Design of CSNS-II MEBT Beam Instrumentation

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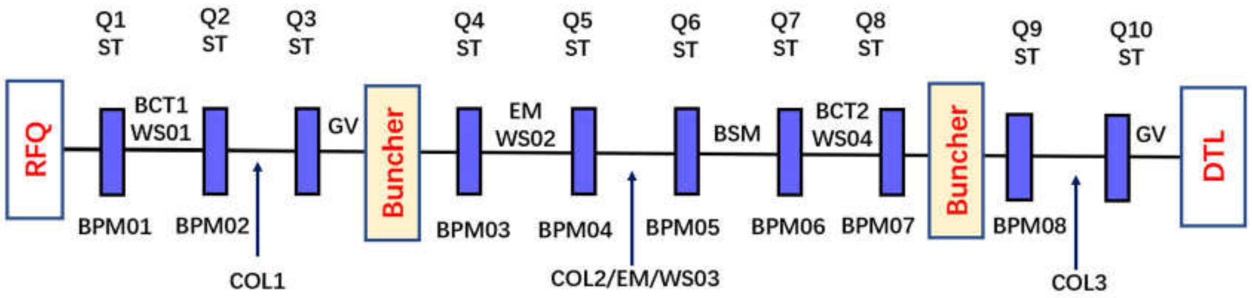
On behalf of MEBT Beam Instrumentation workgroup

Acknowledge to mechanical, beam physics, control, and survey & alignment groups

05/11/2025

- **Overview**
- Beam position monitor （BPM）
- Beam current monitor （BCT）
- Emittancemeter + profile monitor （EM&PM）

物理需求



四、　　束测元件

类型	数量	用途
CT	2	测量流强
BPM	8	1、测量束流相位 2、测量束流横向位置
丝靶	4	束流横向剖面测量
BSM	1	束流纵向剖面测量
发射度仪	1	测量束流横向相空间分布
垃圾桶	1	拦截束流
BLM	3	测量束损

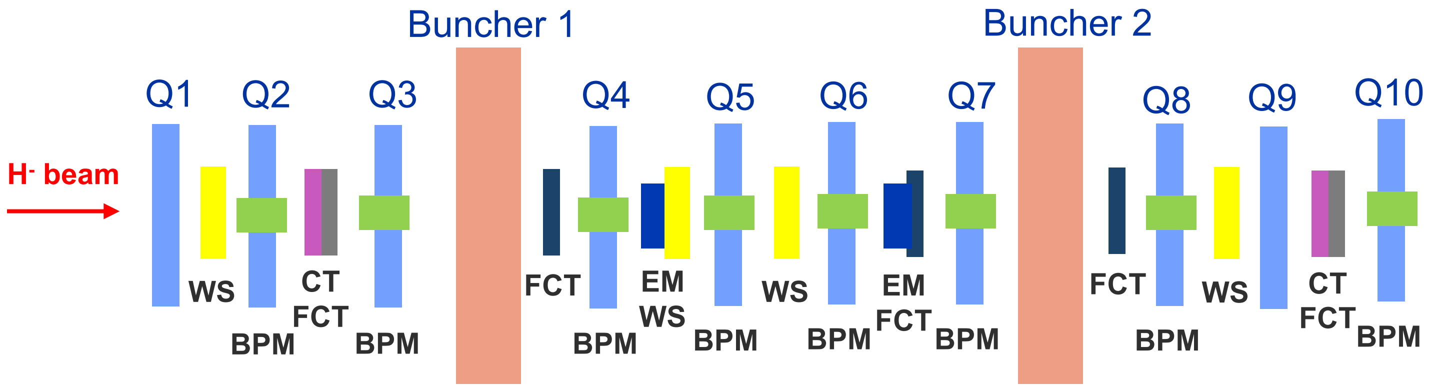
预留位置、方案设计中

集成在COL3

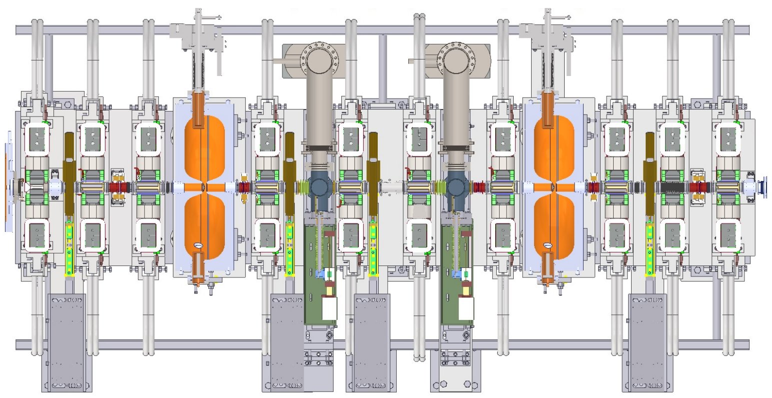
*束测设备在束线上的具体位置未知

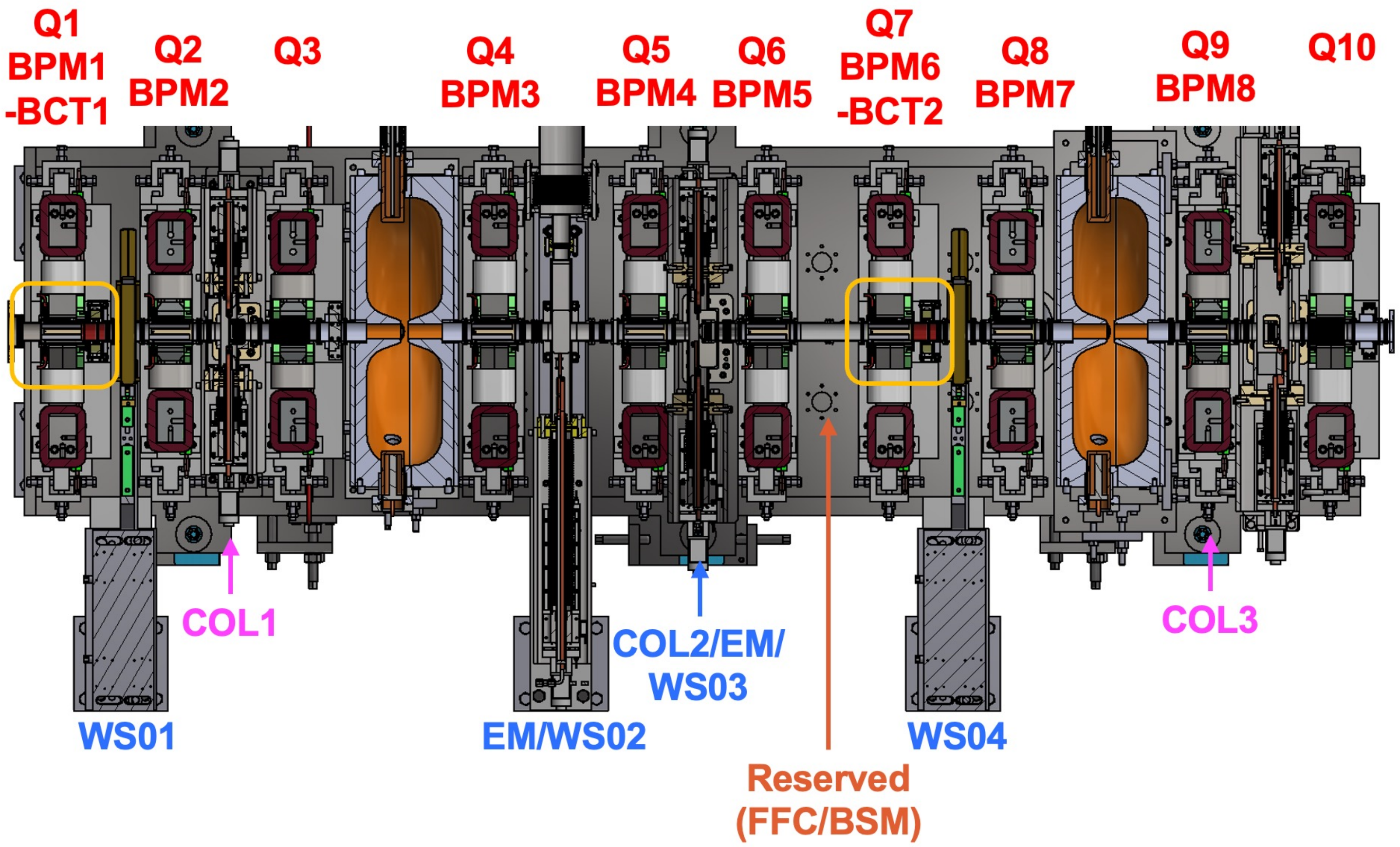
Current MEBT beam diagnostics

Name	No.	Functions	Features
EM	1	Transverse phase-space distributions; emittance and Twiss parameters	Slit-slit/FC scheme, slit widths=0.2 mm, drift distance=0.54 m, BW=30 kHz
BPM	7	Beam central position	BPM inside quad.; Commercial electronics
CT/FCT	2/5	Current/transmission; phase/beam energy	Commercial FCT (Bergoz), customized FCT electronics
WS	4	Beam profile/emittance and Twiss parameters	d33 µm CF wire，x, y & 45 deg



Top View





Q1
BPM1
-BCT1
Q2
BPM2
Q3
Q4
BPM3
Q5
BPM4
Q6
BPM5
Q7
BPM6
-BCT2
Q8
BPM7
Q9
BPM8
Q10
COL1
COL2/EM/
WS03
COL3
WS01
EM/WS02
WS04
Reserved
(FFC/BSM)

CSNS-II MEBT beam diagnostics

Name	No.	Requirements	Features	Budget
BPM	8	Position resolution <0.2%*R, accuracy ±0.1 mm[2]; phase resolution 0.2°@324 MHz, accuracy ±1°@324 MHz[3]	BPM embedded in quad. poles (8 new BPM+1 LIBERA electronics)	85 W
CT	2	Range: 1-50 mA Linearity: ±0.5% Droop: ≤1% Risetime: ≤10 μs	BPM-BCT welded together	20 W
EM	1	Max. beam power: 50 mA*20 μs Accuracy: ~10% @0.2-0.3 mm.mrad[1] Min. time-consuming: <10 mins	Slit-wire configuration, integrated with collimator (COL2) and WS02, WS03, 4 wires for beamlet (4X faster)	50 W
WS	4	Scan range: ±R Resolution: ≤0.2 mm Positioning repeatability: ≤0.5 mm	d100 μm CNT wire, x&y (new WS01/WS04)	48 W

Total: 203 W

[1] in simulation
[2] in lab. (wrt. geometric center)
[3] abs. reference and beam are required, I don't know how to calibrate, for the moment

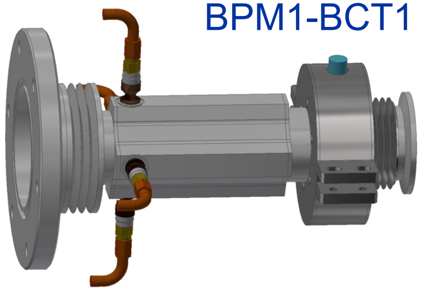
- Overview
- **Beam position monitor（BPM)**
- Beam current monitor（BCT)
- Emittancemeter+profile monitor（EM&PM)

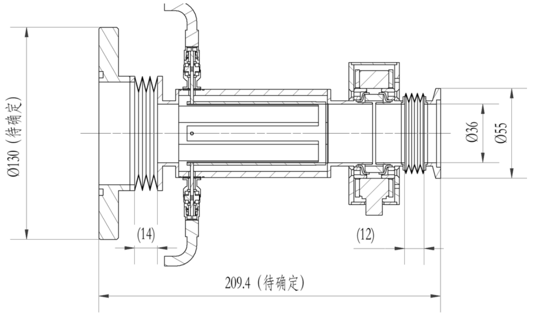
Beam position monitor

Requirements

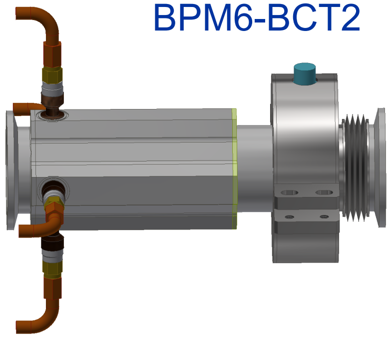
- Two BPMs welded together with the BCT (BPM1-CT1)
- Six BPMs with extra bellow or modified geometry size for installation
- BPM attached to the quad. via a mechanical clamp aiming for a position error of ~0.2 mm (xyz, design)
- Specifications of BPM
  - Range: ≤±R/2
  - Position resolution: R*0.2%@20-40 mA (R=18 mm)
  - Position accuracy: ±0.1 mm (in lab.)
  - Phase resolution: 0.2°@324 MHz
  - Phase accuracy: ±1°@324 MHz (nominally)

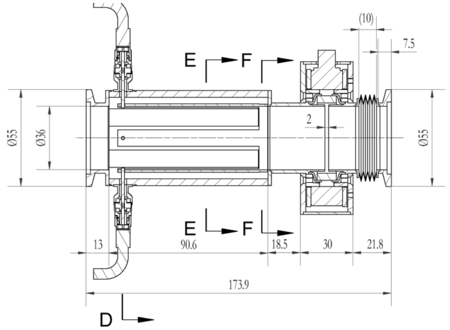
BPM1-BCT1





BPM6-BCT2





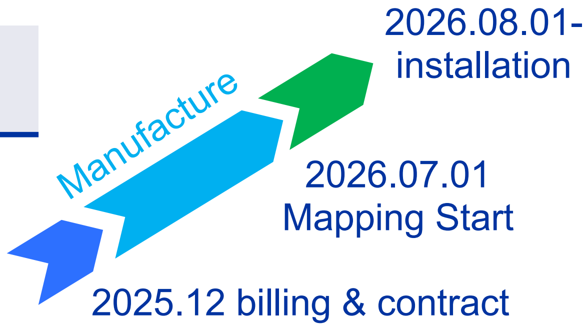
Courtesy: M. Rehman, Xiaojun Nie

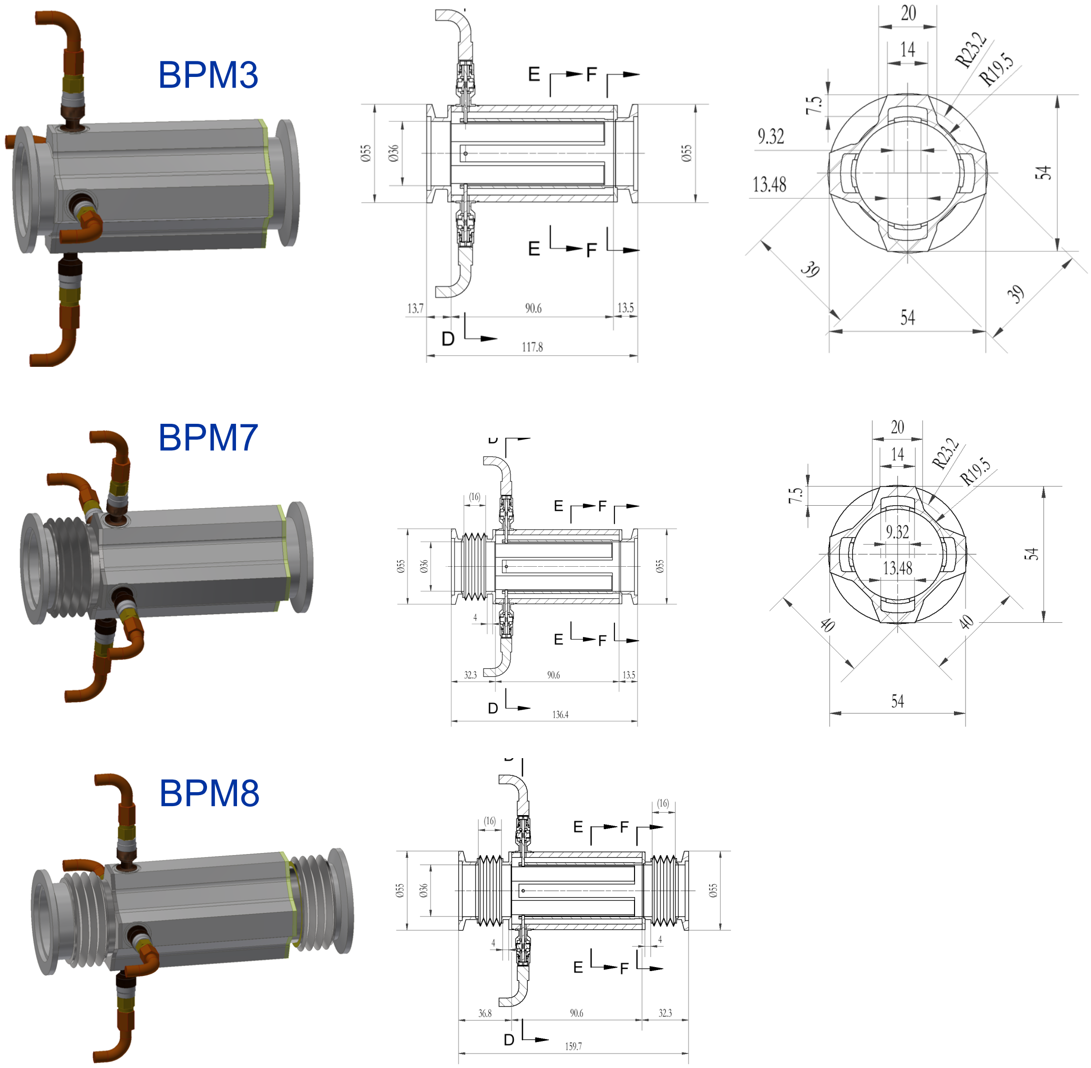
Beam position monitor

- BPM2-BPM5: optimized length adapting the overall arrangement, and the updated outline dimensions (to fix BPM sensor to quad.), old fraught mapping results for the current BPMs (simulation results used)
- BPM7: append bellow to the entrance
- BPM8: append bellows to the both sides
- Maruwa SMA feedthru provided by CSNS

