Status of the ChDR R&D at ATF2

Stefano Mazzoni, Thibaut Lefevre, Andreas Schloegelhofer, Sara Benitez CERN

Pavel Karataev, RHUL

Renjun Yang, CSNS

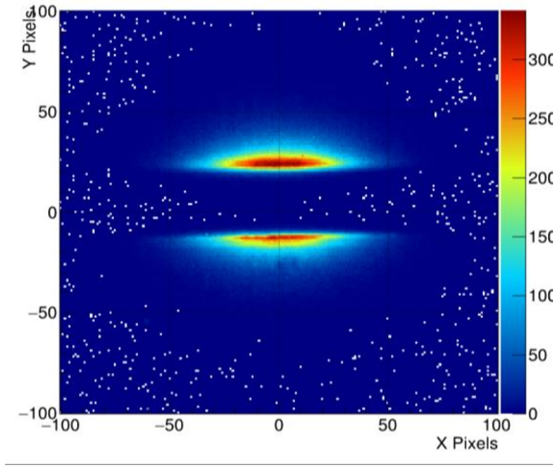
Alex Aryshev, KEK

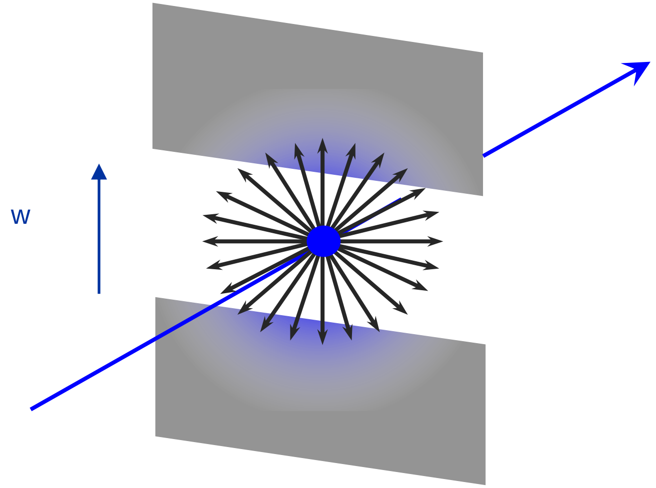
13/12/2023 CLIC mini week

The context: Optical Diffraction radiation

Optical Diffraction Radiation (ODR) studies started in 2011 at CESR and then ATF2 since 2015

- Non invasive transverse beam size with micrometre resolution (CLIC)
- Limitations:
  - low light yield
  - not suitable for rings
  - Synchrotron radiation background





What we need:

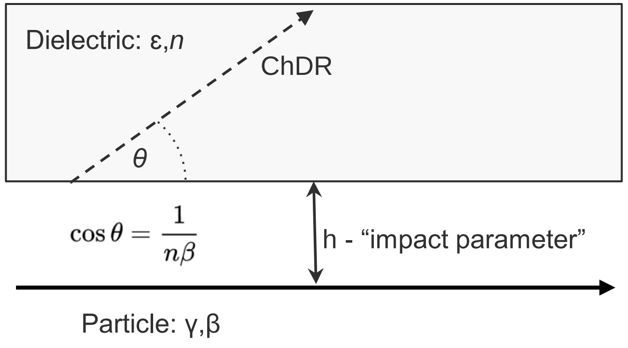
- higher light yield
- emission at larger angles

*T. Aumeyr et al., PRAB **18**, 042801 (2015) ; L. Bobb, PhD thesis, 2017 ; L. Bobb et al., PRAB **21**, 032801 (2018) ; M. Bergamaschi et al. Phys. Rev. Applied **13**, 14041 (2020)*

Cherenkov Diffraction Radiation (ChDR)

The electric field of ultra-relativistic charged particles passing in the vicinity of a dielectric radiator produces photons by the Cherenkov mechanism (polarization effect).

- Large emission angle: $\cos(\theta_{Ch}) = \frac{1}{\beta n}$
- Photons emitted along the target



For <u>cylindrical</u> geometry:

Cherenkov emission – spectral angular

Exponential decay of the particle field

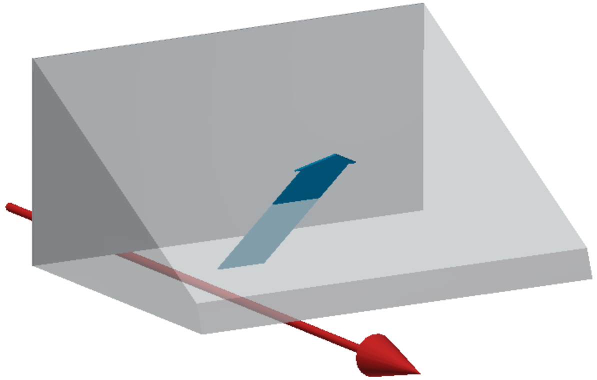
$$\frac{d^2 N_{Dcph}}{d\Omega d\lambda} = \frac{\alpha n}{\lambda}\left(\frac{L}{\lambda}\right)^2 \left(\frac{\sin\left(\frac{\pi L}{\beta\lambda}(1-\beta n\cos\theta)\right)}{\frac{\pi L}{\beta\lambda}(1-\beta n\cos\theta)} \right) \sin^2\theta \; e^{\left(-4\pi\frac{h}{\gamma\beta\lambda}\right)}$$

α, fine structure constant
β, normalised beam velocity
γ, beam relativistic factor
θ, angle of observation
L, radiator length
n, index of refraction
h, impact parameter

ChDR in realistic geometries

a)

In real accelerators, dielectrics emitting ChDR will be elements embedded in beam pipe walls (a) or prisms (b)



b)

