Overview of the EURISOL post-accelerator design and studies

Patrick BERTRAND

On behalf of the TASK 6 team

First EURISOL User Group Workshop
January 2008 , Firenze

Task 6 Team : EURISOL Post Accelerator

TASK LEADER :	Marie-Hélène Moscatello	(GANIL,France)
RFQ :	A. Bechhold	(Frankfurt University, Germany)
	O. Zimmermann	(Frankfurt University, Germany)
	G. Bisoffi	(LNL Legnaro, Italy)
	P.A. Posocco	(LNL Legnaro, Italy)
	A. Palmieri	(LNL Legnaro, Italy)
	A. Pisent	(LNL Legnaro, Italy)
Fast chopper :	M. Di Giacomo	(GANIL, France)
	G. Le Dem	(GANIL, France) (Post-doc 100%)
MEBT & LINAC :	P. Bertrand	(GANIL, France)
	J.L Biarrotte	(IPN/Orsay,France)
	G. Normand	(GANIL, France) (Post-doc 100%)

SUMMARY

1. Experimental requirements
2. General layout of the Post Accelerator
3. LEBT (Low Energy Beam Line)
4. RFQ (Radio Frequency Quadrupole)
5. MEBT (Medium Energy Beam Line)
6. LINAC
7. Safety Aspects
8. Conclusion

1. Maximum beam Energy

- 150 MeV/u for the benchmak 132Sn
- if technically feasible, avoid stripping

2. Minimum beam Energy

- beams of energies below 0.7 MeV/u required , but not within the remit of task 6 (→ task 10)

3. Energy Variability

- finest possible change in energy should be possible
- < 0.5% at energies < 20 MeV/u
- 1 MeV/u at energies > 20 MeV/u

4. Beam Energy Definition

- absolute value better than 0.1%
  (related to task 6 and task 10 work…)

5. Time Resolution

- Time width (FWHM) : 0.5 ns (1 nsec acceptable)
- 100 psec possible ?

6. Beam Time Structure

- 88 Mhz (dt=12 ns) is *too high* for many experiments…
- separation between pulses of 100-200 nsec required !
- Chopping the beam between 10 nsec – 1 msec required

7. Beam Sharing

- strongly recommended to consider 2 acceleretors, fed by a different target-ion source station : (1-5 MeV/u and 5-150 MeV/u)

8. Stable beam operation

- Operation of the post accelerator with stable beams also requested

9. Beam Purity

- Single isotope beams are required *(→beam preparation task)*

10. Beam Emittance and Spot Size

- no exact numbers agreed on … but :
- emittance of 1-2 pi.mm.mrad
- 1-2 mm**2 spot size

General layout of the Post accelerator

Principle:
- LEBT — from and with task 9: beam preparation
- RFQ(s) — Normal temperature or/and super conducting
- MEBT — with challenging fast-Chopper
- SC LINAC — with independently-phased superconducting RF cavities

Why a SC LINAC ?
- Excellent efficiency
- High transverse acceptance (low beam losses)
- High β-profile flexibility:
  (wide range of Q/A ion can be accelerated)

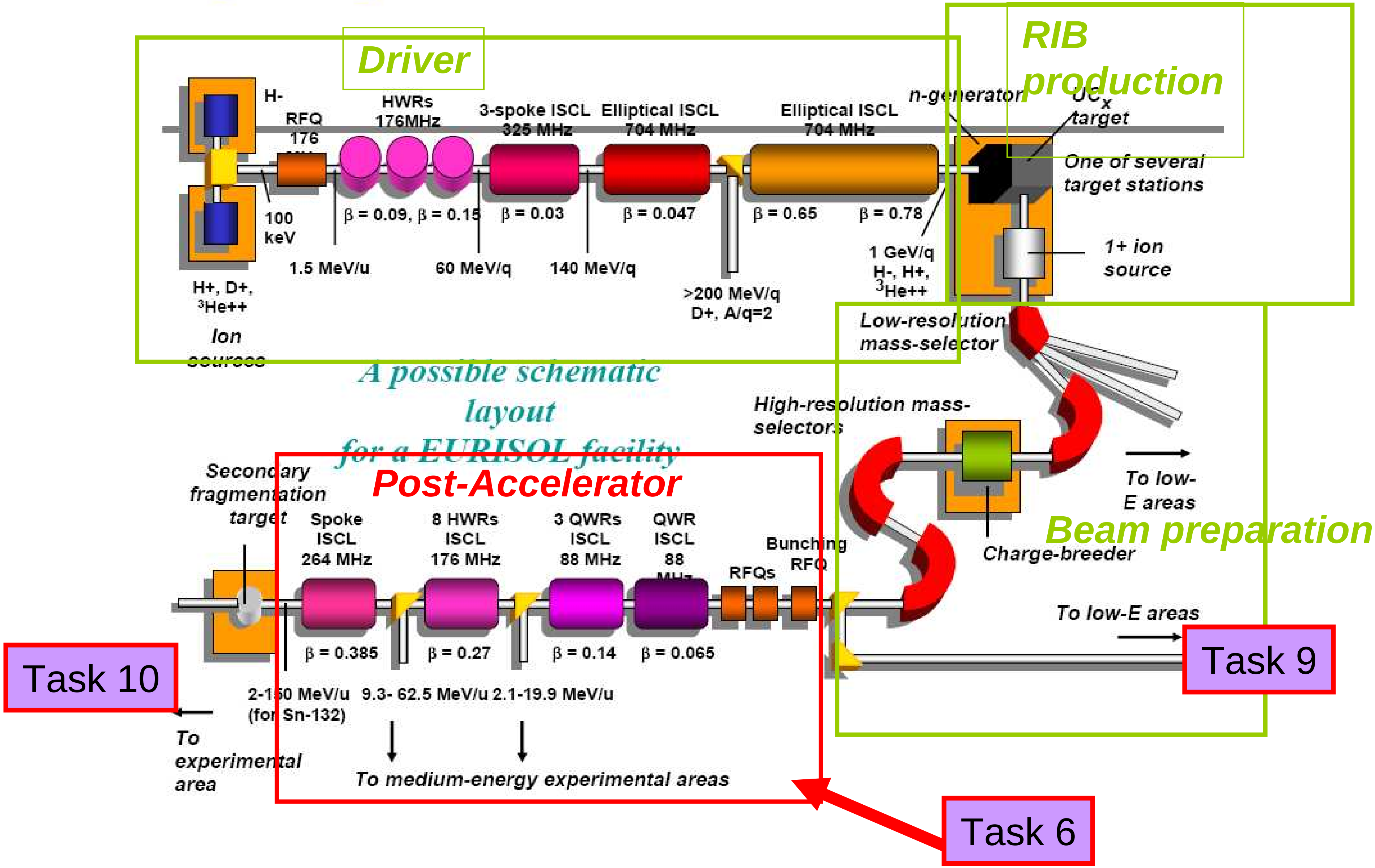
<u>3 independant post-accelerators:</u>

- very low energy (not studied here)

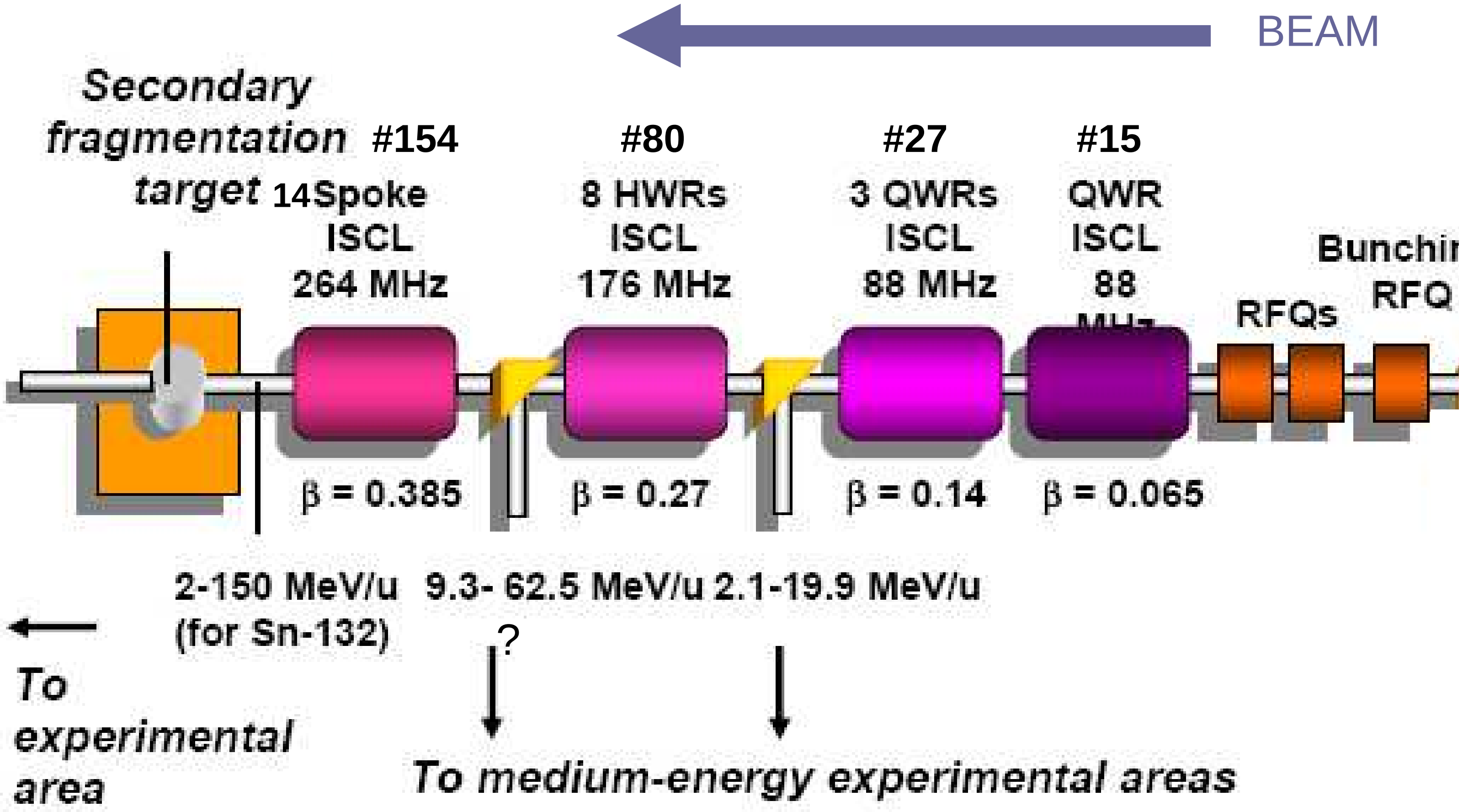
- low energy (1–5 MeV/u)

