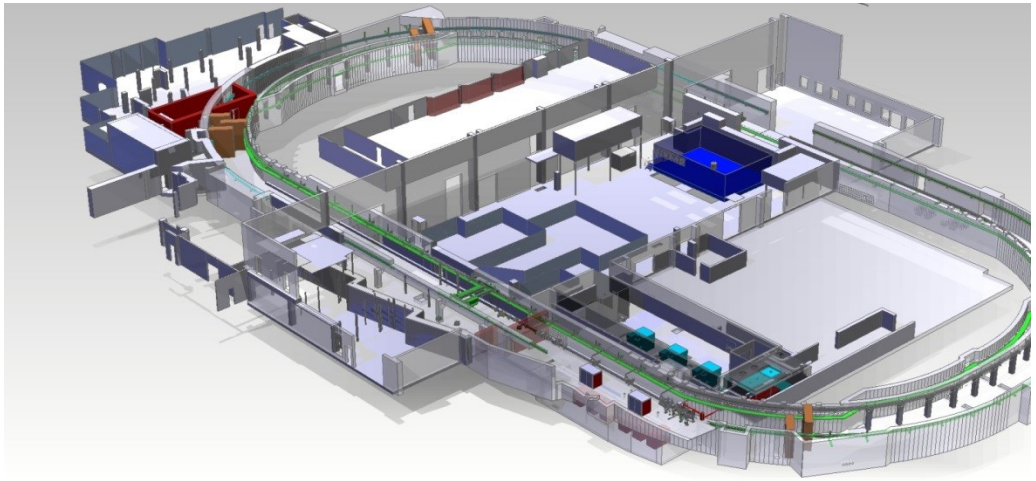
New Measurement Techniques Using a Novel X-band Transverse Deflecting Structure with Variable Polarization

SINBAD



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A Grudiev, B Marchetti
25 September 2017

With thanks to collaborators
and colleagues (listed at end)

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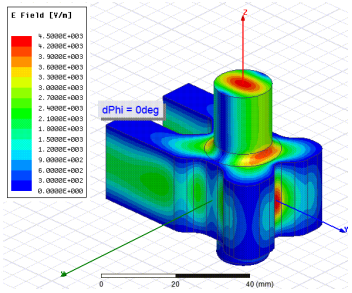
HELMHOLTZ | ASSOCIATION

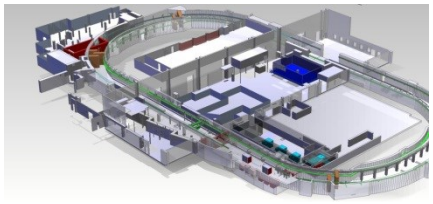
DESY

Outline

- Introduction
  - Technology
  - The collaboration
  - The SINBAD-ARES linac



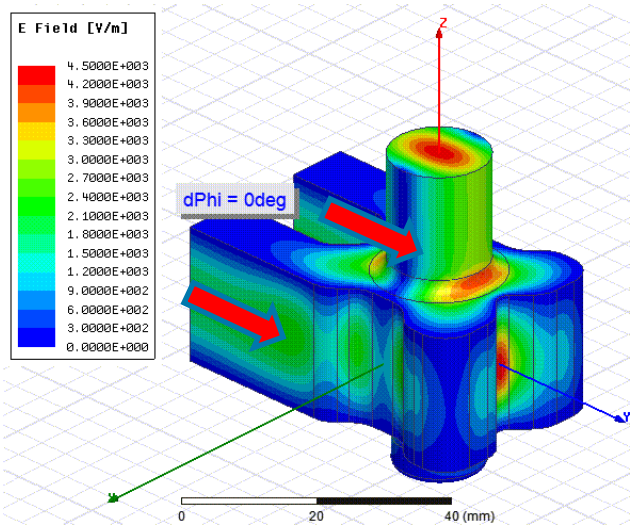
- Planned measurements at SINBAD
  - Overview
  - 3D charge density reconstruction
  - Bunch energy measurement
  - Applications



