PT-1: Superconducting RF: Enabling Technology for Future Accelerators

J. KNOBLOCH (HZB) FOR THE PT-1 GROUP

(DESY, HZB, HZDR, GSI)

Advantage SRF: Nb ≈ 10^6 fewer losses than Cu → vital consequences!

Energy efficient operation

- Low dynamic losses
- Efficient conversion of wall-plug power to beam power (even when including cryopower)

Cavity design not dominated by RF losses → more freedom

- Flexibility to adapt cavity design to match application requirements
- E.g., large aperture designs possible
  - Simple HOM damping possible (wakefield minimization!) for high-current operation
  - Large acceptance to avoid beam intercept/activation

Cu B-Factory Cavity
PEP-II

Beam →

Nb B-Factory Cavity
KEK-B

CW (or long pulse) operation possible at high field:

CW/long pulse = stability

- System is in “equilibrium”
- Feedback can be implemented

CW/long pulse = High average current at moderate bunch charge

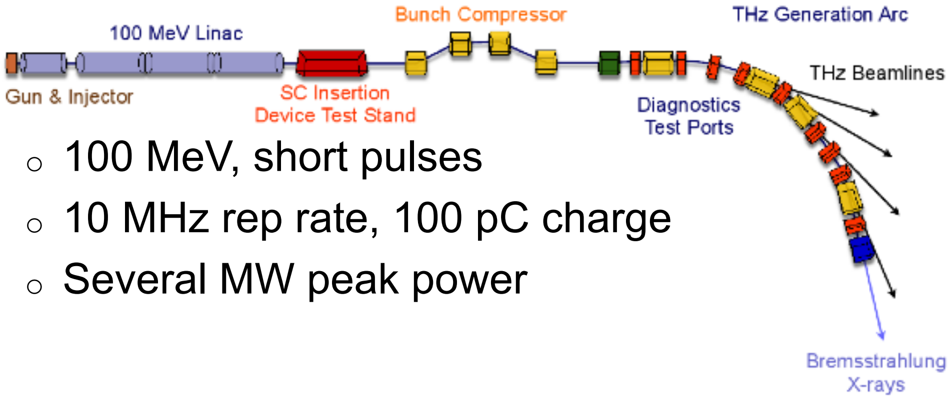
- Avoids non-linear effects (e.g., space charge), reduced wakefield issues …
- Simpler signal recording without detector pile up
- Limit “sample” damage
- …

CW/long pulse = Flexibility to adapt to application requirements

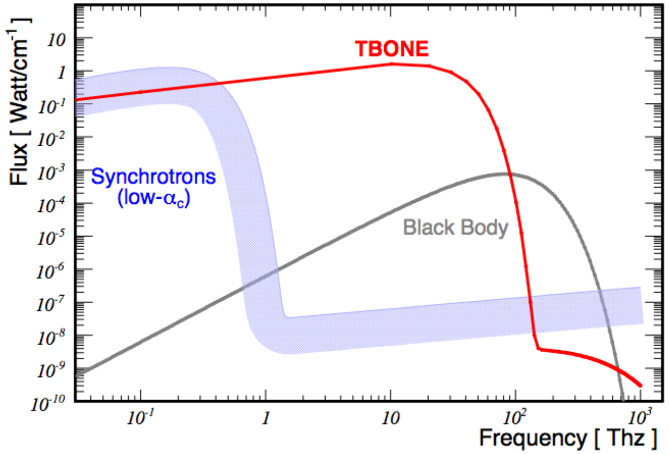
- E.g., Imaging
- Spectroscopy in highest magnetic fields (ms pulses)
- Cavity FELs (including X-ray)
- Spallation sources
- High-rep rate pump probe
- Use powerful signal processing techniques developed for CW systems (e.g., lock-in systems)

High-rep rate LINACs: Beam quality + flexible bunch manipulation

- E.g.: Intense THz Production: TBONE@KIT

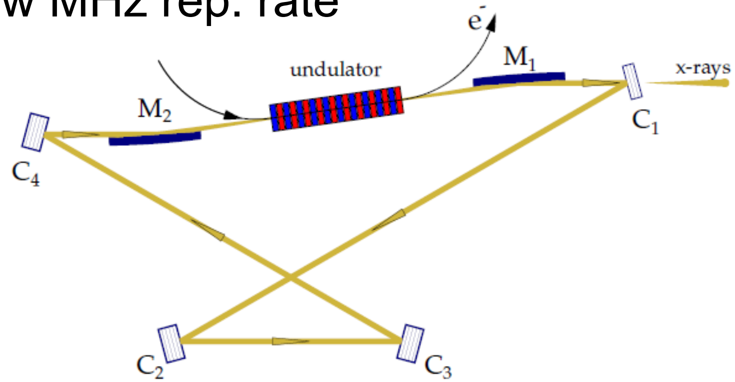


  - 100 MeV, short pulses
  - 10 MHz rep rate, 100 pC charge
  - Several MW peak power



- E.g.: tunable X-ray FEL oscillator
  - Order 5 GeV electron beam
  - MHz rep rate
  - Bunch length = 0.1 ps, emittance = 0.3 mm mrad
  - Tunable, multi-keV X-rays out
  - Full trans/long. coherence
  - Bandwidth in meV range

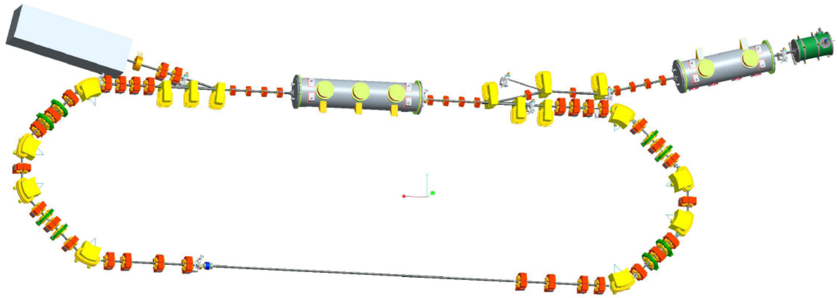
Few MHz rep. rate



Courtesy Kwang-je Kim, ANL

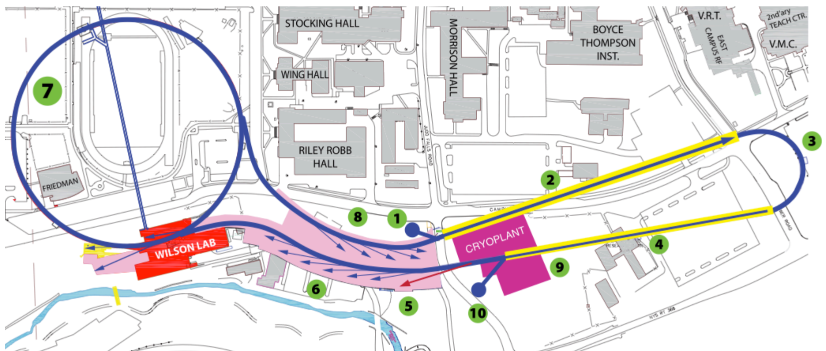
ERLs: Storage-ring-level currents with LINAC-level beam properties

- Recover beam energy in second pass through linac before dumping beam
- Relies on:
  - High efficiency of SRF systems for efficient energy recovery
  - Heavy HOM damping of SRF systems to avoid beam instabilities
  - Appropriate electron source



E.g., for 4th generation x-ray light sources

- Flux as in 3rd gen. storage rings
- Greater brilliance and brightness
- Pulse length control
- Low energy spread



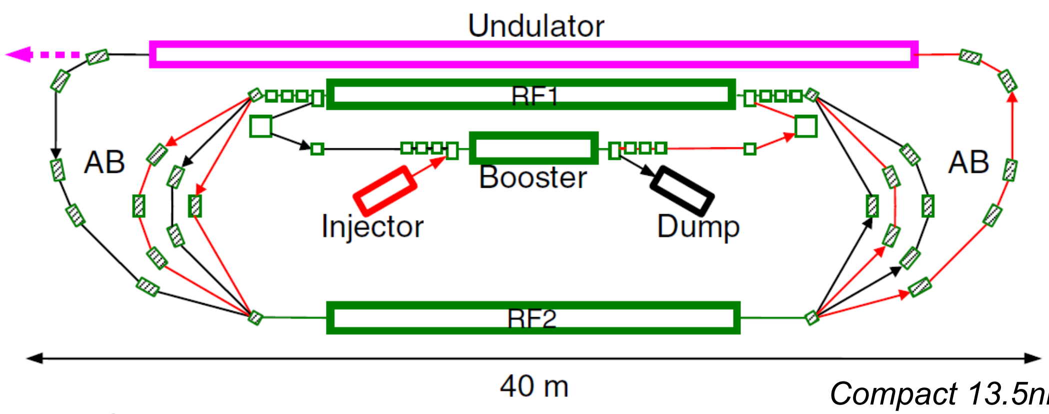
Proposal Cornell University

ERL Applications: Industrial

UV light source for Next-Generation Lithography (beyond 193 nm)

- 13.5 nm (6.5 nm), 100‘s W flux required. Planned plasma sources fail to match requirements.
- LINAC (< 1 GeV MeV) driven light source is an option
- FLASH-type machine provides required flux but:
  - Lithography requires beam rastering and very precise average power per point
  - Pulse-train structure complicates matter
  - Expensive and large
- CW, recirculating LINAC may prove to be a better option

