MDI Summary

for the

65th ICFA Advanced Beam Dynamics Workshop

eeFACT2022

M. Sullivan

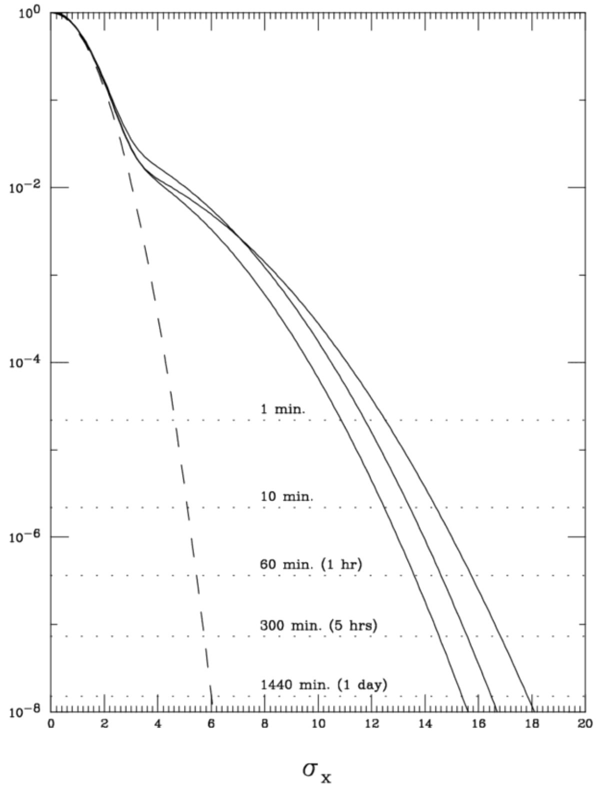
Sep. 15, 2022

MDI WG5

- There were many very interesting presentations on several topics
- I will try to describe them
- The descriptions will have to very brief, and I hope to give you a glimpse of the various presentations
- This is a whirlwind tour with about 3 slides from each presentation

Plenary session

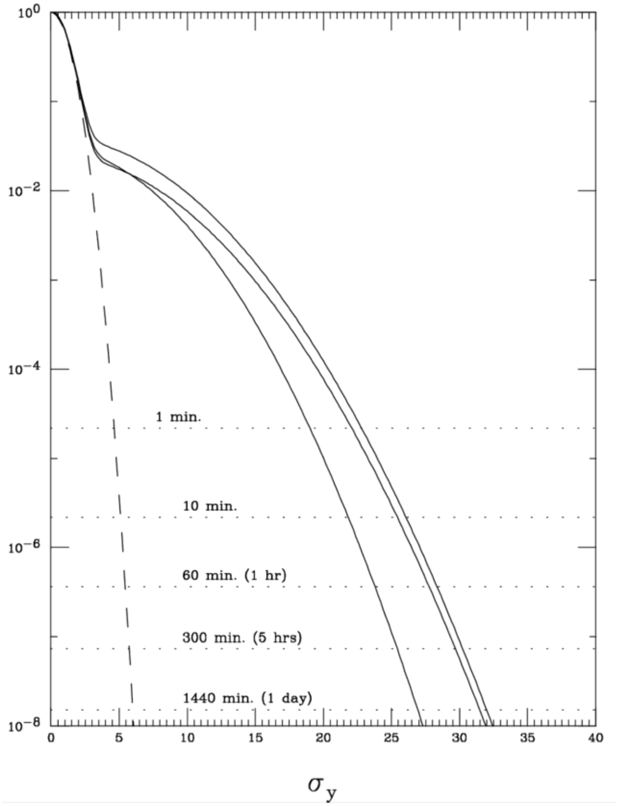
- Mike Sullivan presented some issues regarding high currents and high luminosity
  - High beam currents mean beam pipe "scrubbing" leads to non-gaussian beam tails
  - Large non-gaussian beam tails leads to short lifetimes and high detector backgrounds
  - He showed some examples of second gaussian beam tail models



Tail distributions that can generate the background level seen in the superKEKB pixel detector (PXD) during early running.

They also approximately agree with the measured beam lifetime.

The one-day lifetime is derived by Matt Sands, "The Physics of Electron Storage Rings an Introduction", 1970, SLAC-121



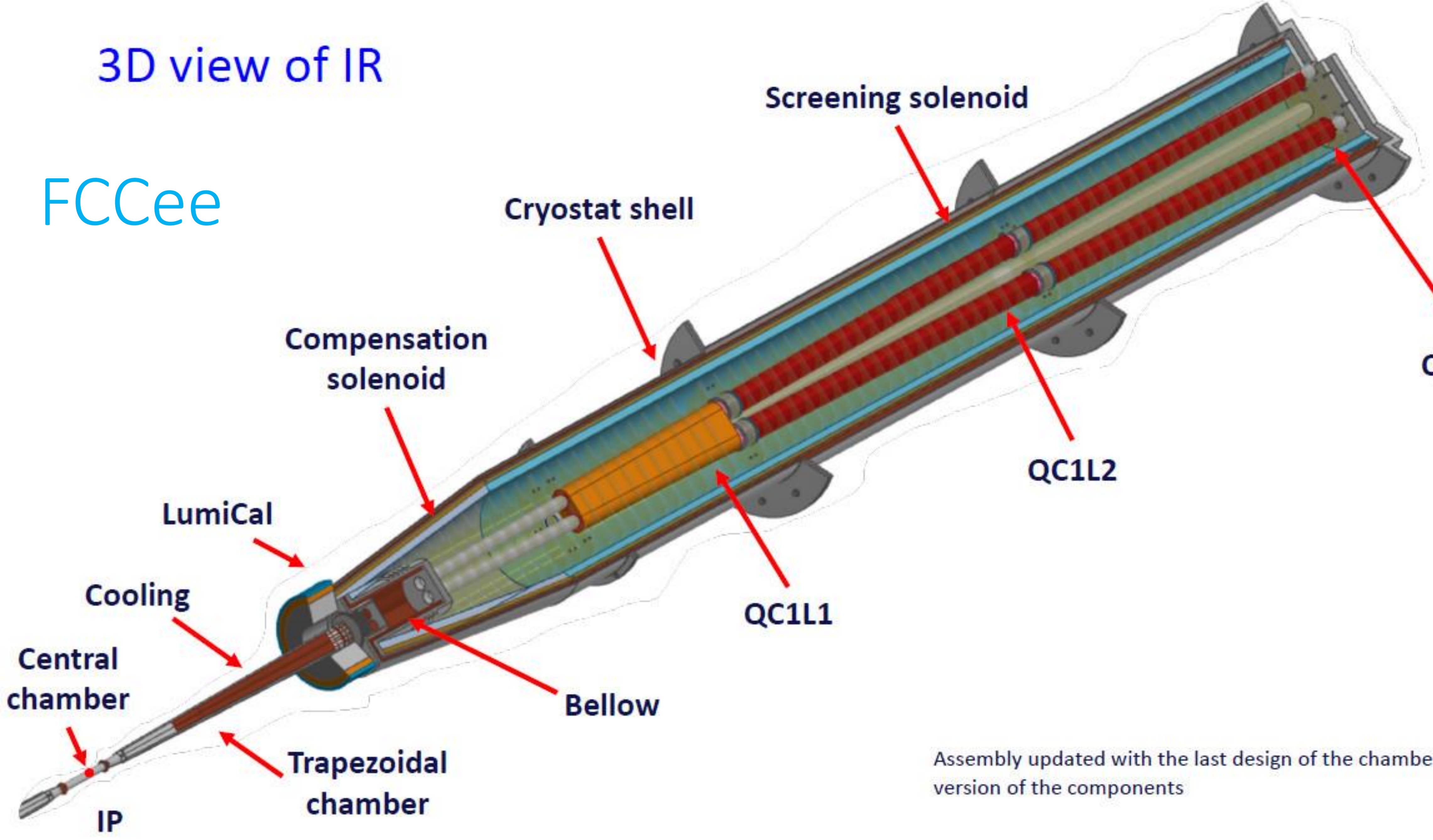
Plenary MDI WG5

- I also mentioned the backgrounds from high luminosity
- Many of these background sources are mentioned in more detail in following talks

- The second talk was by Manuela Boscolo and was about MDI progress for the FCCee design
- Manuela showed progress on several fronts
  - Final focus magnets
  - Inner beampipe
  - Initial assembly concepts

3D view of IR

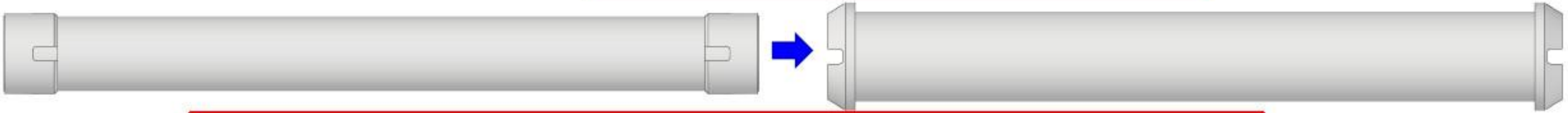
FCCee



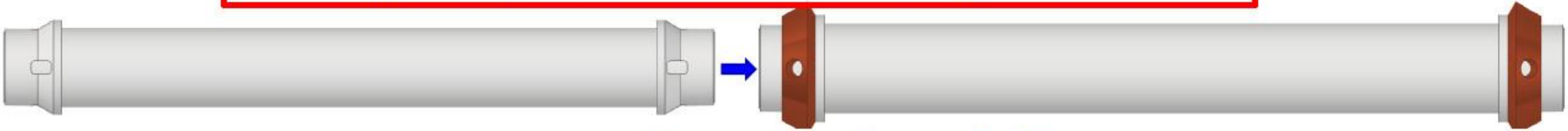
Assembly updated with the last design of the chamber and the last version of the components

