PolariX TDS Project

(Polarizable X-band Transverse Deflection Structure)

Novel device for fs and sub-fs longitudinal beam diagnostics

Barbara Marchetti – MPY1
for DESY team working on the PolariX TDS (see next slides)

Hamburg, 7th September 2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Transverse Deflection Structures - Basics

Transverse Deflection Structures and Crab Cavities

The longitudinal distribution of the e-bunch is mapped into the transverse one thanks to the time dependent transverse deflecting field

Working Principle:

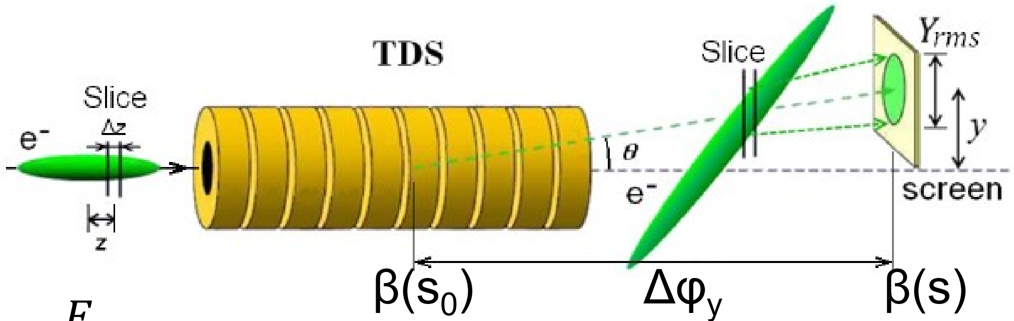


Fig. Credits: D. Malyutin PhD thesis

$$R_t = \frac{\sigma_{y,off}}{S_{y,t}} = \frac{\sqrt{\varepsilon_y \beta_y(s)}}{\sqrt{\beta_y(s)\beta_y(s_0)} sin(\Delta\varphi_y)} \frac{E}{\omega e V_0}$$

Frequency **~12GHz (X-band)** allows having 4 times higher resolution than **~3GHz (S-band)**

e-bunch:

- Kinetic Energy E
- Vertical geometric emittance ε_y

Magnetic Lattice:

- Phase advance in y plane $\Delta\varphi_y$
- Beta function in the TDS $\beta_y(s_0)$

RF cavity:

- Frequency $f = \omega/(2\pi)$
- Peak deflection voltage V_y

In this example streaking on y plane.

Cfr: P. Emma et al., LCLS-TN-00-12
M. Röhrs et. al., PRSTAB 12 050704 (2009)

TDS Capabilities

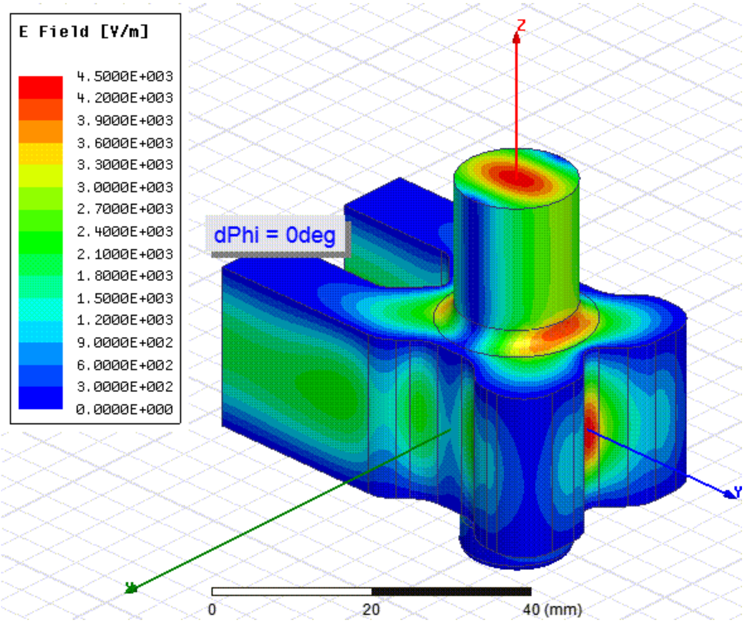
RF deflectors allow a comprehensive characterization of the e-bunch