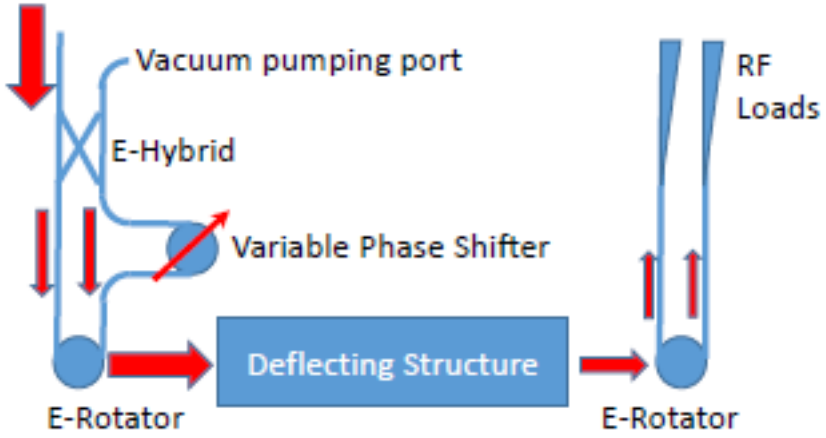
SINBAD

Novel X-band TDS with variable polarization

Variable Polarization Circular TE11 Mode Launcher



A. Grudiev, CLIC-note-1067 (2016)



This new design allows for changing the streaking direction of the TDS.

Collaboration to build and test the first prototype

DESY PAUL SCHERRER INSTITUT CERN

At DESY, also FLASHForward, FLASH2 and potentially XFEL involved

B Marchetti *et al. Proc. IPAC'17*, paper MOPAB044, pp. 184-187.

