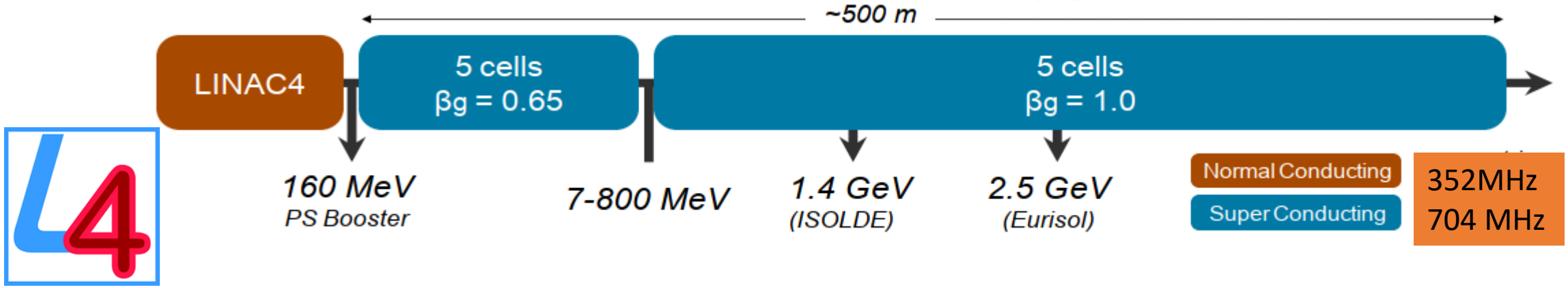
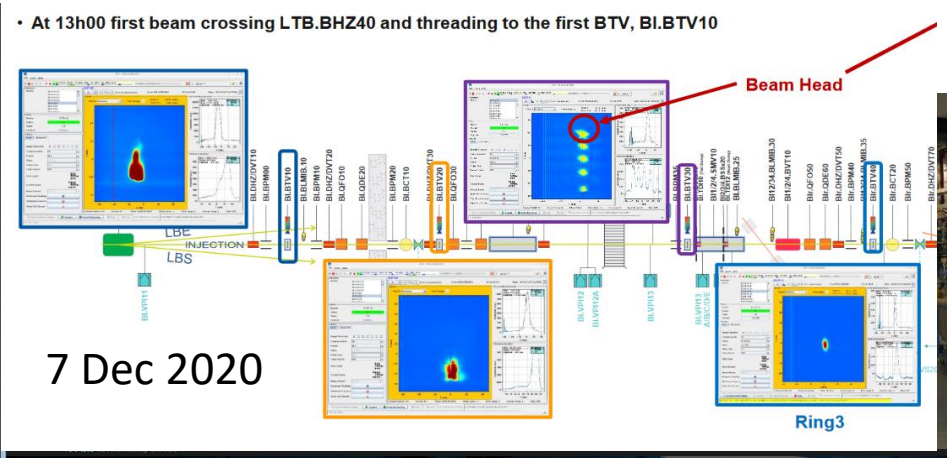
LINAC Activities

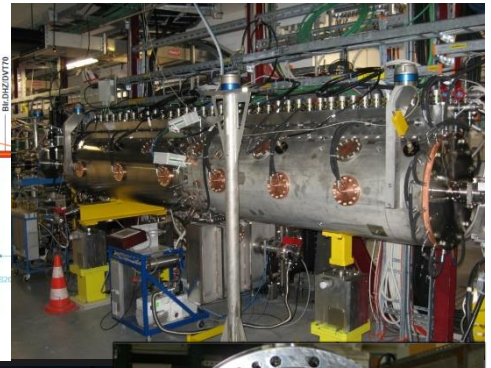
Alessandra Lombardi and the HSL team

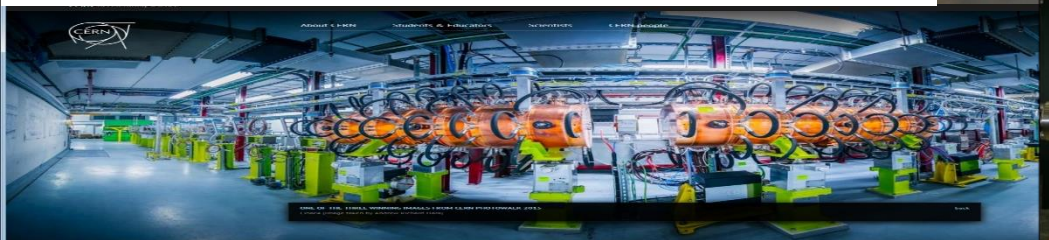
- Introduction
- Activities on the source brightness
- Activities on RFQ redesign
- Conclusions and outlook

LINACs for ν-fact or μ-collider – CERN 2010





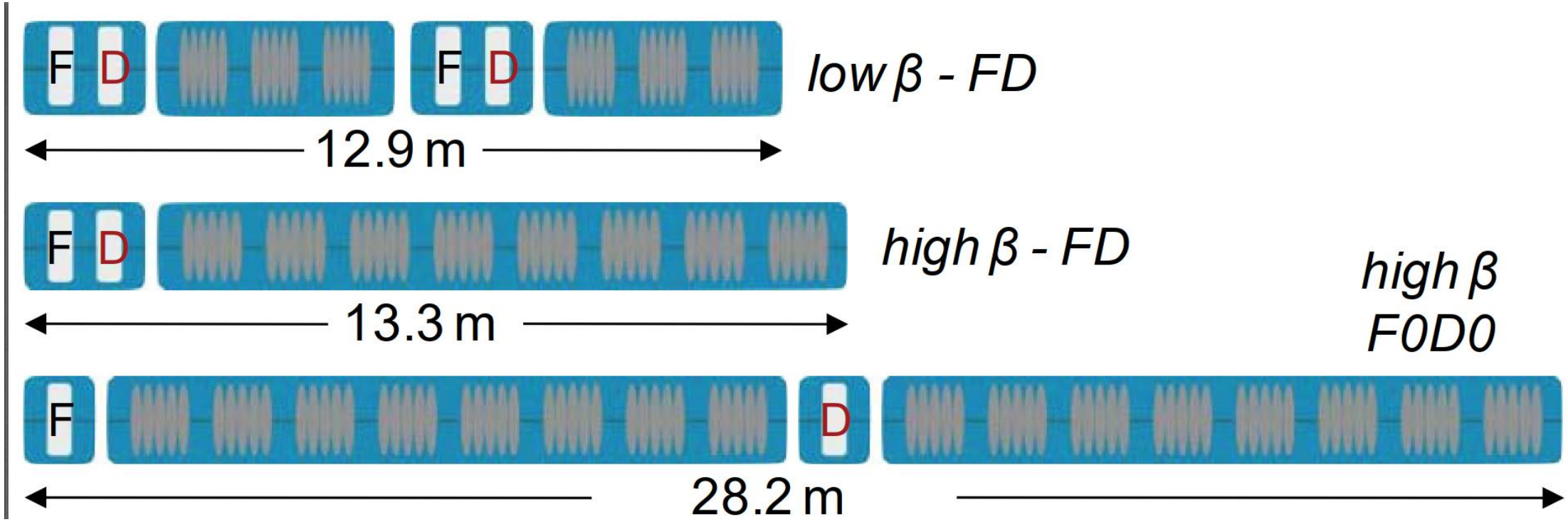




SPL parameters

Parameter	Unit	Low Current	High Current
Energy	[GeV]	5	
Beam power	[MW]	4	
Rep. rate	[Hz]	50	
Av. pulse current	[mA]	20	40
Peak pulse current	[mA]	32	64
Source current	[mA]	40	80
Chopping ratio	[%]	62	
Beam pulse length	[ms]	0.8	0.4
Protons per pulse		10^{14}	
Beam duty cycle	[%]	4	2
Length	[m]	~500	

Building blocks of the superconducting part



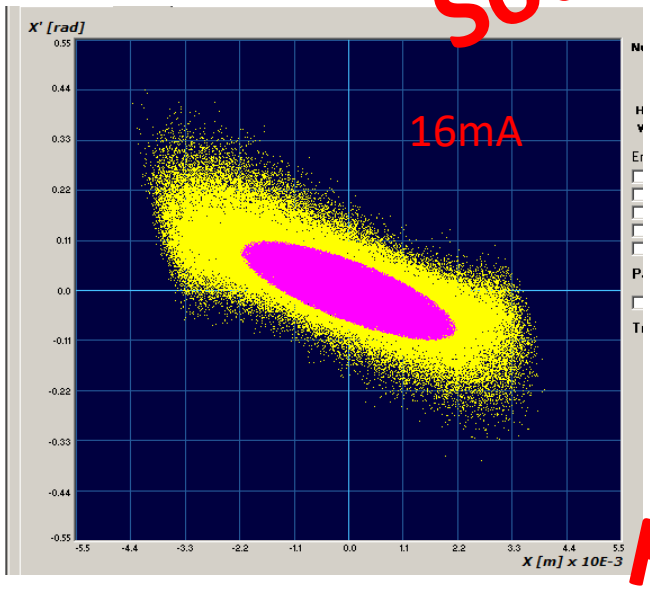
CERN 2013 : pre-injector challenge

Source redesign

IS-O2 (25mA in RFQ acceptance)

IS-O3 (35mA in RFQ acceptance)

IS-04 (50mA in RFQ acceptance)



2013: Comparison of **measured emittance** (yellow) and RFQ acceptance (pink). The expected transmission thru the RFQ is 75%. (PARMTEQ + TOUTATIS).

RFQ redesign

3m high-field (2018)

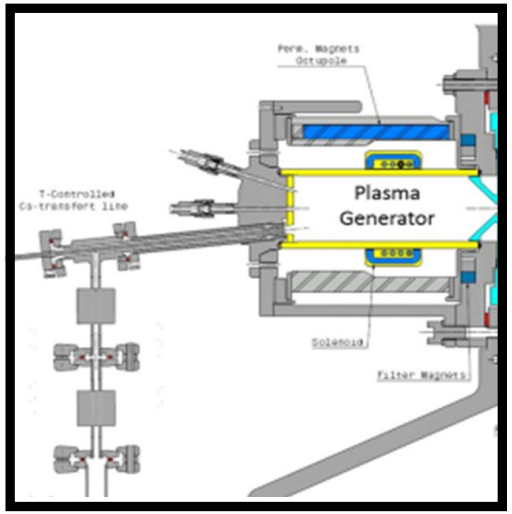
RFQ3 2021

IS04 vs IS03: What's new?

IS03 and IS04 have identical plasma generators:

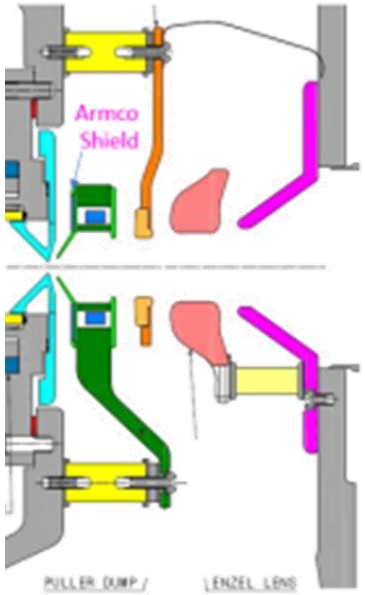
- Plasma chamber.
- RF system (amplifier and antenna).
- Gas injection system.
- Cesiation system.

