Simulation Tools for Heavy-Ion Collimation

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Ion collimation - why think about it ?

- Stored beam energy in the LHC for protons and ions

$$E_{\text{tot}}^{p}/E_{\text{tot}}^{Pb} \approx 100$$

- Collimation system provides excellent cleaning for protons - why should ion collimation be critical ?

Introduction

Ion collimation - why think about it ?

- Stored beam energy in the LHC for protons and ions

$$E^{p}_{\text{tot}}/E^{Pb}_{\text{tot}} \approx 100$$

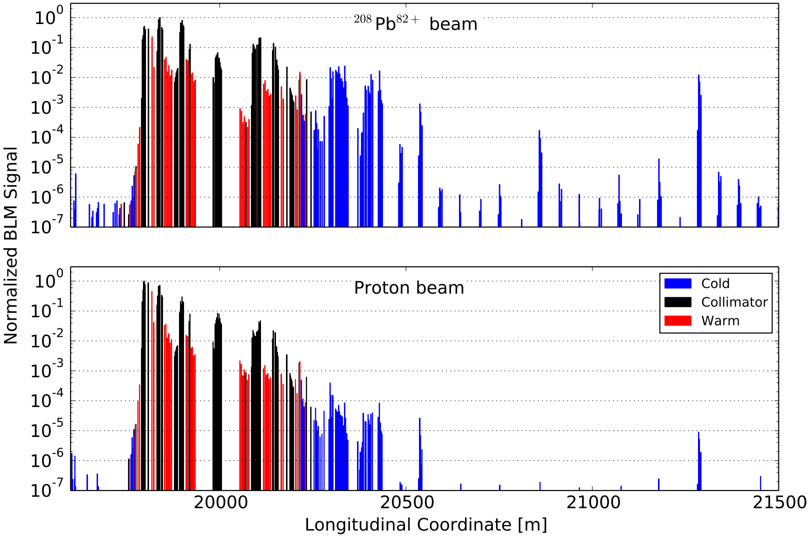
- Collimation system provides excellent cleaning for protons - why should ion collimation be critical ?
- Ion cleaning is much less efficient than proton cleaning

$$\eta_{Pb}/\eta_{p} \approx 100$$

- Quenches might also be caused by ion cleaning losses !

