THE FCC INVERSE COMPTON POLARIMETER DESIGN

Robert Kieffer, on behalf of the EPOL working group and of the CERN BI group.

Mandate of the FCCee Inverse Compton Polarimeters

Detect the resonant depolarization (RDP) transition of the dedicated energy calibration polarized **pilot bunches**.

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Measure the absence of polarization of the **colliding bunches** with great precision (0 ± 10^{-5}) to insure no bias in the physics cross sections at the IP.

FCCee physics program and key parameters

parameter	Z	WW	H (ZH)	$t\bar{t}$
beam energy [GeV]	45.6	80	120	182.5
synchrotron radiation/beam [MW]	50	50	50	50
beam current [mA]	1294	135	26.8	5.1
number bunches / beam	11200	1852	300	64
total RF voltage 400/800 MHz [GV]	0.08 / 0	1.0 / 0	2.09 / 0	2.1 / 9.2
luminosity / IP [10^{34} cm^{-2}s^{-1}]	145	20	7.5	1.4
total integrated luminosity / IP / year [ab^{-1} / yr]	17	2.4	0.9	0.17
beam lifetime [min]	21	13	9	10

RDP on Pilot bunches

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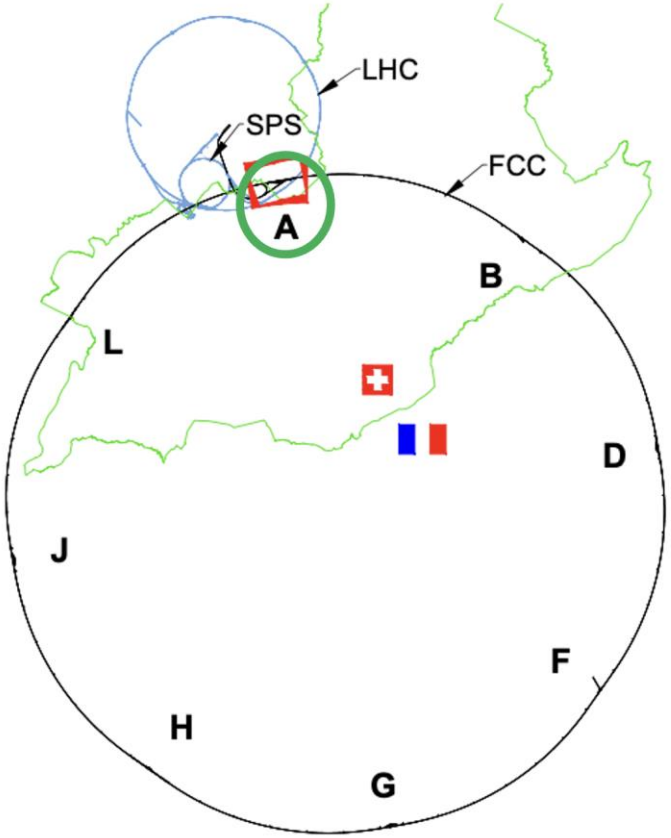
Colliding bunches

RDP on Pilot bunches

FCCee Polarimeters

Objective 95% availability

Original proposal: a single polarimeter per beam (2 total)
- Instrument location: both ends of **LSS** on experimental **IP A.**
- **Needs dedicated laser hutch and 24h/7d access tunnels.**
- **Duplicate the laser system for redundancy**



KEY PLAN

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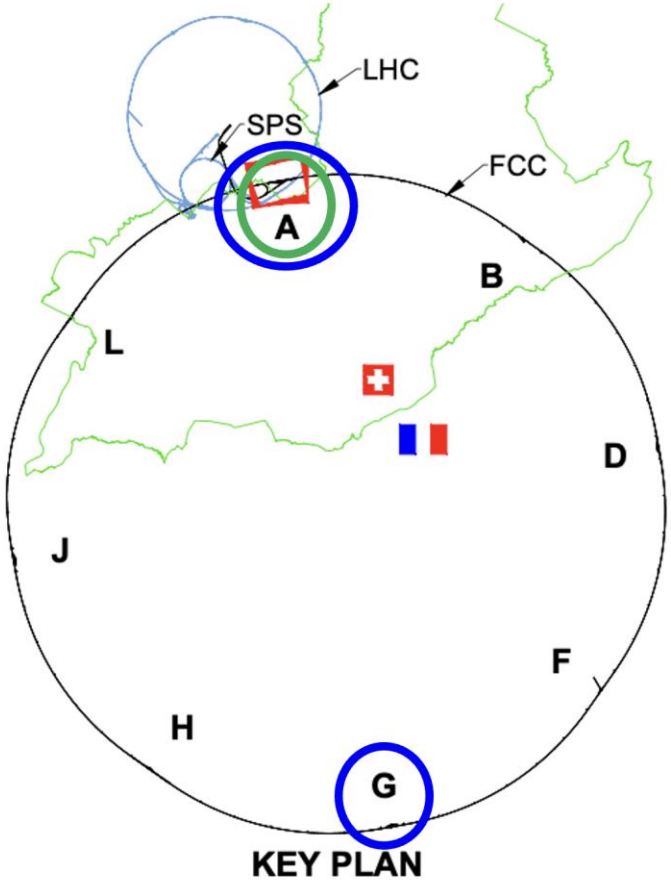
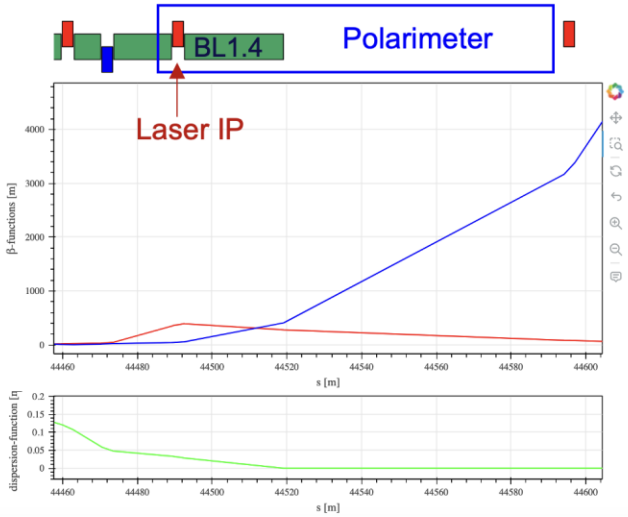
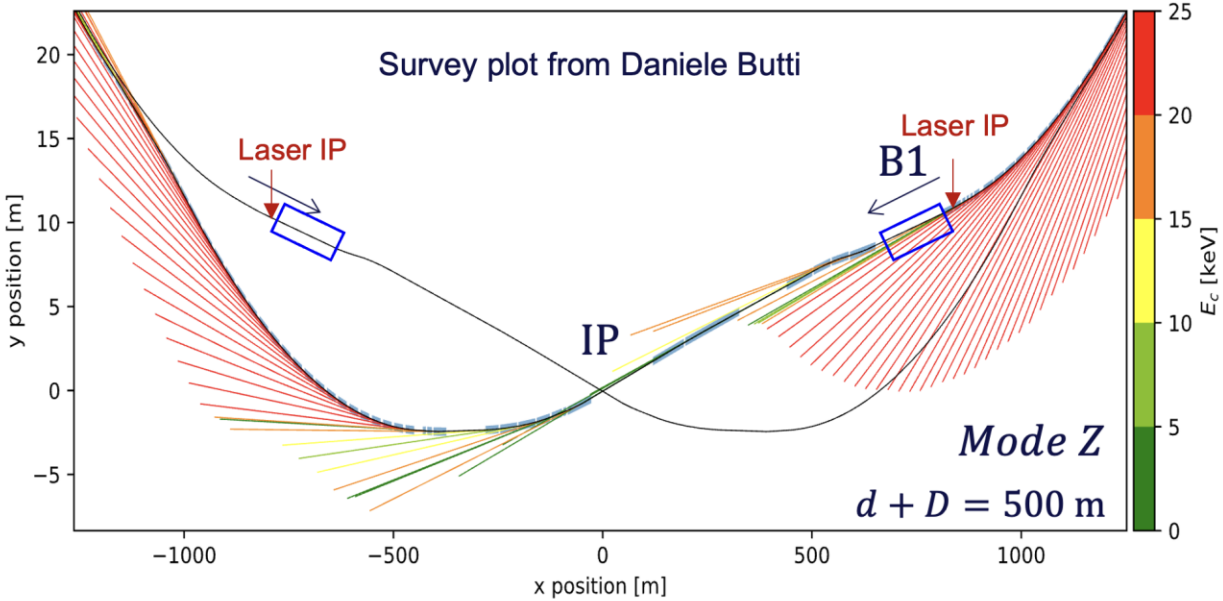
- Instrument location: both ends of **LSS** on experimental **IP A.**
- **Needs dedicated laser hutch and 24h/7d access tunnels.**
- **Duplicate the laser system for redundancy**

Full redundancy option : two polarimeters per beam (4 total)
- Instrument location: both ends of LSS on each experimental IP **points G (or D or J)**
- Each exp. IP would need **dedicated laser hutches.**
- **Full System level redundancy**.
- Still very challenging for the setup phase without access tunnels.



FCCee Polarimeters in Experimental IPs





GHC optics is used. The polarimeter is not yet simulated with the LCC optics but will soon be investigated.

Synchrotron Radiation fan shows a potentially strong contamination from SR in the compton gammas extraction line.

