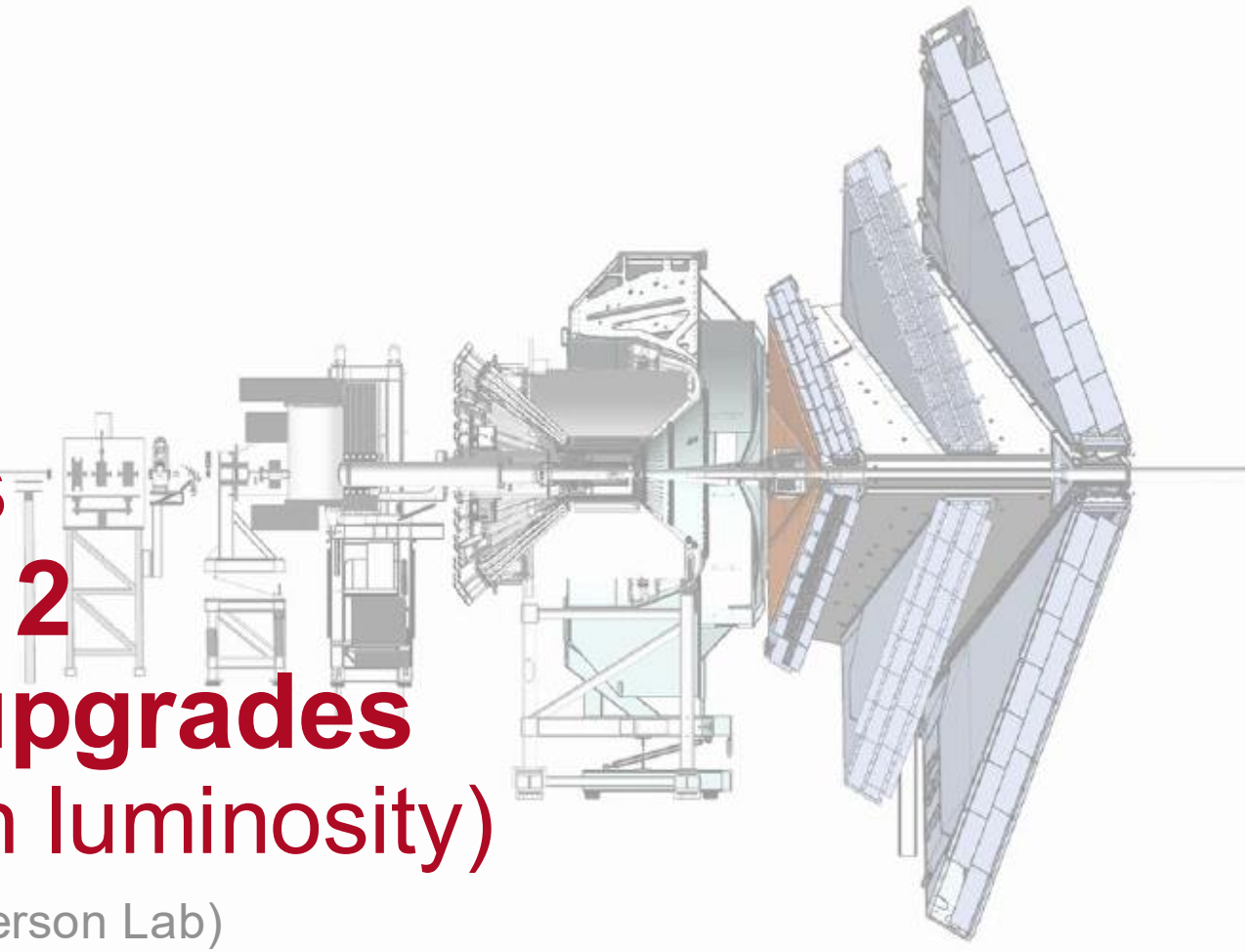
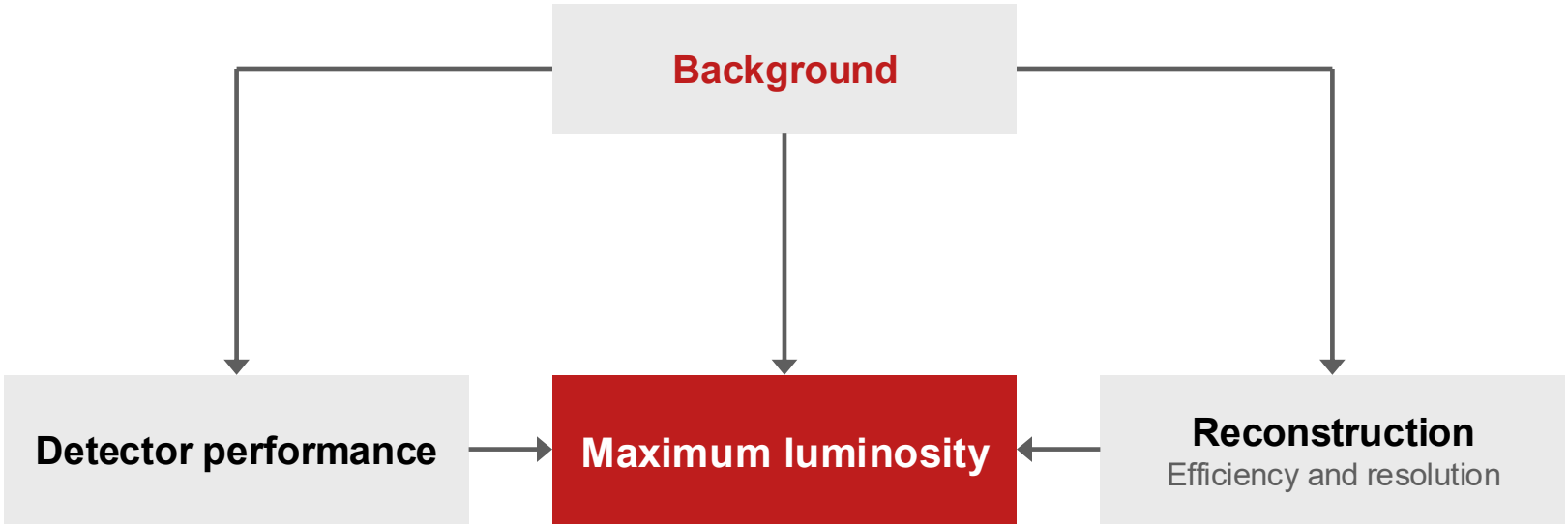


Prospects for CLAS12 detector upgrades (toward high luminosity)

Raffaella De Vita (Jefferson Lab)

High luminosity operation

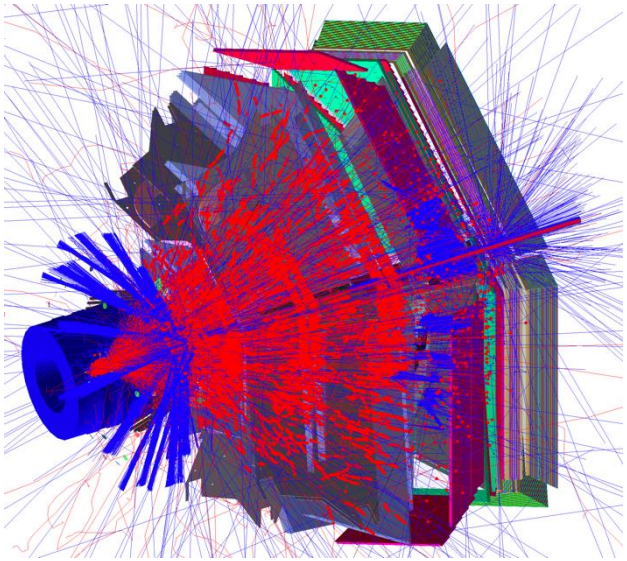
- Maximum luminosity of 1.5 x 10^{35} $cm^{-2}s^{-1}$ achieved on liquid deuterium target with 11 GeV electron beam
- Not a hard limit but chosen as the optimal setting, considering background levels, detector performance, reconstruction efficiency and resolution



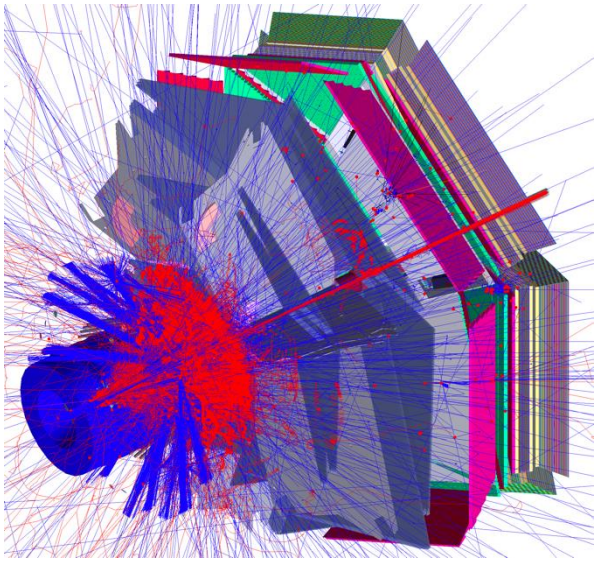
Backgrounds

- Main source is electromagnetic interaction of the electron beam in the target (Moller electrons)
- Suppressed via
  - Active shielding provided by the torus and solenoid magnetic fields
  - Passive shielding: high-Z material surrounding the beamline, outside the detector acceptance
- Highest impact on tracking detectors (DC Region 1)

