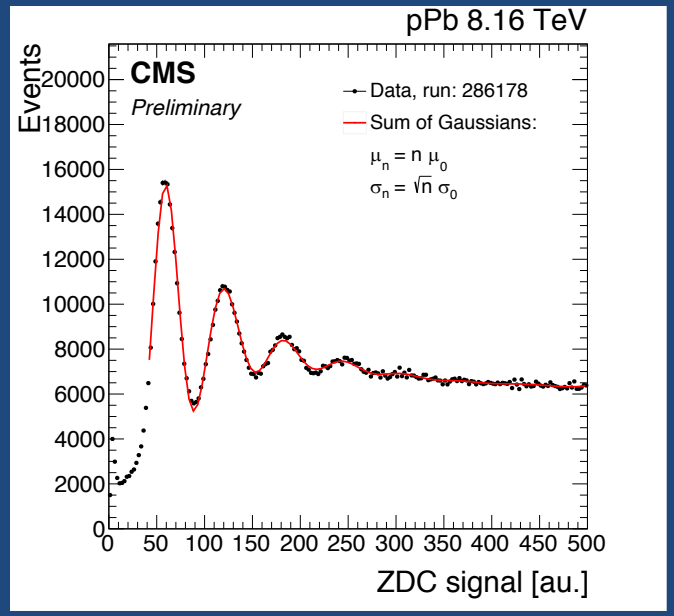
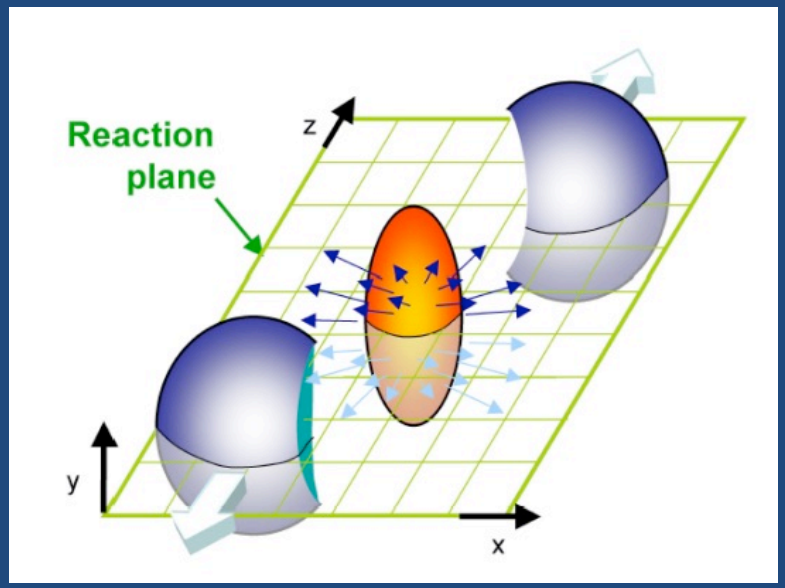
Future ZDCs for the LHC

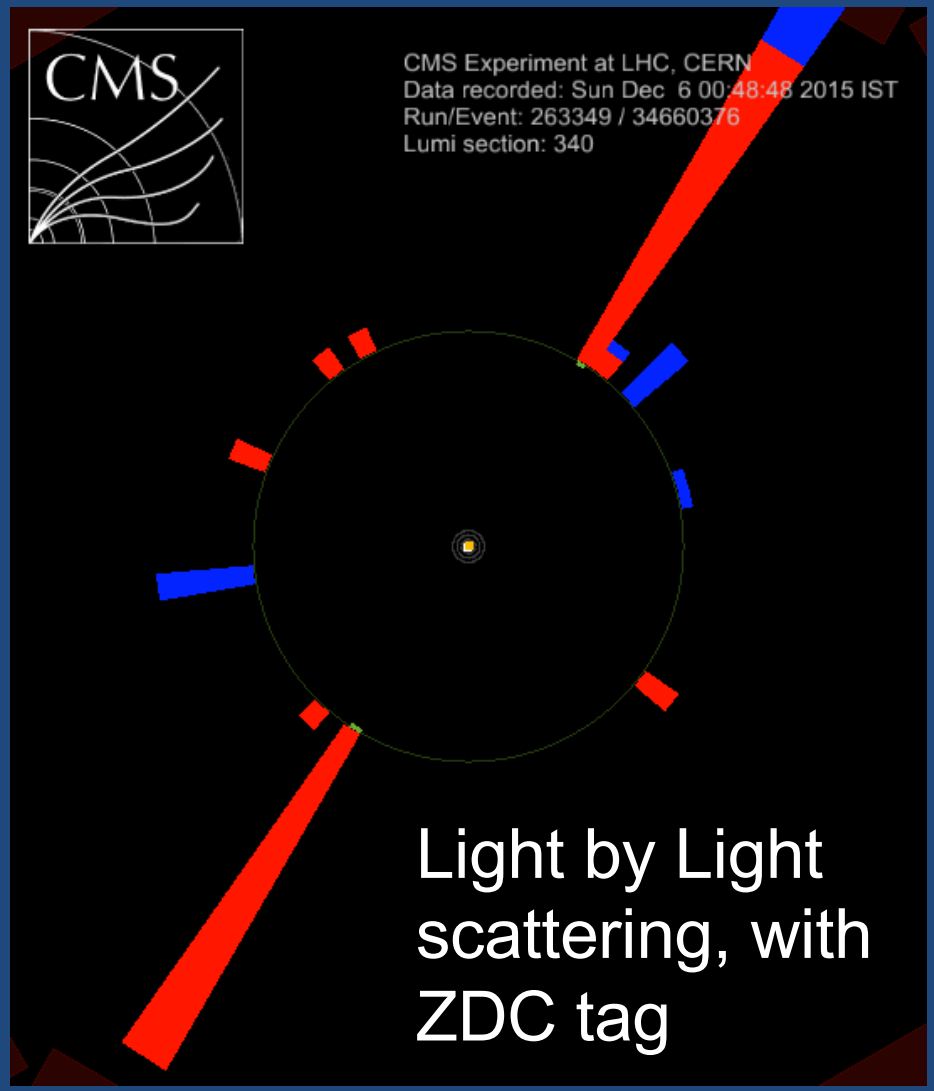
Michael Murray, University of Kansas, 17 Dec 2019

U.S. DEPARTMENT OF ENERGY | Office of Science

Physics Motivation



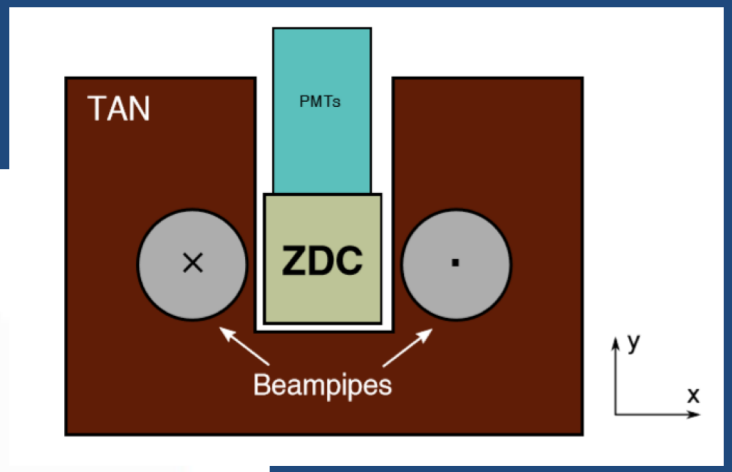


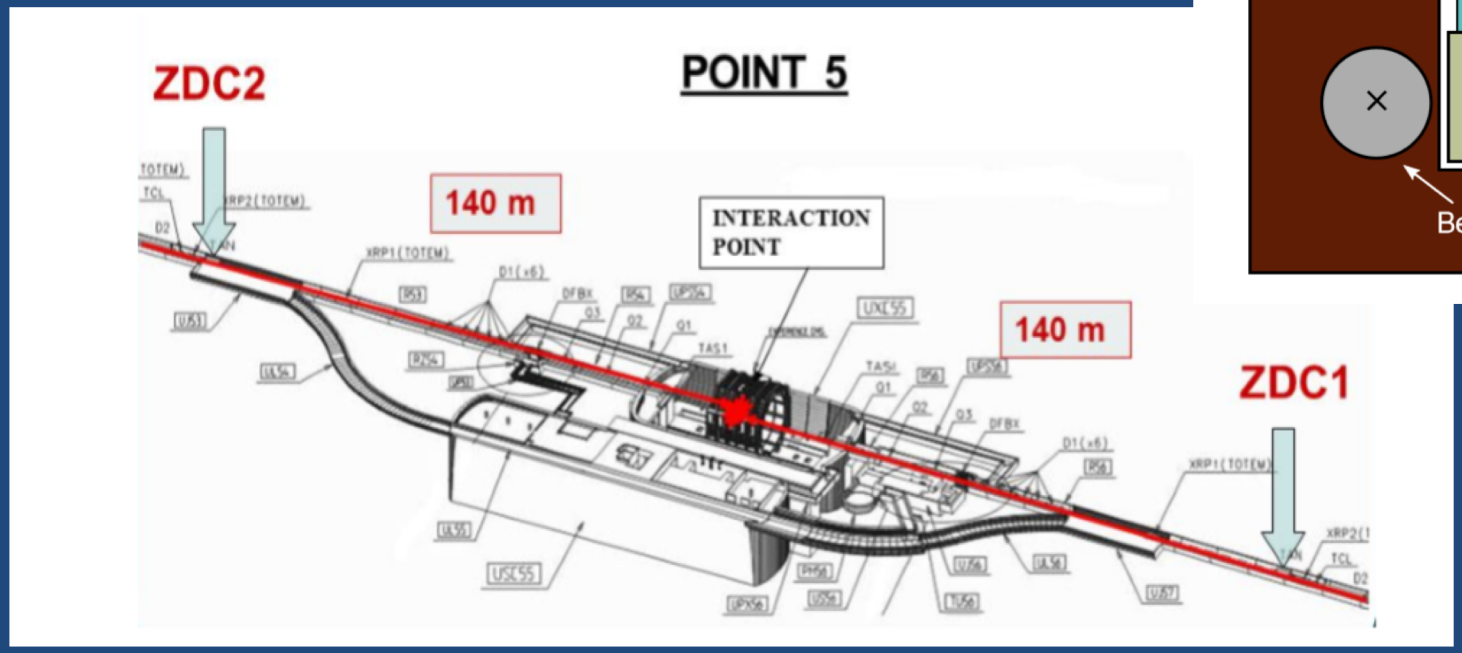


Light by Light scattering, with ZDC tag

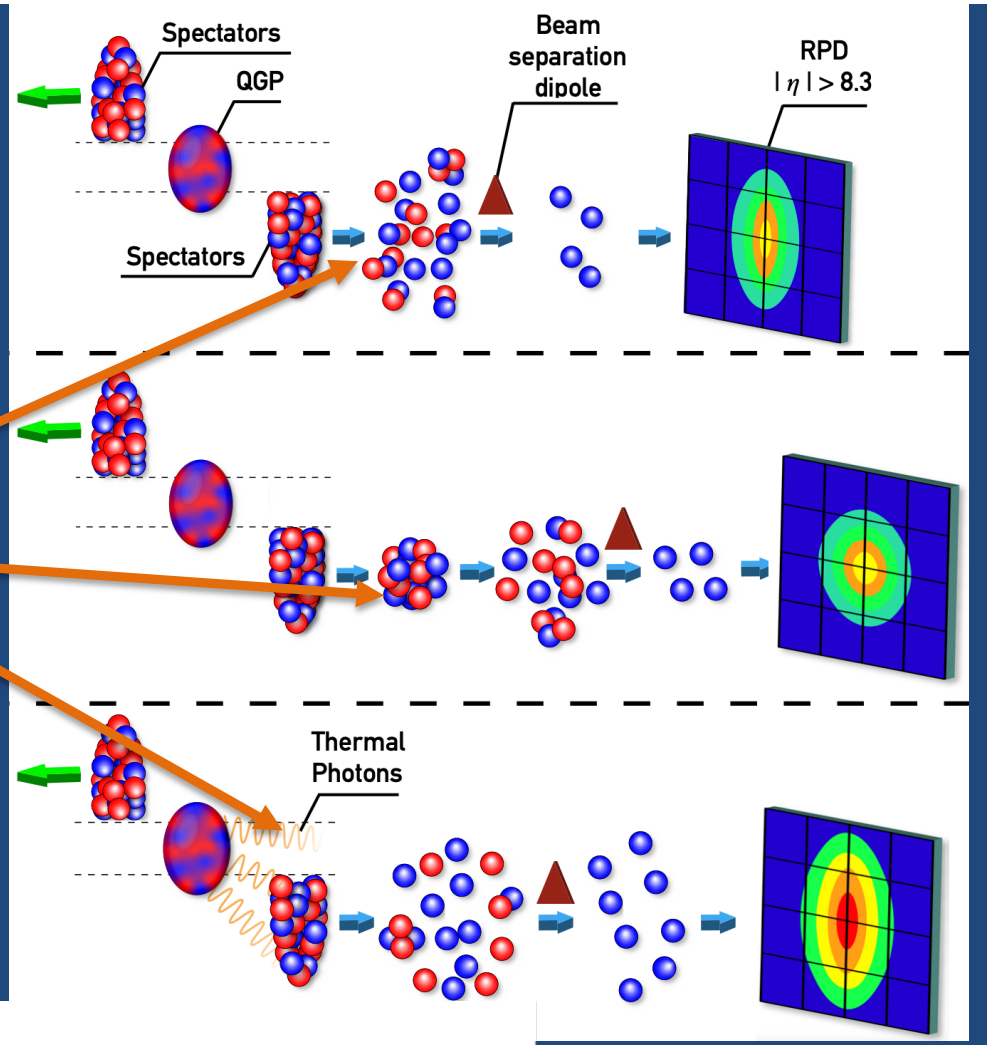
Capabilities of the ZDCs

- Measure energy & orientation of forward photons and neutrons
- Characterize different kinds of events
- Measure the distance between the nuclei and their orientation.



