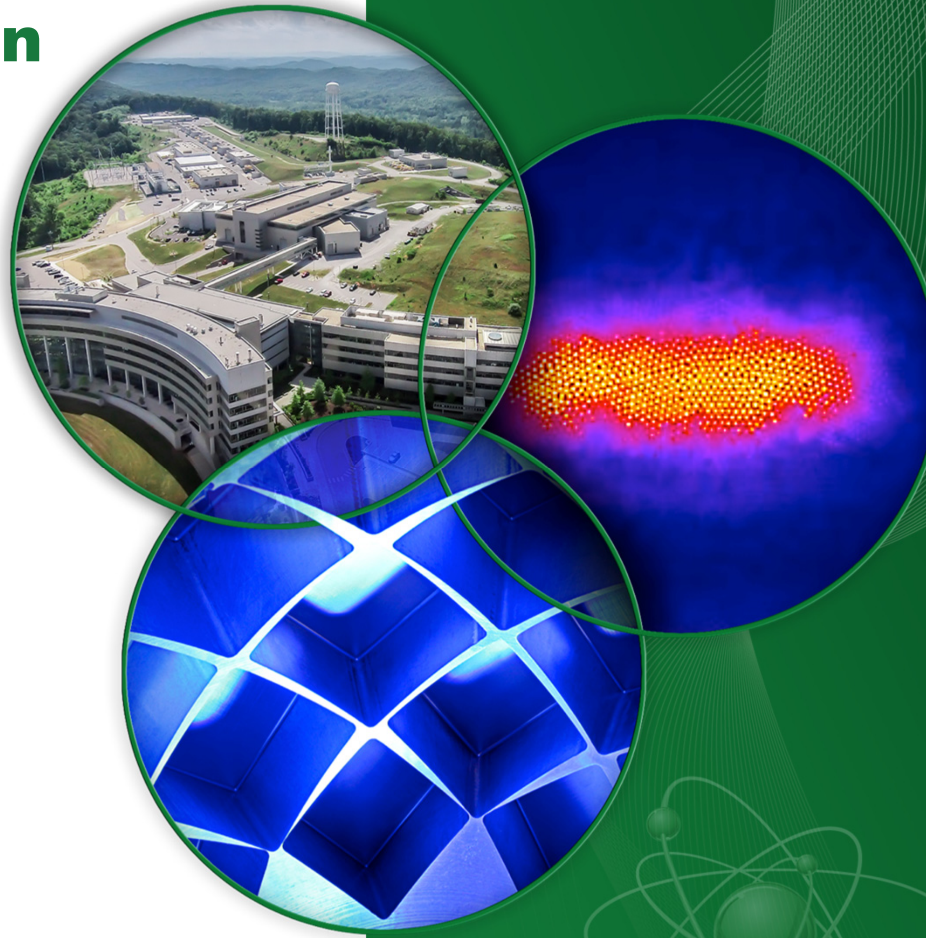
Path to beam loss reduction in the SNS linac using measurements, simulation and collimation



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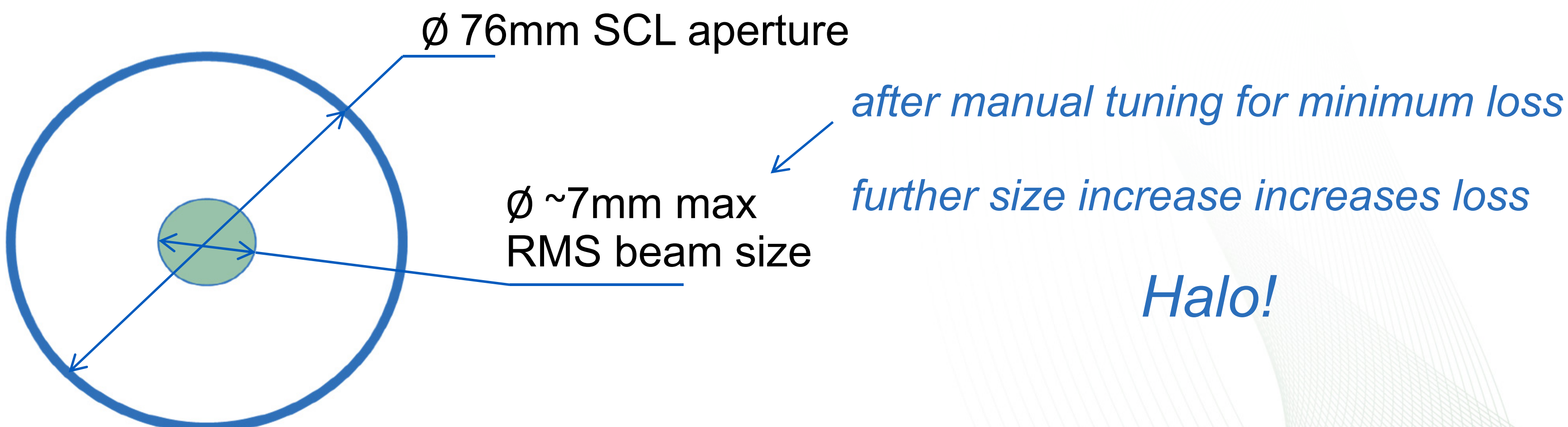
Why do we care about loss reduction and model based methods development

- Beam spill in SNS Linac does not limit operational beam power but still causes issues in long term
  - Equipment damage (cables, hoses, gate valves, etc.)
  - SC cavities performance degradation is suspected
- Last step in low-loss linac set up involves manual tweaking of many parameters
  - Poorly documented and based on a few people experience
  - Time consuming if significant changes to linac configuration are made
- Plan to double beam power and add new pulse ‘flavor’
  - Need to reduce beam spill
  - Need to reduce machine set up time
- Model-based low-loss tuning is crucial for future high power linacs
  - SNS is ideal test bench for beam instrumentation and modeling development

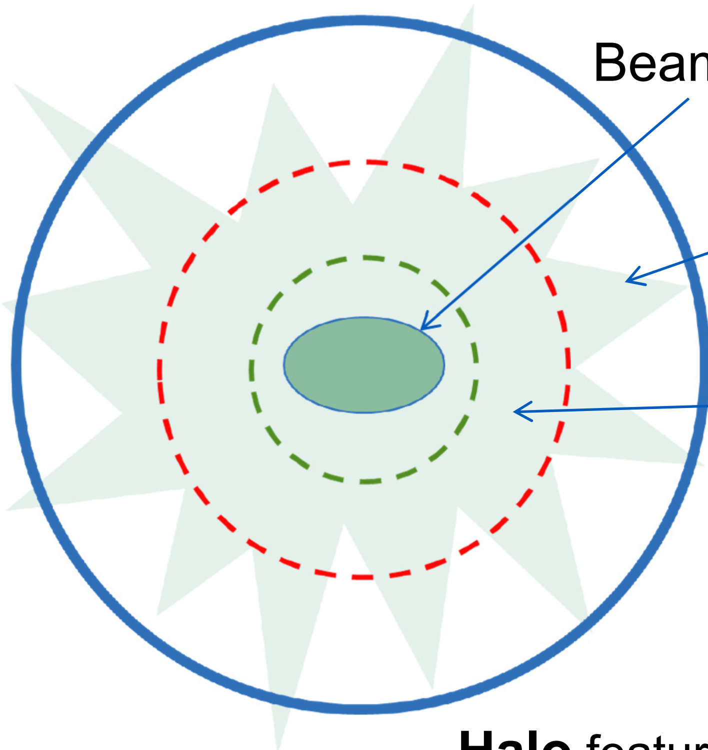
Intra-beam stripping loss reduction in SCL is our first target

- Stripping rate is inversely proportional to bunch density. Increasing bunch size should reduce beam loss
- Requires precise control of 3D bunch size
  - Laser Wire, Beam Shape Monitors, BPMs, modeling techniques
    - We believe we have all these ingredients (Andrey Shishlo' s talk)
- Requires reducing halo to allow for bunch core expansion



What we call ‘halo’

- We adopt agreement from **Workshop on Beam Halo Monitoring**, SLAC National Accelerator Laboratory following IBIC 2014



Beam core, $1 \div 10^{-2}$ of the peak density

Beam halo, $10^{-4} \div 10^{-6}$ of the peak density or lower

Distribution ‘tail’, ‘shoulders’, etc.

