Highlights report on workshop ‘perspective for Accelerator Physics and Technology

H. Qian

PPS
Zeuthen, 09.03.2017

HELMHOLTZ | ASSOCIATION

DESY

Introduction

The workshop is intended to set up a longer-term strategic discussion

-> Strategiepapier ***Beschleunigerphysik 2030***

Three parts:

1. Needs for the community using accelerators for the next 10 - 20 years
2. What facilities are upcomming/ planned / being considered ? What R&D is required to upgrade/ build such facilities ?
3. Technologies for enabling future accelerators

The workshop should provide input for:

1) Strategietreffen PkT, 15-16 Mai 2017, BMBF, Bonn

2) Verbundforschungsworkshop PkT, September, 2017

KfB
Komitee für Beschleunigerphysik

https://indico.cern.ch/event/581462/overview

Empfehlungen:

KOMITEE FÜR BESCHLEUNIGER-PHYSIK KfB

Eine zentrale Empfehlung ist die Stärkung der Zusammenarbeit zwischen Forschungszentren und Universitäten, insbesondere auch bei der Ausbildung des wissenschaftlichen Nachwuchses.

Empfehlungen zur Großgeräteinfrastruktur in Deutschland sowie unter deutscher Beteiligung:

- Ausbau und Weiterentwicklung von Synchrotronstrahlungsquellen und Freie-Elektronen-Lasern zur Erzielung höherer Strahlqualität und -intensität.
- Bau und Weiterentwicklung von FAIR im Hinblick auf die Erzeugung brillanter Ionenstrahlen und die Optimierung der Produktion von Sekundärstrahlen sowie deren Kühlung.
- Unterstützung von Beiträgen zu internationalen – insbesondere europäischen – Großprojekten wie z.B. HL-LHC, ILC, FCC und ESS.

Empfehlungen zur beschleunigerphysikalischen Forschung und Entwicklung:

- Weiterentwicklung der supraleitenden Beschleunigertechnologie, insbesondere von Resonatoren für den Dauerstrich-Betrieb und von Magneten für Strahlen höchster Energie.
- Forschung und Entwicklung in übergreifenden Bereichen wie Strahldiagnose und -stabilität, Simulation, Synchronisation, Kontroll- und Regelsysteme sowie bezüglich der Verfügbarkeit der Anlagen und der Entwicklung neuartiger Hochpräzisionsanlagen
- Weiterentwicklung neuartiger Beschleunigerkonzepte im Hinblick auf deren zukünftige Anwendung.

Beating scaling laws

Need to beat E ~ length (limited by B for circular hadron colliders
limited by SR for circular e^+e^-
limited V_{acc}/m for linear accelerators)

Need to beat E ~ $$$ (limited by public acceptance)

Need to beat $\int \mathcal{L} dt$ ~ GWy (running cost becomes a limiting factor)

Any R&D addressing these challenges is worth the effort!
We (particle physicists) strongly support such R&D!

- high-field low-power (SC) cavities
- high-field magnets
- plasma wakefield acceleration
- ...

be courageous!

Conclusions

- Particle physics relies and will rely on high-energy accelerators
- Mid-term: 1-2 more big machines worldwide (ILC@JP, postLHC@CERN, China??)
  - many side-effects, spin-offs (SCRF, high-field magnets, ...)
- The (long-term) future has to start now – particle physics supports R&D towards fundamentally new and/or cost-saving technologies
- Exploit synergies with other fields (light sources, NP facilities, medical + mat. science applications, ...)
- The physics case for „particle physics“ will remain fascinating for us and for society → technological driver for accelerator physics

Summary New Collider Projects

'New' Collider Projects that are already on their way:

- Super KEKB → DA, beam-beam, space charge, e-cloud, lifetime
- HL-LHC → SC magnets, SC RF [Crab Cavities & HHRF]

Collider Projects for the immediate Future (< 10 years):

- Electron-Ion collider (MEIC, eRHIC, LHeC) → ERL & pol.

