Optical Cherenkov Diffraction Radiation as a Tool for Non-invasive Charged Particle Beam Diagnostics

P. Karataev, M. Bergamaschi, and K. Lekomtsev
John Adams Institute for Accelerator Science, UK

M. Billing, J. Conway, M. Forster,J. Shanks, S. Wang, Y. Padilla Fuentes and L. Ying
CesrTA, Cornell University, USA

R. O. Jones, R. Kieffer, T. Lefevre, S. Mazzoni, and F.Roncarolo,
European Organisation for Nuclear Research, Switzerland

V.V. Bleko, A. S. Konkov, and A. P. Potylitsyn,
National Research Tomsk Polytechnic University, Russia

L. Bobb
Diamond Light Source Ltd., UK

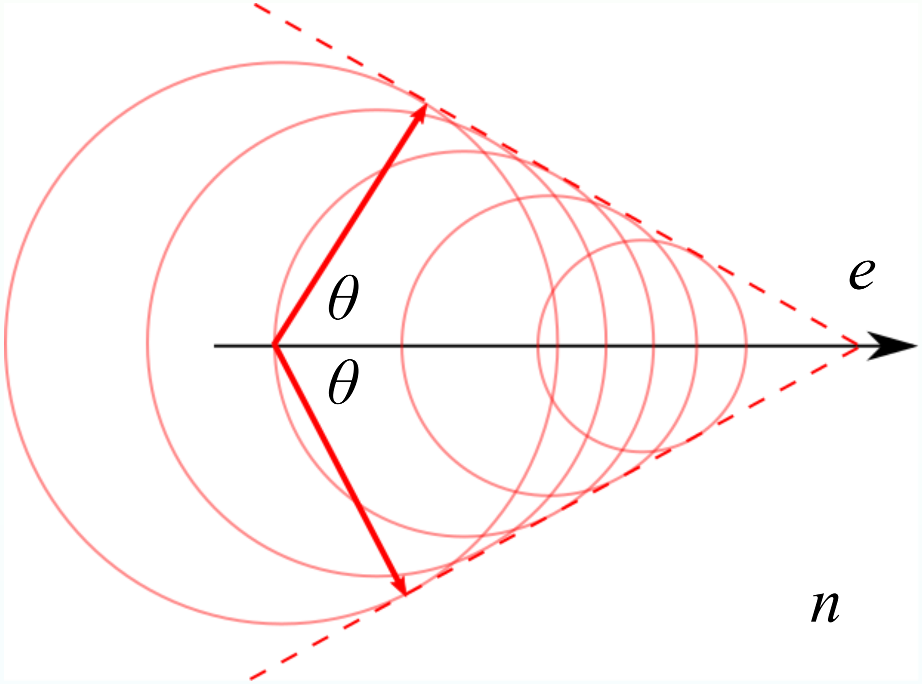
A. Aryshev and N. Terunuma
KEK: High Energy Accelerator Research Organization, Japan

Talk Outline

- **Basic concept**
- **Advantages and Motivation**
  - Theoretical expectation
- **Experiment at Cornell CesrTA facility**
  - Observation of Cherenkov Diffraction Radiation
  - Beam size
  - Beam direction
  - Electron-positron beam collision control
- **Experiment at KEK-ATF2 extraction line**
  - Beam size measurements
- **Conclusion**
  - Main achievements
  - Future plans and prospects

Basic Concept

- Cherenkov radiation was discovered in 1958 by Pavel Cherenkov;
- It appears when a fast charged particle moves in a medium with velocity higher than the speed of light



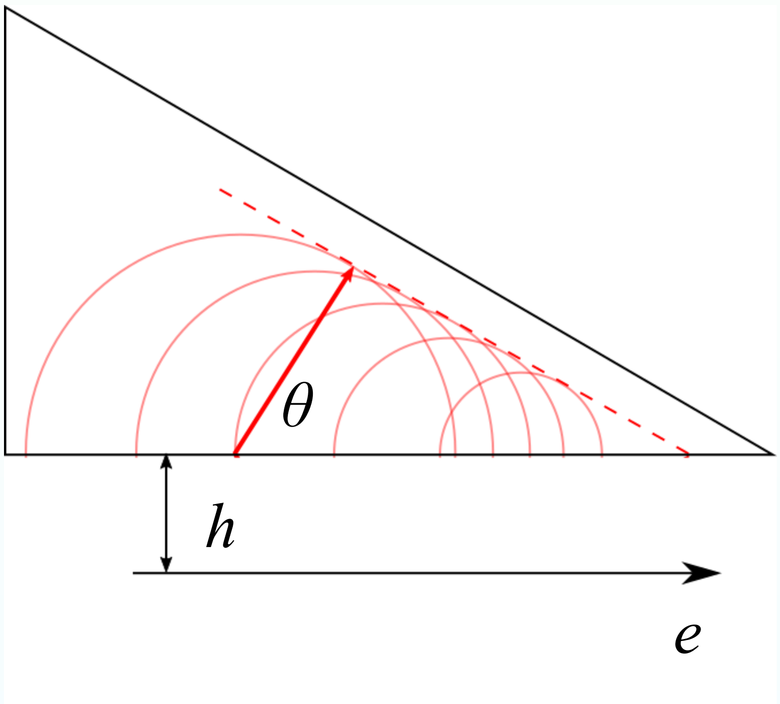
The angle θ is defined by a simple relation

$$\cos(\theta) = \frac{1}{\beta n}$$

where β is the speed of charged particle in units of the speed of light and n is the refractive index

Basic Concept – Cherenkov Diffraction Radiation

- To generate Cherenkov radiation the particle does not have to move through the material;
- In relativistic case the charged particle field can reach macroscopic dimensions;
- Passing in the vicinity of a medium a fast charge particle will polarize the surface of it generating Cherenkov radiation;



However:

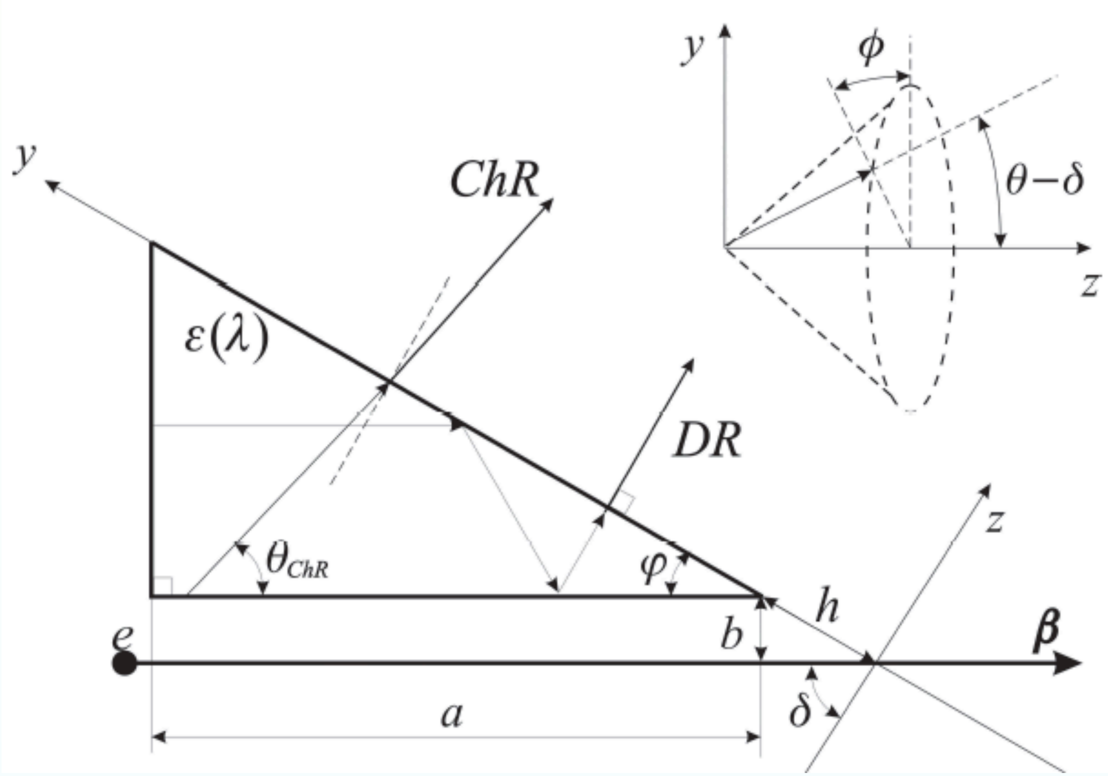
- **The target does not surround the particle beam anymore. It introduces a new angular distribution, different from classical ChR;**
- **Dependence on impact parameter adds additional wavelength dependence.**

Advantages and motivation

- **Advantages:**
  - Non-invasive way to generate;
  - High directivity enabling to separate the ChDR from co-propagating synchrotron radiation background;
  - High intensity, which can be adjusted by increasing the length of the radiator
- **Motivation:**
  - Development of diagnostics instrument:
    - Beam size, emittance, position, direction and arrival time.

Theoretical expectations

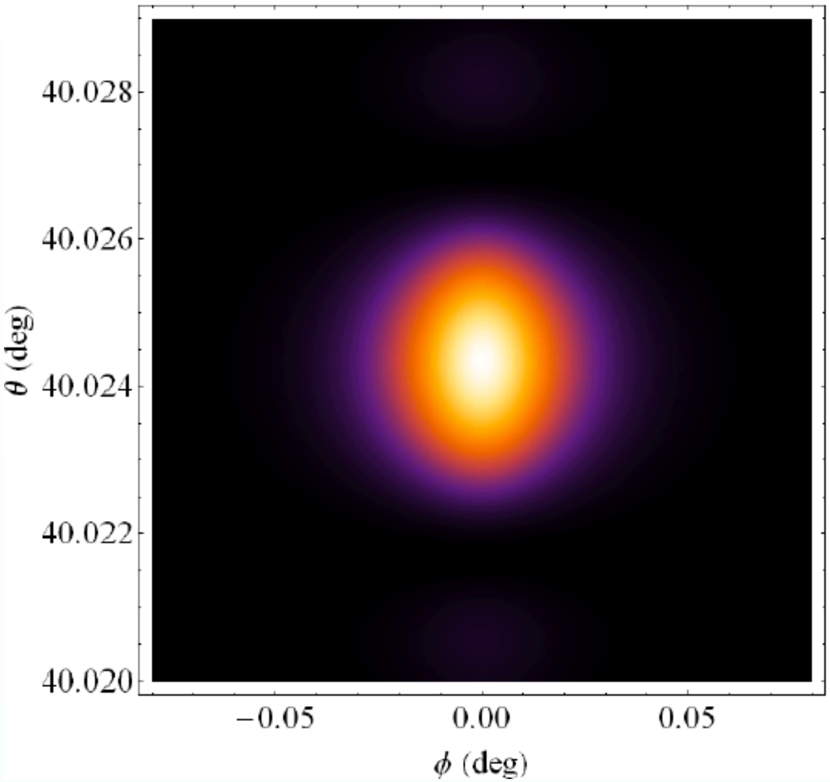
- **Polarization Current Approach (PCA) references:**
  - [1] D.V. Karlovets and A.P. Potylitsyn, JETP Lett. 90, 326 (2009).
  - [3] M.V. Shevelev and A.S. Konkov, J. Exp. Theor. Phys. 118, 501 (2014).



