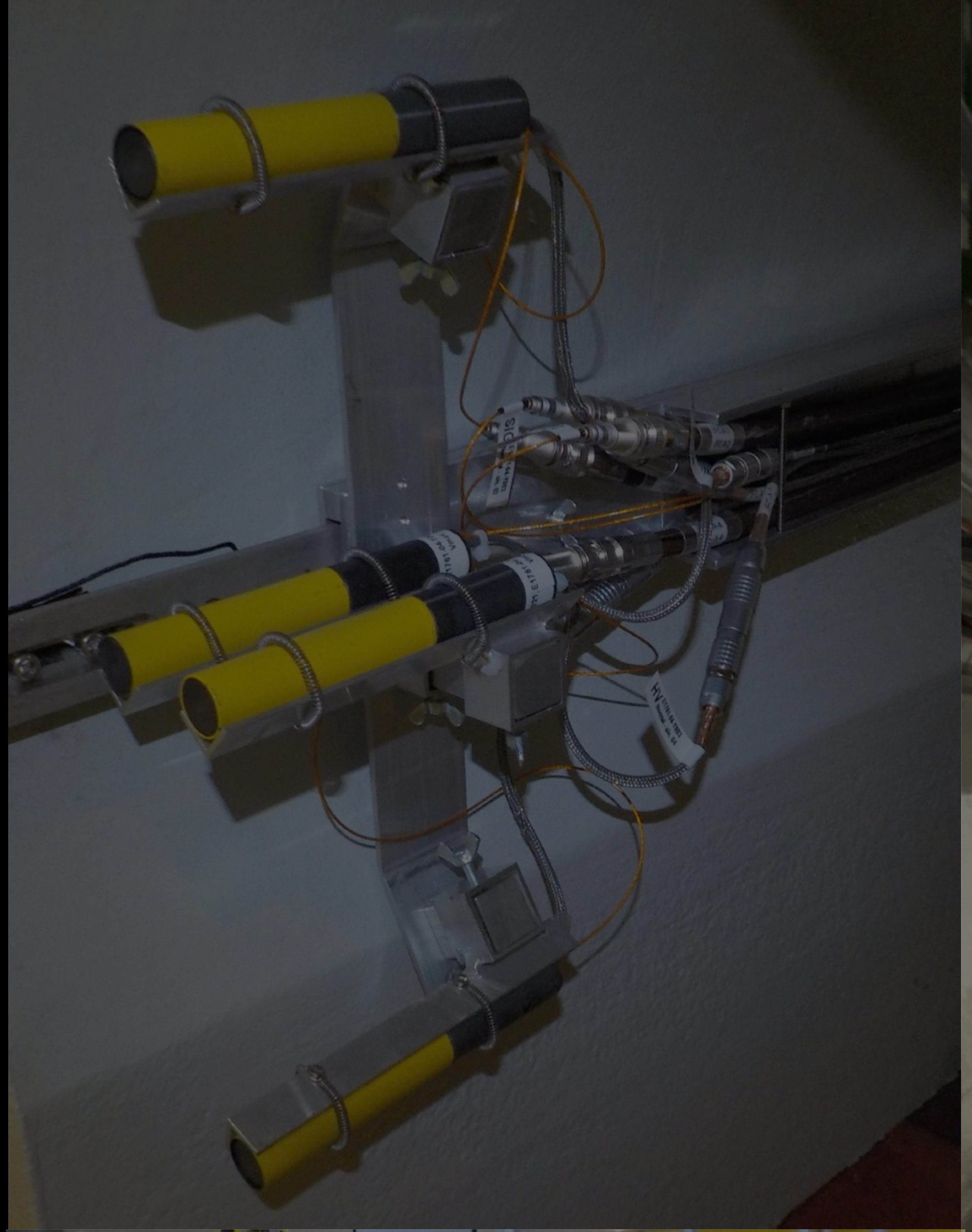
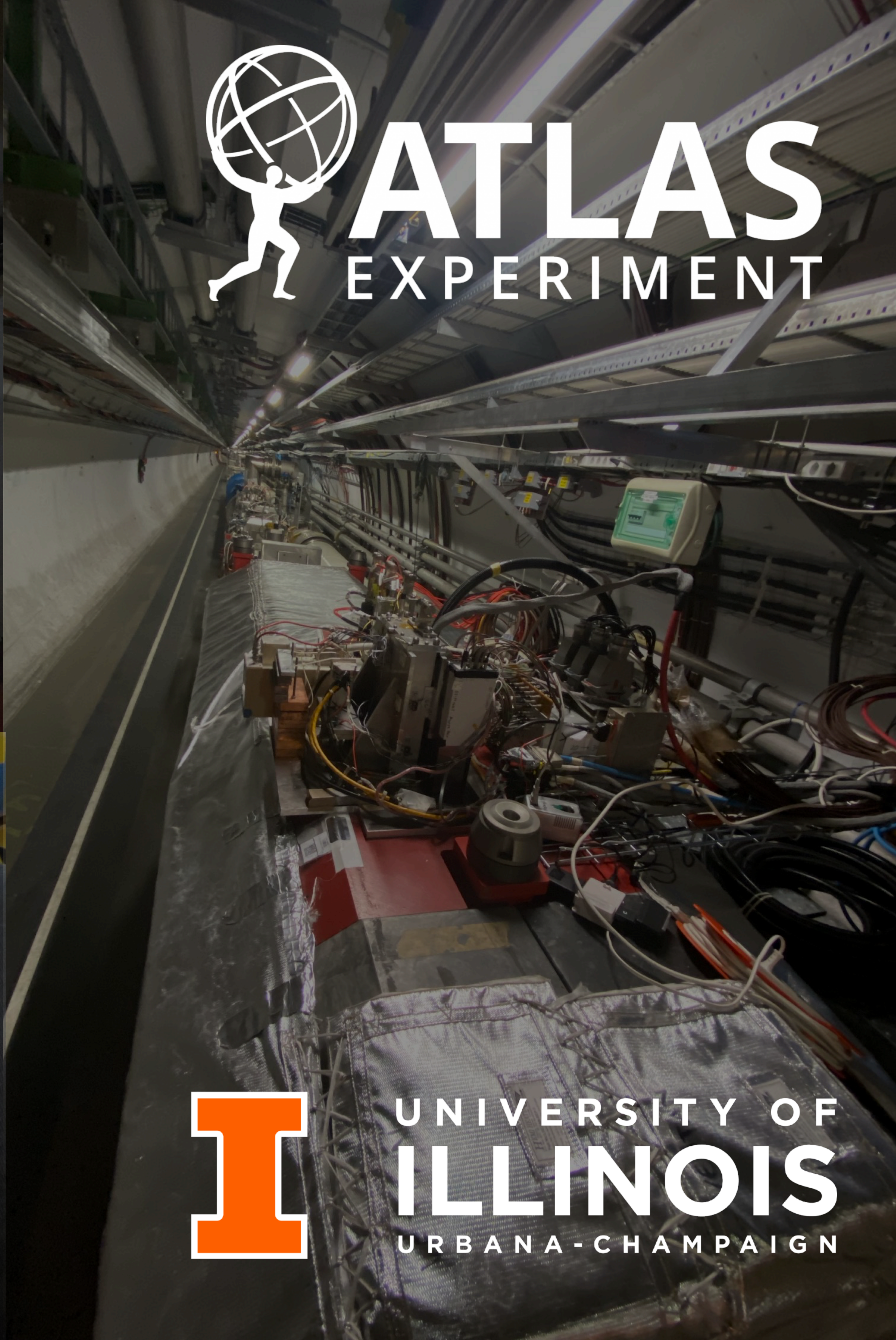
ATLAS FORWARD DETECTORS IN THE HL-LHC ERA

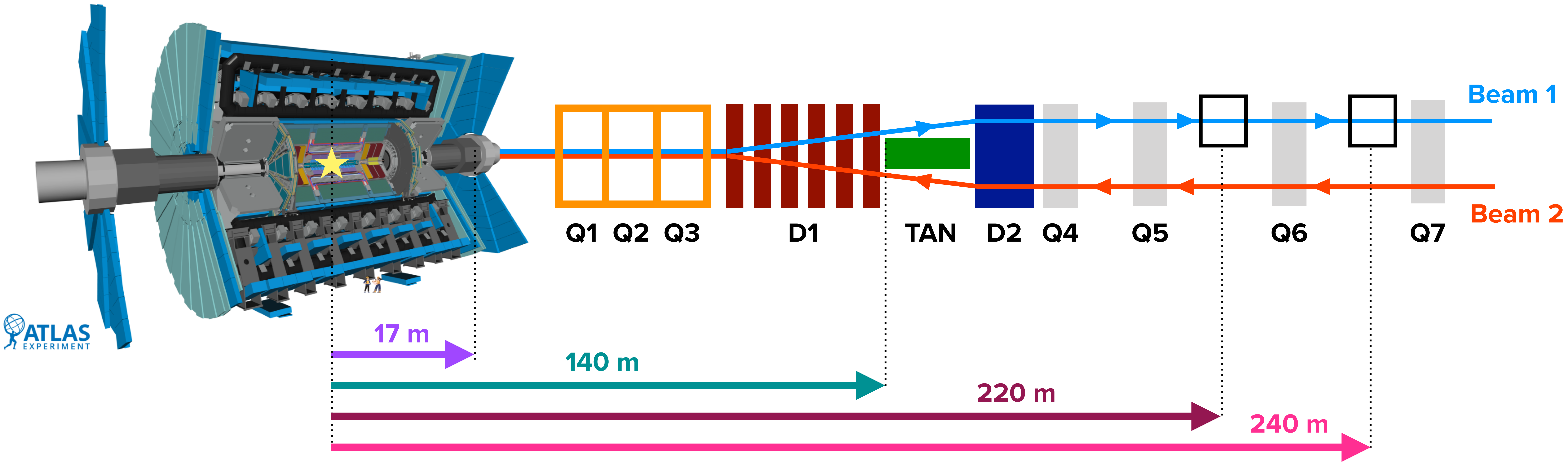


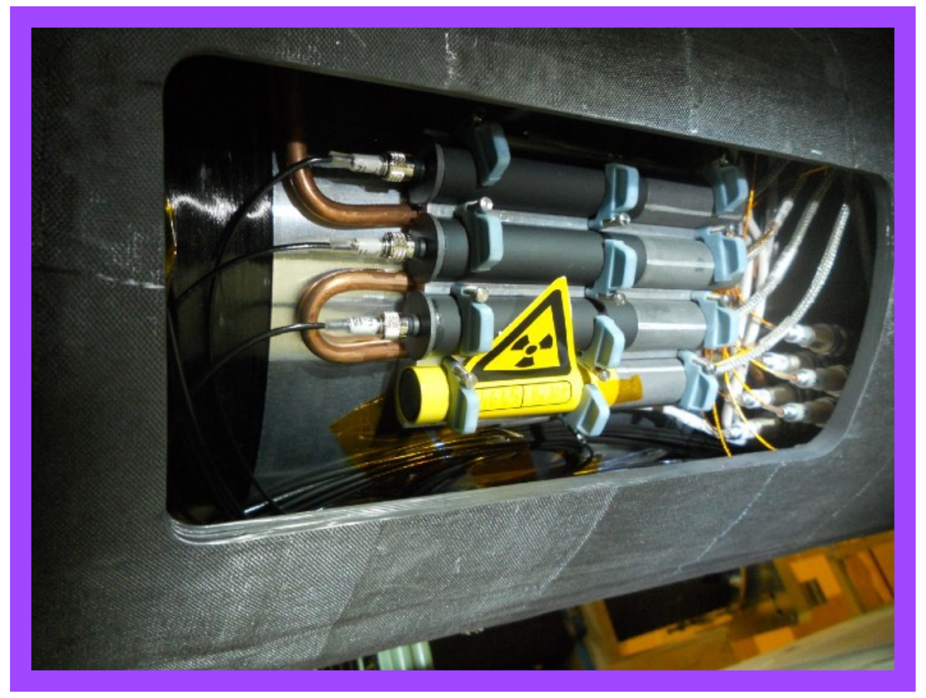


Riccardo Longo
For the ATLAS Forward Group

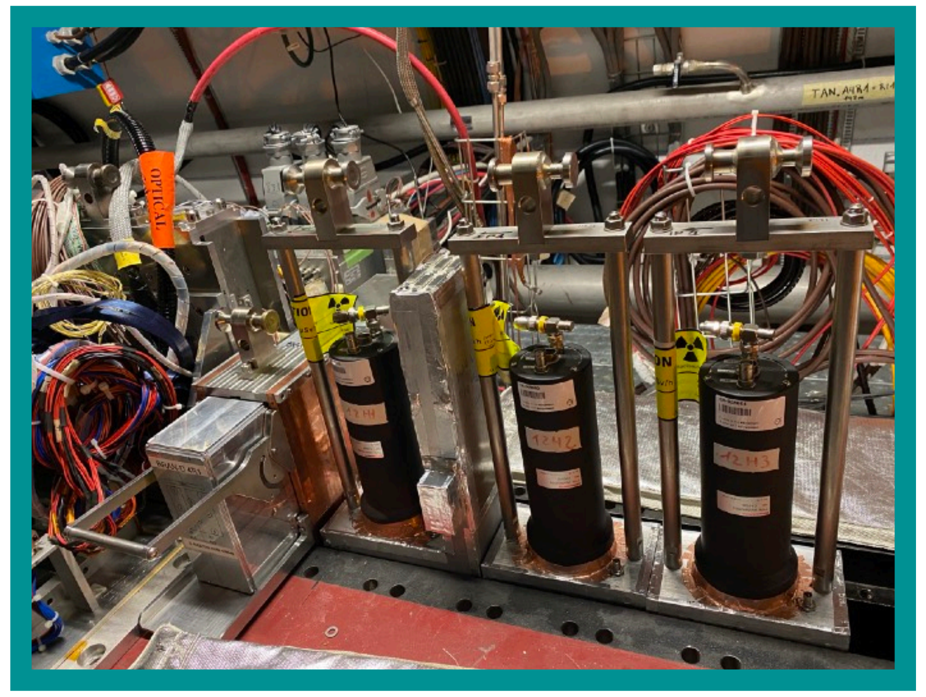
LHC Forward Physics Working Group
9 June 2023
CERN

ATLAS FORWARD DETECTORS IN RUN 3



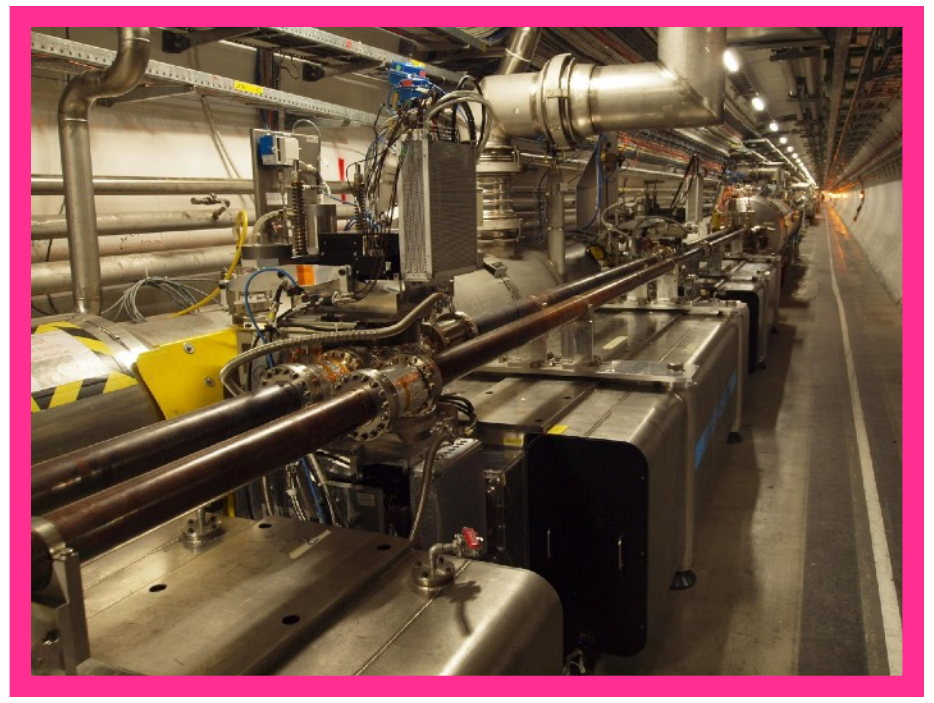


LUCID-2



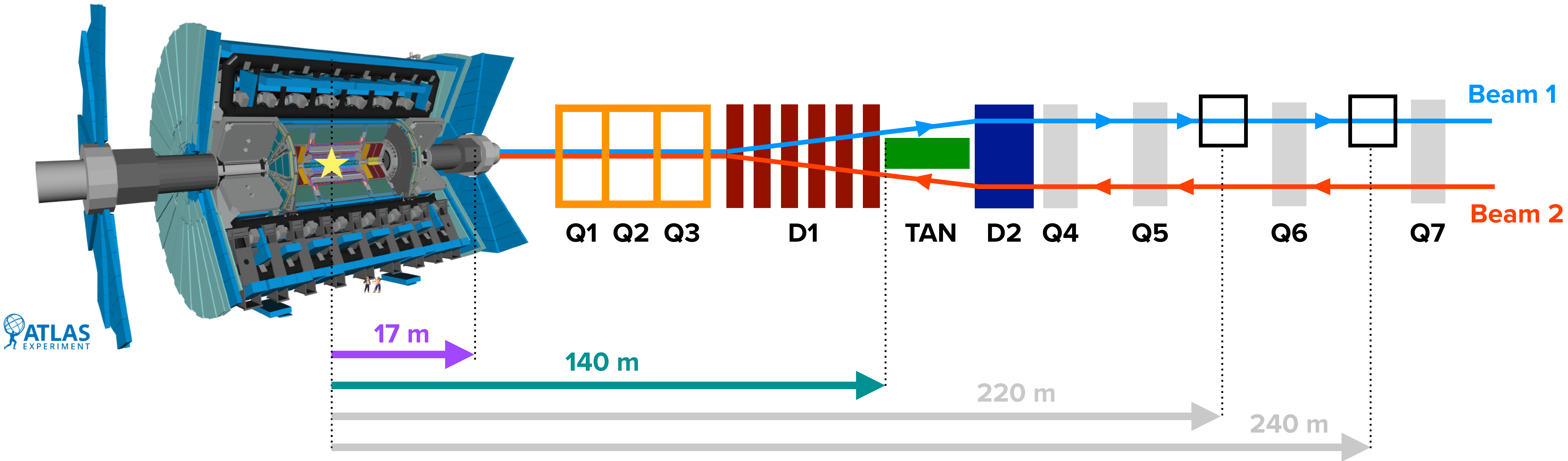
ZDC

AFP

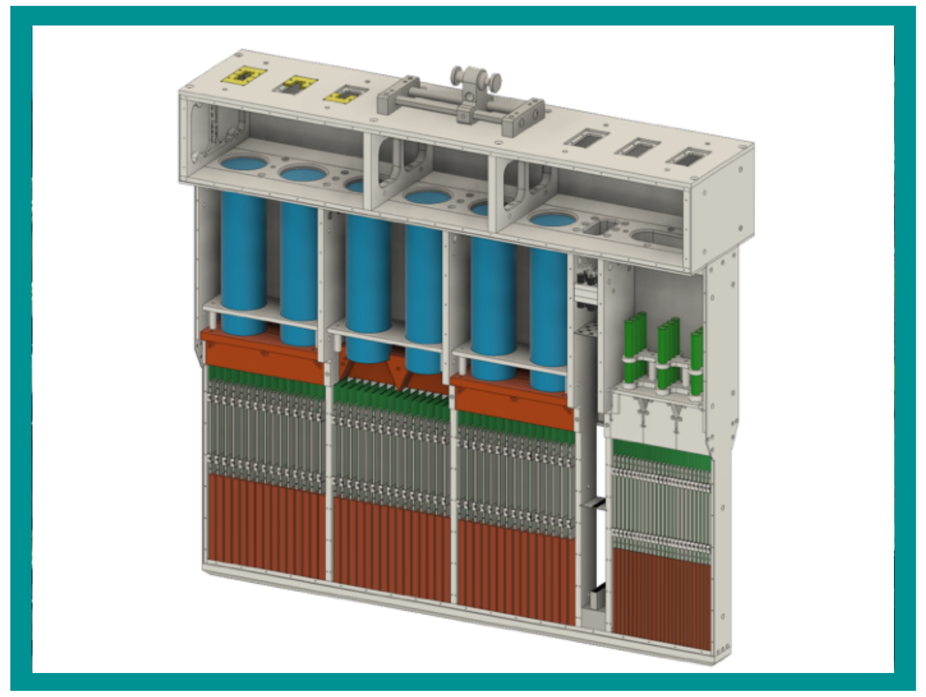


ALFA

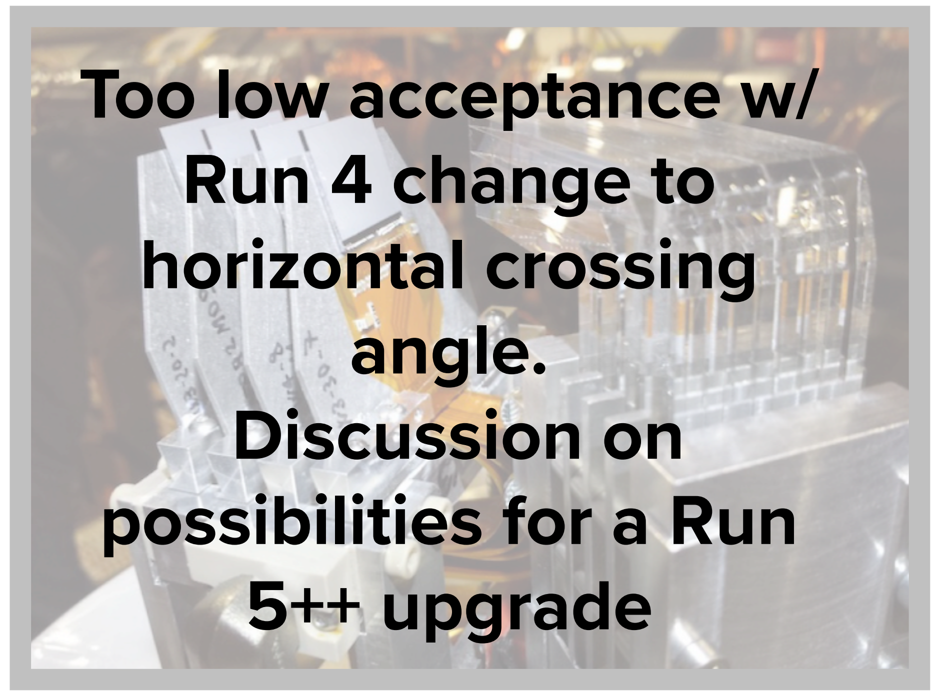
ATLAS FORWARD DETECTORS IN RUN 3 → RUN 4



LUCID-2 ➡ LUCID-3



ZDC ➡ HL-ZDC



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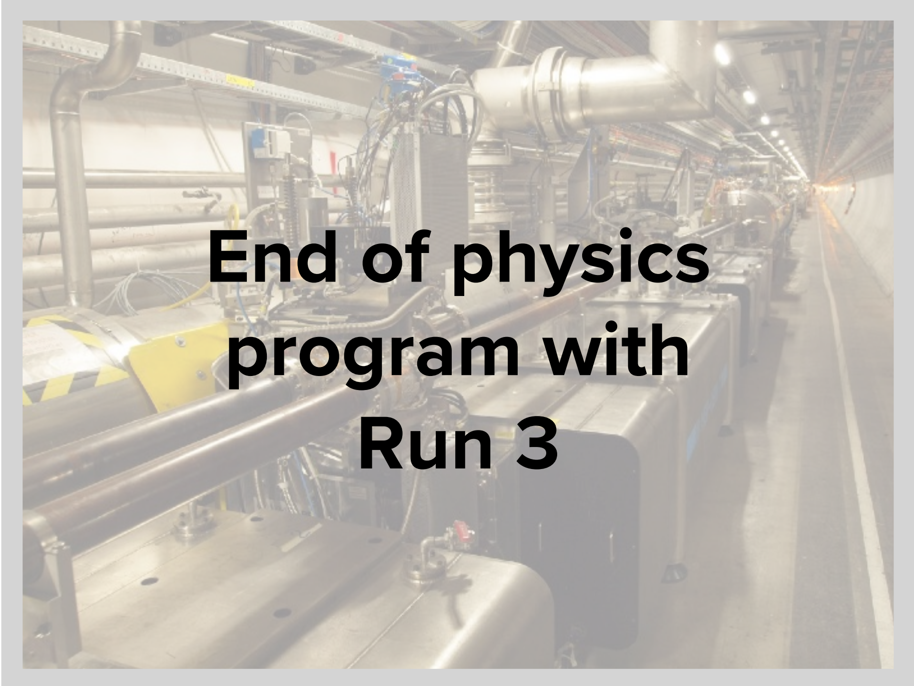


