TRIUMF

Status of DarkLight Beam Optics

Aveen Mahon
Accelerator Division, TRIUMF

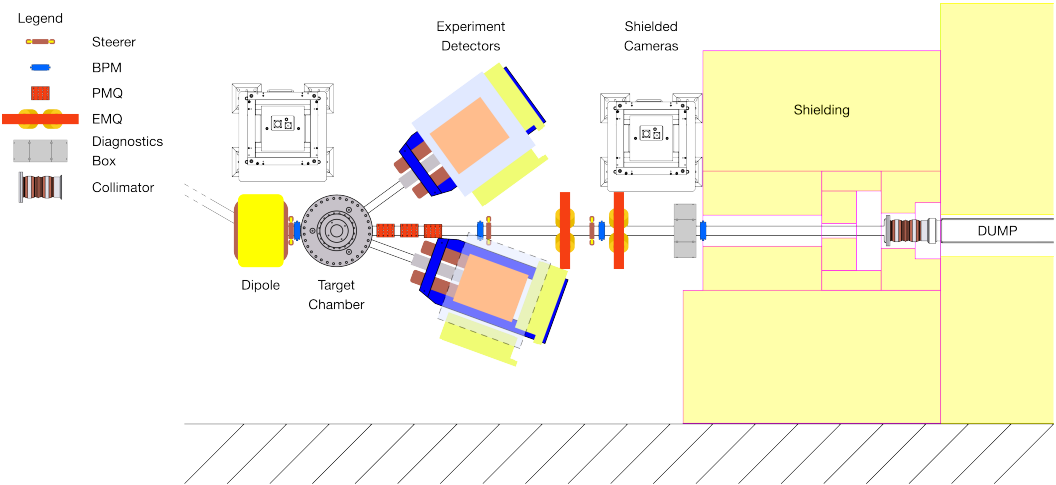
DarkLight Collaboration Meeting

2024-07-10

Outline

1. Improved permanent magnet modelling
2. Updated optics design
3. Matching work with Geant & Fluka
4. Progress on other targets and energies

DarkLight Beamline



Design Requirements

- Minimize beam losses before entering the beam dump shielding;

Design Requirements

- Minimize beam losses before entering the beam dump shielding;
- Maintain minimum beamsize through the dump to not damage it;

Design Requirements

- Minimize beam losses before entering the beam dump shielding;
- Maintain minimum beamsize through the dump to not damage it;
- Valid for an energy range of 27-31 MeV;

Design Requirements

- Minimize beam losses before entering the beam dump shielding;
- Maintain minimum beamsize through the dump to not damage it;
- Valid for an energy range of 27-31 MeV;
- Compatible with regular beam operation (no target);

Design Requirements

- Minimize beam losses before entering the beam dump shielding;
- Maintain minimum beamsize through the dump to not damage it;
- Valid for an energy range of 27-31 MeV;
- Compatible with regular beam operation (no target);
- Include sufficient diagnostics and steering elements for operation.

Design Requirements

- Minimize beam losses before entering the beam dump shielding;
- 2×RMS beamsize at beam dump centre minimum of 8 mm×8 mm.
- Valid for an energy range of 27-31 MeV;
- Compatible with regular beam operation (no target);
- Include sufficient diagnostics and steering elements for operation.

Design Requirements

- 3.7×RMS envelope fully contained within 1 inch radius of beampipe before entering the beam dump shielding;
- 2×RMS beamsize at beam dump centre minimum of 8 mm×8 mm.;
- Valid for an energy range of 27-31 MeV;
- Compatible with regular beam operation (no target);
- Include sufficient diagnostics and steering elements for operation.

Design Requirements

- 3.7×RMS envelope fully contained within 1 inch radius of beampipe before entering the beam dump shielding; Insufficient for FLUKA losses!
- 2×RMS beamsize at beam dump centre minimum of 8 mm×8 mm.;
- Valid for an energy range of 27-31 MeV;
- Compatible with regular beam operation (no target);
- Include sufficient diagnostics and steering elements for operation.