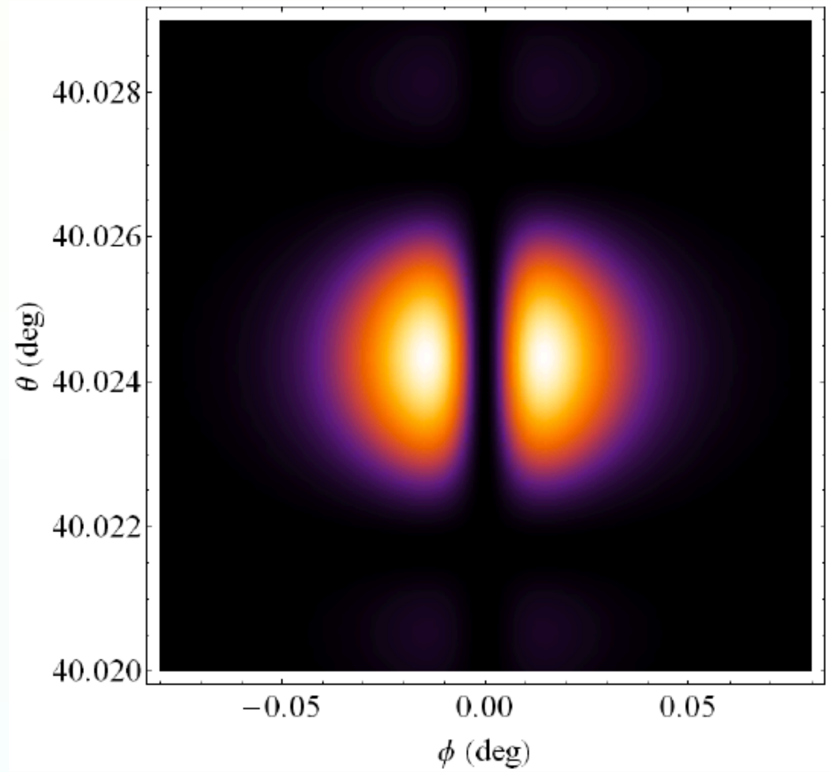
Calculation parameters:
- $a = 18.5$ mm
- $\varphi = 30^0$
- $E_e = 5.1$ GeV
- $\varepsilon(\lambda) = 2.1$

