Instrumentation and Beam Material Interactions
Working Group-F Summary

Conveners: R. Doelling, M. Minty, N. Mokhov, T. Toyama

Part 1. Michiko Minty
Part 2. Nikolai Mokhov

HB2014, East Lansing, Michigan, November 10-14, 2014

WG – F Sessions

Monday: Posters

TUO2AB: F
TUO3AB: Discussions BC&F
WEO2AB: F
WEO3AB: Discussions AC&F

Instrumentation

THO4AB: F, F-Discussions

Beam Material Interactions

WG-F Presentations

1. A Jansson, ”Beam instrumentation and limitations for multi-MW pulsed proton linacs”
2. N. Chauvin, ”Halo matching for high intensity linacs and dedicated diagnostics”
3. K. Wittenburg, ”Beam diagnostics for the detection and understanding of beam halo”
4. Y. Hashimoto, ”Two-dimensional and wide dynamic range profile monitors using OTR/fluorescence screens for diagnosing beam halo of intense proton beams”
5. S. Lidia, “Instrumentation design and challenges at FRIB”
6. M. Sapinski, “Beam loss mechanism, measurements and simulations at the LHC (quench tests)”
7. K. Yamamoto, ”Beam instrumentation at the 1 MW proton beam of J-PARC RCS”
8. E.B. Holzer, “Beam diagnostic challenges for high energy hadron colliders”
9. G. Stancari, “Measurements of beam halo diffusion and population density in the Tevatron and in the Large Hadron Collider”
10. G. Skoro, Material response to high power beams
11. A. Konobeev, DPA and gas production in intermediate and high energy particle interactions with accelerator components
12. A. Bertarelli, Novel materials for collimators at LHC and its upgrades

Instrumentation Challenges – Existing Accelerators

High stored energies - both in the beam and in the superconducting magnets, high brightness beams

Topics: avoiding uncontrolled losses (machine protection, collimation, halo monitoring…), intercepting monitors (quench, need for non-invasive monitors), small beam profiles and sensitivity to systematic errors

E.B. Holzer

"Beam diagnostic challenges for high energy hadron colliders"

Large size of the colliders

Topics: component numbers, location of electronics, signal transport

High radiation levels

Instruments in cryogenic temperatures

Topics: new regime BLMs, high dependability,…

Monitoring of beam instabilities

Topics: bunch-by-bunch and intra-bunch measurements, feedback

Wakefields and rf heating - impedance budget

Instrumentation Challenges – Future Accelerators

Challenges to beam instrumentation

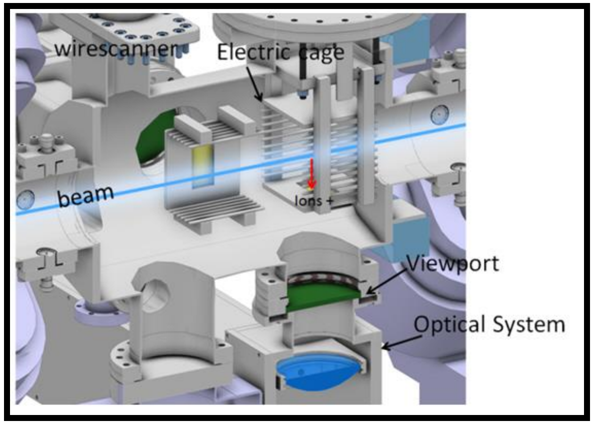
- Multi-MW hadron machines need fast loss detection (for damage protection) with high dynamic range (to avoid activation).
- Non-invasive profile (transverse and longitudinal) measurement needed, and is more difficult with protons than H- (and partially stripped ions).
- Halo measurement important, but difficult to predict.
- Diagnostics with machine protection function need to protect even if timing fails.

Design considerations for beam loss monitors

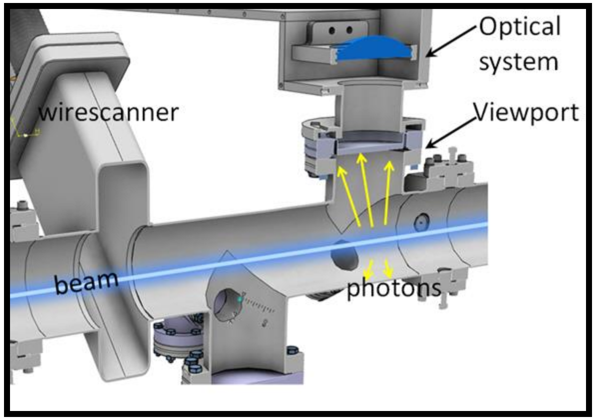
Designs for beam profile monitors

Plans for target imaging

Ionization profile monitor



Beam induced fluorescence monitor



A. Jansson

"Beam instrumentation and limitations for multi-MW pulsed proton linacs"

EUROPEAN SPALLATION SOURCE

Instrumentation Challenges – Future Accelerators

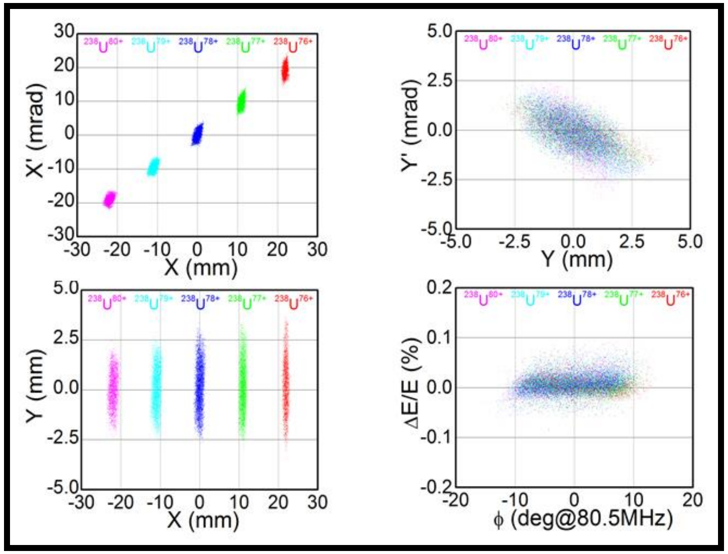
FRIB overview

Challenges to beam instrumentation

S. Lidia

"Instrumentation design and challenges at FRIB"

- Measuring and Tuning High Power Beams
- Accurate Low-β Beam Position Monitoring
- Monitoring Multiple-charge-state Beams
- Measurements Over High Dynamic Range
- Ensuring Machine Protection



Status of requirements, procurements, installations and tests (some already insitu)

Overall instrumentation status

The FRIB instrumentation diagnostic suite

- Designed to provide sensitivity over a large dynamic range to meet the required operational flexibility
- Provides a network of complementary devices to detect errant beam and slow losses
- Meets requirements for commissioning and reliable operation

What is beam halo?

Sources of halo are:

- Space charge forces of the beam
- Mismatch of beam with accel. optics
- Beam beam forces
- Instabilities and resonances
- RF noise
- Scattering (inside beam, residual gas, macroparticles, photons, obstacles (stripping foil, screens etc.)
- Nonlinear forces, e.g. aberrations and nonlinearities of focusing elements
- Misalignments of accelerator components
- Electron clouds
- Beam energy tails from uncaptured particles
- Transverse-longitudinal coupling in the RF field
- etc.

K. Wittenburg

"Beam diagnostics for the detection and understanding of beam halo"

HALO QUANTIFICATION

- There is **no clearly defined separation** between the halo, tail and the main core of the beam. Consequently, there has been some difficulty identifying a suitable quantitative measure of the halo content of a beam in a model-independent way.
- **Methods have been developed, and computationally studied (by simulations), to characterize beam halo.**

1) **Kurtosis**
2) **Ratio of halo to core**
3) **Ratio of beam core to offset**
4) **The Gaussian area ratio method**

1. Devices that directly measure halo and halo evolution. Examples are Wire Scanners and dedicated Halo Monitors.
2. Devices that contribute to the diagnosis of machine conditions that cause halo formation. An example would be a tune measurement system.
3. Devices that measure the effects of halo development. An example would be the loss monitor system.

Our instruments reach a dynamic range of better 10^6!

What about the halo simulations?

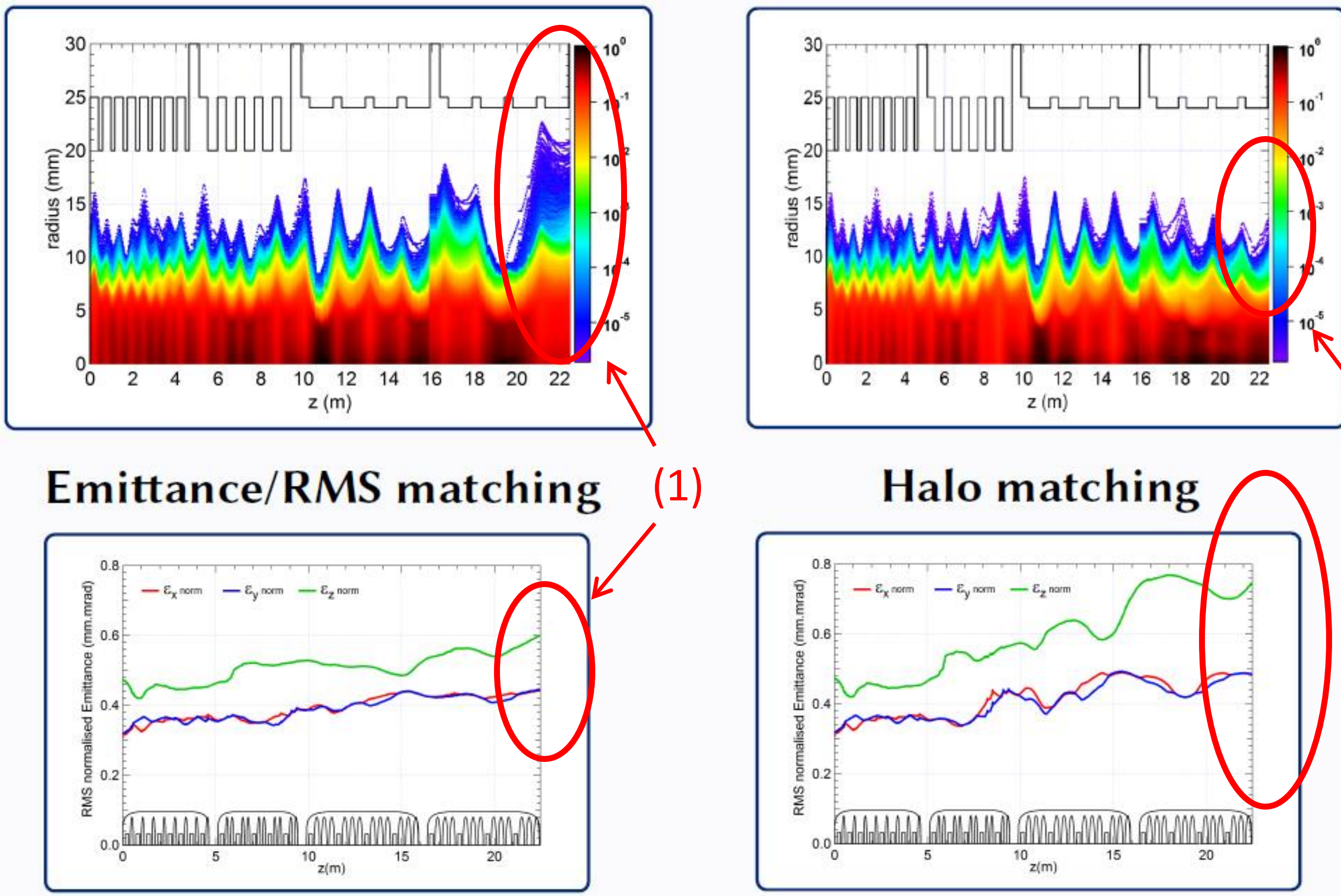
K. Wittenburg

"Beam diagnostics for the detection and understanding of beam halo"

Recent Simulations: emittance vs halo matching

N. Chauvin

Particle Swarm Optimization
A population based stochastic optimization technique



P.A.P Nghiem *et al*, Laser Part. Beams 32, 10-118 (2014).