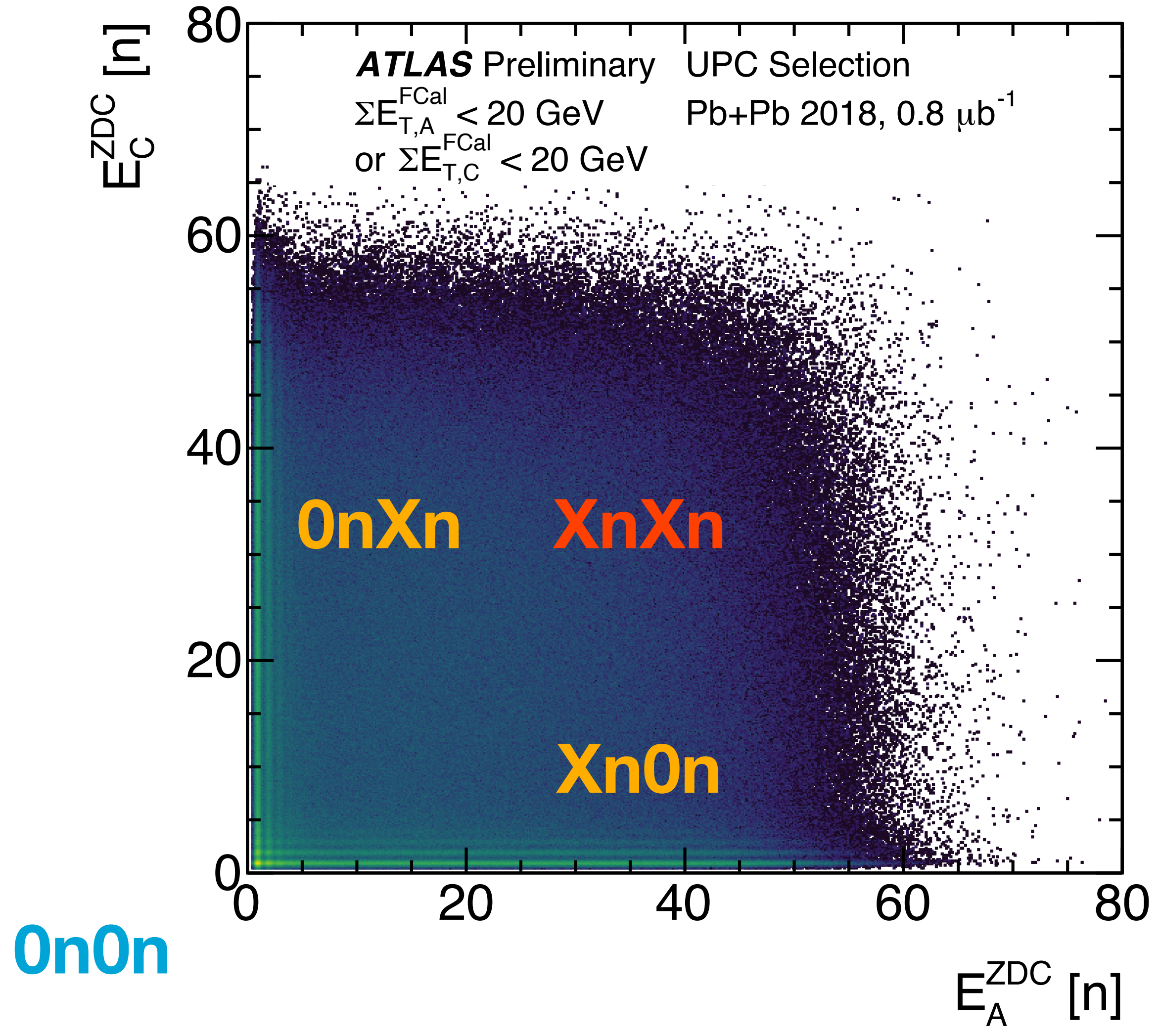
ALFA

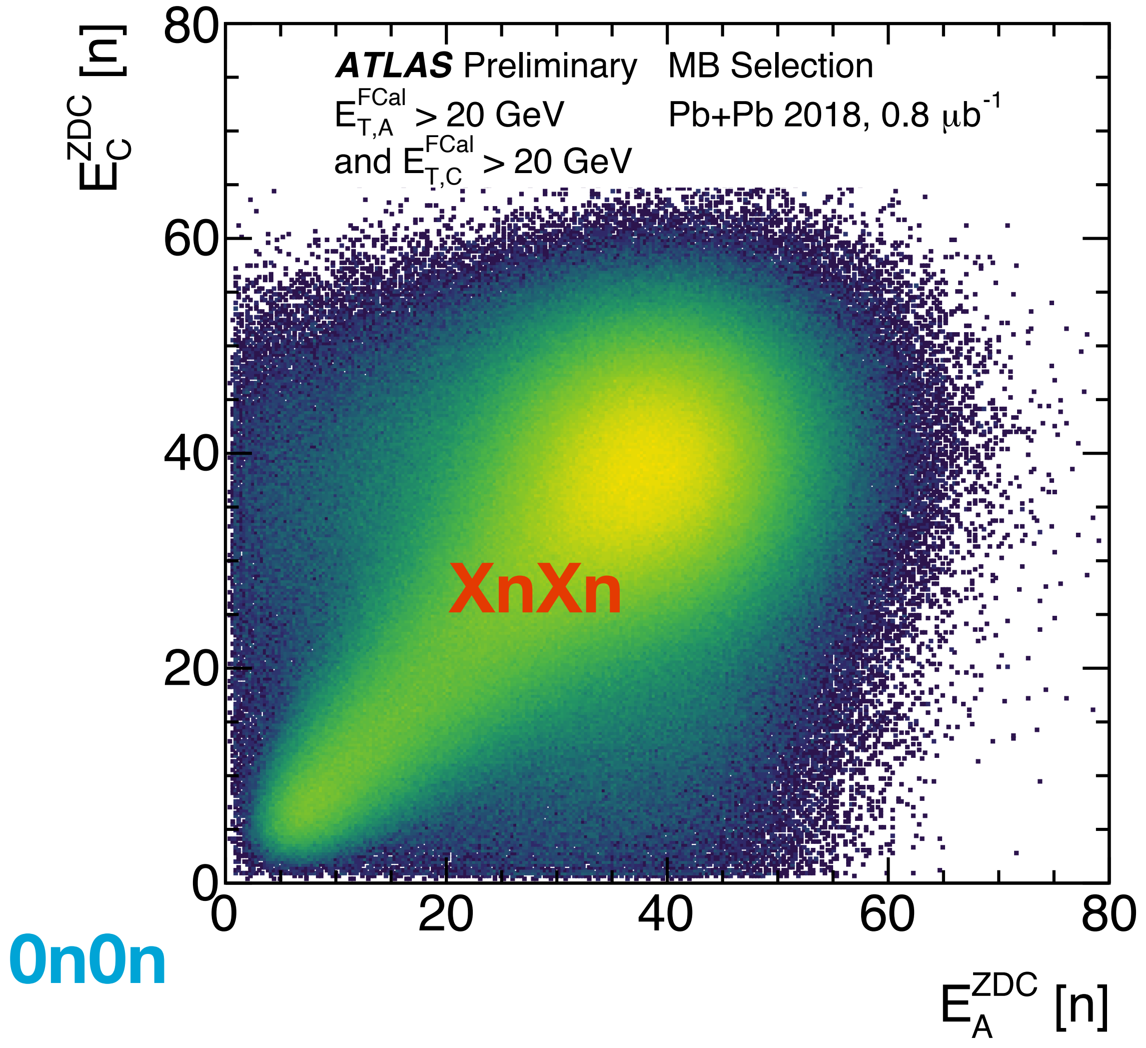
HL-ZDC: PHYSICS CASE

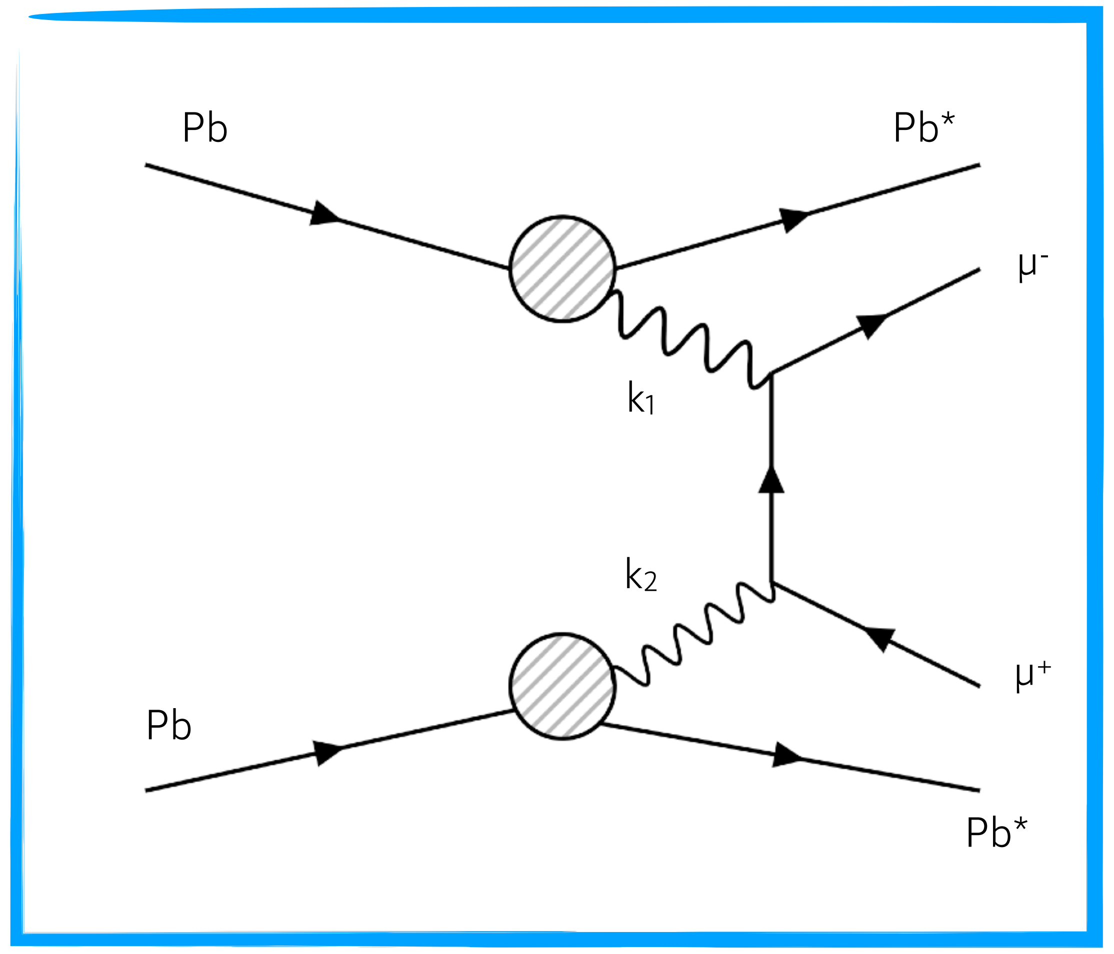
ZDC AS A TAG FOR PRIMARY PROCESSES

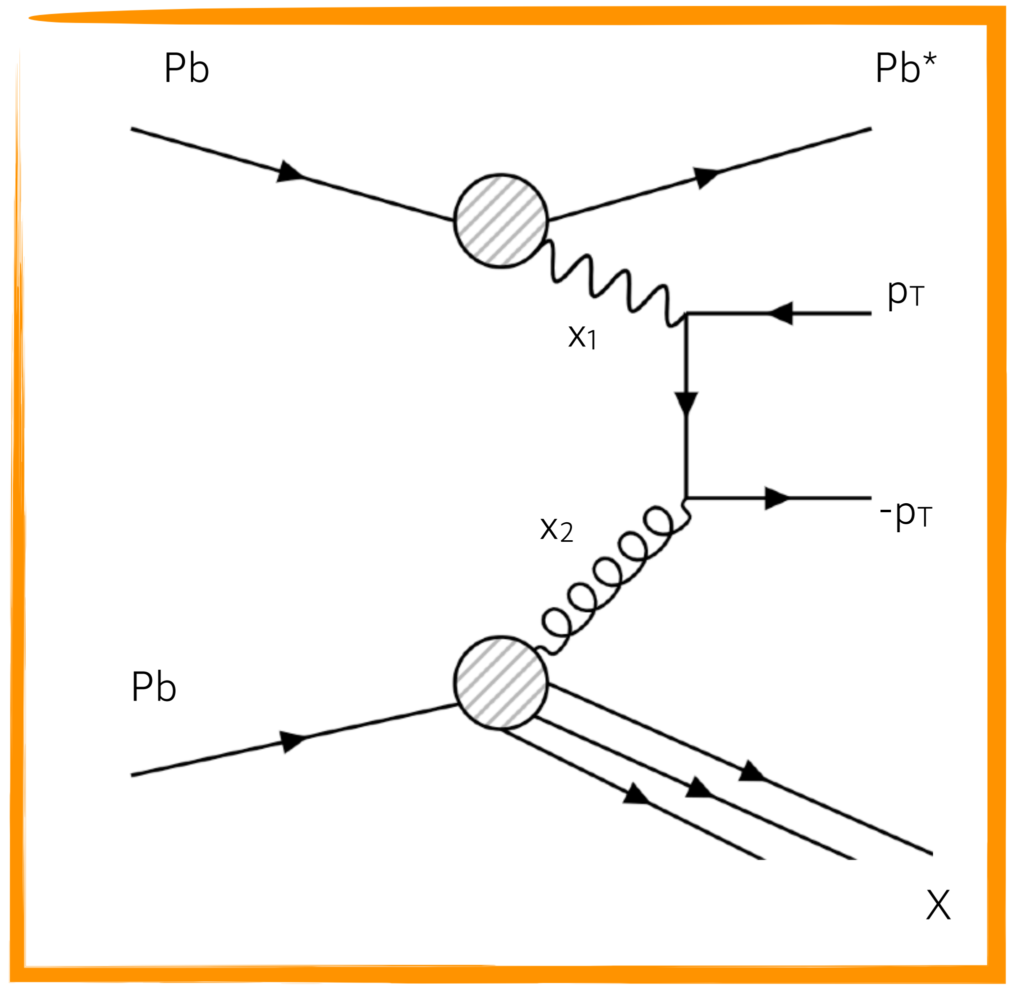
- **The primary means to distinguish between different classes of physics process in HI collisions is by looking at different forward neutron topologies**
  - No neutrons on either side (“**0n0n**”) is typically from gamma-gamma processes
  - Neutrons only on one side (“**Xn0n**”/“**0nXn**”) is typically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

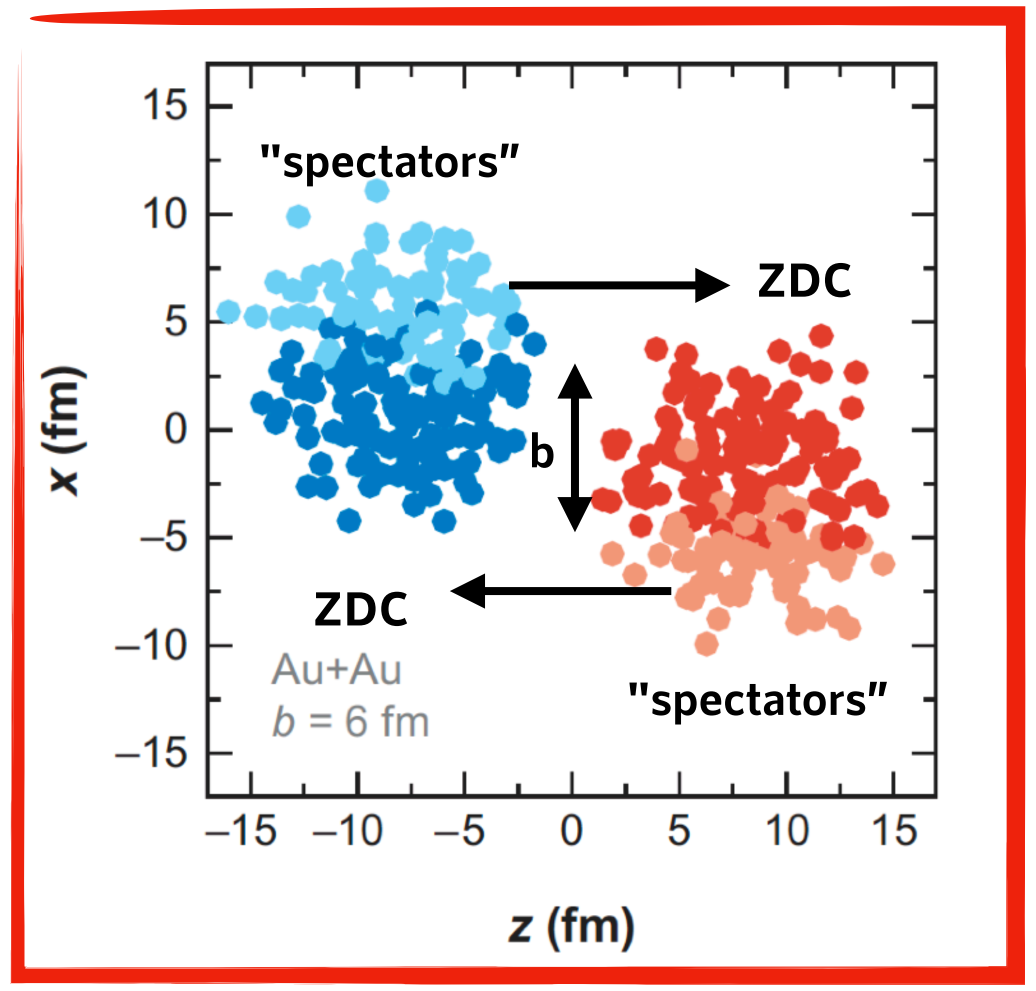
➡ **ZDCs are critical to distinguish these three physics processes!**









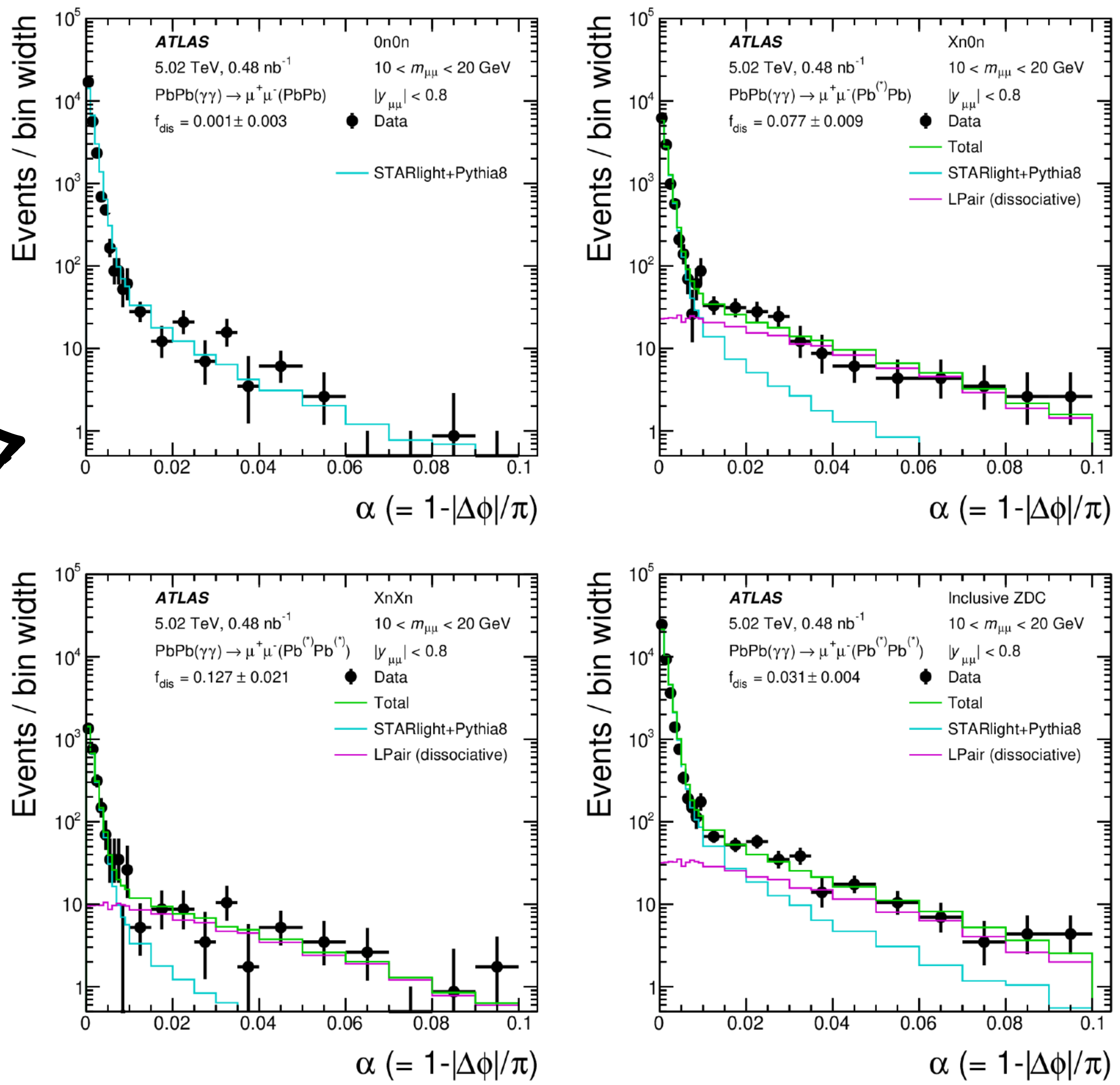


Ann. Rev. Nucl. Part. Sci. 57 (2007) 205

ZDC IN PHOTON COLLISIONS

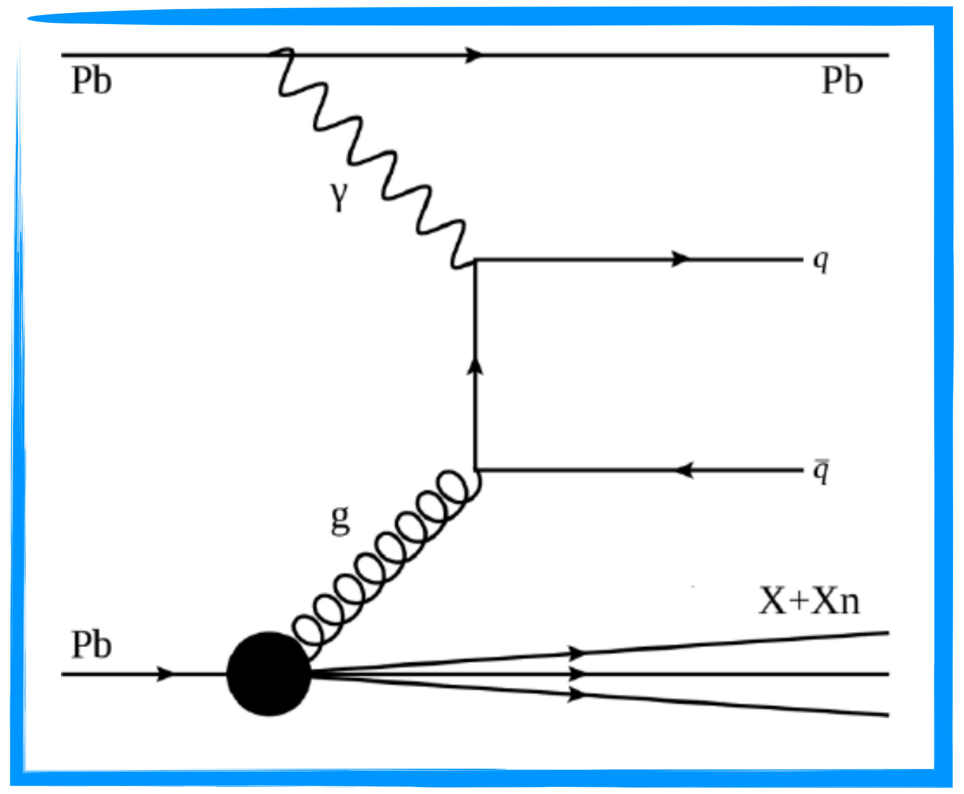
See also talks by **Georgios** and **Andre**

- **$\gamma\gamma$: Light-by-light interactions at the LHC, [Nature Physics 13 (2017) 852](), [PRL 123, 052001 (2019)]()**
  - ZDC used in triggering and to enhance backgrounds from gluon-induced processes in the analysis
- **$\mu\mu$: First systematic measurement of high-mass dimuon pairs ($m_{\mu\mu} > 10$ GeV), [PRC 104, 024906 (2021)]()**
  - ZDC critical to remove dissociative background, which creates tails at large event acoplanarity values
- **$\tau\tau$: Measurement of $\gamma\gamma \rightarrow \tau\tau$ to constrain the τ anomalous magnetic moment, [Arxiv:2204.13478 (submitted to PRL)]()**
  - ZDC used to suppress photonuclear backgrounds where ion dissociation typically occurs



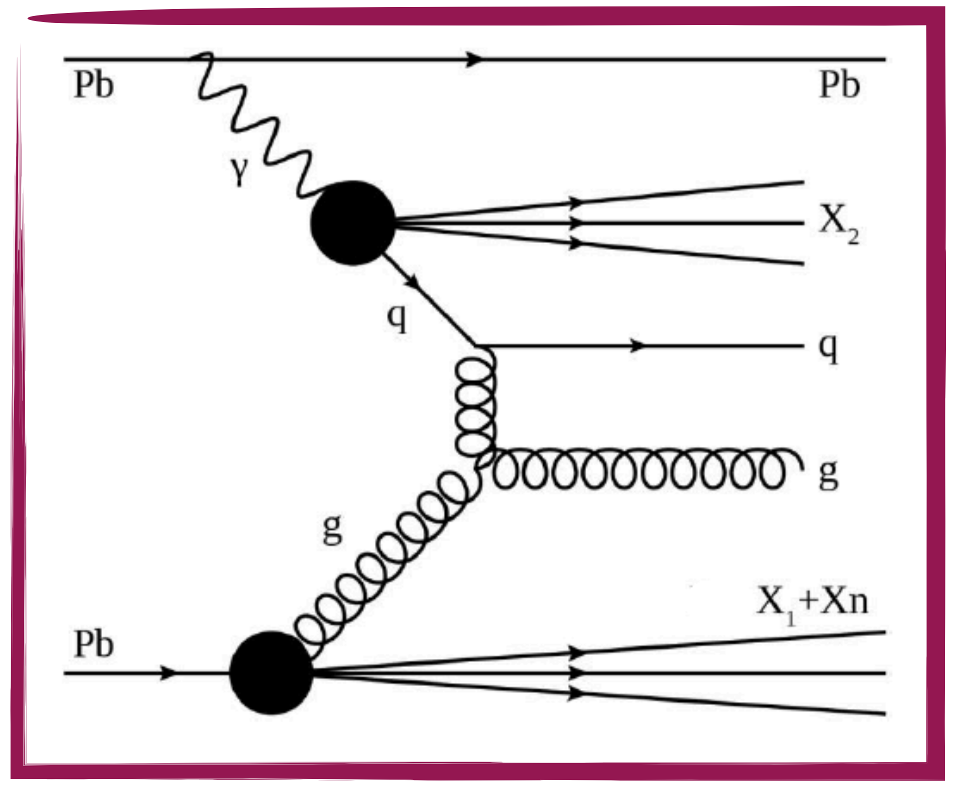
ZDC IN UPC PROCESSES

- **Flux of quasi-real photons in ultra-relativistic Pb+Pb collisions**
  - "Direct" photons scatter off the nucleus
  - "Resolved" photons scatter through a virtual hadronic excitation of the photon



0n

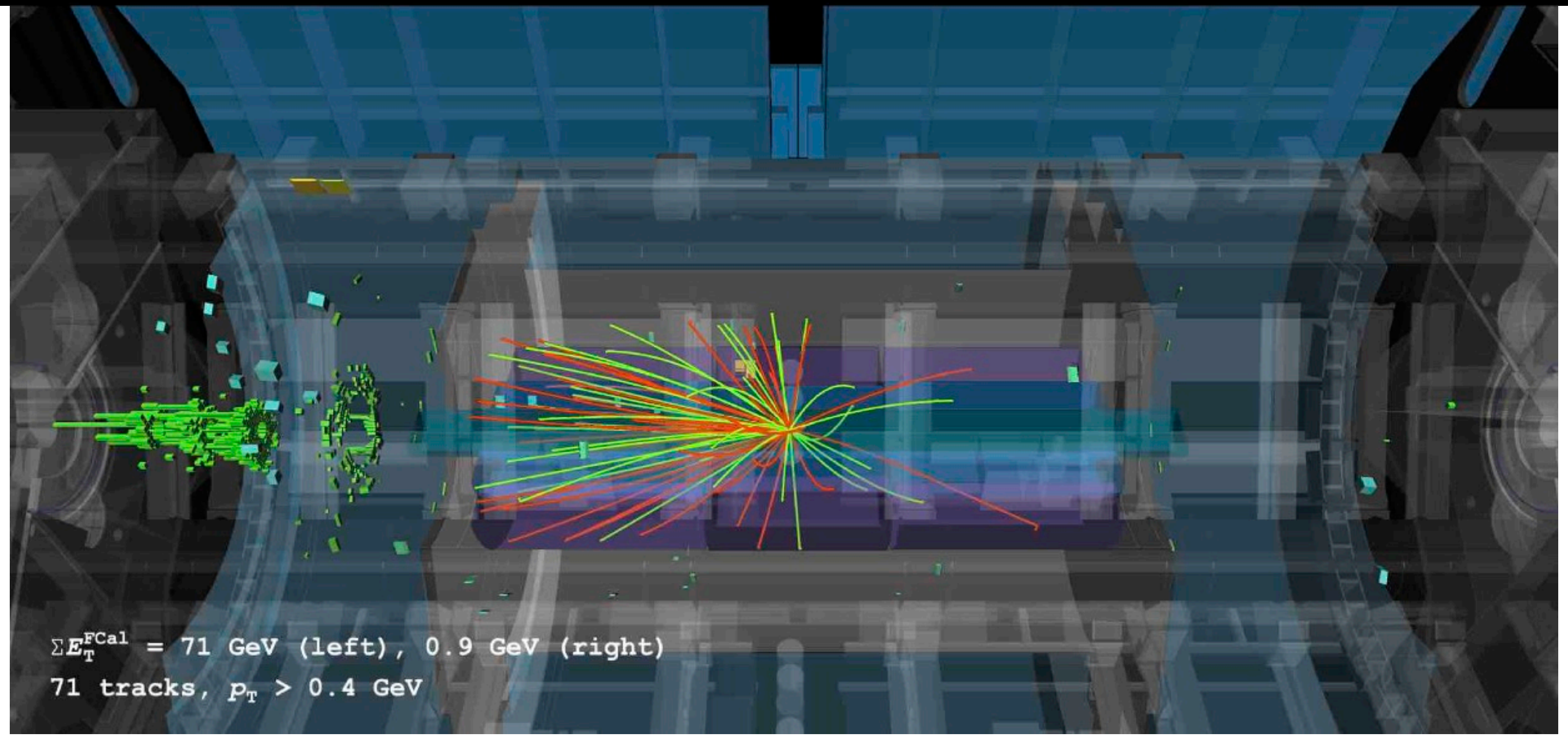
Xn

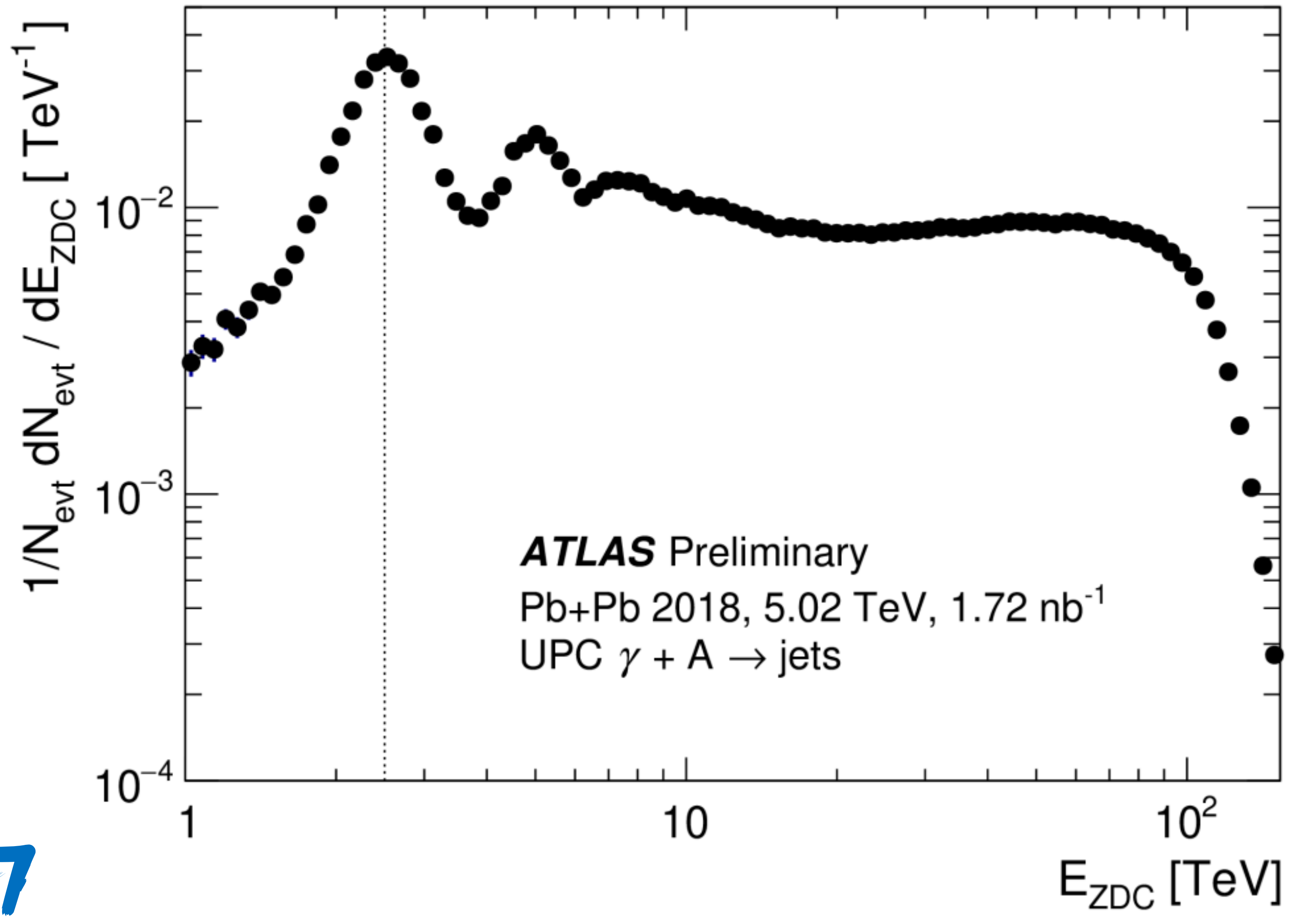


0n

Xn

- **[Photo-nuclear jet production in ultra-peripheral Pb+Pb collisions at 5 TeV with the ATLAS detector]**
- **Clean probe at low-*x* and intermediate Q^2, useful to constrain nPDF**
  - 0nXn requirement for nuclear breakup in exactly one ATLAS ZDC
  - Diffractive photo-production in 0n0n events studied in events with no neutrons in either ZDC
  - ➡ **Key ZDC role in the event selection (and triggering)**





