OVERVIEW AND STATUS OF DIAGNOSTICS FOR THE ESS PROJECT

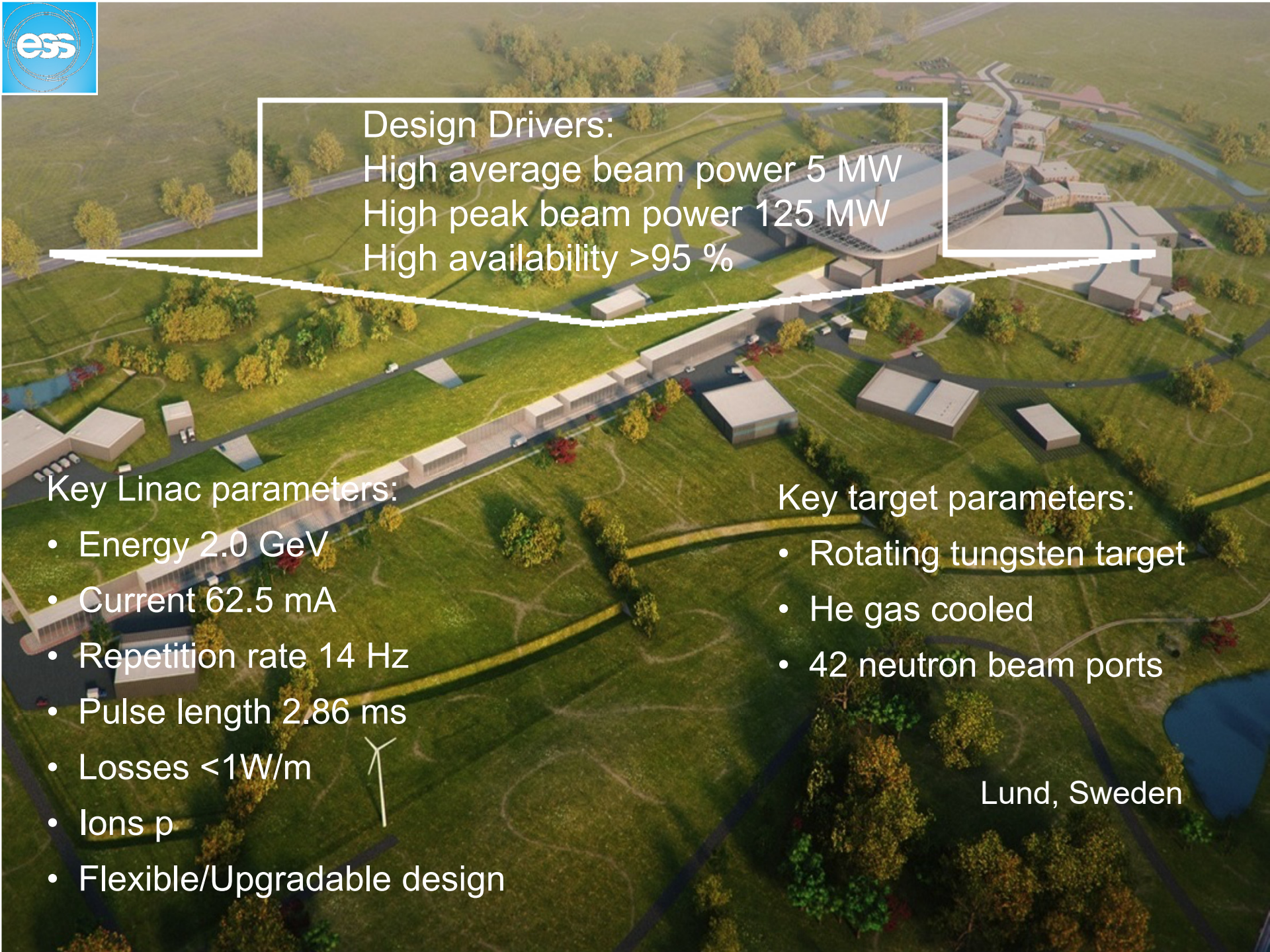
Tom Shea

and the ESS Beam Diagnostics Team

Input from: C. Thomas, B. Cheymol, S. Molloy, R. Baron, H. Hassanzdegan, I. Kittelmann, T. Grandsaert, H. Kocevor, C. Derrez, A. Jansson, M. Eshraqi, E. Adli, M. Poggi, M. Ferianis, I. Bustinduy, P. Aden, T. Papaevangenlou, J. Marroncle, L. Segui, S. Vilcins, A J. Johannson

Outline

- Overview
  - European Spallation Source
  - Diagnostics Team Organization
  - The Beam Diagnostics Suite
- Measurement Capabilities
  - Beam Accounting
  - Measurement of Beam Centroid
  - Measurement of Beam Distribution
- Protection Strategy
- Outlook



Design Drivers:
High average beam power 5 MW
High peak beam power 125 MW
High availability >95 %

Key Linac parameters:

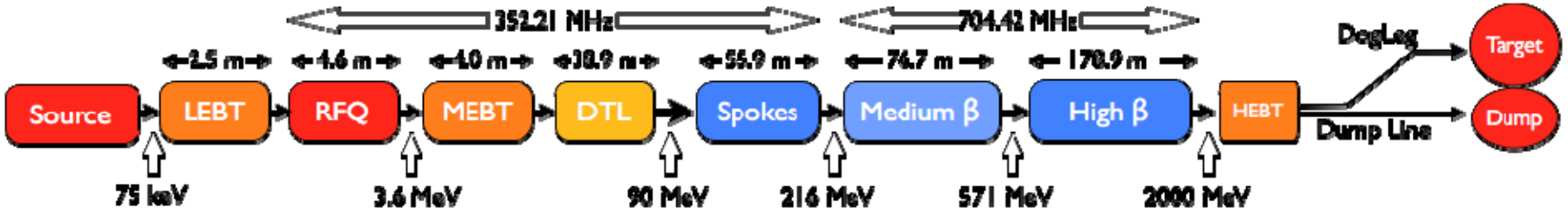
- Energy 2.0 GeV
- Current 62.5 mA
- Repetition rate 14 Hz
- Pulse length 2.86 ms
- Losses <1W/m
- Ions p
- Flexible/Upgradable design

Key target parameters:

