BBLR studies in the SPS

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Thanks to

G. Burtin, J.-P. Koutchouk, E. Laface and and the SPS team!

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Since 2004, a series of MDs on beam-beam studies has been promoted:

- to demonstrate wire compensation,
- to reproduce, within limits, the LHC beam-beam regime,
- to investigate the beam-beam scenarios for the LHC luminosity upgrade

  and

- to benchmark numerical tools,

earlier than the actual observations in LHC

Similar studies have been pursued also by our BNL colleagues at RHIC with a similar approach.

How can we reproduce the LHC beam-beam effect in SPS?

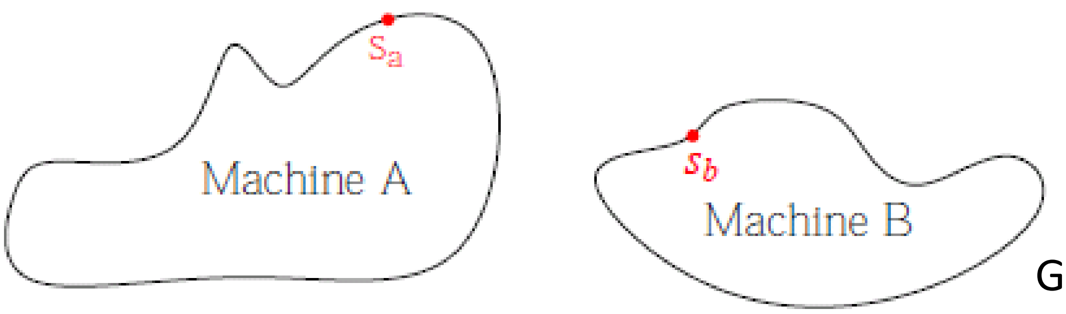
Using two main arguments:

1) equivalence between two non-linear machines,
2) approximation of the electromagnetic field of long-range beam-beam interactions with the magnetic field of a DC wire (valid only in weak-strong approximation),

and discussing all the approximations/limitations of the setup.

1. Equivalence btw two non-linear machines

Two machines, A and B, are equivalent if all particles with same initial conditions in the normalized phase space, Ω, relative to s_a and s_b describe the same trajectory in Ω whatever initial conditions, s_a and s_b.



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E.g.: Two non-linear machines (linear except for a thin non-linear lens in s_a and s_b) are equivalent if they have the same linear parameters (Q's, ξ's, coupling) and

$$\sqrt{\frac{\beta_A}{\varepsilon_A}}\Delta_A x'(x_A, y_A) = \sqrt{\frac{\beta_B}{\varepsilon_B}}\Delta_B x'(x_B, y_B)$$

Time effects have to be rescaled to the machine f_{rev} !

2. Approximation LRBB-wire

If we imagine LHC as a linear machine except 1 long-range beam-beam effect at $n\sigma_{LHC}$ (non-linear thin lens) we can reproduce an equivalent beam dynamics in SPS using a convenient non-linear lens: the wire positioned at $n\sigma_{SPS}$ from the beam using the following scaling law:

$$I_W L_W = \frac{\varepsilon_{n,SPS}}{\varepsilon_{n,LHC}} \cdot qN_b \cdot c$$

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Geometrical condition

Magnetic condition

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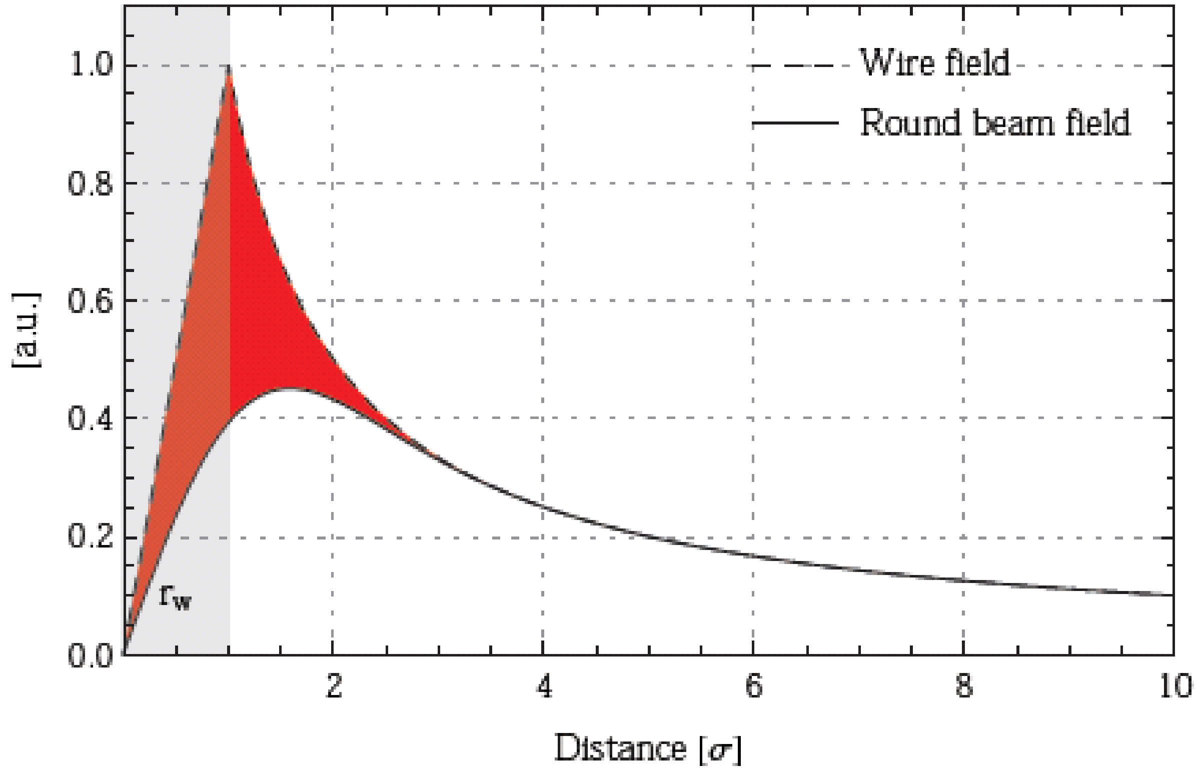

