Overview of the FCC-ee beam instrumentation R&D

A. Boccardi, D. Butti, M. Gasior, E. Howling, R. Kieffer, T. Lefevre, S. Mazzoni, B. Salvachua, A. Schloegelhofer, C. Zamantzas CERN, Geneva, Switzerland

M. Reissig, E. Bründermann, B. Haerer, G. Niehues, R. Ruprecht, A.-S. Müller, Karlsruhe Institute of Technology, Karlsruhe, Germany

M. Potenza, M. Siano, Università degli Studi di Milano, Milan, Italy

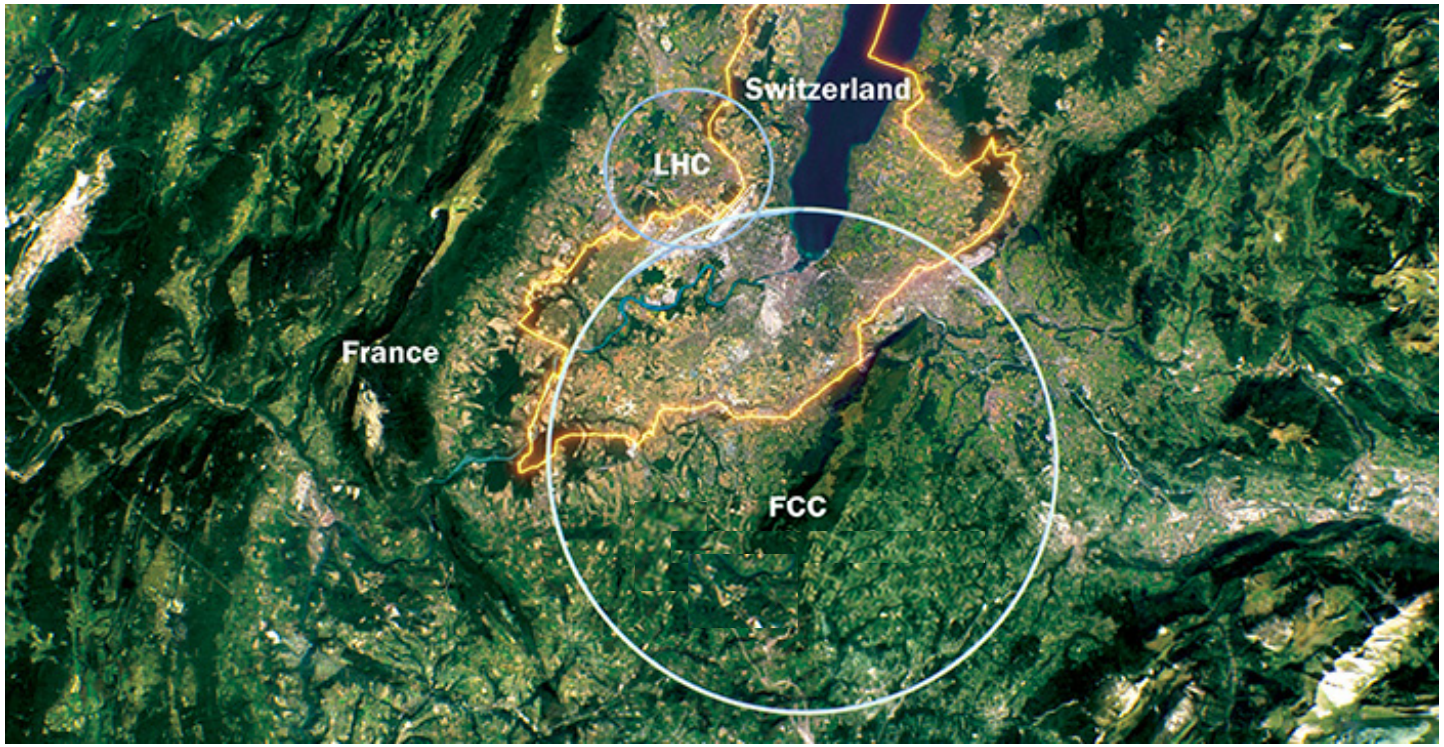
U. Iriso, A. Nosych, L. Torino, ALBA-CELLS, Cerdanyola del Campo, Spain

IBIC24, Beijing, 10 September 2024

Future Circular Collider study

CERN is conducting a feasibility study (2021-2025) for a circular collider for the post-LHC era

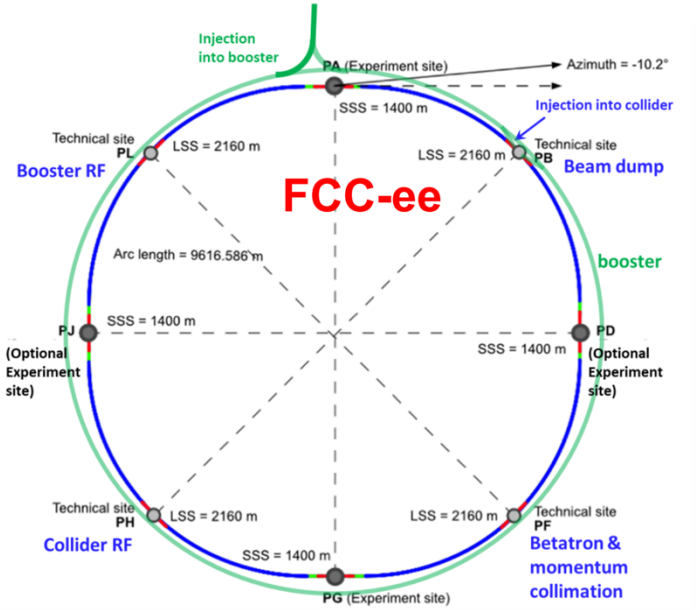
- 91 Km circumference ring with new injector complex

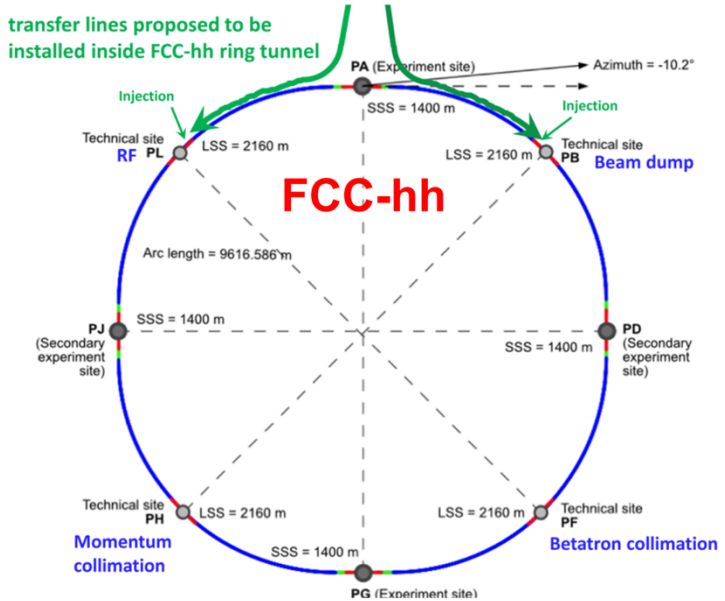


Future Circular Collider study

CERN is conducting a feasibility study (2021-2025) for a circular collider for the post-LHC era

