IPAC'12 International Particle Accelerator Conference 2012

New Orleans Louisiana, USA

May 20-25, 2012

Ernest N. Morial Convention Center

Inorganic scintillators for particle beam profile diagnostics of highly brilliant and highly energetic electron beams

Gero Kube, Christopher Behrens, Christopher Gerth, Bernhard Schmidt, Werner Lauth, Minjie Yan

- OTR and Microbunching
- Scintillating Screen Monitor Studies
- Conclusion and Outlook

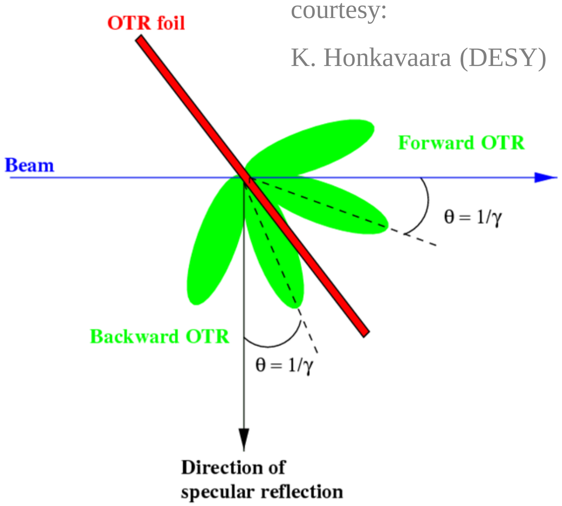
HELMHOLTZ ASSOCIATION DESY

OTR Transverse Beam Profiling

- advantages of Optical Transition Radiation (OTR) beam diagnostics
  - single shot measurement → study of shot-to-shot fluctuations in linac
  - full transverse (2D) profile information
  - linear response → neglecting coherent effects (!)
  - broad selection of available detectors
  - simple and robust setup geometry

  → imaging the beam via OTR in backward direction

courtesy:
K. Honkavaara (DESY)



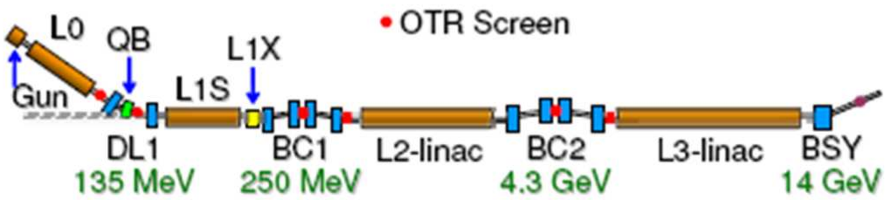
- nowadays standard method for emittance measurements, beam matching, etc.

  - in use at nearly all electron linacs
  - OTR monitors replaced formerly used scintillation screens

Unexpected COTR @ LCLS

R. Akre et al., Phys. Rev. ST Accel. Beams **11** (2008) 030703 H. Loos et al., Proc. FEL 2008, Gyeongju, Korea, p.485.

- Linac Coherent Light Source (LCLS) @ SLAC



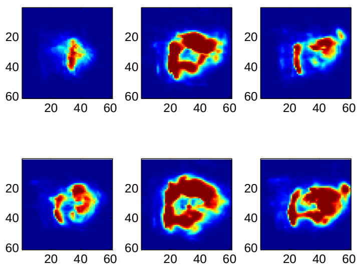
- uncompressed beam, OTR behind BC1
- σ_t = 2.4 ps (rms)
- scan of quad QB → intensity varies by factor 4

  ($\sigma_{x,y}$ increased by 25 %)

comparison with incoherent level → only fraction of $3{\cdot}10^{-5}$

- OTR monitor observation with BC1, BC2 switched on

- OTR 12



measured spot is no beam image!

- OTR 22

- strong shot-to-shot fluctuations
- doughnut structure
- change of spectral contents

courtesy: S. Wesch (DESY)

- interpretation of coherent formation in terms of “Microbunching Instability”

E.L. Saldin et al., NIM **A483** (2002) 516 Z. Huang and K. Kim, Phys. Rev. ST Accel. Beams **5** (2002) 074401

COTR Observations

- APS (Argonne, USA)
  - A.H. Lumpkin et al., Phys. Rev. ST Accel. Beams **12** (2009) 080702
- NLCTA (SLAC , USA)
  - S. Weathersby et al., Proc. PAC 2011, New York, USA, p.1.
- FLASH (DESY Hamburg, Germany)
  - S. Wesch et al., Proc. FEL 2009, Liverpool, UK, p.619.
  - C. Behrens et al., Proc. FEL 2010, Malmö, Sweden, p.311.
- FERMI (ELETTRA , Italy)
  - S. di Mitri, private communication
- SACLA (Spring-8 , Japan)
  - talk by H. Tanaka @ FEL 2011, Shanghai, China, August 2011

courtesy:

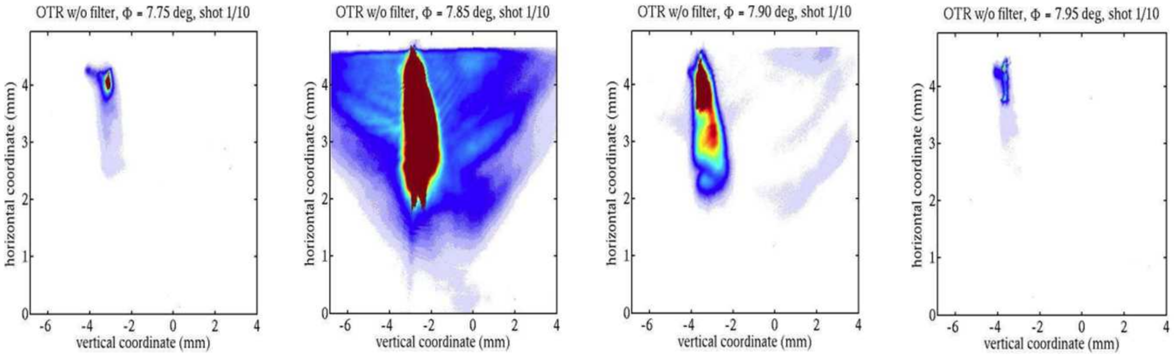
S. Wesch (DESY)

- summary of COTR effects
  - S. Wesch and B. Schmidt, Proc. DIPAC 2011, Hamburg, Germany, p.539.
- 4th microbunching instability workshop
  - University of Maryland, April 11-13, 2012

Consequences

- LCLS: coherent emission compromise use of OTR as reliable beam diagnostics
  - wire scanner for transverse beam diagnostics instead of OTR monitors

- FLASH: COTR observed after modifications to linearize longitudinal phase space



SMATCH screen before FLASH undulator

- **COTR also expected for the E-XFEL**

- alternative schemes for transverse profile diagnostics
  - **long term perspective:** radiation diagnostics at smaller λ

    TR in EUV region L.G. Sukhikh, S. Bajt, G. Kube et al., Proc. IPAC 2012, New Orleans (USA), MOPPR019
  - **short term perspective:** scintillating screen monitors

    widely used at hadron accelerators, nearly no information available for high energy electron machines