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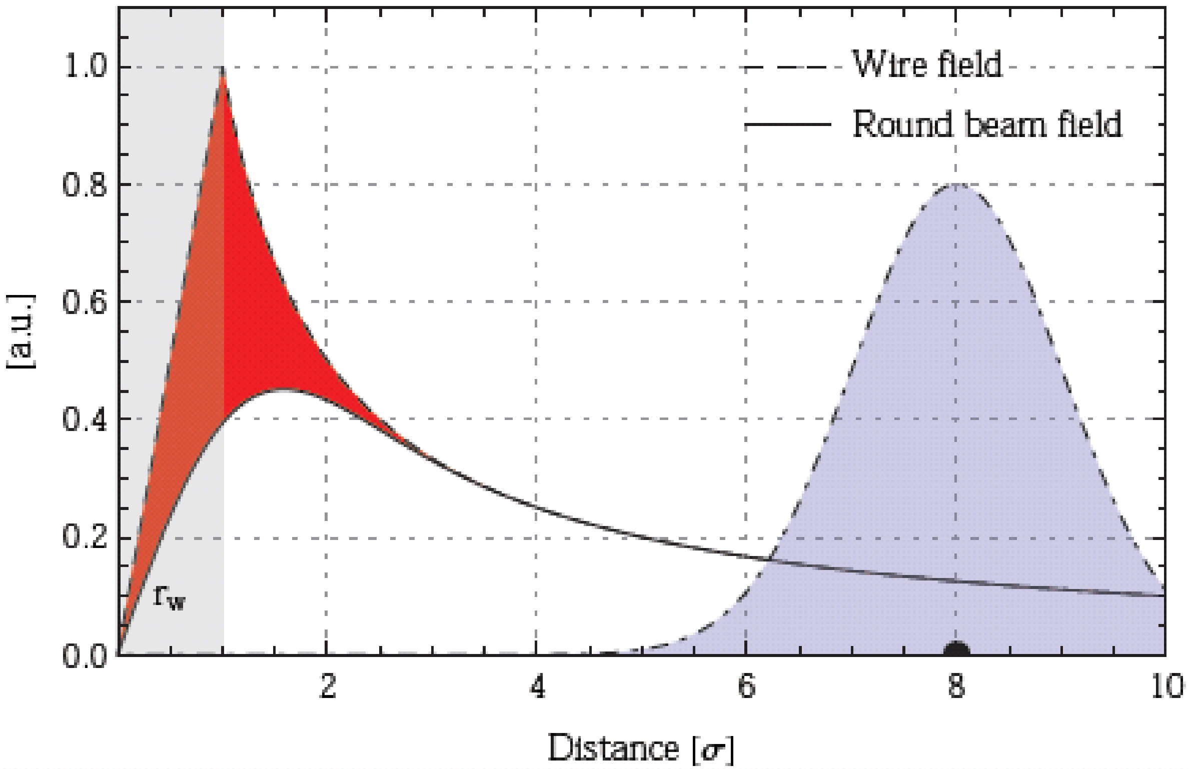

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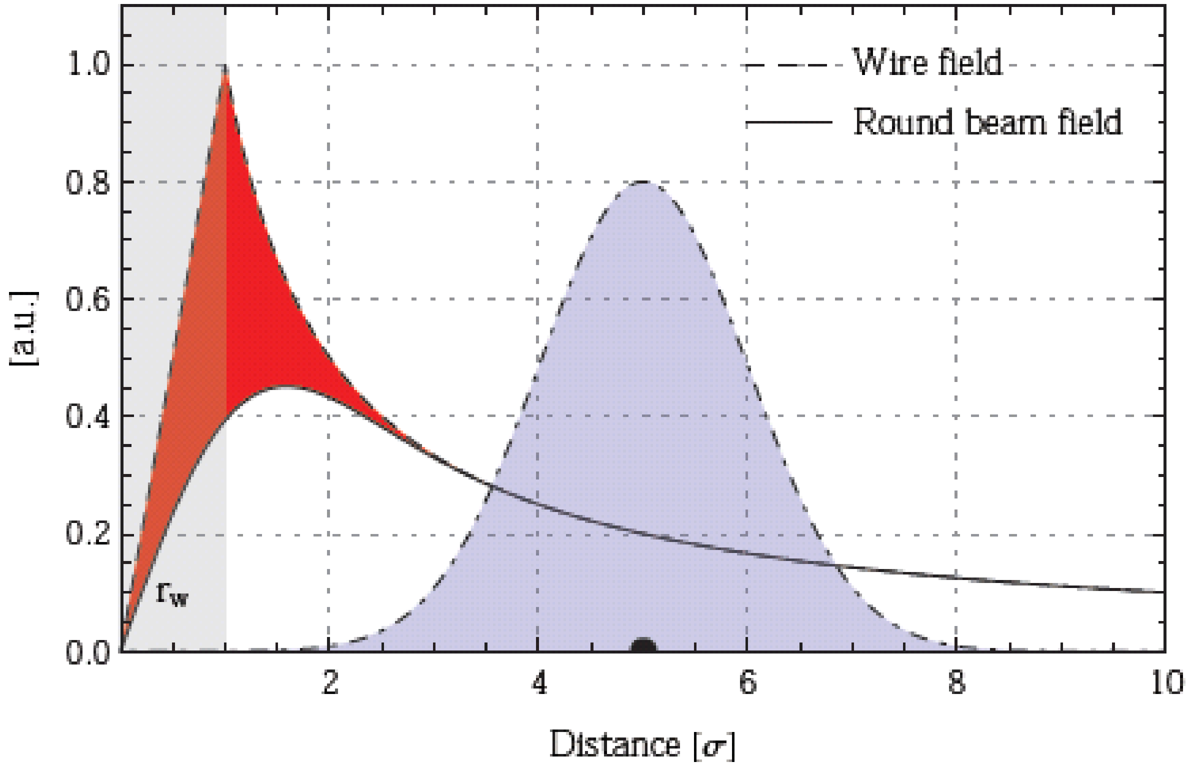