"Halo matching for high intensity linacs and dedicated diagnostics"

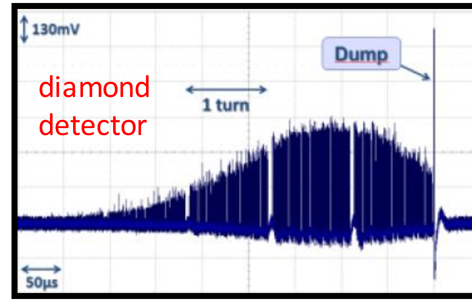
(1)
halo and small emittance

(2)
no halo and larger emittance

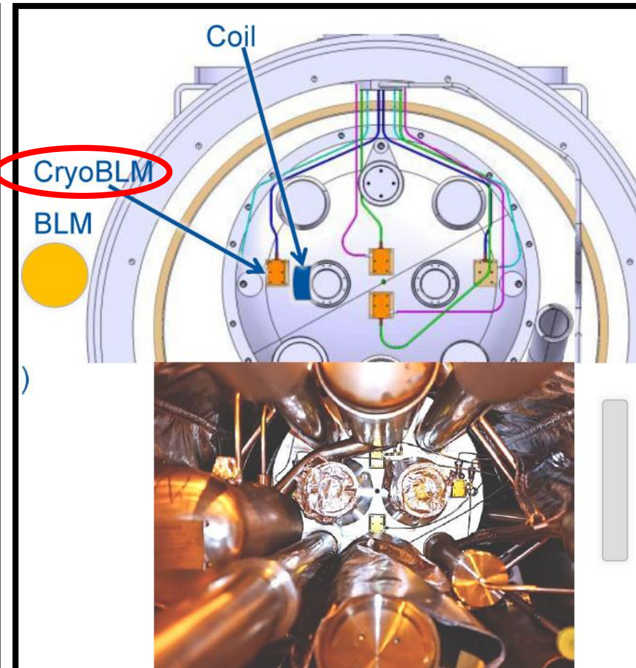
Simulations and Experiments: LHC quench tests

Quench tests are probably most complex beam-loss experiments, their goals:

- **determination of quench-preventing BLM beam-abort thresholds**
- **determination of beam-induced (realistic) quench levels**



1. LHC normal losses account for a few percent intensity loss before collisions.
2. Losses have increased by factor 10 after optimization for luminosity-production.
3. Standard BLM system works very well, developments towards fast diagnostics and measurements closer to the loss location.
4. UFO losses maybe the largest thread to physics run at 6.5 TeV.
5. 17 quench tests performed during Run 1, some very sophisticated.
6. Analysis is very complex and multi-disciplinary.
7. Steady-state quench levels: understood within factor 2.
8. UFO-timescale losses (0.1 ms-10 ms) – factor 4 discrepancy.

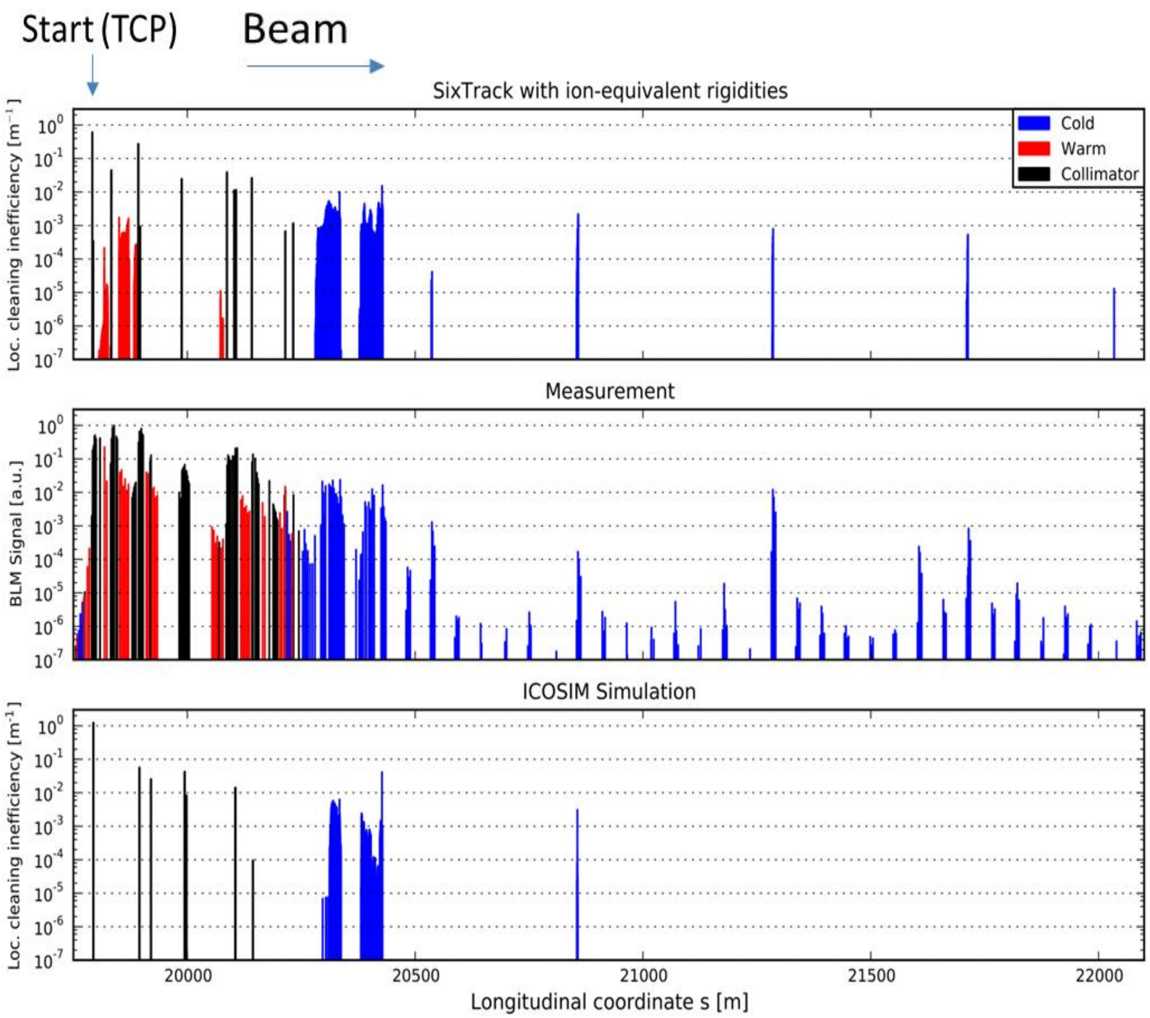


(experiment and particle shower (with FLUKA) vs electro-thermal analyses)

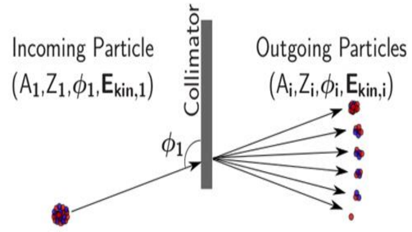
M. Sapinski

"Beam loss mechanism, measurements and simulations at the LHC (quench tests)"

Simulations and Experiments: LHC ion loss maps

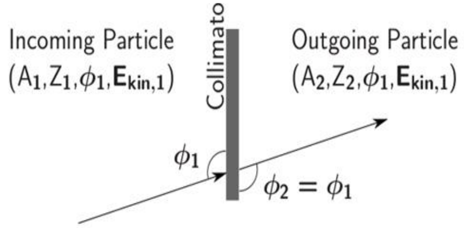


after: SixTrack with ion-equivalent proton rigidities and detailed fragmentation simulation



measurements

before: standard code ICOSIM for heavy ion loss map simulation



P. Hermes

"Studies on heavy ion losses from collimation cleaning at the LHC" **MOPAB43**

New beam diagnostics

K. Yamamoto

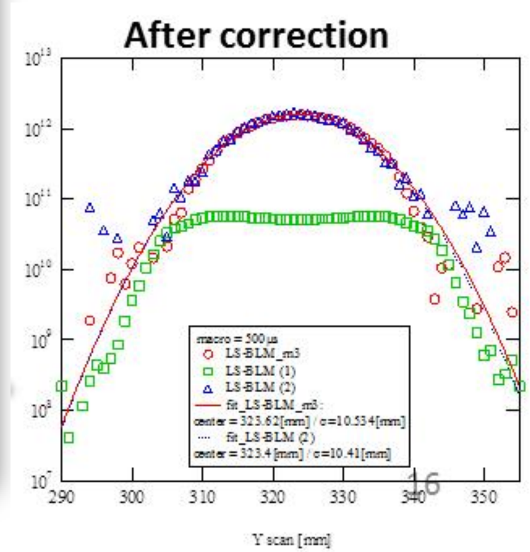
"Beam instrumentation at the 1 MW proton beam of J-PARC RCS"

J-PARC

New monitors for further safety/quality of beam

- **Monitors for safety/stable operation**
  Fast interlock by CT and profile check on target
- **Injection halo monitors**
  VWM (vibration wire monitor)
  L3BT Scrapers & BLM, CT
- **Extraction Halo monitors**
  OTR monitor (next slide/talk)
- **Delayed proton monitor for μ-e conversion measurement**

wire scraper and scintillators with different sensitivities for simultaneous (?) measurements of both the beam core and halo



New beam diagnostics: 2D core and halo monitor

Y. Hashimoto

"Two-dimensional and wide dynamic range profile monitors using OTR and fluorescence screens for diagnosing beam halo of intense proton beams"

- Motivation

J-PARC

OTR/Fluorescence Beam Profile Monitor

Beam halo : It brings serious activation of the accelerator by beam loss

What to see?

Two-dimensional density distribution from beam core to beam halo of 3GeV Proton Beam.