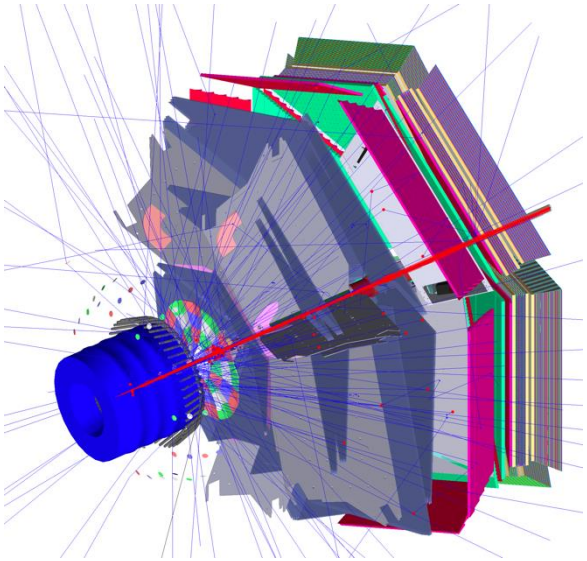
No field



Torus on

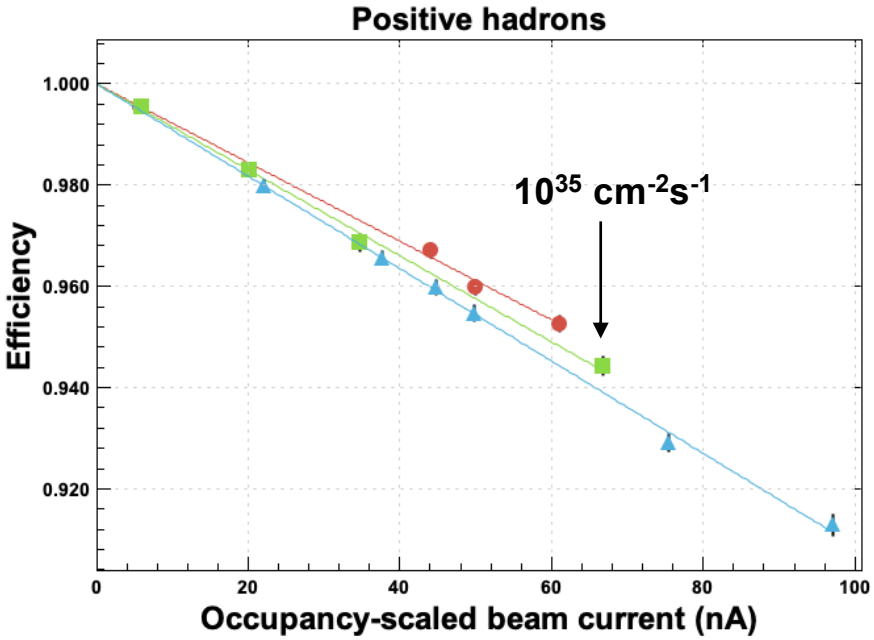


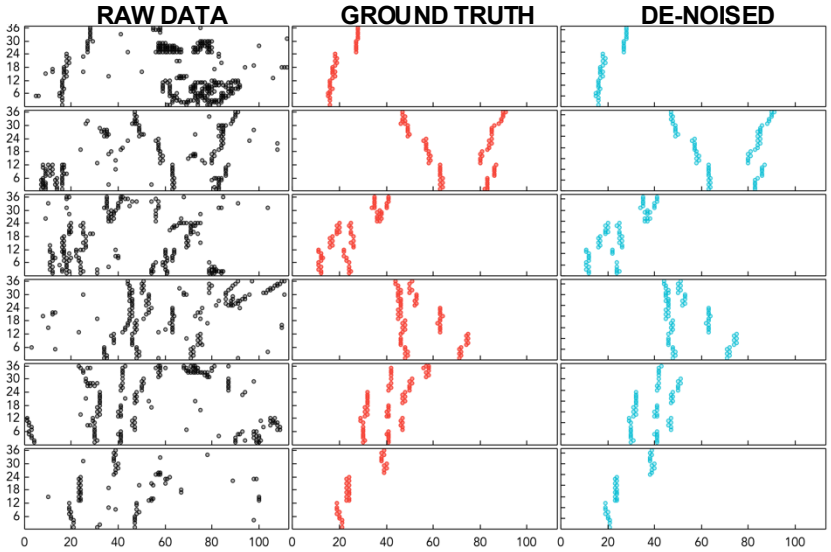
Solenoid on



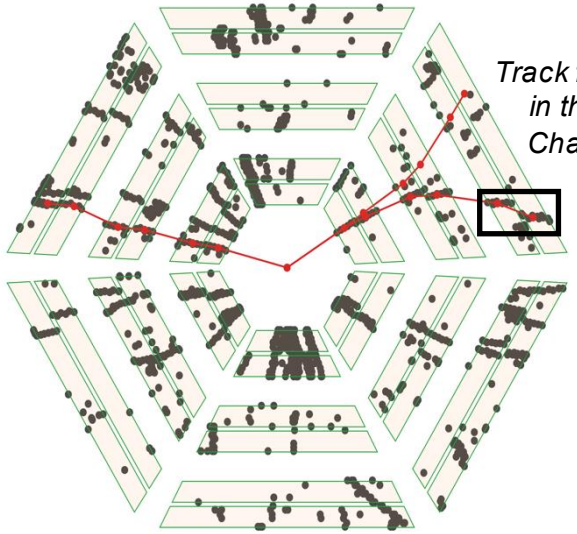
Reconstruction efficiency

- Strong reduction of background impact on reconstruction efficiency achieved using AI
  - Detector denoising
  - Track finding
  - …





Denoising in the Drift Chambers

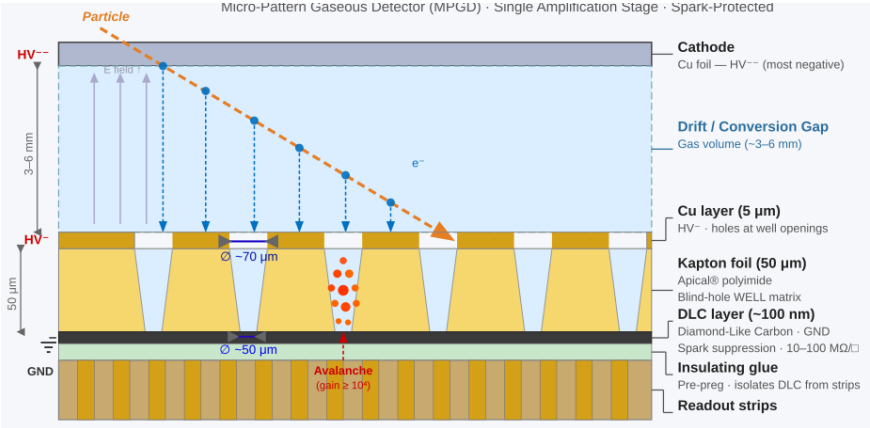


Track finding in the Drift Chambers

μRWELL tracker for DC Region 1

Goal: μRWELL layers in front of DC Region 1 recover hits lost at high luminosity and, with better timing, reject noise (2×10^{35} $cm^{-2}s^{-1}$, >85% track efficiency)

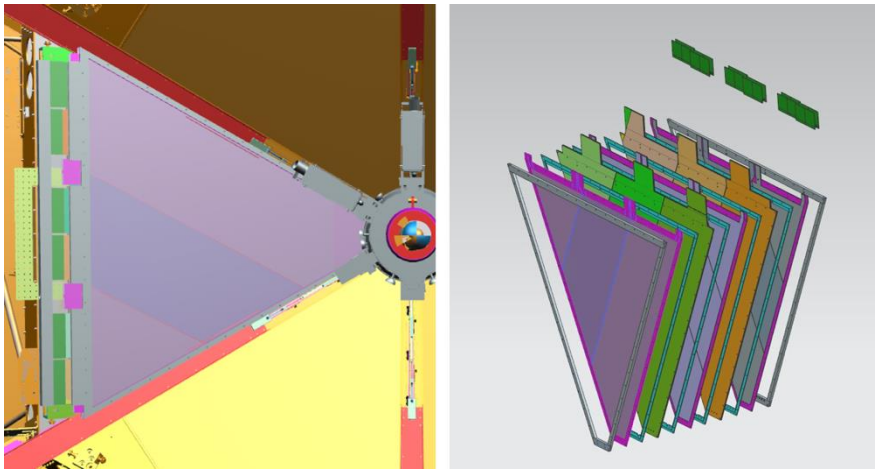
Working principle



μRWELL cross-section

- Single amplification stage in a 50 μm Kapton well matrix, gain ~10^4
- Resistive DLC layer suppresses sparks
- Simpler, cheaper and lighter than a triple-GEM, no frames needed in the active area

Full-size design

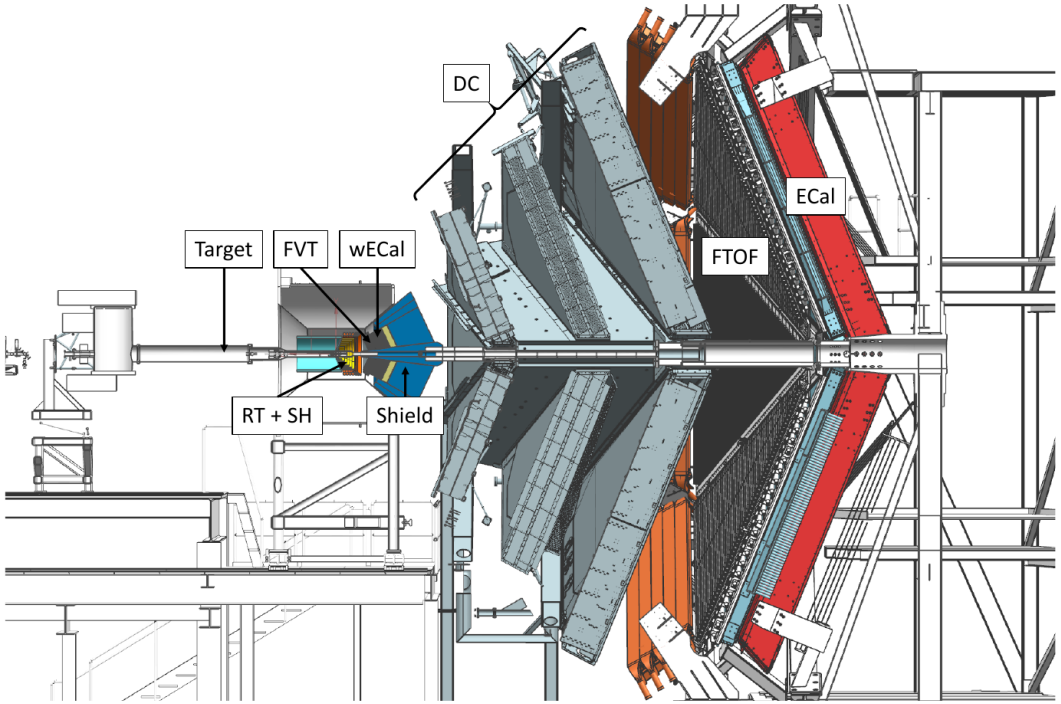


Module in front of R1 (left) and exploded U-V-U-V layers (right)