Total cost: 85 W

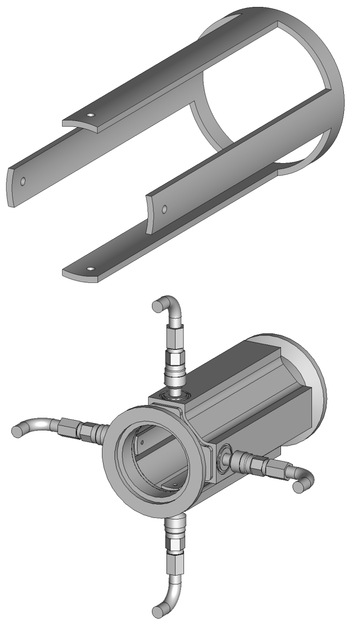
	Cost (W)
BPM bodies	4*8=32
Coax. cable + connector	3
Electronics, cable & connector	50





Beam position monitor

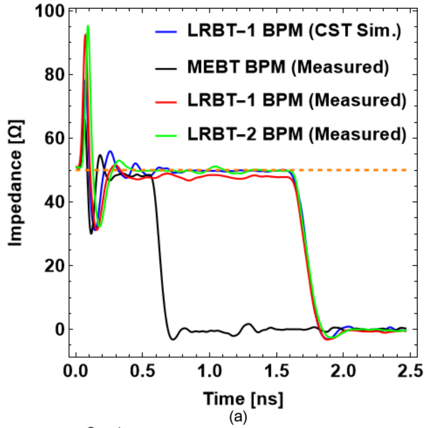
- We plan to re-use the shorted stripline BPM design with necessary modifications of the outer duct
- The resolution of position measurement is <50 µm (experiment w/ beam) and, the position accuracy excluding alignment errors is ~150 µm (<±R/2)

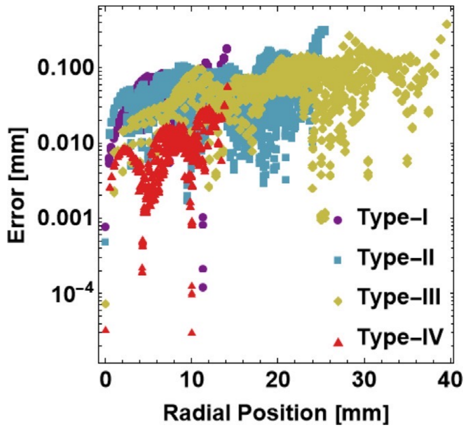


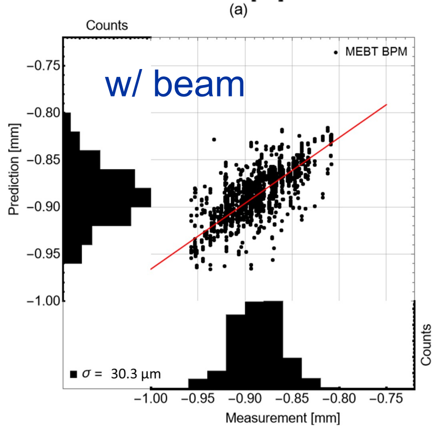
Courtesy: M. Rehman

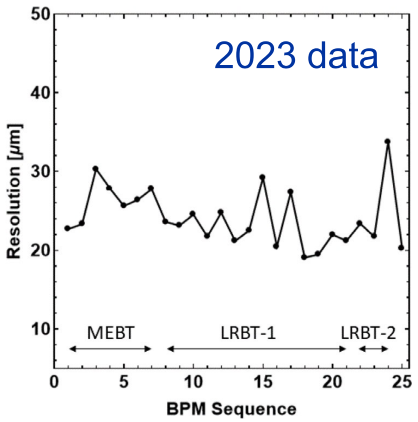
Parameters of CSNS MEBT BPM

	BPM
Inner aperture (mm)	36
Electrode length (mm)	77.6
Electrode opening angle (deg)	29.65
Electrode thickness (mm)	1.5
Gap between electrode and wall	1.5/3 (trans./longi.)
Characteristic impedance (Ω)	50 (design) 48 (meas.)
Relative permeability	<1.05









Electronics & Phase measurement

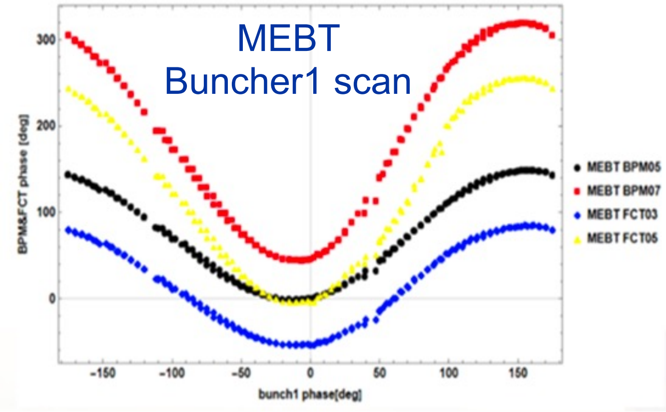
- Option 1#: Reuse the Bergoz LR module (4 pcs) + New Libera SP electronics modules
- Option 2#: Update to Libera SP (position & phase) + Libera Spark (position)*4
- We have compared the phase measurement employing FCT and BPM this year. The methods are validated while the difference are to be understood

FCT electronics at CSNS

Libera single-pass

Price: ~48 W RMB (4 BPMs)

	FCT-based	BPM-based
Frequency (MHz)	324	324 & 648
Input range (Vpp)	0.02~0.45	2
ADC clock frequency (MHz)	$f_b/3$	$f_b/3$
Resolution	0.1°	0.1°
Accuracy (in lab.)	±0.3°	-



Influence of chopper

Probe	WO-Chopping	W-Chopping	Δ
BPM01	160.63° ± 0.10	161.04° ± 0.08	0.25 %
BPM04	92.02° ± 0.14	92.25° ± 0.10	3.3 %
BPM05	222.14° ± 0.16	226.23° ± 0.19	1.8 %
BPM07	147.68° ± 0.40	149.53° ± 0.25	1.2 %
FCT03	158.45° ± 0.15	153.9° ± 0.12	2.9 %
FCT05	42.18° ± 0.24	39.05° ± 0.35	7.9 %

Beam energy measurment

Probe	FCT	BPM
Location	3 and 5	5 and 7
D [m]	0.85378	0.896
N	11	12
Phase [°]	42.98 and 156.81	91.24 and 160.25
T [ns]	3.086	3.086
Offset [°]	178.566 and -140.946	144.92 and 144.92
Energy [MeV]	3.093	2.988

[1] F. Li et al., IBIC2024, THP04 (2024)

- Overview
- Beam position monitor (BPM)
- **Beam current monitor (BCT)**
- Emittancemeter + profile monitor (EM&PM)

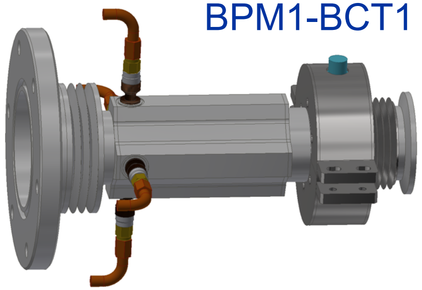
Beam current monitor

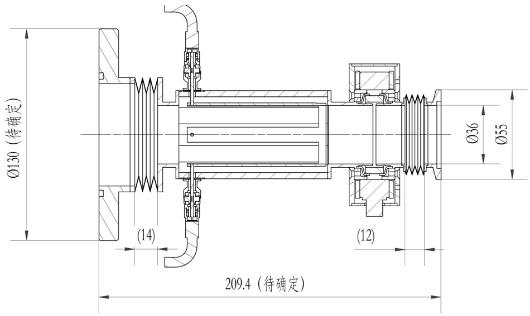
- Two CTs at the entrance and middle of the MEBT section (exits of Q1 & Q6)
- BPM1-BCT1 & BPM6-BCT2 welded together; update PXIe digitizer to customized 20 MSa/s digitizer card to satisfy the diag. at 20 μs pulse width

Key specifications

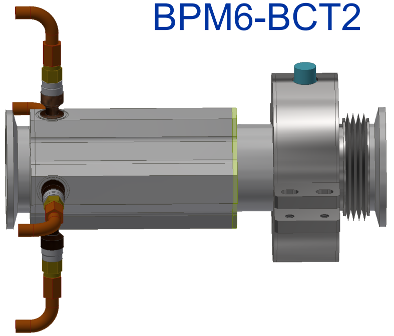
Range	±1 mA~± 50 mA
Risetime	< 10 μs
Droop	≤1%/ms
Linearity	≤±1% FS
Output voltage	±10V
Inner aperture	36 mm
Length	214 mm & 54 mm
Inductance of torus (required)	>0.4 H
Inductance of torus (measured)	1.3 H@10 Hz 3.0 H@50 Hz
Magnetic shield efficiency	~1076 (permalloy 1J85)

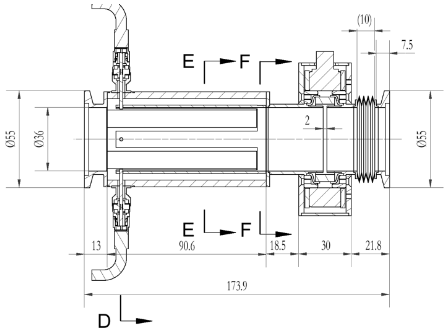
BPM1-BCT1





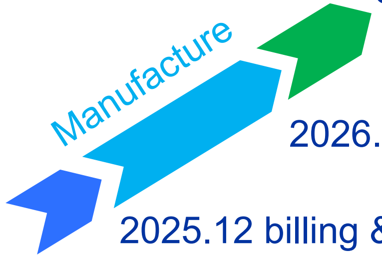
BPM6-BCT2





Total cost: 20 W

	Cost (W)
Torus (Bergoz)	8
Manufacture & support	2
Electronics+Digitizer (20 MSa/s, 16 bit)	10



2026.07-09 calibration & installation

2026.6 arrive CSNS

2025.12 billing & contract

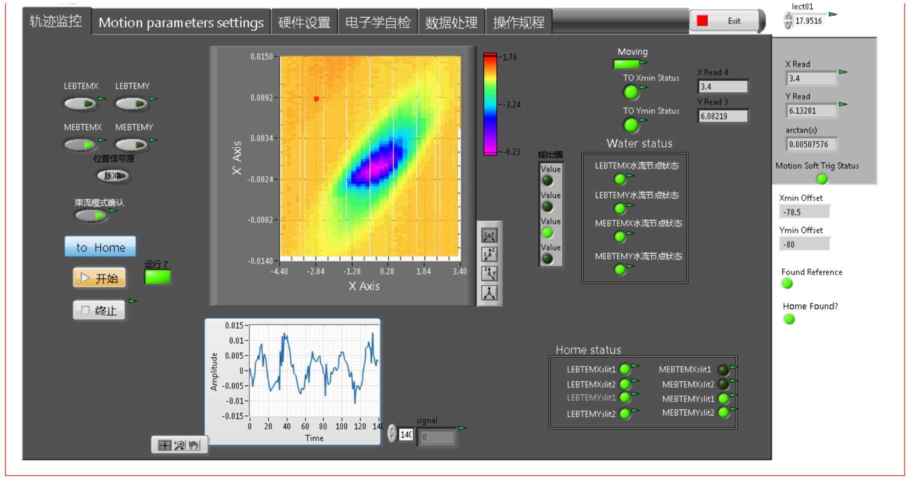
2025.11 design & review

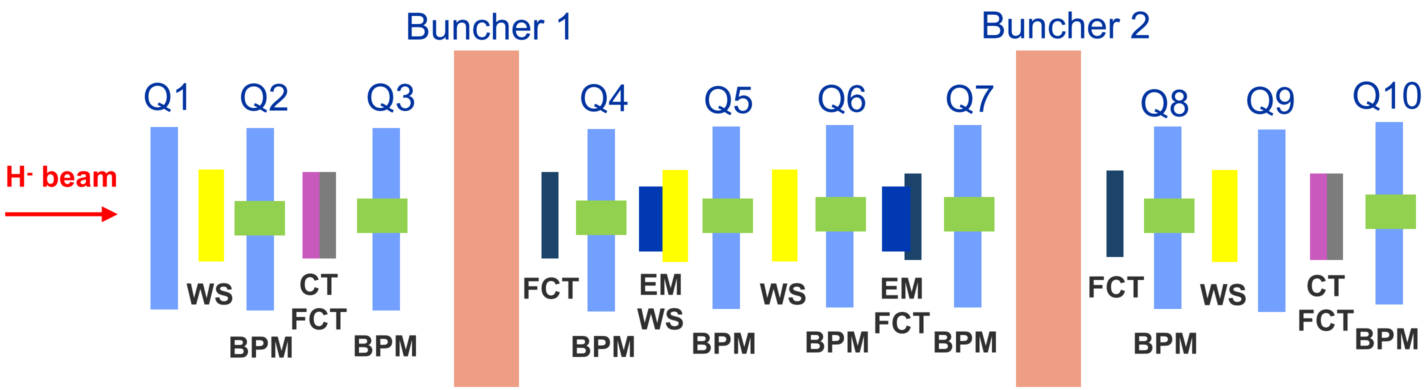
Courtesy: Weiling Huang

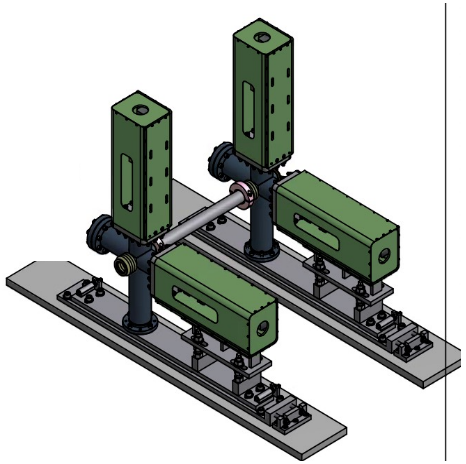
- Overview
- Beam position monitor (BPM)
- Beam current monitor (BCT)
- **Emittancemeter + profile monitor (EM&PM)**

