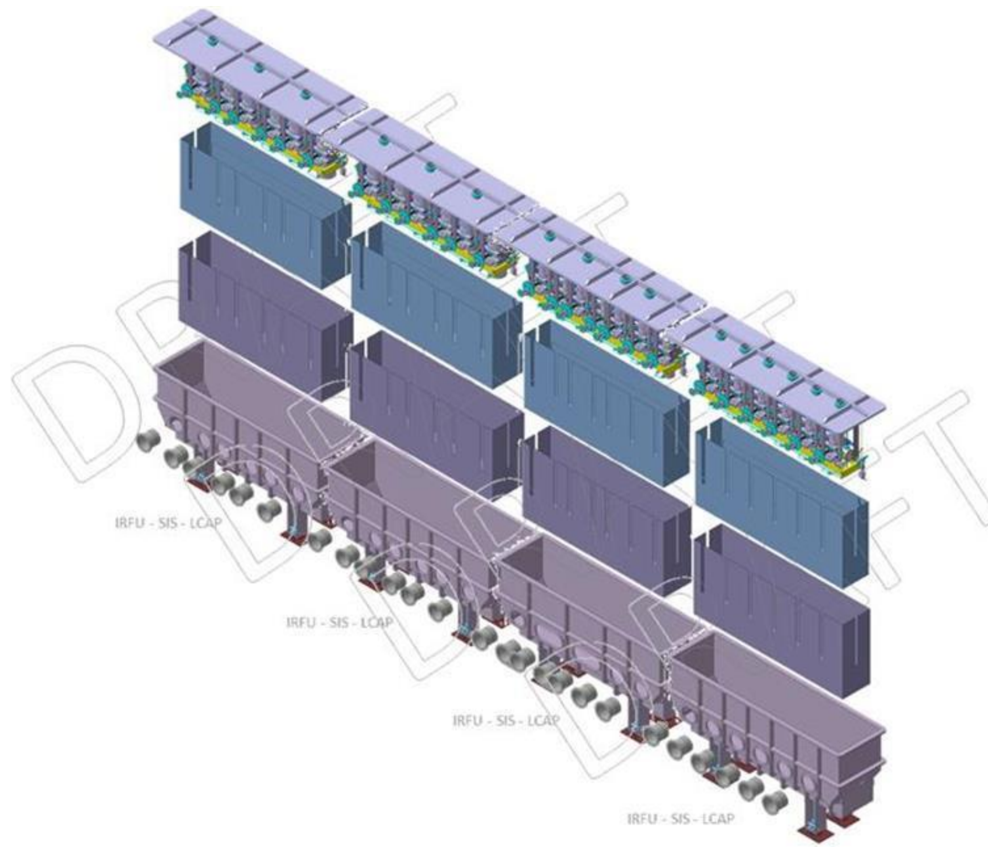
FROM RESEARCH TO INDUSTRY

CEA PROPOSITION FOR SARAF-PHASE 2 LINAC – DESIGN ET BEAM DYNAMICS



EuCARD-MAX workshop at CERN

MARCH 20TH, 2014

www.cea.fr

SARAF BEAM TOP LEVEL REQUIREMENTS (TLR)

Particles : **deuterons** and **protons**

Input energy : **20 keV/u**

Output energy : **1.3 MeV/u → 40 MeV**

Input emittance (rms, norm.) : **0.2 π.mm.mrad**

Emittance growth **< 25%**

Time structure : 0.1-1 ms @ 0.1-400 Hz → **cw**

Beam current : **0.04 – 5 mA**

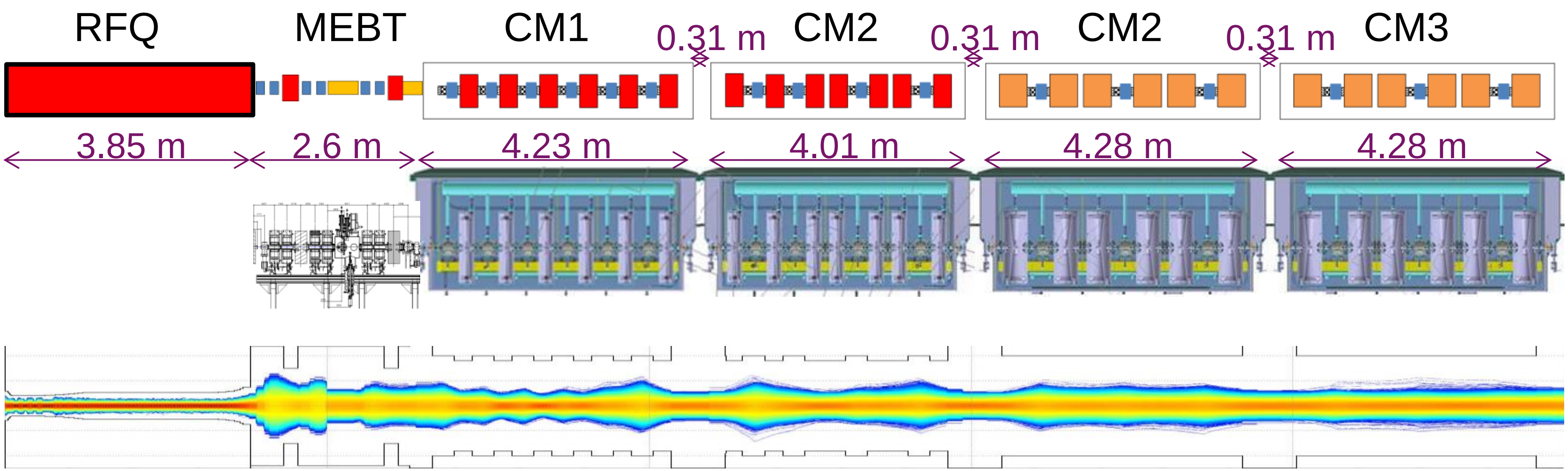
Beam losses :

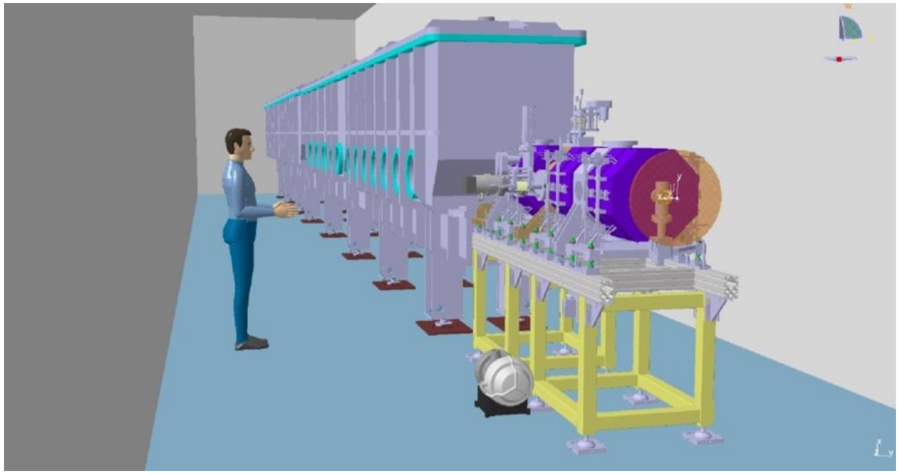
< 150 nA/m	for E < 5 MeV	(0.4-0.75	W/m)
< 40 nA/m	10 MeV	(0.2-0.4	W/m)
< 5 nA/m	20 MeV	(0.05-0.1	W/m)
< 1 nA/m	> 20 MeV	(0.02-0.04	W/m)

<< 1 W/m !!!

