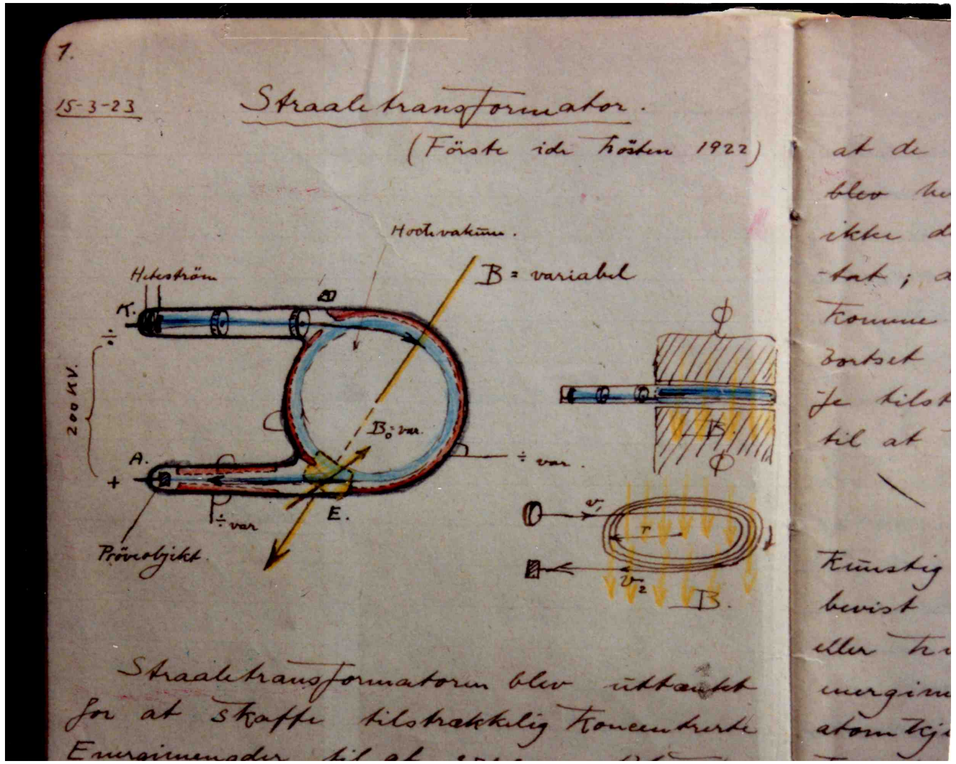
Accelerators: instruments for science and industry

Lenny Rivkin, EPFL & PSI

PAUL SCHERRER INSTITUT

Swiss Physical Society Annual Meeting, Geneva, August 23, 2017

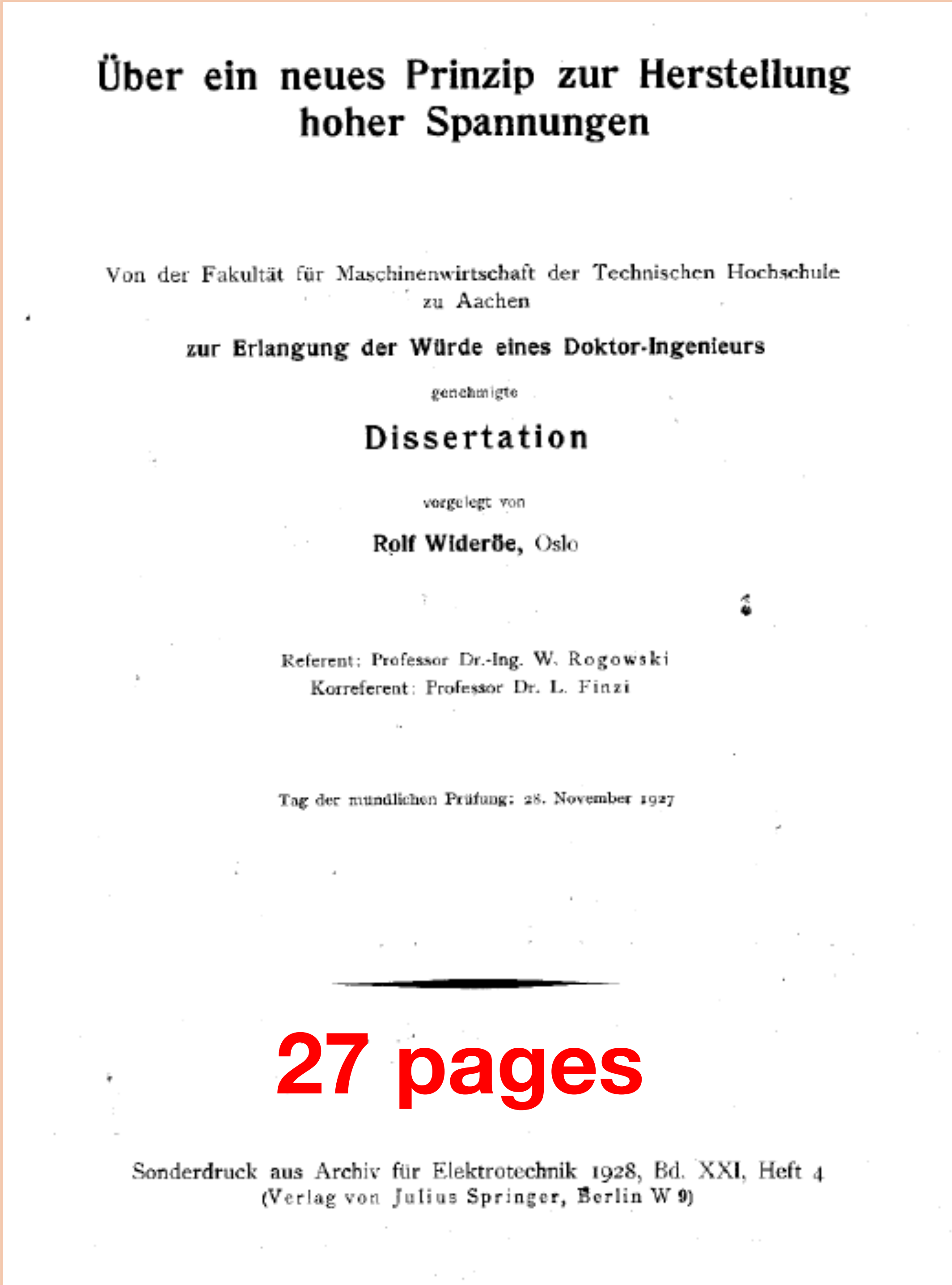
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE



90 years of RF accelerators

Symposium on 6 September, 2017
at the Technical University Aachen
celebrating 1927 PhD thesis of **Rolf Widerøe**

https://90years-rf-accelerators.de/



Über ein neues Prinzip zur Herstellung hoher Spannungen

Von der Fakultät für Maschinenwirtschaft der Technischen Hochschule zu Aachen

zur Erlangung der Würde eines Doktor-Ingenieurs

genehmigte

Dissertation

vorgelegt von

Rolf Wideröe, Oslo

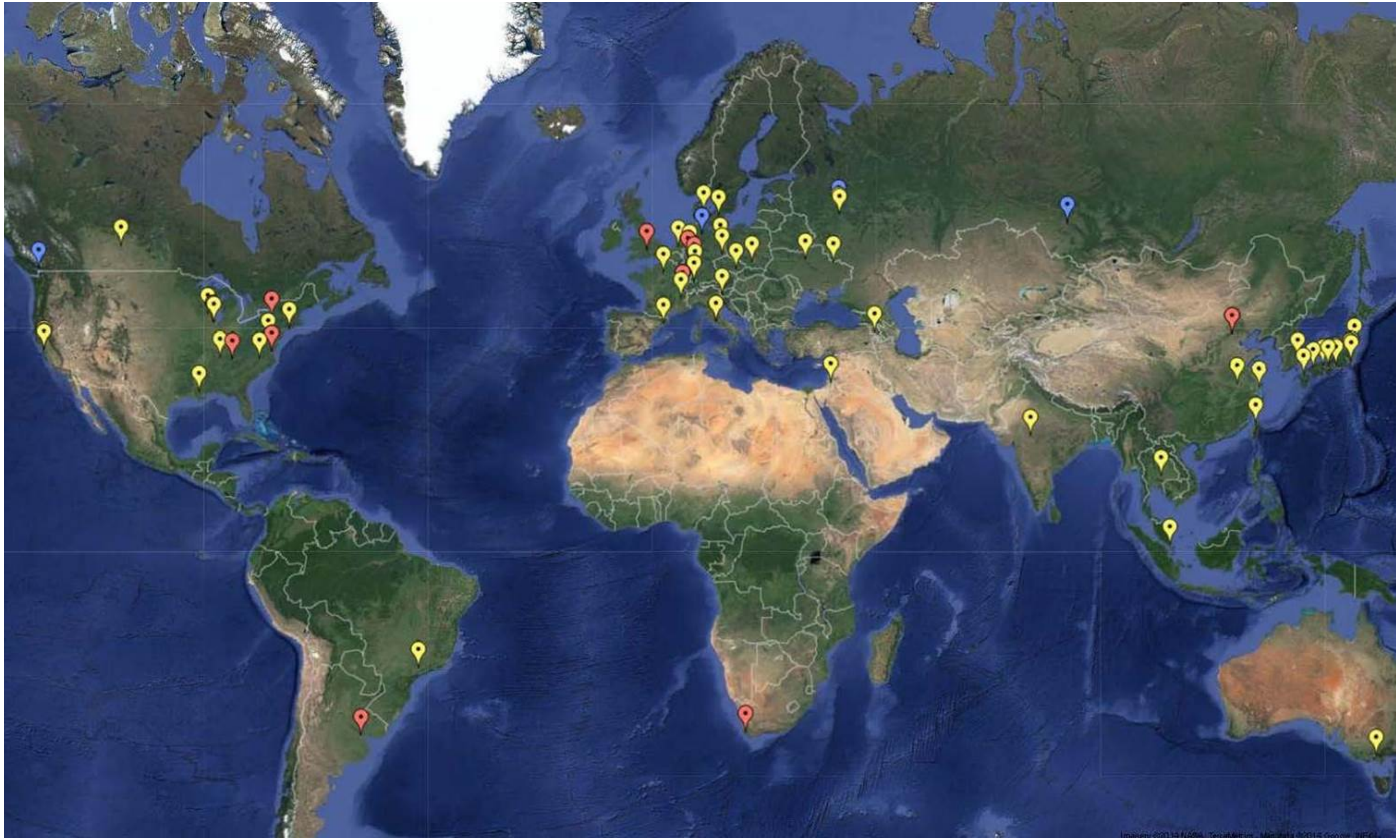
Referent: Professor Dr.-Ing. W. Rogowski
Korreferent: Professor Dr. L. Finzi

Tag der mündlichen Prüfung: 28. November 1927

Sonderdruck aus Archiv für Elektrotechnik 1928, Bd. XXI, Heft 4
(Verlag von Julius Springer, Berlin W 9)

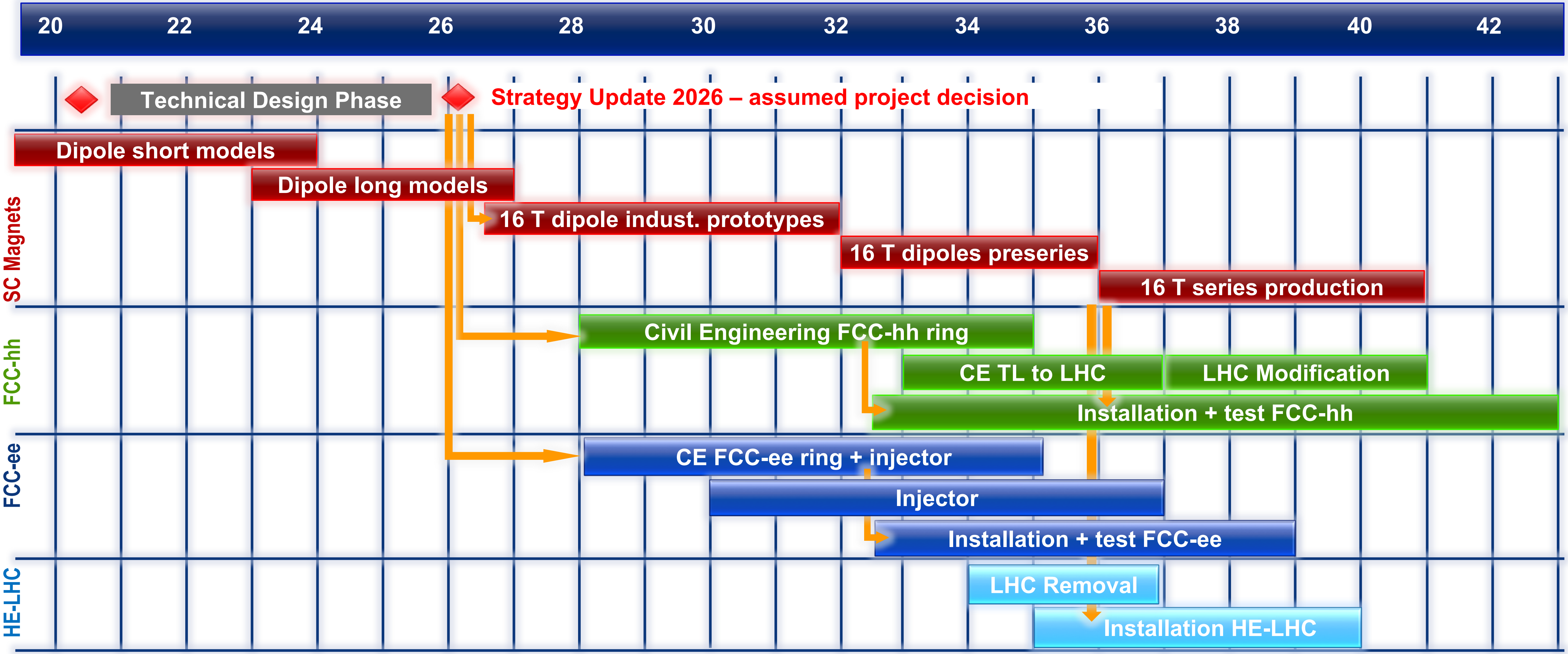
27 pages

World of Accelerators



High energy particle physics

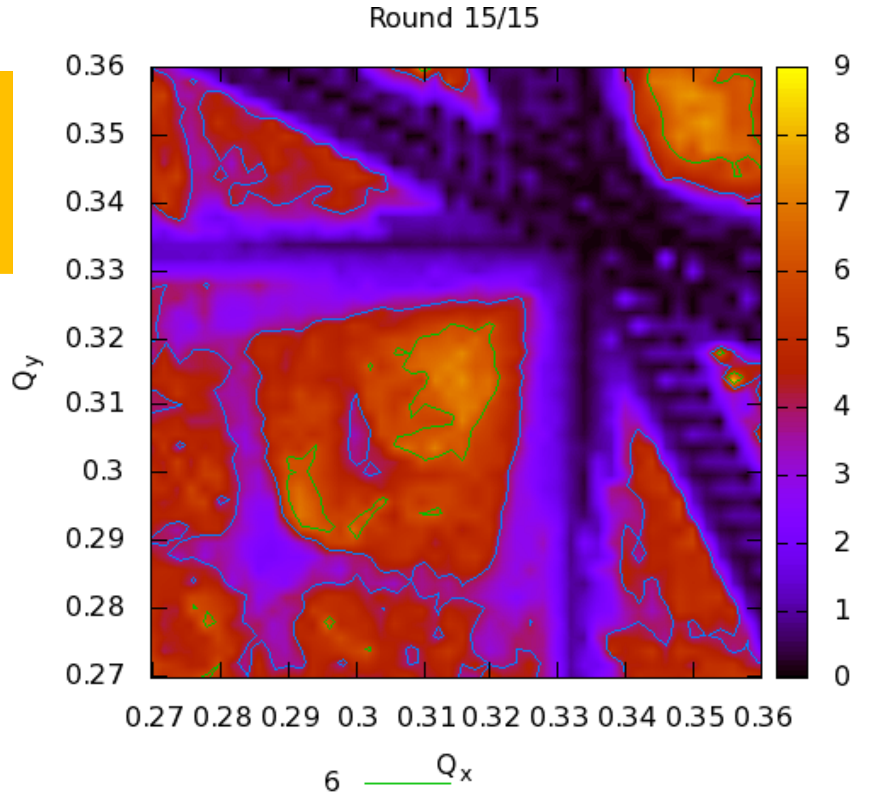
Draft Schedule Considerations

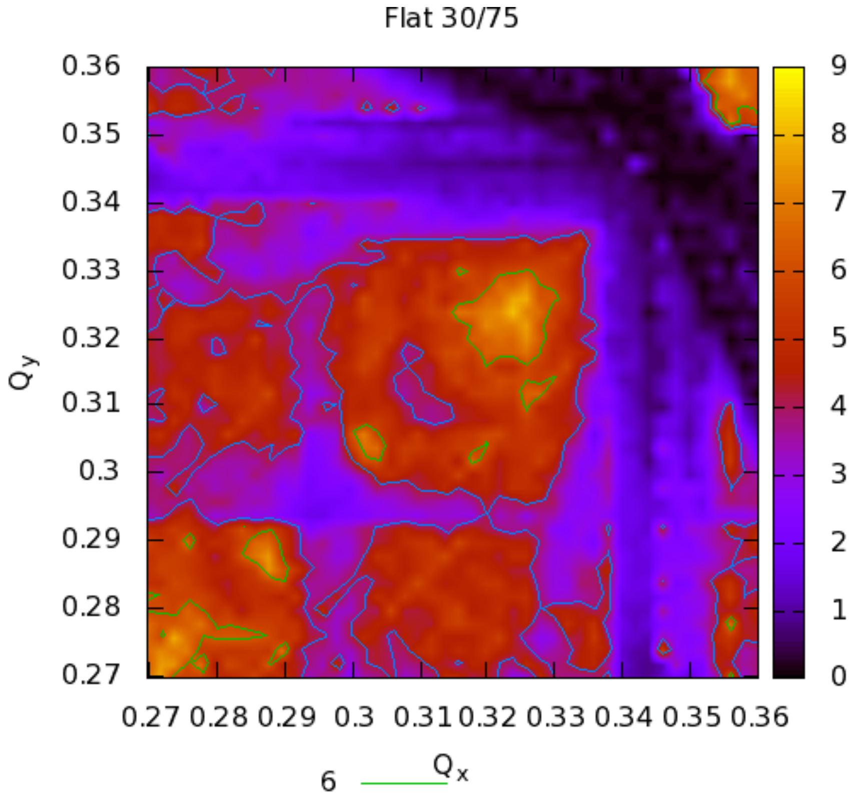


Beam stability studies for the LHC, HL-LHC, HE-LHC and FCC

Flat vs round beams tune space

336
T. Pieloni





447
P. Gonçalves

332
J. Barranco

334
L. Mether

452
C. Tambasco

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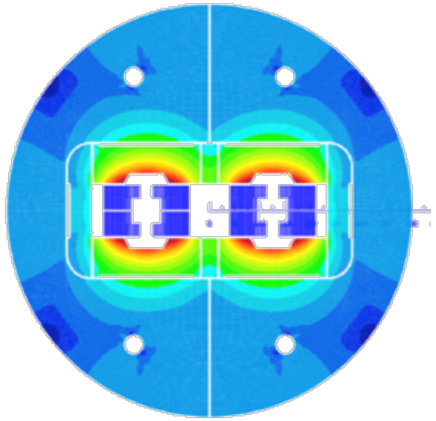
16 Tesla magnet R&D for FCC