- Four 1D layers U-V-U-V, three 44.8-cm sections each
- 1 mm pitch, strips parallel to the sides
- VMM3 readout, 7 ASICs per board
- Candidate production design

μCLAS12 -10^{37} $cm^{-2}s^{-1}$

Turning CLAS12 into a muon detector for the measurement of $ep \rightarrow e'\mu^+\mu^-p'$: a 60-cm lead shield around a $PbWO_4$ calorimeter replaces the HTCC, absorbing EM and hadronic background so that only muons (p > 1.5 GeV/c) reach the Forward Detector



Approved (C1) by PAC53 with A rating

Electron calorimeter (wECal)

~1320 $PbWO_4$ crystals at 60 cm, 7°–30°: scattered electron

Forward Vertex Tracker (FVT)

Six triple-GEM stations, <100 μm: muon angles at the vertex

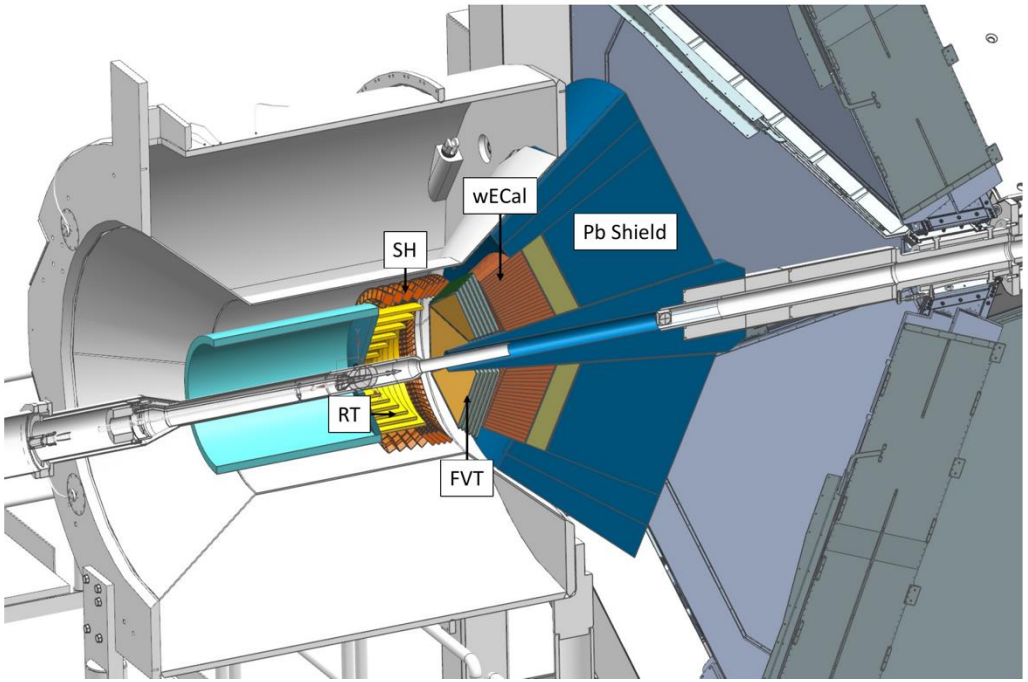
Recoil Tracker + Hodoscope

μRWELL tracker, 540 scintillators: protons at 40°–70°

$\pi^+\pi^-$ suppression	≥ 2×10^4
MIPs Trigger rate	~21 kHz (DAQ: 30 kHz)
Luminosity	**10^{37} $cm^{-2}s^{-1}$**
Beam time	200 days

μCLAS12 - 10^{37} $cm^{-2}s^{-1}$

Turning CLAS12 into a muon detector for the measurement of $ep \rightarrow e'\mu^+\mu^-p'$: a 60-cm lead shield around a $PbWO_4$ calorimeter replaces the HTCC, absorbing EM and hadronic background so that only muons (p > 1.5 GeV/c) reach the Forward Detector



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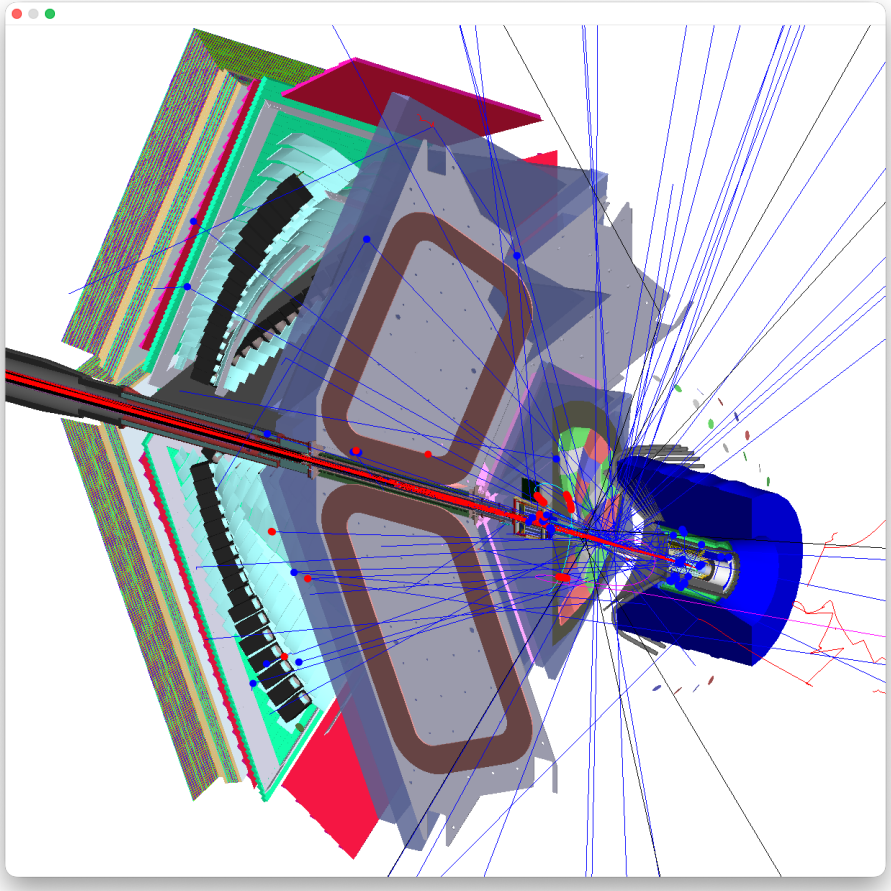
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Luminosity	**10^{37} $cm^{-2}s^{-1}$**
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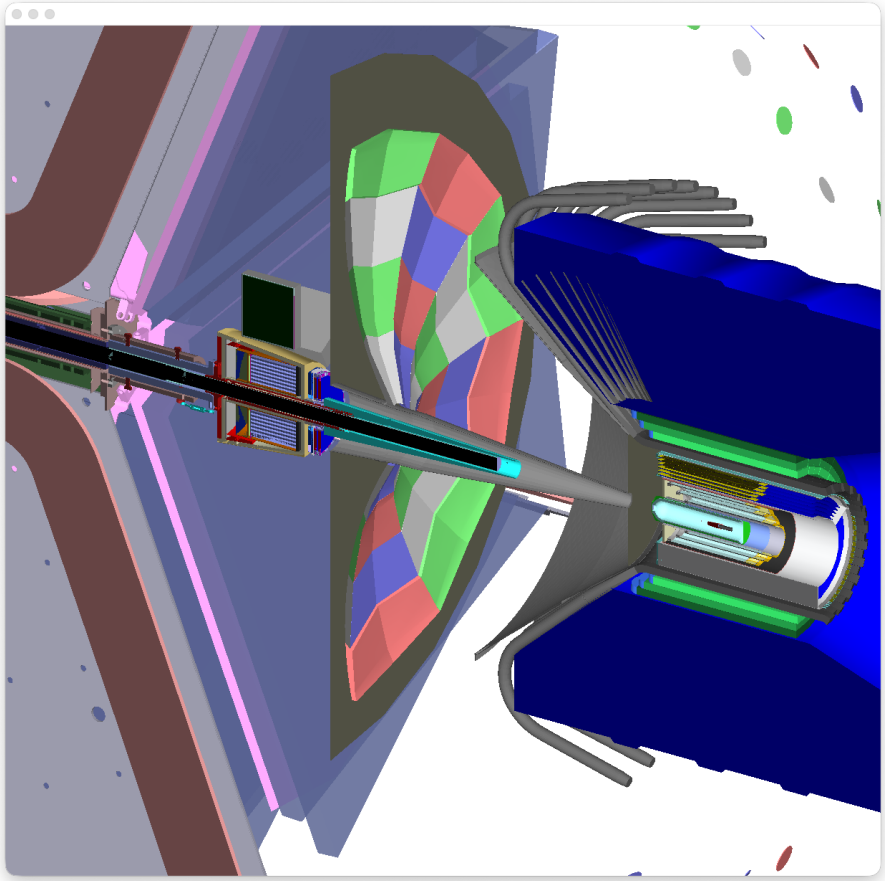
Defining an upgrade path

- Simulating the electron beam going through the target:
  - 5-cm long liquid hydrogen target (RG-A)
  - Time window of 250 ns
  - ~78k electrons/event at 50 nA
- Latest geometry including the new URWT in simulations of new configurations
- Using gemc, 6.1, with support for real-run-numbers calibration constants in detector digitization
- Scaling occupancies and rates, from the simulated time window to the actual readout windows (500, 1400, 1200 ns in R1,2, and 3) for easy comparison with data



