WG-E Summary
Beam Instruments and Interactions

Conveners Hee-Seock Lee (PAL)
Tom Shea (ESS)
Michiko Minty (BNL)

Organization
- 15 invited talks
- 2 discussion sessions
- posters

Topics
- Beam instruments for high intensity accelerators
- Beam loss and activation
- Collimation
- Beam material interactions

Beam instrumentation for high intensity accelerators (5 talks)

Beam loss and activation

Collimation

Beam material interactions

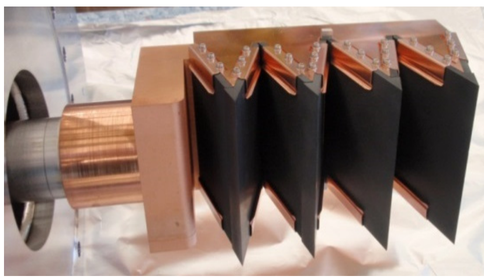
Beam Instrumentation for High Intensity Accelerators

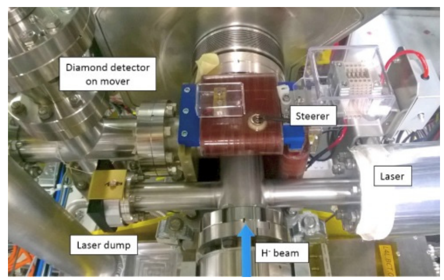
Performance of Linac-4 Instrumentation during Commissioning

Uli Raich

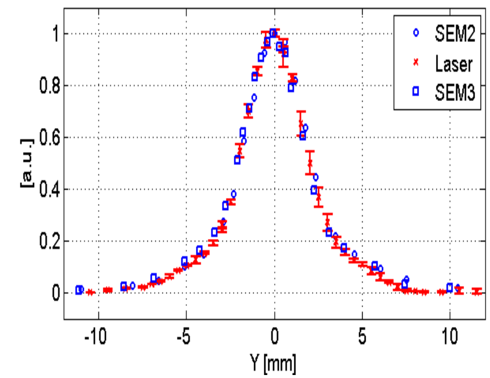
Instruments from various commissioning stages (up to 100 MeV)

Cross-validation between instruments – excellent agreement →

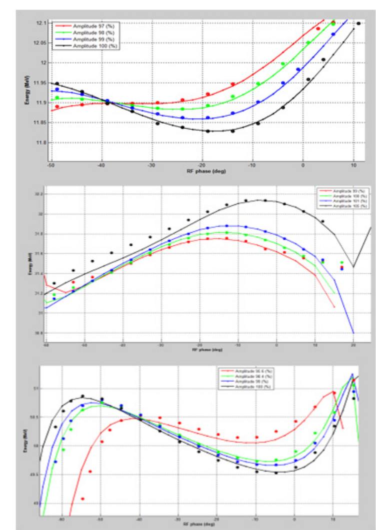




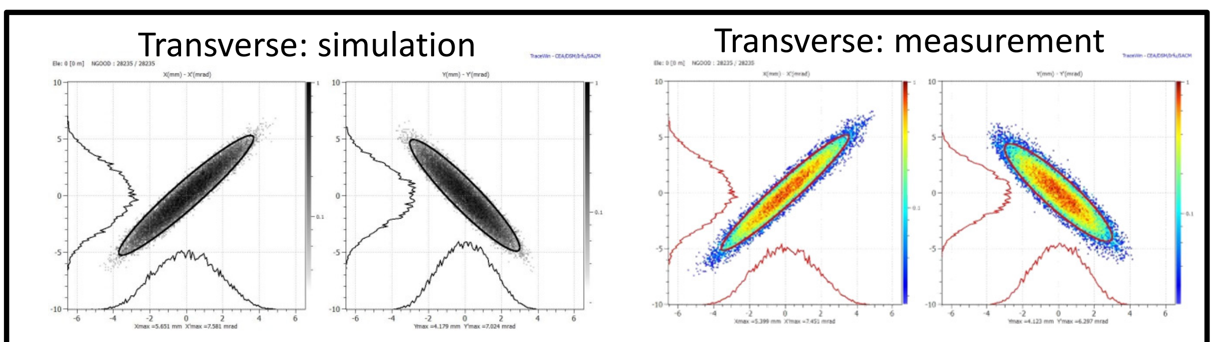
Transverse profiles



Longitudinal: energy vs phase (simulation and measurement)



Comparisons to simulation - excellent agreement



Acceleration to 160 MeV (post PIMS installation) by end of this year

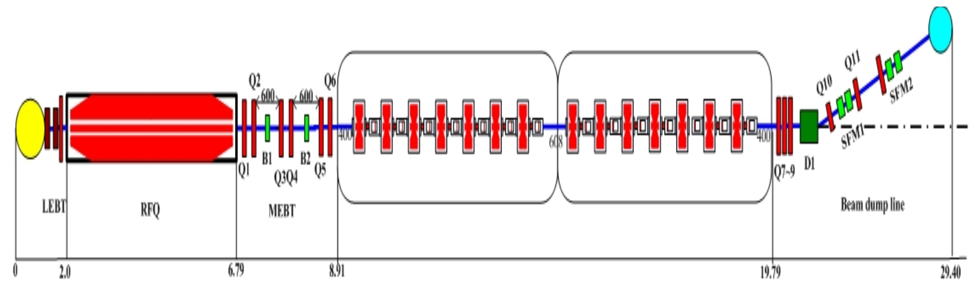
Beam Instrumentation for High Intensity Accelerators

Beam Commissioning of C-ADS Linac Instrumentation

Yanfeng Sui

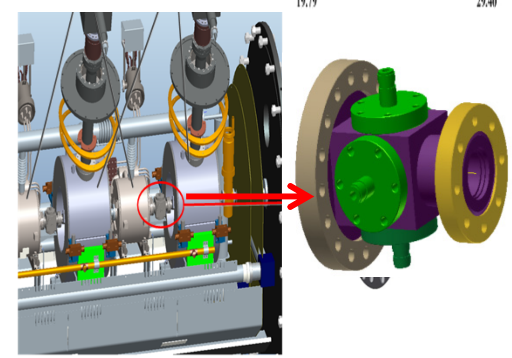
Institute of High Energy Physics
Chinese Academy of Sciences

Presentation with overview and detail on beam commissioning of C-ADS linac beam instrumentation (p, 10 MeV, 10 mA, 100 kW).