The current EM at CSNS MEBT

- Slit-Slit/FC configuration w/ slit widths=0.2 mm, slit thickness= 0.5 mm, slit-slit distance=0.54 m,
- Slit and FC collection plate materials are tungsten and copper, respectively
- Analog electronics: trans. impedance=35 kV/A, BW~30 kHz, Equ. noise level <100 pC
- w/ water cooling to the front slit plate (d=4 mm, flow rate~3 m/s), but the tungsten slit mask is not brazed to frame
- Offline emittance determination by threshold analysis





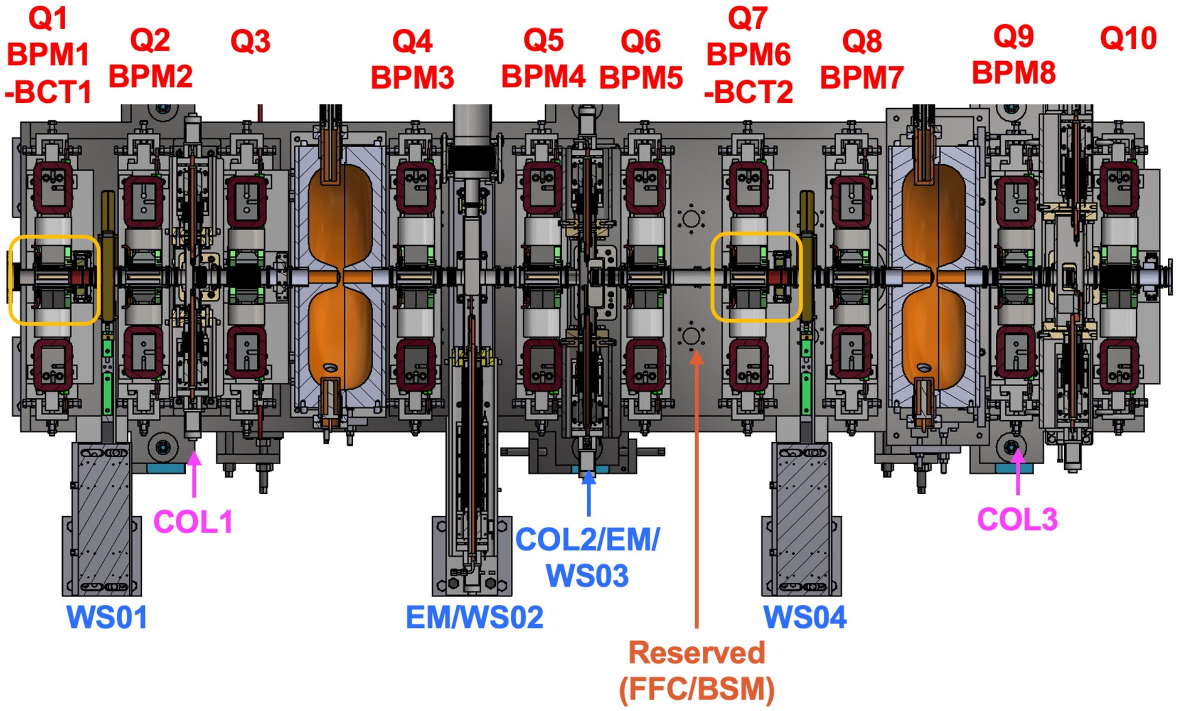


Requirements & design considerations

- **Requirements**
  - Accuracy: 10%@0.2-0.3 mm.mrad
  - Measurement time: <10 min
  - Max. beam power: >50 mA*20 μs
  - No significant vacuum drop during measurement
- Slit width $w \ll \sigma_x$→ w<0.2 mm (σ_x≥1 mm), for instance
- Slit thickness higher than the project range in material
  → A min. thickness>0.2 mm for C/Cu/SS/W…
- Slit acceptance > rms. beam divergence
- Beam size at the beamlet profile monitor <R/5≈3.6 mm
  For beam divergence $\sigma_{x\prime}$~2 mrad, $\sigma_{x\prime} L < 3.6$ mm → L <1.8 m
- Beamlet size at the PM location $\sigma_x(L) > 3w$ (naïve!!). For $w = 0.1 \sim 0.2$ mm, $\sigma_{x\prime}$~2 mrad → L>0.15~0.3 mm
- ~% emittance error due to space charge
- Good SNR of the beamlet visualizations

A compromised design

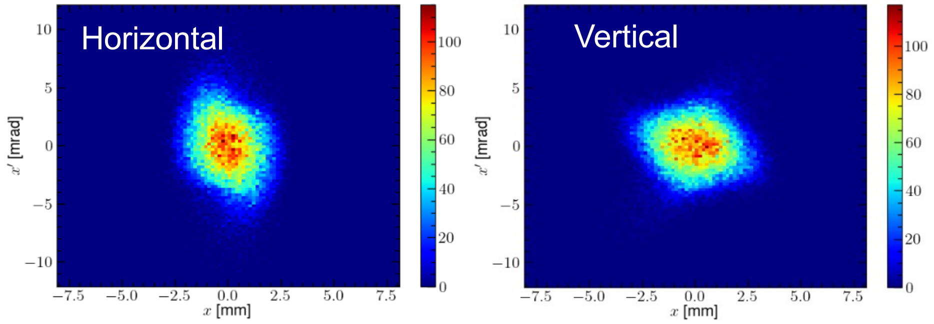
- Two slits integrated with the WS02 and being allocated at Q5-Q6 quad.
- Hor. and Ver. multi-wires (4+4) to image the beamlet distributions (ver. & hor.) at ~0.34 m downstream (Q5 power-off)
- For a σ_x~1 mm → slit width <0.2 mm (reasonable); regarding a σ_x'=2 mrad. → beamlet size>0.6 mm
- Limited by the compact MEBT design, the multi-wires are integrated to the COL2, and will also provide transverse profiles (WS03)



Major beam parameter at Q4 exit

Current [mA]	σ_x [mm]	σ_y [mm]	ε_x [mm.mrad]	ε_y [mm.mrad]
10	0.78	1.48	0.209	0.209
20	0.82	1.37	0.212	0.211
30	0.90	1.33	0.215	0.213
40	1.00	1.33	0.219	0.215
50	1.10	1.35	0.224	0.217

Phase-space distribution at Q4 exit

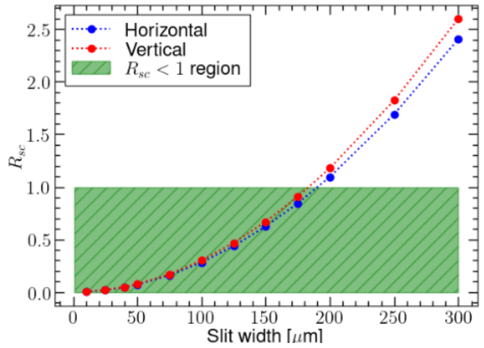


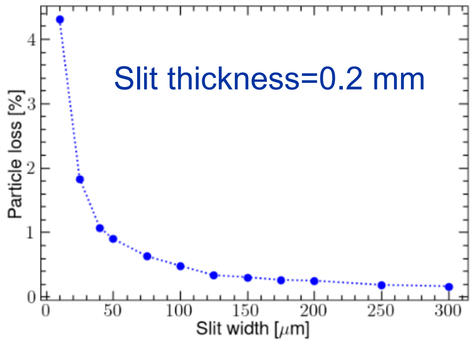
Assessed measurement accuracy

- **Slit width**
  - A slit width <0.2 mm is suggested wrt. the R_{sc} equation

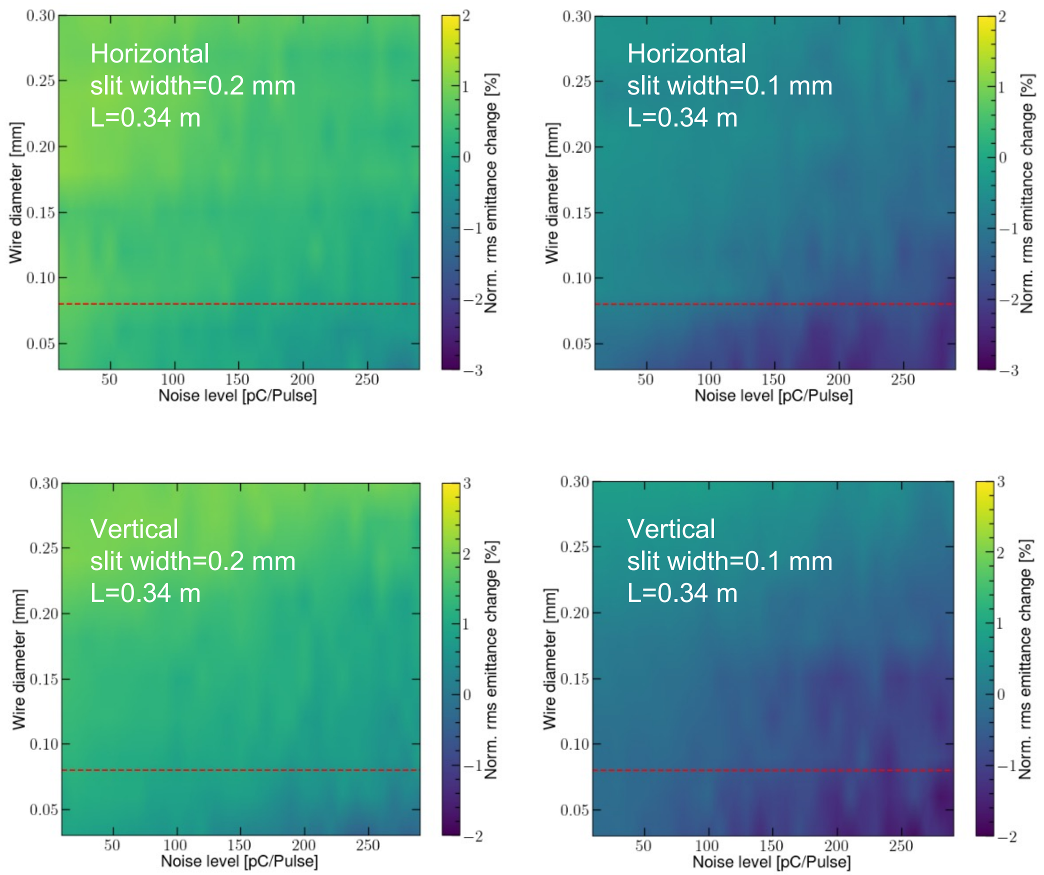
$$R_{sc} = \sqrt{2/3\pi} I/(\gamma I_A)\,(w/\varepsilon_n)^2$$

    where I_A=31 MA and w the slit width
  - Assuming a slit thickness of 0.2 mm, particle loss <1% for a slit width >0.05 mm
- **Wire diameter vs. detection noise**
  - Tracking simulation in ASTRA w/ macro-particle distribution exported from TraceWin
  - Space-charge module benchmarked w/ TraceWin
  - $\Delta\varepsilon_x/\varepsilon_{x0}$<5% and $\Delta\varepsilon_y/\varepsilon_{y0}$<5% for w=0.1~0.2 mm, L=0.34 m and equ. charge noise level<50 pC





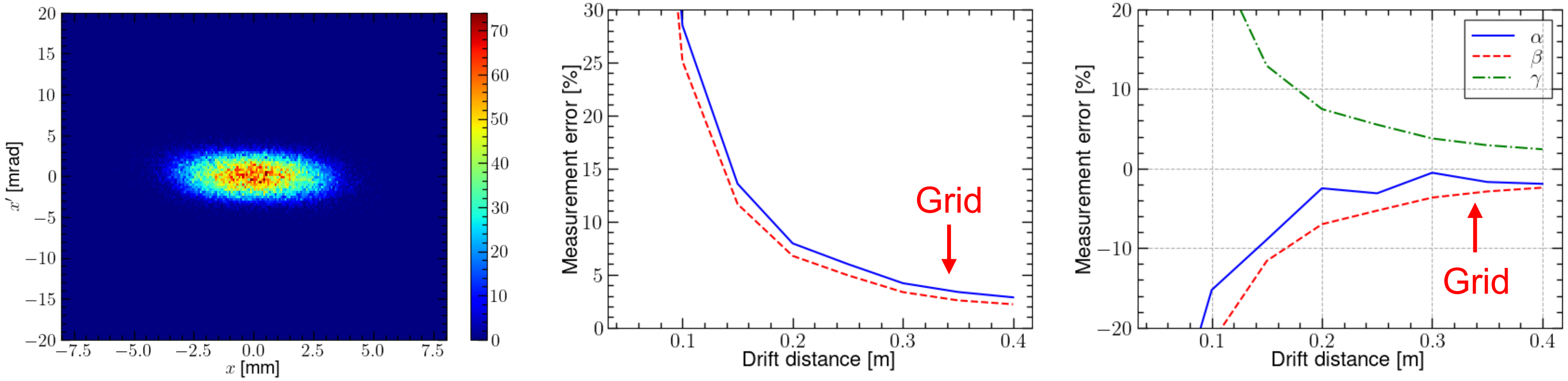
Reconstructed phase-space distributions



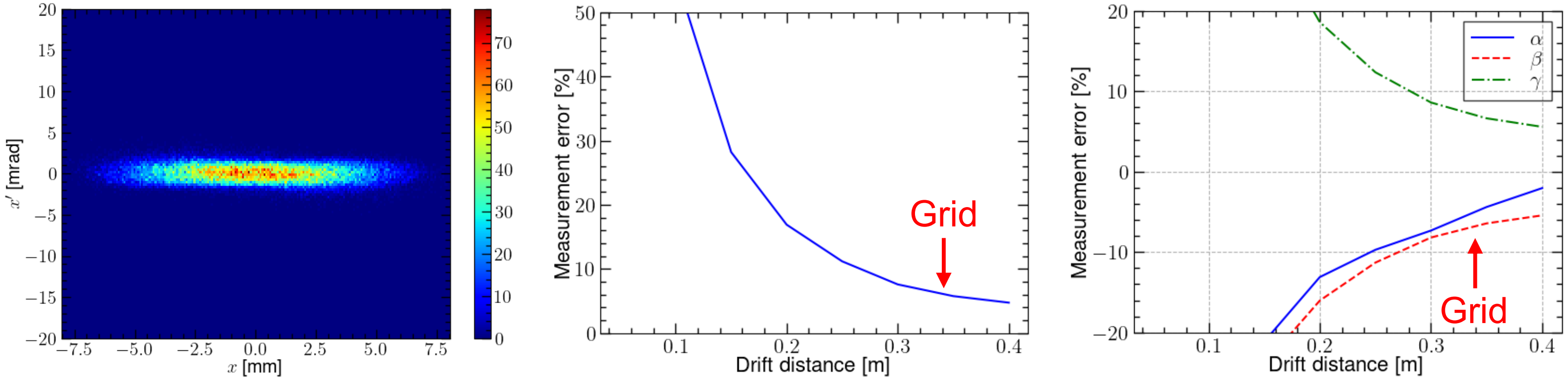
Assessed measurement accuracy

- A rms. spot size of ≤1 mm may melt the slit mask for a high beam power (max. 50 mA*20 μs)
- The spot size at the slit was enlarged to 2-3 mm, and the numerical simulations indicate that the predicted emittance/Twiss-parameter measurement errors are <10% (w/ space charge, w/o dynamic errors)

