
CERN

Beam instrumentation studies for future linear colliders

International Workshop on Future Linear Colliders

Sendai, 28 October – 1 November 2019

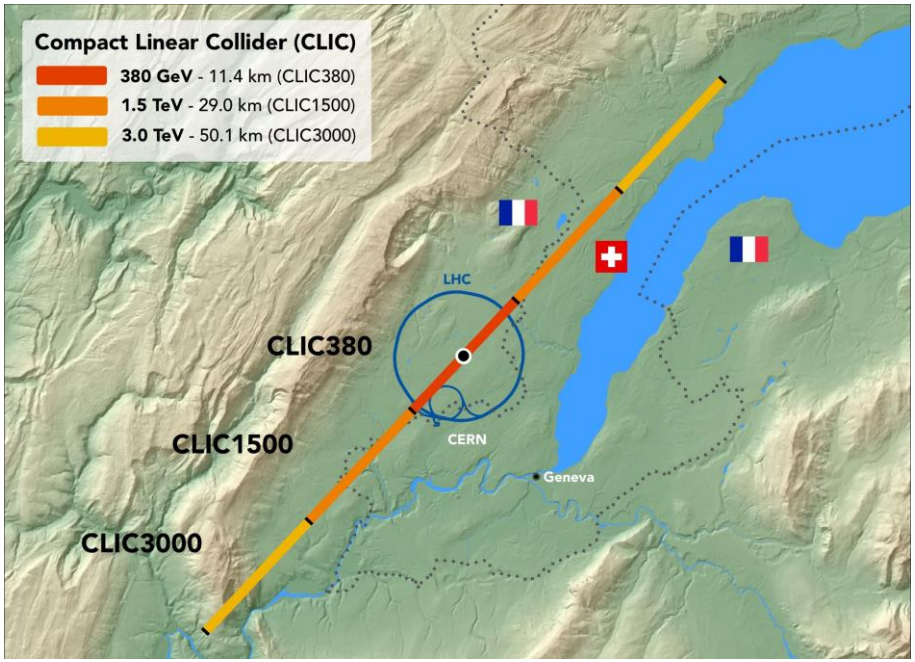
S. Mazzoni, CERN

Outline

- Transverse profile measurement for LCs: studies at KEK & CERN
- Recent development with (C)ChDR
- Several people & labs involved:

D. Alves, M. Bergamaschi, A. Curcio, R.O. Jones, R. Kieffer, K Lasocha*, T. Lefèvre S. Mazzoni, N. Mounet, E. Senes, A. Schloegelhofer, R. Yang, **CERN**, Geneva, Switzerland
K. Fedorov, P. Karataev, D. Harryman, K. Lekomtsev **JAI, Royal Holloway University of London**, Egham, UK
V.V. Bleko, S.Y. Gogolev, A.S. Konkov, J.S. Markova, A.P. Potylitsyn, D.A. Shkitov **Tomsk Polytechnic University**, Tomsk, Russia
M. Apollonio, L. Bobb, **Diamond Light Source**, Oxfordshire, UK
A. Aryshev, N. Terunuma, **KEK**, Tsukuba, Japan
J. Gardelle, **CEA**, Le Barp, France
* also Jagiellonian University, Krakow, Poland


Beam instrumentation challenges in LCs



- Emittance measurement represents a challenge for LCs:
  - Resolution (transverse profile) as small as 1 μm (CLIC main linac)
  - Non invasive measurement
  - Scale up: 800 in Drive Beam, 148 in Main Beam (CLIC 3 TeV)
- Bunch length: σ_z = 44 μm, challenge if number of instruments is high

