PAUL SCHERRER INSTITUT

PSI

DIPAC 2009

Highlights

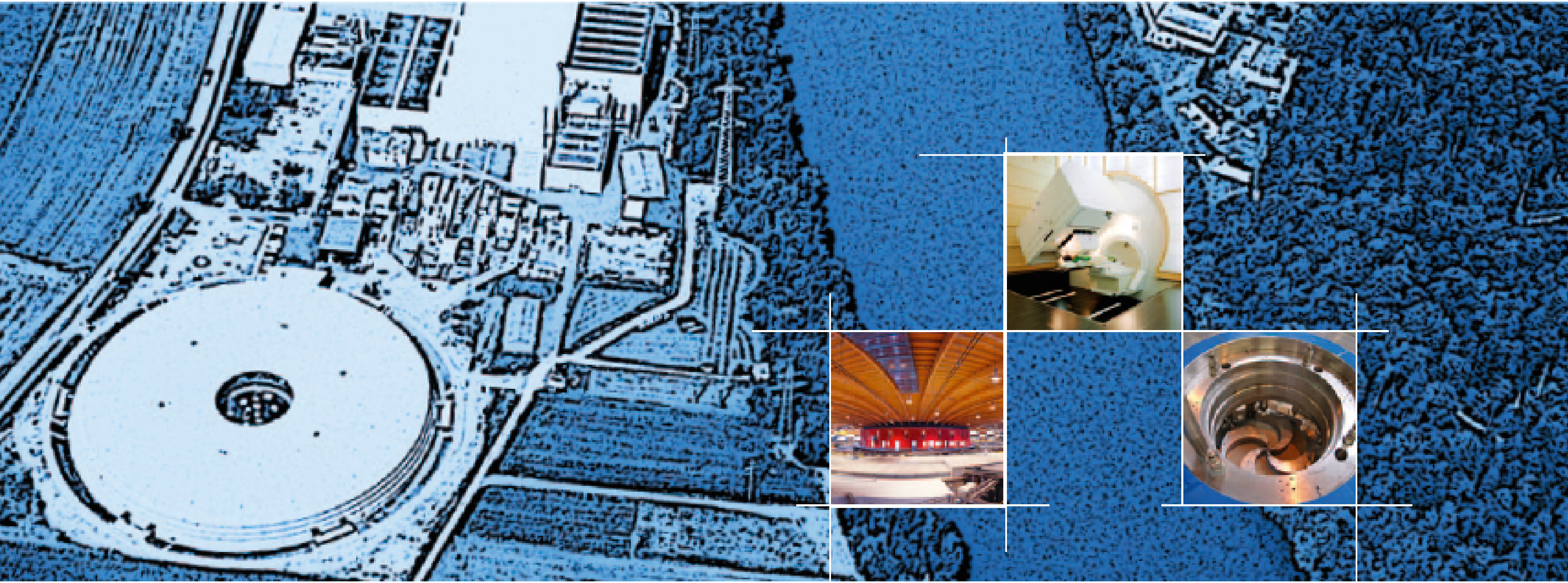
Presented 12/06/2009

Christos Zamantzas

PAUL SCHERRER INSTITUT

DIPAC 2009

9th European Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators



May 25 – 27, 2009

Basel, Switzerland

Hotel Mercure

Numbers & Facts (unofficial)

2.5 days workshop with

- 10 invited talks [Performance of and Experience with the LHC Beam Diagnostics, R.Jones]
- 14 contributed talks [Digital BPM System for Hadron Accelerators, J. Belleman]
- 3 poster sessions with 115 posters [14 from BE/BI]

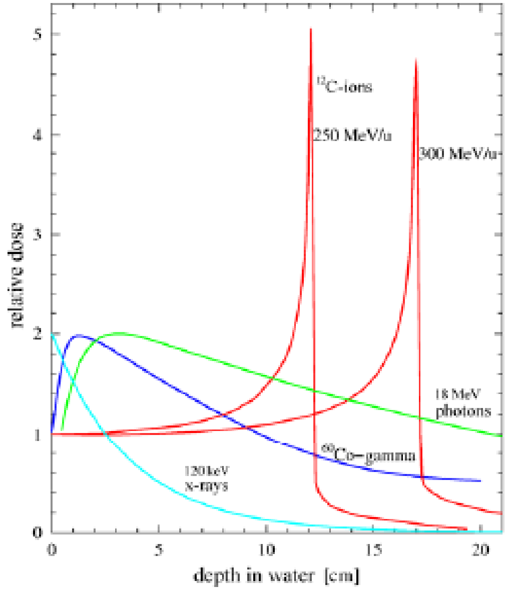
- ~ 200 attendees
- ~ 95 Institutes/Universities
- ~ 7 exhibiting vendors

http://dipac09.web.psi.ch/

Instrumentation Req. for Dif. Accelerator Types

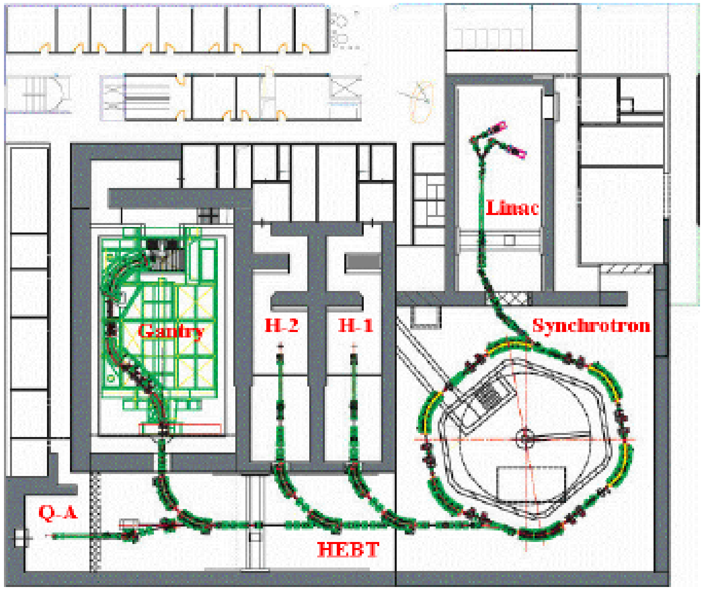
II. Hadron Therapy Machines

the standards: beam energy, intensity, tunes, orbits
not really a problem



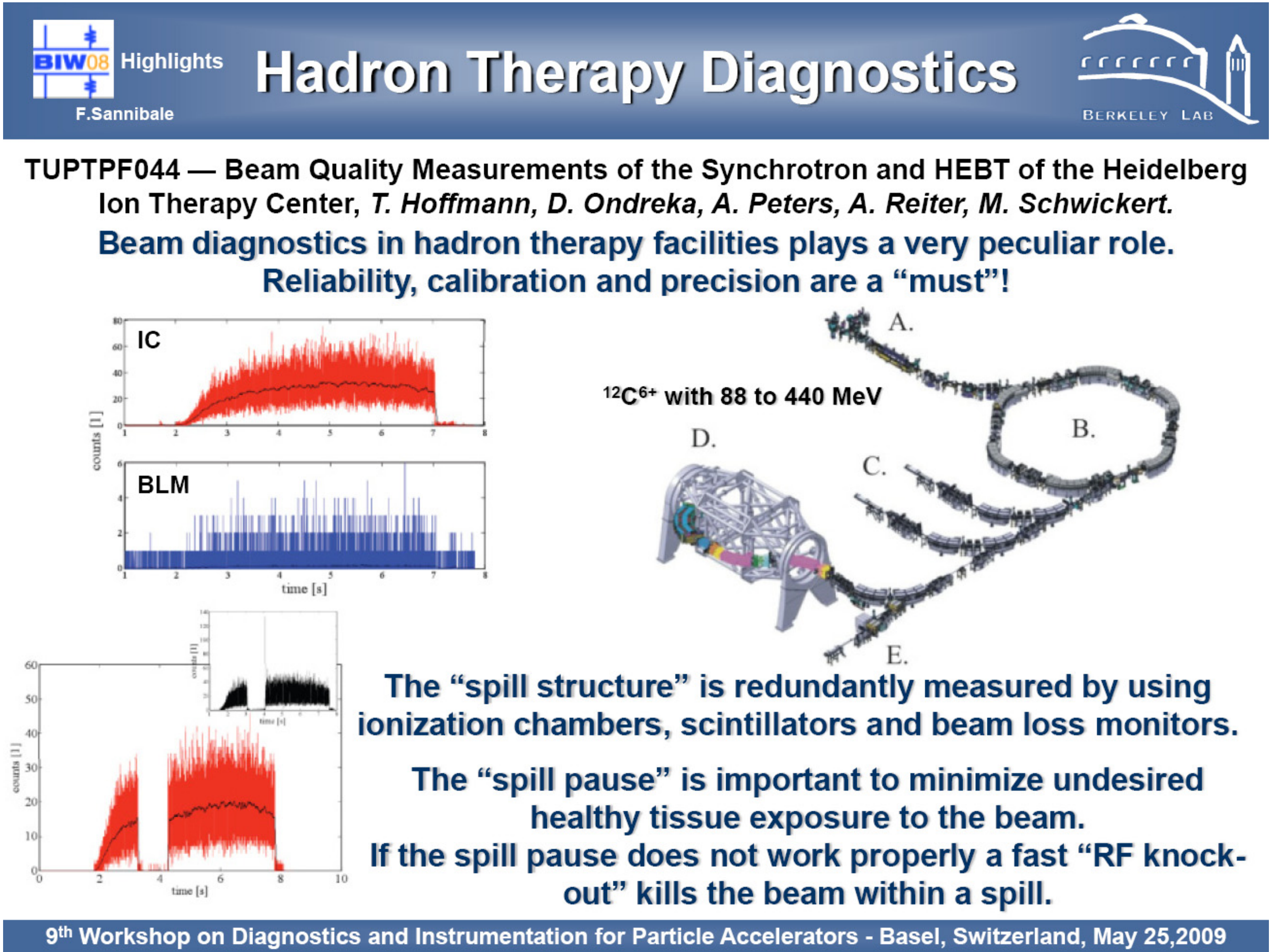
control of penetration depth / Bragg peak via beam energy

Example: parameters of the HIT project in Heidelberg:



particles:	*p, C, He, O*
beam energy	*50 - 430 MeV/u*
beam size	*4-10 mm*
extraction time	*1-10 s*
extraction intensity	*10^6 - 4 * 10^{10} ions / spill*
beam power	*360 W dc power*

Highlights from the 13th BIW



BIW08 Highlights

Hadron Therapy Diagnostics

F.Sannibale

BERKELEY LAB

TUPTPF044 — Beam Quality Measurements of the Synchrotron and HEBT of the Heidelberg Ion Therapy Center, ***T. Hoffmann, D. Ondreka, A. Peters, A. Reiter, M. Schwickert.***

