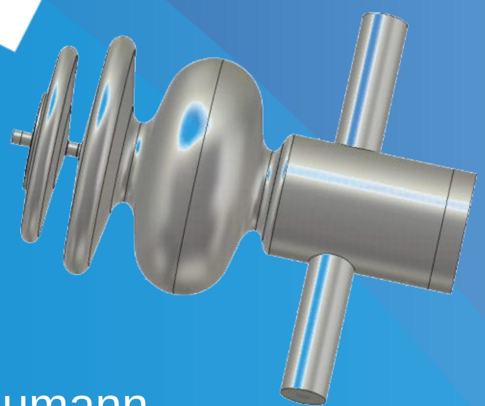
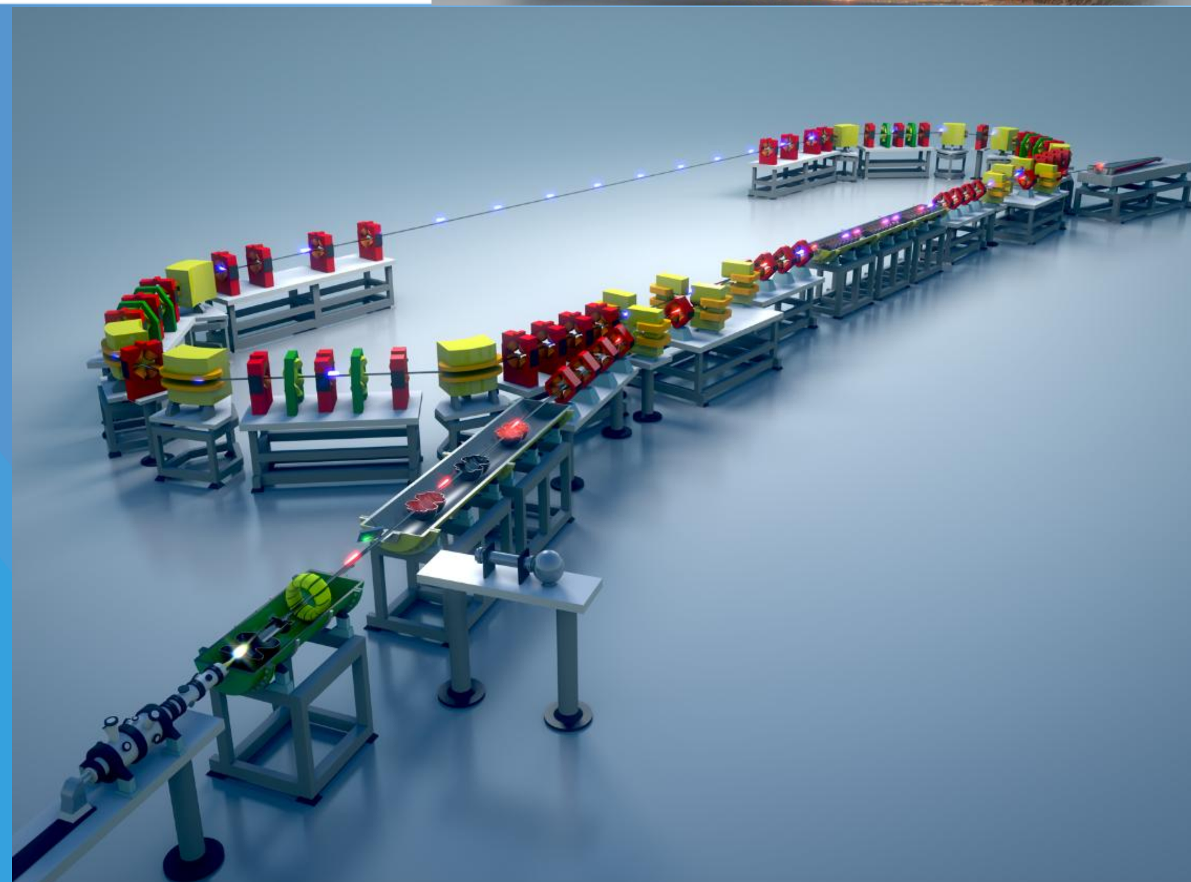
Photoinjector SRF Cavity Development for B*ERL*inPro

THPB066 (+ THPB069, *T. Kamps et al.*)