ZDC IN UPC PROCESSES

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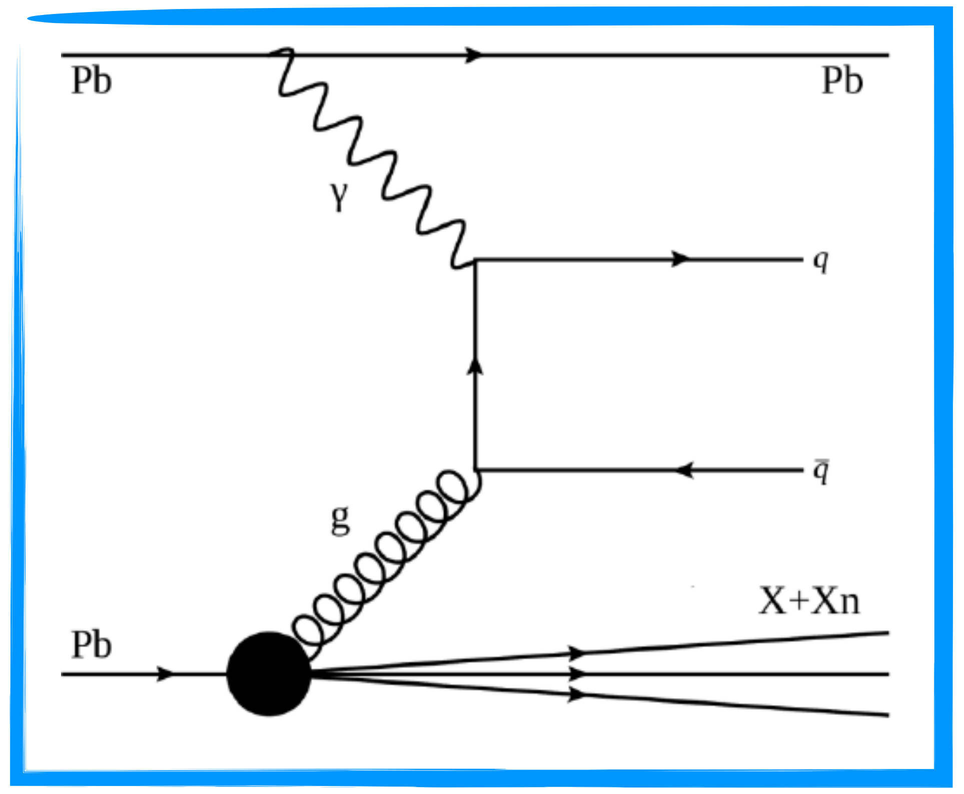
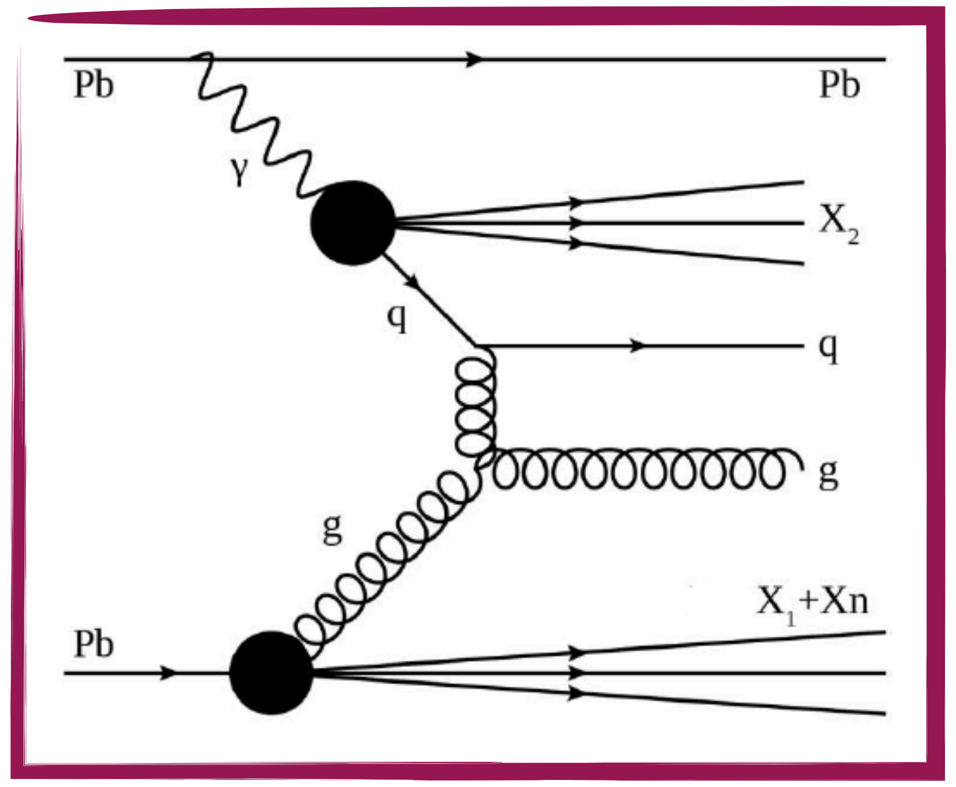


0n

Xn



0n

Xn

- [Photo-nuclear jet production in ultra-peripheral Pb+Pb collisions at 5 TeV with the ATLAS detector]()
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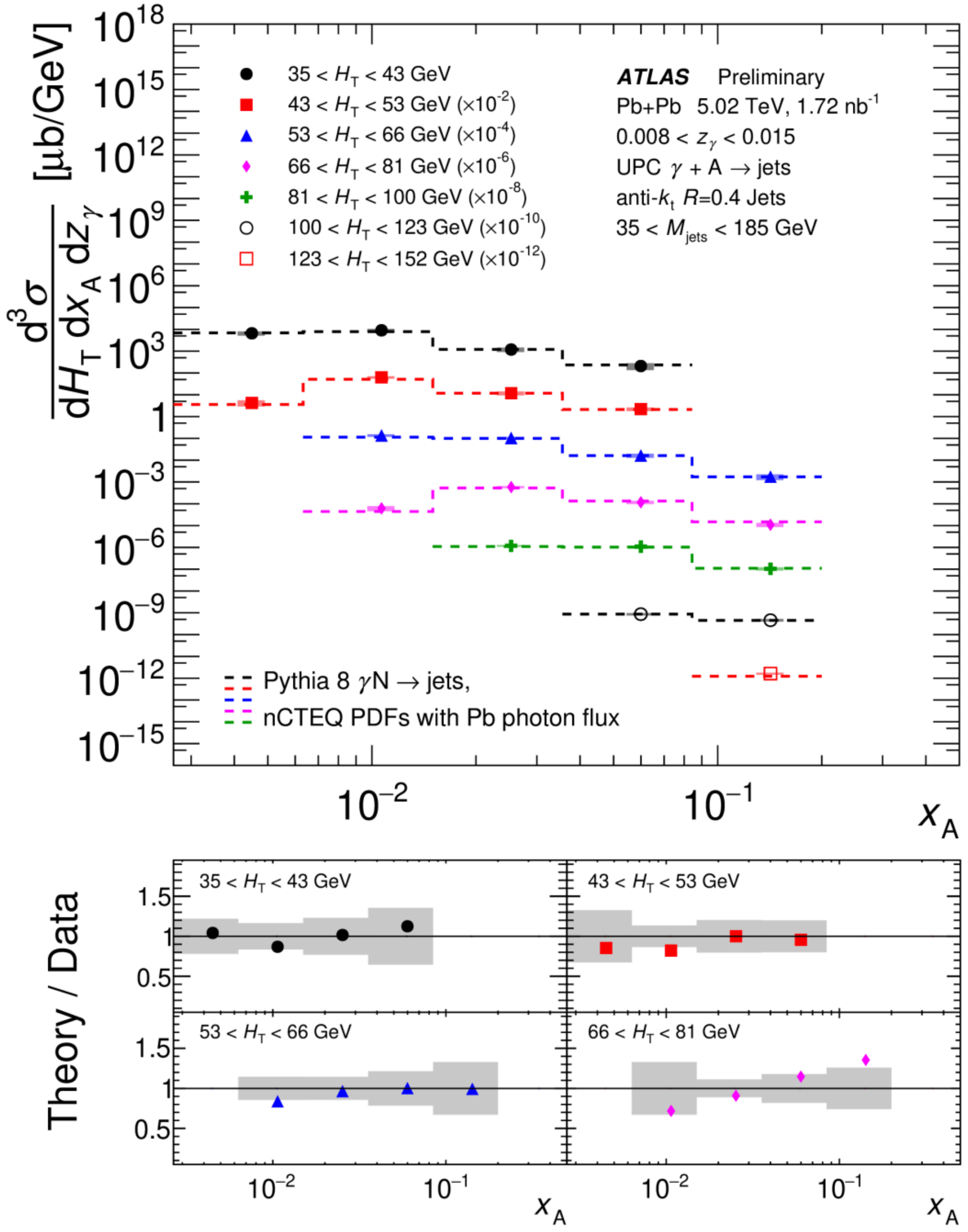
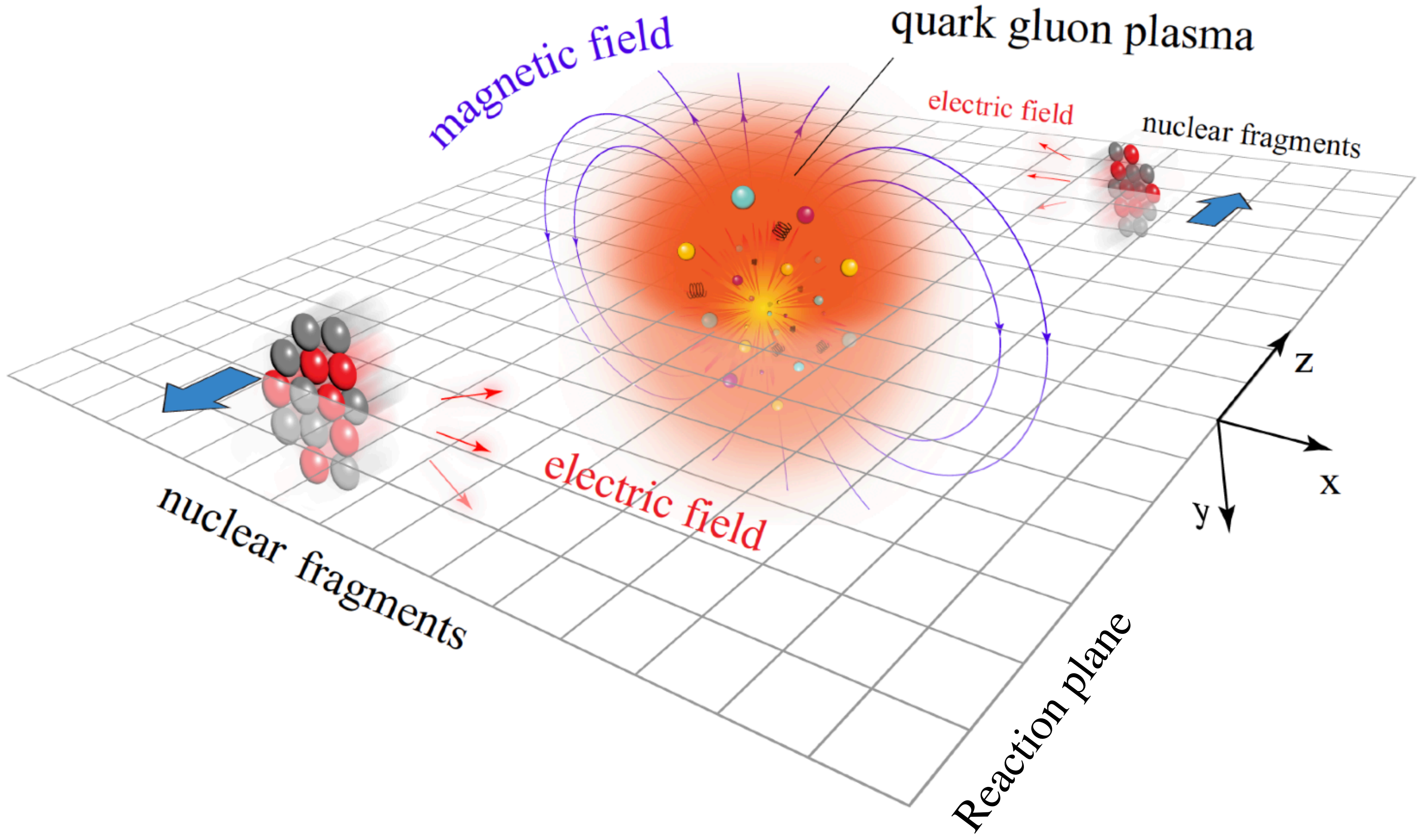
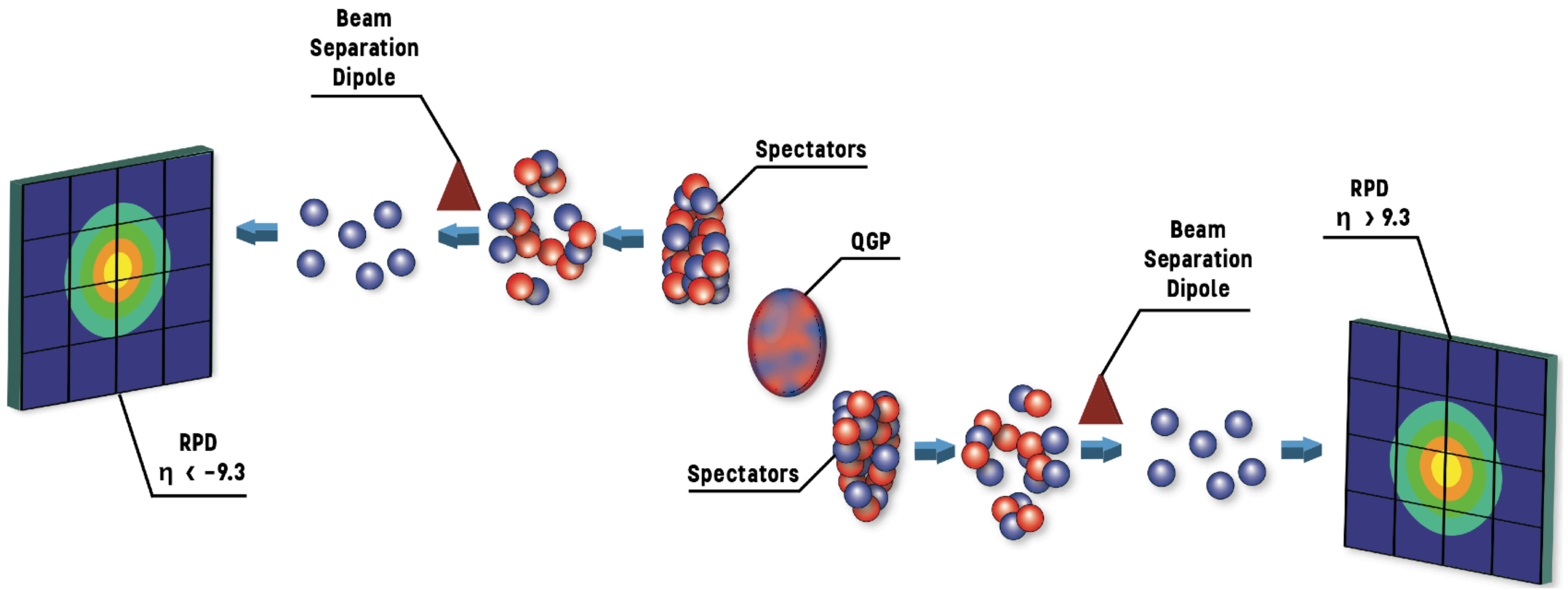


ZDC + RPD FOR DIRECTED FLOW MEASUREMENT

arXiv:2304.03430

- **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
  - **Enables direct access to v_1,"directed flow",** through correlations with particles detected in the central region
- **Sensitive to the EM fields in the initial stages of the collisions**
  - At LHC energies, only ALICE has measured v_1 so far (PRL 111, 232302 - charged particles, and PRL 125, 022301 - charged hadrons and D0)
- **Both ATLAS and CMS will have RPDs starting from Run 3**
  - Joint implementation in Run 4 HL-ZDC





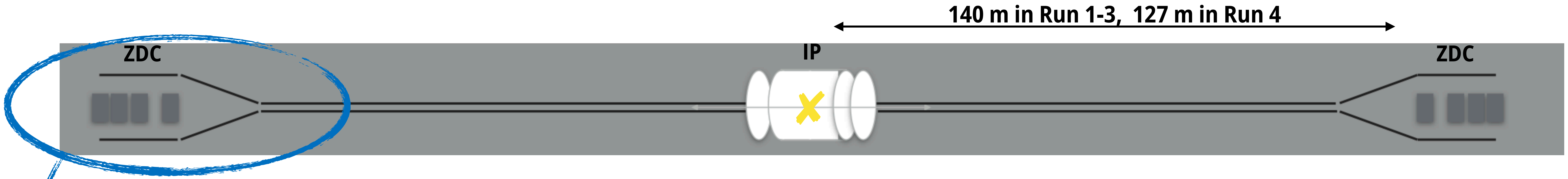
HL-ZDC PHYSICS CASE SUMMARY

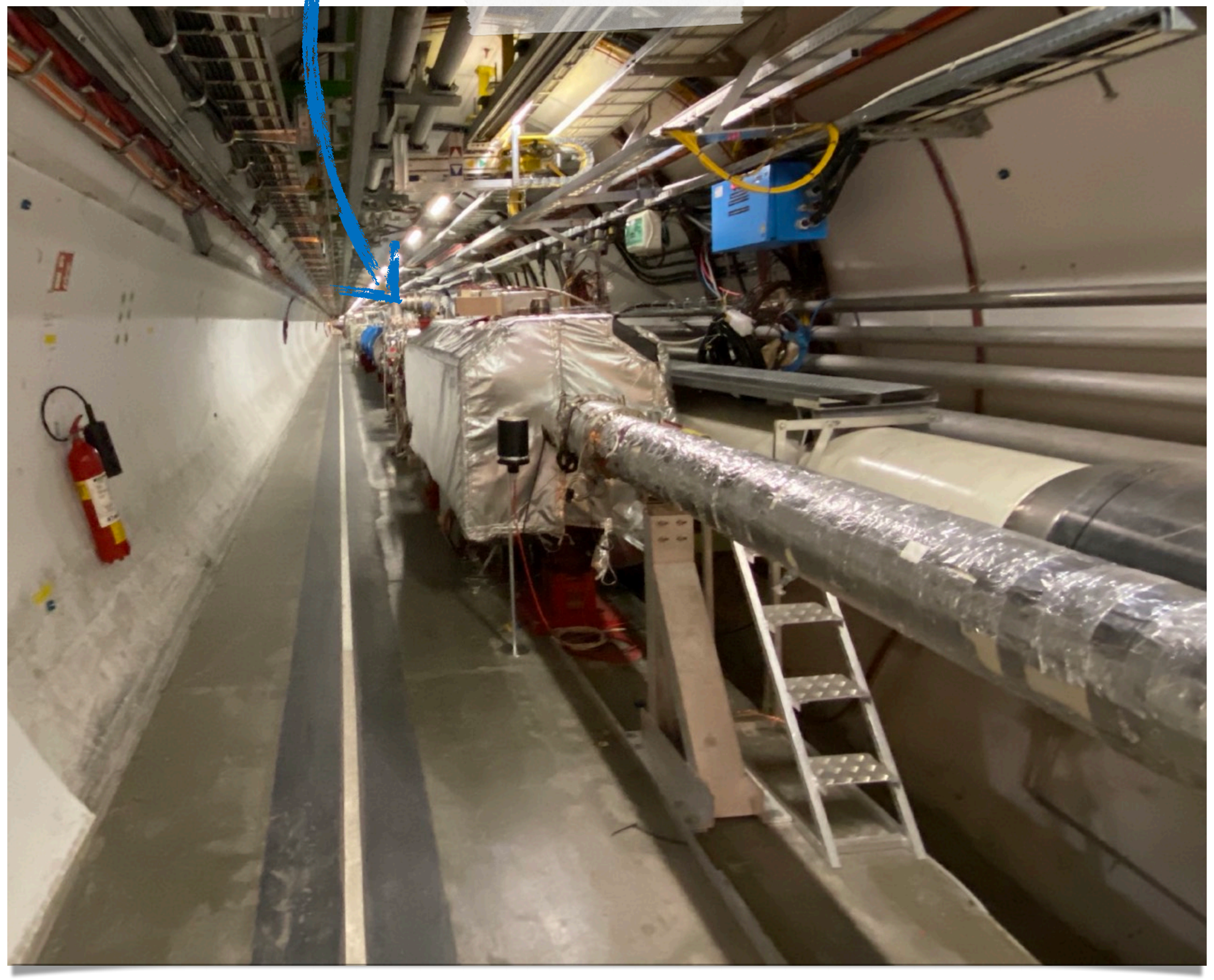
- **HL-LHC Heavy Ion program will offer several new opportunities for intriguing physics measurements**
  - Higher luminosity in Pb+Pb and p+Pb
  - Potential for new special runs with different nuclei (e.g. Ar+Ar)
  - Steep improvement in the capabilities of the detectors to cope with HL p+p challenges

- **The HL-ZDC is essential for the ATLAS Heavy Ion program in Run 4 and beyond**
  - Triggering in (ultra-)peripheral events
  - Characterization of nuclear geometry
  - Classification of EM & hadronic processes
  - Measurement of reaction plane using spectator neutrons

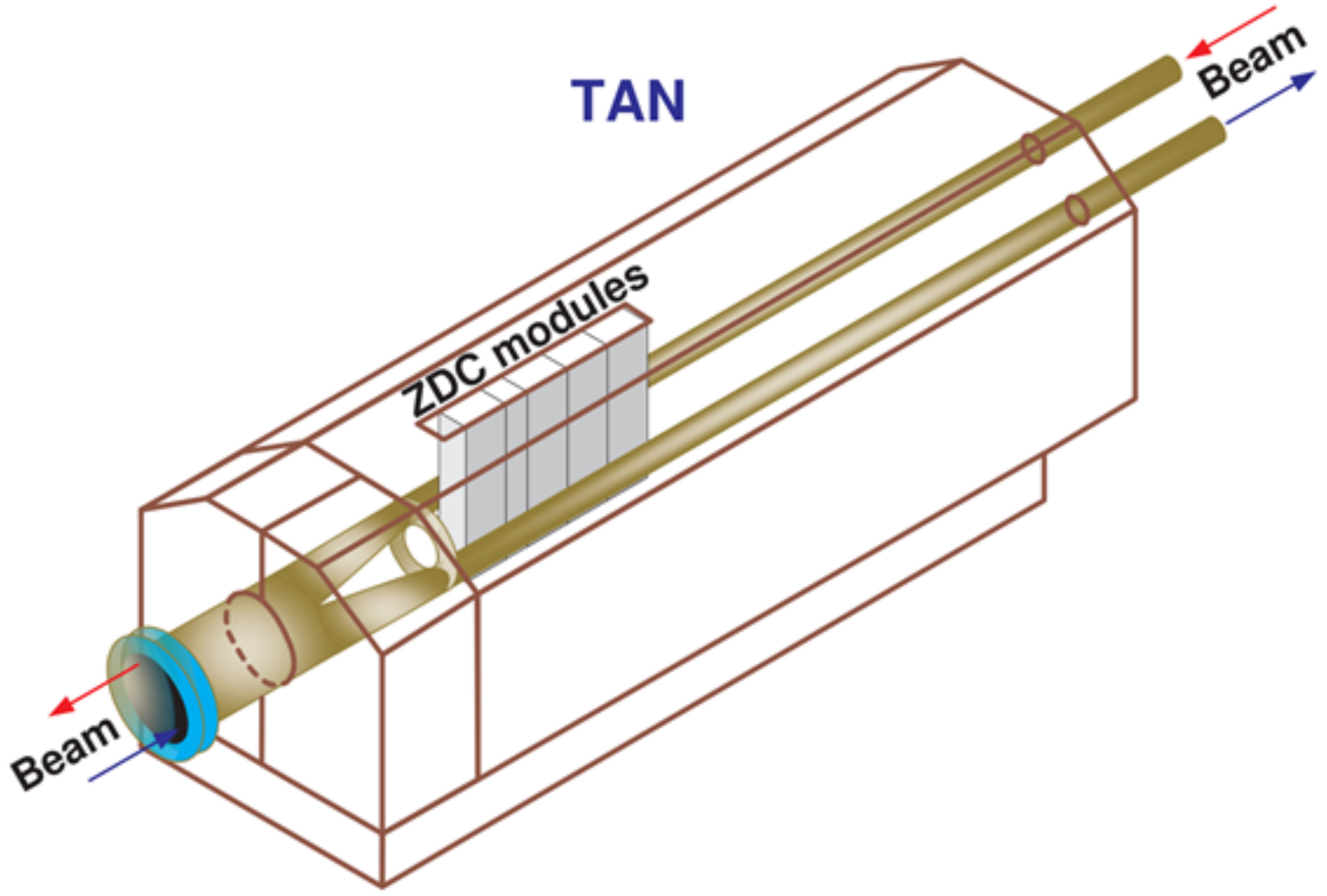
HL-ZDC: CHALLENGES

ZDCs IN ATLAS AND CMS





TAN 8-1 @ IP1

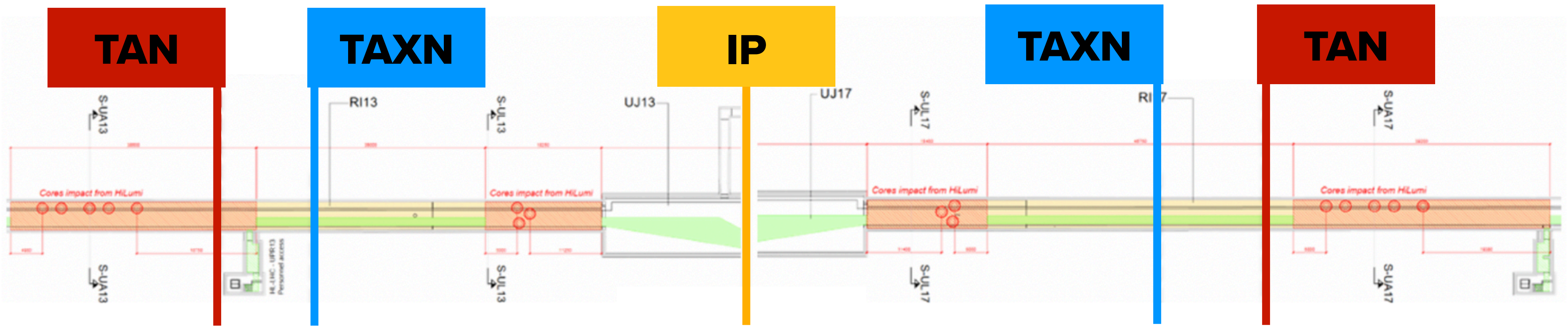


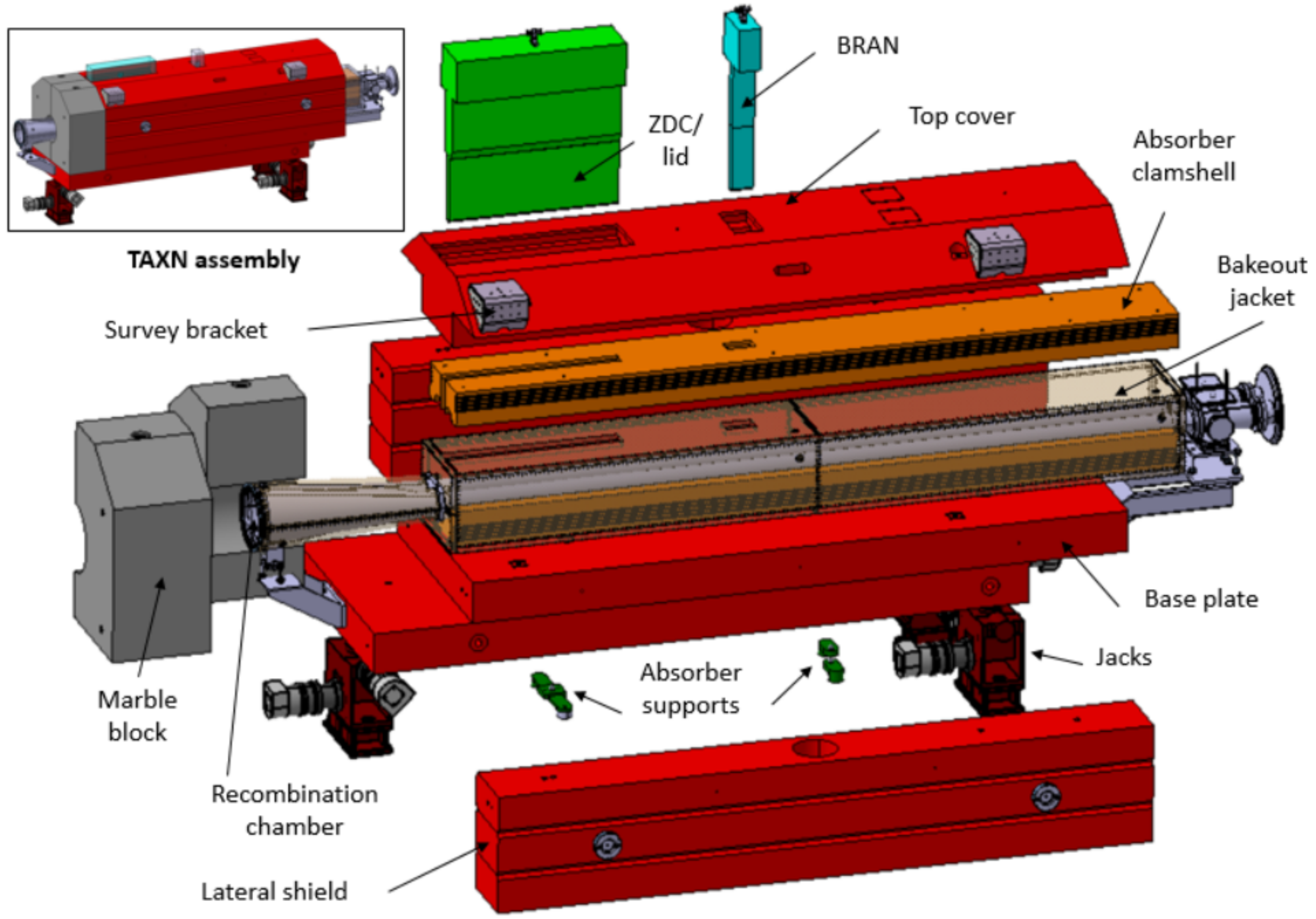
- For HI runs, the ZDCs are installed in the **Target Absorber** for **Neutrals (TAN)**
  - Absorber built around the Y chamber in the long straight section (LSS) to shield the D2 magnet from forward radiation
  - Located at ±140 m from IPs
  - ZDC slot carved out in between the beam pipes in the Cu absorber

- **Same TAN design for both ATLAS and CMS**

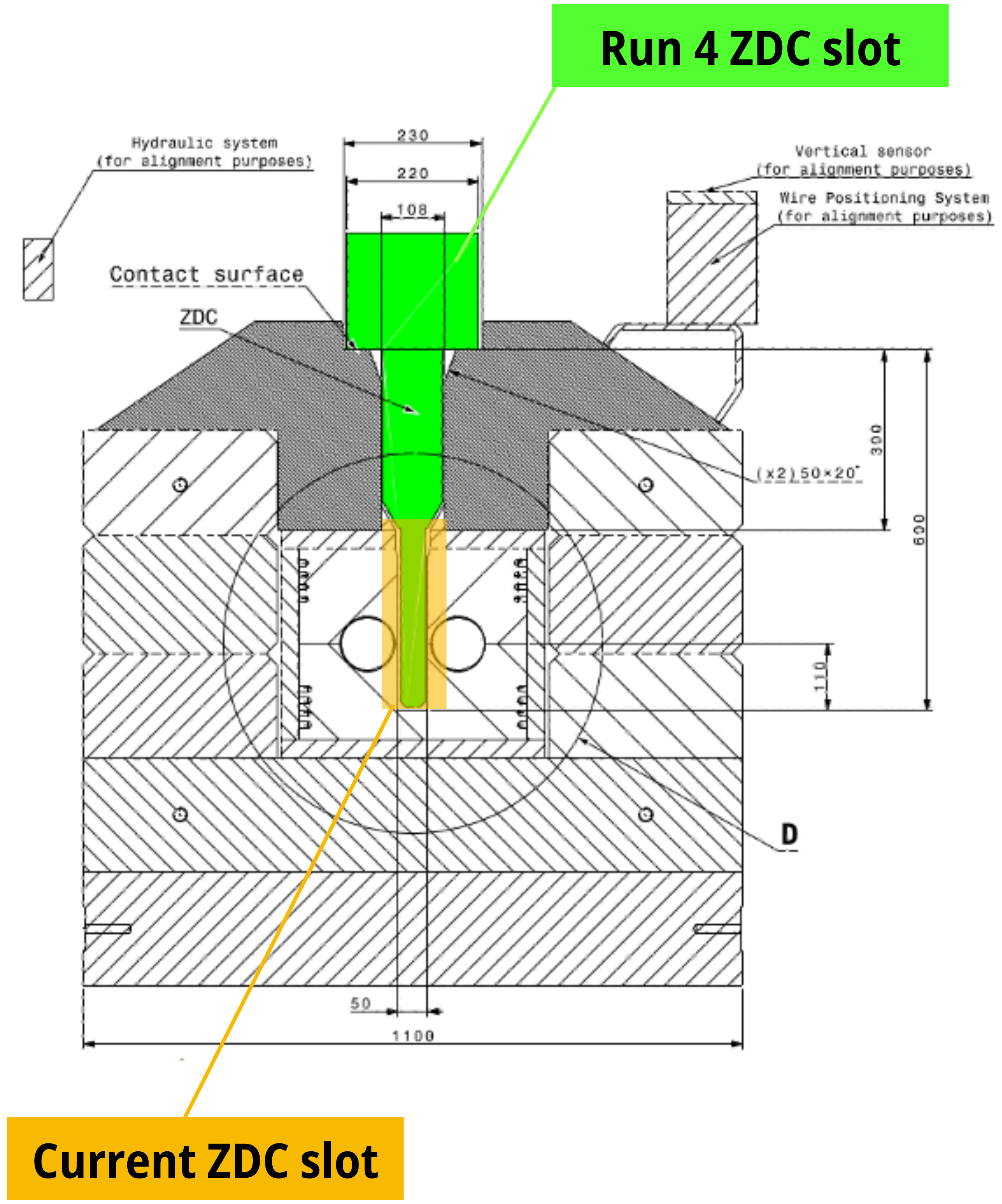
HL-LHC CHALLENGES: NEW ABSORBERS FOR NEUTRALS