- 91 Km circumference ring with new injector complex
- 1st stage **FCC-ee** electron-positron collider. Start of physics ≈ 2040, 15 years of operation
- 2nd stage **FCC-hh** hadron collider **in same tunnel**



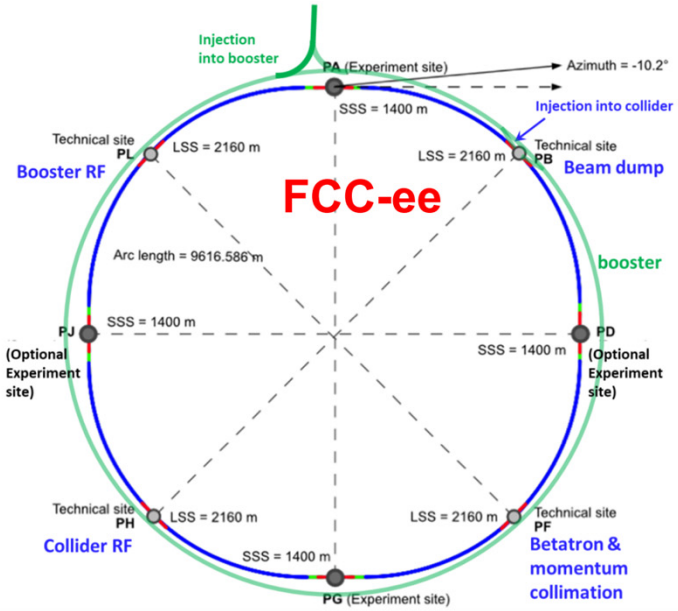


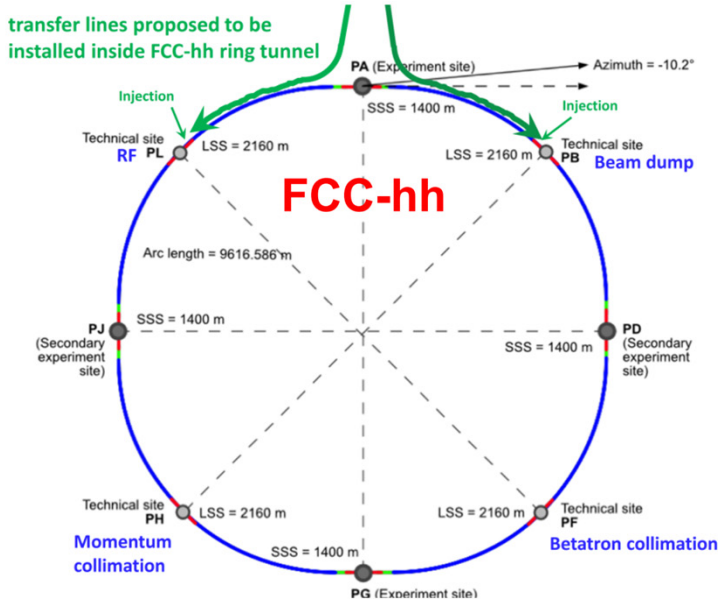
Future Circular Collider study

CERN is conducting a feasibility study (2021-2025) for a circular collider for the post-LHC era