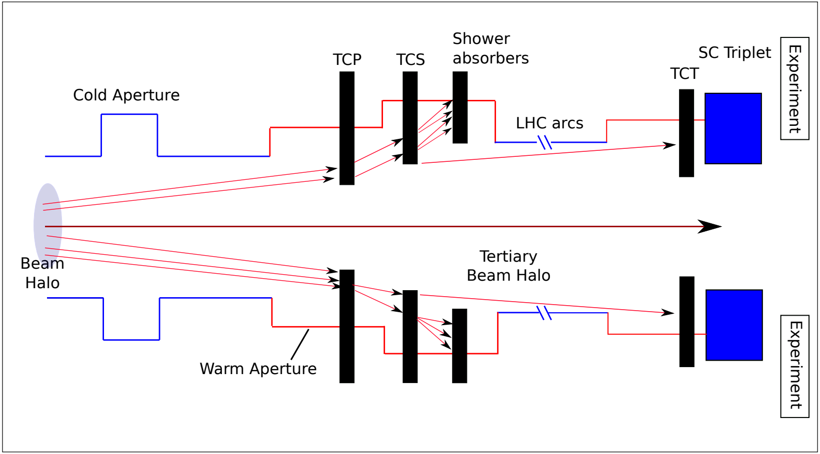
Introduction

Proton vs. Ion losses



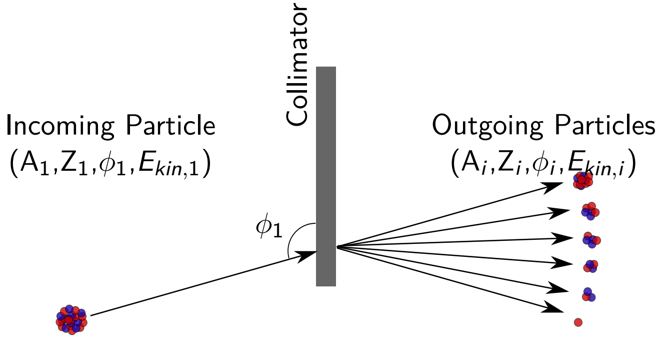
Introduction

The LHC Collimation system - protons



Introduction

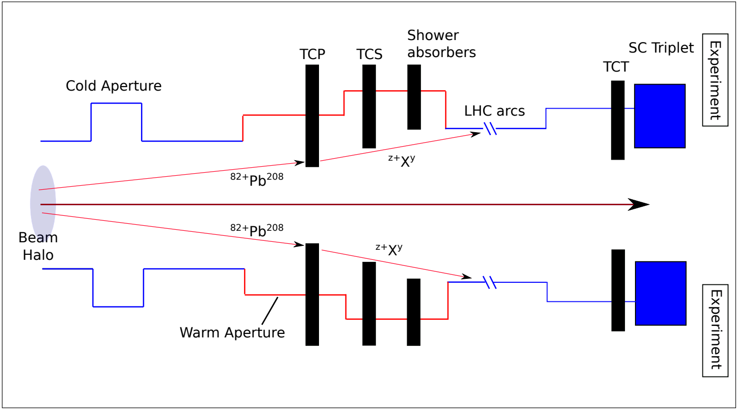
Ion Fragmentation



- Ions are subject to fragmentation into other isotopes with different mass to charge ratio
- Often they are not scattered into the secondary collimators

Introduction

The LHC Collimation system - ions



- Ions are subject to fragmentation
- Many heavy-ion fragments are not scattered enough
- Many end up in the arcs where the dispersion increases !

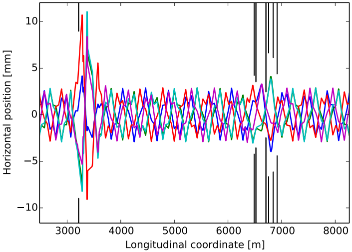
Simulation tools for ion collimation

The key ingredients for ion collimation simulation

Simulation tools for ion collimation

The key ingredients for ion collimation simulation

Appropriate Tracking



- Chromatic effects
- Mass to charge ratio of different isotopes

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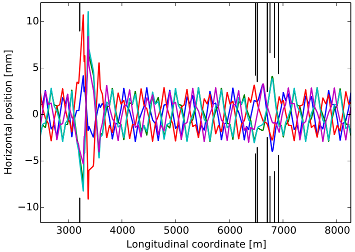

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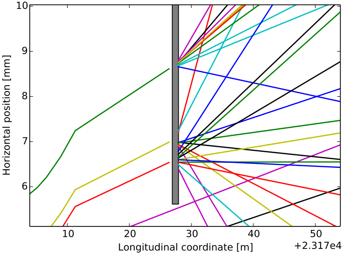
Fragmentation Simulation



- Species, momentum, direction of in- and outcoming ions

Simulation tools for ion collimation

History

2008 ICOSIM (Ion COllimation SIMulation)

- Linear chromatic tracking
- Simplified fragmentation at all collimators
- Good agreement with measurements, especially in DS

2014 STIER (SixTrack with Ion-Equivalent Rigidities)

- SixTrack : Chromatic tracking up to 20^{th} order
- Detailed fragmentation at TCP only
- Better agreement with measurement in arc and DS

2015 hiSix (heavy-ion SixTrack)

- Chromatic tracking up to 20^{th} order
- SixTrack-FLUKA coupling adopted for ions : detailed fragmentation at all collimators
- Test phase - we hope for even better agreement with data

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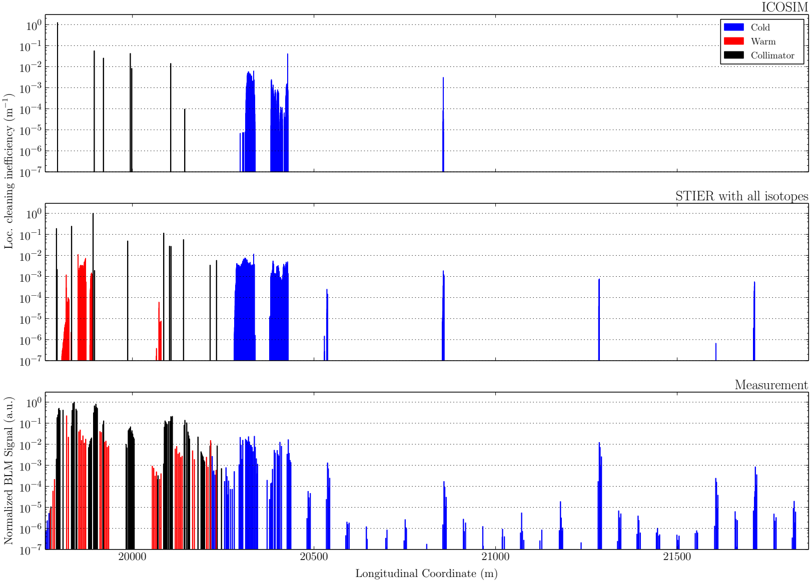
Simulated vs. Measured Loss Maps



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The key ingredients for ion collimation simulation

