FUTURE CIRCULAR COLLIDER
Innovation Study

# Possible Contributions to MDI

R. Assmann, DESY

Thanks to M. Lückhof, H. Burkhardt, M. Boscolo and F. Zimmermann for input and discussions.

Tuesday 10 November 2020

# Outline

**The MDI Challenge**

**Status**

**Possible Future Work**

*FCC Week March 2015 Washington*

*Note: DESY/Uni Hamburg have been involved into MDI during the FCC CDR phase through the doctoral student **Marian Lückhof**, with contact through **Helmut Burkhardt**.*

*Glad to be part of the FCCIS.*

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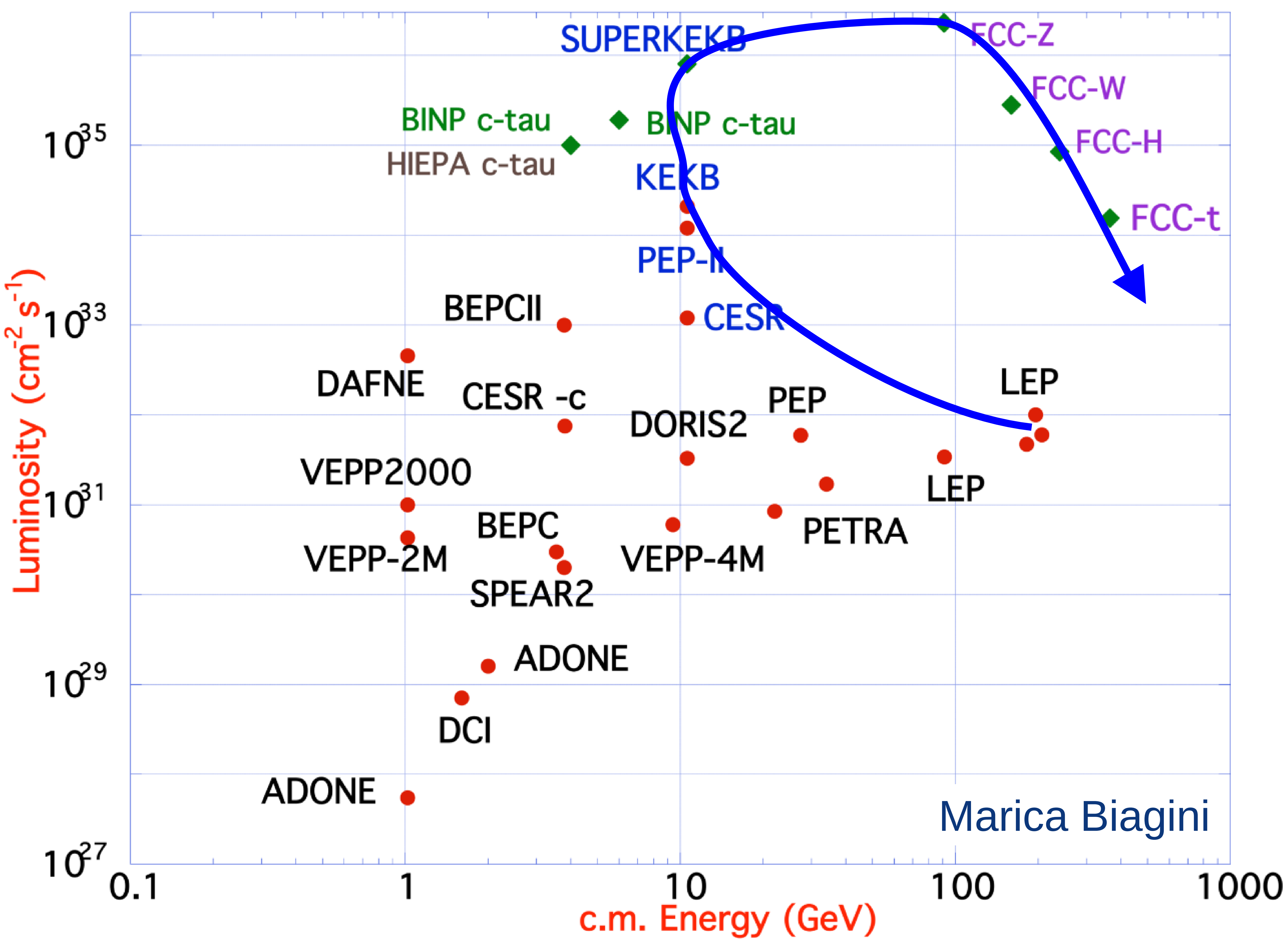
# LEP – b Factory – FCC-ee Development Path