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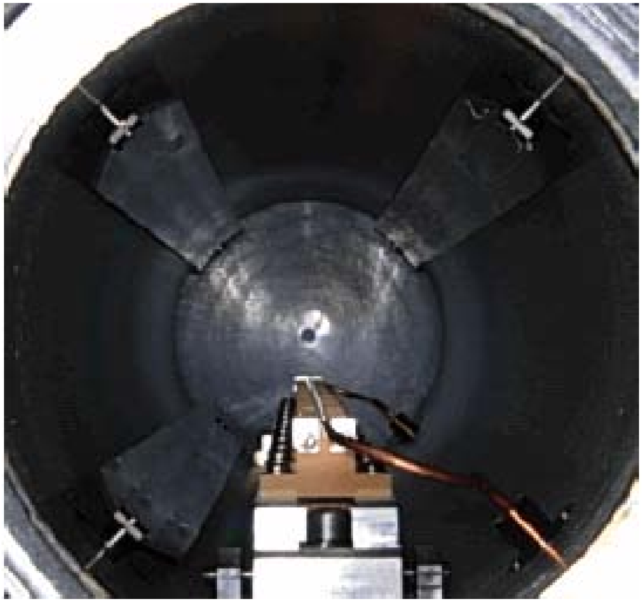
The SPS wires

- In SPS there are 2 families of copper wires that can reach (each) ≈250 A x 1.2 m

- They can be used both to **excite** the beam (I_2 same polarity wrt I_1), or one to excite and the other to **compensate** (I_2 inv. polarity wrt I_1)

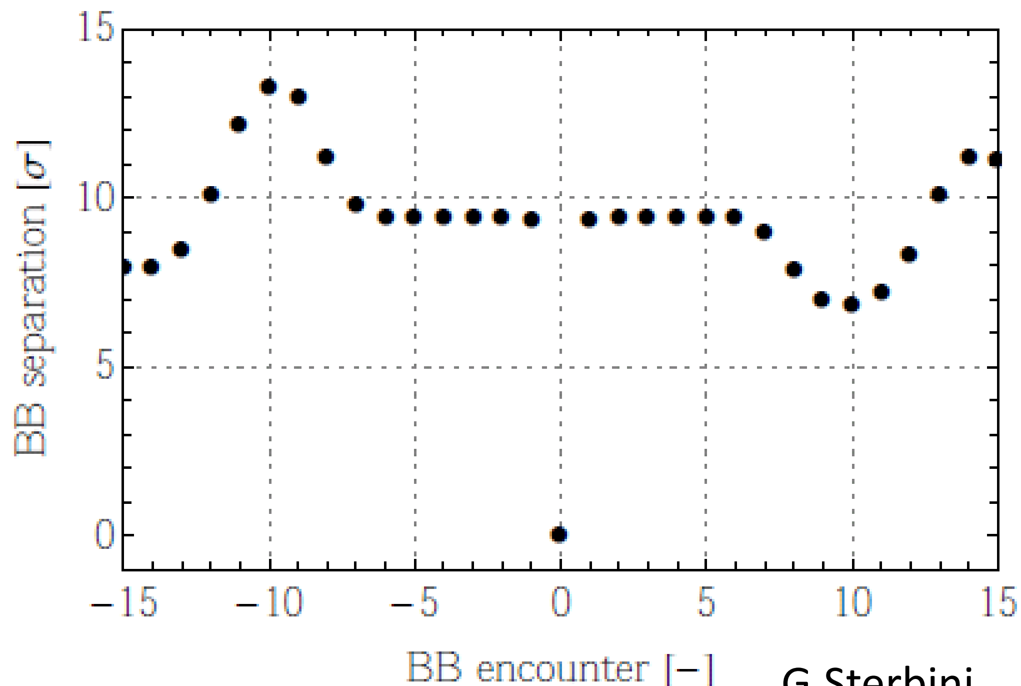
- All wires are (at present) vertical and below the beam

- They do not add exactly in phase ($\Delta\mu \approx 3°$, chosen to reproduce LHC situation)



Additional approximations/limits…

Reproducing an LHC IR in SPS:



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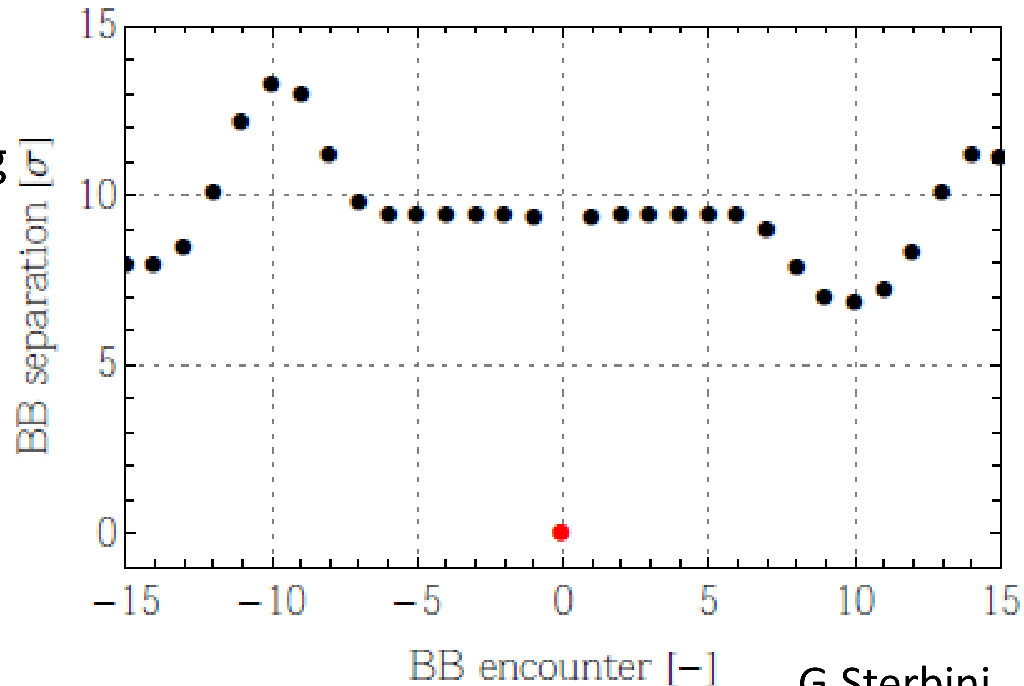
Additional approximations/limits…

Reproducing an LHC IR in SPS:

• No head-on, only vertical crossing



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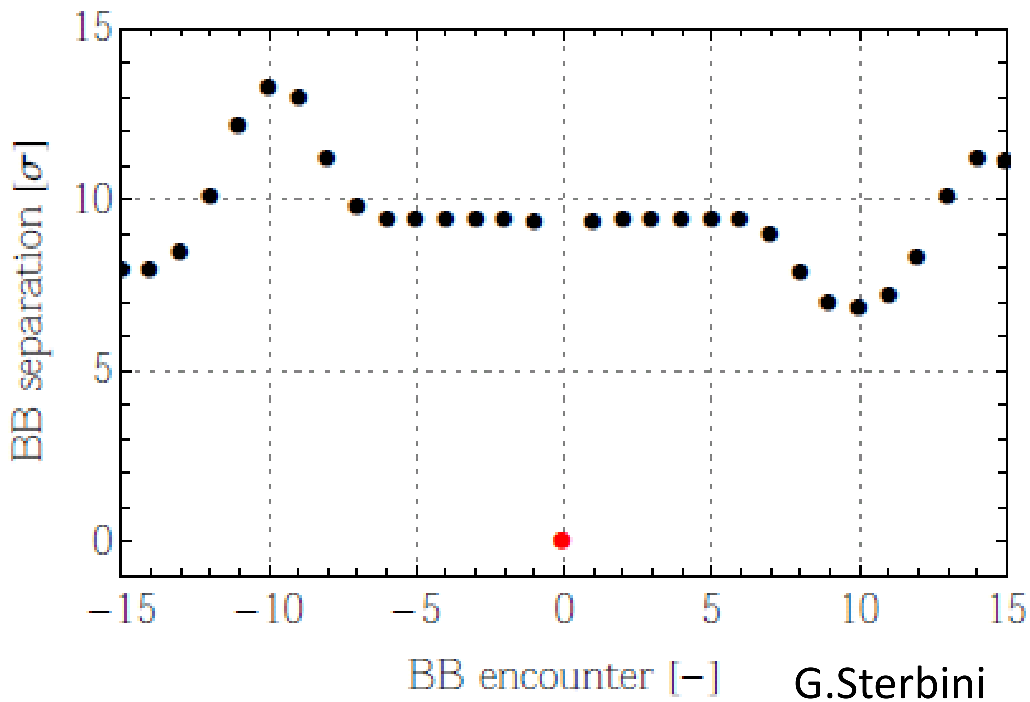
Additional approximations/limits…

Reproducing an LHC IR in SPS:

- No head-on only vertical crossing
- Fixed beam aspect ratio ($\sigma_x = \sigma_y$)



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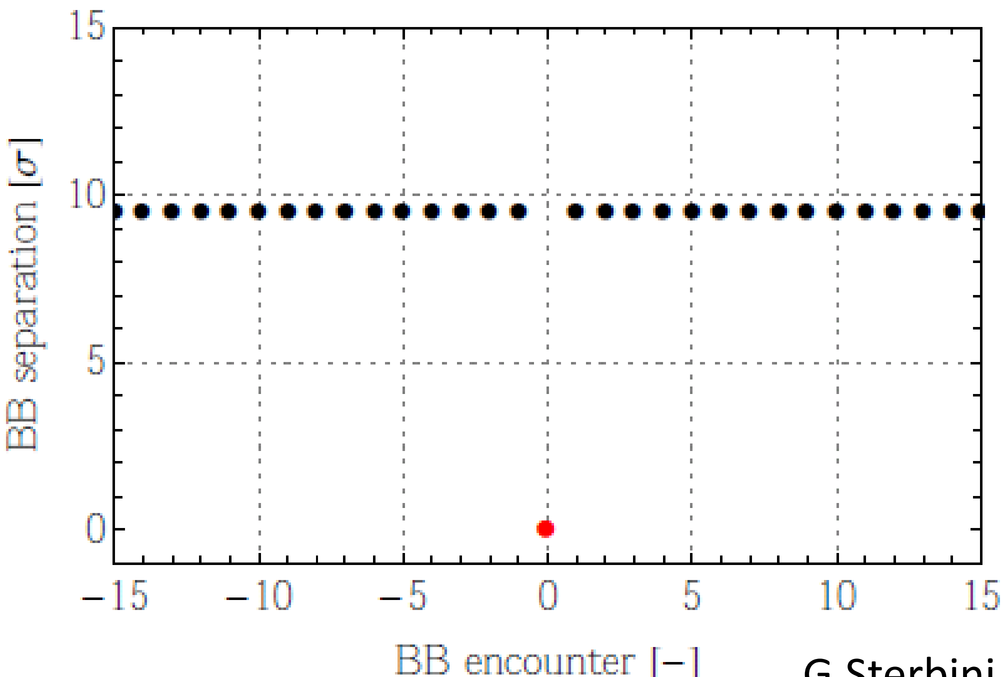
Additional approximations/limits…