- 4 technical, 4 experimental sites

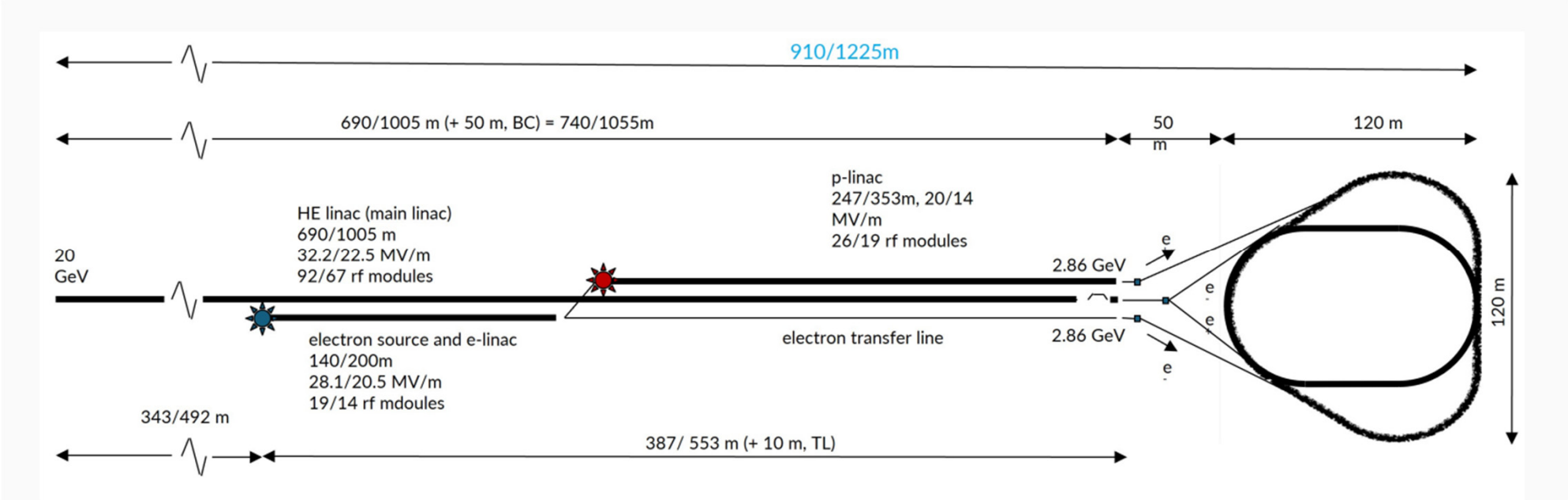
https://fcc.web.cern.ch/





FCC-ee overview and beam parameters

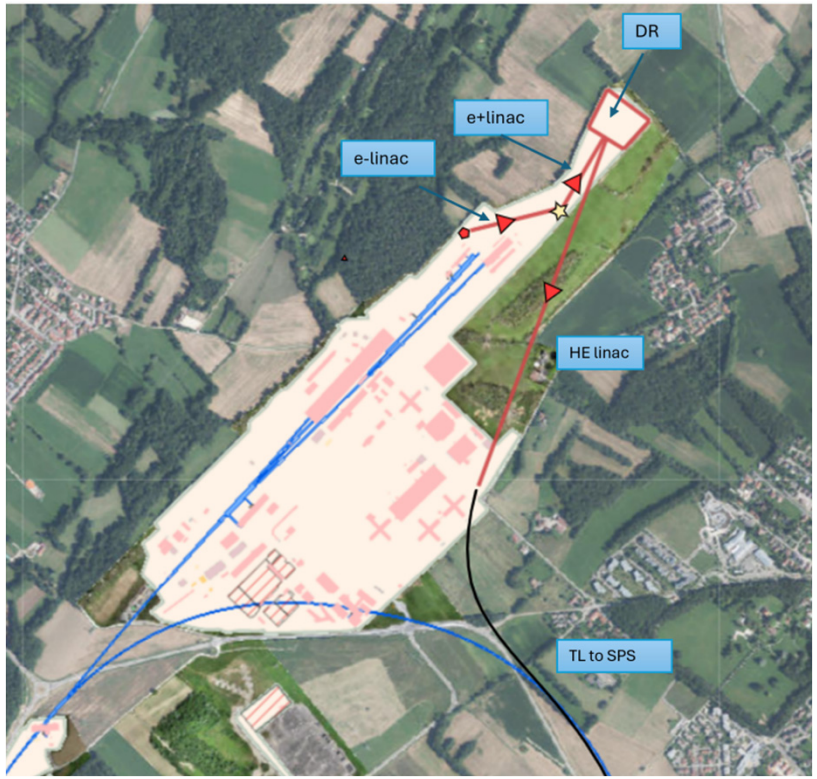
FCC-ee will operate in top-up mode, booster ring in same tunnel fed at 20 GeV by e-e+ injector complex, 4 bunches @ 100 Hz