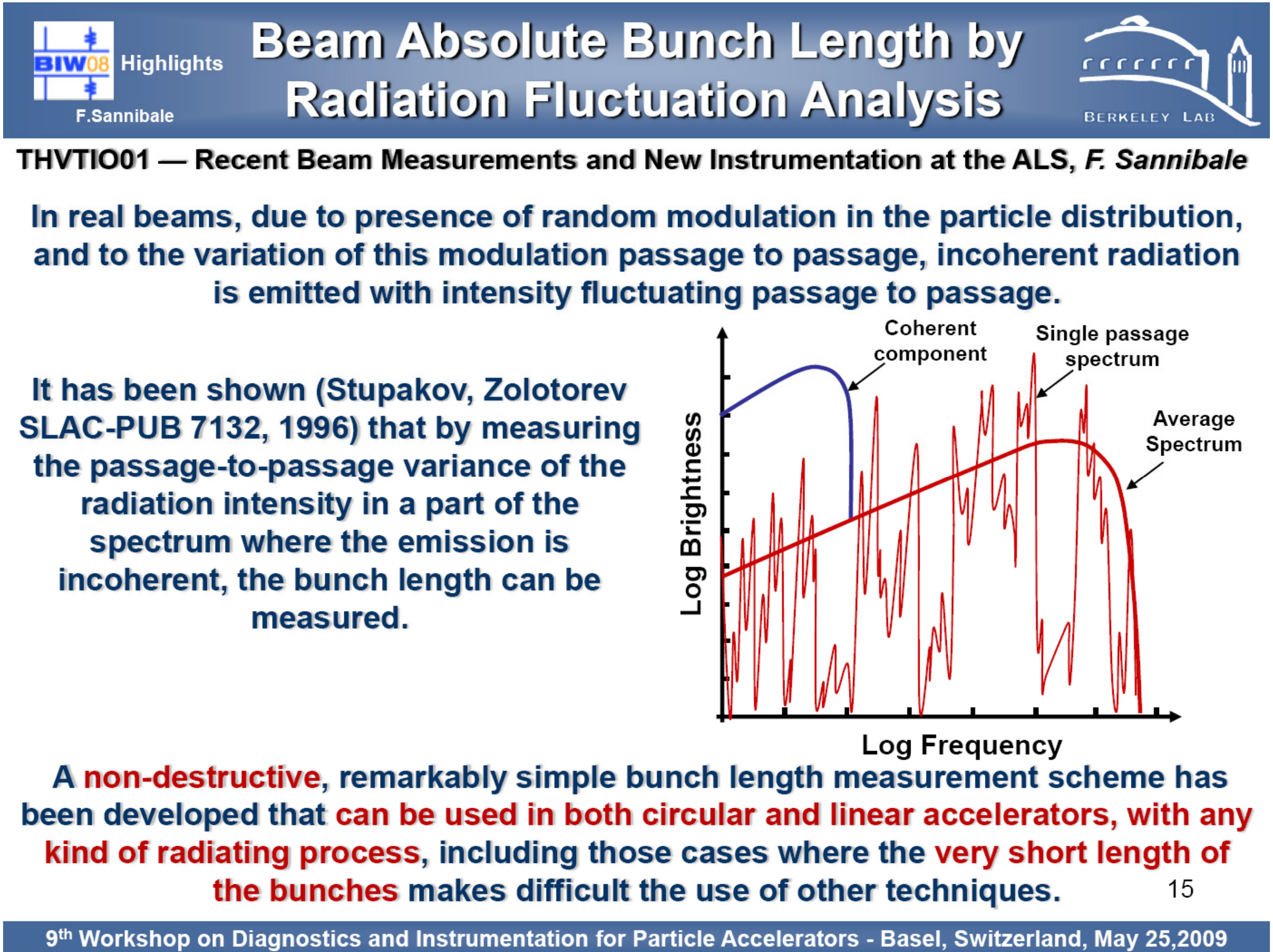
Beam diagnostics in hadron therapy facilities plays a very peculiar role. Reliability, calibration and precision are a "must"!

The "spill structure" is redundantly measured by using ionization chambers, scintillators and beam loss monitors.

The "spill pause" is important to minimize undesired healthy tissue exposure to the beam. If the spill pause does not work properly a fast "RF knock-out" kills the beam within a spill.

9^{th} Workshop on Diagnostics and Instrumentation for Particle Accelerators - Basel, Switzerland, May 25,2009

Highlights from the 13th BIW



BIW08 Highlights

F.Sannibale

Beam Absolute Bunch Length by Radiation Fluctuation Analysis

BERKELEY LAB

THVTIO01 — Recent Beam Measurements and New Instrumentation at the ALS, *F. Sannibale*

In real beams, due to presence of random modulation in the particle distribution, and to the variation of this modulation passage to passage, incoherent radiation is emitted with intensity fluctuating passage to passage.

It has been shown (Stupakov, Zolotorev SLAC-PUB 7132, 1996) that by measuring the passage-to-passage variance of the radiation intensity in a part of the spectrum where the emission is incoherent, the bunch length can be measured.

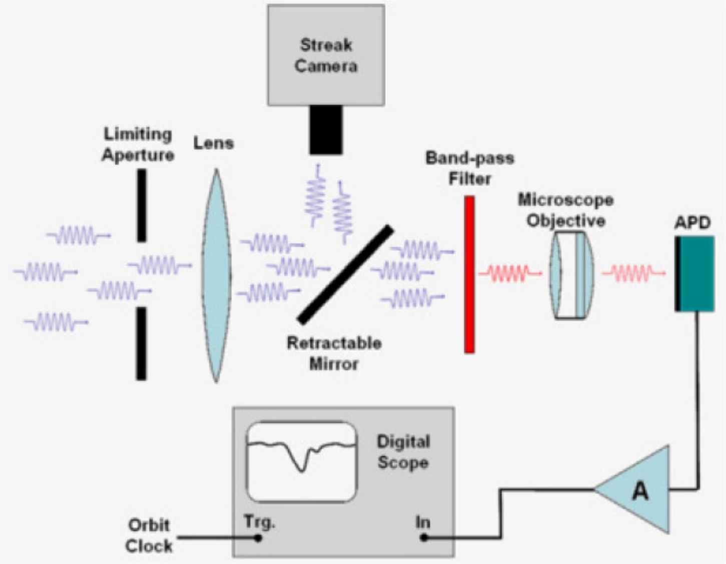
A non-destructive, remarkably simple bunch length measurement scheme has been developed that can be used in both circular and linear accelerators, with any kind of radiating process, including those cases where the very short length of the bunches makes difficult the use of other techniques.

Highlights from the 13th BIW

BIW08 Highlights
F.Sannibale

Beam Absolute Bunch Length by Radiation Fluctuation Analysis

BERKELEY LAB

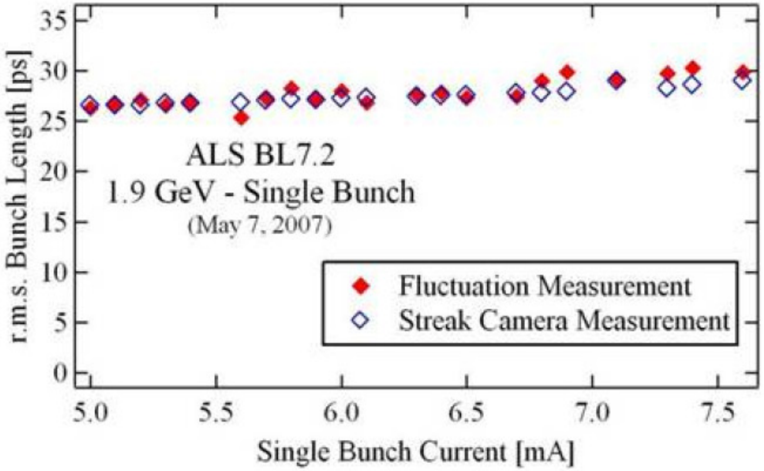


By using a bandpass filter with bandwidth σ_ω and measuring the passage to passage relative variance δ^2 of the radiation intensity, the bunch length σ_τ can be measured from:

$$\boxed{\delta^2 = 1\Big/\sqrt{1+4\sigma_\tau^2\sigma_\omega^2}}$$

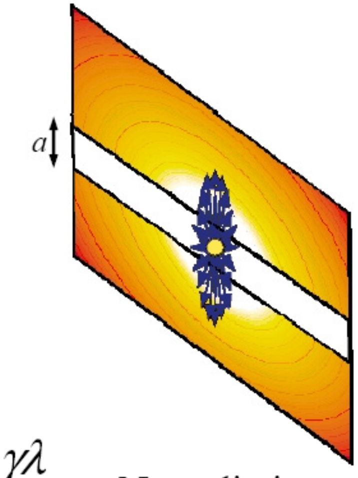
The method has been successfully demonstrated at the Advanced Light Source using synchrotron radiation from a dipole.

Sannibale et al. PRST-AB 12, 032801 (2009).



Optical Diffraction Radiation Interferometry

DIFFRACTION RADIATION



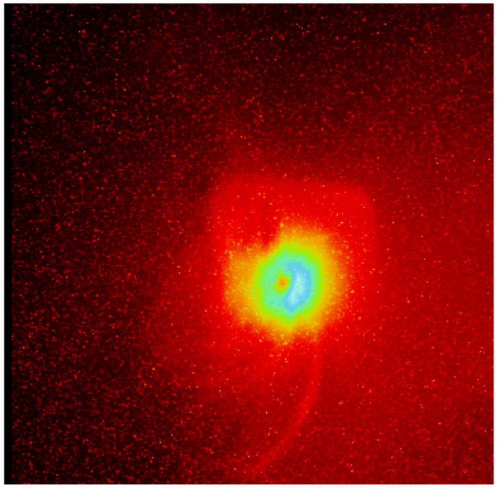
- DR is produced by the interaction between the EM fields of the traveling charge and the conducting screen
- The extension of the electromagnetic field of a relativistic particle is a flat circle of diameter $\gamma\lambda/2\pi$,
- The radiation intensity is $I \propto e^{-\frac{2\pi a}{\gamma\lambda}}$
- DR impact parameter is $\frac{\gamma\lambda}{2\pi} \rightarrow$ if $a \begin{cases} >> \frac{\gamma\lambda}{2\pi} & \text{No radiation} \\ \cong \frac{\gamma\lambda}{2\pi} & \text{DR} \\ << \frac{\gamma\lambda}{2\pi} & \text{TR} \end{cases}$
- Excellent candidate to measure beam parameters **parasitically**

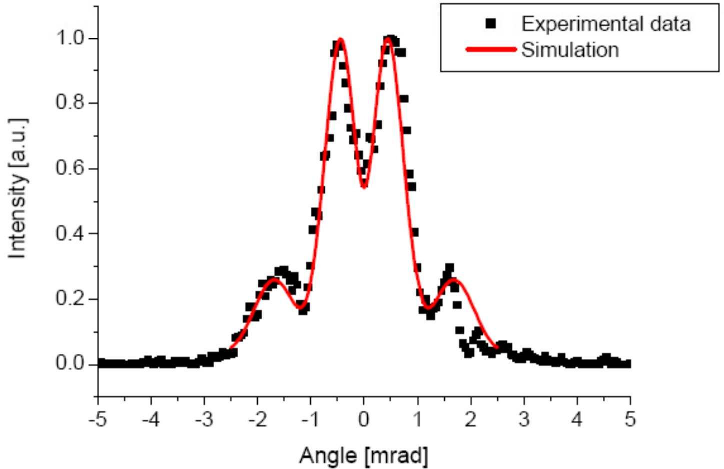
Optical Diffraction Radiation Interferometry

ODR ANGULAR DISTRIBUTION MEASUREMENT

The background has been a severe limitation (even at KEK) for a detailed and quantitative reconstruction of the beam parameters from the ODR angular distribution.
A big effort has been done in order to subtract the SR background via software.

This allowed us to prove a good qualitative agreement between the experimental data and the simulations.





