High Power Proton Diagnostics

Andreas Jansson

European Spallation Source

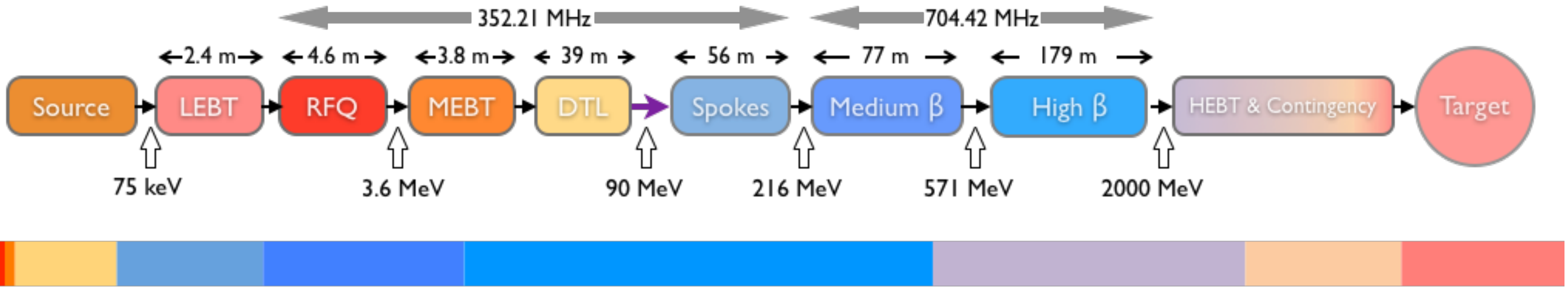
EuCARD Strategy Workshop

Seville Spain, 2017-02-13

Outline

- Shamelessly reporting on the work of others.
  - Give credit where credit is due
- Will base talk on ESS as a representative high power proton linac, taking specific examples from elsewhere
  - 3 B's (BLM, BCM, BPM)
  - Profile measurements
  - Advanced beam instrumentation
  - Advanced use of (3B) instrumentation

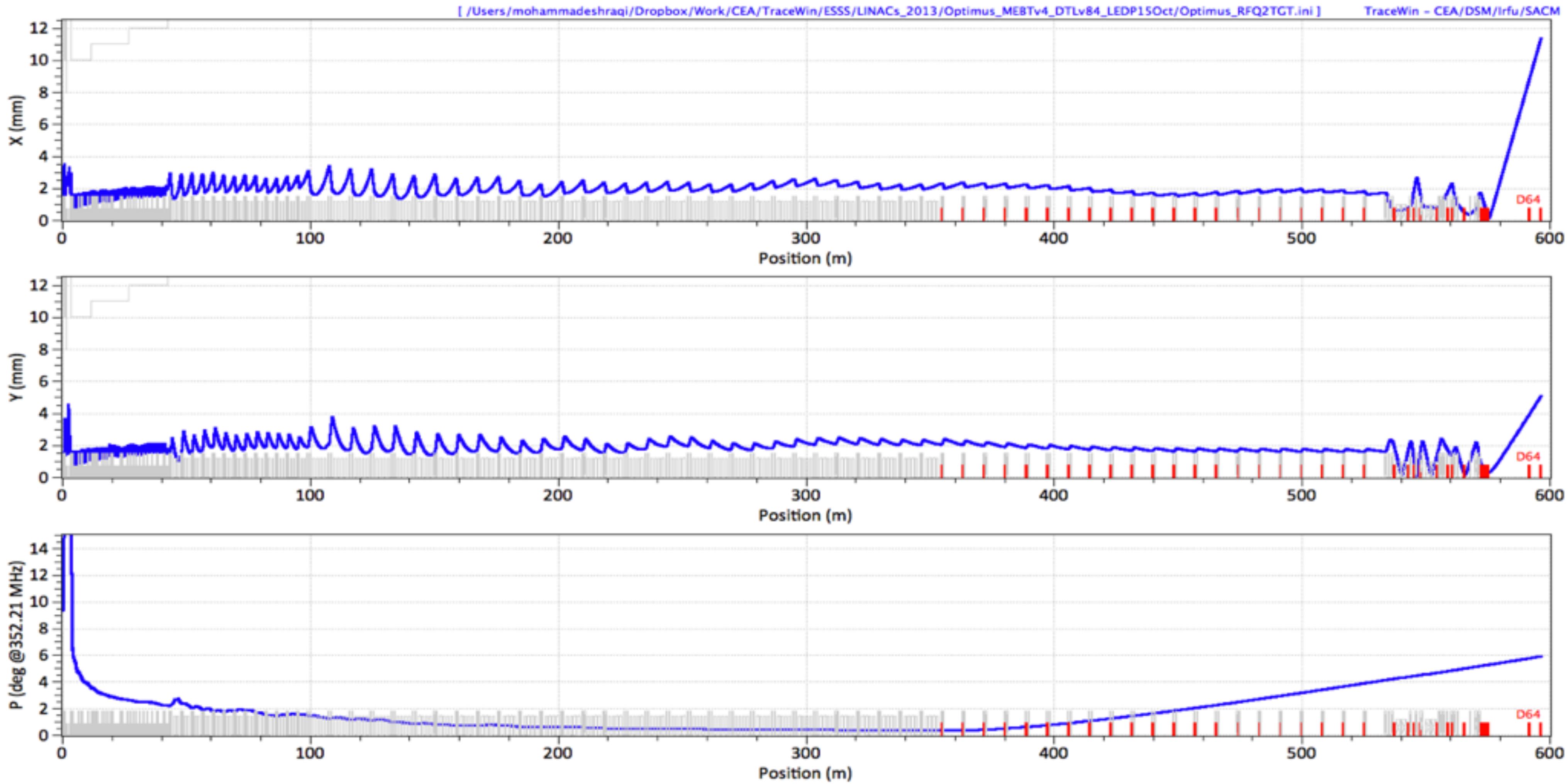
ESS



	Length (m)	W_in (MeV)	F (MHz)	β Geometric	No. Sections	T (K)
LEBT	2,38	0,075	--	--	1	~300
RFQ	4,6	0,075	352,21	--	1	~300
MEBT	3,81	3,62	352,21	--	1	~300
DTL	38,9	3,62	352,21	--	5	~300
LEDP + Spoke	55,9	89,8	352,21	0.50 (Optimum)	13	~2
Medium Beta	76,7	216,3	704,42	0,67	9	~2
High Beta	178,9	571,5	704,42	0,86	21	~2
Contingency	119,3	2000	704,42	(0.86)	14	~300 / ~2

About 500 diagnostics systems (mostly BLM & BPM) of about 20 different types

Beam Envelope



Average Beam Power
5 MW

Pulse length:
2.86 ms

Bunch charge:
180 pC

Pulse Current:
62.5 mA

Bunch repetition rate:
352 MHz

Bunch length (r.m.s.):
10-40 ps

General high power hadron issues

- Beam loss
  - beam can do significant damage, so
    - fast response (~ few us) needed
    - blind spots must be avoided
- Beam Current
  - Differential current may need to trigger abort
- Beam position
  - Large excursions may need to trigger abort
- Beam phase
  - Non-relativistic beam, need to measure time-of-arrival for cavity phasing (linacs)

NB. High power linacs tend to be superconductive, imposing restrictions such as particle clean environment

Specific High Power Proton Issues

- Due to high power, non-invasive or minimally invasive diagnostics needed.
  - Since no electrons to remove, laser (photo-detachment) based diagnostics not an option.
  - Difficult to measure beam dimensions
    - Transverse profile
    - Longitudinal profile
- Some diagnostics not able to take full beam
  - Special short diagnostics pulse (~50us)

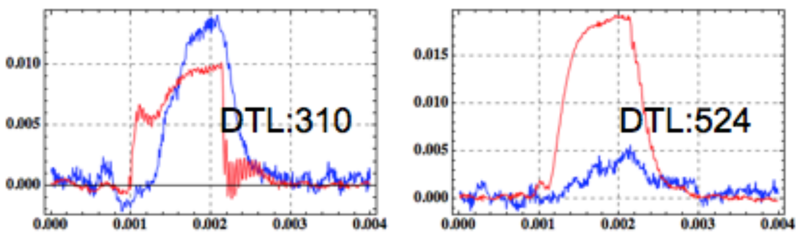
Basic (B^3) Diagnostics

B^3 = BLM BCM BPM

EUROPEAN SPALLATION SOURCE

Beam Loss – Ionization Chamber

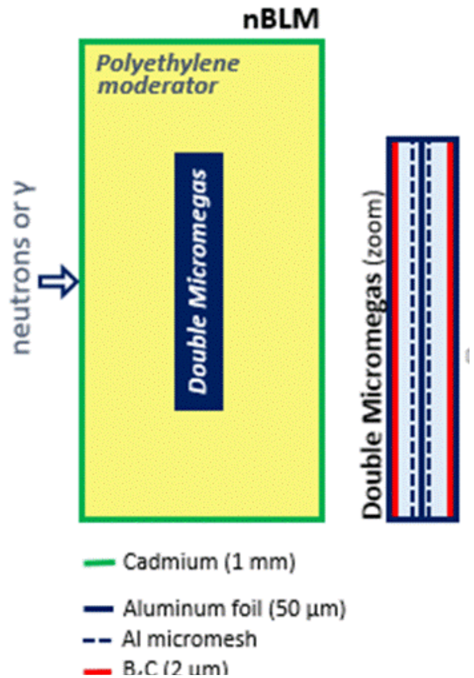
- Proven, robust technology
- Fast detection by design
- But, sensitive to X-ray background from RF cavities

