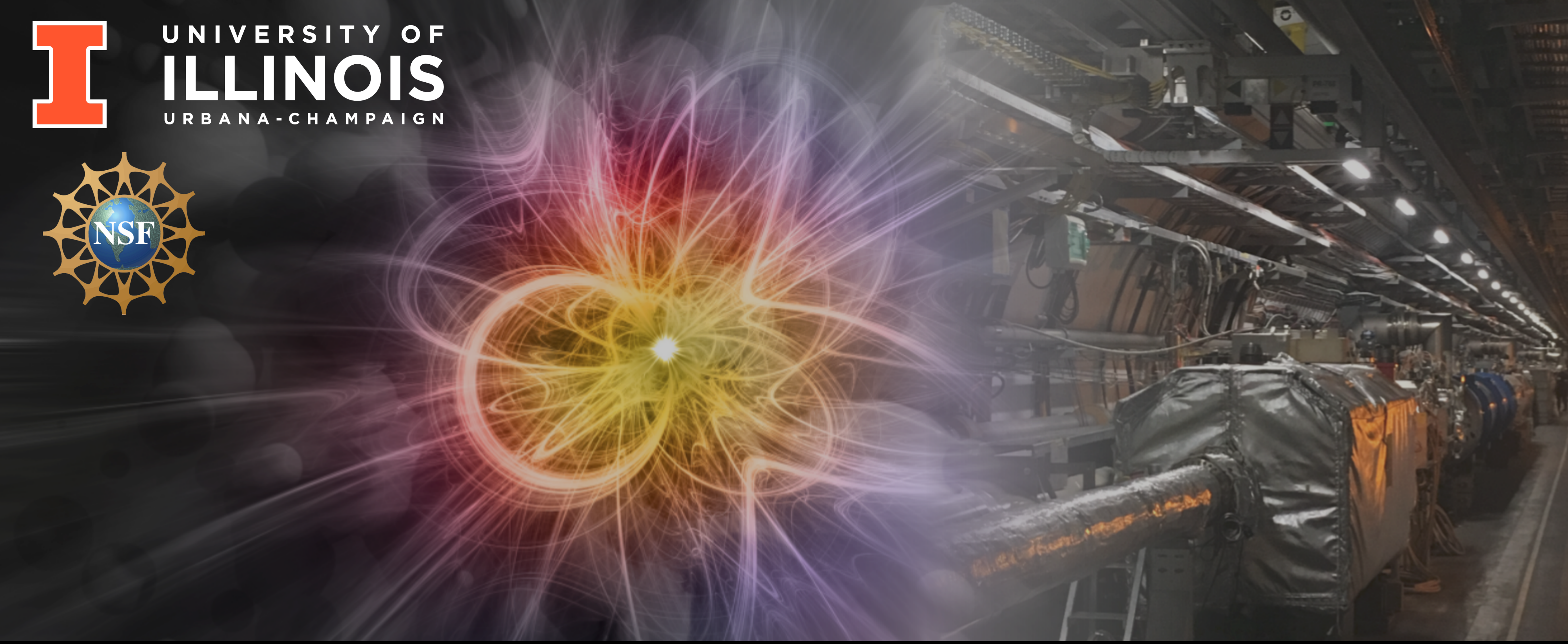


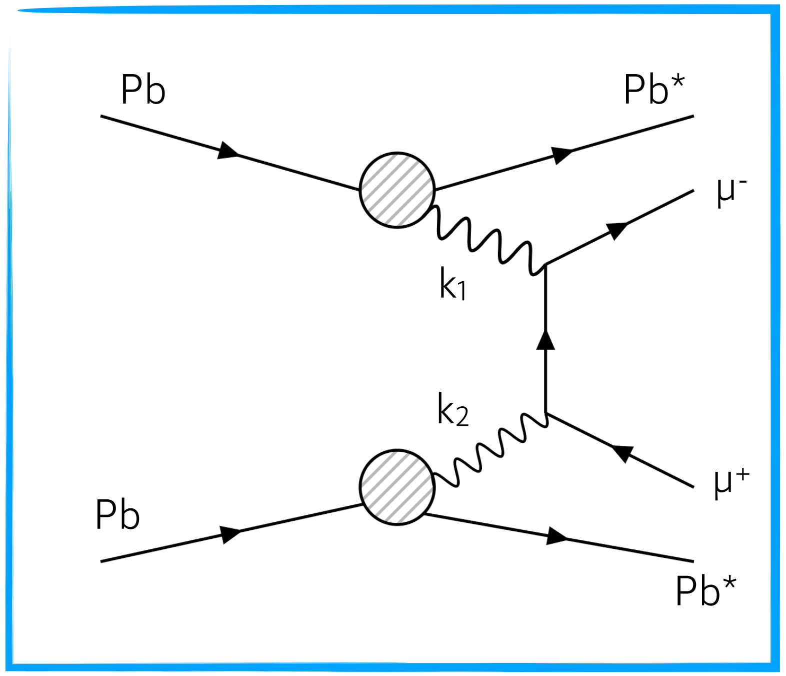
JOINT ATLAS/CMS ZDC UPGRADE PROJECT FOR THE HIGH LUMINOSITY LHC

Riccardo Longo
For the **J**oint **Z**ero-degree **Ca**lorimeter **P**roject between ATLAS and CMS
14th June 2022

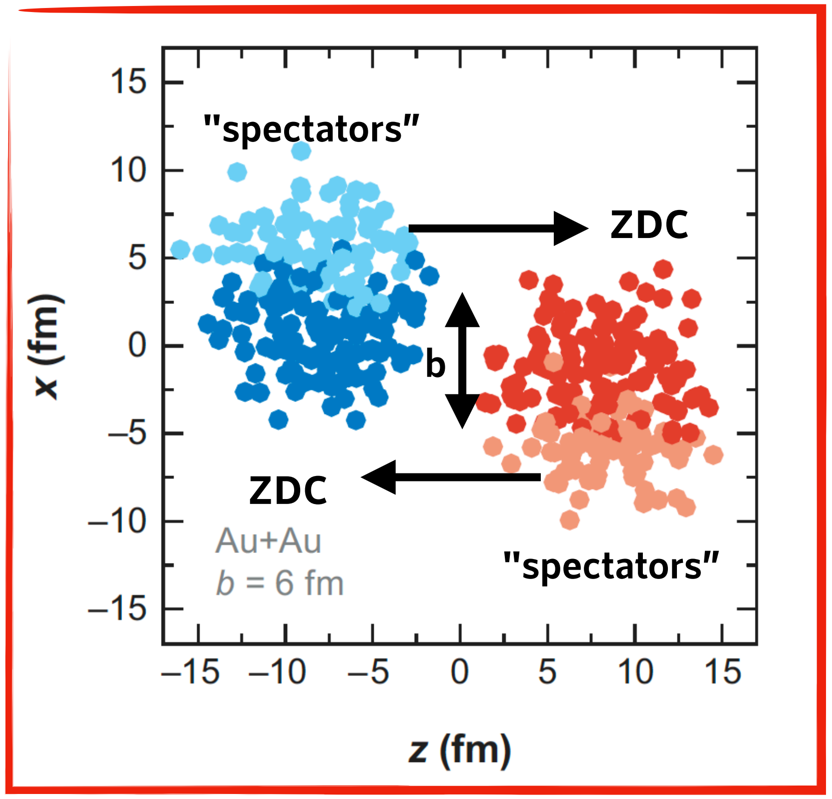
SQM2022

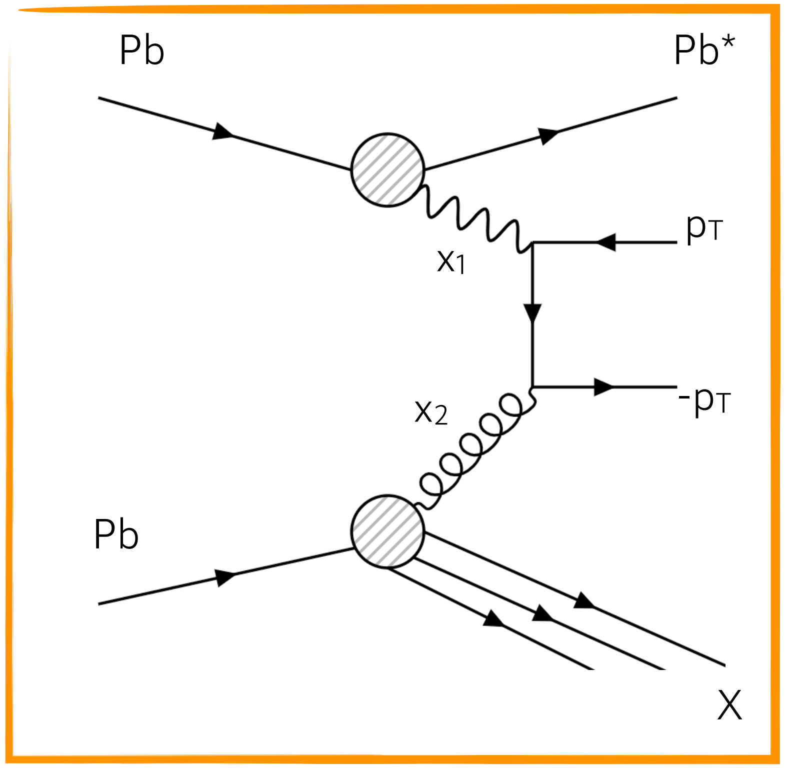
ZDC AS A TAG FOR PRIMARY PROCESS

- The primary means to distinguish between different classes of physics process in HI collisions is by looking at different forward neutron topologies
  - No neutrons on either side (“**0n0n**”) is typically from gamma-gamma processes
  - Neutrons only on one side (“**Xn0n**”/“**0nXn**”) is typically from photonuclear processes
  - Neutrons on both sides (“**XnXn**”) typically come from spectators in hadronic processes

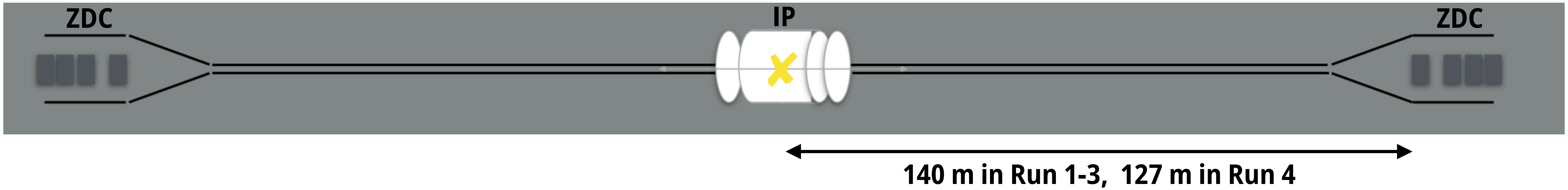


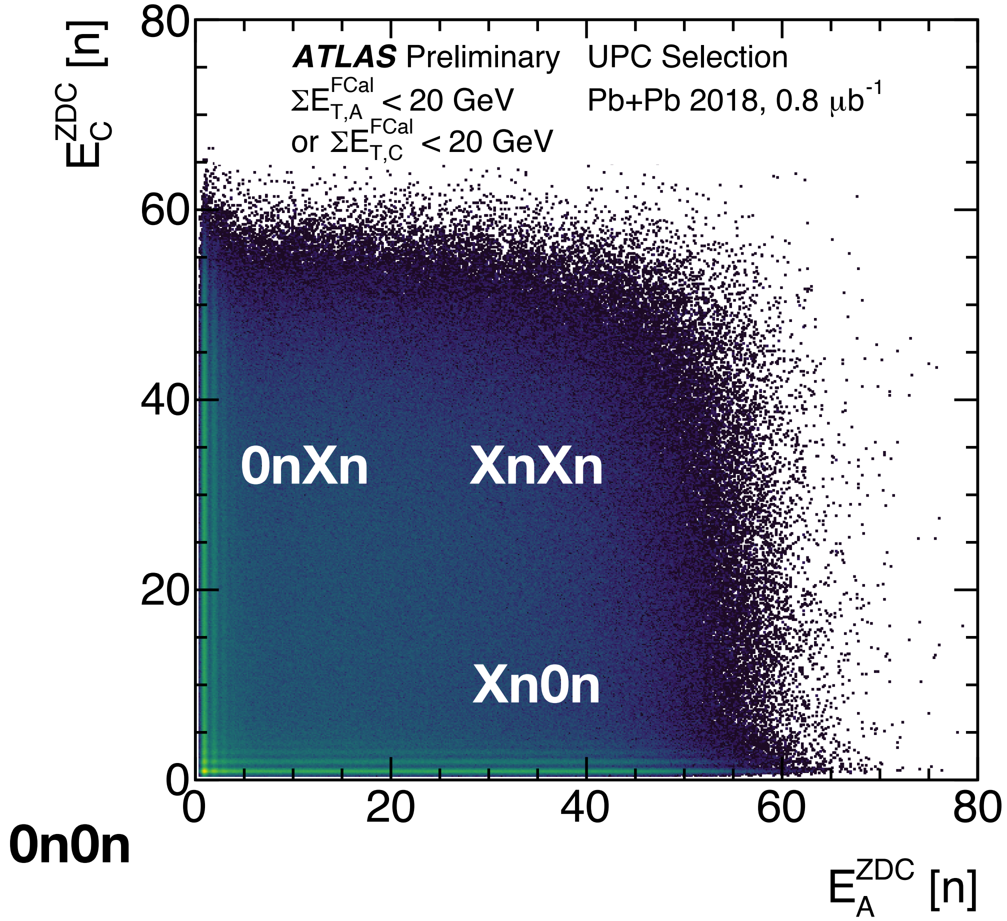
Ann. Rev. Nucl. Part. Sci. 57 (2007) 205