→ Affordable (comparable to LHC)

Collider Projects for the near Future (> 10 years):

- HE-LHC → SC magnets (> 16T → 2 x CME); no HEP for 10y
- Linear Collider projects: ILC & CLIC → cost, power, positrons
- FCC-ee → cost, power, SRF, beam lifetime
- CepC project → cost, power, SRF, beam lifetime

} Super KEKB

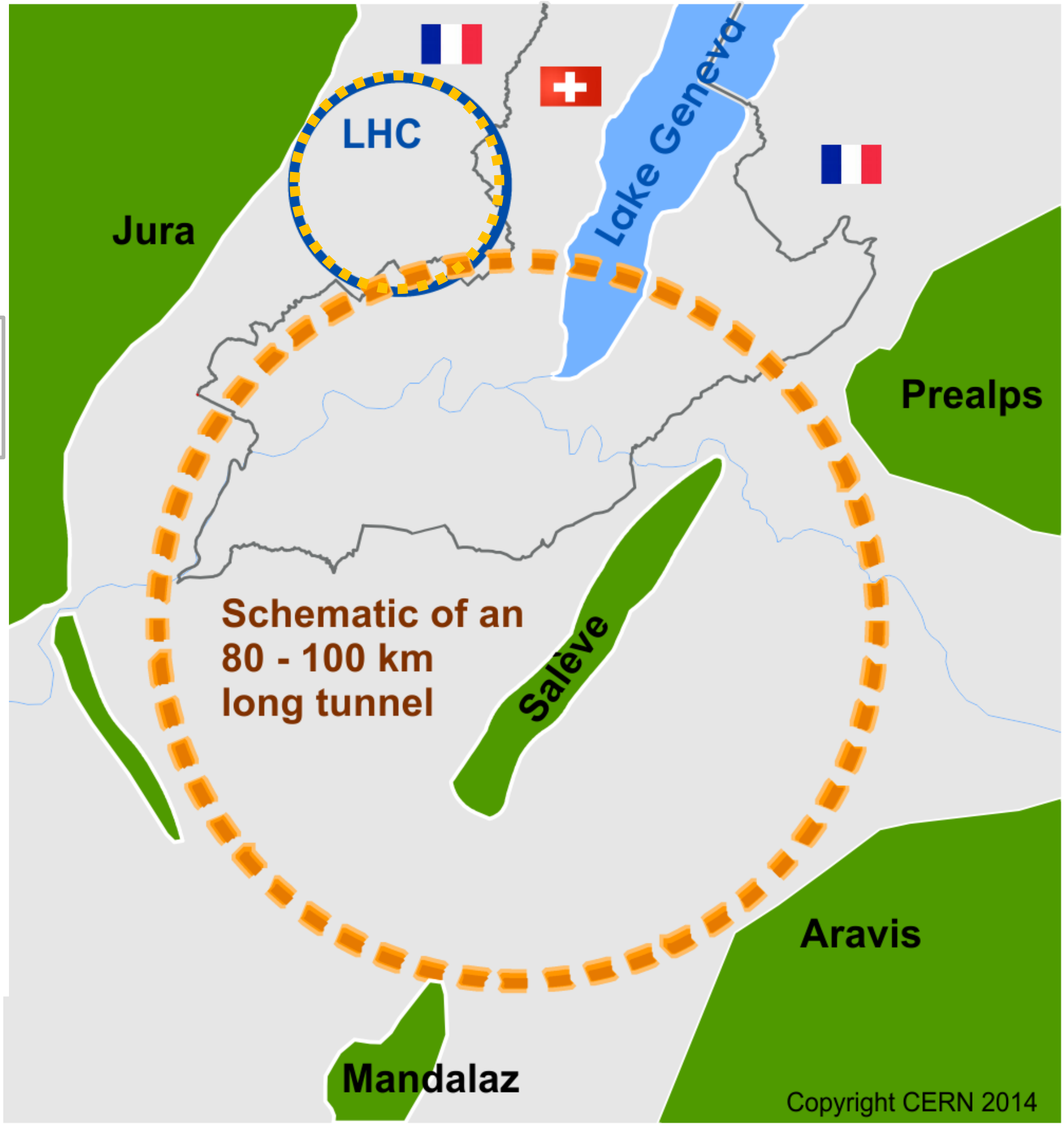
Future Circular Collider (FCC) study; goals: CDR and cost review for the next European Strategy Update (2018)

International collaboration :

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

~16 T ⇒ 100 TeV in 100 km
~20 T ⇒ 100 TeV in 80 km

- including ***HE-LHC*** option: 16-20 T in LHC tunnel
- ***e^+e^-* collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**
- **100 km infrastructure** in Geneva area



M. Benedikt

Linear Collider Technological Challenges

Linear Lepton Collider Challenges:

- Superconducting RF:

  1.3 GHz with high Q_0 & reasonable aperture

  ➔ efficient operation

  Niob, 35MV/m @ 1.8K ➔ limited energy reach!