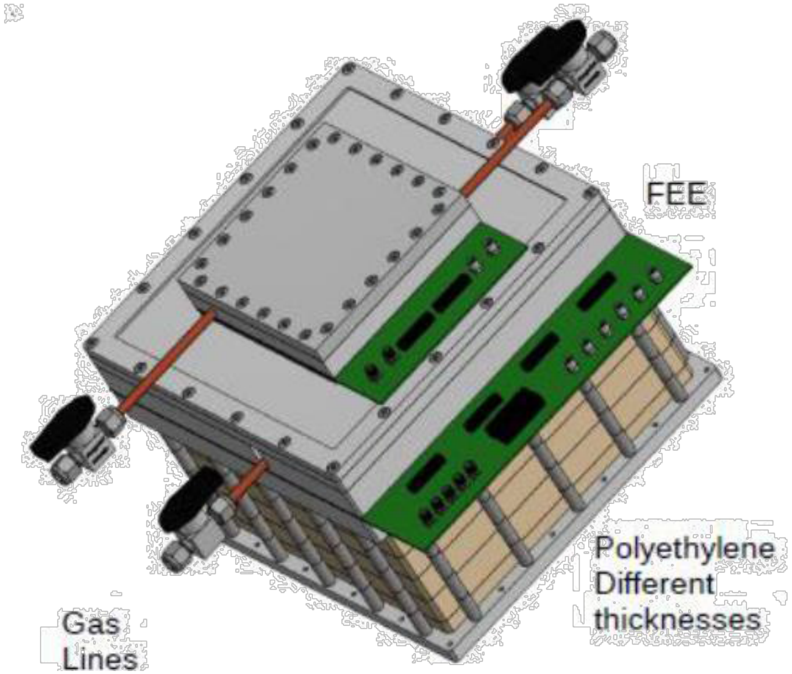


SNS

S. Grishin et al, CERN

(Fast) Neutron Monitor



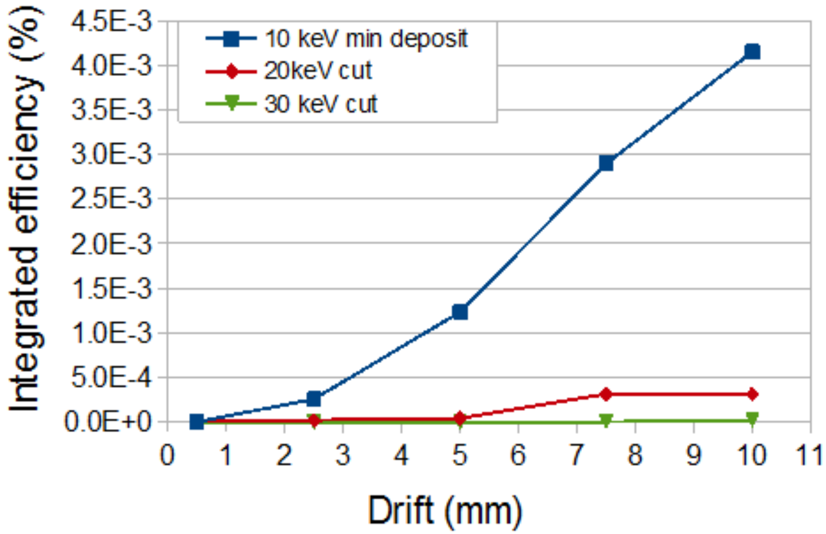


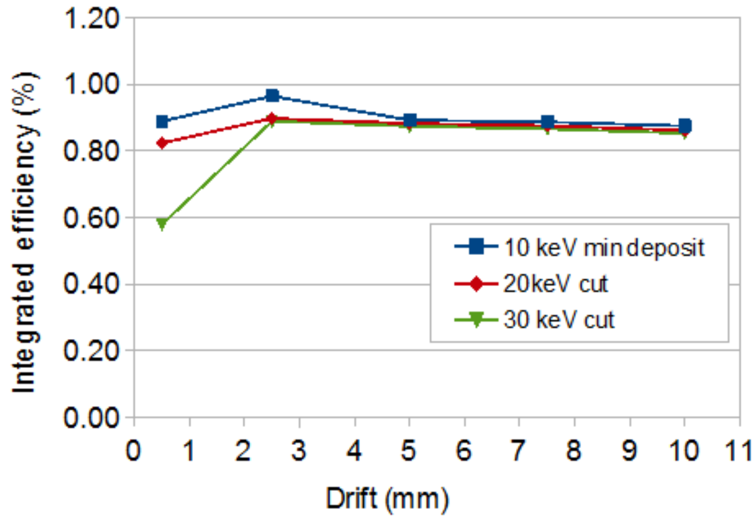
Based on MicroMegas

With appropriate cuts, can be insensitive to gammas

Fast and slow (sensitive) version

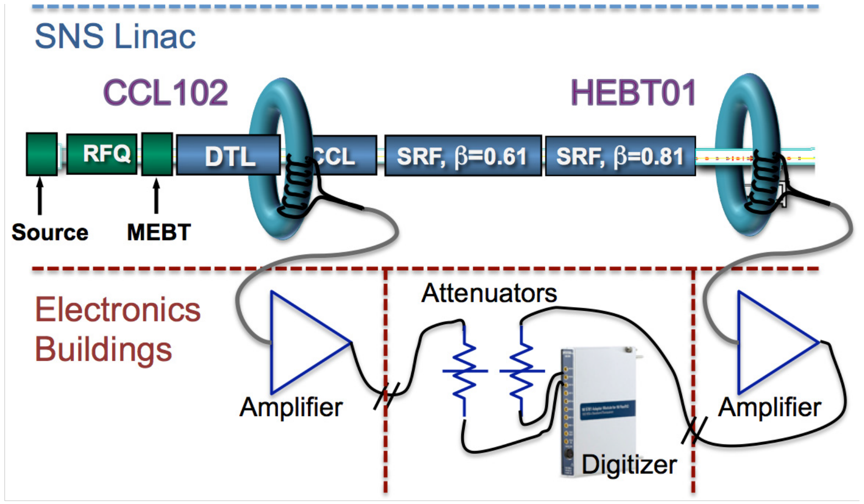
T. Papaenvagelou et al, IRFU/CEA Saclay

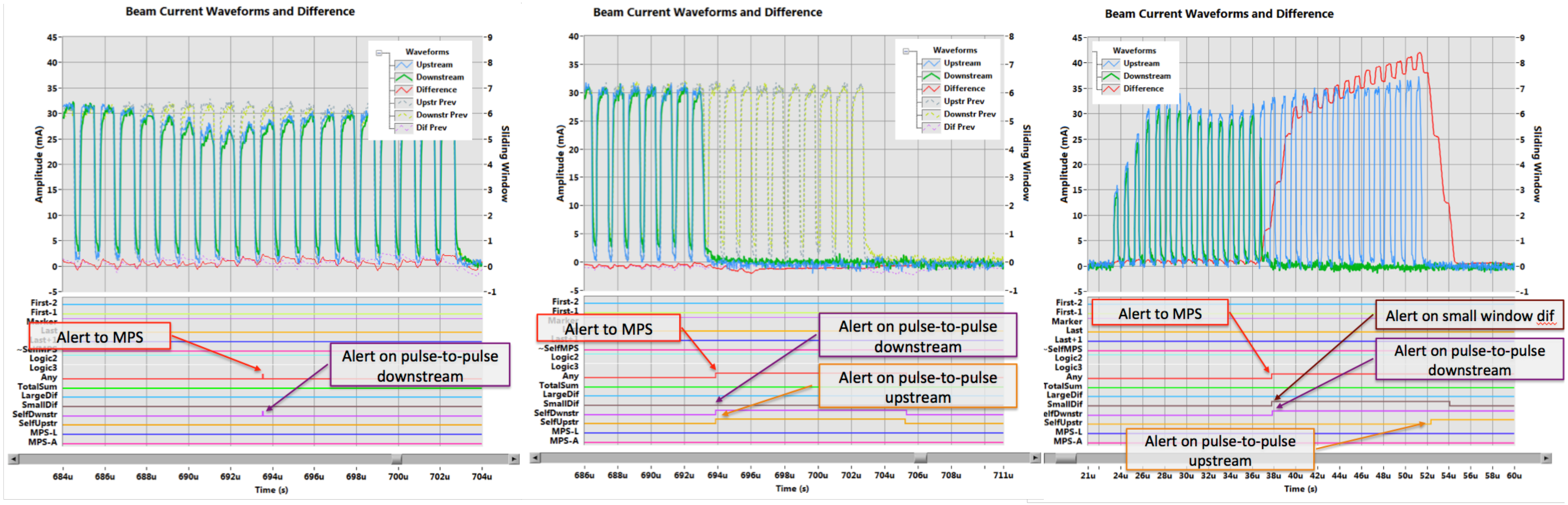




(Differential) BCM

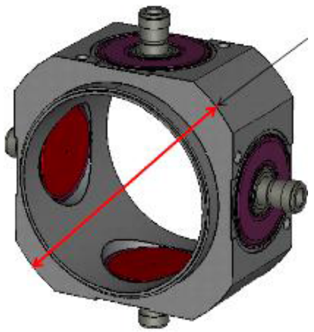
Transmission (startup)
Beam Destination Accounting
Beam loss and “Errant beam”
“Almost abort” cases very important to detect and study!

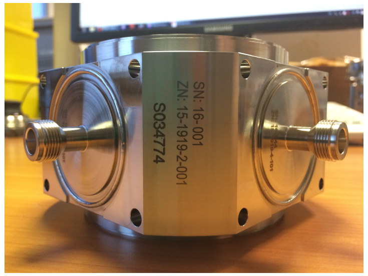


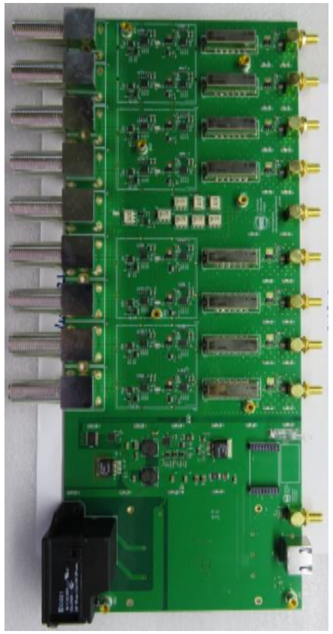


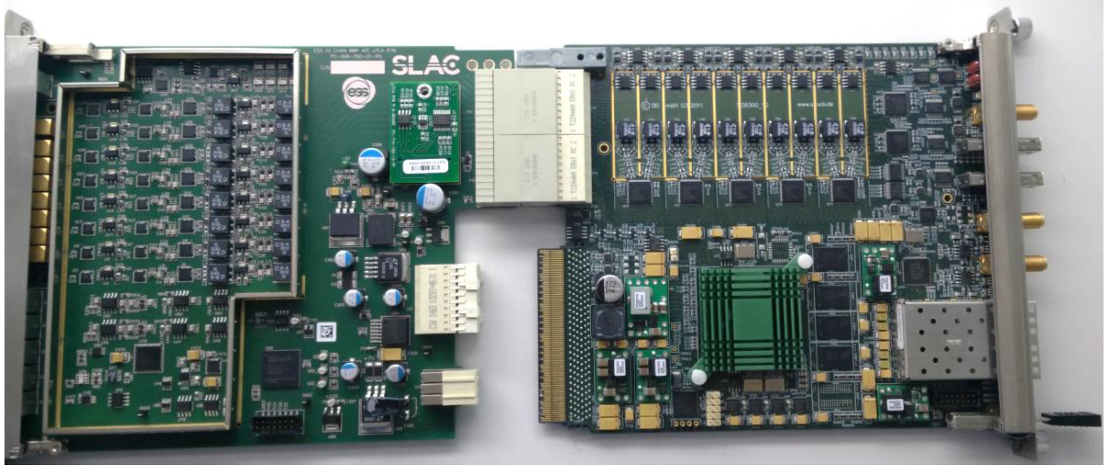
V. Blokland, SNS

Position and Phase









Rafael Baron, ESS

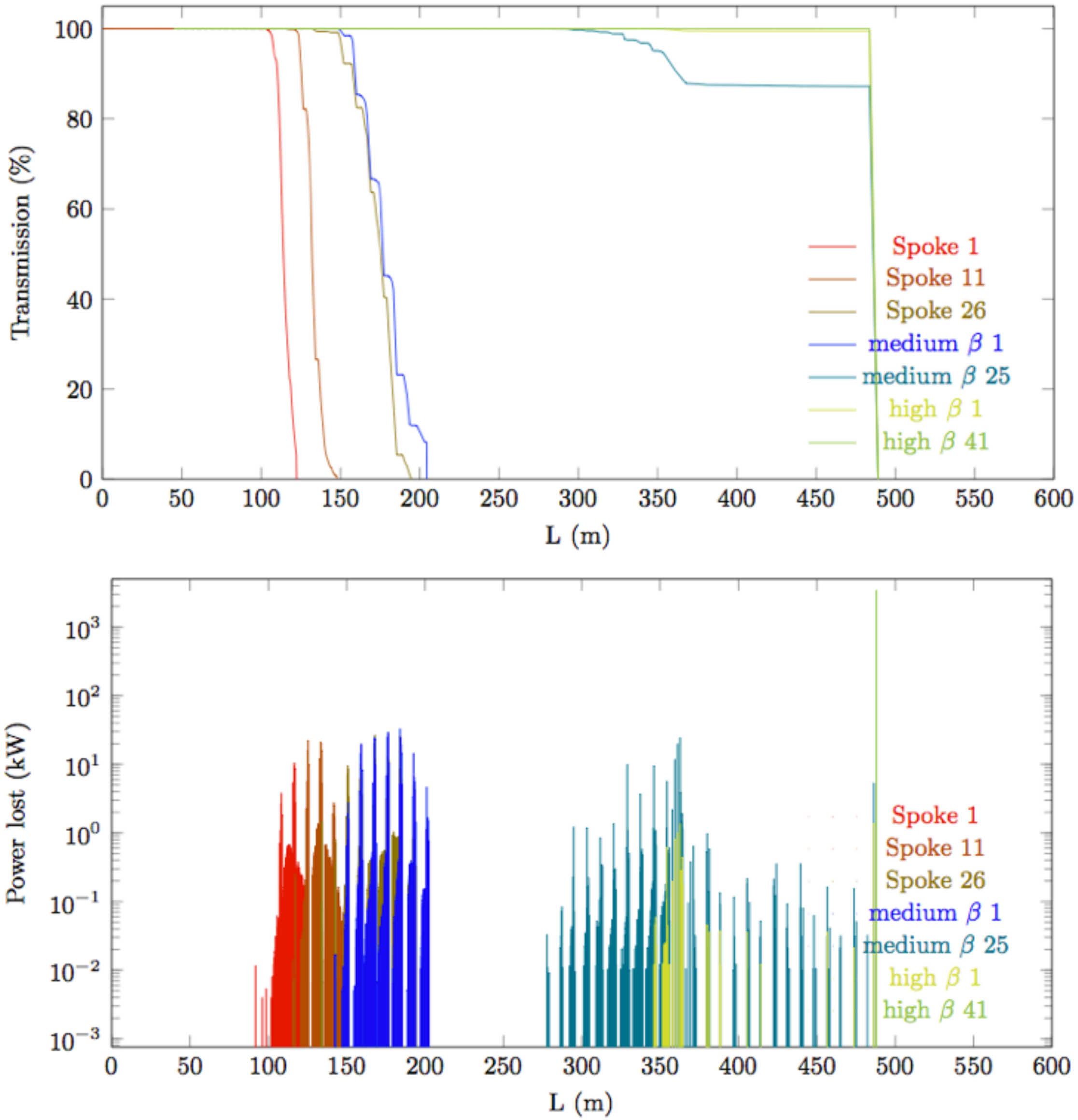
Requirements:	Nominal beam (63ma, 3ms)	Pilot beam (6mA, 5us)	Debunched beam (>6mA, >5us)
Phase resolution	0.2 deg	**2 deg**	**-**
Phase accuracy	1 deg*	1 deg*	-
Position resolution	20 µm	**200 µm**	**2 mm**
Position accuracy	+- 200 µm**	+- 400 um**	**+- 2 mm**
Total response time to AMC	2 µs	2 µs	2 us

