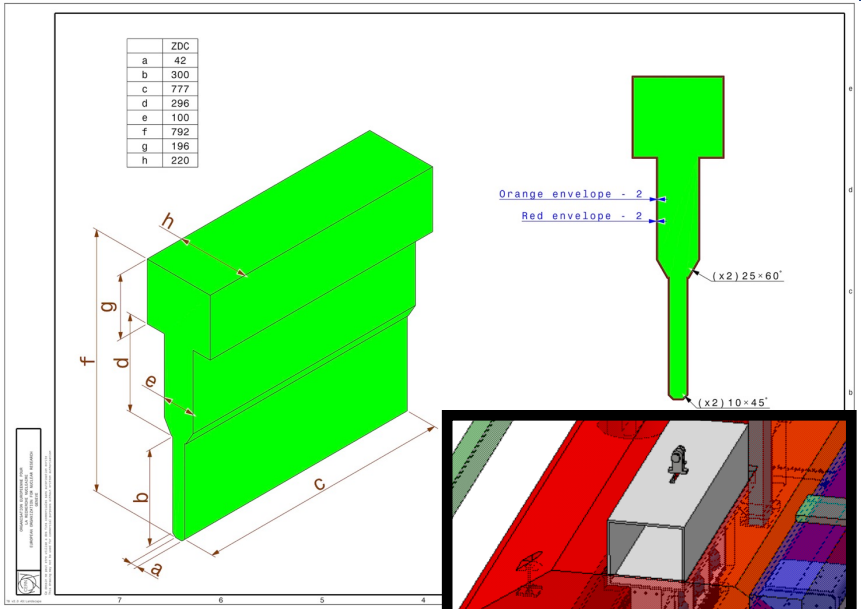


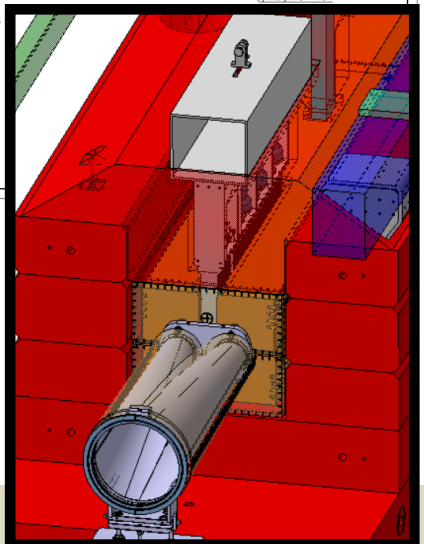




ZDC Key Design Criteria

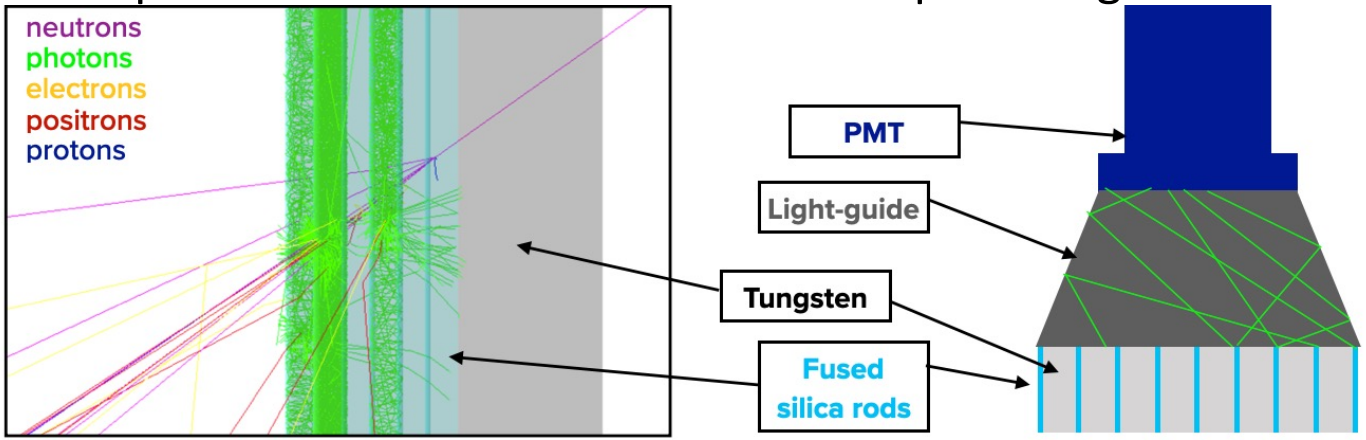
- Physics requirement
  - Clearly resolve 0n~1n~2n~3n
  - Good γ/n separation
- Performance requirement
  - Highly radiation hard
  - Stable over Run 4
- Operation requirement
  - Compatible with TAXN
  - Easy installation/cabling (RP)





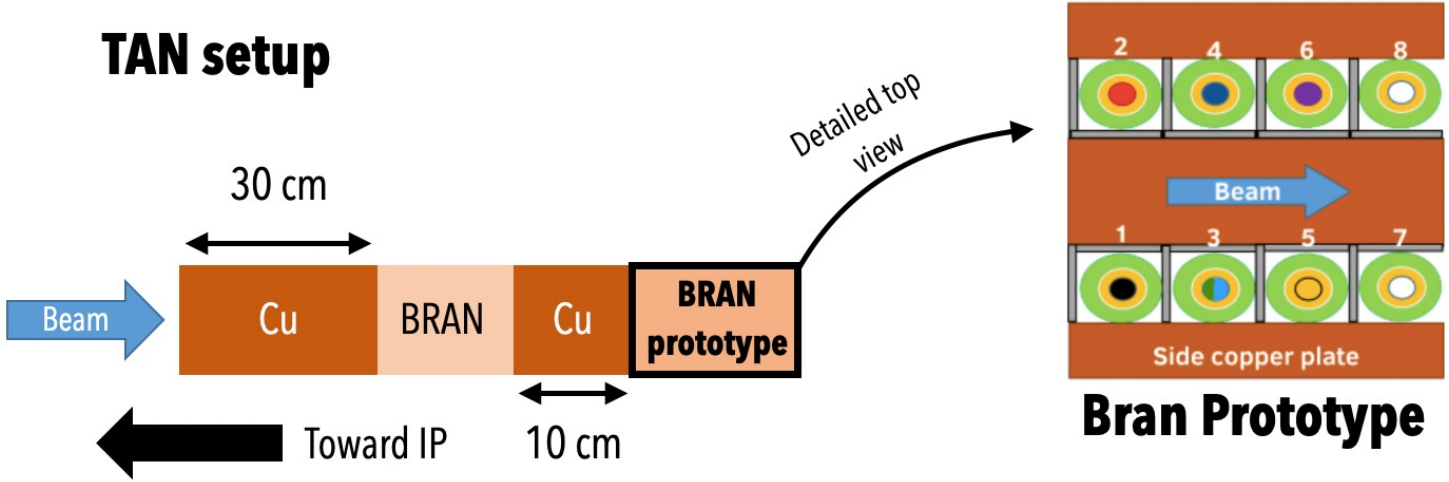
Detector Principle

- **Tungsten / fused silica** sampling calorimeter
- Neutron/photon showers in tungsten
- Charge particles emit Cherenkov light in fused silica rods
- Cherenkov light reflected in the rods towards extremities
- On the top end, light exits into a light-guide that converge to PMT
- Polished top end to maximize the amount of captured light