    B.Walasek-Höhne and G. Kube, Proc. DIPAC 2011, Hamburg, Germany, p. 553

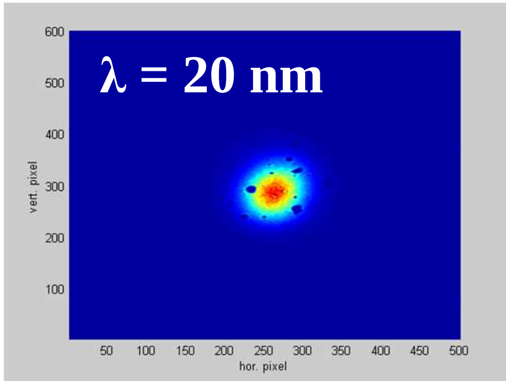
⇒ **ongoing R&D projects @ DESY**

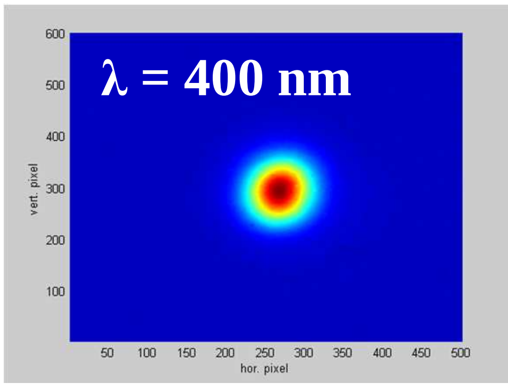
Imaging with EUV-TR

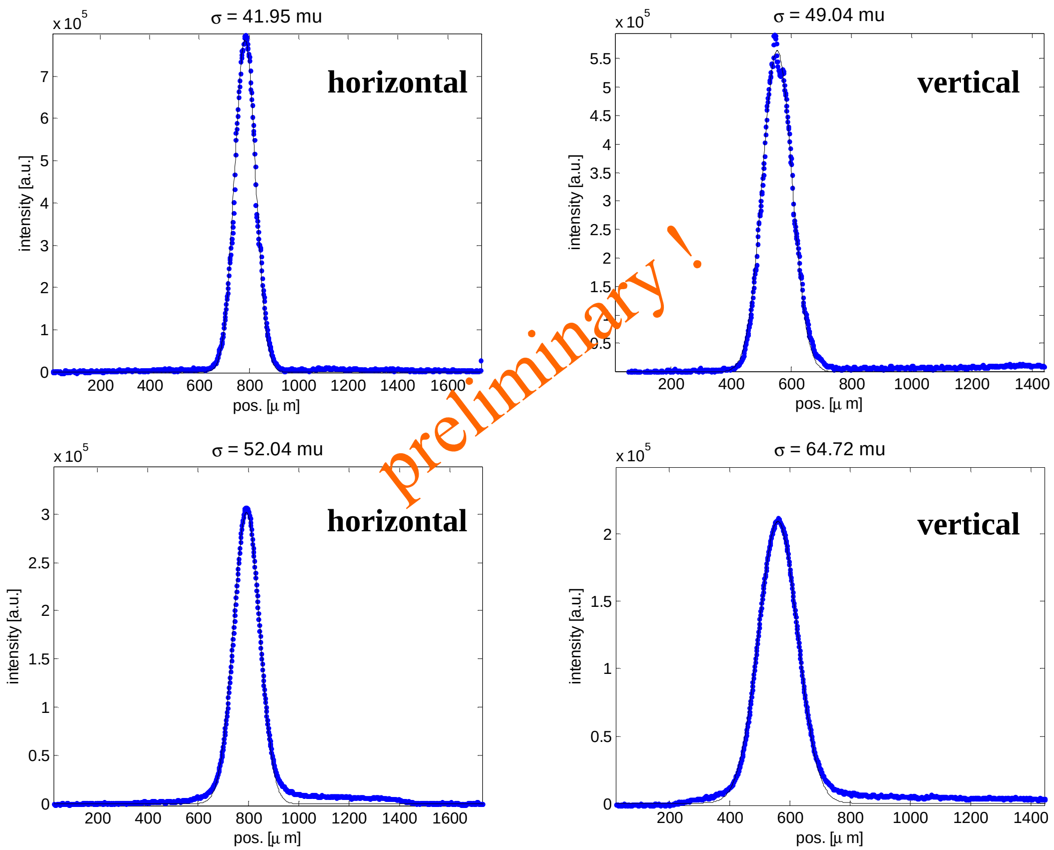
- advantages of smaller wavelength
  - avoid coherent emission
  - better resolution for imaging

- proof-of-principle experiment performed in March 2012 → EUV-TR imaging works

L.G. Sukhikh, S. Bajt, G. Kube et al., Proc. IPAC 2012, New Orleans (USA), MOPPR019







Inorganic Scintillators

- properties
  - radiation resistant → widely used in high energy physics, astrophysics, dosimetry,…
  - high stopping power → high light yield
  - short decay time → reduced saturation

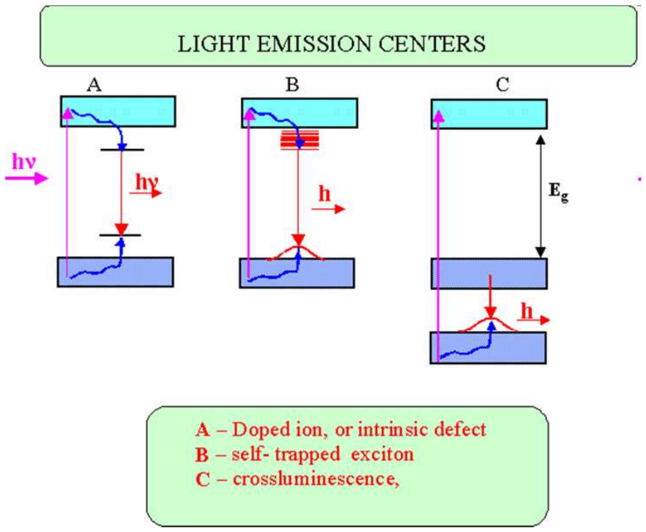
- generation of scintillation light
  - energy conversion (characterstic time $10^{-18} – 10^{-9}$ sec)

    Formation of el. magn. shower. Below threshold of e^+e^- pair creation relaxation of primary electrons/holes by generation of secondary ones, phonons, plasmons, and other electronic excitations.
  - thermalization of seconray electrons/holes ($10^{-16} – 10^{-12}$ sec)

    Inelastic processes: cooling down the energy by coupling to the lattice vibration modes until they reach top of valence resp. bottom of conduction band.
  - transfer to luminescent center ($10^{-12} – 10^{-8}$ sec)

    Energy transfer from e-h pairs to luminescent centers.
  - photon emission (> 10^{-10} sec)

    radiative relaxation of excited luminescence centers



http://crystalclear.web.cern.ch/crystalclear/

Requirements for Beam Diagnostics

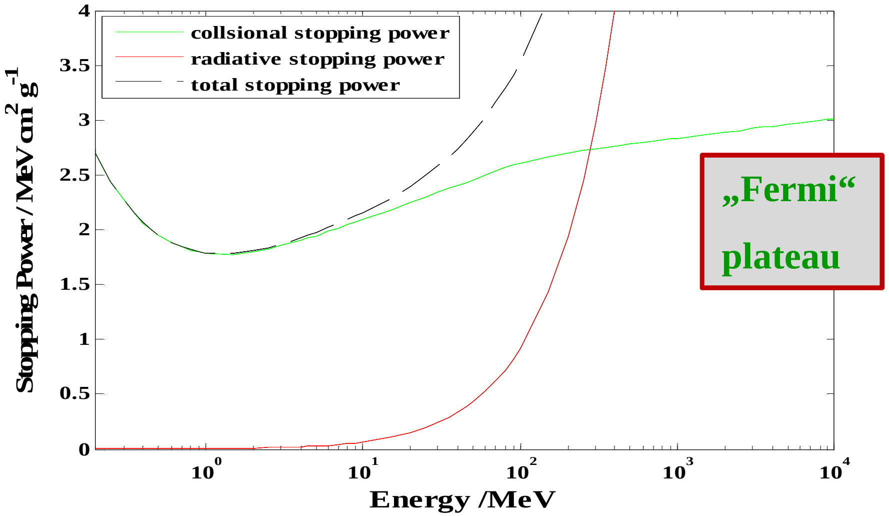
- **high spatial resolution**

  → influences on light generation process

- light generation in thin target (thickness / $X_0 \approx 10^{-2}$)