I=10 mA
ε=0.21 mm.mrad
σ=1.67 mm
β=1.06
$\sqrt{\varepsilon/\beta}$=1.56



I=50 mA
ε=0.23 mm.mrad
σ=2.91 mm
β=2.98
$\sqrt{\varepsilon/\beta}$=0.97

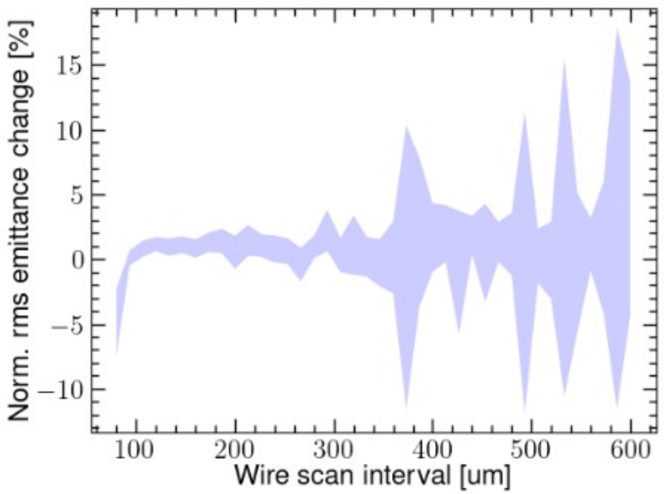


Assessed measurement accuracy

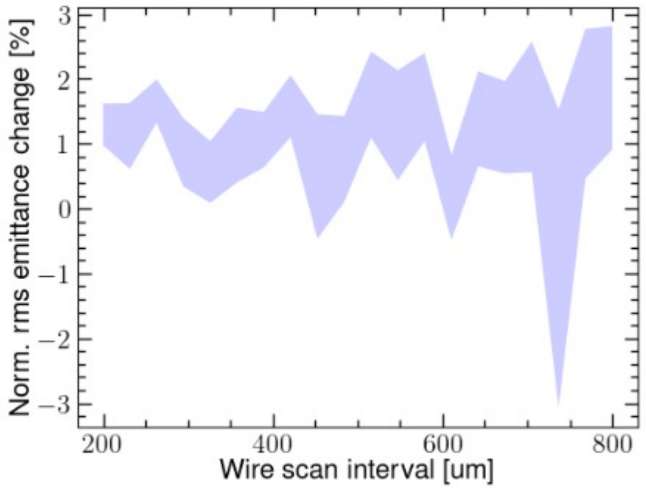
- Beam current=10 mA, slit width=0.2 mm, *L*=0.34 m

=> Grid-scan step length ≤3*d_wire is required to reduce measurement error <10%

Wire diam.=100 μm



Wire diam.=200 μm

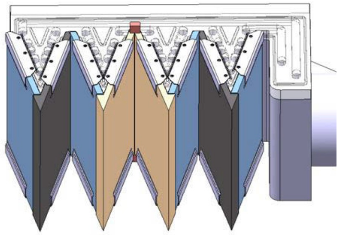


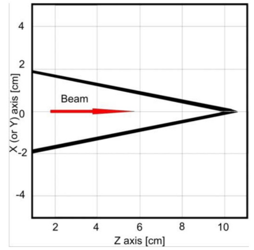
Slit structure & dimensions

Slit structure

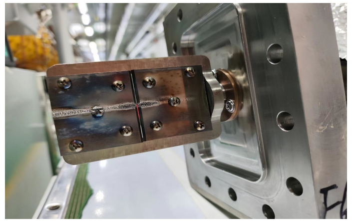
- Carbon materials (Graphite, CFC) have potential outgassing issue
  => tungsten w/ a tilt angle wrt. beam axis?
- d100 μm CNT wire for x/y profile, double-end or floating
- CNT wire clamped to the frame
- Water cooling for the slit mask (diam.=4 mm, 3 m/s)
- Min. scan step length ≥0.1 mm w/ a displacement accuracy≤10 μm
- Two scan modes: WS or EM, max. range>72 mm

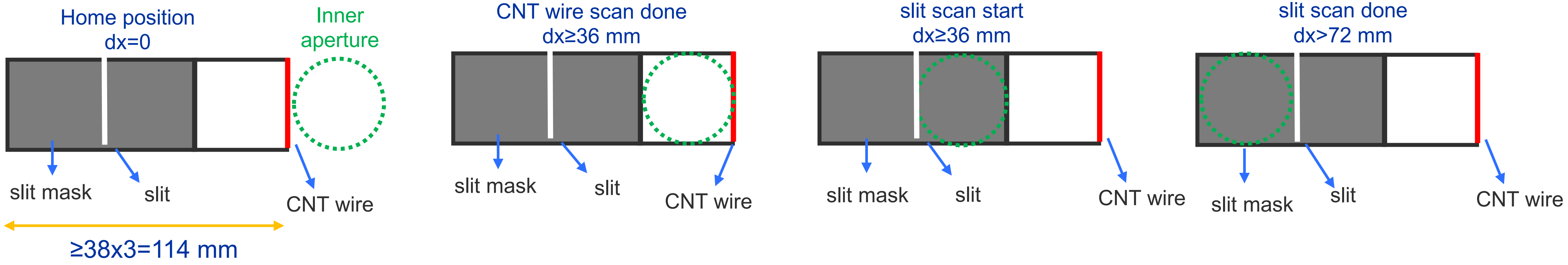
15 deg design @ CERN LINAC4





CSNS design





SEM grid optimizations

Grid structure

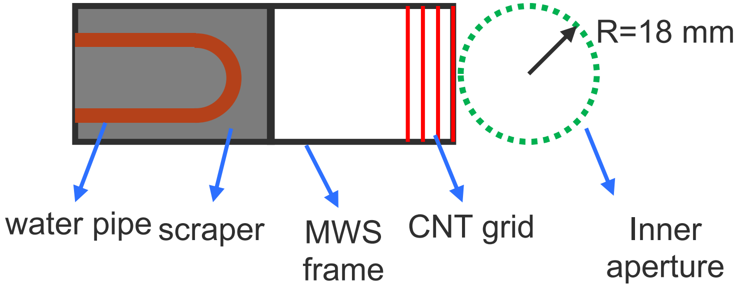
- 4+4 wires as beamlet profilers appended to the hor. & ver. scrapers (head part)
- Adjacent wire spacing ~2 mm, and covering the region of interest by multi-wire scan
- Wire welded/clamped to the frame; biased to 0~+100 V to absorb secondary e-
- Min. scan step length ≥0.1 mm w/ a displacement accuracy≤10 μm
- Full phase-space scan time@1Hz

Slit scan range=20 mm， interval=0.2 mm → 100 beamlets

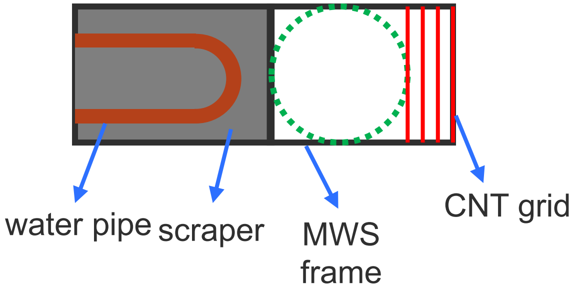
MWS scan range=30 mm → ~8 sec. for every beamlet scan

==> Full scan time<15 mins, and could be reduced to <10 mins for a larger slit or grid scan step

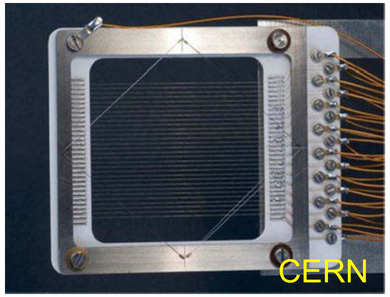
Home position



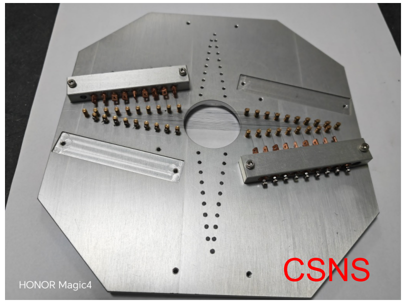
MWS scan done



wire welded to ceramic plate



Clamped to pin connectors



Selection of wire material

Constraints

i. Peak temperature must be lower than the melting or sublimation temperature

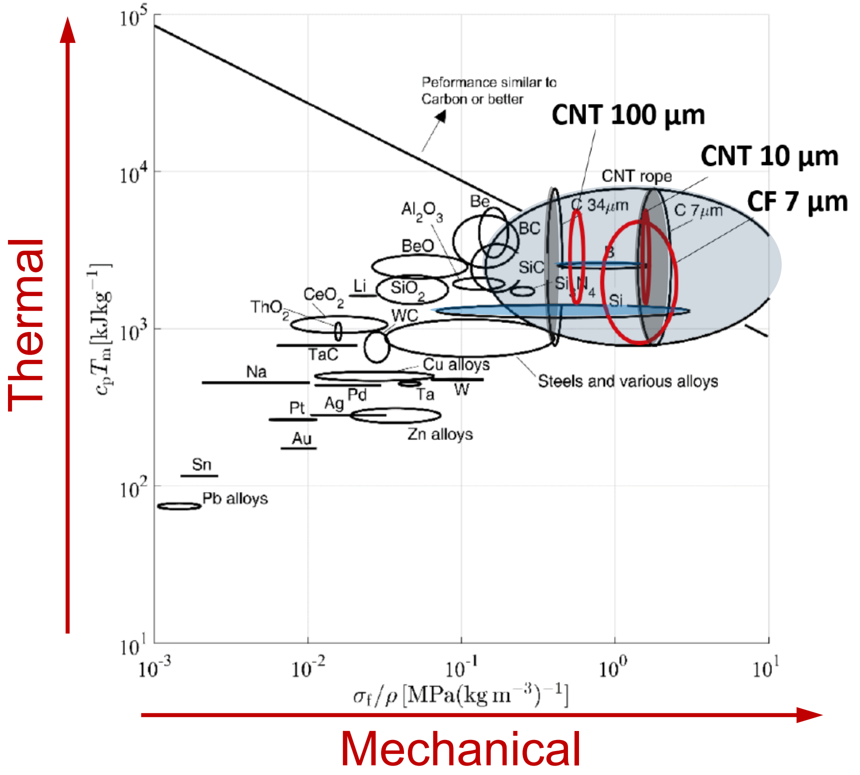
ii. Mechanical stress in the wire must not exceed the failure stress

iii. As high as possible output signal (maximizing SNR)

A merit index has been proposed concerning the above two constraints

$$M = c_p\, T_{max} \sqrt{\sigma_f/\rho}$$

where c_p is the specific heat capacity, T_{max} the max. temperature, σ_f the failure stress and ρ the mass density. The $c_p\, T_{max}$ represents a material-dependent energy per unit mass that should be maximized. σ_f/ρ is for selecting a light & strong material best suited for engineering application. (Ashby selection method)



[1] J. E. Huber et al., ARIES workshop (2021)

[2] M.F. Ashby. Materials selection in mechanical design, 2005.

Selection of wire material (cont')

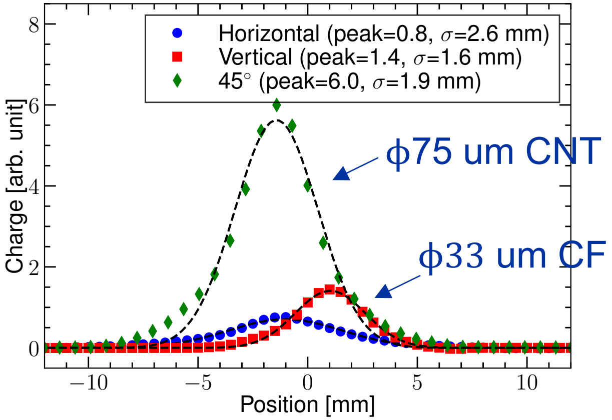
The output current signal mainly consists of the secondary yield and electron strip. The charge creation for a H^- striking a solid wire could be given by

$$Q = \Delta_{in} + \Delta_{ex}\eta_p - \eta_p - 1$$

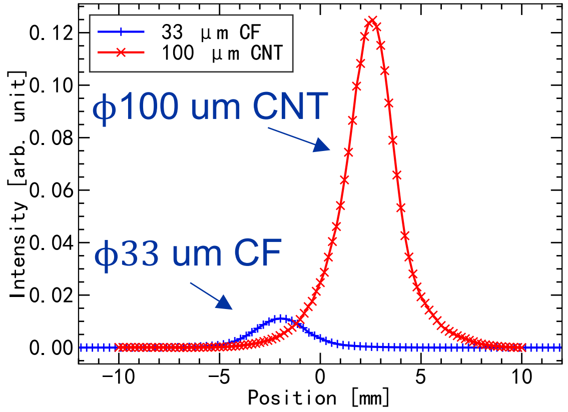
where Δ_{in} and Δ_{ex} are the secondary yields (SEY) at the entry and rear surfaces, respectively and η_p the fraction of stripped particles escaping the wire. The SEY could be theoretically assessed following the E. Sternglass the formulas, and the fraction of stripped particles (H^+) escaping the solid is approximated wrt. the projected range of particles.

For the 3 MeV H- beam, the ϕ75/ϕ100 um CNT rope's signal shew **6X and 10X enhancements comparing to the** ϕ33um CF **, respectively**

Experiments on 10/01/2024



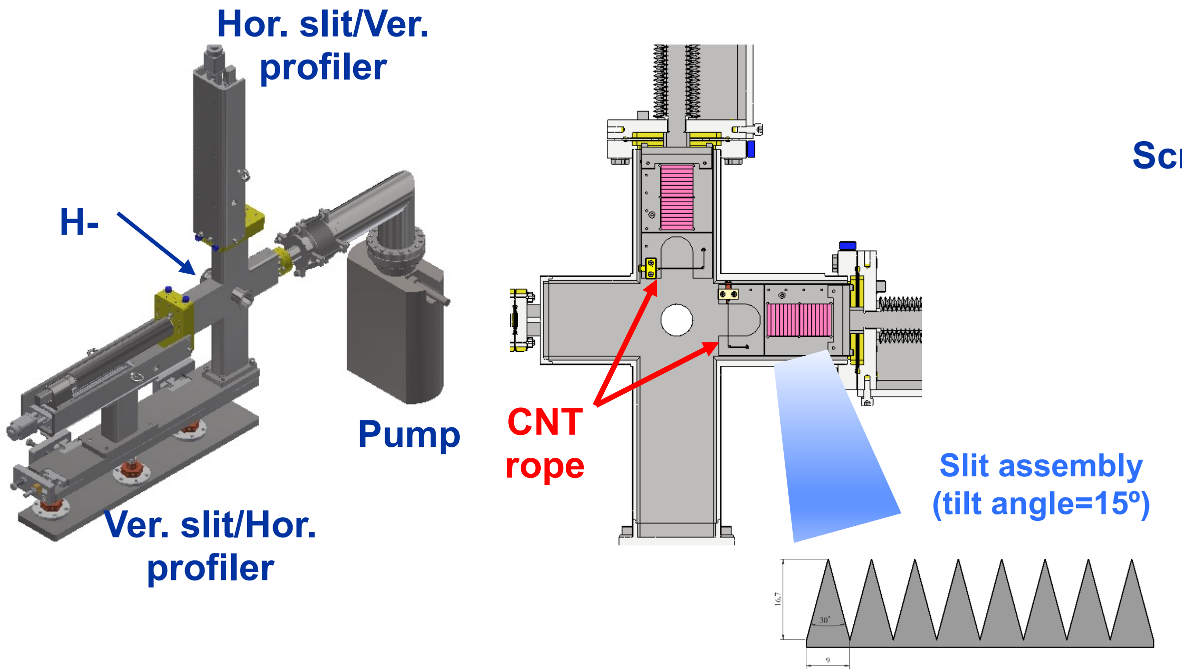
Experiments in 2025

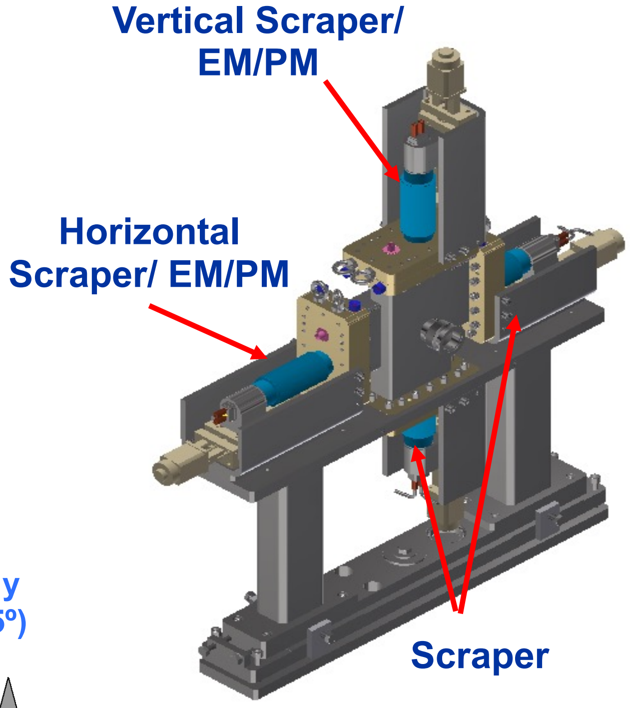


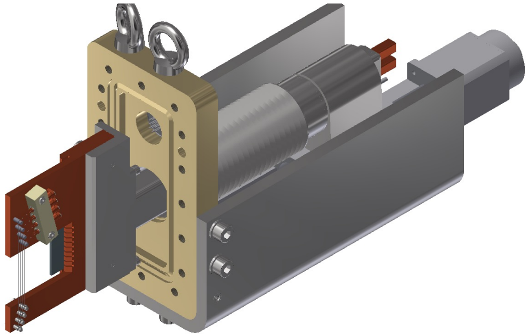
Mechanical structure: a glance

Slit-Wire
- EM mode： generate beamlets (beam at slit mask)
- WS mode: as a wire scanner (w/o intercepting slit mask)