- non-cylindrical geometry
- finite length

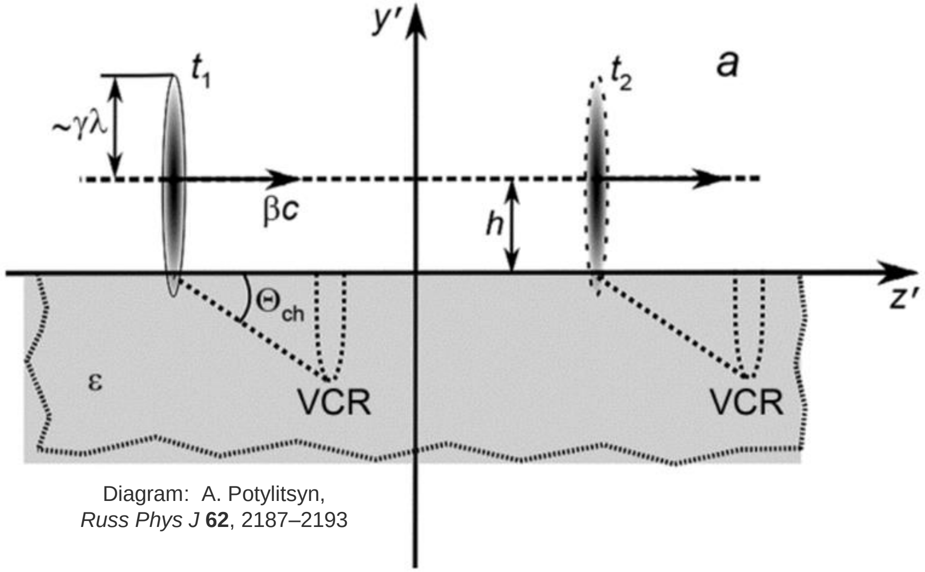
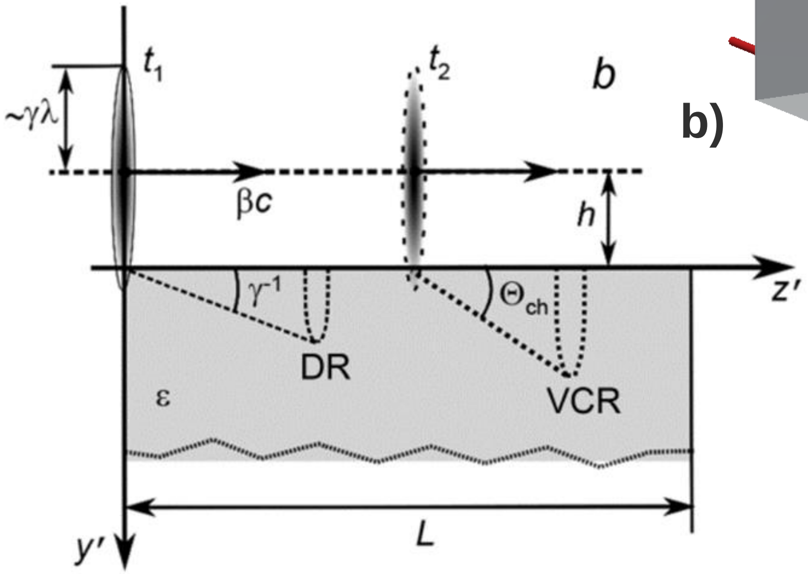


Diagram: A. Potylitsyn,
Russ Phys J **62**, 2187–2193



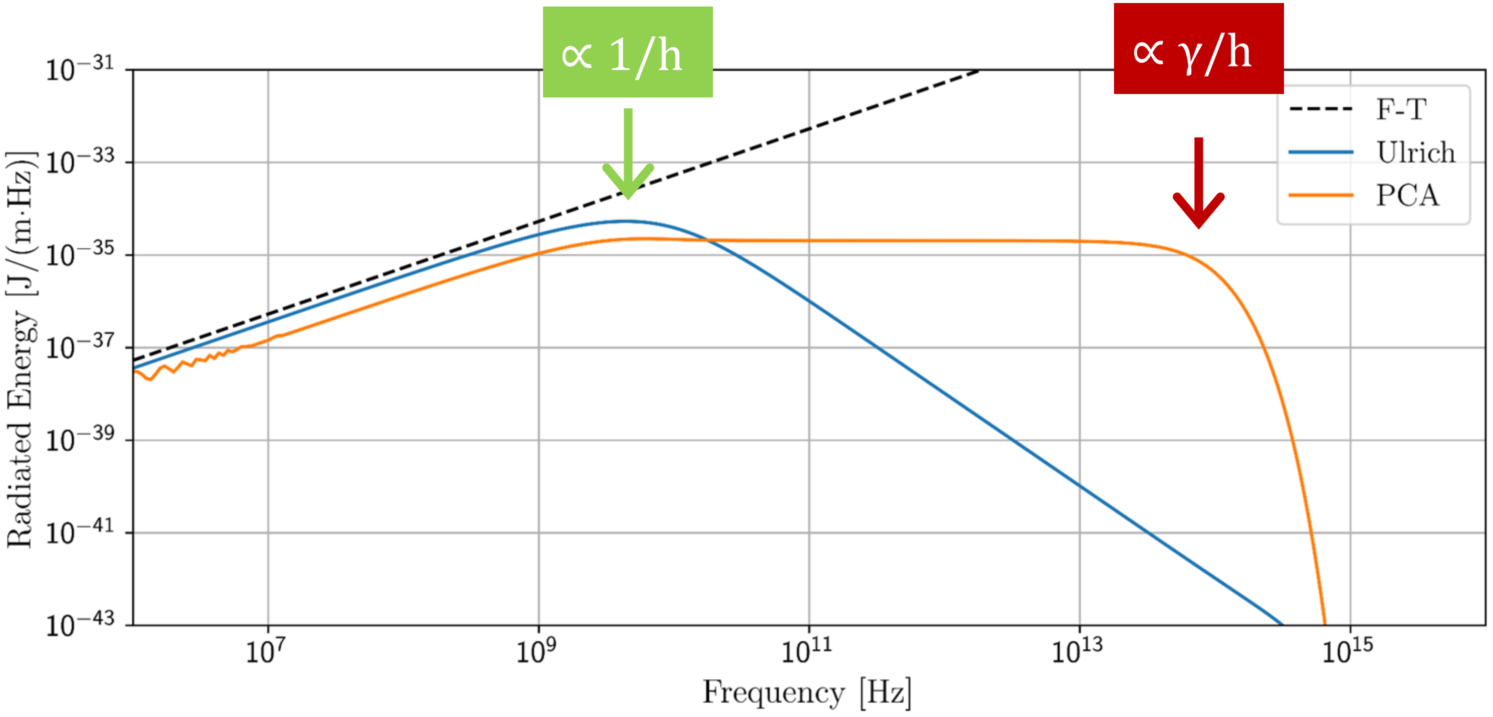
1 B.M. Bolotovskii, Sov. Phys. Usp. 4 781 (1962).
2 Ulrich, Z. Physik 194, 180–192 (1966).
3. H. A. Olsen and H. Kolbenstvedt, Phys. Rev. A, vol. 21, Jun 1980.