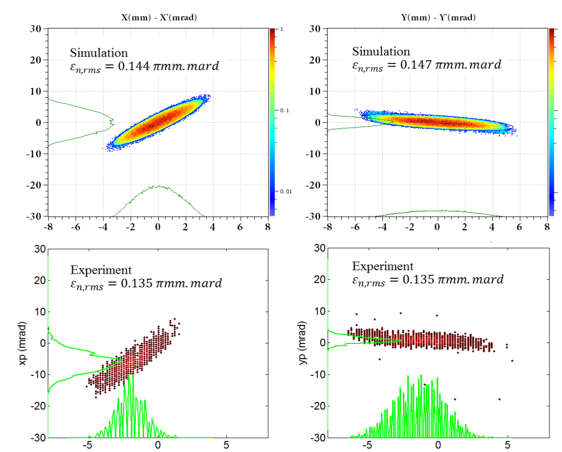


Complete suite of diagnostics successfully commissioned:

- BLMs (ionization chambers and differential transformer msrmts.)
- beam current measurements (ACCT, FCT, NPCT, ACCT, MCT)
- BPMs (including cold button BPMs)
- BPMs for phase measurement, rms phase 0.4 deg, slide 12
- pair of BPMs for energy measurement , phase rms 1 deg
- wire scanners
- emittance: double slit + FC
- electron scanner



Good agreement between simulations and measurements



Future work: extend interlock systems, IPM, longitudinal profiles and tuning of longitudinal matching

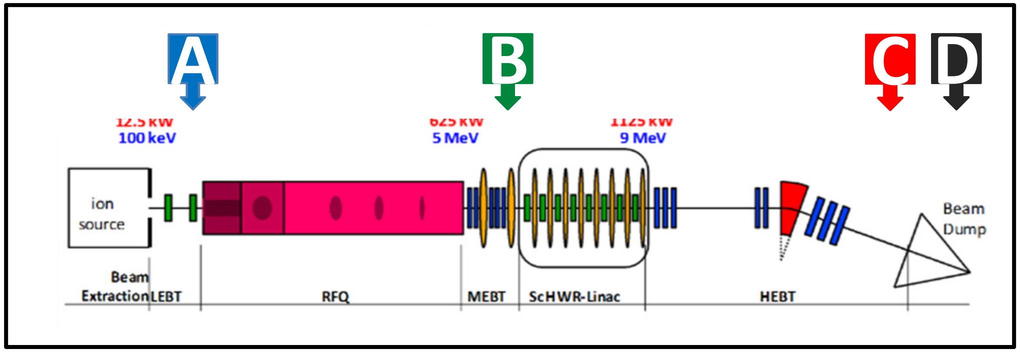
Beam Instrumentation for High Intensity Accelerators

R&D on micro-Loss Monitors for High Intensity Linacs like LIPAc

Jacques Marroncle

CEA - Saclay

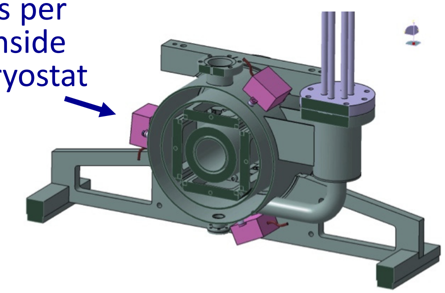
Linear IFMIF Prototype Accelerator (LIPAc) in Rokkasho, Japan supporting the International Fusion Materials Irradiation Facility (IFMIF) to test materials under very high neutron fluxes for future fusion reactors



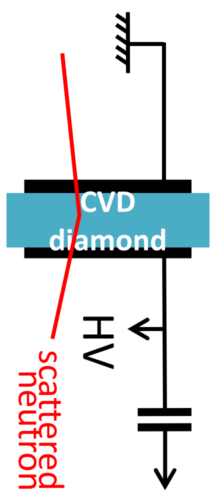
LIPAc…

- Commissioning has already begun, and is almost finish for the injector
- Assembling of the RFQ is in good progress. Beam commissioning should start in June 2017

3 diamonds per solenoid, inside the linac cryostat



µLoM for high intensity Linacs



- µLoM are requested by Beam Dyn. for beam tuning while keeping losses below 1W/m (hands-on maintenance)
- CVD diamonds should be good candidates for this purpose

Propriety: radiation tolerant, cryogenic…

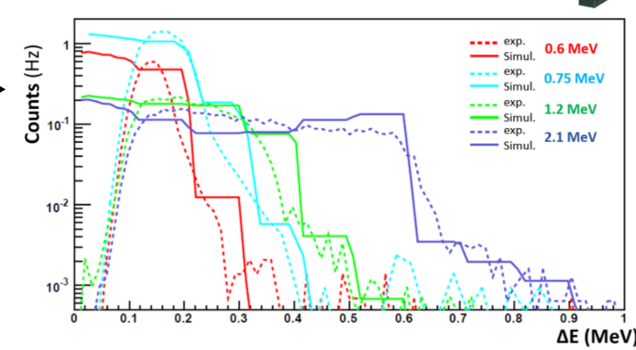
Counting rate estimates:

1W/m → look reasonable and were checked experimentally

BG (vault + cavity emission) < 1W/m

Cautions: electron cavity emission (care about high E_{field})

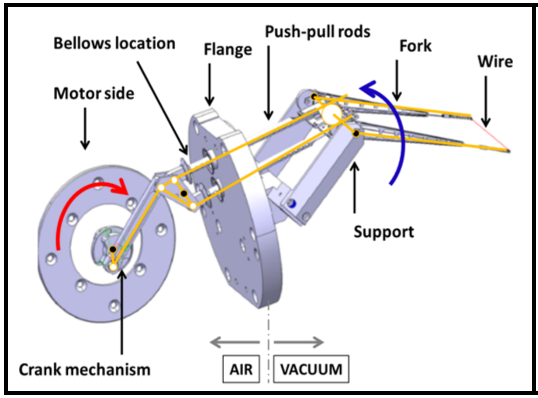
FEE was tested and proposed

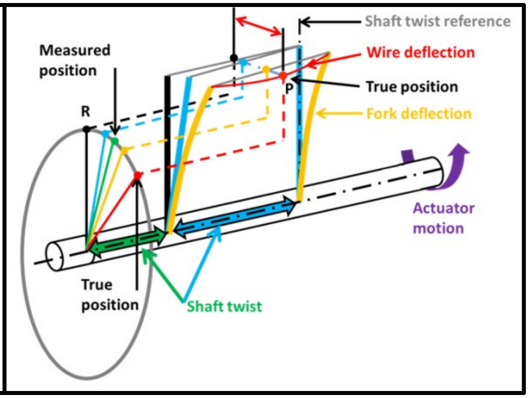


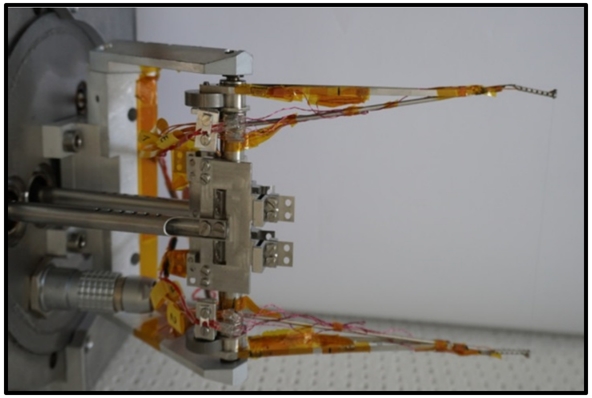
Beam Instrumentation for High Intensity Accelerators

Developments in High-Precision Fast Wire Scanners for High Intensity Proton Accelerators *Bernd Dehning*

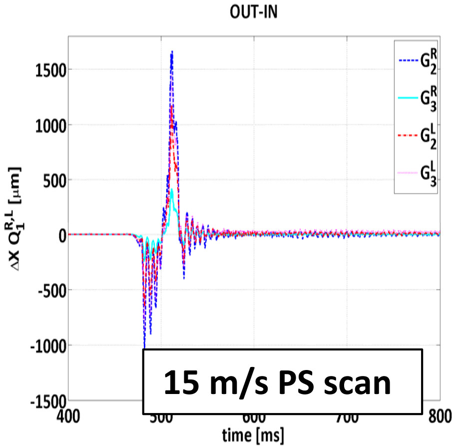
New wire scanner design development for beam profile measurements, features all moveable components in vacuum, permanent magnet – based braking system. Extensive evaluation of systematic effects presented (fork shaft assembly: actuator motion, shaft twist, inertial deflection of fiber support fork, wire deflection)







Systematic studies presented based on analytical models (e.g. ANSYS), vibration measurements (strain gauge, piezoresistive effects) and more.