FCCee Energy calibration RDP

Resonant Depolarization (RDP) method will be used to measure the average ring beam energy.
Depolarization happens when the spin precession tune is coherent with the perturbations from synchro-betatron oscillations.

$$\upsilon_0 = k + k_x Q_x + k_y Q_y + k_s Q_s$$

Closed-orbit spin-tune

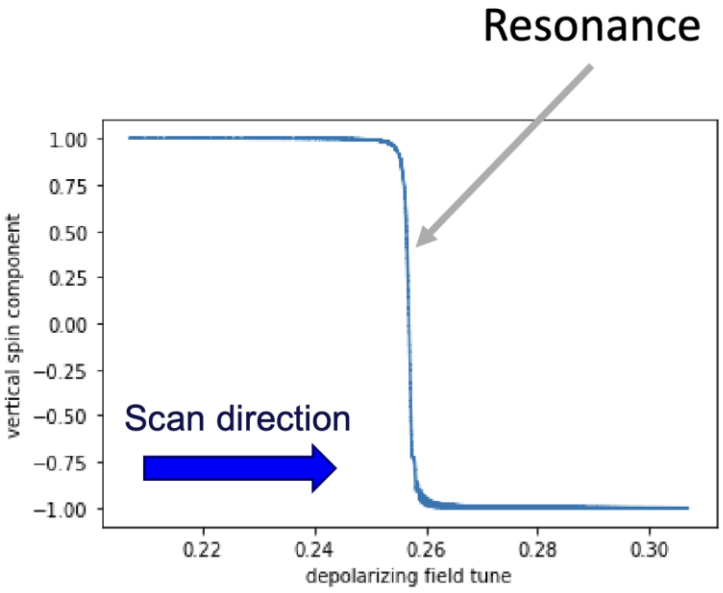
Gyromagnetic anomaly of the electron

$$\upsilon_0 = a\gamma$$

Lorentz factor (energy)

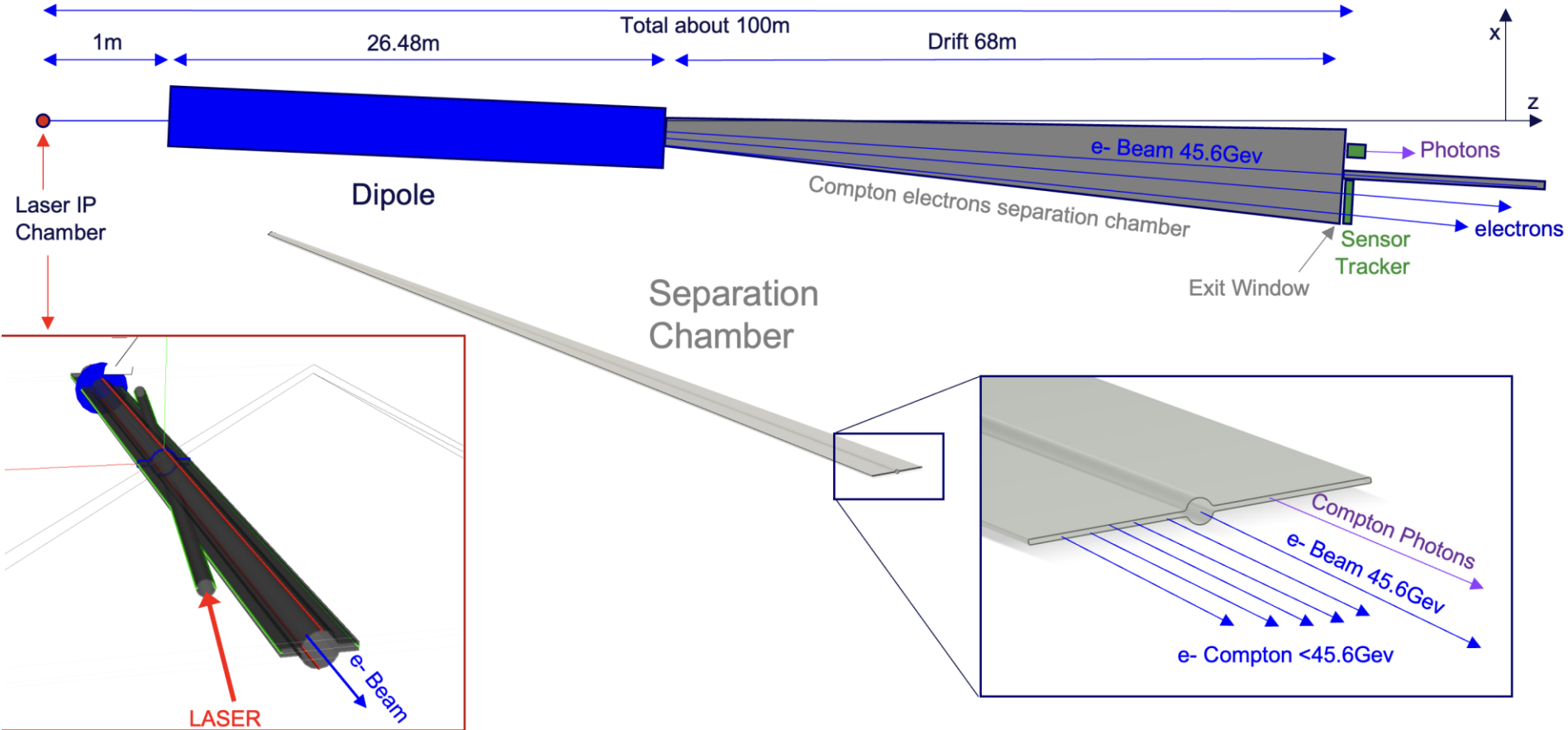
MEASUREMENT SEQUENCE

- 100 pilot bunches are injected, and we wait for the Sokolov-Ternov effect to provide polarization buildup.
- At Z mode a wiggler might be necessary (polarized beams is an option)
- Physics bunches are then injected and start to collide at the IPs.
- Every 15 min a bunch from the polarized pilot train is selected for RDP.
- A dedicated set of kickers, act on the selected bunch.
- The kickers excitation frequency is scanned by small steps (1keV eq.).
- At each frequency step a **polarization measurement is performed** by targeting the selected bunch with a laser pulse.
- The **polarization level** along the scan provide a mean to detect the spin resonance transition. The associated frequency of the spin tune provide the **energy measurement**.



Inverse Compton Polarimeter Instrument development

BDSIM Model description of Compton products separation

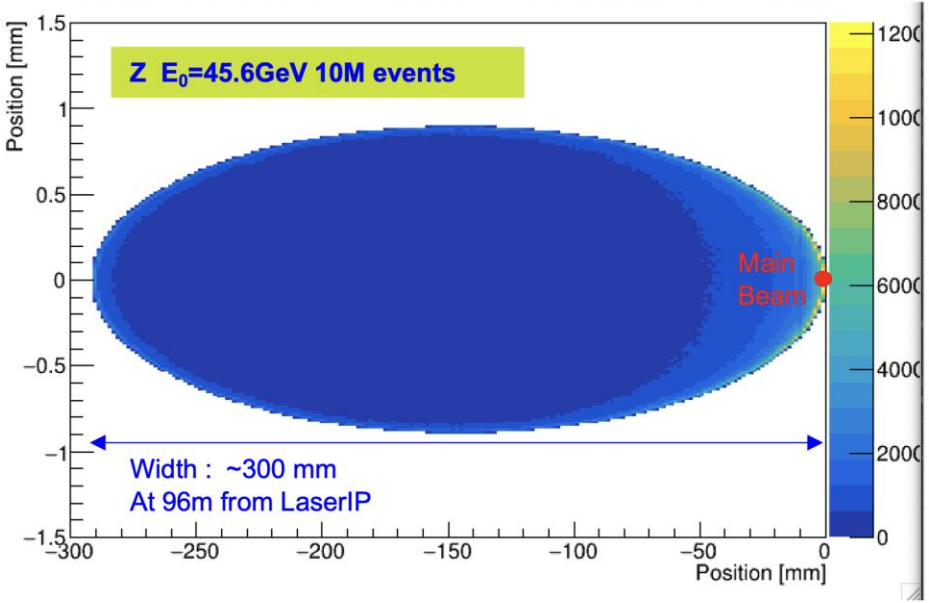


Benchmark of the Compton model at 45.6GeV Z mode

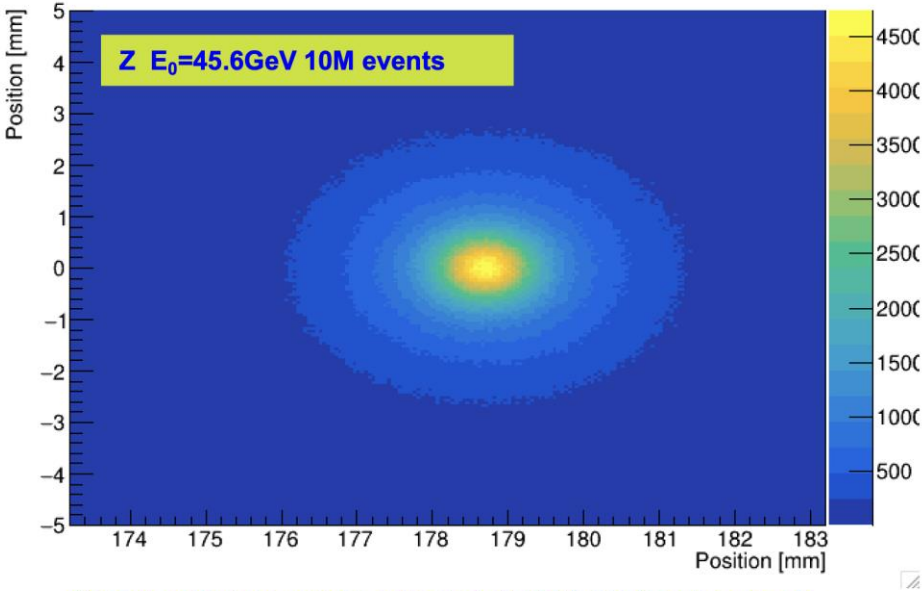
Source: BDSIM Compton simulation of Laser-Beam interaction at 96m from the laser IP

Reference beam (no beam size, no divergence, no dispersion, no polarisation)