Central chamber

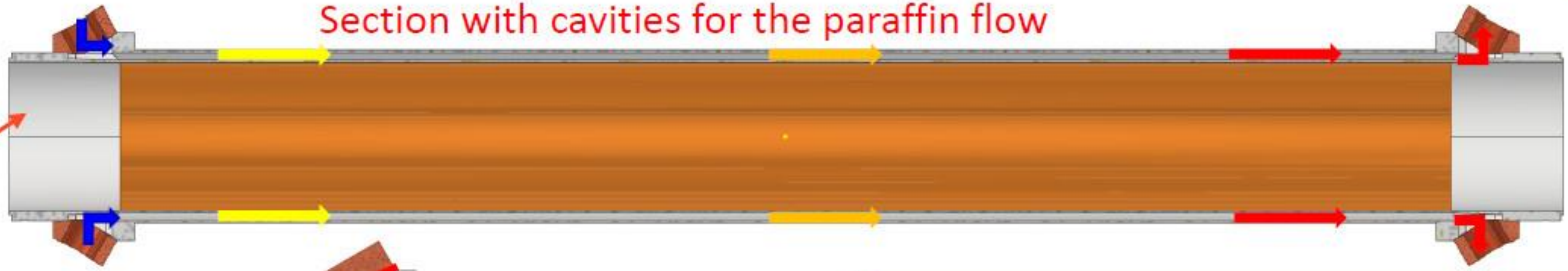
Insertion of the internal part

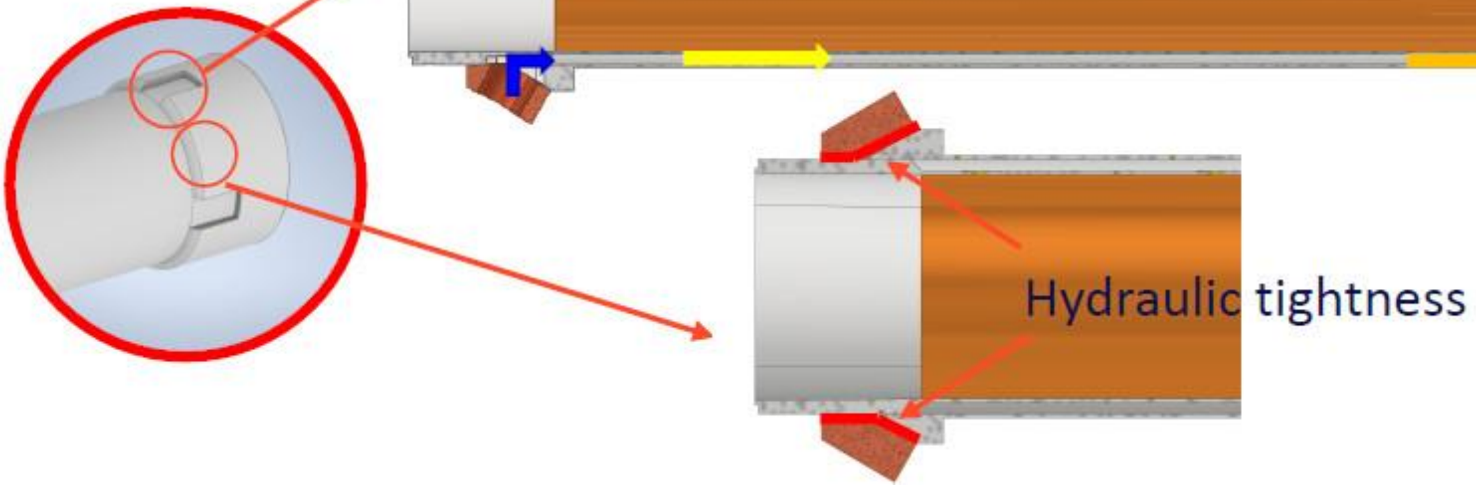


Thick copper deposition to create the cooling inlet and outlet



FCCee





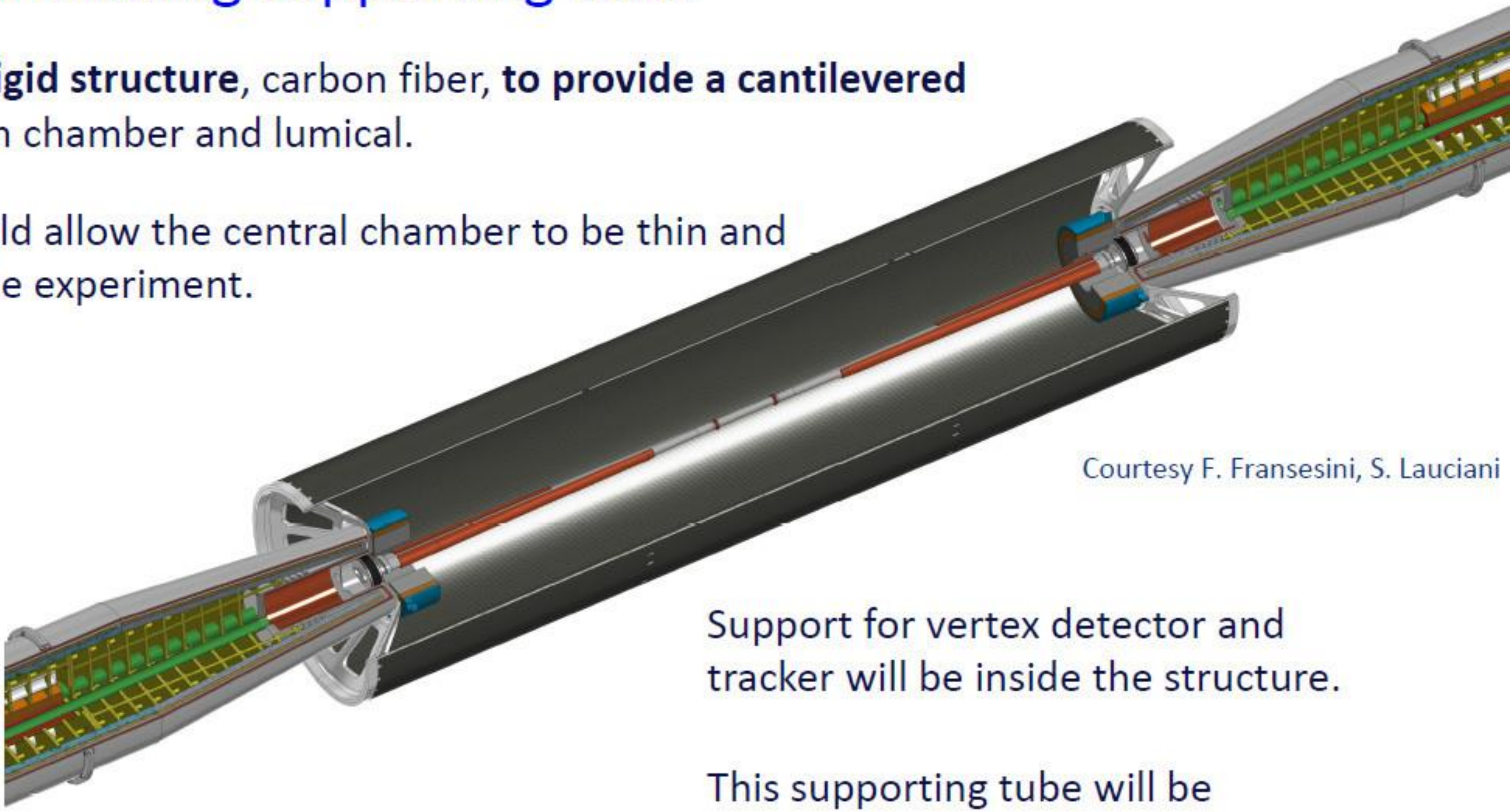
The channel for paraffin is opened only in the part where the internal central chamber has cavities. Using the "*thick copper deposition*" the hydraulic tightness is assured in the parts in contact with AlBeMet

3D view of IR including supporting tube

Proposed lightweight **rigid structure**, carbon fiber, **to provide a cantilevered support** for the vacuum chamber and lumical.

The rigid structure would allow the central chamber to be thin and light as requested by the experiment.

FCCee



Courtesy F. Fransesini, S. Lauciani

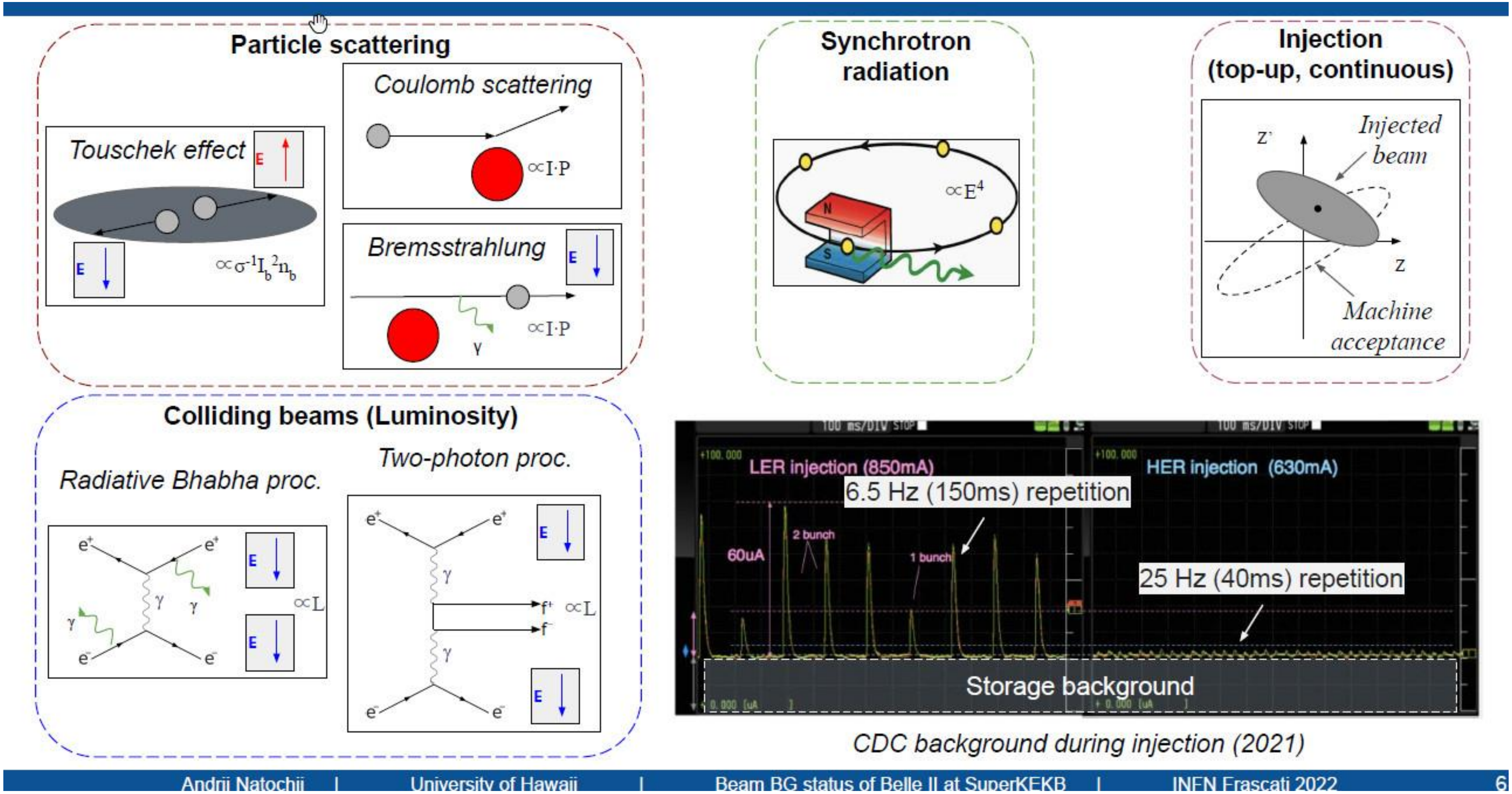
Support for vertex detector and tracker will be inside the structure.

This supporting tube will be anchored to the detector.

WG5 Plenary (cont.)

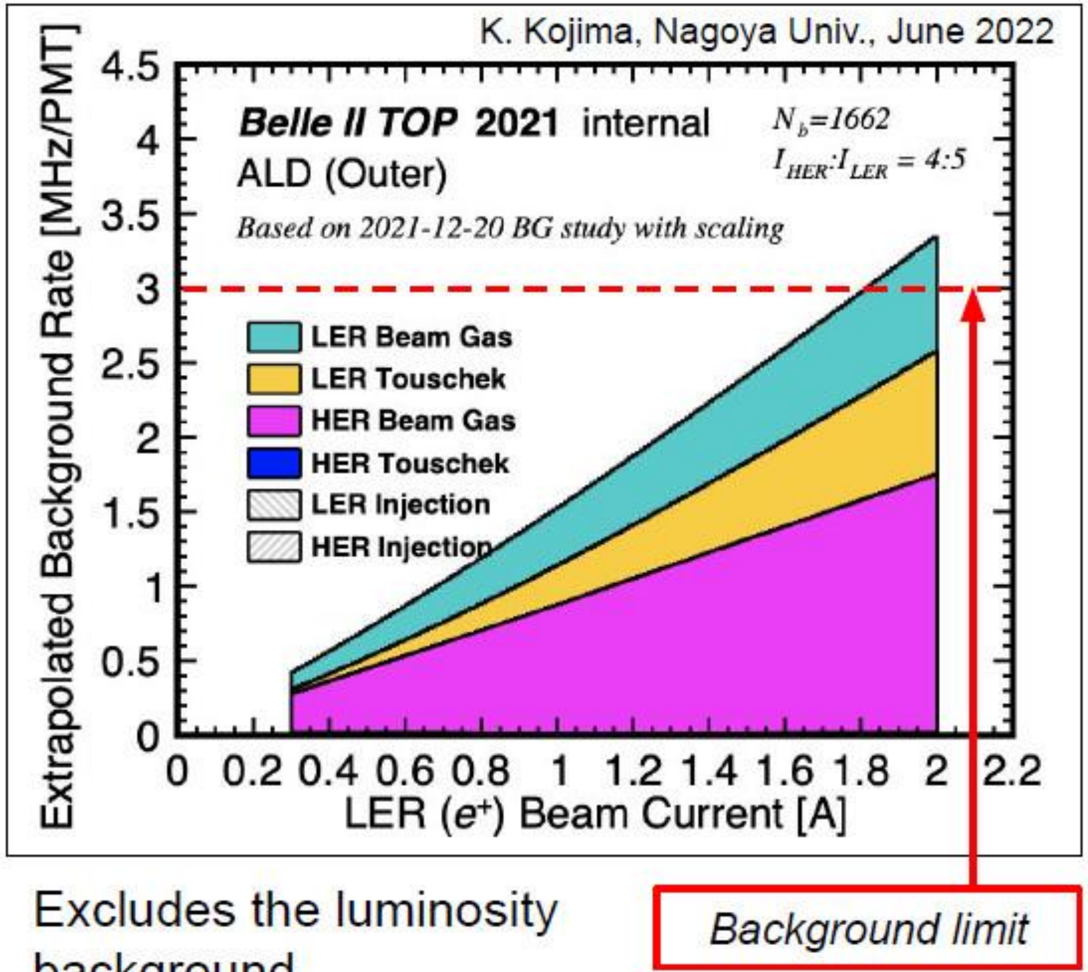
- Following Manuela's talk we had two very interesting talks by Andrii Natochii about superKEKB backgrounds
- The first showed the current status of background measurements compared to MC simulation
  - The measurements divided by the MC simulation are all approaching one
- The second presentation described in more detail the MC background simulator
  - The simulation of the detector and local region has gradually improved, and this has been a major factor in getting good agreement between MC and data

