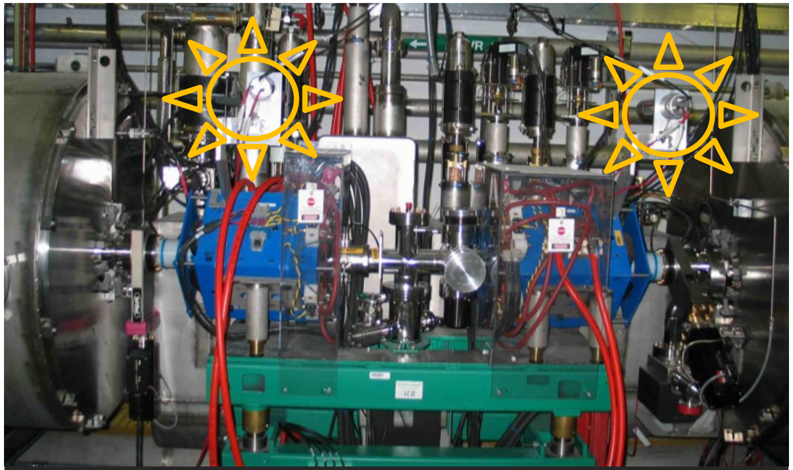
Intra-Beam stripping at SPL: should we be worried?

P. A. POSOCCO
CERN – BE/ABP

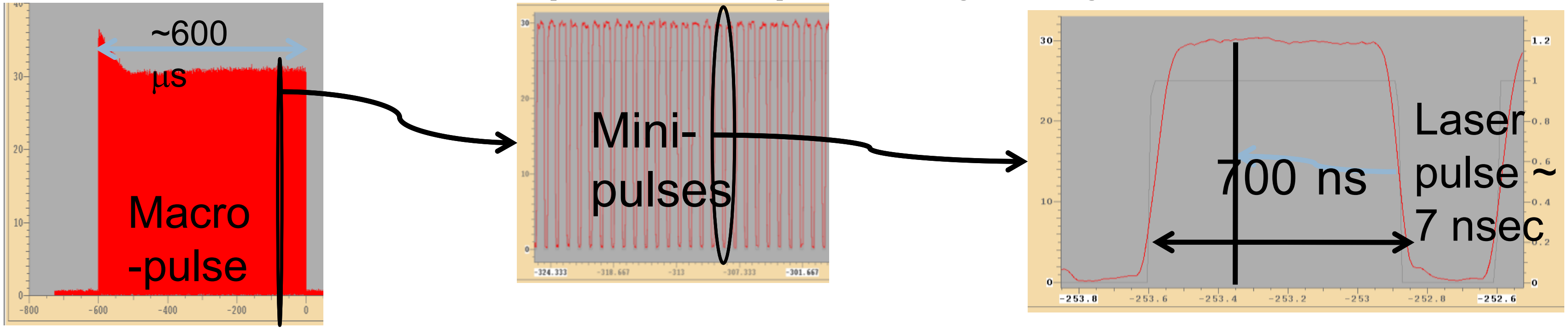
5th SPL Collaboration meeting

How it started…

- SNS experienced uniform losses all along the Super Conducting part
- The residual radiation is about 30mrem/h at 30cm
- They calibrated the losses with laser wire profile system giving: $\leq 10^{-4}$ loss



Inter cryo section @ SNS

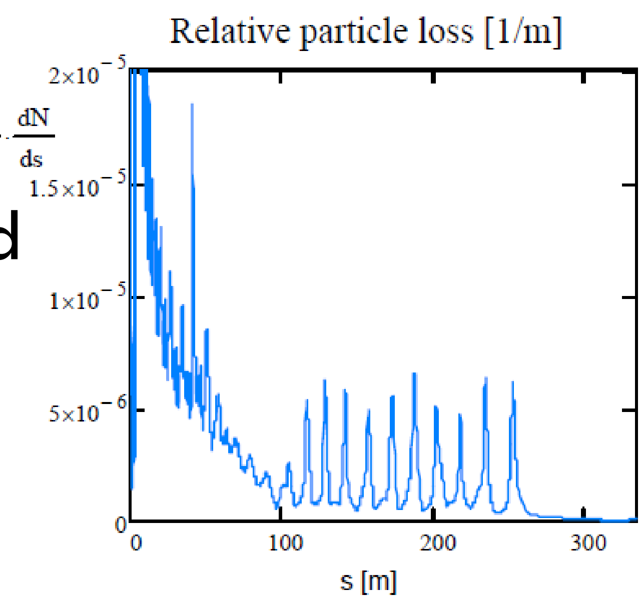


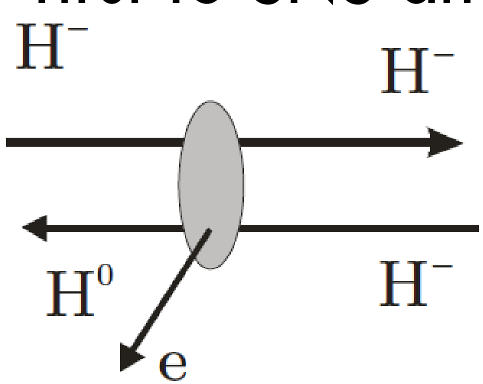
First attempts to understand the problem

- Scraping at low energy:
  - lower localized losses but still a uniform pattern along the linac
- Longitudinal emittance measurements:
  - found some longitudinal halo partially mitigated with a linac retuning. The simulations didn't predict it…
- High order magnetic components in the quads equipped with steerers not taken into account for the linac design:
  - sextupole: since it is proportional to the corrector current (normally very low) it is an issue only for very mismatched beams
  - dodecapole: they may excite a high order resonance at 60 degs (the design phase advance is around this value for all the linac length). Reducing the focalization helps reducing the pile-up loss component, but not the baseline.