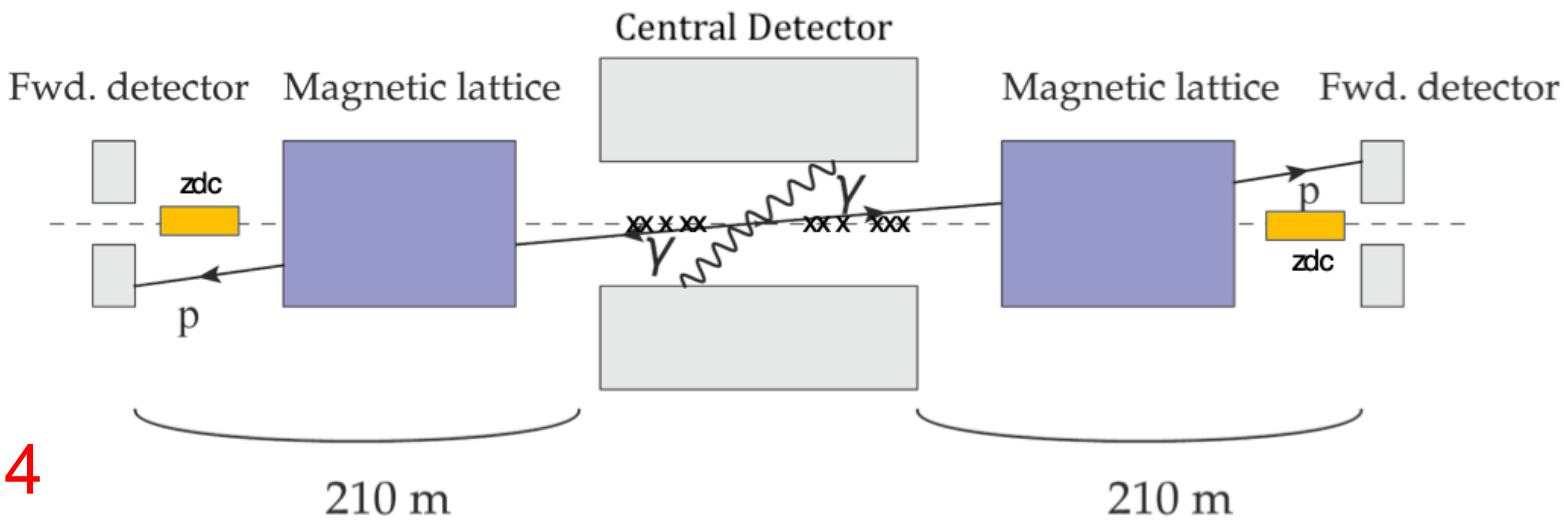


Other possible measurements



PbPb
Flow
Fragments
Photons

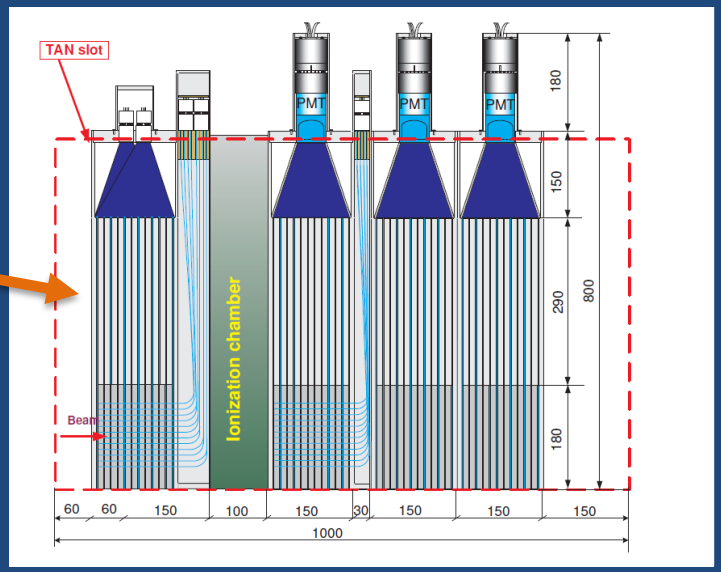
Search for invisible particles in pp

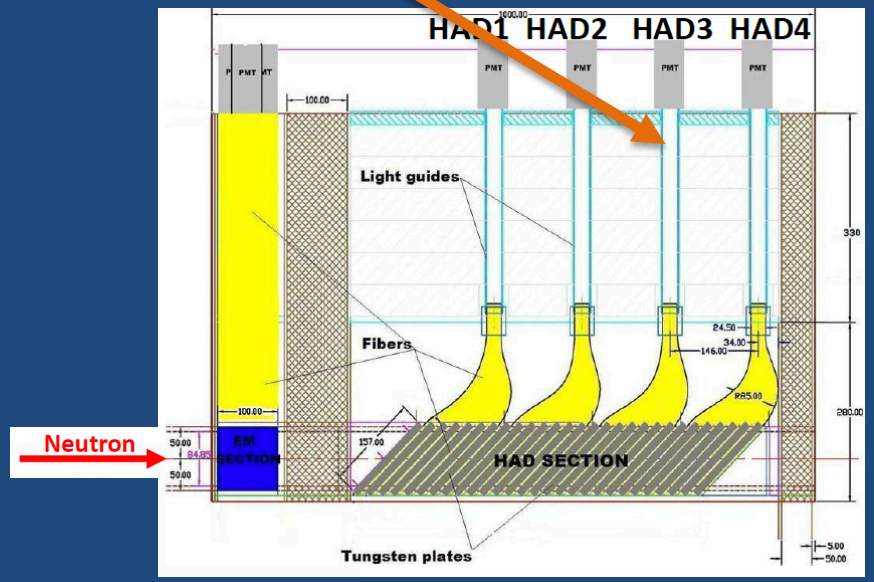


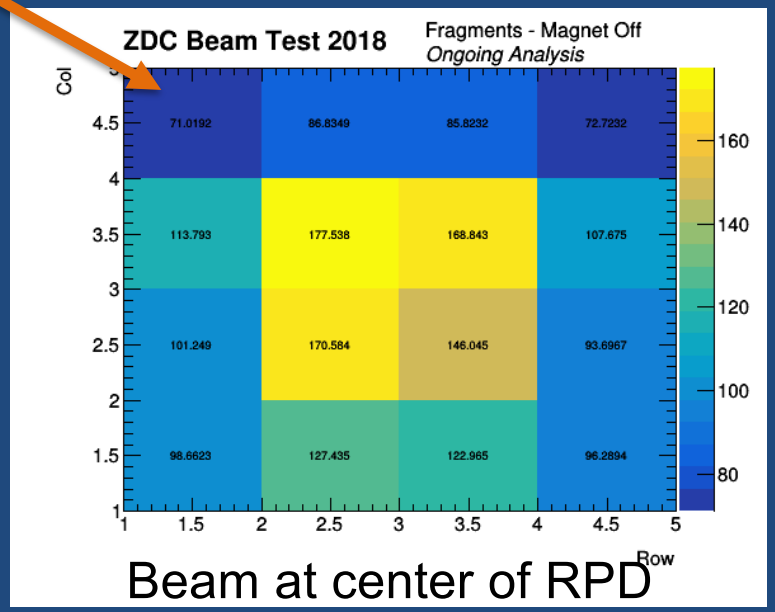
Current ATLAS & CMS ZDCs

Both tungsten/quartz Cerenkov calorimeters

- ATLAS: EM + 3 Had modules
- CMS: EM + Reaction Plane Detector (RPD) + 4 Had





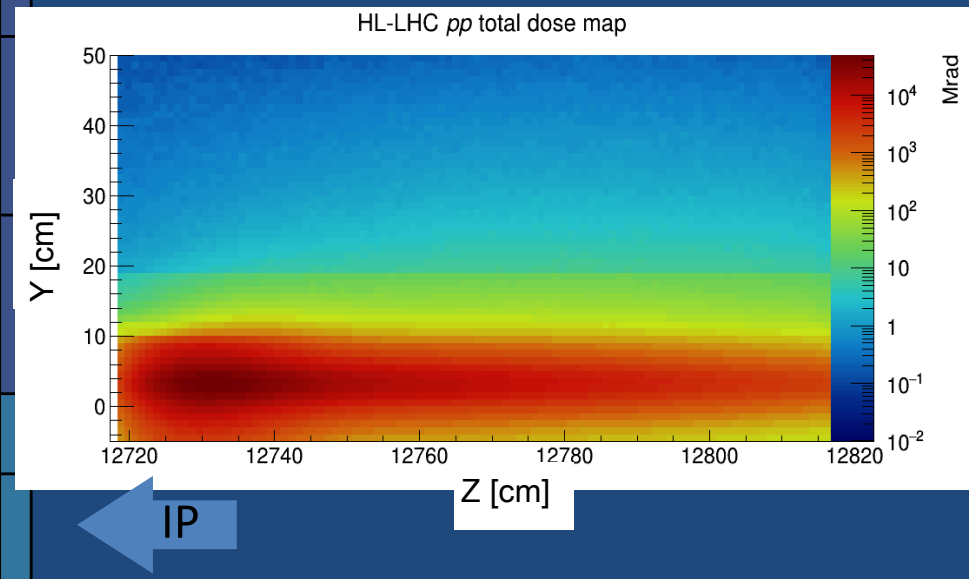


Beam at center of RPD

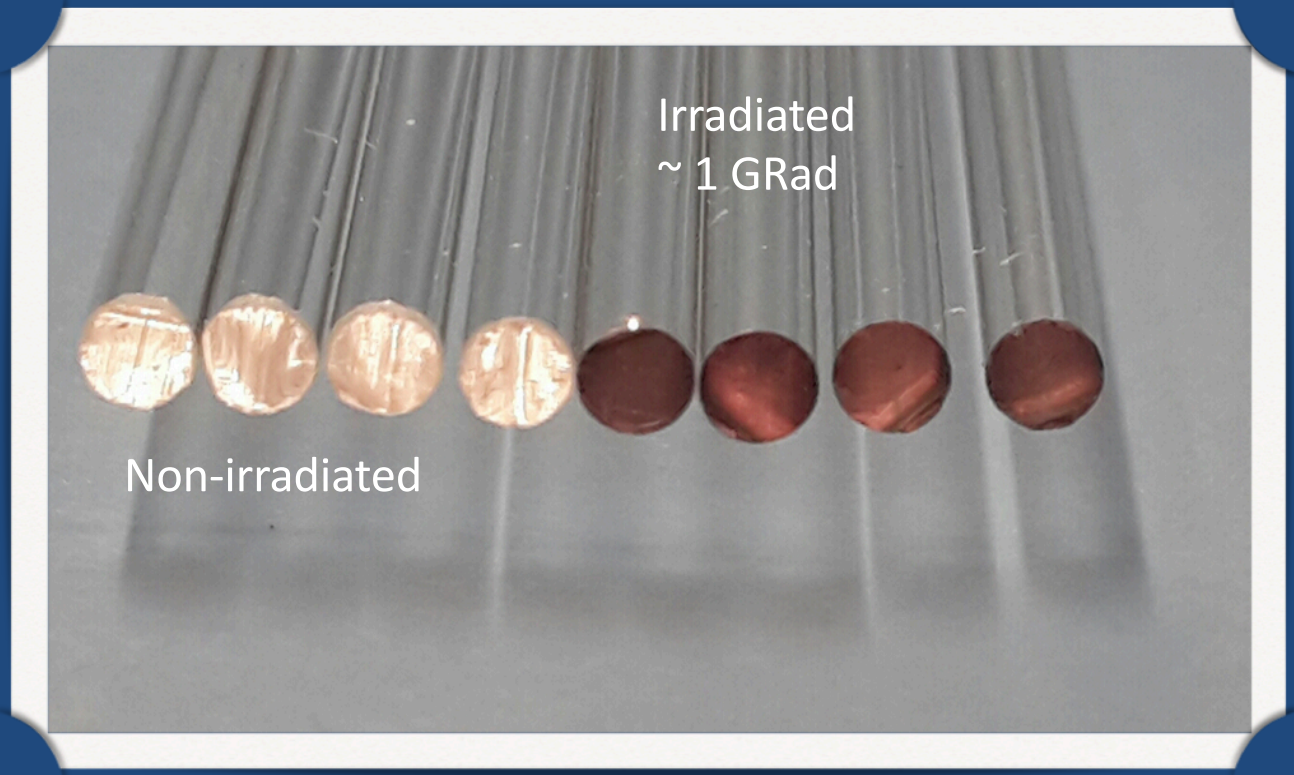
LHC luminosity upgrade

		pp	Pb+Pb
Run 2	Energy	13 TeV	5.02 TeV/n
	Total Int. Lumi	156 fb^{-1} (3 years)	1 nb^{-1}
	max dosage in TAN	8 Grad/2017	8 Mrad/2018
Run 3	Energy	14 TeV	5.5 TeV/n
	Total Int. Lumi	270 fb^{-1} (3 years)	6 nb^{-1} (3 years)
	max dosage in TAN	15 Grad/year	53 Mrad/year
Run 4	Energy	14 TeV	5.5 TeV/n
	Total Int. Lumi	750 fb^{-1} (3 years)	7 nb^{-1} (3 years)
	max dosage in TAN	30 Grad/year	62 Mrad/year

Fluka simulation of TANX dose for 1 year



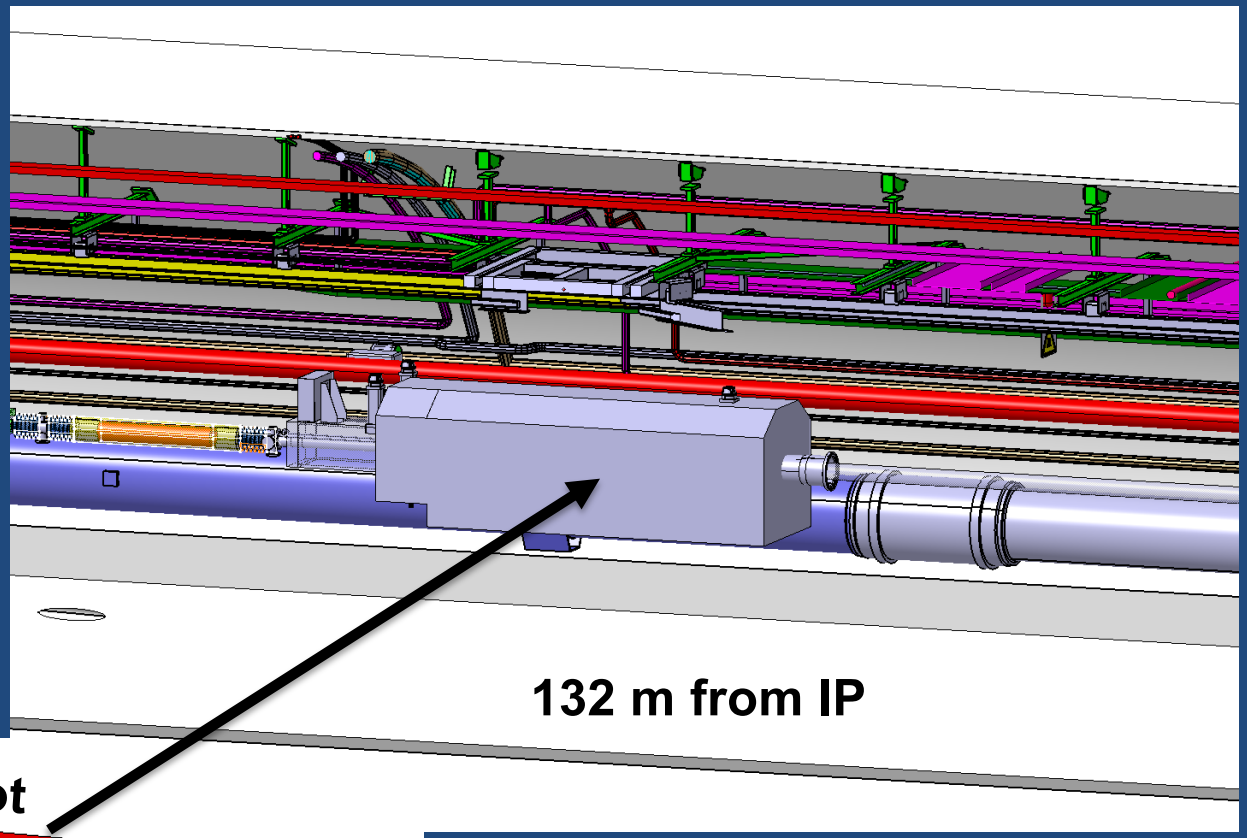
Radiation quartz rods (ATLAS)

