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Terry Garvey - Paul Scherrer Institut

Accelerators

RECFA visit of Switzerland, 1st April 2016

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Presentation outline

- PSI park of accelerators
  - Cyclotron up-grade
  - SwissFEL project R&D
- X-band structure developments for the CLIC linear collider
- CLIC damping ring studies with the Swiss Light Source (SLS)
- Solid state amplifier developments for SLS
- Swiss contributions to E-XFEL
- ACHIP – Dielectric structure R&D
- FCC, FCC-ee, EuroCirCol..........
  - Superconducting magent R&D
- CHART funding for accelerator R&D

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Accelerators at PSI

- 590 MeV Proton cyclotron – HIPA
  - neutron spallation source, thermal and ultra-cold neutrons
  - physics program UCN, MEG
  - high flux muon beams - μSR
- 2.4 GeV, 400 mA electron storage ring:

  Swiss Light Source (SLS)
  - for synchrotron radiation
- 250 MeV super conducting proton cyclotron – COMET
  - for proton therapy.
- 5.8 GeV electron linac - under construction for SwissFEL

Particle beams available at PSI
protons, photons, neutrons and muons

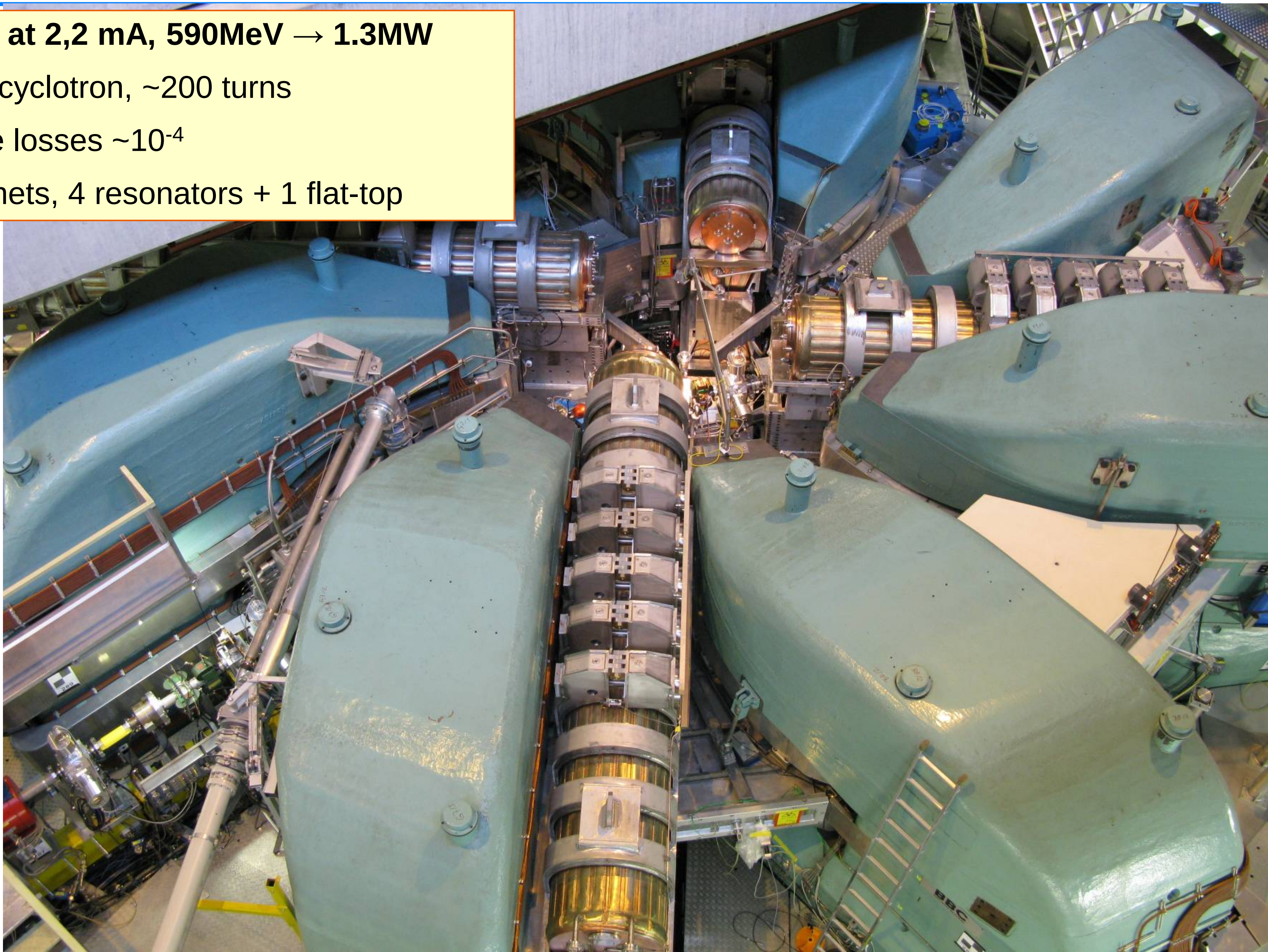
The Ring Cyclotron

Operated at 2,2 mA, 590MeV → 1.3MW

➔ sector cyclotron, ~200 turns

➔ relative losses ~10^{-4}

➔ 8 magnets, 4 resonators + 1 flat-top



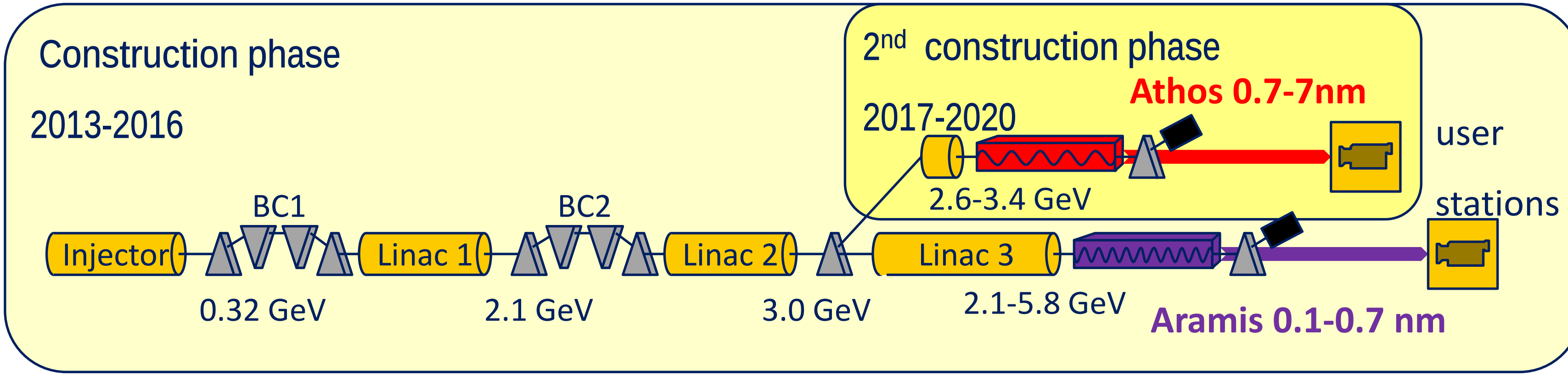
Upgrade Plans for HIPA

- An upgrade program is in progress for the facility, aiming for **3mA, 1.8MW**
- the major upgrade path foresees increased turn separation by **higher energy gain per turn (new resonators)**, thus **reducing losses** at extraction.

new Ring Cavity (copper)

New Resonator for Injector 2

The Swiss Free Electron Laser - SwissFEL



Aramis

Hard X-ray FEL, λ=0.1-0.7 nm

Linear polarization, variable gap, in-vacuum Undulators

First users 201

Athos

Soft X-ray FEL, λ=0.7-7.0 nm

Variable polarization, Apple II undulators

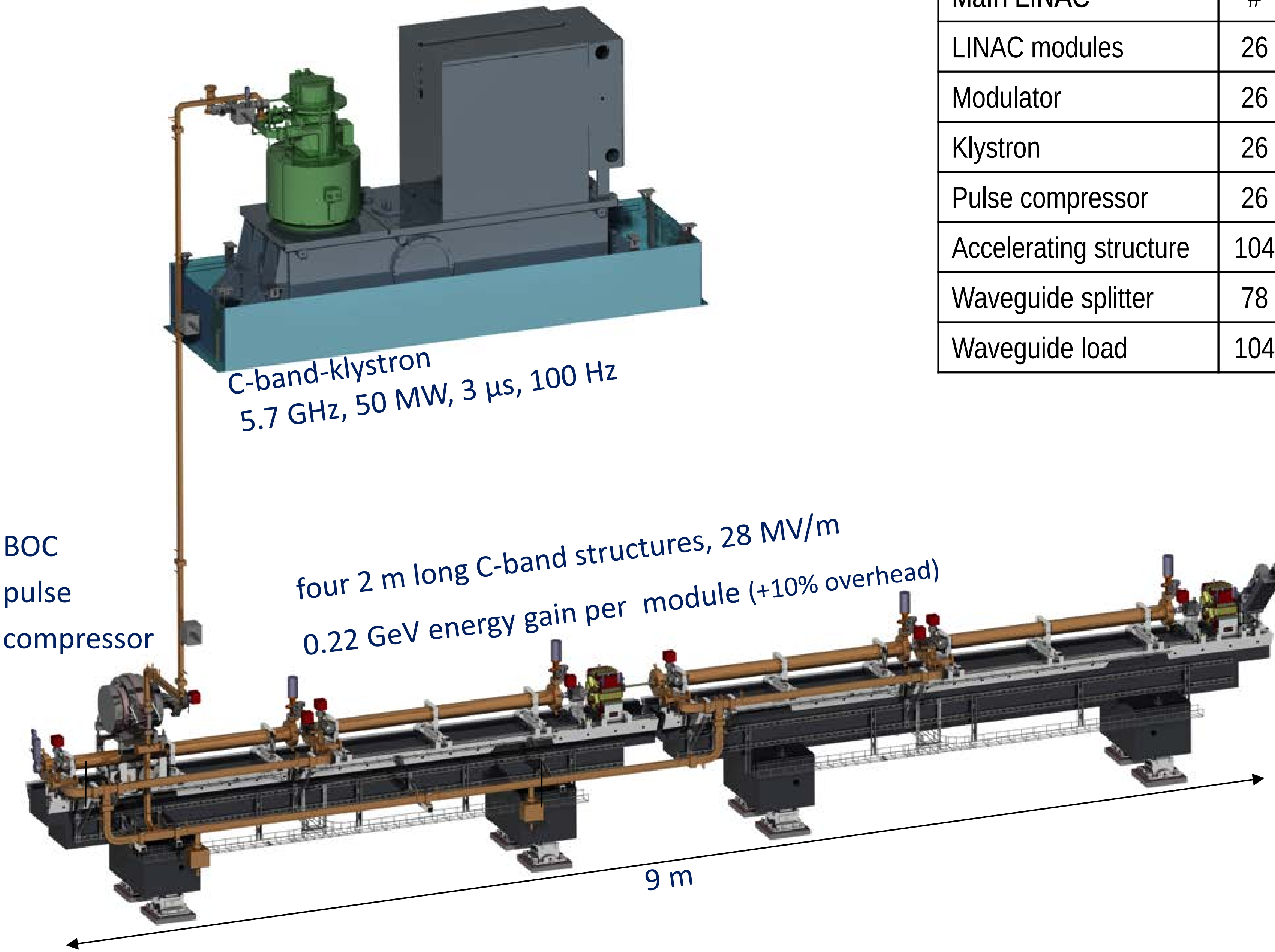
First users 2019 ?

Main parameters

Wavelength from	0.1nm-7nm
Photon energy	0.2-12 keV
Pulse duration	1 fs - 20 fs
e^- Energy	5.8 GeV
e^- Bunch charge	10-200 pC
Repetition rate	100 Hz

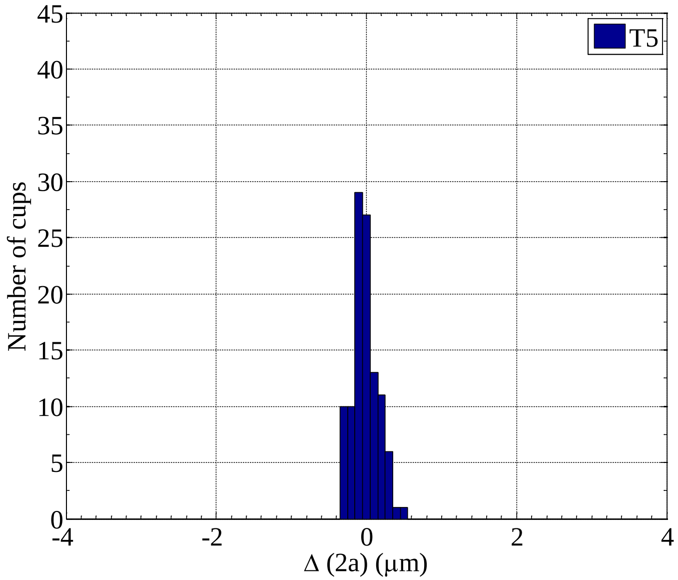
RF Technology developments for the SwissFEL linac

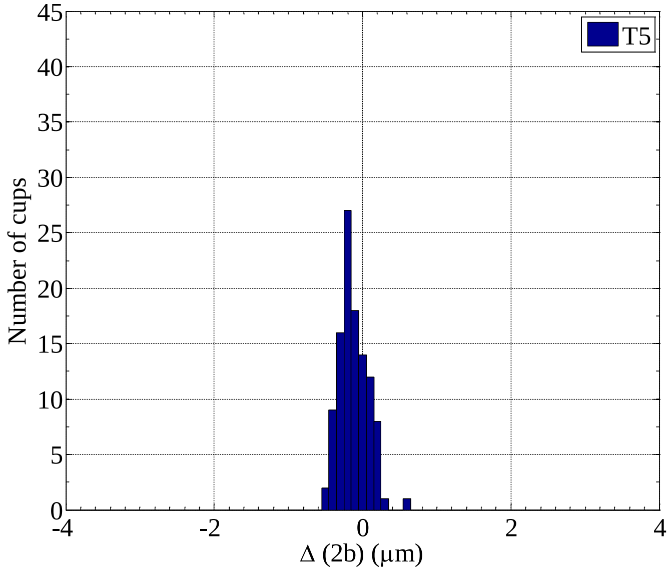
Main LINAC	#
LINAC modules	26
Modulator	26
Klystron	26
Pulse compressor	26
Accelerating structure	104
Waveguide splitter	78
Waveguide load	104

