Delivery Ring

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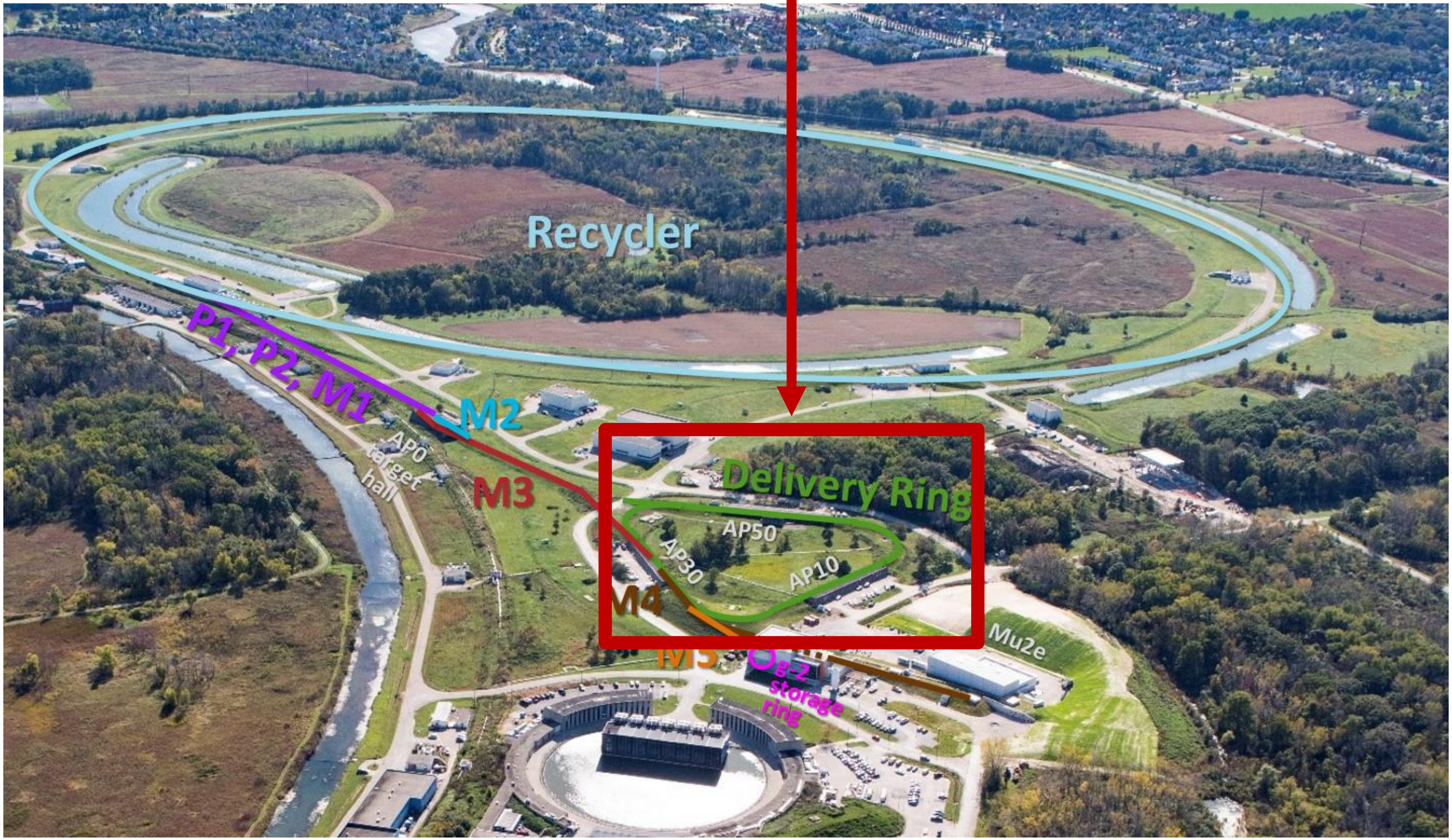
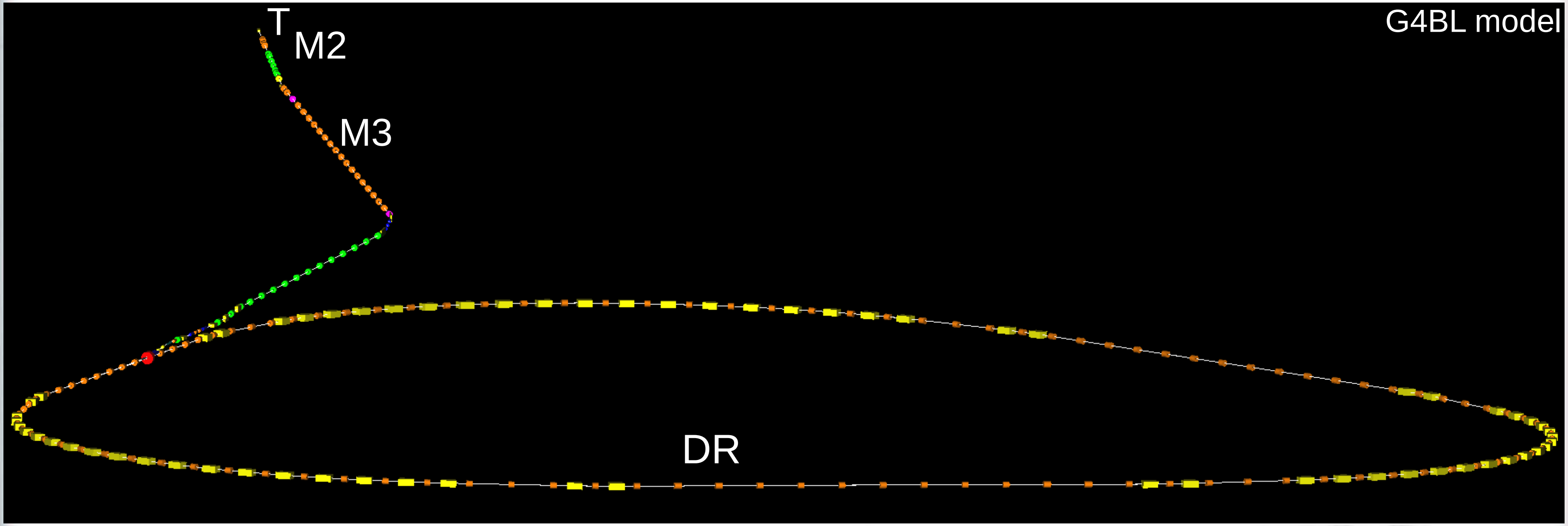
Outline

- Injection and extraction
- Beamline optics and performance
- Proton removal in the DR
- Triggers of errors in the DR

Deliver Ring (DR)



Simulation model



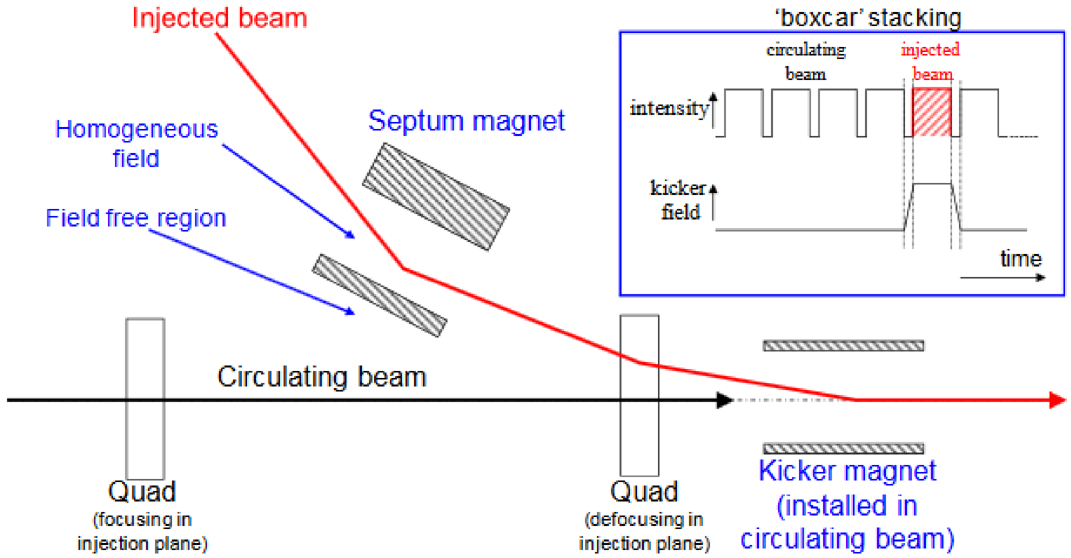
- M2 & M3 lines will carry the secondary beam from the target (T) to the delivery ring (DR)
- Loop four times until μ^+ yield peaks and all p are removed

Injection & extraction

- What makes a good injection?
  - Inject a particle beam into a circular accelerator at the appropriate time
  - Minimize loss and place injected particles onto the correct trajectory, with the correct phase-space parameters
- What makes a good extraction?
  - Extract the particles from an accelerator to a transfer line or a beam dump, at the appropriate time
  - Minimize loss and place the extracted particles onto the correct trajectory, with the correct phase-space parameters
- Both are important for good performance of an accelerator
- For g-2, we are interested for single turn (fast) injection and extraction