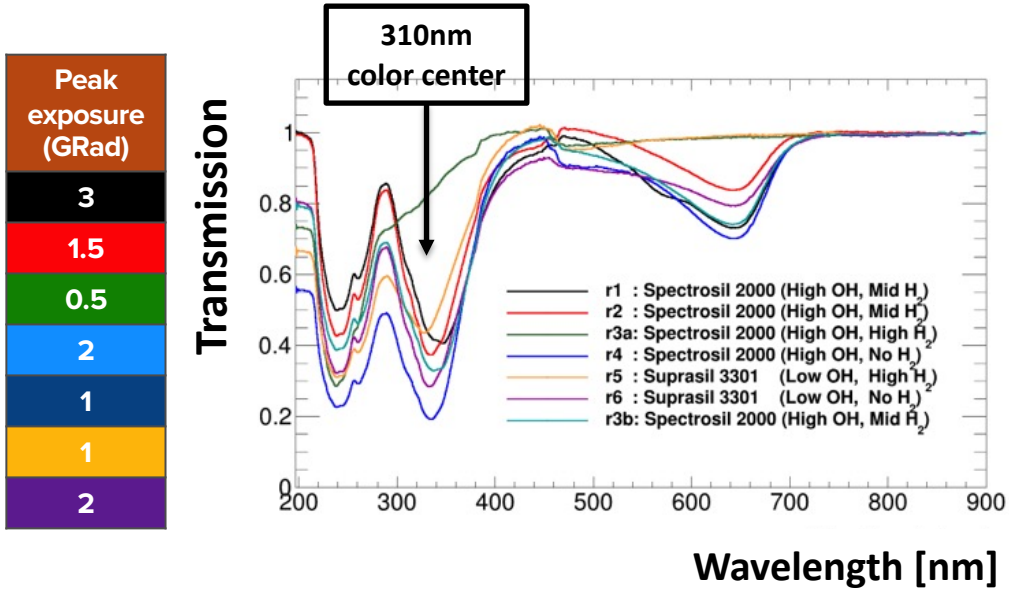
Fused Silica Radiation Hardness

- Radiation hard fused silica rods used as Cherenkov radiator
  - Various fused silica rods irradiated by BRAN group in TAN during Run 2



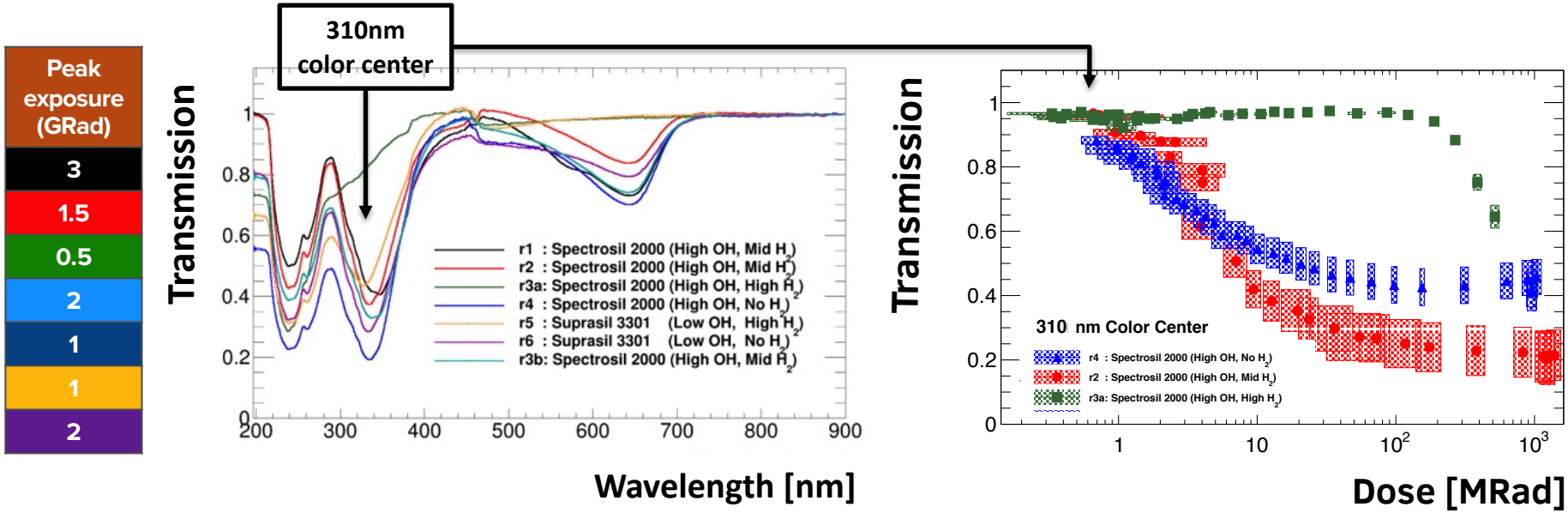
Fused Silica Radiation Hardness

- Radiation hard fused silica rods used as Cherenkov radiator
  - Various fused silica rods irradiated by BRAN group in TAN during Run 2