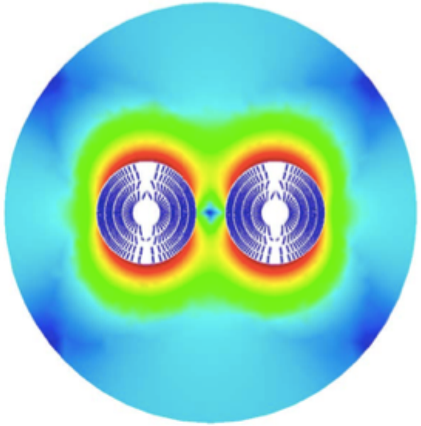
333
B. Auchmann

Block coil



cea

Canted Cosine Theta



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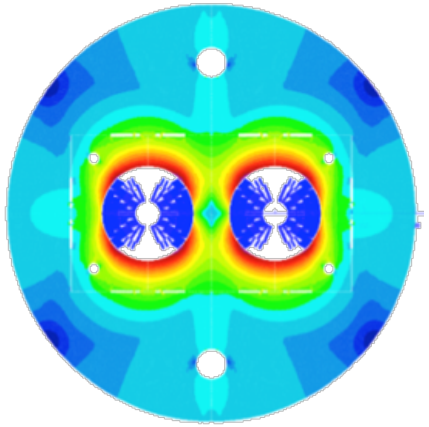
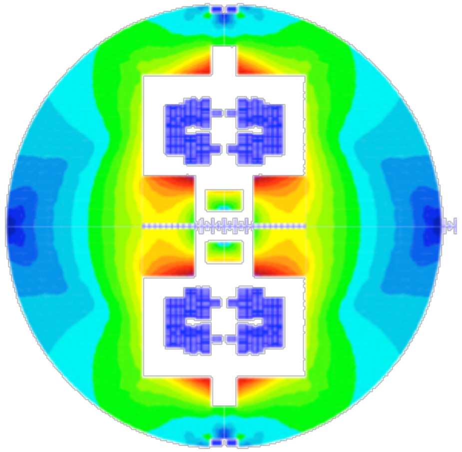
PSI

Cos-theta



INFN
Istituto Nazionale di Fisica Nucleare

Common coils



GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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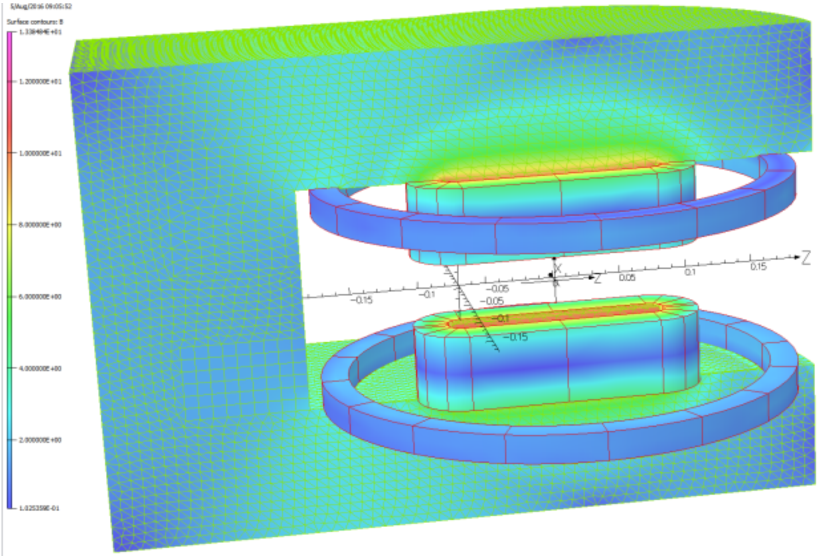
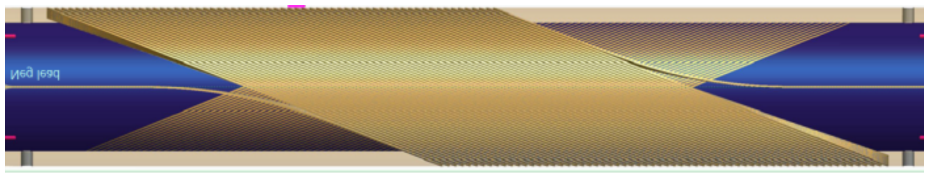
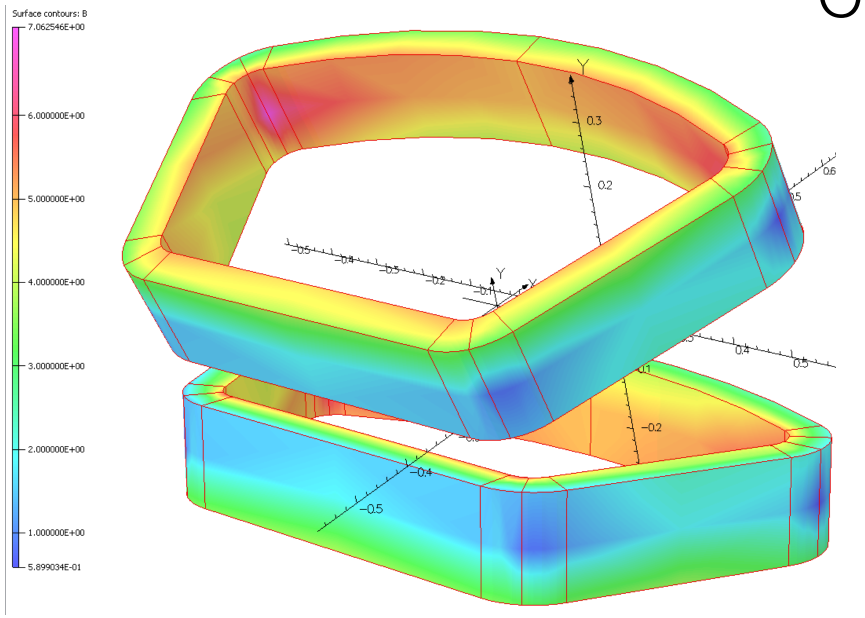
High field magnets for HEP, medicine and light sources



SLS 2 Superbend
(2015-2018)

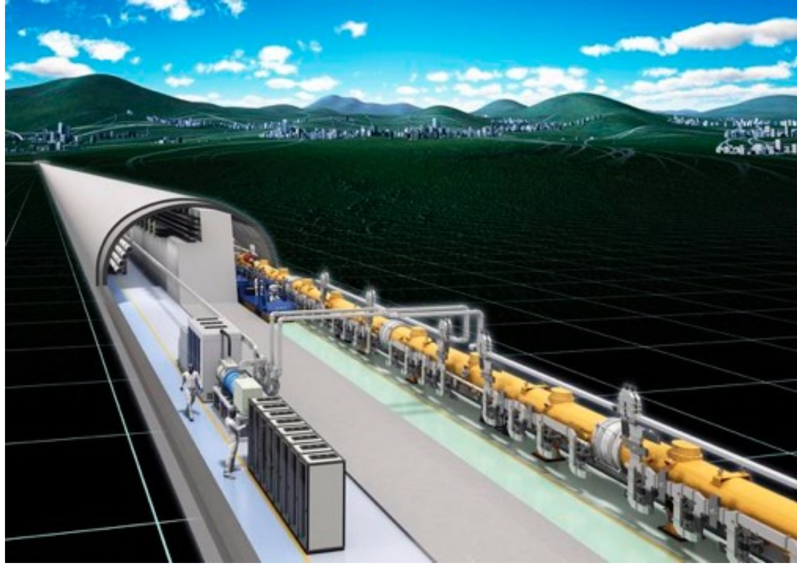


16 T Dipole magnet for the Future Circular Collider
(2016-2019)



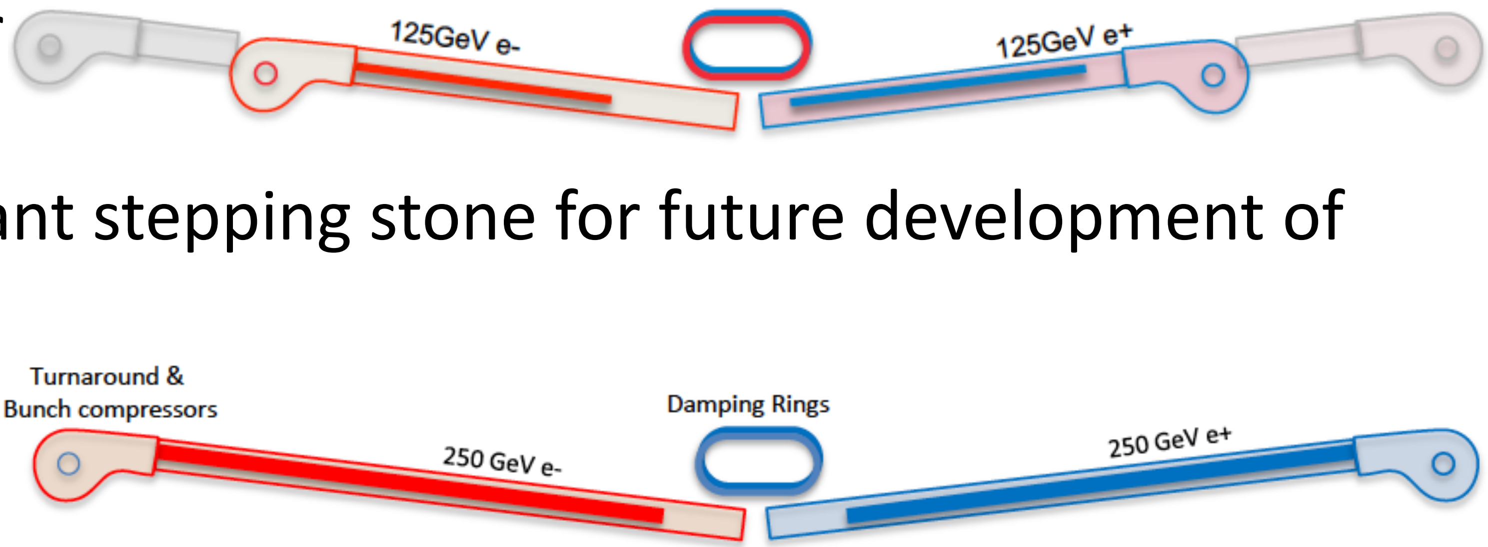
Superconducting dipole for gantry
(2015-2019)

ILC



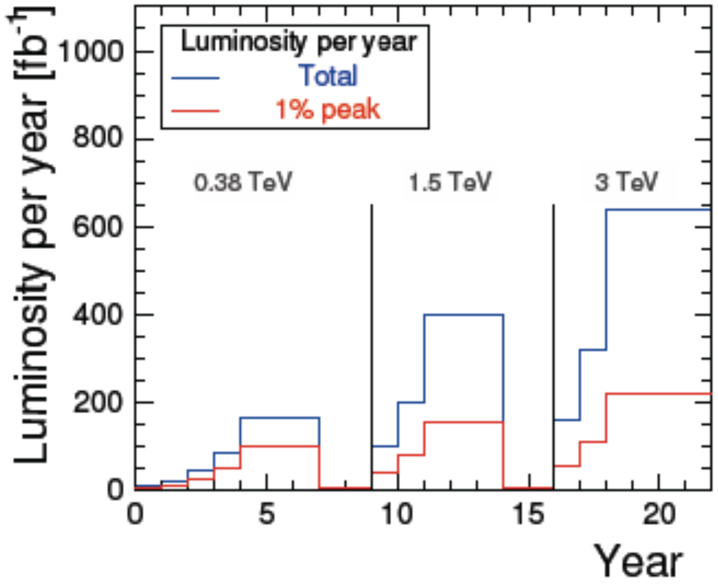
- ILC TDR describes 500 GeV machine
- LCC Physics and Detector Group and JAHEP study: compelling physics case for 250 GeV ILC

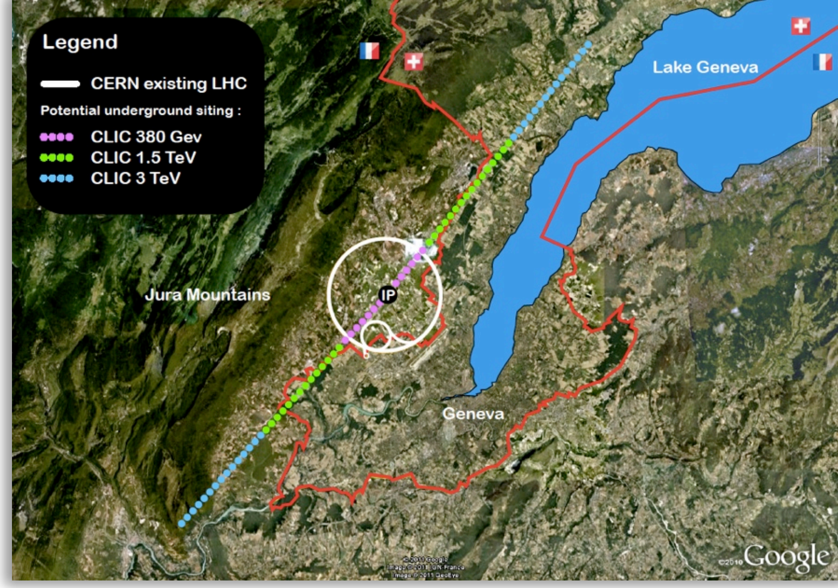
- Starting with a 250 GeV Higgs factory + cavity R&D could allow for 40% lower cost than TDR
- The energy of a linear collider can be increased
- 250 GeV would be an important stepping stone for future development of the linear collider technology



CLIC

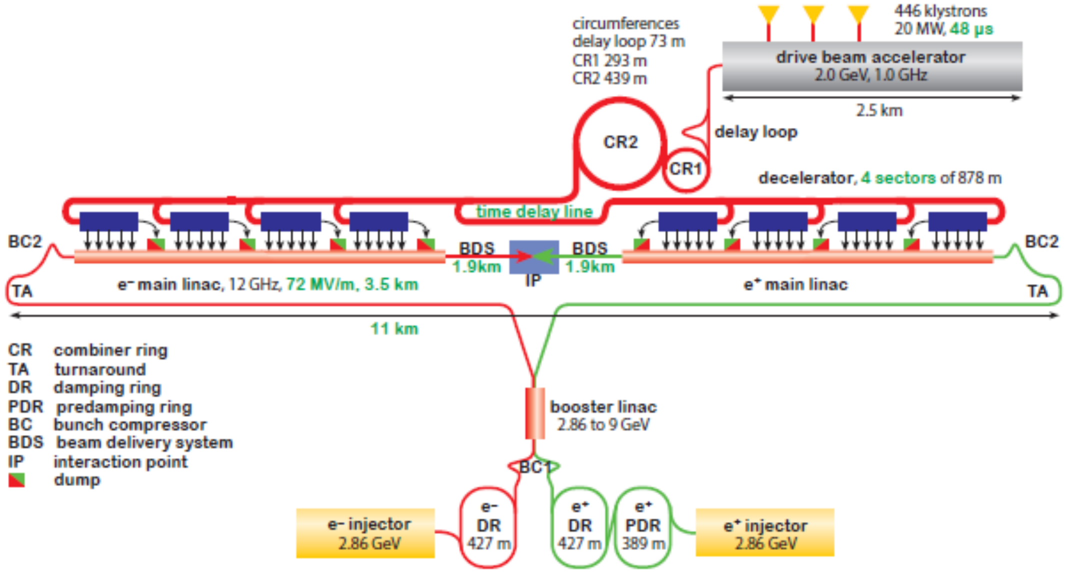
Accelerator collaboration with ~50 institutes
Detector collaboration with ~29 institutes





Under study is also klystron based machine for initial stage

Parameter	Unit	380 GeV	3 TeV
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of √s	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100
Site length	km	11	50



