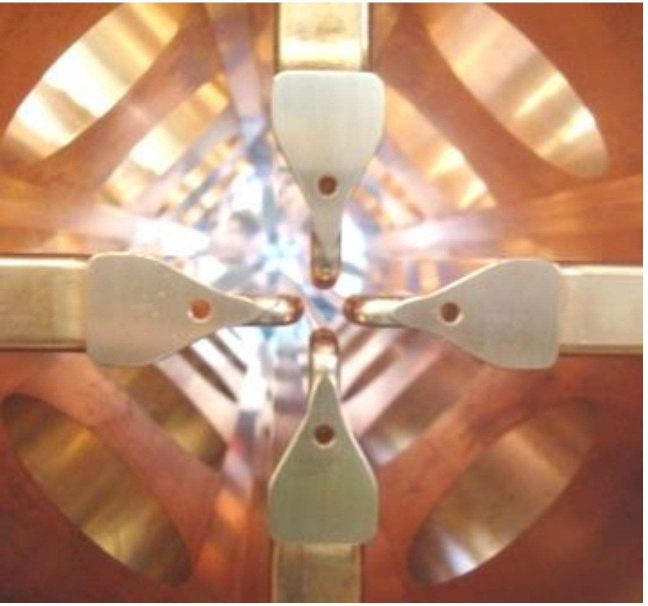
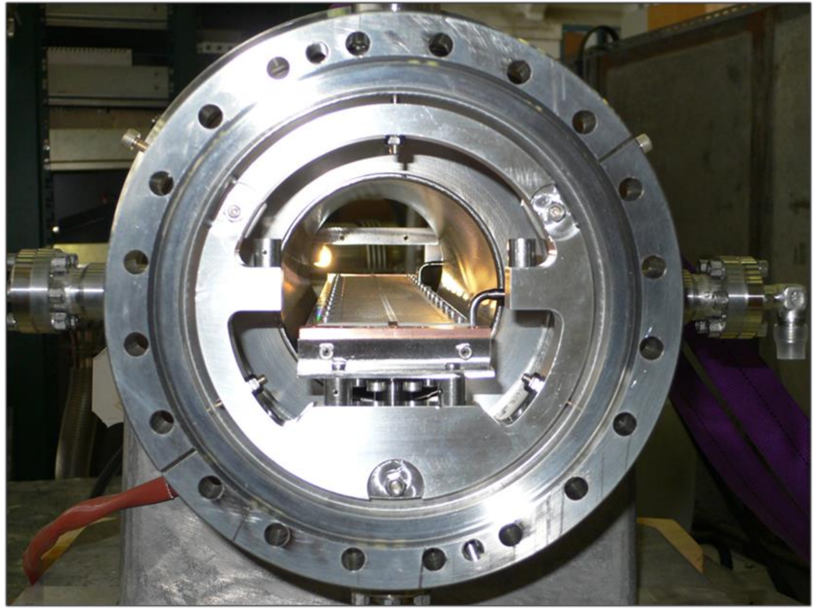
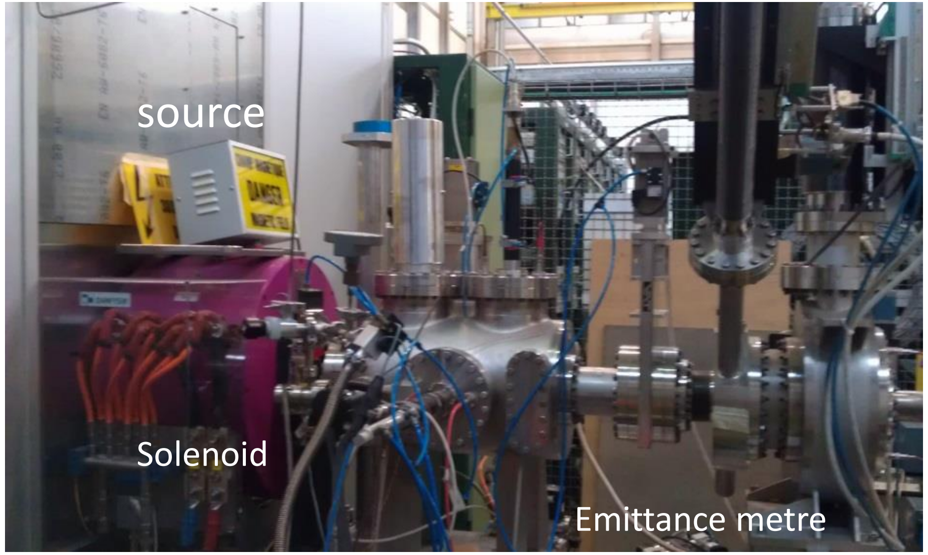


Radio Frequency Quadrupole
352MHz



Fast Chopper – 1MHz



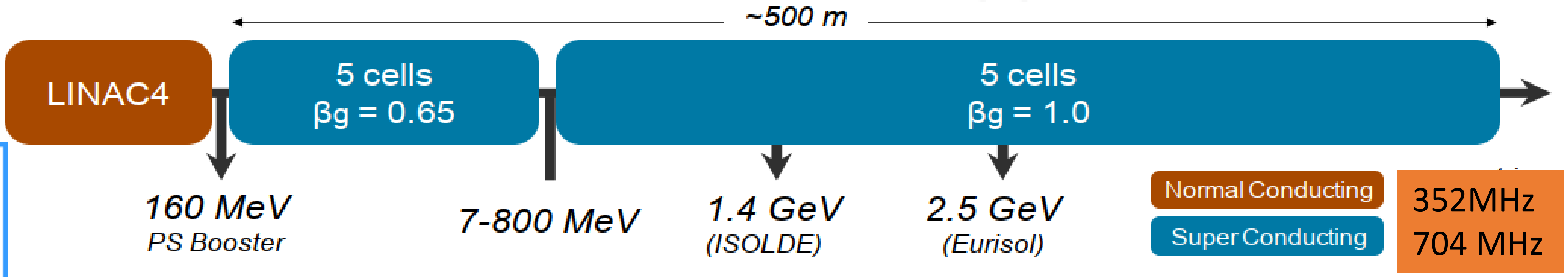
Source test stand

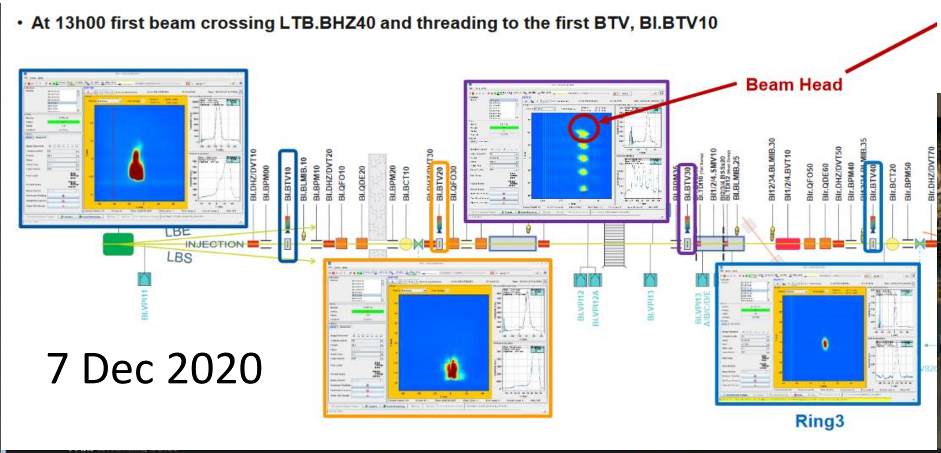
LINAC Activities at CERN

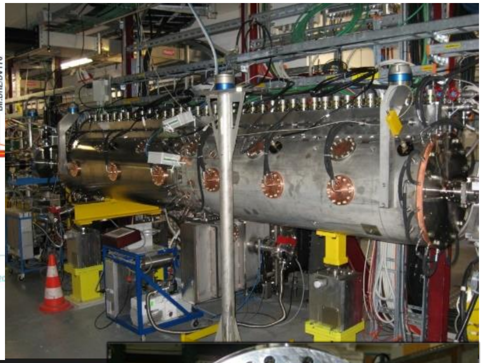
Alessandra Lombardi and the Hadron Sources and Linac team

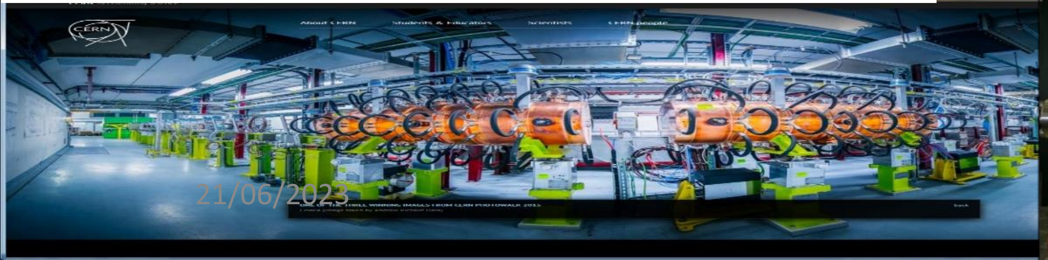
- The Superconducting Proton Linac (SPL)
- Achievements with LINAC4
- Activities on RFQ redesign
- Conclusions and outlook

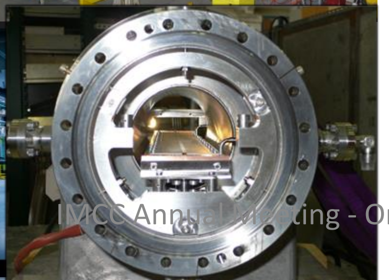
LINACs for ν-fact or μ-collider – CERN 2010