* Depends on phase reference line
** Except DTL, where 100 µm accuracy is required

Cavity Failure Loss Signatures

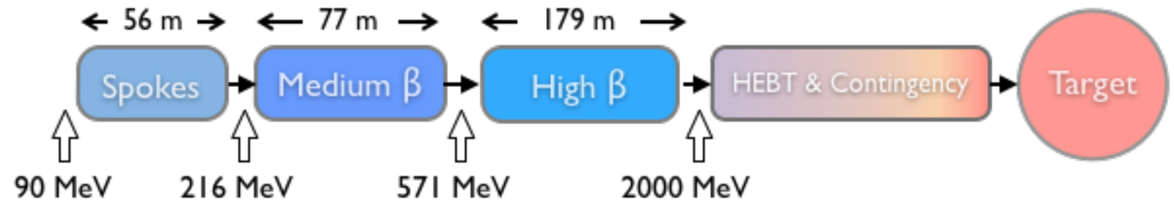
Impact of full loss of gradient in single cavity

Possible to tune around lost cavity (but this requires some time)

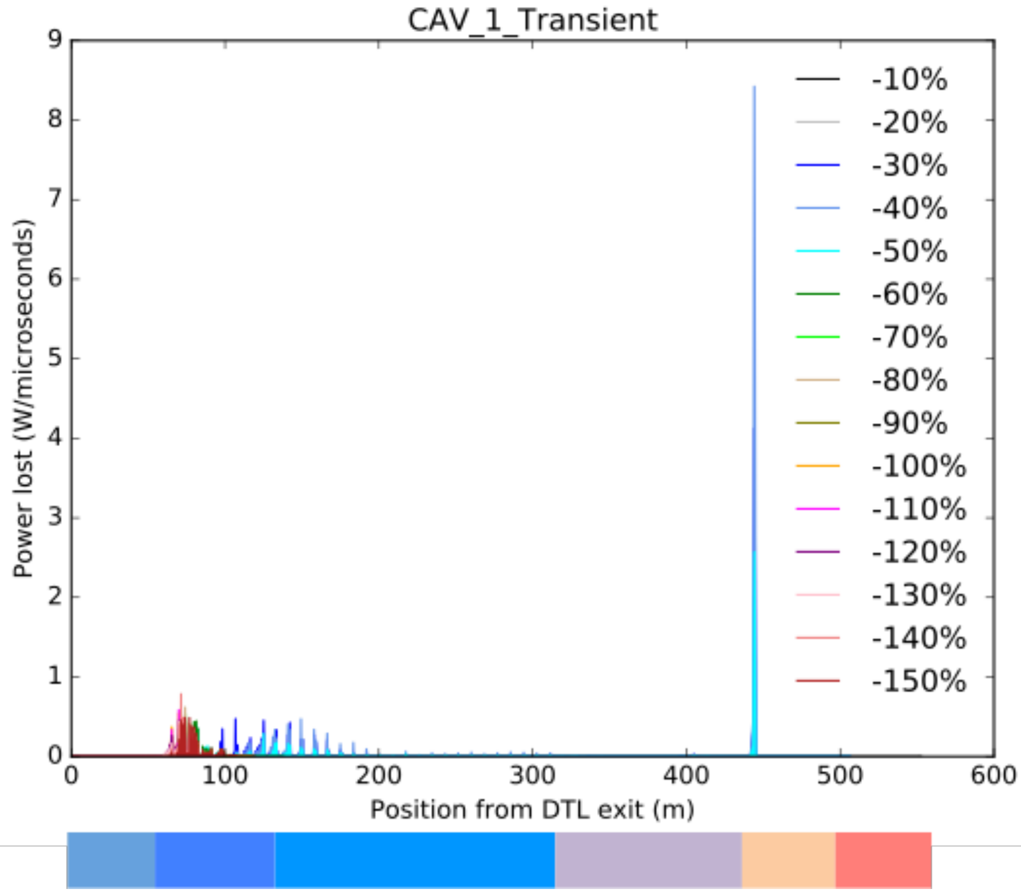


Mohammad Eshraqi et al, ESS

Beam loss time distribution



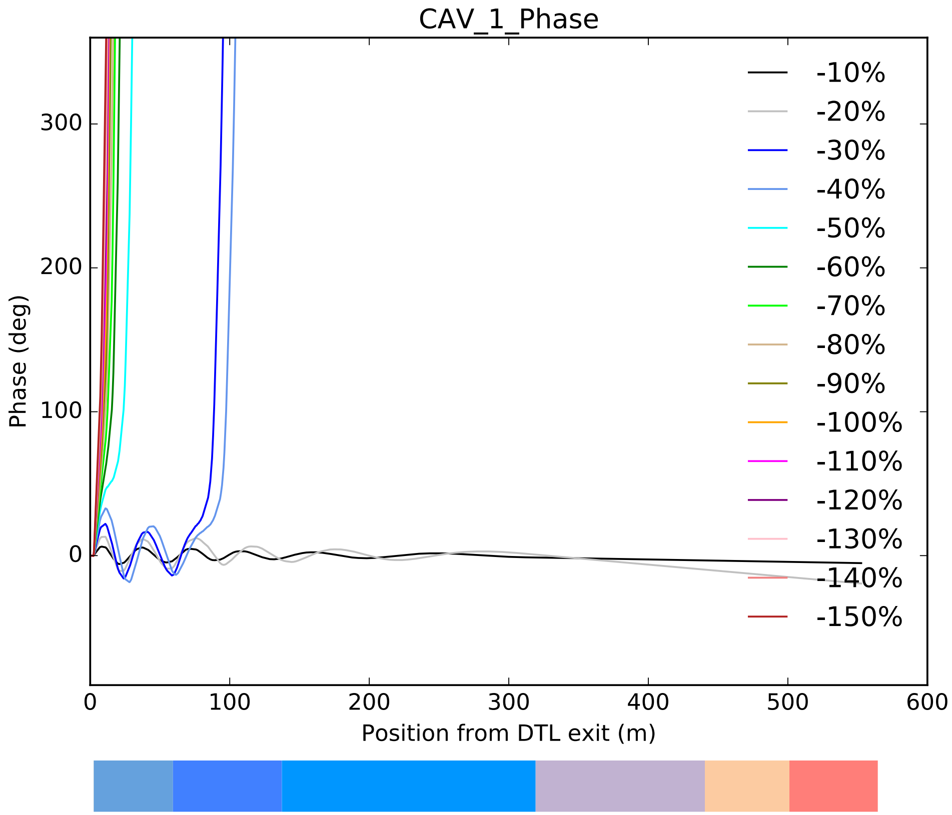
Cavity field does not go to zero instantly, but decays at some rate and may also have undershoot due to beam loading

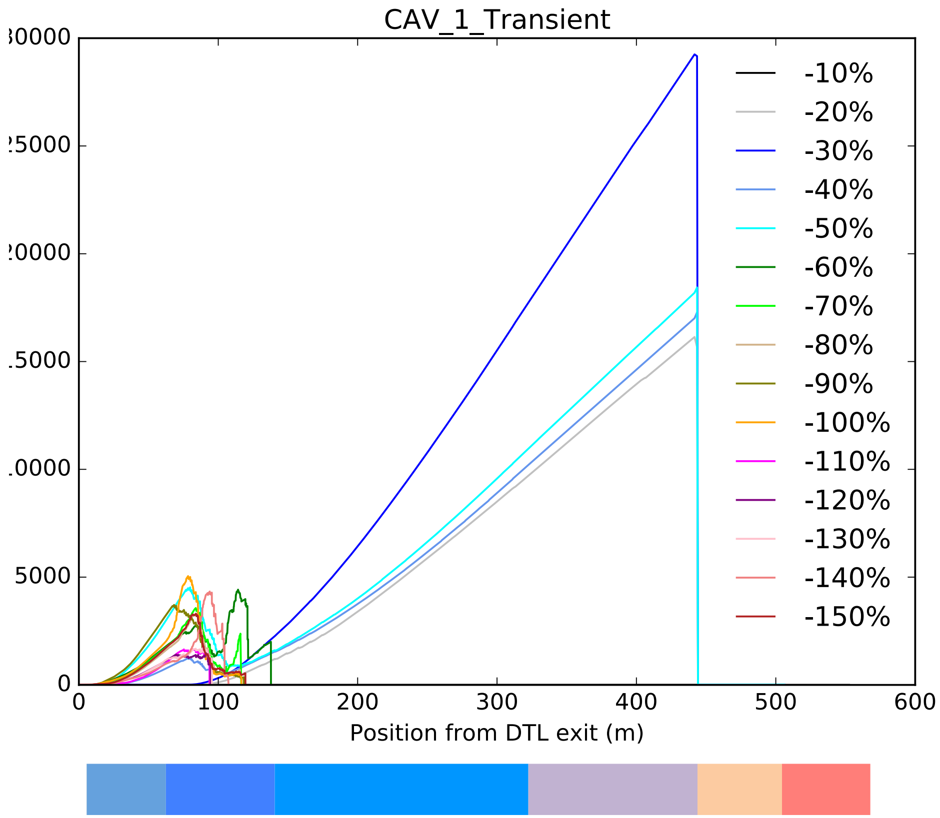


Mohammad Eshraqi et al, ESS

Predicting impending beam loss

Mohammad Eshraqi et al, ESS

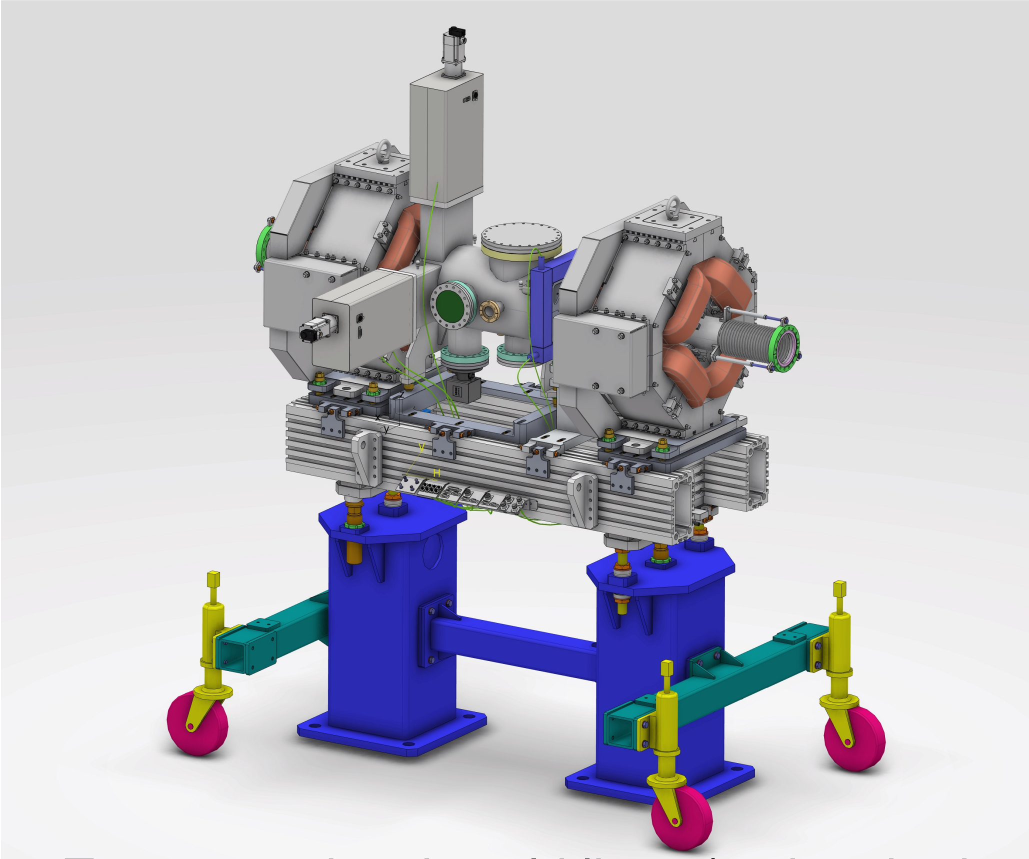


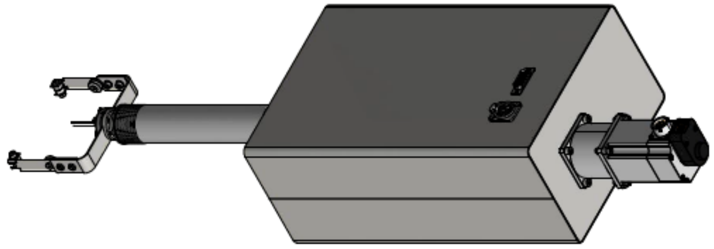


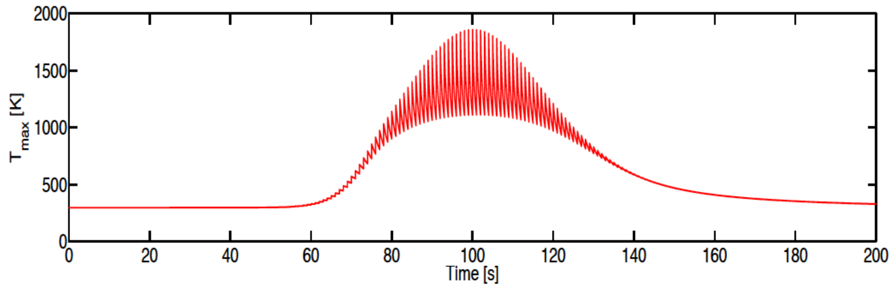
BPM phase and amplitude signals can predict impending beam loss from cavity failures!!!