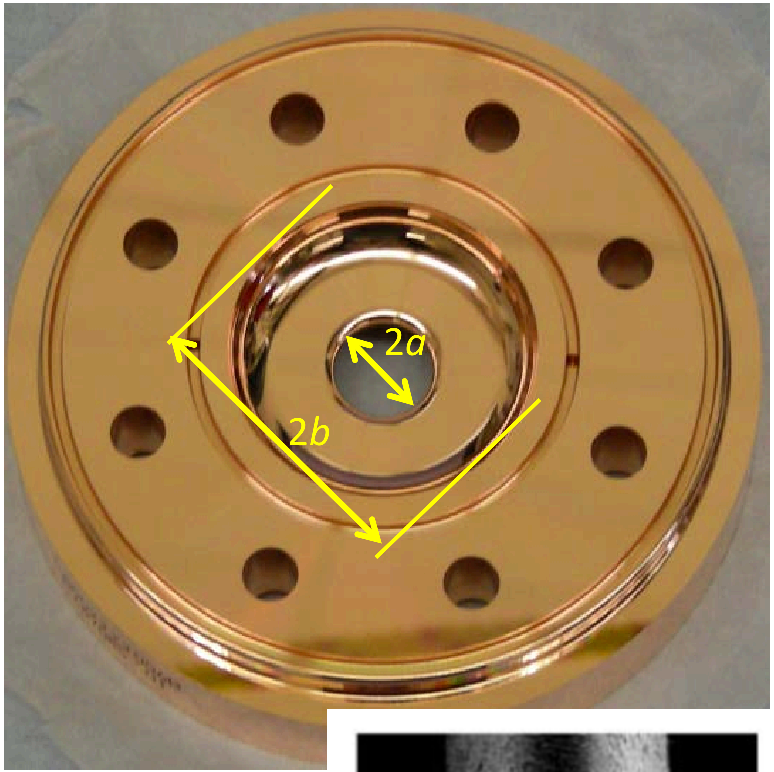


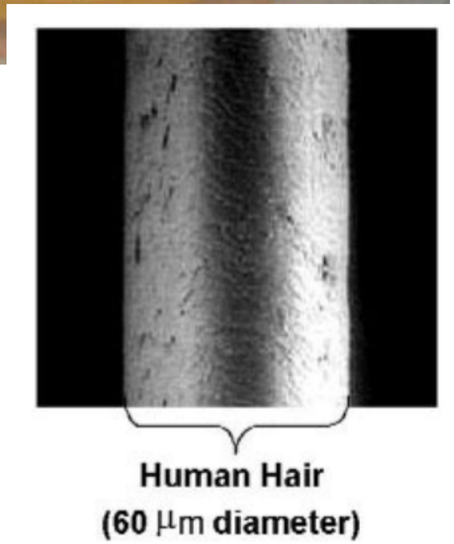
Precision manufacturing of copper disks in Trübbach

Challenge: machine the discs sufficiently precise such as to avoid post-brazing tuning









Courtesy of J.Y. Raguin

Typical examples of metrology on a structure: Top: histogram iris diameter; Bottom: histogram iris cell diameter

Assembly of an accelerator structure at PSI

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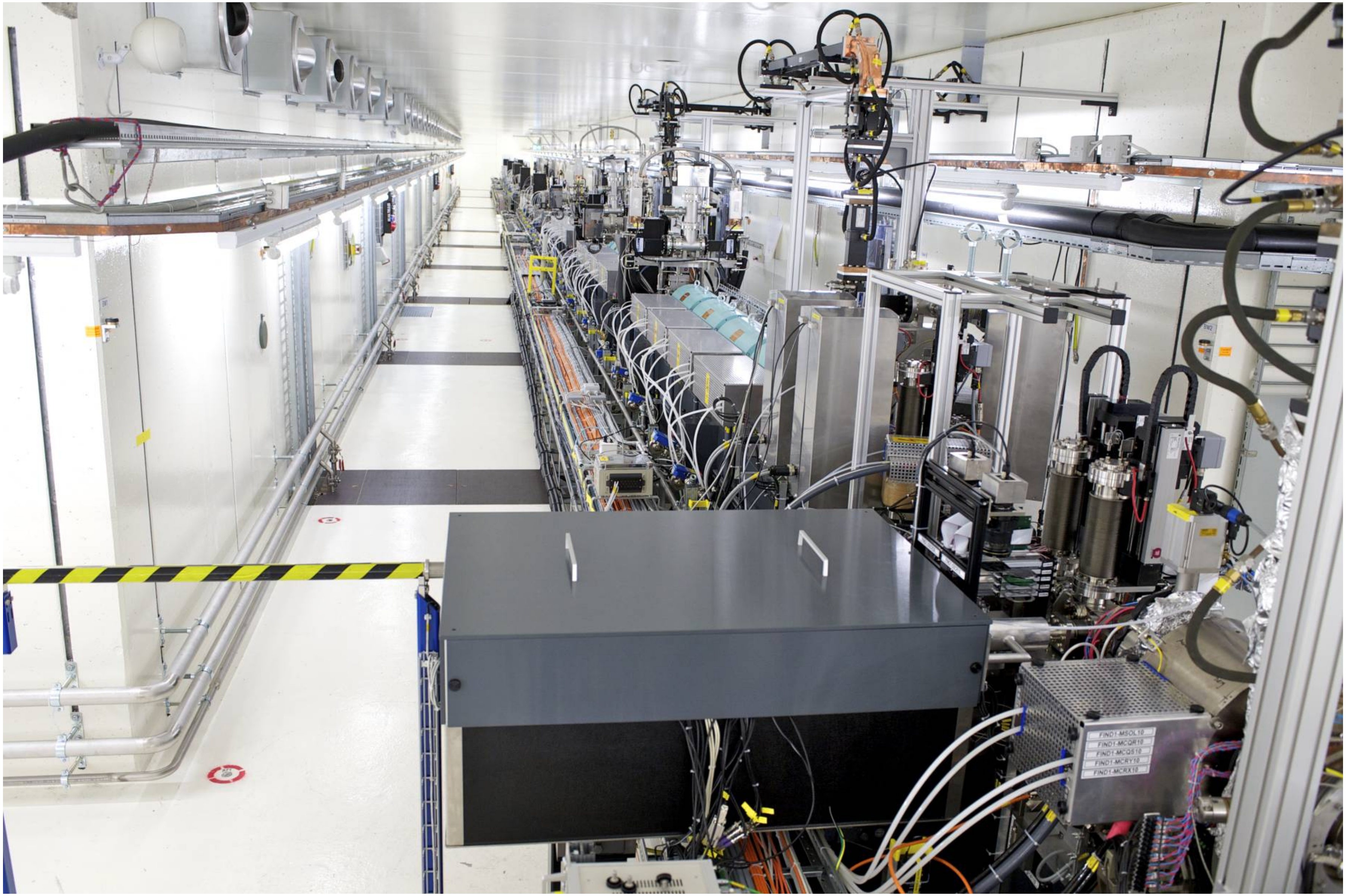
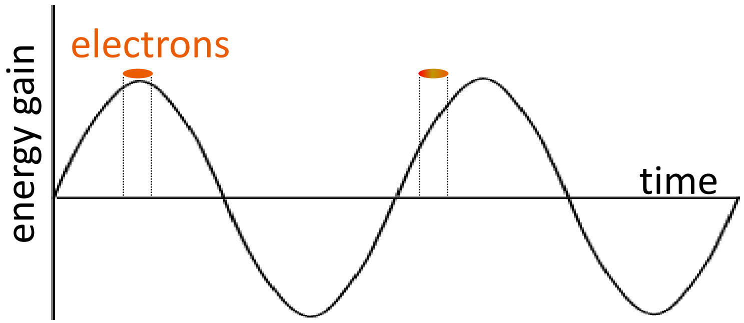
The first 240 m of the accelerator are installed in the tunnel

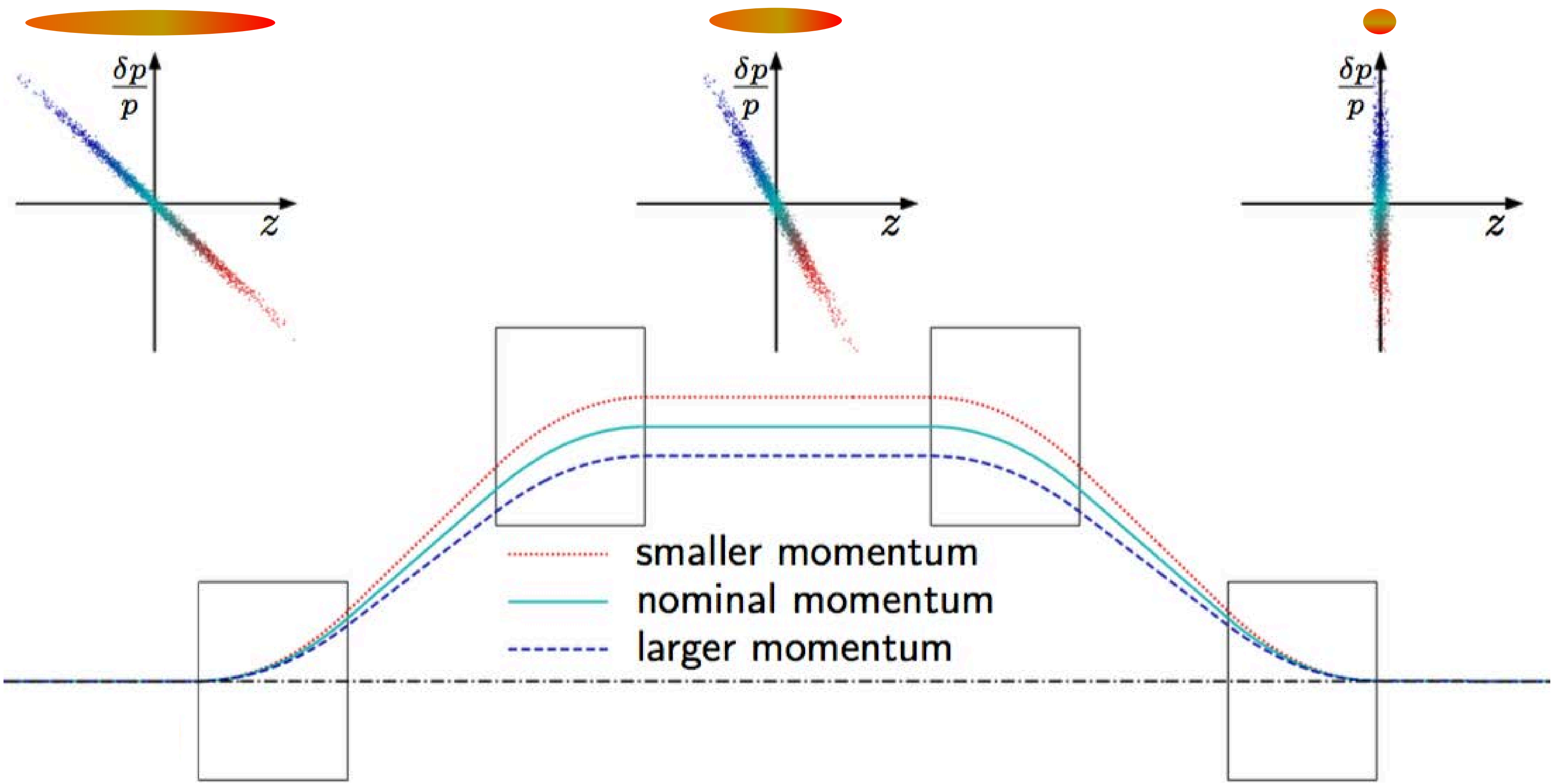
View looking downstream of SwissFEL injector



How do you generate femtosecond electron bunches

Acceleration of electrons in accelerating structures:





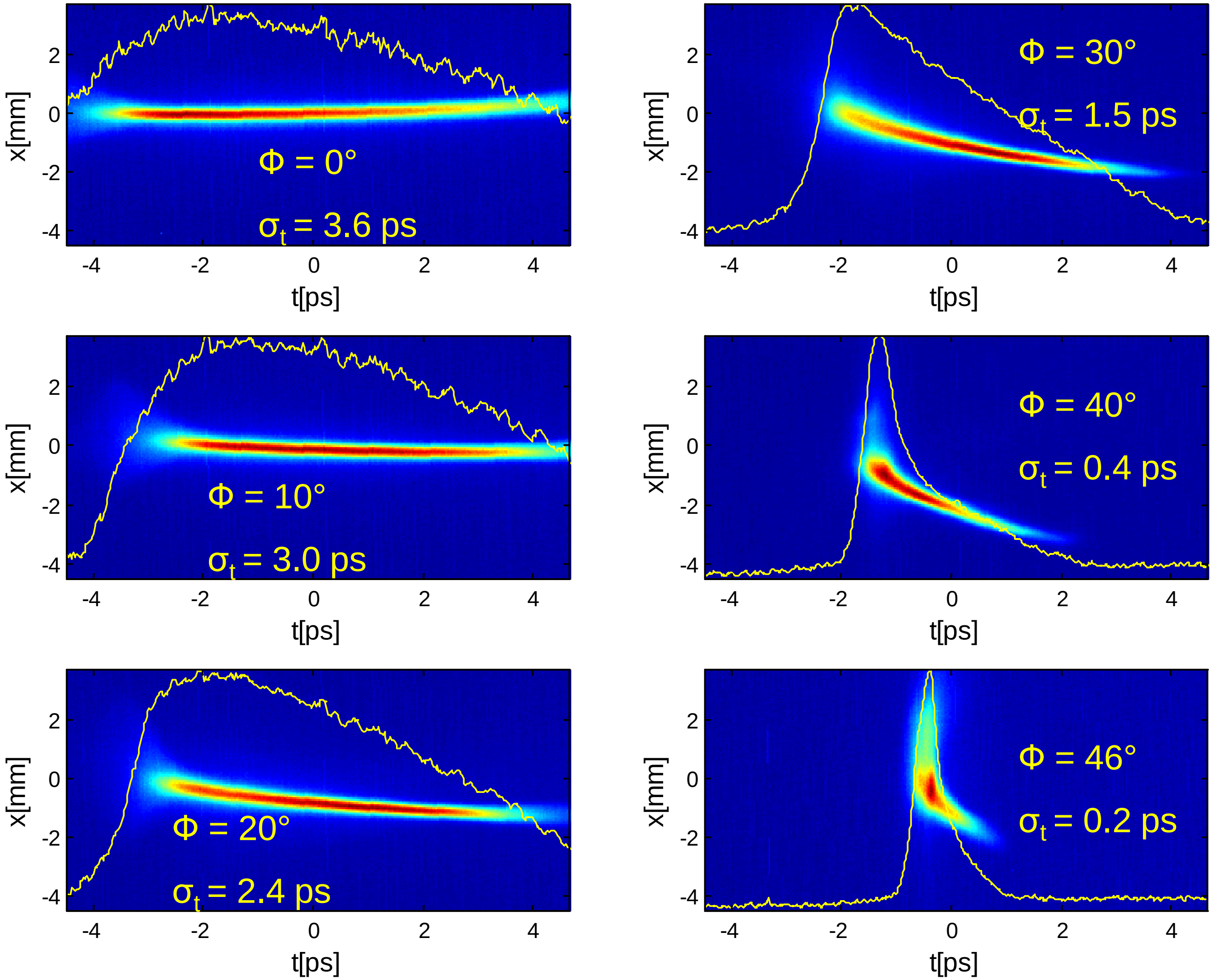
Demonstration of bunch compression (April 2012)

- First demonstration of bunch compression (April 18, Jaguar Laser, 200pC)
- Bunch length reduced from 3.6 ps to 200 fs (rms from Gauss fit)
- BC angle at 4.07°

(R_{56} = - 46.19 mm)

Φ: phase in FINSB03/04

σ_t: bunch length



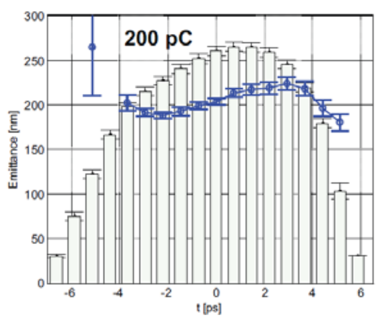
3.6 ps → 200 fs (rms)