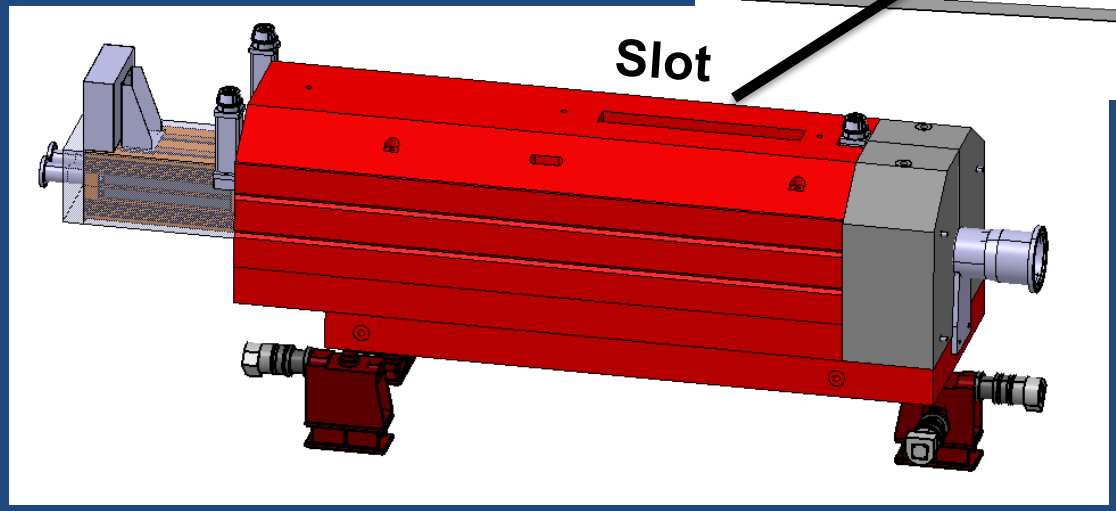


Need to develop a rad hard medium for high luminosity running

7

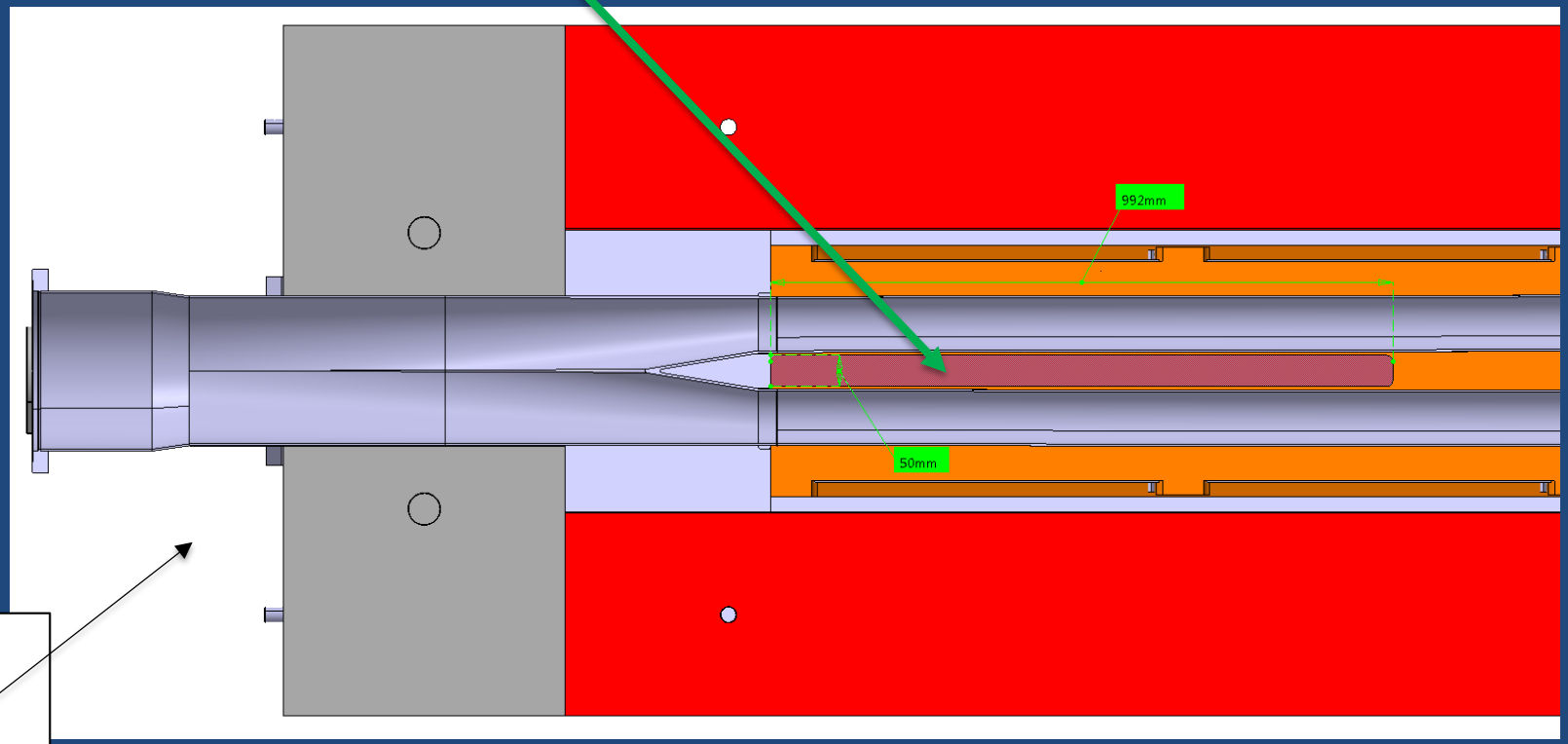
New TAXN absorber for HL-LHC

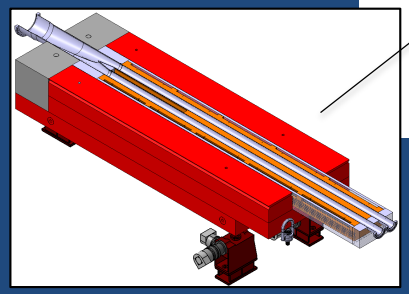




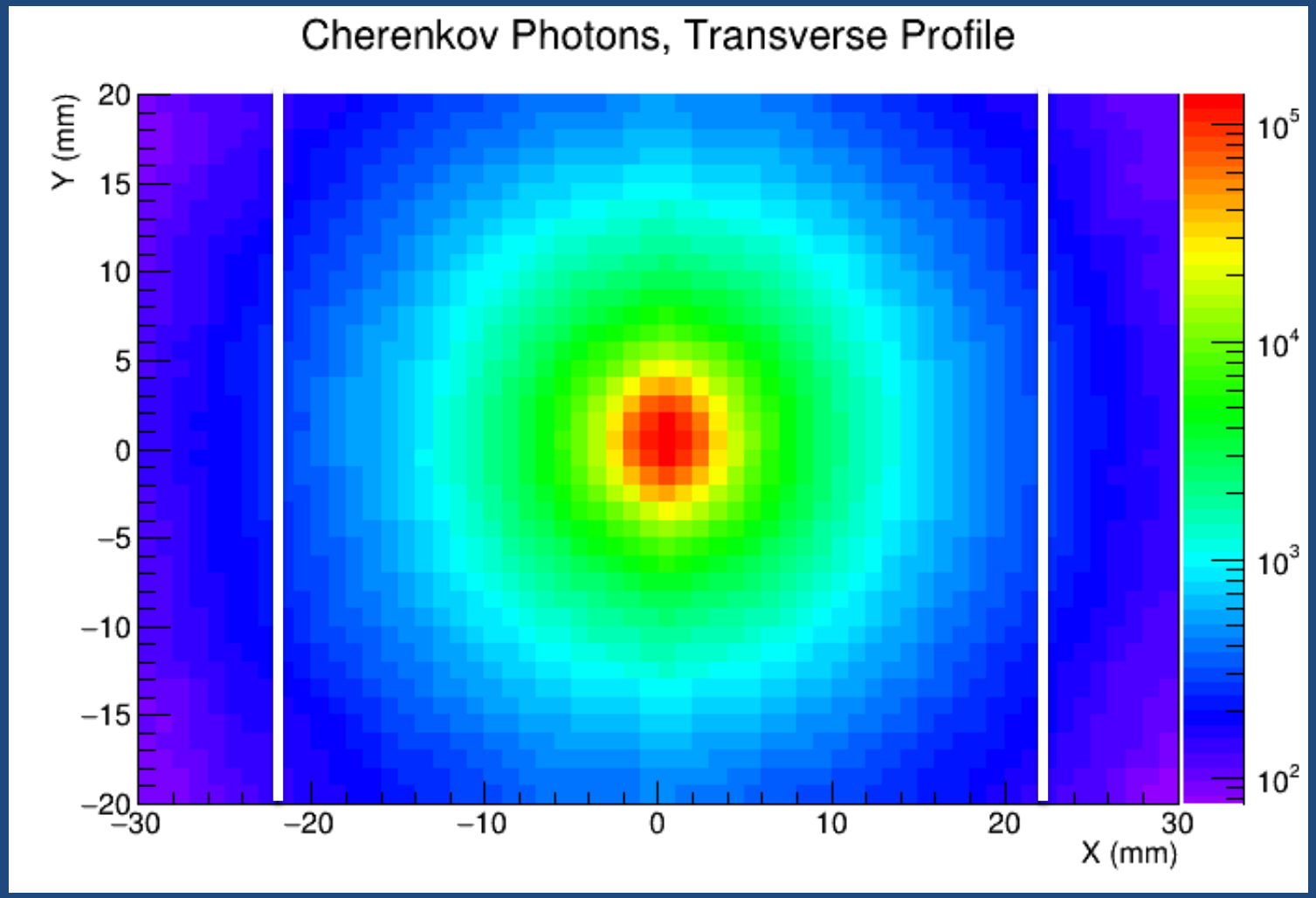
Cross section of TAXN

Slot is 5cm wide (ZDCs will be much lighter)





Is 5cm wide enough?

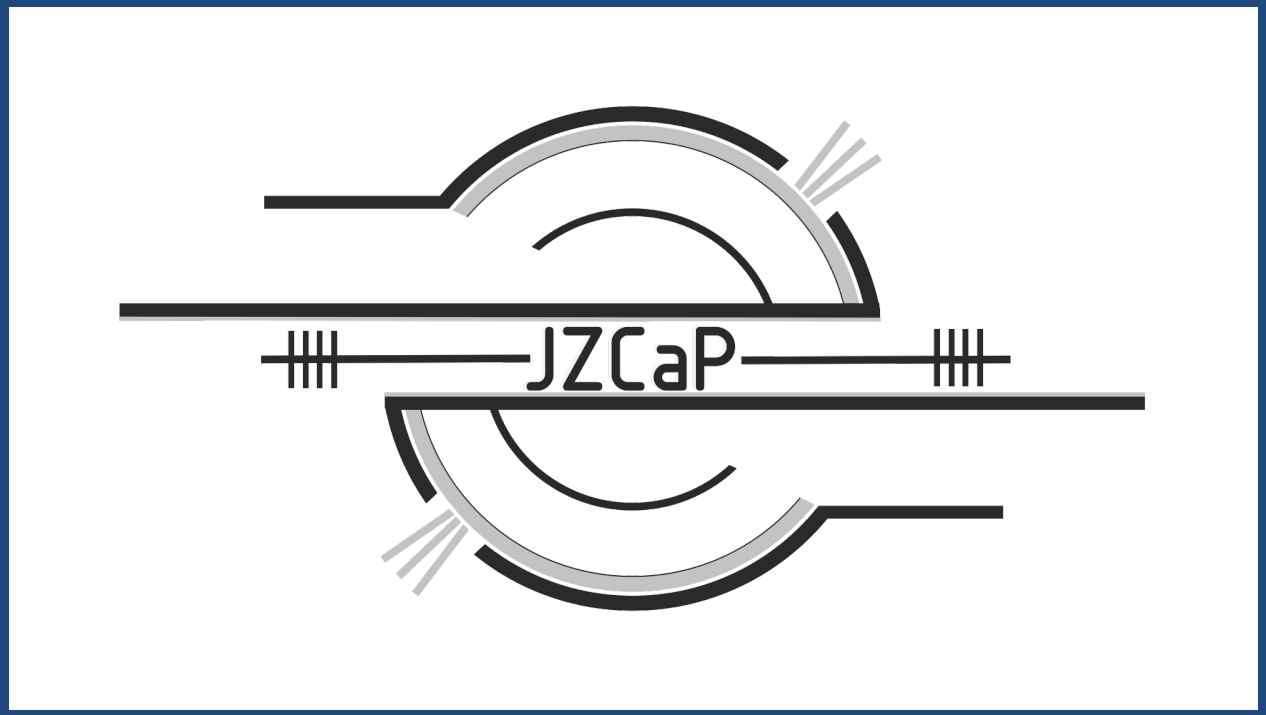


Transverse profile of Cherenkov photons from 1 TeV neutron.
No significant losses from reducing active width to 4.5 cm.

We have to change for Run 4

- Current ZDCs will be too wide, and not radiation hard enough to operate in Run 4
- To support the physics program of ATLAS and CMS we must develop new, fast, segmented and rad hard detectors.
- Take advantage of new materials, fused silica and new electronics with 30ps timing opens many possibilities.
- CMS and ATLAS groups are working together to realize new ZDCs.

Joint Zero degree Calorimeter Project

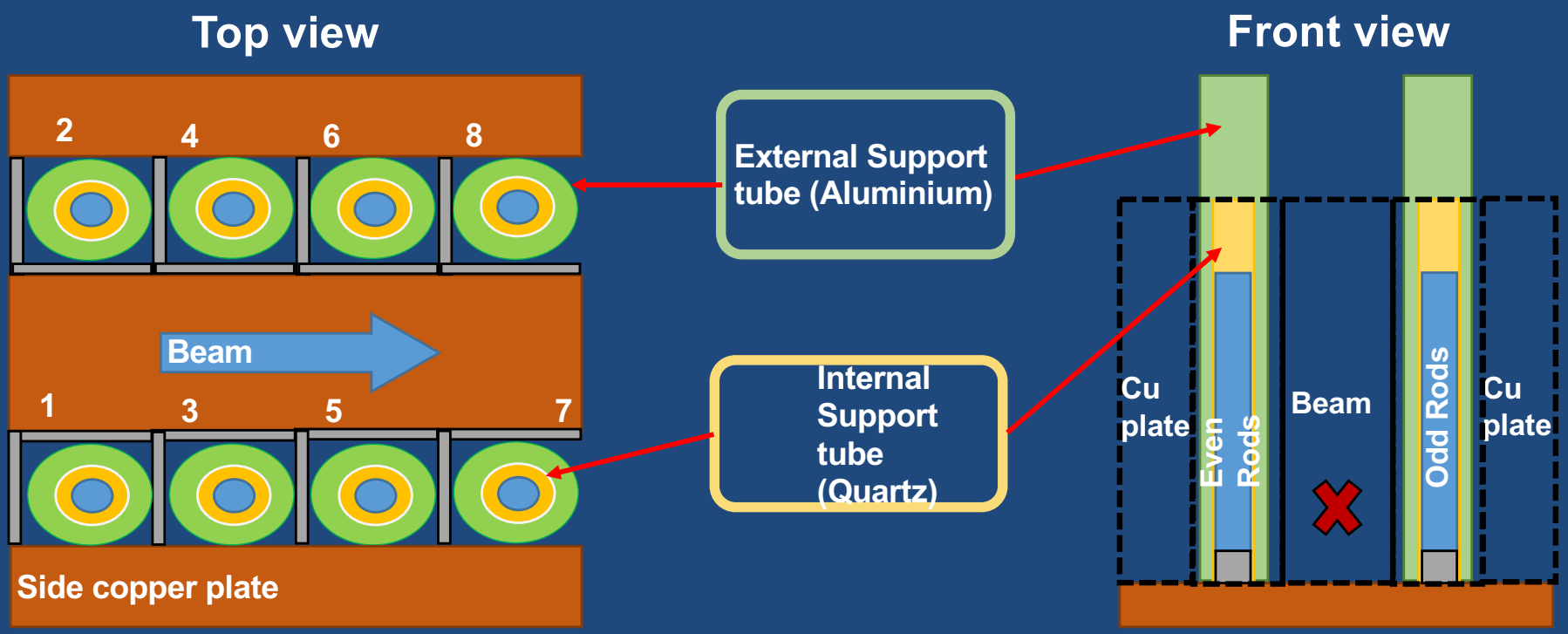


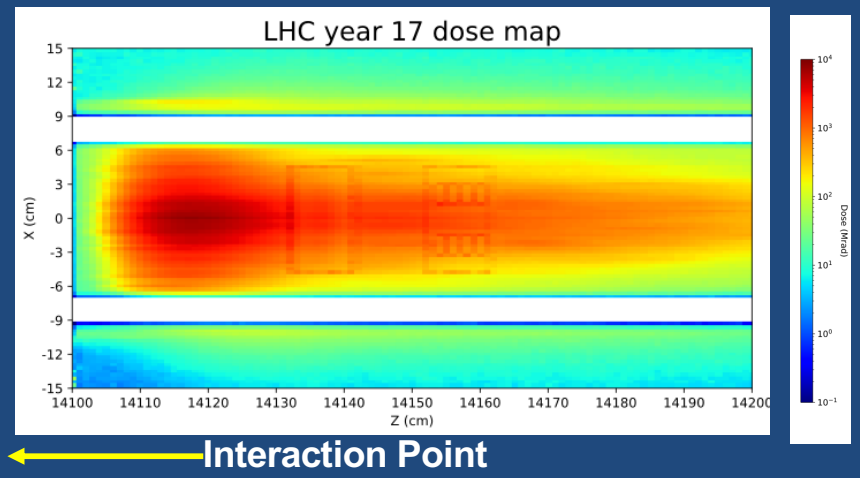
ATLAS + CMS joint R&D effort New collaborators are welcome! j.zdcrd@cern.ch

- University of Kansas
- University of Maryland

- Ben Gurion University
- BNL
- Columbia University
- University of Illinois

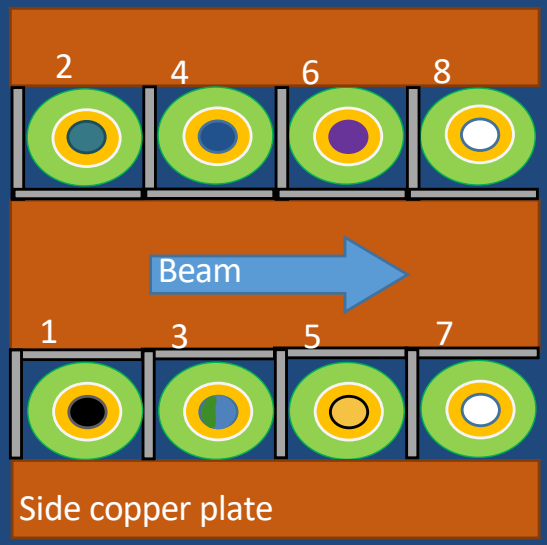
Irradiation of fused silica rods





- BRAN group inserted fused silica rods from Hereaus into TAN during 2017,2018.
- Rods1cm diameter, 40cm high