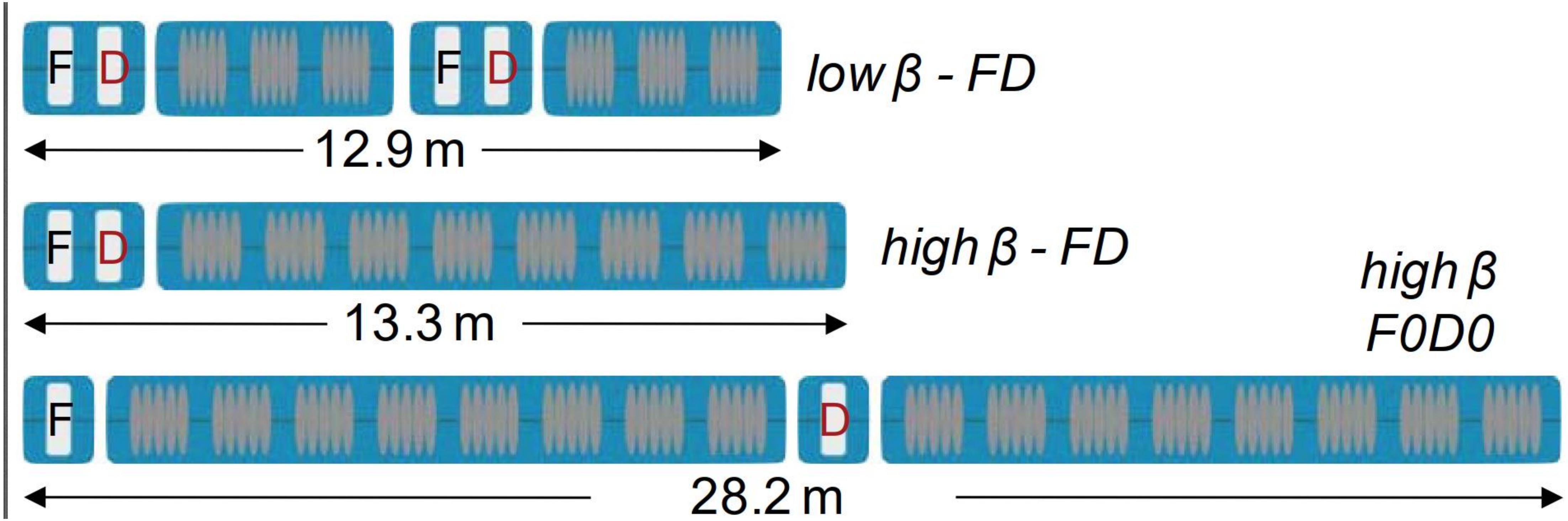




SPL parameters

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

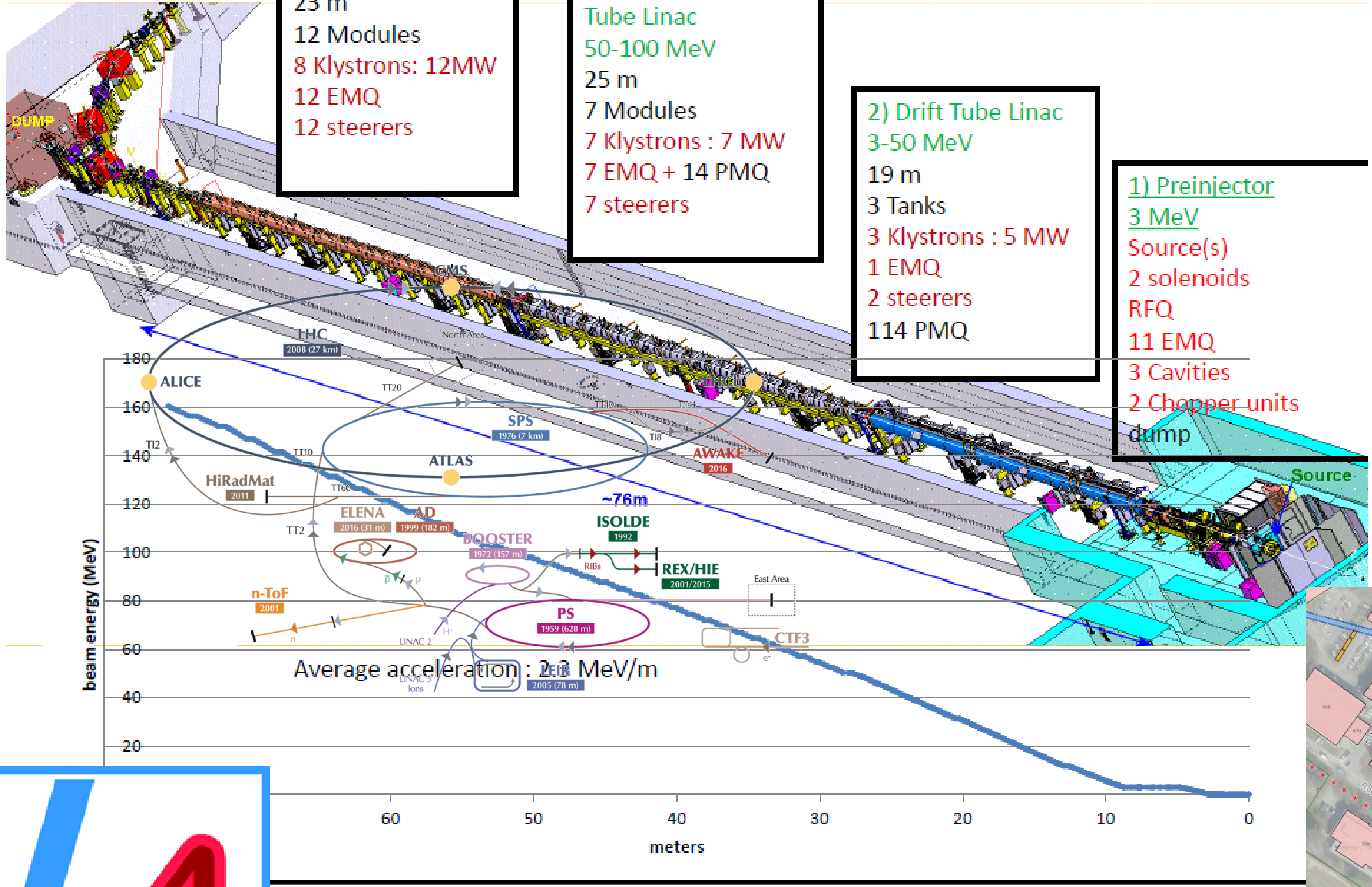


4) Π-mode Structure
100-160 MeV
23 m
12 Modules
8 Klystrons: 12MW
12 EMQ
12 steerers

3) Cell-Coupled Drift Tube Linac
50-100 MeV
25 m
7 Modules
7 Klystrons : 7 MW
7 EMQ + 14 PMQ
7 steerers

2) Drift Tube Linac
3-50 MeV
19 m
3 Tanks
3 Klystrons : 5 MW
1 EMQ
2 steerers
114 PMQ

1) Preinjector
3 MeV
Source(s)
2 solenoids
RFQ
11 EMQ
3 Cavities
2 Chopper units
dump



Frequency : 352 MHz
Duty cycle for PSB : 0.06 %
Max duty cycle : 5%

Located 12m underground

Baseline beam parameters

LINAC4 – CDR -2006	LINAC4 – achieved (2016)	Comments – general	Comments – mucoll specific
H-	Stripping and more tested in Half Sector Test		
70mA peak at the source 65 ma peak at 3 MeV 40 mA after chopping	50mA peak (in twice the acceptance of the RFQ) 30 mA peak at 3 MeV (record) 20 mA after chopping	Peak current from the source Average beam current after chopping (LEBT and RFQ transmission and chopping factor)	Missing a factor 2 for the high current
160 MeV	160.48 MeV	All RF structures performing to specs	
0.4 π mm mrad	0.3 π mm mrad (at 160MeV)	Smaller emittance , allows for more turns injected	
400 µsec 1Hz (4 rings)	Up to 600 µsec 1Hz	Longer injection in the PSB (100-150turns)	Longer pulse and ducty cycle is possible
Fast Chopping at 3 MeV 2µsec inj kicker rise-time	Demonstrated , including transmitted beam quality	Unprecedented flexibility, to be exploited Beam from 1µsec to 150µsec	Repetition rate (40MHZ) not demonstrated
Energy painting with the last accelerating modules			Flexibility in the longitudinal plane

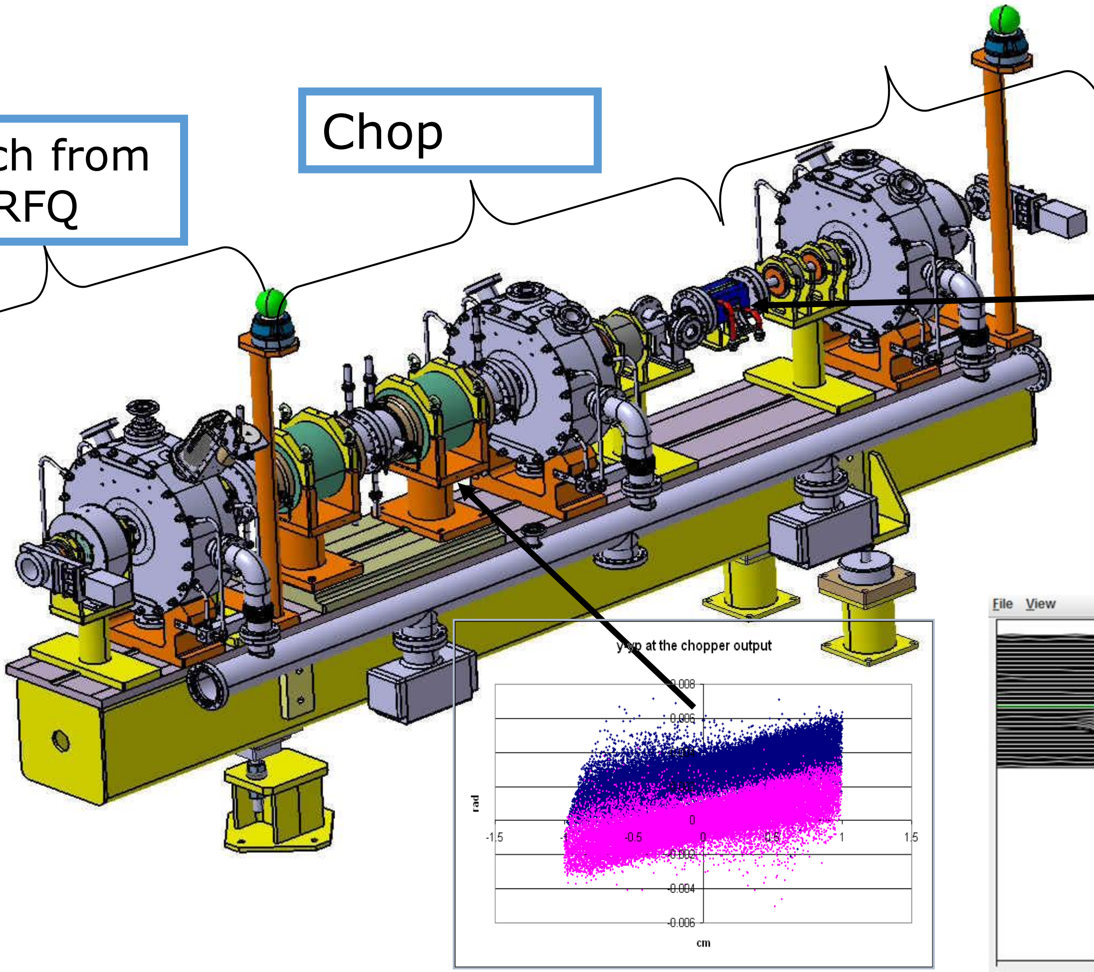
Measuring at 3 MeV : CHOPPING

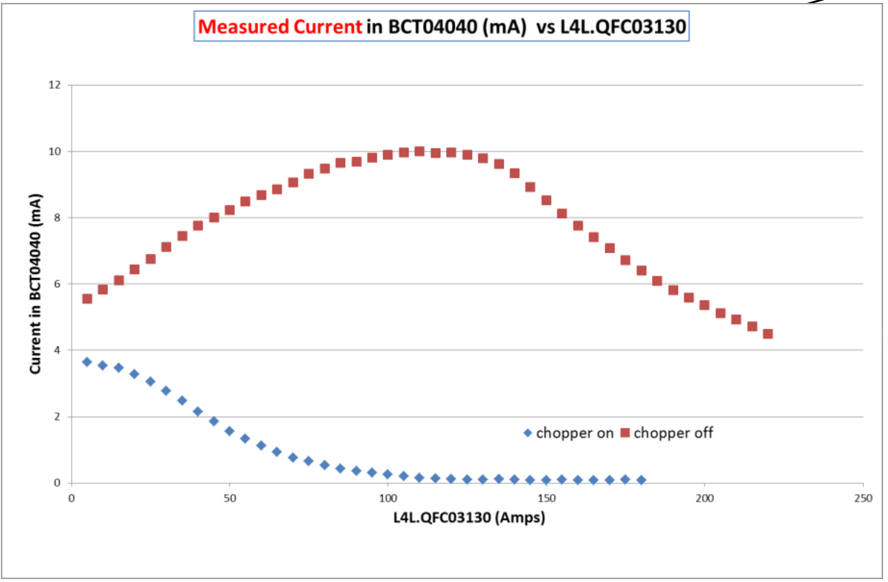
removing microbunches (150/352) to adapt the 352MHz linac bunches to the 1 MHz booster frequency