SuperKEKB background sources studied by the background team



One of the most vulnerable sub-detectors is the Time of Propagation (TOP) particle ID system

SuperKEKB



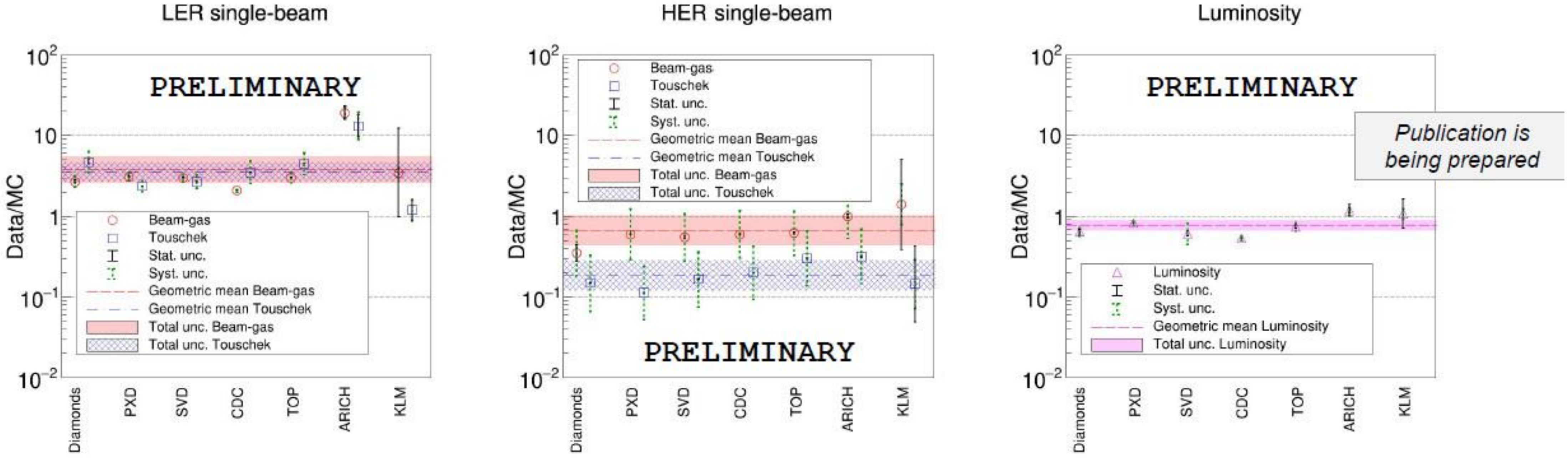
Excludes the luminosity background

- Current background rates in Belle II at ~1.2 A are acceptable and below limits
- Belle II did not limit beam currents in 2021 and 2022
    - It will limit SuperKEKB eventually, without further background mitigation
- To reach the **target** luminosity of 6.3x10^{35} $cm^{-2}s^{-1}$ an upgrade of crucial detector components is foreseen (e.g. TOP short lifetime conventional PMTs)

Snowmass Whitepaper arXiv:2203.11349

SuperKEKB

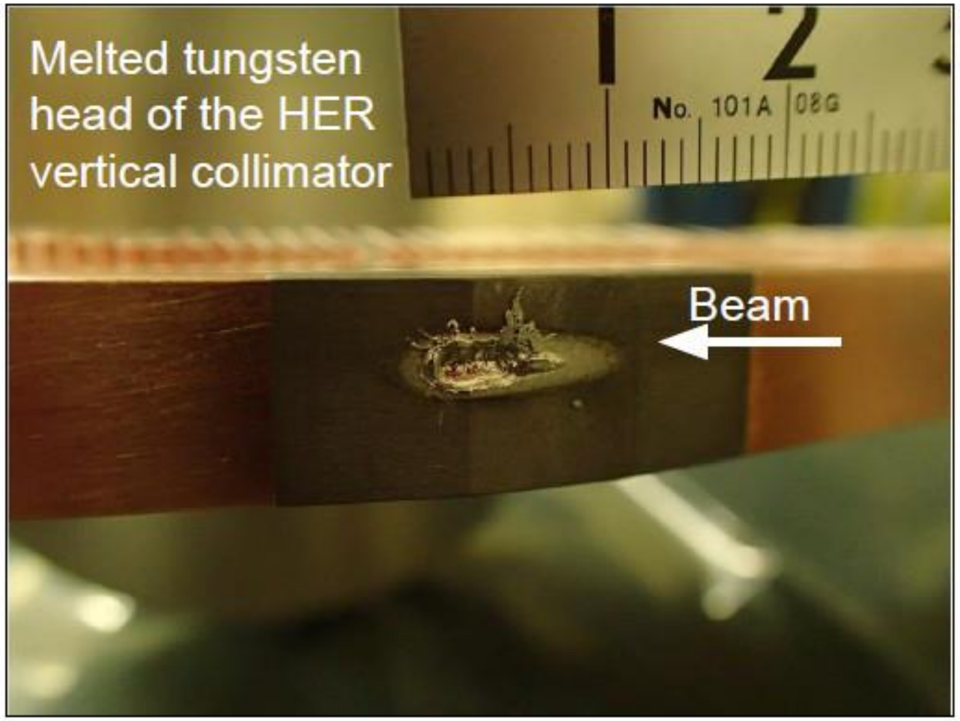
Ratios of measured (**data**) to simulated (**MC**) backgrounds based on dedicated studies in 2020-2021



- Current data/MC ratios are within one order of magnitude from unity
  - **Substantial improvement** compared to measurements in 2016 [*link*] and 2018 [*link*]
  - It confirms our good understanding of beam loss processes in SuperKEKB
- These ratios are used to rescale simulated backgrounds toward higher luminosities

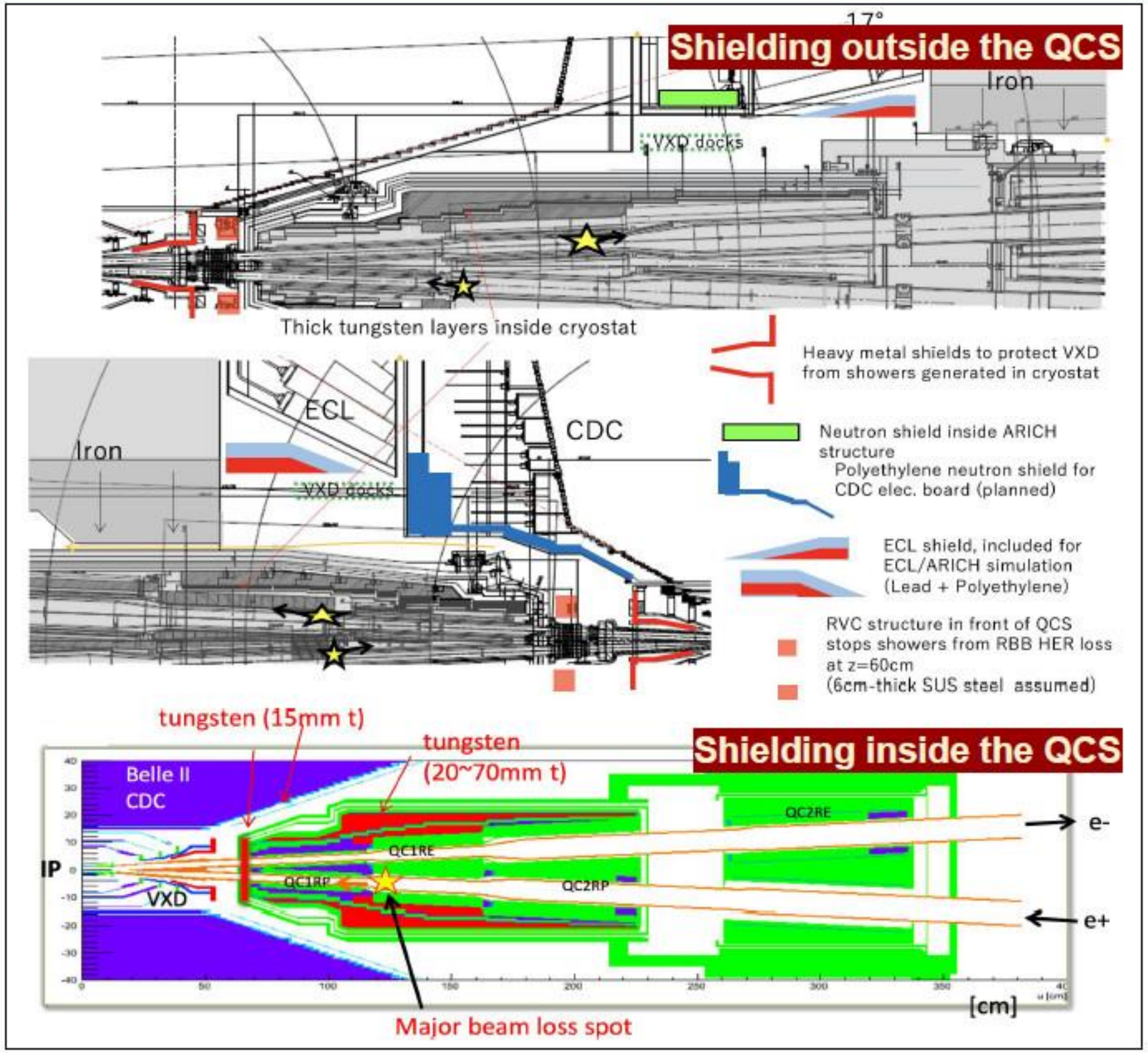
superKEKB sudden beam loss event causing coll. damage

- During stable machine operation unexplained beam instabilities and beam losses may occasionally occur in one of the rings causing **sudden beam losses (SBLs)** at a specific location around the ring due to
  - Machine element failure
  - Beam-dust interaction
  - Vacuum element defects
- **Consequences**
  - Detector and/or collimators damage, see Figure
    - Belle II background increase
  - Superconducting magnet quenches
- Usually only a few such catastrophic beam loss events happen per year in each ring
  - In 2022, we had many (>50) SBLs in the LER trying to go beyond 0.7 mA/bunch
- **Cures**
  - Upgraded abort system → fast abort signal
  - Low-Z materials for collimator heads (MoGr, Ta+Gr) → robust collimators
  - Understand the source of the unstable beam (vacuum system inspection, beam dynamics study, installation of additional beam loss monitors around the rings)