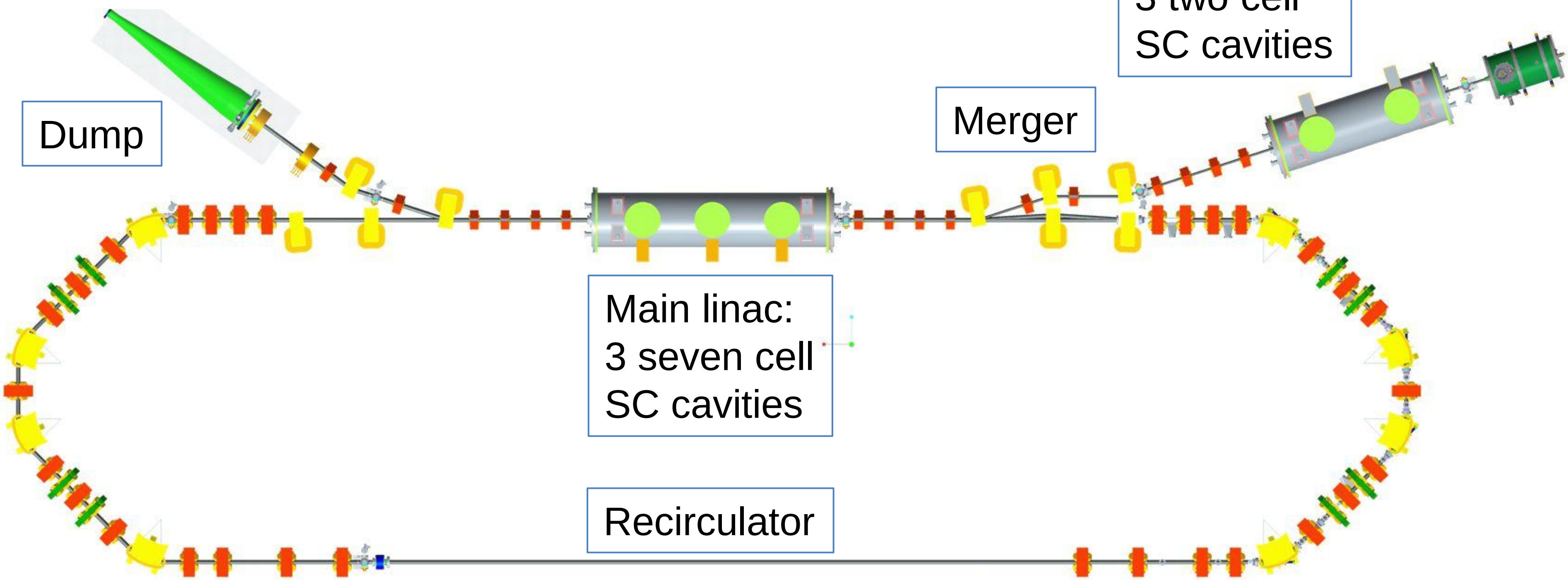


Axel Neumann
W. Anders, T. Kamps,
J. Knobloch
E. Zaplatin (FZ Jülich)

LINAC12, 13.09.2012
Tel Aviv, Israel

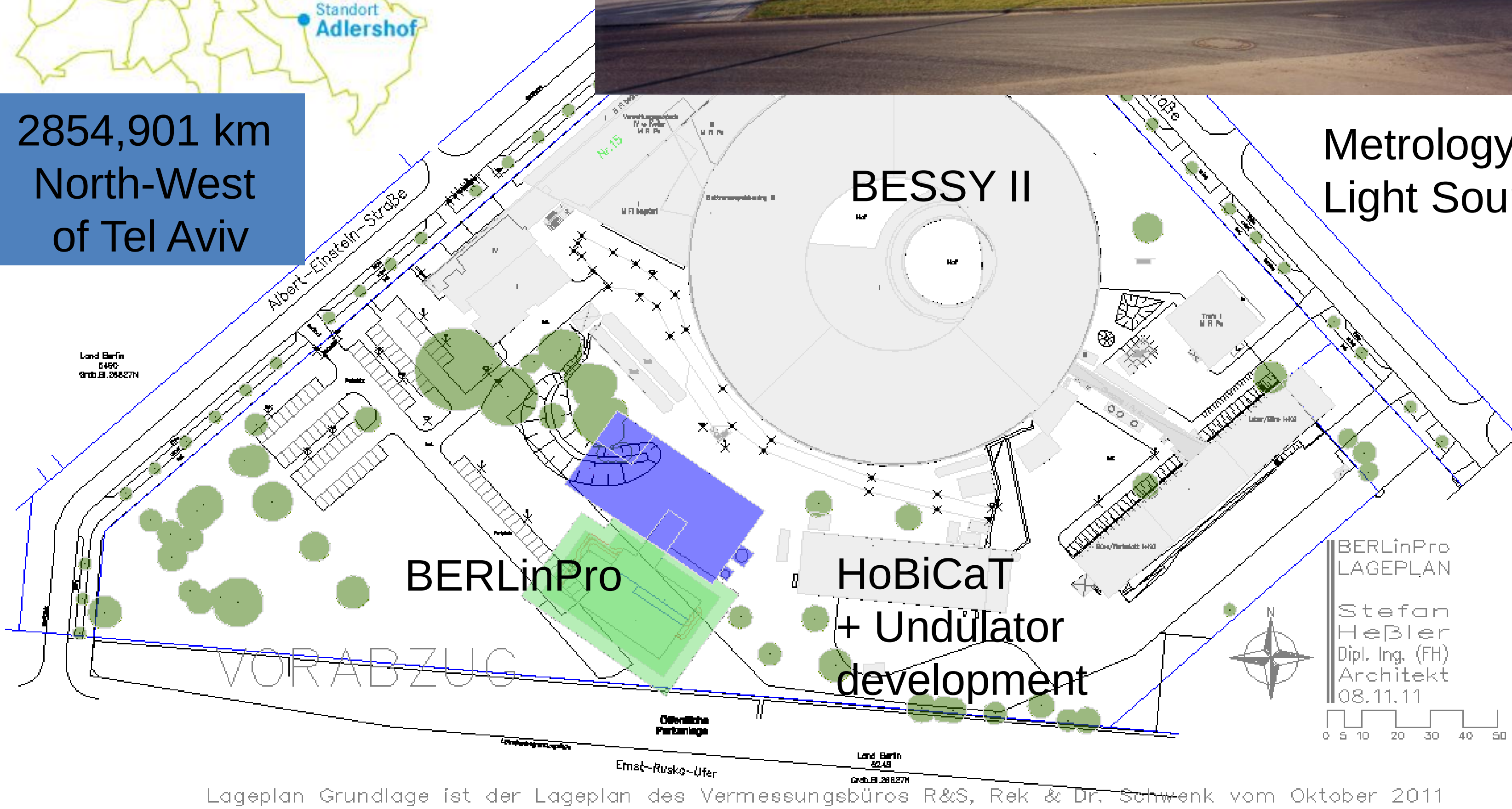
(current) Layout of *BERL*inPro

	Basic Mode	Short Bunch Mode
Bunch charge, pC	**77**	~ 10
Bunch repetition rate, GHz	**1.3**	variable
Max average current, mA	**100**	≤ 1
Beam kinetic energy, MeV	**50**	50
Transv. emitt., norm., mm mrad	**~ 1**	1…5
Bunch length, ps, rms	**2.0**	0.1
Relative energy spread, % rms	**~ 0.5**	1…3