- high energy 5 – 150 MeV/u for 132Sn25+

General layout of EURISOL

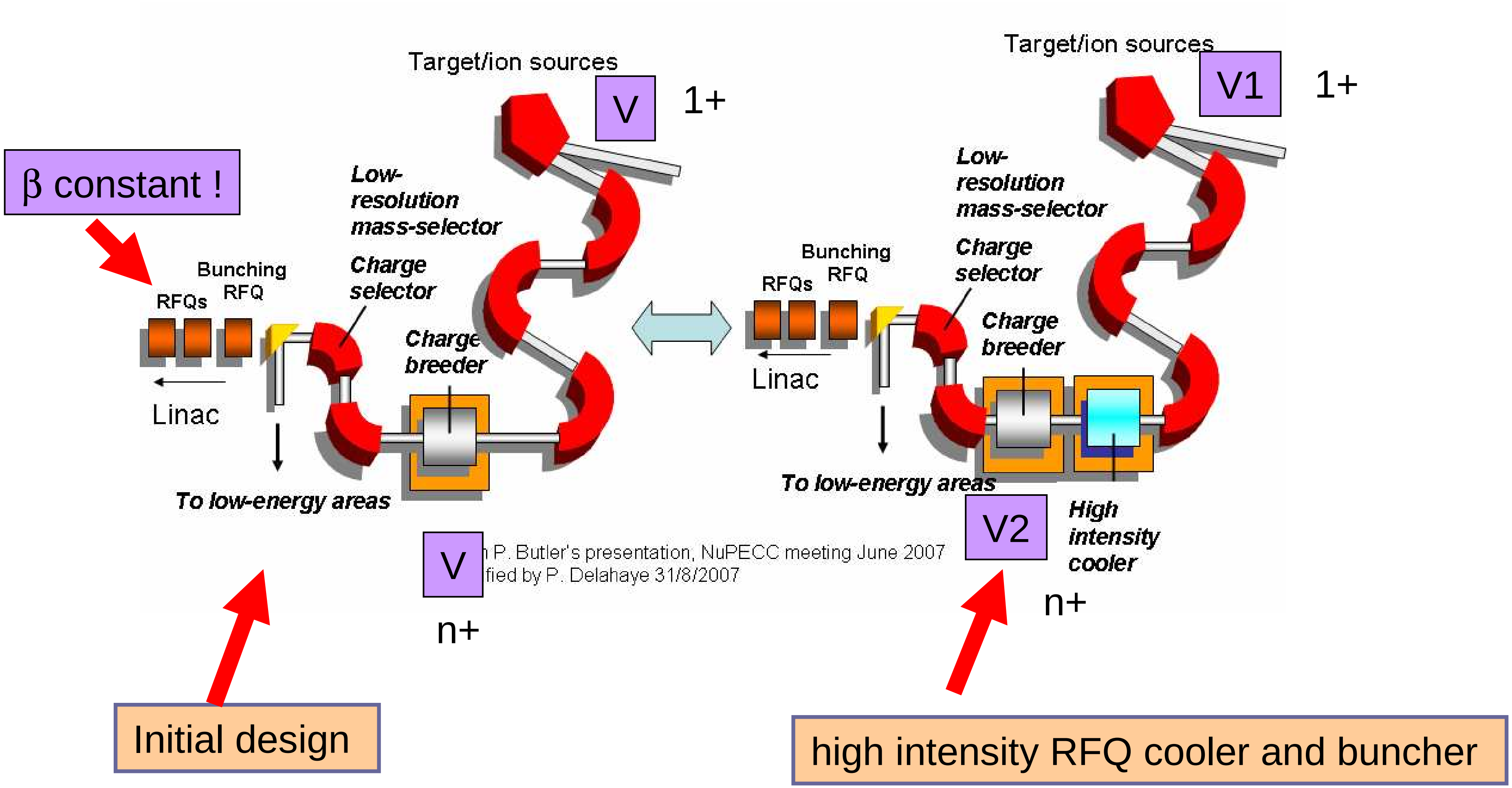


General layout of the Post accelerator

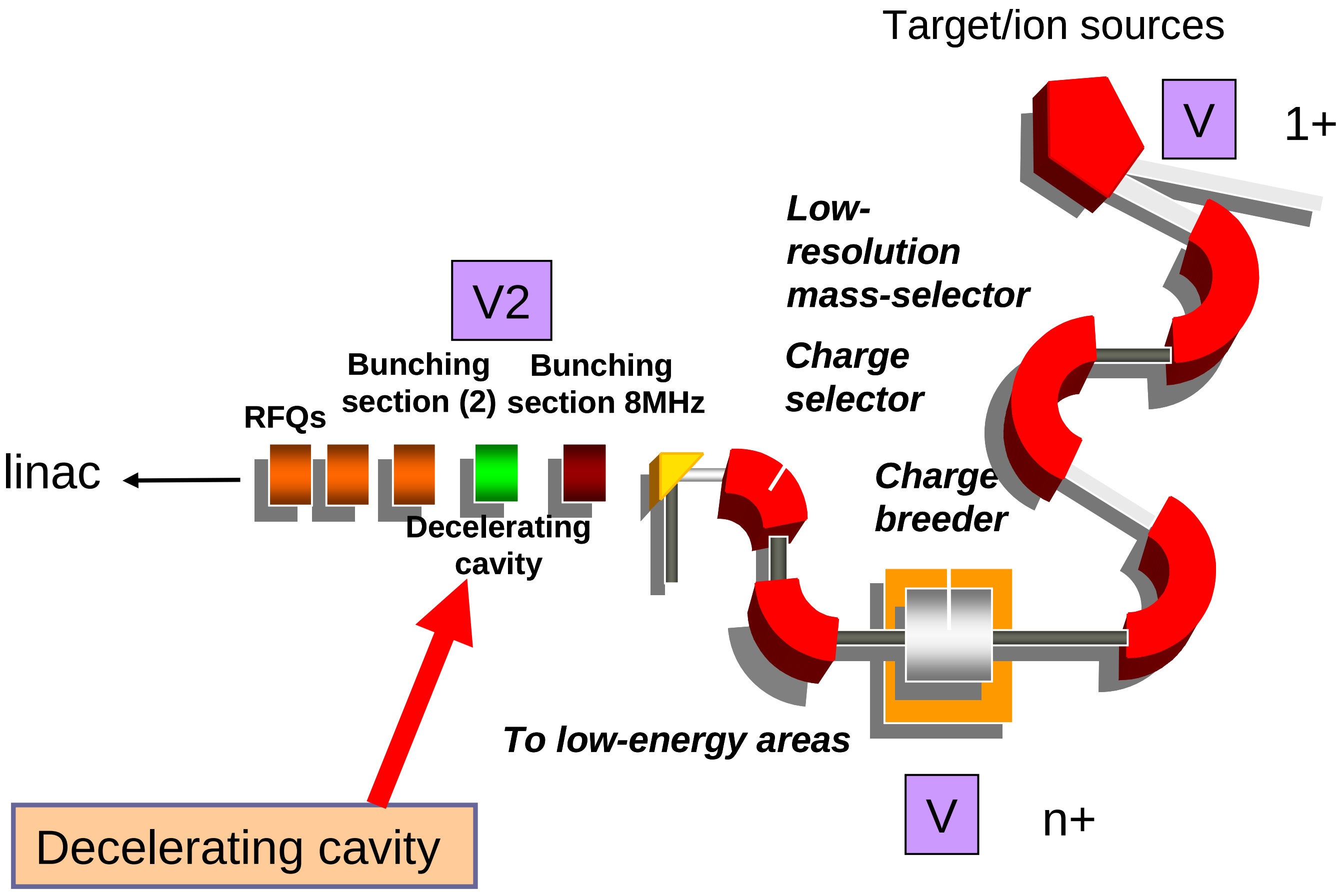


Low Energy Beam Line transfer : LEBT
(from Task 9 : P. Delahaye June 2007)

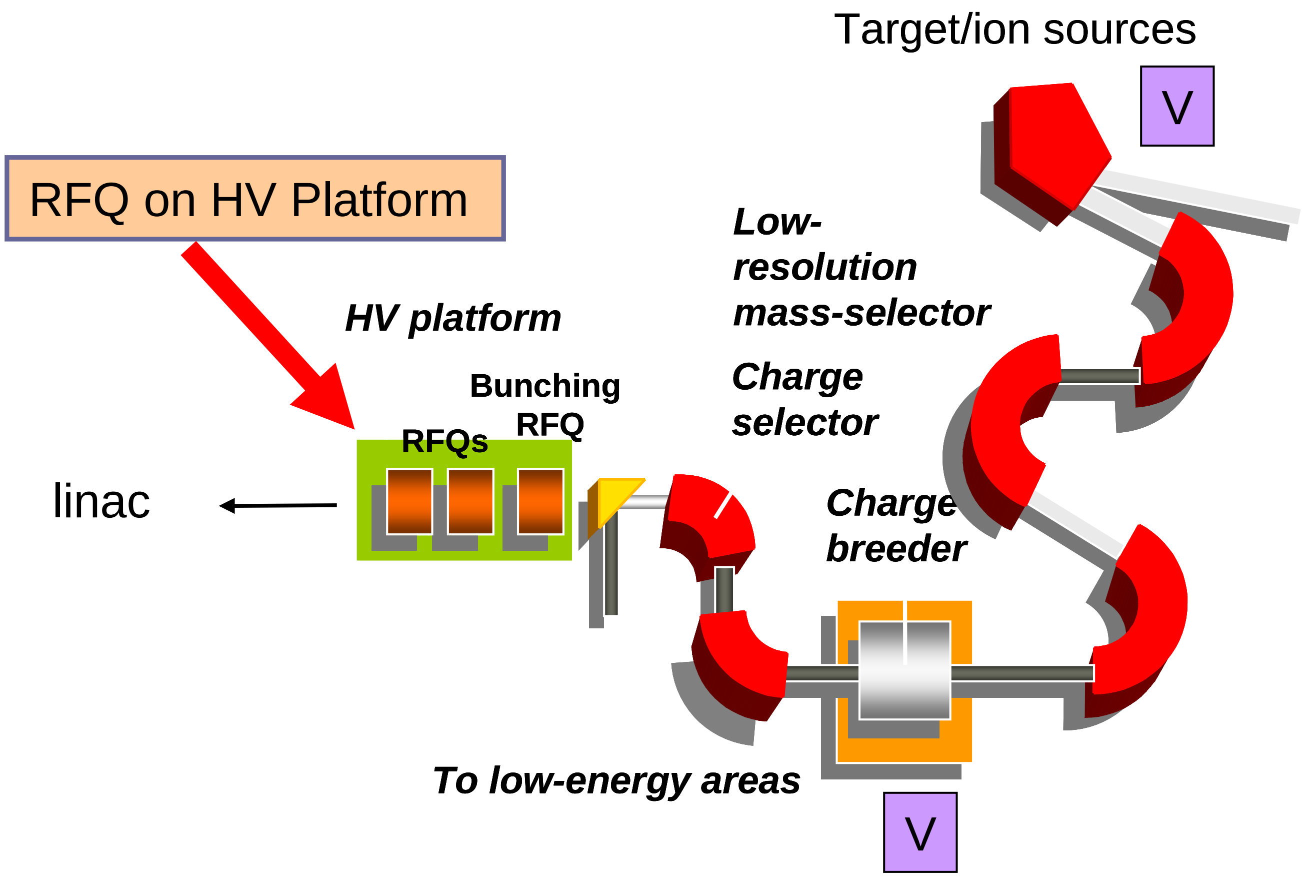
First hypothesis : 1+ beam energy variation



Second hypothesis : n+ beam energy variation by decelerating cavity



Third hypothesis : RFQ on HV platform (P. Ostroumov, PAC 2001)

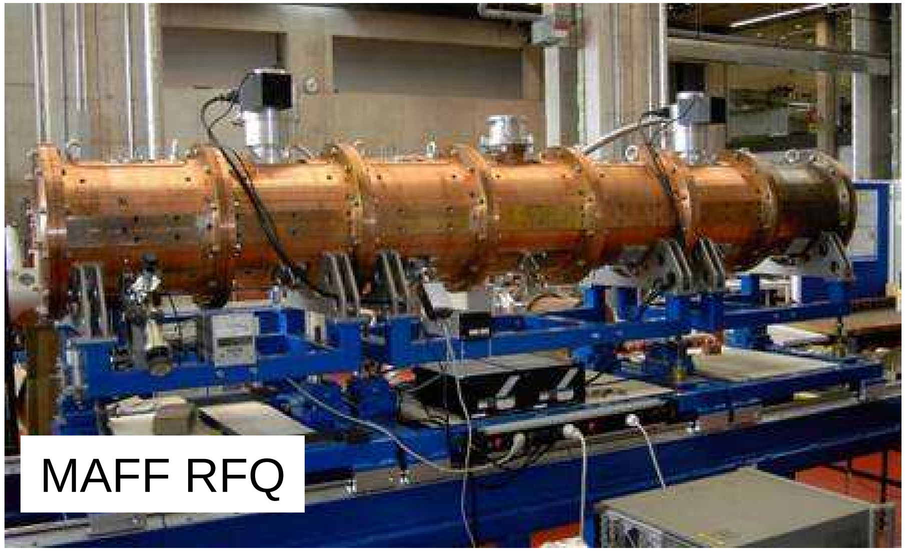


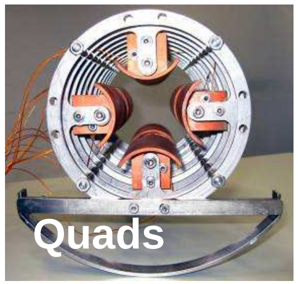
Normal conducting RFQ : MAFF RFQ INJECTOR
(RFQ team from Frankfurt University…)

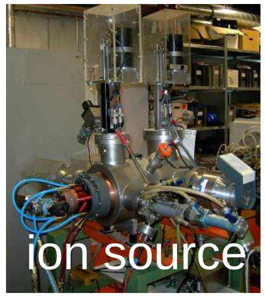
. MAFF RFQ Injector under testing at the MAFF test stand

. New NC RFQs for EURISOL under design, based on the MAFF technology

length	3 m
frequency	104 MHz
m/q	≤ 6.3
Voltage	≤ 60 kV (9.5 kV *m/q)
Q-value	5750
Shunt impedance	168 kΩ*m
W_{in}	2.5 keV/u
W_{out}	300 keV/u



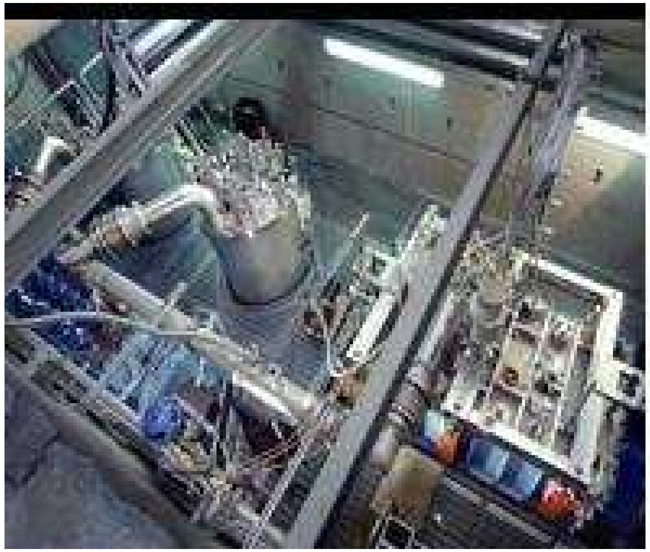




SC RFQ : Legnaro TESTS on PIAVE INJECTOR
(RFQ team from INFN Legnaro…)

•The superconducting RFQs in LNL are now in operation on the PIAVE injector

• EURISOL NC/SC RFQs under design.