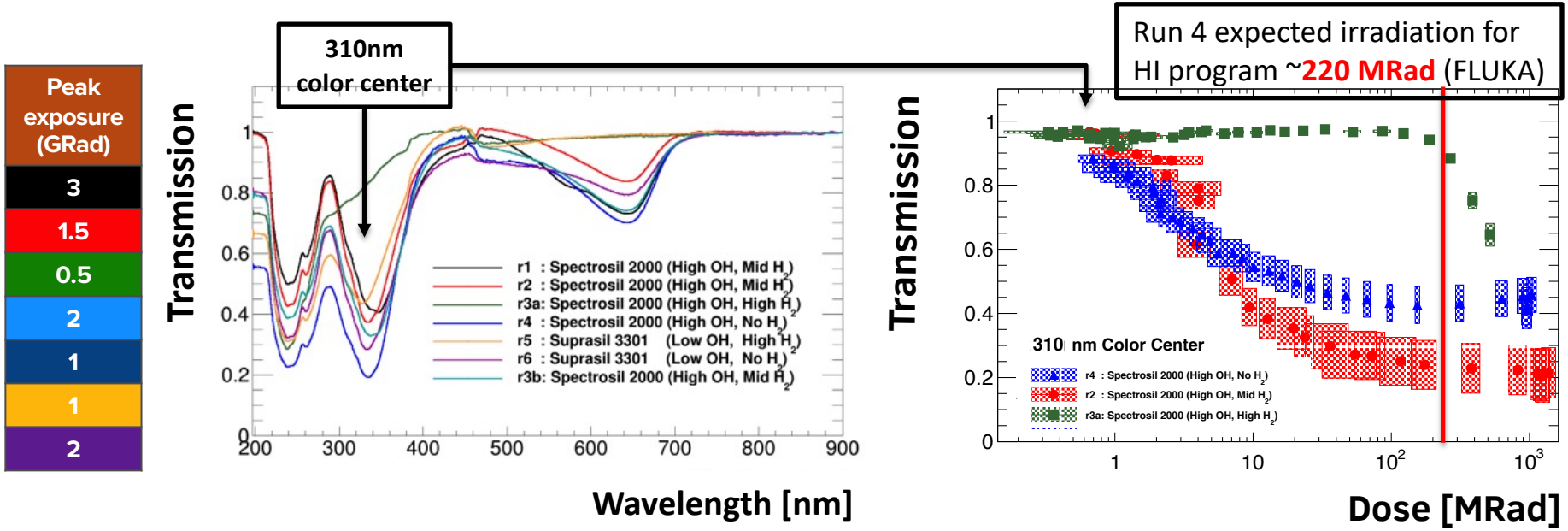
Fused Silica Radiation Hardness

- Radiation hard fused silica rods used as Cherenkov radiator
  - Various fused silica rods irradiated by BRAN group in TAN during Run 2



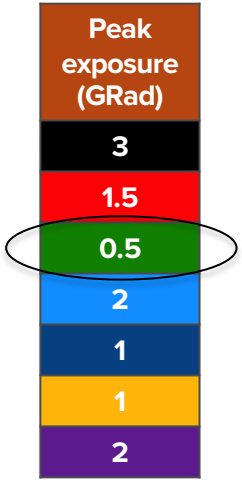
Fused Silica Radiation Hardness

- Radiation hard fused silica rods used as Cherenkov radiator
  - Various fused silica rods irradiated by BRAN group in TAN during Run 2

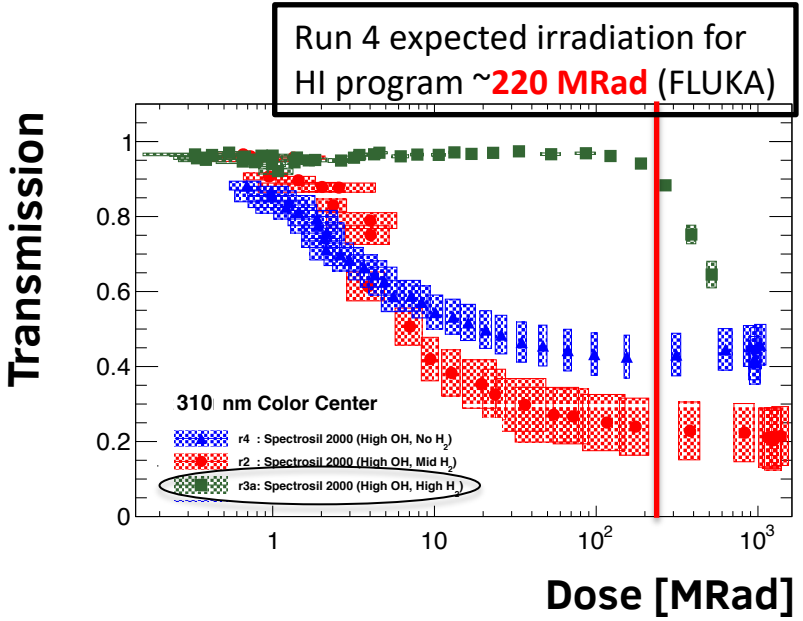


Fused Silica Radiation Hardness

- Radiation hard fused silica rods used as Cherenkov radiator
  - Various fused silica rods irradiated by BRAN group in TAN during Run 2