E. Chiadroni et al.,
Non-intercepting electron beam transverse diagnostics with optical diffraction radiation at the DESY FLASH facility
NIM B 266 (2008) 3789–3796

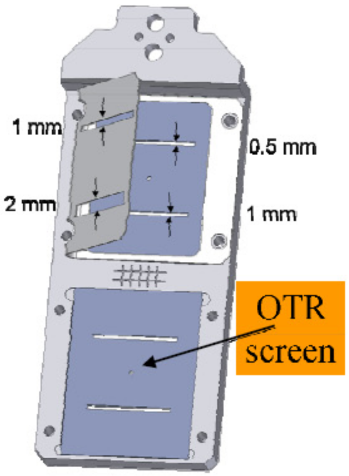
Beam transport optimization
- 0.7 nC
- 25 bunches
- 2 s exposure time
- E_{beam} (nominal) = 680 MeV
- 800 nm filter and polarizer in

Simulation parameters:
- a = 0.5 mm
- Gaussian distributed beam
- $\sigma_y = 80\ \mu m$
- $\sigma'_y = 125\ \mu rad$
- $E_{beam} = 610$ MeV

Optical Diffraction Radiation Interferometry

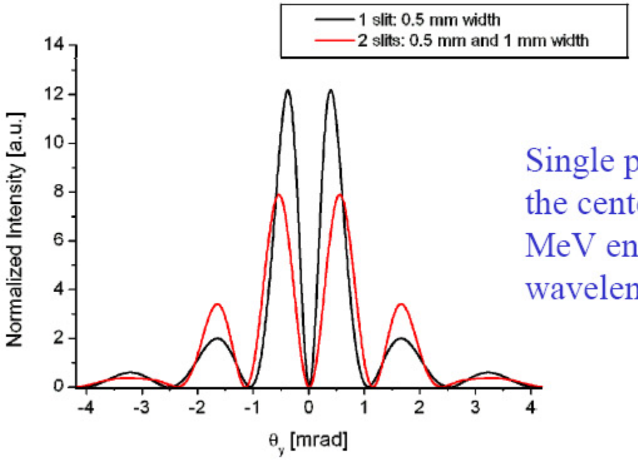
OPTICAL DIFFRACTION RADIATION INTERFEROMENTRY (ODRI)

To reduce the synchrotron radiation background, we mounted a stainless steel shield in front of our ODR screen, with a larger cut in it.



In the case of a wavelength of 800 nm and 1 GeV beam energy the 1 mm cut is not large enough to prevent the production of ODR in the forward direction, reflected by the screen and interfering with the backward ODR produced by the screen itself.

An ODR analogous of the Wartski interferometer used for OTR, with the difference that in this case the two interfering amplitudes are different in intensity and angular distribution



Single particle going through the center of both slits with 900 MeV energy and 800 nm wavelength

Ring Electron Scanner

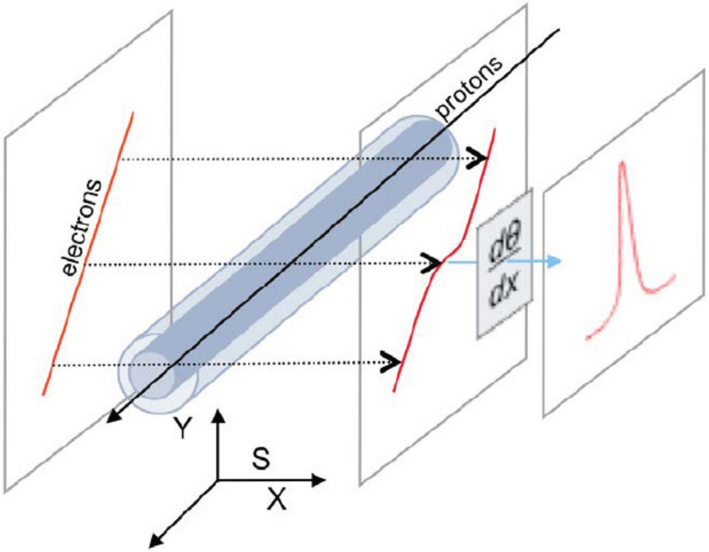
Principle

Look at the deflected projection of a tilted sheet of electrons due to the proton beam charge [1,2,3]

- Neglect magnetic field (small displacement of projection)
- Assume path of electrons is straight (they are almost straight)
- Assume net electron energy change is zero (if symmetric).

→ $$\frac{d\theta_0(x)}{dx} = \int_L \frac{e}{mv^2}\frac{\delta(x,y)}{\varepsilon_0}dy$$ or, take the derivative to get the profile[3]

Imperfections estimated at 5-10%, .

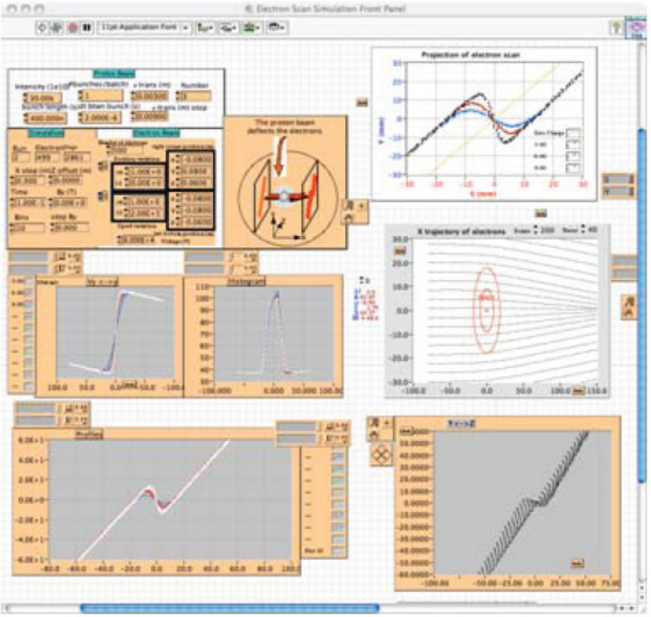


Ring Electron Scanner

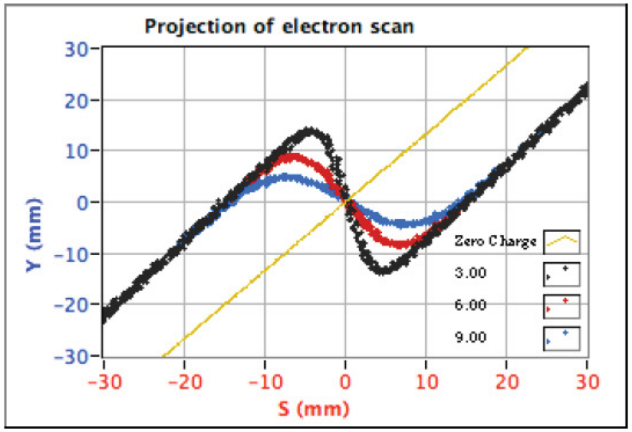
Principle

Approach:

1) **Build an electron gun (75kV)**
2) **Shoot a tilted line of electrons through the proton beam**
3) **Use a fluorescent screen and video camera to get the projected curve**



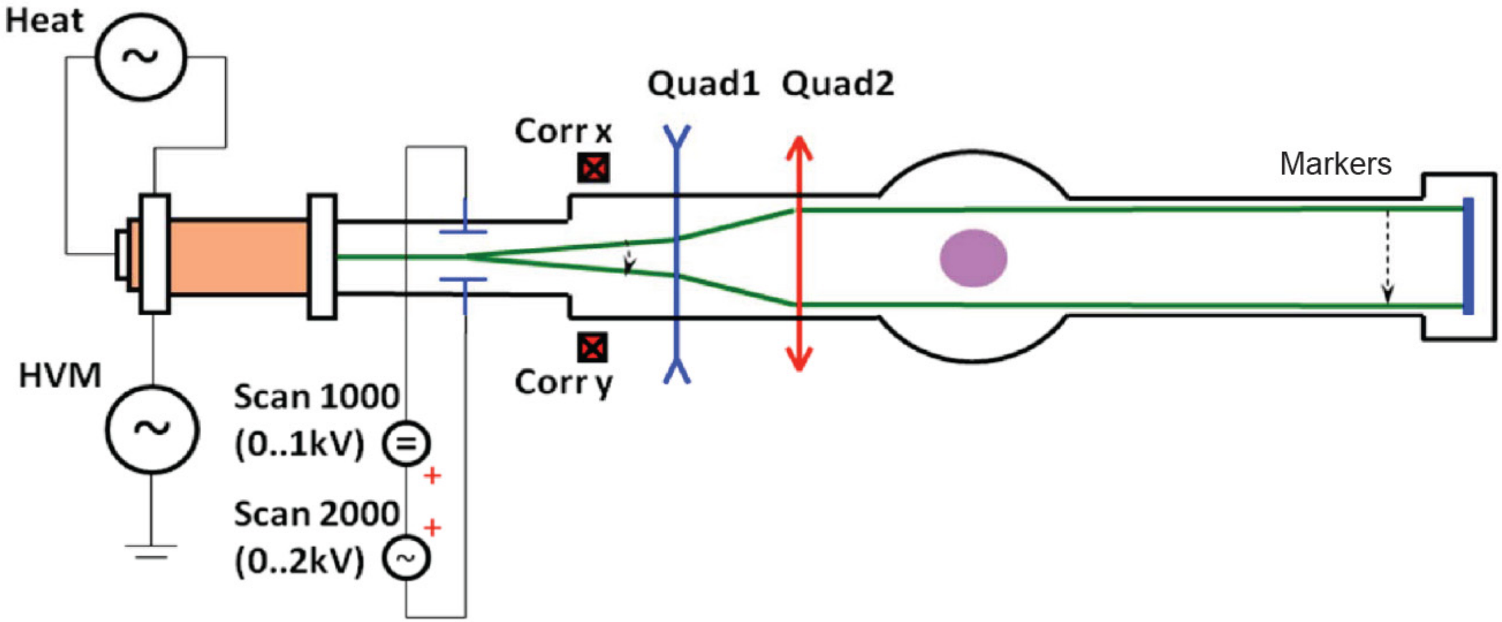
LabVIEW Simulation



Projection of electrons (LabVIEW simulation)

Ring Electron Scanner

Hardware: Electron Scanner



Electron scanner diagram

Electron Scanner made by Budker Institute of Nuclear Physics:
Dmitriy Malyutin, Sasha Starostenko, Sasha Tsyganov
Vacuum vessel by SNS.