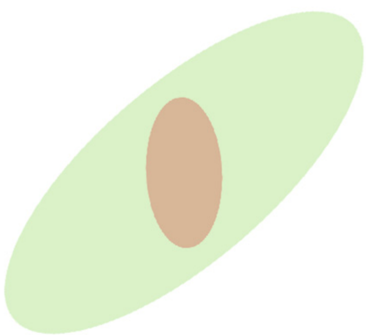
Halo features relevant for this talk:

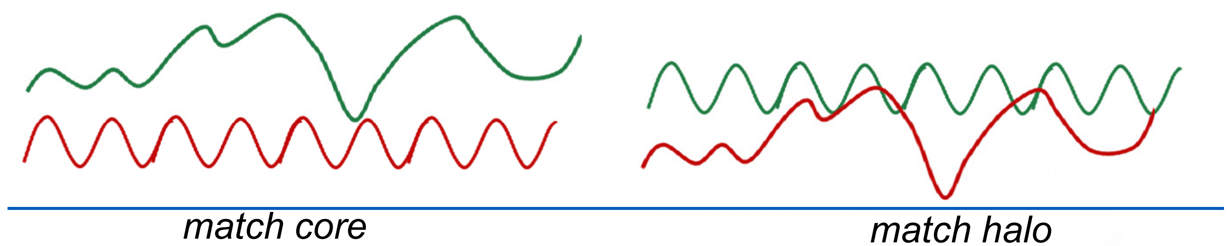
Low intensity
Far from core => creates problems => requires mitigation

How we can reduce halo in SCL

– Halo collimation
  - Only practical at low energy i.e. 2.5MeV MEBT
  - Removes halo created in injector (IS + RFQ)

– Matching between linac sections: MEBT-DTL, DTL – CCL, etc.
  - Bunch core RMS matching prevents halo formation (a proposition, never proved experimentally in real linac)
  - Halo matching reduces maximum beam size
  - Trade off between RMS and halo matching to minimize overall beam spill





– Halo measurements
  - Needs to be in a form usable for modeling
  - Required for halo matching
  - Useful for collimation optimization

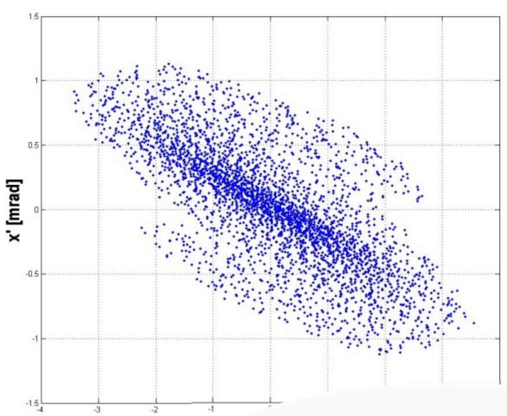
What we call "measuring halo"

- Detecting lost particles or monitoring <u>is not</u> halo measurement in context of this talk
  - BLMs, 'Halo rings', etc.
  - Do provide some quantitate measure: 'more', 'less'
  - Useful tool for empirical loss minimization
- We need data in form usable for beam modeling

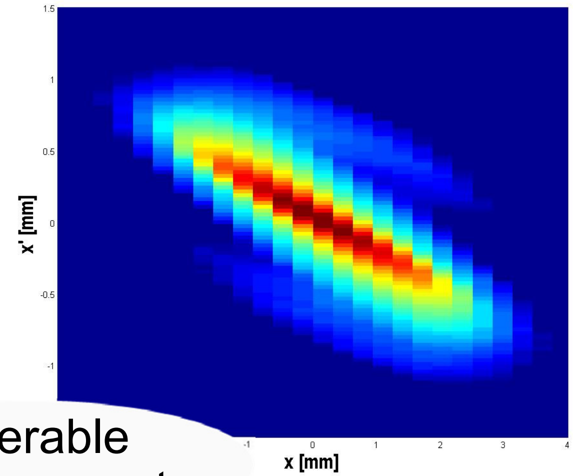
Particle-In-Cell codes require detailed particle distribution as input