- **Bunch length** measurement
- **Longitudinal charge profile** measurement
- Combined with dipole → **longitudinal phase space** measurement
- Combined with quadrupole scan or multi-screen lattice → **slice emittance** measurement <u>on the plane perpendicular to the streaking direction</u>, **slice transverse phase space** reconstruction
- <u>**Method capable of fs and sub-fs longitudinal resolution**</u>

Cfr:
- C. Behrens *et al.*, Nat. Commun. **5**, 3762 (2014)
- J. Maxons *et al.*, PRL **118**, 154802 (2017)

Novel TDS Concept

PolariX TDS RF Design - CERN

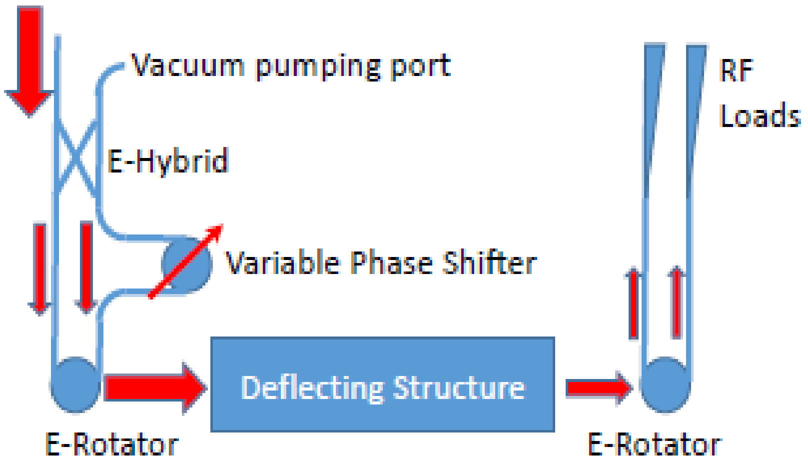


Variable Polarization Circular TE11 Mode Launcher

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

Phase difference between port 1 and port 2:

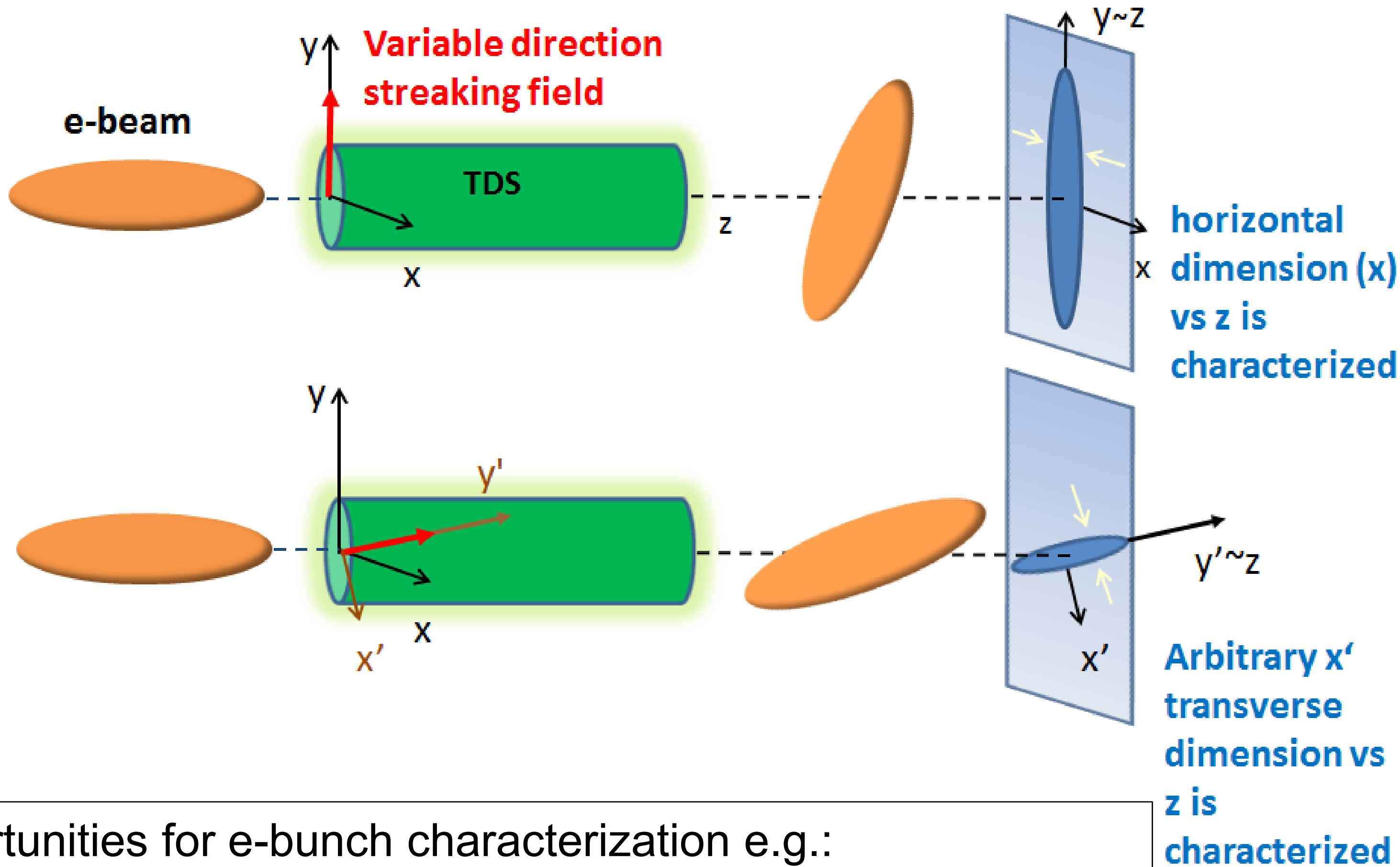
- 0 degree -> vertically streaking field
- 180 degree -> horizontally streaking field



Novel X-band TDS Concept with Variable Polarization

Impact on Applications

Characterization of arbitrary x' direction versus z possible



New opportunities for e-bunch characterization e.g.:

- slice emittance measurement on different planes
- 3D charge density distribution reconstruction (see next slides)
- potentially 6D beam phase space characterization

Modes of the RF cavity and Tolerances

- The structure supports only the propagation of the operating modes TM11x and TM11y at the cavity operating frequency.
- **BOTH these polarizations must be synchronized with the beam**, otherwise the polarization phase will rotate and the integrated dipolar kick in the operating plane will be reduced.

High azimuthal symmetry is required !

See talk A.Grudiev at the CLIC Workshop, CERN 7/03/2017

Modes of the RF cavity and Tolerances

- **Tuning Free Assembly Procedure* developed at PSI allows the fulfillment of the tolerances**
  - Allows for maintaining the cups shape after assembly (no RF tuning needed);
  - Developed by PSI for fabricating 104 structures in the Swiss FEL linac;
  - Collaboration CERN-PSI on first-tuning-free X-band Structures: CLIC X-band prototypes.

Dominant axially symmetric error

- **Machining precision down to 2 µm** can be obtained for the cups**
- **Max deviation of cups from straight trajectory** usually **< 20um****

Dominant axially non-symmetric error

*U. Ellenberger *et al.*, *Proc. FEL 2013, paper TUPSO17*
** See talk by P. Craievich CLIC Workshop 2017

History and Status of DESY-CERN-PSI Collaboration

Collection of potential users in 2016

At DESY

- **FLASHForward**
  - PWFA experiment
- **FLASH2**
  - FEL single spike at ~30 nm wavelength
- **SINBAD**
  - LWFA, DLA, THz driven acceleration etc.
- **Potentially XFEL**