Beam Intensity ≥ 10^{13} proton/bunch

What kind of instrument?

High Dynamic Range Beam Profile Monitor

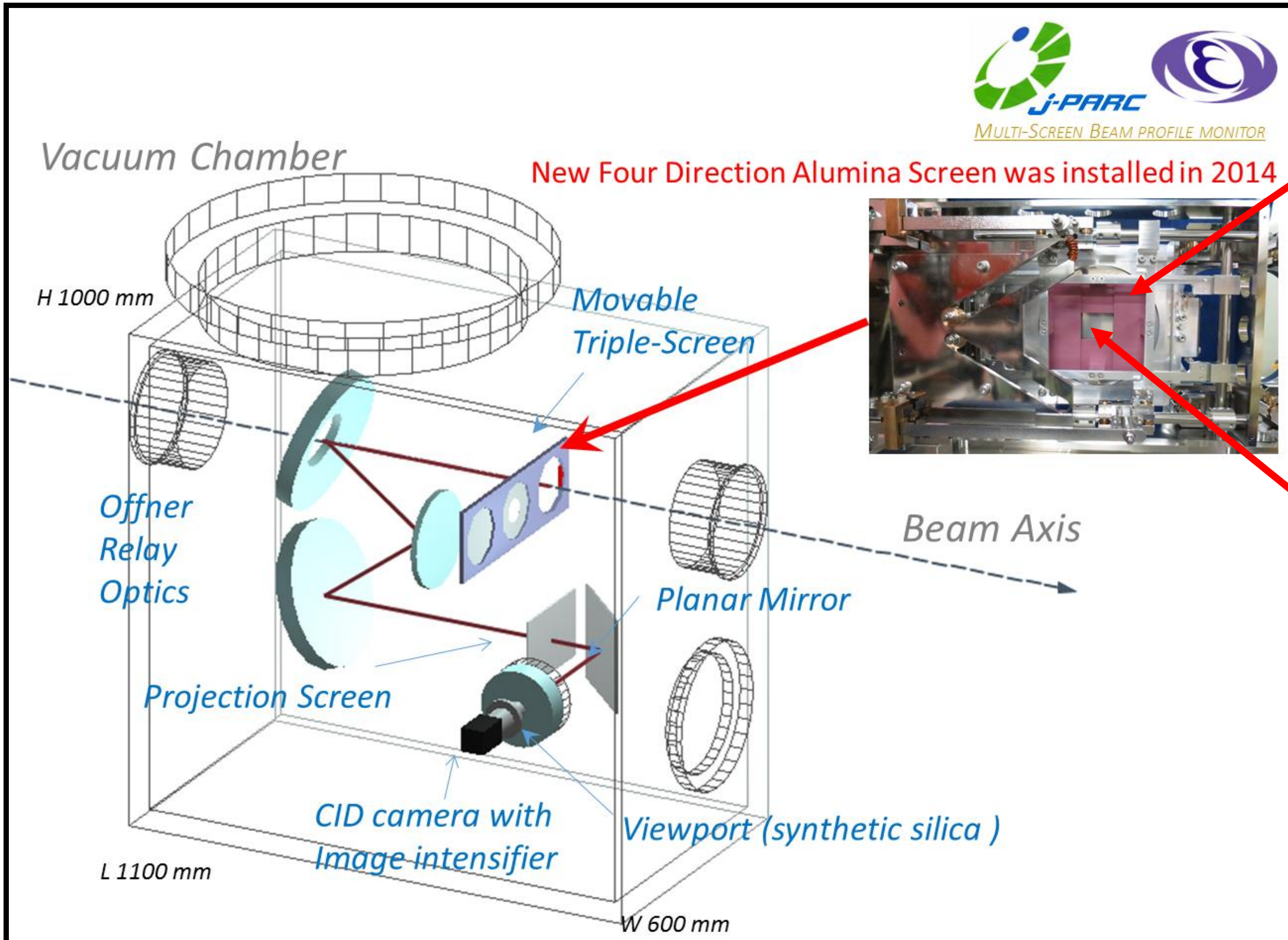
Dynamic Range: 10^6

What is carried out?

Beam diagnosing for injection beam of J-PARC MR which is extracted beam from RCS.

Evaluation for validity of beam collimation by the collimator

Y. Hashimoto



Beam Halo

Measure Fluorescence From Chromium Doped alumina Screen

Beam Core

Measure OTR From 10 micron Titanium foil

OTR/FLUORESCENCE BEAM PROFILE MONITOR

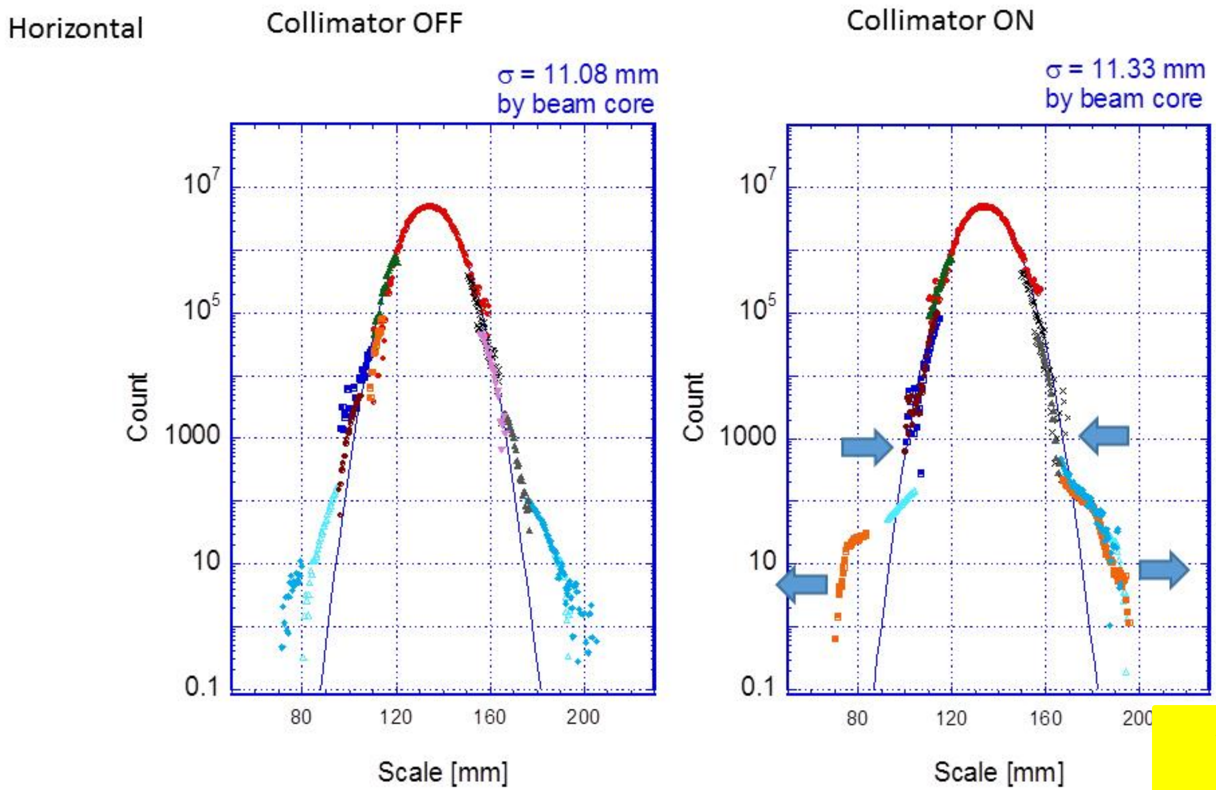
measured profile of beam core and halo with > 1E6 dynamic range

Effect of the beam cut by 3-50 BT collimator (3)