Can be produced from measured 6D phase space distribution or

under certain assumptions, from 2D projections or even 1D projections

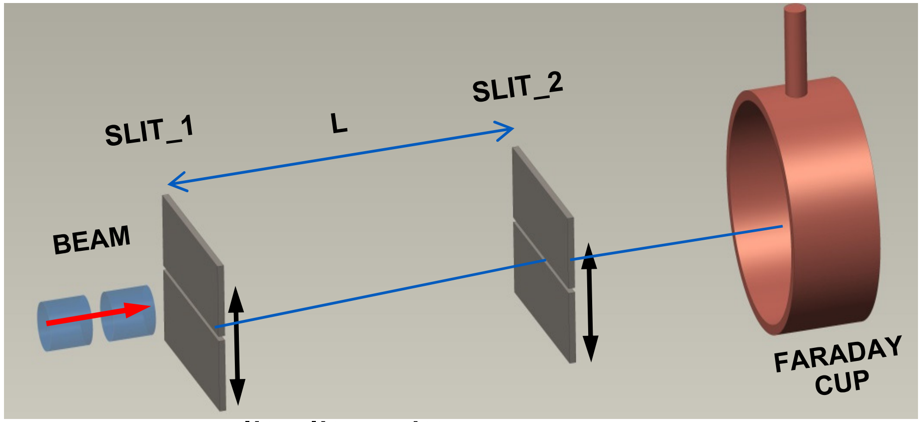


required characterization

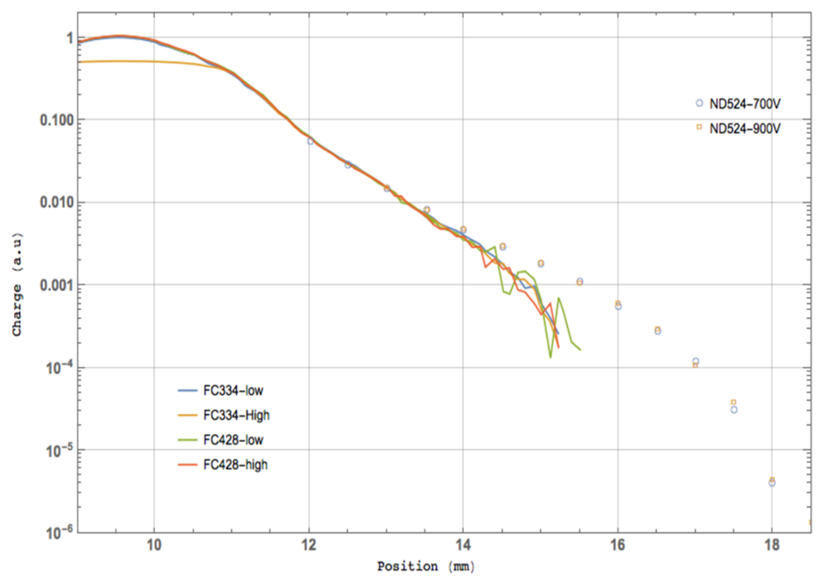


preferable measurement

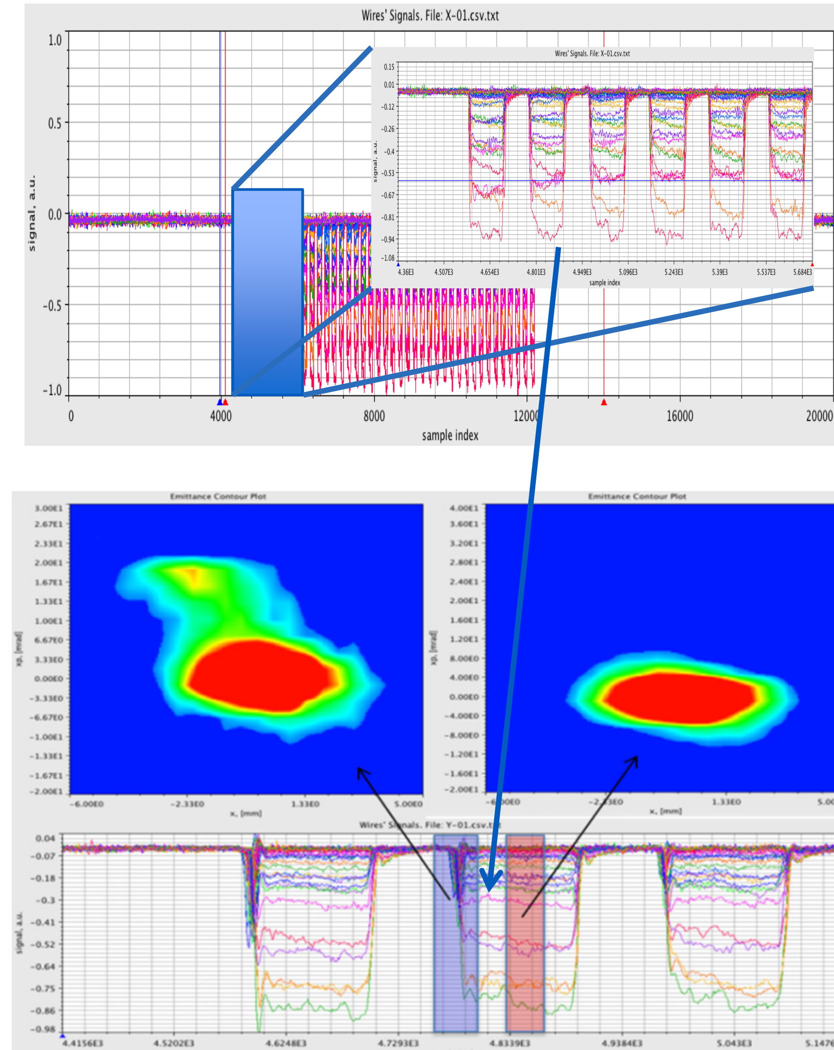
Measuring 2D phase space at low energy



slit-slit emittance scanner



~ 10^5 dynamic range or 20ns temporal resolution



Courtesy of A. Zhukov, SNS

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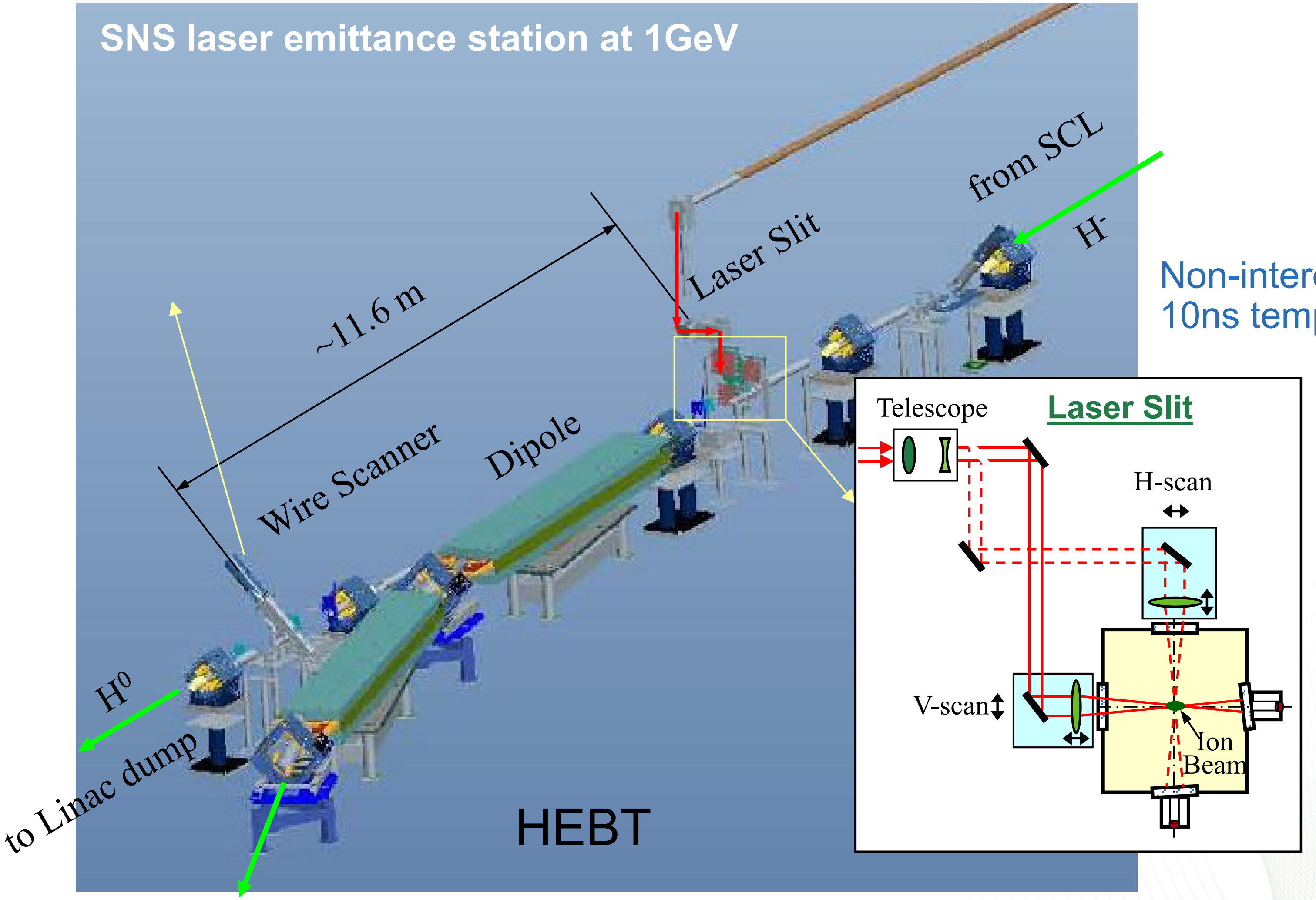
Measuring 2-d at high energy: laser wire emittance measurement for H⁻ beam

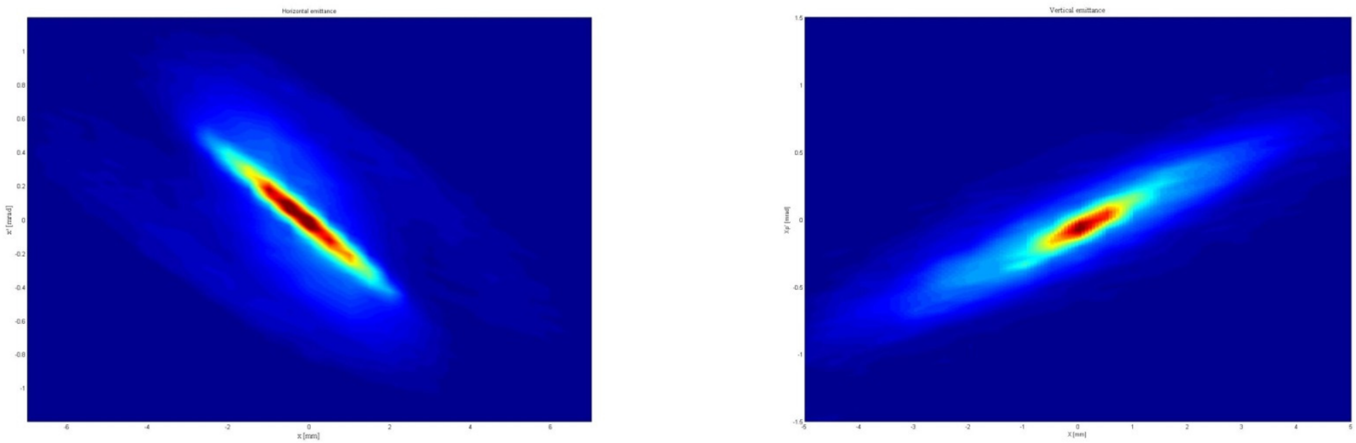


Non-interceptive
10ns temporal resolution

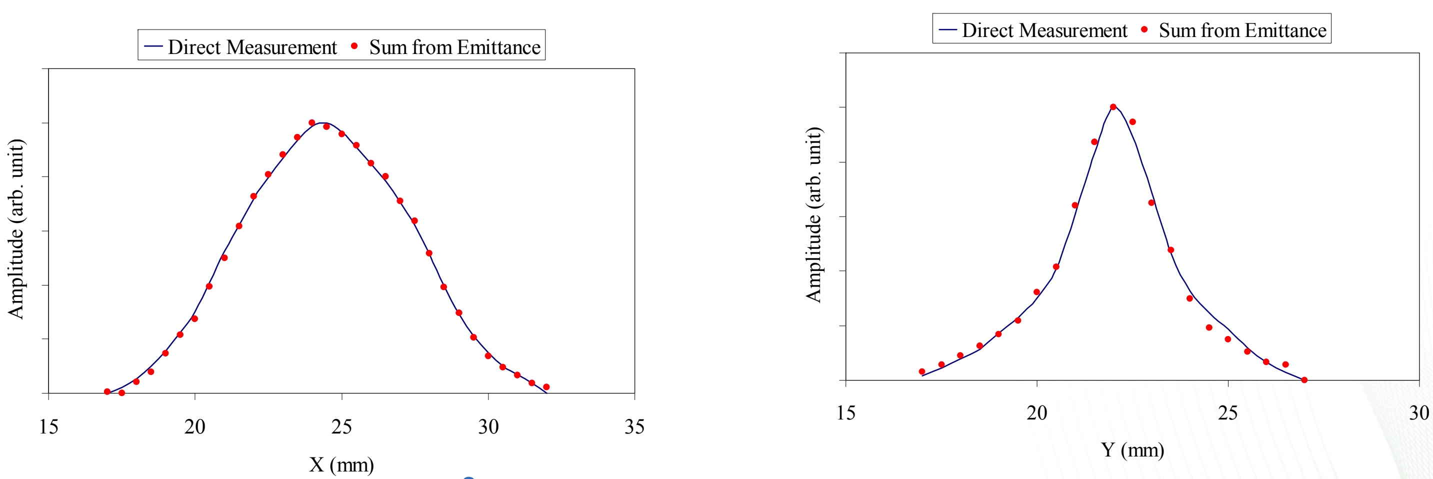
Courtesy of Y. Liu, SNS

State-of-the art diagnostics require robust verification methods

$$\varepsilon_{HEBT} \approx \frac{1}{25}\,\varepsilon_{MEBT}$$



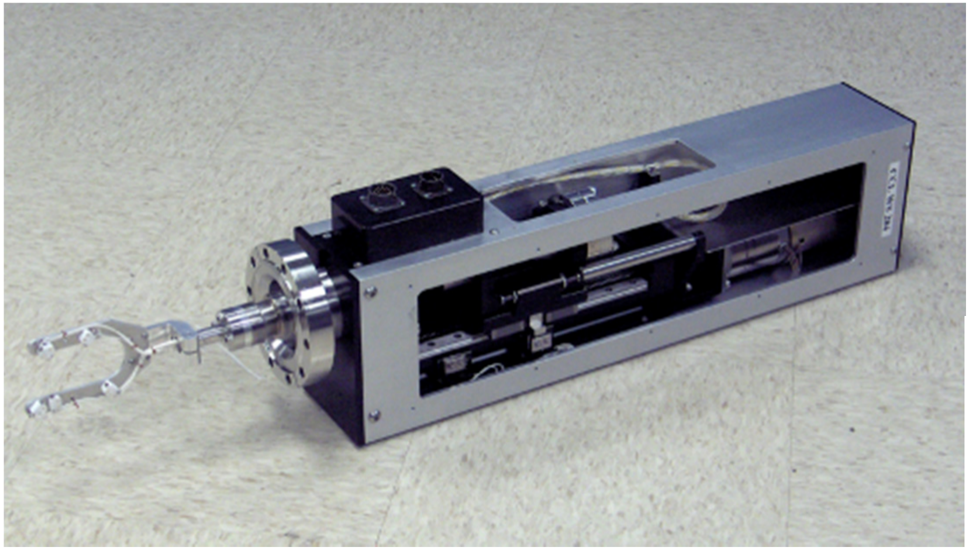
Self-consistency check – comparison between the integration of the emittance (over the angle) with the directly measured profiles