SEM Grid
- EM mode： imagine beamlet
- Profiler mode: fast wire scanner







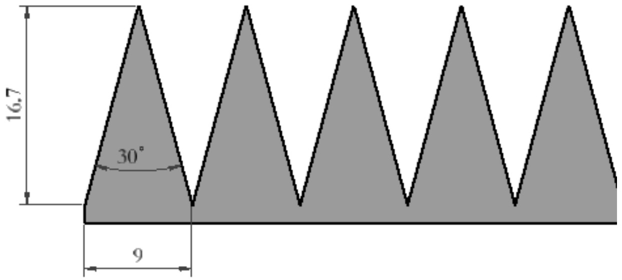
- CNT wires clamped to L shape small pin connectors pressed into holes of a ceramic wind frame
- $\phi 0.5$ mm coil springs to apply tension (0.2-0.3 N)
- wire spacing at 2 mm to avoid capacitive coupling[1]

[1] S. Hiroki et al., EPAC08, TUPC036 (2008)

More details see MEBT Collimator design review report

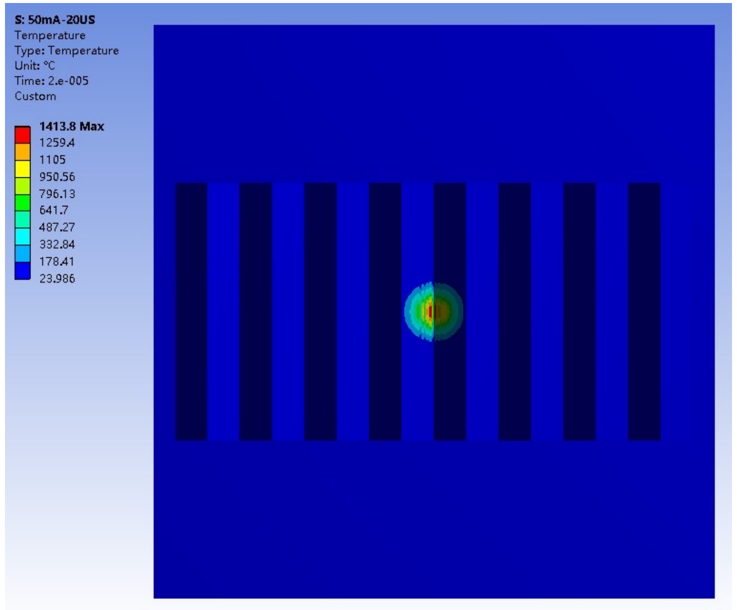
Slit mask mechanical structure

- Slit arm: segment the slit in several blades made of tungsten
- Max. beam power= 50 mA * 20 us * 3 MeV
- Initial design: tilt angle 15 deg, width=2 mm, slit thickness 3 mm, slit width=0.2 mm
- For an aver. spot size of 2 mm, the max. temperature is 2993 °C (tungsten melts at ~3422 °C)

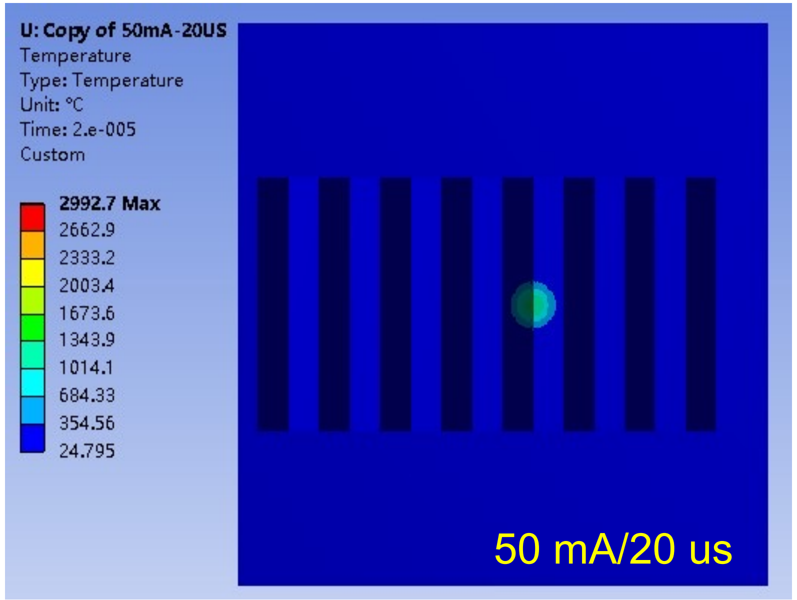


Low-Z material (graphite, CFC) is favoured, but the gas leak and surface spalling, contamination of RFQ/Buncher hold its application!

Max. temperature = 1413.8℃

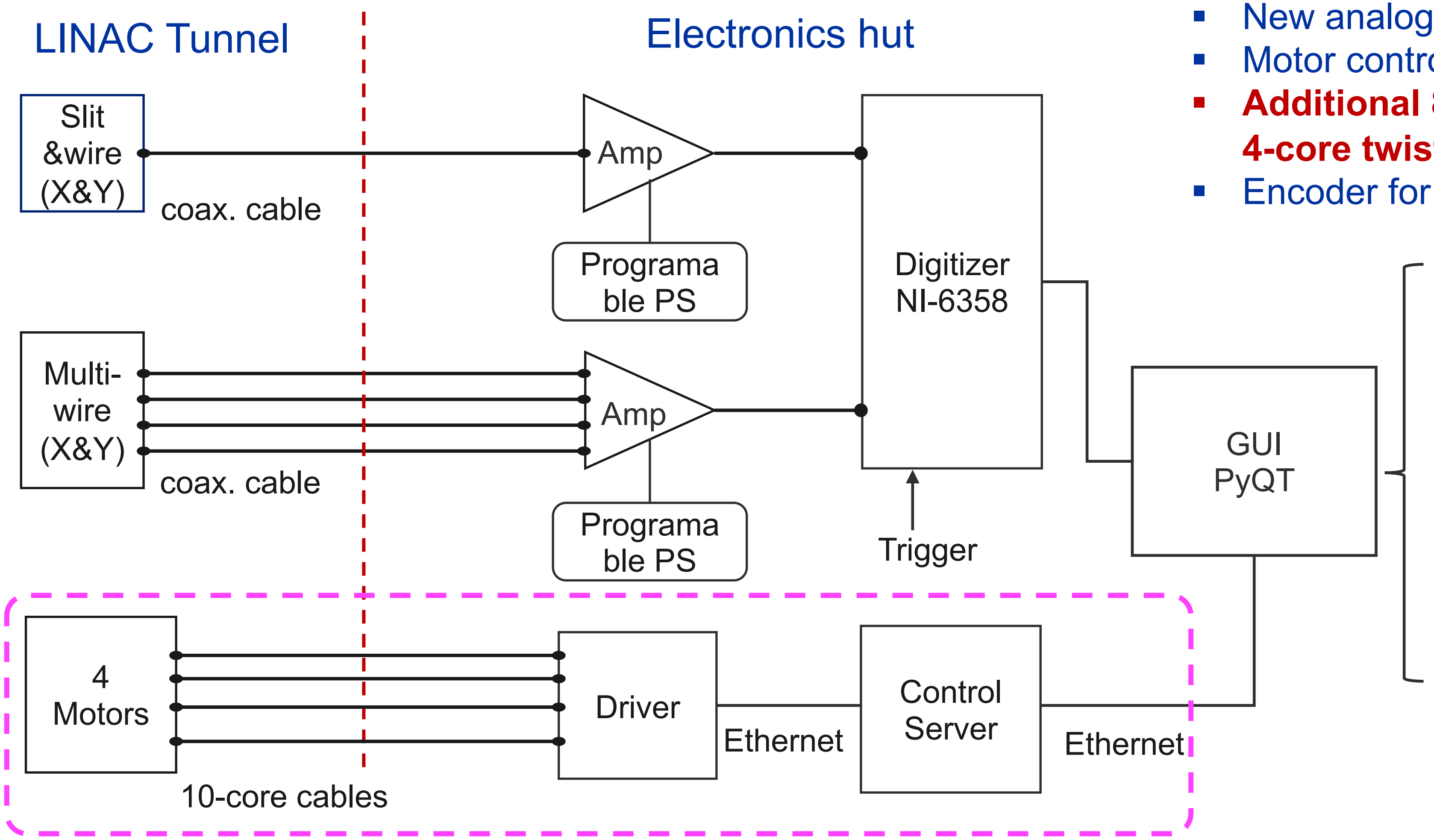


Max. temperature = 2992.7℃



Courtesy: Jiebing Yu

DAQ and control



- A button for switching to the profile/emittance measurement mode (RCS control room)
- New analogue electronics (2+4+4 ch) + 1*PS
- Motor control: Control + Beam Instr.
- **Additional 8-core twisted*2, 10-core twisted*2, 4-core twisted*2**
- Encoder for a higher positioning accuracy

- Display: raw signal, slit/wire position, profile, 2D density plot…
- Scan: scan range, step, velocity…
- Parameter setting: Bias, amp. gain, digitizer config., trigger, ..
- Quick analysis: beam size, Twiss, emit.
- Status & alarm: home, moving, limit switch, failure …

Twisted cables: 2 W

Analog electronics

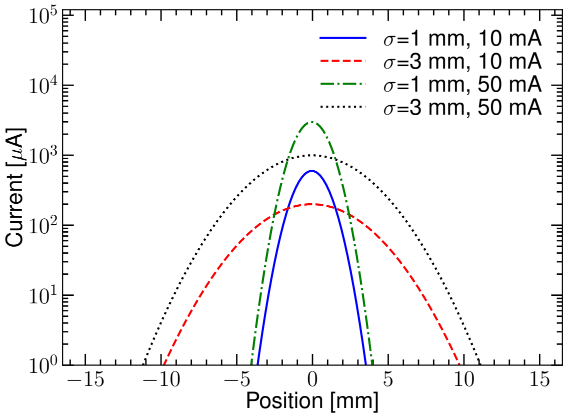
Requirements:

- Input signal: 1 μA-10 mA, 30-50 μs
- equ. input current noise: <50 pC (50 us)
- Bias output range: 0-100 V
- Channel numbers: 12 (3CH*4)

Design & Specifications

- Transimpedance 35 V/mA, gain accuracy 1%
- Bandwidth (-3 dB): 45kHz
- Rise/Fall time: 10us
- Linear output voltage range: ±10V
- Equ. input current noise : 0.3 μA
- Bias output range: 0~100 V

- **Cost evaluations**
  - 5k/ch*12 = 6 W



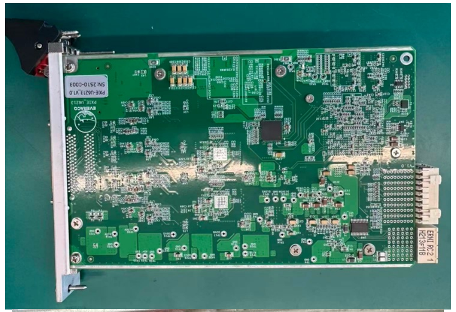
Digitizer & Controller

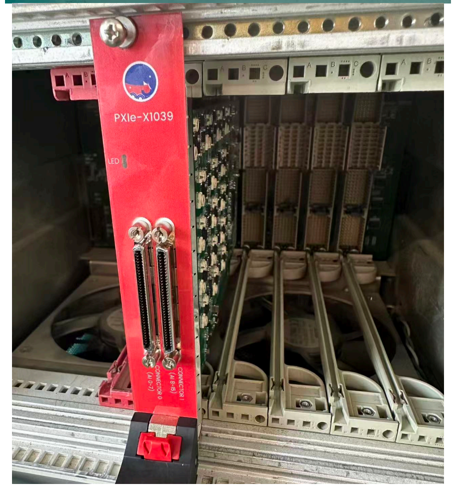
Needs:

1, Data acquisition: 10 CH; ≥10 MSPS (min. pulse width~10 μs)@16 bits, Input range: ±10 V (New)

2, Analog amplifier gain control, wire bias voltage control (4 CH, 0~100 V), step motor control (Modbus, Control)

=> Hardware: Digitizer*2+Caen DT5519E*1 + Connector/feedthru/cable ≈ 24 W





PXIe-X1039 Digitizer
Ch. No.: 16
Resolution: 16 bit
Sampling rate: ~20 MS/s
BW: 65 MHz
Input ranges: ±1 V、±5 V or ±10 V (programmable)
Input: differential/high impedance
ENOB: >11 bits
FIFO depth: >20 kSa/ch
Driver support: EPICS
System support: Linux
Development Language: C, C++

	CAEN DT5519E	ISEG SHR4020
Range	500 V/3 mA	2 kV/6 mA
Ripple	2 mVpp (typ.)	<10mVPP (typ.)
CH.	4	4
Lead time	6 month	6 month
Price	4.5 W	~8 W

Caen DT5519E

Iseg SHR4020

Schedule

Review
Decision making

2025.11

2025.12

Billing
Contract

~Delivery

2026.05

2026.06-

Arrive CSNS
calibration,
control, software,
integration, …

Task allocations

- **Beam Instr.**
  - W. Huang: BCT sensor & integration
  - M. Rehman: BPM sensor & mapping & implementation
  - Z. Lu: WS sensor & integration
  - R. Qiu: Analogue electronics for WS & EM
  - F. Li: DAQ (digitizer), implementation & commissioning
  - Z. Xu: BPM electronics
  - L. Zeng & J. Tian: FBLM (re-used)
  - R. Yang: overall design, manufacture, implementation & commissioning
- **Mechanical**
  - X. Nie: BPM & CT sensor
  - R. Liu: WS sensor
  - J. Yu: EM sensor
- **Control**
  - Y. He
- **Alignment:** T. Wang

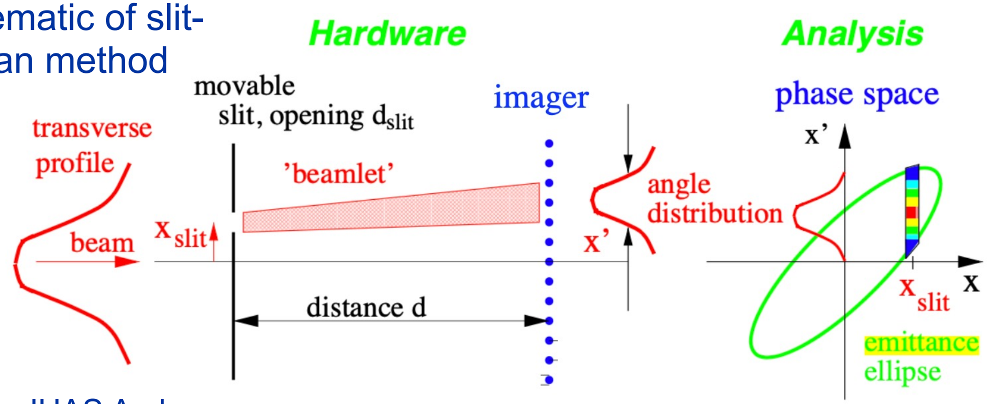
Thank you!