- Normal conducting RF:

  12 GHz ➔ high gradients (100MV/m) & novel power sources

  ➔ energy reach for given length

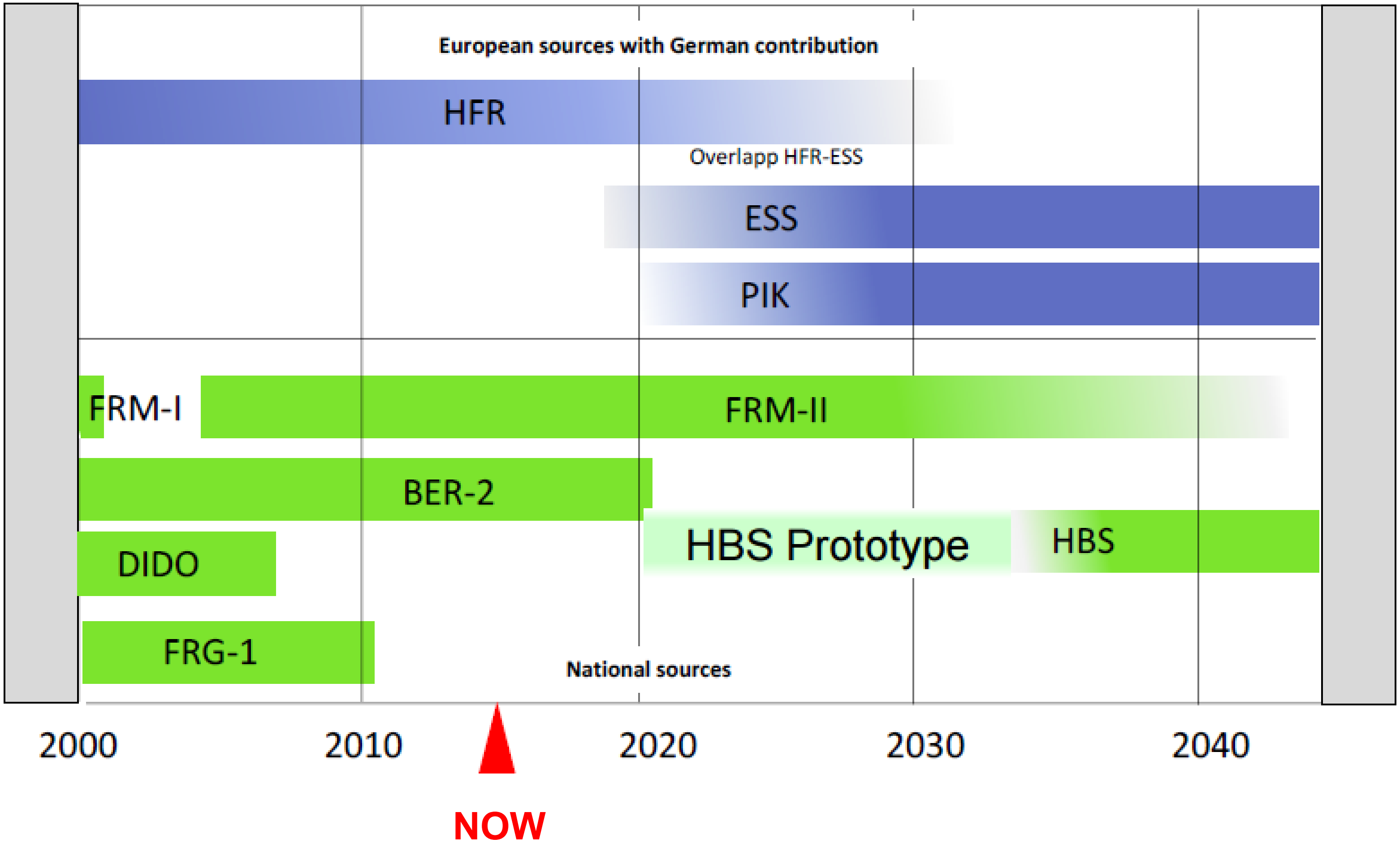
  small apertures and low Q_0 ➔ efficiency and power consumption