Future EUV source (13.5nm → 6.5nm) for next generation lithography



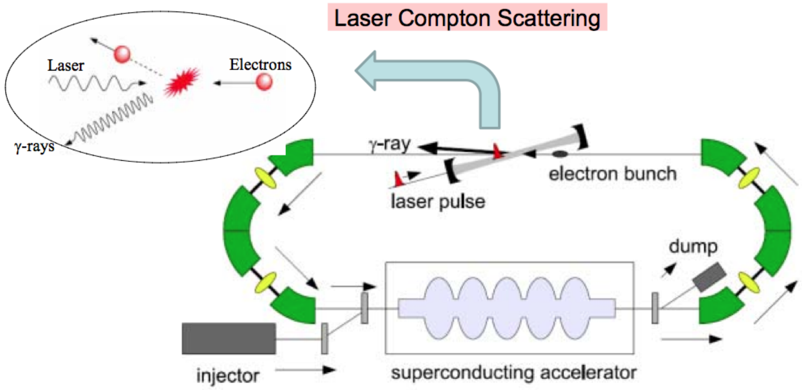
Linac energy ≈ 250 MeV (each)
Beam current ≈ 10 mA
Output in EUV ≈ kW

E~1GeV, I~10mA, ε_{norm}~1 mm mrad

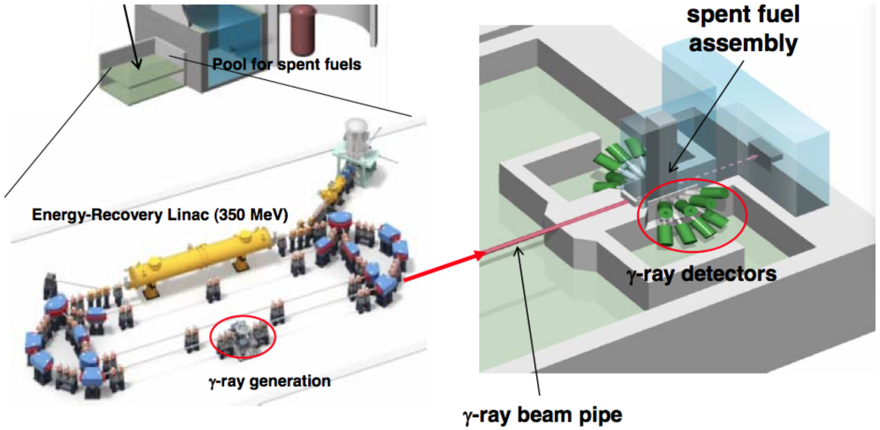
Compact 13.5nm FEL for extreme uv-lithography
Y. Socol et al., PRST-AB, 14, 040702 (2011)

E.g., for compact gamma-ray Compton Sources

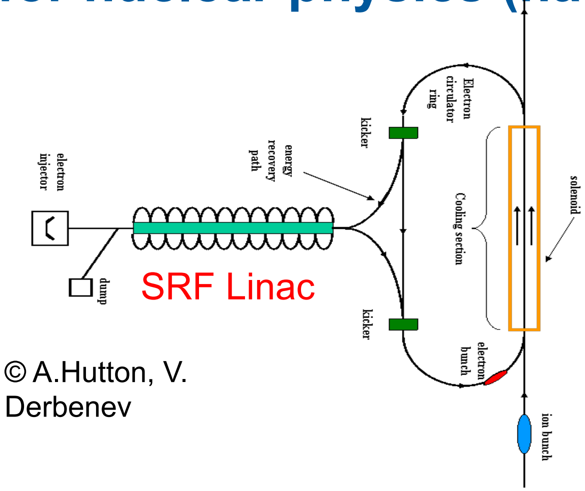
- Require ultra-low emittance (0.1 mm mrad) for narrow energy spread
- High average current



R. Hajima et al., AccApp'07 (2007).



E.g., for nuclear physics (hadron-electron colliders), LHeC, eRHIC



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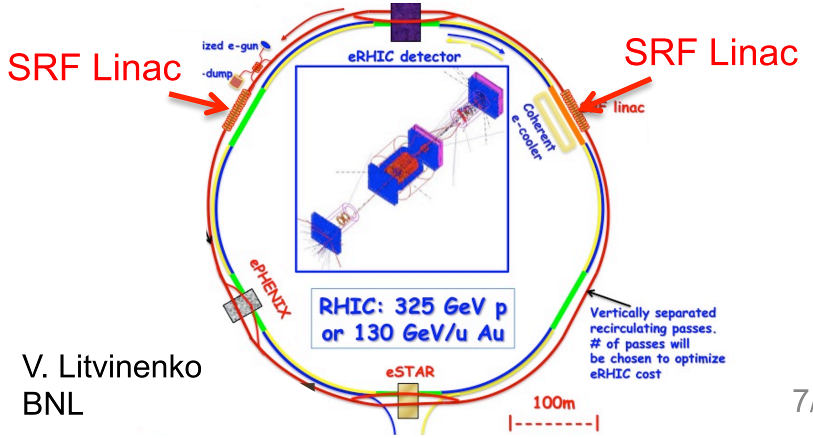
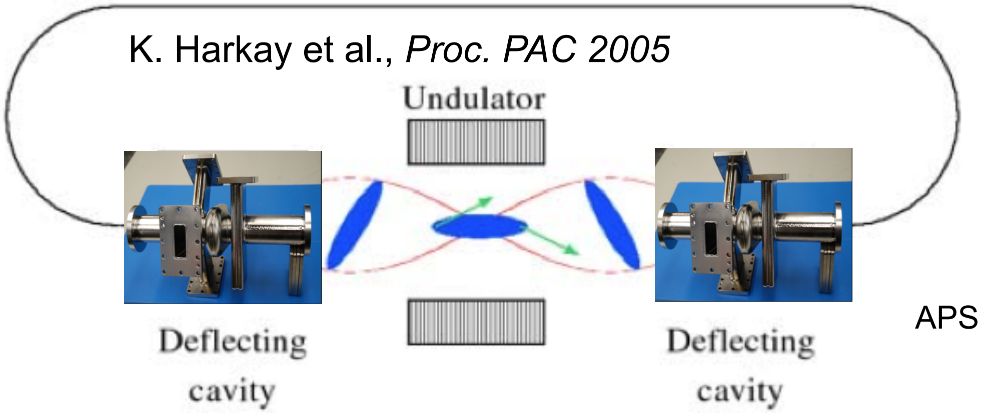
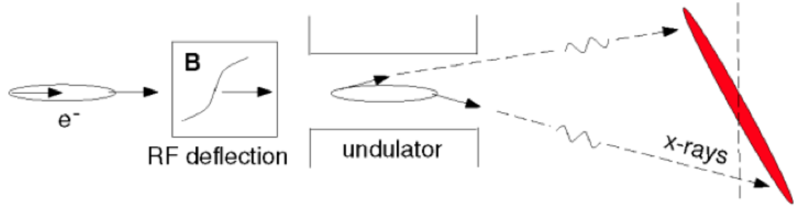


V. Litvinenko BNL

E.g., Bunch-length manipulation via crab cavities (ANL)

K. Harkay et al., *Proc. PAC 2005*

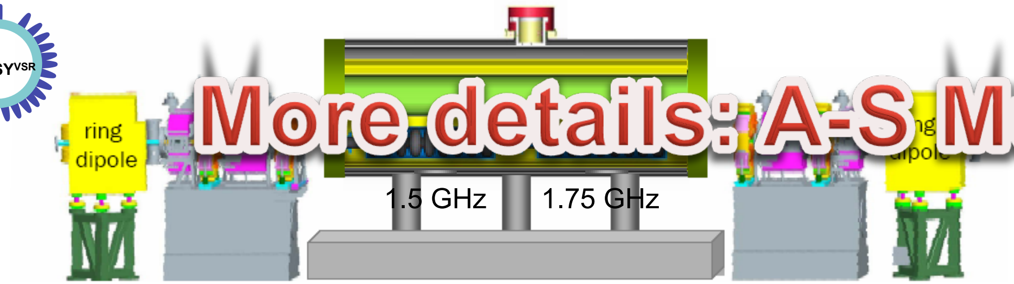


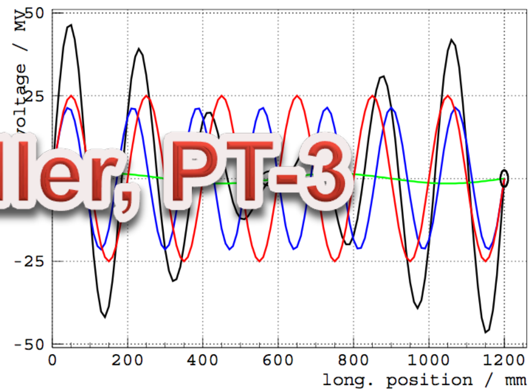


APS, Argonne

E.g., Flexible bunch-lengths via overvoltage

- Requires high-voltage CW cavities operating at several frequencies
- Low impedance, heavily damped systems to avoid instabilities
- Long and short bunches possible simultaneously