Transverse and longitudinal profile

Transverse Profile





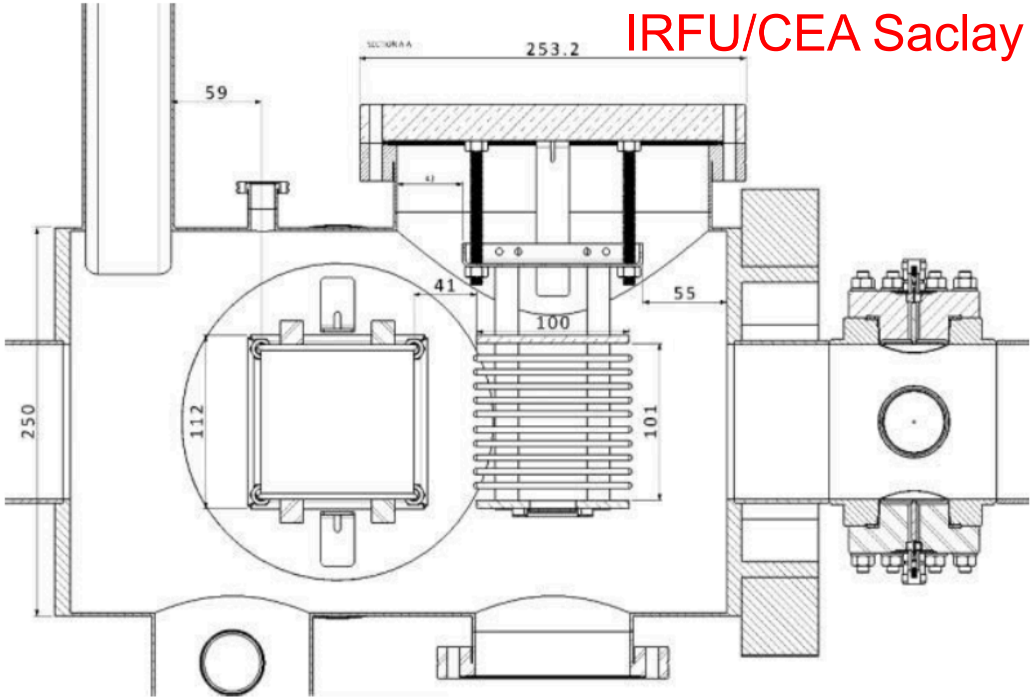


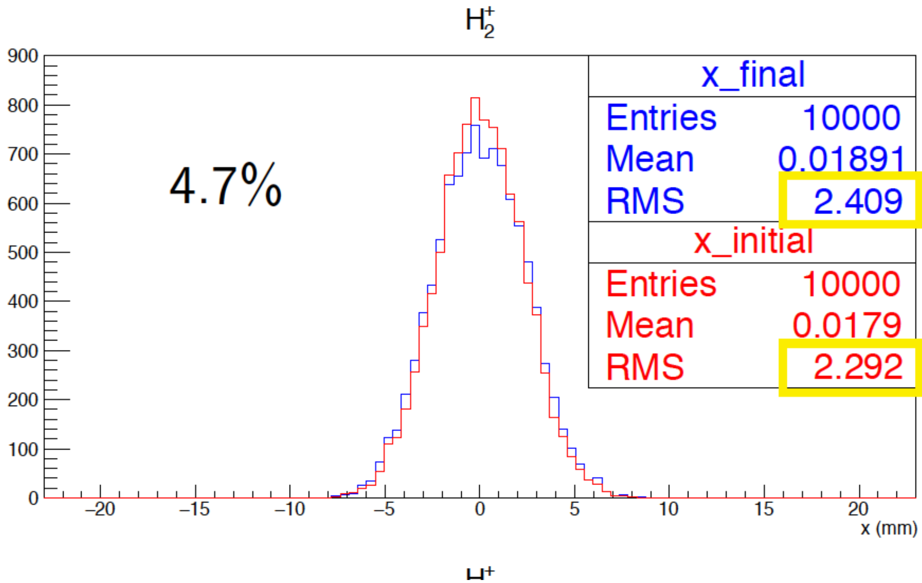
- Tungsten wires in cold linac (carbon bad to cavities)
  - Special vacuum bellows for particle clean environment
- Both SEM and shower readout planned
- Wire scanners limited in pulse length (thermionic emission and wire breakage)
  - Co-located with non-invasive profile (IPM)
  - Must have overlap in performance range

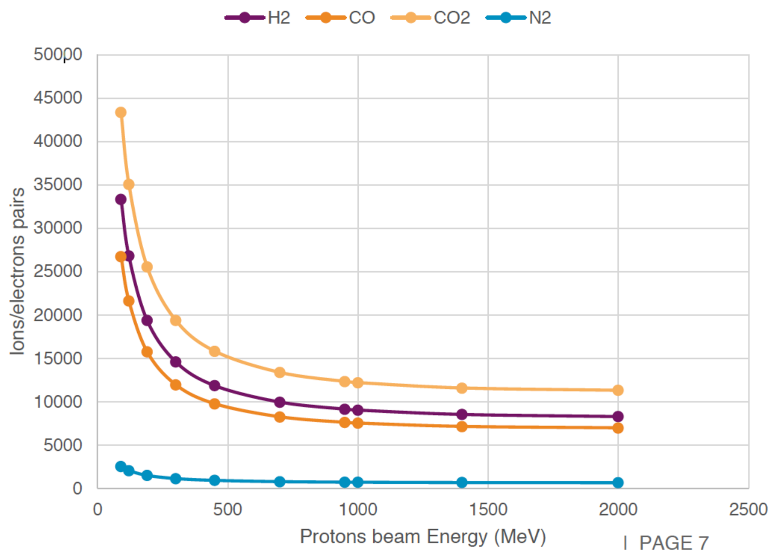
Ionization Profile Monitor

J. Marroncle et al,
IRFU/CEA Saclay

- Lack of space for magnet.
- Ion collection possible with manageable space charge effects and reasonable E-field.
- Suffient signal in warm sections of cold linac