Transverse Plane Electrons Side

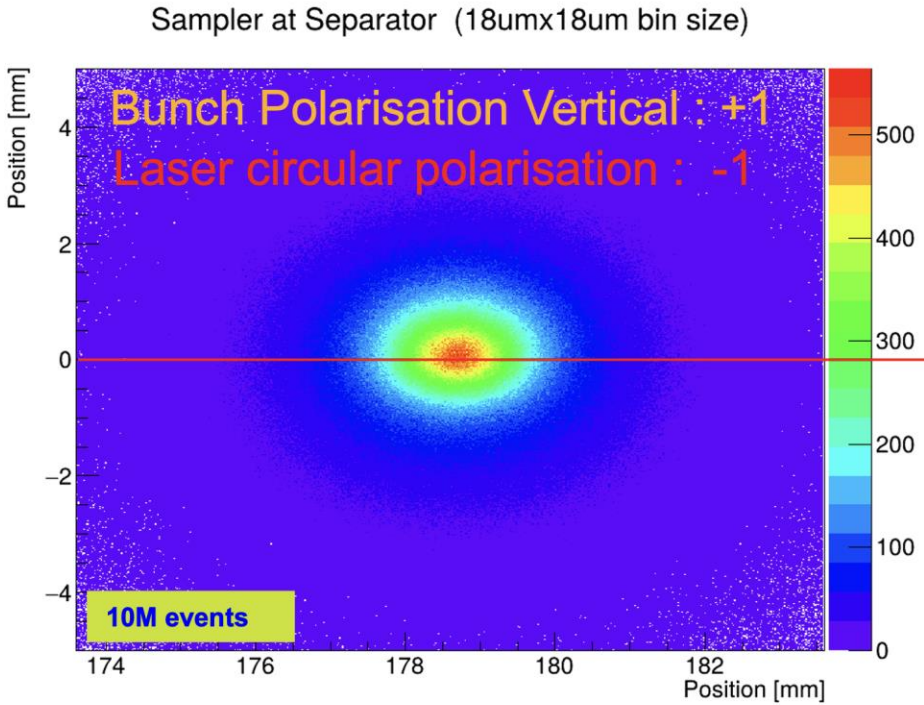


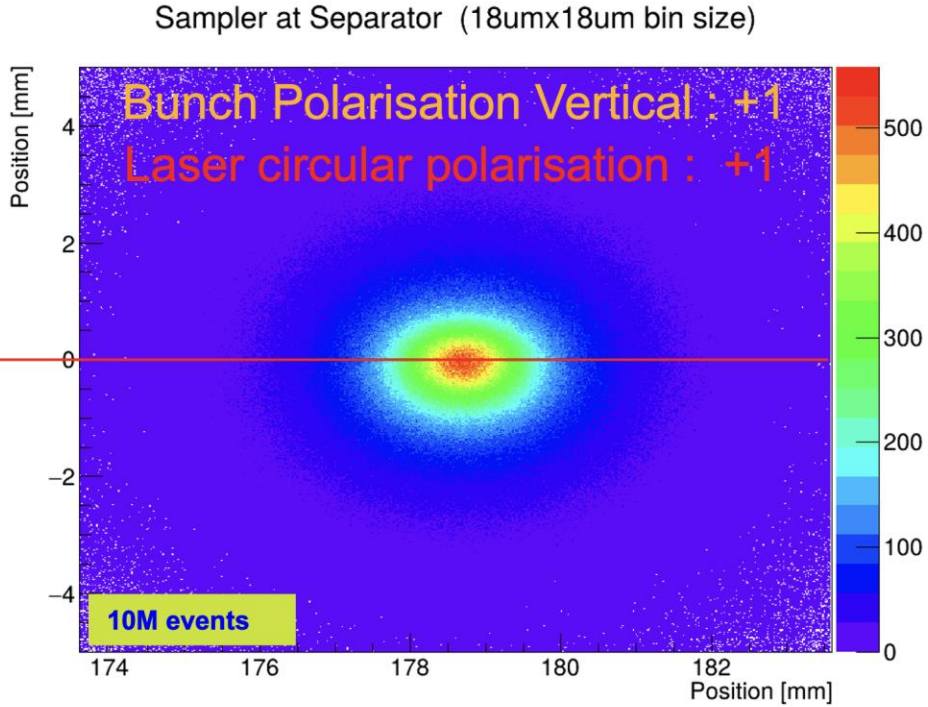
Transverse Plane Photons side



Compton photons pattern extracted at 178.6mm from beam axis

Compton Photons model at 45.6GeV Z mode (V24.2)



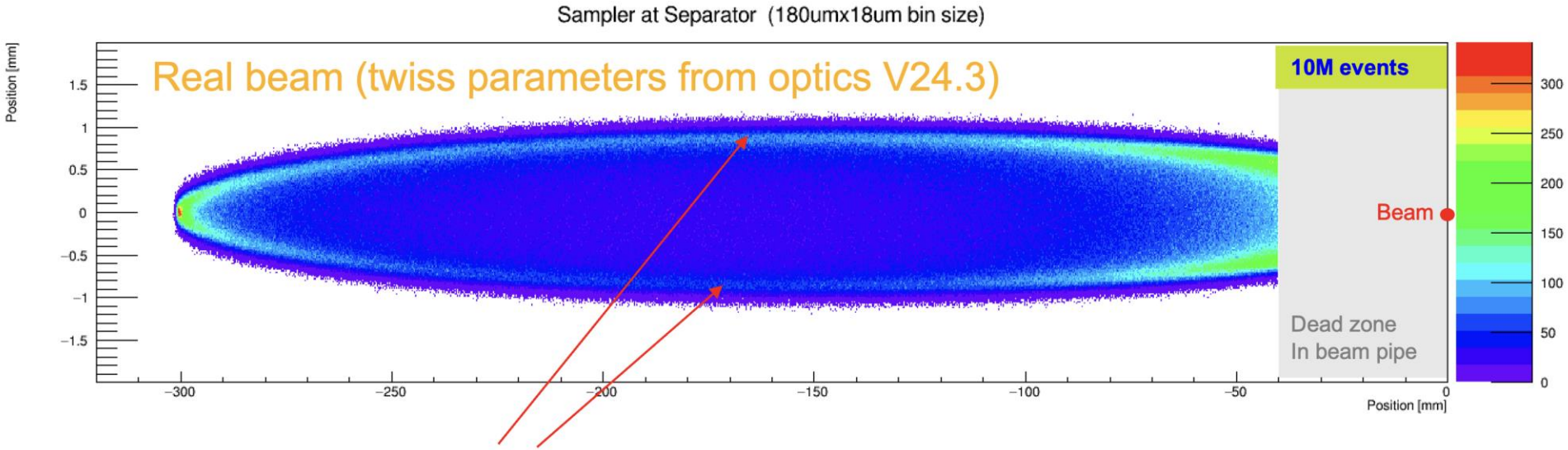


Flipping the laser circular polarisation moves the Compton photon pattern vertically (This technique was used at LEP to detect RDP transitions).

Compton Electrons model at 45.6GeV Z mode

Source: BDSIM Compton simulation of Laser-Beam interaction at 96m from the laser IP

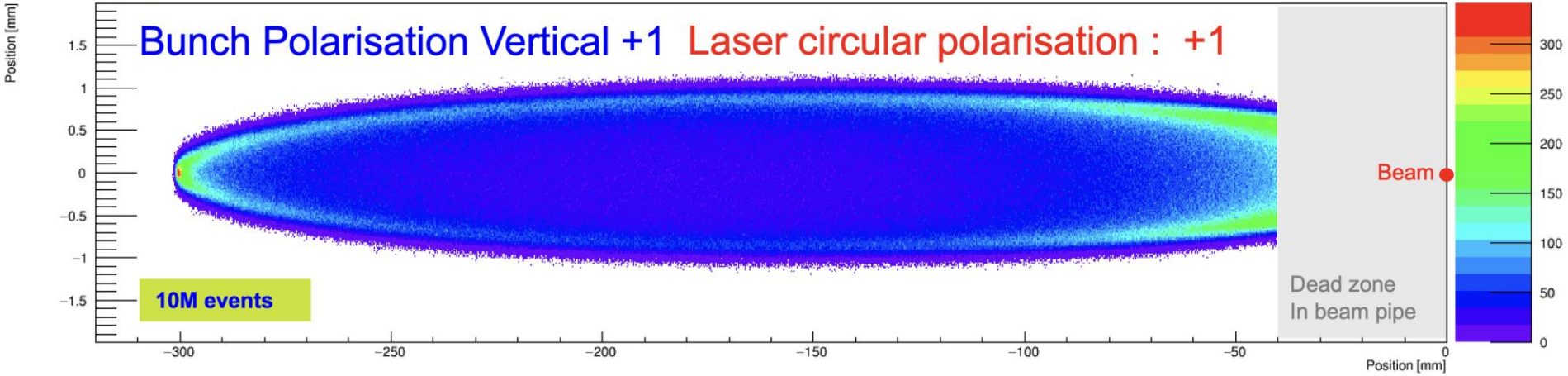
Transverse Plane Electrons Bunch Polarisation Vertical 100%

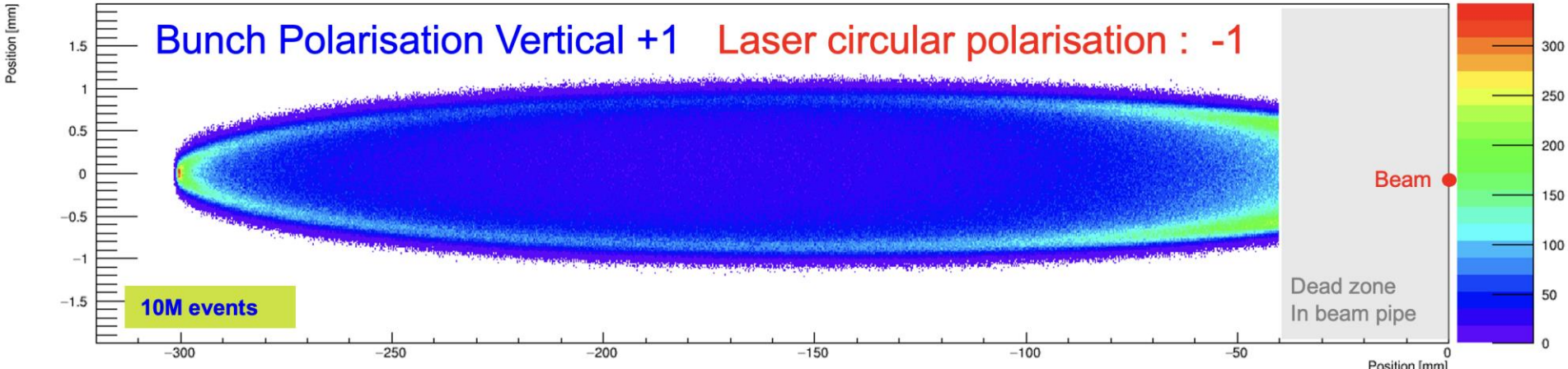


Vertical transverse polarisation create an asymmetry in the Compton electrons pattern.

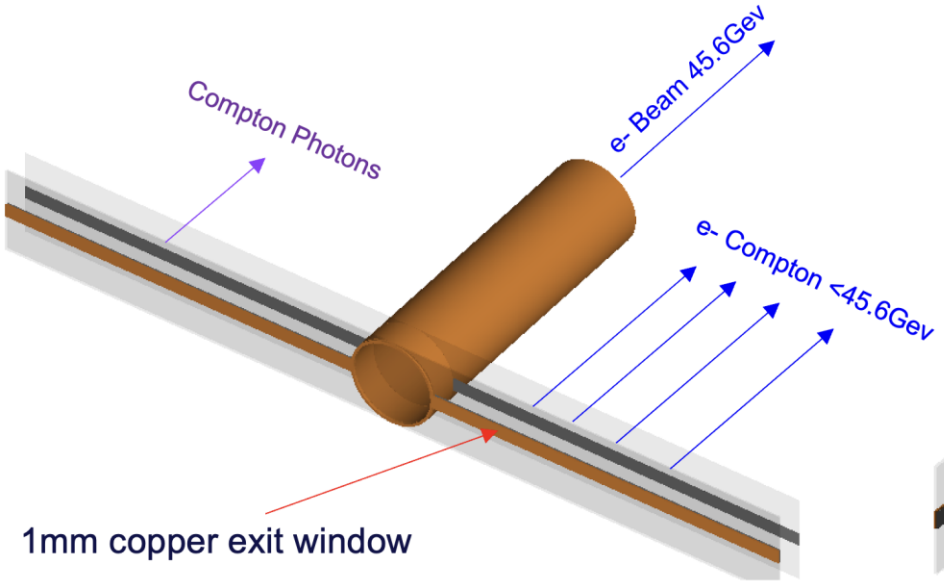
Fitting this shape against our model together with the photon distribution provides the 3D polarisation state.