DESY

SINBAD-ARES linac

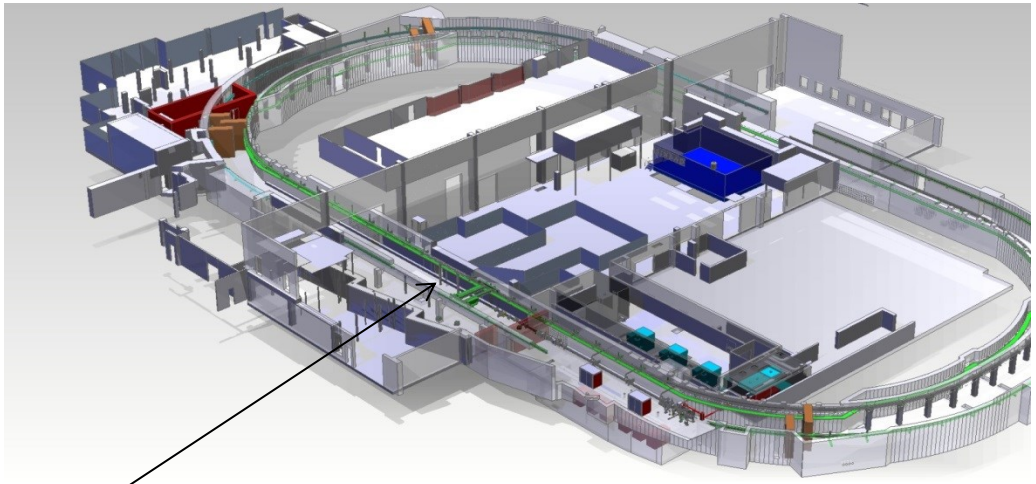
SINBAD

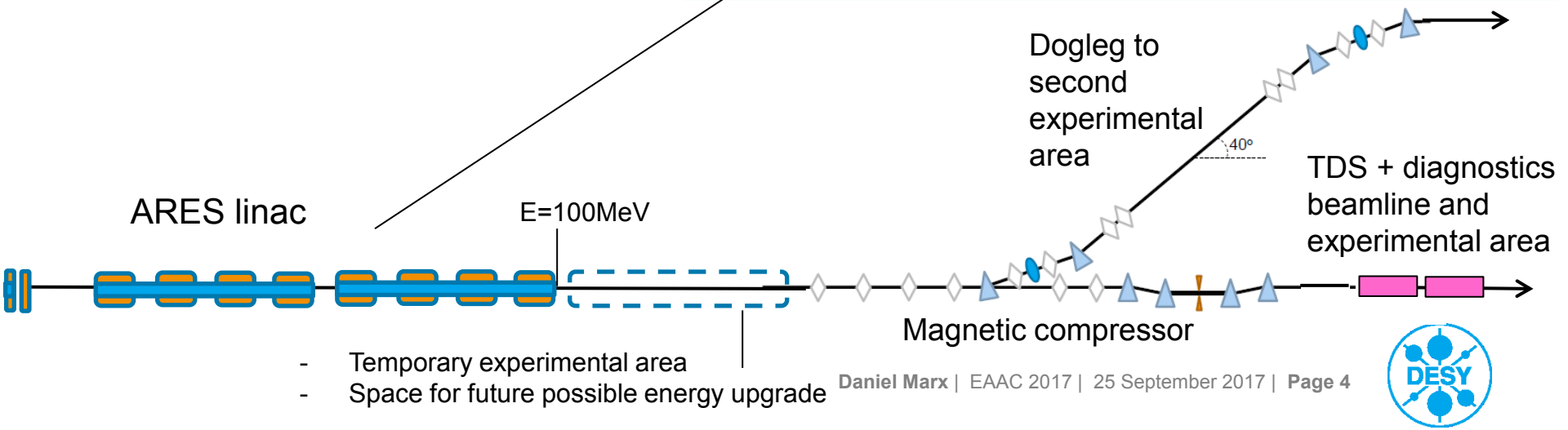
Planned delivery of TDS:
2019-2020

Talk by U Dorda (now)
Talk by J Zhu 18:30 Wednesday

SINBAD overview

U Dorda *et al. Proc. IPAC'17*, paper MOPVA012, pp. 869-872.





DESY

Planned measurements

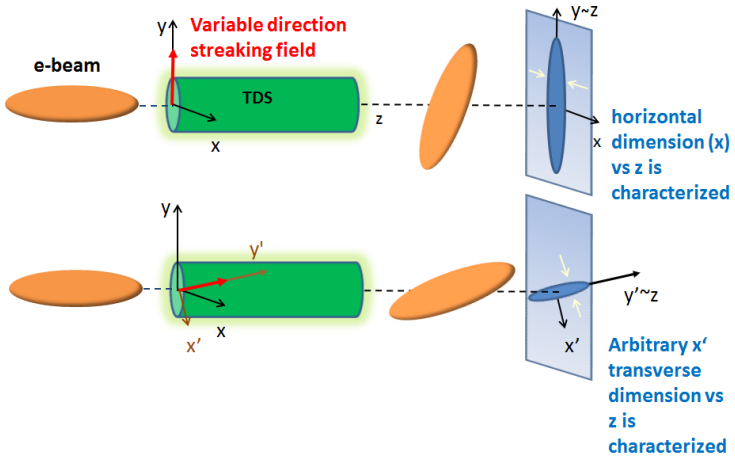
- Bunch Length

- 3D charge density profile using tomographic reconstruction (real space)
- Slice emittance measurement (transverse phase space)
- Slice energy measurement using dipole (longitudinal phase space)

6D phase space characterization

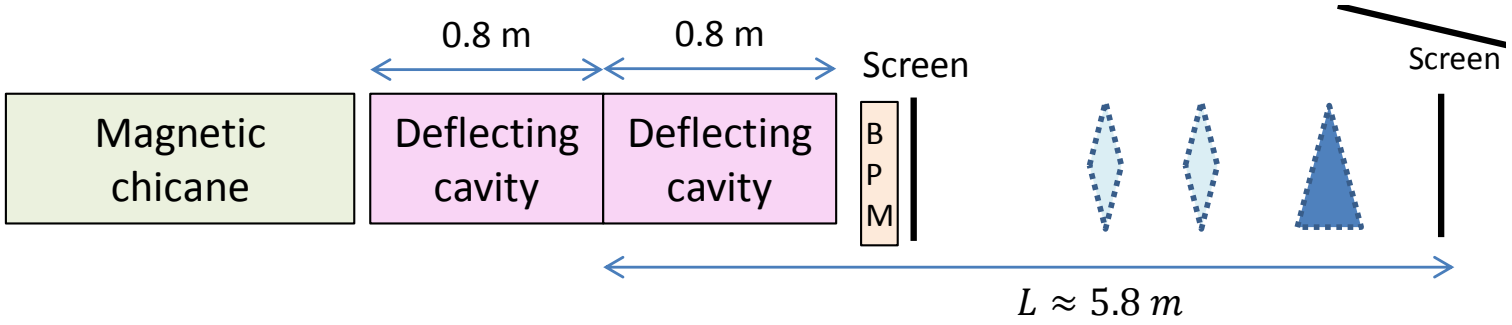
Tomographic reconstruction

- Aim: to reconstruct the 3D charge density distribution
- Relies on streaking at multiple angles => completely new measurement
- Principle:
  - Streak beam at different angles and measure intensity at screen
  - Slice profiles in time
  - Combine 1D profiles from different streaking directions to form a 2D transverse profile for each temporal slice
  - Stack slices together to form complete 3D charge profile reconstruction



