EUROPEAN SPALLATION SOURCE

ESS Normal Conducting Linac Commissioning Results

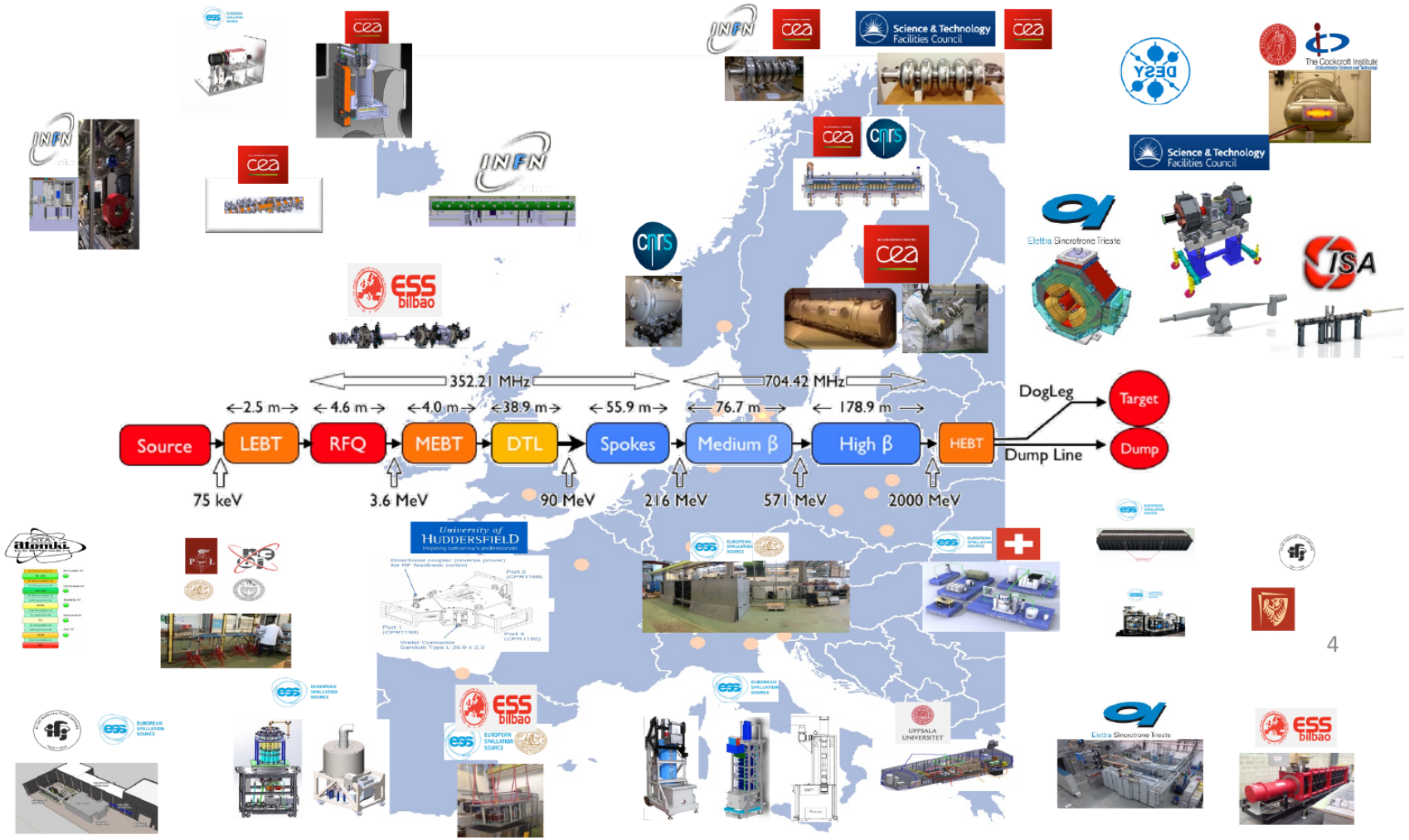
HB 2023, Geneva, Switzerland

TUA3I3

Dr. Yngve Levinsen
Accelerator Scientist, ESS
On behalf of the ESS Accelerator Collaboration

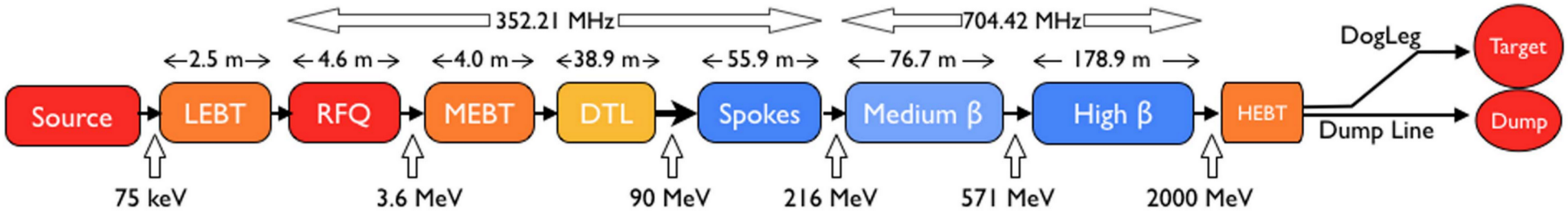
The ESS In-Kind model

With a lot of help from our friends



ESS Project

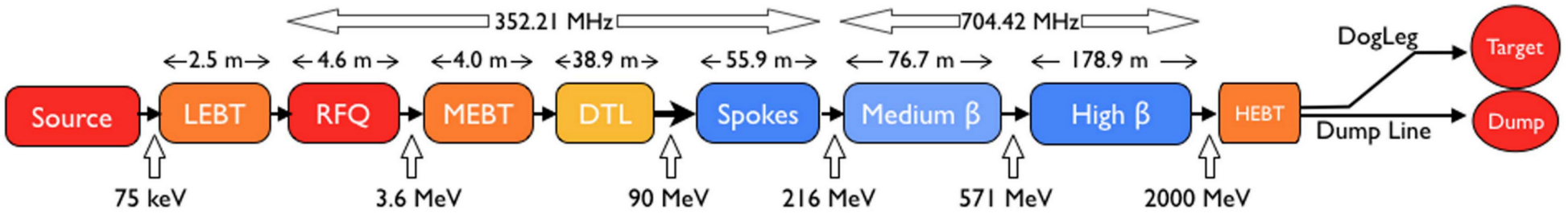
A world leading spallation source



Parameter	Value
Proton beam power	5 MW
Proton beam energy	2 GeV
Peak current	62.5 mA
Pulse length	2.86 ms
Rep rate	14 Hz
Duty factor	4 %
Bunching frequency	352.21 MHz

Beam Diagnostics

Beam modes and pulse structure



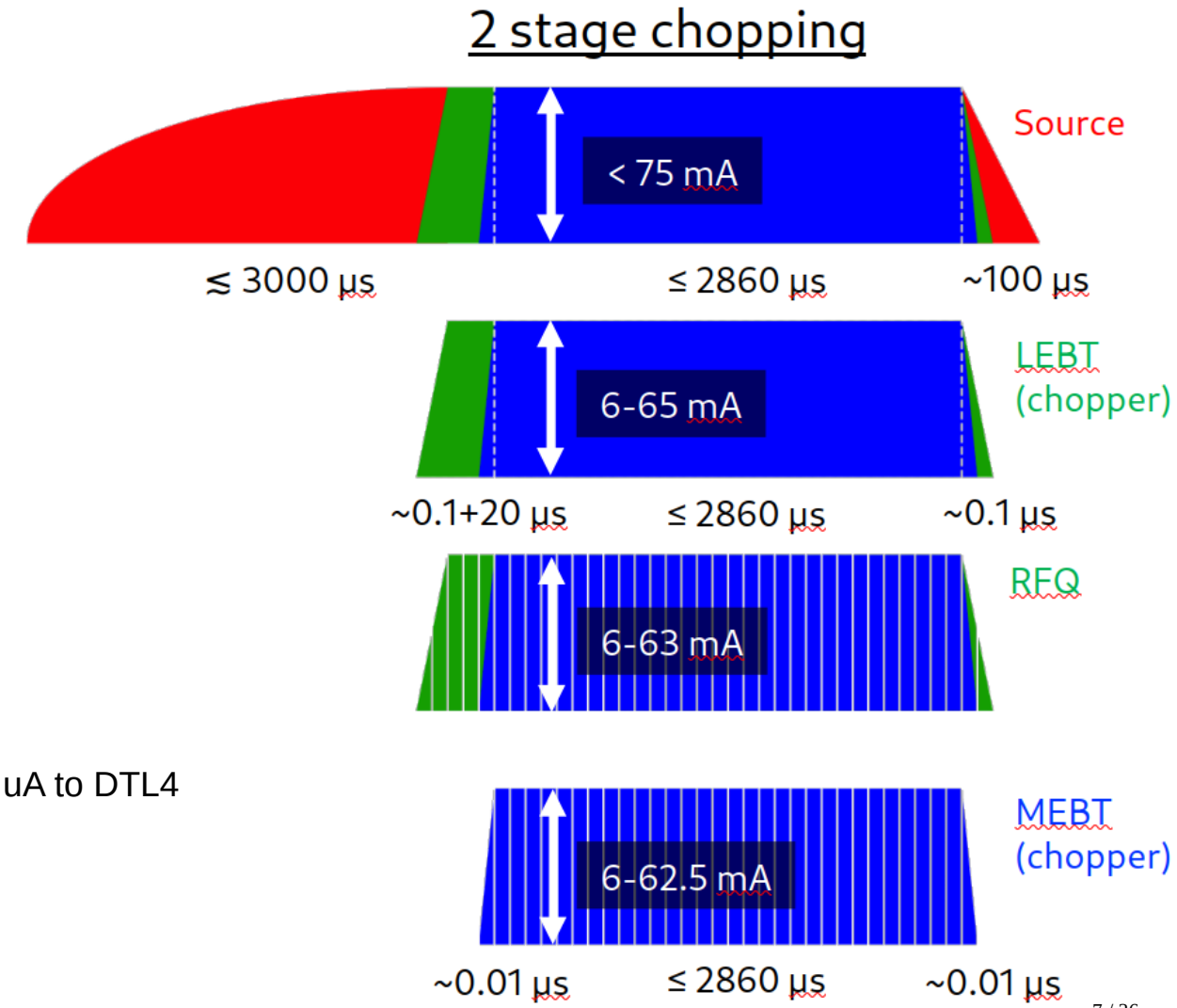
Device	Type	IS	LEBT	RFQ	MEBT	DTL	SPK	MBL	HBL	HEBT	A2T	DmpL	Total
Faraday cup	Current		1		1	2							4
BCM		1	1	1	2	5		1	1	2	3	2	19
Fast BCM					2								2
Doppler			1										1
BPM	Parasitic transverse				7	15	14	9	21	16	12	4	98
Non-invasive profile			2		2		1	3	1		1		10
Imaging	Parasitic target/dump transverse										2	1	3
Grid											1		1
Aperture											3	1	4
Emittance	Non-parasitic		1		1								2
Bunch shape					1		1						2
WS					3		3	3	1	3	1		14
BLM	Loss				4	47	78	38	86	51	38	6	348