At PSI

- **ATHOS** at SwissFEL
  - Soft X-rays FEL

DESY-CERN-PSI Collaboration

Contract Agreement signed beginning 2018

- Goal: Develop PolariX TDS with variable polarization
- Cavity design and RF distribution system were developed by CERN
- **Common Mechanical Design** of the cavity fulfills the requirements of many experiments:
  - FLASHForward, FLASH2, SINBAD at DESY. XFEL observer of the project.
  - ATHOS beamline at SwissFEL.
- Cavity will be assembled at PSI using the tuning free assembly procedure (2018).
- **Test of the prototype cavity** with beam at **DESY** (**FLASHForward** beamline, 2019).
- After successful test of the prototype **six other cavities will be produced** for the experiments (starting in 2019).

Project Updates

IPAC 17, MOPAB044

X-BAND TDS PROJECT

B. Marchetti*, R. Assmann, B. Beutner, J. Branlard, F. Christie, R. D‘ Arcy, W. Decking,
U. Dorda, J. Herrmann, M. Hoffmann, M. Huening,
O. Krebs, G. Kube, S. Lederer, F. Ludwig, F. Marutzky, D. Marx, J. Osterhoff,
I. Peperkorn, S. Pfeiffer, F. Poblotzki, J. Roensch-Schulenburg, J. Rothenburg, H. Schlarb,
M. Scholz, S. Schreiber, M. Vogt, A. de Z. Wagner, T. Wilksen, K. Wittenburg
DESY, 22607 Hamburg, Germany
A. Grudiev, N. Catalan Lasheras, G. Mcmonagle, W. Wuensch
CERN, 1211 Geneva 23, Switzerland
P. Craievich , M. Bopp, H.-H. Braun, M. Pedrozzi, E. Prat, S. Reiche, K. Rolli, R. Zennaro
PSI, 5232 Villigen PSI, Switzerland

STATUS OF THE PolariX-TDS PROJECT

IPAC 18, THPAL068

P. Craievich*, M. Bopp, H. Braun, R. Ganter, T. Kleeb, M. Pedrozzi, E. Prat, S. Reiche, R. Zennaro
Paul Scherrer Institut, 5232 Villigen PSI, Switzerland
A. Grudiev, N. Catalan Lasheras, G. McMonagle, W. Wuensch
CERN, 1211 Geneva 23, Switzerland
B. Marchetti, R. Assmann, F. Christie, R. D’Arcy, U. Dorda, M. Foese, P. Gonzalez Caminal,
M. Hoffmann, M. Huening, R. Jonas, O. Krebs, S. Lederer, V. Libov, D. Marx, J. Osterhoff,
F. Poblotzki, M. Reukauff, H. Schlarb, S. Schreiber, G. Tews, M. Vogt, A. de Z. Wagner
DESY, 22607 Hamburg, Germany