D Marx *et al* 2017 *J. Phys.: Conf. Ser.* **874** 012077

Tomographic reconstruction



Not to scale
Magnet & screen positions not yet fixed

~20 MV per cavity = 40 MV max kick

Tomographic reconstruction

Beam parameters:

Energy [MeV]	84.2
Charge [pC]	3
σ_t [fs]	5.15
$\sigma_{x/y}$ [μm]	87.9 / 96.8
$\epsilon_{x/y}^{\text{norm}}$ [mm mrad]	0.224 / 0.190
$\beta_{x/y}$ [m]	5.69 / 8.14
$\alpha_{x/y}$	-0.377 / 0.258

Lattice: TDS (two 0.8-metre cavities) + 5-metre drift

Simulations in *elegant*

Tomographic reconstruction in *Python*

16 streaking angles

No space charge
No jitter
No misalignments

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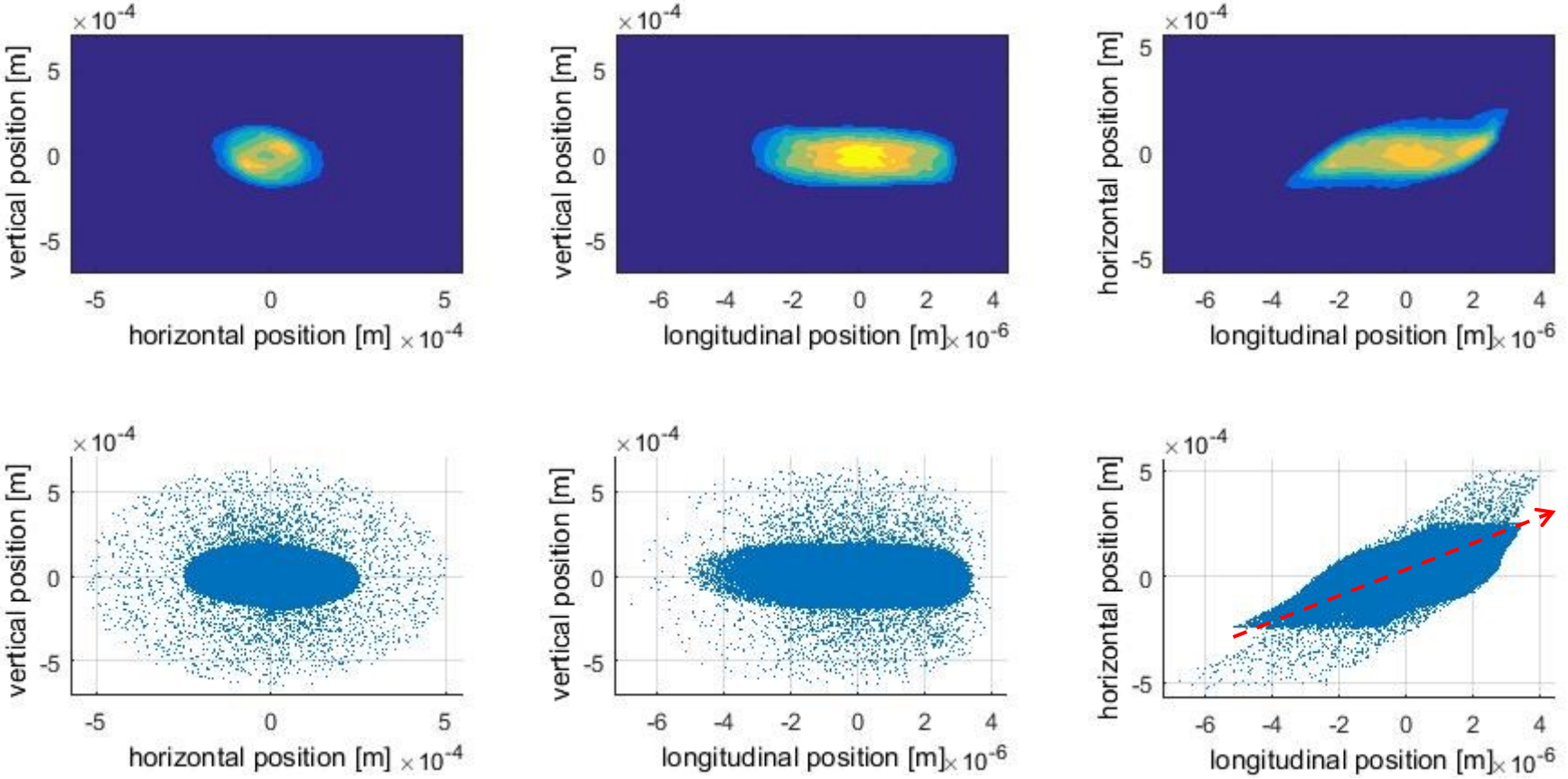
Tomographic reconstruction