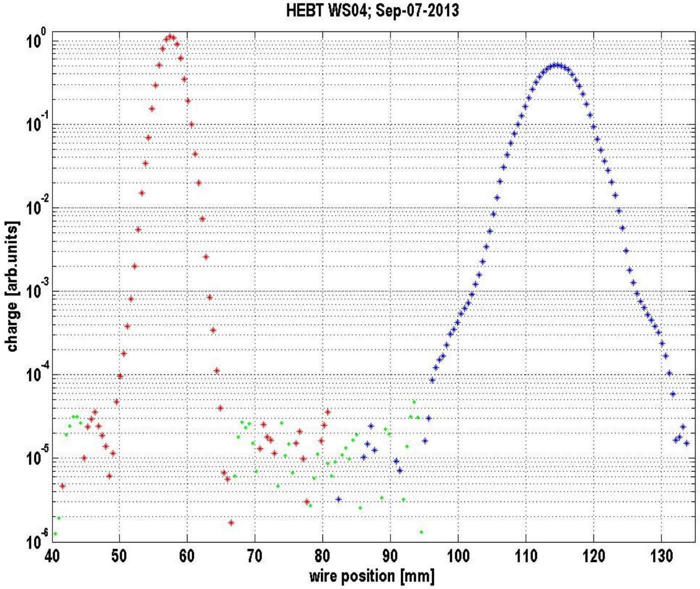
~ 10^3 dynamic range demonstrated
expect to improve by ~1 order of magnitude

Courtesy of Y. Liu, SNS

Halo Measurement Using Large Dynamic Range Wire Scanners (1D projection)



- SNS Wire scanner
  - *charge collected on wire*
- Factors limiting dynamic range
  - *Capacitive coupling to beam core*
  - *Residual gas ionization*
  - *Nearby beam loss*



Dynamic range: ~10^5 BW: ~1kHz

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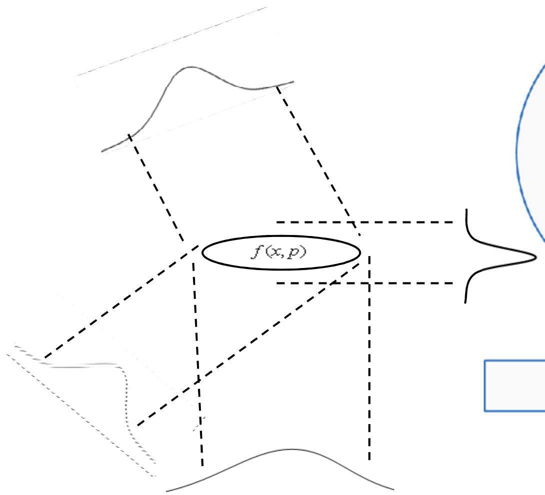
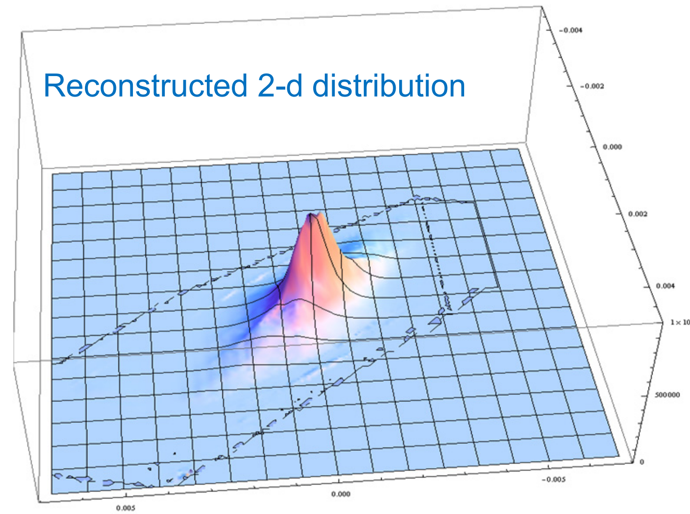
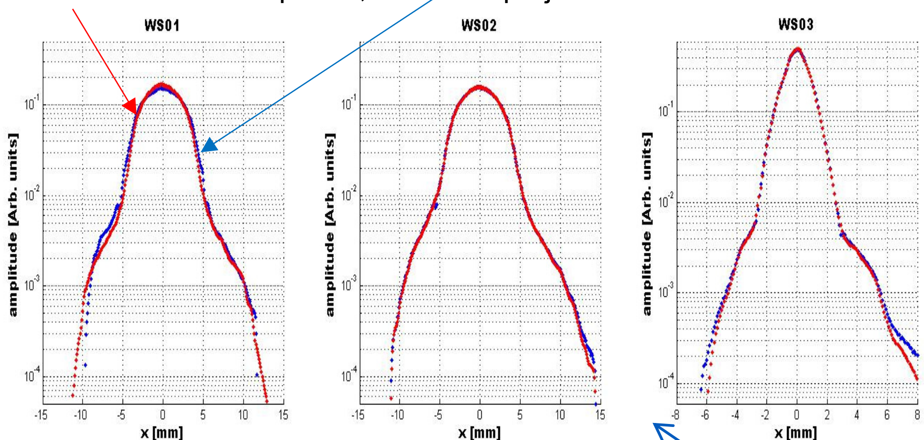
Reconstruction of 2D distributions from 1D profiles

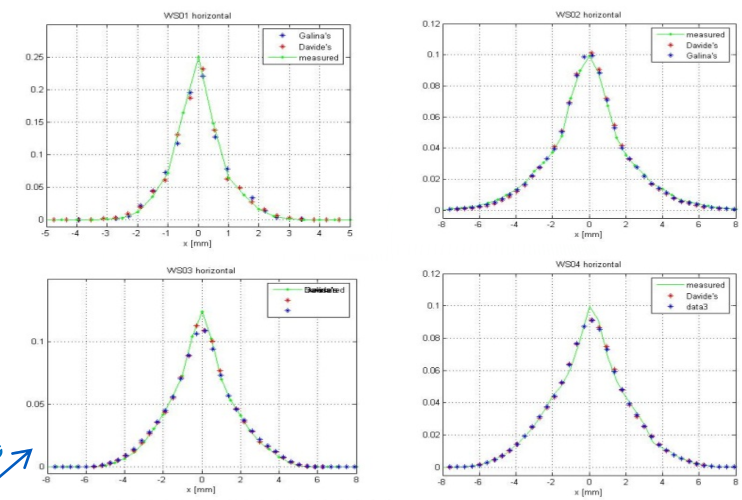


Various tomography algorithms are in use and being developed



red – measured profile; blue – projection of reconstructed 2D





Log scale

Linear scale

Courtesy of T. Gorlov, SNS

Comparison of measured and reconstructed profiles using modified MENT algorithm

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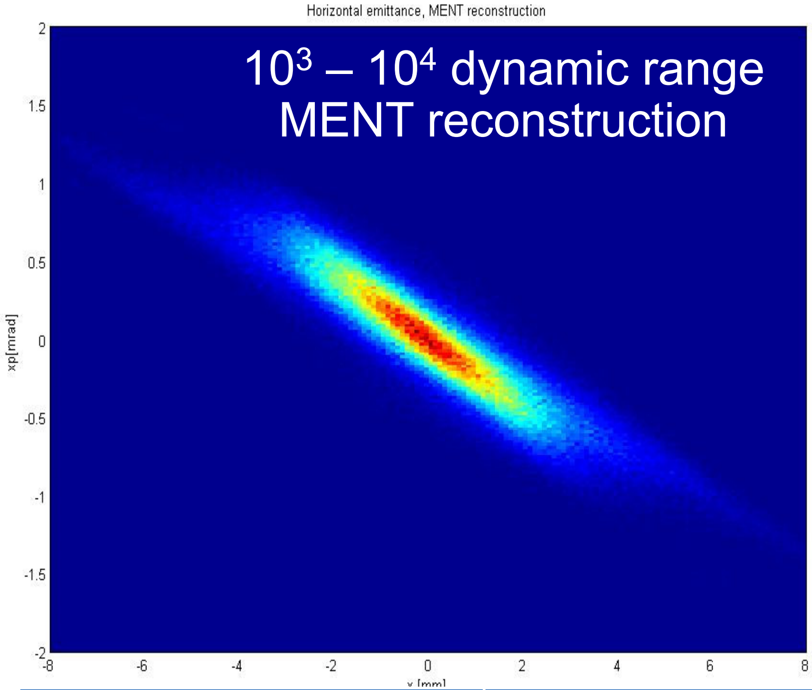
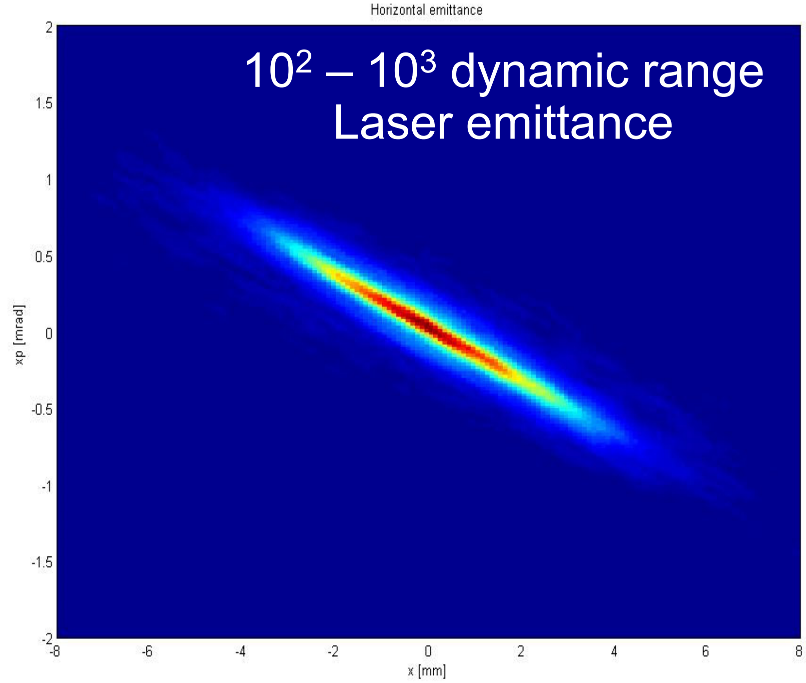
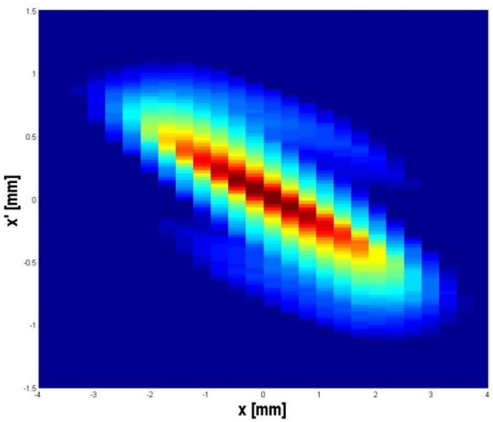
MENT reconstruction vs. Laser Emittance measurement