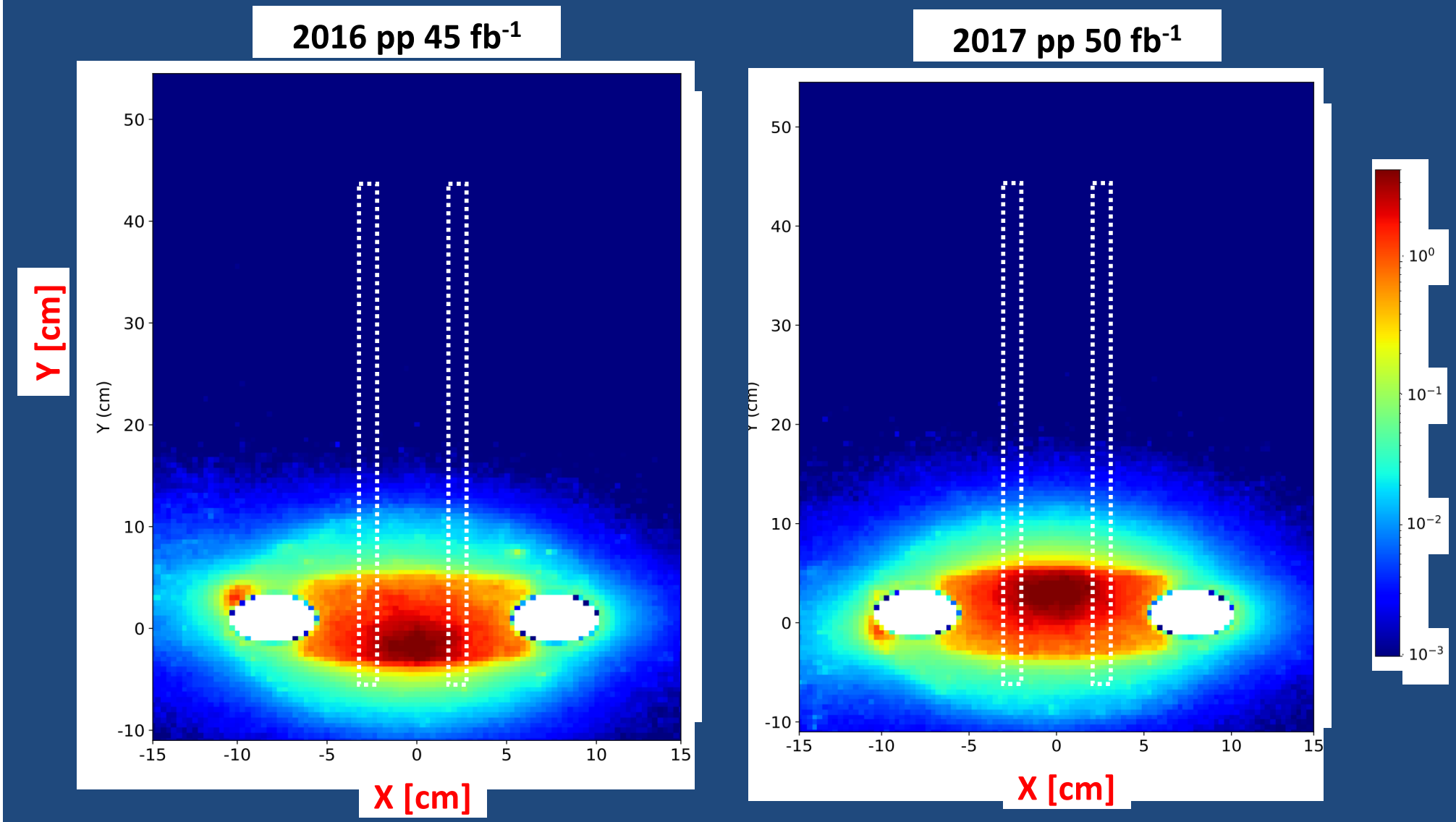
H_2 and OH content of rods varied



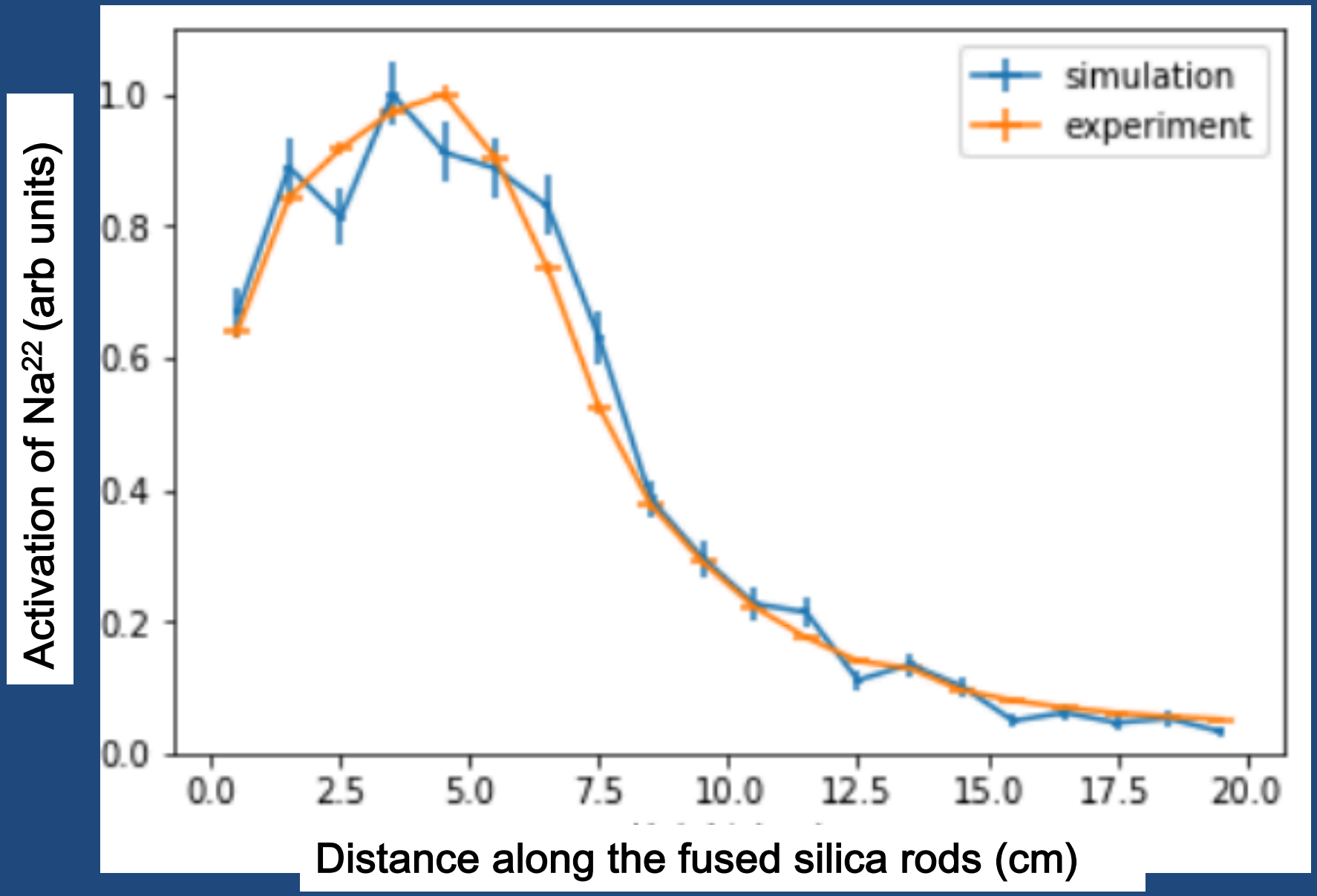
Bran Position	Irradiation period	Peak exposure (Grad)	Material	H_2 [mol/cm^3] (10^{-17})	OH [ppm]
Control	None	0	Spectrosil 2000	7.2	1120
1	04/2016 - 12/2018	3	Spectrosil 2000	7.2	1120
2	04/2016 - 12/2017	1.5	Spectrosil 2000	7.2	1120
3a	04/2016 - 12/2016	0.5	Spectrosil 2000	28.0	1000
3b	04/2017 - 12/2018	2	Spectrosil 2000	7.2	1120
4	04/2016 - 12/2017	1	Spectrosil 2000	0	1011
5	04/2016- 12/2017	1	Suprasil 3301	30.0	15
6	04/2016 - 12/2018	2	Suprasil 3301 (	0	14

14

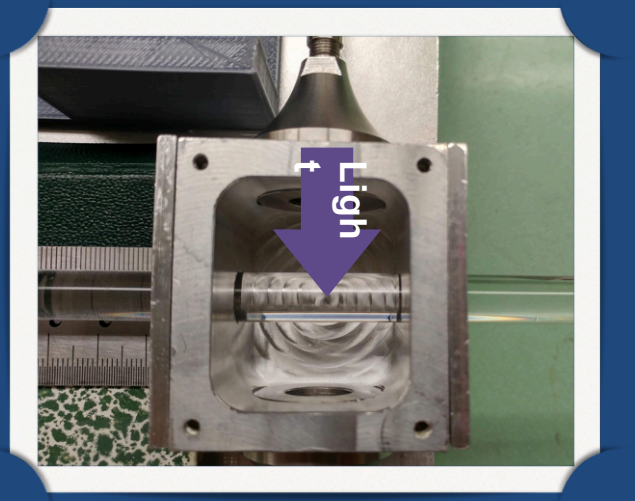
FLUKA simulation of radiation environment

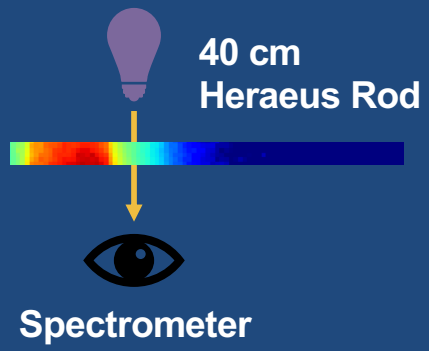


Simulation of activation matches data

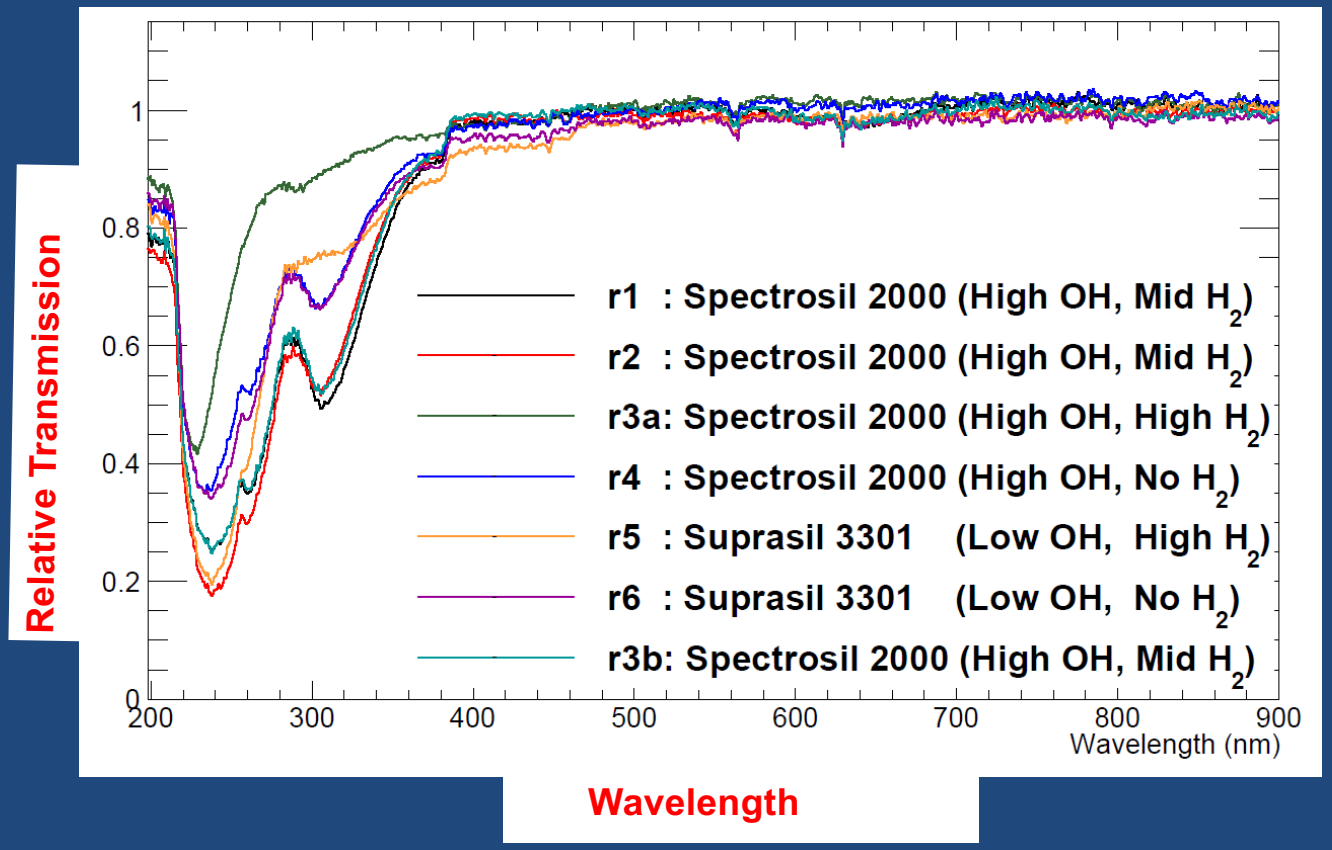


Transmission measurement



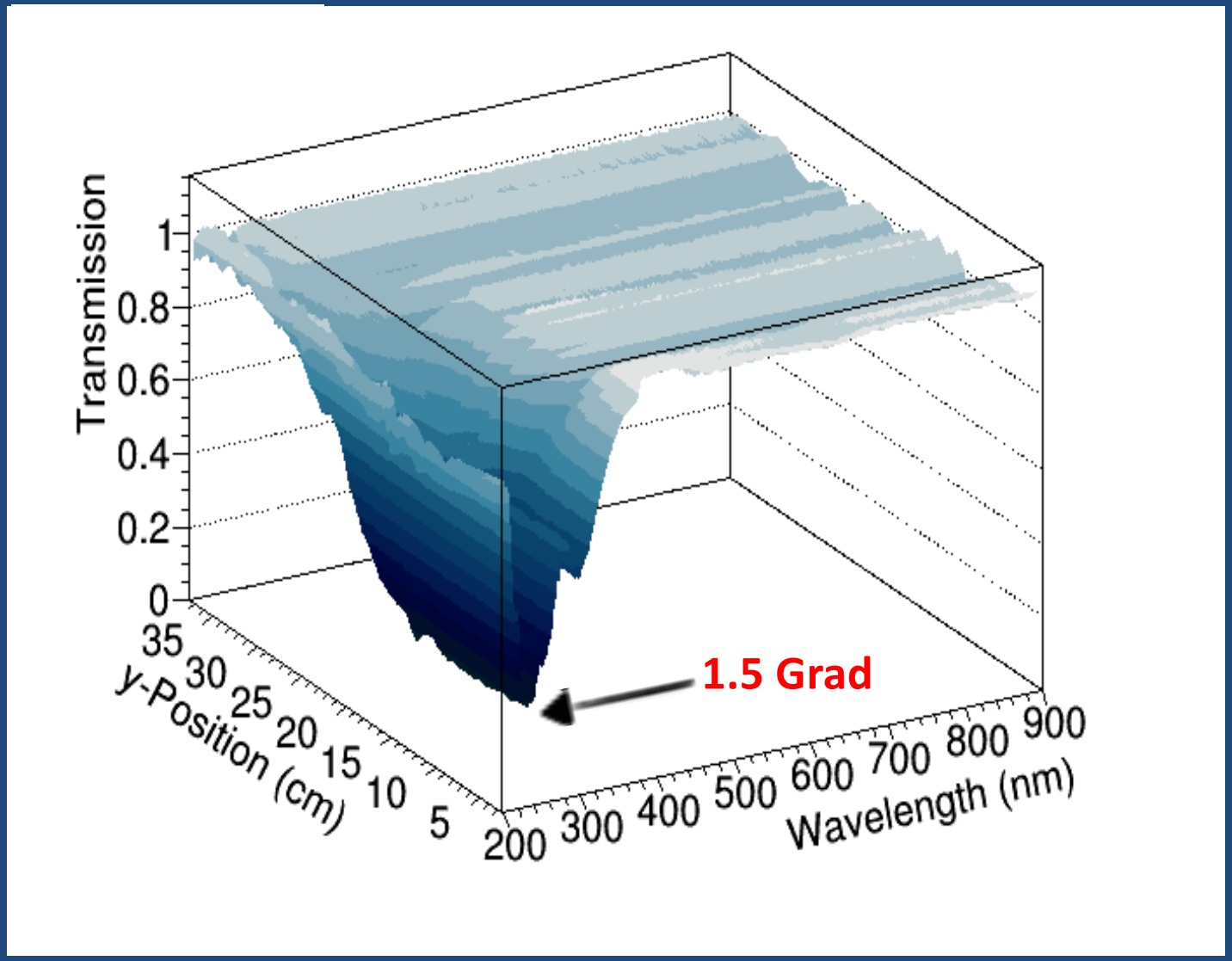


- Two color centers observed:
  - C1 ~ 240 nm
  - C2 ~ 310 nm
- Further studies on the path length dependence require cutting the rods