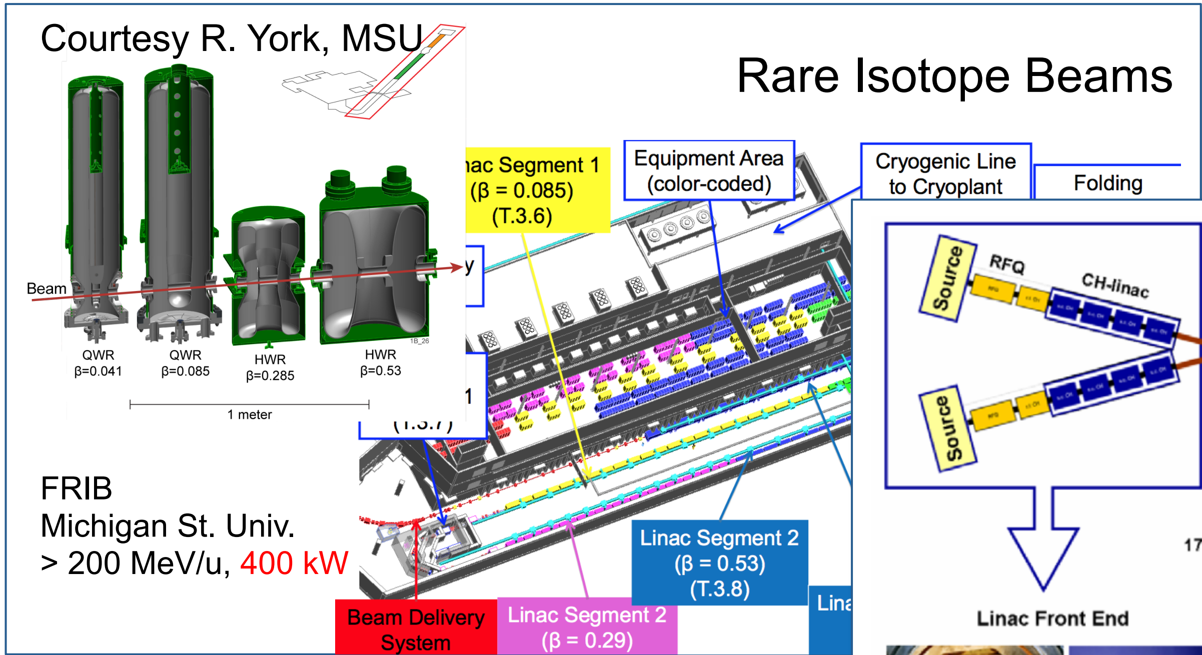




More details: A-S Müller, PT-3

BESSY^{VSR} concept for BESSY II G. Wüstefeld et al., *Proc. IPAC 2010*

High-power proton/ion accelerators



J. Delayen, *Proc. LINAC 2010*

Nucl. Waste Transmutation

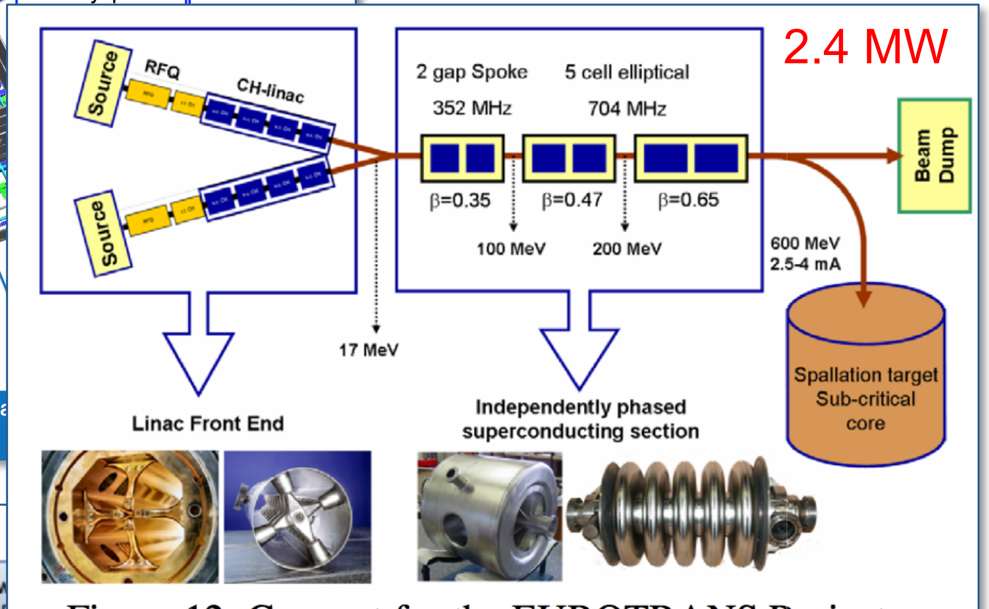
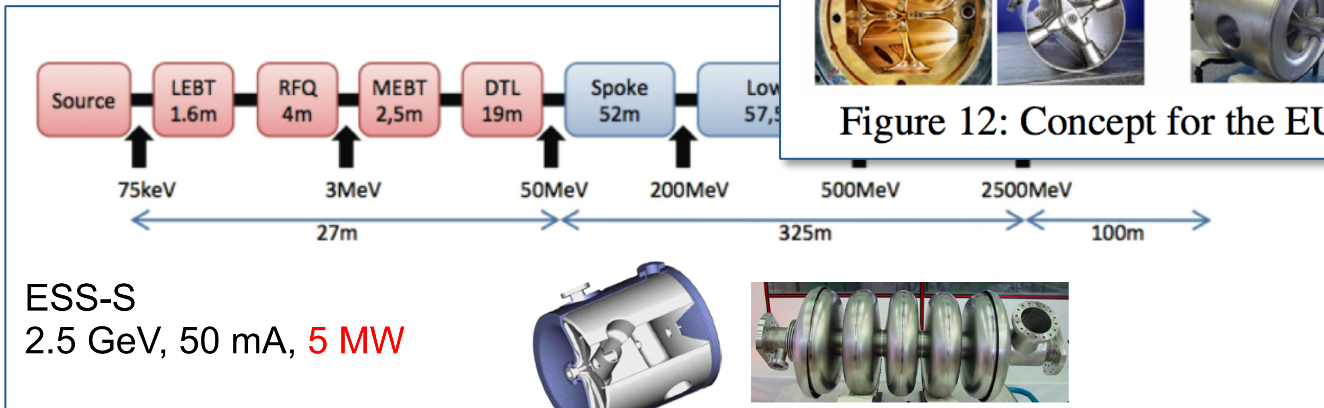


Figure 12: Concept for the EUROTRANS Project.



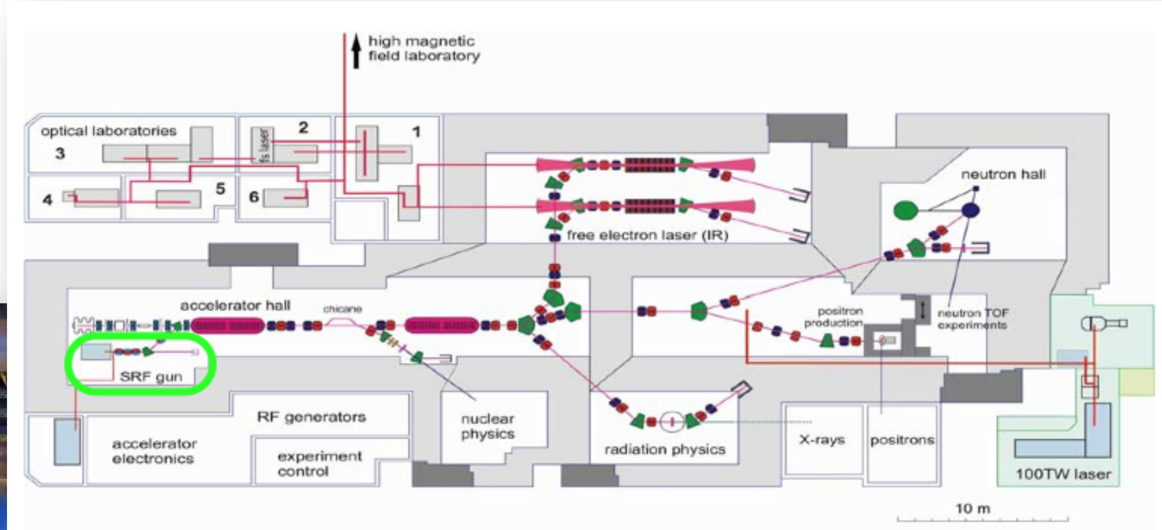
ESS-S
2.5 GeV, 50 mA, 5 MW

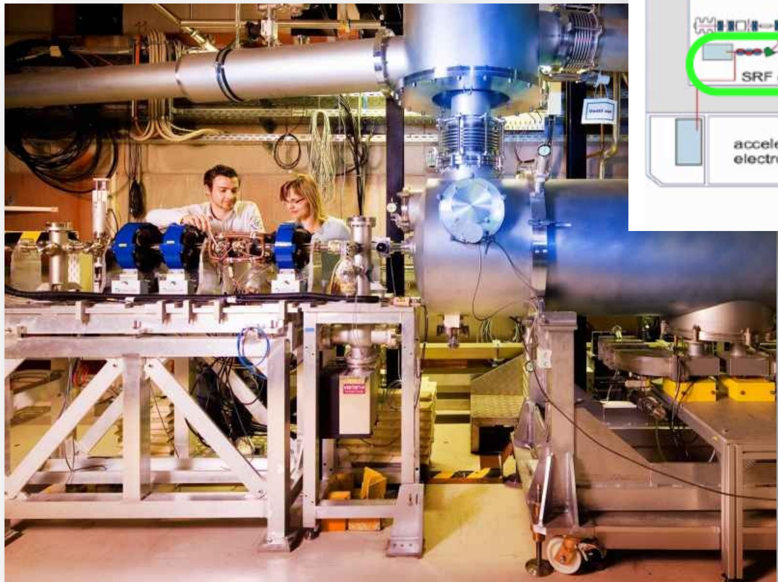
Spallation Neutrons

M. Eshraqi et al., *Proc. IPAC 2010*

ELBE: Fully CW accelerator, including SRF Photoinjector

- Photon science, neutron science
- Both CW and pulsed modes are offered, <u>but for FEL operation only 10% demand for pulsed mode → Illustrates attractiveness of CW</u>
- Upgrade in process