- **New HL-LHC beam optics demand new Target Absorber for Neutrals (TAN ➜ TAXN)**
  - Relocated to ± 127 m (currently ± 140 m)
  - Still same design for ATLAS and CMS





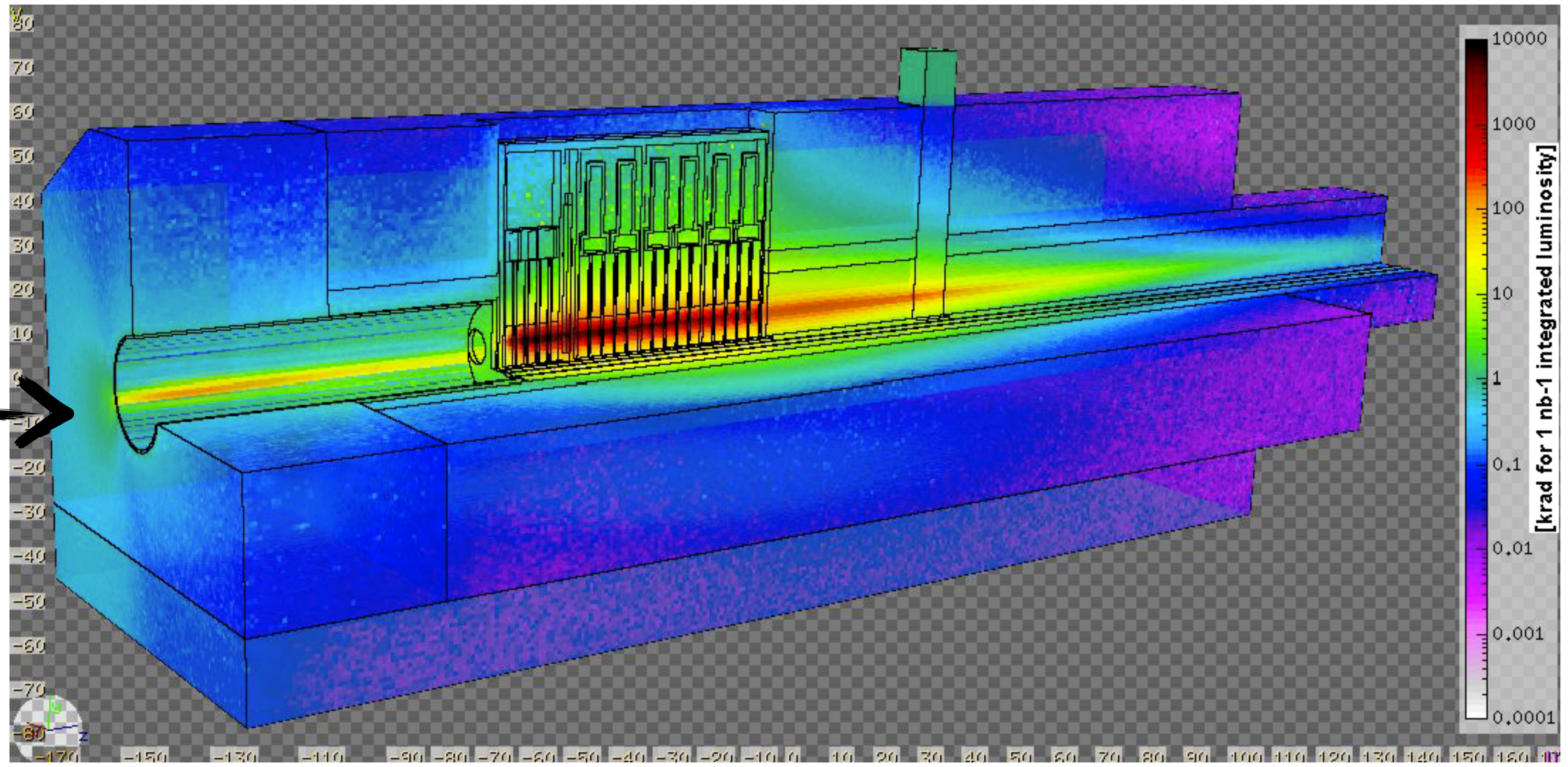
[Phys. Rev. Accel. Beams 25, 053001](),
"Mechanical and thermal design of the Target Neutral Beam Absorber for the HL LHC Upgrade"

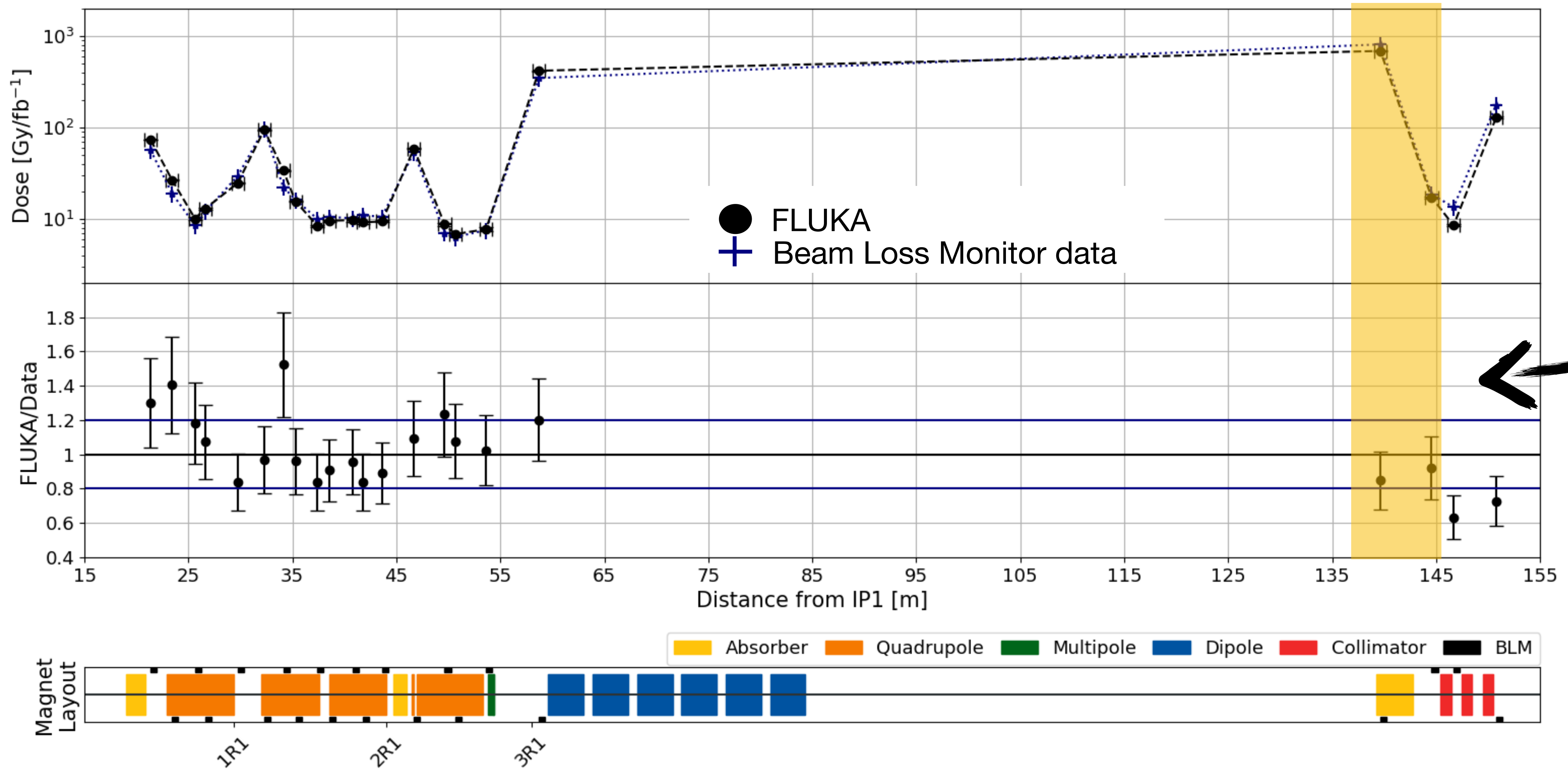


- **Slot for Forward detectors (ZDC, BRAN) narrowed to 5 cm (currently 10 cm)**
  - ➡ **Brand-new detectors need to be built**

HL-LHC CHALLENGES: RADIATION LEVELS

- The radiation levels on the ZDC will increase with the HL upgrade of the accelerator
- **CERN FLUKA group (F.Cerutti, M.Sabate Gilarte)** provides detailed simulations of the radiation environment in the TA(X)N region





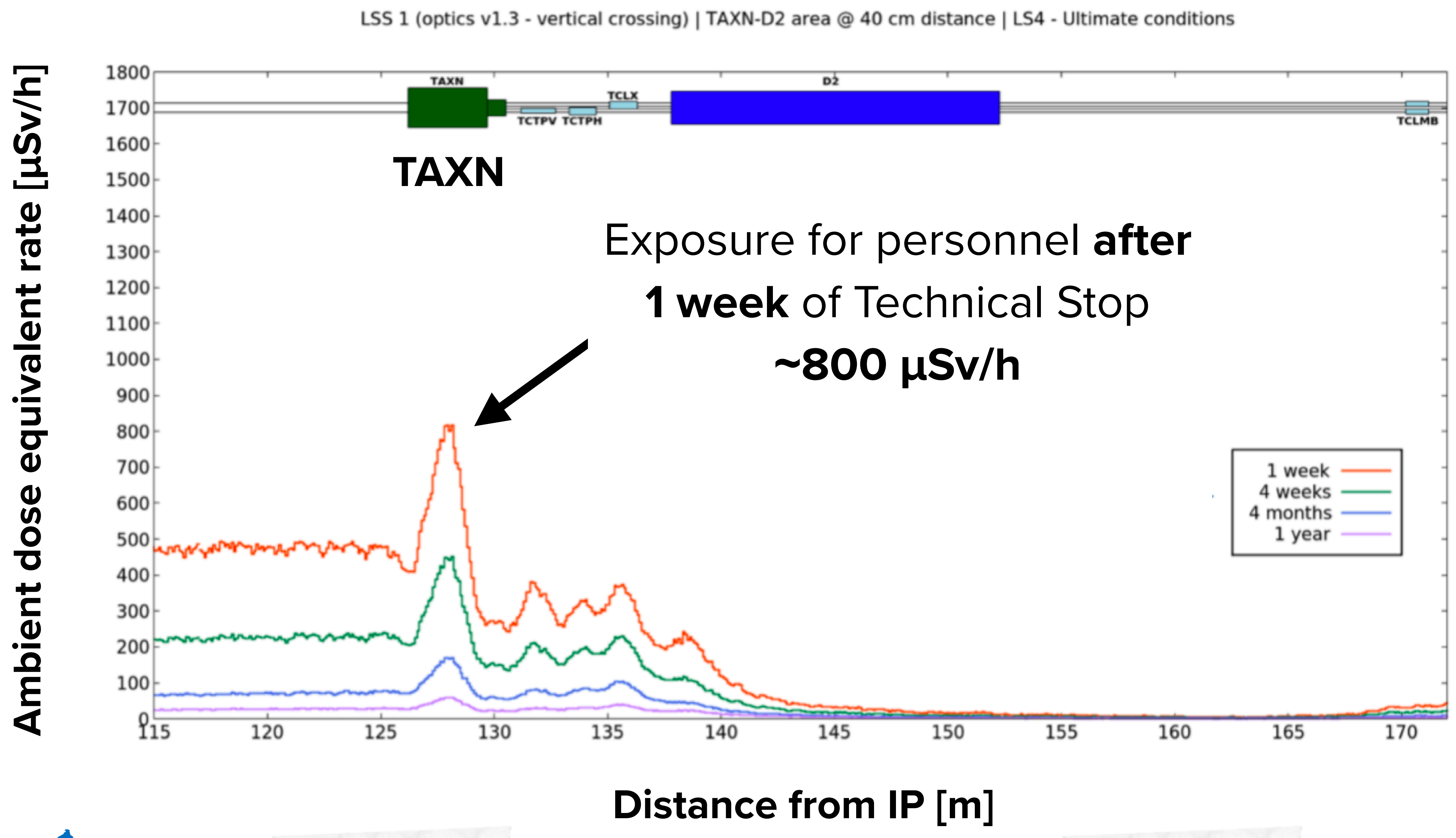
Phys. Rev. Accel. Beams 25, 091001 (2022)

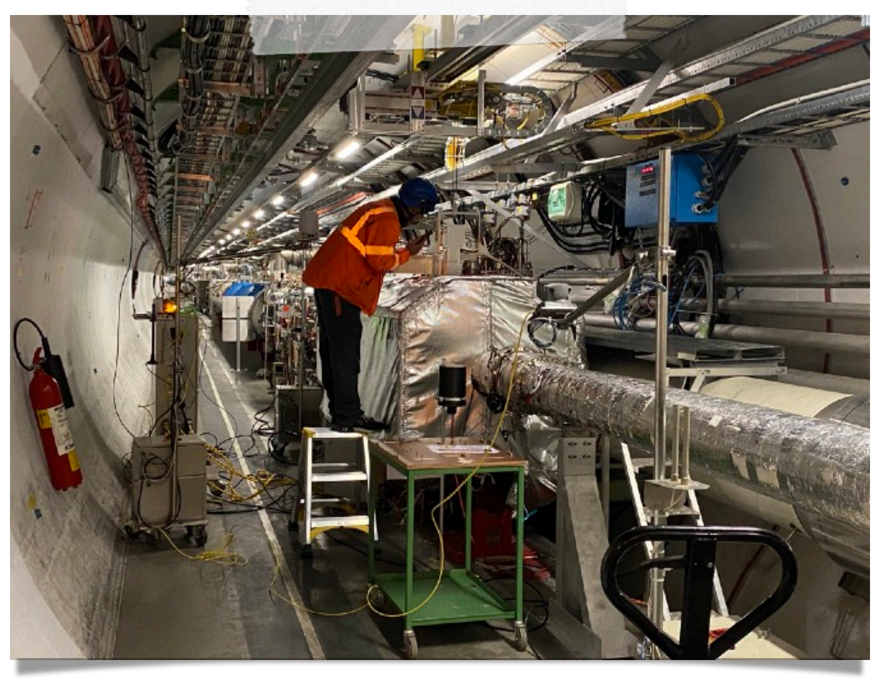
- Comparison between simulations and radiation monitors shows **agreement within 20%** in the TAN area measurement in ATLAS
- TAXN radiation levels for Run4 HI program (Pb+Pb, p+Pb, low μ p+p) **~4.5 MGy in total**

➡ **Need to identify radiation hard materials to instrument the HL-ZDC and all the ancillary systems in the tunnel**

HL-ZDC DESIGN REQUIREMENTS: SUMMARY

- **Rad-hard detector**: stable performance during the running period
- **Well-controlled energy scale** (via good 1n, 2n and 3n resolution)
- **Good γ/n separation**
- Inclusion of a **Reaction Plane Detector**
- Compatible with TAXN slot constraints and **fully integrated with the machine**
- **Easy to connect** after craning into TAXN to **reduce exposure for personnel**





Remote handling setup

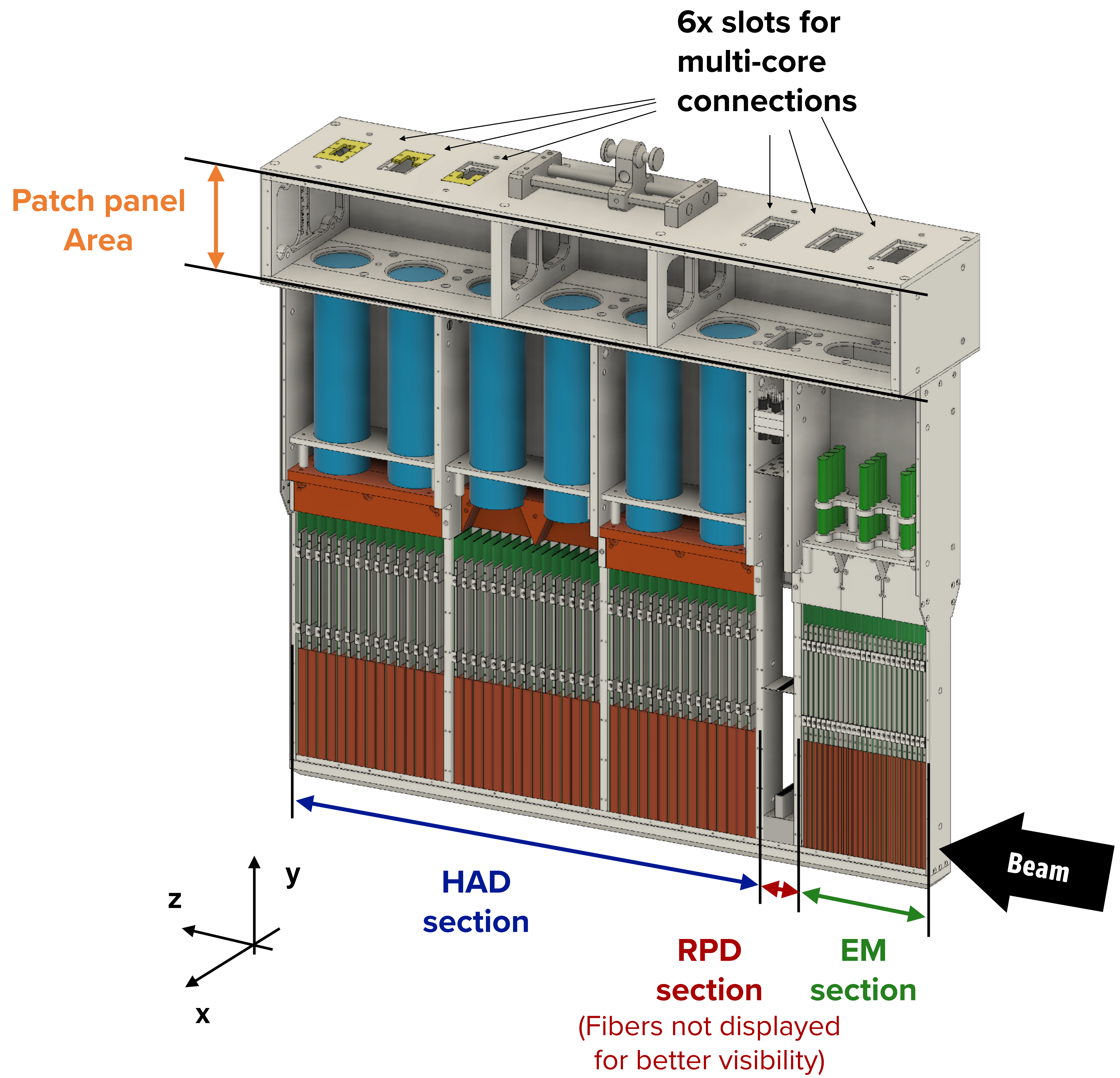
ZDC connection

HL-ZDC: JOINT PROJECT BETWEEN ATLAS AND CMS

- **Collaboration between ATLAS and CMS ZDC groups to tackle common challenges**
  - About 35 scientists from 6 different institutions
  - Share expertise and resources for R&D on rad-hard ZDC & RPD technology
  - Cost efficiencies
- **2.5 M$ proposal submitted to the DOE in July 2022** - awaiting formal approval in the upcoming weeks

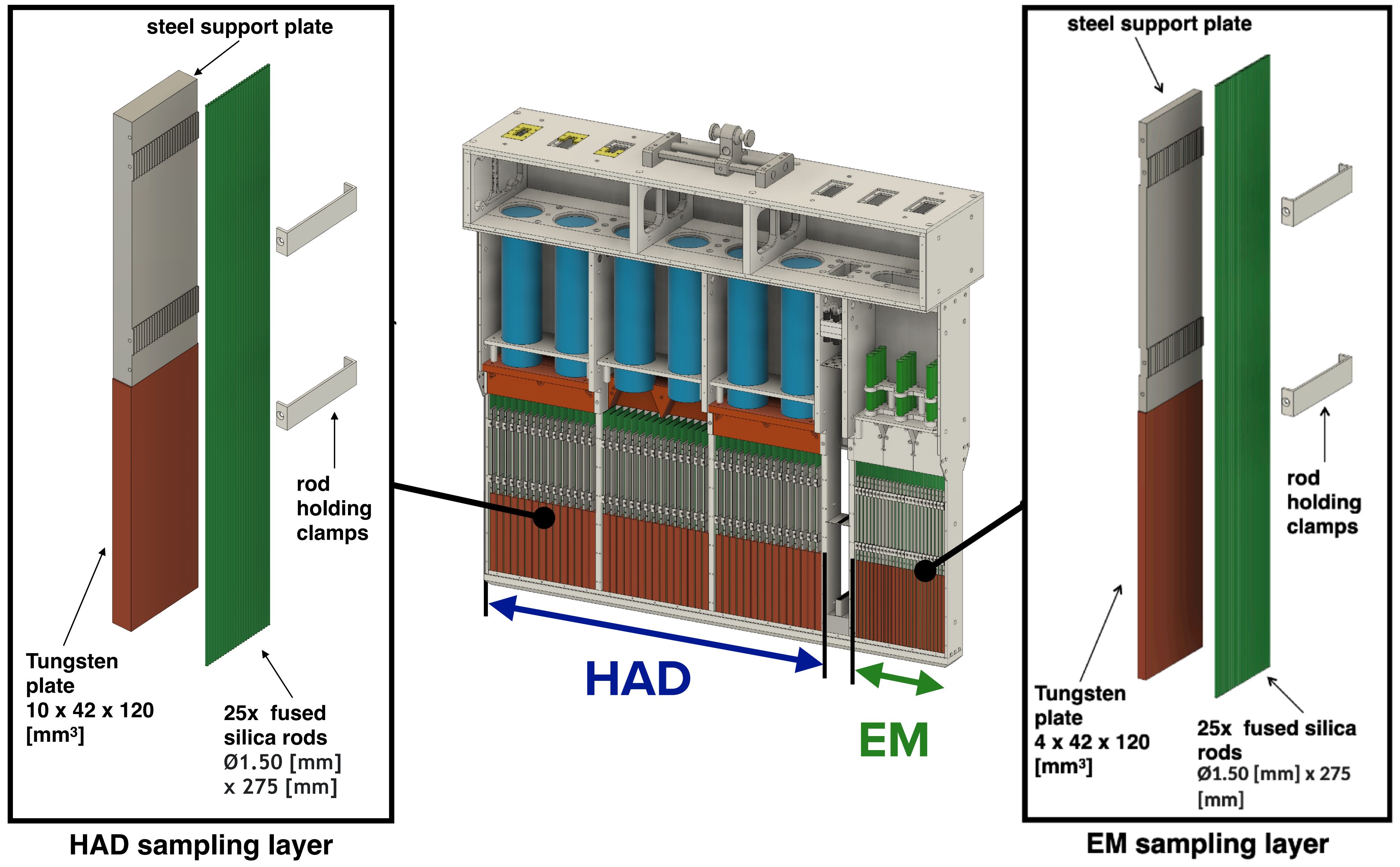
HL-ZDC: DETECTOR DESIGN & EXPECTED PERFORMANCE

HL-ZDC DETECTOR DESIGN

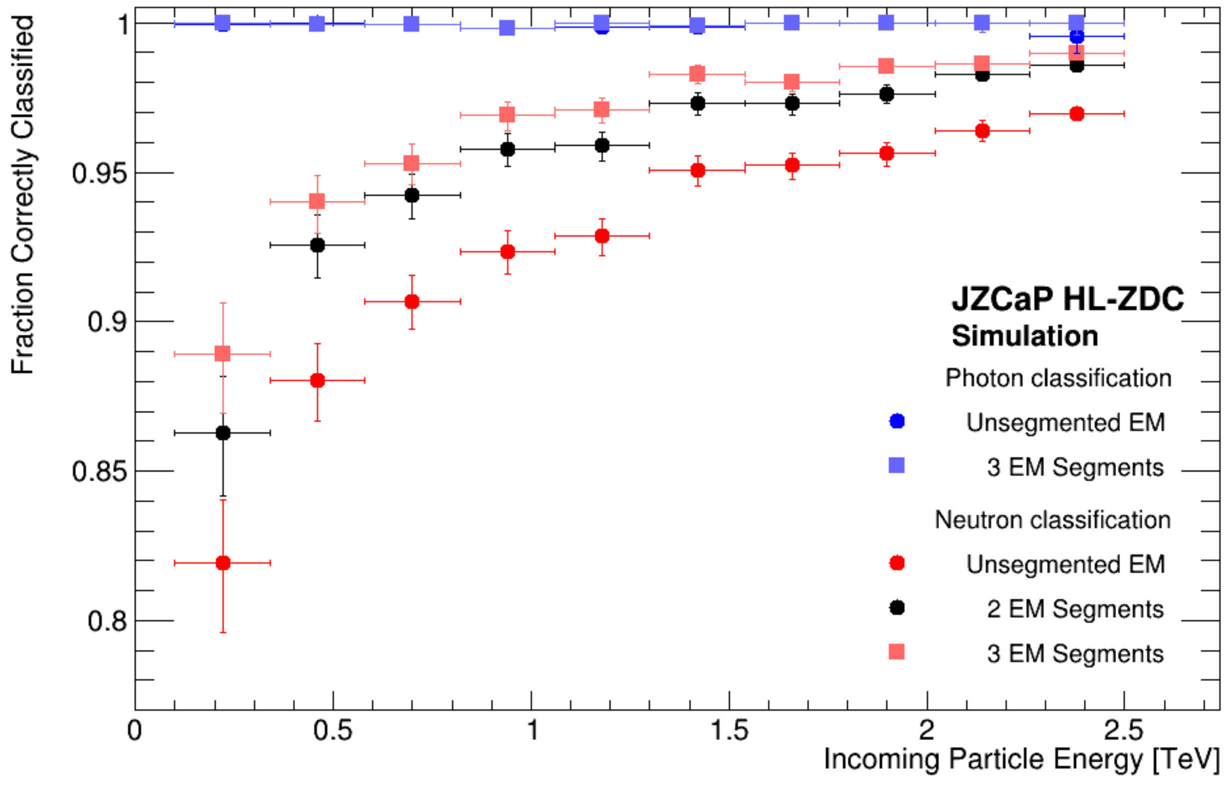


- **Tungsten - fused silica sampling calorimeter**
- Three sections:
  - **Electromagnetic (EM)**
  - **Reaction Plane Detector (RPD)**
  - **Hadronic (HAD)**
- **Time-efficient installation in high-radiation environment**
  - Single module structure
  - **Patch panels** for rapid cabling

HL-ZDC: CALORIMETER SECTIONS



- **EM section** **w/ *x-z* segmentation (3x3)**
  - *z* segments enable γ/n discrimination (99%++ efficiency w/ basic algorithms)
  - *x* segments locate beam in case of horizontal crossing angles
- **HAD section**
  - 6 PMTs coupled with trapezoidal light-guides
- **Cherenkov radiator for both sections: radiation-hard fused silica rods**

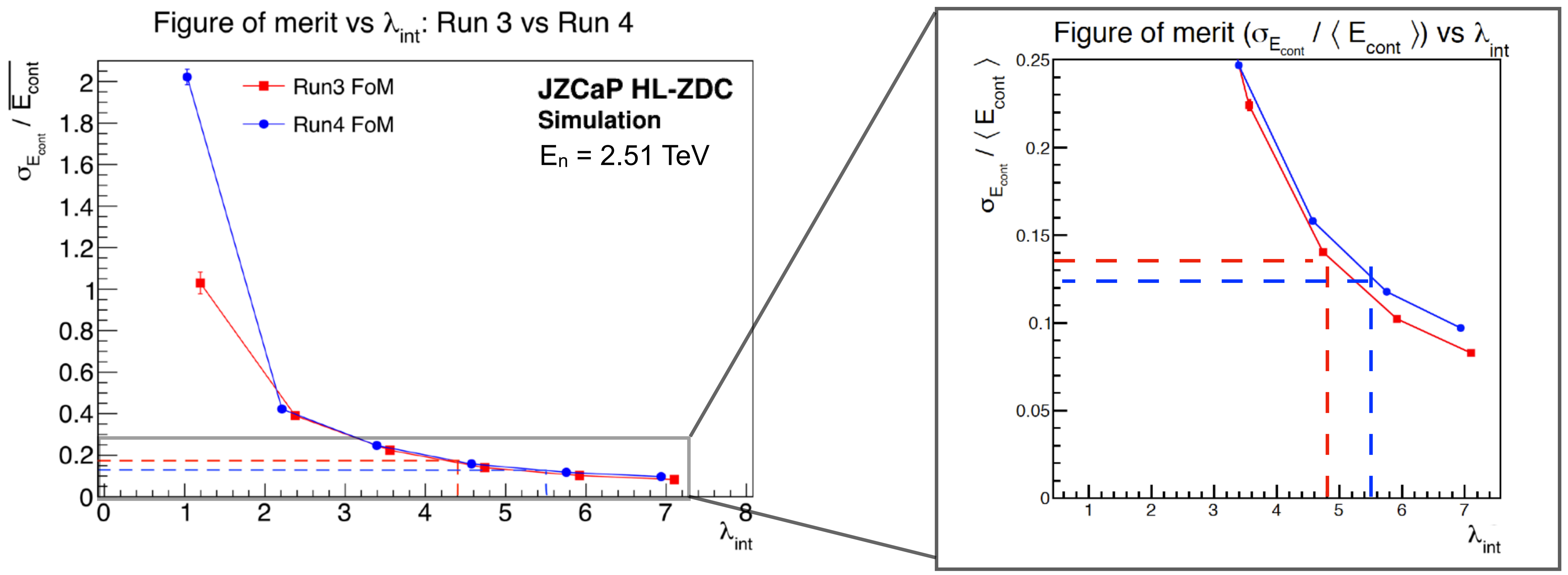


Arxiv:2212.03392, submitted NIM-A

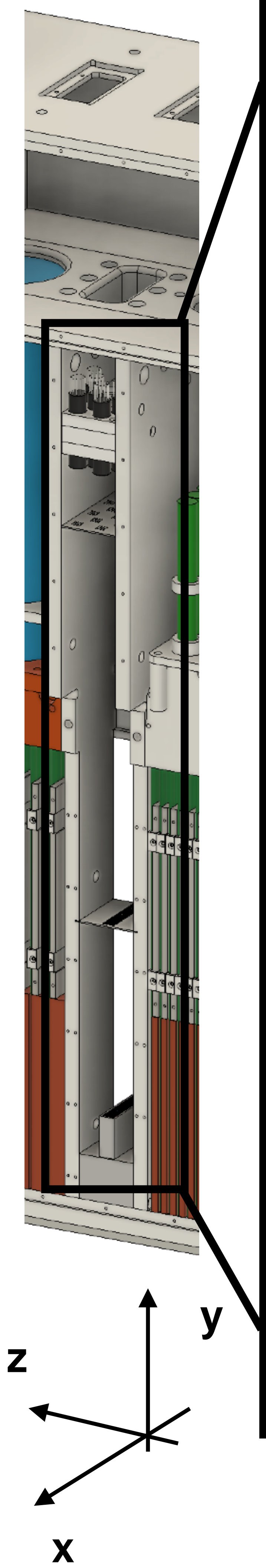
Optical Transmission Characterization of Fused Silica Materials Irradiated at the CERN Large Hadron Collider