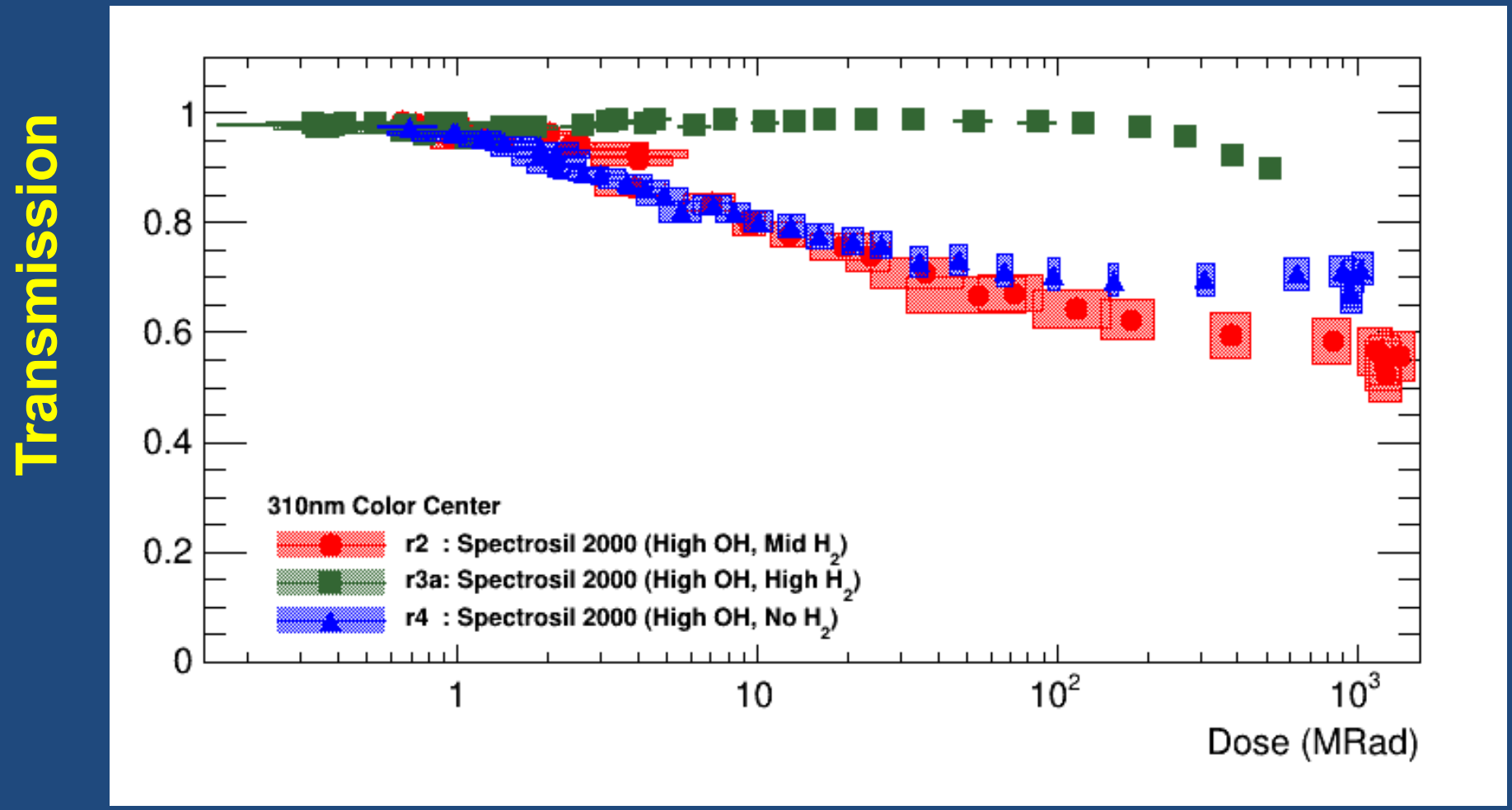


Transmission vs wavelength, dose

Rod 2: Spectrosil 2000, High OH, Low H_2 , 2 years of irradiation



Transmission vs dose λ=310nm



Further irradiation tests

- n flux ~$1.9*10^{10}$ cm^{-2} s^{-1}
  ~ 0.05 MRad/hour
- γ ~ 2 MRad/hour

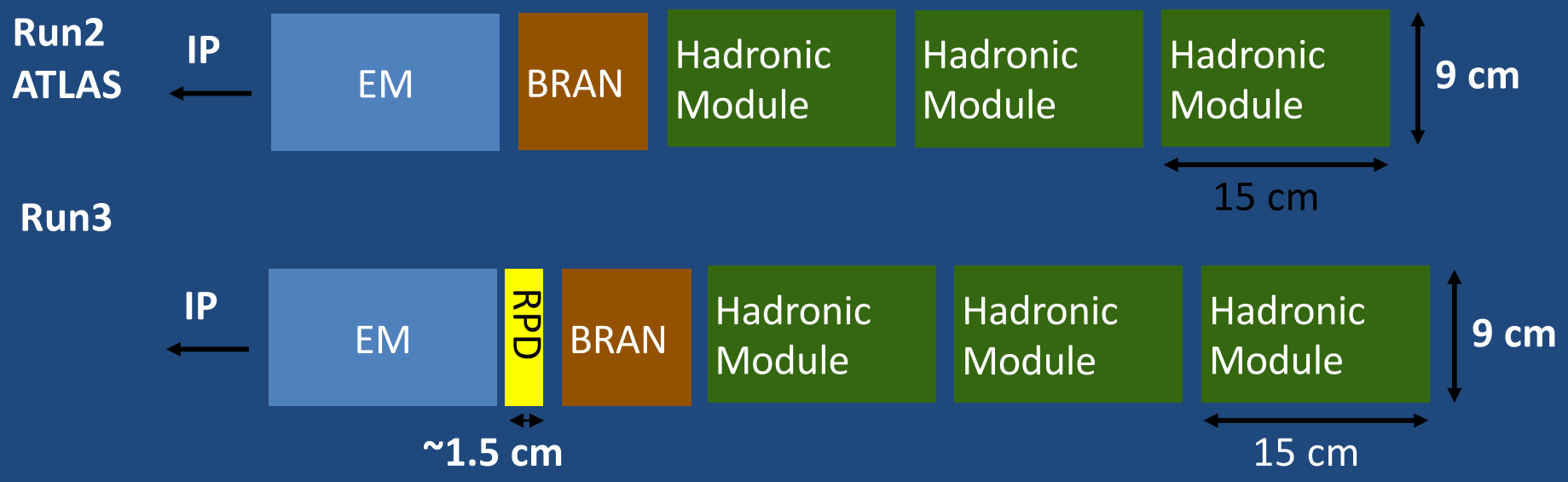
- n
  - n flux ~$2.5*10^{13}$ cm^{-2} s^{-1}
  - ~ 0.1 GRad/hour
- γ ~ 12 GRad/hour

- 3 MeV Van de Graaff
- e^- up to ~0.6 GRad/hour
- γ ~ 1.3 MRad/hour

Increase irradiation a few Grad (3-4) to study transmission loss

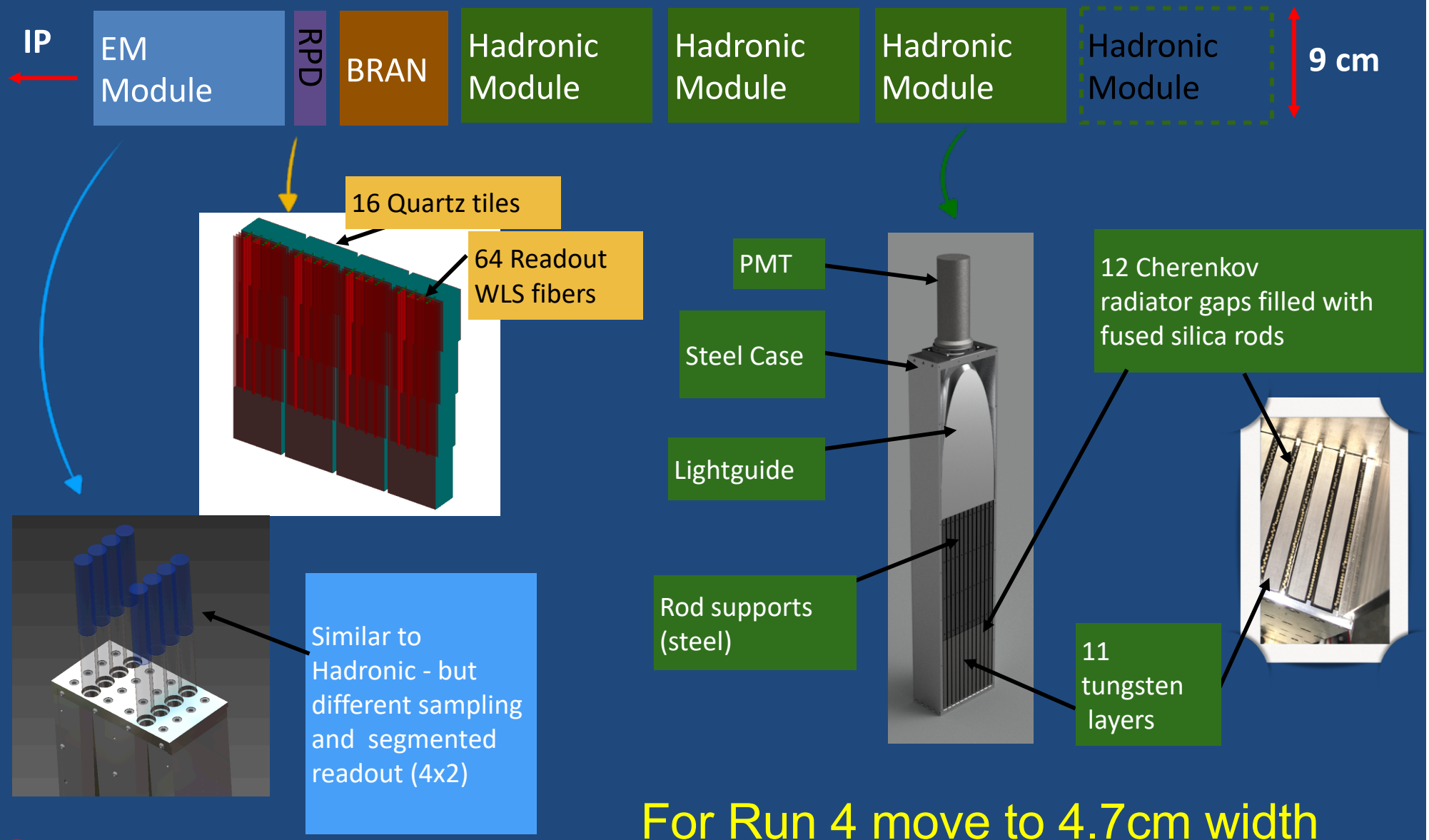
20

Detector configuration



- **RPD placed at Cherenkov shower max;**
- **For Run4, the detector will be rebuilt (narrower space in TAN - 5cm).**

Run3: Preliminary detector configuration



For Run 4 move to 4.7cm width

Future work

- Test fused silica up to several Grads in reactors
- Make a full Run 3 prototype for May 2020
- Refurbish ATLAS ZDC for Run 3 with fused silica, and add RPD
- CMZ ZDC is rad hard enough for Run 3
- For Run 4 develop rad hard identical ZDCs for CMS, ATLAS with fast electronics for timing.
- Segmented EM, RPD and hadronic sections should identify photons neutrons and their orientation in azimuth.

Summary

- New materials allow the possibility for the ZDCs to operate at the highest LHC luminosities.
- Increased segmentation and improved electronics will allow the ZDCs provide fast triggers for minimum bias A+A, p+A, γ+A, and γ+ γ events.
- ZDCs should also be able to operate for months of pp running.
- RPD and segmented EM section allow greatly increased separate of neutrons and photons and should allow us to measure orientation of collision.

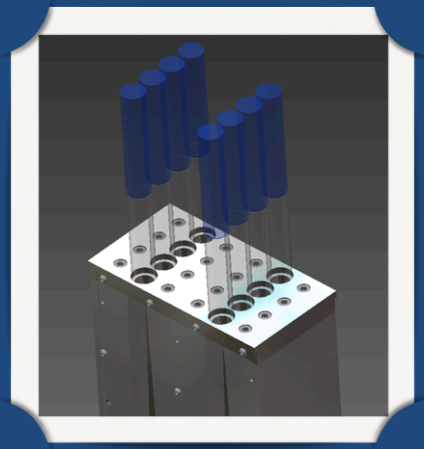
Backup

Upgraded EM module

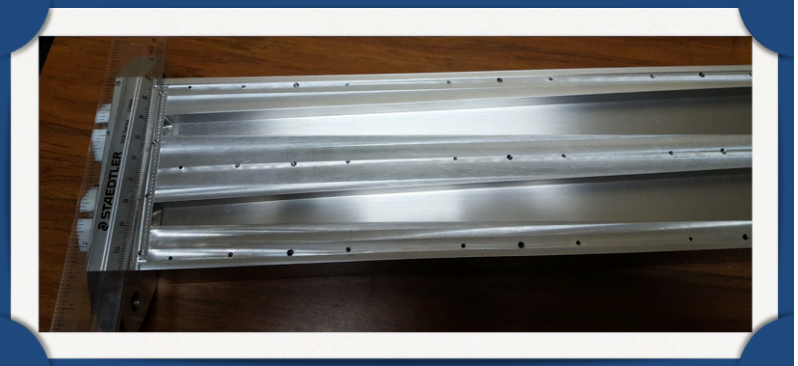
- Segmented design: 4 segments in x, 2 in z.
- Small Run4 prototypes tested @ Fermilab.

EM module
2 mm sampling

EM module
4 mm sampling



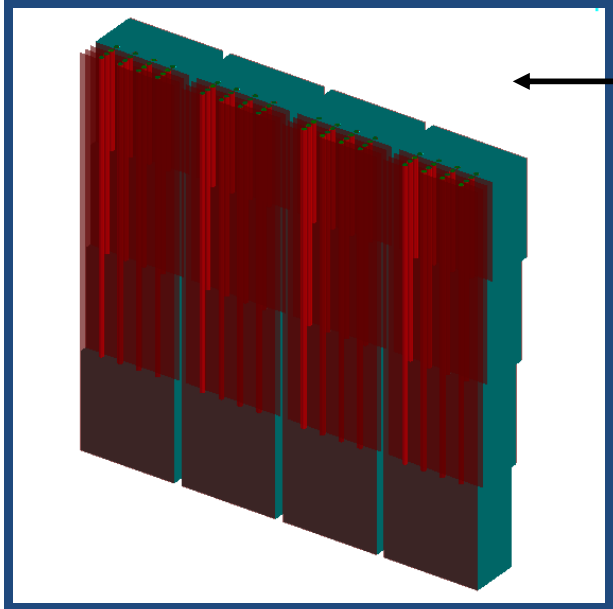
Segmented
PMT readout



Light-guides of two z-segments

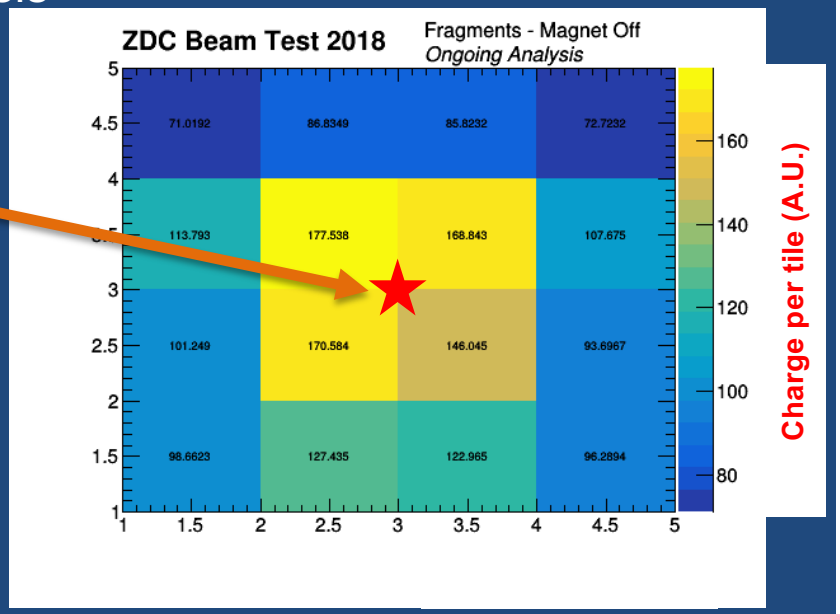
Will use rad hard fused silica rod and Winston cone light-guides

Reaction plane detector in CMS



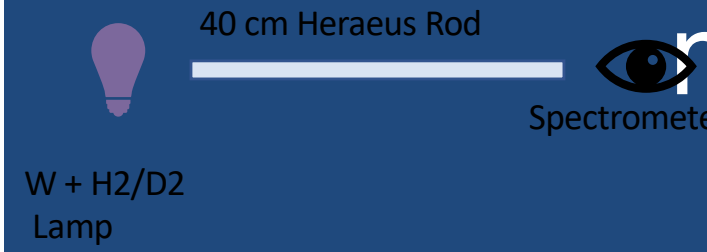
- 4 x 4 array of quartz tiles, with wavelength shifting fibers.
- Background signal induced in the WLS fibers running behind other tiles
- WLS fibers currently not radiation hard
- Size 8.5 x 8.5 x 1.5 cm^3
- CMS 2018 HI data analysis
- SPS Test beam

