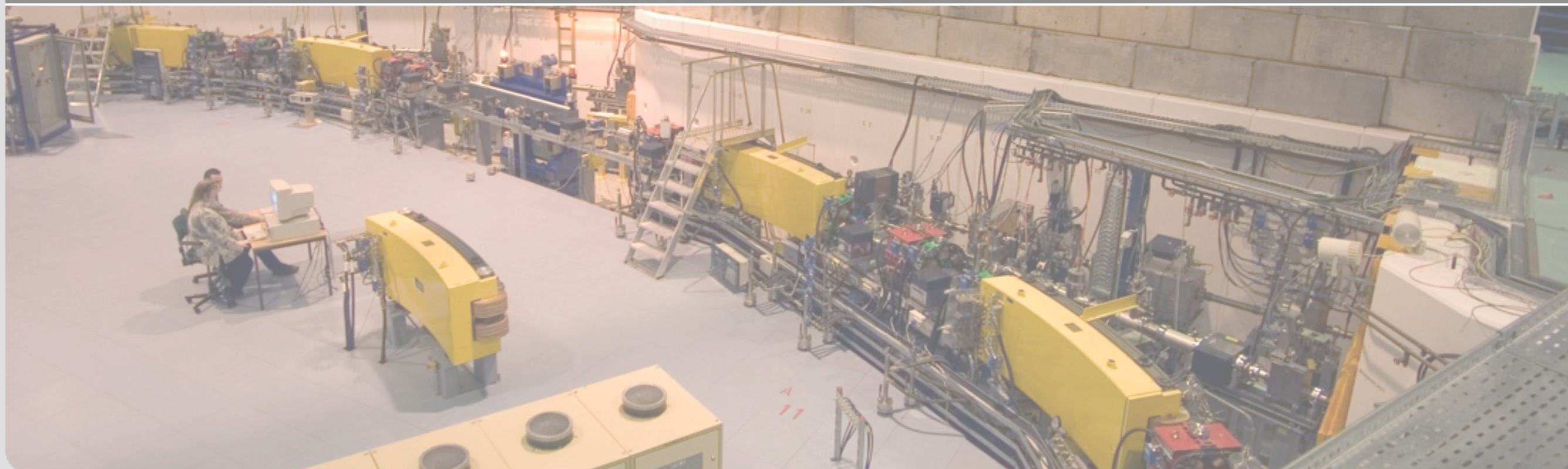


Beam studies with coherent THz Radiation at ANKA

Marcel Schuh
On behalf of the ANKA THz-Group

Laboratory for Applications of Synchrotron Radiation (LAS) / Institute of Synchrotron Radiation (ISS)



Outline

● Introduction

- Measurements possibilities at ANKA
- Low- α optics at ANKA

● Observation of CSR in THz range

● Analysis of microwave radiation at ANKA

● Bunch length and shape diagnostics at ANKA

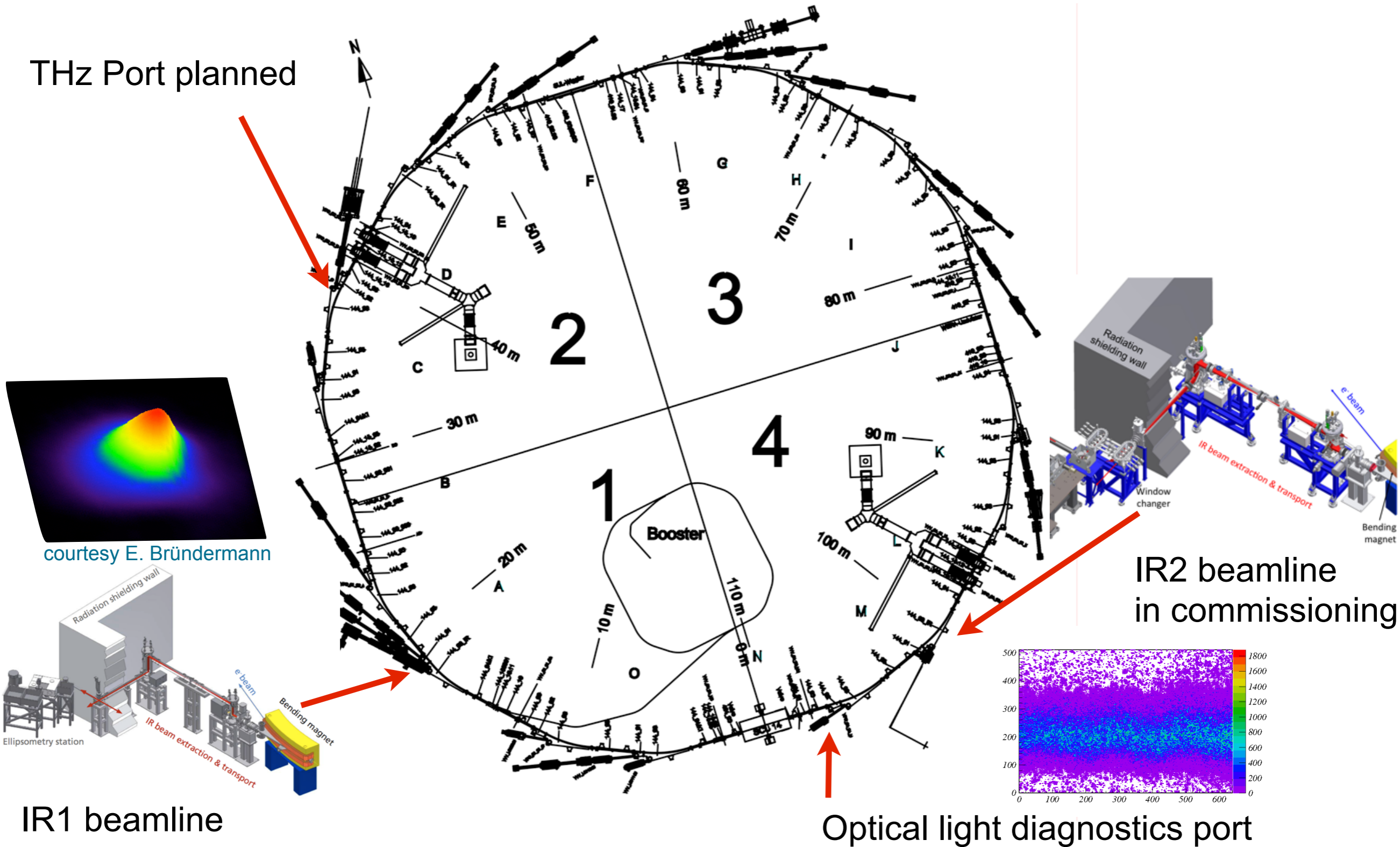
● Future Projects

- Electro-Optical-Sampling (EOS) at ANKA
- Flute

● Summary

Measurements possibilities at ANKA

THz Port planned



IR1 beamline

Optical light diagnostics port

Low- α_c Optics at ANKA

Coherent synchrotron radiation (CSR) is emitted, if the bunch length is shorter than or equal to the wavelength

- Vacuum chamber suppression cutoff:

$$\lambda_{\text{cutoff}} \approx 2h \sqrt{\frac{h}{\rho}}$$

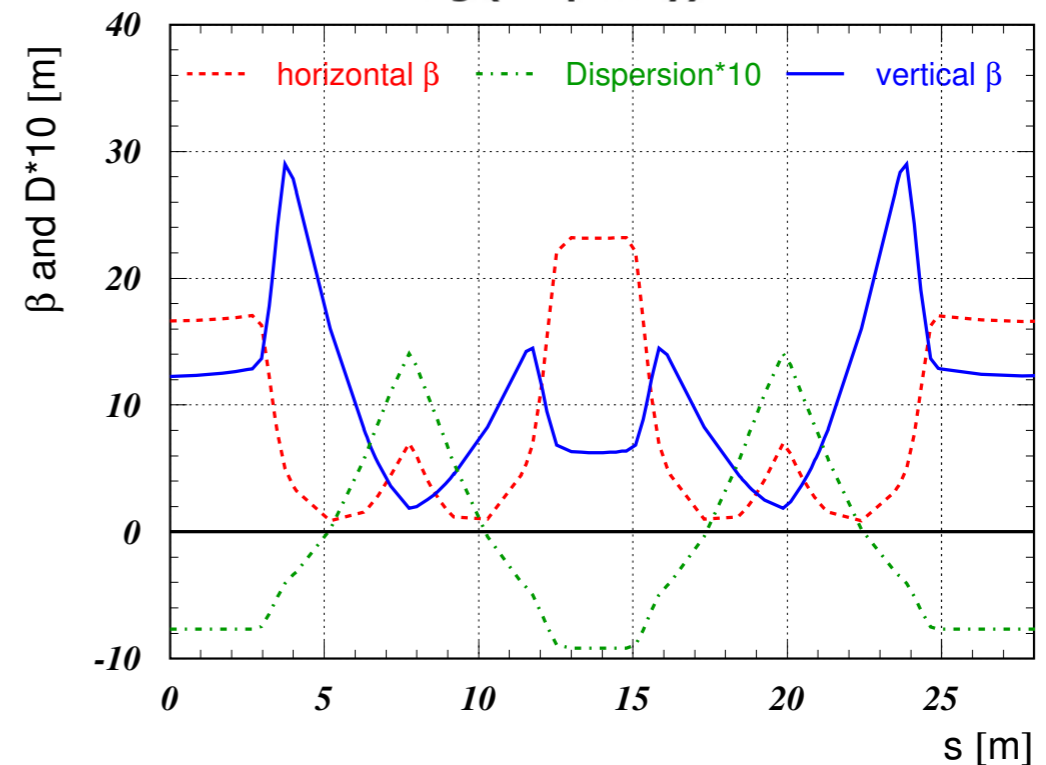
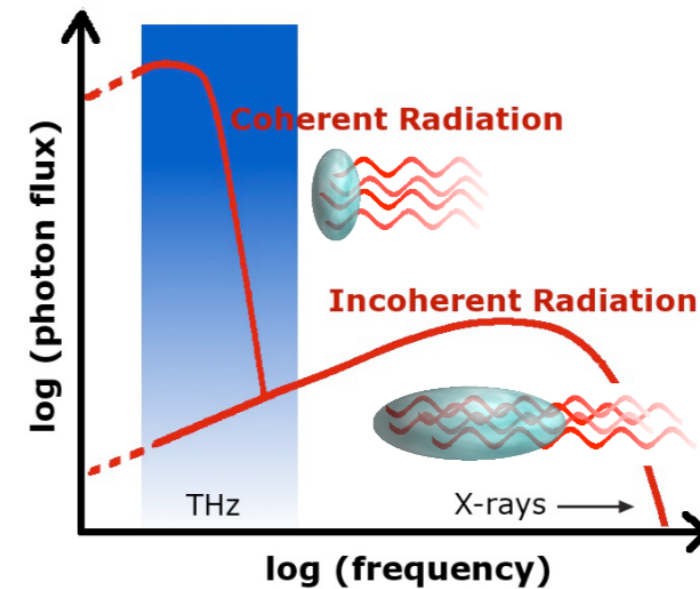
short bunches are needed for CSR

- Dedicated optics with negative dispersion in the long and short straight sections can be applied:

$$\alpha_c = \frac{1}{L} \oint \frac{D(s)}{\rho(s)} ds$$

- Bunch length can be tuned due to:

$$\sigma_s \propto \sqrt{\alpha_c}$$

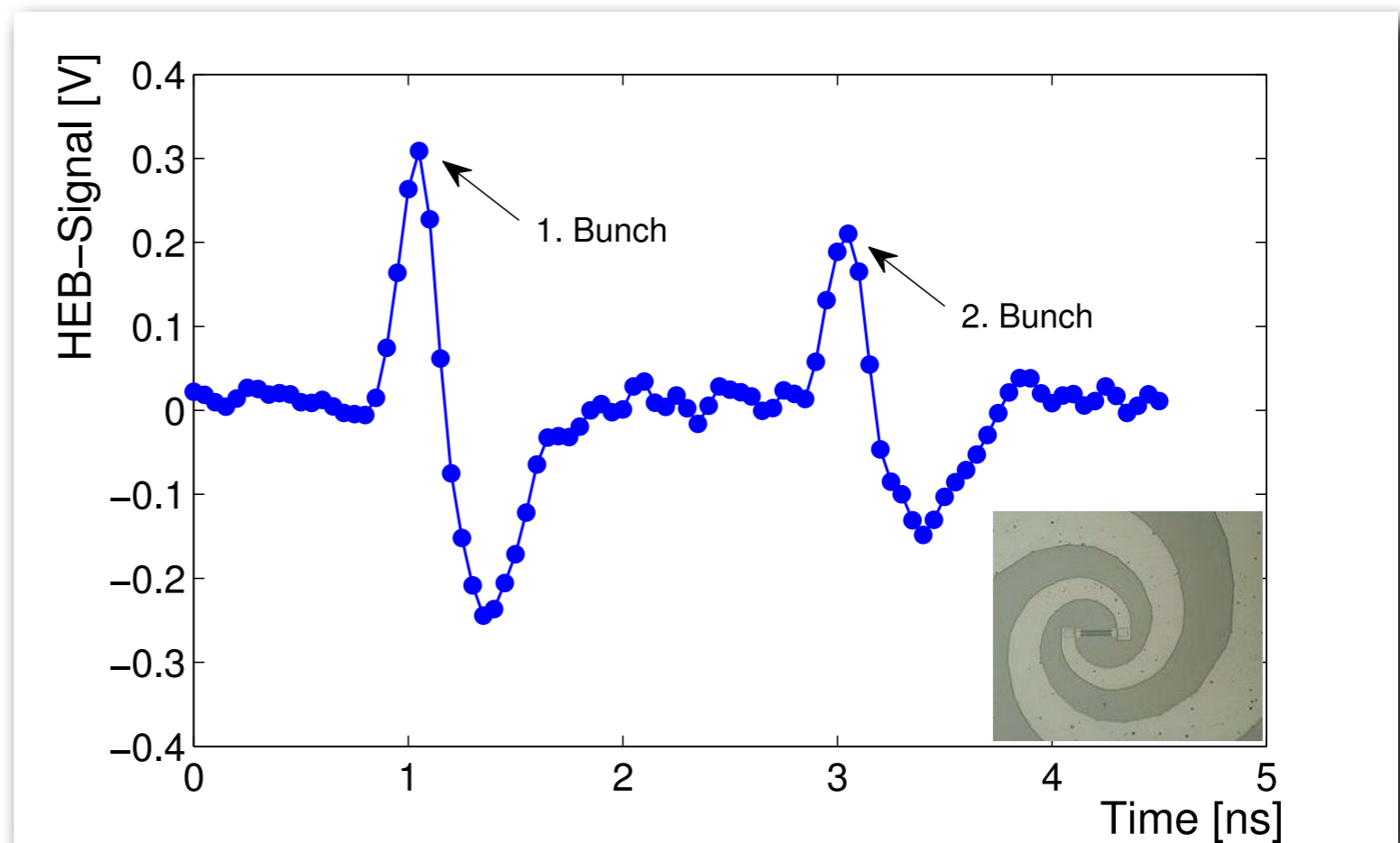
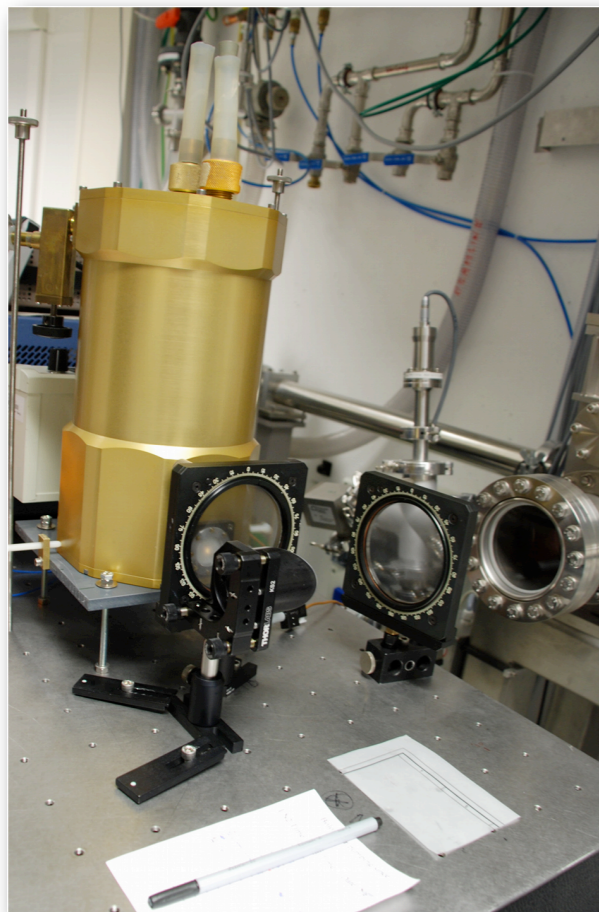


