FUTURE CIRCULAR COLLIDER

Bunch length measurement studies using Cherenkov Diffraction radiation

gratefully acknowledging:
Michael Benedikt, Candy Capelli, Nicolas Sebastien Chritin, Ashley Churchman, Can Davut, Wilfrid Farabolini, Daniel Harryman, Pavel Karataev, Pierre Korysko, Kacper Lasocha, Thibaut Lefevre, Stefano Mazzoni, Collette Pakuza, Eugenio Senes

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the European Union's Horizon 2020 research and innovation programme under grant agreement No 951754

Table of contents

FCC-ee bunch length diagnostics

Synchrotron radiation (SR) in LEP

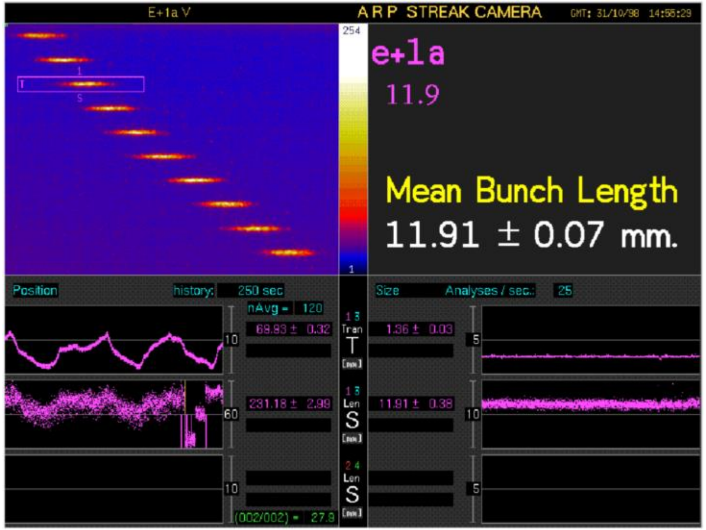
Bunch length measurements using SR
on streak camera

SR in FCC-ee:

Distance of ~100m necessary to separate the photon beam from the electron or positron beam[1] and X-rays dominating the spectrum

Cherenkov Diffraction Radiation (ChDR) at FCC-ee

- Non-invasive
- Simple geometries with small space requirements
- Photon emission at large and well-defined angle



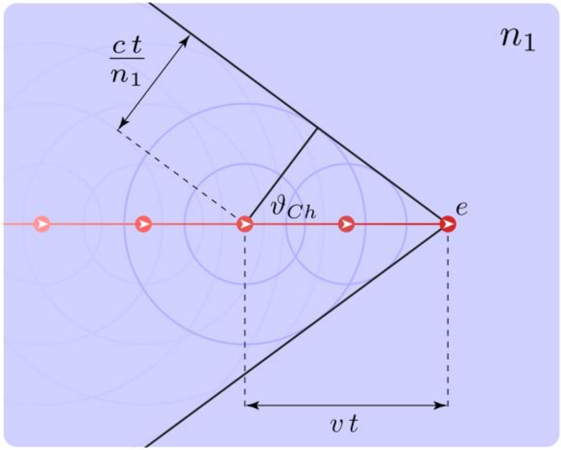
Bunch length measurement in LEP [2]

[1] Abada, A., Abbrescia, M., AbdusSalam, S.S. et al. FCC-ee: The Lepton Collider. Eur. Phys. J. Spec. Top. 228, 261–623 (2019). https://doi.org/10.1140/epjst/e2019-900045-4

[2] A. J. Burns, H. Schmickler, Bunch length measurements in LEP, Proceedings DIPAC (1999) https://cds.cern.ch/record/398768

Cherenkov (Diffraction) Radiation

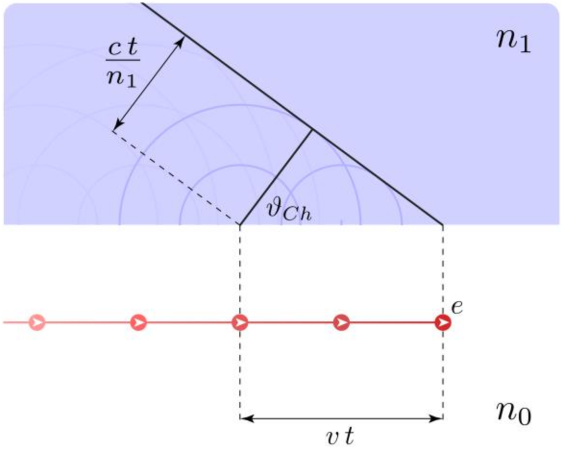
Cherenkov Radiation



Frank-Tamm

$$\frac{dW}{dl} = \frac{q^2}{4\pi}\mu_0 \int_0^\infty \omega \cdot \left(1 - \frac{1}{\beta^2 n^2(\omega)}\right) d\omega$$