Discovering the truth

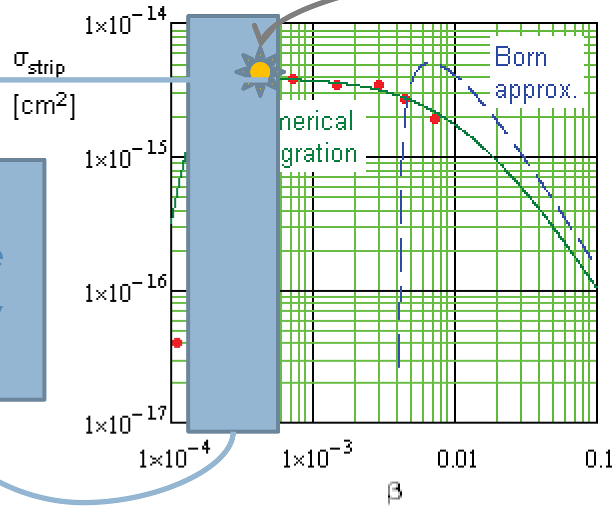
- After a lot of work they managed to reduce the losses down to 10^{-5}
- Not an issue anymore in terms of power loss for SPL, but still an unsolved problem
- V. Lebedev had the idea of the Intra Beam Stripping and applied first to SNS and then to the ProjectX design





Intra-Beam stripping cross section [1]

$\sigma_{max} = \max(\sigma_H(v)) \approx 4 \cdot 10^{-15}\ \mathrm{cm}^{-2}$



$\sigma_H = (3.6 \pm 1) \cdot 10^{-15}\ \mathrm{cm}^2$ at $\beta \approx 4 \cdot 10^{-4}$

SPL relative velocity range

Cross-section measured at LEAR [2] (1987)

Semi-empirical formula:

$$\sigma_H(\beta c) = \frac{240 \alpha_{FS}^2 a_0^2}{(\beta + \alpha_{FS})^2} \frac{(\beta - \beta_m)^6}{(\beta - \beta_m)^6 + \beta_m^6} \ln\left(1.79 \frac{\beta + \alpha_{FS}}{\alpha_{FS}}\right)$$

with:

$a_0 \approx 0.529 \cdot 10^{-8}$ cm Bohr radius	$\beta = v/c$ Ion relative velocity
$\alpha_{FS} \approx 1/137$ Fine structure constant	$\beta_m \approx 7.5 \cdot 10^{-5}$ Minimum β

Fractional Loss [1]

Particle loss rate in the beam frame:

$$\frac{dN}{dt} = \frac{N^2}{2}\int |\mathbf{u}|\,\sigma_H\left(|\mathbf{u}|\right) f\left(\mathbf{v}_1,\mathbf{r}_1\right) f\left(\mathbf{v}_2,\mathbf{r}_2\right)\delta\left(\mathbf{r}_1-\mathbf{r}_2\right) d\Gamma_1 d\Gamma_2$$

½ factor to remove the double counting

Evaluating the velocity distribution for each r

where $d\Gamma_{1,2} = d\mathrm{v}_{1,2}{}^3 dr_{1,2}{}^3,\quad \mathbf{u} = \mathbf{v}_1 - \mathbf{v}_2$

For a Gaussian distribution:

$$\frac{dN}{dt} = N^2 \int_{-\infty}^{\infty} \frac{|\mathbf{u}|\,\sigma_H\left(|\mathbf{u}|\right) e^{-\frac{u_x{}^2}{4\sigma_{vx}{}^2}-\frac{u_y{}^2}{4\sigma_{vy}{}^2}-\frac{u_z{}^2}{4\sigma_{vz}{}^2}}}{128\pi^3\sigma_x\sigma_y\sigma_z\sigma_{vx}\sigma_{vy}\sigma_{vz}} du^3$$