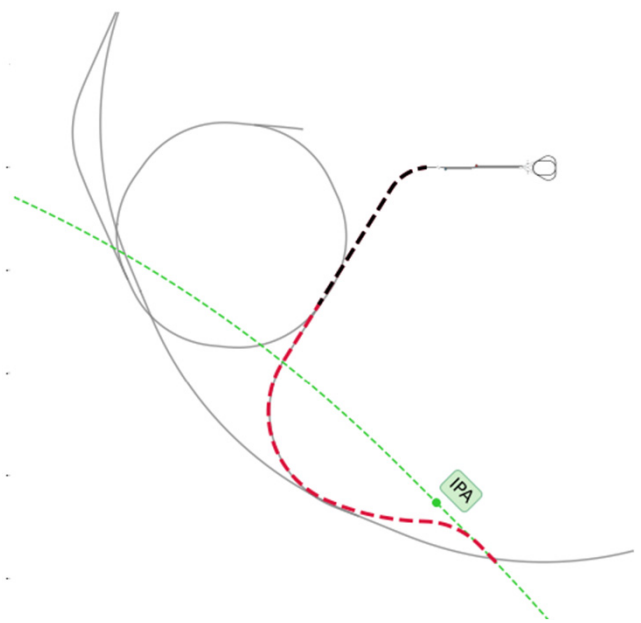


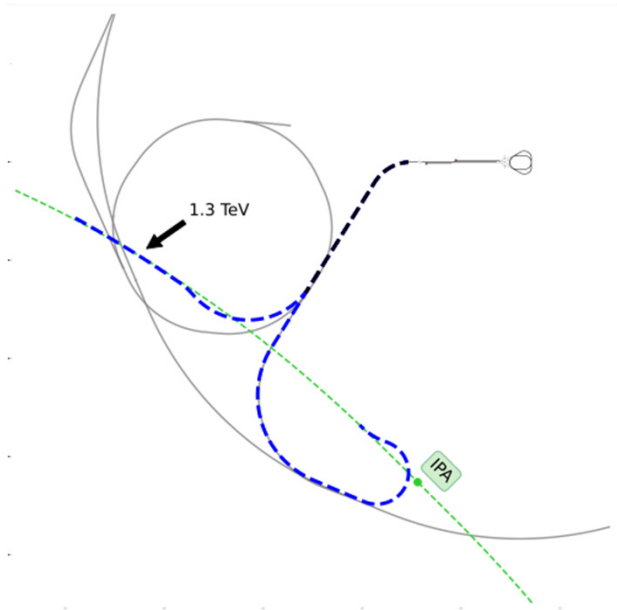
P. Craievich, PSI

FCC-ee overview and beam parameters

Placement of injector complex, effort to reuse existing infrastructure

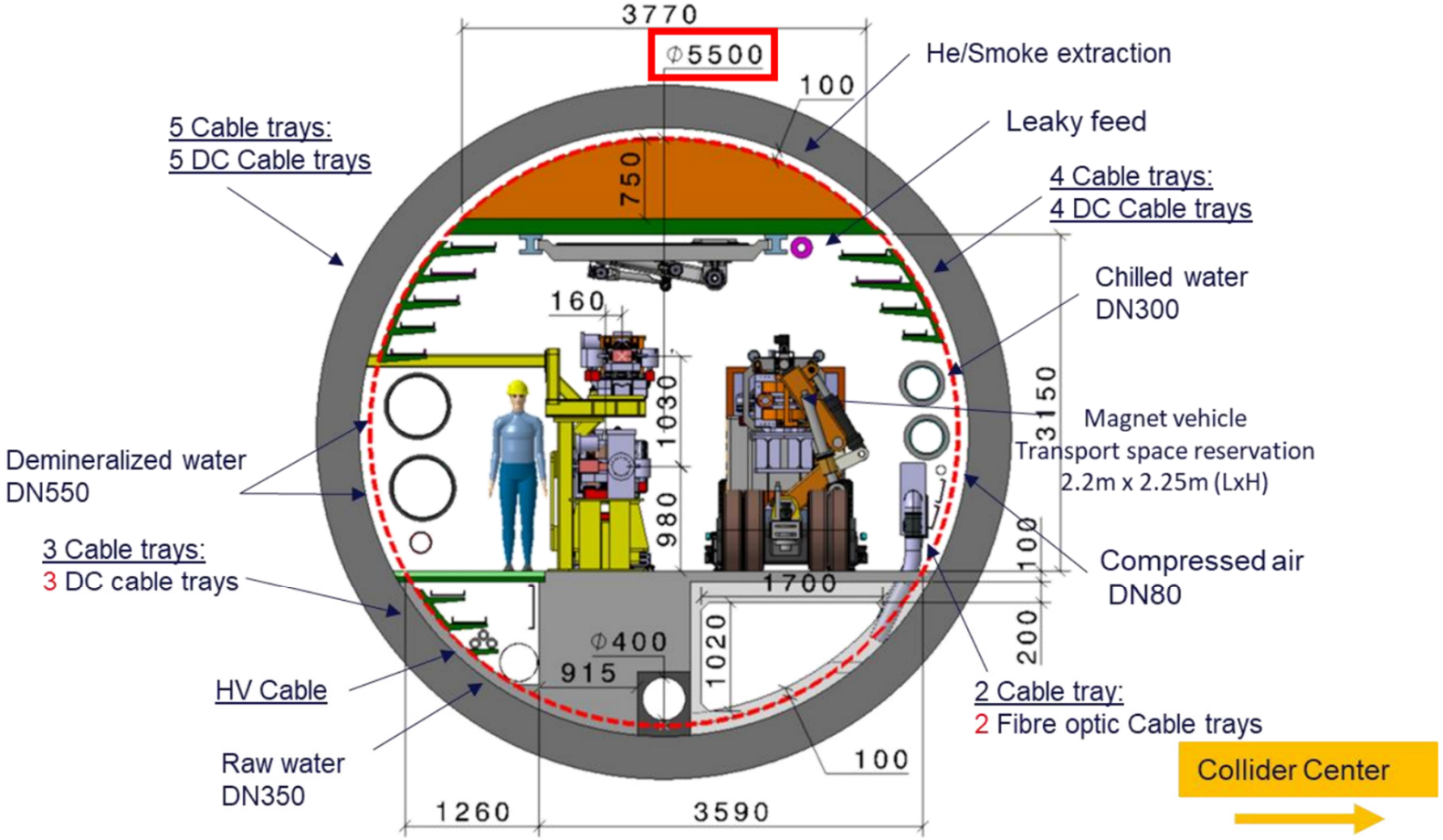






FCC-ee overview and beam parameters

Booster ring for continuous top-up operation



- Booster and collider in same tunnel, vertical positioning
- Booster stores 1/10 of collider bunch charge
- total cycle (injection – ramp - extraction) time between 30 (Z) and 4 s (ttbar)

A. Chance, B. Dalena, Q. Bruant, CEA
A. Ghribi, CNRS

FCC-ee overview and beam parameters

FCC-ee covers the electro-weak sector: Z, W bosons, Higgs, Top quark

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]	1270	137	26.7	4.9
number bunches/beam	11200	1780	440	60
bunch intensity [10^{11}]	2.14	1.45	1.15	1.55
SR energy loss / turn [GeV]	0.0394	0.374	1.89	10.4
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.1/0	2.1/9.4
long. damping time [turns]	1158	215	64	18
horizontal beta* [m]	0.11	0.2	0.24	1.0
vertical beta* [mm]	0.7	1.0	1.0	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.71	1.59
vertical geom. emittance [pm]	1.9	2.2	1.4	1.6
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter ξ_x / ξ_y	0.002/0.0973	0.013/0.128	0.010/0.088	0.073/0.134
rms bunch length with SR / BS [mm]	5.6 / 15.5	3.5 / 5.4	3.4 / 4.7	1.8 / 2.2
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	140	20	≥5.0	1.25
total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.6	0.15
beam lifetime rad Bhabha + BS [min]	15	12	12	11
	4 years 5 x 10^{12} Z LEP x 10^5	2 years > 10^8 WW LEP x 10^4	3 years 2 x 10^6 H	5 years 2 x 10^6 tt pairs

- 50 MW synchrotron radiation per beam
- Bunch spacing: 25 ns (LHC)
- pilot bunches for energy calibration

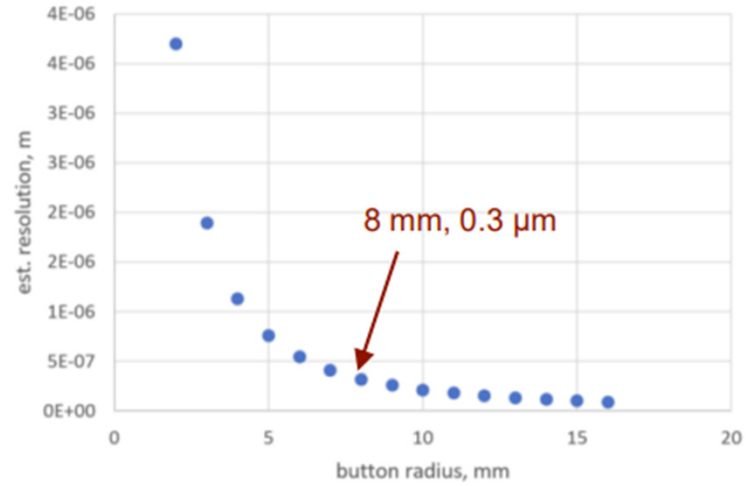
Challenges for FCC-ee BI systems

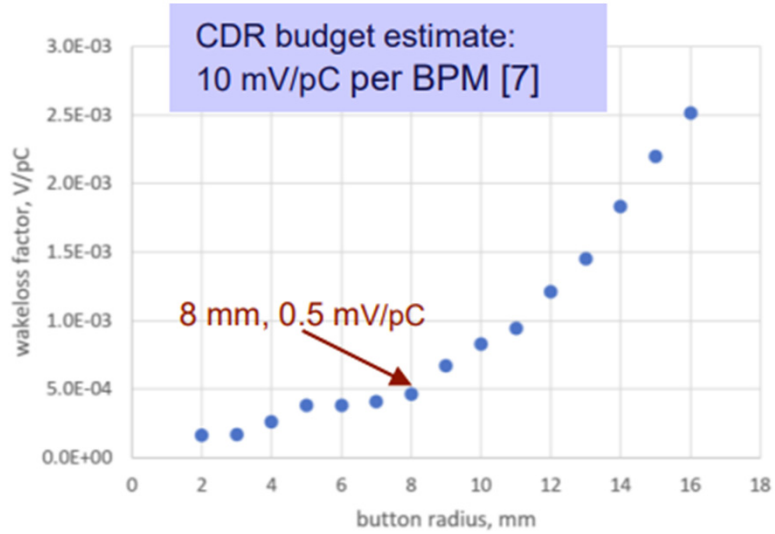
FCC-ee presents many challenges to beam instrumentation systems

- size of infrastructure brings technical and organizational issues: impedance, signal transmission, production & maintenance (eg almost **9000** arc BPMs in booster and main ring)
- radiation levels in the arc (value) for electronics, fibres. Mitigation vs. development or purchase of rad-hard products
- stored beam energy and SR power for temperature stability and alignment
- spectrum of SR (λ_{cr} up to MeV) for integrity of SR-based systems
- precision measurements: polarimetry, bunch length (% level)