Common goals and key aspects:

- Site size: between 30km and 50km
- Peak luminosity: > 10^{34} $cm^{-2}s^{-1}$
- Beam power (> 1MJ) ➔ machine protection
- Site power consumption: > 300MW ➔ 600MW
- Price: > 4 x LHC cost

Research with Neutrons (Thomas Brückel, JCNS)

German Neutron Strategy until 2045



Research with Neutrons

High Brilliant neutron Source

Novel sources:

- high brilliance for small samples
- easy access for universities and industry
- education, user recruitment

Price tag	
small	10 M€ - 30 M€
full facility	200 M€ - 300 M€

Present Design Parameters (Accelerator)

Energy (MeV)	5	10	30	50
duty cycle	1-2% (1:100, 1:50)	1-5% (1:100, 1:20)	1-3.3% (1:100, 1:30)	1-2% (1:100, 1:50)
duty cycle of power supply		1.2-6 %		
average power (kW)	1	10	20	100
peak power (kW)	50	200	600	5000
peak current (mA)	10	20	20	100
frequenzy (Hz)	100 (20-400 variable)	100 (20-400 variable)	100 (20-400 variable)	24, 96, 384 (20-400 variable)
pulse length (μsec)	50-2500	50-2500	50-1000	50-1000
ion source	D^+	H^+, D^+	H^+, D^+	H^+, D^+

Conclusions

EUROPEAN SPALLATION SOURCE

- ESS will be the frontier (accelerator-based) facility for neutron science in Europe for the next 10-20 years
  - Hard to see that a second facility of that scale could be funded and built any time soon.
- ESS cannot by far satisfy the need for neutron sources in Europe
  - Compact sources would be important to foster the field
  - Compact: affordable by a single institute or university
    - In the spirit of light sources
  - Building new reactor-based facilities does not look promising
- Complementary features of neutron scattering and synchrotron radiation should be better exploited
  - Could open up totally new perspectives
- Accelerator technology has to be complemented by powerful control systems and data handling capabilities
  - “big” data is coming to the accelerator world

Nuclear Physics (Thomas Aumann, GSI)

Summary and my rough view on the time line of radioactive beams

0 - 10 years: FAIR construction
upgrades and completion of ISOL facilities
(SPIRAL, Hi-Isolde, SPES,..)

10 - 20 years: FAIR operation
FAIR moderate upgrades
EURISOL distributed facility