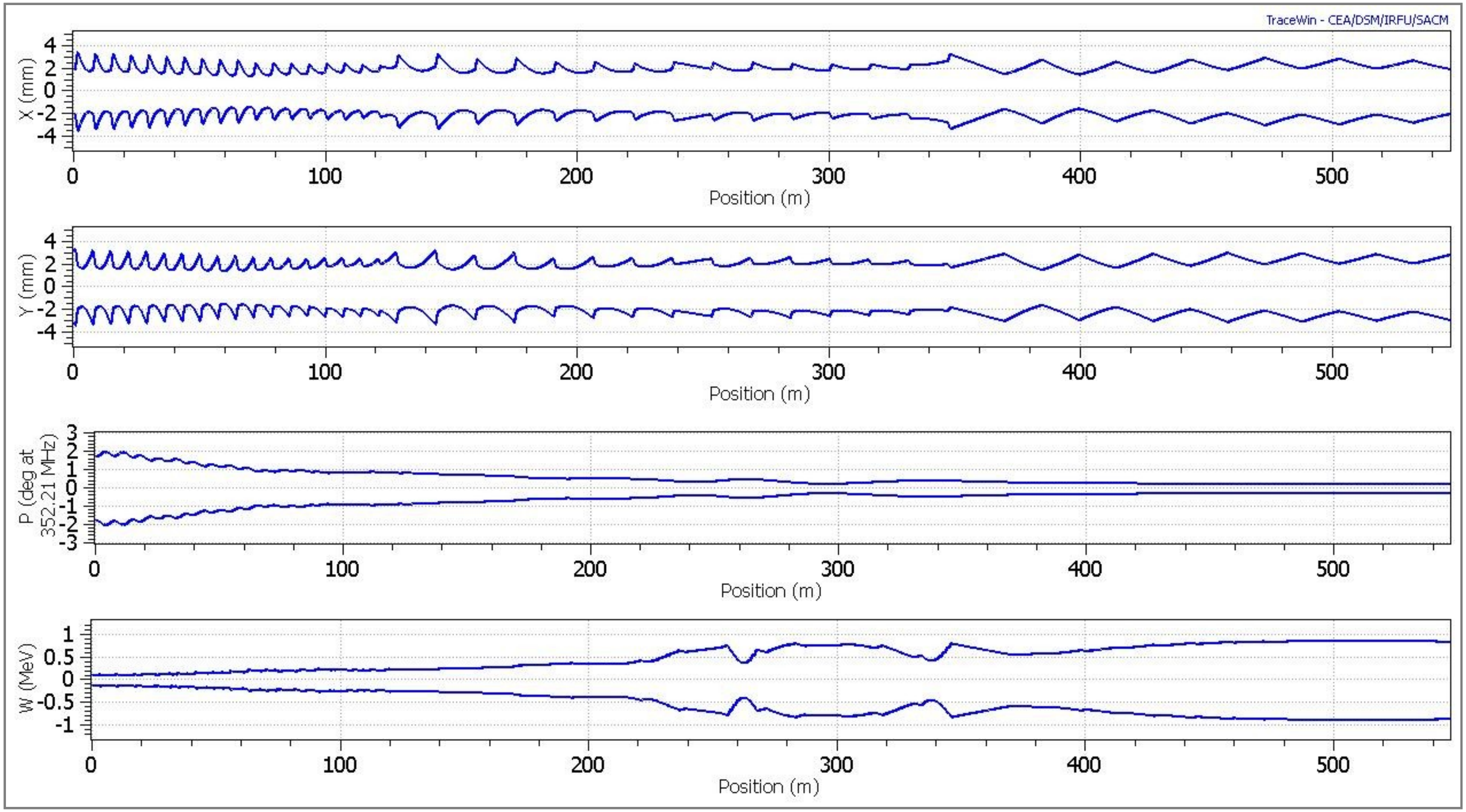
Cross section independent of the velocity

F is a form factor which is =2/√3 (max) when all 3 velocity spreads are equal

Which becomes in the lab frame:

$$\frac{1}{N}\frac{dN}{ds} = \frac{N\sigma_{max}\sqrt{\gamma^2\theta_x{}^2+\gamma^2\theta_y{}^2+\theta_s{}^2}}{8\pi^2\sigma_x\sigma_y\sigma_s\gamma^2} F\left(\gamma\theta_x,\gamma\theta_y,\theta_s\right)$$