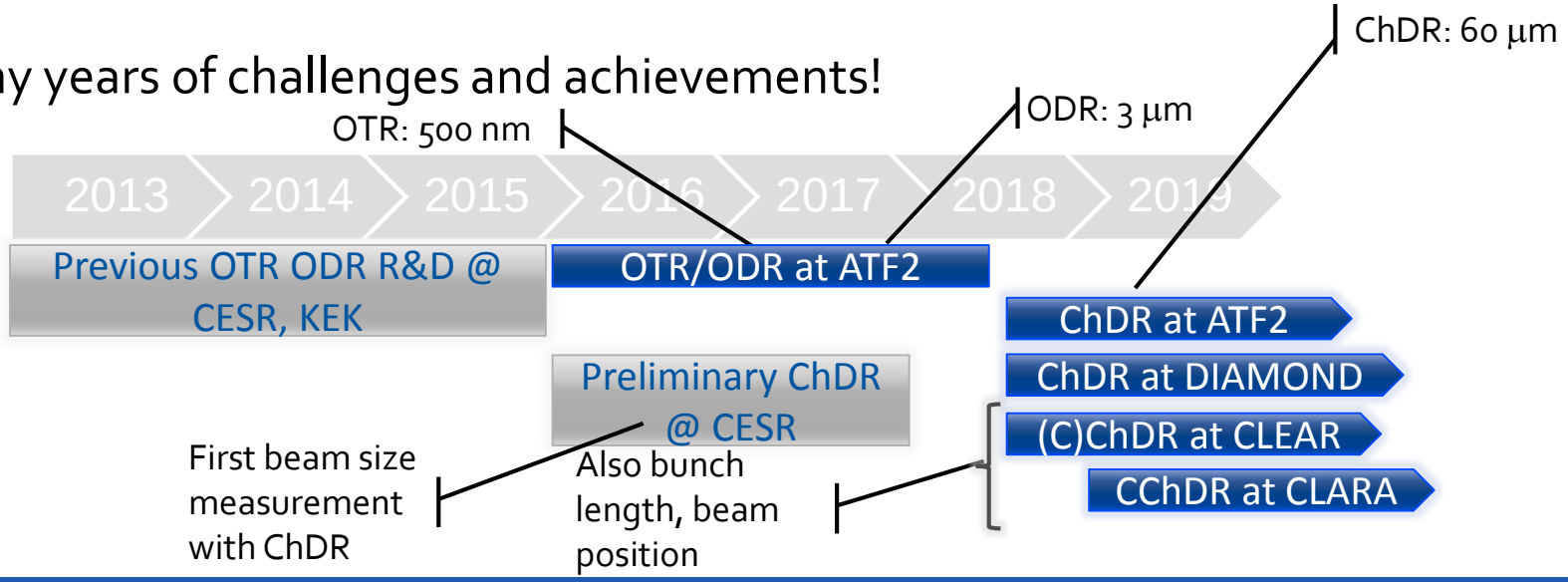
Measuring emittance in LC

- Ultimate goal of emittance monitoring in a LC:
  - A high –resolution (sub μm) technique (can be invasive) for commissioning / beam setup with pilot bunches.
    - **Optical Transition Radiation**
  - A non-invasive technique (lower resolution tolerated) for full intensity beam
    - **Optical Diffraction Radiation**
    - **Cherenkov Diffraction Radiation**

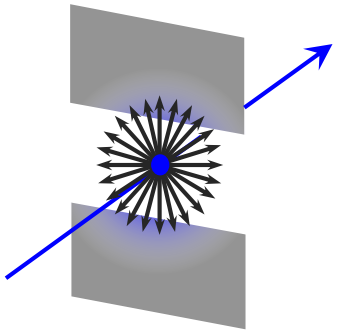
- Many years of challenges…

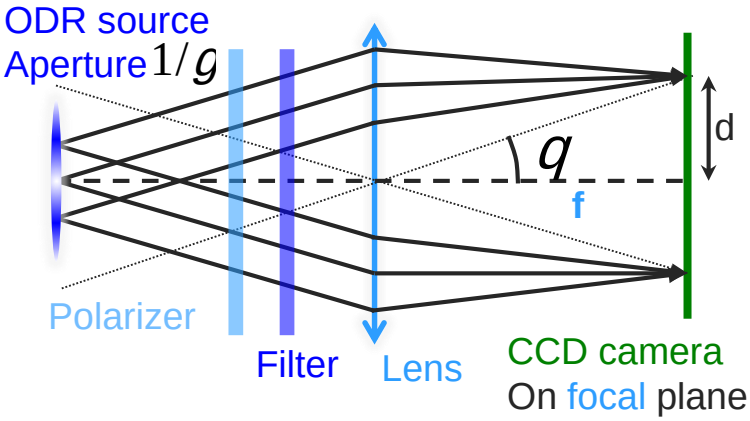
Measuring emittance in LC

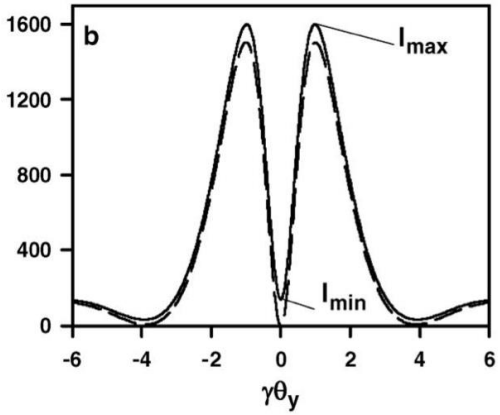
- Ultimate goal of emittance monitoring in a LC:
  - A high –resolution (sub μm) technique (can be invasive) for commissioning / beam setup with pilot bunches.
    - **Optical Transition Radiation**
  - A non-invasive technique (lower resolution tolerated) for full intensity beam
    - **Optical Diffraction Radiation**
    - **Cherenkov Diffraction Radiation**
- Many years of challenges and achievements!