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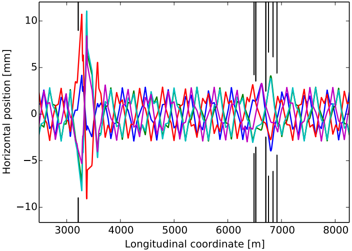
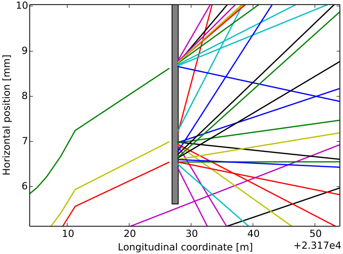


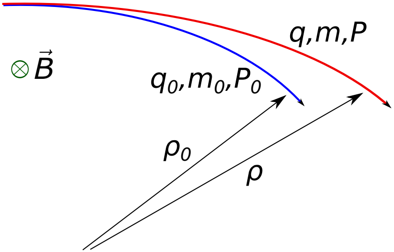
Fragmentation Simulation



What has changed from STIER to hiSix?

Heavy-Ion Tracking

Chromatic and isotopic dispersion



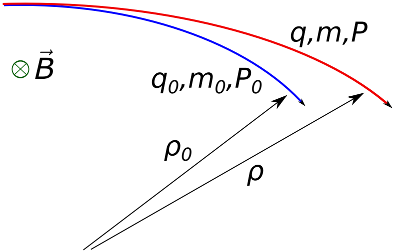
Magnetic Rigidity

$$\boxed{B\rho = \frac{P}{q}}$$

$$P = m\beta\gamma$$

Heavy-Ion Tracking

Chromatic and isotopic dispersion



Magnetic Rigidity

$$B\rho = \frac{P}{q}$$

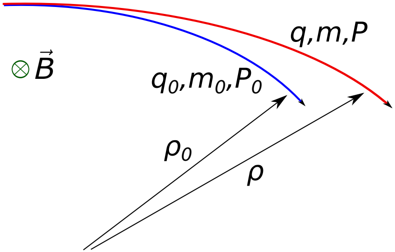
$$P = m\beta\gamma$$

- Momentum offset in mono-isotopic case $m = m_0$, $q = q_0$:

$$\frac{\rho}{\rho_0} = \frac{\beta\gamma}{\beta_0\gamma_0} = (1+\delta) \qquad \delta = \frac{\beta\gamma - \beta_0\gamma_0}{\beta_0\gamma_0} = \frac{P - P_0}{P_0}$$

Heavy-Ion Tracking

Chromatic and isotopic dispersion



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- If different isotopes $m \neq m_0$, $q \neq q_0$ are in the machine

$$\frac{\rho}{\rho_0} = \frac{q_0}{q}\frac{m}{m_0}\frac{\beta\gamma}{\beta_0\gamma_0} = \frac{(1+\delta)}{\chi} \qquad \delta = \frac{\beta\gamma - \beta_0\gamma_0}{\beta_0\gamma_0} = \frac{P\frac{m_0}{m} - P_0}{P_0}$$

Implementation of the isotopic dispersion - STIER

Ion Equations

$$\frac{\rho}{\rho_0} = \frac{(1+\delta)}{\chi}$$

$$\delta = \frac{P\frac{m_0}{m} - P_0}{P_0}$$

$$\chi = \frac{q}{q_0}\frac{m_0}{m}$$

How can we implement this ?

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How can we implement this ?

Effective Momentum Approach

- Track particles of the reference species, but use ion equivalent rigidities by applying

$$\delta_{\text{eff}} = \frac{1+\delta}{\chi} - 1$$

- Advantage : quick and simple approach
- No need to change tracking maps only the initial distribution

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$$\delta_{\text{eff}} = \frac{1+\delta}{\chi} - 1$$

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- No need to change tracking maps only the initial distribution
- Only applicable to magnetic lattice elements, no cavities etc.
- Used in STIER (SixTrack with Ion Equivalent Rigidities)

Implementation of the isotopic dispersion - hiSix

Ion Equations

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How can we implement this ?

New accelerator Hamiltonian

- Re-define accelerator Hamiltonian : incorporate new definition of δ, χ

$$H = -\sqrt{(1+\delta)^2 - (\tilde{p}_x - \chi a_x)^2 - (\tilde{p}_y - \chi a_y)^2} - \chi a_z$$