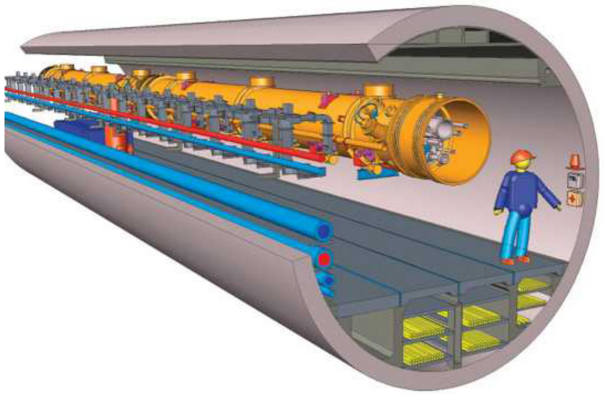
FLASH/FLASH II

- Currently pulsed, ca. 1% DF with 1 MHz rep rate in the pulse
- Efforts under way to enable fully CW operation
  - Demands operation at lower energy
  - Demands lowest emittance to still achieve saturation

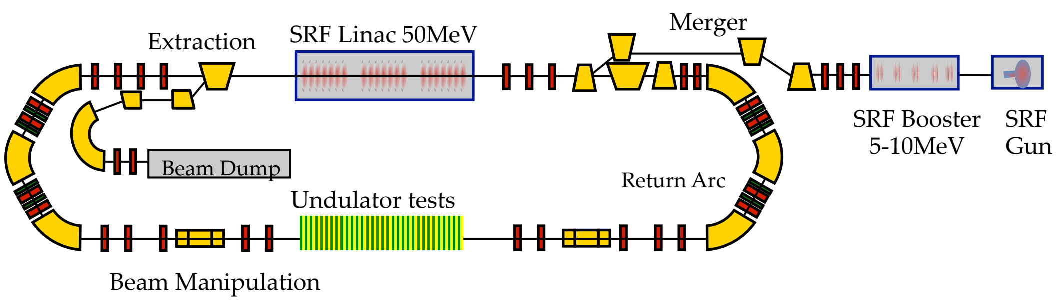
More details: H. Weise

Under construction @DESY : XFEL

- Tunnel ready for infrastructure installation Feb. 2012



Approved: B*ERL*inPro

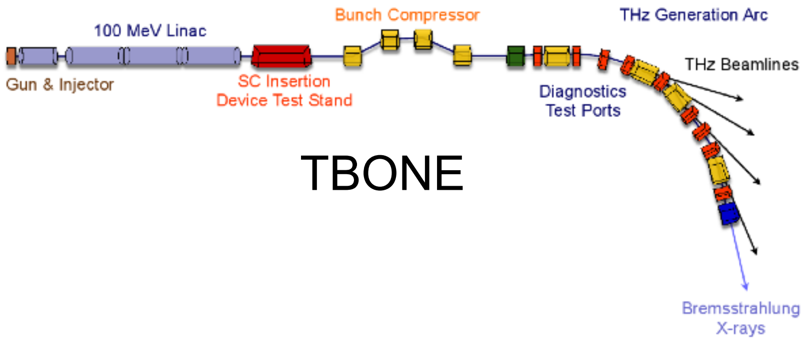


J. Jankowiak et al., *Proc. LINAC 2010*

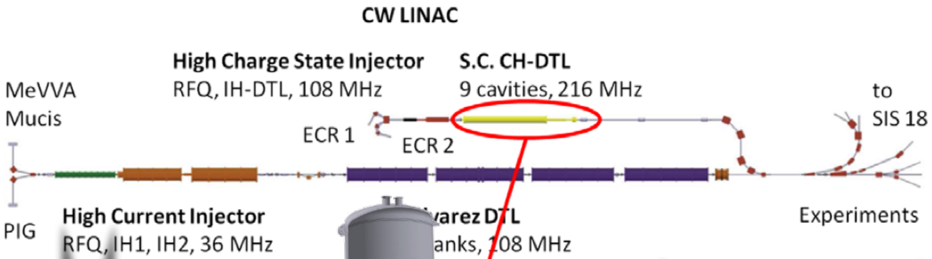
SRF Accelerators in the Helmholtz Association

In the application or planning stage:

- CW SRF LINAC for ions (GSI), on HGF Roadmap
- TBONE (PT-3, KIT), on HGF Roadmap
- BESSY VSR (PT-3, HZB)
- ESS-S (several HGF labs associated)



TBONE



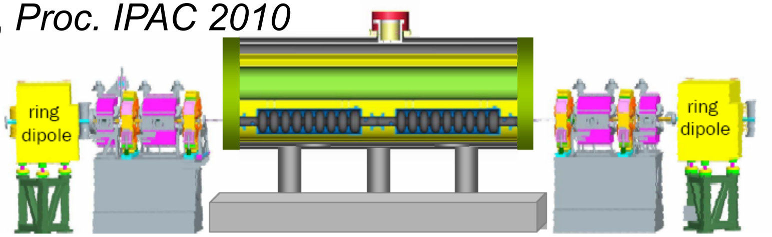
More details: W. Barth

F. Dziuba et al., *PRST-AB* ***13*** 041302 (2010)

ESS-S

G. Wüstefeld et al., *Proc. IPAC 2010*

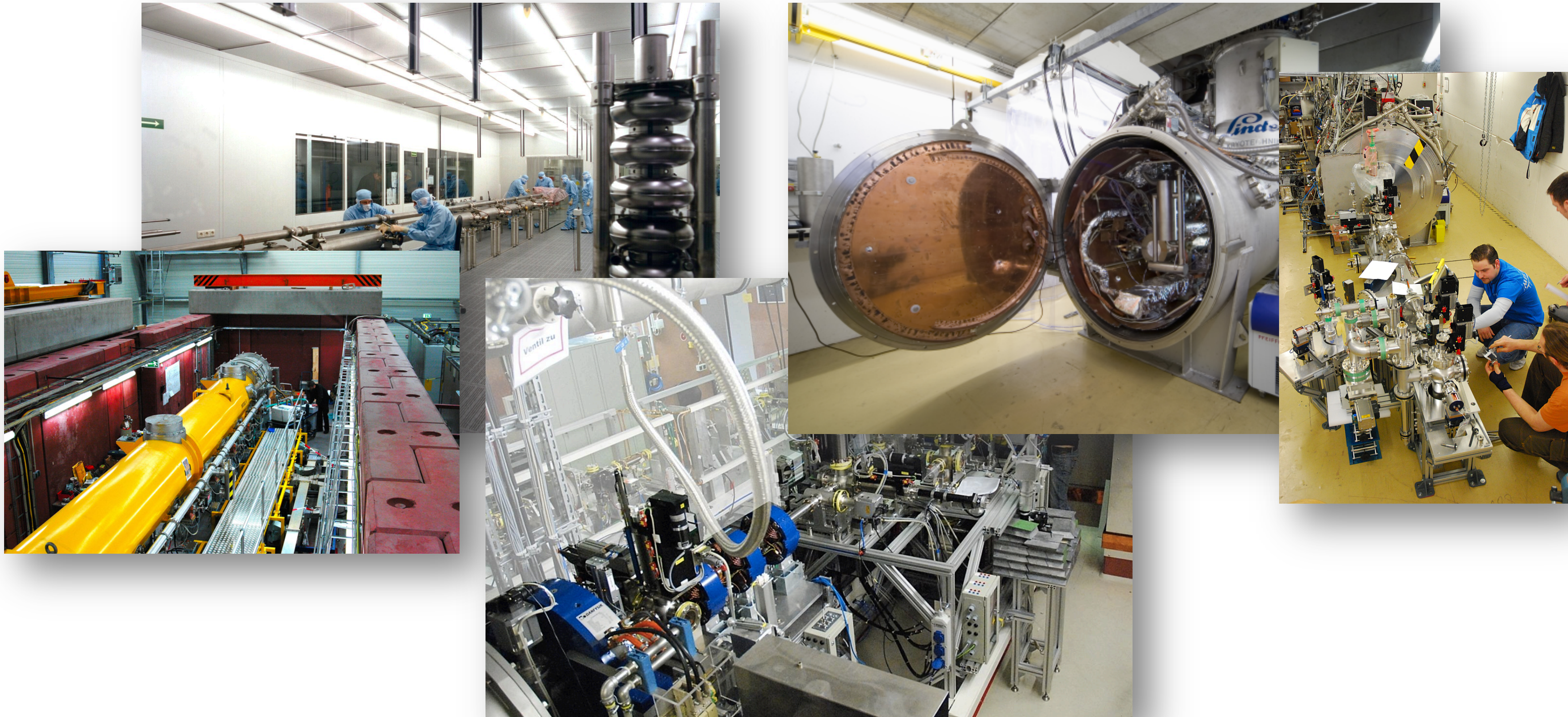
BESSY^{VSR}



Germany: World leader in SRF activities

Four Helmholtz Centers pursue SRF Development

- DESY: Long-pulse systems, XFEL, ILC, extensive infrastructure
- HZDR: SRF Photoinjector for moderate currents, ELBE
- HZB: CW SRF systems, Testing infrastructure, B*ERL*inPro
- GSI: Development of structures for ion accelerators