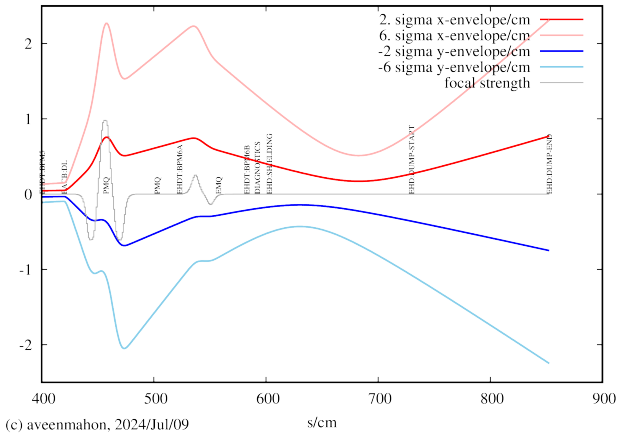
Design Requirements

- **6×RMS envelope** fully contained within 1 inch radius of beampipe before entering the beam dump shielding.
- 2×RMS beamsize at beam dump centre minimum of 8 mm×8 mm.
- Valid for an energy range of 27-31 MeV;
- Compatible with regular beam operation (no target);
- Include sufficient diagnostics and steering elements for operation.

Where we left off:

30 MeV beam on 1 μm Ta target:

- 3 PMQs - fixed strengths:
  - -0.62 T
  - 1 T
  - -0.62 T
- 2 EMQs - variable strengths

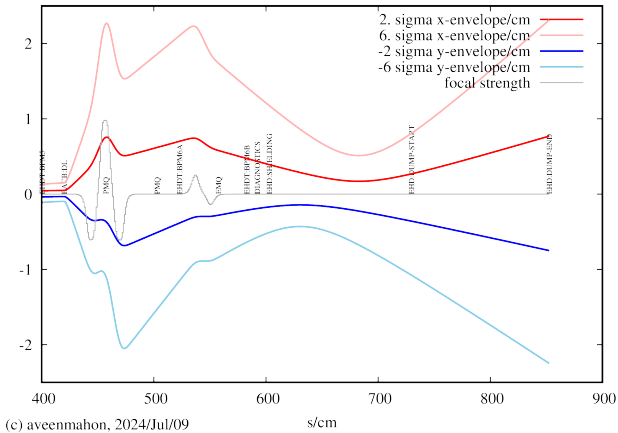


Where we left off:

30 MeV beam on 1 μm Ta target:

- 3 PMQs - fixed strengths:
  - -0.62 T
  - 1 T
  - -0.62 T
- 2 EMQs - variable strengths

Analytic description for better match with FLUKA input.



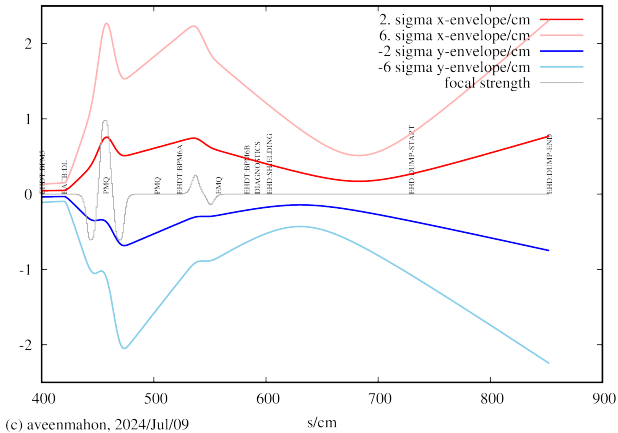
Where we left off:

30 MeV beam on 1 μm Ta target:

- 3 PMQs - fixed strengths:
  - -0.62 T
  - 1 T
  - -0.62 T
- 2 EMQs - variable strengths

Analytic description for better match with FLUKA input.

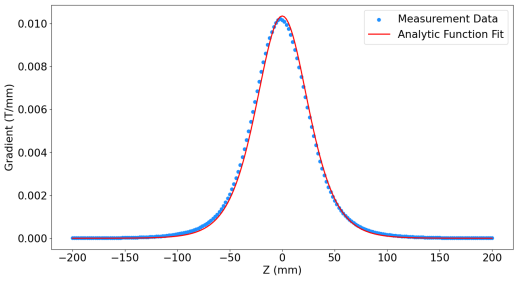
BUT soft edge approximation of PMQ fields not spot on...



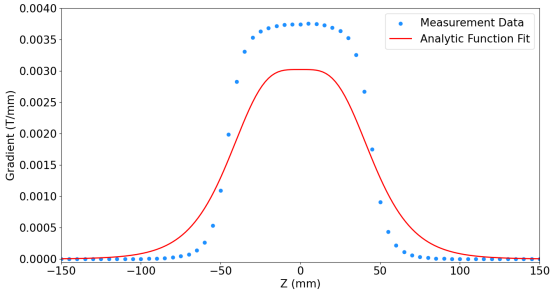
Parameterization of Permanent Magnet Quads

Initially applied analytic description of short quadrupoles from Baartman (2012).