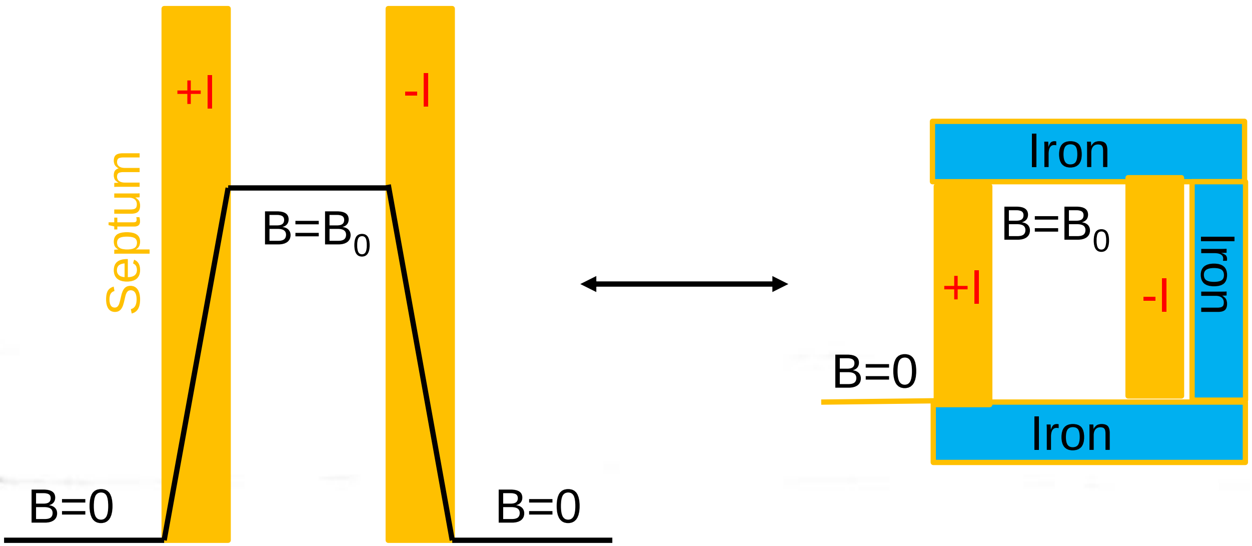
Injection mechanism

- Requires a combination of septa and kicker magnets
- Septa:
  - Can be magnetic or electrostatic
  - Have two vacuum chambers
  - Provide slower field rise/fall times but stronger field compared to kickers
- Kickers:
  - One vacuum chamber (like dipoles)
  - Fast field rise/fall times (<< 1 μs) but weaker field compared to kickers



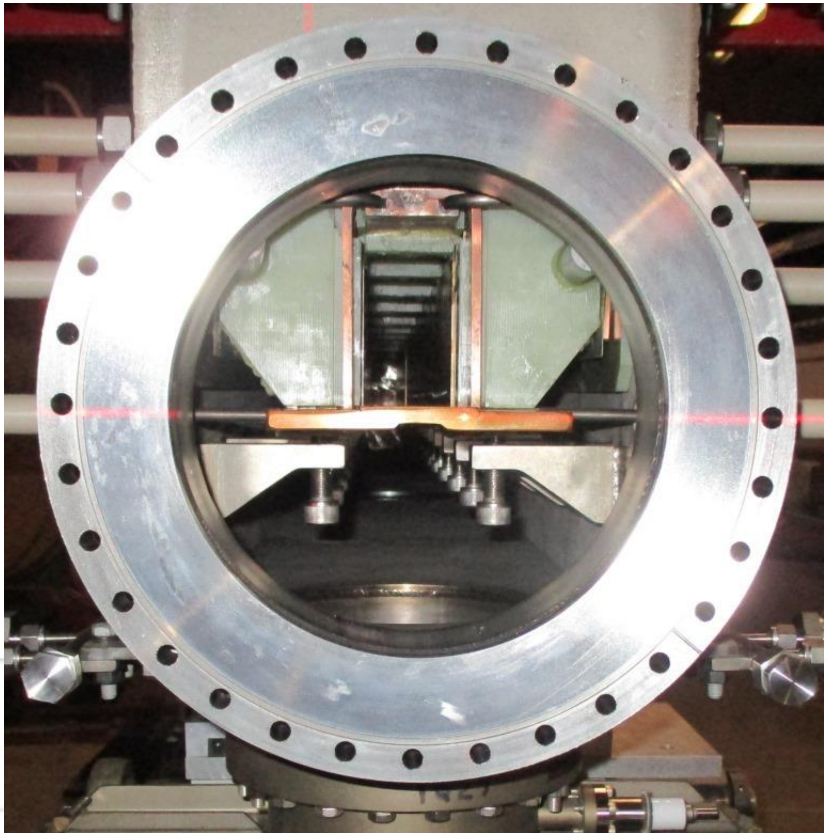
Magnetic septum

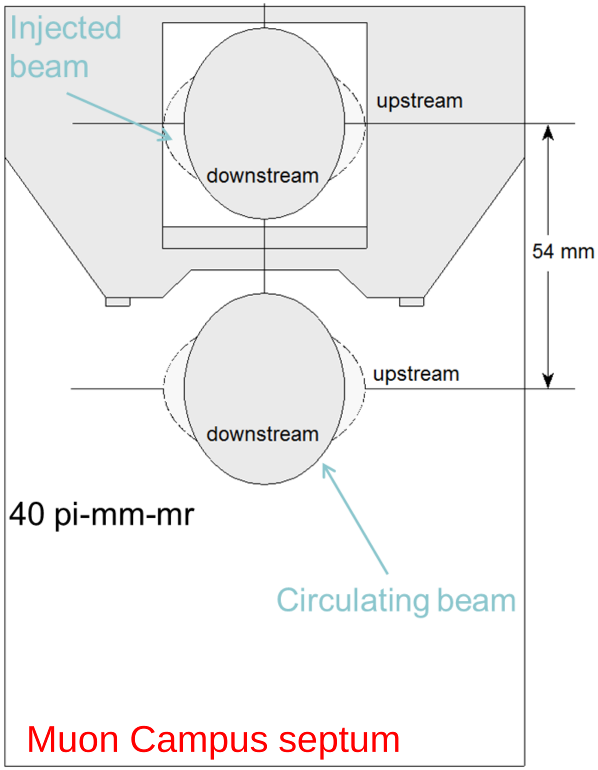
- The deflected beam goes through homogeneous B-field established between magnetic coils. The circulating beam passes next to the main magnetic circuit and “sees” no B-field.
- It uses current (I) to separate field regions



Muon Campus magnetic septum

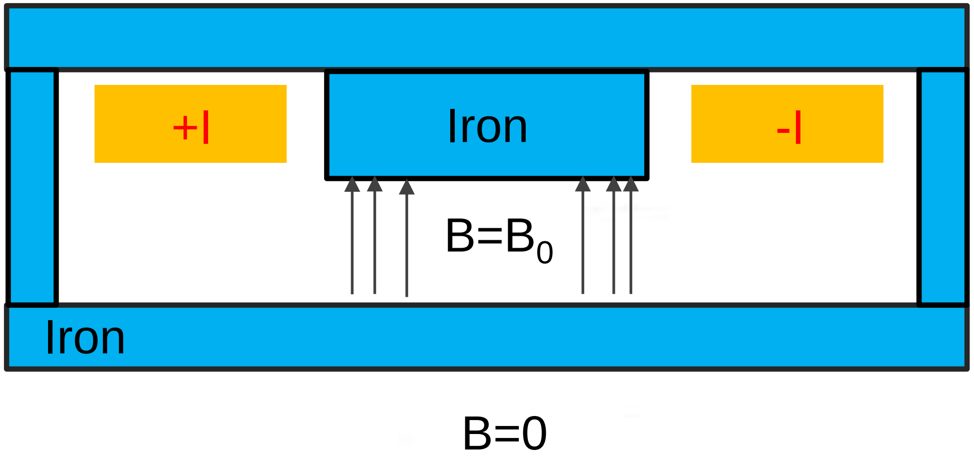
- For the Muon Campus, a magnetic septum is used to inject beam to the DR and to abort the proton beam