Procedure: Injection \Rightarrow Ramping to 1.3 GeV \Rightarrow "Squeeze" ($\alpha_c [10^{-3}]$: 8.5 \rightarrow 0.46)

THz Detector System

- Hot Electron Bolometer (HEB) detector
- Based on: SC niobium nitride
- Response time < 160 ps
- Spectral range 150 GHz - 3 THz

high temporal resolution of HEB
allows to study signals from
individual bunches in multi-
and single bunch environment



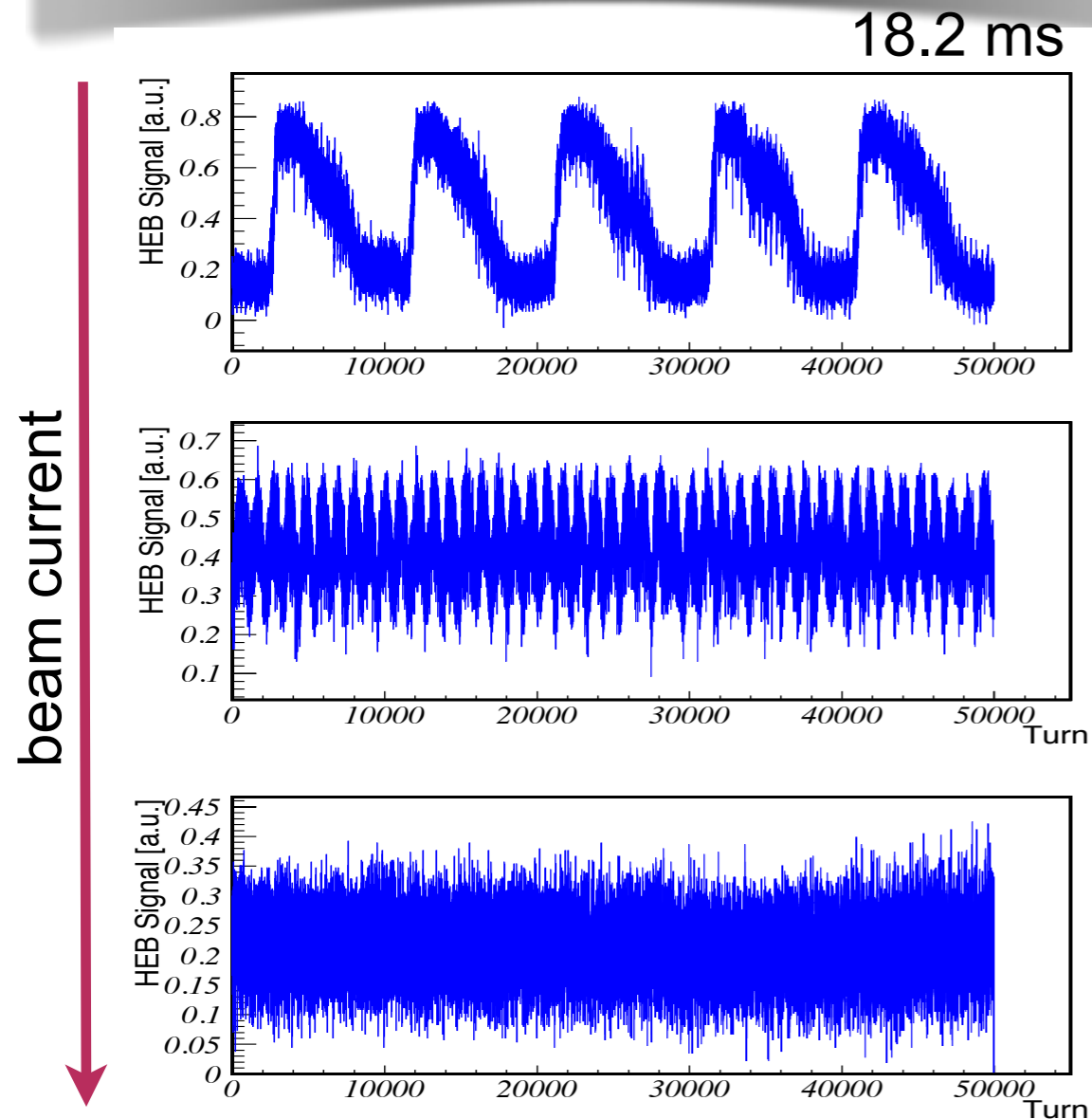
Joint development of IMS (KIT) & DLR (Berlin)

courtesy V. Judin

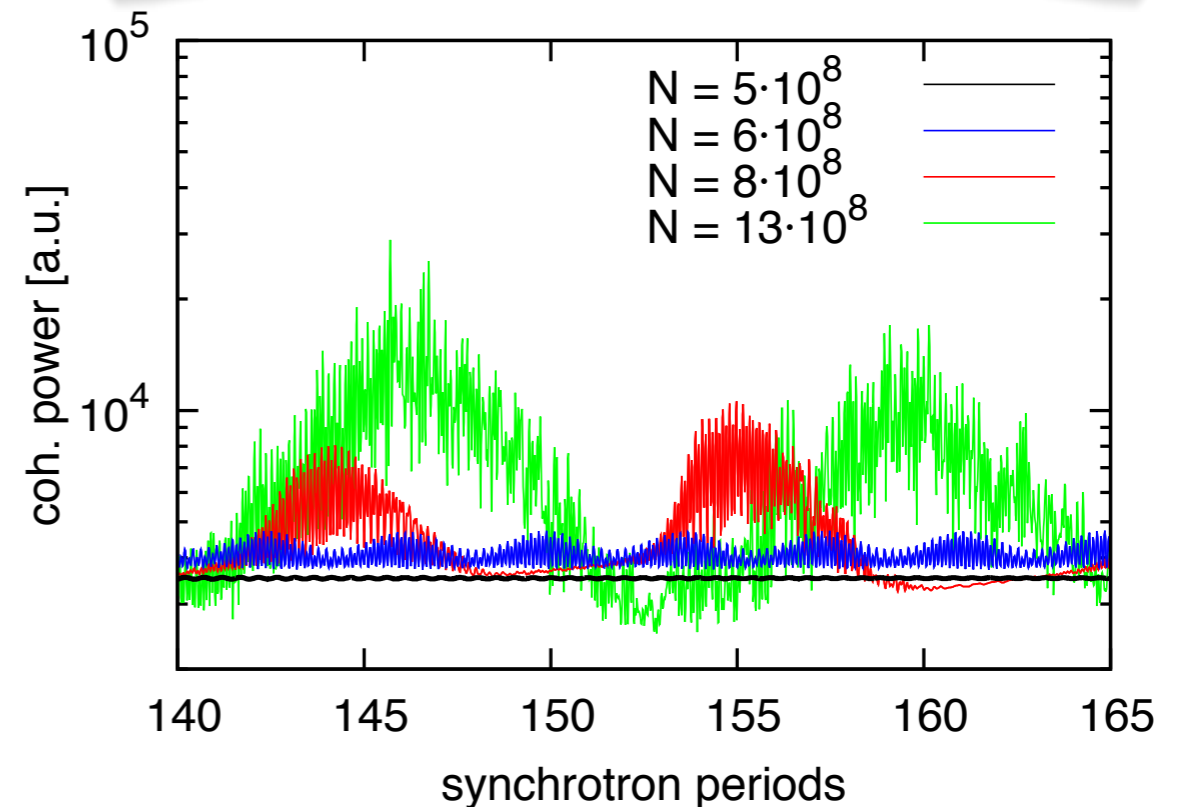
Current Dependent Longitudinal Instabilities

“Bursts” of radiation can be observed using fast THz detector above the bursting threshold