Cherenkov Diffraction Radiation (ChDR)

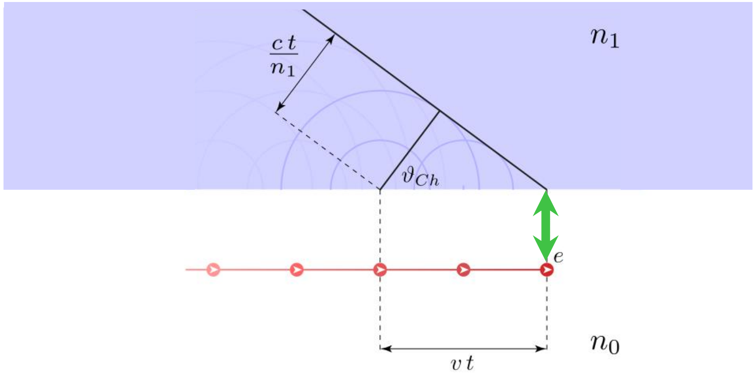


Two analytical models →

[2] I.M. Frank and I.E. Tamm. Coherent visible radiation of fast electrons passing through matter. *Compt. Rend. Acad. Sci. URSS*, 14(3):109– 114, 1937

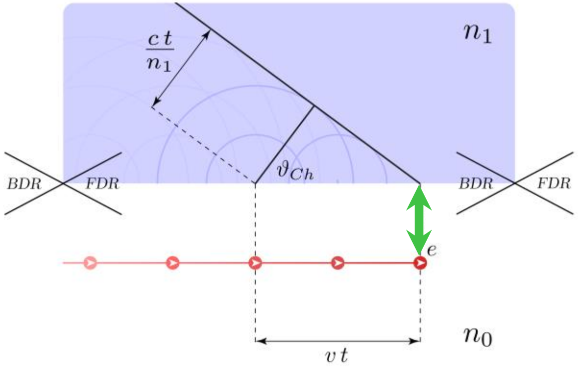
Analytical Models

Stationary Model (1,2)



Electrons moving parallel to the boundary of **infinite** length radiators

Non-Stationary Model (3,4)



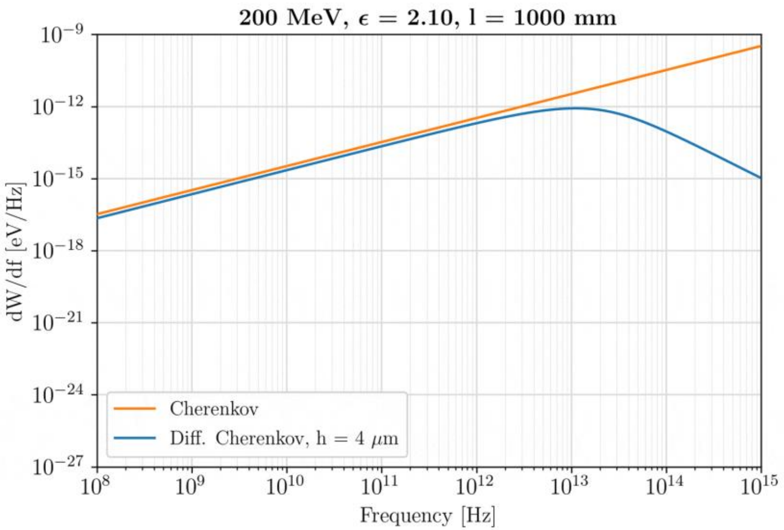
Electrons moving parallel to the boundary of **finite** length radiator