  → energy **deposition** of importance

  → ignore radiative stopping power



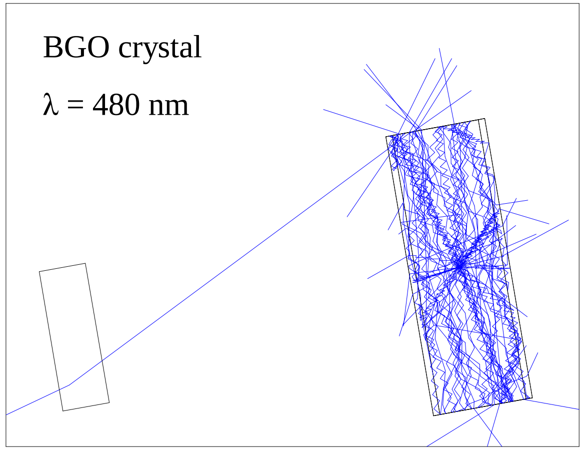
- Fermi plateau: cancellation of incoming particle field by induced polarization field of electrons in medium

  → saturation range $R_\delta = \frac{\hbar c}{\hbar \omega_p}$ ω_p: plasma frequency

- **low signal distortion**

  → light propagation

- light generated inside scintillator has to cross surface



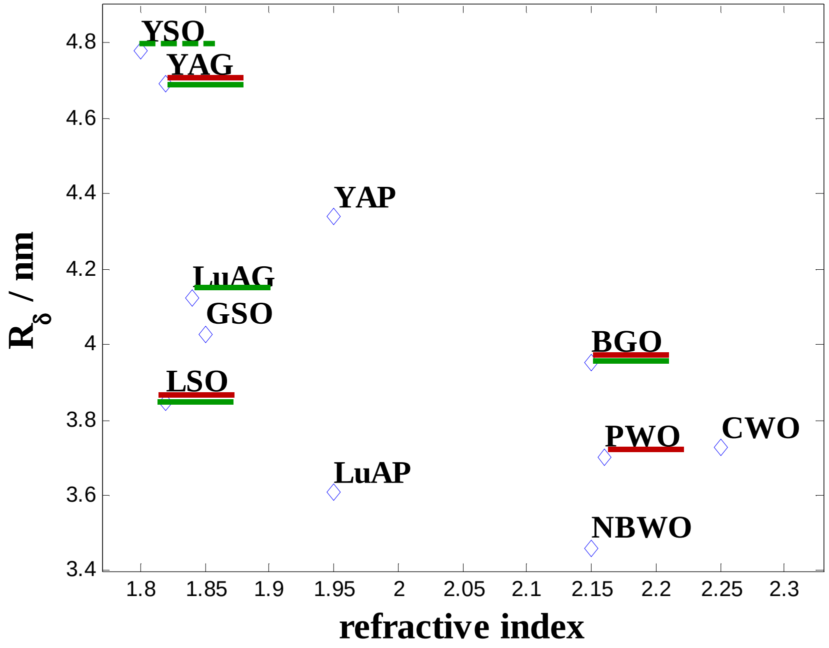
  → refractive index n

- inorganic scintillotors: **high n**

  → large contribution of total reflection

  → **influence on observation geometry**

Scintillator Material Properties



	ρ / g/cm^3	$\hbar\omega$ / eV	λ_{max} / nm	yield / 1/keV	n @ λ_{max}	R_δ / nm
BGO	7.13	49.9	480	8	2.15	3.95
PWO	8.28	53.3	420	0.1	2.16	3.70
LSO:Ce	7.1	51.3	420	32	1.82	3.85
YAG:Ce	4.55	42.1	550	11	1.82	4.69
LuAG:Ce	6.76	47.8	535	14	1.84	4.12
YSO:Ce	4.45	41.3	420	9.2	1.80	4.78