- Rotating tungsten target
- He gas cooled
- 42 neutron beam ports

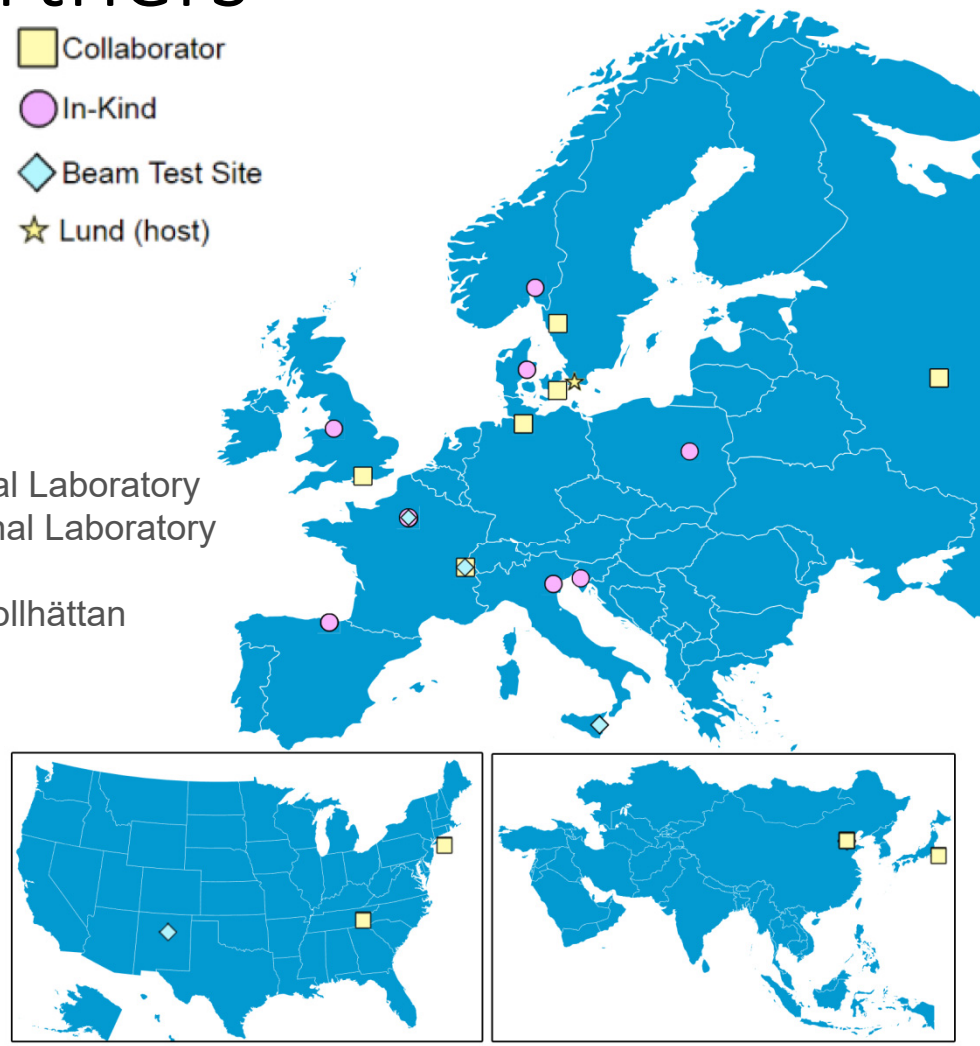
Lund, Sweden

The ESS Linac



	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

ESS Diagnostics Partners and Collaborators

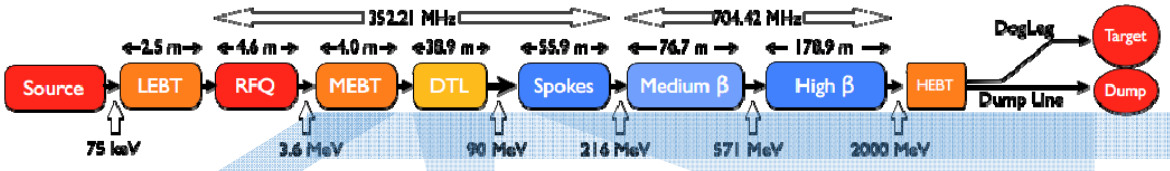


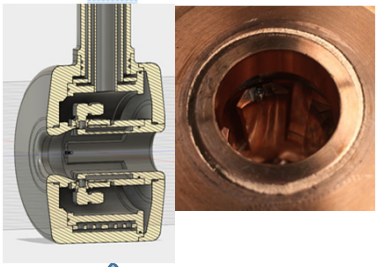
- Aarhus University
- CEA Saclay, Paris
- CERN, Geneva
- Cockcroft Institute, Daresbury
- DESY, Hamburg
- Elettra – Sincrotrone Trieste
- ESS Bilbao
- INFN, Catania
- INFN, Legnaro
- Lund University
- University of Oslo
- Technical University of Denmark
- Science and Technology Facilities Council, Daresbury
- Warsaw University of Technology
- Chinese ADS
- J-PARC, Japan
- Oak Ridge National Laboratory
- Los Alamos National Laboratory
- INR, Moscow
- Högskola Väst, Trollhättan

	LEBT	RFQ	MEBT	DTL	Spk	MBL	HBL	HEBT	A2T	DumpL	TOTAL
BPM	-	-	7	15	14	9	21	16	12	4	98
IPM	-	-	-	-	1	3	1	-	-	-	5
BIF	1	-	2	-	-	-	-	-	1	-	4
ICBLM	-	-	-	5	52	36	84	49	37	6	269
nBLM	-	-	5	11	14	4	-	1	-	-	35
WS	-	-	3	-	3	3	1	3	1	-	14
LBM	-	-	1	-	1	1	-	-	-	-	3
FC	1	-	1	2	-	-	-	-	-	-	4
BCM	1	1	4	5	-	1	1	2	3	2	20
EMU	1	-	1	-	-	-	-	-	-	-	2
IMG	-	-	-	-	-	-	-	-	2	1	3
APTM	-	-	-	-	-	-	-	-	3	1	4
DPL	1	-	-	-	-	-	-	-	-	-	1