SuperKEKB MC details: All possible places filled with shielding

- Most of IR beam losses occur inside the QCS
  - Partially considered in the TDR 2010 [1]
- In 2021-2022, detector saw single-event upsets (SEU) of FPGAs electronics boards
  - SEUs are presumably from neutrons created in the EM showers
  - Still acceptable level
- Installed additional detector protection
  - Heavy metal shield inside VXD
  - Polyethylene+lead shield inside ECL, ARICH & CDC
- Planned detector protection for the LS1 (2022-2023)
  - Additional EM and neutron shielding around QCS and Belle II to suppress SEUs



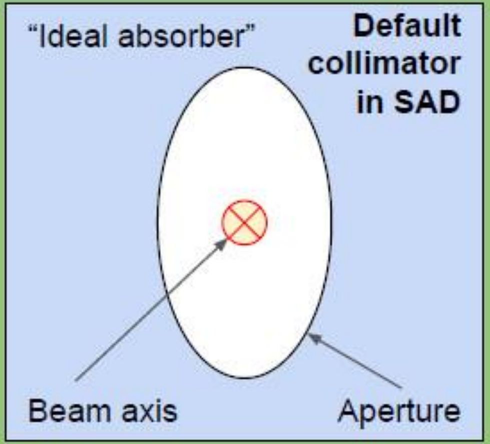
[1] T. Abe, et al., "Belle II Technical Design Report", KEK-REPORT-2010-1, 2010, https://doi.org/10.48550/arXiv.1011.0352

SuperKEKB MC details: Some of the modeling improvements

Data/MC ~ 10^{-3}–10^{3} → **Data/MC ~ 10^{-1}–10^{1}** → **Data/MC ~ 1**

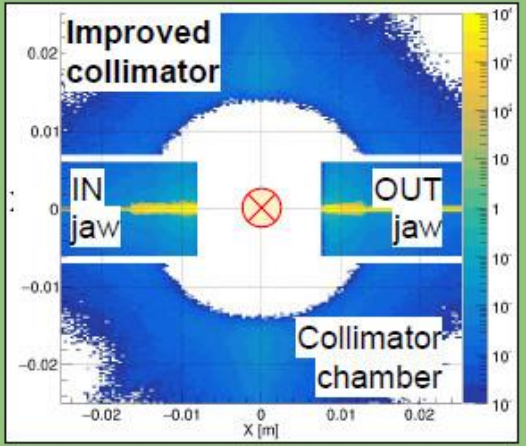
Phase 1 and Phase 2 experiences 2016–2018

IR beam pipe geometry improvement
+
Measured background decomposition methodology



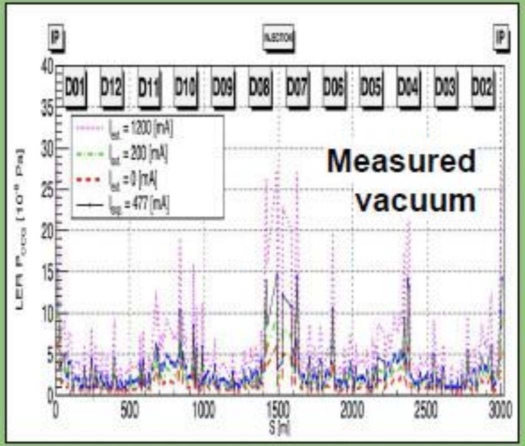
Early Phase 3 experiences 2019–2022

IR beam pipe geometry improvement
+
Realistic collimator profile
+
Particle interaction with collimator materials



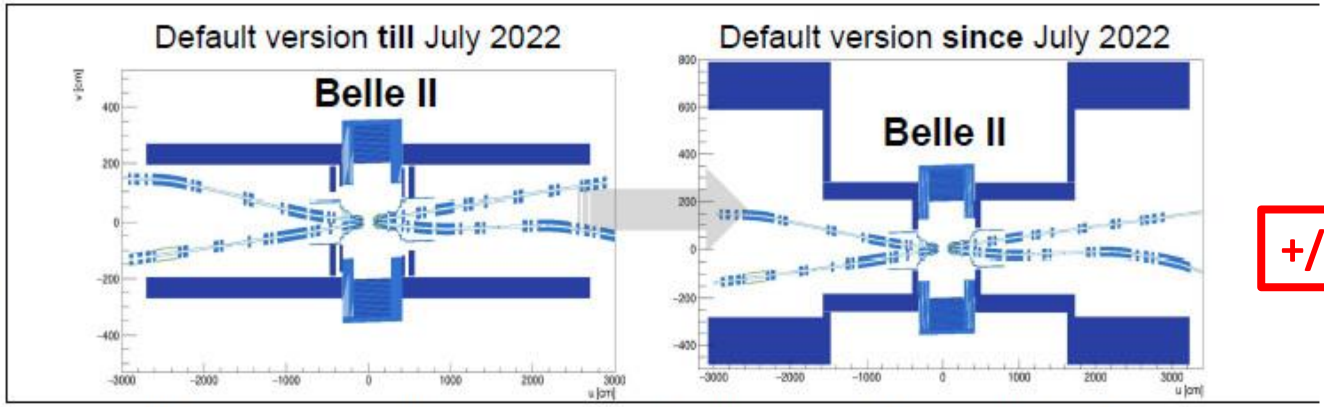
Early Phase 3 experiences 2019–2022

Measured beam pipe gas pressure
+
Accurate translation of beam losses from `SAD` to `Geant4`
+
Improved `Geant4` model



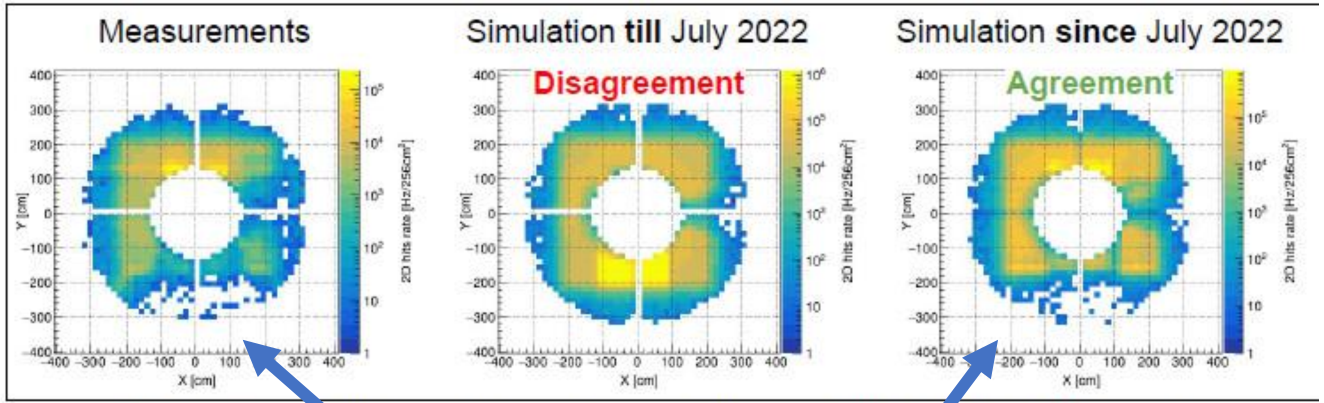
SuperKEKB MC details: Improving the model of the tunnel

- In the past two years we put a lot of efforts to improve the `Geant4` modelling of the Belle II and SuperKEKB interaction region
- The latest version realistically describes detector materials and accelerator tunnel
  - Accurate IP beam pipe
  - Belle II shielding
  - Tunnel wall
  - Machine equipment (e.g. collimators)
- **Improved** the data/MC agreement
  - ARICH Lumi BG data/MC 10 → 1
  - Better end cap KLM hits 2D distribution
- Allows us to study the impact of the additional shielding planned for the LS1



IR `Geant4` model improvement. Skipping intermediate steps

+/- 30 m



2D background hits on the outermost layer of the FWD KLM end cap

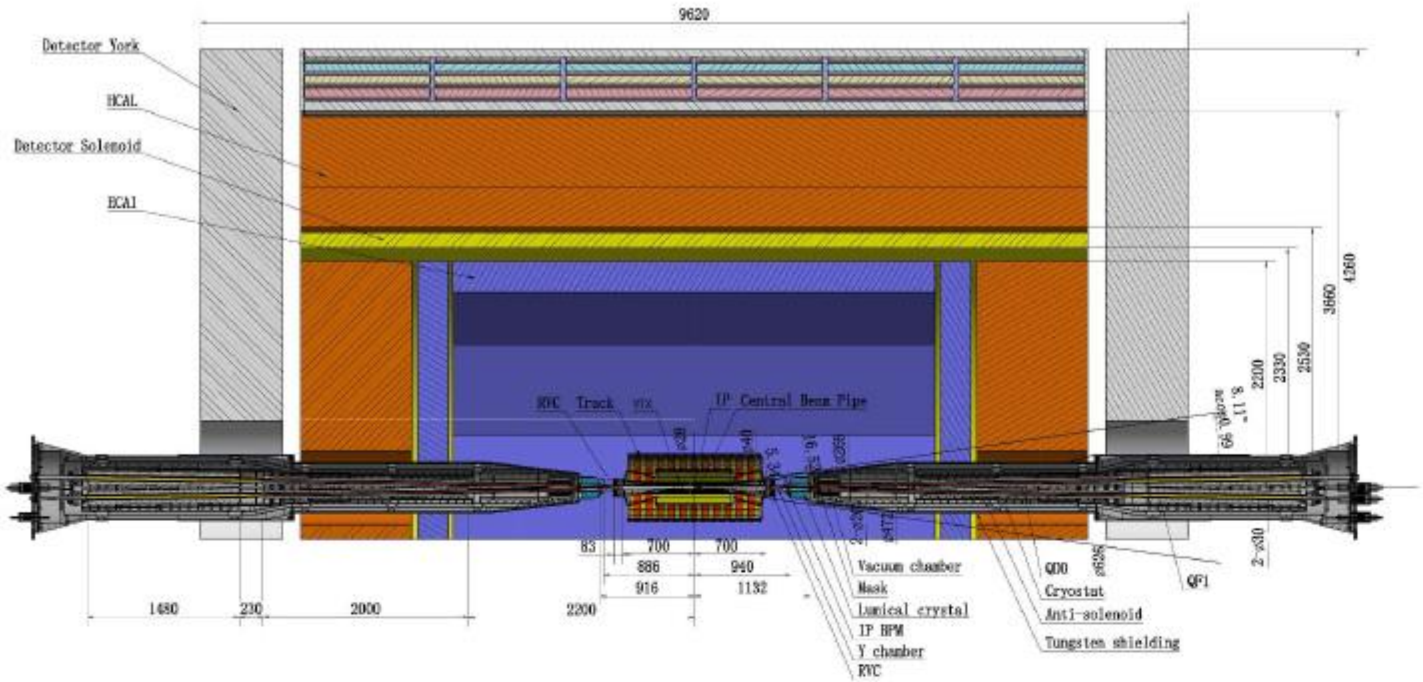
This is very impressive

Parallel session

- We also had a parallel session with five very interesting presentations
  - Sha Bei gave up an update on the MDI design for CEPC
    - Calculating and controlling background levels from various sources
  - Sasha Novokhatski presented studies of HOM power in the FCCee IR
    - Current HOM power levels are under control
  - Andrea Ciarma talked about background studies for FCCee IR
    - Discussed a very interesting list of backgrounds
    - Finds a very high-power beam of photons from Beamsstrahlung
  - Holger Witte presented the FF design elements for the EIC
    - Presented a very detailed magnet study of the IR magnets
  - Antonio De Domenico discussed the possibility of a zero-angle detector for a fast luminosity measurement
    - This possible signal has to be found inside the Beamsstrahlung photon beam