Common Parameter table

IPAC 17, MOPAB044

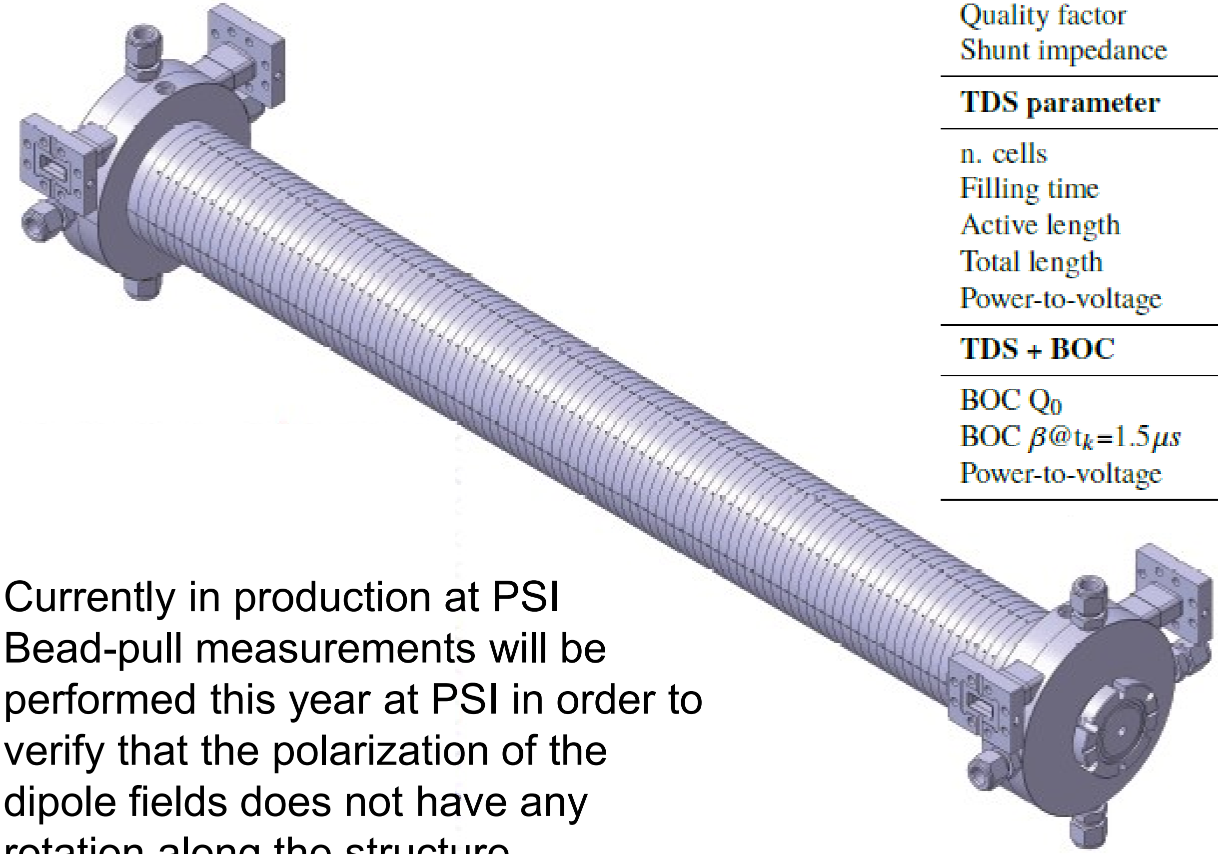
Parameters	SINBAD	FLASH II	FLASHForward	ATHOS SwissFEL	Unit
Charge	0.5-30	20-1000	20-500 (driver) 10-250 (witness)	10-200	pC
Norm. emit. (rms)	0.1-1	0.4-3	2.0-5.0 (driver) 0.1-1.0 (witness)	0.3	mm
Bunch length (rms)	0.2-10	<3-200	50-500 (driver) 1-10 (witness	2-30	fs
β function @TDS	10-50	7-20	50-200	50	m
Beam energy	80-200	400-1400	500-2500	3400	MeV
Rep. rate	10-50*	10**	10**	100*	Hz
TDS voltage	25-40	30-45	25-30	30-60	MV
# TDS	2	2	1	2	
Max. length (flange to flange)	3	<1.91(8)	<2	4	m
TDS iris	4	4	4	4	mm
TDS frequency	11991.6	11988.8	11988.8	11995.2	MHz
Temperature range	48	62	62	25-35	°C

* single bunch
** 10 Hz per burst, 40 kHz-1MHz in burst, maximum burst length 800ms (minimum bunch distance 1ms)

RF Structure Design and Tolerances

Constant Impedance,
back-wards travelling wave
structure

Cell parameter		Unit	
Frequency	11995.2	MHz	
Phase advance/cell	120	°	
Iris radius	4	mm	
Iris thickness	2.6	mm	
Group velocity	-2.666	$\%c$	
Quality factor	6490		
Shunt impedance	50	$M\Omega/m$	
TDS parameter	**Short**	**Long**	**Unit**
n. cells	96	120	
Filling time	104.5	129.5	ns
Active length	800	1000	mm
Total length	960	1160	mm
Power-to-voltage	5.225	6.124	$MV/MW^{0.5}$
TDS + BOC	**Short**	**Long**	**Unit**
BOC Q_0	145000	145000	
BOC $\beta@t_k=1.5\mu s$	7	7	
Power-to-voltage	12.010	13.626	$MV/MW^{0.5}$