Device, with FPGA-based digital control, is under test in the SPS; an optimized second design for the CERN Booster is in production. This design is envisioned to be the basis for the LHC injector rings with installation during the 2019/20 technical stop.

Beam Instrumentation for High Intensity Accelerators

The Cockcroft Institute
of Accelerator Science and Technology

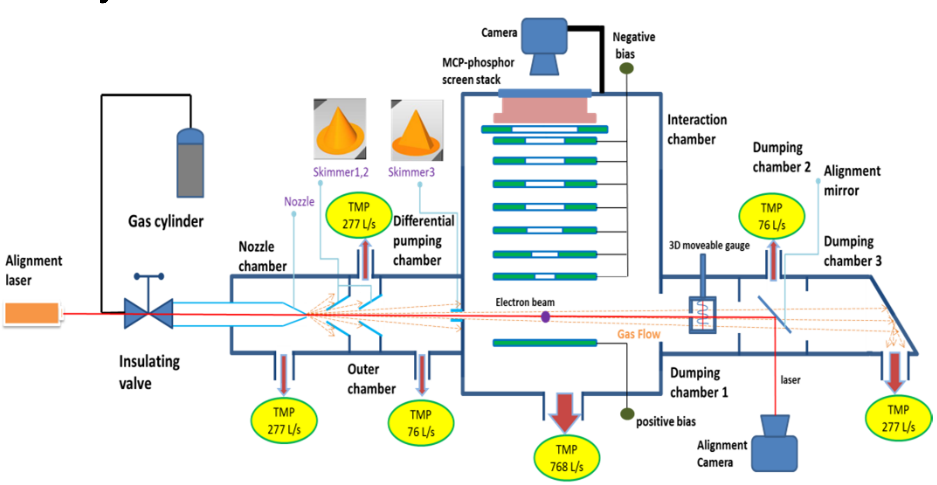
Developments in Non-destructive Beam Profile Monitors, *Carsten Peter Welsch*

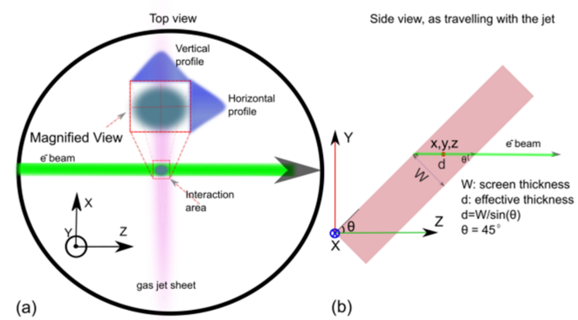
UNIVERSITY OF LIVERPOOL

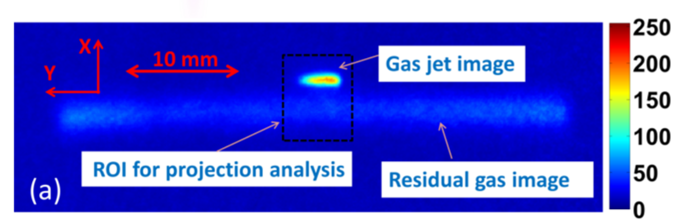
Presentation with examples on beam monitoring options for high E and high I beams

- Synchrotron light – challenges: need to separate radiation from beam, large bending radius, depth-of-field issues, diffraction limit ← new developments with interferometry and core masking (coronograph)
- Ionization profile monitors – challenges: required residual gas pressure, 1D only
- Beam-induced fluorescence – challenges: low cross section, isotropic light emission, rest gas pressure requirements
- Gas sheet/jet monitor (also 2-D image) – challenges: jet focussing, pressure in vacuum

Gas jet at the Cockcroft Institute :







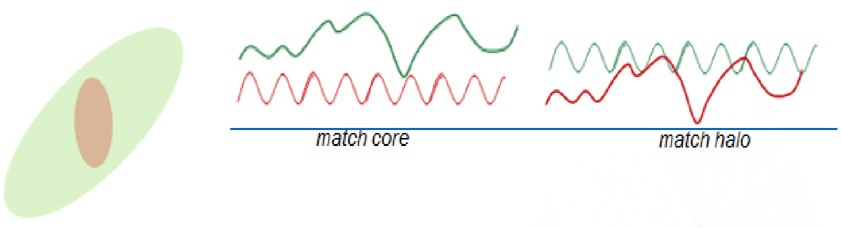
Simulations (CST and WARP) underway, working on jet focussing (with Fresnel zone plate)

- Beam instrumentation for high intensity accelerators
- Beam loss and activation (2 talks)
- Collimation
- Beam material interactions

Beam Loss and Activation

Path to Beam Loss Reduction in the SNS Linac Using Measurements, Simulation and Collimation *Alexander V. Aleksandrov*

Presented development of tools for large dynamic range (DR) measurements, simulation and collimation to facilitate low loss linac tuning.



Have tools for control of rms, 'matching', yet not guaranteed to prevent halo formation.

Detection lost particles not a halo measurement.

Reviewed measurement methods and the DR achievable including
- 2D phase space measurement at low energy using double-slit emittance measurements / at high energy using laser wires for H- beam
- halo measurements using large DR wire scanners (1D)
- reconstruction of 2D distributions from 1D profiles

Compared methods.

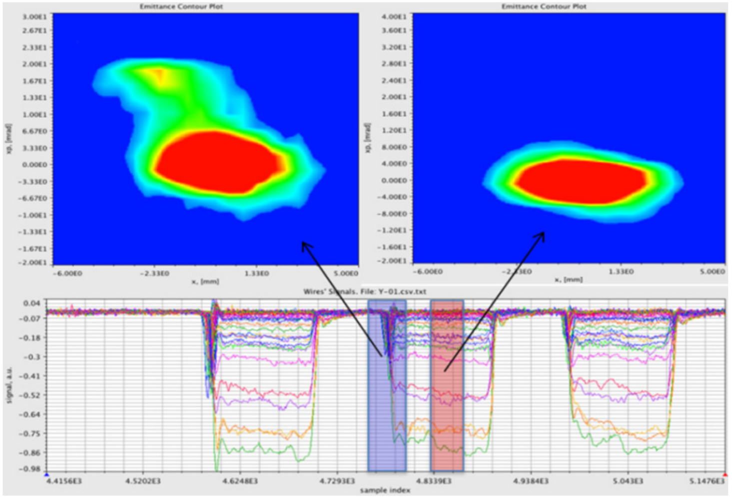
SNS linac is a good test bench for new methods development, reducing beam loss due to intra-beam stripping is a realistic first goal.

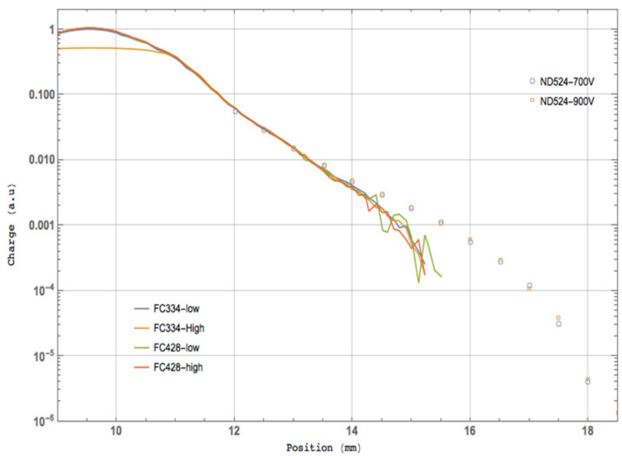
SNS 2.5 MeV Beam Test Facility to address: (1) how to construct 6D from 1D, 2D, 4D?
(2) does mismatch create halo?