IS03 and IS04 have different extraction and electron dumping schemes

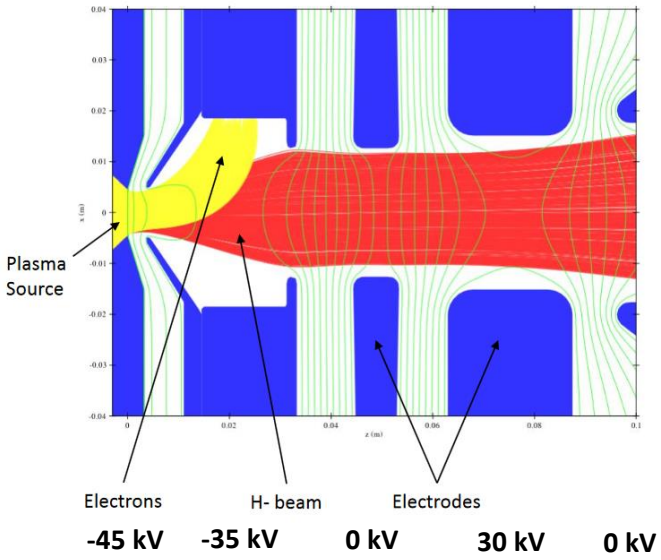


IS04 vs. IS03

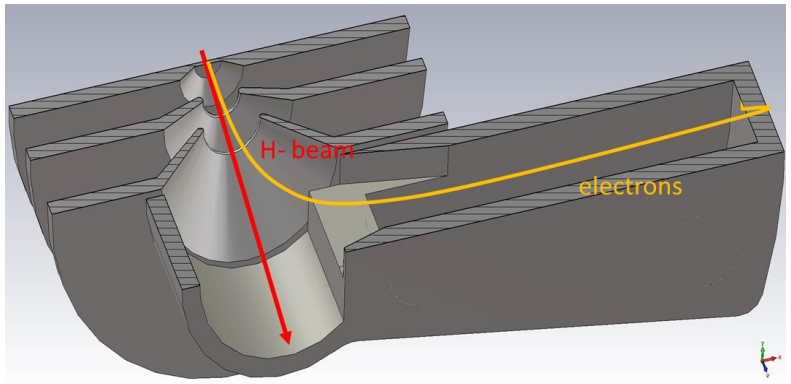
- ✓ Simplified design with only plasma, puller and ground electrodes: Eliminated puller-dump and Einzel lens causing emittance growth.
- ✓ 6 cm shorter.
- ✓ Co-extracted 45 keV e^- onto a dedicated dump.

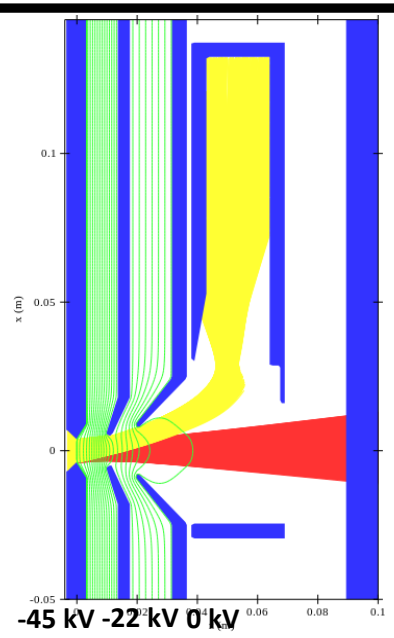


IS03 – Dumping 10 keV e^-



IS04 – Dumping 45 keV e^-

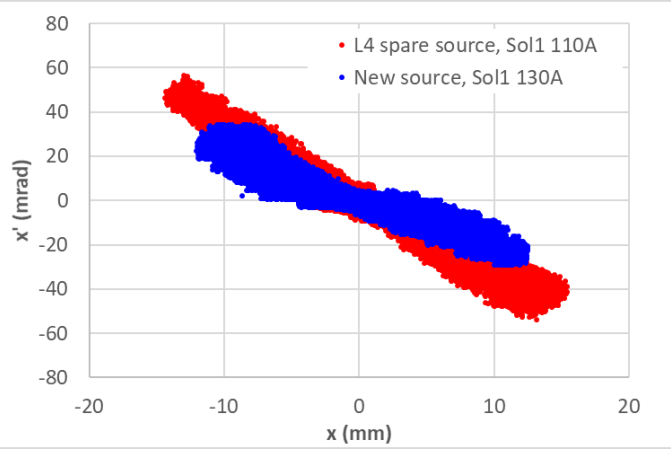


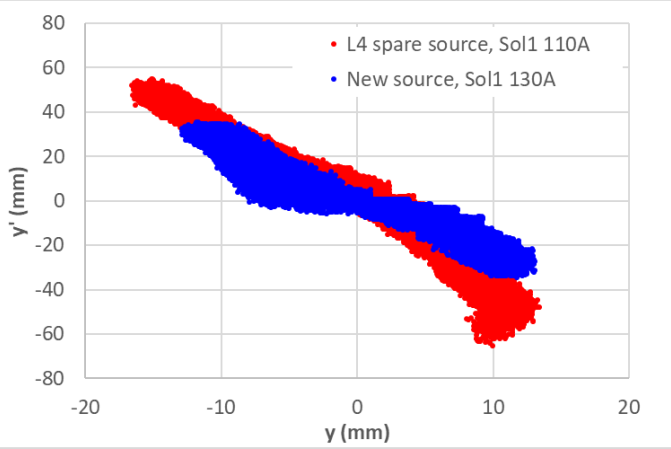


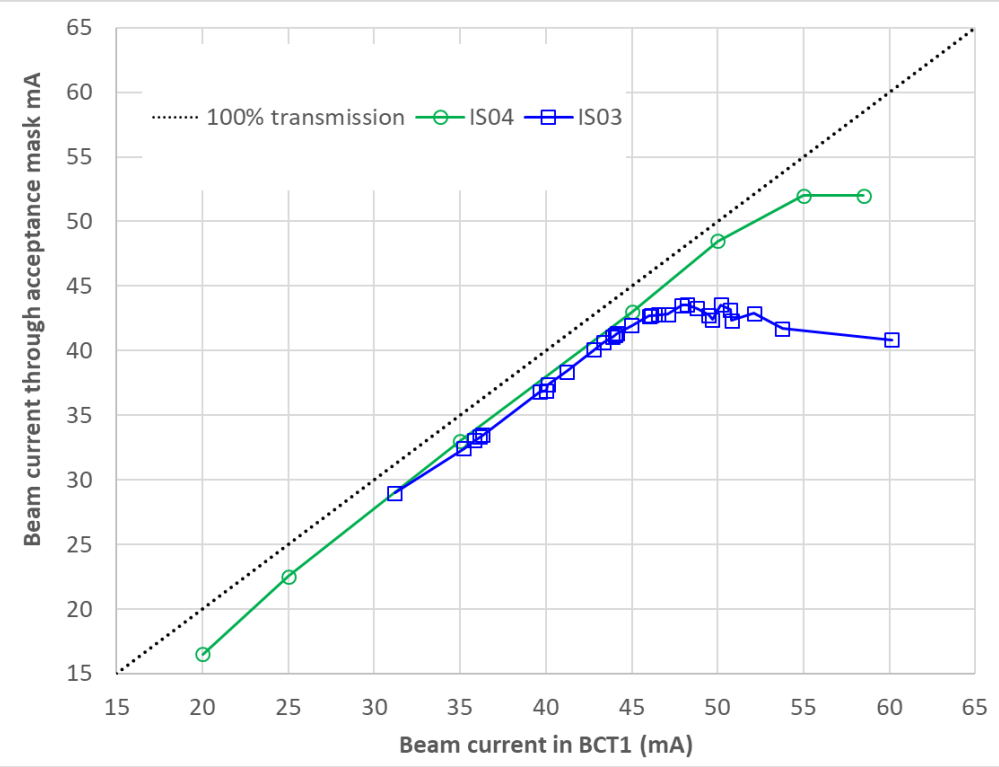
Test Stand results

With IS04 better quality beam at the test stand during 2021 (run for 20 weeks total)

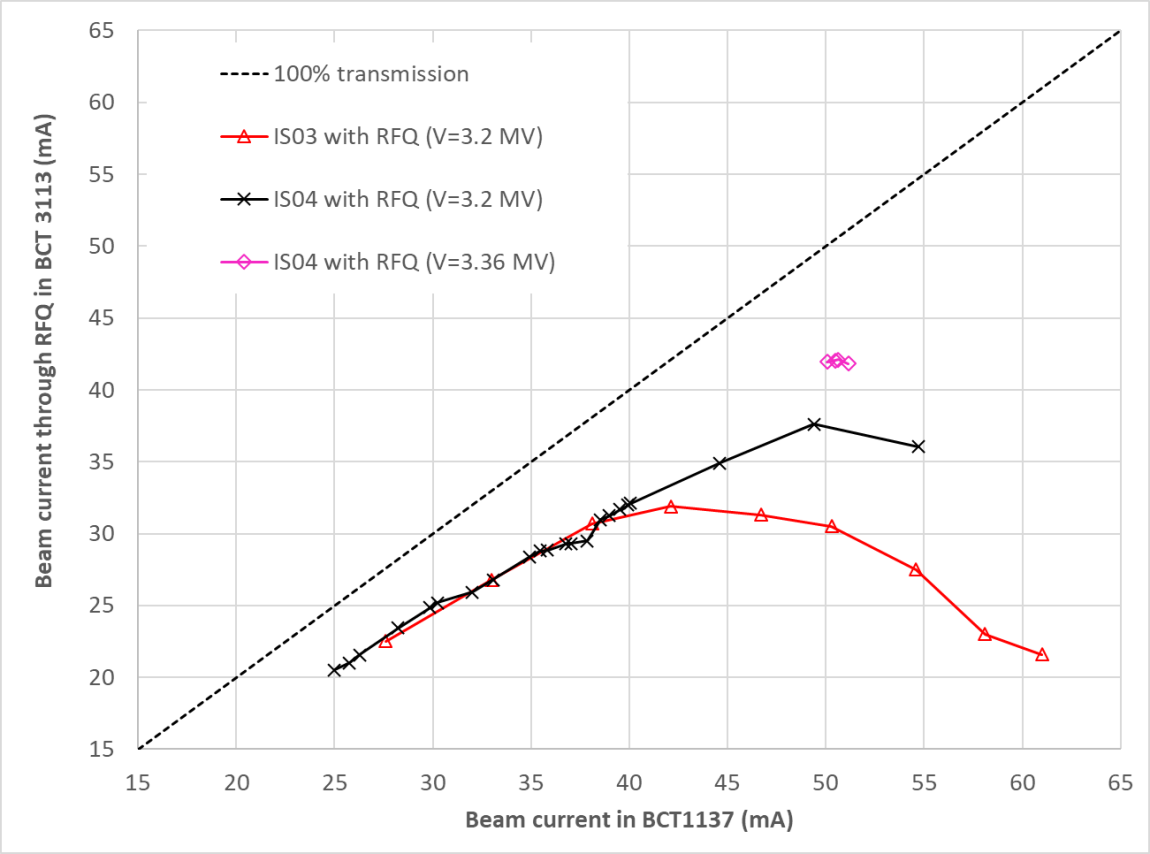
Emittance at 35 mA	IS03	IS04	Δ (%)
XX' norm. RMS emittance (π.mm.mrad)	0.34	0.26	-23.5
YY' norm. RMS emittance (π.mm.mrad)	0.40	0.32	-20.0
Stability at 35 mA	**IS03**	**IS04**	**factor**
Sigma (%) over 24 h	0.81%	0.41%	2
Sigma (%) over a week	1.1%	0.61%	1.8