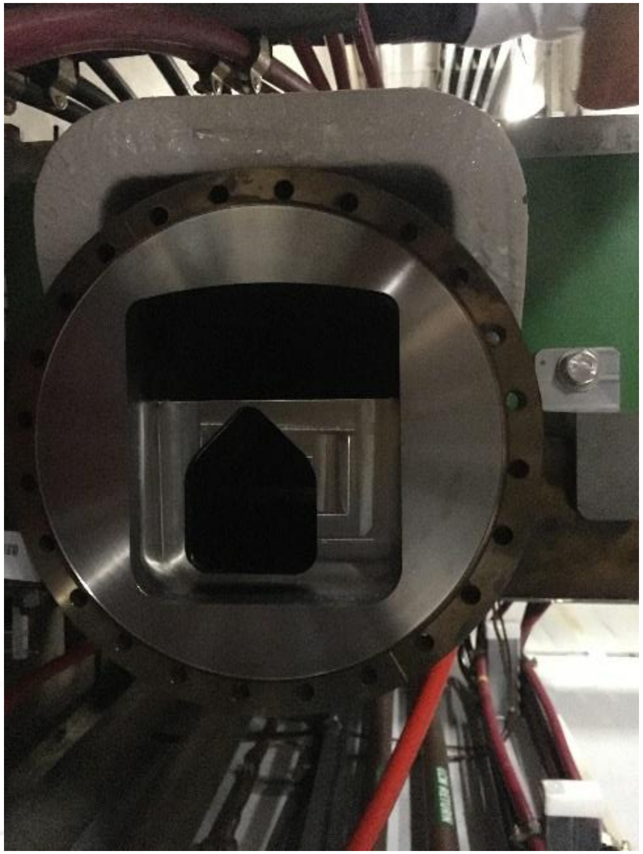
Lambertson septum

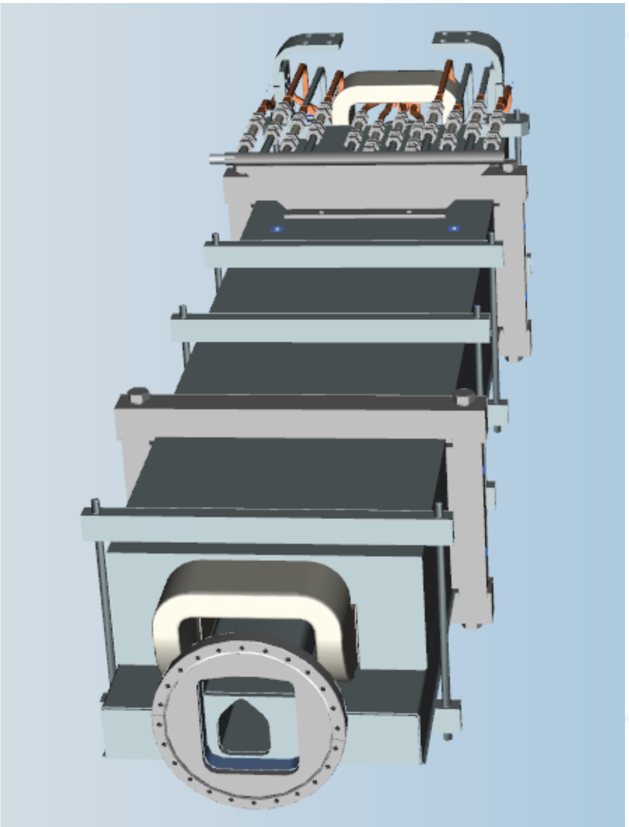
- Two field regions like a magnetic septum. BUT there is magnetic material that separates the two field regions
- A kicker magnet is used to deflect the beam vertically first and then the Lambertson magnet deflects the beam horizontally or vice versa



Muon Campus Lambertson septum

- For the Muon Campus, a magnetic septum is used to extract the beam out of the DR