PIAVE

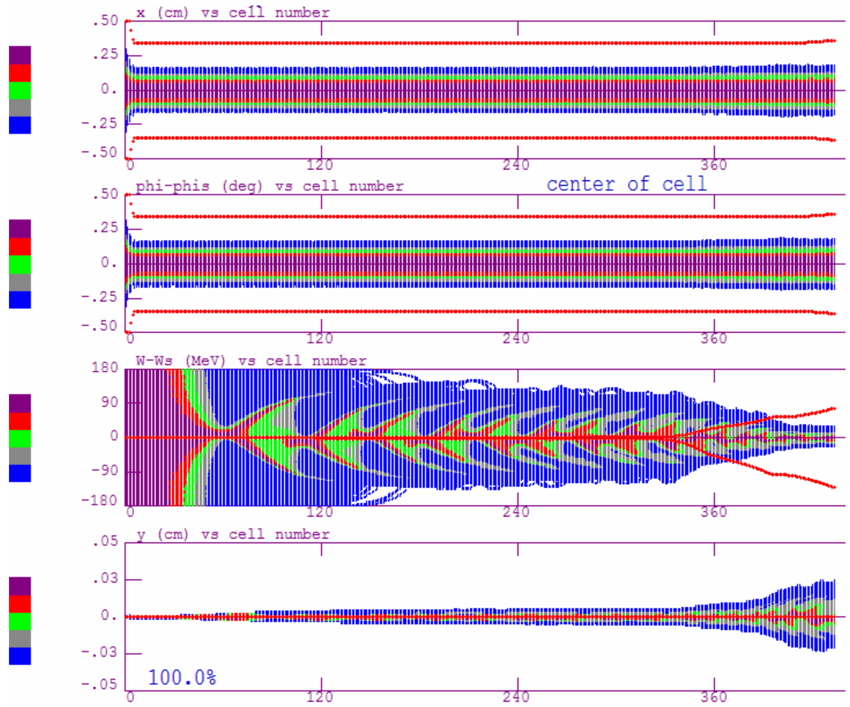
LNL PIAVE RFQ

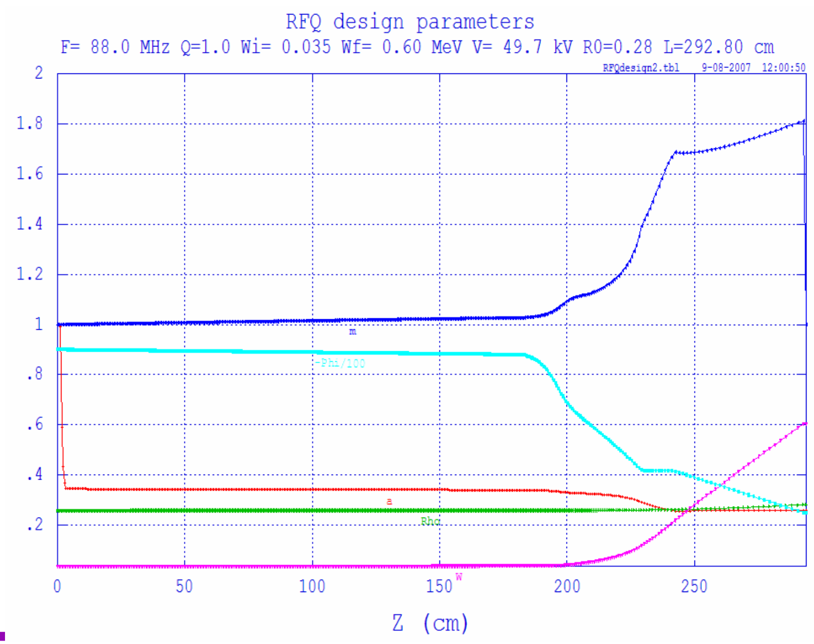
Transverse emittance measurement		
Energy at the end of PIAVE	ε_{norm} x RMS (mm.mrad)	ε_{norm} y RMS (mm.mrad)
0.58 MeV / u	0.100	0.103
1.2 MeV / u	0.200	0.125

Normal conducting EURISOL RFQ 1

(P.A. Posocco, Legnaro, 7th January 2008)

Frequency	**88 MHz**
Ion m/q	7
Input energy	5 keV/u
Output energy	88 keV/u
Max suf. E Field	~18 MV/m (1.8 Kilpat.)
B	7.2
Length	**~3m**



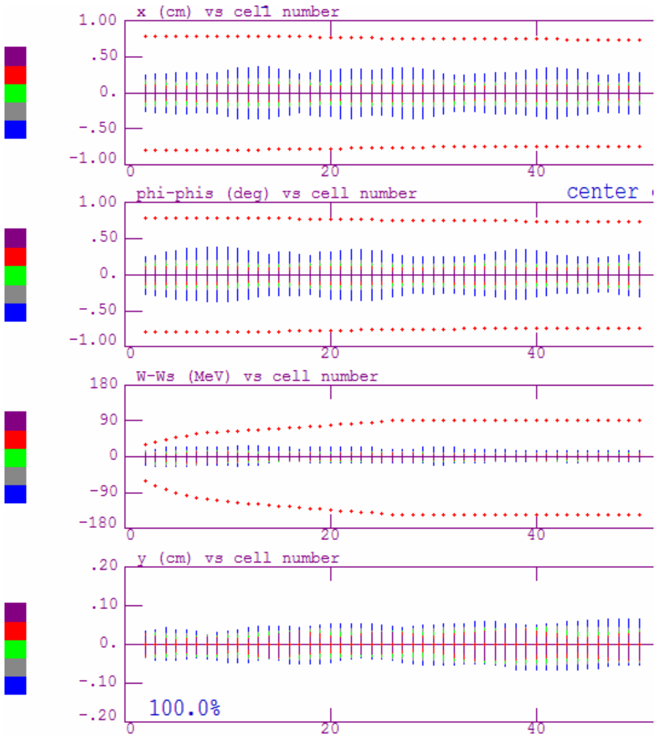


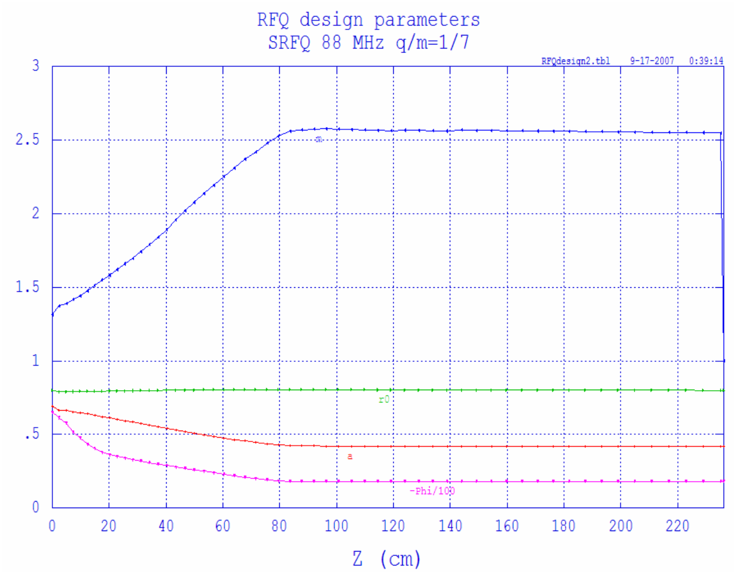
Emittances (100k particles, 100% transm.)			
t. norm. RMS (mm mrad)		longitudinal RMS	
in	out	MeV Deg	mm mrad
0.100	0.100	0.065	0.094
0.150	0.151	0.068	0.098
0.200	0.201	0.072	0.104

Super conducting Eurisol RFQ 2

(P.A. Posocco, Legnaro, 7th January 2008)

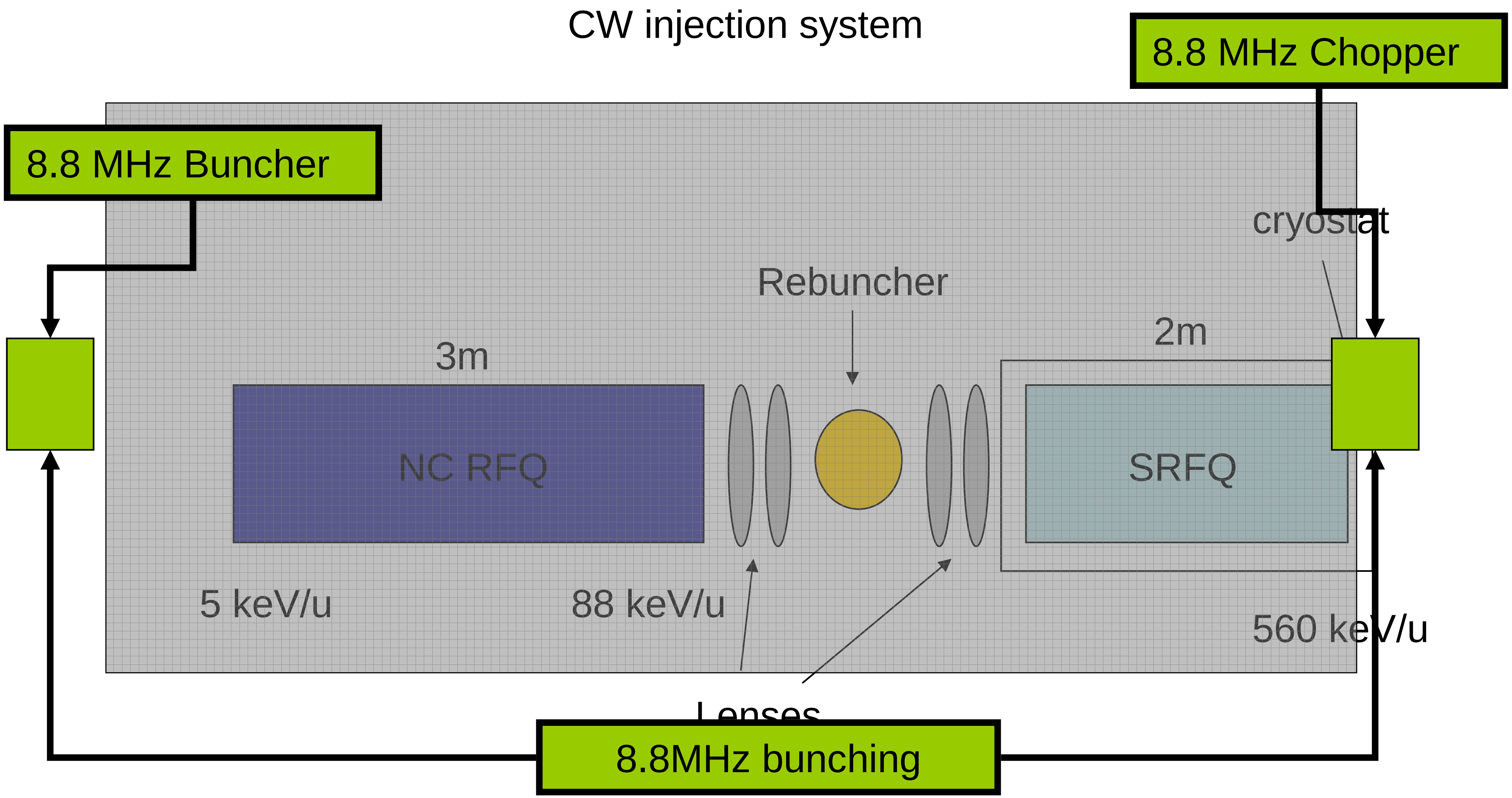
Frequency	**88 MHz**
Ion m/q	7
Input energy	88 keV/u
Output energy	560 keV/u
Max suf. E Field	~25 MV/m
B	4.5
Length	~2m