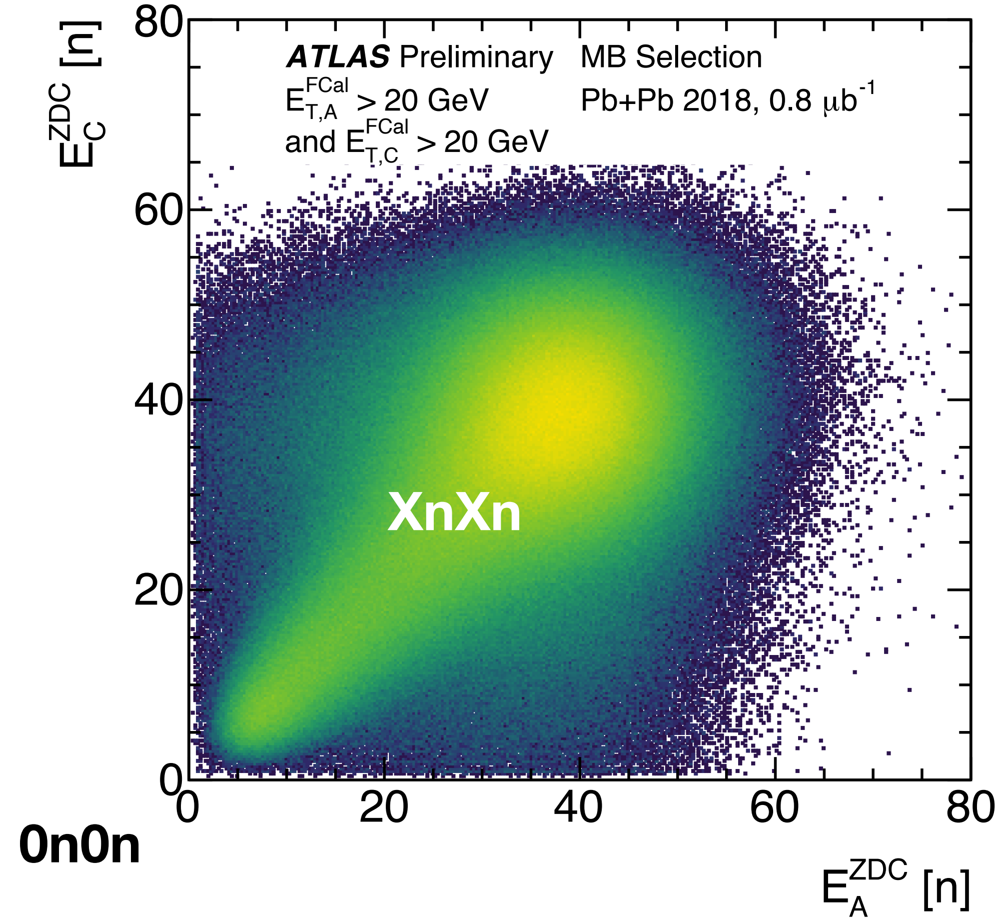




ZDC CORRELATIONS IN Pb+Pb

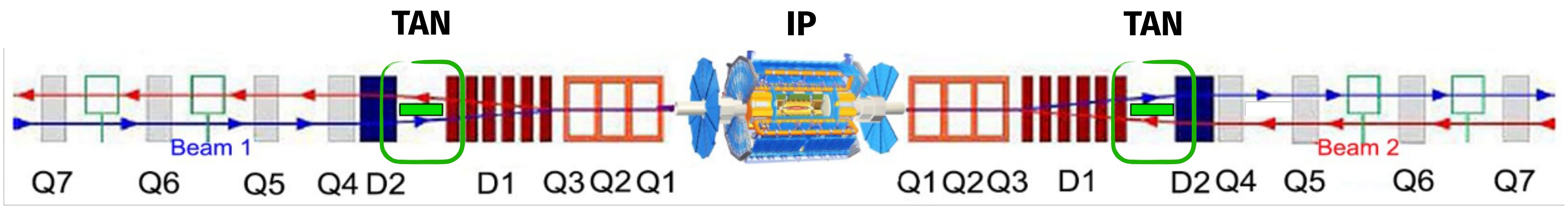


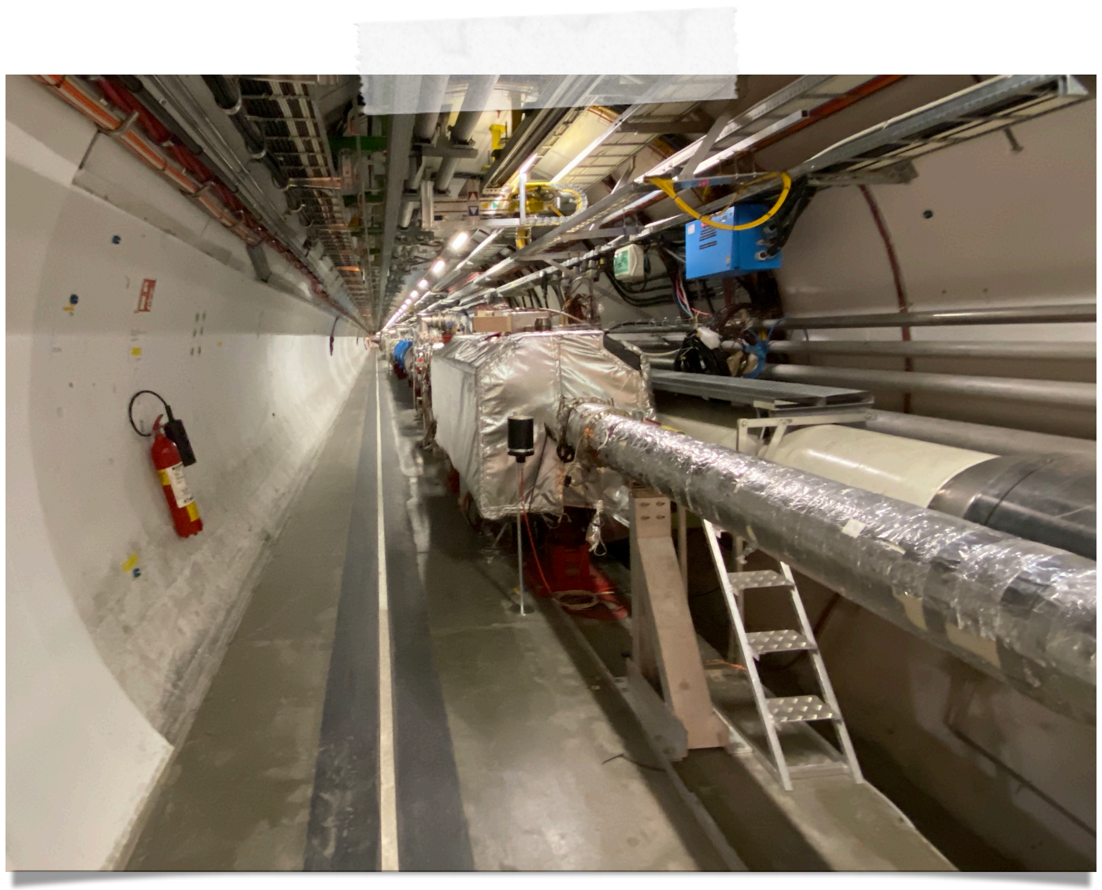


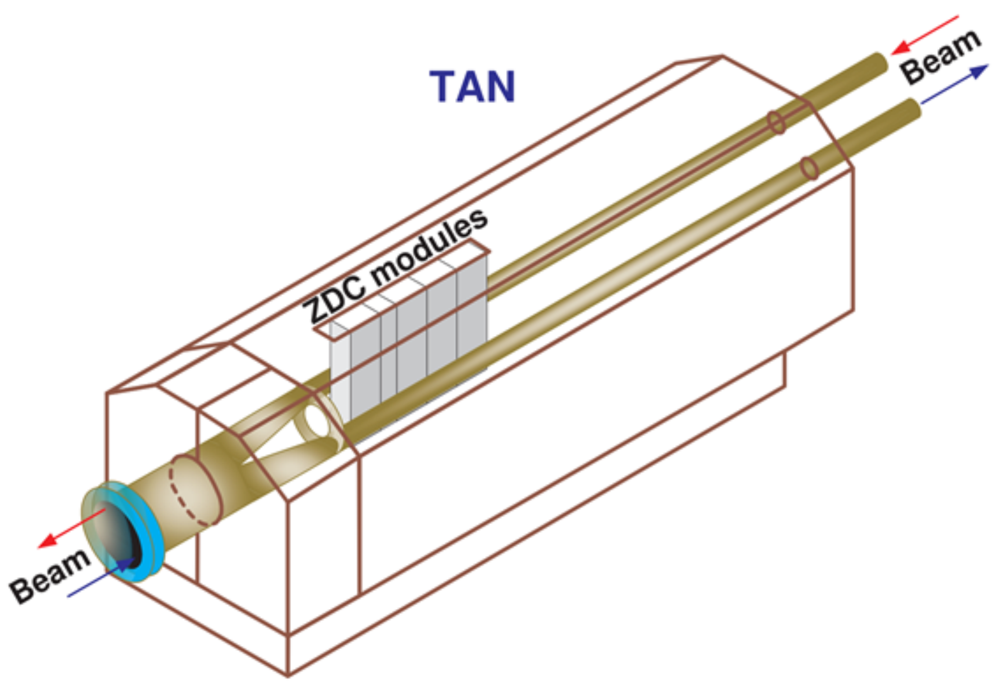


- Correlations of the number of neutrons in each ZDC for substantial energy on both sides (right) or with a gap (left)
  - **ZDCs are critical to distinguish these three physics processes!**
  - Key role at both trigger and analysis level