4. Karlovets, D.V., Potylitsyn, Jetp Lett. 90, 326 (2009).

Incoherent ChDR light yield: not measured to date!

Incoherent ChDR has a potential for longitudinal diagnostics for high energy future colliders (CLIC, ILC, FCCee), but models predict large differences in photon yield

$\gamma \approx 88000$
$h = 1$ cm



Overview of ChDR experiments

CERN BI and collaborators established a comprehensive study on ChDR for beam instrumentation applications

- Observation / characterization of coherent / incoherent ChDR:
  - CESR (Cornell University): first observation of incoherent ChDR (2017)
  - CLEAR (CERN): incoherent / coherent photon yield studies (2018 - present)
  - ATF2 (KEK): incoherent light yield (present)
  - Tomsk Microtron (Tomsk): far-IR ChDR superradiant emission (2020)
  - Diamond Light Source (UK): coherent and incoherent ChDR (2018-2019)
- Beam diagnostics studies
  - ATF2 (KEK): transverse beam profile (2018-2019)
  - CLEAR (CERN) and CLARA (Daresbury UK): bunch length via incoherent ChDR (2018-present)
  - CLEAR and AWAKE (CERN): beam position via coherent radiation (2018 - present)
  - Diamond Light Source (UK): incoherent BPM (2022 - present)

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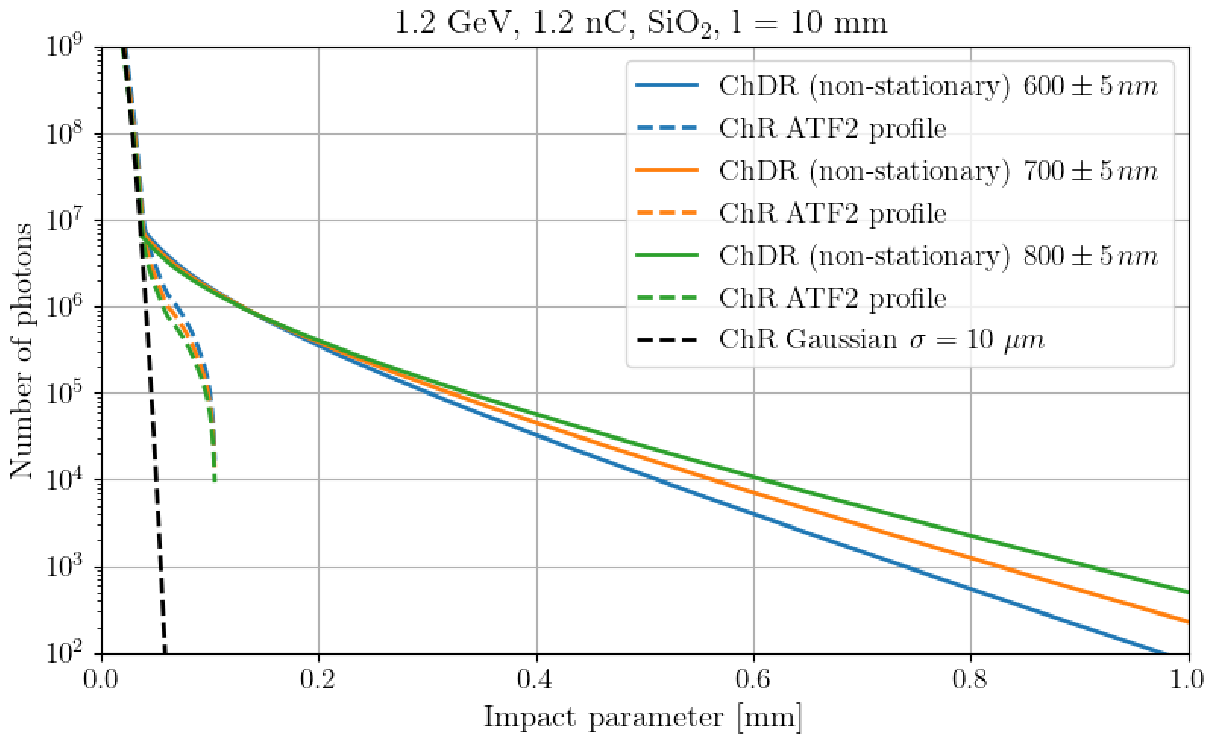
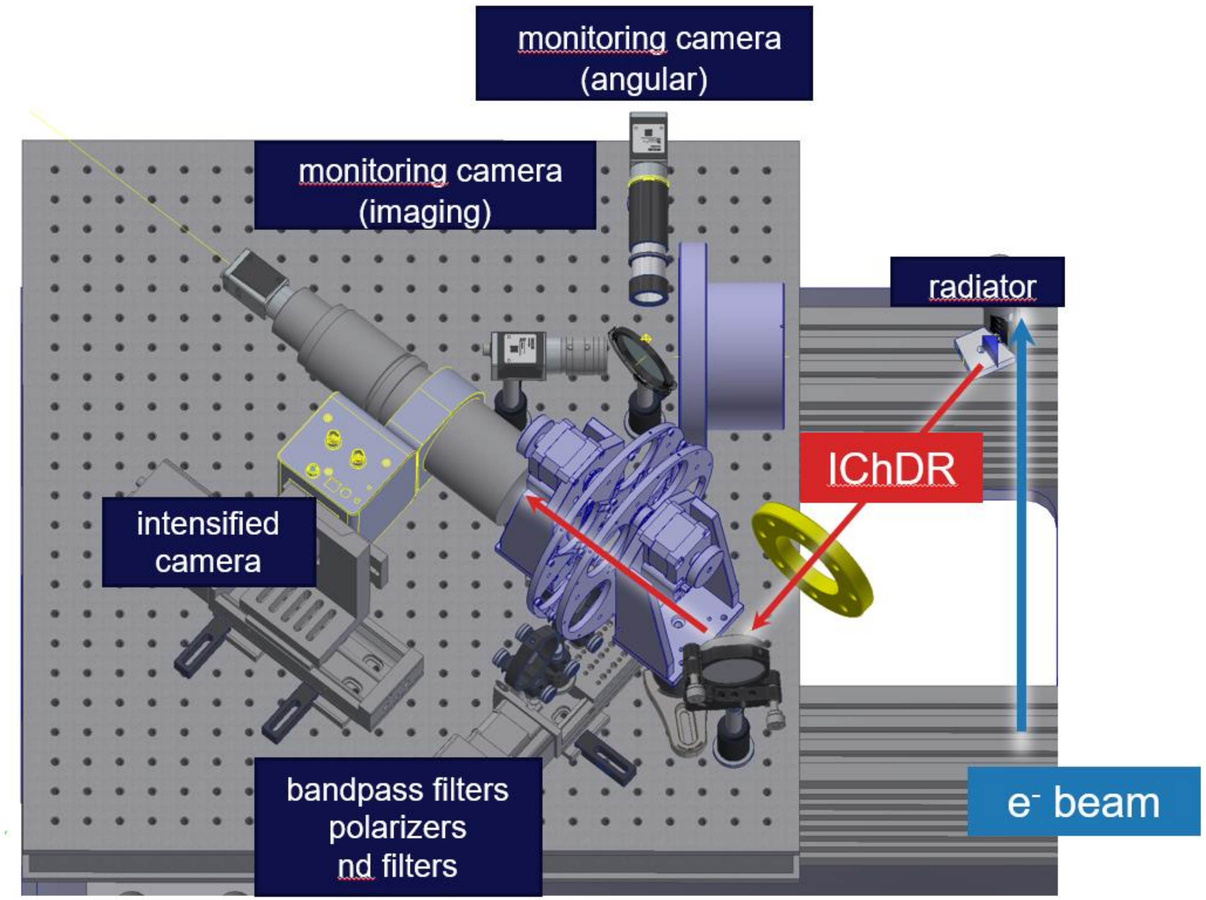
Incoherent ChDR yield at ATF2