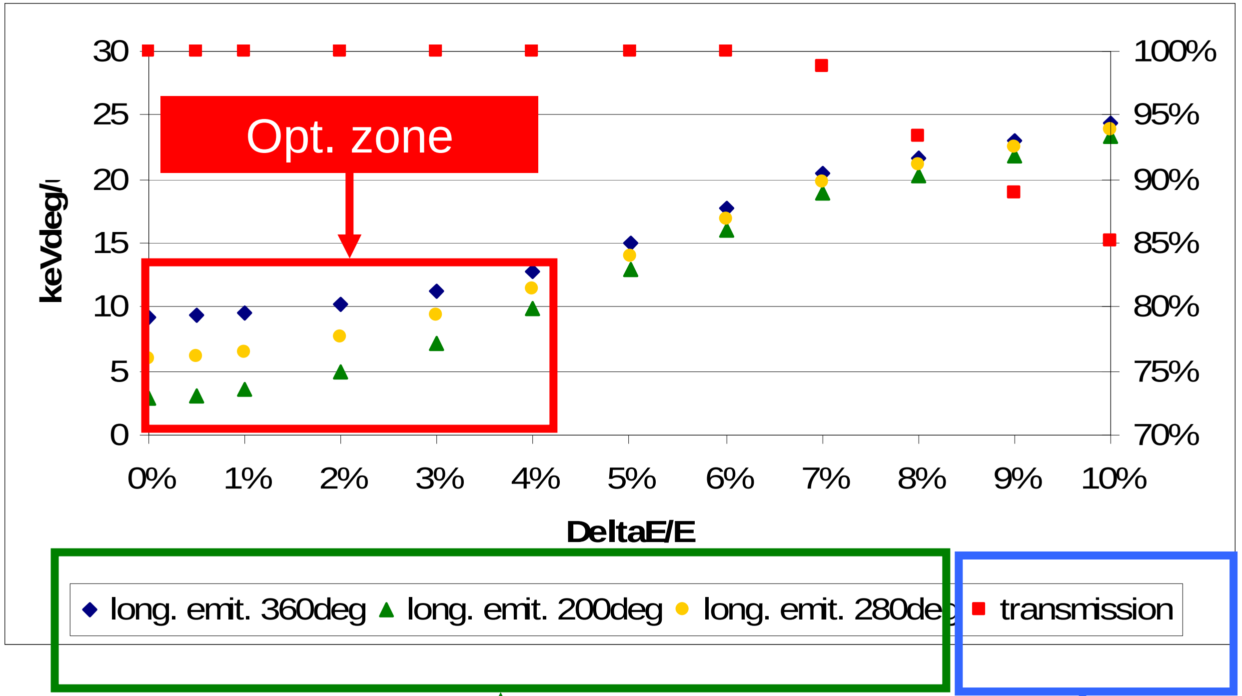


Emittances (100k particles)			
t. norm (mm mrad)	growth	transm	with an uniform longitudinal distribution,
0.100	1%	100%	
0.150	2%	100%	Δφ=15°
0.200	4%	99.6%	ΔE=0.03MeV

8.8 Mhz Buncher + NC RFQ + SC RFQ principle
(P.A. Posocco, Legnaro, 7th January 2008)



The buncher 8.8 Mhz will generate energy dispersion… what happens in RFQ1 ?



The output longitudinal emittance depends on either the bunch length and the energy spread.

Good transmission up to

$\Delta E/E = 6\%$

Functions :

- to transport the bunched beam from the exit of the 2nd RFQ to the entrance of the LINAC with appropriate transverse and longitudinal matching.

- to permit fast-chopping of bunches

- to stop deviated bunches.

Devices needed along the MEBT:

- Transverse focusing elements	:	7 quadrupoles
- Longitudinal focusing elements	:	2 rebunchers
- Deviator	:	1 fast chopper
- Deviated beam stop	:	1 beam stop
- Diagnostics, pumps…		

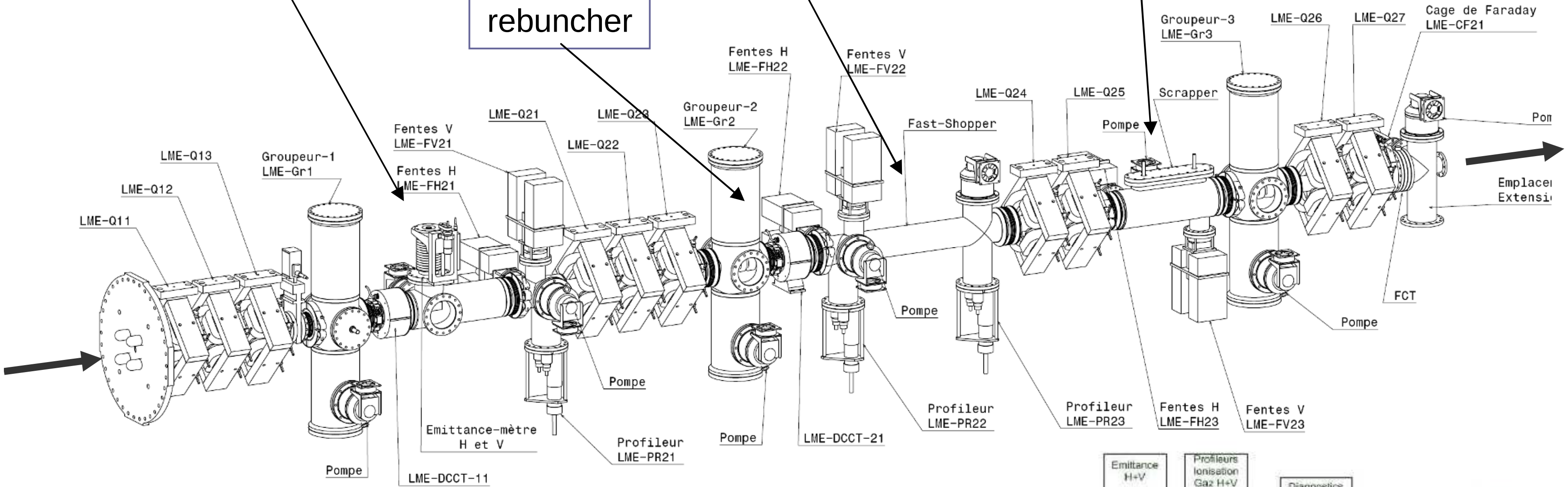
example of a completely designed MEBT : SPIRAL2

1/6 future connection

rebuncher

Fast chopper position

7.5 kW Deviated beam stop



D-plate for RFQ beam tests and diags.tests

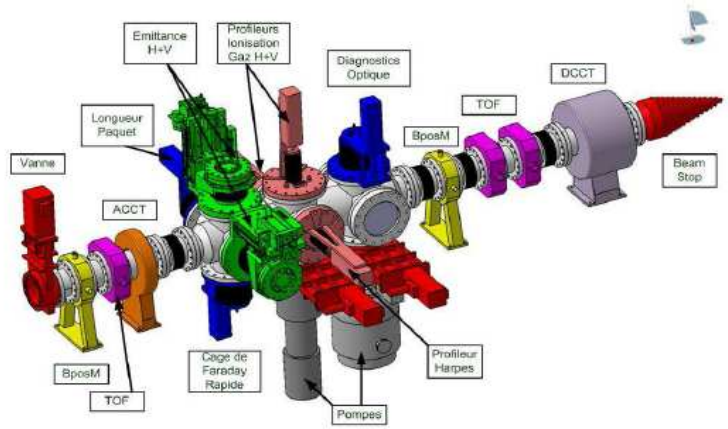
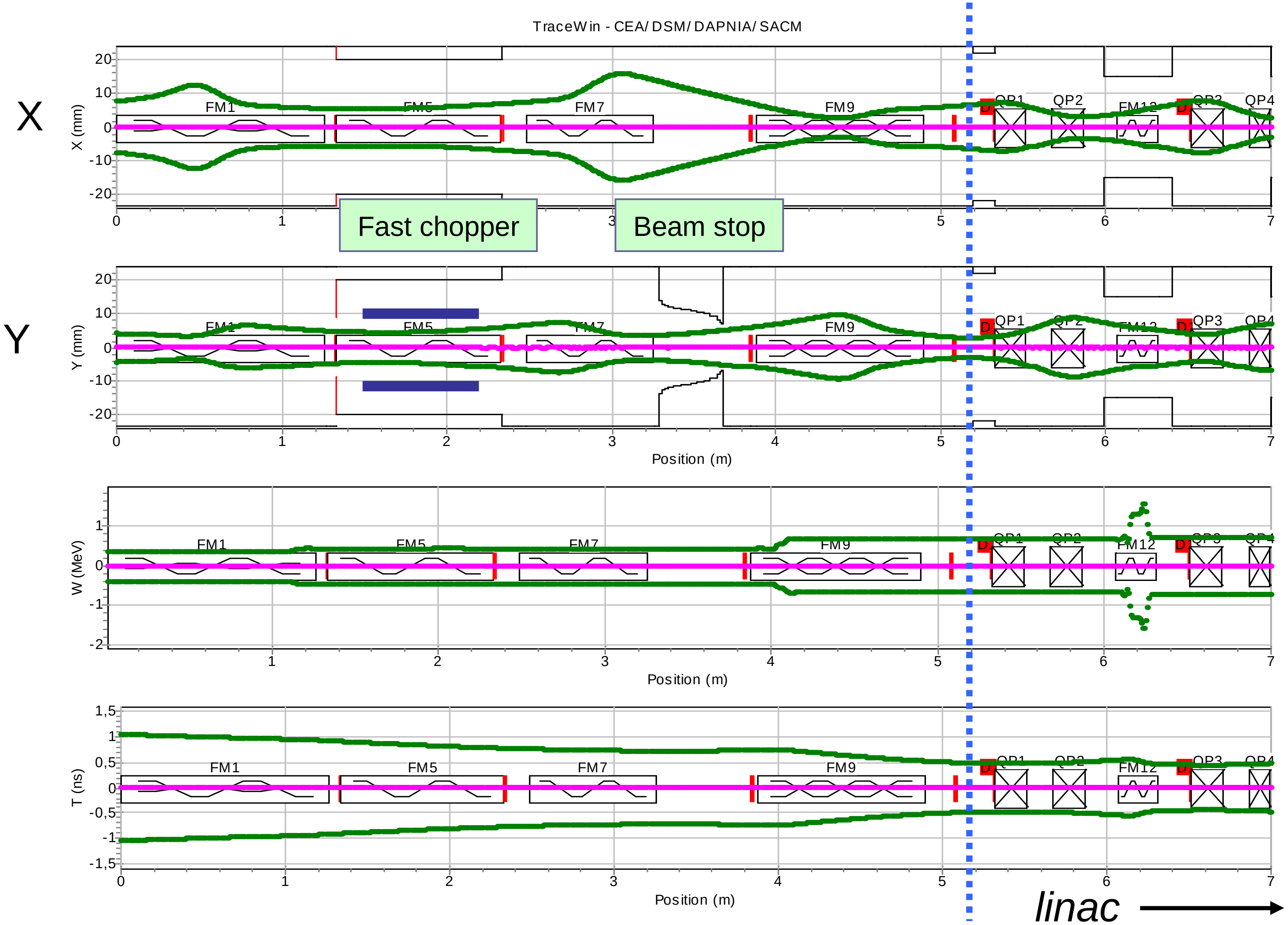


Figure 33 : Répartition des diagnostics le long du B.T.I

Eurisol Post-accelerator/MEBT
(G. Normand, GANIL)