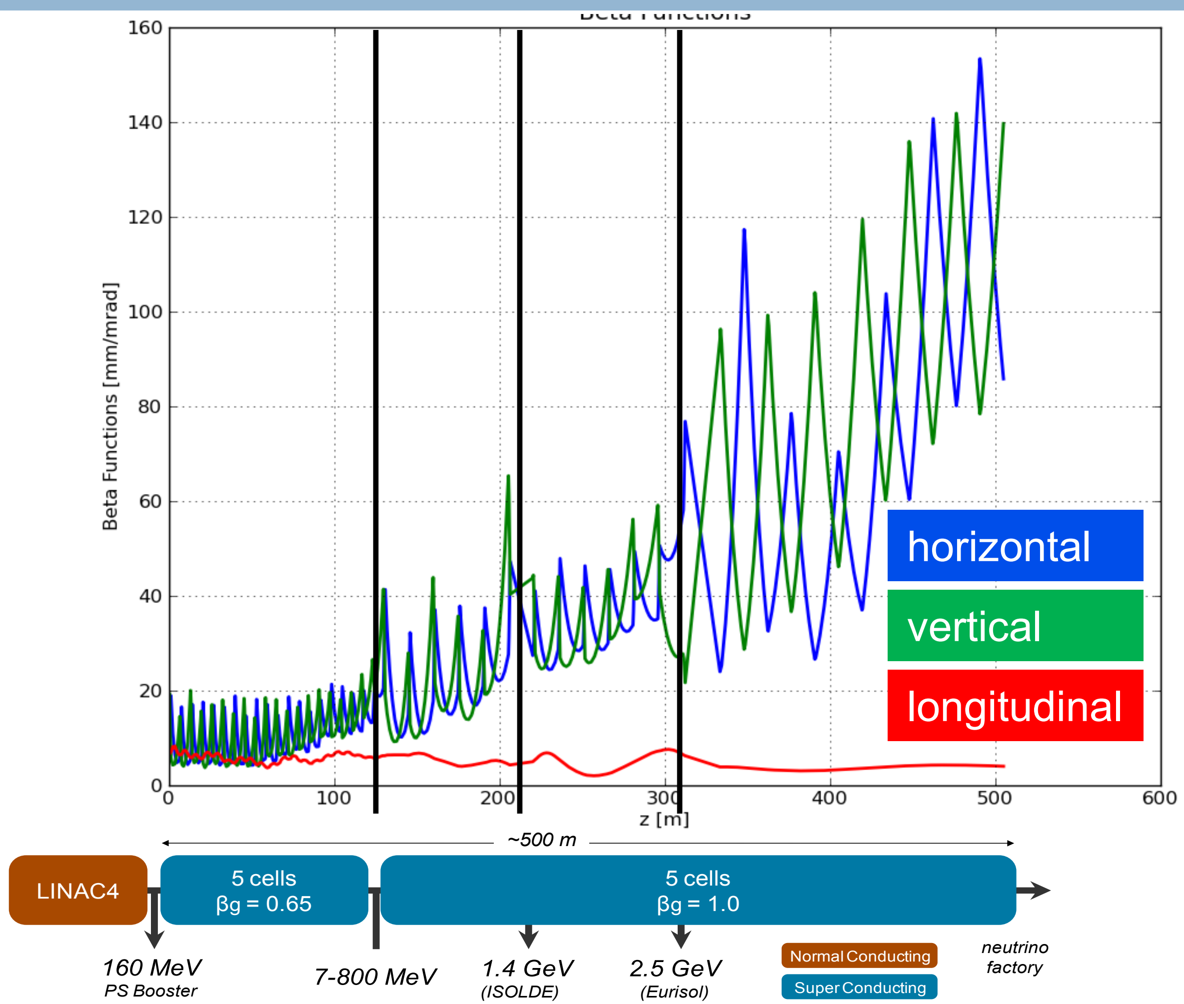
Envelopes


TraceWin - CEA/DSM/IRFU/SACM
X (mm)
Position (m)
Y (mm)
Position (m)
P (deg at 352.21 MHz)
Position (m)
W (MeV)
Position (m)

