The RF-separated beams for the M2 beamline: update

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Outline

• What is an RF-separated beam?
• Our strategy
• Optics design
• RF requirements
• 3D integration
• Outlook
RF-separated Beams

Reminder: Panofsky-Schnell-System with two cavities (CERN 68-29)

- Particle species: same momenta but different velocities
- Time-dependent transverse kick by RF cavities in dipole mode
- RF1 kick compensated or amplified by RF2
- Selection of particle species by selection of phase difference
  \[ \Delta \Phi = 2\pi \left( \frac{L f}{c} \right) (\beta_1^{-1} - \beta_2^{-1}) \]
- For large momenta: \[ \beta_1^{-1} - \beta_2^{-1} = \frac{(m_1^2 - m_2^2)}{2p^2} \]
RF-separated Beams - Phases

For $K^\pm$ beams: $\Delta \Phi_{\pi p} = 360^\circ$ and $\Phi_{RF2}$ such that both $\pi$ and $p$ go straight i.e. dumped

$\Delta \Phi_{pK} = 94^\circ$, i.e. a good fraction of $K$ outside the dump, depending on phase at 1st cavity

For $p\bar{p}$ beams: $\Delta \Phi_{\pi p} = 180^\circ$ and then $\Delta \Phi_{p e} = 184^\circ$, $\Delta \Phi_{pK} = 133^\circ$ with phase of RF2 such that pions go straight,

Antiprotons get reasonable deflection, electrons are dumped effectively and $K$ reduced.
Requirements from the existing M2 beam line:
• All elements until Bend1 cannot move because of high radiative doses.
• The bending angles cannot change because of the shape of the tunnel.
Optics design (1)

First work: M2 design with a more flexible software

Transport

Starting point: 2 RF cavities to separate particles
Optics design (2)

<table>
<thead>
<tr>
<th>Distance from the T6 target (m)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Momentum selection at collimator 1</td>
<td>57.98</td>
</tr>
<tr>
<td>1st RF cavity</td>
<td>136.5</td>
</tr>
<tr>
<td>2nd RF cavity</td>
<td>862.5</td>
</tr>
</tbody>
</table>

L = 726 m, which gives a frequency ≈ 5 GHz
Optics design (3)

At collimator 1:
• Focus
• Beam size sufficiently small
• But, no large dispersion

Add a new quadrupole before Q7 to increase the dispersion
Strategy

A) Rely on the user requirements and the former studies:
   • Momentum of the wanted particles
   • Phase difference (selection of particles)
   • Frequency
     → Distance between cavities

B) Discussion with the RF group
RF equipment requirements (1)

For example: \( f = 5 \text{ GHz} \)

**Beam spot requirements:**

- RF wavelength \( \lambda = \frac{c}{f} = 3 \times 10^{10} \text{ cm s}^{-1} / 3.9 \times 10^9 \text{ s}^{-1} = 6 \text{ cm} \)
- Coherence length ("phase is sufficiently preserved", \( \Delta \phi \approx \pi/10 \))
  \[
  L_{coh} \approx \lambda \cdot (\pi/10) / (2\pi) \approx 3 \text{ mm}
  \]
  Beam spot has to remain within \( \pm 1 \text{ mm} \) throughout the cavity.

**Requirements on divergence:**

- \( p_t \)-kick 15 MeV/c (see CKM system), i.e. 0.15 mrad at 100 GeV
- Beam divergence must be smaller than this in the bending plane
- Non-bending plane: sufficiently small divergence, e.g. \( \pm 0.5 \text{ mrad} \)
  RF system limits transverse emittance.
RF equipment requirements (2)

Requirements on the momentum dispersion in the RF cavities:
\[ \Delta \Phi_{\text{final}} = \Delta \Phi_{\text{initial}} \left( 1 - 2 \frac{\Delta p}{p} \right) \]

It limits \( \frac{\Delta p}{p} \) to about 1\%.

If the phase difference \( \Delta \phi_{\text{final}} \) is too high, then the momentum dispersion becomes large!

\[ \text{Graph showing the relationship between } \Delta \phi \text{ and } p \text{ at } 16 \text{ GeV/c and } 90^\circ. \]
Crab cavities example

Currently available technology at CERN: Crab Cavities for LIU SPS upgrade (400 MHz superconducting dipole cavities)

Assume availability of $L=800\text{m}$:

<table>
<thead>
<tr>
<th>RF frequency</th>
<th>Limit $p(K)$</th>
<th>Limit $p(p\bar{p})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 MHz</td>
<td>20 GeV/c</td>
<td>30 GeV/c</td>
</tr>
<tr>
<td>1.3 GHz</td>
<td>37 GeV/c</td>
<td>55 GeV/c</td>
</tr>
<tr>
<td>5 GHz</td>
<td>72 GeV/c</td>
<td>102 GeV/c</td>
</tr>
</tbody>
</table>

Conclusion: crab cavity design so far not compatible with user requirements, new developments necessary.
3D integration of the tunnel

- Define the RF equipment requirements
- Design the optics of the new beam
- Make the infrastructure and integration
- Determine the total cost

2D plan

3D plan

• Add 3D drawing of the future experiment?
Outlook

• There is a strong correlation between RF requirements and optics design.

• In order to address the requirements, some optimisations in the optics design have to be done: add quadrupoles, move the location of collimators, maybe add an achromat for better momentum selection.

• These changes have to be taken into account in the cost estimate and scheduling as well as the R&D of the RF system.

• The next round of discussions with the RF group is expected soon.

• The 3D integration of the EHN2 tunnel will be done during the next month.

• A dedicated study for the required beam instrumentation will start end of this year.
Thanks!