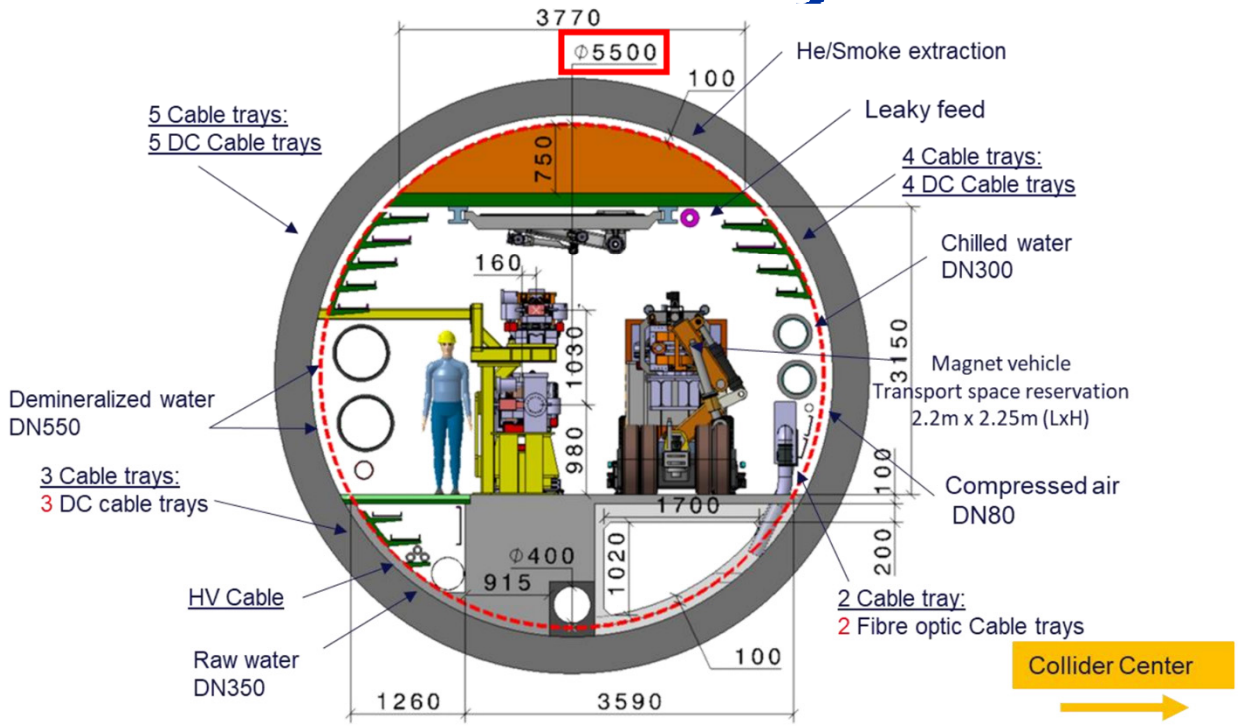
Beam Position systems

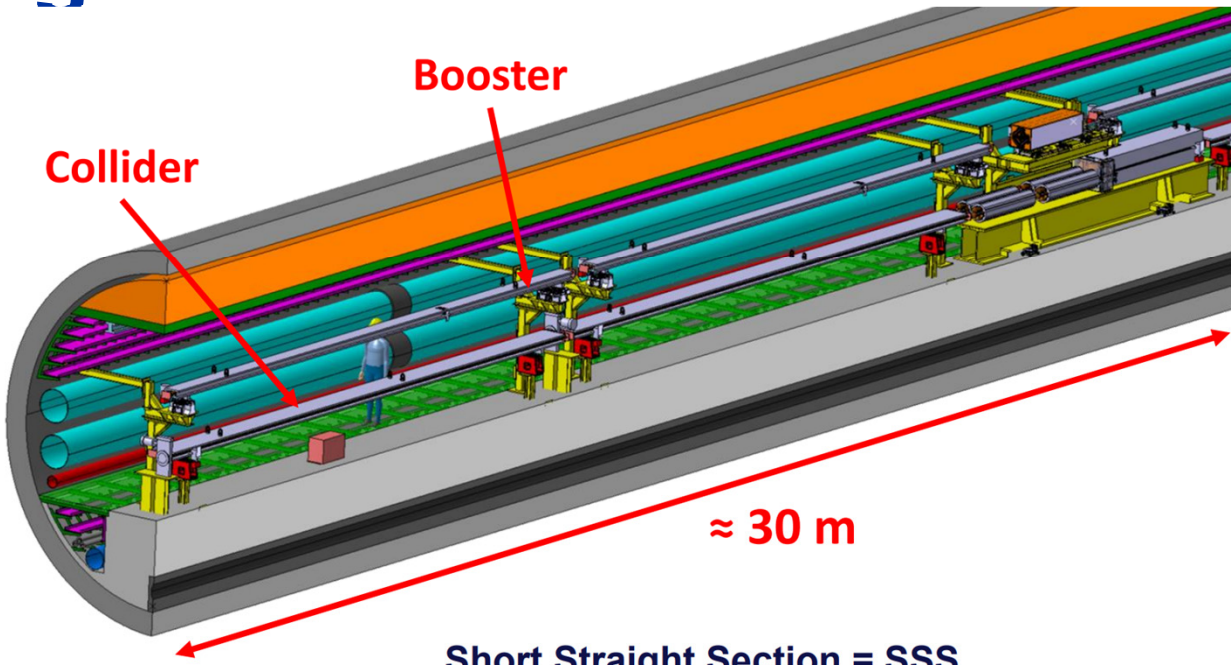
- Arc button BPMs shall provide orbit, TxT and bxb measurement with **0.1 um (orbit) / 10 um (turn by turn) resolution**.
- Simulations and experimental validation ongoing at CERN for choice of optimal button size and gap. **8 mm** radius, **1 mm gap** current compromise between signal and wakeloss . Work ongoing.
- Beam based alignment could bring quad-BPM accuracy to 20 um, but **alignment strategy to be defined**