ZDCs IN ATLAS AND CMS



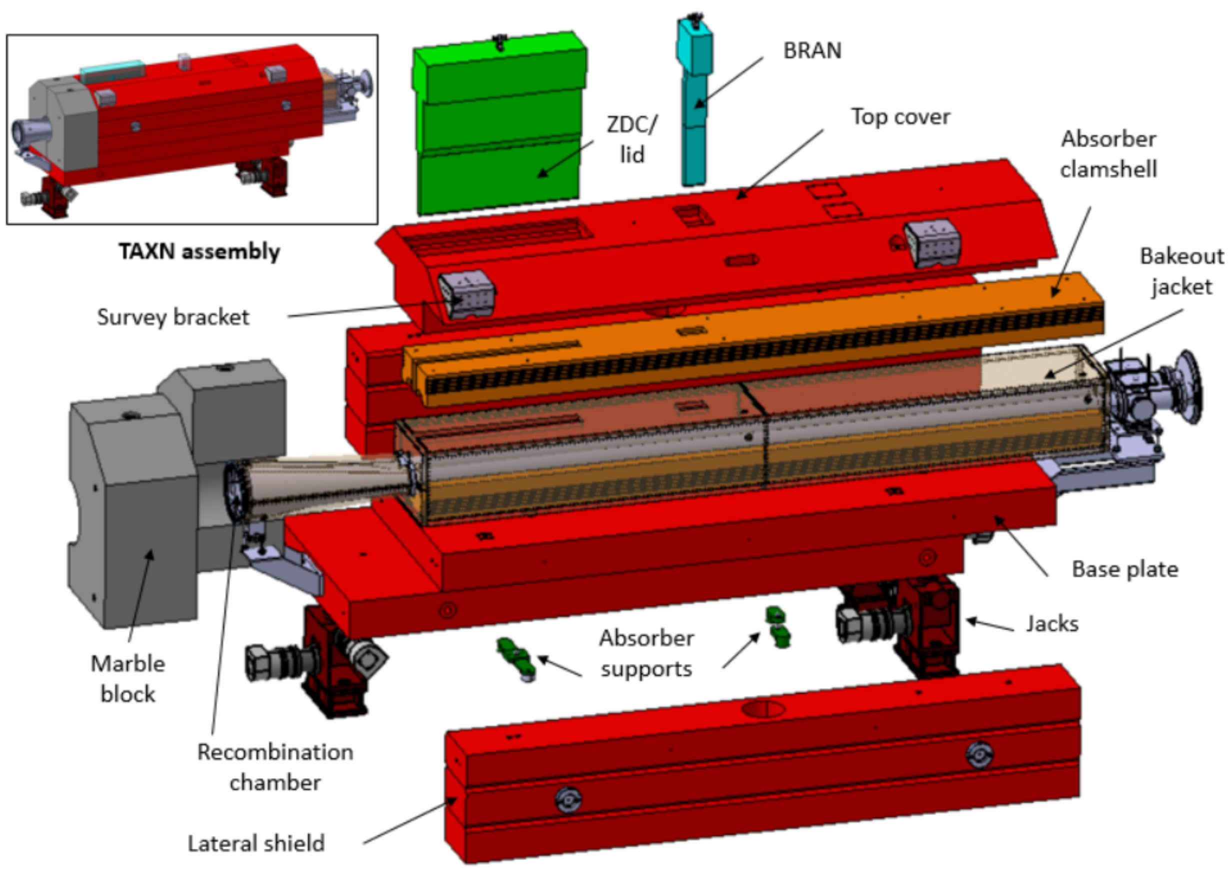


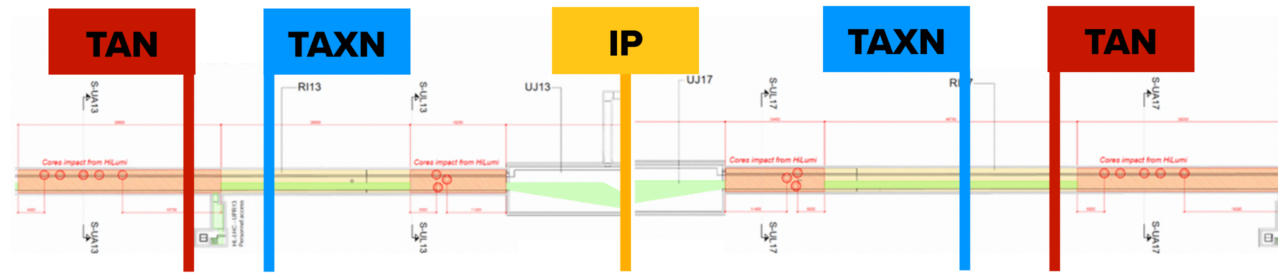


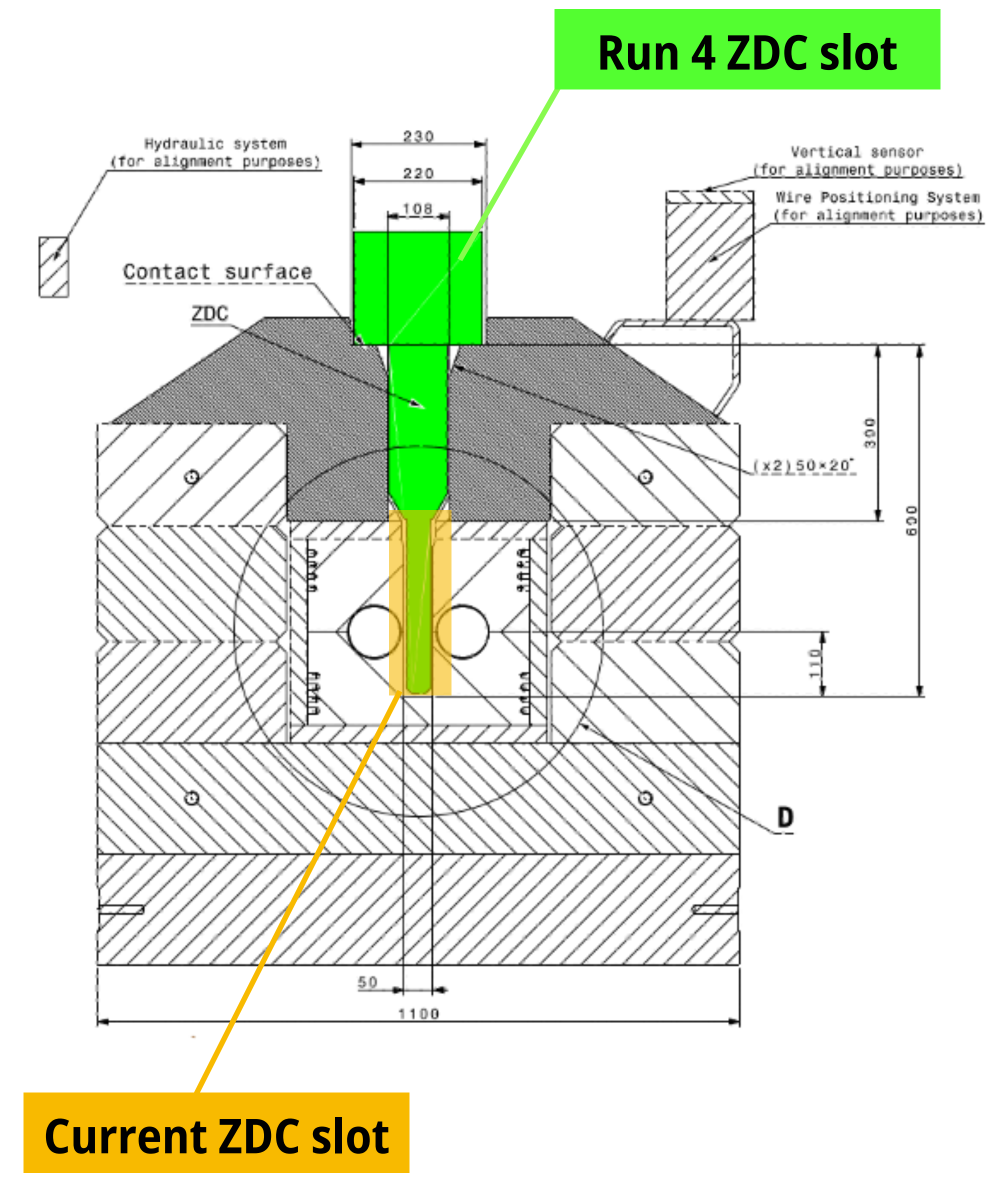
- ZDCs located in the **Target Absorber** for **Neutrals (TAN)**
- TAN located at ±140 m from IPs
- ZDC slot carved out in between the beam pipes in the Cu absorber
- Same absorber design for both ATLAS and CMS

RUN 4 HL-LHC: NEW ABSORBERS FOR NEUTRALS

- New HL-LHC beam optics demands new Target Absorber for Neutrals (TAN ➜ TAXN)
    - Relocated to ± 126 m (currently ± 140 m)







[Phys. Rev. Accel. Beams 25, 053001](#)

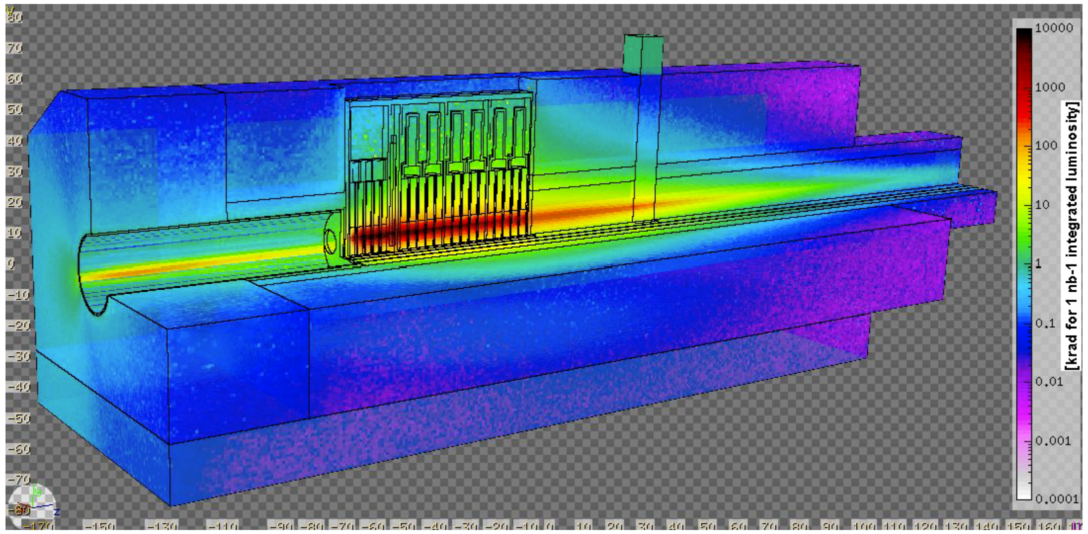
P.Santos Diaz et al., "Mechanical and thermal design of the Target Neutral Beam Absorber for the HL LHC Upgrade"

- Slot for Forward detectors (ZDC, BRAN) narrowed to 5 cm (currently 10 cm)

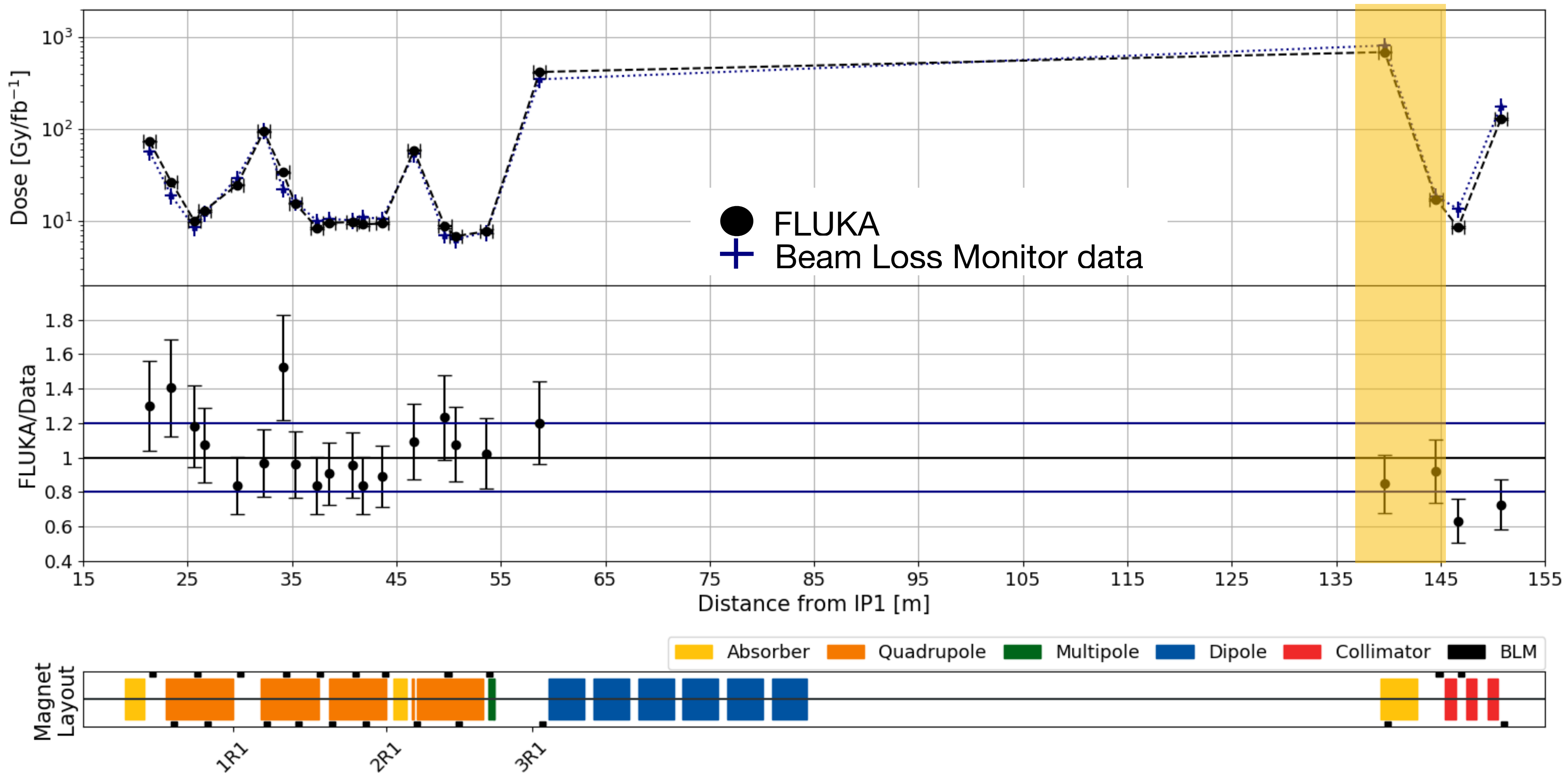
  ➡ **Brand-new detectors need to be built**

RADIATION LEVELS IN THE TAXN

- Radiation levels increase with the HL upgrade of the LHC
- CERN **FLUKA** group (F.Cerutti, M.Sabate Gilarte) provides detailed simulations of the radiation environment in the TA(X)N region
- Comparison between simulations and radiation monitors shows agreement within 20% in the **TAN area**