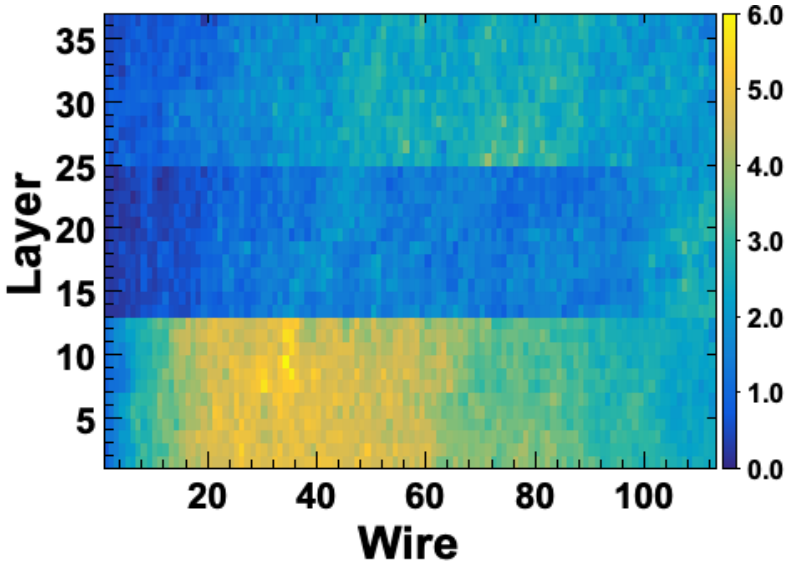
GEMC rendering of an event with 12k electrons hitting the LH2 target and CLAS12 in FTon configuration

RG-A at 50 nA



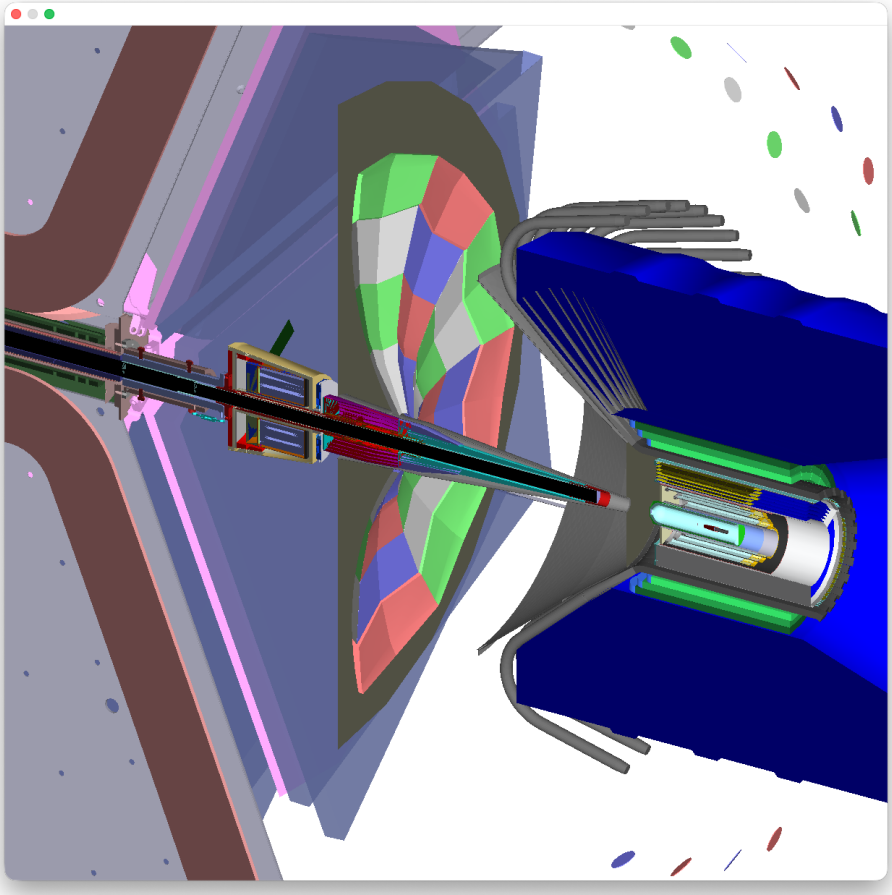
FTon configuration:

- 2.5 deg tungsten cone
- 30 mm inner radius
- ~50 cm air gap between the scattering chamber and the cone entrance



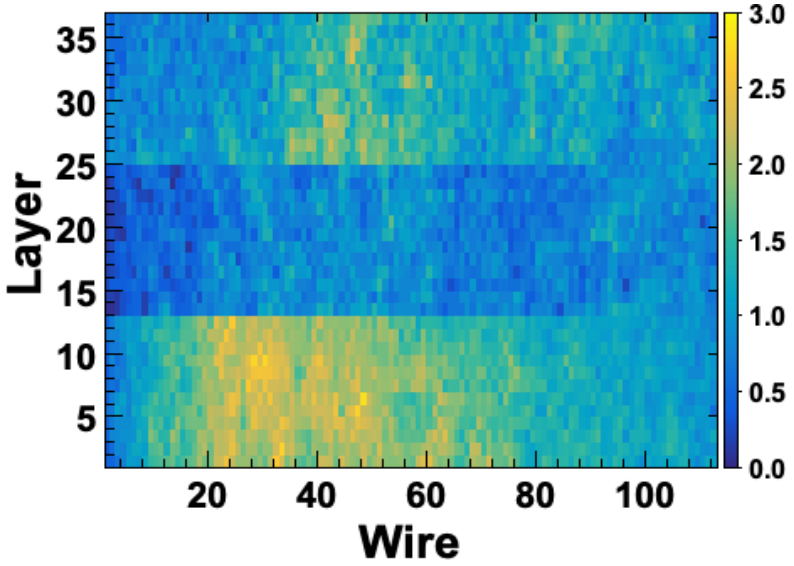
Configuration		FTon
Average Occupancy at 50 nA (%)	R1	3.71
	R2	1.51
	R3	2.02

FToff at 50 nA



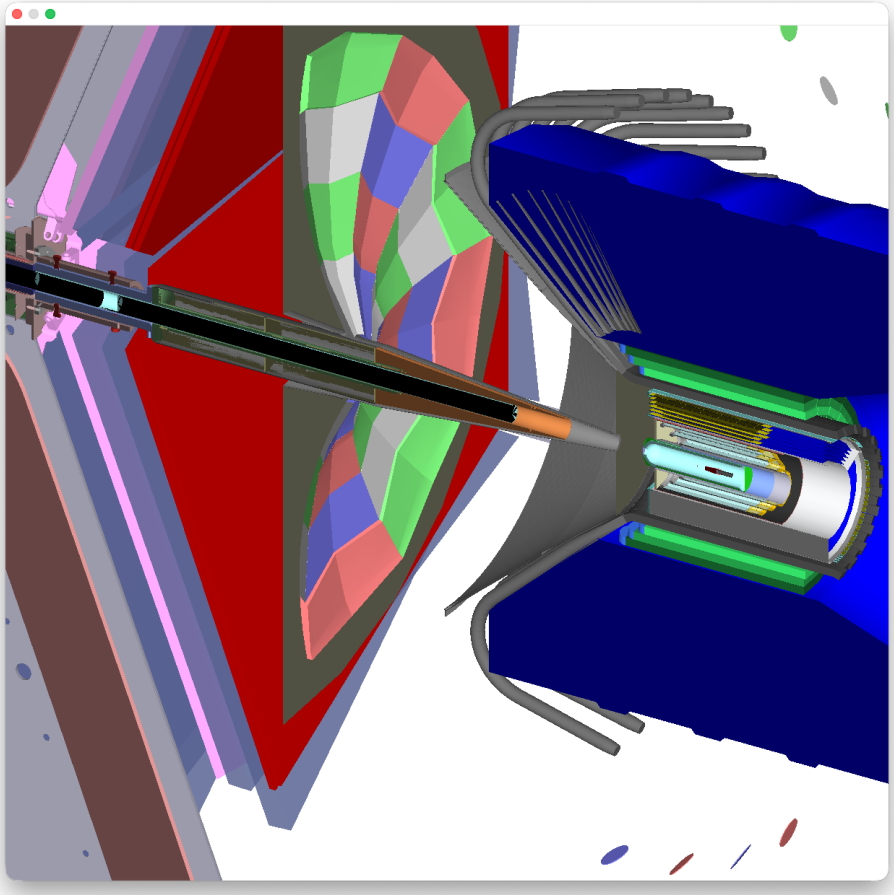
FToff configuration:

- FTon cone reconfigured with additional elements to shield up to 4.5 deg
- 30 mm inner radius
- ~20 cm air gap



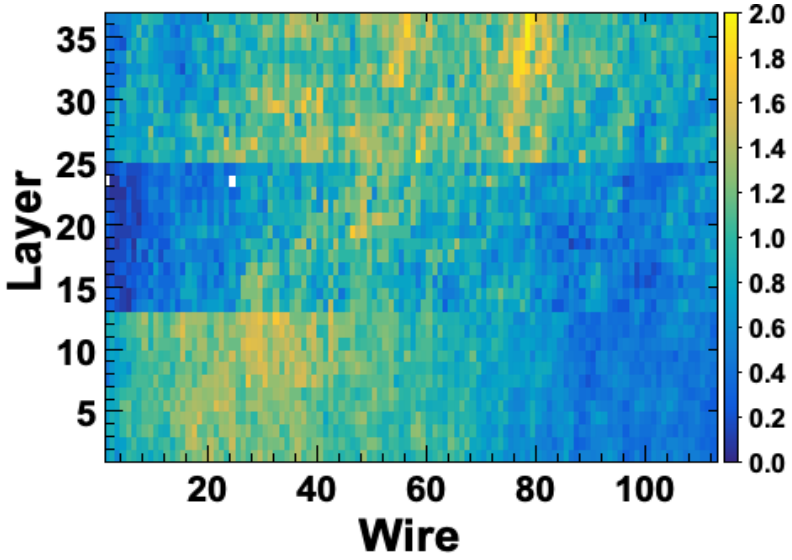
Configuration		FTon	FToff
Average Occupancy at 50 nA (%)	R1	3.71	1.59
	R2	1.51	0.83
	R3	2.02	1.22