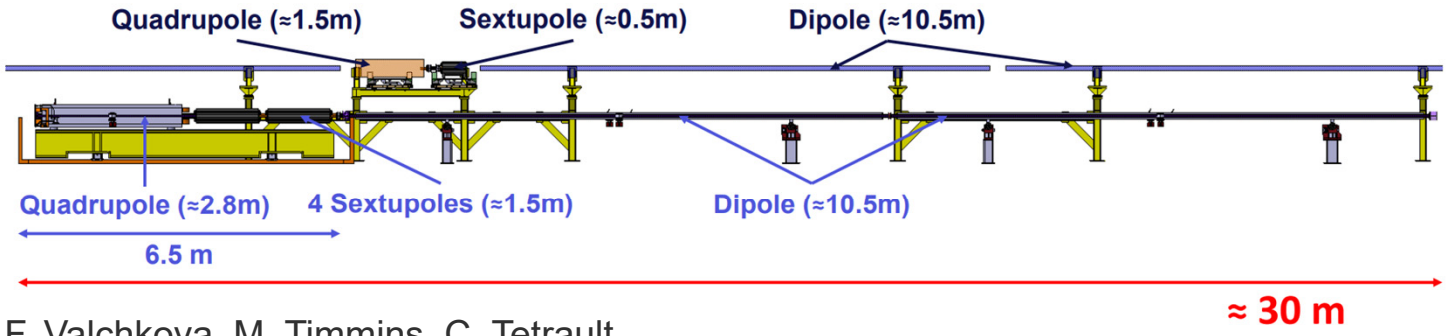




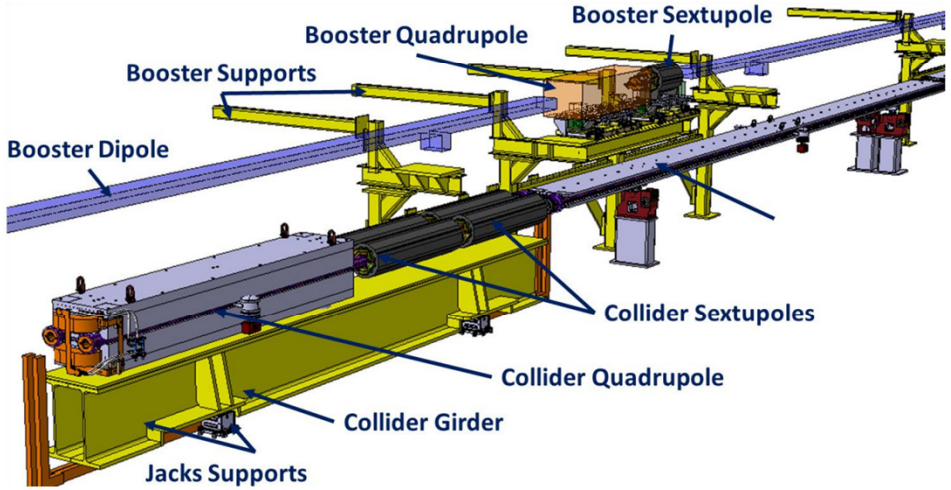
Beam Position systems integration







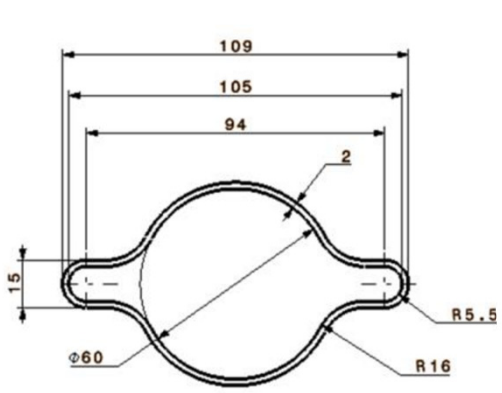
Short Straight Section = SSS

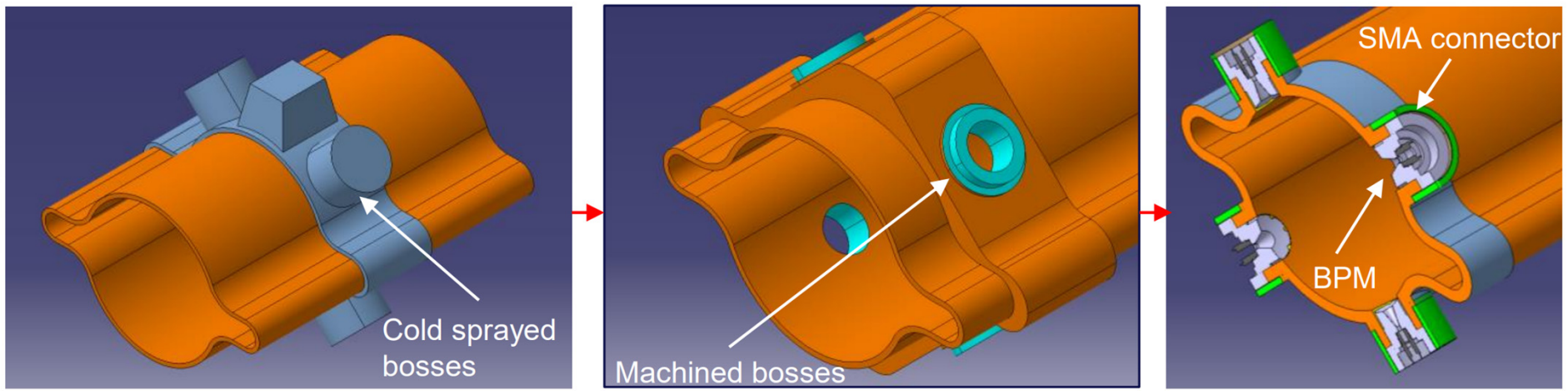


F. Valchkova, M. Timmins, C. Tetrault

Beam Position systems integration

- Copper chamber with thin NEG coating. Winglets equipped with SR absorbers
- BPM directly integrated in vacuum chamber. Cold-spray additive manufacturing technique proposed.
- Button connected with Shape Memory Alloy connectors

