ATLAS ZDC for Run3 and Run4

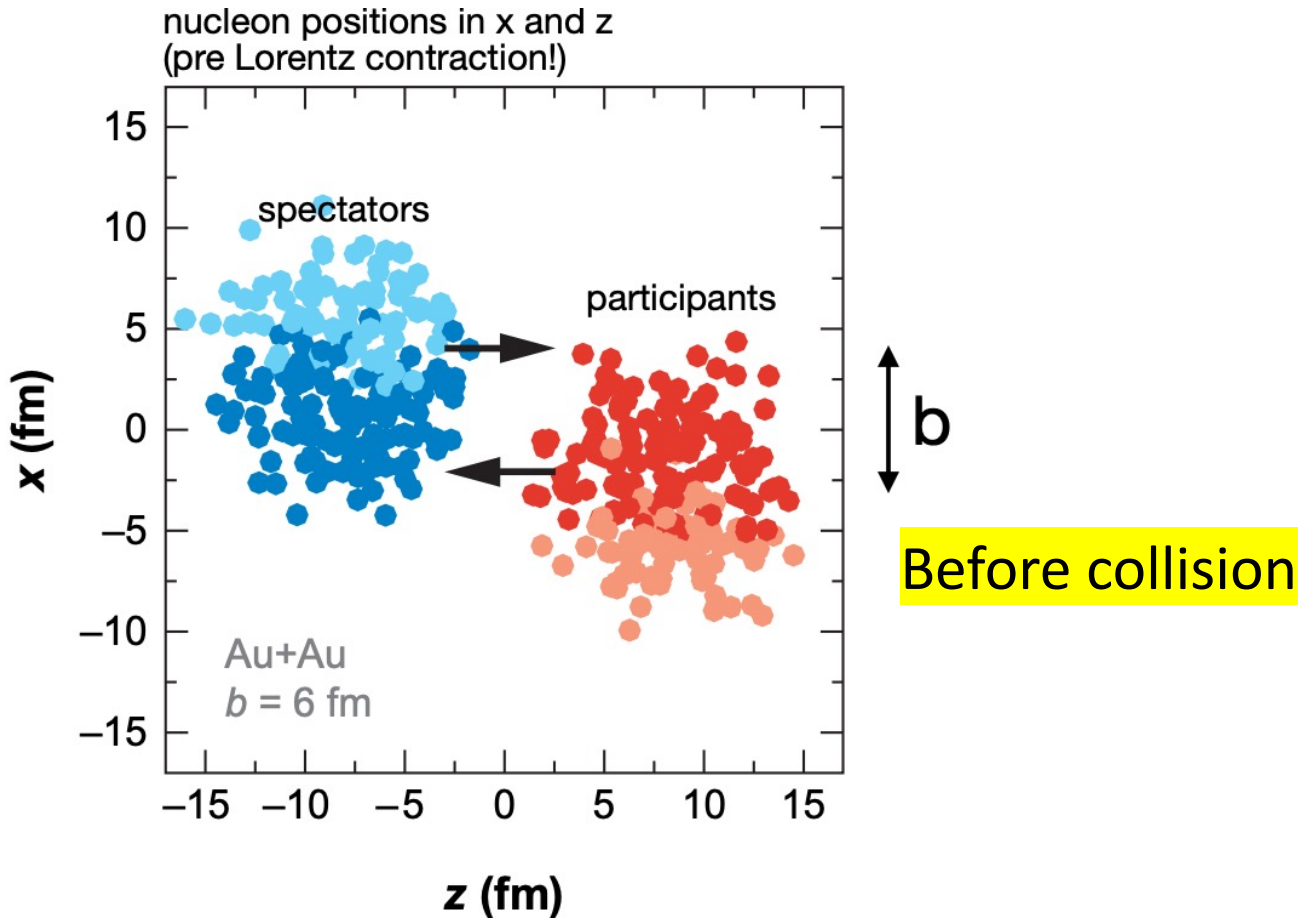
Yuhan Guo, on behalf of ATLAS Forward Detectors

Columbia University

ICHEP - July 20, 2024

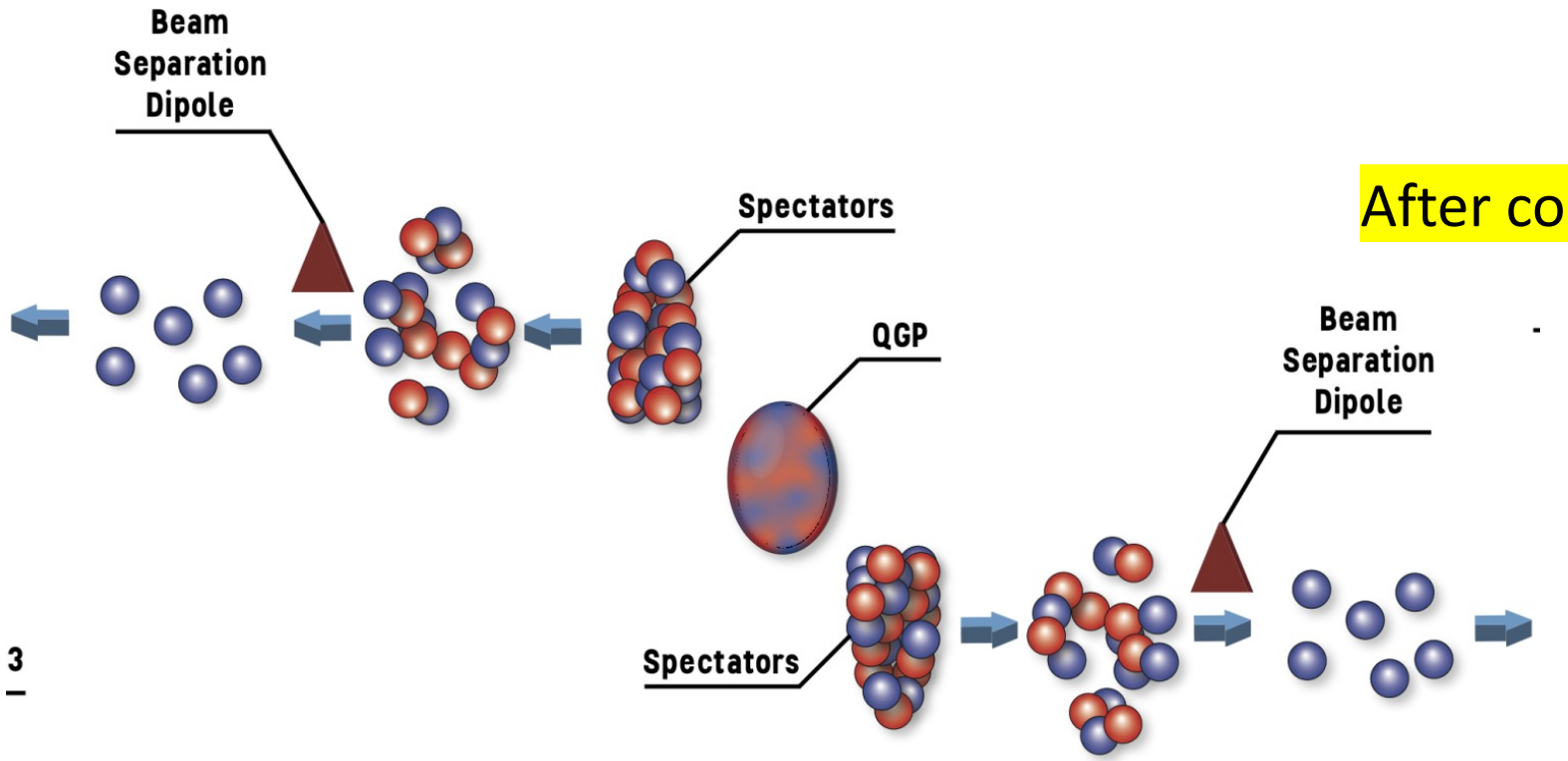
COLUMBIA UNIVERSITY

ATLAS EXPERIMENT



Before collision

- In a heavy ion collision, nuclei overlap partially, with **impact parameter b**
- **Participants**: nucleons that interact (typical-pp-collision-like)
- **Spectators**: nucleons that don't interact → continue at beam energy



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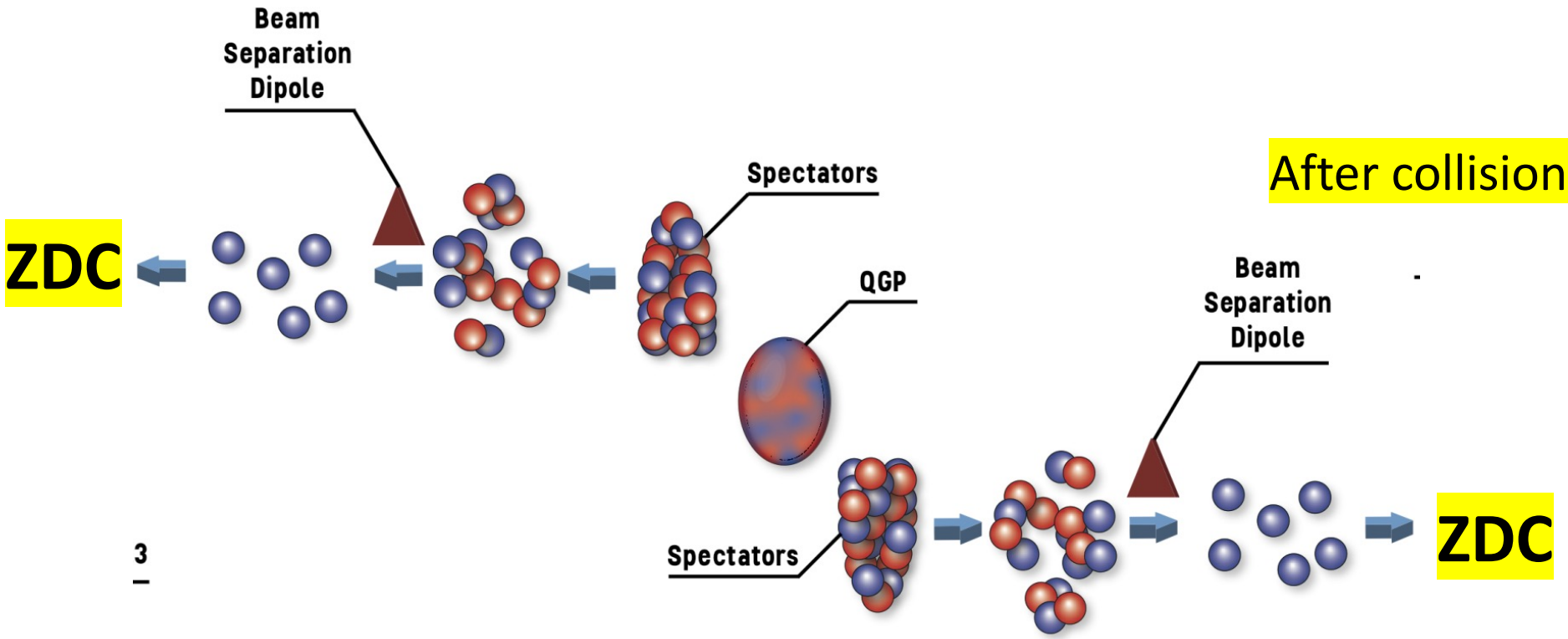
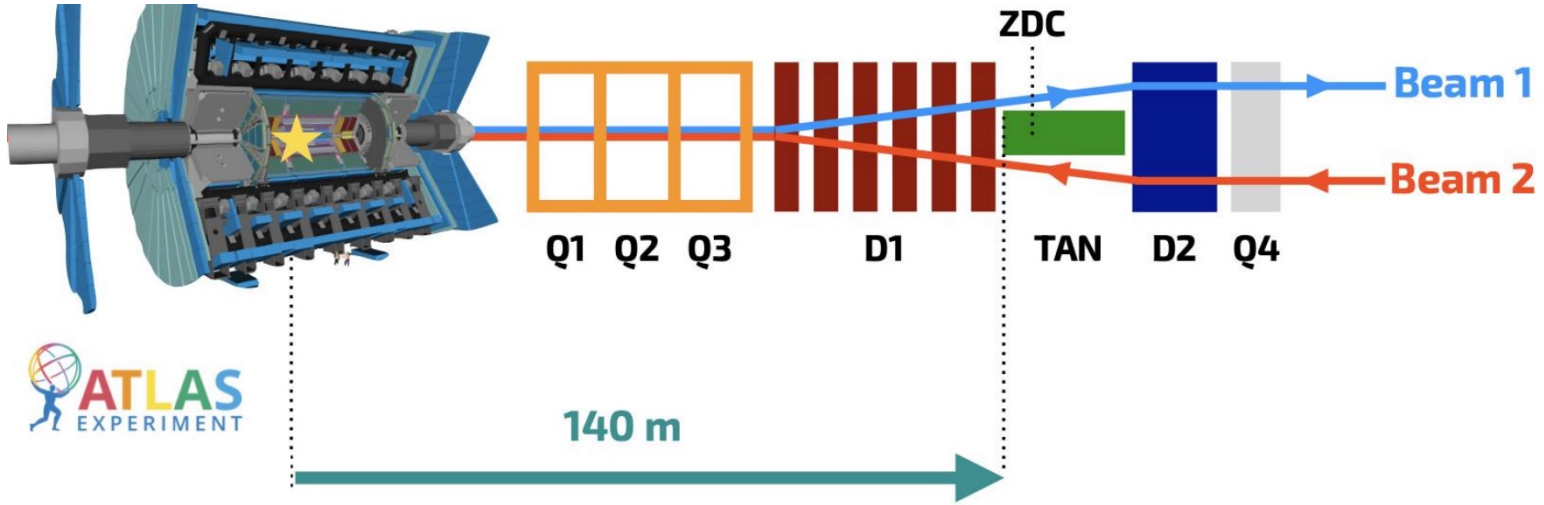
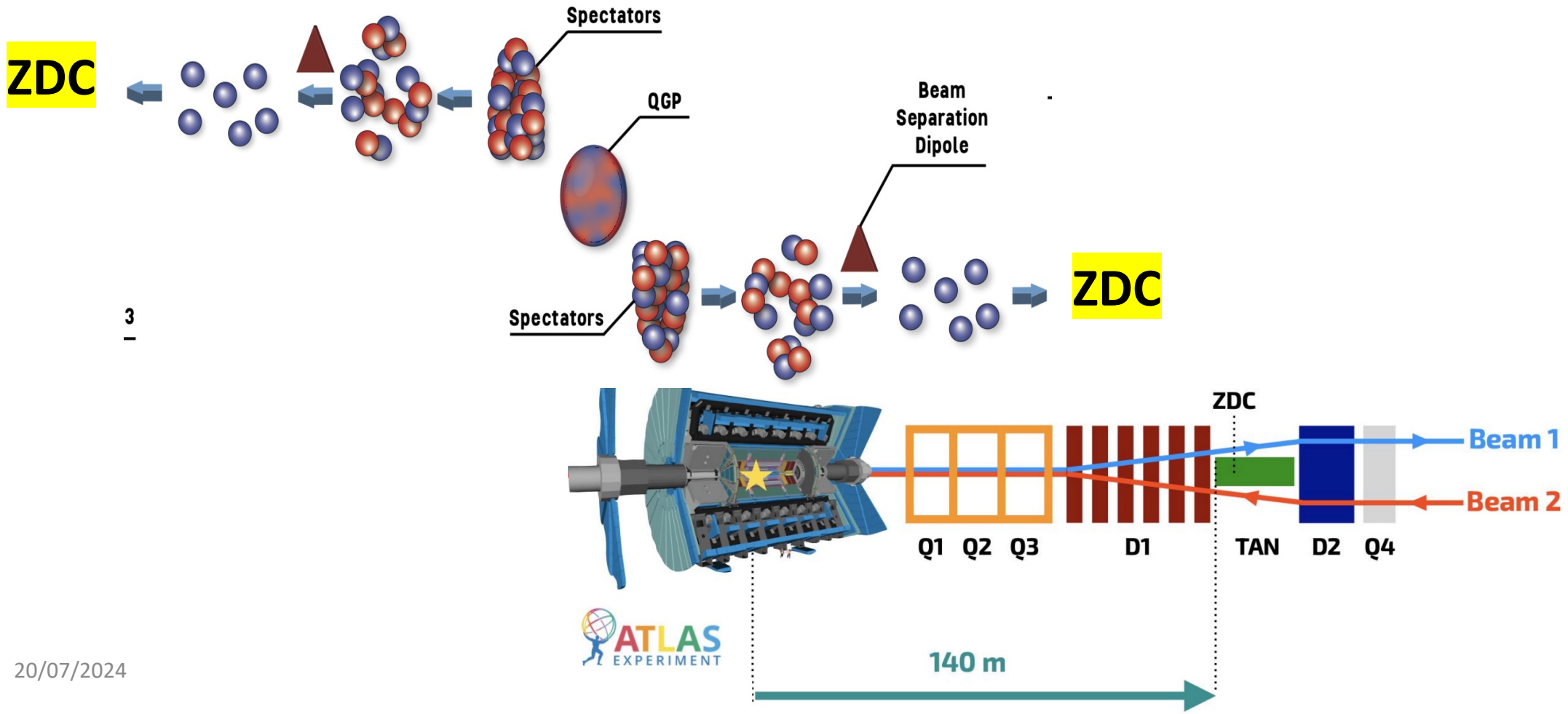