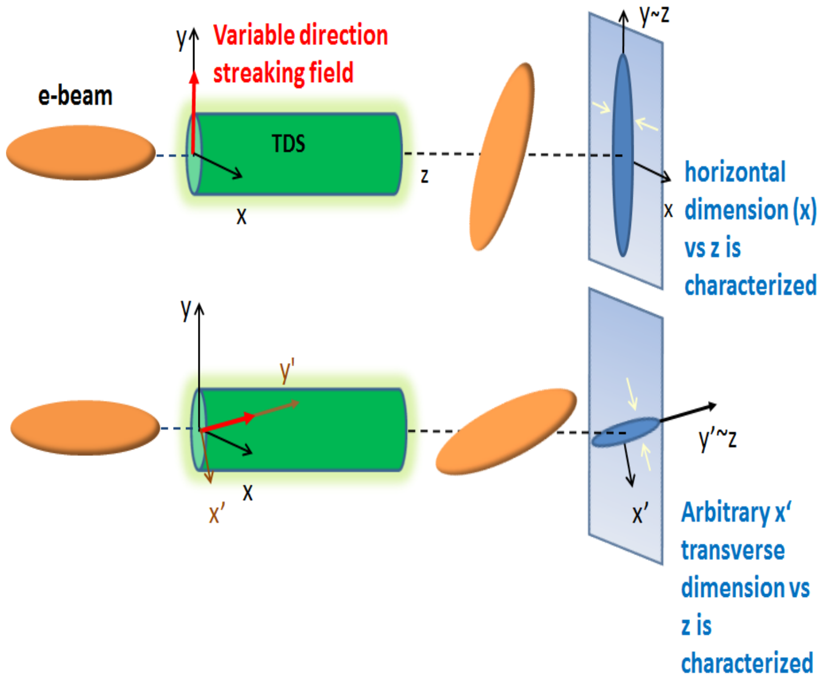


- Currently in production at PSI
- Bead-pull measurements will be performed this year at PSI in order to verify that the polarization of the dipole fields does not have any rotation along the structure

IPAC 18, THPAL068

Ultimate Goal: Novel Applications in fs/sub-fs Beam Diagnostics

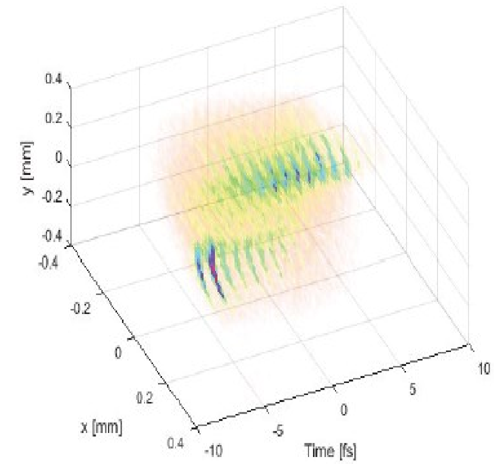
3D Charge Distribution Reconstruction



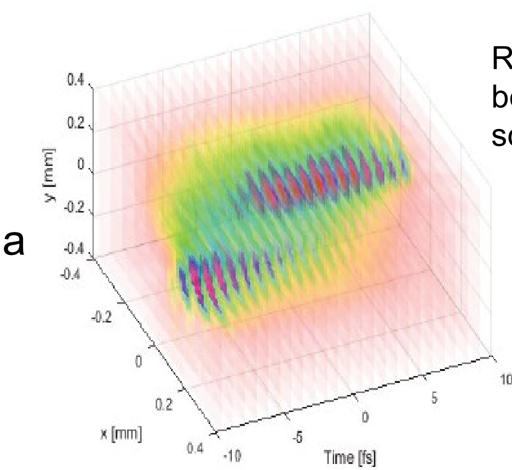
- Beam streaked in different directions;
- Reconstruction of 3D charge density distribution using a tomographic algorithm;

- Simulation done with Elegant (TDS matrix formalism);
- 3D space charge force not included.