Match from the RFQ

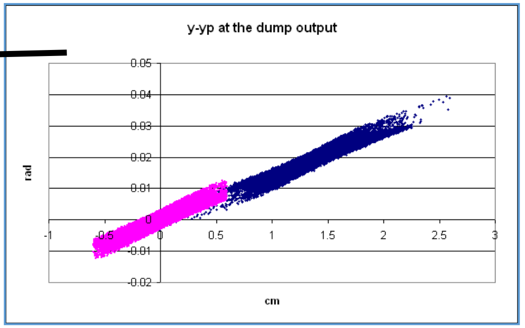
Chop

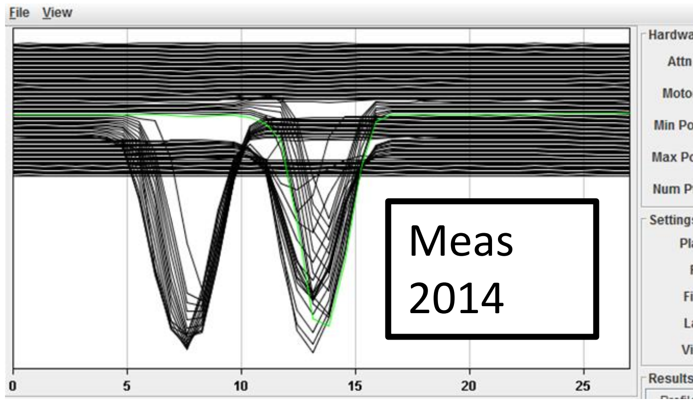
Match to the DTL



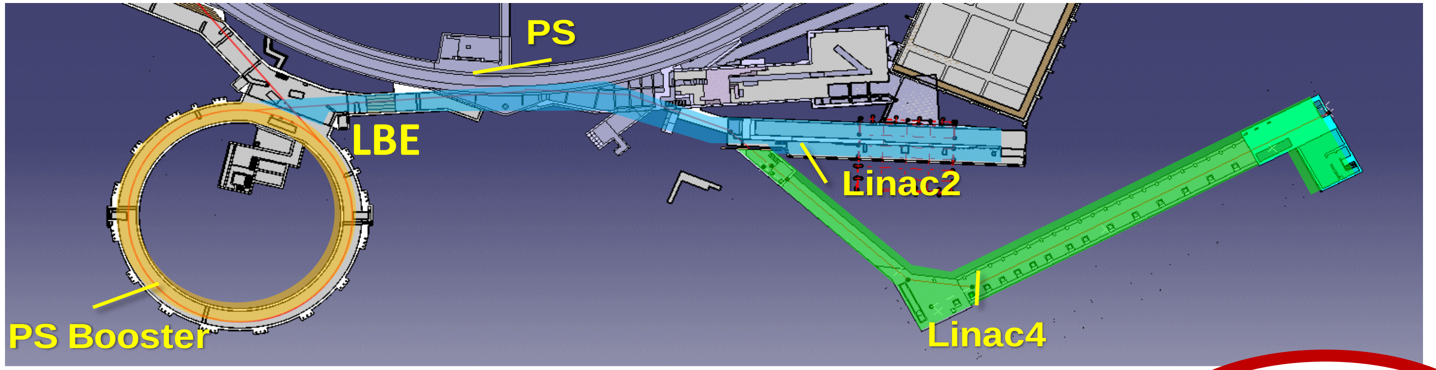


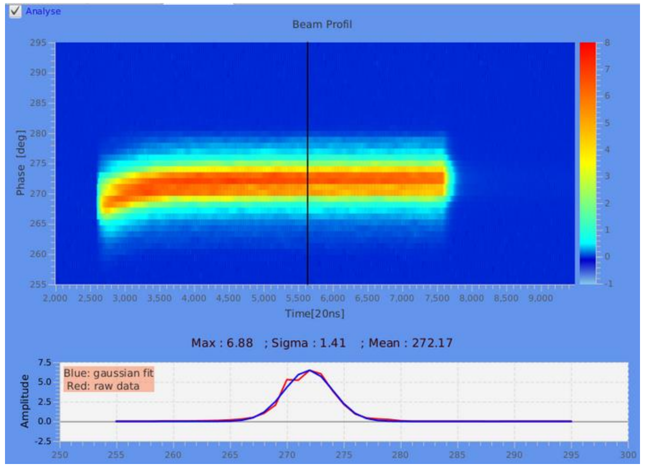
Beam current downstream the dump





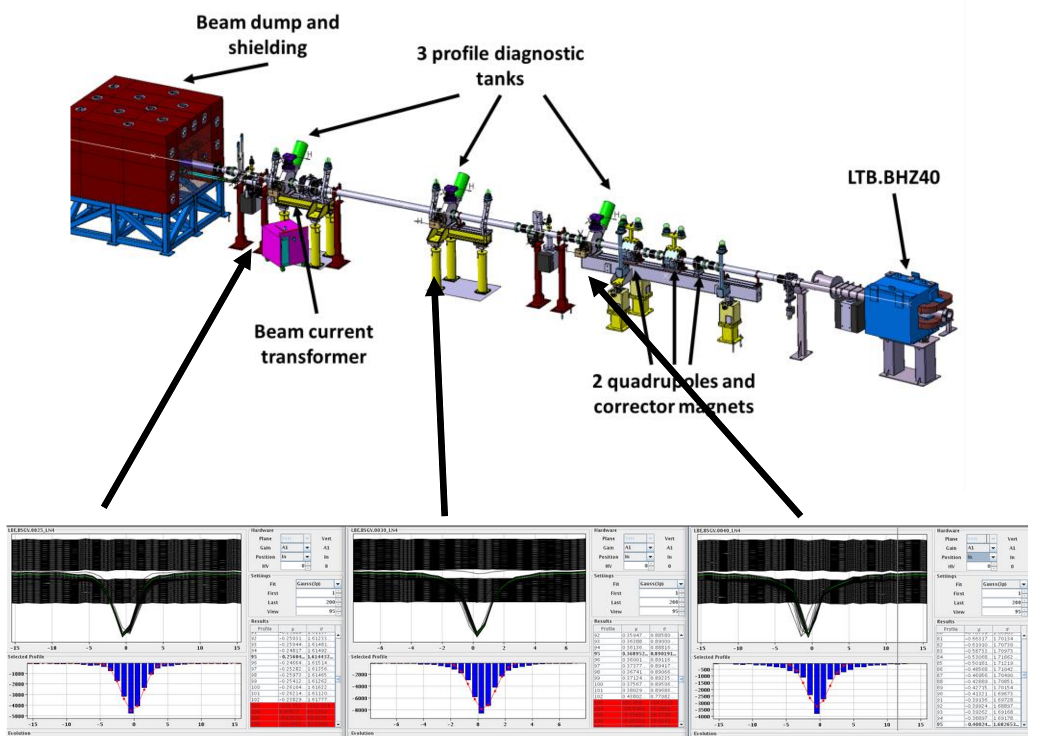
Beam to the LBE !



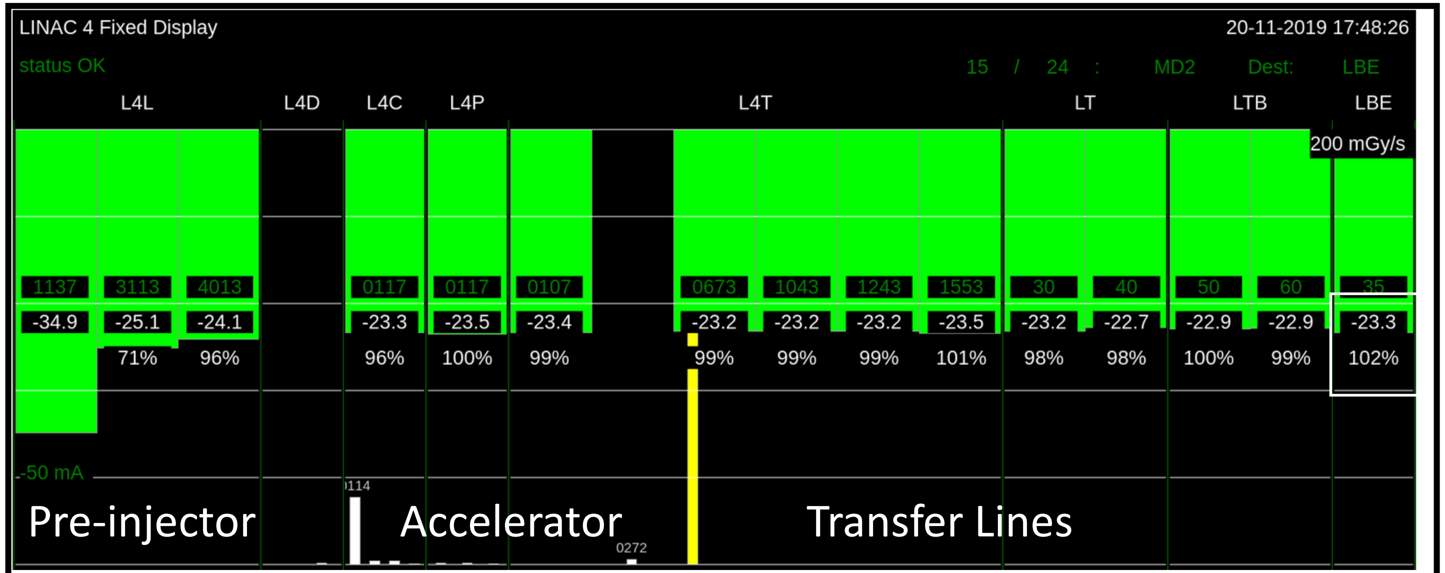


Beam phase spread at 160 MeV – in specs.