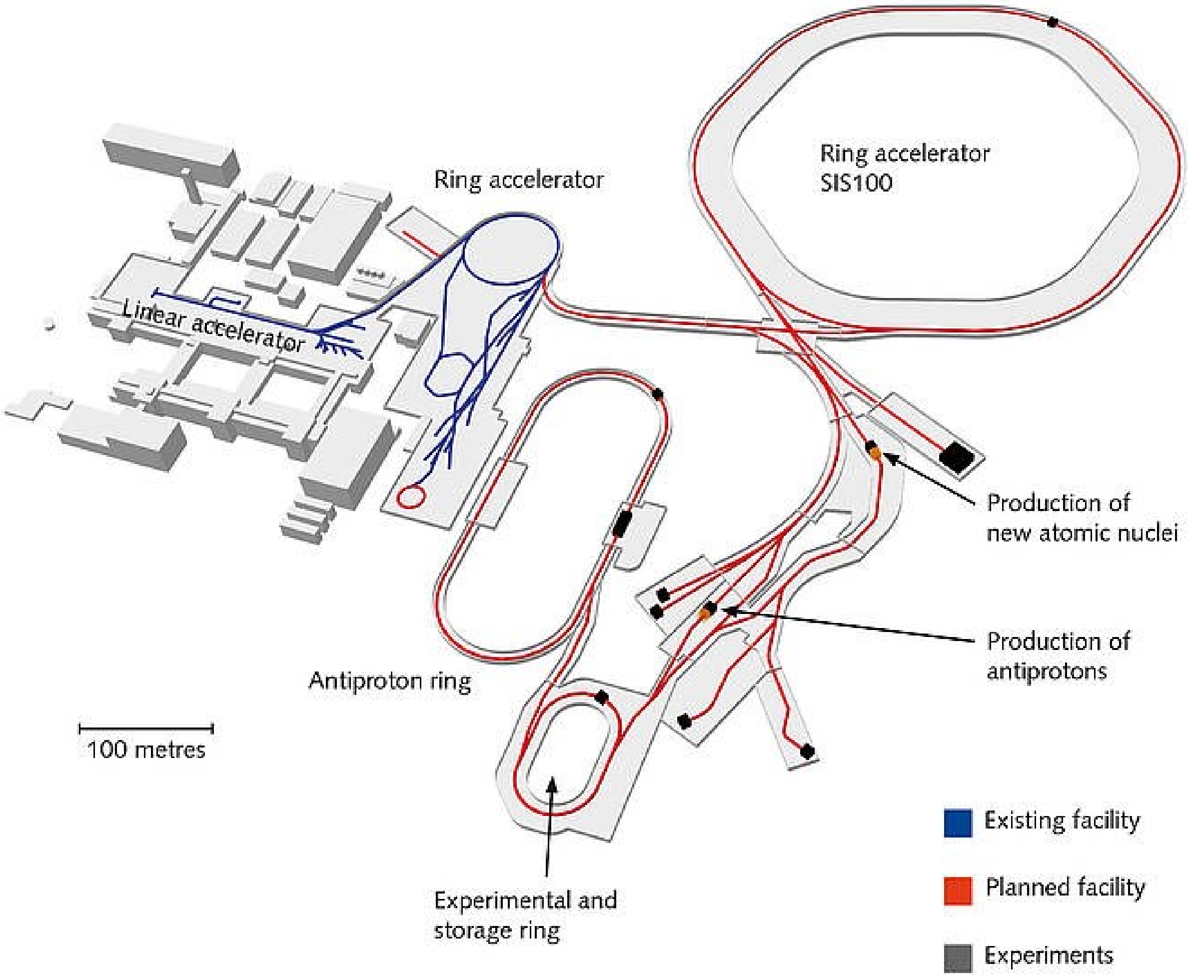
20 - 30 years: FAIR operation and completion of full FAIR
EURISOL ?

Definition of the ultimate Radioactive-Ion-Beam facility ?
It is about intensity ... But not only !

➔ we need the ‚eierlegende Wollmilchsau'

Nuclear physics

Price tag: 1.357 Billion Euro



FAIR
Facility for Antiproton and Ion Research in Europe GmbH

- Highest particle intensity (10^{12}/s Uranium)
- highest precision
- highest diversity of accelerated ions
- high particle energies (1.5 GeV/u)
- parallel operation of up to four experiments at the same time

High-intensity mono-energetic gamma source: ELI-NP

TECHNISCHE UNIVERSITÄT DARMSTADT

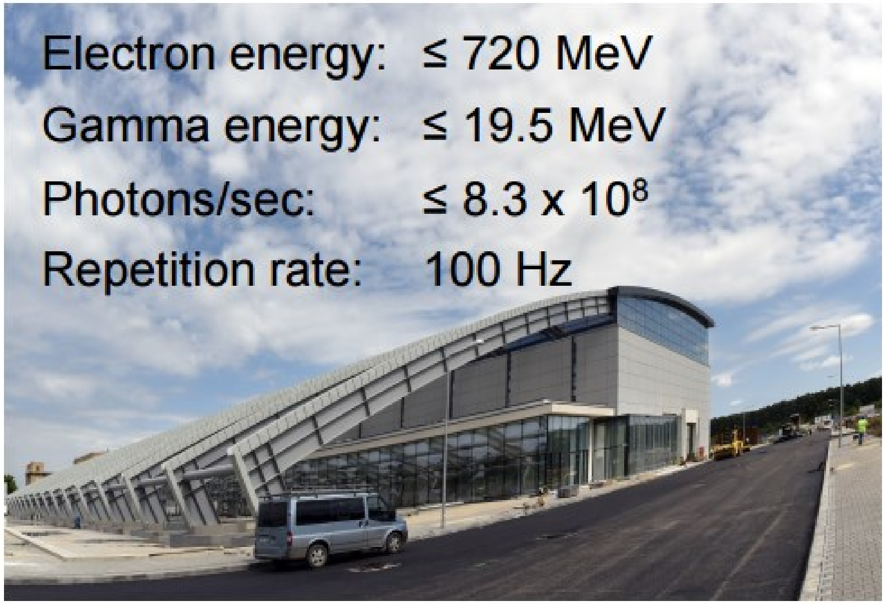
Low-emittance electron beam +
Compton back-scattering