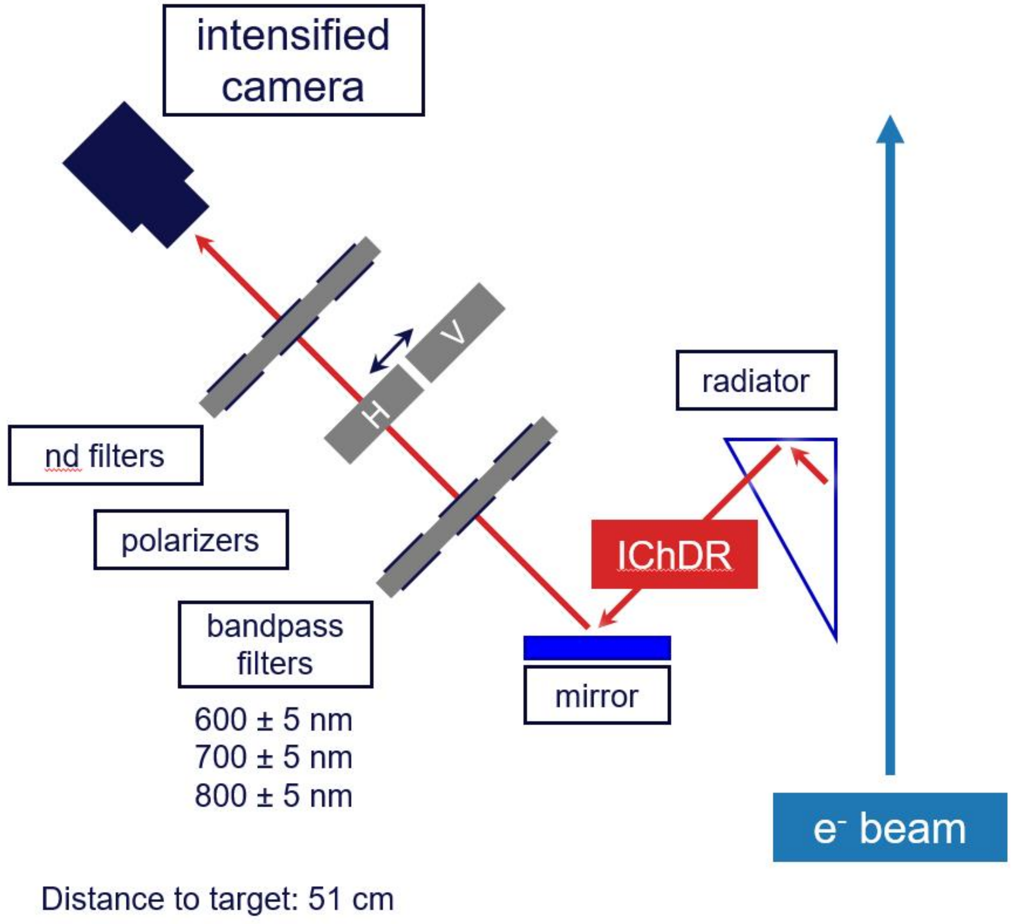
Incoherent ChDR has a potential for longitudinal diagnostics for high energy future colliders (FCCee,…), but incoherent light yield not known precisely …challenging measurement!