Simulations of the micro-bunching instability using Vlasov-Fokker-Planck solver

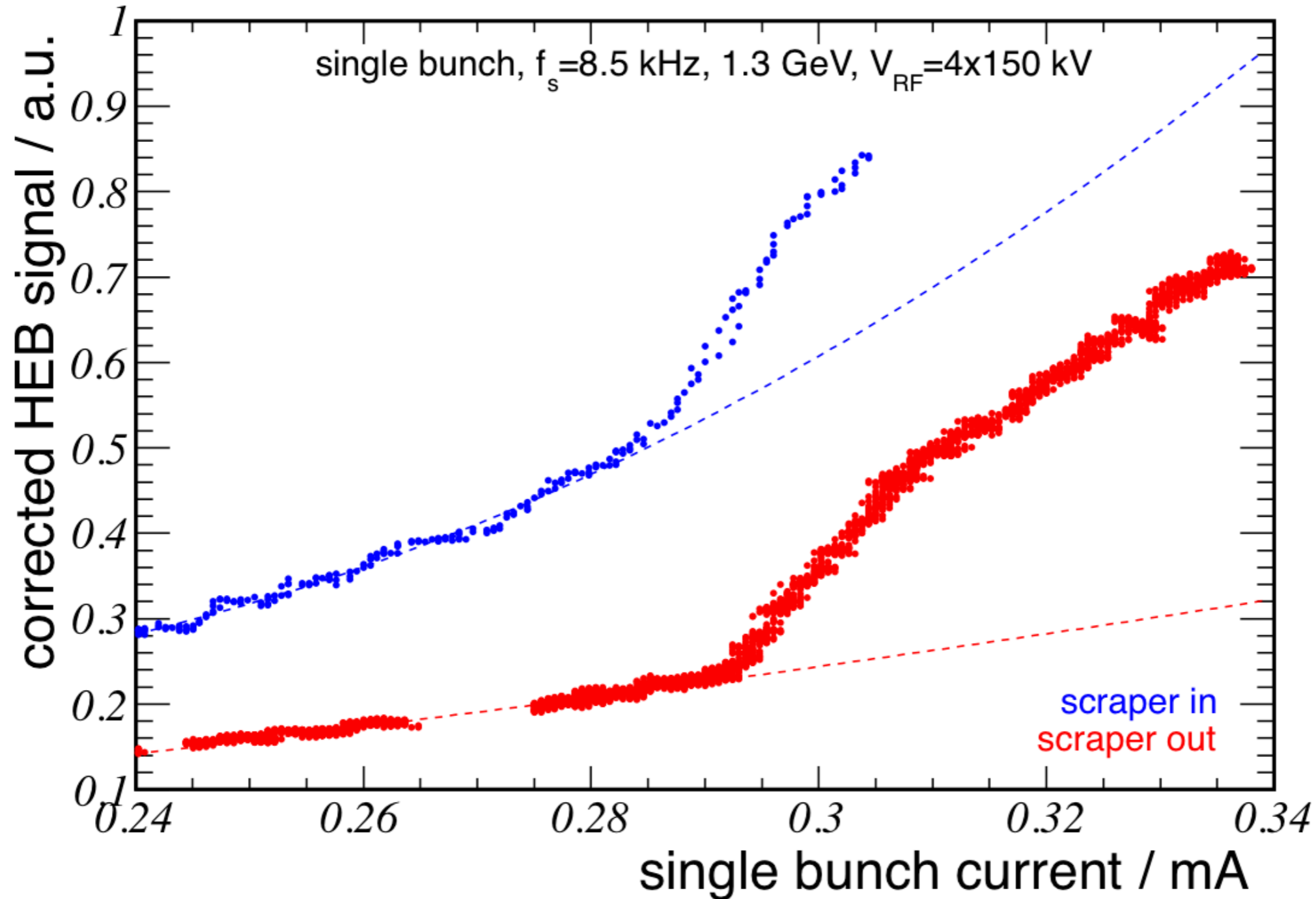


V. Judin et al.: IPAC10, WEPEA021



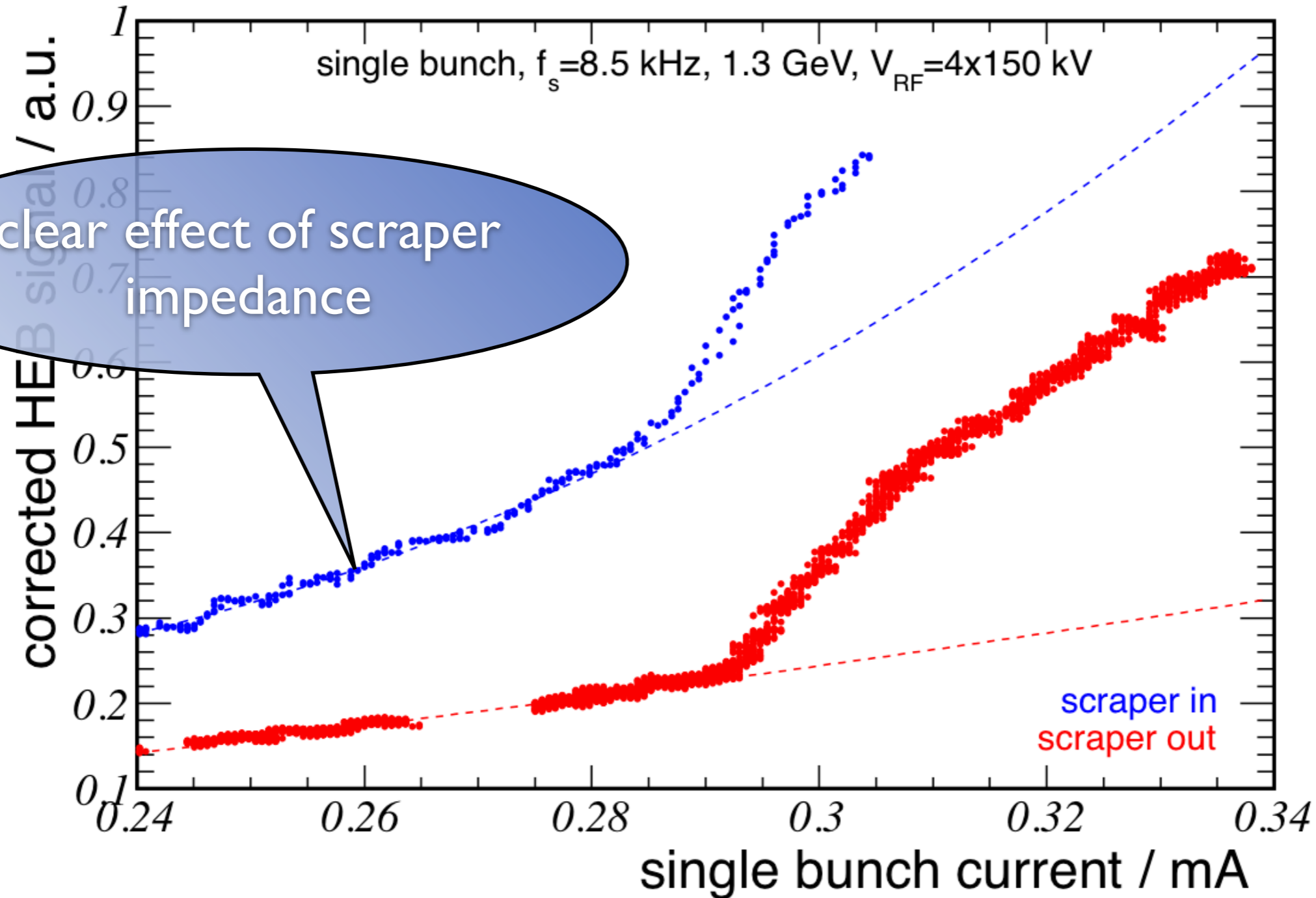
M. Klein et al.: IPAC11, WEPC095

Scraper effects



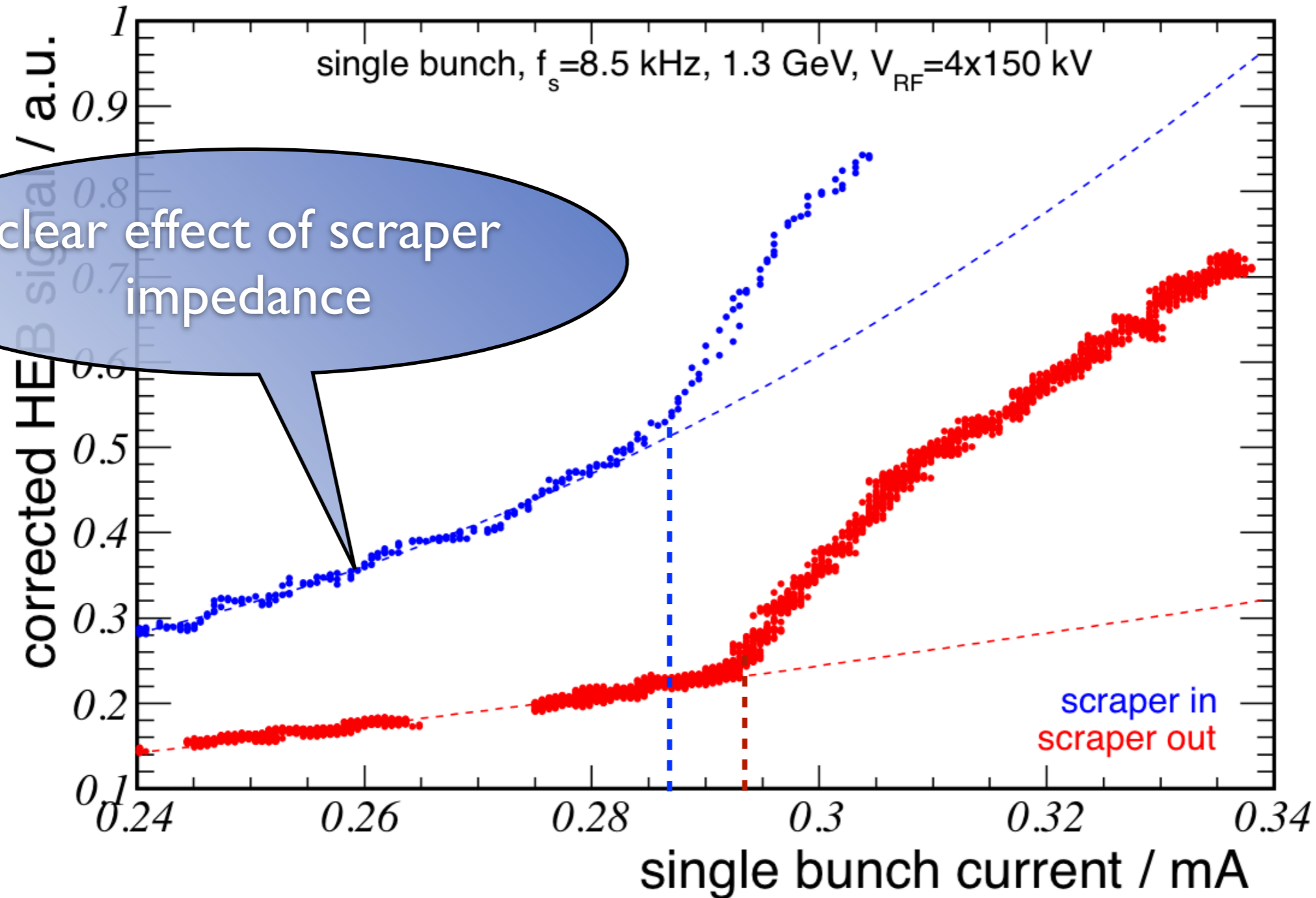
courtesy
A.-S. Mueller

Scraper effects



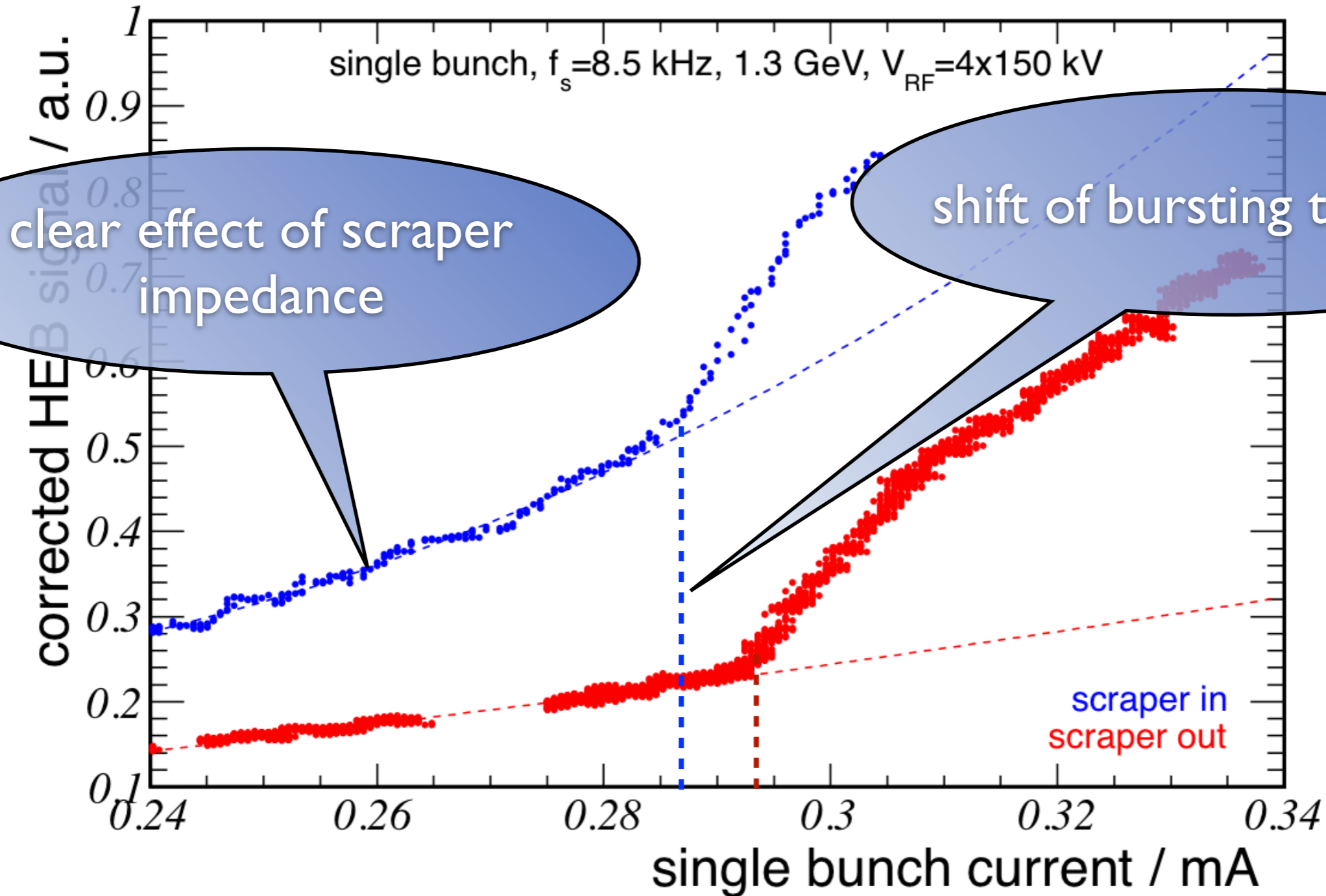
courtesy
A.-S. Mueller

Scraper effects



courtesy
A.-S. Mueller

Scraper effects

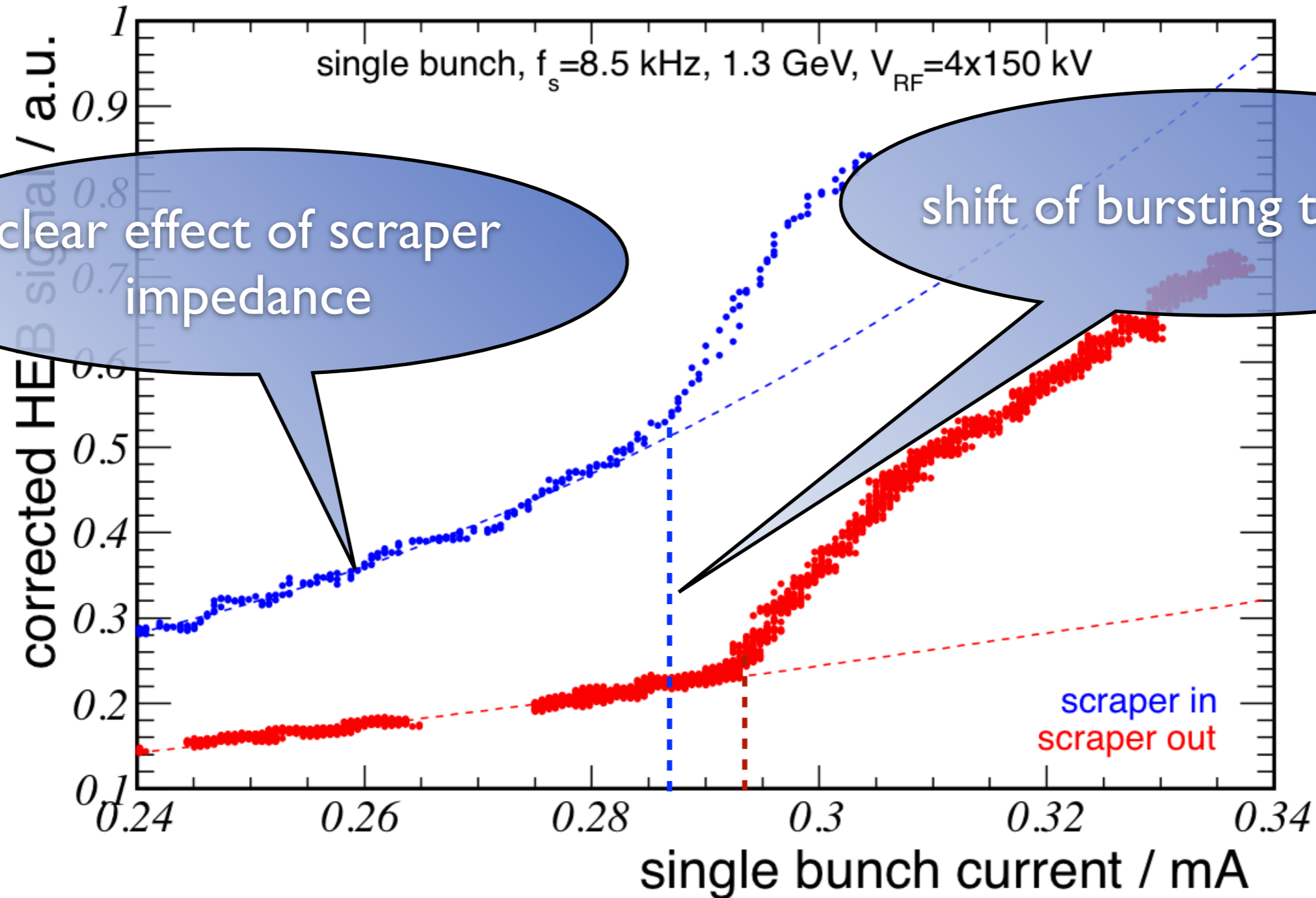


clear effect of scraper impedance

shift of bursting threshold

courtesy
A.-S. Mueller

Scraper effects

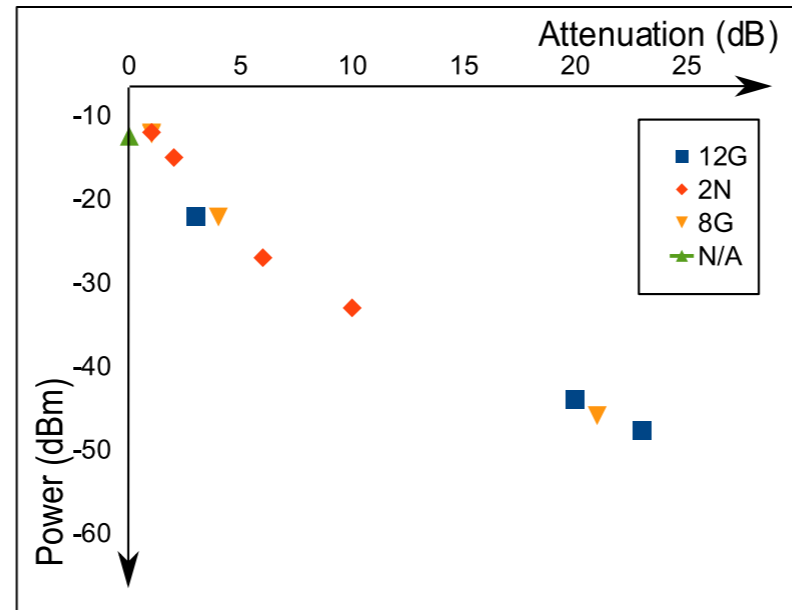
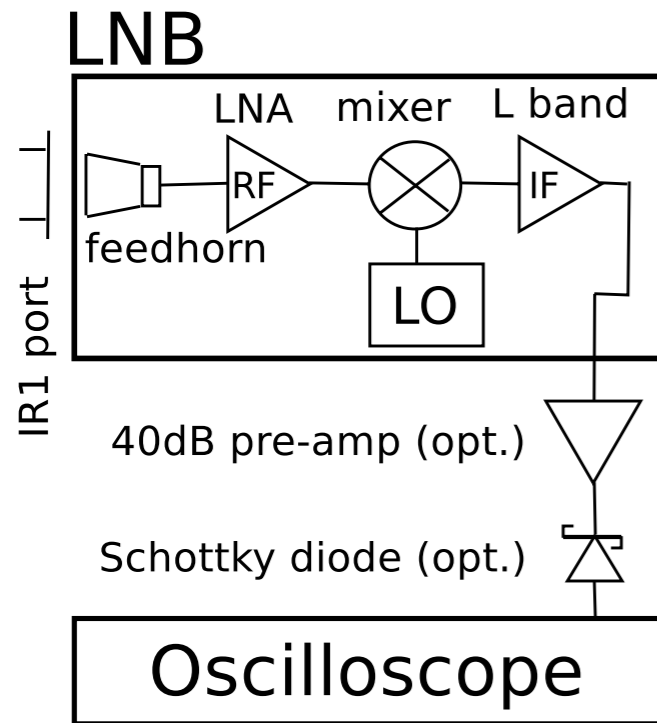


courtesy
A.-S. Mueller

➔ geometrical impedance plays an important role for CSR!

