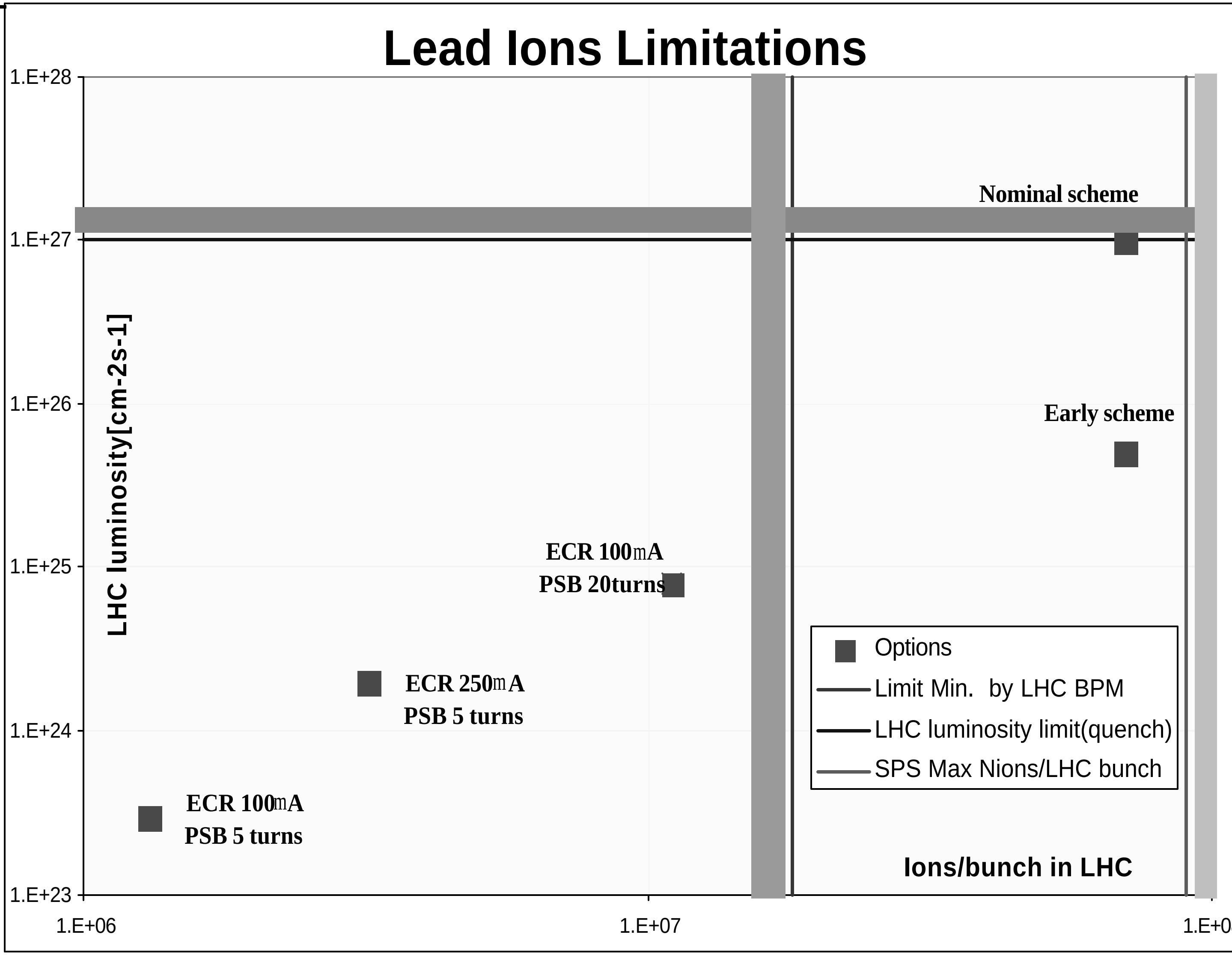
LEIR

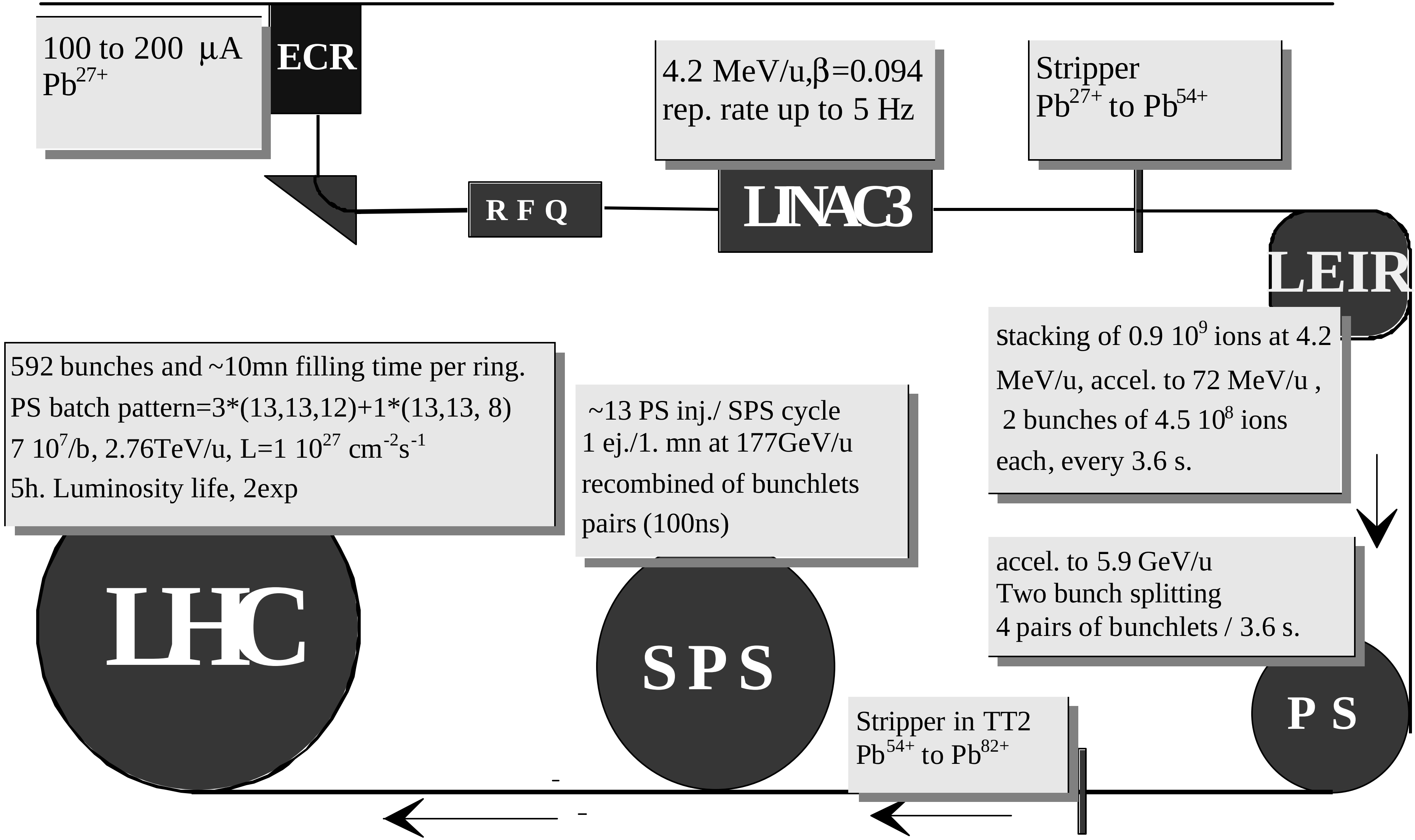
LHC NEEDS

- LEAD ions
- At 2.7 TeV/n, L=10^{27} $cm^{-2}s^{-1}$ limited by central detector and by magnet quenches (note: σ_{tot}=437 barns-e.m.d.,ecpp hadronic-, $\sigma_{hadronic}$=8 barns !!!)
- Luminosity is obtained by about 592 bunches, 7 10^7 ions/bunch, ε_n=1.5μm and β*=0.5m
- First run, early scheme, L=5 10^{25} $cm^{-2}s^{-1}$ (60 bunches, 7 10^7 ions/bunch, β*=1)
- ALICE, ATLAS, CMS
- http://documents.cern.ch/AGE/current/fullAgenda.php?ida=a021004