h … Impact Parameter | E … Particle Energy

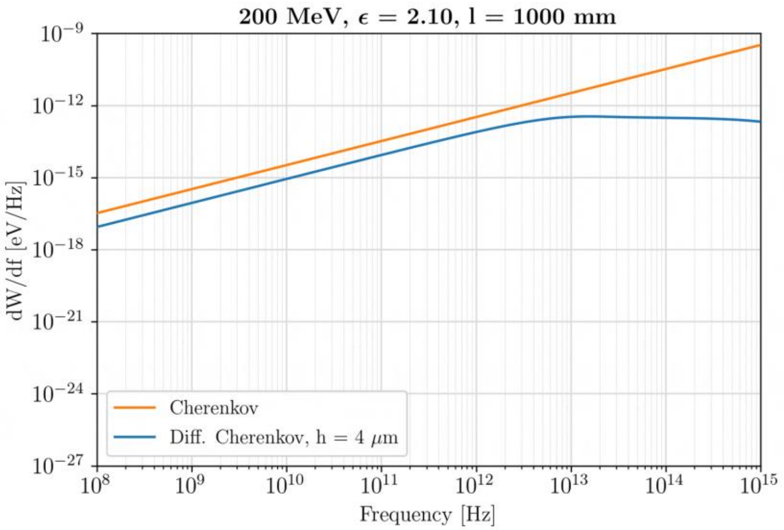
[1] B.M. Bolotovskii, Sov. Phys. Usp. 4 781 (1962) [2] Ulrich, R. Zur Cerenkov-Strahlung von Elektronen dicht über einem Dielektrikum. Z. Physik 194, 180–192 (1966). https://doi.org/10.1007/BF01326045 [3] Karlovets, D.V., Potylitsyn, A.P. Diffraction radiation from a finite-conductivity screen. Jetp Lett. 90, 326 (2009). https://doi.org/10.1134/S0021364009170032 [4] Konkov, A.S., Potylitsyn, A.P., Shevelev, M.V. et al. On the polarization characteristics of Cherenkov radiation from a dielectric screen. Jetp Lett. 105, 227–231 (2017). https://doi.org/10.1134/S0021364017040105

Impact parameter h

Stationary Model



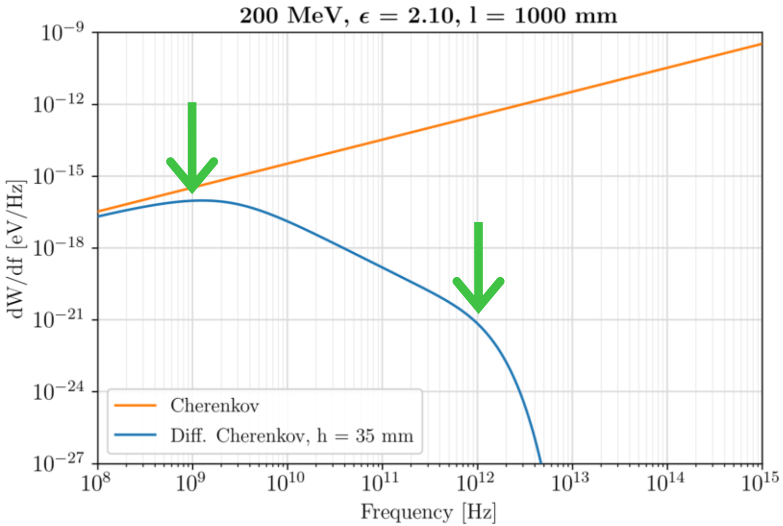
Non-Stationary Model



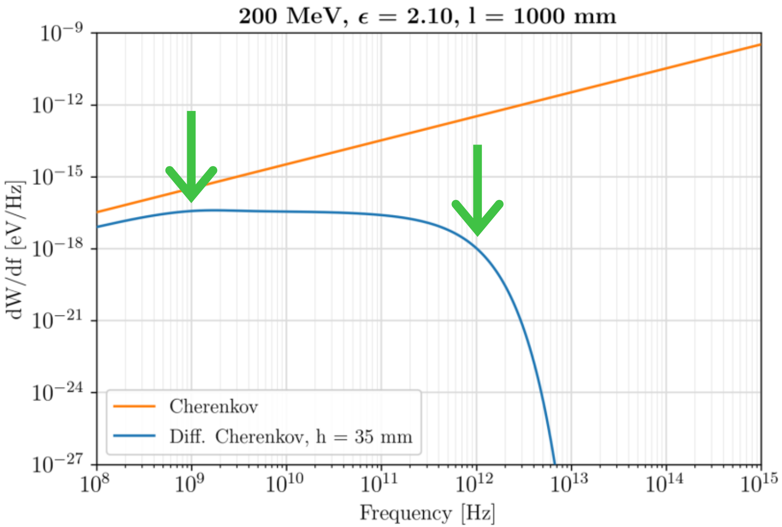
Fixed particle energy, only distance between particle and radiator is increased