Ring Electron Scanner

Data

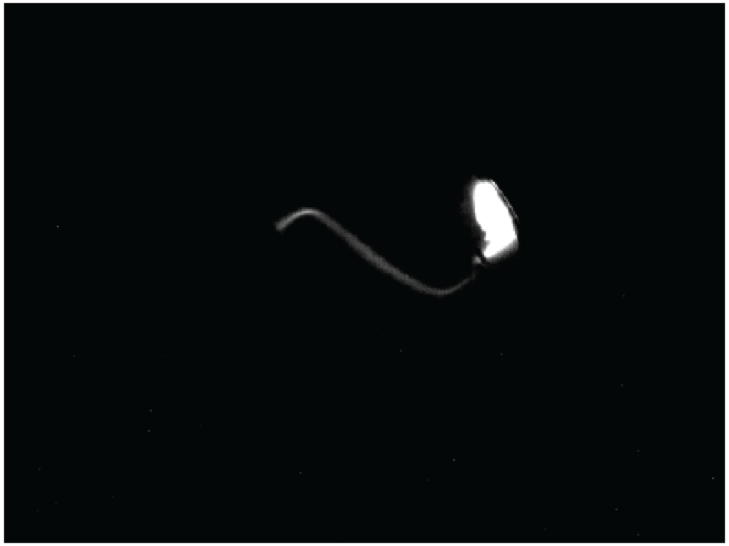
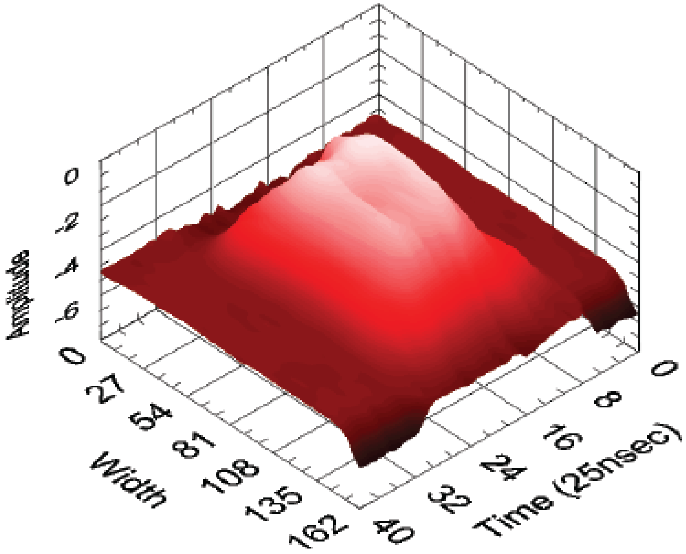


Image of horizontal curve

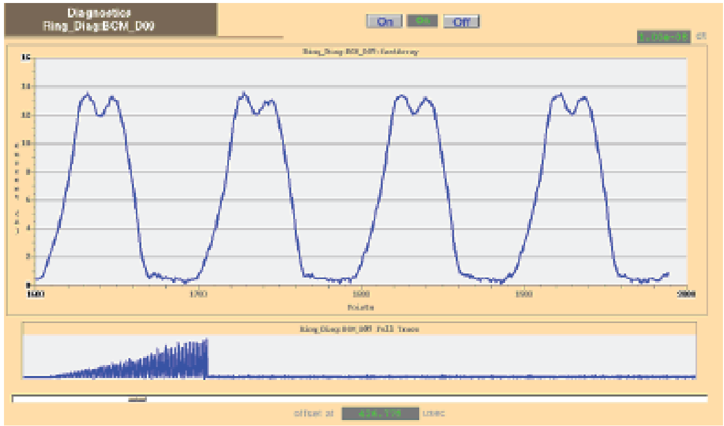
Image of vertical curve

Ring Electron Scanner

Data



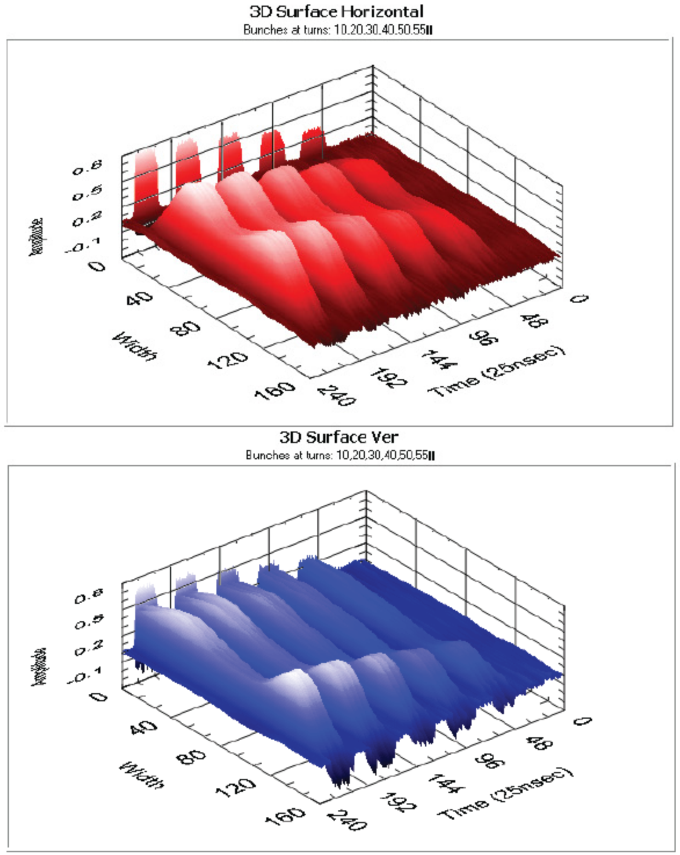
3D plot of Turn 343.



Ring BCM around Turn 343.

Ring Electron Scanner

Data



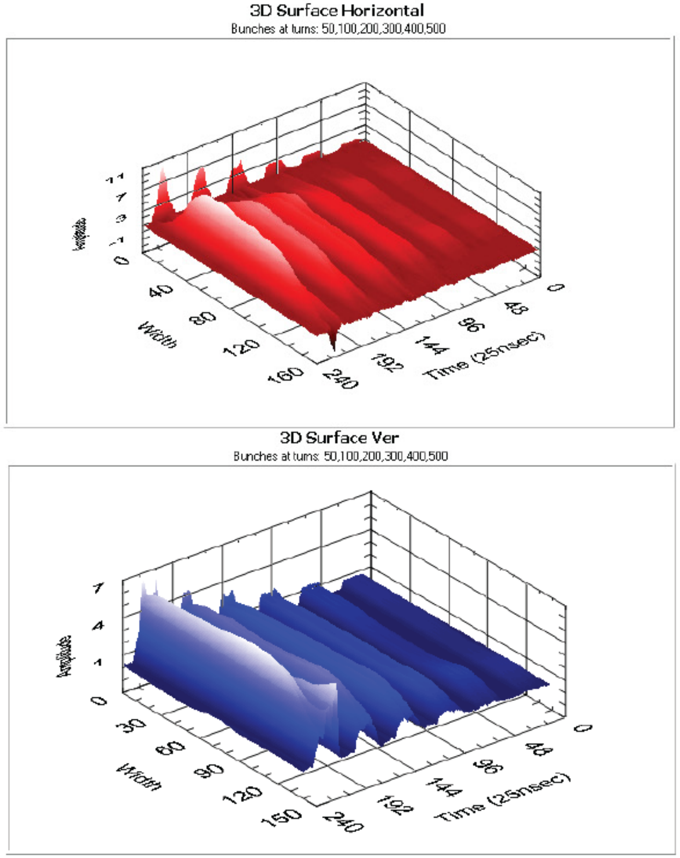
3D Surface Horizontal

Bunches at turns: 10,20,30,40,50,55

3D Surface Ver

Bunches at turns: 10,20,30,40,50,55

3D plot of turns 10,20,30,50, and 55.



3D Surface Horizontal

Bunches at turns: 50,100,200,300,400,500

3D Surface Ver

Bunches at turns: 50,100,200,300,400,500

3D plot of turns 50,100,200,300,400, and 500.

Ring Electron Scanner

Conclusions

- Can deliver a profile for a 20 ns slice of beam anywhere in accumulation and anywhere along the bunch width.
- Can be operated completely parasitically during production.
- Profiles delivered look physical and quality (beam tilt, pulse to pulse jitter) is improving rapidly.
- The profiles the ELS is delivering look reasonable and physical, and the device has uniquely attractive features compared to traditional harp and wire scans.

- The profile shape are very sensitive to precise setting of the device hardware (quads and correctors).
- In it's current state, aperture is too small for large beams, and profiles not available for very low (< 2uC) or very high (> 9uC) intensities.

This is a great success for a new device.

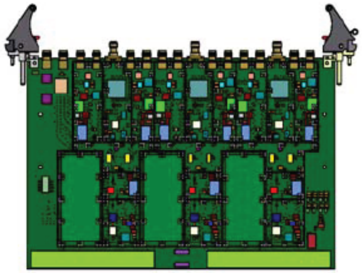
Once minor issues are addressed, there will be a strong case for upgrading to a full tomography device.

Electron Beam Diagnostics for the E-XFEL

Cavity & Button BPM Electronics (PSI Designs)

Undulator RFFE

- 3.3GHz (cavity BPM)
- IQ demodulation
- Requirements: Sub-➚m resolution & drift



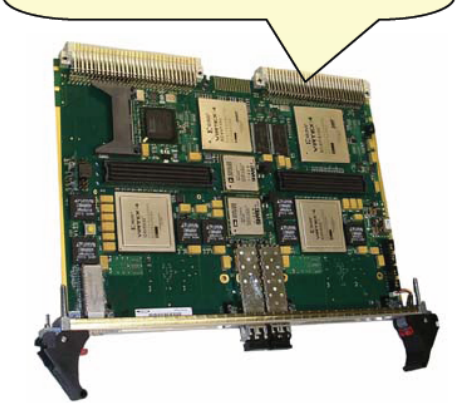
ADC Mezzanine

- Six 16-bit ADCs
- 160Msps

FPGA Carrier Board

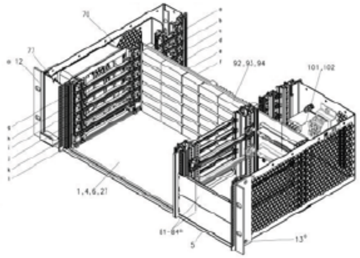
- Virtex-5 FPGAs
- Flexible interfaces: 1-5Gbit Rocket IO, VME, VXS, Ethernet
- Two mezzanines: 500-pin connectors