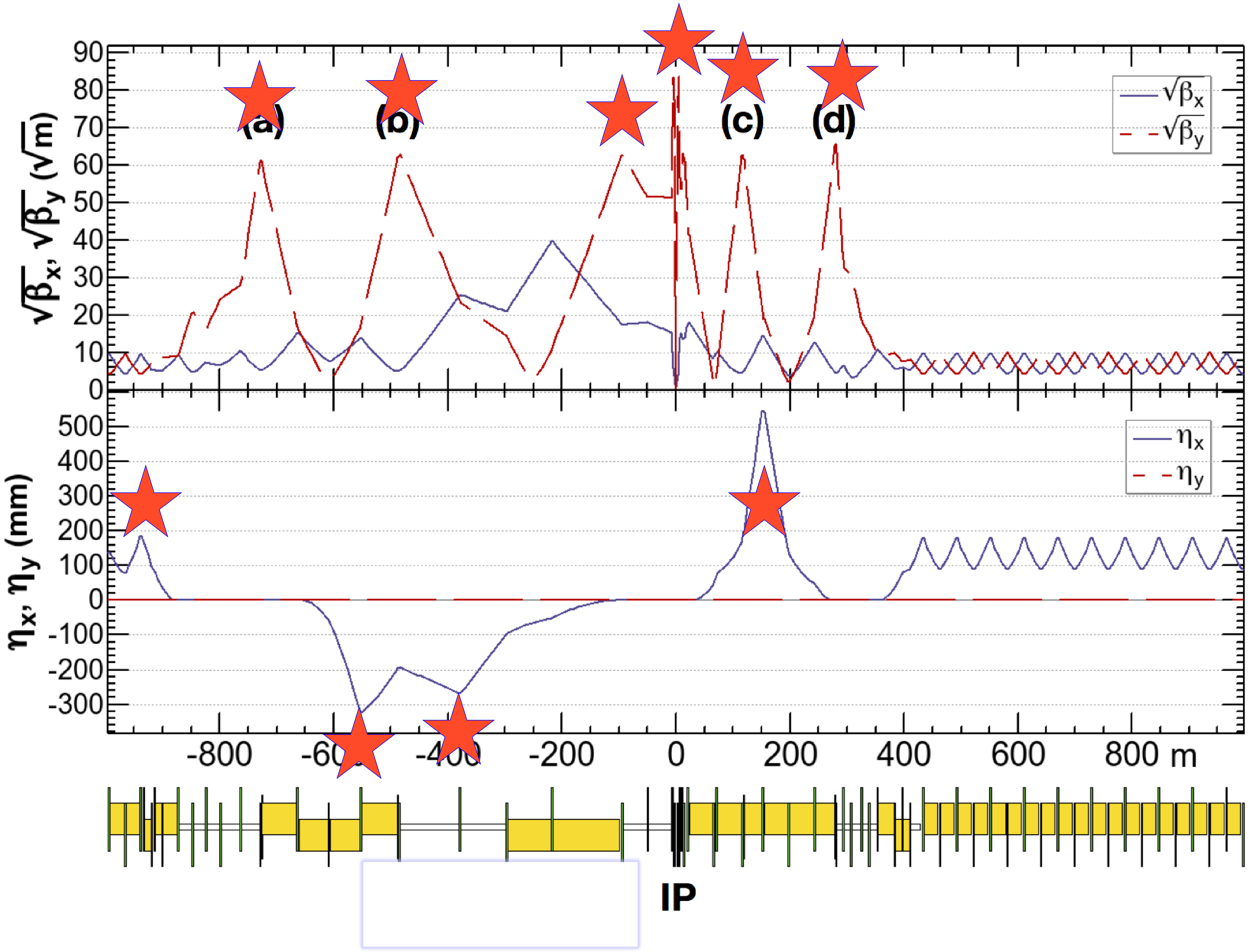



- **LEP 1&2** setting the energy frontier in e+e- colliders for 20 years by now.
- The **b factories** have been and will be advancing luminosities into new regimes at lower energy, pioneering new accelerator physics solutions and technologies
- **FCC-ee** will combine the high energy of LEP and high luminosity of the b factories and will advance it to (final?) limits (for 100 km footprint).
- **Clean experimental conditions** are a signature of e+e- colliders → challenges in machine detector interface → innovations

# FCC-ee: High Energy – High Luminosity – Small beta* – High Synchrotron Losses

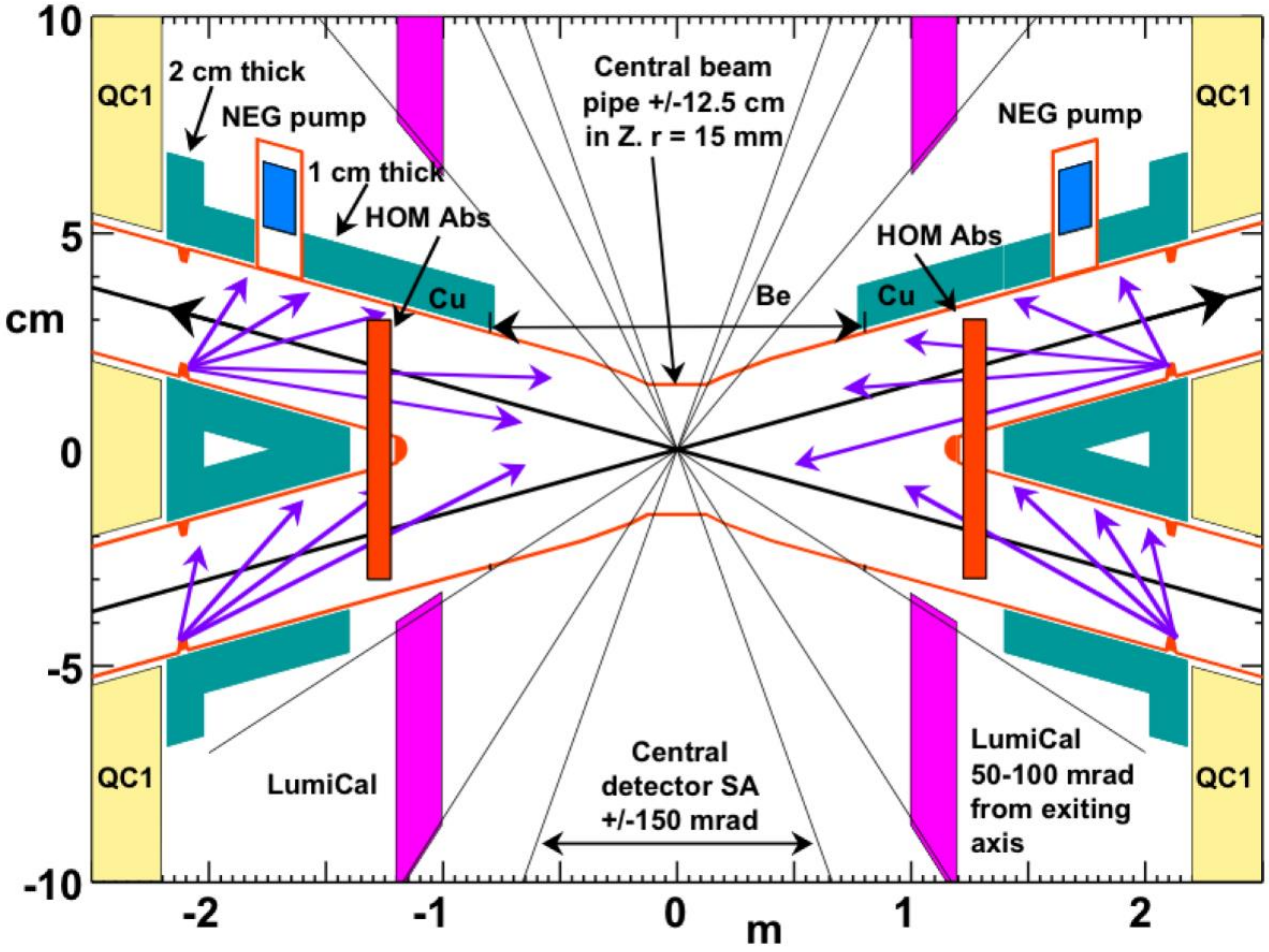
| parameter | Z | WW | H (ZH) | ttbar |
|---|---|---|---|---|
| beam energy [GeV] | 45 | 80 | 120 | 182.5 |
| beam current [mA] | 1390 | 147 | 29 | 5.4 |
| no. bunches/beam | 16640 | 2000 | 393 | 48 |
| bunch intensity [$10^{11}$] | 1.7 | 1.5 | 1.5 | 2.3 |
| SR energy loss / turn [GeV] | 0.036 | 0.34 | 1.72 | 9.21 |
| total RF voltage [GV] | 0.1 | 0.44 | 2.0 | 10.9 |
| long. damping time [turns] | 1281 | 235 | 70 | 20 |
| horizontal beta* [m] | 0.15 | 0.2 | 0.3 | 1 |
| vertical beta* [m] | 0.0008 | 0.001 | 0.001 | 0.0016 |
| horiz. geometric emittance [nm] | 0.27 | 0.28 | 0.63 | 1.46 |
| vert. geom. emittance [pm] | 1.0 | 1.7 | 1.3 | 2.9 |
| bunch length with SR / BS [mm] | 3.5 / 12.1 | 3.0 / 6.0 | 3.3 / 5.3 | 2.0 / 2.5 |
| luminosity per IP [$10^{34}$ $cm^{-2}s^{-1}$] | 230 | 28 | 8.5 | 1.55 |
| beam lifetime rad Bhabha / BS [min] | 68 / >200 | 49 / >1000 | 38 / 18 | 40 / 18 |