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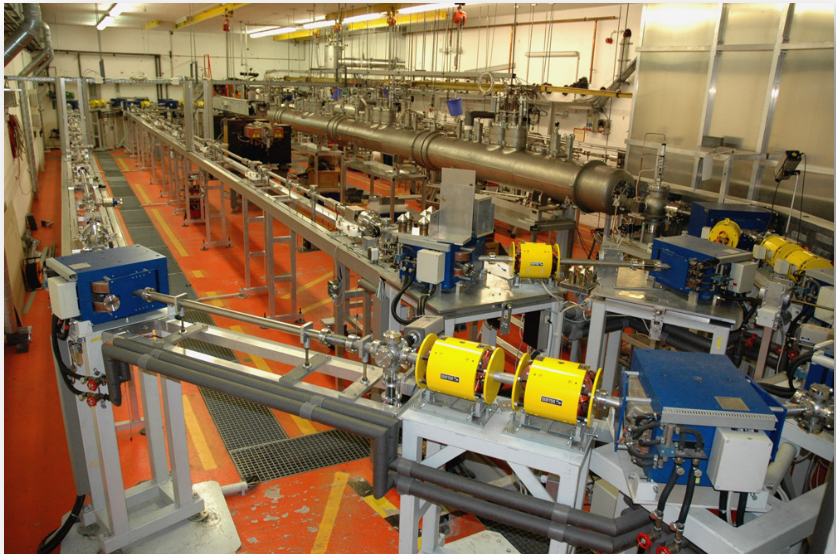
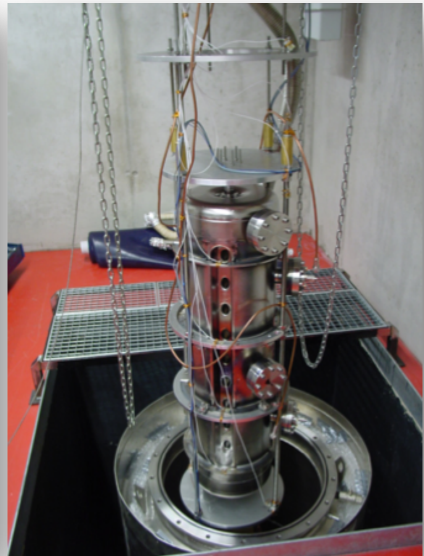
- GSI: Development of structures for ion accelerators

Universities

- TU-Darmstadt: S-DALINAC, first operating SRF Accelerator in Germany
- Universität Frankfurt: Structures for Ion Accelerators





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CH Structure for Frankfurt U.

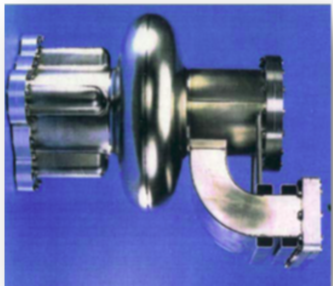
ELBE-style module, Cavity from DESY, Cryostat design from HZDR

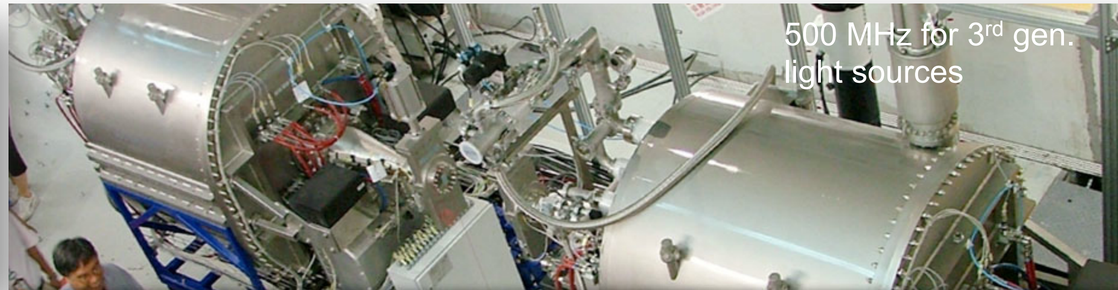
Universities

- TU-Darmstadt: S-DALINAC, first SRF Accelerator in Germany
- Universität Frankfurt: Structures for Ion Accelerators

Industry

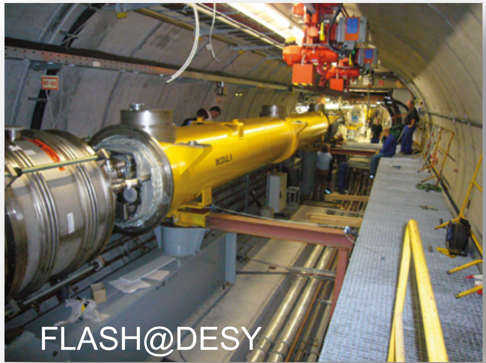
- Research Instruments, world leading supplier of SRF structures/turn key systems





Challenges for the future

SRF works, amply demonstrated!



Next generation systems require:

- significantly more current (orders of magnitude)
- significantly lower dynamic losses (at least factor 3)
- More stable/reliable/precise (e.g., emittance) operation
- significantly reduced cost
  - cavity production
  - ancillary components
  - RF systems (invest and operating)

Many challenges are common to different applications

- E.g., Cavity designs for high-current LINACs can find application in storage rings
- E.g., low-dynamic-loss systems are vital for large LINACs but benefit turn-key compact systems.

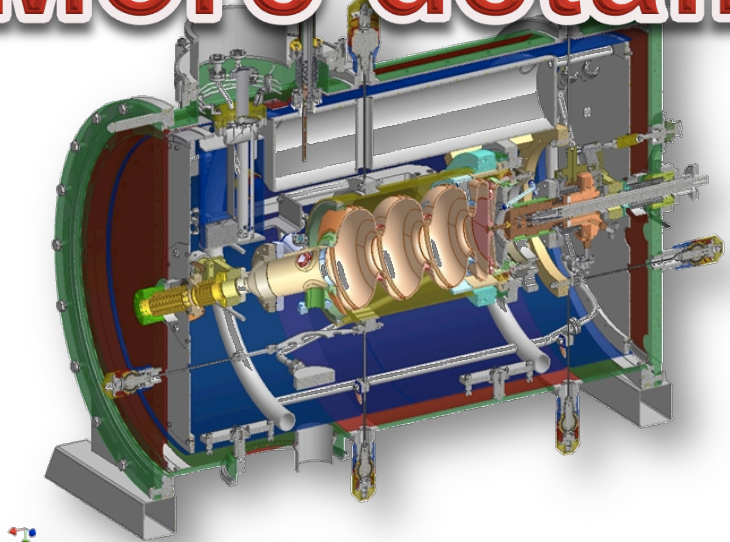
High-current CW electron beams at lowest emittance requires:

- Low power dissipation for CW
- High-rep rate, short-pulse emission control
- High field *and* high voltage (→ high power)
- Stability in beam parameters
- Long life time

SRF photoinjectors have most potential.

- Challenge: Improvement in current by ×100 and emittance ÷10 required

More details: P. Michel

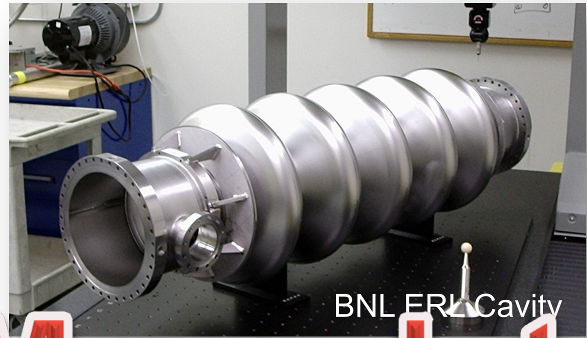


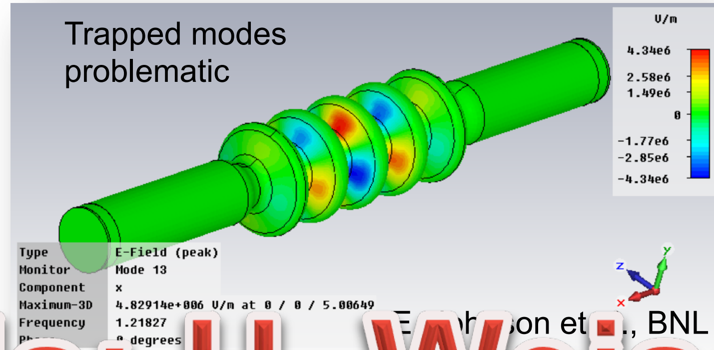
SRF Photoinjector @ HZDR

SRF Photoinjector development at HZB with DESY, JLAB and Soltan Inst. of Nucl. Studies

High-current applications require new structure designs

- High current (100 mA – Amperes) requires “nearly-HOM-free” designs

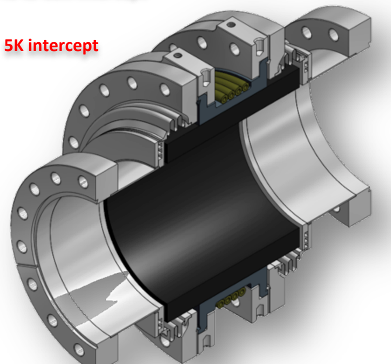




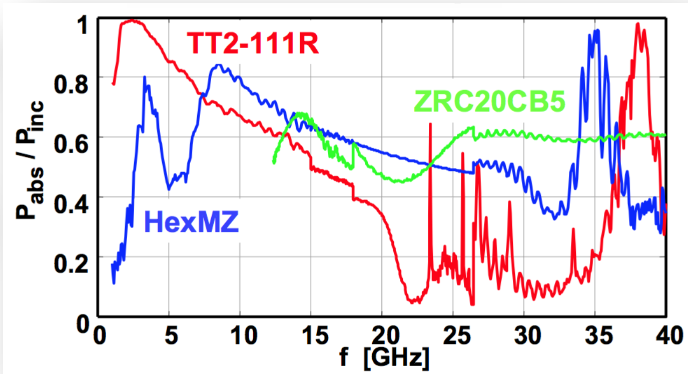
…on et …, BNL

More details: H. Weise

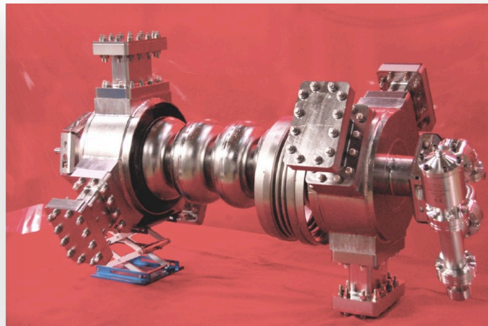
- High current requires efficient HOM damping