- *series of measurements*

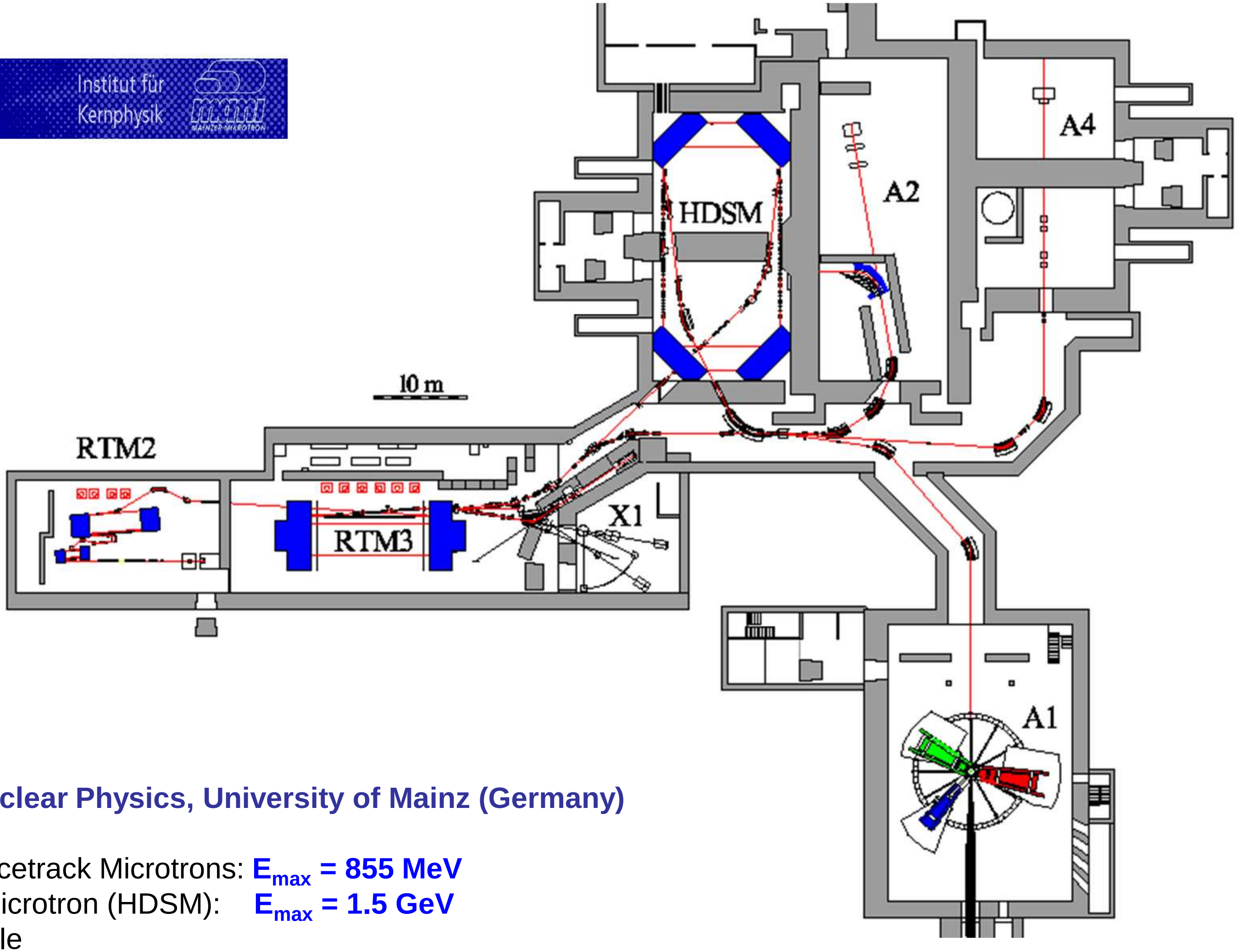
October 2009

- BGO 0.5 mm
- PWO 0.3 mm
- LYSO:Ce 0.8 mm, 0.5 mm (Prelude 420)
- YAG:Ce 1.0 mm, 0.2 mm, powder
- Al_2O_3 1.0 mm (ceramic)

March 2011

- BGO 0.3 mm
- LYSO:Ce 0.3 mm (Prelude 420, CRY-19 (?))
- YAG:Ce 0.3 mm
- LuAG:Ce 0.3 mm
- YSO:Ce (?) 0.3mm (CRY-18)

Mainz Microtron MAMI

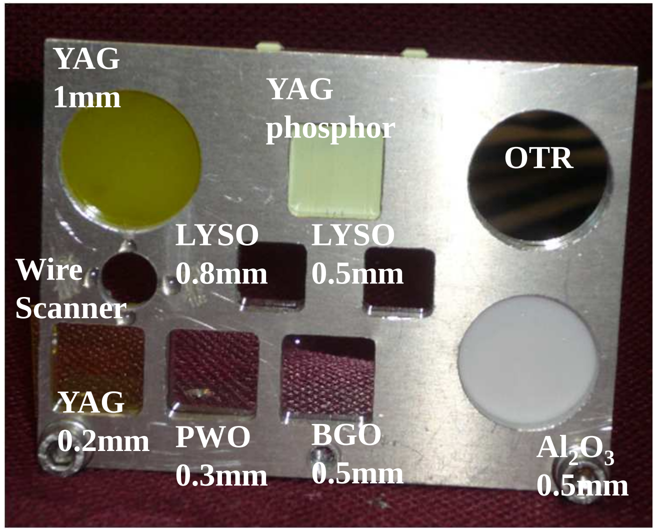


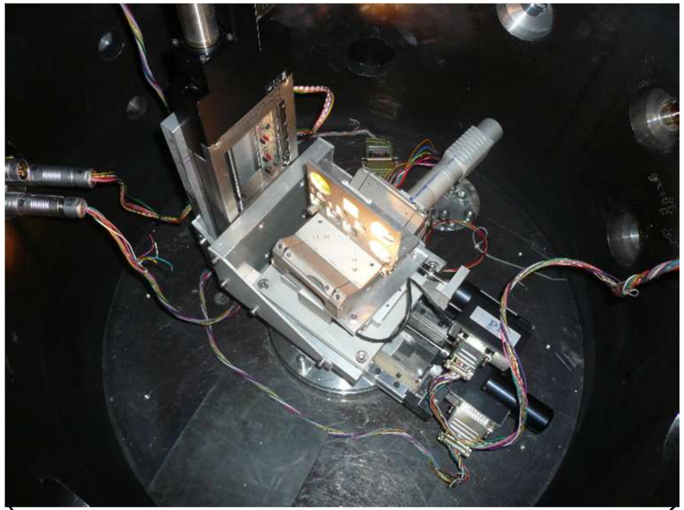
Institute of Nuclear Physics, University of Mainz (Germany)

3 cascaded Racetrack Microtrons: E_{max} **= 855 MeV**
double-sided Microtron (HDSM): E_{max} **= 1.5 GeV**
100 % duty cycle
polarized electron beam (~ 80%)

Experimental Setup

- target





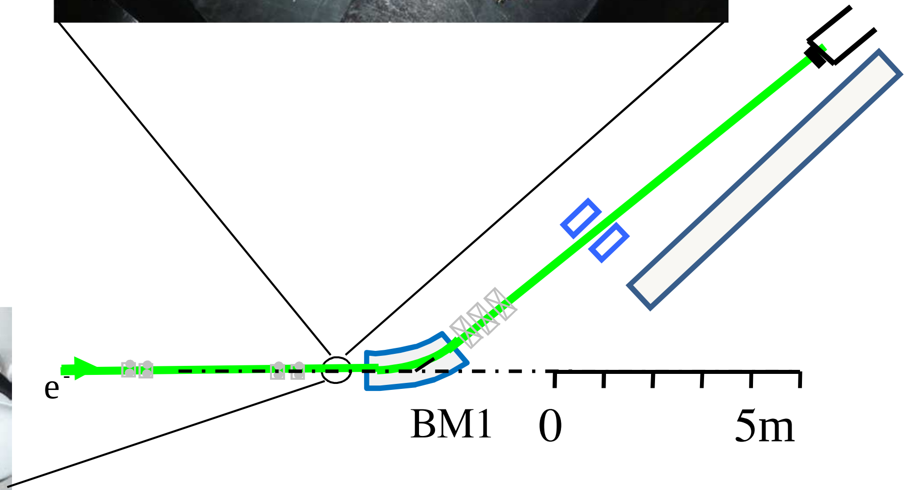
- observation geometry

-22.5° w.r.t. beam axis

camera: BASLER A311f

659 x 494 pixel

pixel size 9.9µm x 9.9µm



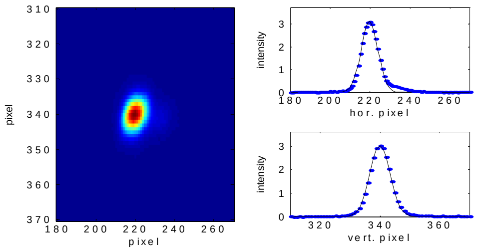
- X1 beamline

Beam Images

- **measurement and analysis:** I = 46 pA 5 signal and 1 background frame

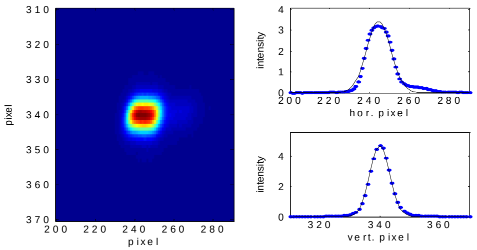
LYSO:Ce

(0.5mm)



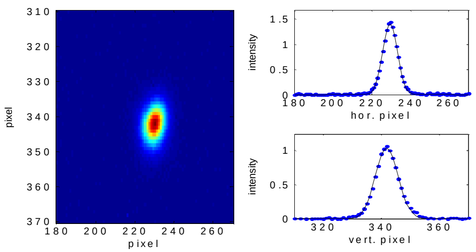
LYSO:Ce

(0.8mm)