BPM Position Monitors

	LEBT	RFQ	MEBT	DTL	Spk	MBL	HBL	HEBT	A2T	DumpL	TOTAL
BPM	-	-	7	15	14	9	21	16	12	4	98



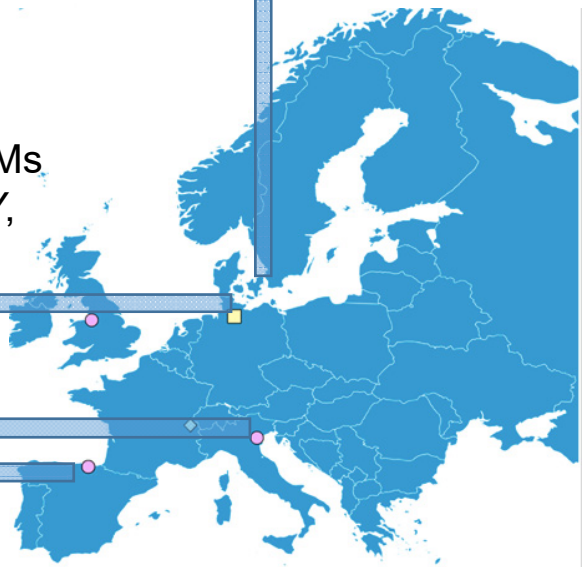


Electronics from ESS-Lund

Striplines from Bilbao

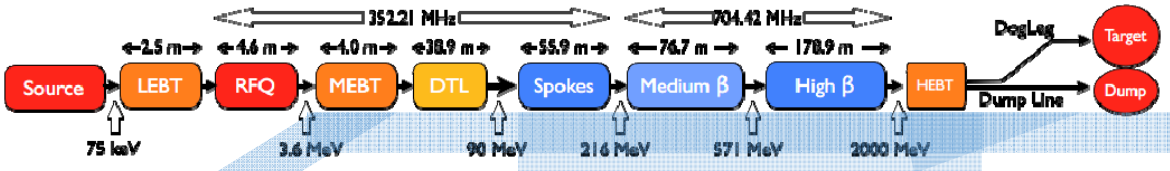
Striplines from Legnaro

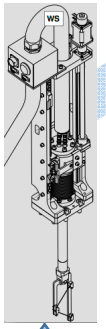
Button BPMs from DESY, Daresbury

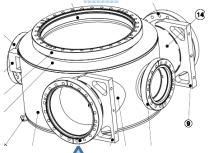


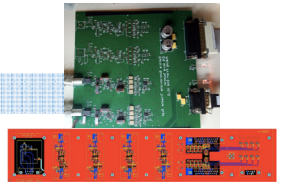
Wire Scanners

	LEBT	RFQ	MEBT	DTL	Spk	MBL	HBL	HEBT	A2T	DumpL	TOTAL
WS	-	-	3	-	3	3	1	3	1	-	14







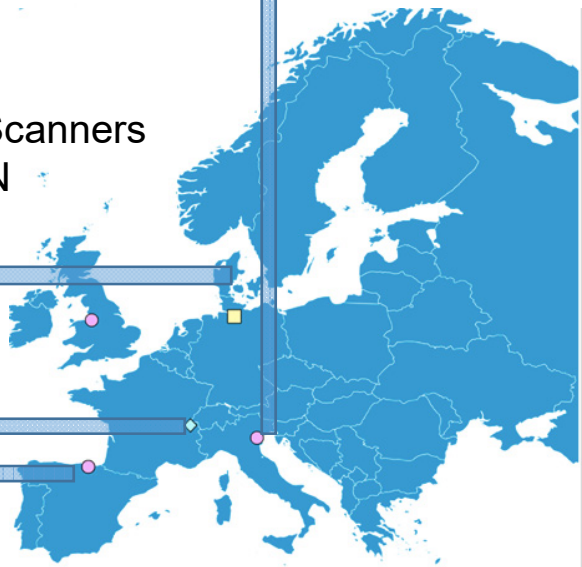


Electronics from Trieste

Scanning Actuators from Bilbao

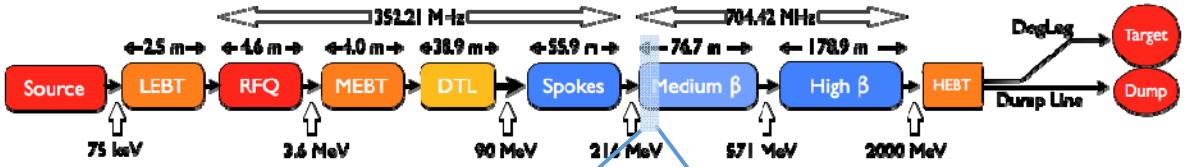
Scanning Actuators from Århus

Fast Wire Scanners from CERN



The Lattice

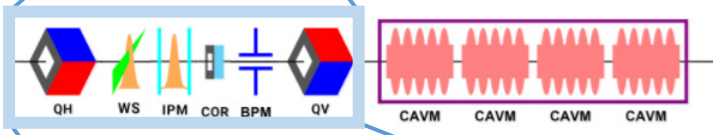
(keeping track of the diagnostics layout)

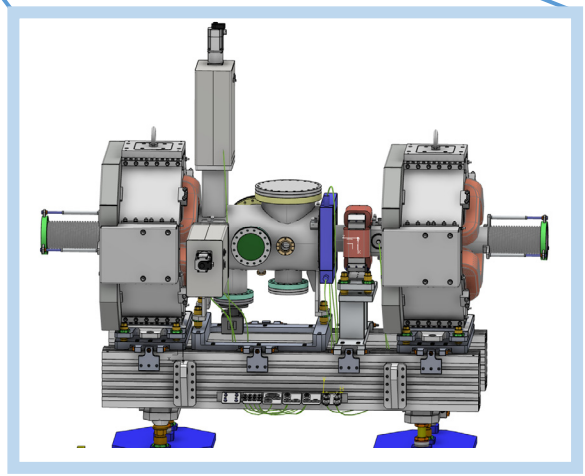


Lattice file

```
QUAD 350 4.12767 50 0 0 0 0 0 0
DRIFT 59.7 50 0 0 0
DIAG_SIZE 53001 2.642 3.381 ; [WS WS3]
DRIFT 150.25 50 0 0 0
DIAG_SIZE 53901 2.642 3.381 ; [NPM NPM2] first camera for NPM
DRIFT 131 50 0 0 0
DIAG_SIZE 53901 2.642 3.381 ; second camera for NPM
DRIFT 267.05 50 0 0 0
ADJUST 59002 1 0 -0.0024 0.0024 0
ADJUST 59002 2 0 -0.0024 0.0024 0
THIN_STEERING 0 0 50 0
DRIFT 82.2 50 0 0 0
DIAG_POSITION 59001 0 0 0.2 ; [BPM BPM6]
DRIFT 39.8 50 0 0 0
QUAD 350 -4.18001 50 0 0 0 0 0 0
```

Automated generation of synoptic view





- Automated generation of reference points in mechanical model
- Automated comparison of model and lattice file

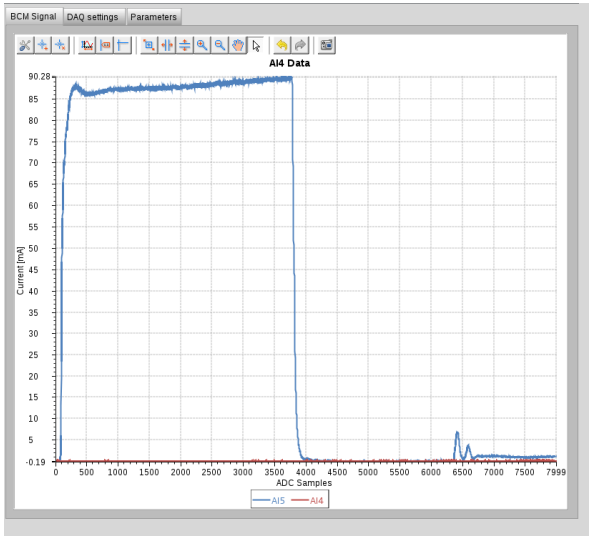
Beam Accounting

- Measuring beam current and where it is lost
  - Constituents of beam extracted from ion source
  - Losses that damage or activate accelerator
  - Beam leaving aperture and overheating target/dump components
- Systems
  - Doppler
  - Faraday Cups
  - Beam Current Monitors
  - Beam Loss Monitors
    - Neutron detectors
    - Ion chambers
  - Aperture Monitors

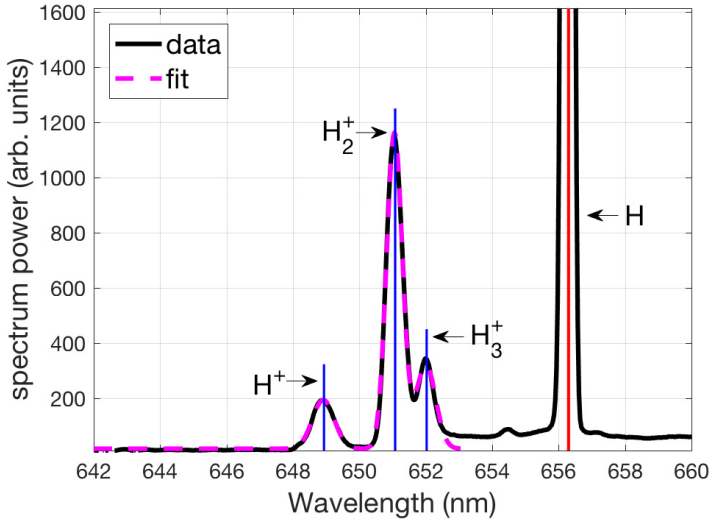
Beam pulse parameters for diagnostics measurements extend from **a few mA for a few µs at low repetition rate** up to **full duty factor**.

Beam Accounting: Beam Current, Doppler, Faraday Cup

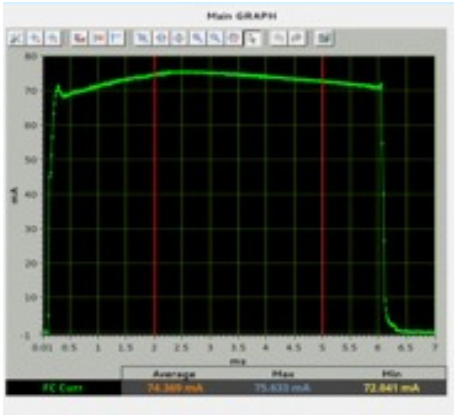
BCM from ESS Lund - Bergoz FCT measuring source supply current. Same type used throughout linac.