Proton beam

Beam modes and pulse structure

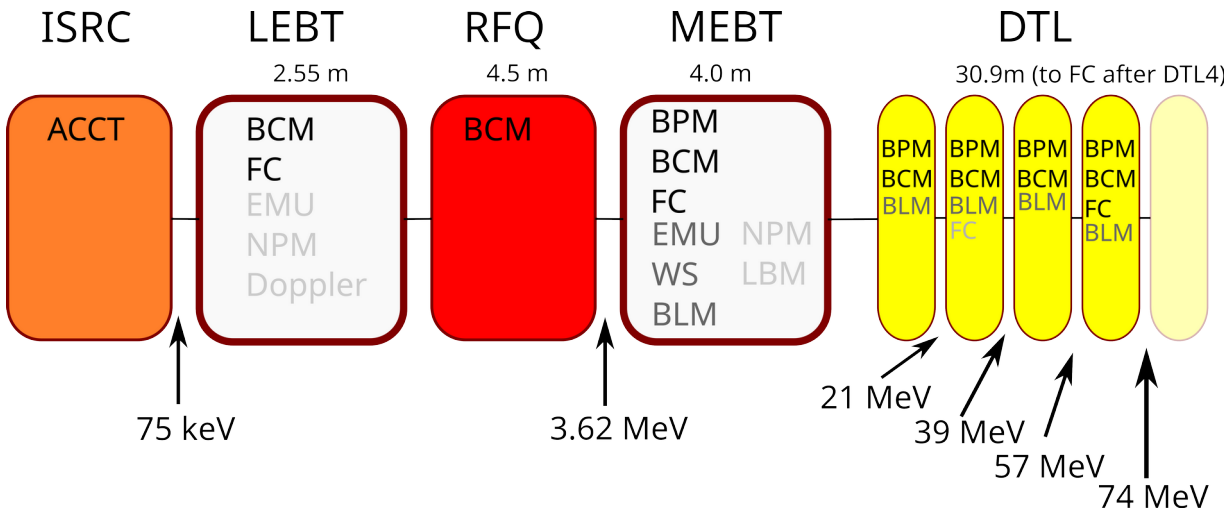
Mode	Current [mA]	Length [µs]	Rep [Hz]
Probe	≤ 6	≤ 5	≤ 1
Fast commissioning	≤ 6	≤ 5	≤ 14
Slow commissioning	≤ 62.5	≤ 5	≤ 1
Fast tuning	≤ 62.5	≤ 5	≤ 14
Slow tuning	≤ 62.5	≤ 50	~~≤ 1~~ ≤ 0.2
Long pulse verification	≤ 62.5	≤ 2860	≤ 1/30
Production	≤ 62.5	2860	14

< 1 uA to DTL4



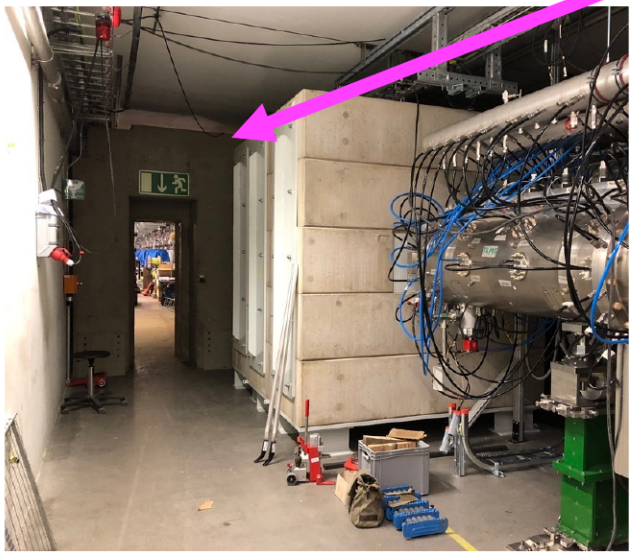
NCL Overview

- ISRC & LEBT
  - DC beam > 70 mA @ 75 keV
  - Chop pulse, diagnose, focus & match for RFQ
- RFQ
  - 4.5 m, 5 segments, 4-vane, accelerate to 3.62 MeV
- MEBT
  - Diagnose beam, fine chop, collimate, match for DTL
- DTL
  - 5 tanks, accelerate to 90 MeV (74 MeV after DTL4)
  - Temporary beam stop & shield wall in place of 5th tank



Tunnel configuration

NCL commissioning



Milestones

Throughout commissioning

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- January 31st Start of RF commissioning in DTL

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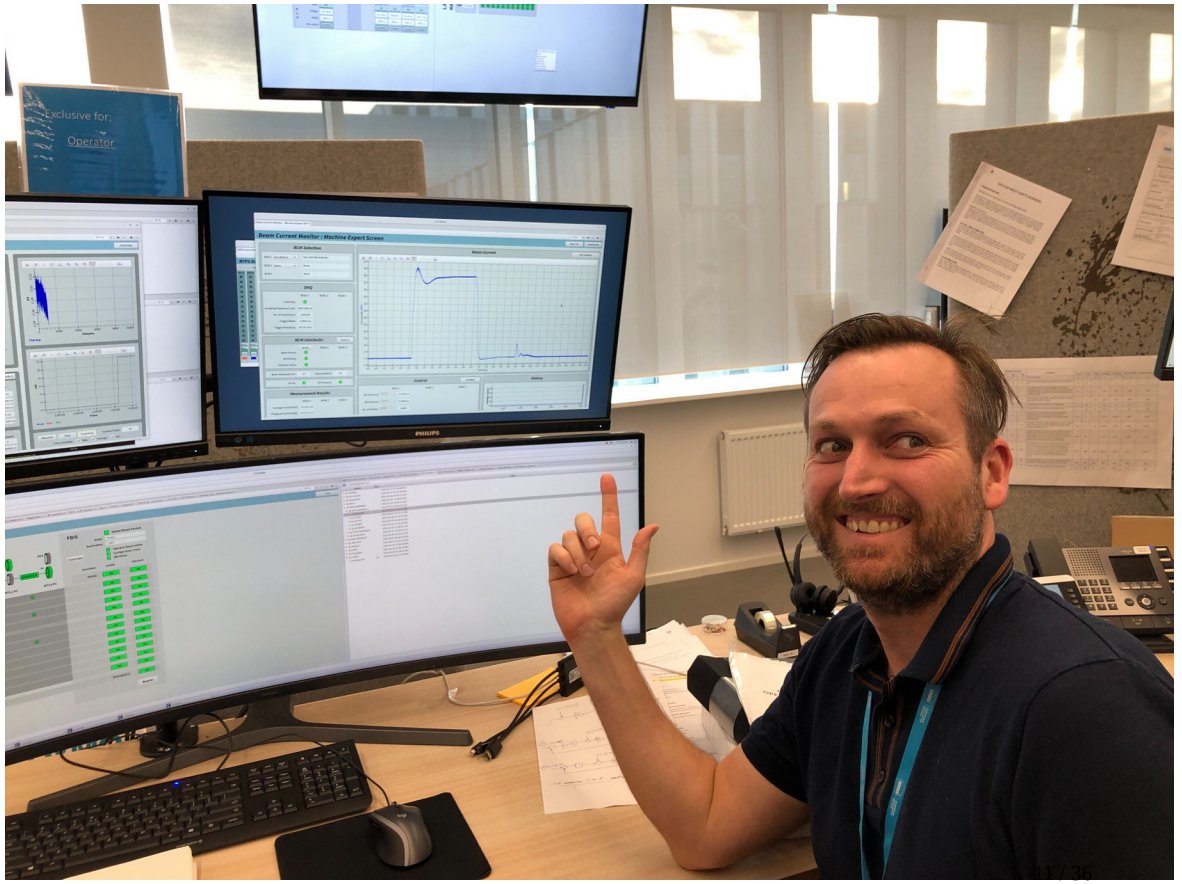

Milestones

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- April 19th First beam to MEBT FC

Milestones

Throughout commissioning

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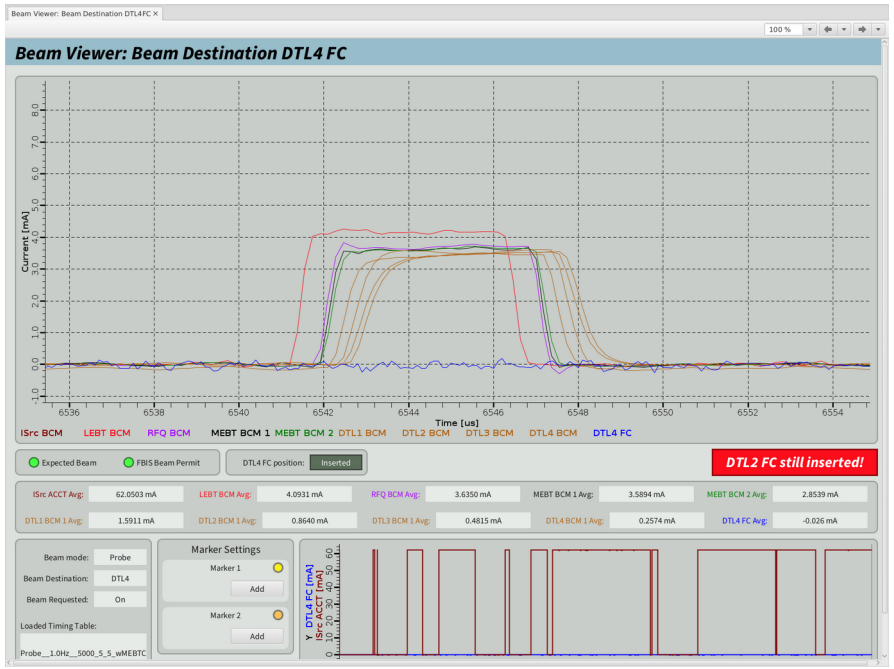
- April 19th First beam to MEBT FC
- April 20th First beam through DTL4