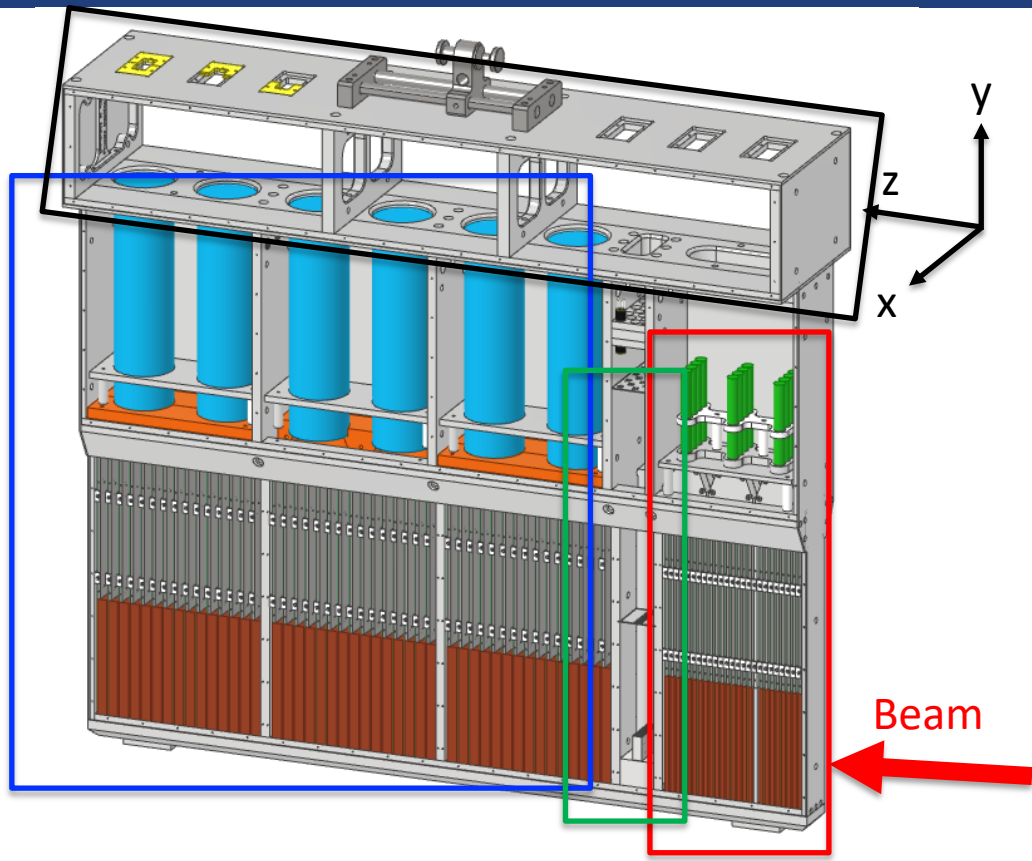


- r3a: Heavily H2 loaded Spectrosil 2000 rods for Run 3 refurbishing
- Run 4 decision to be made after Run 3 irradiation



Zero Degree Calorimeter

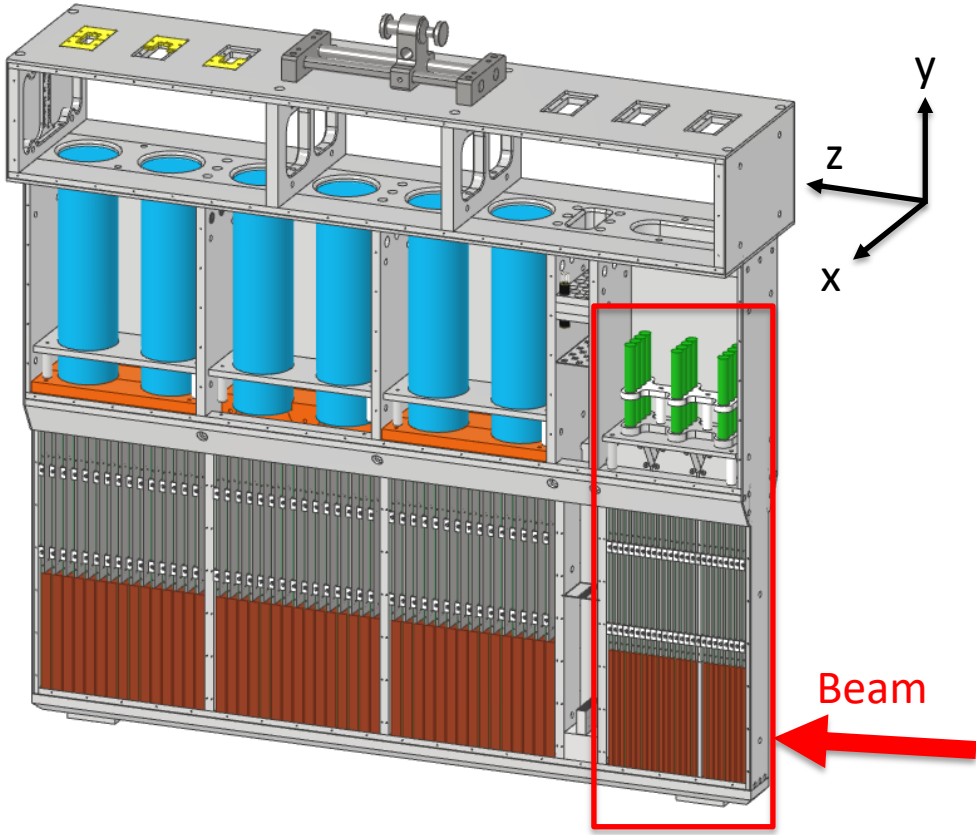
- Detector design
  - Electromagnetic [EM] section
  - Hadronic [HAD] section
  - Reaction Plane Detector[RPD]
- Operation requirement
  - Single piece structure
  - Easy access **patch panels**
- Specs
  - 46mm X 766mm
  - 120-125 kg
  - 5.5 λ_{int} of W



Zero Degree Calorimeter

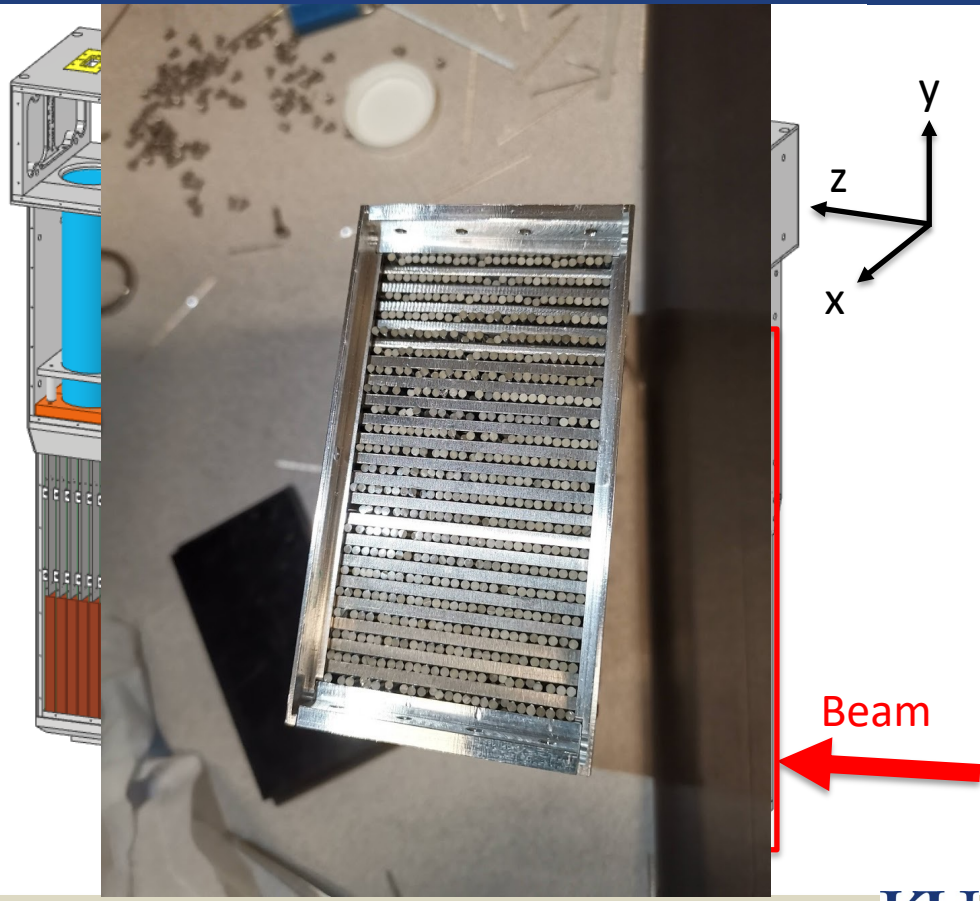
➢ EM section

- ❑ 25 tungsten plates [42mm X 120mm X 4mm]
- ❑ 15 fused silica rods per layer [ϕ1.5mm]
- ❑ ~30 X_0
- ❑ 4x3 [X-Z] segmentations
- ❑ Winston cone light-guide
- ❑ Hamamatsu R2496 [ϕ10mm]
- ❑ Beam test in 2019 at Fermi lab