CEA PROPOSITION @ 176MHZ

Design is still evolving, it should be not far from :





Hypothesis :
1 – European legislation
2 – No security constraints

RFQ MAIN PARAMETERS

Main parameters :

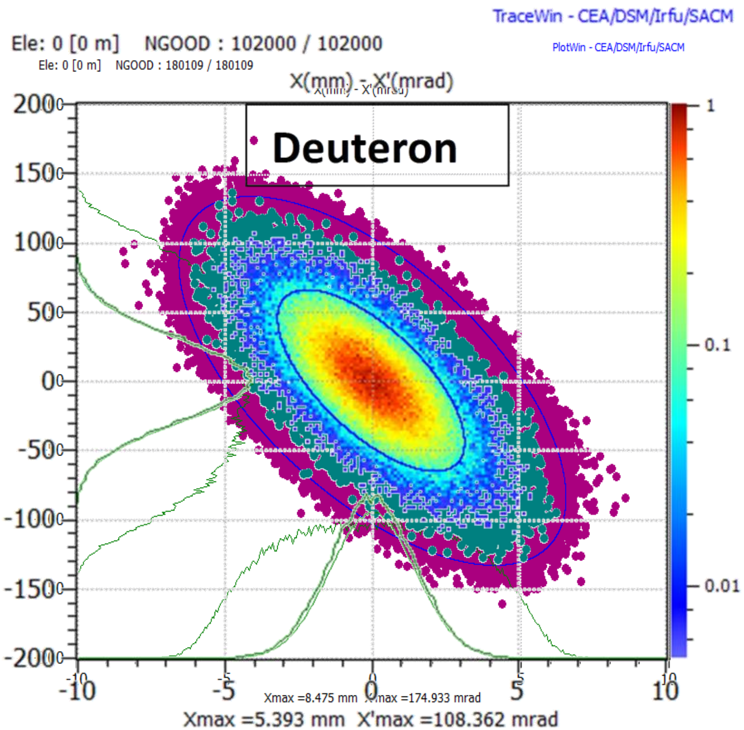
Technology :	4-vanes,
Length :	3.85 m
Energy range :	0.020 – 1.3 MeV/u
Voltage :	V = 70 kV (D^+) < 1.6 Kp
Average radius :	R > 4 mm
Pole modulation :	m < 2

RFQ ACCEPTANCE AT RFQ ENTRANCE

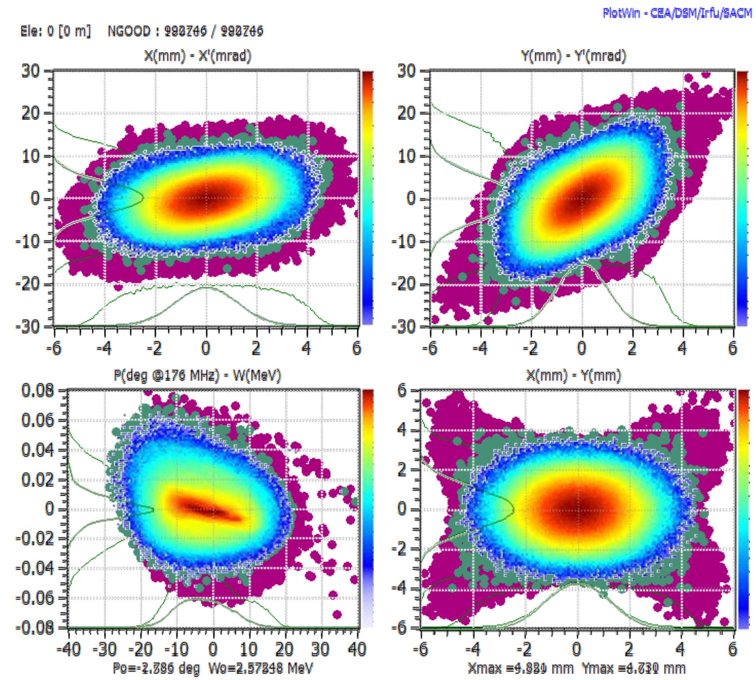
<u>RFQ Acceptance</u> : phase-spaces region at RFQ entrance where a particle can survive (exit with the nominal energy) a transport through the RFQ