Low-cost version of IBFB carrier board (no DSPs, …), used for all E-XFEL BPMs

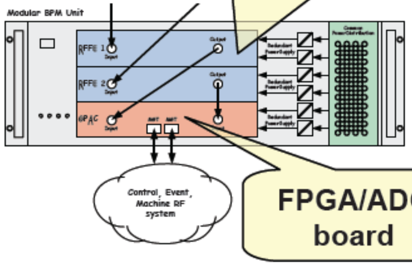


Modular BPM Unit

Crate: customized power, backplane & cooling: low noise, high temp. stability



2 cavity BPM or 4 button BPM RFFEs



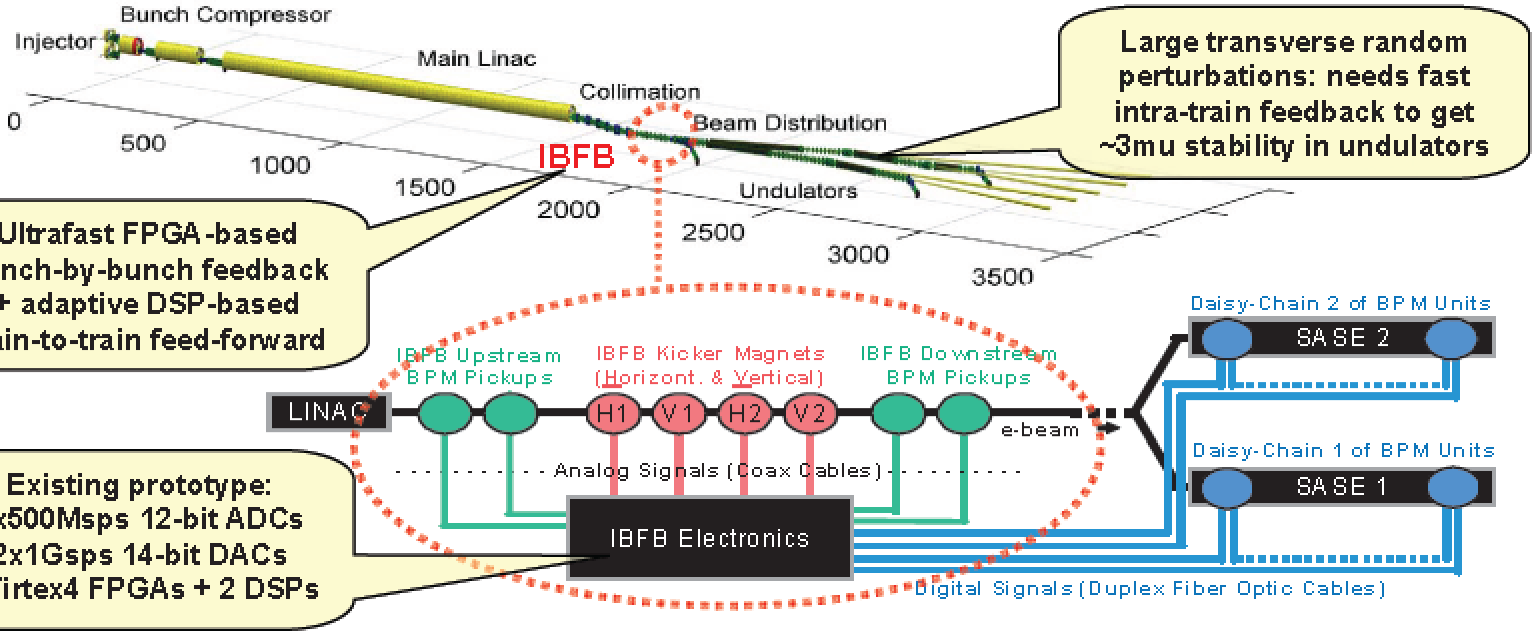
FPGA/ADC board

by Courtesy of B. Keil, PSI

B. Keil, 20.5.09

Electron Beam Diagnostics for the E-XFEL

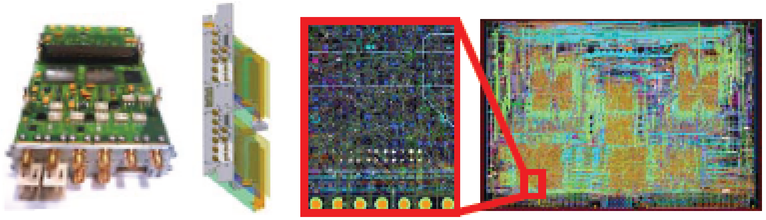
Intra-Bunchtrain Feedback (PSI Contribution)



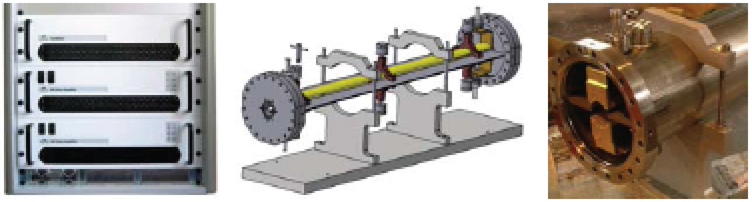
Large transverse random perturbations: needs fast intra-train feedback to get ~3mu stability in undulators

Ultrafast FPGA-based bunch-by-bunch feedback + adaptive DSP-based train-to-train feed-forward

Existing prototype:
4x500Msps 12-bit ADCs
2x1Gsps 14-bit DACs
4 Virtex4 FPGAs + 2 DSPs



Low-Latency BPM & Signal Processing Electronics



High-BW Stripline Kicker Magnets & Power Amps

by Courtesy of B. Keil, PSI

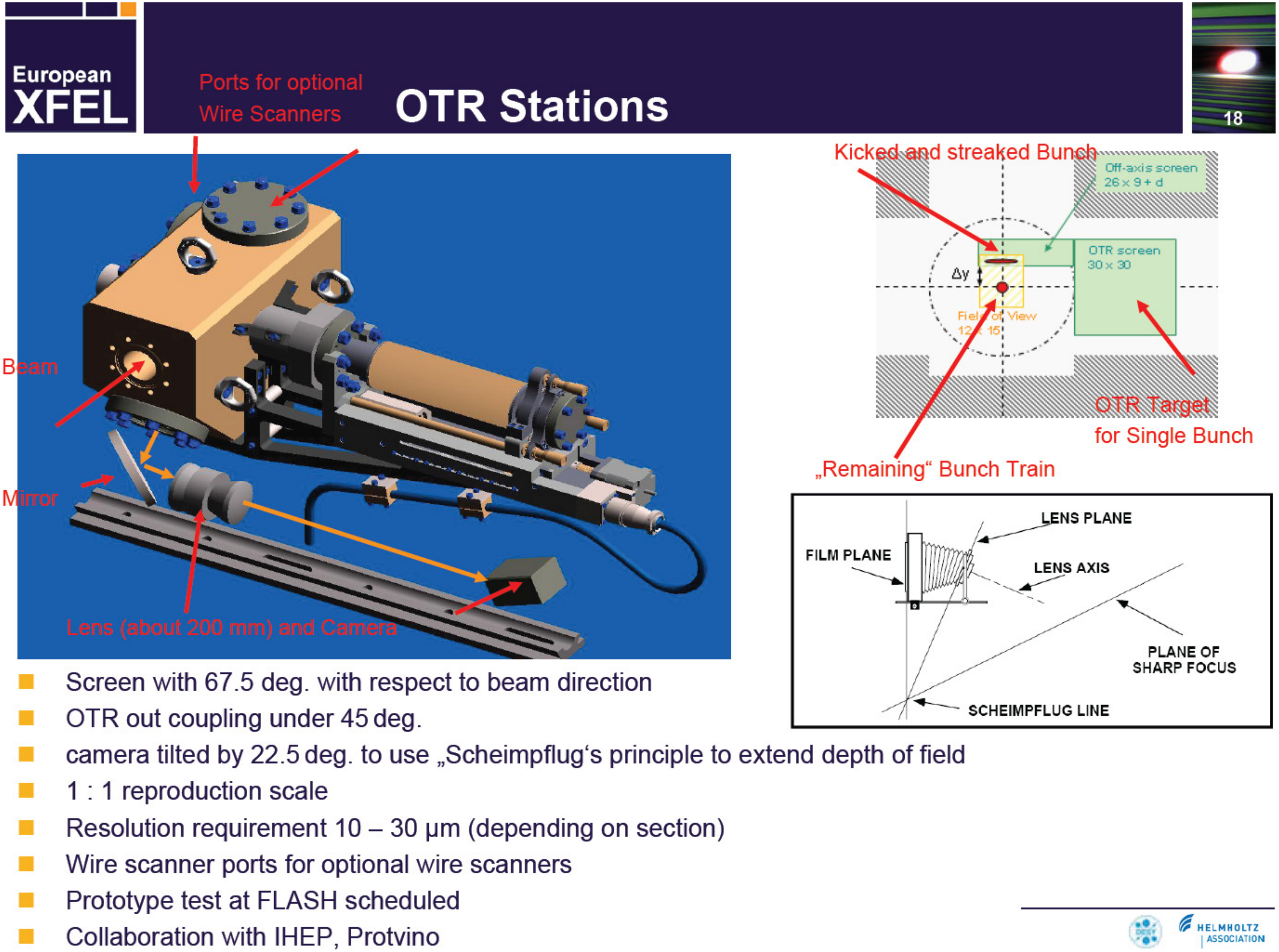
B. Keil, 20.5.09

BPMs for E-XFEL

BPM Type	Number	Diameter	Single Bunch Resolution
Standard Button BPM	228	40 mm	50 µm
“cold” BPM (Button, 30% Re-entrant Cavity)	104	78 mm	50 µm
Precision BPM (Cavity)	117	10 mm	1 µm
Precision BPM (Cavity)	12	40 mm	1 µm

- Collaboration between PSI, CEA and DESY
  - PSI will provide Electronics, except RF front-end of the Reentrant Cavity BPM
  - DESY will provide Mechanics, except Reentrant Cavity BPM
  - CEA will provide Reentrant Cavity BPM, incl. RF front-end

Electron Beam Diagnostics for the E-XFEL

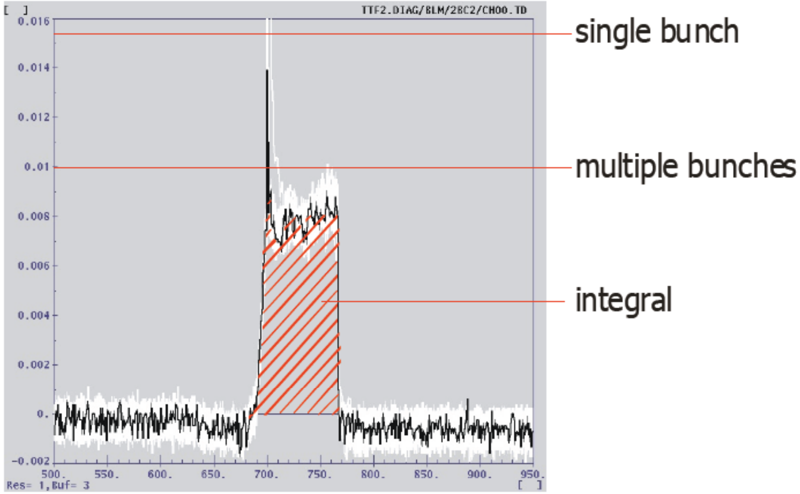


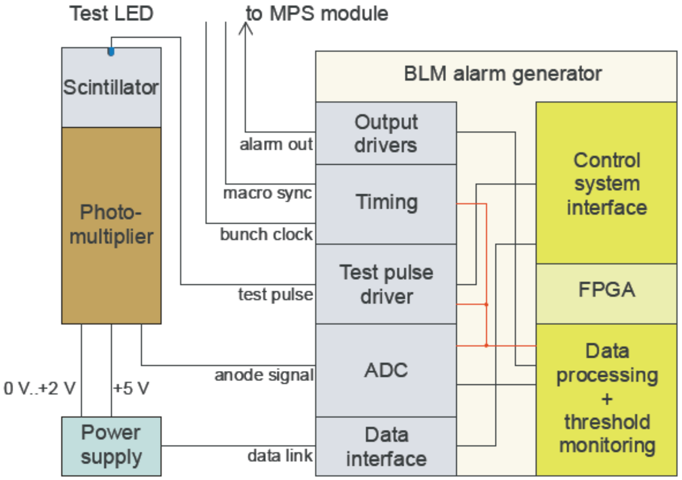
OTR Stations

- Screen with 67.5 deg. with respect to beam direction
- OTR out coupling under 45 deg.
- camera tilted by 22.5 deg. to use „Scheimpflug‘s principle to extend depth of field
- 1 : 1 reproduction scale
- Resolution requirement 10 – 30 µm (depending on section)
- Wire scanner ports for optional wire scanners
- Prototype test at FLASH scheduled
- Collaboration with IHEP, Protvino

Electron Beam Diagnostics for the E-XFEL

Beam Loss Monitors



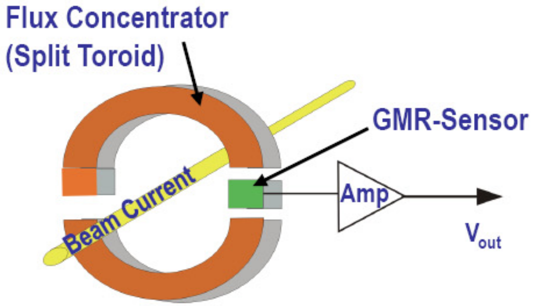


- Good experience with FLASH system
- Stay with plastic scintillators and photomultipliers
- about 250 channels distributed over the entire machine
- Reengineering of the FLASH system
  - go to a pure digital readout and FPGA processing
  - AMC, µTCA form factor
- Collaboration with IHEP, Protvino