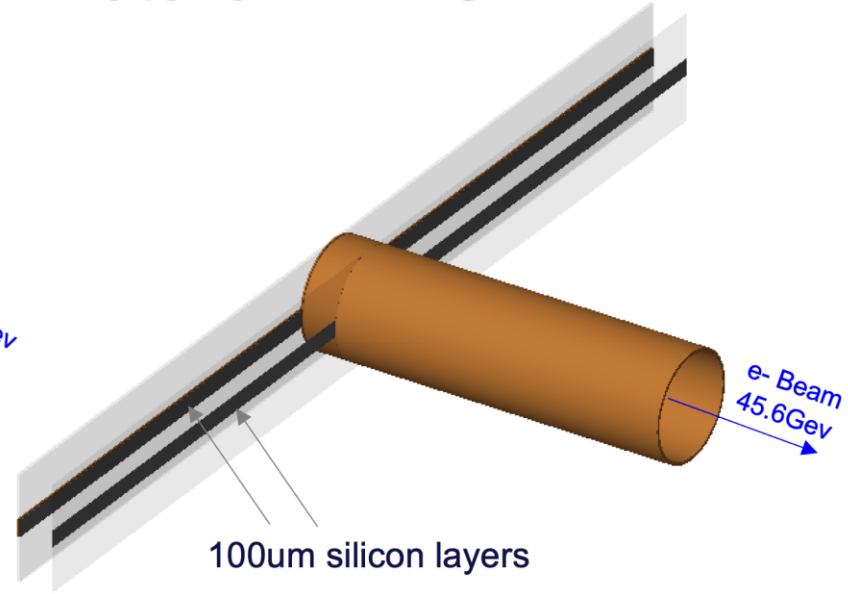
Compton Electrons model at 45.6GeV Z mode (V24.2)





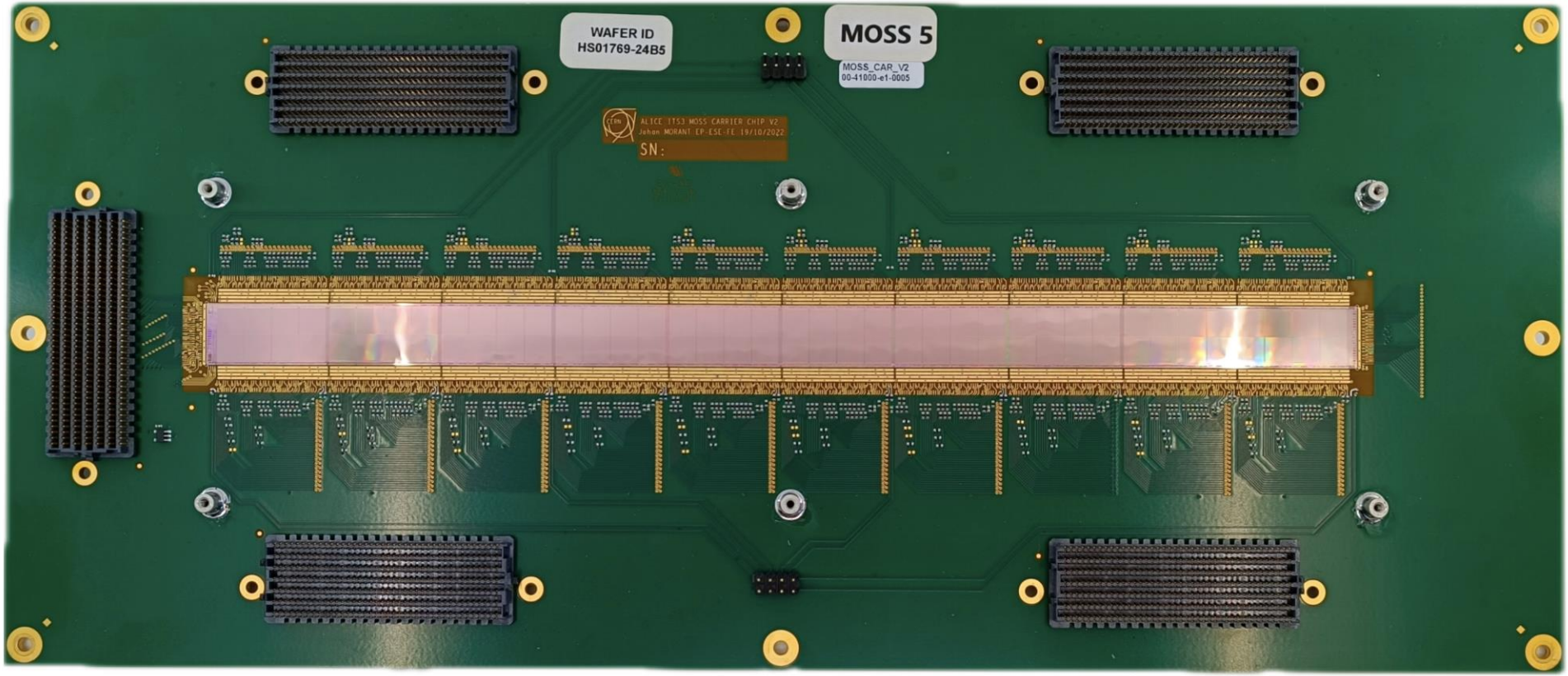
Simulation of interaction with sensor material in BDSIM



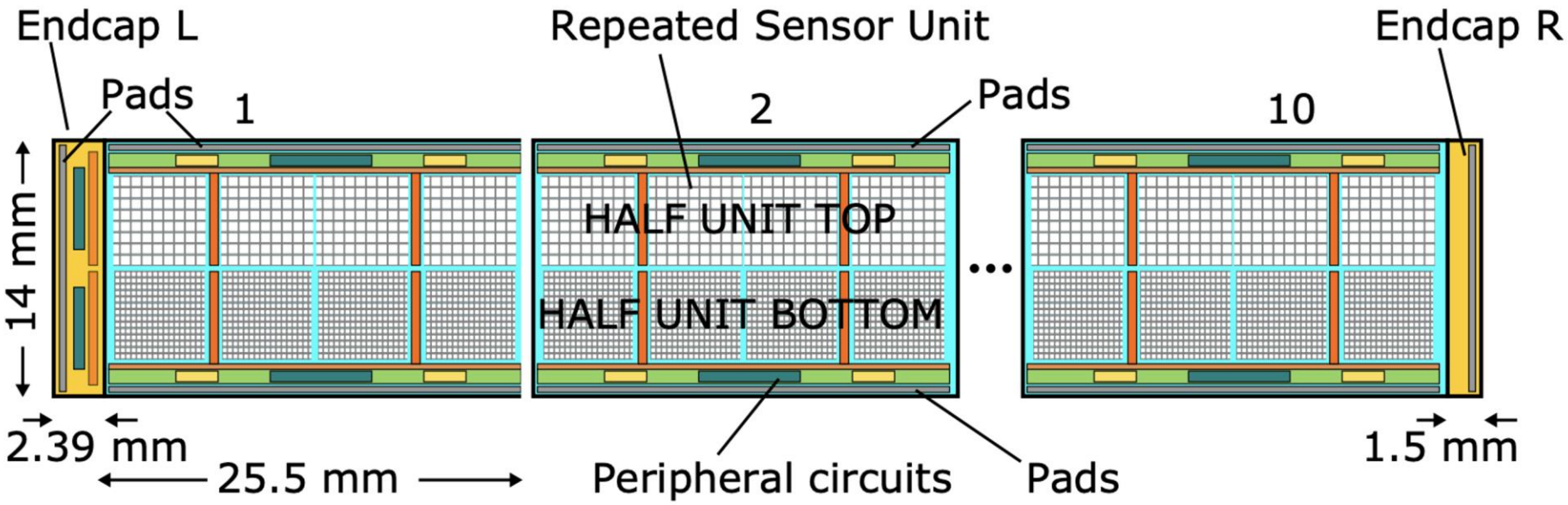


The compton products are transported through the copper exit window.
It is followed by two layers of 100um of silicon, in which we study the energy deposition.