Horizontal Projection

Dynamic Range :More than six order obtained

Beam Size: More than 120 mm at 10^{-6} order



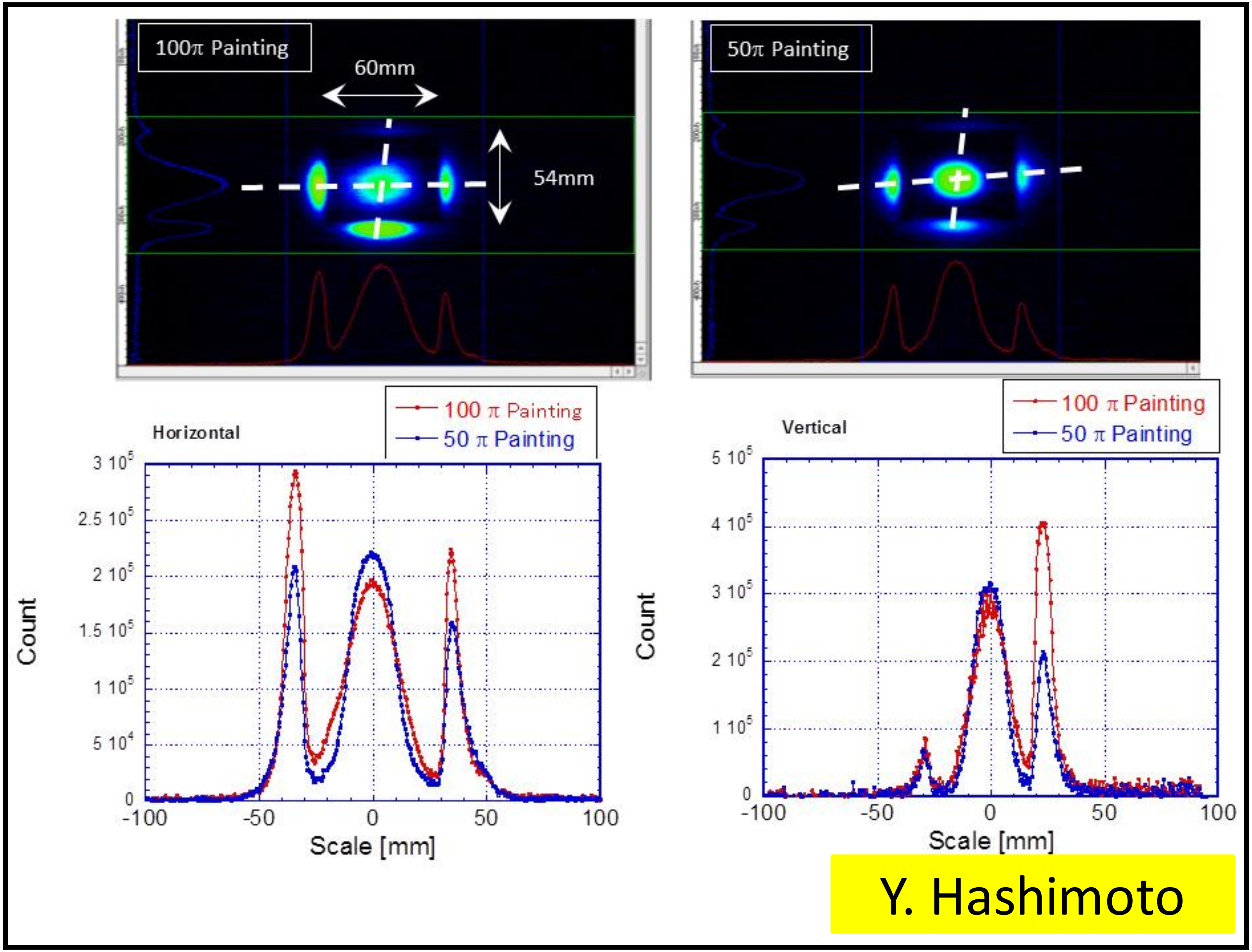
Collimator-ON

Waist appears at 10^{-4}

Expansion at 10^{-6}

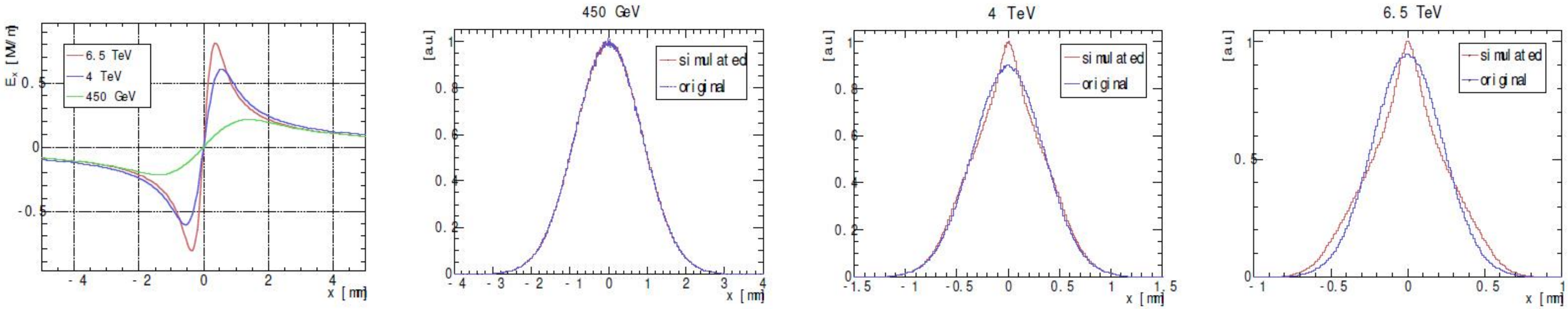
Y. Hashimoto

phase space painting: two-dimensional imaging reveals halo rotation



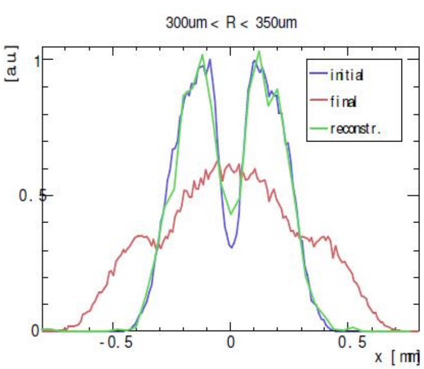
New beam diagnostics design: LHC IPM upgrades

Effect of space charge on profiles



The electric field of the protons bunch perturbs the trajectories of the to-be-collected electrons.

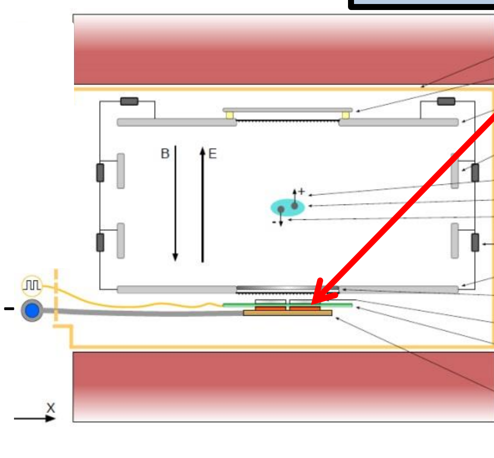
Electron Sieve Concept



sieve filters electrons of different gyration radii

original partial profile constructed by deconvoluting the PSF

Novel Readout Design



Timepix3 ultrahigh BW Hybrid pixel detector

- Fast readout speed enabling bunch-by-bunch measurement
- Reduced thickness with respect to an optical readout
- No need for MCP amplification
- Low RF coupling
- Highly radiation hard system

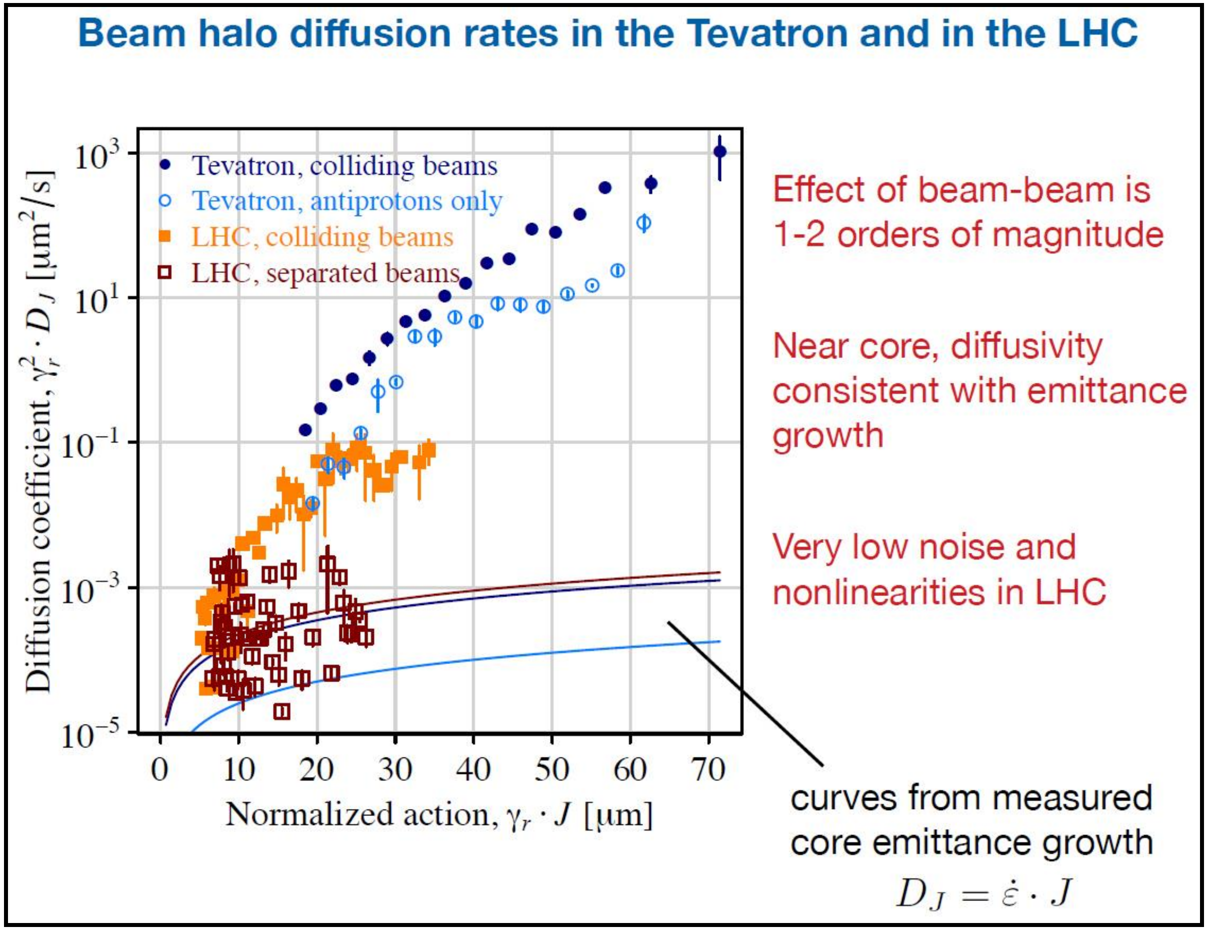
M. Sapinski

MOPAB41 "Feasibility Study of a Novel, Fast Read-out System for an Ionization Profile Monitor Based on a Hybrid Pixel Detector"
MOPAB42 "Investigation of the Effect of Beam Space-charge on the trajectories in ionization profile monitors"