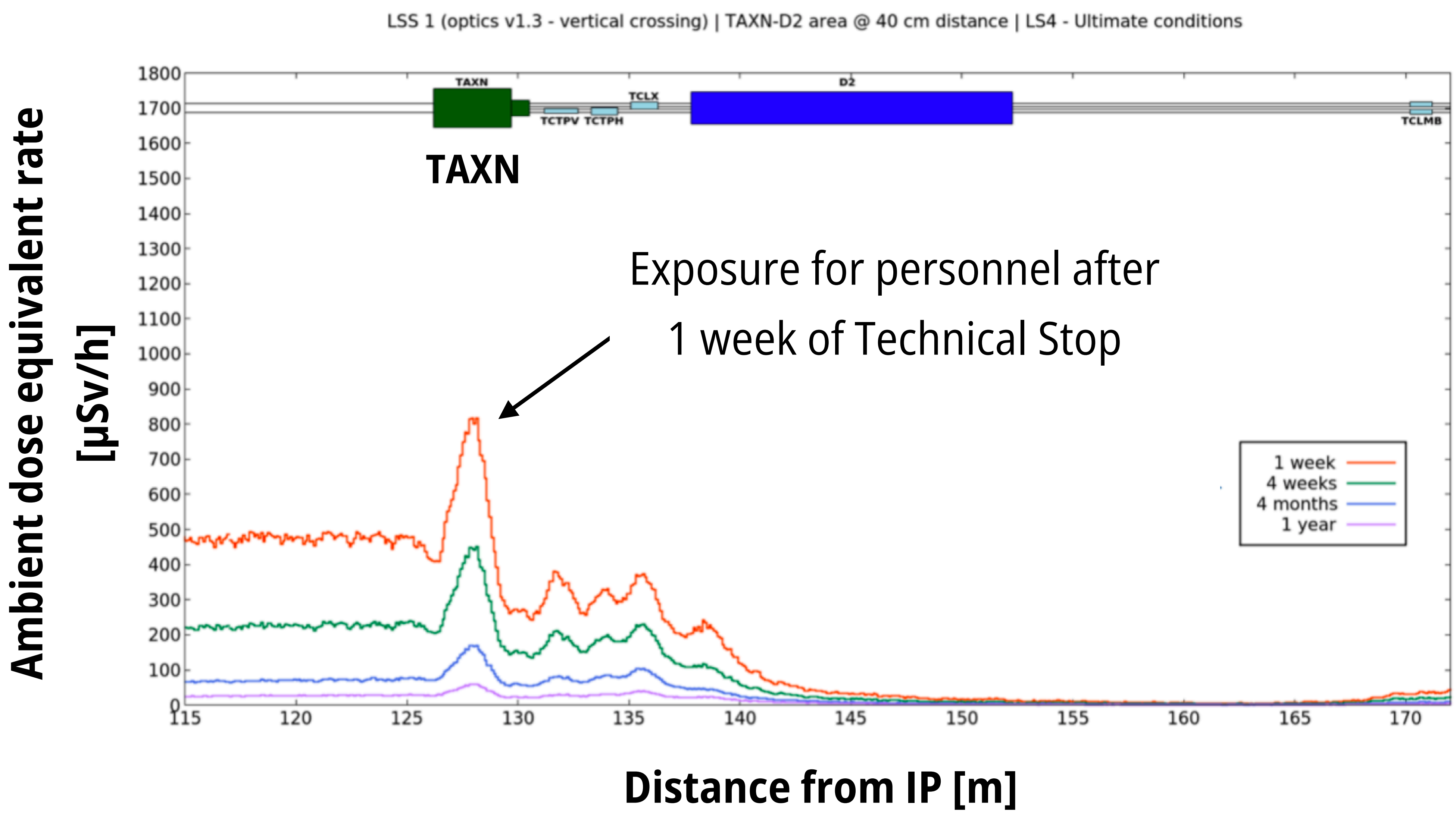


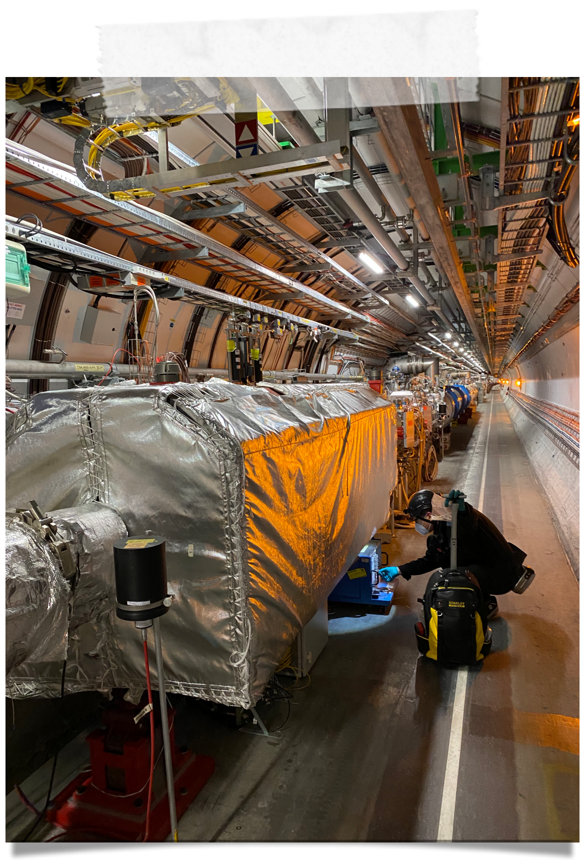
Plot from arXiv:2204.01937



- Radiation levels for Run4 HI program (Pb+Pb, p+Pb, low μ p+p) **~4.5 MGy in total**

RADIATION EXPOSURE DURING INSTALLATION

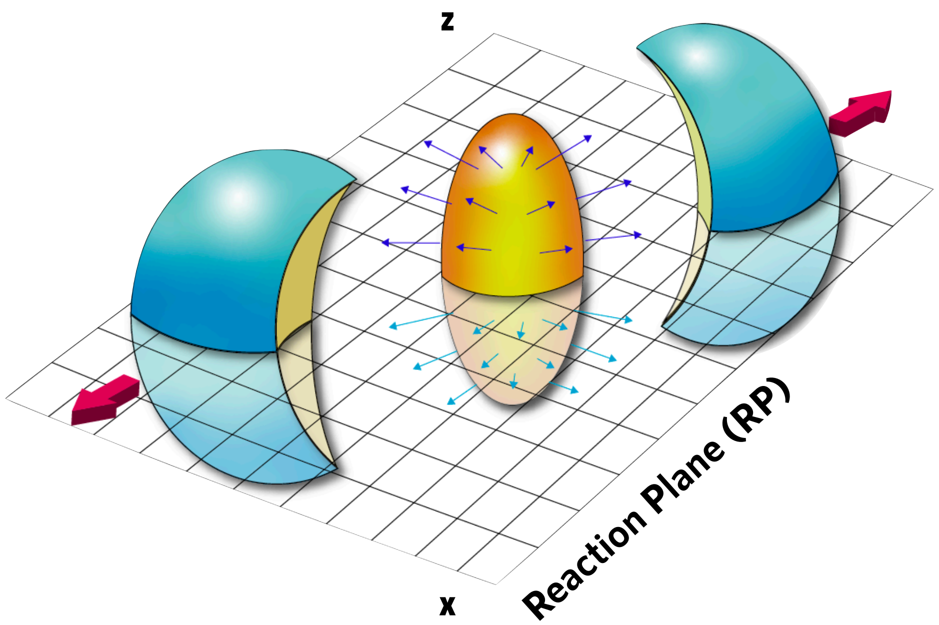


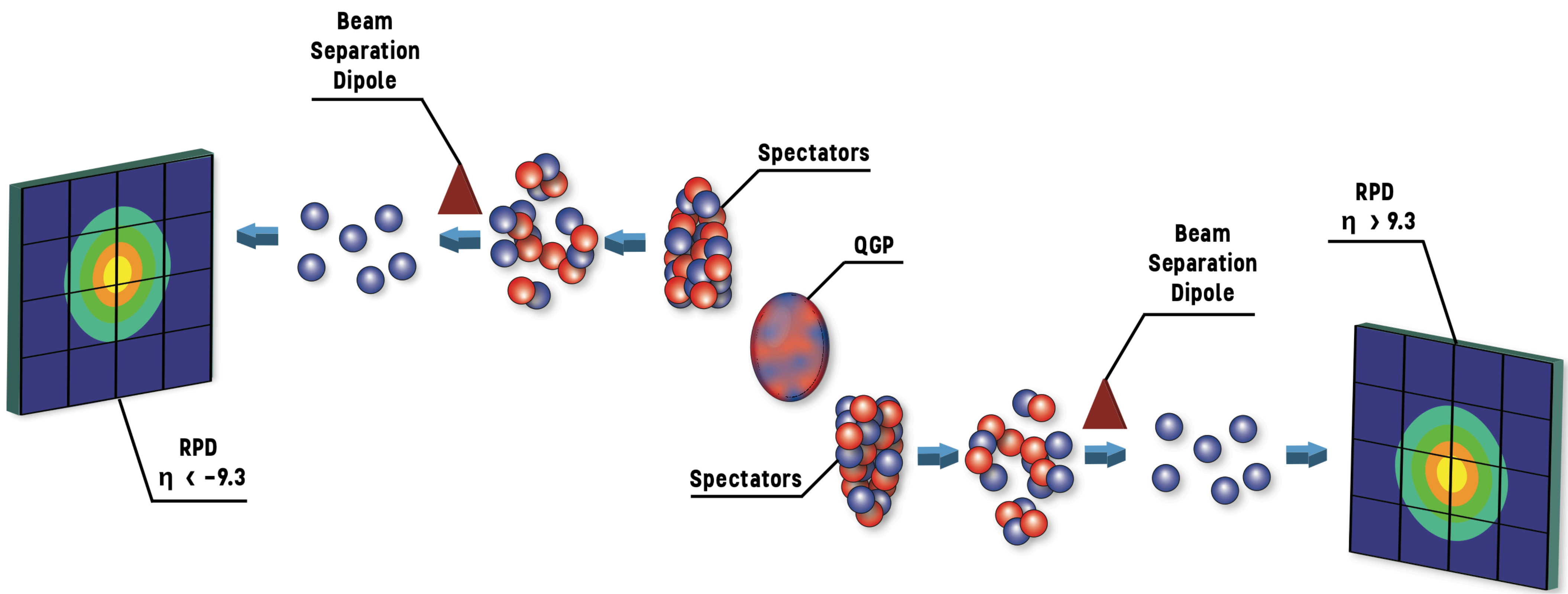


- Hot radiation environment for detector installation after p+p run
  - ➡ **Need for an easily maneuverable and connectible detector - to reduce exposure for personnel**

CHALLENGES &... OPPORTUNITIES

- The HL ZDC Upgrade also offers the opportunity to expand the physics capabilities of the existing detectors
  - Implementation of **Reaction Plane Detector (RPD)** to measure correlated deflection of forward neutrons in the direction of reaction plane **(v_1,"directed flow")**
  - Both ATLAS and CMS will have an RPD in Run 3 - key experience toward Run 4 design & implementation

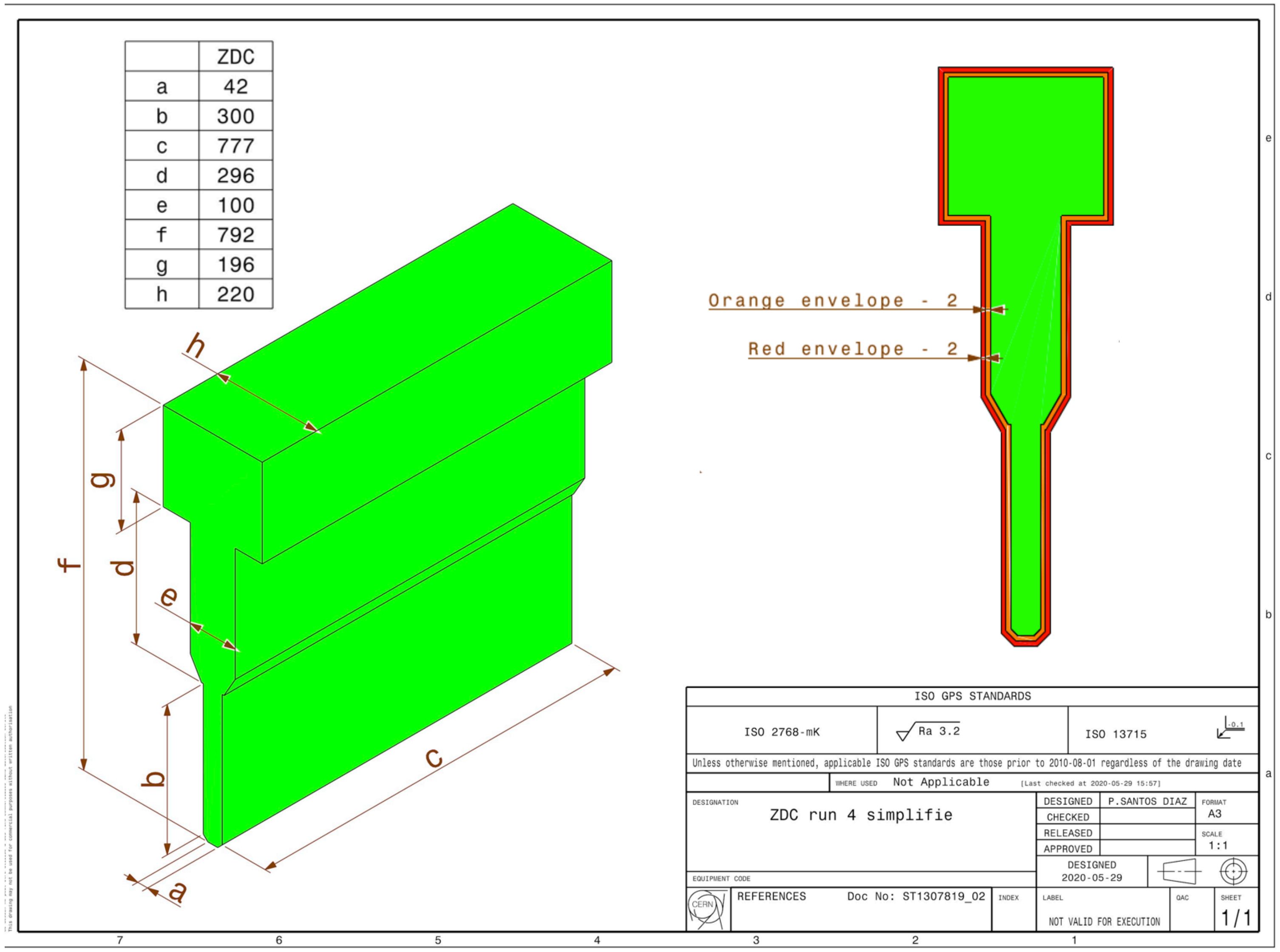




DETECTOR DESIGN AND EXPECTED PERFORMANCE

HL-ZDC DESIGN REQUIREMENTS: SUMMARY

- Rad-hard detector: stable performances during the running period
- Well-controlled energy scale (via good 1n and 2n resolution)
- Good γ/n separation
- Inclusion of a Reaction Plane Detector
- Compatible with TAXN slot constraints
- Easy to connect after craning into TAXN



