Karlsruhe Institute of Technology

Button BPMs for the cSTART project: design and challenges

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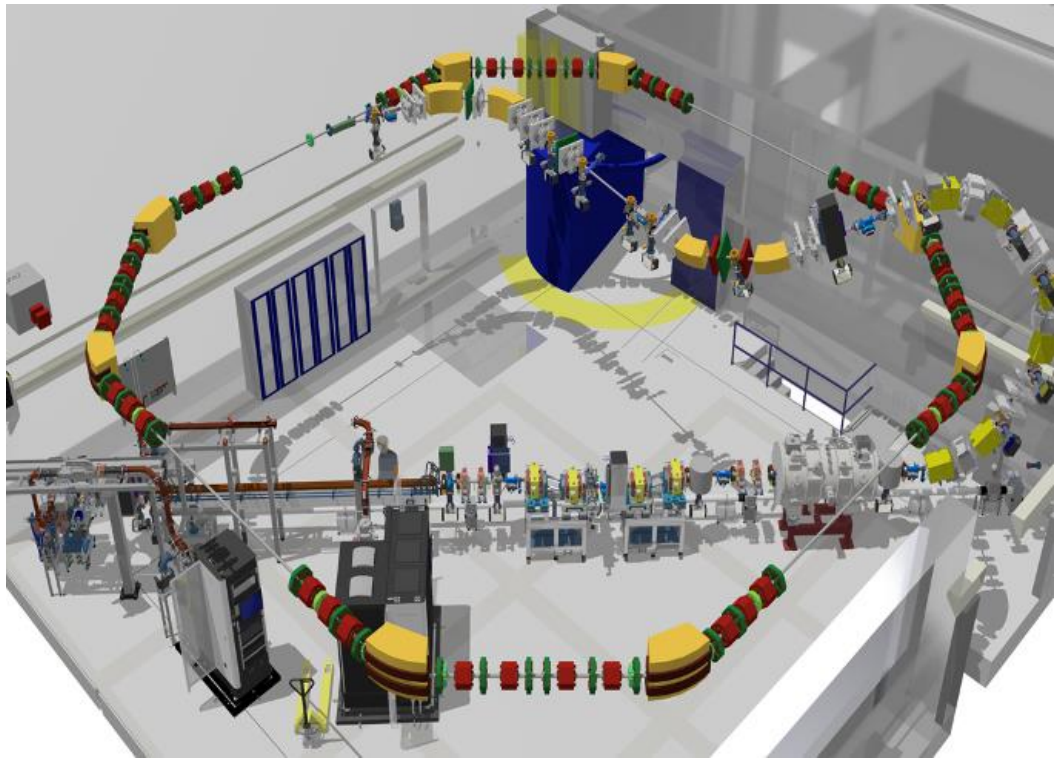
Outline

- General description of the cSTART project
  - Goals
  - Layout and parameters
- Button BPMs
  - Design details and general requirements
  - Simulation results
- Test plans at KIT
- Summary

cSTART goals

- cSTART[1]: compact STorage ring for Accelerator Research and Technology

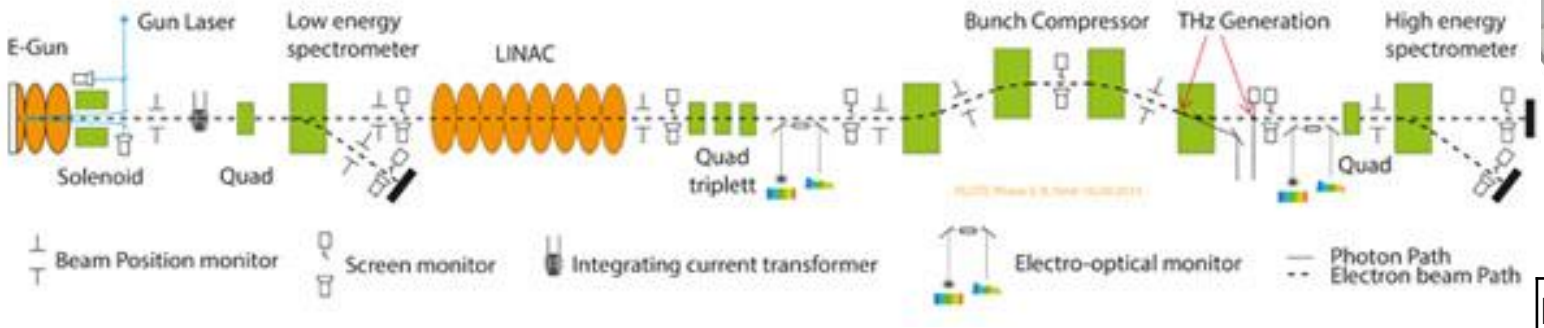
- Goals:
  - Demonstration of the injection of electron beams like / from a LPA (Laser Plasma Accelerator)
  - Storage of sub-ps bunches in a very large acceptance storage ring
  - Study of non-equilibrium beam physics