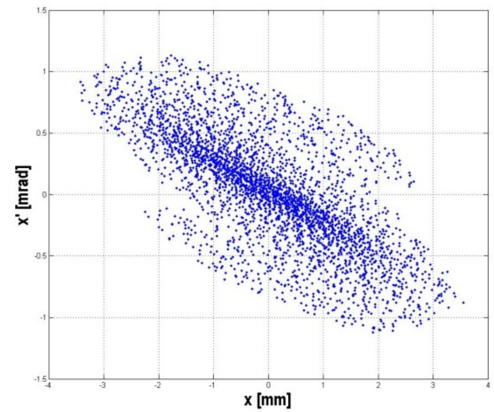


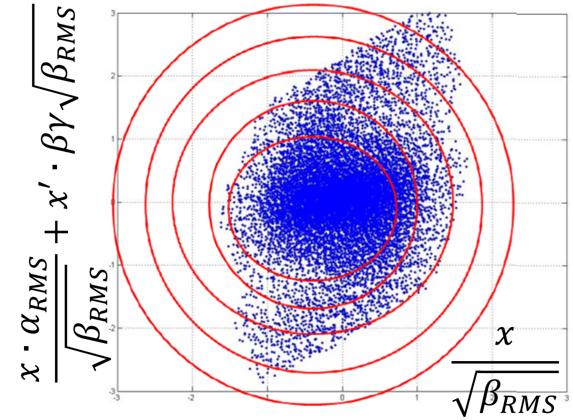


	RMS Emittance [mm*mrad]	α	β [m]
Laser emittance	.42	2.49	15.9
MENT reconstruction	.41	2.47	13.4

Phase space density plot for distribution characterization





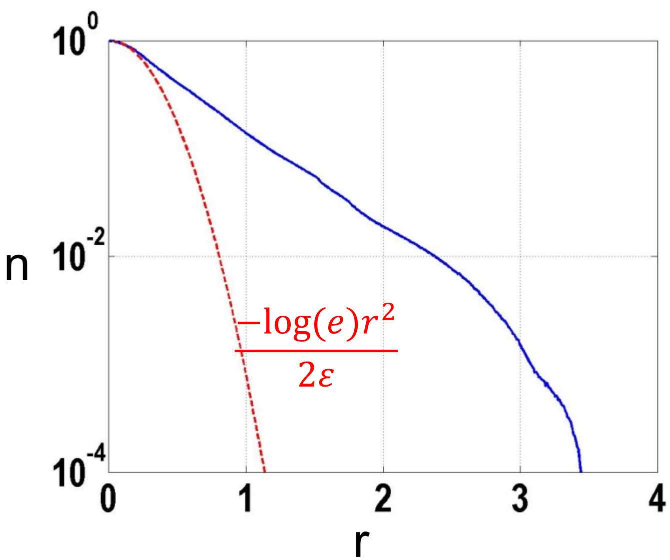


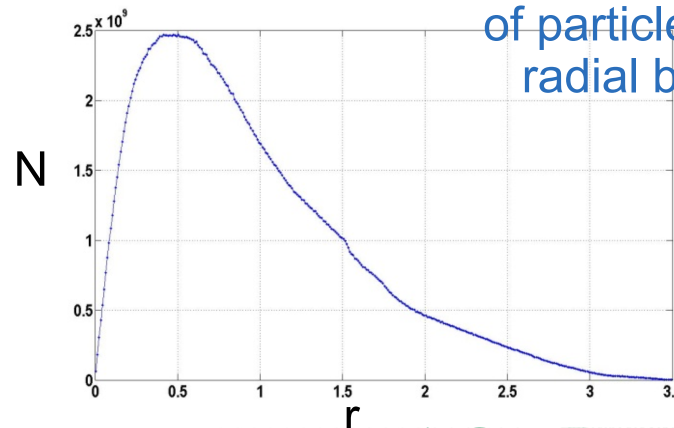
measure → generate particles → Transform to normalized coordinates

↓

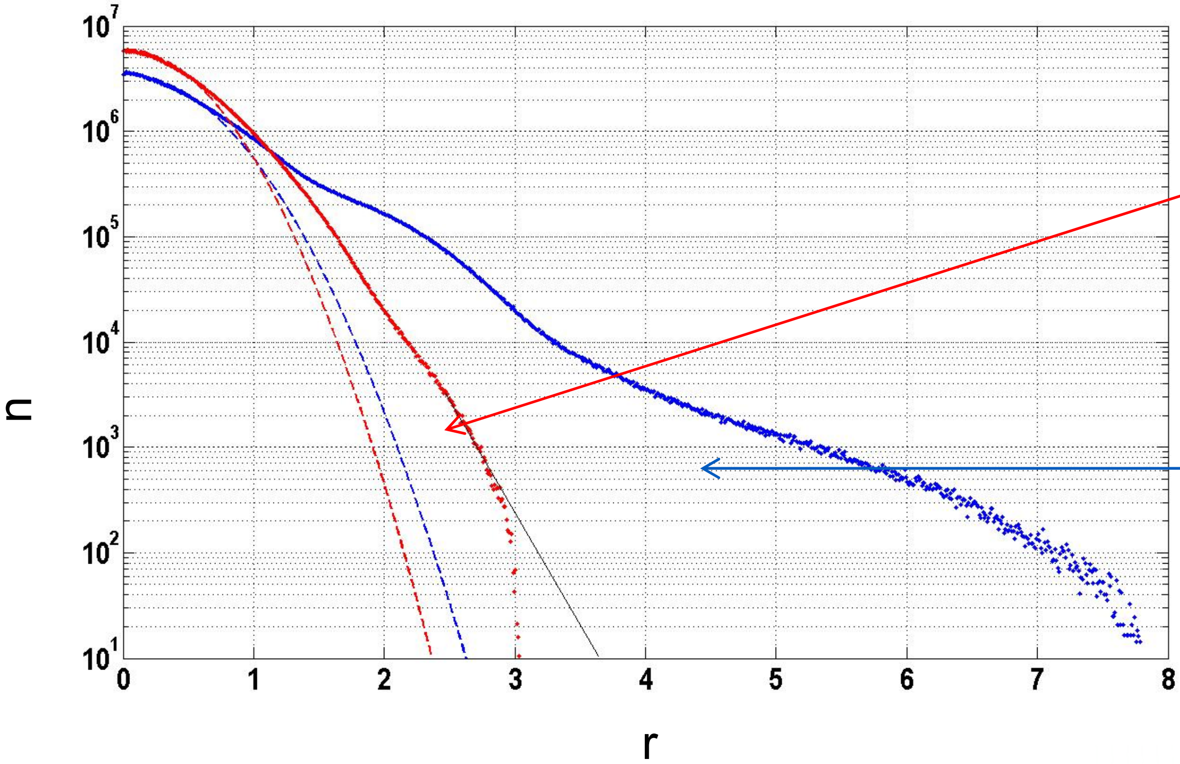
Count number of particles per radial band