Intensity Frontier

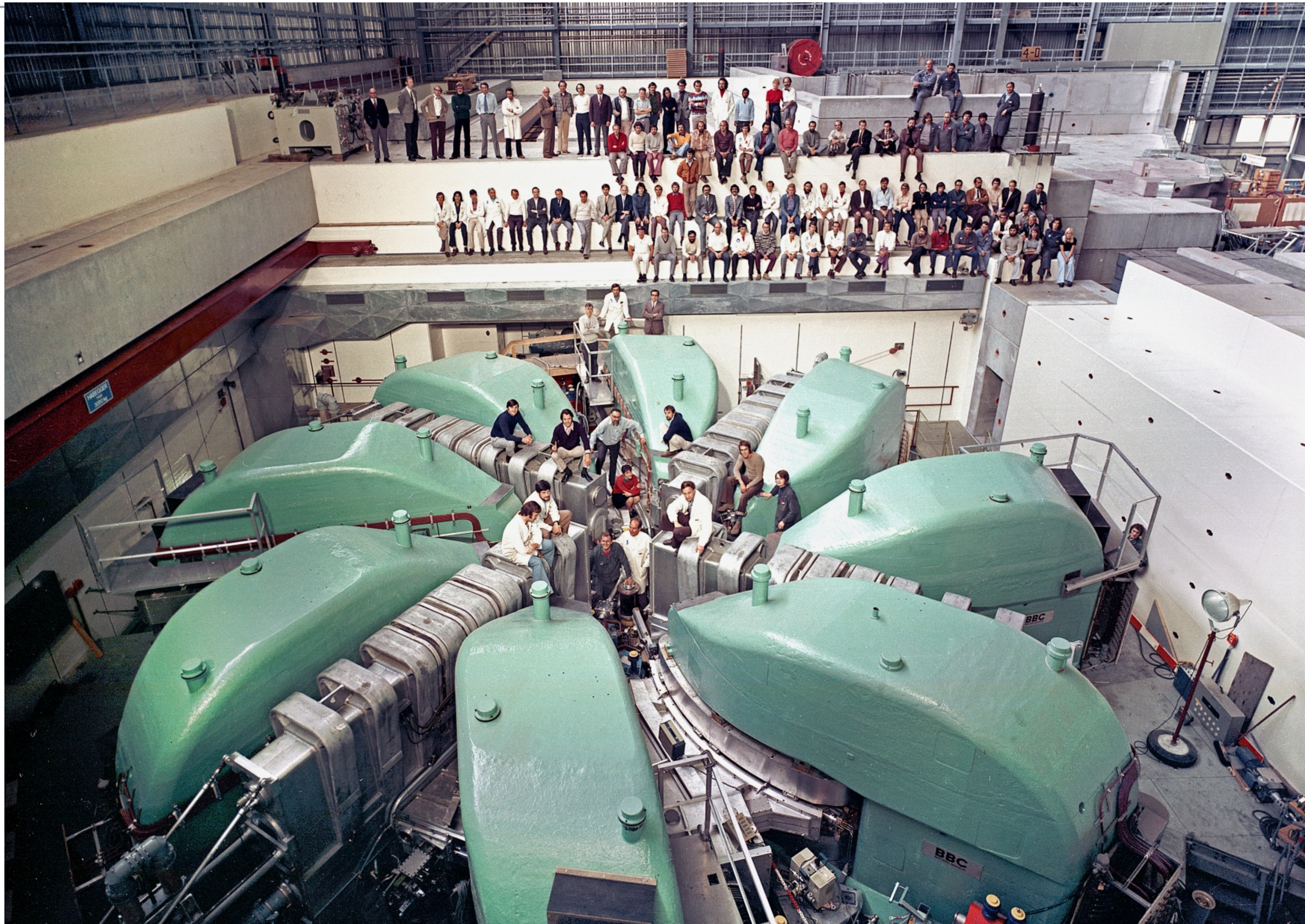
PSI Ring Cyclotron in 1973 planned for 100 μA

590 MeV proton cyclotron was planned for **100 μA**

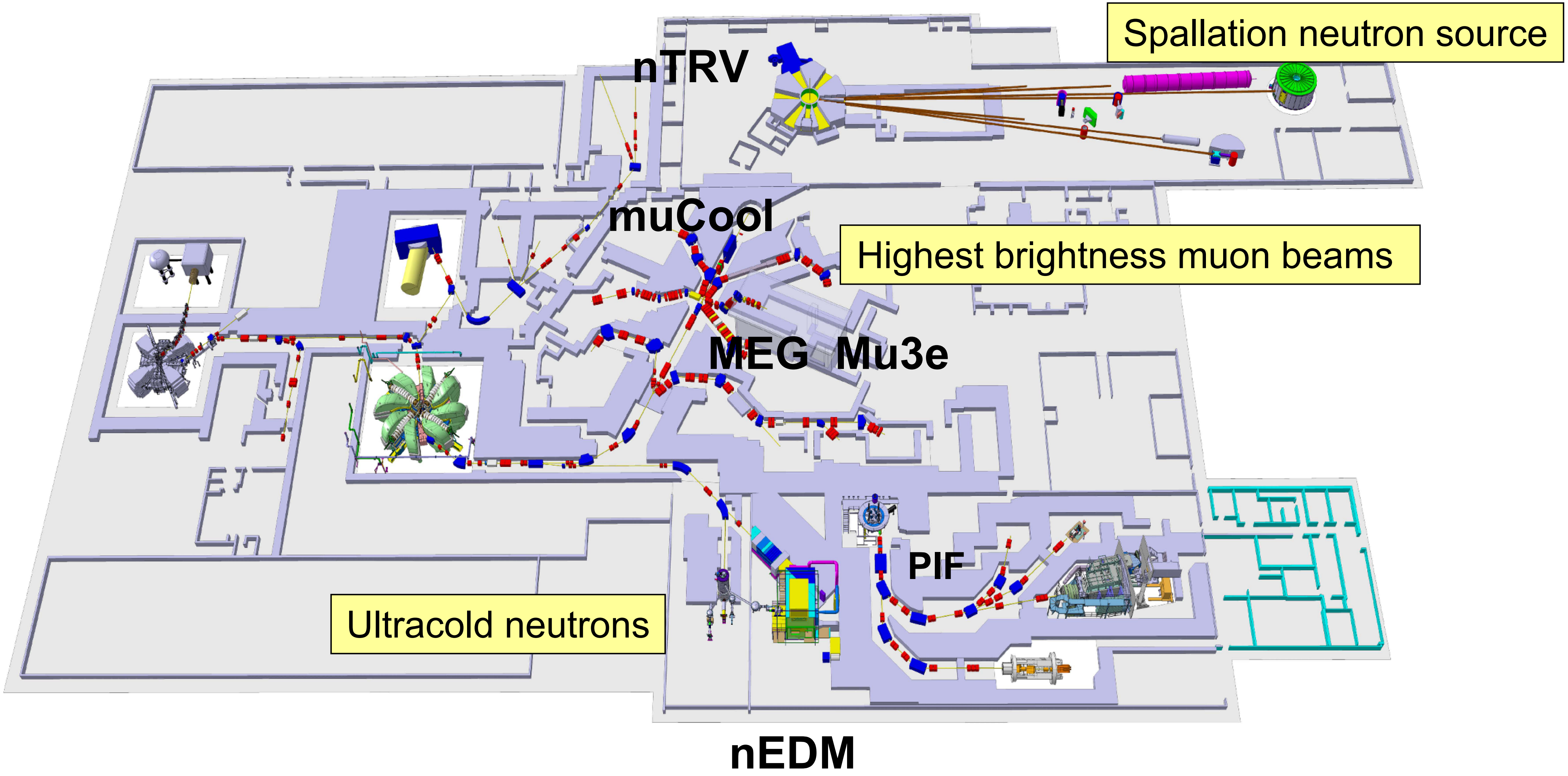
Today **2400 μA**

or

1.4 MW beam power



High intensity accelerators for research and industry



High intensity frontier: essential to have low beam losses

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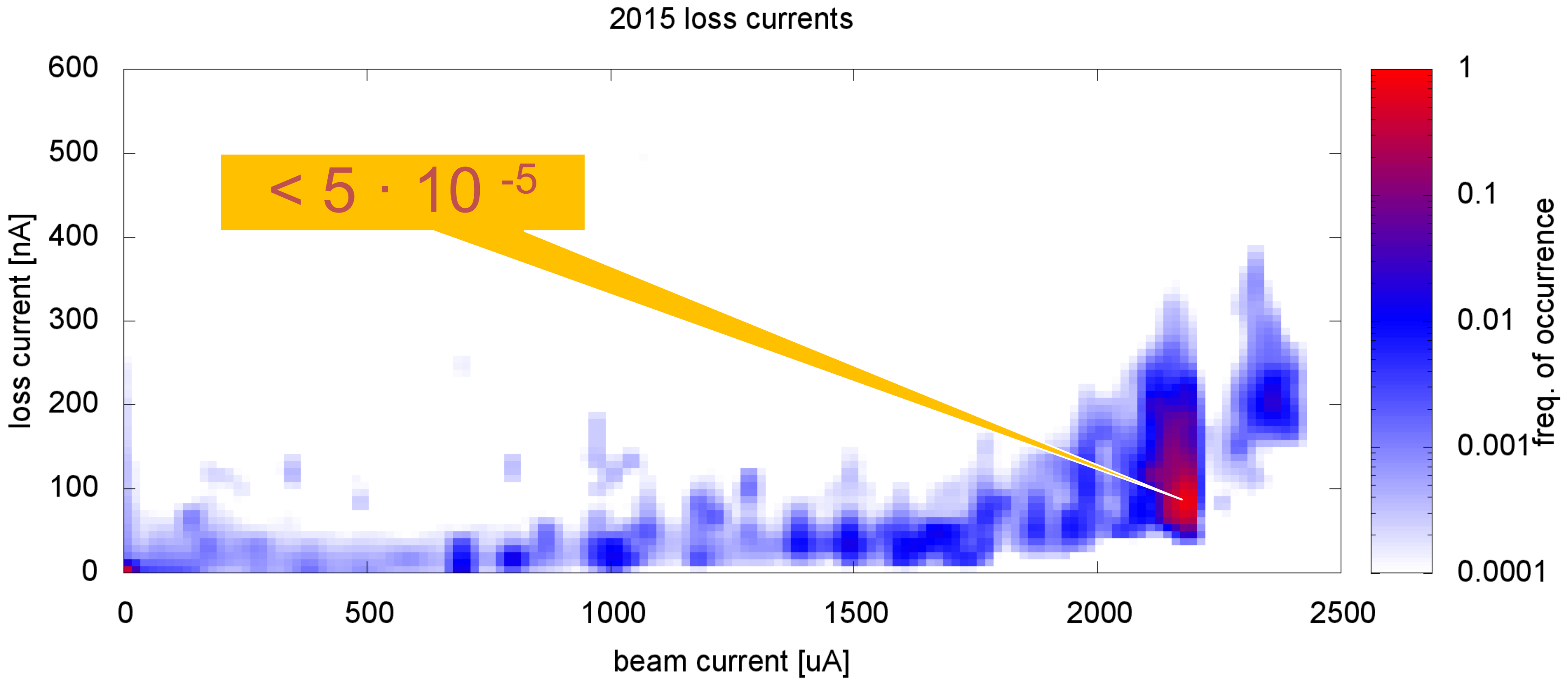
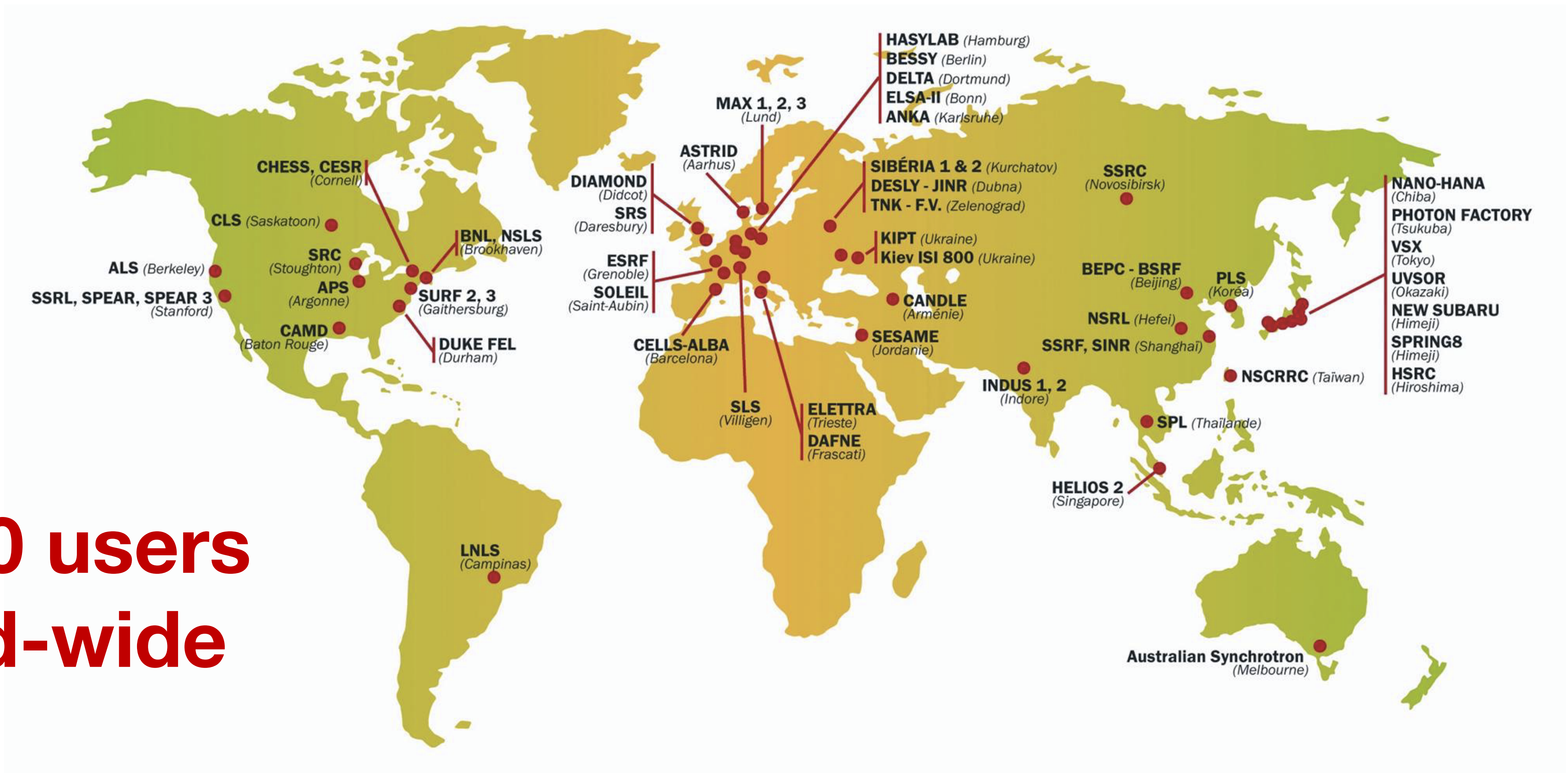
Frequency of operation at certain level of beam losses