SwissFEL Injector Test Facility performance

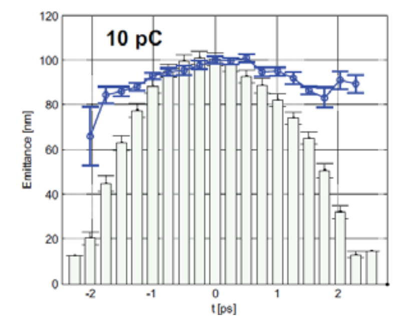
TRANSVERSE

- Emittance optimization (projected and slice)
- Emittance increase for compression factor > 5 (angle from 2.5° to 4.07 °)
- Thermal emittance contribution ~1/3 to the total emittance (Cu cathodes)

	Uncompressed		Compressed	
	Projected	Slice	Projected	Slice
200 pC	0.33±0.01	0.19±0.01	0.33±0.01 → 0.64±0.01	0.19±0.01 → 0.36±0.01
10 pC	0.15±0.01	0.10±0.01	/	/

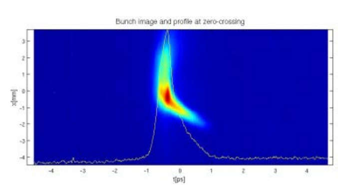


	$\varepsilon_{Thermal}/\sigma_{Laser}$ (nm/mm)
λ = 260.1 nm	547±10
λ = 267.6 nm	508±35



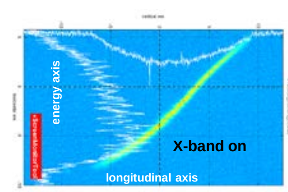
LONGITUDINAL

- Bunch compression focused on 200 pC case (compression, full compression, over-compression)
- X-band linearization

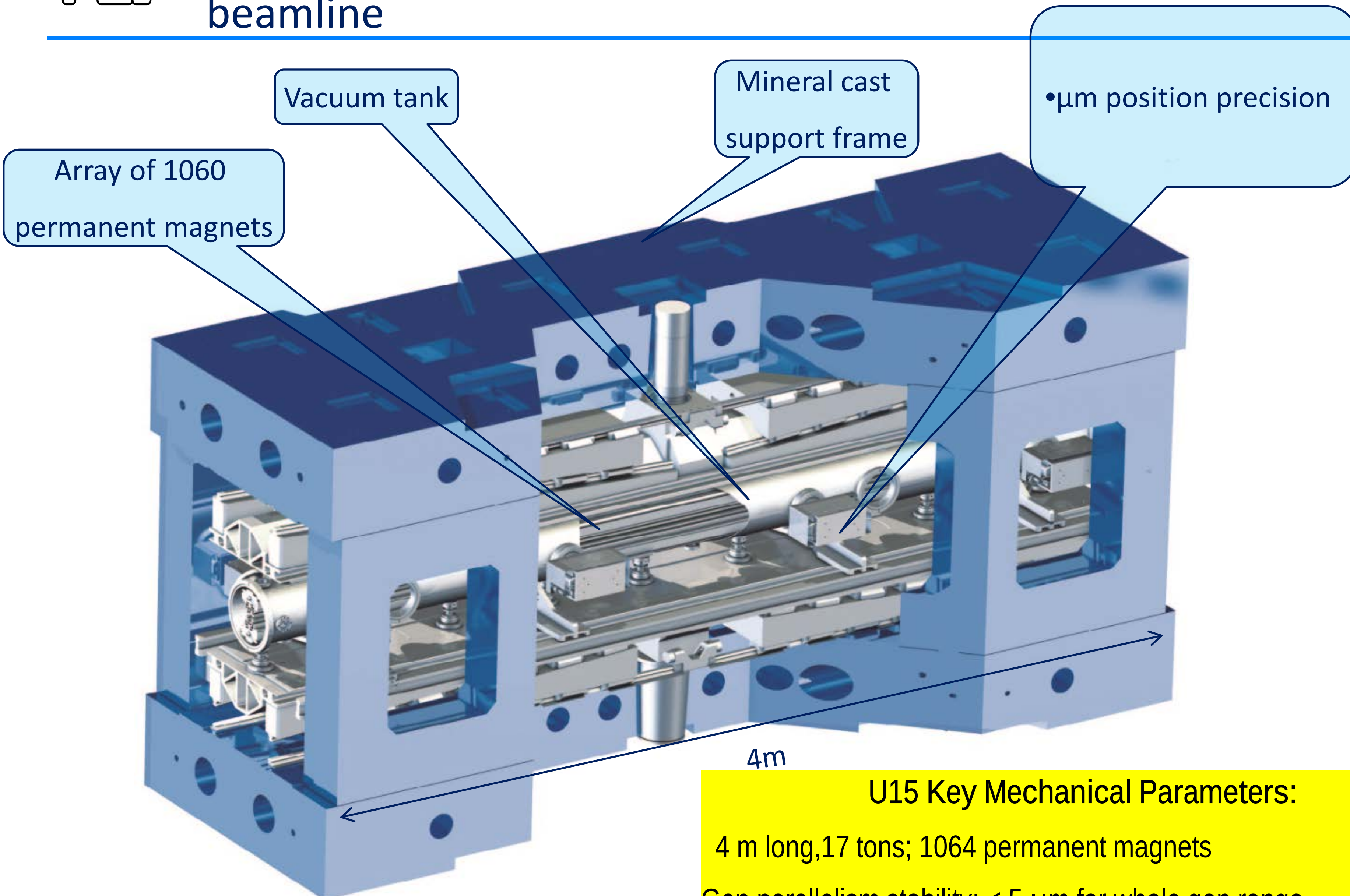


Energy spread (keV) @ 100 MeV	
Projected	Slice
22±3	18±2

Minimum bunch length (fs)
204±1



Short period (15 mm)Undulator magnets for the ARAMIS beamline



U15 Key Mechanical Parameters:

4 m long,17 tons; 1064 permanent magnets

Gap parallelism stability: < 5 µm for whole gap range

Magnet / Pole position height: sub-micrometer shimming

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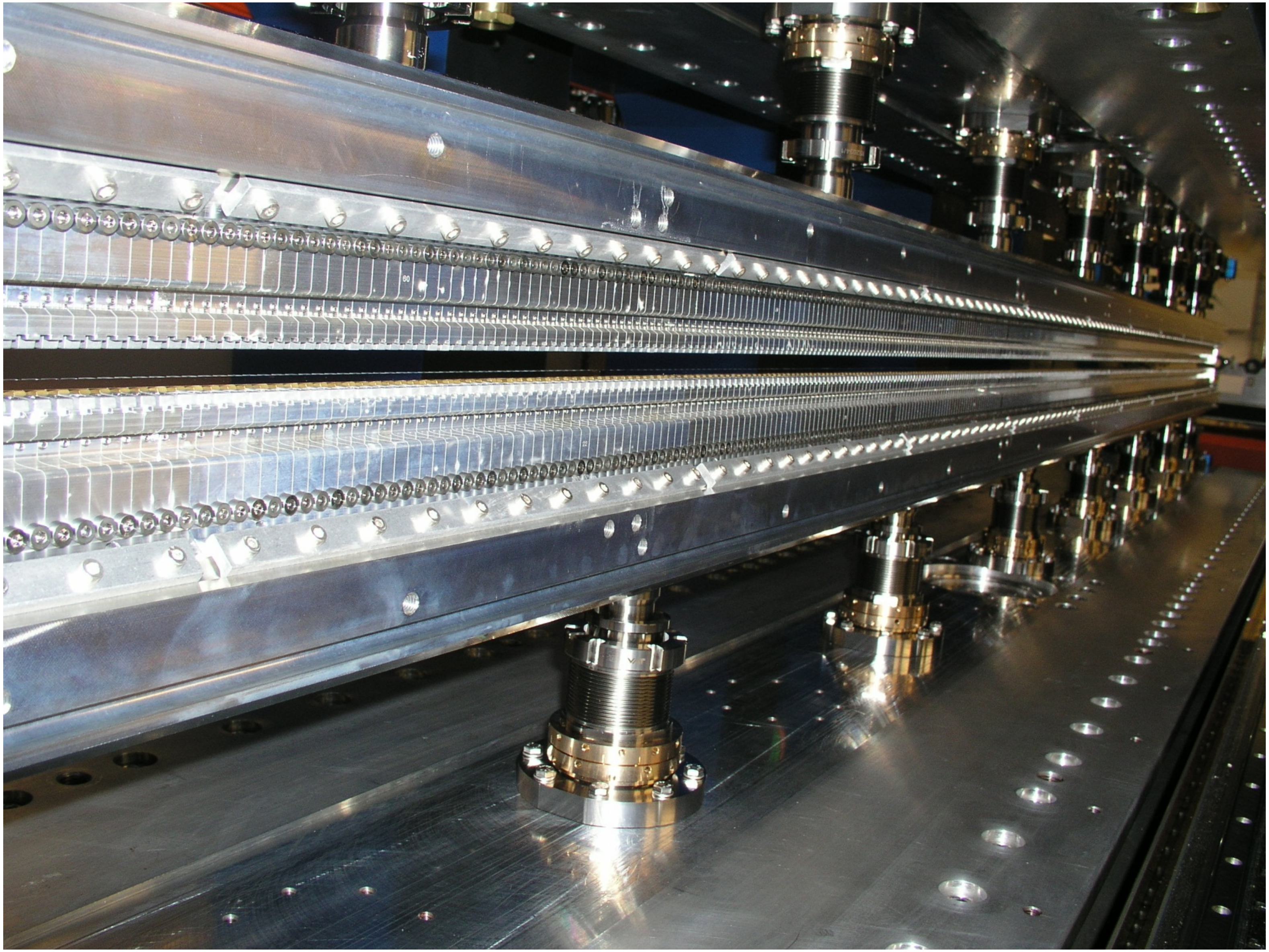
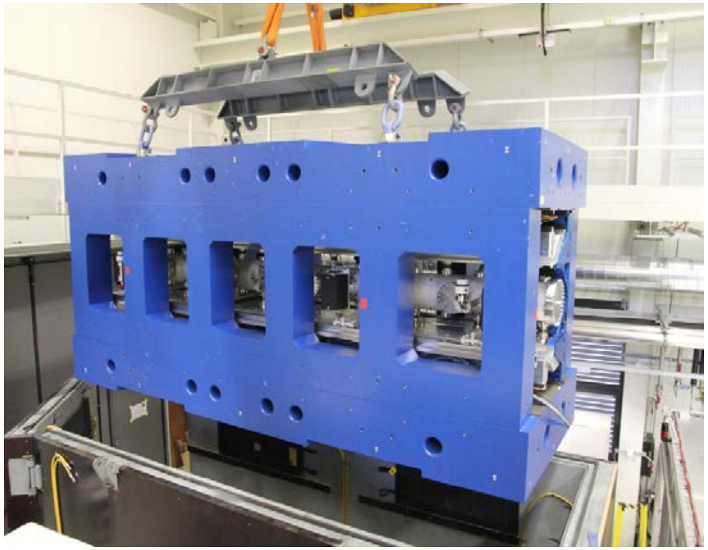
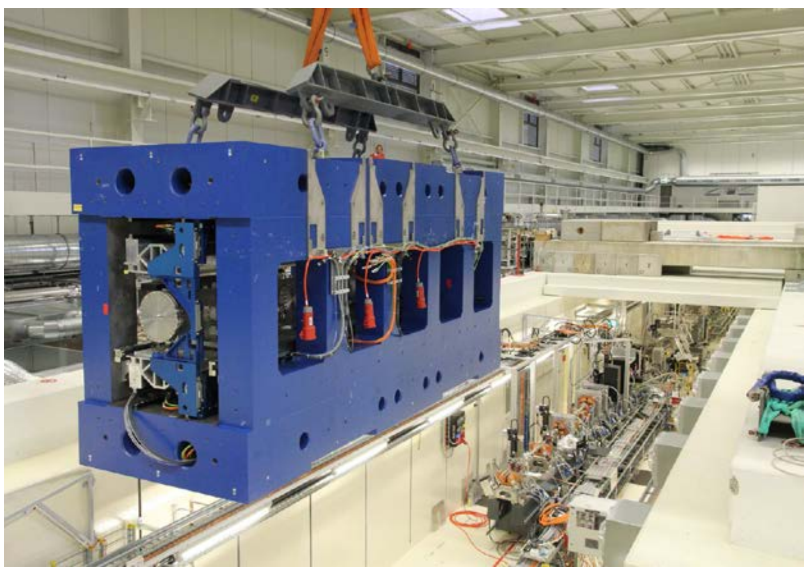
Magnet Array for U15 Undulator (outside of the vacuum chamber)



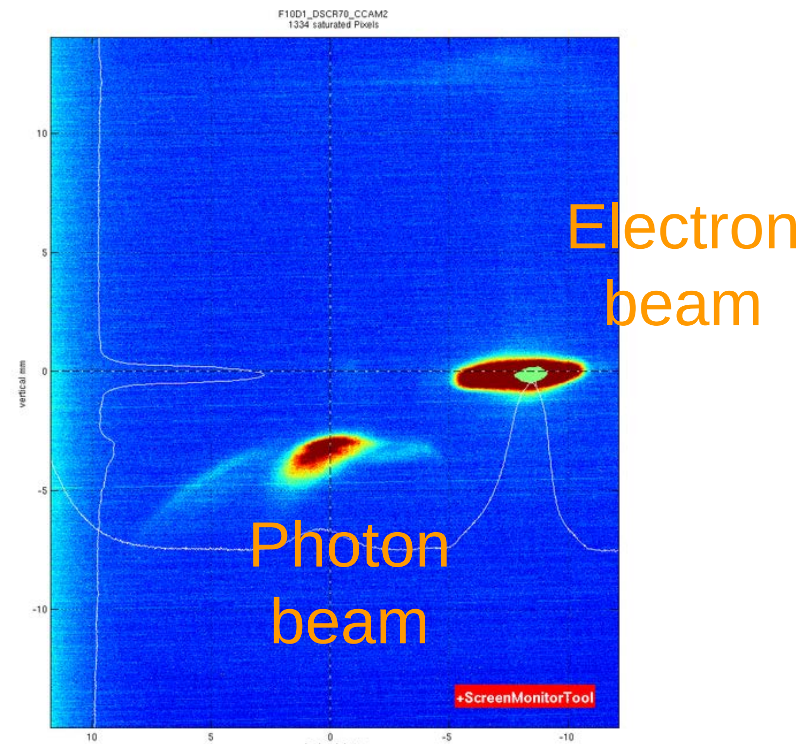
First SASE at SwissFEL Test Injector (January '14)





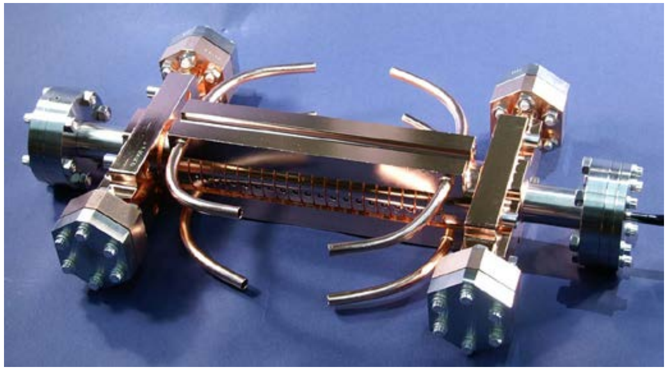
Courtesy of J. Wickstroem

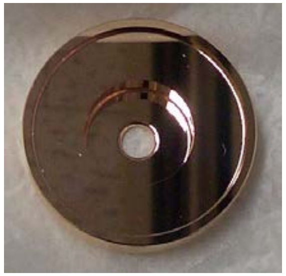
- Beam parameters: E=220MeV, Q=200pC
- Radiation wavelength derived from undulator parameters and electron energy:
  λ ~ 90 nm
- First FEL light generated in Switzerland