Microwave Radiation at ANKA

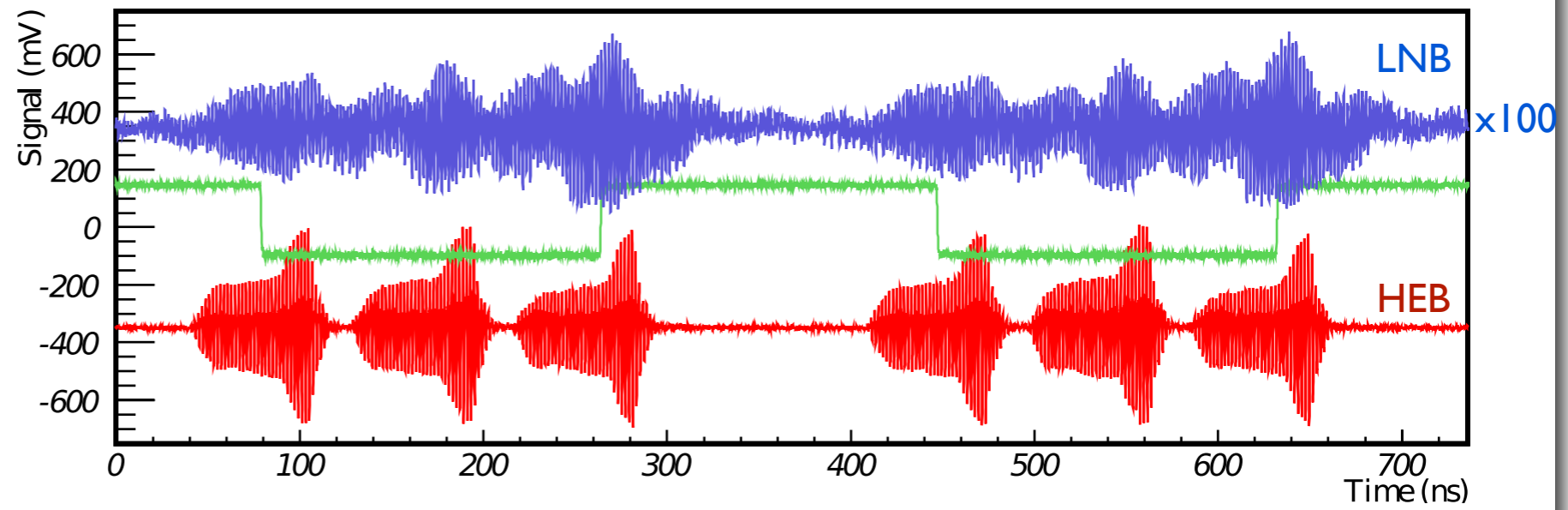
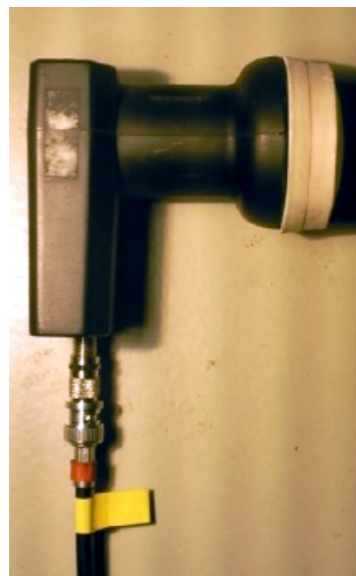
Low cost Low Noise Block (LNB) device used as detector (10.7 - 12.75 GHz)



Small frequency band low noise detector with reasonable dynamic range

PRICE < 10€

LNB signal correlates to the filling pattern

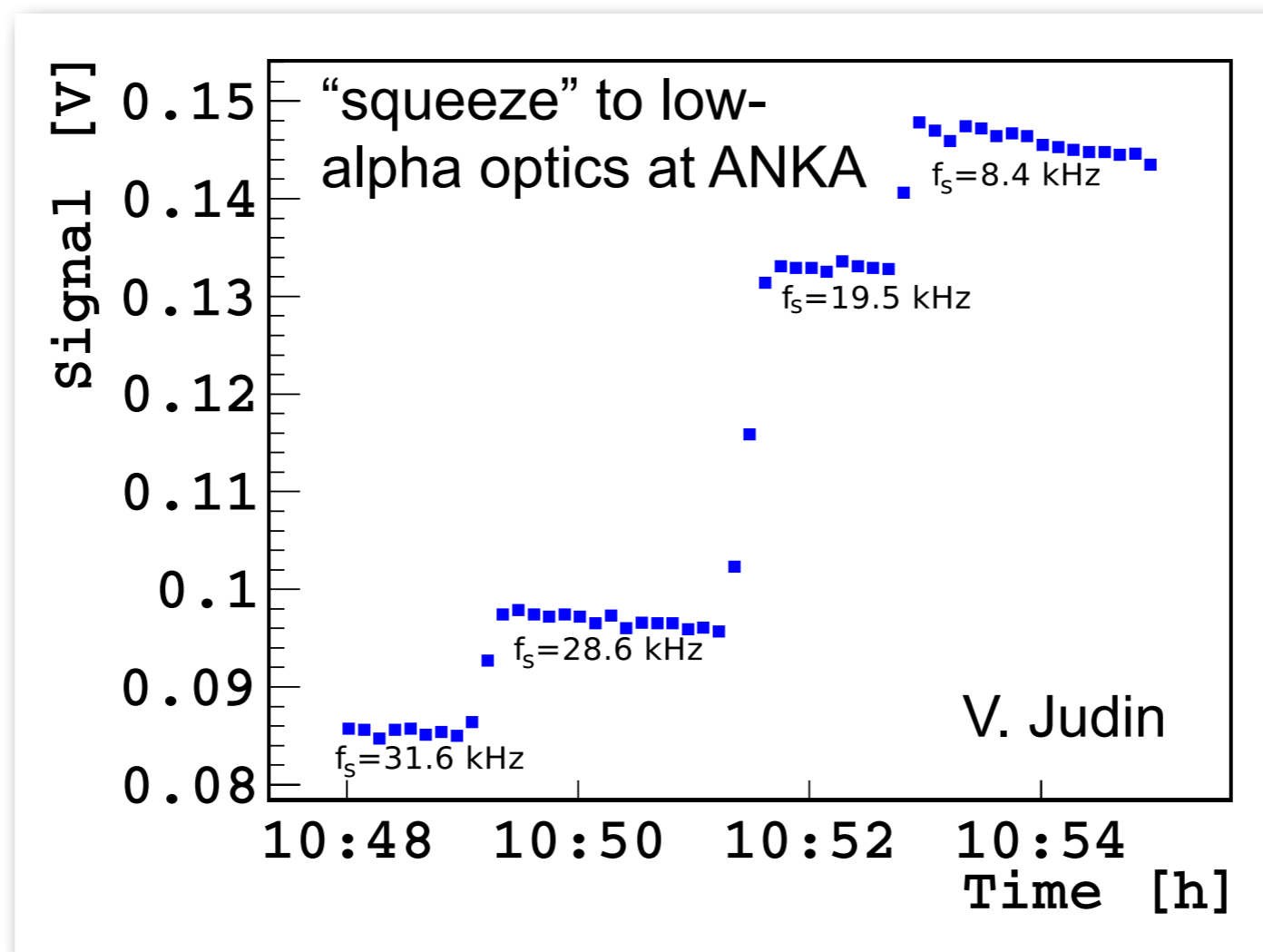


cooperation with F. Caspers, CERN

Microwave Radiation at ANKA

Signal depends strongly on the bunch length

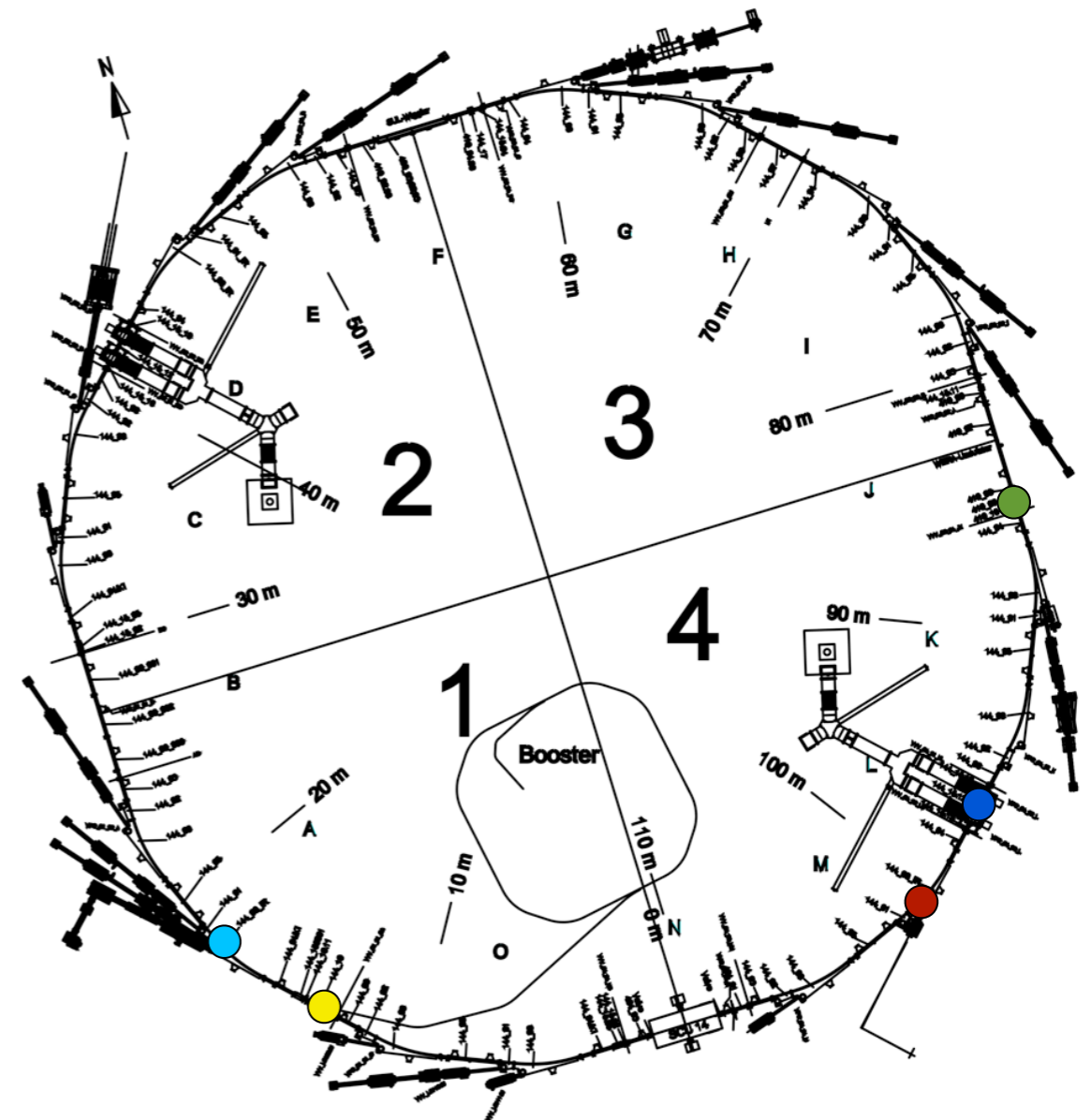
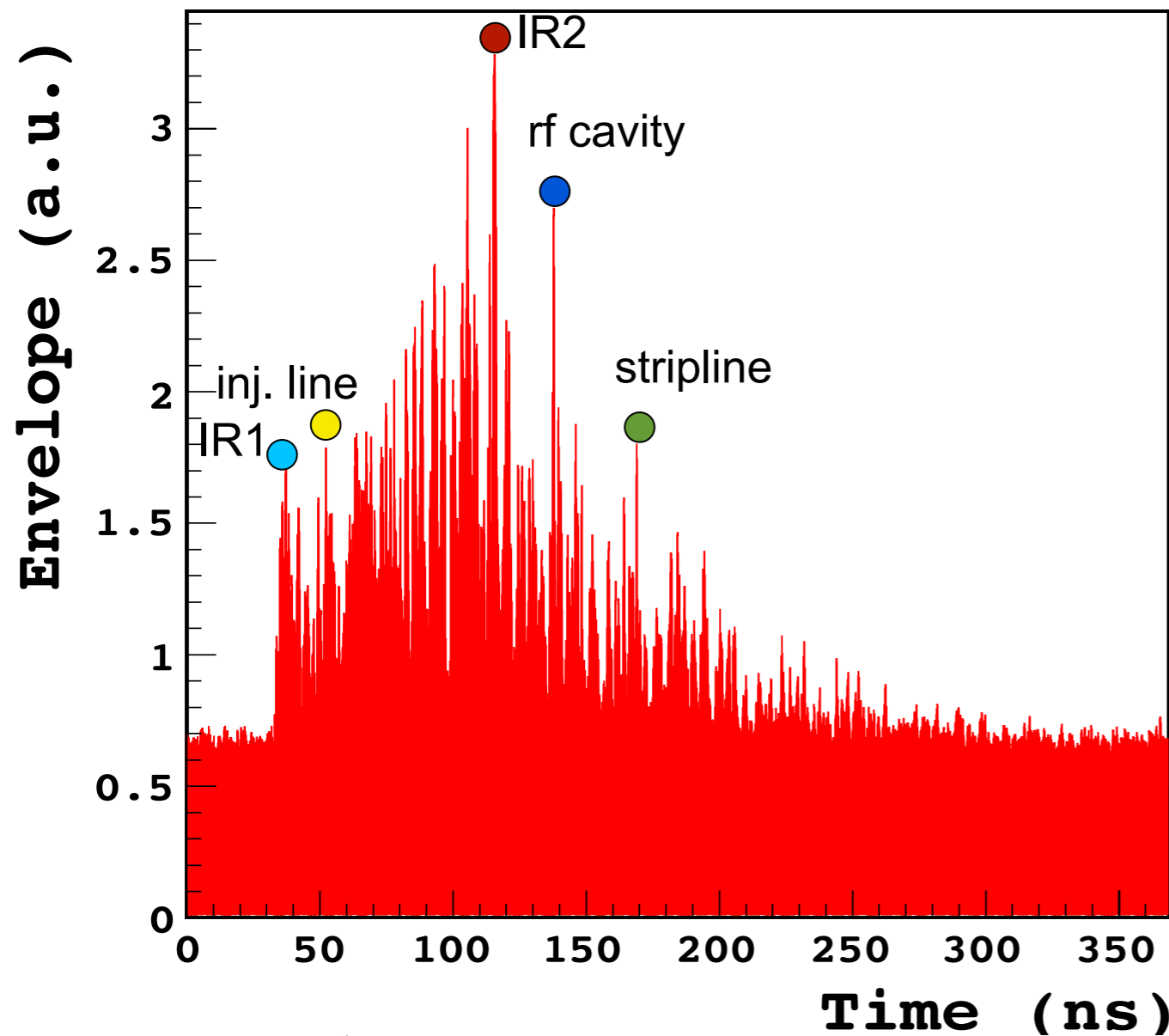
A Schottky diode allows to determine the power of the LNB signal