Input beam used for test simulations at the TDS

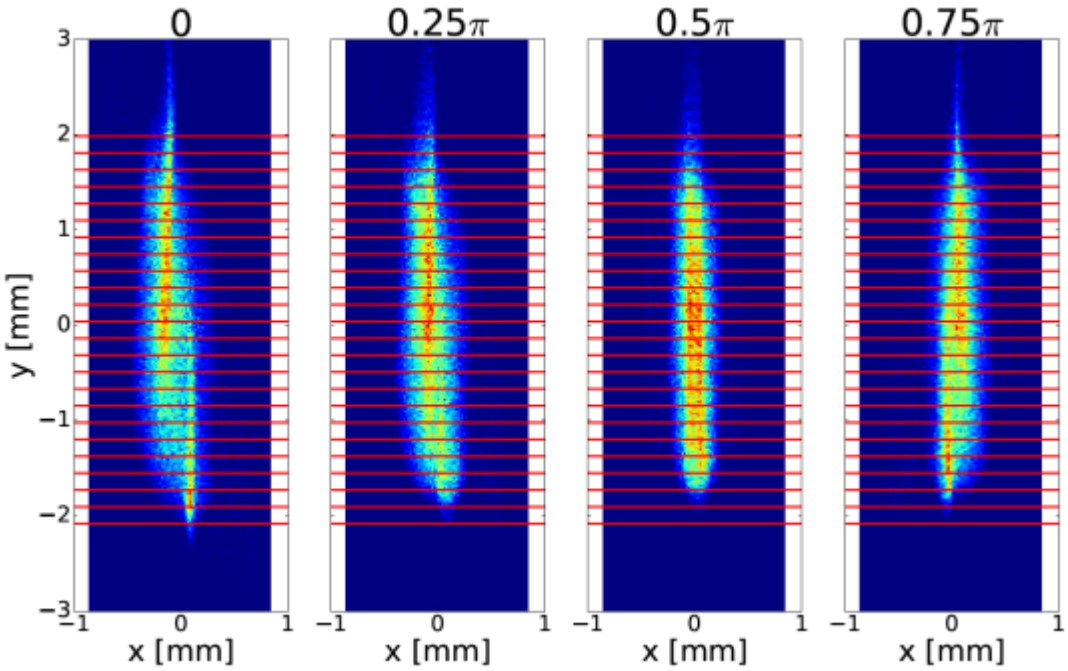


Example of correlation x-z that we wish to detect

Input beam production simulated by J. Zhu

Tomographic reconstruction

- 16 *xy* screen profiles [2D]
  - Convert *y* to *t* and divide into slices (0.85 fs) [2D]



  - For each slice, take projection on *x* axis [1D] and combine using tomographic reconstruction (SART algorithm) [2D]
  - Stack slices [3D]