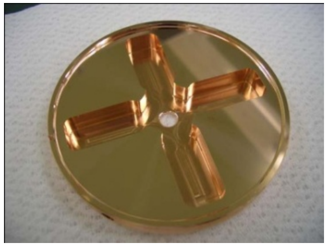
X-band RF structure developments for CLIC

- **C**ompact **LI** **C**ollider is a CERN led linear collider study
  - Requires 12 GHz radio-frequency structures operating at 100 MV/m with strong damping of beam excited wake-fields to prevent emittance dilution, beam loss of electron bunch train.





undamped

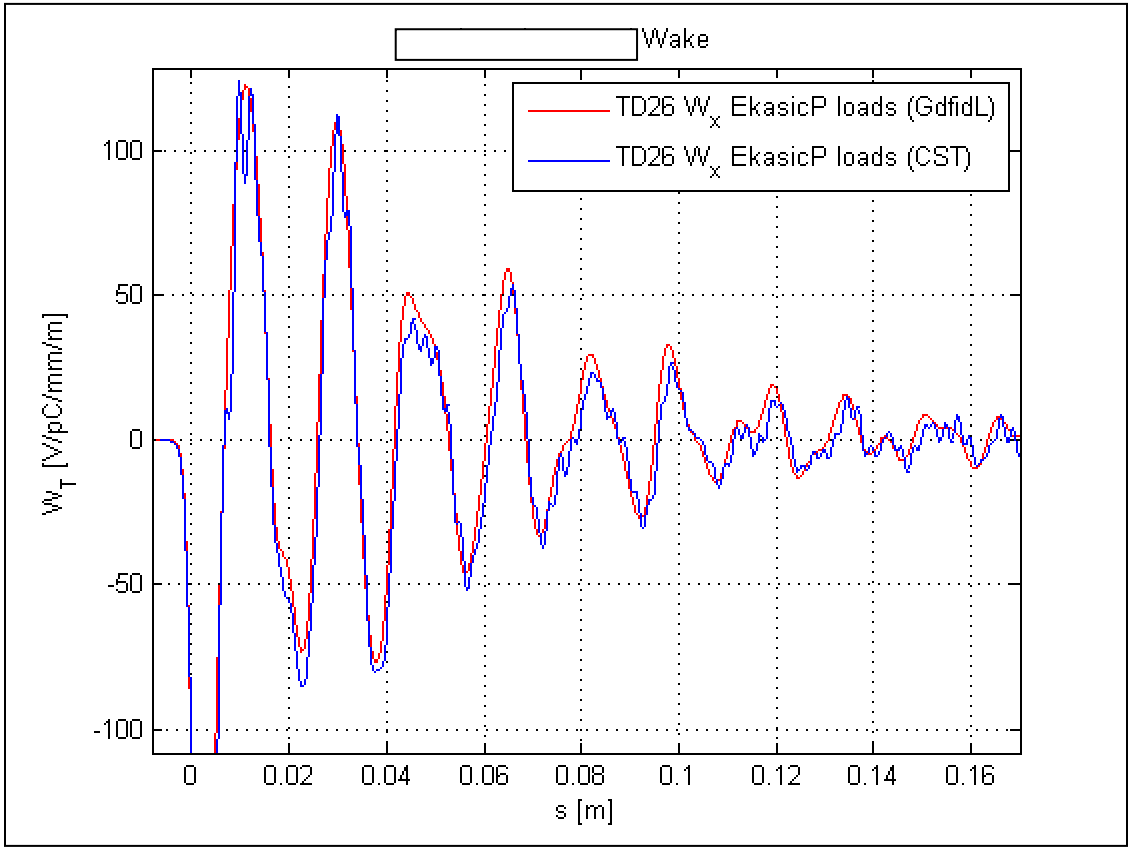


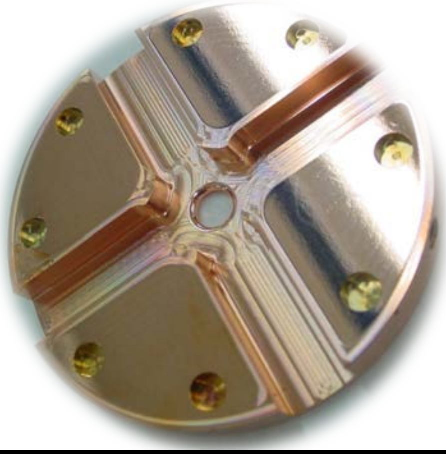
damped

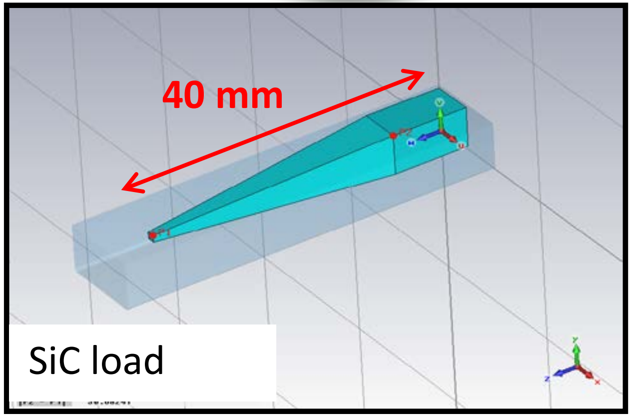
EPFL / PSI contributions to CLIC accelerating structures

- Characterisation of HOM damping materials - (T. Pieloni, G. De Michele)
- Wake-field simulations (De Michele)
- Engineering design effort
- Conception of SLAC/FACET experiment - CLASSE structure
- Wake-field monitors (M. Dehler)

Simulations of the wake-field with damping

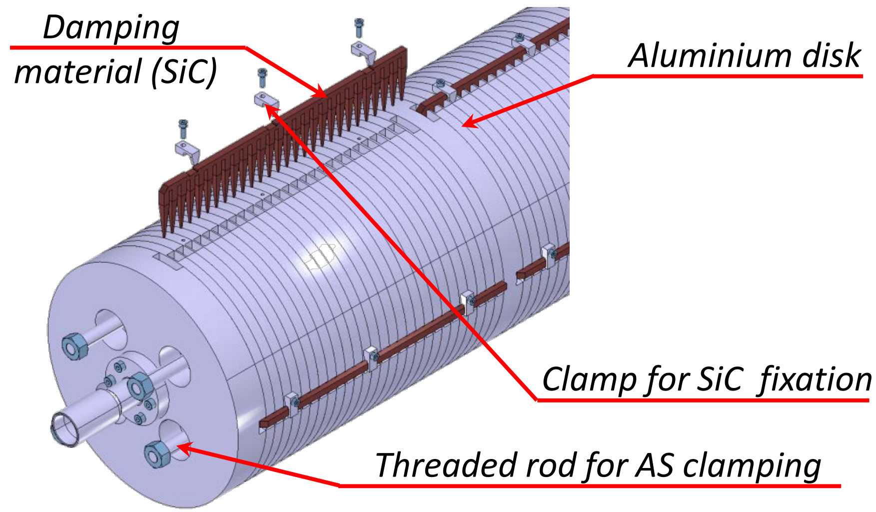


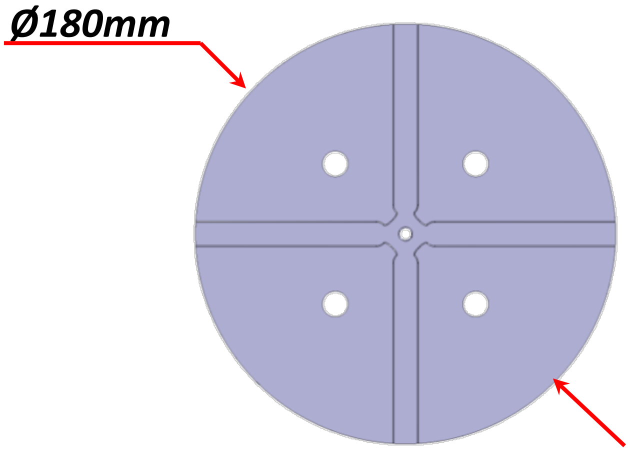




Experimental confirmation would be desirable (before building 30 km of them!)

Multi-Purpose Test (CLASSE) Structure





Cell shape accuracy 20µm

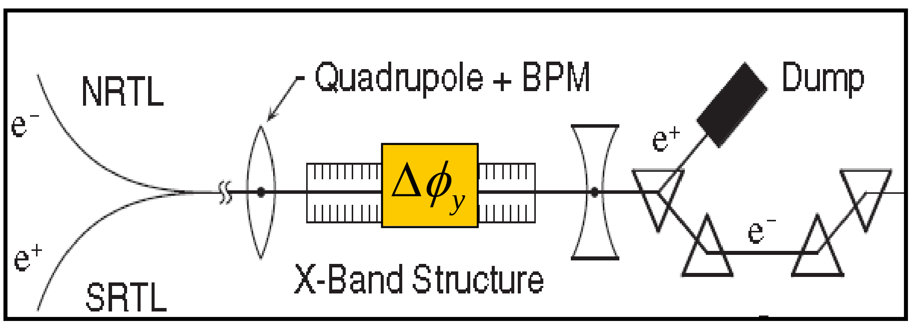
6 sections, 26 cells each, compact coupler design.

Clamped aluminum disks

Wakefield measurements at FACET (SLAC)

- Aim: Measure the wake-fields using positron (drive) and electron (witness) bunches.
- Wake-fields are excited by **driving positron bunch** passing through the structure with an offset from the linac axis.
- The **electron witness bunch** gets a kick from the excited wake-fields.
- The **transverse wakefield** can be calculated from the measurements of the deflection angle of the witness bunch with respect to a reference trajectory.

$$\Delta\phi_y = \frac{q_w Q_d L e^{-\left(\frac{\omega\sigma_d}{2c}\right)^2} e^{-\left(\frac{\omega\sigma_w}{2c}\right)^2}}{E_w} \cdot W_\perp(t)\Delta y_d$$



PHYSICAL REVIEW ACCELERATORS AND BEAMS **19,** 011001 (2016)

Beam-based measurements of long-range transverse wakefields in the Compact Linear Collider main-linac accelerating structure

Hao Zha,[1] Andrea Latina,[1] Alexej Grudiev,[1] Giovanni De Michele,[1,2,3] Anastasiya Solodko,[1] Walter Wuensch,[1] Daniel Schulte,[1] Erik Adli,[4,5] Nate Lipkowitz,[4] and Gerald S. Yocky[4]
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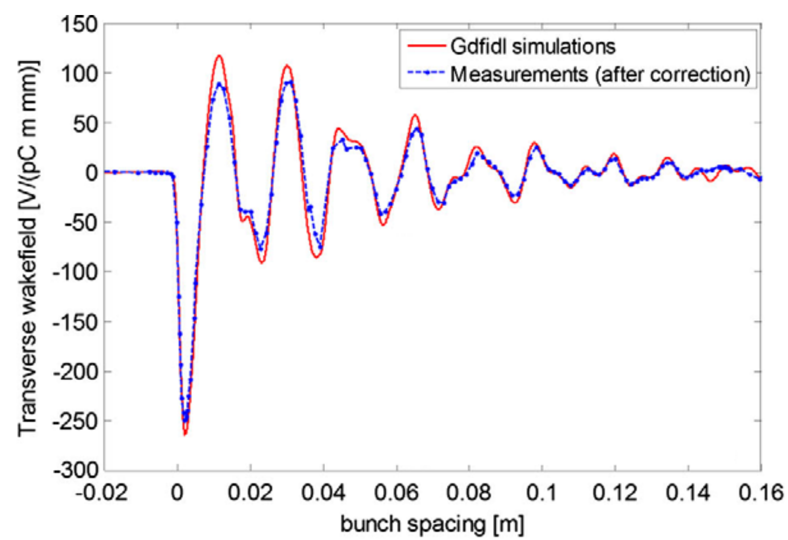
[2]*PSI, Paul Scherrer Institut, 5232 Villigen, Switzerland*
[3]*EPFL, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland*
[4]*SLAC National Laboratory, 2575 Sand Hill Road, Menlo Park, California 94025, USA*
[5]*Department of Physics, University of Oslo, 0316 Oslo, Norway*
(Received 15 May 2015; published 20 January 2016)



ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Damping ring developments on the SLS

Test **I**nfrastructure and **A**ccelerator **R**esearch **A**rea
www.eu-tiara.eu

Work package 6 "SVET"

Partially funded by the European Commission under the FP7-INFRASTRUCTURES-2010-1/INFRA-2010-2.2.11 project TIARA (CNI-PP). Grant agreement no 261905

Swiss Light Source

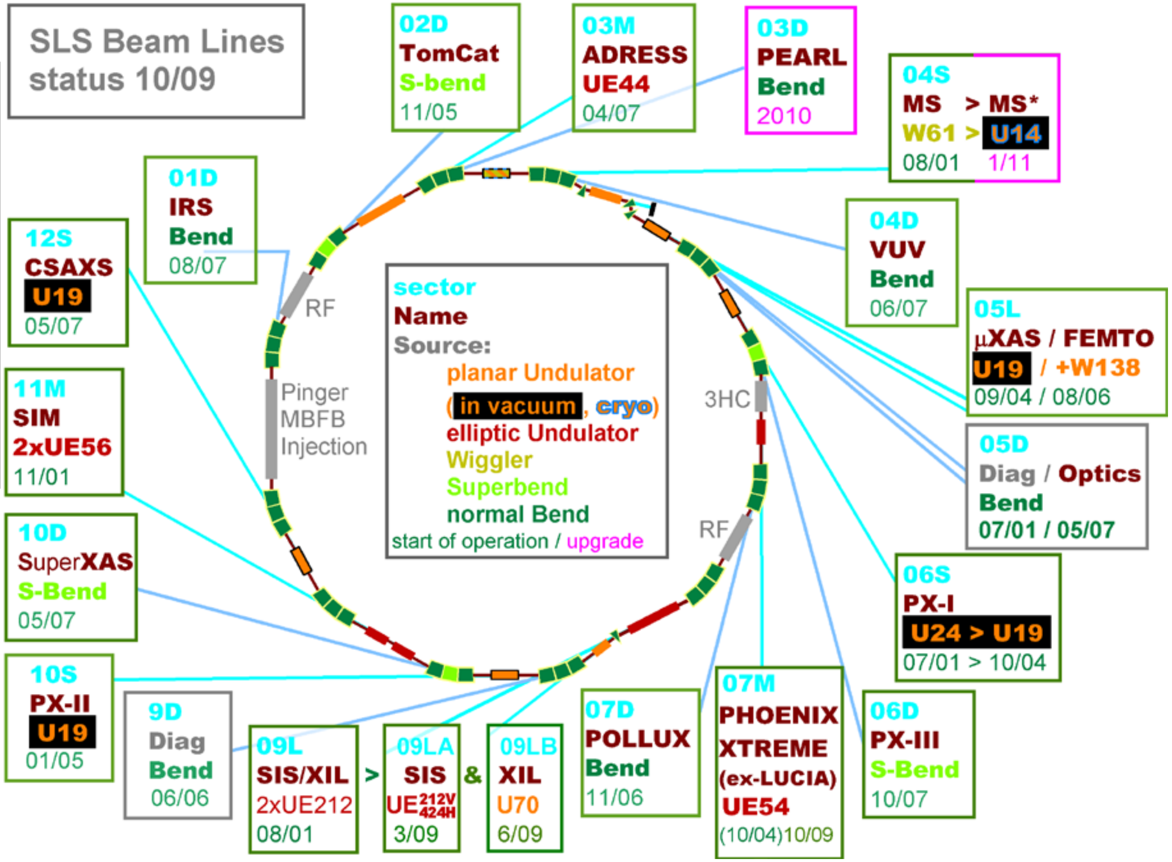
-2.4 GeV electron storage ring

for synchrotron radiation.