- At moderate γ (GeV), impact parameter is limited
- Imperative to avoid spurious photons:
  - Cherenkov from beam halo
  - synchrotron radiation



Incoherent ChDR at ATF2 - setup





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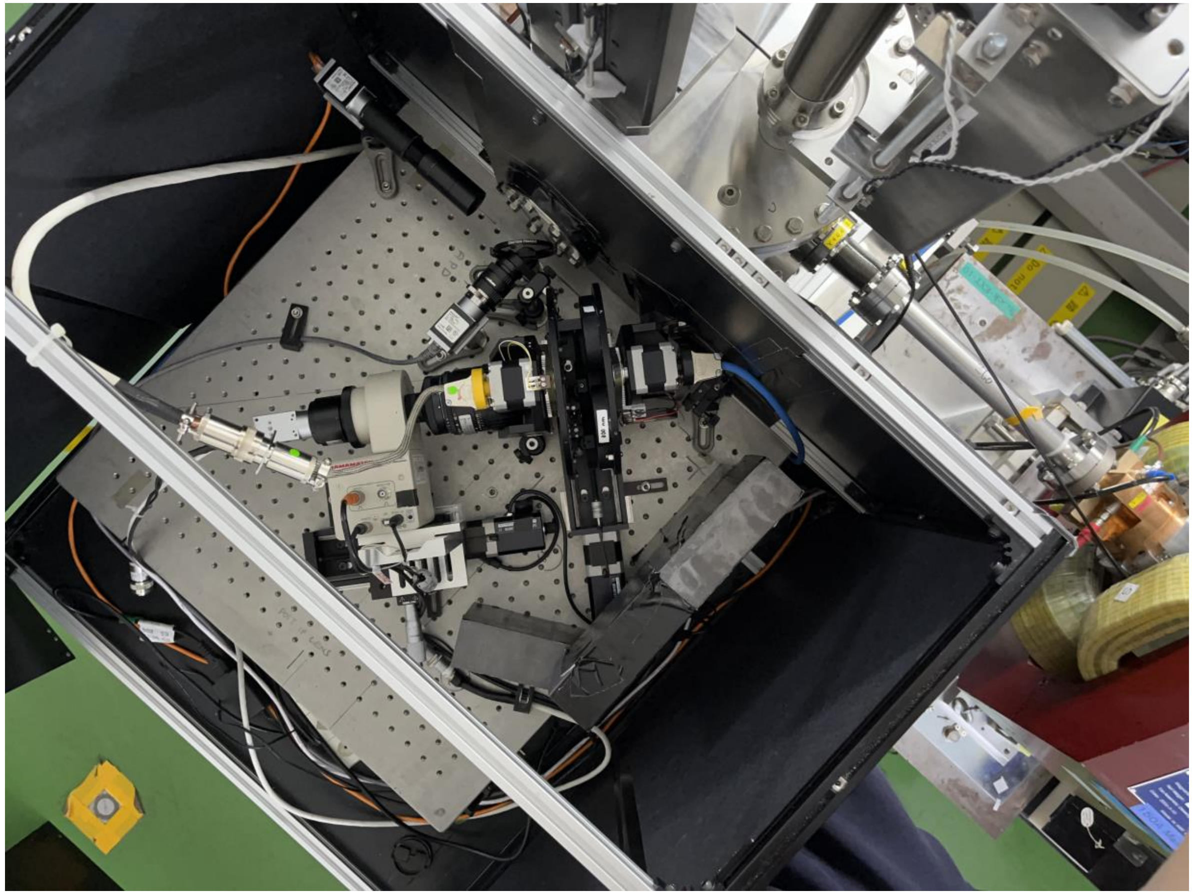
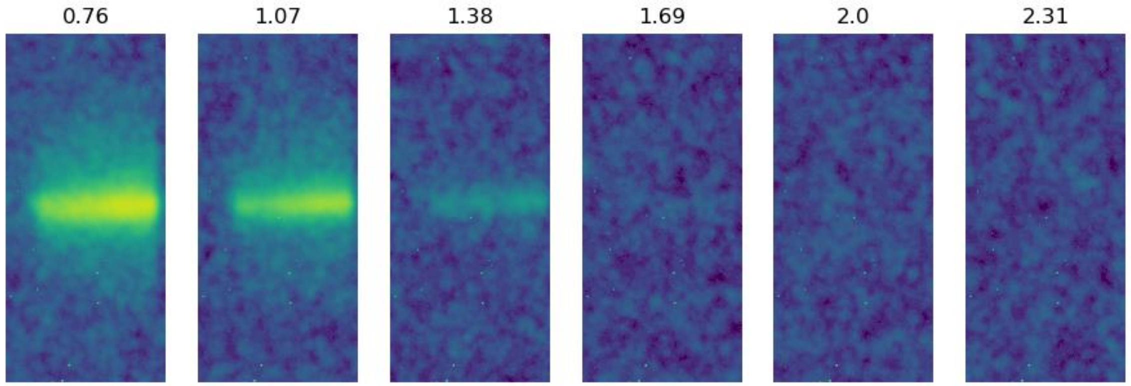


