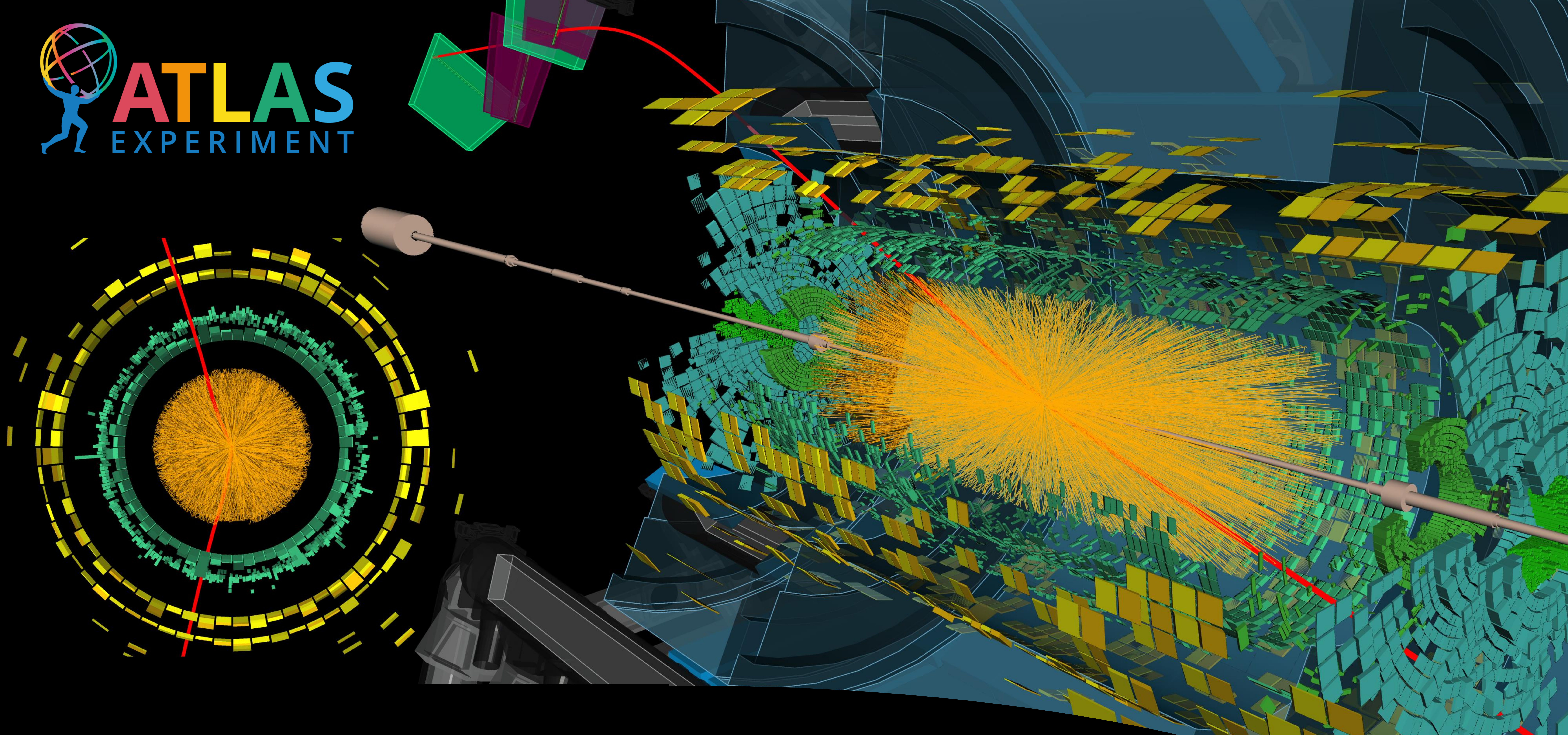
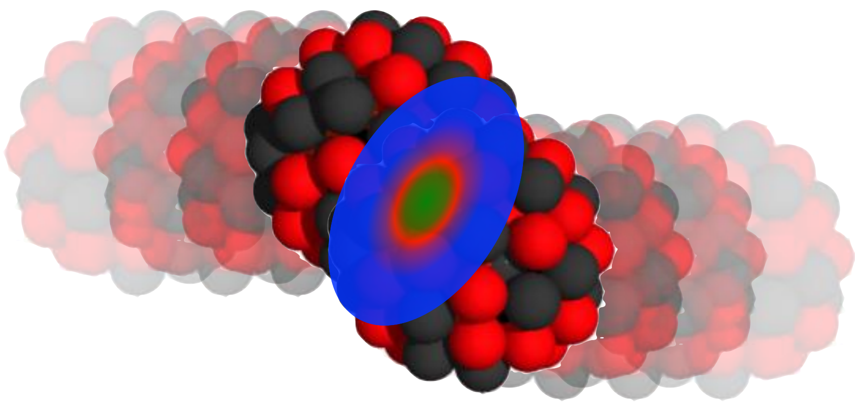


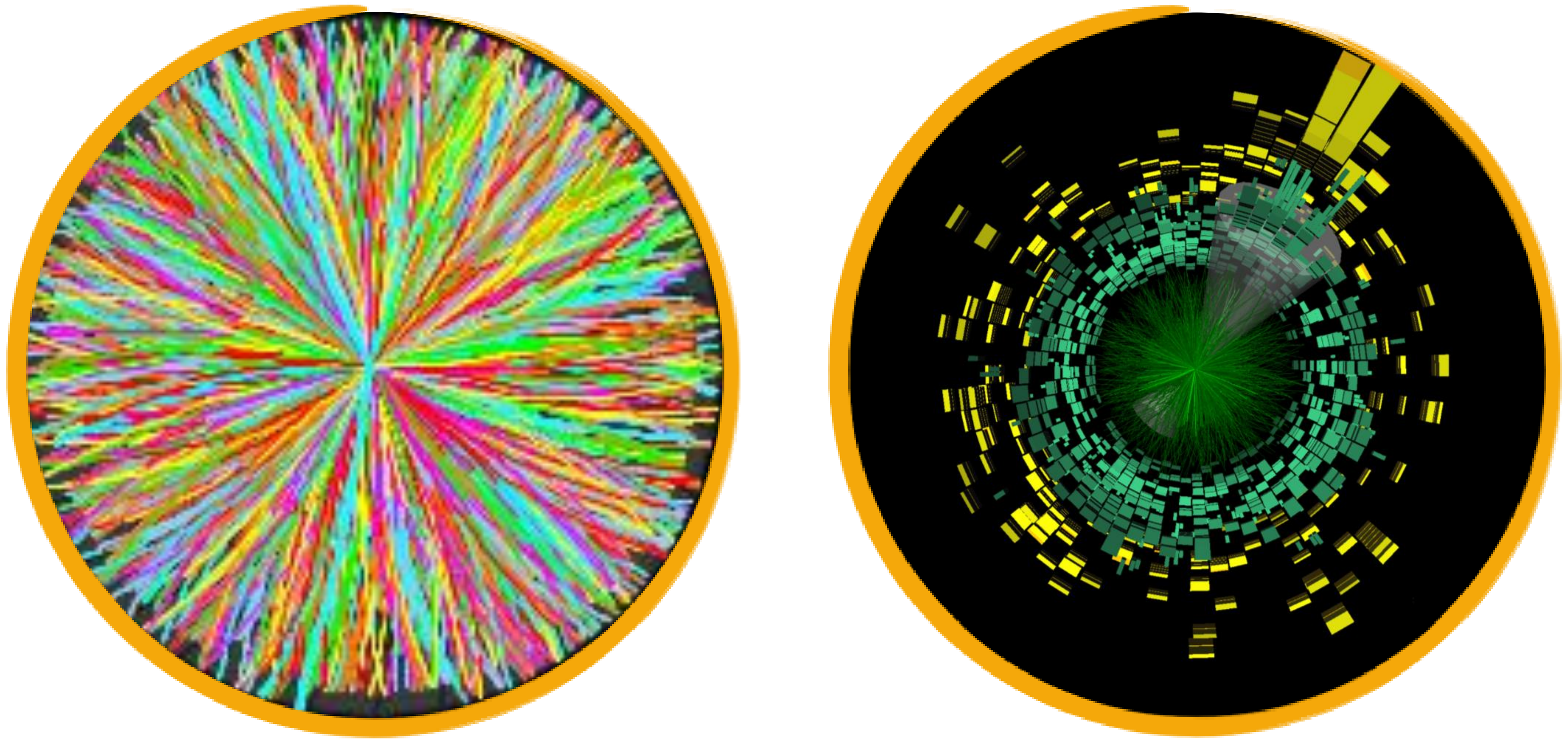
ZERO-DEGREE CALORIMETERS FOR HEAVY-ION COLLISIONS @ THE ATLAS EXPERIMENT

Thanks to Riccardo Longo
For providing slides

HEAVY IONS - IN A NUTSHELL

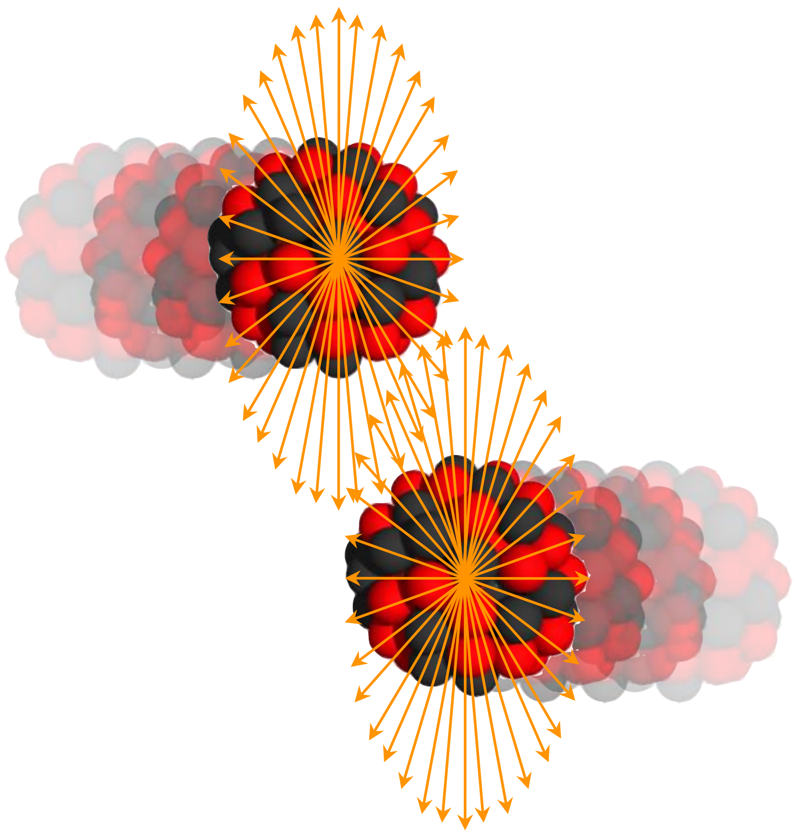
Hadronic A+A collisions

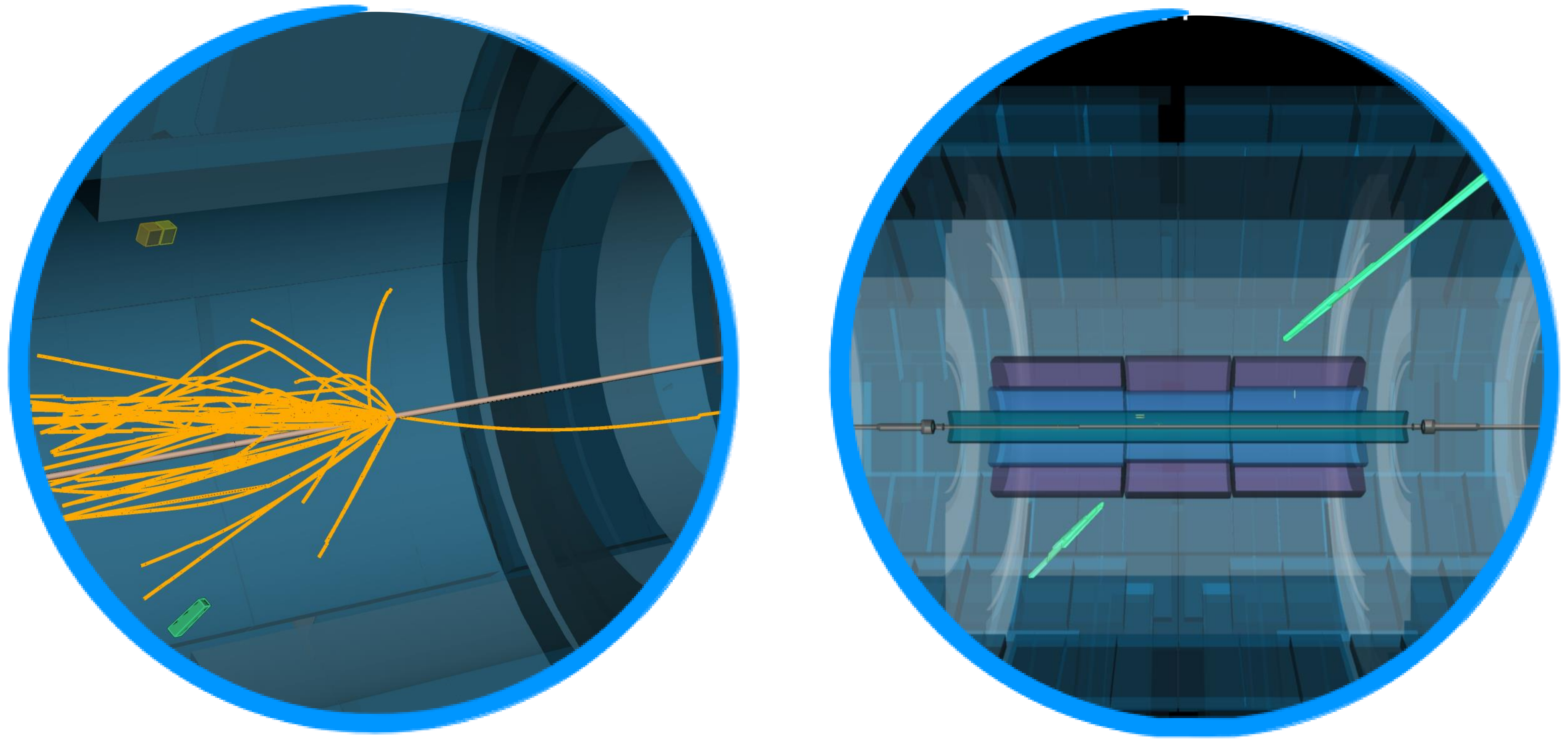




- Investigate the early universe via characterization of the Quark Gluon Plasma (QGP)