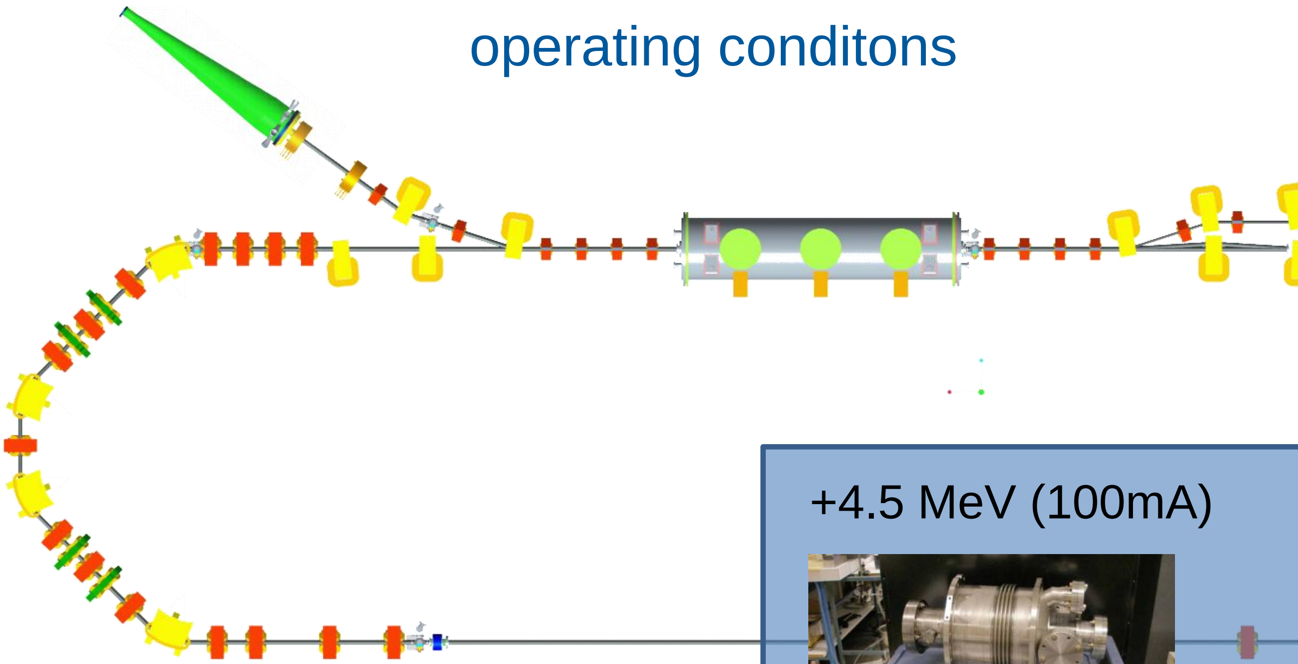


Site for BERLinPro

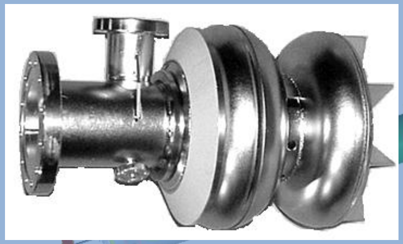
2854,901 km
North-West
of Tel Aviv



BERLinPro: Cavity types and operating conditons



SRF Photo-injector



1.5-2 MeV, 100 mA

- High beam power
- High beam current
- Intermediate field levels 12 MV/m

→ **Beam pipe absorber**

+4.5 MeV (100mA)

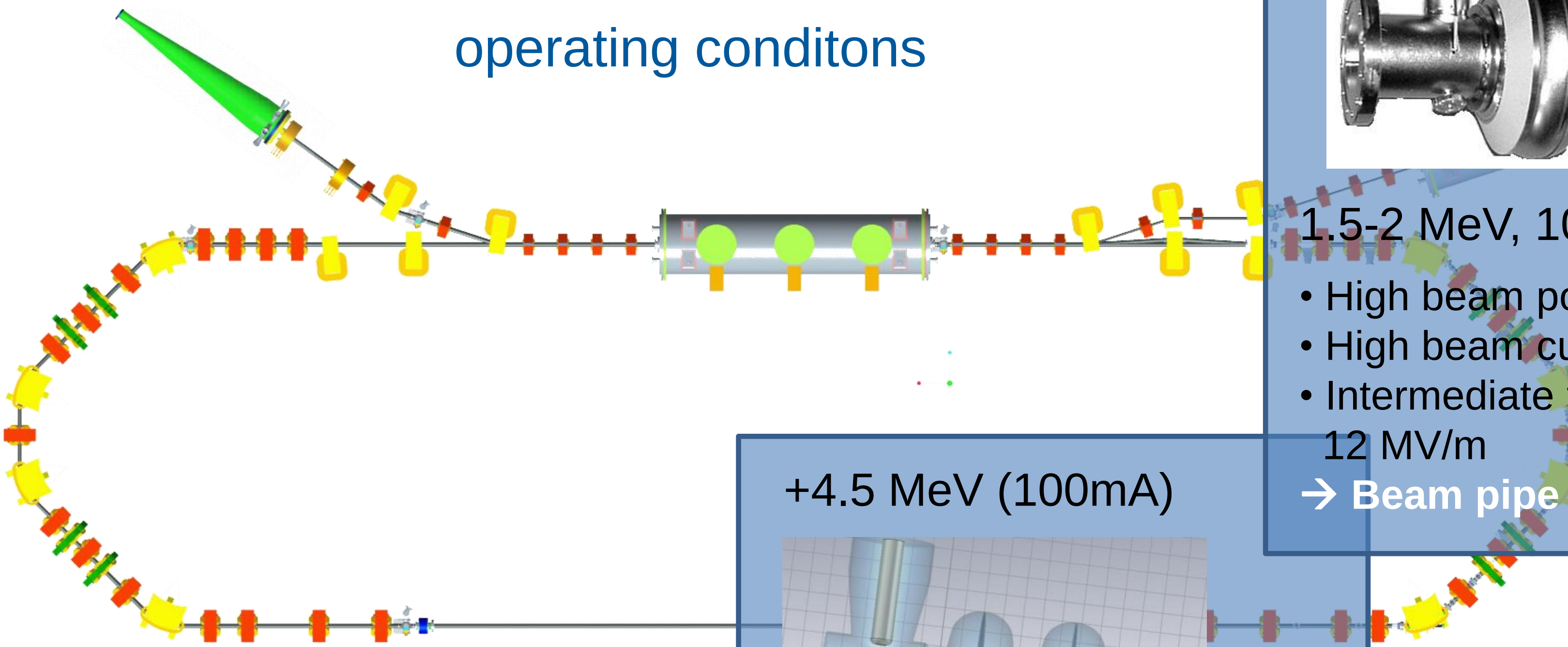
SRF booster cavity (Cornell)