Beam spot

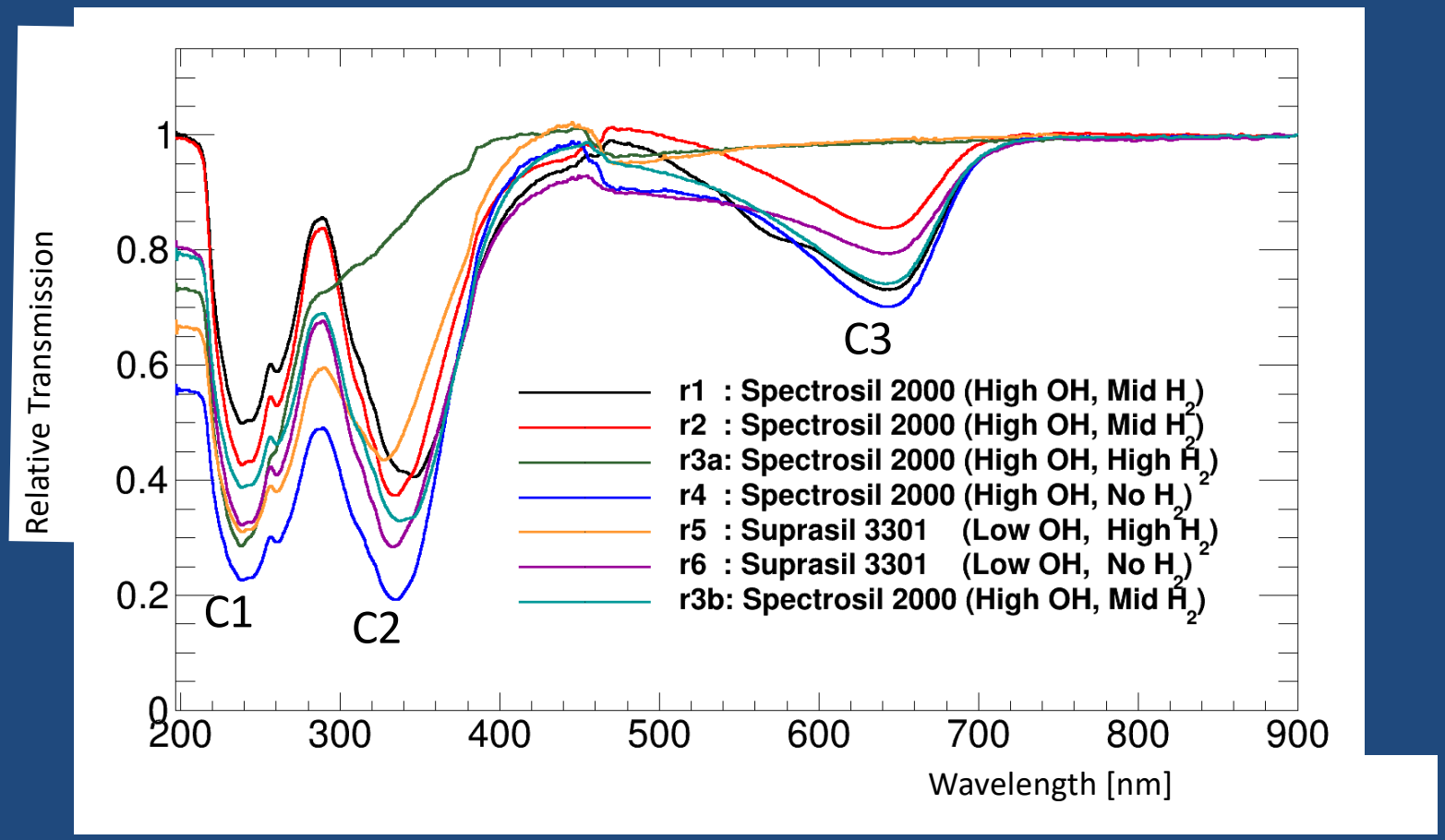


- Different designs considered
- Final implementation will be rad hard
- Coupled reconstruction of the reaction plane

Longitudinal Transmission measurement



- Longitudinal transmission measurements allow to determine attenuation over similar scales relevant to ZDC and BRAN



- Three main color centers observed: **C1** ~ 240 nm, **C2** ~ 310 nm , **C3** ~ 640 nm

28

λ = 240 nm - Different H_2 level

Increasing level of H_2

Rod	Irr. Period	Peak exp.	Material	H_2 [mol/cm^3]	OH [ppm]
4	04/2016 - 12/2017	1 Grad	Spectrosil 2000 (High OH, H2 free)	0	1011
2	04/2016 - 12/2017	1.5 Grad	Spectrosil 2000 (High OH, Low H2)	7.20e17	1120
3a	04/2016 - 12/2016	0.5 Grad	Spectrosil 2000 (High OH, High H2)	2.80e18	1000

- Similar trends to 310 nm, but higher level of damage
- Transmission cut-off for high H_2 confirmed at 240 nm

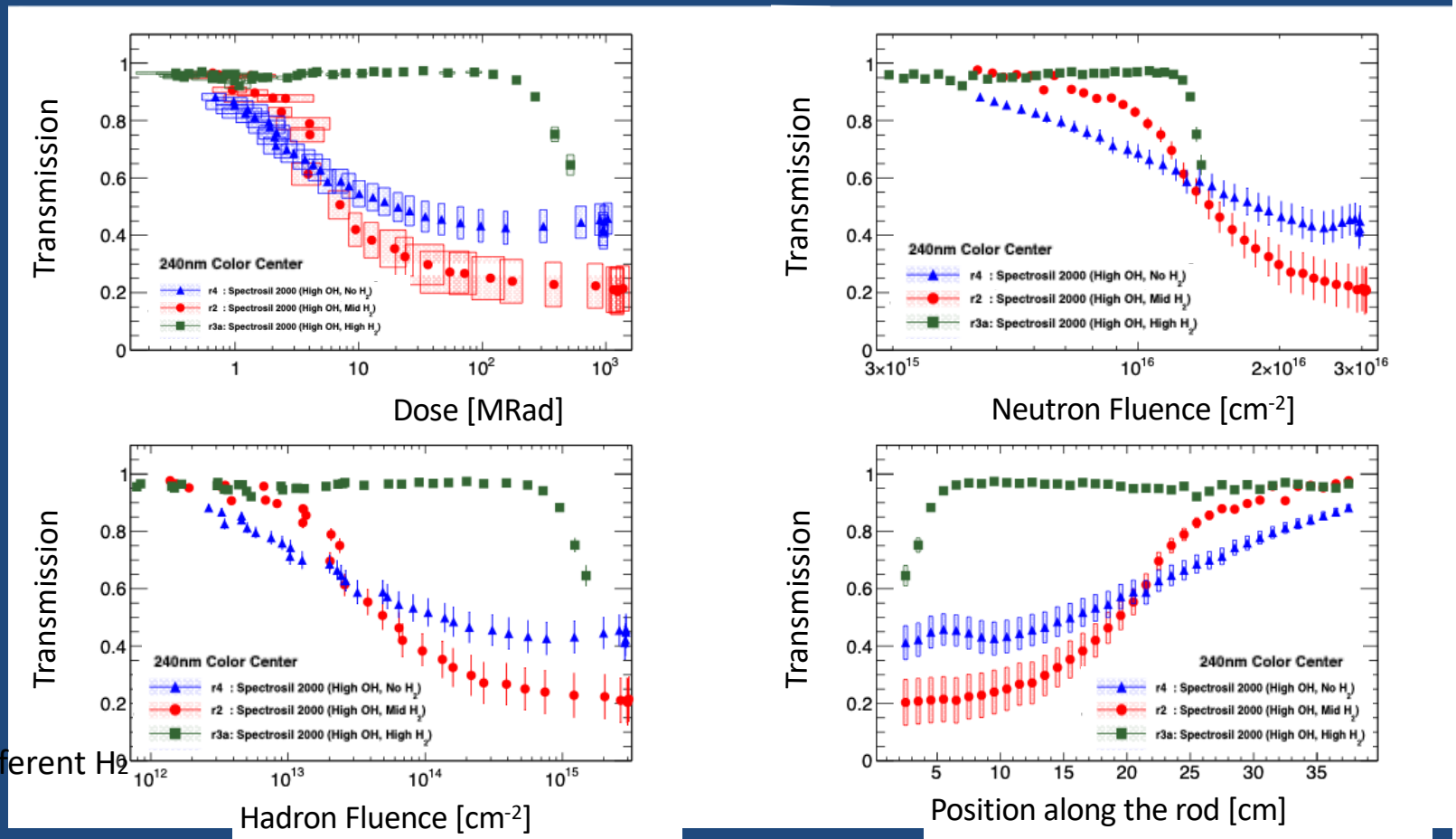
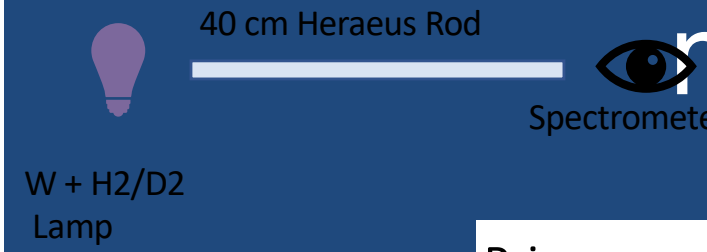


Fig.19: Transmission for λ = 240 nm for rods with different H_2 level

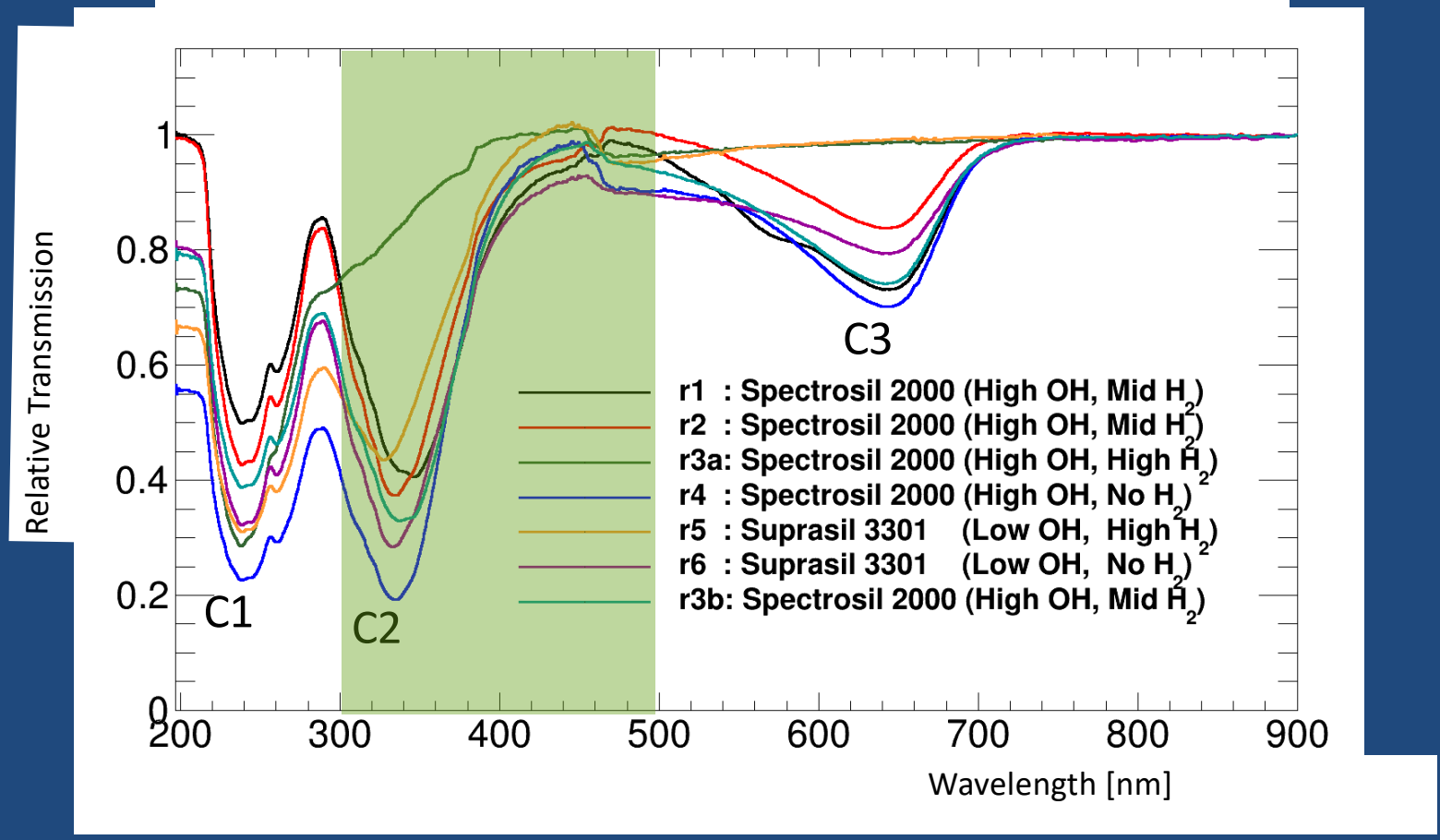
29

Longitudinal Transmission measurement



- Longitudinal transmission measurements allow to determine attenuation over similar scales relevant to ZDC and BRAN

Primary sensitivity region of the PMT [300 ; 500] nm



- Three main color centers observed: **C1** ~ 240 nm, **C2** ~ 310 nm , **C3** ~ 640 nm

30

λ = 310 nm - SAME MATERIAL

- Self-repairing effect observed with increasing H_2 concentration
- Hints for a cut-off of this effects (lack of H_2?)
- Measurement of remaining H_2 quite difficult. Different possibilities being inspected
- H_2 free rod shows initial loss but stable plateau above 100 MRad

Increasing dose

Rod	Irr. Period	Peak exp.	Material	H_2 [mol/cm^3]	OH [ppm]
1	04/2016 - 12/2018	3 GRad	Spectrosil 2000 (High OH, Mid H2)	7.20e17	1120
3b	04/2017 - 12/2018	2 GRad	Spectrosil 2000 (High OH, Mid H2)	7.20e17	1120
2	04/2016 - 12/2017	1.5 GRad	Spectrosil 2000 (High OH, Mid H2)	7.20e17	1120

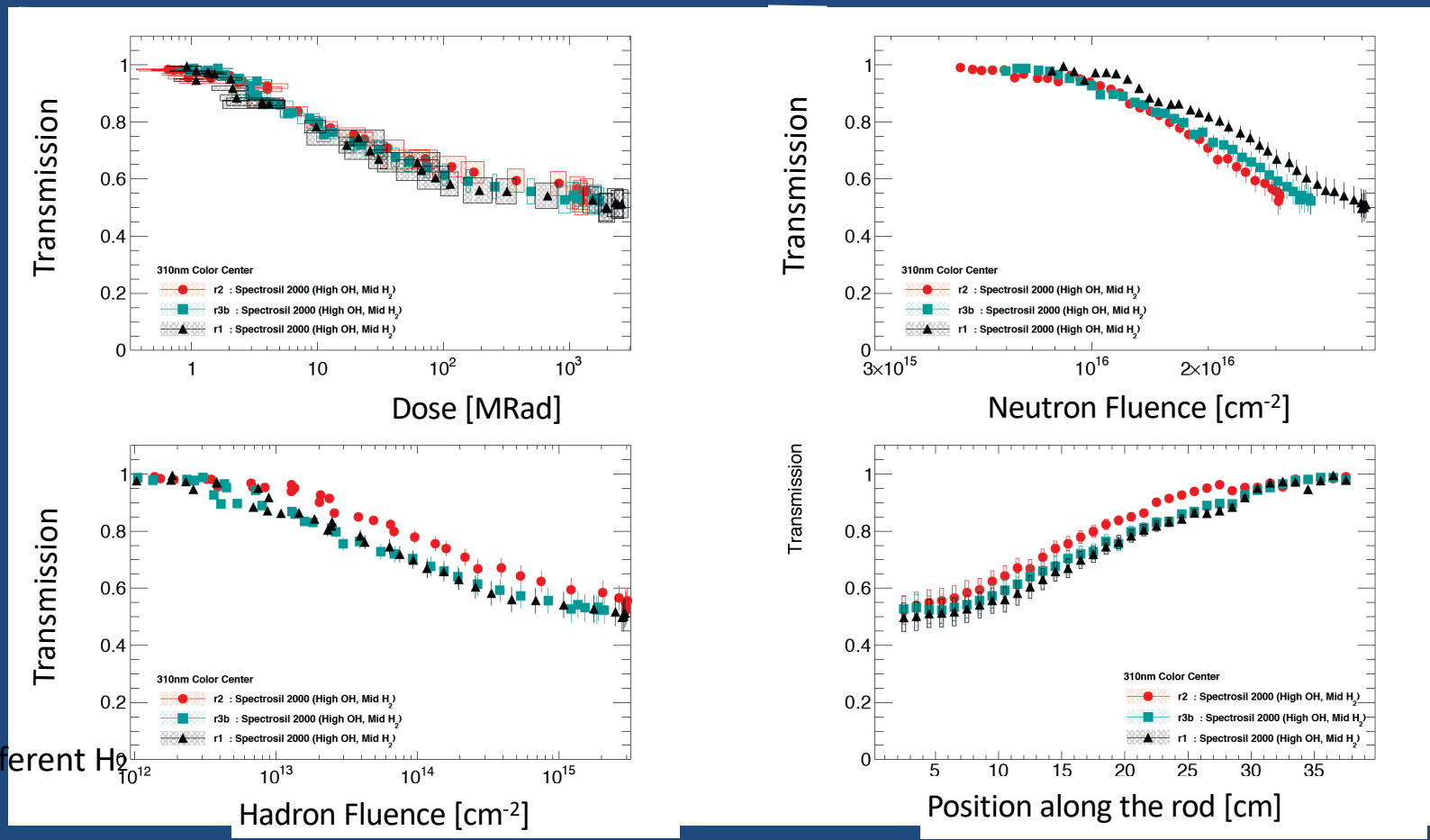
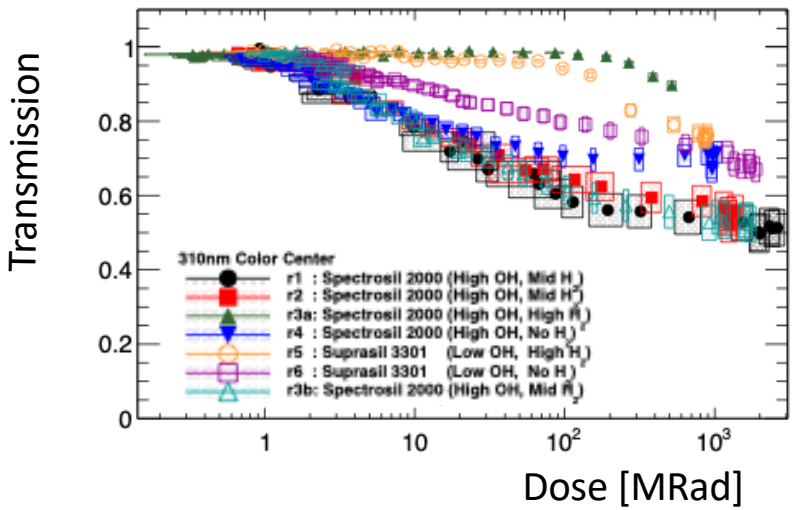
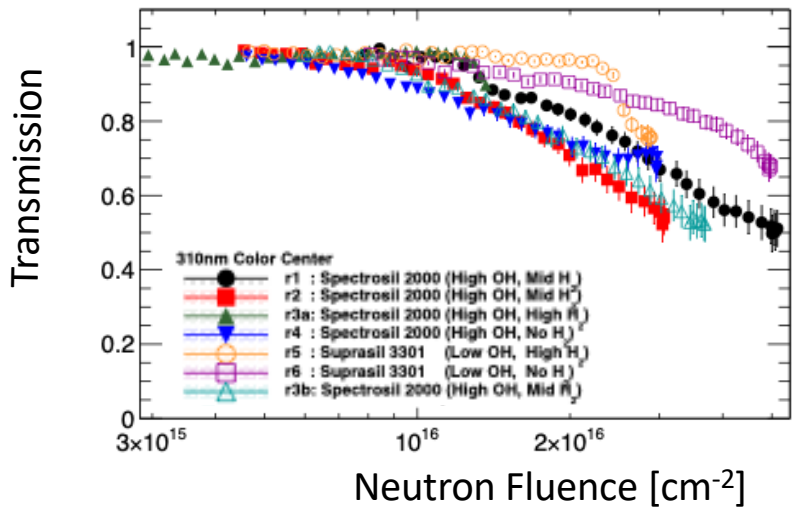