MOSS the Alice ITS3 Monolithic Active Pixel Sensor MAPS

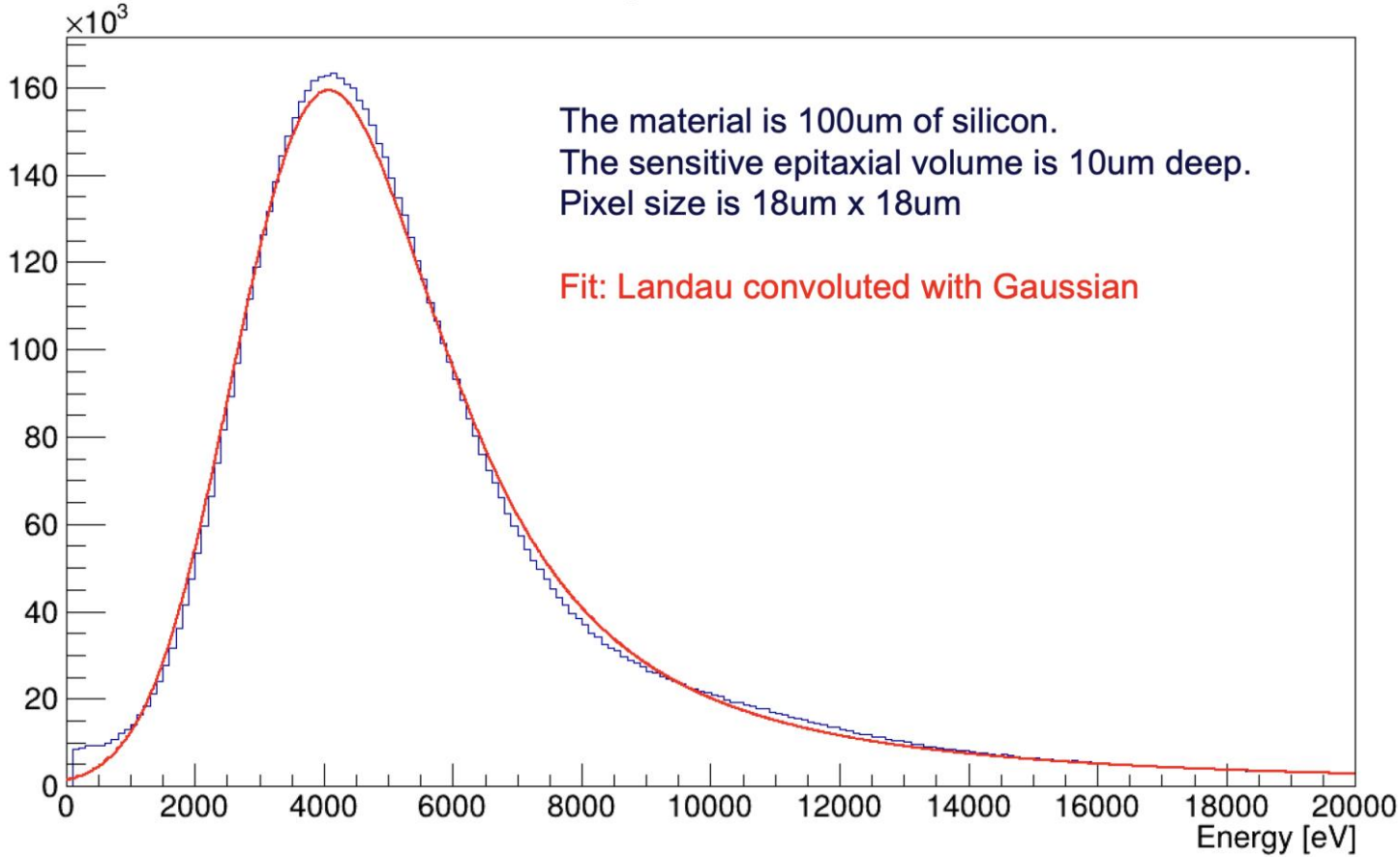


MOSS chip sensor configuration

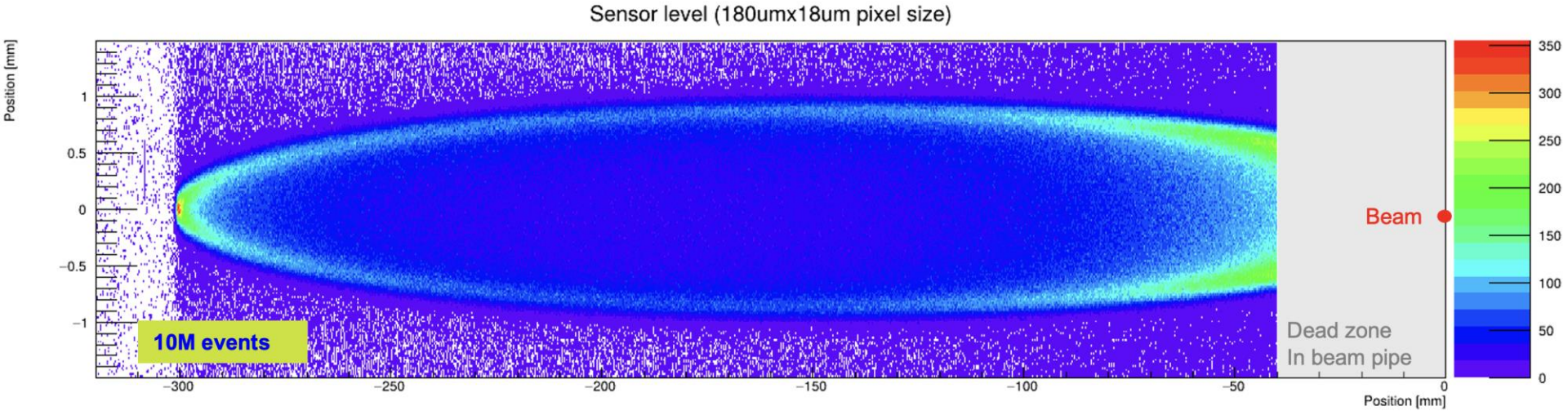


Bottom: Each matrix is 320x320 pixel (pixel pitch 18um)
Between matrixes we do have a dead zone.
It corresponds to 34 pixel of 18um that need to be removed.
The horizontal pixel are made 180um long by summing 10x18um pixel response.

Energy deposition in silicon sensor by Compton Electrons



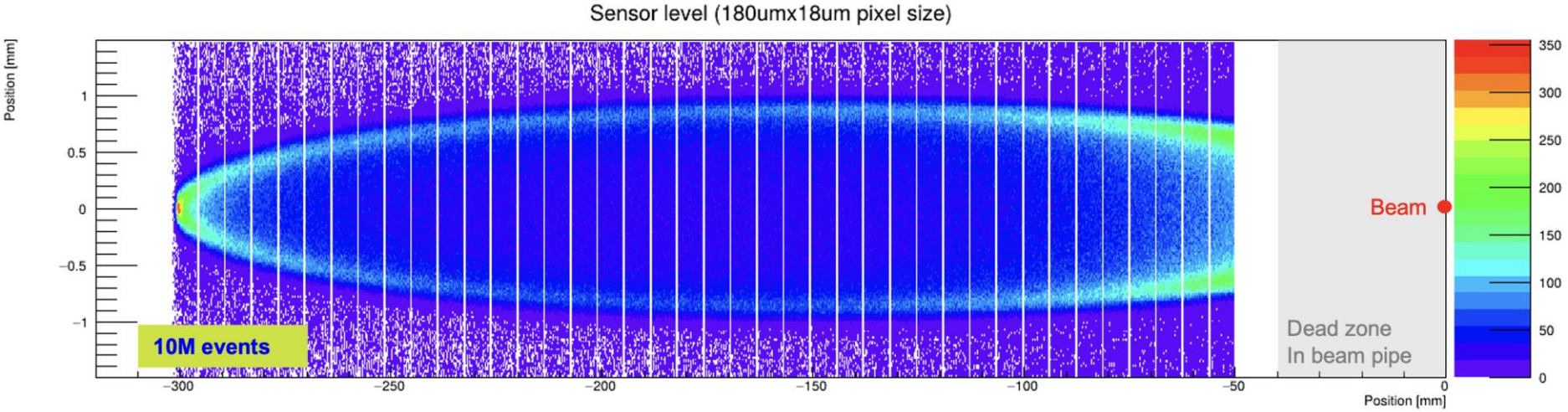
Compton Electrons pattern at Z mode energy scale Seen by an ideal silicon sensor after the Exit Window



The sensitive epitaxial volume is 10um deep.
Pixel size is 180um x 18um
10M events simulated Vertical Polarisation 0.5

The Background comes from the interaction of the Compton Electrons with the Exit window (1mm copper)

Compton Electrons pattern at Z mode energy scale Recorded by a real silicon sensor (dead zones)

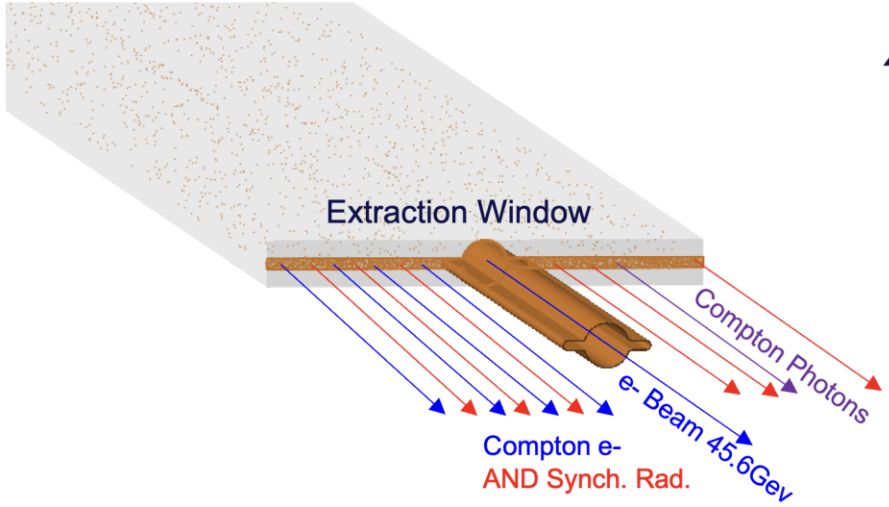


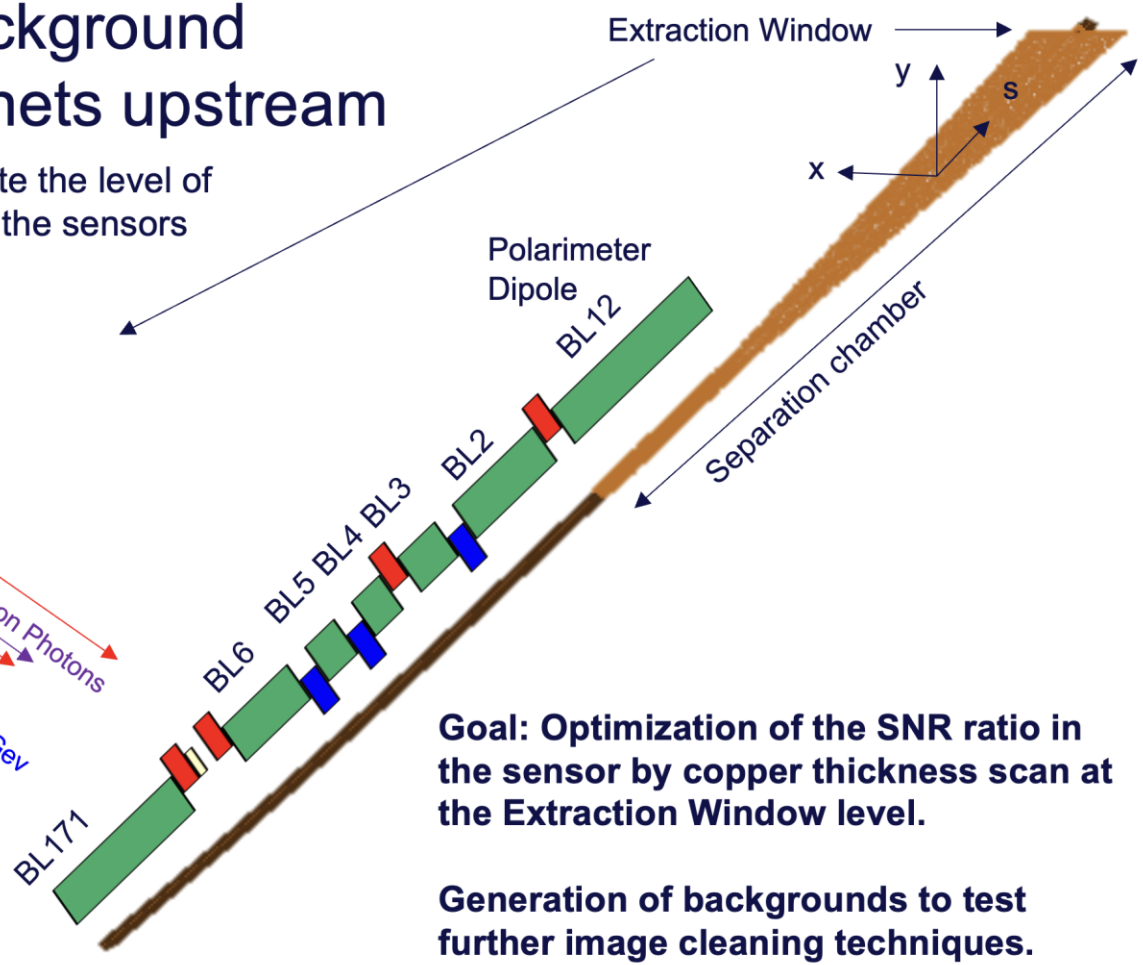
Including the dead zones from the MOSS sensor (40 matrixes of 320x320 pixel)
10Mevts simulated Vertical Polarisation 0.5