Doppler system (from CEA Saclay) measuring ion species fractions

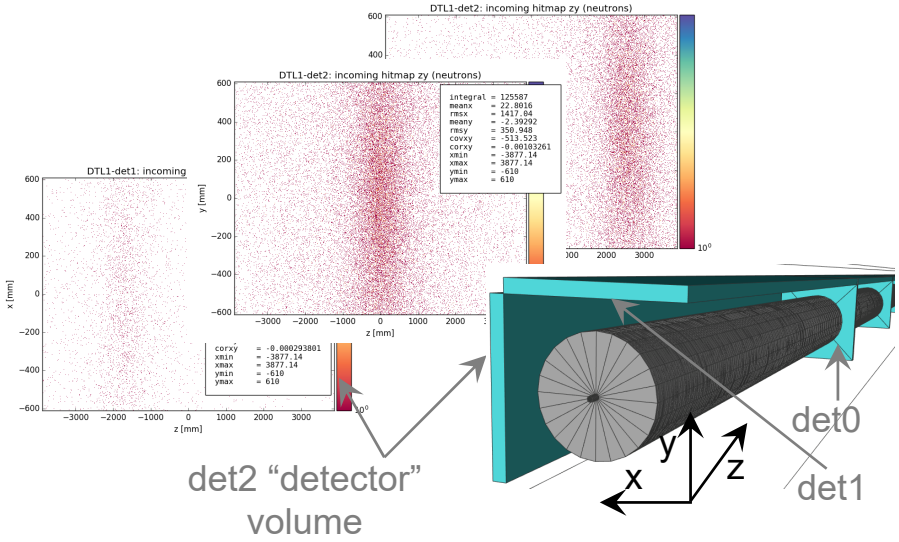


Faraday cup (from ESS Lund) measuring 75 keV beam



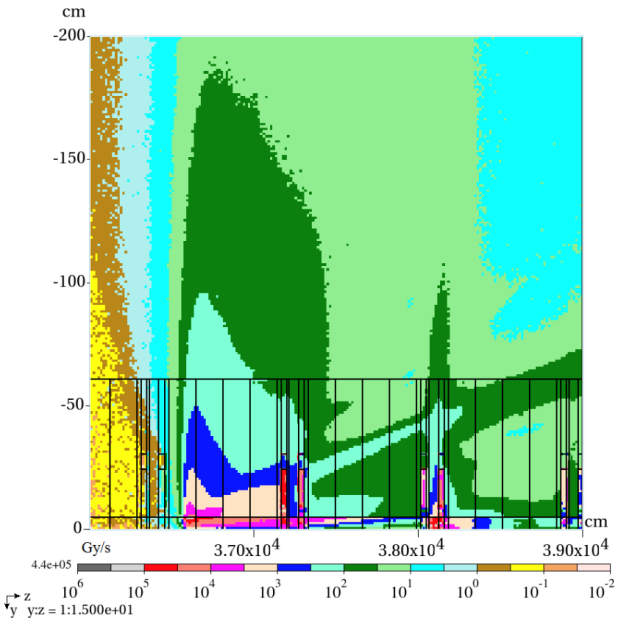
Beam Accounting: Beam Loss

Neutron hit maps for 3 different localized loss locations along the DTL tank1: possible correlation of the distribution peak position with the loss location



I. Kittelmann

Absorbed dose map, all particles, from point loss @ 2 GeV



M. Jarosz

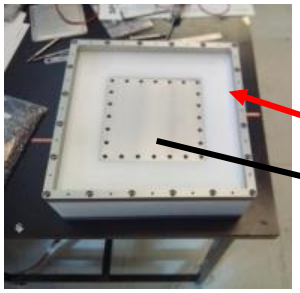
Beam Accounting: nBLM detectors

SLOW

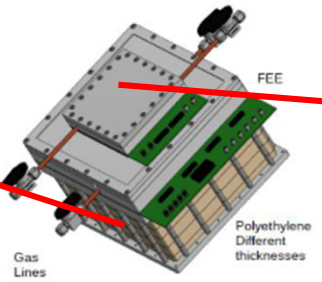
- (n, α) ^{10}B reaction
- Detection of fast neutrons after moderation in polyethylene (~4cm)
- More efficient, 4π, but slower response

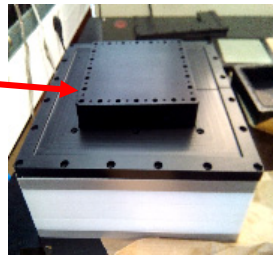
FAST

- Recoil protons produced by neutrons in polypropylene
- High flux high energy n's (>0.1 MeV)
- Faster response



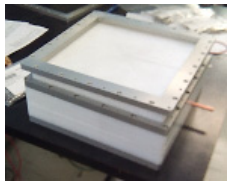
Gas chamber



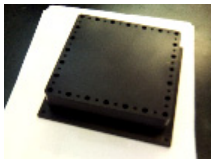


Fast module integrated in the slow

Different thickness of polyethylene can be added



Detector size
~30x30x30cm3
~3kg
Easy to transport



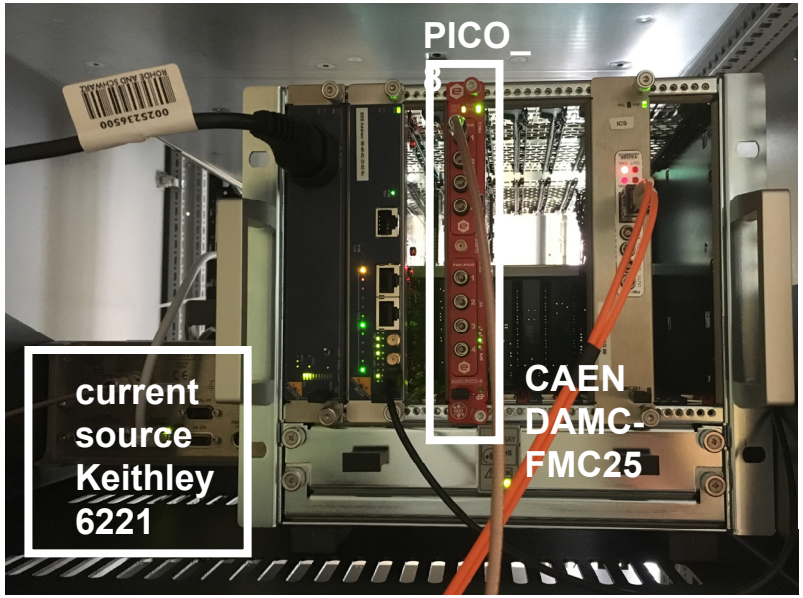
Both can be tested separated

CEA Saclay

Beam Accounting: Ion Chamber Beam Loss Monitors

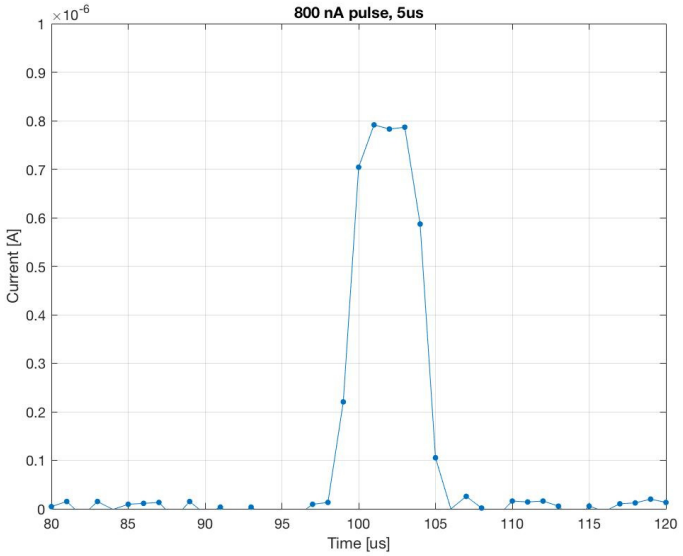
- Prototype electronics: COTS 20 bit current digitizer
- Also evaluating CERN front end plus ESS MTCA readout – decision by end of 2017

See Slava Grishin's poster for details on ion chambers



- Shortest pulse (5 us):