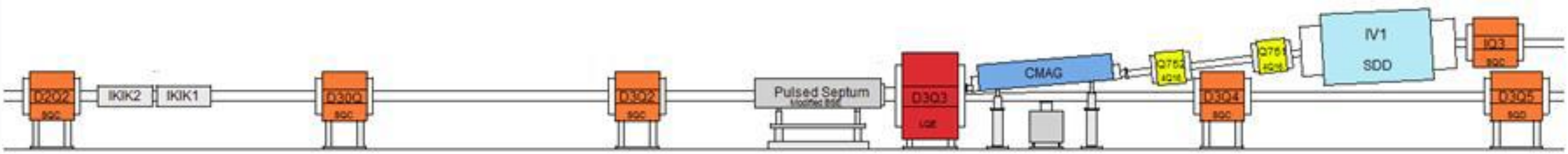




Muon Campus Lambertson

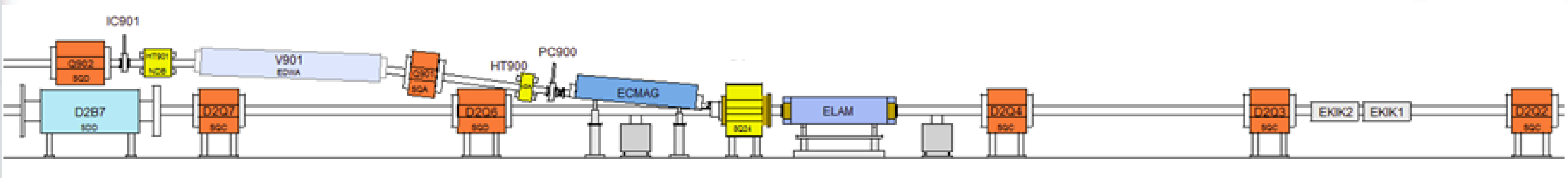
Injection to the Delivery Ring

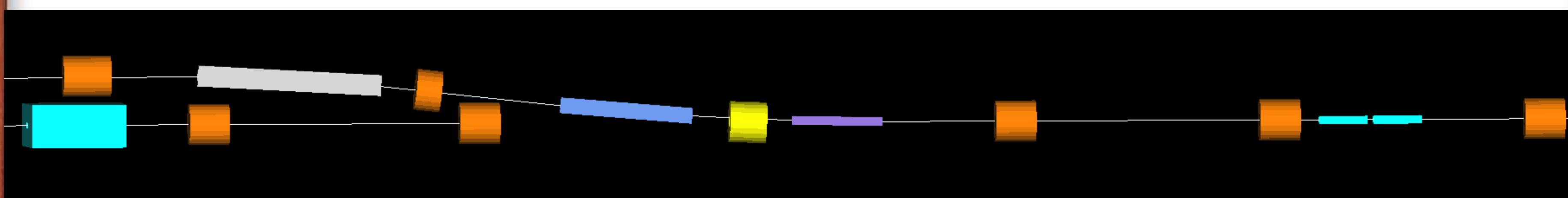
- Conceptual design



- Simulation model

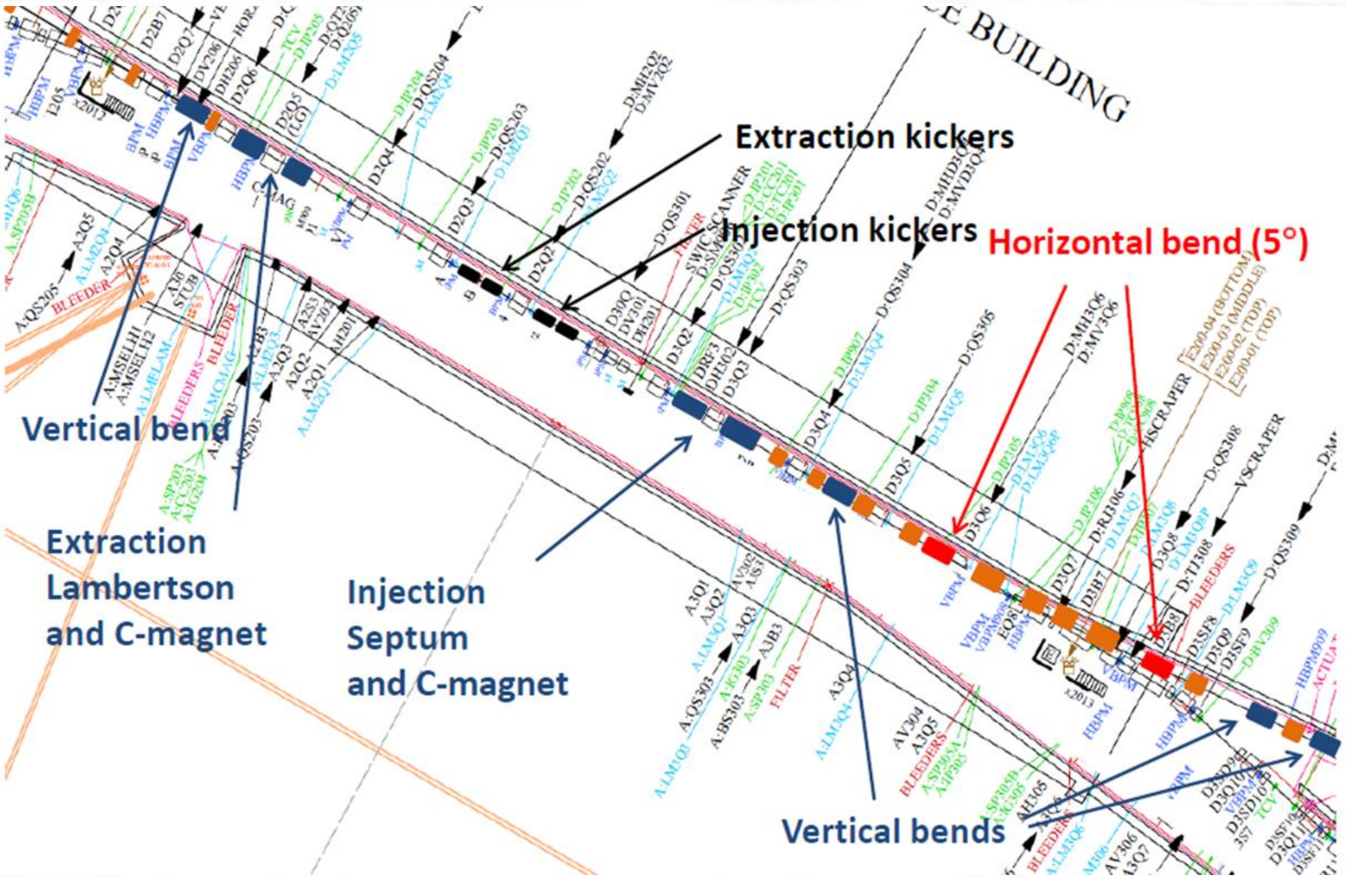
Extraction from the Delivery Ring





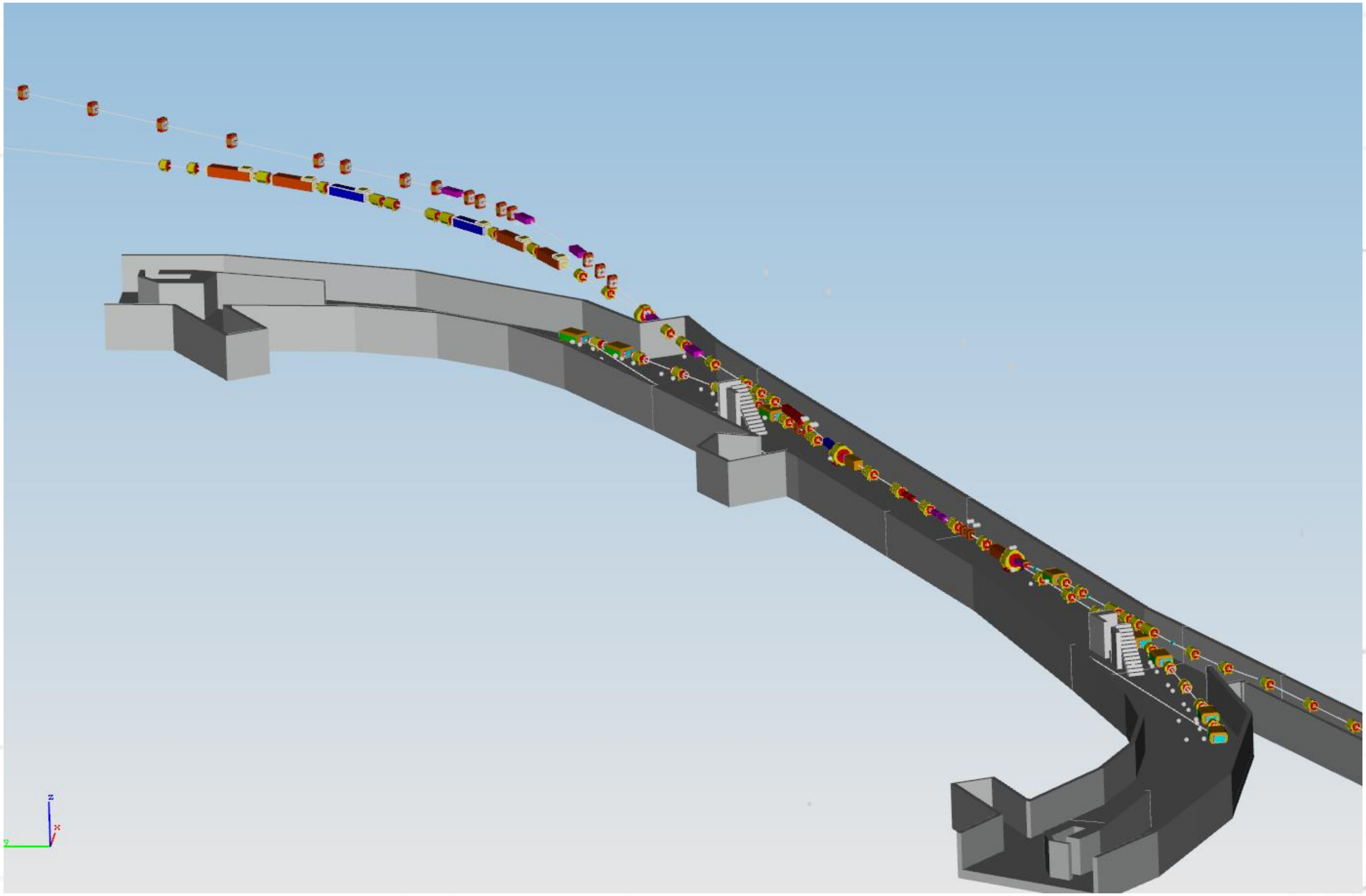
- Beam is extracted with a pair of horizontal kickers
- Subsequently, a Lambertson and C-magnet pair will be used to bend the beam upward out of the Delivery Ring

Straight D30 section



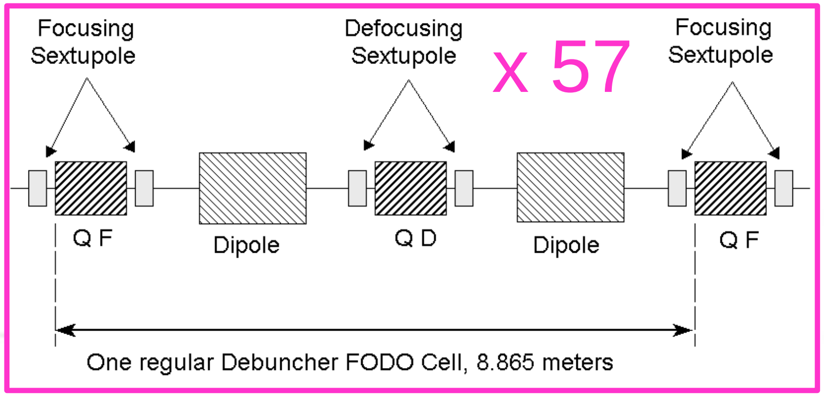
- Injection into and extraction out of the DR happens at the same straight section and contains the smallest apertures.

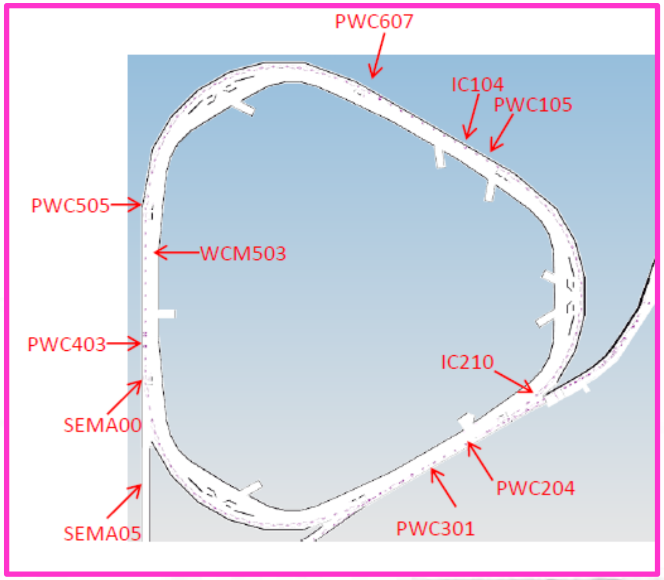
Straight D30 section



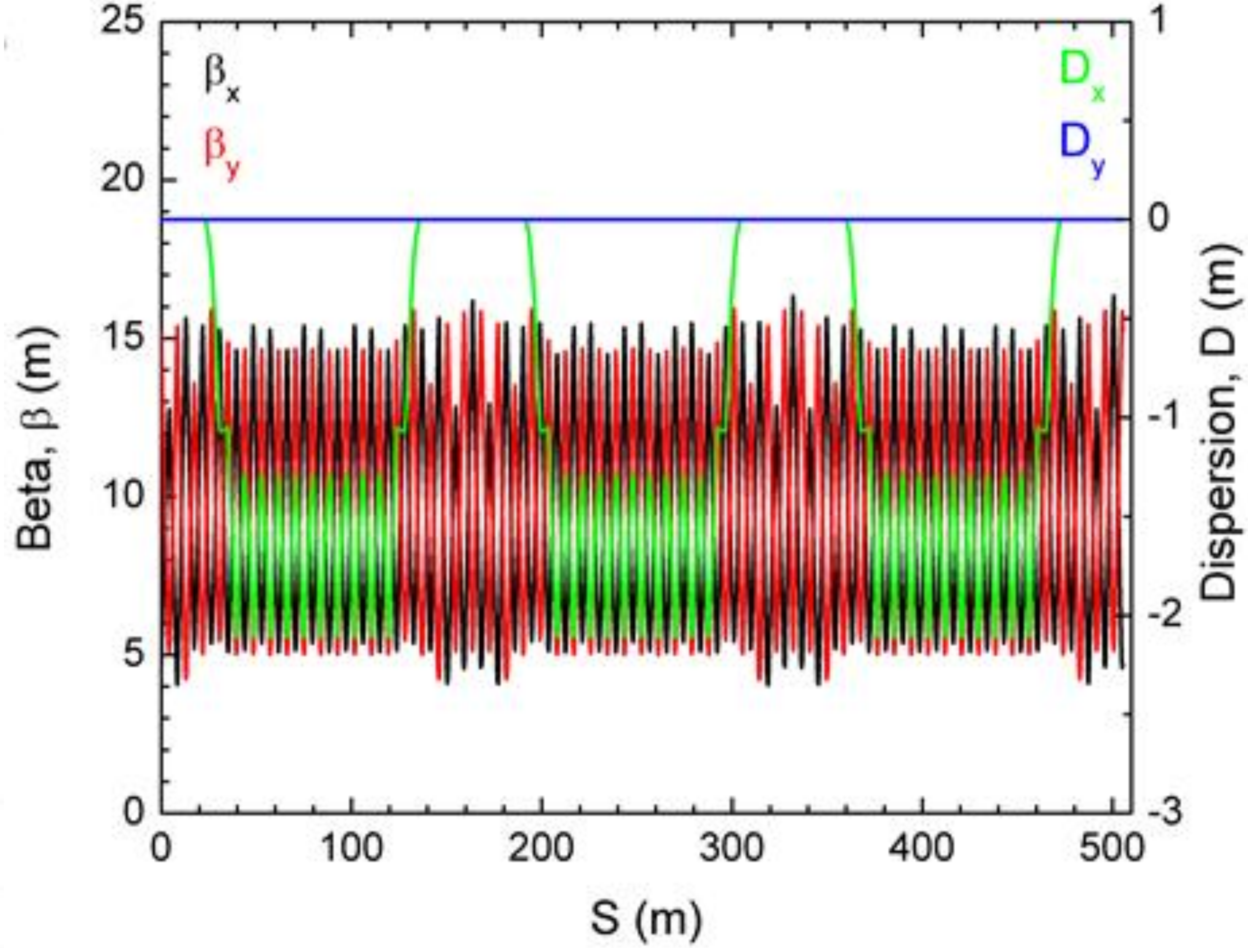
Delivery Ring lattice

- Features of the DR
  - Three long dispersion free straight sections together with 3 arc sections
  - 57 FODO cells and 66 dipoles
  - Ideal particle will follow a particular trajectory, which closes on itself after one turn (closed orbit)