Reproducing an LHC IR in SPS:

- No head-on only vertical crossing
- Fixed beam aspect ratio ($\sigma_x = \sigma_y$)
- Constant separation (e.g. 9.5 σ)



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- No head-on only vertical crossing
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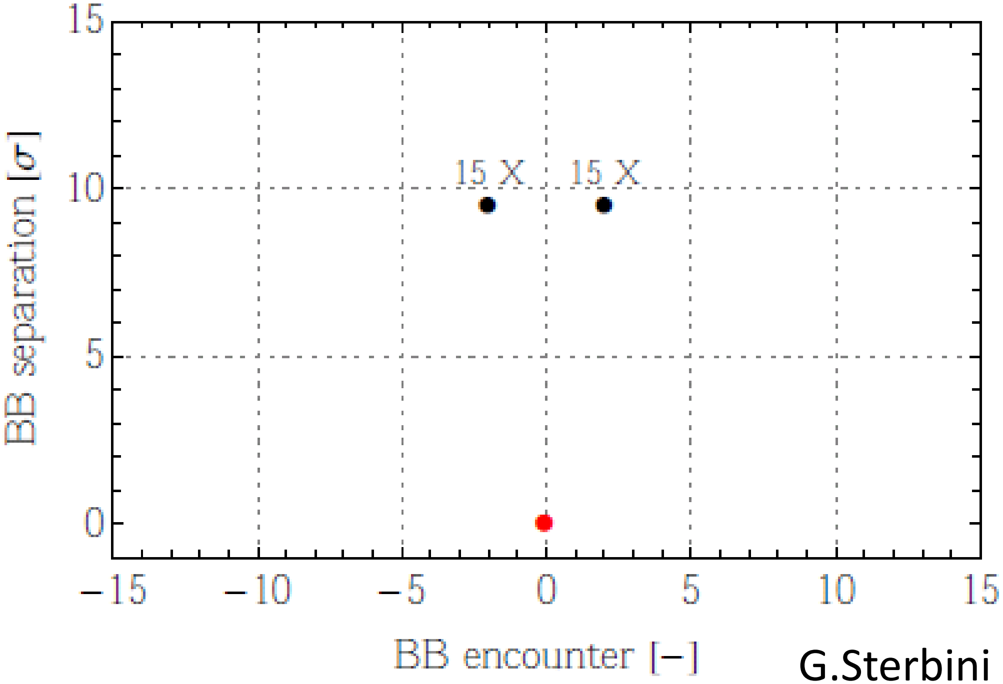
- $\mu \approx 0$ at the LX & RX of the IP



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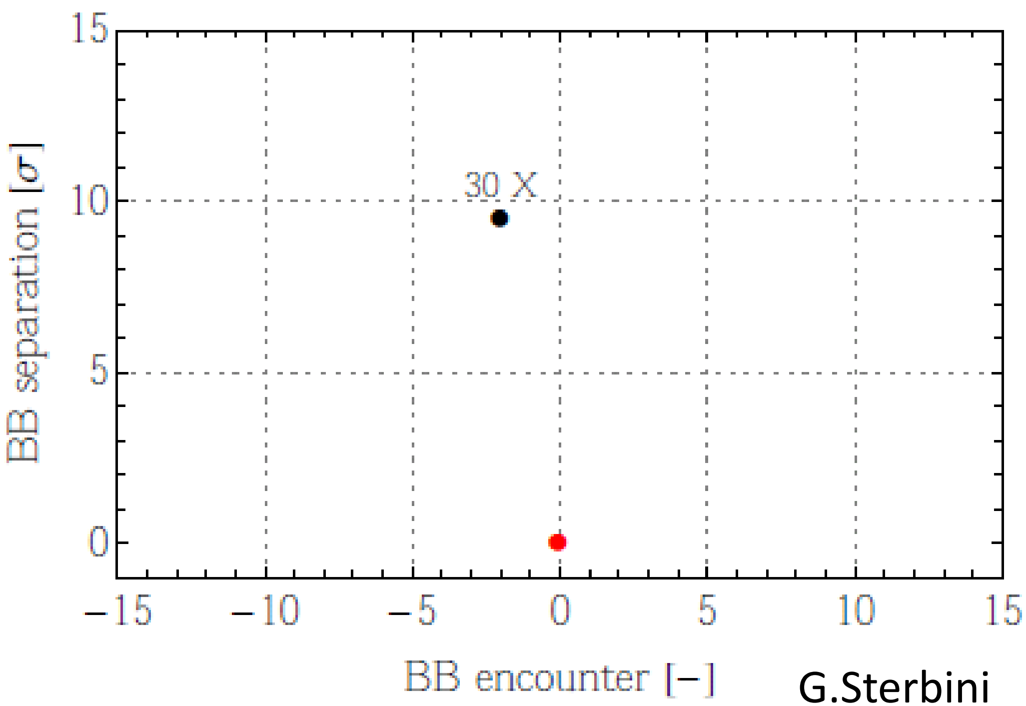