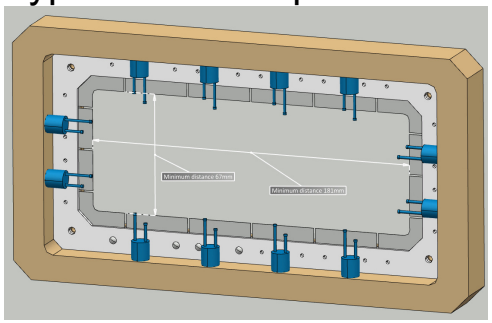
→ 1% of 1 W/m

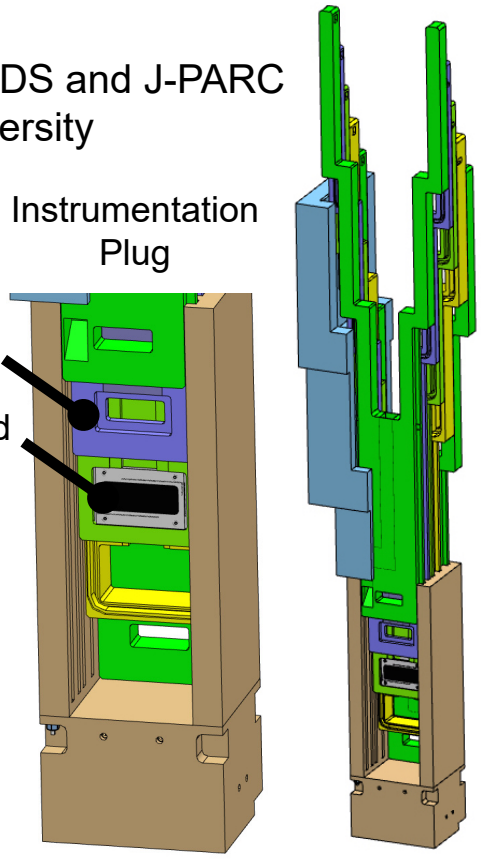


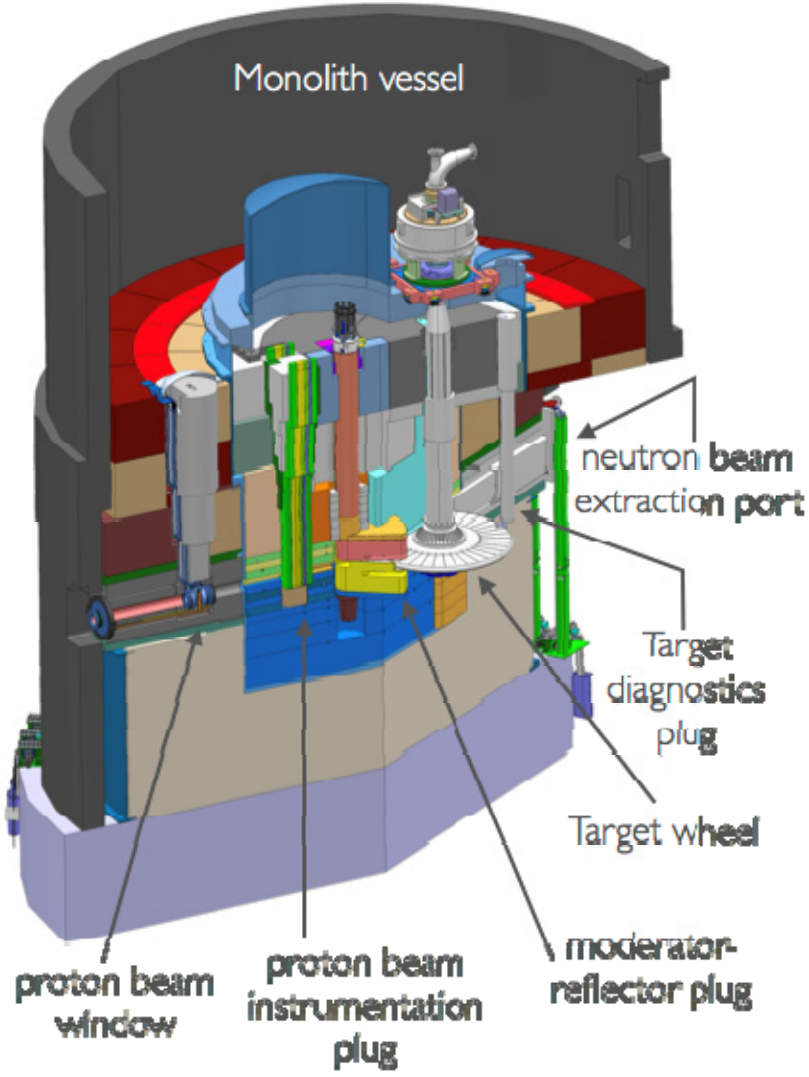
Beam Accounting: Aperture Monitors

Collaboration with C-ADS and J-PARC
Electronics: Lund University

Aperture Monitor concept:
Nickel blades and K-type thermocouples



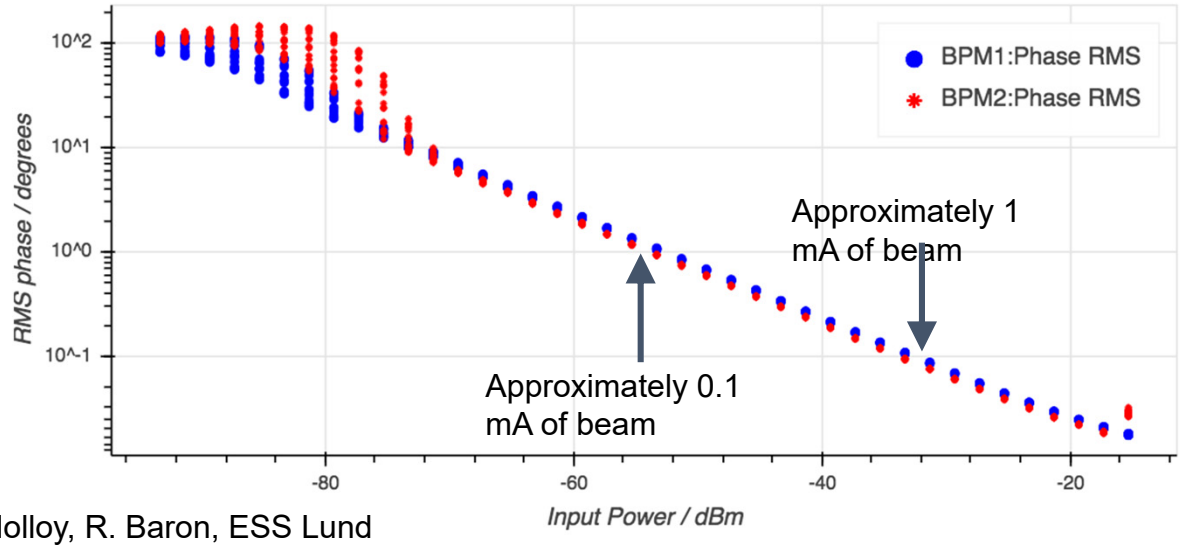




Centroid Measurements: Beam Position and Phase

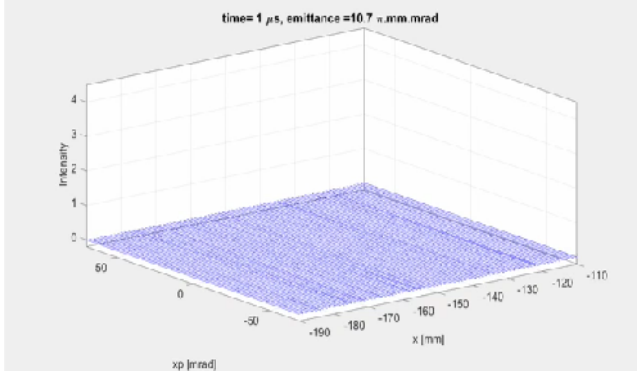
- Centroid is primarily measured by BPM system
  - Focus on phase performance
  - Electronics, non-IQ receiver design coordinated with LLRF team
- Additional systems
  - Profile monitor measures position in LEBT (no RF)
  - Imaging and grid systems measure centroid on target, dump
  - Bunch Shape Monitor also reports phase centroid vs. RF reference

Struck transition module, Digitizer w/Xilinx KU in MTCA
Also, custom RF front end