After collision



Introduction – ATLAS Zero Degree Calorimeter

- located at **± 140 m from ATLAS collision point** (|η|>8.3)
- Measures **forward spectator neutrons** in heavy-ion collisions



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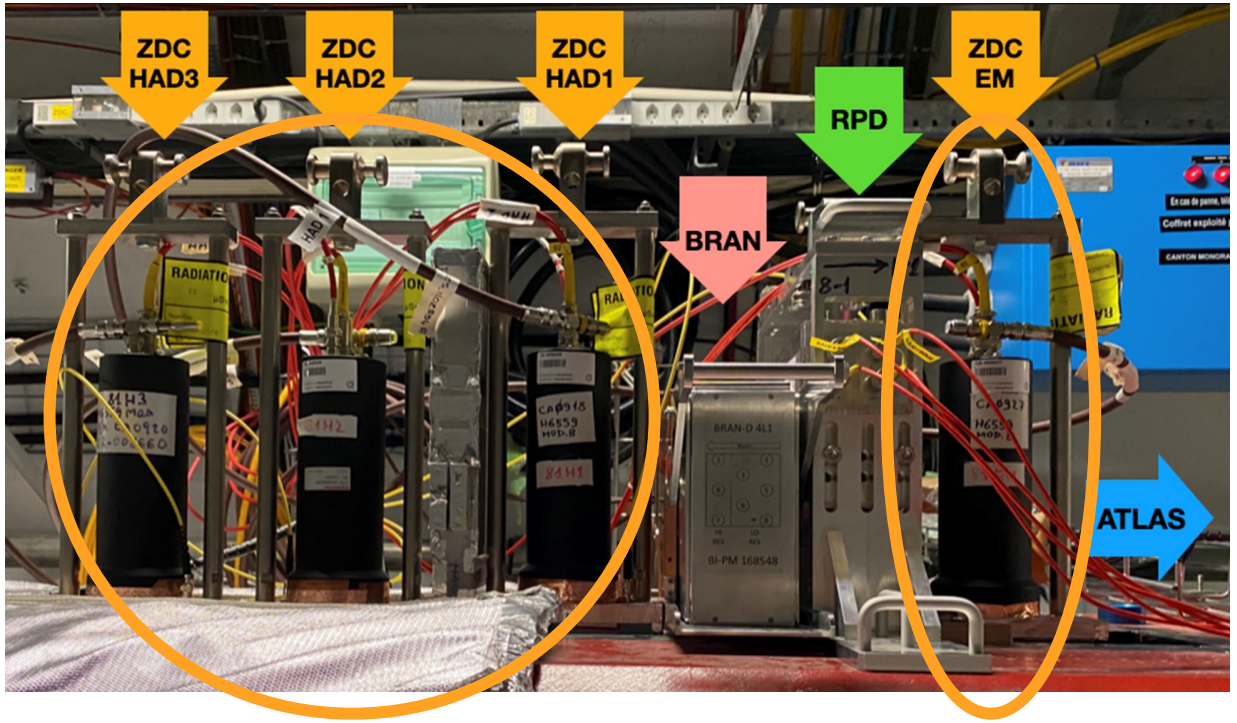
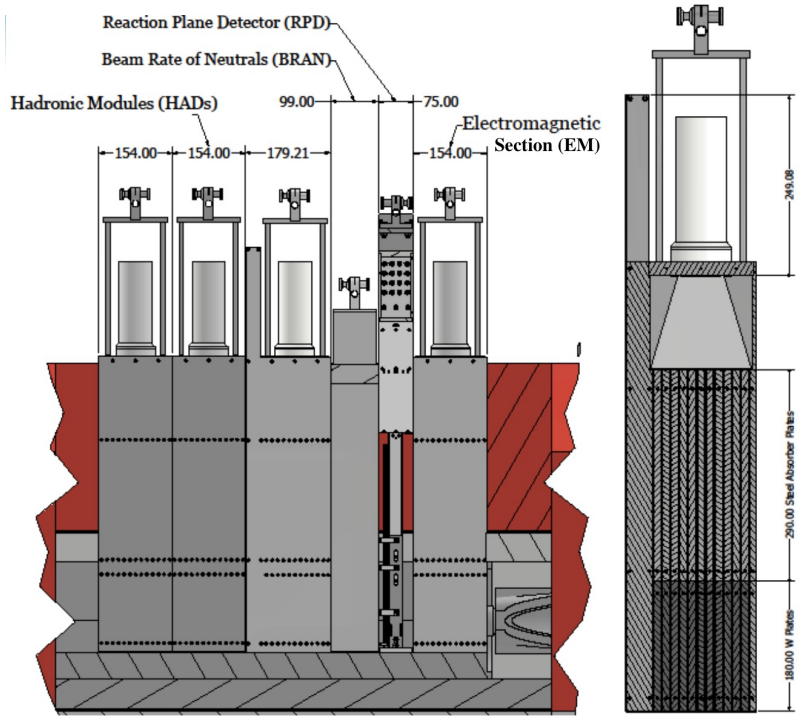
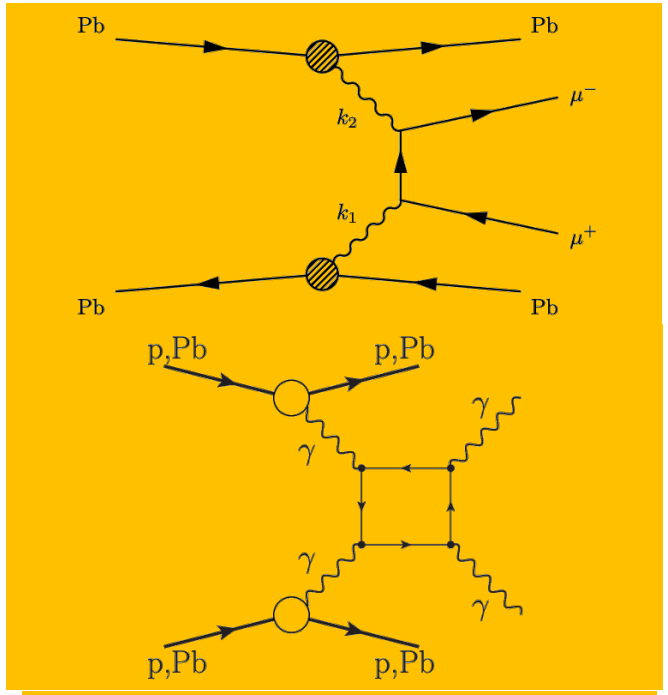
- Measures **forward spectator neutrons** in heavy-ion collisions
- **Tungsten-fused silica calorimeters**



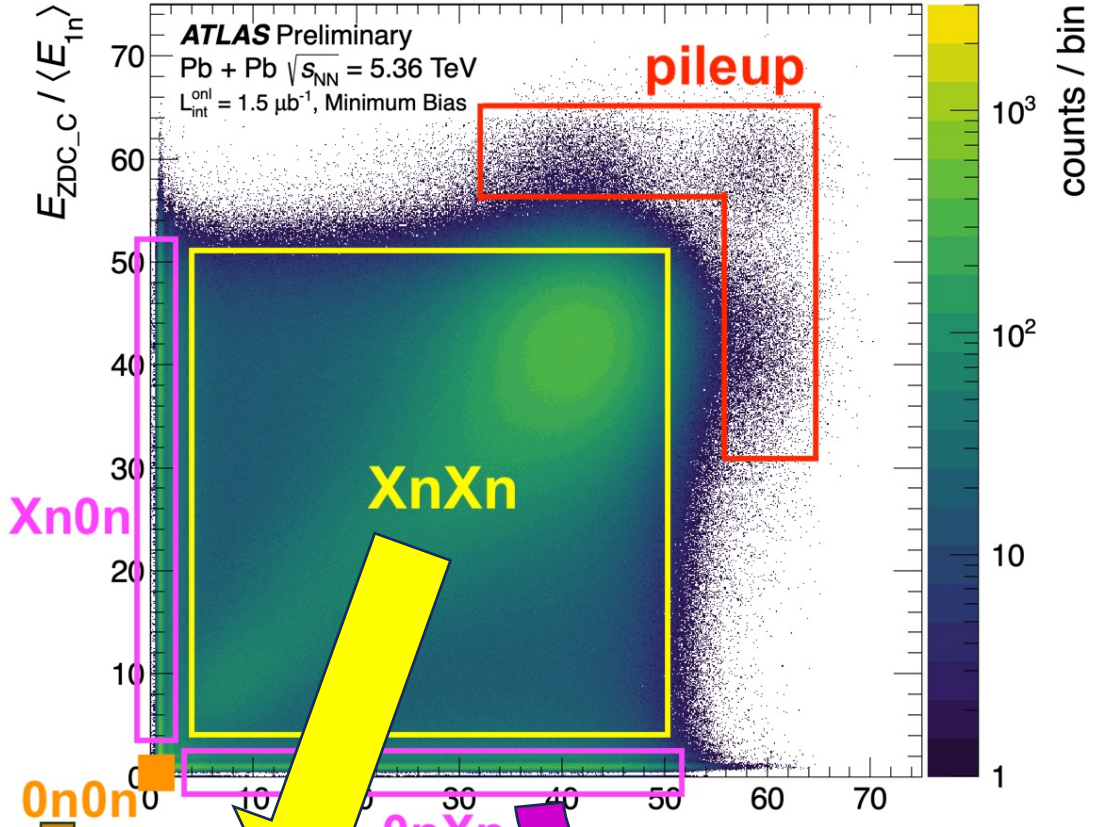


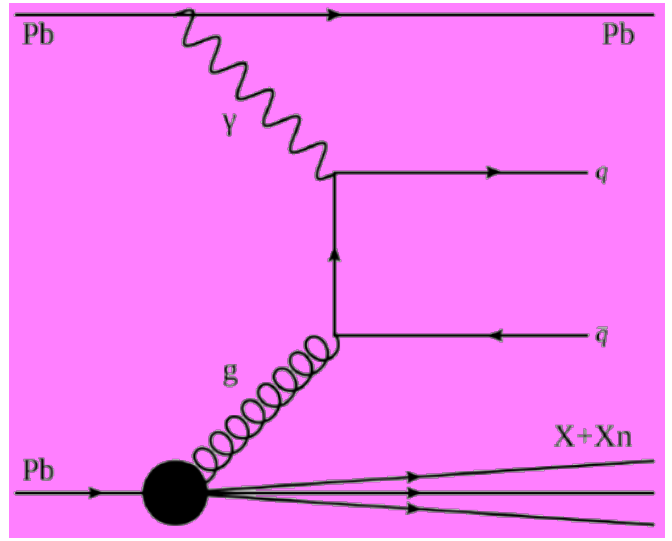
Physics motivation

- Neutron topology – distinguishes between 0n0n, 0nXn/Xn0n, XnXn

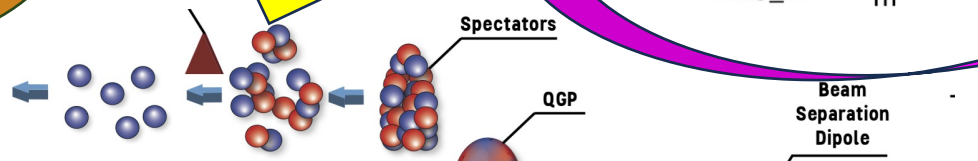


photoproduction



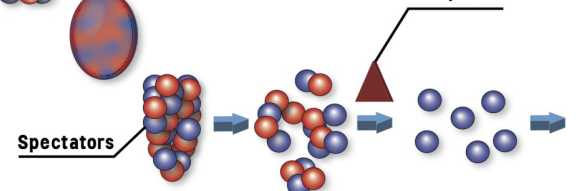


photonuclear



ZDC

Hadronic → QGP



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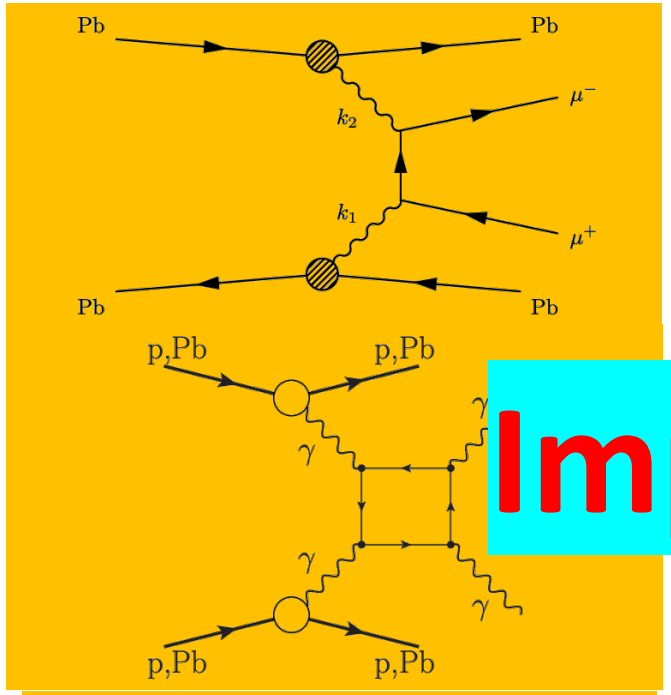