Pink : 0 mA acceptance
Green : 5 mA acceptance

Multicolor : Beam at RFQ entrance



RFQ entrance

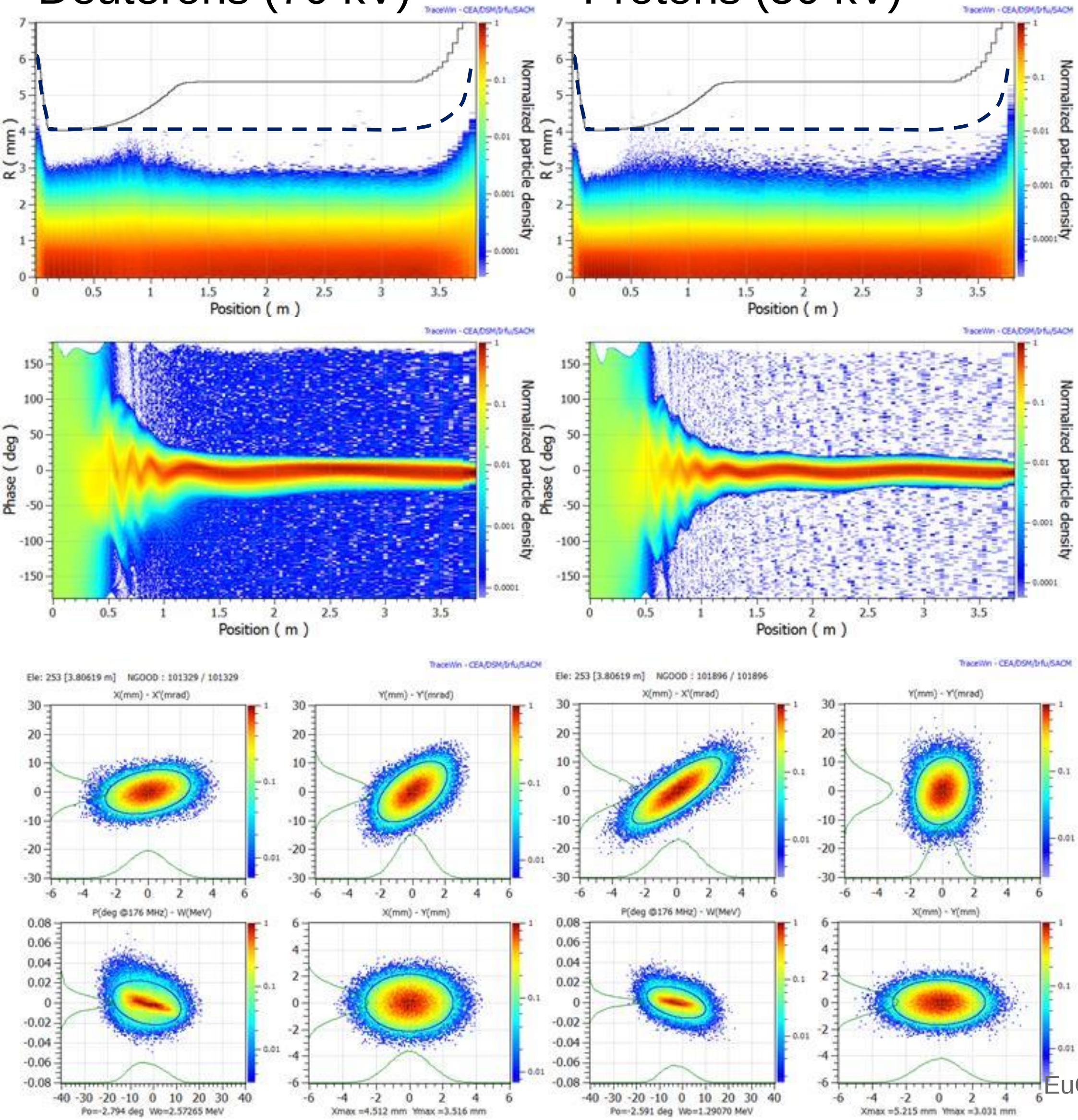


Associated RFQ exit

Injected beam (including tails to ±4 σ) close to the RFQ acceptance

RFQ – NOMINAL BEAM DYNAMICS – 5.1 MA

Deuterons (70 kV) Protons (50 kV)



Deuterons :

- Transmission : 99.3 %
- Emit T : 0.202 π.mm.mrad
- Emit L : 31.8 π.°.keV/u
- Halo T : 0.99
- Halo L : 1.66

Protons :

- Transmission : 99.0 %
- Emit T : 0.204 π.mm.mrad
- Emit L : 37.3 π.°.keV/u
- Halo T : 1.05
- Halo L : 1.87

MEBT FUNCTIONS

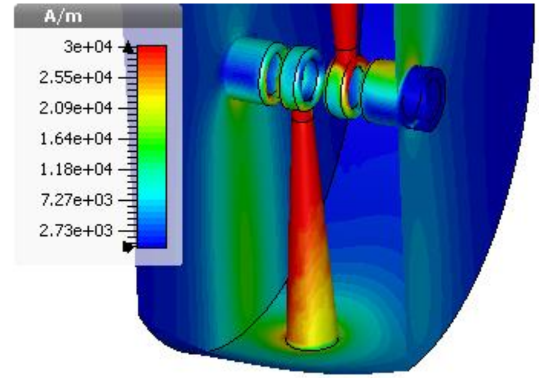
- Match the beam from the RFQ to the SCL,
- Diagnose the beam,
- Clean the beam,
- Stop the beam,
- Leave room **to host a fast chopper system in future**.

The fast chopper system has been based on what has been achieved for SPIRAL2 (@ 88MHz) and Linac4 (@352 MHz) :

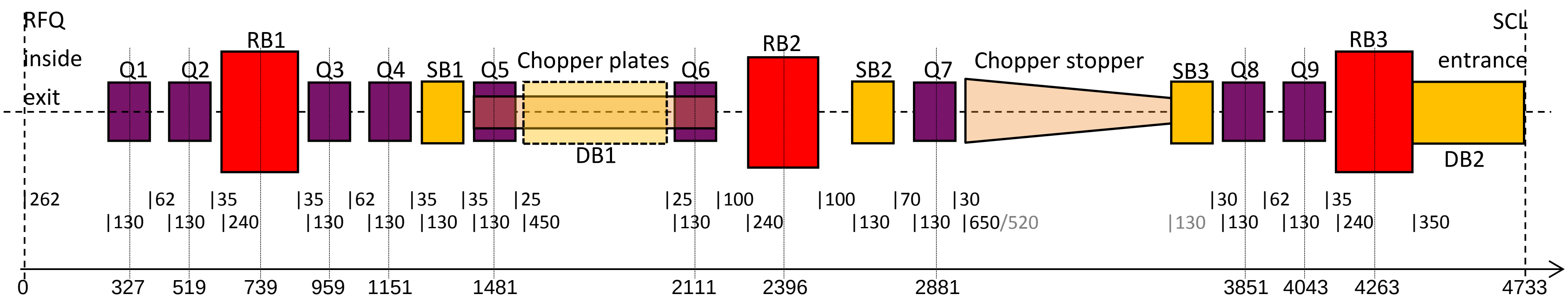
- A conservative **±800 V** voltage switched in less than **4.5 ns**, between **790 mm** plates,
  - SPIRAL2 : ±2000 V in 9 ns between 272 mm long plates,
  - Linac4 : ±650 V in 2.0 ns between 800 mm long plate.
- The plates will be placed **in a doublet** of quadrupoles.
- The beam transport from deviator to beam stop is inspired by this used on Linac4.
- The 1.3 kW beam stop is 650 mm long (400 mm for SP2 @ 7.5 kW)