Optical Diffraction Radiation

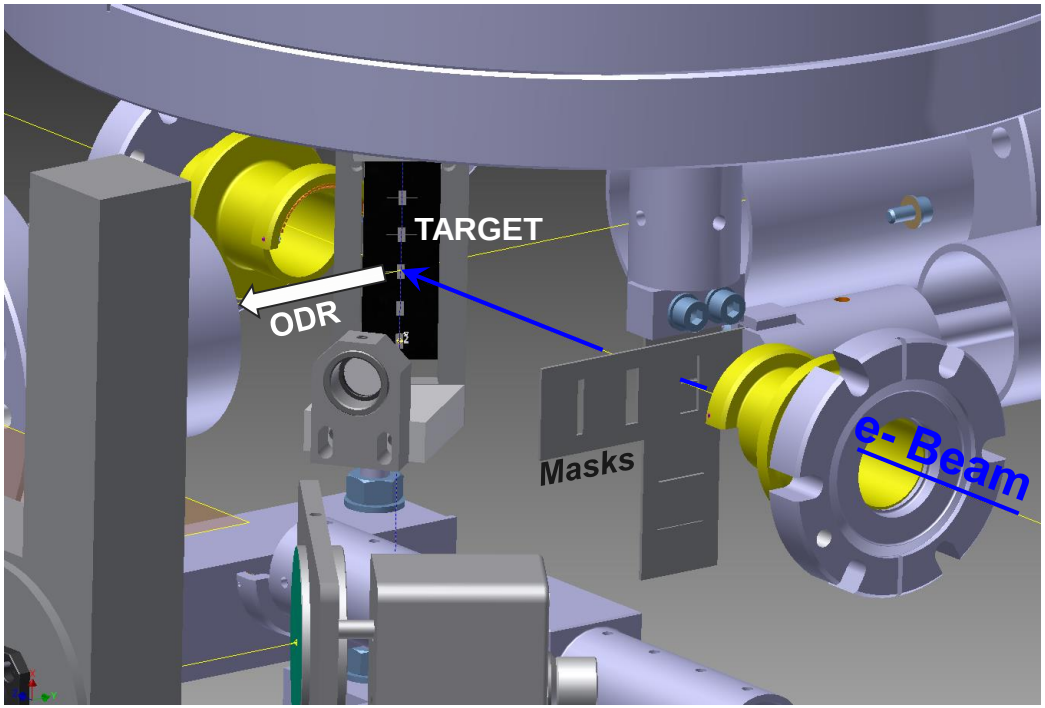






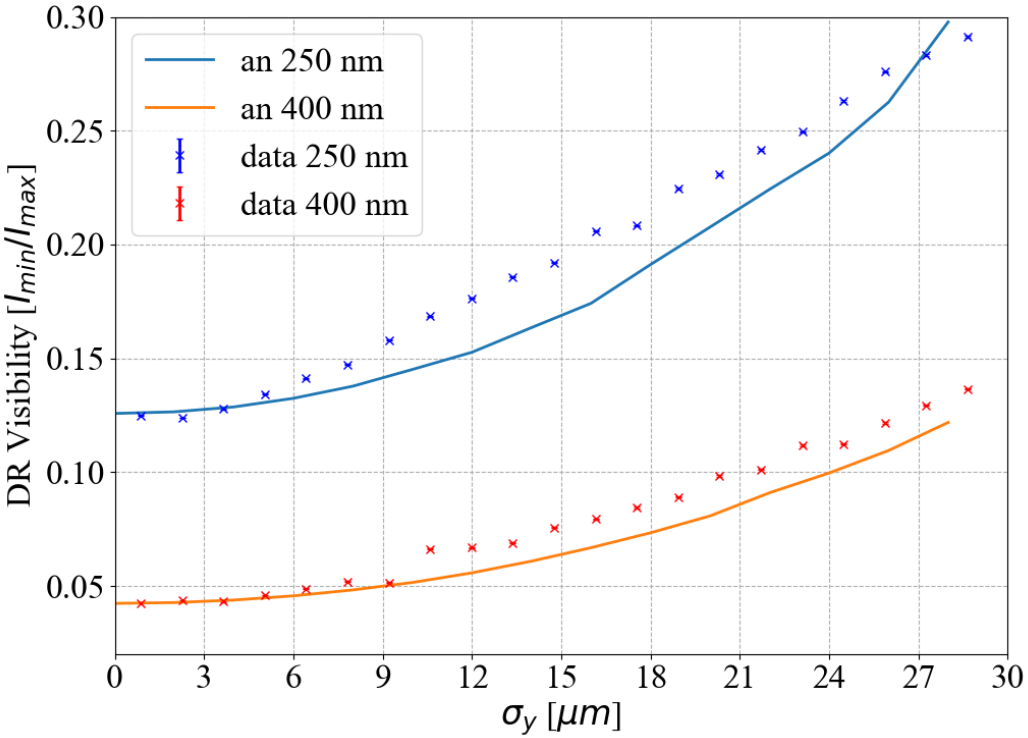
- Beam goes through a narrow horizontal slit (for vertical beam size). EM field interacts with edges, broadband radiation is produced
- The **beam size** is extracted from the **visibility I_{min}/I_{max}** of the projected vertical component of the DR **angular distribution**
- Challenges: alignment, suppression of SR and optical noise

ODR setup at KEK



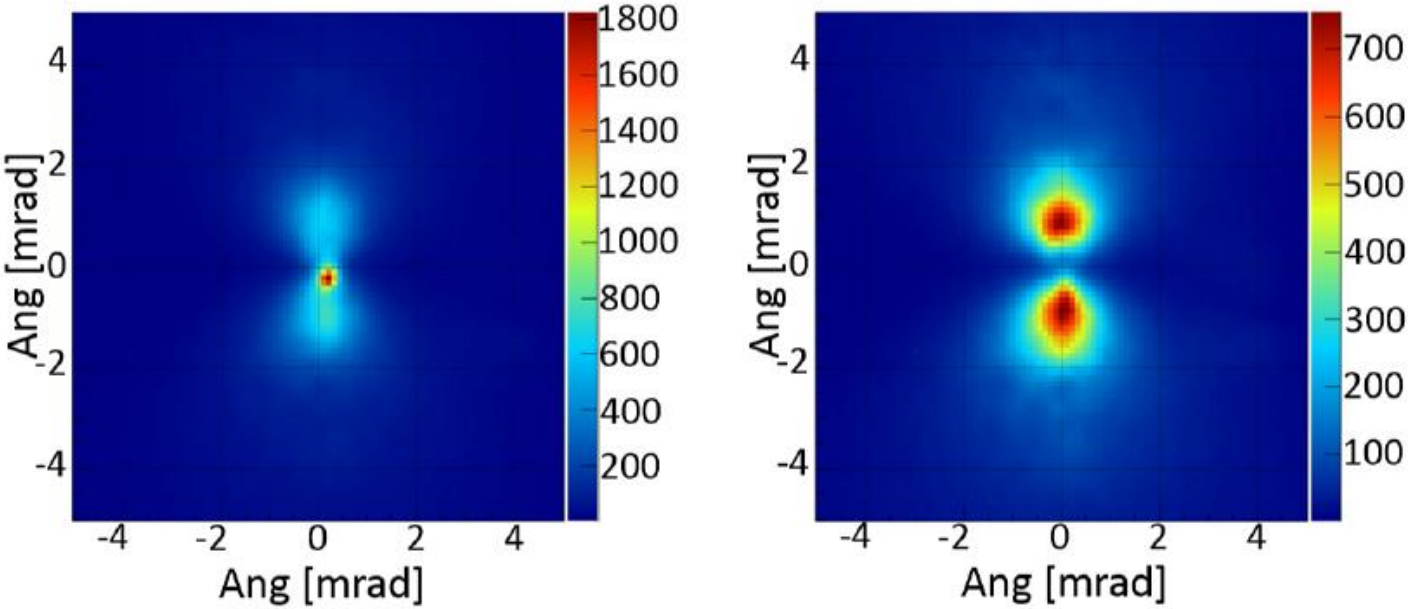
- 4 slits (201 to 50 μm) & 4 mask to reduce SR background (interference)
- Simultaneous imaging and angular acquisition (intensified camera)
- Acquisition at various λ, down to 250 nm for improved resolution

ODR@KEK results



- Better sensitivity in the UV (250 nm) than visible (400 nm)
- Sensitivity to **4 μm** achieved at 250 nm
- Relatively simple and inexpensive setup > scale up OK
- Ease of use in real operational scenario to be improved / studied.