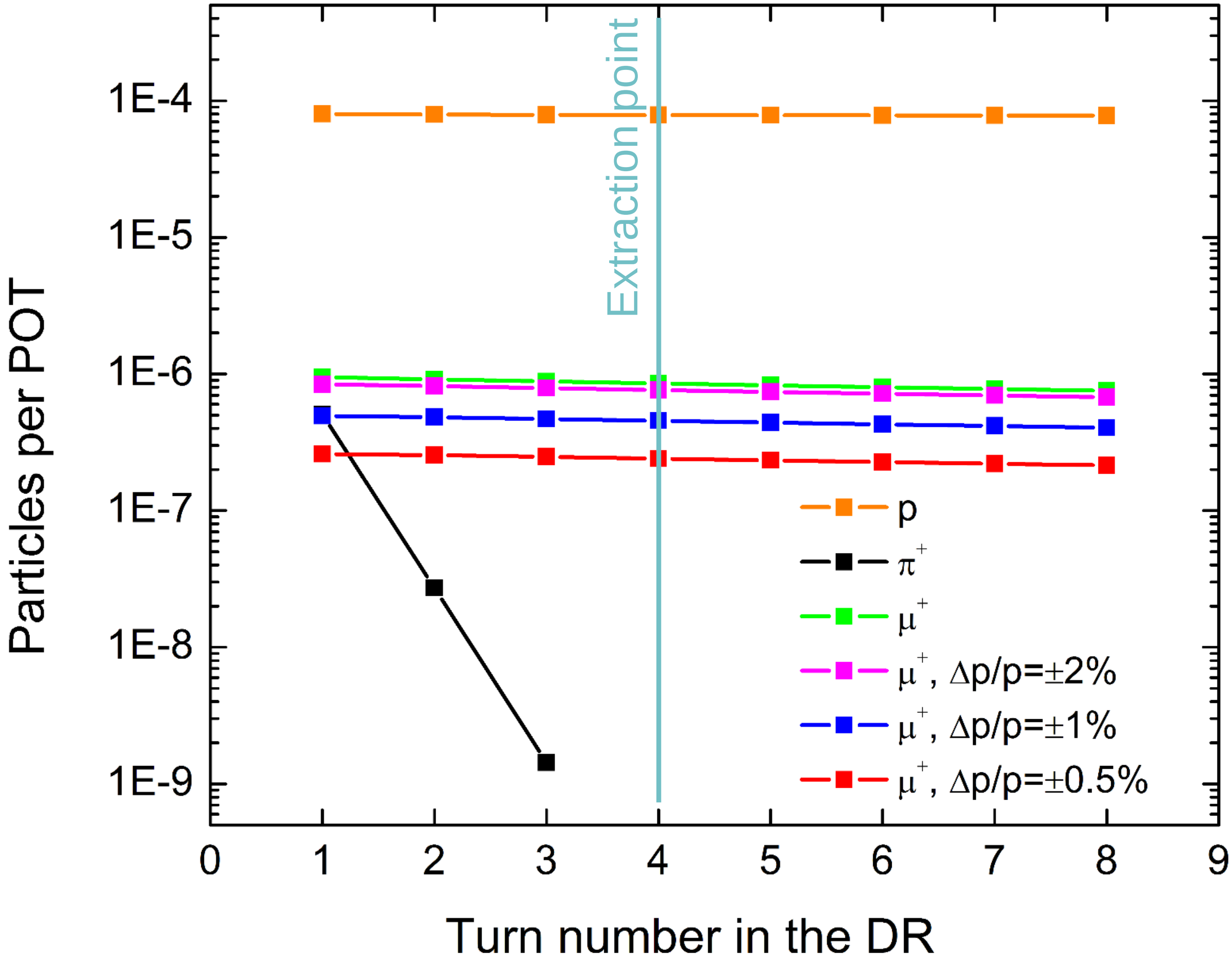




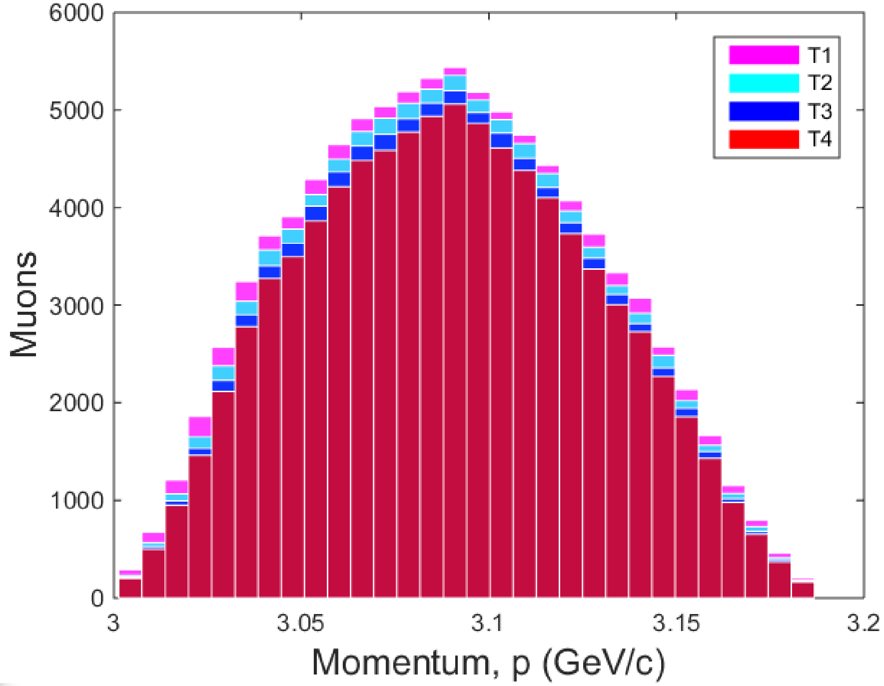
Delivery Ring optics

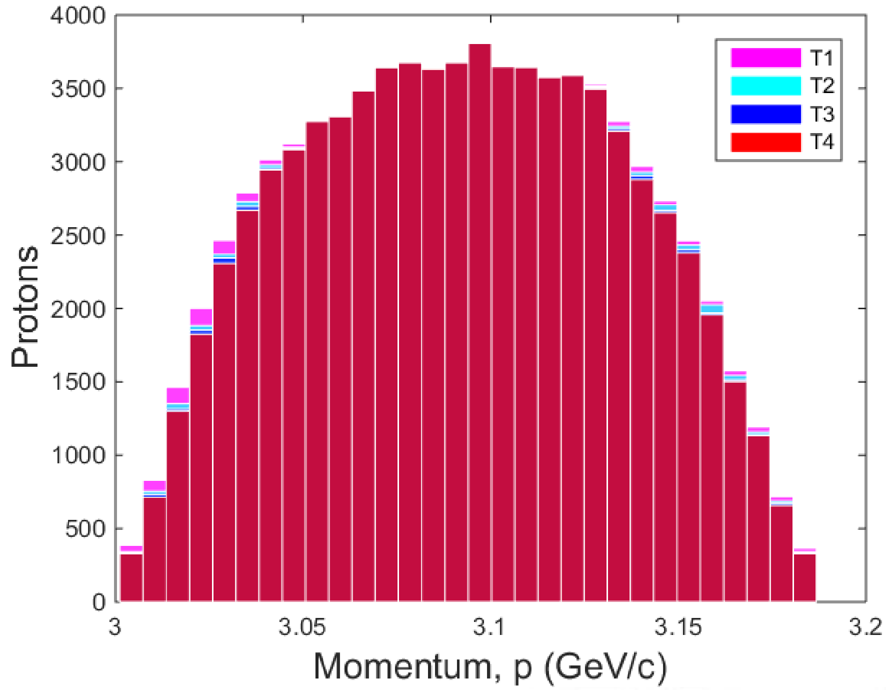


Performance of the Delivery Ring



Performance of the Delivery Ring

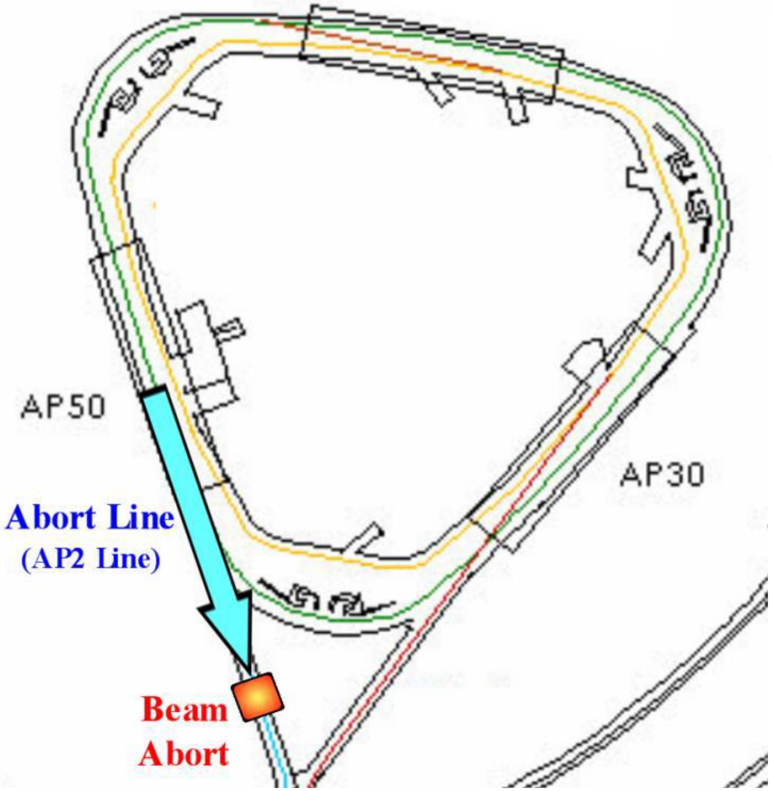




- Muon beam is peaked near “magic” momentum with $\Delta p/p = \pm 1.5\%$

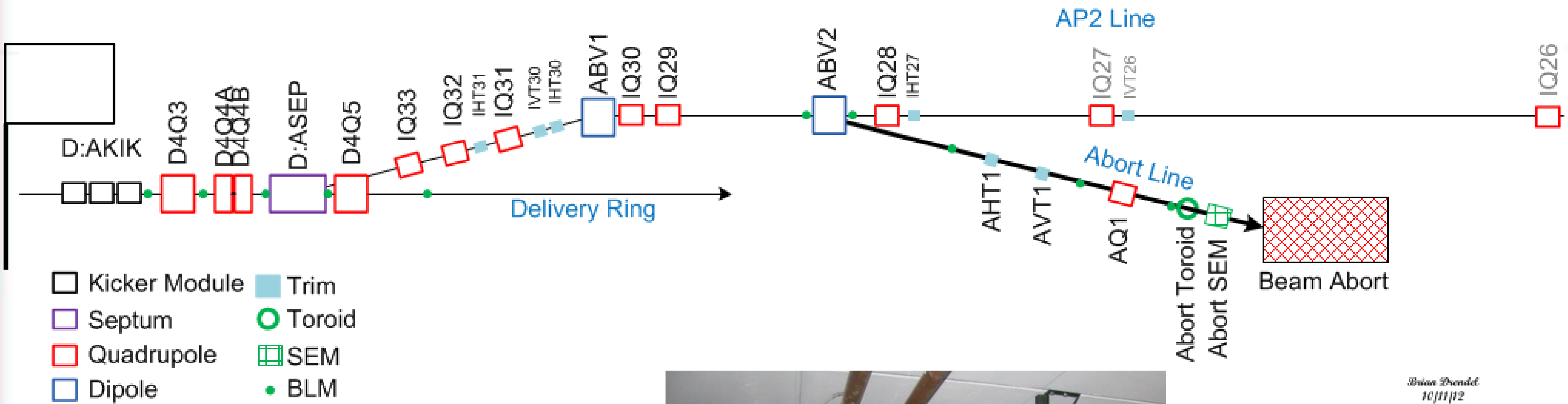
Proton removal

- Proton beam is removed by means of kicker magnet