For EMQs:



Initial approximation for PMQs:



$$k(z) = \frac{K_0}{2}\,\mathrm{sech}^2\left(\frac{z}{\lambda}\right)$$

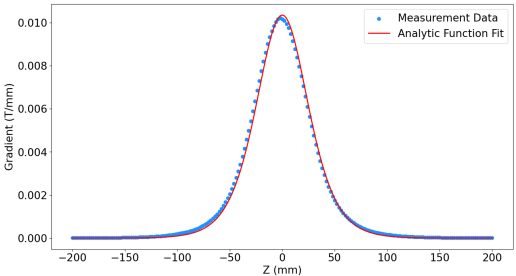
Sum of two sech^2 functions

With parameters $K_0 = 1.04\times10^{-2}$ T/mm and $\lambda = 33.1$ mm in both cases.

Parameterization of Permanent Magnet Quads

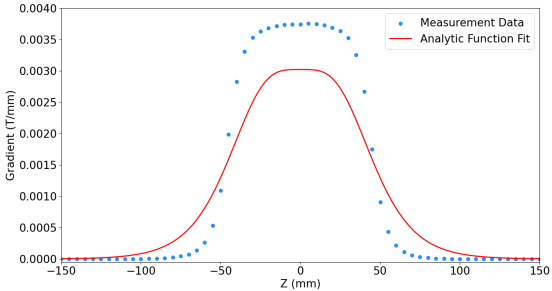
Initially applied analytic description of short quadrupoles from Baartman (2012).

For EMQs:



$$k(z) = \frac{K_0}{2}\,\mathrm{sech}^2\left(\frac{z}{\lambda}\right)$$

Initial approximation for PMQs:



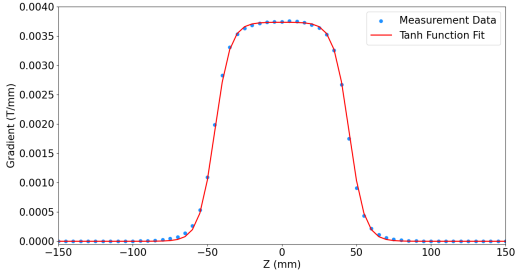
Correct integrated field strength but fringe field has much sharper falloff

Parameterization of Permanent Magnet Quads

Re-parameterization using hyperbolic tangent function:

$$k(z) = \frac{K}{2L}\left(\tanh\left(\frac{z + L/2}{\lambda}\right) - \tanh\left(\frac{z - L/2}{\lambda}\right)\right)$$

With parameters K = 0.337 T,
L = 90.14 mm and λ = 10.36 mm.



For further details on the hyperbolic fits and PMQ magnetic measurement see TRI-BN-23-28 and TRI-BN-23-20 Beam Physics notes.

Optics Design - Matching

Goal: Ensure we are inputting the correct optics into FLUKA for dose and shielding calculations.

Optics Design - Matching

Goal: Ensure we are inputting the correct optics into FLUKA for dose and shielding calculations.

Ironed out spacing with CAD model → updated beam optics:

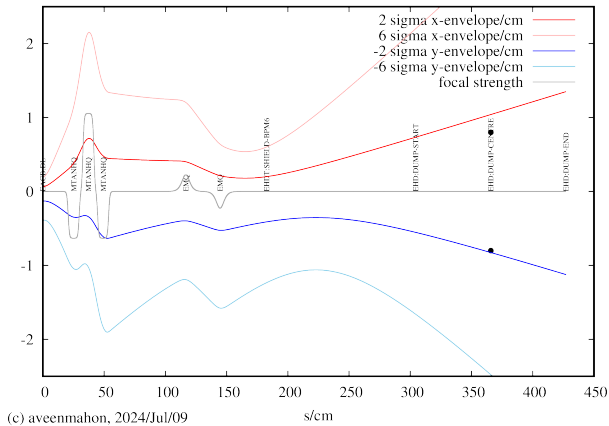
Optics Design - Matching

Goal: Ensure we are inputting the correct optics into FLUKA for dose and shielding calculations.