➔ continuous monitoring bunch length changes possible

Microwave Radiation at ANKA

The LNB signal of a single bunch shows spikes corresponding to ring structures

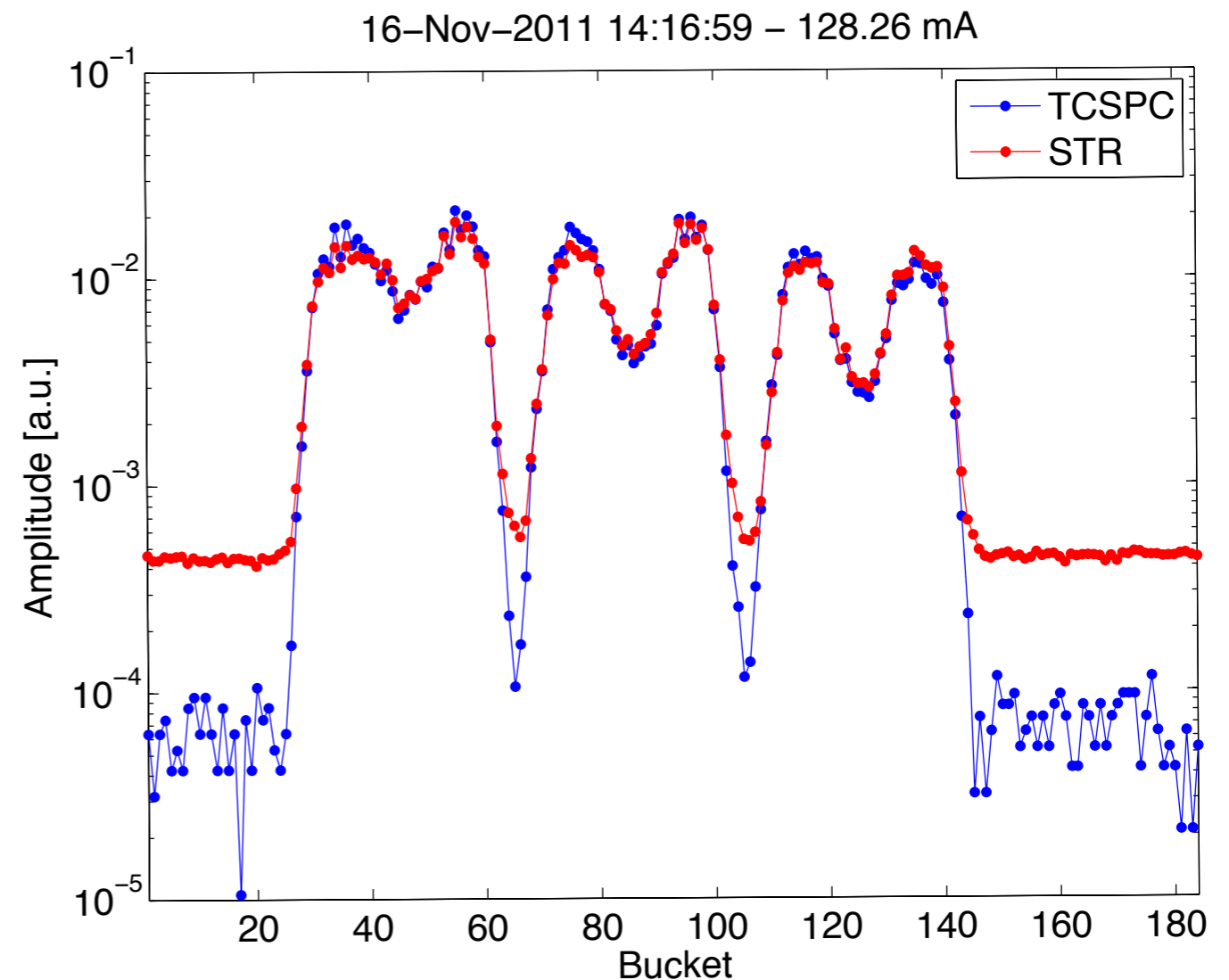
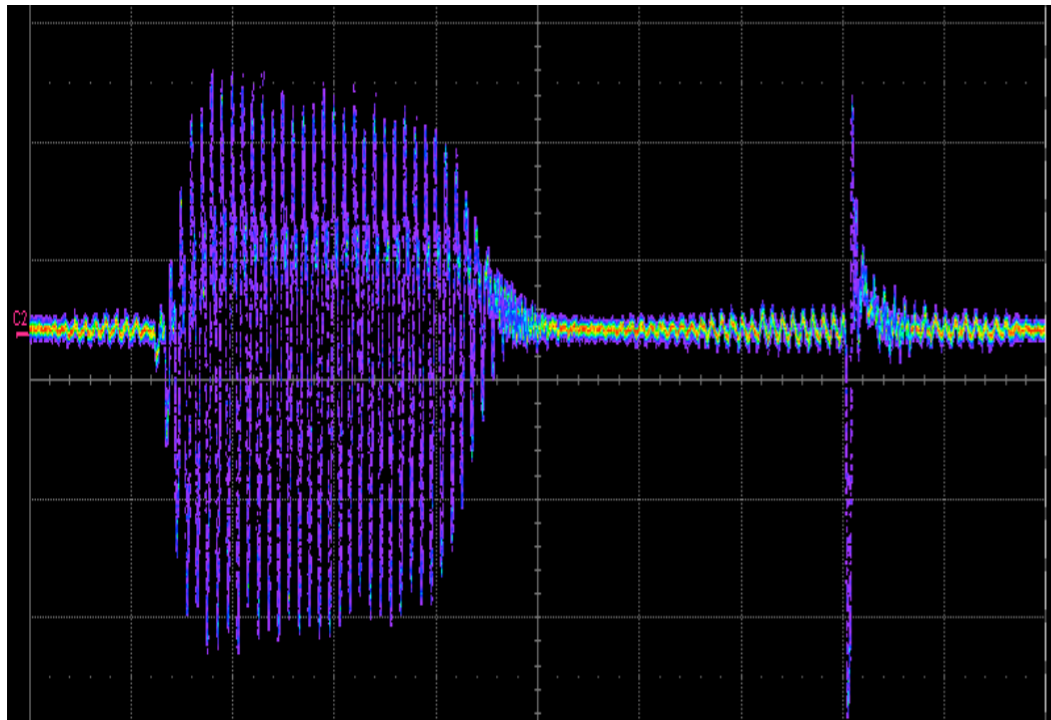


➔ vacuum chamber diagnostics

Filling Pattern Measurement

- Time-correlated single photon counting (TCSPC) using APD at new visible light diagnostics port
- Low noise level and larger dynamic range compared to existing analog filling pattern measurement devices (stripline)

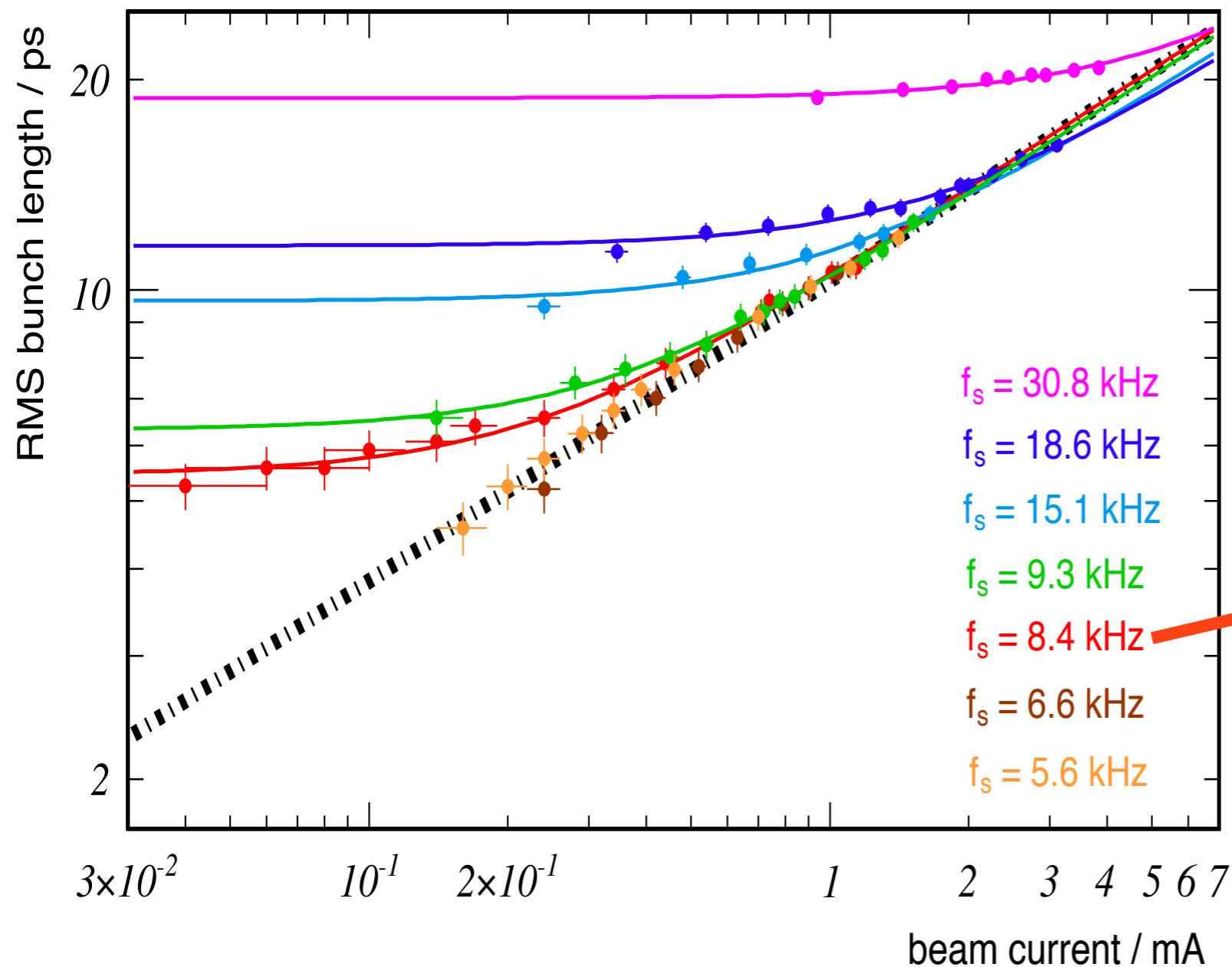
Stripline signal



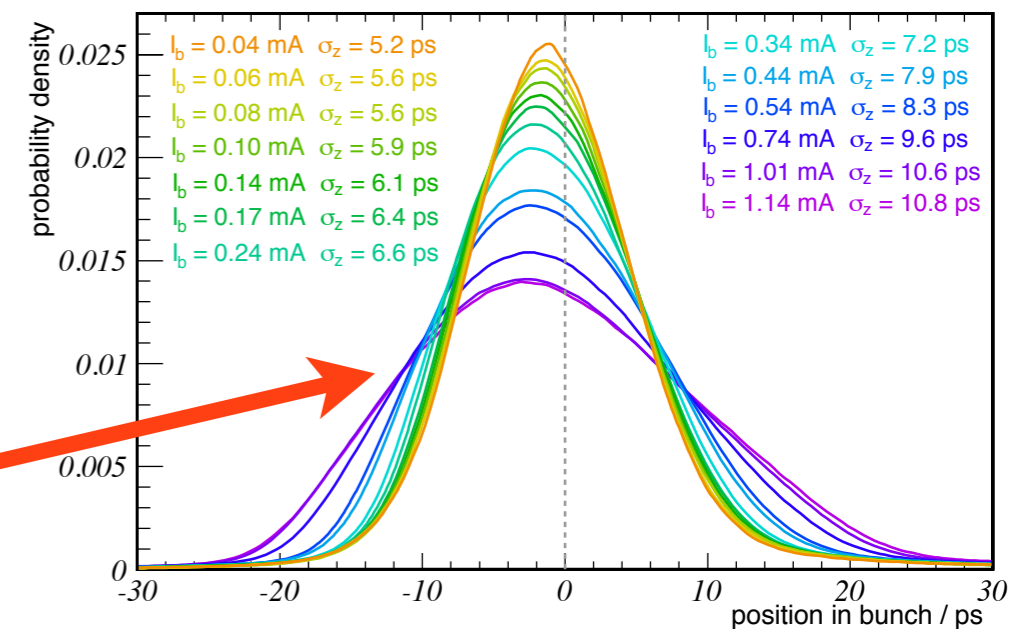
B. Kehrer et al.: IPAC11, TUPC087

Bunch Length and Shape Diagnostics

Observations using Streak Camera



current dependent deformation
of the charge distribution



N. Hiller et al.: IPAC11, THPC021

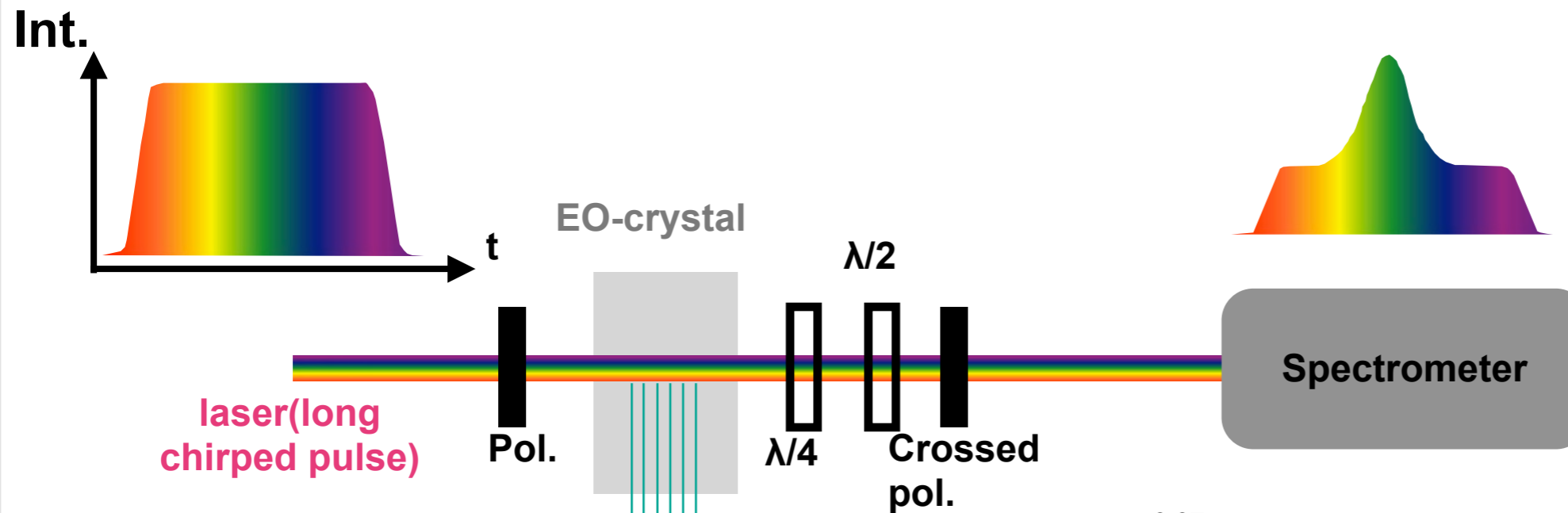
Electro Optical Bunch Length Measurement

Spectral decoding (single shot)

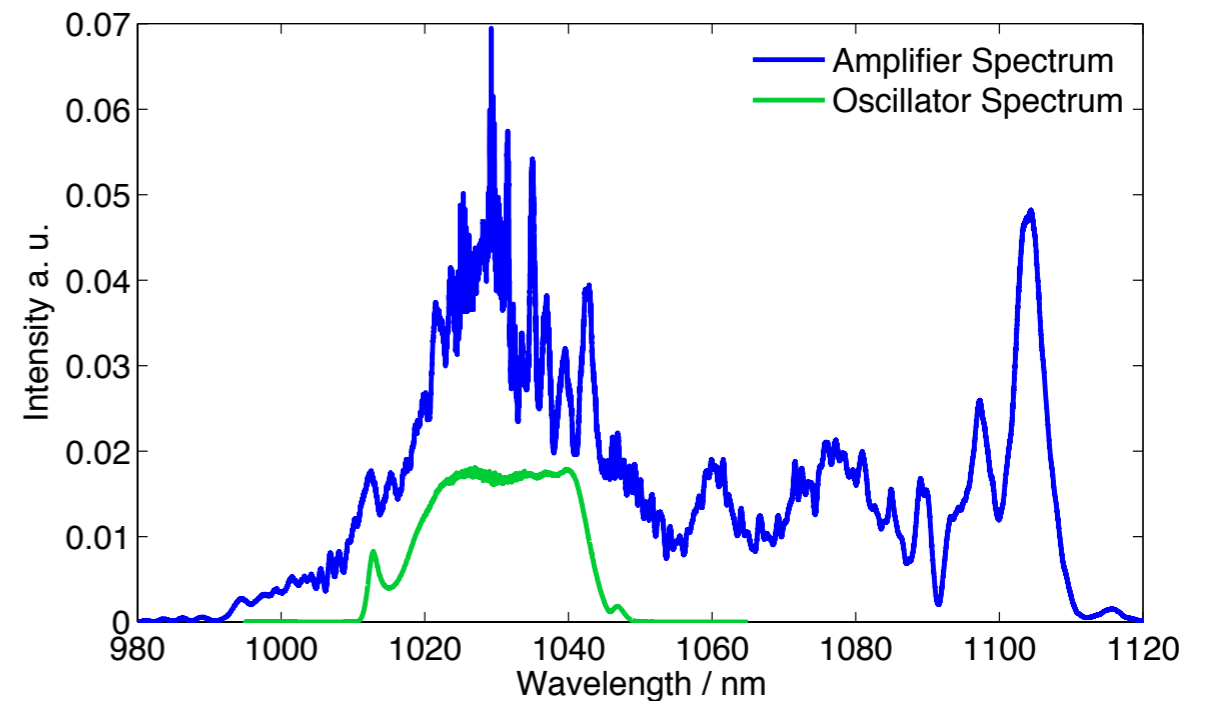
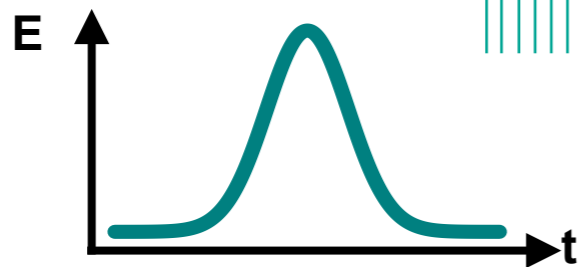
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Federal Ministry of Education and Research