+ reliability increases to over 90 %



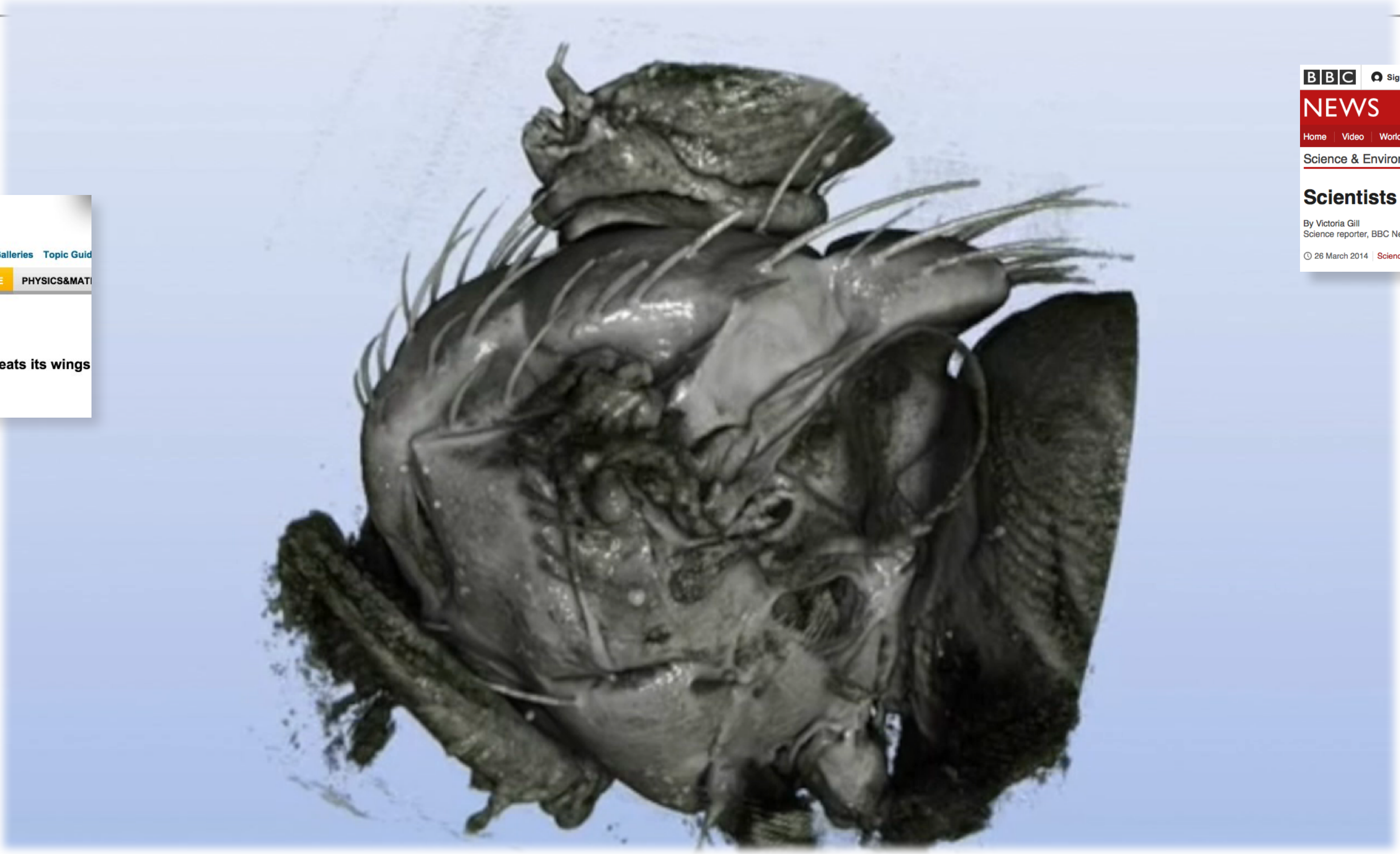
Synchrotron Light Sources

Synchrotron Light Sources: about 50 storage ring based



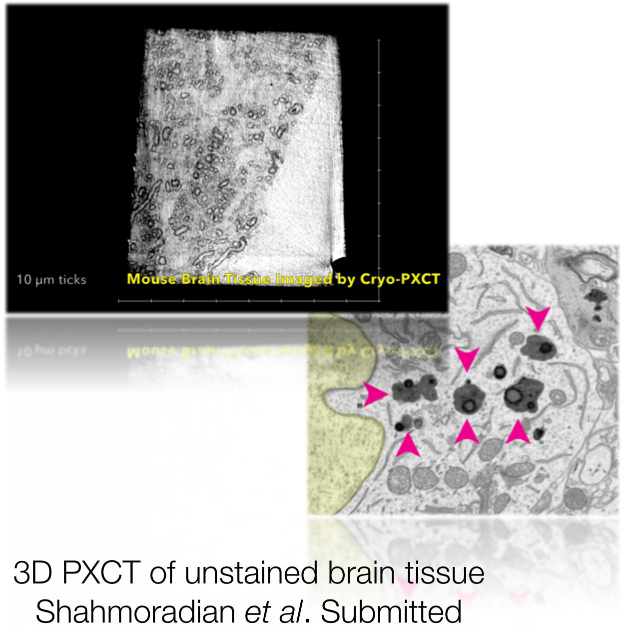
60‘000 users world-wide

Muscles and tracheal network *during* flight

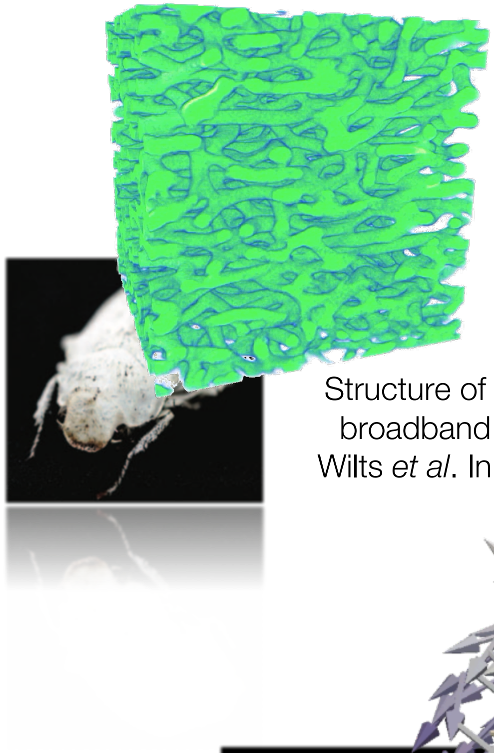


R. Mokso *et al.*, Scientific Reports **5** 8727 (2015)

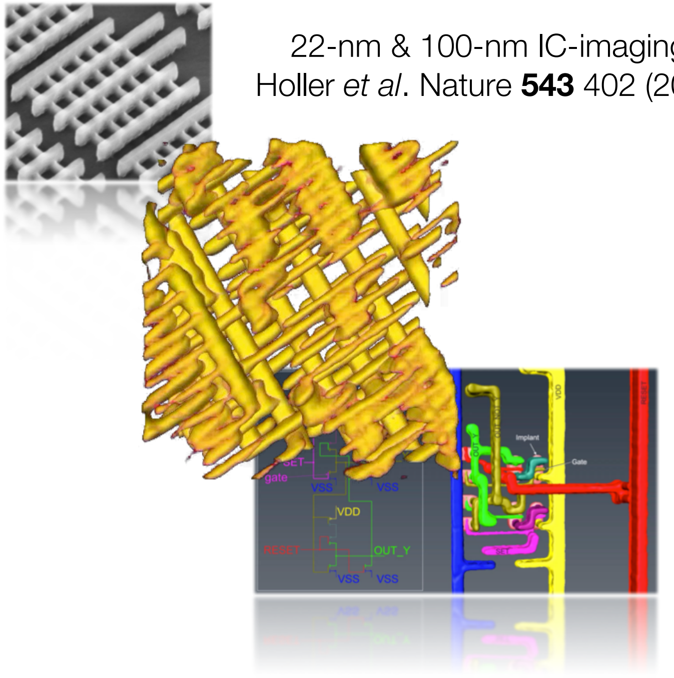
Ptychography applications



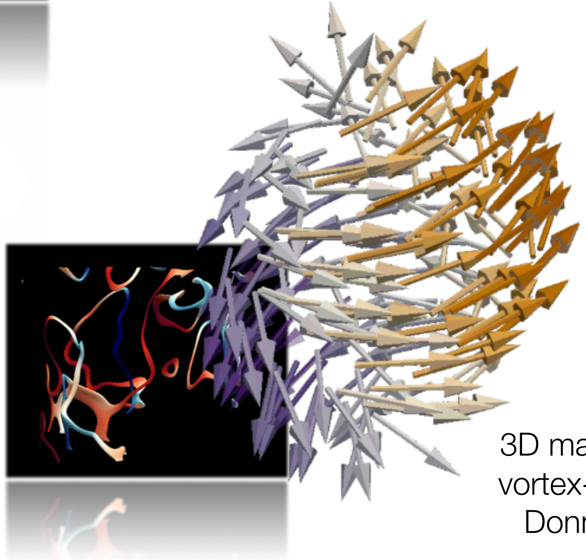
3D PXCT of unstained brain tissue
Shahmoradian *et al*. Submitted



Structure of disordered broadband scatterers
Wilts *et al*. In preparation



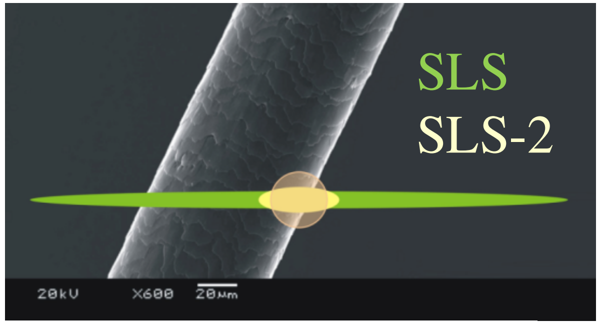
22-nm & 100-nm IC-imaging
Holler *et al*. Nature **543** 402 (2017)

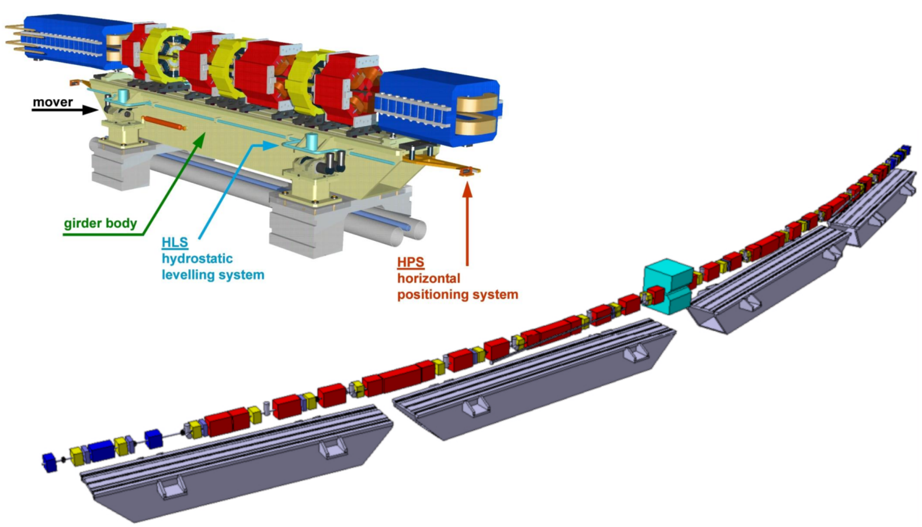


3D magnetic vector PXCT of vortex-antivortex interactions
Donnelly *et al*. Submitted

Next generation of diffraction limited storage ring based sources

Two orders of magnitude increase in source brightness: needed for the flagship applications like ptychography





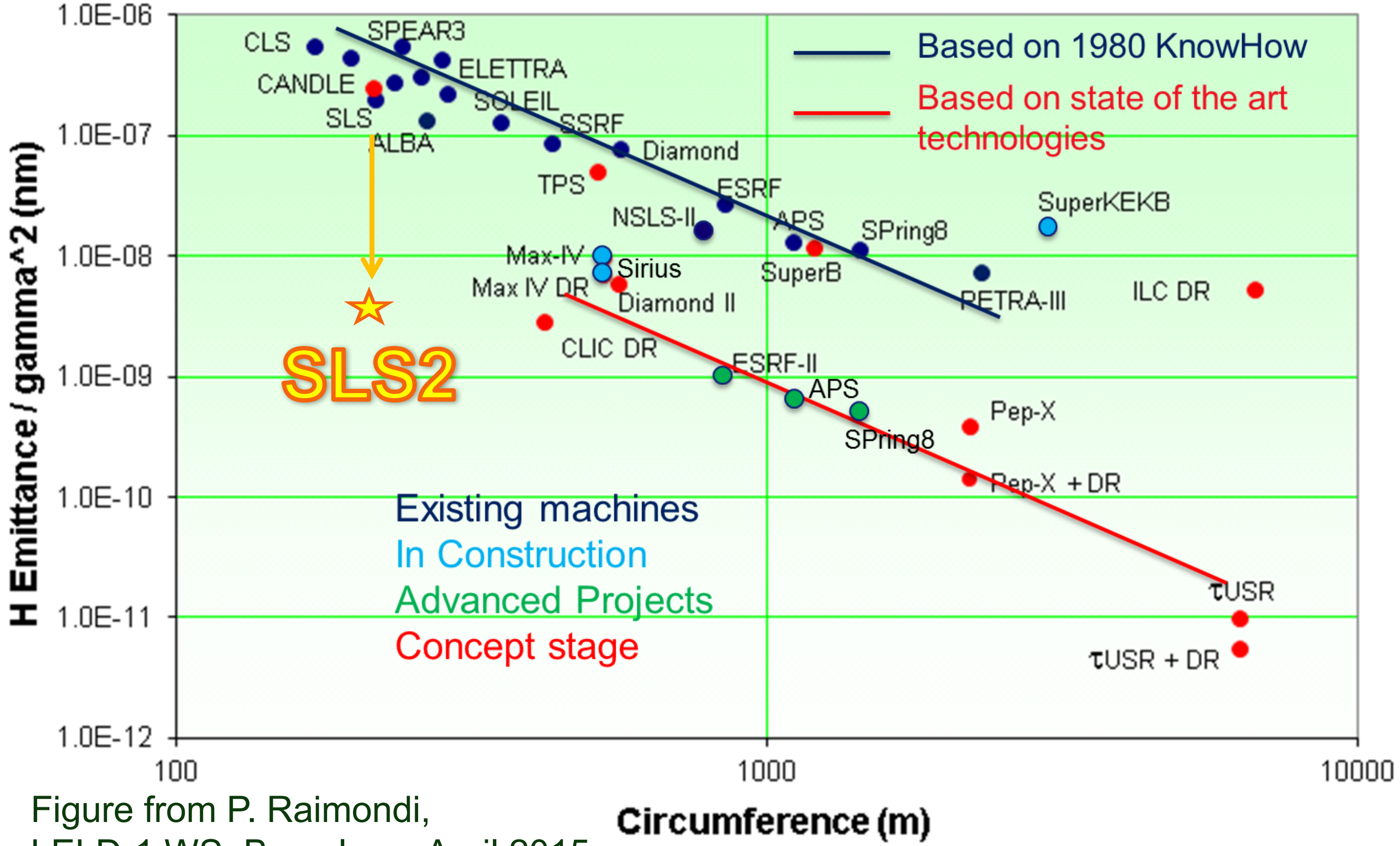


Figure from P. Raimondi, LELD-1 WS, Barcelona, April 2015

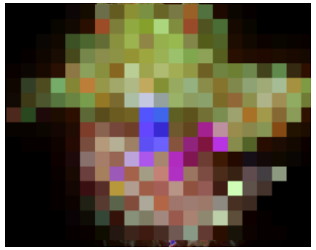
SwissFEL – a new accelerator based Research Infrastructure

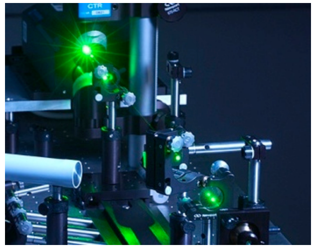
3rd gen. synchrotron

fine, slow

optical lasers

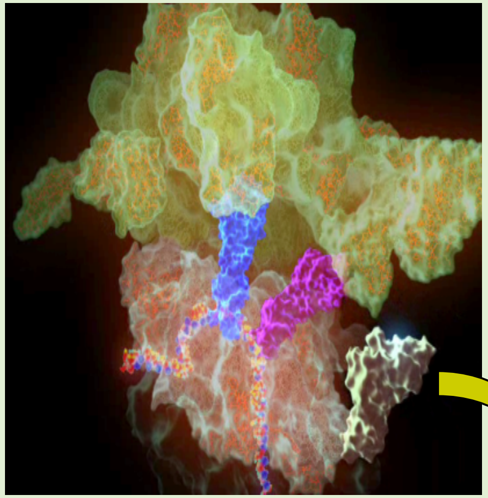
fast, coarse

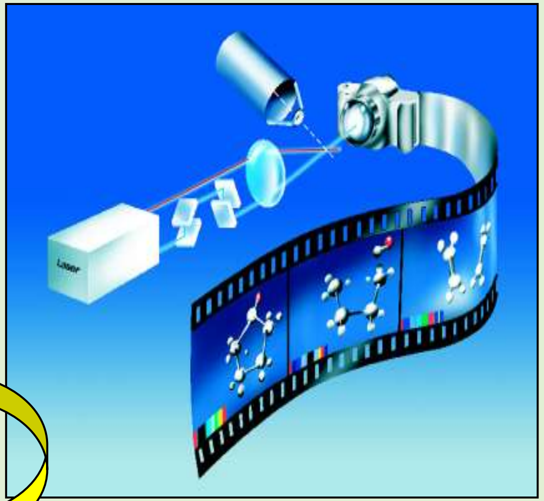




701 -- 718 SwissFEL

SwissFEL fine **and** fast
at extreme high intensity





new direct insights into chemical, physical, biological mechanisms governing our daily-life