Path to Beam Loss Reduction in the SNS Linac Using Measurements, Simulation and Collimation *Alexander V. Aleksandrov*

Presented many beautiful measurements, two selected here:

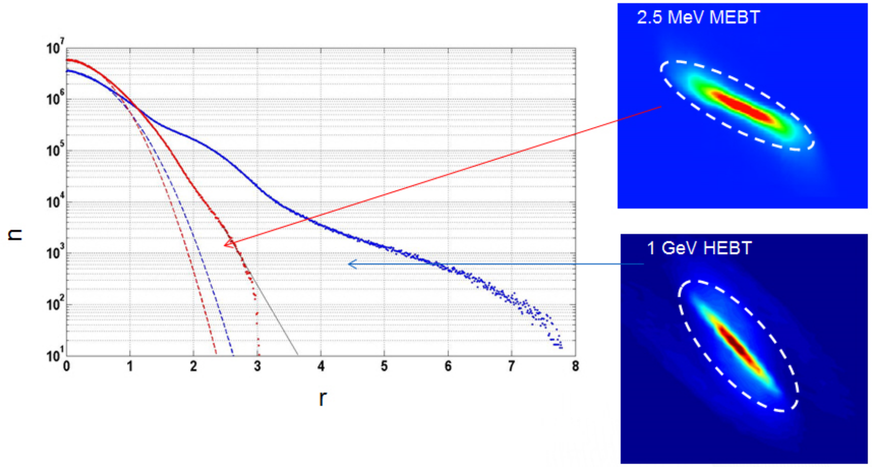
1) 2D phase space (2-slit measurements) corresponding to 2 different times along the chopped linac pulse length





~ 10^5 dynamic range or 20ns temporal resolution

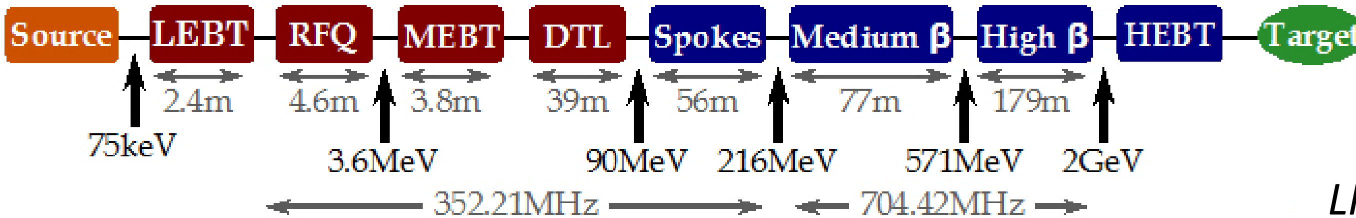
2) Comparison of phase space density measured at SNS MEBT and HEBT



Beam Loss and Activation

Simulations and Detector Technologies for the Beam Loss Monitoring System at the ESS Linac *Irena Dolenc Kittelmann*

EUROPEAN SPALLATION SOURCE



LHC BLM

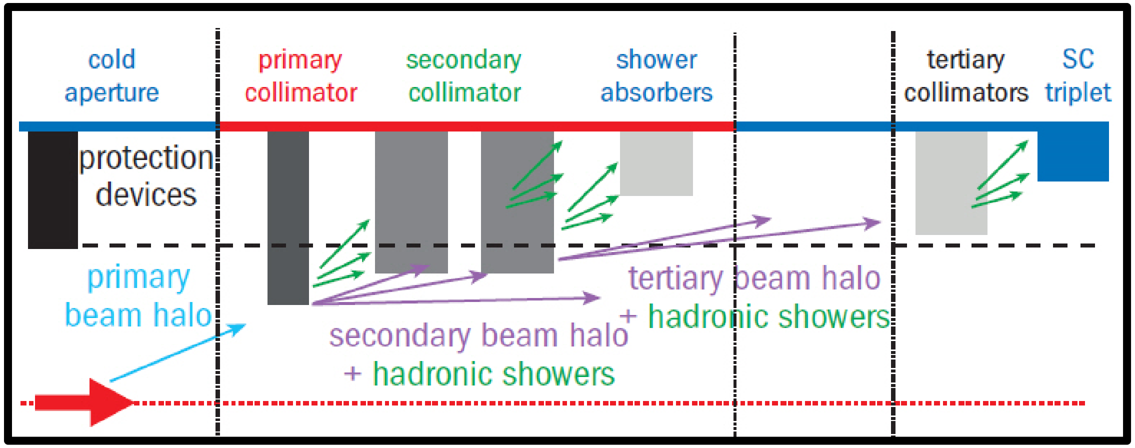
- **ESS BLM detector technologies:**
  - Ionization chambers will be used as the primary detector in the SCL parts (ICBLM).
  - Future plans: explore an option to use Cherenkov radiation based detectors as a complementary monitor to the ICBLM in SCL. Advantage: inherent rejection of the RF cavity background.
  - Novel neutron sensitive micromegas detectors will be used as BLMs in the NCL parts – detector design in development by the micromegas team from CEA Saclay.
- **ESS BLM Monte Carlo simulations:**
  - All past efforts connected to simulations exclusively focused on the ICBLM.
  - Currently the focused turned to the nBLMs due to the need for the nBLM detector design specifications.
  - Strategies to determine the specifications needed for the design of the BLM system (response time, detector locations, dynamic range) were discussed.
  - Some preliminary results for the nBLMs were presented, together with the past results focused on the ICBLMs.

- Beam instrumentation for high intensity accelerators
- Beam loss and activation
- Collimation (5 talks)
- Beam material interactions

Collimation

Roles of LHC collimation system

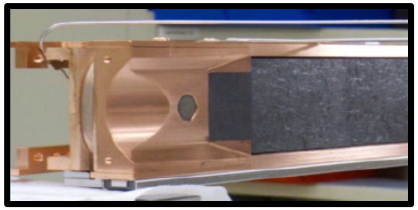
- **Halo cleaning** versus quench limits (super-conducting machines)
- Passive **machine protection**
  First line of defence in case of accidental failures.
- **Concentration of losses/activation** in controlled areas
  Ease maintenance by avoiding many distributed high-radiation areas.
- **Reduction total doses** on accelerator equipment
  Provide local protection to equipment exposed to high doses (like the warm magnets in cleaning insertions)
- **Cleaning of physics debris** (physics products, in colliders)
  Avoid magnet quenches close to the high-luminosity experiments
- Optimize **background** in the experiments
  Minimize the impact of halo losses on quality of detector's data
- Beam tail/halo **scraping**, **halo diagnostics**
  Control and probe the transverse or longitudinal shape of the beam



Well-defined hierarchy
5 stages
10 σ aperture requires
 5.5 σ primary cut
beam-based alignment
 applied to determine
 local orbit and beam size

☑ Reviewed the collimation system for the LHC Run II (2015-18)

Important performance improvements following upgrades in the first long shutdown
New BPM collimators, better reliability and physics debris cleaning, fast alignment.



will employ orbit position interlocks for lower β^* reach

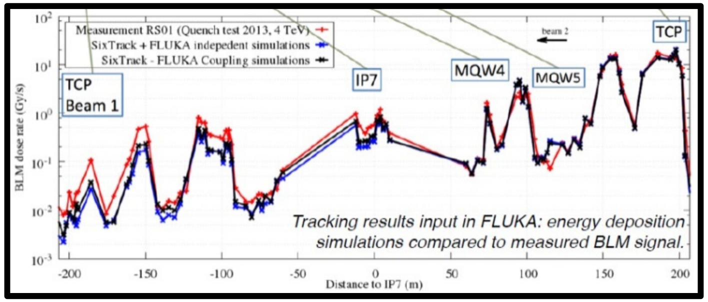
☑ The performance at 6.5TeV is very satisfactory

Cleaning efficiencies down to ~1e-4 ensured a quench-free operation with >250MJ
Continued improving duration and accuracy of collimator alignment campaigns.
Excellent machine and collimation stability.
Used the good performance to push the beta to ~30% beyond nominal!*

☑ Reported on recent results from continued effort to improve in simulations the understanding of collimation losses

Important improvements in the last years: integrated simulations.
Better modelling of heavy-ion loss mechanisms and patterns.