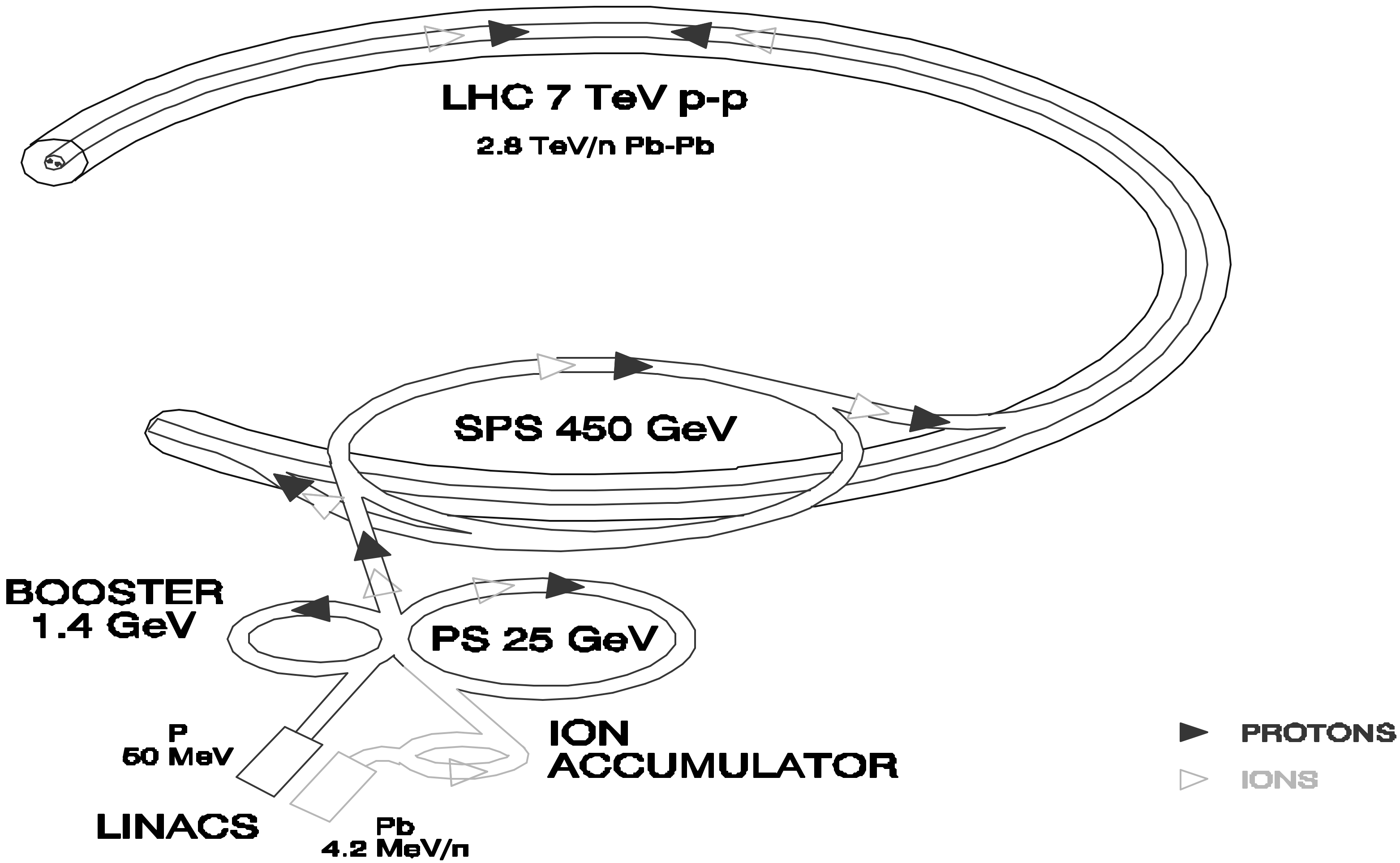
LIMITATIONS



GENERAL SCHEME



Overall injection chain

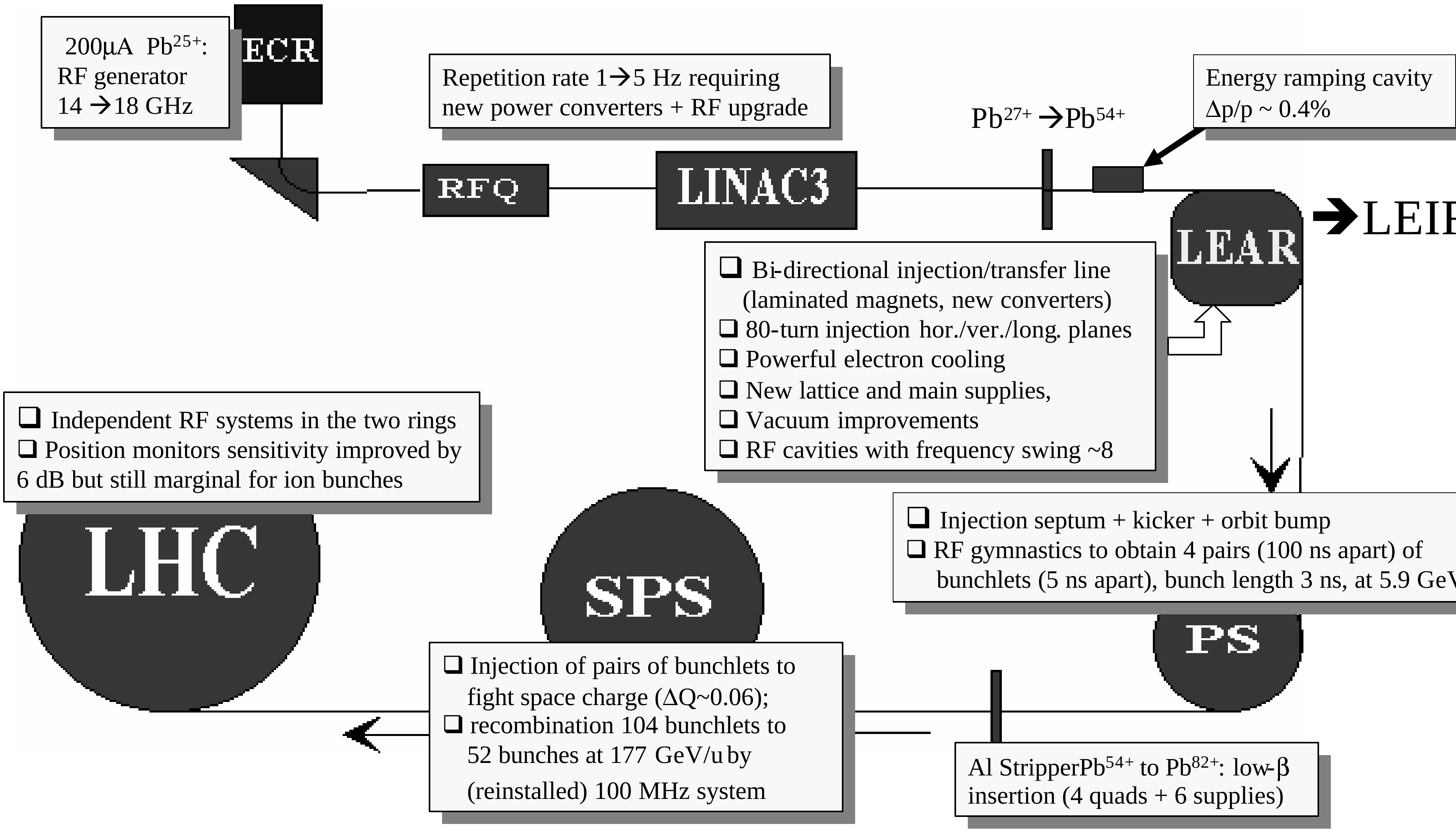


BEAM PARAMETERS

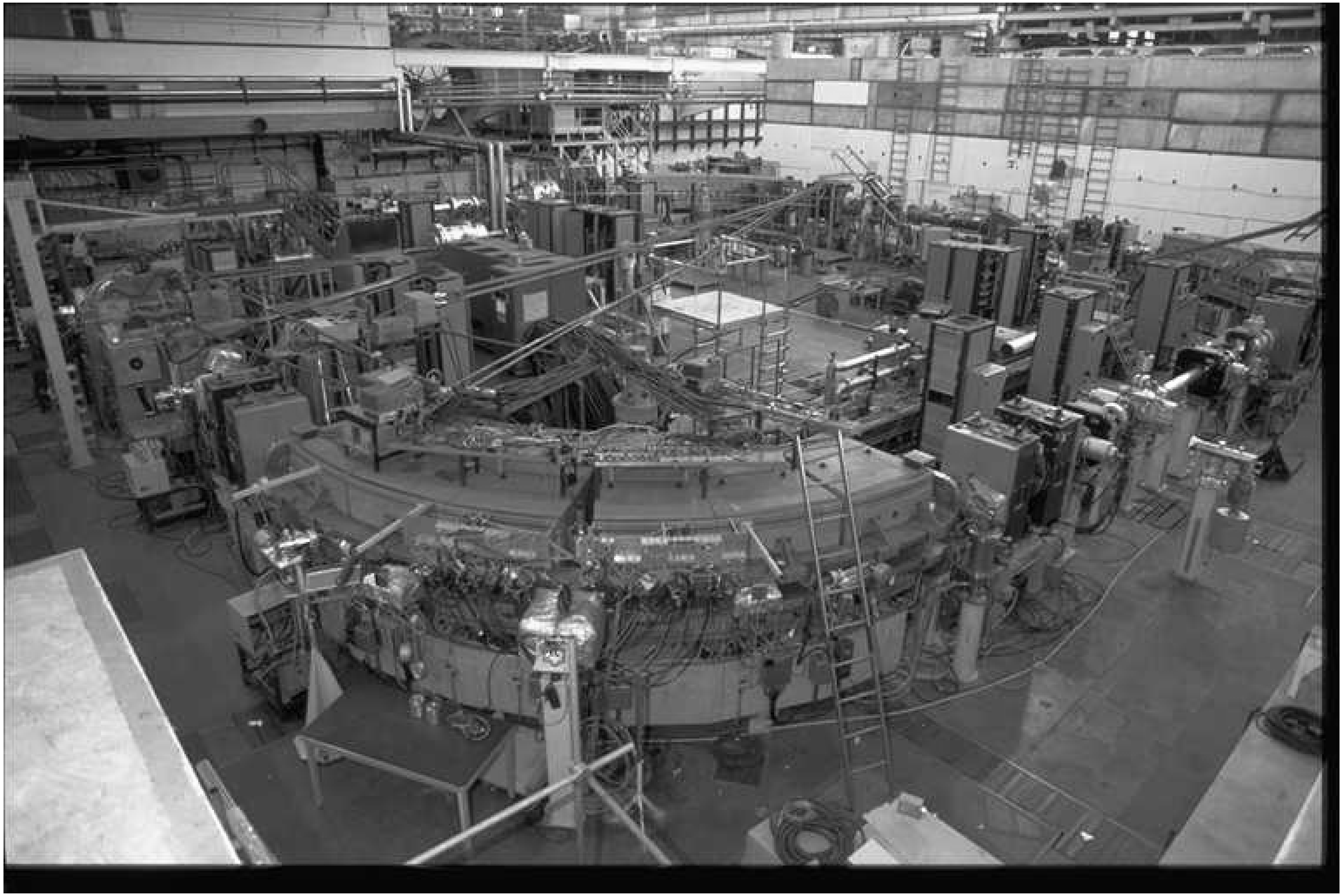
- Overall efficiency 30%

- LHC ε_t=1.5μm, ε_l=1.0 eVs/n/bunch
- SPS extraction ε_t=1.2μm, ε_l=0.28 eVs/n/bunch
- SPS injection after stripping (4 pairs of bunchlets) ε_t=1.0μm, ε_l=0.025 eVs/n/bunchlet
- PS injection(2 bunches) ε_t=0.7 μm, ε_l=0.05 eVs/n/bunch