Projected completion date: mid-2019

Full facility operation +1-2 years

(Sydney Gales, Town Meeting talk, 2017)

New opportunities for nuclear physics using photon scattering (Nuclear Photonics)



<u>Dream for the future ? Ideal gamma source for nuclear physics:</u>

Mono-energetic, high intensity, high resolution

plus

Full nuclear-physics energy scale: 1 – 140 MeV

High repetition rate: coincidence / scattering experiments

Conclusion: Perspectives 10-20 years

Major new facilities/upgrades will come available in 2018-2025 !

Examples: Spiral 2 / France, FRIB / USA , FAIR / Germany

The next 10-20 years: Commissioning, Optimization for high-intensity, Exploitation

Key or critical components (with ongoing R&D efforts):

- Compact rf cavities (low/medium beta): post-acceleration
- Ion sources: ECR, Lasers ?, …
- Strippers: Gas, Plasma or „advanced materials"
- Beam cooling at medium/high-energies: stochastic, electron, laser, „advanced"
- Accelerator physics, „advanced" full-scale simulation codes, optimization schemes

Afterwards:

- Eurisol (MW proton driver) ? Compact high rep. rate laser ion accerators ?

Always:

- New ideas are welcome: Multi-charge state acceleration and FFAG, ….

Research with Photons (Stefan Eisebitt, MBI)

Some Perspectives (my personal view)

Max-Born-Institut

Storage Rings:

- Nanoscale information (focussing, imaging)
  → **high brightness**, diffraction limited sources
- Time resolved information (pump-probe)
  → **short pulses**, timing modes
- In-situ / in operando experiments
  → complex addl. instrumentation (**stable beams**)

FELs:

- many new topics
- e.g. non-linear x-ray matter interaction
  → **laser-like beams**
  (wavelength, pulse energy, pointing, pulse profile)
- e.g. fast & short range excitations
  → **2 x-ray pulses, 2 colors**
- pump lasers (or 2nd x-ray pulse) are as important as FEL beam
- Solids: few femtoseconds, AMO: attoseconds

Issues

Max-Born

- short time scale (Auger < 1 fs)
  → FEL pulse duration
- well defined x-ray spot on sample (nonlinear process!):
  → λ, I(r)
- 2 x-ray pulses λ1, λ2 at Δt would be helpful
  → x-ray optics vs. accelerator-based

Accelerators for Research with Photons (Andreas Jankowiak, HZB)

Conclusion

- **many existing large scale facilities are aiming for upgrades**
  DLSR – ESRF, PETRA, ALS, APS, DIAMOND, SOLEIL, …
  VSR – BESSY
  FEL – cw upgrades FLASH, XFEL, … / more beam lines / higher Energy
  but upgrade = possibilities always somewhat constrained

- **at present no proposal for a "new, greenfield" large scale facility**
  - we have many tools in hand (DLSR, VSR, cwFEL, ERL)
  - science case "for the facility" will decide about technology

- **technology development will be important driver**
  - high gradient (100 T/m and more), multipole and combined function magnets
  - permanent magnets, also for "more efficiency"
  - fast kicker magnets (ns), transparent injection, beam separation in switch yeards
  - new ID concepts, short period, low gap, making use of round beams and small dynamic aperture
  - low aperture vacuum systems (< 5mm)
  - high brightness, high current photon sources (< 0.1 μm rad, mA – 100mA+)
  - high gradient, high Q, high temp. SRF / cwSRF, HOM extraction
  - laser for seeding, pump-probe, synchronisation, seeding technics, ….