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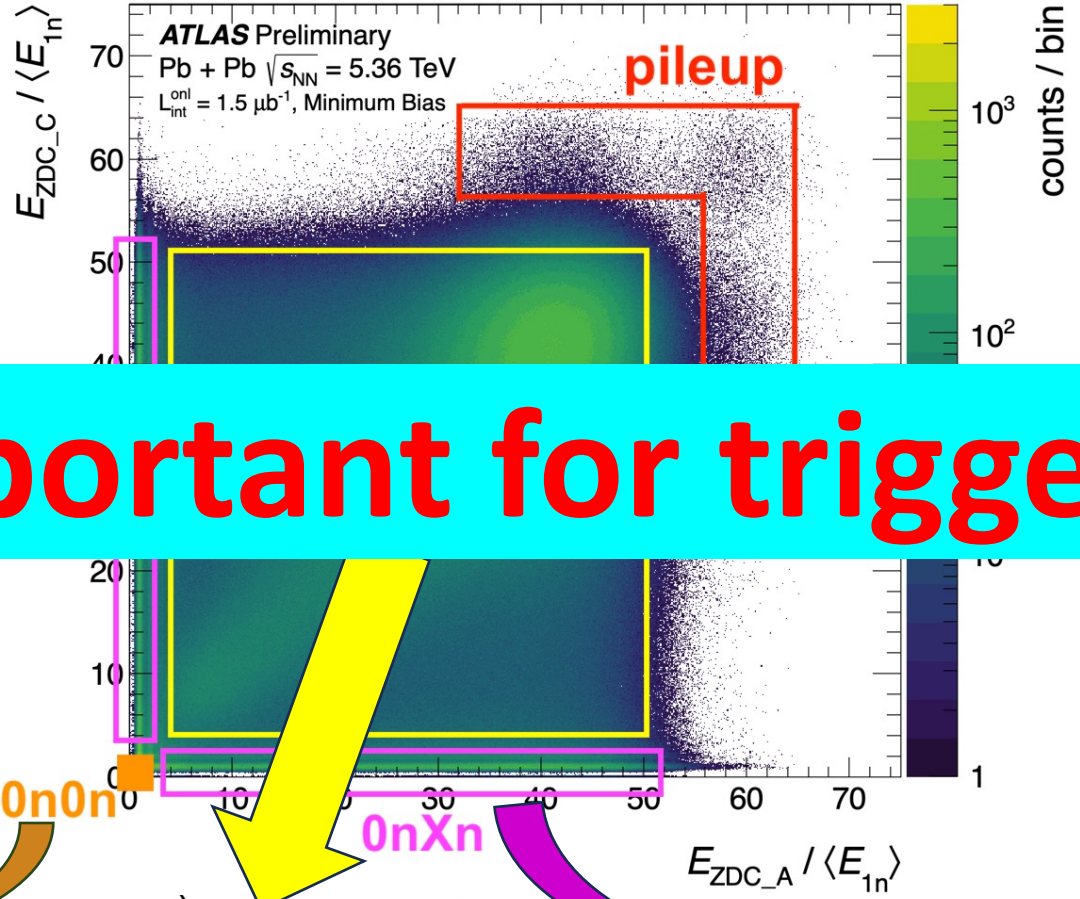
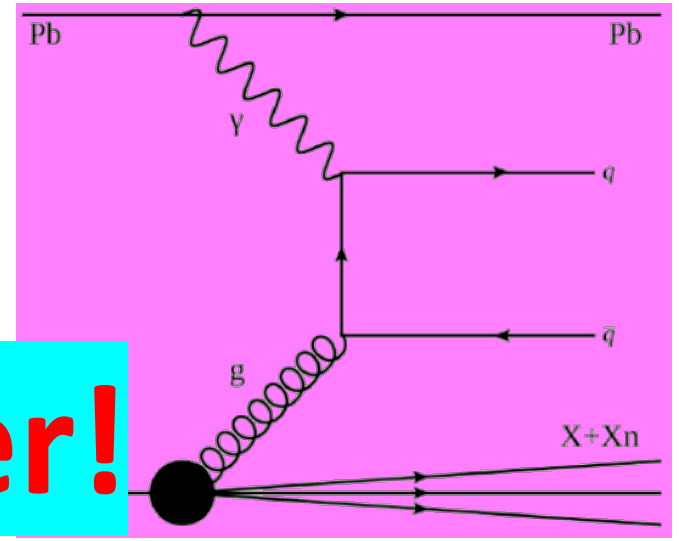


Important for trigger!



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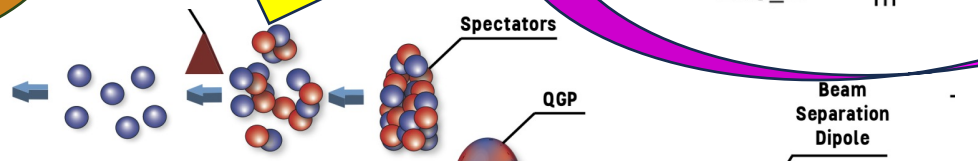
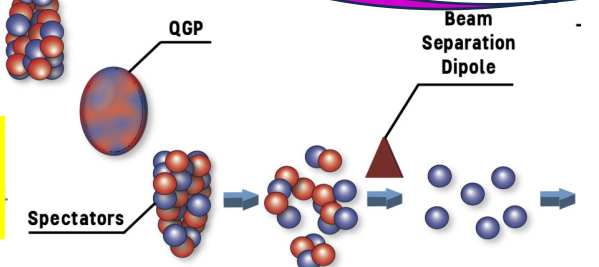
ZDC



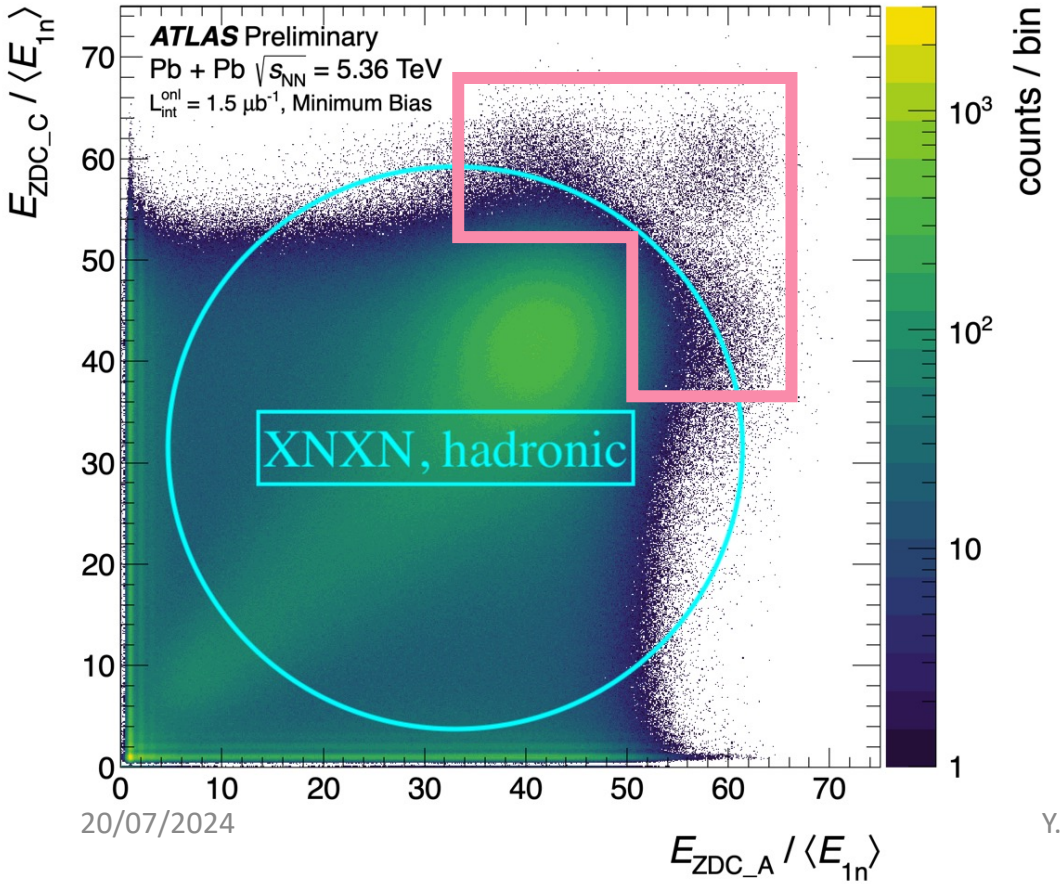
Hadronic → QGP

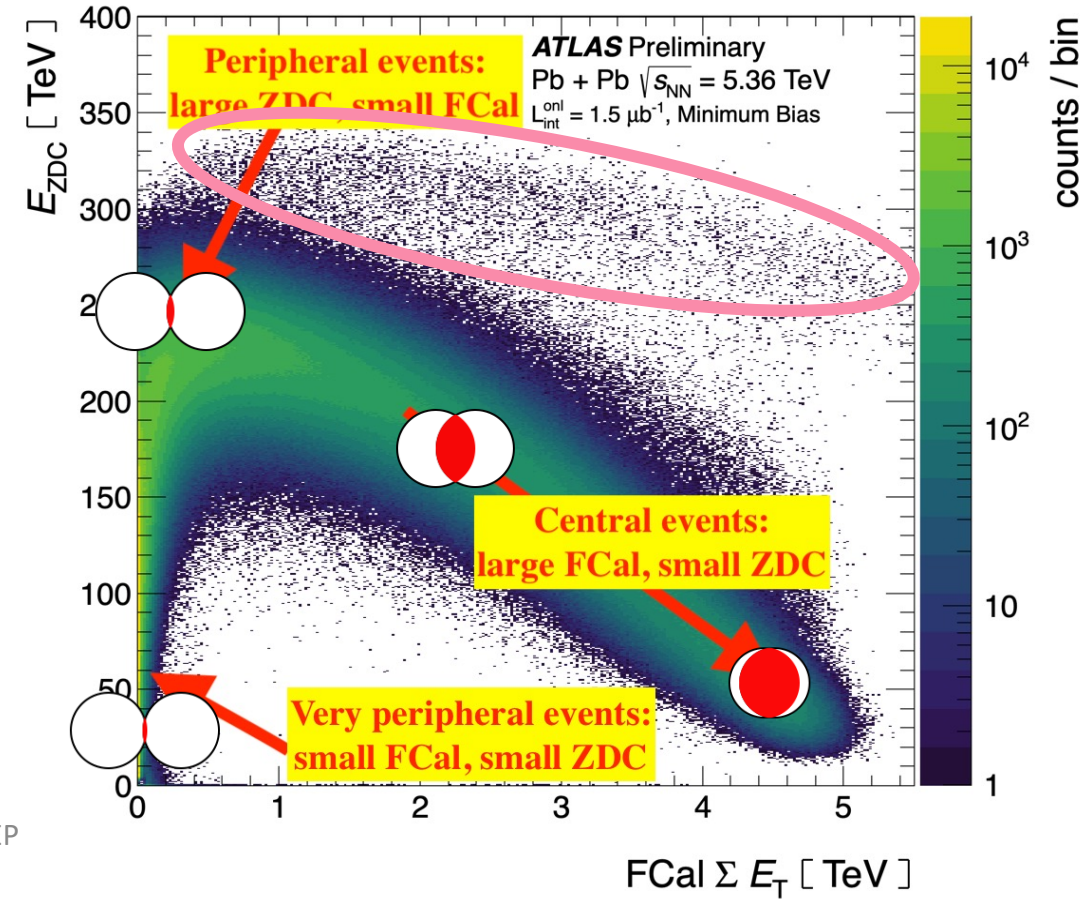


ZDC

Physics motivation

- Distinguishes between 0n0n, 0nXn/Xn0n, **XnXn**
  - Hadronic; creates hot dense medium - **quark gluon plasma (QGP)**
- Correlation with total transverse energy in ATLAS forward calorimeters (FCal; 3.1 < |η| < 4.9): **centrality** measurement; **pileup** identification





Run3 ZDC refurbishment

- New **radiation-hard**, high-OH high-H2 fused silica rods (Heraeus Spectrosil-2000)
  - High transmission in the UV even at high dosage
  - Ensures **stable performance** over entire Run 3

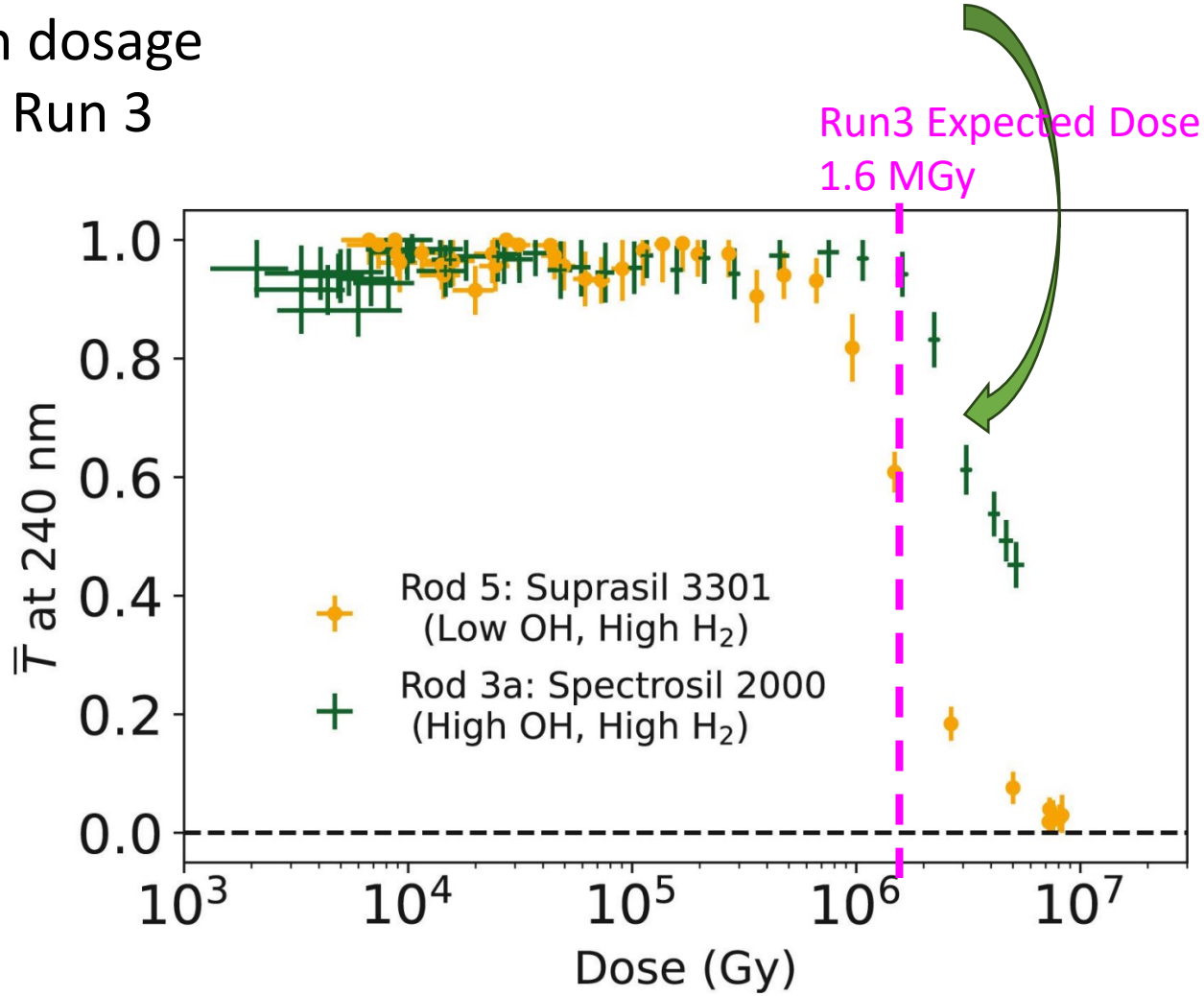


Figure: Comparison of the transmittance at 240 nm between Rod 5 (Suprasil 3301, Low OH and High H_2) and Rod 3a (Spectrosil 2000, High OH and High H_2), used by Run3 ZDC, at different dose levels.