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- Derive symplectic tracking maps ; e.g. p_x for transverse kicker dipole :

$$p_x^f \rightarrow p_x^i - \chi\, k_0\, L$$

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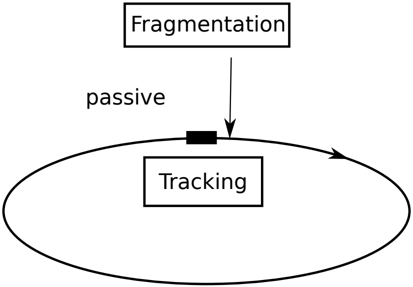
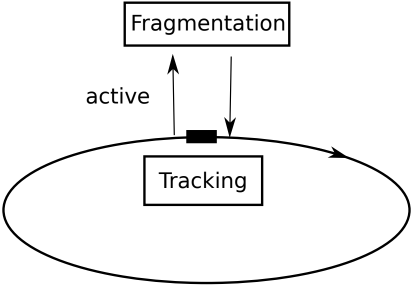
- Universal : applicable to all beam line elements
- All tracking maps must be re-derived
- Implemented in hiSix

Fragmentation Simulation in STIER



- Passive coupling : Initial fragmentation simulation (e.g. at the TCP) and tracking without interactions at other collimators
- Can be done with two separate runs of FLUKA and SixTrack
- Used in STIER to track ion fragments from the TCP

Fragmentation Simulation in hiSix



- Active coupling : particles sent to Monte Carlo software at every collimator location, fragments sent back to tracker
- Available framework : SixTrack-FLUKA coupling (protons)
- Used for hiSix in an ion-adapted framework

Heavy-Ion SixTrack

Summary

- Aim : Make SixTrack accessible for heavy-ion tracking and collimation studies

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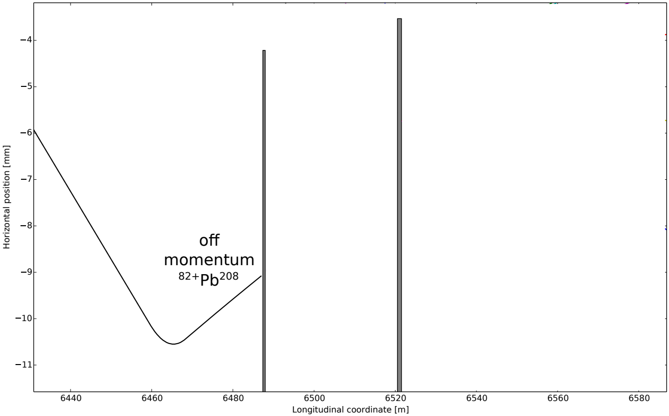
- Modify SixTrack-FLUKA coupling simulates fragmentation and sends back ion fragments to the tracker $\rightarrow$ implemented
- Still in beta phase, tests ongoing to check tracking behaviour, fragmentation, loss map generation ...
- We hope for better agreement with measured loss maps compared to ICOSIM and STIER

Joint tracking and fragmentation in hiSix



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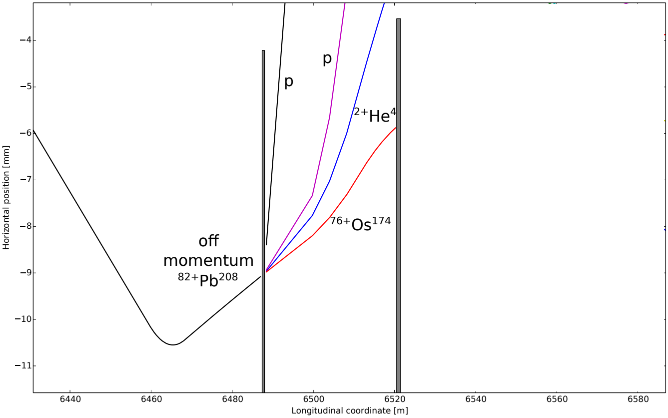

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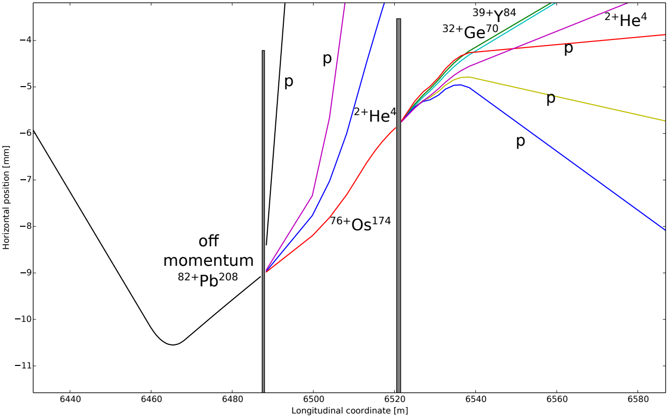

Summary and Outlook

- Fragmentation : Ion collimation efficiency worse than for p
- Simulation requires appropriate implementation of tracking and fragmentation
- Former software with simplified tracking and/or fragmentation modelling
- Presently developed heavy-ion SixTrack expected to provide better agreement with measured data
- First loss map simulations expected soon