- High beam power
- High beam current
- Intermediate field levels 10 MV/m

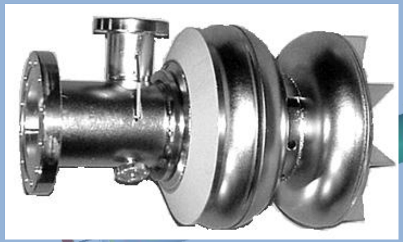
→ **Beam pipe absorber**

SRF CW Mode machine

BERLinPro: Cavity types and operating conditons



SRF Photo-injector



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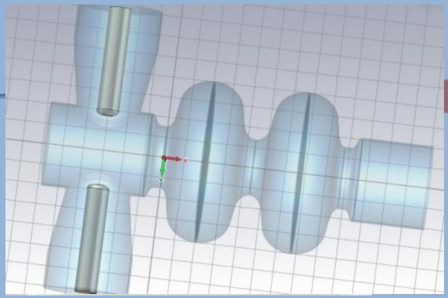


SRF booster cavity (Cornell)

- High beam power
- High beam current
- Intermediate field levels 10 MV/m

→ **Beam pipe absorber**

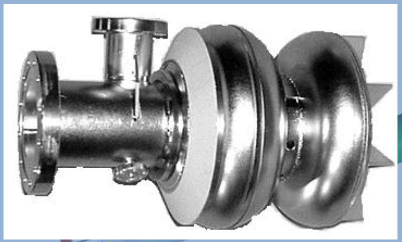
SRF
CW
Mode
machine

BERLinPro: Cavity types and operating conditons

THPB066

THPB069

SRF Photo-injector



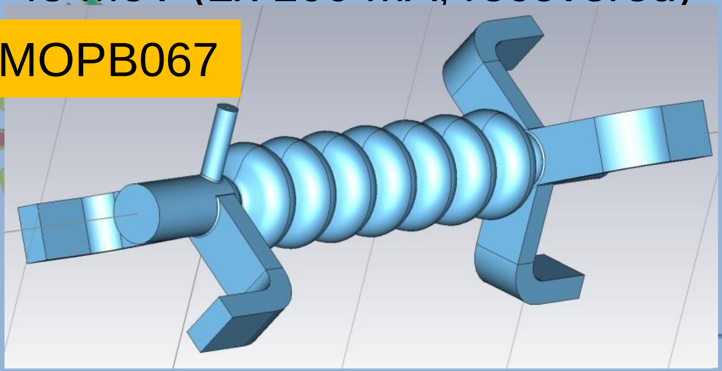
1.5-2 MeV, 100 mA

- High beam power
- High beam current
- Intermediate field levels 12 MV/m

→ **Beam pipe absorber**

+45 MeV (2x 100 mA, recovered)

MOPB067

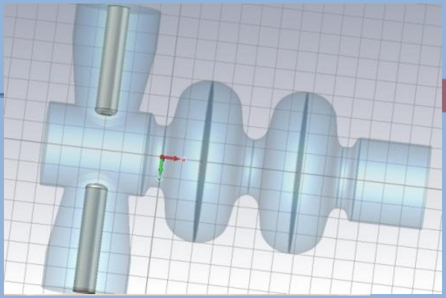


Main linac cavity

- Low beam power
- High beam current
- Higher field levels 19 MV/m
- Multi-pass beam

→JLAB style waveguide absorber

+4.5 MeV (100mA)



SRF booster cavity (Cornell)

- High beam power
- High beam current
- Intermediate field levels 10 MV/m

→ **Beam pipe absorber**

SRF CW Mode machine

Requirements for B*ERL*inPro: Staged approach

Gun 0: **Objective:** Beam dynamics studies

see T. Kamps et al. IPAC11, A. Neumann et al. IPAC11

Design: J. Sekutowicz (DESY)

Gun 1: **What do we aim for?**

Objective for peak brightness:

Insert a NC high QE cathode in a SC environment, demonstrate some mA beam current: Cathode studies, insert design, choke filter studies

→ 3-D RF and thermo-mechanical calculations, multipacting studies

→ ***Insert + choke layout (HZDR Design)***

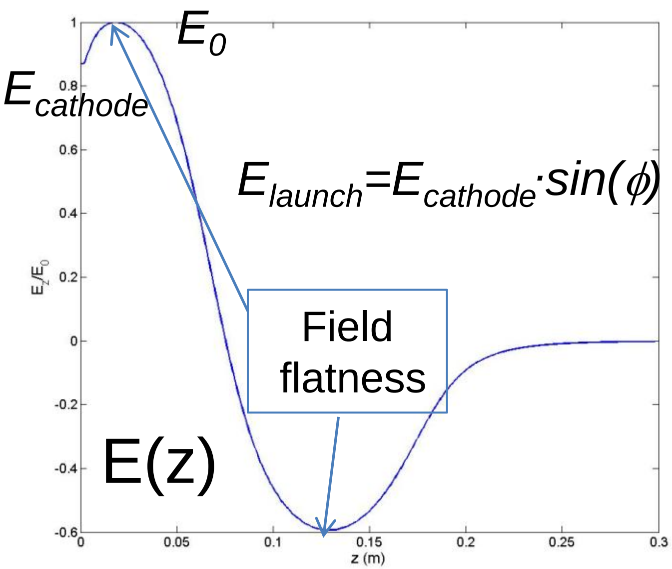
Objective for beam dynamics:

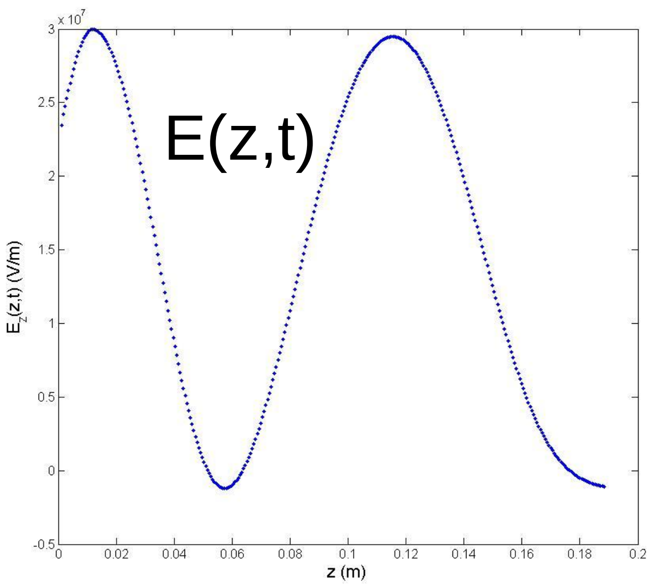
Optimize beam dynamics to meet BERLinPro requirements, combined Superfish/CST design studies including feedback by ASTRA based beam dynamic calculations → ***Cavity shape***

Followed by: Design coupler section, calculations of coupler kicks, full 3-D studies with **HOM** and multipacting calculations

Tuning and field flatness studies (E. Zaplatin, FZ Jülich)

Some Limits and Objectives:

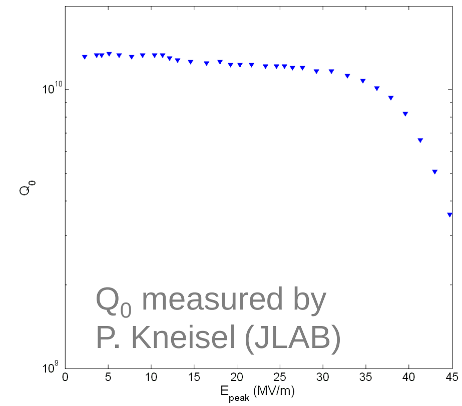




- Power limit about 230 kW by 2 FPCs (KEK style)

Courtesy KEK

- Maximum field amplitude $\leq$ 40-45 MV/m (E_{peak})?
- HOM damping



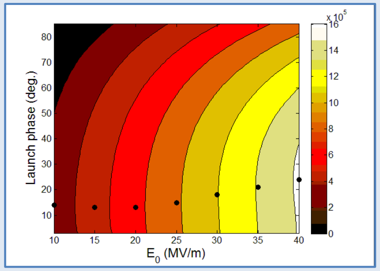
- E_{kin}>2 MeV, I_b=100 mA, ε_n<1mm mrad

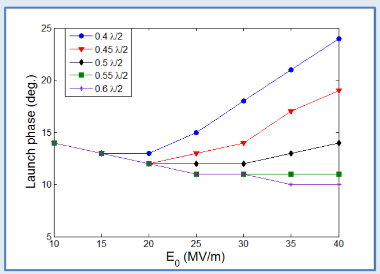
- **Aim at:**

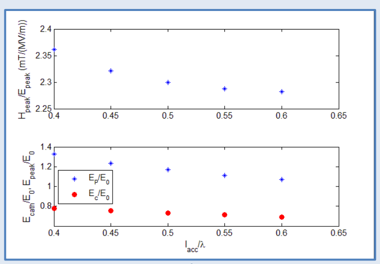
E_{peak}/E_0 minimized
(avoid Field emission)
$E_{cathode}<E_0$ (avoid Dark current)
$E_{launch}=E_{cathode}\cdot\sin(\Phi)$ maximized
(avoid Space charge effects)
→ Φ close to on-crest
High Φ_{opt} reduces E_0!

Cavity design flow

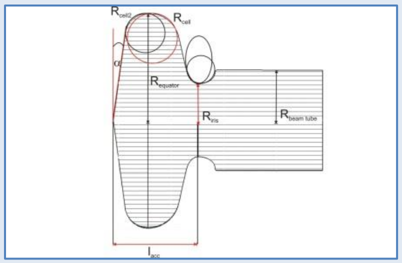
Analyze results,
Parameter scan
Optimizer



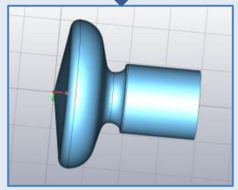




2-D studies: 0.X-cell

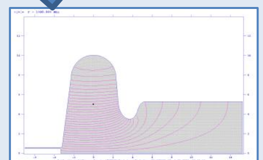


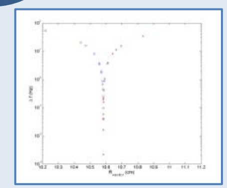
Change geometry parameter



Optimize for
1. Beam dynamics
2. HOM properties
3. SRF parameters

Tune frequency by Golden Section Search Optimizer





Calculate Cavity parameter

Energy-phase-field scan

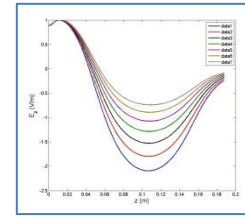
Power limit met?

$$Q_L = \frac{V_{cav}}{\frac{r}{Q} I_b \cos\varphi_b}$$

$$P_f = \frac{V_{cav}^2}{\frac{r}{Q} Q_L 4}\left(1 + \frac{\frac{r}{Q} Q_L I_b}{V_{cav}} \cos\varphi_b\right)^2$$