https://doi.org/10.1016/j.nima.2023.168523

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- New radiation-hard, high-OH high-H2 fused silica rods (Heraeus Spectrosil-2000)
  - High transmission in the UV even at high dosage
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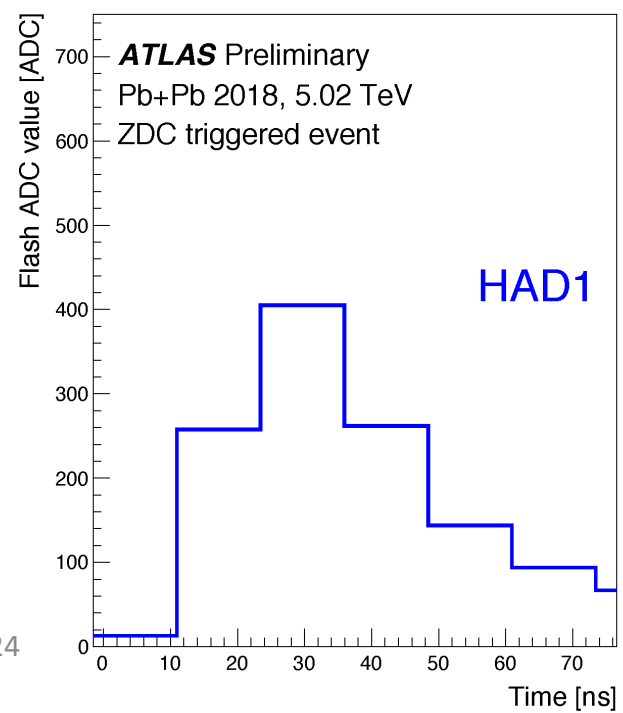
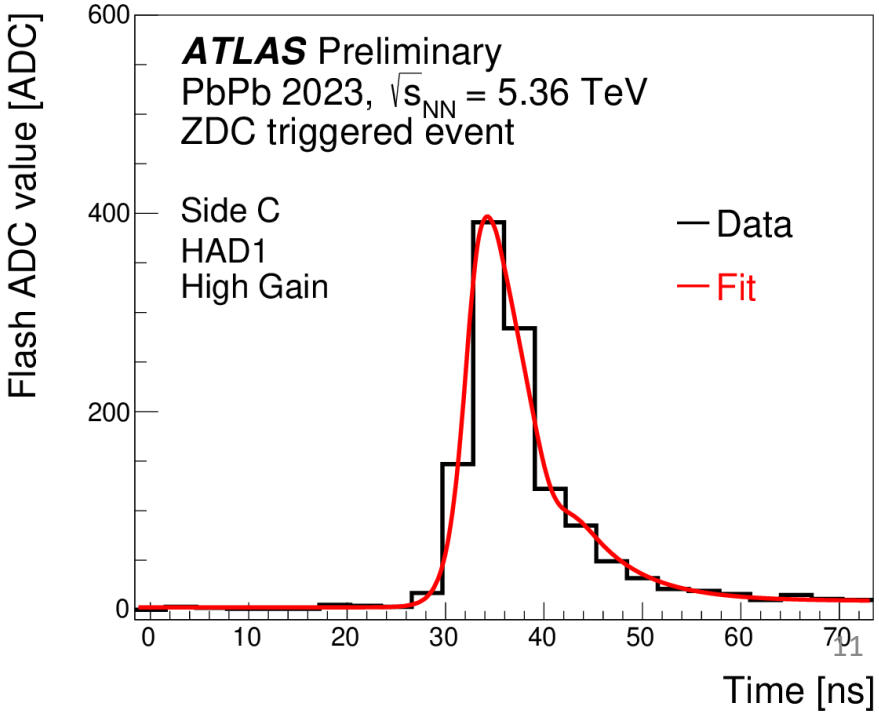
- New **readout electronics** (**LUCROD**; adapted from ATLAS LUCID detector)
  - Increases **waveform sampling rate**: 80 → 320 MHz
  - **Fully-digital trigger** based on lookup tables (3 bits)



Run2 (80MHz) →
Run3 (320 MHz)



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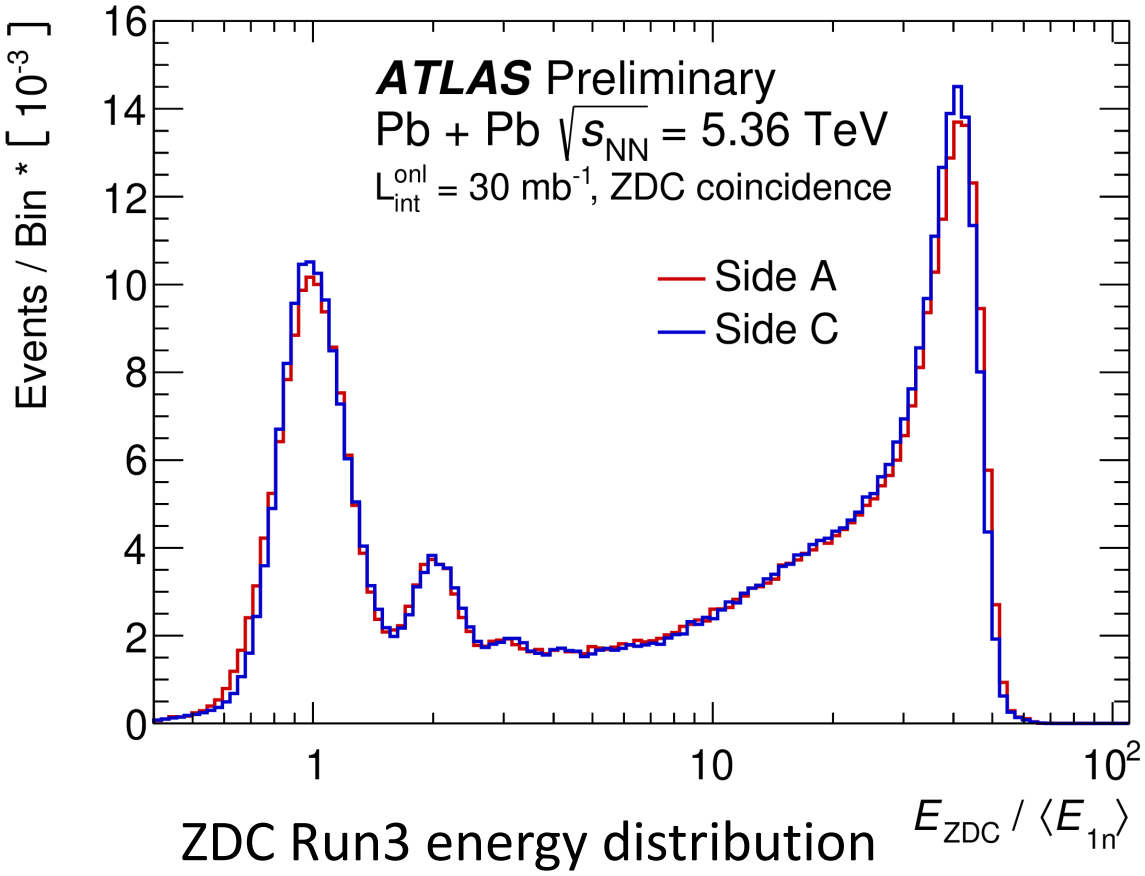
- New readout electronics (LUCROD; adapted from the ATLAS LUCID detector)
  - Increases waveform sampling rate: 80 → 320 MHz
  - Fully-digital trigger based on lookup tables (3 bits)
- New **air-core cables**
  - Low dispersion and attenuation over 220m of **signal transport**
- New **LED-based calibration system**
  - **Monitors PMT performance**; factors out effects from PMT/fused silica rods in time dependence of detector performance
- Offers **key experience for HL-LHC**

Run3 ZDC Performance

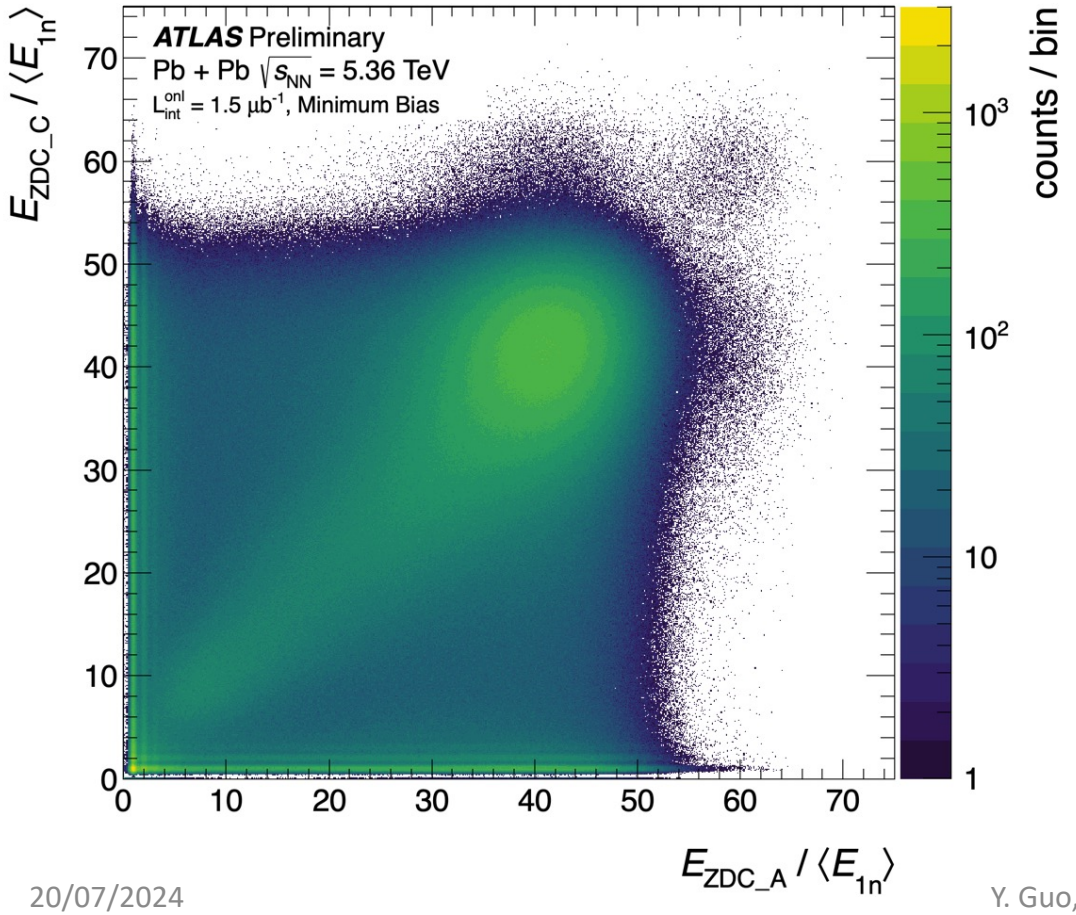
- Good resolution for 1,2-neutron peaks; 3-neutron peak visible

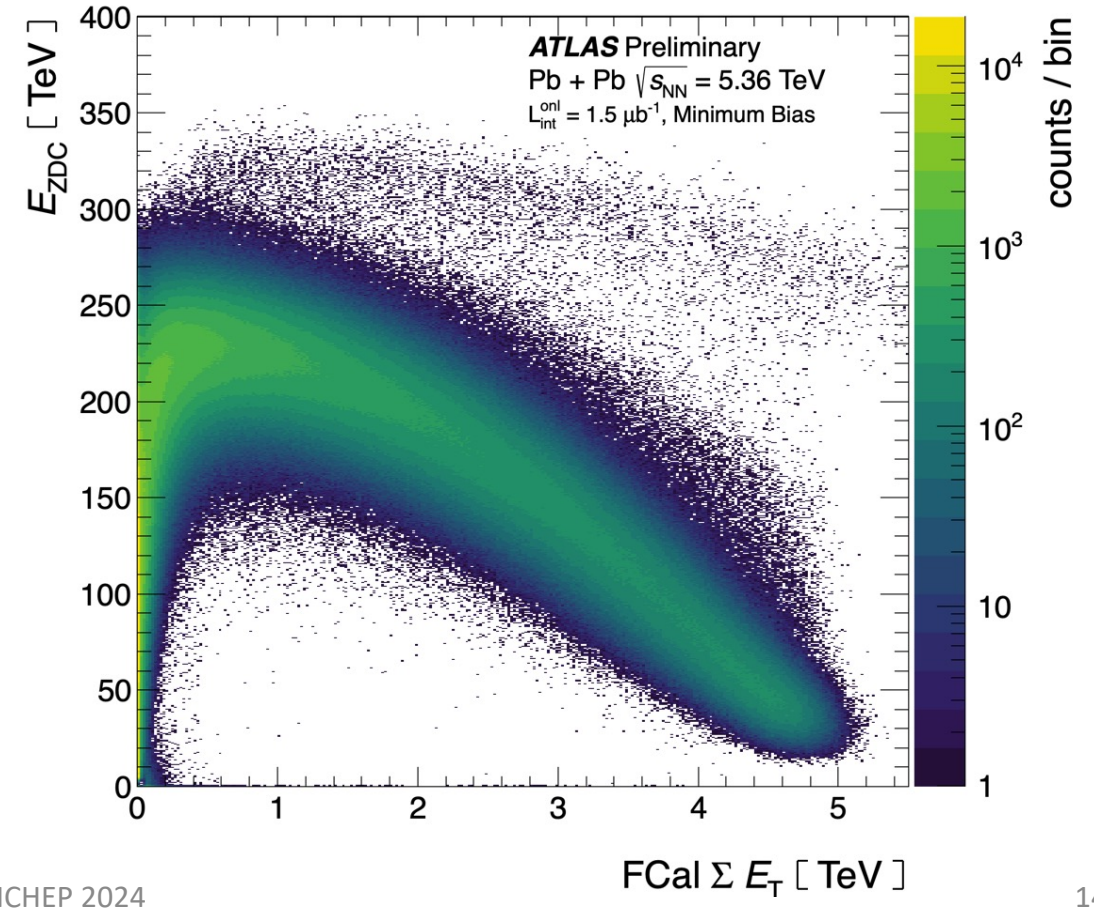


ZDC Run3 energy distribution

Run3 ZDC Performance (extended)

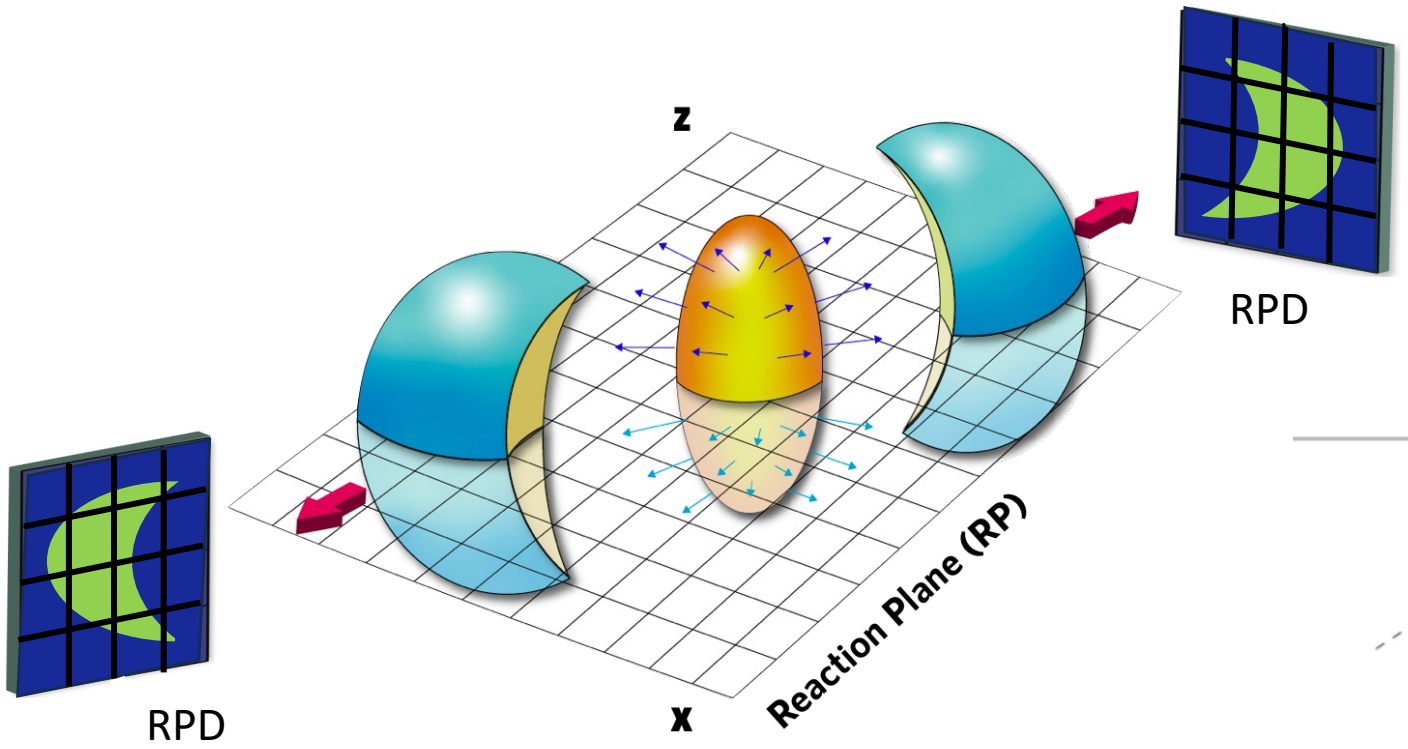
- Clear correlation between ZDC energy on A, C sides (left)
- Clear correlation between ZDC energy and transverse energy (E_T) in ATLAS forward calorimeters (FCal; 3.1 < |η| < 4.9) (right)