[1] M. Schwarz *et al., Recent developments of the cSTART project, TU4P34, FLS2023,* DOI: 10.18429/JACoW-FLS2023-TU4P34

cSTART

- Two injectors:
  - Phase 1: FLUTE[2] (Ferninfrarot Linac- und Test-Experiment) as a linac-based injector for early phases of the project
  - Phase 2: Laser Plasma Accelerators (LPA) as injector(s)



FLUTE Linac

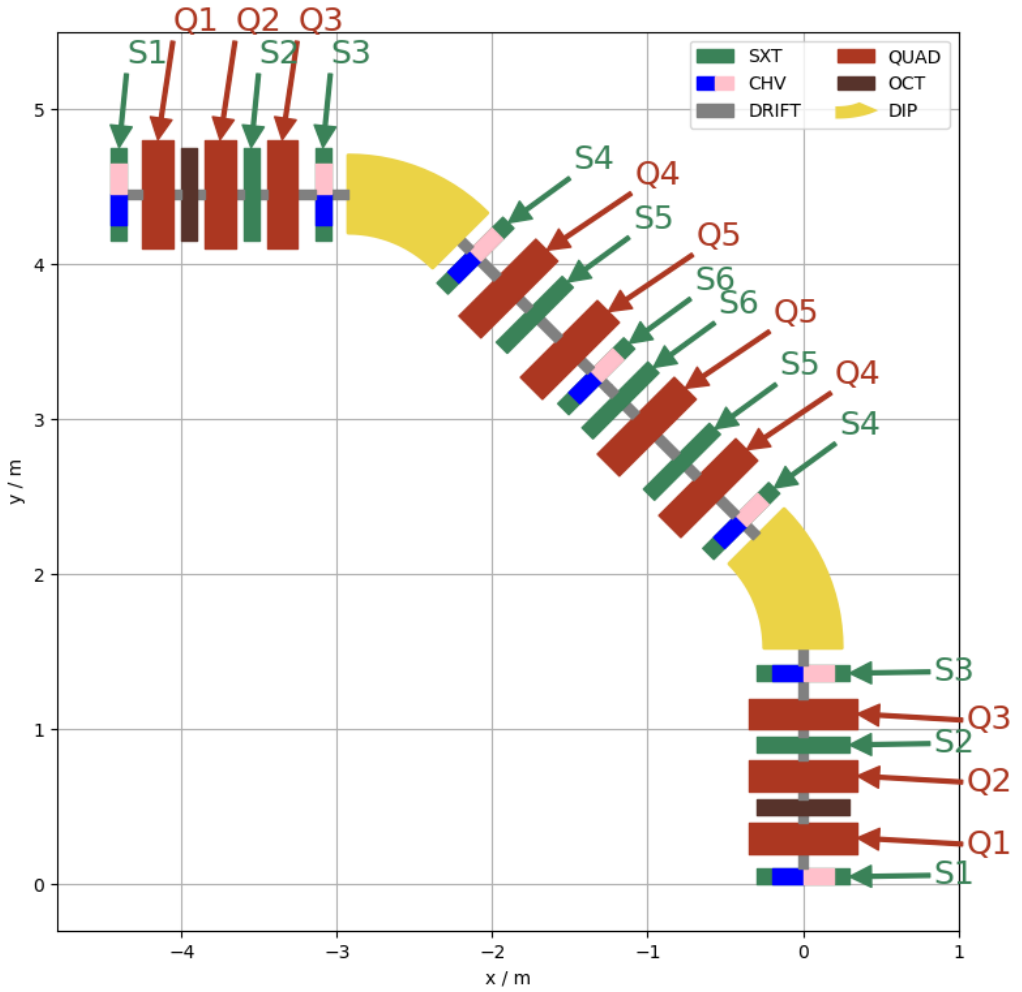
FLUTE main parameters

Energy	40 - 90 MeV
Repetition Rate	1 Hz to 50 Hz
Electron Bunch Charge	1 pC to 1nC
Electron Bunch Length	1 fs to 300 fs
Spectral Band Coverage	up to 30 THz
THz E-field strength	up to 1 GV/m