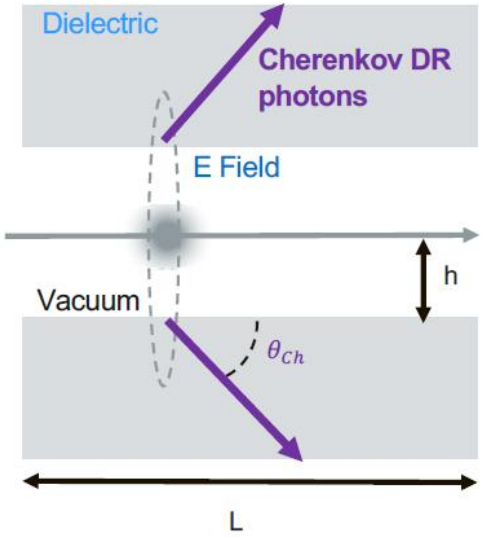
From ODR to ChDR



Main challenge of ODR is suppression of Synchrotron Radiation generated upstream:

both have $1/\gamma$ angular spread

Cherenkov Diffraction Radiation (ChDR)



- The electric field of ultra-relativistic charges particles passing in the vicinity of a dielectric radiator produces photons through the Cherenkov mechanism (surface polarization currents)
- Key features:
  - **Photons emitted *along* the target**
  - Large emission angle $\cos\theta_{ch} = {}^{1}/_{\beta n}$
  - Different spectral properties wrt Cherenkov (high frequency cutoff)

Cherenkov Diffraction Radiation (ChDR)

For a cylindrical geometry

Cherenkov emission

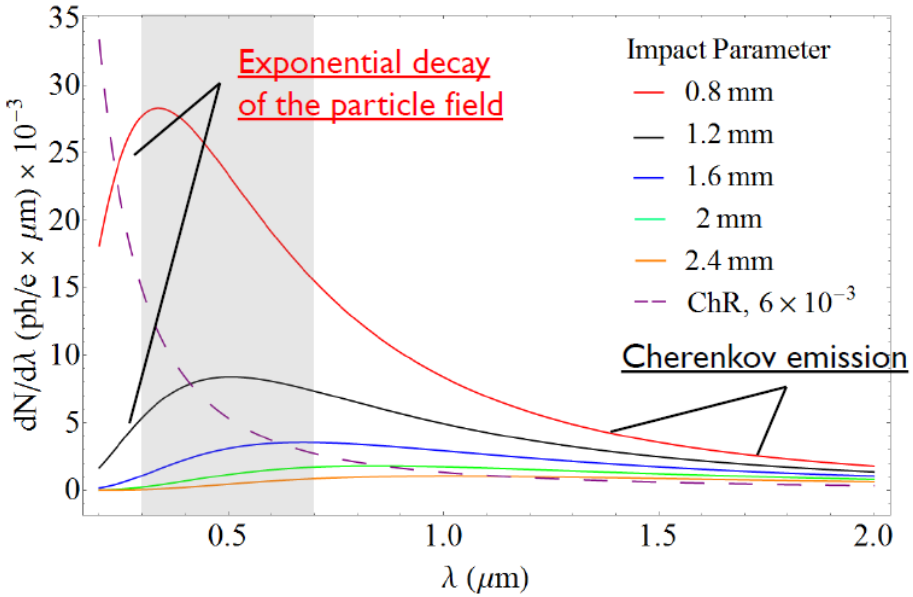
$$\frac{d^2N_{Dcph}}{d\Omega d\lambda} = \frac{\alpha n}{\lambda}\left(\frac{L}{\lambda}\right)^2 \left(\frac{\sin\left(\frac{\pi L}{\beta\lambda}(1-\beta n\cos\theta)\right)}{\frac{\pi L}{\beta\lambda}(1-\beta n\cos\theta)} \right) sin^2\theta \cdot e^{\left(-4\pi\frac{h}{\gamma\beta\lambda}\right)}$$

Exponential decay of the particle field

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

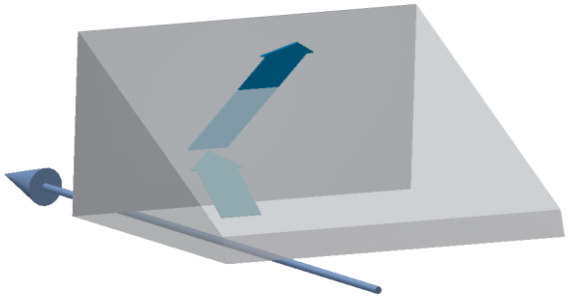
- The electric field of ultra-relativistic charges particles passing in the vicinity of a dielectric radiator produces photons through the Cherenkov mechanism (surface polarization currents)
- Key features:
  - Photons emitted *along* the target
  - **Large emission angle $cos\,\theta_{ch} = {}^{1}/_{\beta n}$**
  - Different spectral properties wrt Cherenkov (high frequency cutoff)