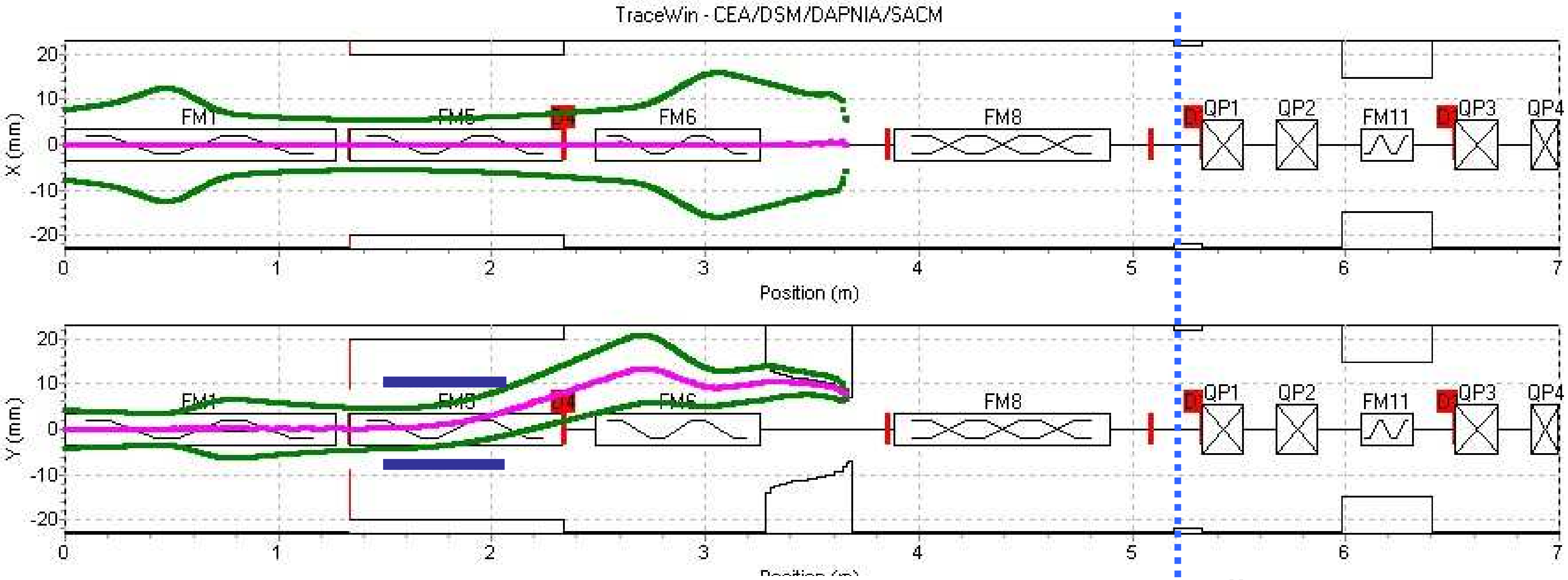
Beam transport with chopper off



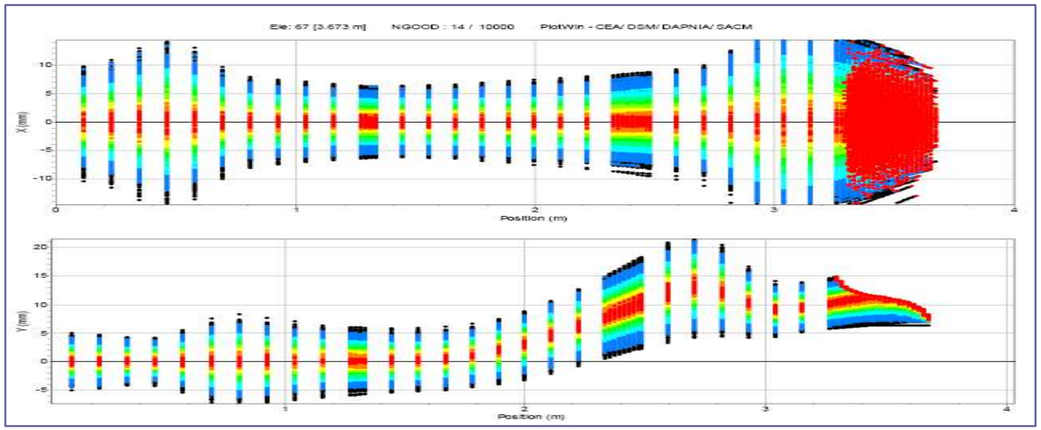
Eurisol Post-accelerator/MEBT

(G. Normand, GANIL)

Beam transport with chopper on



linac →

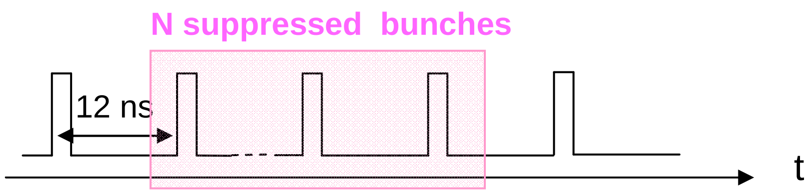


Eurisol Post-accelerator : MEBT/CHOPPER

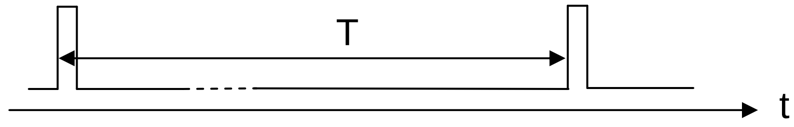
(G. Ledem , M. Di Giacomo , GANIL)

Physicists requirements	***Chopper specifications***
Suppressed bunches > 90 % Max. bunches rate after chopper : 1/10	Rise/fall times : 6 ns Angle deflection : 11 mrad Max. high voltage (HV) : 2.5 kV

Bunch repetition rate	1/10	1/100	1/1000	1/10000
Chopping pulse frequency (1/T)	8.8 MHz	880 kHz	88 kHz	8.8 kHz



Beam before chopper



Beam after chopper

2 technical solutions :

Eurisol Post-accelerator : MEBT/CHOPPER

(G. Ledem , M. Di Giacomo , GANIL)

Solution 1 : Travelling-wave chopper

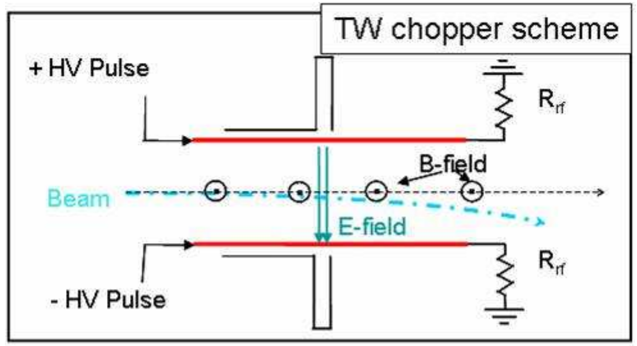
Description :

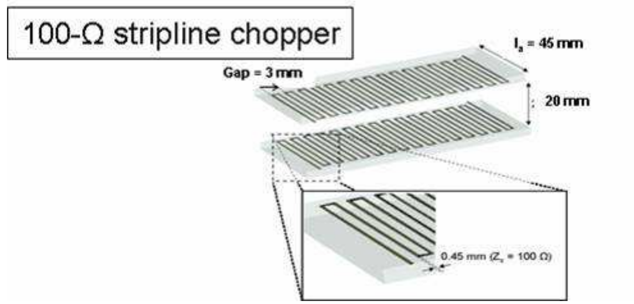
- Association of a static B-field steerer and a 100-Ω stripline :
  - Beam always deflected by the B-field,
  - HV pulse in the stripline allows one bunch to pass
    - ⇒ Duty cycle < 10 % (instead of > 90 % !),
    - ⇒ Power consumption < 5 kW,
    - ⇒ Power losses < 600 W per plates,
- No pulse, no beam in the LINAC.

Limitations :

- Coverage Factor < 75 %,
- Max. power dissipation per ceramic plate electrode : 600 W ?
- Stability of the high voltage ?
- Attenuation & overshoot of the pulse along its propagation (effects on the deflection ?),
- Effect of the E- and B-field superposition on the beam emittance ?

Status : under development.



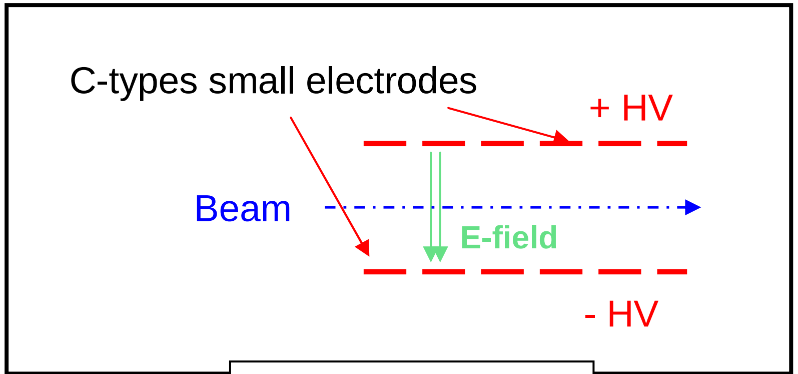


Solution 2 : C-type chopper

Description :
➢ Electrode divided in small plates driven by fast switchers.

Limitations :
➢ Present max. power dissipation into commercial switches : around 1kW (water cooled),
➢ Effective total capacitance (plates, connections, switch) ≈ 70 pF,
➢ Many feedthroughs (vacuum ?), one switch per plate
➢ Max repetition rate of switches < 1 MHz @ 2.5 kV (10 MHz needed)
➢ No pulse, all the beam in the LINAC.

Status : under study.

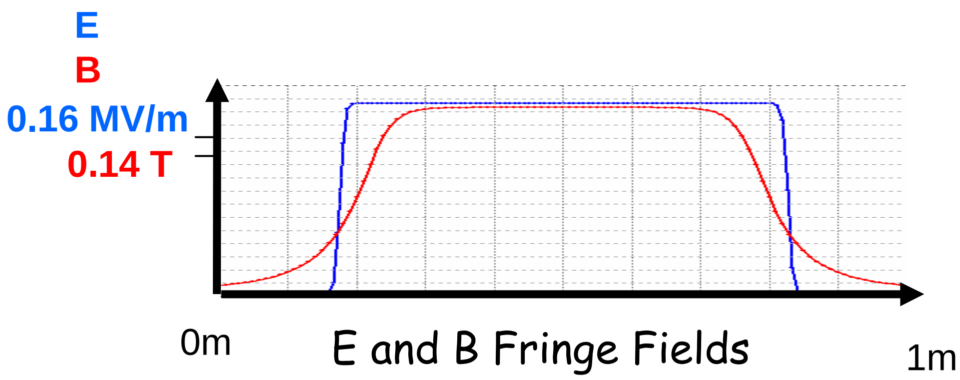


C-type scheme

Perspective

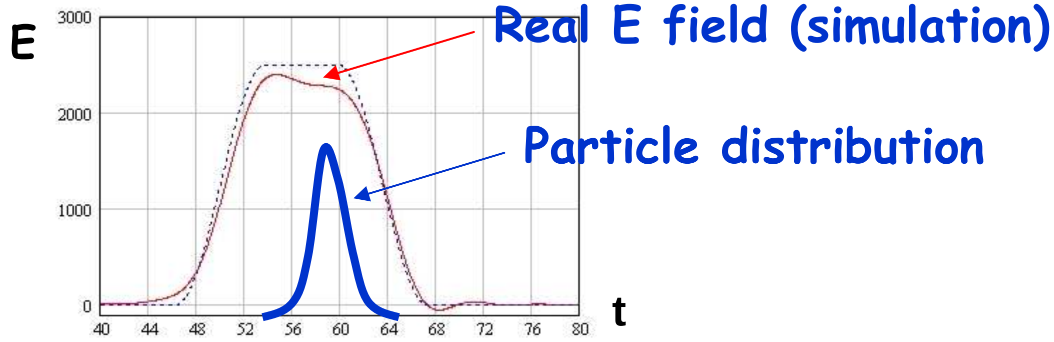
➢ Full beam dynamic studies,
➢ Development & test of a Travelling Wave 100-Ω stripline,
➢ Tests of pulse generators.

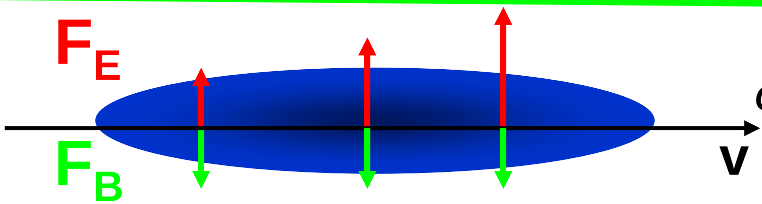
Solution 1 (TW) : Emittance growth sources due to chopper



- Same integral for E and B…
- But frindge fields different !
- (Even for central particle…)

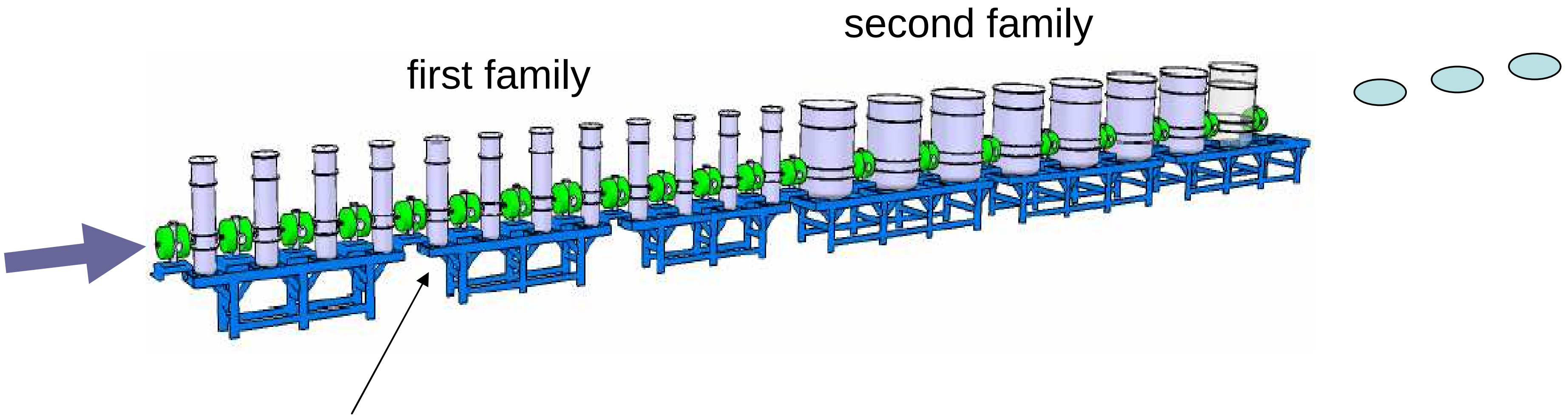
The E field can be not the same for all particles