MEBT DESIGN

9 SPIRAL2-type quadrupoles



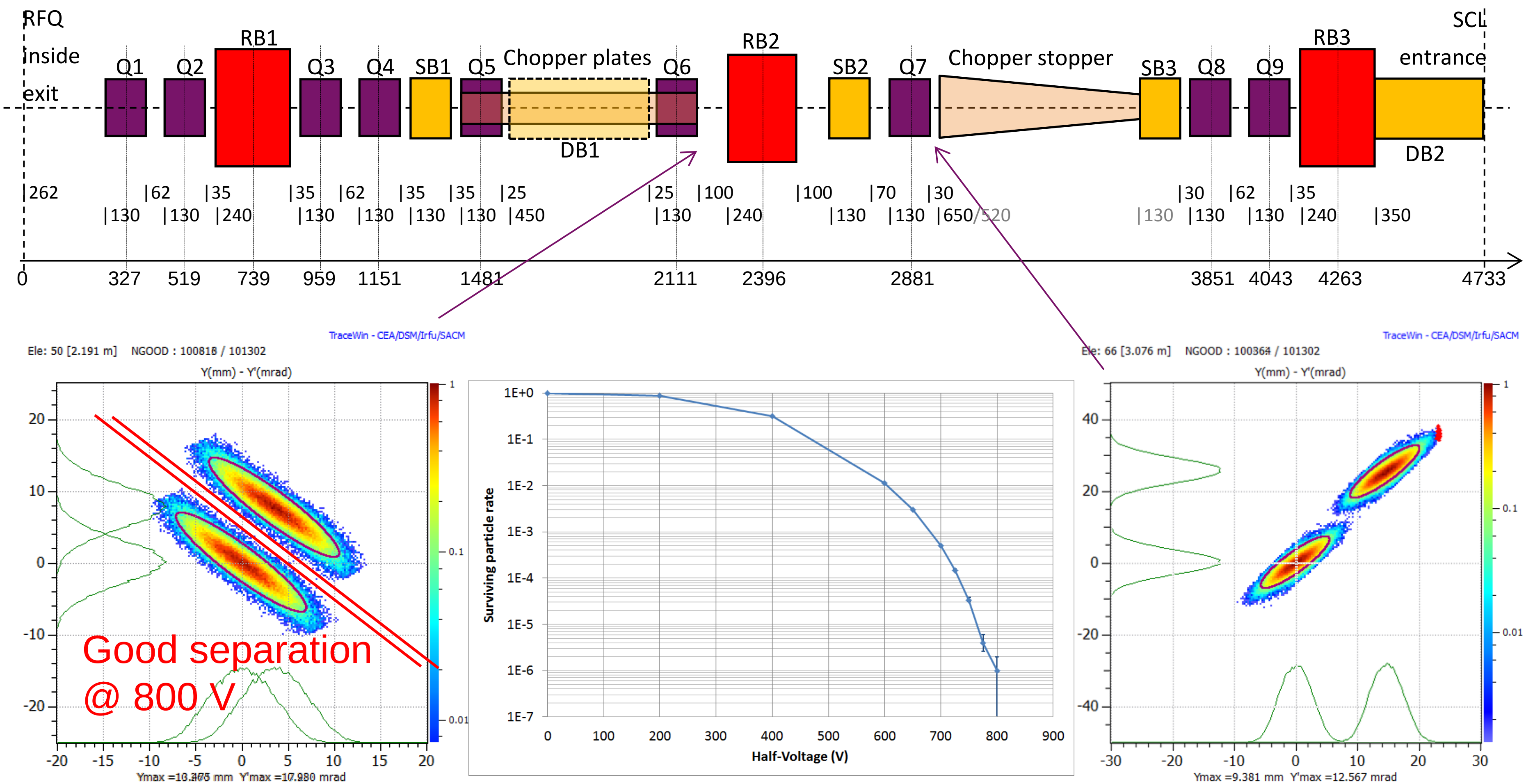
3 three-gap bunchers



3 sets of H/V slits

2 diagnostics boxes for current, position, profile, emittance measurements.

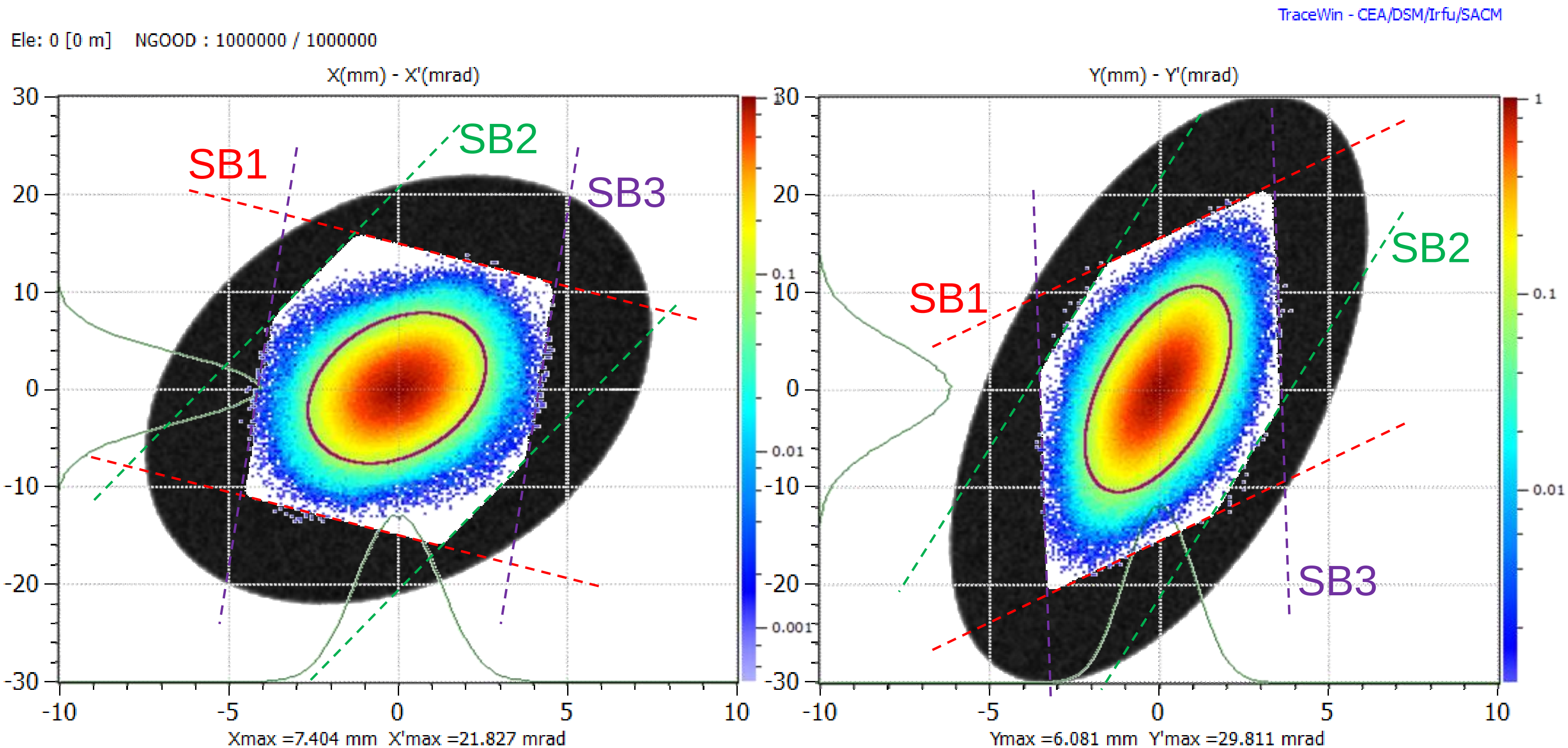
FC SEPARATION



→ A good separation could be achieved even with low (800 V) voltage.