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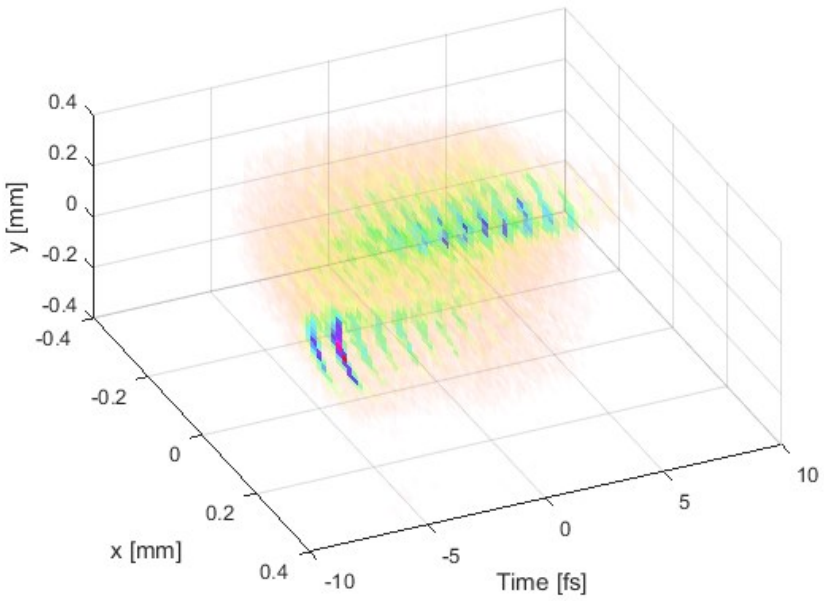
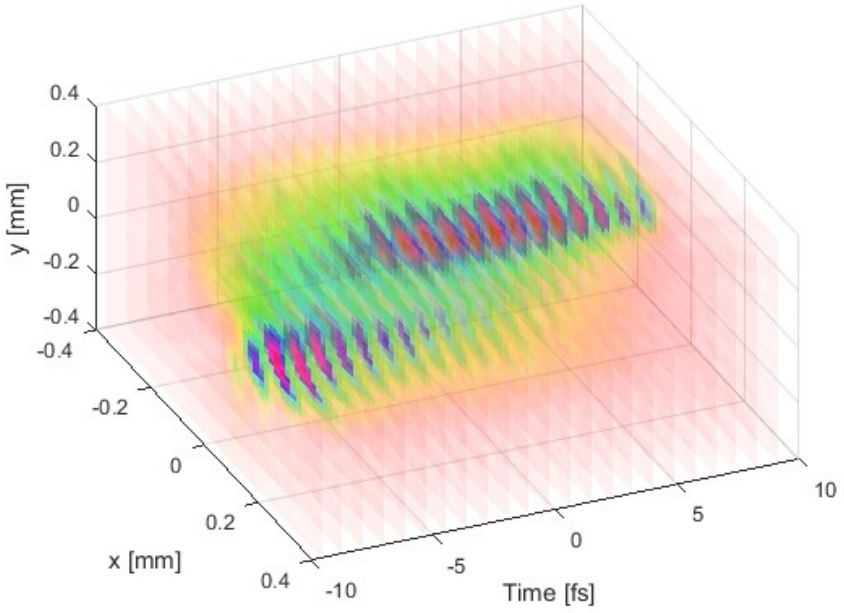
Tomographic reconstruction

Actual distribution at screen with TDS off



Reconstruction



Simulations in *elegant*

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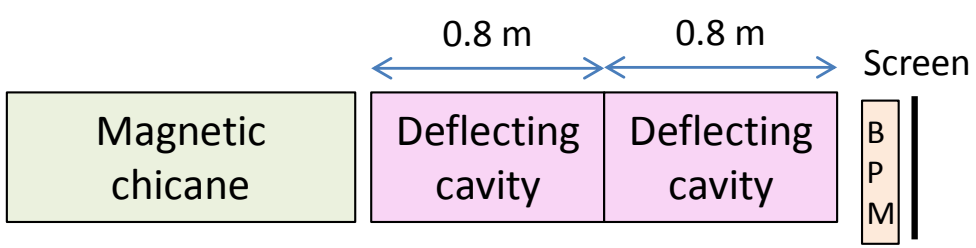
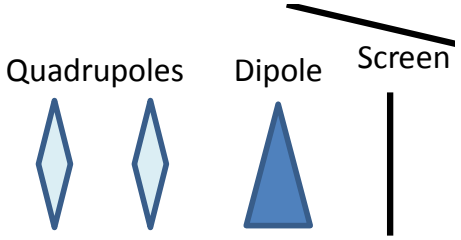
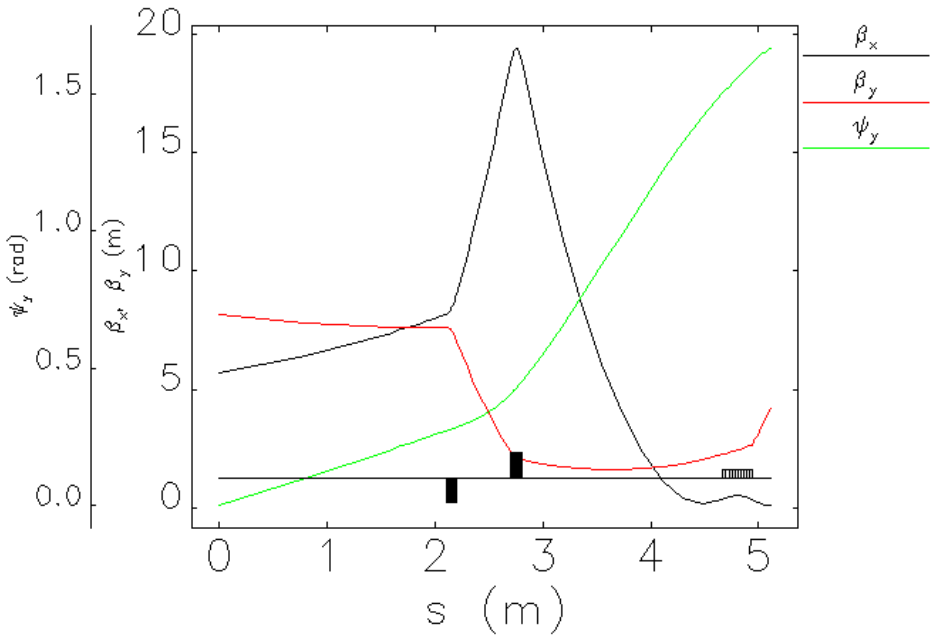
Slice energy measurement