- The kicker rise time is ~180 ns
- Multiple revolutions are required to provide enough kicker gap between muons and protons

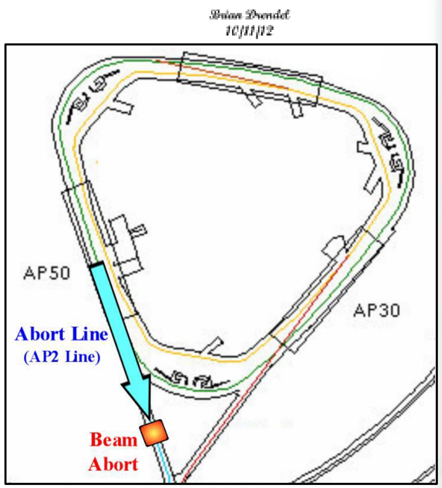


Abort line

Vertical Profile of the Delivery Ring Abort Line



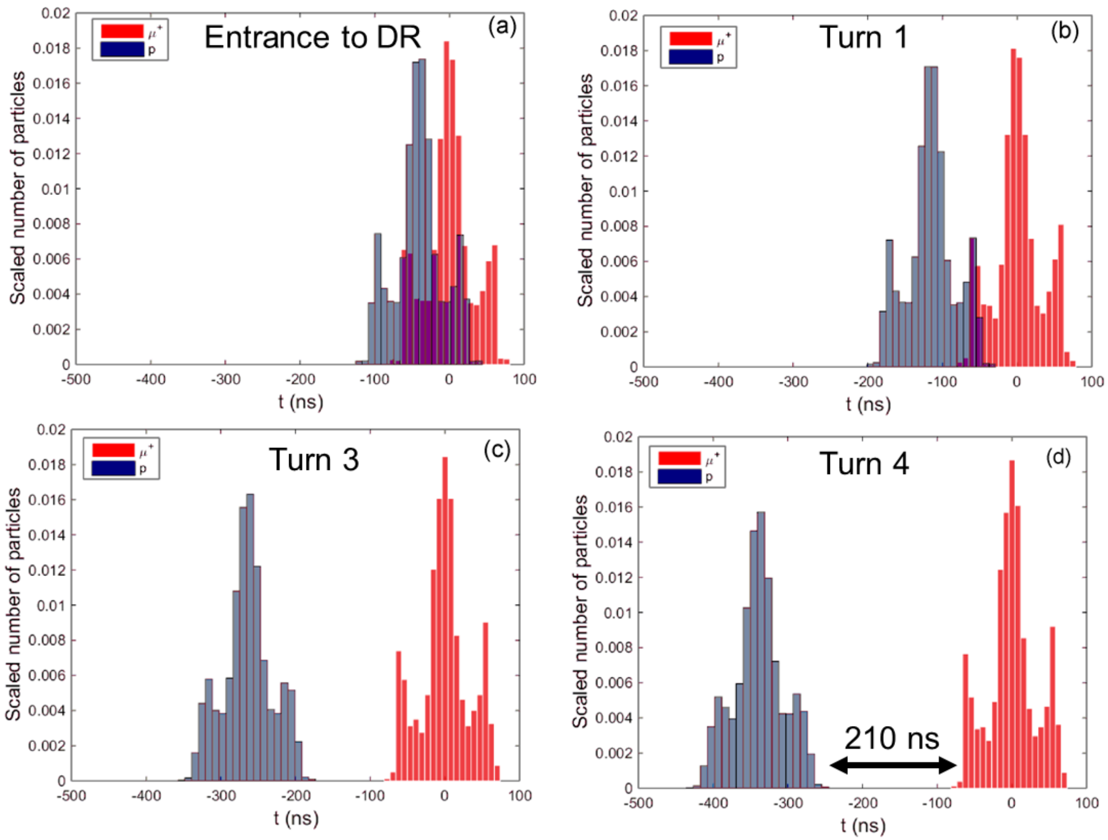
Kicker rise time ~180 ns



Bunch separation

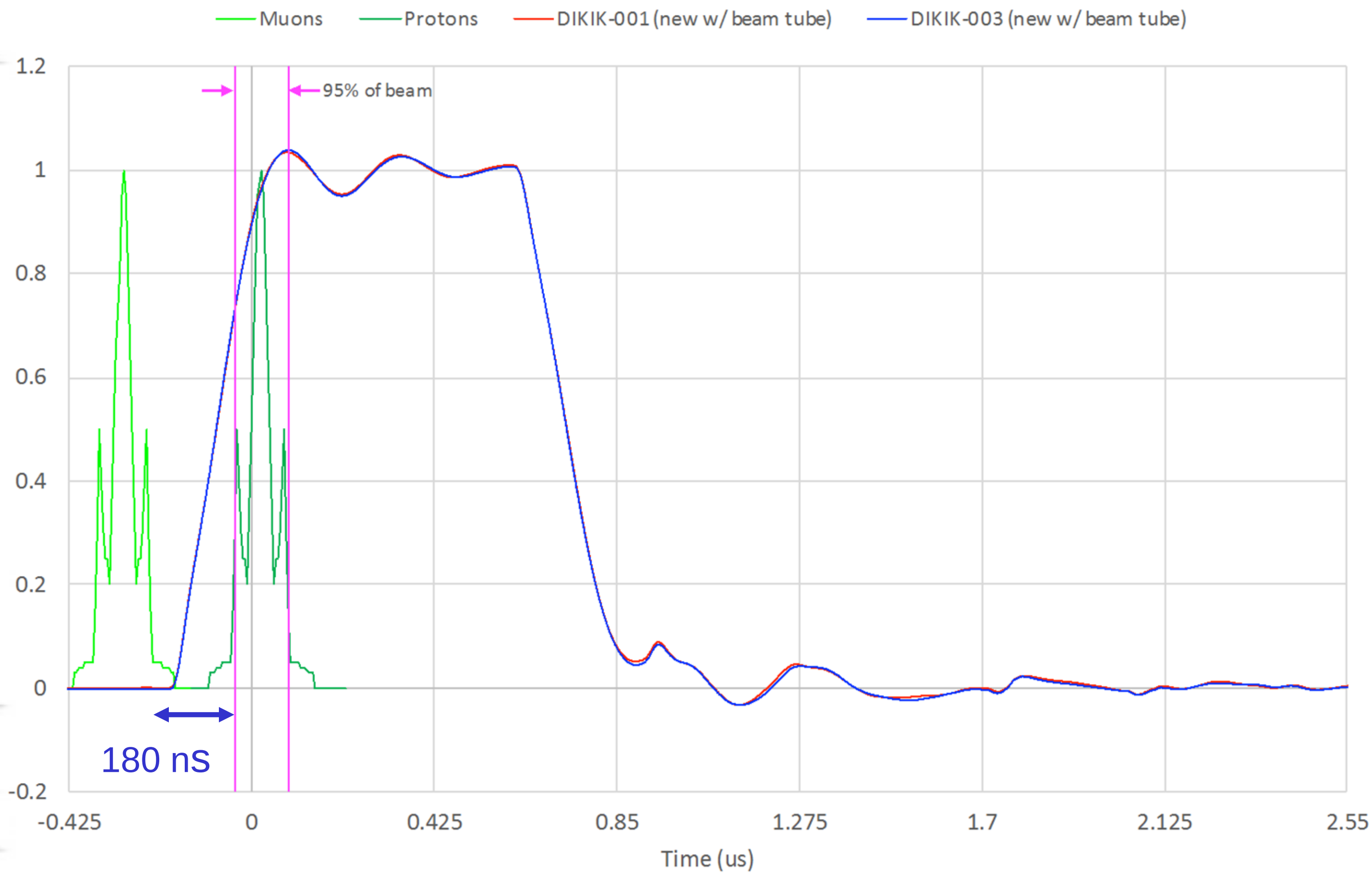
- Revolution times for 3.1 GeV/c beam:

$\mu^+, \beta = 0.999,\ T = 1685.5$ ns $e^+, \beta = 0.999,\ T = 1684.5$ ns $p,\ \beta = 0.957,\ T = 1760.2$ ns

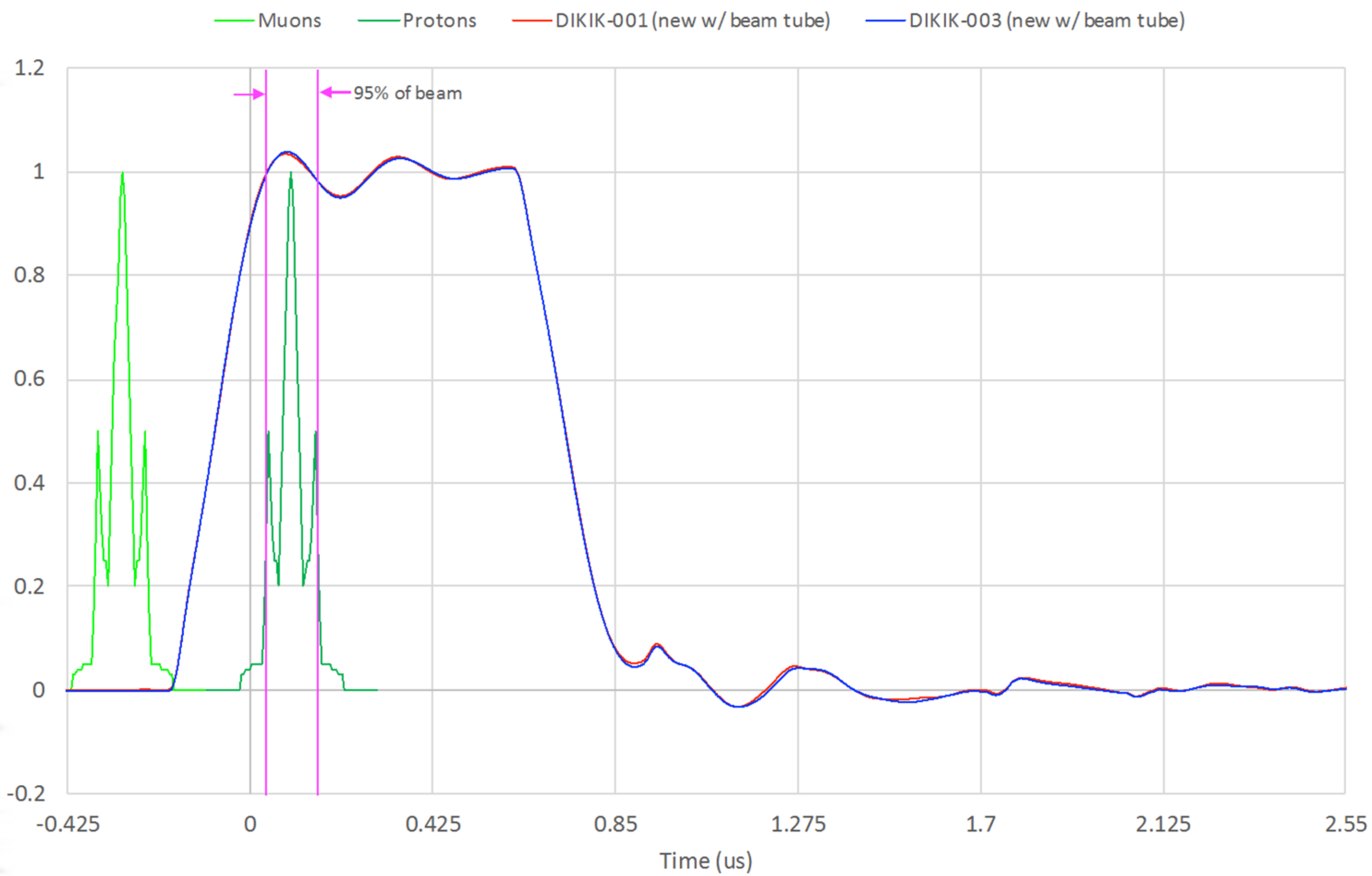


Proton removal – 4 turns

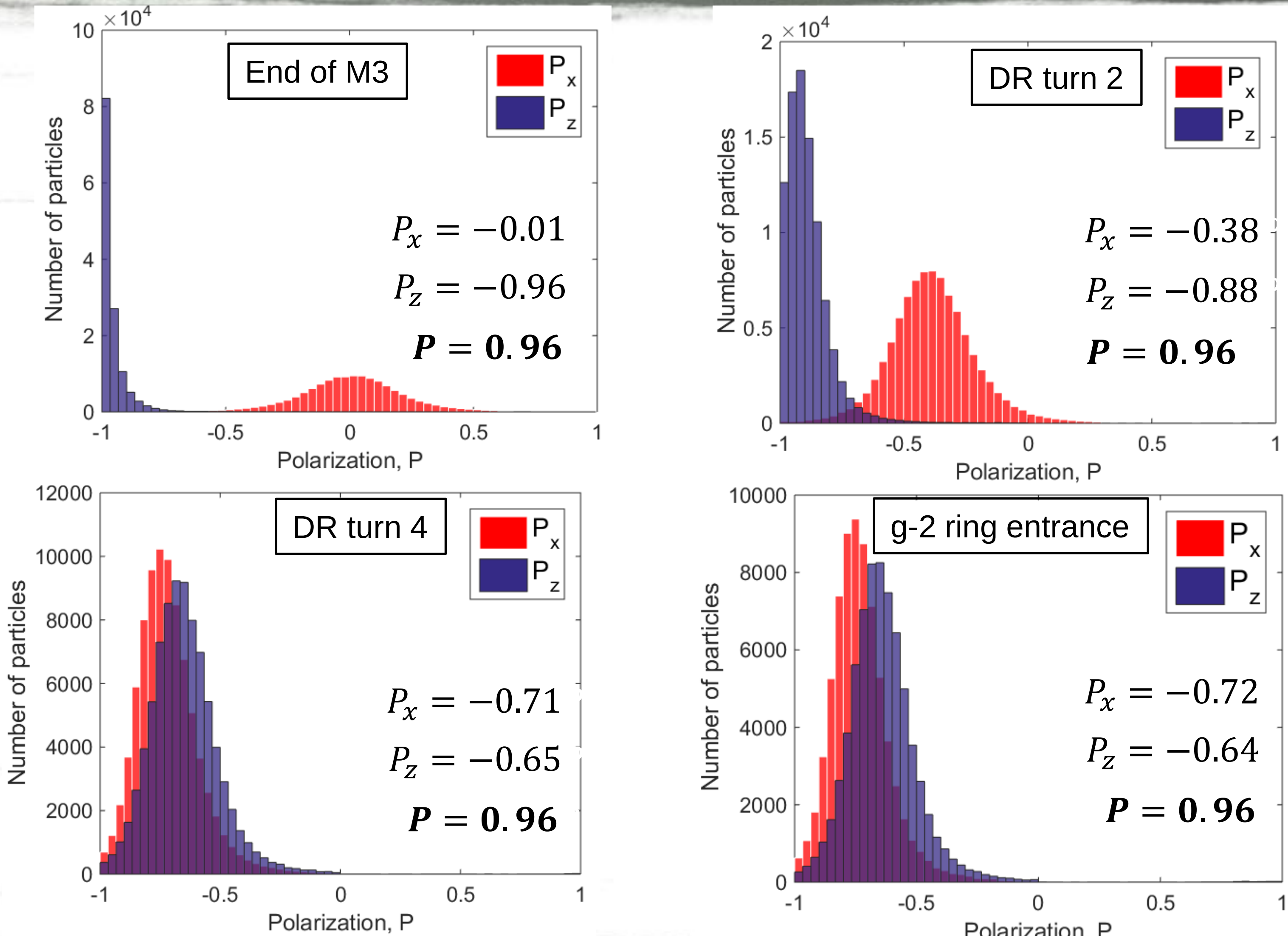
- Recall that kickers have a relative fast rise time (~180 ns)