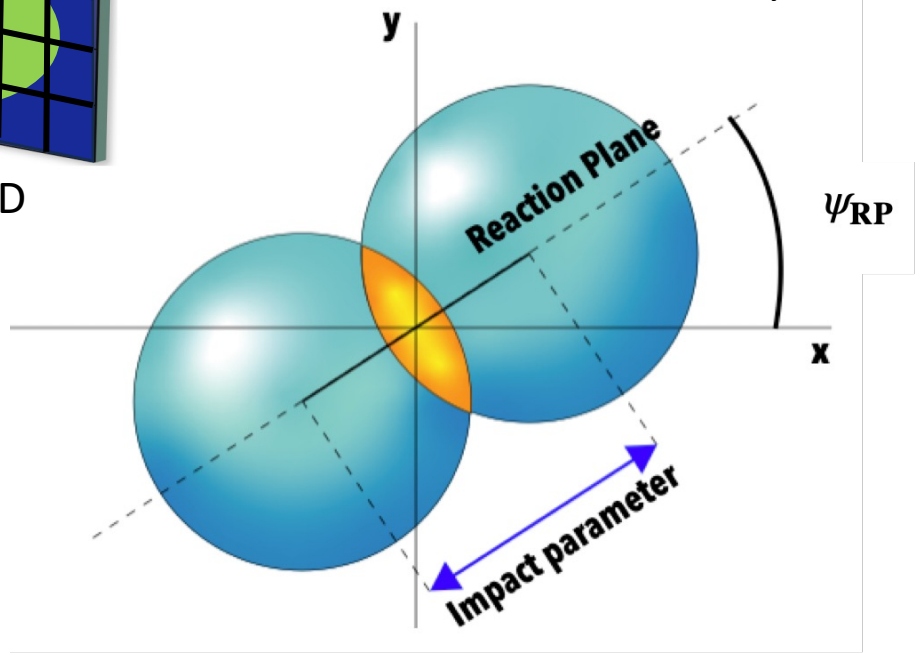


Run3 upgrade: New Reaction Plane Detector (RPD)

- Estimates the **reaction plane event-by-event**
  - 2D mapping of **transverse shower profile**
  - measures **correlated deflections of spectators**
  - Enables **new variety of measurements** before only possible at ALICE

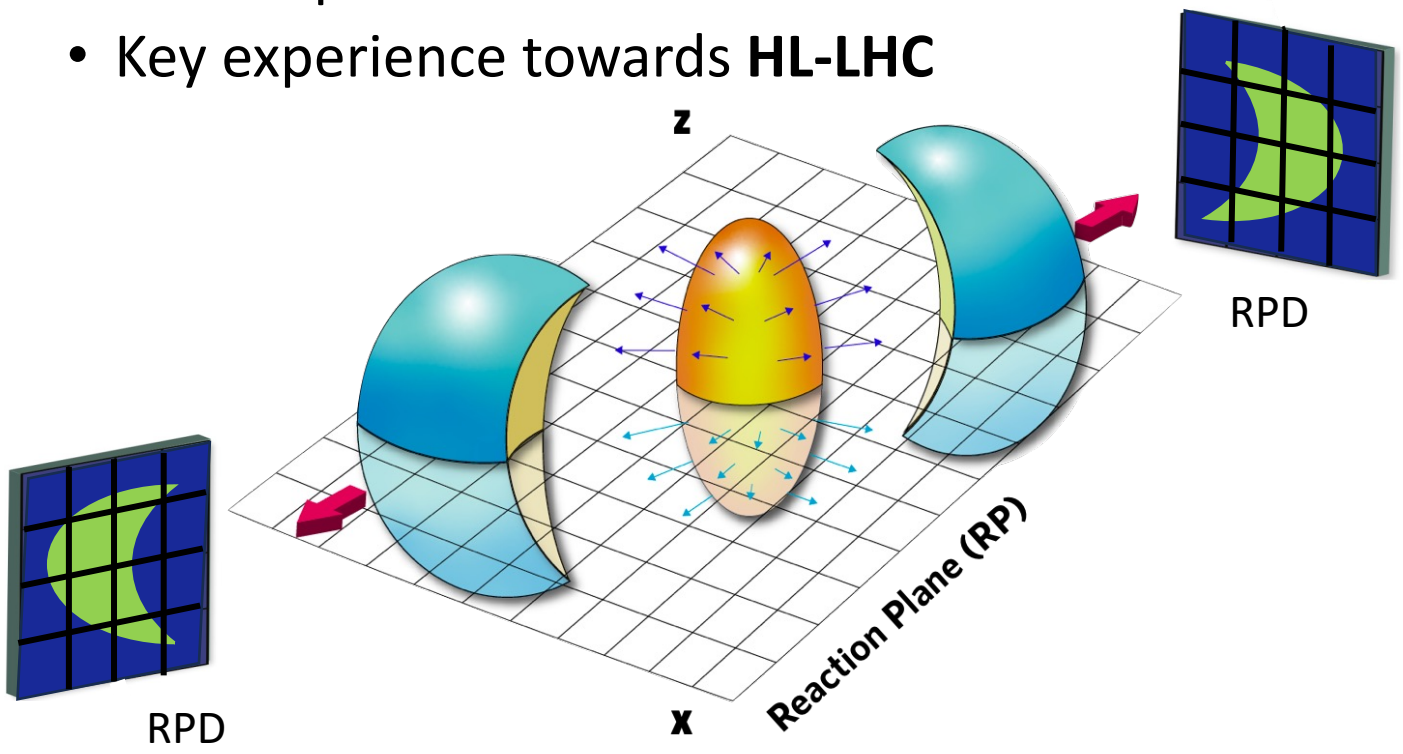


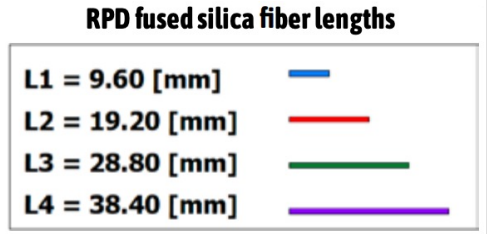
Illustrations made by A. Tate

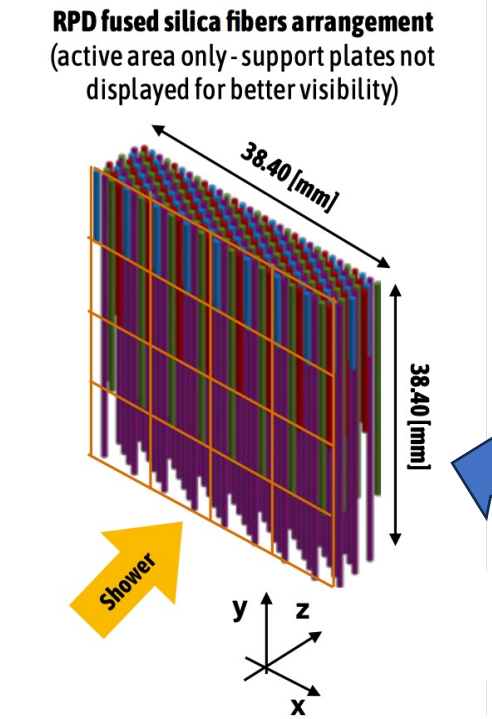


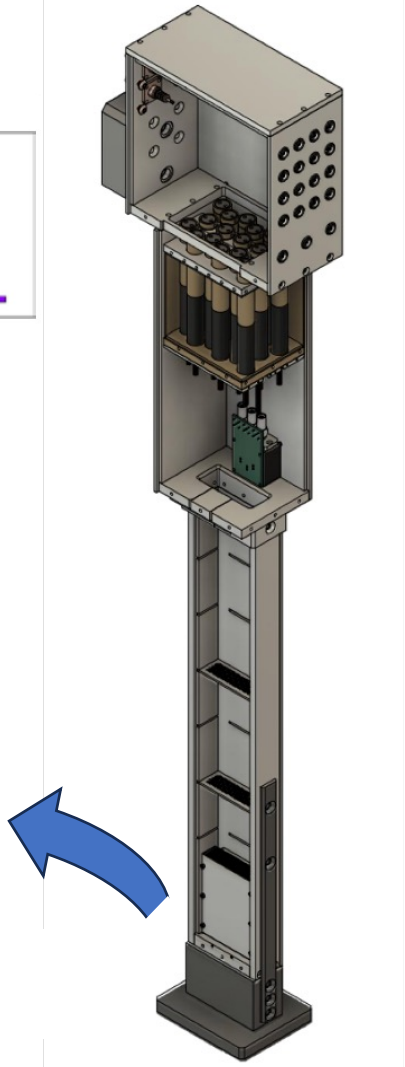
Run3 upgrade: New Reaction Plane Detector (RPD)

- Estimates the **reaction plane** **event-by-event**
- Novel **"Pan Flute"** **design**
  - 4 x 4 "virtual" square tiles in the x-y plane
  - Made up of 256 **radiation-hard** fused silica fibers
  - Key experience towards **HL-LHC**









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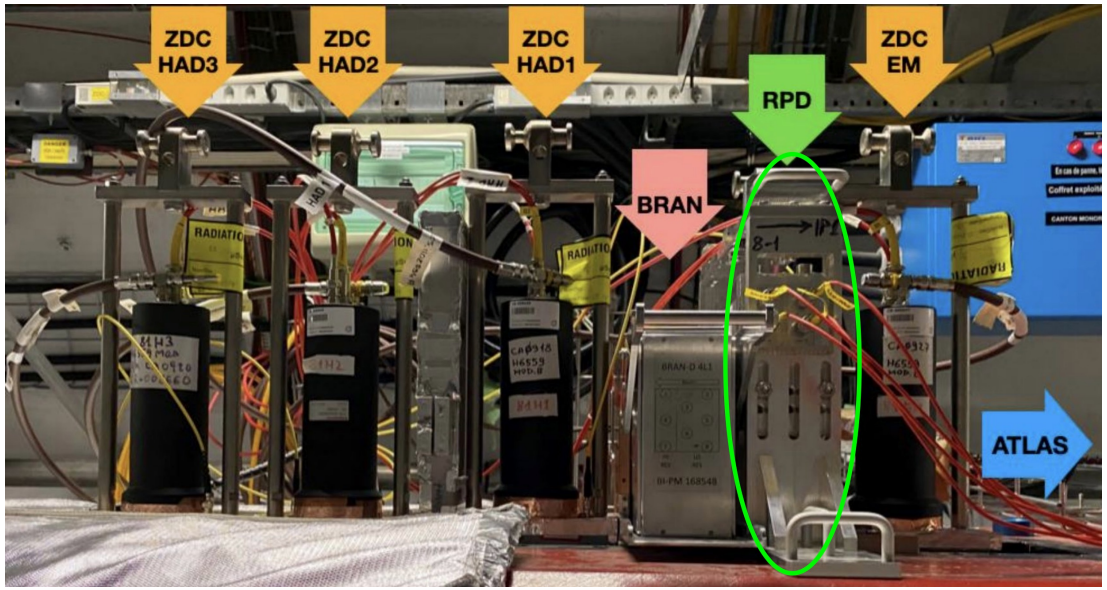
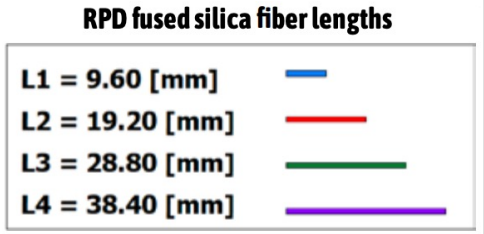
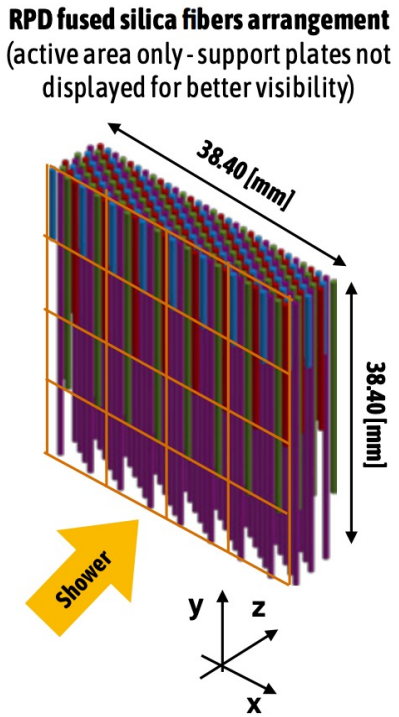
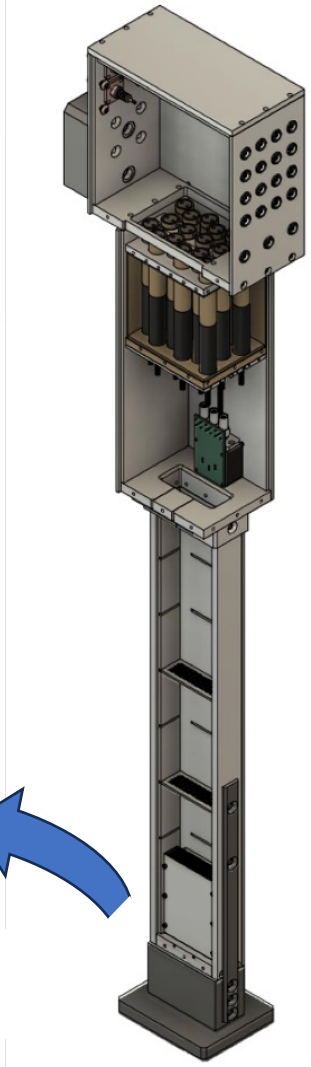
- Novel **"Pan Flute"** **design**
  - 4 x 4 "virtual" square tiles in the x-y plane
  - Made up of 256 **radiation-hard** fused silica fibers
  - Installed just behind the electromagnetic (EM) section: Cherenkov component of shower at its maximum