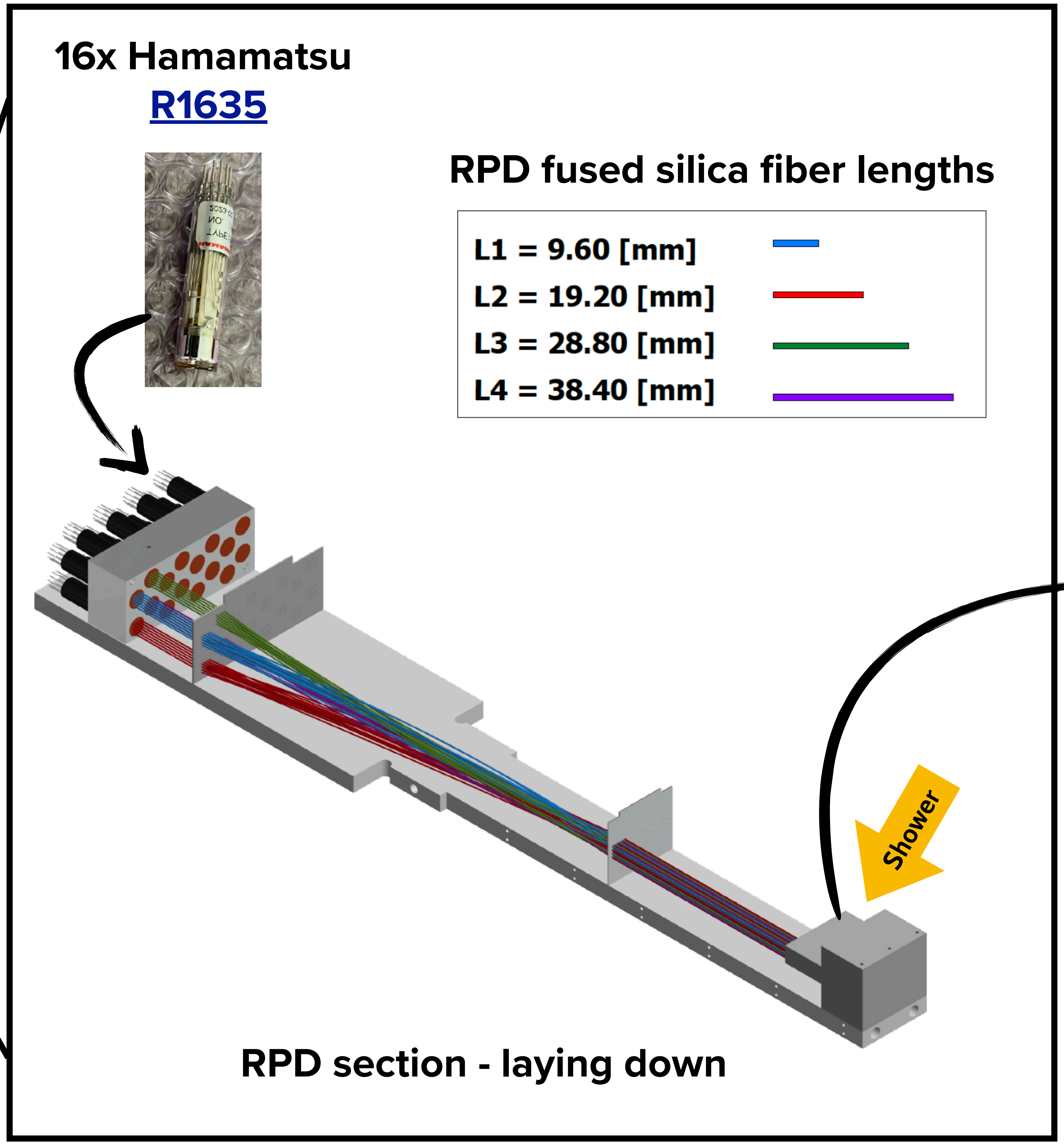
S. Yang, A. Tate, R. Longo, M. Sabate Gilarte, F. Cerutti, S. Mazzoni, M. Grosse Perdekamp, E. Bravin, Z. Citron, B. Kühn, F. Nürnberg, B. Cole, J. Fritchie, I.Gelber, M. Hoppesch, S. Jackobsen, T. Koeth, C. Lantz, D. MacLean, A. Mignerey, M. Murray, M. Palm, M. Phipps, S. Popescu, N. Santiago, S. Shenkar, P. Steinberg

- **Expected Performance**
  - HL-ZDC will have reduced transverse acceptance but a total of 5.5 λ_{int} (vs 4.4) and no BRAN detector in between
  - ➡ **Similar containment, but HL-ZDC has better resolution!**

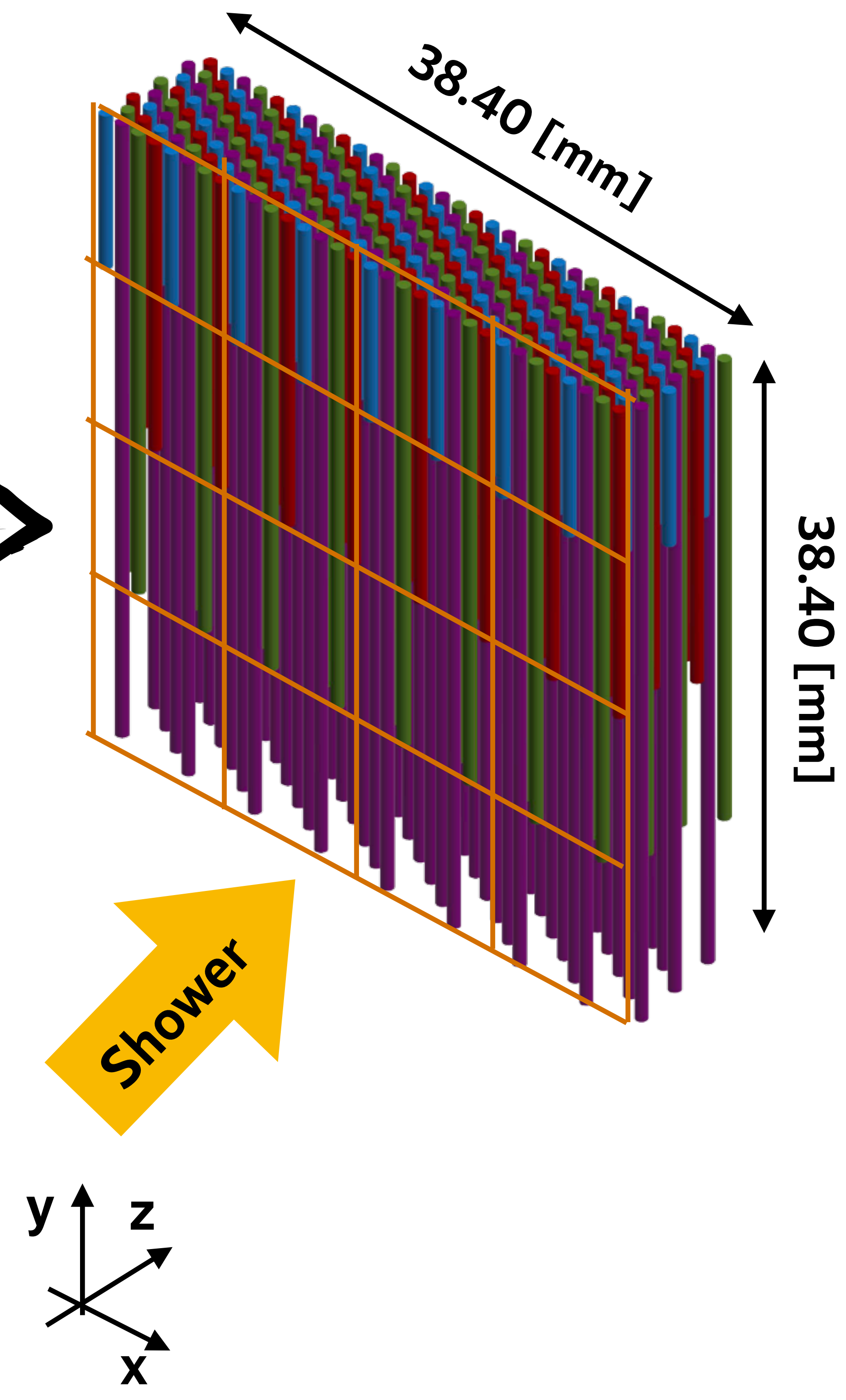


HL-ZDC: RPD SECTION





RPD fused silica fiber arrangement in the active area (Aluminum support plates not displayed for better visibility)

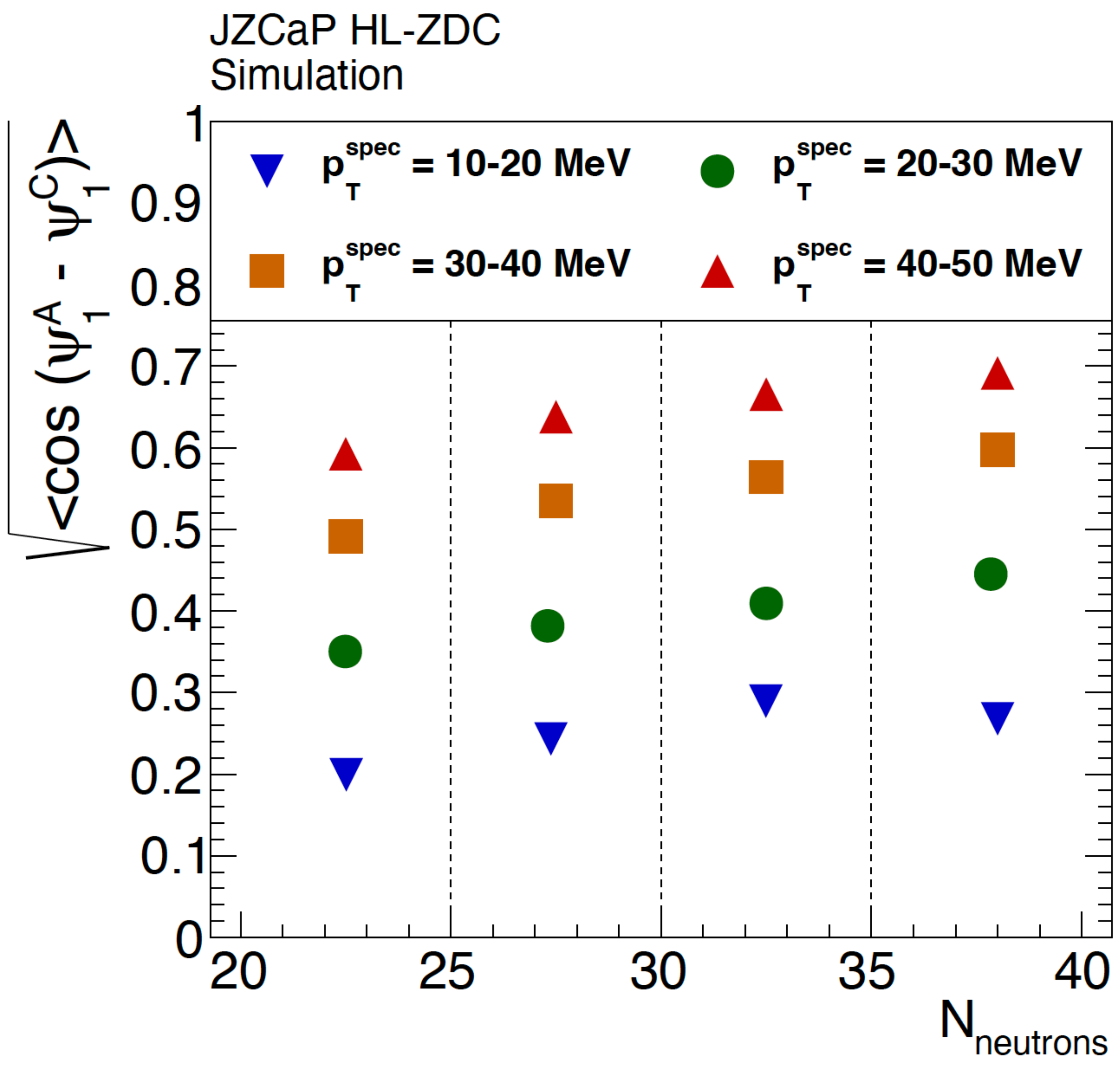


- **Rad-hard fused silica fibers** ϕ = 710 µm, act as both Cherenkov radiator and readout fibers
- Signal from 8 layers of staggered fused silica fibers of 4 different lengths collected by **16 PMTs**
- Fiber pattern provides an effective **4x4 tile segmentation**, but requires dedicated algorithm to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

HL-ZDC: RPD - EXPECTED PERFORMANCE

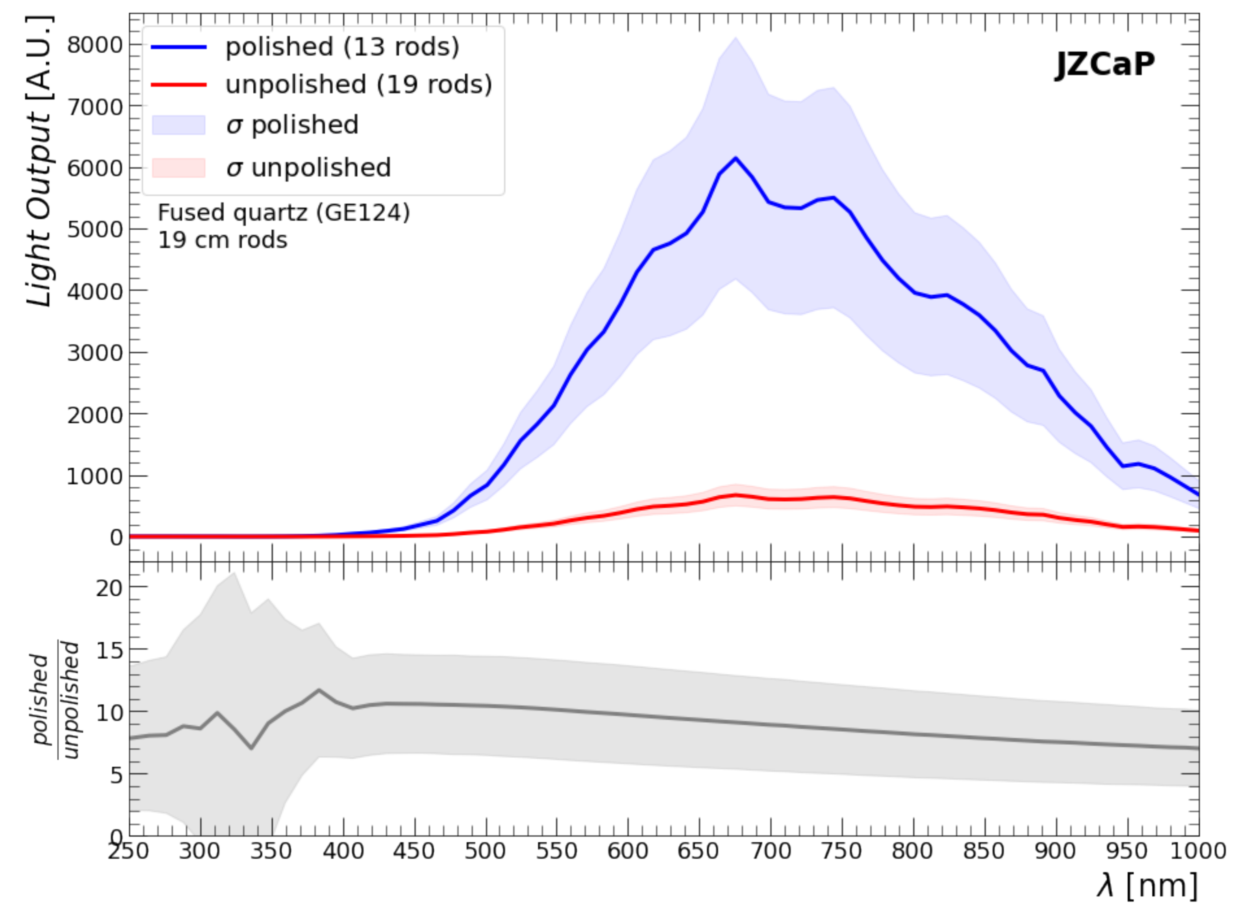
- **Characterization of RPD performance by "resolution", $\sqrt{\langle\cos(\psi_1^A - \psi_1^C)\rangle}$, built comparing ψ values measured from different (parts of) detectors**
  - Actually a multiplicative factor used to correct measurement of flow coefficients
  - Machine Learning algorithms tested 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 case of low p_T kick
  - Performance comparable w/ STAR SMD, **J.Phys.G 34 (2007) S1093-1098**

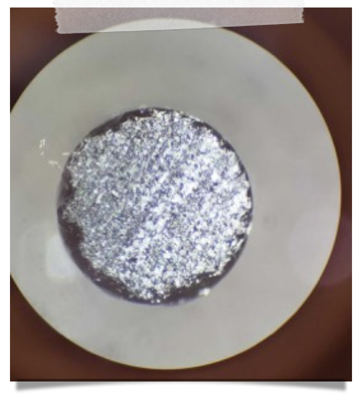


HL-ZDC: RUN 3 ATLAS ZDC EXPERIENCE

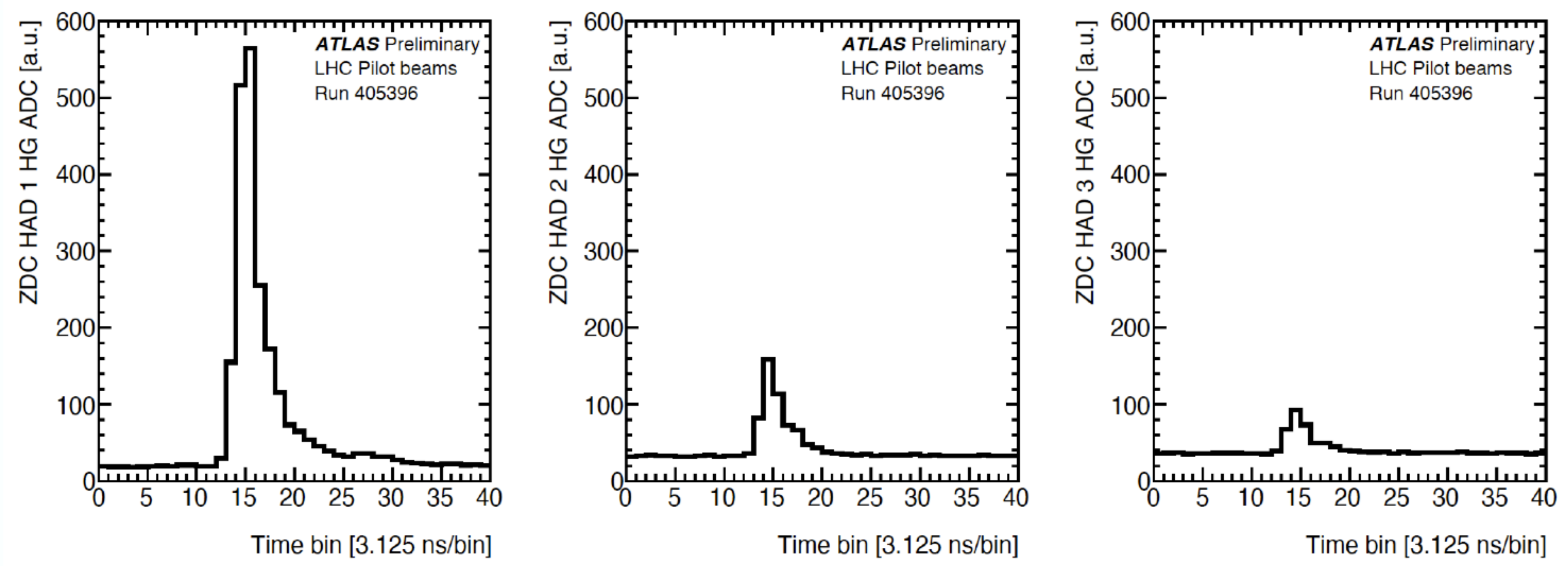
- Several Run 3 implementations will be pivotal in the upgrade process towards Run 4
- **New H_2 doped fused silica core**
  - Radiation hard + polished on the surface facing the PMTs (x5 more light transmission)
- **New LUCROD electronics (adapted from LUCID)**
  - 32 samples per ch - 3.125 ns per sample
  - Fully digital trigger
    - 3 bit pattern sent to ATLAS CTP fully driven by a 2-stage lookup table
    - Successfully operated already during the 2021 pilot run and the 2022 ZDC+LHCf run
  - Will be the base also for Run 4 detector (w/ needed upgrade to integrate w/ new ATLAS acquisition system)
- **New air-core cables for detector signal readout**
  - Superior performance compared to old CC50 cables (much lower signal dispersion)
  - Minimize contribution from Out Of Time pile-up



Unpolished Rod



Polished Rod

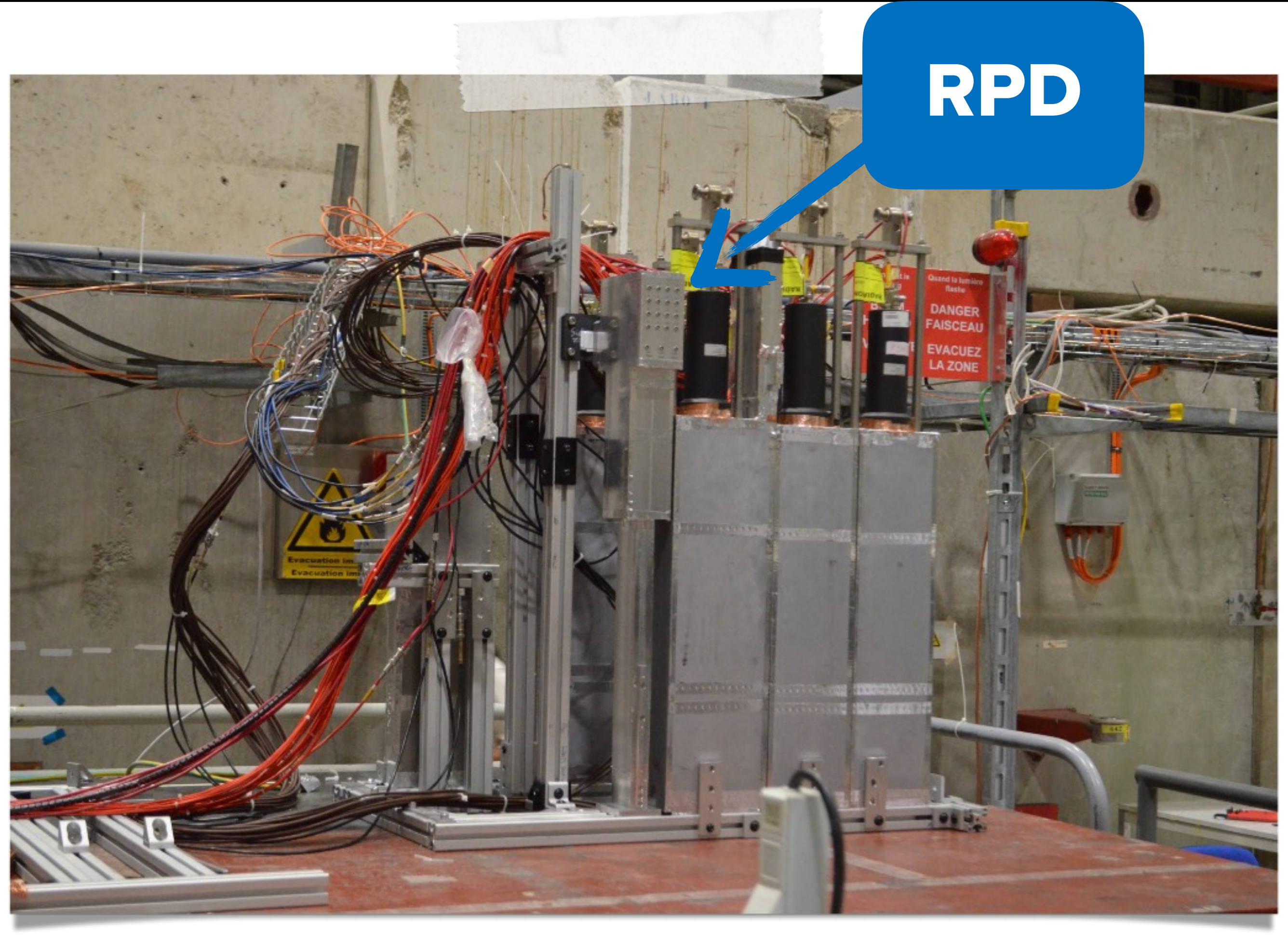


Refurbished ATLAS ZDC, LHC pilot beam, [October 2021]
ATL-COM-FWD-2021-025

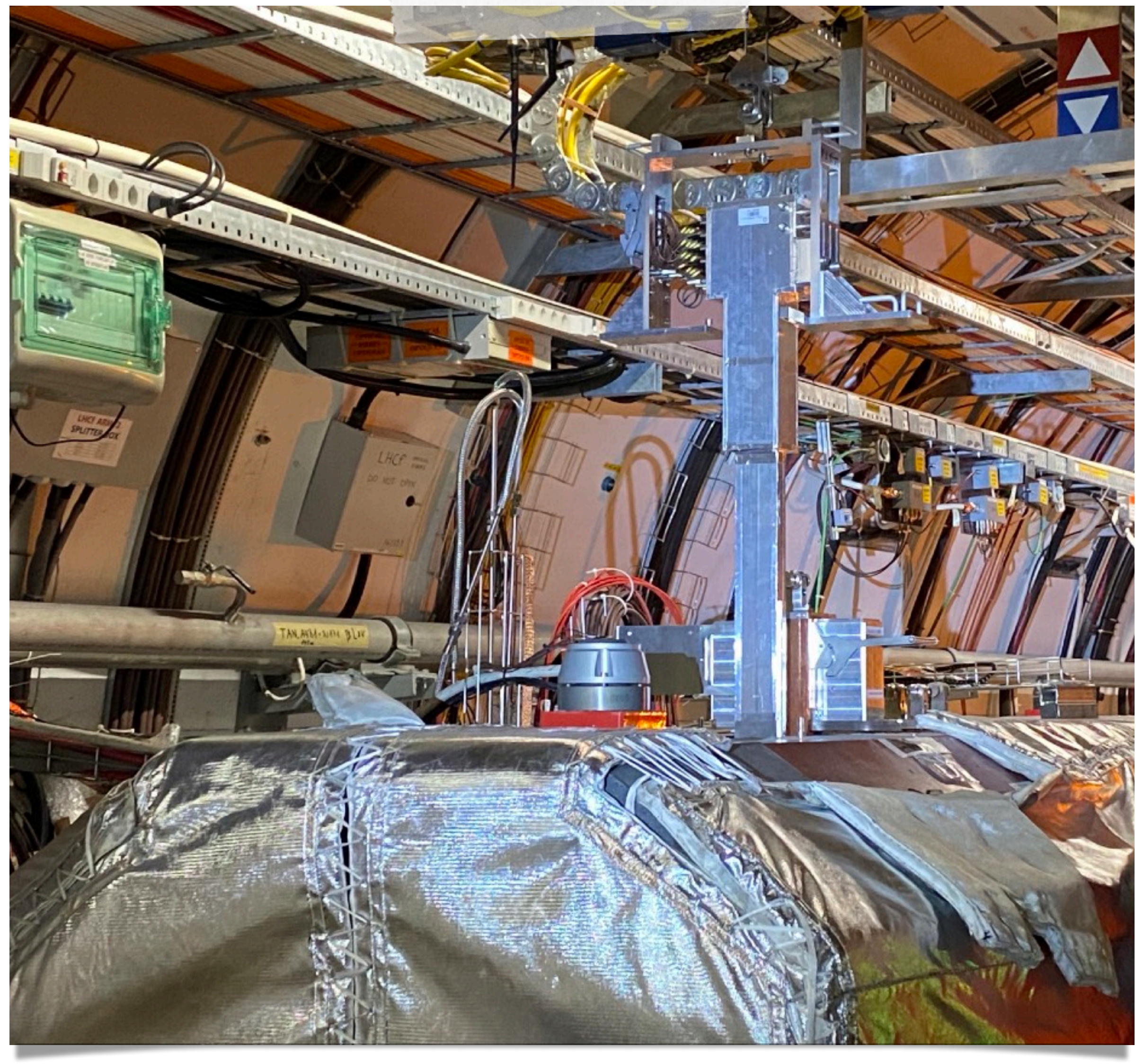
HL-ZDC: RUN 3 ATLAS RPD EXPERIENCE

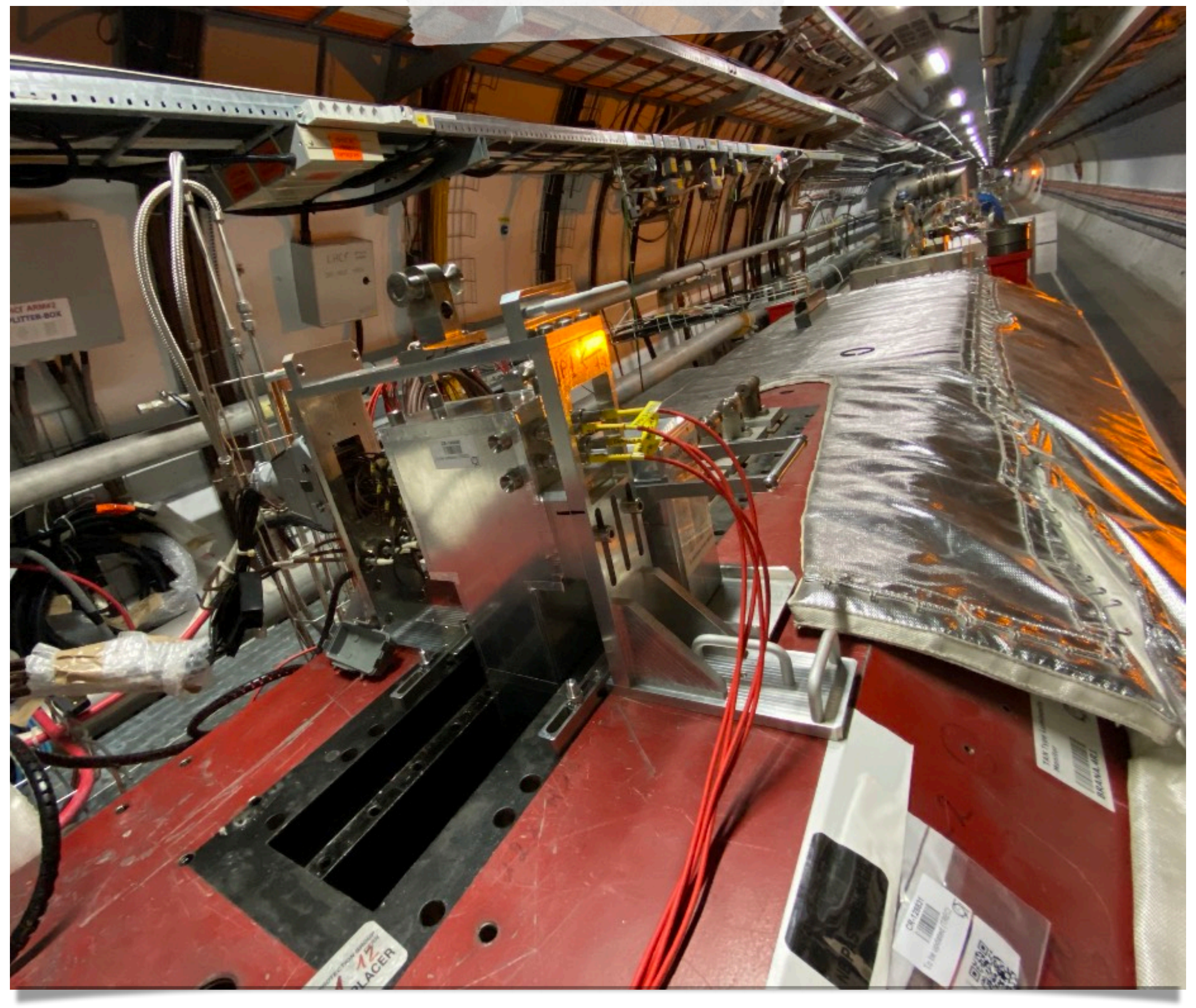
- **RPD designed to detect bunches of 10-40 spectator neutrons @ 2.5 TeV**
  - Hard to benchmark detector performance in test beams
  - Best opportunity offered by Run 3