Zero Degree Calorimeter

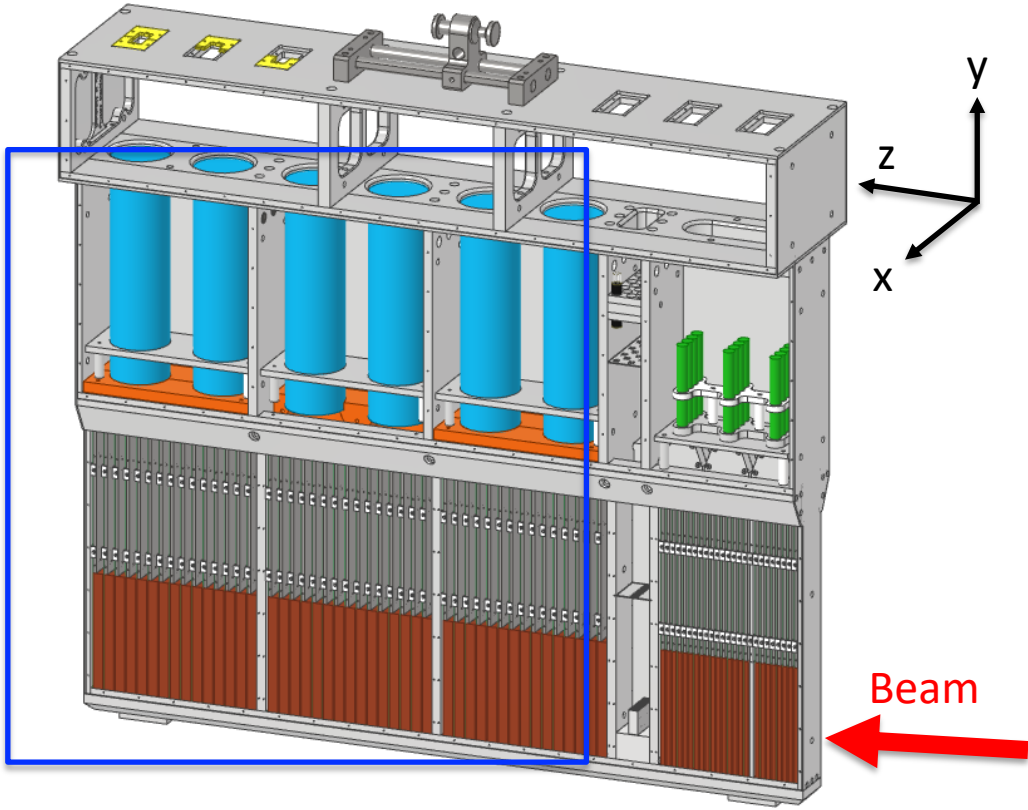
- **EM section**
  - 25 tungsten plates [42mm X 120mm X 4mm]
  - 15 fused silica rods per layer [ϕ1.5mm]
  - ~30 X_0
  - 4x3 [X-Z] segmentations
  - Winston cone light-guide
  - Hamamatsu R2496 [ϕ10mm]
  - Beam test in 2019 at Fermi lab



Zero Degree Calorimeter

➢ HAD section

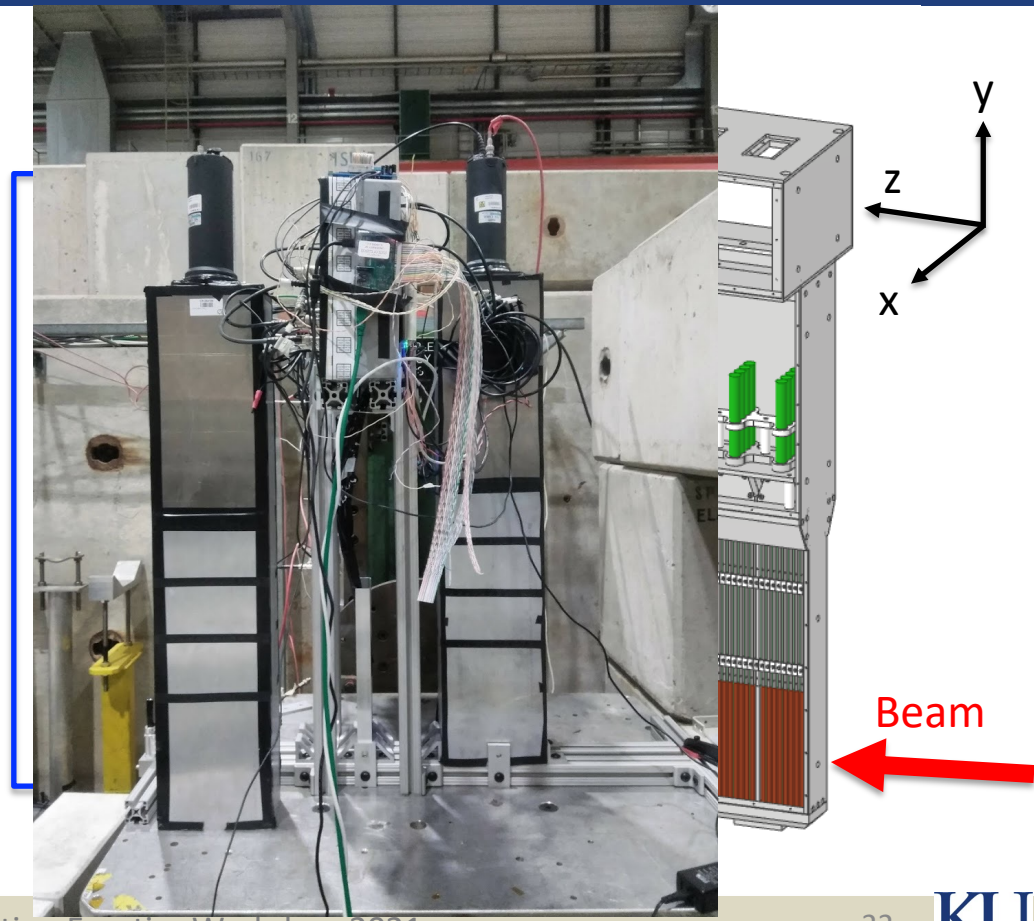
- ❑45 tungsten plates [42mm X 120mm X 10mm]
- ❑15 fused silica rods per layer [ϕ1.5mm]
- ❑~4.5 λ_{int}
- ❑6 [Z] segmentations
- ❑Trapezoidal light-guide
- ❑Hamamatsu R2059 [ϕ51mm]
- ❑Beam test in 2018 at SPS