MEBT ZERO CURRENT ACCEPTANCE

MEBT Acceptance : phase-spaces region at RFQ exit where a particle can survive (exit with the nominal energy) a transport through the MEBT



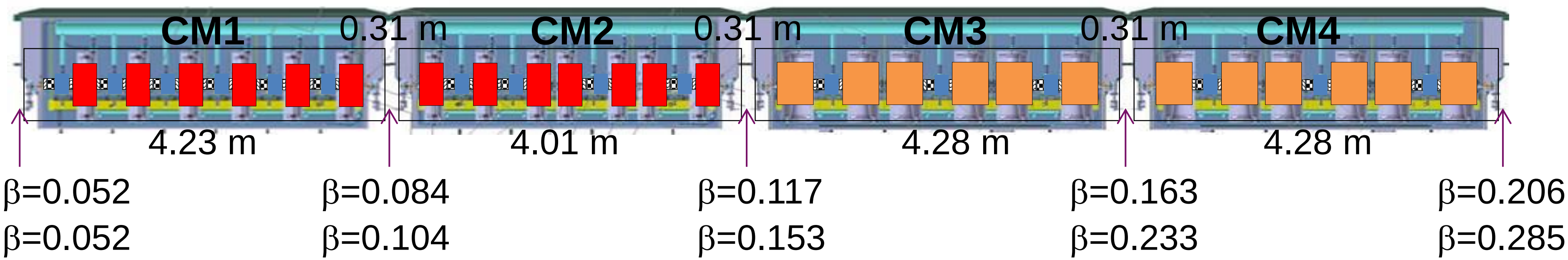
→ Slits are well positioned and phase-space area can be precisely cut.

SCL (JANUARY DESIGN)

Main parameters :
4 cryomodules,
4.23+4.01+2×4.28+3×0.31 = 17.7 m.

13 low-beta (0.091) cavities
$Eacc_{max}$ = 7 MV/m

12 high-beta (0.194) cavities
$Eacc_{max}$ = 8.1 MV/m



16 BPM | 16 SC solenoids

NOMINAL BEAM DYNAMICS

Nominal :

From **RFQ entrance** to **SCL exit**,

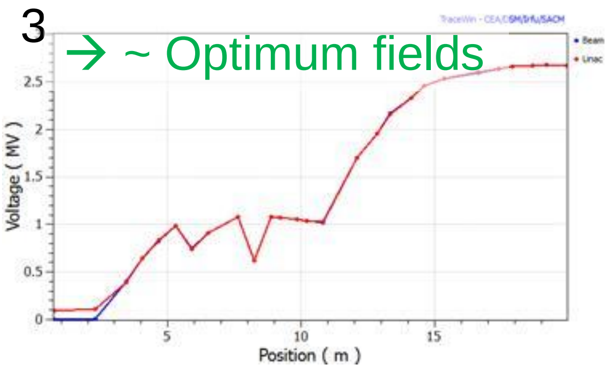
Input distribution: **matched**, **gaussian** (H=1), **±4 σ**, **0.2 π.mm.mrad** (rms, norm.)

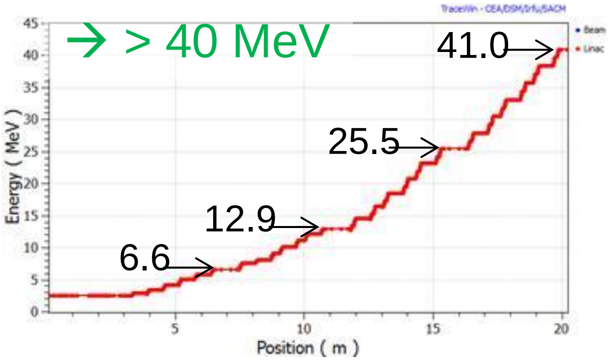
Particles (**P**): Deuterons – Protons

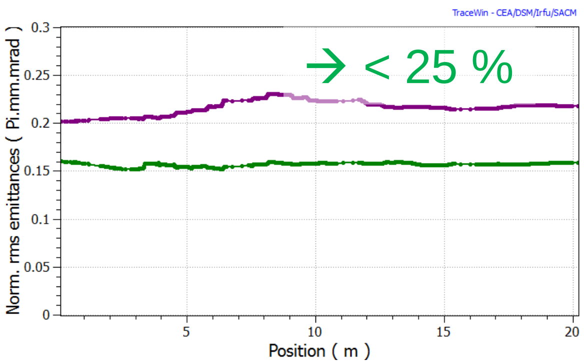
Currents (**I**): 0.1 – 5.1 mA

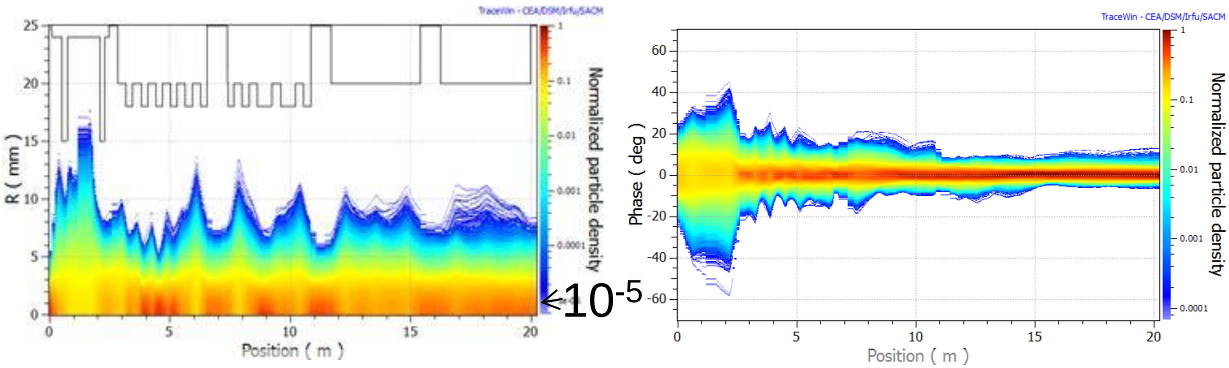
Final energies (**E**): 1.3 MeV/u – 40 MeV