Milestones

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- May 4th First beam seen by DTL4 FC

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- May 30th First 50us beam through DTL4

Milestones

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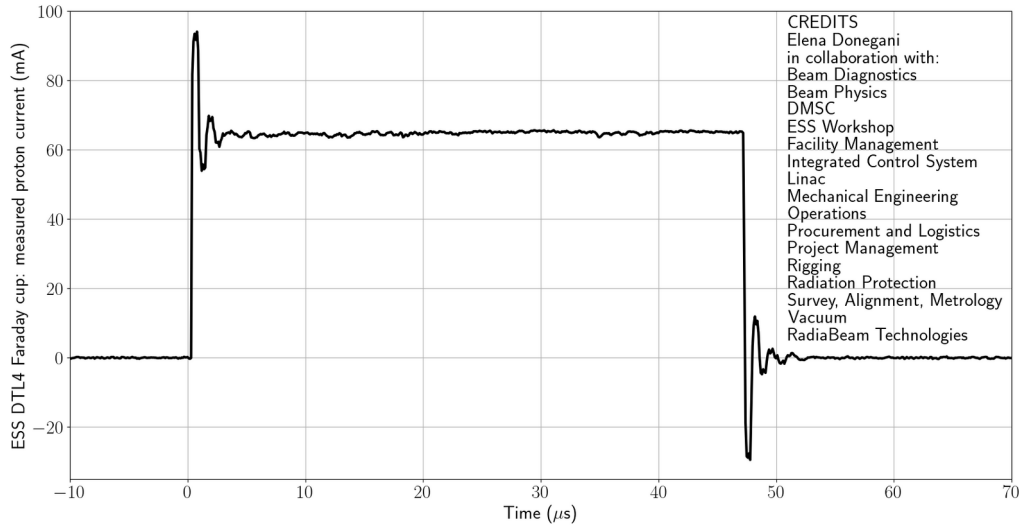
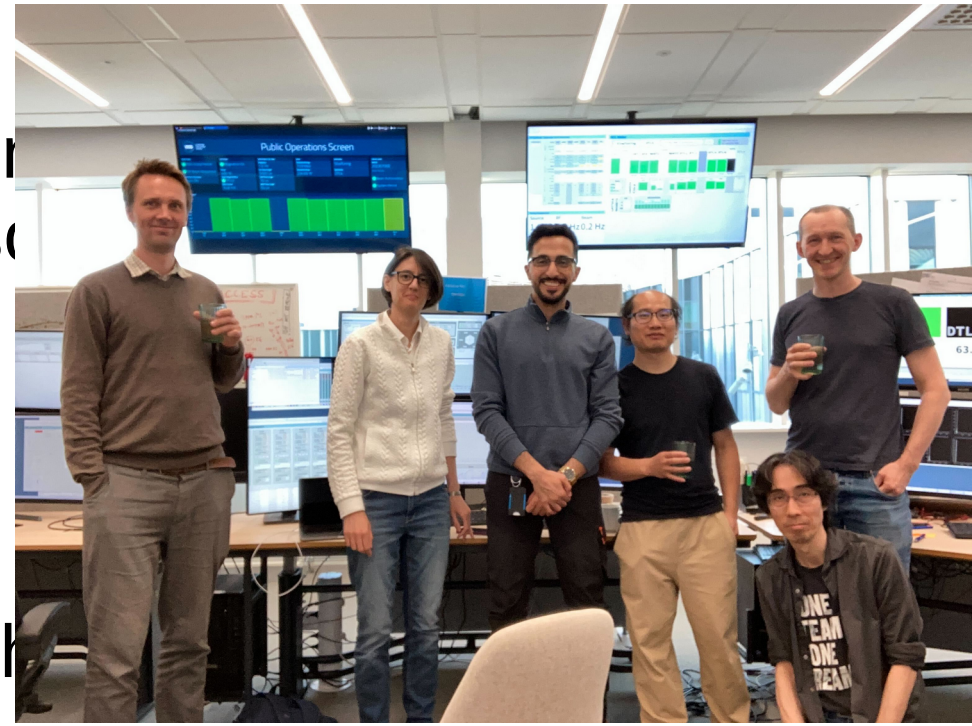
- July 6th First 50us, 62.5 mA beam through DTL4

Milestones





- May 30th First 50us beam through DTL4
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- July 14th End of beam commissioning to DTL4

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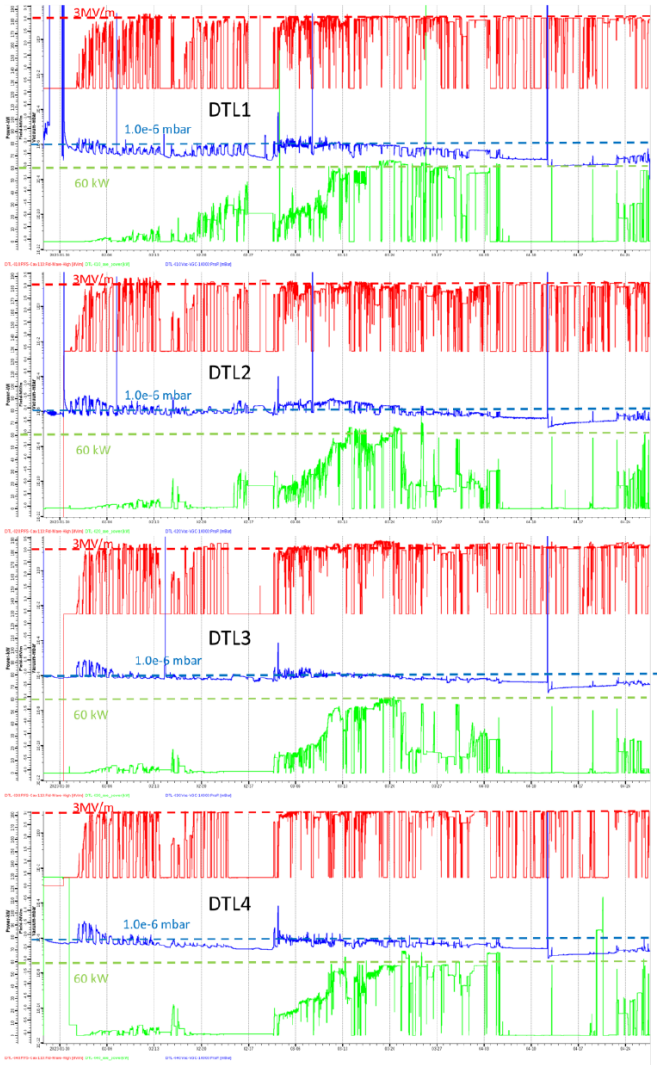
- May 4th First beam seen by DTL4 FC
- May 30th First 50us beam through DTL4
- July 6th First 50us, 62.5 mA beam through DTL4
- July 14th End of beam commissioning to DTL4
- August 1st Last day of beam commissioning run

RF Commissioning

A major non-beam goal of the commmissioning

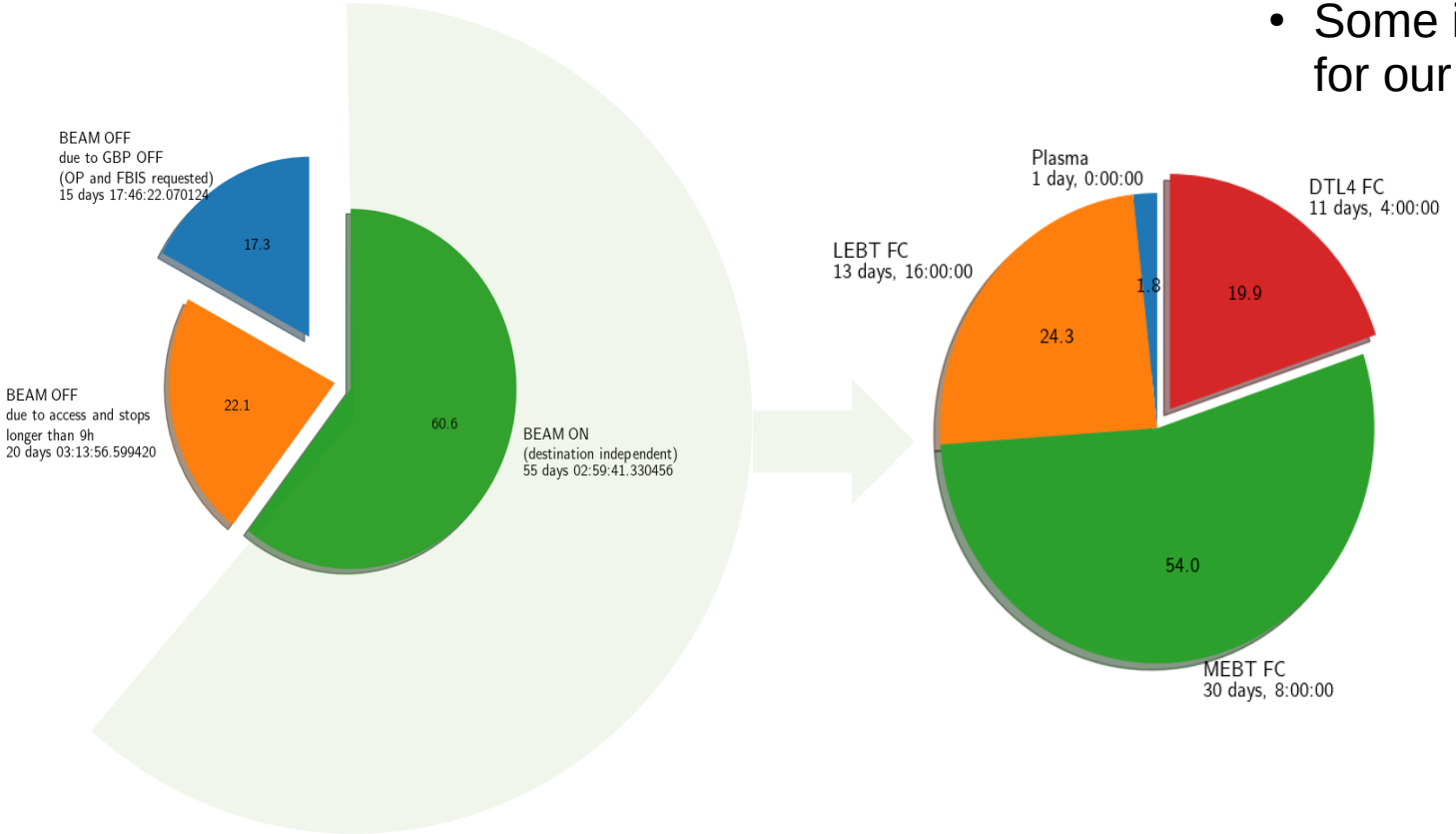
- Overall goal for DTLs was >12hrs with >95% RF at nominal parameters
- Started January 31st (first beam planned mid April)
- One DT replaced in DTL1 after 2022 commissioning
- Quickly reached nominal field for short pulse
- First half of March all DTLs close to reach goals
- Second half of March DTL2&3 RF windows arching