Impact parameter h

Stationary Model



Non-Stationary Model

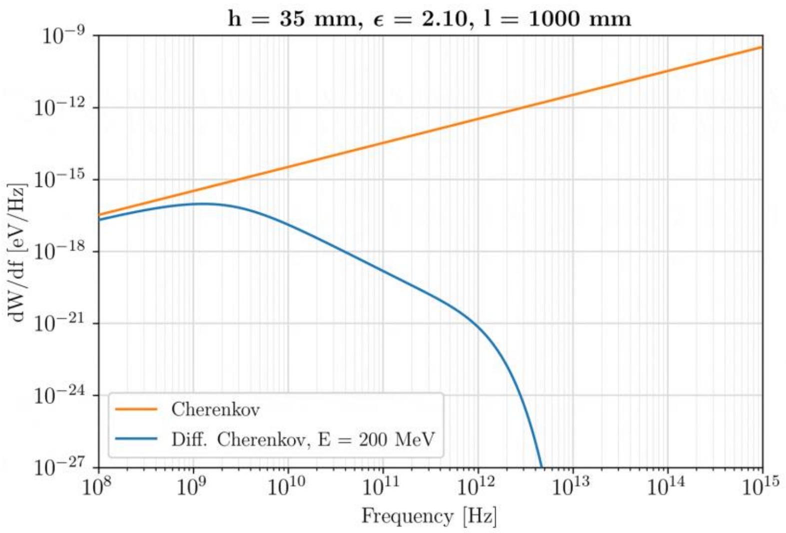


$\propto 1/h$

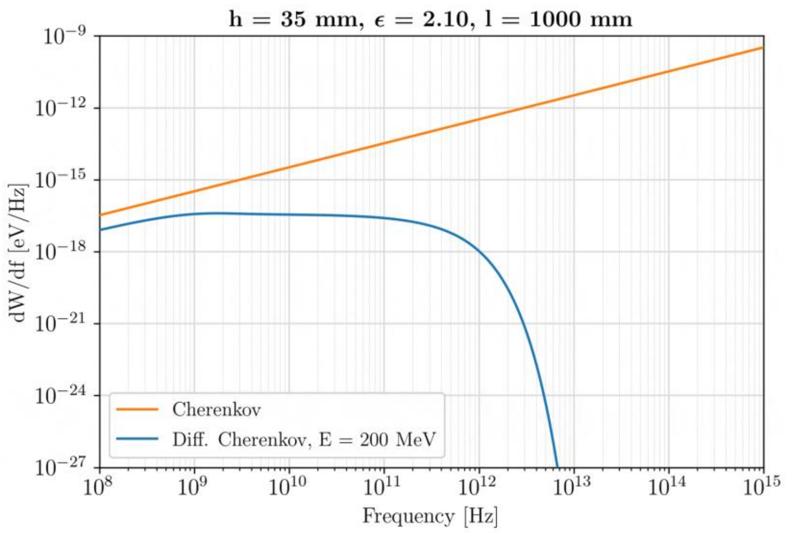
turning points show the same behavior in both models