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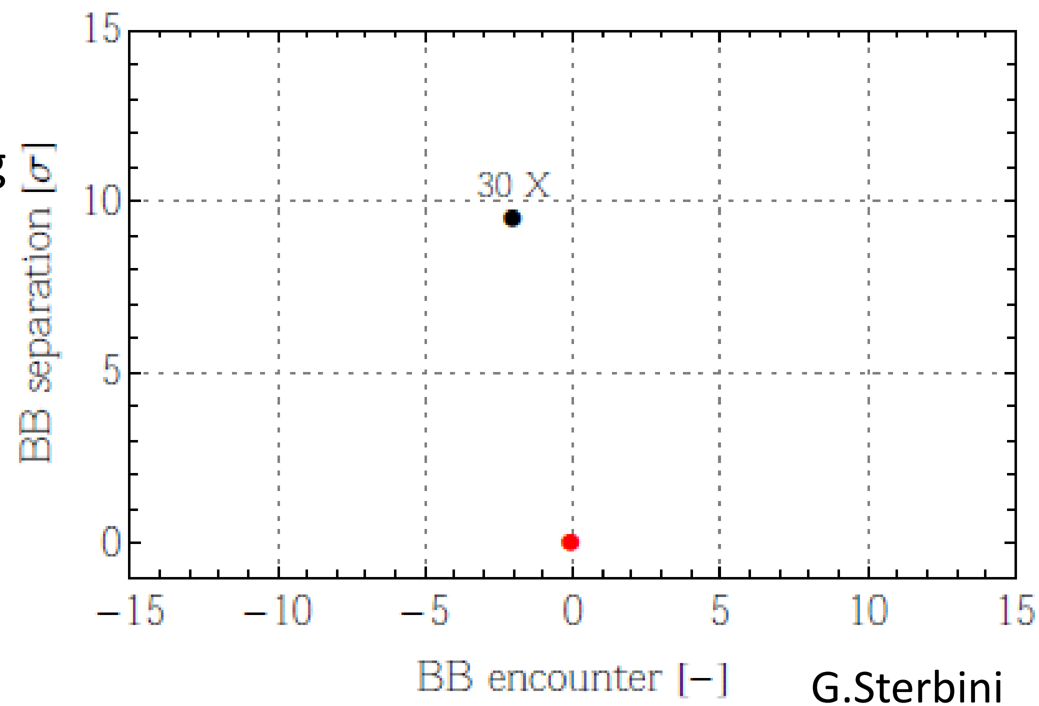

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E.g. to simulate 1 LHC IR (30 BBLRs at nominal bunch current, 9.5 σ_{LHC} separation, $\varepsilon_{n,SPS} = \varepsilon_{n,LHC}$) we need $I_w L_w$ = 168 Am with a wire-beam separation of 9.5 σ_{SPS}.

The players of the game...

- The wire current I_w
- The separation beam-wire in σ_{SPS}
- The SPS normalized emittance $\varepsilon_{n,SPS}$
- The linear parameters of the machine (Q's, ξ's and coupling)
- The beam momentum p is NOT signicant

→Our observable... the beam current decay! Warning!

- We assume that the aperture restriction of the machine (p > 37 GeV/c) is dominated by wire driven DA (not by the MA)
- Since $f_{SPS} \approx 4 f_{LHC}$, we have to rescale all time-dependent quantity (e.g. beam lifetime)
- We assume that the normalized SPS beam distribution is the same of the LHC's one. **This is reasonable only after the transient: coast beam is needed**.

- In past years different beam energies/momenta have been used for the BBLR studies in the SPS: 37 GeV/c (2008), 55 GeV/c (2008 and 2009), 120 GeV/c (2009)

- Before 2010 a SPS cycle with a coast beam at 55 GeV/c was not done (only at 120 GeV/c).

- Working with 120 GeV/c is difficult for several reasons (stiffer beam to bump, controlled blow up needed, lower tune shift (less accurate wire positioning))

- In 2010 was possible to work in coast at 55 GeV/c (in principle better for our purposes)

- We got 1 x 8h + 1 x 5h MDs

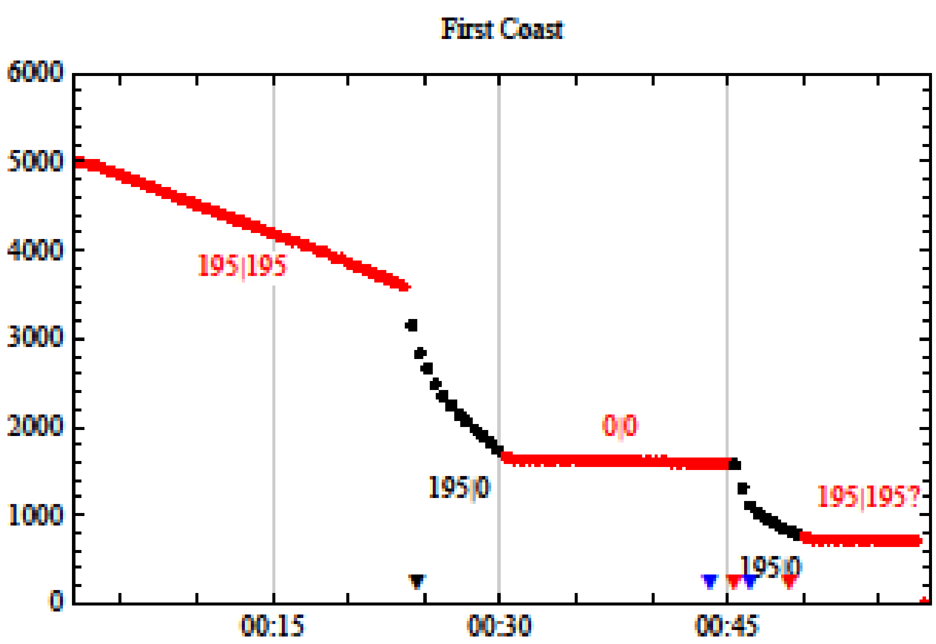
- Main goal was to compare steady state losses at 120 GeV/c and 55 GeV/c