Availability
93.9%

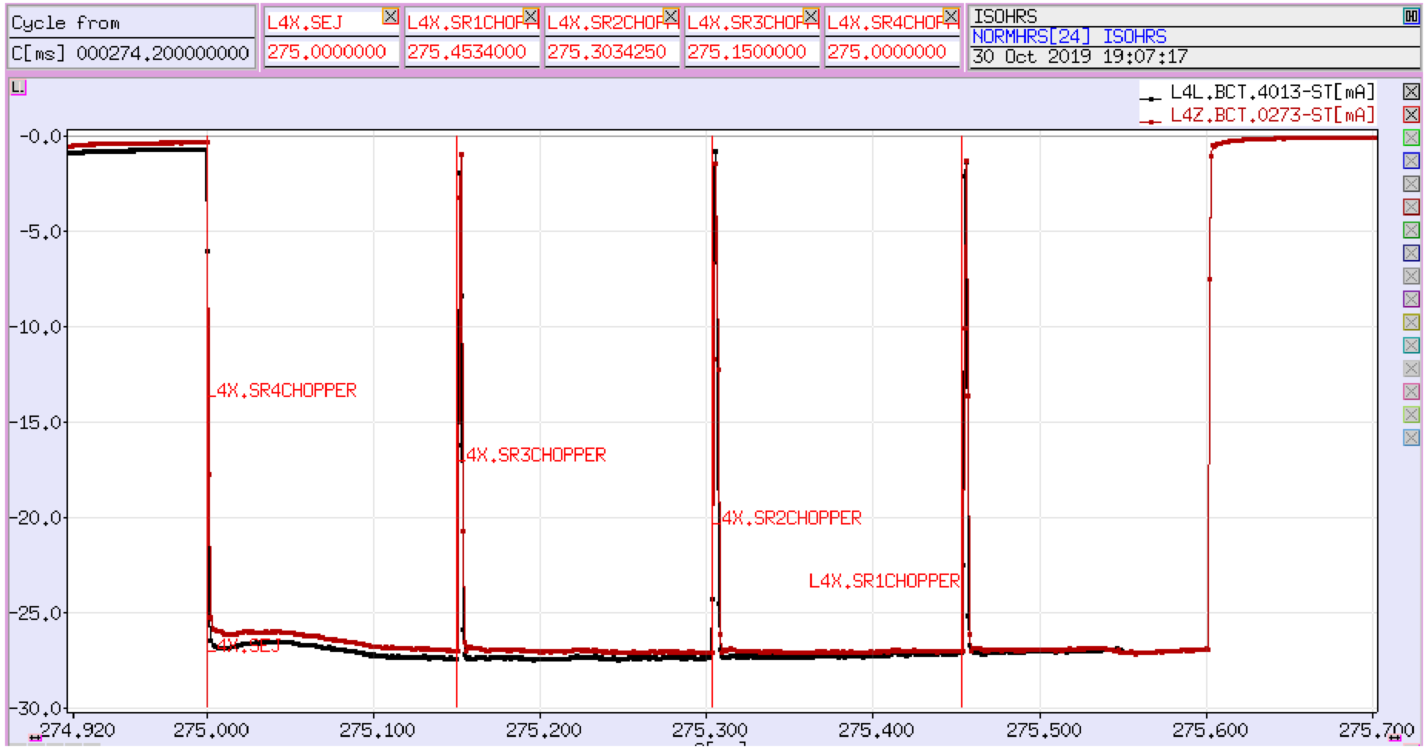


Emittance measurements in LBE – as expected

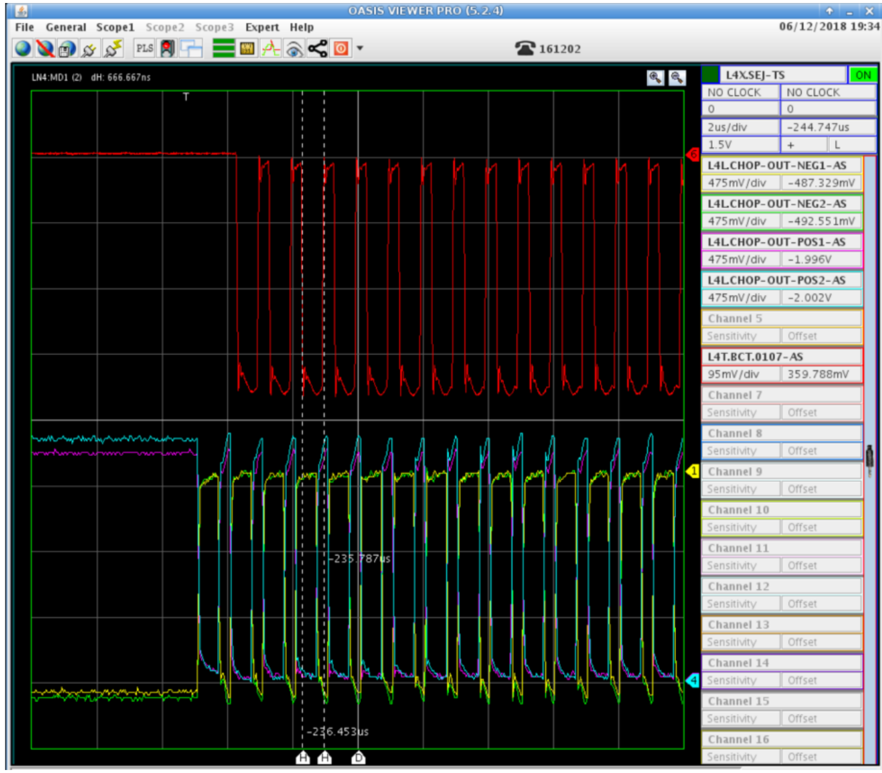


96% transmission from 3 MeV to the LBE – 23mA suitable for all pre-LS2 beams

Pulse Flatness and chopping

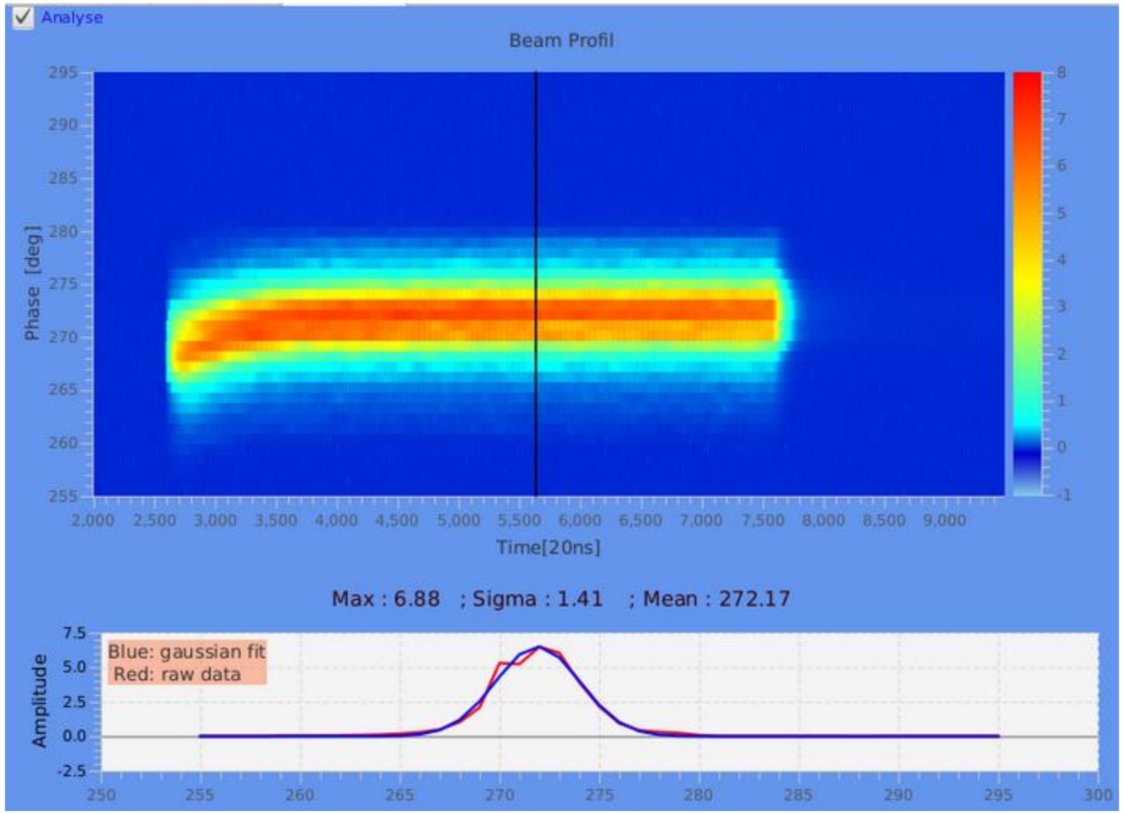


600 µs long 25.5 mA pulse just upstream the LINAC4 dump (red curve). The pulse flatness meets the specification for each of the 4 Booster rings

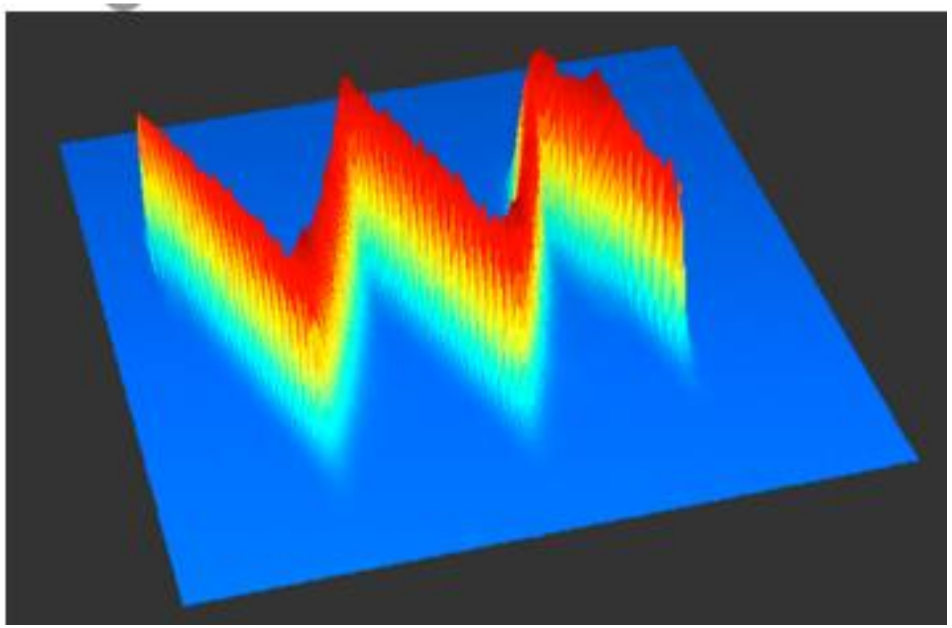


Zoom into start of Ring 4 with **nominal chopping pattern**;
Top: BCT in transfer line; bottom: output voltage (neg./pos.) of chopper plates.

Longitudinal stability and painting

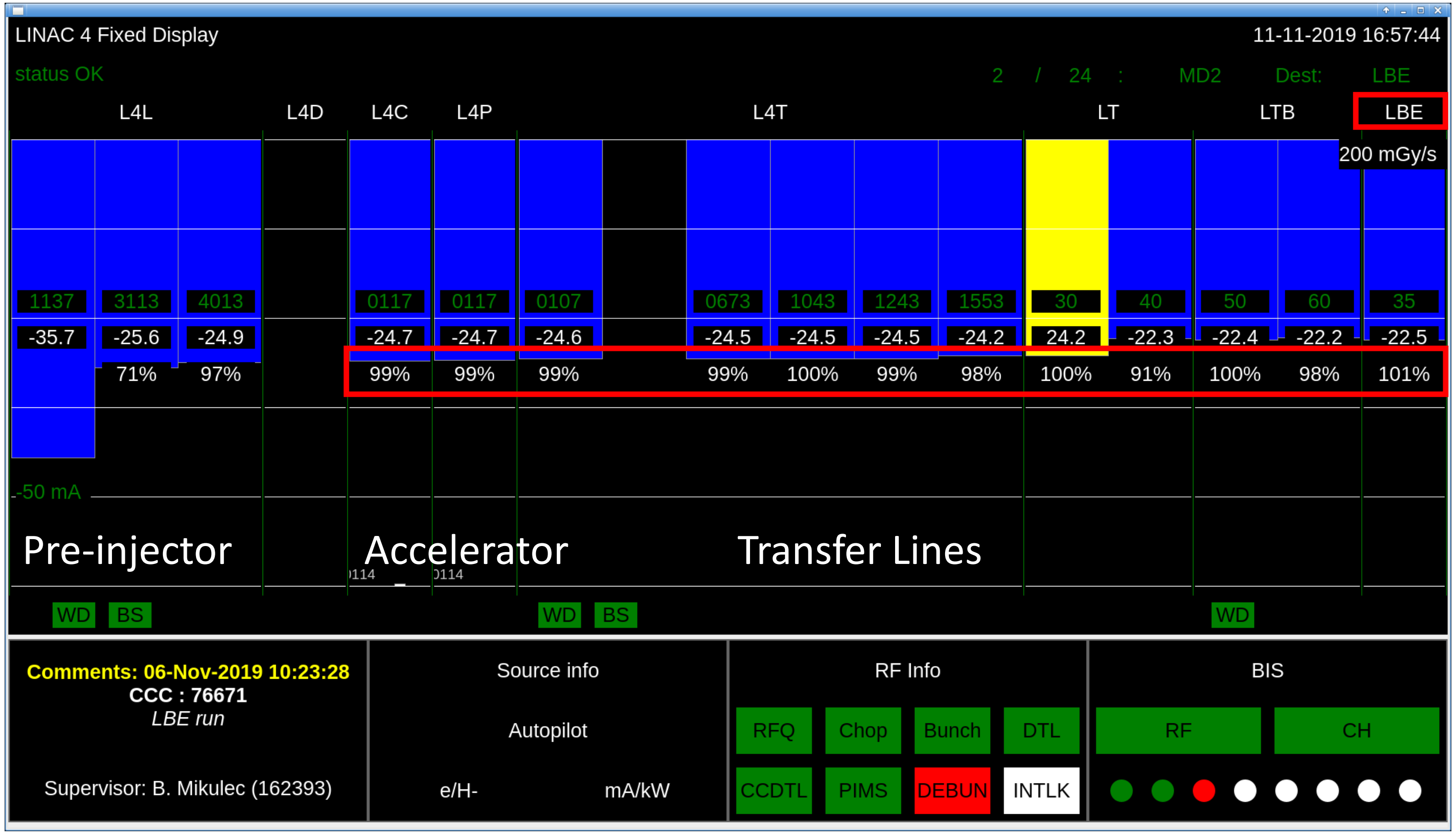


The beam phase spread along the pulse is within specs – RF regulation is ok



Measured phase variation for 100 µs long pulse when a energy variation is programmed along the pulse –proof of principle of energy painting

Beam Intensity and Transmission



H- beam intensity on the 15 transformers along the linac and transfer lines

- Excellent transmission from 3 MeV to the LBE
- Routinely 23mA (un-chopped) that allows the production of all the pre-LS2 beams

CERN 2013 : pre-injector challenge

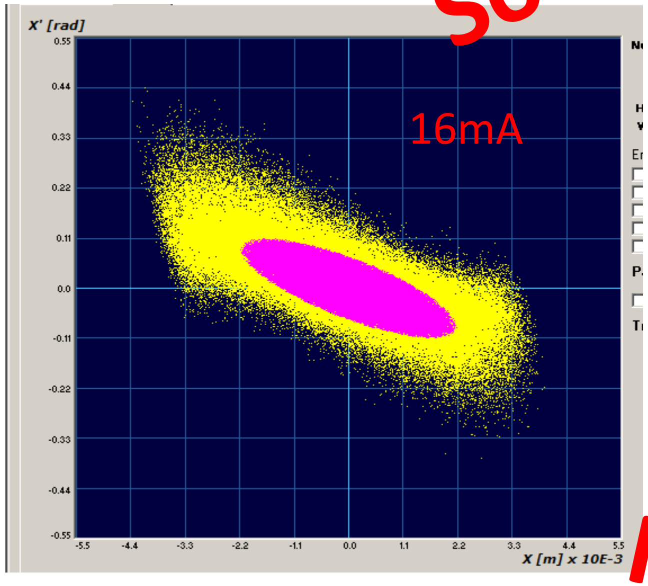
Source redesign

IS-O2 (25mA in RFQ acceptance)

IS-O3 (35mA in RFQ acceptance)