Theoretical expectations

- **Angular distribution:**



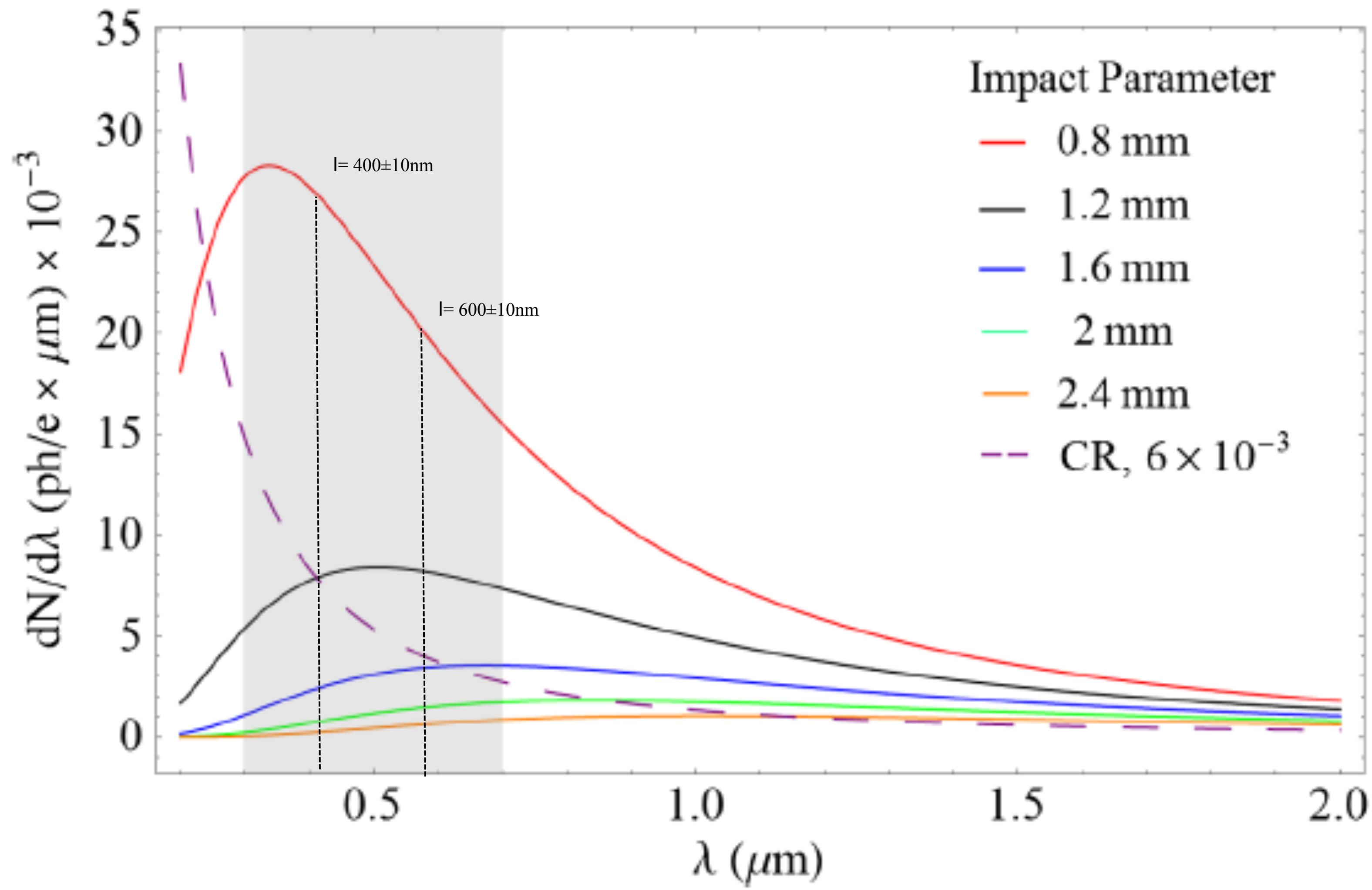
Vertical polarization component



Horizontal polarization component

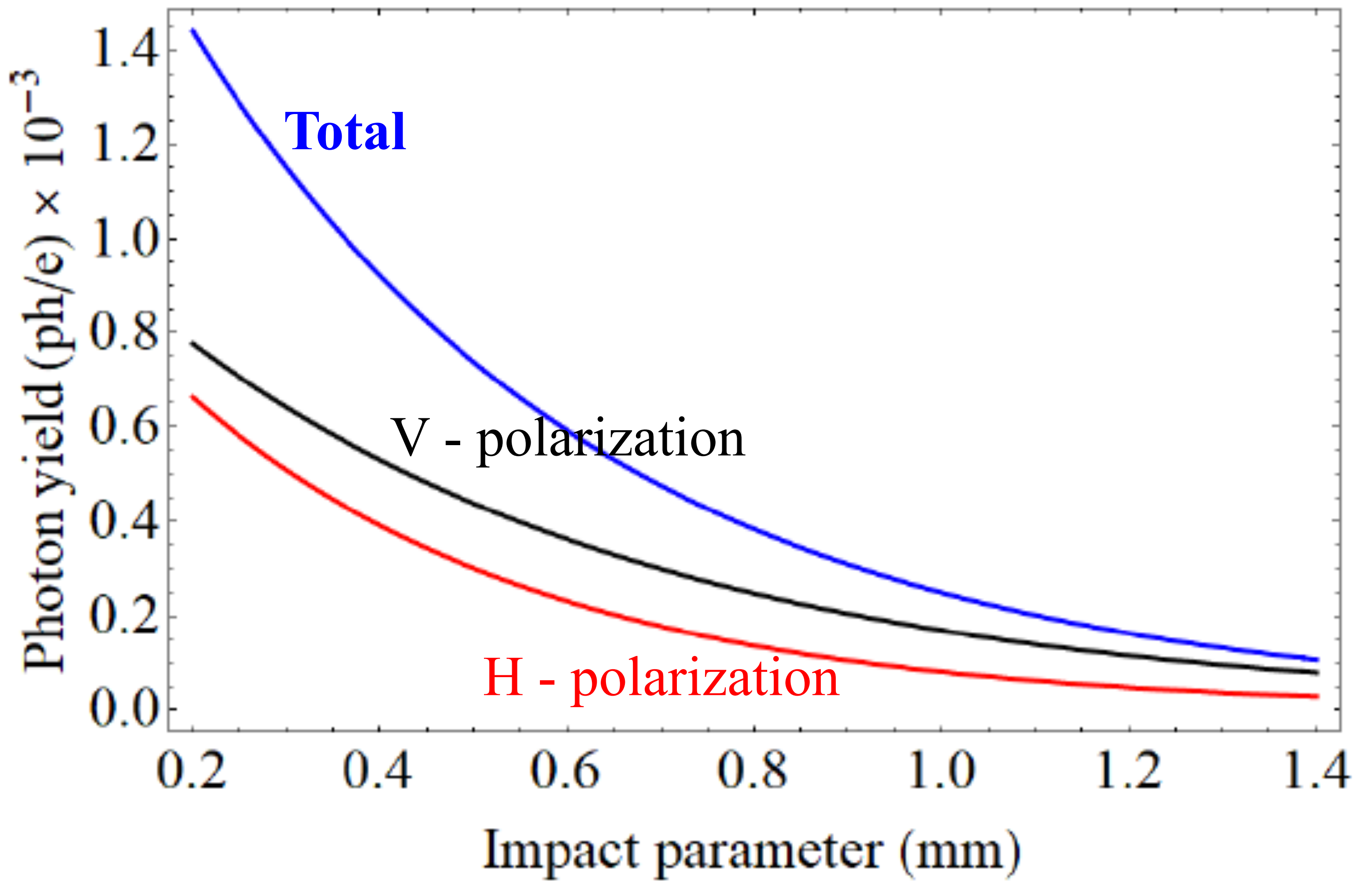
Theoretical expectations

- **Spectrum:**



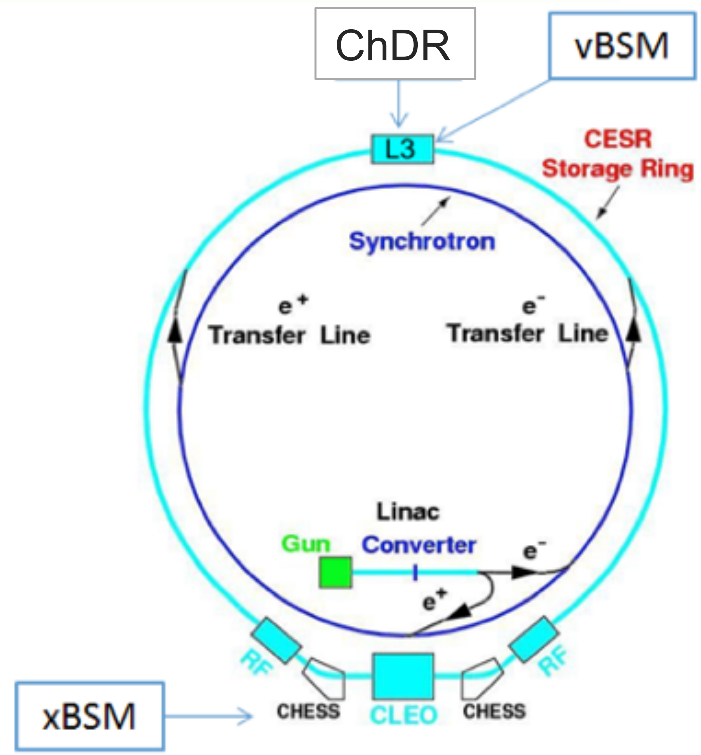
Theoretical expectations

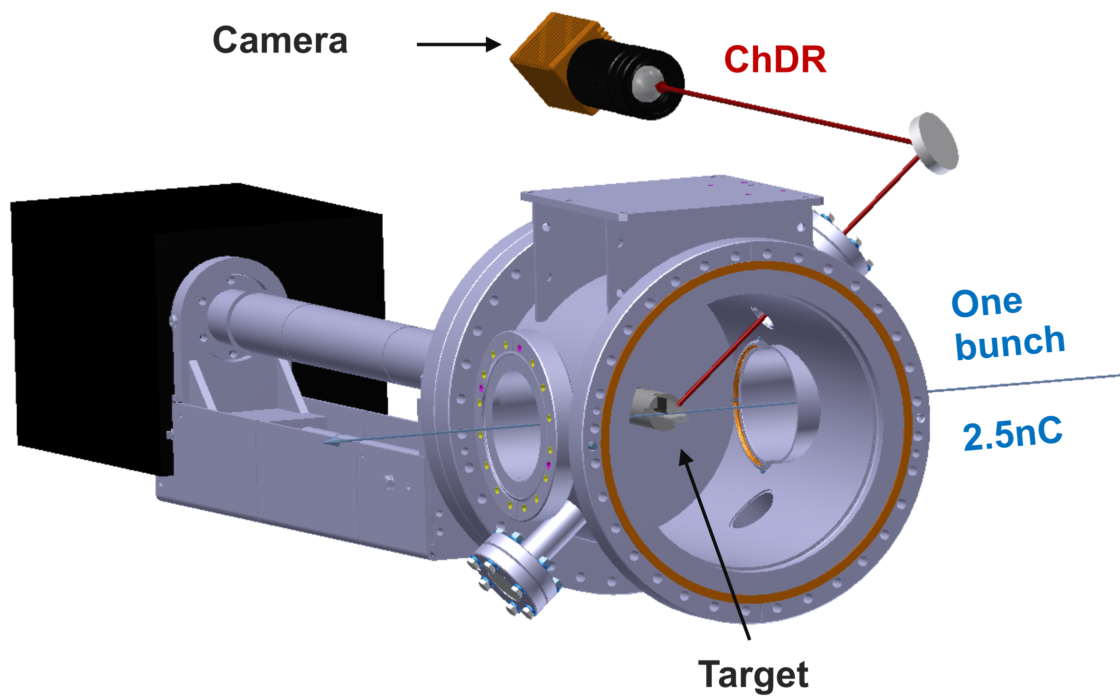
- **Dependence on impact parameters:**



Experimental installation in Cornell Uni.

- **CesrTA: Cornell Electron/positron Storage Ring Test Accelerator**

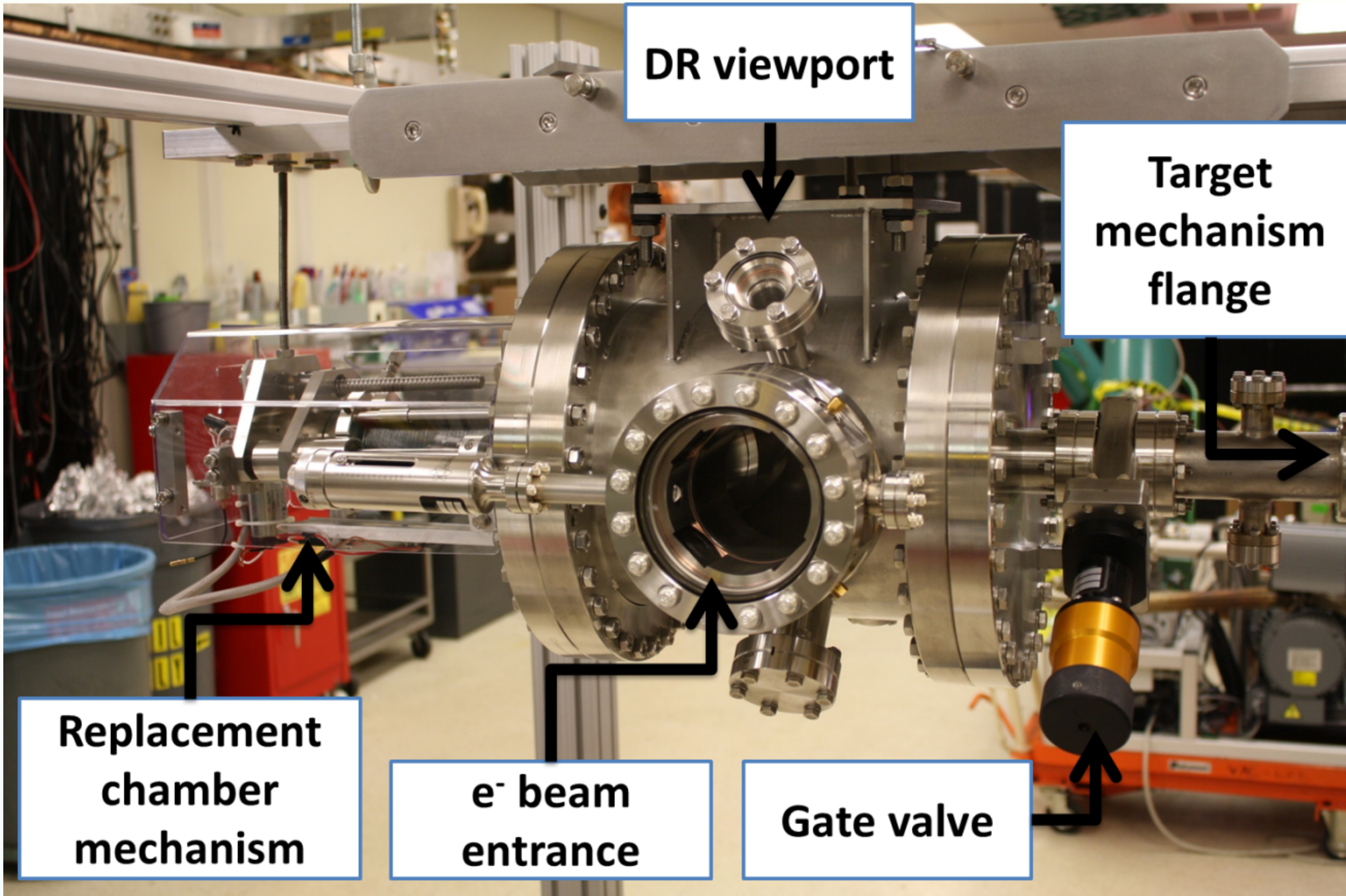




Both image and angular distribution can be measured

(R. Kieffer, et al., Phys. Rev. Lett. 121, 054802 (2018))

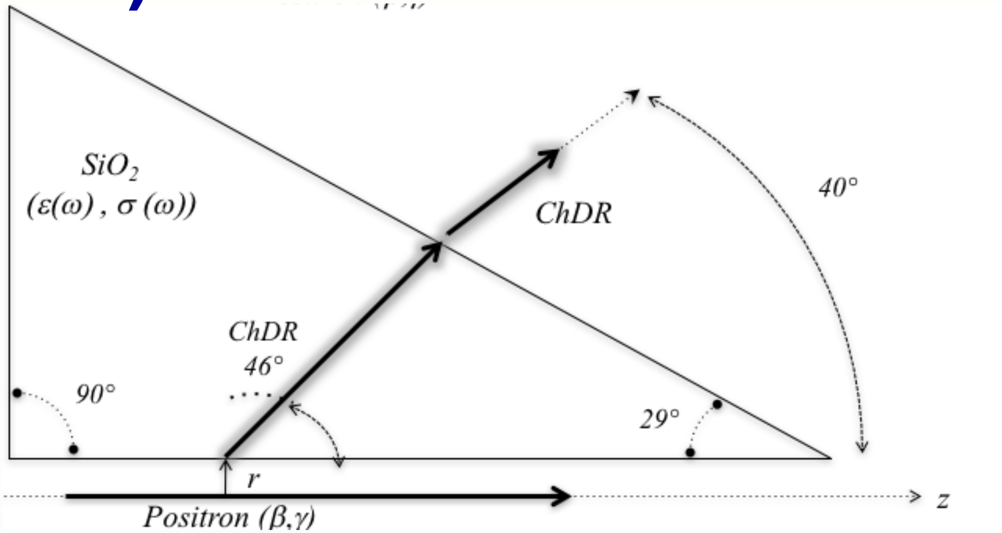
Experimental installation in Cornell Uni.