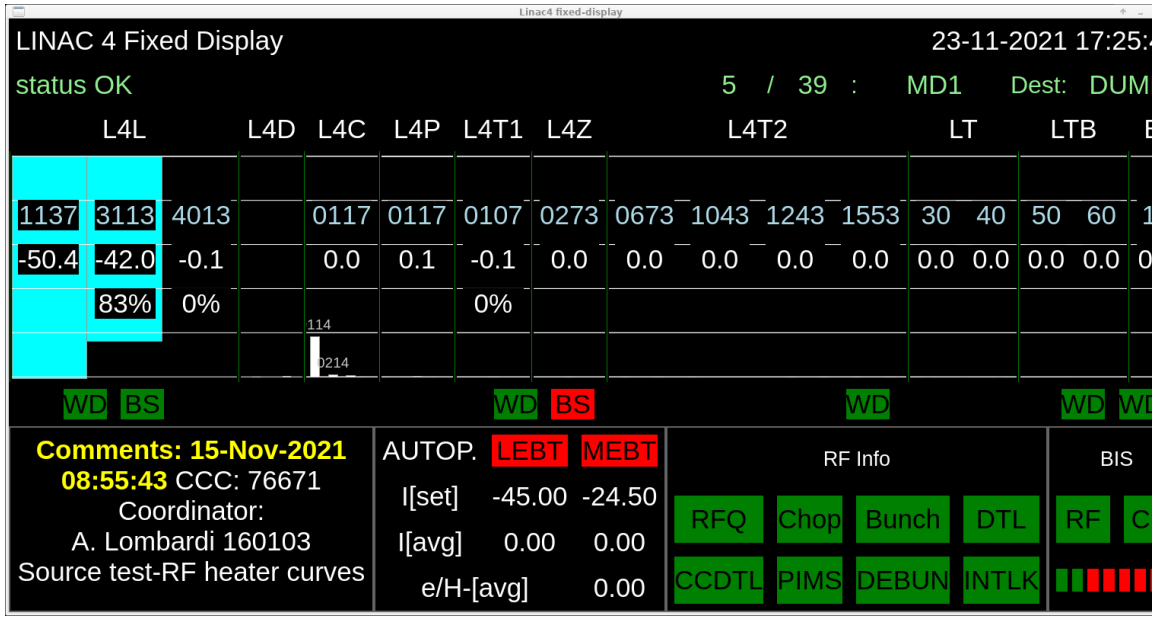




Confirmed at LINAC4 19-23 November 2021



RFQ V=3.2 MV (operational): Comparable performance (and potentially better with further optimization) for beam current <40 mA but considerably better above that.



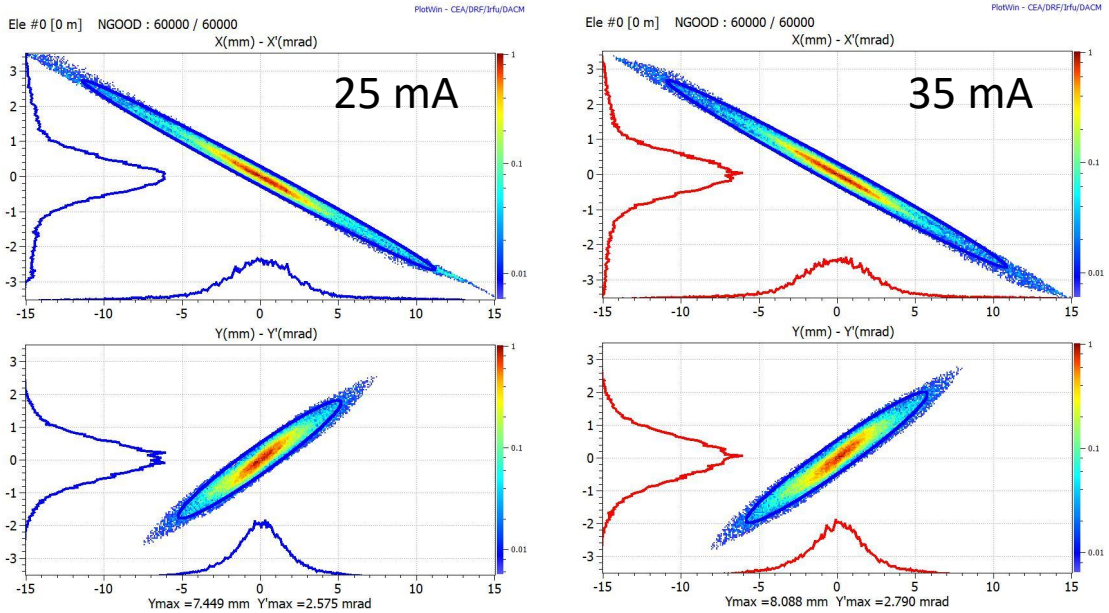
RFQ V=3.36 MV: 42 mA out of the RFQ for 50.4 mA input – RECORD

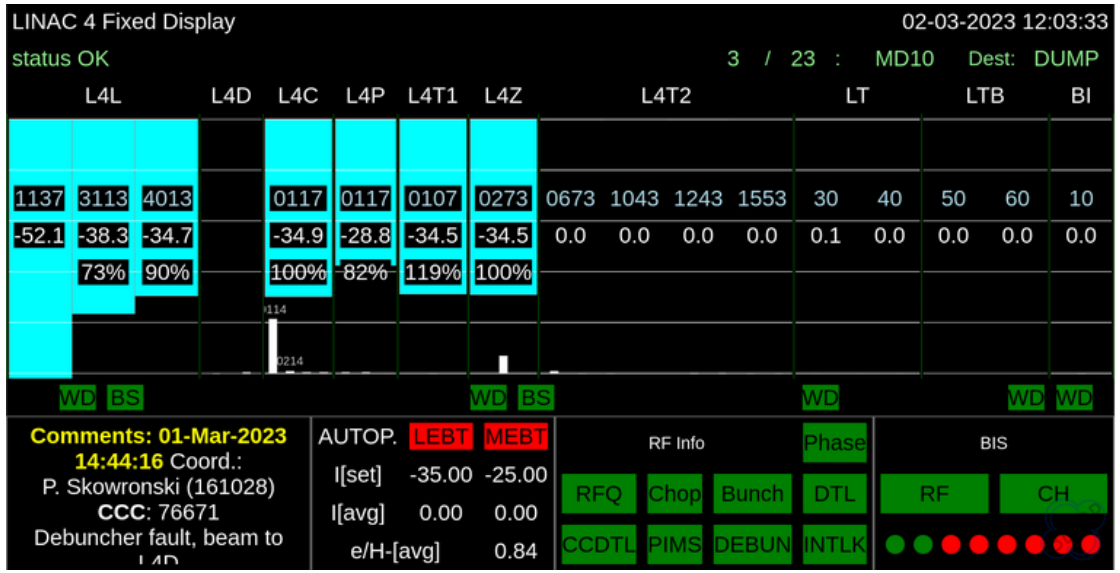
IS04 installed as operational source 2023

Allows for Machine Developments at higher current

On 02/03/2023 we increased the source current in steps to 50 mA.

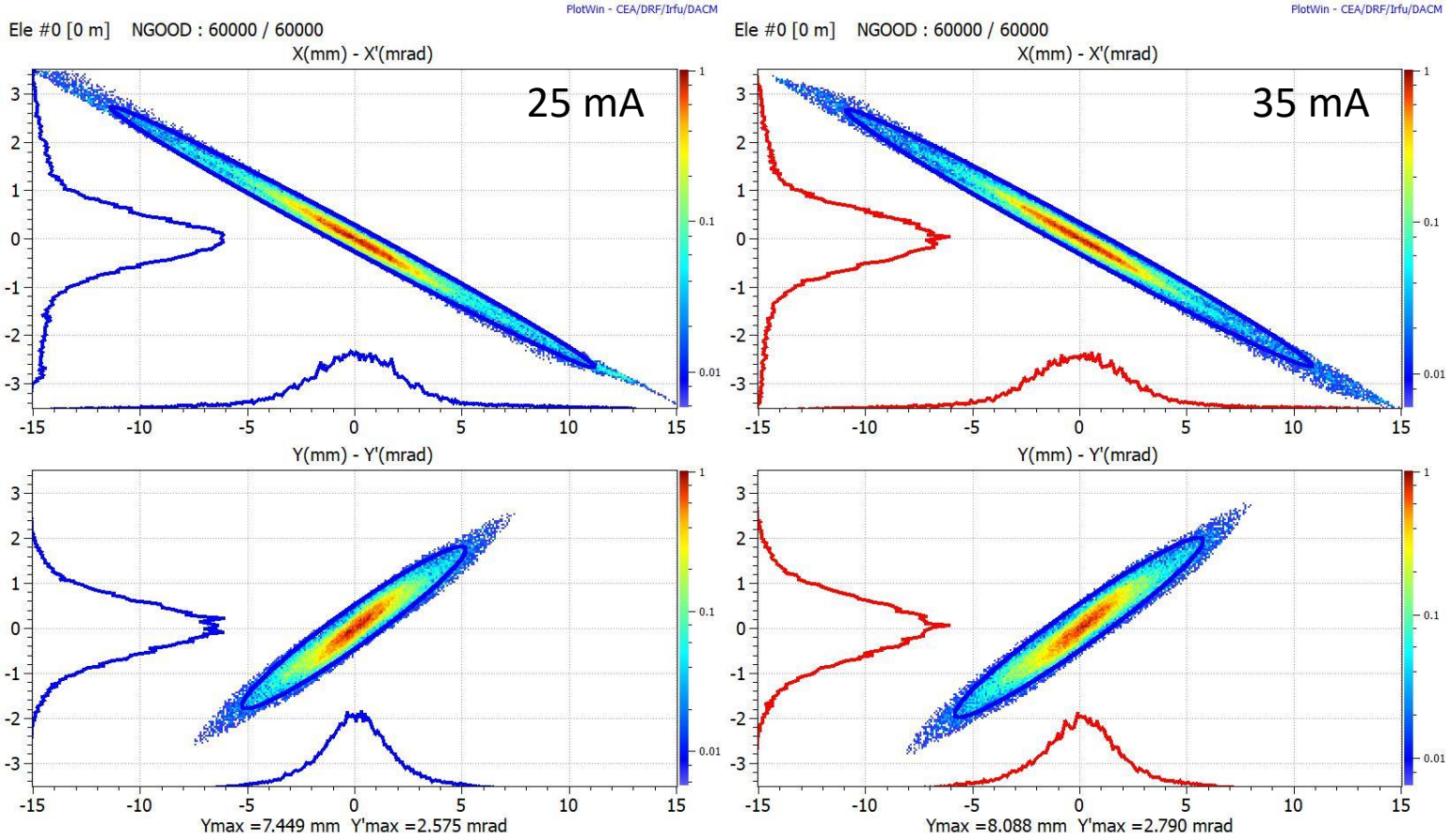
- 35 mA at 160 MeV in the L4Z and in the LBE.
- Reaching the limit of cavities available RF power. 3 MeV chopping needed.
- Small difference on L4Z transverse emittance comparable to what found with 30 mA.
- 352 MHz bunch length ? No clear conclusion as our diagnostic suddenly gave larger phase spread even for the nominal.
- 35 mA transverse emittance measured at the LBE…