CEPC MDI

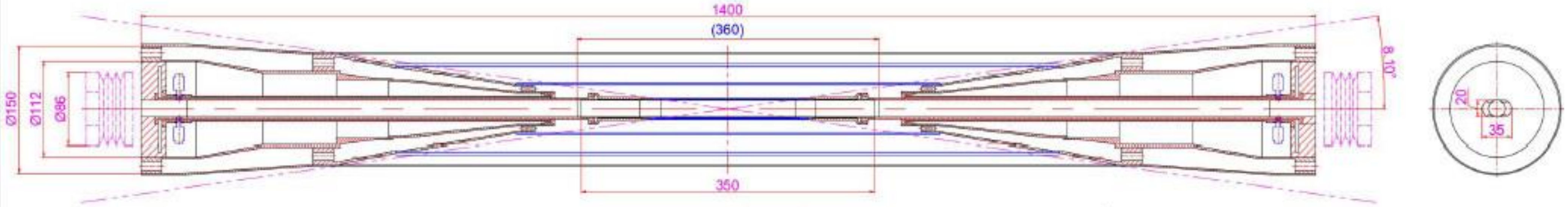
MDI layout and IR design



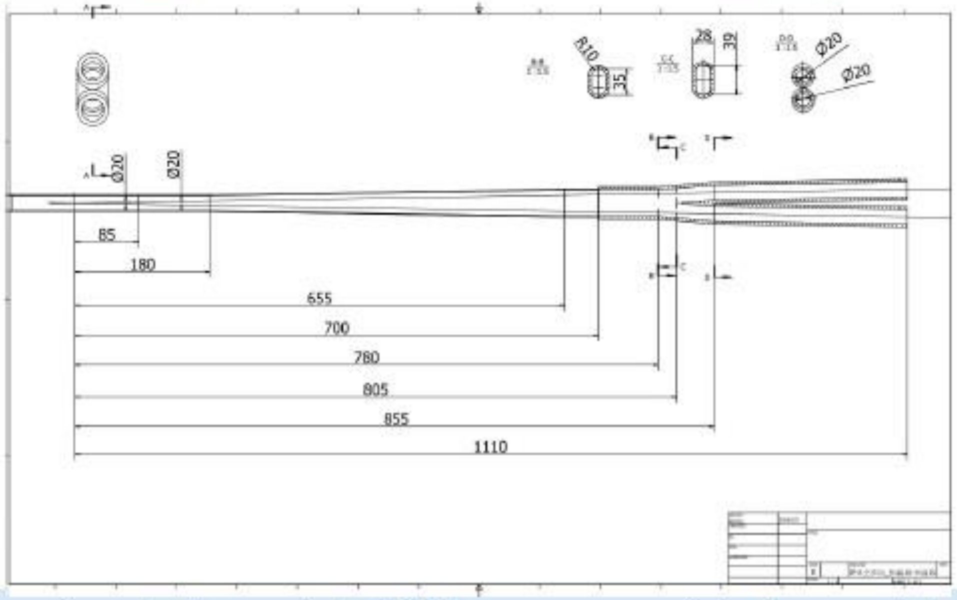
- The Machine Detector Interface (MDI) of CEPC double ring scheme is about ±7m long from the IP.
- The CEPC detector superconducting solenoid with 3T magnetic field （2T in Z） and the length of 7.3m.
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993. Detective angle: acos0.99
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is to 1.9m.

CEPC MDI

The new central beampipe design

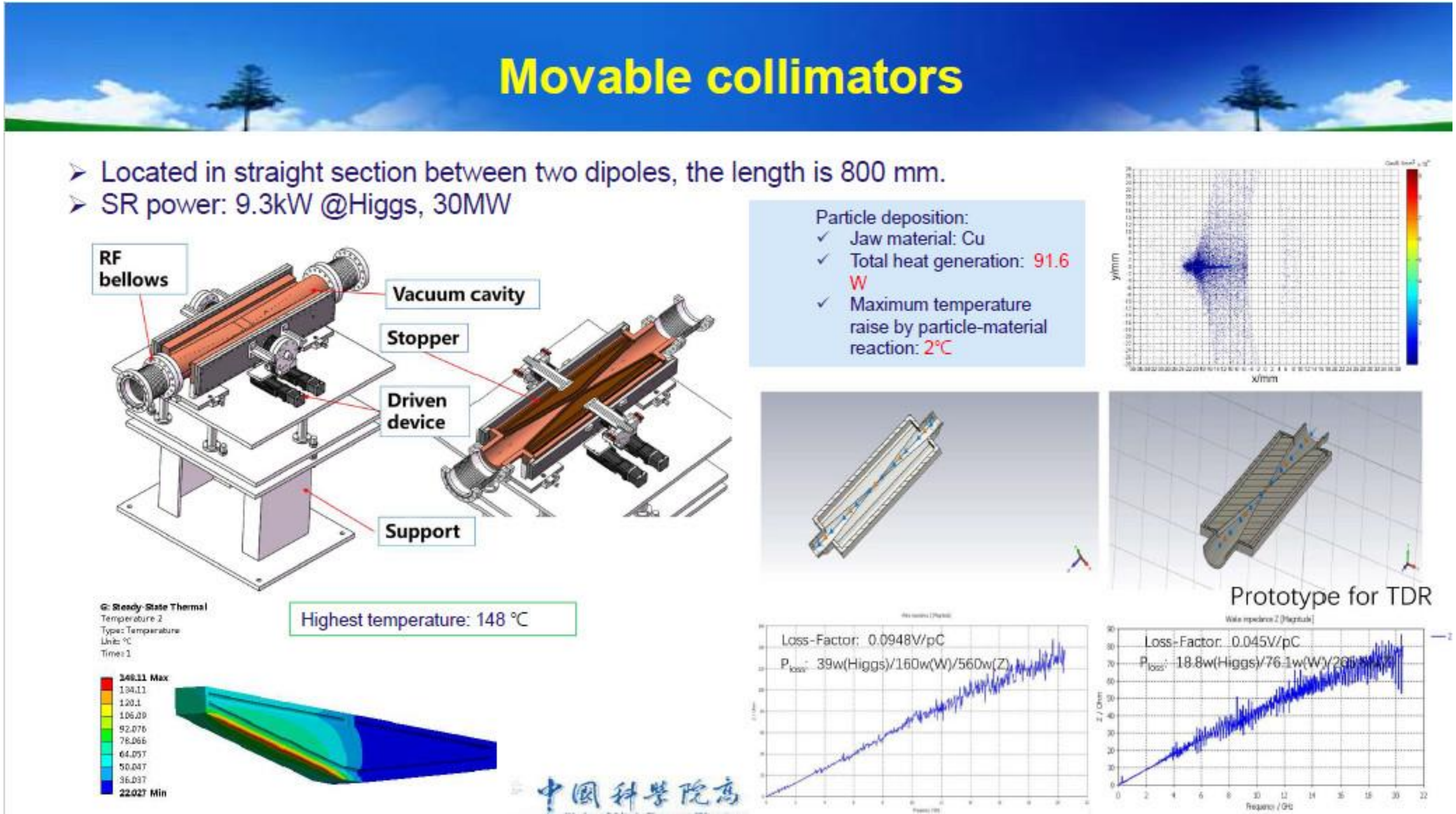


From IP(mm)	Shape	Inner diameter(mm)	Material	Marker
0-85	Circular	20	Be	
85~180	Circular	20	Al	
180~655	Cone	20~35	Al	Taper: 1:70
655~700	Circular	35	Al	
700~780	Circular	35	Cu	
780~805	Cone	35~39	Cu	
805~855	Race-track	39~20 double pipe	Cu	



➢ Crotch point at 805mm, with slope, breeches pipe starting point at 855mm, cone, interface point at 700mm

CPEC MDI: looking at SR on collimators



Also loss factors and impedance calculations

FCCee IR HOM: Initial larger IP pipe design needed a HOM absorber

The concept of the HOM absorber

Based on the property of the trapped mode we have designed a special HOM absorber.

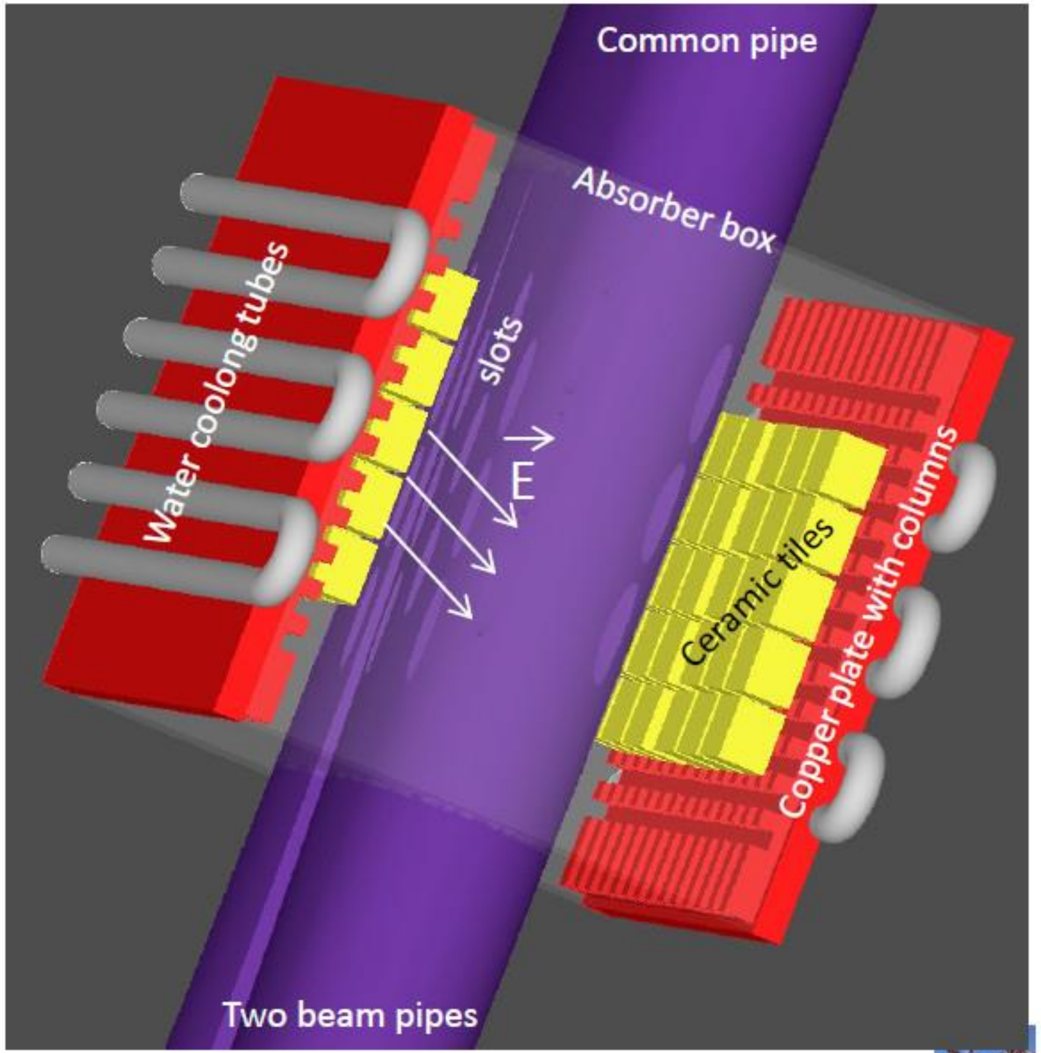
The absorber vacuum box is placed around the beam pipe connection. Inside the box we have ceramic absorbing tiles and copper corrugated plates .

The beam pipe in this place have longitudinal slots, which connect the beam pipe and the absorber box. Outside the box we have stainless steel water-cooling tubes, braised to the copper plates.