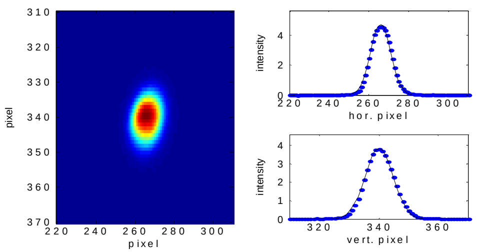
YAG:Ce

(powder)



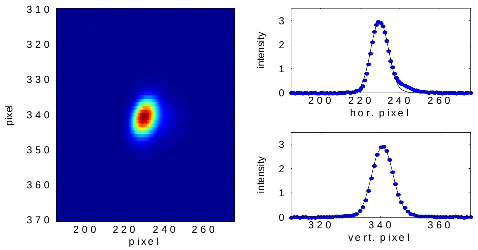
YAG:Ce

(0.2mm)



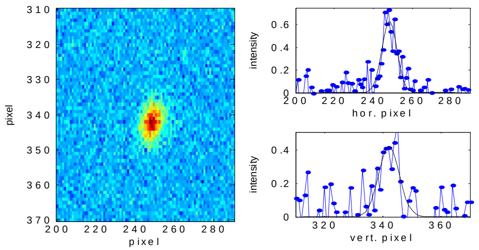
BGO

(0.5mm)



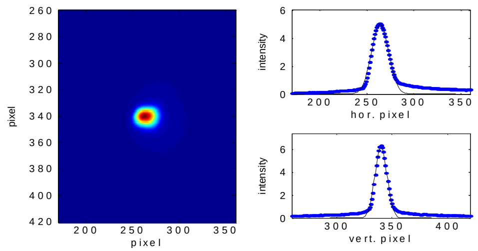
PWO

(0.3mm)



YAG:Ce

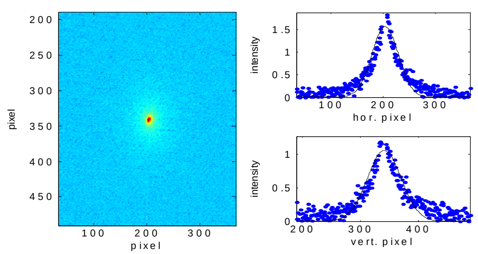
(1mm)



different scale !

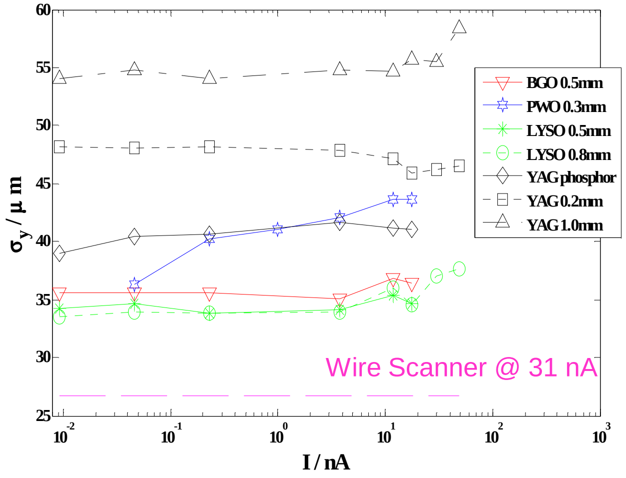
Al_2O_3

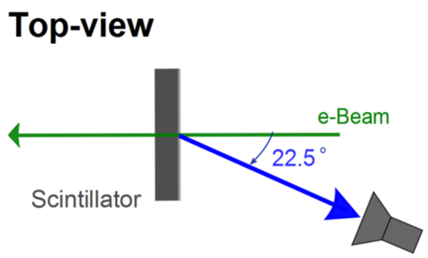
(0.5mm)

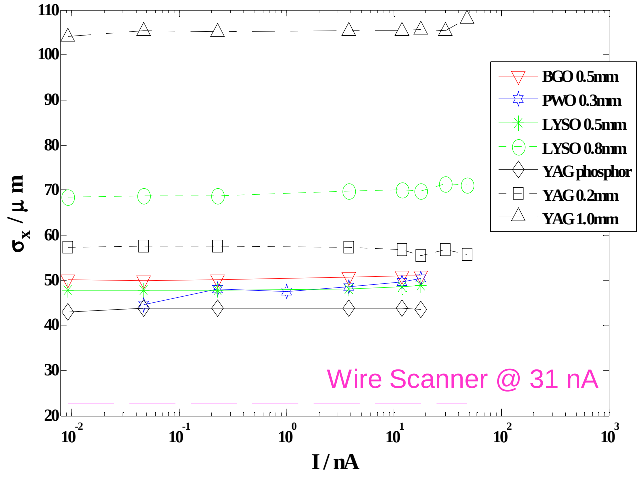


Spatial Resolution

- experiment 2009

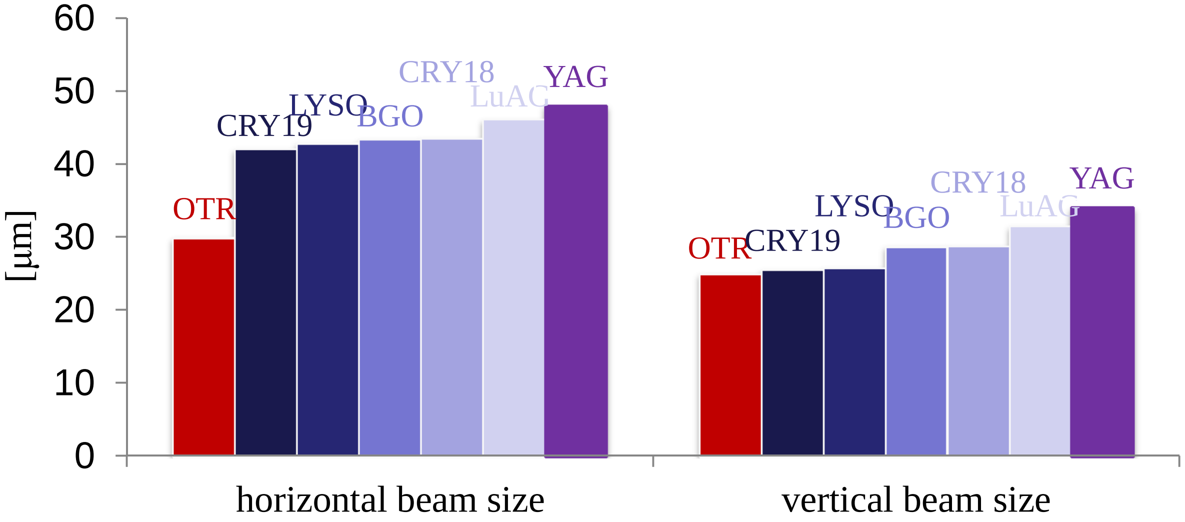






G. Kube et al., Proc. IPAC'10, Kyoto (Japan), 2010, p.906

- experiment 2011



favorite materials

BGO and LYSO

⇒ dependency on observation geometry

Observation Geometry

- beam diagnostics

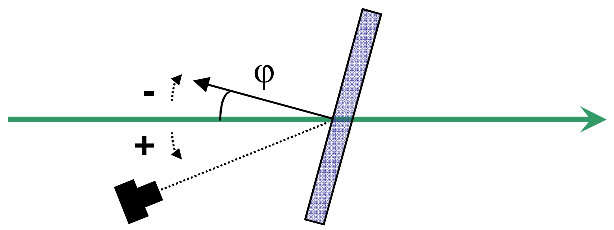
  → popular OTR-like observation geometry:

45°tilt of screen

observation under 90°

→ **turns out to be bad!**

- scintillator tilt versus beam axis

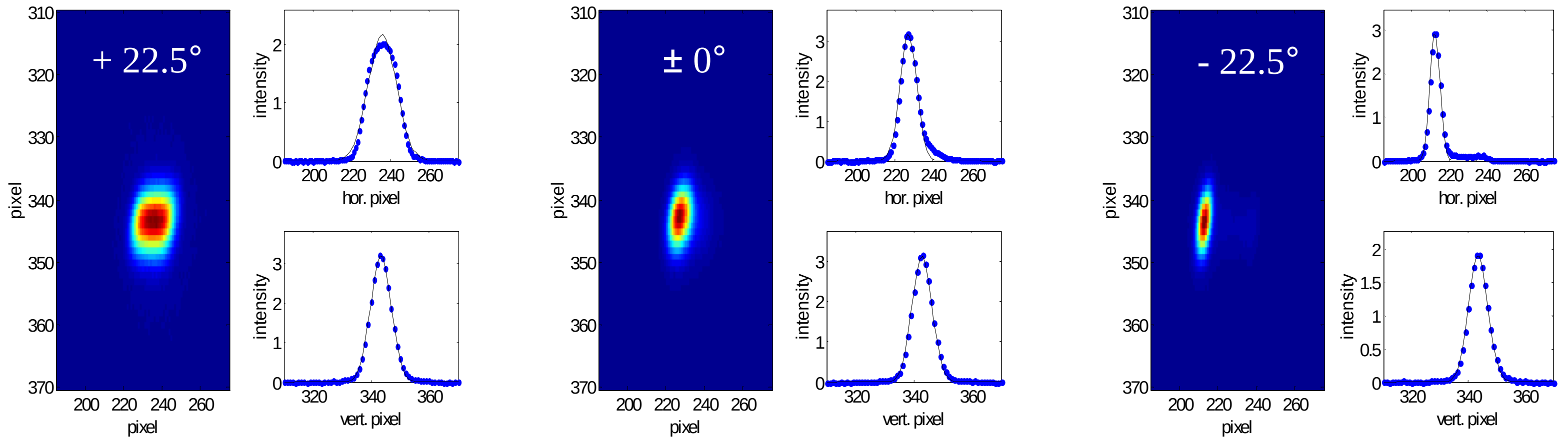


BGO crystal

micro-focused beam

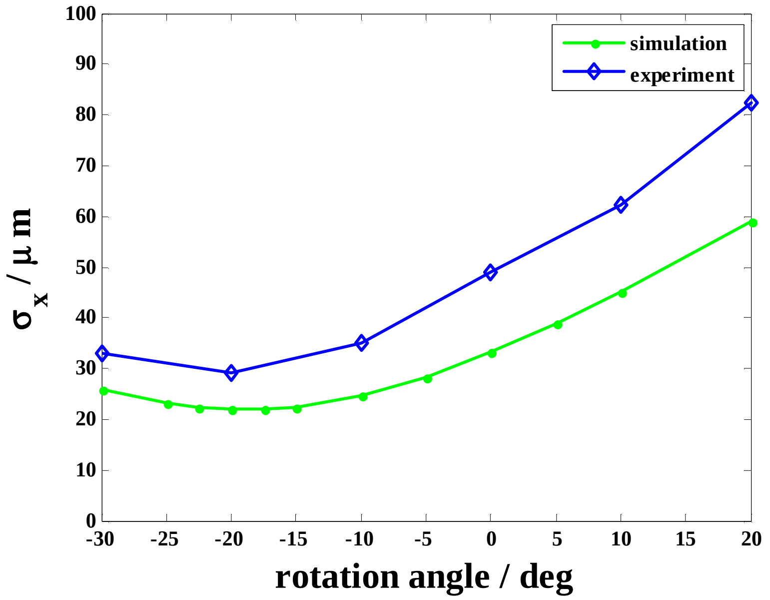
I = 3.8 nA

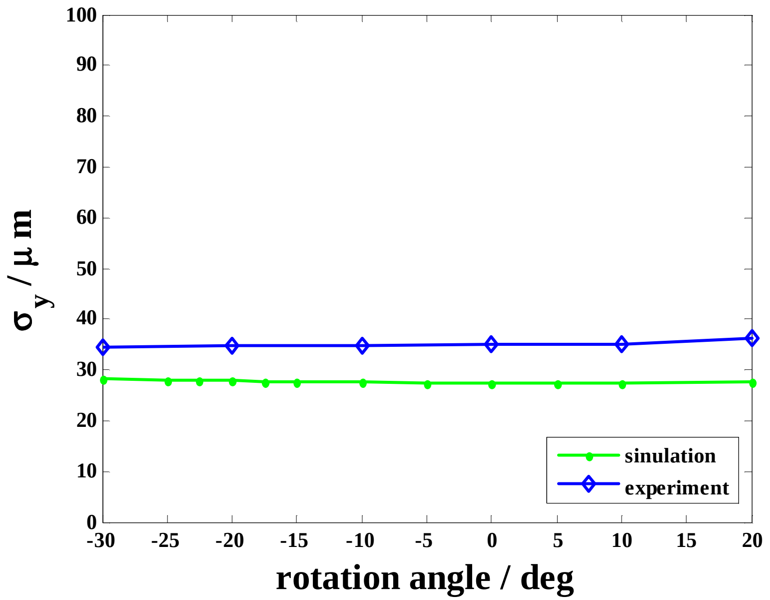
- measured beam spots



Comparison

- light propagation in scintillator
  - simple ZEMAX model → light generated by line source, scintillator characterized by n





- satisfactory agreement between simulation and measurement

  → simulation reproduces observed trend in beam size

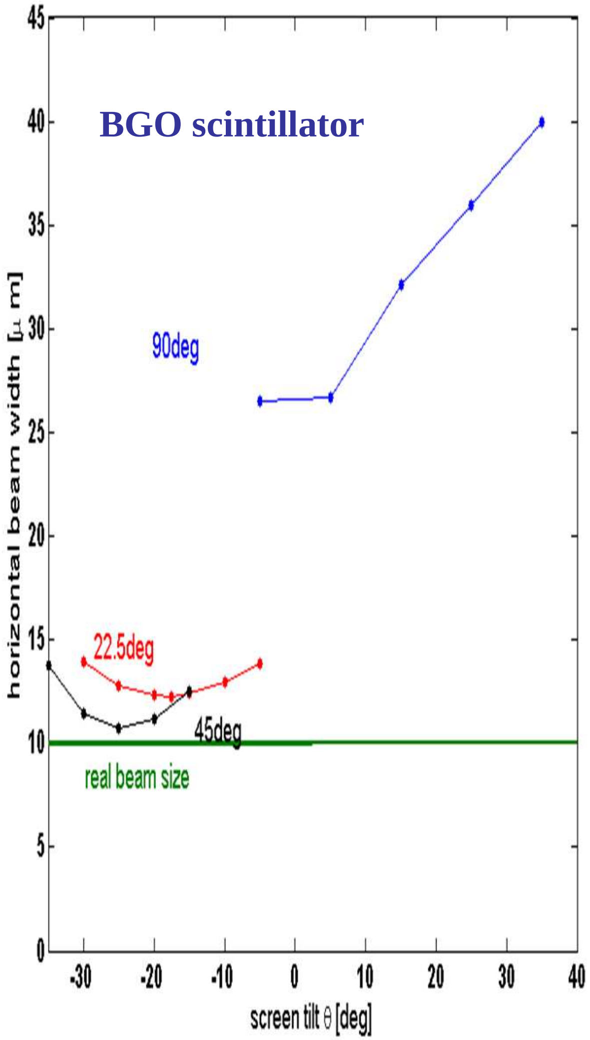
- measured beam size systematically larger than simulated one

  → effect of extension radius not included in calculation → increase in PSF

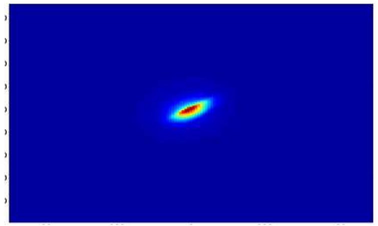
G. Kube, C. Behrens, and W. Lauth, Proc. IPAC 2010, Kyoto, Japan, p.906.