Elmo at 50 nA



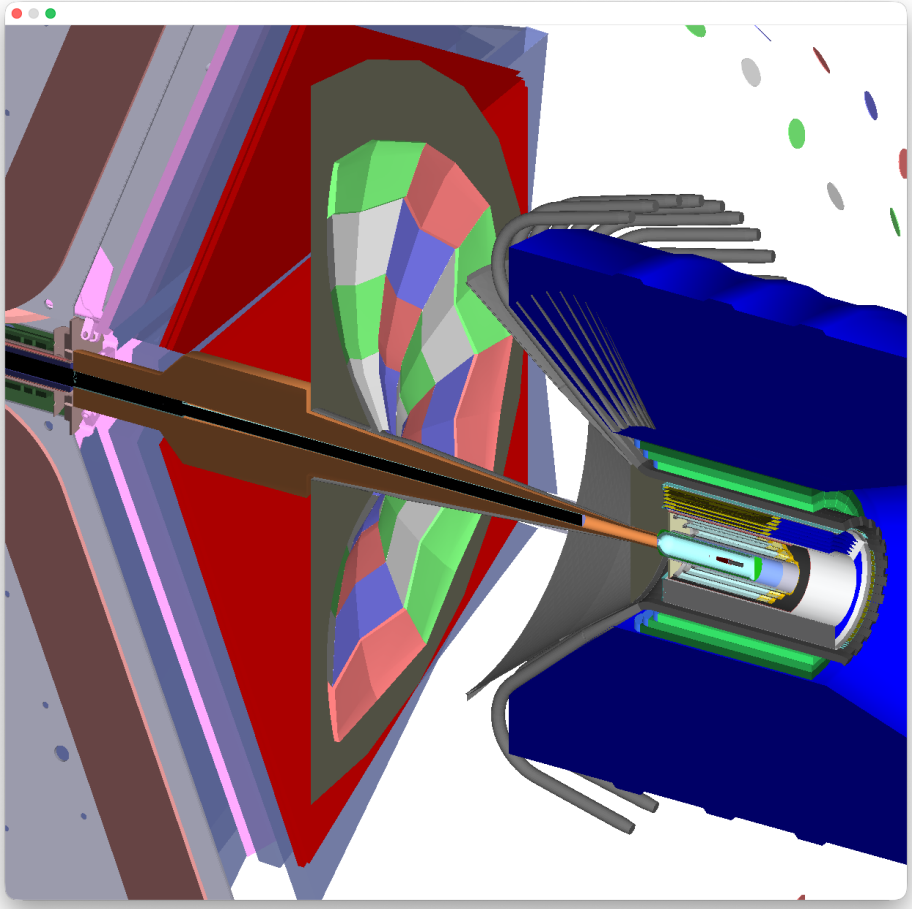
Elmo configuration:

- No FT, shields up to almost 5 deg
- 38 mm inner radius, optimized for rastered beam
- ~30 cm air gap



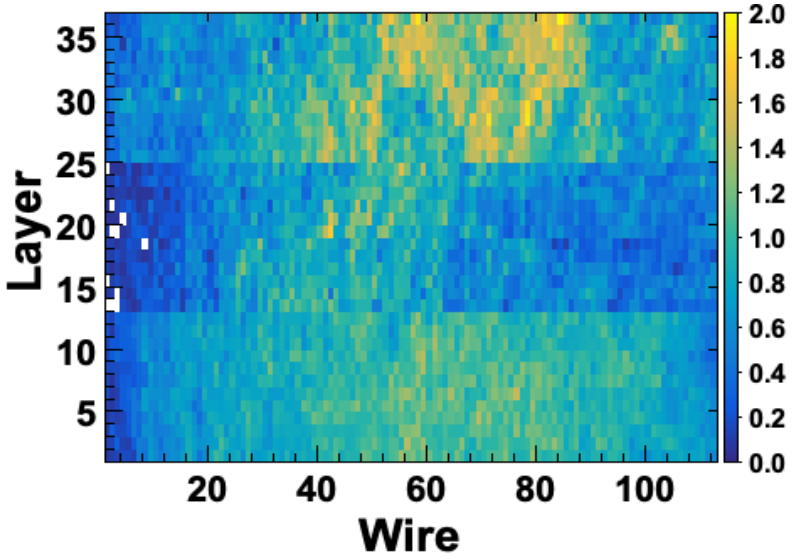
Configuration		FTon	FToff	Elmo
Average Occupancy at 50 nA (%)	R1	3.71	1.59	0.91
	R2	1.51	0.83	0.74
	R3	2.02	1.22	1.09

Modified Elmo at 50 nA



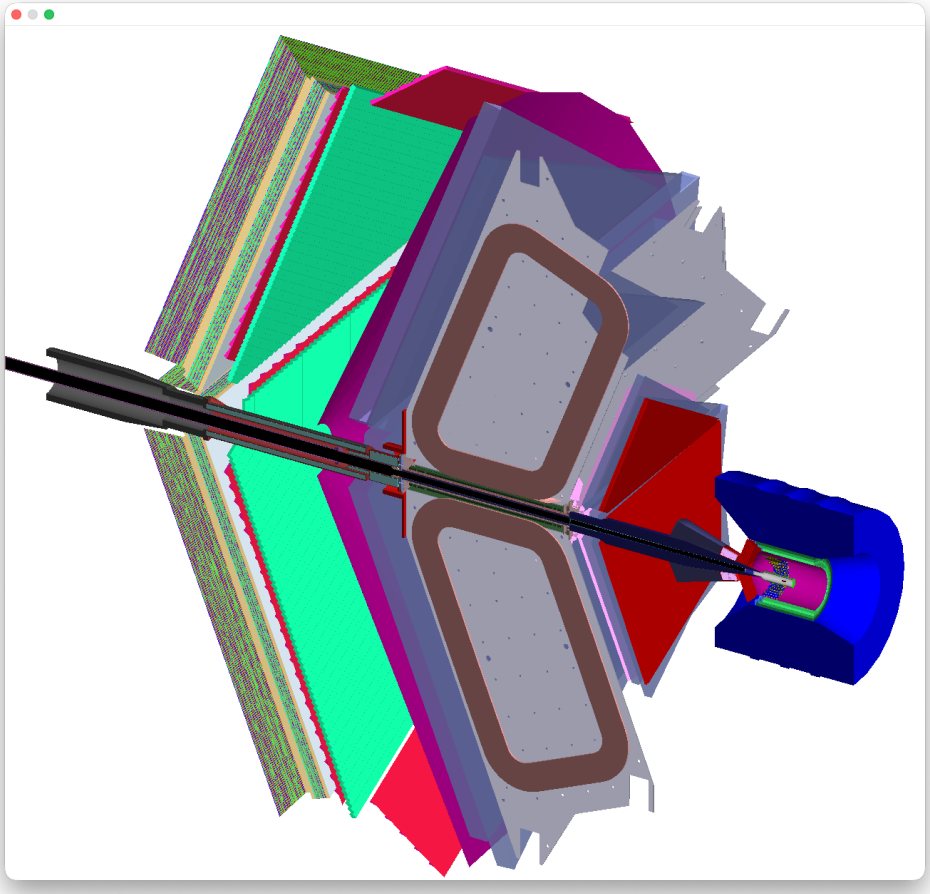
Elmo7 configuration:

- Elmo-like shield with extensions to 7 deg in front and behind the HTCC
- 21 mm inner radius
- No air gap



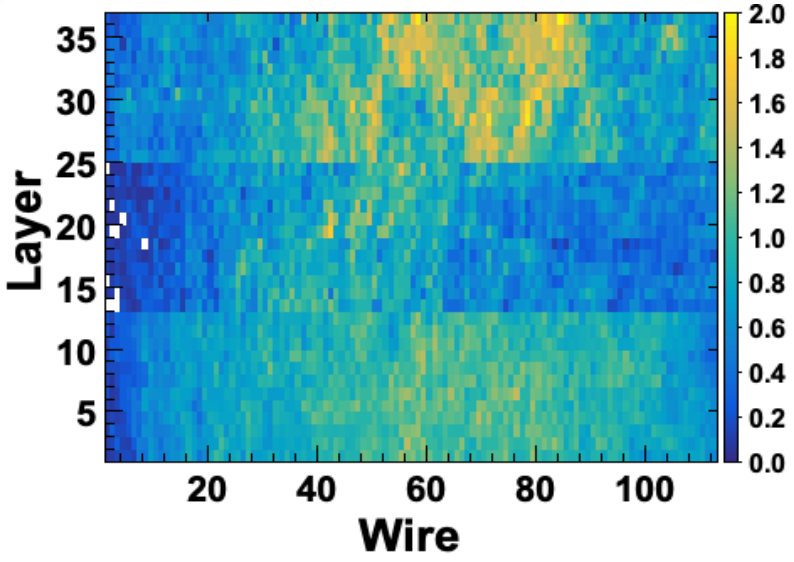
Configuration		FTon	FToff	Elmo	Elmo7
Average Occupancy at 50 nA (%)	R1	3.71	1.59	0.91	0.67
	R2	1.51	0.83	0.74	0.63
	R3	2.02	1.22	1.09	0.89

mini-μCLAS12 at 50 nA



mini-μCLAS12 configuration:

- 7 deg W cone, <15 deg PbWO calorimeter with 60cm lead absorber, no HTCC
- 26 mm inner diameter
- ~5 cm air gap



Configuration		FTon	FToff	Elmo	Elmo7	mini-μCLAS12
Average Occupancy at 50 nA (%)	R1	3.71	1.59	0.91	0.67	0.25
	R2	1.51	0.83	0.74	0.63	0.35
	R3	2.02	1.22	1.09	0.89	0.42