35 mA at the PS Booster

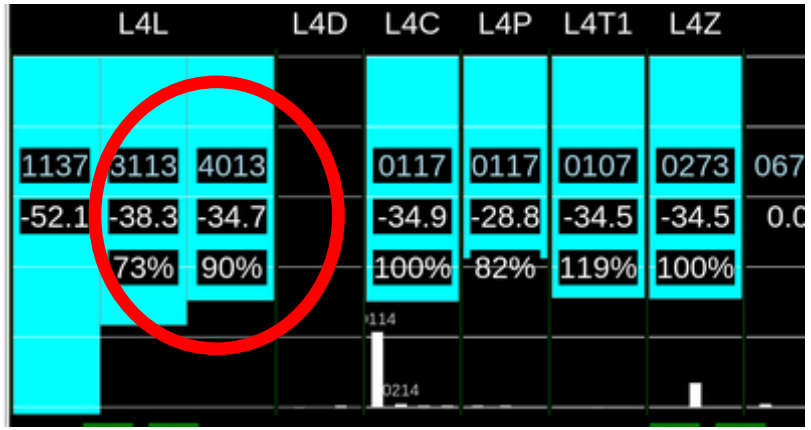
- H and V emittances very similar.
  - Well within PSB matching tolerances.
  - Always influenced by the dispersion in H.
  - A small E spread (100 keV) measurement would make more sense.



Source summary and outlook

- 35 mA at 160 MeV.
  - With a reasonable RFQ voltage…
  - Chopping pattern needed to relax on the RF power side.
  - Transverse emittances look under control, with NO re-matching in the Linac4 above 3 MeV.

- What's next – experimentally
  - Inject in the PSB 10th may
  - Look at a different MEBT optics – Could request some iterations…
  - Optimise also …
    - RFQ level.
    - Source and LEBT.
    - MEBT quad settings.
- What's next – calculations and R&D
  - Optimise extraction and low energy
  - Study direct injection into the RFQ



Source redesign

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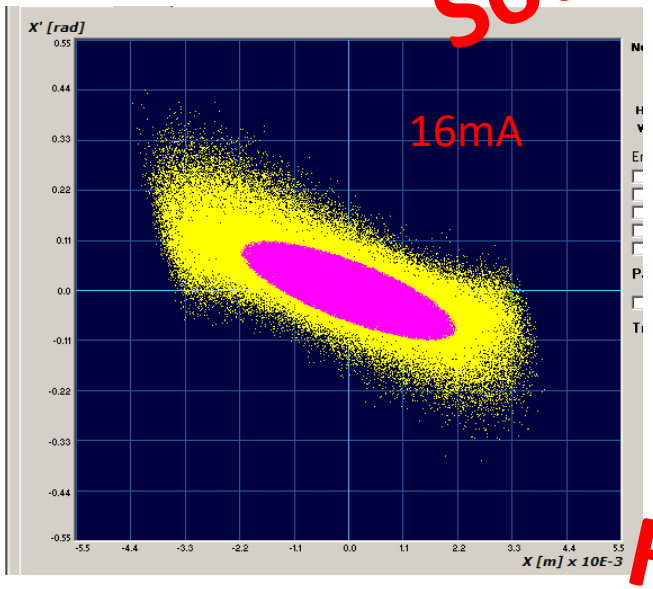


2013: Comparison of **measured emittance** (yellow) and RFQ acceptance (pink). The expected transmission thru the RFQ is 75%. (PARMTEQ + TOUTATIS).

RFQ redesign

3m high-field (2018)

RFQ3 2021

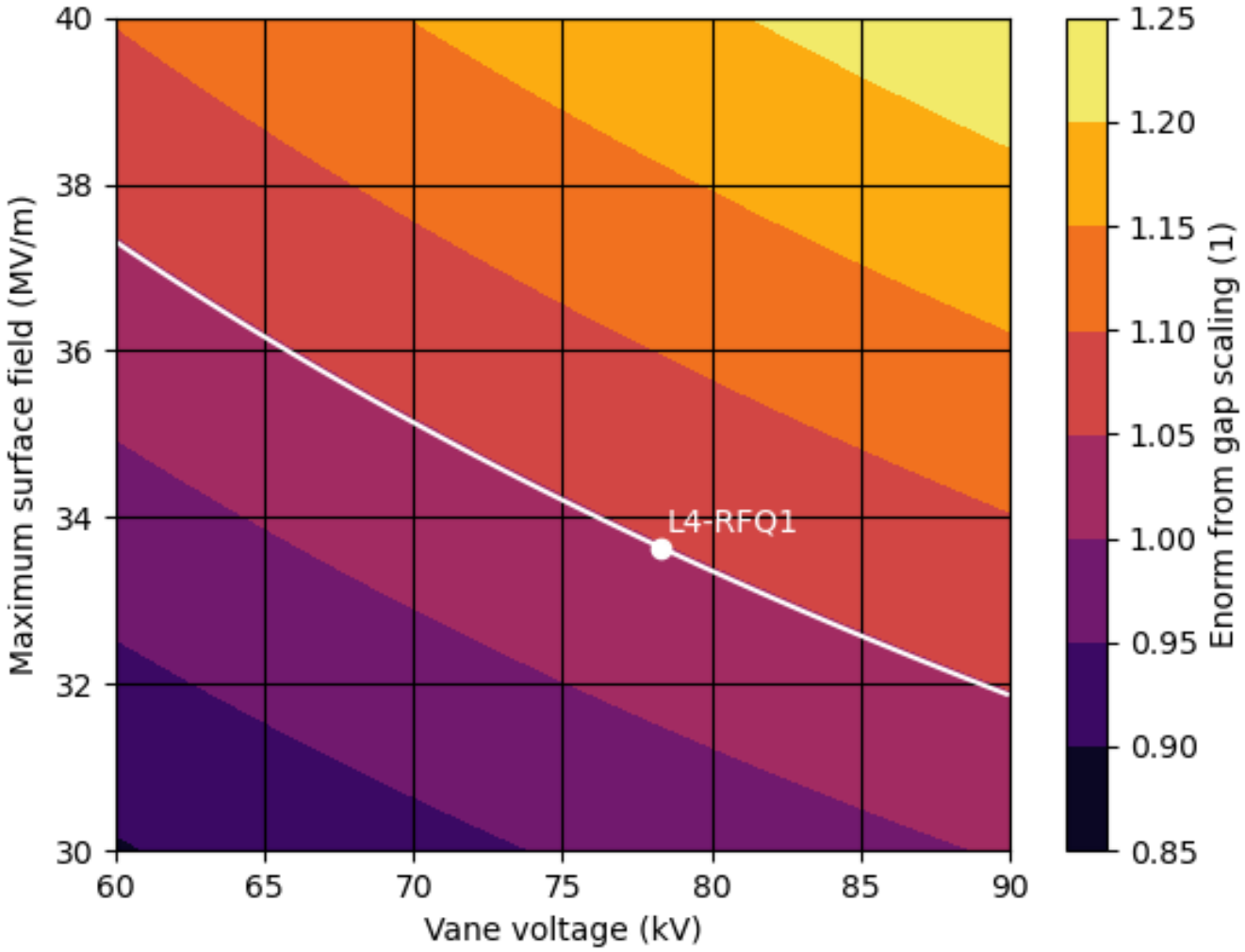
Common design guidelines

- Input/output energy : 45 keV/3MeV;
- a **two-term potential** vane profile, a **constant** average aperture **radius** and a **constant transverse radius of curvature** for an easier tuning and the possibility of machining with a 2D cutter;
- **Constant voltage profile;**
- Transmission higher than 90% for emit=0.5µm rms normalised I=70mA

RFQ design – copper

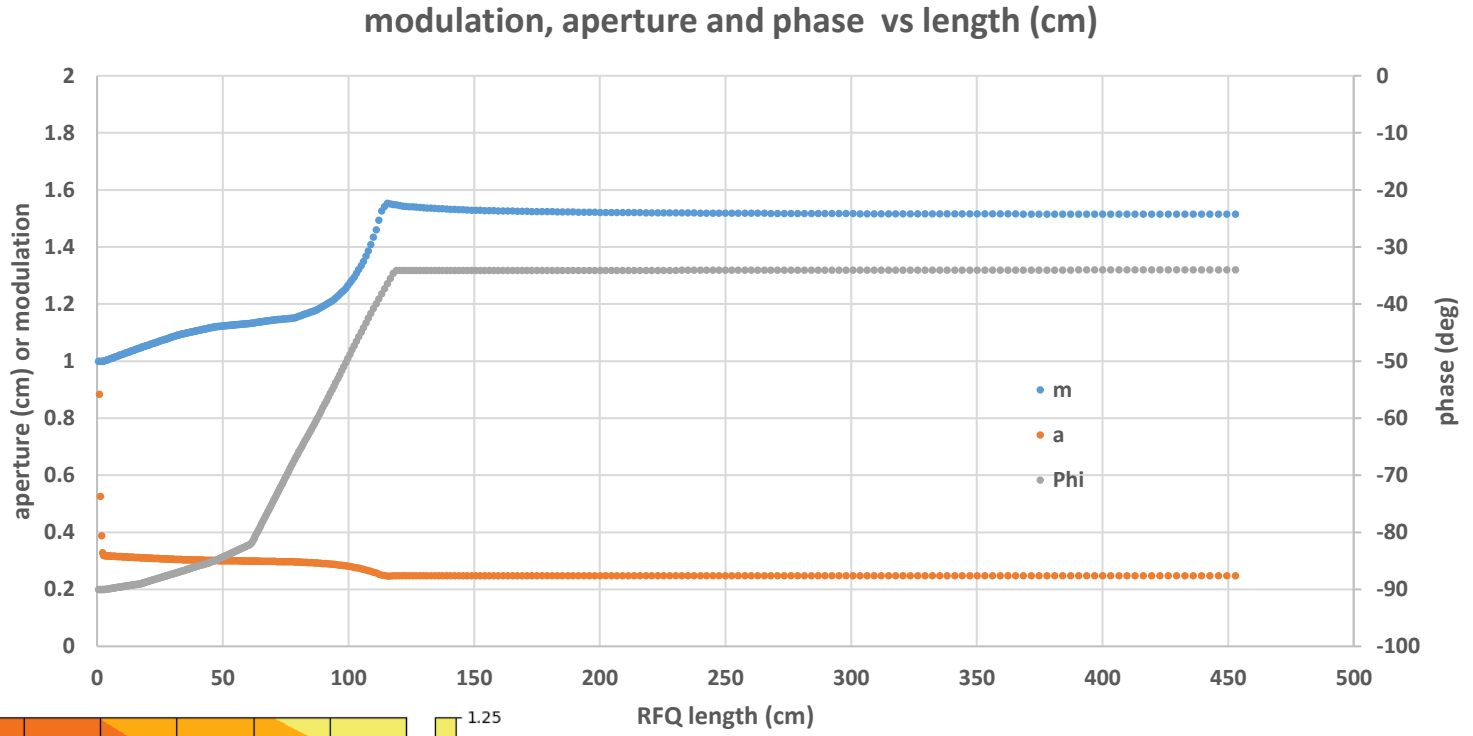
General Guidelines:

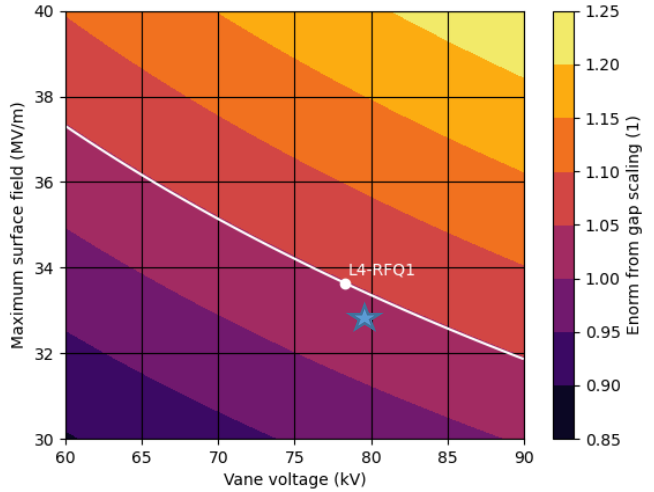
- **Stay below the RFQ1 line**
- Transmission>90 for emit=0.5 mm mrad and I=70mA
- rho/ro=0.7 -1
- Two versions
  - L=4.5 m to avoid dipole rods
  - L=as short as possible.

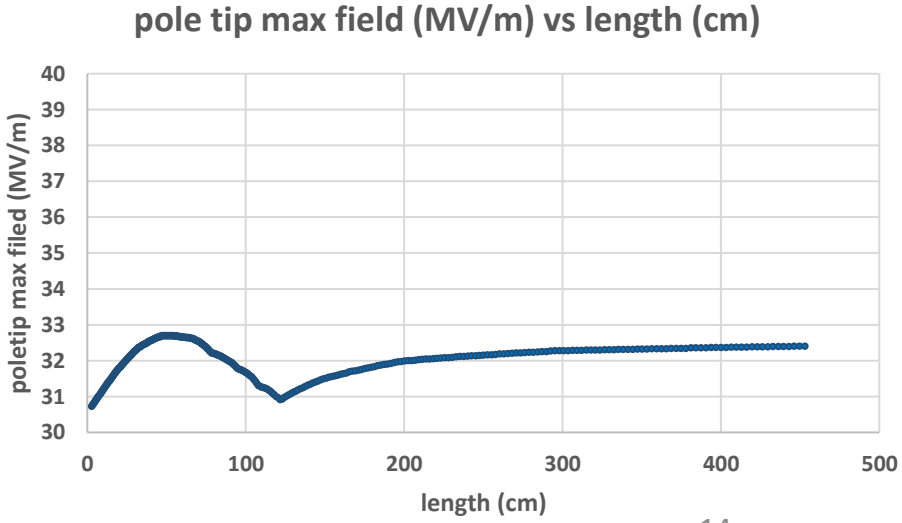


4.5 m

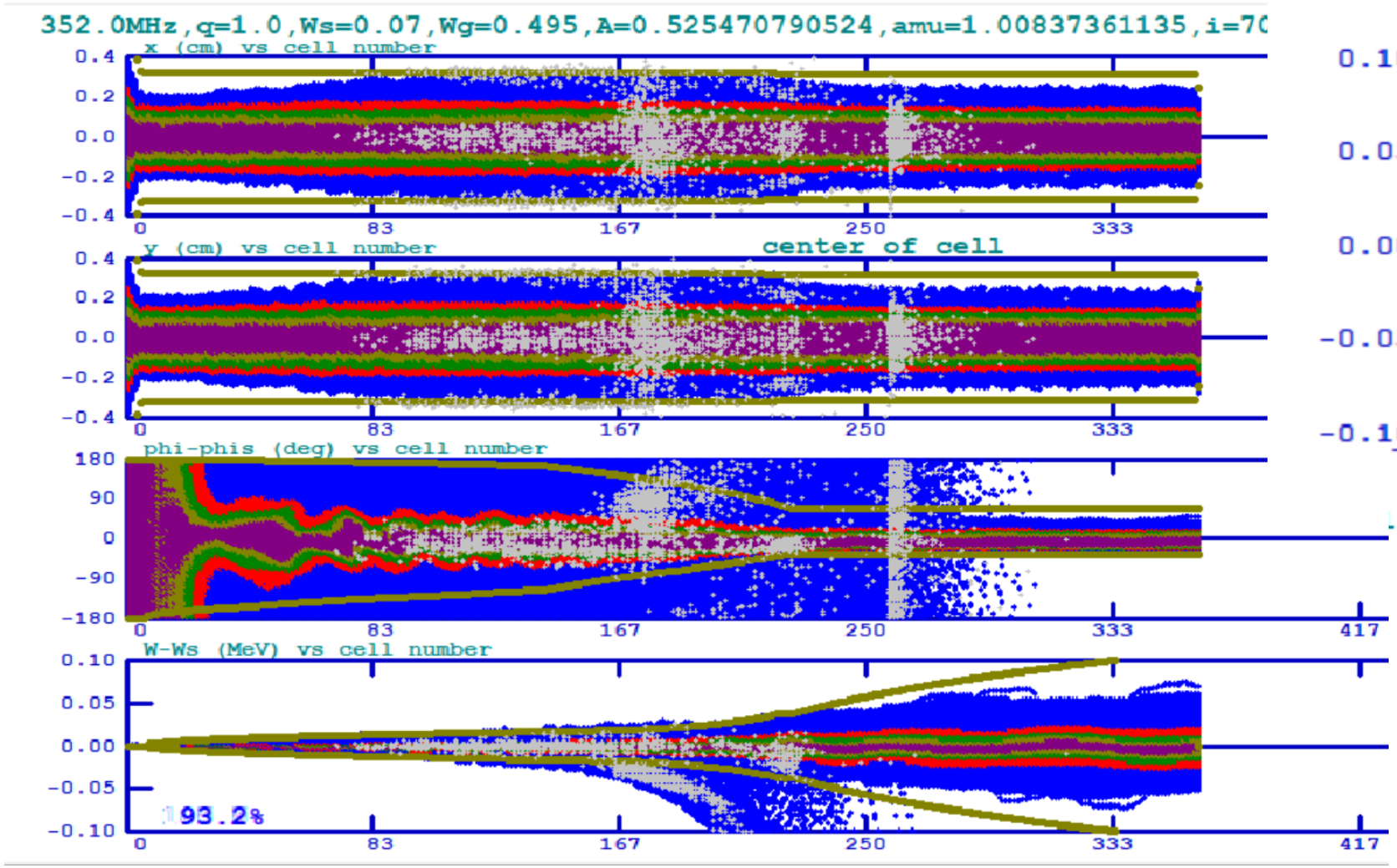
RFQ parameters	
Length m	4.5
Vane voltage kV	79
Max electric field (MV/m)	33
Peak RF power kW	750
Average aperture (r0) mm	3.2
Transverse radius (ρ)	2.7
Maximum modulation	1.5
Minimum aperture mm	2.5
Focusing parameter (B)	5.87
Phase at gentle buncher deg	-35
Transmission % (70mA , 0.5 mm mrad)	93.2



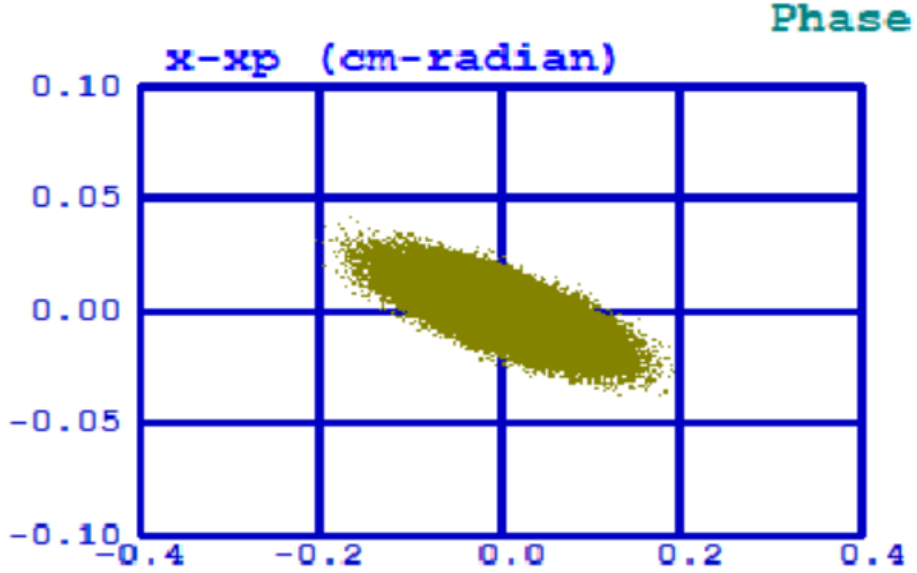


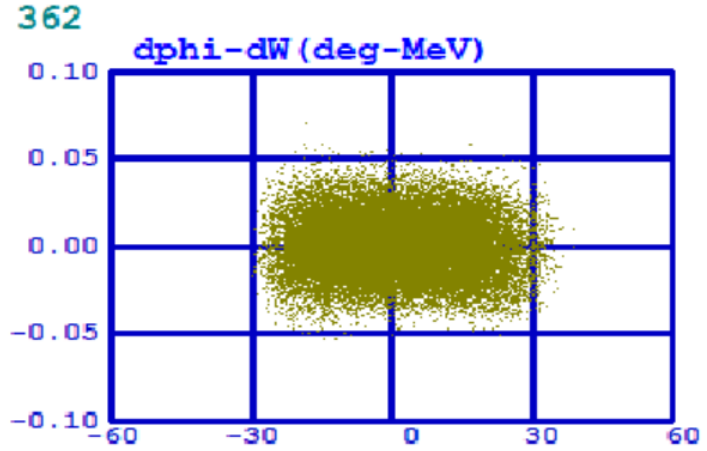


Beam dynamics – 70mA emit =0.5mm mrad



Transverse (x, y top) and longitudinal planes (phase, energy spread) along the RFQ