Ultra-Peripheral A+A collisions

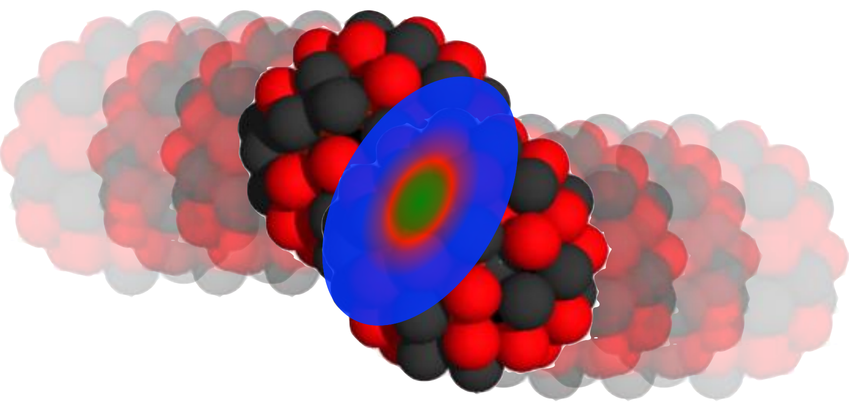


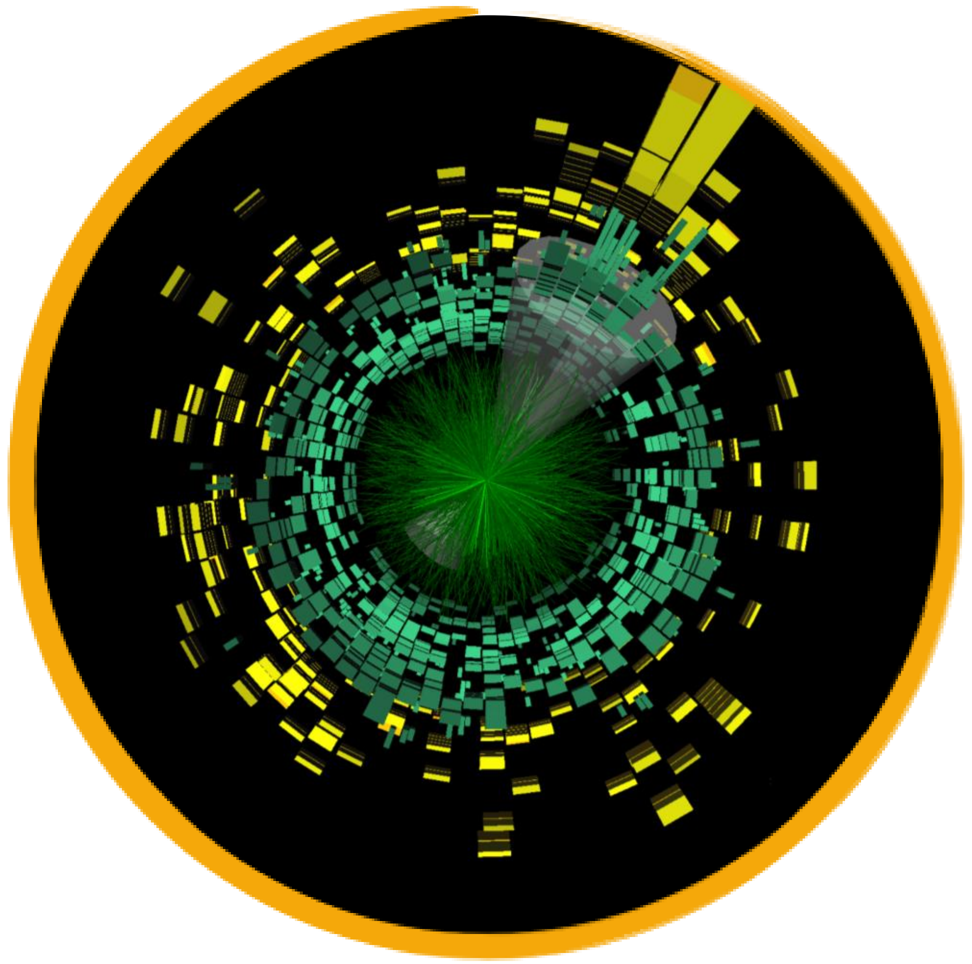


- Precision Quantum Electro-Dynamics
- Study of the nuclear structure

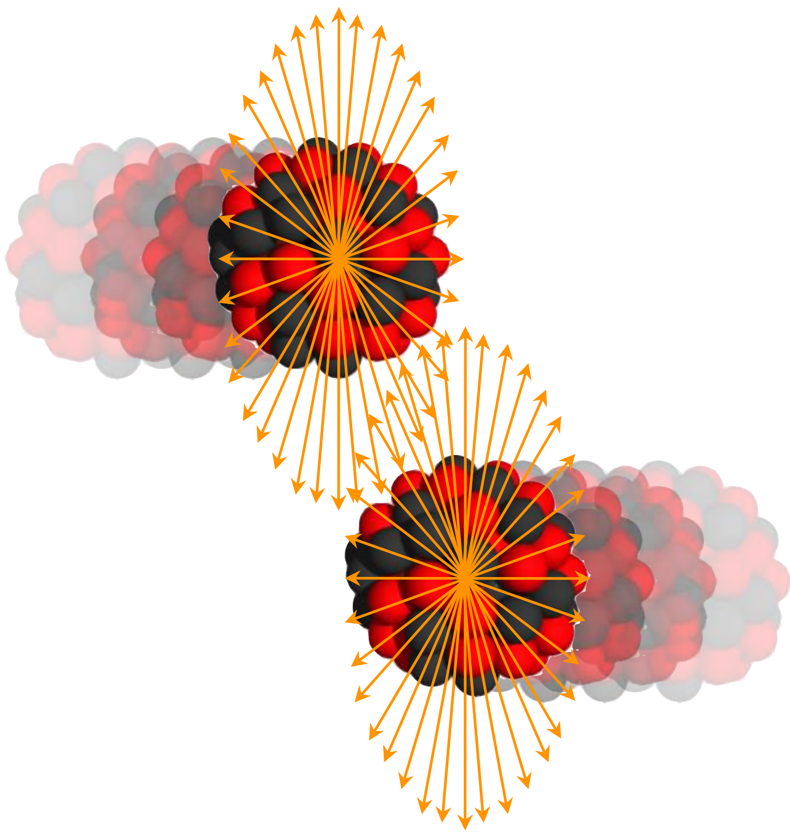
HEAVY IONS - IN A NUTSHELL

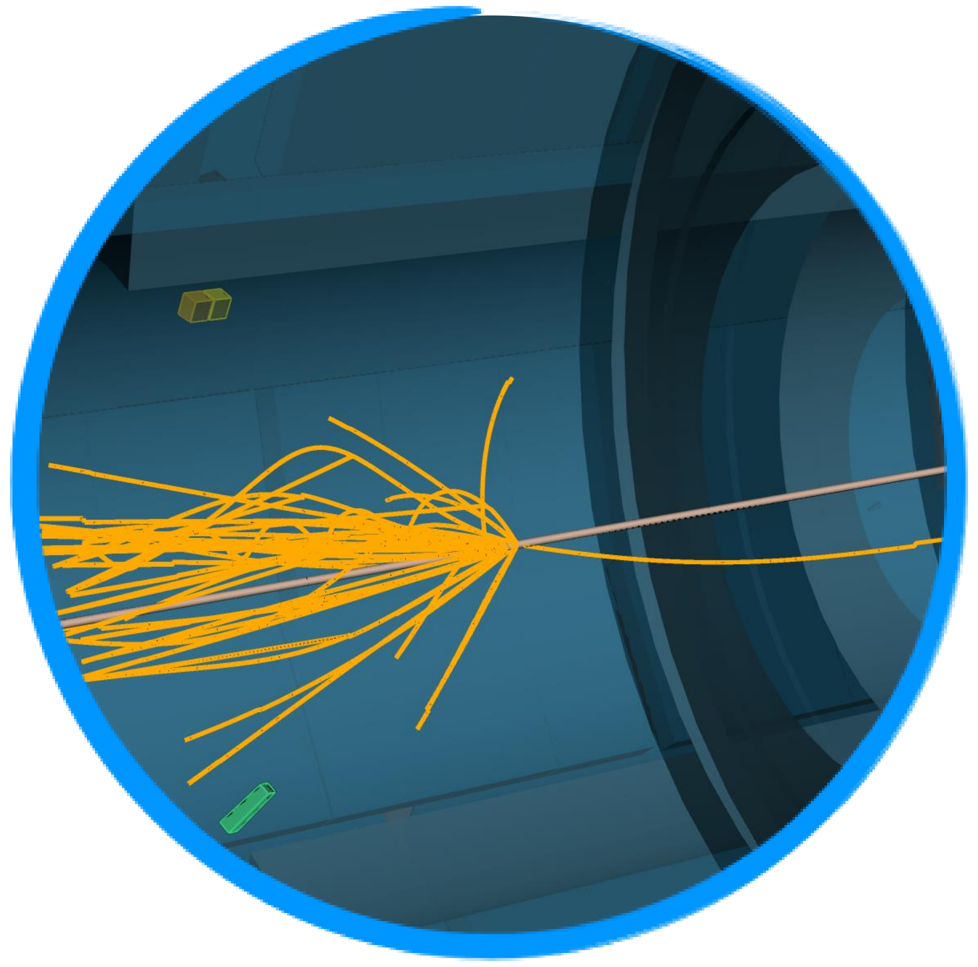
Hadronic A+A collisions

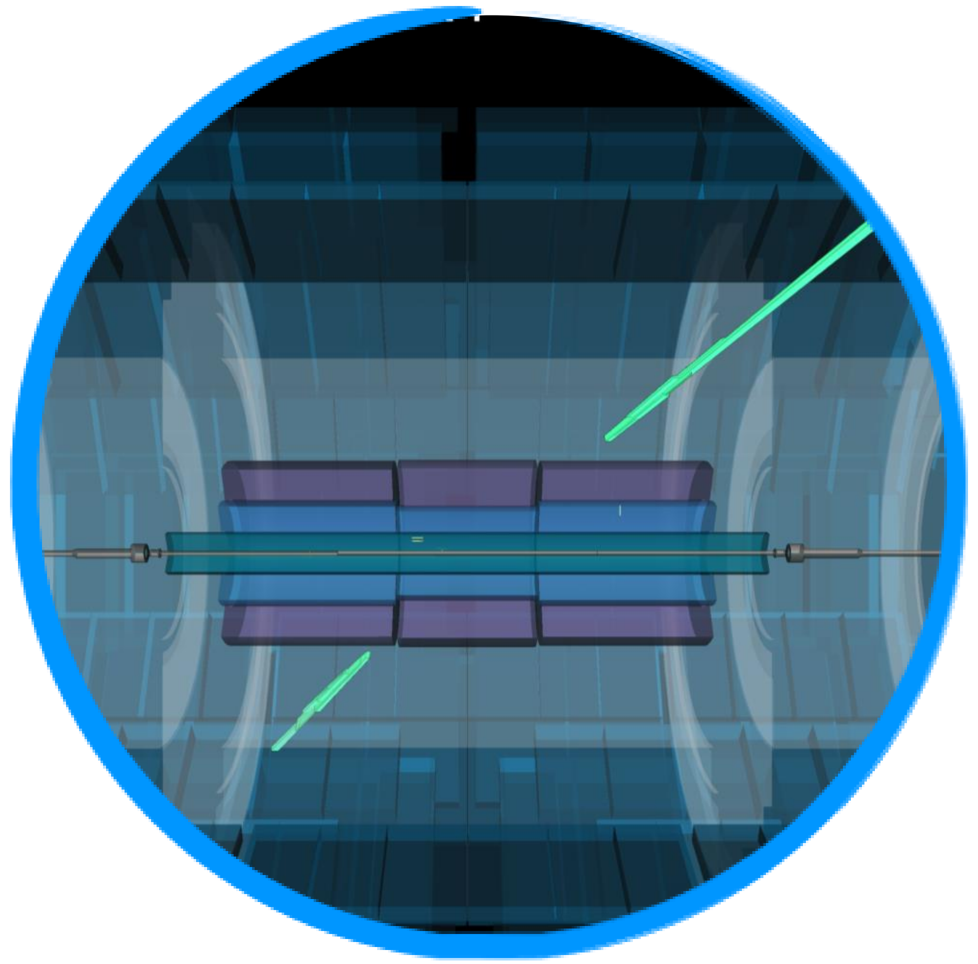




Ultra-Peripheral A+A collisions





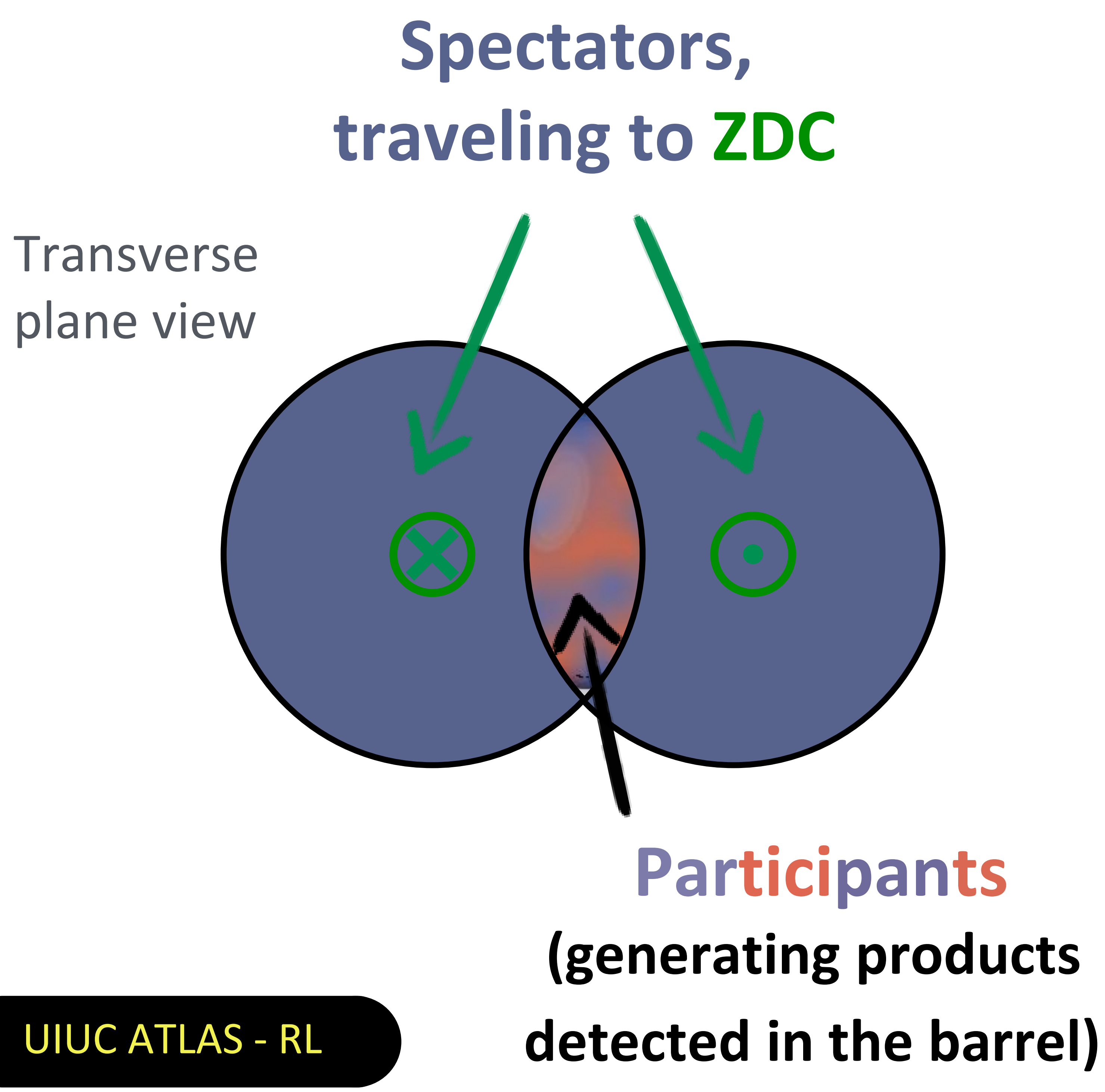


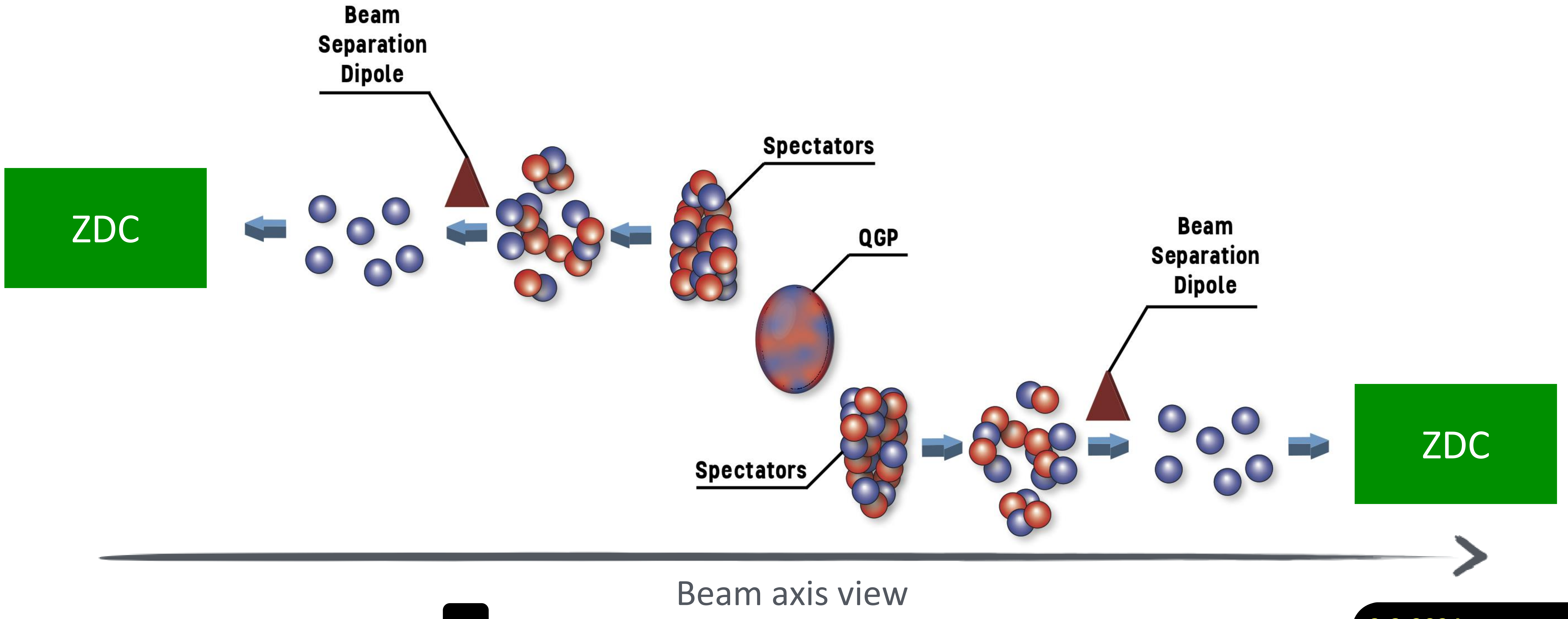
Geometry in these collisions drives nearly everything

Distinguishing between these classes of physics processes is key to having a proper trigger for the experiment

ZERO DEGREE CALORIMETERS

- When colliding ions, additional calorimeters are usually installed on the beamlines: the **Zero Degree Calorimeters (ZDCs)**
- The ZDCs measure **spectator neutrons** that did not interact in the collision
- The ZDC is installed in the Target Absorber for Neutrals (TAN), at ±140 m from ATLAS IP





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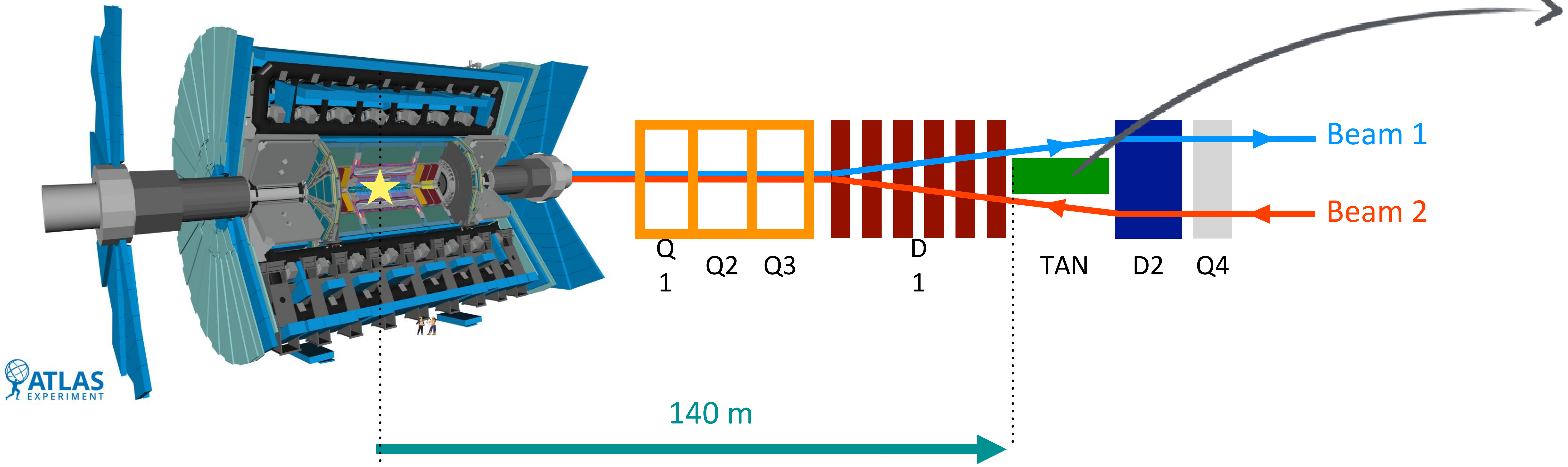
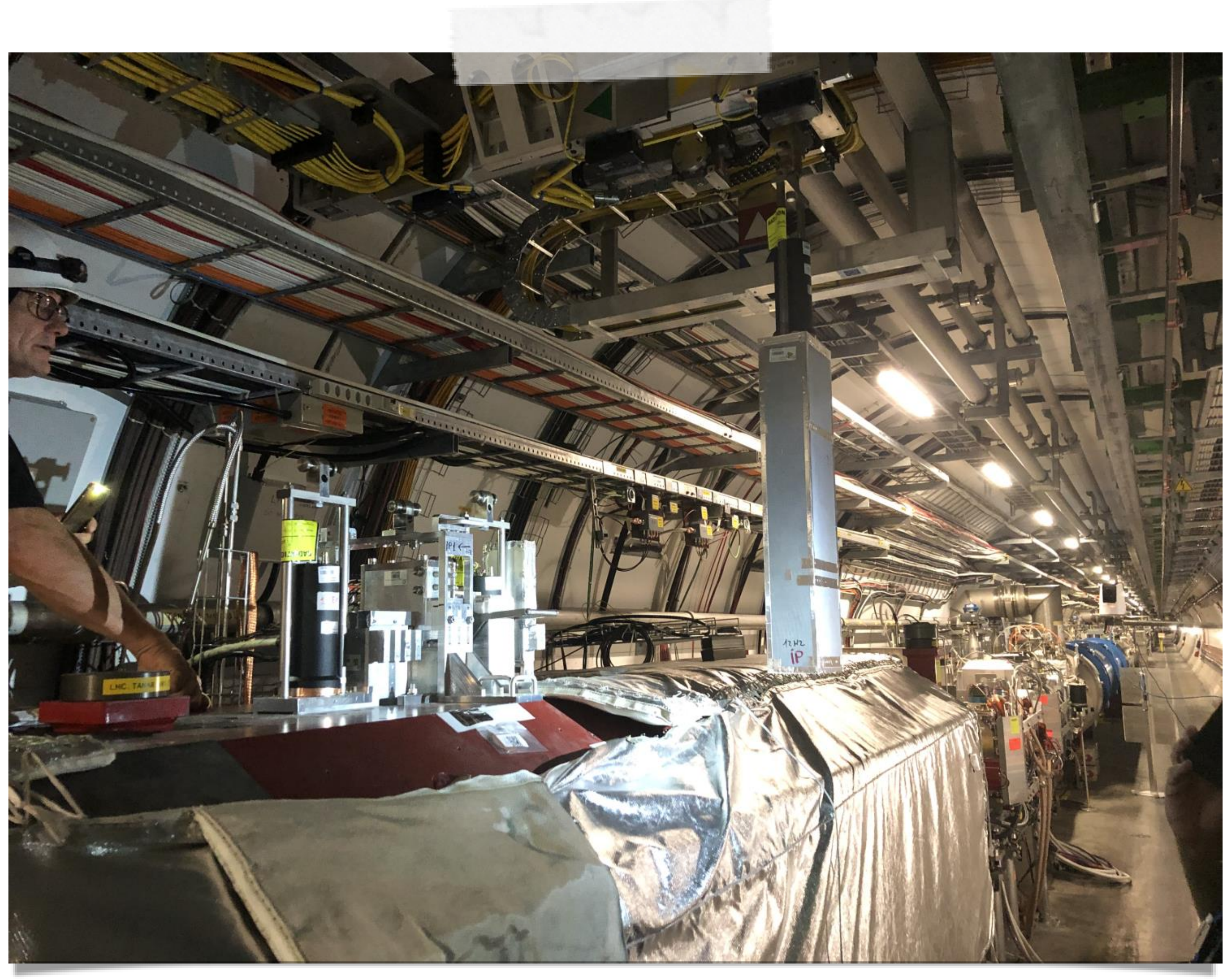
ZDC location in ATLAS