Upgrade path: Stage I

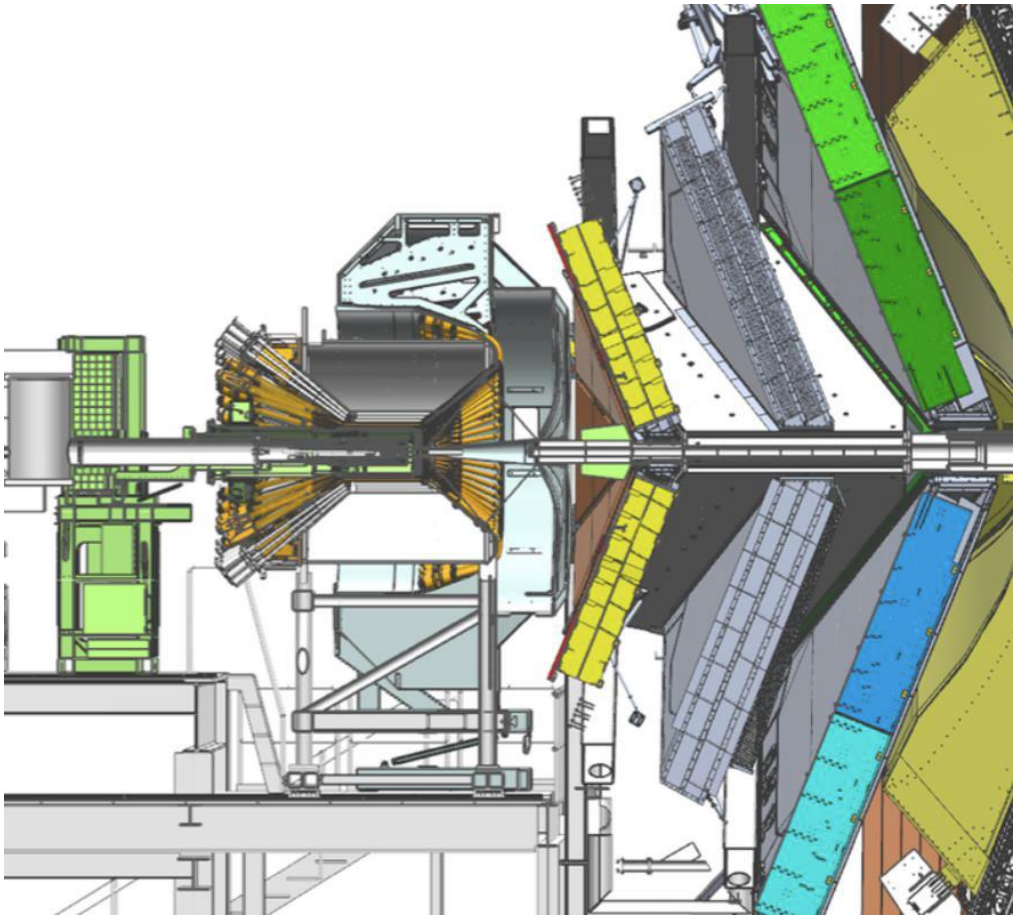
Stage I
7° Møller cone, no Forward Tagger
up to 5 x10^{35} cm^{-2}s^{-1}

➡

Stage II
wECal + Pb shield, 7°–15°,no HTCC
up to 10^{36} cm^{-2}s^{-1}

➡

Stage III = μCLAS12
full FD shield and wCal
10^{37} cm^{-2}s^{-1}



Configuration

- Large Møller cone, as used for RG-C, with extension to 7°
- Forward Tagger removed
- Luminosity up to 5 x10^{35} cm^{-2}s^{-1} (×5 design)

Required upgrades

- Replace the MicroMegas of the CVT
- New forward vertex tracker (FVT)
- Better shielding downstream of the torus for DC Region 3

Physics

- Most exclusive and semi-inclusive reactions at high Q^2

Upgrade path: Stage II

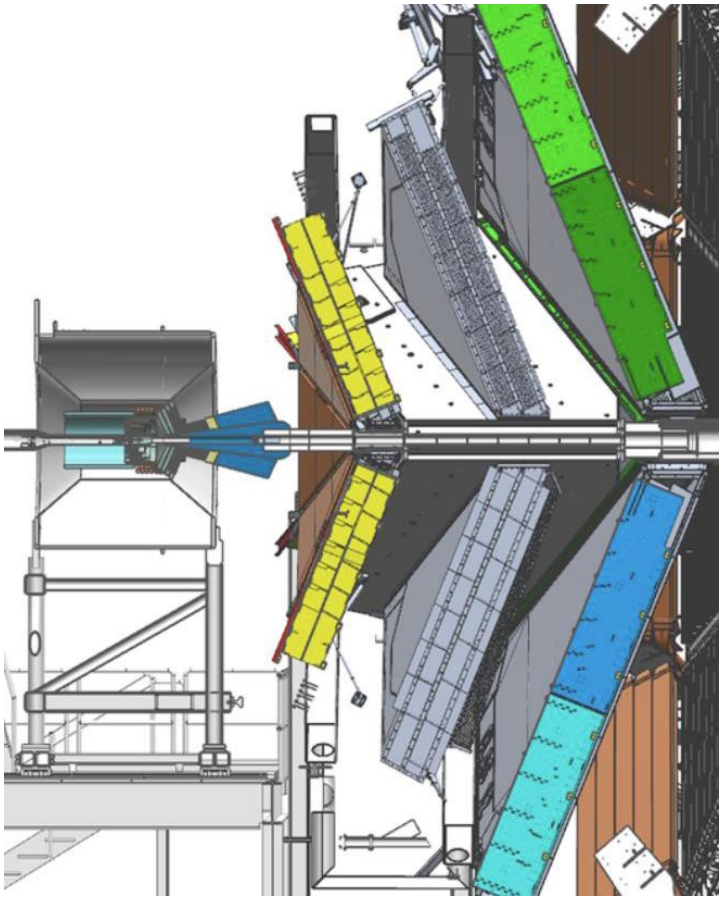
Stage I
7° Møller cone, no Forward Tagger
up to 5 x10^{35} cm^{-2}s^{-1}

➡

Stage II
wECal + Pb shield, 7°–15°,no HTCC
up to 10^{36} cm^{-2}s^{-1}

➡

Stage III = µCLAS12
full FD shield and wCal
10^{37} cm^{-2}s^{-1}



Configuration

- wECal + Pb shield from the 7° Møller cone to 15°
- HTCC removed

Physics

- CLAS12 program, limited to high-rate kinematics
- J/ψ quasi-real photoproduction tagging the recoil nucleon
- Deuteron target: separate bound neutron and proton
- Possible first DDVCS measurements

Operations

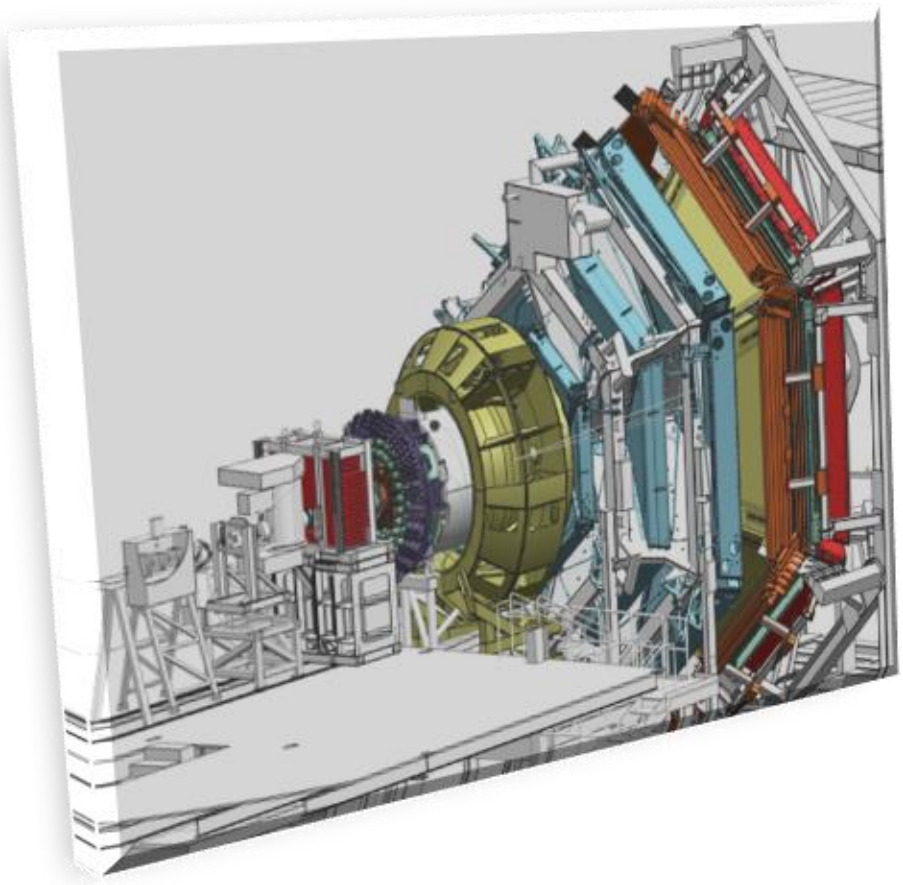
- Experience running with µA beam currents

Simulation studies

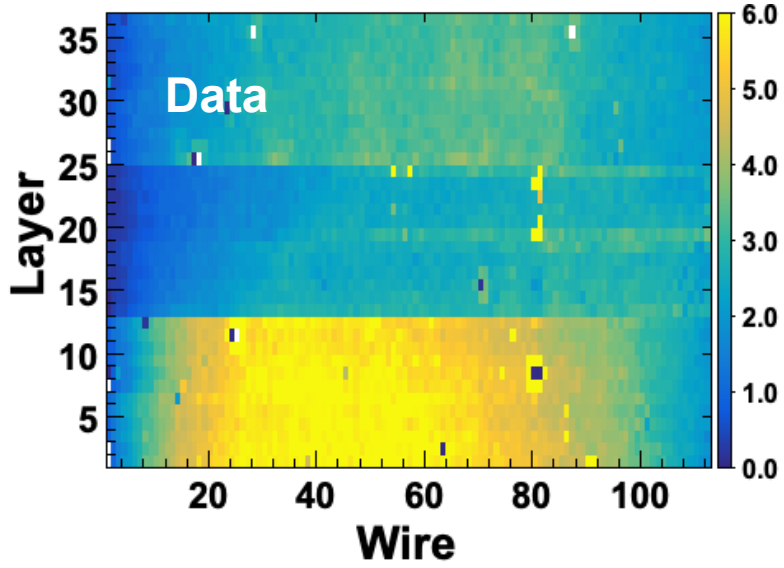
- Luminosity up to 10^{36} cm^{-2}s^{-1}, based on estimated background levels
- First estimates for J/ψ production on neutron