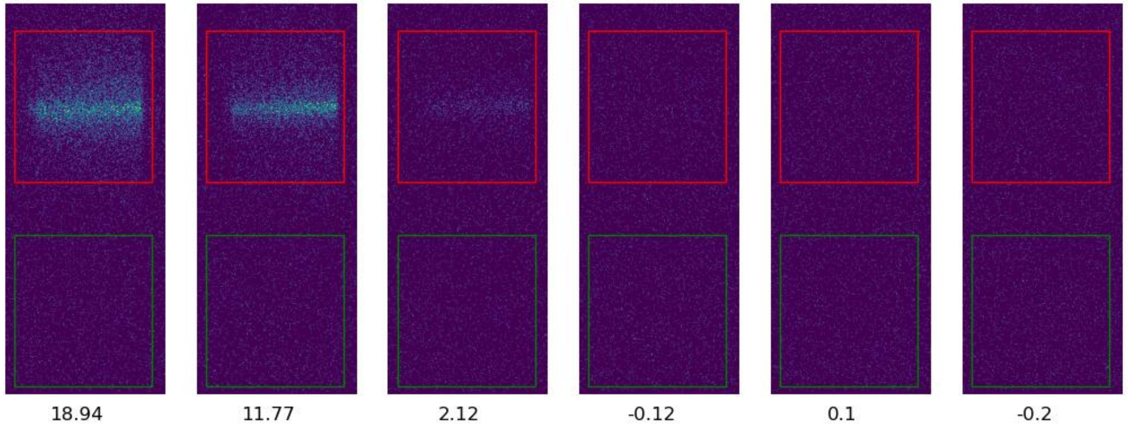
Summary of June tests

Integrated images

Impact parameter



Photon counting



Number of Photons

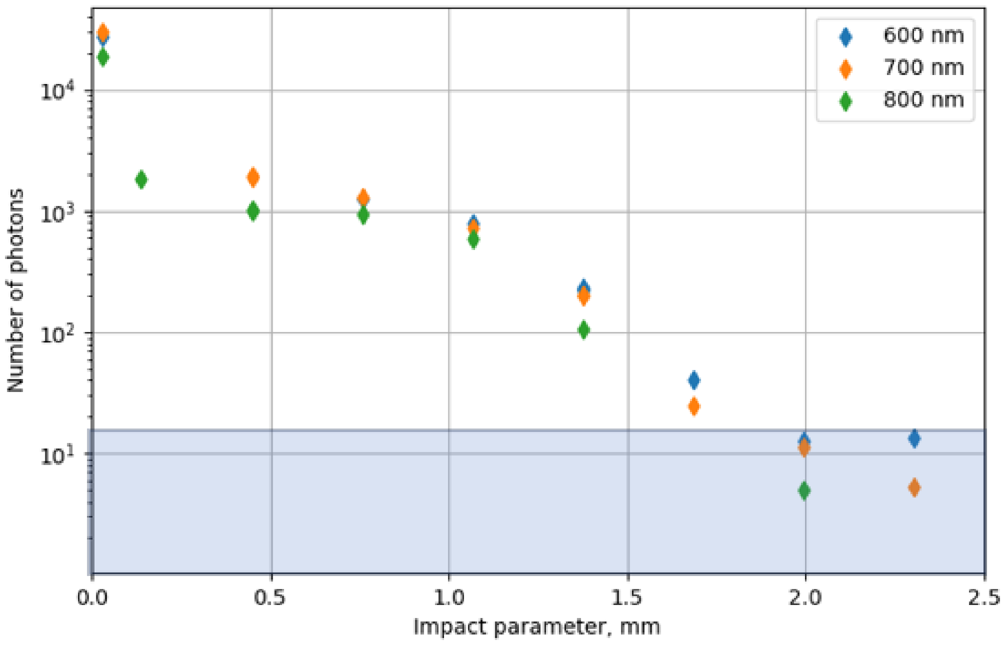
20 different distances/bandpass filter
500 images per position