Zero Degree Calorimeter

➢ HAD section

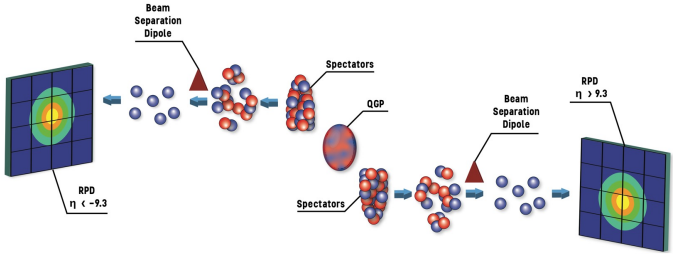
- ❑45 tungsten plates [42mm X 120mm X 10mm]
- ❑15 fused silica rods per layer [ϕ1.5mm]
- ❑~4.5 λ_{int}
- ❑6 [Z] segmentations
- ❑Trapezoidal light-guide
- ❑Hamamatsu R2059 [ϕ51mm]
- ❑Beam test in 2018 at SPS

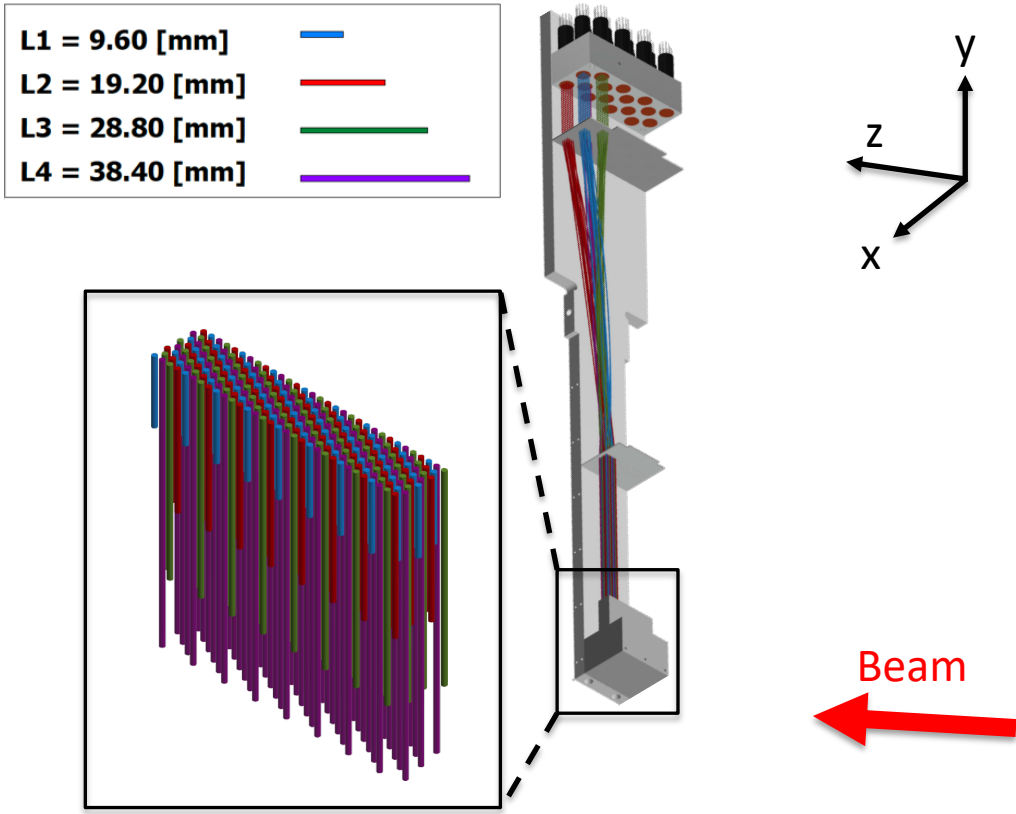


Zero Degree Calorimeter

➢ RPD section

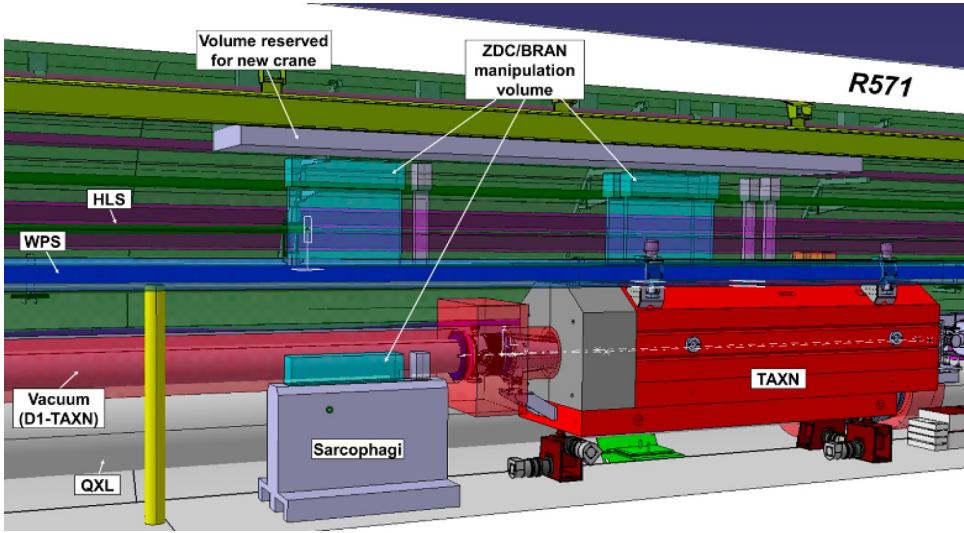
- ❑ "Pan flute" design
- ❑ Fused silica core and polyamide buffer
- ❑ 4X4 [X-Y] segmentations
- ❑ Machine learning algos
- ❑ Hamamatsu R2496 [ϕ10mm]