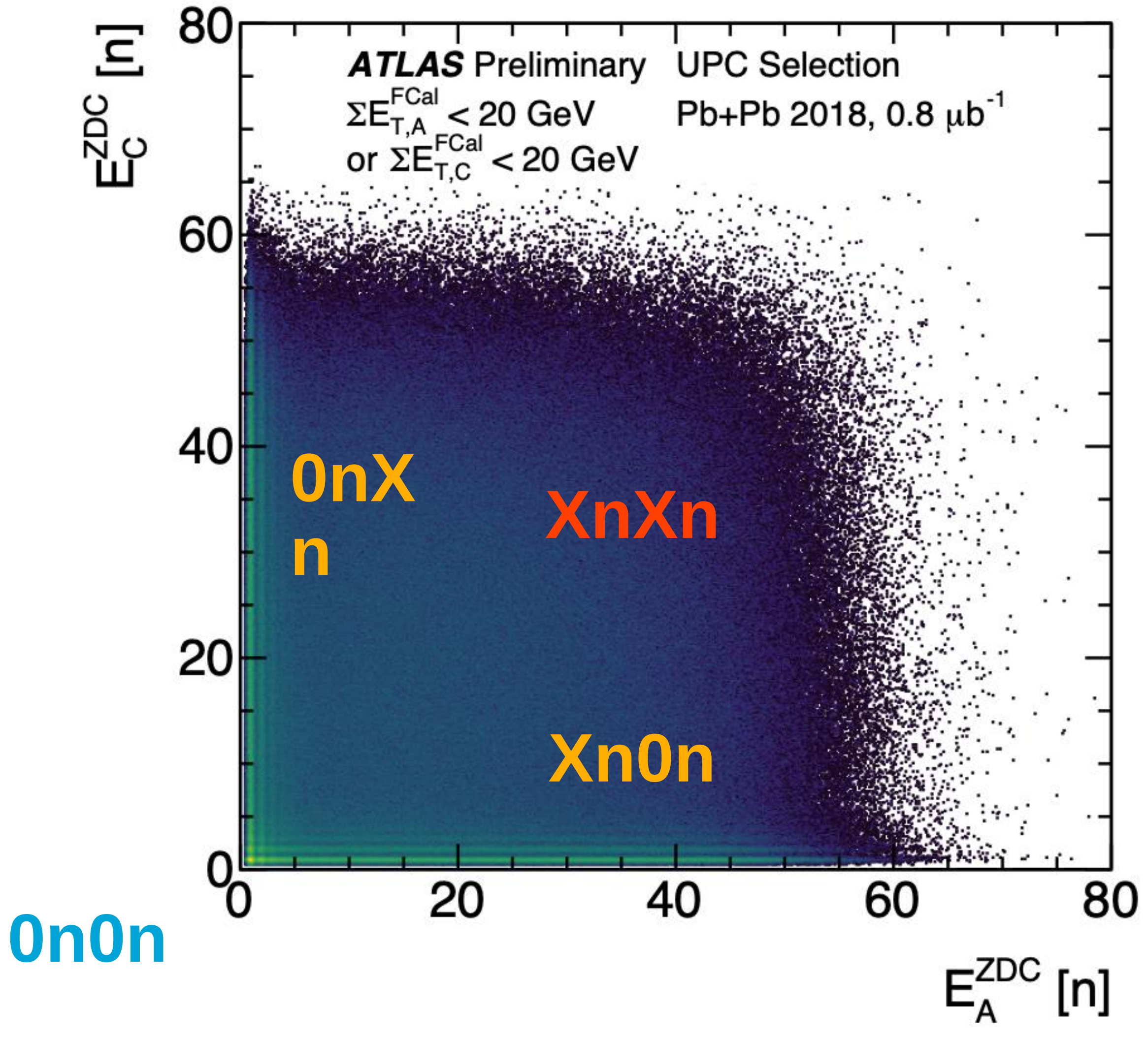


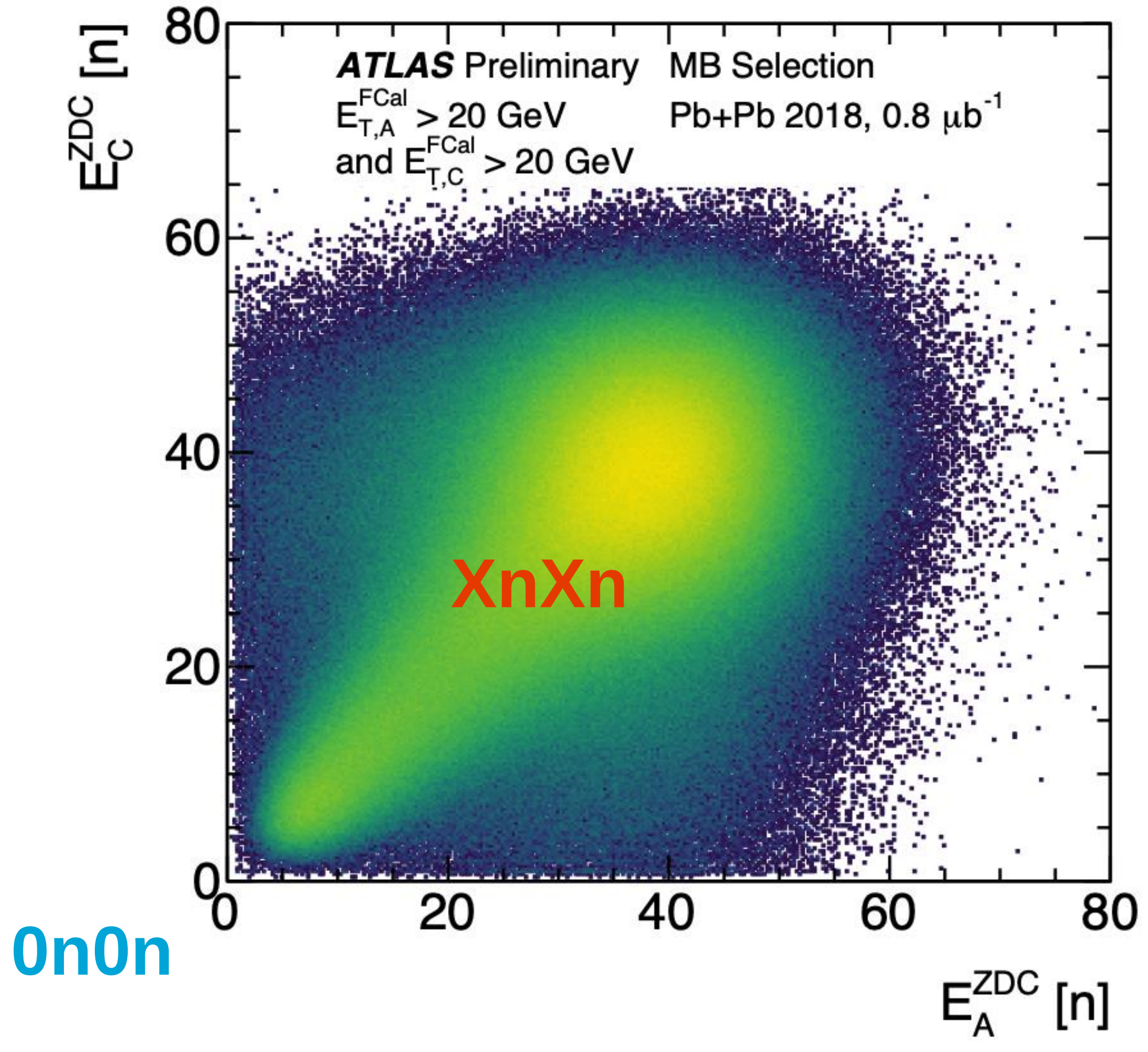


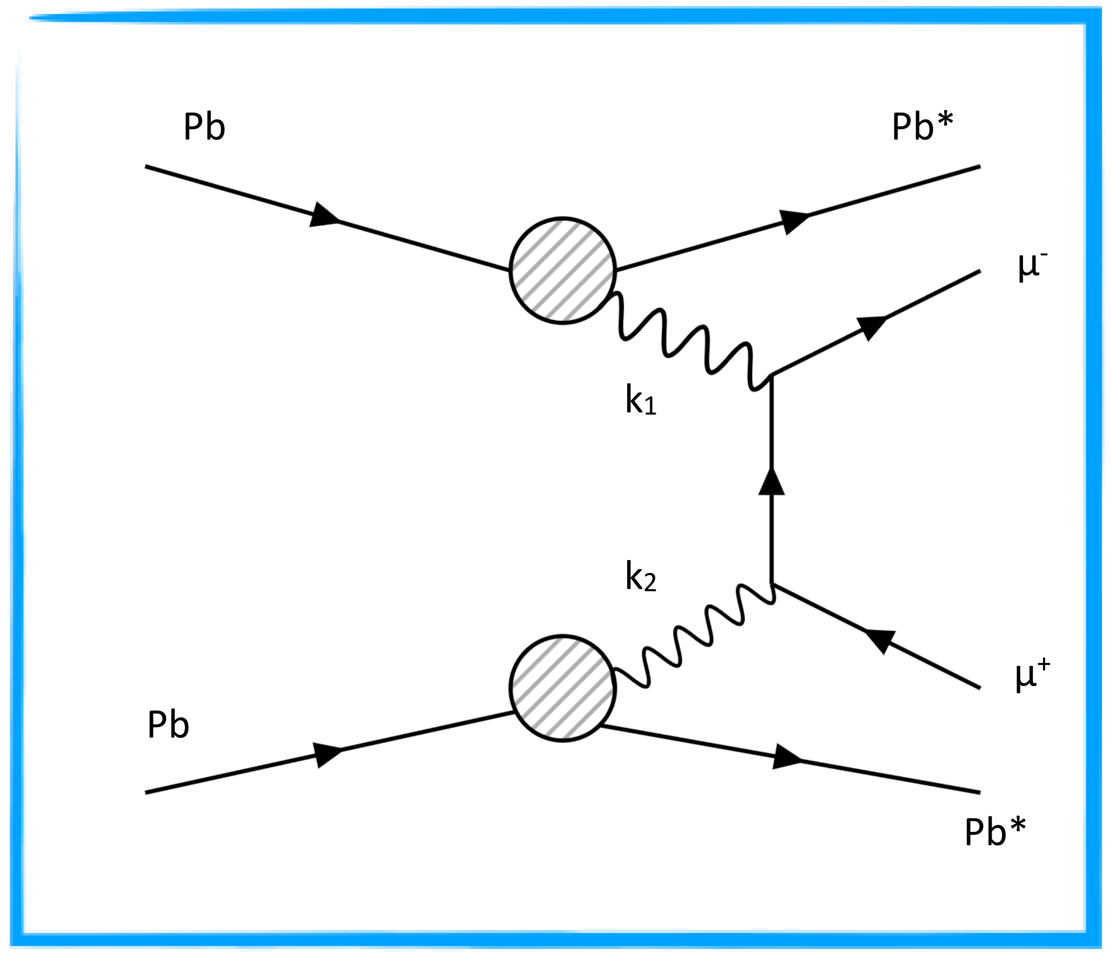
ZDC installation in the TAN
August 2023

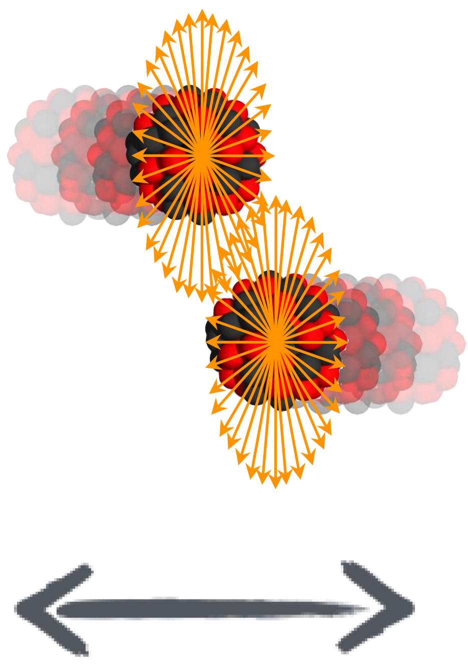
ZDC AS PRIMARY PROCESS TAGGER

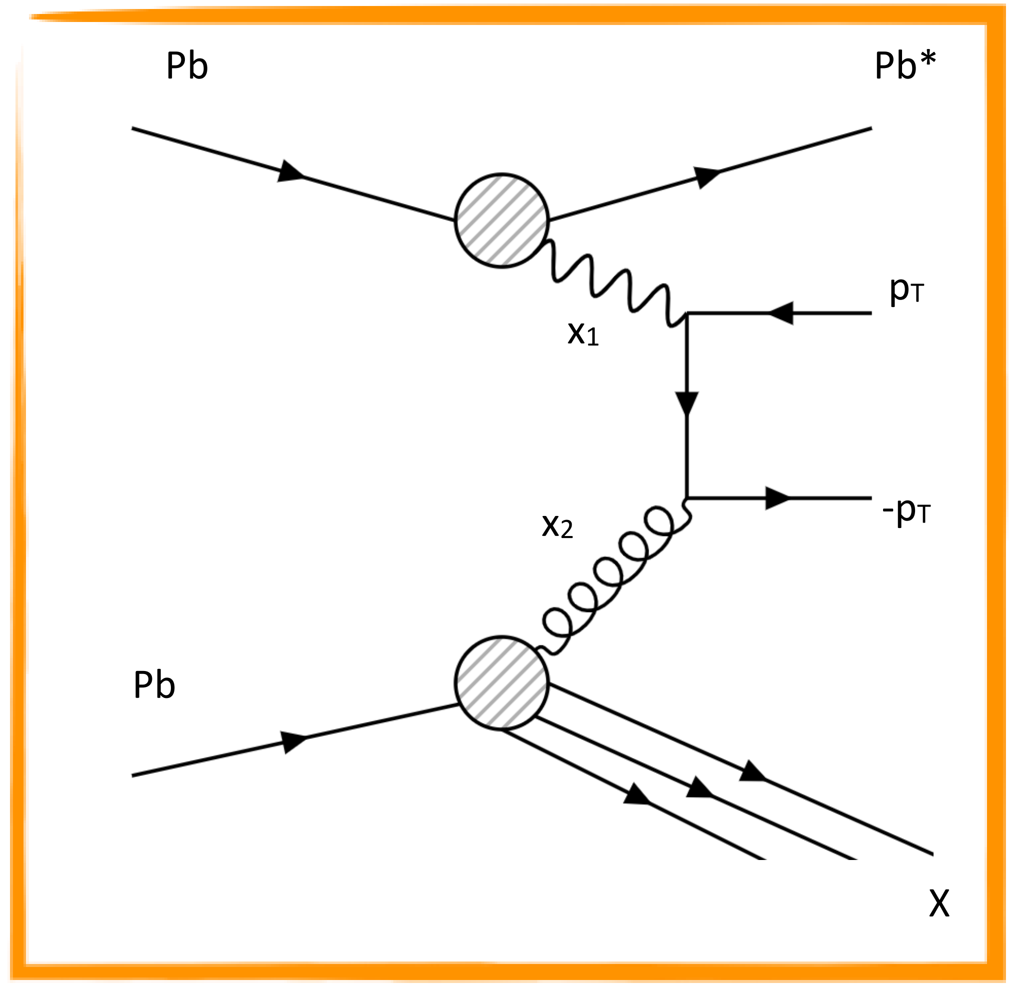
- By counting **spectator neutrons,** the **ZDC** can infer the type of interaction between the ions and the geometry of the collision
  - No neutrons on either side ("0n0n") is typically from γ-γ processes
  - Neutrons only on one side ("Xn0n"/"0nXn") is typically from photonuclear processes
  - Neutrons on both sides ("XnXn") typically come from spectators in hadronic processes

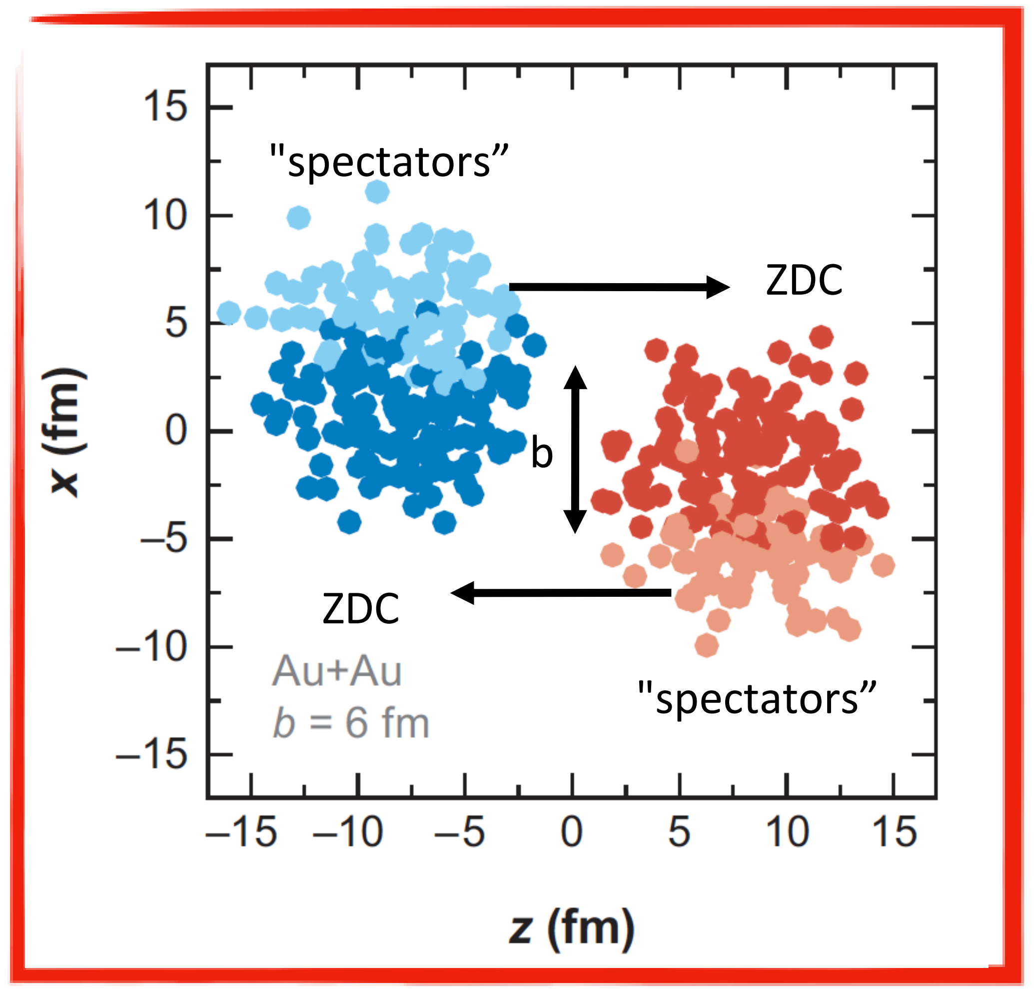


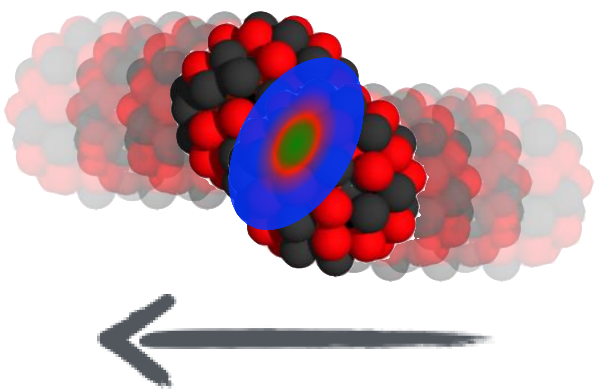






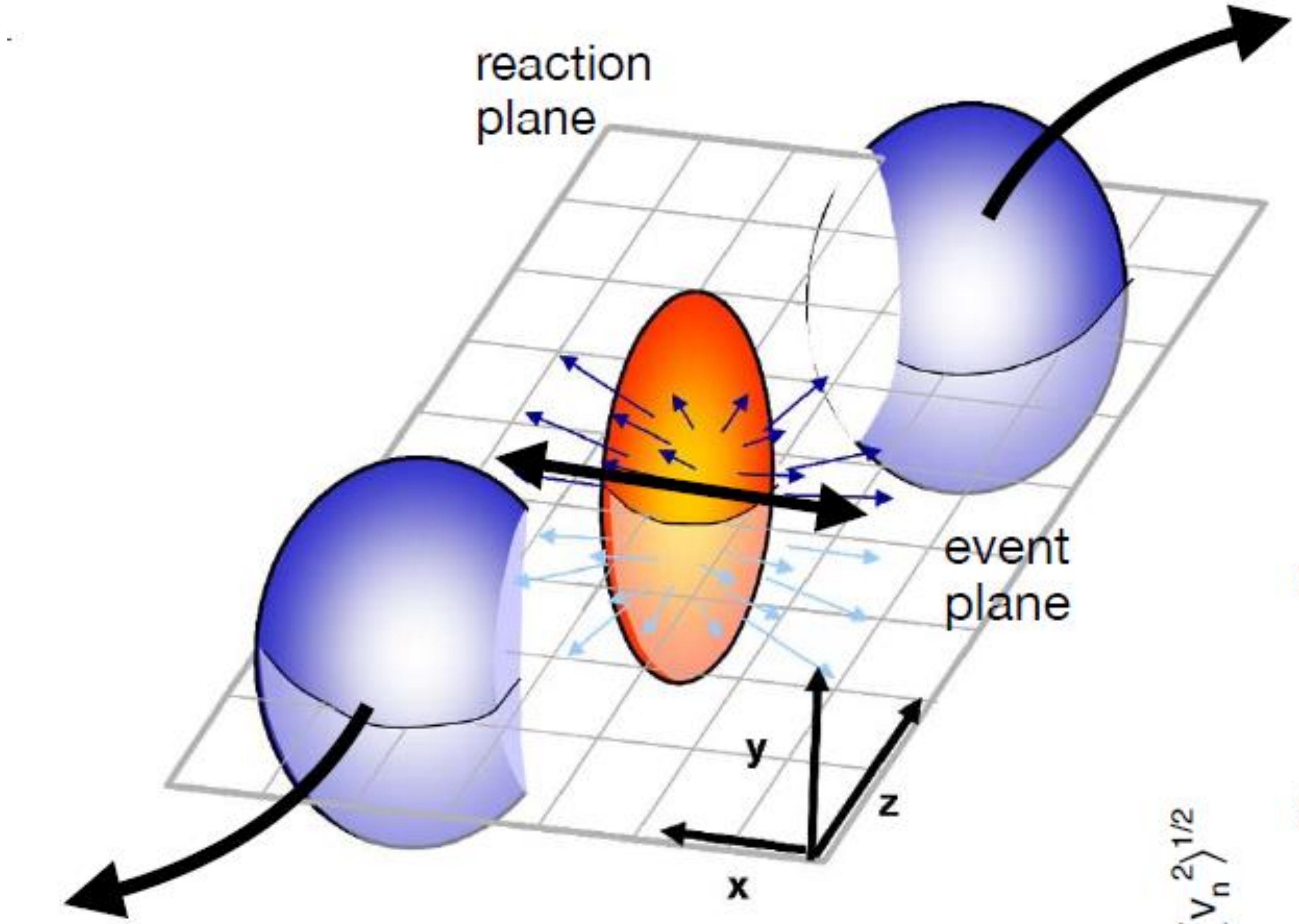


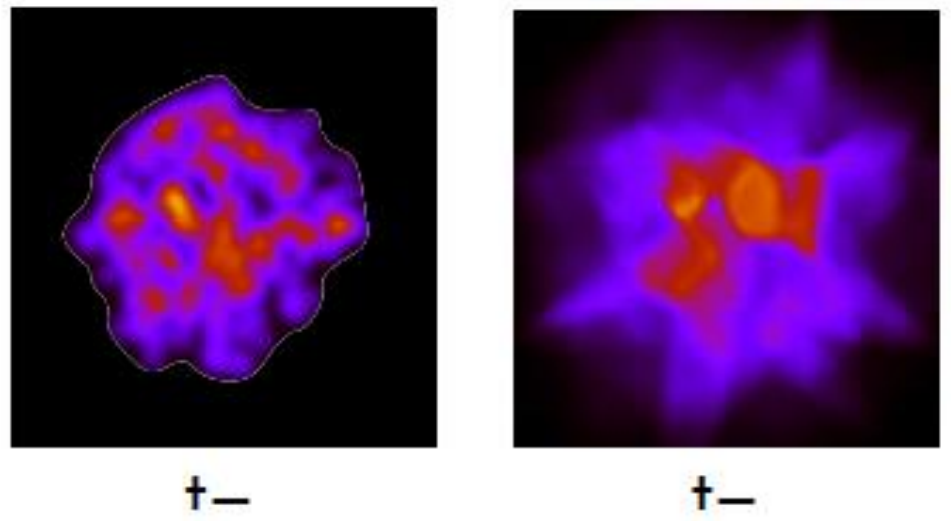


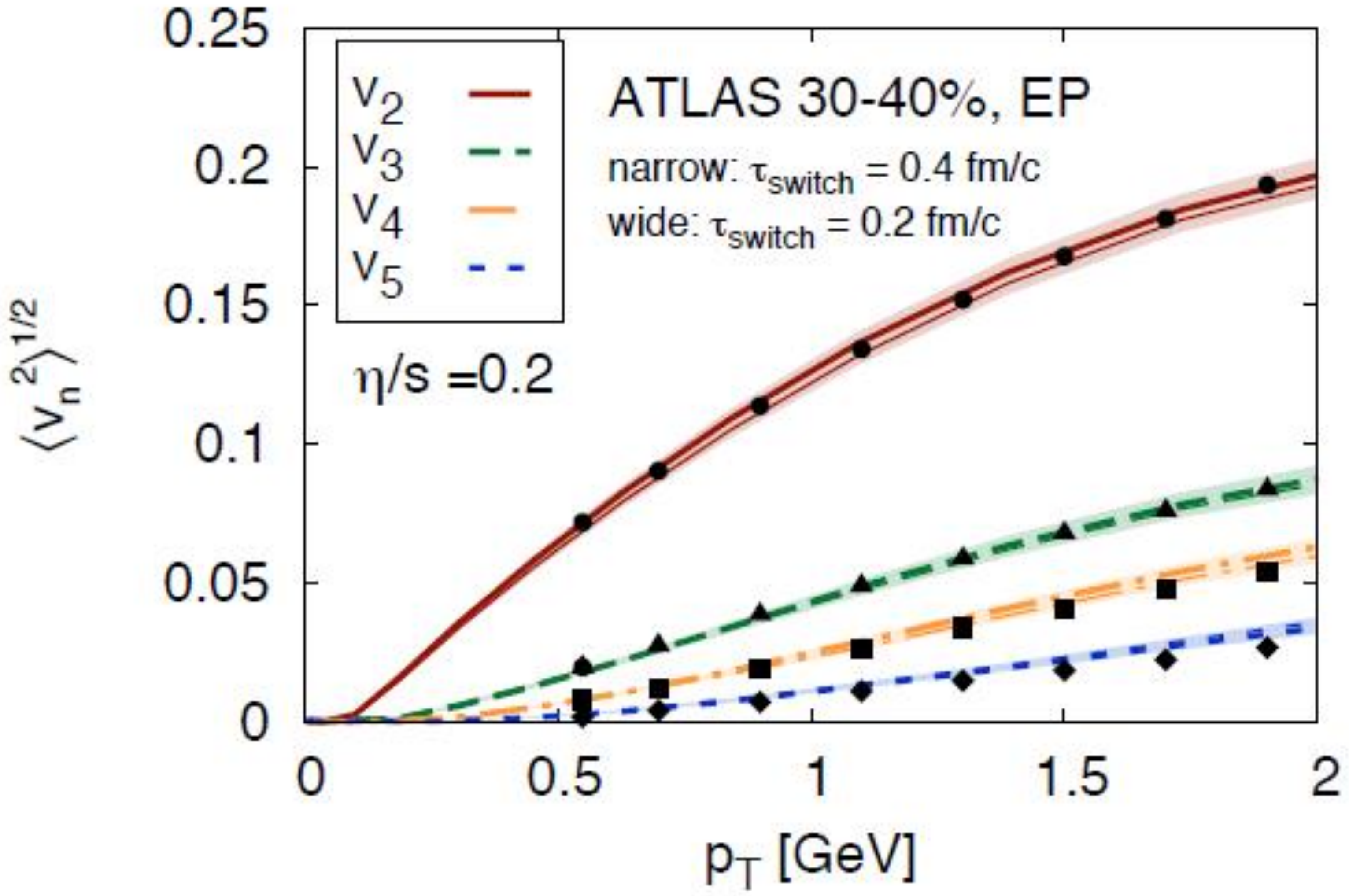


[Ann. Rev. Nucl. Part. Sci. 57 (2007) 205]

REACTION PLANE DETECTOR, RPD, IN THE ZDC







Gale et al, PRL 110 (2012) 012032

Heavy ion collisions (and pp and p+Pb) show strong evidence for hydrodynamic evolution in the final state, observed with Fourier coefficients of azimuthal distributions v_n relative to “event plane” (defined by angle of maximum particle emission)

Measuring v_1 (“directed flow”) is difficult without a direct measurement of the “reaction plane”: available using correlated deflection of neutrons (first done at LHC by ALICE in 2015)