Normalized for bunch charge

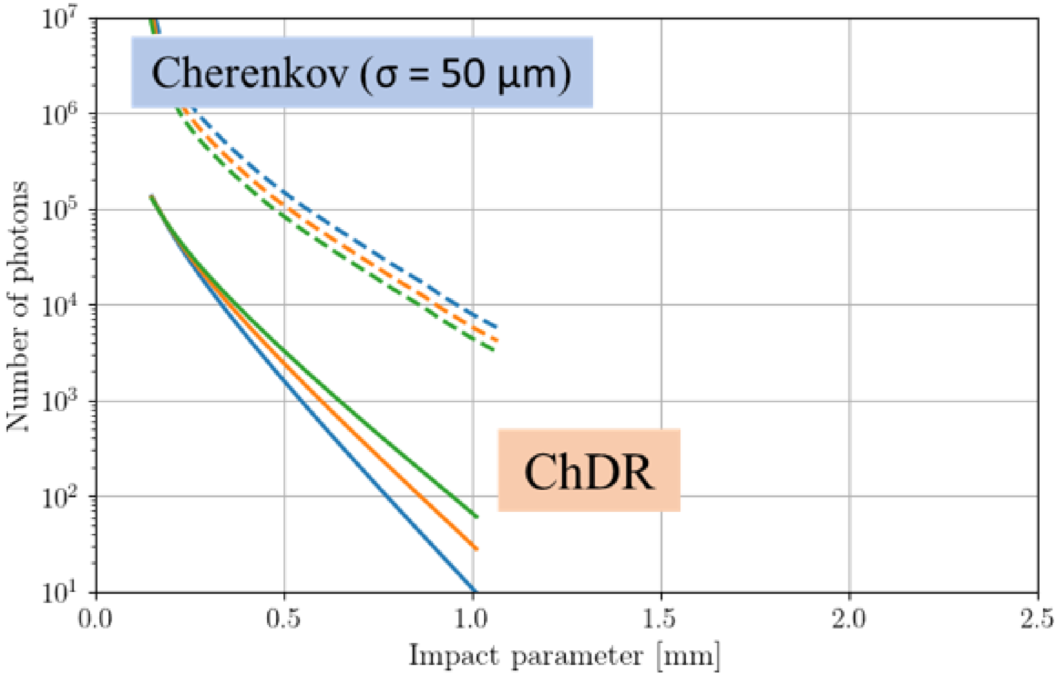
Signal

Background

Summary of June tests

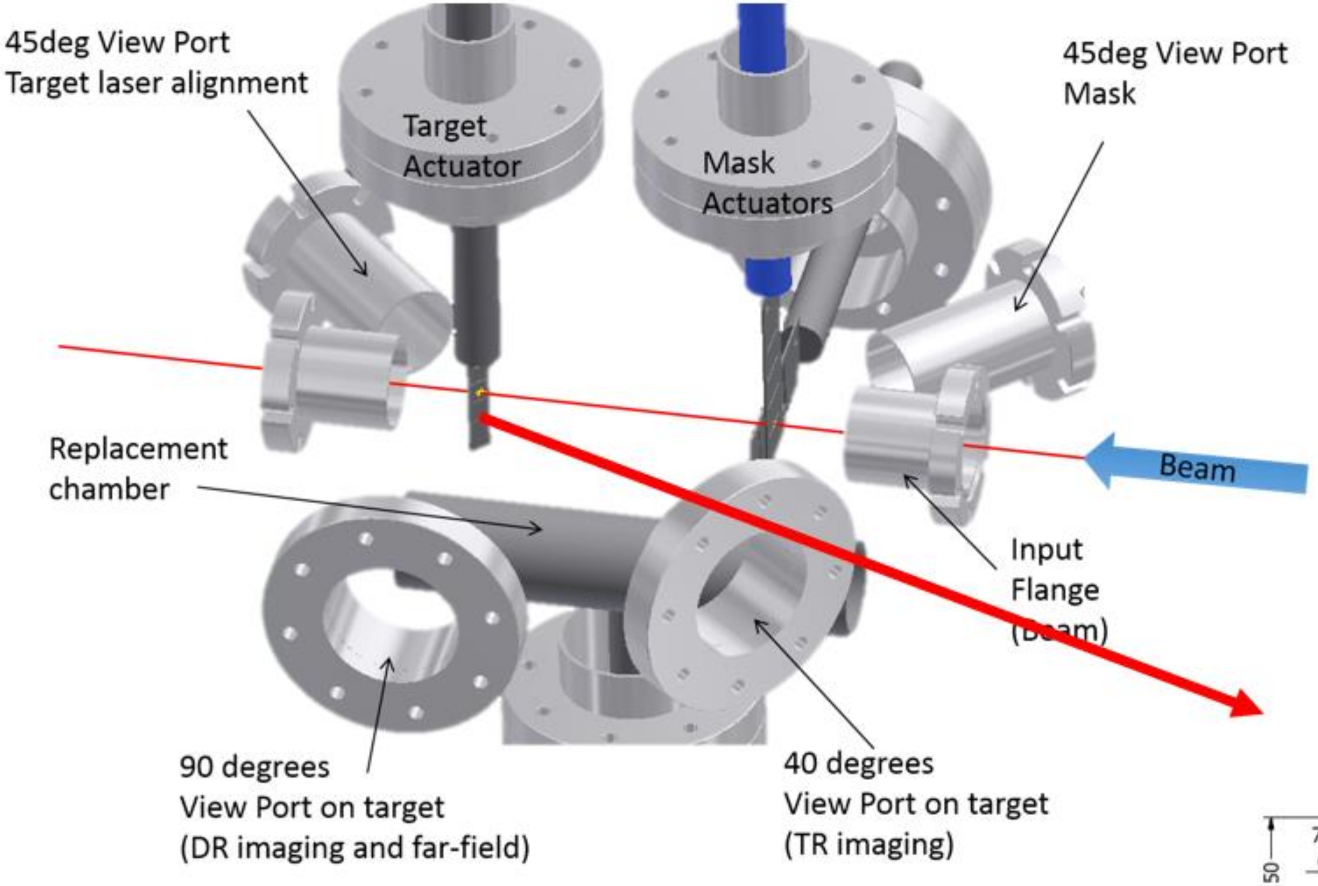


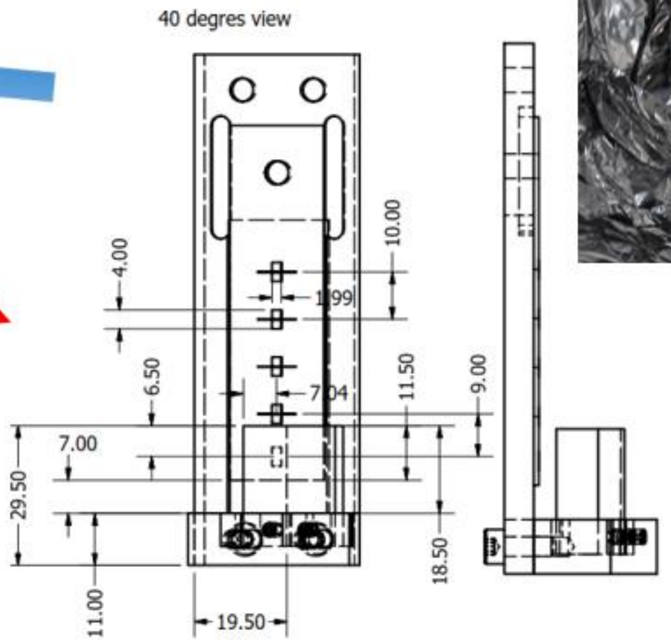
1.0 GeV, 150 pC

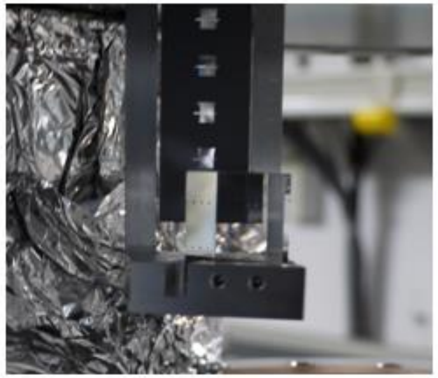


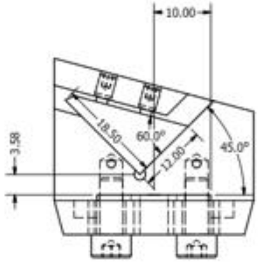
Signal dominated by Cherenkov produced by halo particles crossing the target!