Energy E

Stationary Model



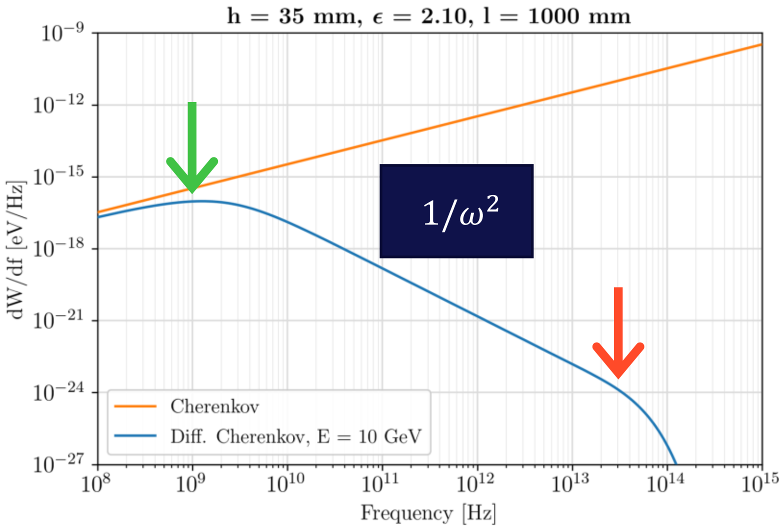
Non-Stationary Model



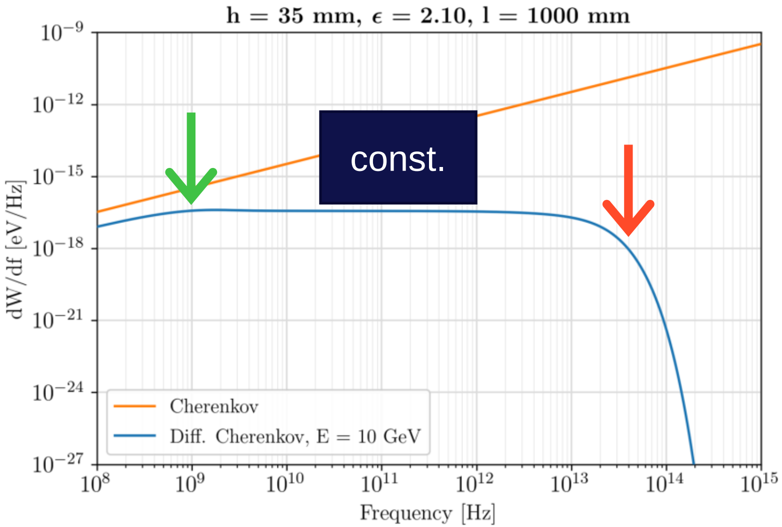
Fixed distance, only particle energy is increased

Energy E

Stationary Model



Non-Stationary Model

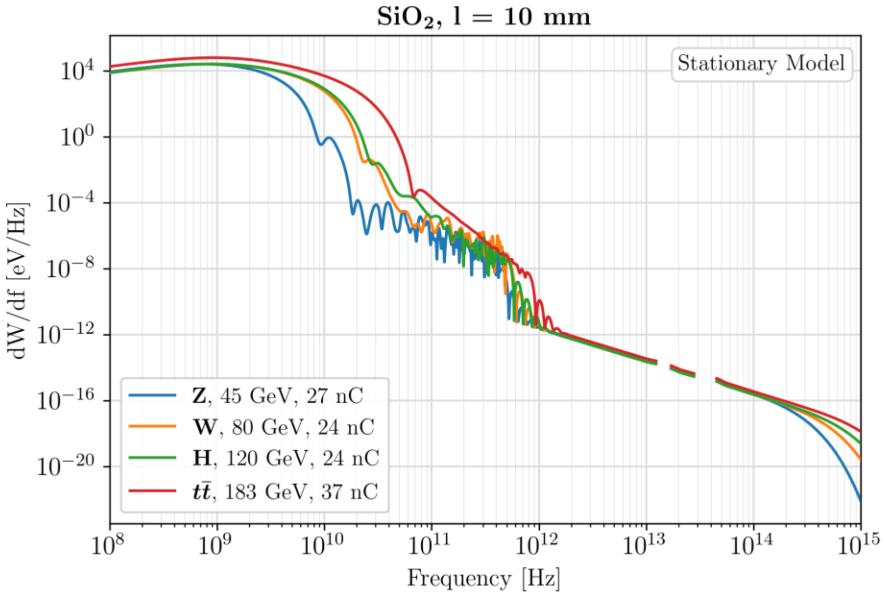


$\propto 1/h$ $\propto \gamma/h$ turning points show the same behavior in both models

Coherent and Incoherent ChDR

$\lambda > \sigma_{bunch}$

$\propto N^2$



$\lambda \ll \sigma_{bunch}$

$\propto N$

$$\frac{dW}{d\omega} = \left(\frac{dW}{d\omega}\right)_1 \cdot \left(N + N(N-1) \cdot \left|F(\vec{k})\right|^2\right)$$