IS-04 (50mA in RFQ acceptance)

Edgar Sargsyan talk



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

Source redesign

IS-O2

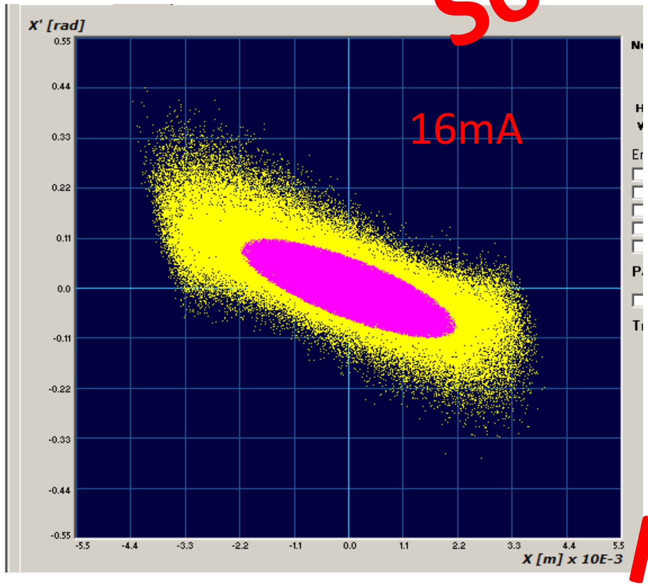
(25mA in RFQ acceptance)

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

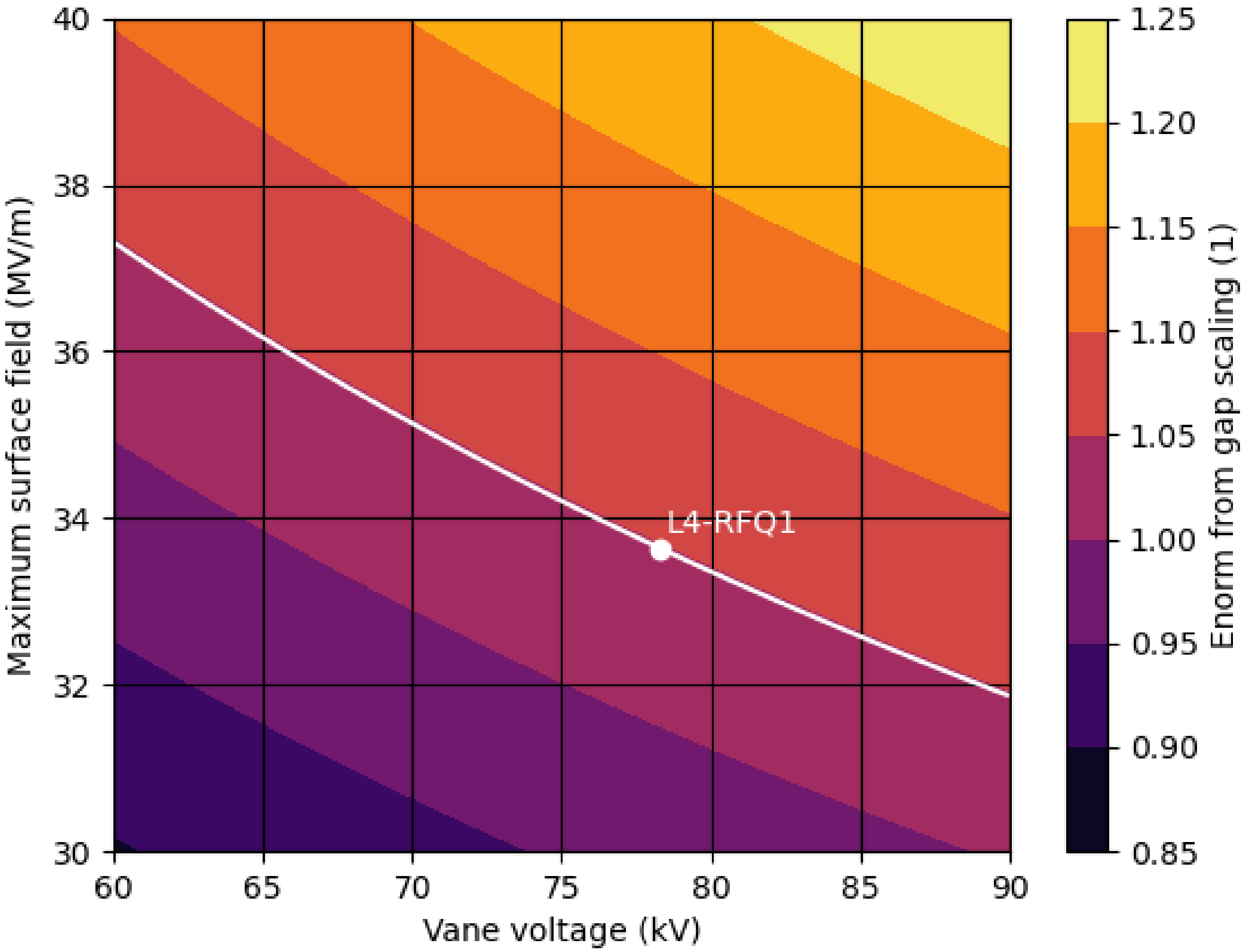
Common design guidelines

- 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

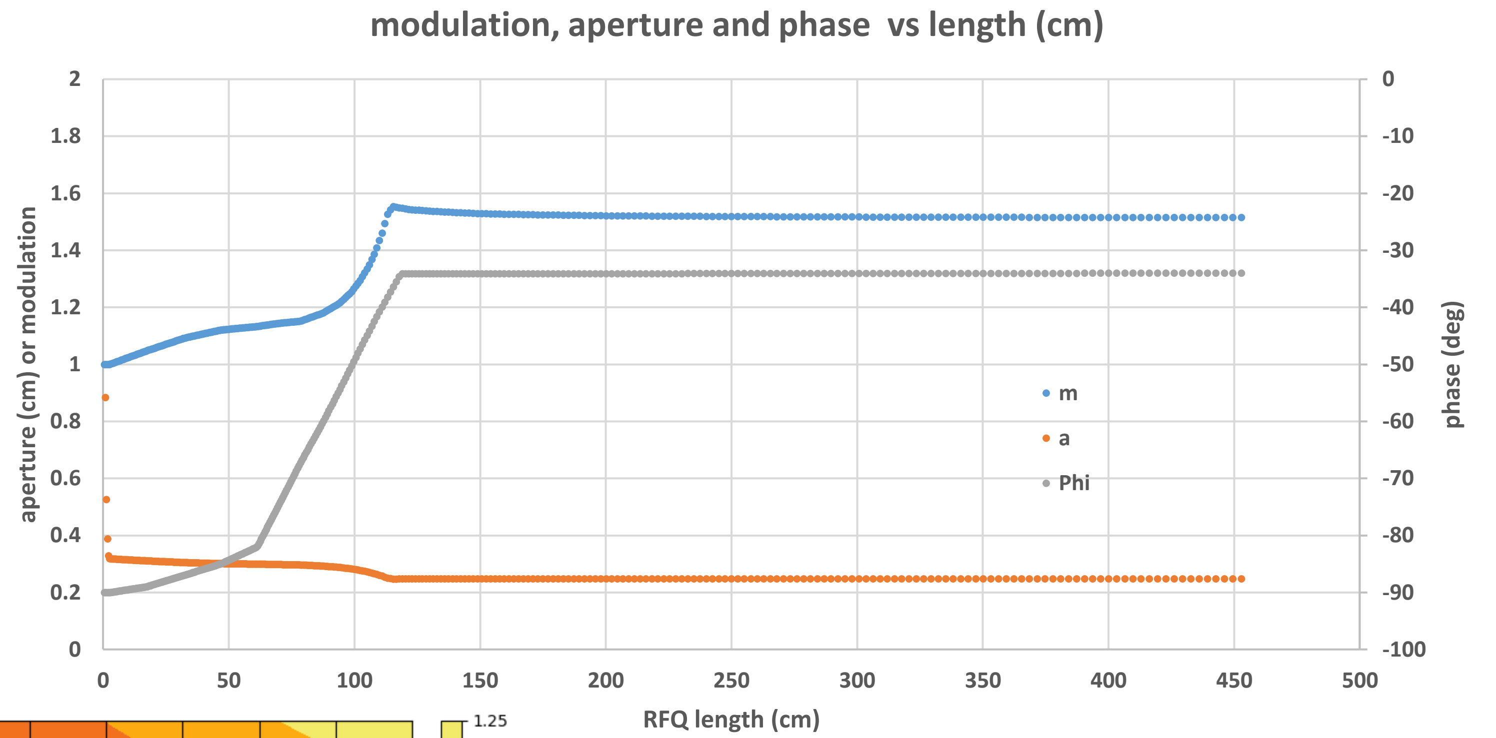
General Guidelines:

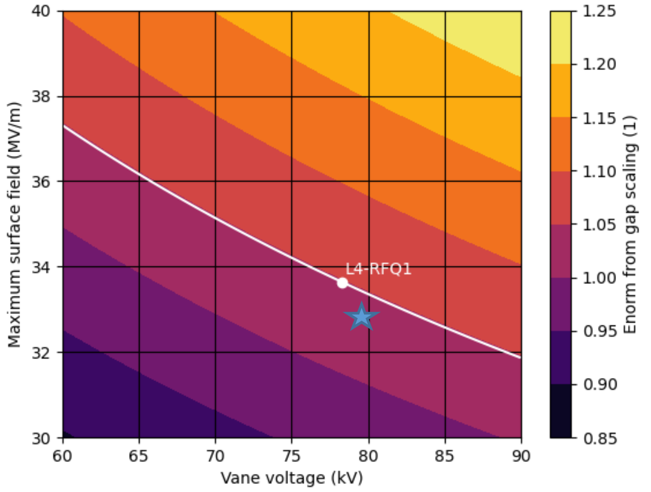
- **Stay below the RFQ1 line**
- Transmission>90 for emit=0.5 mm mrad and I=70mA
- rho/ro=0.7 -1
- Two versions
  - L=4.5 m to avoid dipole rods
  - L=as short as possible.