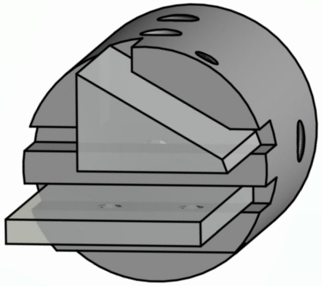
(R. Kieffer, et al., Phys. Rev. Lett. 121, 054802 (2018))

Two target geometries (fused silica)

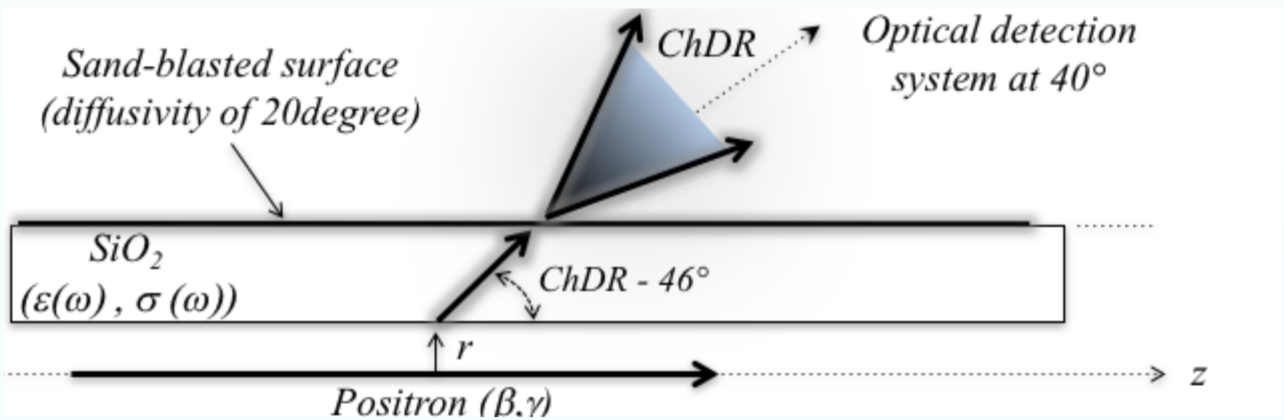
- **a) Prismatic radiator**

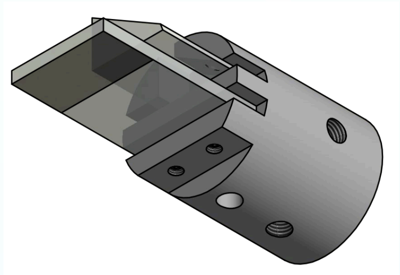


Two 3D views of the target holder



- **b) Flat radiator**

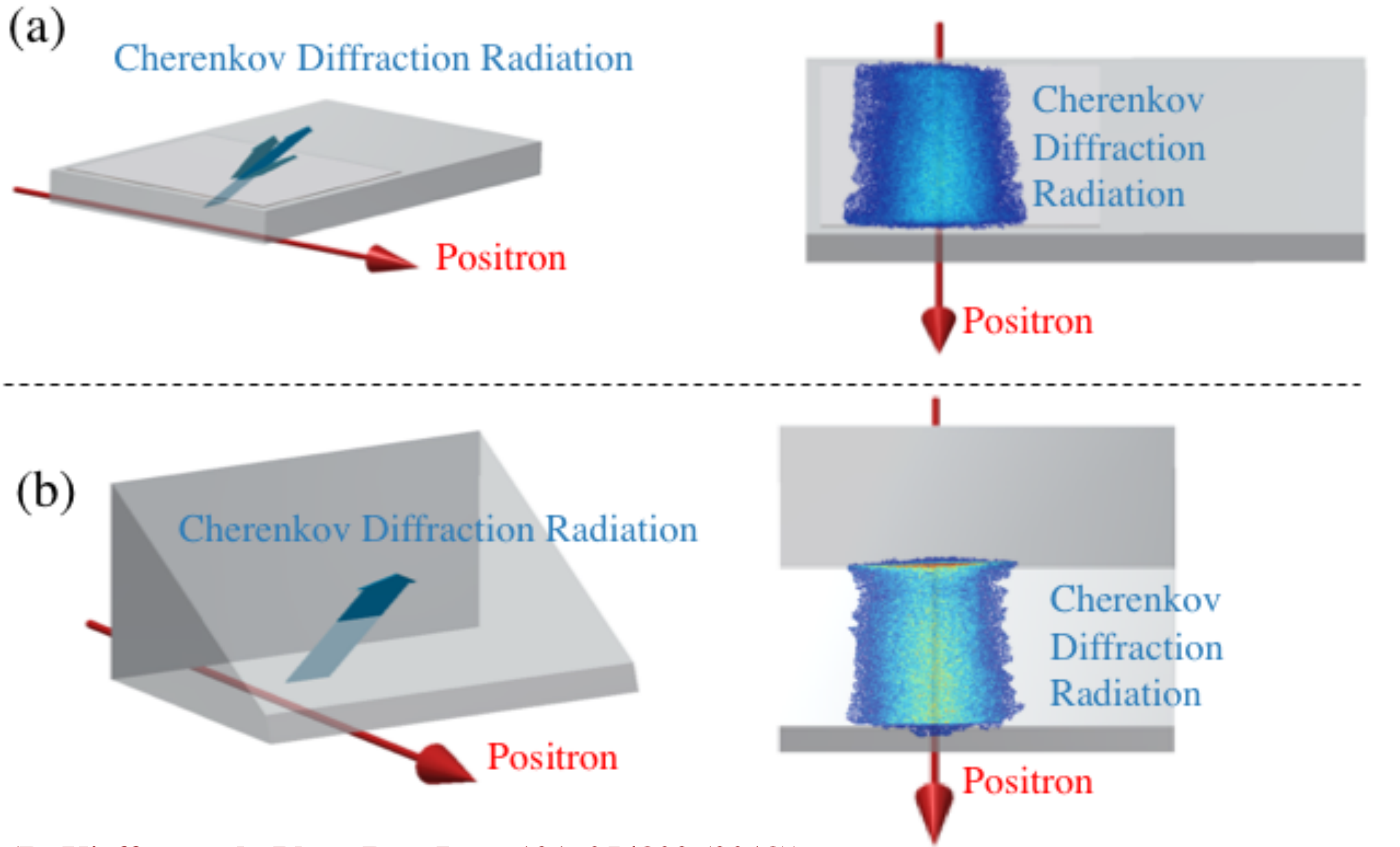




(R. Kieffer, et al., Phys. Rev. Lett. 121, 054802 (2018))

Two target geometries

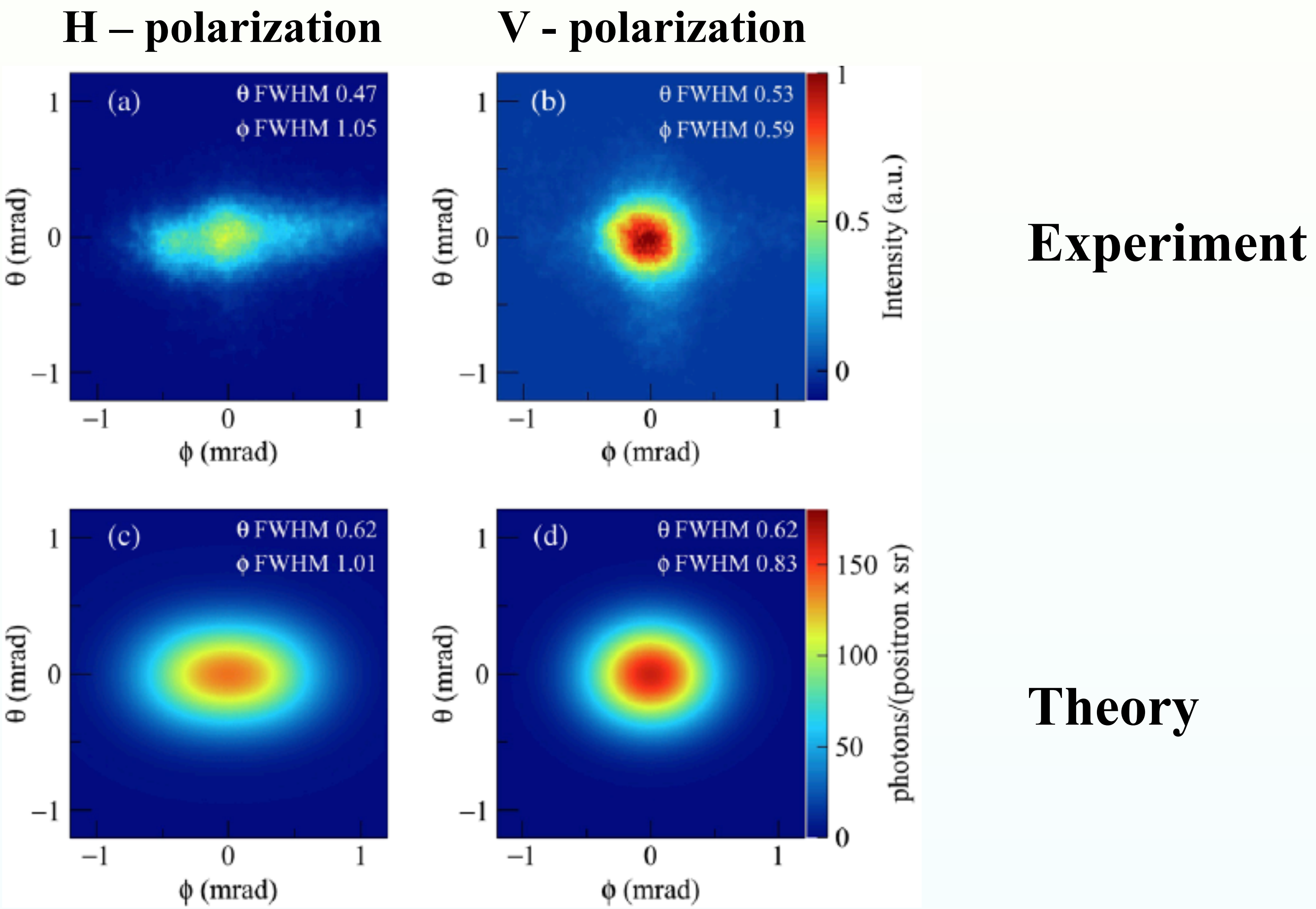
- **Positrons with energy of 5.3 GeV**



(R. Kieffer, et al., Phys. Rev. Lett. 121, 054802 (2018))