    ➡ the ATLAS ZDC group constructed a pair of new RPDs during LS2
- **A series of preparation steps toward the Run were successfully accomplished in the last year**
  - Detector tested @ H4 beam line in July 2022
  - Detector integrated w/ the LHC and w/ ATLAS TDAQ, and tested in a Full System Test during the YETS 2022-2023
  - New PMTs installed 10 days ago - refurbished detector will be tested at H2 next week
- **Next step: the 2023 Heavy Ion run!**



ATLAS ZDC/RPD test beam 2022





ATLAS RPD Full System Test, YETS 2022-2023

LUCID UPGRADE FOR THE HL-LHC

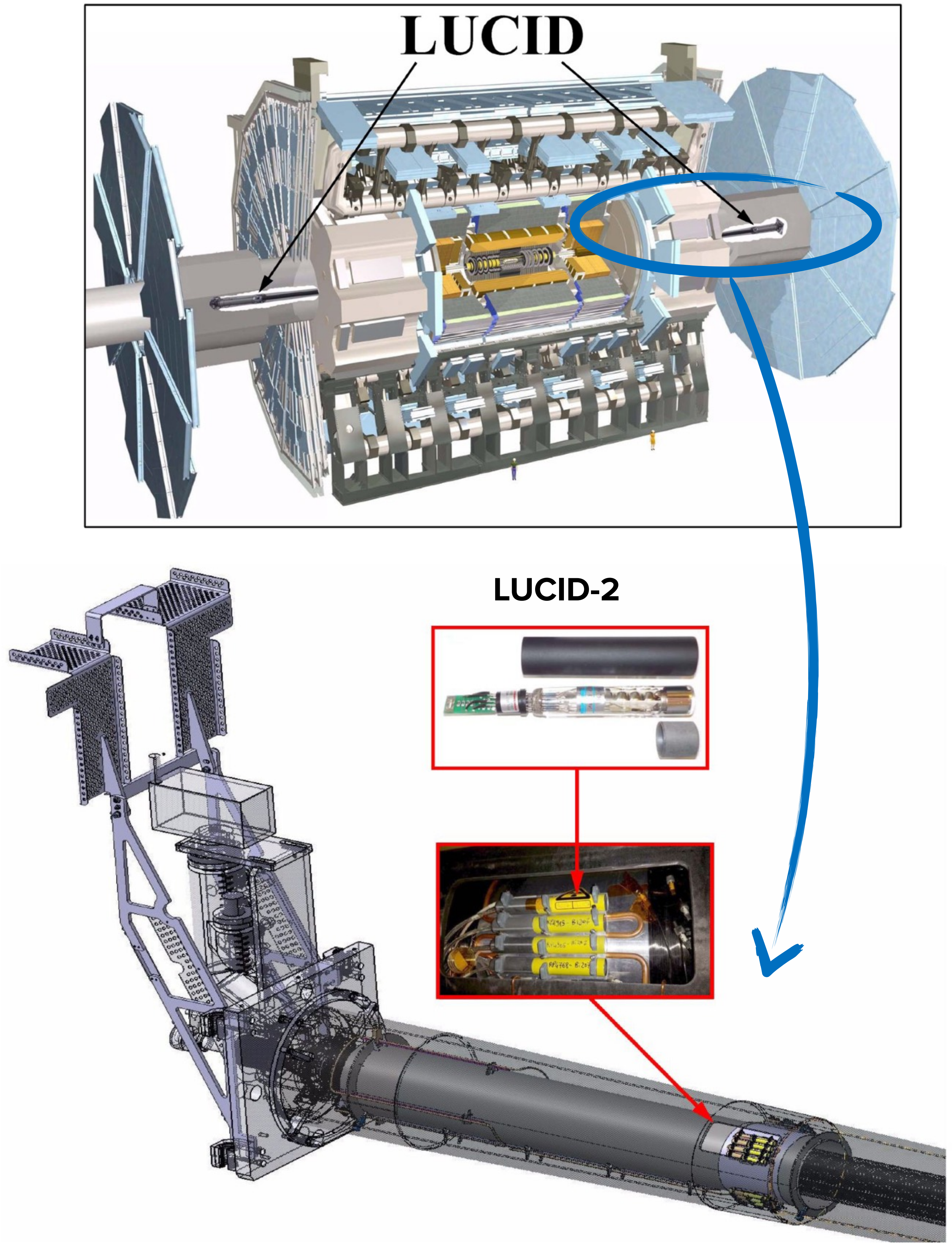
ATLAS STRATEGY FOR LUMINOSITY MEASUREMENT

Thanks to B.Giacobbe and A.Sbrizzi for providing material and for useful discussion

- **ATLAS strategy based on a redundancy of detectors with different technologies, instrumental and systematic effects, sensitivity to background and beam-conditions**
  - A set of "main" detectors that can be calibrated in vdM (low luminosity) and are linear (or precisely correctable) up to the physics data taking conditions
  - A set of ancillary detectors including the tracker, EM and HAD Calorimeters (in the FWD region) needed to cross-check and apply corrections to (some of) the main luminosity.
- This redundancy must be **reinforced in the HL-LHC** with
  - LUCID based on a solid technology, widely and successfully tested in Run2/3: considered as lower risk project BUT needs to be upgraded
  - HGTD, BCM' and tracking detector being developed ➡ higher risks for different reasons
- **Focus on the LUCID-3 upgrade in the next slides**

LUCID-2 MEASUREMENTS IN RUN 2

Thanks to B.Giacobbe and A.Sbrizzi for providing material and for useful discussion



- **LUCID-2 based on PMT-technology stably and reliably provided both online and offline bunch-by-bunch luminosity to ATLAS in Run2**
  - In all beam-conditions, luminosity ranges and type of colliding particles
  - Does not provide data for forward physics measurements
- **Key to the success was the ability to maintain stable conditions:**
  - Use of radioactive ^{207}Bi source to monitor (and correct for) PMT gain-loss at every inter-fill
  - Each PMT provides an independent luminosity measurement, or can be grouped with others in combined algorithms (Event / hit / particle-counting)
  - Flexibility in case of malfunctioning and internal redundancy
- **0.8% precision achieved in Run 2! [Arxiv:2212.09379]**

CASE FOR A LUCID UPGRADE

Thanks to B.Giacobbe and A.Sbrizzi for providing material and for useful discussion

- **LUCID luminosity measurement in ATLAS in Run 4 and beyond**
  - The ATLAS precision measurements program in ATLAS calls for a **1% luminosity precision**
  - Otherwise, luminosity will be the limiting factor in the systematic uncertainty
  - Same effective strategy adopted in previous runs to target this precision
- **HL-LHC conditions will be significantly more demanding**
  - Pile-up increase up to $\mu \sim 200$

    ➡ saturation of the luminosity algorithms
  - $L_{int} \sim 260$ to $330\ fb^{-1}$/year

    ➡ large radiation dose impacting detector aging
  - Luminosity range from $10^{29}\ cm^{-2}s^{-1}$ (vdM calibration) to $7.5 \cdot 10^{34}\ cm^{-2}s^{-1}$ (physics)

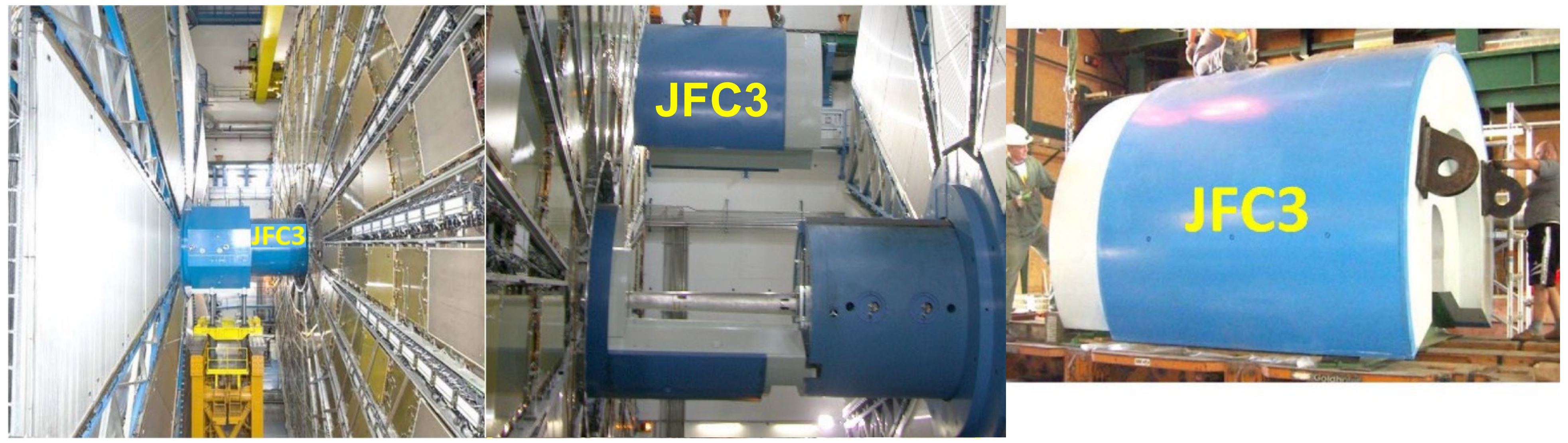
    ➡ linearity needed over 5 to 6 orders of magnitude
- **Run-2/3 detectors (including LUCID) not able to ensure the needed precision in HL-LHC**

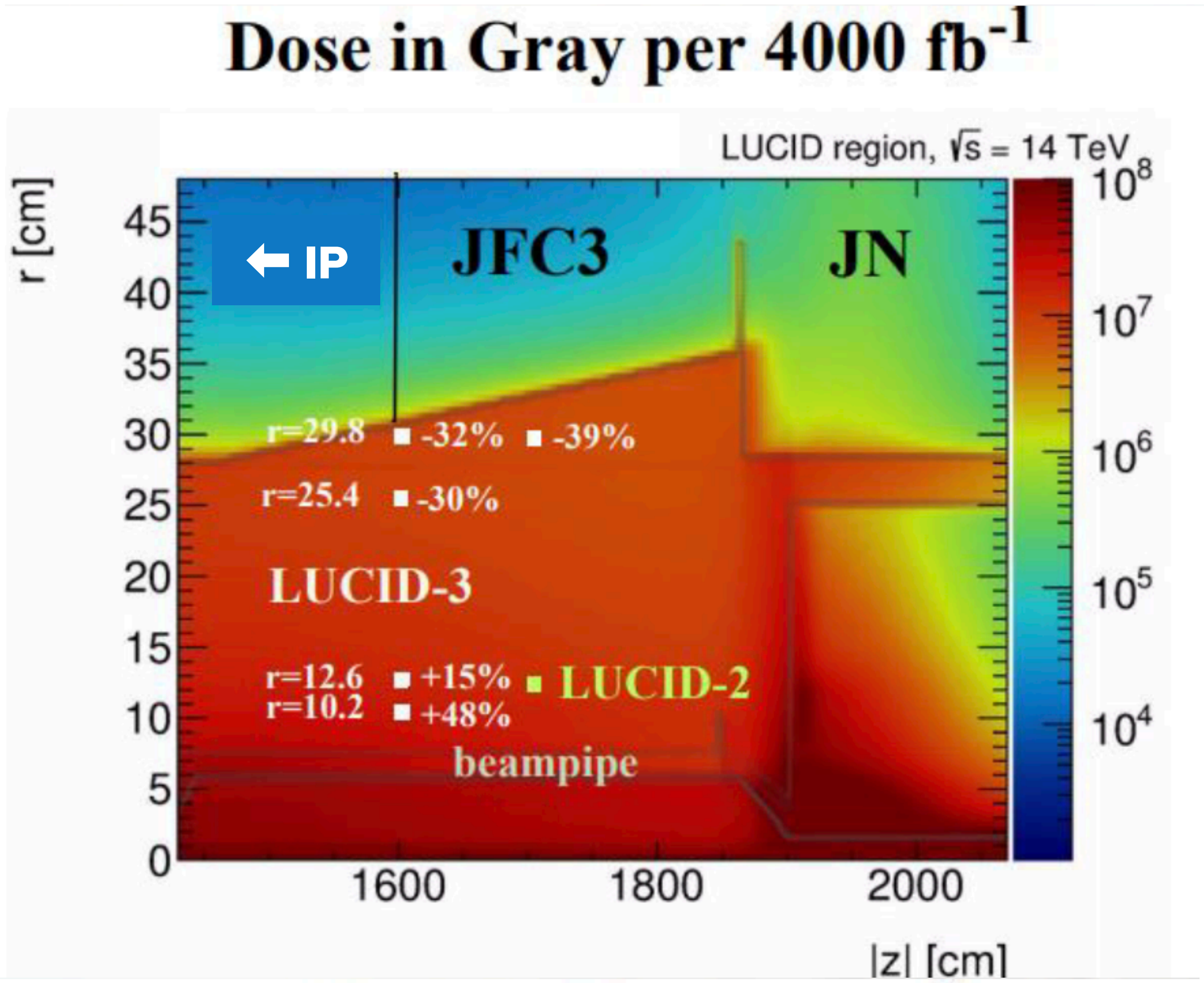
  ➡ **Upgrade of LUCID-2 to LUCID-3 for the HL-LHC era**

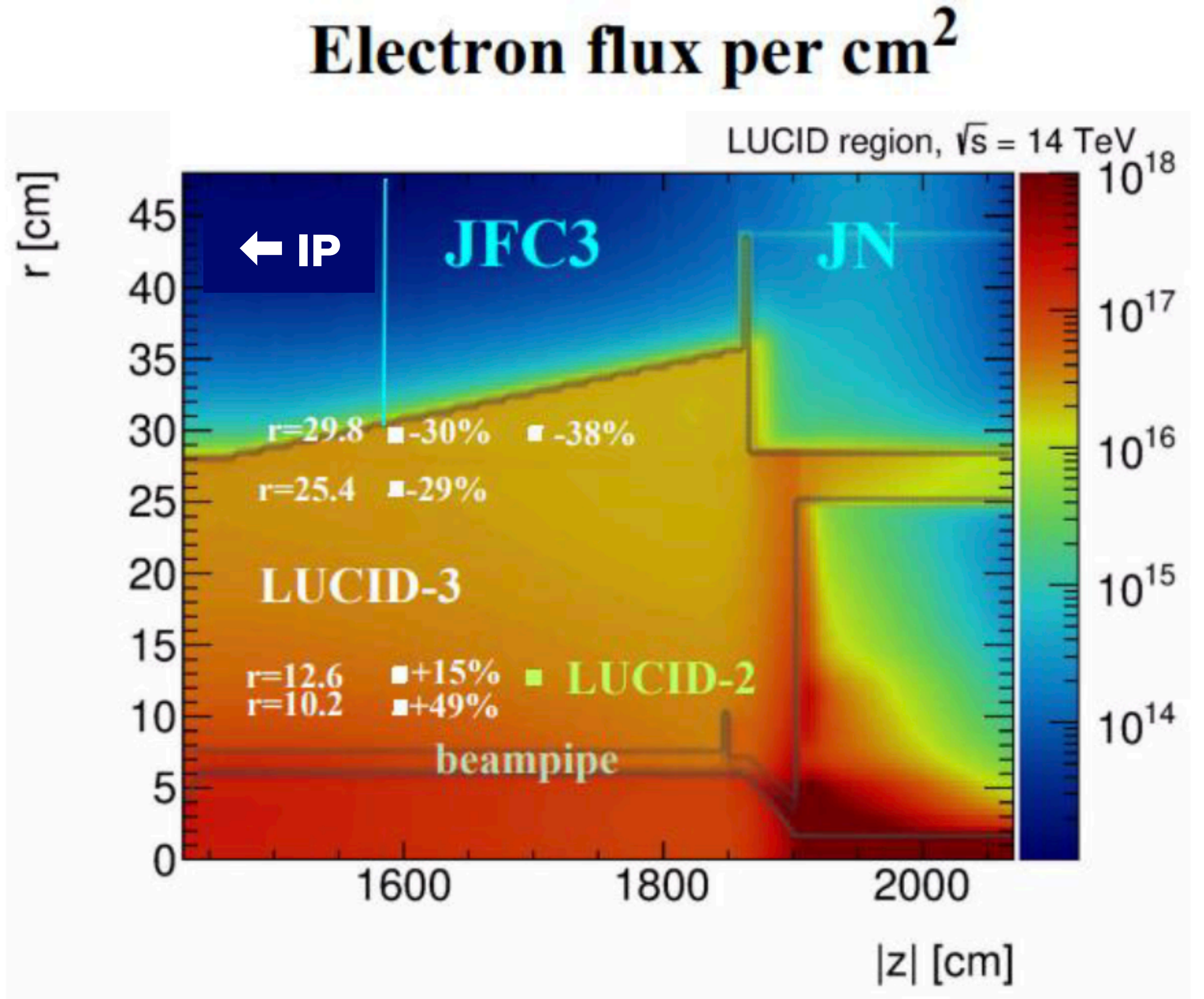
LUCID-2 [LHC] → LUCID-3 [HL-LHC]

Thanks to B.Giacobbe and A.Sbrizzi for providing material and for useful discussion

- **LUCID-2 detector will not work in the HL-LHC**
  - Issue not related to PMT technology, but too large acceptance/particle flux on the detector



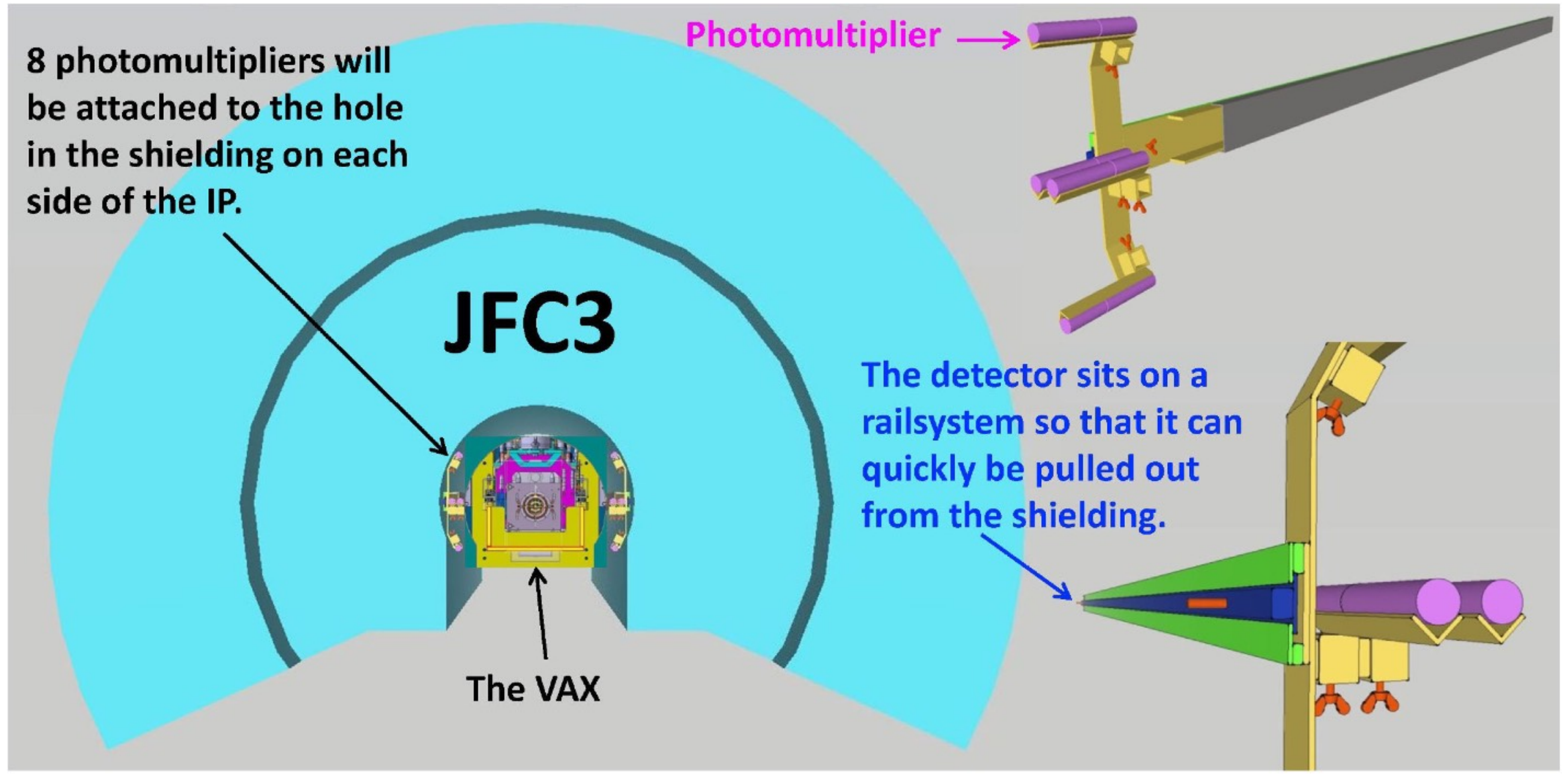




Issue	Reason	Consequence	Mitigation	Detector type/ location	Pro/Cons
Too large acceptance	r~12.6 cm	Saturation	r~29.8 cm	PMT in FWD shielding (JF)	Easy early maintenance
Too large acceptance	ϕ_{PMT} = 10 mm	Saturation	ϕ_{PMT} = 8 mm	Hamamatsu R1635 PMTs 🔗	Expected low non-linearity
Too large acceptance / radiation	Particle flux	Non linearity / Ageing	Re-location in very low acceptance region	PMTs behind FWD shielding (JN)	Low PMT currents; Expected low non-linearity; Impossible yearly replacement
High radiation levels	Location	Aging	Re-location in a lower acceptance region	Inside and behind FWD shielding (JF and JN)	

LUCID-3 PROTOTYPES IN RUN 3

Thanks to B.Giacobbe and A.Sbrizzi for providing material and for useful discussion



- **Run 3 offered a unique possibility to benchmark LUCID-3 approach and simulations**
  - Increase of < μ > up to 60-70 (intermediate between Run 2 and Run 4++)
- **LUCID-3 prototypes were installed during LS2 and will take data for the whole Run 3**
  - **JF-prototypes:**
    - Both R760 (ϕ = 10 mm) and R1635 (ϕ = 8 mm) installed and taking data
    - PMT Replacement very fast (1 minute / PMT): no issue with safety
  - **JN-prototypes:**
    - R760 installed and taking data
    - No replacement possible, but no issue with aging expected

LUCID-3 PROTOTYPES IN RUN 3

Thanks to B.Giacobbe and A.Sbrizzi for providing material and for useful discussion

FIRST RUN 3 TAKEAWAYS

- **Acceptance reduction:**
  - Simulations-based estimate confirmed by prototypes results both for JF and JN and both for R760 and R1635 PMTs ➡ **crucial confirmation for LUCID-3 design**
- **Non-linearity:**
  - **First prototype data confirms lower pile-up dependence of LUCID-3 (both JF and even more JN) wrt LUCID-2**
- **Yearly maintenance:**
  - First experience during 2022-23 YETS: **fast and easy PMT replacement on surface**

- **Run 3 offered a unique possibility to benchmark LUCID-3 approach and simulations**
  - Increase of $<\mu>$ up to 60-70 (intermediate between Run 2 and Run 4++)
- **LUCID-3 prototypes were installed during LS2 and will take data for the whole Run 3**
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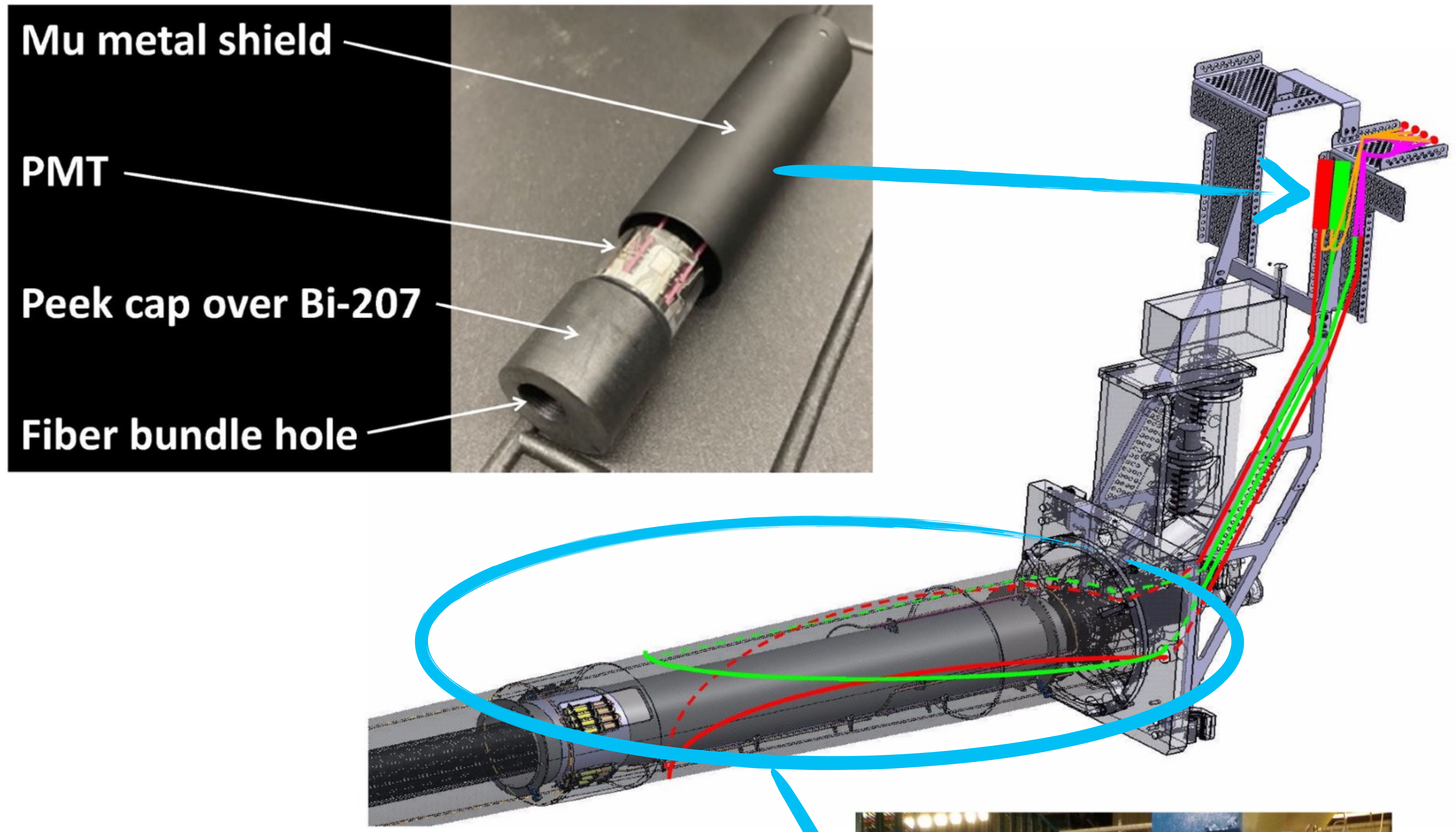
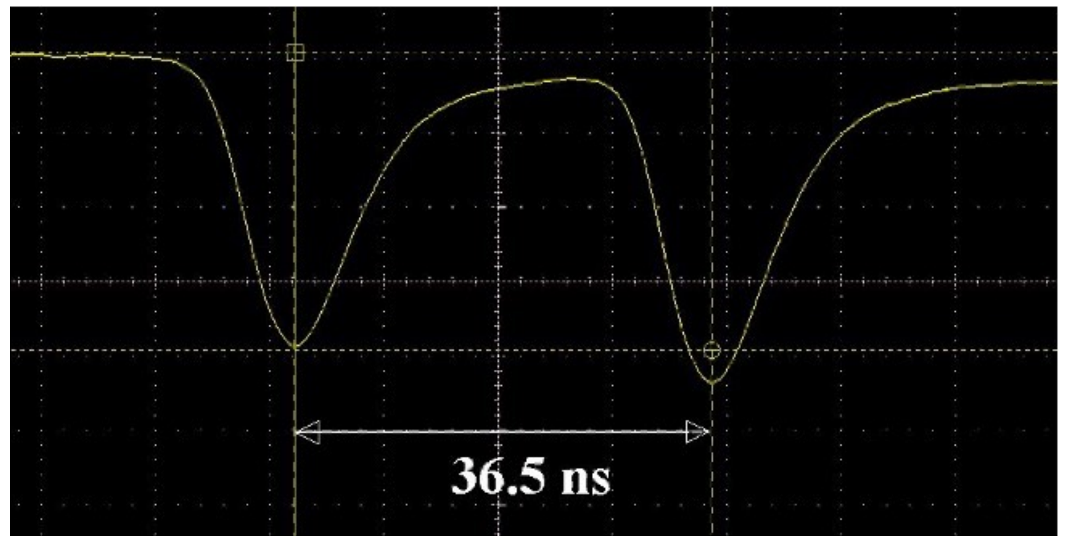
  - **JN-prototypes:**
    - R760 installed and taking data
    - No replacement possible, but no issue with aging expected