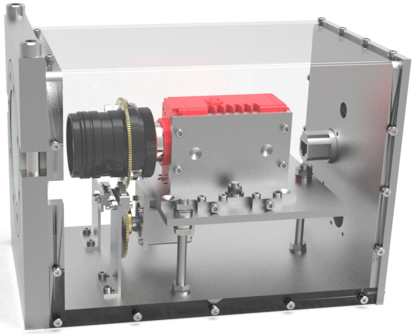


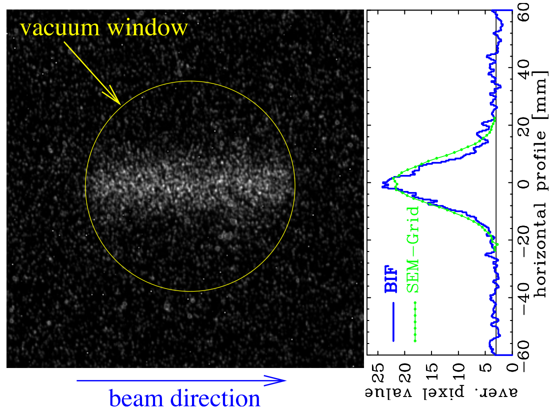


BIF & Emittance

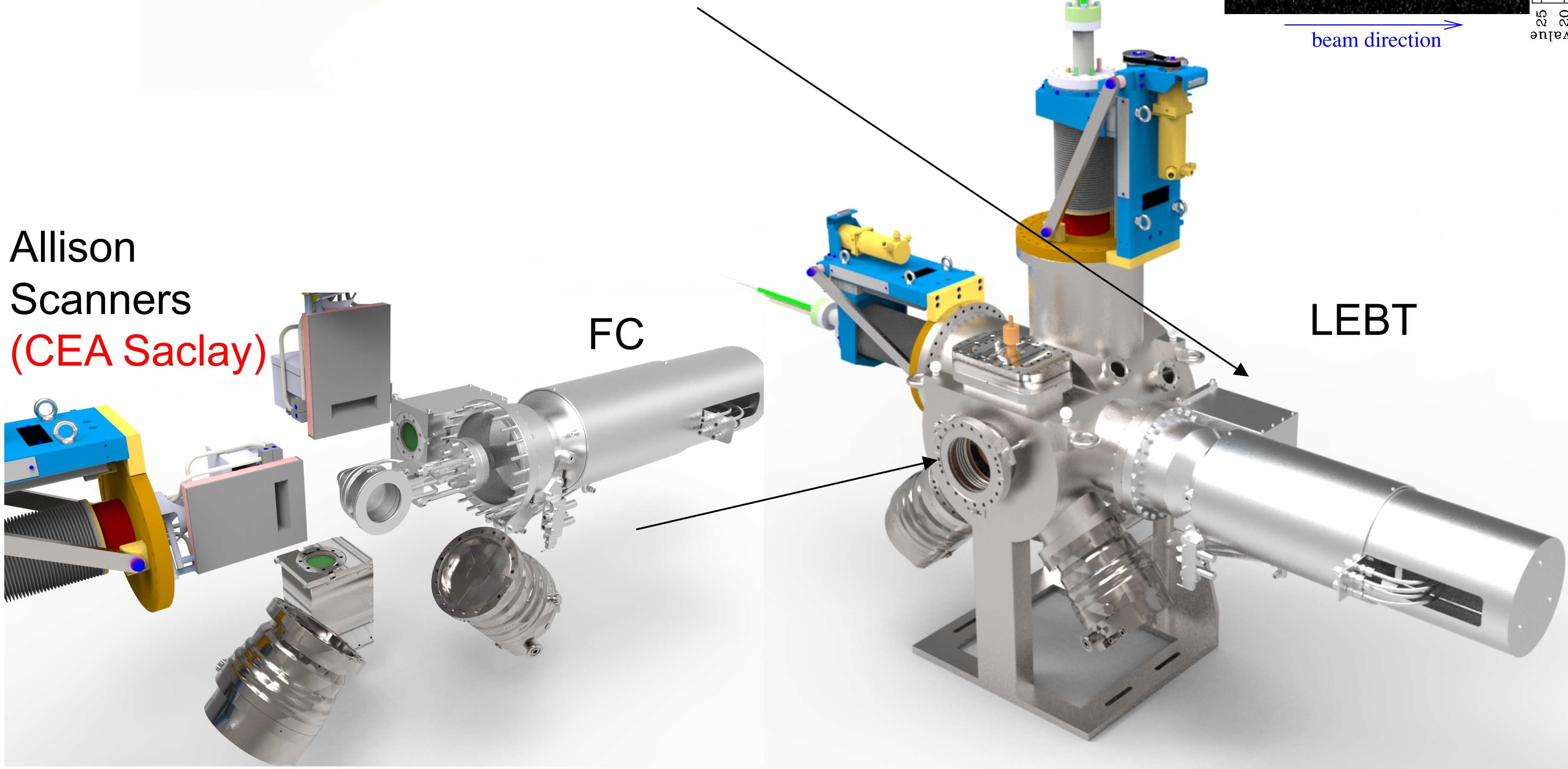
F. Becker et al, GSI

Beam Induced
Flouresence monitor
C. Thomas, ESS

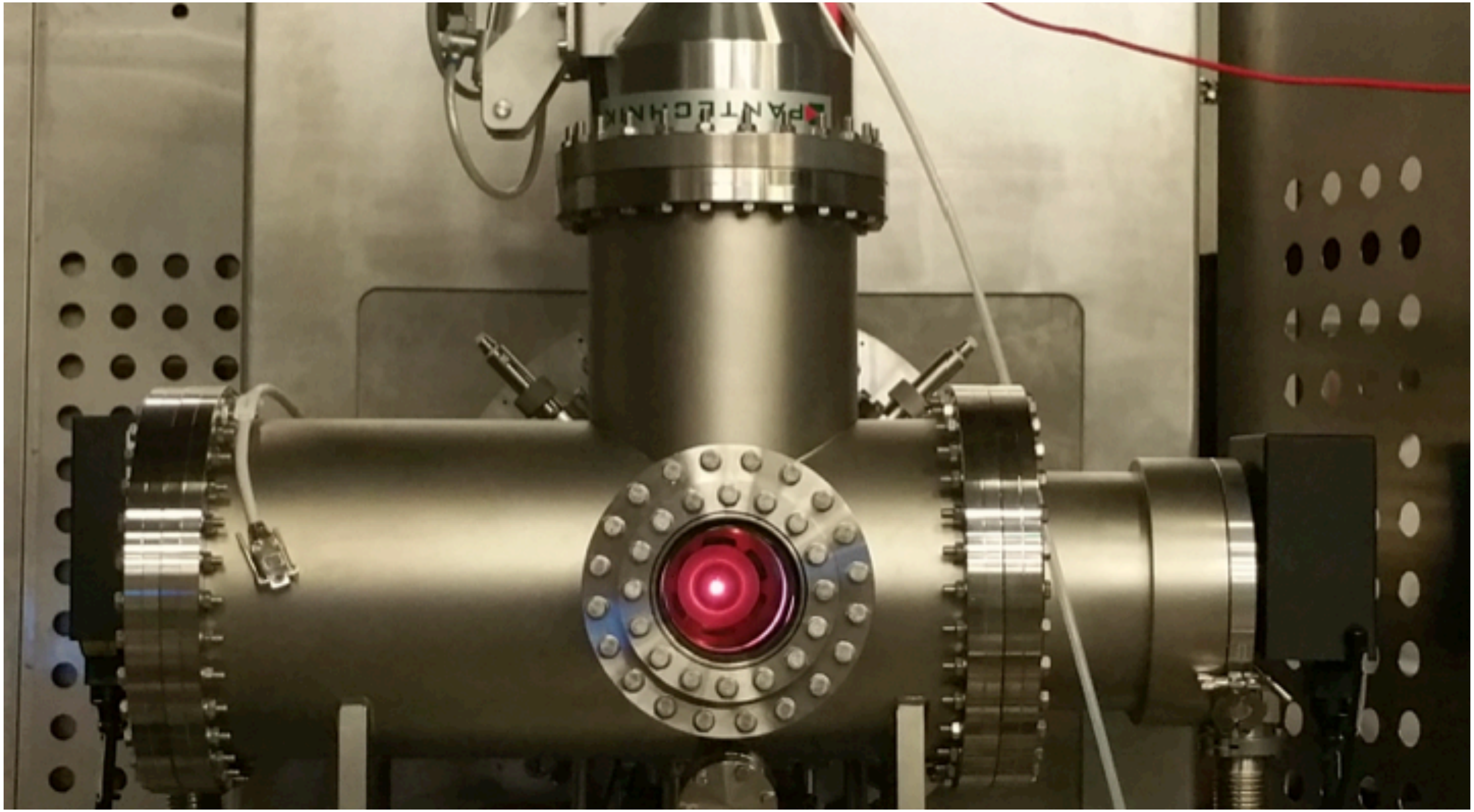




Allison
Scanners
(CEA Saclay)

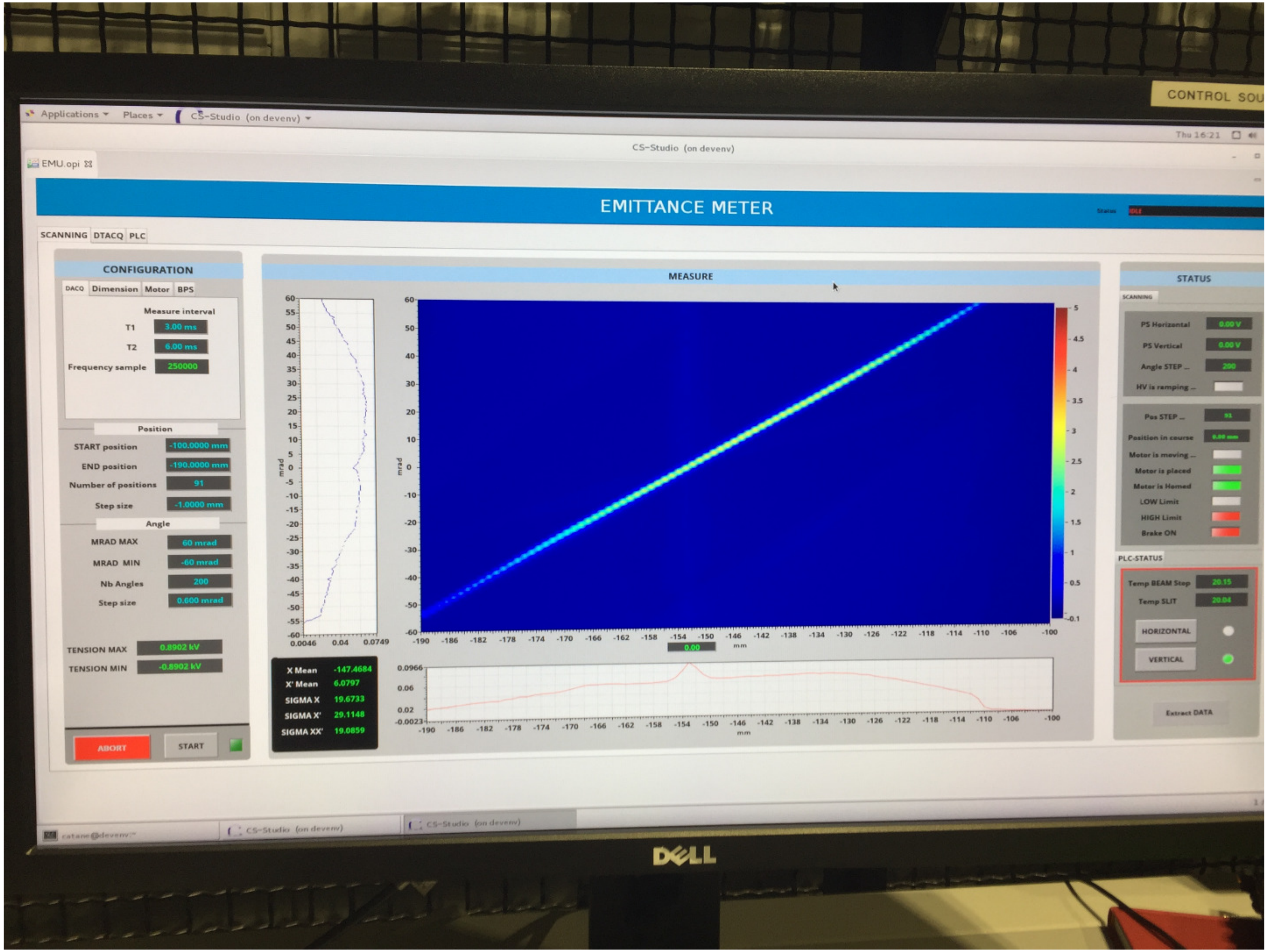


First beam



L. Neri et al, INFN-LNS

First ESS Emittance Measurement



Olivier Tuske et al, CEA Saclay
Benjamin Cheymol, ESS

Flying wire

Developed for CERN injectors

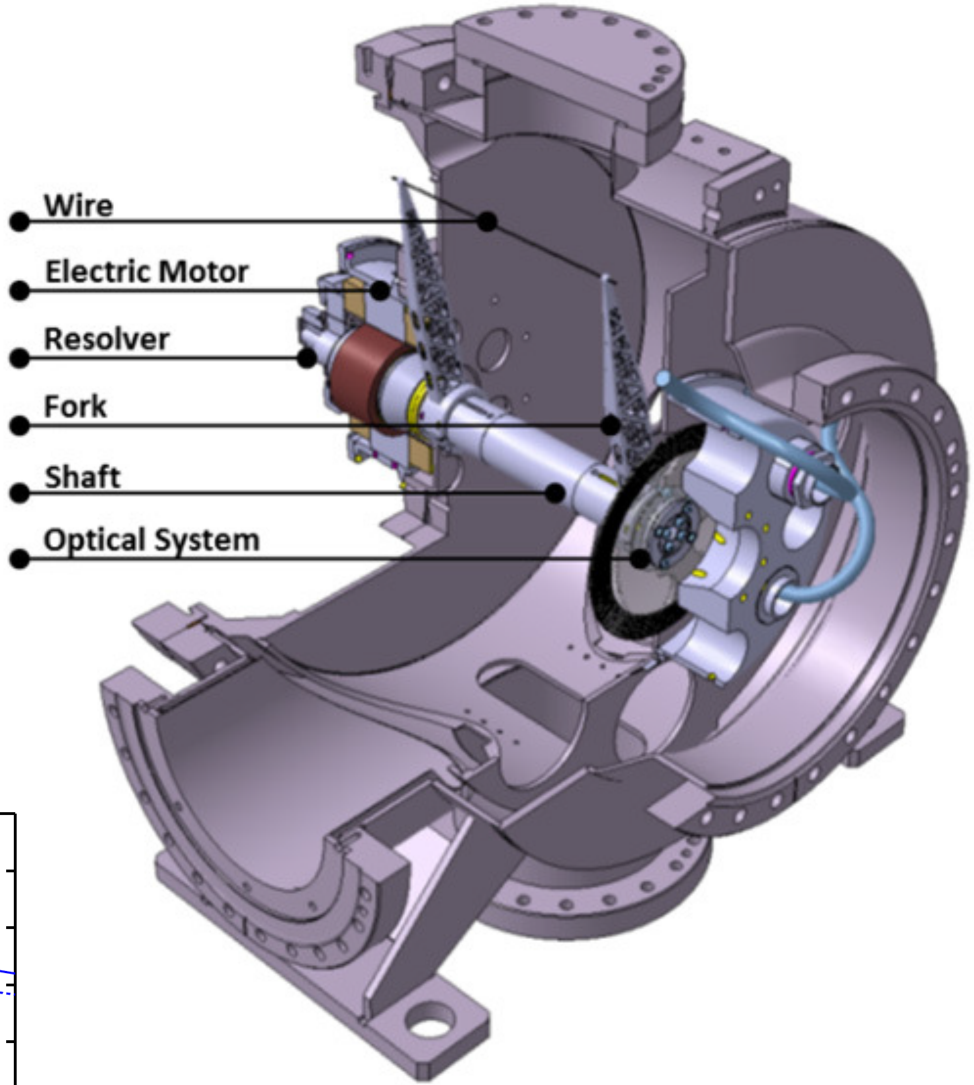
Innovative in-vacuum motor

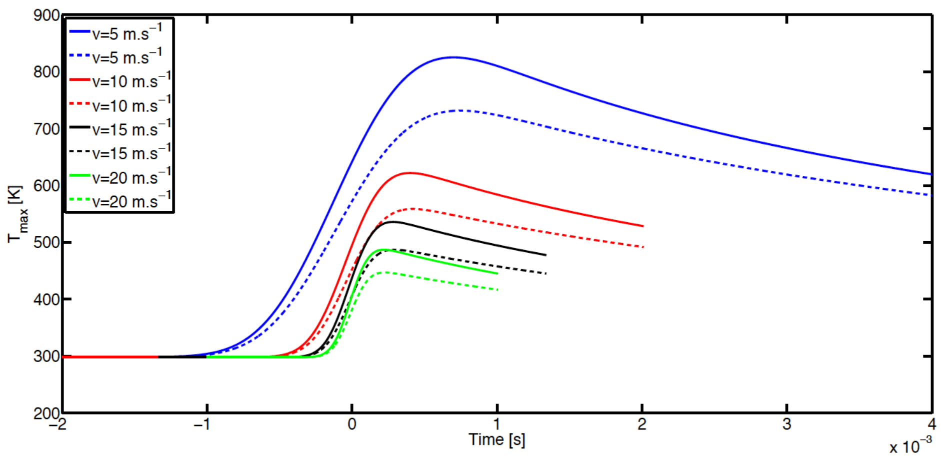
Can fly through the ESS beam in a fraction of pulse length (20m/s)