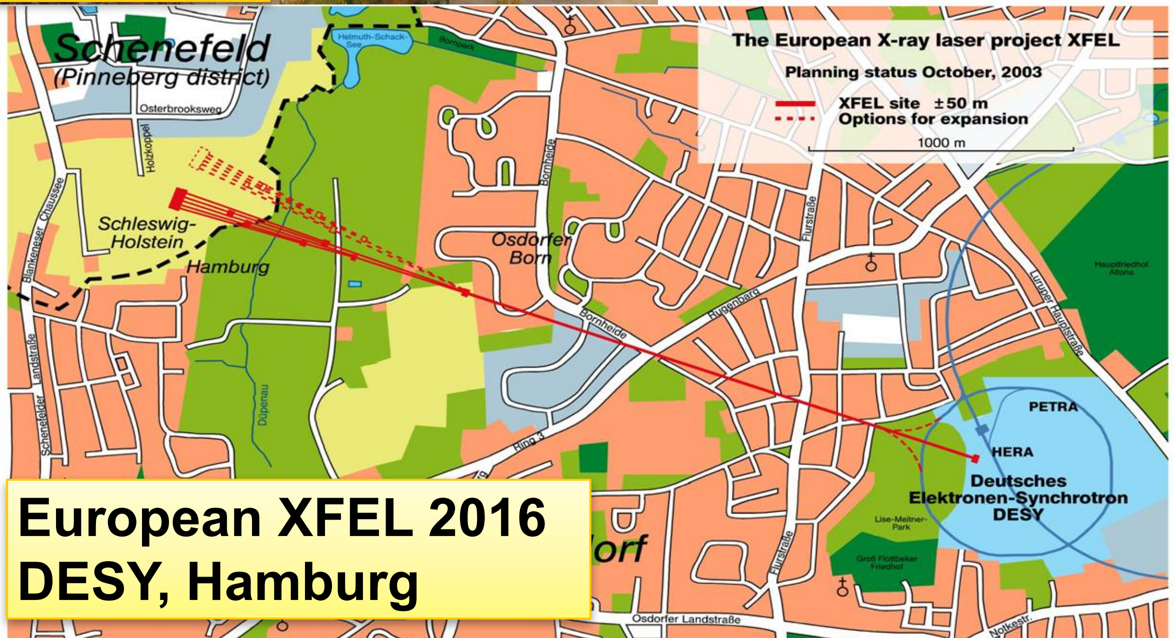
X-Ray Free Electron Lasers

PAL XFEL 2016

SwissFEL 2017

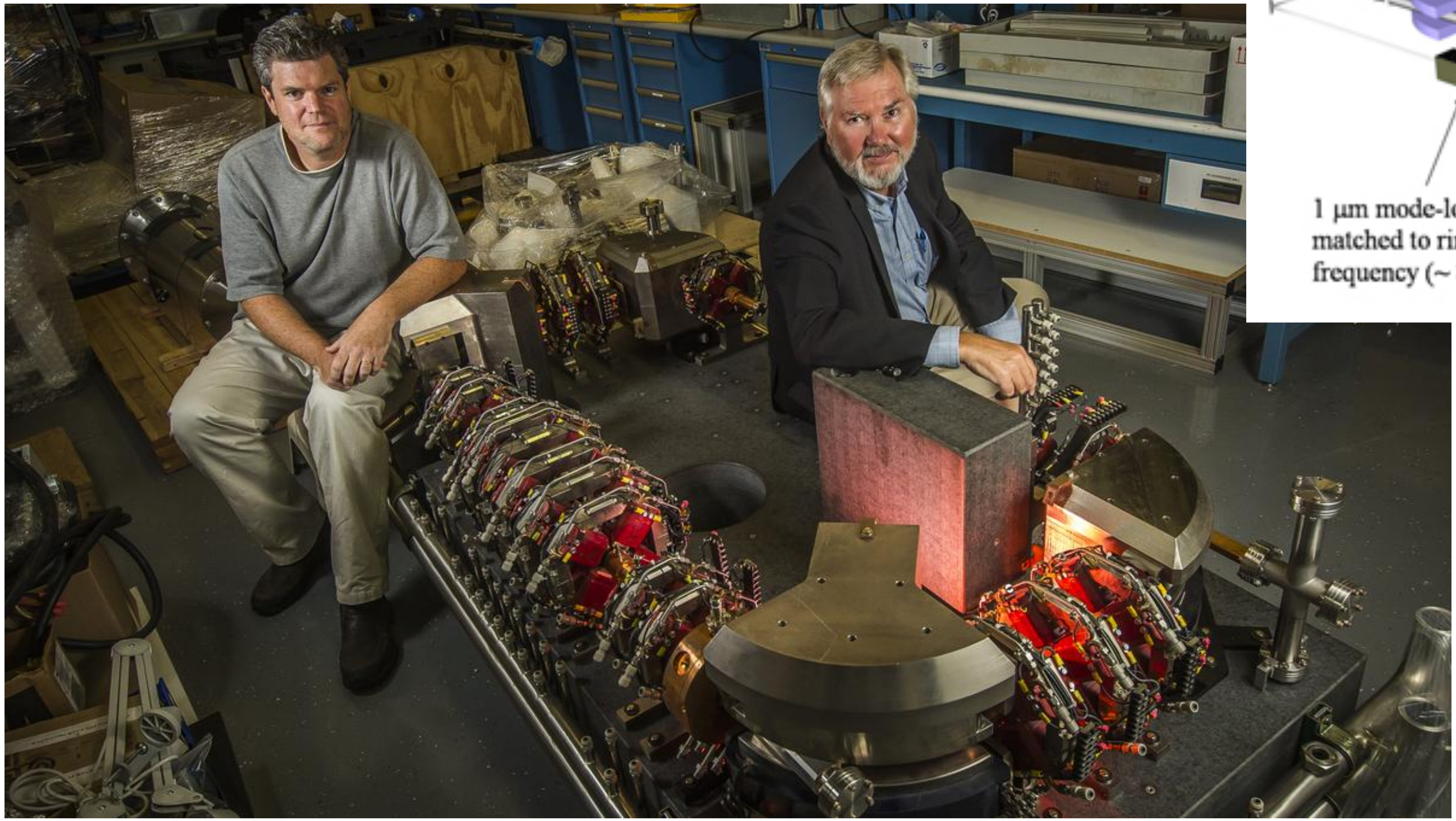
LCLS I, II 2009, 2019

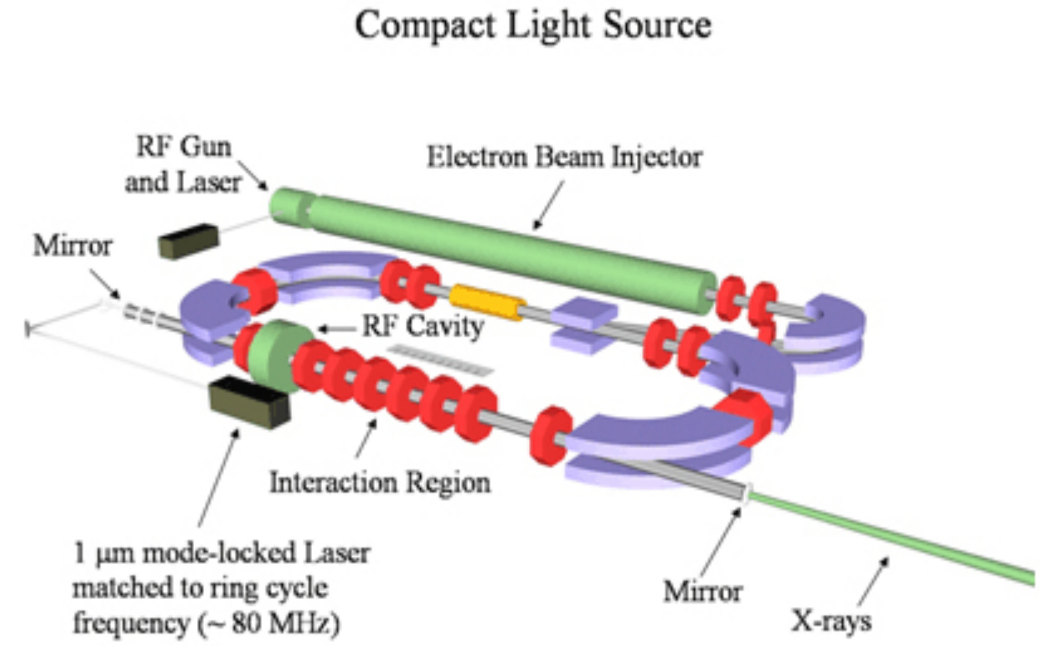
SACLA 2011
8.5 GeV, 60 Hz NC



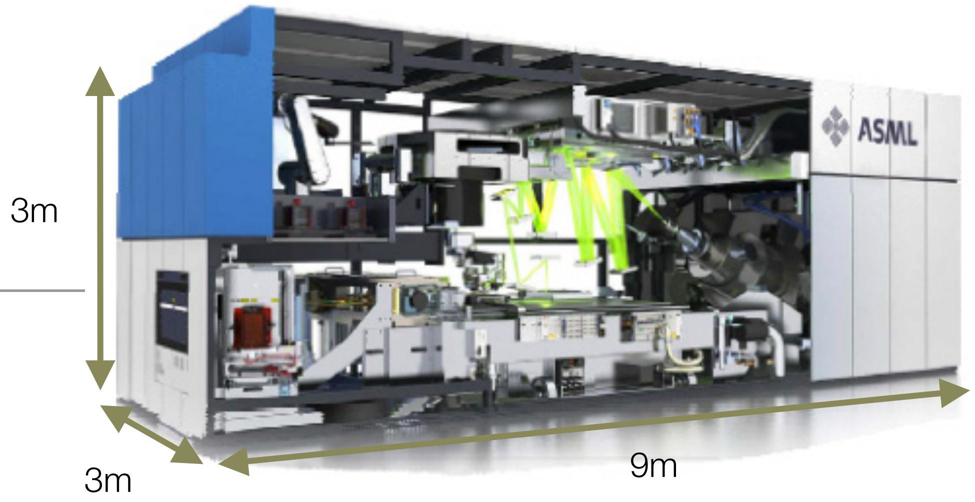
European XFEL 2016
DESY, Hamburg

Compact light sources based on Compton scattering

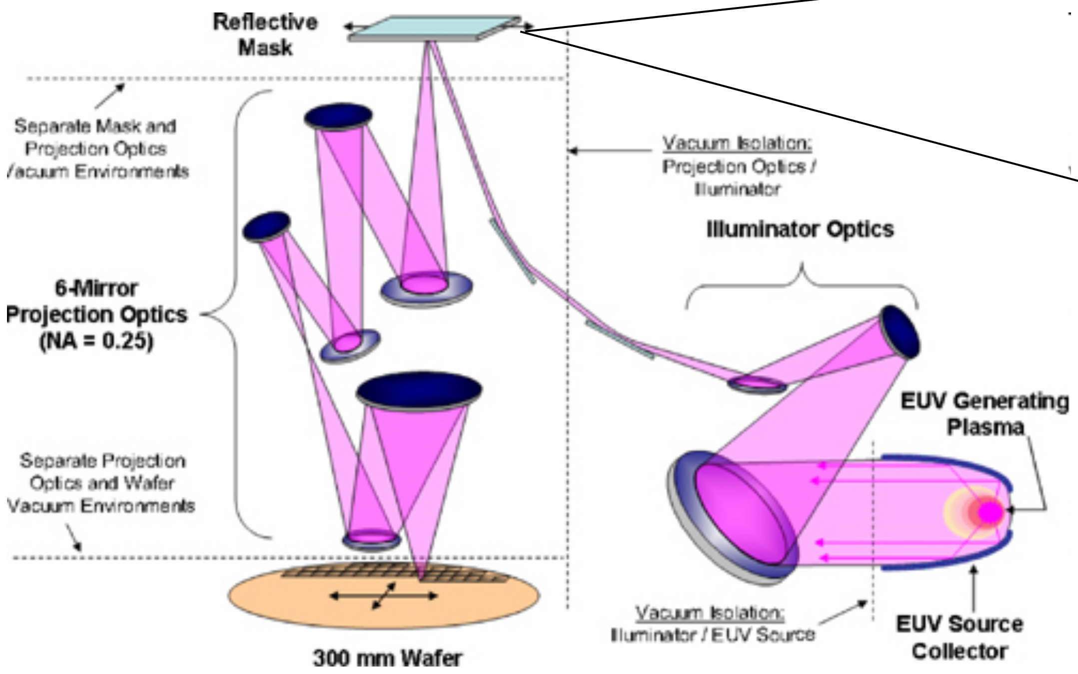


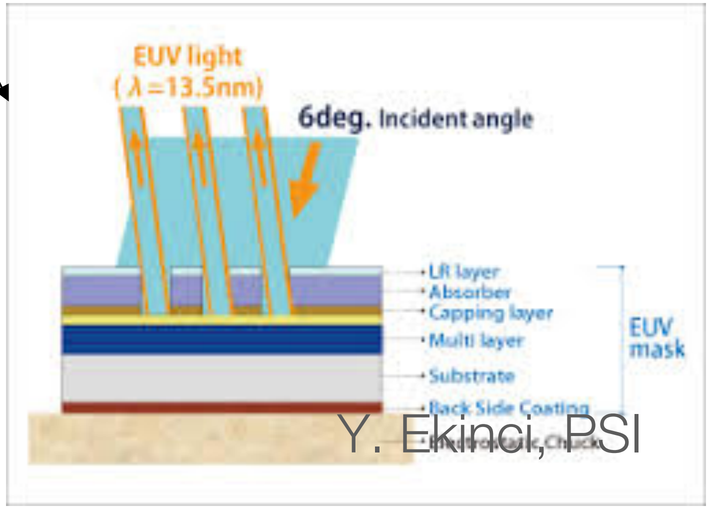


The Problem: EUV Lithography needs mask inspection



- Chip production using Extreme UV radiation (EUV, λ=13,5nm) for lithography to follow Moore's law.
- EUV lithography: Planned for HVM production in 2019
- All reflective optics and mask, plasma source
- Conventional photomask inspection does not work for EUV masks
- Finding the elusive defects on the mask is a big problem



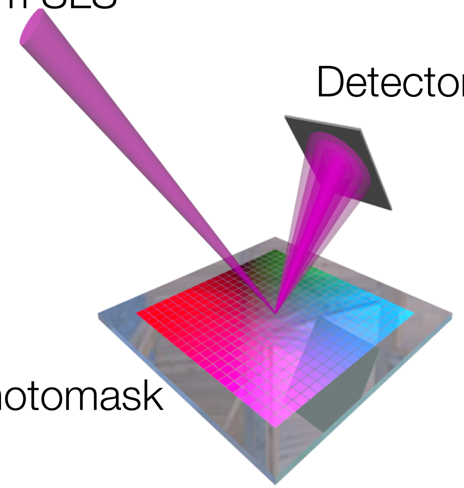


Y. Ekinci, PSI

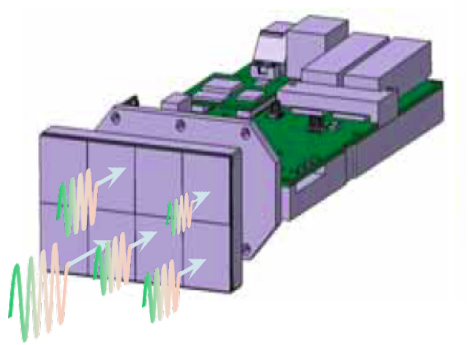
RESCAN project
Lensless EUV mask inspection tool for semiconductor industry

Required is:

1. **Experience in EUV coherent scattering microscopy**

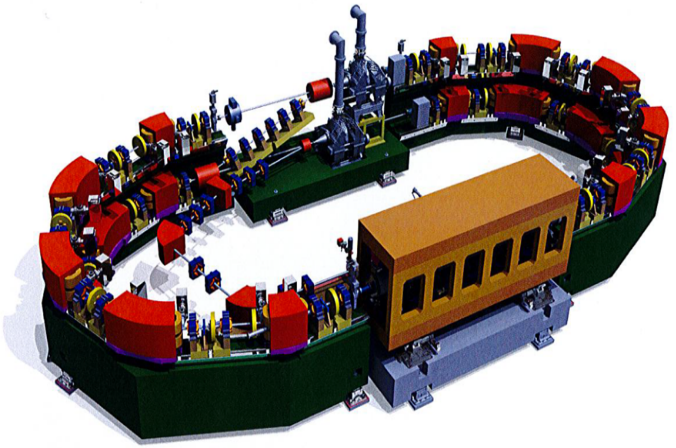


2. **Fast, sensitive detectors**



Jungfrau detector

3. **Know-how in accelerator physics & design**

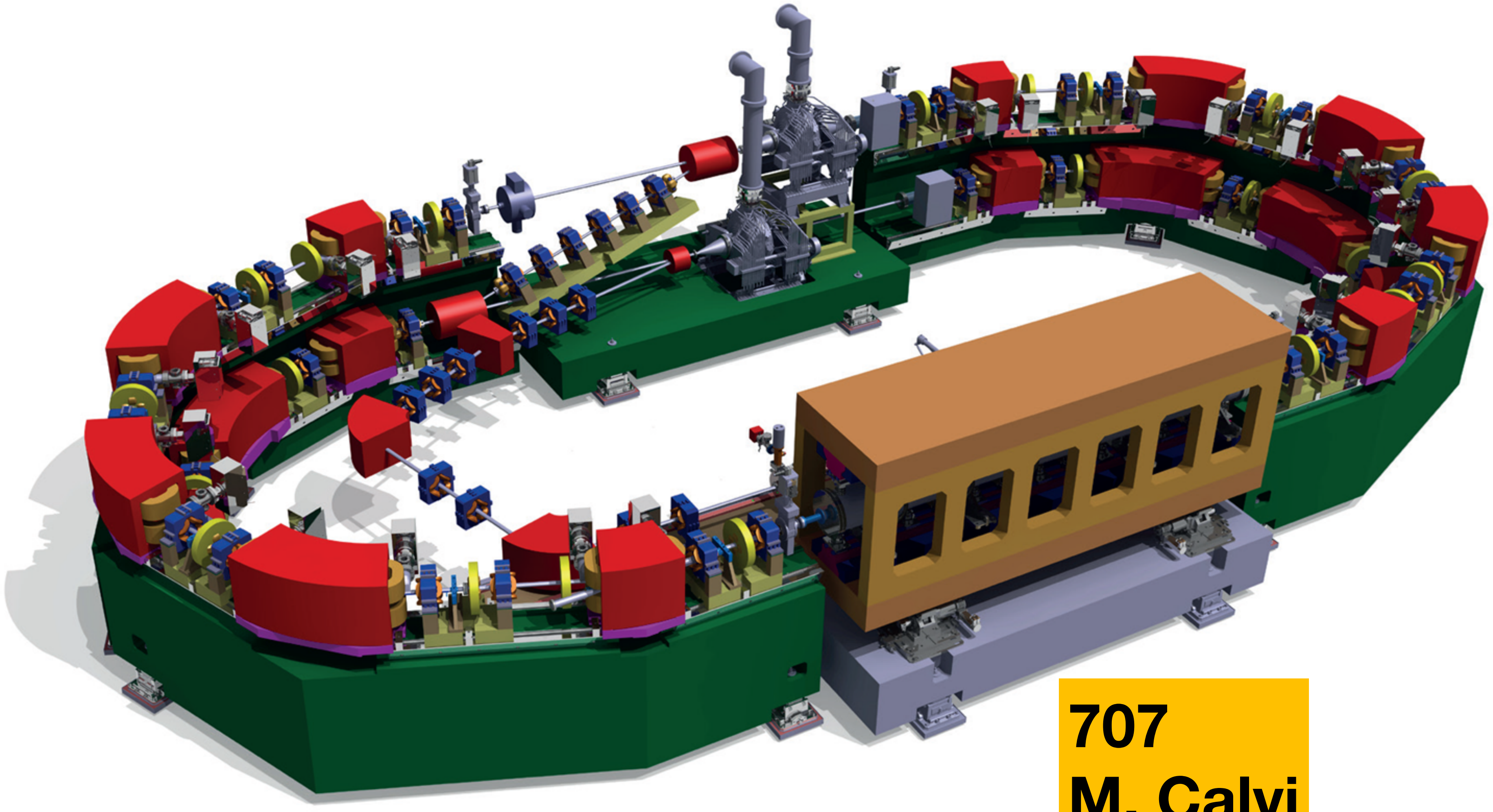


Compact synchrotron

All available at PSI!