- Combine TDS with dipole





Not to scale



Max field = 1.4 T
Bending angle = 1.331 rad = 76.3°

Induced energy spread

- Panofsky-Wenzel Theorem:
  - Transverse deflection only possible if there is a transverse gradient of the longitudinal electric field present

$$\Delta\vec{p}_\perp = \left(\frac{e}{\omega}\right)\int_0^L (-i)\nabla_\perp E_z dz$$

$$\nabla_\perp E_z \neq 0 \quad \Rightarrow \quad E_z \text{ present}$$

- Relative momentum gain: uncorrelated + correlated

$$\sigma_\delta = \frac{eV_0 k}{pc}\cdot\sigma_y = K\cdot\sigma_y \qquad \frac{d}{dz}\delta = \frac{1}{6}K^2 L$$

- Fundamental resolution limitation

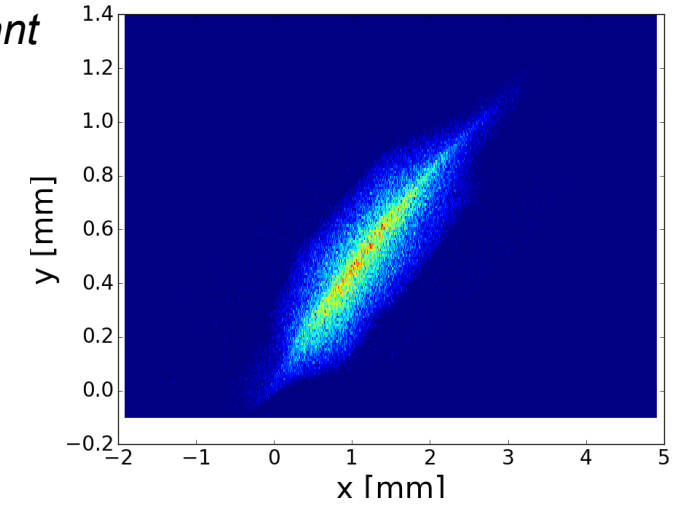
$$\sigma_\delta \cdot \sigma_\zeta > \frac{\epsilon_y}{\sin(\Delta\Phi)}$$

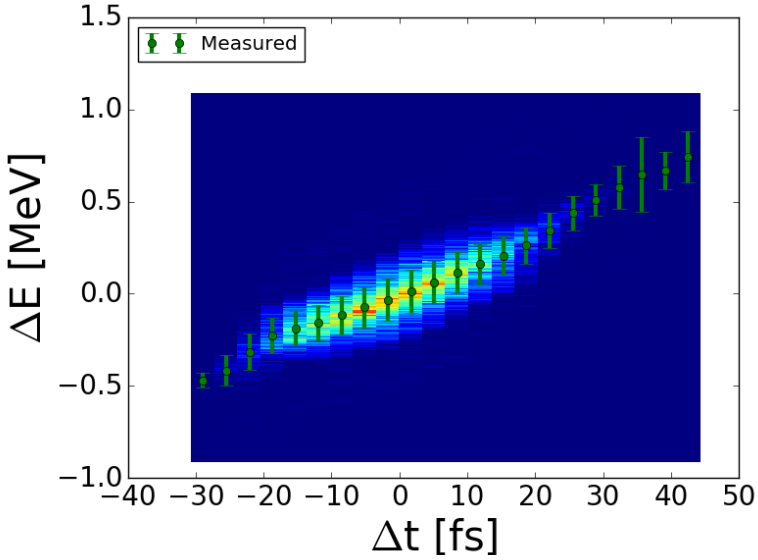
$$T = \begin{pmatrix} 1 & L & KL/2 & 0 \\ 0 & 1 & K & 0 \\ 0 & 0 & 1 & 0 \\ K & KL/2 & K^2L/6 & 1 \end{pmatrix}$$