[2] Nasse MJ *et al.*, FLUTE: a versatile linac-based THz source. Rev Sci Instrum. 2013 Feb;84(2):022705. doi: 10.1063/1.4790431. PMID: 23464187.

VLA-cSR layout

- A very compact DBA (double bend achromat) arc section filled with
  - Two families of bending magnets (8 dipoles)
  - Five families of quadrupoles (40 Q)
  - Six families of sextupoles (48 Sxt) (chromaticity correction, 20 extra-winding coils as corrector magnets for orbit correction)
  - One family of octupoles (8 Oct)
  - Diagnostics (BPM, BLM, ICT, Screens)
- Four straight sections hosting
  - Injection (septum and kicker)
  - RF cavity
  - Future experiments
  - Diagnostics (Stripline Kicker,…)



VLA-cSR parameters

- The project aims to inject and store a single ultra-short electron bunch
- An on-axis injection scheme, extraction of the circulating bunch after e.g. 100 ms and on-axis injection of a new electron bunch
- Long damping time allows the study of non-equilibrium beam dynamics
- The design of the DBA arcs allows the operation at different momentum compaction factors, low- and ultra-low alpha modes

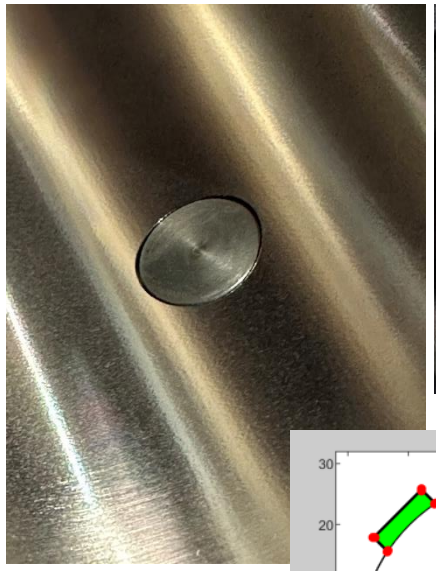
Circumference of the storage ring	43.2 m
Operation mode	single bunch
Energy range	40 to 90 MeV
Energy spread	~2%
Bunch charge	1 pC to 1 nC
Bunch length within one turn	~10 fs up to~10 ps
Injection rate	1 to 10 Hz
Revolution / repetition frequency	6.94 MHz (144 ns)
Damping time (h / v / l) (50 MeV)	29.5, 26.5, 12.6 s
Nominal momentum compaction	14.8×10^{-3}
Reduced momentum compaction	3.9×10^{-3}

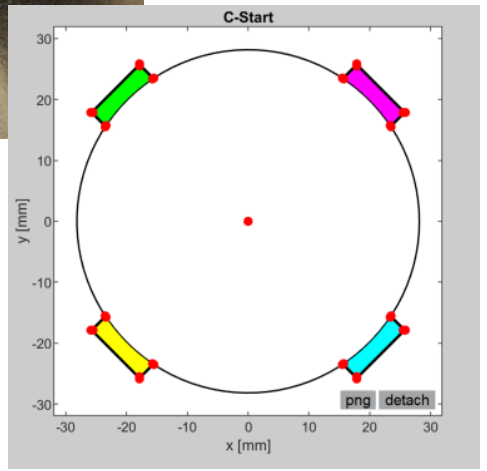
Requirements on beam diagnostics

- A wide range of bunch charge (1 pC to 1 nC), bunch length (10 fs to 10 ps within one turn) and energy spread (from the LPA)
- Beam characteristics are changing dramatically during and over one turn; necessary Turn-by-Turn measurements
- Choosing beam diagnostics with large dynamic ranges that can operate within specifications
- Beam position resolution 100 µm @ 100 pC (LPA requirement to keep an ultra-short bunch)