Comparison between experiment and theory

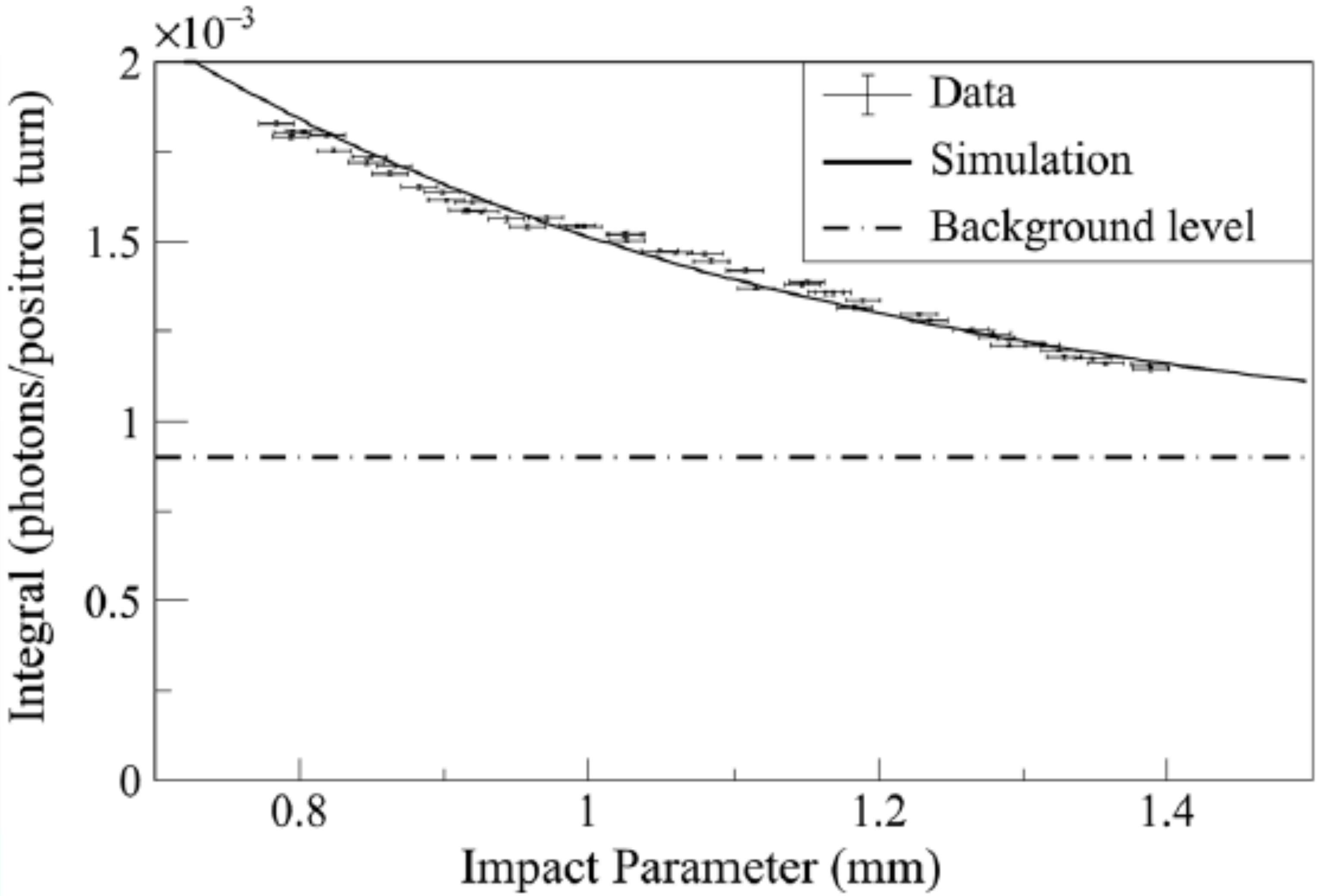
- **Angular distribution**



(R. Kieffer, et al., Phys. Rev. Lett. 121, 054802 (2018))

Comparison between experiment and theory

- **Dependence on impact parameter**

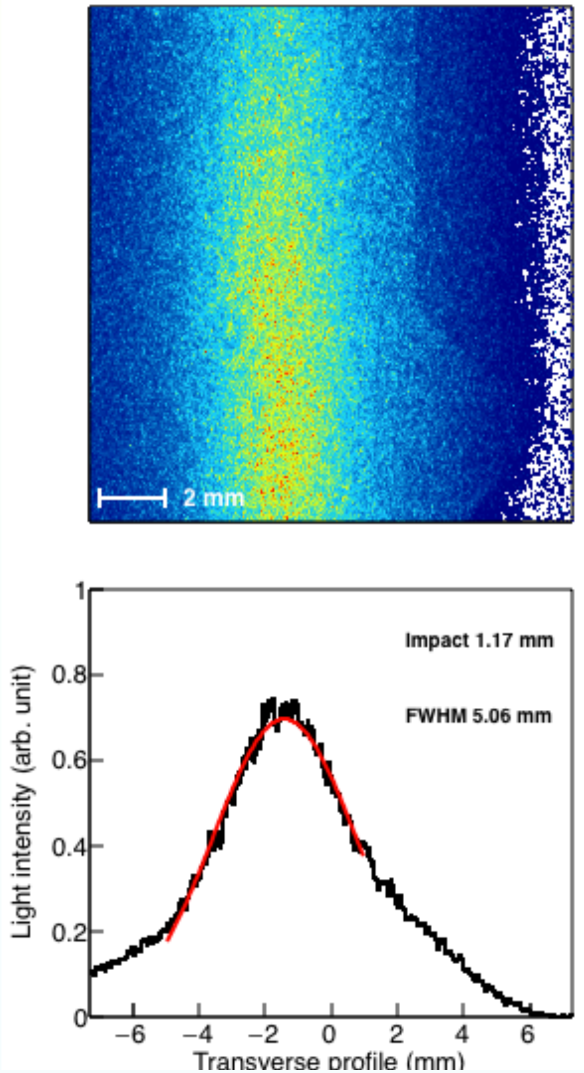


(R. Kieffer, et al., Phys. Rev. Lett. 121, 054802 (2018))