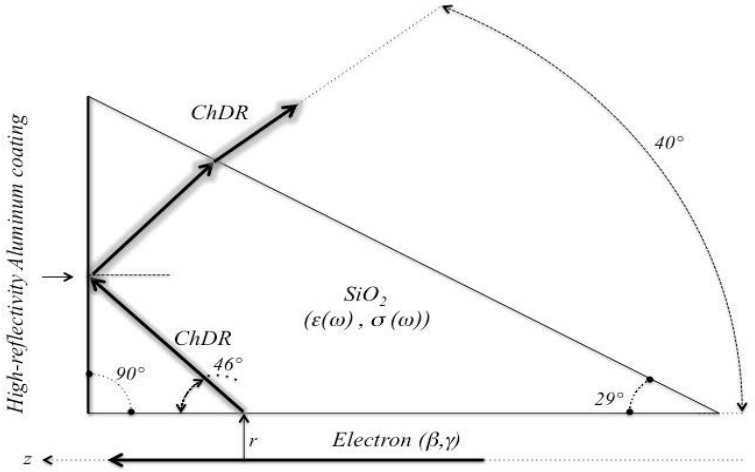
Cherenkov Diffraction Radiation (ChDR)

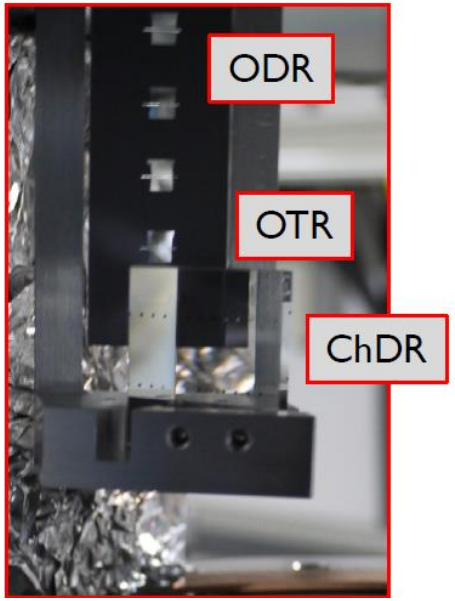


- The electric field of ultra-relativistic charges particles passing in the vicinity of a dielectric radiator produces photons through the Cherenkov mechanism (surface polarization currents)
- Key features:
  - Photons emitted *along* the target
  - Large emission angle $cos\,\theta_{ch} = {}^{1}/_{\beta n}$
  - **Different spectral properties wrt Cherenkov (high frequency cutoff)**

ChDR studies at KEK



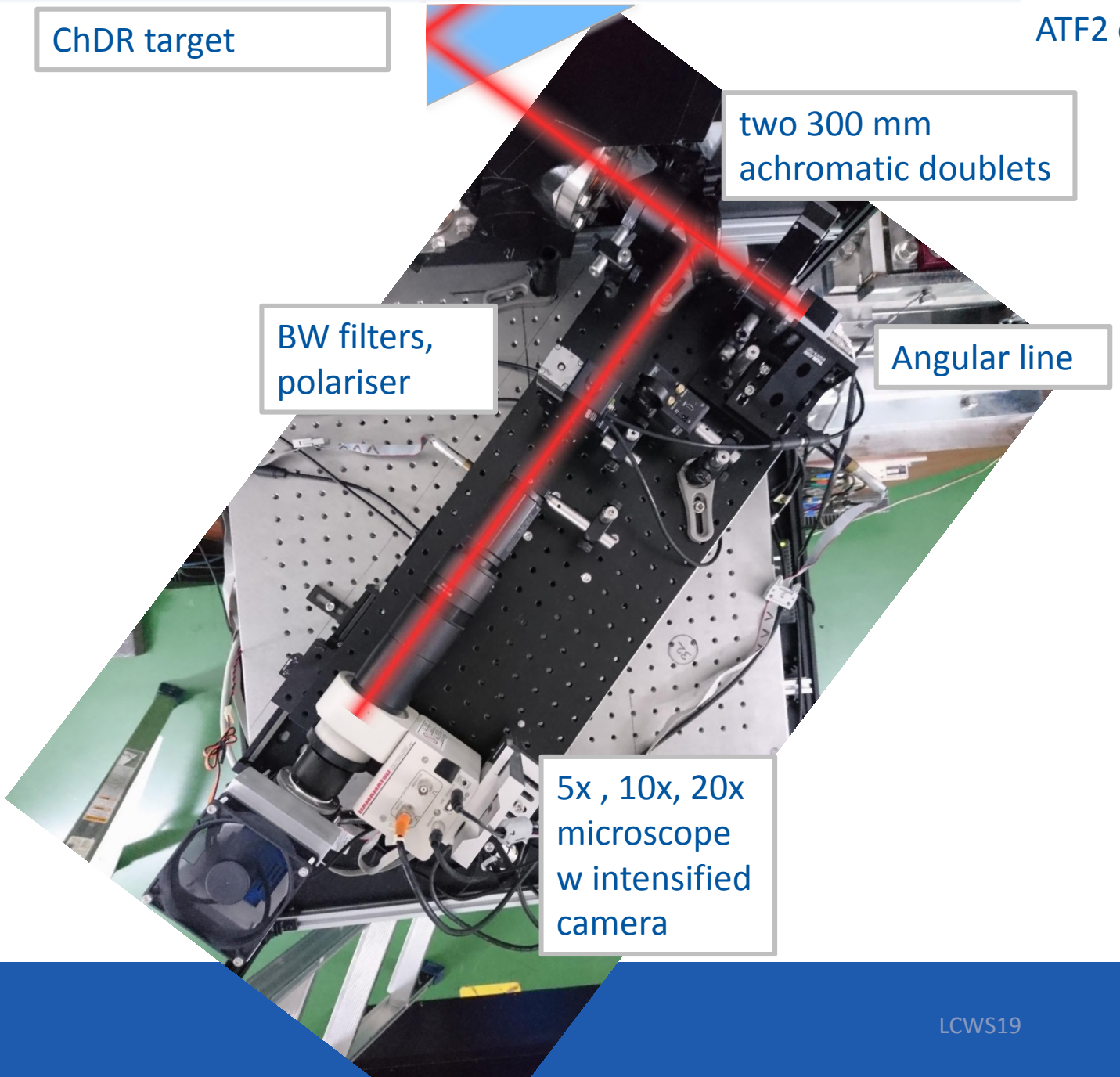




- In 2018 we modified the ODR setup and mounted a ChDR prismatic target
- IR-VIS-UV setup to
  - study spatial resolution of ChDR (small beams)
  - Angular distribution (test of theoretical models)
- OTR used for cross-calibration