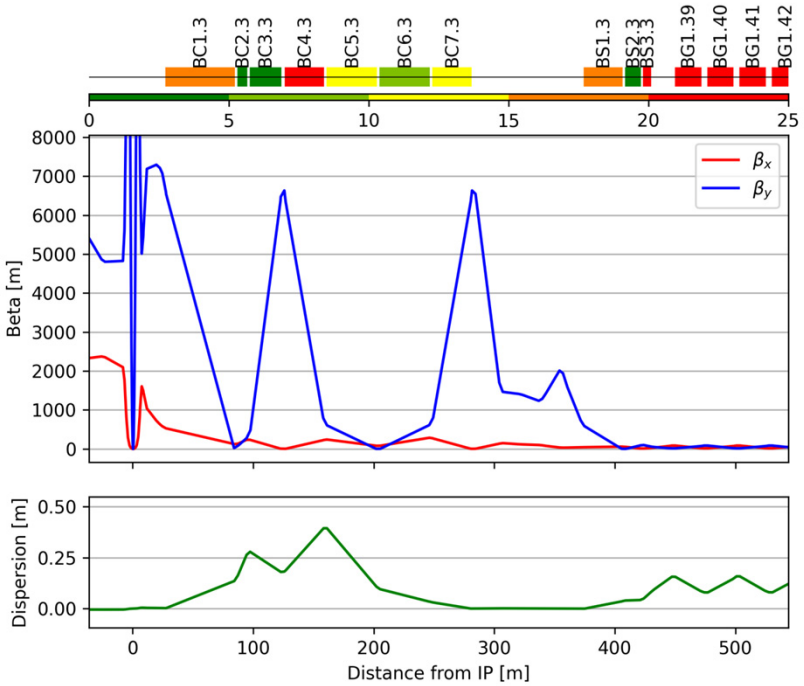




M. Morrone, C. Garion, R. Kersevan, M. Ady

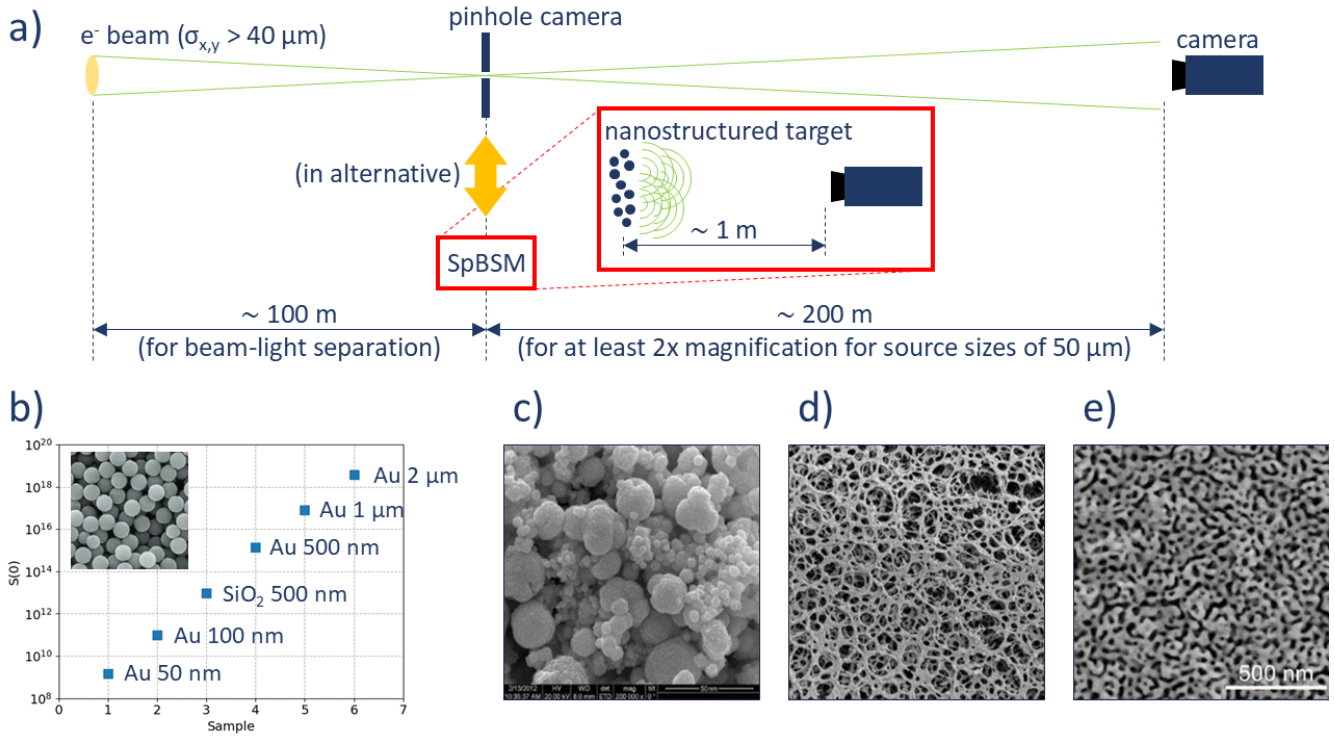
Transverse profile measurement

- BxB transverse profile shall be measured with **2% precision, 10% accuracy**, with minimum measurable emittance of 1.7 nm (H), 1.6 pm (H). From LEP experience: emphasis on a % precise, bXb relative change of emittance typ at 1 Hz.
- Study ongoing to find appropriate source: suitable beta, suitable spectrum (E_{cr} = 10-100 keV): BS-type dipoles downstream IPs.
- Focus on either pinhole or interferometry. **Long extraction lines**



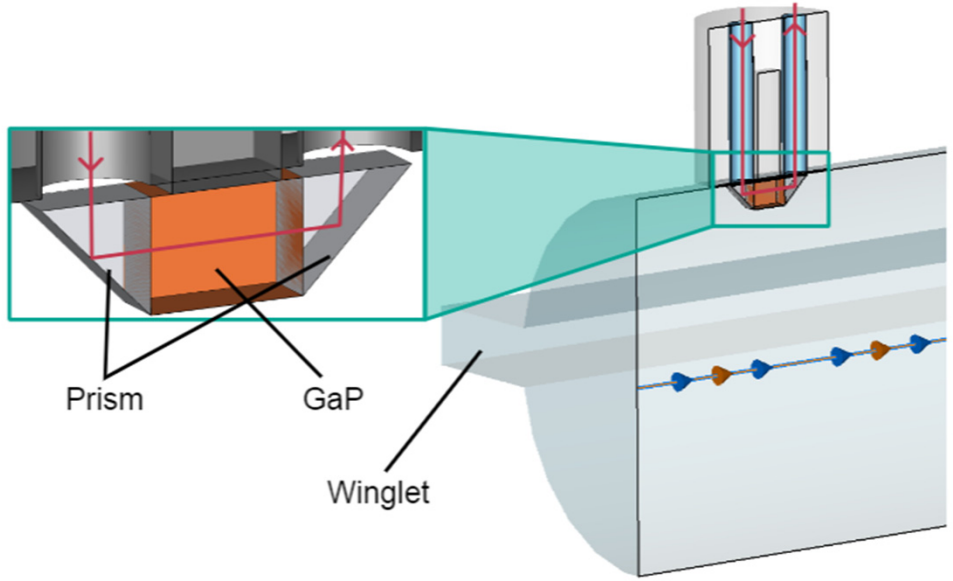
Transverse profile measurement

- Interferometry with um-resolution being studied with U. Milan and ALBA. Setup is compatible with pinhole. **See poster of U. Iriso today**
- Development of target based on high-Z metallic nanostructures (gold non-powders (c), nano-membranes (d), nanoporous gold(e))
- Test on FE1 line at ALBA in 2025 (3GeV dipole radiation, 23.7 keV, 1.7% BW)