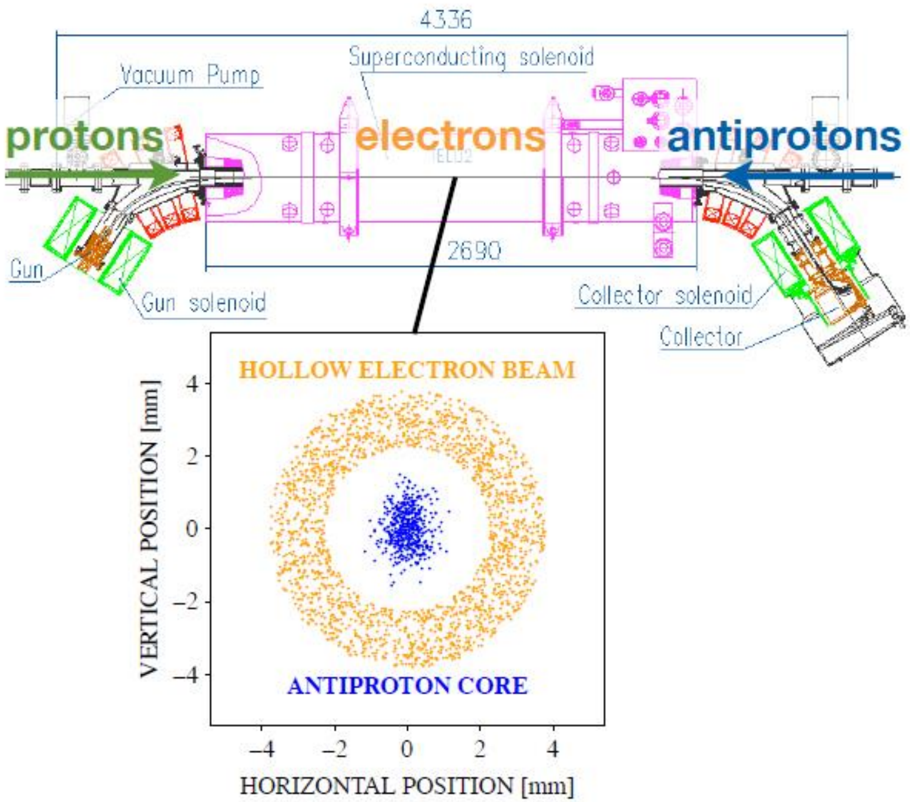
Halo dynamics

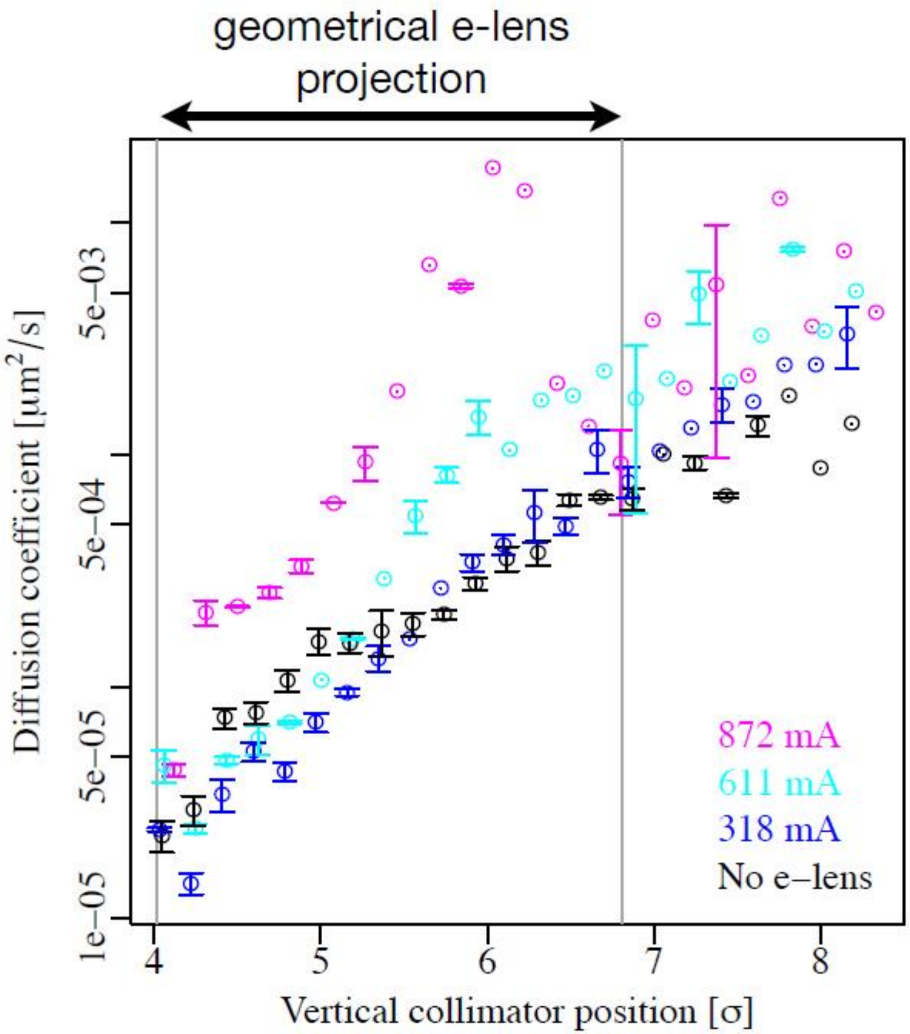
Giulio Stancari

"Measurements of beam halo diffusion and population density in the Tevatron and in the Large Hadron Collider"



Effect of hollow electron lens on diffusion in the Tevatron





Giulio Stancari

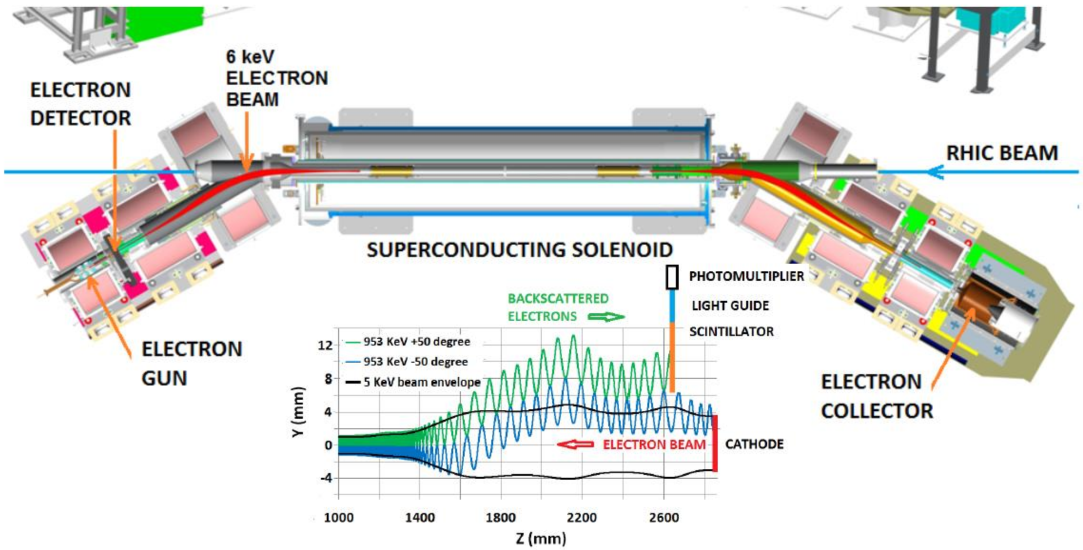
To our knowledge, first direct observation of controlled diffusion enhancement in specific amplitude range!

New diagnostics: electron back scattering detector

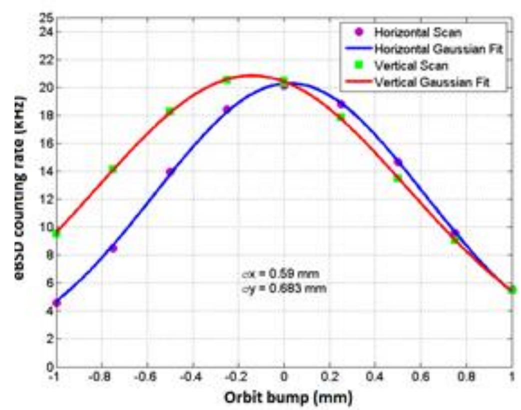
- New tool for the precise alignment of electron with ion beam
- Small plastic scintillator installed close to the e-gun
  - Measures back-scattered electrons
- Automatic procedure for beam alignment by maximizing eBSD counting rates

E.B. Holzer

Backscattered electron detector in RHIC electron lenses



P. Thieberger et al., IBIC 2014



- Might also be used for hollow electron lens considered as option for HL-LHC (CERN_LARP collaboration), based on Tevatron lens design

Slide with theory and demonstration of truly parasitic beam-gas scattering data (appended)

Discussion

Rudolf Dölling, HB2014

a question to beam dynamics / simulation:

what quantity and quality of information beam diagnostics have to deliver ...

number of measurement locations along beam path

one / few / many / continuous

quality

dynamic range
accuracy

covered dimensions

6D (x, x', y, y', z, p_z)		ideal
4D (x, x', y, y')		emittance pepper pot
2D (x, x')+2D (y, y')		emittance slit-grid
2D*(x, y)		SEM foil (+ electron optics) / gas sheeth fluoresc.
2D*(x, y)	only tail	screen / scanning ionization chamber
2D*(x, z)+2D*(y, z)		wire + TOF (bunch shape)
1D (p_z)		spectrometer
1D*(x)+1D*(y)		wire scanner
1D*(x)+1D*(y)	only core	residual gas fluorescence
~0.5D*(x)+~0.5D*(y)		4-segment foil or collimator
1D* (φ)	only lost tail	micro loss monitors (circumferential)
~0.5D*(φ)	only lost tail	4-segment loss monitors (circumferential)
0D*	only lost tail	external loss monitor
~0D*(<x>) +~0D*(<y>)		BPM
~0D*(<z>)		phase probe
~0D*(<I>)		current monitor

* usable while beam delivered   Rudolf Dölling, HB2014

added up

all information useful?
and "digestable"?
quality weighting?

what (exactly) is enough? (if at all)

... to allow the prediction of beam losses?

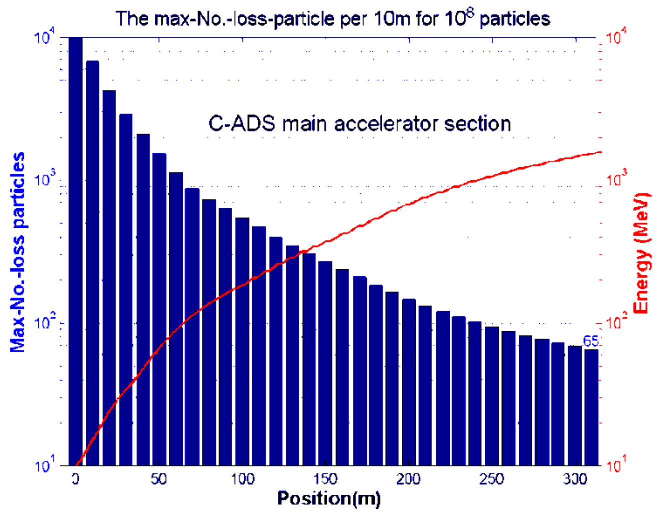
(of the order of 10 nA)

Discussion / Open Questions

In addition to those distributed (in call for contributions, appended) …

Experience from existing high power accelerators shows that reliability may be compromised by not anticipating or realizing the impact of certain physical phenomena (SNS: space charge, intrabeam stripping, LHC: unidentified falling objects, electron clouds, fast ion instabilities …). Are we doing enough to ensure that future accelerators are not unexpectedly compromised?

Safety margin criteria for future accelerators often cited in terms of figures of merit;
e.g. permissible maximum beam loss = 1e-6 * total beam current
maximum power deposition = 1 W/m
These are too general (and should not be interpreted as specifications by physicists or engineers).



A fractional beam loss is not the appropriate measure for a safety margin. It is the total absolute beam loss and/or total power deposition that is relevant.

Discussion / Open Questions

The success of the LHC collimator design (with 100+ collimators) is truly noteworthy (no unintentional quenches to date). The designing methodologies should be "kept alive" and, if not already done, applied to collimation system designs for future accelerators.

At the Halo'03 workshop, available computing power was considered a limiting factor for understanding beam halo and its evolution. With today's technologies, is this still the case? Has our understanding of beam halo improved commensurately? Do we still think to need such simulations?

Will simulations guarantee that we can achieve the requirements on maximum allowable beam loss in future accelerator designs (FRIB, ESS, ADSs)? Should we expect them to?