TAXN ZDC slot - all units in mm - EDMS 2349145

THE JOINT ZERO DEGREE CALORIMETER PROJECT

JZCaP

- About 35 scientists from 6 different institutions
- Share expertise and resources for R&D on rad-hard ZDC & RPD technology
- Cost efficiencies

CMS Compact Muon Solenoid

THE UNIVERSITY OF KANSAS

UNIVERSITY OF MARYLAND

ATLAS EXPERIMENT

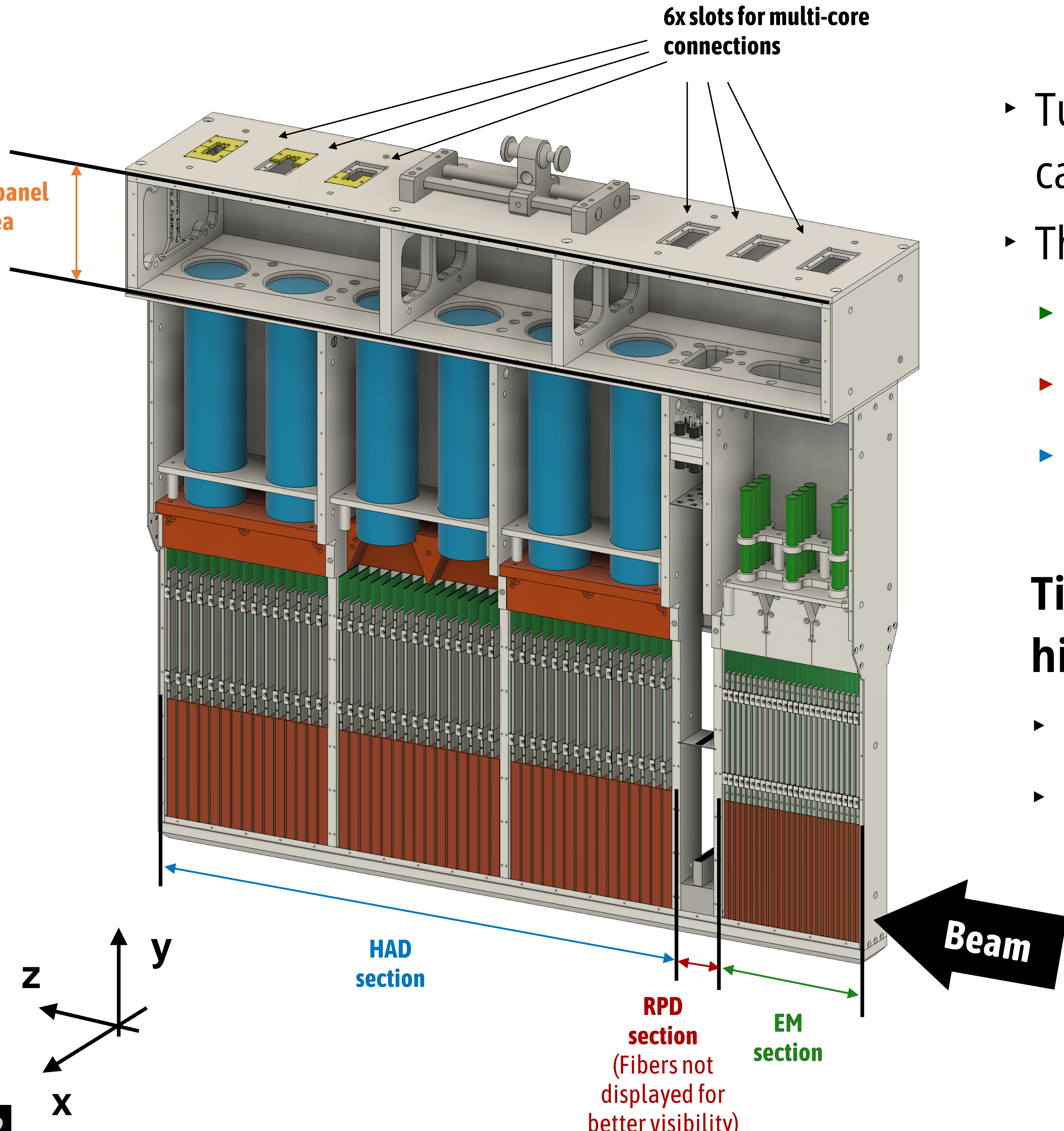
Ben-Gurion University of the Negev

Columbia University in the City of New York

Brookhaven National Laboratory

University of Illinois Urbana-Champaign

HL-ZDC DESIGN

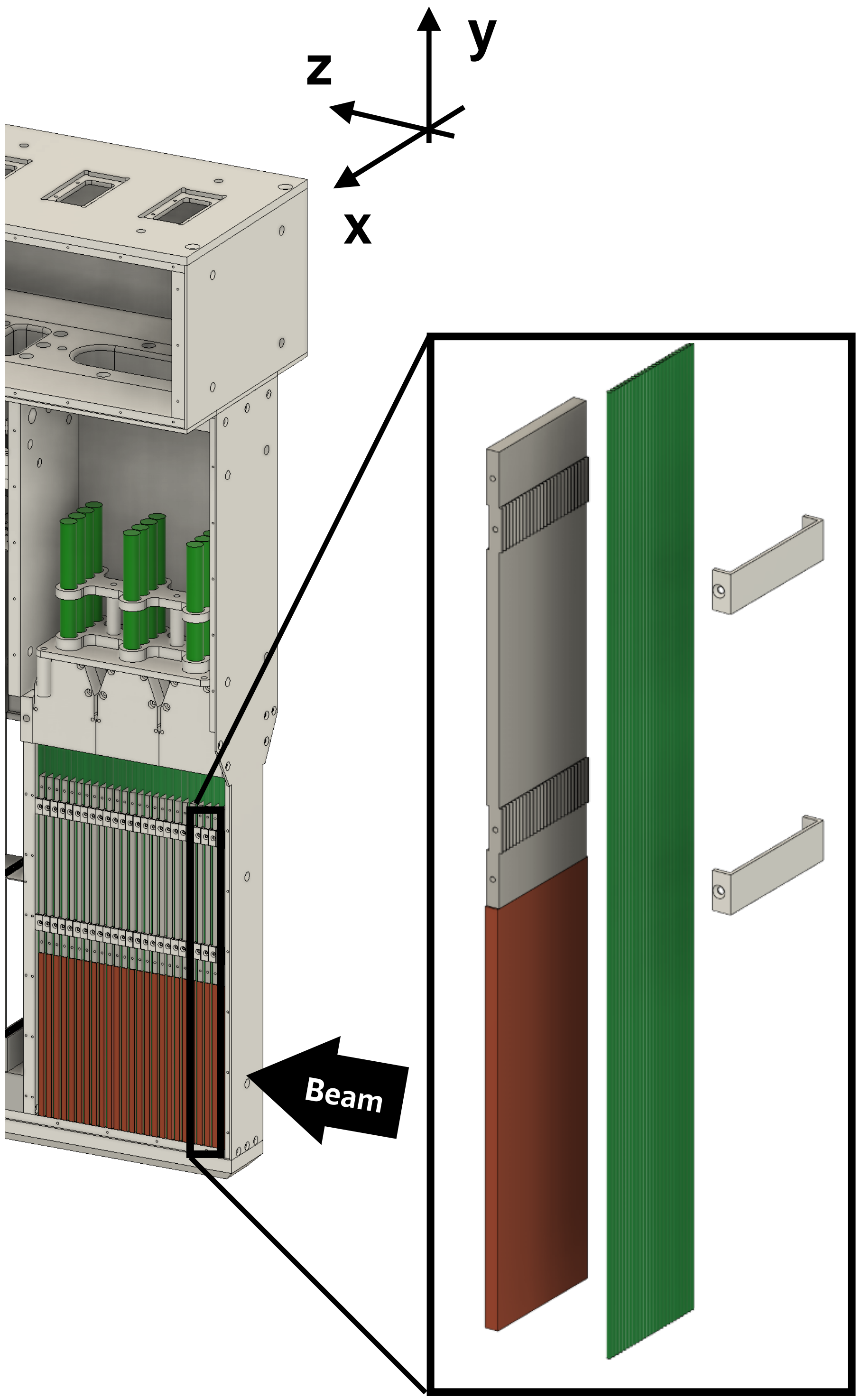


- Tungsten - fused silica sampling calorimeter
- Three sections:
  - **Electromagnetic (EM)**
  - **Reaction Plane Detector (RPD)**
  - **Hadronic (HAD)**

Time-efficient installation in high-radiation environment

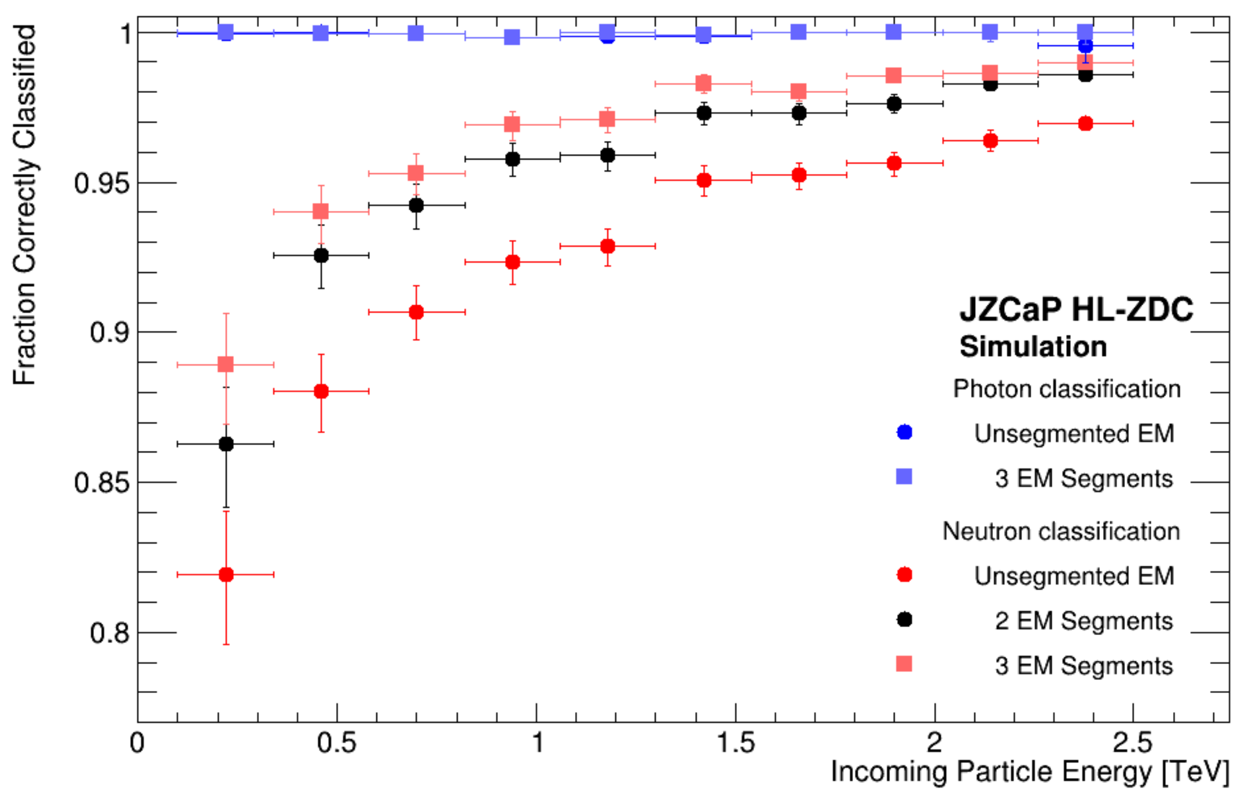
- Single module structure
- **Patch panels** for rapid cabling