Beam Diagnostic Developments for FAIR

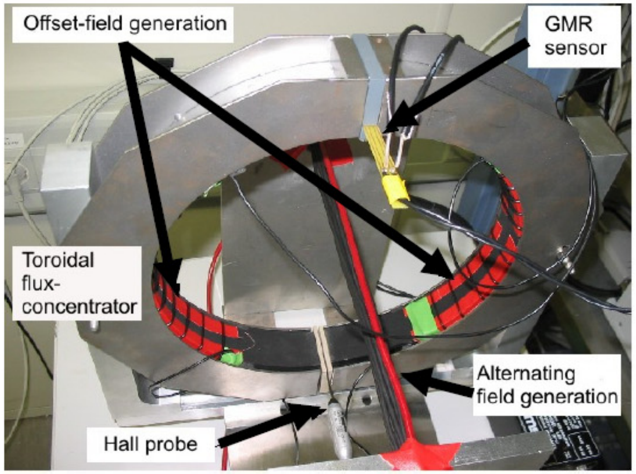
Beam Current Measurement – Novel DCCT

Measurement Principle

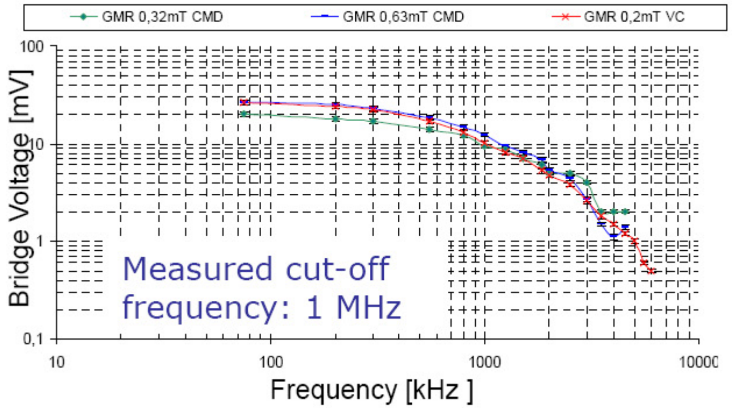


- idea: **clip-on Amperemeter** design
- **split toroid** to allow **dismounting** before bake-out
- soft-magnetic **flux concentrator** (amorph. VITROVAC®)
- **gap** with induction of 80 μT @ 1 A beam current
- **sensitive GMR** (Giant Magneto Resistance) magnetic field sensor (resolution: 10^{-9} T/√Hz) → used for harddisks

Test Setup



Frequency Response (GMR+Pre-amp)



Measured cut-off frequency: 1 MHz

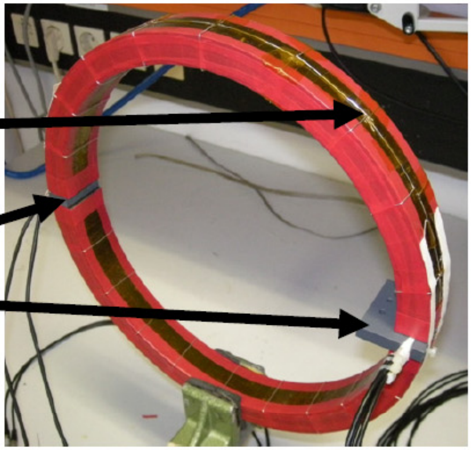
- Reasons: induced voltages in sensor material, eddy currents in NiFe-layer

Beam Diagnostic Developments for FAIR

2nd Iteration: Combined ACT-DCCT-System

NDCCT Version 2.0

- add single ACT-winding to core
- add high-pass filtered ACT-branch to electronics
- use 2 GMR sensors (1 sensor per gap)



New: dc and ac measurement on single core!

Pulse Response (Combined System)

Improvements

- For S/N=2: 88 nV/√Hz
- calculated resolution threshold: **220 µA**
- Bandwidth: $\frac{0.35}{t_{rise}} = \boxed{f_{co} \approx 13\ MHz}$

Ongoing R&D

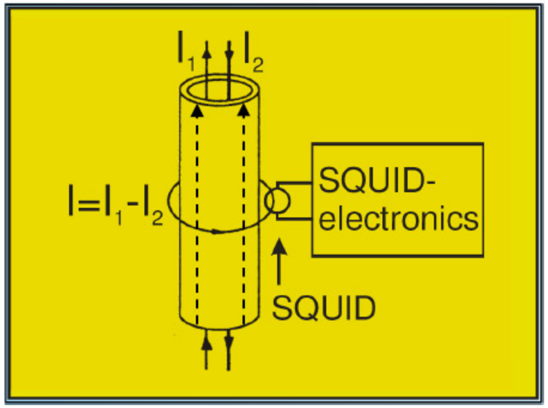
- design & layout of readout electronics
- investigation of NDCCT rf- characteristics

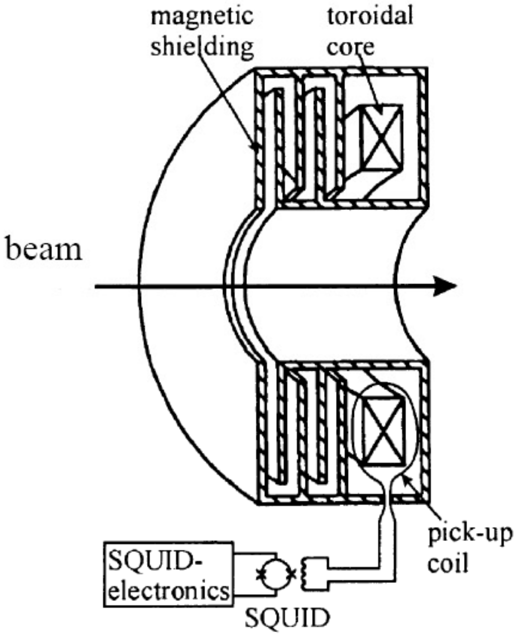
Intensity and Profile Measurements [...] in CSR

Cryogenic Current Comparator (CCC) Principle

Max-Planck-Gesellschaft

Max-Planck-Institut für Kernphysik





CCC (Harvey 1972):

- Uses Meissner-effect and SQUID for I_1/I_2 measurement
- If $I_1 \neq I_2$ magn. field produces compensation current
- Magnetic flux through SQUID → voltage change

For charged particle beams:

$I_{comp} = I_1 - I_2 = I_{beam} - 0$ (position independent)

- SC shielding for non-azimuthal fields
- SC pickup coil with toroidal core ($\mu_r \approx 50000$)
- Low noise, high performance DC SQUID control electronics (FSU Jena)

Intensity and Profile Measurements […] in CSR

Optimisation of CCC Performance

Max-Planck-Gesellschaft

Max-Planck-Institut für Kernphysik

Achievements so far: $250\,pA/\sqrt{Hz}, BW = 0...50kHz$ at GSI (A. Peters et al. 1999) ⇒ TARN II

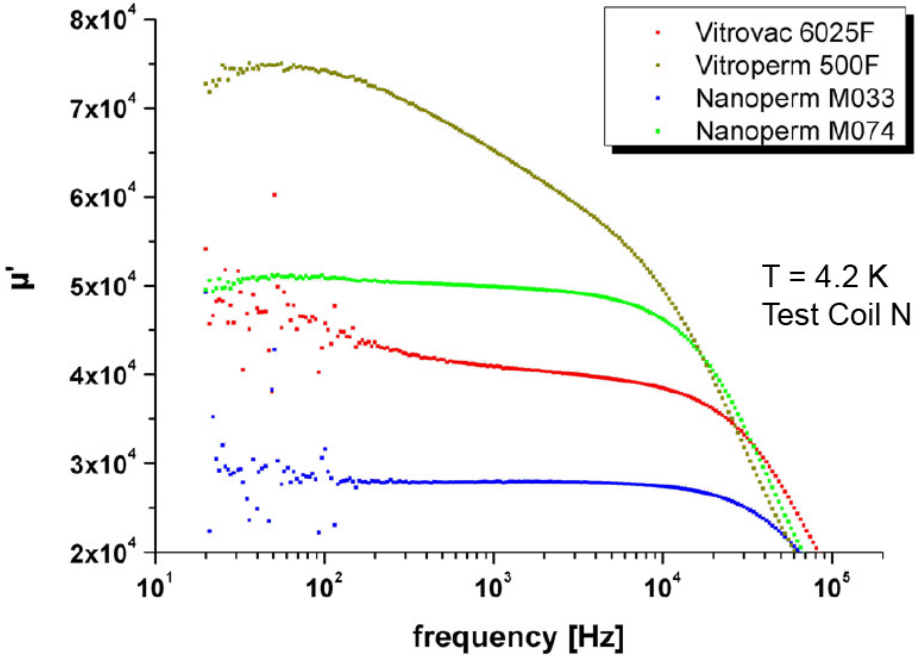
$40\,pA/\sqrt{Hz}, BW = 0...70kHz$ at test setup for DESY (W. Vodel et al. 2007)

Limitations of the system:

- Mechanical vibrations
- Magnetic shielding
- Noise from toroidal core
- SQUID intrinsic flux noise
- Electronics (amplifier input noise, crosstalk etc.)
- Slew rate / core mat. (BW)

Current detection limit from pickup coil:

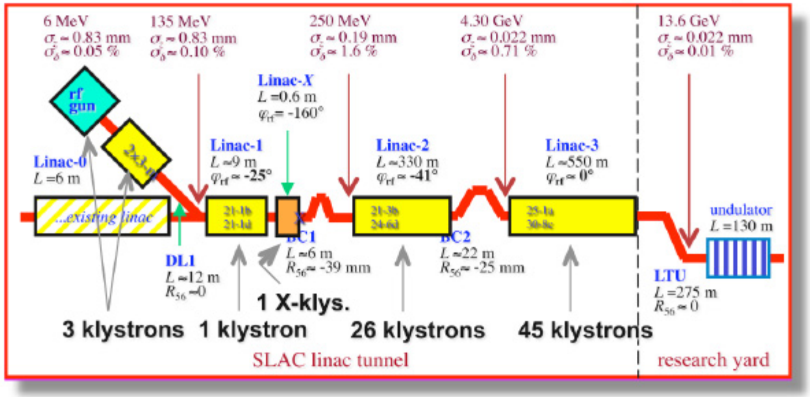
$$I_S = \frac{2\pi\sqrt{k_b T L}}{\mu_0 \mu_r f(R_a, R_i, b)}$$



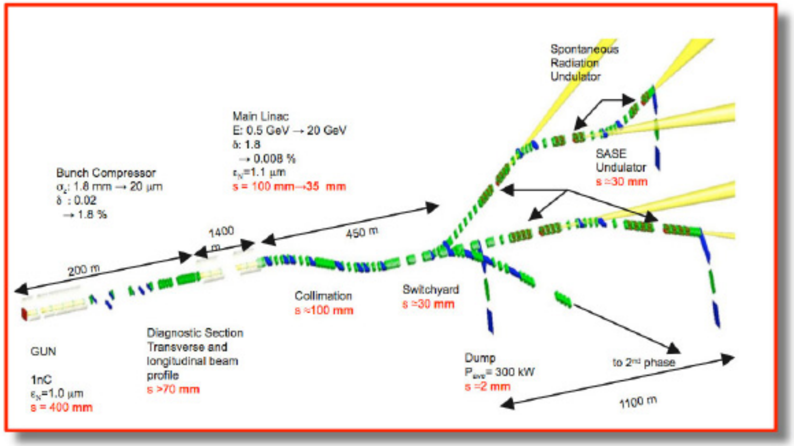
W. Vodel, R. Geithner (FSU)

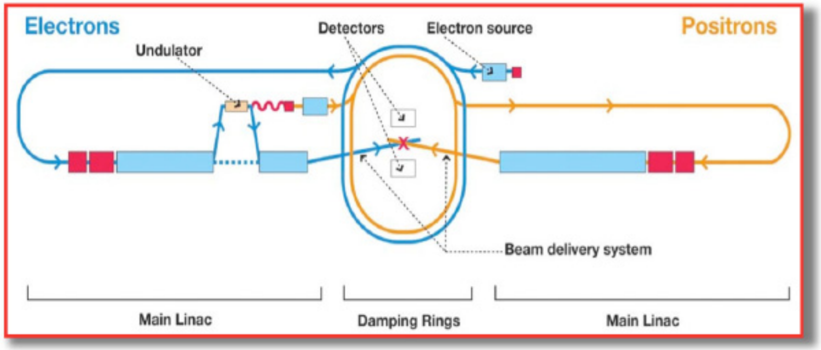
Physics requirements for LINAC stabilization...