Francesco Grespan/INFN

Beam Availability

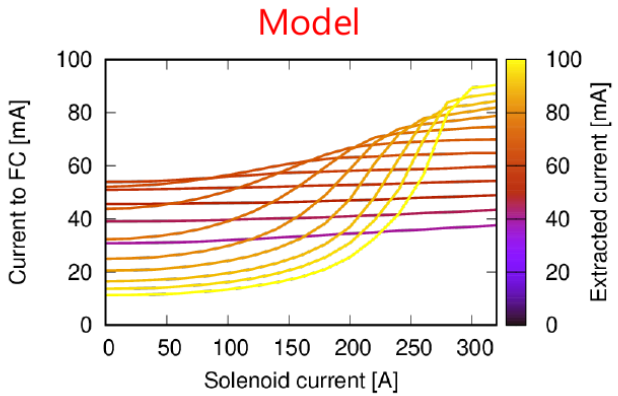
- 24/7 running March – mid July
- Excellent support from the OPs crew
- Beam availability good for early stage
- Some interlock/trip analysis work to be done for our 95% availability goal

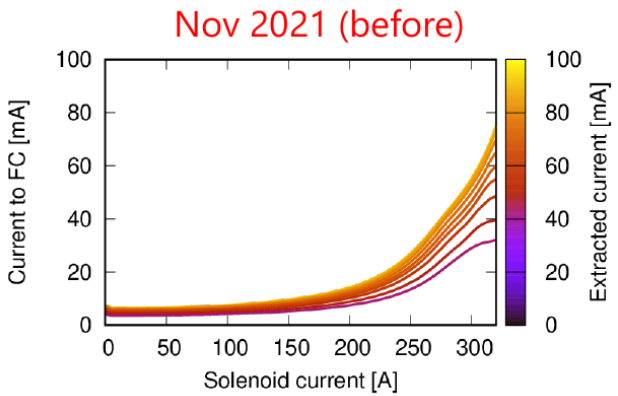


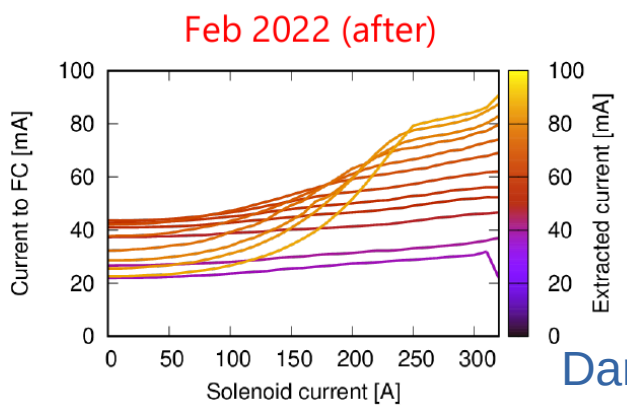
Arkadiusz Gorzawski

Ion Source extraction

Repeller issue

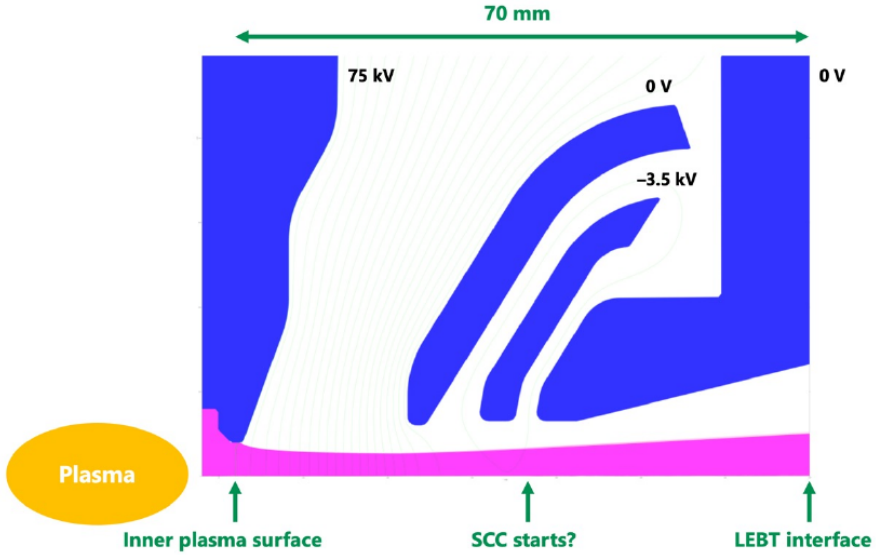






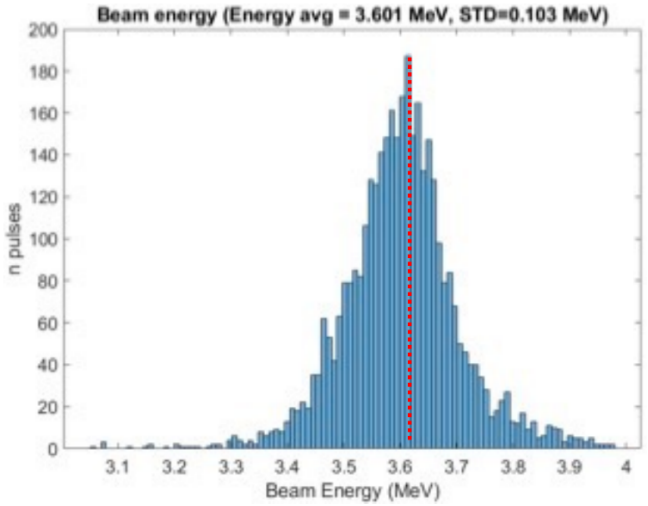
Daniel Noll

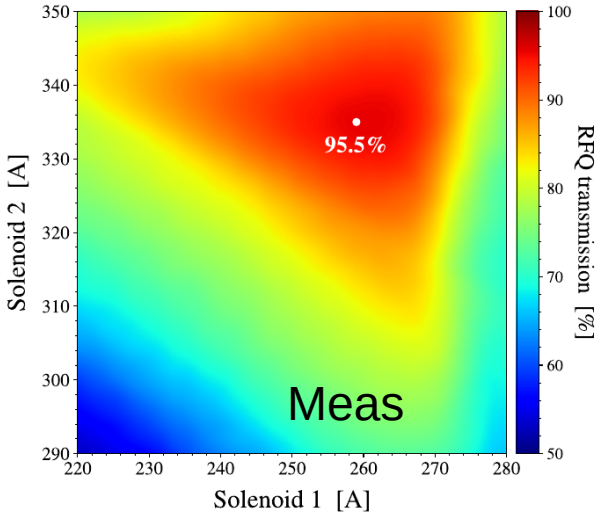
- Large initial divergence and emittance observed during the source+LEBT commissioning in 2019.
- Discovered source repeller was disconnected (maintenance Jan 2022)
- Significantly improved model consistency!
- Data from 2019 less relevant

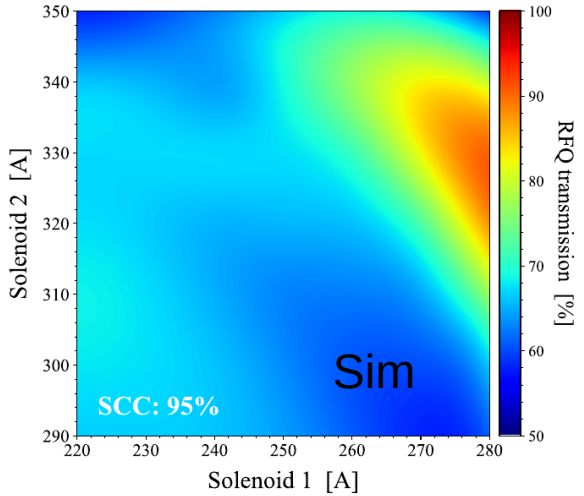


RFQ Characterization

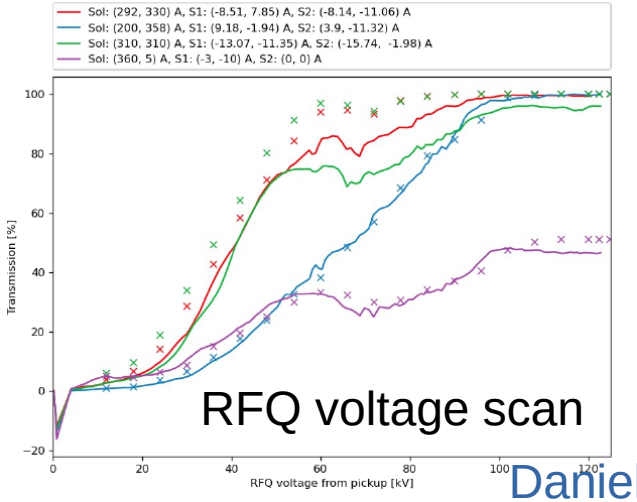
MEBT ToF - FBPM







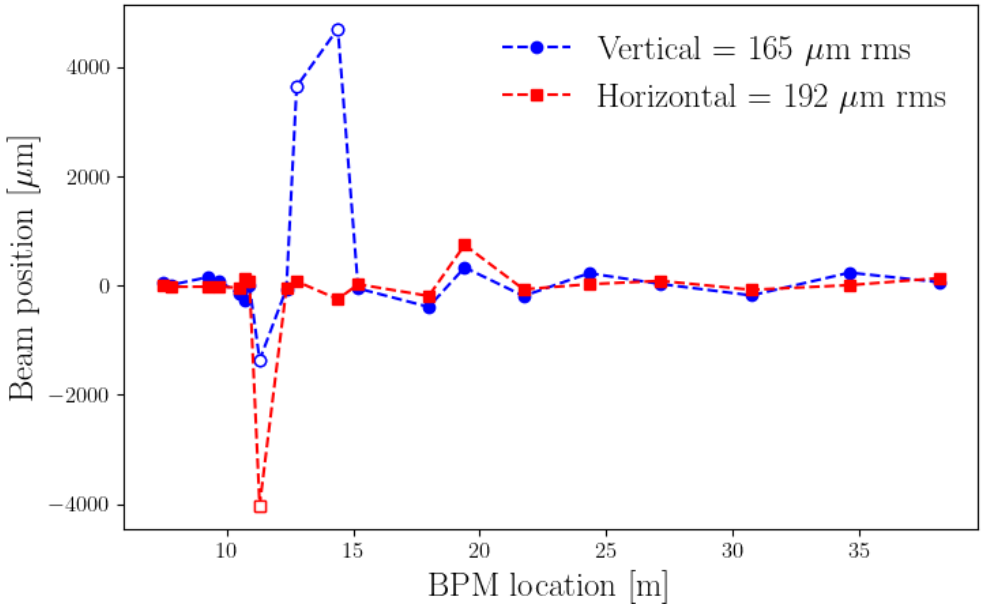
- Time-of-flight confirmed ~3.6 MeV
- Voltage scan matched well to reconstructed model
- Transmission match expectations from model (96-98%), solenoid scan pattern differ