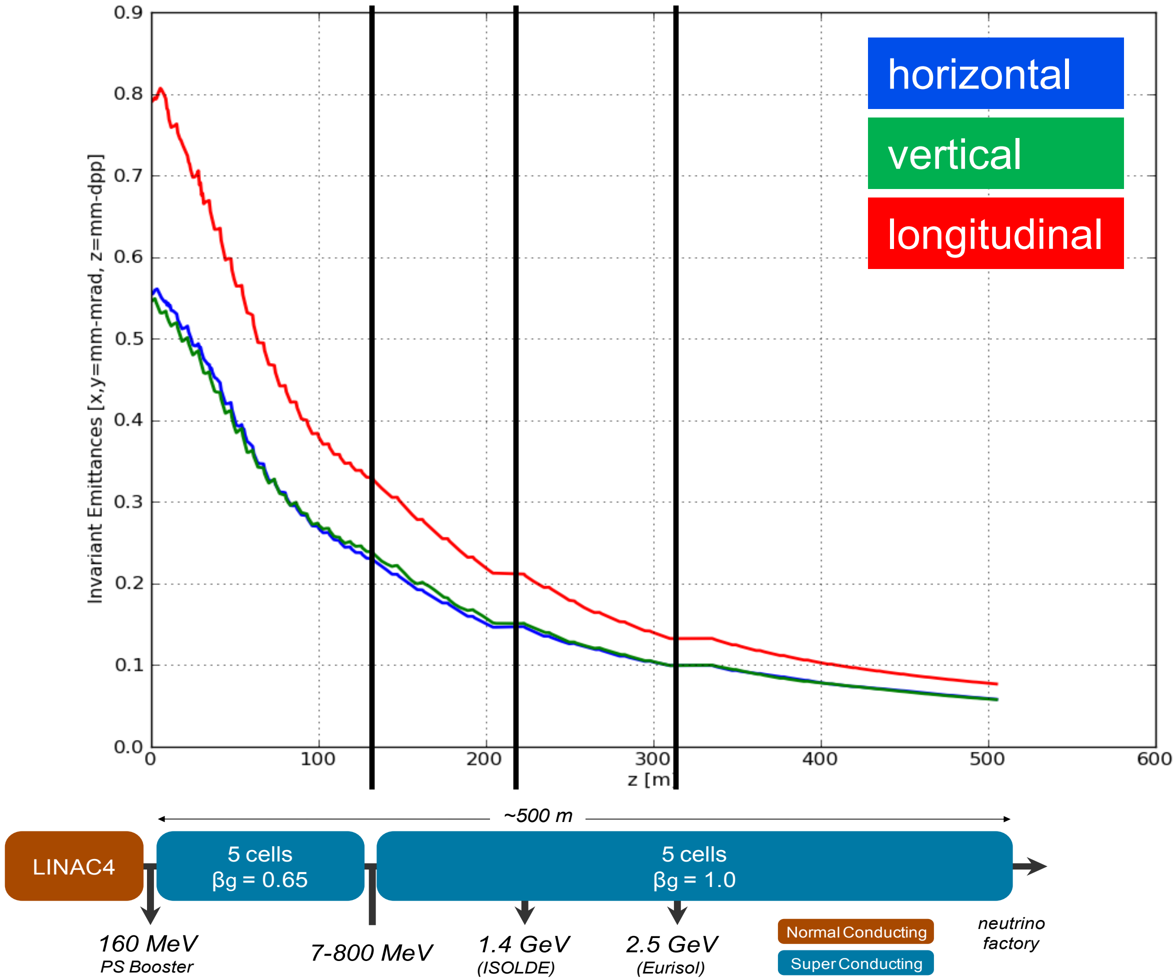
SPL main parameters

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	