12

ZERO DEGREE CALORIMETERS + RPDS

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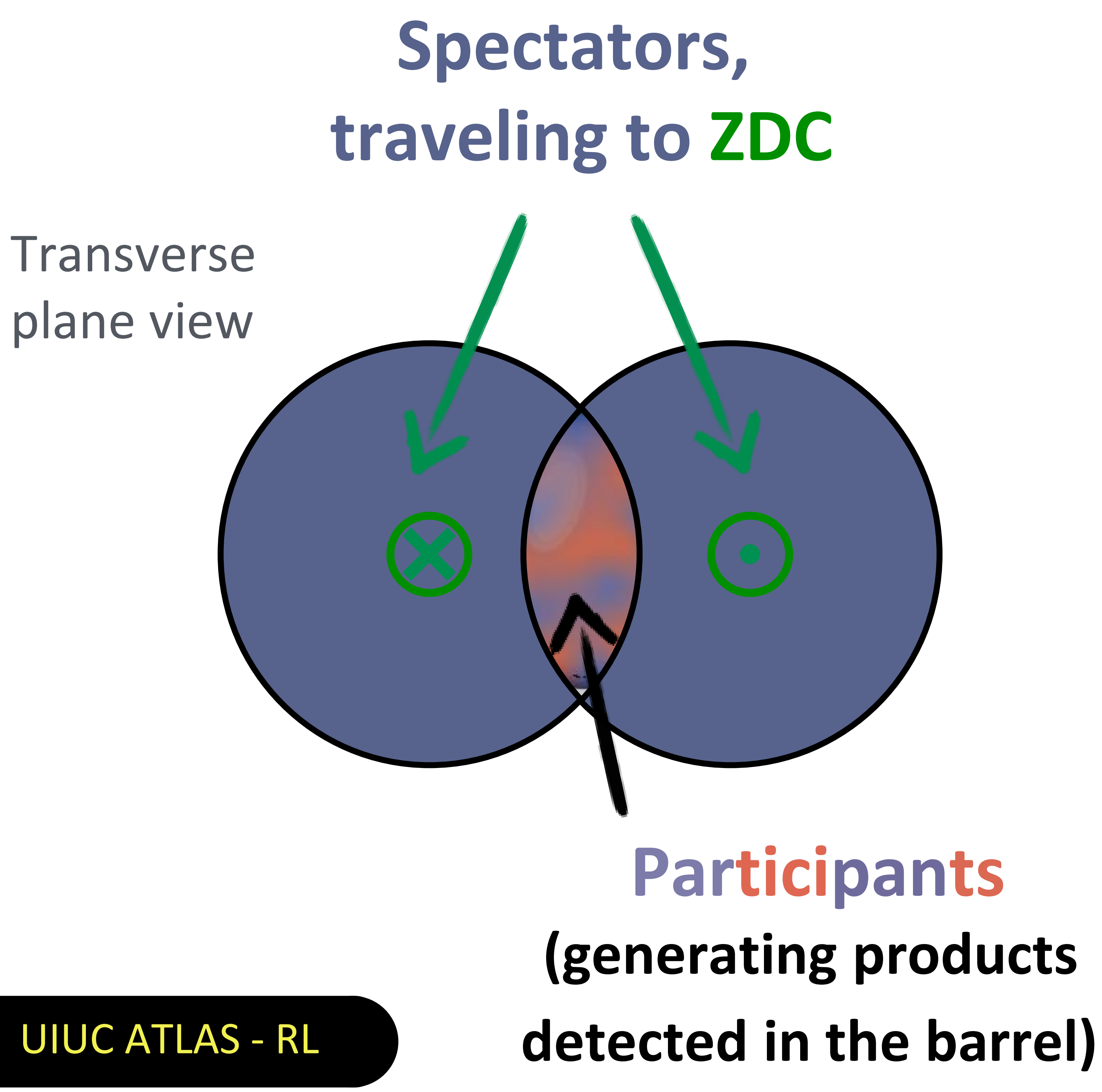

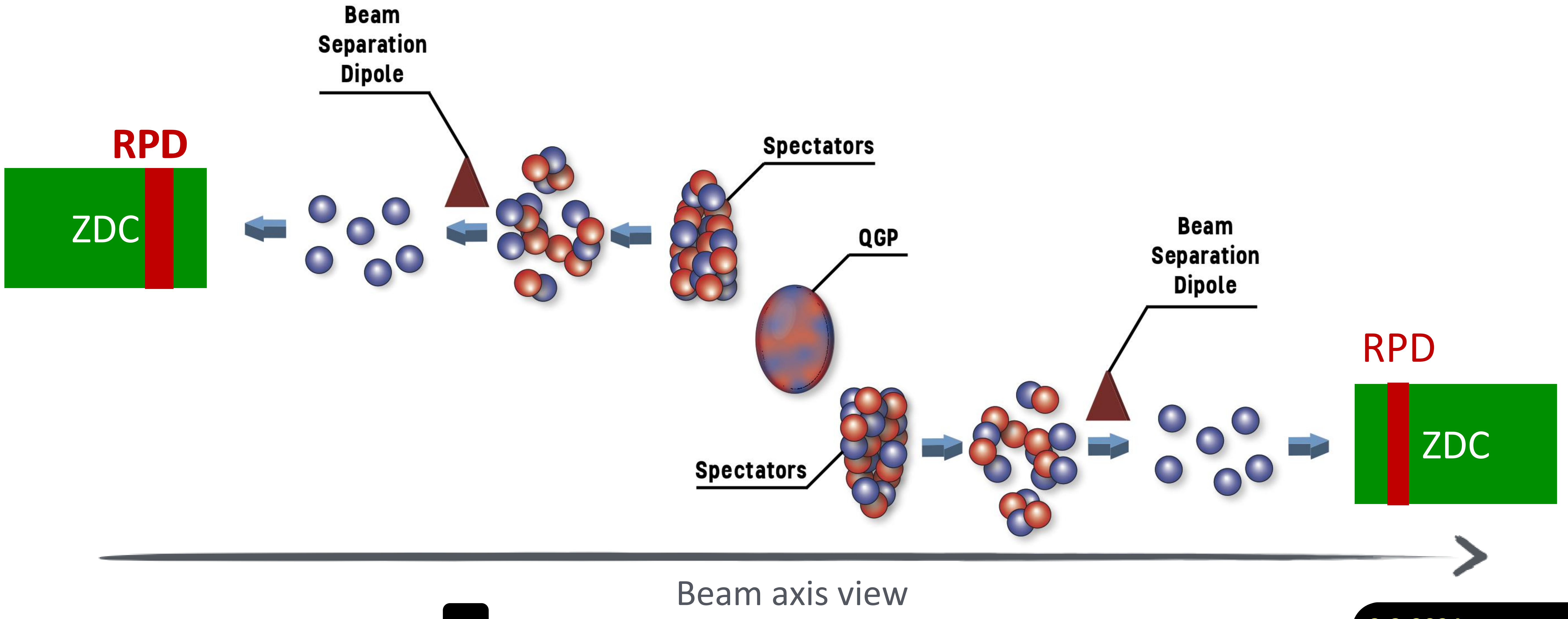

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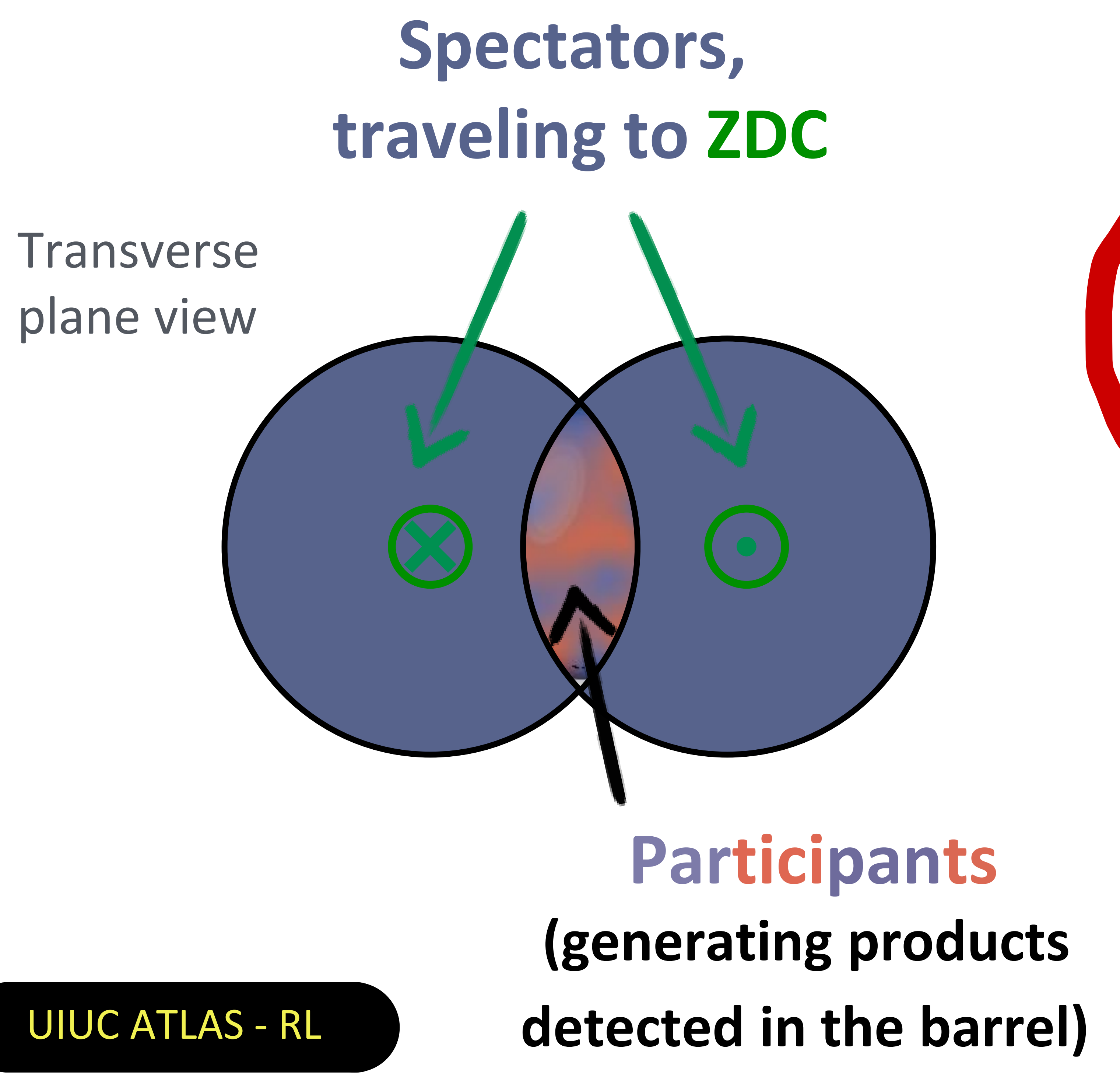
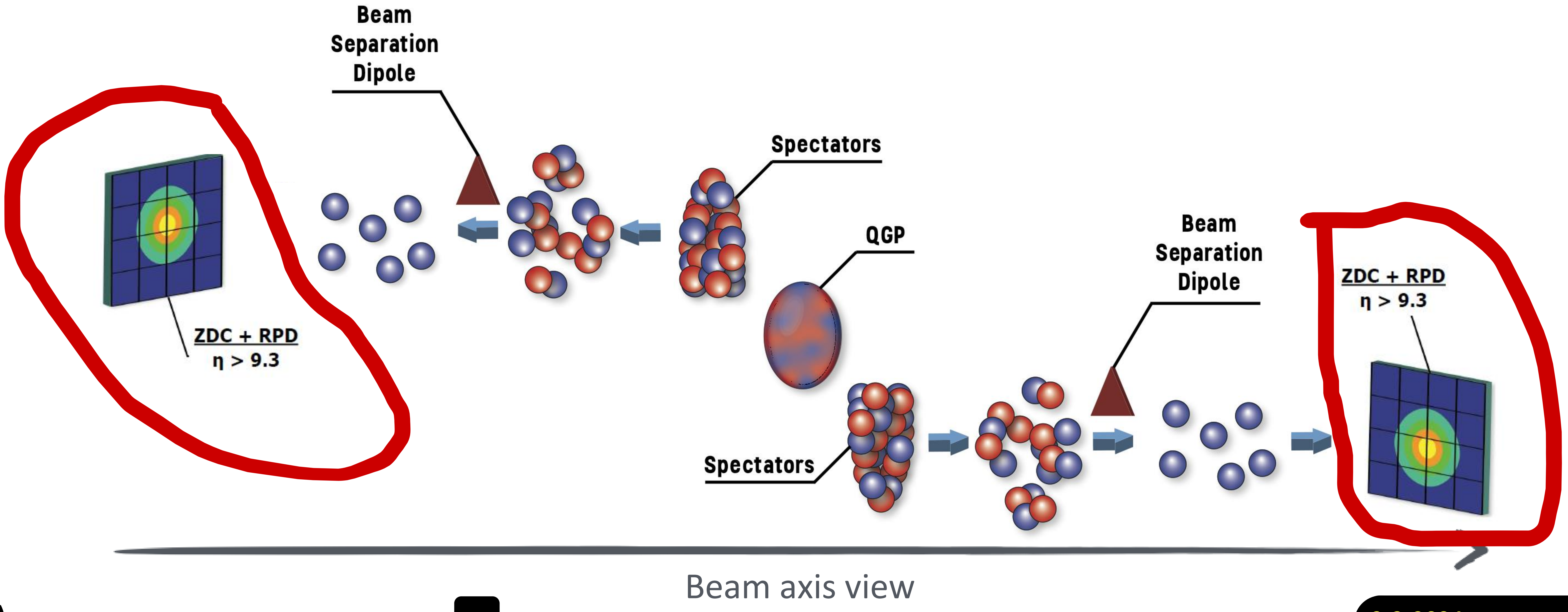
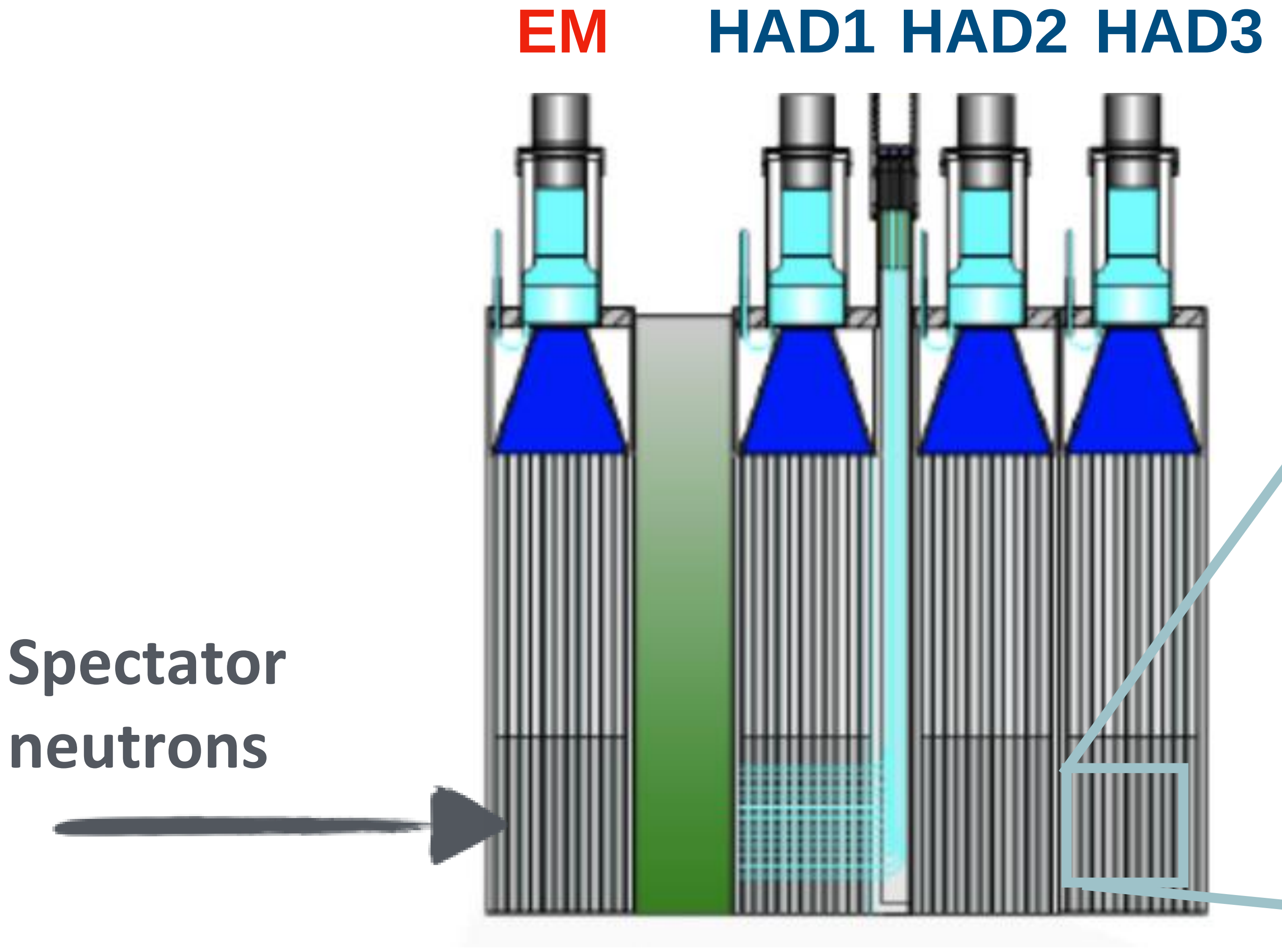
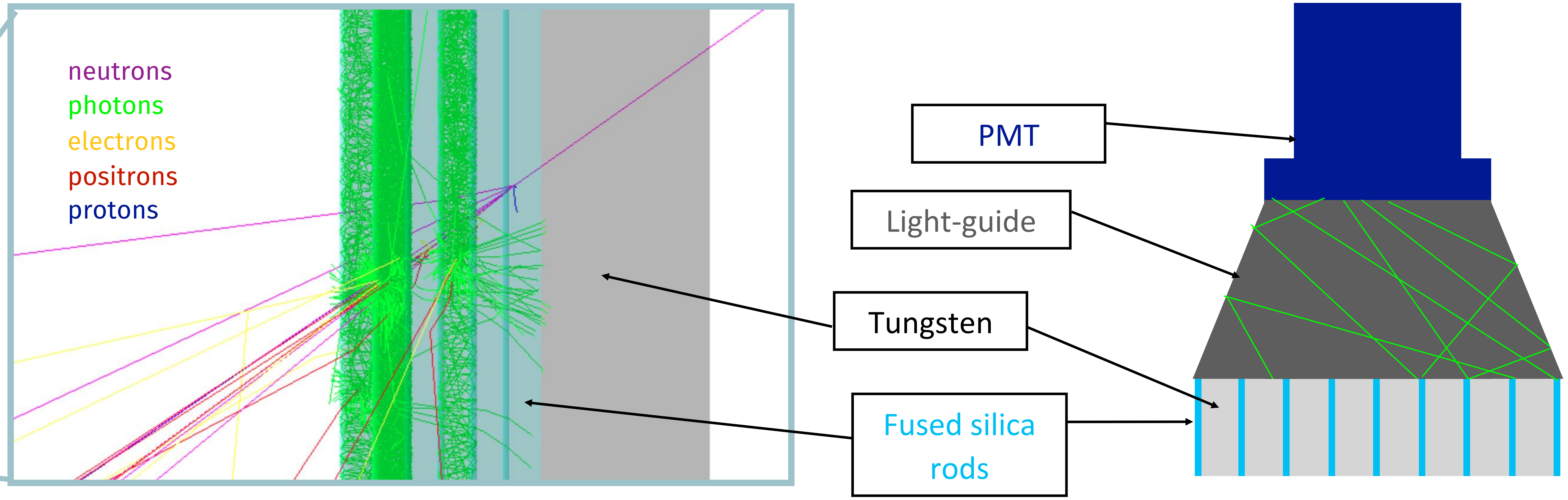