Things Not Covered

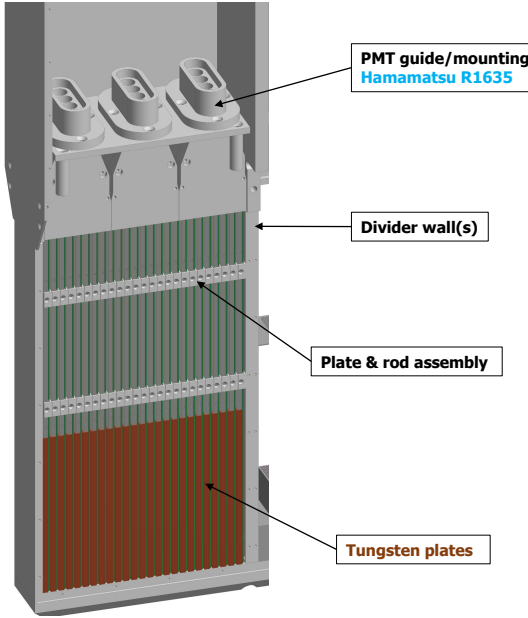
- PMT considerations
  - Radiation hardness, diameter, rising time
- LED gain monitoring system
  - Online calibrations
- HL-LHC integration
  - Installation, RP
- Experiment integration
  - Readout, DAQ, DCS, monitoring
  - Software



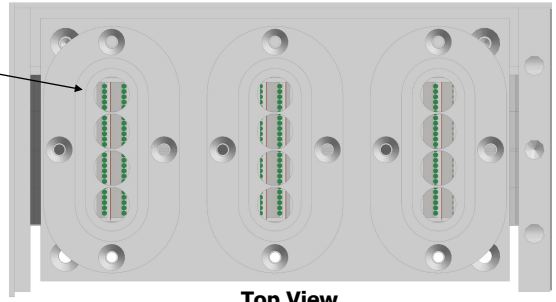
Summary

- Zero Degree Calorimeters developed for Run 4 HL-LHC
  - Better energy resolution and γ/n separation
  - Reaction Plane Detector for neutron orientation measurement
- Radiation hard and compact ZDC design
  - Radiation tolerance for increased luminosity in Run 4
  - Compatible with TAXN modification
- Beam tests
  - 2018, 2019, 2021
- Well defined schedule