Example of beam reconstruction (simulation) for the ARES linac



Original beam at the screen (TDS off)



Reconstructed beam at the screen

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

Example of potential Challenges towards the final Goal

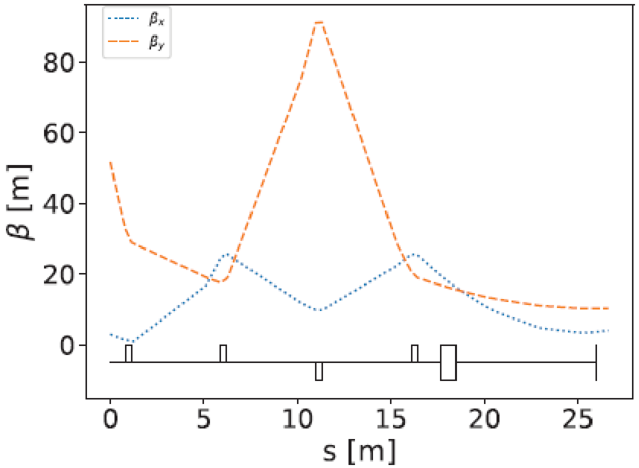
- Specific field distribution of the cavity:
  - Machining imperfections
  - RF-field imperfections
  - Potential coupling between RF-knobs (e.g. amplitude, phase, polarization etc.)
- Stability/Reproducibility of the measurements:
  - Stability of the temperature of the cavity
  - Stability of the phase/amplitude of the cavity
  - Stability of the orbit of the beam and its alignment
  - Vacuum activity for high power measurements
- Reliability of the measurement calibration
- Specific to SINBAD-ARES: control space charge effect and beam elongation
- Etc…

PolariX TDS Network within DESY

Goal: share knowledge and contribute to the preparatory work for the prototype commissioning

- **34 mailing-list subscribers** from different groups (MPY1, FLA, MFL, MPY, MXL, MIN, MVS, MSK, MKK, MDI);
- Invitation to **PolariX TDS monthly meetings** (average attendance ~ 10 people)
- The meetings are used for DESY-**INTERNAL** and **EXTERNAL** coordination:
  - General updates about the project (e.g. review meetings, publications);
  - Clarify technical questions regarding interfaces with CERN and PSI (via video-conferences);
  - Request technical information within the collaboration (e.g. technical drawings);
  - Status of infrastructure work and installation planning for the prototype cavity @ FLASHForward (coordinated by R. D'Arcy);
  - Status of the procurement and performances of components of the RF station and RF network (M. Huening, G. Tews, R. Jonas);
  - Overall strategy for the commissioning of the cavity;
  - Beam Dynamics simulations;
  - Technical issues.

Simulations of 3D Charge Reconstruction for Prototype Commissioning at FLASHForward



$$R_t \approx \frac{\sigma_y^{\text{off}} |p| c}{2\pi f e V_0 L} \quad \Rightarrow$$