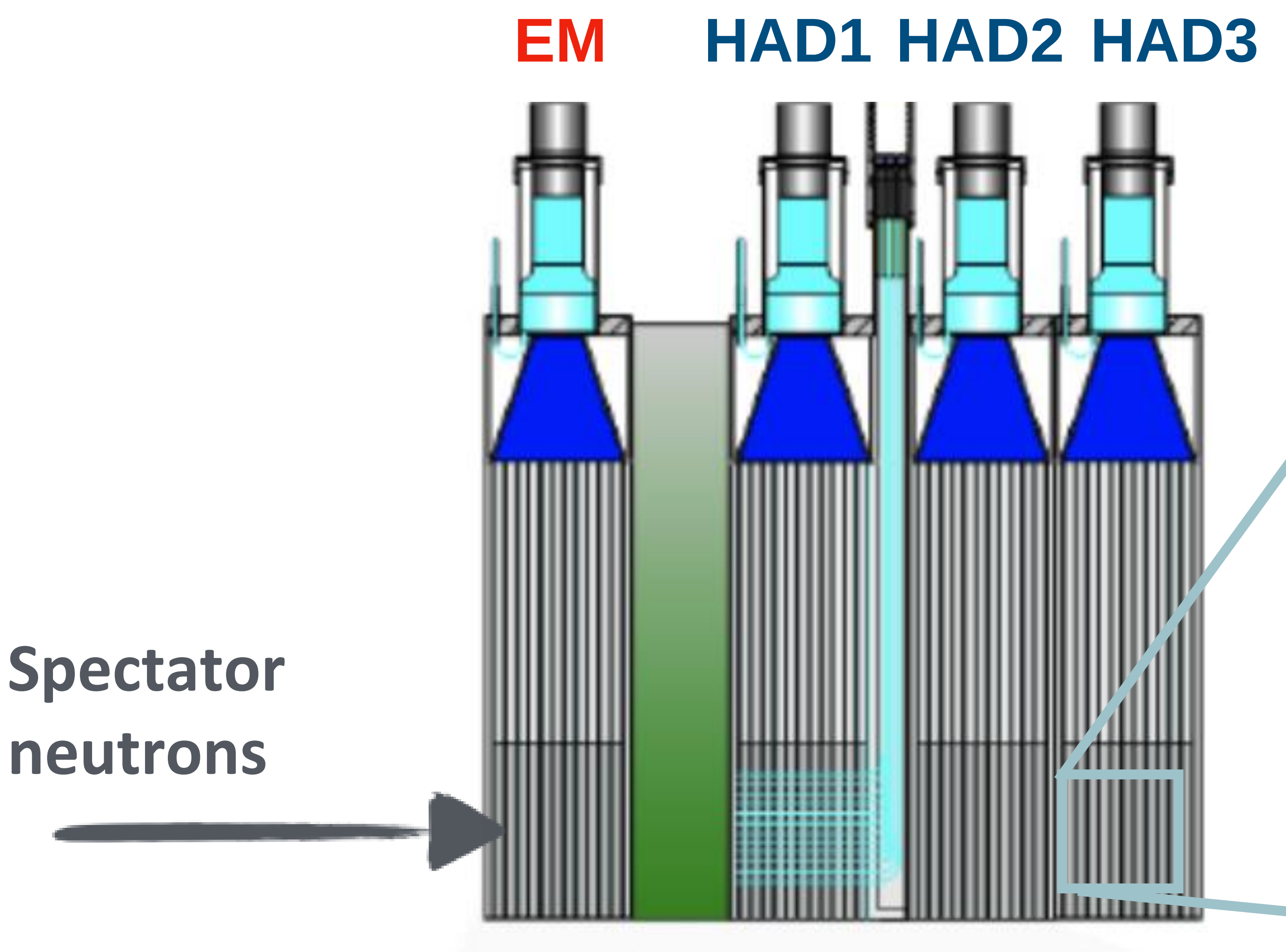
ZDC: FROM NEUTRON TO ELECTRICAL SIGNAL

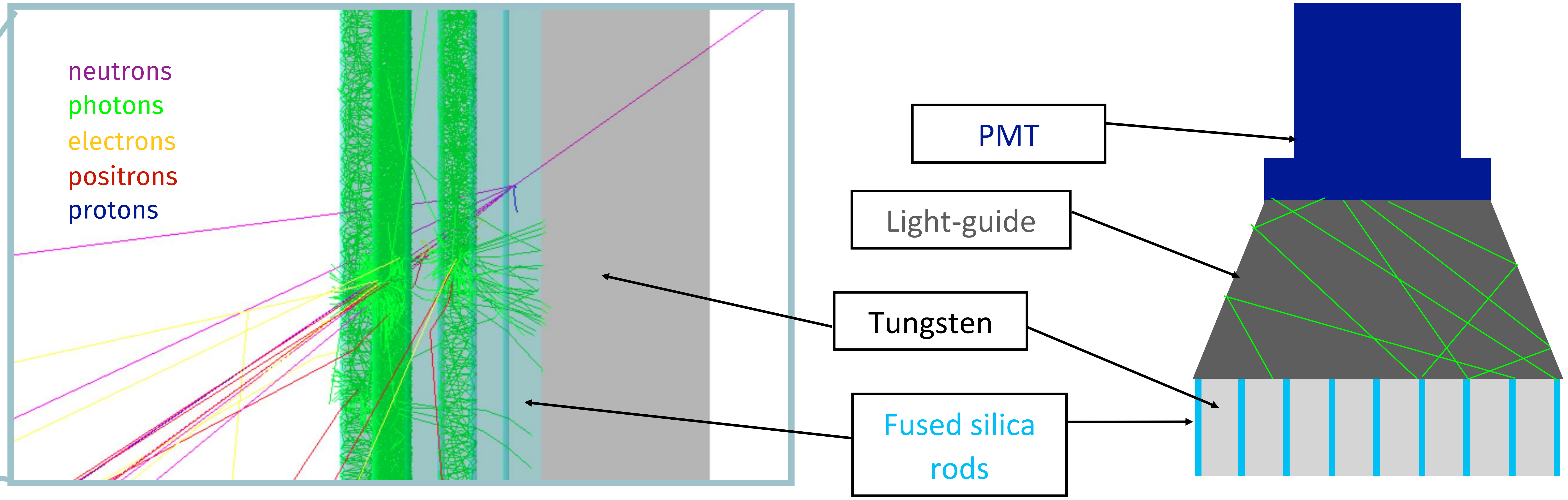




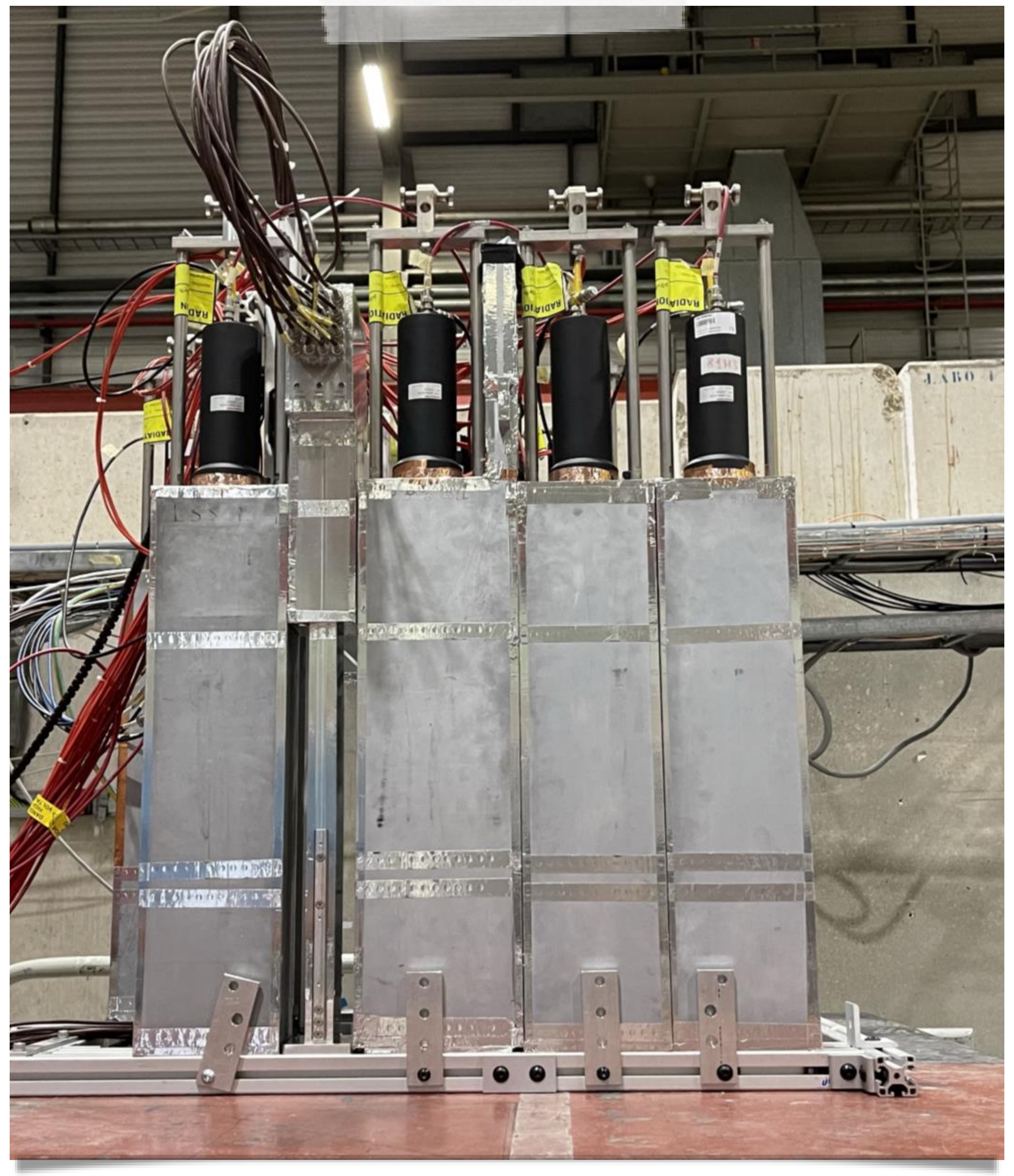
- The W absorber smashes the neutrons - generating a high-energy particle shower
- The charged fraction of the shower generates Cherenkov light in the fused-silica rods
- A considerable fraction of the light is retained within the rods by Total Internal Reflection (TIR) and travels towards the extremities of the rods
- At the top of the rods, the light is injected into an air-light guide, that focuses it over a PMT window → the PMT converts the light into an **electrical signal**!

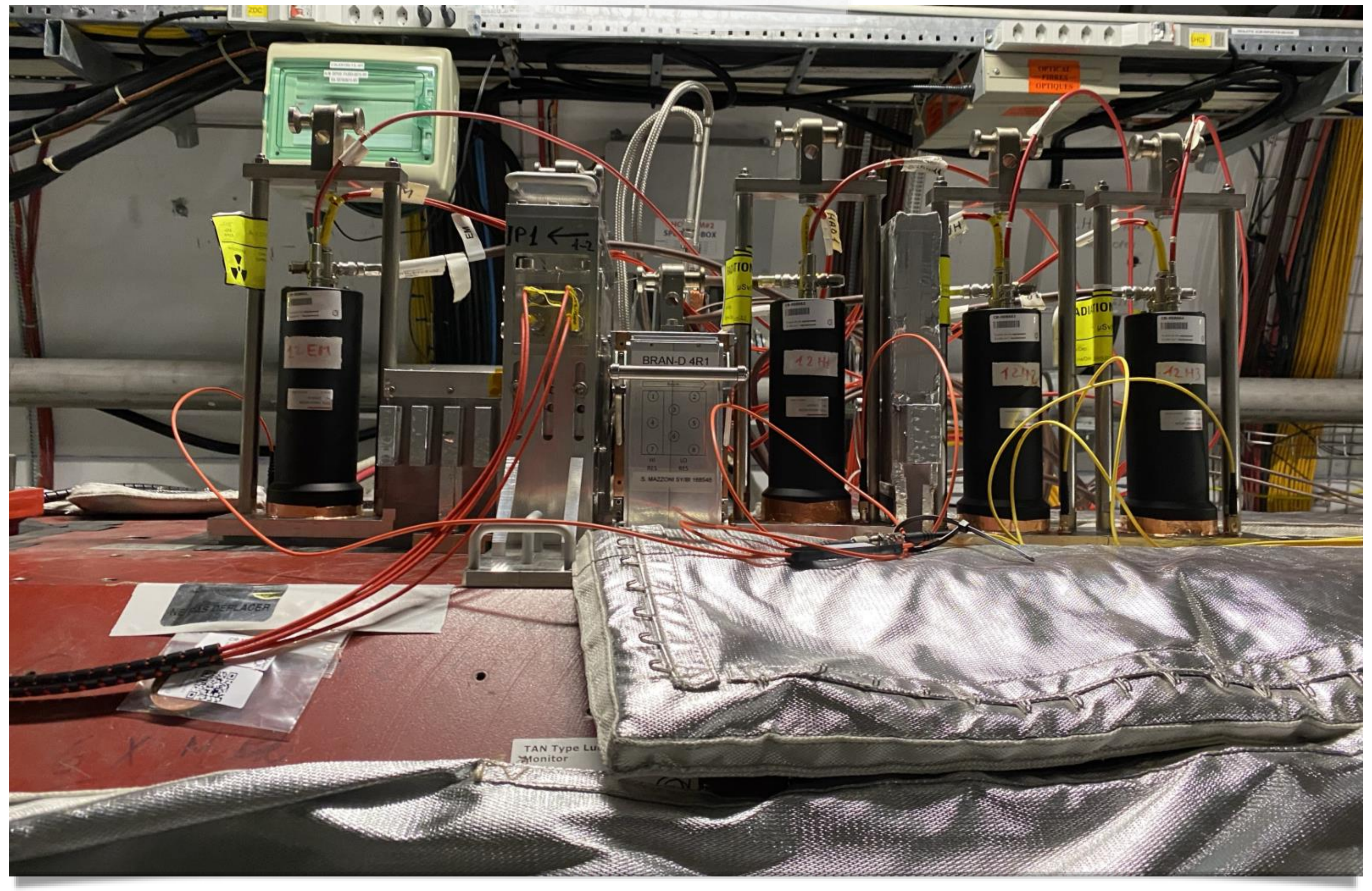
ZDC: FROM NEUTRON TO ELECTRICAL SIGNAL





ZDC @ CERN SPS Test Beam, this summer





ZDC installed in the LHC - 1 month ago!

- Why a Cherenkov radiation and not directly a detector? With the TAN **radiation environment**, a PMT would not survive too close to the detector core

REACTION PLANE DETECTOR, RPD

ATLAS Run 3 RPD – Sheng Yang (NPRE+Physics)

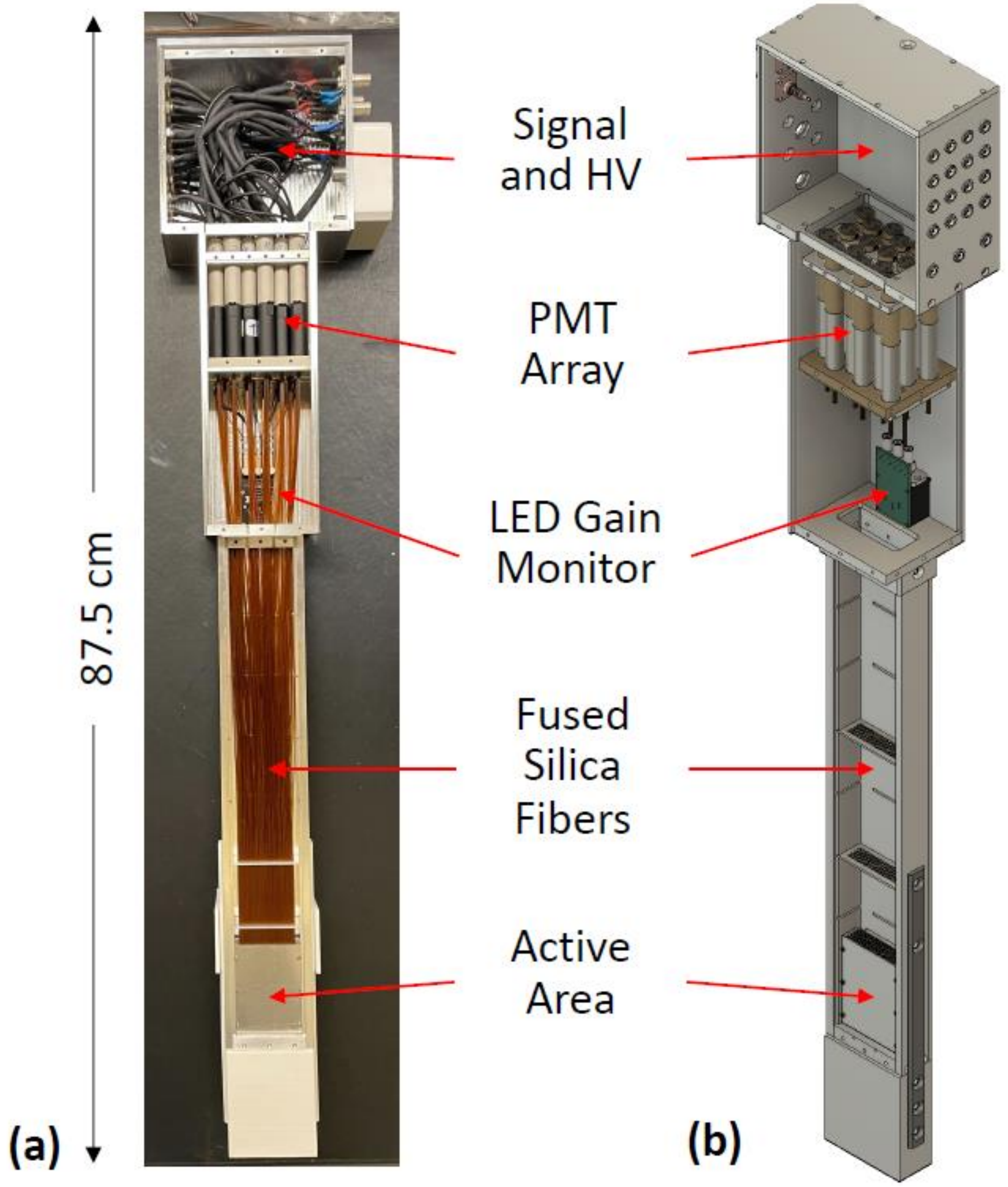
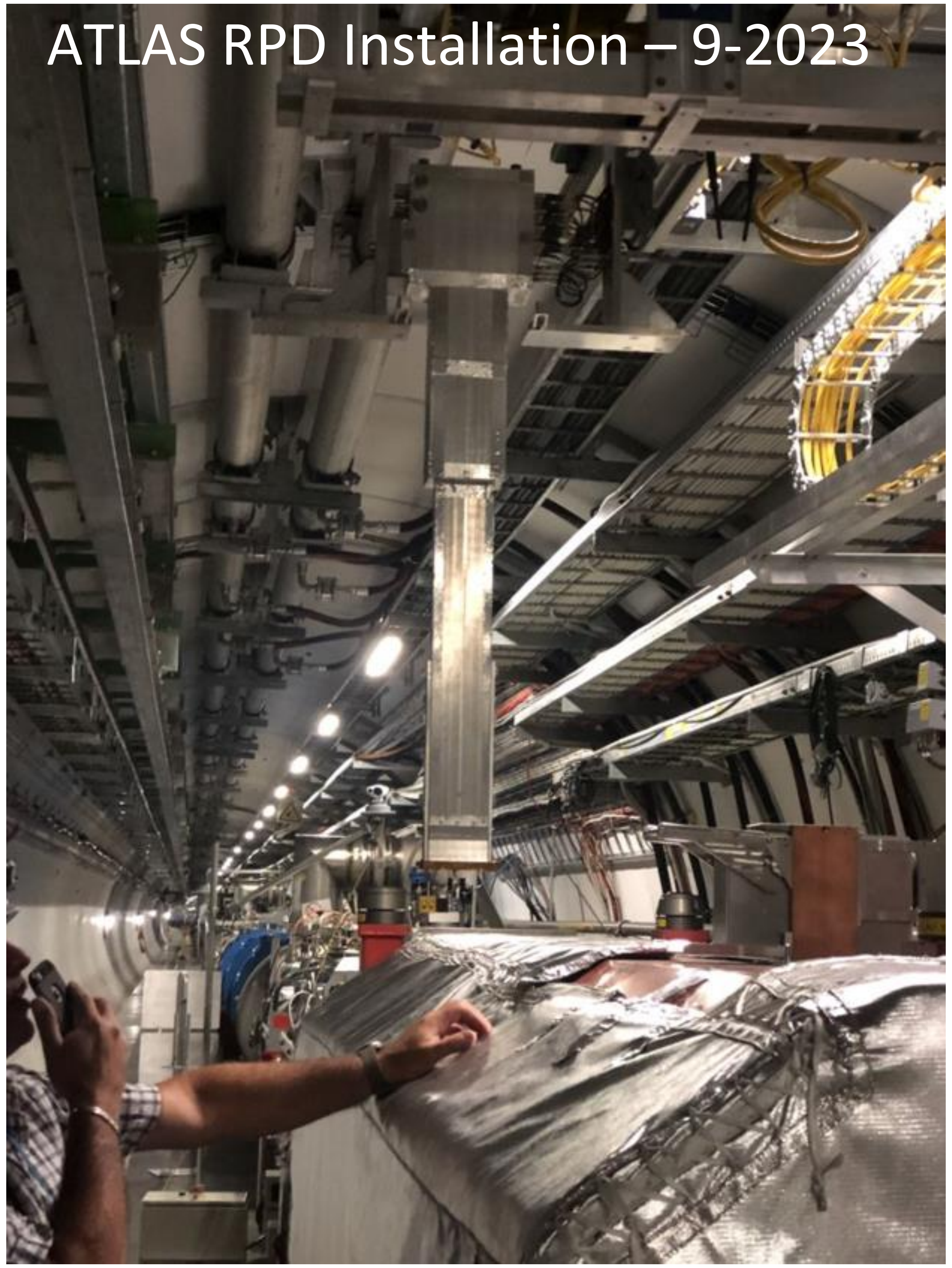


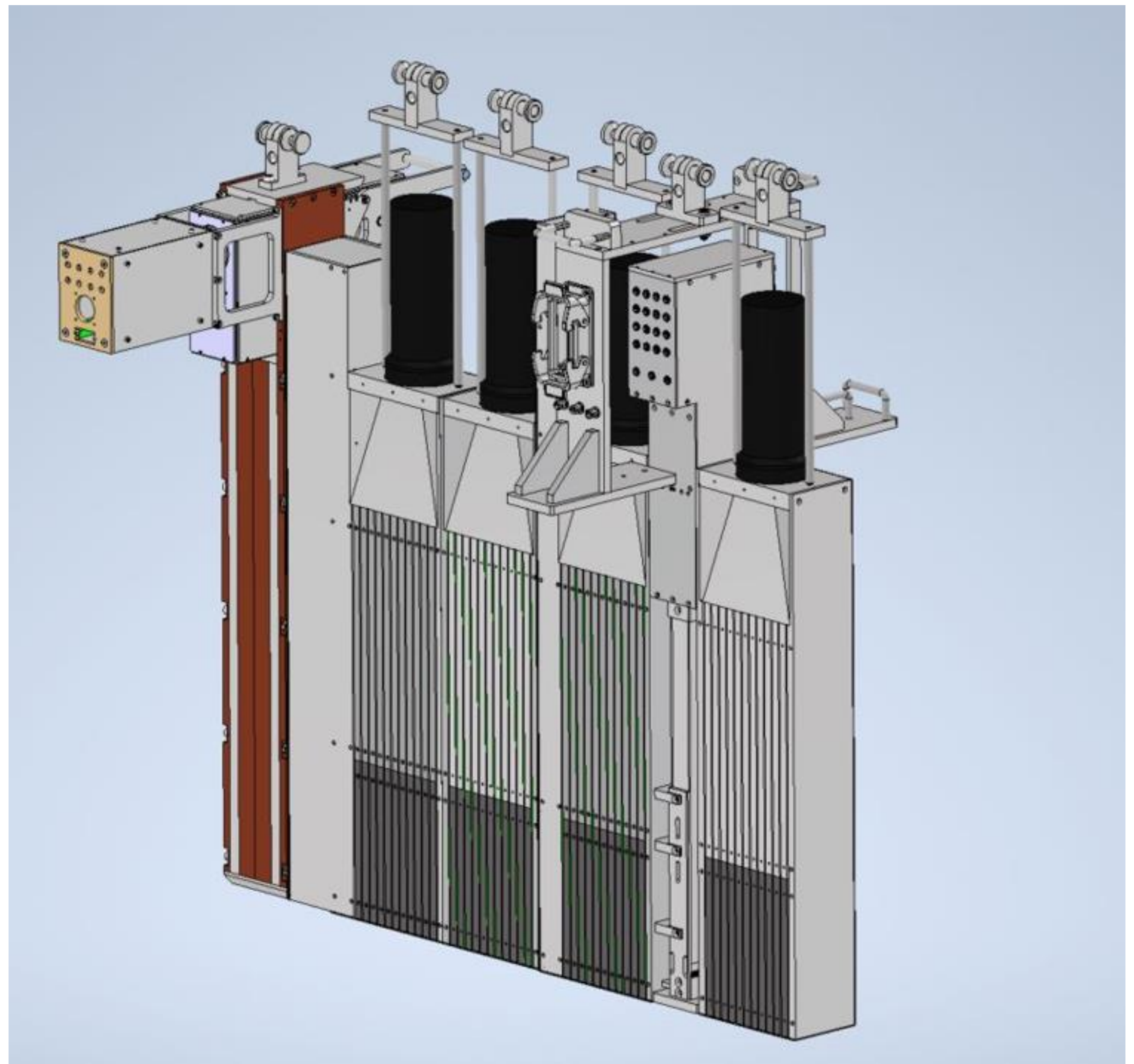
Figure 2.17: Side-by-side diagram of the finalized ATLAS RPD for Run 3 (a) and the corresponding technical drawing (b). Note that the front panel was removed for demonstration. Taken from [39]