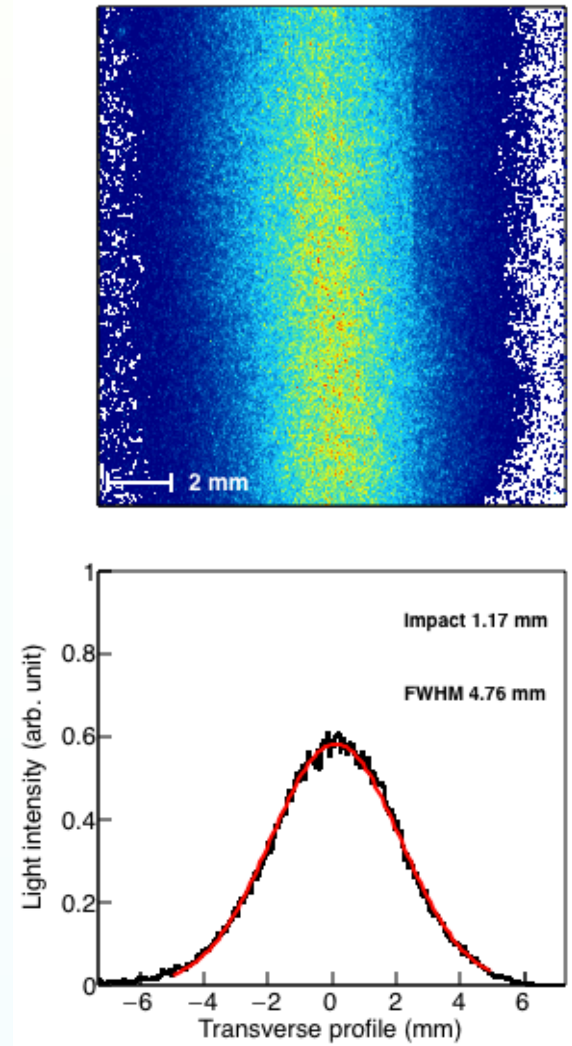
Image of ChDR and Beam Size

- **Positrons with energy of 5.3 GeV**

Horizontal polarization



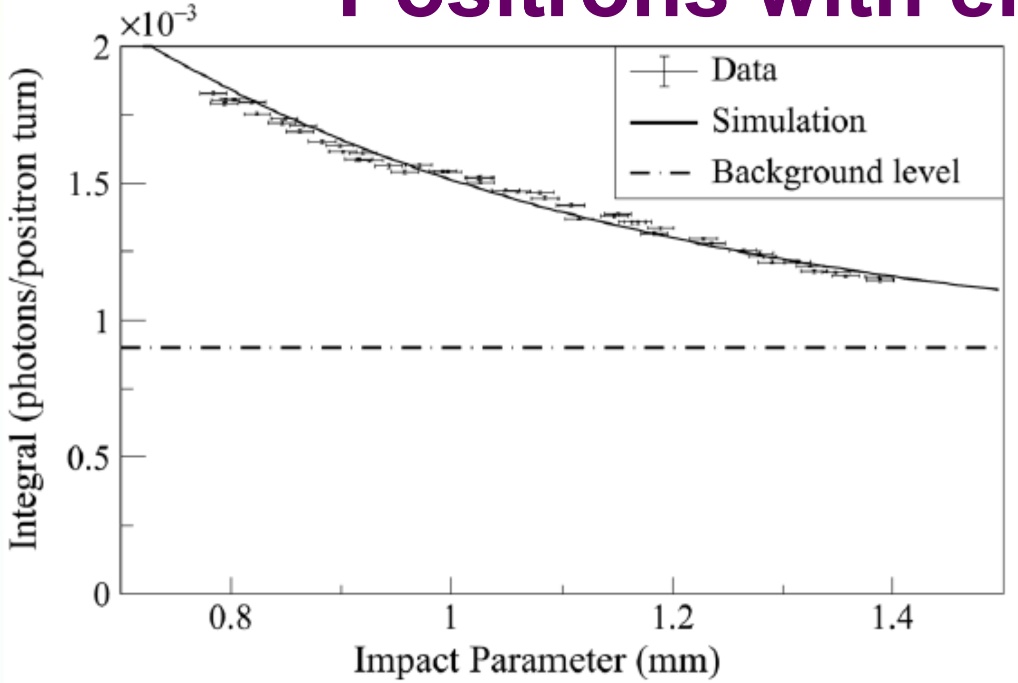
Vertical polarization



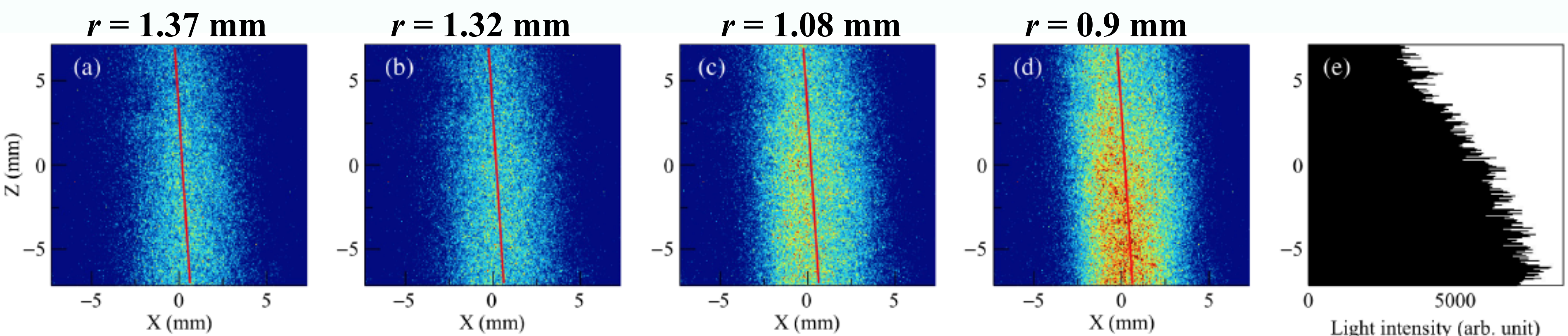
(R. Kieffer, et al., Phys. Rev. Lett. 121, 054802 (2018))

Image of ChDR and Beam Direction

- **Positrons with energy of 5.3 GeV**



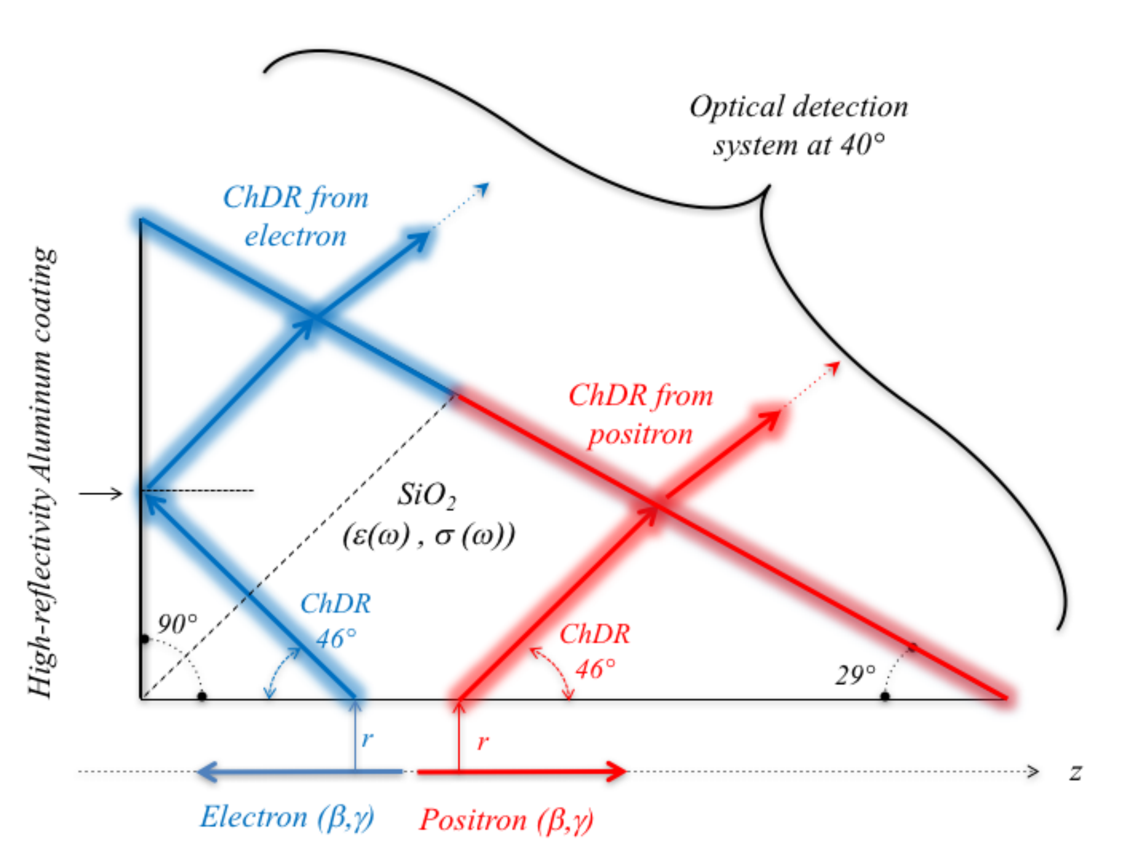
Dependence on impact parameter



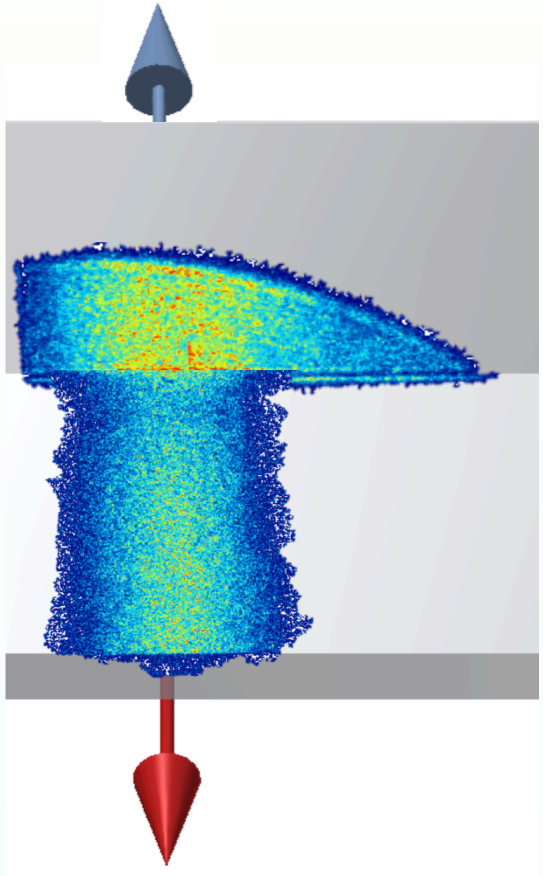
(R. Kieffer, et al., Phys. Rev. Lett. 121, 054802 (2018))