Observation Geometry Influence

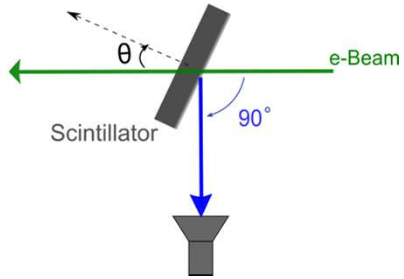
- comparison observation geometry



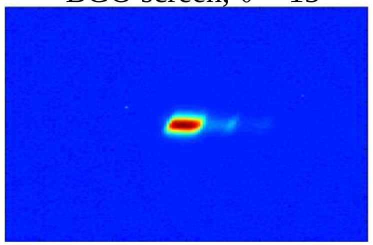
OTR screen



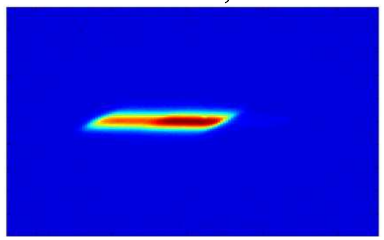
Top-view



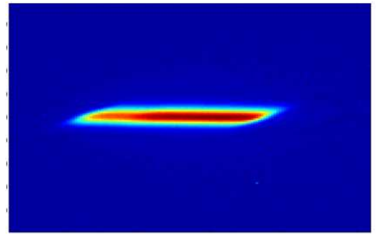
BGO screen, θ = 15°



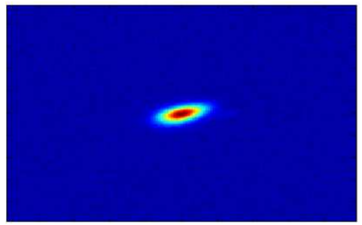
BGO screen, θ = 45°



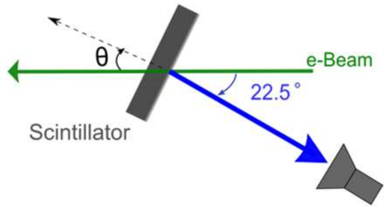
BGO screen, θ = 55°



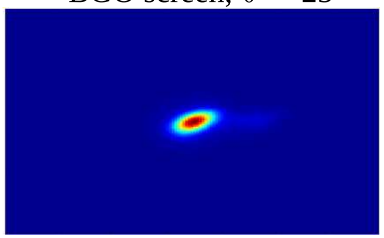
OTR screen



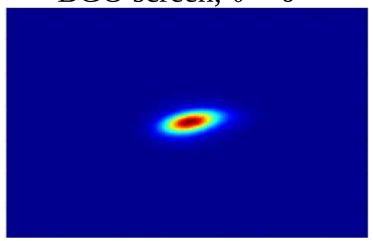
Top-view



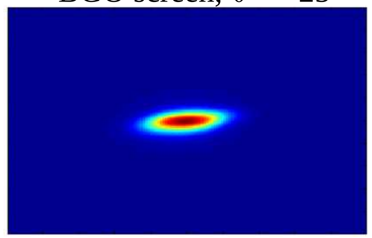
BGO screen, θ = -25°



BGO screen, θ = 0°



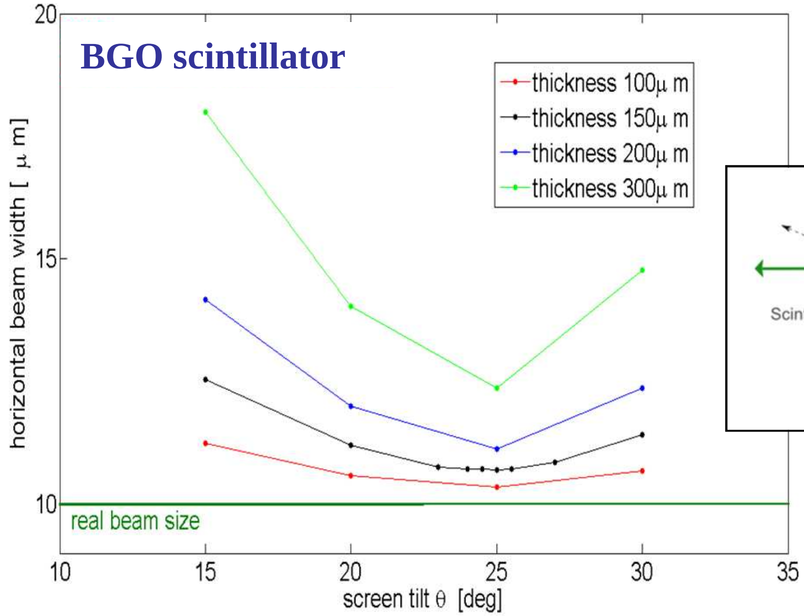
BGO screen, θ = +25°

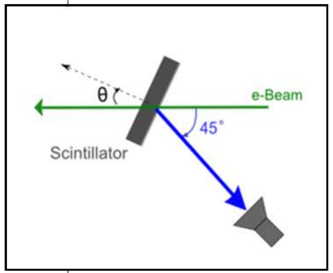


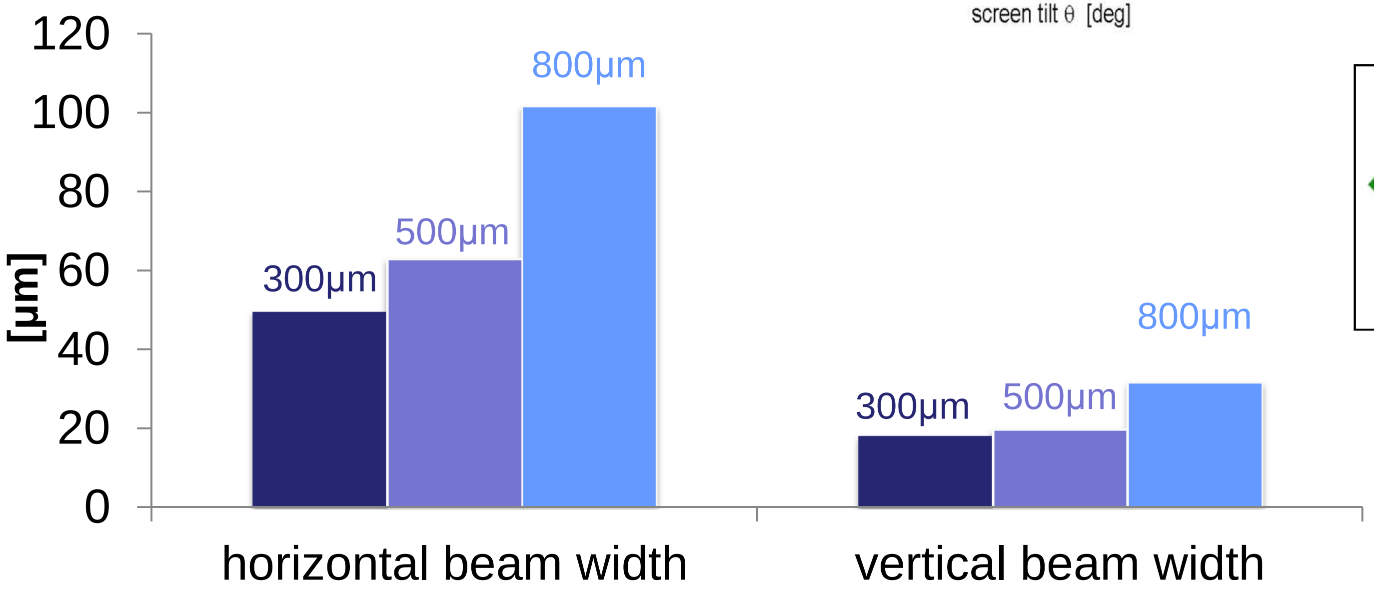
Influence of Scintillator Thickness

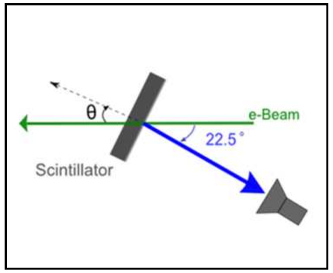
- resolution simulation
  - thicker screen shows worse resolution
  - optimum screen tilt angle not affected by screen thickness

- experiment
  - LYSO sceens with various thicknesses
  - thickness dependence observed









Conclusion and Outlook