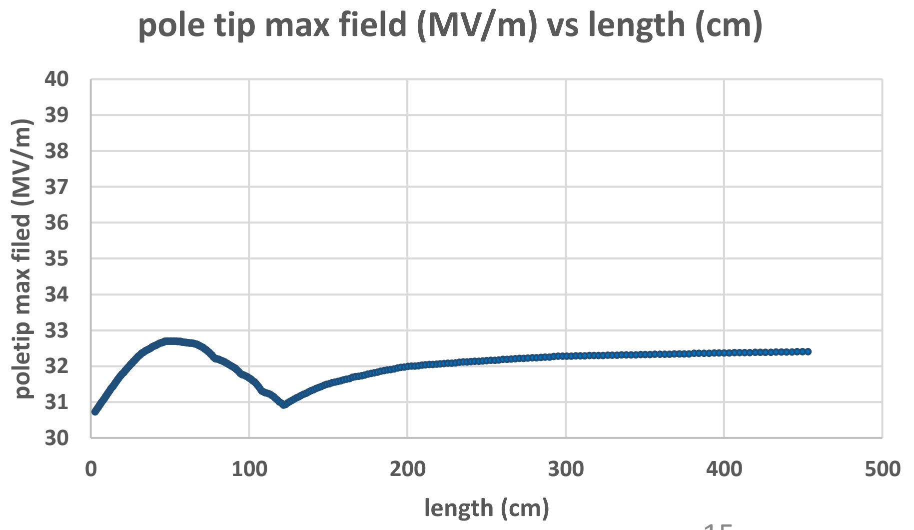


4.5 m

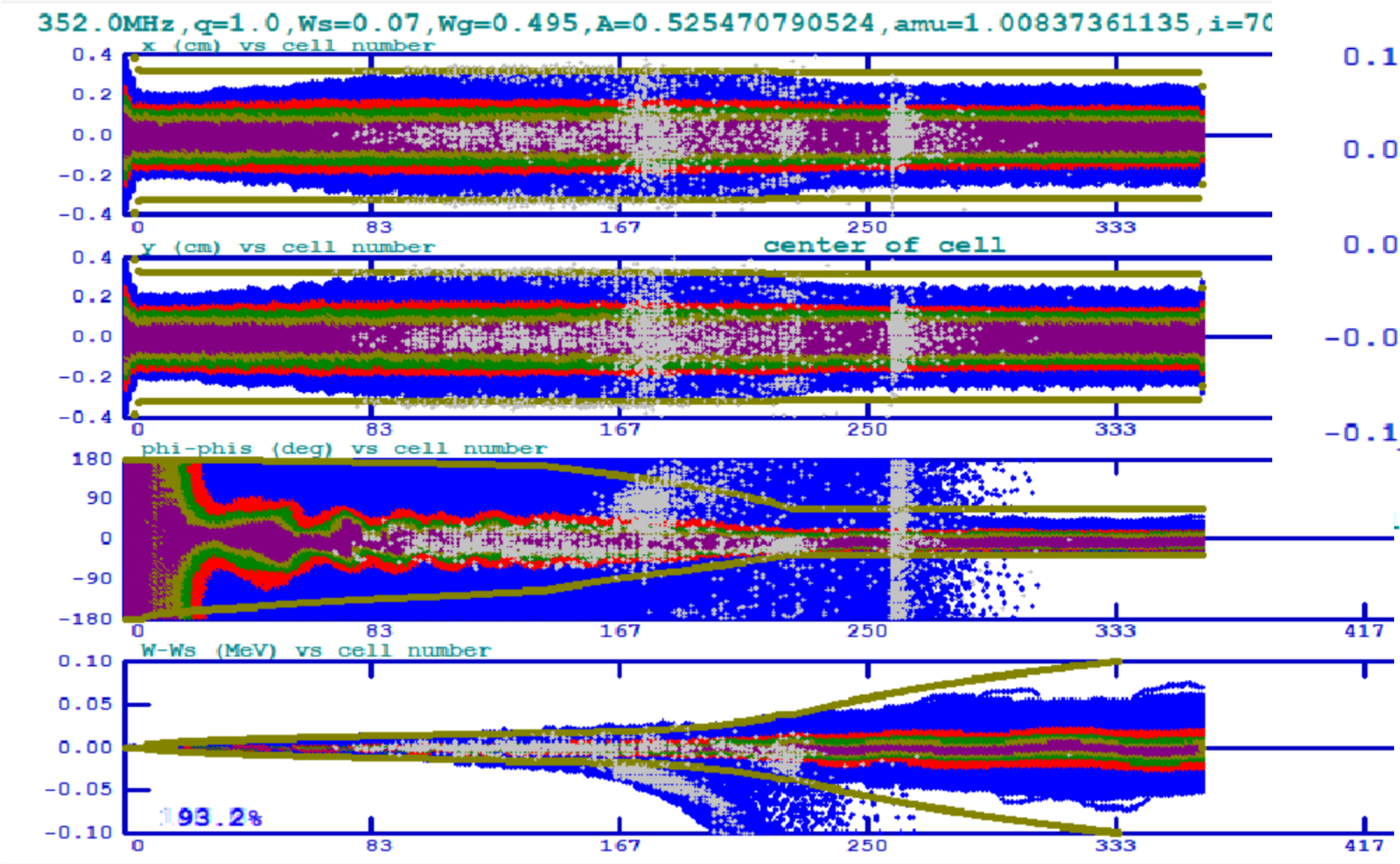
RFQ parameters	
Length m	4.5
Vane voltage kV	79
Max electric field (MV/m)	33
Peak RF power kW	750
Average aperture (r0) mm	3.2
Transverse radius (ρ)	2.7
Maximum modulation	1.5
Minimum aperture mm	2.5
Focusing parameter (B)	5.87
Phase at gentle buncher deg	-35
Transmission % (70mA , 0.5 mm mrad)	93.2



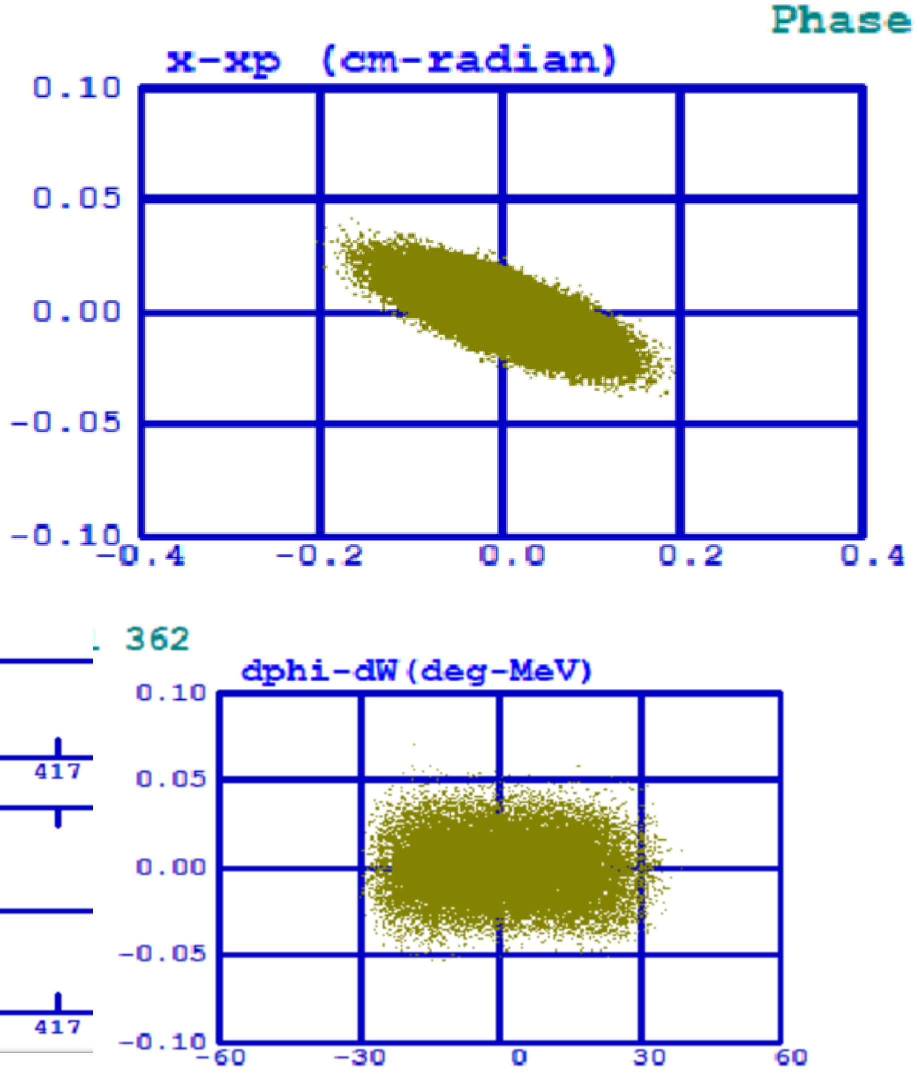




Beam dynamics – 70mA emit =0.5mm mrad



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

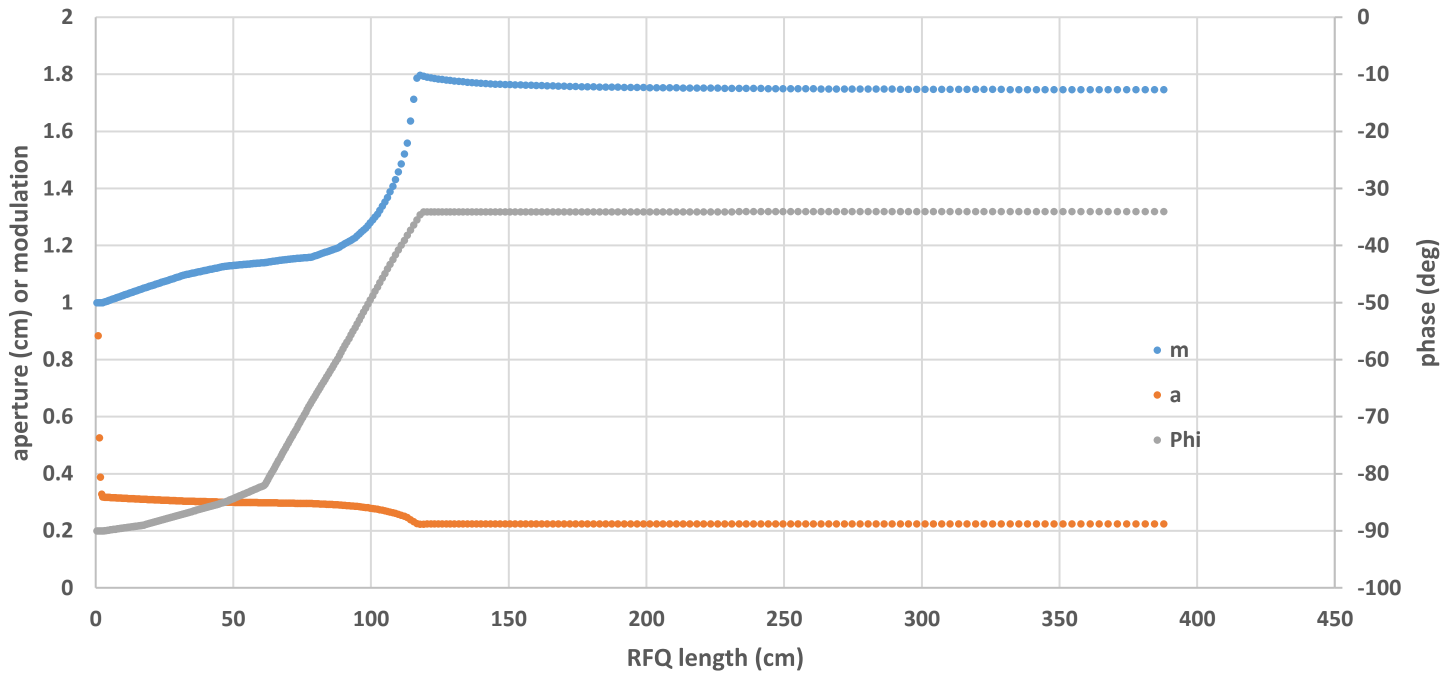


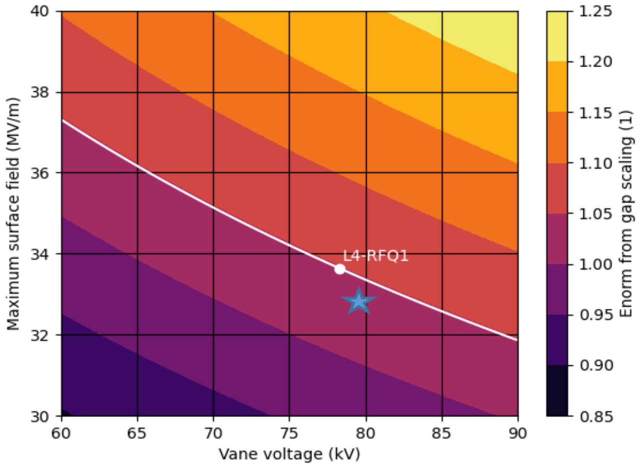
Beam at the RFQ output plane

3.9 m

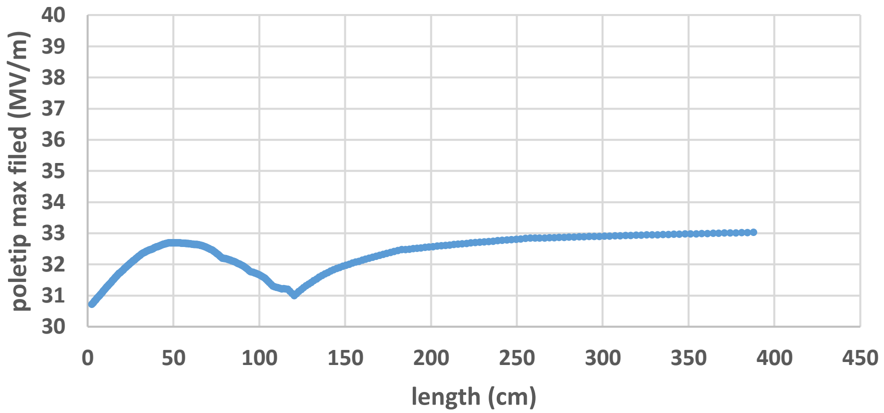
RFQ parameters	
Length m	3.9
Vane voltage kV	79
Max electric field (MV/m)	33
Peak RF power kW	650
Average aperture (r0) mm	3.2
Transverse radius (ρ)	2.2
Maximum modulation	1.8
Minimum aperture mm	2.2
Focusing parameter (B)	5.76
Phase at gentle buncher deg	-32
Transmission % (70mA , 0.5 mm mrad)	95.4

modulation, aperture and phase vs length (cm)