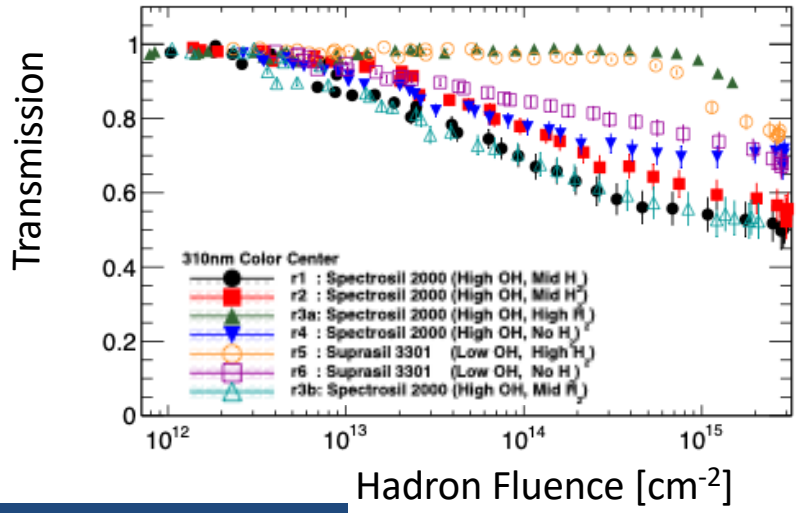
Fig.18: Transmission for λ = 310 nm for rods with different H_2 level

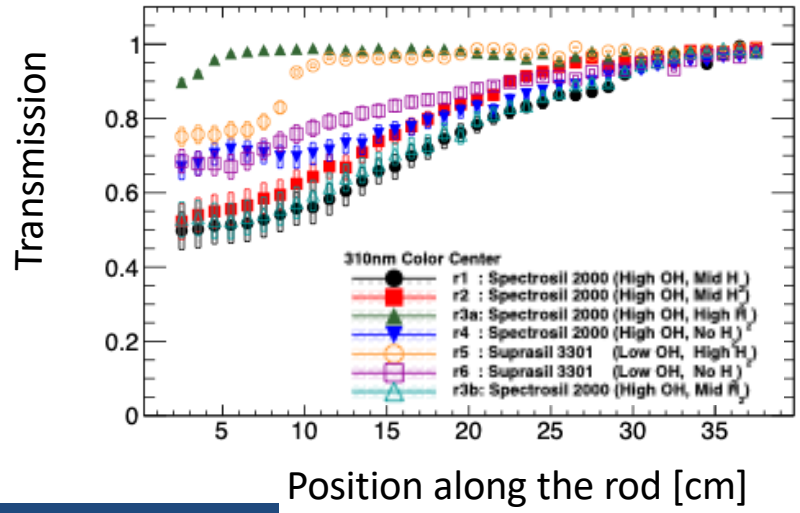
Results: λ = 310 nm

- Using FLUKA simulations we can transform from transmission vs position along the rod to transmission vs [dose, hadron fluence and neutron fluence]









32

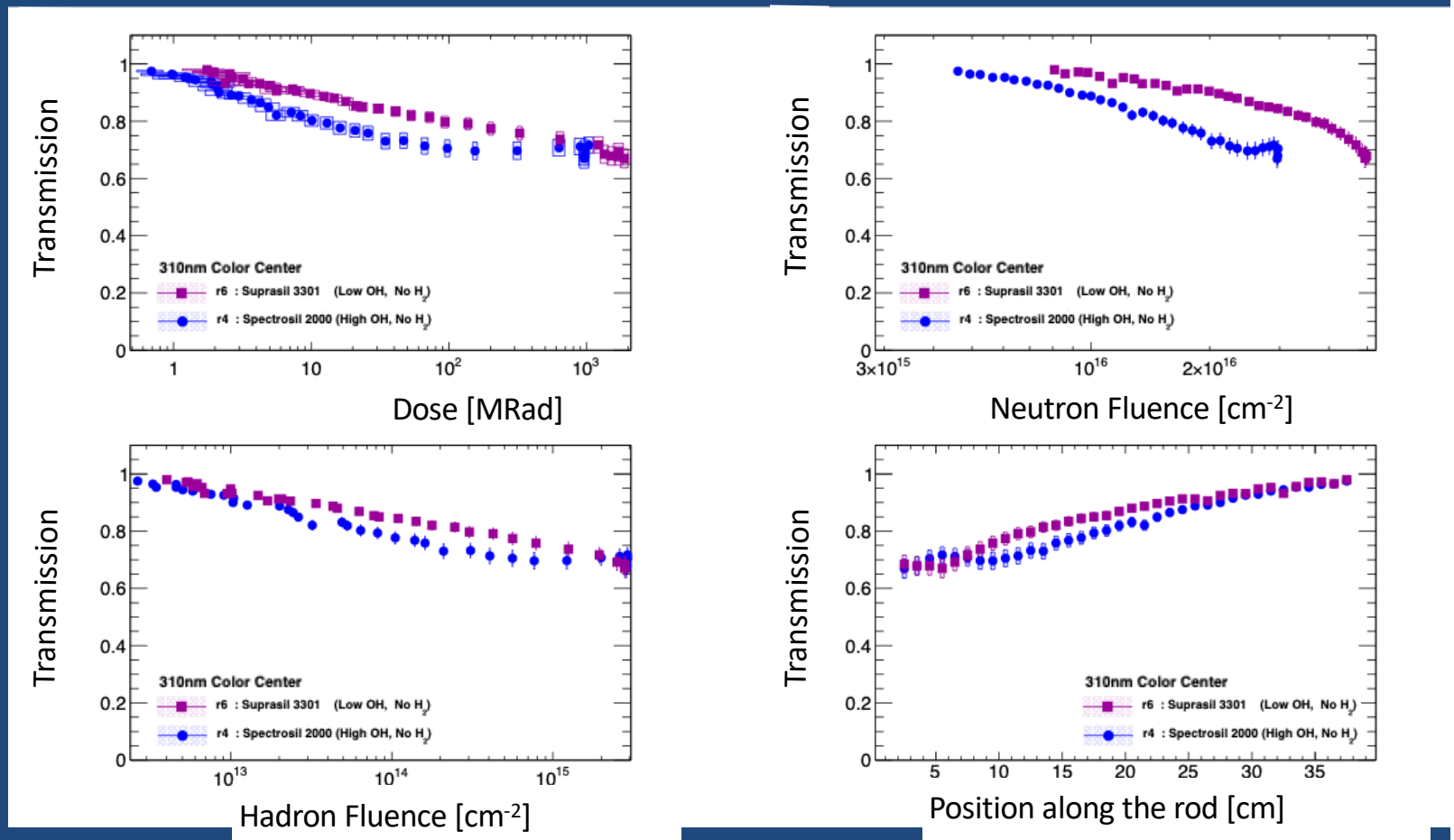
λ = 310 nm - Different H level

Increasing level of OH

Rod	Irr. Period	Peak exp.	Material	H_2 [mol/cm^3]	OH [ppm]
6	04/2016 - 12/2018	2 GRad	Suprasil 3301 (Low OH, H2 free)	0	14
4	04/2016 - 12/2017	1 GRad	Spectrosil 2000 (High OH, H2 free)	0	1011

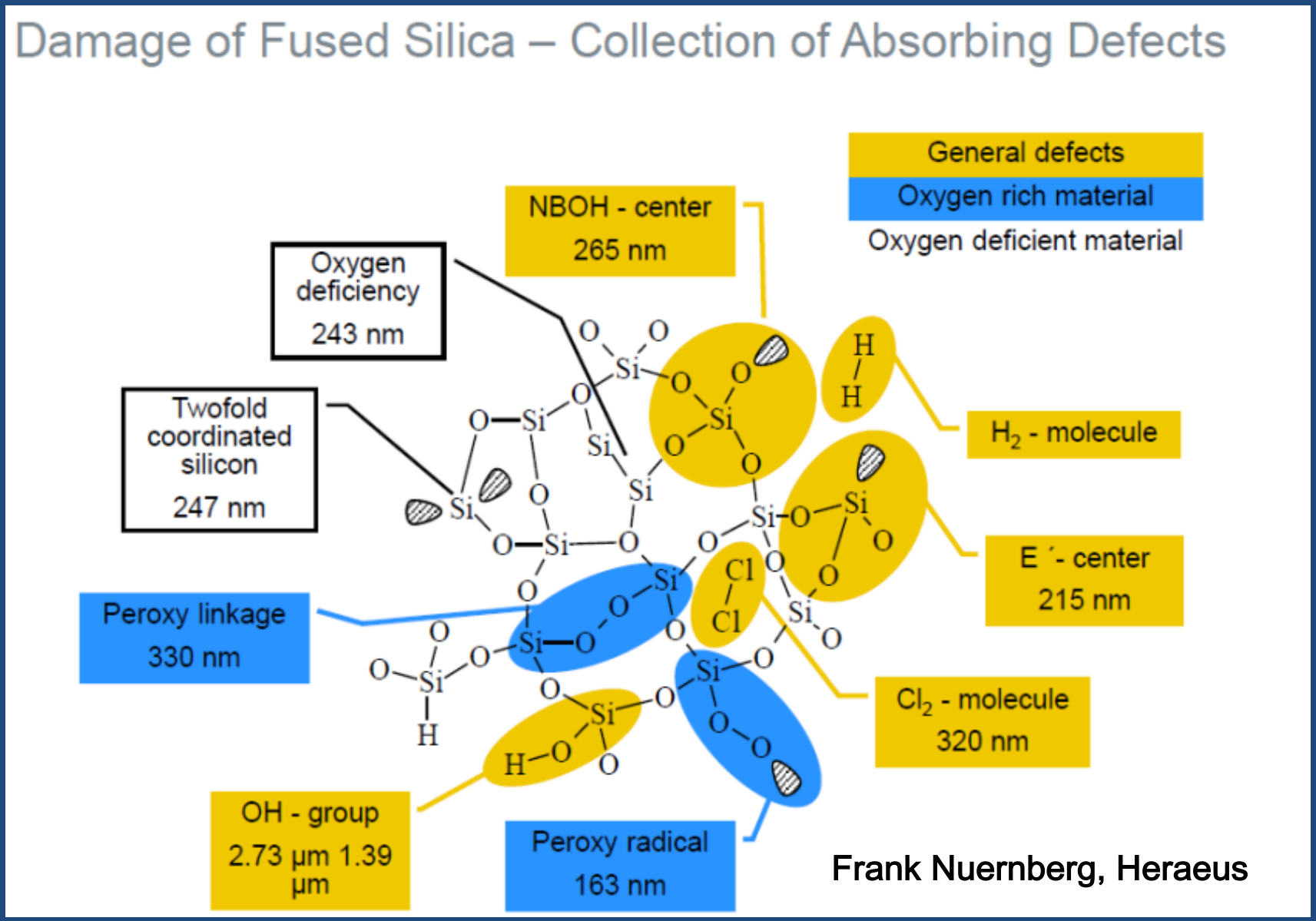
- Rod with lower level of OH shows better transparency up to 1 GRad
- Hints for crossing point around 1 GRad
- More irradiation needed to extend analysis to higher doses and confirm interesting features (e.g. plateau for

Fig.20: Transmission for λ = 310 nm for rods with different OH level



33

Fused Silica

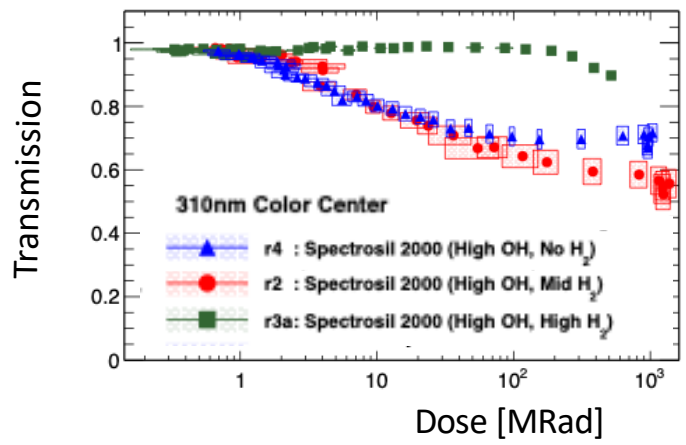


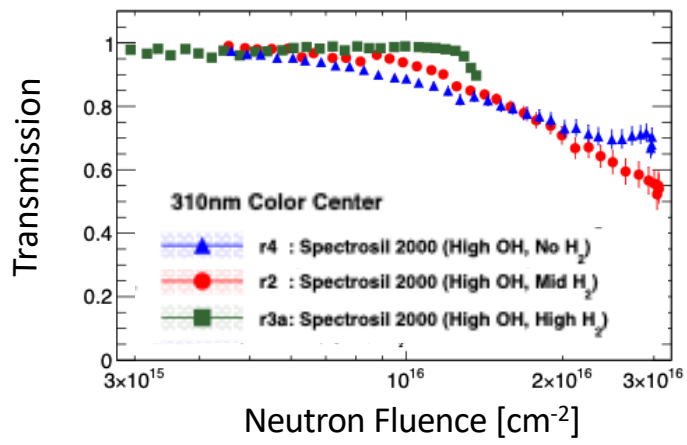
λ = 310 nm - Different H_2 level

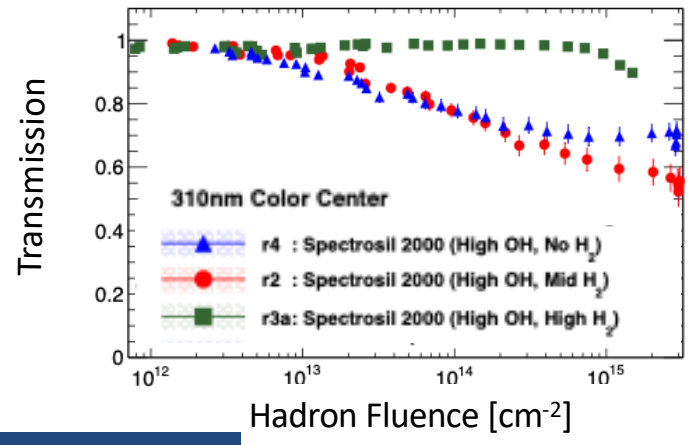
- Self-repairing effect observed with increasing H_2 concentration
- Hints for a cut-off of this effects (lack of H_2?)
- H_2 free rod shows initial loss but stable plateau above 100 MRad
- More irradiation needed to extend analysis to higher doses and confirm observed features

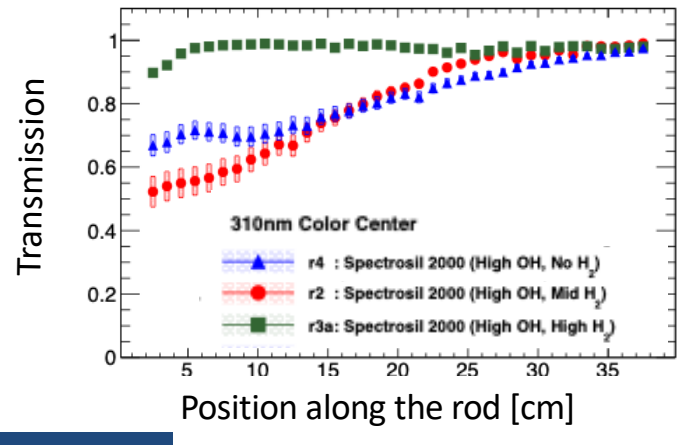
Increasing level of H_2

Rod	Irr. Period	Peak exp.	Material	H_2 [mol/cm^3]	OH [ppm]
4	04/2016 - 12/2017	1 Grad	Spectrosil 2000 (High OH, H2 free)	0	1011
2	04/2016 - 12/2017	1.5 Grad	Spectrosil 2000 (High OH, Mid H2)	7.20e17	1120
3a	04/2016 - 12/2016	0.5 Grad	Spectrosil 2000 (High OH, High H2)	2.80e18	1000