SR Background impacting the Polarimeter

Synchrotron Radiation background BDSIM model with 6 magnets upstream

Study of the SR background pattern, to evaluate the level of contamination of Compton pattern recorded in the sensors

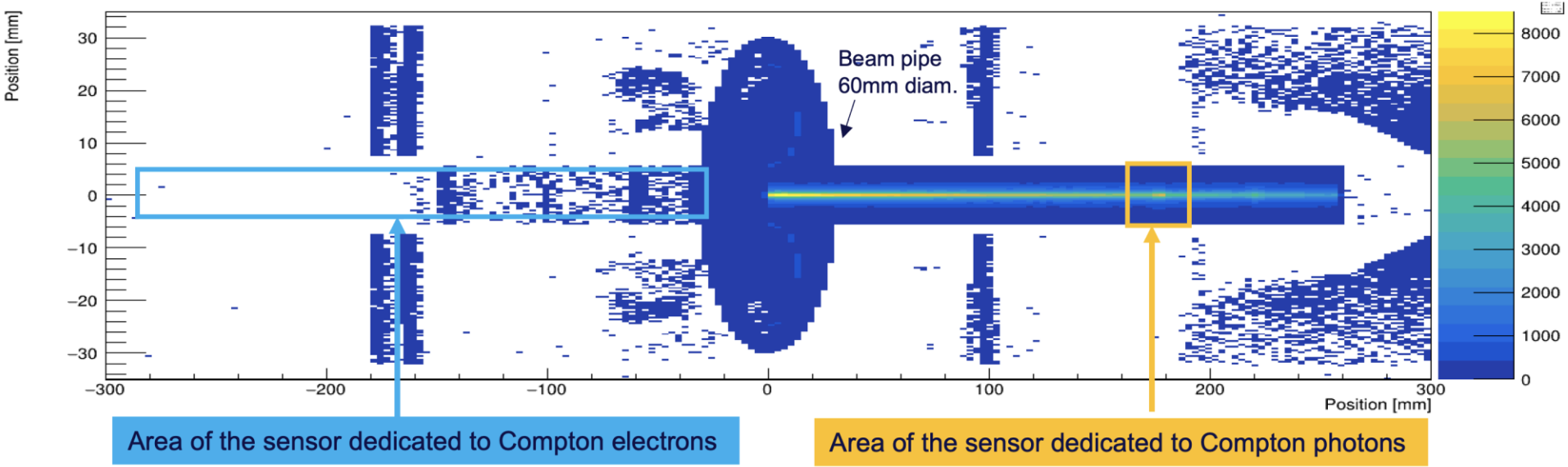




Goal: Optimization of the SNR ratio in the sensor by copper thickness scan at the Extraction Window level.

Generation of backgrounds to test further image cleaning techniques.

SR background reaching the exit window internal face.



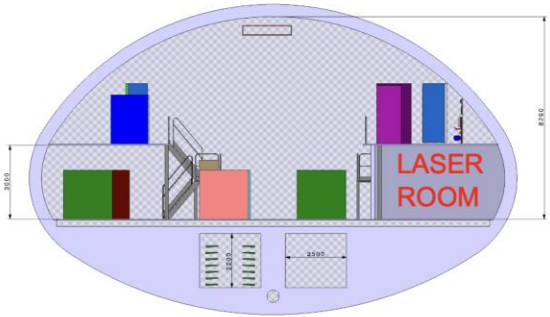
- SR Radiation generated by 6 dipoles upstream the laser IP, plus the main polarimeter spectrometer dipole.
- Internal xray reflection in beam pipe, with surface roughness parameter set to 100nm.
- SR Absorber from R.Kesevan not yet implemented in the simulation (will reduce the photon flux).

Ref: BDSIM option. physicsList="synch_rad em xray_reflection"

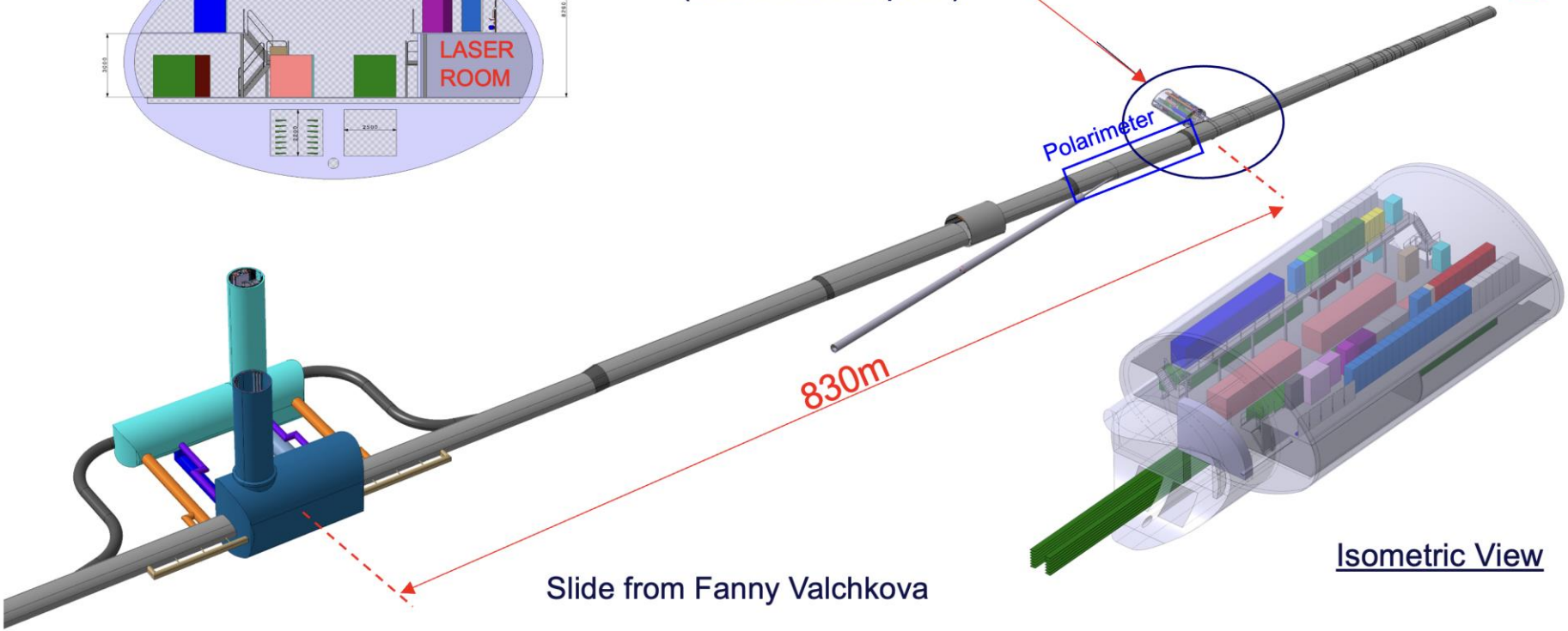
Polarimeter Integration

FCC-ee Underground Structure Big Alcove point A

Section View



Laser alcove as close as possible to the laser IP (830m from exp. IP)



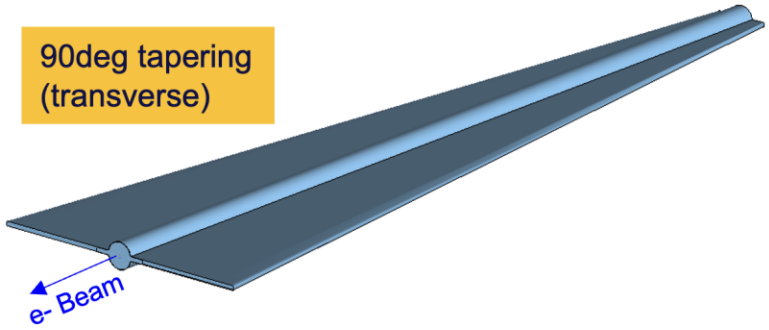
Isometric View

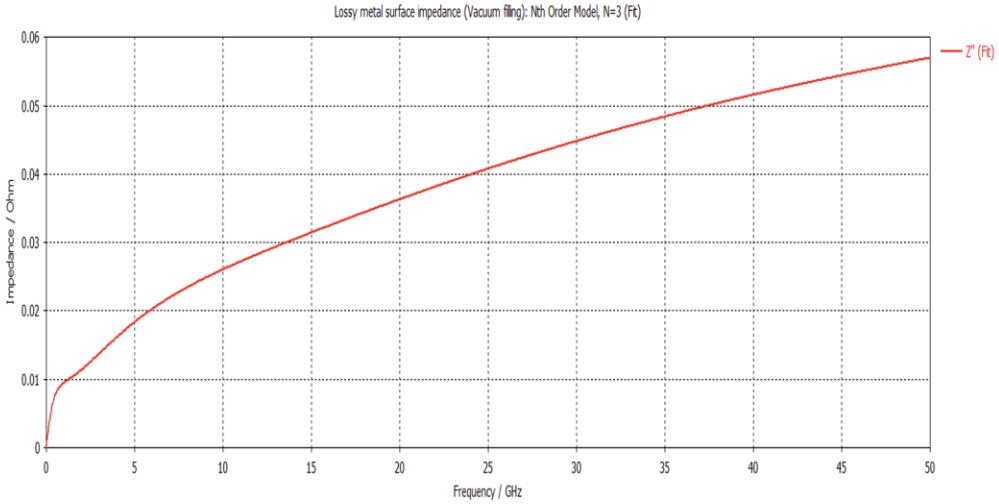
Slide from Fanny Valchkova

Impedance budget

CST Model of the Polarimeter chamber tested.

Thanks to Mauro Migliorati, Dora Gibellieri, Carlo Zannini





- The CST models that we provided to the FCC **impedance simulation** team have been tested. The study consisted in a scan of different extraction windows angle. From transverse (90deg), to (15deg) tapering.
- All models have successfully passed the impedance evaluation. They fall well bellow the 0.01% of the Total Machine budget impedance.
- Based on this result we will use the **transverse (90deg) extraction window geometry** for best performances.

Outlook and plans

- The main tools to simulate the Inverse Compton Polarimeter are being developed under BDSIM and HTCondor for massive event generation.
- Main focus has been on the Compton electron sensor.
- Start of the detector digitization simulation.
- Complementary models to evaluate the SR background have been developed.