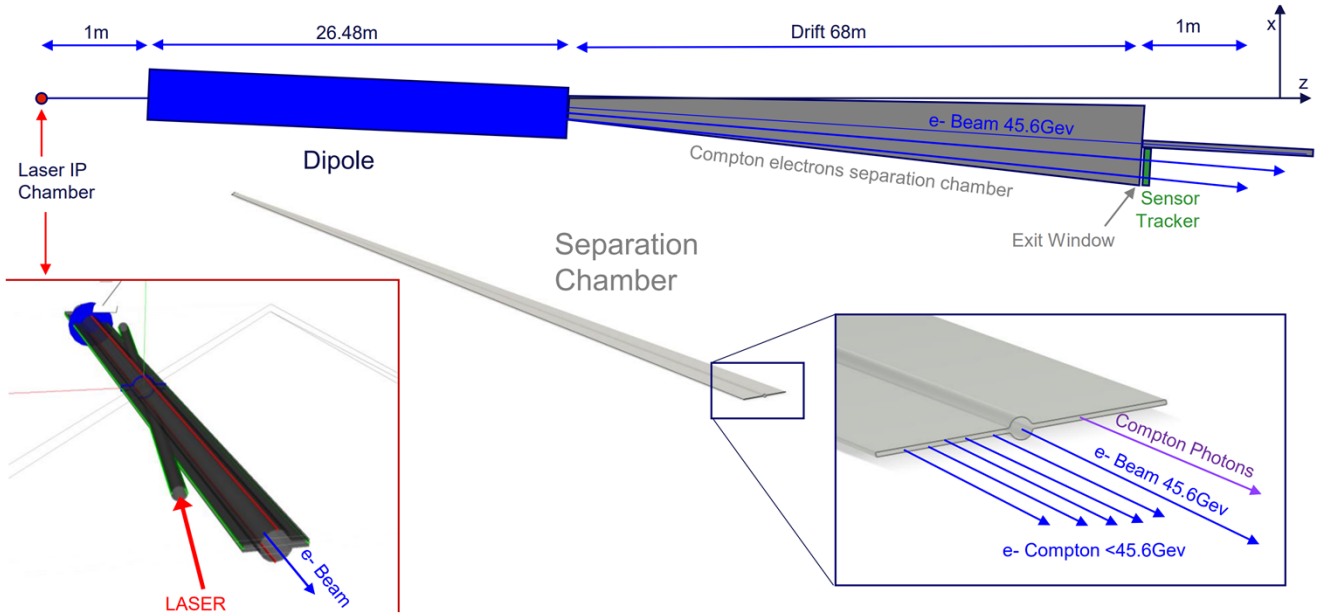
Longitudinal profile measurement

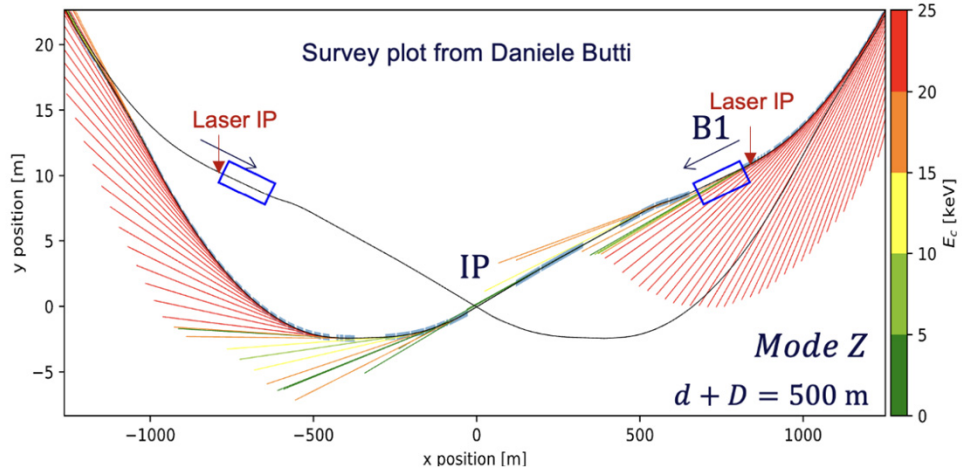
- 6-50 ps (σ) bunch profile depending on physics case. **BxB** needed for beam beam effects, **1% resolution** typical
- KIT studying E-O monitor with sub-ps resolution, MHz repetition rate, based on system at KARA. Challenges: high bunch charge, long bunches, impedance. Successful test performed in CLEAR (2024).
- CERN progressing in fast acquisition with time-stretched optical pulses with E-O-modulators. Latest tests show 7 ps resolution. **See talk of A. Schloegelhofer (Wed. 9:30)**
- For machine protection: need to monitor one or more abort gaps: high sensitivity measurement, probably doable through visible SR



Polarimetry

- Polarimeter needed for **accurate centre of mass energy calibration** through resonant depolarisation scans on pilot bunches (Z,W, possibly ZH). Detected through inverse Compton scattering. Resonance affects shape of scattered electrons and photons
- Complex instrument (physics, laser control, signal generation and propagation, detectors, …). At present location identified upstream IP, first simulations of e-ph patterns, check of impedance of separation chamber





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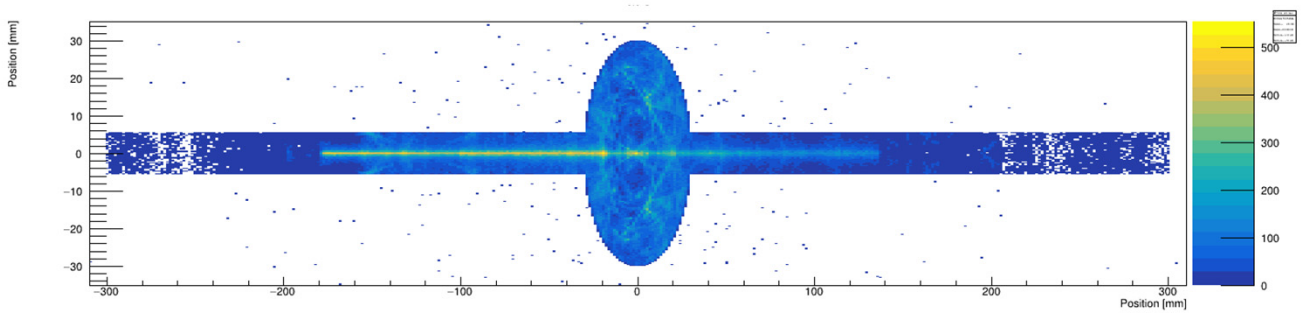
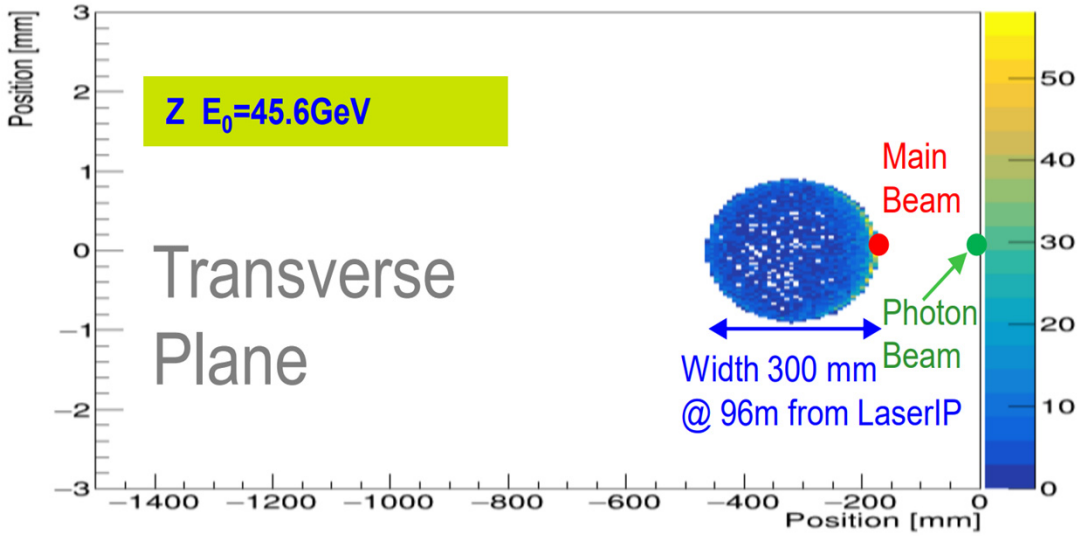


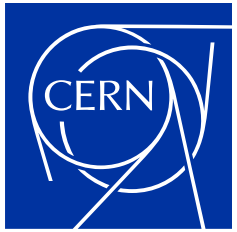
Background SR fan at polarimeter's exit window



Much more to do…

At present only the most crucial studies are carried out. Will need additional resources

- development of beam loss monitoring system and concept
- transverse instability monitors
- instrumentation in IR Region
- development of orbit feedback system
- instrumentation in booster ring (position, transverse and longitudinal profiles)



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