electron bunch



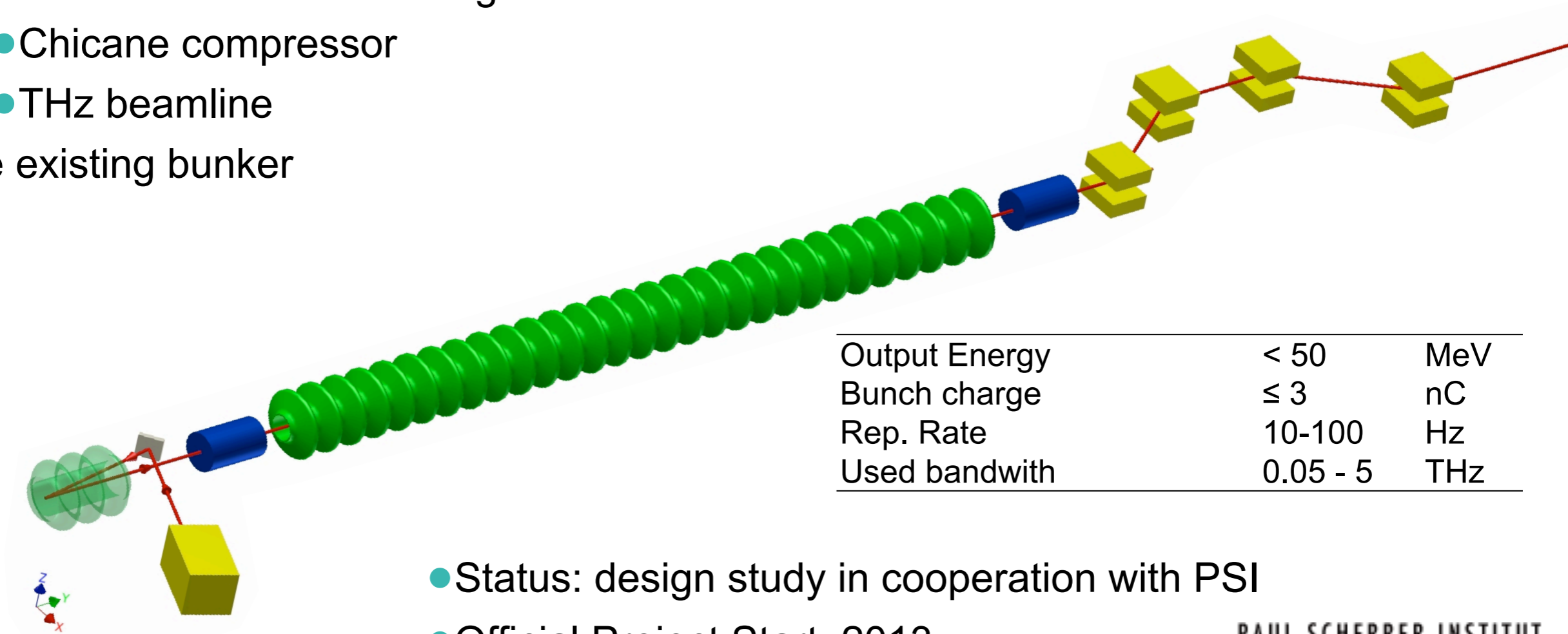
Installation at ANKA → Spring 2012

N. Hiller et al.: IPAC11, TUPC086

FLUTE: A Test Experiment



- Allow small scale tests of THz generation, compression, radiation transport and instrumentation, ...
- Outline:
 - Photo injector (CTF 3 type)
 - S band normal conducting linac
 - Chicane compressor
 - THz beamline
- Use existing bunker



Output Energy	< 50	MeV
Bunch charge	≤ 3	nC
Rep. Rate	10-100	Hz
Used bandwidth	0.05 - 5	THz

- Status: design study in cooperation with PSI
- Official Project Start: 2013

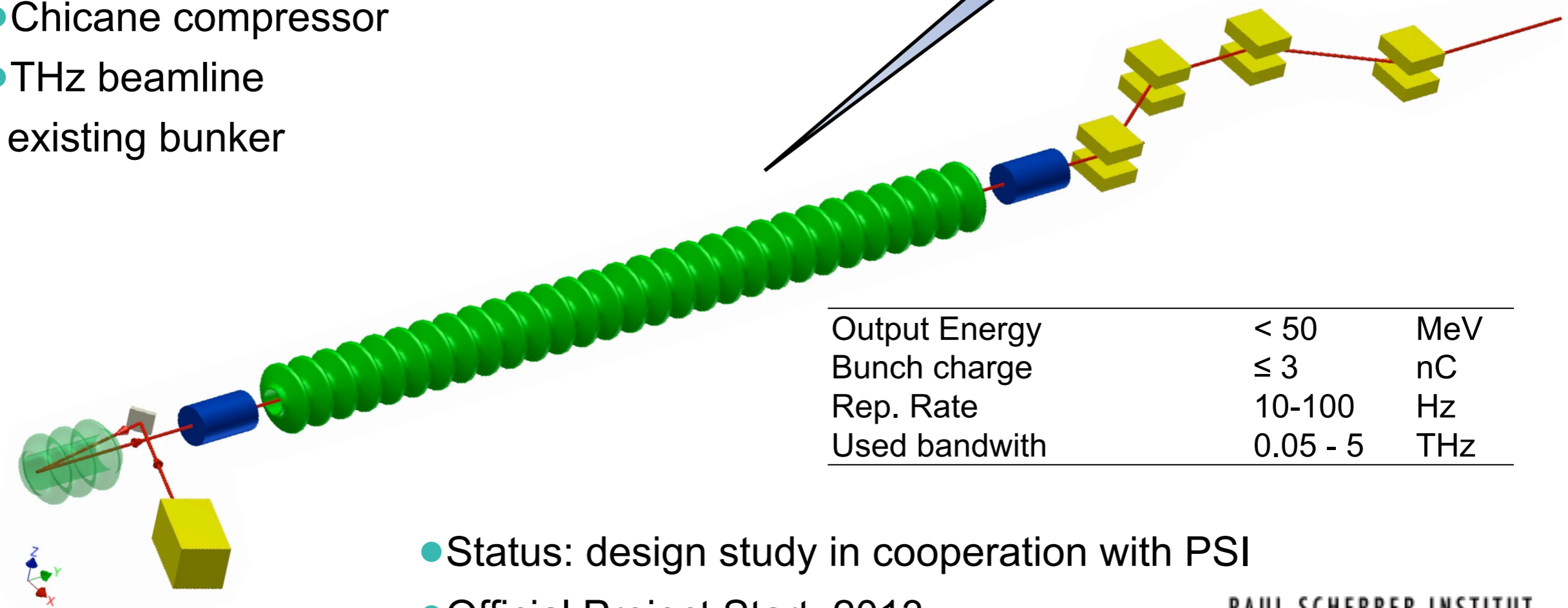


FLUTE: A Test Experiment



- Allow small scale tests of THz generation, compression, radiation transport and instrumentation, ...
- Outline:
 - Photo injector (CTF 3 type)
 - S band normal conducting linac
 - Chicane compressor
 - THz beamline
- Use existing bunker

approved by KIT
Gründungsausschuss in July 2011



Output Energy	< 50	MeV
Bunch charge	≤ 3	nC
Rep. Rate	10-100	Hz
Used bandwidth	0.05 - 5	THz

- Status: design study in cooperation with PSI
- Official Project Start: 2013



LA3NET - PhD Positions

- Measurement of the bunch shape with electro-optical sampling in an electron accelerator
- Precision determination of electron beam energy with Compton backscattered laser photons at ANKA

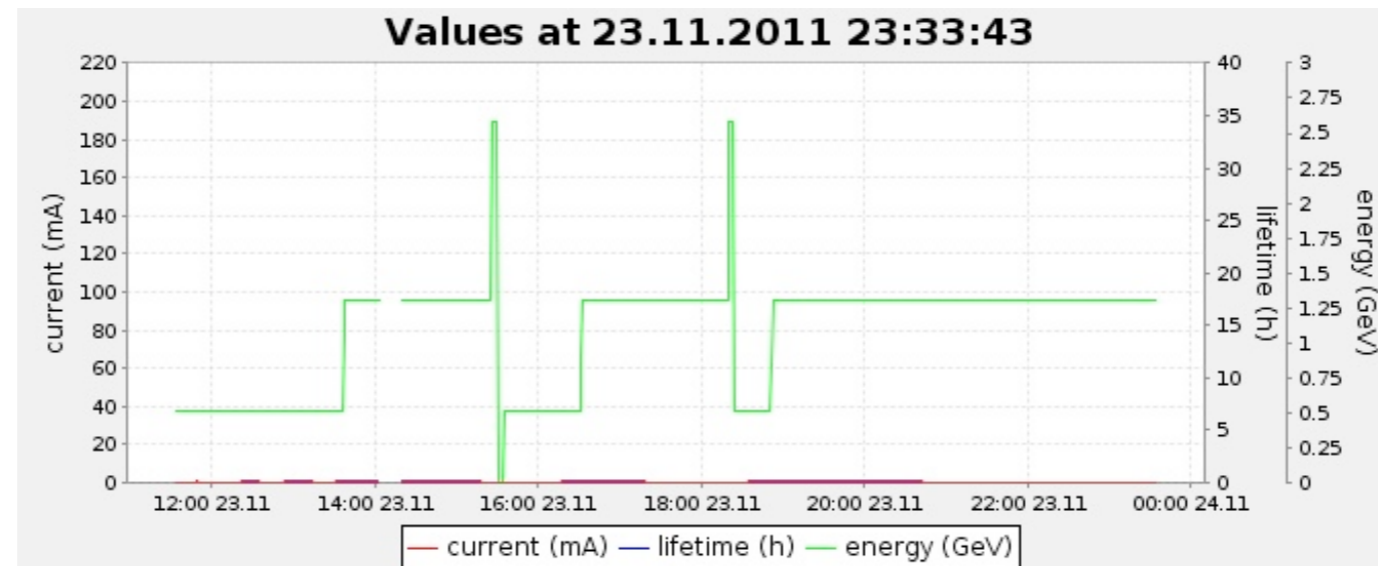


<http://www.liv.ac.uk/la3net/>

Summary

- **Different diagnostics devices are used to explore the radiation spectrum in the microwave, THz and visible range**
- **For short bunch operation CSR is a important issue which depends on:**
 - **Bunch current**
 - **Impedance**
- **Microwave range provides information on:**
 - **Bunch length from bunch spectrum**
 - **Structure of vacuum chamber**
- **Short bunches are very useful for diagnostics**
- **Future projects to explore the THz-Regime and beam properties more precisely**

Thank you for your attention!



Acknowledgments:

KIT ISS / LAS, Karlsruhe, Germany:

V. Judin, N. Hiller, A. Hofmann, B. Kehrer, M. Klein, S. Marsching, S. Naknaimueang, M. Nasse, N.J. Smale, E. Huttel, A.-S. Müller

KIT IMS, Karlsruhe, Germany:

P. Probst

DLR, Berlin, Germany:

A. Semenov

MLS, Berlin, Germany:

M. Ries

SLS, Villingen, Switzerland:

P. Peier, V. Schlott

CERN, Geneva, Switzerland:

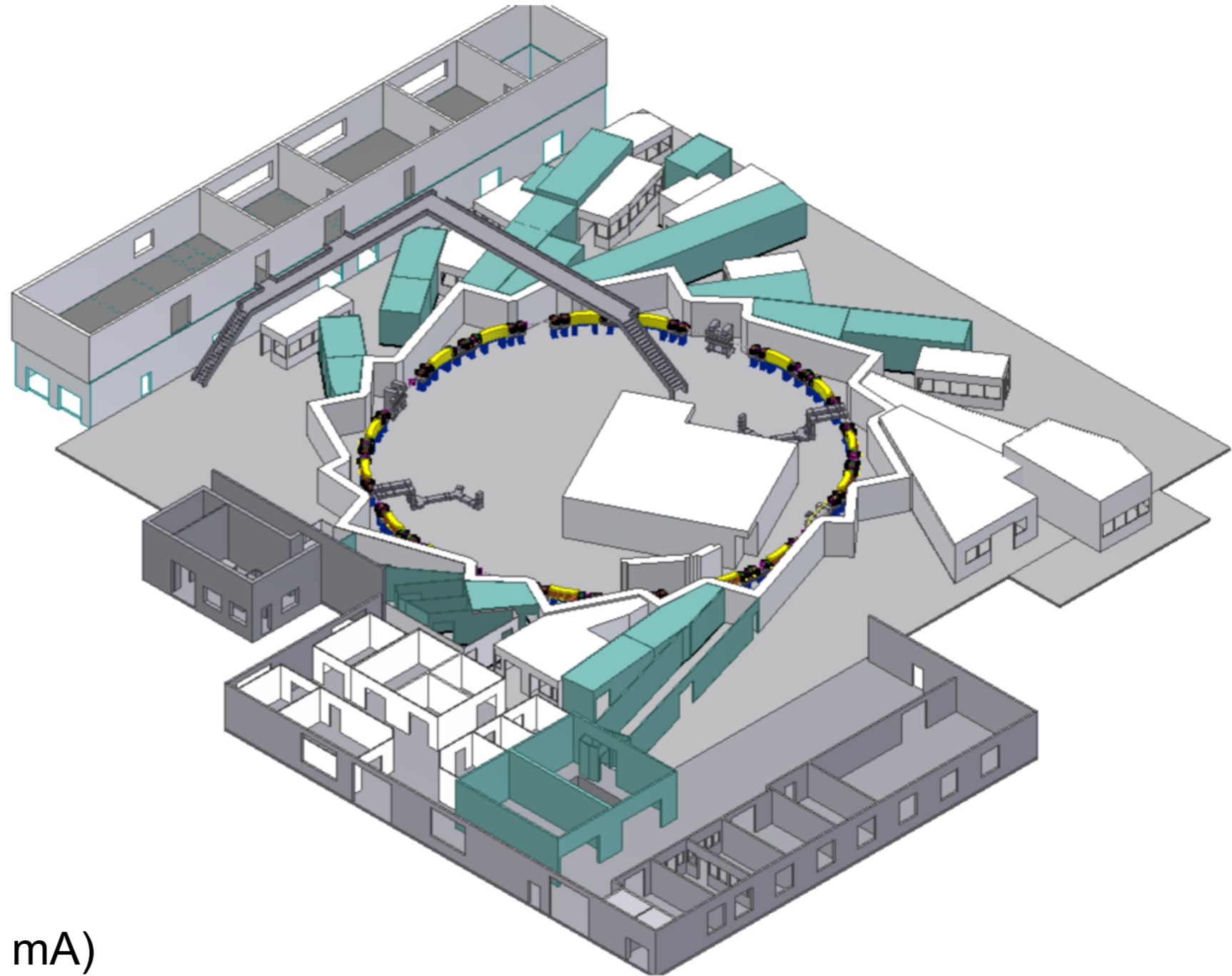
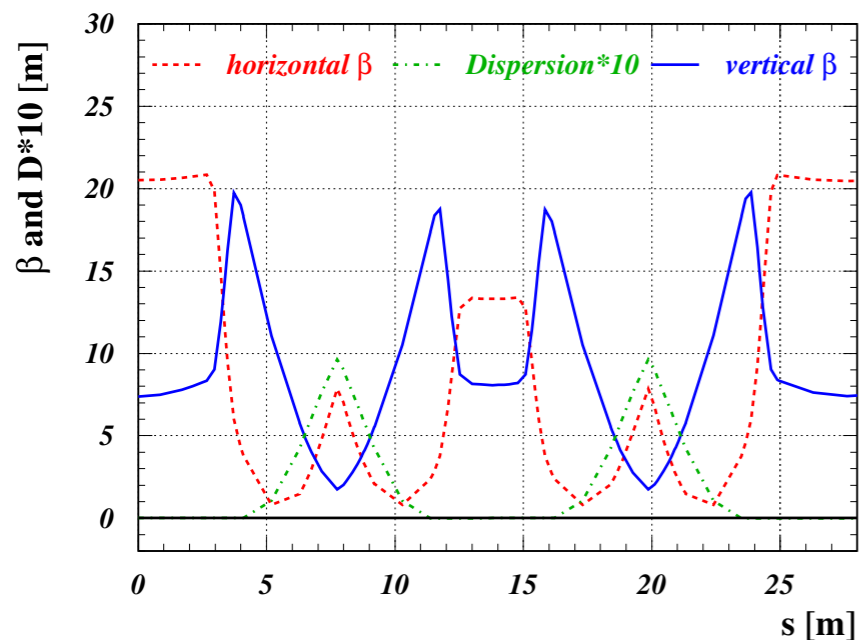
F. Caspers