On the topic of "what is halo":

(my view) need to expand to multiple definitions which depend on context

the definition of dynamic aperture seemed also not so clear

Working Group-F Summary

Part 2: Beam-Material Interactions

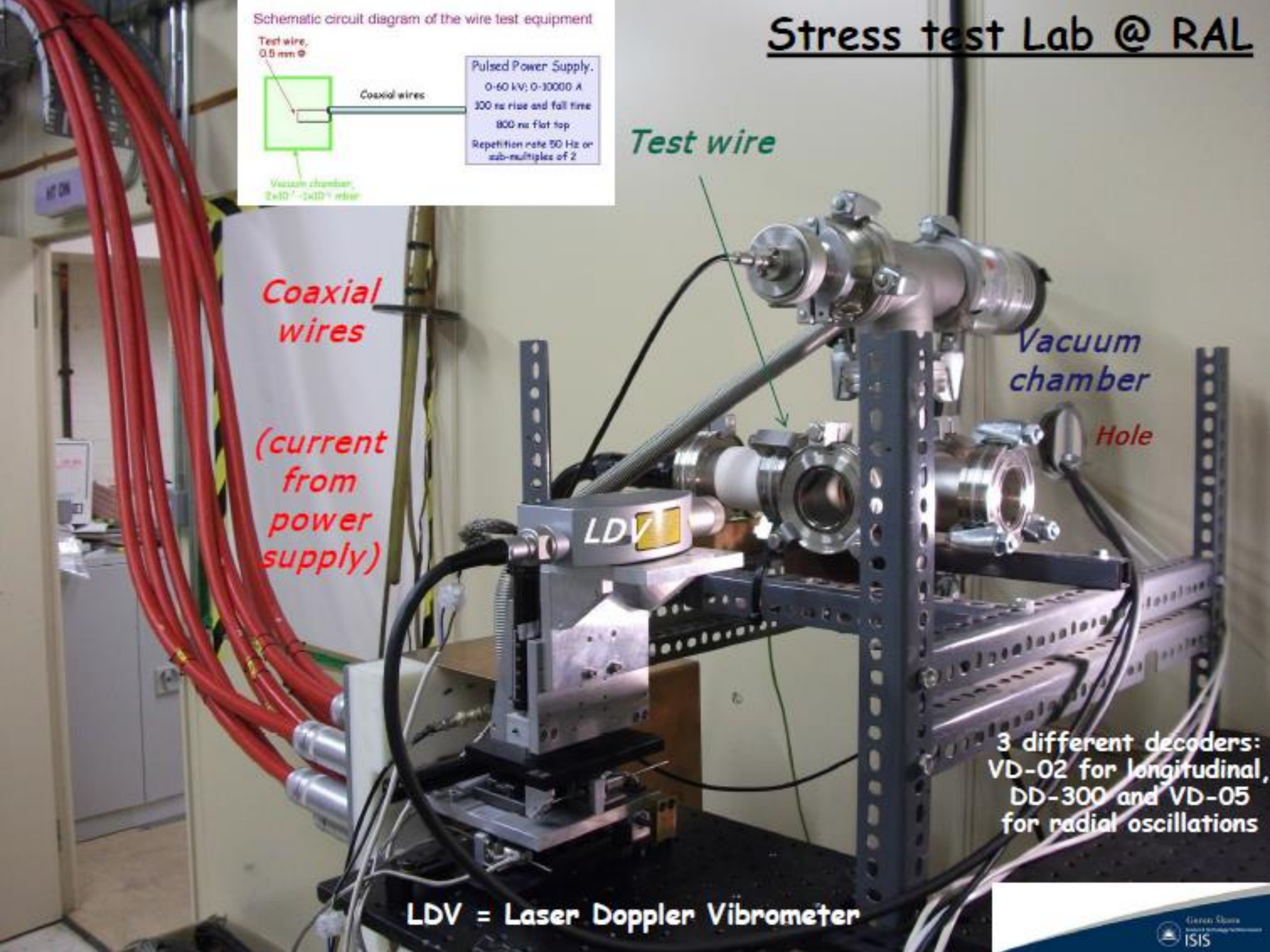
Nikolai Mokhov

Fermilab

G. Skoro: Material Response to High-Power Beams

- **Solids: thermal stress**
  - Minimization via segmentation, no stress concentration, compressive preloading, beam size/shape, material selection
  - Stress quality factor
  - Stress test Lab at RAL: direct measurements of material strength
  - Dynamic measurements
  - Material fatigue
- **Liquids**
  - Mercury jet
- **In between**
  - Fluidized tungsten powder

Stress test Lab @ RAL

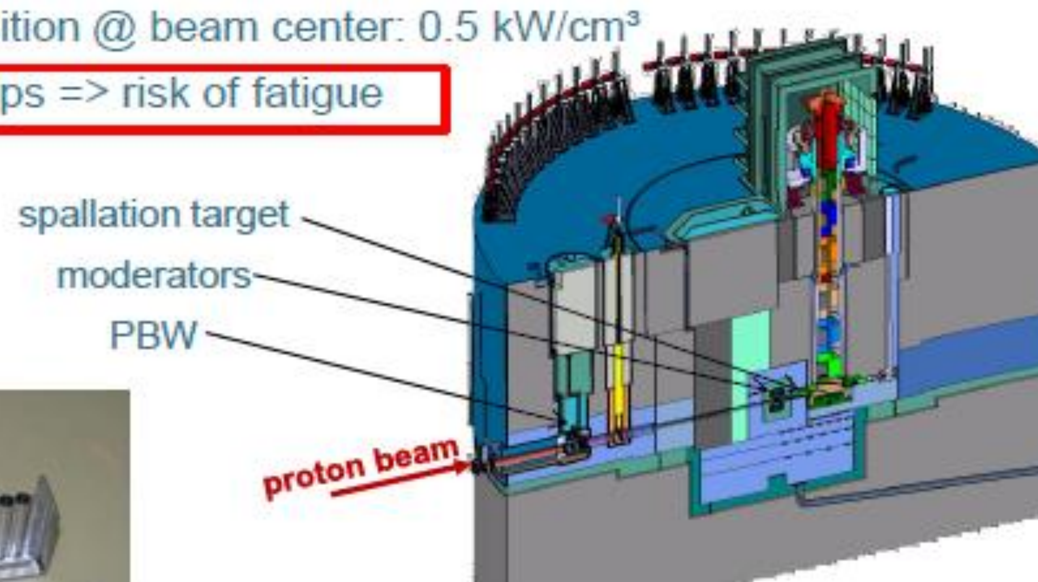


Proton Beam Window (PBW) for ESS

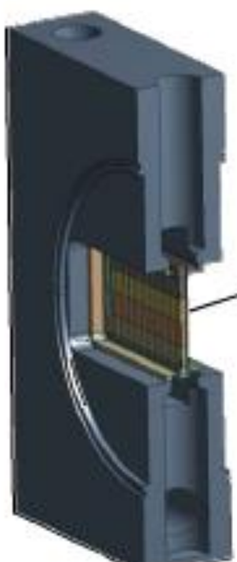
J. Wolters[1], M. Butzek[1], B. Laatsch[1], Y. Beßler[1], G. Natour[1], P. Nilsson[2], P. Sabbagh[2]

[1]Forschungszentrum Jülich GmbH, Jülich, Germany; [2]European Spallation Source ESS, Lund, Sweden

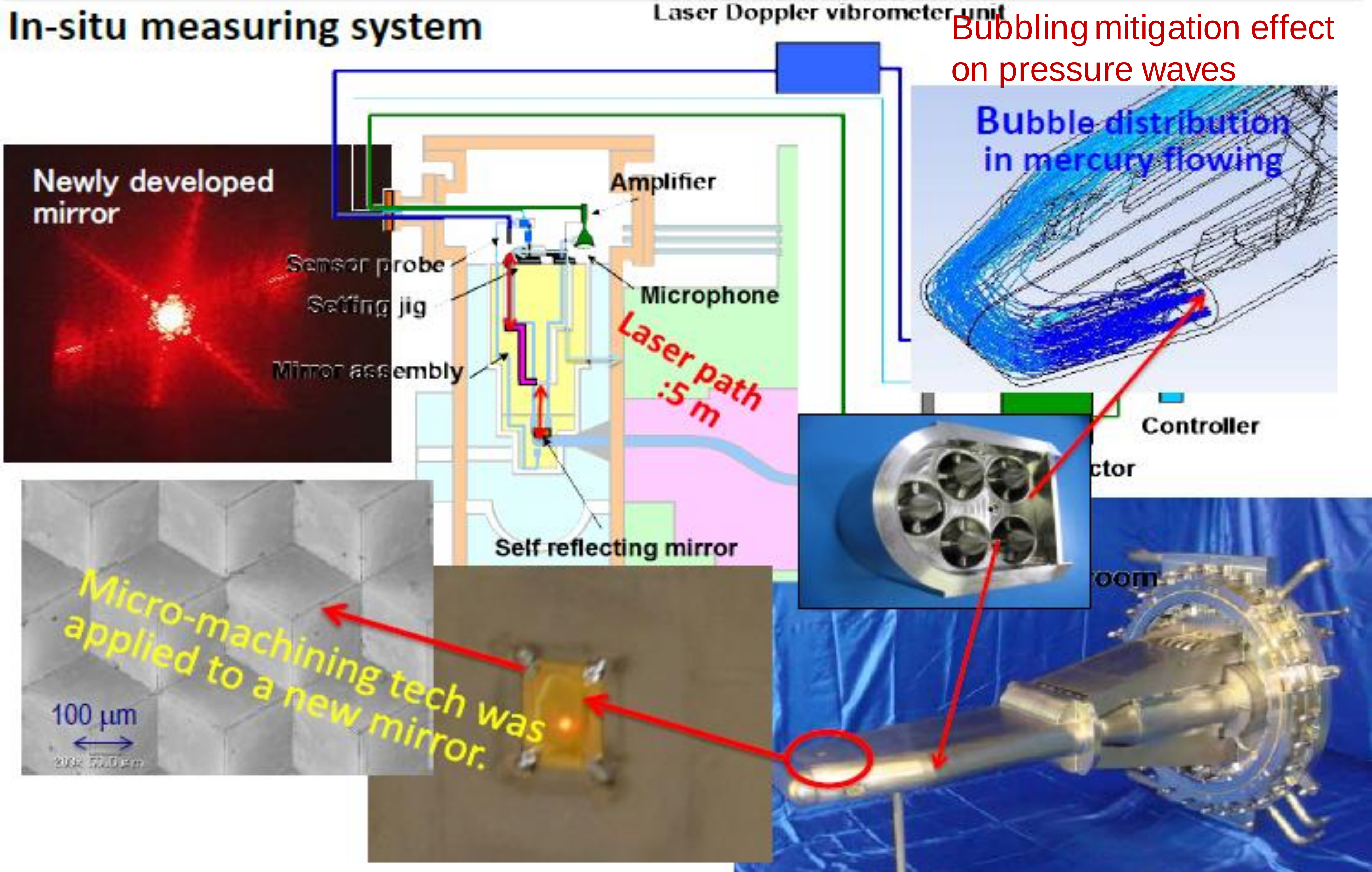
- the PBW separates the accelerator vacuum from the helium atmosphere in the target room at 1 bar
- Al6061-T6 is the preferred material for the PBW
- helium at 10 bar is used for PBW cooling (customer request: no water cooling!)
- Maximum time-averaged heat deposition @ beam center: 0.5 kW/cm³
- pulsed operation at 14 Hz & beam trips => risk of fatigue



New concept: panpipe design



J-PARC Mercury Target:
Detection of vibration induced by proton beam

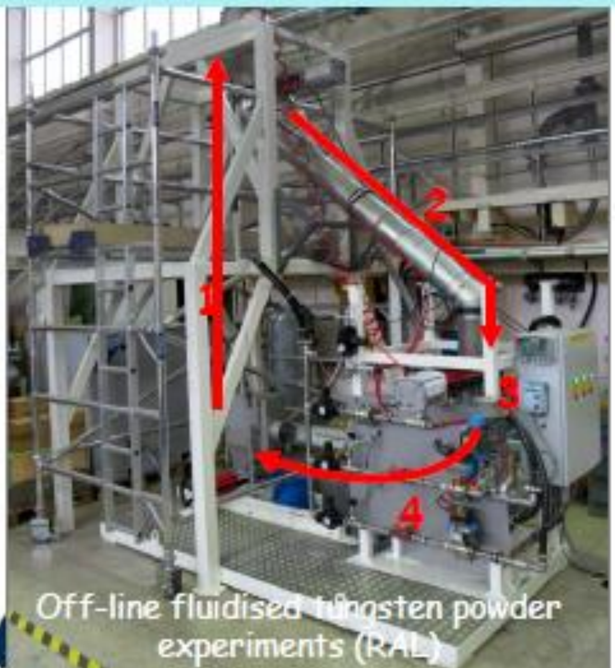


Between Solid and Liquid:
Fluidized Tungsten Powder

Motivation: Material already fragmented; no cavitation; thermal stress contained within grains; target can be continuously reformed; can be 'pumped' away, externally cooled and recirculated.