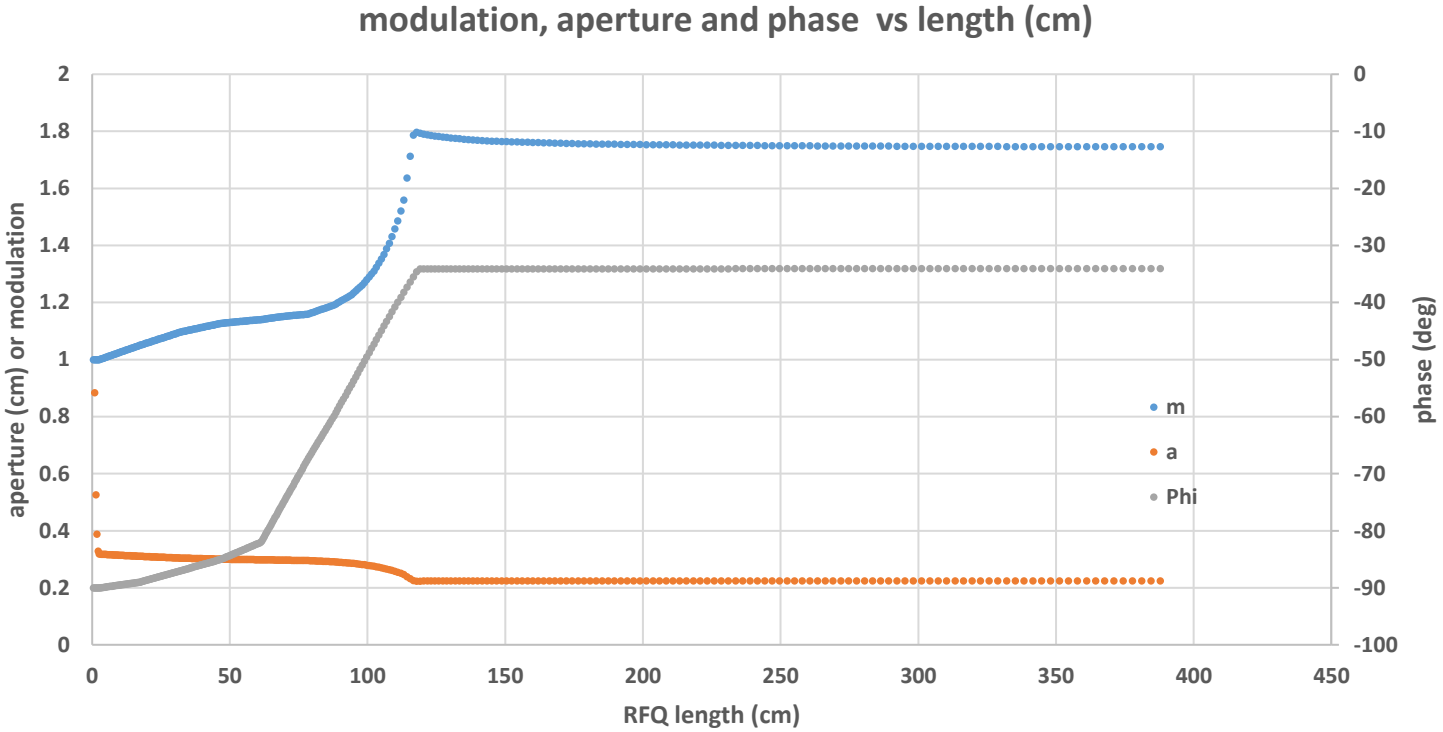


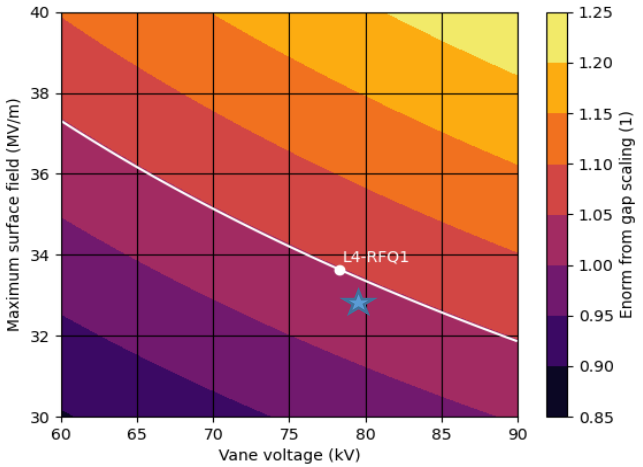


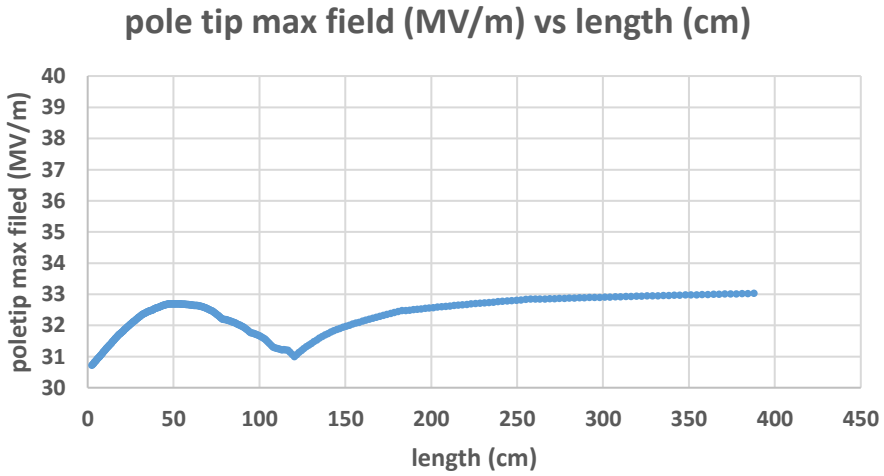
Beam at the RFQ output plane

3.9 m

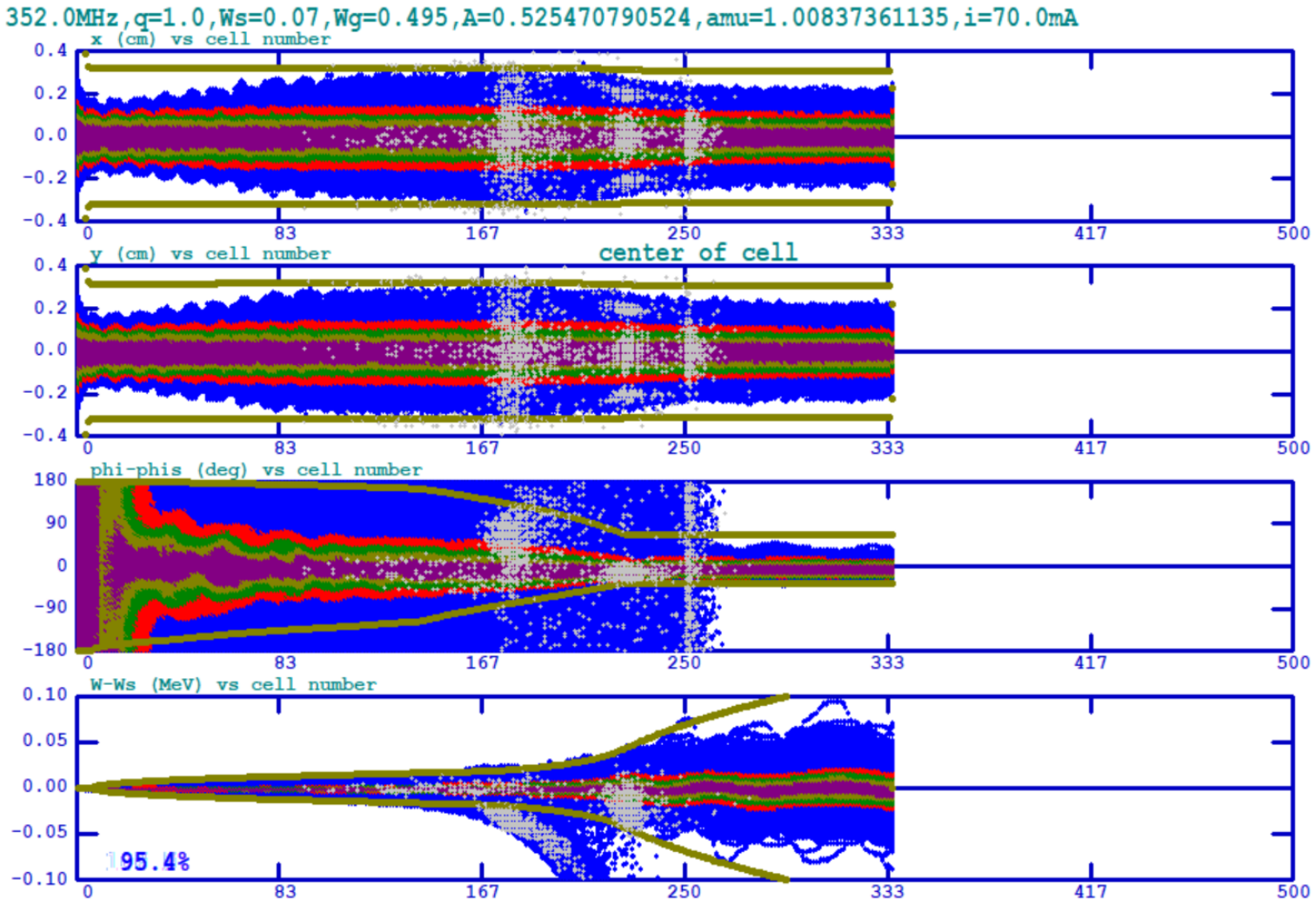
RFQ parameters	
Length m	3.9
Vane voltage kV	79
Max electric field (MV/m)	33
Peak RF power kW	650
Average aperture (r0) mm	3.2
Transverse radius (ρ)	2.2
Maximum modulation	1.8
Minimum aperture mm	2.2
Focusing parameter (B)	5.76
Phase at gentle buncher deg	-32
Transmission % (70mA , 0.5 mm mrad)	95.4