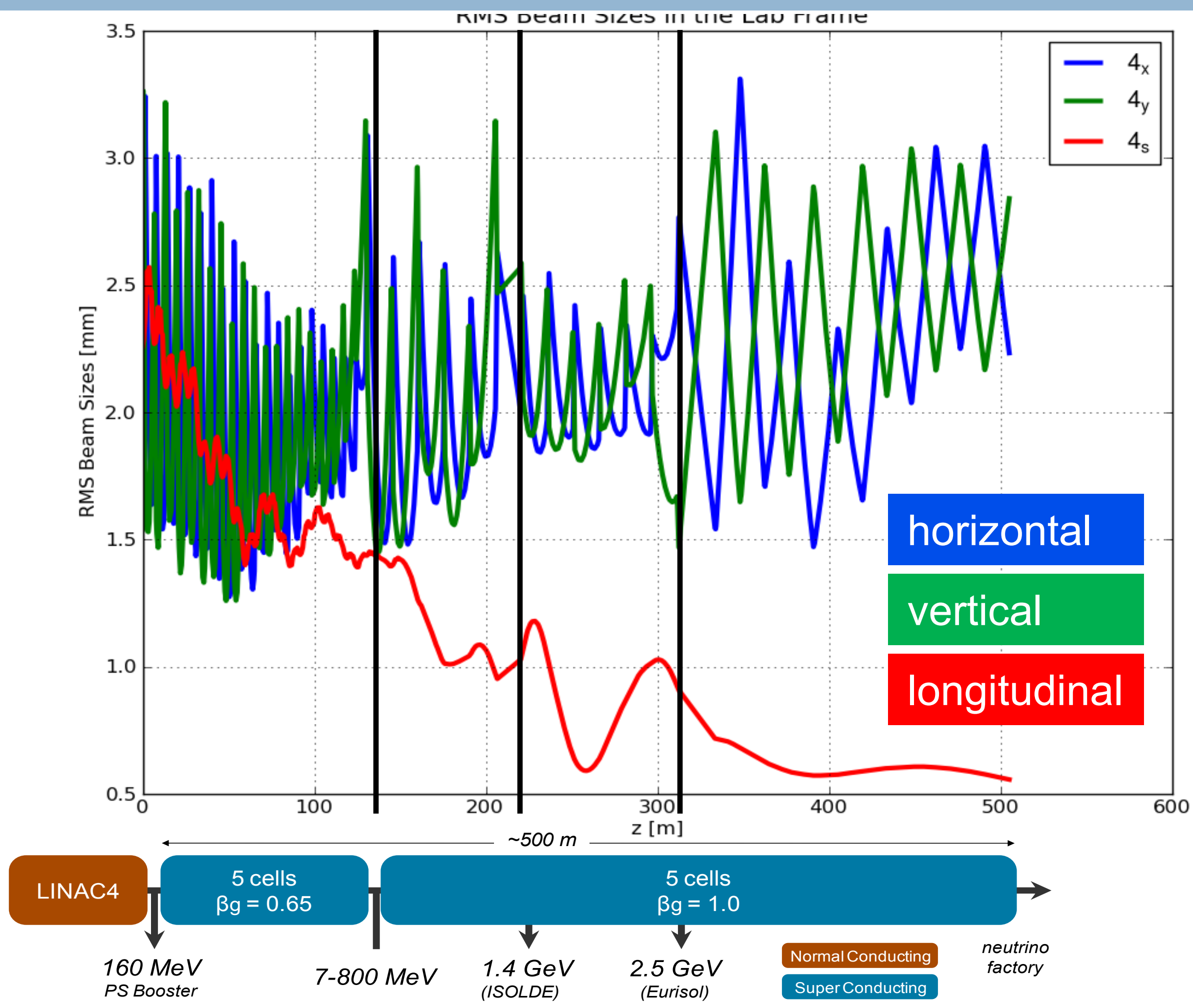
Beta Functions along SPL



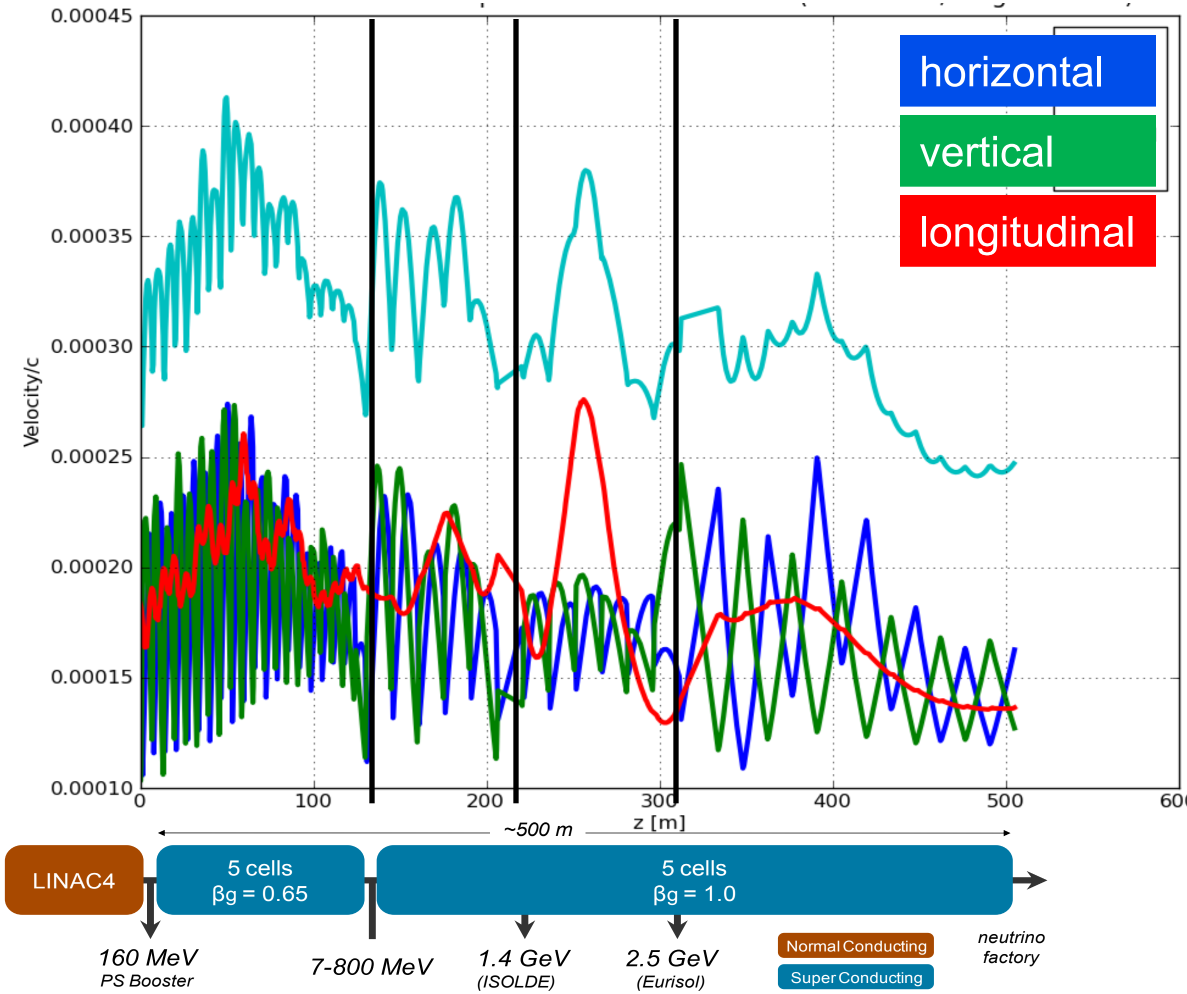
Un-normalized emittances