Daniel Noll

Trajectory Correction

- Total of 20 BPM’s in the NCL
- RF noise challenges on certain DTL BPMs
- Polarity checks BPMs, correctors
- Ignoring a few BPMs we got a good RMS
- We use SVD for matrix inversion



Natalia Milas

Phase Scans

3 MEBT bunchers and 4 DTL tanks

- 3 bunchers
- 4 DTL tanks (3 new)
- 20 BPMs
- Manual set up still achievable
  - For SCL 146 cavities → automation essential
- Frequency jump between Spoke-MBL
  - Amplitude match particularly important

DTL scans

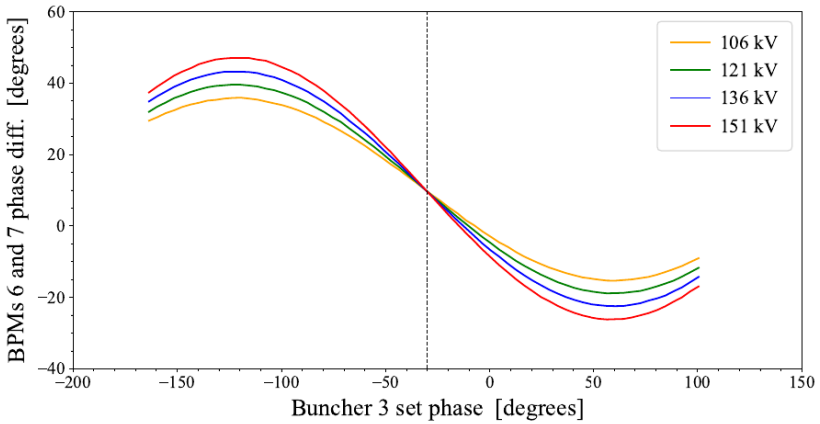
- First (few) internal BPM(s) → sine-like response
- Here we focus on online modelling & fitting
- For more details on DTL measurements, see
  M. Comunian et al. - THBP07

Buncher scans

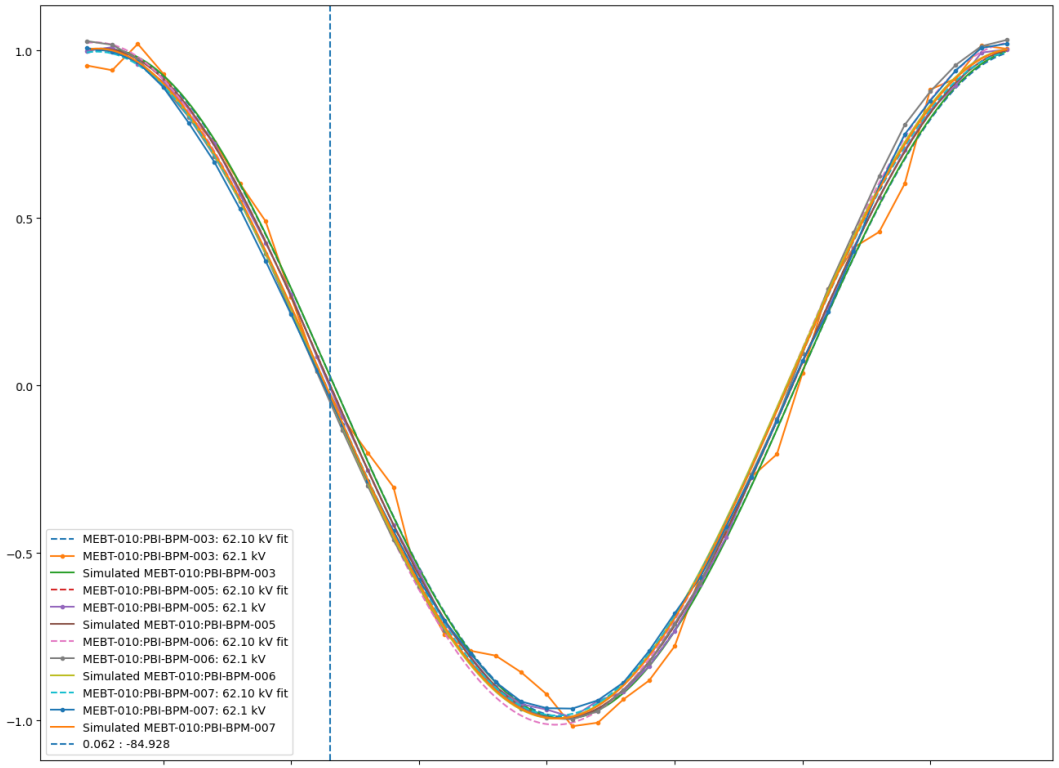
- Closest BPM may observe RF noise
- Model based (OpenXAL) BPM response fitting
- “Turning off” with time delay is fast
- Fully detuning is time consuming
- Aim for scans w/o needing to detune
  - Lowering current
  - Short pulse

Buncher Phase Scans

- Weighted sum of fit to expected model response of all BPMs
- BPMs close to buncher may see RF noise (orange)
- Automated fit in ~1 min per buncher



Buncher 2 scan

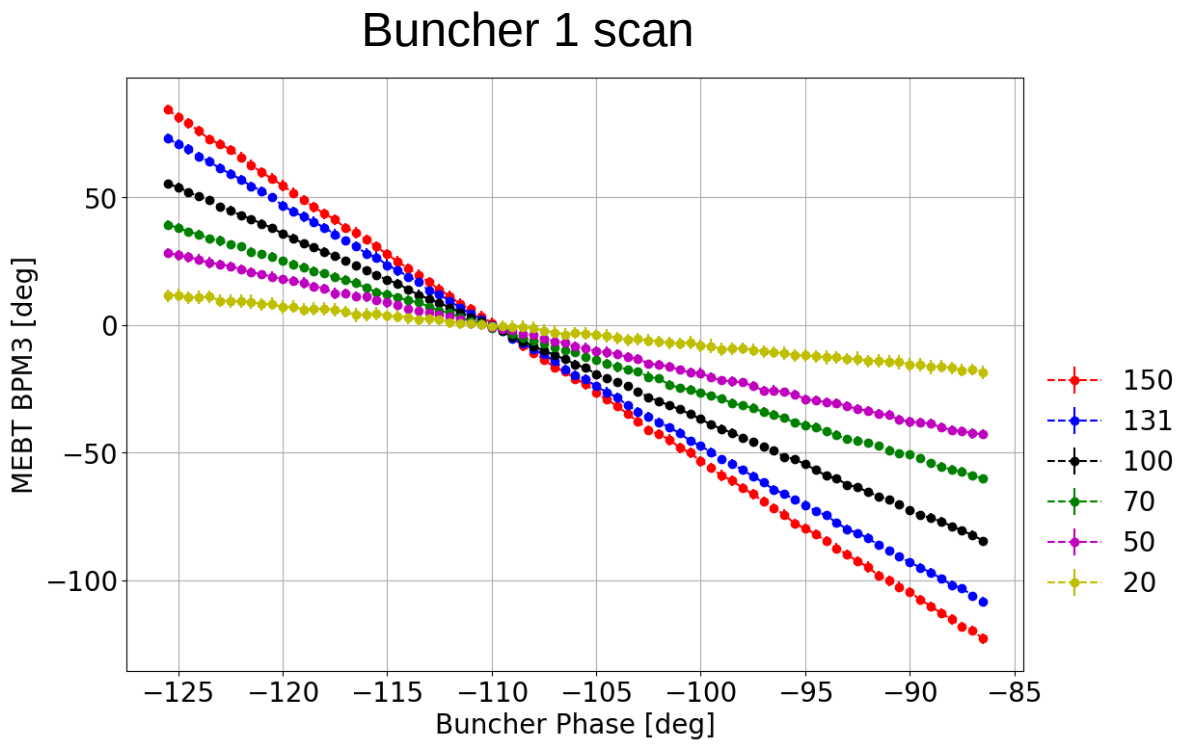


Buncher Phase Scans

To detune or not to detune

- Compared to measurements with fully detuned buncher 2
- BPM3 & 5 gave -110.4 & -111.2 deg
- Compared to -110.7 deg with no detuning
- Amplitude still to be fully verified
- Low current and short pulse seems reasonable

But ...