Can take full beam intensity

Results in seconds instead of minutes

Will be used in ESS HEBT

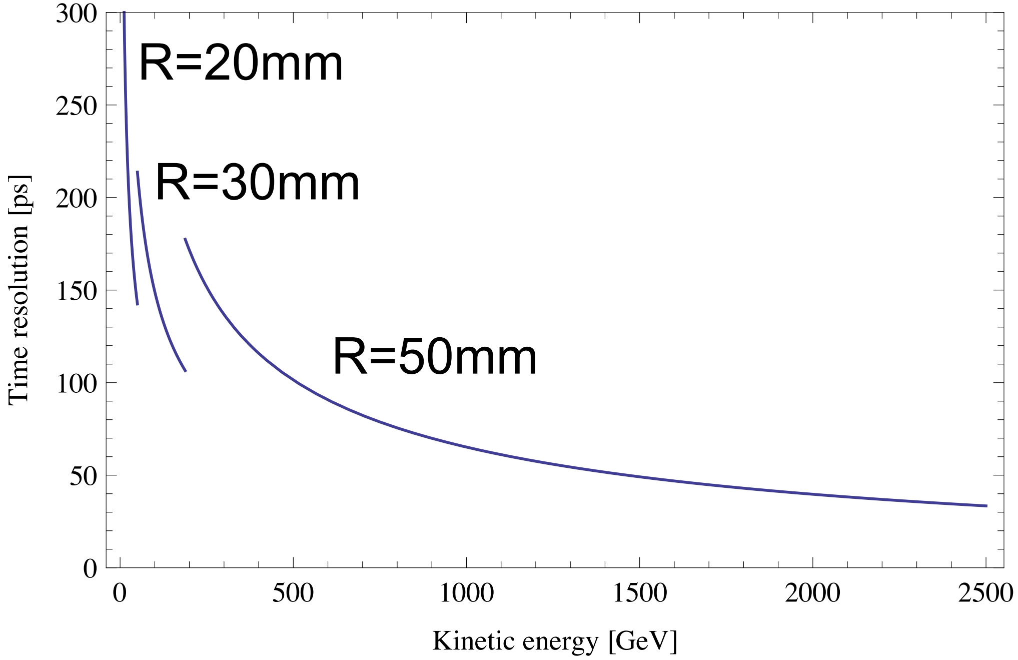


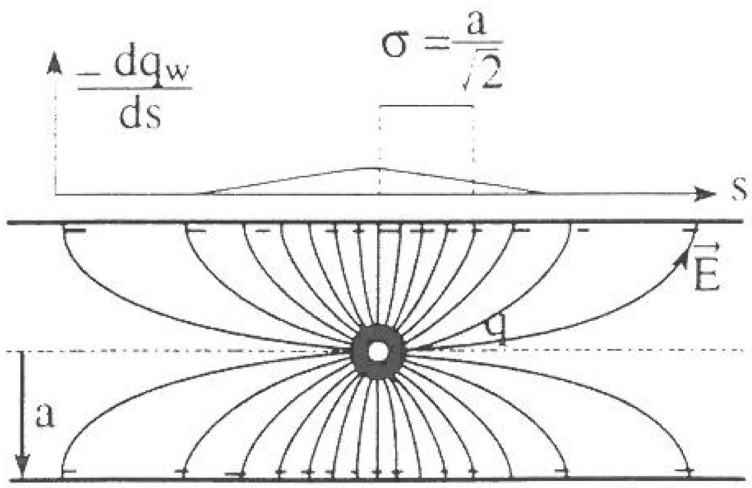


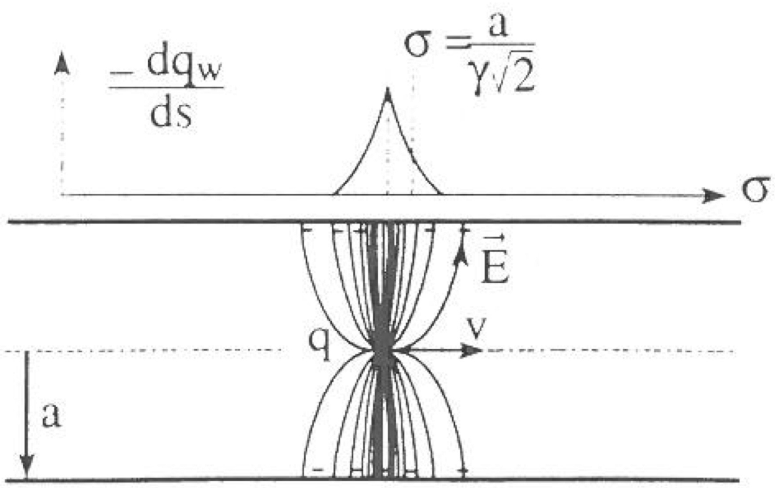
R. Veneess et al, CERN

Bunch Shape Measurement

- At low beta, field is not transverse, and wall current does not reflect beam pulse length
- At ESS, this effect is significantly larger than the beam size in entire accelerator

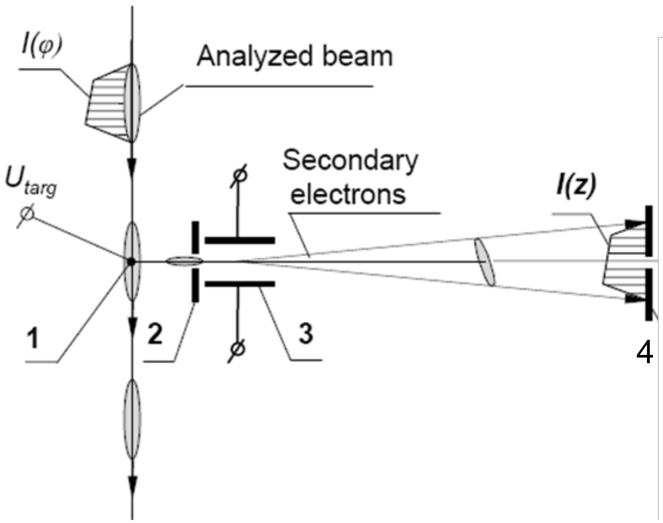


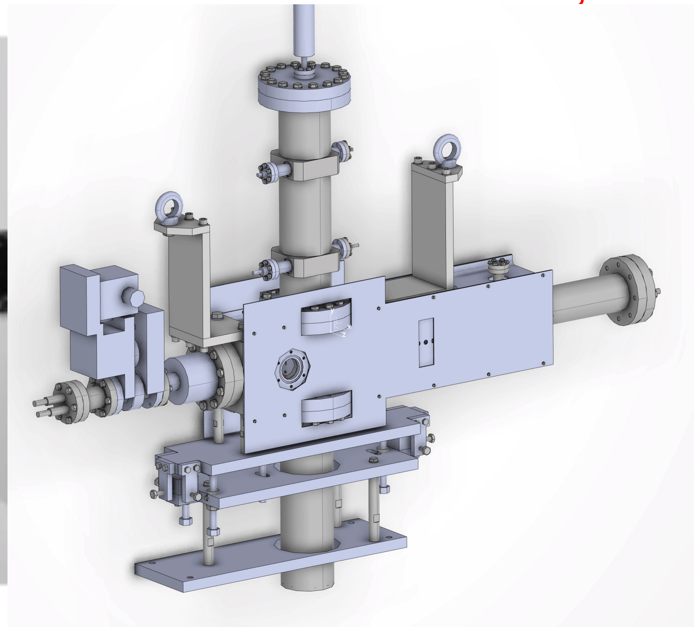




Bunch Shape Monitor

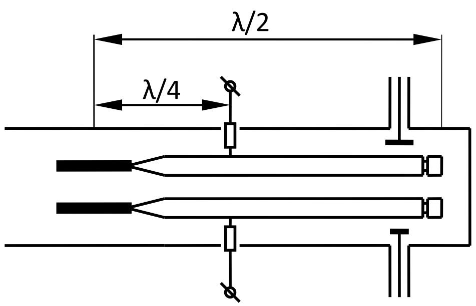
A. Feschenko, INR

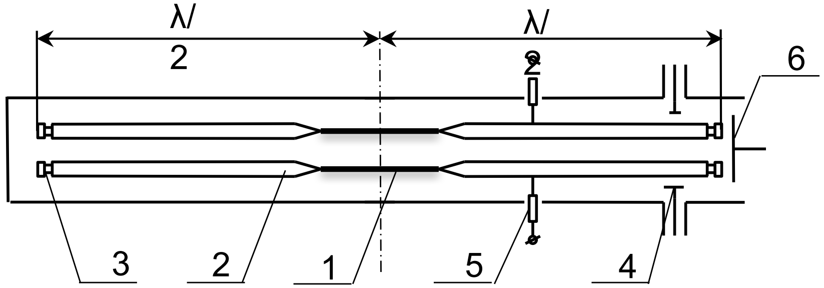


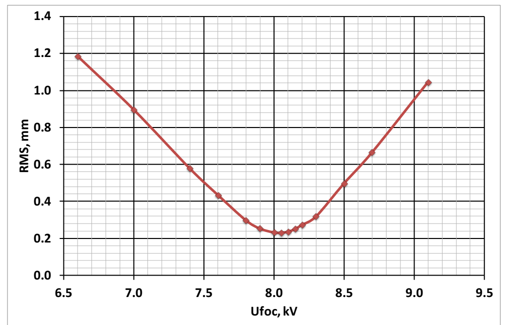


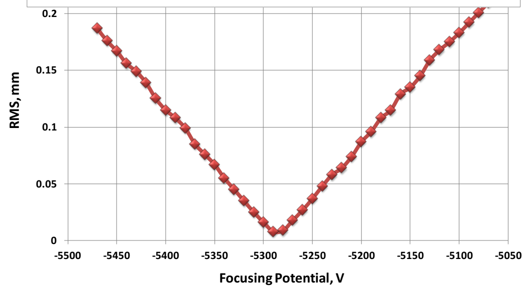
With new symmetric deflector, expect resolution limited by electron time dispersion, which is very small (but of unknown magnitude)

Expect 0.2-0.5°





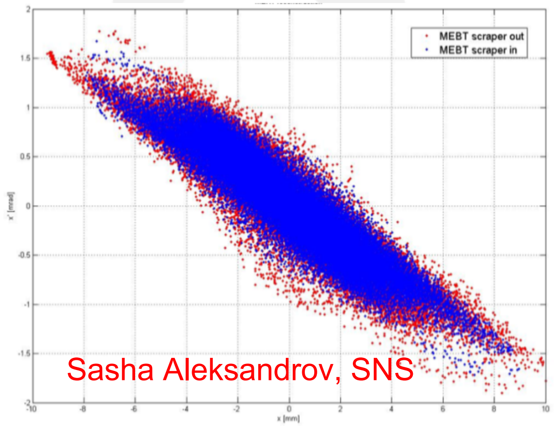




Fancy diagnostics

Dream Diagnostics

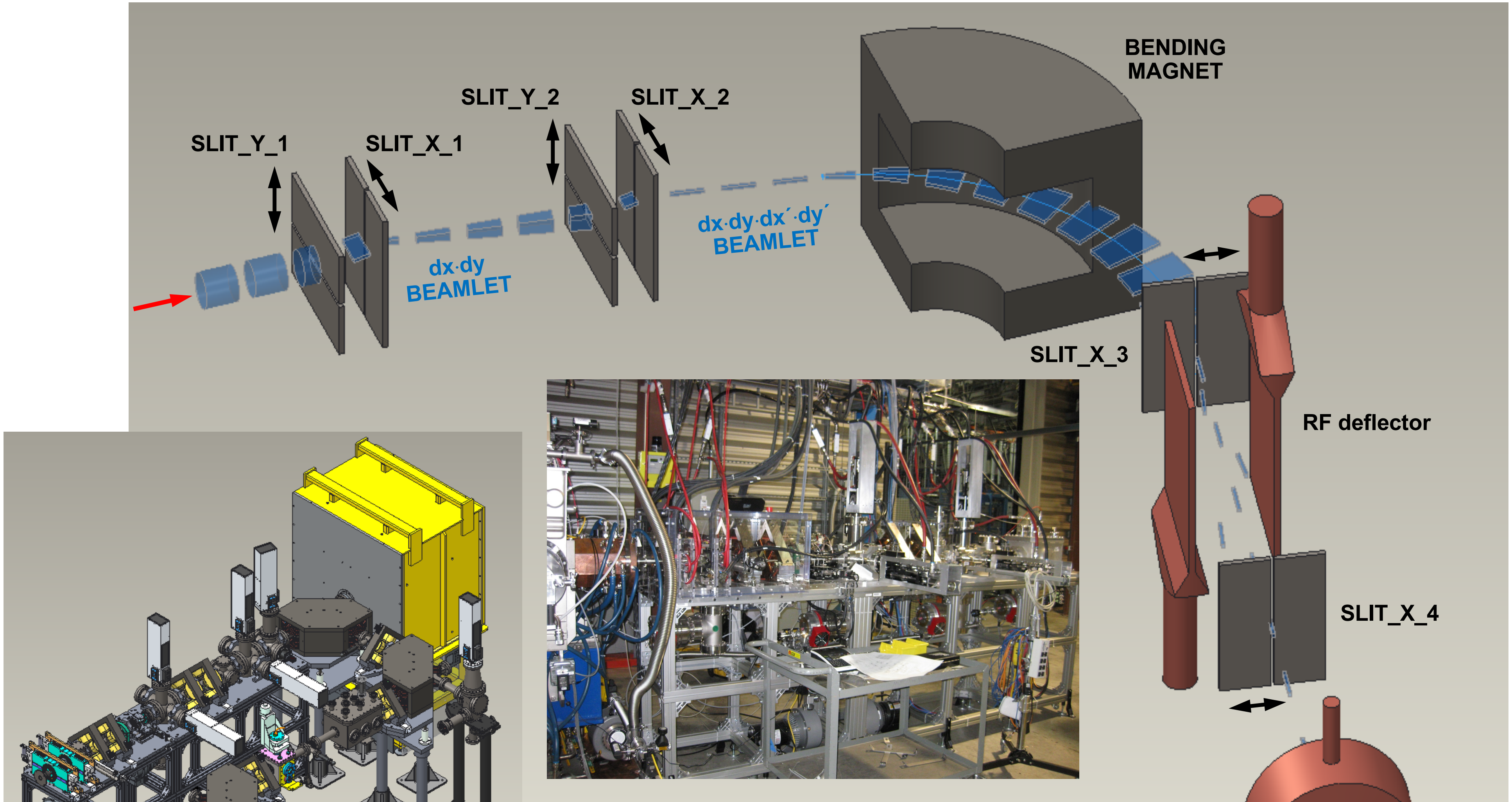
```
DRIFT 4 18.4 0
DIAG_CURRENT 24005 0 ; FBCM (BPM pick-up)
STEERER 0 0 0.035 0 0 1866.6 ; BLmax ~ 28 Gm, b3 ~ 4200 (@ 15 mm)
;MATCH_FAM_GRAD 20000 13
QUAD 80 -14.7599 18.4 0 0 0 0 0 0
DRIFT 4 18.4 0
DRIFT 6 18.4 0

DRIFT 50 18.4 0
APERTURE 18.4 18.4 0 ; SLIT open
DIAG_SIZE 21003 3.230 3.772 ; WS
DIAG_EMIT 23001 0.2529 0.2517 ; EMU
DIAG_TWISS 20001 -7.194 3.629 12.519 4.972 0 0 ; EMU
;DIAG_EMIT 23001 0.2884 0.2671 ; EMU (Partran)
;DIAG_TWISS 20001 -6.173 3.112 12.370 4.889 0 0 ; EMU (Partran)
DRIFT 50 18.4 0
PLOT_DST
DRIFT 6 18.4 0
DRIFT 4 18.4 0
DIAG_POSITION 29004 0 0 0.2
ADJUST_STEERER 29005
STEERER 0 0 0.035 0 0 1866.6 ; BLmax ~ 28 Gm, b3 ~ 4200 (@ 15 mm)
;MATCH_FAM_GRAD 20000 3
;Q7: QUAD 80 9.79193 18.4 0 0 0 0 0 0
QUAD 80.0 9.82142 18.4 0.0 0.0 0.0 0.0 0.0 0.0
DRIFT 4 18.4 0
DRIFT 6 18.4 0

DRIFT 80 18.4 0
DIAG_SIZE 21101 0 0 21.18 ; LBM
DRIFT 80 18.4 0

DRIFT 30 18.4 0
```