FLUKA+SixTrack+coupling versus measurement



☑ Briefly recalled upgrade plans within HL-LHC project

Lower impedance, dispersion suppressor cleaning and new IR layouts are the keys to achieve a further factor 2 in stored beam energies at the HL-LHC
Exciting R&D program on hollow lenses and crystal collimation continues

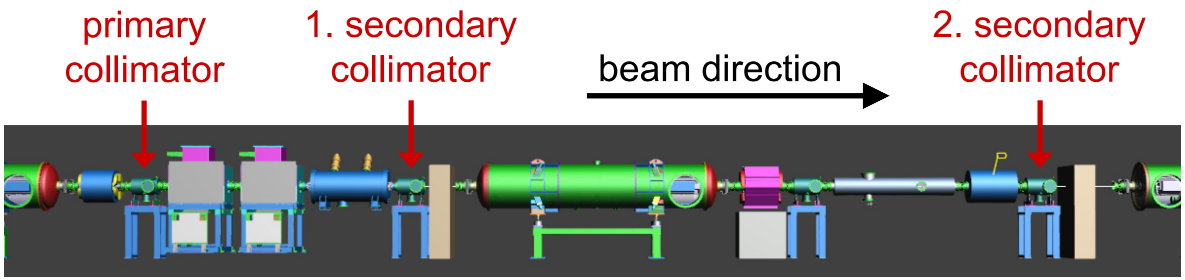
Collimation

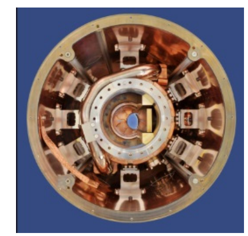
Beam Halo Collimation Over Wide Range Charge-to-Mass Ratio

Ivan Strasik

Presentation on halo collimation of ion beams (proton sup to uranium) in the FAIR heavy ion synchrotron SIS100. Two design concepts:

<u>for protons and fully stripped ion beams</u>: the two stage betatron collimation system

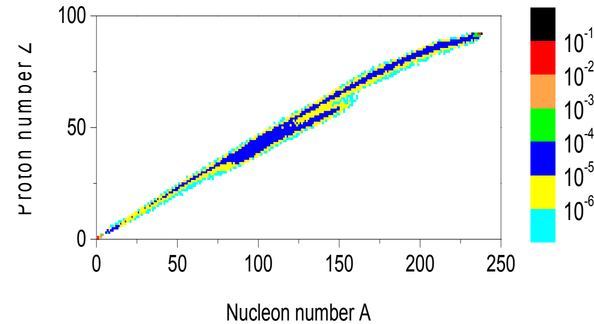




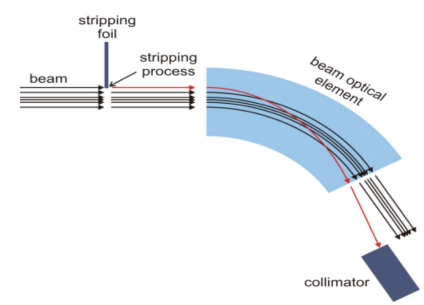
Cryocollimator prototype

Simulations (FLUKA+MADX) presented : loss maps, interactions of ions with primary collimator, beam loss maps and collimation efficiencies with primary ions, imperfections and lattice errors, inelastic nuclear interaction processes and loss and angular distributions of ^{238}U fragments →

Products of ^{238}U inelastic interactions



<u>for partially stripped ion beams</u>: The collimation of partially stripped ions relies on the change of the charge state using a stripping foil →

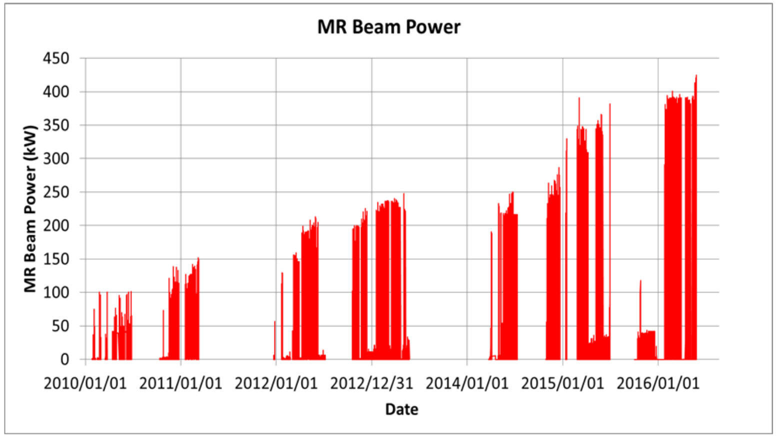


Possible improvements using hollow electron beams are being considered

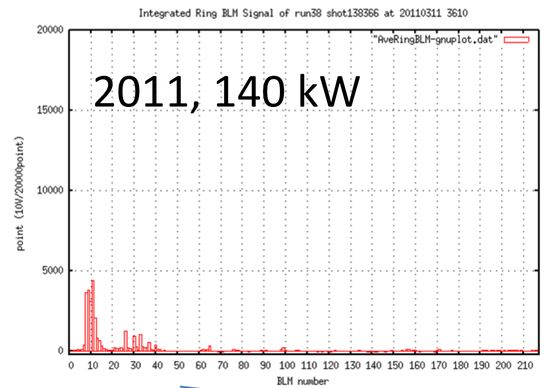
Collimation

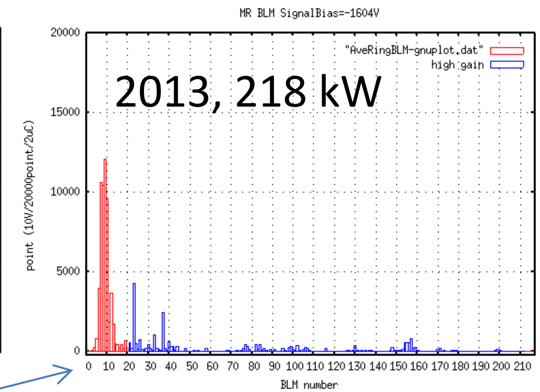
New Arrangement of Collimators of J-PARC Main Ring