Button BPM design and dimensions

- Ceramex (ESRF design):
  29 B-BPMs distributed around the ring
  - Beampipe radius = 28.15 mm
  - Button radius = 5.4 mm
  - Button thickness = 2.5 mm
  - Button gap = 250 µm
  - R load = 50 Ω
  - coupling coefficient = 0.047957
  - button capacitance = 4.7811 pF
  - expected longitudinal Wakefield @ 8.8 GHz



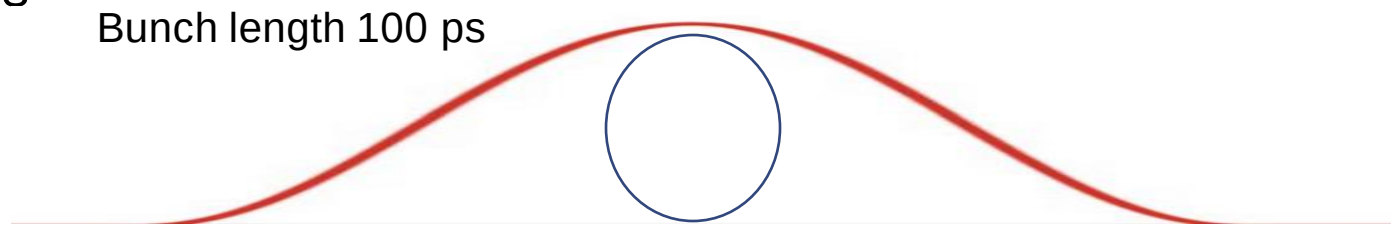


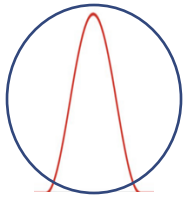
Bunch length vs button size

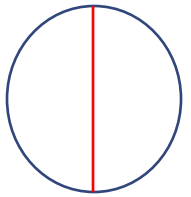
- We assume that 10 ps is comparable to the button size
- Squeezing the bunch to shorter lengths will not modify the button output response, however, is this the case:

If the bunch length becomes comparable to the size of the BPM, the signal propagation time leads to a signal deformation, or in other words: ***for short bunches button BPMs must be small and can therefore deliver only a low signal strength.***
(Beam Position Monitors, Peter Forck, GSI)

Button diameter 10.8 mm
A single c-START bunch will transverse the button in ~36ps