EM SECTION



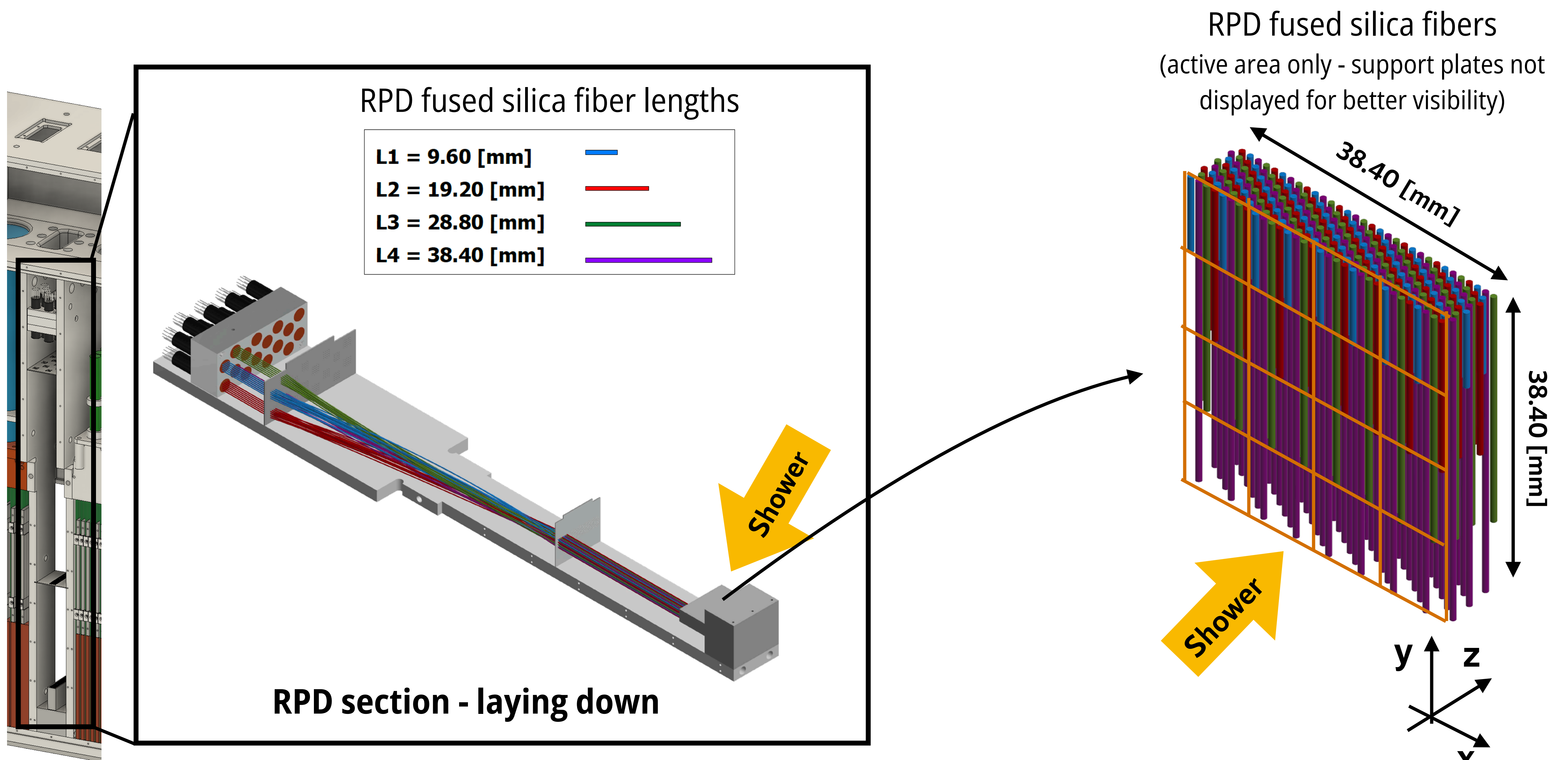
EM sampling layer

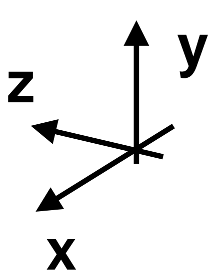
- Total of 25 sampling layers, each composed of:
  - 4 mm tungsten plate
  - Fused silica rods array (25 rods of ϕ = 1.5 mm)
- Total EM Material budget: **28.5 X_0, 1 λ_{int}**
- *x-z* segmentation
  - *z* segments to enable γ/n discrimination
  - *x* segments to locate beam in case of horizontal crossing angles



- Basic γ/n discrimination algorithms using the light fraction in the longitudinal segments show ~99% efficiency for n identification and even higher performance for photons

RPD SECTION: PAN FLUTE DESIGN

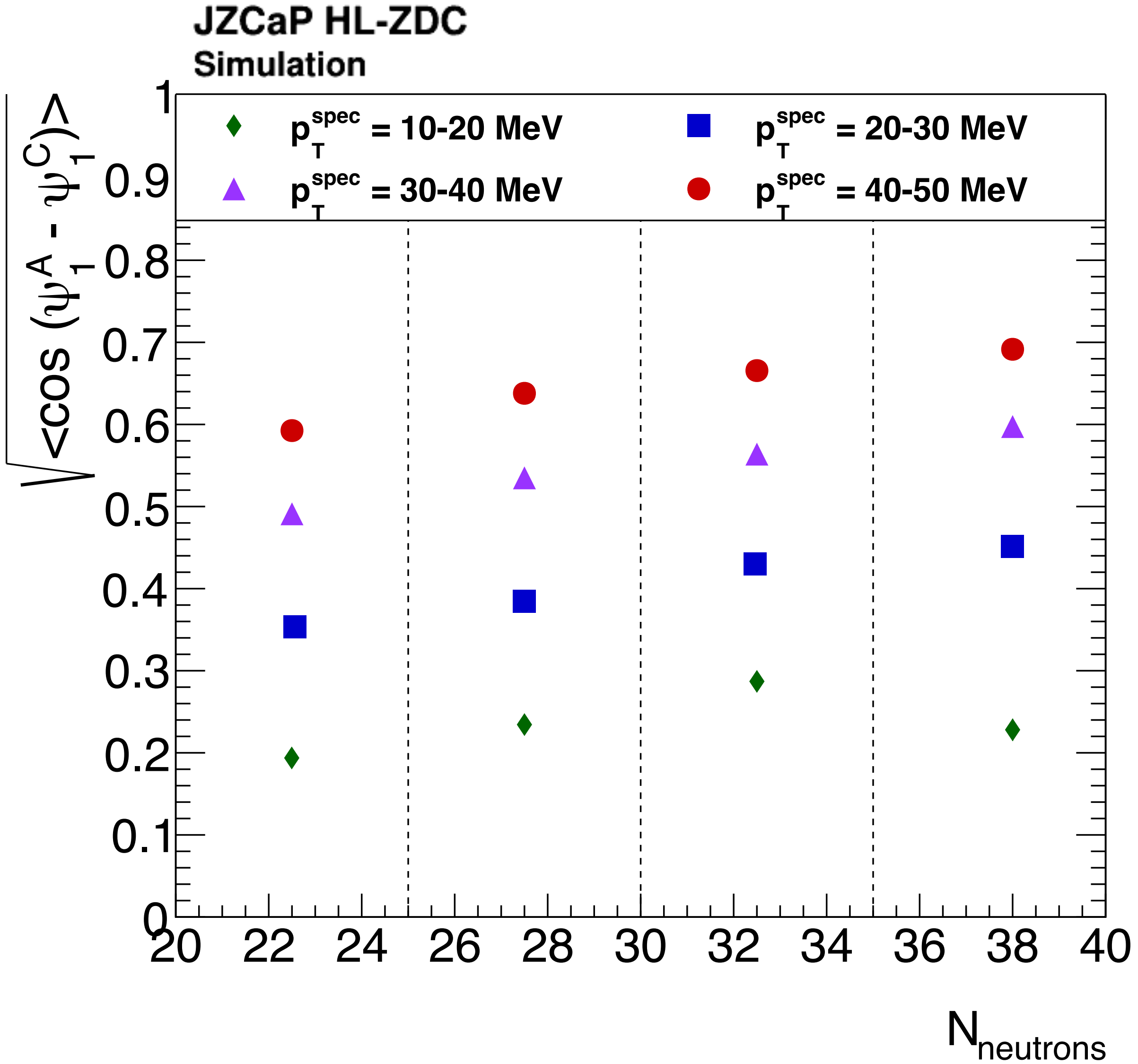




- Signal from 8 layers of staggered fibers of 4 different lengths collected by 16 PMTs
- Rad-hard fused silica fibers, ϕ = 710 μm, that acts as both Cherenkov radiator and readout fibers
- Fiber pattern provides an effective 4x4 tile segmentation, but requires dedicated algorithm to account for the fiber overlap
- Machine Learning reconstruction algorithms to maximize performance

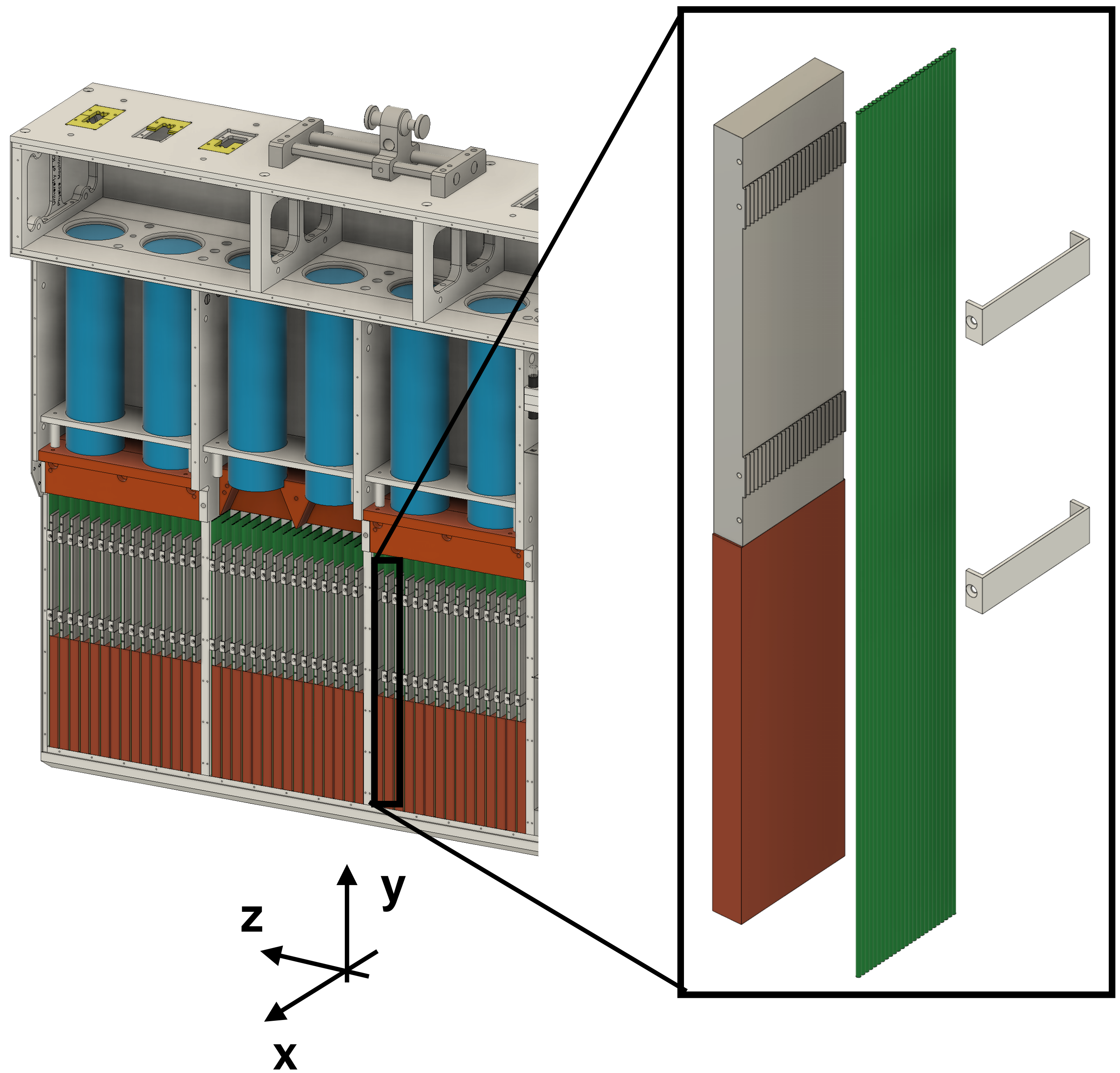
RPD PERFORMANCE W/ MACHINE LEARNING

- Characterization of RPD performance by "**resolution**", $\sqrt{\langle\cos(\psi_1^A - \psi_1^C)\rangle}$, built comparing ψ values measured from different (parts of) detectors
- Actually a multiplicative factor used to correct measurements of flow coefficients
- **ML algorithms** tested on MC data
  - Resolution will depend on still poorly known physics
    - p_T kick / nucleon - only results available at LHC energies from ALICE @ 2.76 TeV, PRL 111 (2013) 232302
  - The RPD will be sufficient to provide access to new physics measurements also in cases of low p_T kick
  - Performance comparable w/ STAR SMD, J.Phys.G 34 (2007) S1093-1098