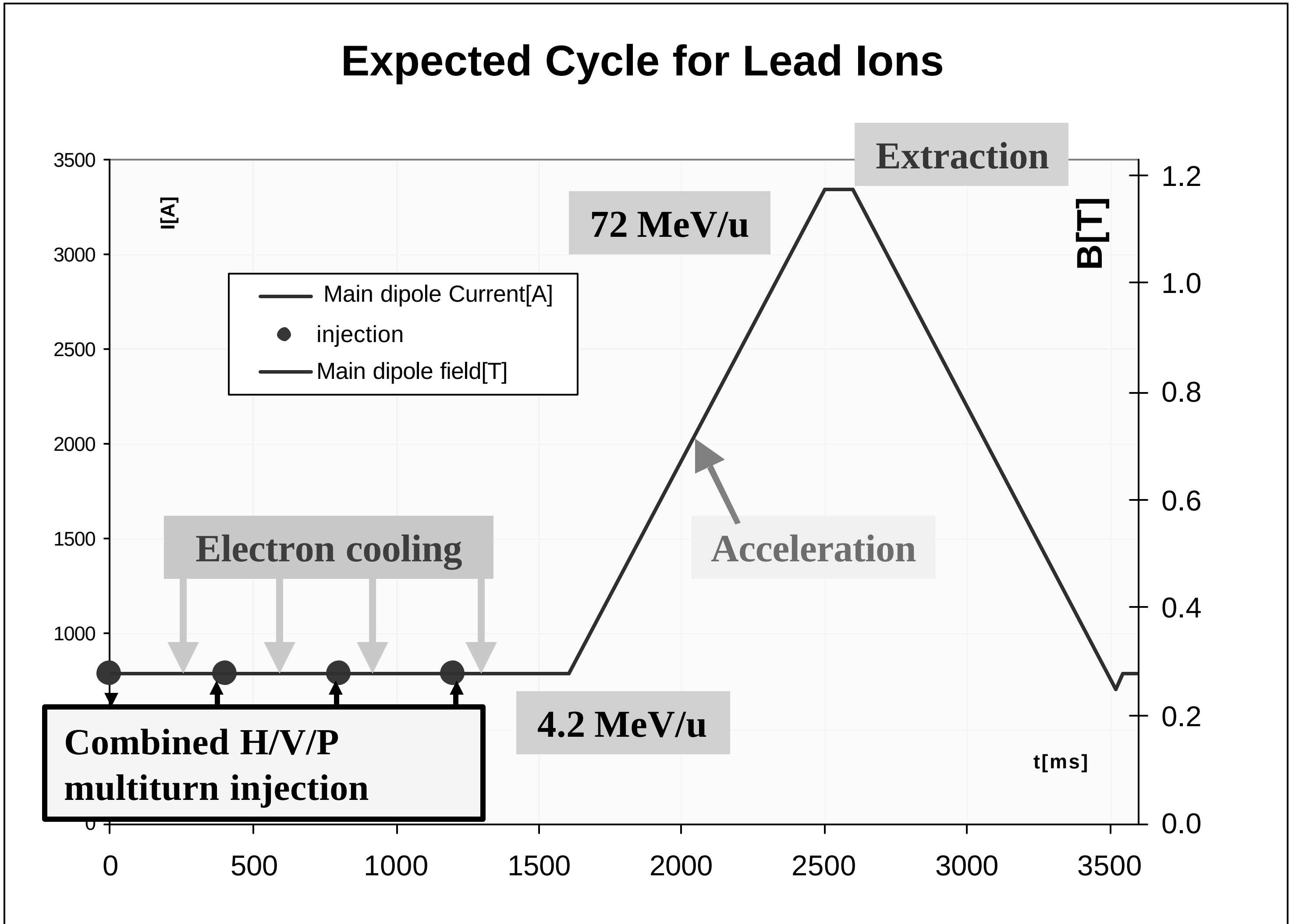
Hardware Upgrades



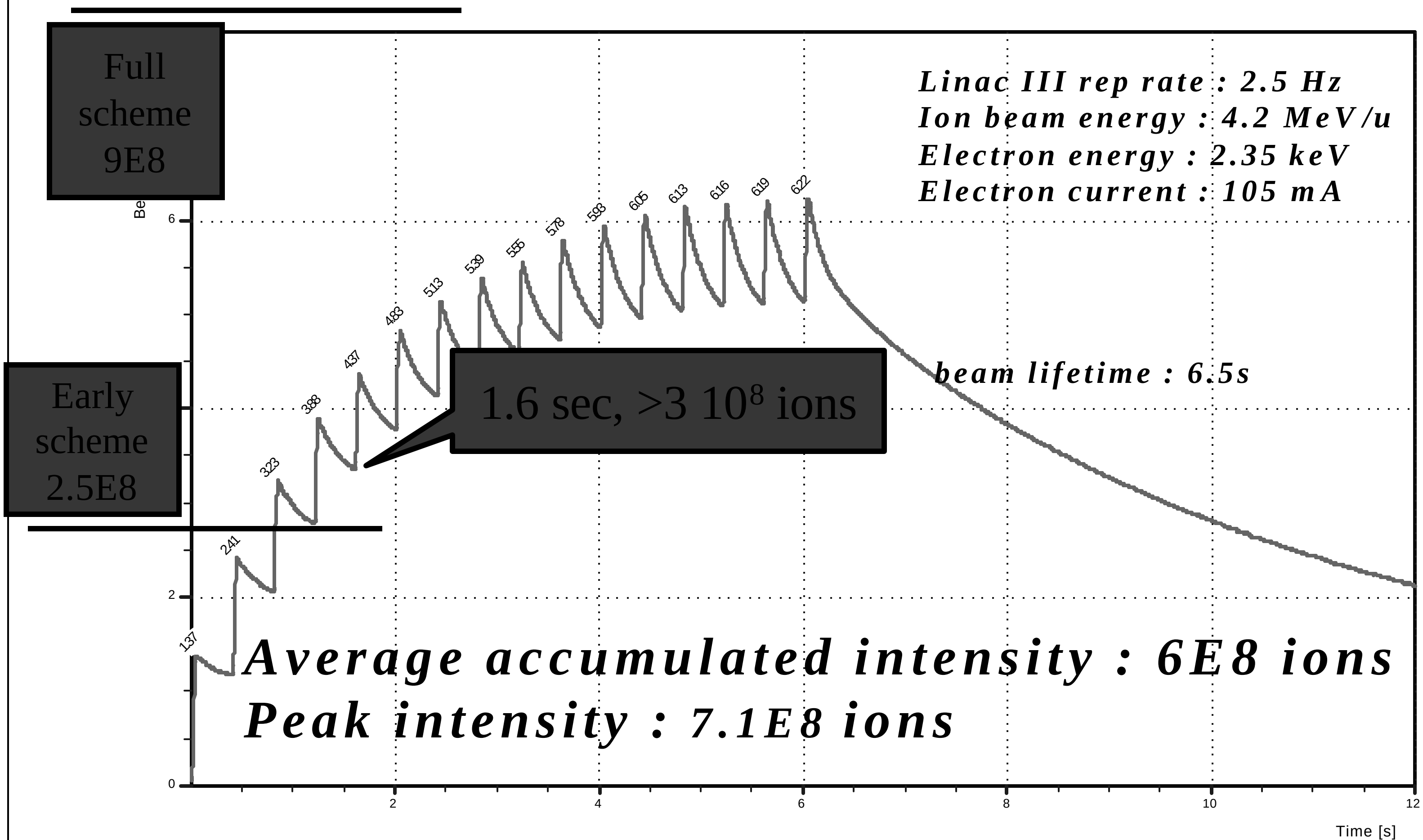
LEAR in 1997



LEAD IONS in LEIR



1997 tests

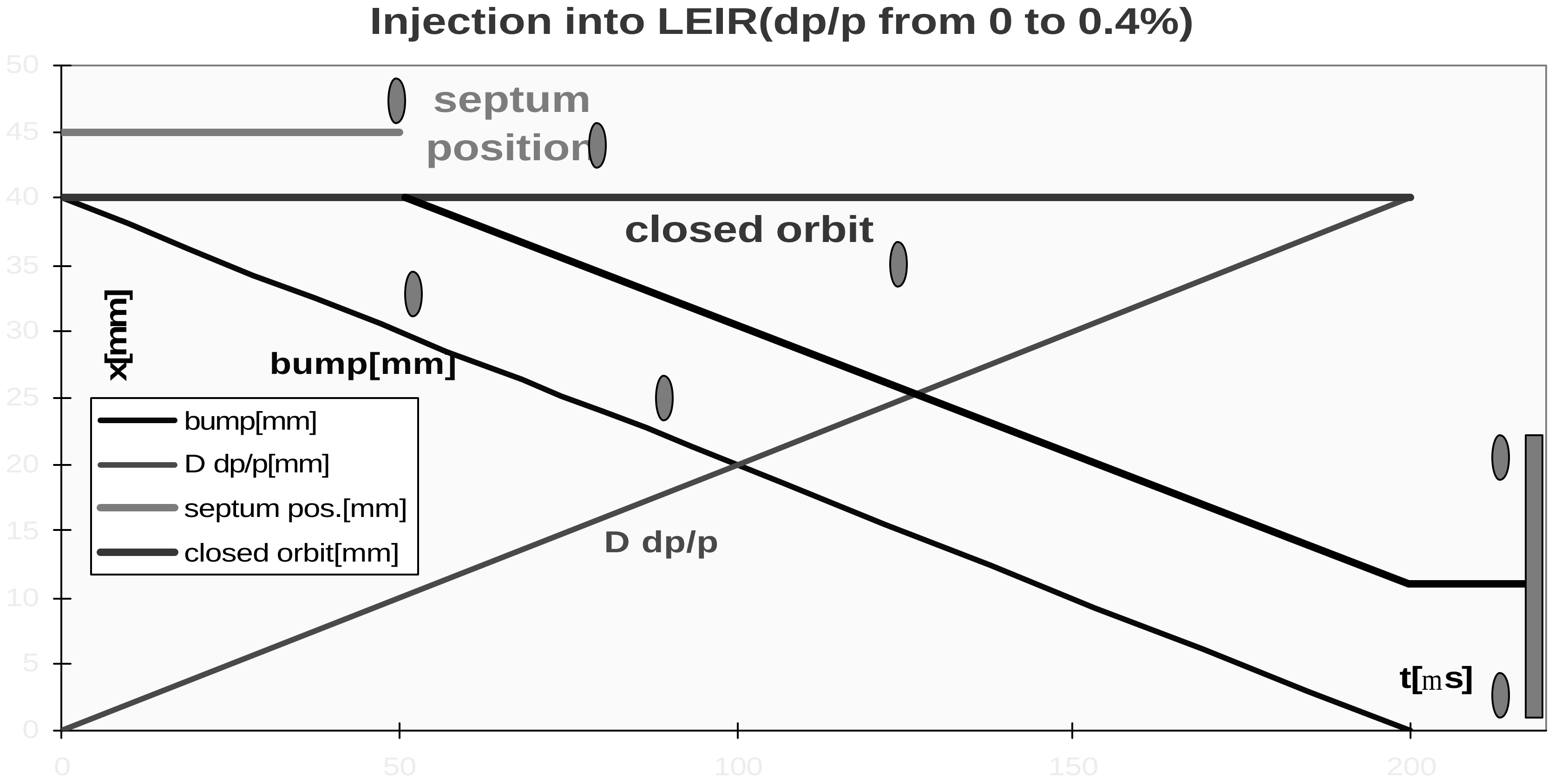


Full scheme 9E8
Early scheme 2.5E8
1.6 sec, >3 10^8 ions
Linac III rep rate : 2.5 Hz
Ion beam energy : 4.2 MeV/u
Electron energy : 2.35 keV
Electron current : 105 mA
beam lifetime : 6.5s
Average accumulated intensity : 6E8 ions
Peak intensity : 7.1E8 ions
137
241
323
388
437
483
513
539
555
578
593
605
613
616
619
622
0
2
6
4
8
10
12
Time [s]