“magic 6D zero length monitor”

SNS 6D monitor

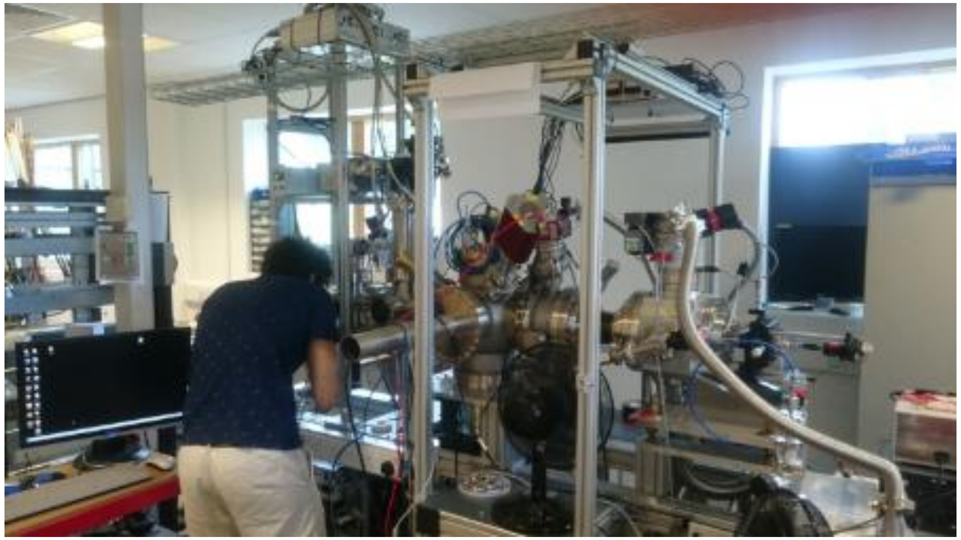
Sasha Aleksandrov, SNS



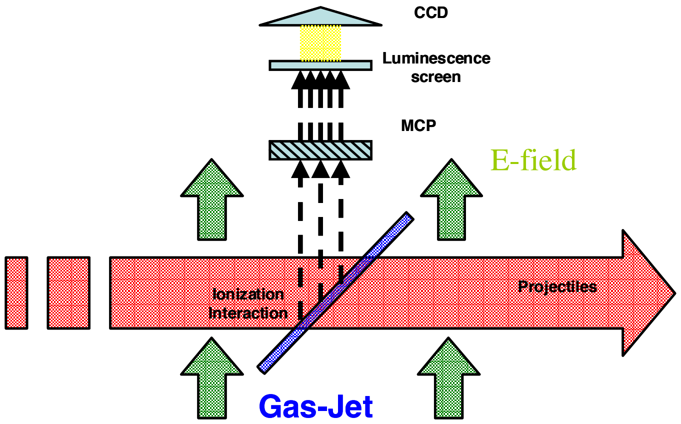
Measure all 6D correlations.
Takes a loooooong time
Can only be done in dedicated setup
Very useful tool to understand initial conditions

Gas Jets

- Using a gas jet can boost fluorescence signal without raising overall gas pressure.
- Ongoing work with Cockcroft, CERN and GSI to develop simplified and ruggedized version to be used in tunnel

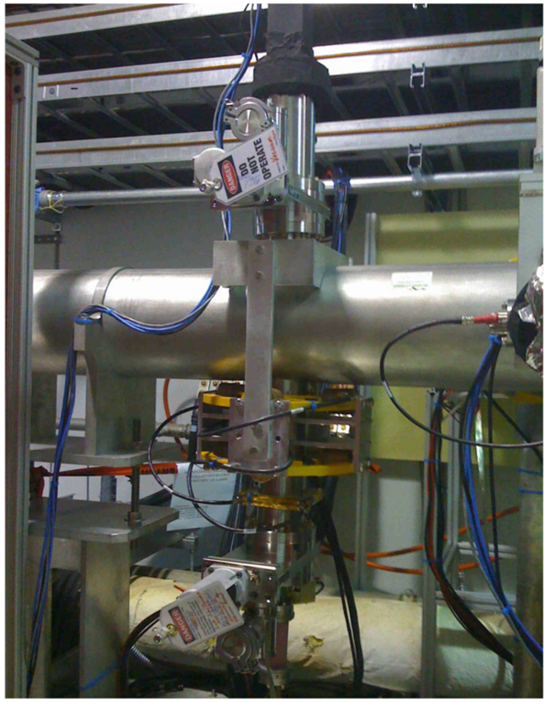


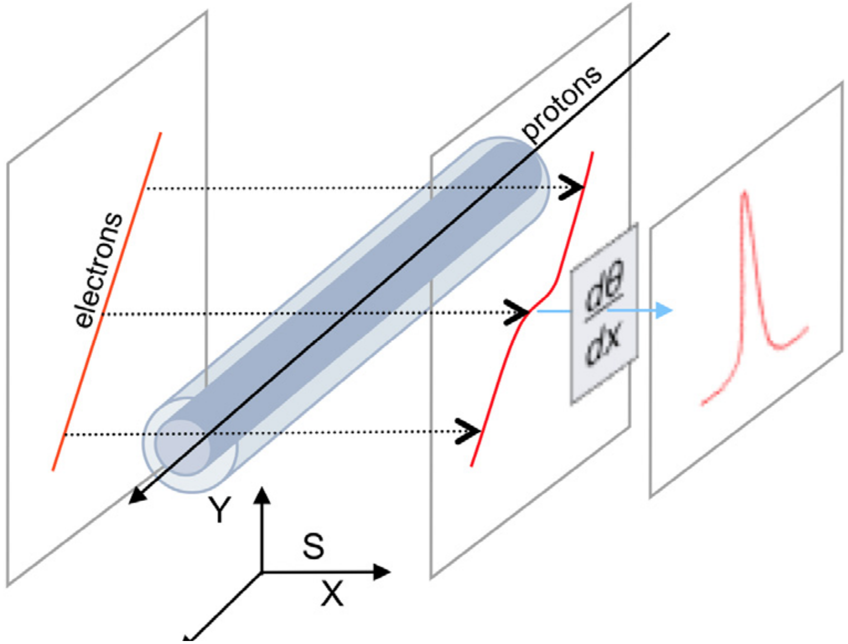
C. Welsch et al, Uni Liverpool



Kuehnel et al, EPAC08

E-beam scanner/Profilometer





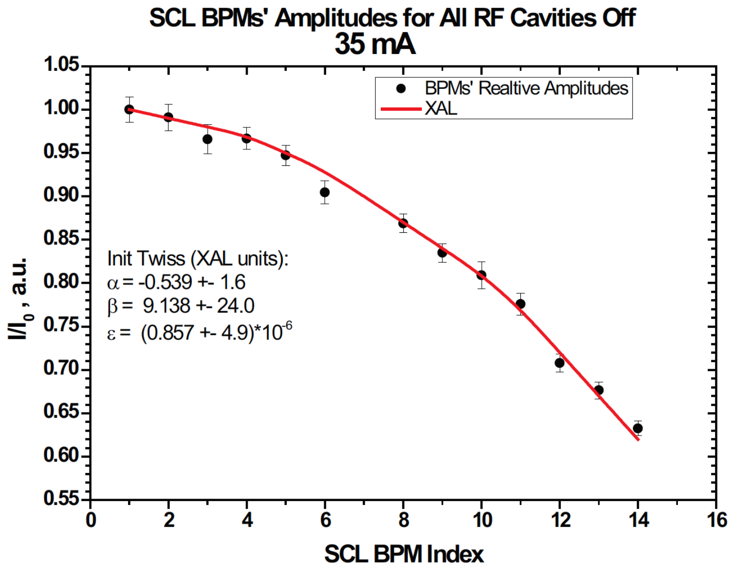
- Scan probe beam of ions or electrons perpendicular to main beam, measure displacement and differentiate to get profile

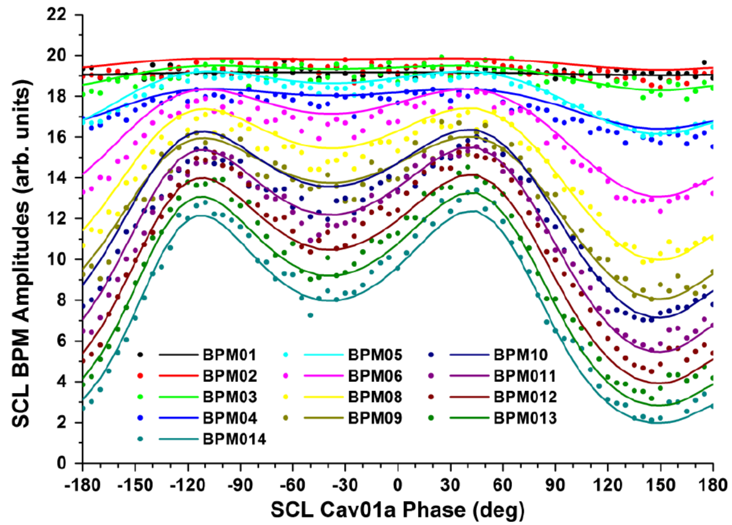
W Blokland, SNS
R Thurman-Keup, FNAL
R. Jung, CERN (ion version)

- Slow ions average over many bunches, while electrons probe instantaneuos beam current.
- Very short (round) bunches in ESS, cause longitudinal displacement that is hard to disentangle from transverse.