Masashi Shirakata



History of collimation at the JPARC MR was presented





MR Beam Collimation System

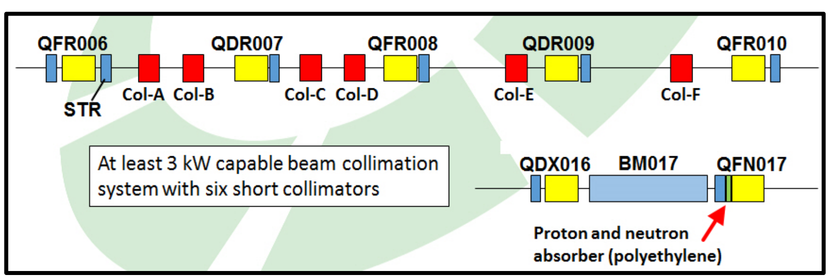
First design: Scraper-catchers

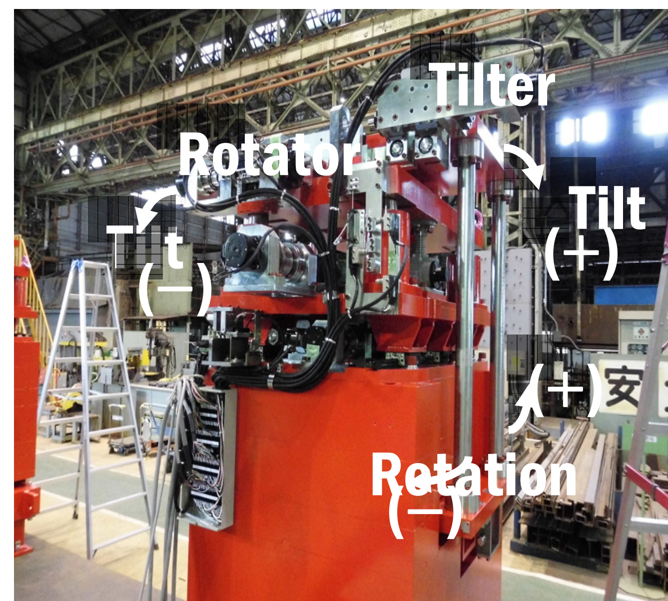
First update: Replace of scraper (2012)

Second update: Seven collimators (2014, design loss capacity 3.5 kW) but later removed

Third update: Add 2 4-axis collimators (2015)

Fourth update: Requirements and future layout





Collimation

The Application of the Optimization Algorithm in the Collimation System for CSNS/RCS, *Hongfei Ji*

Institute of High Energy Physics
Chinese Academy of Sciences

The robust conjugate direction search method is applied to optimize the beam collimation system for Rapid Cycling Synchrotron (RCS) of the China Spallation Neutron Source (CSNS).

Physics analysis and modelling methods presented.

The parameters of secondary collimators are optimized with RCDS algorithm based on
- a two stage collimation system
- a realistic intitial distribution arising from the injection painting scheme

The study presents a way to quickly find an optimal parameter combination of the secondary collimators for a machine model for preparation for CSNS/RCS commissioning.

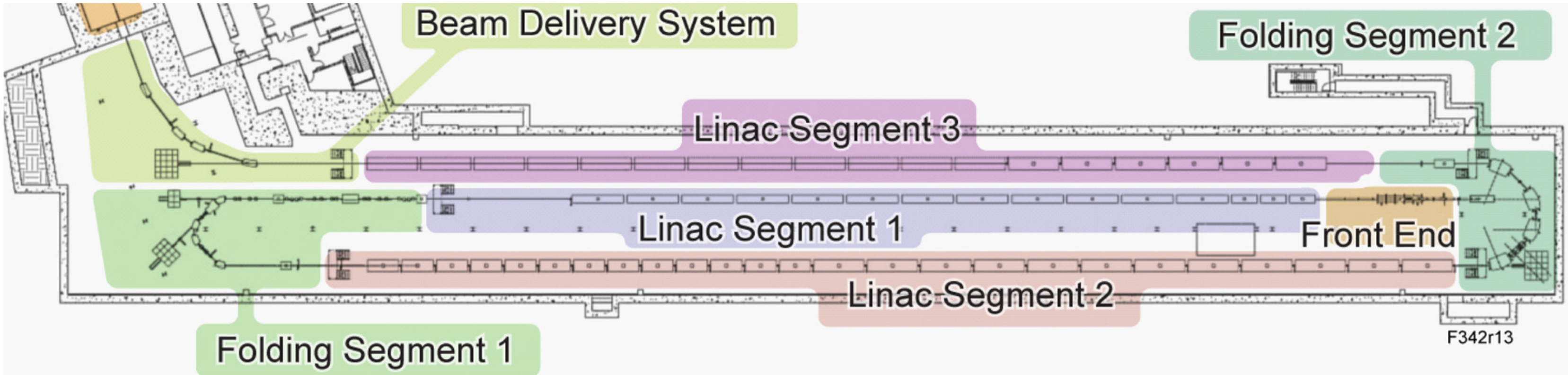
The uncontrolled beam loss of the total beam during acceleration can be reduced to 1.7×10^{-4}, which is lower than that obtained by previous optimization.

As a result, an approach is established to efficiently give an optimal parameter combination of the secondary collimators for the present machine model.

Collimation

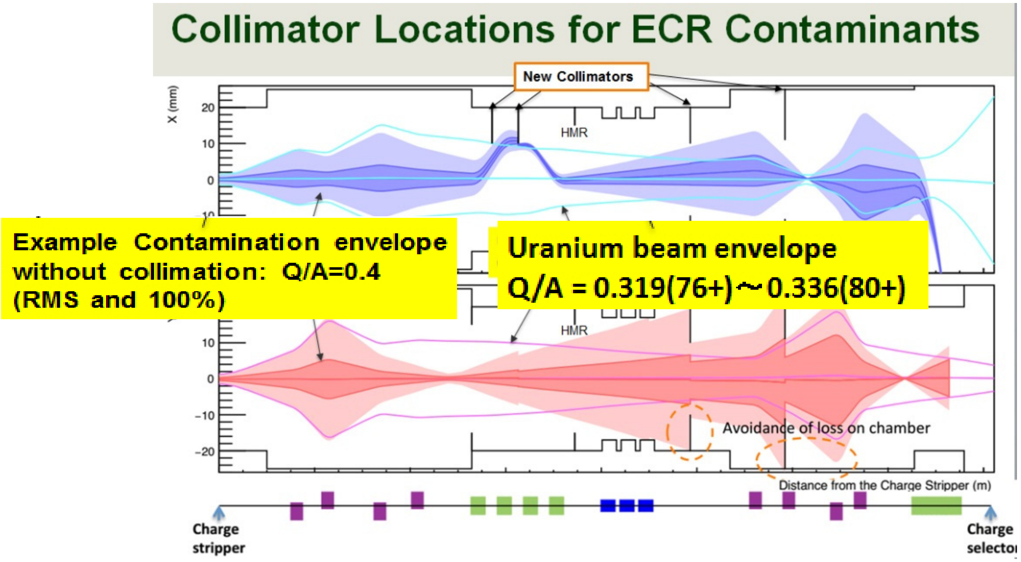
Collimation Design and Beam Loss Detection at FRIB