LCLS XFEL: 13.6GeV NC linac (~1km)

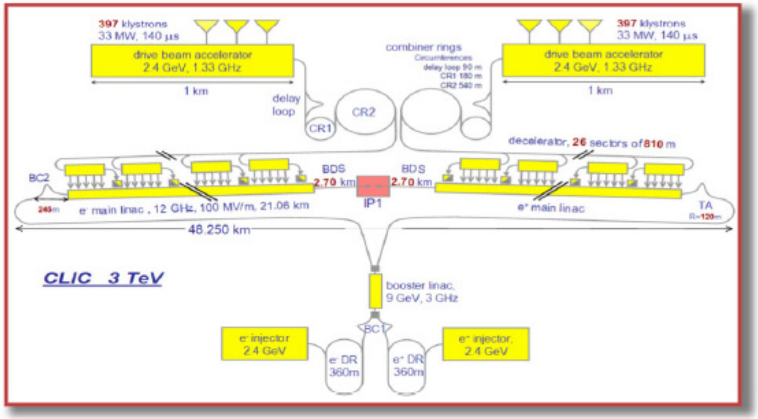


EU-XFEL: 20GeV SC linac (~1.6km)





ILC: 2x 250GeV SC linacs (2x ~11km)

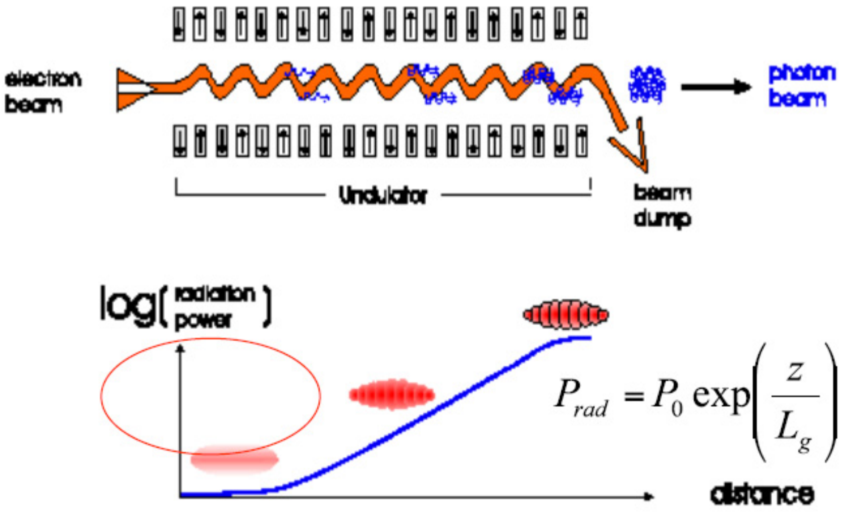


CLIC: 2x 1.5TeV NC linacs (2x ~21km)
(+ drive beam linacs)

Physics requirements for LINAC stabilization...

XFEL Principle

Linac based Self Amplification of Spontaneous Emission (SASE) Free Electron Lasers (FELs) in the X-Ray regime (~0.85 - 60 Å)



$$P_{rad} = P_0 \exp\left(\frac{z}{L_g}\right)$$

Electron bunch modulated with its own synchrotron radiation field
$\Rightarrow$ micro-bunching
$\Rightarrow$ more and more electrons radiate in phase until saturation is reached

Requires excellent electron beam quality:
- low (slice) emittance
- low energy spread
- extremely high charge density

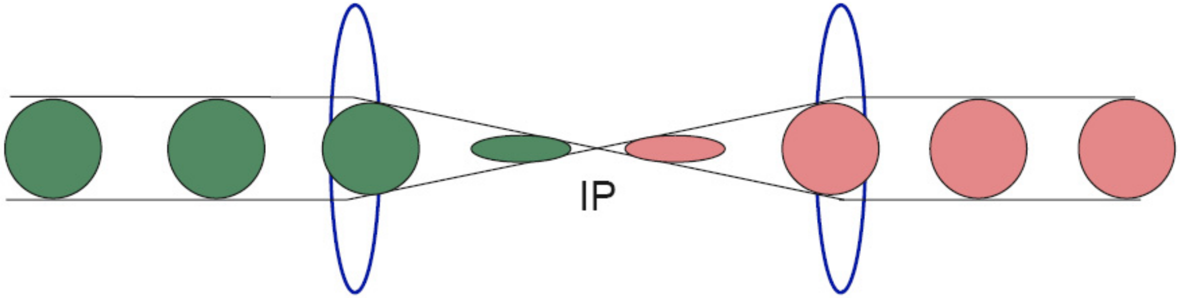
Gain Length $L_G = \frac{1}{\sqrt{3}}\left(\frac{I_A \gamma^3 \sigma_r^2 \lambda_u}{4\pi \hat{I} K^2}\right)^{\frac{1}{3}}$

Winni Decking

Physics requirements for LINAC stabilization...

Colliders

Squeeze as much as possible to get the highest luminosity



Luminosity (cm^{-2} s^{-1})

$$L \approx \frac{n_b N^2 f_{rep}}{A} H_D$$

n_b = bunches / train
N = particles per bunch
f_{rep} = repetition frequency
A = beam cross-section at IP
H_D = e+/e- enhancement factor

Requires excellent beam quality:

- Extremely high particle densities
- Bunches colliding at the focal point

Physics requirements for LINAC stabilization...

Linac stability expectations

- **FEL Photon Source**
  - Photon beam pointing accuracy and stability
  - Photon wavelength, intensity (brilliance)
  - Photon bunch arrive time relative to a fiducial (pump probe experiments)

- **Linear Collider**
  - Energy precision and stability
  - Luminosity
  - Integrated luminosity

→

Particle density

Relative pointing accuracy at the IP

Relative arrival time at the IP

Small beams (nm)
Low emittance (nm-rad)

→

Very tight tolerances
High-resolution diagnostics

Instrumentation Req. for Dif. Accelerator Types

III. Light Sources

The Standards: beam energy, intensity, tunes etc ... not really a problem

BUT measurement & control of beam size & beam orbits is a real challenge

photon flux $$F = \frac{number\ of\ photons}{s * 0.1\% BW * A}$$

brilliance $$B = \frac{F}{4\pi^2 \varepsilon_x \varepsilon_y}$$

emittanz ≈ 1 nm rad (PETRA 3)

$$\varepsilon_y \approx 1\%\ \varepsilon_x$$

	ϵ_x [nmrad]	E [GeV]	ϵ_x/E^2		ϵ_x [nmrad]	E [GeV]	ϵ_x/E^2
USR	0.3	7	0.006	SLS	4.4	2.4	0.763
PETRA III	1	6	0.027	ELETTRA	7	2.4	1.215
SPring-8	3.4	8	0.053	BESSY II	6	1.9	1.66
APS	3	7	0.061	Spear III	18	3	2
ESRF	3.9	6	0.108	MAX II	9	1.5	4
Diamond	2.5	3	0.2	ANKA	41	2.5	6.56
Soleil	3	2.5	0.48	DORIS III	450	4.5	22.2

Parameters of some synchrotron light sources

HERA / LEP Emittance: 20 ... 30 nm

Physics requirements for LINAC stabilization...

Sensitivity to a 1 degree error in BC1 Phase (1 klystron)

BC1
V = 448MV
f = -105°

1 RF station

BC2
V = 11.4 GV
ϕ = -27.6°

14 RF stations

MAIN LINAC
V = 85-235 GV
ϕ = +5°

280 RF stations

1° error ⇨	**7.5MeV** ⇨	**76MeV** ⇨	**76MeV**
	581µm	**274µm**	**274µm**

For bunch to arrive within 70µm of IP:
BC1 phase error must be less than 0.25 deg

N. Walker

Physics requirements for LINAC stabilization...

Sensitivity to a 1% error in BC1 Amplitude (1 klystron)

BC1	BC2	MAIN LINAC
V = 448MV f = -105°	V = 11.4 GV ϕ = -27.6°	V = 85-235 GV ϕ = +5°
1 RF station	14 RF stations	280 RF stations

1% error ⇨	**2.6MeV** ⇨	**26MeV** ⇨	**26MeV**
	199µm	**94µm**	**94µm**

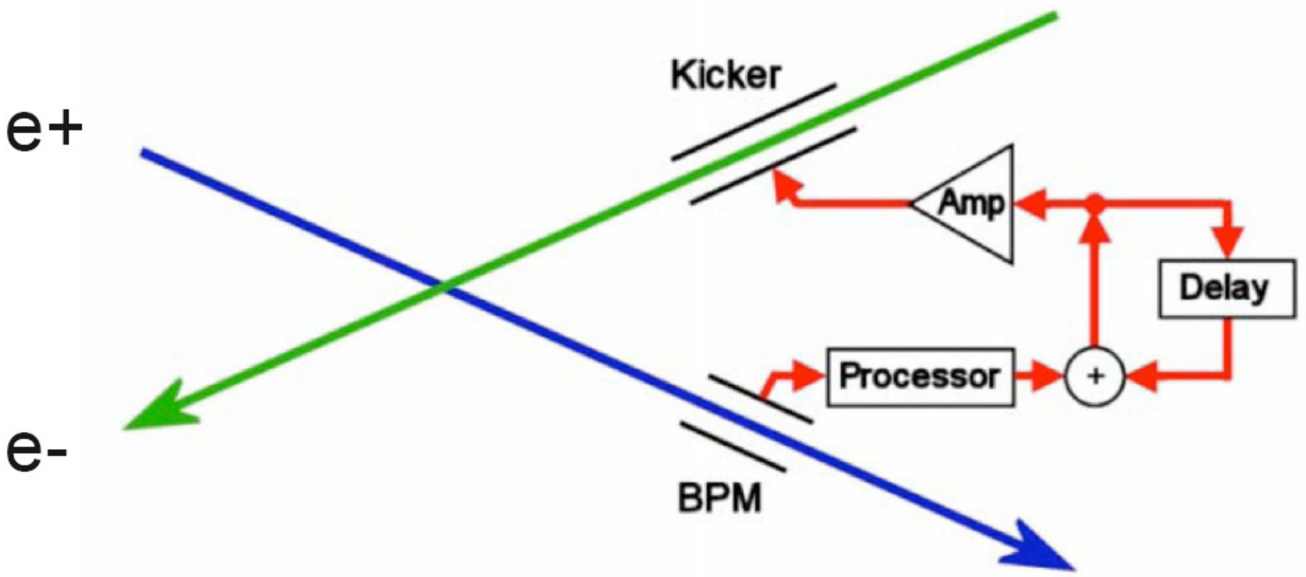
For bunch to arrive within 70µm of IP:
BC1 amplitude error must be less than 0.74%

N. Walker

Physics requirements for LINAC stabilization...