Results

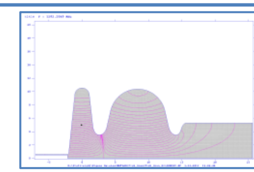
Field distributions



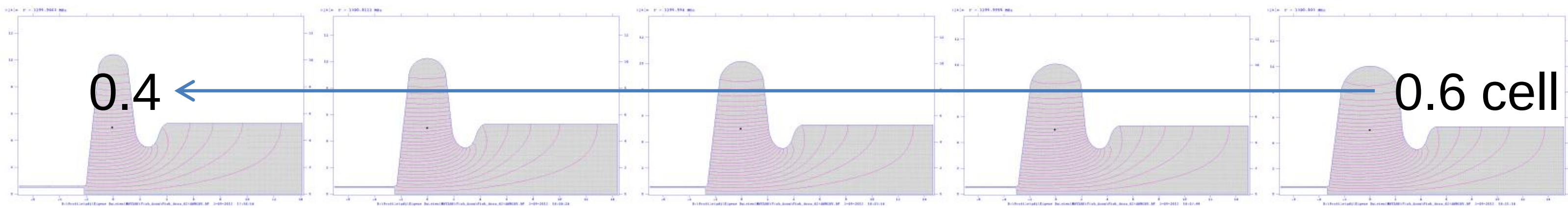
E_z, E_r

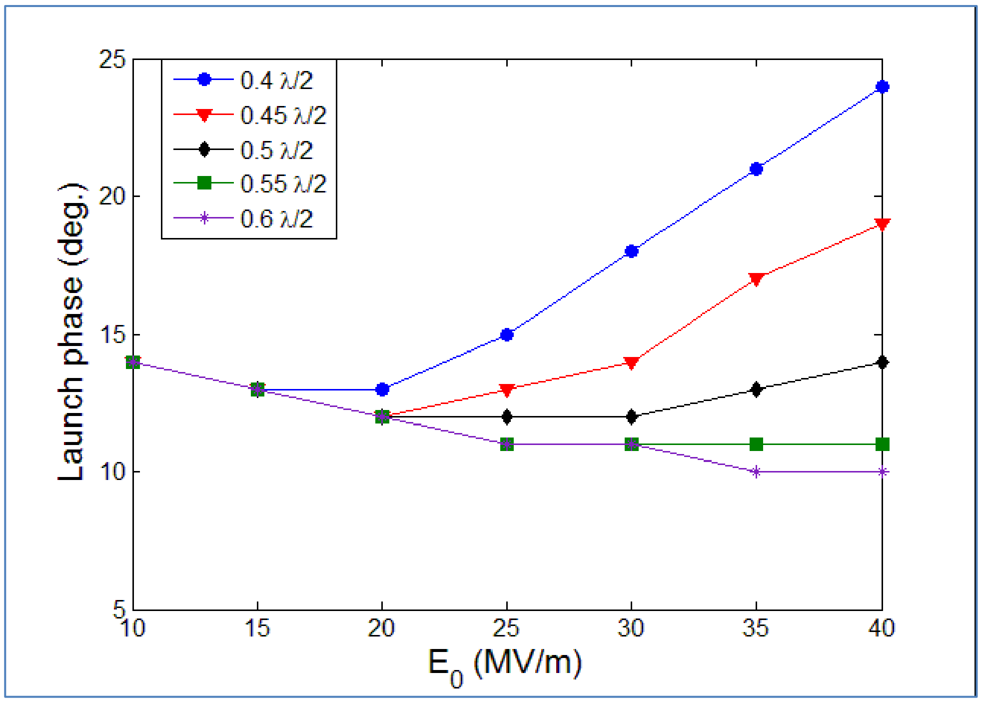
External ASTRA scans beam dynamics group
T. Kamps