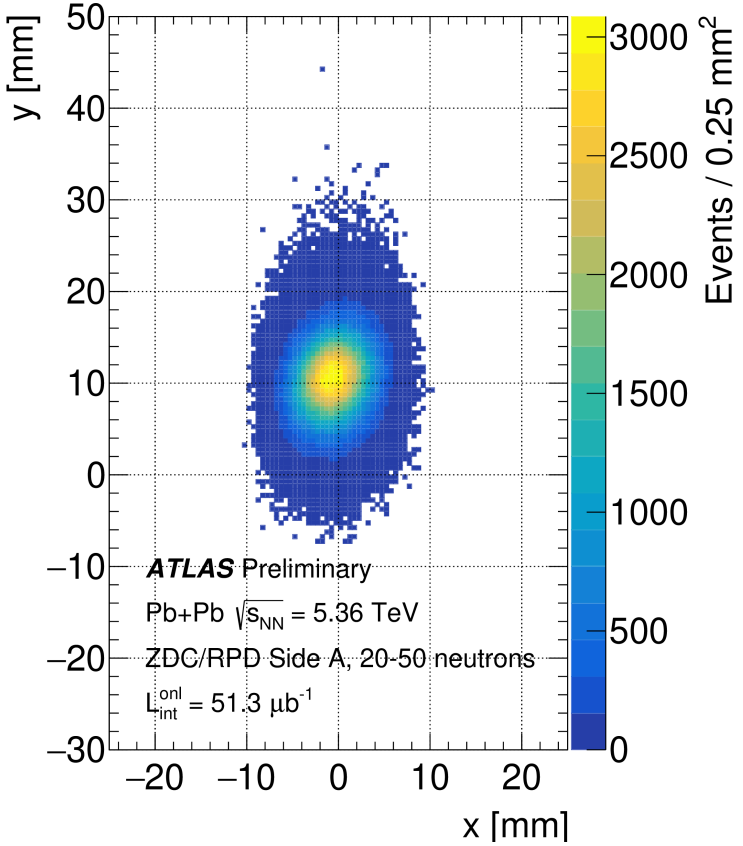


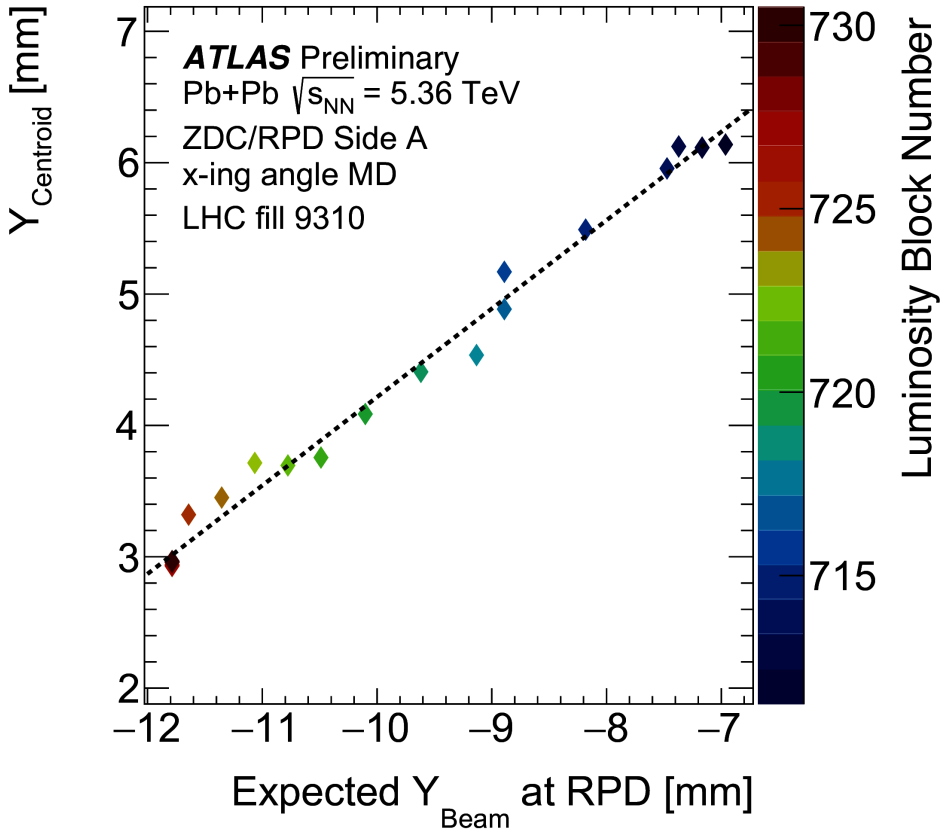






Run3 RPD Performance

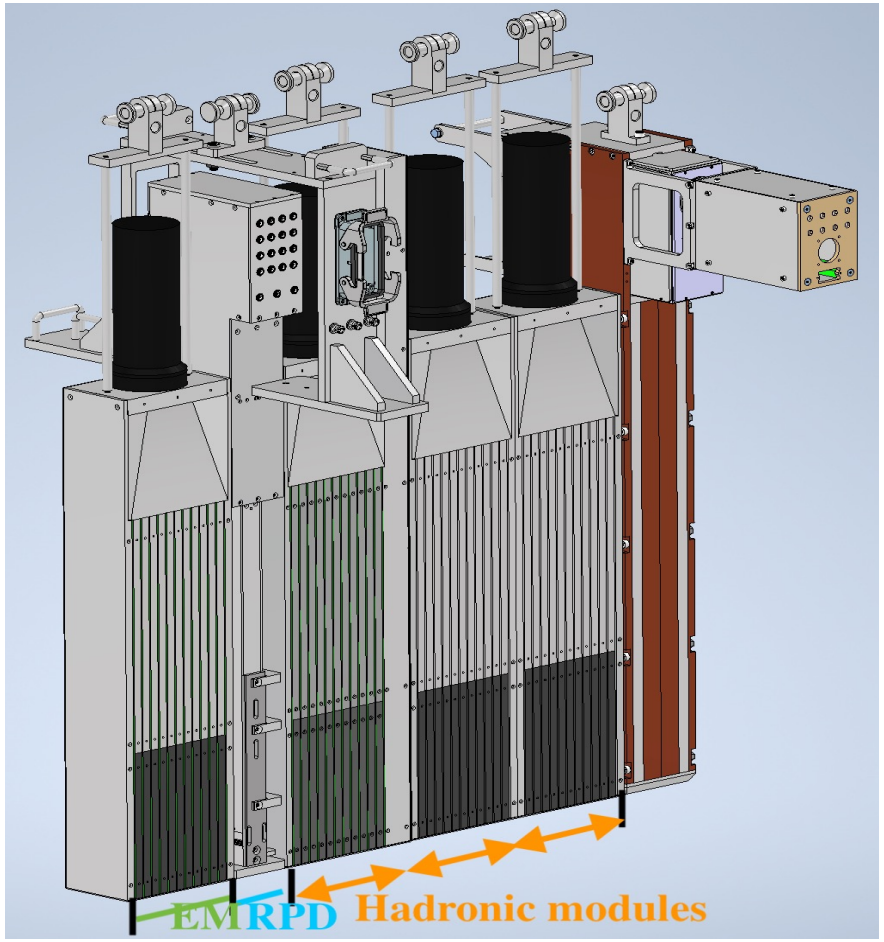




- Offline analysis (subtraction scheme with center-of-mass calculation) gives per-event centroid
- RPD is sensitive to changes in beam position
  - Residual horizontal crossing angle of 20-30 μrad during HI run complicates calibration
  - Calibration ongoing; Relies on MC input

ZDC upgrade for HL-LHC

- Joint effort between ATLAS and CMS



HL-LHC

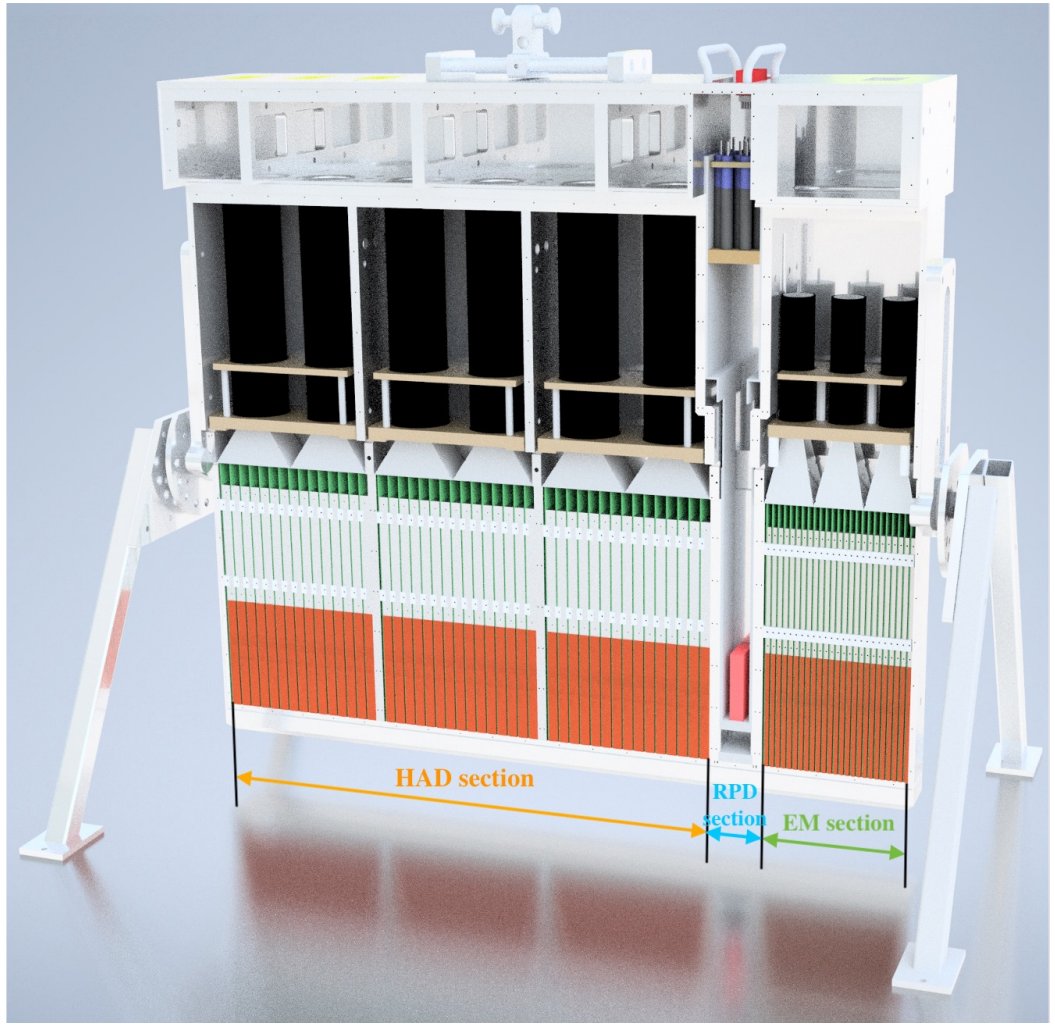


Figure: Run-3 ZDC design, with one EM module, RPD, and three hadronic modules each of ~ 1 interaction length.

Figure: Run-4 ZDC design - **single-unit structure** including the EM section, RPD, and a single hadronic section of 4.5 interaction length.

ZDC for HL-LHC: Geometric constraint

- Run3: ZDC installed in the Target Absorbers for Neutrals (TAN)

  → HL-LHC: **TAN** upgraded to **TAXN**. (Same design for ATLAS and CMS.)

- Narrower width: **TAN 10cm → TAXN 5cm**
  - Additional length **4.4 λ_{int} → 5.5 λ_{int}**
  - Ensures good energy resolution

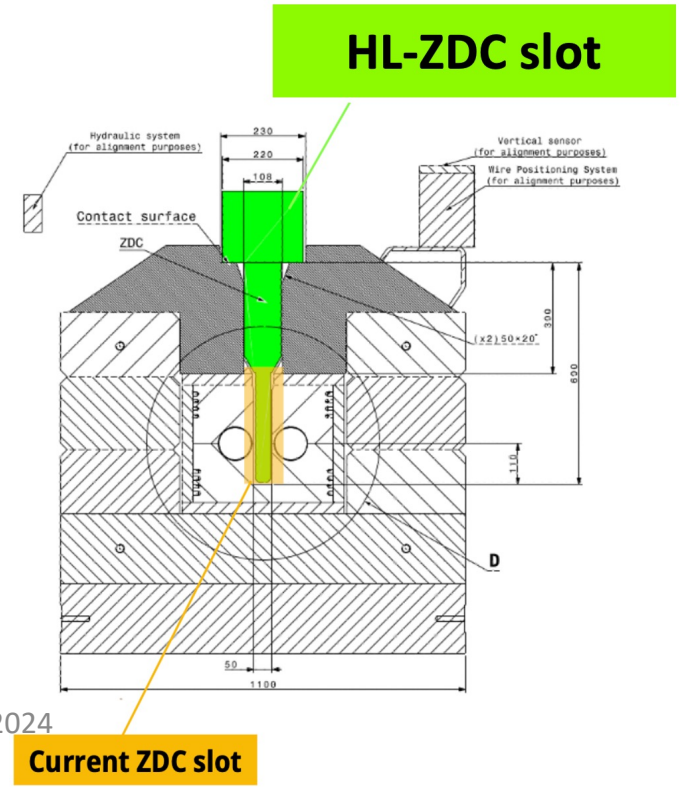
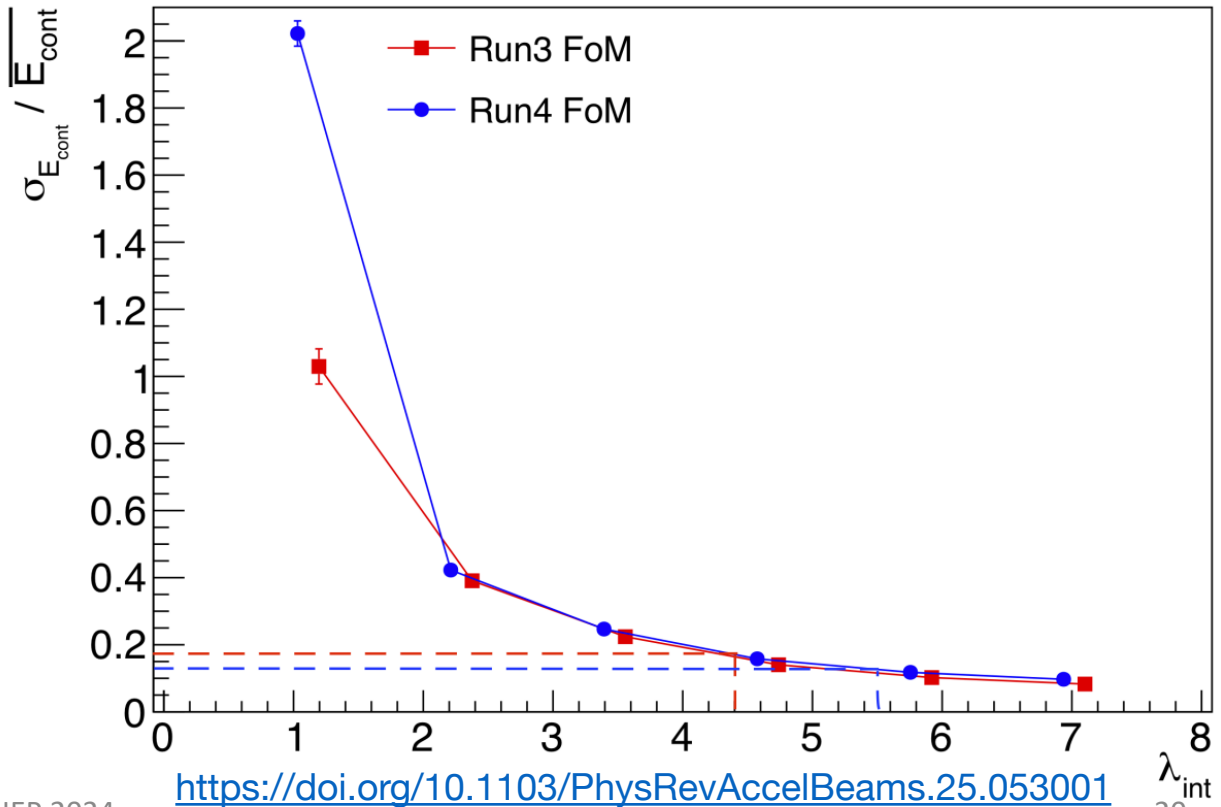


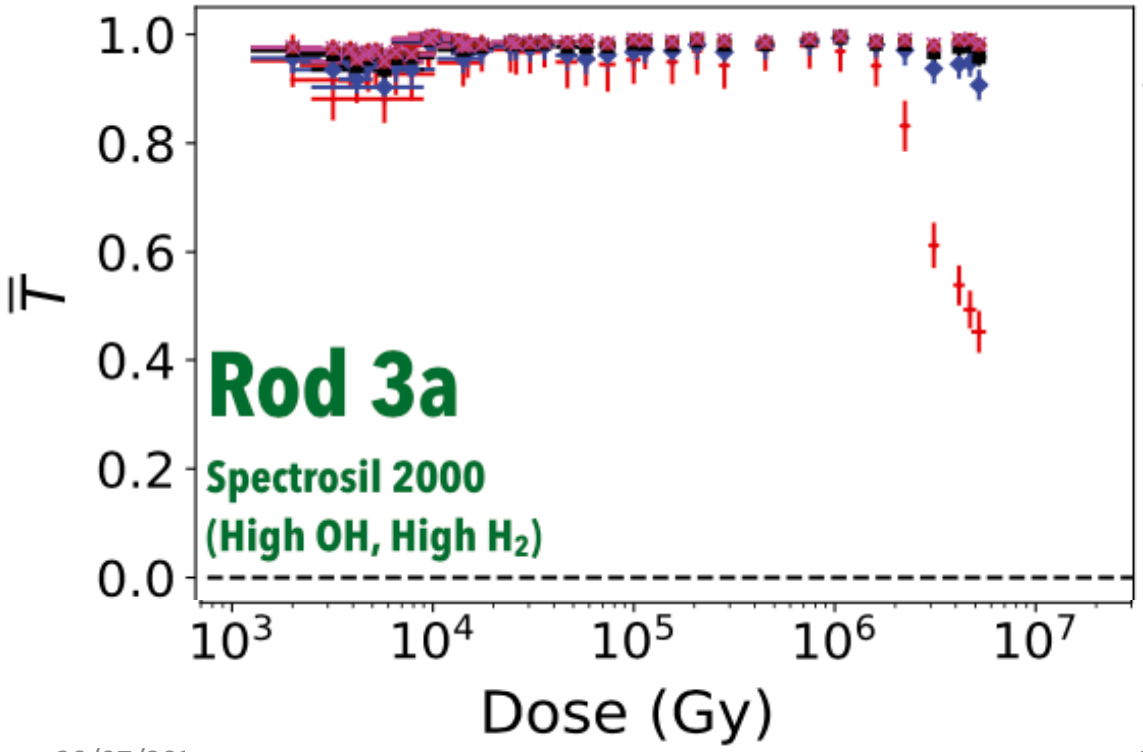
Figure: Comparison of energy resolution of the Run3 and Run4 ZDC as a function of interaction length. Geant4 simulation for single 2.5 TeV neutron events.