The HOM fields, which are generating by the beam in the Interaction Region pass through the longitudinal slots into the absorber box.

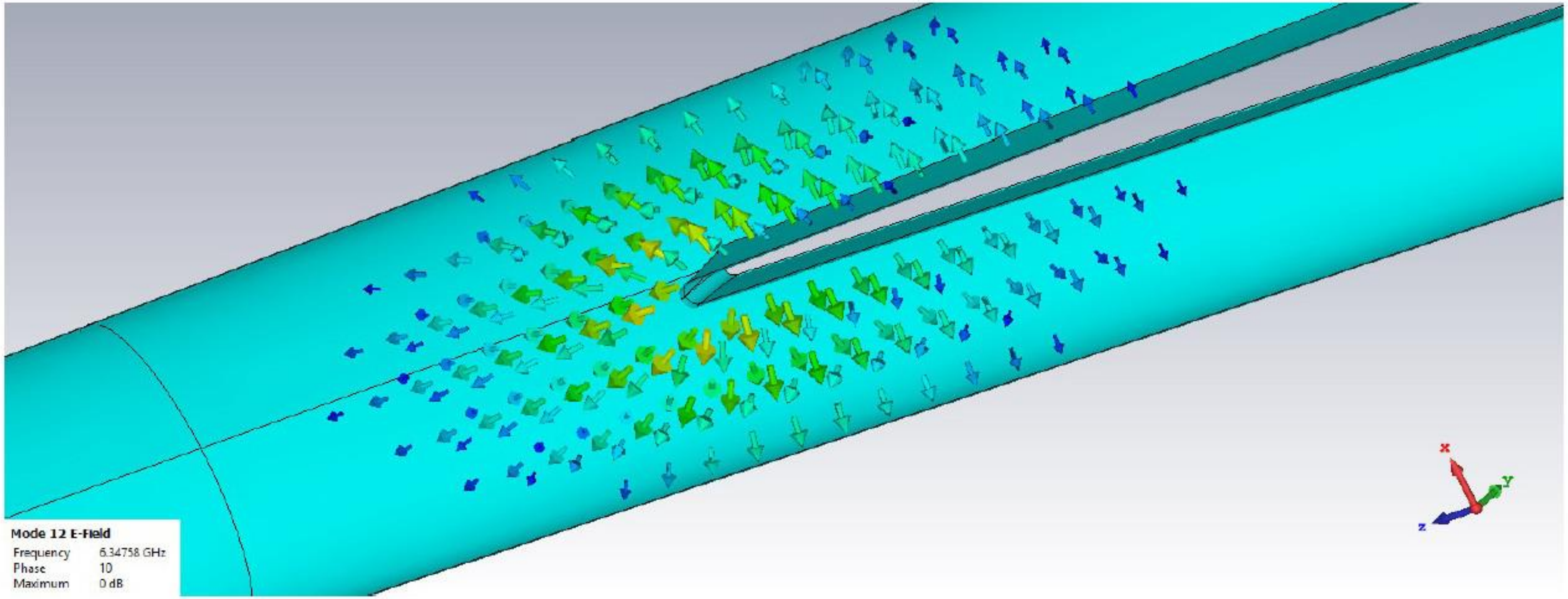
Inside the absorber box these fields are absorbed by ceramic tiles, because they have high value of the loss tangent.

The heat from ceramic tiles is transported through the copper plates to water cooling tubes.

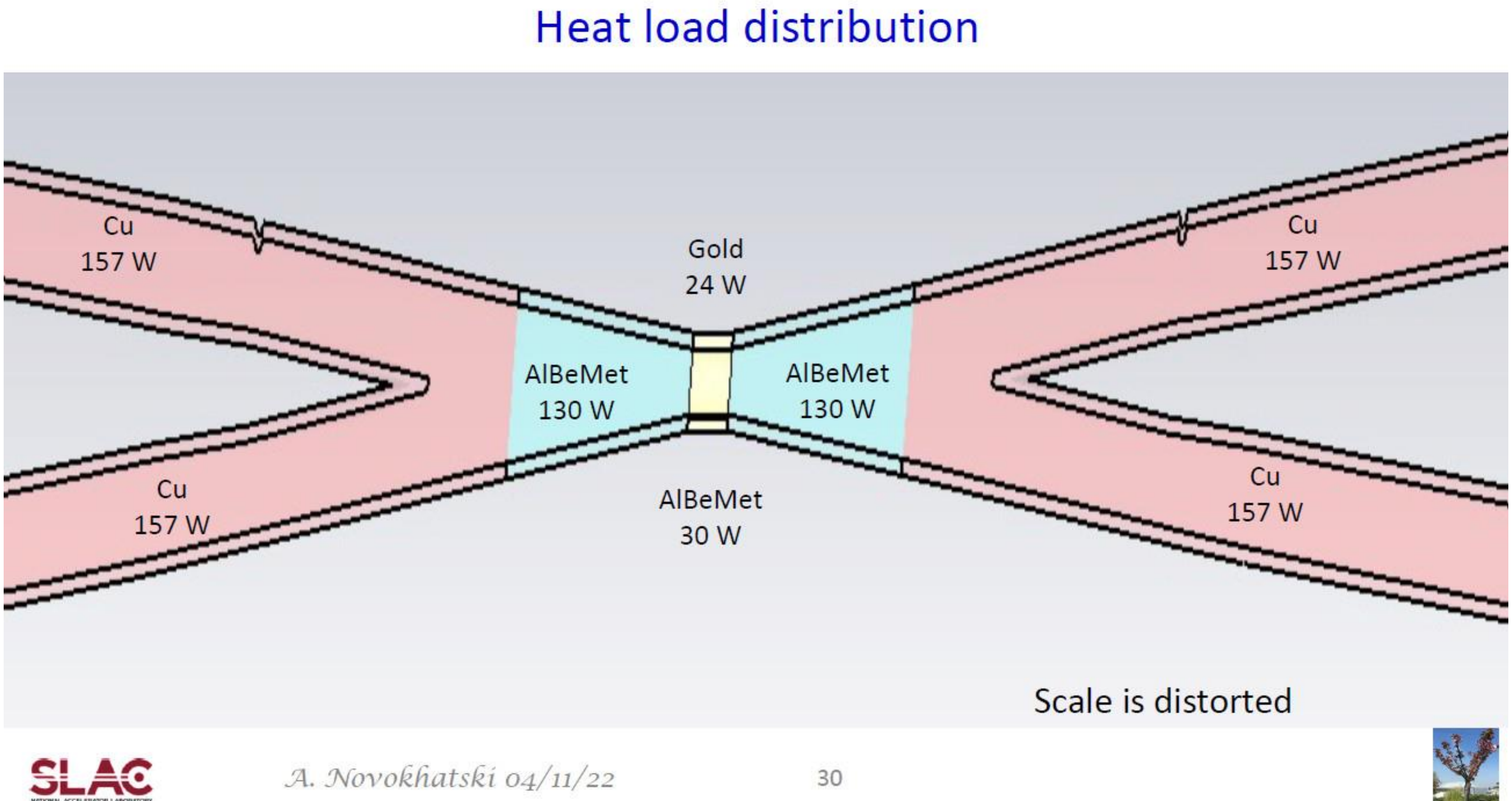


FCCee IR HOM: Smaller IP beam pipe reduces the trapped HOM power

An unavoidable trapped mode still exists, but has much smaller amplitude due to much higher frequency 6.1 GHz



FCCee HOM: The beam pipe discontinuities generate a lot of power but most of it now travels outside of the IR



All of this power must still be accounted for

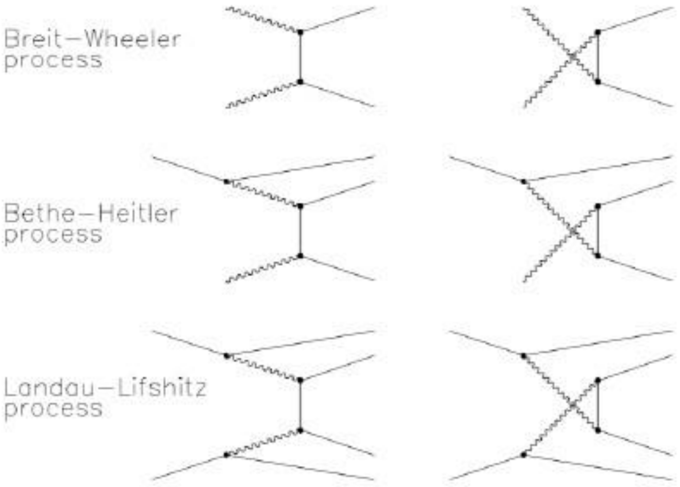
FCCee machine induced backgrounds

Incoherent Pairs Creation (IPC)

Secondary e^-e^+ pairs can be produced via the interaction of the beamstrahlung photons with real or virtual photons emitted by each particle of the beam during bunch crossing.

Previous studies with the old R=15mm central beam pipe showed that the induced occupancy was well below 1%, but it is important to check the increase due to the now closer VXD.

This process has been simulated using the generator **GuineaPig++** and tracking in the CLD detector using **Key4HEP.** The beam parameters for the latest 4IP lattice ($\beta_x^* = 0.10\,m$) have been considered at the four working energies.



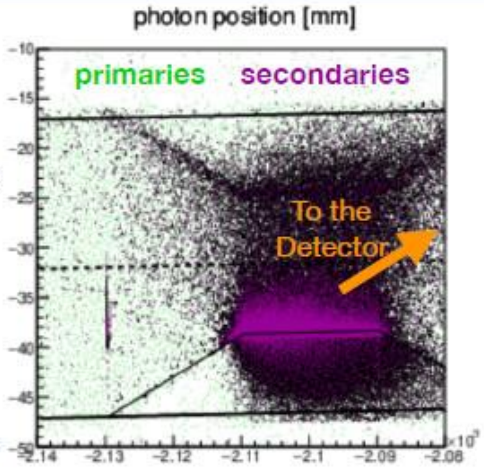
$$occupancy = hits/mm^2/BX \cdot size_{sensor} \cdot size_{cluster} \cdot safety$$

$$size_{sensor} = \begin{matrix} 25\mu m \times 25\mu m \ (pixel) \\ 1mm \times 0.05mm \ (strip) \end{matrix} \qquad size_{cluster} = \begin{matrix} 5 \ (pixel) \\ 2.5 \ (strip) \end{matrix} \qquad safety = 3$$

This is in addition to the e+e- pairs produced by the luminosity part of the collision

FCCee machine bkgds

FCC eeFACT2022 - Frascati - 13/09/2022 Andrea Ciarma SR Mask and Shieldings 16

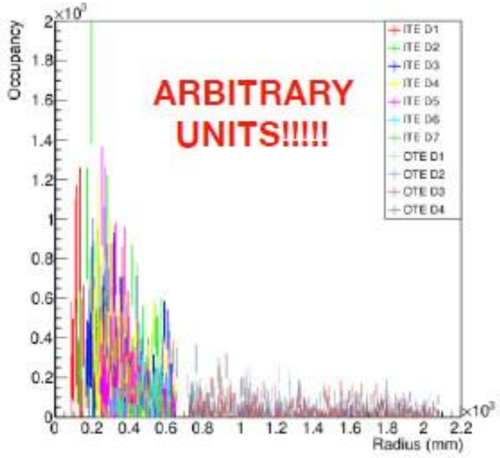


Special attention should be given to the photons which will impact **the tip of the mask**, as they are the main source of potential background in the detector.

As a **first approach** I simulated a monochromatic pointlike 1MeV photon beam impinging 50um from the edge of the mask, showing a large number of hits in the detectors, in particular in the **tracker endcaps**.

More detailed studies (using key4HEP, ddsim, Geant4) are currently in progress in order to understand better the **nature** and **features of the secondary particles** produced.

At the moment, the interaction of the particles with the material of the mask is left to Geant4, but the use of a **dedicated tool** to produce the scattered particles is of course still a valid an option.