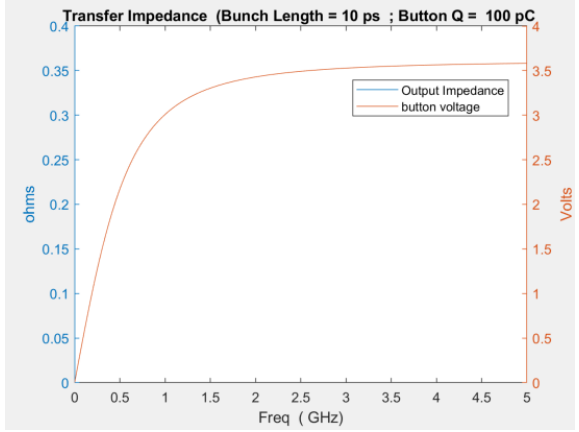




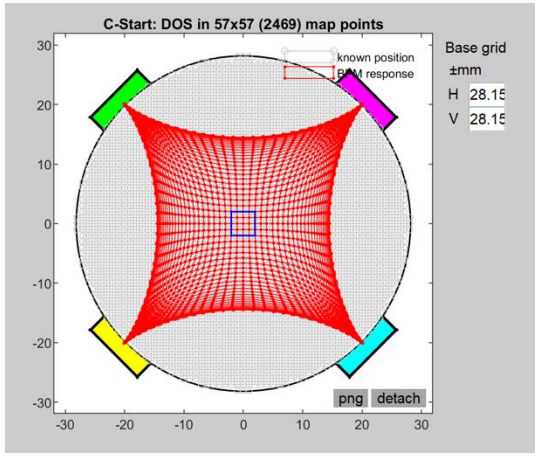


Matlab simulations

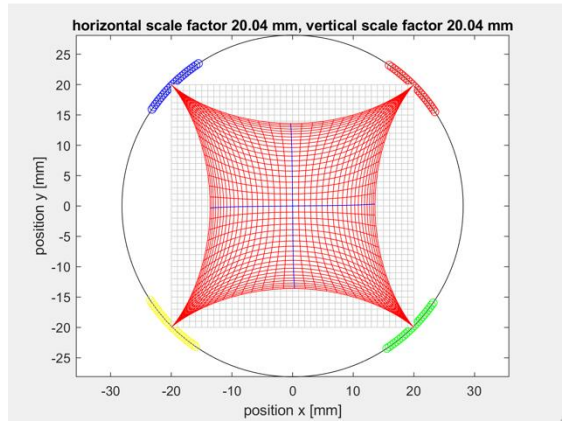
- For Matlab simulation the following was used:
  - Filter centre Freq = 500 MHz
  - Filter Bandwidth (F_t) = 6.9 MHz
  - Noise Figure set = 0
  - Bunch Length set = 10 ps
  - Bunch Charge Q = 100 pC
  - I_b (average beam) = Q x F_t = 690 µA



Thanks to Laura Torino, ALBA



Finite Element Method (FEM), thanks to Andriy Nosych, ALBA



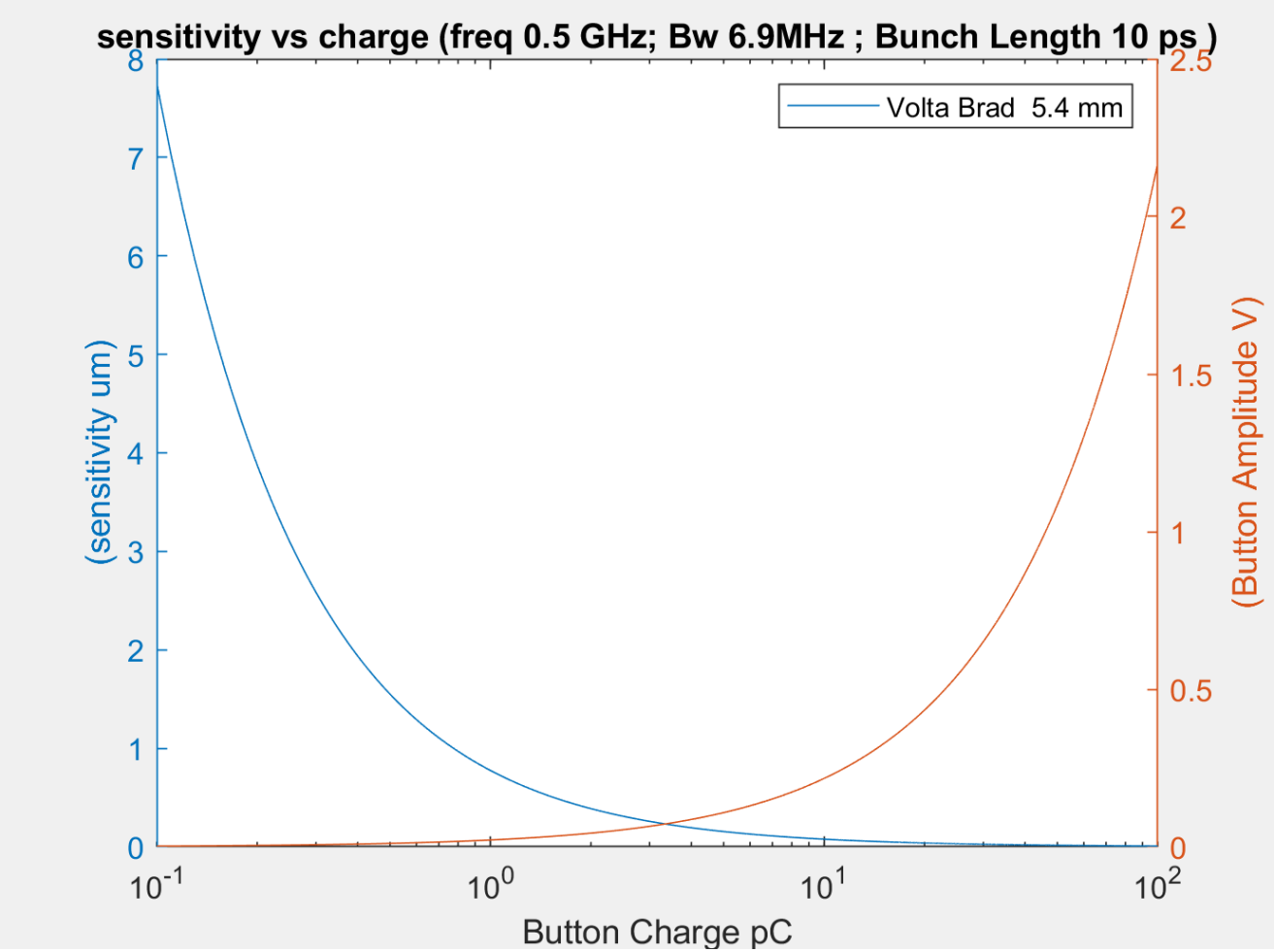
Boundary Element Method (BEM), thanks to Günther Rehm. HZDR