ANKA Storage Ring

Key parameters:

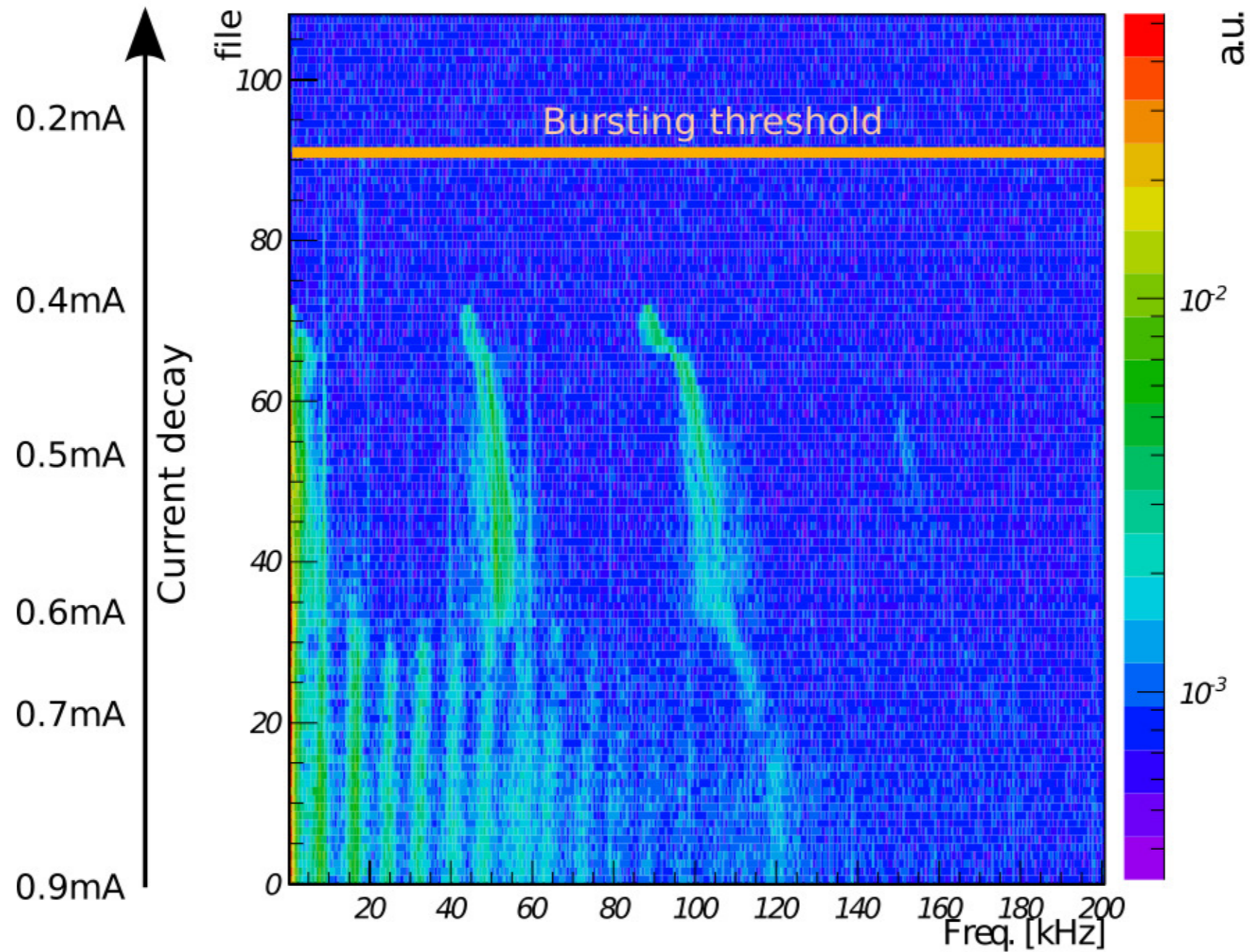
- Circumference: 110.4 Meter
- RF-frequency: 500 MHz
- Revolution time: ≈ 368 ns
- Harmonic number: 184
- Lattice: double DBA



Normal operation mode:

- Beam energy 2.5 GeV
- Multi bunch mode (up to 200 mA)
- Bunch length > 30 ps

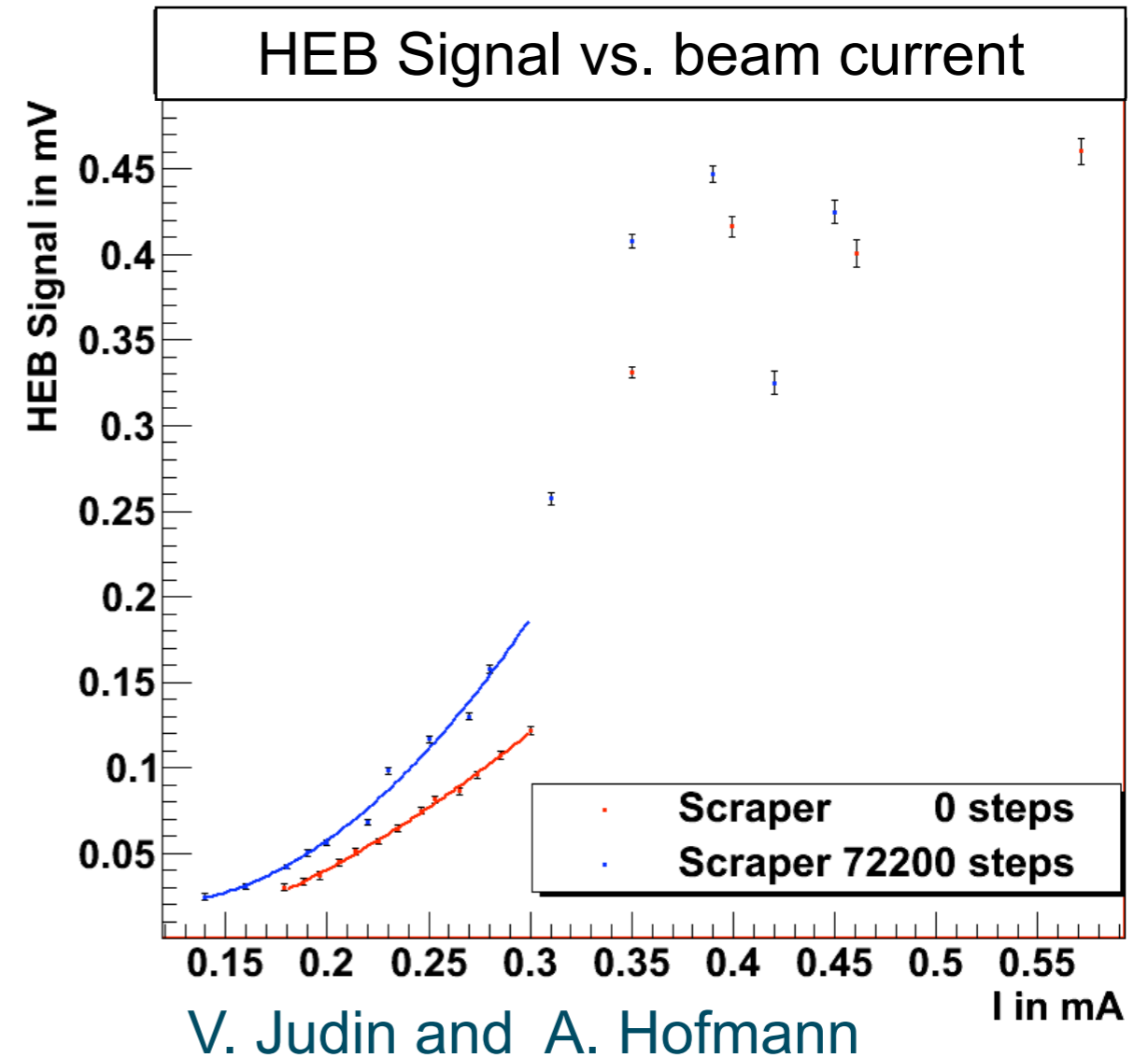
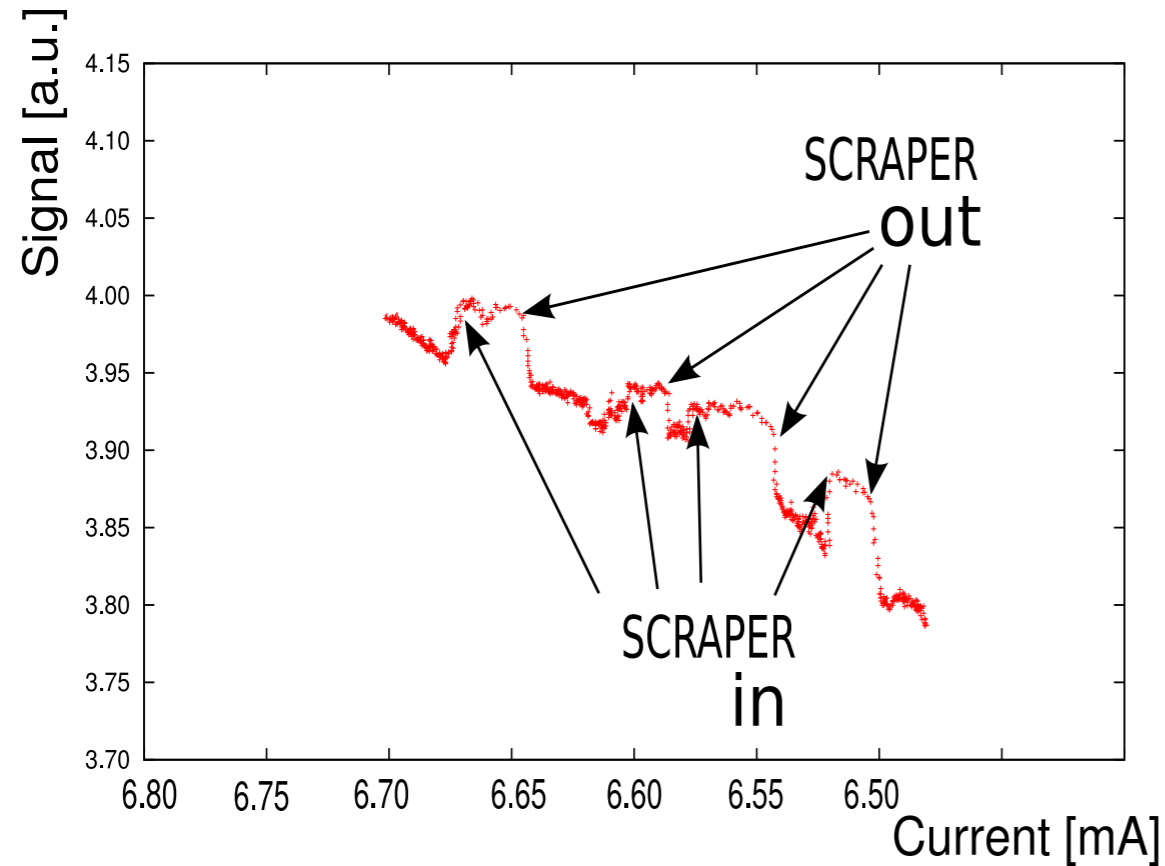
Current Dependent Longitudinal Instabilities



courtesy V. Judin

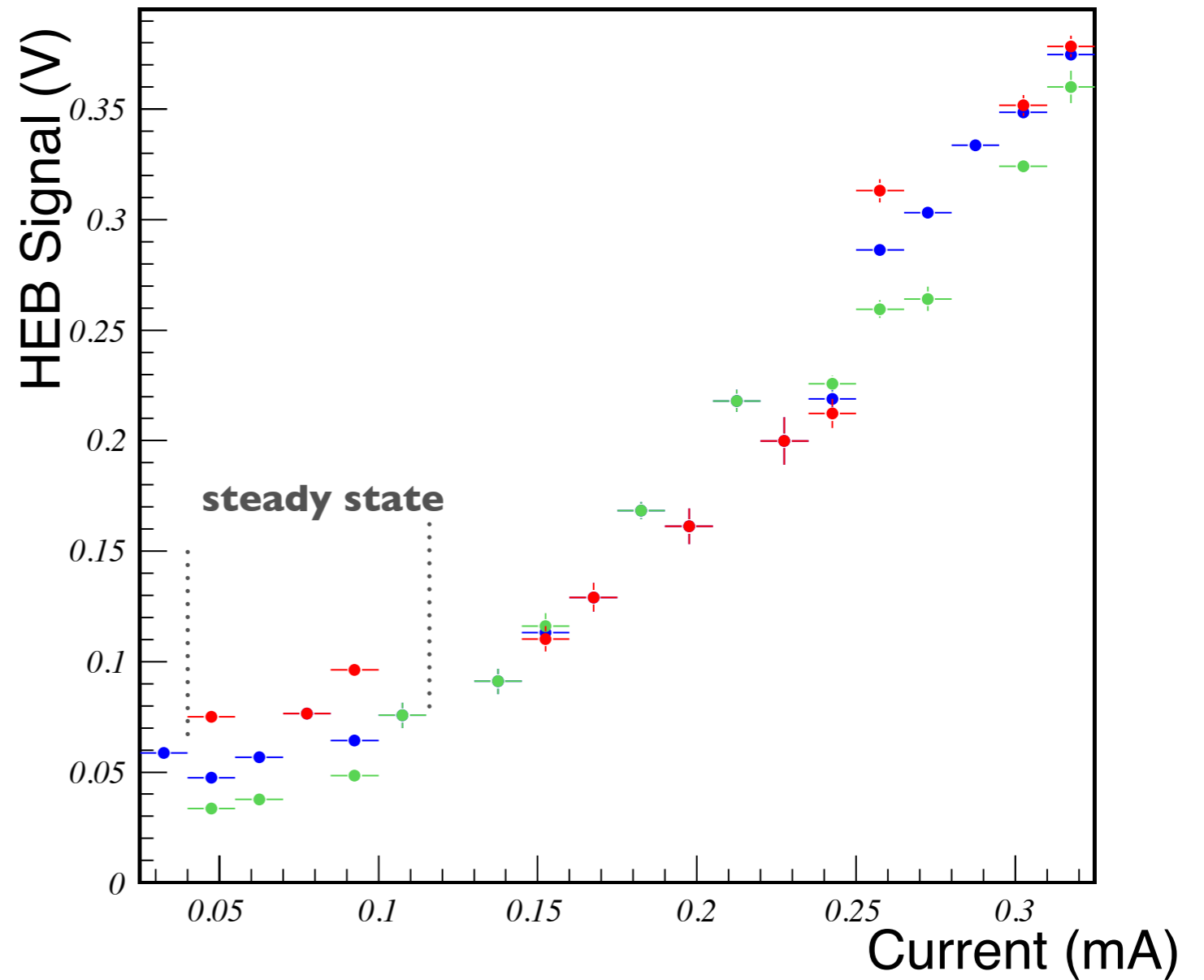
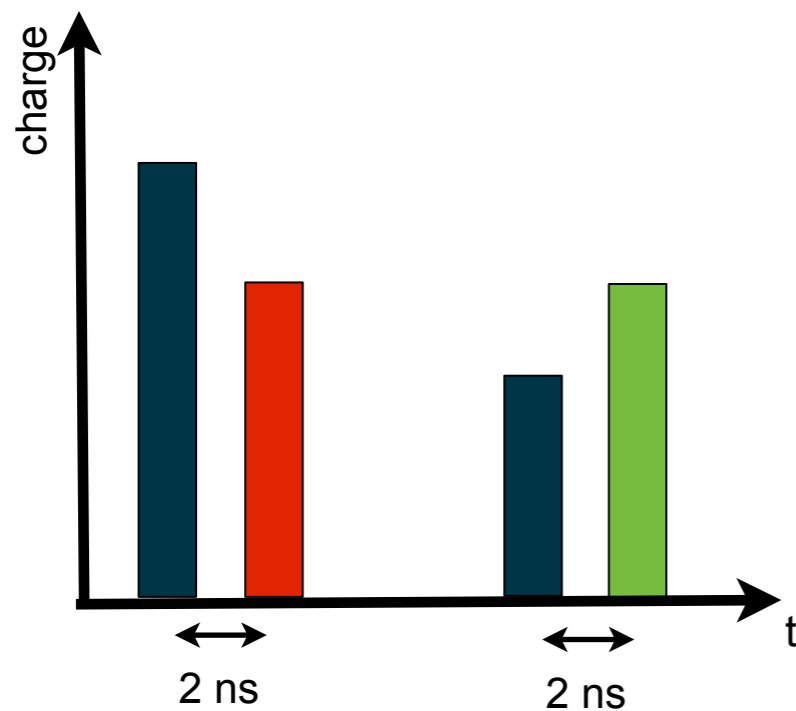
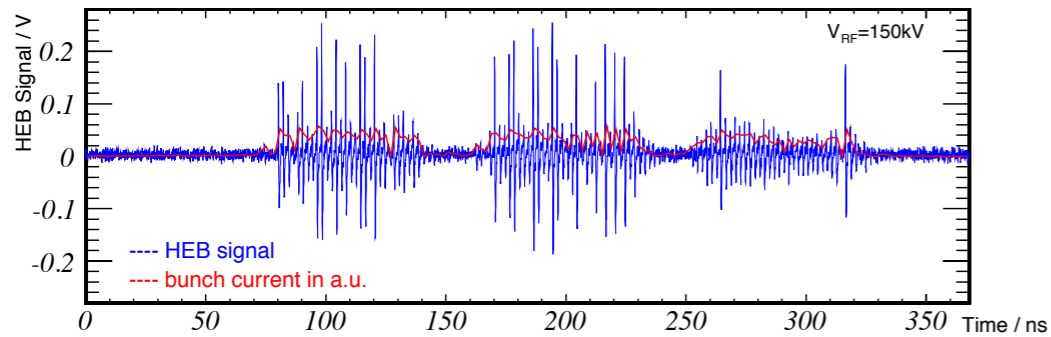
Scraper effects