D.Möhl, S.Maury, C.Carli, M.Chanel

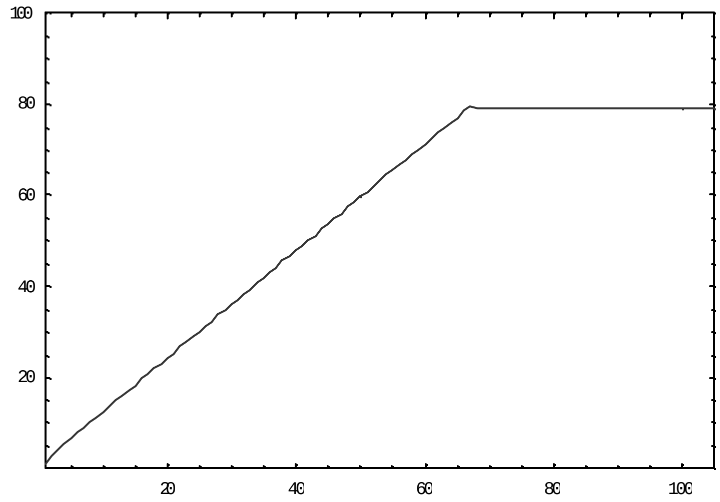
INJECTION

- Combined injection gives decreases ε_t (better cooling time) compared to normal multiturn but increases mom. spread (good long. cool.).
- Combined injection implies large D and D/ $_h$ ~5m$^{1/2}$ (D=10, β_h=3).



ANIMATED INJECTION

- Bump 60mm-0.6mm/turn, 70turns injected (efficiency. 80%), 105 turns shown, δp/p from –0.1% to 0.3%, stack at –0.2%

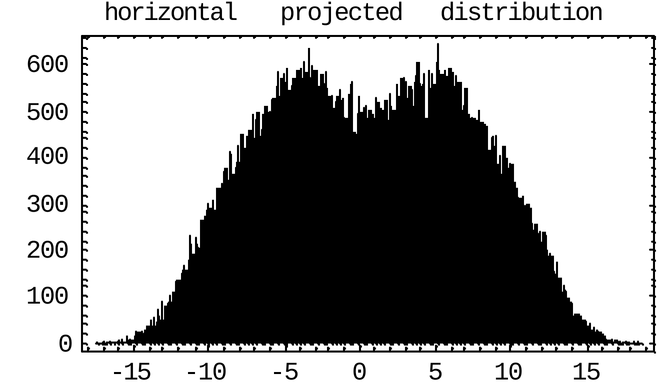


Out[252]= - Graphics -

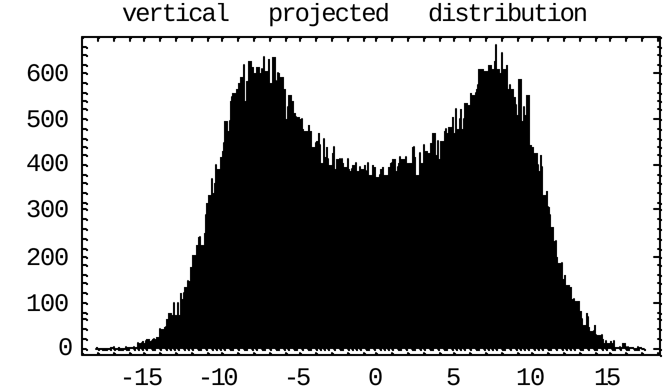
The momentum spread at the end of stacking is 4.22 10^{-3}

After 68 turns injected there are 54 efficient turns injected i.e. an efficiency of 78.7761%

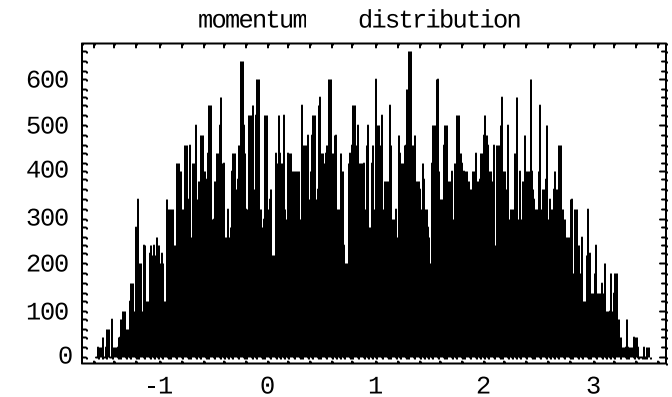
injection



emittanceh= 71.8913at 95%



emittancev= 30.6782at 95%



dp/p= 4.12586E-3 at 95%

- x and y and momentum projected distributions of the injected beam

Cooling and Stacking

- Electron cooling theory gives:

$$\tau \propto \frac{\theta^3}{\eta \cdot I_e} \frac{A}{Q^2}$$

- where θ is the relative difference in angle between the ions and electrons [$\theta_i = \sqrt{(\varepsilon/\beta)}$]
- the parameter $\eta_{ecool} = L_{cooler}/L_{machine}$
- and I_e is the electron current.
- A and Q: atom mass and charge state

•Large β desirable but ion beam size should remain smaller then e-beam size and mind the effect of the e-beam space charge…. optimum around β=5m

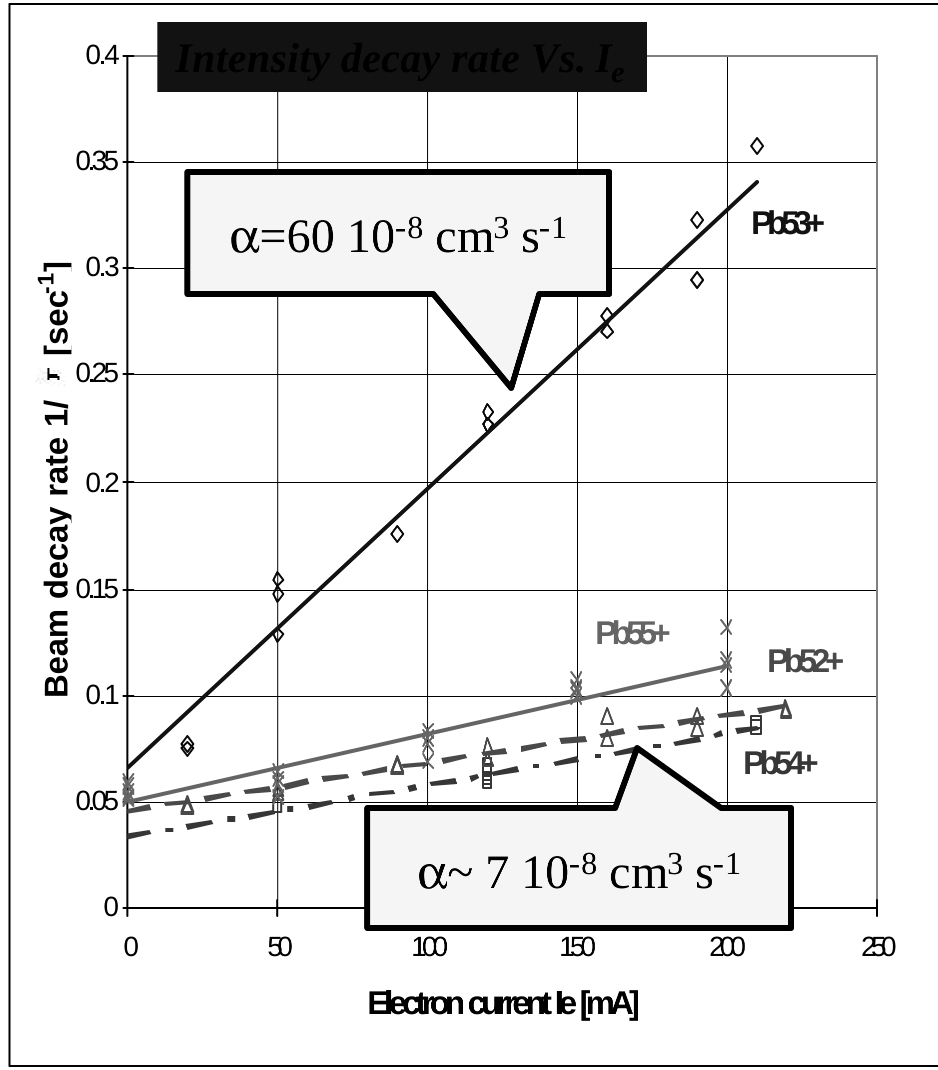
•With D=0, stack and injected beam are in the centre of the e-beam, but this is not the best value for cooling.