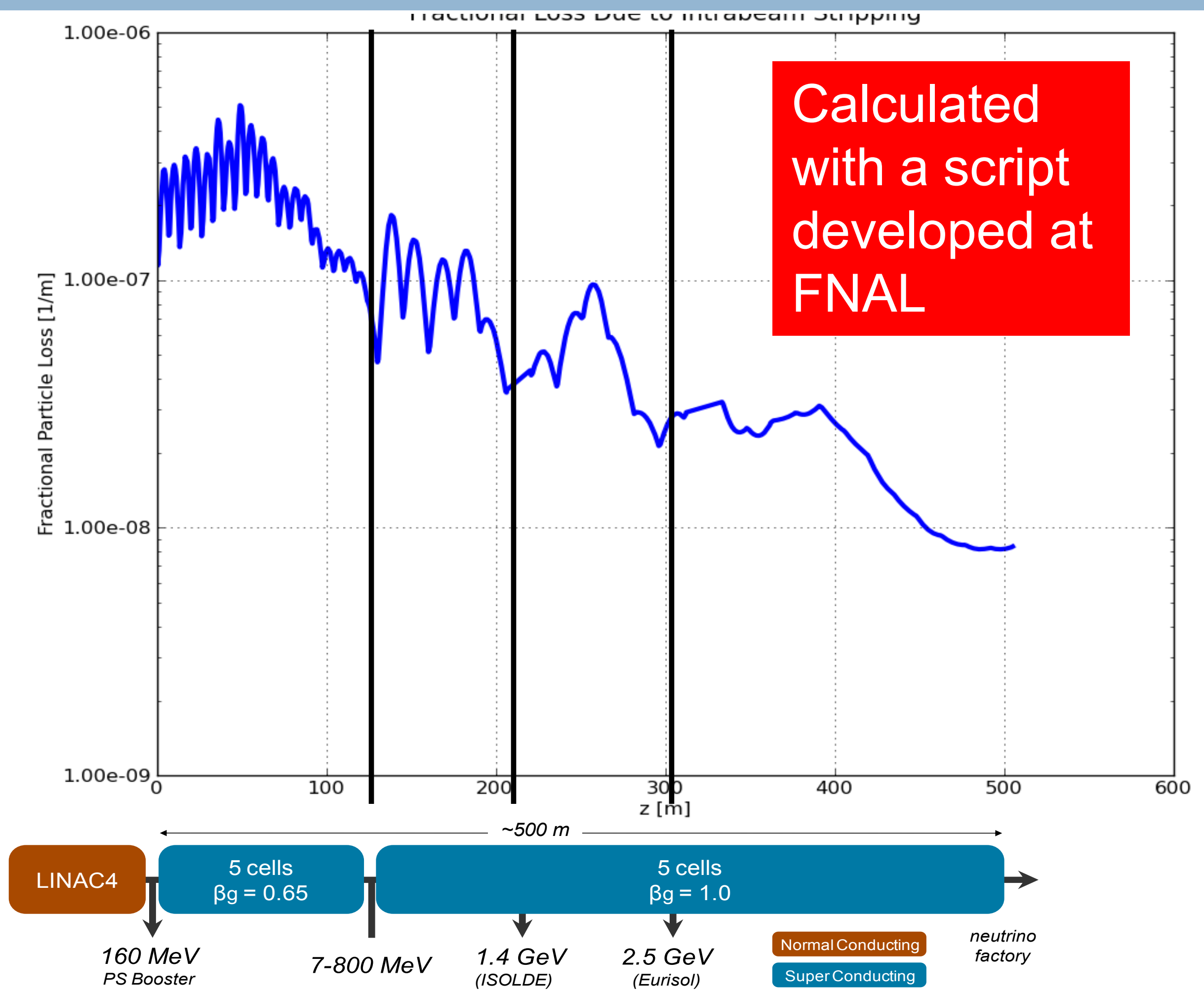
RMS Beam Sizes



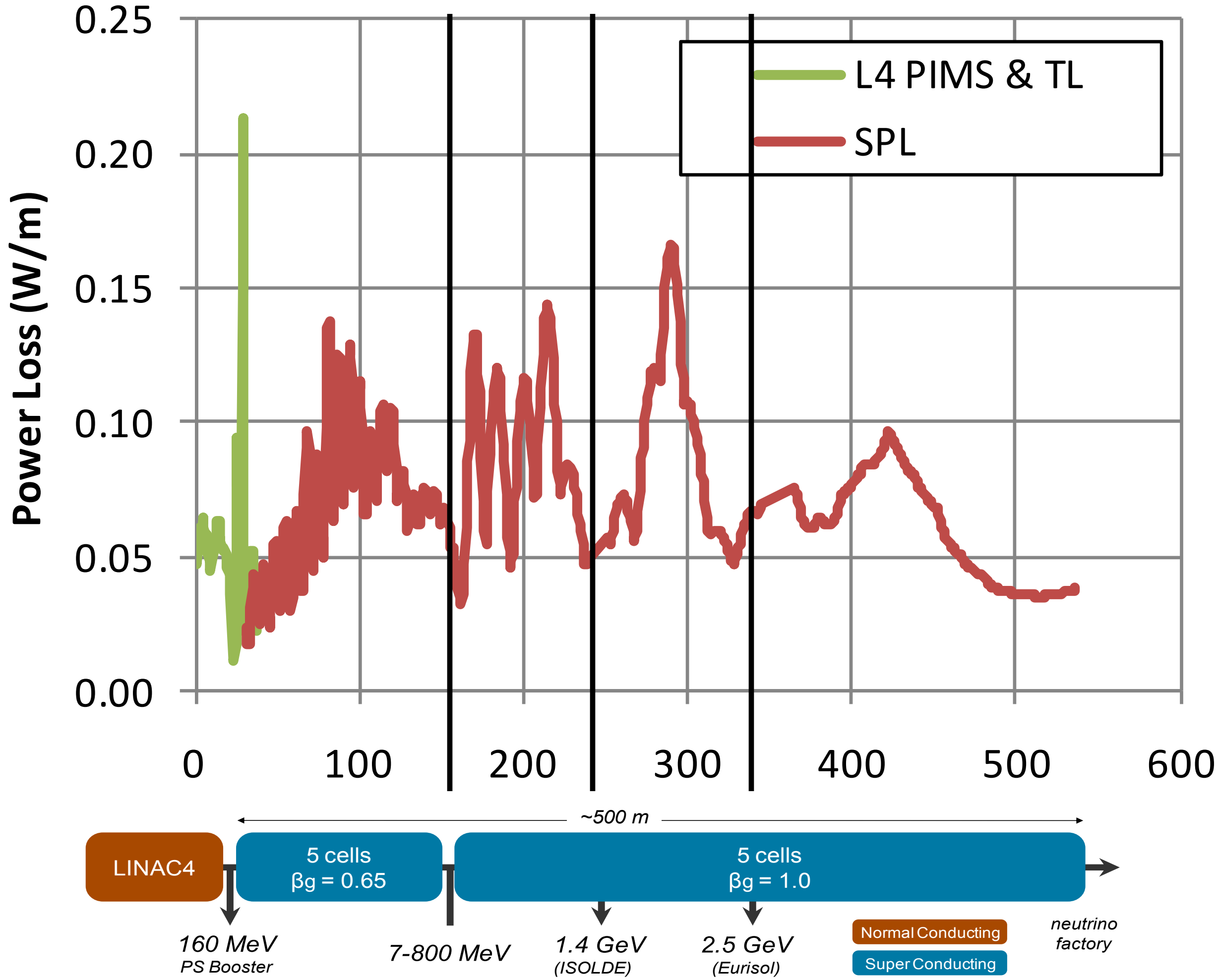
Velocity distributions (beam frame)