NOMINAL: DEUTERONS – 5 MA – 40 MEV

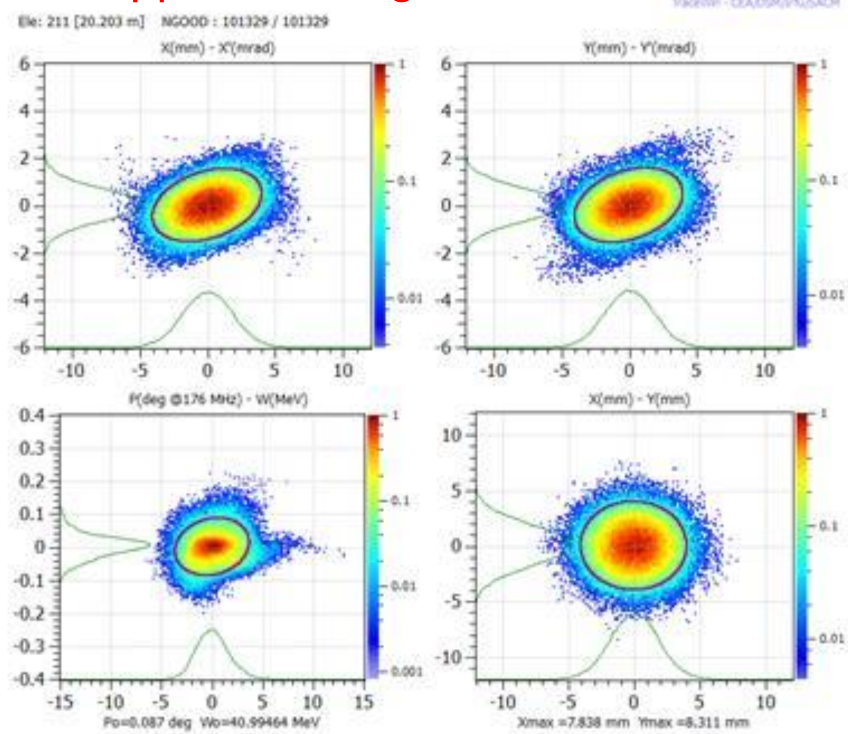








→ Less apparent margins at CM1-CM2 transition



NOMINAL BEAM DYNAMICS – SUMMARY

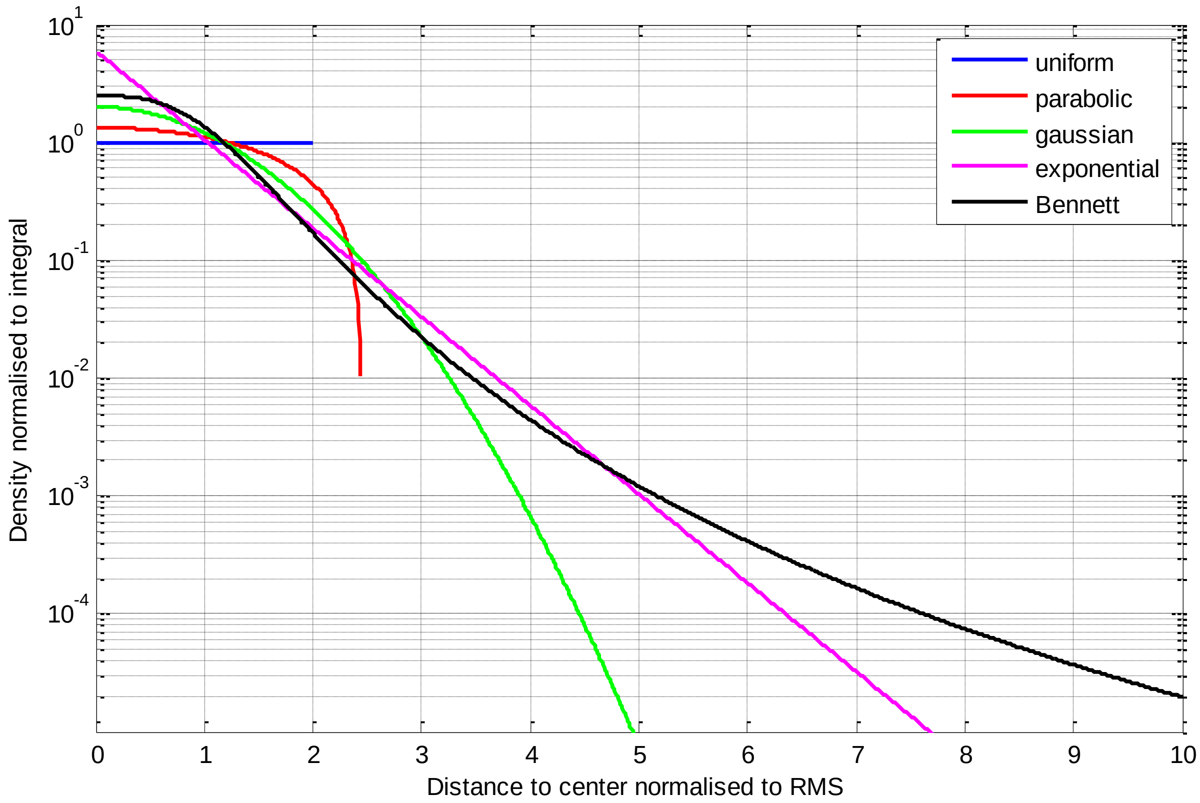
Beam dynamics results summary :

P-I-E	D-5-40	P-5-40	D-0.1-40	D-0.1-40	D-5-1,3
Energy [MeV]	41.0	40.7	40.2	40.6	2.6
Emit.T [π.mm.mrad]	0.22 (0.20)	0.23 (0.20)	0.22 (0.20)	0.23 (0.20)	0.20
Emit.L [π.°.keV/u]	31.5 (31.8)	41.2 (37.3)	49.4 (47.4)	57.5 (53.4)	56 (cw)
Halo.T	1.22 (0.99)	1.36 (1.05)	1.23 (1.00)	1.59 (1.01)	0.98
Halo.L	2.18 (1.66)	1.83 (1.87)	1.07 (0.84)	1.11 (0.83)	3.53 (cw)

→ Emittance and halo are under control

HALO PARAMETER ILLUSTRATION

Halo parameter : ratio between 4th and 2nd order momentum in 2D phase-space centered and normalized to : 0 – for uniform distribution
1 – for gaussian distribution



H = 0
H = 0.25
H = 1
H = 3
H = 4.7
(truncated to 10σ)

→ The higher the halo parameter, the larger/denser the tails

ERRORS STUDIES : AMPLITUDES

MEBT quad

Error type	Static	Dynamic
Δx [mm]	±0.2	±0.010
Δy [mm]	±0.2	±0.010
θx [°]	±0.1	±0.005
θy [°]	±0.1	±0.005
θz [°]	±1	±0.05
ΔG/G [%]	±1	±0.05