Need for?
- RF focusing
- Launch phase
- Launch field



Half-cell optimization: Length scan, velocity and transit time effects



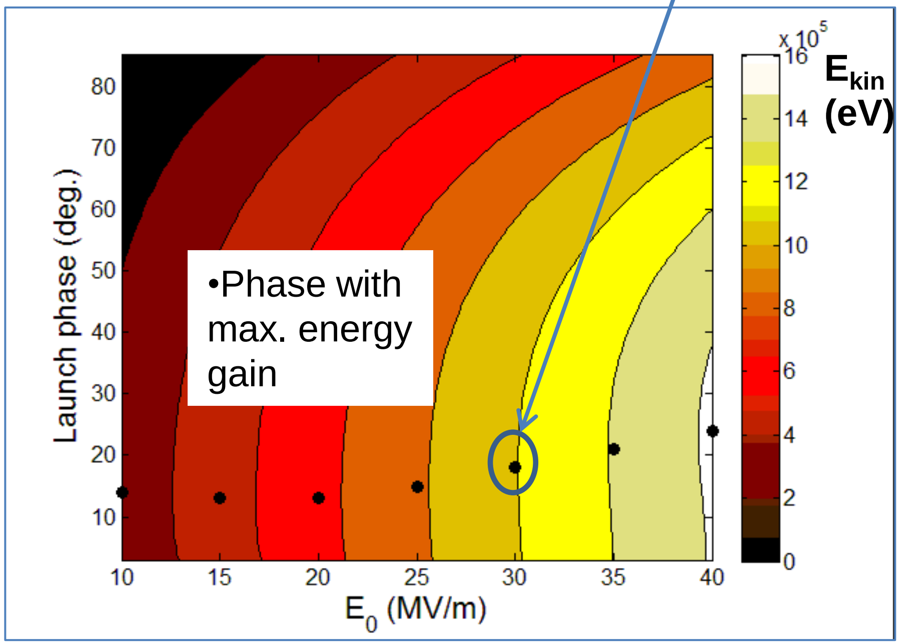


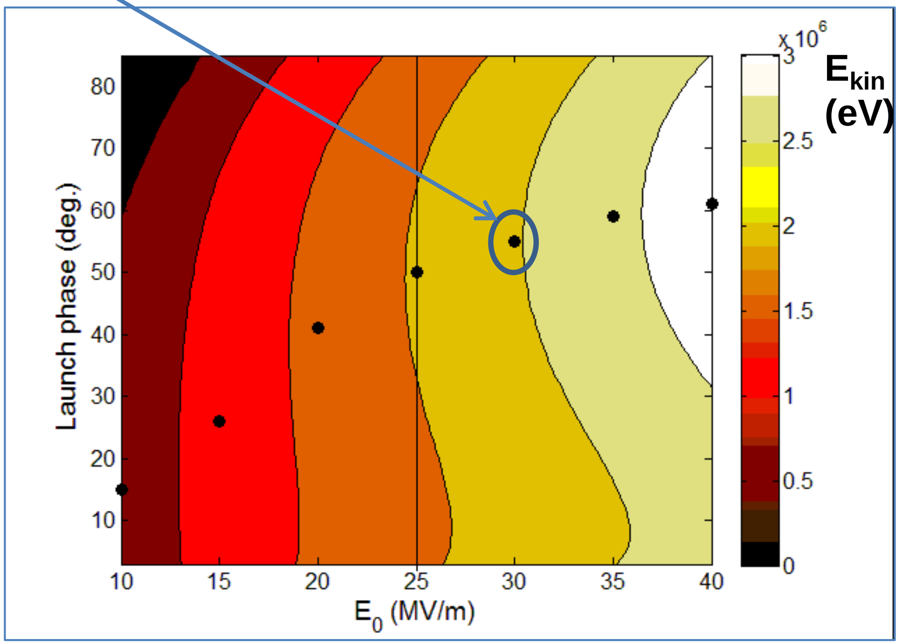
Operating conditions: 0.4 cell

- Launch phase 18 degrees, $\boldsymbol{E_0}$=30 MV/m, $\boldsymbol{E_{cathode}}$=24 MV/m
- Energy gain 1.2 MeV, $\boldsymbol{E_{acc}}$=26 MV/m
- Launch field $\boldsymbol{E_{launch}}$=24MV/m·sin(18)= 7.42 MV/m ☹
- $\boldsymbol{E_{peak}}$=30 MV/m·1.35=40.5 MV/m
- $\boldsymbol{P_{forward}}$=120 kW at minimum

Optimized half-cell: 0.4 cell vs. 1.4 cell

Design field





Even under limited RF power boundary condition:

1.X beats 0.X cell design

Operating conditions: 0.4 cell vs. 1.4 cell

Typical design parameters:

$R/Q = 90\ \Omega$

$H_{peak}/E_{peak} = 2.3$ mT/(MV/m)

$E_{peak}/E_0 = 1.3$

$E_{cath}/E_0 = 0.7\text{-}0.9$

with operating parameters:

$E_{kin} = 1.2$ MeV at:

$E_0 = 30$ MV/m

$\phi_{launch} = 18$ deg

$E_{launch} = \mathbf{7.4}$ MV/m

$E_{cathode} = 24$ MV/m

at best:

$E_{kin} = 1.6$ MeV at:

$E_0 = 40$ MV/m

$\phi_{launch} = 24$ deg

$E_{launch} = 13.0$ MV/m

$E_{cathode} = 32$ MV/m

Typical design parameters:

$R/Q = 150\ \Omega$

$H_{peak}/E_{peak} = 2.2$ mT/(MV/m)

$E_{peak}/E_0 = 1.5$

$E_{cath}/E_0 = 0.7\text{-}0.9$

with operating parameters:

$E_{kin} = 2.4$ MeV at:

$E_0 = 30$ MV/m

$\phi_{launch} = 50$ deg

$E_{launch} = \mathbf{18.4}$ MV/m

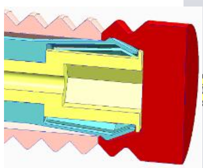
$E_{cathode} = 24$ MV/m

Decision: First cavity design will be a 1.4 cell cavity

High launch field at lower peak and cathode field, higher energy

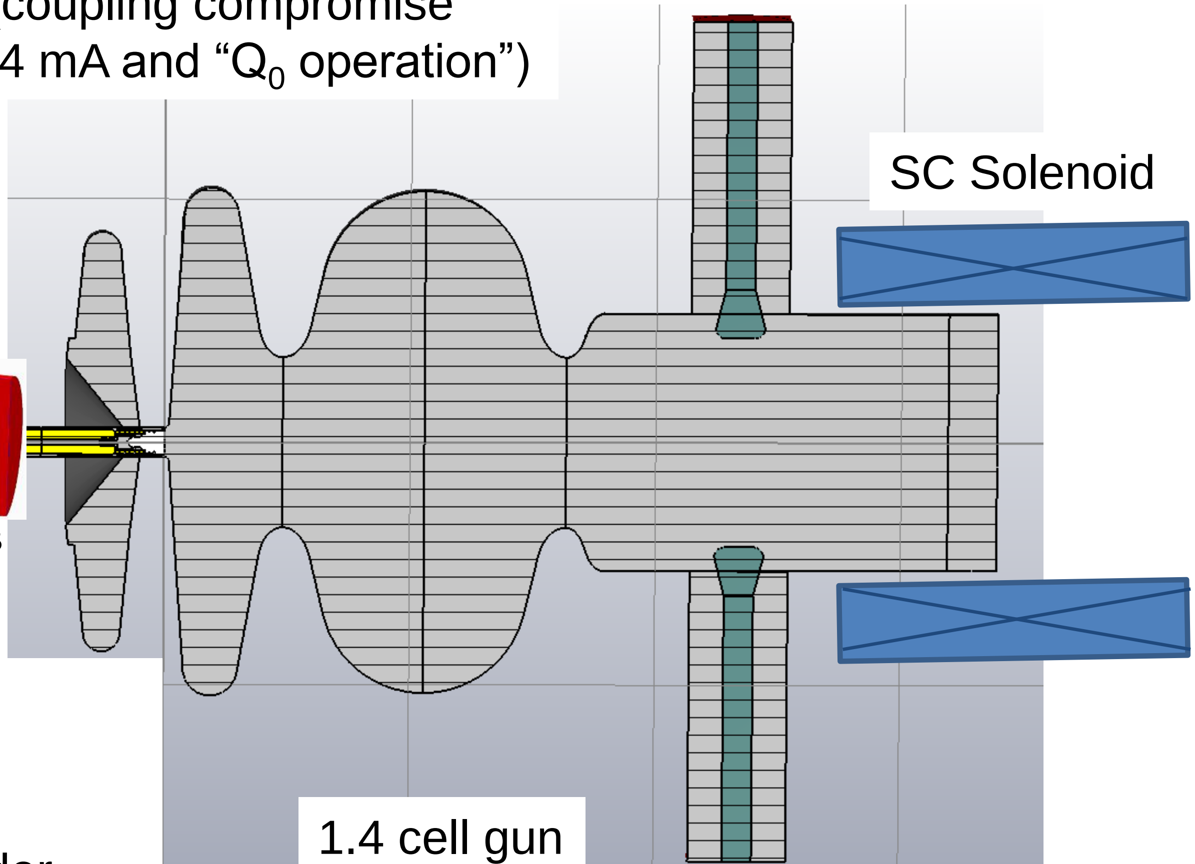
Design for next Gun

CW-modified TTF/XFEL Coupler (coupling compromise between 4 mA and “Q_0 operation”)