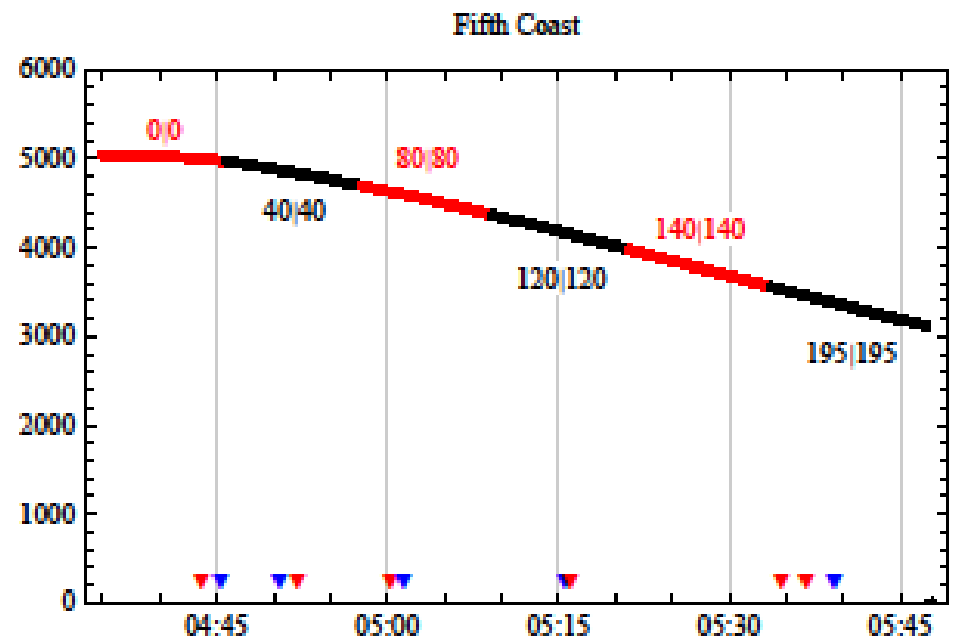
- With the measured emittance we decided to simulate 2 LHC IPs at ultimate intensity (N_b=1.7·10^{11} ppb) → 60 BBLR interactions

- We observed losses even for the situation with both wires off! (around 6% in 15 min.)

- Compensation seems not to work well (much higher losses than expected)

- A significant **emittance growth** was observed (factor 2 in both planes!!!!)





2010 MDs – Results – MD 2

- No compensation mode (expert to move the wires was not available)

- We basically were devoted to measure the emittance growth, also detected by other colleagues in different MDs

- No relevant results for our main goal were achieved

Contents

2010 MDs – Conclusions

• It is **difficult to set properly the distance beam-wire** at this energy → Maybe SPS is not stable enough for BBLR at 55 GeV/c

• For a long time, a **remote control system** for the wire positioning has been requested (no success yet):

- It would ease the positioning and would make it more accurate
- We would not depend on external experts (nights are not the best moment for manpower)

• The emittance growth in SPS should be suppressed as much as possible, since LHC and SPS are not comparable under the conditions observed.

- Come back to 120 GeV/c despite difficulties

- Measure distances of $10\sigma - 11\sigma \rightarrow$ Of interest for some HL-LHC scenarios

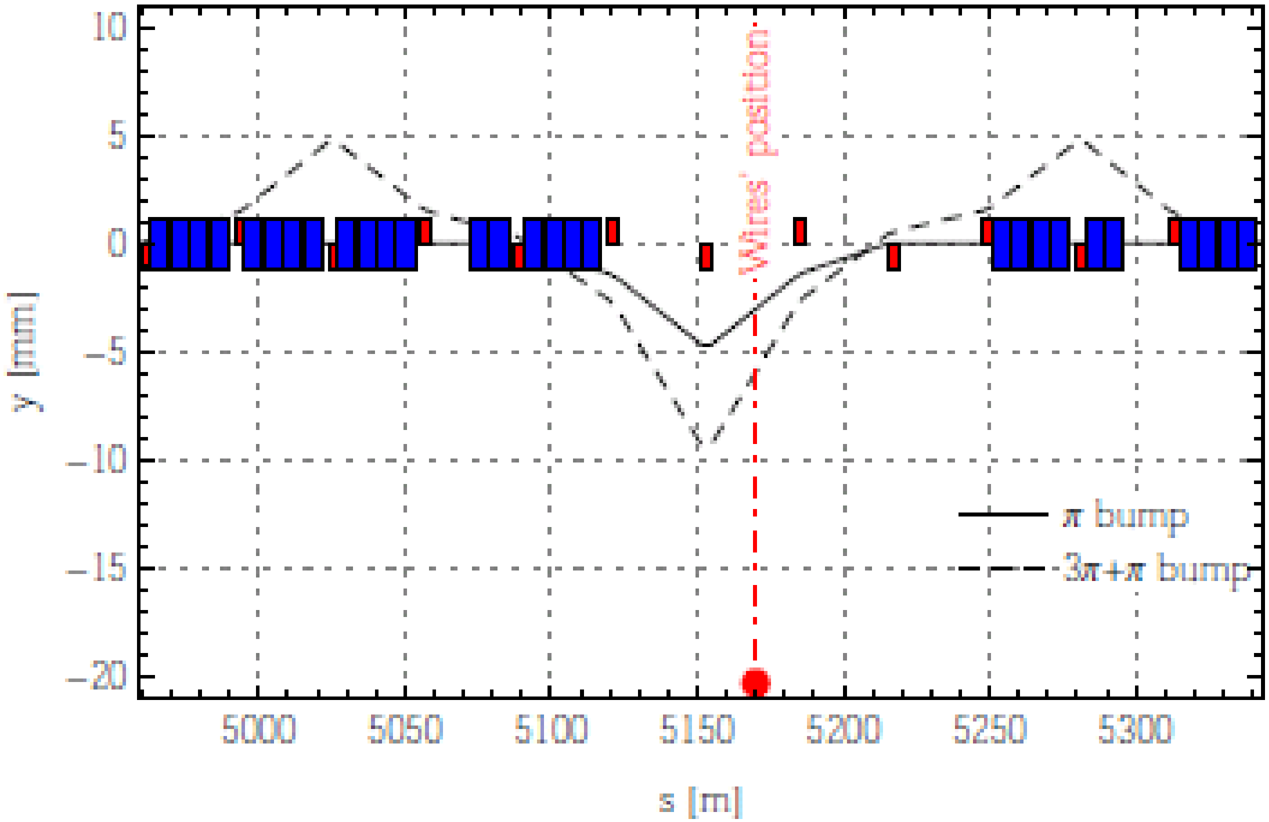
- Main goal: **Wire position scan** to study compensation dependence wrt this parameter and to **reproduce 2009 measurements**