# High luminosity → small beta* → aperture limits at detectors




- Final quads at IP's are bottlenecks for passage of particles and photons.
- Most e+e- colliders have experienced **high background levels** preventing particle physics detectors to be switched on, **IR quad quenches** due to loss spikes, **local IP damage** to machine or detector components from mis-kicked beam.
- Exposure depends on **geometry, loss origin, type, phase advance**.
- MDI work to provide a safe and clean IP environment → see talk of task leader **Manuela Boscolo**.

# Complicated IR Layout with higher energy and luminosity




See talks **Manuela Boscolo** and **Frank Zimmermann**.

For example, challenge of **IR heat loads**:

- rad Bhabha (kW)
- beamstrahlung (MW)
- resistive wall (kW)
- HOMs
- quadrupole synchrotron radiation

→ vacuum pumps, masks, absorbers, collimators (movable absorbers), protection devices, loss detectors, ...

M. Boscolo, N. Bacchetta, A. Bogomyagkov, H. Burkhardt, M. Dam, D. El Khechen, M. Koratzinos, E. Levichev, M. Luckhof, A. Novokhatski, L. Pellegrino, S. Sinyatkin, M. Sullivan, et al.

# The MDI Background Challenge

M. Boscolo

**Synchrotron radiation** power loss:

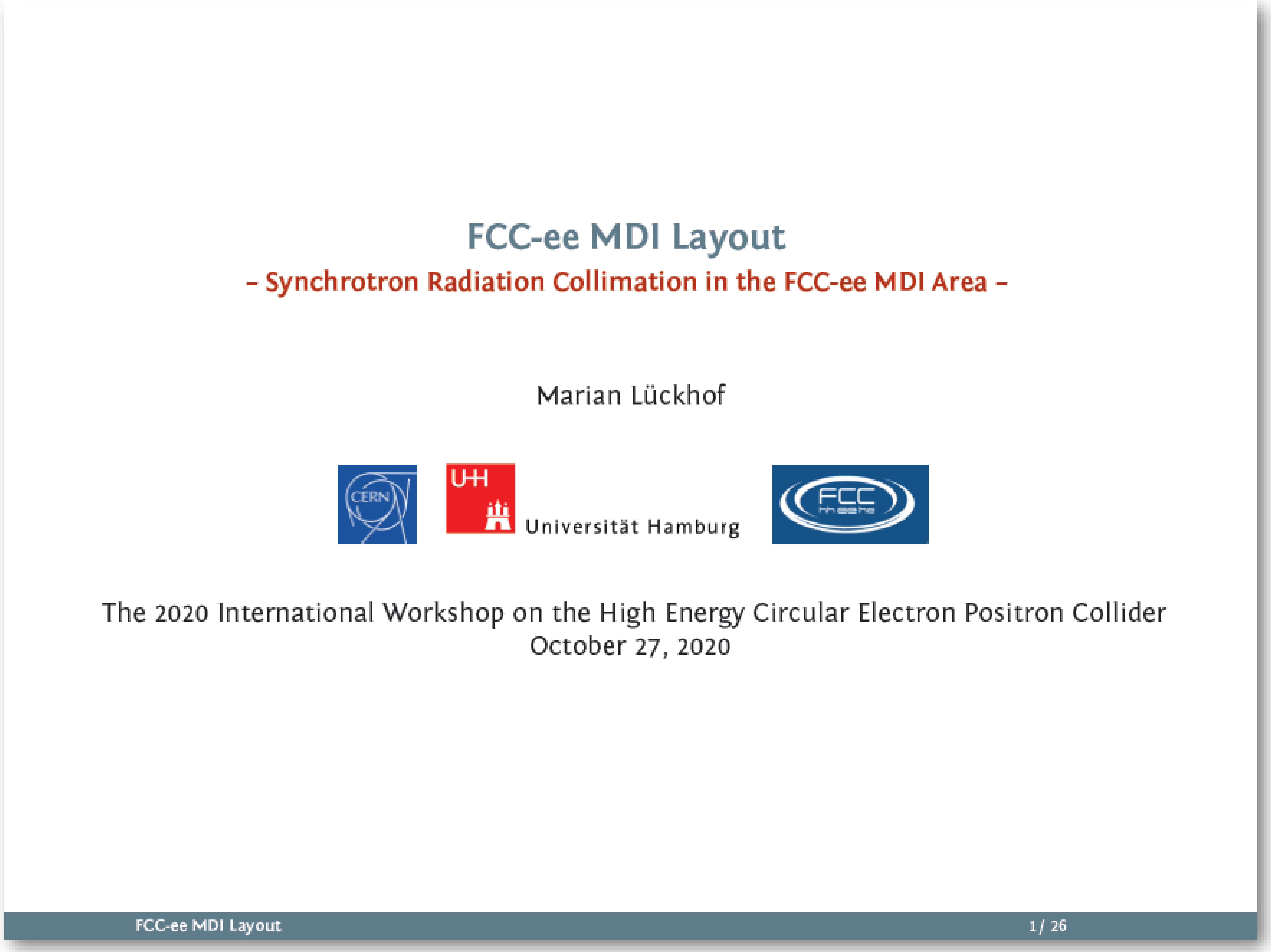
- 50 MW/beam at 182.5 GeV (ttbar)
- Critical energies $\epsilon_c \geq 1$ MeV (around the ring)
- Critical energies limited to $\epsilon_c \leq 0.1$ MeV (within 450 m of the IP → weak bends)