T. Noll, HZB

HZDR-style choke with modified cathode holder

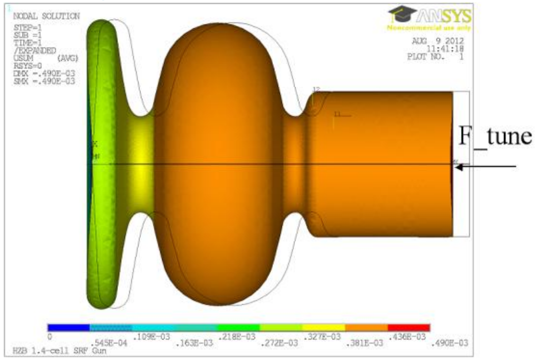


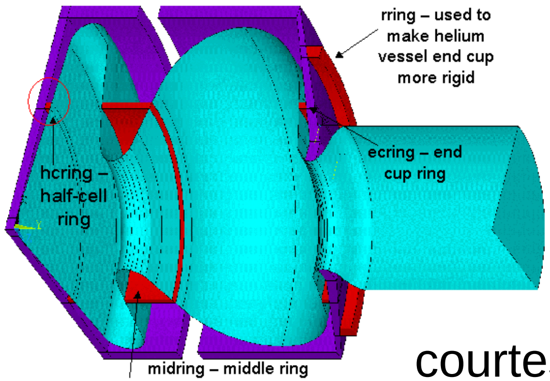
SC Solenoid

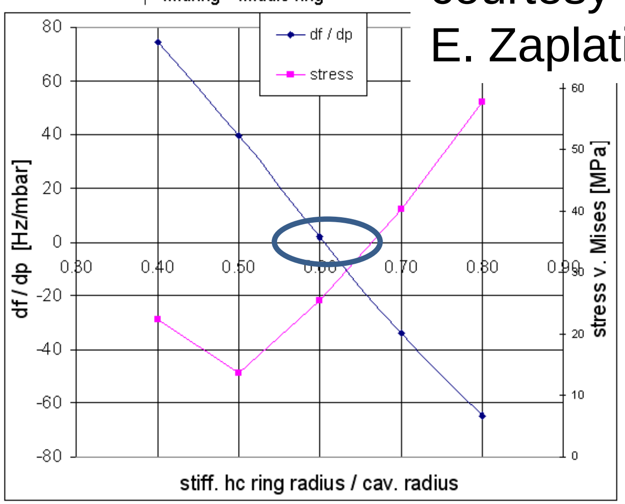
1.4 cell gun cavity

DESY style absorber using SiC
(courtesy J. Sekutowicz)

Ongoing: 3-D studies: HOM, tuning, field flatness

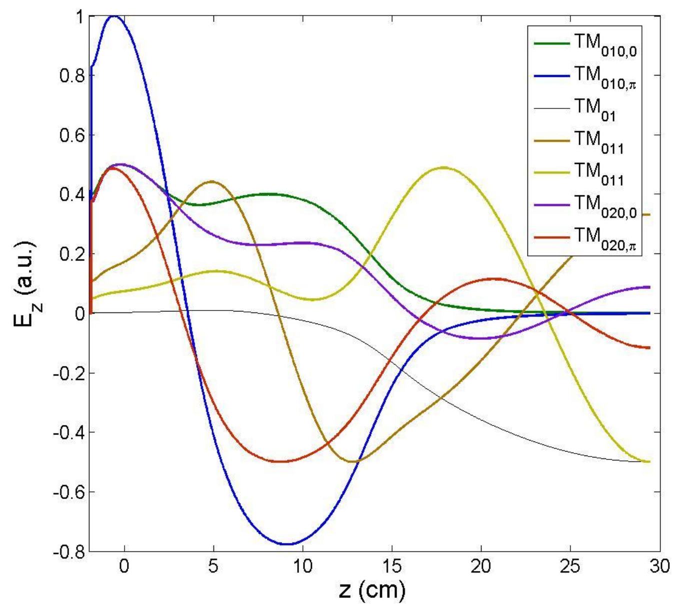






courtesy
E. Zaplatin

f (MHz)	$R/Q_{\parallel}$ ($\beta = 1$)	$R/Q_{\parallel}$ E_0=16MV/m	$R/Q_{\parallel}$ E_0=30MV/m
1270	59	4.9	0.51
1300	150	125	147
2403	16.1	3.0	14.8
2510	49	24.9	20.8
2663	36.8	3.5	0.9
2750	28.6	3.5	0.04



HOMs:
Loss factor and BBU:
$R/Q_{\parallel}$ and $R/Q_{\perp}$ depend on $\beta(E_0,\Phi)$!

That’s it

Thank you for your attention and many thanks to all people involved with B*ERL*inPro:

T. Kamps, W. Anders, M. Abo-Bakr, R. Barday, D. Böhlick, A. Frahm, M. Dirsat, F. Hoffmann, A. Jankowiak, S. Klauke, J. Knobloch, O. Kugeler, J. Rudolph, A. Matveenko, A. Neumann, T. Noll, T. Quast, M. Schenk, M. Schuster, S. Schubert, J. Völker, B*ERL*inPro project team,

and

A. Arnold (HZDR), P. Kneisel (JLAB), R. Nietubyc (NCBJ), J. Sekutowicz (DESY), J. Smedley (BNL), J. Teichert (HZDR), V. Volkov (BINP), I. Will (MBI), E. Zaplatin (FZ Jülich) + co-workers

For discussion visit: THPB066+THPB069 right after the exit of the Plenary Hall A