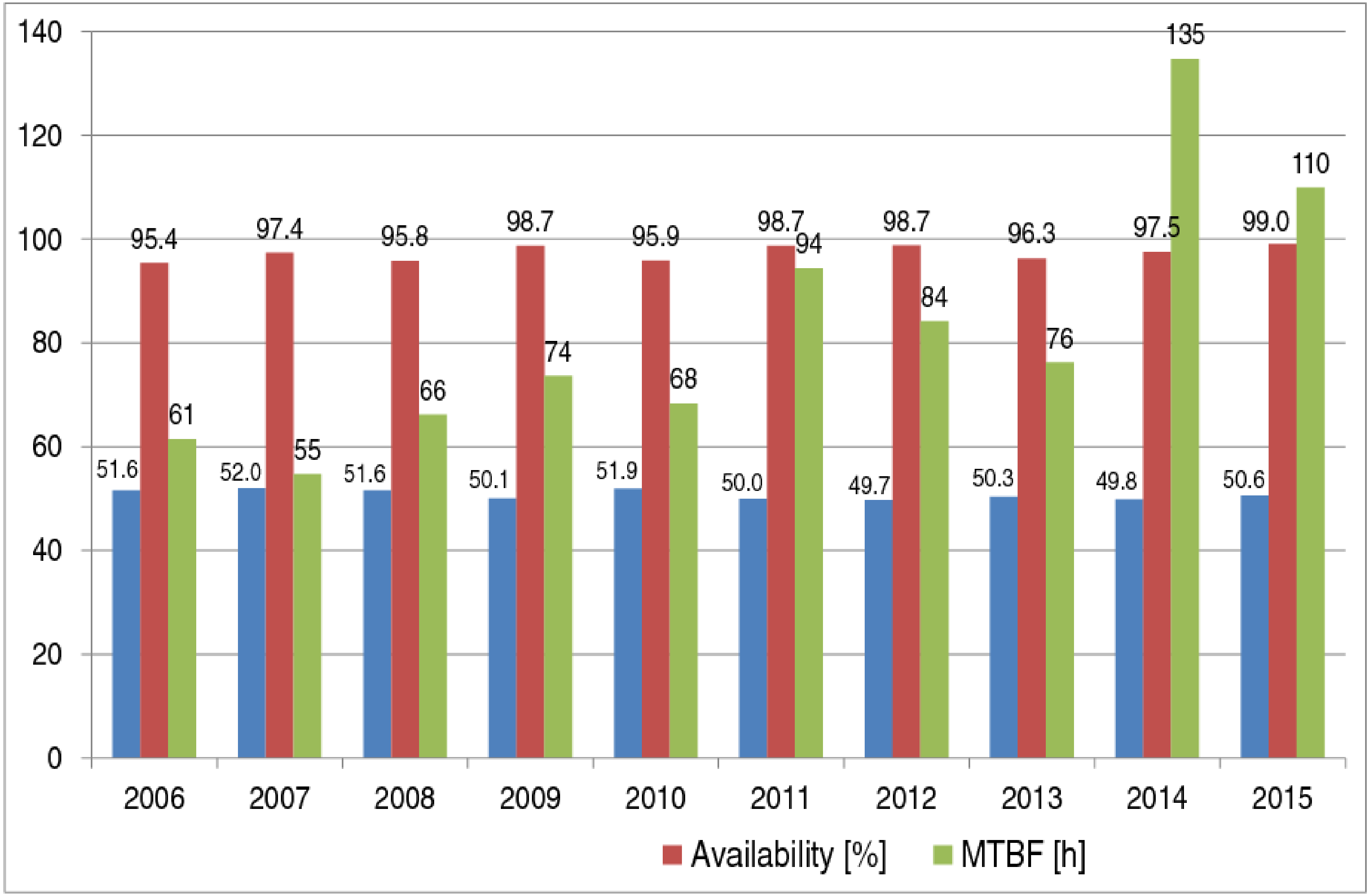
Used for vertical emittance tuning

and studies of transverse coupling

control.



SLS operational reliability



Procedure for SLS Vertical Emittance Tuning

1. re-alignment of magnet girder to remove main sources of vertical dispersion

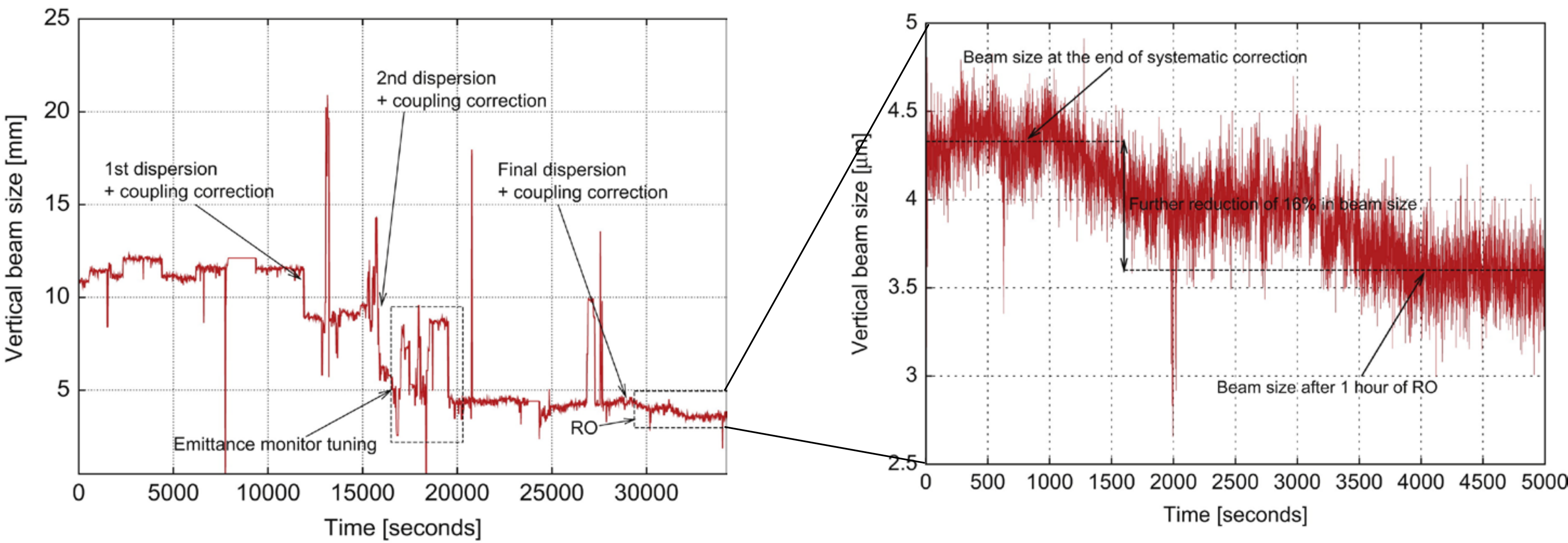
   → reduction of rms vertical correction kick from ~ 130 µrad to ~ 50 µrad

2. measurement & correction of vertical dispersion and betatron coupling

   → model-based skew quadrupole corrections (12 dispersive and 24 non-dispersive skew quads)

3. "random walk" optimization of vertical beam size

   → skew quadrupole corrections using beam size measurements from profile monitor

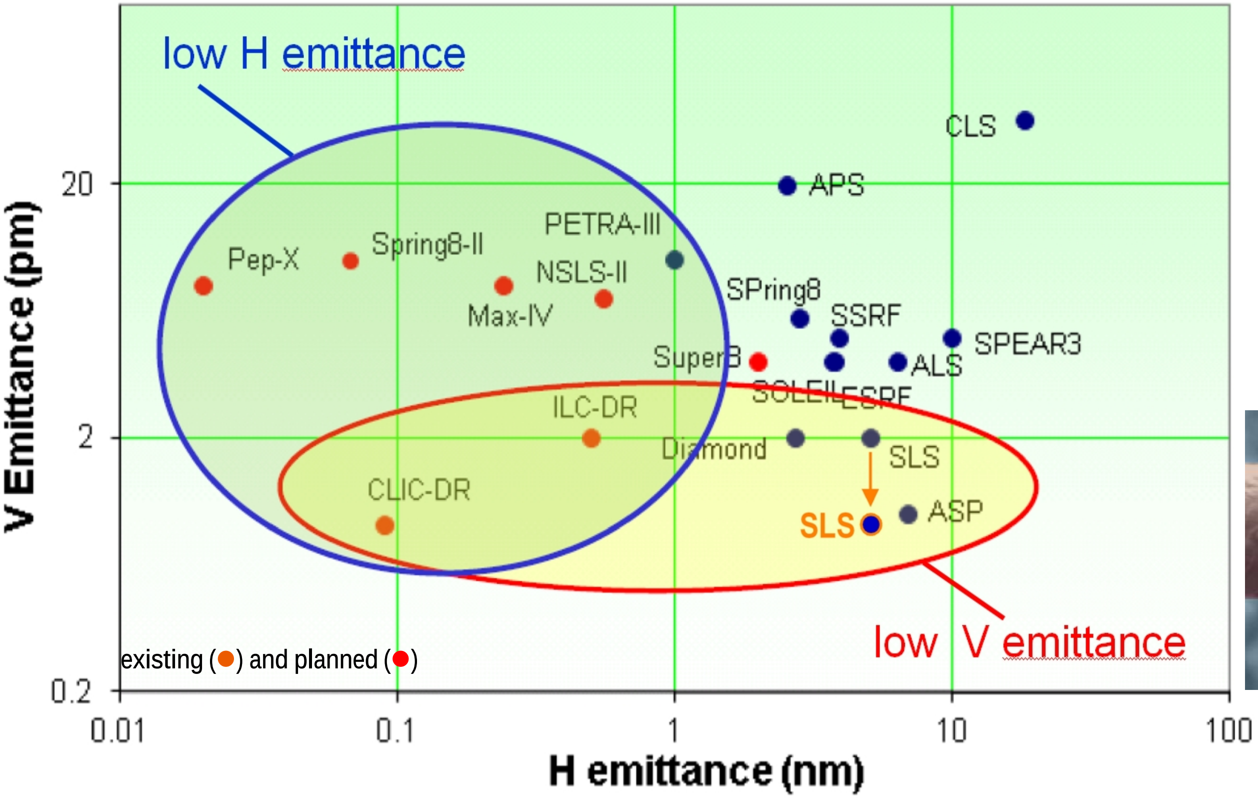


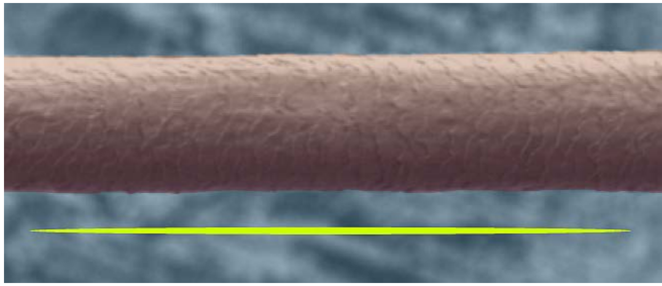
M. Aiba, et al., *Ultra Low Vertical Emittance at SLS Through Systematic and Random Optimization*, NIM-A 694 (2012) 133-139

SLS Vertical Emittance Optimization – Results

- vertical beam size: 3.6 ± 0.6 μm
- vertical emittance: 0.9 ± 0.4 pm
- error estimate from beam size and β-function at monitor

Limited by monitor resolution!





Horizontal and Vertical Emittances of Storage Rings

Figure based on:

R. Bartolini, Low Emittance *Ring Design,* ICFA Beam Dynamics Newsletter, No. 57, Chapter 3.1, 2012.

Solid state amplifier project – funded by Swiss CTI intended for use with the Swiss Light Source

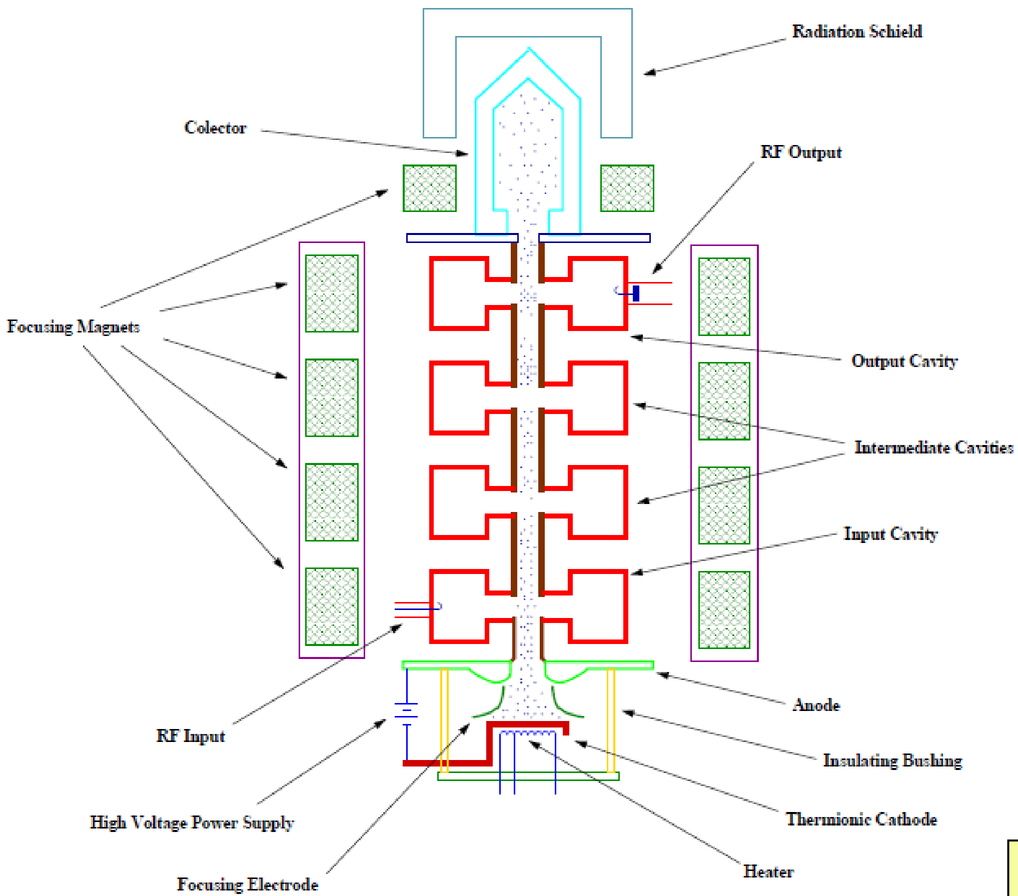
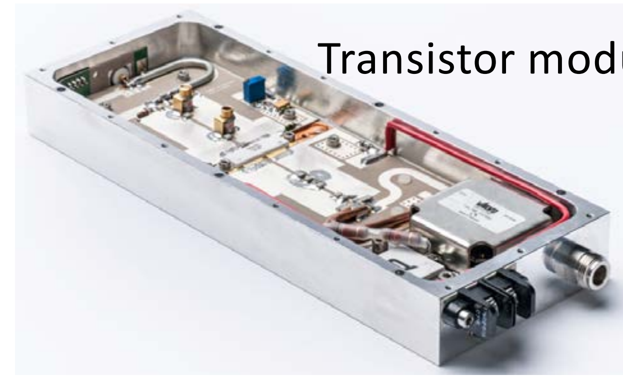


Figure 1.5: The Klystron

150 kW klystron tube SLS ~ 50 kV, 6 A



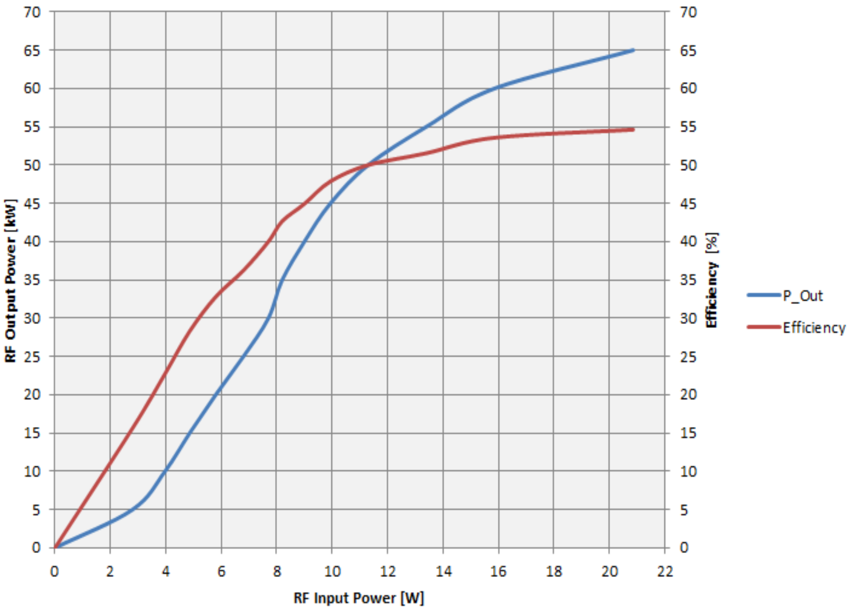
A combination of 9x6x2 700 W transistors allows 75 kW to be obtained from a single tower.