ATLAS RPD Installation – 9-2023

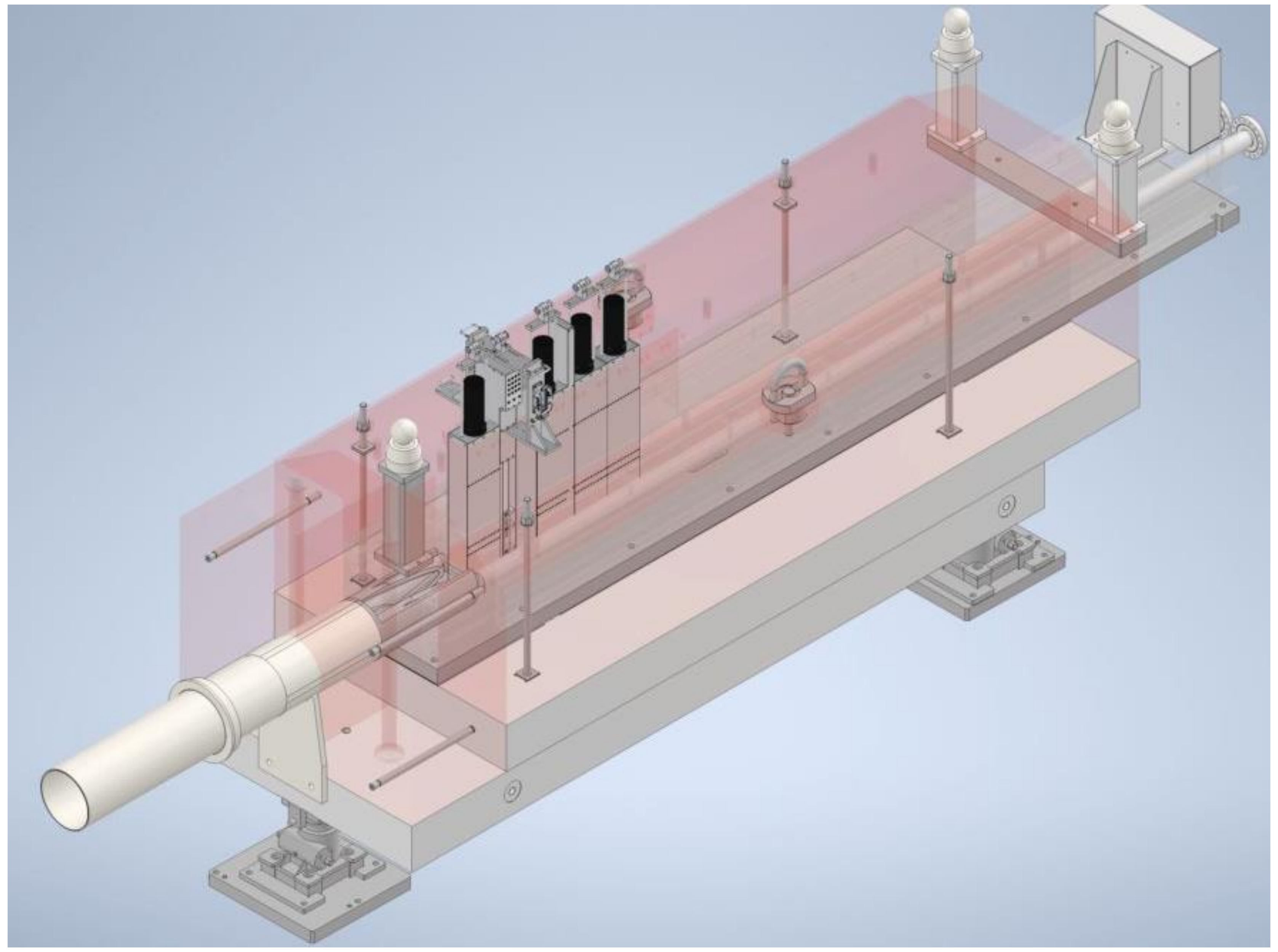


INTEGRATED RPD + ZDC IN ATLAS RUN 3

ATLAS Run 3 ZDC+RPD

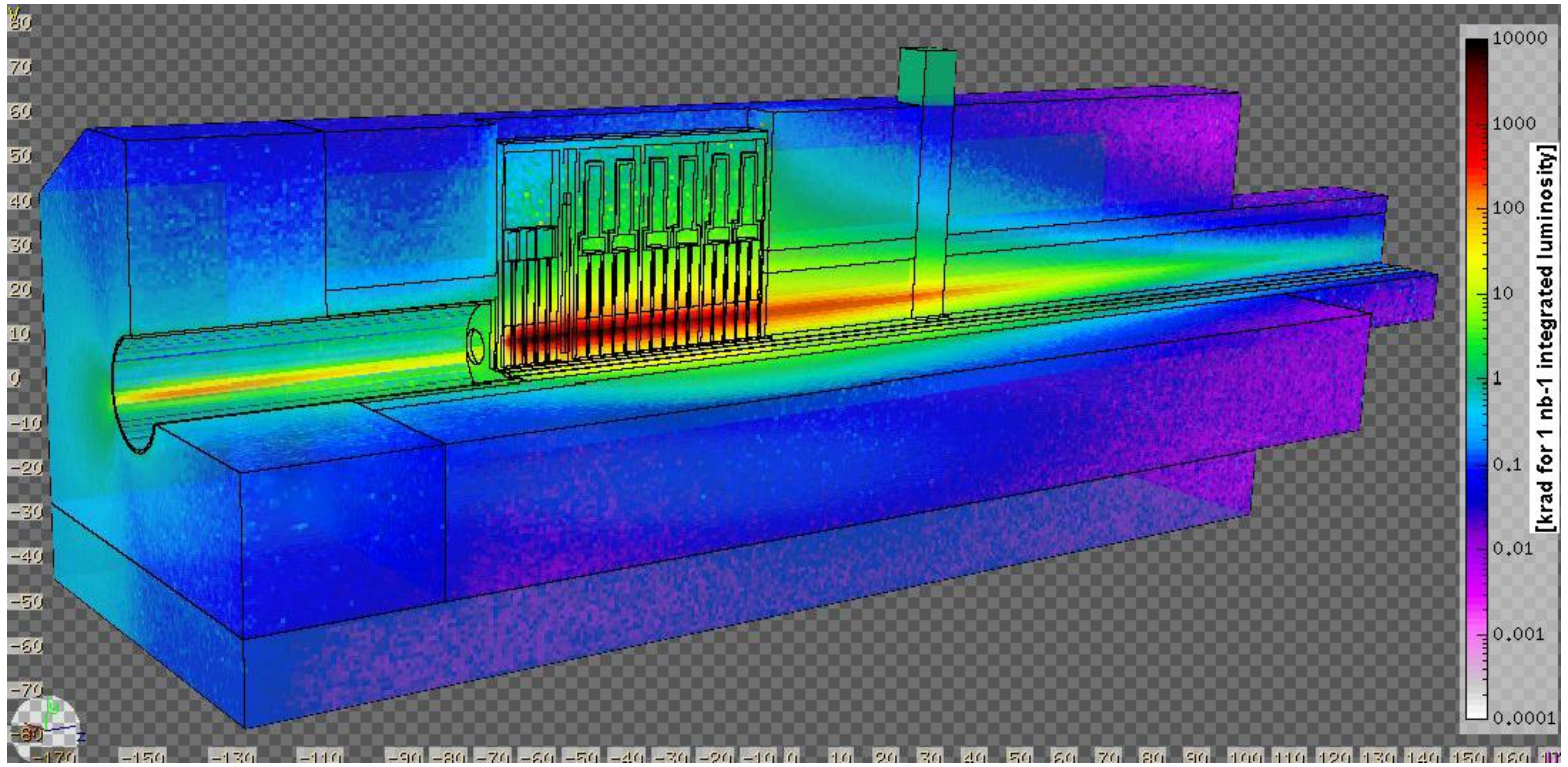


ZDC+RPD in TAN



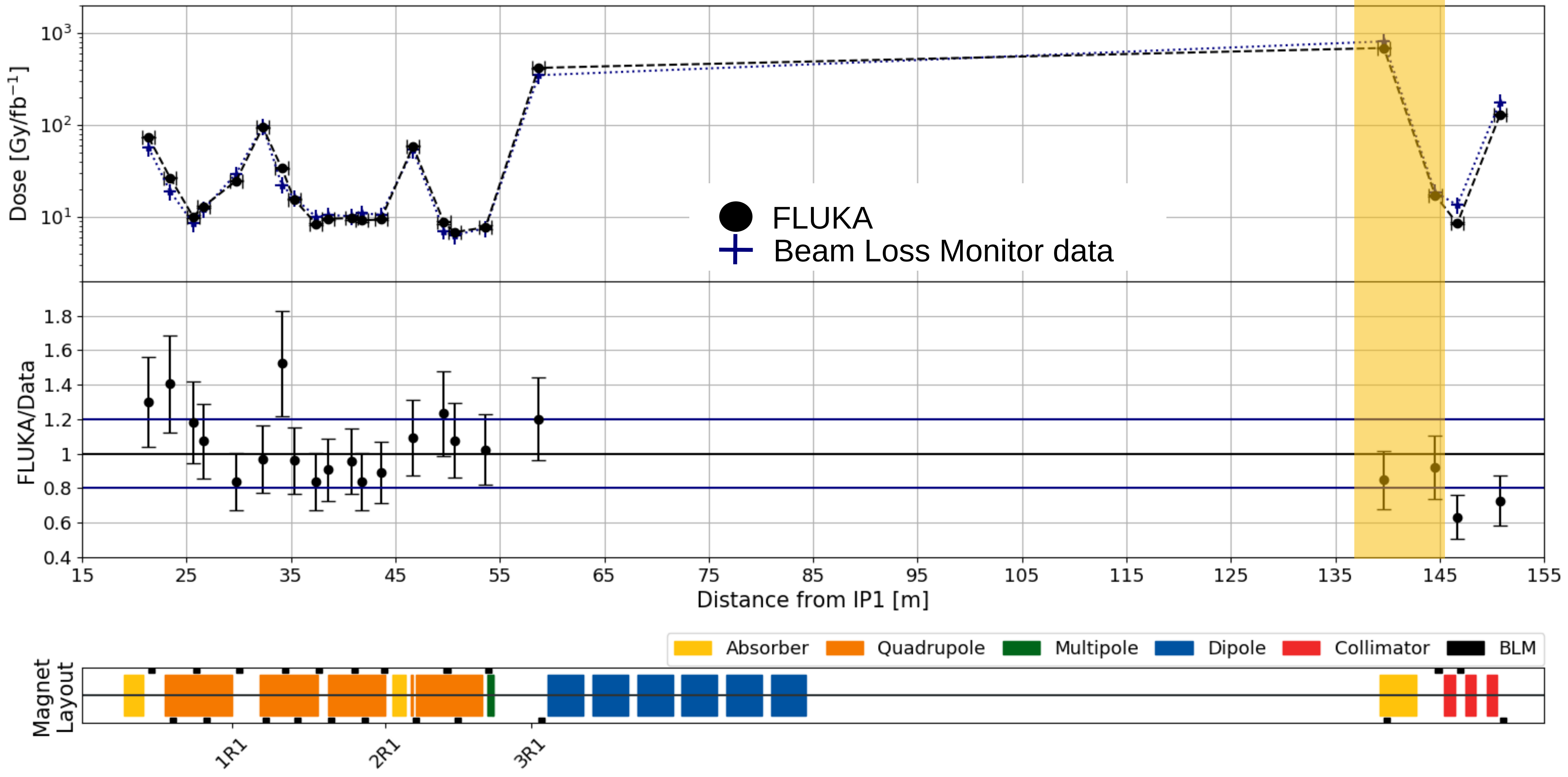
ZDC+RPD Installation

ZDC CHALLENGES: RADIATION [A LOT OF]



- CERN FLUKA team (F.Cerutti, M.S.Gilarte) provides detailed simulations of the radiation environment in the TAN
- Peak radiation load on the ZDC estimated to be of several **5++ MGy !!!**

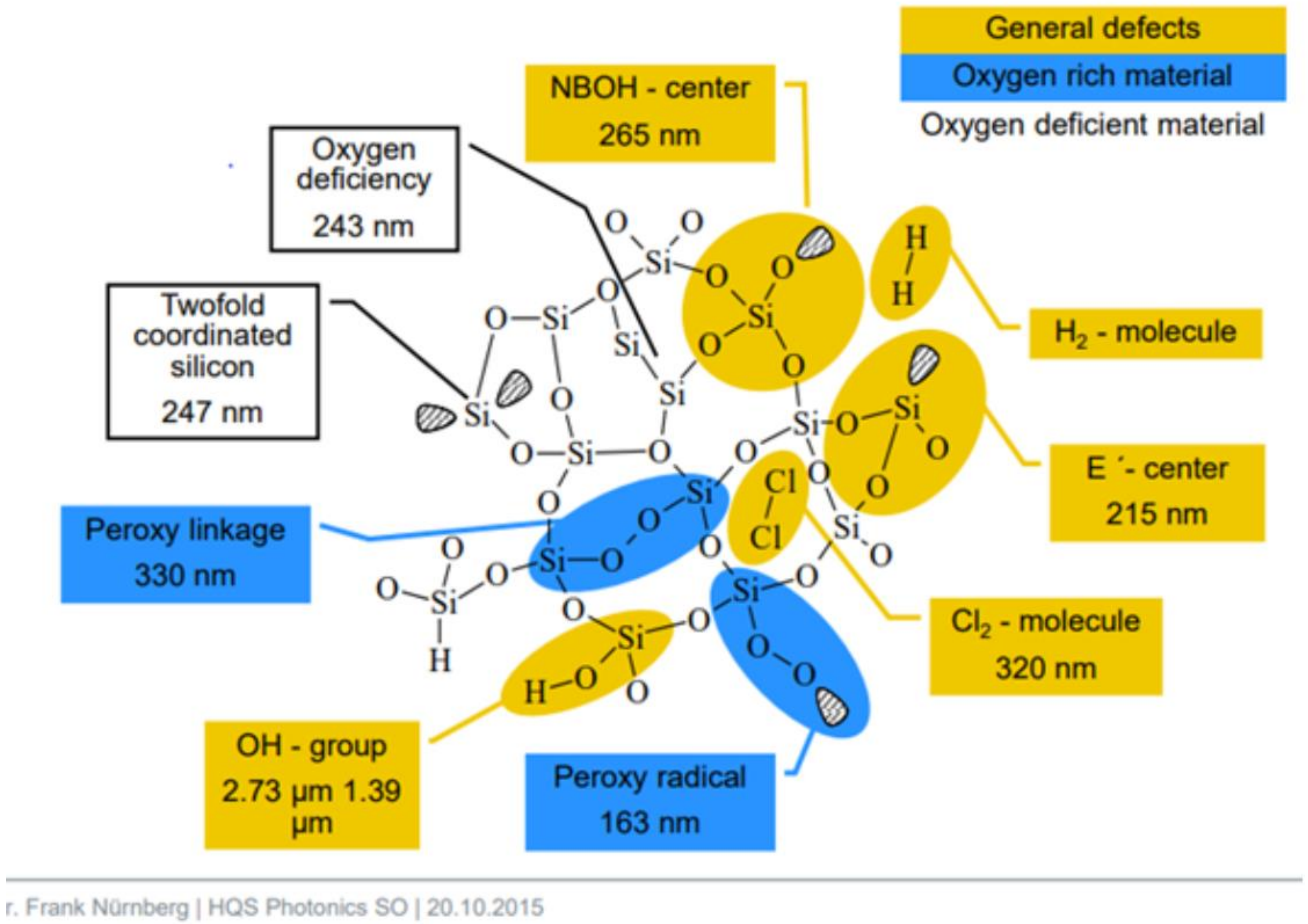
To have stable operation - the zdc needs radiation hard materials



[Phys. Rev. Accel. Beams 25, 091001 (2022)](), Yang (NPRE grad), Tate (NPRE grad), RL et al

- Benchmark against LHC Beam Loss Monitor data: **FLUKA can describe radiation levels in the LHC tunnel within 20% uncertainty**

RADIATION DAMAGE IN FUSED SILICA



Schematics showing known defects to SiO4 tetrahedral characteristics (courtesy of Frank Nuernberg [Heraeus])

- Increasing number of defects and color centers induced by radiation damage decreases the transmission
- Materials with a high purity level show a lower absorption and a better radiation hardness.
- In the UV region:
    - Saturation of absorbing defects by H_2
    - Decrease in transmittance more pronounced/rapid
- Our results represent the first study of radiation hardness of fused silica exposed to **high energy hadron cocktail**

RADIATION DAMAGE IN FUSED SILICA

from Sheng Yang's thesis

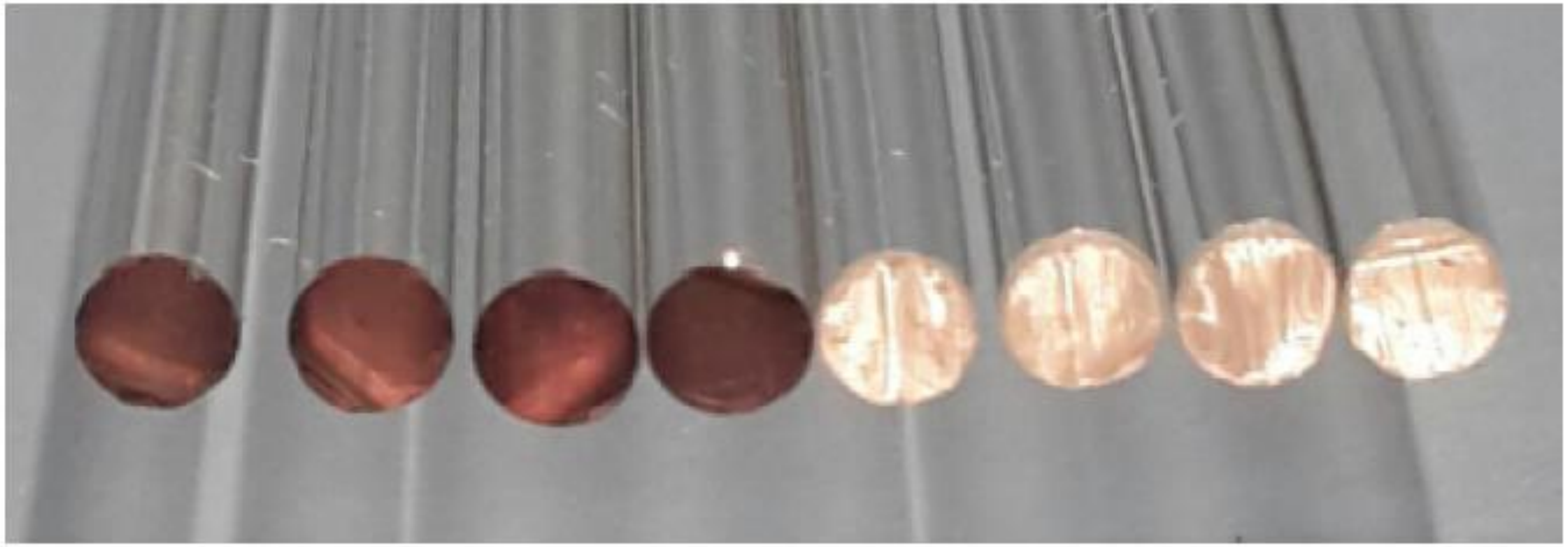
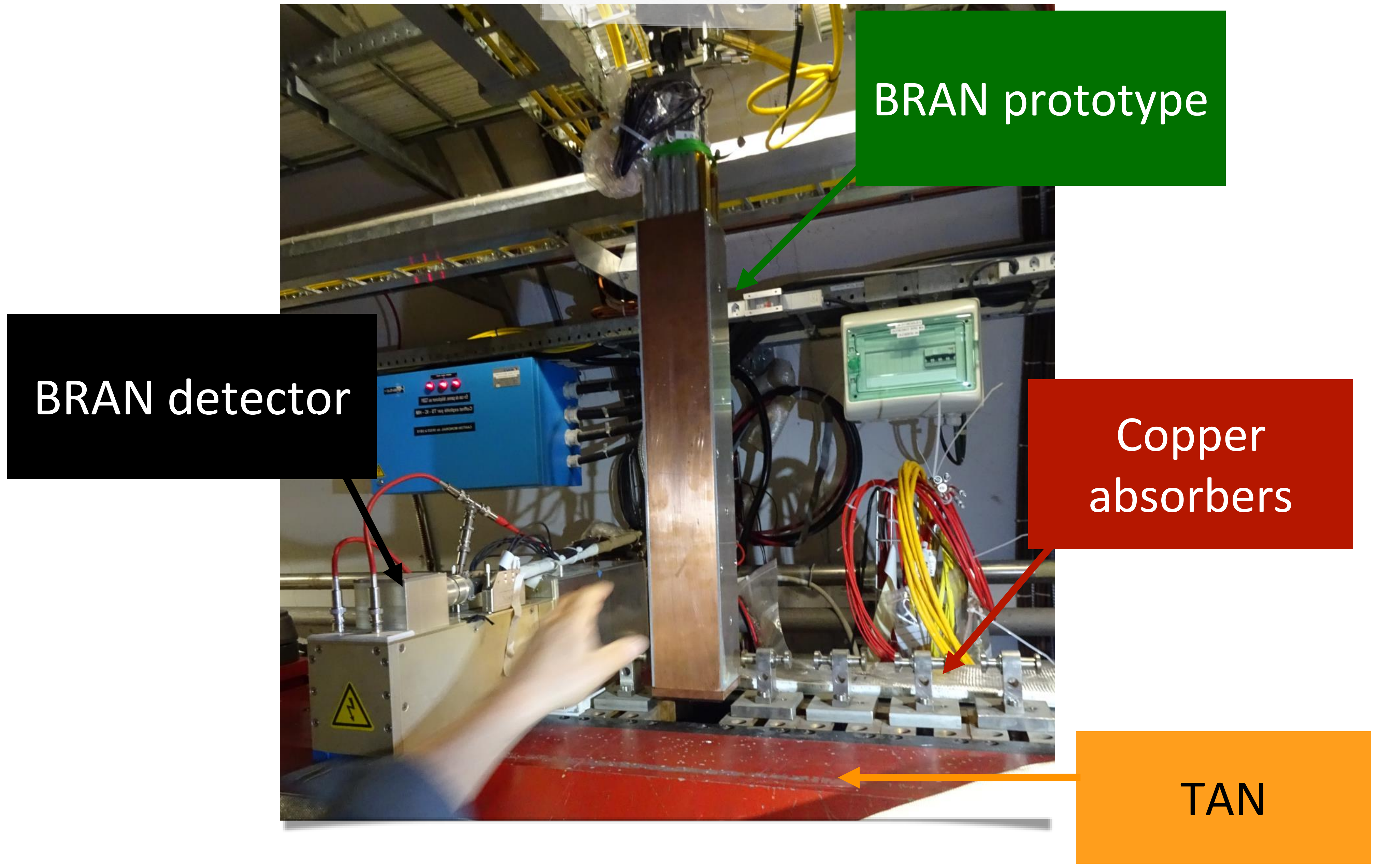


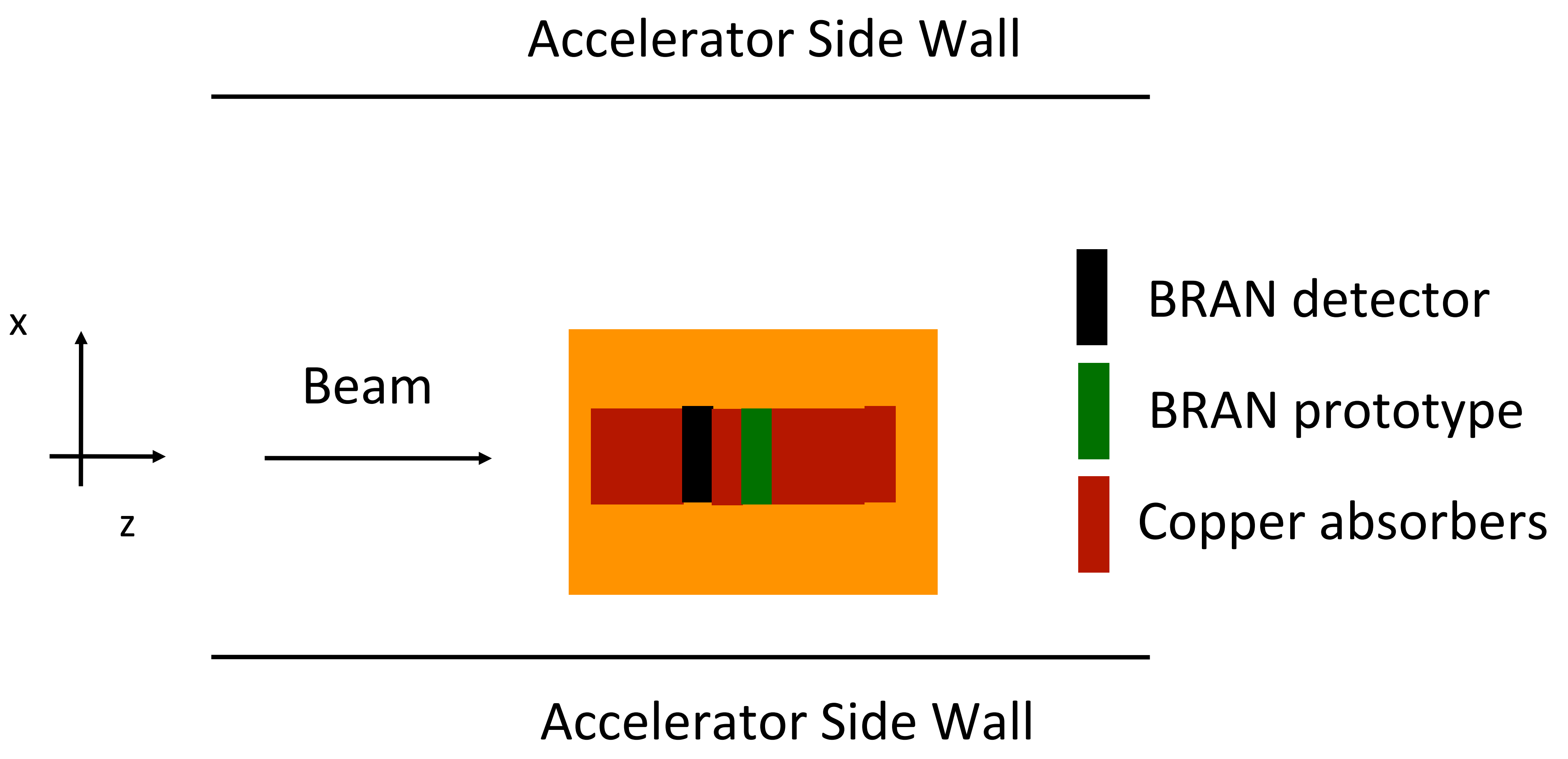
Figure 2.18: Comparison between brand new GE214 [41] fused quartz rods (right) and the same type of rods irradiated in the LHC during Run 1 (∼ 10 MGy, left).