Felix Marti / Zhengzheng Liu

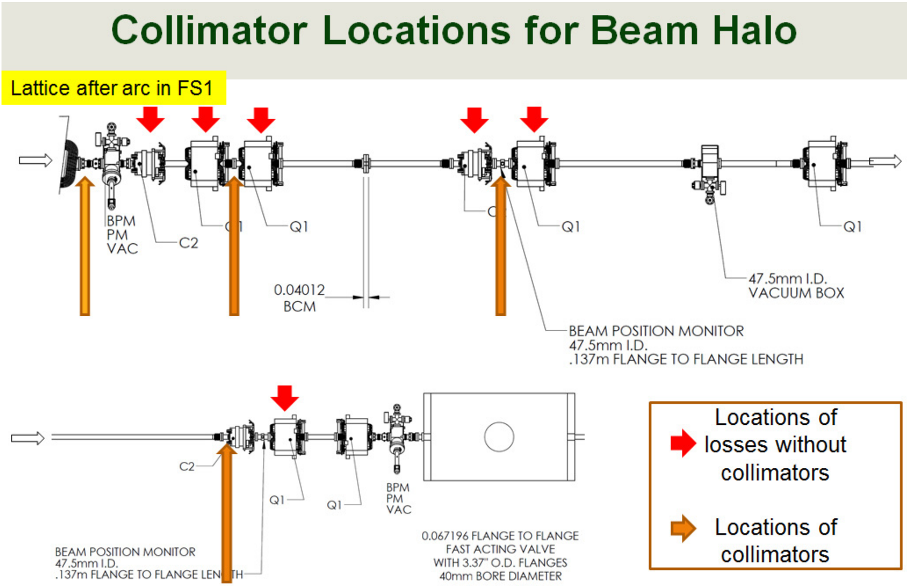


Presentation on simulations and design for collimation systems designed particularly for

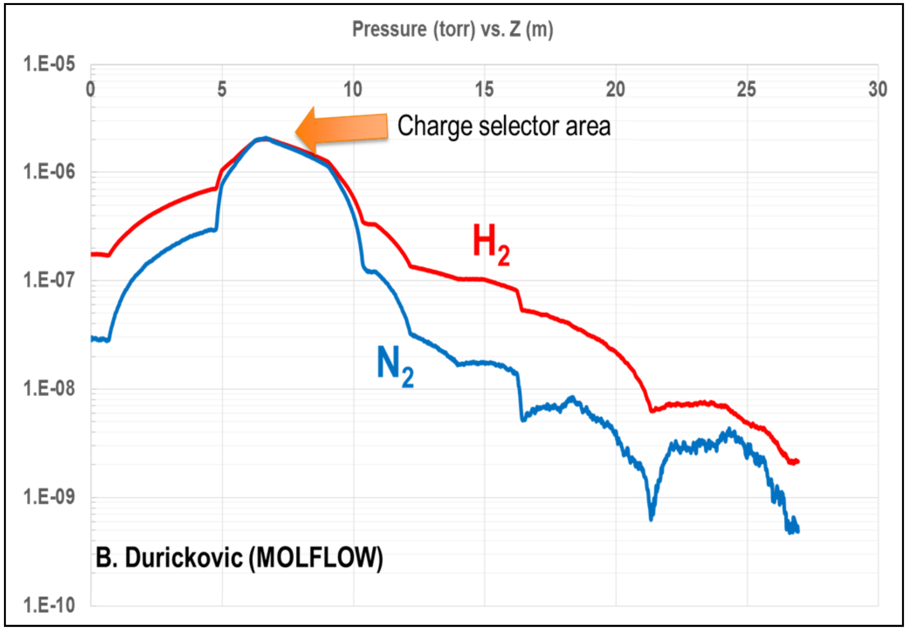
(1) ECR contaminants that are separated from primary beam after stripper



(2) beam halo induced by stripper or bending arc



(3) in FS1 potential charge exchange with residual gas due to higher pressure



Due to FRIB folded structure, linac faces big challenges on loss detection. A loss monitor network is designed to fulfill MPS requirements (15µs for large losses and 1 W/m slow losses)

Large intentional losses in FS1 make loss detection very difficult there. If the intentional losses are stable on the time scale of slow loss monitoring, we should be able to detect small uncontrolled losses

Beam instrumentation for high intensity accelerators

Beam loss and activation

Collimation

Beam material interactions (3 talks)

Beam-Material Interactions

High Power Target Instrumentation at J-PARC for Neutron and Muon Sources
Shin-ichiro Meigo

Recently achieved equivalent power of 1 MW to targets.

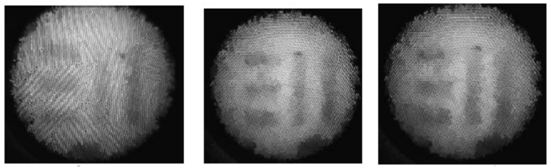
Beam power limited (0.5 MW) due to target pitting erosion / cavitation damage, which scales as 4th power of peak current density.

Several measures to mitigate:
- gas micro-bubbles (offer 'padding' to cavitation bubbles)
- dual-octupole beam flattening system: SAD code used as beam tuning tool. Beam profiles controlled as designed; peak intensity will be reduced by 30%.
- "anti-correlated" painting reduced beam losses further

Octupole: 800 T/m^3

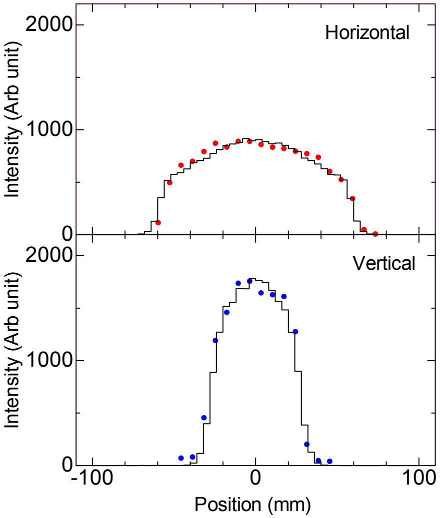
New 2D profile monitor developments.

Fujikura rad-hard fiber



0 Gy 1 MGy 2 MGy

Simulation and measurement



Planning underway for new facility at J-PARC for R&D of ADS.

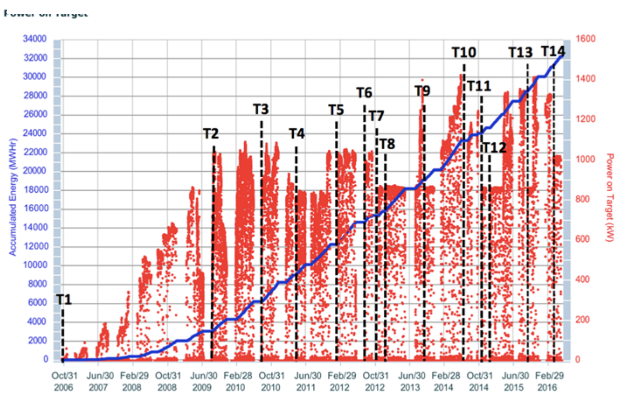
Beam power will be ramped up to 1 MW after revisions to mercury target welds.