with $F(\vec{k}) = \int S(\vec{r}) \cdot e^{-i\vec{k}\,\vec{r}}\, d\vec{r}$

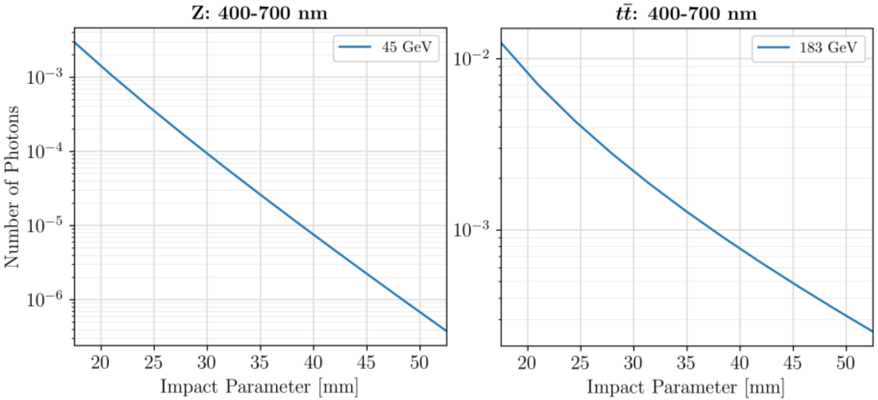
$F(\vec{k})$ … bunch form factor

$S(\vec{r})$ … particle density distribution

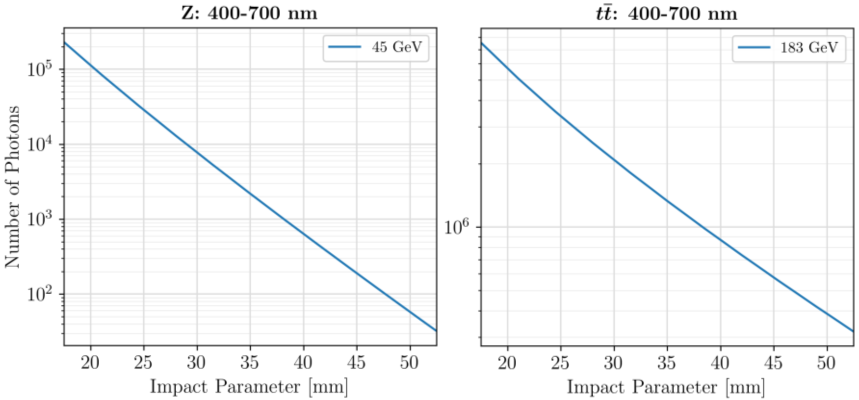
$\left(\frac{dW}{d\omega}\right)_1$ … energy spectrum of one particle

Incoherent ChDR

Stationary Model



Non-Stationary Model



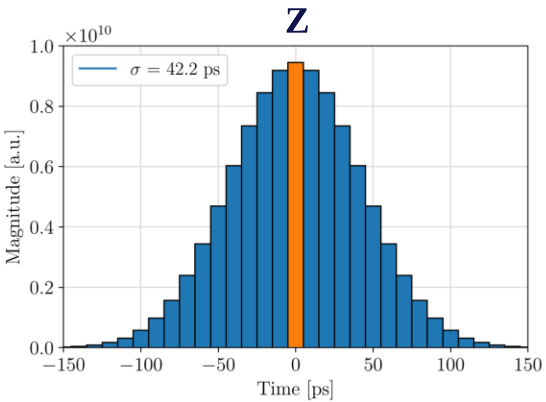
≈ **10^{-5}-10^{-3}** photons per bunch at nominal distance

≈ **10^{3}-10^{6}** photons per bunch at nominal distance

Ways to increase → moving closer + integrating

Incoherent ChDR for Longitudinal profile measurement

Stationary Model



Integrated no. of photons for 100 fs time frame

Impact parameter		15 mm	5 mm
Z	Max. photons/(bunch · minute)	1.47	78.4
W	Max. photons/(bunch · minute)	4.52	155
H	Max. photons/(bunch · minute)	5.94	179
$t\bar{t}$	Max. photons/(bunch · minute)	20.5	583

Photons/bunch @ 5 mm
0.45
0.42
0.43
0.67

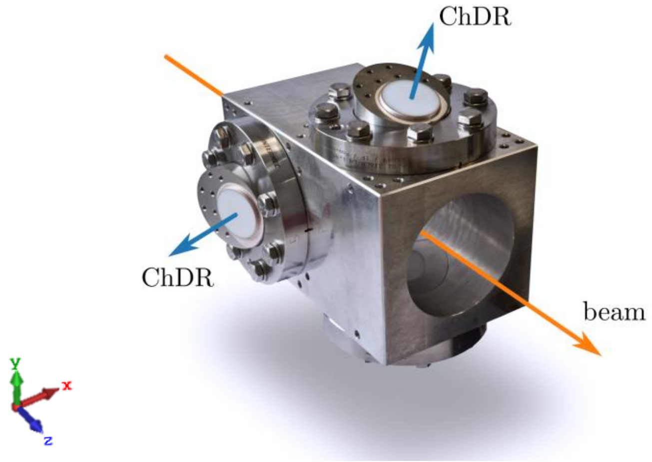
→ Need for ultra-high energy particles to test analytical models