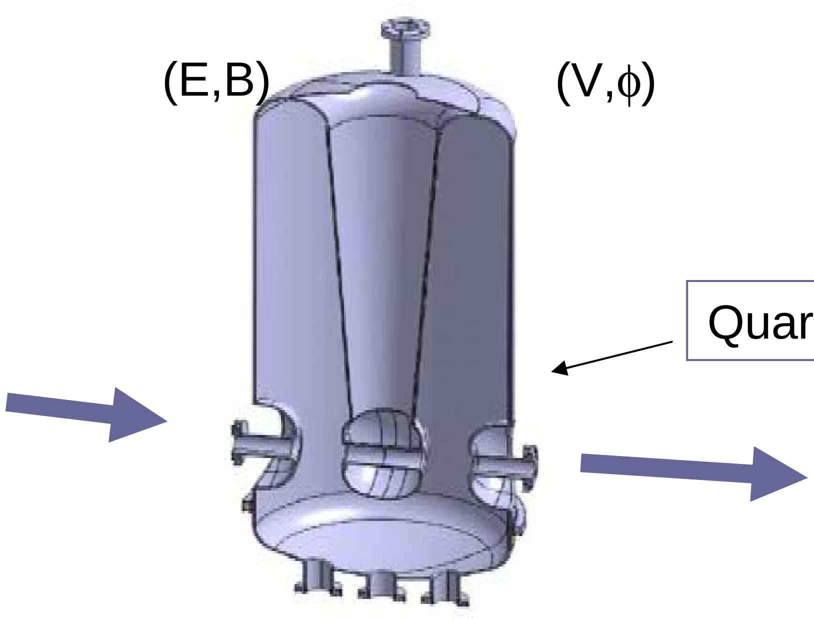




q (**v** ^ B) = - qE , only for the central particle

And now , the LINAC…



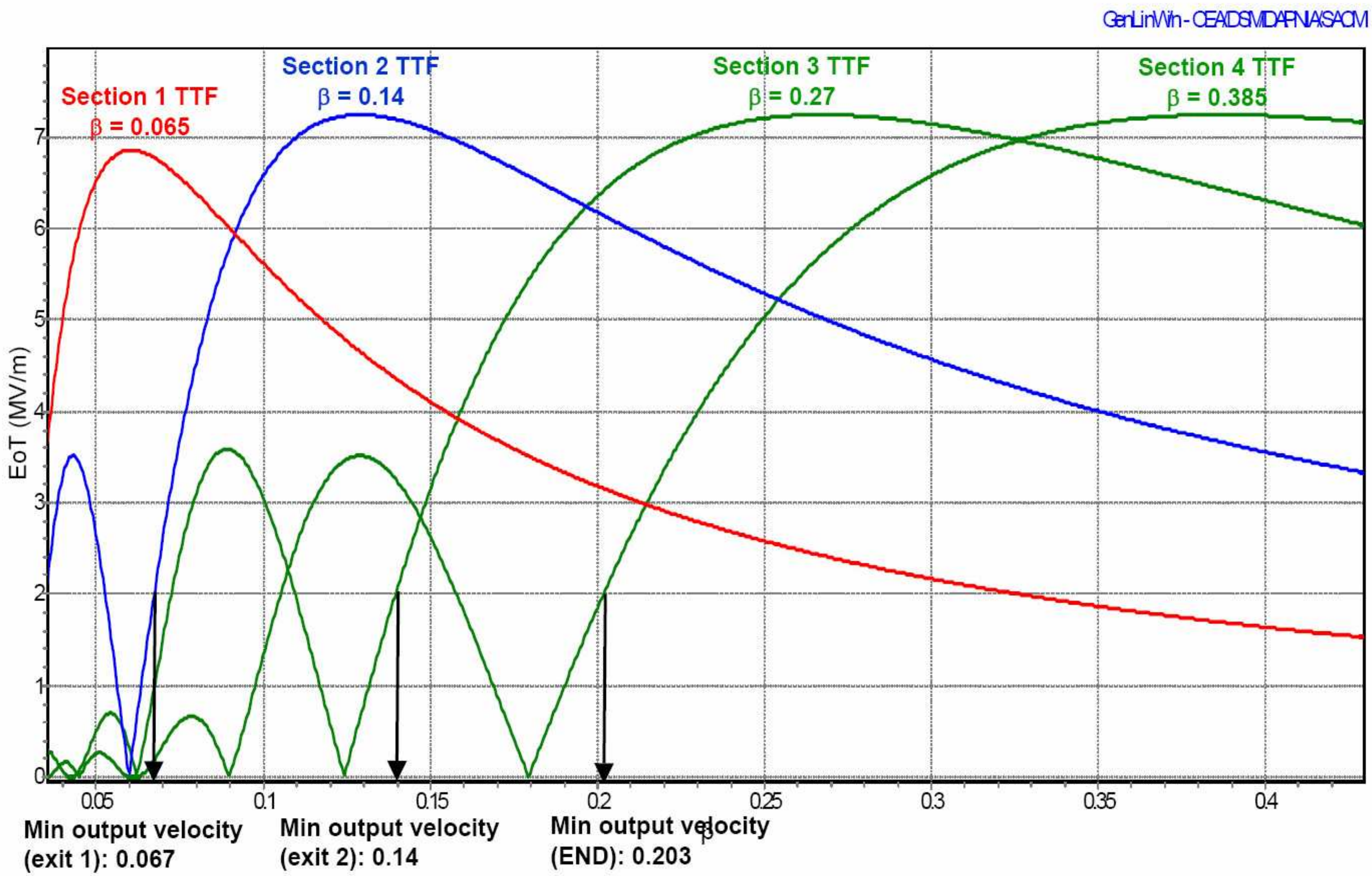


Reference design : 7.8 MV/meter

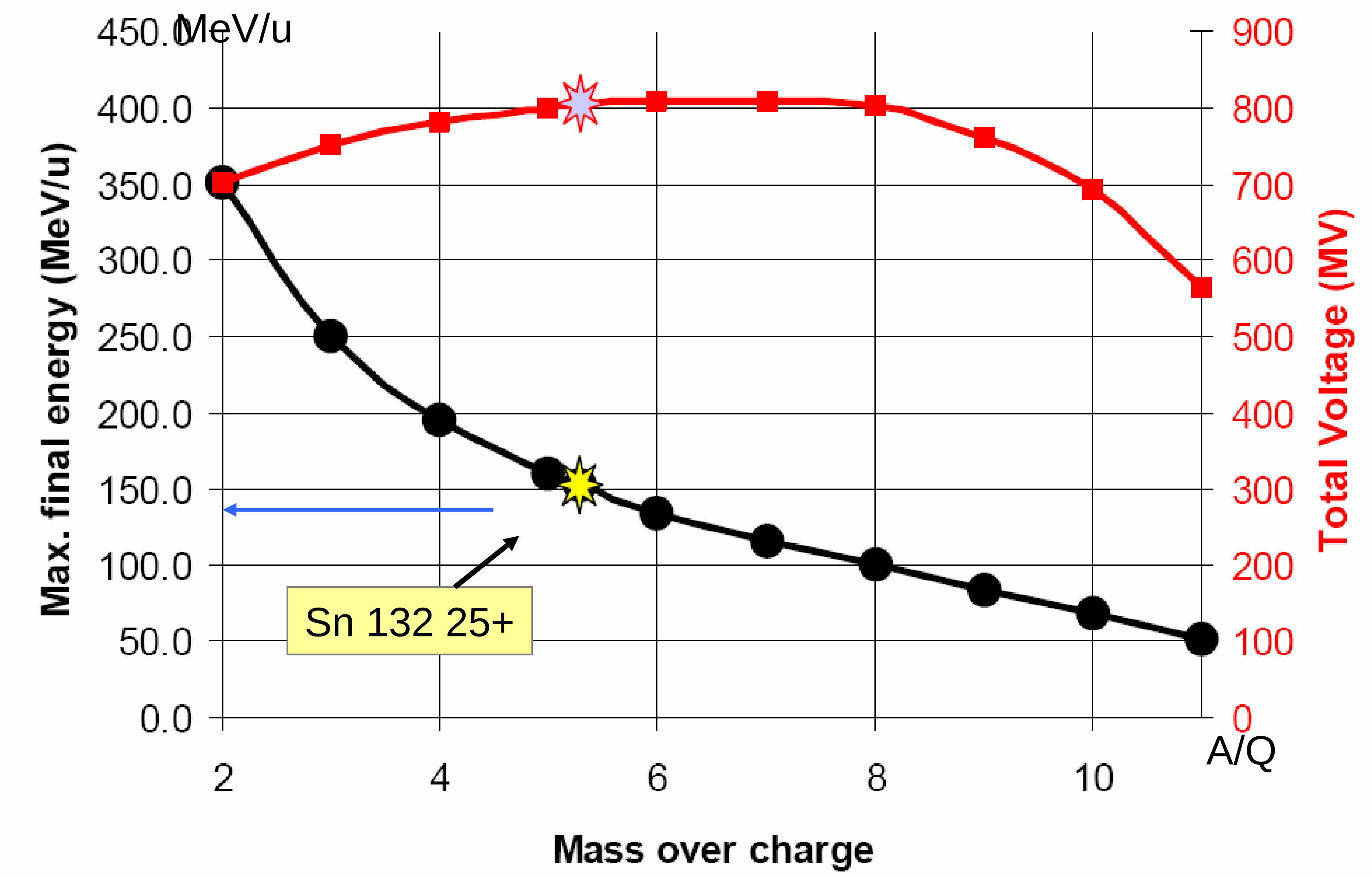
Optimisation of linac structure using Genlin code (Saclay)

$^{132}Sn^{25+}$	Section 1	Section 2	Section 3	Section 4	TOTAL
Cavity Freq.	88.05 MHz	88.05 MHz	176.1 MHz	264.15 MHz	-
Cavity β	0.065	0.14	0.27	0.385	-
# cav./ cryo	1 QWR	3 QWR	8 HWR	14 SPOKE	-
# cavities	15 cav	27 cav	80 cav	154 cav	**276 cav**
Length	17.9 m	26.1 m	59.0 m	103.8 m	**206.8 m**
Ouput energy range	-	2.1 – 19.9 MeV/A	9.3 – 62.5 MeV/A	20.0 – 150.0 MeV/A	**2.1 – 150.0 MeV/A**