ChDR target

ATF2 e- beam

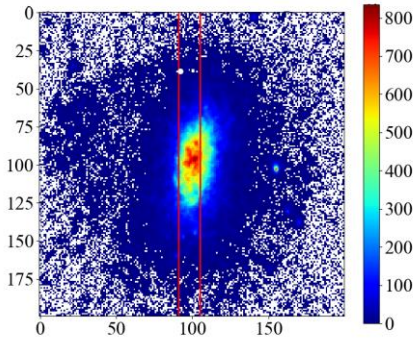


ChDR @ KEK: results…so far

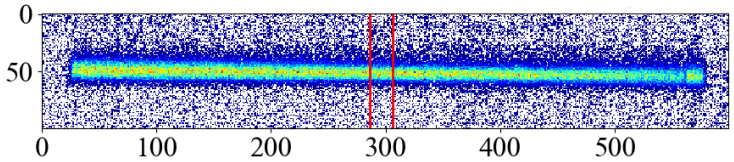
OTR, H pol

H rms: 30 ± 2 µm

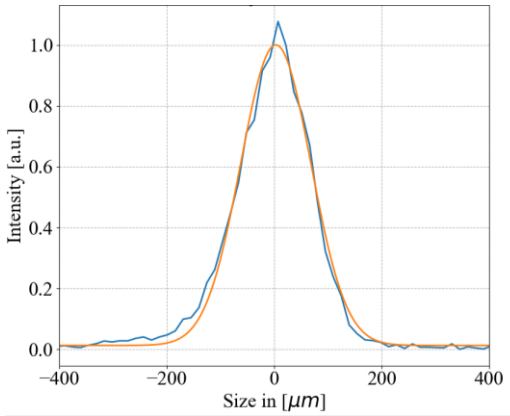
OTR V rms 67 ± 2 µm



ChDR, H pol

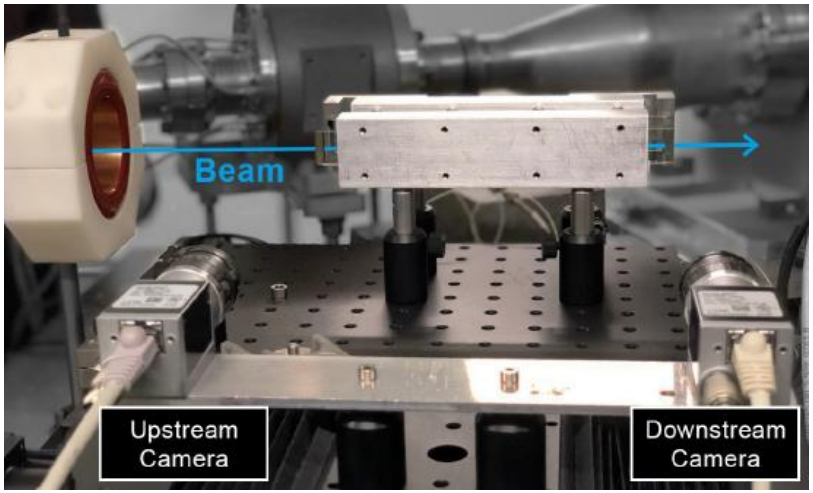


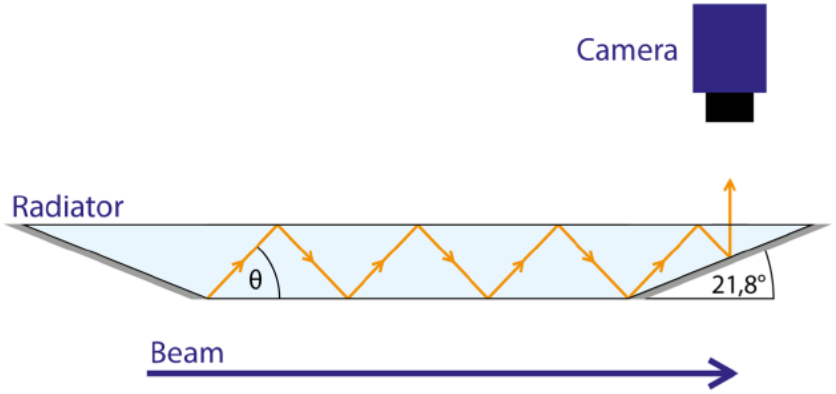
ChDR V rms 65±2 µm



- Experiments ongoing: June 18, Nov 18, March 19, Nov 19,…
- 60 um beam correctly measured at 700 nm (40 nm BW).
- Smaller beams down to 30 um also observed. LSF still to be assessed
- Ongoing tests also at Diamond light source (UK)