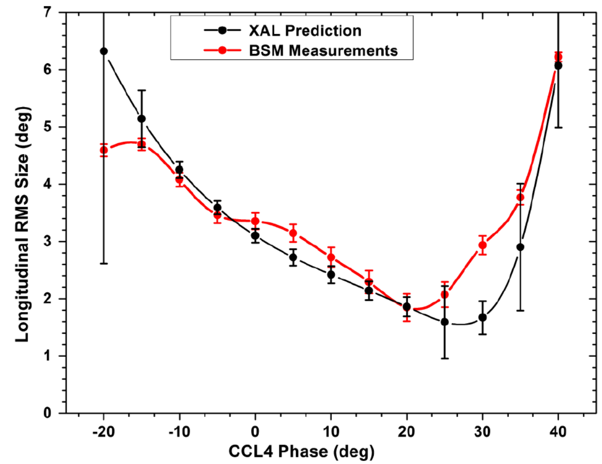
Fancy use of basic (B^3) diagnostics

"Shishlo Method"

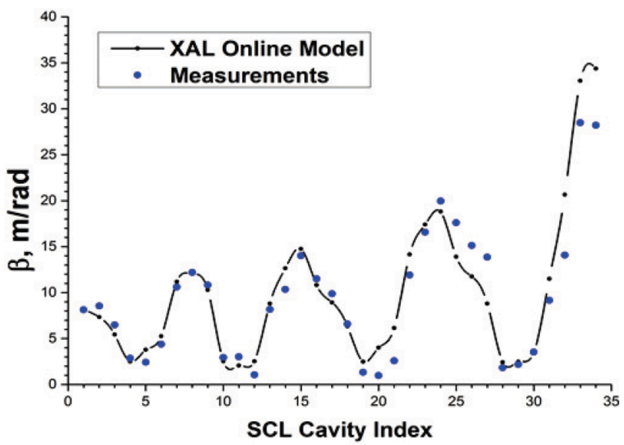




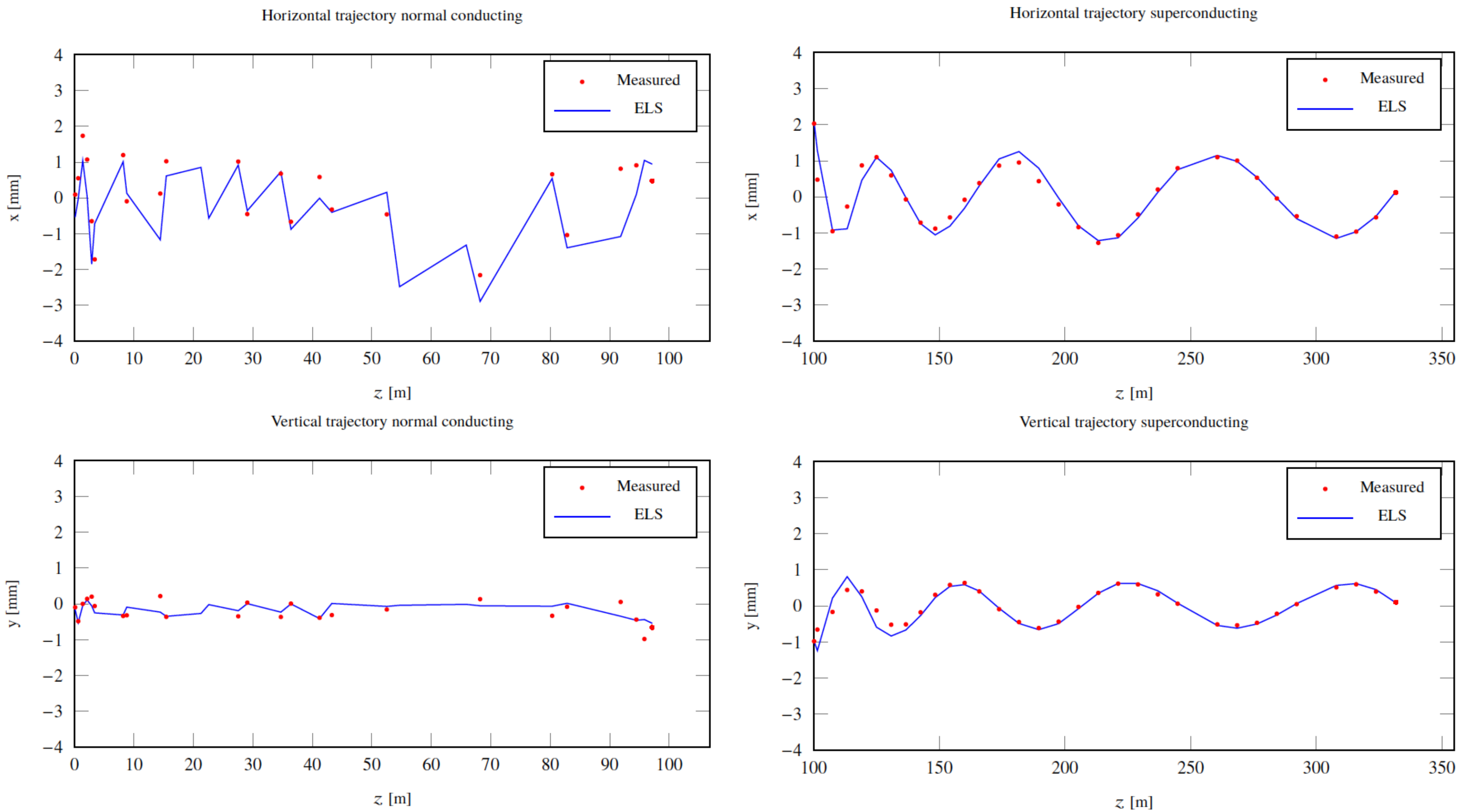
Use **sum signal** from multiple BPMs to measure bunch lengthening from energy spread. Combine with cavity scan to measure longitudinal Twiss parameters



A. Shishlo, A. Aleksandrov, Phys. ST Accel. and Beams 16, 062801 (2013).



Differential trajectories



Method proven very powerful in rings.
Can also be applied to linacs.
Note significant transverse focussing from RF

E. Laface/Y. Levinsen ESS
T. Pelaia, SNS
IPAC16

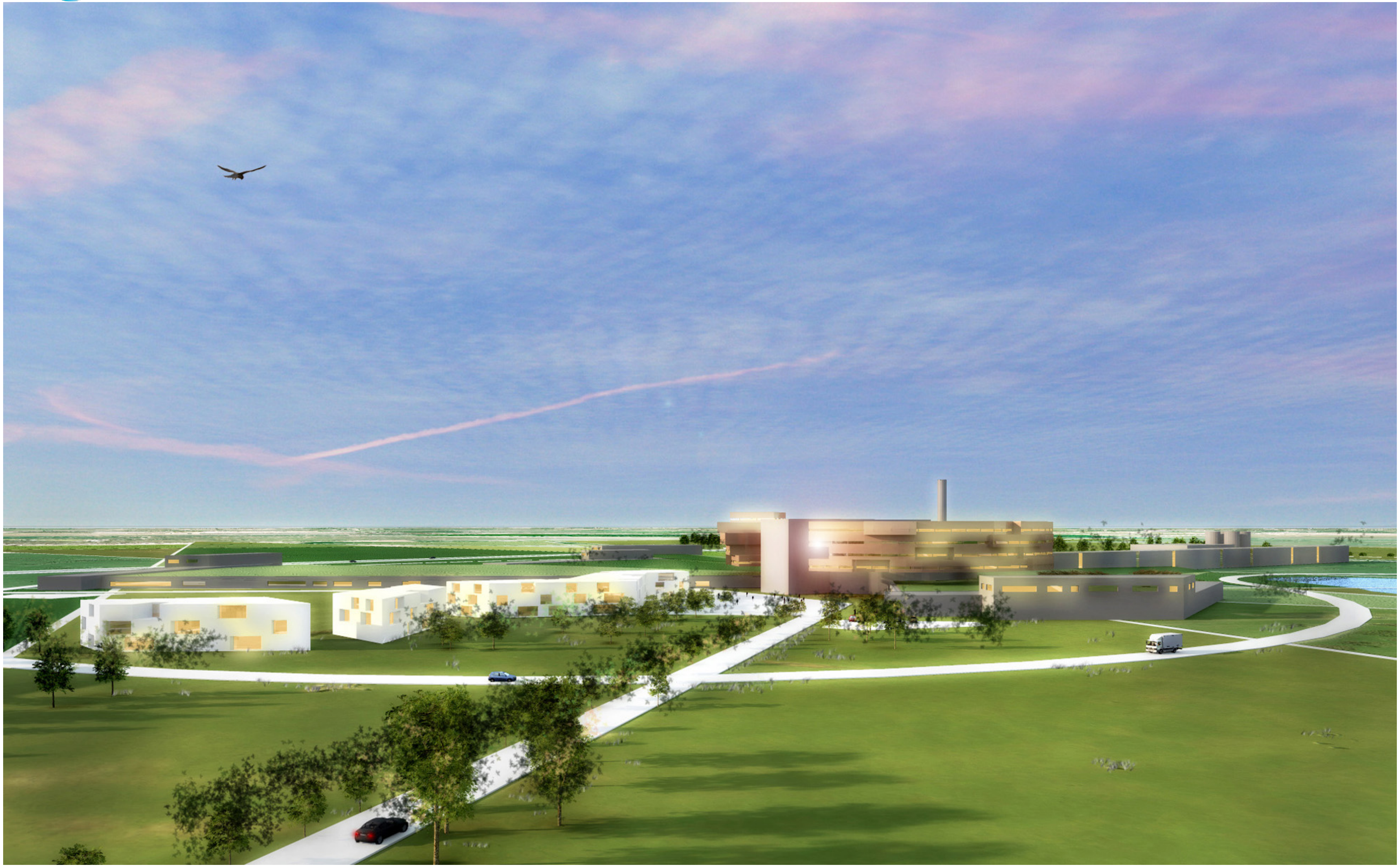
Areas of future improvement

- Gas jets (ruggedized)?
- Pump laser to generate distinct signature for BIF?
- Optical Diffraction Radiation?
- ...<insert new ideas here>...

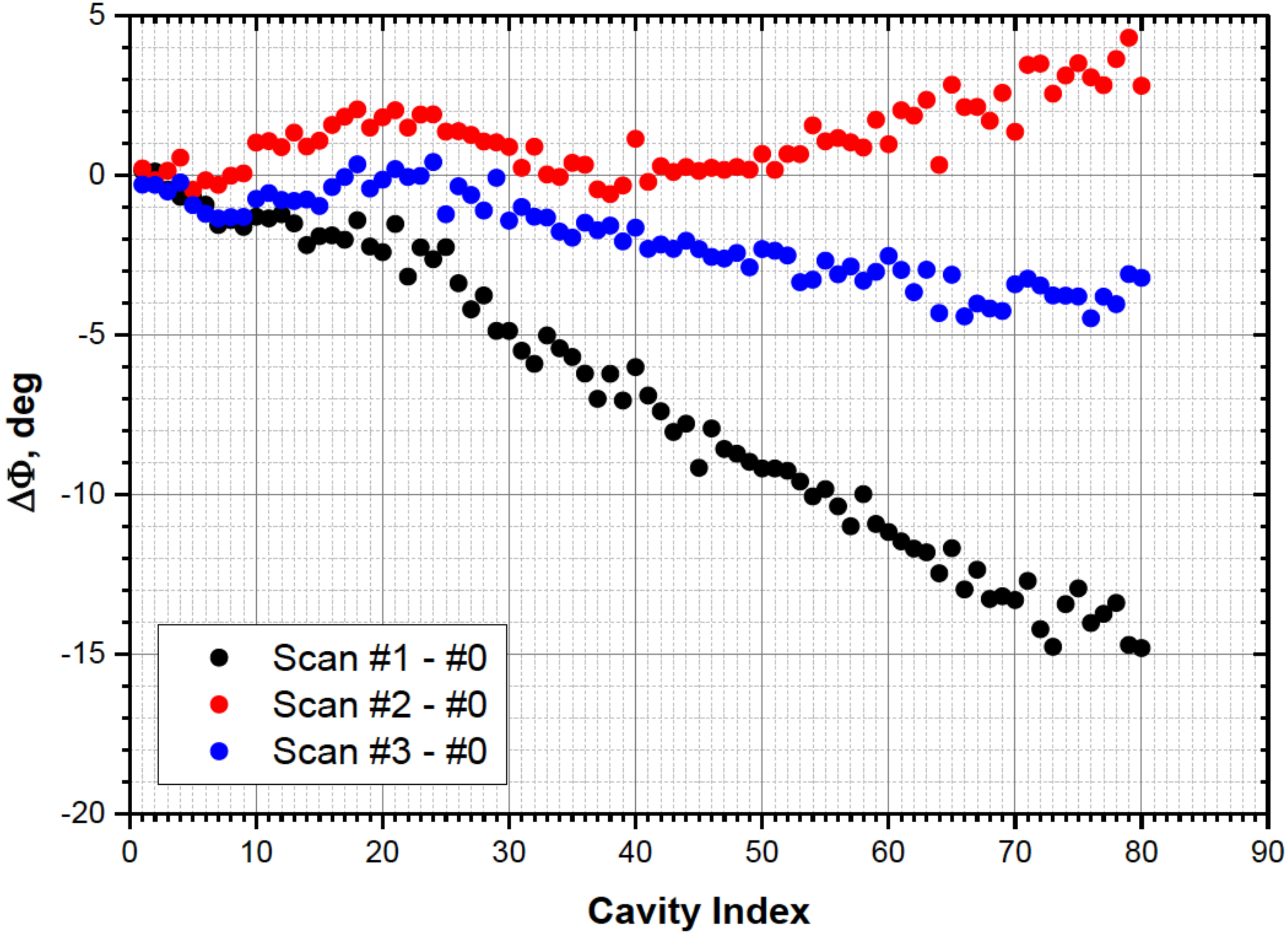
- Better use of existing diagnostics!
- (Even) closer cooperation between beam diagnostics and beam physics people.

Thanks for your attention!

EUROPEAN
SPALLATION
SOURCE



SNS phase scan stability



A. Shishlo, SNS