Ion Beam Lifetime Vs. I_e

- **Ion beam lifetime measured as a function of electron current.**
  - $\mathbf{1}/t = \mathbf{1}/t_{vac} + \mathbf{1}/t_{rec}$
- **Zero crossing gives the lifetime due to charge exchange with the residual gas.**
- **Slope of the curves gives the recombination rate coefficient**

$$a = \frac{1}{t_{rec}} \times \frac{1}{2.25\times10^{6}} \times \frac{1}{I_e}$$

- **Lead53+ dielectronic recomb.**
- **Lead 54+: Life time ~15s with 2.5 10^7 e^-/cm^3**



Cooling and Stacking

- Loss rate(LR) due to recombination between electrons and well cooled ions is:

$$\frac{1}{t_{rec}} = n_{eff}\, a \qquad n_{eff} = \frac{I_e}{e p a^2 b c} h_c$$

$$a[10^{-13}\, cm^3 s^{-1}] = \frac{3.02\, Z_{eff}^2}{\sqrt{kT}} \left(\ln\left(\frac{11.32\, Z_{eff}}{\sqrt{kT}} + 0.14 \left(\frac{kT}{Z_{eff}^2} \right)^{\frac{1}{3}} \right) \right)$$

- To limit LR and also have a good cooling:
  - Low electron density on stack (e-beam center)
  - High electron density elsewhere for large amplitude ions

J. Bosser, G. Tranquille

ELECTRON COOLER

Magnetic characteristics

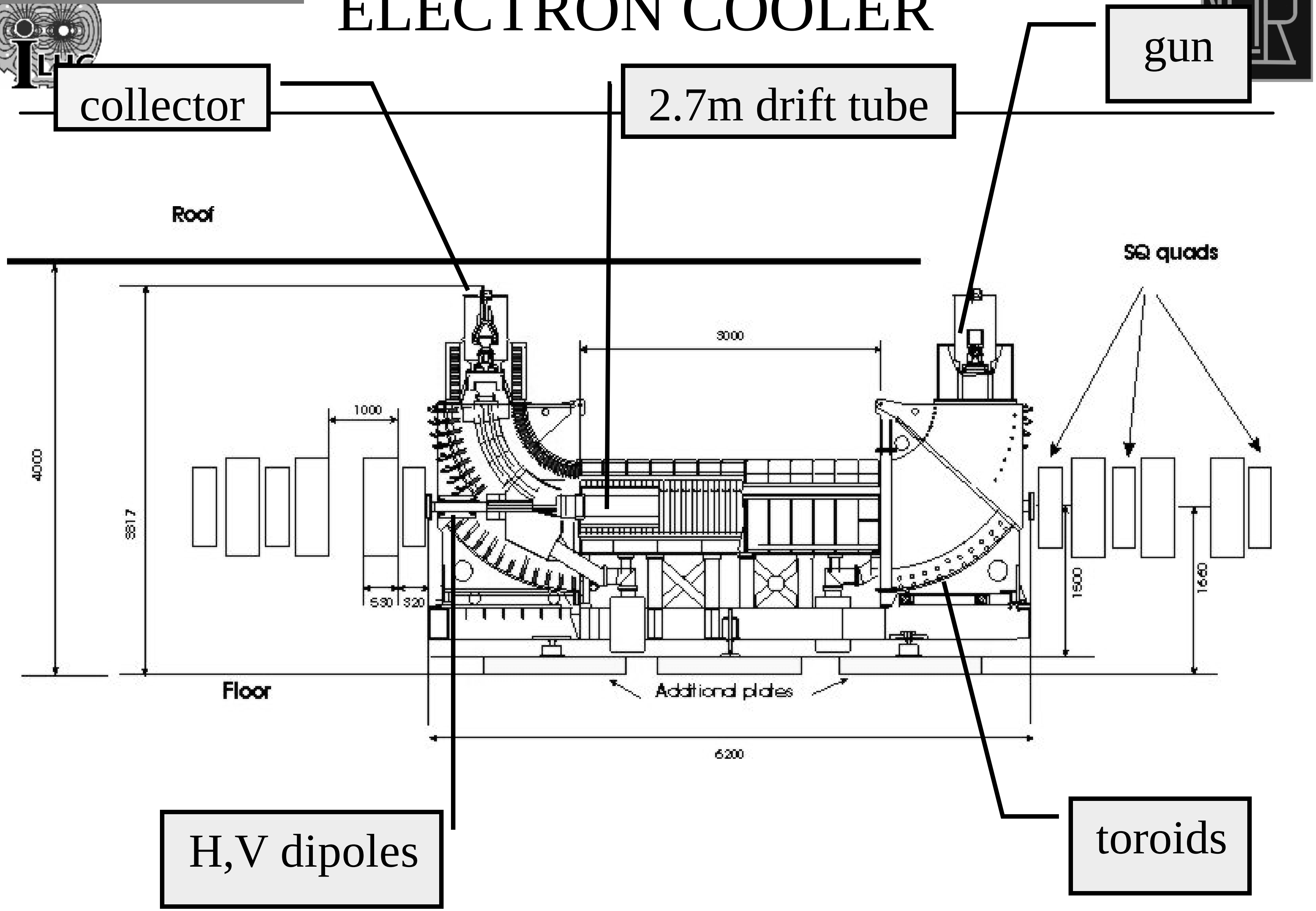
			Comments
B Gun max	up to 2.4	kG	still normal conducting
B Toroid and Drift Max	up to 1	kG	
B Toroid and Drift Nominal	0.75	kG	insure magnetisation

ELECTRON BEAM CHARACTERISTICS

			Comments
CATHODE VOLTAGE	2.4	kV	up to 40kVpossible
Cathode diameter(convex)	29	mm	
GUN PERVEANCE	3 to 6	μP	Ie=P* Vo3/2
Electron current at β=0.0945	0.6	A	
Electron current max	3	A	
Expansion Max	6		
E-Beam diameter max	70	mm	
Cooling length wanted	2.7	m	

V. Parkomchuk&al

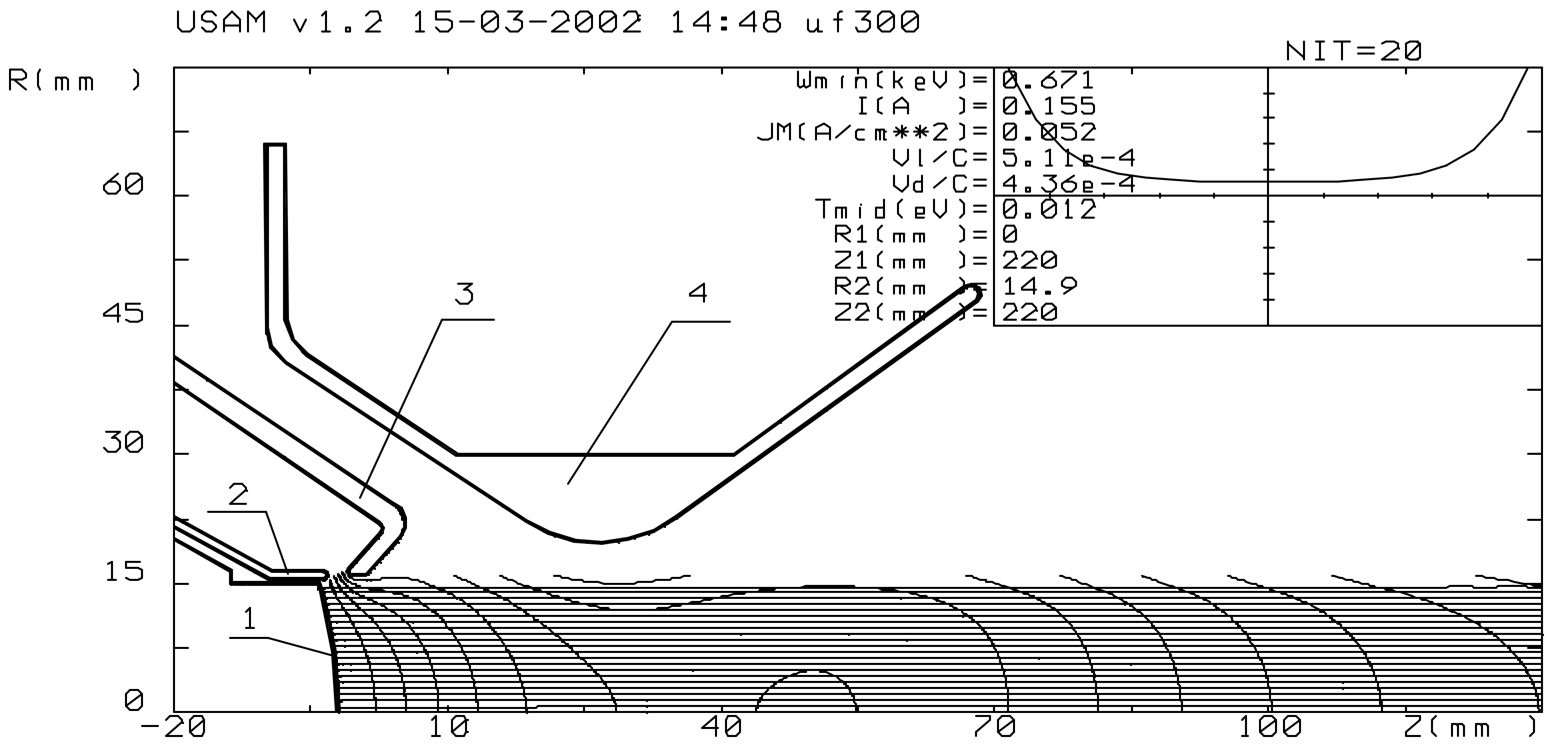
ELECTRON COOLER



V. Parkomchuk&al

ELECTRON COOLER

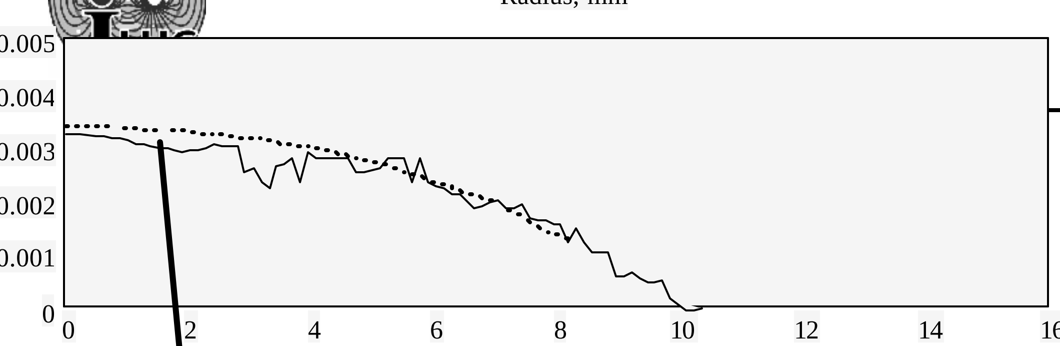
preliminary

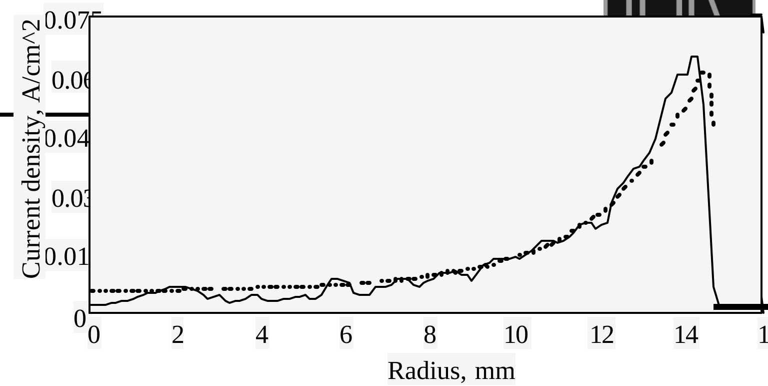


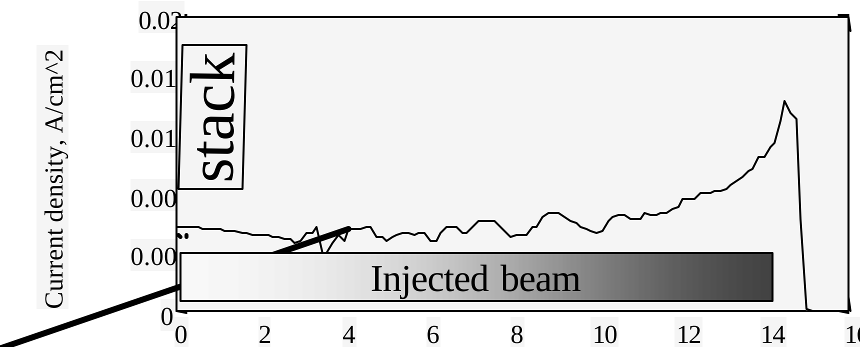
Geometry of electron gun with variable beam profile; equipotentials, trajectories; beam profile on the exit from the gun. (1)cathode, (2) forming electrode, (3)control electrode, (4) grid