- Potential solution for applications requiring highest pulsed beam powers e.g. alternative to Neutrino Factory liquid mercury jet
- Pneumatically (helium) recirculated tungsten powder

1. Suction / Lift
2. Load Hopper
3. Pressurise Hopper
4. Powder Ejection and Observation



Off-line fluidised tungsten powder experiments (RAL)

In-beam experiment

Location of HiRadMat

HiRadMat Beam Parameters:

A high-intensity beam pulse from SPS of proton or ion beams is directed to the HiRadMat facility in parasitic mode, using the existing fast extraction channel to LHC..

Beam Energy 440 GeV
Pulse Energy up to 3.4 MJ
Bunch intensity $3.0 \cdot 10^9$ to $1.7 \cdot 10^{11}$ protons
Number of bunches 1 to 288
Maximum pulse intensity $4.9 \cdot 10^{13}$ protons
Bunch length 11.24 cm
Bunch spacing 25, 50, 75 or 150 ns
Pulse length 7.2 μs
Beam size at target variable around 1 mm²

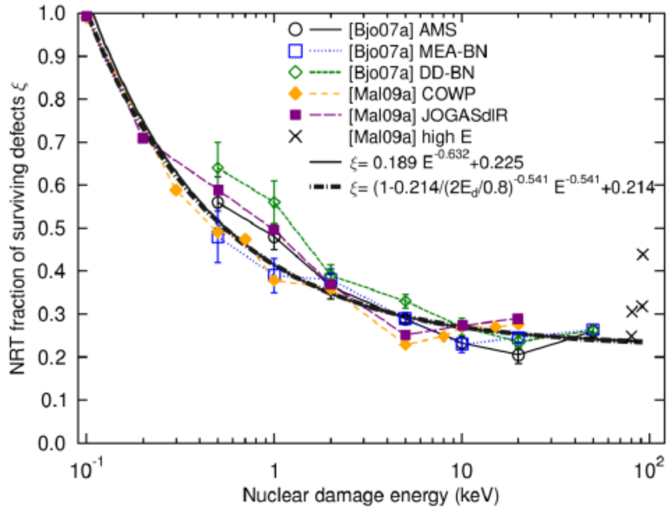
HiRadMat: very interesting and important results (characterisation of novel, more robust materials for beam collimation at higher power).

A. Konobeev: DPA and gas production in intermediate and high energy particle interactions with accelerator components

- Overview of recent developments in modeling of primary radiation damage relevant to dpa rate calculations

Corrections to the reference NRT model: BCA, MD, BCA-MD (IOTA code at KIT) and various forms of defect production efficiency. Most recently by Nordlund:

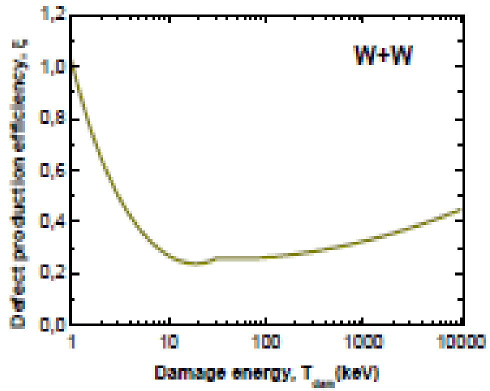
$$\xi(E) = \frac{1-c}{(2E_d/0.8)^b} E^b + c$$



Kinetic Monte Carlo (up to 10^4 s cf to ns in MD): Individual defects, clusters, impurities, annealing

Complete simulations: particle interaction and transport codes coupled to BCA+MD(+KMC)

3. Modeling using pre-calculated ξ(T) dependence



ξ(T): parameterized or pointwise

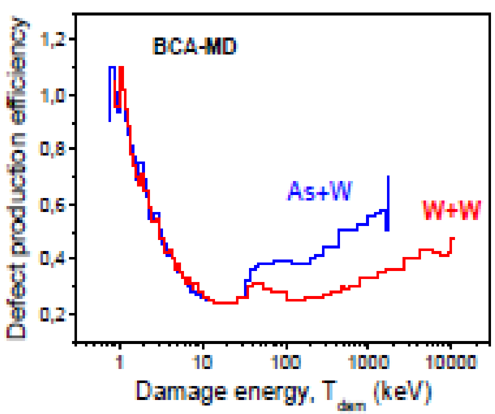
Implemented: MARS15, FLUKA, PHITS

Simulation: BCA-MD

Correction: measured <ξ> values, *JNM 328, 197 (2004)*

Important

- Evaluated data at low energies (ENDF/B, JEFF, JENDL etc): processing dpa- cross-sections with ξ(T)
- ξ(T) dependence for various PKA



4. Modeling using pre-evaluated σ_d cross-sections

The most flexible way to keep

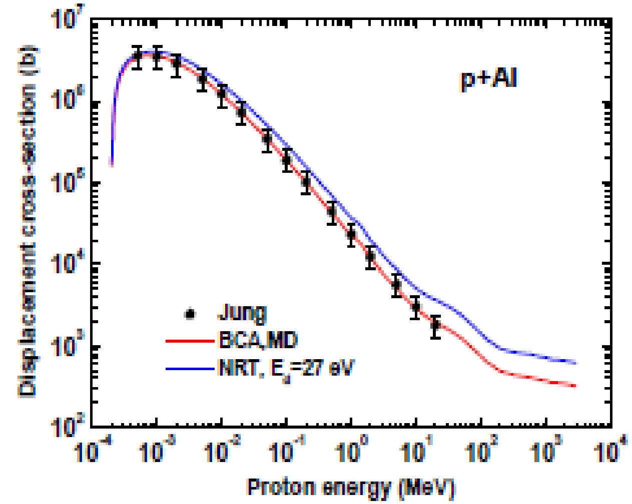
- justified theoretical information
- experimental data

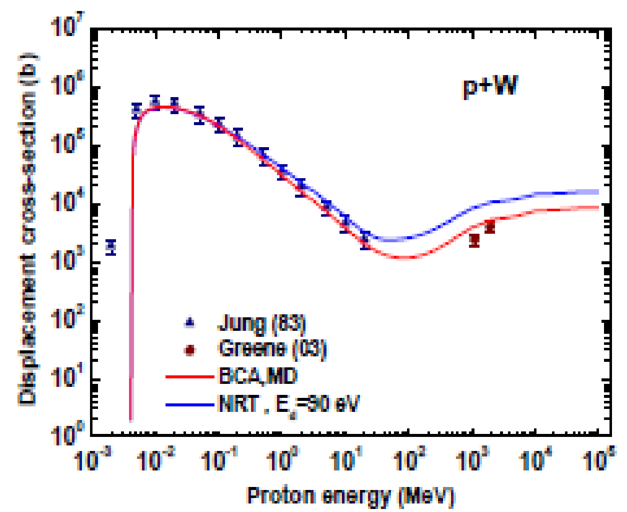
DXS data file (KIT, 2011-2014) (IAEA)

Projectile: neutron, proton

Energy: 10^{-5} eV to 3 GeV

Target: Al, Ti, V, Cr, Fe, Ni, Cu, Zr, W

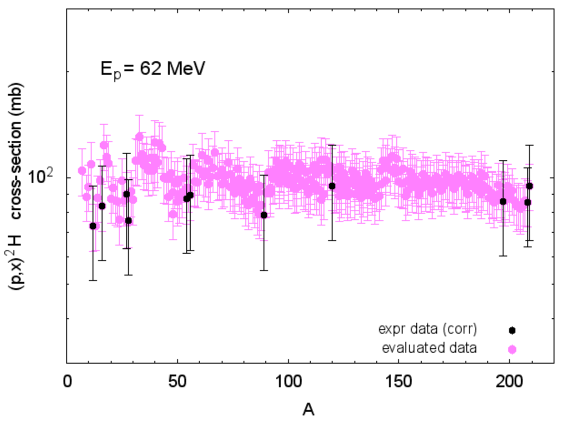


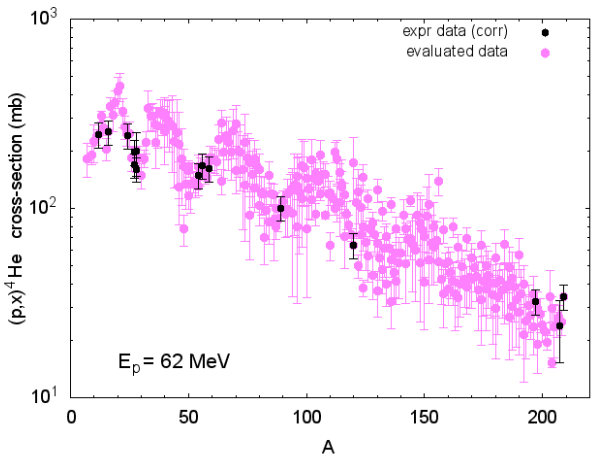


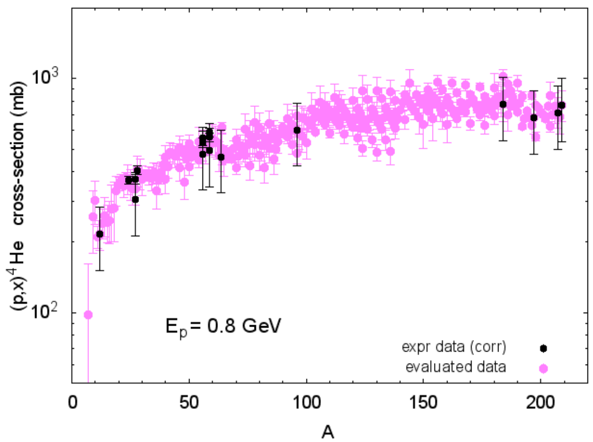
Gas Production: p, d, t, ^{3}He and ^{4}He