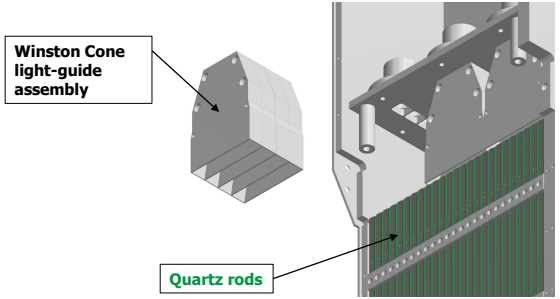
BACKUP



Electromagnetic Section

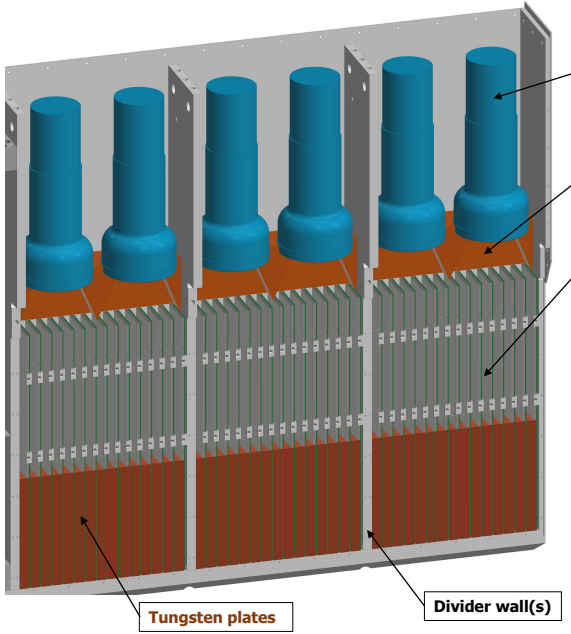


Top View

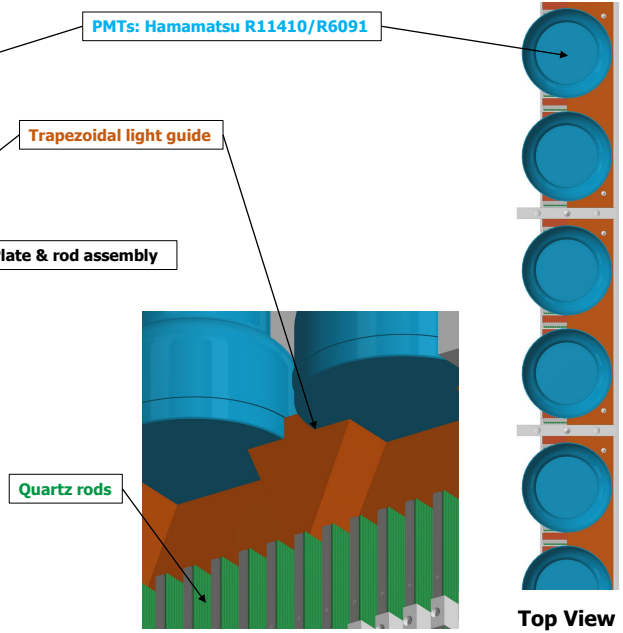


Rod/Light-Guide Interface

BACKUP



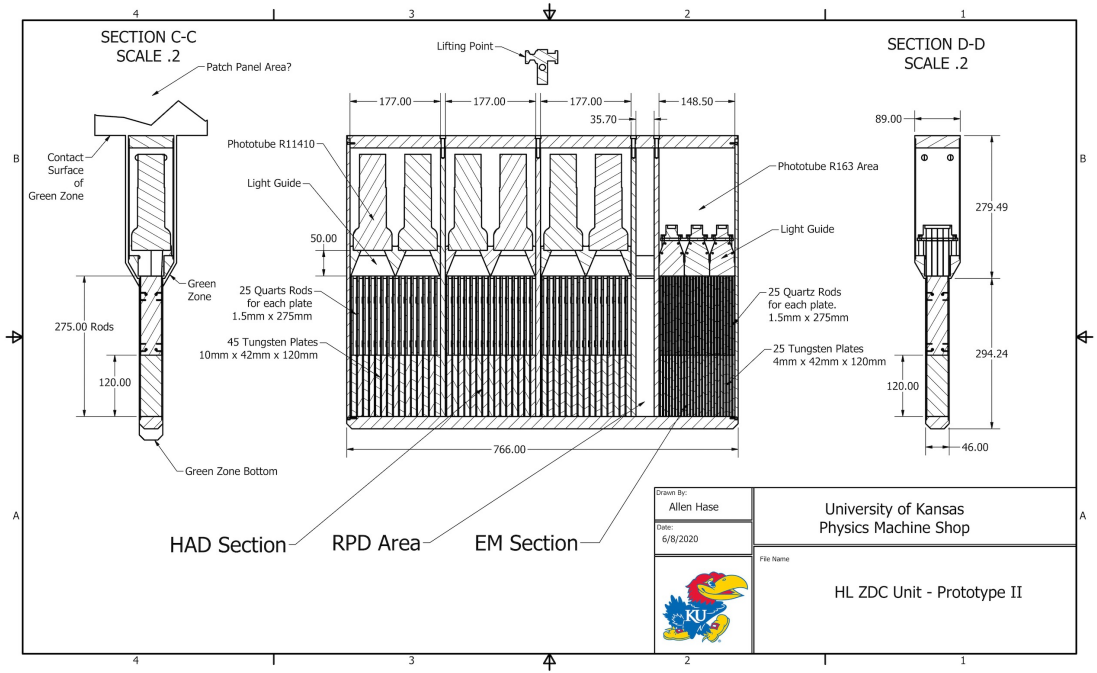
Hadronic Section



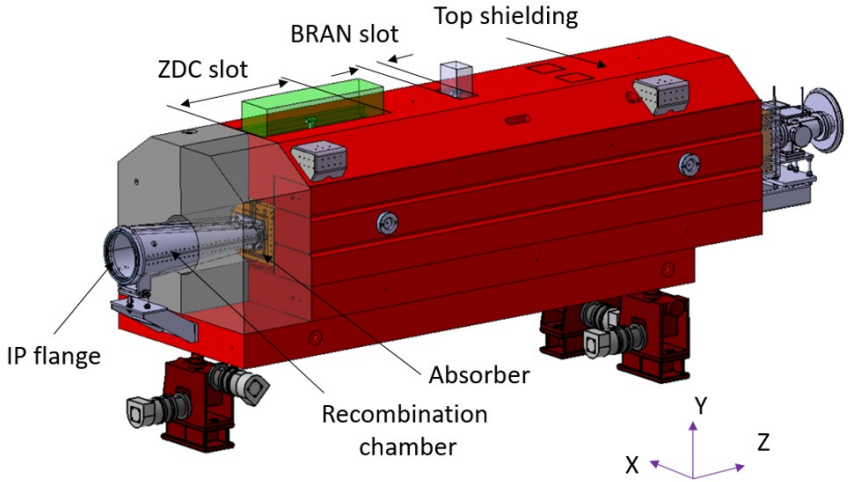
Rod/Light Guide Interface

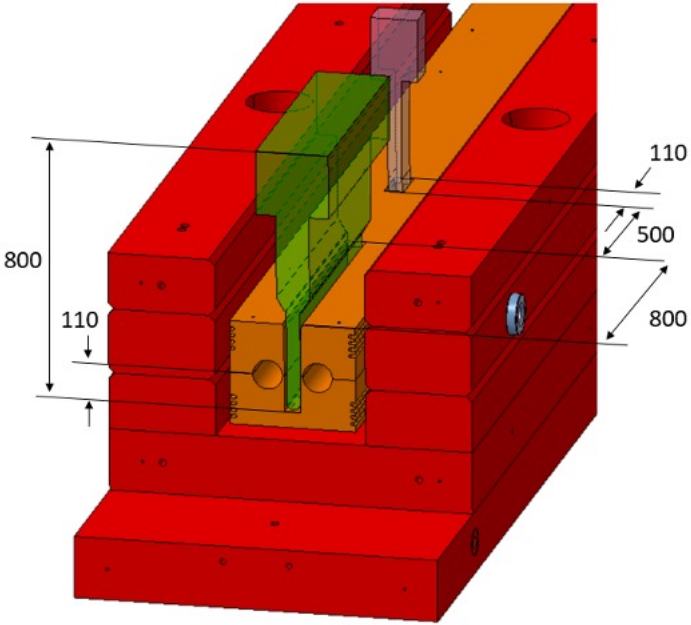
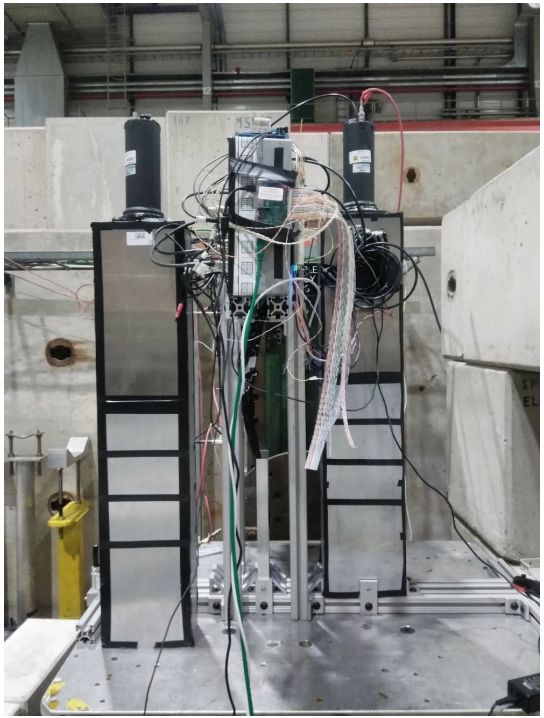
Top View

BACKUP


SECTION C-C
SCALE .2
Patch Panel Area?
Contact Surface of Green Zone
Green Zone
275.00 Rods
120.00
Green Zone Bottom
Lifting Point
177.00
177.00
177.00
148.50
35.70
Phototube R11410
Light Guide
50.00
25 Quarts Rods for each plate 1.5mm x 275mm
45 Tungsten Plates 10mm x 42mm x 120mm
766.00
Phototube R163 Area
Light Guide
25 Quartz Rods for each plate. 1.5mm x 275mm
25 Tungsten Plates 4mm x 42mm x 120mm
SECTION D-D
SCALE .2
89.00
279.49
294.24
120.00
46.00
HAD Section
RPD Area
EM Section
Drawn By:
Allen Hase
Date:
6/8/2020
University of Kansas
Physics Machine Shop
File Name
HL ZDC Unit - Prototype II

BACKUP


Top shielding
BRAN slot
ZDC slot
IP flange
Absorber
Recombination chamber
Y
Z
X


110
500
800
800
110