Y. Ekinci, PSI

Diffraction limited rings technology: a much brighter compact source

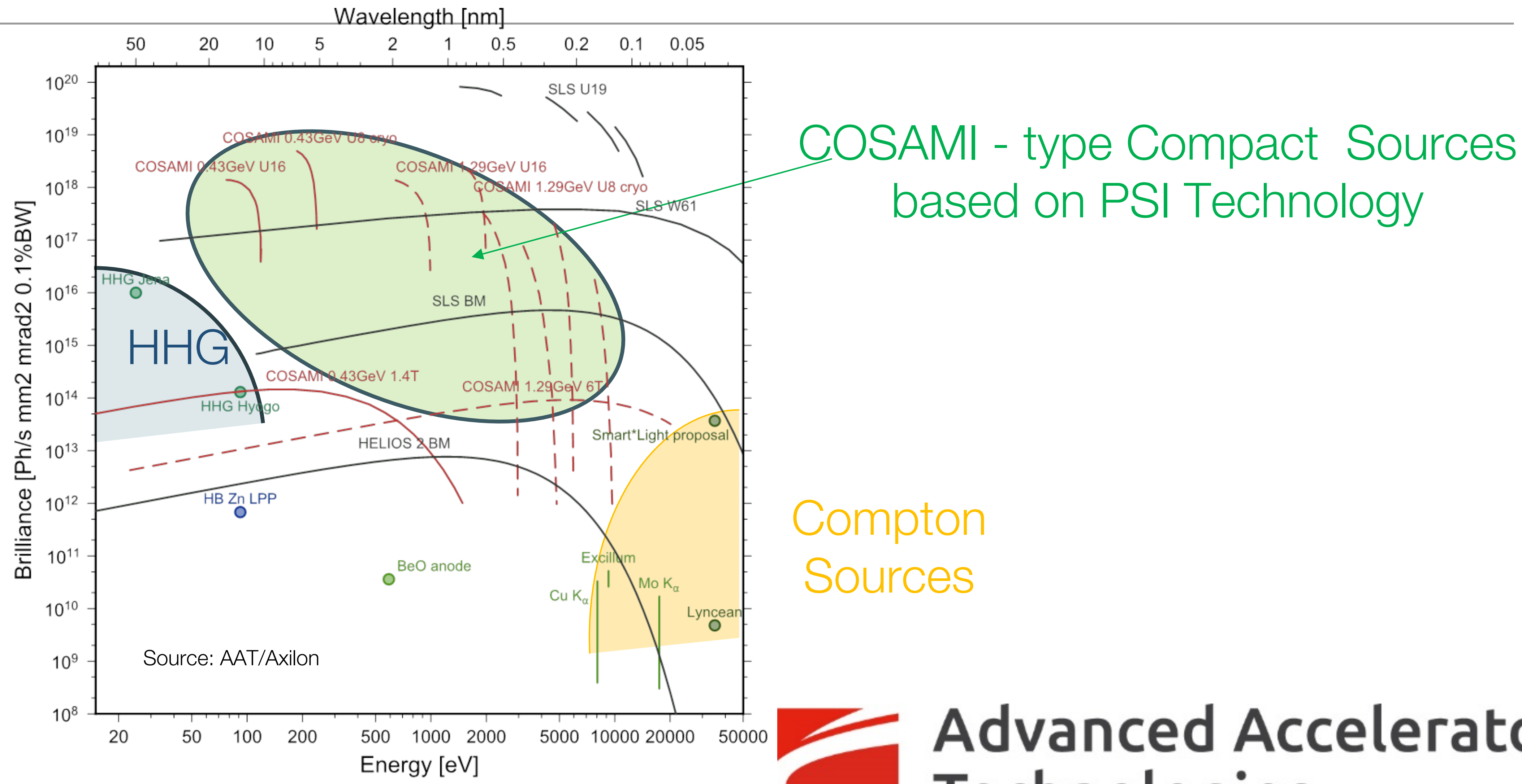


203
T. Garvey

707
M. Calvi

COSAMI design
5 x 10 meter
Footprint

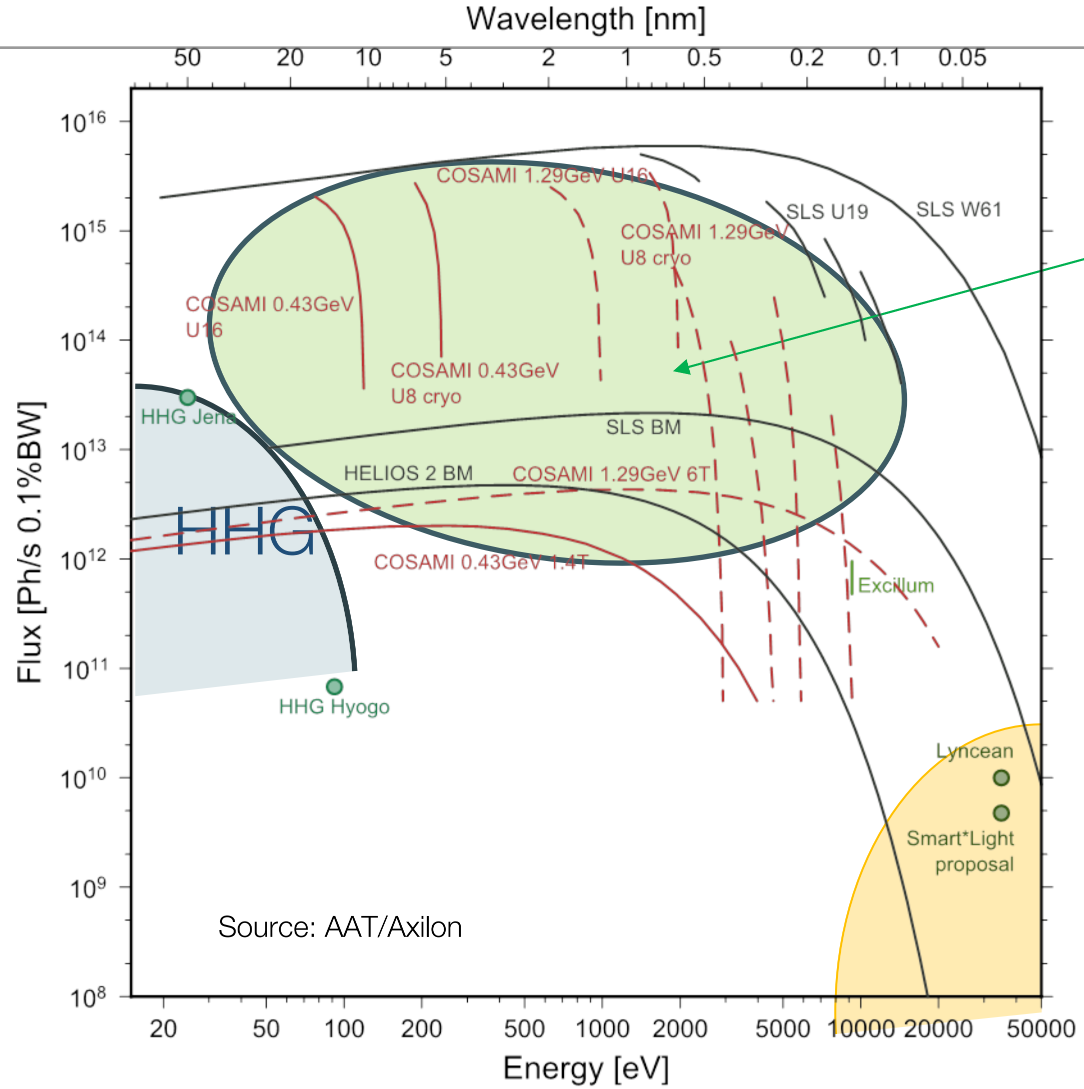
Brightness vs photon energy of various sources