SR masking schemes generally can reduce the SR background to the scattering of SR photons near the tip of the masks

FCCee machine bkgds: Beamsstrahlung

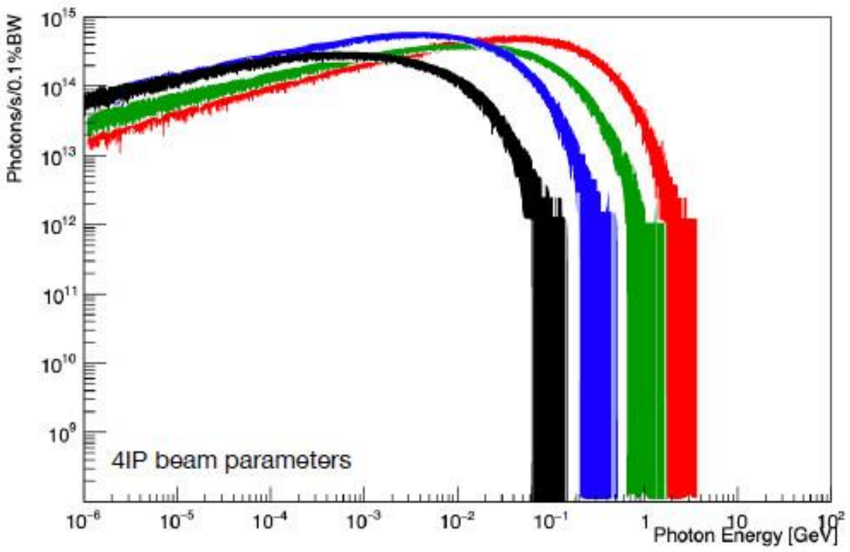
FCC eeFACT2022 - Frascati - 13/09/2022 Andrea Ciarma Beamstrahlung Radiation 17

Beamstrahlung radiation Characterisation

Beamstrahlung is a **dominant process** for the lifetime at FCCee due to the small beam size and high population.

$$< E_\gamma > \sim E \times 0.462\Upsilon$$

$$\Upsilon \sim \frac{5}{6}\frac{r_e^2 \gamma N_e}{\alpha \sigma_z (\sigma_x + \sigma_y)} \qquad n_\gamma \sim 2.54 \left[\frac{\alpha^2 \sigma_z}{r_e \gamma}\Upsilon\right] \frac{1}{[1+\Upsilon^{2/3}]^{1/2}}$$



The photons are emitted **collinear to the beam** with an angle proportional to the beam-beam kick. This radiation is extremely intense **O(100kW)** and **hits the beam pipe** at the end of the first downstream dipole.

	Total Power [kW]	Mean Energy [MeV]
Z	370	1.7
WW	236	7.2
ZH	147	22.9
Top	77	62.3

These studies were performed using **GuineaPig++**.

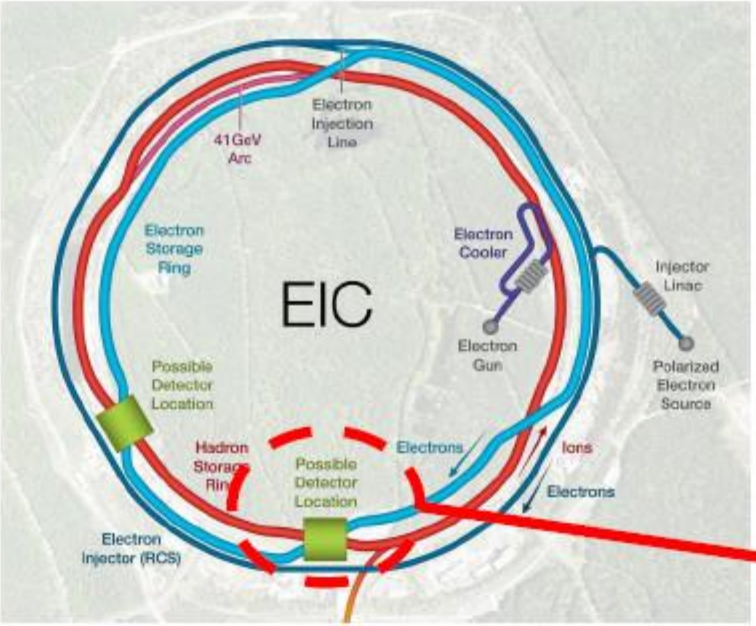
This source generates a powerful beam of photons which escape the IR but deposit an enormous amount of energy on the downstream beam pipe near the first bend magnet.

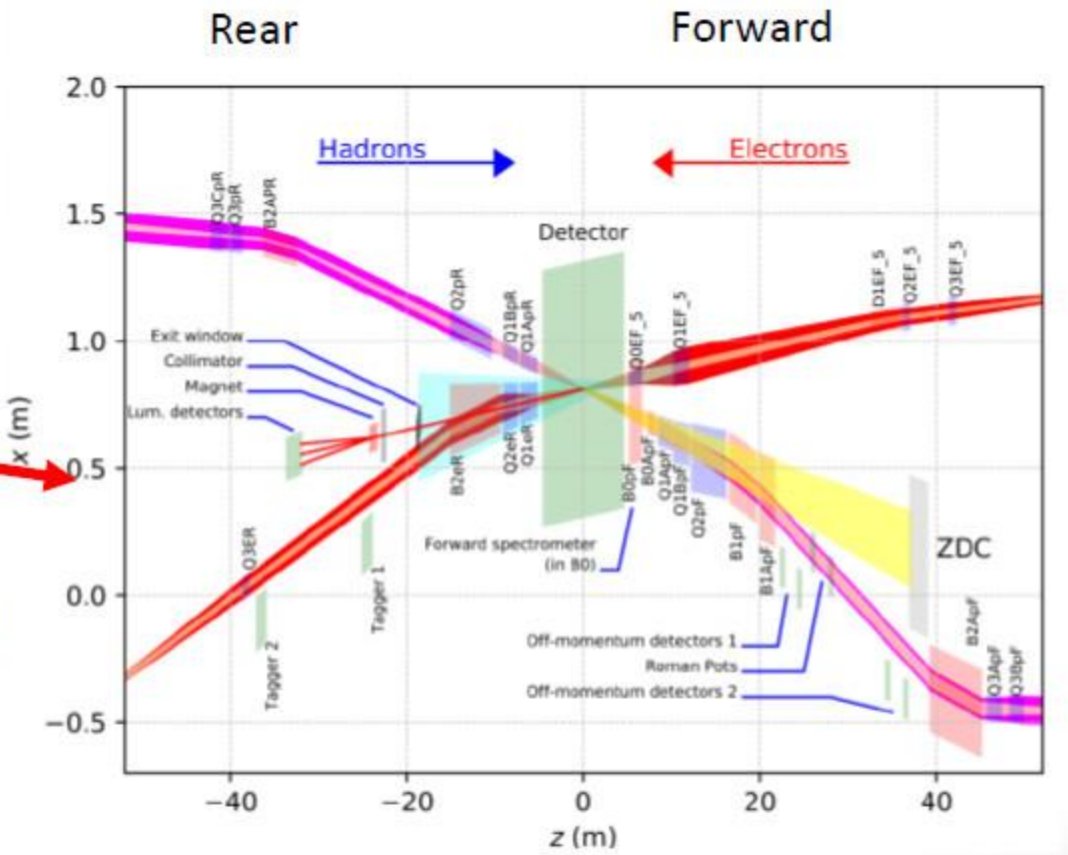
The power in this beam is almost 1% of the total SR power for the ring (50 MW) at the Z pole.

There are eight of these beams for a 4 IP design

EIC IR: Overview

EIC IR





Hadron storage ring (HSR): 4 yellow and 2 blue RHIC arcs

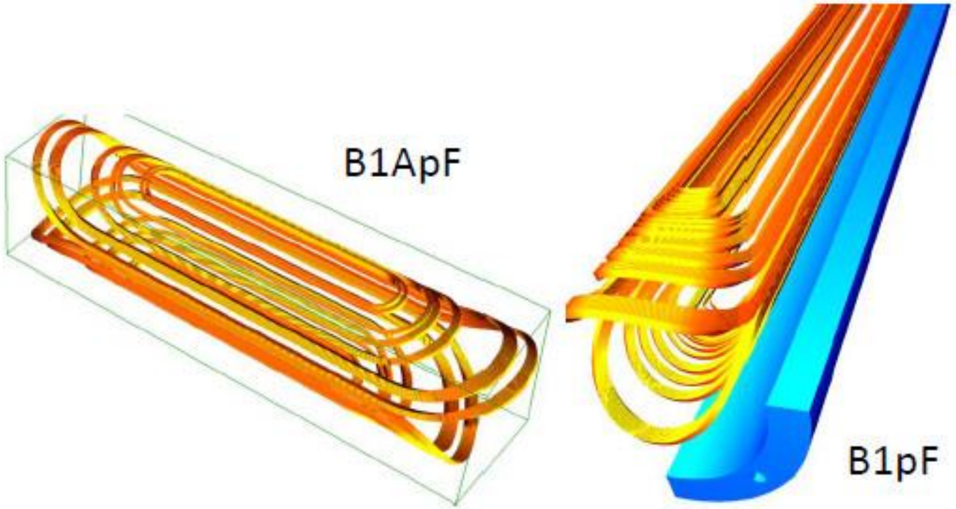
Add electron storage ring (ESR) in existing tunnel (and the RCS)

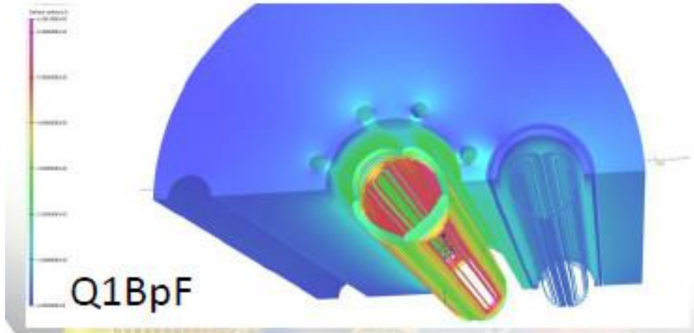
IR location: IR6

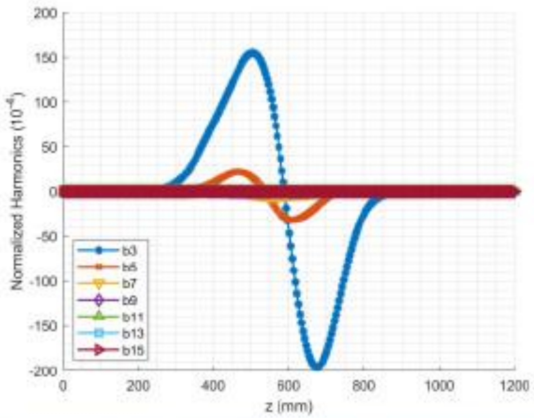
EIC IR magnets

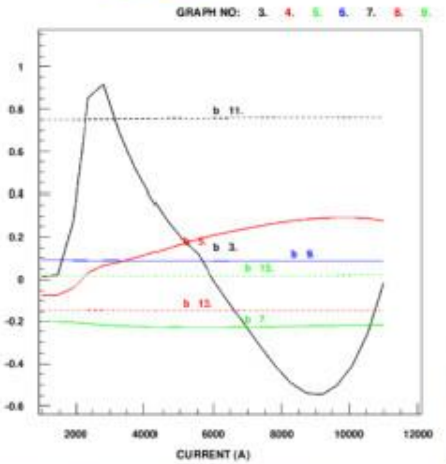
3D Designs

- Preliminary designs for all magnets
  - Minimized peak field in ends
  - Good harmonics
- Sufficient margin (>30%)