Fractional Loss along SPL [3] High Current



Power Loss (High Current)

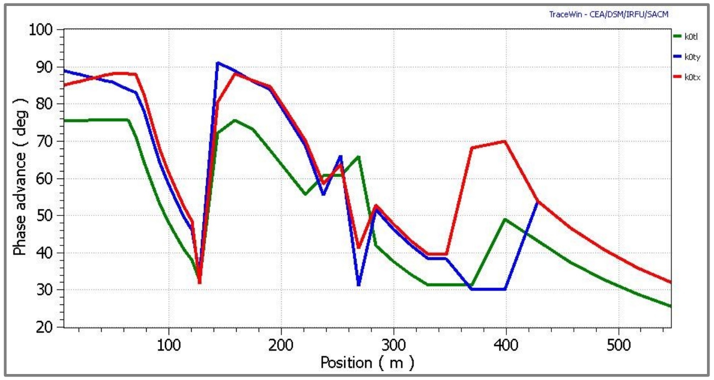


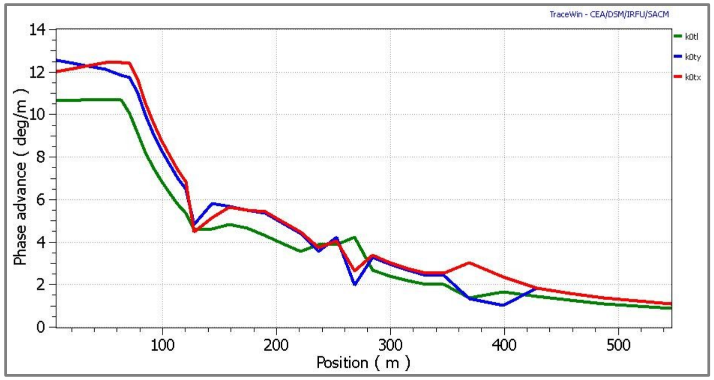
Mitigating the IBS

$$\frac{1}{N}\frac{dN}{ds}=\frac{N\sigma_{\max}\sqrt{\gamma^2\theta_x^{\ 2}+\gamma^2\theta_y^{\ 2}+\theta_s^{\ 2}}}{8\pi^2\sigma_x\sigma_y\sigma_s\gamma^2}F\left(\gamma\theta_x,\gamma\theta_y,\theta_s\right)$$

- Keeping the beam power constant, the power loss is proportional to the bunch peak current
- Reducing the transverse focalization increases the beam size and reduces the velocity spread, but:
  - The transverse phase advance must be higher than the longitudinal one for stability
  - The focalization must compensate at least the cavity defocusing force for every particle in the phase space (space charge has to be included)
- Reducing the longitudinal focalization:
  - Reducing the accelerating gradient / efficiency
  - Reducing the synchronous phase / non linearity
  - Reducing the cavity frequency / general linac design

What can we do for SPL?





Phase advance:
Stability / resonances

Phase advance/m:
matching

Since we don't want losses taking place because of a bd design against the theoretical predictions:

Let's reduce the peak bunch current!
or, in other words,
Let's go for the low-current option!

References

1. V. Lebedev et al. “Intrabeam Stripping in H- linacs”, Proceedings of LINAC-2010, THP080.
2. M. Chanel et al., “Measurement of the H- beam stripping cross section by observing a stored beam in LEAR”, Phys. Lett. B, volume 192, number 3-4, 2 July 1987.
3. F. Ostiguy, private communication.
4. J. Galambos and Y. Zhang, various articles and talks about SNS commissioning and performances.