**Beamstrahlung** generating up to 460 kW hitting in a 5m wide region

## Background studies: generators and tools

| | Background source | generator | tracking code for loss map |
|---|---|---|---|
| IP | **Beamstrahlung** | *GuineaPig , BBWS* | *SAD, MADX* |
| | **Radiative Bhabha** | *GuineaPig, BBBrem* | *SAD, MADX* |
| | **Pair production** (incoherent dominant) | *GuineaPig* | *Geant4* |
| | **γγ to hadrons** (small effect) | combination of *GuineaPig and Phythia* | *Geant4* |
| Single beam | **Synchrotron Radiation** | *Geant4, SYNRAD+, BKG_SYNC* | *MDISim / G4* |
| | **Thermal photons** | *MC by H. Burkhardt* | *MADX* |
| | **Beam-Gas Bremstrahlung (BGBrem)** | *Geant4* | *MDISim (G4/ROOT/MADX)* |
| | **Beam-Gas Coulomb (BGCoul)** | *MC by A. Ciarma & M.B. (in progress)* | *interface with PTC_MADX* |
| | **Touschek** | *MC by A. Ciarma & M.B. (planned)* | *interface with PTC_MADX* |

M.Boscolo, 3rd FCC workshop, CERN, 13-17 Jan. 2020



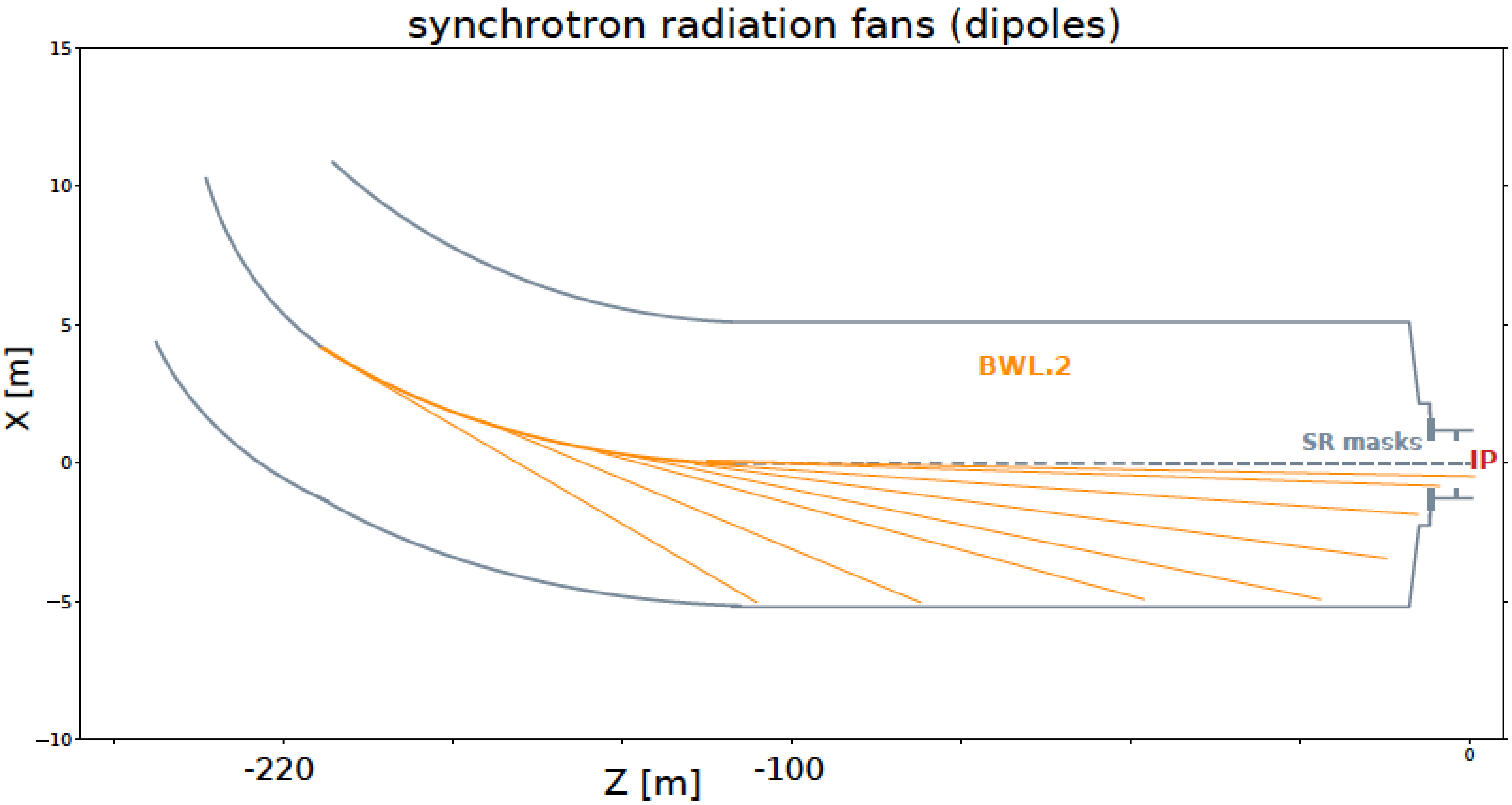

**PhD work of M. Lückhof** on synchrotron radiation collimation in the FCC-ee MDI area.

Several talks (see left). E.g. Last on Oct 27th.

Big contribution of Marian with Helmut and others:

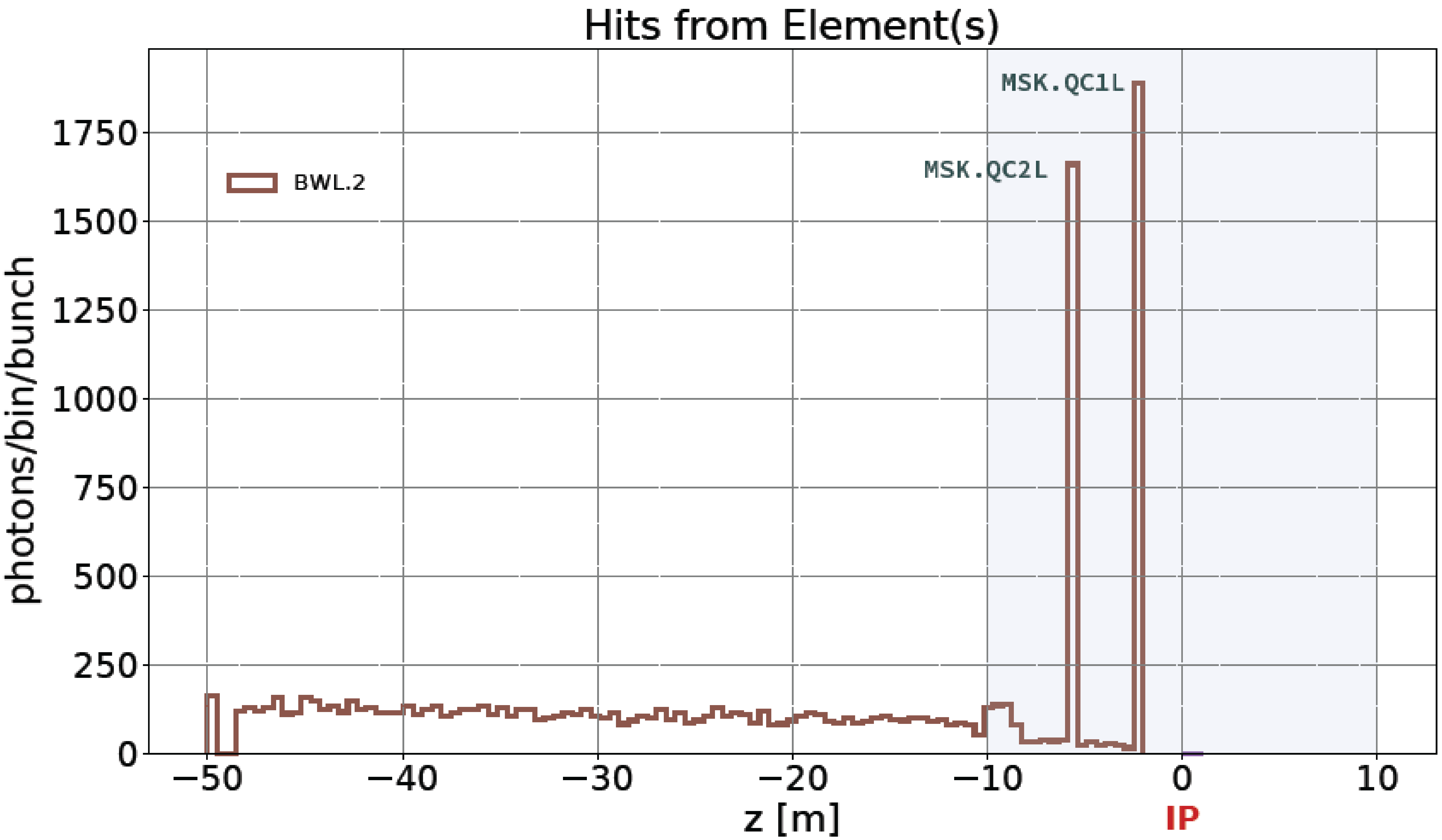
- **MDISim** as flexible software framework
- improvements wherever needed
- useful **tool for background estimates**
- first **collimation** proposal