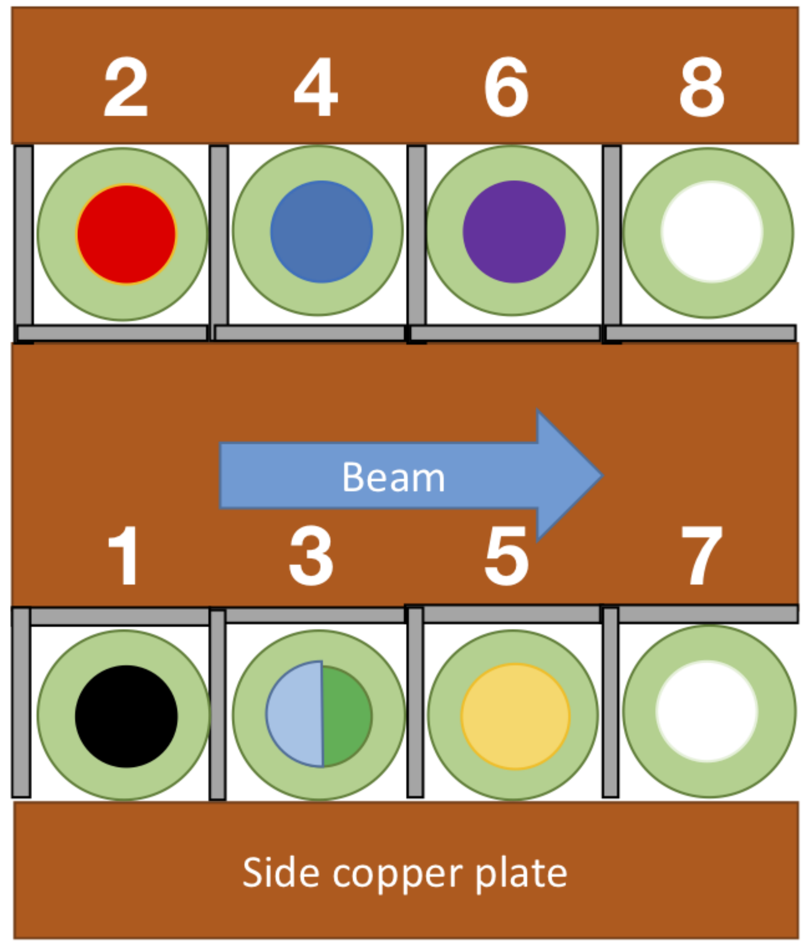
IRRADIATION OF FUSED SILICA MATERIALS

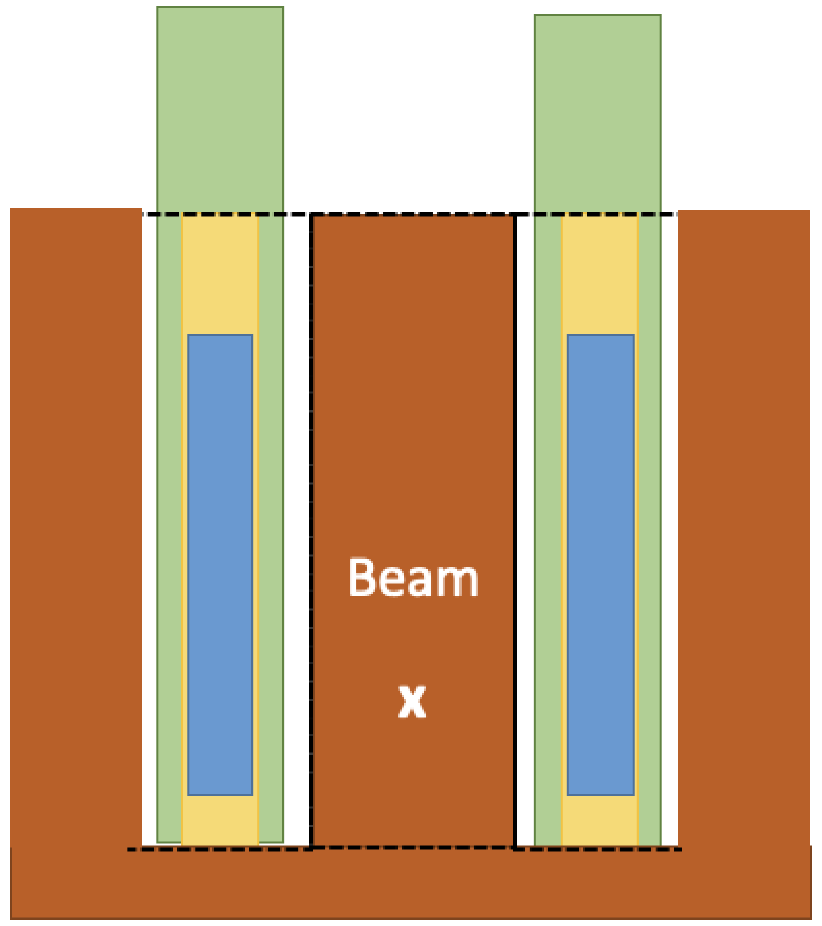
- **Fused silica rods irradiated over 3 years (2016-2018) in the TAN (IP1), in a BRAN detector prototype**
  - Installed in addition to the **actual BRAN detector** (ion chamber) for p+p running only
    - During HI the ZDC replaces the copper bars
  - Equipped w/ **different fused silica materials**

Collaboration with Heraeus









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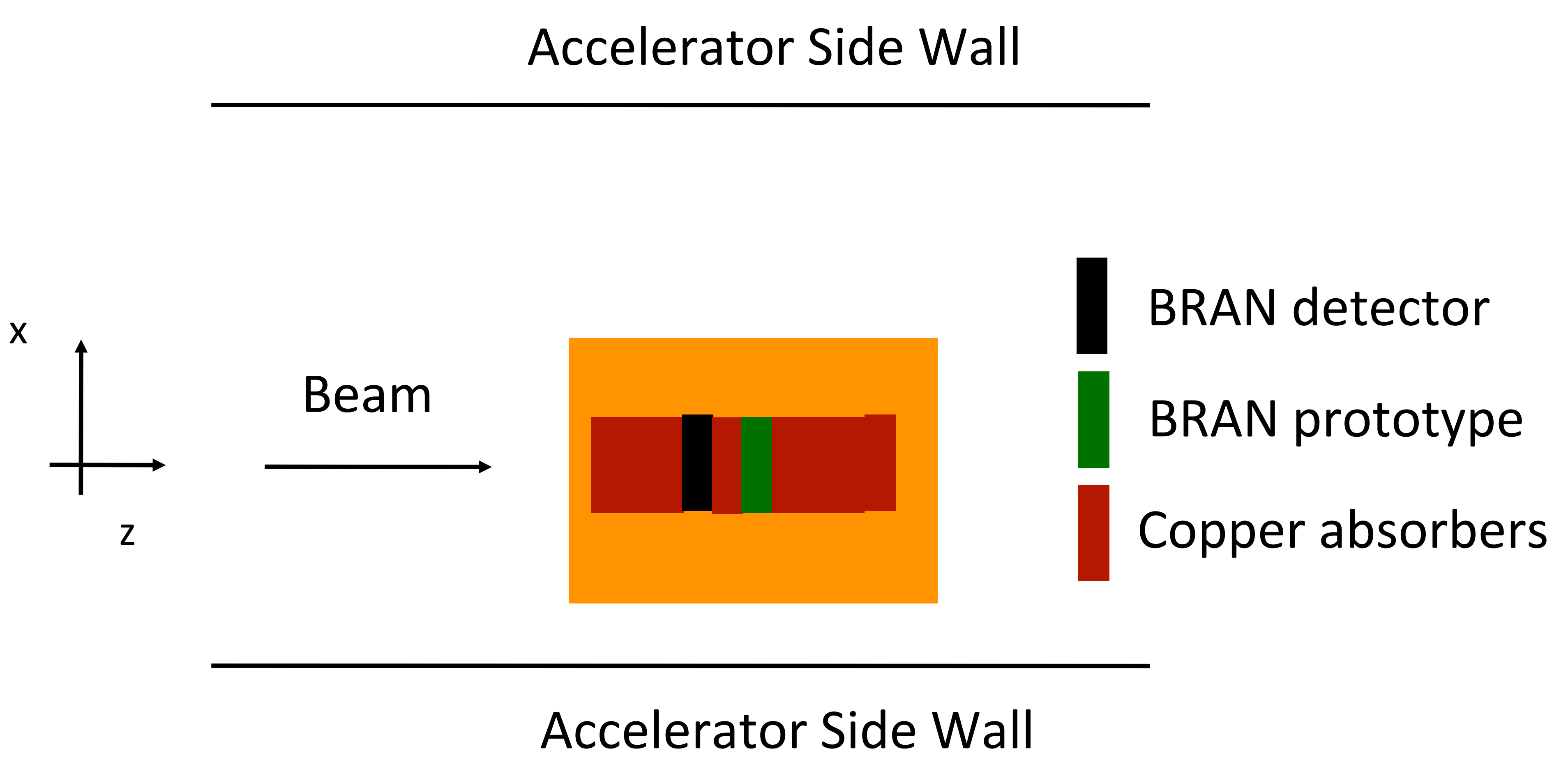
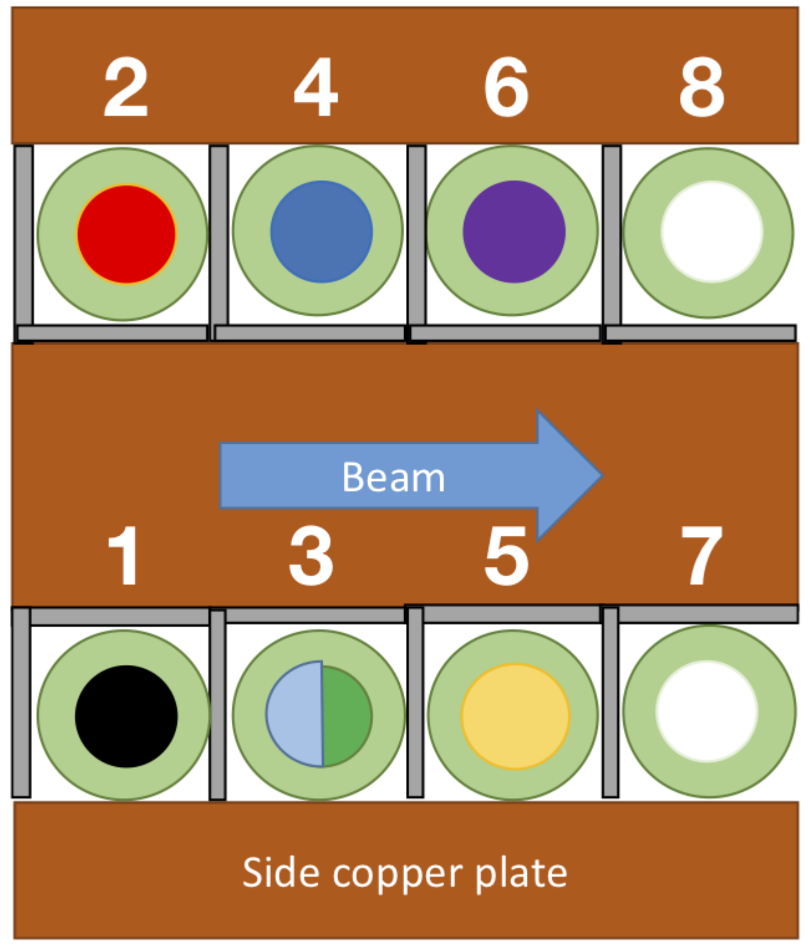
Collaboration with Heraeus

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)

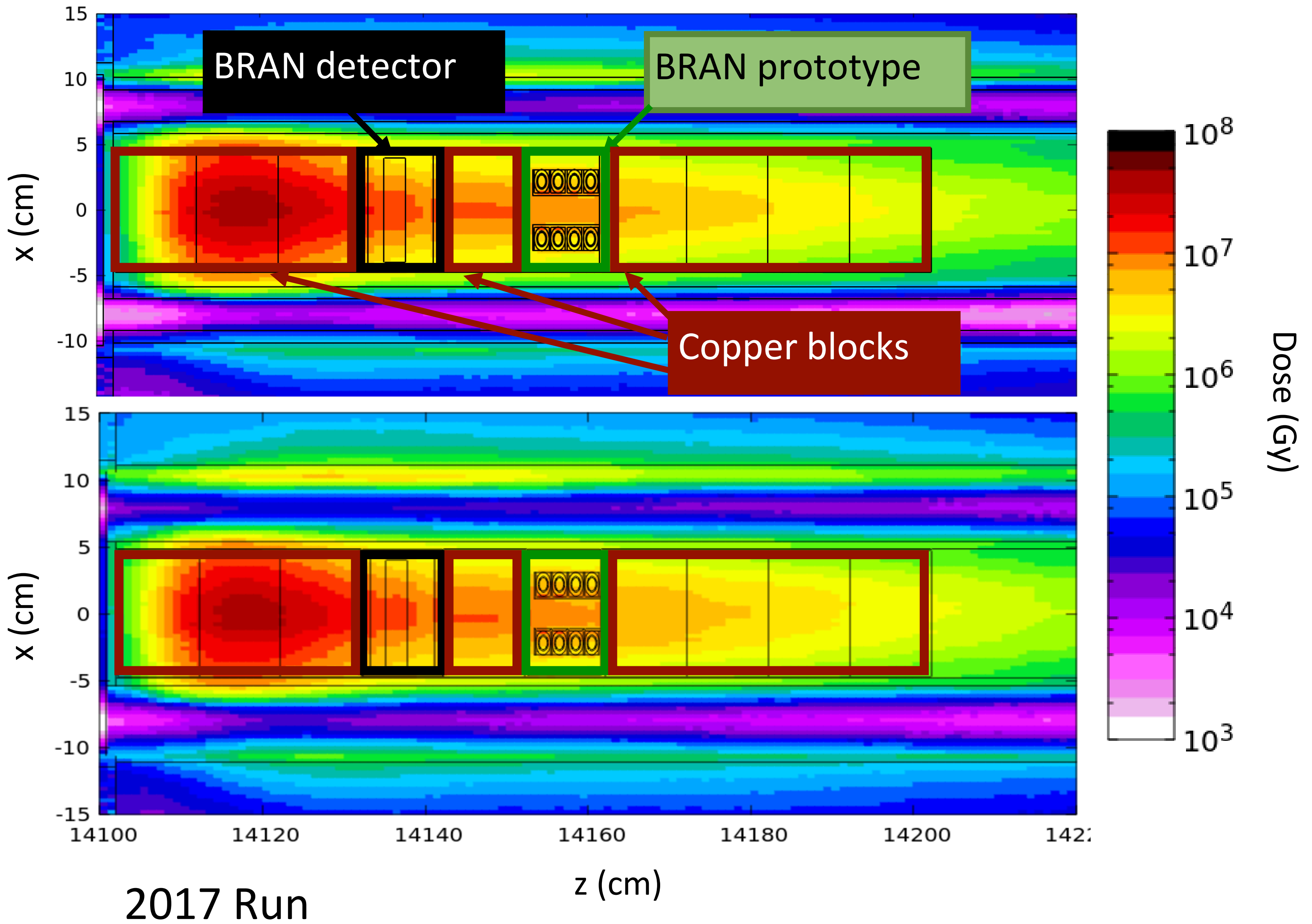




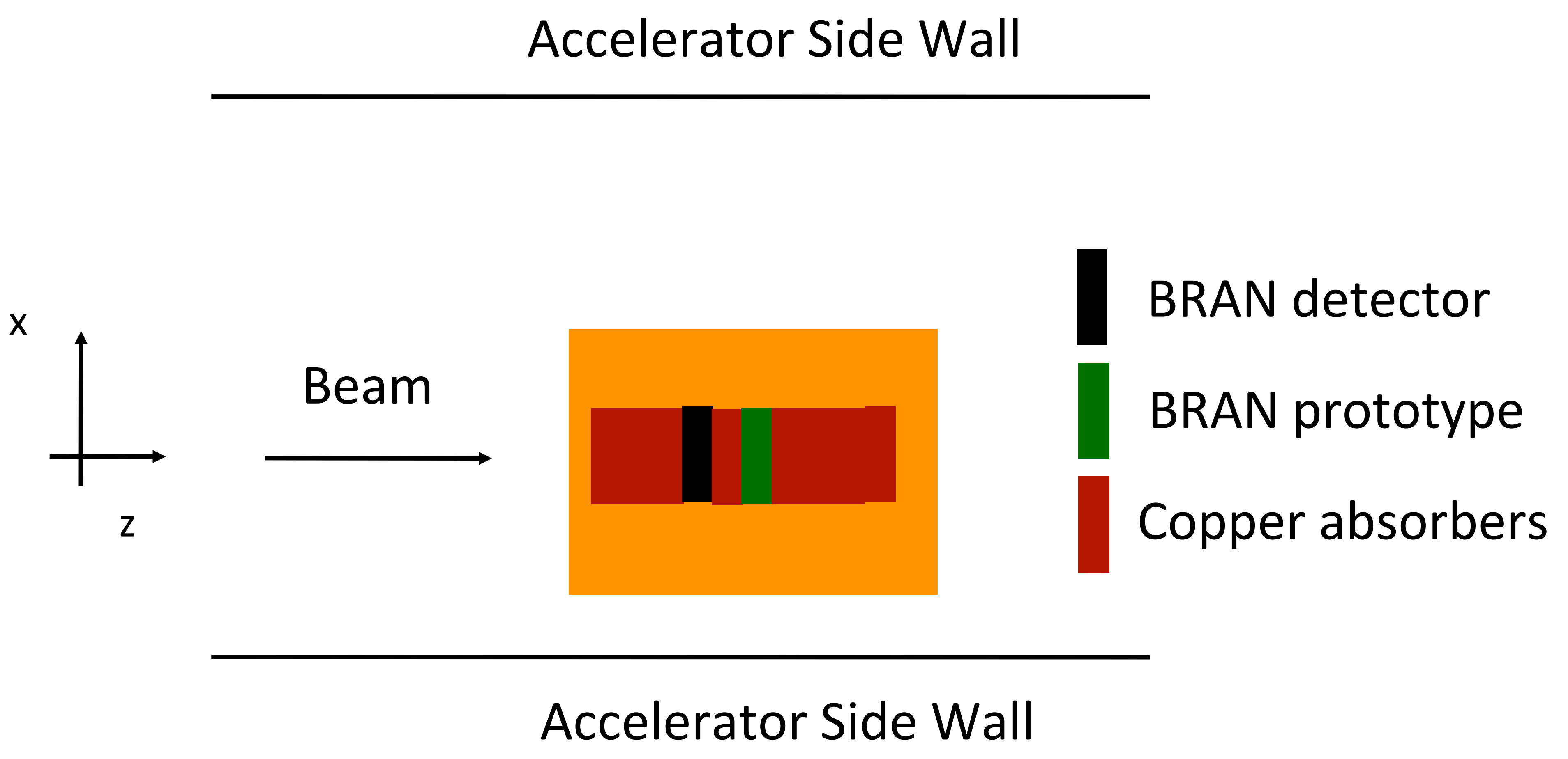
ANALYSIS OF IRRADIATED SAMPLES

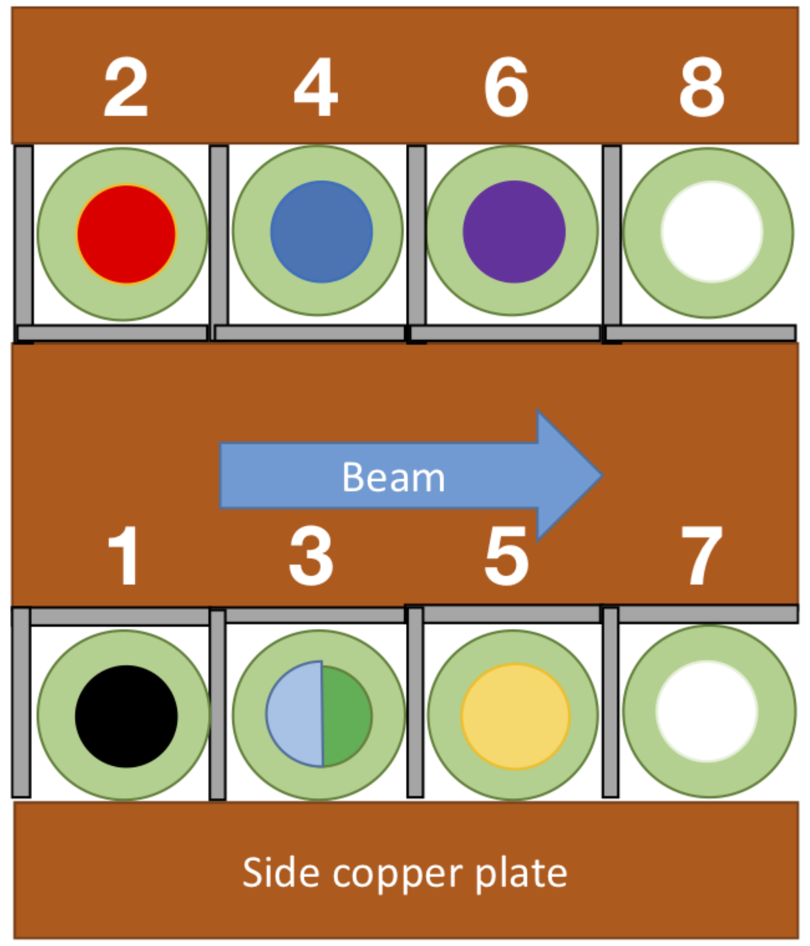
- **Detailed FLUKA simulations of the TAN allow for precise evaluation of dose deposited in the fused silica rods**
  - ➞Possibility to determine the dose received by each rod segment