- search for high resolution scintillator materials
  - suitable candidates: LYSO:Ce and BGO
- influence of observation geometry
  - considerable influence on spatial resolution
  - basic understanding in frame of geometrical light propagation
- thickness dependence
  - better spatial resolution for thinner crystals
- OTR generation at scintillation screen
  - boundary between scintillation screen and vacuum

    → (C)OTR generation

    → may be reflected to camera
  - different concepts to mitigate COTR effects → spectral / spatial / temporal suppression schemes

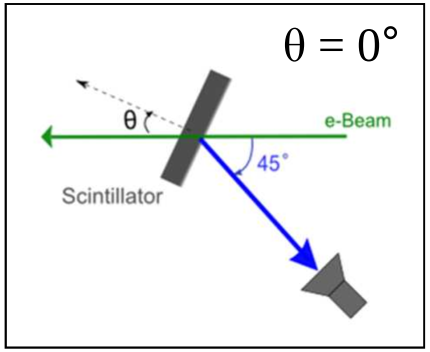
    C. Behrens, C. Gerth, G. Kube, B. Schmidt, S. Wesch, M. Yan, submitted to Phys. Rev. ST Accel. Beams

    http://arxiv.org/abs/1203.1169
- influence on screen monitor design for E-XFEL

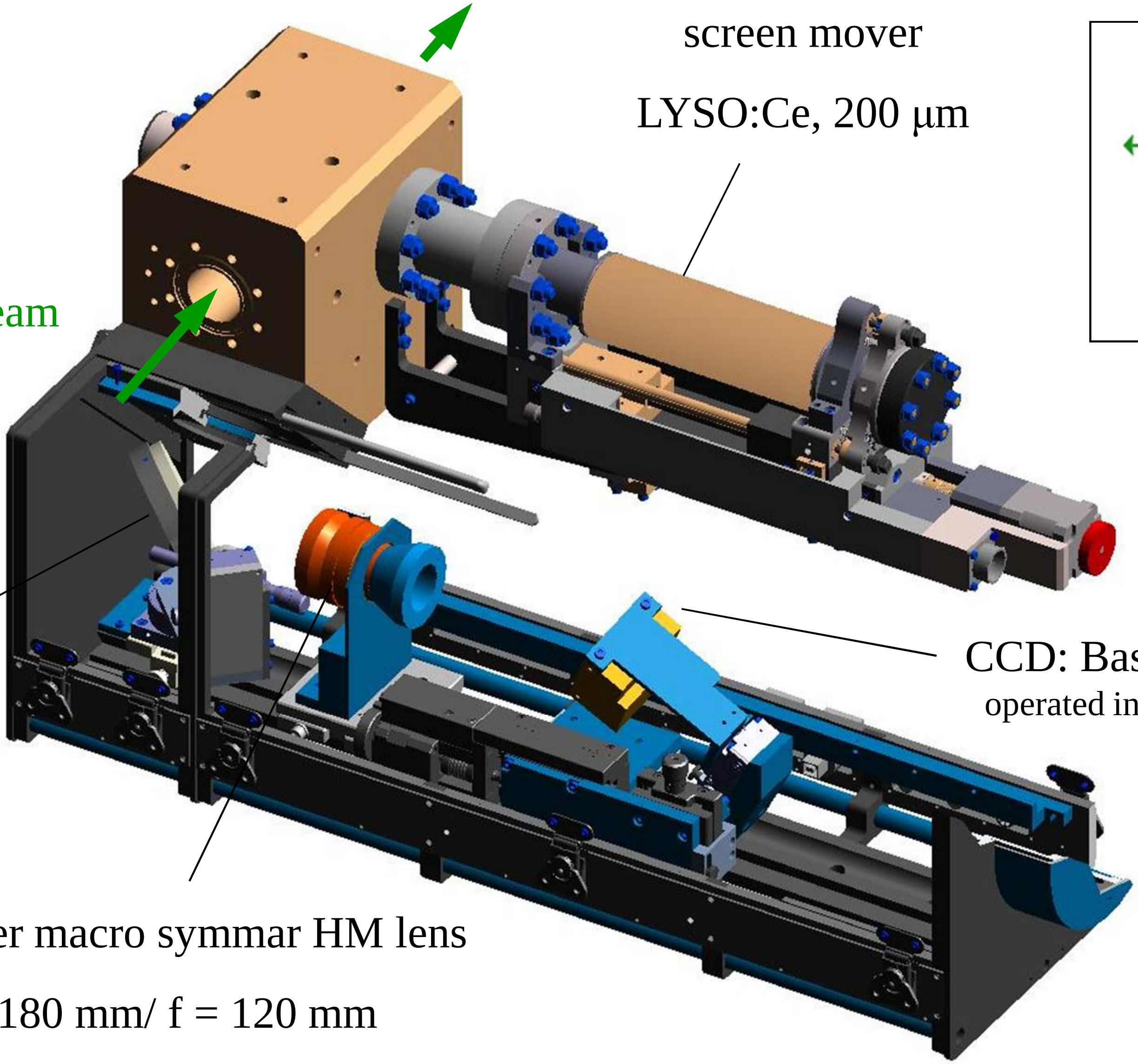
Screen Station for E-XFEL

screen mover

LYSO:Ce, 200 μm



e-beam



mirror

CCD: Basler avA2300-25gm

operated in Scheimpflug geometry

Schneider macro symmar HM lens

f = 180 mm/ f = 120 mm

courtesy:

Ch. Wiebers (DESY)