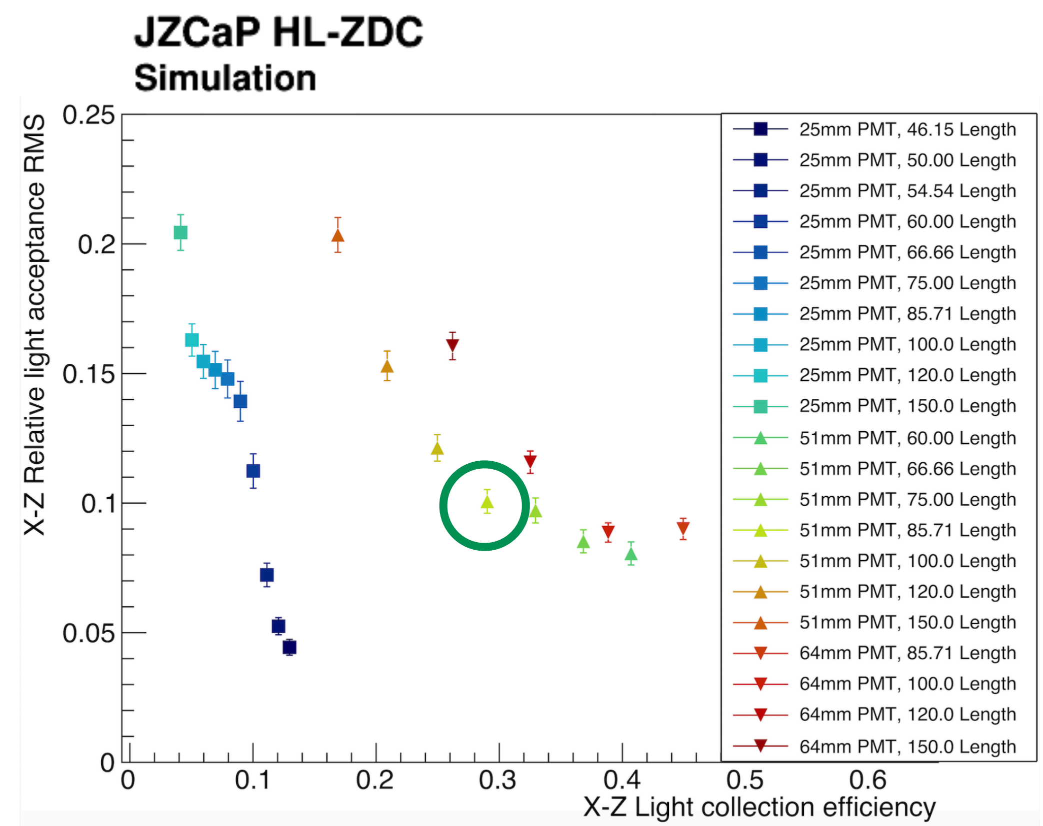


HAD SECTION

HAD sampling layer



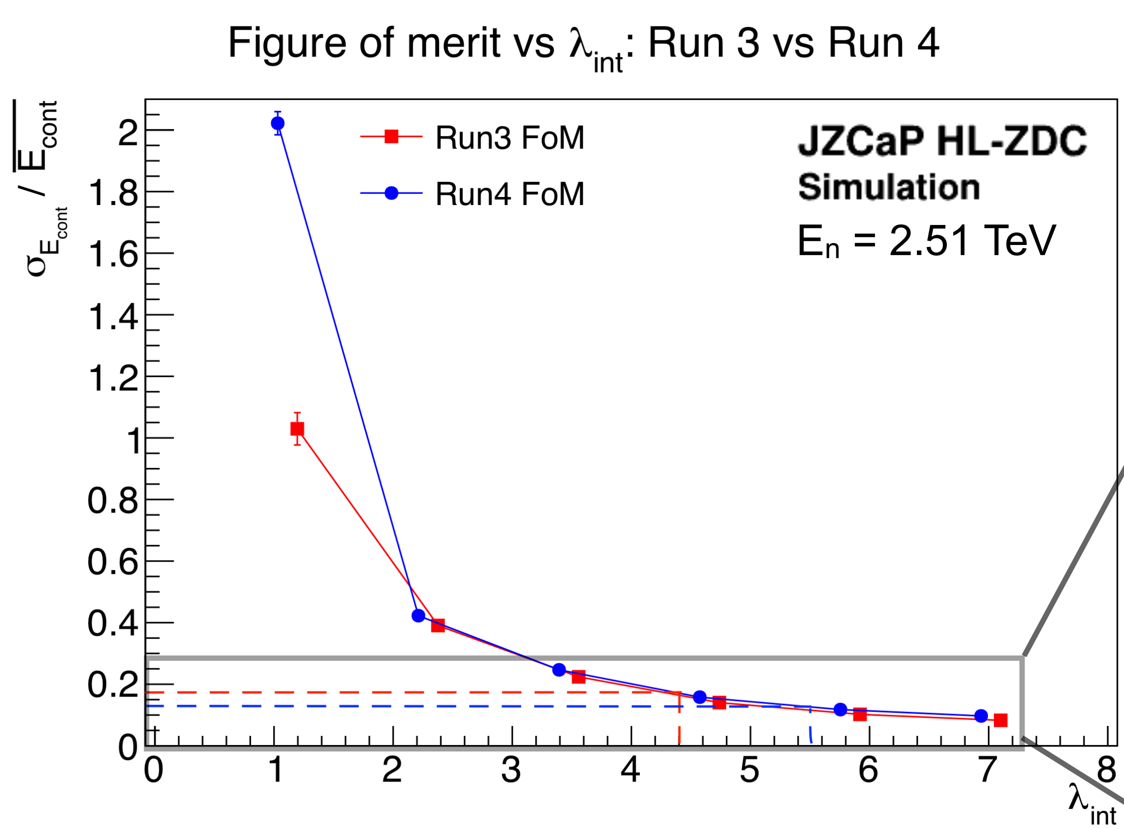
- Total of 45 sampling layers, each composed of:
  - 10 mm tungsten plate
  - Fused silica rods array (25 rods of ϕ = 1.5 mm)
- Total HADs Material budget: **4.5 λ_{int}**
- 6 PMTs coupled with trapezoidal light-guides

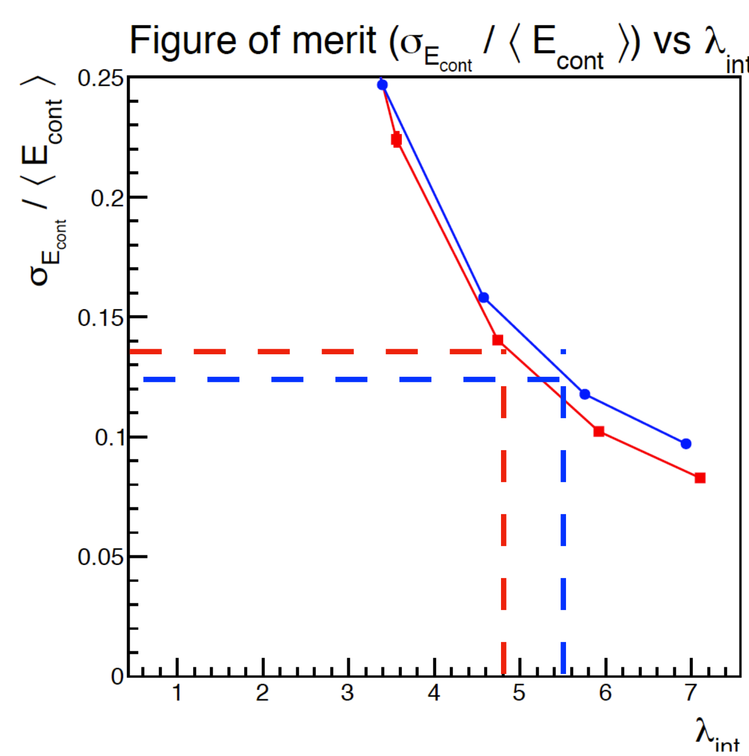


HAD light guide efficiency study

ZDC ENERGY RESOLUTION

- Geant4 simulations carried out to optimize detector design
- Reduced transverse acceptance in the TAXN implies less containment at the same depth
  - But for λ > 2, fluctuations dominate
- Current ZDCs have ~4.4 λ and BRAN detector in between EM and HAD sections
- Effort done to secure a longer slot for ZDC only in the TAXN
  - HL-ZDC will have a total of **5.5 λ** w/o BRAN detector in between





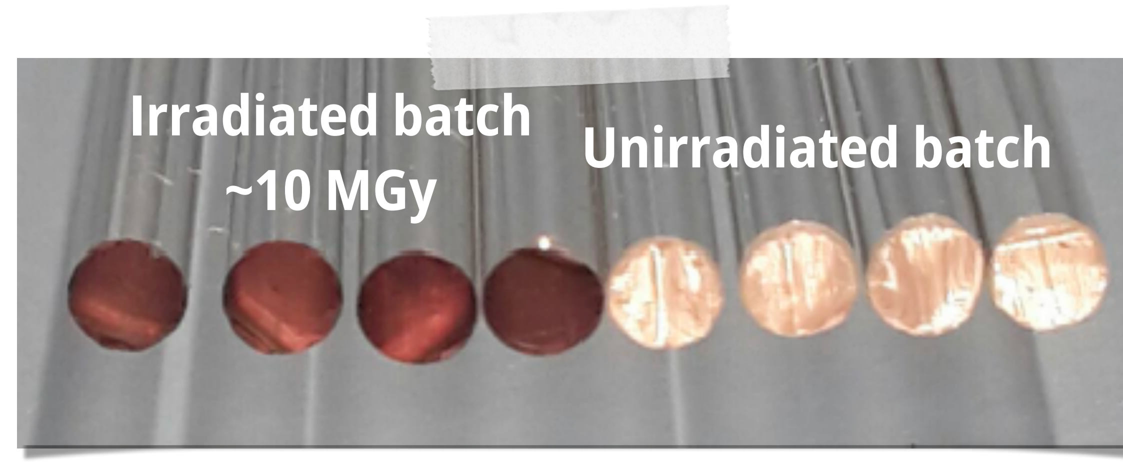
Similar containment, but HL-ZDC has better resolution!

R&D HIGHLIGHTS

FLUKA-BRAN-JZCAP R&D ON RAD-HARD MATERIALS

- Radiation hardness challenge common for all the forward detectors - in particular for those sitting in the TA(X)N, e.g. BRAN, ZDC
- Joint R&D effort on radiation hardness of **fused silica materials** started during Run 2
- Fused silica rod with different material composition purchased from Heraeus Group

Fused quartz irradiated in the ATLAS ZDC during Run 1 p+p beam time

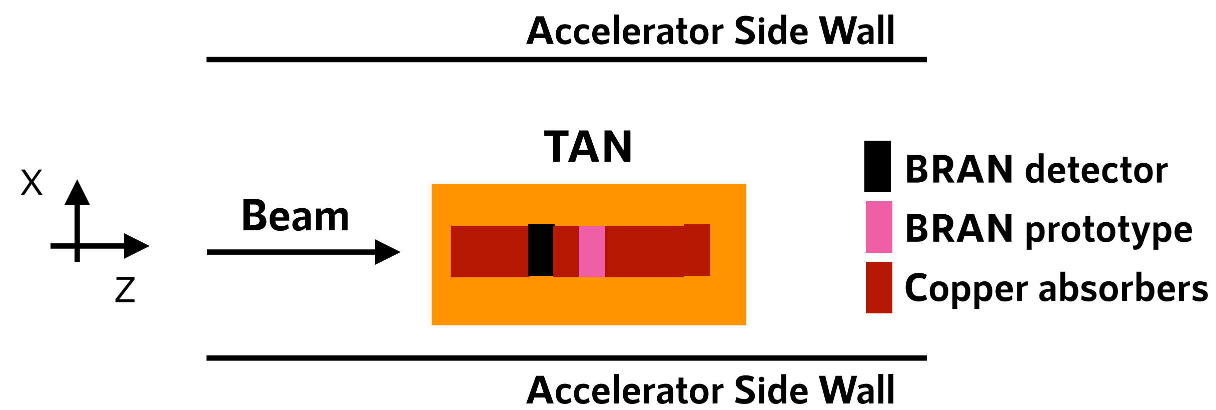


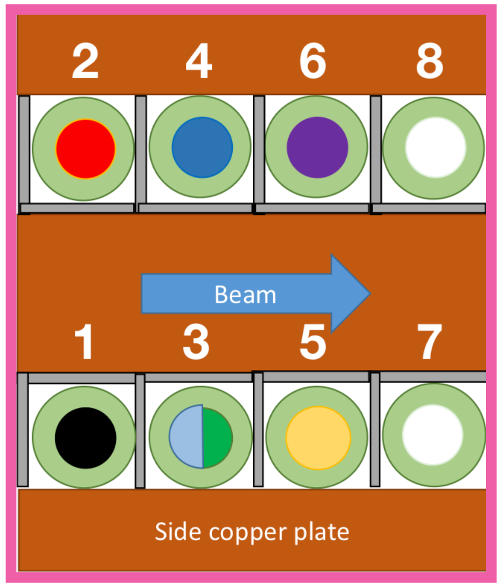
CERN FLUKA group
Francesco Cerutti
Marta Sabate Gilarte

CERN BRAN group
William Andreazza
Enrico Bravin
Sune Jakobsen
Stefano Mazzoni
Marcus Palm