- **novel acceleration concepts (PWA, dielectric structure) have great potential**
  - LPWA as "laboratory scale devices", low rep. rate
  - BD PWA have potential for "compact" multi user facility

Medical accelerator (HEINRICH RÖCKEN, VARIAN)

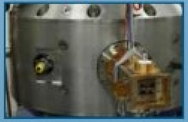
Technology Future
Timeline

Now | +5 Years | +10 Years | +15 Years

SC Cyclo

Very Compact SC Cyclo

SC Synchro Cyclo

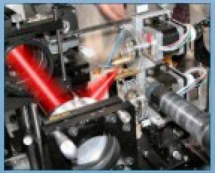


Compact Proton Synchro

Dielectric Wall Acc

Proton FFAG

Laser Plasma Acc



Technology Future
Technology Ranking

VARIAN medical systems

Requirements for Future Particle Therapy Accelerators
Wish List

- Small / light
- CW beam
- Multiple energies
- High dynamic beam intensity range (1-250nA at the patient)
- High efficiency = low activation
- 1-day installation
- 1-day commissioning
- Stable operator-less operation
- High uptime (MTBF, preventive maintenance)
- Maybe most important: low TCO
    - Building / footprint
    - Service / parts
    - Power consumption
    - Radiation safety licenses
    - Easy disposal
    - ...

Accelerator Technology used for Particle Therapy (Andreas Peters, HIT)

Summary / Perspectives

- There is still a lot of potential for the advancements of existing (cyclotron and) synchrotron based facilities, e.g. usage of superconductivity or enhanced "multiple-energy" operation modes.
- In Particle Therapy a view on the whole chain – accelerator, irradiation technique, diagnostics – is necessary to lower the costs of such facilities and/or to enhance the functionality, e.g. combining proton/ion treatment with MRI.
- One potential candidate for future particle therapy sources are laser driven acceleration schemes, but still a lot of fundamental research is necessary! A closer collaboration of the laser community and the accelerator physicists may help sometimes, e.g. in the field of diagnostics.

Accelerator Technology used for Particle Therapy (Andreas Peters, HIT)

Combining proton/ion beams with MRI

<u>Furthermore:</u>
Doctors normally use large margins around the tumor volume because of possible range uncertainties, movement of the tumor along the irradiation, etc. → Better diagnostics is necessary to shrink these margins!

A 6.5 mm thick margin (peel) consists of the same volume as a 5 cm diameter target (orange).

Challenges for CW SRF systems

Power dissipation

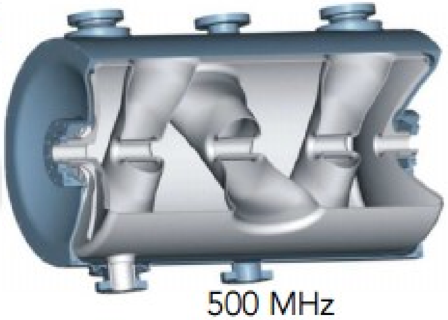
- P_{diss} amounts to a few kW for a machine as LCLS-II (10's W/m)
- This sounds negligible but it is dissipated in liquid helium
  - Expensive and complex cryoplant + large wall-plug power (MW's!)
- Especially for CW LINACs, the dissipation cannot be neglected.
- Even for "small" installations (e.g., BESSY VSR) the plant is costly/complex
- Careful management and understanding of losses is required

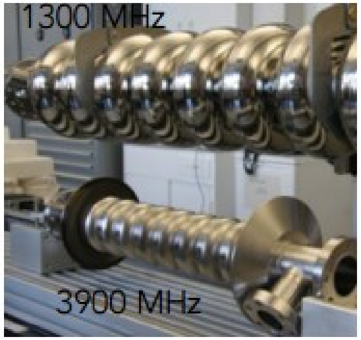
Challenges for CW SRF Systems

Structure geometry

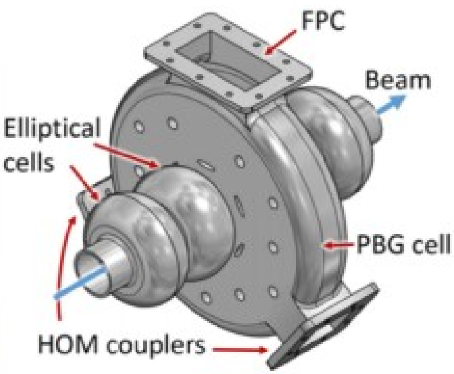
SRF's design flexibility has spawned applications with very challenging design requirements that must address many aspects:

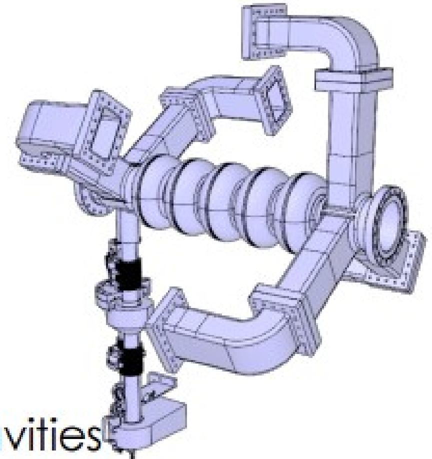
- Frequency
- Particle species (electrons, protons, ions)
- Beam current I_b & impedance
- Field E_{acc} and voltage V_{acc}
- Beam loading $V_{acc} \times I_b$
- Operating mode: accelerating, deflecting, zero-crossing . . .





Ion accelerators





High current cavities

Challenges for CW SRF systems

Beam source

For LINAC-based systems the onus is on the beam source to deliver the prerequisite (often challenging) beam properties!

- Full CW operation must be possible
- (Sometimes) high charge required
- Low normalized emittance and shortest pulses
  - Rapid acceleration to high energy needed to avoid non-linear space
- High average current
- Longevity of operation
- Flexibility to adapt to changing user requirements
- . . .

- Non-SRF based source options exist, but SRF systems have unique potential to outperform the others.

Superconducting RF (Jens Knobloch, HZB)

Take-home message!

HZB Helmholtz Zentrum Berlin

UNIVERSITÄT SIEGEN

New accelerator have demanding source & RF system requirements

- SRF is established technology but far from end of the development
- SRF: Freedom to optimize designs & operating modes for sources, acceler-ation & beam manipulation w/o crippling constraints of power dissipation
- Some key areas of R&D
  - Reliable, high-brightness sources
  - Eliminating anomalous losses/development of new materials for a drastic reduction (if not elimination) of the cryoplant
  - Structures that are able to handle very high-currents (only partially discussed)
  - Reduction of the cost (not discussed): SRF+cryogenics can be order 50% of project cost: Cavity/Module, RF transmitters, couplers + many more things …
  - Attaining, maintaining and recovering high performance → "turn-key system"
- All of these are challenging, but (a) SRF has proven its mettle in the last 2 decades and (b) much exciting progress has been made recently that leaves us with a "can do" spirit!

Summary

- **Today, accelerators are large-scale, cutting-edge tools for photon science, high energy physics, cancer therapy, …**
- **Plasma technology offers a promising path to miniaturize accelerators by a thousandfold**
- **Hope:** miniaturization of accelerators leads to
  - significant cost reduction
  - widespread proliferation of compact accelerator technology → universities, hospitals, developing countries…
  - beams with new and extreme properties
- **Overarching goal must be:**
  - plasma accelerator research → usable plasma accelerators
- **Staged approach to get there:**
  - First (~10 year frame): demonstrate controlled, stable single stage → sufficient for most of applications (except HEP)
  - Then (>> 10 years): scale technology to energy frontier
- **Development of stable, controlled, plasma-based accelerator is (likely) beyond average university lab capabilities**
- **Needs close, international collaboration between universities (for basic research), national labs (for research and engineering resources), and industry (e.g. laser engineering)**
- **If we do this right, plasmas may have a revolutionary impact on future accelerator applications**

Beam instrumentation in 15…20 years

- **“Bread and butter” instrumentation**
  - copy and paste
  - collaborations with industry/institutes/universities
- **The R&D frontiers:**
  1) Unprecedented request for precision
     - Positioning down to well below the micron level
  2) Treatment of increasingly more data
     - Bunch by bunch measurements for all parameters
  3) Dealing with high beam powers
     - Non-invasive measurement techniques
     - Robust and reliable machine protection systems
  4) Dealing with the ultra-fast
     - Measurements on the femto-second timescale
  5) Dealing with the ultra-low
     - Measurement of very small beam currents
- **Timing and synchronization (not treated today… …somewhere between LLRF, controls and BI)**