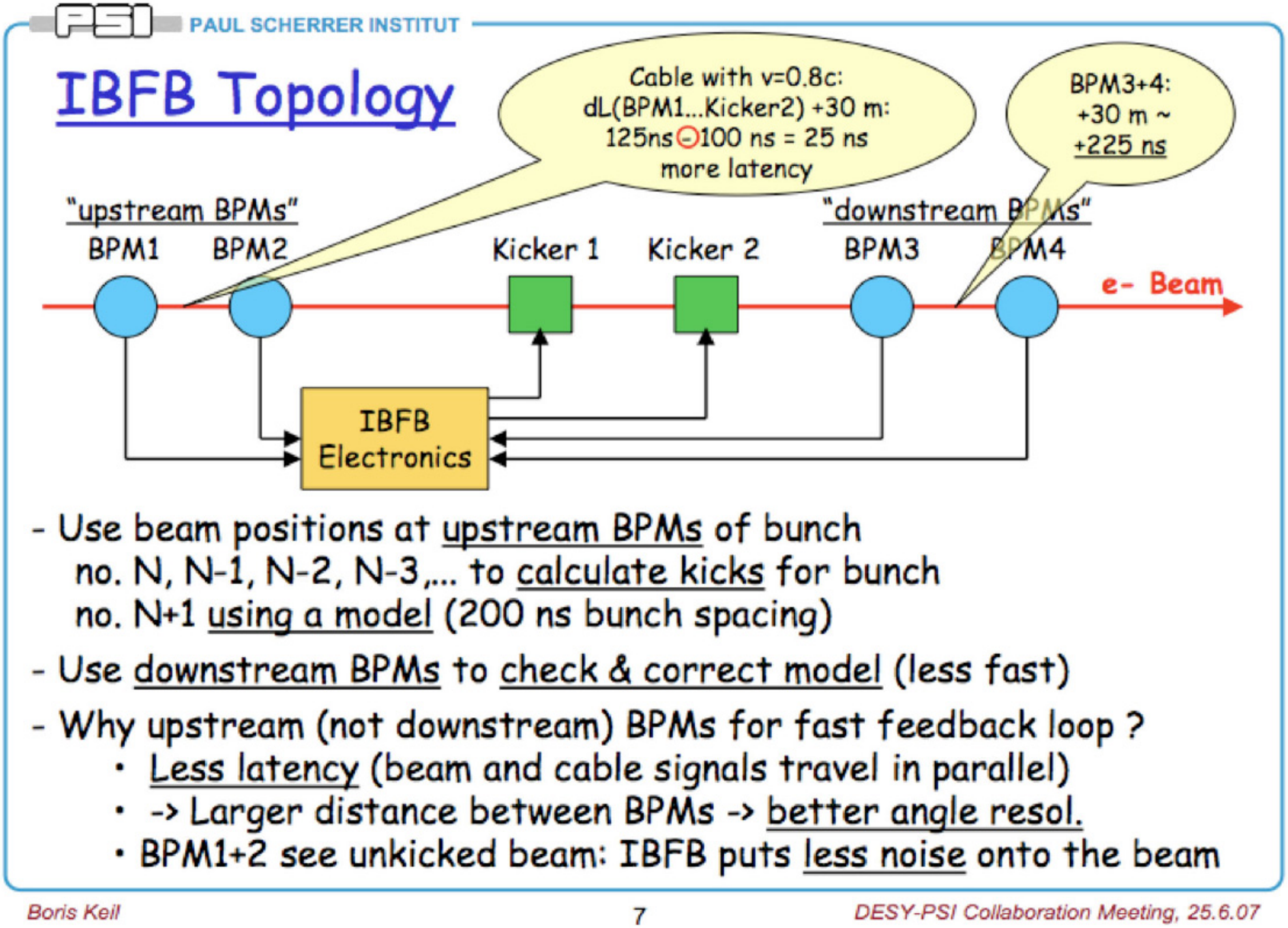
IP beam-based feedback for LC

- Maximize luminosity by correcting trajectory within bunch train
- Kicker and bpm must be close together for fast correction rate
- Need very high precision single-pass bpms



P. Burrows

Physics requirements for LINAC stabilization...



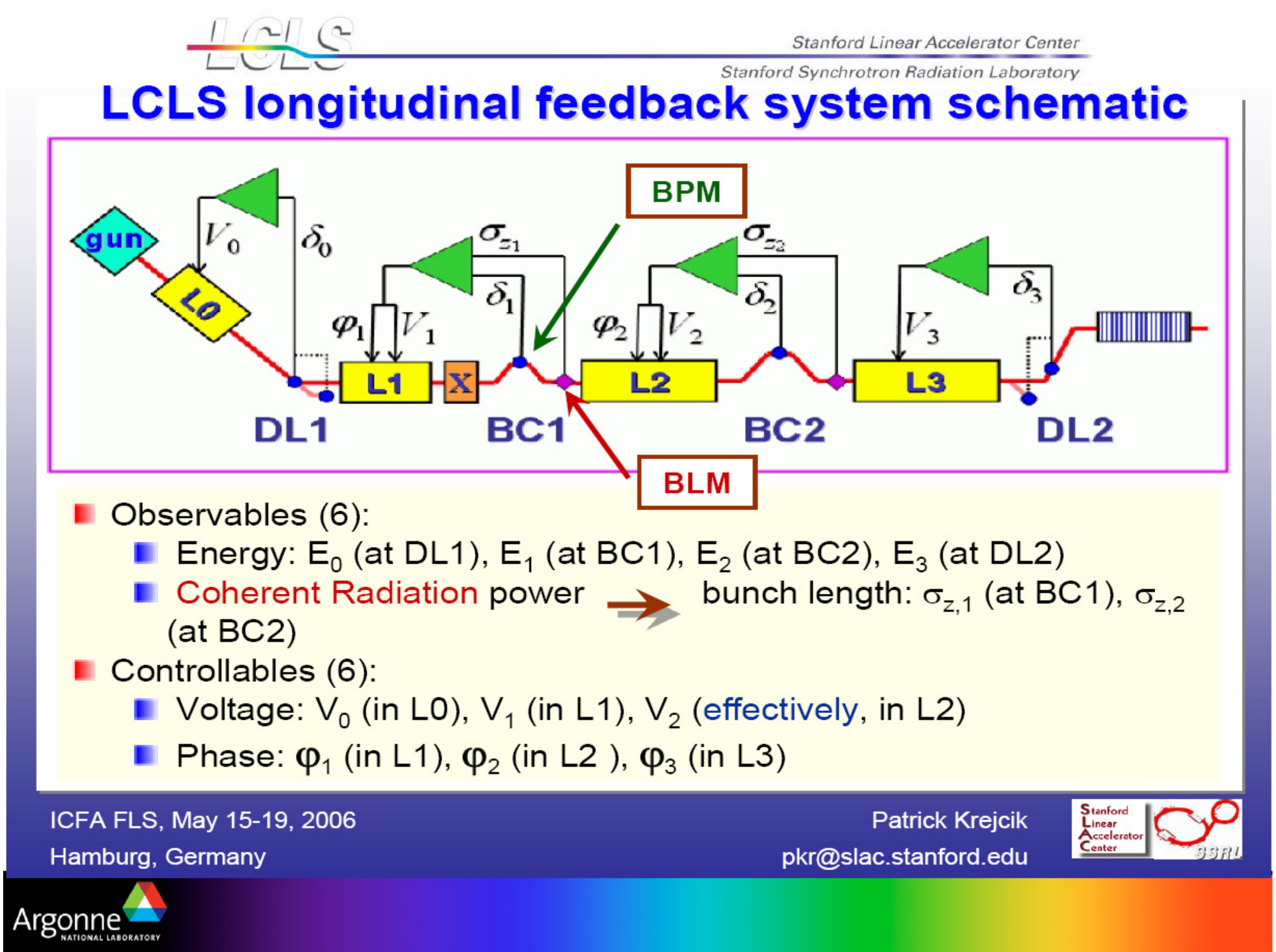
PAUL SCHERRER INSTITUT

IBFB Topology

- Use beam positions at upstream BPMs of bunch no. N, N-1, N-2, N-3,... to calculate kicks for bunch no. N+1 using a model (200 ns bunch spacing)
- Use downstream BPMs to check & correct model (less fast)
- Why upstream (not downstream) BPMs for fast feedback loop ?
  - Less latency (beam and cable signals travel in parallel)
  - -> Larger distance between BPMs -> better angle resol.
  - BPM1+2 see unkicked beam: IBFB puts less noise onto the beam

Boris Keil 7 *DESY-PSI Collaboration Meeting, 25.6.07*

Physics requirements for LINAC stabilization...



Stanford Linear Accelerator Center
Stanford Synchrotron Radiation Laboratory

LCLS longitudinal feedback system schematic

- Observables (6):
  - Energy: E_0 (at DL1), E_1 (at BC1), E_2 (at BC2), E_3 (at DL2)
  - Coherent Radiation power → bunch length: $\sigma_{z,1}$ (at BC1), $\sigma_{z,2}$ (at BC2)
- Controllables (6):
  - Voltage: V_0 (in L0), V_1 (in L1), V_2 (effectively, in L2)
  - Phase: φ_1 (in L1), φ_2 (in L2), φ_3 (in L3)

ICFA FLS, May 15-19, 2006
Hamburg, Germany

Patrick Krejcik
pkr@slac.stanford.edu

Stanford Linear Accelerator Center SSRL

Argonne NATIONAL LABORATORY

Poster highlights

MOPD11: **INVESTIGATION OF PRECISE PIPELINE-TYPE ADCS IN A BURST REGIME FOR A SINGLE-SHOT BPM**

MOPD13: **IMPLEMENTATION OF AN FPGA-BASED LOCAL FAST ORBIT FEEDBACK AT THE DELTA STORAGE RING**

MOPD42: **PROFILEVIEW - A DATA ACQUISITION SYSTEM FOR BEAM INDUCED FLUORESCENCE MONITORS**

TUPB02: **BEAM INDUCED FLUORESCENCE MONITOR & IMAGING SPECTROGRAPHY OF DIFFERENT WORKING GASES**

TUPB12: **BEAM TEST OF THE FAIR IPM PROTOTYPE IN COSY**

TUPB13: **IR PHOTON ARRAY DETECTOR FOR BUNCH BY BUNCH TRANSVERSE BEAM DIAGNOSTICS**

TUPB18: **VIMOS, BEAM MONITORING FOR SINQ**

TUPB24: **BEAM HALO MONITOR USING DIAMOND DETECTOR FOR INTERLOCK SENSOR AT XFEL/SPring-8**

TUPB35: **VELOCITY OF SIGNAL DELAY CHANGES IN FIBRE OPTIC CABLES**

Pre-press Proceedings:
http://dipac09.web.psi.ch/ppp/papers/

THANK YOU.