Possible upgrade of ChDR setup









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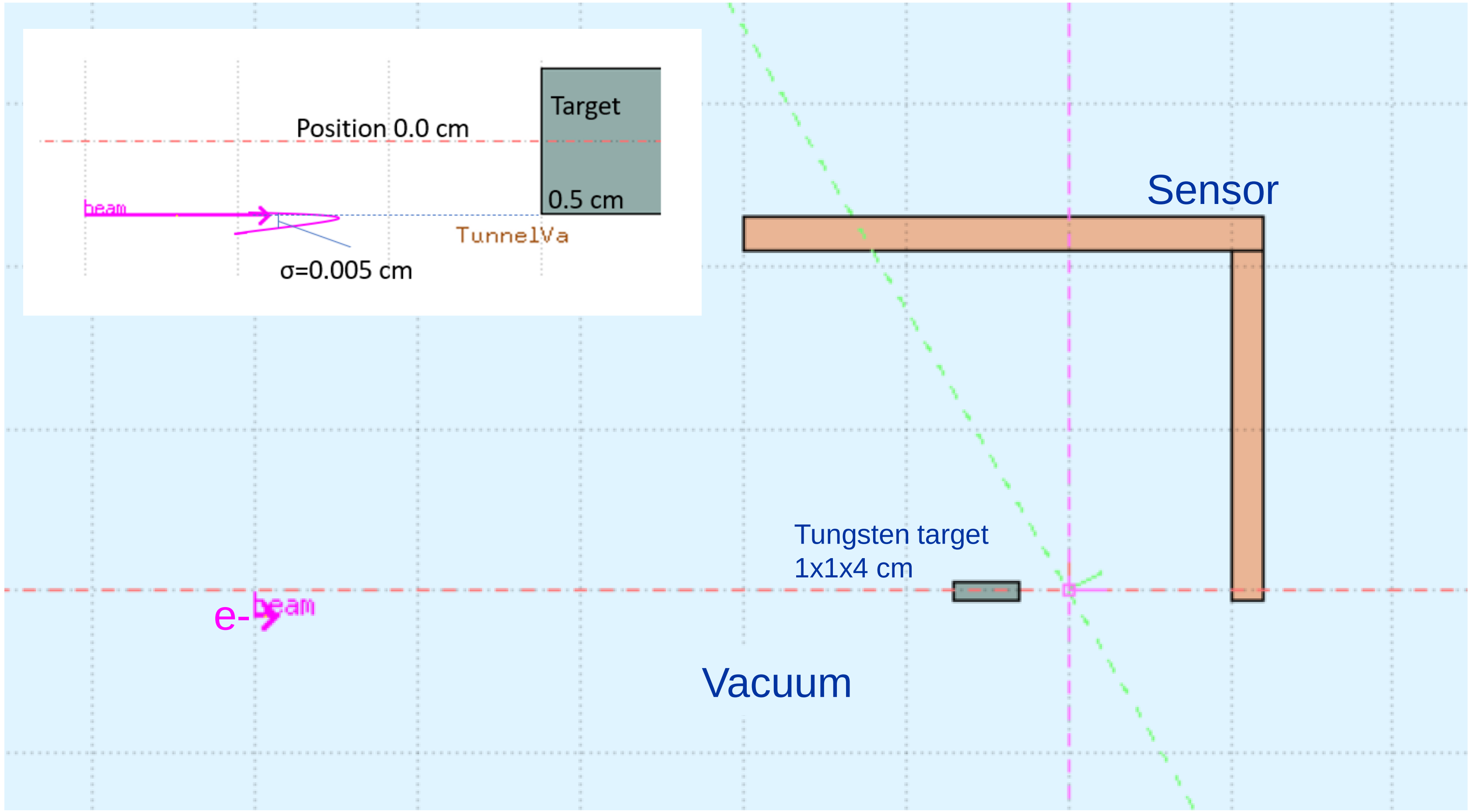
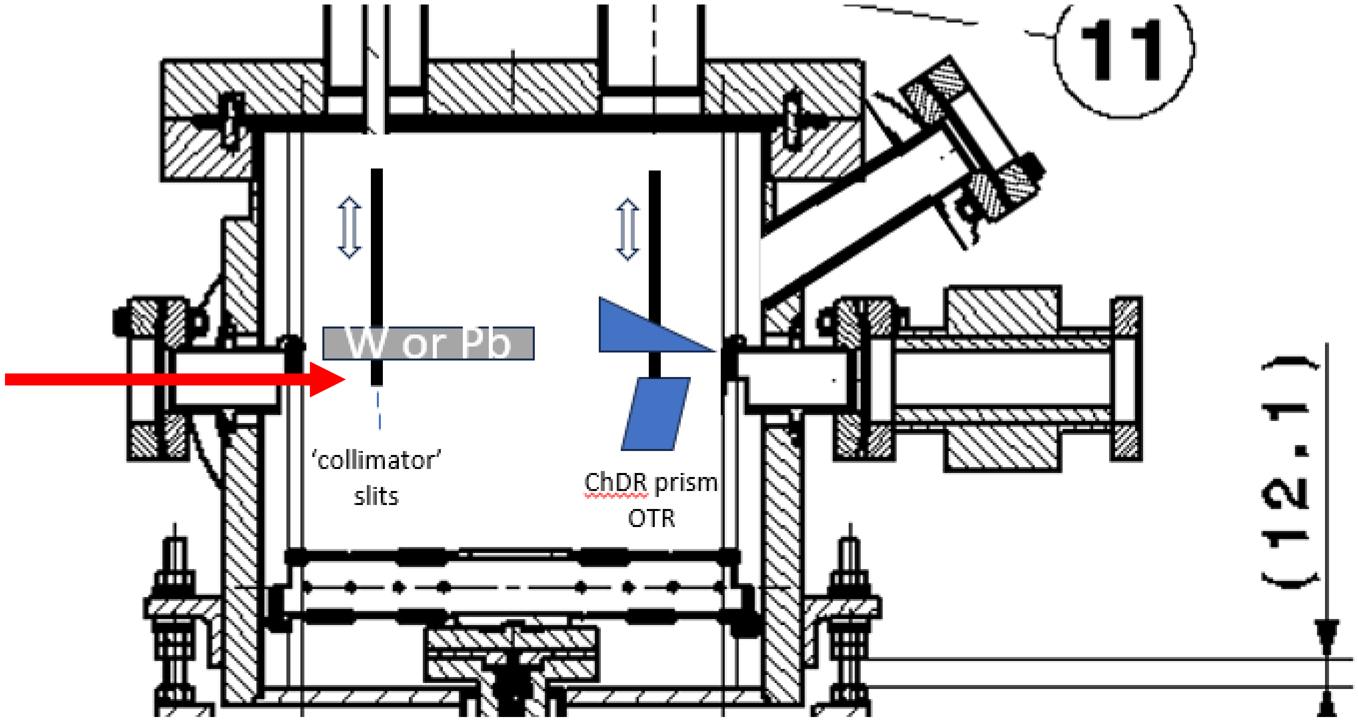


- **FLUKA simulation: effect of 1x1x4 cm W absorber**
- **1.2 Gev, 1,2 nC, 50 um sigma gaussian bunch**
- **Look for charged particles with b>0.685 in a 10 mrad cone co-axial with beam direction**
- **Expected reduction order 10^6**

PRELIMINARY

Possible upgrade of ChDR setup



- preserve most of existing design: vertical actuators, support, replacement chamber
- new chamber probably needed for adding 45 deg viewport
- new design should better reject synchrotron radiation (vertical polarisation)

Summary

- Incoherent ChDR can be source for beam diagnostics for future high energy colliders
- Attempts at ATF2 unsuccessful so far, partially due to setup not adapted to ChDR
- (Very) preliminary studies show a possible new setup design that would allow better noise rejection

- New PhD student starting in 2024 to measure incoherent ChDR light yield and possibly perform longitudinal profile measurement at ATF2.
- We look forward to discussing with ATF2 team for beam time availability, modification of setup, upgrade of controls etc. etc.

CERN