Currently investigating possible tests in SPS North Area

- 40-300 GeV electrons
- up to 10^7 particles per spill

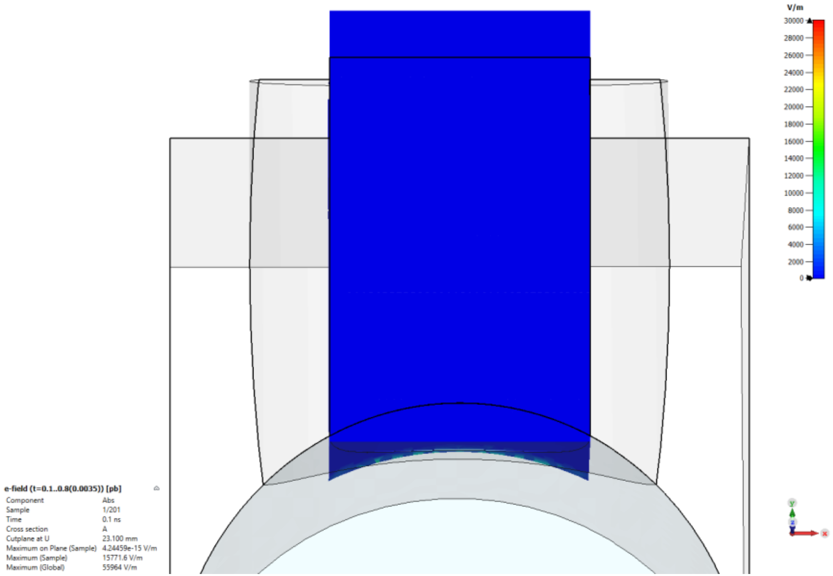
Coherent ChDR

ChDR radiators to be tested at CLEAR



- 36 mm diameter Alumina rods
- brazed to DN 60 flange, vacuum tight
- curvature for Ø 80 mm beam pipe

E-field, transverse plabe (xy-plane tilted)

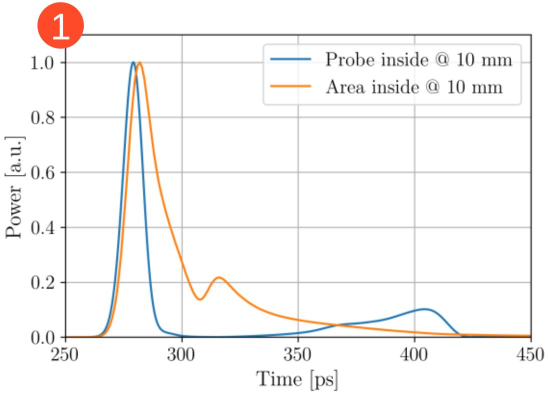


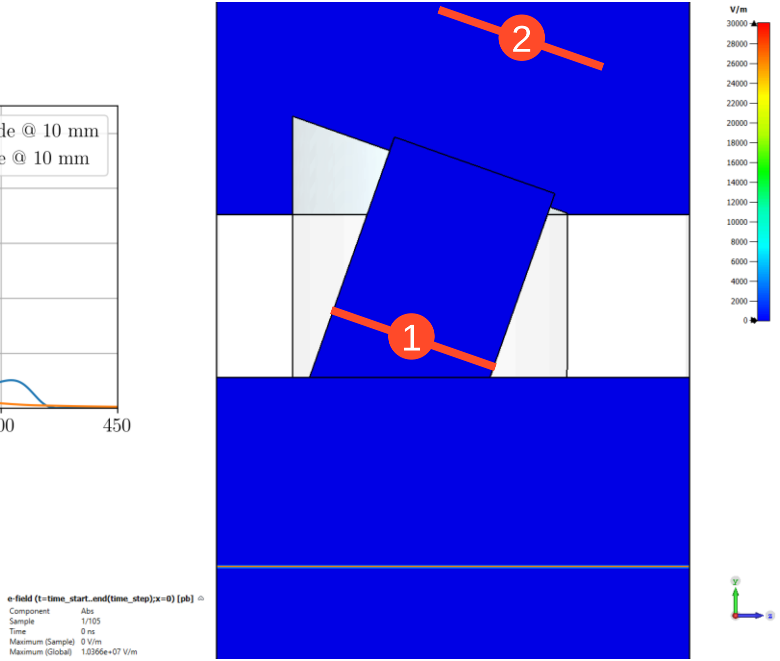
beam

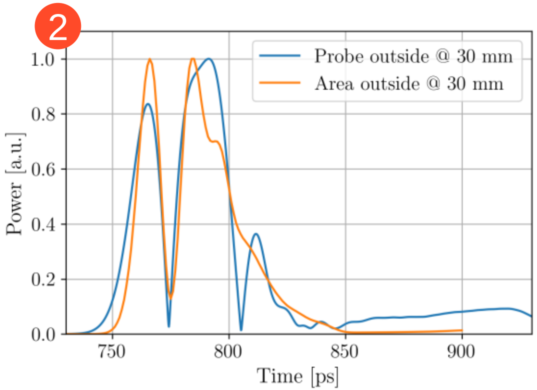
Coherent ChDR

Numerical studies with CST

E-field, Median plane (yz-plane)