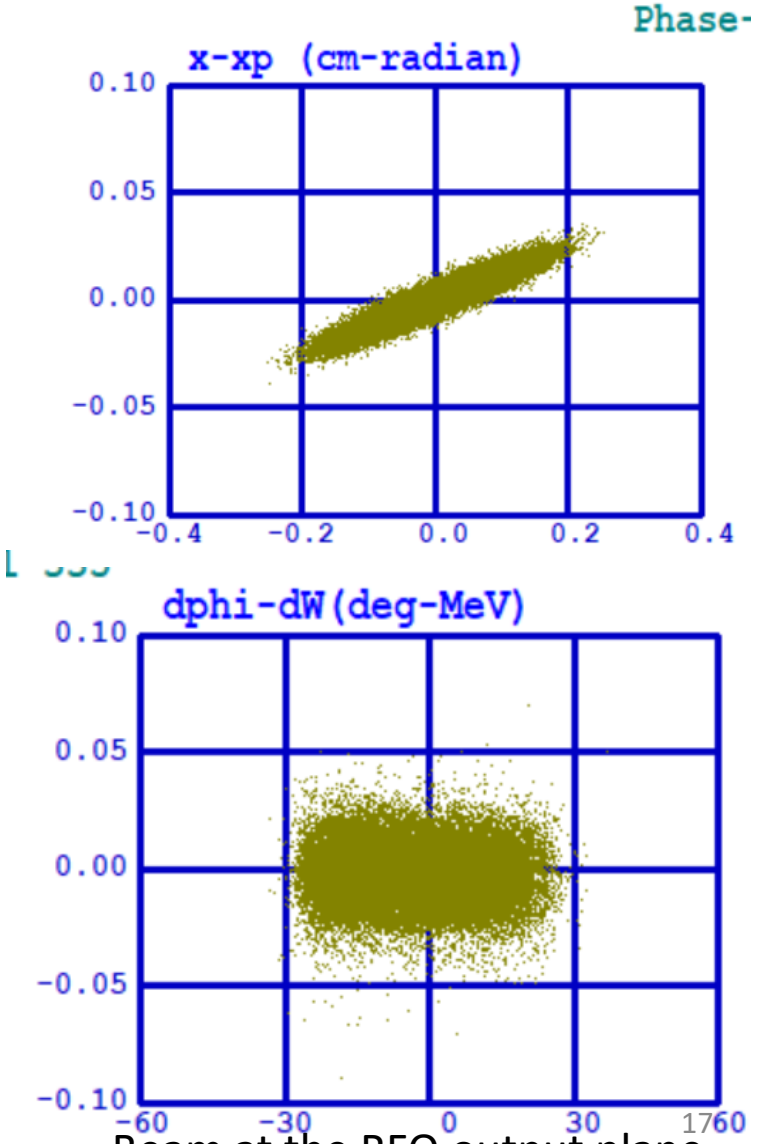




Beam dynamics – 70mA emit =0.5mm mrad



Transverse (x, y top) and longitudinal planes (phase, energy spread) along the RFQ



Beam at the RFQ output plane

RFQ design – new material

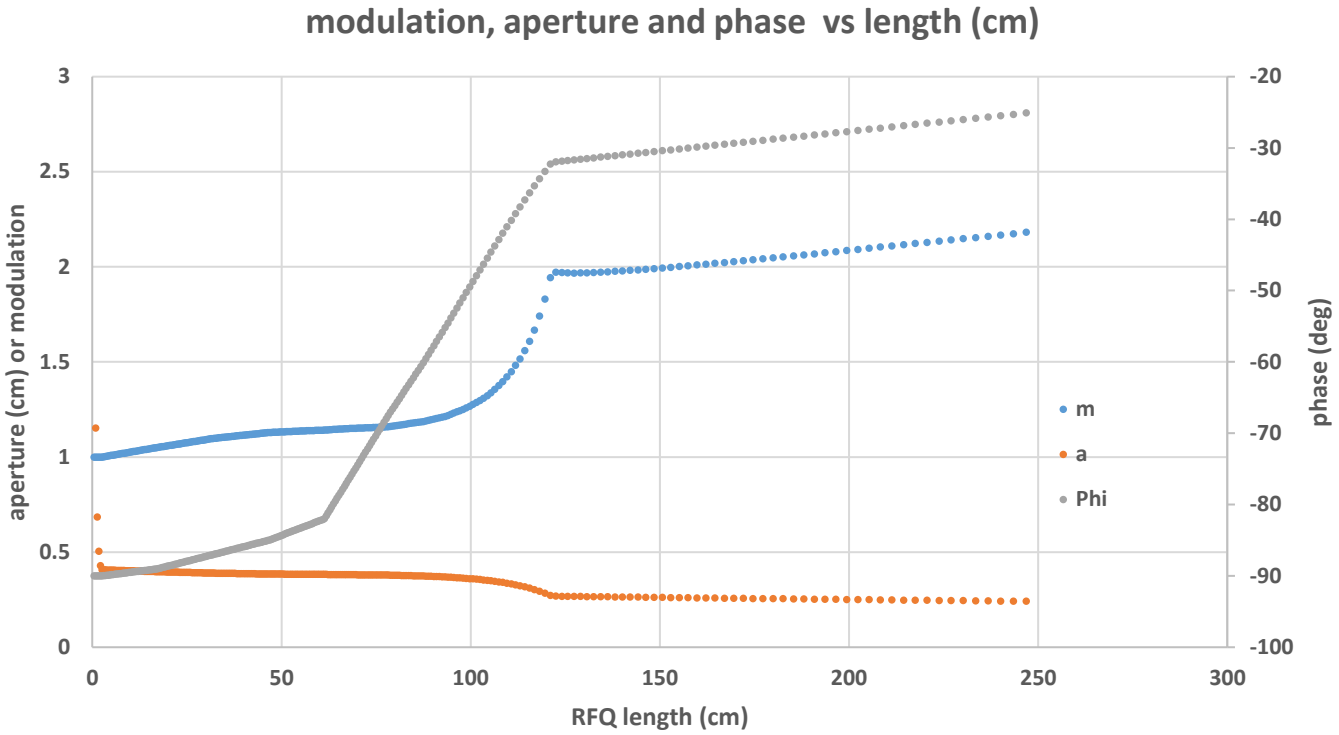
General Guidelines:

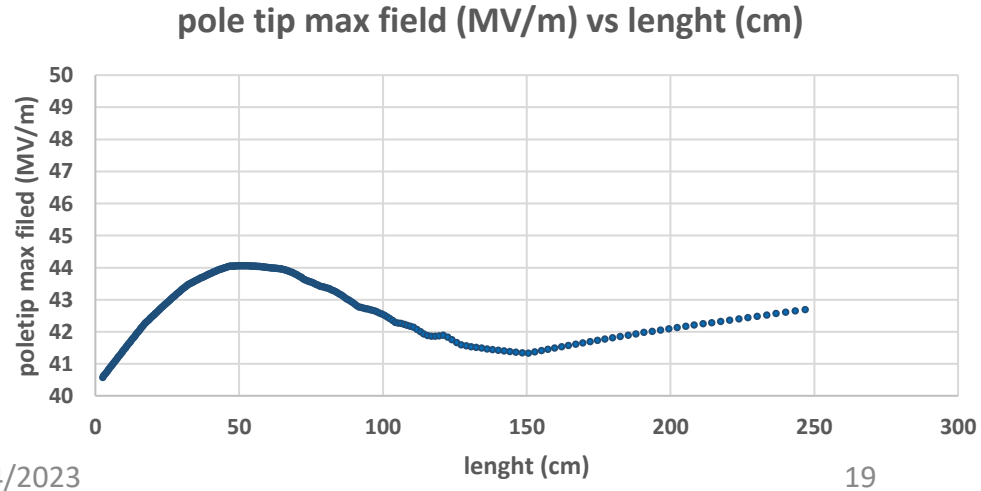
- **Field up to 50MV/m for 78 kV (cryo-copper)**
- Respect scaling –
  - 120kV and 42.3 MV/m
  - 140kV and 39.3 MV/m
- Transmission > 90% for emit=0.5 mm mrad and I=70mA
- rho/ro=0.7 -1

- L as short as possible
- Best beam quality

2.5 m 120 kV

RFQ parameters	
Length m	2.5
Vane voltage kV	120
Max electric field (MV/m)	44
Peak RF power kW	960
Average aperture (r0) mm	4.1
Transverse radius (ρ)	4.1
Maximum modulation	2.2
Minimum aperture mm	2.4
Focusing parameter (B)	5.54
Phase at gentle buncher deg	-32
Transmission % (70mA , 0.5 mm mrad)	91.2