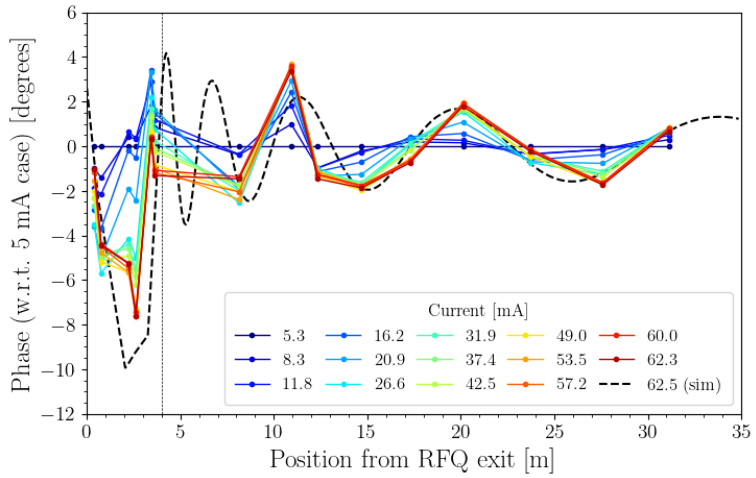


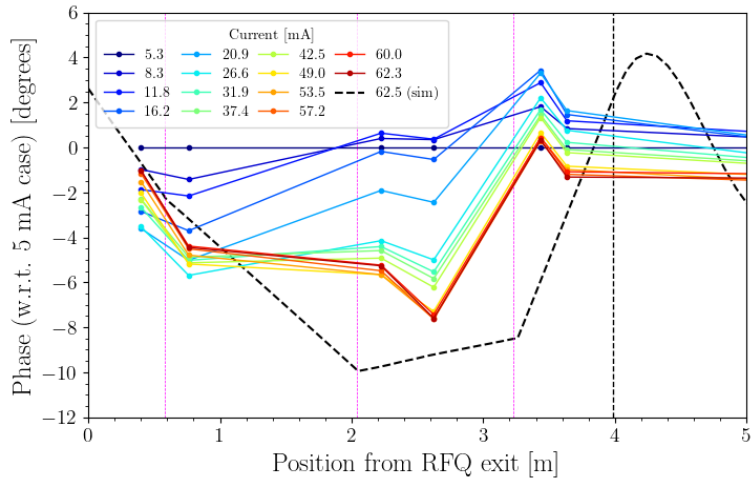
Phase/current dependence

Significant current dependence on beam phase out of RFQ

- Iris cuts of transverse tails → change energy distribution?
- Less severe when current is lowered by Sol2
- RF phase scan at low current, operations at full current
- Effect dampens with energy but emittance blows up.
- Depends on ISrc HV. (Energy mismatch?)

Note: requirements on the set phase/amp is 1-deg & 1%



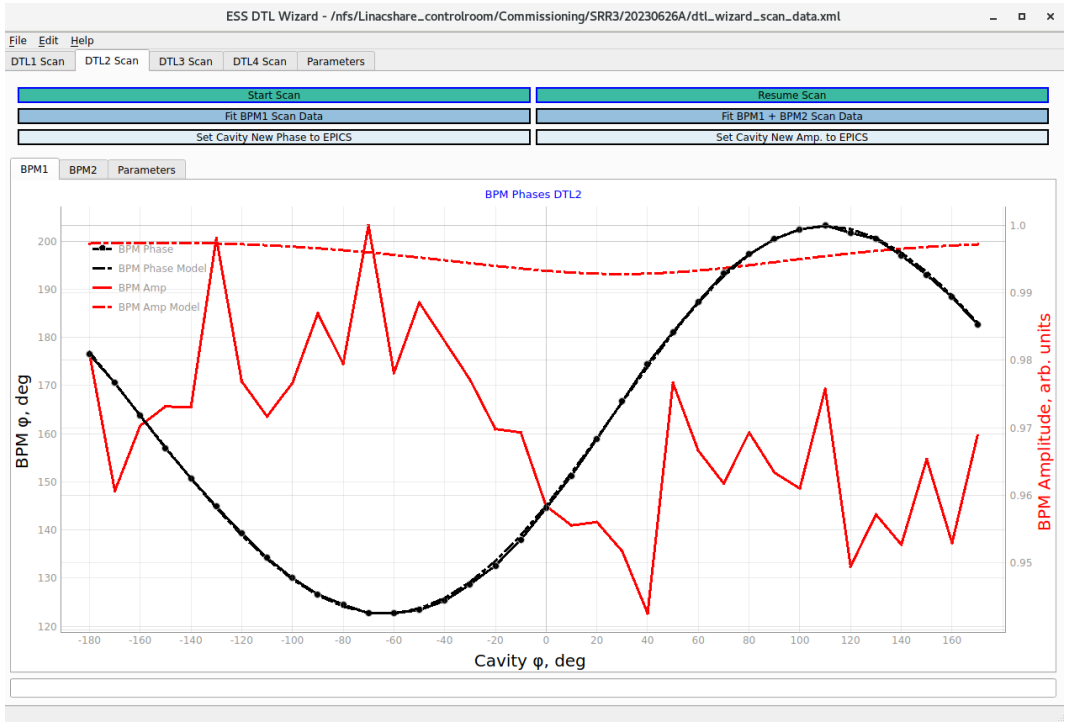


Ryoichi Miyamoto

DTL Phase Scans

DTL Wizard application

- Dr. A. Shishlo from SNS visited us for 3 months
- Focus on DTL phase scan strategy
- Developed a new application based on PyORBIT
- Together with Dr. S. Zhukov transitioned PyORBIT from Python2 to Python3
  github.com/PyORBIT-Collaboration/PyORBIT3
- Evaluated fitting strategy
  - Suggest BPM1 for first guess, BPM2 for precise fitting
- Model improvement identified: calibration of cavity amplitude should take into account the longitudinal bunch size



$$\Delta W = qV_0 \cdot TTF \cdot \cos(\phi_0)$$

$$\rho(\phi) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(\phi - \phi_0)^2}{2\sigma^2}}$$

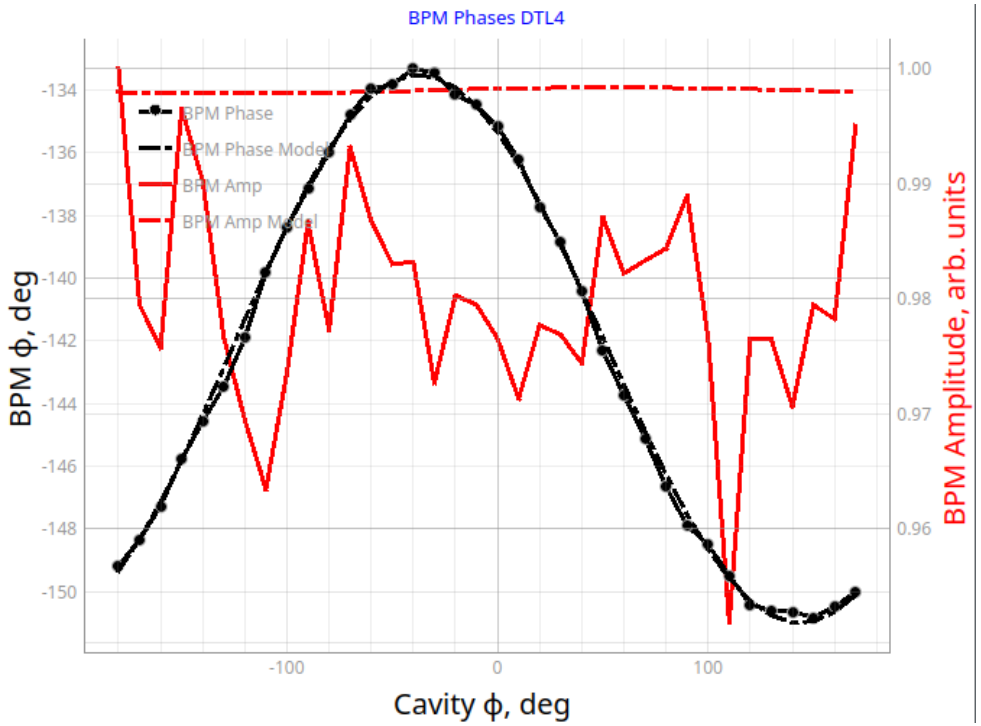
$$\langle \Delta W \rangle = \int \rho(\phi) \cdot qV_0 \cdot TTF \cdot \cos(\phi_0) d\phi = qV_0 \cdot TTF \cdot e^{-\frac{\sigma^2}{2}} \cdot \cos(\phi_0)$$