# Identifying synchrotron radiation fans



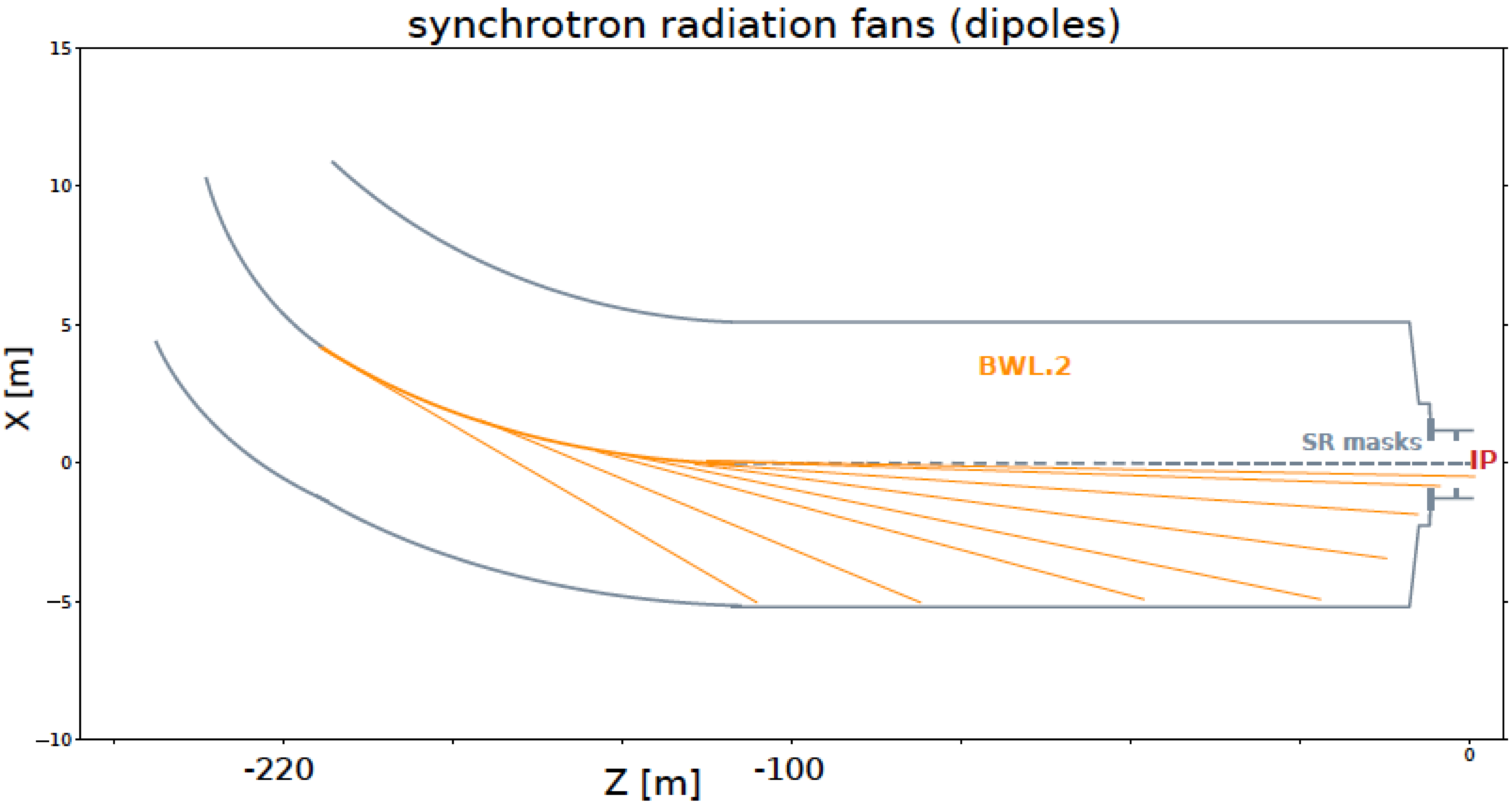

M. Lückhof

# Synchrotron radiation creates losses before IP



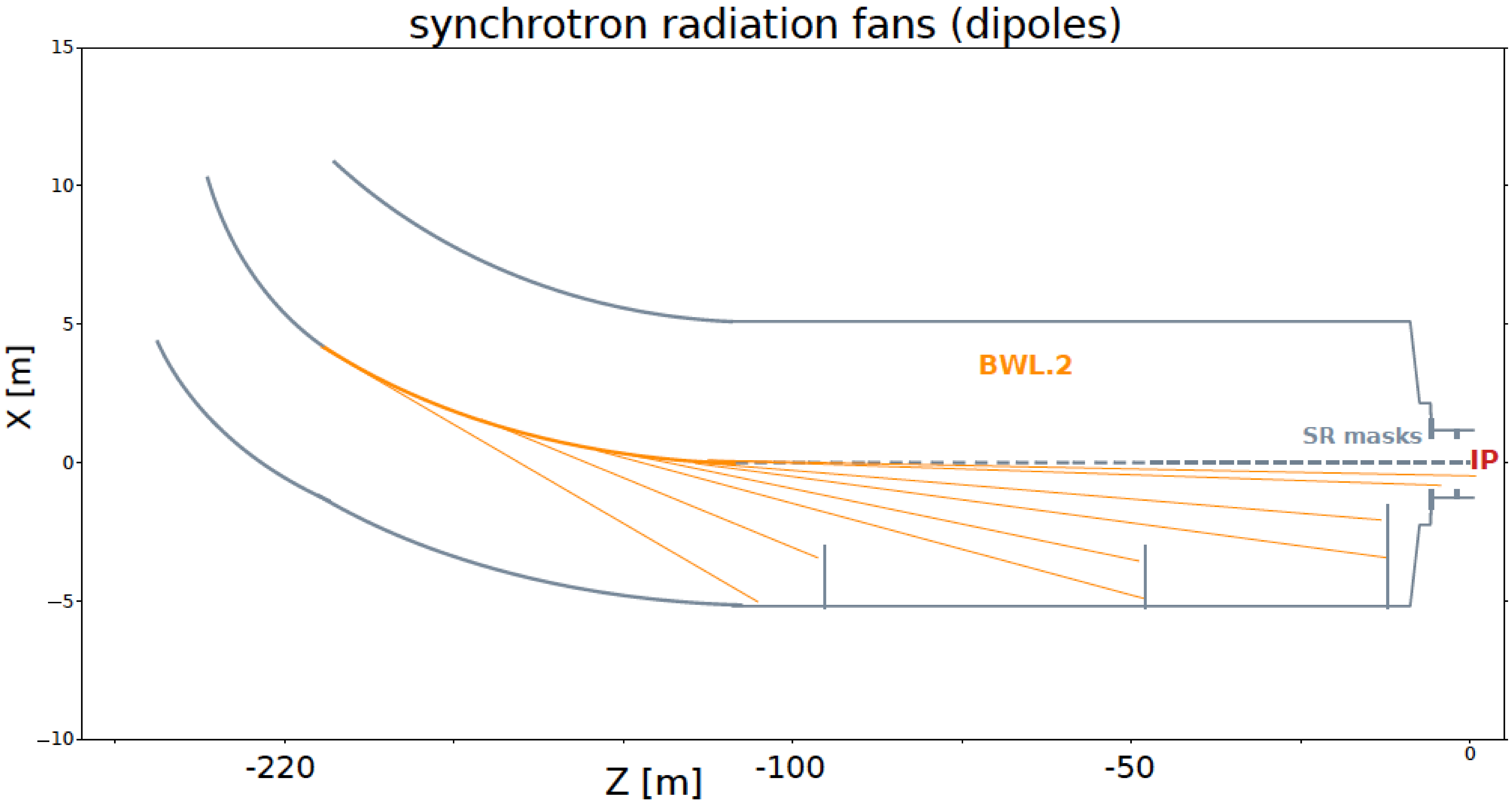

M. Lückhof

# Identifying synchrotron radiation fans



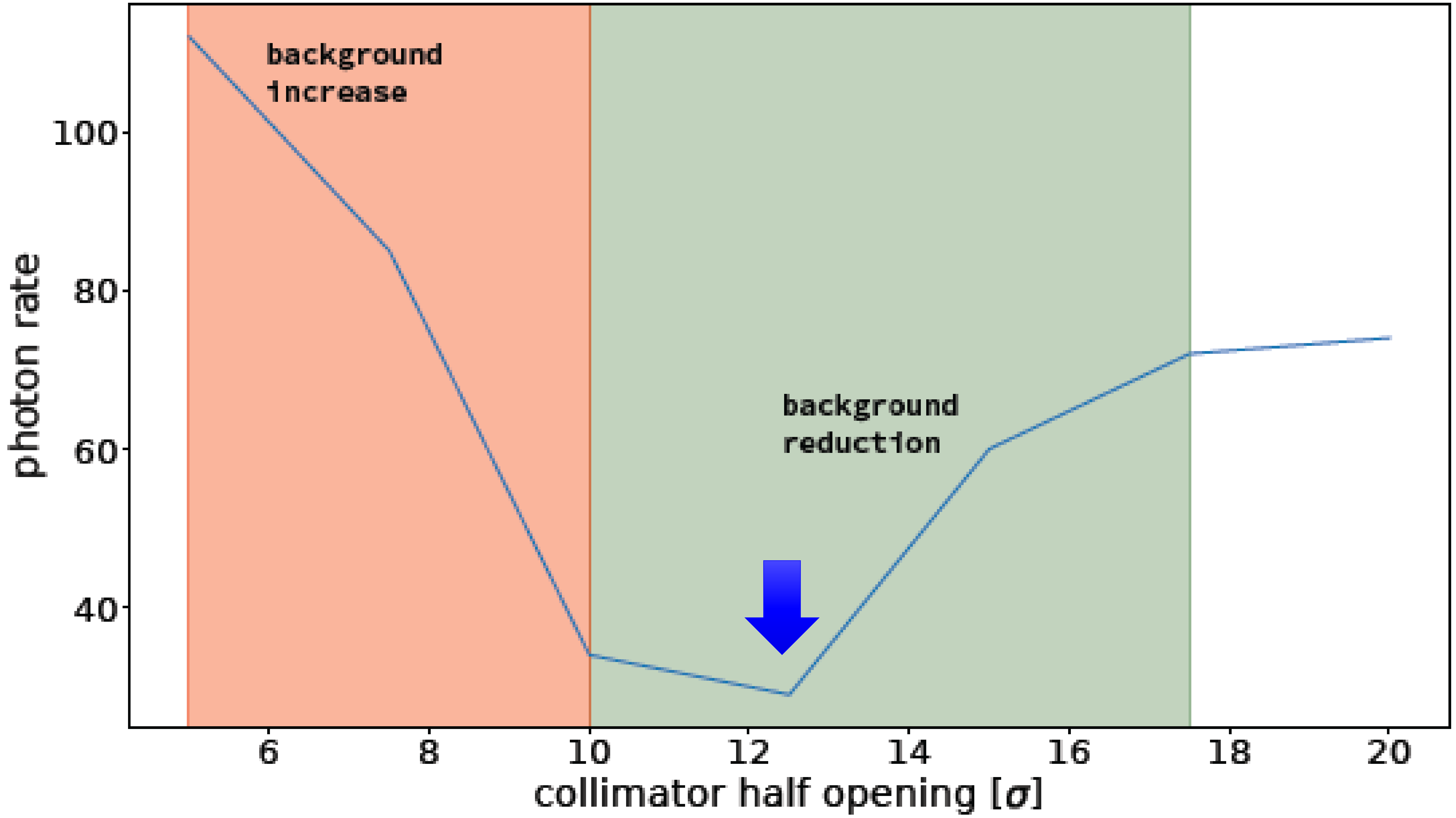

M. Lückhof

# Controlling synchrotron radiation fans



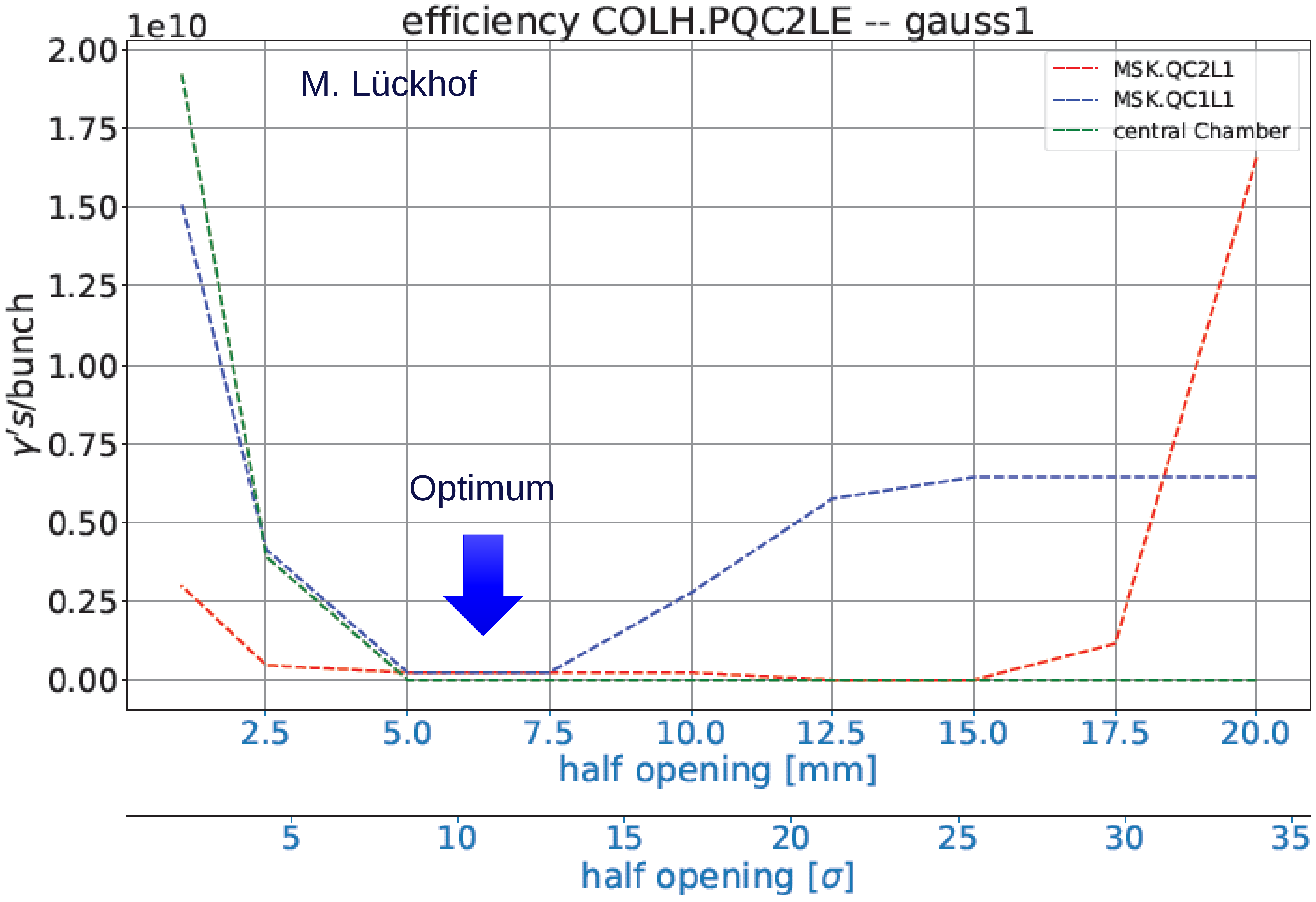

M. Lückhof

# Movable collimators allow optimization




M. Lückhof

# Near Collimator ≈ 10 m (Gaussian distribution)




- In the perfect machine optimum at about 11 σ for the case simulated by Marian
- Excellent progress but more work needed:
  - *Impact of unavoidable imperfections?*
  - *Role of those collimators in case of failures*
  - *Understand required background reduction*
  - *Role of beam tails*
  - ...

# Small collimator gaps do not only create showers but also limit beam lifetime

- More complicated for lepton machines than for proton machines like LHC where we managed to master this problem very nicely
- FCC-ee cannot run with collimators as tight as in LHC
- Mandatory to understand and model halo beam dynamics in detail.