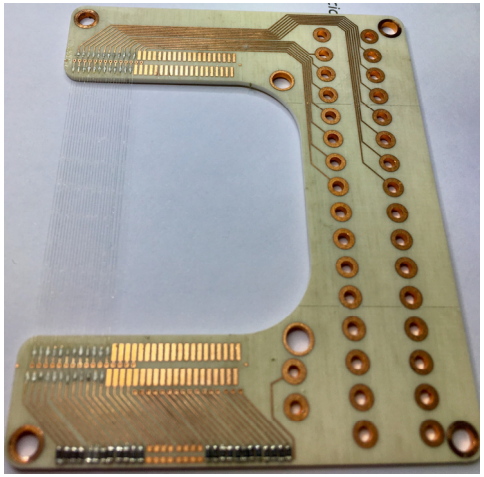
Distribution Measurements: Emittance

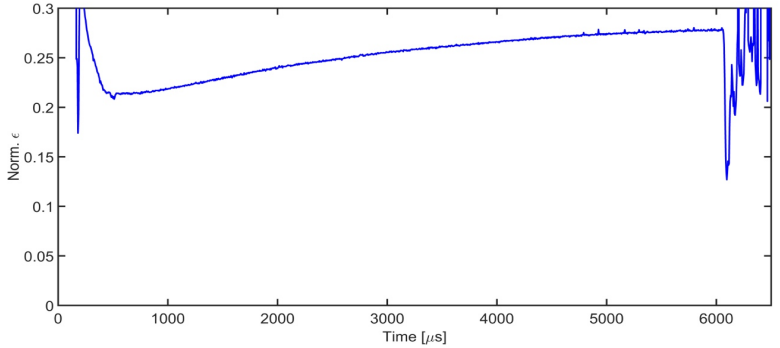
Allison scanner for LEBT constructed by CEA Saclay; making time-resolved emittance measurements at Catania, 75 keV



Slit and Grid emittance device designed and now under construction by ESS Bilbao for 2.5 MeV

Emittance grid prototyping by ESS Bilbao:



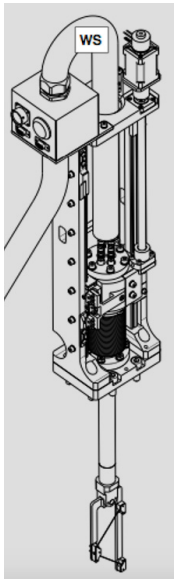


Emittance system lead and analysis: B. Cheymol, ESS Lund

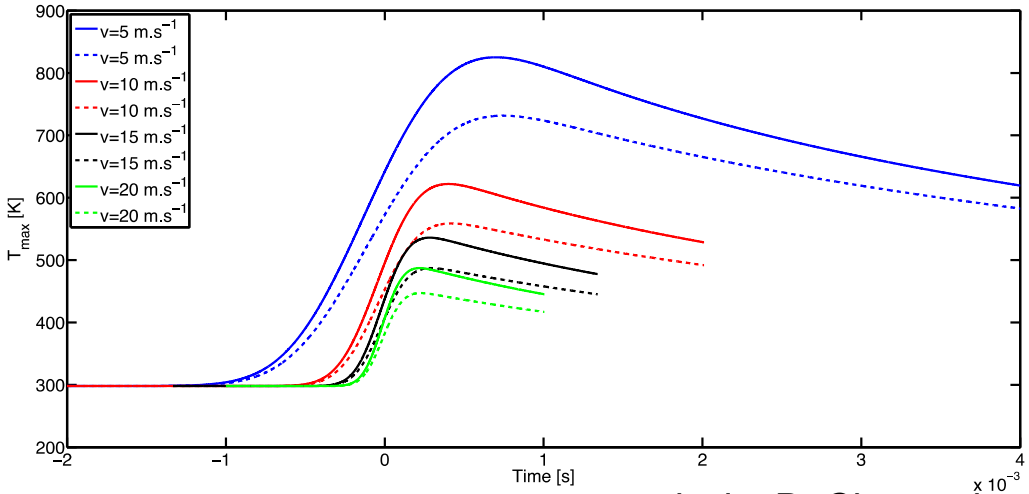
Distribution Measurements: Invasive Profile and Shape

Increasing beam handling capability

Linear wire scanners and Bunch Shape Monitors in MEBT and cold linac

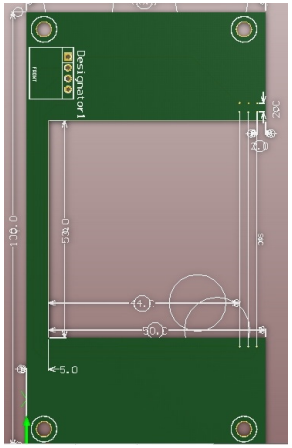


Fast CERN wire scanners in High energy transport line



analysis: B. Cheymol

Multi-wire grid in target station



Prototyping by C-ADS, J-PARC collaboration. Electronics: Lund U

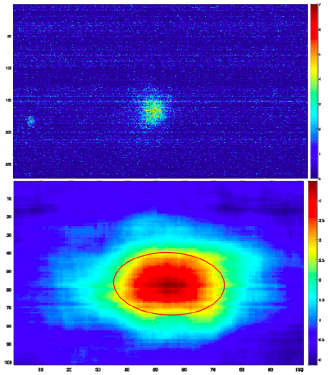
MEBT wire actuator: Bilbao; Cold linac: Århus; Electronics: Trieste; BSM: INR

Distribution Measurements: Non-Invasive Profile

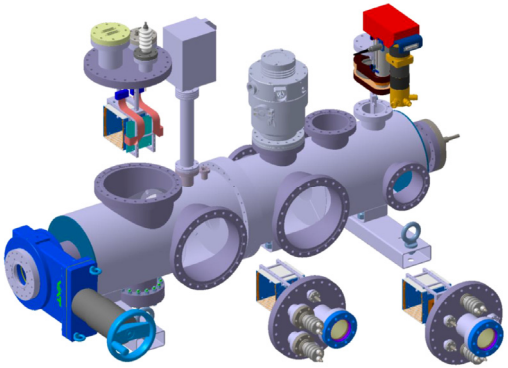
Beam induced fluorescence
for warm linac and transport lines

- LEBT device nstalled @Catania
- Prototype for high energy bench tested
- ESS Lund development

3000 photons / 100x100 px



Prototypes to be assemble and tested at IPHI (CEA Saclay)



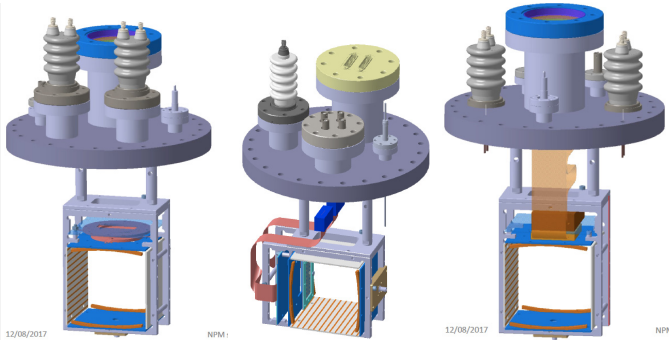
NPM system lead: C. Thomas, ESS Lund

Ionization Profile Monitor for Cold Linac (CEA Saclay)

- 3 readouts to be tested
- CEA Saclay development

MCP+scintillator

TimePix3

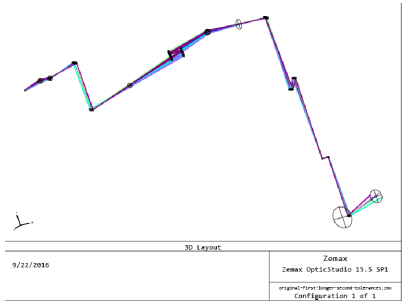


MCP
+ conducting strips

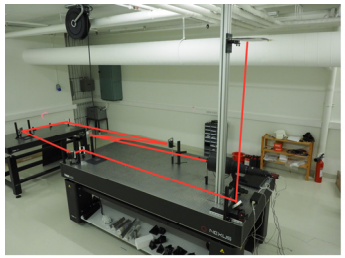
CEA project leader: J. Marroncle

Distribution Measurements: Imaging Systems for the Target, Dump

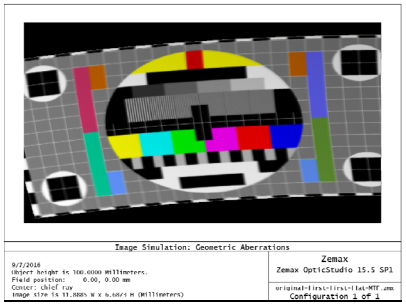
Optics Development



Target Design (simpler for dump)