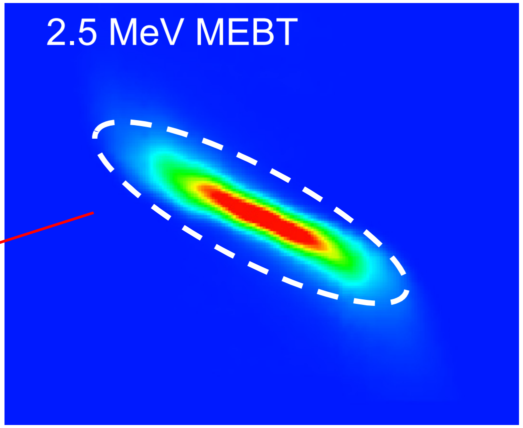
← Normalize by band area

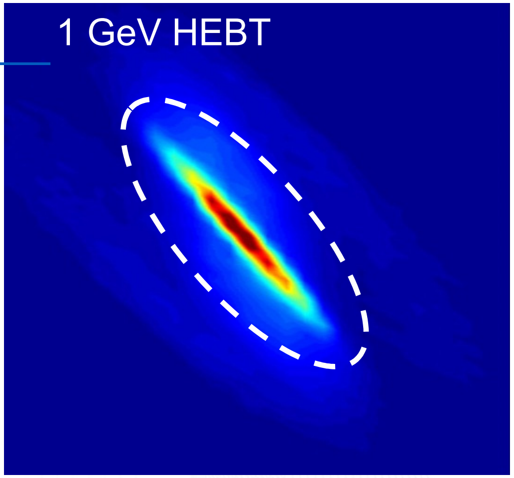




Example: comparison of phase space density measured at SNS MEBT and HEBT







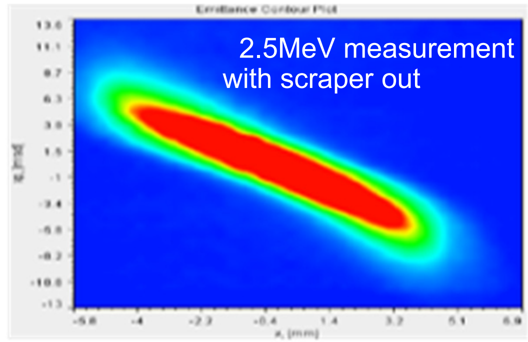
Phase space density plot is independent of

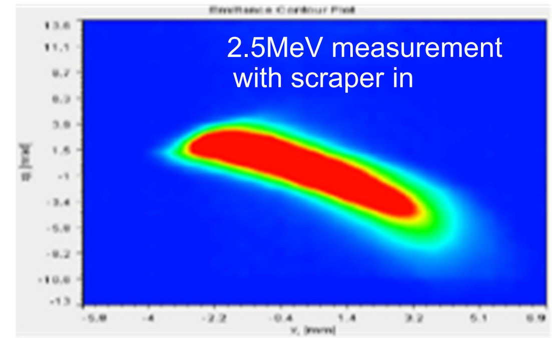
- beam energy
- beam line optics
- measurement technique or simulation

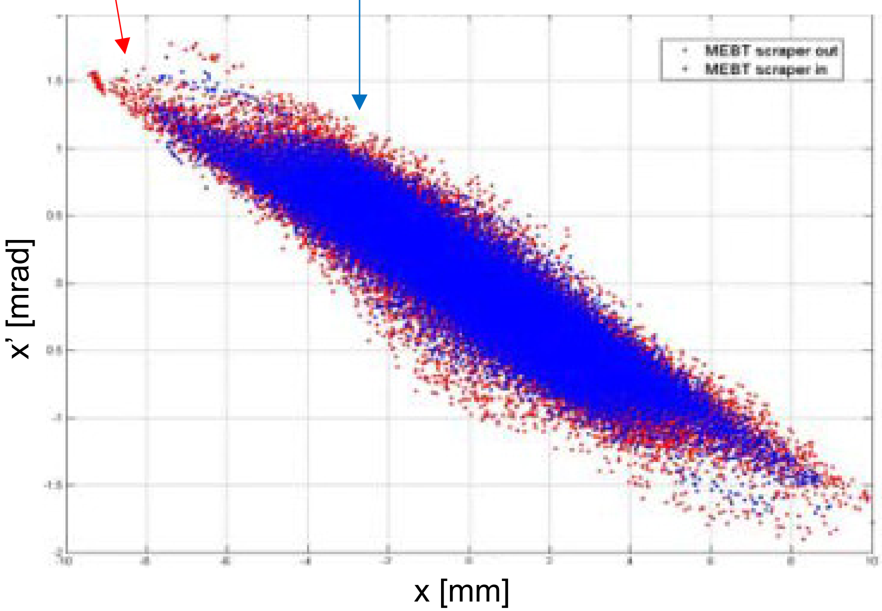
2D reconstruction example: SNS 1GeV HEBT

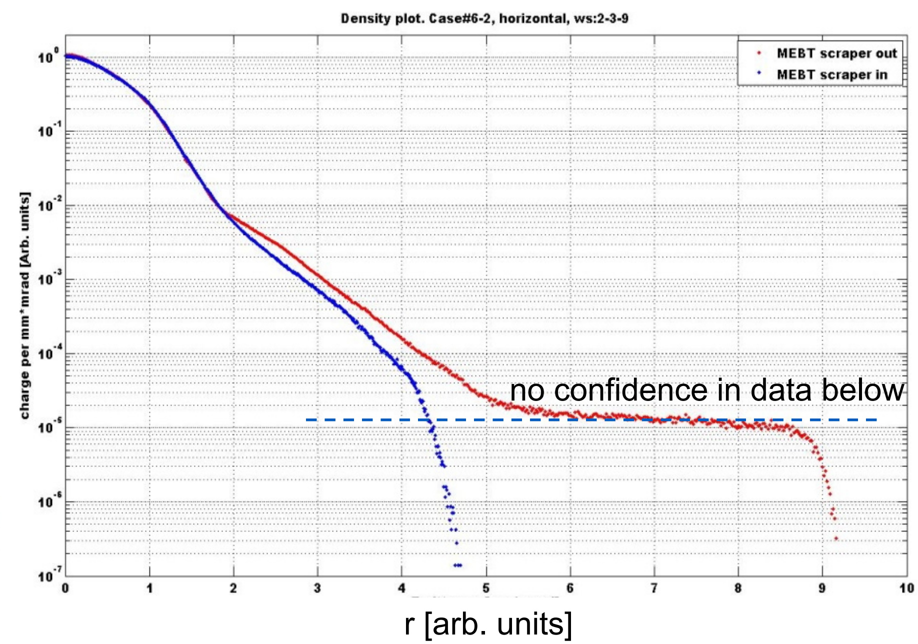
Red - no scrapers inserted

Blue – left scraper inserted in 2.5MeV MEBT





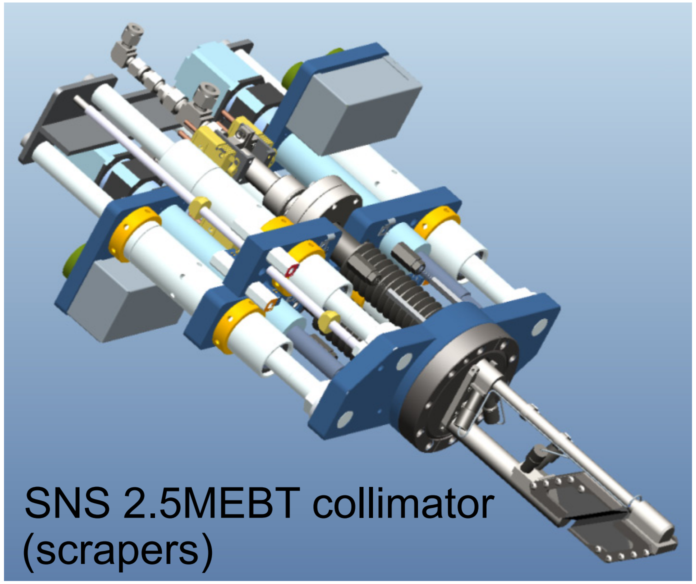


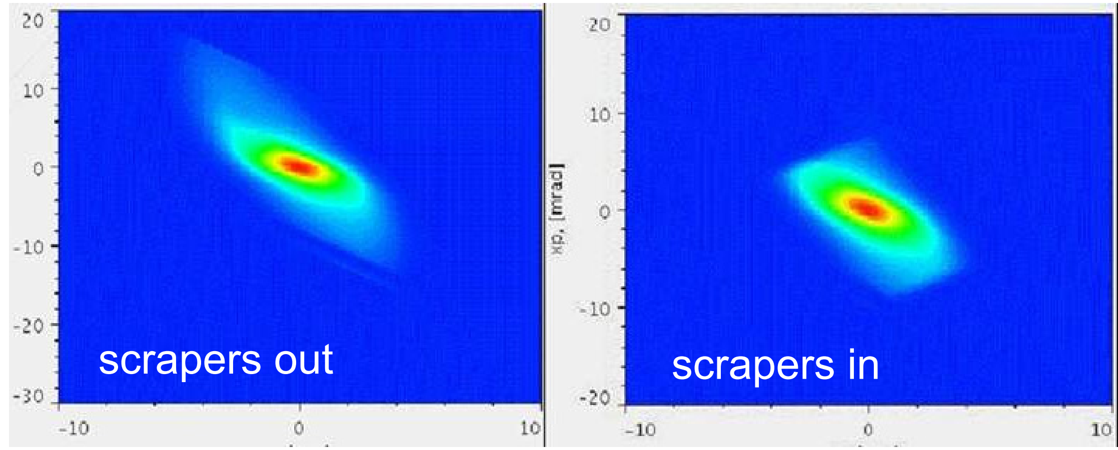


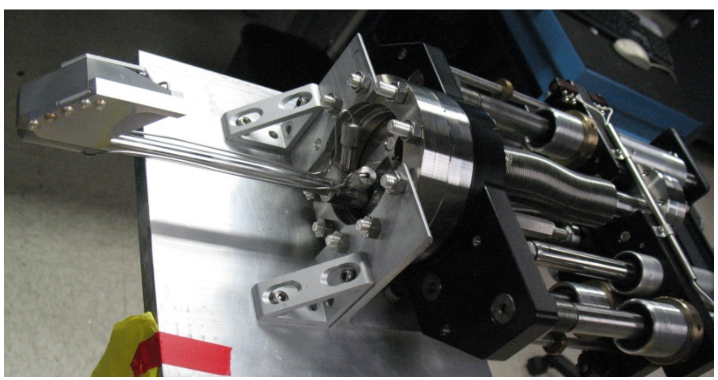
Particles generated from reconstructed 2D distribution.
Modified MENT algorithm with 4 projections