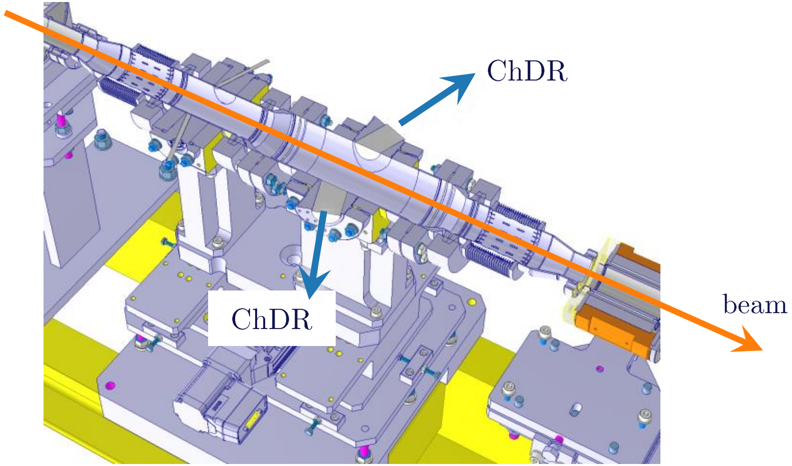


Electron bunch
5 ps Gaussian, 300 pC, 200 MeV

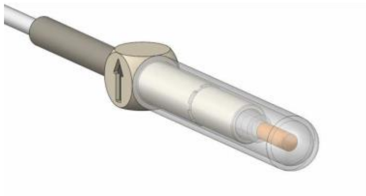
Upcoming experiment

Coherent ChDR experiments at CLEAR

- Coherent ChDR can be tested at low energies
  - CLEAR facility at CERN typically provides 1-5 ps electron bunches with energies up to 220 MeV
  - measure transfer function and benchmark simulations in the low frequency part of the spectrum
- Vacuum chamber with ChDR inlets to be expected during June
  - foreseen installation during summer shut down of CLEAR
- Electro-optical probing
  - Transverse and longitudinal electric field modulus and polarization



Beam line integration at CLEAR



EO-probe by Kapteos (www.kapteos.com)

Summary

ChDR possible candidate for bunch length diagnostics at FCC

Incoherent ChDR

- ultra-high energy particles needed for validation of incoherent ChDR
- investigating possible testing at SPS North Area

Coherent ChDR

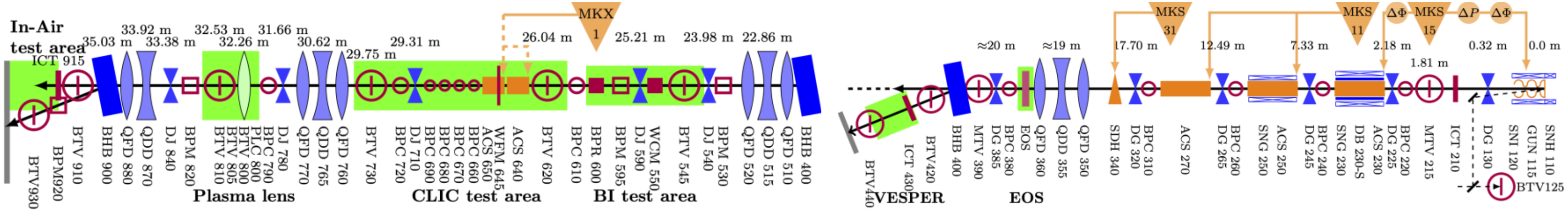
- CLEAR provides suitable parameters to test with short bunches at low energies
- all vacuum components ready for installation in the coming weeks
- experiments scheduled after summer

→ Experimental validation/benchmarking of different models necessary

FCC

Thank you
for your attention.

CLEAR



Beam parameter (end of linac)	Value range
Energy	60 - 220 MeV
Bunch charge	0.01 - 0.5 nC
Normalized emittances	3 um for 0.05 nC per bunch 20 um for 0.4 nC per bunch (in both planes)
Bunch length	~100 um -1.2 mm
Relative energy spread	< 0.2 % rms (< 1 MeV FWHM)
Repetition rate	1 - 5 Hz (25 Hz with upgrade)
Number of micro-bunches in train	1 and more than 100
Micro-bunch spacing	1.5 GHz