Proton removal – 5 turns



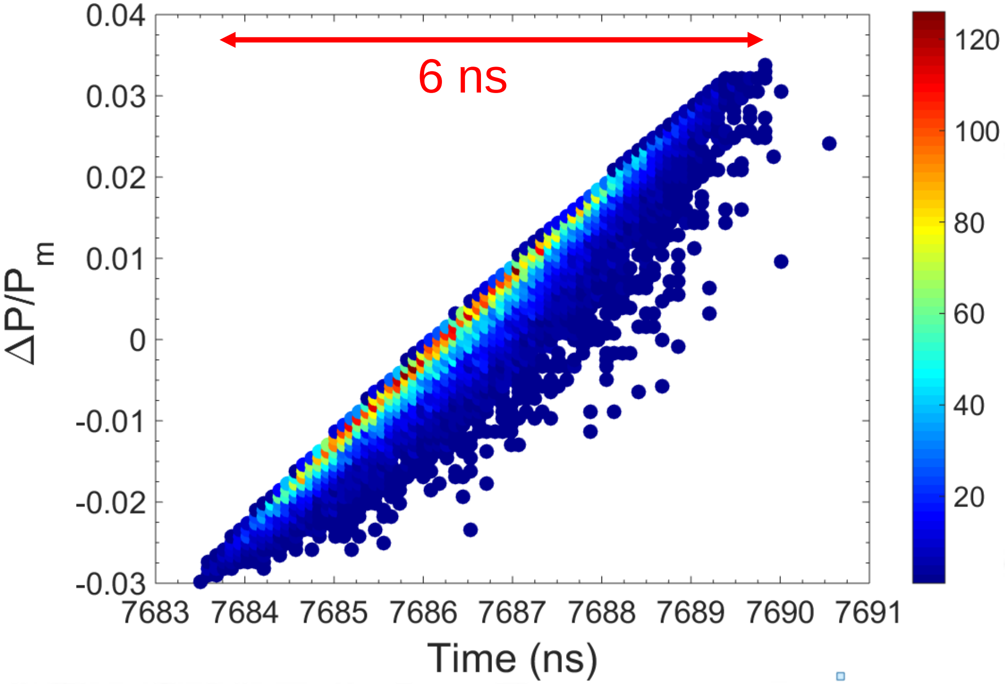
Spin precession in the DR



Momentum compaction

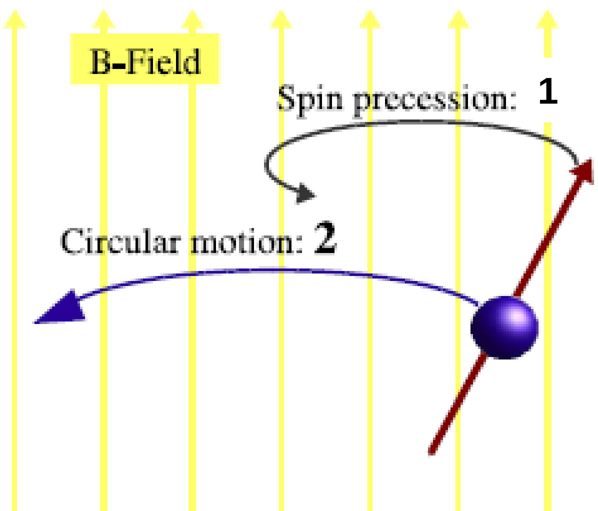
- In a circular machine, a nominal closed orbit is defined for a particle with a nominal momentum p_0
- For a particle with momentum $p_0 + \Delta p$ the trajectory is different from length L_0 due to the dipole bending radius. We call ΔL this extra length and define the momentum compaction as $\alpha_c = \frac{\Delta L / L_0}{\Delta p / p_0}$
- Time for one turn: $\tau = \frac{L}{v}$ or $\frac{\Delta\tau}{\tau} = \frac{\Delta L}{L} - \frac{\Delta v}{v}$
- But $\frac{\Delta v}{v} = \frac{1}{\gamma^2}\frac{\Delta p}{p}$
- We can re-write the above equations as: $\frac{\Delta\tau}{\tau} = \left(\alpha_c - \frac{1}{\gamma^2}\right)\frac{\Delta p}{p}$

Error trigger: Path length



- Momentum compaction is a constant of the machine and for the DR $a_c = 0.017$
- $\Delta\tau = \frac{L}{c\beta}\left(\alpha_c - \frac{1}{\gamma^2}\right)\frac{\Delta p}{p}$
- For the DR, $L = 505$ m, $\Delta p/p = 1.5\%,\ \gamma = 29.3,$
- After 4 turns: $\Delta\tau = \sim 1.6$ ns

Error trigger: Spin-mom. correlations

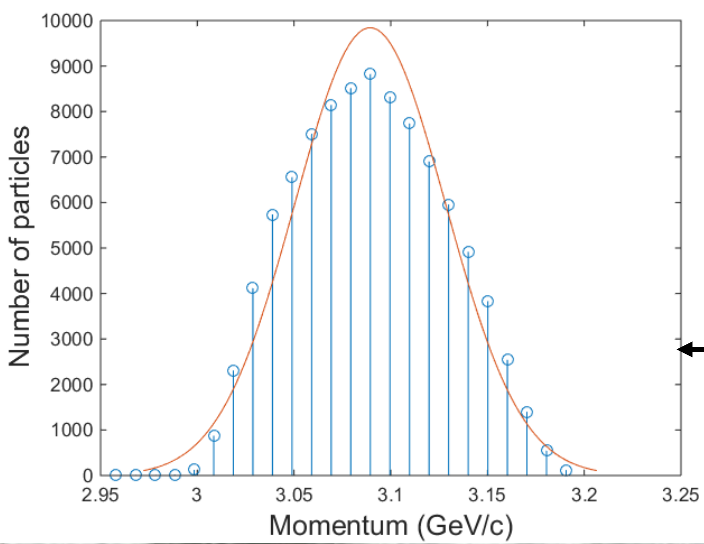


Spin precession relative to momentum:

$$\omega_a = a_\mu \frac{eB}{m_\mu c} = \gamma \alpha_\mu \omega_c$$

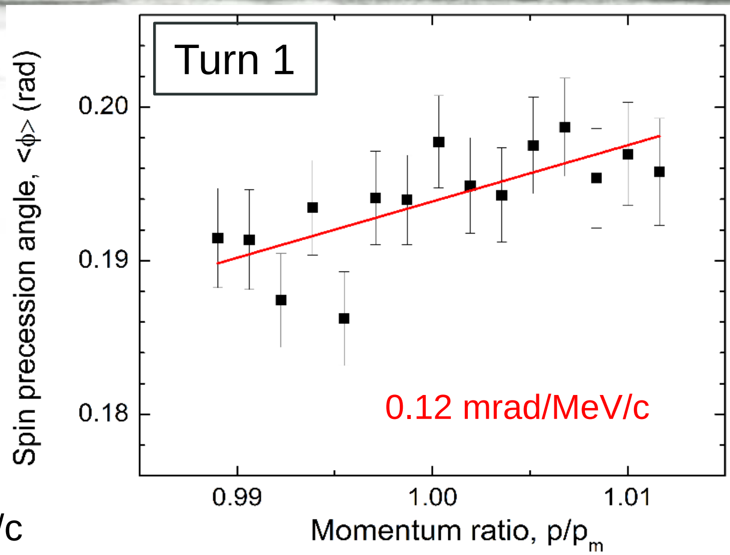
Precession after N turns: $\varphi_a = 2\pi N \gamma a_\mu$

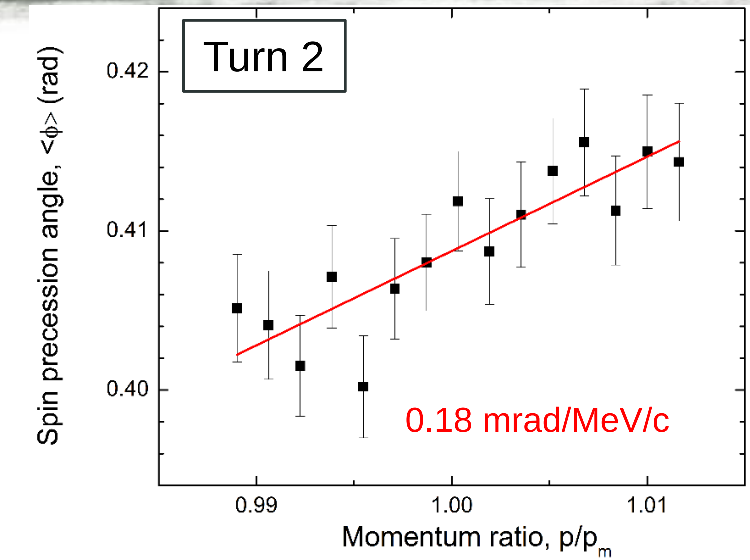
Slope of spin-momentum correlation: $\frac{d\varphi_a}{dp} = \frac{2\pi N a_\mu}{m_\mu c}$



Momentum spread after DR turn 1

Spin-mom. correlations in the DR





p_m : 3.094 GeV/c