Has the potential to replace vacuum electronic tubes (klystrons)

Advantages: Cheaper
- More compact
- More reliable
- No high temperature filament
- No need for large focusing electro-magnet
- No high voltage power supply required
- No beam collector and no x-ray shielding required

500 MHz Solid State Amplifier funded by Swiss CTI

- Technology Transfer PSI -> Industry (Ampegon)
- Solid state RF source to replace existing klystron amplifiers
- Technology pioneered at SOLEIL - France



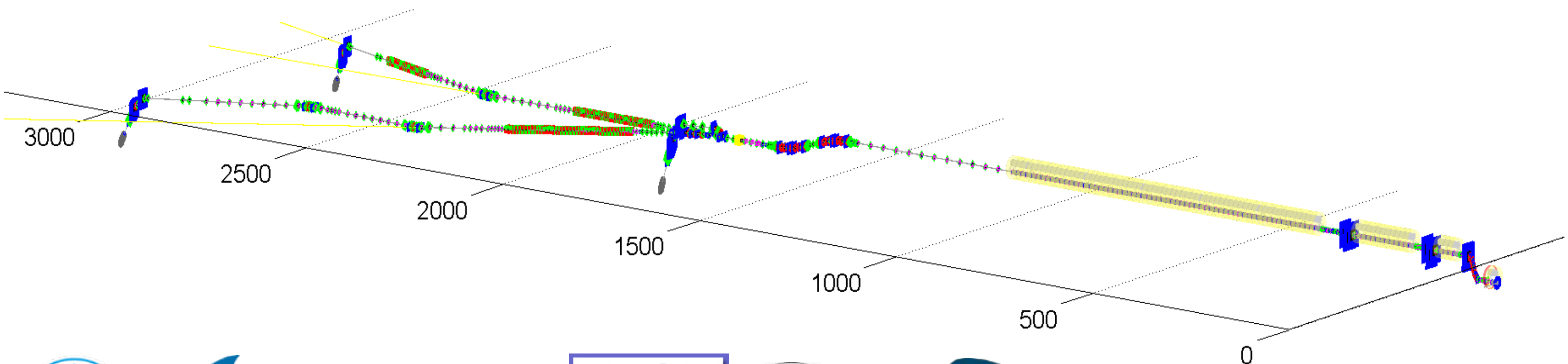
M. Gaspar

European X-FEL (Accelerator Consortium)

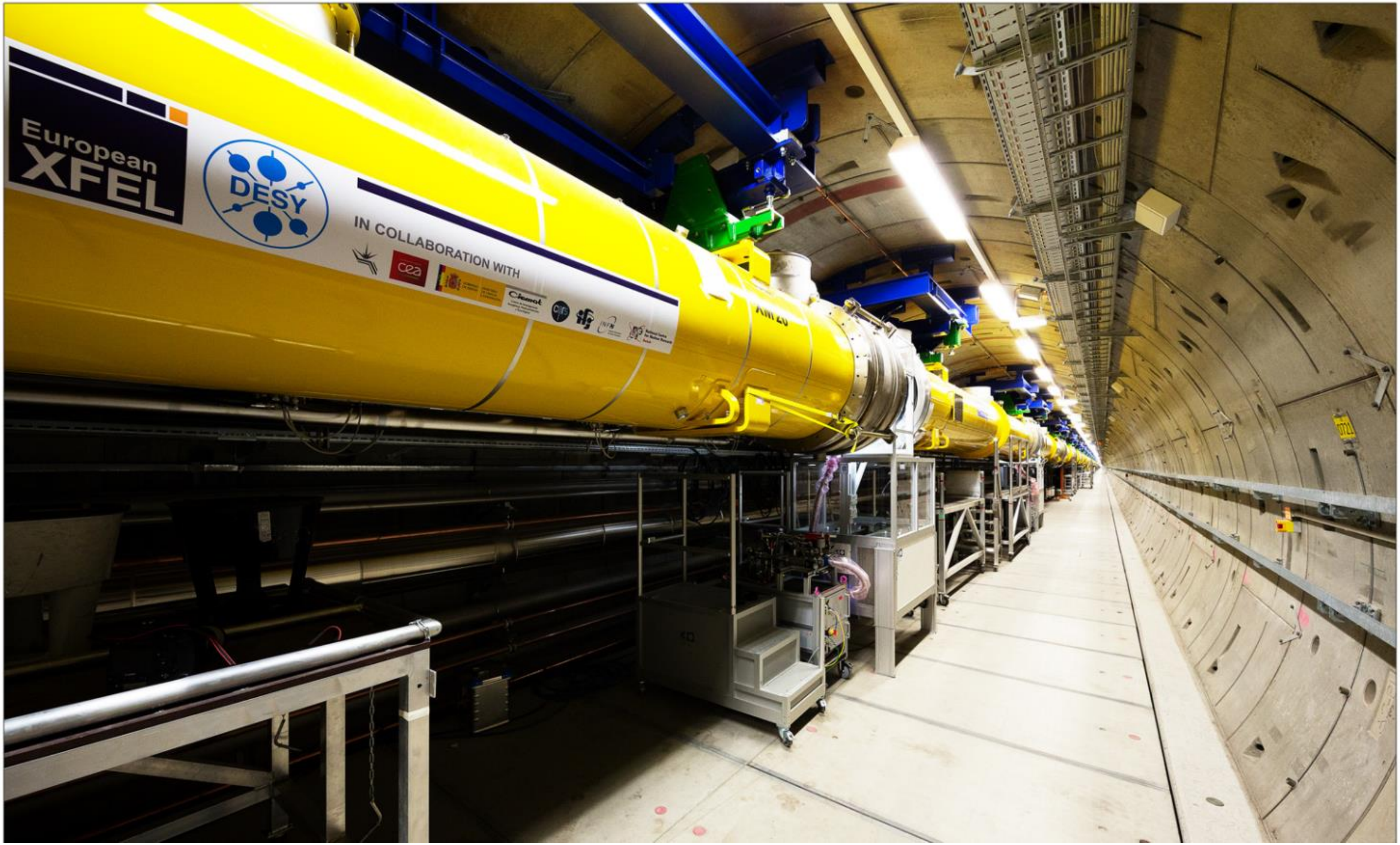
17.5 GeV superconducting linac. ***In many ways an ILC prototype !!***

Swiss in-kind contribution via PSI

TESLA RF technology



European X-FEL currently being installed



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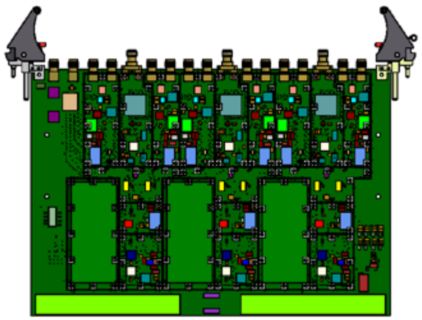
Swiss/PSI E-XFEL Contribution: BPM/IBFB Electronics

BPM RF Front-Ends

- Undulators: 3.3GHz cavity BPMs, few 100nm resolution



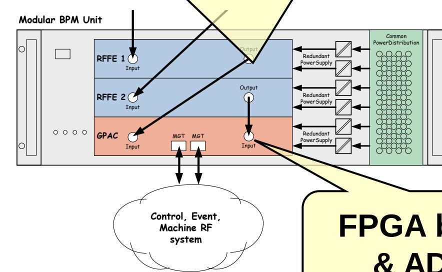
FPGA/DSP Carrier Boards

- Same FPGA board type for all BPM types (button, cavity, …)
- FPGA/DSP board for Intra-Bunchtrain Feedback

Modular BPM Unit

Customized crate, temperature stabilized

2 cavity BPM or 4 button BPM RF front-ends



FPGA board & ADCs

DSPs/PowerPCs: Real-time digital signal processing software

FPGAs: Huge number of logic gates & memory cells, programmable interconnections

Fast Precision ADCs

- Modular: Mezzanine for FPGA/DSP carrier board

PSI Synergies

- SLS BPM/FOFB upgrade
- SwissFEL BPMs, LLRF, …

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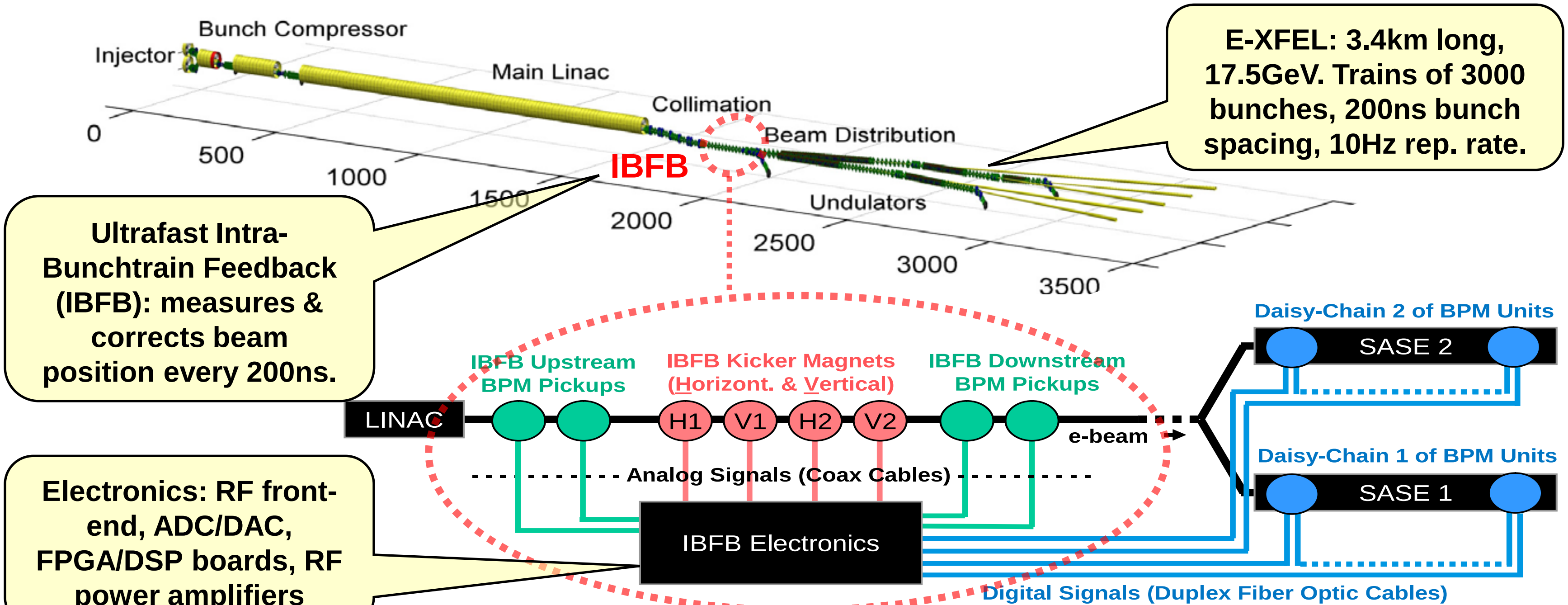
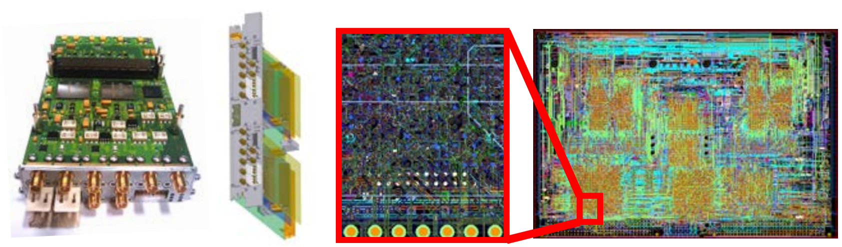
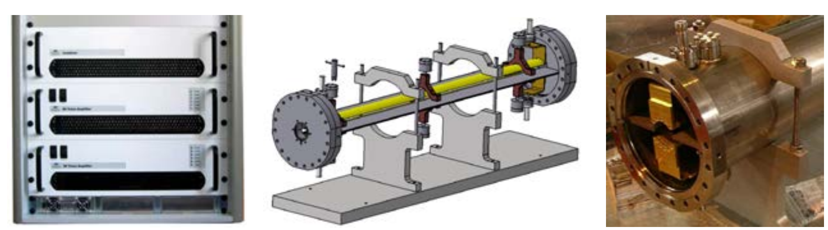
Swiss/PSI E-XFEL Contribution: Transverse Feedback





Ultrafast ADC/DAC + Digital Signal Processing



Ultrafast Kicker Magnets & RF Power Amplifiers

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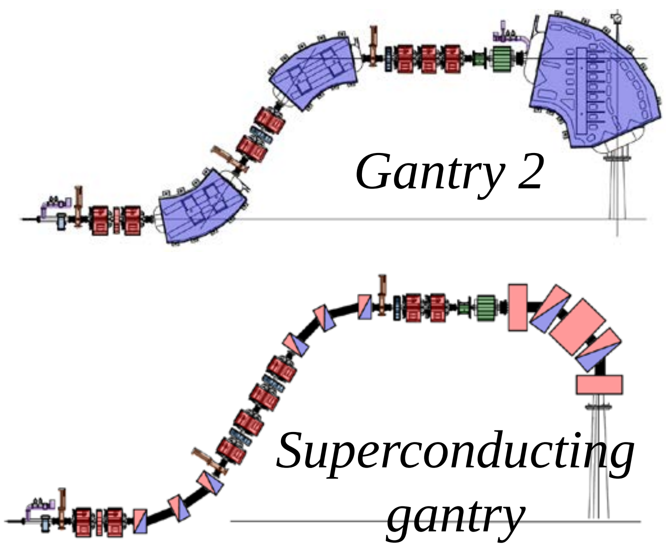
R&D on superconducting gantry designs for particle therapy