Backups…

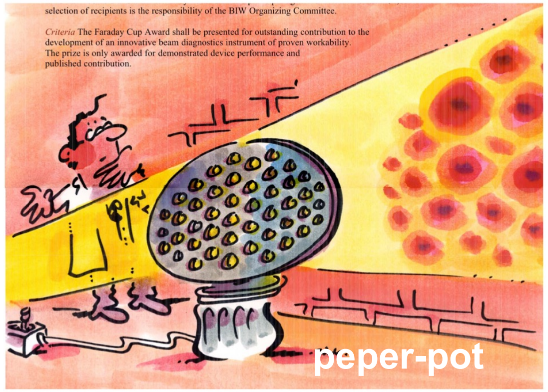
Needs and methods

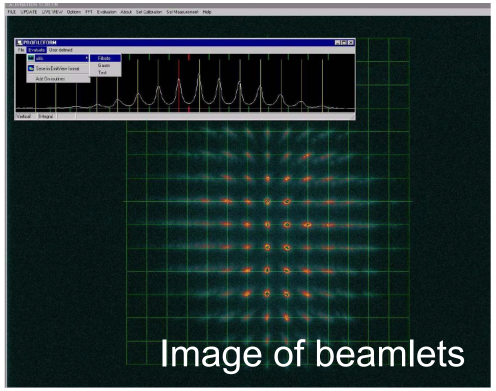
- **Requirements**
  - Accuracy: 10%@0.2-0.3 mm.mrad (both emittance and Twiss parameters)
  - Measurement time: <10 min
  - Max. beam power: 50 mA*20 μs
  - No significant vacuum drop during measurement
- **Methods for the emittance measurement of the low-β beam**
  - slit scan（2D）: multi-shot, relative complete phase-space visualization, simple but time consuming,
  - multi-slit（2D）: fast & capable of single-short emittance measurement, giving an incomplete phase-space
  - peper-pot（4D）: capable of providing 4D phase-space distributions in single-shot

Schematic of slit-scan method



[1] P. Forck, JUAS Archamps

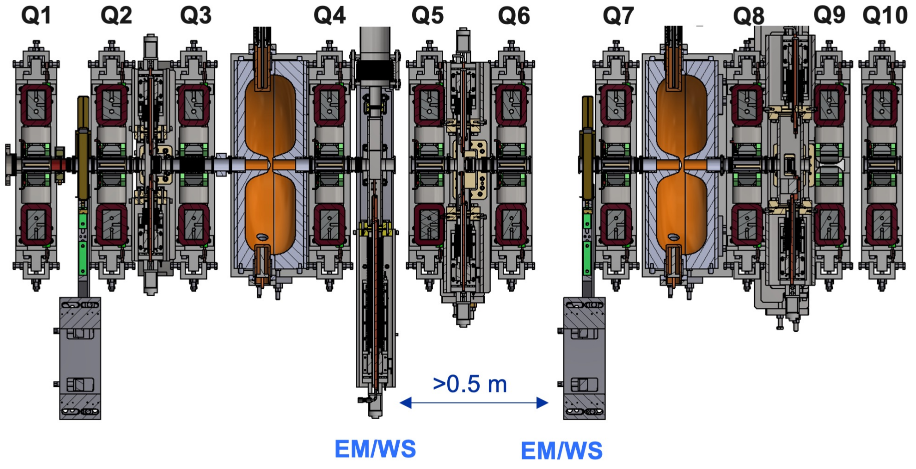


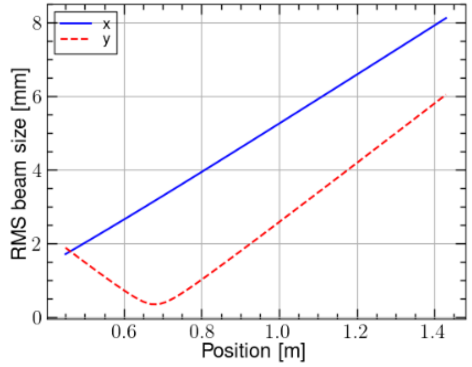


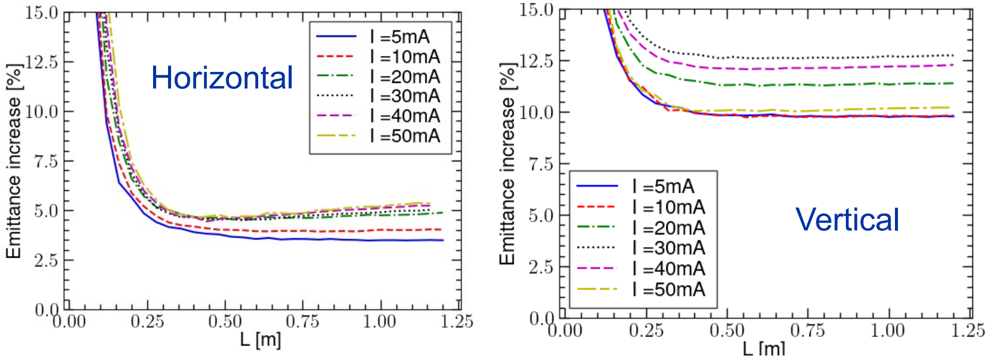
Scheme1: Slit-Q3-Q4-grid

- The slit-grid scheme was adapted to shorten the scan time using SEM grid as beamlet profile monitor
- An independent emittancemeter (WS functioned): Slit-Q3-Q4-grid
  - pros: sufficient beamlet drift distance
  - cons: measurement accuracy>10% (vertical, slit width=0.1 mm, slit thickness=1 mm); $\sigma_y(L)$=6-8.5 mm (L=0.5 m)≈1/3*R !!

Not promising at all → Upstream!

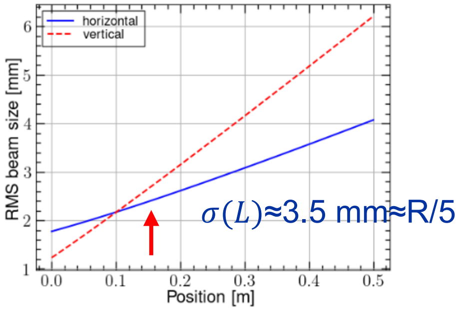




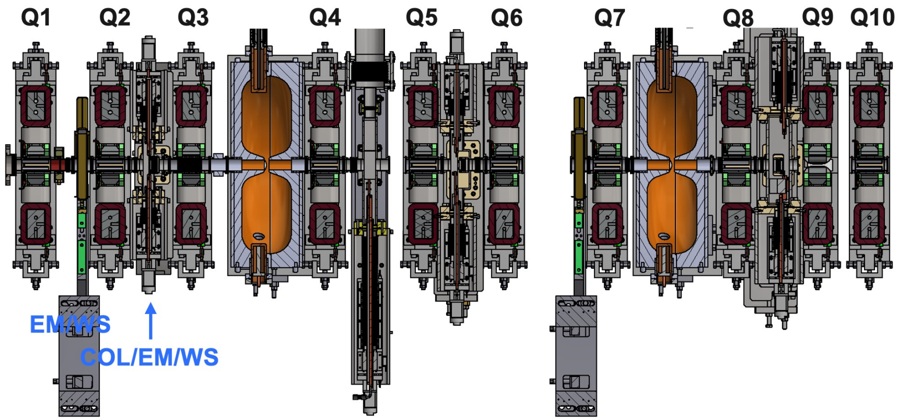


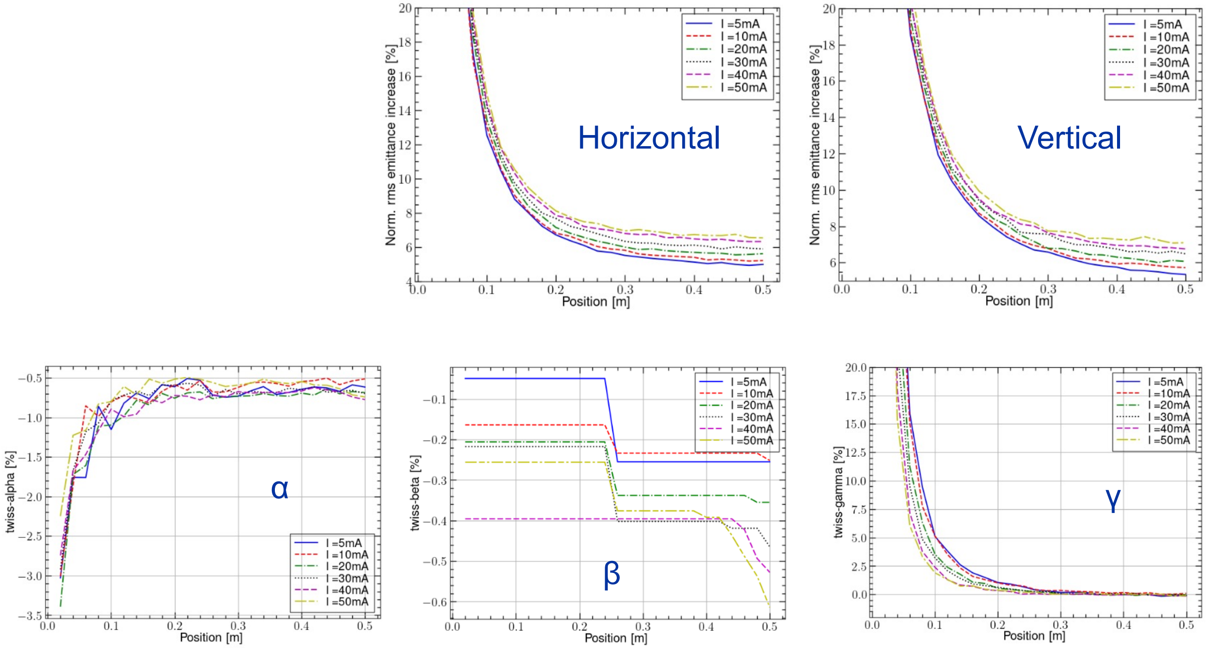
Scheme2: Slit-Q2-grid

- Portray transverse phase-space distribution at very upstream
- To control the beam size at the grid, the Q1 strength has to be halved
- For a slit width=0.1 mm, slit thickness=0.2 mm, and L=0.2~0.3 m, the emittance measurement error is 6-8%. Assessed Twiss parameters beats as <10%
- EM/WS-Q2/BPM-COL/EM/WS make things become super complicate and compact!



Looks good, still margins for improvement.





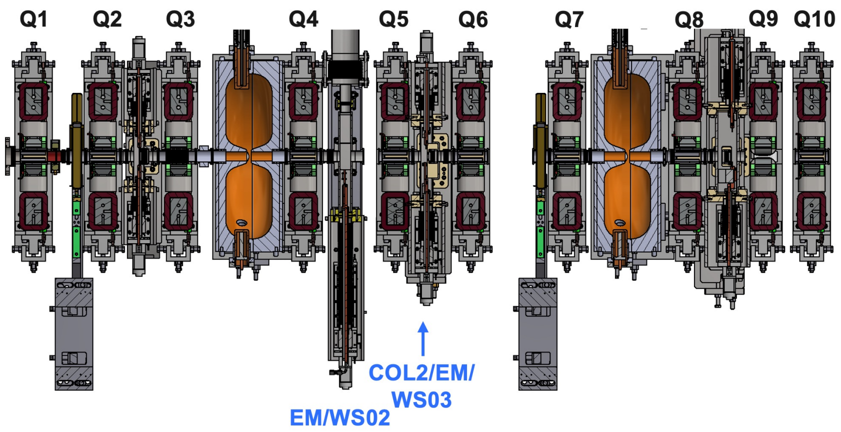
Scheme3: Slit-Q5-MWS

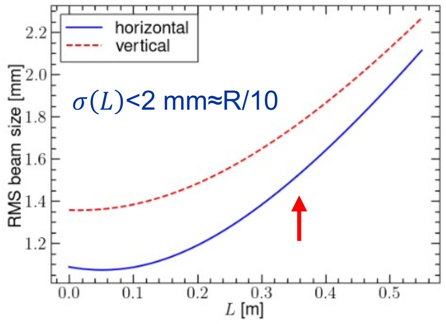
- Slit-Q5-MWS vs. ~~Slit-Q6-MWS~~
- Leaving a dedicated space in between Q6 and Q7 for an instr. capable to obtain x/y/z profile
- Power off Q5 and the rms. beam size at grid is <2 mm (favourable)
- For a spot size at slit ~1 mm → slit width <0.2 mm (reasonable)
  Regarding a rms. beam divergence of 2 mrad. → beamlet size>0.6 mm
- SEM grid integrated into COL2 (feasible)

==> Optimization of the slit and grid!