Counter-propagating Beams

Prismatic target



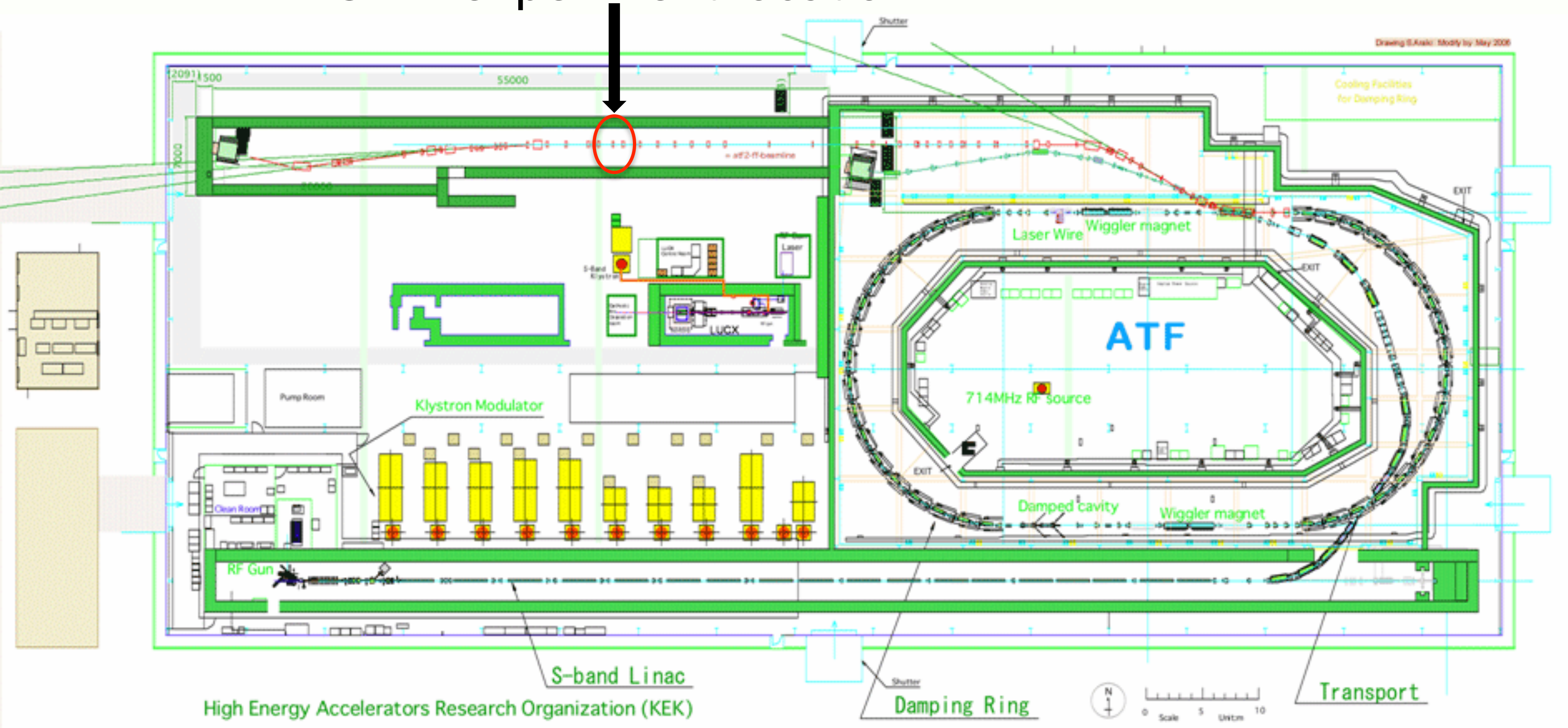
Electrons



Positrons

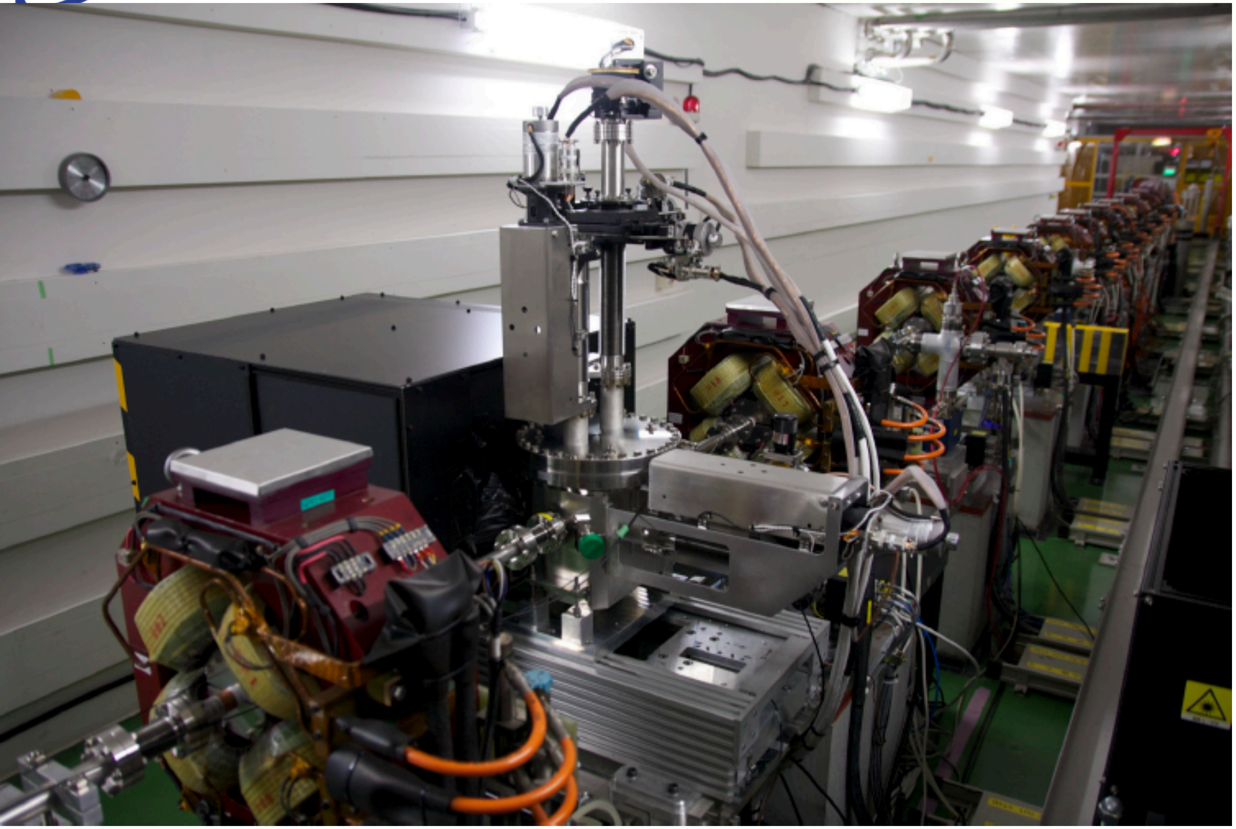
KEK-ATF2: Accelerator Test Facility

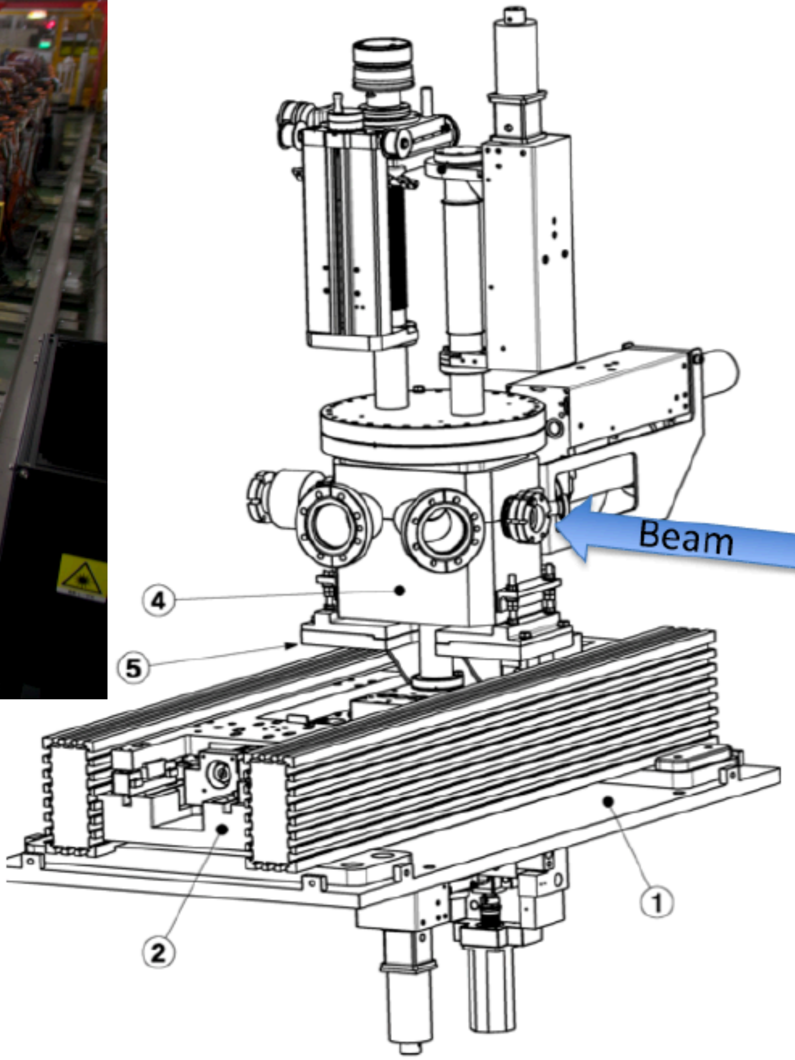
ODR experiment location



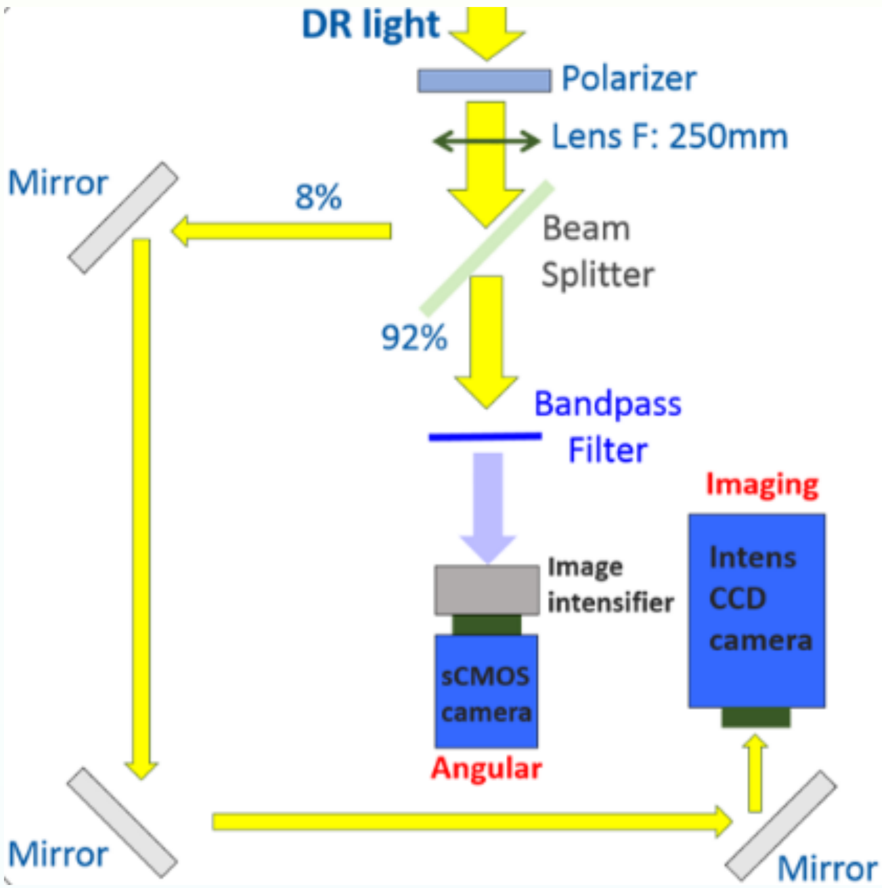
Beam size changes from sub-micron to hundreds of micron dimensions