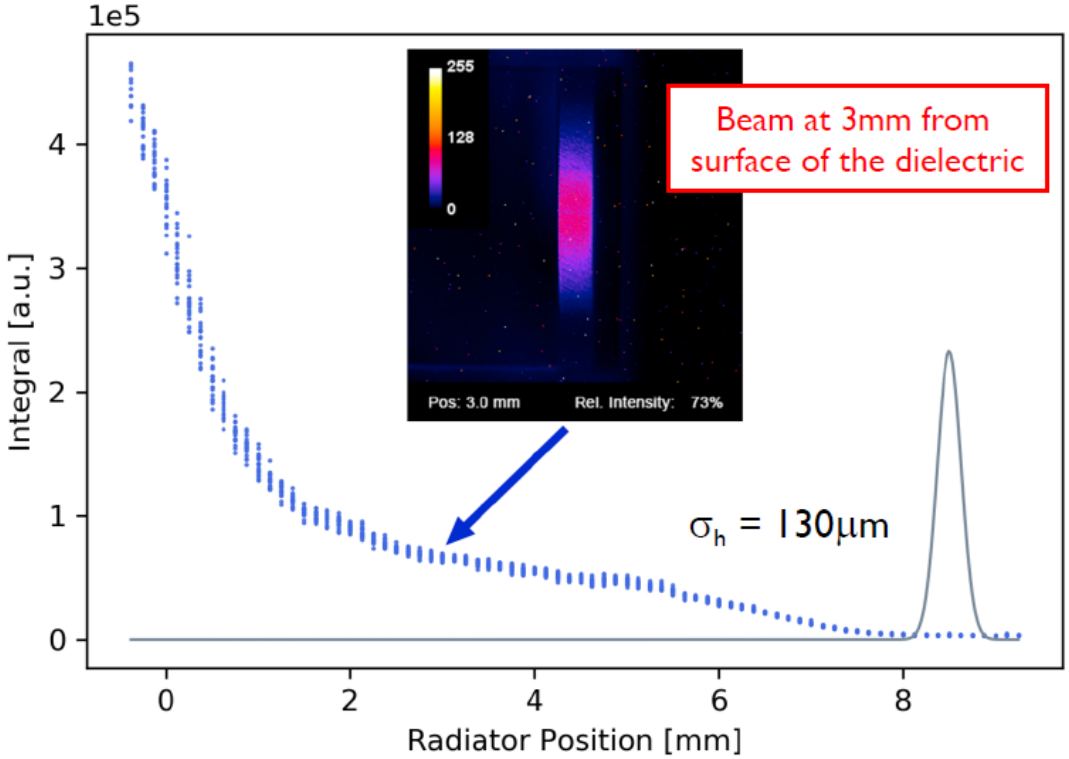
ChDR at CLEAR





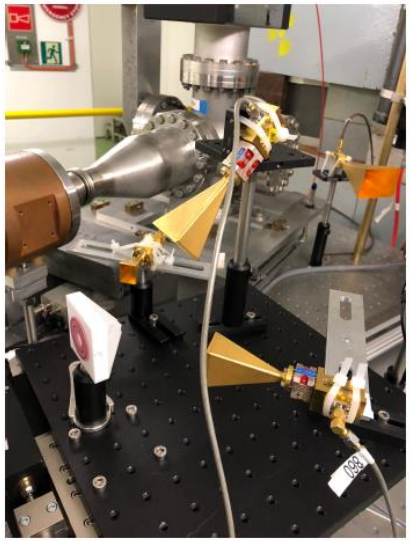
- CLEAR: 200 MeV electron test facility at CERN
- Test of ChDR in longer dielectrics to increase sensitivity
- Signal produced in 20 cm long fused silica strips in air

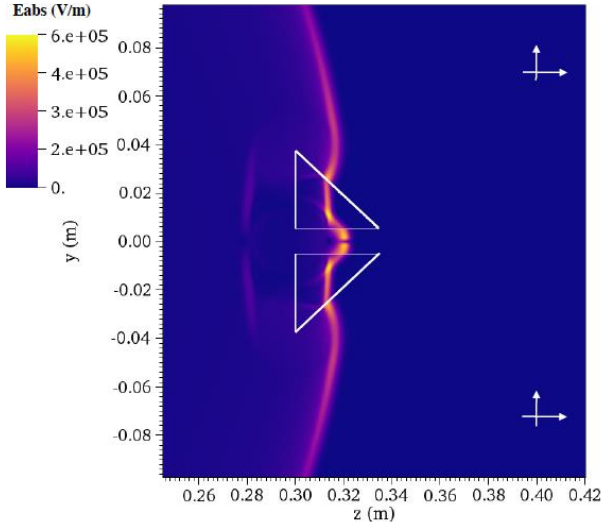
ChDR @ CLEAR



- Impact parameter scan with 200 MeV, 500 pC bunch
- Measuring at 600 +/- 10 nm: **signal present at h> 7 mm**
- Work in progress…