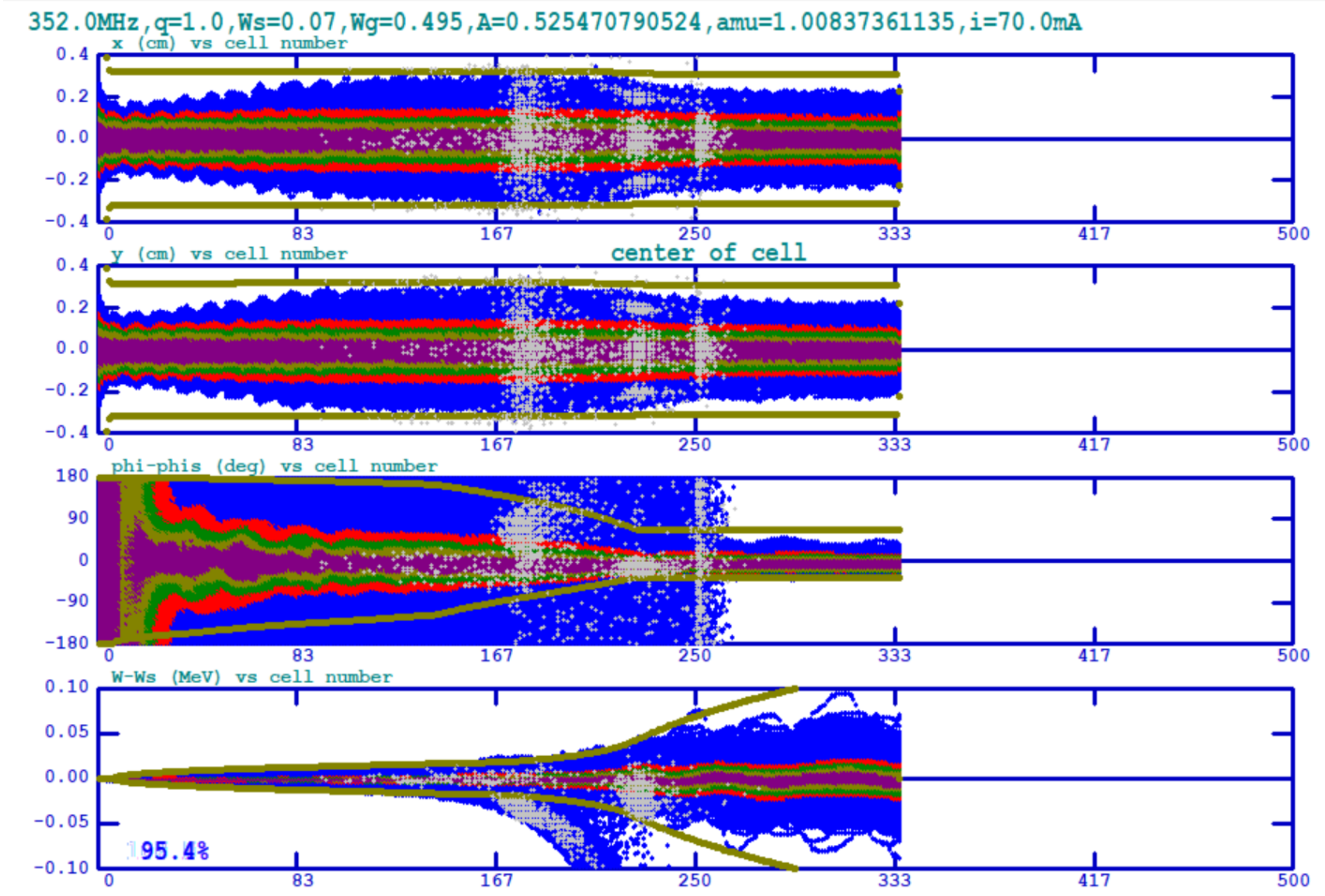




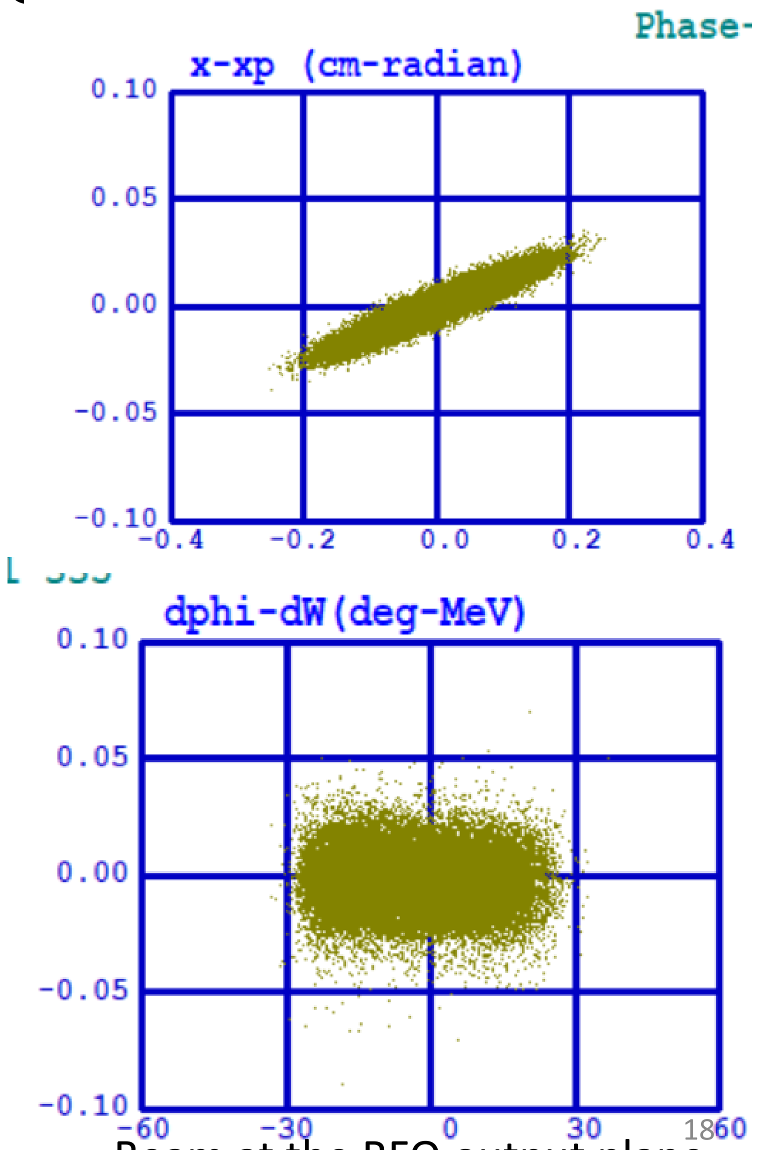
pole tip max field (MV/m) vs length (cm)



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

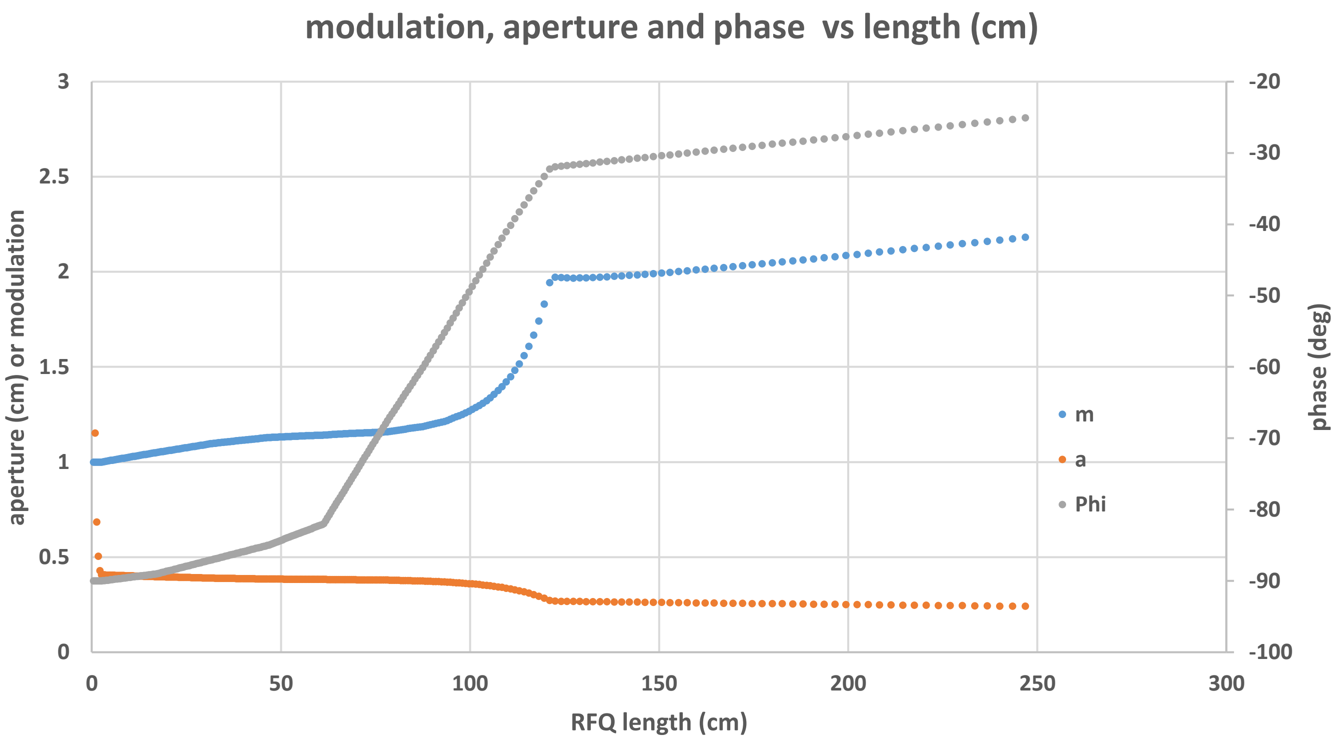
General Guidelines:

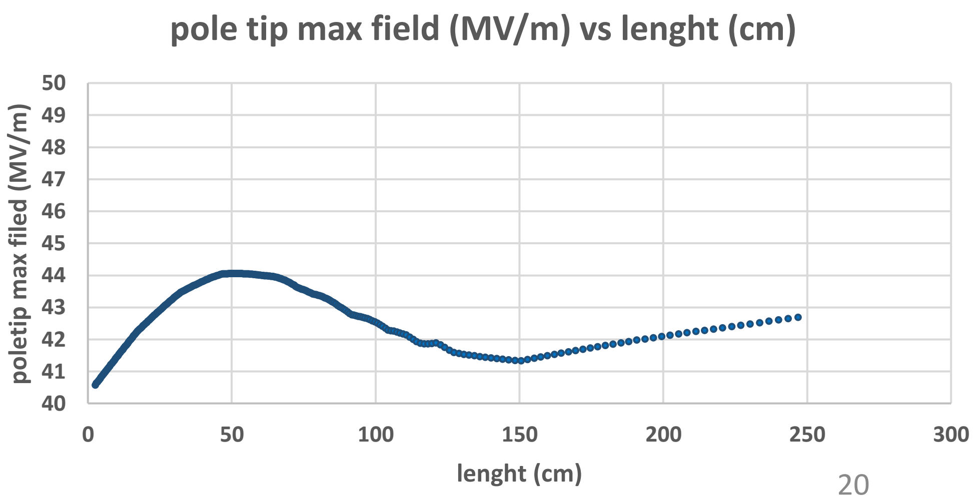
- **Field up to 50MV/m for 78 kV (cryo-copper)**
- Respect scaling –
  - 120kV and 42.3 MV/m
  - 140kV and 39.3 MV/m
- Transmission > 90% for emit=0.5 mm mrad and I=70mA
- rho/ro=0.7 -1