Beam-Material Interactions

Measurements of Beam Pulse Induced Mechanical Strain inside the SNS* Target Module, *Willem Blokland*

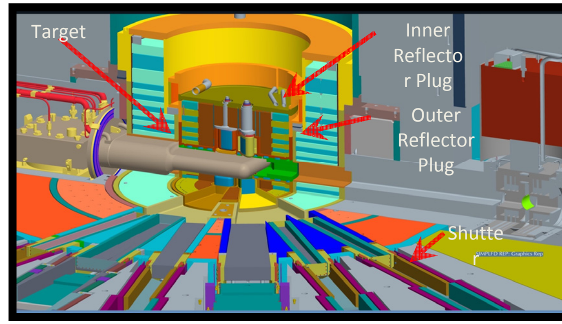
OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

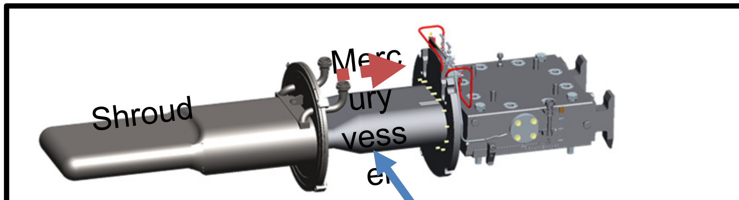
Beam power on target at SNS



5000 MW-hr design, two recent target failures – costly to replace (1 M$, 1 week)

Cause believed to be due to tensile pressure wave / strain on Mercury vessel wall





sensors positioned on vessel nose-cone

Presentation of functional tests and test results with optical strain sensors:

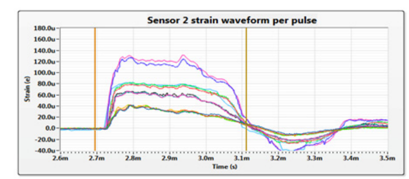
new multi-mode fiber (2 week survival)

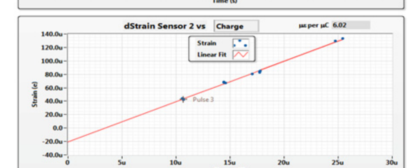
new single-mode fiber (5 week survival)

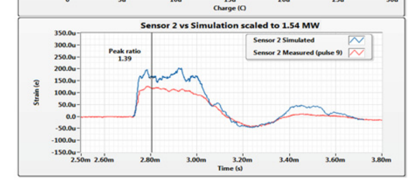
Tests successfully addressed these questions:

- Is the strain on the target higher than we expected? ⟶
- Are we hitting a resonance frequency? ⟶ no dynamic stress build-up
- How will we know if future mitigation methods are working?

No additional cause for target failures found, no additional mitigation besides those already planned





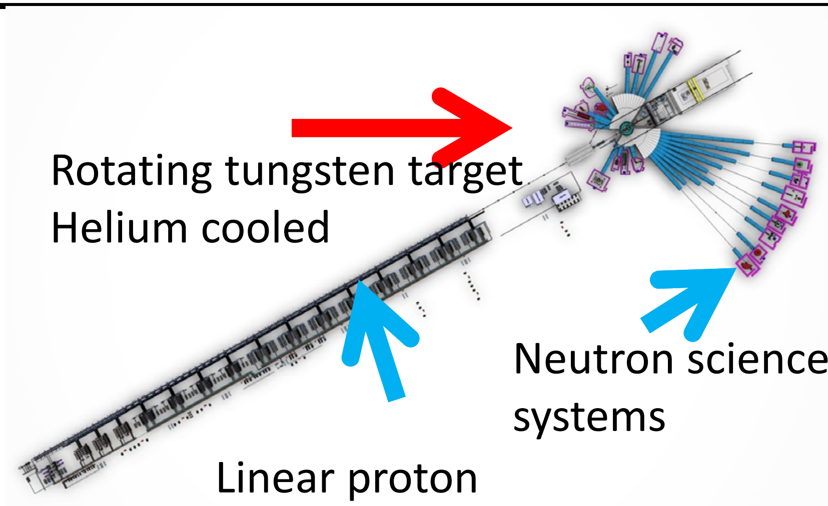


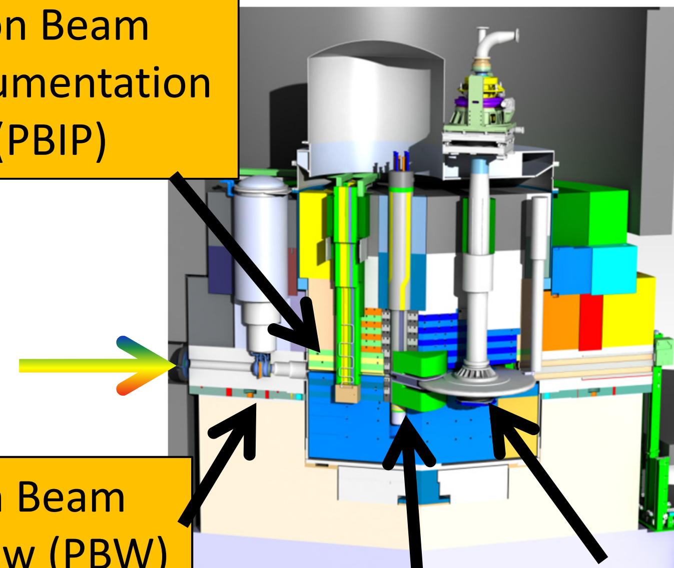
Beam-Material Interactions

Beam-Material Issues for Instrumentation in a 5 MW Monolith

Monika Hartl

EUROPEAN SPALLATION SOURCE





Presentation of challenges for

- multi-wired grids for beam profile monitoring,
- TCs s and secondary emission blades for aperture monitoring
- a luminescent coating for imaging the beam spot on the target.

Radiation damage is to be expected and it is challenging to ensure full functionality of the diagnostic system over a set period of runtime.

Material choices for these components in the PBIP with respect to lifetime in a radiation field and operational criteria were reviewed.

Discussion session #1

- What instrumentation should be planned for rapid commissioning?
- What are the lessons learned from the facilities that have been recently commissioned or recommissioned after upgrade?

One starts with an accelerator one doesn't know , instruments one doesn't know → cross-checking instruments is vital to guarantee performance (think: LINAC4 and C-ADS linac!)

For safety, instruments are crucial; redundancy is very important

Need more diagnostics for commissioning than for operations; diagnostics for commissioning is insurance

Sometimes add diagnostics for better under-standing, but usually for R&D (not operations)

- What did you wish you had but did not? What did you have that you could have left out? ← Linac energy at injection to RCS's, better resolution TOF measurements

Discussion session #2

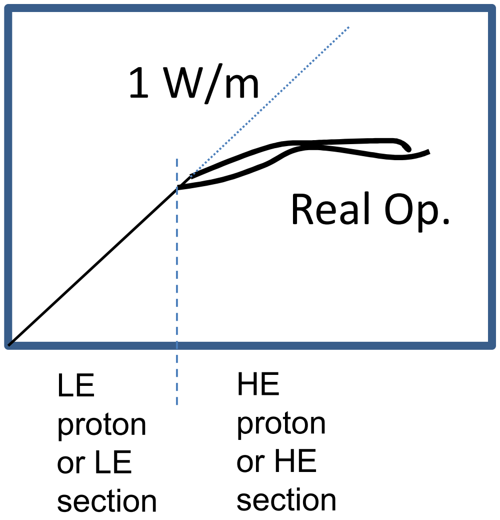
BEAM HALO AND SCRAPING

The 7th ICFA Mini-workshop on High Intensity High Brightness Hadron Beams

Wisconsin, USA, September 13-15, 1999

"One important outcome of this workshop is the agreement that an average beam loss of 1 W/m in the uncontrolled area should be a reasonable limit for hands-on maintenance." (page 3 in workshop proceedings)

1 W/m ~ 6.2×10^9 protons/m/s at 1 GeV



- Is the limitation of 1 W/m still the rule of thumb? What is the suggestion based on two operational experiences at SNS and J-PAR(

1 W/m should be used for shielding but not for actual maintenance; most accurate way is to calc-ulate (with e.g. GEANT) to yield 10's of mW/m

If activation of interest, use FLUKA to know precisely loss per unit length

For HI it should be less because of Bragg peak

For <25 MeV or SC cavities, 1 W/m is too high

- Is any practical data of damage of SC material available from high energy accelerators? ← TBD, if not available, measurements should be performed