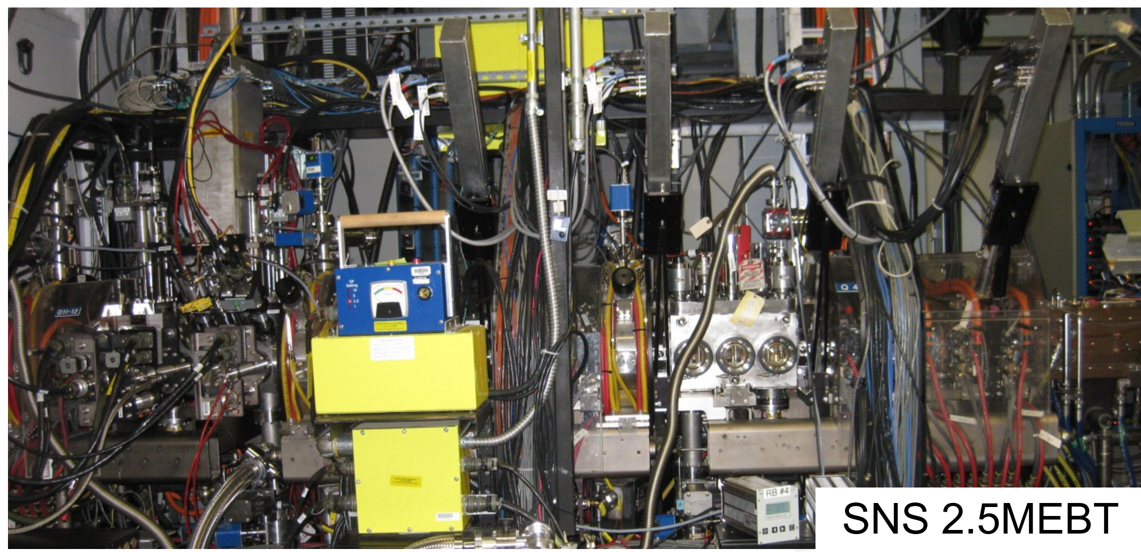
Phase space density plot

Halo Mitigation: *Collimation at low energy*



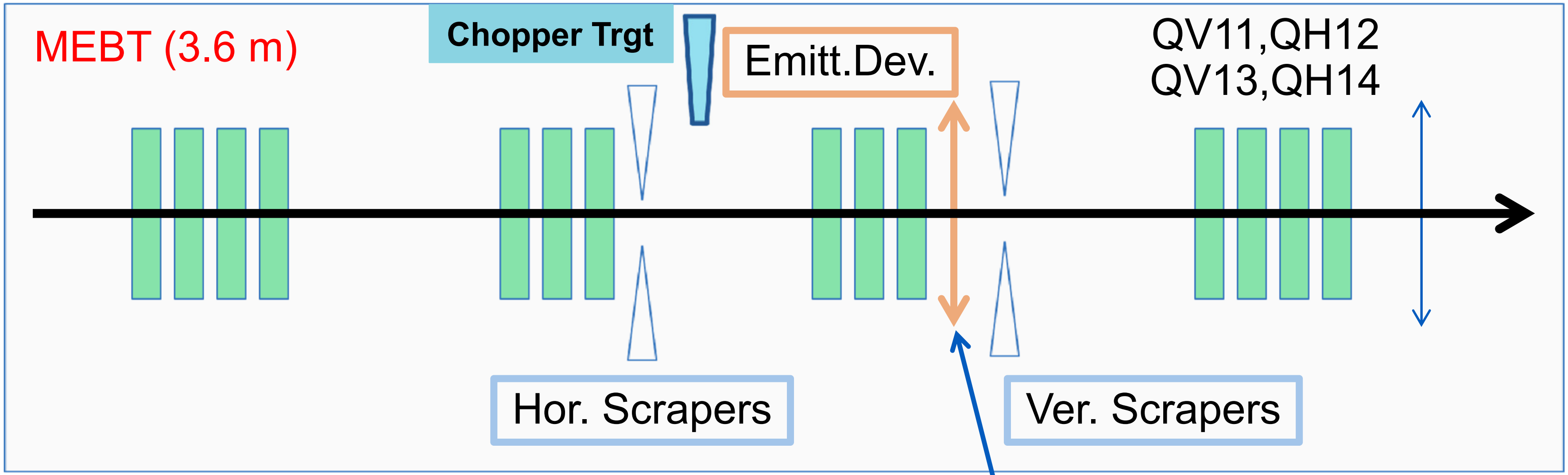




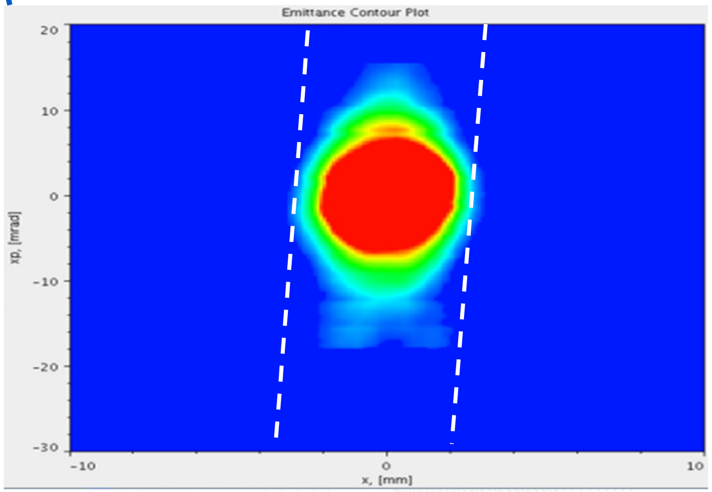


Simple concept and implementation but often hard to find space,
Halo measurement can help to optimize scraper location

Example: improving collimation in SNS MEBT

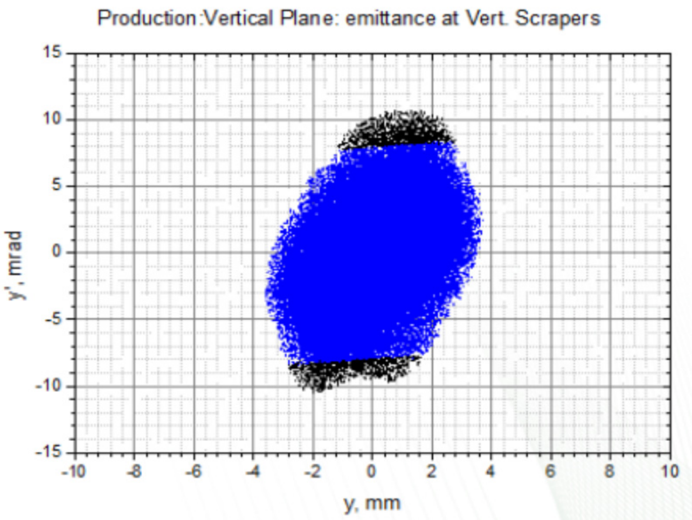


- Vertical scraper is not effective at current location with base line beam optics
- Measurements show halo at 90º to scrapers
- Modify optics to rotate vertical halo and satisfy other constraints
  - Horizontal scraper effectiveness
  - RFQ matching
  - DTL matching
- Virtually impossible to find a solution without measurements and model