Advanced Accelerator Technologies

Udo Klein, AAT

Brightness vs photon energy of various sources



COSAMI - type Compact Sources
based on PSI Technology

Compton
Sources

Advanced Accelerator
Technologies

Udo Klein, AAT

Accelerators for medicine

X-Ray radiotherapy

Varian brothers start at Stanford

1947, 2 MeV/m
One meter long

50,000,000

patients treated with photons

250 MeV proton cyclotron (ACCEL / Varian)

100,000

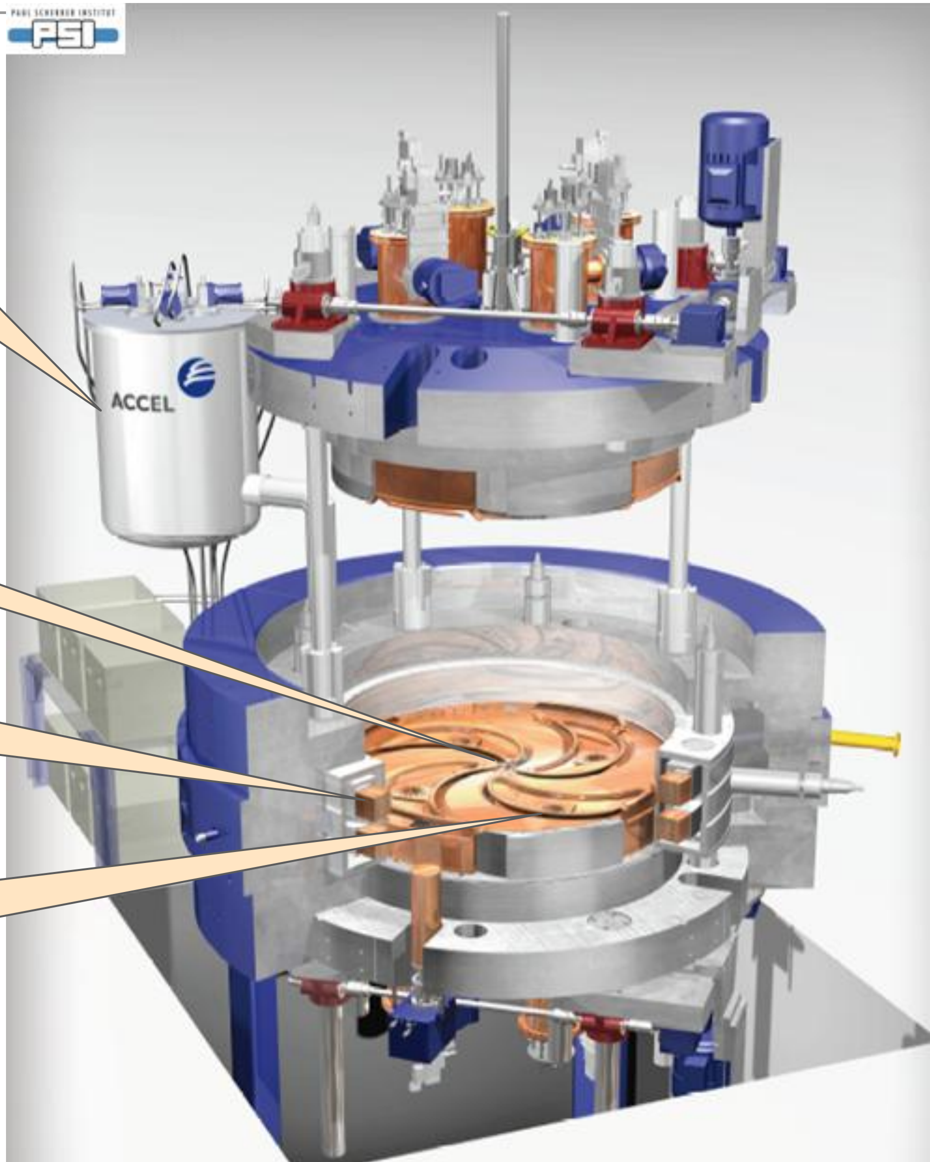
patients treated with hadrons

Closed He
system
4 x 1.5 W @4K

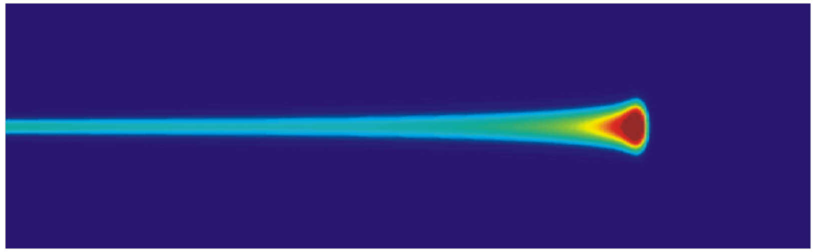
Proton source

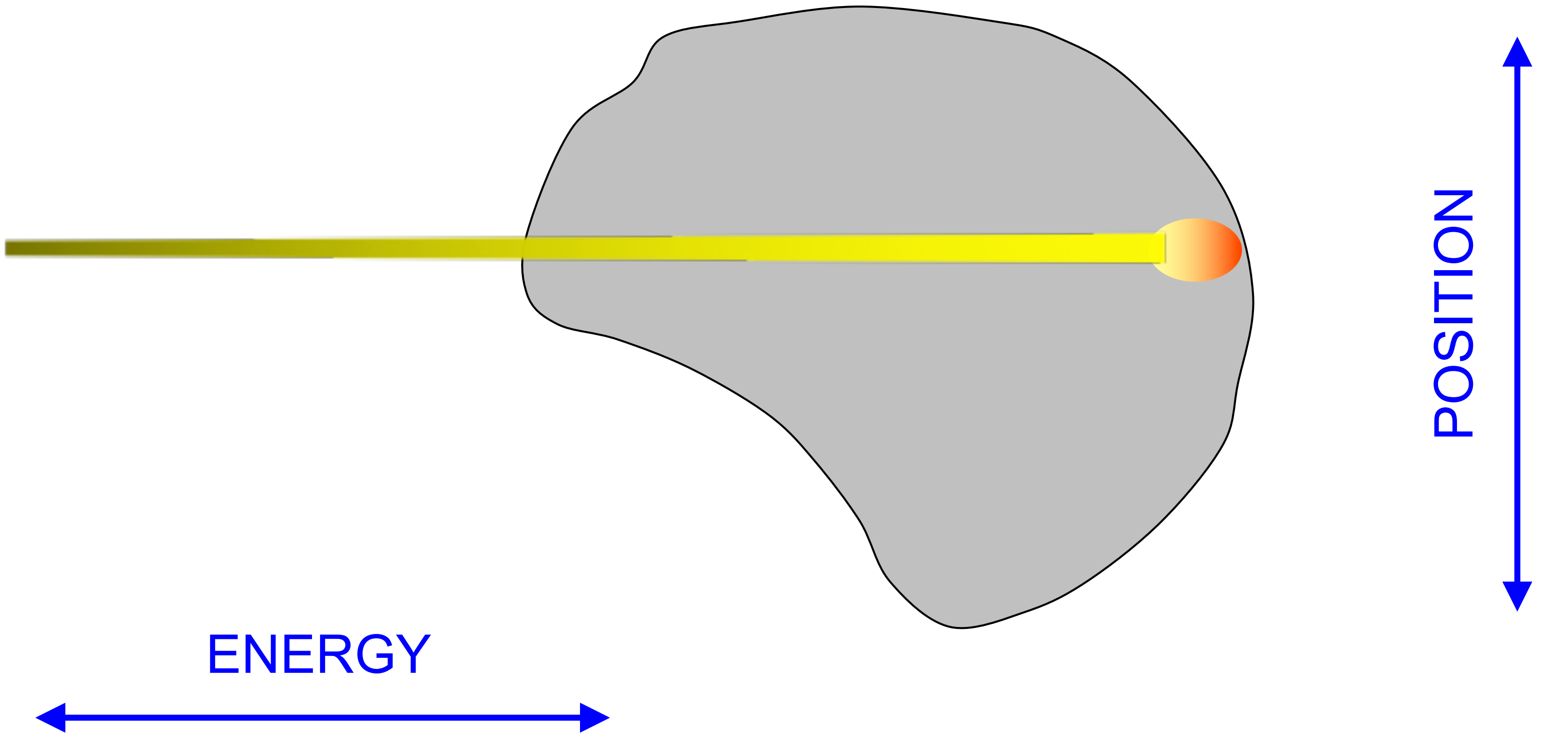
superconducting coils
=> 2.4 - 3.8 T

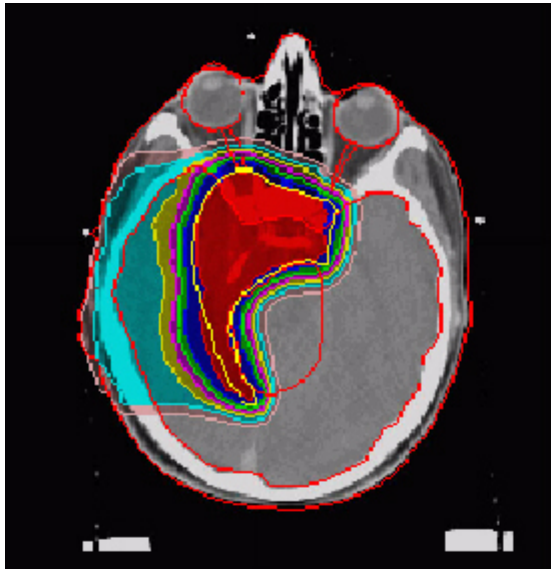
4 RF-cavities
≈100 kV on 4 Dees



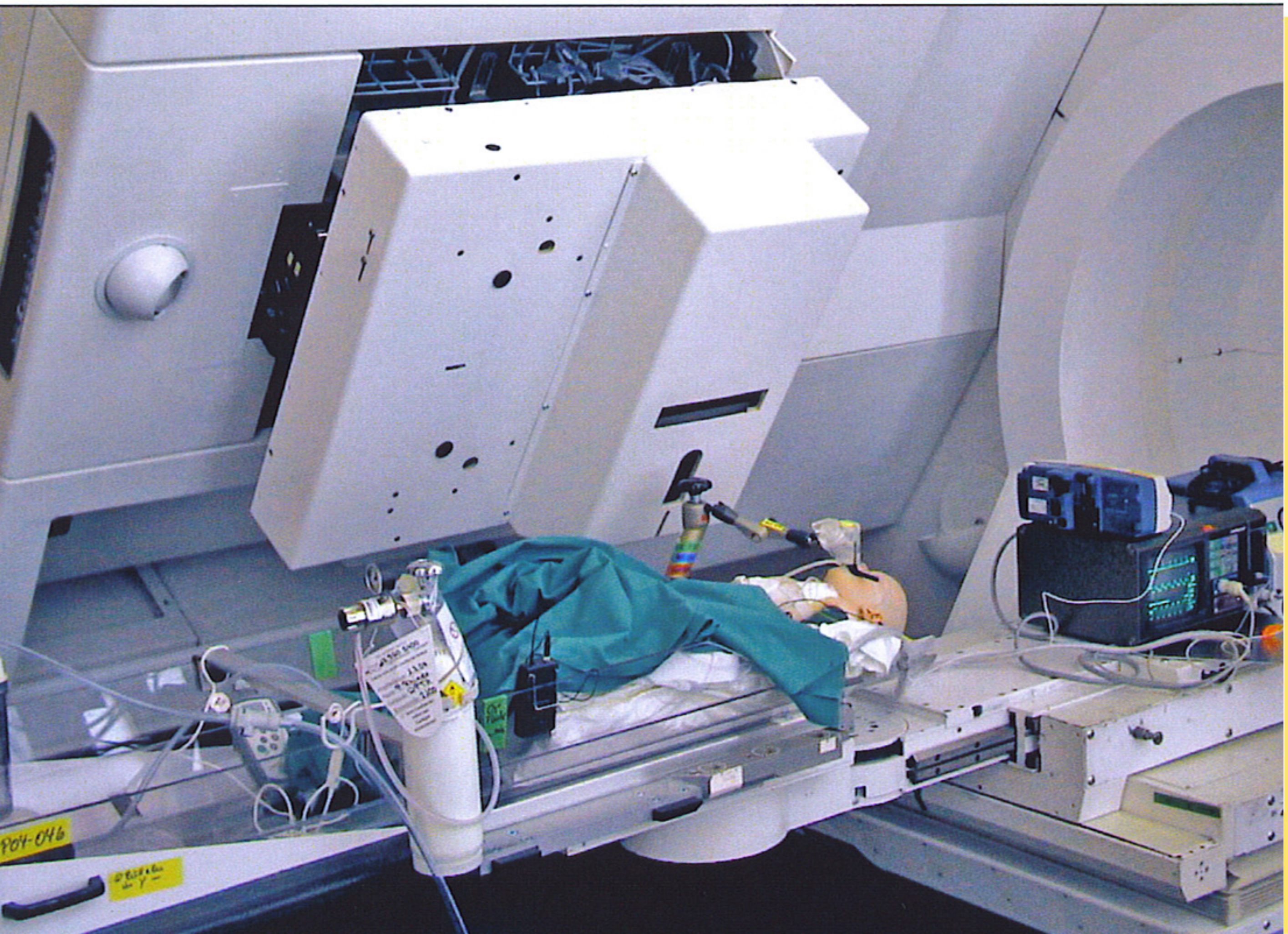
BRAGG PEAK: SPOT SCANNING

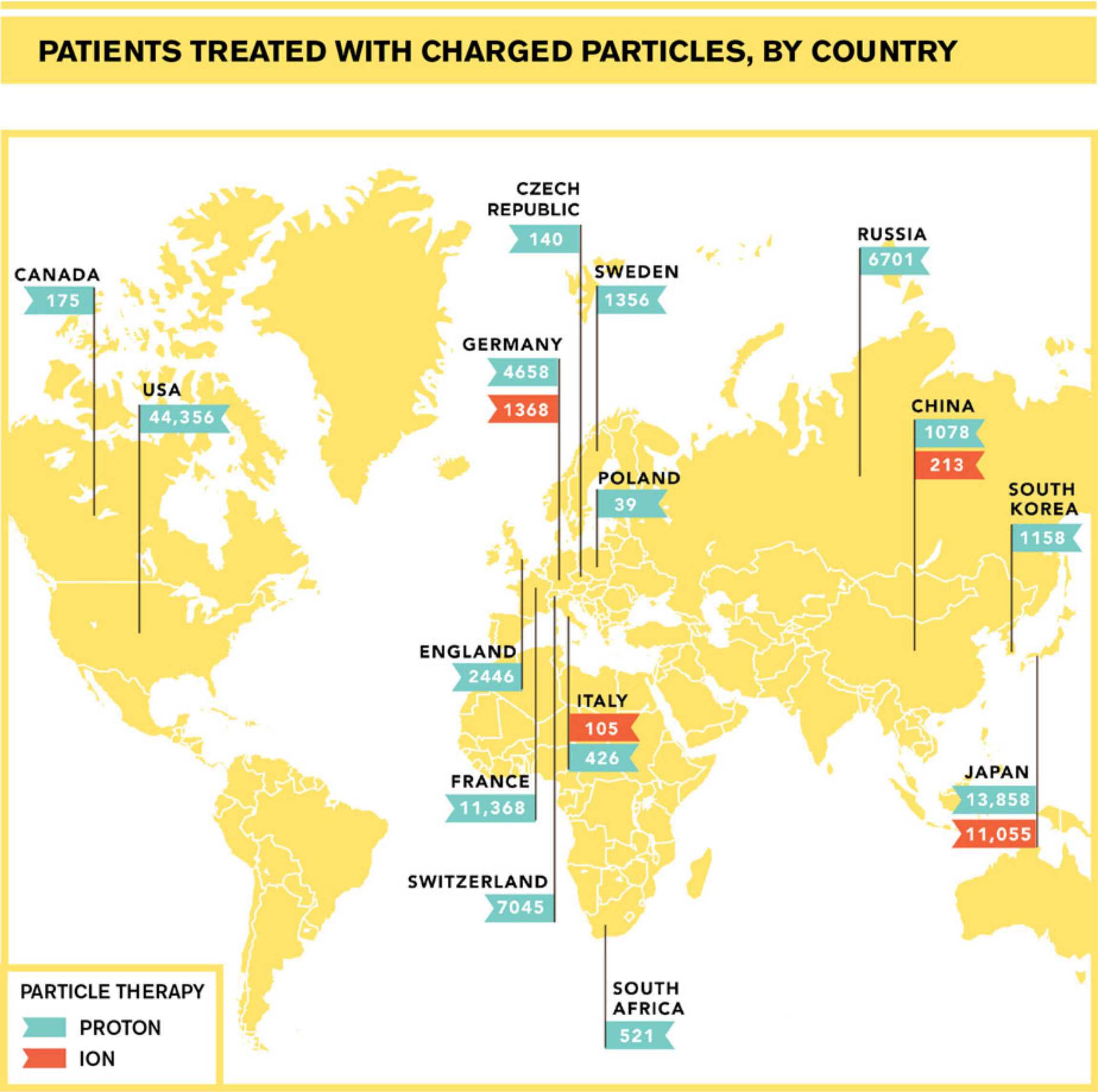






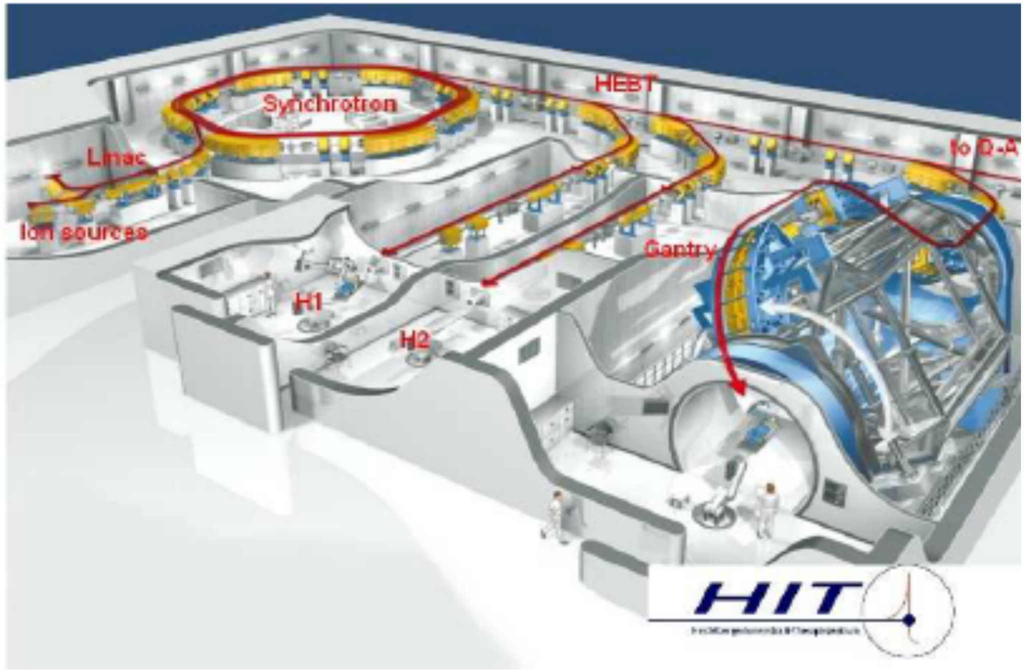
Hadron therapy: method of choice for pediatric cancers

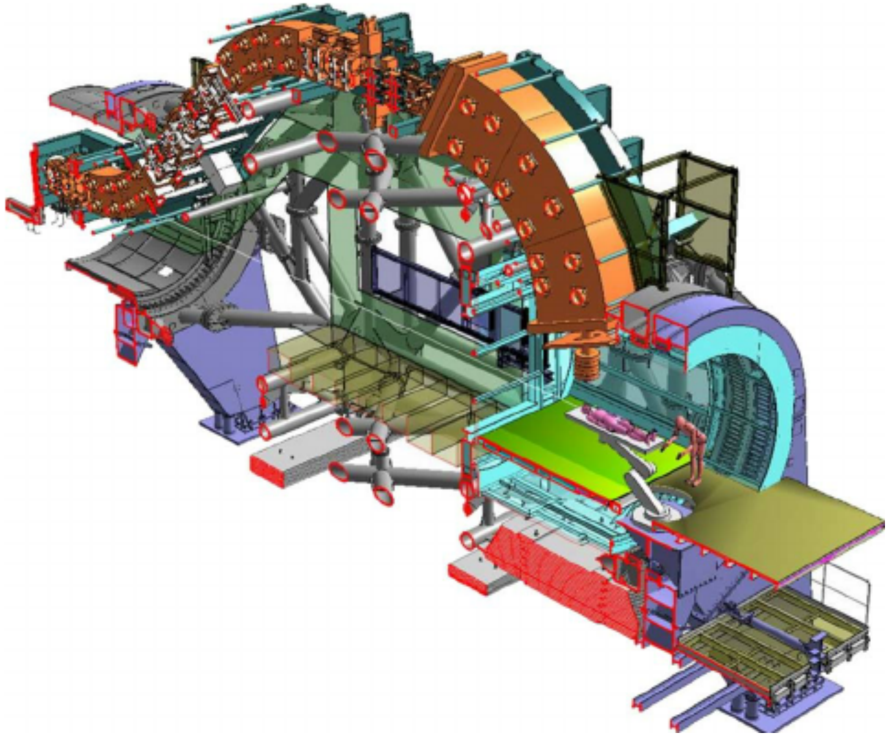




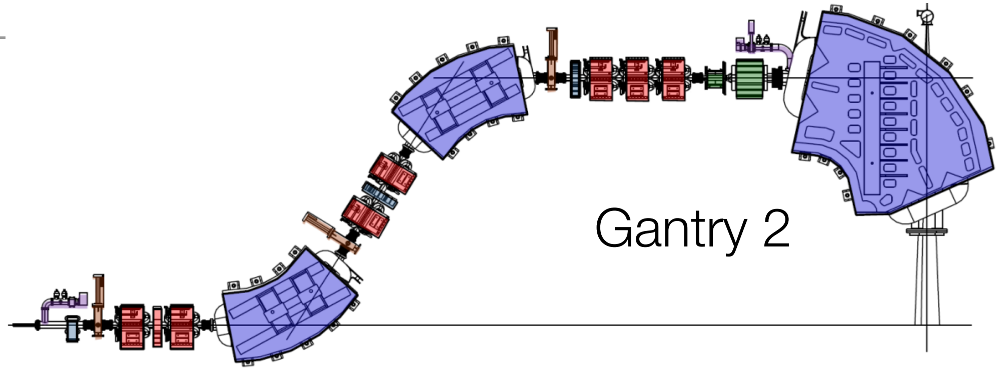
Gantries for hadron therapy

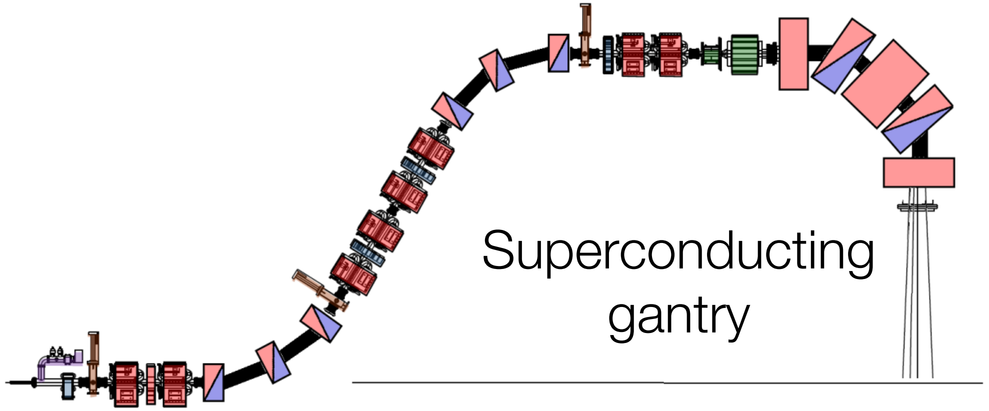
Gantry for carbon therapy (Heidelberg)

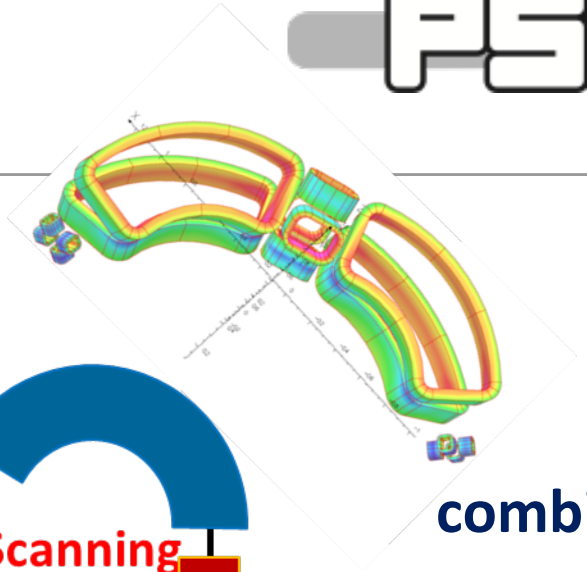


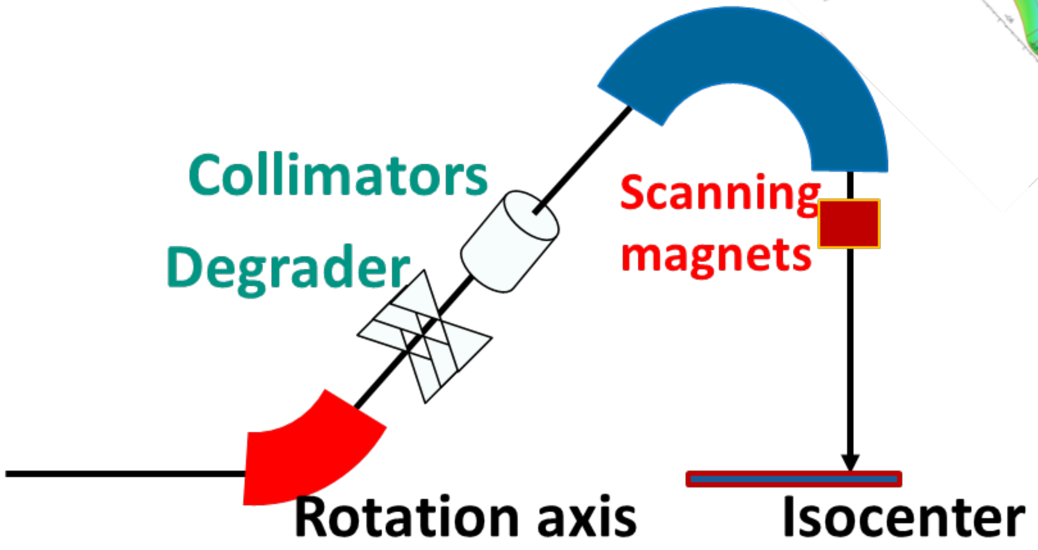


PSI Superconducting gantry designs









combined function, achromatic bending

EXPECTED IMPROVEMENTS: NOT much smaller, but:

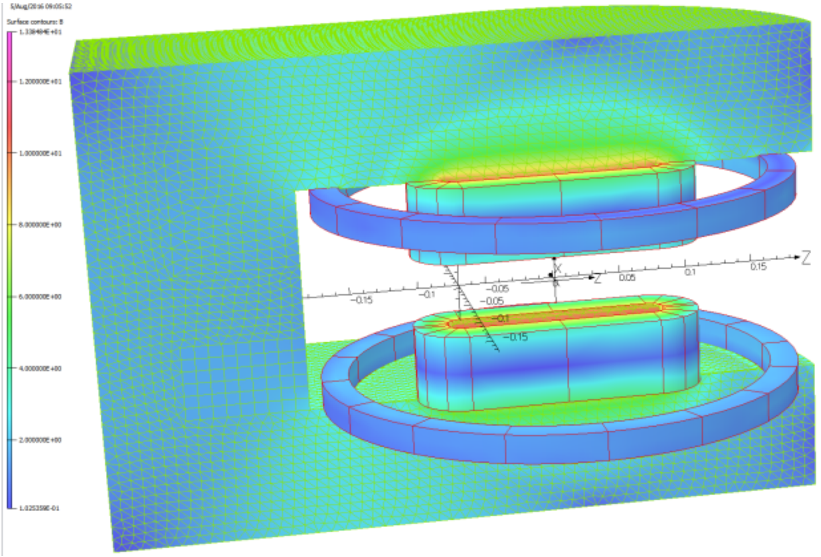
⇒ Weight: 200 tons → 50 tons

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

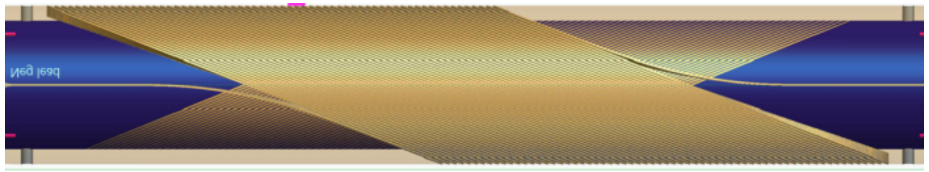
⇒ Energy acceptance 1.5% → 20 %

914
C. Calzolaio, S. Sanfilippo

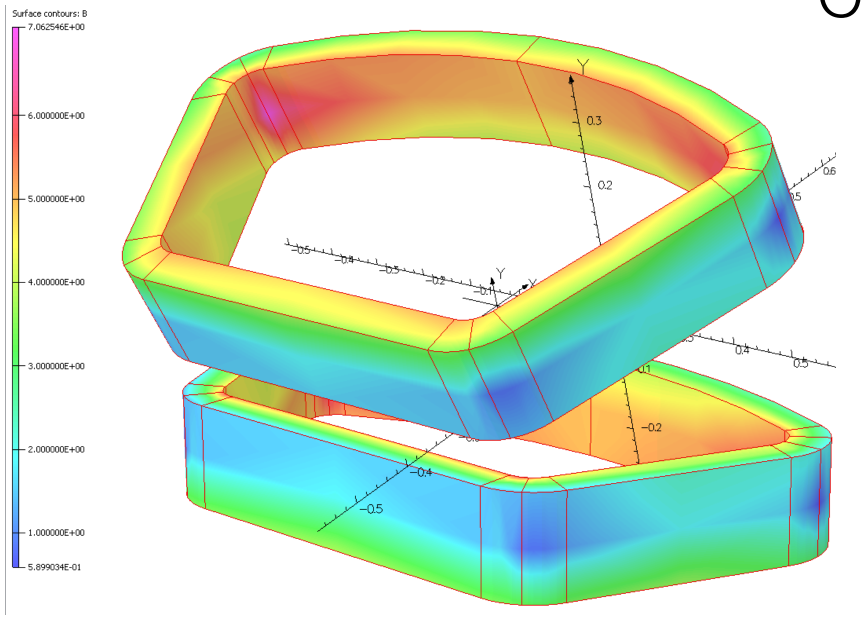
High field magnets for HEP, medicine and light sources



SLS 2 Superbend
(2015-2018)



16 T Dipole magnet for the Future Circular Collider
(2016-2019)



Superconducting dipole for gantry
(2015-2019)

Compact accelerators:
sources of photons, neutrons, electrons etc.

Compact is relative…

Quest for high gradient acceleration

e.g. compact sources for electron diffraction

Laser-Based Accelerators

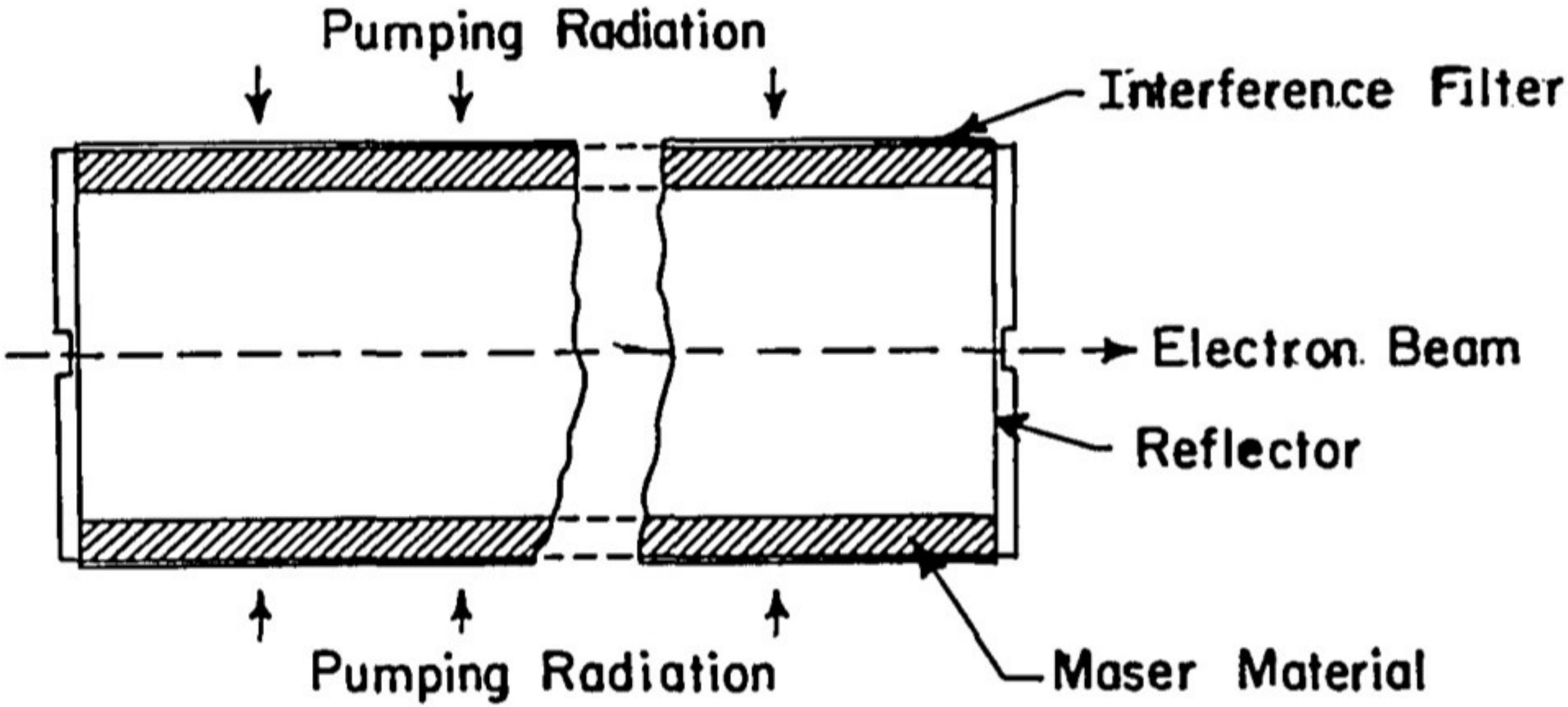
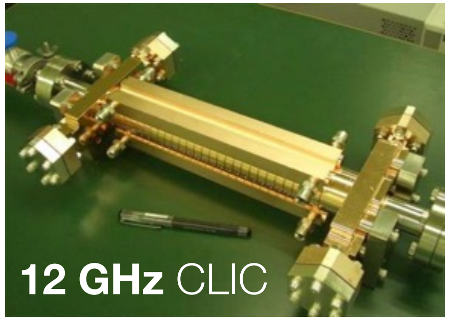
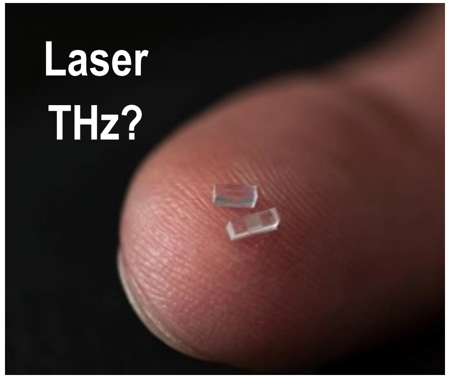


Fig. 1. Schematic diagram of an electron linear accelerator by optical maser.

Shimoda
Appl. Opt. **1 (1)**, 33 (1961)

RF Acceleration: scaling with frequency





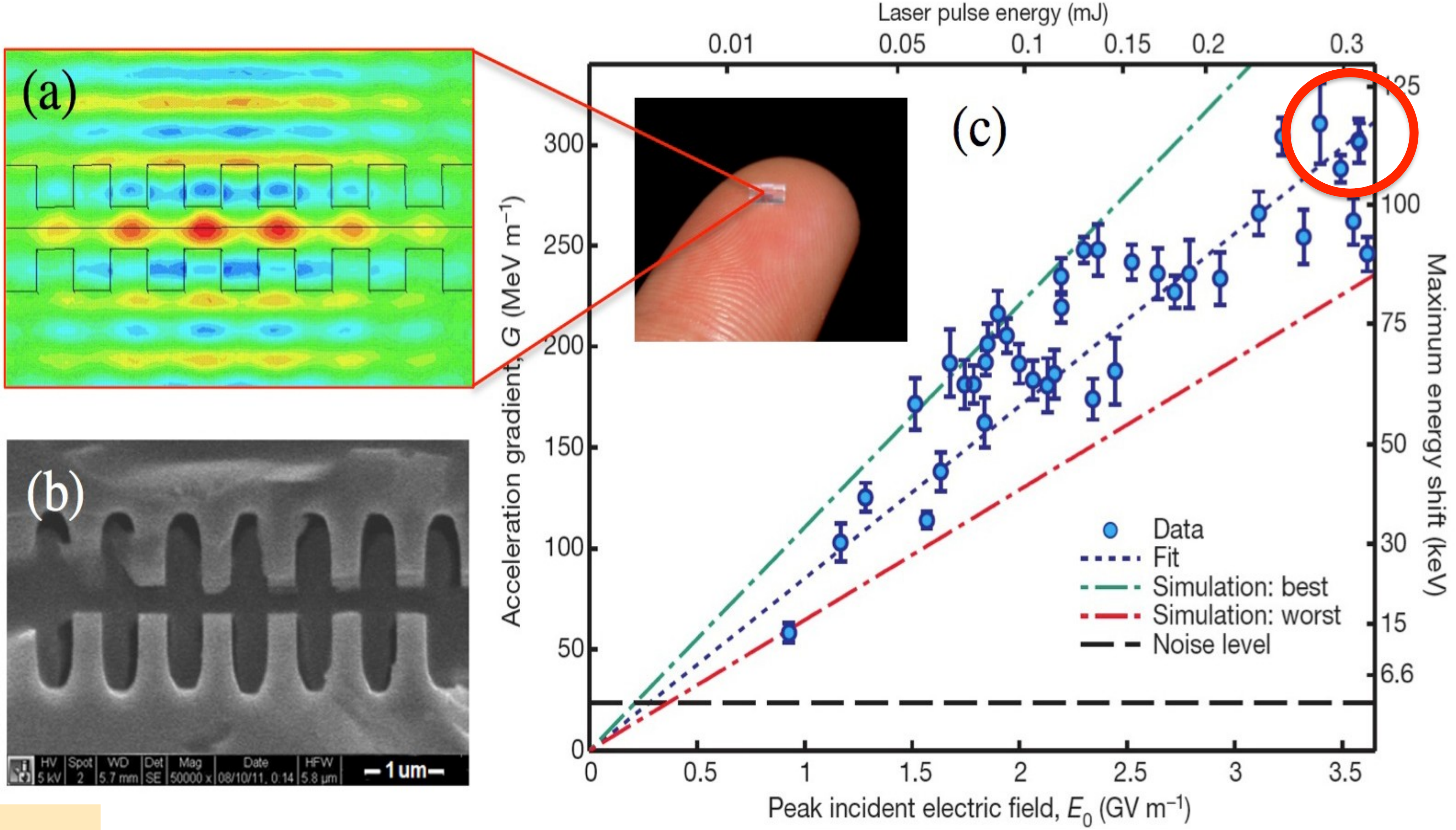
ACHIP

GORDON AND BETTY MOORE FOUNDATION

DESY · EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE · FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG · PAUL SCHERRER INSTITUT PSI · SLAC NATIONAL ACCELERATOR LABORATORY

STANFORD UNIVERSITY · TECH-X · TECHNISCHE UNIVERSITÄT DARMSTADT · UH Universität Hamburg

Peak gradient as a function of Laser Field



Peralta et al.,
Nature **503**, 91 (2013)

Switzerland: host to two world leading accelerator centres

Swiss Accelerator Research and Technology CHART Collaboration supports the future accelerator projects at CERN and the development of accelerator concepts beyond the existing technology for synchrotron light sources and medical applications. An extraordinary grant has been released by SERI as initial funding for these activities.

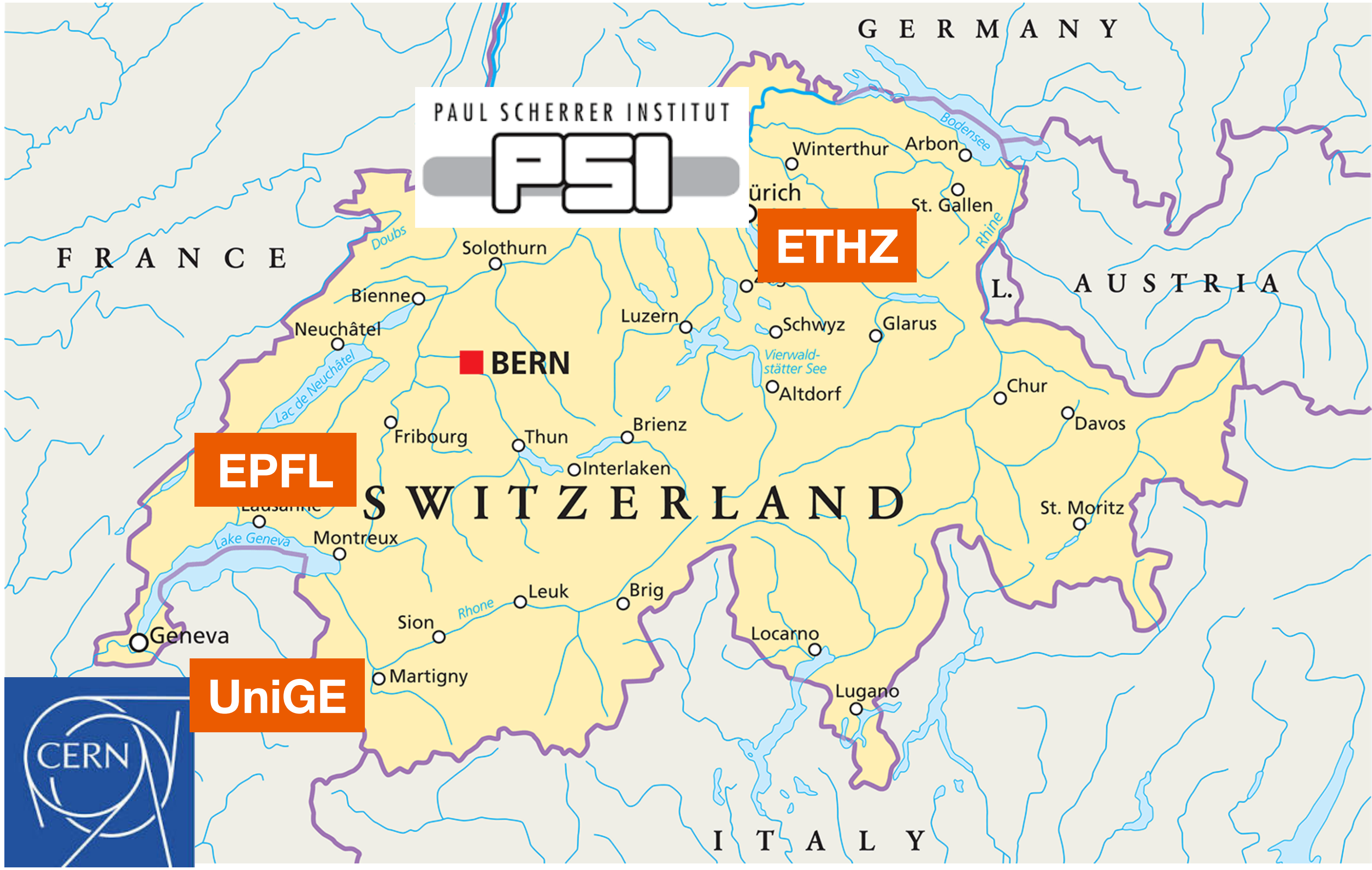


CHART: Swiss Accelerator Research and Technology

CERN

Beam Dynamics and Technologies
for Future Colliders,
21 February – 6 March 2018, Zürich

PAUL SCHERRER INSTITUT
PSI

The CERN Accelerator School

ENGINES OF
DISCOVERY

A Century of Particle Accelerators

Andrew Sessler • Edmund Wilson

"Le véritable voyage de découverte ne consiste pas à chercher de nouveaux paysages, mais à avoir de nouveaux yeux"

Marcel Proust

Summary

In the past 90 years accelerators have become an essential tool for research and numerous applications, able to address society’s essential needs

Future poses formidable challenges for the accelerator R&D, not the least of them is educating the new generation of specialists

CERN and PSI provide a very strong local advantage in Switzerland, for both academia and industry