Results

- We use the standard equation for sensitivity calculation:

$$\sigma_{\text{int}} = \frac{b}{2\sqrt{2}} \frac{1}{\sqrt{SNR}}$$

  - For single bunch: 0.017706 µm @ 100pC
  - Average over one turn 100 µm @ 100 pC (more likely to be the resolution after readout with the Libera SPARK)
- We will integrate over one turn in the time domain, so we will be at a sensitivity level somewhere in that range.



Estimated power on buttons

- Averaged over one turn:
  - Power from one button with beam at centre: 0.000284 uW or -65.466493 dBm
  - Noise power of receiver 27.61 fW or -105 dBm
  - Estimated resolution X/Y 99 um / 99 um
  - Loss factor estimate for four buttons: 0.1 mV/pC

- Single bunch.

  - Power from one button with beam at centre = 47 mW or 16.7 dBm
  - Noise power of receiver 28.566 fW or -105 dBm

Tests at KIT

- Tests are being mainly carried out at FLUTE: installation of a prototype of B-BPM at the end of FLUTE after the bunch compressor:
  - Measure using the Libera SPARK ERXR
  - Measure at different bunch length
  - Vary bunch charge and see effect on the measurement

- Characterisation tests of the Libera SPARK using a signal generator (some tests have been carried out with an AWG so far)

Questions to the community

- Will there be issues if the bunch length is much smaller than the BPM in :
  - Resolution/ bunch signal distortion
  - Too much power on buttons
  - Too much peak voltage signal on electronics

- Will there be issues with impedance loading e.g. power taken out of the beam
  - For first experimental periods, the bunch is not supported by RF, no power recovery
  - The bunch will last perhaps 100 ms @ 6.7MHz
  - We have 29*4 buttons = 116 buttons of power loss

- We do not believe that there will be any problems with wake fields acting back on the bundle if it is only a single bunch;
  expected wake frequency = 8.8 GHz, revolution 6.9 MHz?

- With what accuracy can the position of the B-BPM be measured and how much deviation is tolerable?

Summary

- The unique cSTART project is very demanding from many aspects, amongst the wide range of beam parameters.
- Turn-by-turn measurements are necessary because beam characteristics are expected to change dramatically within one turn.
- A defined B-BPM design is chosen, simulations result in an expected resolution of 100 µm @ 100 pC, which is acceptable.
- Further characterisations of the b-BPM prototype and the Libera SPARK ERXR readout electronics is envisaged.

Acknowledgments:

The cSTART team:

- Michael Bank, Axel Bernhard, Edmund Blomley, Till Borkowsi, Erik Bründermann, Samira Fatehi, Thomas Fischböck, Matthias Fuchs, Stefan Funkner, Julian Gethmann, Andreas Grau, Bastian Härer, Houssameddine Hoteit, David Saez de Jauregui, Dima El Khechen, Bennet Krasch, Anton Malygin, Yves-Laurent Mathis, Wolfgang Mexner, Akira Mochihashi, Anke-Susanne Müller, Michael Nasse, Gudrun Niehues, Alexander Papash, Robert Ruprecht, Jens Schäfer, Jürgen Schmid, Steffen Schott, Marcel Schuh, Markus Schwarz, Nigel Smale, Johannes Steinmann, Andreas Völker, Pawel Wesolowski, Christina Widmann and IBPT support team
- Lisa Mucks and Christiane Weiss from PPQ

Thank you very much for your attention

Questions?? Suggestions??