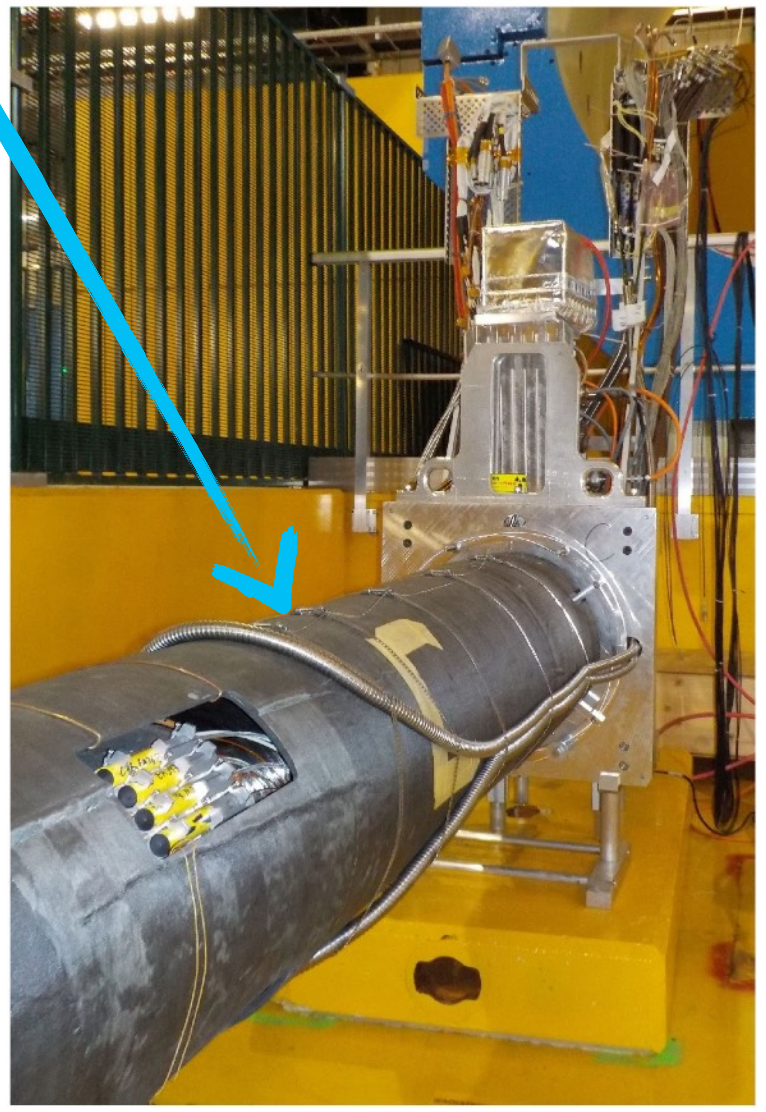
THE COMPLEMENTARY RUN 4 FIBER DETECTOR PROTOTYPE

Thanks to B.Giacobbe and A.Sbrizzi for providing material and for useful discussion

- **Alternative approach that uses charge instead of hits**
  - Intrinsically linear with luminosity
  - Sensitive to the gain variation and the fiber degradation
  - Approach not yet validated with data - key input from Run 3 experience
- **2 fiber bundle prototypes built and installed in Run-3 around the beam-pipe with:**
  - ~50 new radiation hard quartz fibers per bundle
  - Hamamastu R7459 PMTs monitored with Bi-207 source
  - LED light with various λ injected simultaneously into the PMT (prompt signal) and the fiber-end (delayed signal)
  - Relative amplitude of the prompt and fiber signals to be used as monitor of the fiber aging
- **Both calibration and data analysis started**
- **If built, not decided yet whether to install in the JF-shielding or around the beam pipe**







SUMMARY

Thanks to B.Giacobbe and A.Sbrizzi for providing material and for useful discussion

HL-ZDC Upgrade

- ATLAS & CMS ZDC groups teamed up in the Joint Zero Degree Calorimeter Project to tackle HL-LHC challenges and design the next generation of ZDCs
- Radiation hard detector design, fully integrated with the accelerator lattice, to be funded by DOE
- Run 3 experience will be a key step in the HL-ZDC upgrade process

LUCID-3 Upgrade

- LUCID detector needs to be upgraded to perform the ATLAS luminosity measurement with the needed precision in HL-LHC
- Prototypes of the PMT detector both inside and behind the forward shielding were installed and are taking data in Run-3
- Overall, the design of the PMT-detector is confirmed. More detailed analysis needed for the fiber detector

THANKS FOR YOUR ATTENTION!

BACKUP SLIDES

ATLAS AFP BEYOND RUN 3

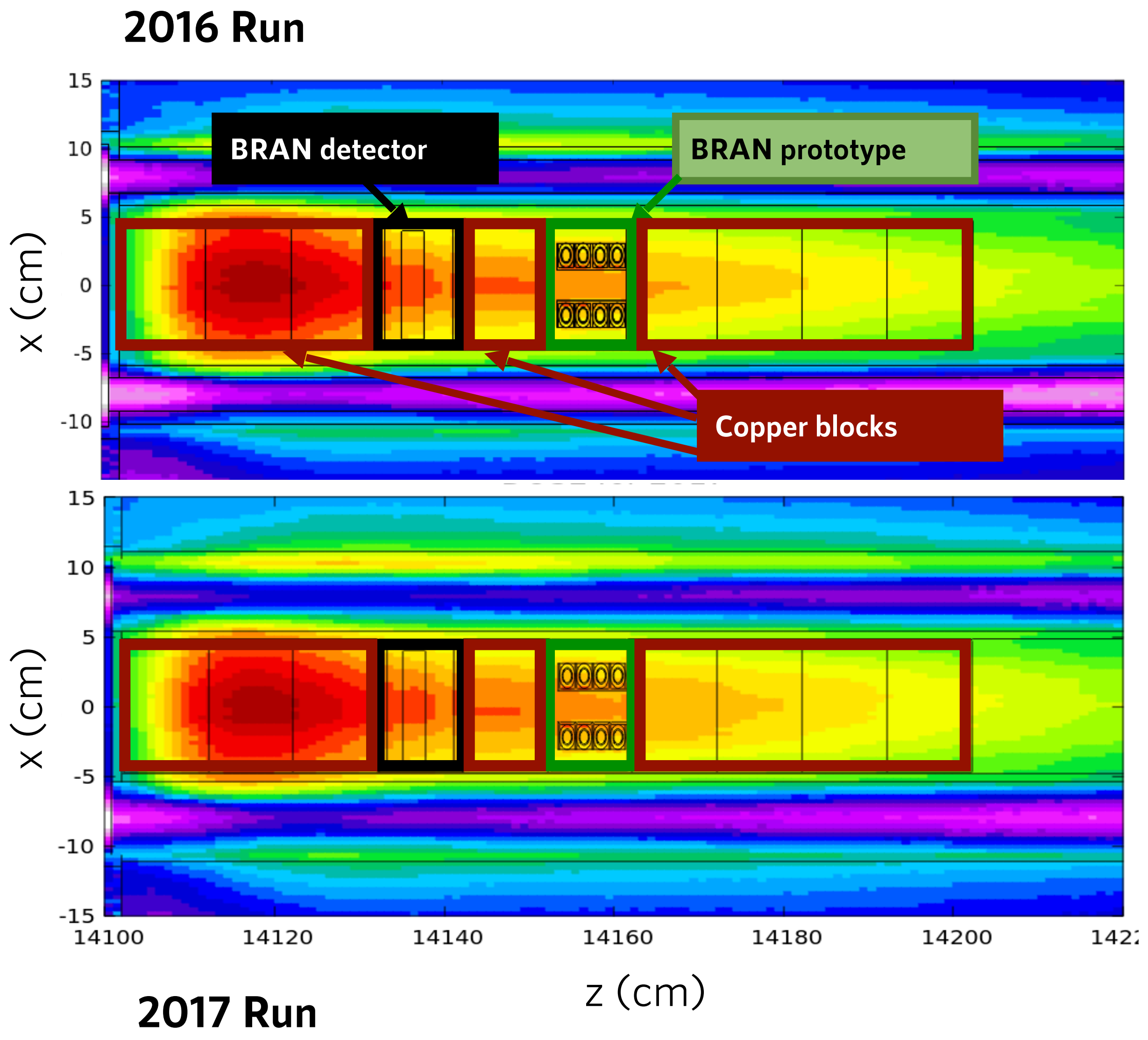
- **Feasibility studies for Run 4 and beyond**
  - In Run 4, there will be a switch in the crossing angles at IP1 (vertical -> horizontal) at IP5 (horizontal -> vertical)
  - Such a change, combined with the constraints from the machine on possible locations of an upgraded detector, will cause significant acceptance reduction for a HL-LHC AFP
  - On September 2022, an Initial Design Report for AFP detectors at the HL-LHC was sent to a review panel called by ATLAS Upgrade Coordinator
    - The main recommendation of the panel to ATLAS was not to approve the development of an AFP upgrade program for HL-LHC for Run 4, but to reserve the space for possible Run 5 or beyond projects if this is possible for the machine w/o constraints or additional cost
    - The result was endorsed by the ATLAS Upgrade Steering Committee, the ATLAS Executive Board and the HL-LHC Coordination Group in October 2022

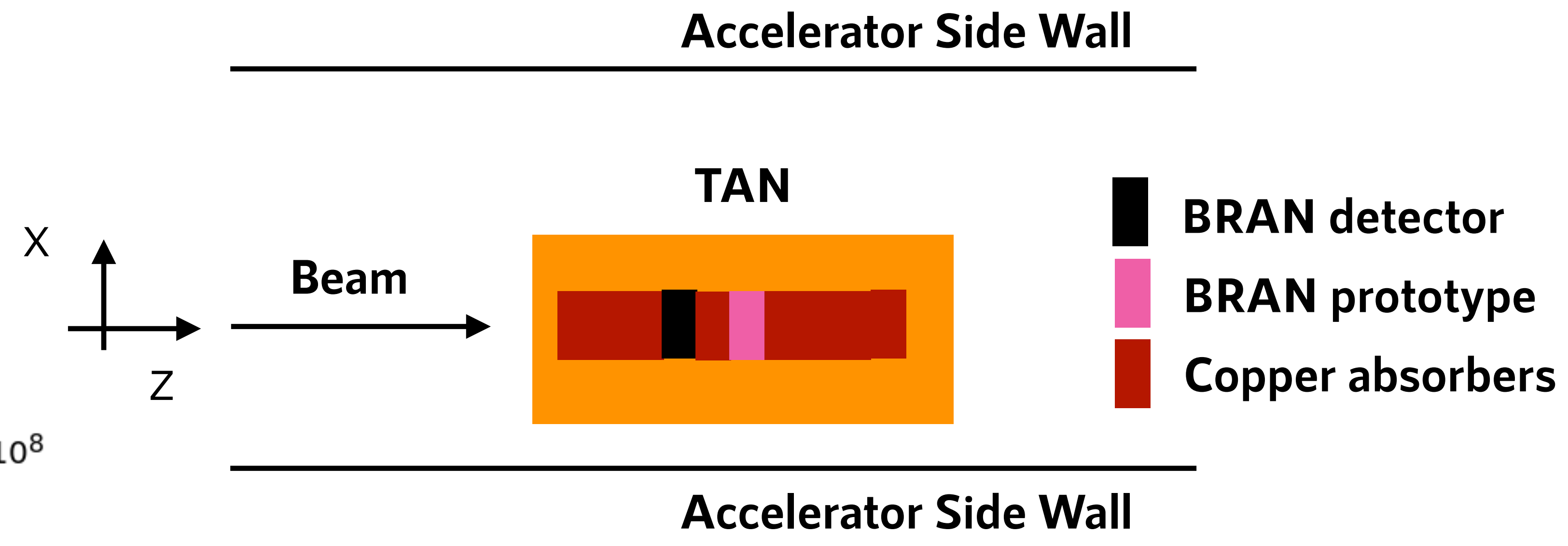
➡ **No upgrade of AFP for Run 4**

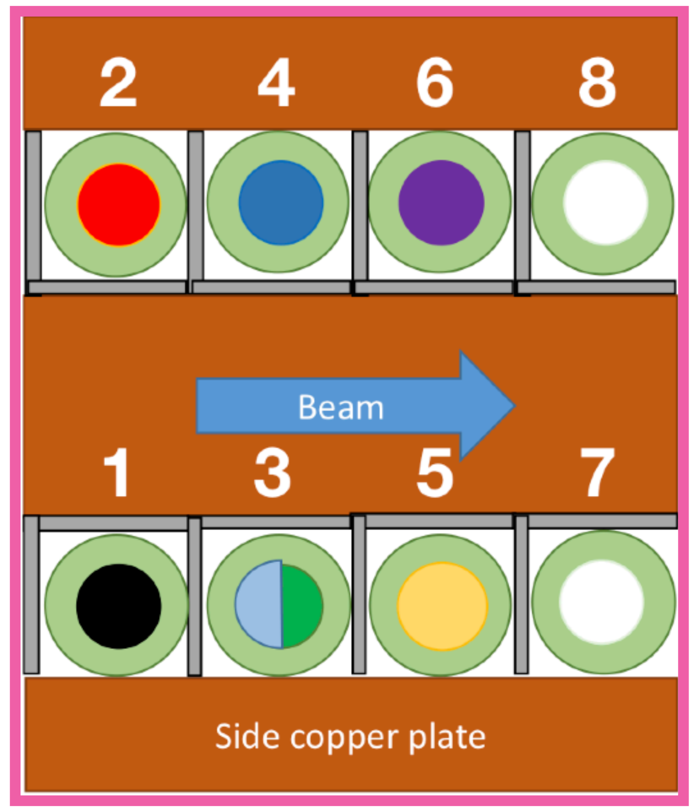
FUSED-SILICA RADIATION HARDNESS

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)

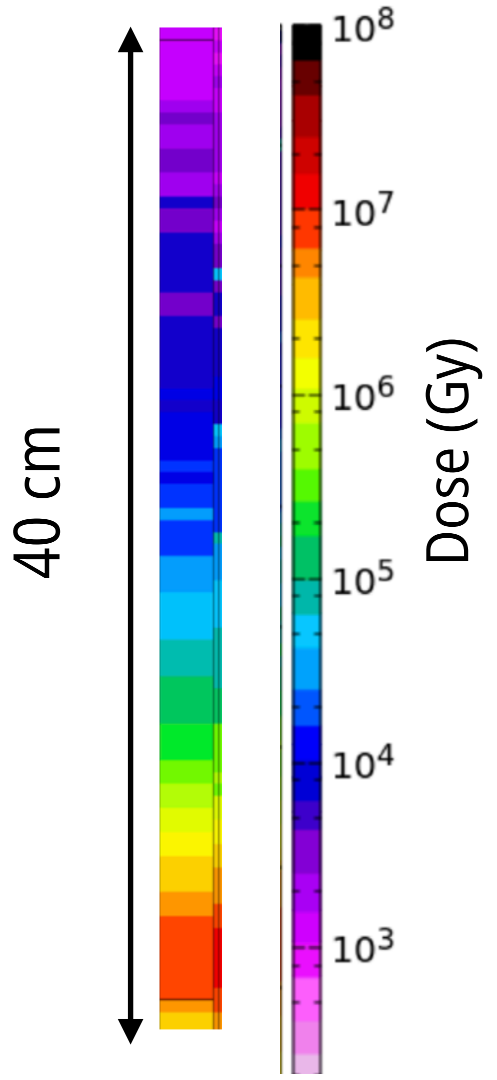
Arxiv:2212.03392, submitted NIM-A





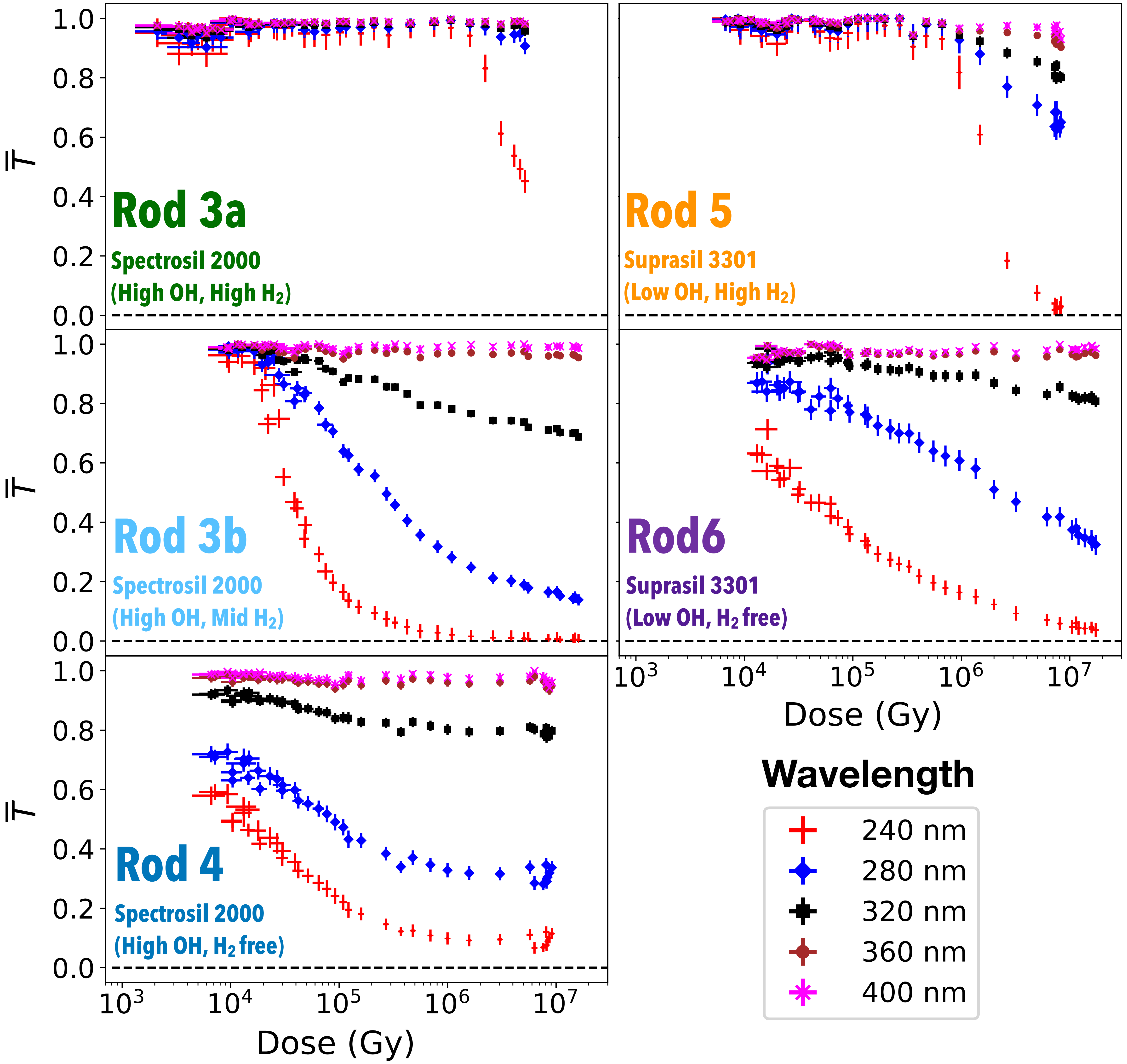


Dose profile along one rod (1 year of run)



- **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, 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 RADIATION HARDNESS



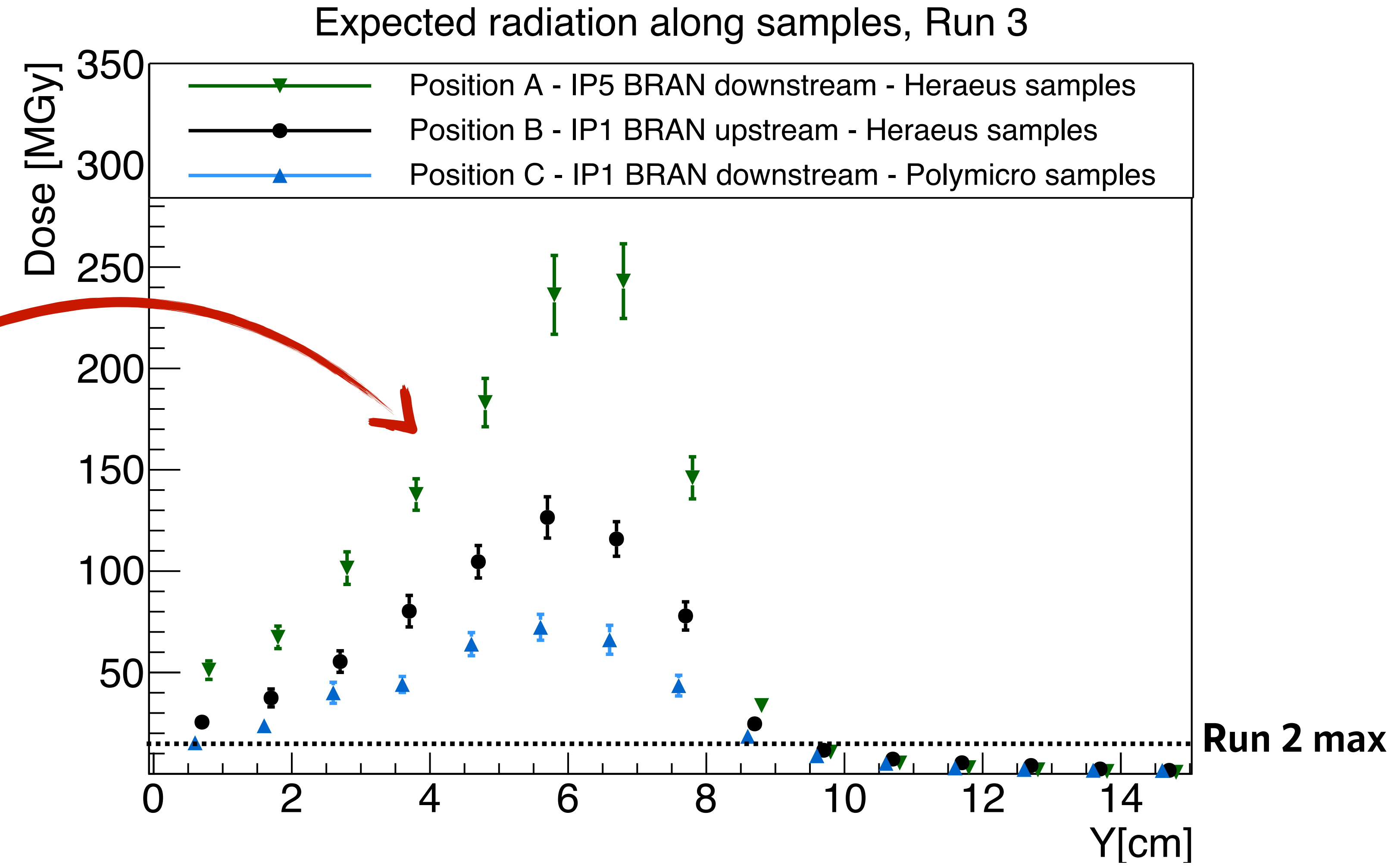
Arxiv:2212.03392, submitted NIM-A

- 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

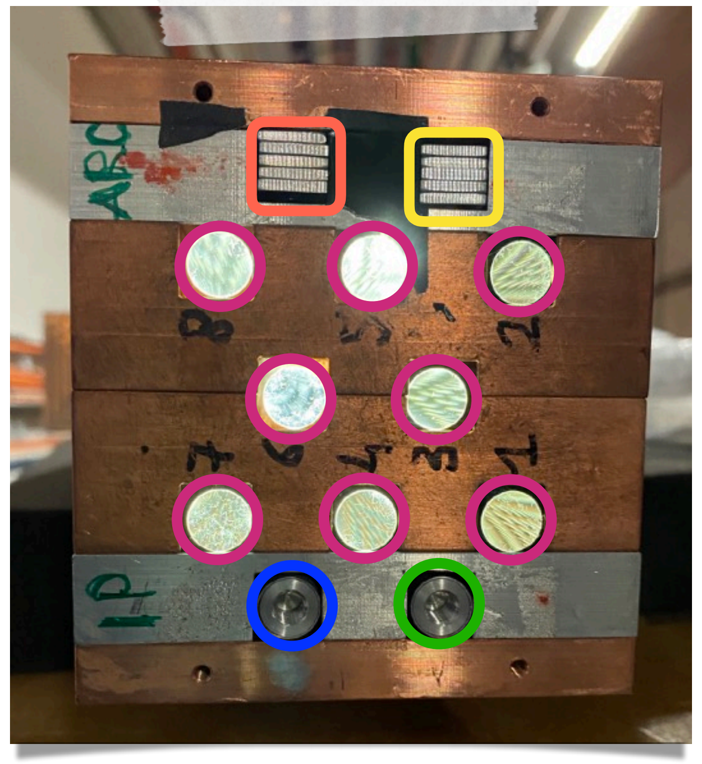
RUN 3 IRRADIATION CAMPAIGN

- **The BRAN group replaced the Run 2 detector with a new one (BRAN-D), fused silica based**
  - Run 1 & 2 detectors stared to show aging effects
  - 2/4 BRAN replaced in 2022, 2/4 in 2023
- **BRAN-D installed on January 2022**
  - Equipped with Heraeus fused silica samples and Polymicro fused silica fibers samples
  - Will be extracted in 2025 after 3.5 years of irradiation
  - All the samples polished on both ends for fast analysis after extraction

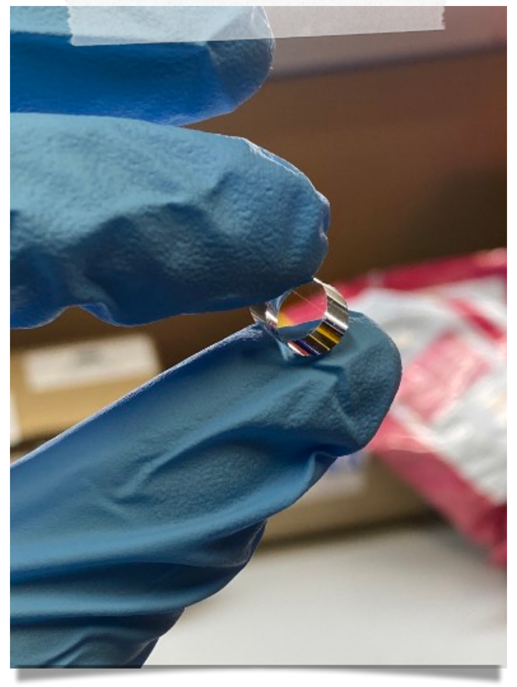
Factor 10x more in irradiation!
Same HE hadron cocktail as our detector



Holder #1 - 4 types of Polymicro samples
Holder #2 - 4 types of Polymicro samples
Spectrosil 2000, H2 free, 40x1cm samples
Spectrosil 2000, H2 load > 2.8e18, 40x 1cm samples
Suprasil 3302, BRAN Rods

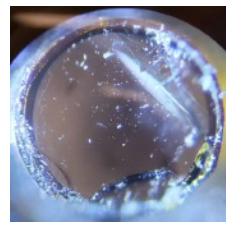


BRAN-D, sample holders installed in irradiation bays(bottom view)

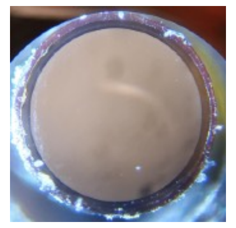


Heraeus sample

Fiber sample holder

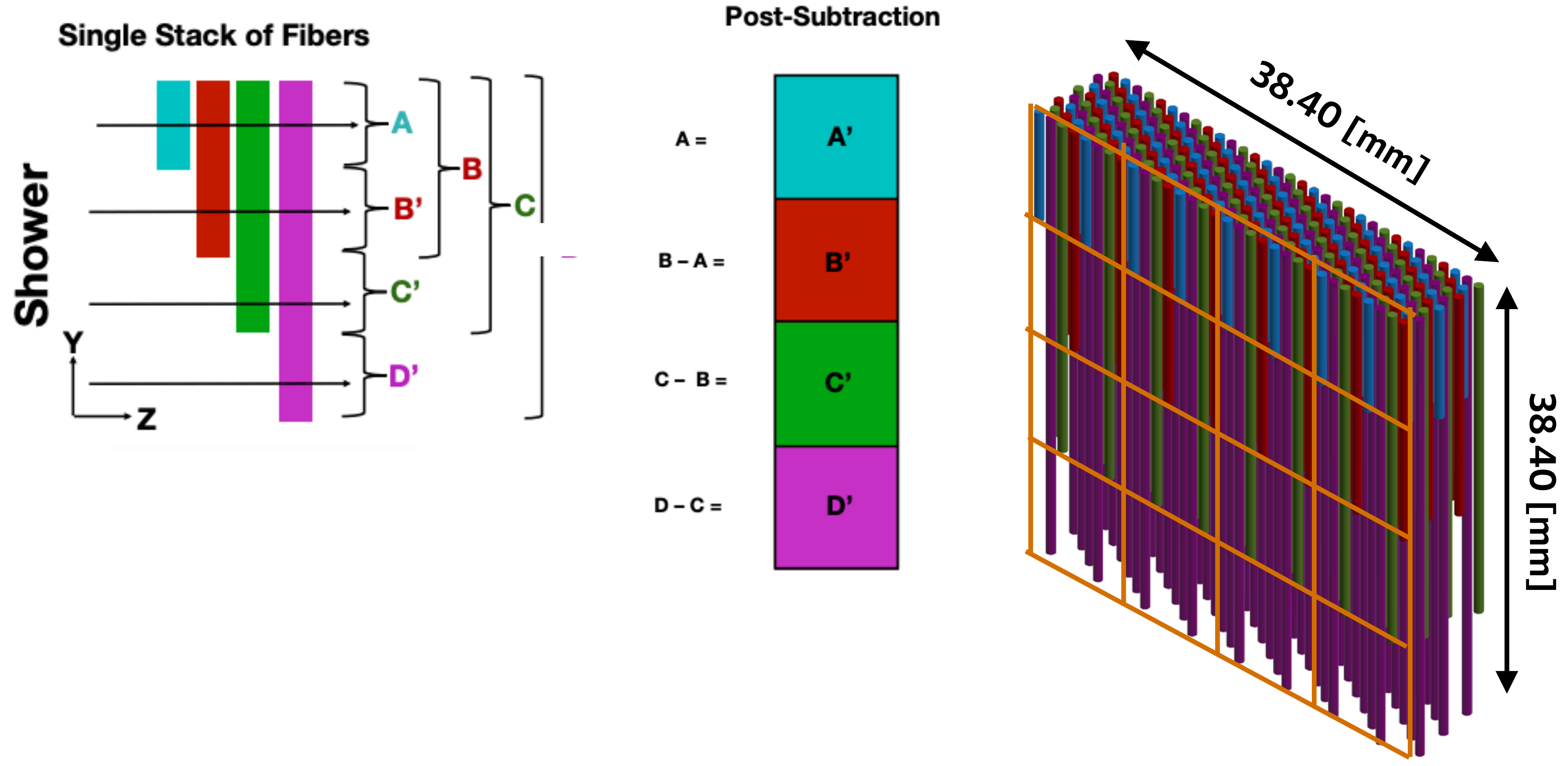


Raw fiber cut



Polished fiber cut

RPD SIGNALS



RPD fused silica fibers
(active area only - support plates not displayed for better visibility)

$$Q_x = \frac{\sum_{i=1}^{i=16} E_i C_{i,x}}{\sum_{i=1}^{i=16} E_i} \qquad Q_y = \frac{\sum_{i=1}^{i=16} E_i C_{i,y}}{\sum_{i=1}^{i=16} E_i}$$