MEBT rebunchers

Error type	Static	Dynamic
Δx [mm]	±0.5	±0.01
Δy [mm]	±0.5	±0.01
θx [°]	±0.12	±0.005
θy [°]	±0.12	±0.005
ΔE/E [%]	±1	±0.1
φ [°]	±1	±0.1

SCL solenoids

Error type	Static	Dynamic
Δx [mm]	±1	±0.02
Δy [mm]	±1	±0.02
θx [°]	±0.5	±0.01
θy [°]	±0.5	±0.01
θz [°]	±1	±0.1
ΔG/G [%]	±1	±0.05

SCL cavities

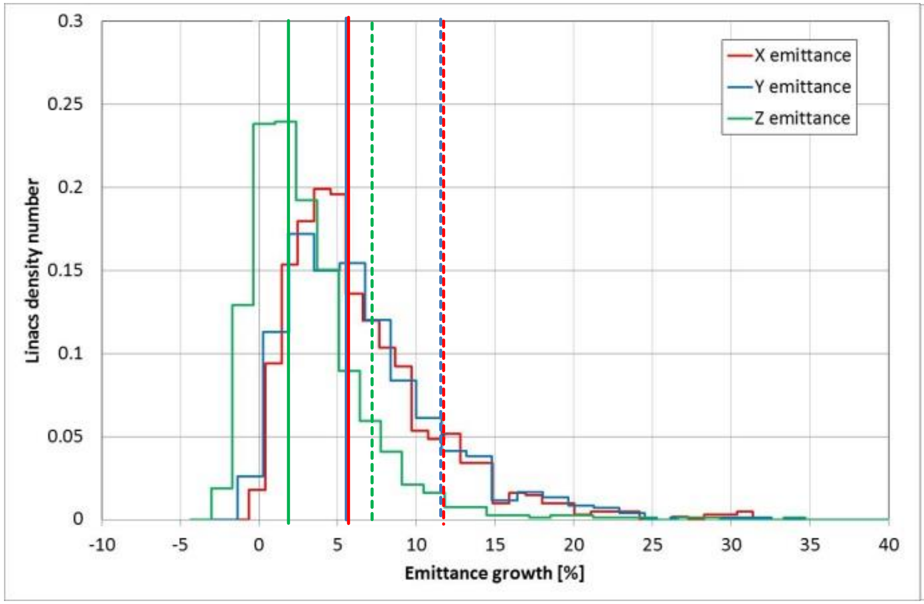
Error type	Static	Dynamic
Δx [mm]	±1	±0.02
Δy [mm]	±1	±0.02
θx [°]	±0.5	±0.01
θy [°]	±0.5	±0.01
ΔE/E [%]	±1	±0.1
φ [°]	±1	±0.1

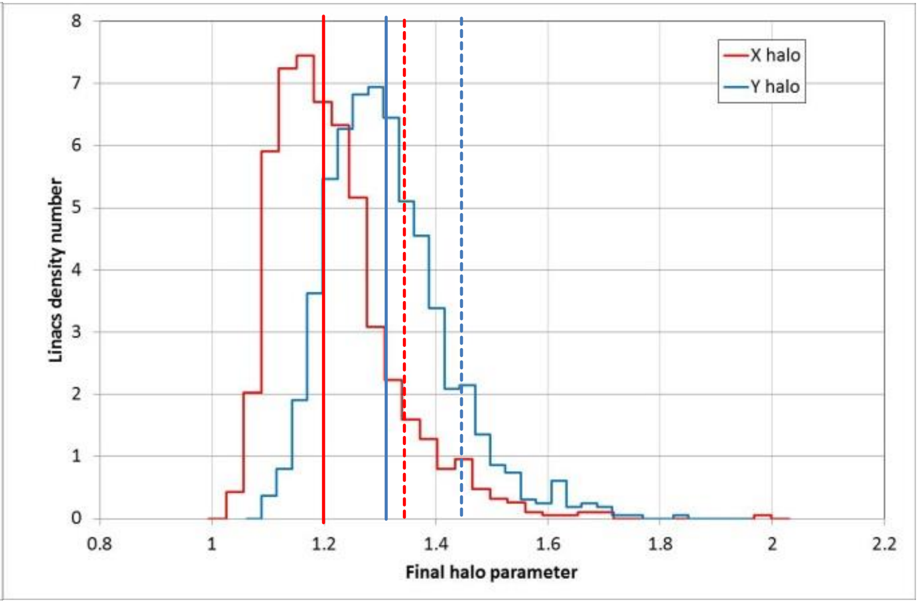
1000 linacs, 510 000 particles at RFQ input → equivalent to **5 10^8 particles**

Static errors corrected (only) with steerer-BMP correction scheme

ERRORS STUDIES : EMITTANCE AND HALO

Emittance and halo histograms





Emittance growth (compared to nominal) :
Average : < 5.5%(T); < 2%(L)
90% : < 12%(T); < 7% (L)

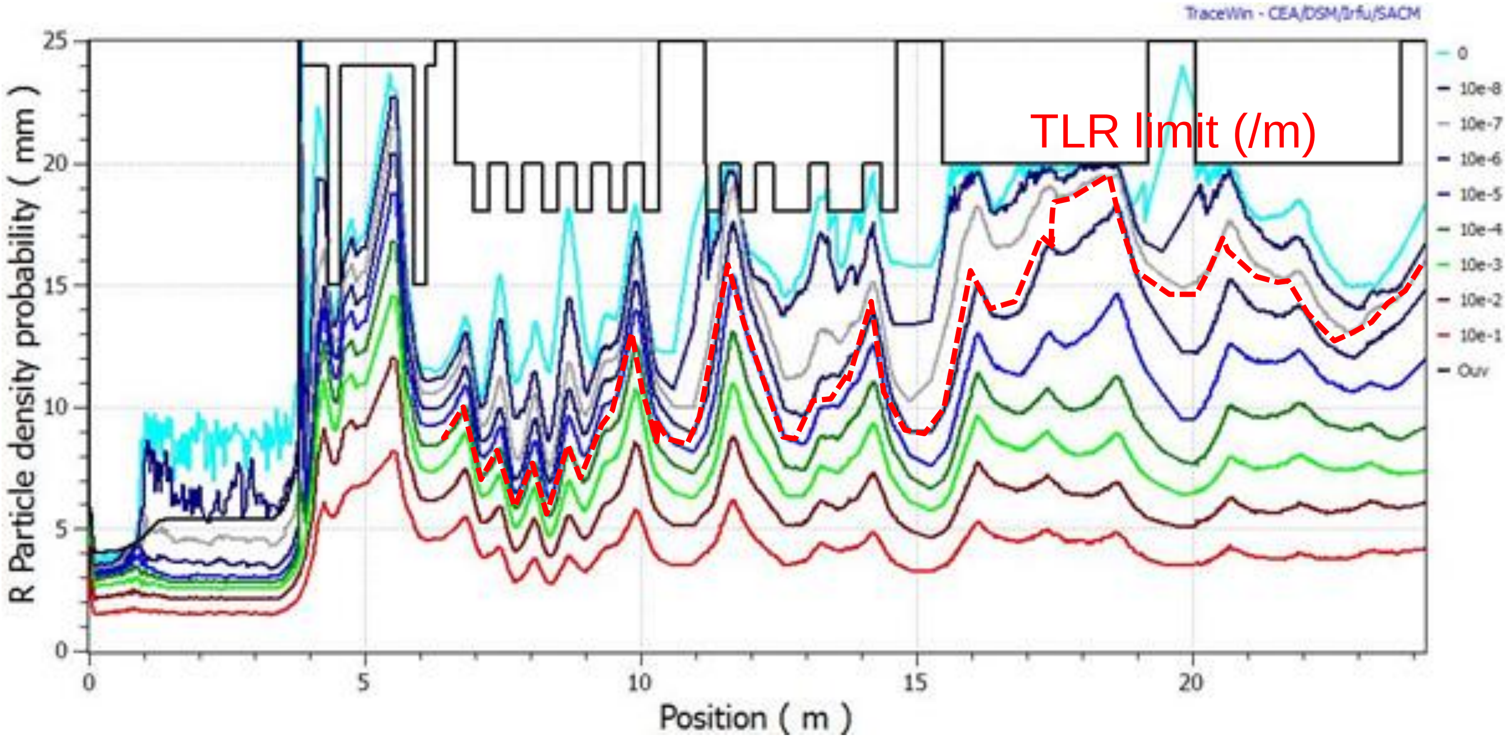
Final Halo parameter (nom. : 1.22) :
Average : < 1.26
90% : < 1.4
→ A little more halo in y (due to MEBT).