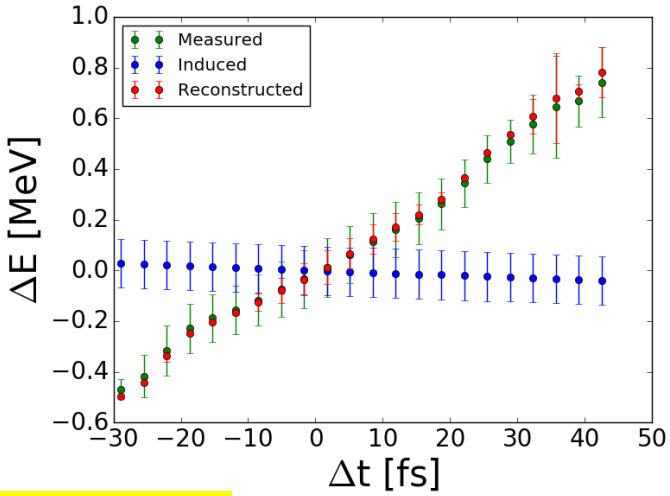
C Behrens and C Gerth, *Proc. DIPAC09*, paper TUPB44
C Behrens and C Gerth, *Proc. DIPAC11*, paper TUPD31

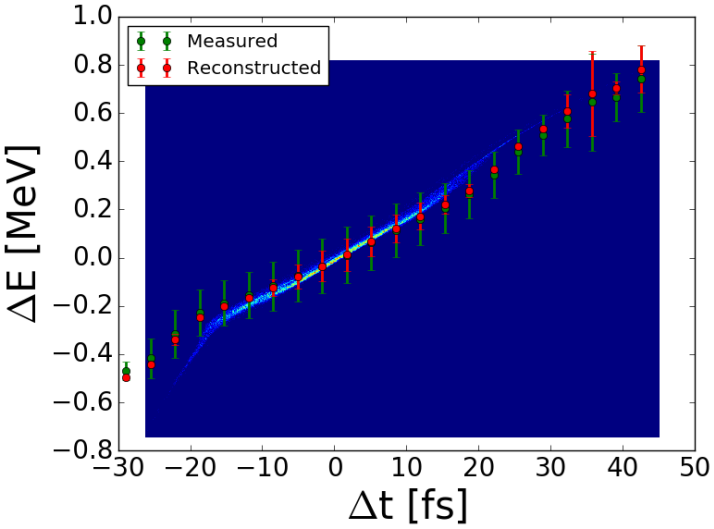
Slice energy measurement

Simulations in *elegant*









2 MV kick per cavity = 4 MV total

Preliminary results for 10.3 fs rms generated beam
No space charge

Applications

- SINBAD will provide short bunches for use as a witness beam in LWFA experiments and for testing dielectric structures
- TDS will allow characterization of input beam
- Dielectric structures
  - Inject asymmetric beams
  - Characterizing beam important for matching & aperture considerations
- LWFA experiments
  - Plasma fields (and matching conditions) have longitudinal dependence in certain regimes
  - Accelerating fields also influenced by beam offsets so charge profile can help, e.g. for beam loading

See W Kuropka & F Mayet posters tonight

Summary

- New X-band TDS being developed for use at DESY & PSI facilities
- Allows streaking of bunch at all angles
- Allows several different measurements of beam, which together provide a characterization of the beam
- Novel 3D charge density reconstruction and longitudinal phase space reconstruction techniques presented
- Induced momentum spread and longitudinal resolution make measurements at short bunch lengths a challenge
- Further studies needed, incl. collective effects
- Key applications for LWFA and dielectric experiments

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Acknowledgements

Present team working on application of X-band technology at DESY:
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