Nuclear models implemented in popular computer codes predict gas production cross-section with varying degrees of success depending on the energy of projectiles

The use of cross-sections evaluated using nuclear model calculations and measured data is one of the most reliable and flexible approach for advanced calculation of gas production rate, certainly at intermediate energies. KIT: 278 targets from ^{7}Li to ^{209}Bi; incident proton energies: 62, 90, 150, 600, 800, 1200 MeV







A. Bertarelli ““Novel materials for collimators at LHC and its upgrades”

Challenging applications - LHC collimators. Key properties to be optimized to meet the requirements (no existing material can simultaneously meet all the requirements):

- **Electrical Conductivity (g)** Maximize to limit Resistive-wall Impedance
- **Thermal Conductivity (l)** Maximize to maintain geometrical stability understeady-state losses
- **Coefficient of Thermal Expansion (a)** Minimize to increase resistance to thermal shock induced by accidental beam impact.
- **Melting/Degradation Temperature (T_M)** Maximize to withstand high temperatures reached in case of accidents.
- **Specific Heat (c_p)** Maximize to improve thermal shock resistance (lowers temperature increase)
- **Ultimate Strength (R_M)** Maximize to improve thermal shock resistance (strain to rupture)
- **Density (r)** Balance to limit peak energy deposition while maintaining adequate cleaning efficiency
- **Radiation-induced Damage.** Minimize to improve component lifetime under long term particle irradiation

Novel Materials R&D Program

- Extensive materials R&D program in **collaboration** with **EU institutes** and **industries** (**EuCARD**, **EuCARD2**, **HiLumi**)
- **Aim**: explore composites combining the properties of **graphite** or **diamond** (**low** ρ, **high** λ, **low** α) with those of **metals** and **transition metal-based ceramics** (**high** R_M, **good** γ)
- Materials investigated are **Copper-Diamond** (**CuCD**), **Silver-Diamond** (**AgCD**), **Molybdenum-Copper-Diamond** (**MoCuCD**), **Molybdenum Carbide-Graphite** (**MoGr**)
- Production techniques include **Rapid Hot Pressing**, **Liquid Phase Sintering** and **Liquid Infiltration**
- Most promising are **CuCD** and (especially) **MoGr**

EuCARD²

High Luminosity LHC

RHP TECHNOLOGY

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Figures of Merit

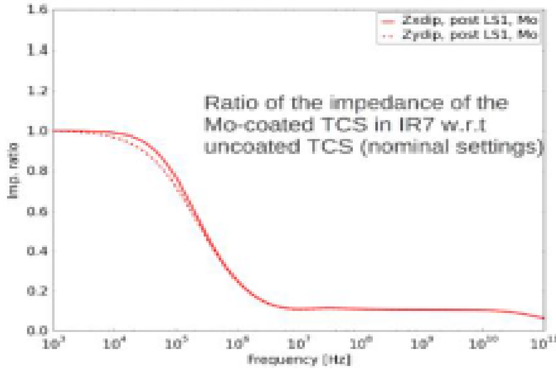
- Several **Figures of Merit** defined to compare and rank materials against most relevant requirements
- ***Thermomechanical Robustness Index*** (*TRI*) is related to the ability of a material to **withstand the impact** of a short particle pulse.
  - In thermal shock problems, **admissible strain** is the most meaningful quantity
  - The term in T_m (**melting temperature**) provides an indication of the loss of strength at increasing temperature

$$TRI = \frac{\varepsilon_{adm}}{\varepsilon_{ref}} \cdot (\frac{T_m}{\Delta T_q} - 1)^m$$

- ***Thermal Stability Index*** (*TSI*) provides an indication of the ability of the material **to maintain the geometrical stability** of the component (e.g. Collimator jaw)
  - It is related to the **inverse of the curvature** of a long structure induced by a non uniform temperature distribution (for given **steady-state particle losses**).

$$TSI = \frac{\overline{\lambda} X_g}{\overline{\alpha} C_S \rho^n}$$

- ***Electrical conductivity*** (γ) Resistive-wall impedance is inversely proportional to electrical conductivity ⇨ **highest electrical conductivity** is sought for materials sitting **closest to circulating beams!**



A. Bertarelli HB2014 – East Lansing, MI, USA – 13 November 2014 13

Comprehensive beam test program:

- 450-GeV protons, HiRadMat at CERN
- 10 MeV to 1.2 GeV C to U, UNILAC at GSI
- 100 to 200 MeV protons, BLIP at BNL

Discussion: Issues and Questions

- **DPA, gas production, fluence and dose**
  - Material and environment
  - Beam energy and particle type (e.g., accelerators *vs* reactors)
  - Energy deposition density level
  - Irradiation time structure
  - Observations (e.g., accelerators, RRR at cryo temperatures)
- **Model/code capabilities, uncertainties and questions**
  - EDD, dose, fluence, DPA and He/H_2 gas production
  - Corrections to the reference NRT model: BCA, MD, BCA-MD (IOTA code at KIT) and various forms of defect production efficiency.
  - Data needs
- **Link of calculated quantities (DPA etc) to observable changes in critical properties of materials remains on the top of the wish-list (coupling EDD codes and MD?)**

Data Needs & Further Issues

- Well-thought experiments – covering various regions of the parameter space - are extremely desirable, including measurements with charged particle beams, their relation to neutron data and degradation measurements at cryogenic temperatures.

- Annealed versus non-annealed defects.

- Low-energy neutron DPA in compounds.

Possible topics (call for contributions)

1) **Is it possible to understand the beam losses in detail and to predict them?**
   - at a level of 1e-5 to 1e-6 of the beam current
   - from different loss mechanisms/with protons and ions/at different machines
   - examples pro/con from existing accelerators; examples of comparison between simulation and measurement
   - open questions for future accelerators?

2) **What really has to be provided by simulation and diagnostics to make this possible?**
   - what information is really needed/sufficient/can be digested by simulations?
   - dynamic range/precision of transversal/longitudinal profile/halo measurement? of simulation?
   - emittance measurement, tomographic methods, full 6D phase space, projections?
   - losses, how detailed?
   - requirements of future accelerators?

3) **What seems actually feasible/has been delivered?**
   - dynamic range/accuracy of transversal/longitudinal profile/halo measurement? of simulation?
   - emittance measurement, tomographic methods, full 6D phase space, projections?
   - examples of comparison between simulations and measurement
   - is there recent progress? what can we hope for/dream of? what are the bottlenecks?

4) **If a detailed understanding of losses were possible, affect on operation/tuning/hardware improvements?**
   - commissioning strategy integrating beam dynamics/diagnostics
   - strategy if simulation and measurement disagree?
   - can we overcome empirical tuning?
   - different requirements to simulation for support of tuning and support of hardware changes?

5) **How important is an detailed understanding for decreasing/limiting the beam losses?**
   - for improvements at existing accelerators/for future accelerators
   - is what we have reached already good enough?
   - are we optimistic/pessimistic on the further development?
   - is a better coordination of beam dynamics/diagnostics needed?

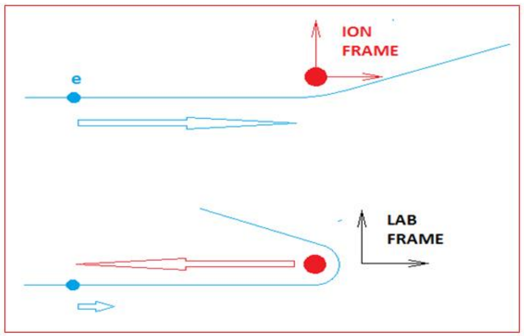
(not presented)

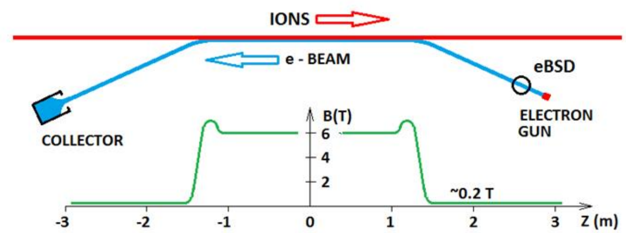
Coulomb scattering calculations

p = momentum E = energy θ = angle of the electron in the ion frame

$$\frac{d\sigma}{d\Omega}=\frac{Z^2}{4}\left(\frac{e^2}{E}\right)^2\frac{1}{\sin^4(\theta/2)}\times\left[1-\left(\frac{pc}{E}\right)^2\sin^2\frac{\theta}{2}\right]\times\left[1+\frac{2E\sin^2(\theta/2)}{M_pc^2}\right]^{-1}\times\left[1-\frac{q^2\tan^2(\theta/2)}{2M_p^2}\right]$$

Rutherford — Quantum corr. — Recoil corr. — Magnetic moment corr.



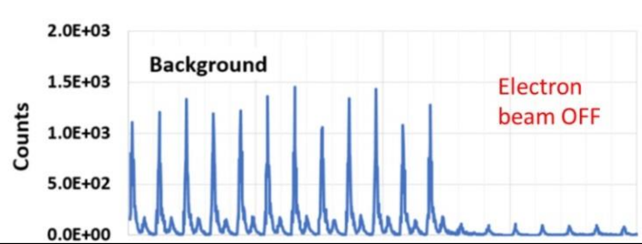


Small deflections in the ion frame leads to large deflections in the lab.

(not presented)

Time-resolved eBSD counts

Ion Beam:	Gold
Beam energy: GeV/u	100
Bunch intensity:	$1.1*10^9$
# of bunches:	2



The background is due to electrons from the residual gas (~~ 5E-10 Torr at pump)

BROOKHAVEN NATIONAL LABORATORY

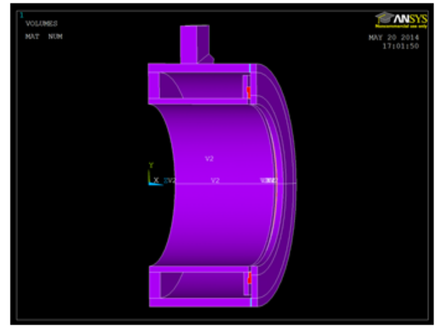
P. Thieberger

"Scattered electrons as possible probes for beam halo diagnostics"

Workshop on
Beam Halo Monitoring
19 September, 2014
at SLAC National Accelerator Laboratory
following IBIC 2014 in Monterrey

New beam diagnostics design: current monitor at PSI

Detailed Design



Passive Compensation

- 2 mm Aluminum shim for self-compensation, since Aluminum's Thermal Expansion Coefficient is 3 times higher than Graphite

Ceramic Ring

- Acts as a thermal bridge
- High permittivity to increase the capacity gap (relax the mechanical tolerances)

ID: 1101 – MOPAB47/48 Simulation/Design of a New Beam Current Monitor Under Heavy Heat Load

PSI

J. Sun

should be less sensitive to drifts caused by unequal thermal expansion under heating by particle shower