V. Parkomchuk&al

ELECTRON COOLER



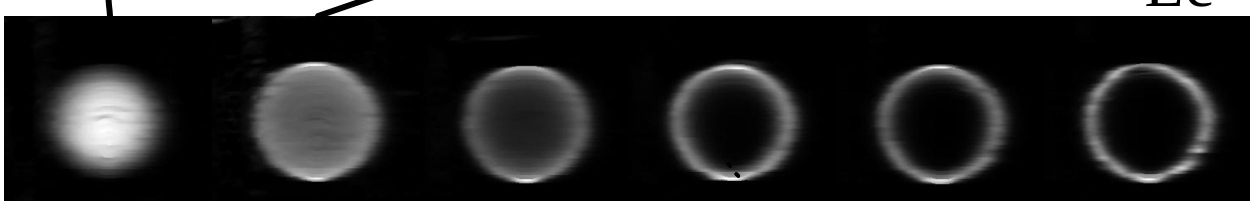




Ec=0

Ec=100 V

Ec=300 V



preliminary

http://accelconf.web.cern.ch/AccelConf/e02/PAPERS/WEPRI049.pdf

Radius, mm

Calculation

C. Carli

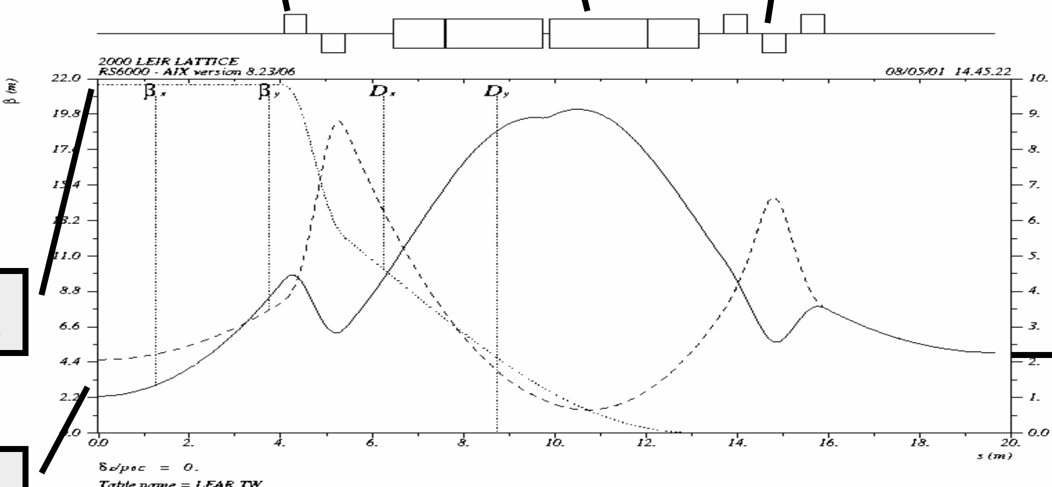
LEIR LATTICE

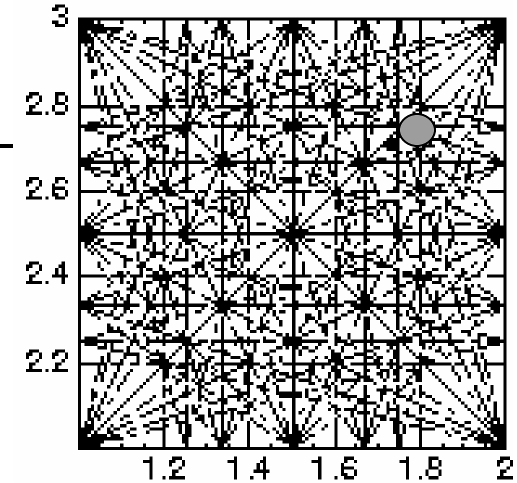
doublet

90 deg. bending

triplet

Injection …





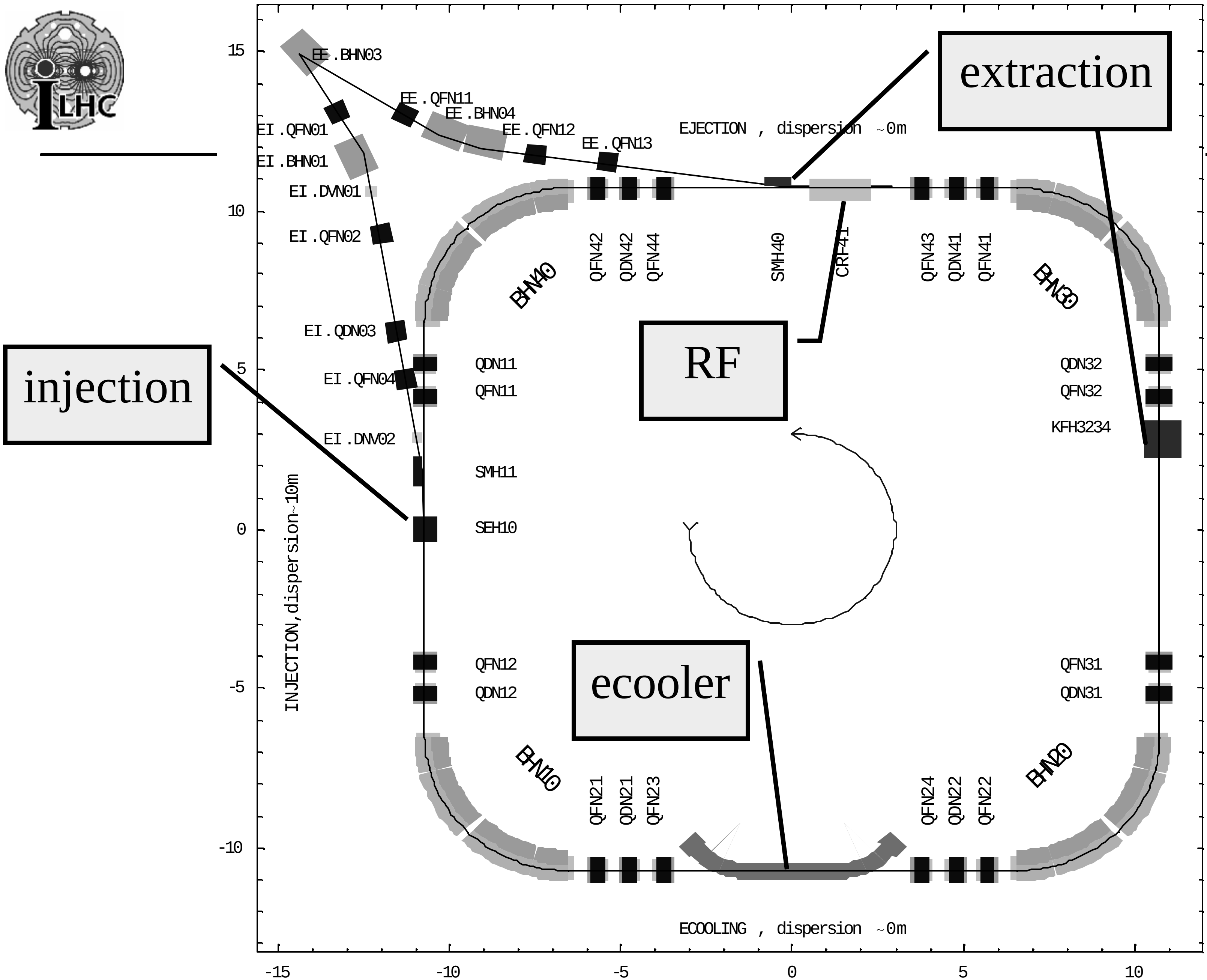
D=10m

βh=3m, βv=4m

βh=βv= 5m, D=0

Ecooler,ejection

- still 2 periods , tune=(1.8,2.7) ,long. acceptance reduced to δp/p ~1%
- 5 quad families, more flexibility.


extraction
injection
RF
ecooler
EE.BHN03
EE.QFN11
EE.BHN04
EE.QFN12
EE.QFN13
EJECTION , dispersion ~0m
EI.QFN01
EI.BHN01
EI.DVN01
EI.QFN02
EI.QDN03
EI.QFN04
EI.DNV02
INJECTION,dispersion~10m
QFN42
QDN42
QFN44
SMH40
CRF41
QFN43
QDN41
QFN41
BHN40
BHN30
QDN11
QFN11
SMH11
SEH10
QDN32
QFN32
KFH3234
QFN12
QDN12
QFN31
QDN31
BHN10
BHN20
QFN21
QDN21
QFN23
QFN24
QDN22
QFN22
ECOOLING , dispersion ~0m
15
10
5
0
-5
-10
-15
-10
-5
0
5
10

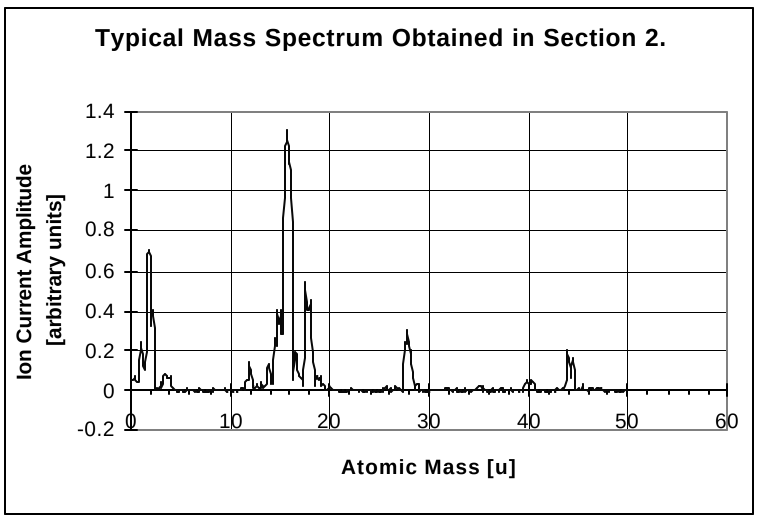
VACUUM

•During the tests in 1997, the static Lear vacuum was good (~5E-12T without beam) but the lost lead ions (multiturn injection, e-ion recombination..lead 54+ or res. gas charge exchange or..) degas the chamber walls.