NEXT

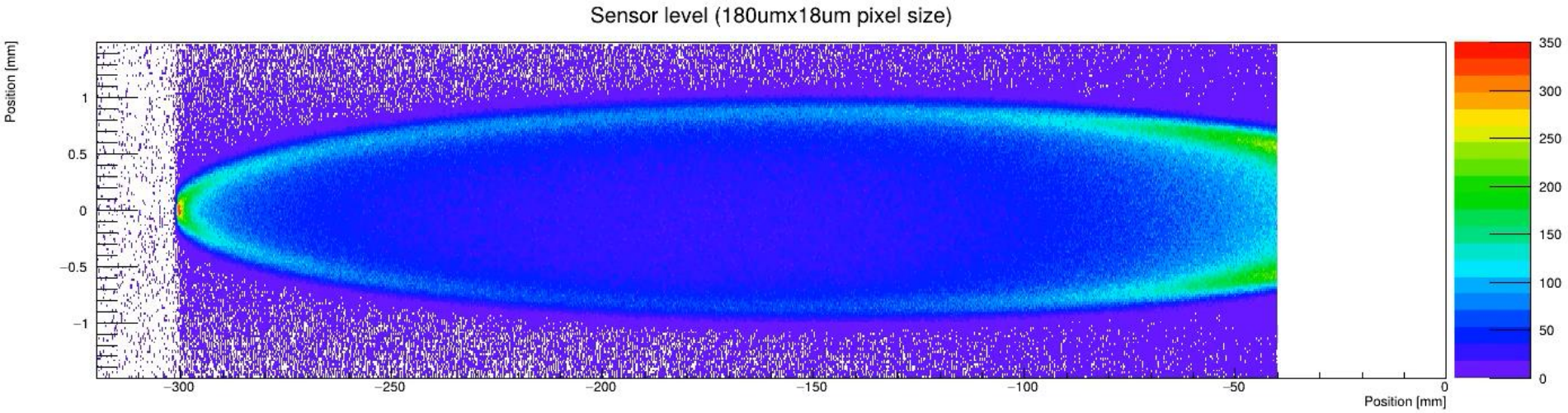
- The fitting algorithms tools are being developed by IJClab (see next talk).
- The Compton Gamma tracking-calorimeter will soon be addressed.
- A new PhD student will work on the Gamma sensors from October 2025
- More backgrounds will be simulated (thermal photons, beam-gas).

Thank you
for your attention.

Compton Electrons model at 45.6GeV Z mode

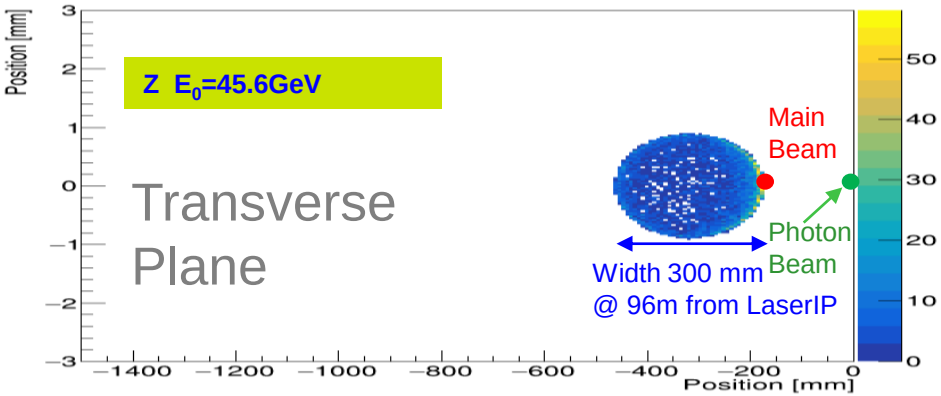
Source: BDSIM Compton simulation of Laser-Beam interaction at 96m from the laser IP

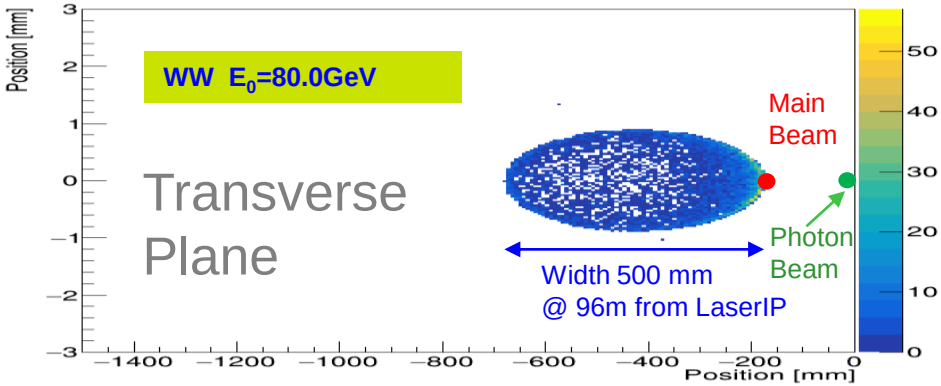
Transverse Plane Electrons Bunch Polarisation from 1 to 0



The asymmetry vanishes in the Compton electrons pattern.

Compton electron pattern at different run energies Exiting the Separation Chamber (96m from LIP)

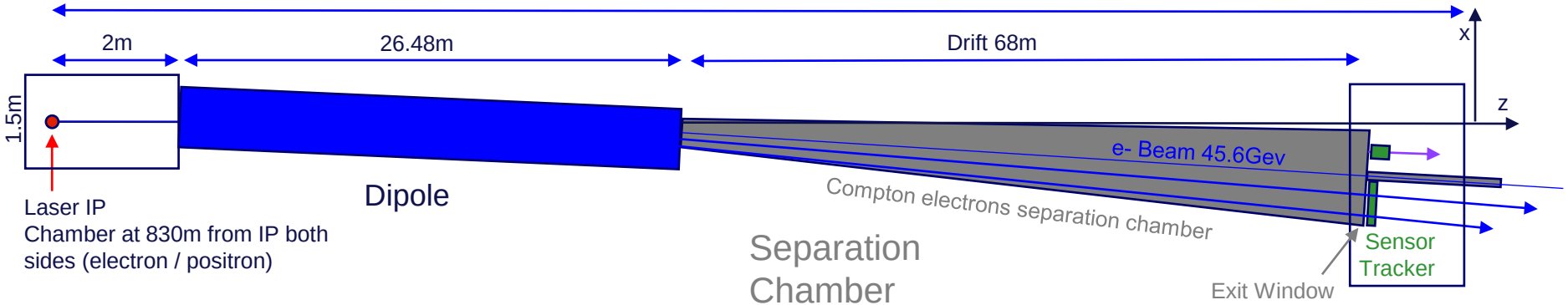




To allow running the polarimeter for both Z and WW modes without hardware changes, the Compton electron sensor transverse acceptance need to reach about 500mm

Space reservation volume in the collider tunnel

Total about 100m fully dedicated to the polarimeter



Laser IP
Chamber at 830m from IP both sides (electron / positron)

Laser safety isolating box
1.5m large
2.0m long (as the LIP chamber)
1.8m height

Volume of the chamber
FCC beam pipe shape
Winglets aperture extention
0.5m large exiting the Dipole
1.5m large at the Exit window

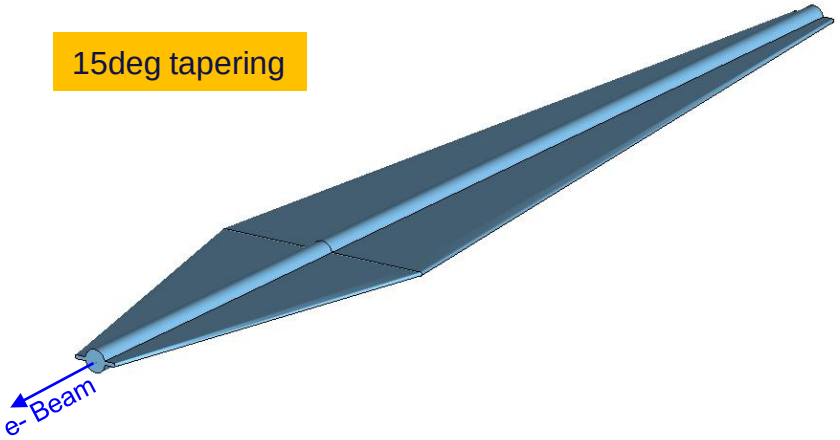
Box containing the instruments
1.5m large 1.5m long (along beam)
1.8m height

Laser Transport pipes
Needed volume to be defined by STI

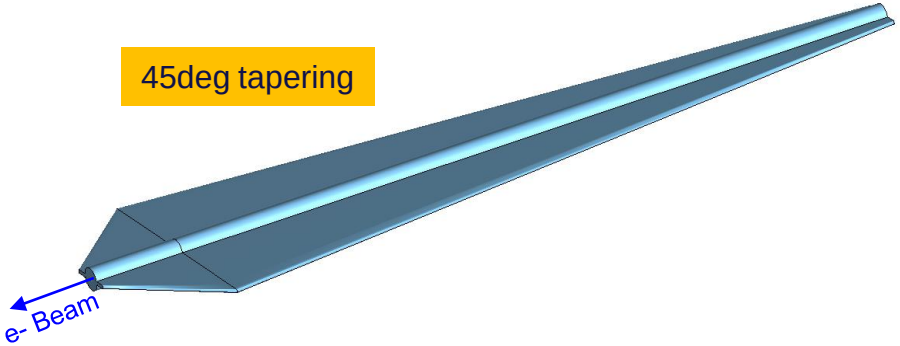
First CST Models of the Polarimeter chamber tested.