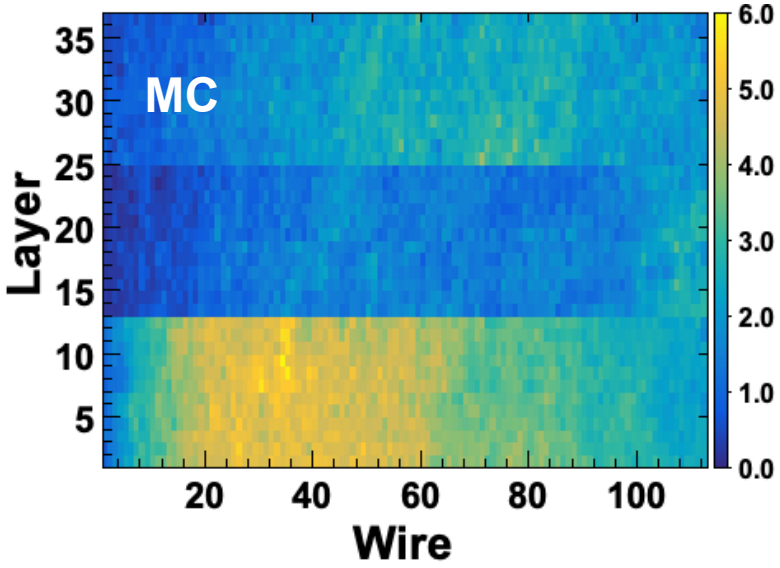
Summary

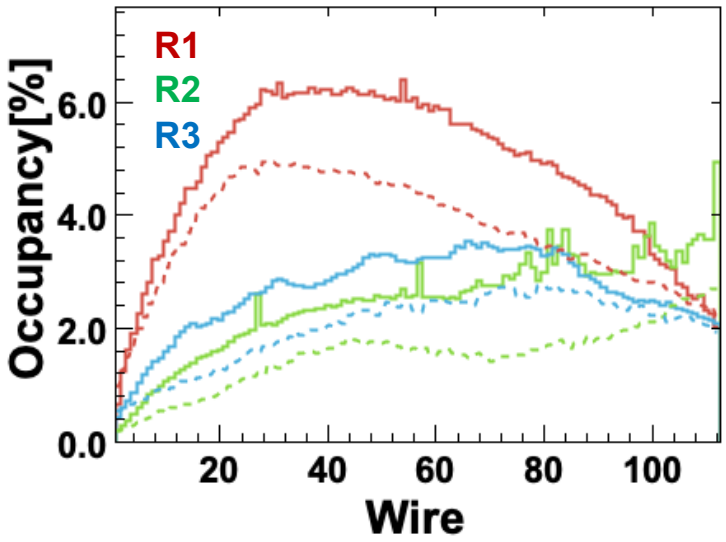
- CLAS12 physics reach can be significantly enhanced by increasing the luminosity
- Important steps already made:
  - First high-luminosity upgrade (x2) already approved and being implemented
  - μCLAS12 proposal approved for 200 days at 10^{37} $cm^{-2}s^{-1}$ (x100)
- Simulation studies indicate Intermediate stages (x5, x10) are feasible
  - Consolidate the path toward high luminosity
  - Early access to new physics