2016 Run



2017 Run





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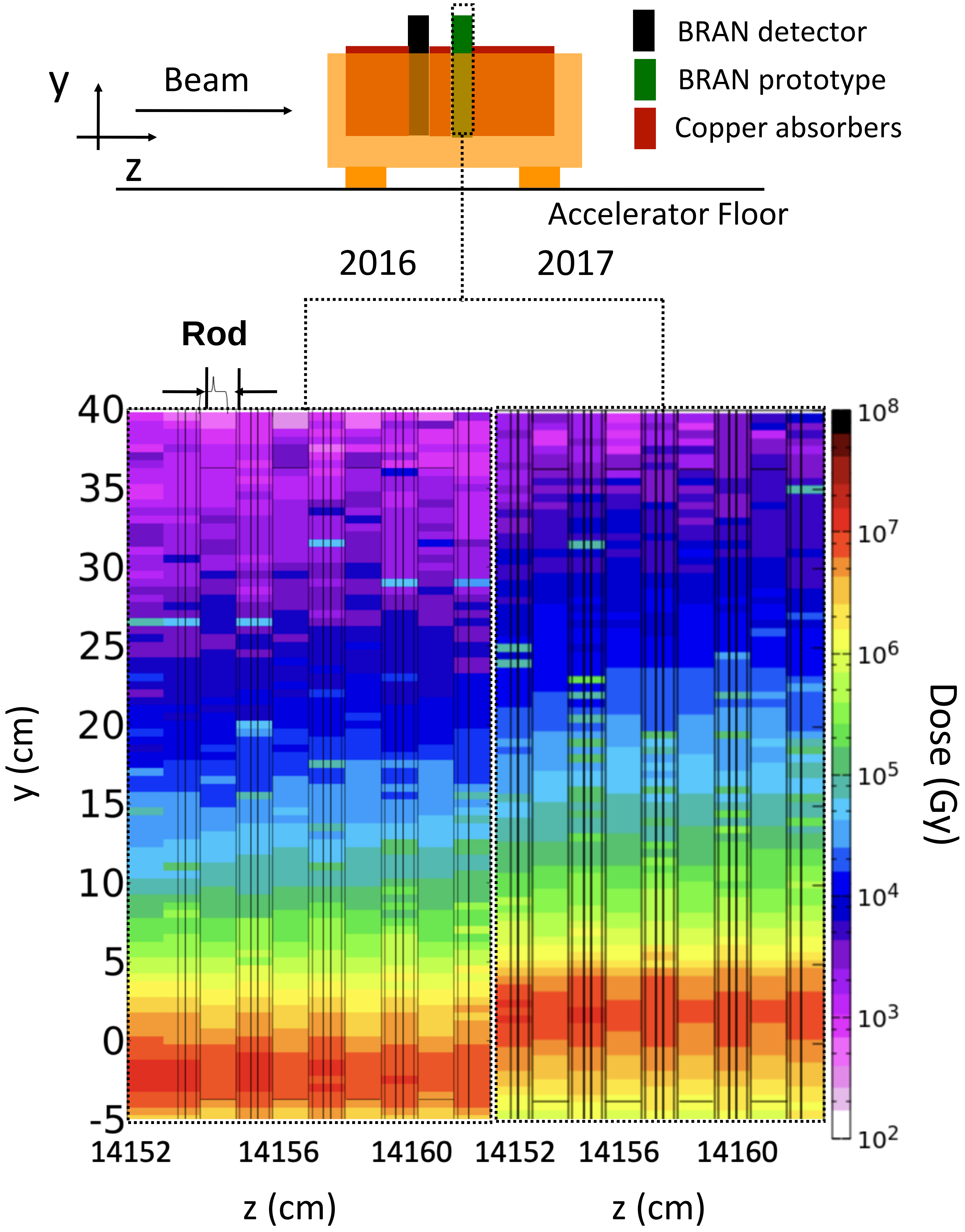
5	04/2016-12/2017	8	Suprasil 3301 (Low OH, High H_2)
6	04/2016 - 12/2018	17	Suprasil 3301 (Low OH, H_2 free)

ANALYSIS OF IRRADIATED SAMPLES

- The TAN is characterized by a **steep dose profile in the vertical direction**
  - ➞BRAN rods received dose spanning **over four orders of magnitude**
- Simulation of the **whole particle propagation from the interaction point to the TAN**
  - ➞Beam configuration reproduced for every year of running - crucial input to describe the dose profile along the rods



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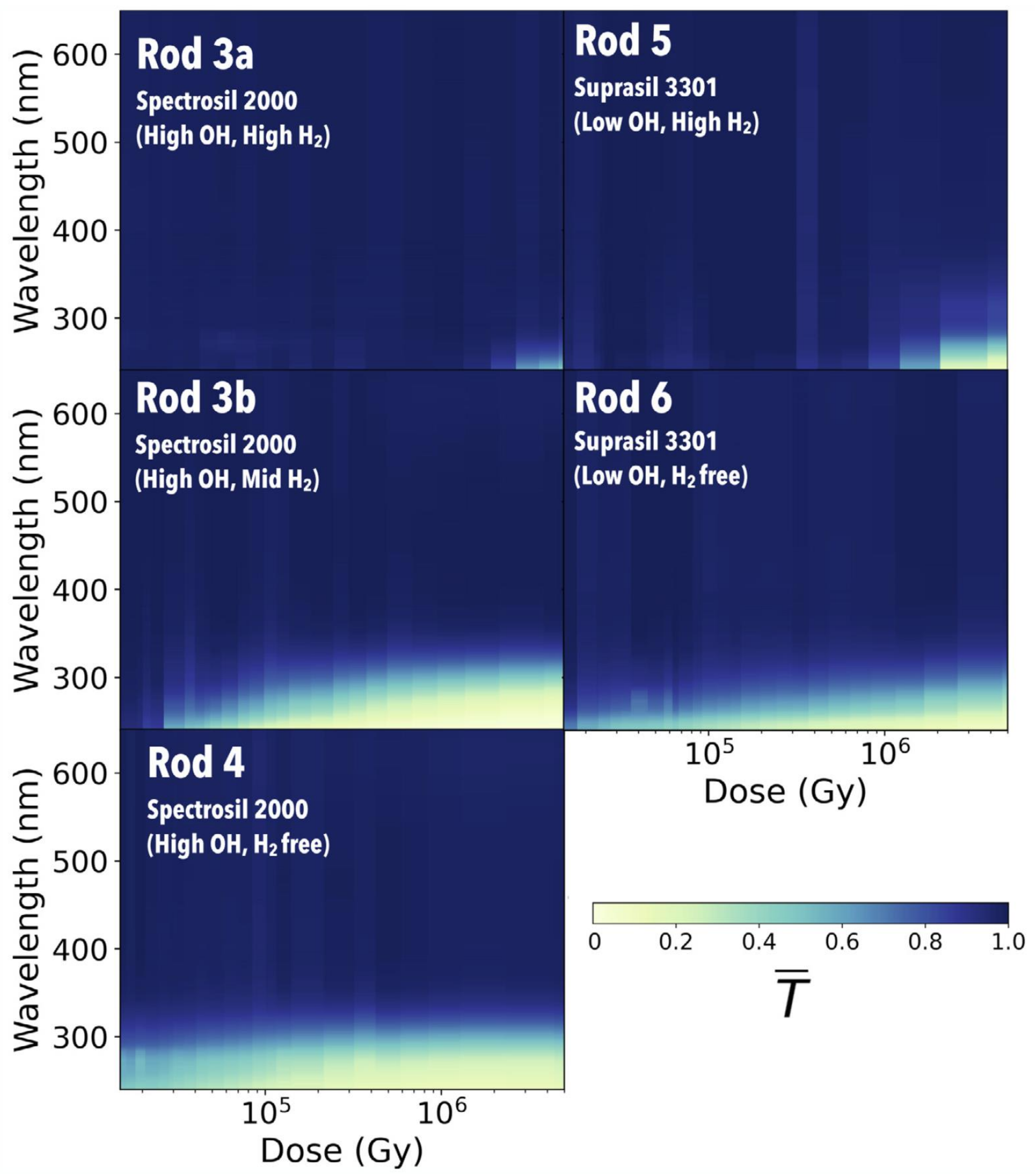
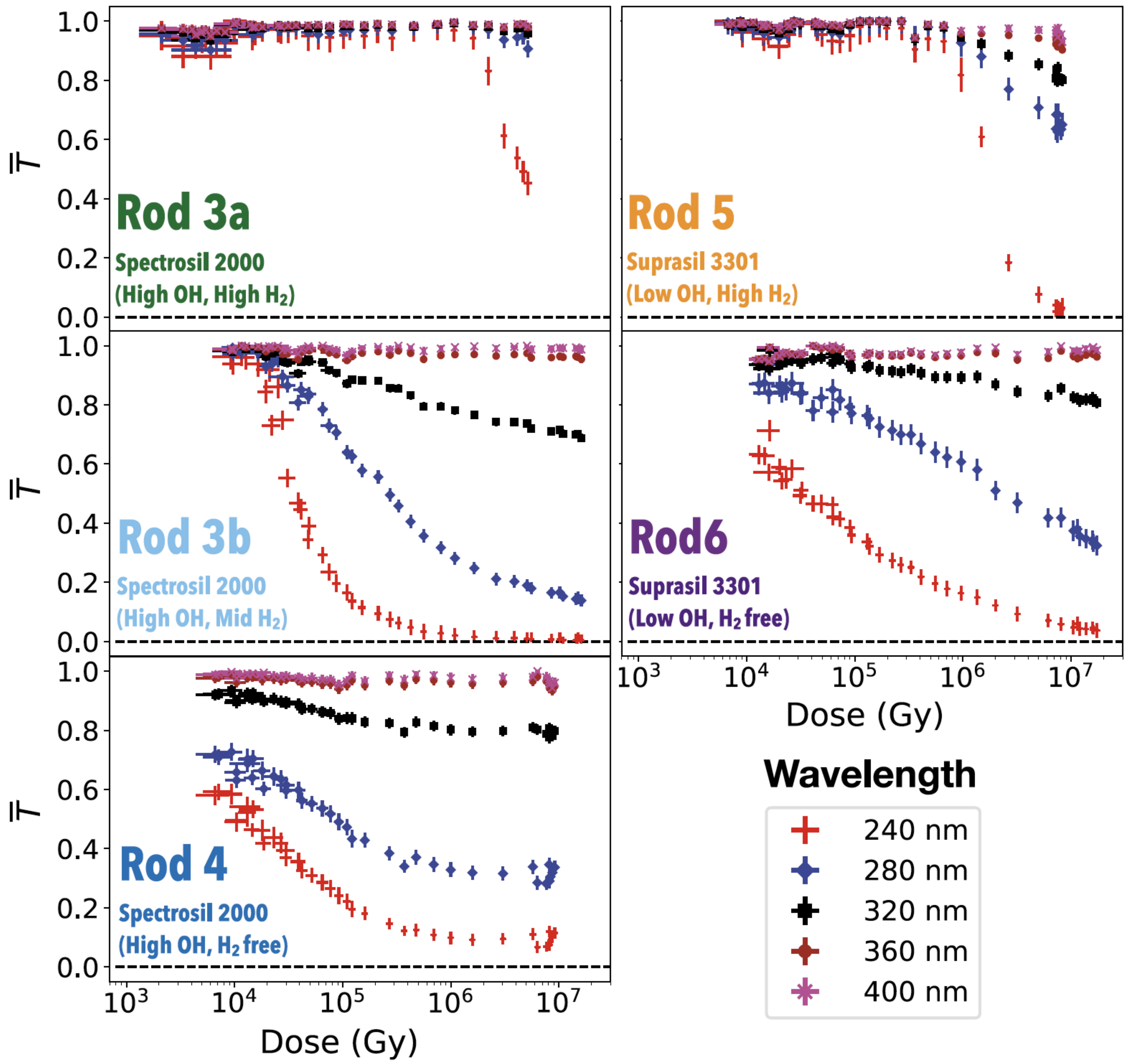
RAD-HARD FUSED SILICA MATERIALS: RESULTS



[*Nuclear Inst. and Methods in Physics Research, A 1055 (2023) 168523, S.Yang, A.Tate, RL et al.*]

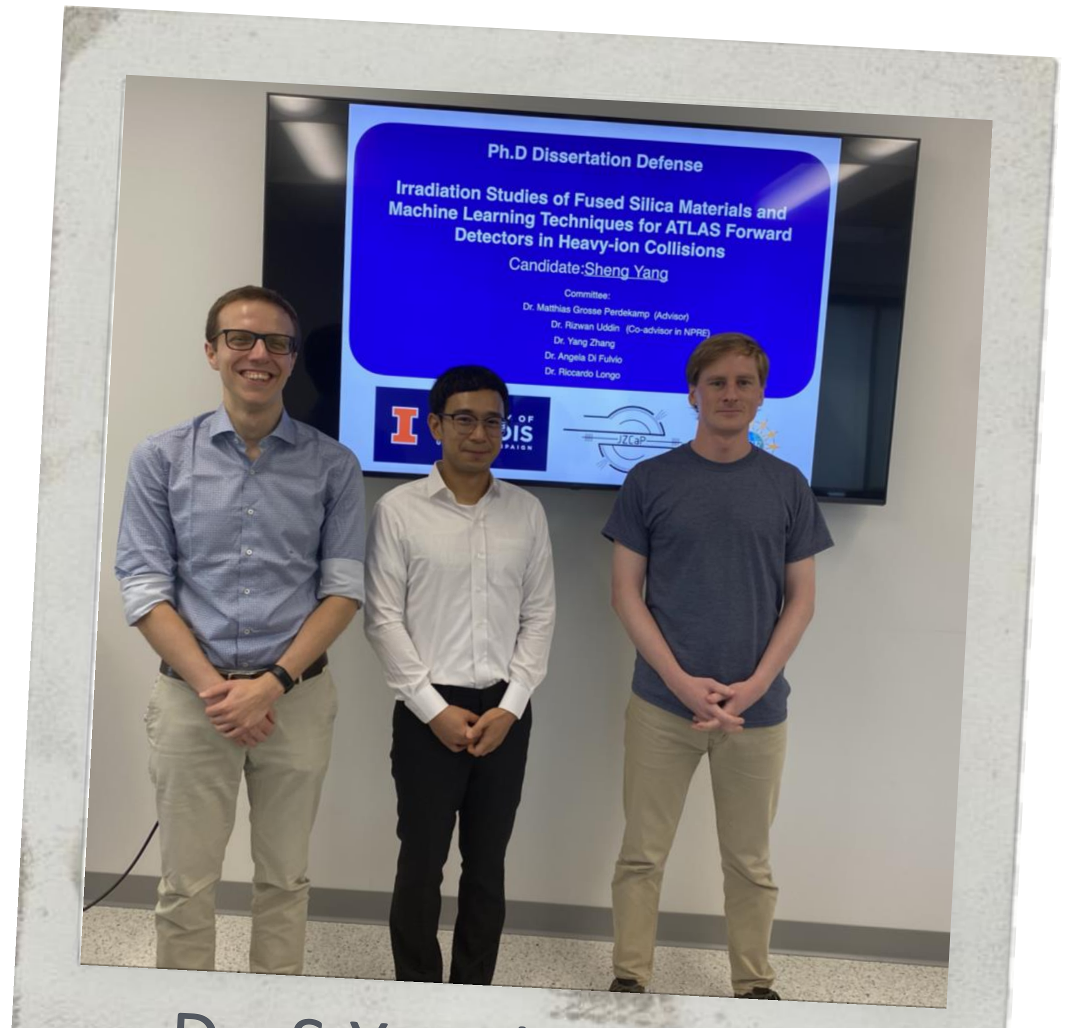
- Unprecedented characterization of fused silica transmittance as a **function of irradiation, wavelength and material composition**
- Samples irradiated up to several MGy

RAD-HARD FUSED SILICA MATERIALS: RESULTS



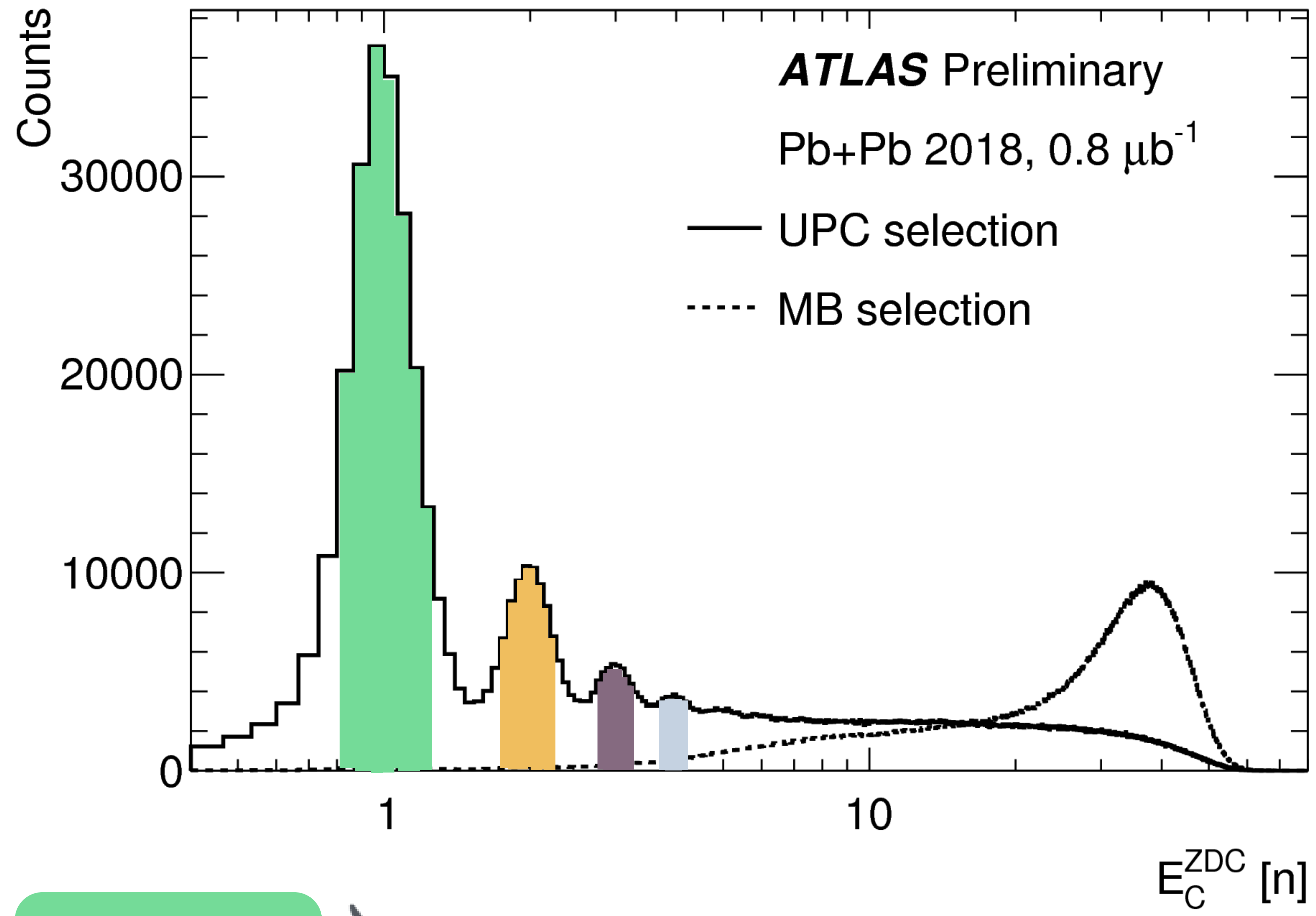
[*Nuclear Inst. and Methods in Physics Research, A 1055 (2023) 168523, S.Yang, A.Tate, RL et al.*]

- Unprecedented characterization of fused silica transmittance as a **function of irradiation, wavelength and material composition**
- Samples irradiated up to several MGy
- **Remarkable radiation hardness of high-H2 load Spectrosil 2000** (very little damage up to the MGy scale)
- Interesting **plateau for H2-free materials** after initial fast damage



Dr. S.Yang's defense
July 2022

ZDC DATA DRIVEN CALIBRATION



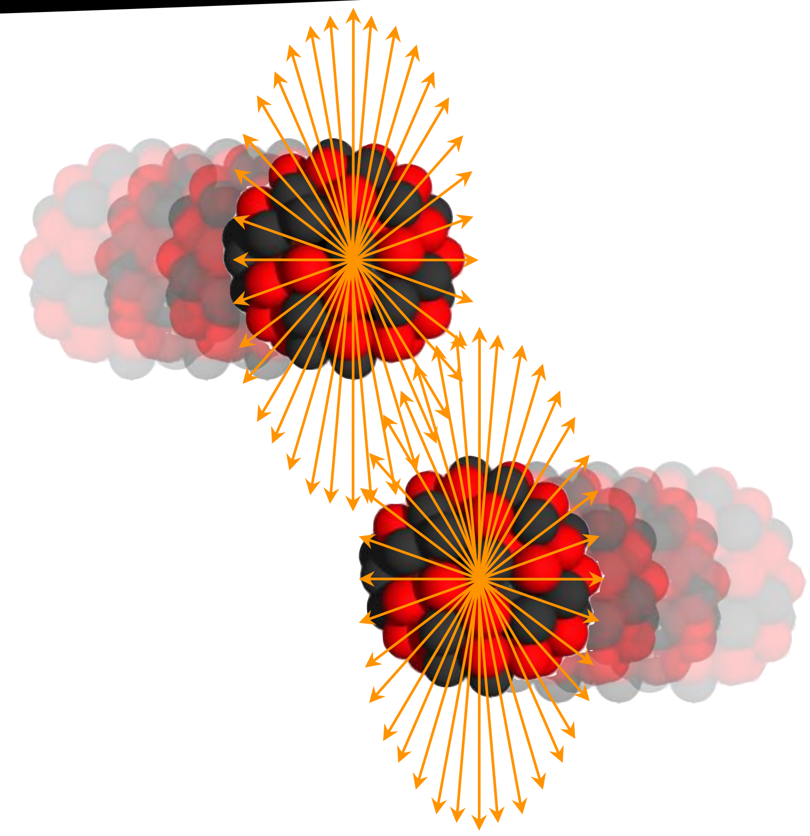
1 n peak

2 n peak

3 n peak

4 n peak

Simultaneous fit to determine data-driven **single neutron resolution, ~17-18%** in this case



- When two ultra relativistic Pb ions cross, their strong EM fields can interact even without nuclear overlap
- The large photon fluxes at very low photon energies give a cross section for forward neutron production from EM dissociation (EMD) in each arm of about 200 barn
- This process provides plenty of events with low number of neutrons, that can be used for **data driven calibration procedures**

New data just collected in October! Performance currently being assessed!

LAST WEEK AT LHC

BEAM POSITION WITH THE ILLINOIS RPD