- Design study of: **Gantry** with **Superconducting magnets**



- **EXPECTED IMPROVEMENTS:**

⇒ **NOT much smaller, but:**

⇒ **Weight: 200 tons → 50 tons → Cost !**

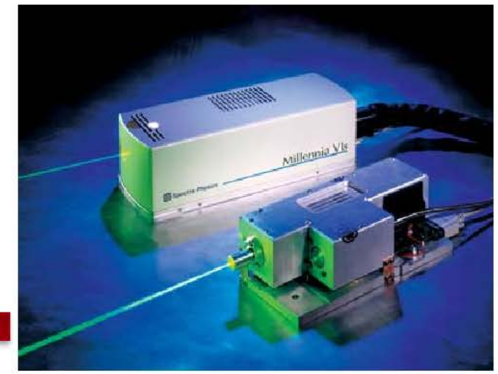
⇒ **Field size: 12 x 20 cm^2 → 20 x 20 cm^2**

⇒ **Energy acceptance 1.5% → 20 %**

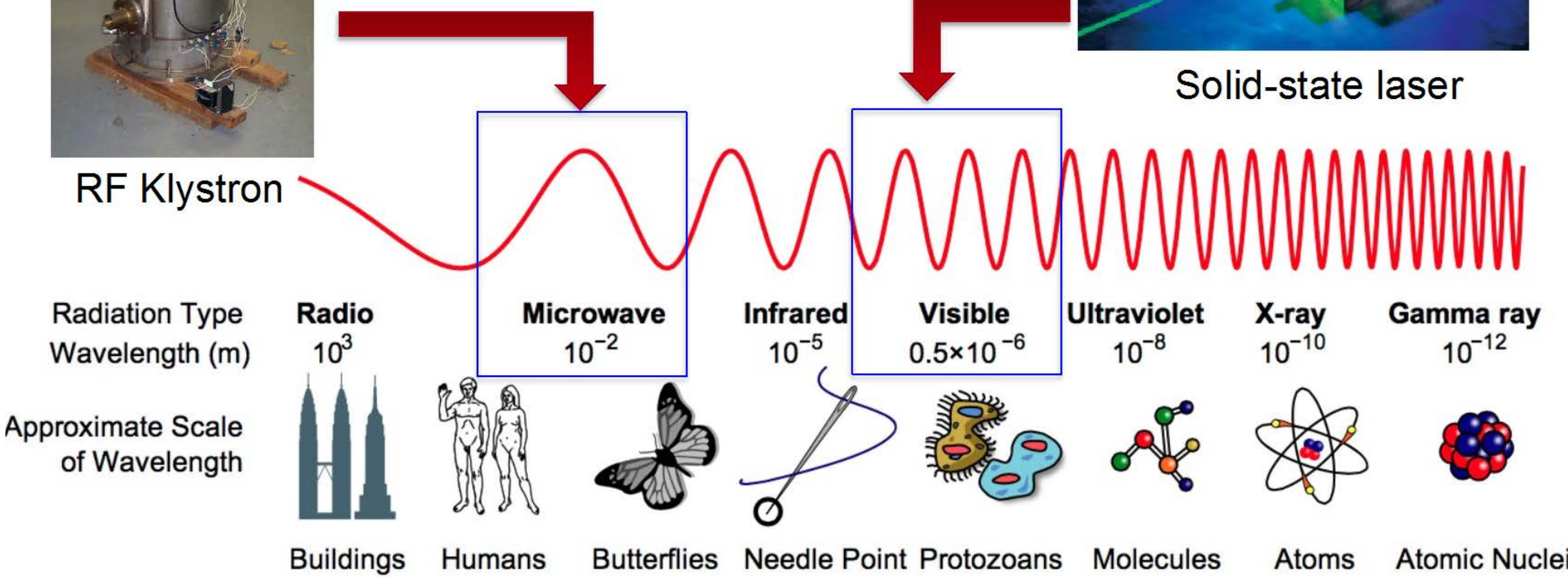
Lasers as power sources for dielectric structures

RF Klystron

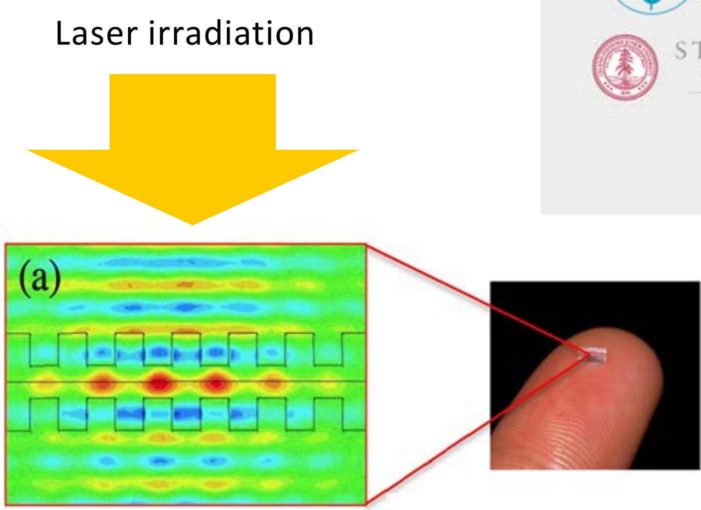
1. Smaller/less expensive than RF.
2. Energy efficient (near 50%).
3. High repetition rate (1 to 100 MHz).
4. Large electric fields (GV/m).

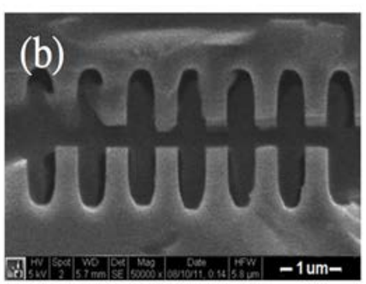


Solid-state laser



Accelerator on a Chip International Program (ACHIP)





Rasmus Ischebeck, Lenny Rivkin

Experiments planned on on SwissFEL linac
Tests on injector - measure wakes, damage thresholds
Full tests on ATHOS beam line ~ 2019.

Future Circular Collider Study

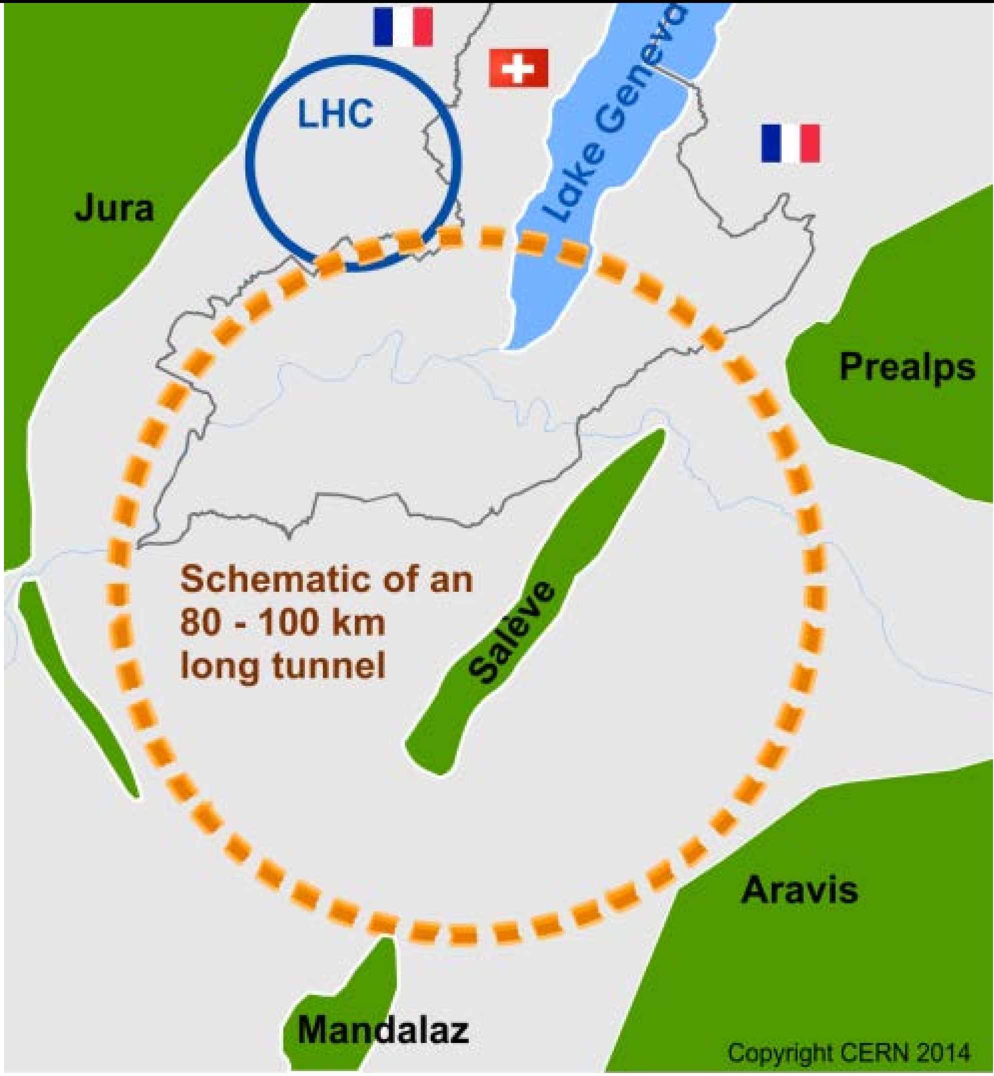
GOAL: CDR and cost review for the next ESU (2018)

International FCC collaboration (CERN as host lab) to study:

- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km

- **80-100 km infrastructure** in Geneva area
- ***e*$^+$*e*$^-$ collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (FCC-he) option**
- **HE-LHC** with FCC-hh technology



PAUL SCHERRER INSTITUT PSI

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

CERN

FCC Collaboration Status

61 collaboration members & CERN as host institute, 14 September 2015

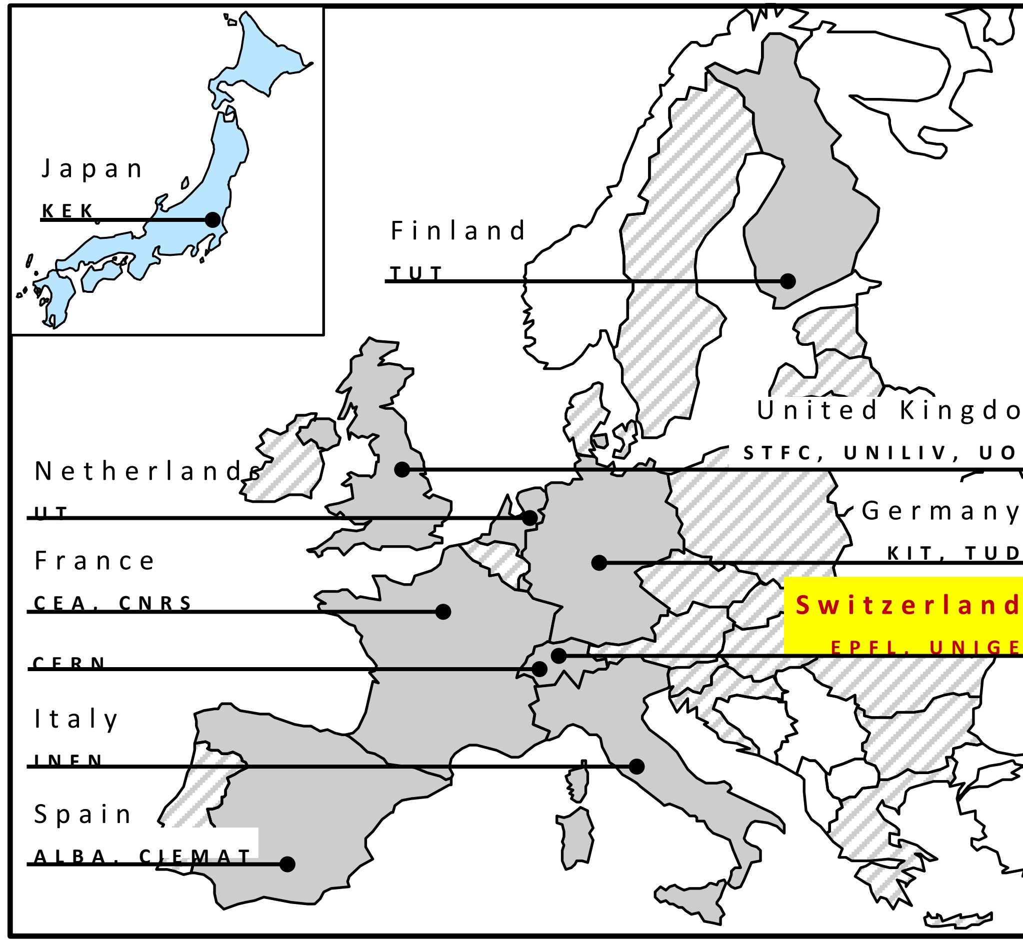
ALBA/CELLS, Spain
Ankara U., Turkey
U Belgrade, Serbia
U Bern, Switzerland
BINP, Russia
CASE (SUNY/BNL), USA
CBPF, Brazil
CEA Grenoble, France
CEA Saclay, France
CIEMAT, Spain
CNRS, France
Cockcroft Institute, UK
U Colima, Mexico
CSIC/IFIC, Spain
TU Darmstadt, Germany
TU Delft, Netherlands
DESY, Germany
TU Dresden, Germany
Duke U, USA
EPFL, Switzerland
GWNU, Korea

U. Geneva, Switzerland
Goethe U Frankfurt, Germany
GSI, Germany
Hellenic Open U, Greece
HEPHY, Austria
U Houston, USA
IIT Kanpur, India
IFJ PAN Krakow, Poland
INFN, Italy
INP Minsk, Belarus
U Iowa, USA
IPM, Iran
UC Irvine, USA
Istanbul Aydin U., Turkey
JAI/Oxford, UK
JINR Dubna, Russia
FZ Jülich, Germany
KAIST, Korea
KEK, Japan
KIAS, Korea

King's College London, UK
KIT Karlsruhe, Germany
Korea U Sejong, Korea
MEPhI, Russia
MIT, USA
NBI, Denmark
Northern Illinois U., USA
NC PHEP Minsk, Belarus
U. Liverpool, UK
U Oxford, UK
PSI, Switzerland
U. Rostock, Germany
Sapienza/Roma, Italy
UC Santa Barbara, USA
U Silesia, Poland
TU Tampere, Finland
TOBB, Turkey
U Twente, Netherlands
TU Vienna, Austria
Wroclaw UT, Poland

EuroCirCol Consortium + Associates

CERN	IEIO
TUT	Finland
CEA	France
CNRS	France
KIT	Germany
TUD	Germany
INFN	Italy
UT	Netherlands
ALBA	Spain
CIEMAT	Spain
STFC	United Kingdom
UNILIV	United Kingdom
UOXF	United Kingdom
KEK	Japan
EPFL	Switzerland
UNIGE	Switzerland
NHFML-FSU	USA
BNL	USA
FNAL	USA
LBNL	USA



Consortium Beneficiaries, signing the Grant Agreement

PAUL SCHERRER INSTITUT

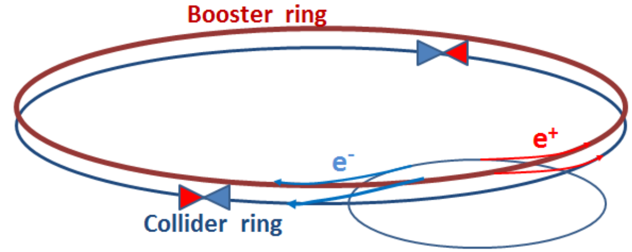
EPFL activities in EuroCirCol -Beam-beam interactions

- Will perform simulations of dynamic aperture and instabilites
  - Establish acceptable limits to beam-beam interaction(round beam / flat beam)
  - Investigate schemes to reduce impact of beam-beam interactions
    - Electron lenses, crab cavities...
  - Studies of beam-beam effects due to impedances and related instabilities

  Aim is to establish preferred beam currrents and crossing angles at the IPs.