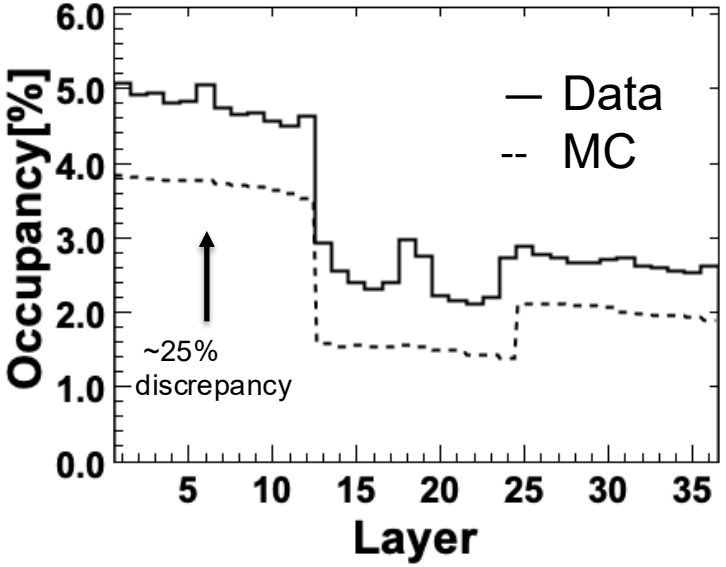


Comparison to data

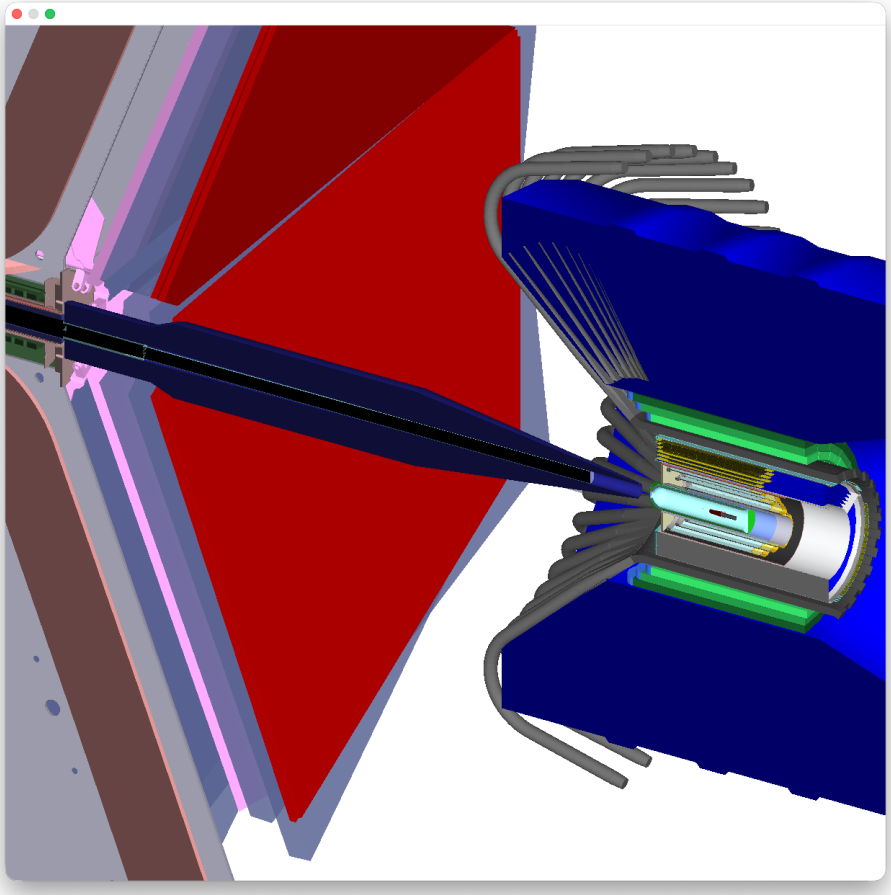






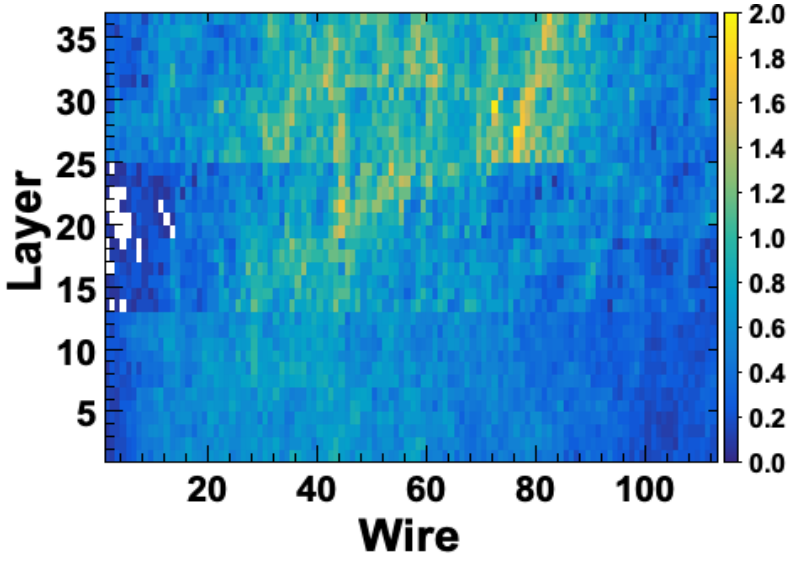


muCLAS12 cone at 50 nA



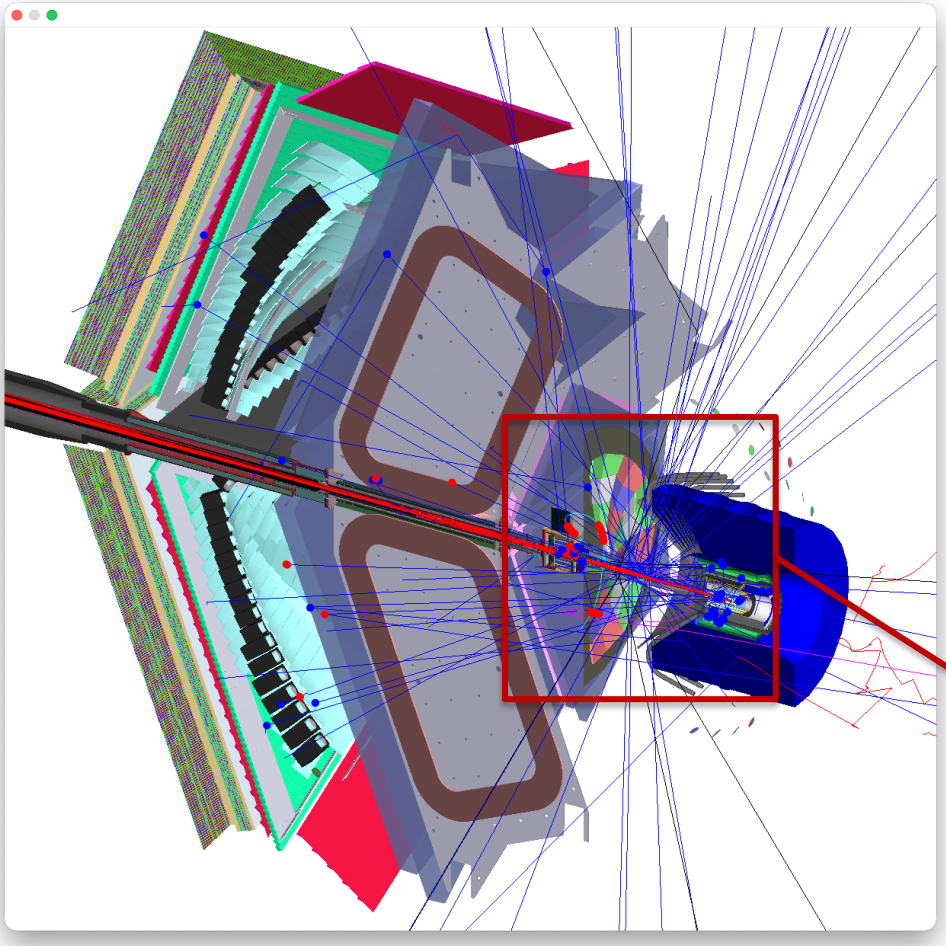
muCLAS12-like configuration:

- 7 deg tungsten shield incompatible with HTCC
- 26 mm inner diameter
- ~5 cm air gap

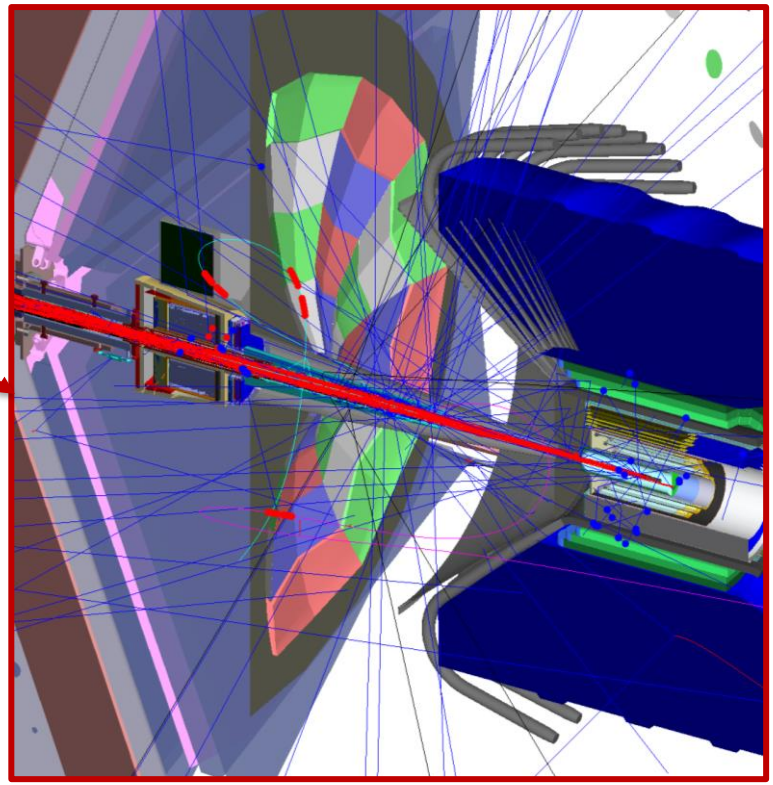


Configuration		FTon	FToff	Elmo	muCLAS12
Average Occupancy at 50 nA (%)	R1	3.71	1.59	0.91	0.49
	R2	1.51	0.83	0.74	0.58
	R3	2.02	1.22	1.09	0.76

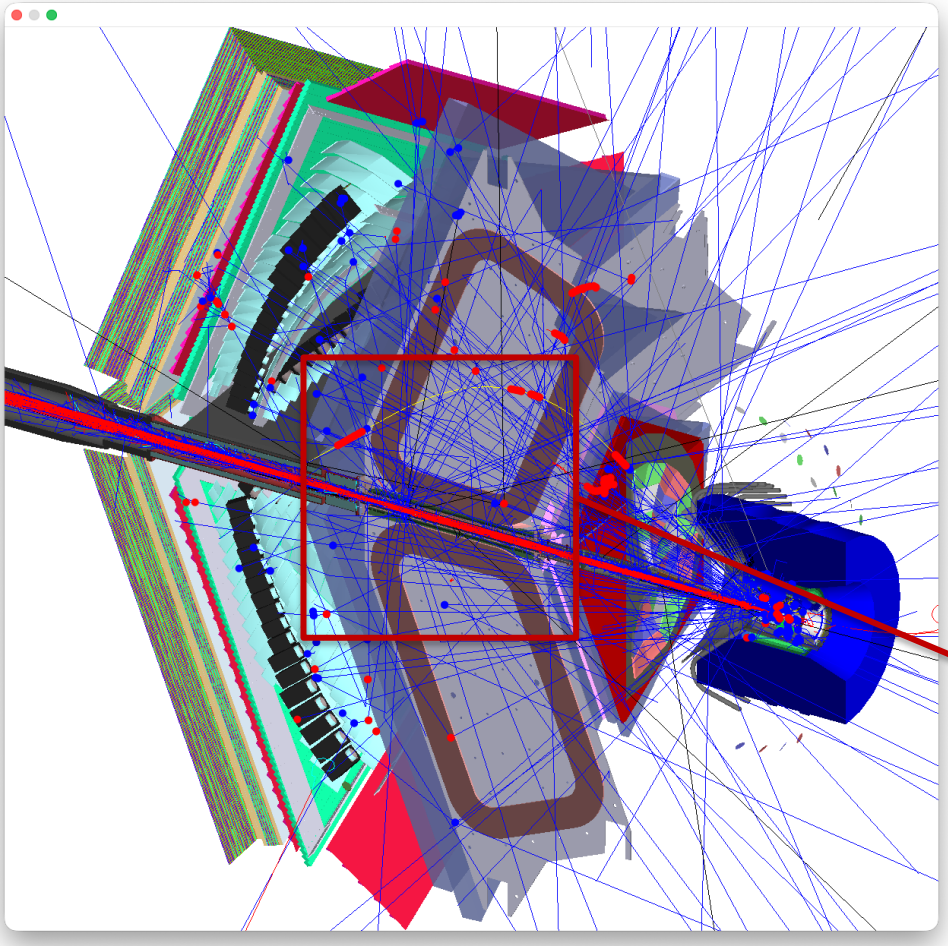
Background origin – R1



R1 background depends on the efficiency of the cone in collecting Moller electrons, i.e. the cone angle

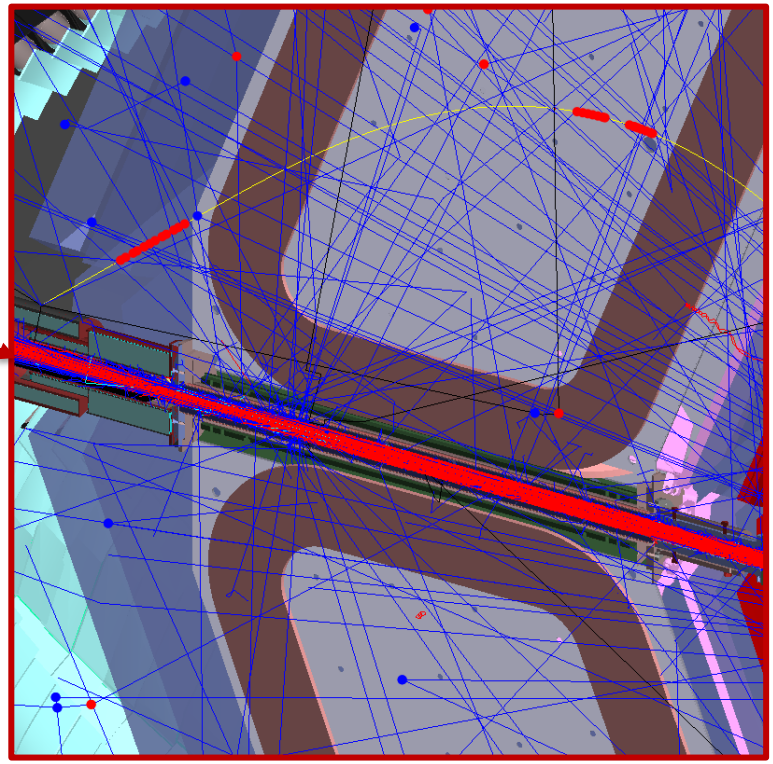


Background origin – R3



This can be mitigated by reducing the cone inner radius

For large angle Moller cones, R3 background strongly depends on the transverse size of the Moller electrons envelope, with a hot spot at the end of the torus bore



Summary

- DC occupancies for selected beamline configurations were studied looking for viable options to increase the luminosity by a factor several
- Significant reductions of occupancies in all regions can be achieved with Moller cones shielding up to 5 deg or more
- In those configurations, R3 (and the Forward Carriage?) becomes the limiting factor, requiring further optimization of the beamline

…still very exploratory but quite promising!