J. Müller - TUC2C2

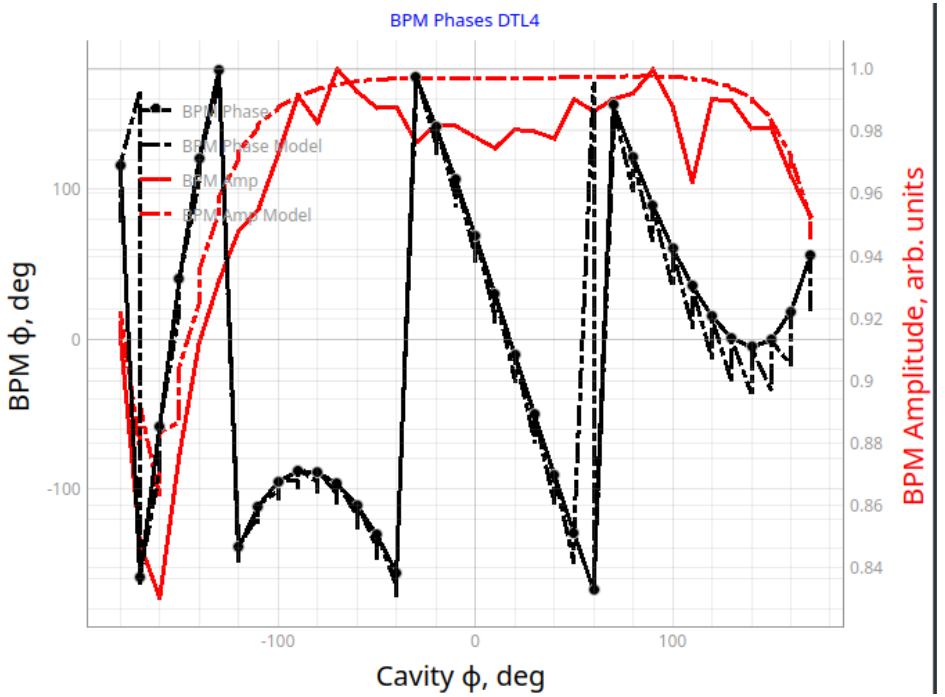
DTL Phase Scans

Fitting to internal BPM1 only

BPM1



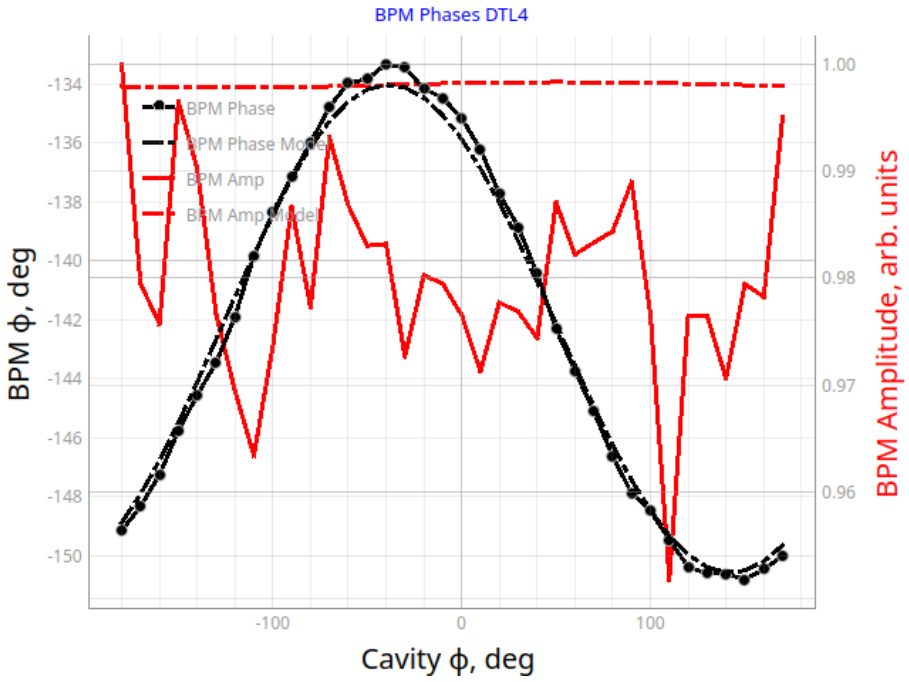
BPM2



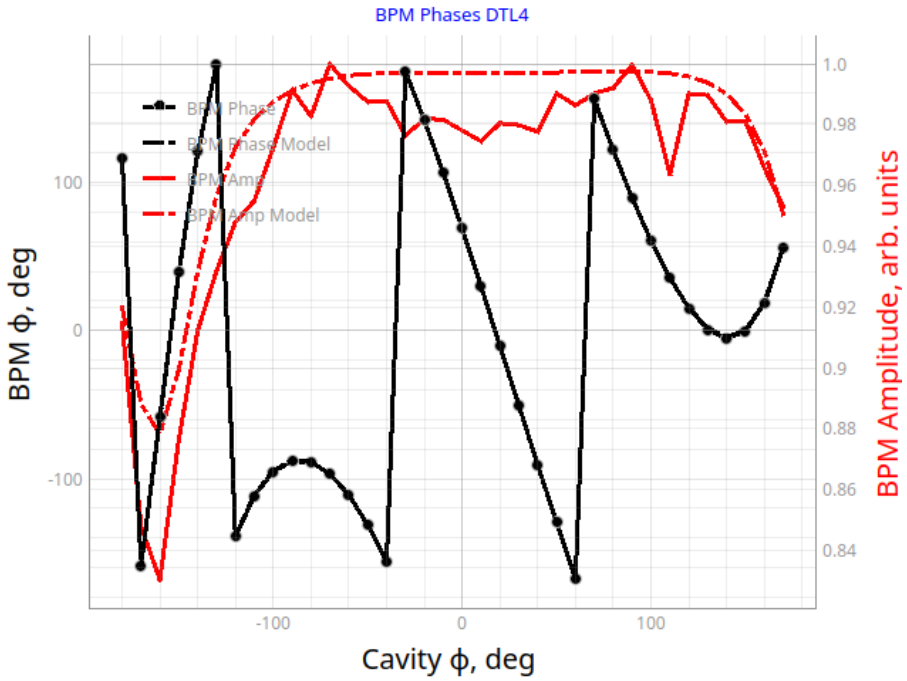
DTL Phase Scans

Fitting to internal BPM1 + BPM2

BPM1



BPM2

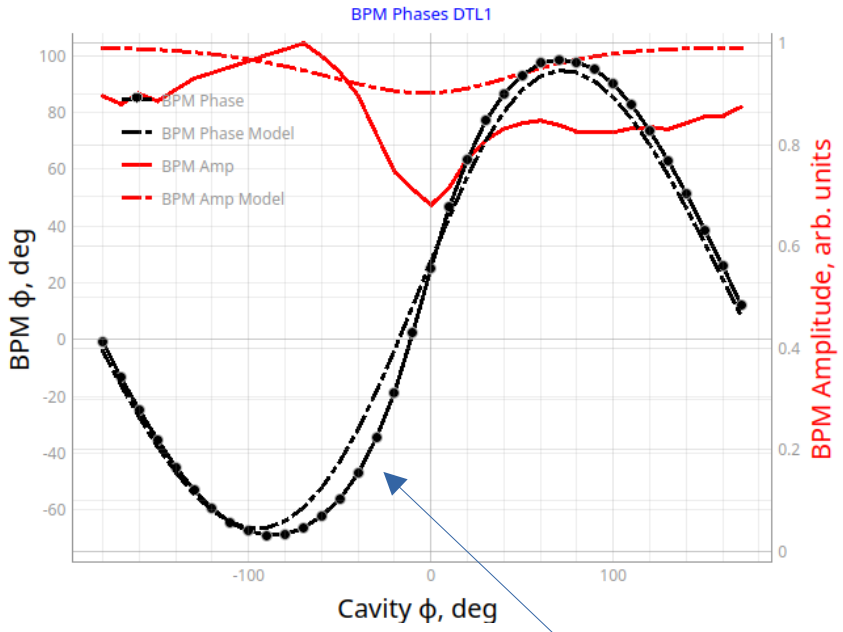


Improved fitting BPM1+2: Use predominantly BPM2 data

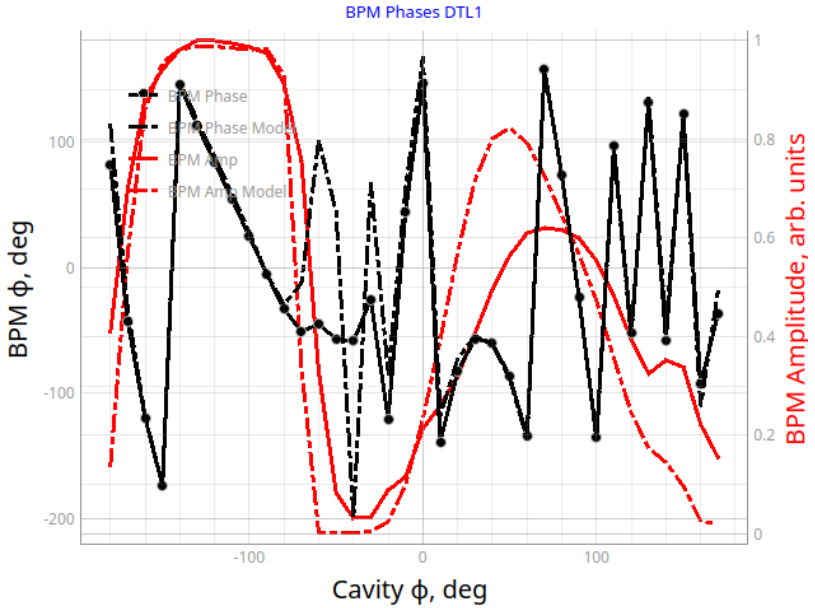
DTL1 Phase Scans

Fitting to internal BPM1 + BPM2

BPM1



BPM2



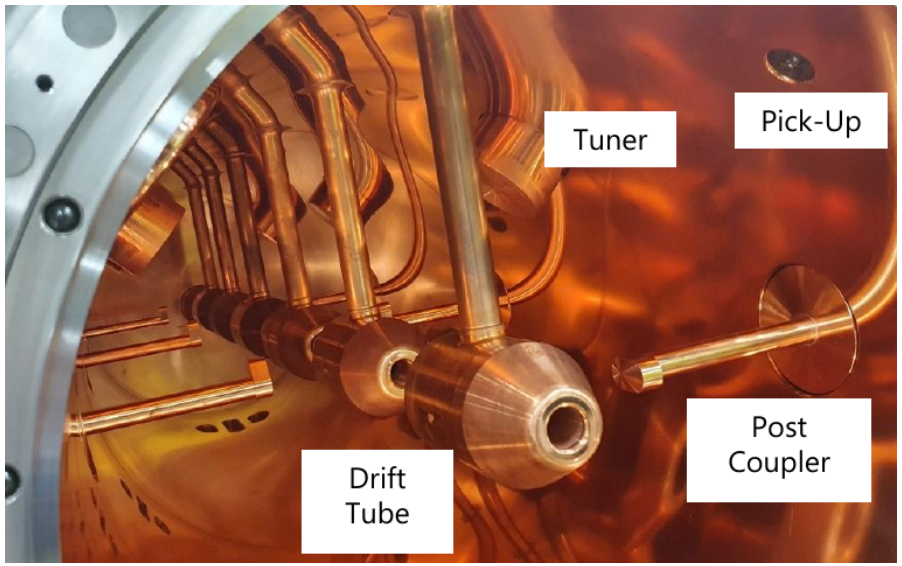
Generally DTL1 harder to fit
- matching issues?

DTL1 Phase Scans

Reproducibility?