M. Liepe et al., Cornell University



Measurements at 80 K

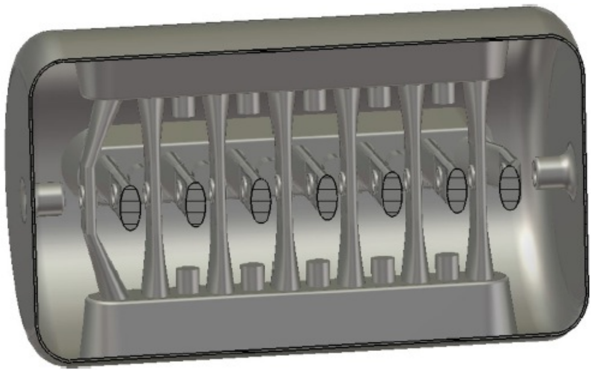


JLAB

Challenges for the future: Structure design

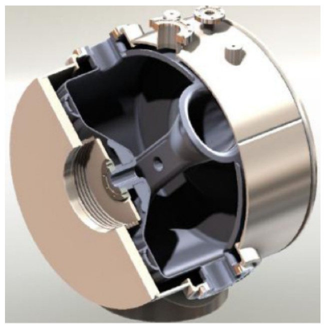
Ion Accelerators: New structures for high current CW systems

- CH Structures for use in GSI's CW SRF Linac project
- Application in other ion machines



- Spoke resonators

Spoke cavities for large range of β



Project X, FNAL

EUROTRANS

J. Delayen, *Proc. LINAC 2010*

To enable 4-K operation consider using spoke cavities for electrons

- Could be of interest for “industrial” applications that want to avoid 2-K operation.

β = 1 Spoke cavities

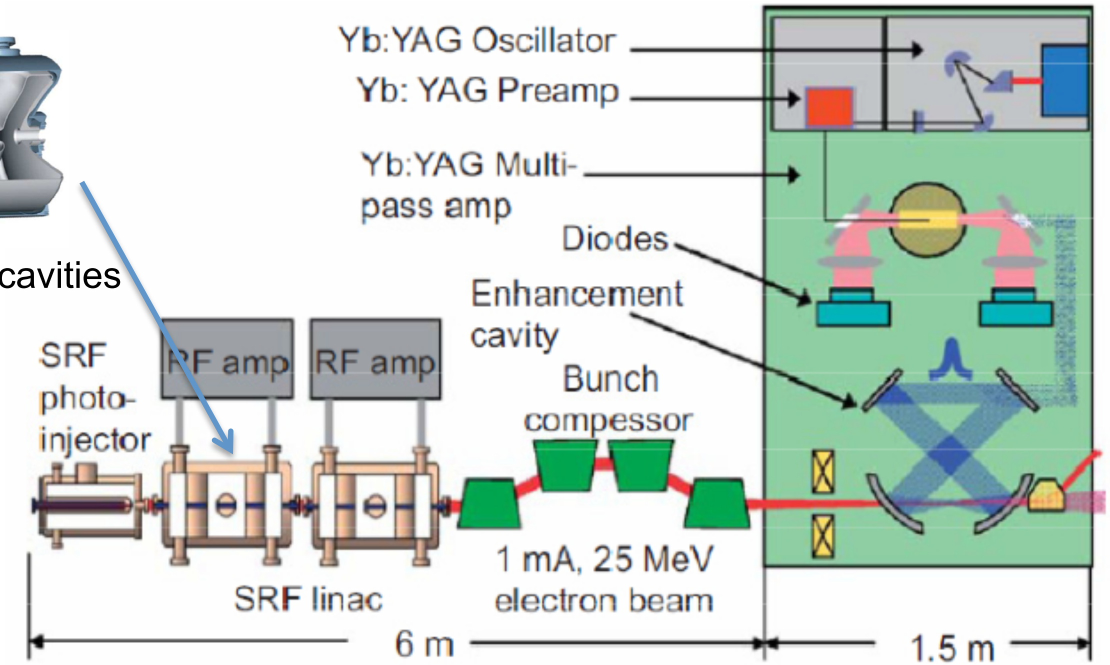


Figure 16: Layout of the MIT reverse Compton Source.

J. Delayen, *Proc. LINAC 2010*

Challenges for the future: Dynamic Losses

CW GeV LINACs require cryogenic capacities in the multi-kW range

- Costly cryogenic plant, can be of order 20% of total linac cost

Compact Sources (100's MeV range) require cryogenic capacities in the 100's W range

- Often prohibitive in size/cost and operation for industrial applications

kW's → 100's W → 10's W

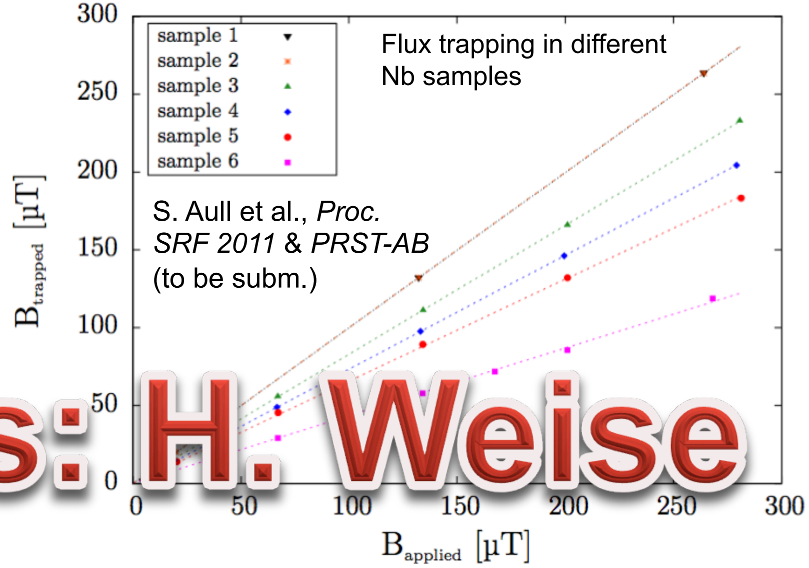
Power dissipation in SRF cavities

ARD

HELMHOLTZ GEMEINSCHAFT

Understand why niobium does not achieve the theoretical losses

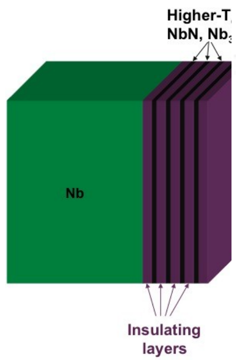
- Understanding flux trapping
- Role of cooldown conditions, thermo-currents
- Impurities ...