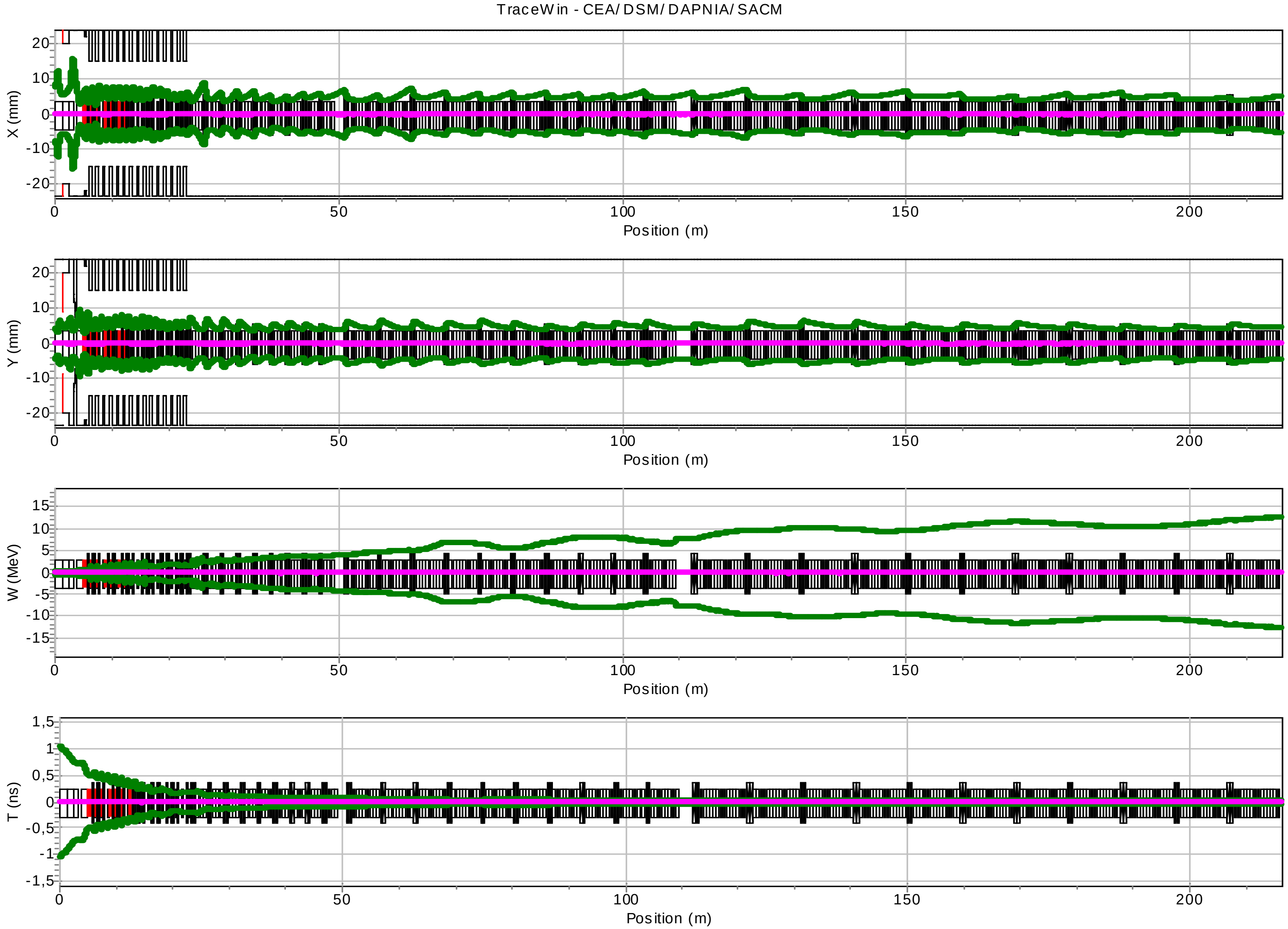
TTF = Transit Time Factor



Linac Design
(J. Biarrotte, G. Normand…)

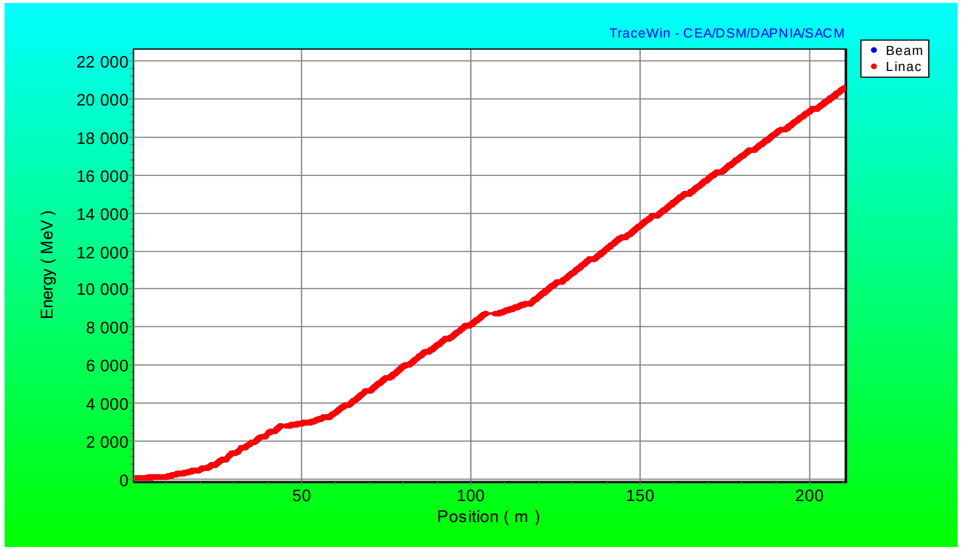


MEBT + LINAC Beam Dynamics

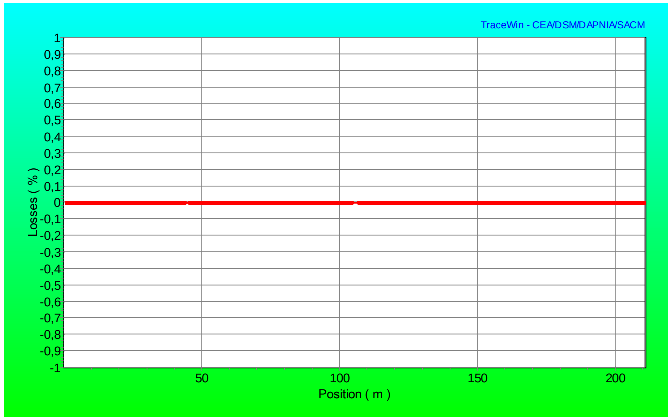


Linac Design
(J. Biarrotte, G. Normand…)

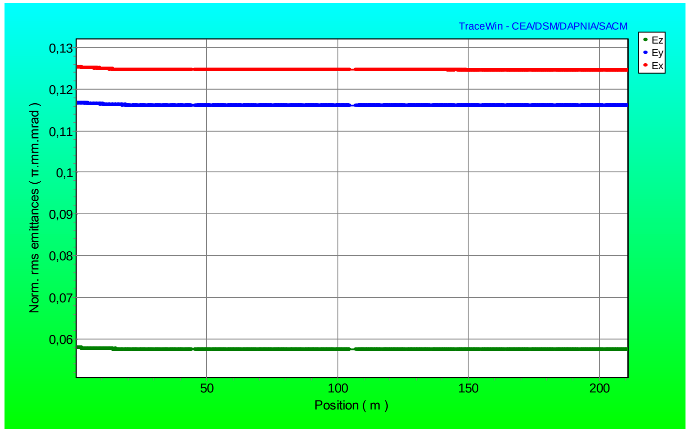
Energy evolution



No Losses



Normalised Emittances



- The design is able to accept I = 1 mA (margin if prebuncher 8.8 Mhz…)

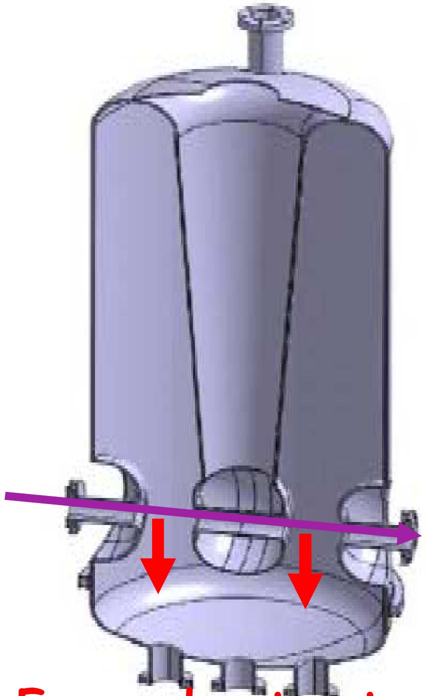
- Calculations with 3D electromagnetic maps

- Huge number of particles

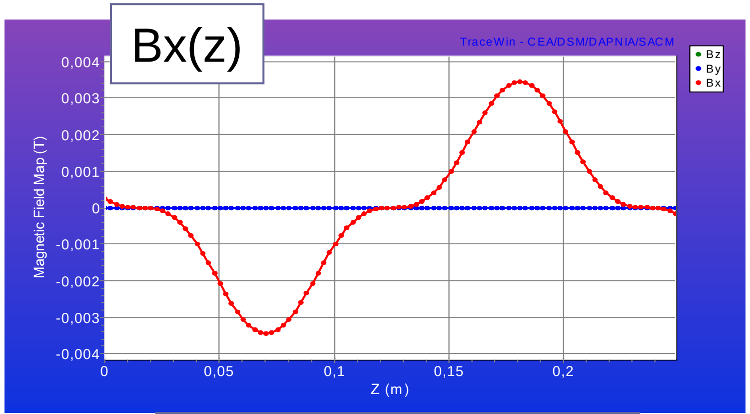
Steering Effect

QWR → non-zero Bx(z) → steering (well known)

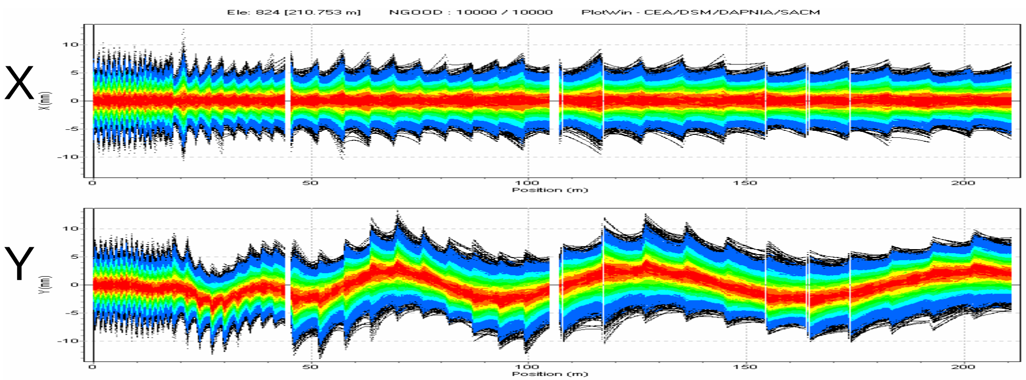
…checked with analytical and real 3D (E,B) maps