https://doi.org/10.1103/PhysRevAccelBeams.25.053001

ZDC for HL-LHC

- **Higher radiation (Run3: 1.4 MGy → Run 4: 4.5 MGy**, full physics program)
  - Requires **radiation-hard** detector with **stable performance** over entire Run4
    - Radiation-hard fused silica rods
    - Radiation-hard PMT (fused-silica window)



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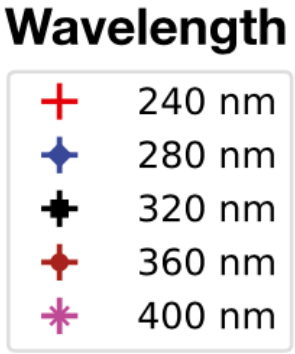
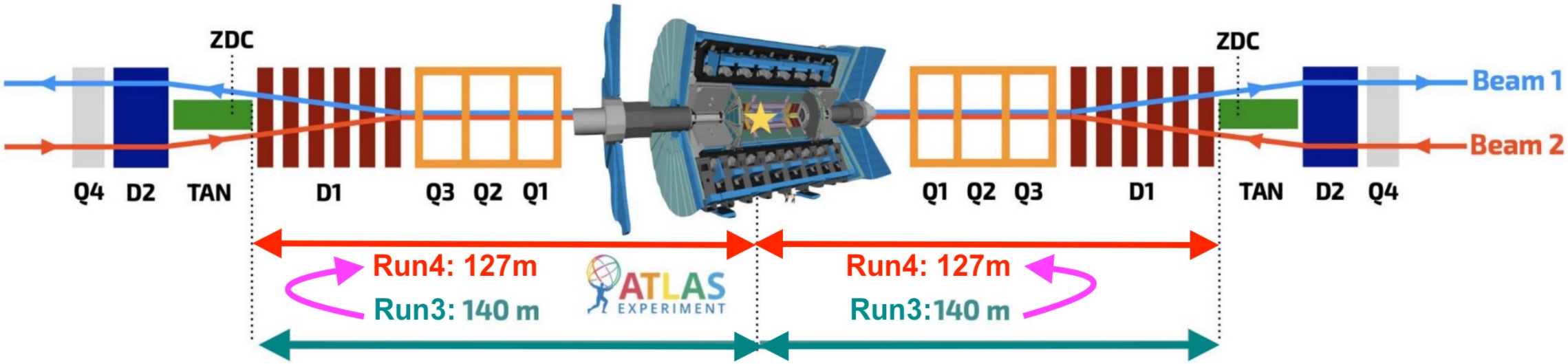
- Figure shows transmittance of the fused silica rod Spectrosil 2000 (High OH and High H2), used by the Run3 ZDC, as a function of dose, for five different wavelengths in the UV and visible-light region.



ZDC for HL-LHC

- **Higher radiation** (**Run3: 1.4 MGy → Run 4: 4.5 MGy**, full physics program)
  - Requires **radiation-hard** detector with **stable performance** over entire Run4
- TAXN at 127m from the IP (Run 3: TAN at 140m from the IP)
- Harsh radiation environment → **Radiation Protection (RP)** considerations
  - Limit exposure of workers (Easy installation/cabling and remote handling)

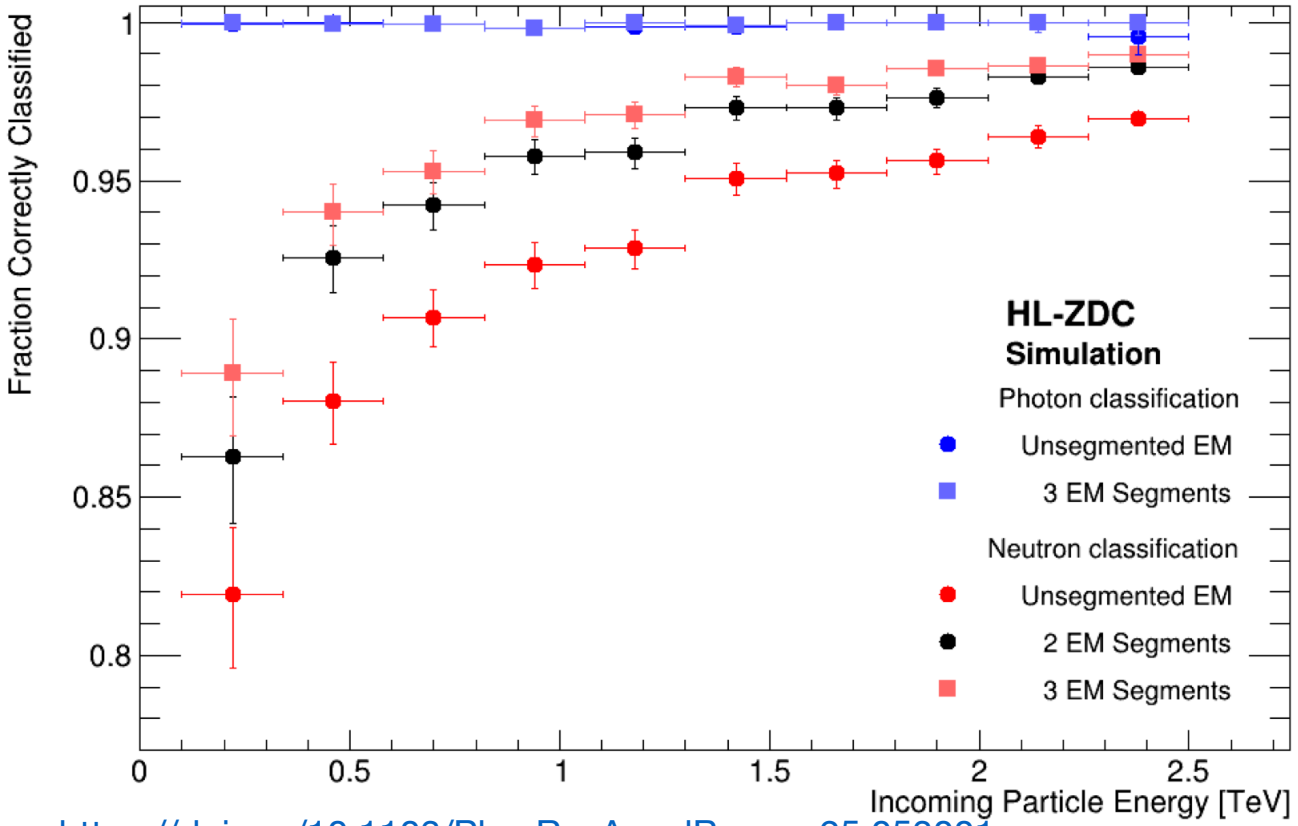


Summary

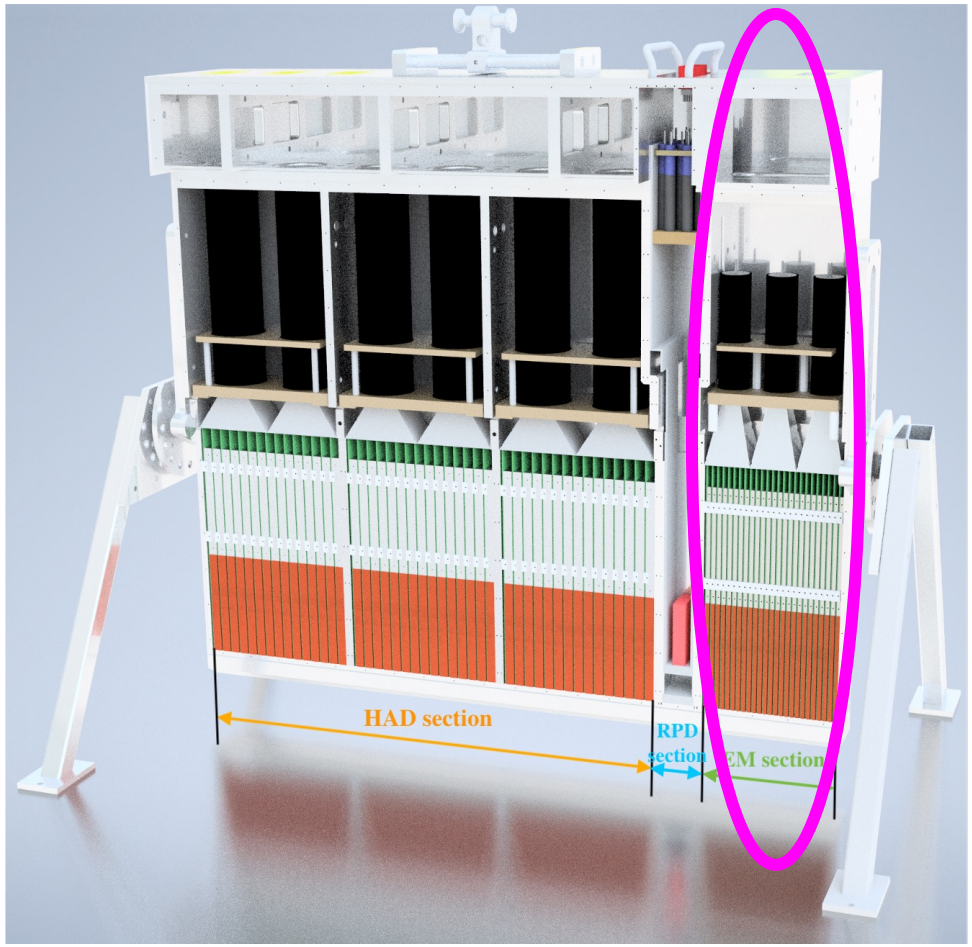
- The ATLAS Zero Degree Calorimeter is crucial both for triggering and for offline analysis in the ATLAS heavy ion program. It is important both for studies of the ultra-peripheral (UPC) physics in HI collisions, and for pileup identification and unbiased centrality determination in hadronic-process-dominated events.
- Run-3 ZDC refurbishment of radiation-hard fused silica materials, cables, electronics, and trigger ensures stable performance and good resolution.
- The new Reaction Plane Detector in Run-3 allows estimate of the reaction plane event-by-event, opening doors to various novel measurements.
- Run-4 ZDC needs to be compatible with the TAXN geometry and cope with the high radiation environment of the HL-LHC, both in terms of detector radiation hardness, and for Radiation Protection of workers.
- The Run-3 ZDC and RPD offer key experience to the HL-LHC.

Thank you for your attention!

Run4 ZDC – EM Section

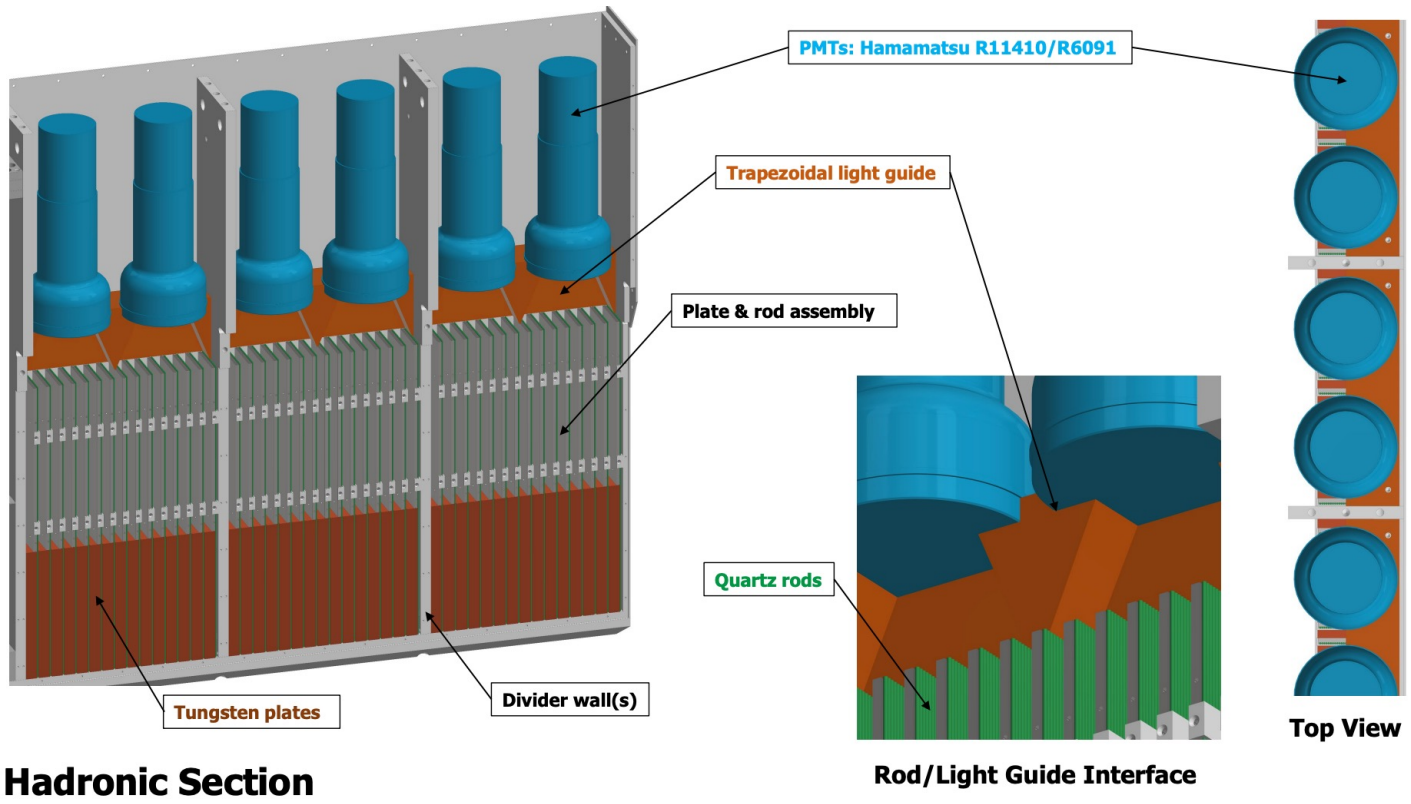


https://doi.org/10.1103/PhysRevAccelBeams.25.053001



- Alternating layers of 4mm-thick tungsten plates (42×120 mm^2 in the x-y plane) and 1.5mm-diameter fused silica rods (each layer: 25 rods of 275 mm length)
- 1 nuclear interaction length (~ 30 radiation lengths)
- 3 longitudinal sub-sections (3 lightguides + 3 PMTs)
  - discrimination between neutrons and photons