C_i = vector identifying the center of each tile

$$C_{i,x} = C_i \cos\phi_i, \qquad C_{i,y} = C_i \sin\phi_i$$

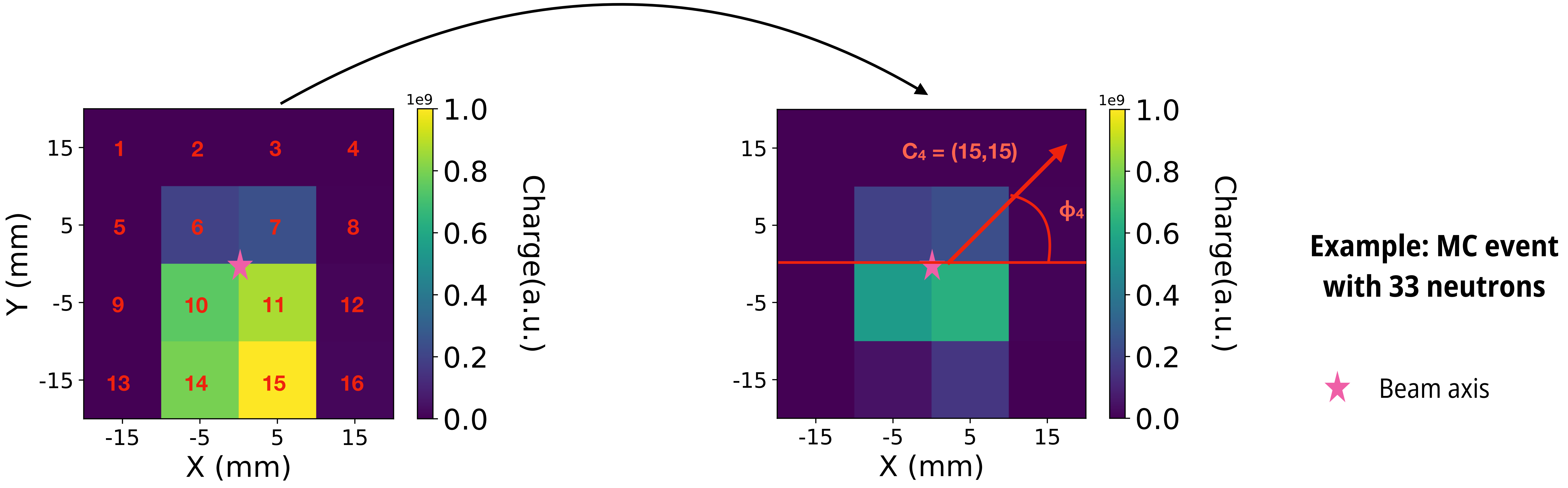
E_i = energy deposited in each tile

ϕ_i = azimuthal angle characterizing the center of tile i

- Subtraction mechanism that allows mapping the 16 recorded signals onto 16 tiles to be used to reconstruct the flow vector Q

$$\psi_{RP} = \tan^{-1}\left(\frac{Q_y}{Q_x}\right)$$

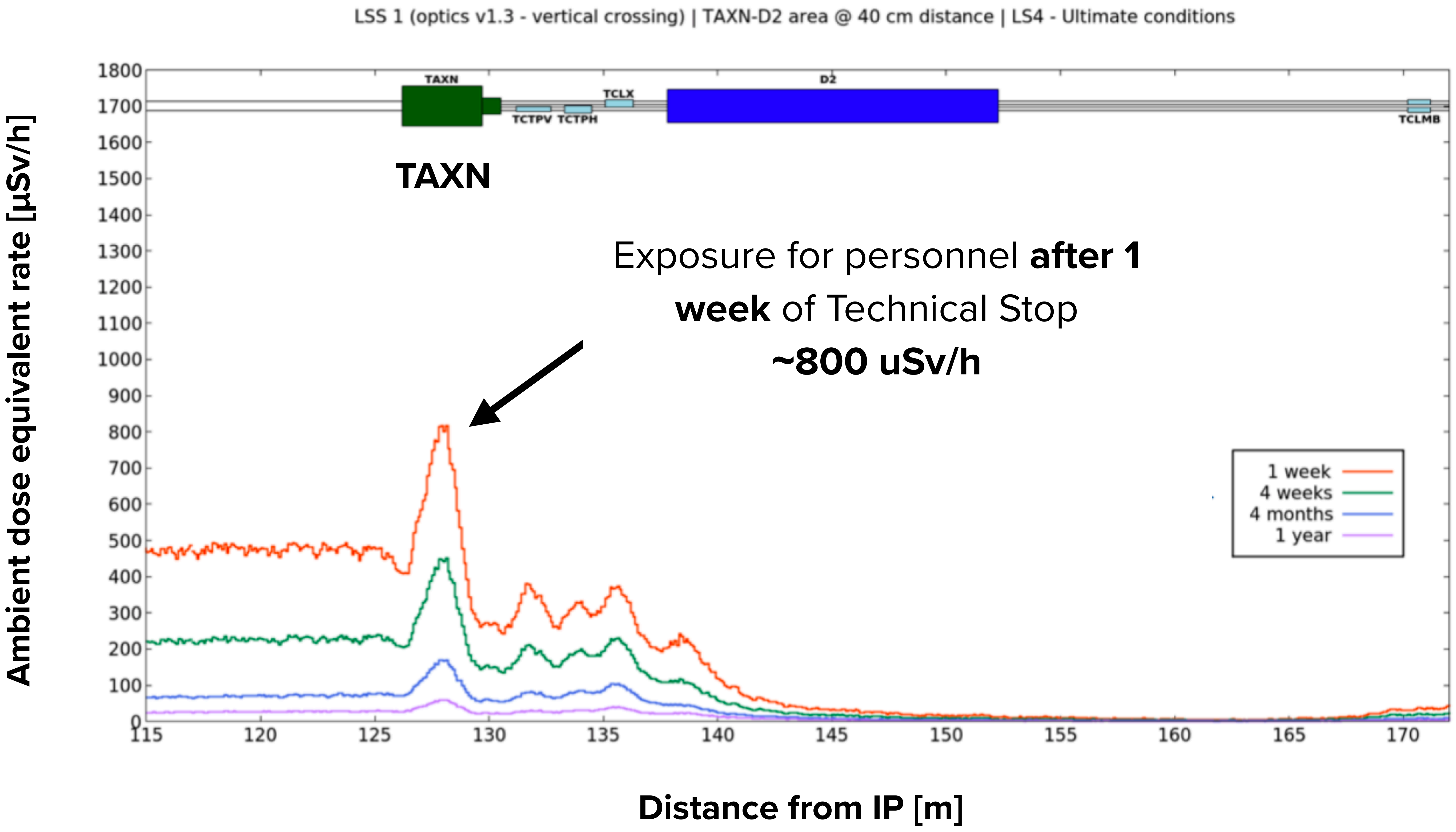
- Machine Learning reconstruction algorithms to maximize performance

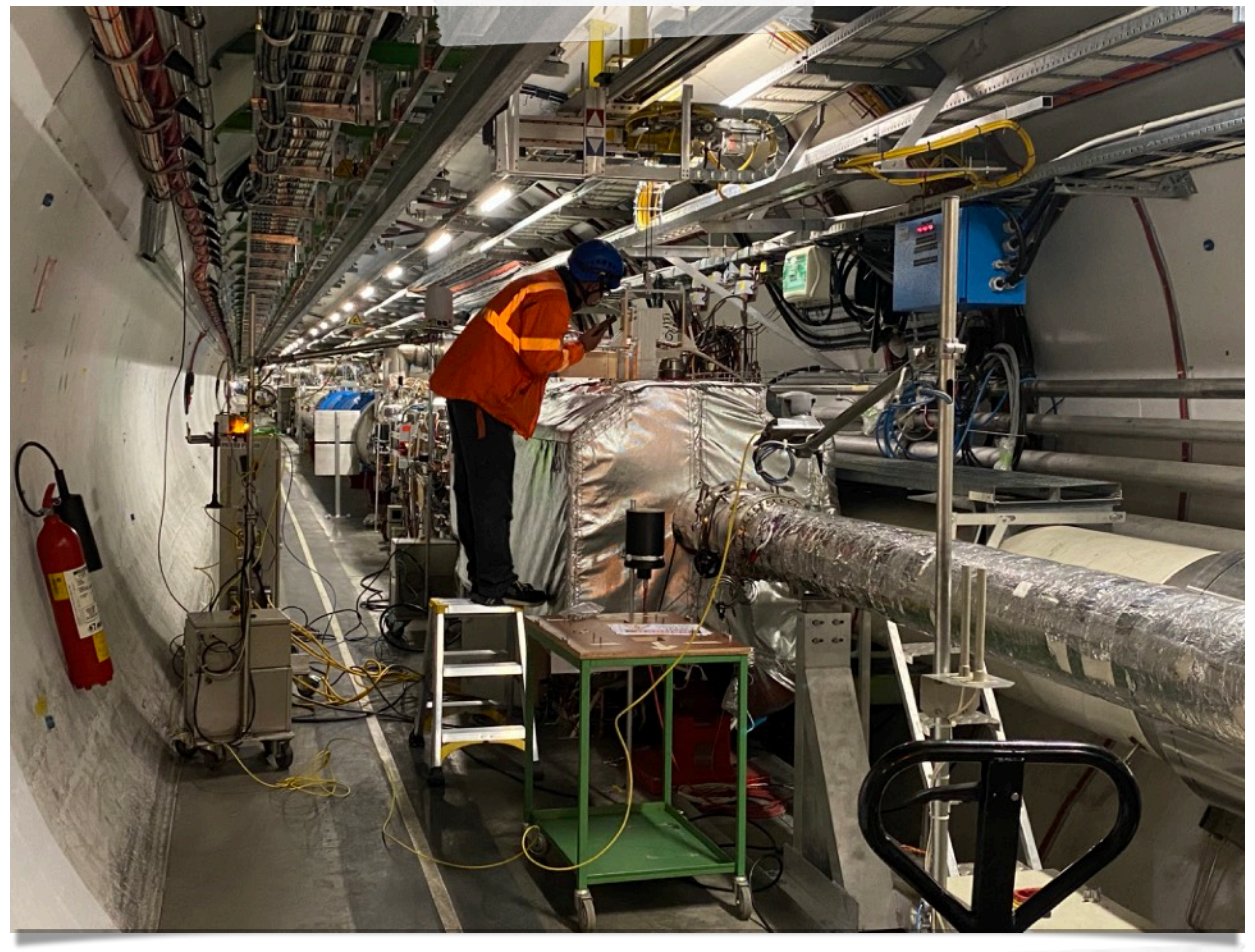


Pre-subtraction signals

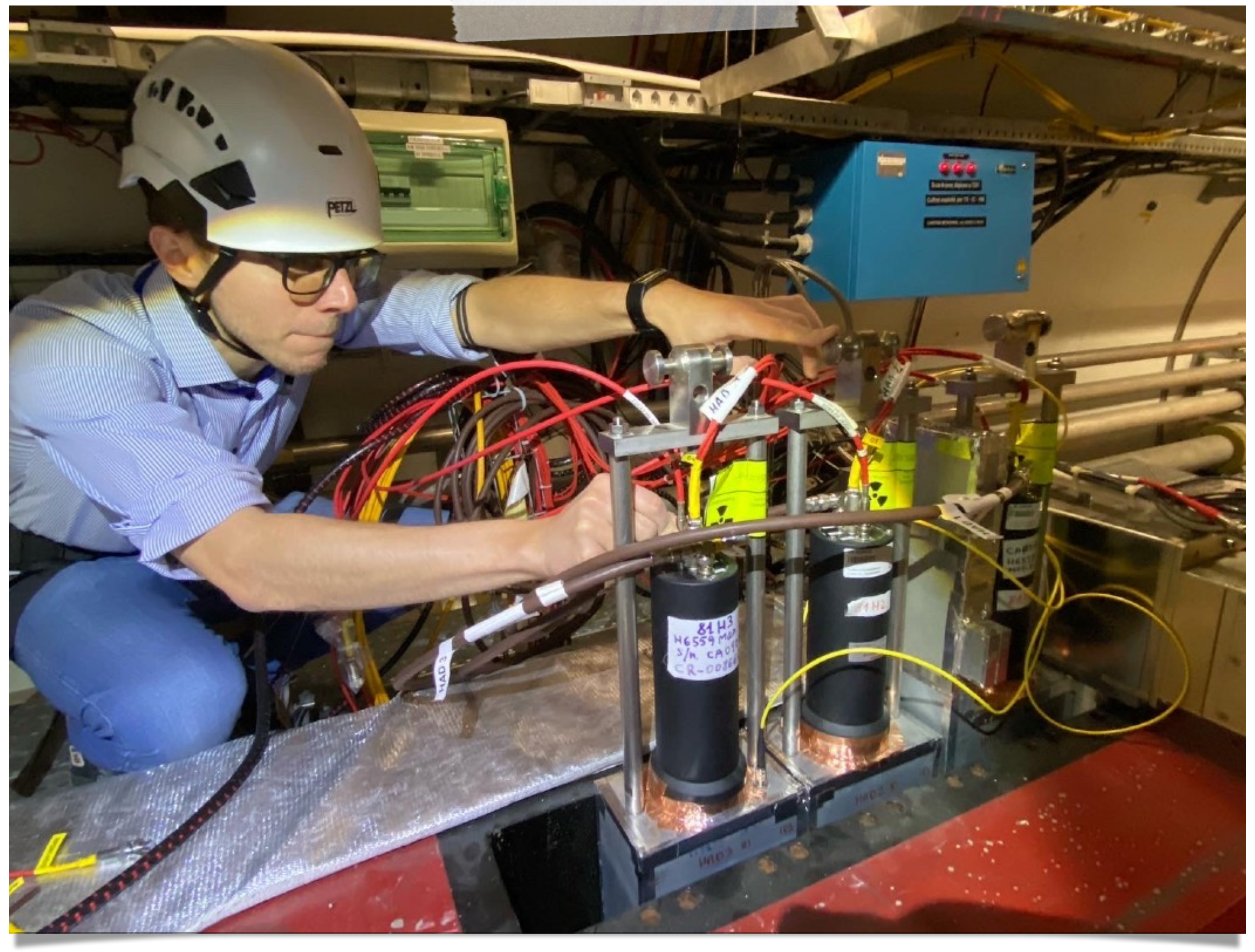
Post-subtraction signals

HL-LHC CHALLENGES: RADIATION LEVELS (ON PERSONNEL)





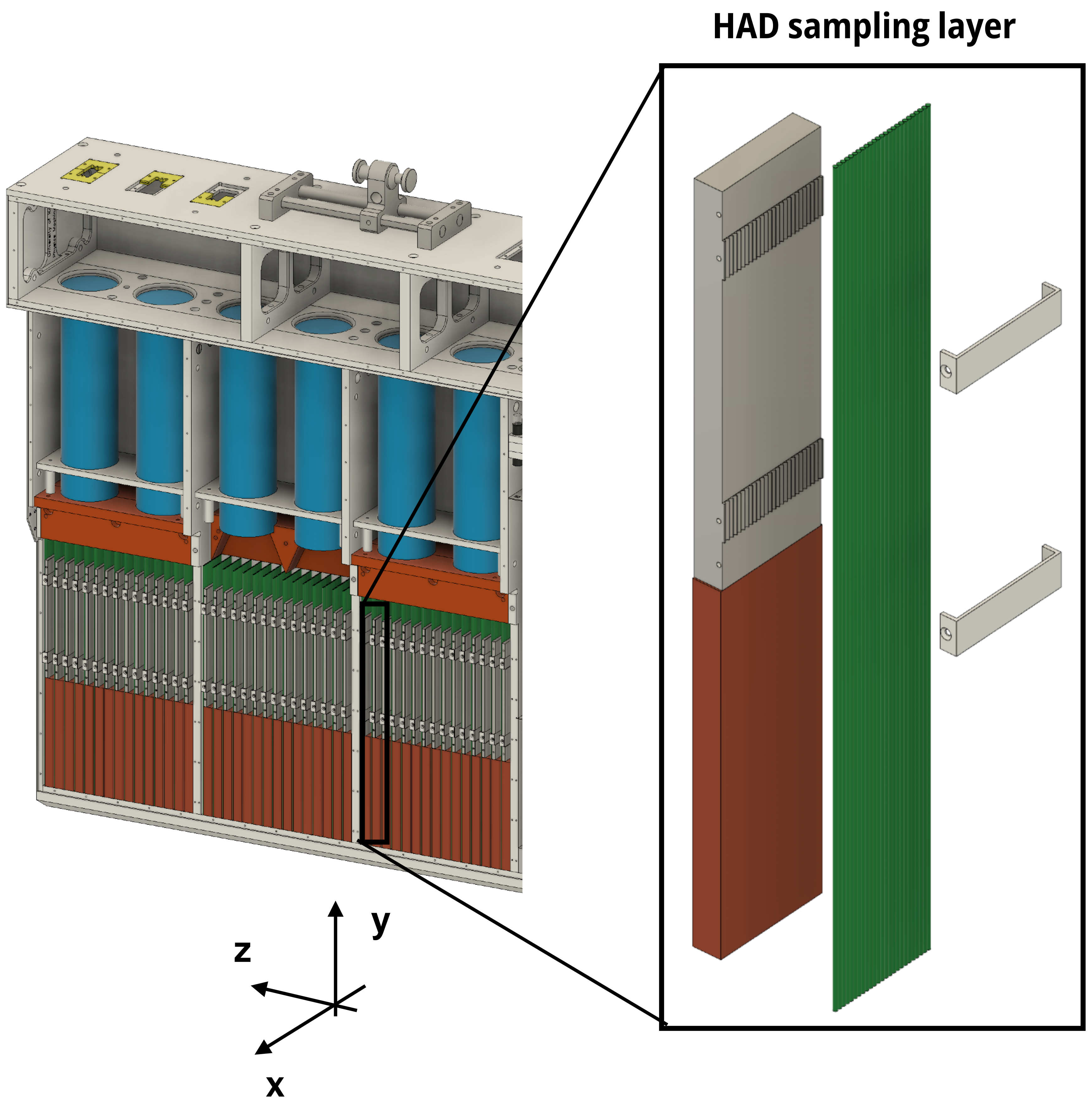
Remote handling setup



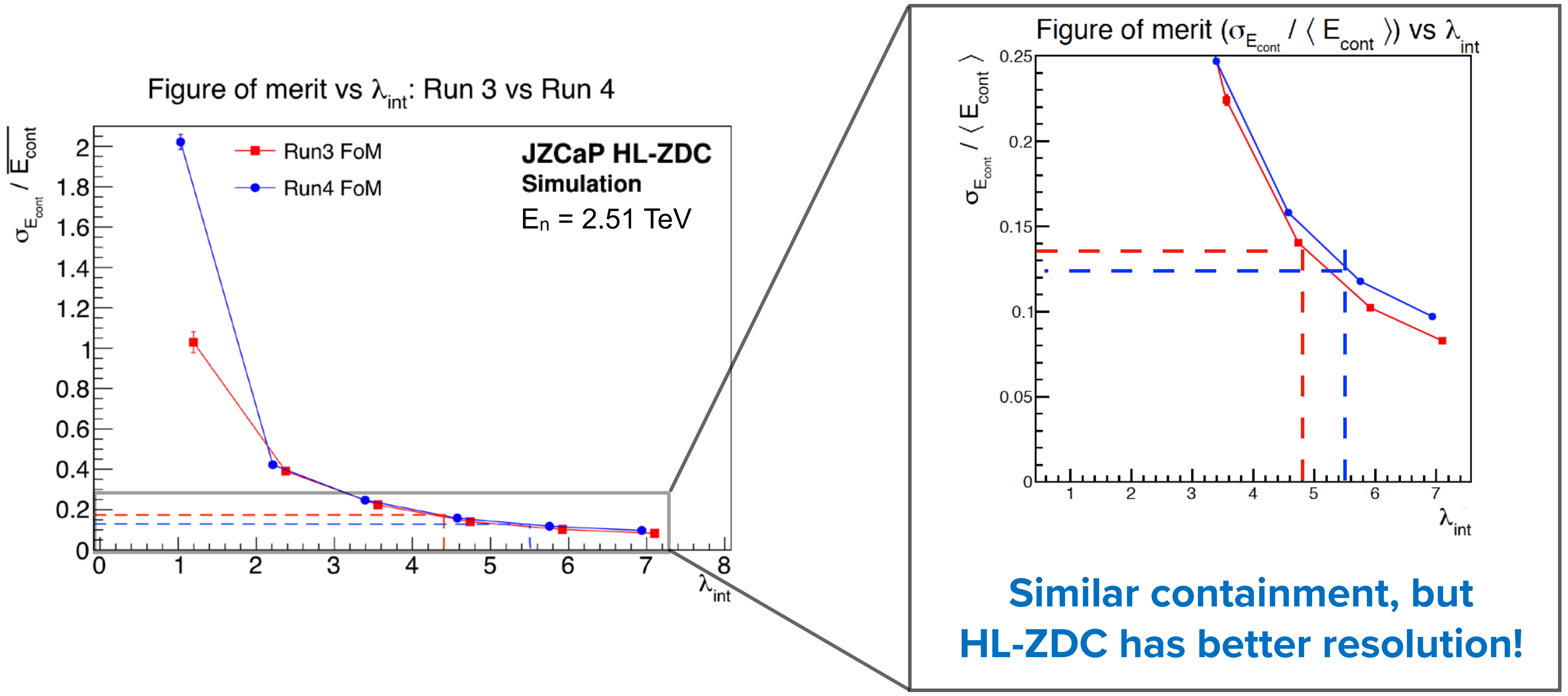
ZDC connection

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

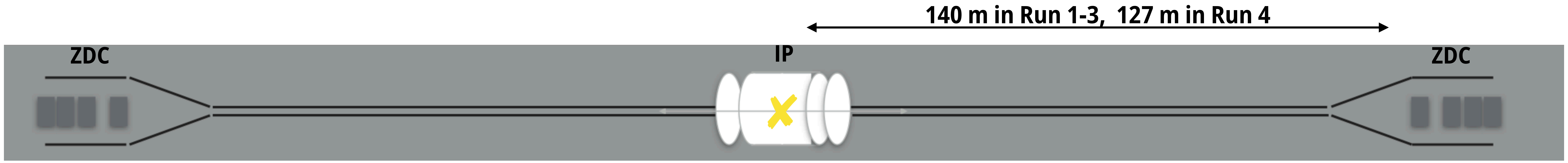
HL-ZDC: HAD SECTION

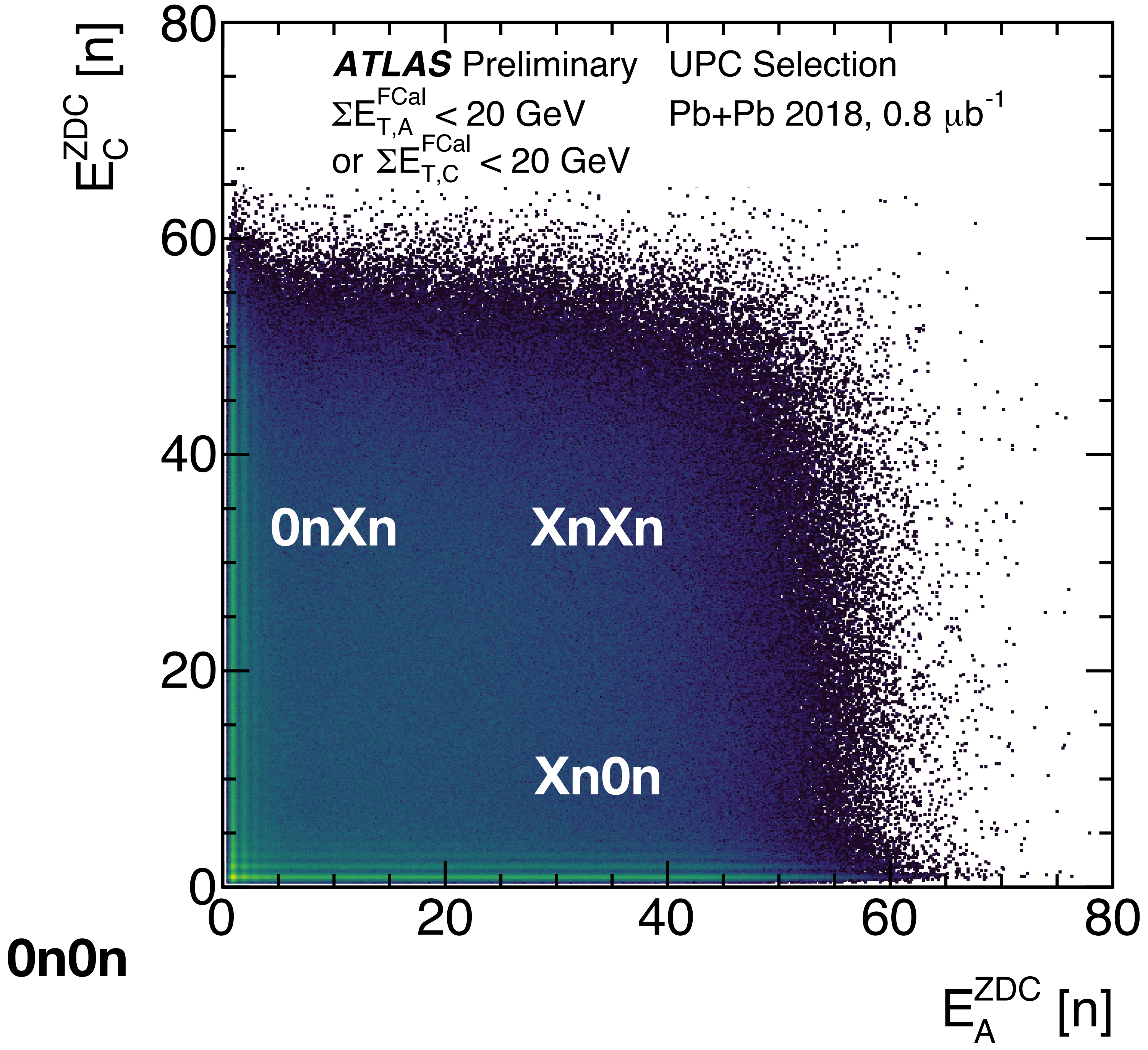


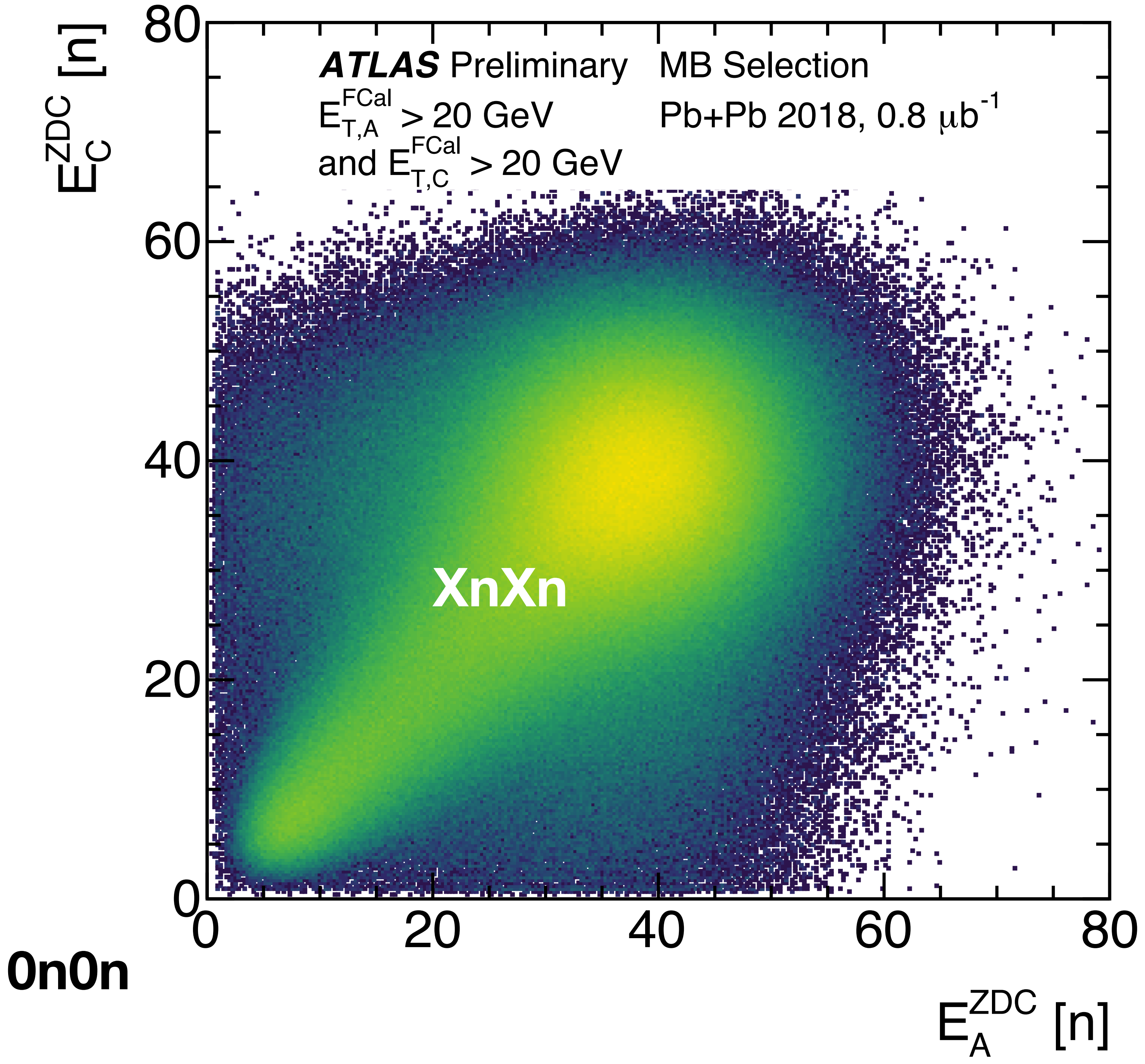
- **Total of 45 sampling layers (4.5 λ_{int}), each composed of:**
  - 10 mm tungsten plate
  - Rad-hard fused silica rods array (25 rods of ϕ = 1.5 mm)
- **6 PMTs coupled with trapezoidal light-guides**
- **Reduced transverse acceptance in the TAXN ➡less containment at the same depth**
  - But for λ_{int} > 2, fluctuations dominate
- **HL-ZDC will have a total of 5.5 λ_{int} w/o BRAN detector in between**
  - Current ZDCs have ~4.4 λ_{int} and BRAN detector in between EM and HAD sections



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