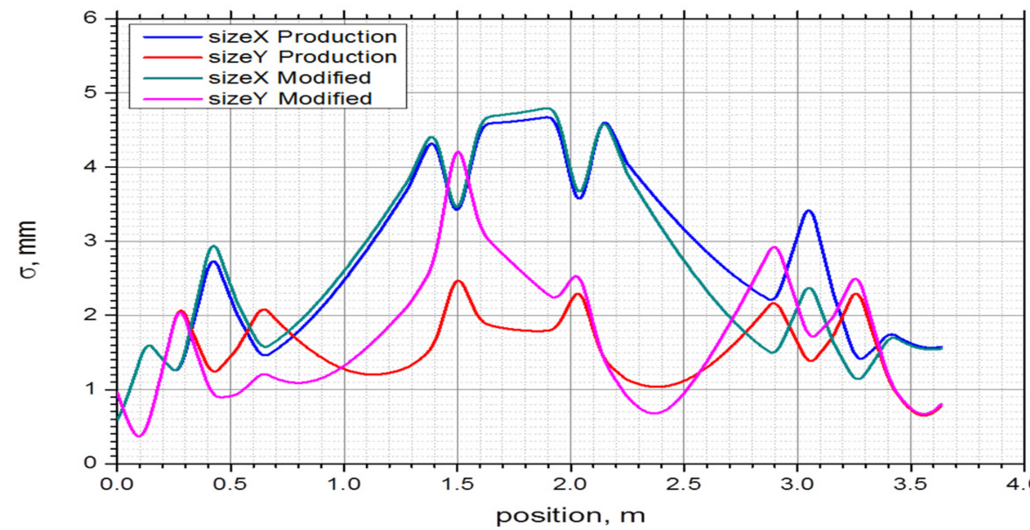
Vertical emittance

MEBT optics adjustment to improve collimation

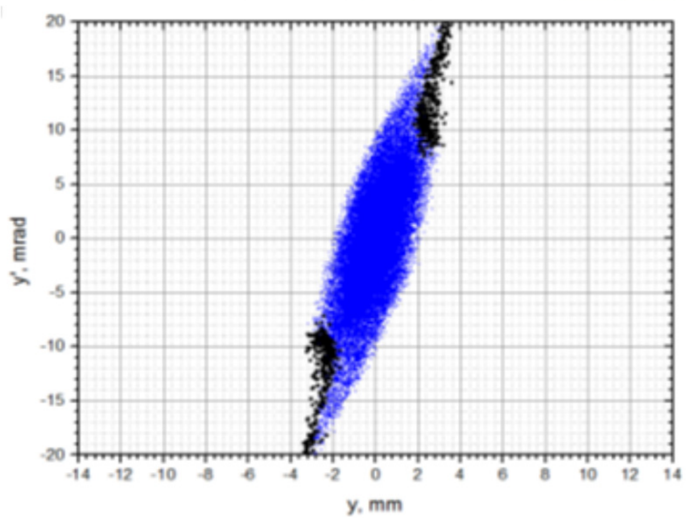


Old

Derived from measurements, 'bad' particles are in black



Old and new transverse beam sizes in MEBT



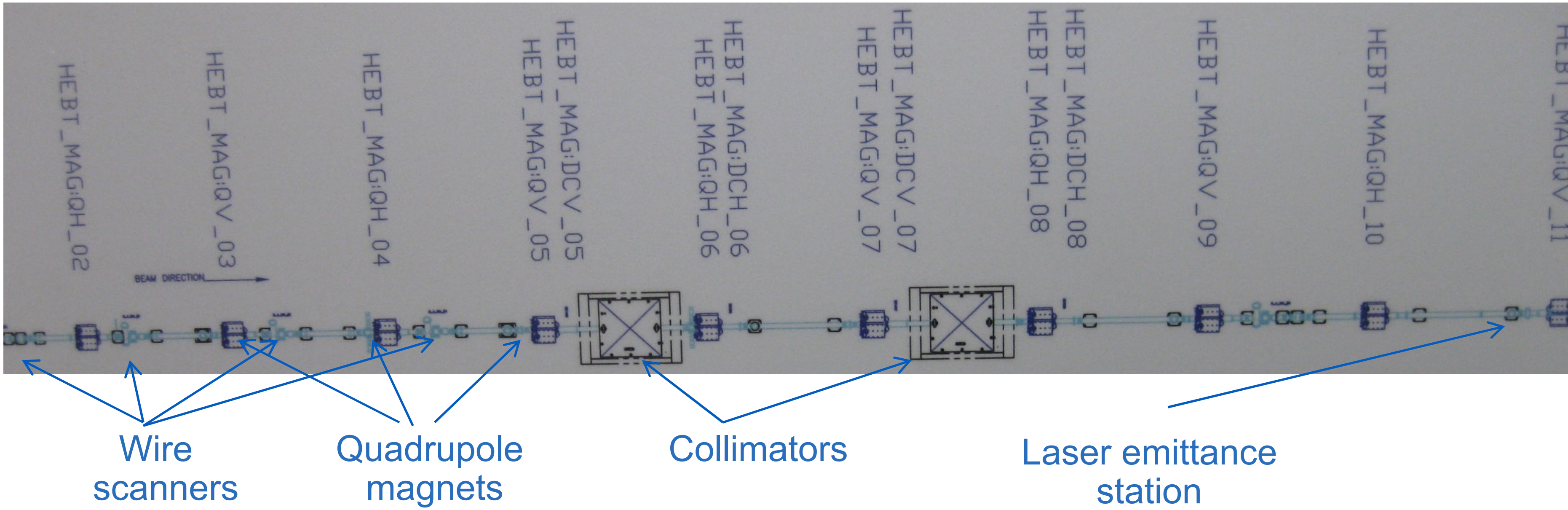
New

Calculated distribution for modified optics

particle distribution at vertical scrapers location

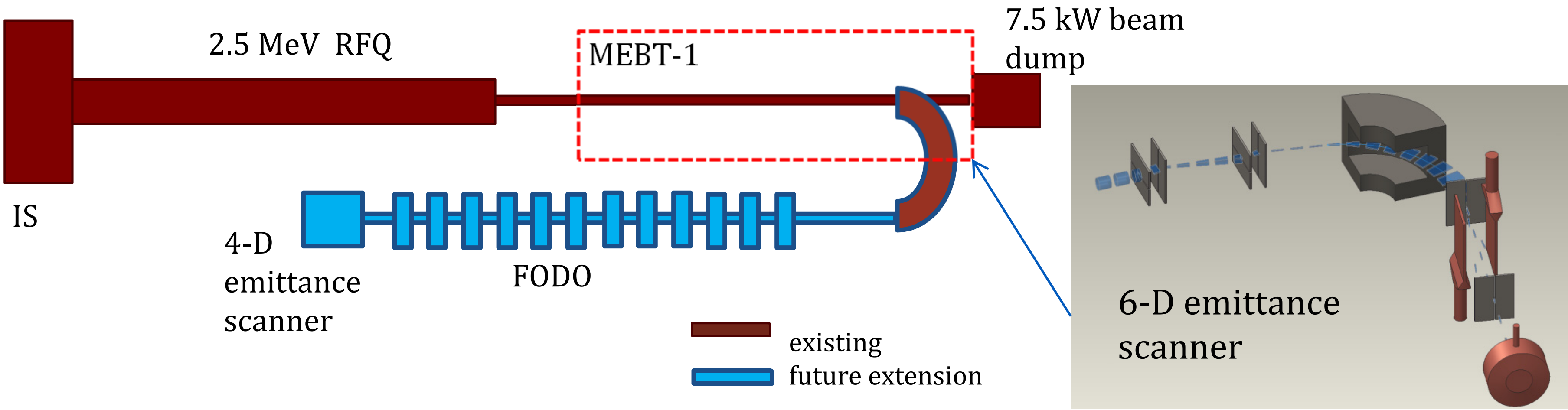
Courtesy of A. Shishlo, SNS

SNS 1 GEV HEBT beam line is well equipped large dynamic range tomography development test bench



- Five high dynamic range wire scanners
- FODO line with independent magnet controls
- Laser emittance station for reconstruction validation
- Two 2-stage collimation sections as application test case

SNS 2.5MeV Beam Test Facility (BTF)

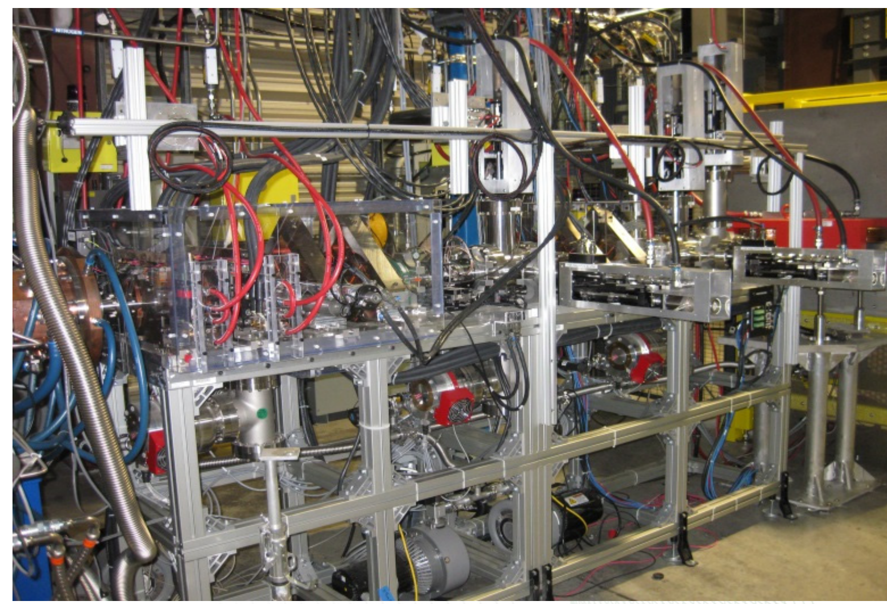


Experimental answer to:

1. **How to construct 6D from 1D,2D,4D?**

2. **Does mismatch create halo?**

- Instrumentation for direct measurement of 6D distribution function
  - summer 2016 commissioning
- Halo development experiment
  - LEDA-style FODO line
  - in planning for 2017 – 2018



Summary

- Model-based loss reduction is an attractive capability for SNS operation and future LINACs
- Requires accurate RMS and halo diagnostics integrated with model
- SNS linac is a good test bench for new methods development
  - Large dynamic range emittance and profile measurements
  - 2D phase space reconstruction from 1D profiles
  - 6D PIC input distribution generation from measured data
  - more
- Collimation is a proven method for loss reduction
  - Measurements and modeling provide tool for tuning for efficient operation
- Reducing beam loss due to intra-beam stripping in SNS SCL is realistic first goal to demonstrate the approach
- A lot of work in progress and future plans

Thank you for your attention!