Run4 ZDC – Hadronic Section

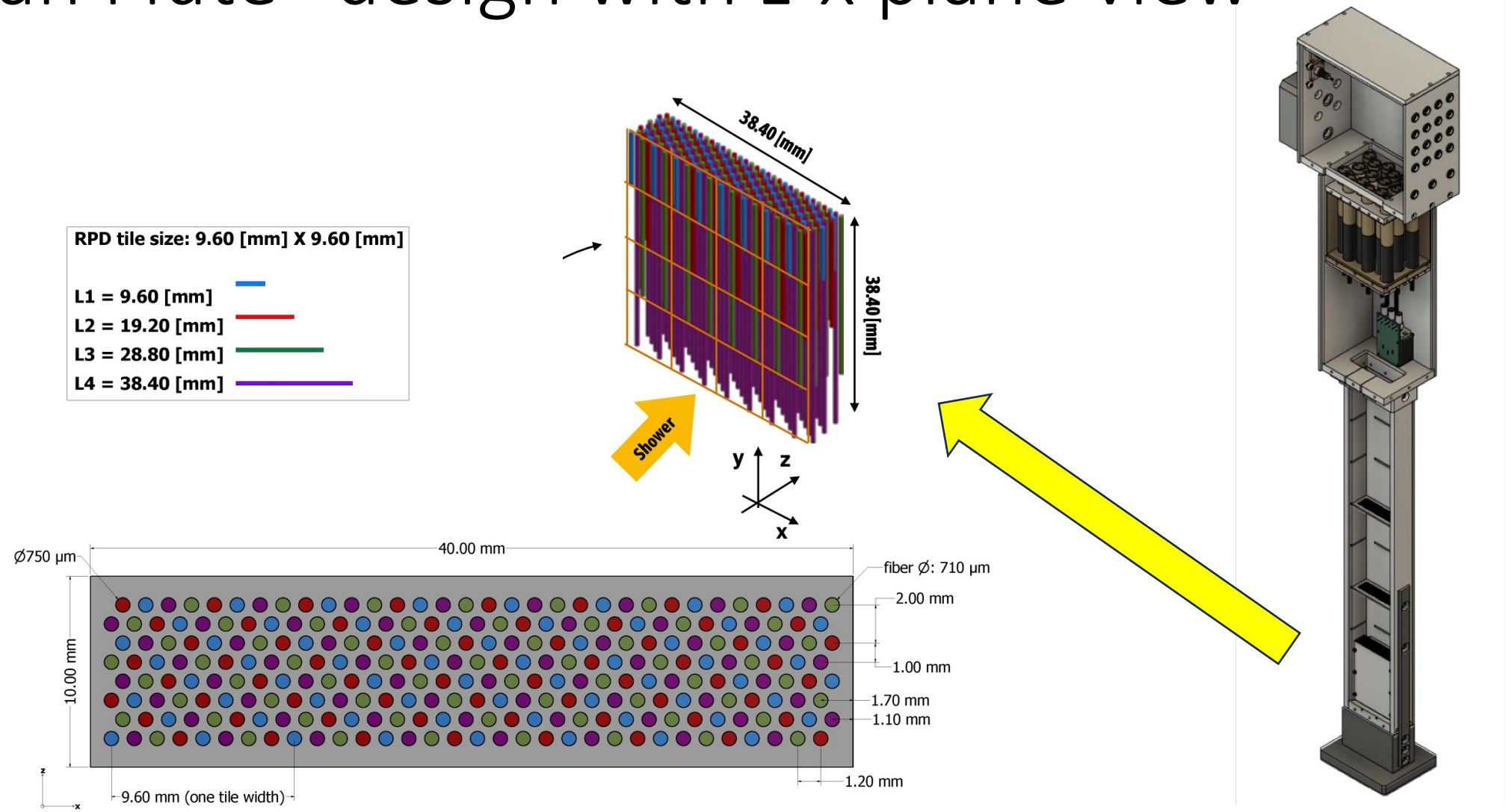


- Single long section of 4.5 interaction length; 3 submodules
- alternating layers of 10mm-thick tungsten plates (42×120 mm^2 in the x-y plane) and 1.5mm-diameter fused silica rods (each layer: 25 rods of 275 mm length)
- each HAD submodule: 2 lightguides and 2 PMTs
- Radiation-hard PMTs: Hamamatsu R11410/R6091

Important tool for triggering

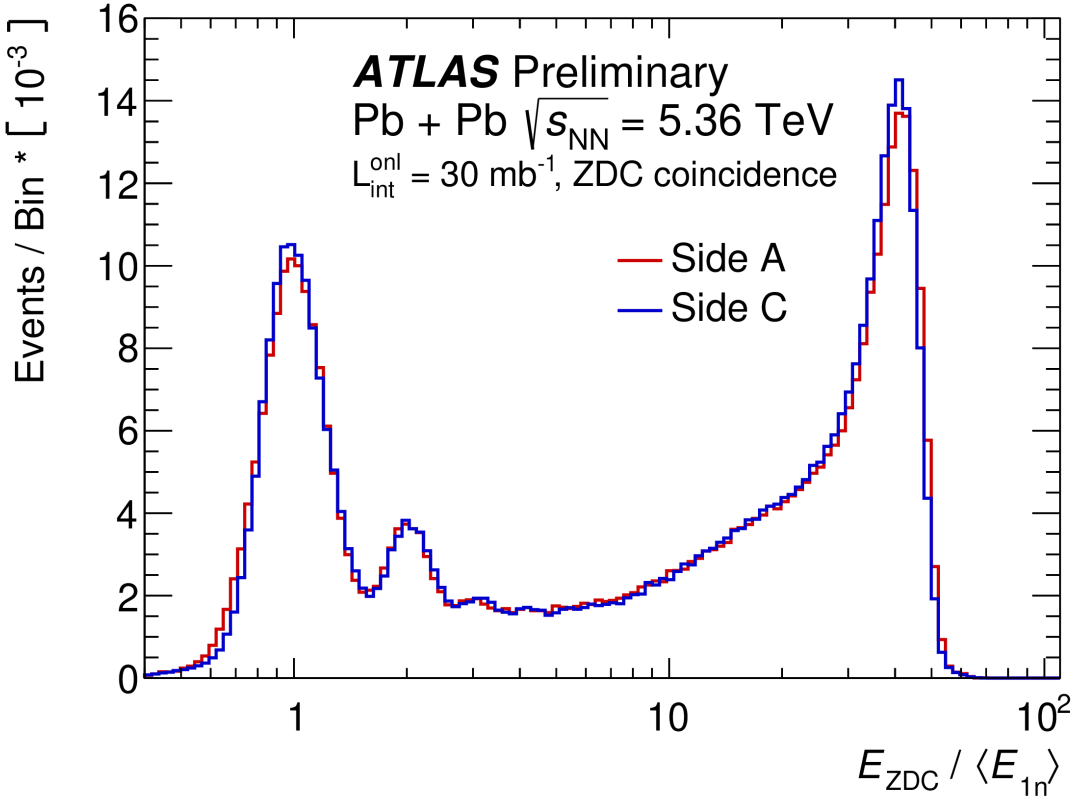
- Level-1 ZDC triggers feeding into HLT trigger chains
  - Lookup table with 3 bits
- On **photoproduction** and **photonulear** processes for **ultraperipheral (UPC)** events
  - Photoproduction: require zero neutron on both sides of ZDC (5 GeV < TE < 200 GeV)
  - Photonuclear: require at least one neutron on one side, and no neutron on the other side (5 GeV < TE < 200 GeV)
- On **minimum-bias hadronic** processes (suppressing electromagnetic background) for **peripheral** events
  - In MinBias and PC (peripheral-collision) streams: require ZDC activities on both sides at low transverse energy (TE lower than 50GeV)

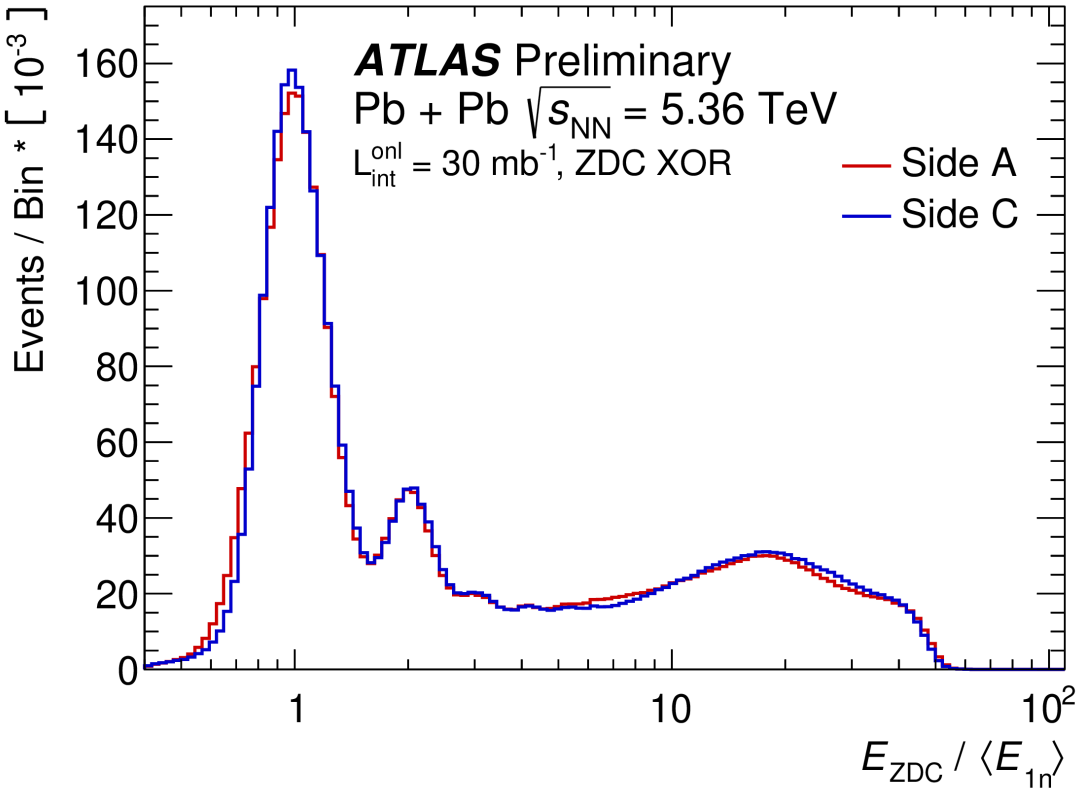
RPD “Pan Flute” design with z-x plane view



Effect of trigger selection on energy distribution

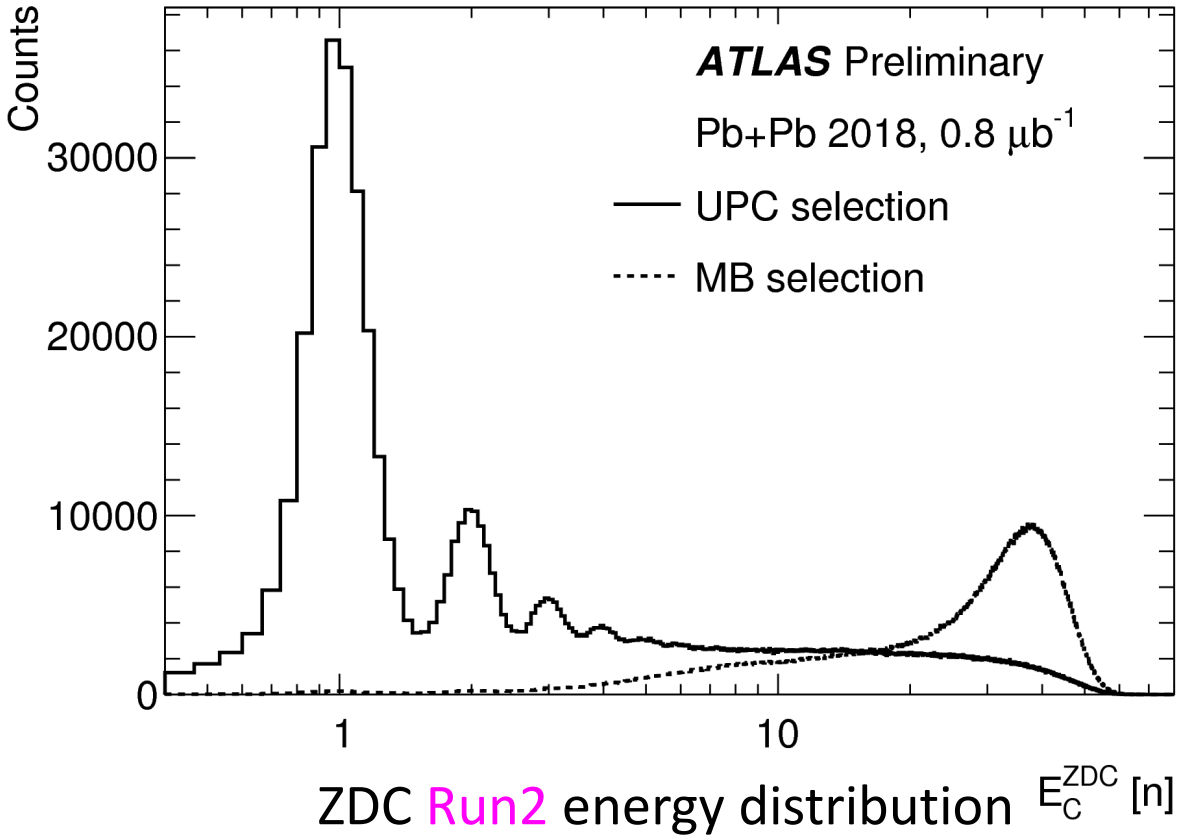
- Left: ZDC energy spectrum for events having **at least 1 neutron on each side**
- Right: ZDC energy spectrum for events having **at least 1 neutron on one side** and **no neutrons on the other side**

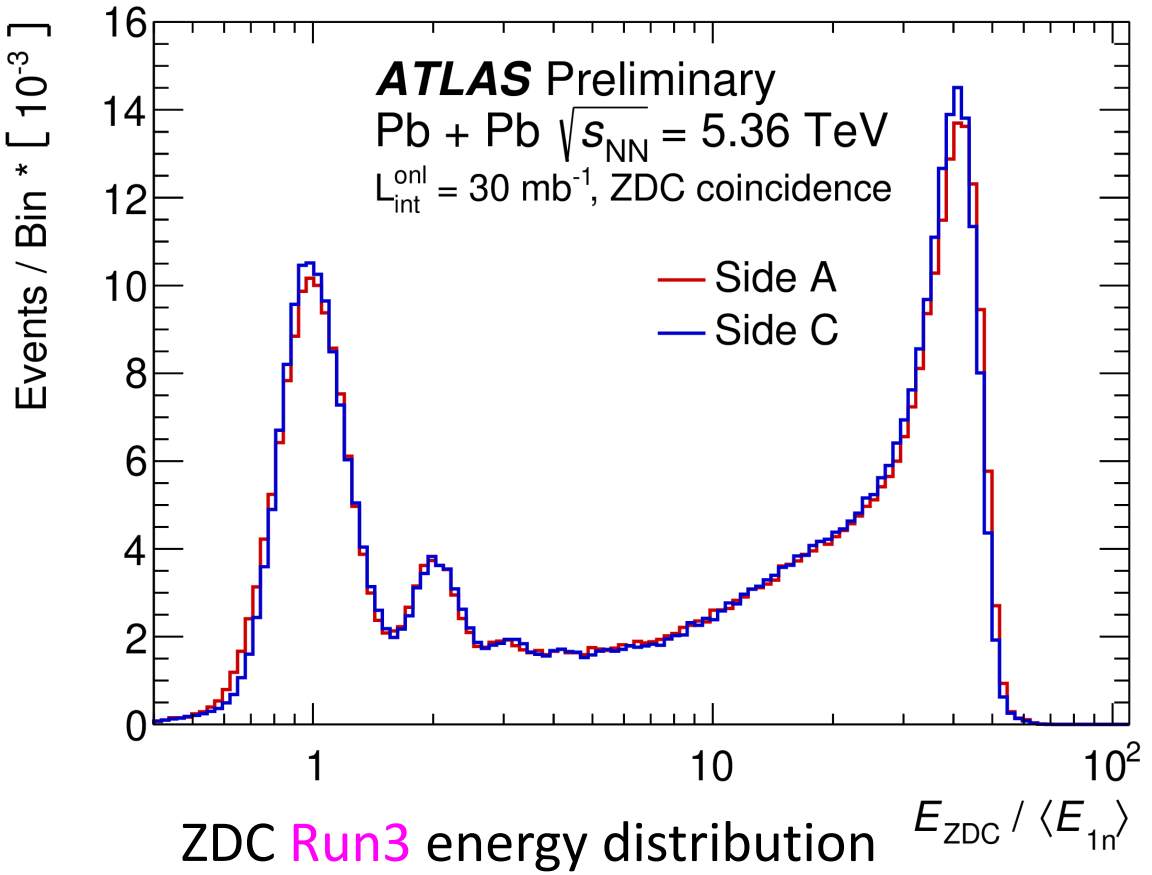




Run3 ZDC Performance

- Left: ZDC reconstructed energy distribution for Run2 (with UPC and MinBias trigger selections)
- Right: ZDC reconstructed energy distribution for Run3 (requiring at least one neutron on both sides)





Run3 ZDC Performance – Effect of BRAN

- The BRAN (Beam RAte of Neutrals) detector causes a fluctuating amount of energy loss between the EM and hadronic modules
  - Exact effect on energy resolution under MC study
  - Possibility to **move the BRAN detector downstream** of the ZDC for the remaining HI runs in Run 3