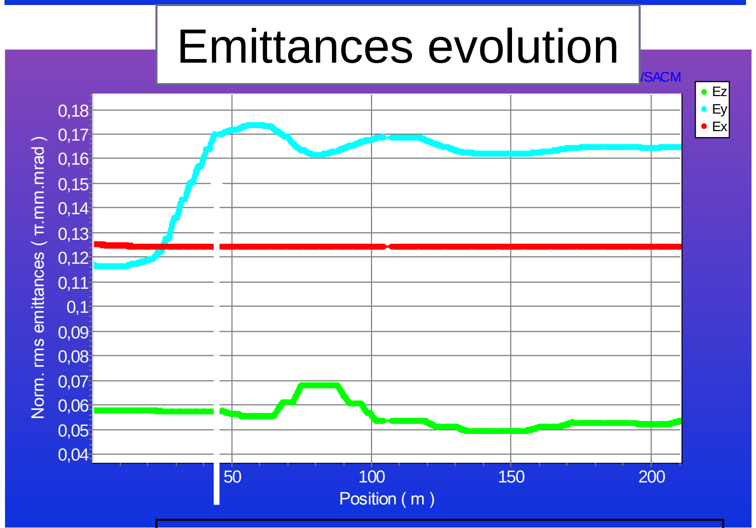


Force due to steering



Steering effect before correction

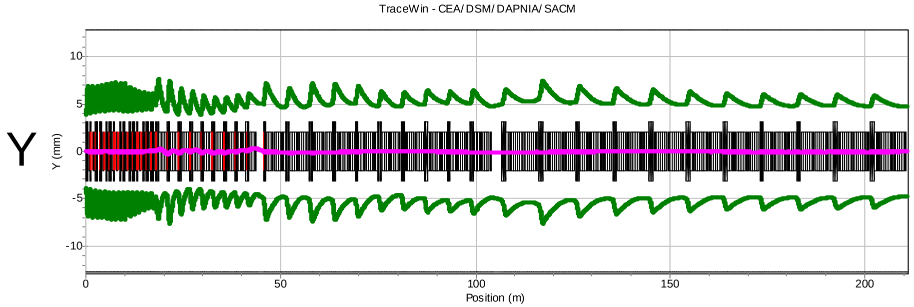


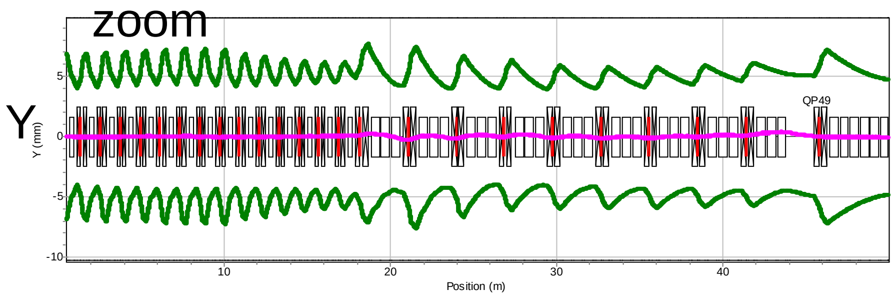


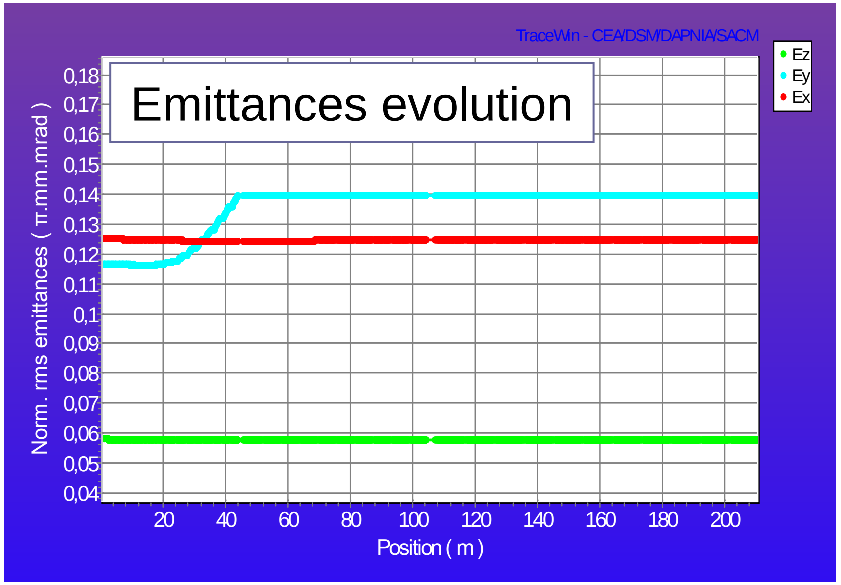
End of the quarter-wave sections

EURISOL Design Study

Steering effect with steerers correction







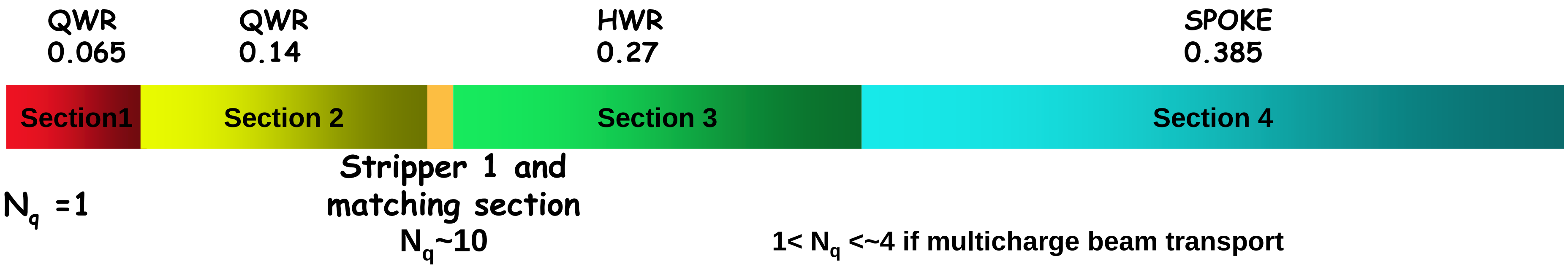
Simulations results

π.mm.mrad	ε_x	ε_y	ε_z
Entrance	0.125	0.117	0.058
Exit B = 0	0.126	0.120	0.060
Exit full Steering	0.126	0.164	0.070
Exit steering and correction	0.126	0.143	0.060

Steering effect can be corrected with steerers incorporated to warm quads
The y emittance growth is ~ 20 %.

Stripping studies

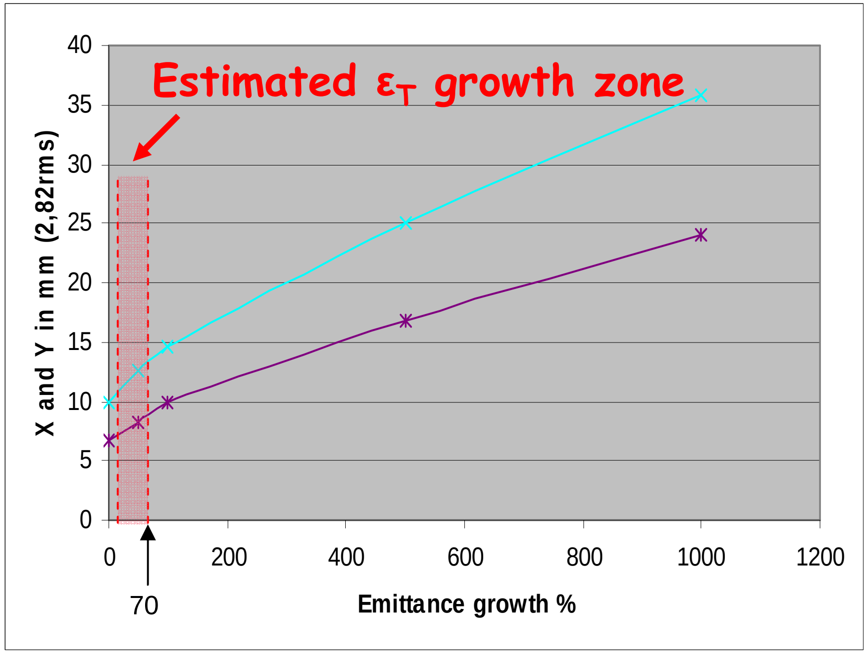
Stripping by using thin foil of carbon generates:
- a lower intensity (about 40% of nominal one)
- a bigger emittance
- safety issues.
- positive point: better acceleration for the same LINAC or a shorter LINAC length for the same energy…



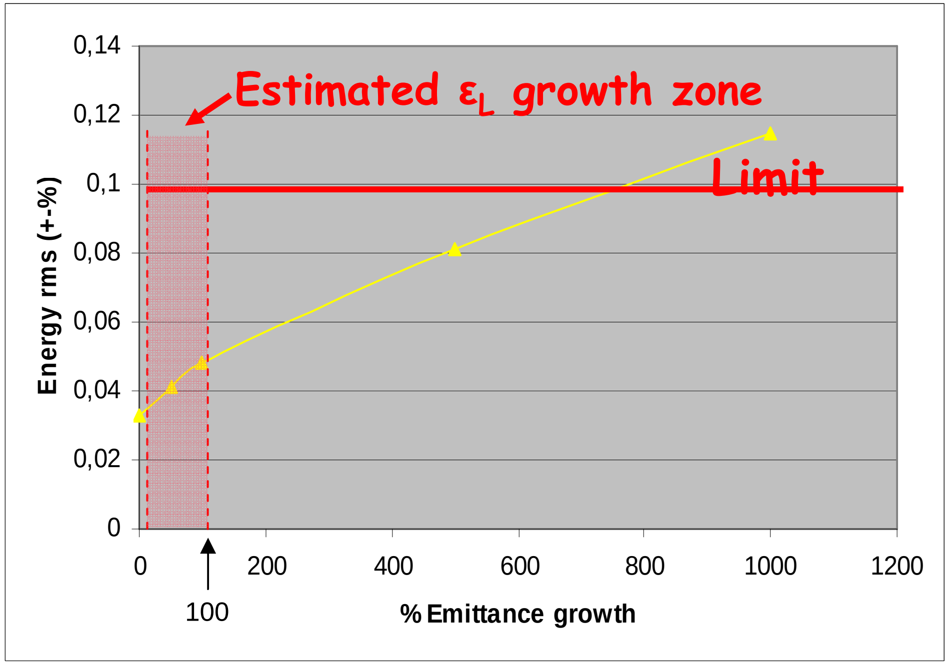
- Length reduction with 2 stripper stations : 206m → 138+20 = 158m
- Length reduction with 1 stripper station : 206m → 146+10 = 156m
- For 132Sn: stripper <Q>= 47 , Q Dispersion= σ = 1
- Fluctuation of foil thickness… (*Ostroumov et al. Phys.Rev.STAB vol.7 090101 (2004)*)

Stripping option : Emittance growth (Preliminary)

Transverse impact



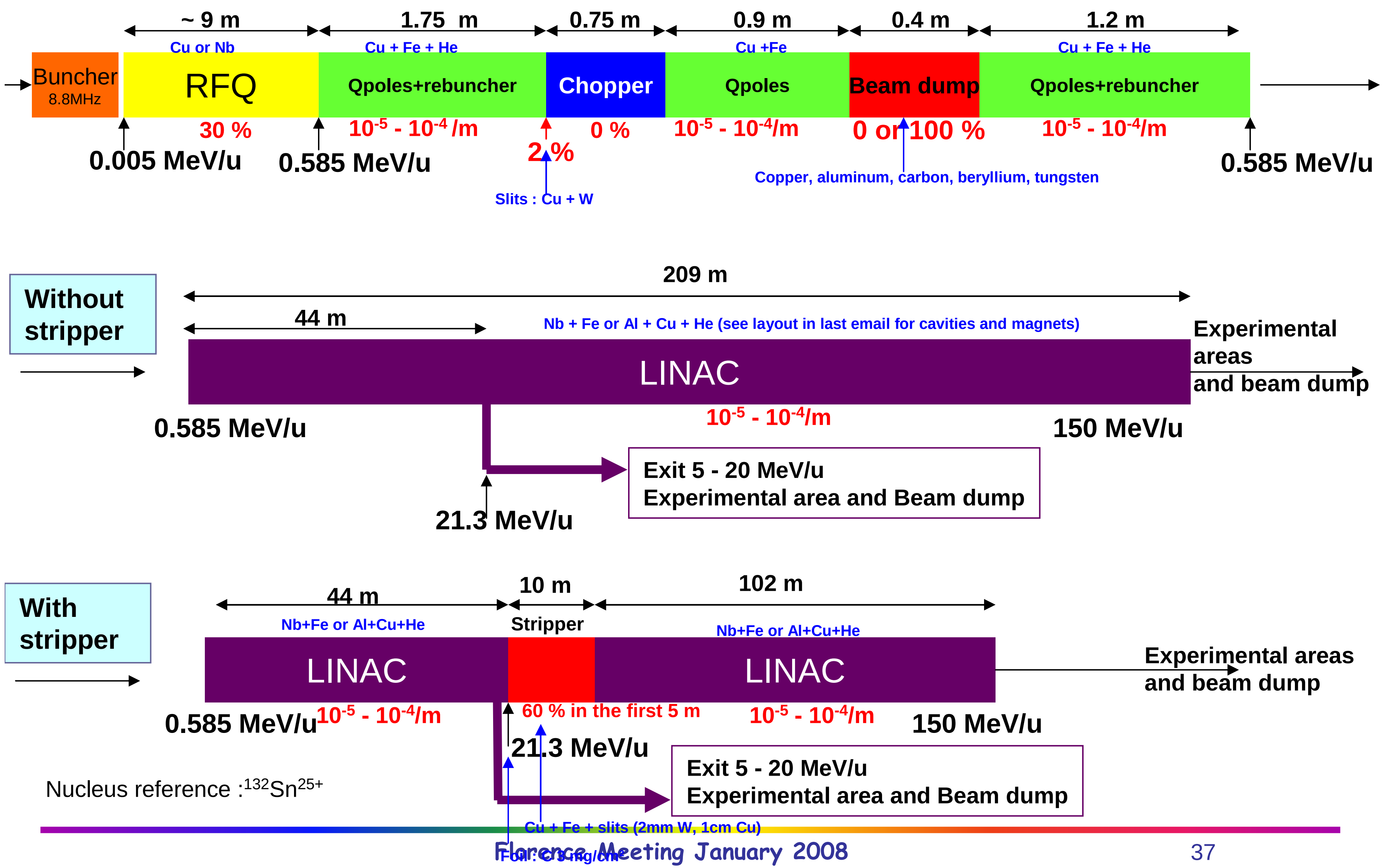
Longitudinal impact



→ Emittance growth due stripping seems not to be a problem

Decision : - LINAC 150 MeV/A for SN 132 25+
- 1 optional stripper for heavier masses.

Schematic view of the 2 options post-accelerator



Conclusions …

1- Beam dynamics of the LINAC is studied. Good matching between MEBT and LINAC has been obtained

2- Steering effect not negligible, but can be corrected (as for SPIRAL 2)

3- Physics requirements reachable.
(remark: for low energy output (5 MeV) ΔE/E = ±0.2% (instead of ±0.1%)

4- Stripping option investigated, partial conclusions are :
- One stripper at around 21.3 MeV/u OK,
- Length of the LINAC is 25 % smaller than without stripper
- But 60% decrease intensity (one charge kept, multicharge not obvious)
- Best solution : keep 132 Sn 25+ at 150 Mev/A without stripper

5- Collaboration well started with the safety group, some results are available

… and perspectives

6 - LEBT : We have to choose between the 3 hypothesis…

7 - RFQs : Comparison between NC-NC and NC-SC RFQs…
Optimization of the matching section between RFQs

8 - MEBT : Study rebunchers in more detail
Choice of chopper type

9 - LINAC : Study section for intermediate energy output and stripper

10 - END TO END : Errors studies (dynamic and static) and refine safety

Thank you !

(Grazie !)