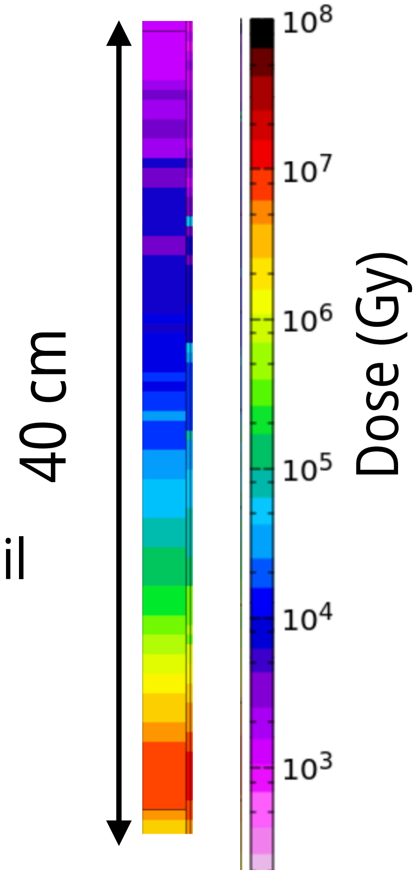
RUN2 IRRADIATION CAMPAIGN

Bran Position	Irradiation Period	Max. Dose (MGy)	Material
Control	None	0	Spectrosil 2000 (High OH, Mid H_2)
1	04/2016 - 12/2018	18	Spectrosil 2000 (High OH, Mid H_2)
2	04/2016 - 12/2017	10	Spectrosil 2000 (High OH, Mid H_2)
3a	04/2016 - 12/2016	5	Spectrosil 2000 (High OH, High H_2)
3b	04/2017 - 12/2018	16	Spectrosil 2000 (High OH, Mid H_2)
4	04/2016 - 12/2017	9	Spectrosil 2000 (High OH, H_2 free)
5	04/2016- 12/2017	8	Suprasil 3301 (Low OH, High H_2)
6	04/2016 - 12/2018	17	Suprasil 3301 (Low OH, H_2 free)



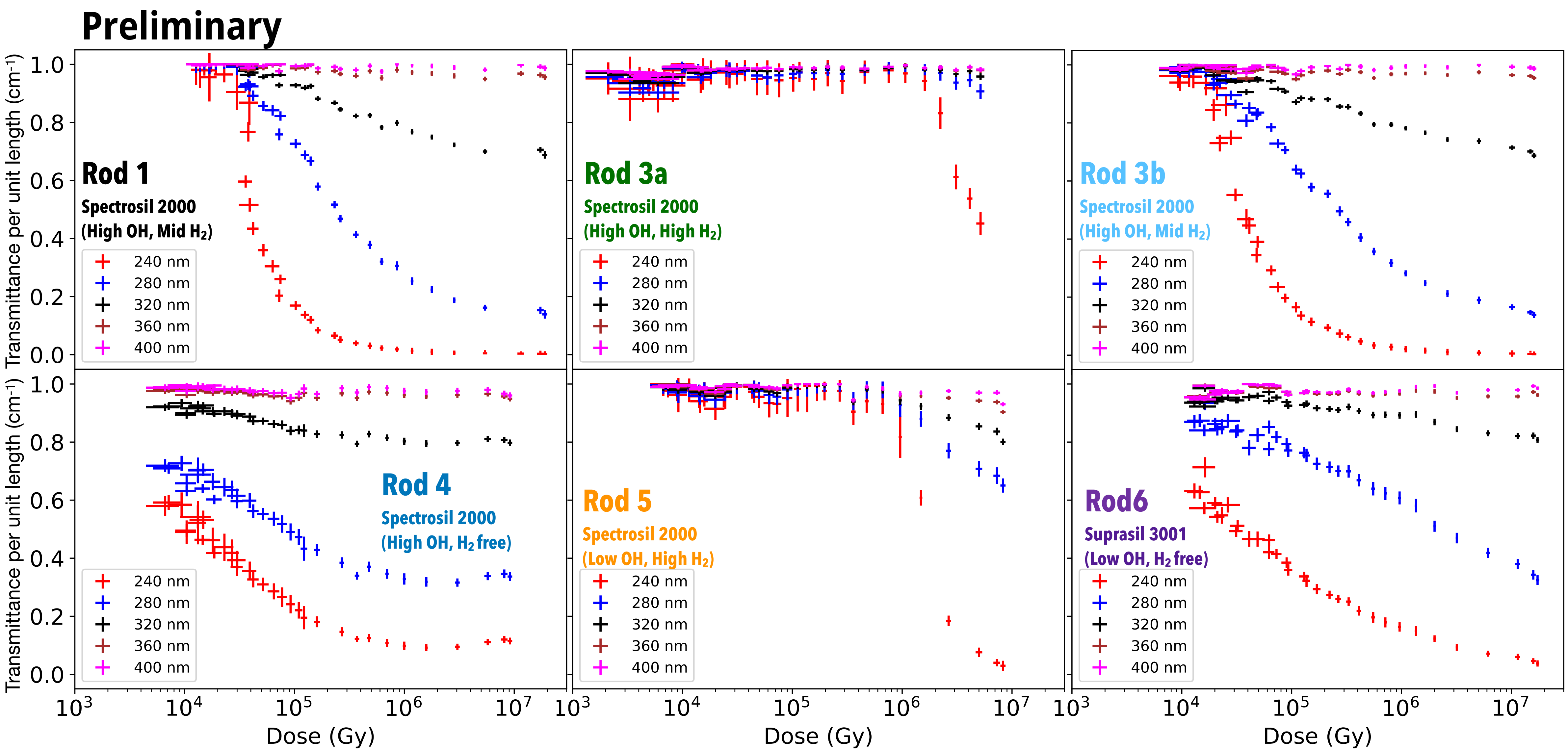


Dose profile along one rod (1 year of run)



- **Fused silica rods irradiated over 3 years (2016-2018) in the TAN (IP1), in a BRAN detector prototype**
  - Heraeus high-purity fused silica rods with different dopant, $\mathbf{H_2}$ and **OH**, levels
- **TAN irradiated by the shower of forward neutral particles**
  - Unique environment where irradiation occurs by means of a high-energy particle cocktail
  - BRAN rods irradiated during Run 2 received dose spanning over four orders of magnitude
  - Dose accumulated on different rod segments determined using FLUKA simulations

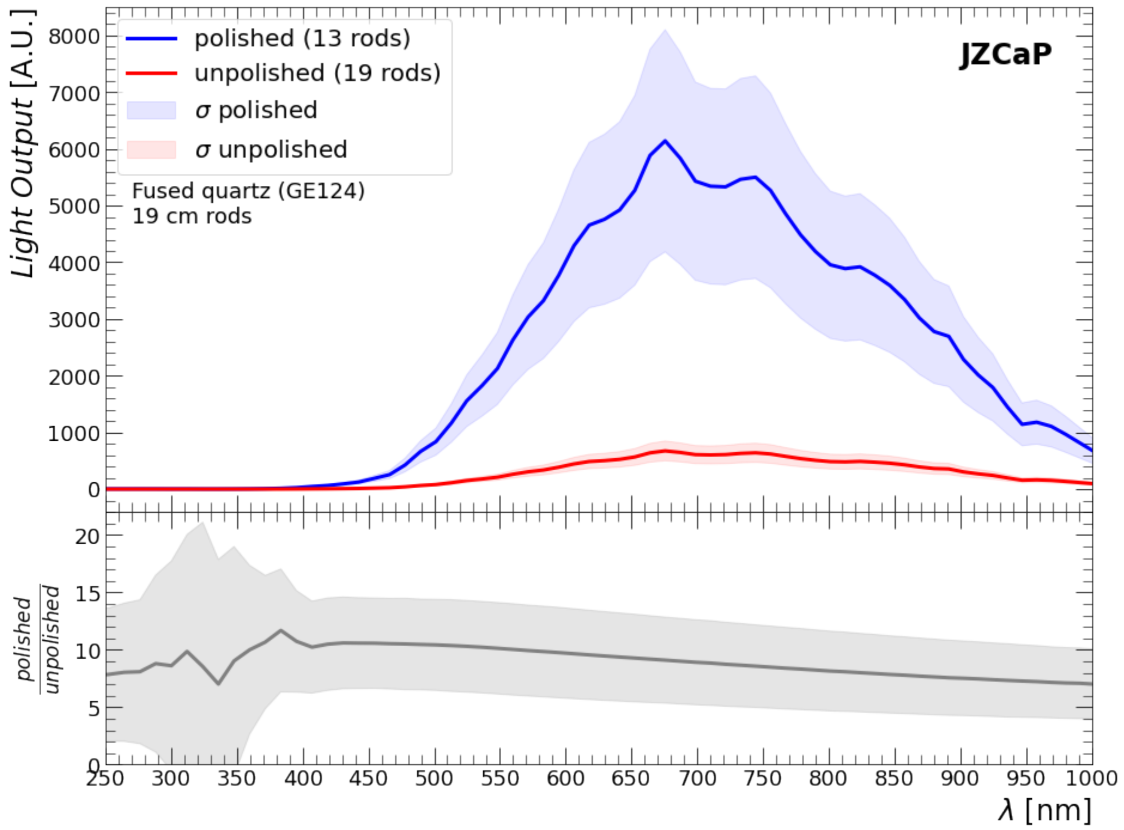
FUSED SILICA TRANSMISSION VS DOSE

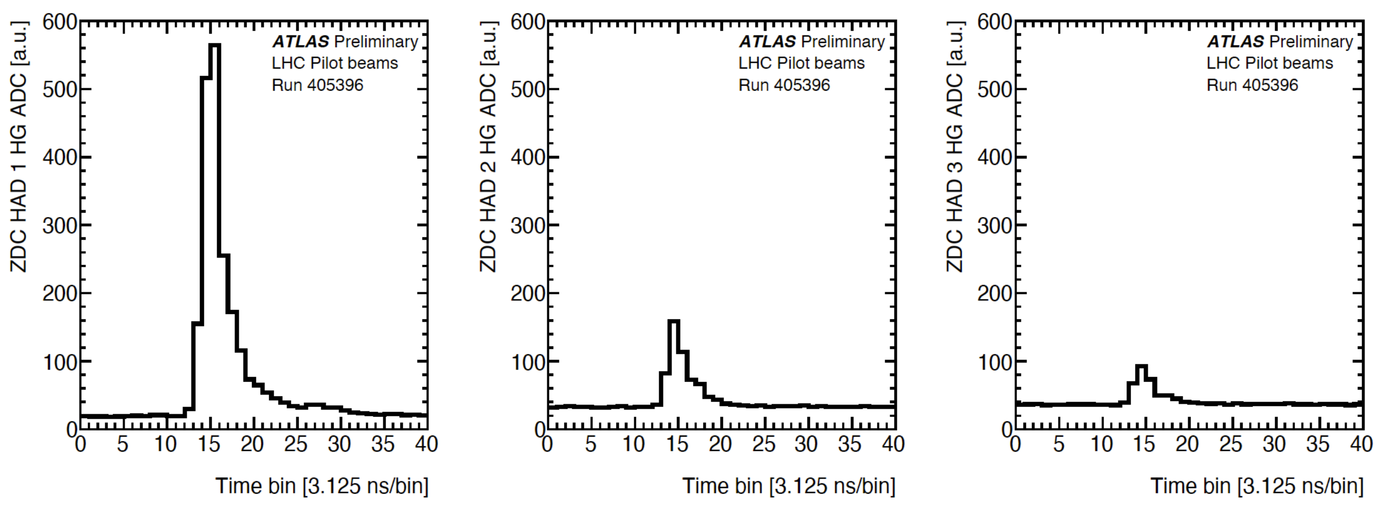


- Analysis that correlates wavelength, transmittance, dose received and material composition
- Results informed the choice of the **new material (Spectrosil 2000, High OH, High H_2)** for **ATLAS Run 3 ZDC refurbishment**
  - No relevant losses in the irradiation range expected on the ZDC in Run 3 (~1.4 MGy)
- Analysis mostly completed - publication currently being drafted
- **New campaign in Run 3** - will extend the irradiation range of ~1 order of magnitude

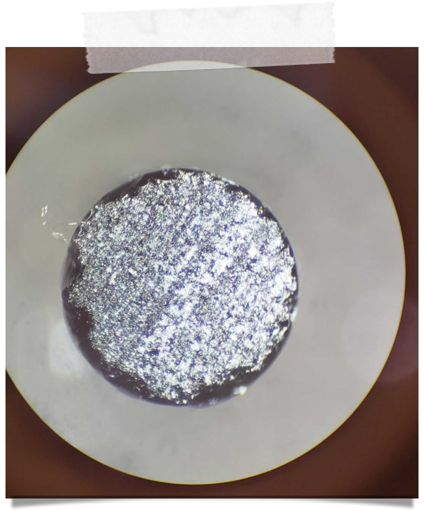
ROD'S END POLISHING

- Fused silica rods used for EM and HAD sections will be polished on the extremity facing the light guide, to minimize light losses
- Polishing setup established & tested for ATLAS ZDC refurbishing with fused silica rods in view of Run 3 (Summer 2021 - 6000 rods polished)





Refurbished ATLAS ZDC, LHC pilot beam, [October 2021]
ATL-COM-FWD-2021-025



Unpolished Rod

Polished Rod

SUMMARY

- **ATLAS & CMS ZDCs face similar challenges in view of Run 4**
  - TAN upgrade to TAXN: reduction of ZDC's slot width
  - Increasing radiation levels on ZDC & exposure during installation
- **ATLAS & CMS ZDC groups teamed up in the Joint Zero Degree Calorimeter Project to tackle these challenges and design the next generation of ZDC for the HL-LHC**
  - Share expertise and resources for R&D on rad-hard ZDC & RPD technology + Cost efficiencies
- **Detector Design**
  - Radiation hard detector design ready and fully integrated with the accelerator lattice
  - Better performance than the existing detectors
  - New RPD for reaction plane measurement using spectators' deflection
- **R&D**
  - **Phase I (Run 2 & LS2):** identification of radiation hard fused silica materials, optimization of light transmission & collection
  - **Phase II (Run 3 & LS3):** new irradiation studies + Run 3 experience (performance refurbished ATLAS ZDC, CMS & ATLAS RPDs)

THANK YOU FOR YOUR ATTENTION!

BACKUP SLIDES