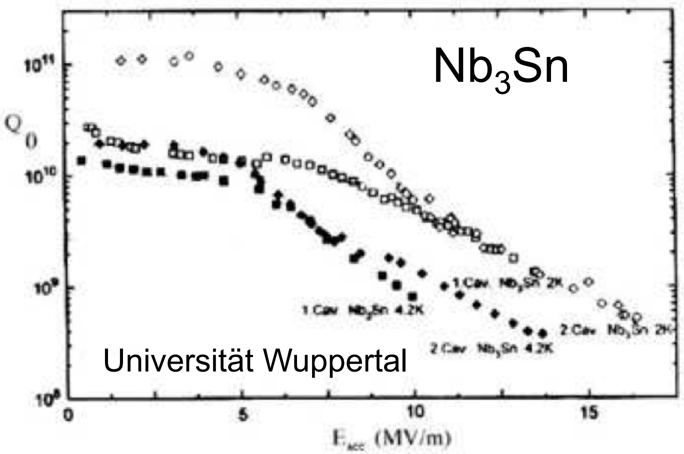


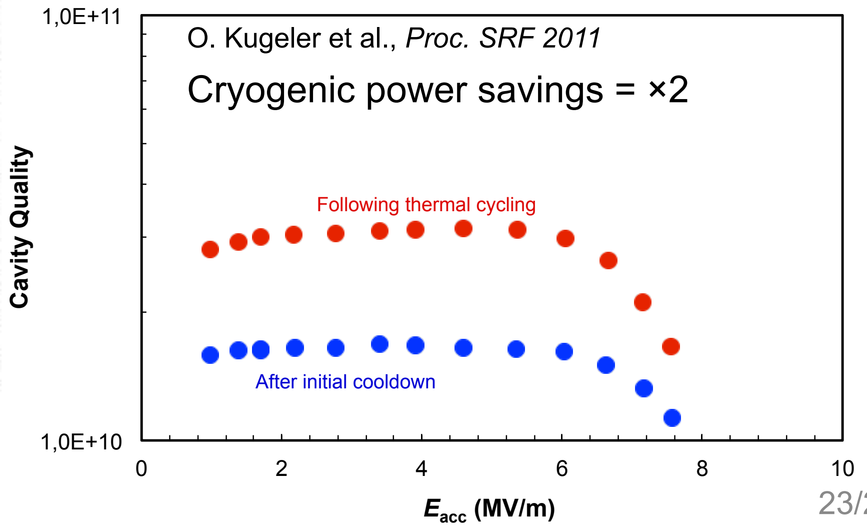
Develop new materials

- M
- Multilayer superconductors

More details: H. Weise



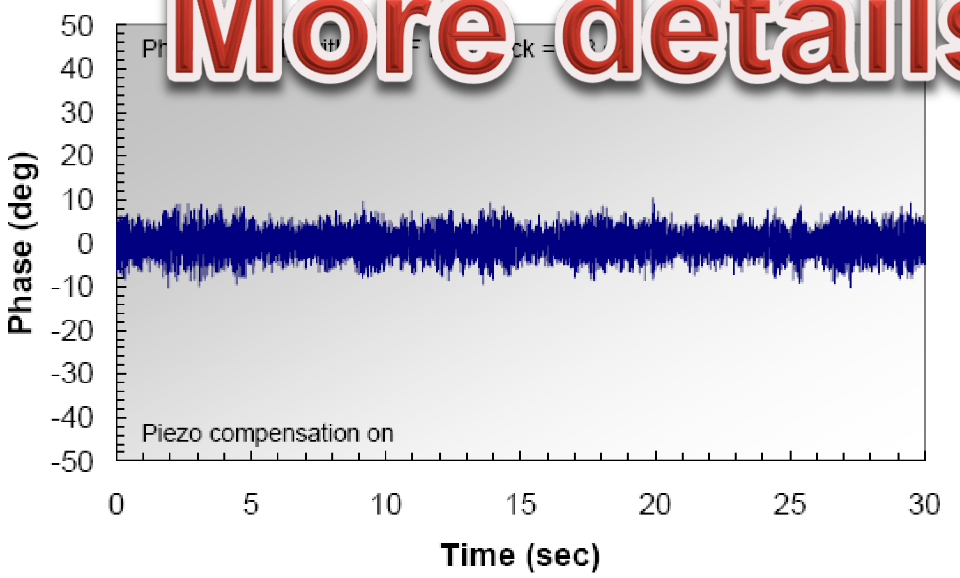




A large portion of wall-plug power is not converted to beam power

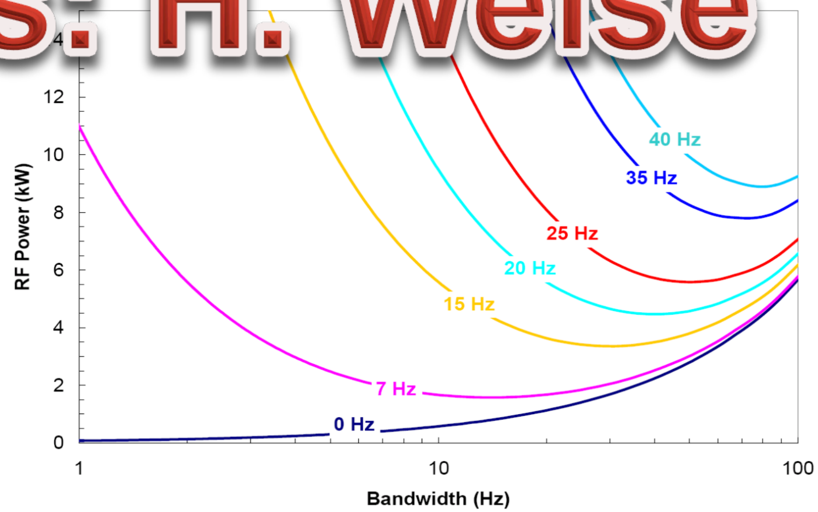
- Efficient transmitters, e.g., IOT or solid state amplifiers
- Learn how to power several cavities with one, larger transmitter.
- Efficient use of RF power: Minimizing external noise sources (e.g., microphonics) through passive and active means. In this example: more than ×4 in installed RF power savings

More details: H. Weise



Microphonic detuning in CW-TESLA cavities measured at HoBiCaT, HZB

A. Neumann et al., *PRST-AB* **13, 0**82001 (2010)



Required RF power for CW-TESLA cavities for different detuning (@ ca. 17.4 MV)

PT-1 Goals: Solving the challenges for NG-SRF Accelerators

Structure design

- Electron accelerators: > 100 mA L-Band system, heavily HOM damped (HZB)
- Ion accelerators: CH Structure for low-beta acceleration of ions (GSI)

RF systems

- Efficient CW RF systems for LINACs (DESY, HZB)
- CW LLRF and microphonics compensation, vector-sum operation of narrow-bandwidth systems (DESY, HZB)

Cryogenic losses

- Understanding and reducing losses in niobium (DESY, HZB)
- New SRF materials (DESY, HZB)

Electron sources

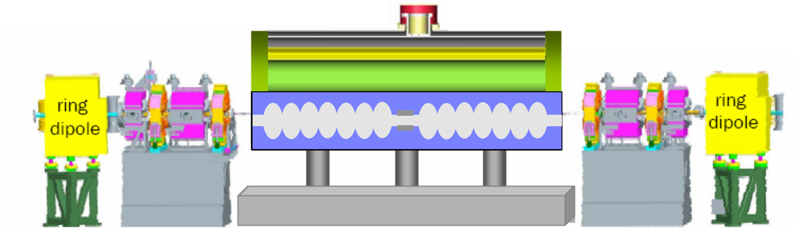
- High-current SRF photoinjector system (HZDR, HZB)

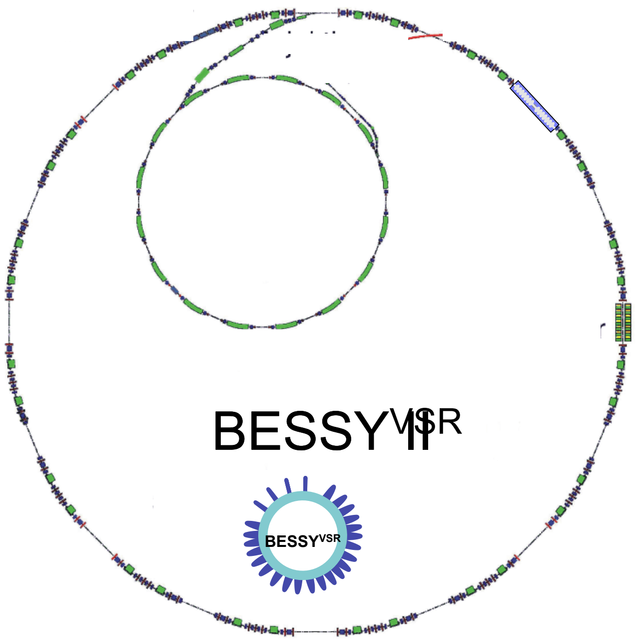
Combine these for a complete CW SRF system for use in high-current machines

Goal: CW SRF Systems with many applications

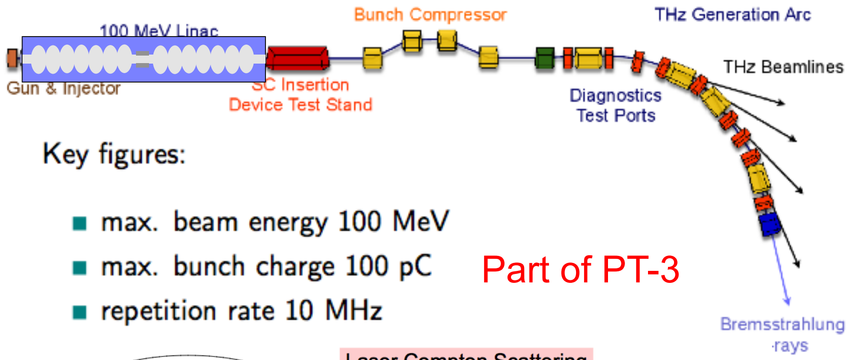
Develop generic CW/long-pulse technology for various applications

- Combine features in a CW System that has broad applicability
- E.g., high-current cavity module with
  - Low power dissipation
  - Optimized RF system for narrow bandwidth
  - Heavy HOM damping for high current operation
  - …





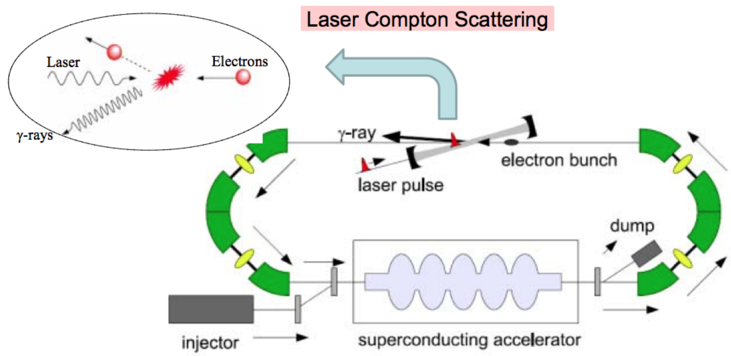
Part of PT-3



Key figures:

- max. beam energy 100 MeV
- max. bunch charge 100 pC
- repetition rate 10 MHz

Part of PT-3



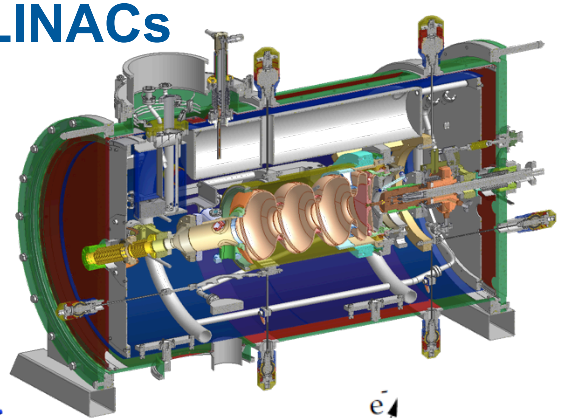
R. Hajima et al., AccApp'07 (2007).