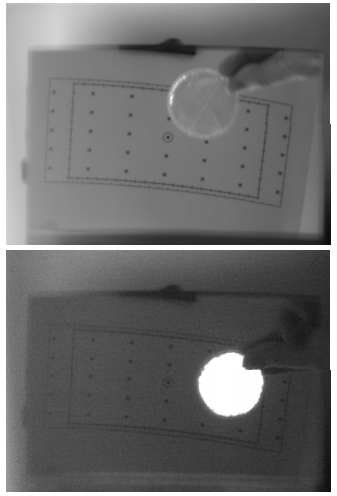


Prototype @Oslo



Zmax results

Retroreflector for the fiducials

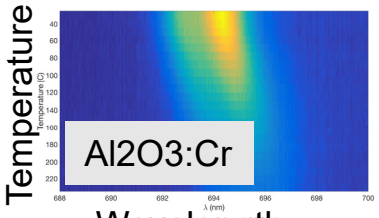


In-kind partner: U Oslo; for ESS: Accelerator and Target Divisions; Dump Optics/Fluka: Cockroft Institute

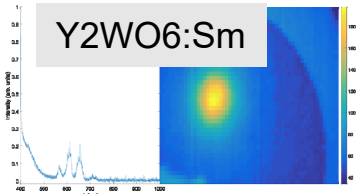
Luminescent Material Development

- Spectrum
- Yield
- Decay time
- Temp, Radiation Tolerance

Baseline

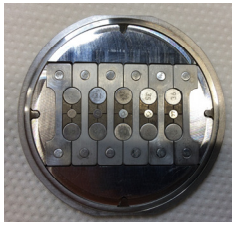


Several alternatives



Spectrum, Yield

Irradiation tests:



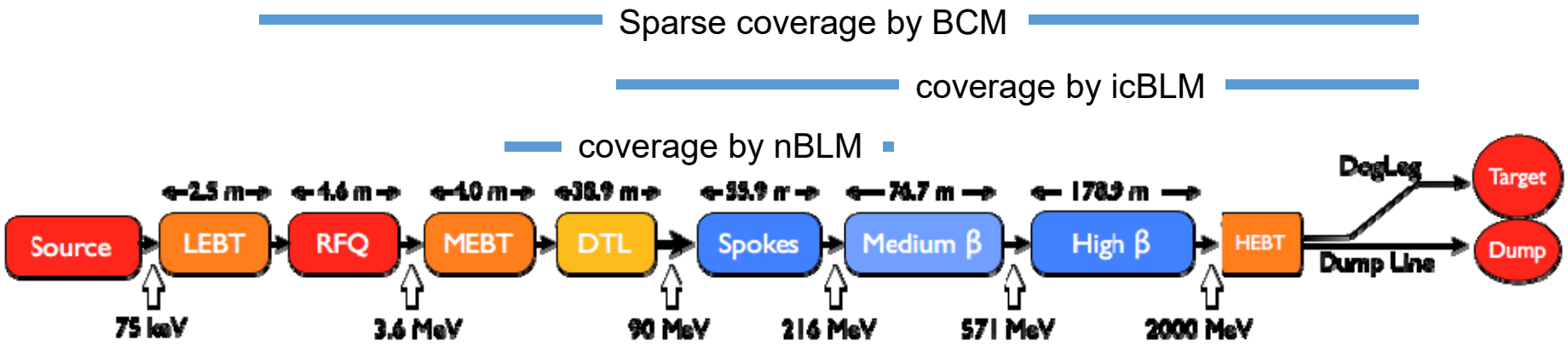
Capsule @BNL
Also @DTU

Additional Development

- Beam tests: @ORNL, LANL, Oslo, CERN
- XRD, XANES / XAS,TEM
- Coating technology: HV, Stony Brook

Protection: from Beam Loss

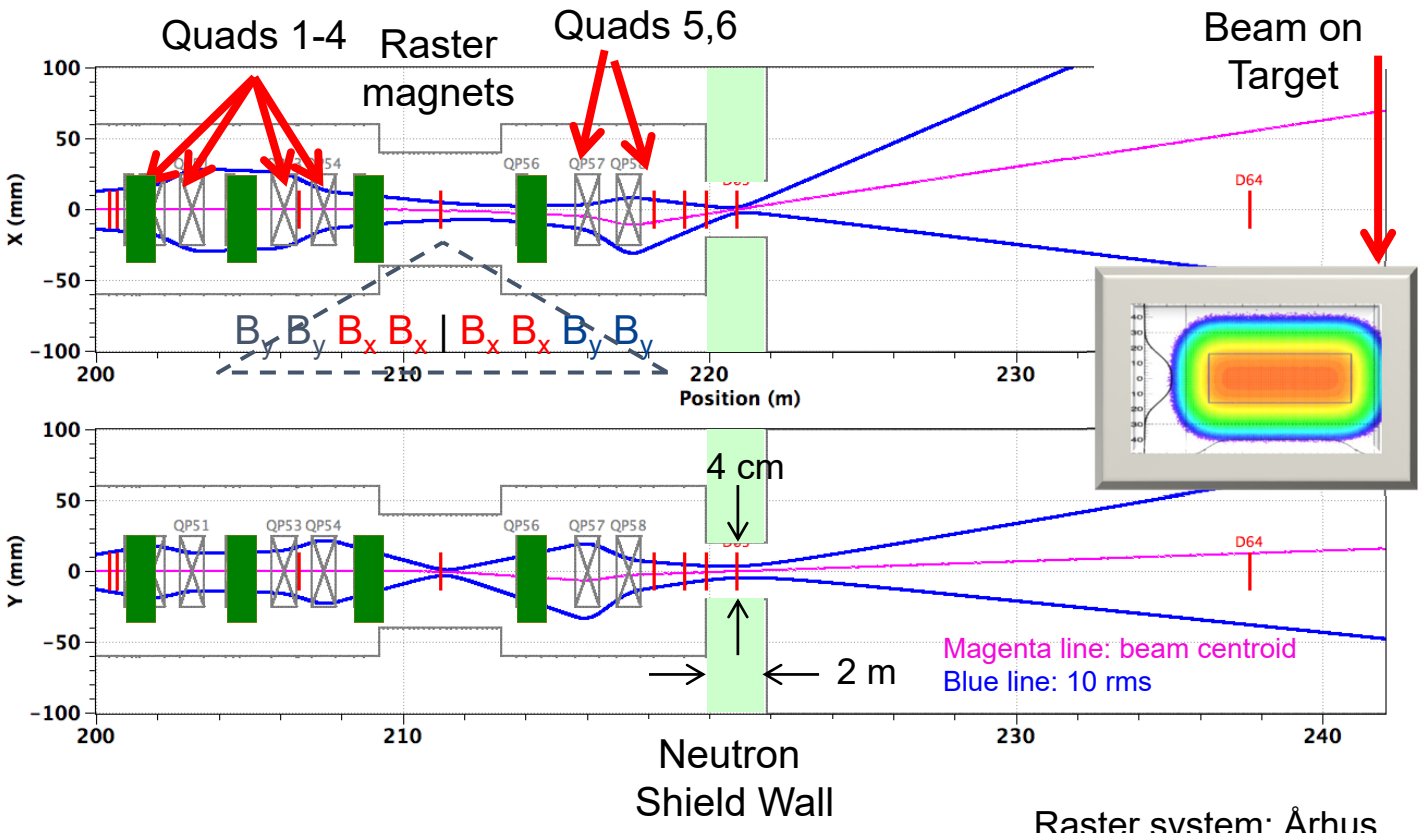
- Total beam loss, ~μs measurement latency required for protection
  - BCM, icBLM (saturation, nBLM (current mode) -> Interlock; Threshold/derivative term for fast protection
- > 1.6 mA lost for up to 200 μs
  - BCM, icBLM, nBLM -> Interlock; Damage model for protection
- ~ μC lost over 200 μs to ~ seconds (diffusion time)
  - icBLM, nBLM -> Interlock; Damage model for protection
- ~ W/m dose management
  - icBLM, nBLM -> alarm based on dose/activation plan