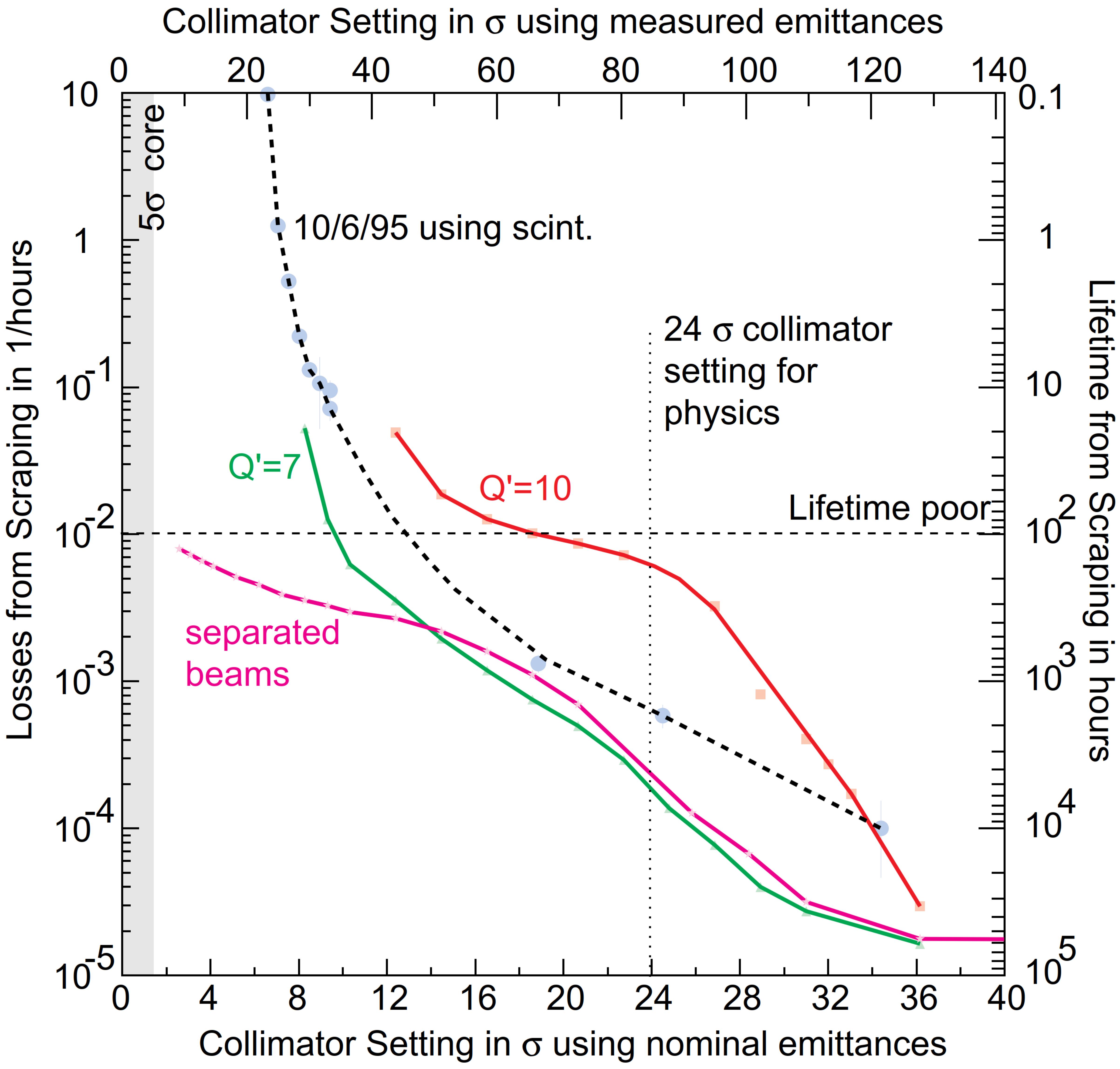



Figure 4: Measured beam tails in the vertical plane.

**H. Burkhardt, LEP data 1995**

# Follow-up topics from F. Zimmermann

## FCC-ee issues requiring further studies (top factory)

1. **Interaction region optimization and shielding of the hard synchrotron radiation** including radiation from the final quadrupoles.
2. **Beam-tail collimation** for background control.
3. Further **off-momentum dynamic aperture optimisation** to maximize beamstrahlung lifetime.
4. **Operational scenarios supporting higher luminosity and shorter beam lifetimes** with more frequent injections.
5. **Single-bunch beam instabilities with highest bunch charge.**
6. **RF system changes for collider and booster, with associated modified optics configuration.**
7. Maximum **energy efficiency.**
8. **Machine protection and radioprotection**.

F. Zimmermann

# To Do's and Possible Contributions (new Phd or Post-Doc) I

- **Improvements in tools and physics models:**
  - Include *X-ray reflections* in Geant4
  - Improve modeling of *halo and tails*
  - Higher *statistics*
  - Realistic *aperture model* with fine longitudinal resolution (e.g. steep transitions)
  - Unification with *detector simulations*
  - *Benchmarking* of various codes
- **Refine IR collimation:**
  - Understand and specify *required performance* (allowed background?)
  - Understand and specify *allowed range of collimator settings* due to beam lifetime, impedance, HOM's and instabilities
  - Provide *performance* for low and tunable background
  - IR collimators/absorbers/masks must have a well-defined *role in machine protection* (either not exposed or act as well defined MP device with adequate phase advance)

# To Do’s and Possible Contributions (new Phd or Post-Doc) II

- **Check and optimize robustness of IR collimation scheme**:
  - System must be fully consistent with *IR mechanical and vacuum constraints*
  - System must be robust against *e+/e- beam dynamics and realistic halo populations*
  - System must be robust against *unavoidable and realistic imperfections* (offsets, optics errors, orbit errors, tuning ranges, conditions during top-up injection, conditions during beam dump, conditions during calibration or special runs)
  - System must be robust against *design failures* (MP)

# Conclusion and Outlook

- MDI is a critical topic for the success and the performance reach of the FCC-ee.
- Glad we can continue to be part of **exploring MDI for FCC-ee** in the task led by Manuela Boscolo.
- Building on past work of M. Lückhof, H. Burkhardt et al there are a multitude of intellectually stimulating and challenging topics for a PhD or a post-doc.
- At the moment, considering the work of M. Lückhof and the needs ahead, my favorite is:
  - Continue developing a **model for IR synchrotron losses from a realistic beam** (including halo/imperfections)
  - Include the **impact that IR collimators might have on background and beam lifetime** within a parameterized model.
  - Predict FCC-ee performance reach in the IR but also **benchmark** such a model with SuperKEKb, if possible.
- **Detailed tasks will depend on the interest/skills of the person we still need to hire and discussions within the task.**

**Thank you to M. Lückhof, H. Burkhardt, M. Boscolo and F. Zimmermann for material and input!**

# Thank you
# for your attention.