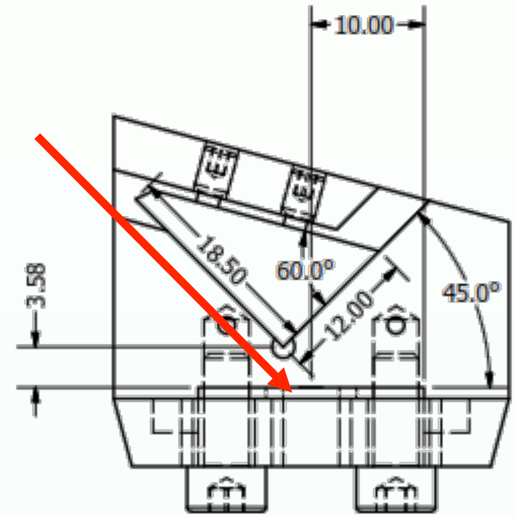
Experimental installation at KEK-ATF2





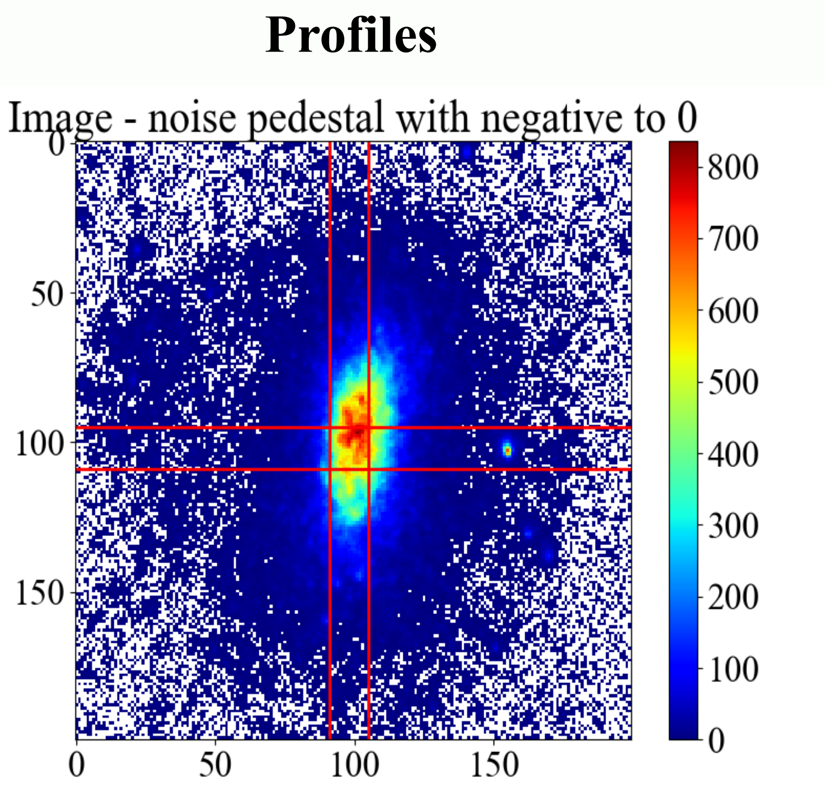
Experimental installation at KEK-ATF2

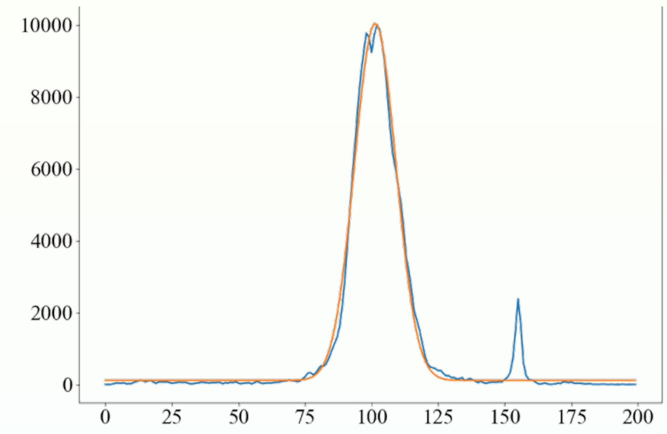




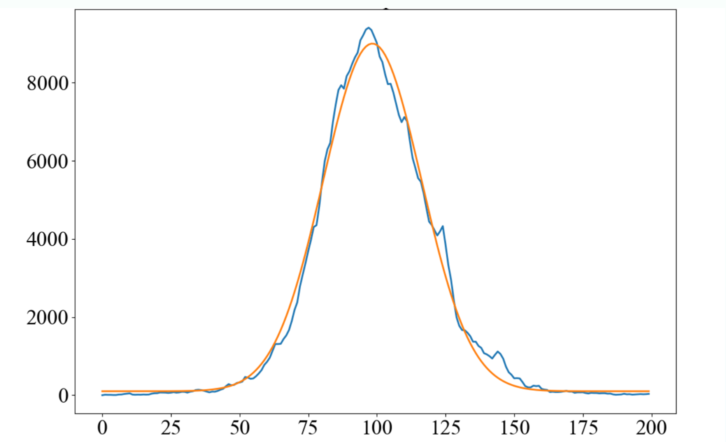
Experimental results at KEK-ATF2

OTR reference beam size measurement





horizontal rms is: 30.08±0.93 um

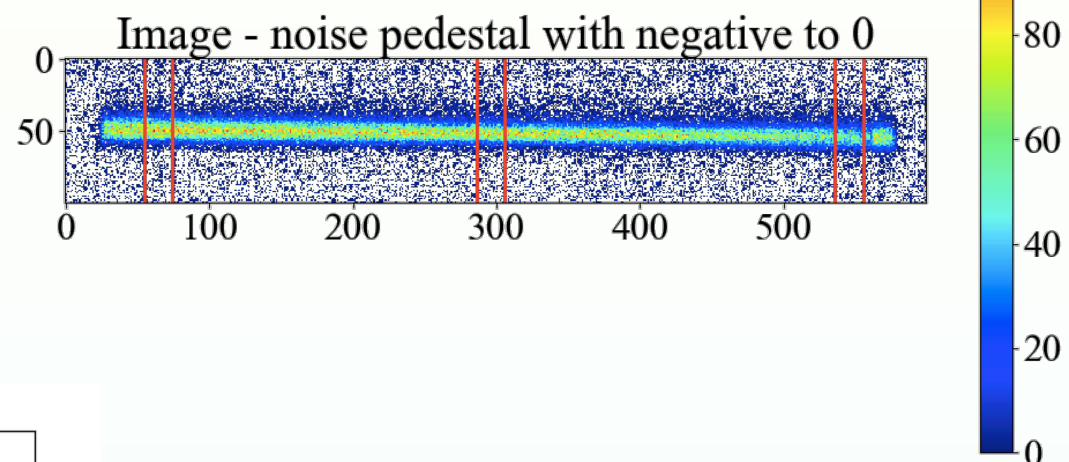


vertical rms is: 67.22±1.36 um

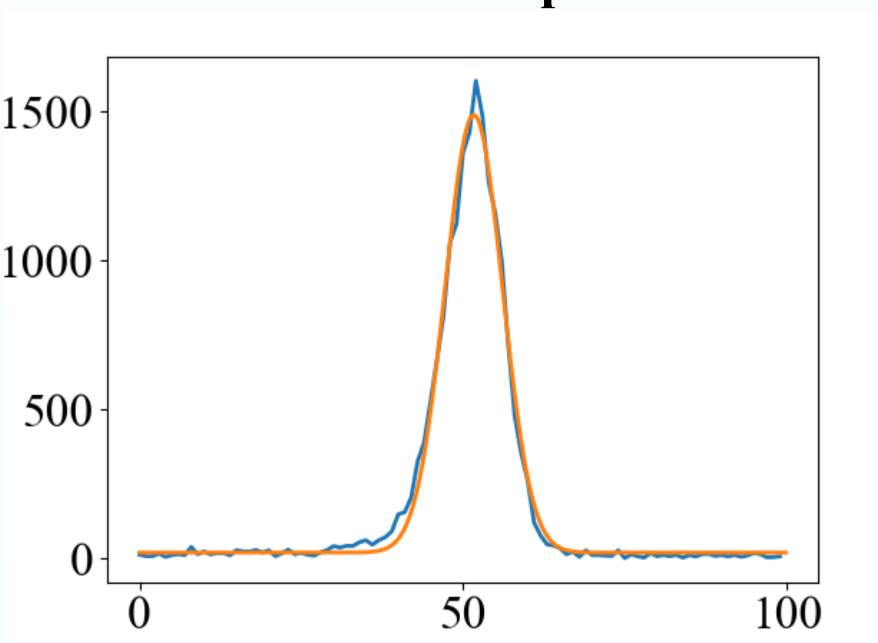
Experimental results at KEK-ATF2

Optical ChDR beam size measurement

ChDR image



Vertical beam profile



Vertical rms: 63.49 um

Conclusion

- **Main Achievements**
  (R. Kieffer, et al., Phys. Rev. Lett. 121, 054802 (2018)):
  - **Directly observed ChDR from a fused silica target;**
  - **Good consistency with theory:**
    - **Angular distribution**
    - **Dependence on impact parameter**
  - **Sensitivity to the beam parameters**
    - **Beam direction in two dimensions**
    - **Beam position**
    - **Beam size down to 65μm, actual resolution ?**
    - **Beam divergence, emittance, arrival time are yet to be measured**

Conclusion

- **Plans and Prospects:**
  - Develop theory for a Line Spread Function;
  - Observe the LSF in KEK-ATF2:
    - Determine actual resolution
    - Emittance diagnostics
  - Detailed studies of Coherent ChDR
    - Bunch length diagnostics
    - THz radiation generation
  - Develop simulation technology
    - CST Studio Suite; V-SIM; ZEMAX
  - Optimize radiator geometry for a given application

Title