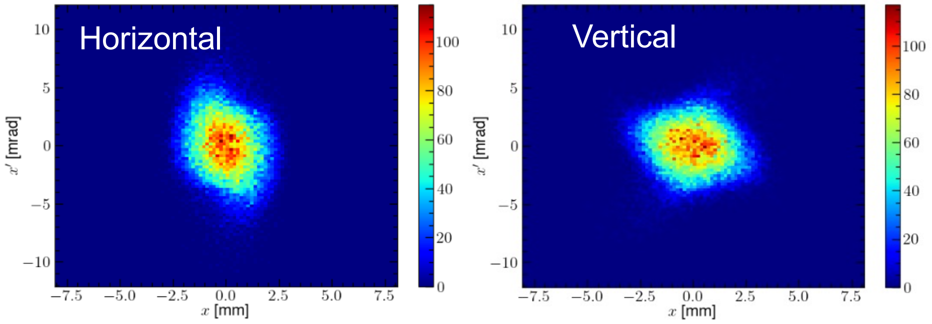
Major beam parameter at Q4 exit

Current [mA]	σ_x [mm]	σ_y [mm]	ε_x [mm.mrad]	ε_y [mm.mrad]
10	0.78	1.48	0.209	0.209
20	0.82	1.37	0.212	0.211
30	0.90	1.33	0.215	0.213
40	1.00	1.33	0.219	0.215
50	1.10	1.35	0.224	0.217





Phase-space distribution at Q4 exit



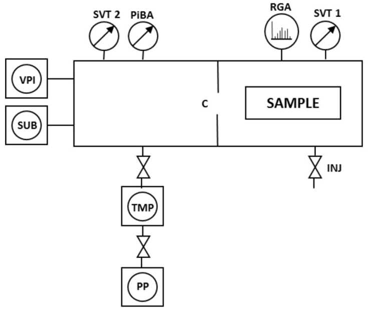
Vacuum compatibility

- The figures of merit for determining the best slit material are melting (or sublimation) temperature, heat capacity and thermal conductivity. graphite, tungsten and tantalum can be considered for their high melting point (above 3000 K), while beryllium and again graphite for high specific heat capacity.
- If we remove the surface contaminants by a proper chemical cleaning, the outgassing flow coming from a material, which has been exposed to air, is dominated by water vapour (≥80%)
- Method to reduce materials outgassing: bake-out and vacuum firing
  Baking (250 ℃, 24h) → reduce LHC collimator outgassing by ~1.3

VAS furnace. Maximum temperature 1600°C, used for small sample

@CERN

- vacu. level: 1e-5 mbar@900 ℃
  recommended vacu. firing: 2 h@950 ℃



Sample heating in chamber

~940 ℃
10-20 °C/min

Treatment	$Q-Q_{bg}$ [mbar·l·s^{-1}]	Q_s [mbar·l·s^{-1}·cm^{-2}]
None	$6.7\cdot10^{-8}$	$1.3\cdot10^{-11}$
48 h firing	$4.6\cdot10^{-9}$	$9.1\cdot10^{-13}$

~4e-10 mbar.L.s^{-1} (S=30 cm^2)

~3e-11 mbar.L.s^{-1} (S=30 cm^2)

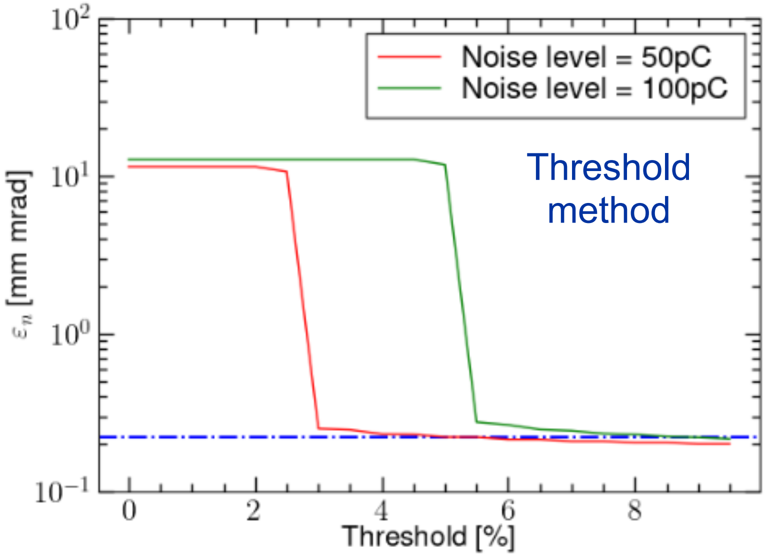
However, these are not the outgassing rate w/ beam heating!

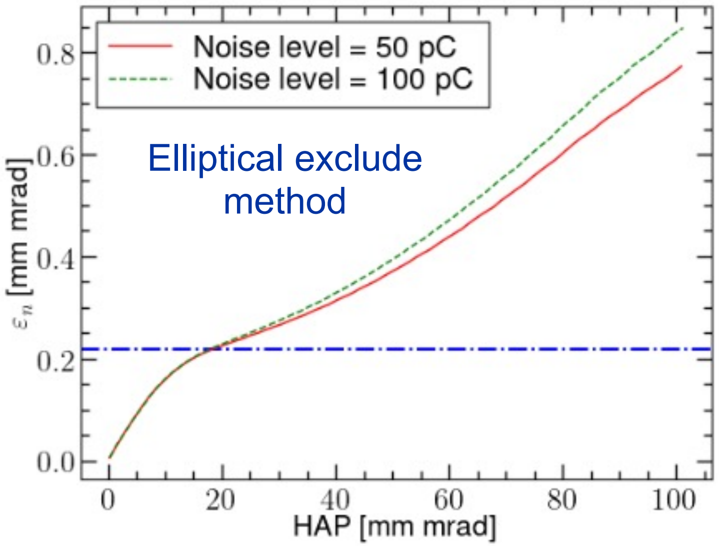
[1] C. Accettura, PhD thesis (2017)
[2] C Accettura et al 2019 J. Phys.: Conf. Ser. 1350 012085

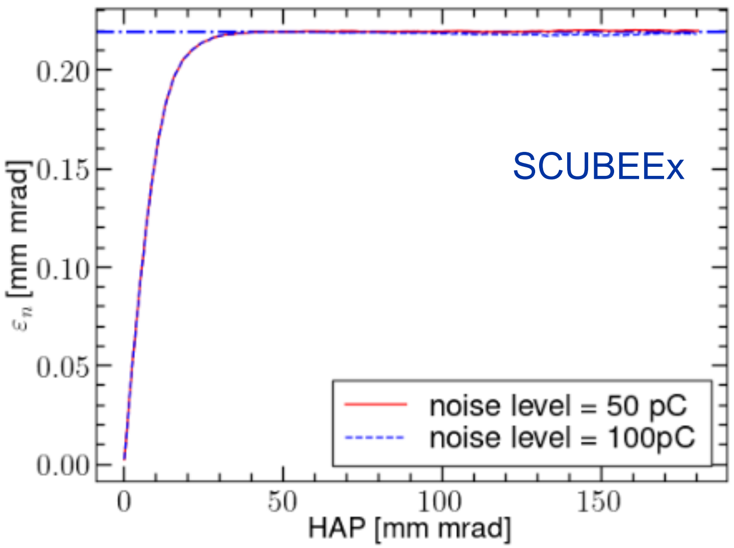
Emittance calculations

	Threshold analysis	Eliptical exclude method	SCUBEEx
Features	1. set a BG threshold value K 2. Zero all the signal values below K, and assess the rms. emittance ε(K) 3. Repeat 1-2 for a sequence of thresholds, e.g., 1%, .., 10% 4. Determine the rms. emittance when ε(K) tends to be const. for a higher threshold	1. Define an elliptical boundaries wrt. the calculated β, α values; 2. Ignores the values outside of the exclusion boundary 3. Adjust HAP and repeat 1-2 4. Determine the rms. emittance when ε(HAP) tends to be const. for a higher HAP	1. Define an elliptical boundaries wrt. the calculated β, α values; 2. Estimate a noise level K using data outside of the exclusion ellipse 3. Adjust HAP and repeat 1-2 4. Determine the rms. emittance when ε(HAP) tends to be const. for a higher HAP
Applications	PITZ、CSNS..	ISIS	SNS, SARAF、IFMIF

- The threshold analysis w/ extra delegated threshold adjustment is currently employed for MEBT EM.
- SCUBEEx method will be appended to the future GUI





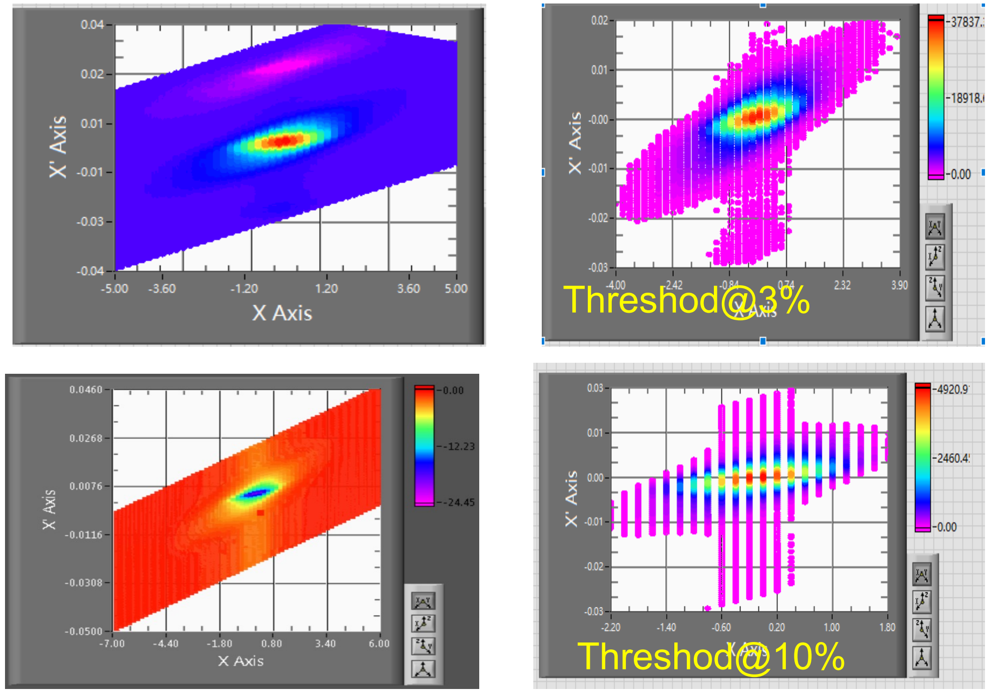


Feasibility studies at MEBT

- Use MEBT EM 1# slit and downstream WS03 (drift distance = 225 mm, ϕ33 μm CF wire)
- Experimental campaigns in 2024 early half year w/ many failures (setting, beam…)
- Succeeded to map the hor. phase space and reconstructed the emittance
  However, the discrepancies between slit-slit/FC and slit-harp are visible (wrong wire?)

Courtesy: Fang Li

24/06/24 data

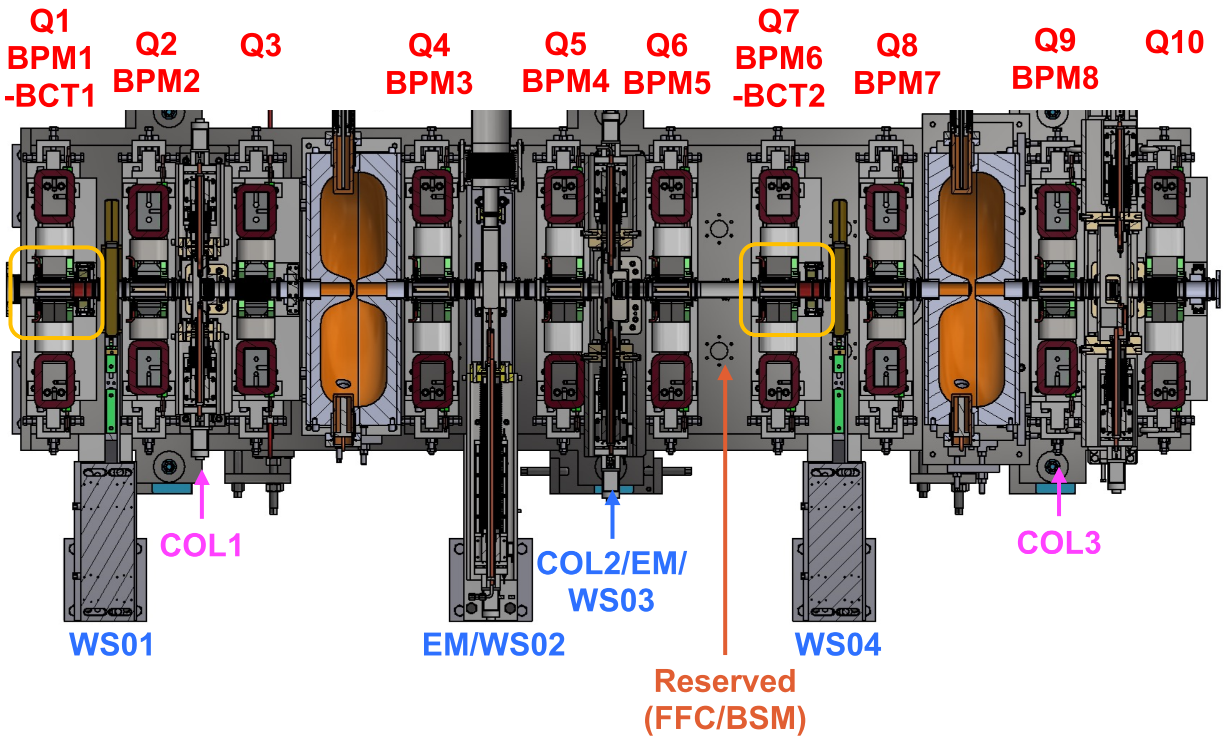


Emittance by threshold analysis

	Threshold	ε_n [mm mrad]	α	β
Slit + slit	3%	0.207	-1.04	0.318
	8%	0.13	-0.91	0.32
Slit + wire	8%	0.207	-0.58	0.172
	11%	0.163	-0.74	0.24

Emittance by SCUBEEX method

	ε_n [mm mrad]	α	β	σ_x [mm]	$\sigma_{x'}$ [urad]
Slit + slit	0.180	-0.98	0.31	0.942	1.87
Slit + wire	0.190	-9.04	0.85	0.992	2.60

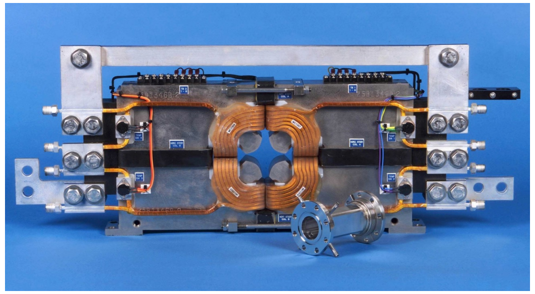


Q1
BPM1
-BCT1
Q2
BPM2
Q3
Q4
BPM3
Q5
BPM4
Q6
BPM5
Q7
BPM6
-BCT2
Q8
BPM7
Q9
BPM8
Q10
WS01
COL1
EM/WS02
COL2/EM/
WS03
Reserved
(FFC/BSM)
WS04
COL3

SNS MEBT

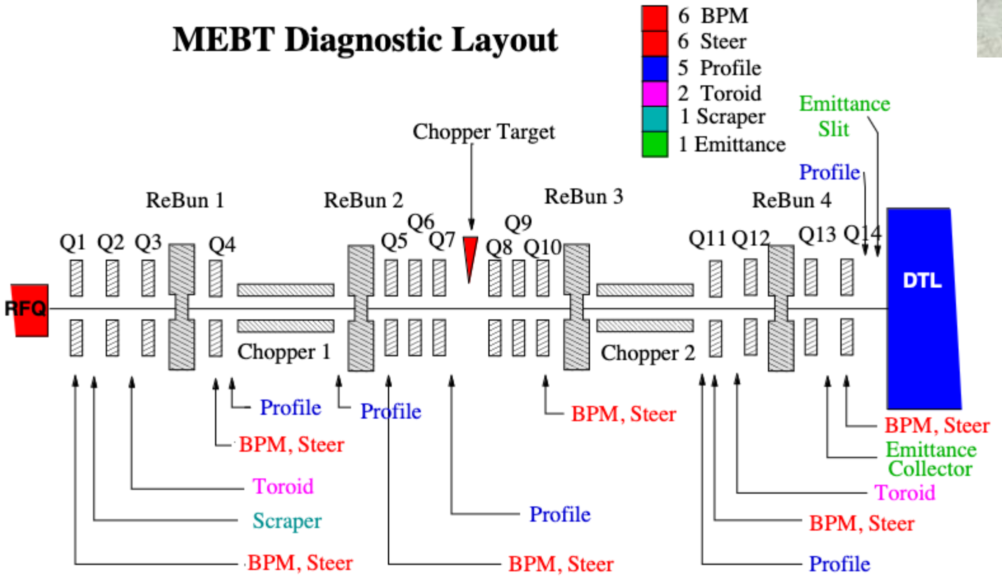
Highlights

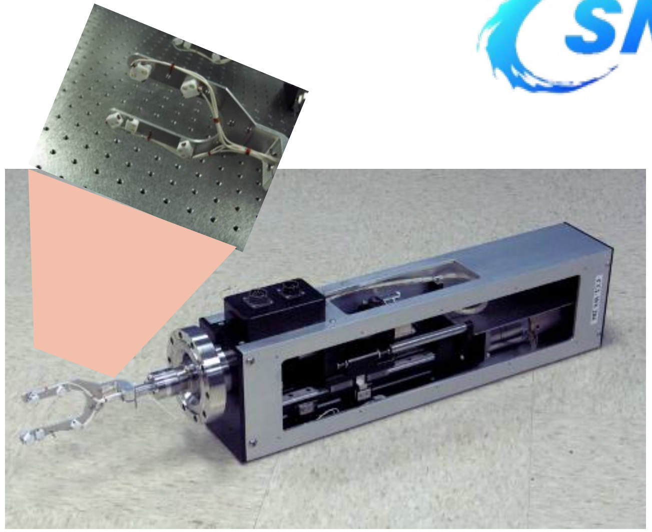
- 6 BPMs spaced roughly every π/2 phase advance
- CT: nearly Bergoz FCT-082-50:1, droop 0.06%/us, 37 mm from the quad. (magnet fringe field)
- WS (d100 μm W wire) works at 100 us, 6 Hz