• One lead ion releases >10^4 molecules!!!!

Measurement of the Vacuum Lifetime

- Vacuum quality measured with RGA.
- Lifetime due to the residual gas can be estimated from the spectra and agrees quite well with measurement.



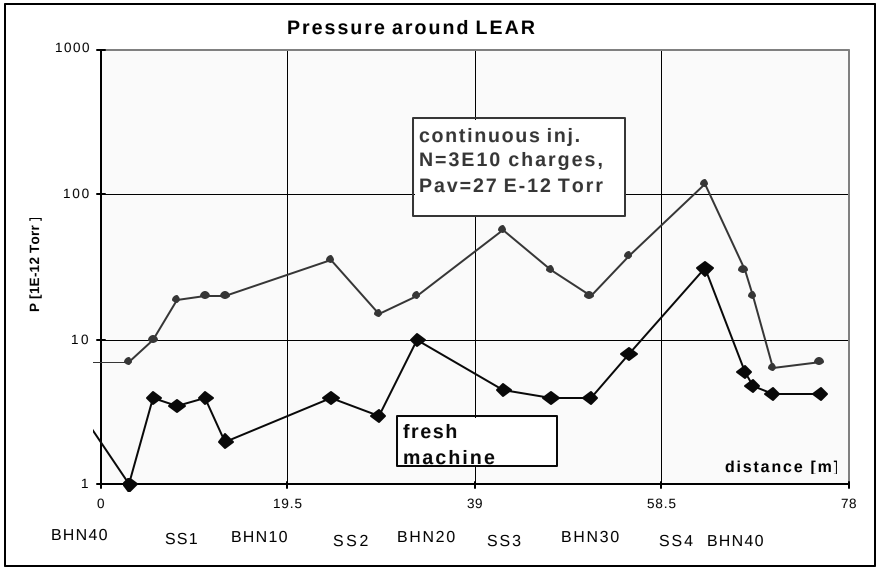
Measured mass spectrum

QMS mass spectrum
time & date
10:01 Apr. 30 1996

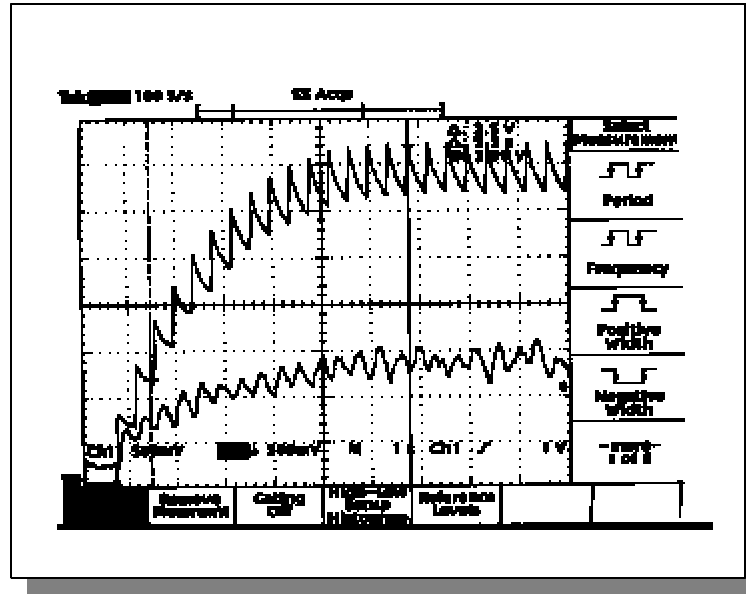
Gas Species	Mass (u)	calibration SVT305	factors QMA120	Peaks	Pi (N2 equ)	Pi (abs)	Percentage
H2	2	2.5	1.54	0.68	2.72218E-12	6.81E-12	31.75120619
He	4	2.27	3.13	0.07842	1.54796E-13	3.51E-13	1.639416298
	14			0.12109			
	15			0.5376			
CH4	16	0.78	0.71	1.27207	1.10689E-11	8.63E-12	40.28129801
H2O	18	1	1	0.52279	3.22981E-12	3.23E-12	15.06886059
	28			0.28268			
CO	28	0.83	1	0.13202	8.15638E-13	6.77E-13	3.15848809
N2	28	1	1	0.15065	9.30751E-13	9.31E-13	4.342473834
O2	32	1.43	1	0.00889	5.49027E-14	7.85E-14	0.366297166
Ar	40	0.69	0.83	0.04275	3.18188E-13	2.2E-13	1.024322581
CO2	44	0.72	1.54	0.17569	7.04821E-13	5.07E-13	2.367637235
Kr		2.1	2.94		0	0	0
GAUGE PRESSURE =	2E-11			3.23726	2E-11	2.14E-11	100

Gas composition analysis

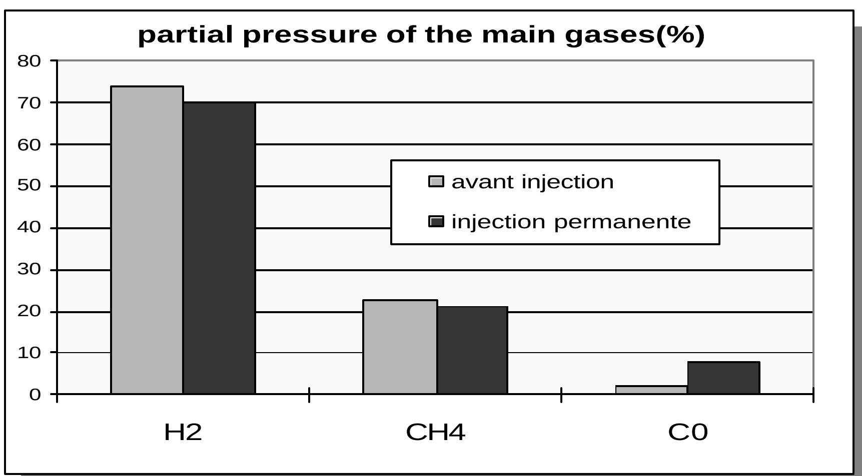
Effects on the Machine Vacuum



Recorded pressures around the machine



Evolution of the CO peak seen on a QMS during stacking



Partial pressures of main residual gas components

Michel CHANEL

VACUUM

- At end of linac3, tests of different vacuum chamber have been done which confirms the high outgassing rate and the desorption of CO, CO2, CH4 molecules.
- When ions are lost perpendicularly to walls, outgassing is decreased: then organise the losses on collimators made of a low outgassing material when possible.
- Beam scrubbing is effective
- More pumping speed
- The goal is to obtained an overall life time of 10-15 sec (30s due to vacuum only and 15-20s due to RR in ecool)