controlled change of the impedance
by an vertical scraper



clear effect on CSR-power

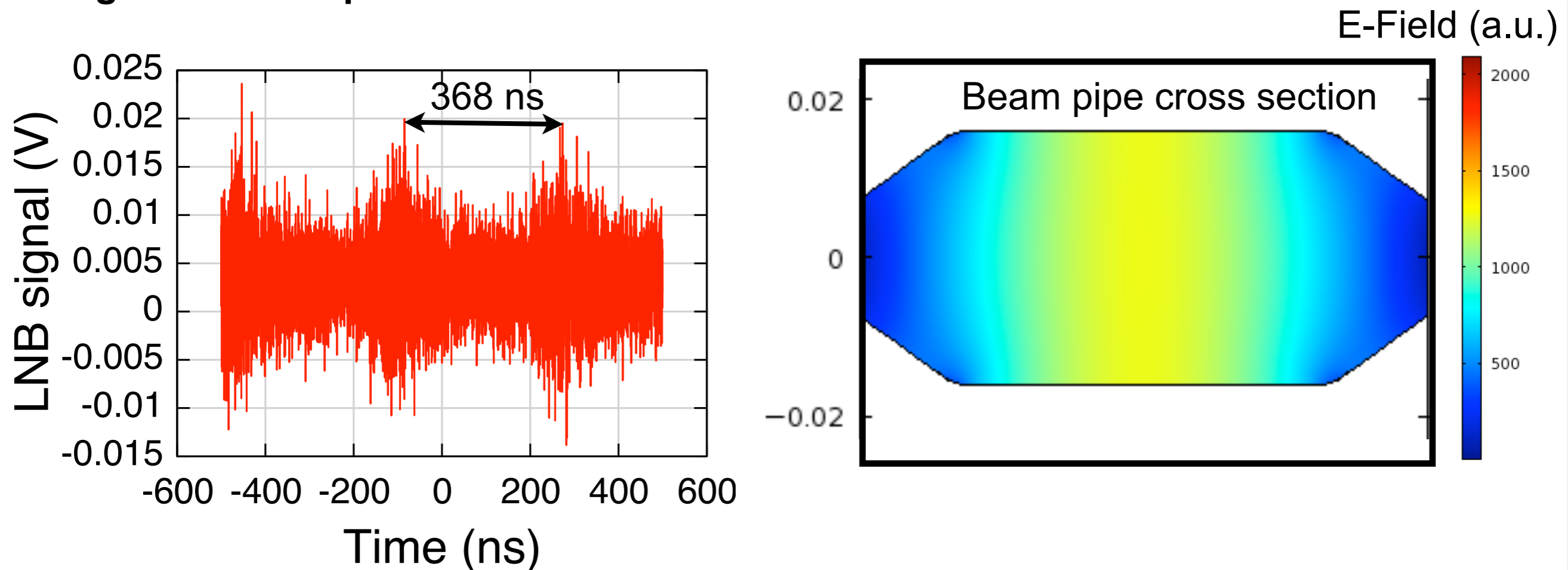
Multibunch Effects



THz emission depends on filling pattern

Microwave Radiation at ANKA

Single bunch response

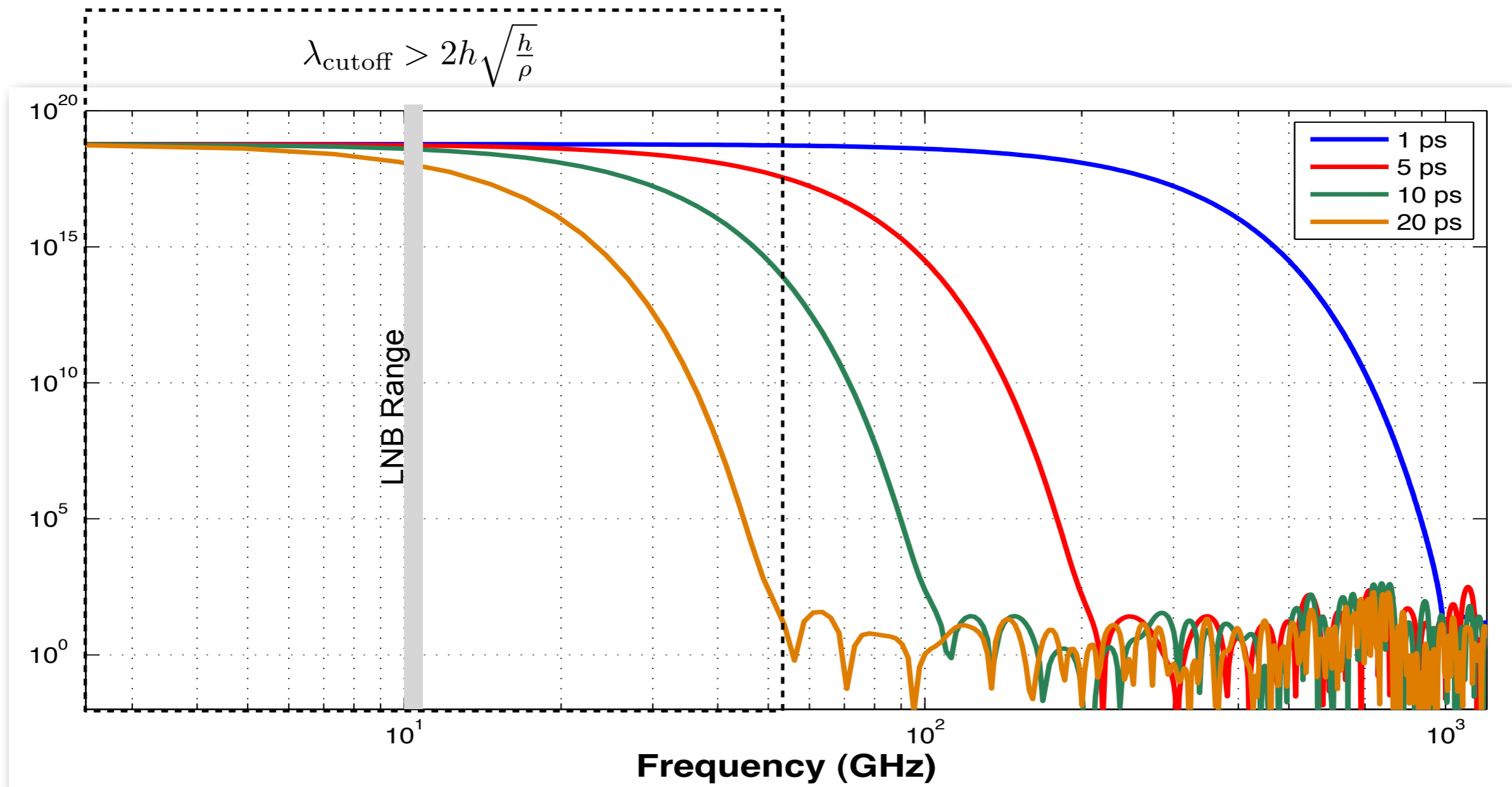


- Fundamental mode of vacuum chamber at ANKA: 2.21 GHz
- $v_g \approx 0.98c$ for the LNB frequency band (10.7 - 12.75 GHz)

Are spikes in LNB signal due to structures of the vacuum chamber?

Microwave Radiation at the ANKA Storage ring

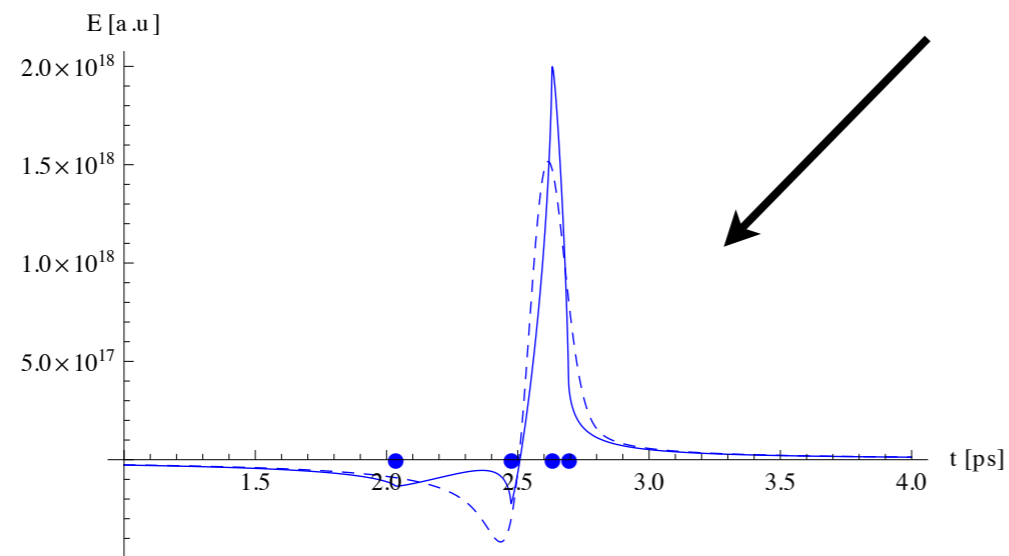
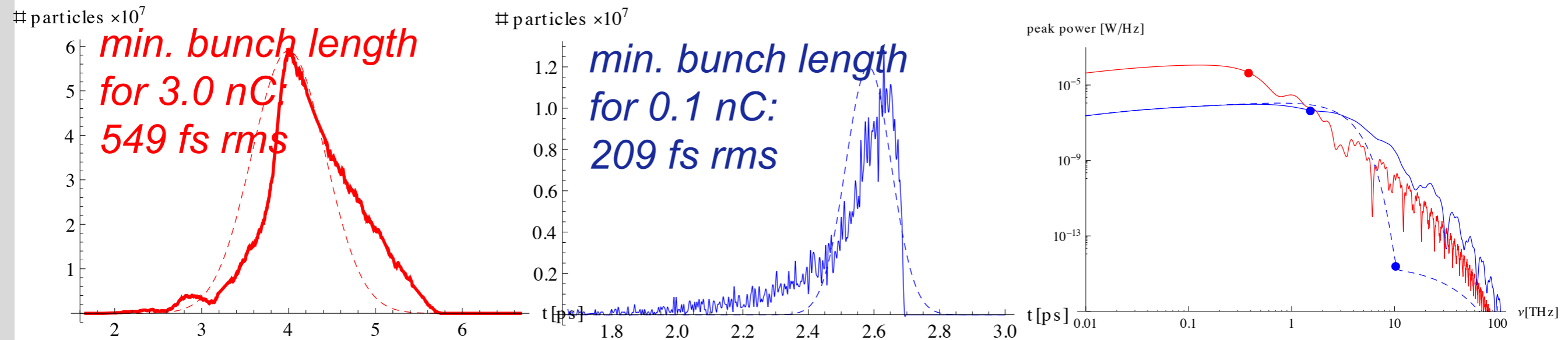
CSR in microwave range



for Gaussian bunch shape in free space

Bunch Compression & E-Field

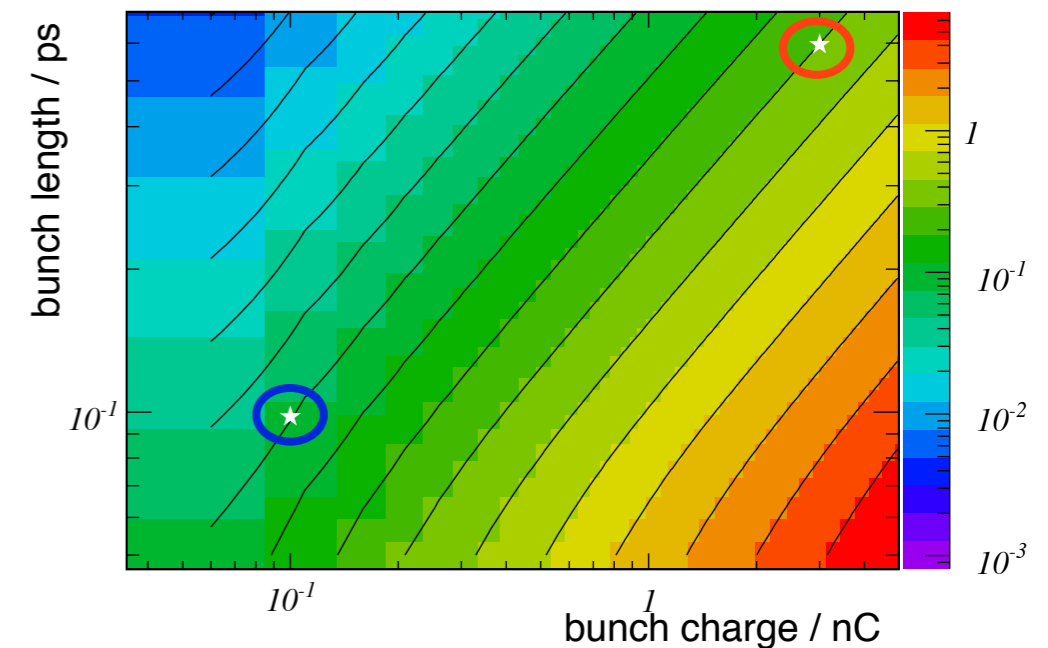
Simulation of electron beam with ASTRA & CSRtrack



Peak E-fields

- for 0.1 nC bunch 7.5×10^7 V/m
- for 3.0 nC bunch 3.0×10^8 V/m

E in GV/m for Gauss equivalent bunches



S. Naknaimueang, M. Schwarz, R. Rossmanith