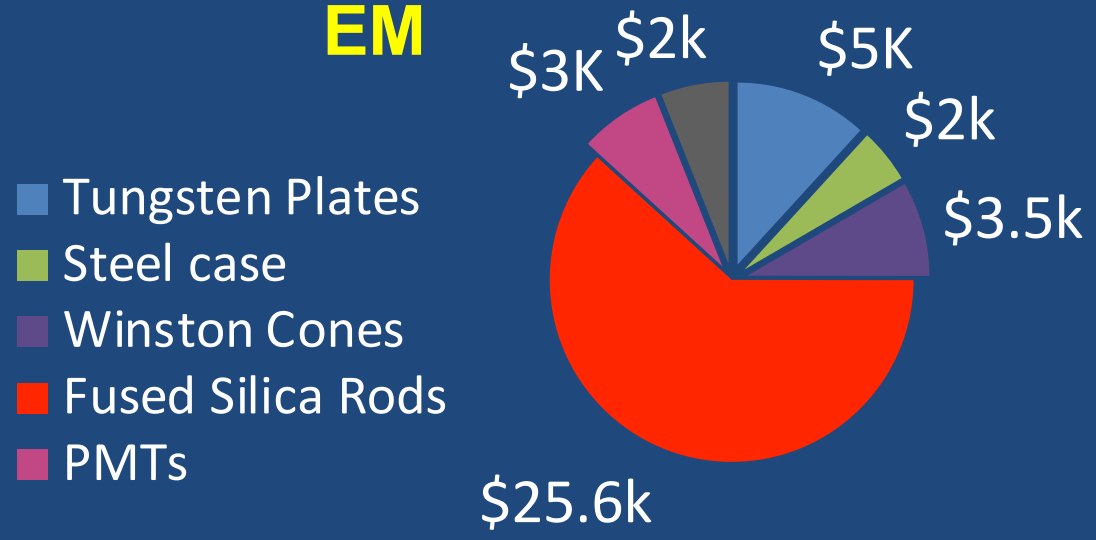




35

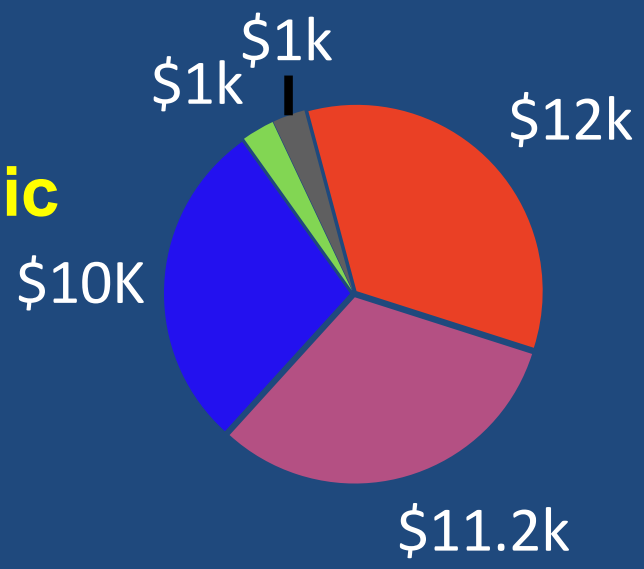
Costs per module

EM

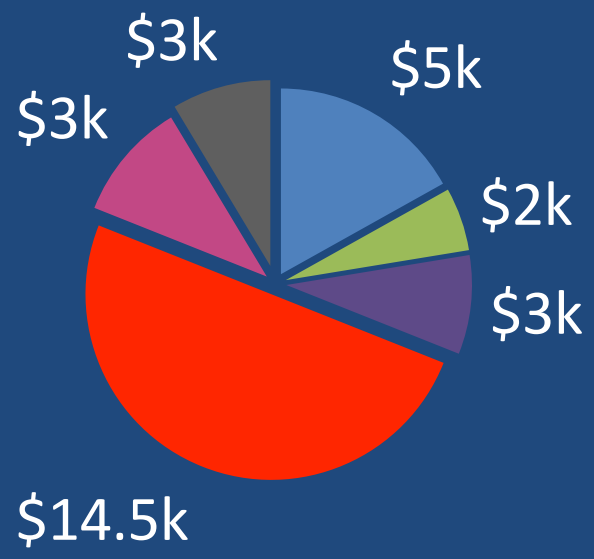


Prices include 10% contingency

Hadronic



RPD



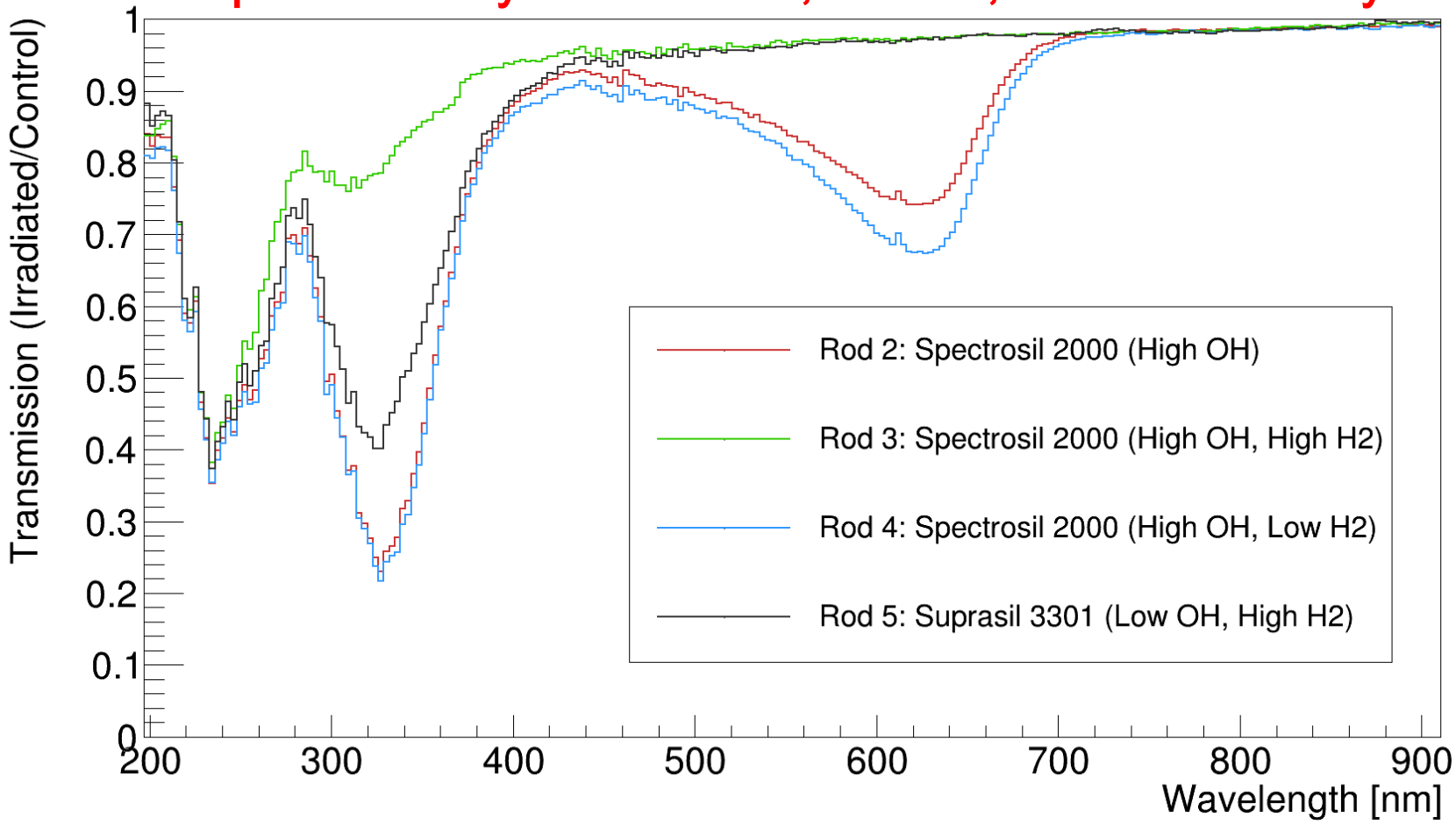
Detector Costs

Module	Cost	#	Total
Hadronic	$29.1K	6	$175k
EM	$42.2K	2	$83k
RPD	$35.2	2	$70k
Final cost			$328k

For Run 3 there are no additional electronic costs for CMS

Optical Spectrometry of Bran Rods

Rod 3 exposed for 1 year in BRAN, Rods 2,4 and 5 for two years.

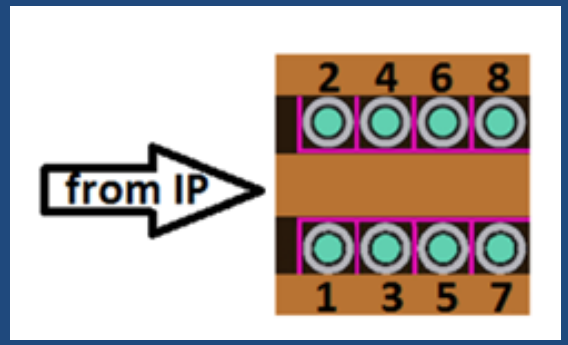


Rods irradiated for 2 years show same loss as rod irradiated for 1 year. Suggests saturation of absorption site

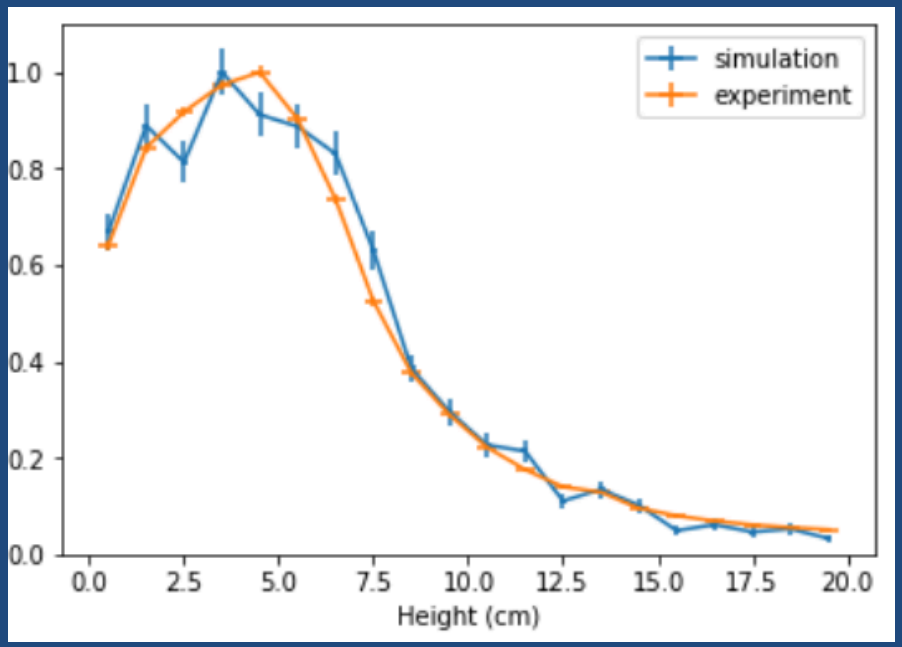
Simulation vs data for activation

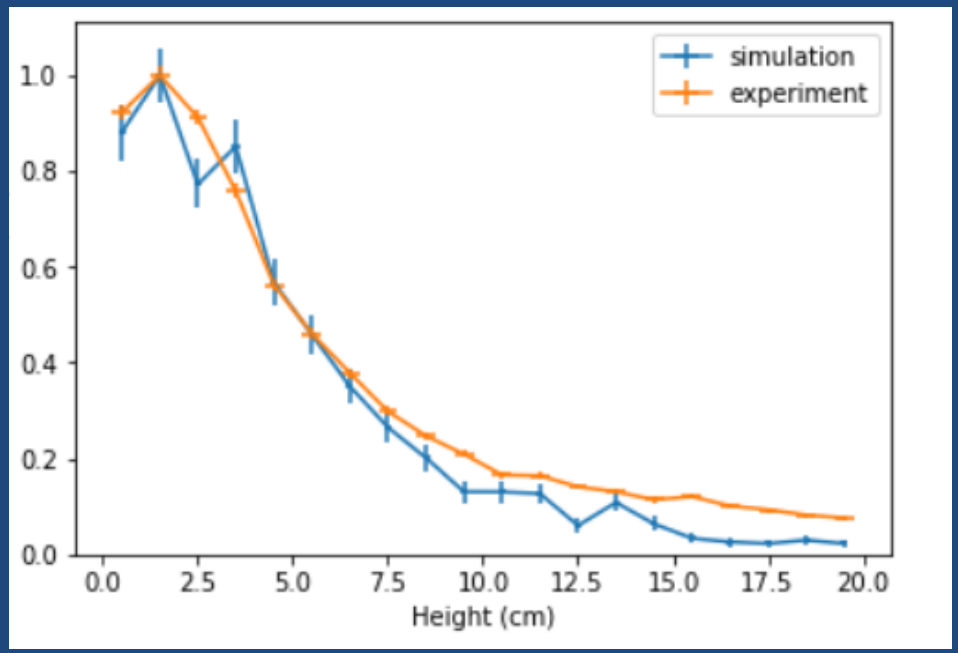
Simulation: Activity of Na-22 in rods vs length in FLUKA simulation (Marta Sabate Gilarte, Francesco Cerutti)

Experiment: Count rate of 511 keV photon peak with GE-detector



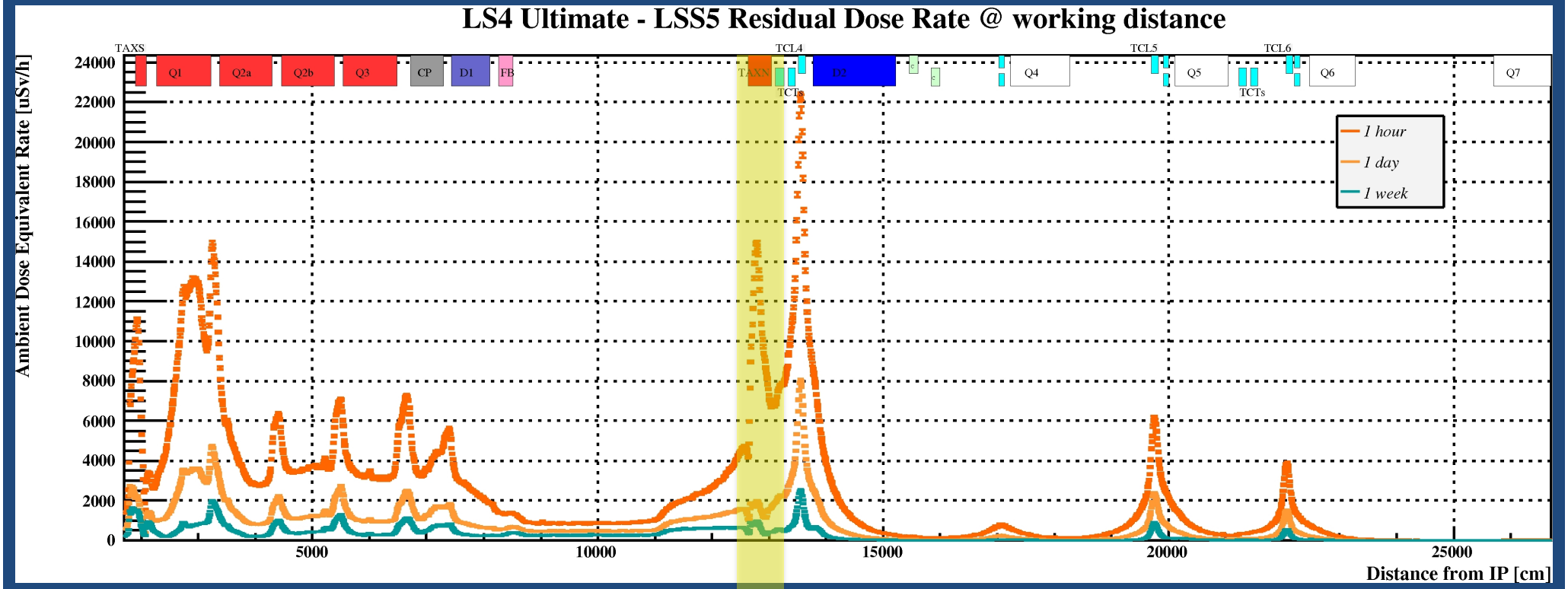
Rod order in BRAN module





Dimension along the fused silica rods

Residual Dose Rate Profiles



ZDC

Dose estimate for installation

- LS4 Ultimate scenario
- 10 minutes next to each element end (only part of the work)
- 2 worker: 1 in the aisle, 1 next to the element

		dose rate (μSv/h)				10 minute dose (μSv)			
	distance from IP	1 week	1 month	4 month	1 year	1 week	1 month	4 month	1 year
TAXN	**126m**	**900**	**450**	**150**	**55**	**150**	**75**	**25**	**9**
	130m	**400**	**220**	**90**	**30**	**67**	**37**	**15**	**5**
						2 hour dose (μSv)			
Aisle	**-**	**50**	**25**	**10**	**5**	**100**	**50**	**20**	**10**

Light-guide studies