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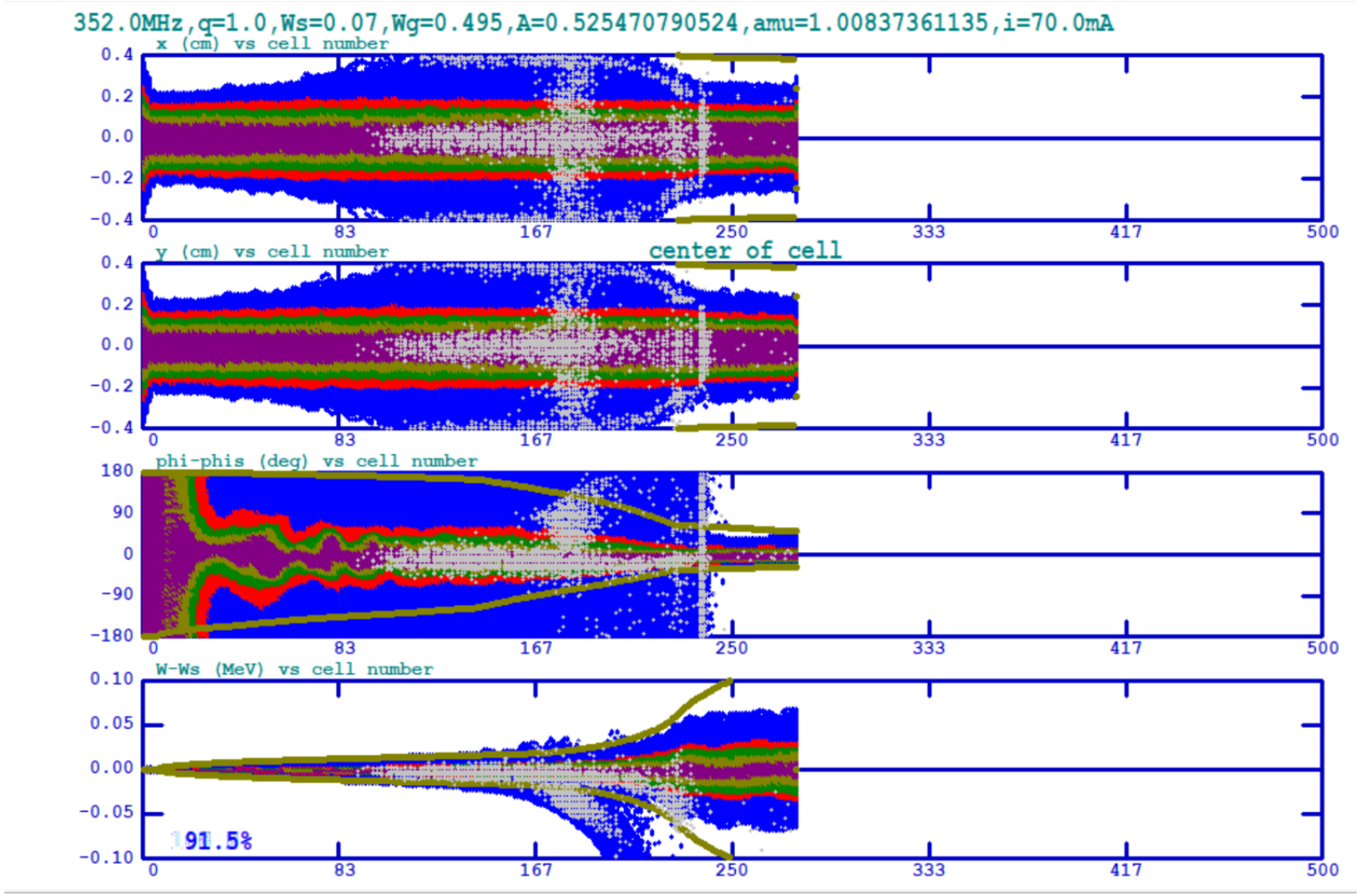
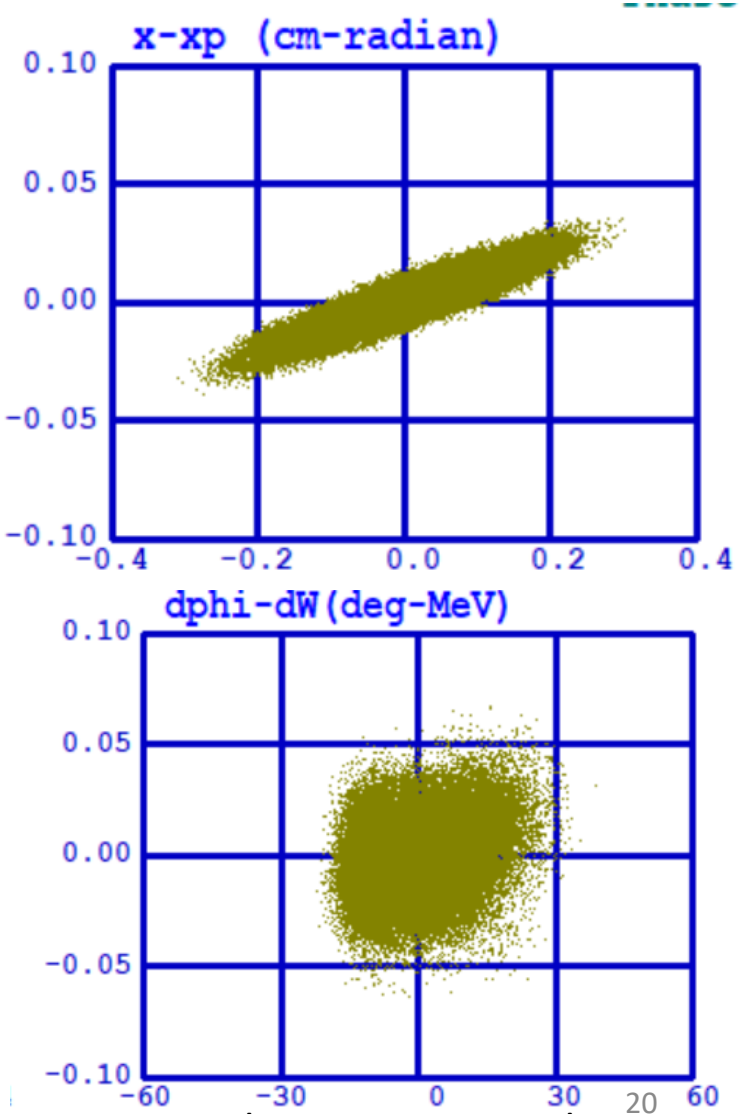


Transverse (x, y top) and longitudinal planes (phase, energy spread) along the RFQ



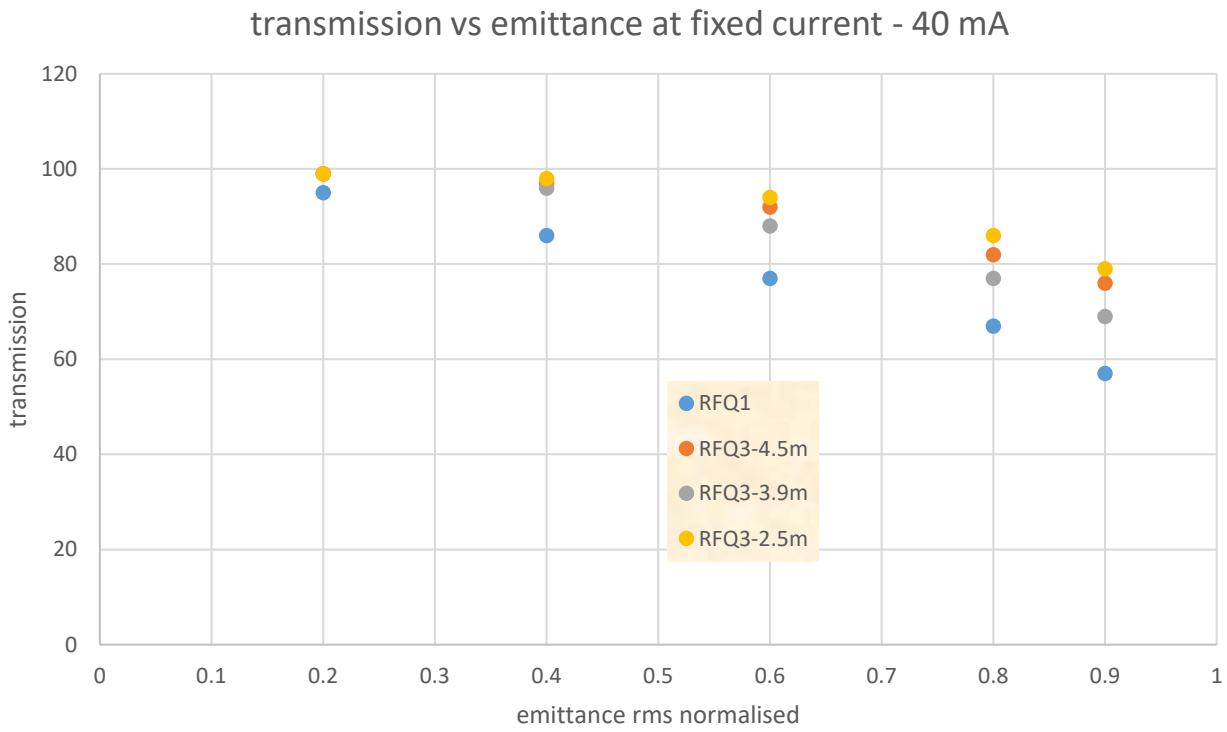
Beam at the RFQ output plane

Comparison of performance-method

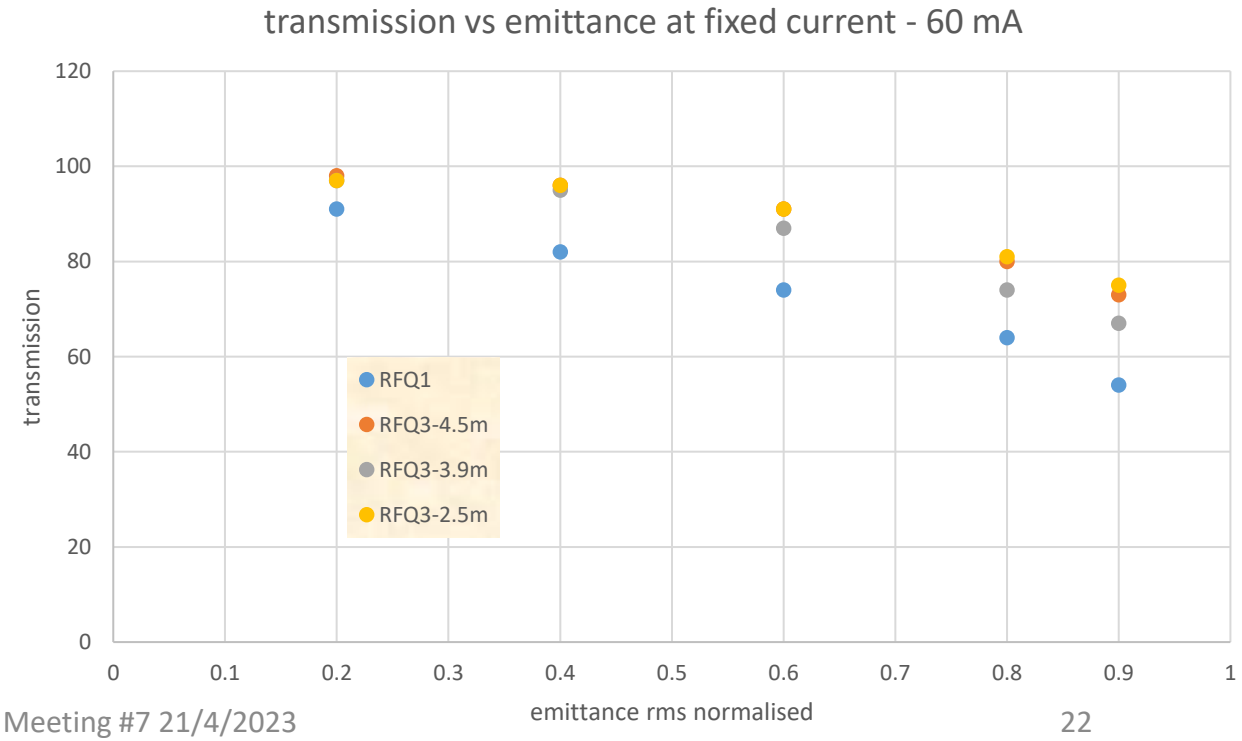
- Comparison of performance
  - Simulations
  - Current through the RFQ

- Parameters :
  - emittance at the RFQ input plane : 0.2 to 0.9 µm
  - Matching :
  - Transverse beam distribution : uniform, parabolic, gaussian
  - Current : range 0-60mA
  - Energy dispersion

Comparison of performance – results



Current of 60 mA needs to fit in an emittance of 0.4 for RFQ1 vs in an emittance of 0.8 for RFQ3 to give 48mA out of the RFQ



Summary

- The SPL design of 2010 still holds
- Substantial progress on the source brightness and more avenue to explore – low current target is met.
- There are 3 designs for an RFQ that fits the specifications of LINAC4 at higher beam current and emittance. All designs have a transmission of more than 90% for a beam of 70mA with rms emittance 0.5 mm mrad. Two of the RFQ designs are based on RF parameters similar to RFQ1 whereas a very short RFQ is based on a surface field higher than what is attainable with room temperature copper.