- Linear and non-linear optics distortions due to BB (P. Gonzalves Jorge TPIV student X. Buffat and R. Tomas)
  - Dynamic beta effects: 1-2 IPs impact, benchmark of codes MADX + phase advance scans
  - Beta* impact and beating: beam dynamics and possible implication to collimation
- Long-Range Studies: Orbit Effects, Tune shift, Chromaticity (possible study with PhD student)
  - Different crossing schemes effects:
- Compensation Studies (wires, e-lenses, multipoles): PhD student to be hired asap
- Collective effects- Beam stability studies: Landau damping and interplay with impedance and e-cloud effects…

UniGE: High Luminosity Circular Colliders at the weak scale



LEP3 (2011) TLEP, CEPC (2012), FCC-ee (2014-)

100 TeV pp collider and High Luminosity 90-350 GeV e+e- collider form the core of the CERN FCC design study.

-- e+e- collider is potential first step (provides infrastructure and cryogenics for pp collider)

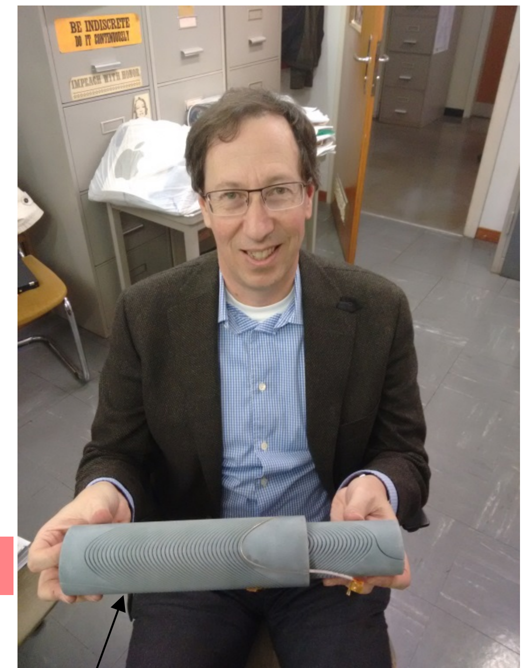
Unequalled luminosity from Z peak to top 5 10^{12}Z, 10^8 WW, 2.10^6 ZH, 10^6 $\bar{t}$ t events

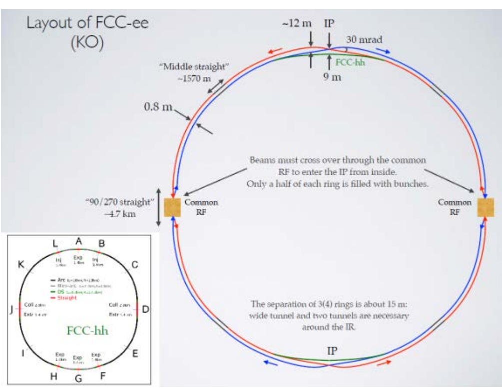
-- ΔE_{CM} <0.1MeV → precision Z mass (100 keV) and W mass (500 keV) etc…

-- new physics discovery in EW loops, top and Higgs

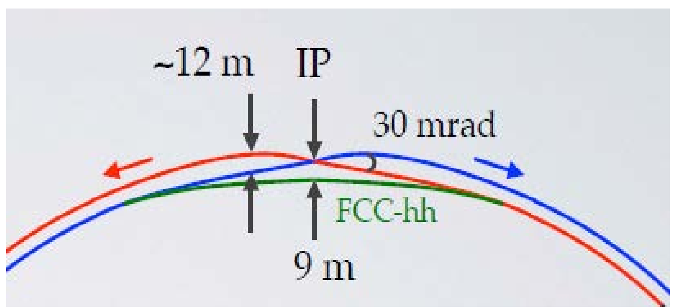
-- high statistics and clean environment: access to rare processes

ex: Z→ νN_{RH} to 10^{-12} , invisible H and Z decays, FCNCs etc.





The two machines fit in the same tunnel!



Asymmetric IR to cope with Synchrotron Radiation

@UniGe: Blondel: FCC coordination group and MDI/ experiment studies

Koratzinos: beam polarization for E_{CM} calibration and MDI (final focus quads --CCT design)

Robson: FCC software-infrastructure and simulations

With Basel (**Antusch, Fischer**), EPFL (**Shaposhnikov**) and Zürich(**Serra, Graverini**): right-handed neutrino studies

Group of Applied Superconductivity @ UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES

Prof. Carmine SENATORE *Département de Physique de la Matière Quantique & Département de Physique Appliquée - Université de Genève - Switzerland*

Advanced superconductors for accelerator applications

EuCARD² CAPACITIES

FP7 EuCARD-2 project - WP10 Future magnets

Development of the first High Temperature Superconductor (HTS) dipole magnet with accelerator field quality

EuroCirCol FCC hh ee he

H2020 EuroCirCol project – WP5 High-Field Accelerator Magnet Design

Innovative designs for future accelerator magnets to achieve high-quality fields up to 16 T in view of the 100 TeV energy frontier

CERN UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES

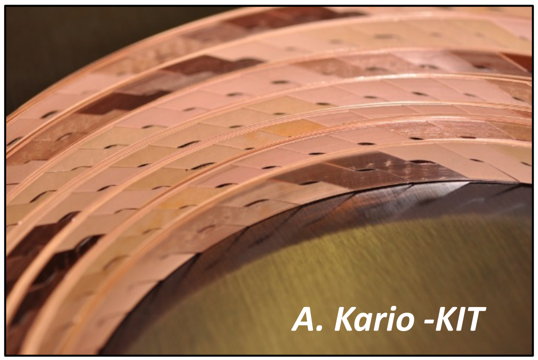
Collaboration agreement K2196/TE

A research program focused on development and characterization of new, advanced superconducting wires and cables for the high luminosity LHC

more info at http://dqmp.unige.ch/senatore/collaboration/

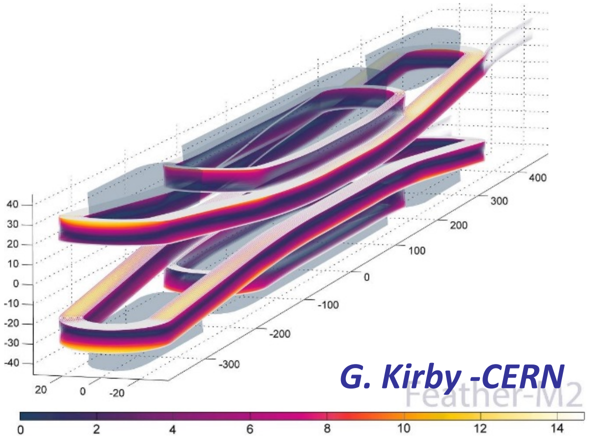
The path towards 20 T dipole magnets based on High Temperature Superconductors (HTS)

C. Senatore & L. Bottura @ WAMHTS-2



A collaboration of 7 European laboratories to produce 10 kA-20 T HTS cables for coil winding

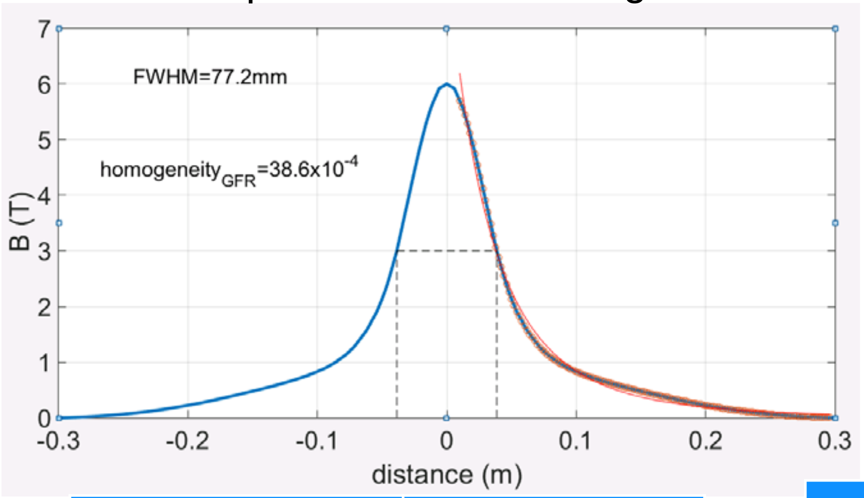
An activity at UNIGE focused on the improvement of the performance of HTS materials



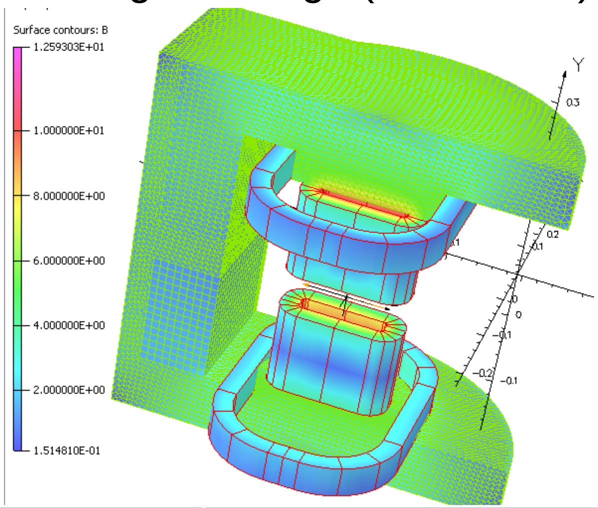
The goal to develop an accelerator-quality dipole demonstrator magnet based on HTS

6 T- Superbend for the SLS 2.0- Design

Field profile-from the design



Magnet design (OPERA3D)

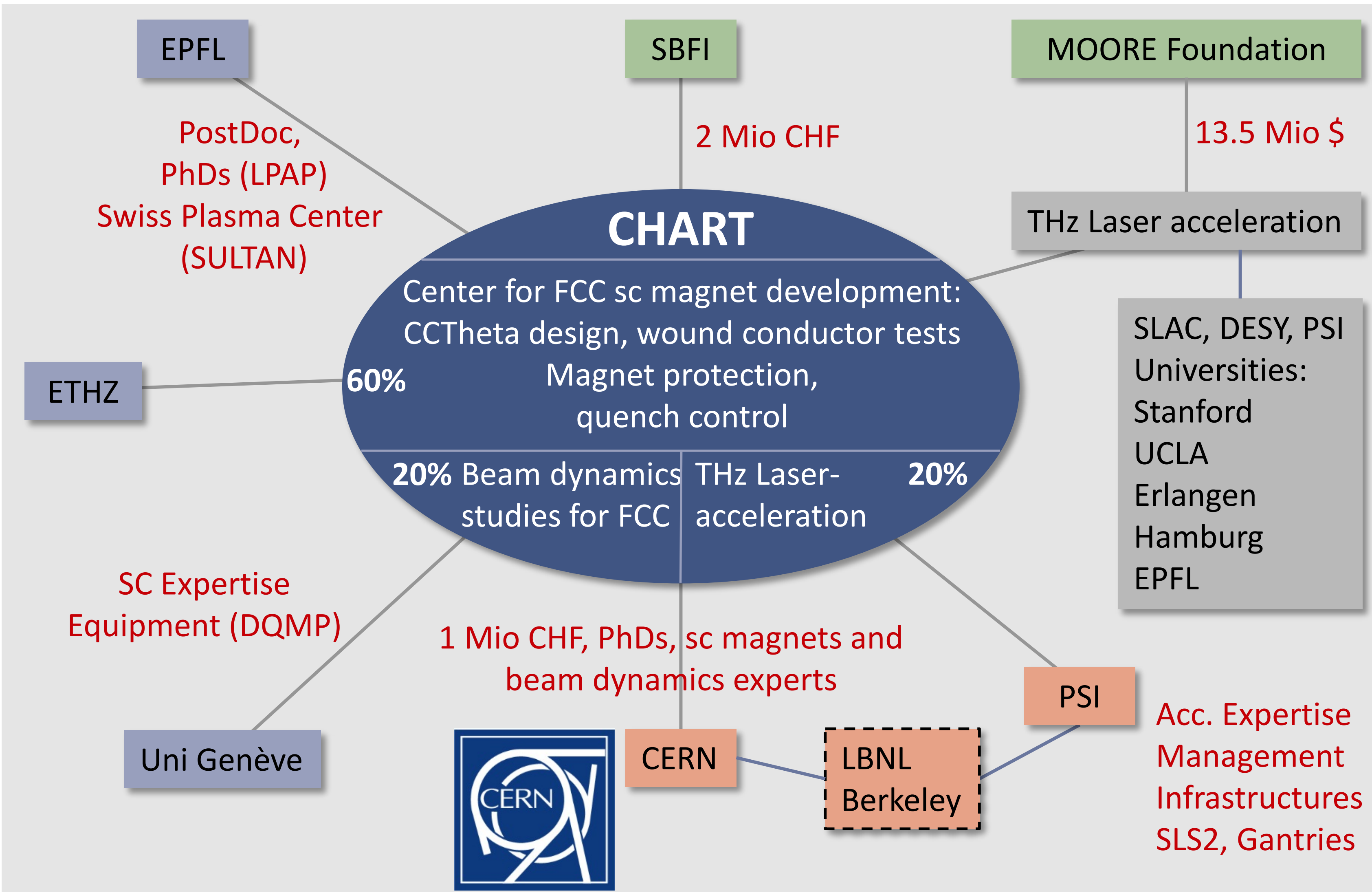


Specification	value
B_{peak}	≥ 5.0 T
FWHM	≤ 65 mm
GFR	6_H x 8_V mm^2
ΔB/B	≈$2x10^{-4}$

From A. Streun

Magnet parameters	value
Aperture	57 mm
B_{peak}	6 T
Tot. Magnetic energy	105 kJ
I_{op} Tot inner coils	1.12 MA
I_{op} Tot outer coils	0.23 MA
Cooling	Indirect (conduction)
T_{op}	4.5 K
Superconducting wires	Nb_3Sn

Swiss Center for Accelerator Research and Technology (CHART)



- In conclusion
  - I hope to have convinced you that there is a healthy and vibrant program of accelerator physics in Switzerland.
  - And that, even if it is not all centered on particle physics, much of it is.

Many thanks for your attention !

Many thanks for your attention

My thanks go to

- L. Rivkin
- F. Loehl
- R. Ischebeck
- M. Gaspar
- C. Senatore
- B. Keil
- M. Dehler
- S. Sanfilippo
- G. De Michele
- S. Bettoni / E. Prat