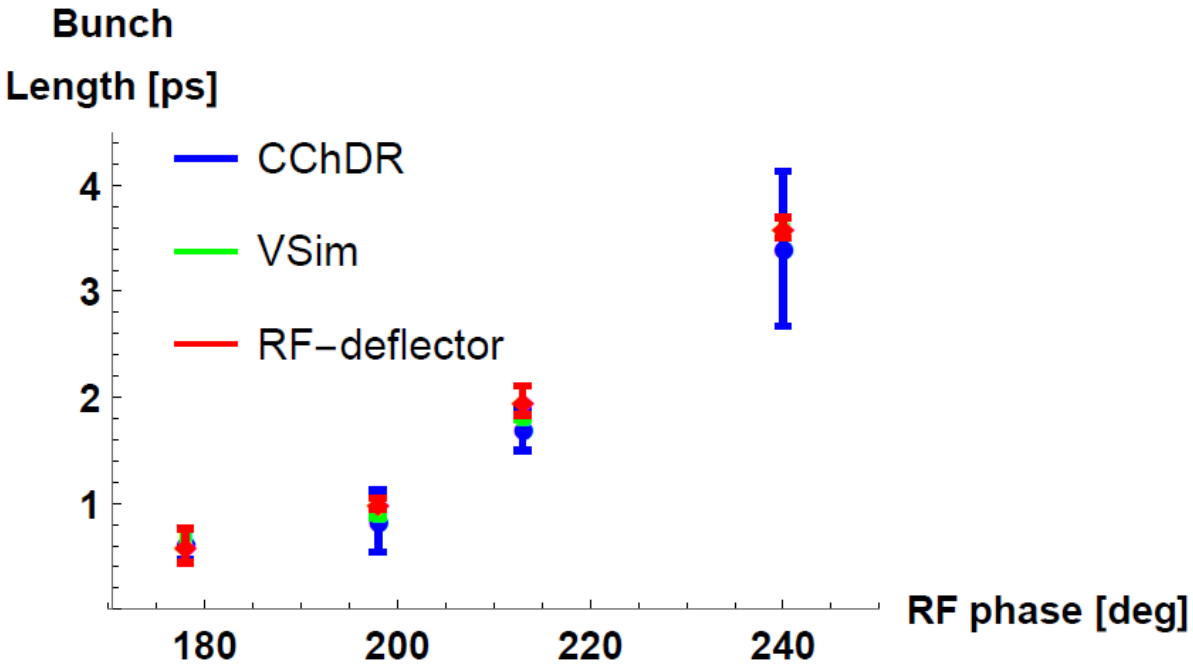
Coherent ChDR





- Testing coherent emission (as $\lambda \cong$ BL) of ChDR for bunch length and beam position measurement
- Prototypes are being tested since 2018 in the in-air section at CLEAR. CChDR generated in Teflon, detected by Schottky diodes at 20- 110 GHz
- CChDR propagation simulated with Vsim

Coherent ChDR

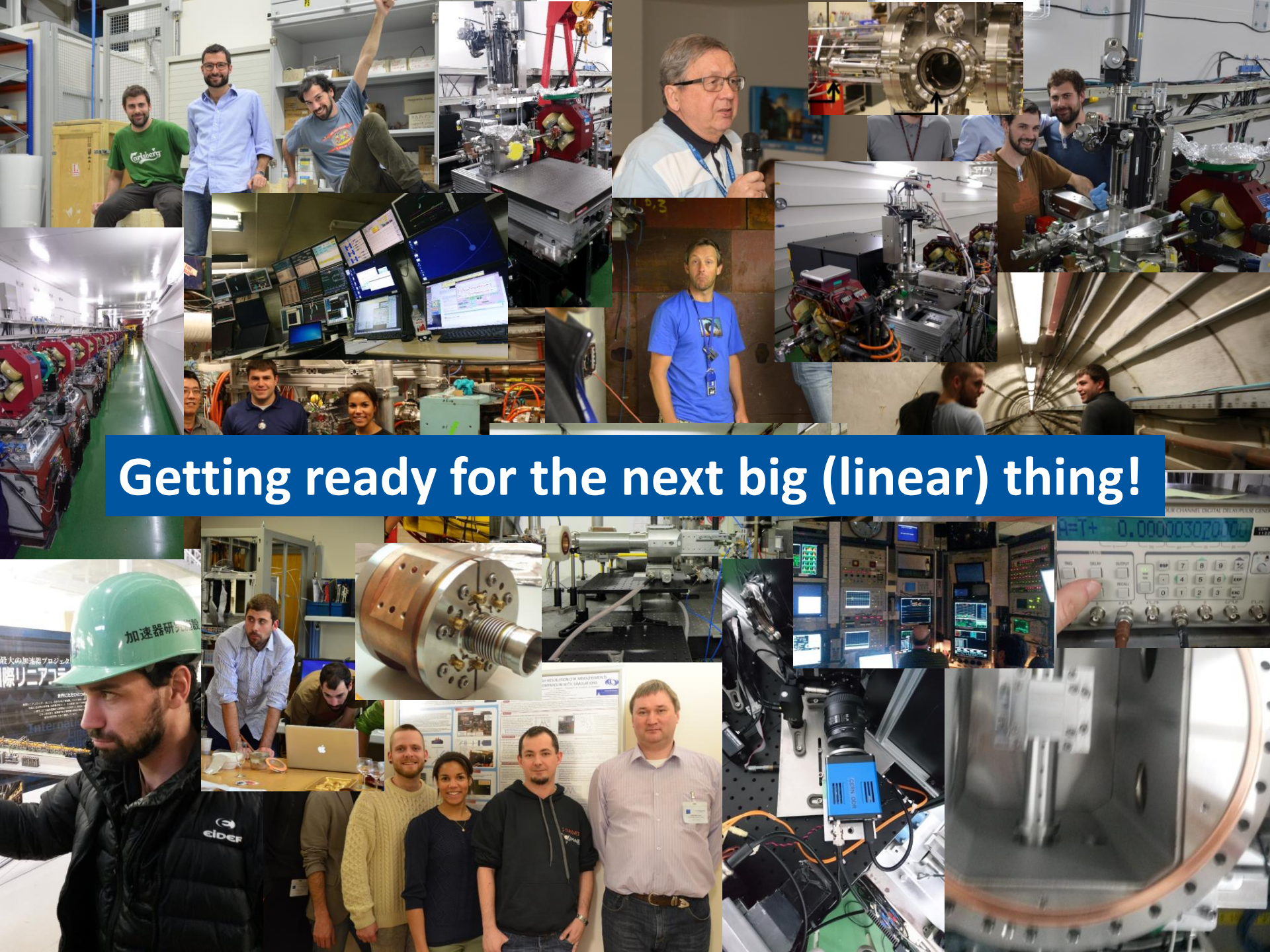


- Good agreement with benchmark (RF deflector) for Teflon pyramid geometry.
- Very recently: promising results on beam position (data analysis in progress).
- Studies ongoing also at CLARA (UK)

Conclusions

- Well articulated R&D programme on beam instrumentation for Linear colliders involving international partners
- More established studies reached targets:
  - **500 nm** resolution for OTR
  - **4 μm** resolution non invasive (ODR)

  and the know-how on how to build and operate these instruments
- Since 2016 we started R&D on ChDR:
  - **60 μm (sigma)** beam measured, possibly smaller, resolution limit not yet determined, presently under investigation. Angular, LSF in progress
  - Demonstrated **sub-ps** bunch length measurement with Coherent ChDR, beam position in progress


Getting ready for the next big (linear) thing!


CERN