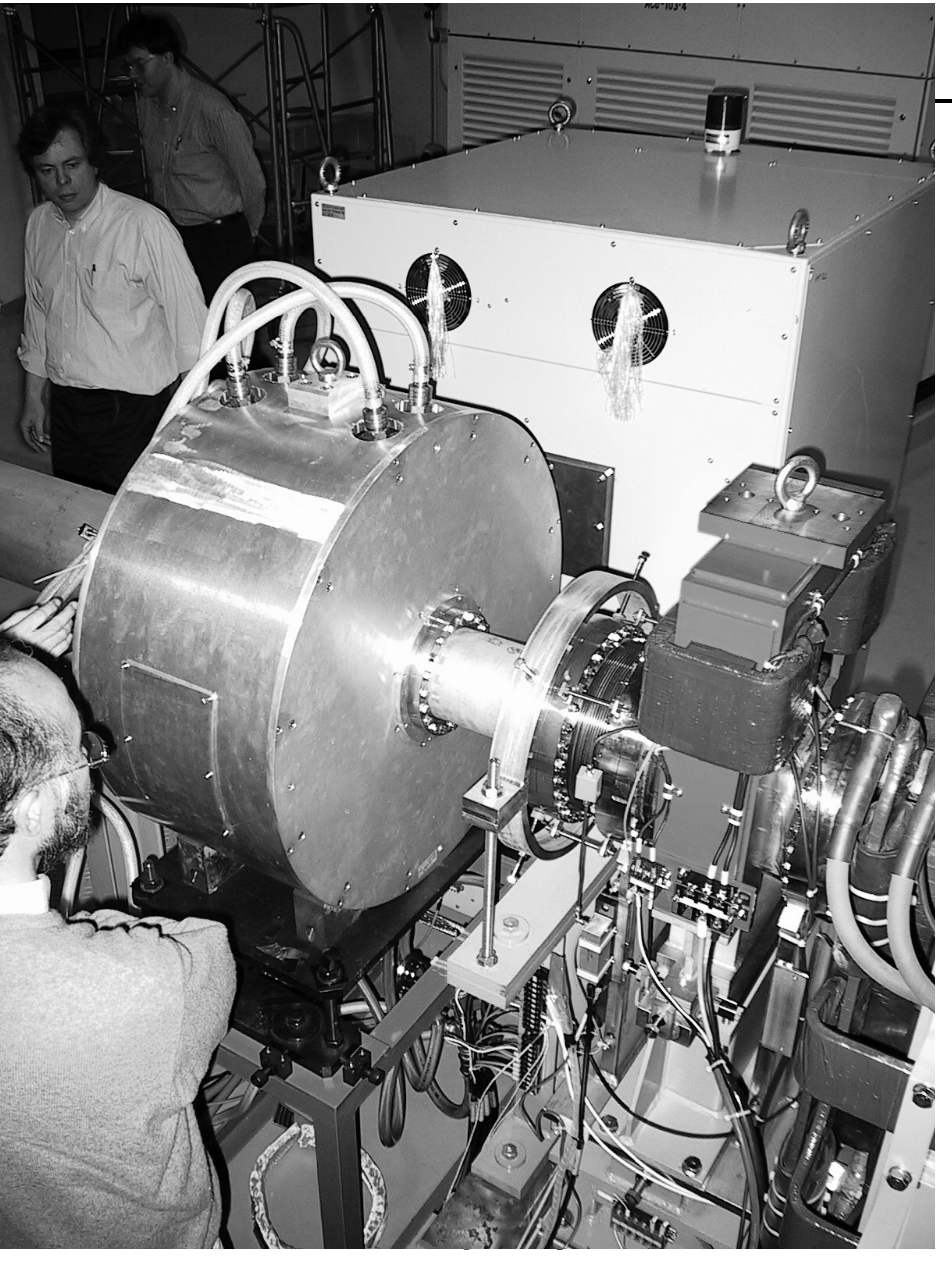
R. Garoby & al

LEIR RF

	Q/A=0.25	Lead 54+	Q/A=0.5	
Energy d'injection	4.2	4.2	4.2	MeV/u
Momentum injection(p eq.)	353.691	353.691	176.845	MeV/c/Q
beta injection	0.095	0.095	0.095	
gamma injection	1.004	1.004	1.004	
Injection field	0.2827	0.2827	0.1414	T
Revolution frequency	3.61E+05	**3.61E+05**	3.61E+05	Hz
Bunching frequency(h=2)	7.22E+05	7.22E+05	7.22E+05	Hz
Ejection Bρ	4.8	4.8	4.8	Tm
Ejection field min	1.1511	1.1511	1.1511	
Momentum(proton eq.)	1440	1440	1440	MeV/c/Q
Energy	67.145	72.2	245.824	MeV/u
β	0.3605	0.3725	0.6116	
γ	1.072	1.078	1.264	
Revolution frequency	1.377E+06	1.423E+06	2.336E+06	Hz
RF frequency(h=2)	2.754E+06	**2.845E+06**	**4.672E+06**	Hz

- 2 RF cavities using Finemet® giving 4kV each, built in collaboration with KEK
- Large swing in frequency but high impedance, Very short

A nice cavity in HIMAC (Japan)



To the courtesy of
M. Paoluzzi

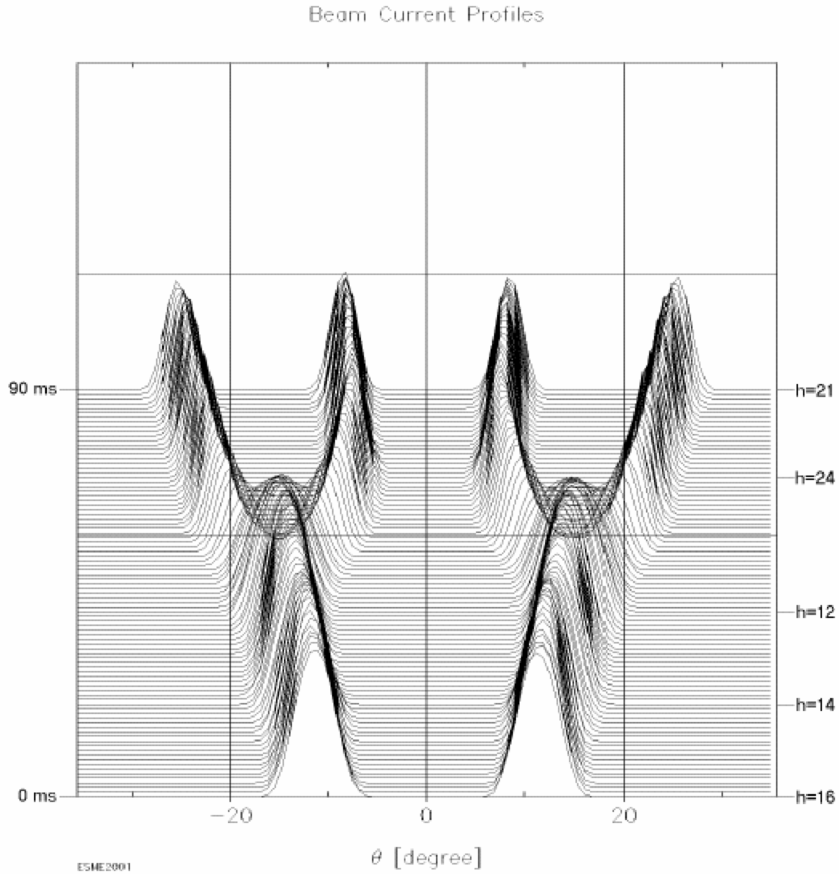
CONCLUSIONS

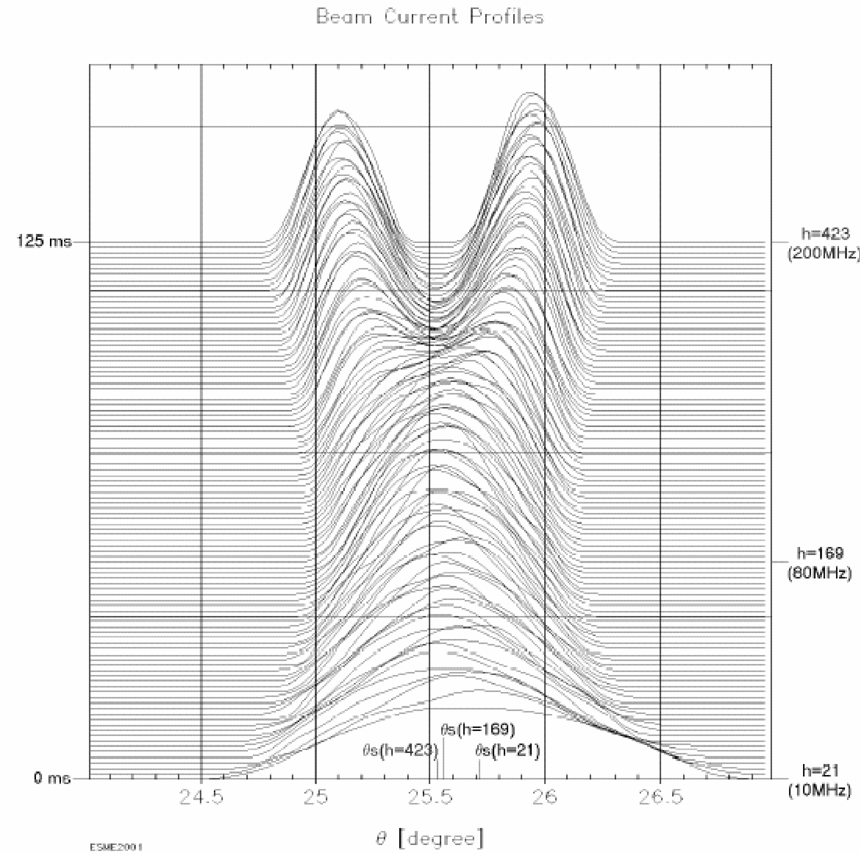
- Project is now on its way
- The main problems have been understood, solutions proposed and are being applied.
- Commissioning of LEIR in 2005, PS/SPS in 2006/2007…LHC ions in 2008

S. Hancok

RF in PS

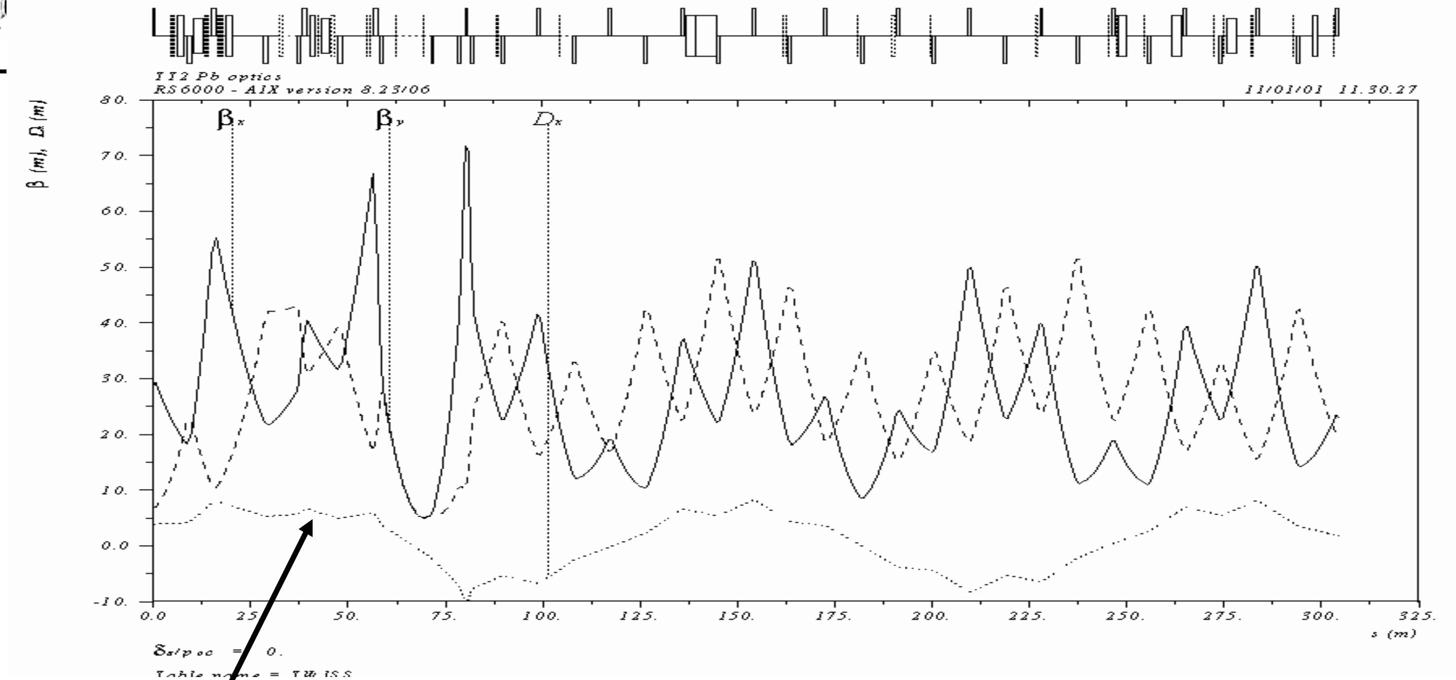
Batch Expansion and Bunch Splitting - Rebucketing and Bunch Splitting





M. Martini

Transfer line to SPS(TT2)



- At stripper $\beta_{h,v}$~20m→5m, D~-1m
- Blow-up reduced by a factor 4 compared to old(normal)optic….needs MD for SPS matching. $\Delta\varepsilon$~0.2μm after re-matching in SPS?.
- Need of 4 quads, 6 power supplies.(mostly recuperated)

Recombination e⁻-ions