- Problem: We might depend on blow up experts

For the long term future...

RHIC wires are/will be delivered to CERN: to plan an installation strategy in SPS to study, e.g., alternating crossing and optimize the phase advance between IP1 and IP5 (or installation in LHC to compensate the BBLRs).

Thank you for you attention


10
5
0
−5
−10
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−20
y [mm]
5000
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5150
5200
5250
5300
s [m]
Wires' position
π bump
3π+π bump

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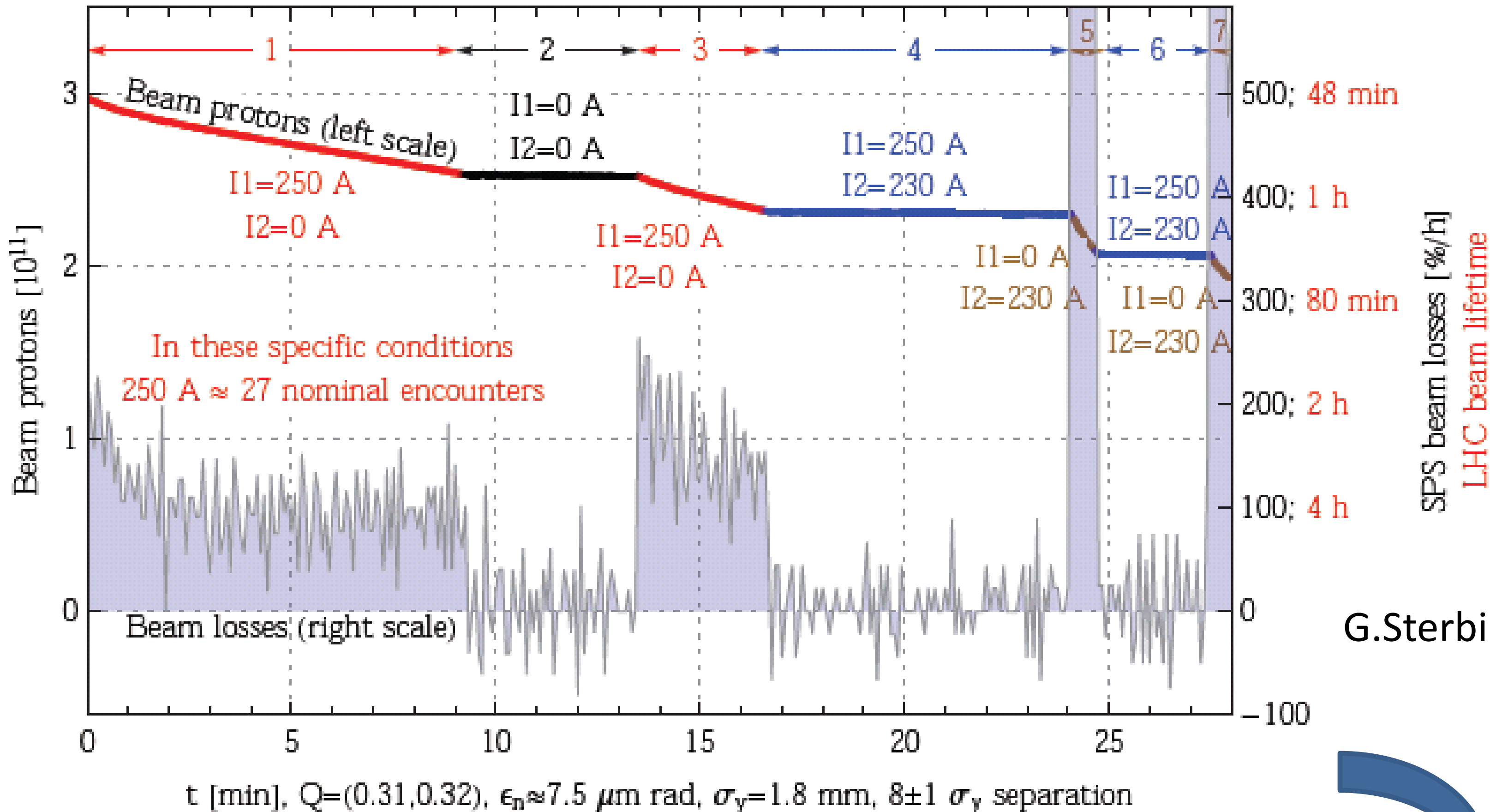
Apendix



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