→ Low halo and emittance production

ERRORS STUDIES : PROBABILITIES

Probability density

→ Lower margins at CM3-CM4 transition

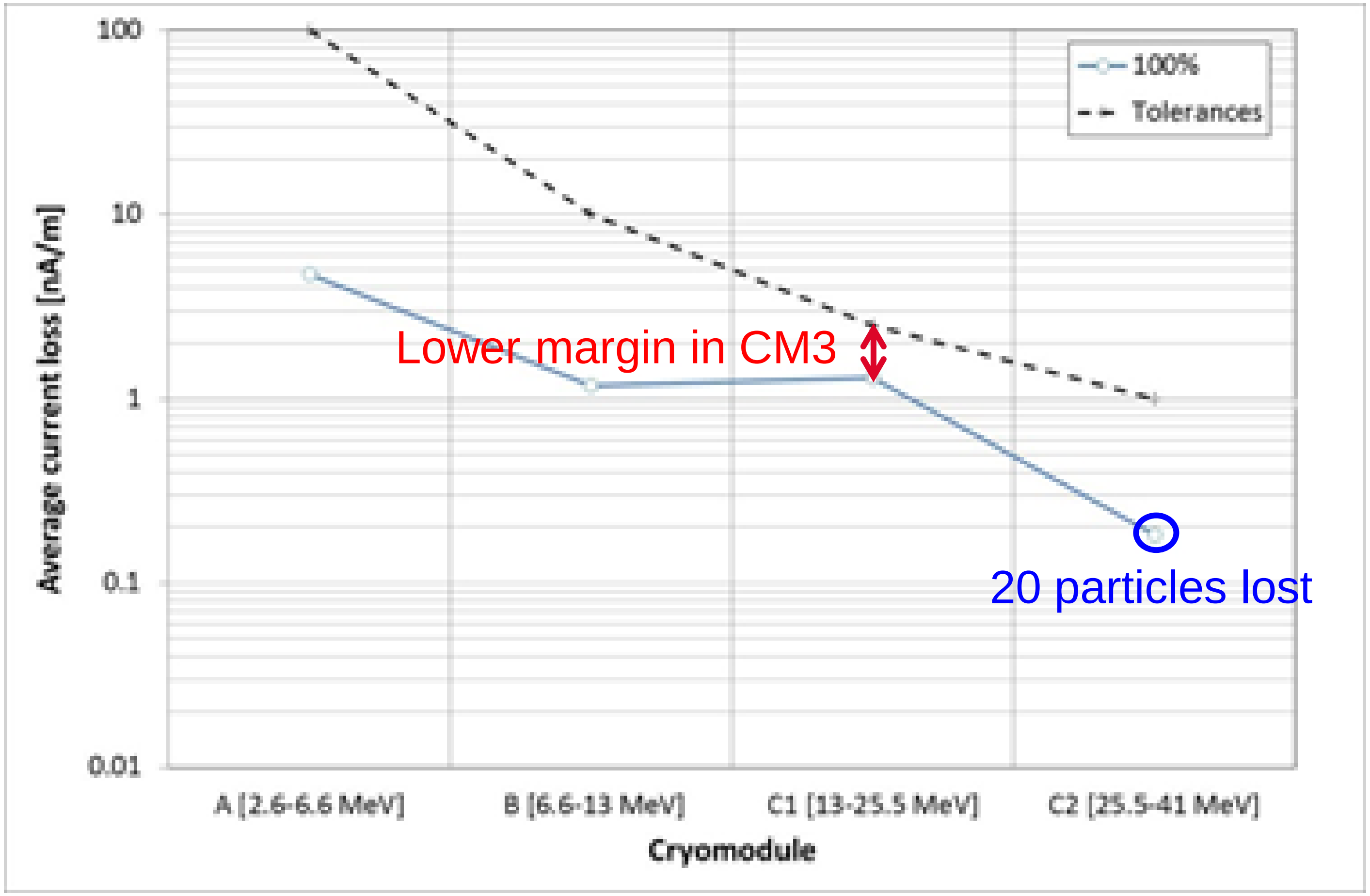


<u>For example</u> :

The 10^{-7} line represents the radius of a cylinder outside which one can find :
$10^{-7} \times 1000 \times 510000 = 51$ particles in all simulations

ERRORS STUDIES : LOSS ESTIMATION

Losses per CM estimation



CONCLUSION

- RFQ acceptance of about 5 π.mm.mrad (~± 5 σ @ 0.2 π.mm.mrad)
  → RFQ : good initial beam scraper, good transmission @ 0.2 π.mm.mrad

- MEBT with room for fast chopper, diagnostics and slits

- 5 nominal simulations (Deuteron/Proton; 0.1-5 mA; 1,3 MeV/u-40 MeV)
  → Satisfying TLR

- Error study for more “sensitive” conditions (Deuterons, 5 mA, 40 MeV)
  → Satisfying TLR

- A new reference design (more robust) in progress

NEW CONFIGURATION (LAST TUESDAY)