- L as short as possible
- Best beam quality

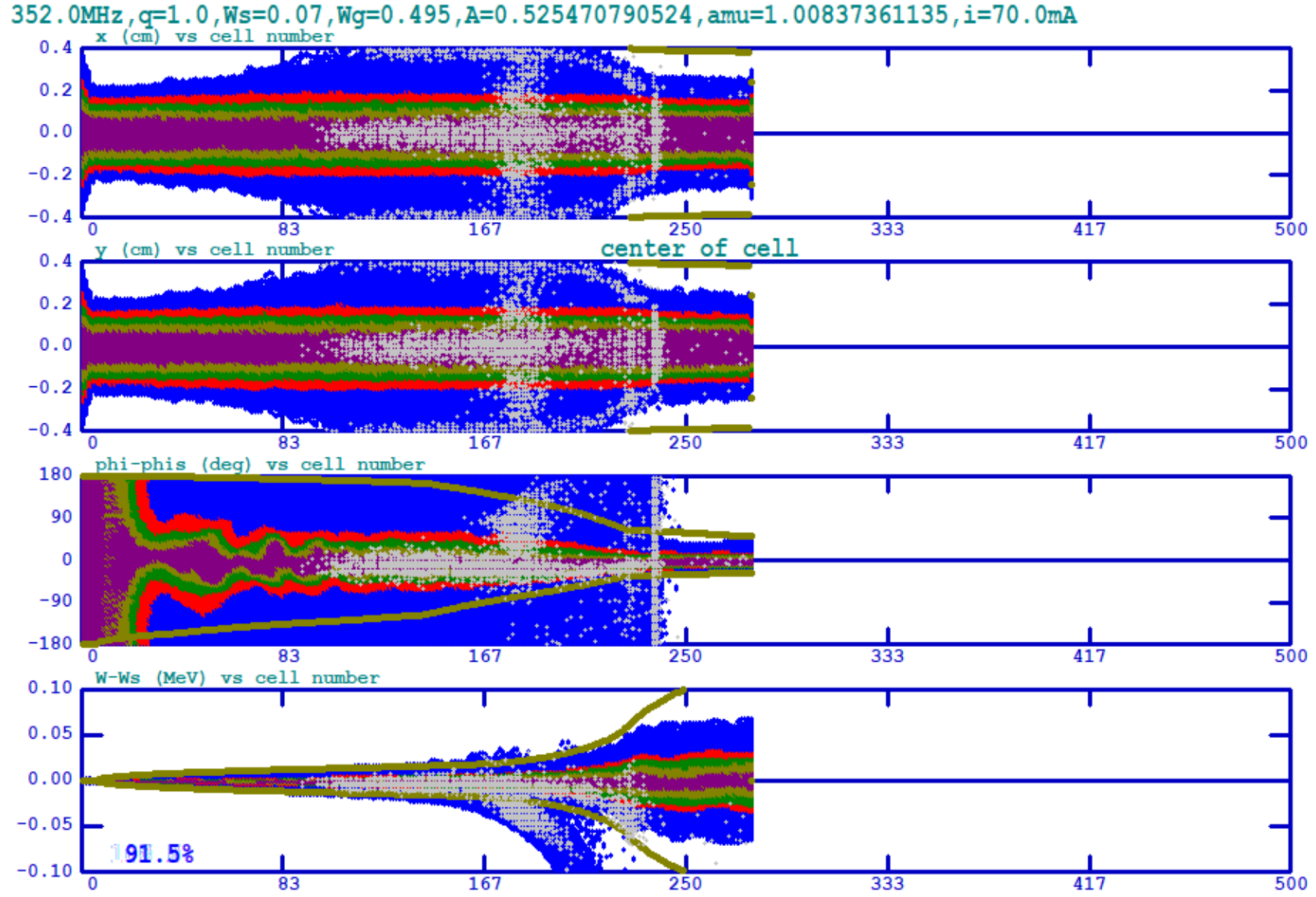
2.5 m 120 kV

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

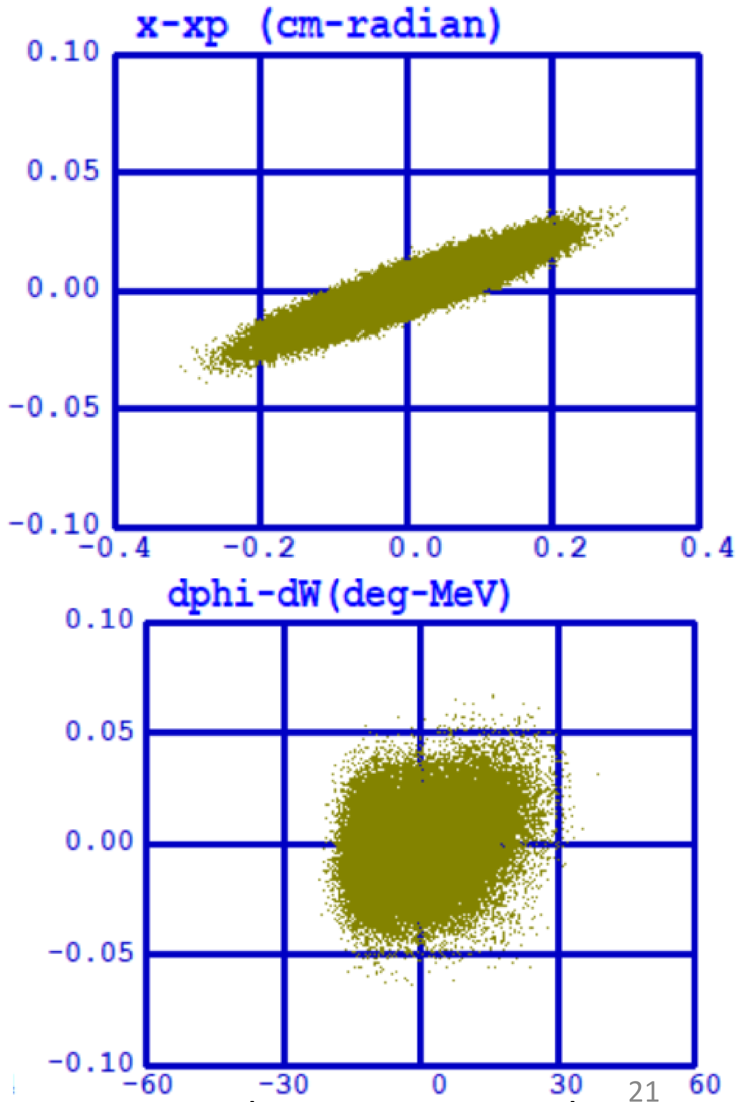




Beam dynamics – 70mA emit =0.5mm mrad



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



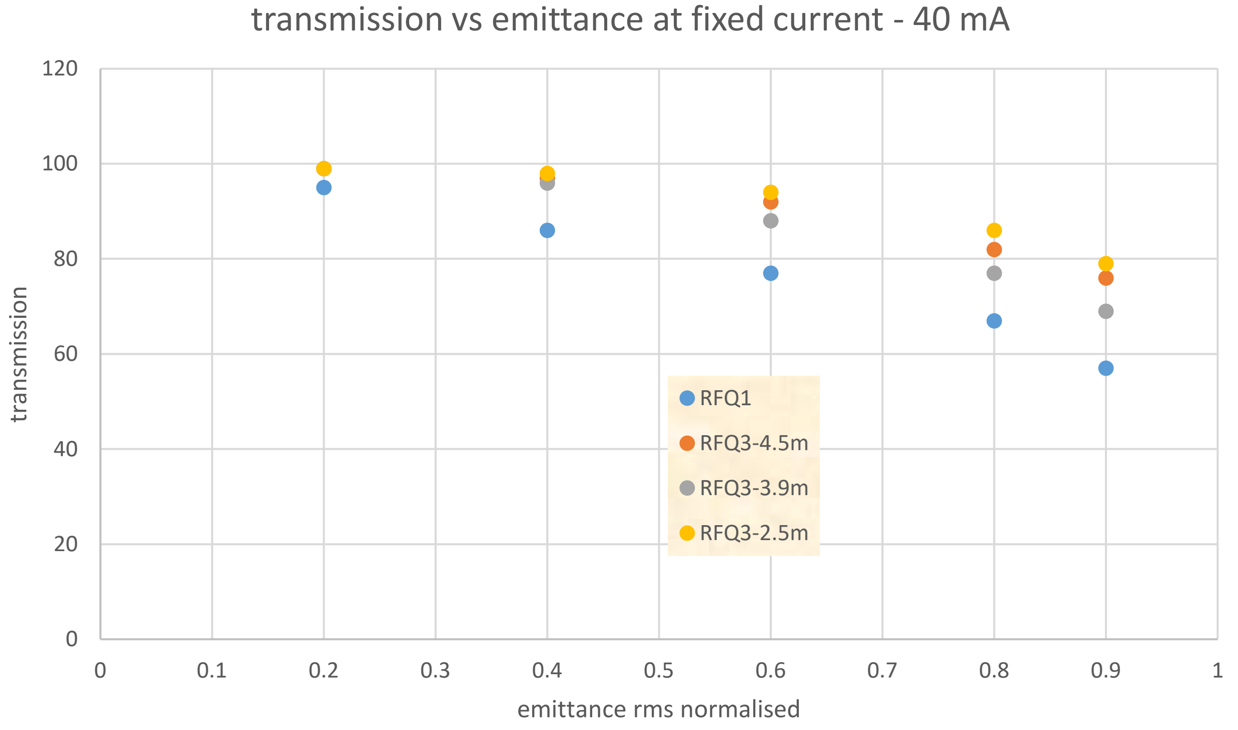
Beam at the RFQ output plane

Comparison of performance-method

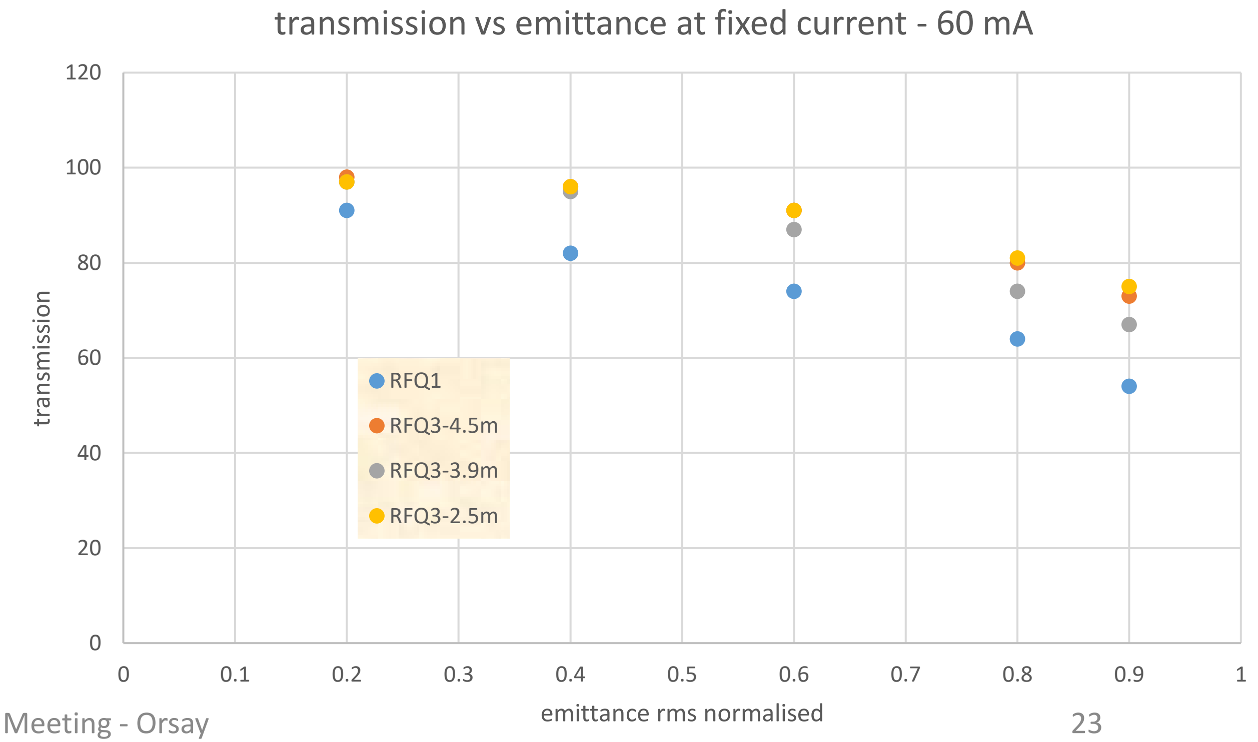
- Comparison of performance
    - Simulations
    - Current through the RFQ

- 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
- The normal conducting part of the proton driver (LINAC4) is almost fit for high power linac : main issue is brightness of the pre-injector.
- Chopping should be upgraded to faster rep rate
- Substantial progress on the source brightness : next talk by Edgar Sargsyan
- 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.