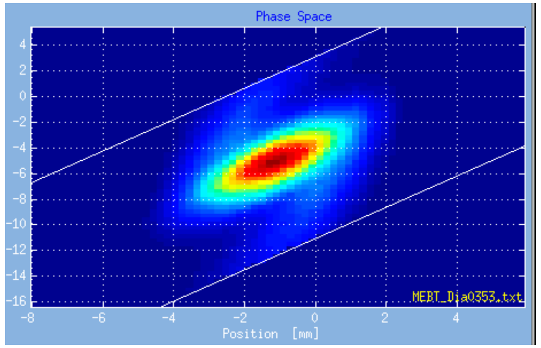


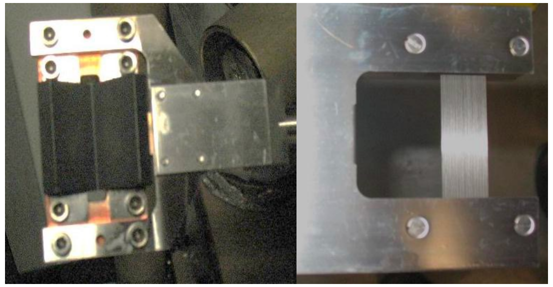
Quad. and BPM

MEBT Diagnostic Layout









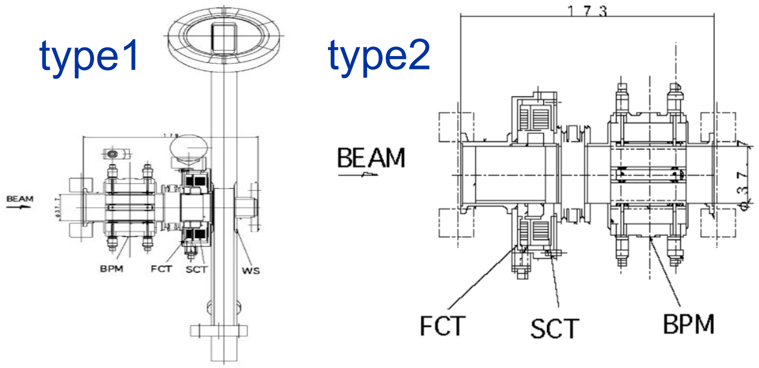
Faraday cup in 2002

[1] A. Aleksandrov, SNS beam diagnostics (2011)
[2] L. Doolittle et al., SNS Front End Diagnostics (2000), D. Oshatz et al., LBNL-047343 (001)

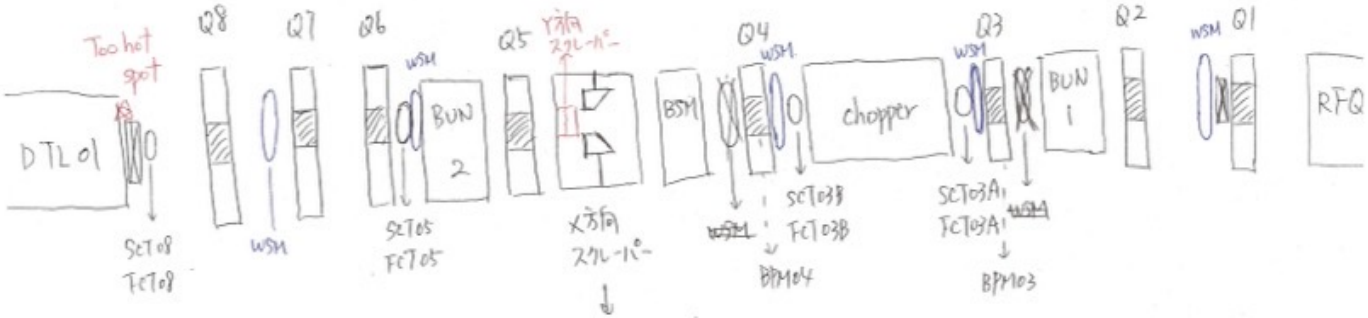
J-PARC MEBT

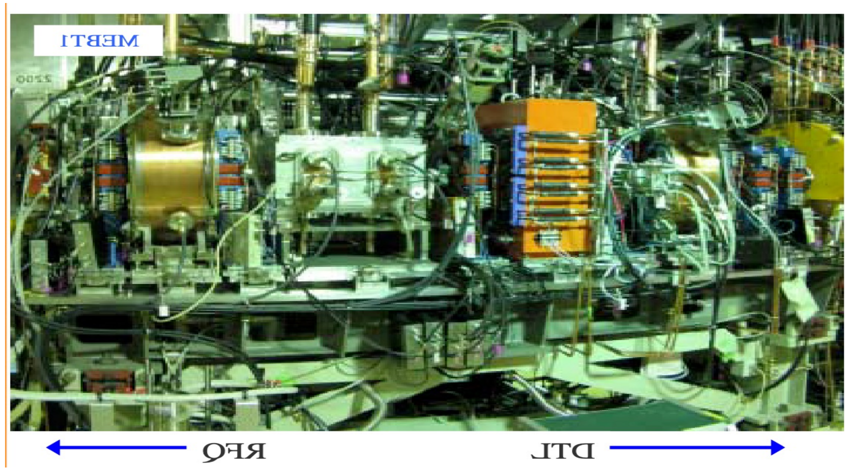
Highlights

- BPM embedded in every quad.
- SCT+FCT+X assembly
  type1: BPM+FCT+SCT+WS welded (179 mm)
  type2: FCT+SCT+BPM welded (173 mm)
- No emittancemeter, but do desired to have one (Y. Liu)
- BSM newly installed, but not used properly (Y. Liu)



Section	SCT	FCT	BPM	WSM	BLM
MEBT1	6	5	8	4	0





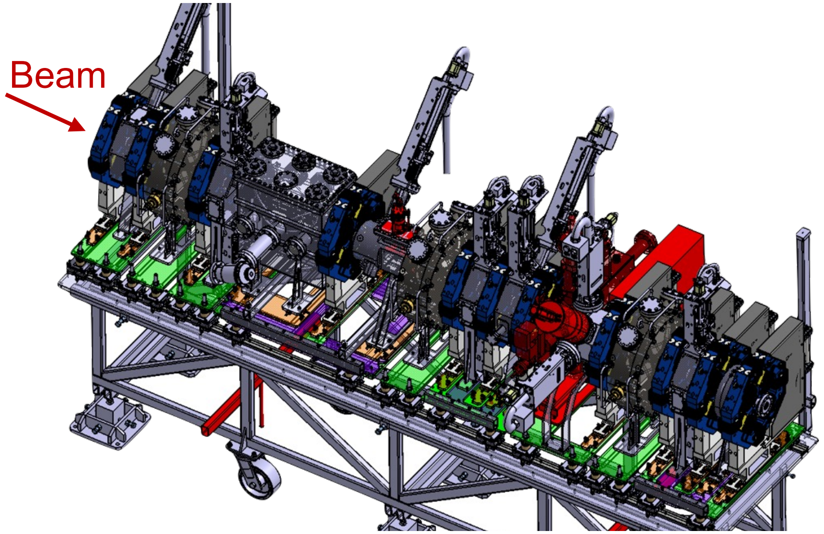
[1] H. Sasaki et al., IFMIC mini-workshop on beam instruments (2007)
[2] A. Miura et al., IBIC2012
[3] Y. Liu, private communication (2024)

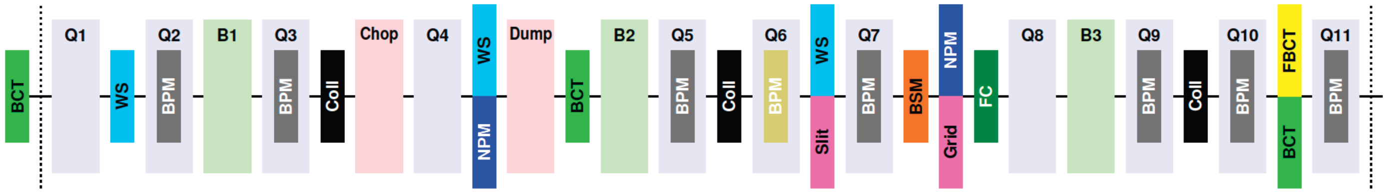
ESS MEBT beam diagnostics

Highlights

- longitudinal margin for almost all instruments except for the stripline BPM embedded in quad. as usual

Instr.	Number
BCT	3
FCT	1
BPM	7 (w/ 11 quads.)
Profiler Monitors	4
Emittancemeter	1 (slit-grid)
BSM	1
FC	1



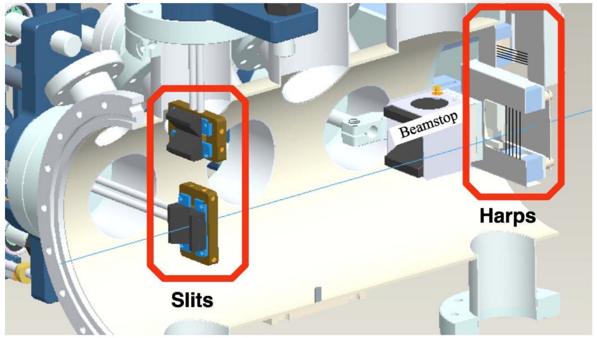


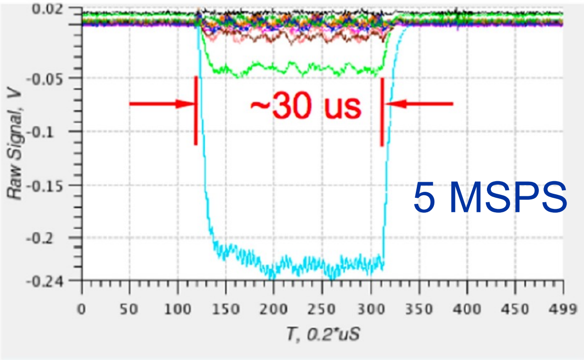
[1] N. Milas et al., IBIC2022, M02C2 (2022)

SNS/ESS/LINAC4 MEBT EM

SNS (Allison scanner, slit-harp)

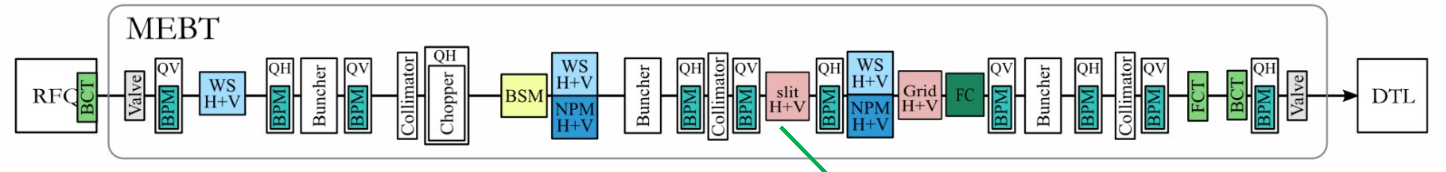
- H- beam: 2.5 MeV, ~30 mA, 40 μs
- slit width = 0.1 mm (graphite, tilt angle=π/4)
  slit thinkness= 0.5 mm
- slit-harp distance = 353 mm
- 16 tungsten wires (d=0.1 mm, bias +300 V)
  with a wire space of 1 mm

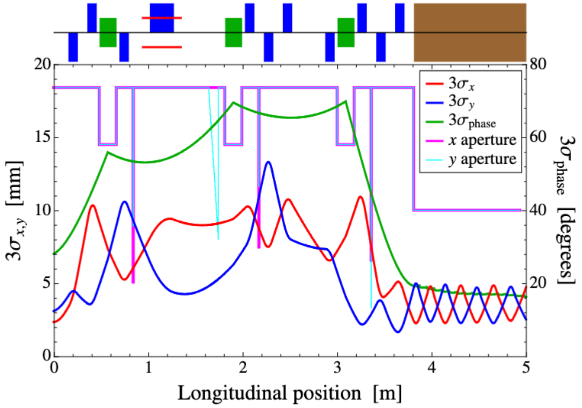


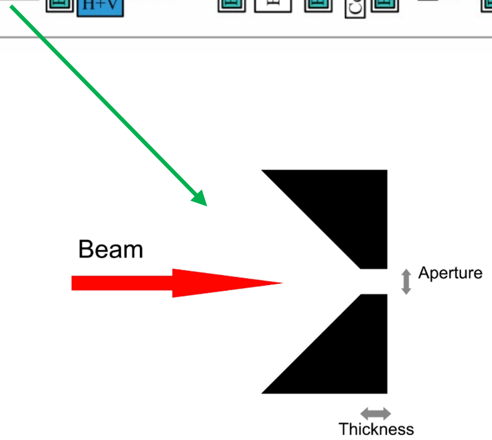


ESS

- **Mimic SNS/CERN-LINAC4's EM w/ necessary improvements**
  - slit width = 0.1 mm, thickness = 0.2 mm
  - d0.05 mm tungsten wire, wire space = 0.5 mm







[1] J. Pogge, AIP Conf. Proc. 868, 435-444 (2006)
[2] A. Zhukov and A. Aleksandrov, LINAC2012 (2012)
[3] B. Cheymol, LINAC2014, TUPP039 (2014)

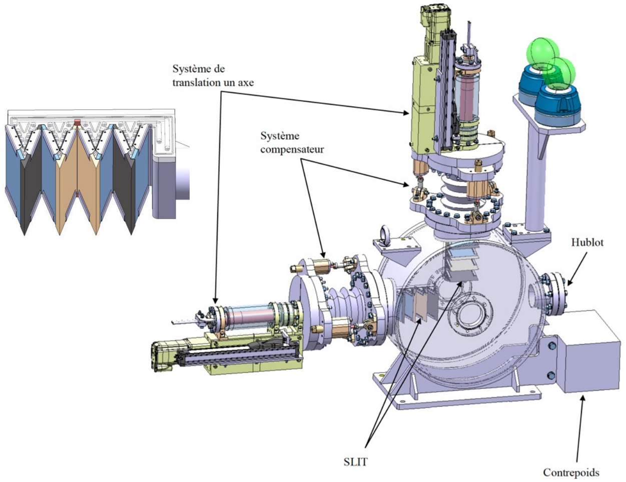
LINAC4 MEBT EM

LINAC4 MEBT EM

- H- beam： 3 MeV, 65 mA, 100 μs (design)
  3 MeV, 40 mA, 50 μs (recommended)
- **Slit-grid scheme** (shorten measurement time)
- slit width = 0.1/0.2 mm (graphite, tilt=15º), slit width = 3 mm
- d33 μm carbon fiber as wire material (eager for d100μm carbon wire, but not adequate material available at that time)
- **Exist there only for front-end commissioning phase**

Evaluation of the slit temperature w/ 65 mA, 100 us H-

	SRIM	FLUKA		
Angle [deg]	90	90	45	15
RFQ	1359	1342	1216	937
MEBT	2673	2613	2065	1696
DTL	4669	4594	3931	2790



[1] B. Cheymol, PhD thesis (2011)