Thanks to Mauro Migliorati, Dora Gibellieri, Carlo Zannini

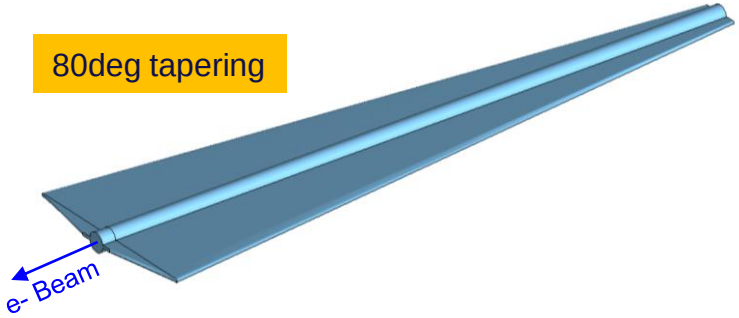
15deg tapering



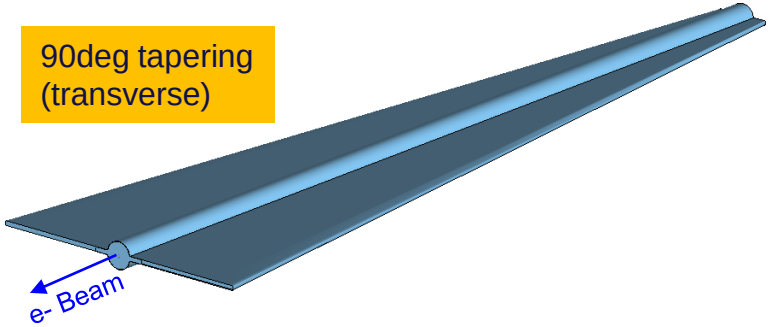
45deg tapering



80deg tapering



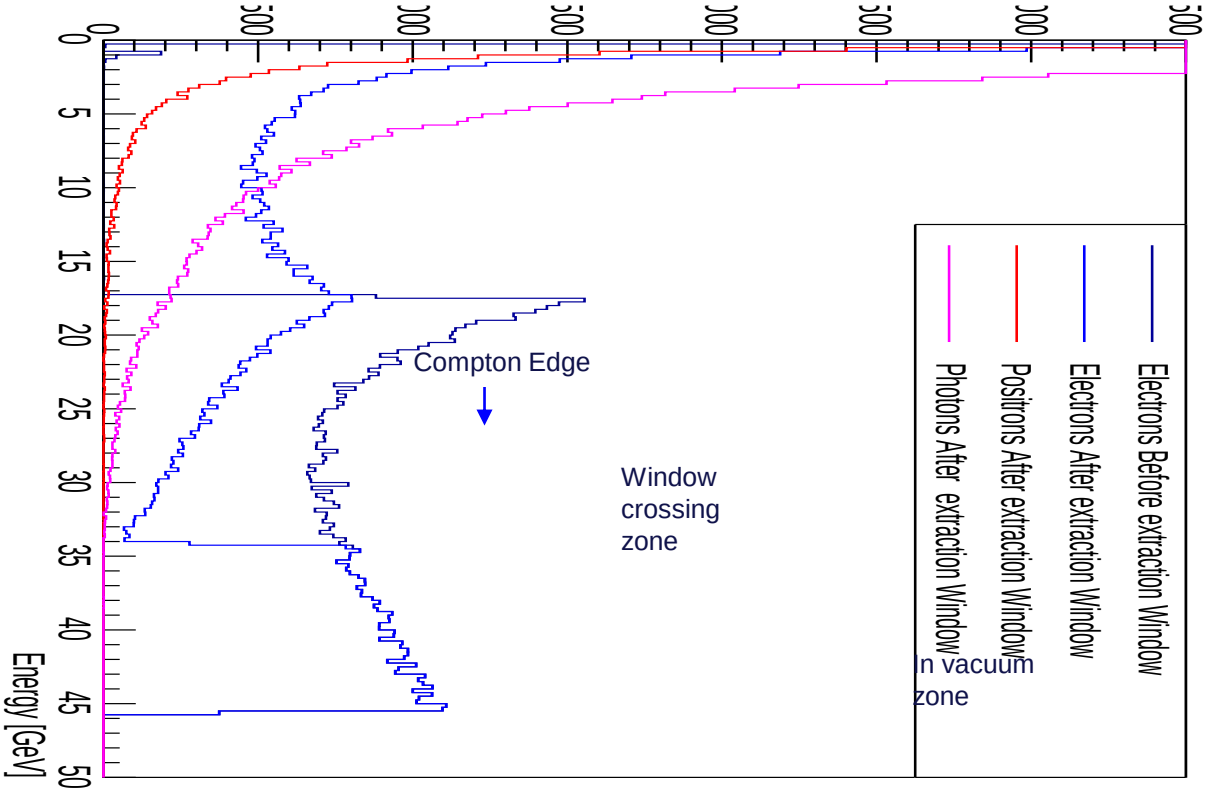
90deg tapering (transverse)



Compton electrons extraction spectra

Z mode 45.6GeV beam energy
Extraction window at 15 deg angle
Window thickness 2mm copper.
Makes a 7.7mm seen by the particles along the track.

We can see that the Compton electrons are undergoing electromagnetic interaction when crossing the exit window.

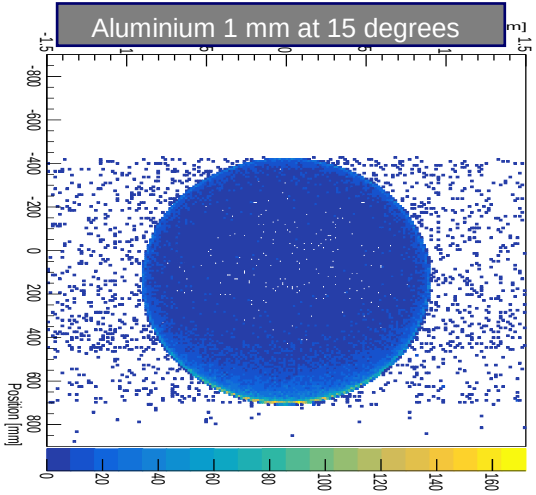


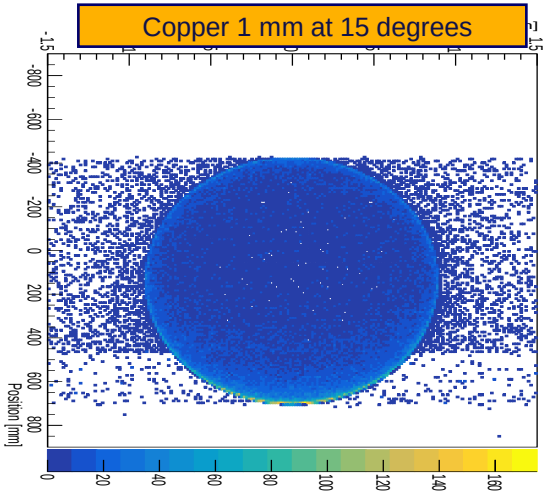
Extraction window material/thickness

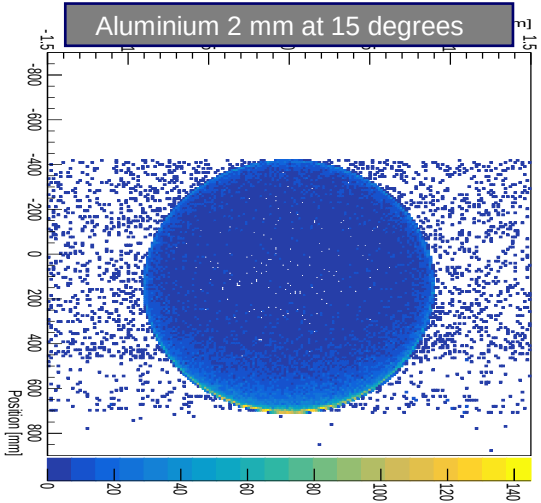
Study at Z pole sampling plane is 1mm after the extraction window.

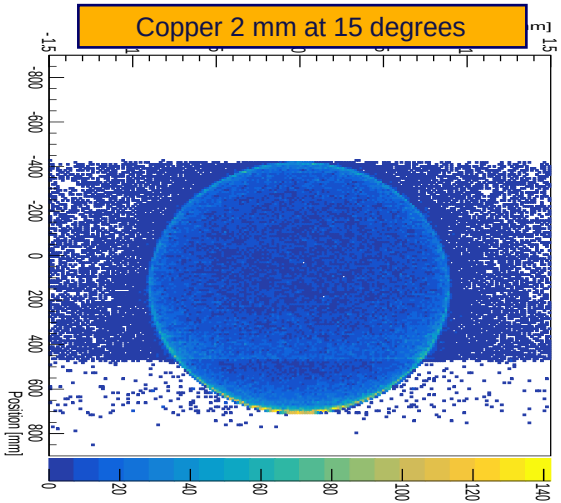
Aluminium and Copper
Two ticknesses 1-2 mm

1 mm Aluminium is the most transparent solution.



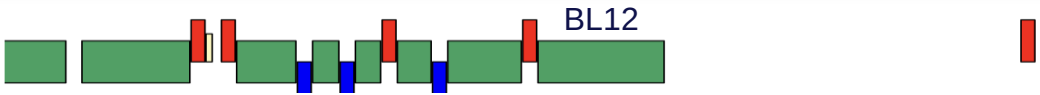






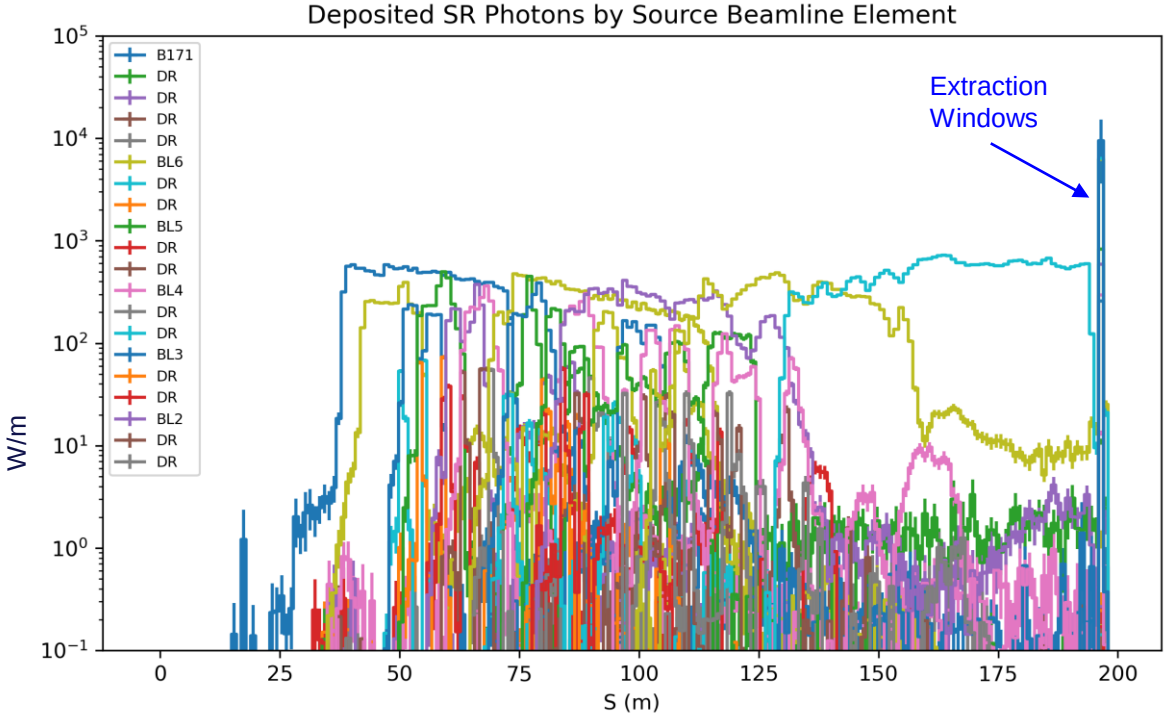
Power deposited by All elements (Dipoles, Quads, Drift)

BEAMLINE FOR THE STUDY



Thanks to the toolkit of Kevin Andre, I was able to simulate SR generation at the polarimeter location including reflections in the beam pipe from upstream magnets.

In average a power dissipation of 1kW/m is expected.

We might reach 10kW on the exit window surface (to be confirmed) .

Special cooling of the exit window would eventually be needed.