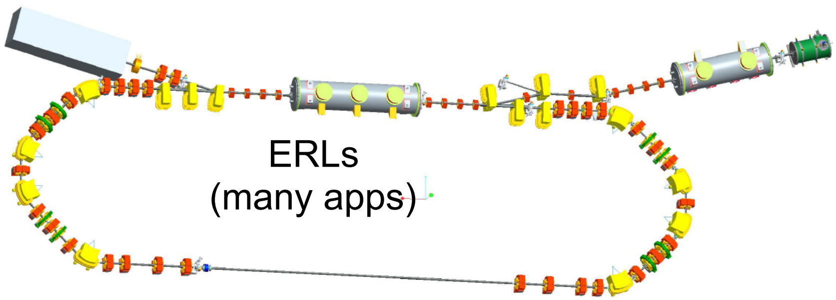
Goal: CW SRF Systems with many applications

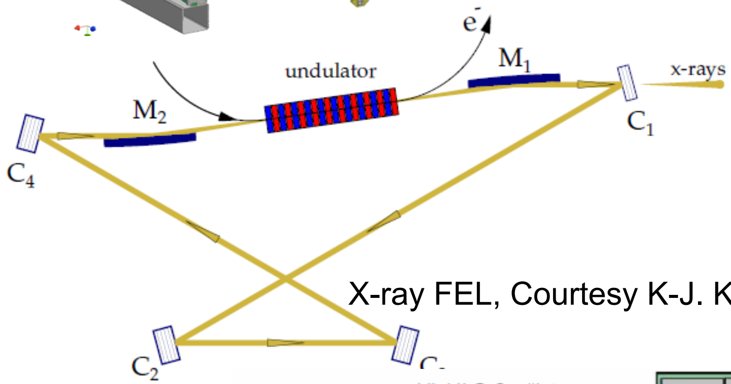
Development of SRF injectors for CW LINACs

- High current
- Low emittance
- Short pulses

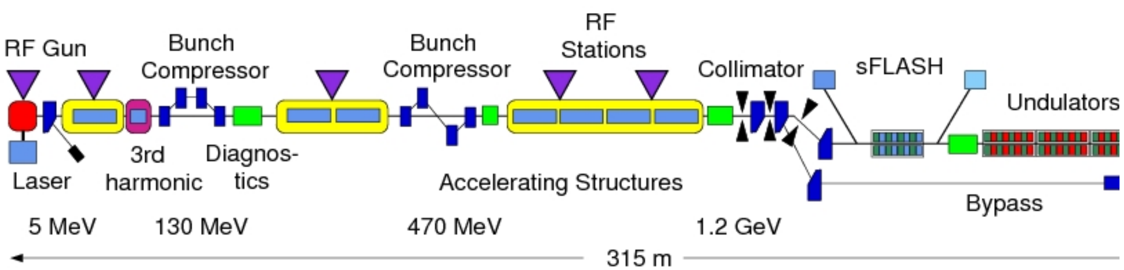
E.g.:







X-ray FEL, Courtesy K-J. Kim, ANL



FLASH operating CW?

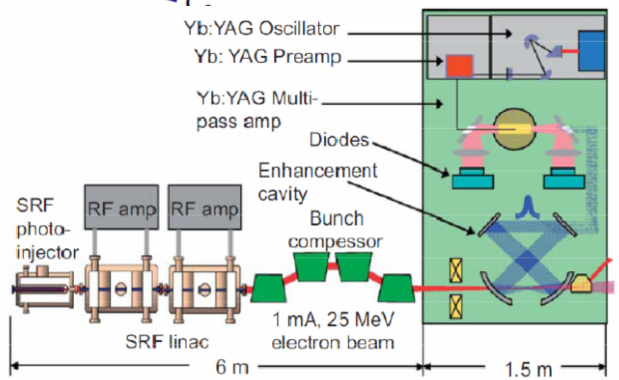
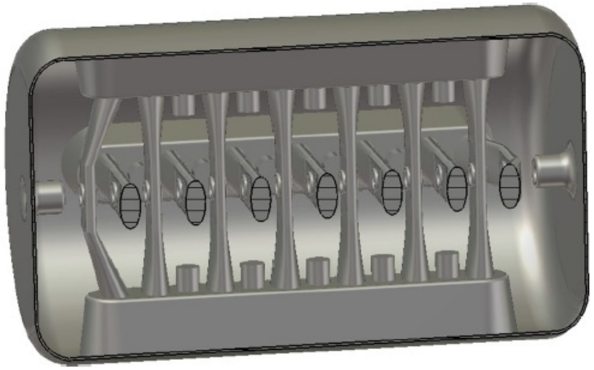
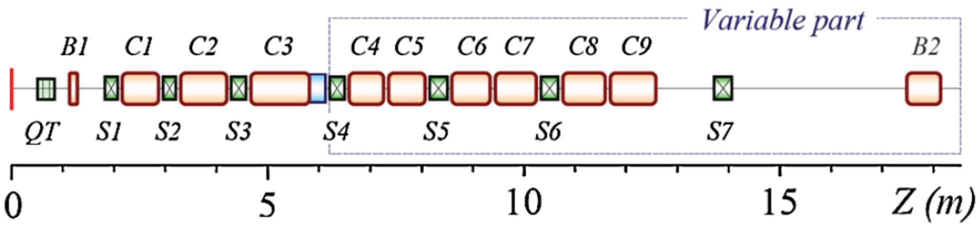


Figure 16: Layout of the MIT reverse Compton Source.
J. Delayen, *Proc. LINAC 2010*

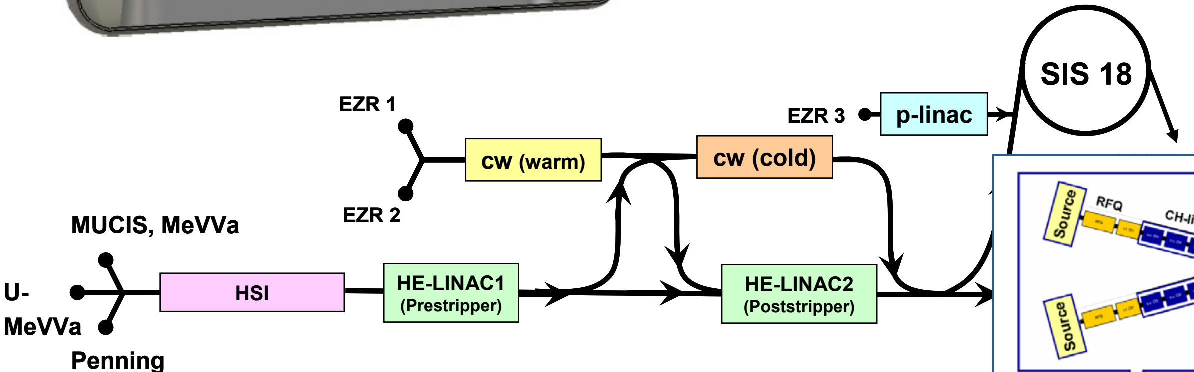
Goal: Ion structures for CW applications

GSI Superconducting CW LINAC

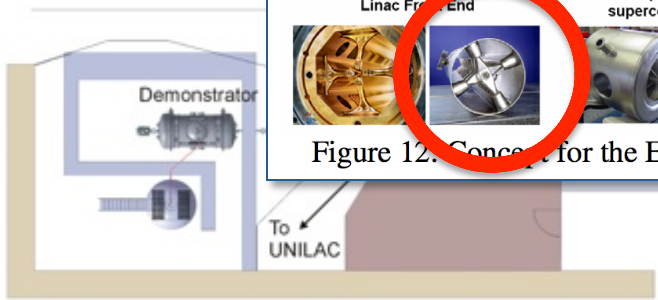




Mass/Charge		1/6
Frequency	MHz	217
max. beam current	mA	1
Injection Energy	MeV/u	1.4
Output energy	MeV/u	3.5 – 7.5



Demonst



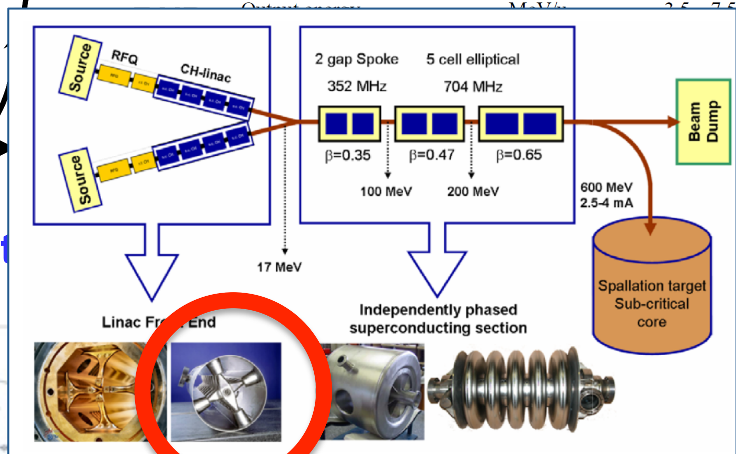


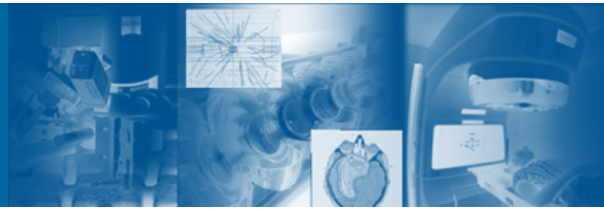
Figure 12. Concept for the EUROTRANS Project.

Motivation:

Element 120, <0.1 pb (1pb <-> 1 event/week)

	GSI-UNILAC	cw-LINAC
Beam Intensity (particles/sec) *(S. Hofmann et al, EXON 2004)*	3 $*10^{12}$	6 $*10^{13}$
Beam on target	10 weeks	4 days

Thank you



Thank you for help in compiling this talk

Winfried Barth (GSI)
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Peter Michel (HZDR)
Anke-Susanne Müller (KIT)
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