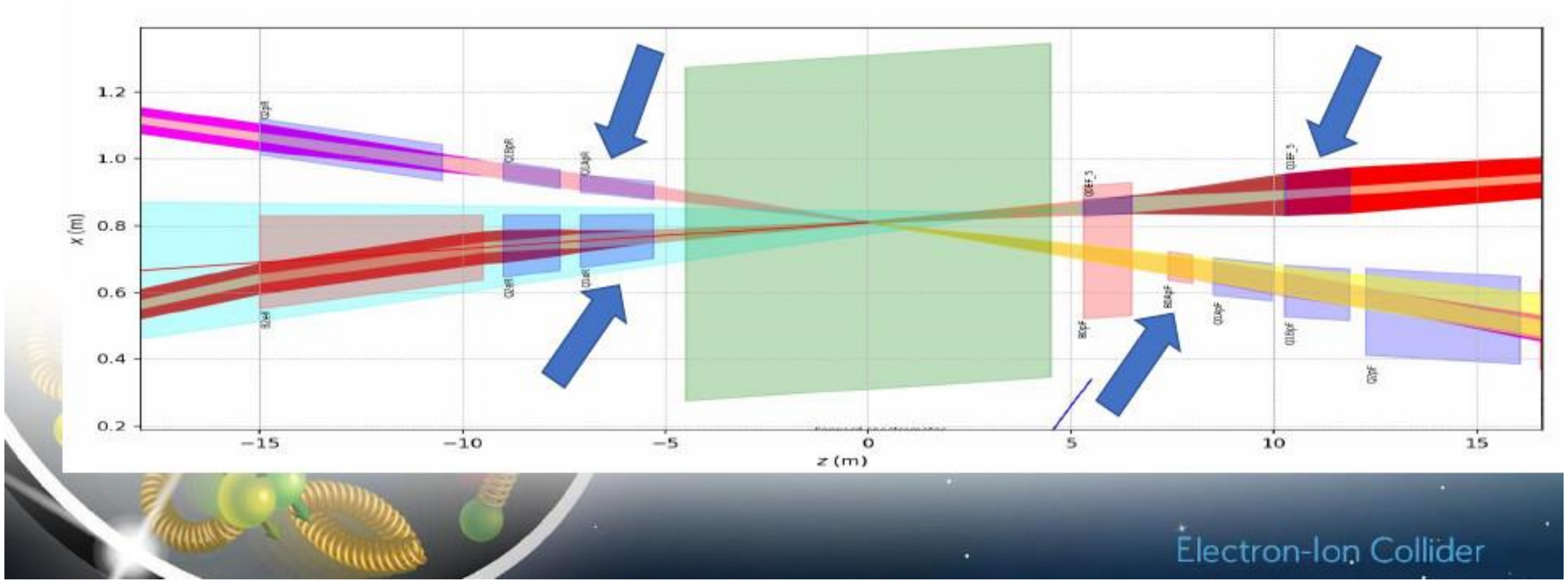
Courtesy of BNL SMD

Electron-Ion Collider

EIC magnets

Detector Solenoid Compensation

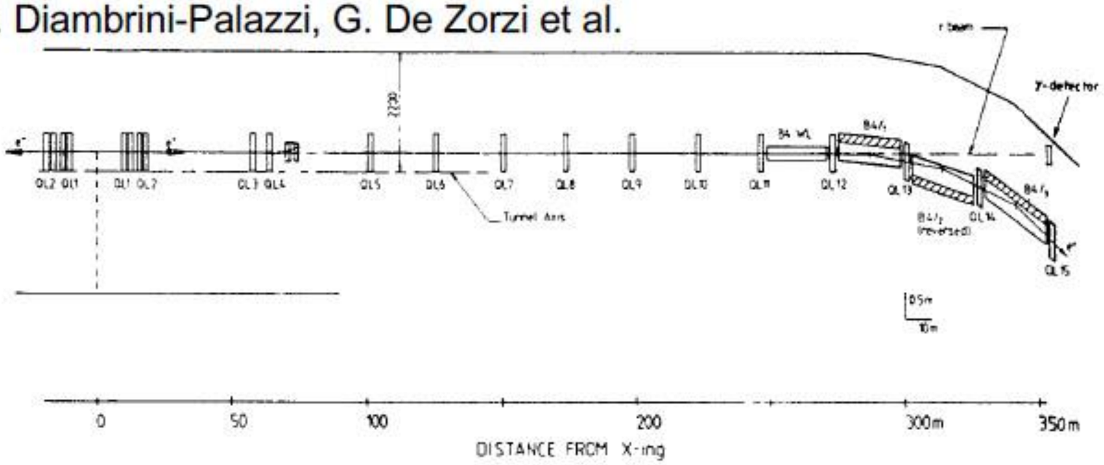
- Need four skew quadrupole magnets
  - 0.6T/m over 1.8m (assuming 3T solenoid)
- Possible locations
  - Hadrons: B0ApF, Q1ApR
  - Electrons: Q1eF, Q1eR
    - Q0eF: technically possible, but cuts into acceptance

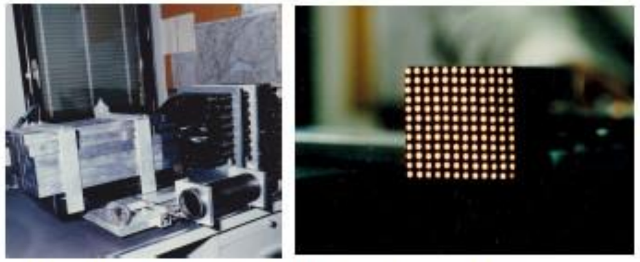


FCCee Fast lumi detector: LEP experience

LEP-5 experiment (1987-1992)

G. Diambrini-Palazzi, G. De Zorzi et al.

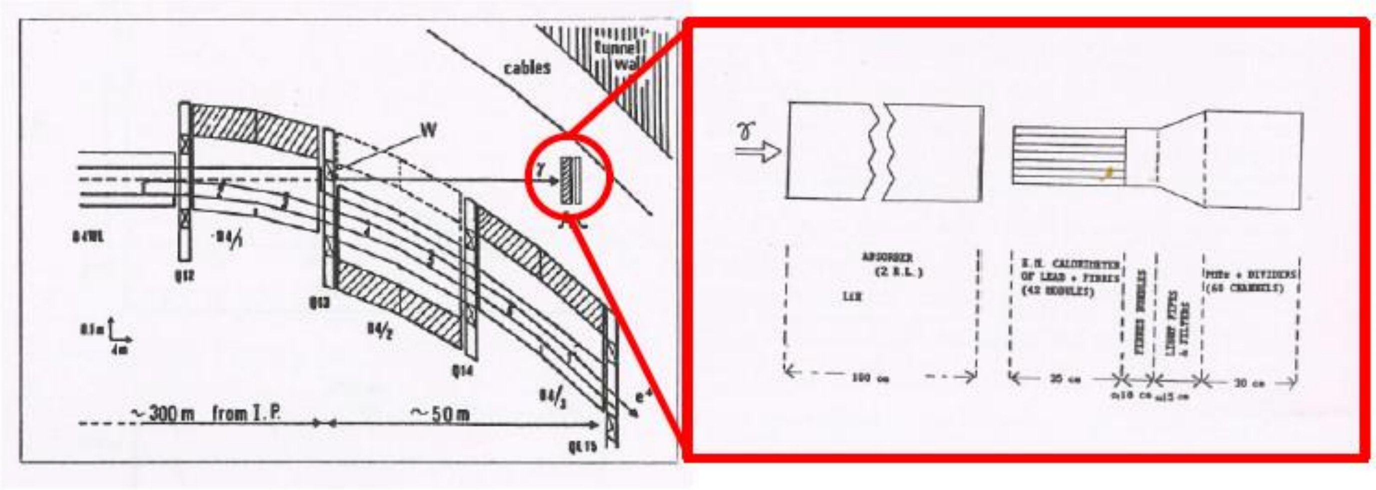




Lead scintillating fiber calorimeter
Spatial resolution ~ 1 mm @ 10-50 GeV

M. Bertino et al. NIM **A315** (1992) 327

Experimental set-up in IP-1 (no other expts at that time)



W = thin AL window, 2 × 5 cm^2

2 X_0 of LiH (180 cm) in front of the calorimeter to absorb synchrotron radiation

Counting room near IP-1
⇒ 420 m long cables

FCCee Fast lumi detector: LEP experience

SB luminosity monitor at FCCee: some considerations (II)

Background:

- beam gas bremsstrahlung $\propto I^2$
  extrapolating from LEP (P~2×10^{-10} Torr) beam gas/SB < 10^{-4} => negligible
  Residual gas pressure at LEP IP-1 was exceptionally good (P~2×10^{-10} Torr)
  At FCCee at Z peak P ~ 1×10^{-9} Torr is expected
  => could worsen beam gas bremsstrahlung background

- Inverse Compton scattering of thermal photons
  extrapolating from LEP (Temp=291 K) ther.phot./SB < 10^{-4} => negligible

- Synchrotron radiation: absorber and collimator required =>
  worsening of downstream detector performance => attenuation
  depends also on the detector characteristics => to be studied

FCCee Fast lumi detector at FCCee

It is recognized that this lumi signal may be difficult to dig out of the Beamsstrahlung photon beam, but the detector could still be very useful especially in the early running

SB luminosity monitor at FCCee: some considerations (III)

Background:

- Beamstrahlung (negligible at LEP) has to be taken into account
  The huge energy flux must be attenuated (at Z peak Beamstrah./SB $O(10^3)$).
  To be studied the compatibility of a SB luminosity monitor with a beam dump.

FCC | FCC Week 2022 - Paris - 02/06/2022 | Andrea Ciarma | Beamstrahlung Radiation | 17

Beamstrahlung radiation Characterisation

Beamstrahlung is a **dominant process** for the lifetime at FCCee due to the small beam size and high population.

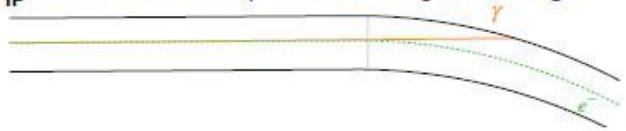
$$\Upsilon \sim \frac{5}{6} \frac{r_e^2 \gamma N_e}{\alpha \sigma_z (\sigma_x + \sigma_y)}$$

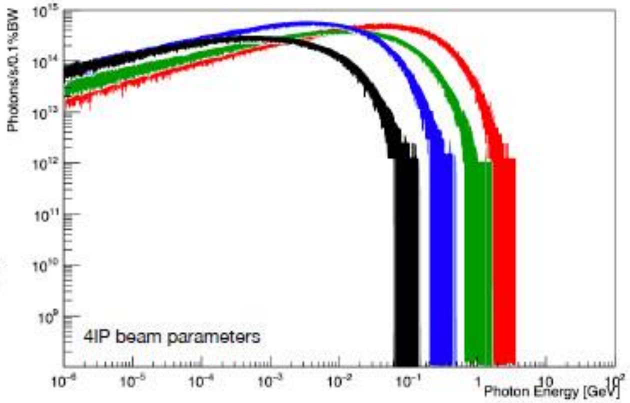
$$< E_\gamma > \sim E \times 0.462 \Upsilon$$

$$n_\gamma \sim 2.54 \left[\frac{\alpha^2 \sigma_z}{r_e \gamma} \Upsilon \right] \frac{1}{[1 + \Upsilon^{2/3}]^{1/2}}$$

The photons are emitted **collinear to the beam** with an angle proportional to the beam-beam kick. This radiation is extremely intense **O(100kW)** and **hits the beam pipe** at the end of the first downstream dipole.

These studies were performed using **GuineaPig++**.





	Total Power [kW]	Mean Energy [MeV]
Z	370	1.7
WW	236	7.2
ZH	147	22.9
Top	77	62.3

Conclusions

- I have tried to convey a quick glimpse from all of the excellent presentations we had in WG5
- I have left out many topics from each presentation that merit further review
- I encourage anyone interested in more detail to go directly to the talks
- I think this part of the writeup will be a very useful and important reference

- Thank You