Shift	DTL1	DTL2	DTL3	DTL4
20230530B	2.89/-131.8	3.0/-101.4	3.25/-198.1	**2.58**/75.8
20230602B	N/A	3.09/-95.1	3.24/-162.9	2.84/101.0
20230602B	N/A	3.11/-99.0	3.27/-161.6	2.84/101.3
20230626A	2.85/-131.3	3.08/-96.2	3.22/-159.6	2.86/109.1
20230711A	**2.91**/-152.4	3.08/-115.2	3.22/-179.6	2.85/88.01
20230711A	**2.65**/-155.9	3.09/-122.9	3.22/-180.3	2.84/90.2

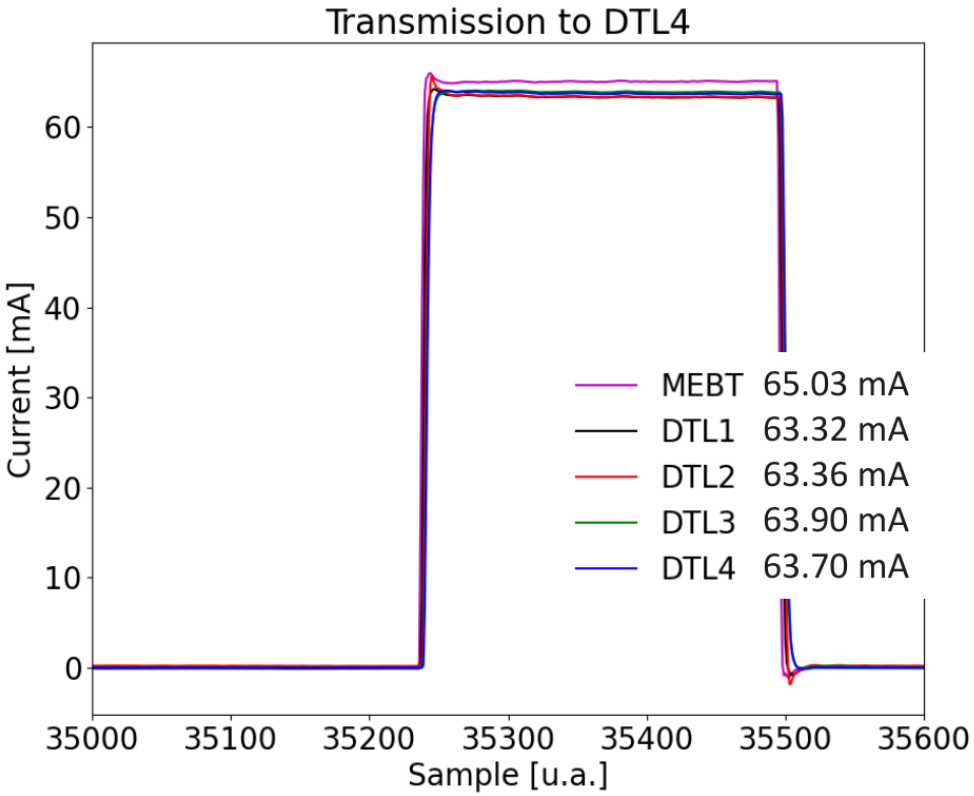
Selecting a different reference pickup?



Francesco Grespan/INFN

DTL Transmission

- Transmission in DTL ~100%
- Lose beam into DTL1
  - Input conditions?
  - Alignment issues?
  - Beam phase dependency on current in RFQ?



Natalia Milas

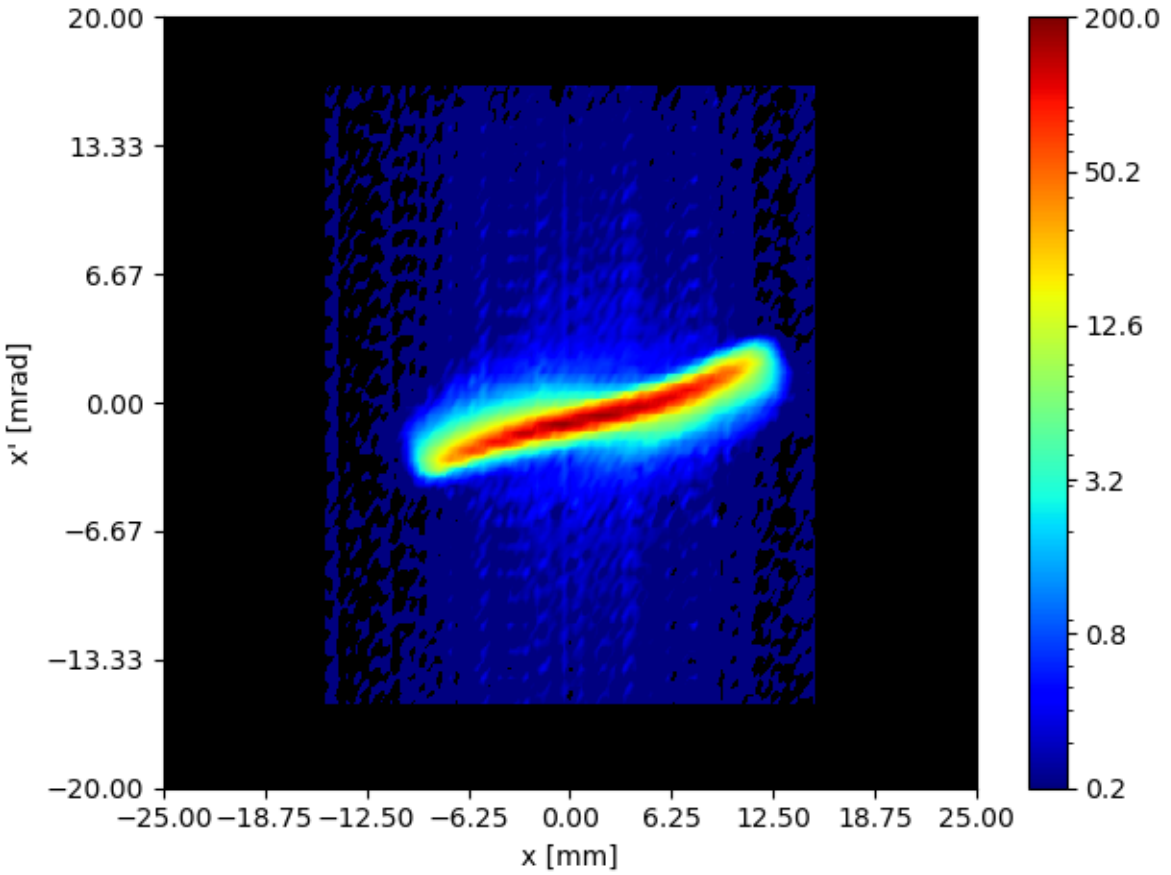
EMU H data

We had horizontal EMU available last days

Technical hurdles and resource limitations

Results fit very well with model predictions!

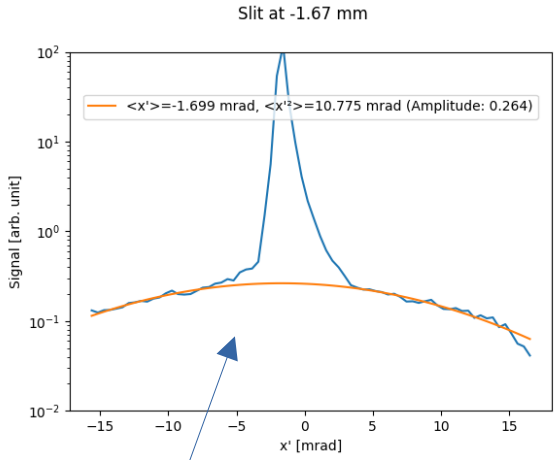
- very encouraging but we need more data

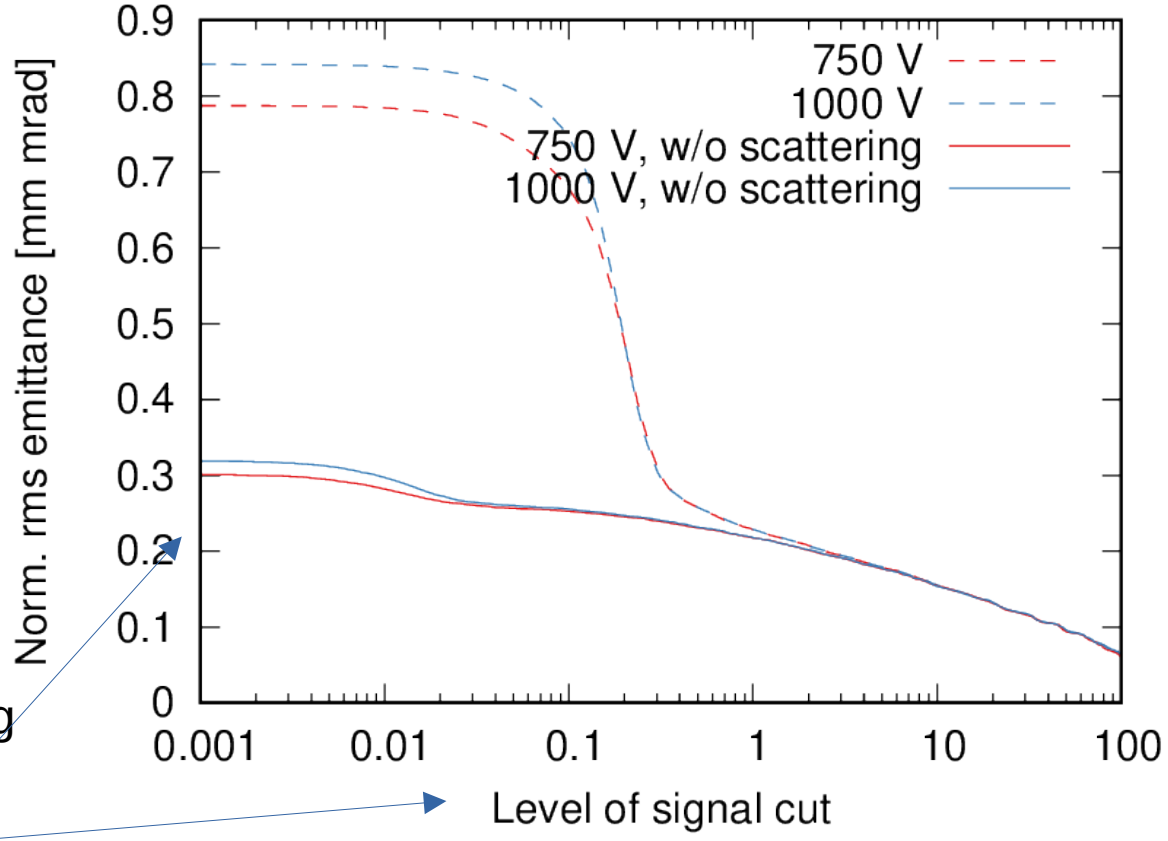


Daniel Noll

EMU H data

Background subtraction





- Assumes background comes from slit scattering
  - Gaussian distributed
- Fit Gaussian to background and subtract
- Then apply flat signal cut
- ESS design 0.25 mm mrad out of RFQ

Daniel Noll

Full NCL installed

End of September we had the entire NCL installed

A particular congratulations and thanks to the INFN Legnaro colleagues!

Summary

- **Nominal, 50us beam transported through DTL4**
- Trajectory correction worked well
- Phase scan strategy works well
  - Seems precise, uncertain accuracy?
- Transverse measurement – encouraging
- More attention needed...
  - Matching into DTL1
  - Phase out of RFQ
  - Source characterization
  - 50 us → 2860 us
  - ...
- **A successful commissioning campaign**
  - **Many systems come together**
  - **Learn how to operate**
  - **Learn where attention is needed**