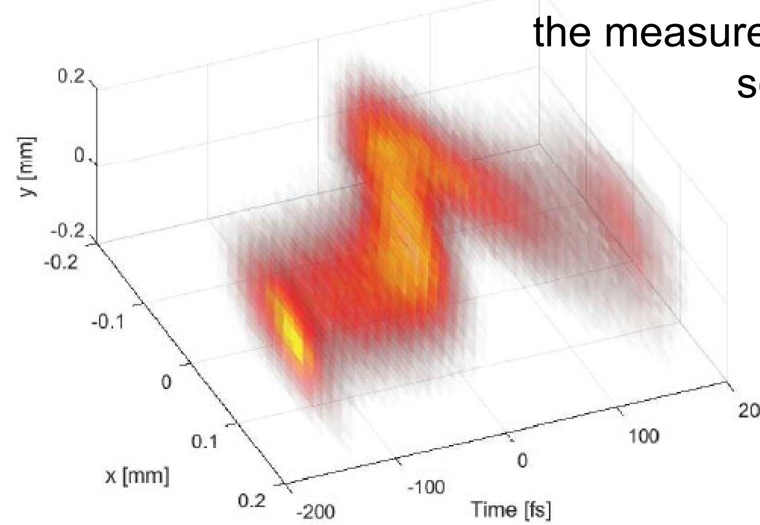
V_0=14 MV
R_t~10 fs

- Simulation done with Elegant (TDS matrix formalism)
- 3D space charge force not included

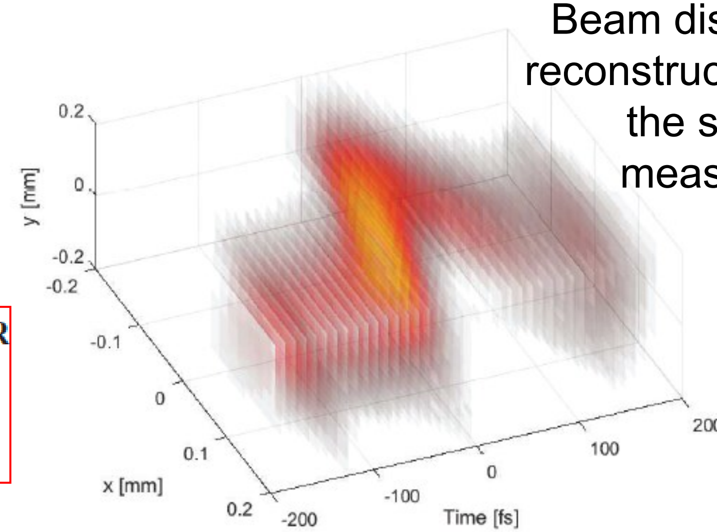
SIMULATIONS OF 3D CHARGE DENSITY MEASUREMENTS FOR COMMISSIONING OF THE PolariX-TDS

D. Marx[1,*], R. Assmann, R. D'Arcy, B. Marchetti, DESY, 22607 Hamburg, Germany
[1]also at University of Hamburg, Germany

Beam distribution at the measurement screen



Beam distribution reconstructed from the simulated measurement



Other Applications of PolariX TDS in different Experiments

- **FLASHForward**
  - R. D'Arcy et al., Proc. of IPAC18, paper TUPML017, (2018);
- **FLASH2**
  - F. Christie et al., Proc. IPAC'17, paper WEPAB017, (2017);
- **SINBAD-ARES**
  - D. Marx et al., J. Phys.: Conf. Ser., vol. 874, p. 012077, (2017);
  - D. Marx et al., J. Phys.: Conf. Ser., vol. 874, p. 012078, (2017);
  - D. Marx et al., Nucl. Inst. And Meth, A (2018);
- **ATHOS**
  - P. Craievich et al., Proc. FEL'17, paper WEP040, (2017).

Conclusions

- A novel TDS design (called PolariX TDS) , invented by CERN, with possibility of changing the streaking direction of the field is being realized thanks to a **collaboration of DESY with CERN and PSI**.
- At DESY several experiments are involved in the project: **SINBAD, FLASHForward, FLASH2**. Moreover **XFEL** joins the PolariX TDS Network.
- This design would allow performing **3D reconstruction of the charge density** in electron bunches.
- The prototype cavity is currently in production (PSI). Next steps: assembly and low power characterization of the RF fields.
- **First installation of the prototype: Summer 2019 at FLASHForward.** Preparation ongoing.
- After successful test of the prototype, **series production** for installation at FLASH2, SINBAD (at DESY) and ATHOS (at PSI).

Thank you for the attention!

… Are there any questions?

Contact

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