Protection: from Damaging Beam Conditions @Target/Dump

Candidate interlock inputs

- BPM (target)
- Aperture
- Grid
- Imaging



Raster system: Århus

Outlook

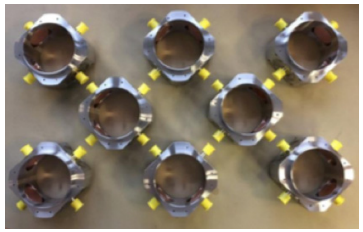
2017
- Transitioning from Design phase to Production/Deployment phase
- Install Ion Source and LEBT diagnostics

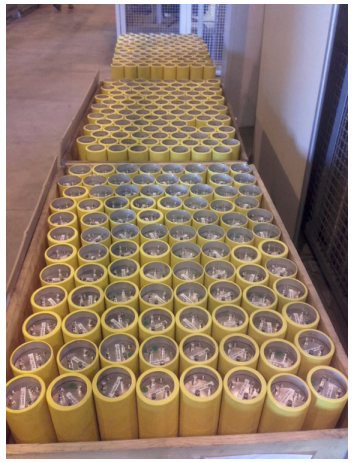
2018
- Ramp up linac diagnostics installation
- Continue design and R&D activities in parallel

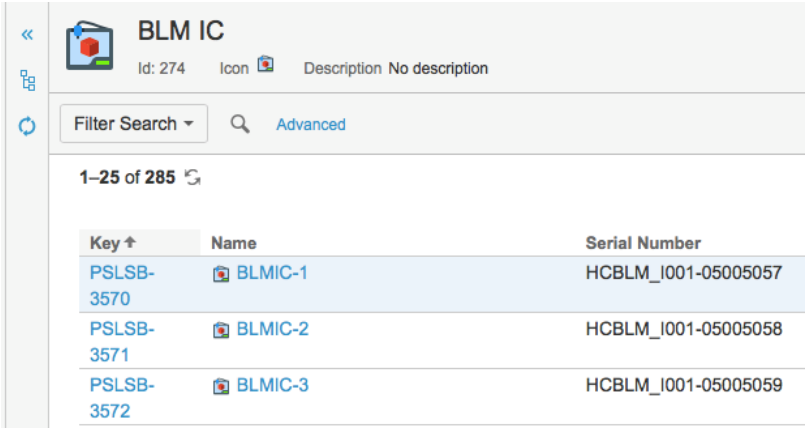
2019
- Begin commissioning at scale

2020 to mid-2020s
- Ramp to full performance
- Continue instrument construction

Supply chain metrics:
- 500 Systems
- 10,000 managed units
- Constructed by over a dozen institutes







ESS Progress - Buildings

ESS Progress - Buildings

ESS Progress - Buildings

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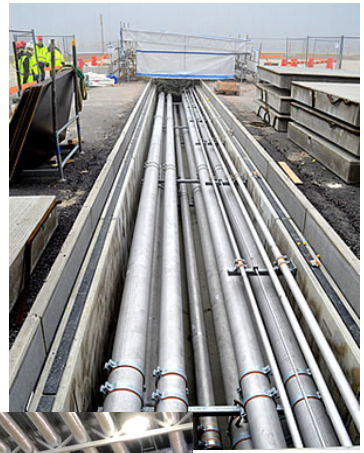
ESS Progress - Buildings

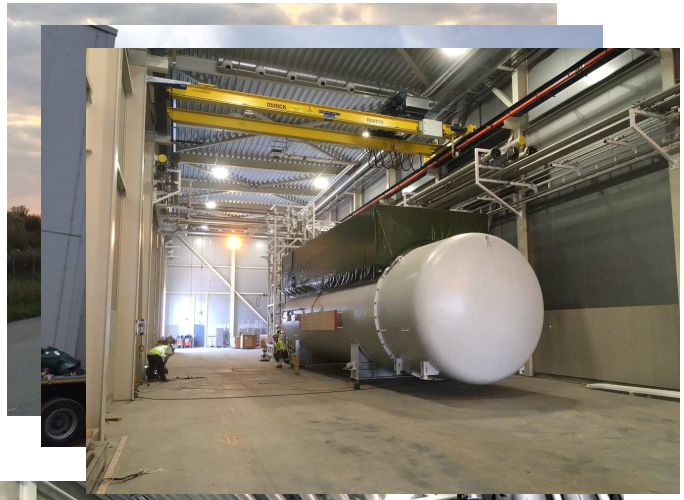
ESS Equipment



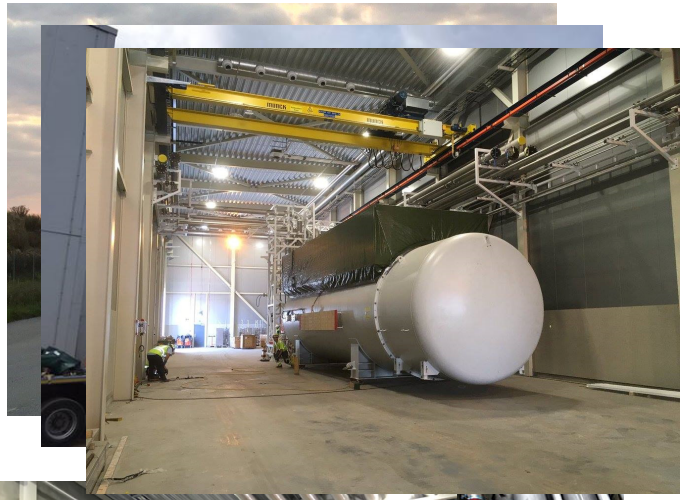
ESS Equipment

ESS Equipment

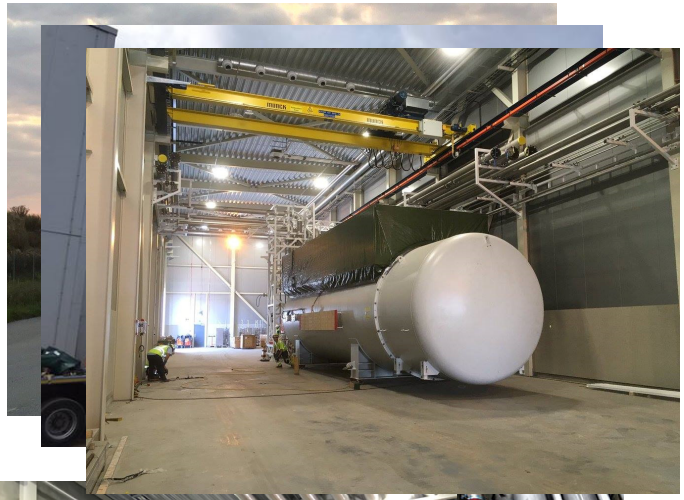
ESS Equipment

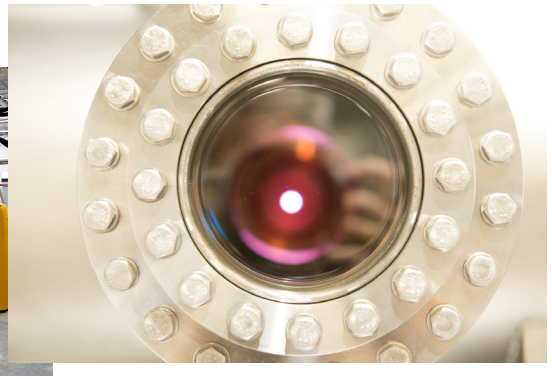


ESS Equipment



ESS Equipment





Thank you

Yes, we still need talented instrumentalists and technicians in Sweden: thomas.shea@esss.se