Ironed out spacing with CAD model → updated beam optics:

- 3 PMQs:
  - -0.6 T
  - 1 T
  - -0.6 T
- 2 EMQs
  - ±0.2 T

31 MeV beam on 1 μm Ta target:



Optics Design - Matching

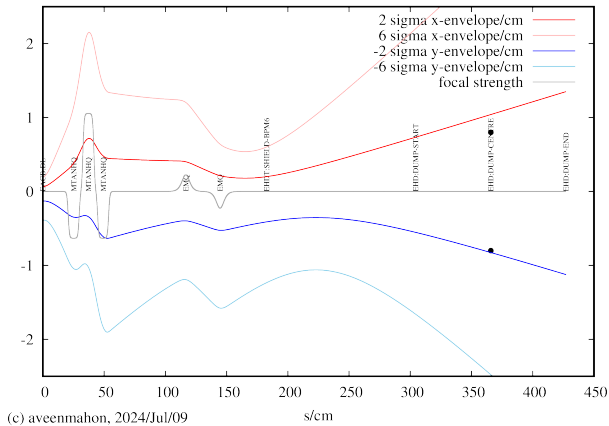
Goal: Ensure we are inputting the correct optics into FLUKA for dose and shielding calculations.

Ironed out spacing with CAD model → updated beam optics:

- 3 PMQs:
  - -0.6 T
  - 1 T
  - -0.6 T
- 2 EMQs
  - ±0.2 T

"Nominal" arrangement

31 MeV beam on 1 μm Ta target:



Matching with Geant

Why Geant?

Matching with Geant

Why Geant?

- Faster turnover than FLUKA.

Matching with Geant

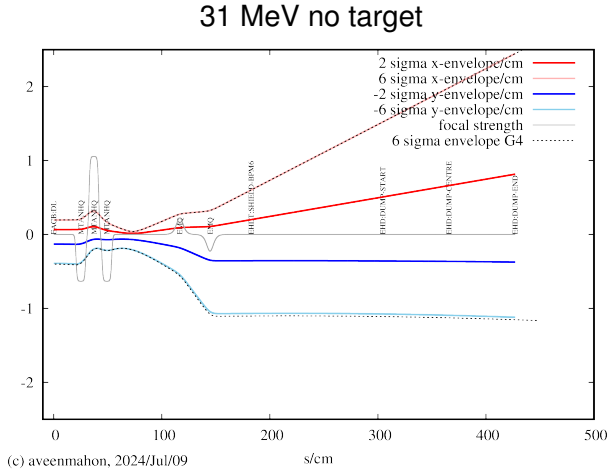
Why Geant?

- Faster turnover than FLUKA.
- Easier for debugging.

Matching with Geant

Why Geant?

- Faster turnover than FLUKA.
- Easier for debugging.



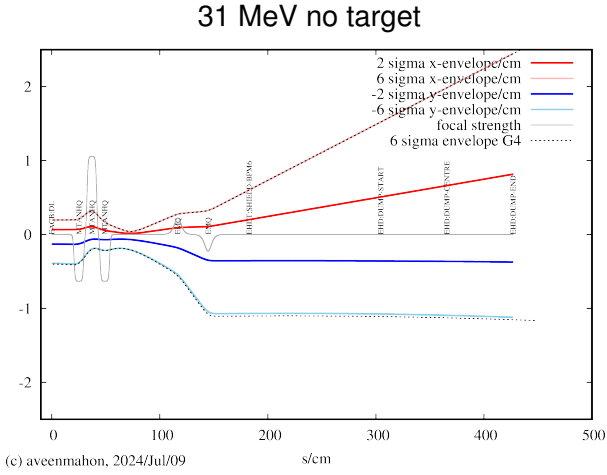
Matching with Geant

Why Geant?

- Faster turnover than FLUKA.
- Easier for debugging.

Confident that we have the same inputs → same physics

Note: This matching was done with uncorrelated initial beam parameters.

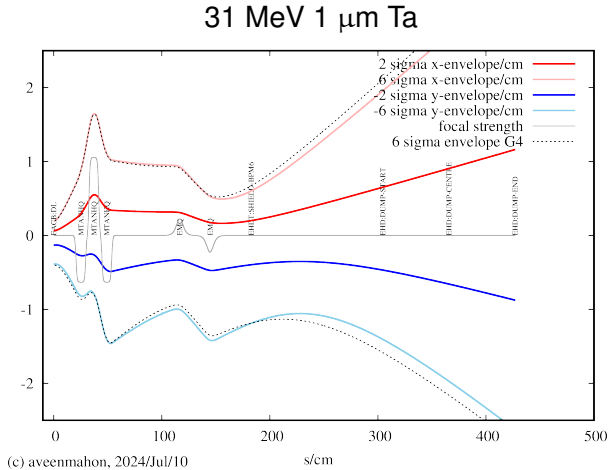


Matching with Geant

Scattering case not as straightforward:

- Cuts applied to particles that fall outside any of the magnetic fields from any of the magnets.
- Geant will deal with non linearities at large beamsize that transoptr will not

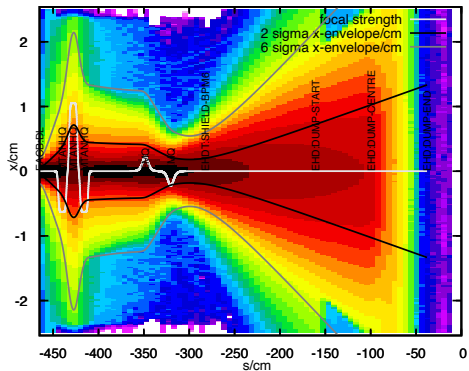
Same general shape but not a 1-to-1 comparison.



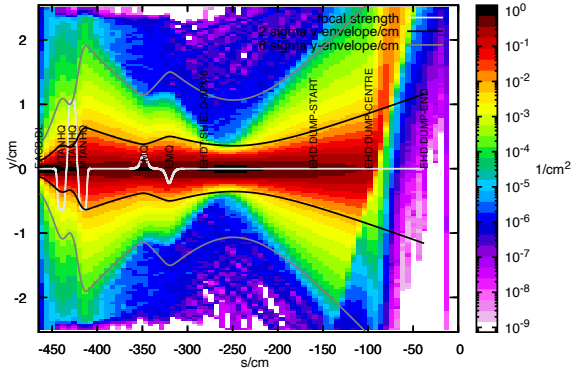
Matching with Fluka

Matching with Fluka

Top down view



Side view



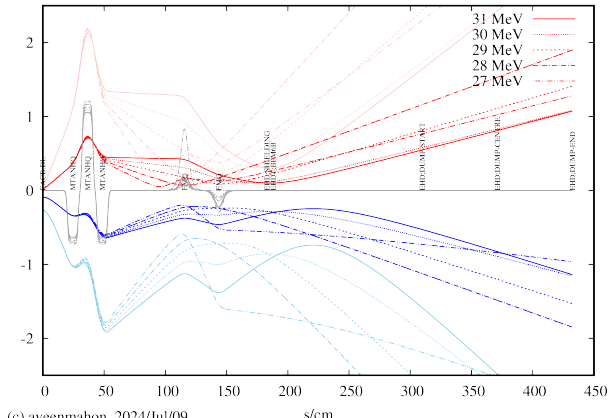
Fluence : density of particle tracks per volume

Requirement: 27-31 MeV range

Previously sweeping energies using 31 MeV scattering angle for all.

Model satisfies requirements.

BUT incorrect assumption

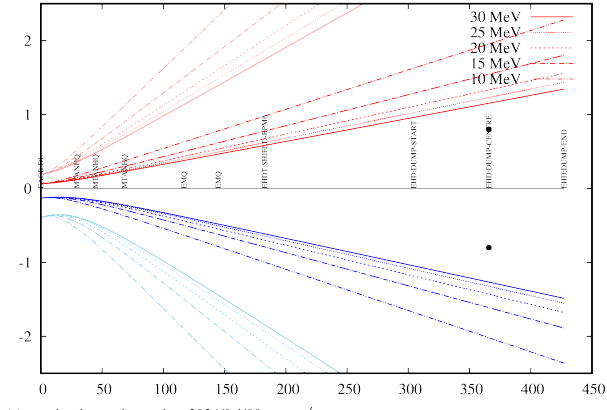


Note change in focal strength due to changing energy/momentum

Requirement: 27-31 MeV range

Reality:

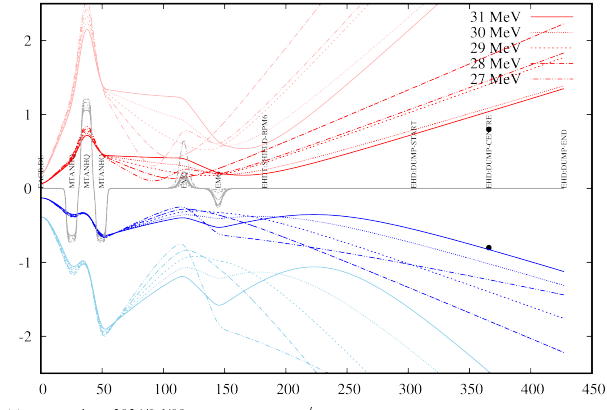
Multiple scattering scales with beam energy



Requirement: 27-31 MeV range

New scattering angles from Angela for 27-31 MeV.

Lower beam energy multiple scattering becomes an issue!!

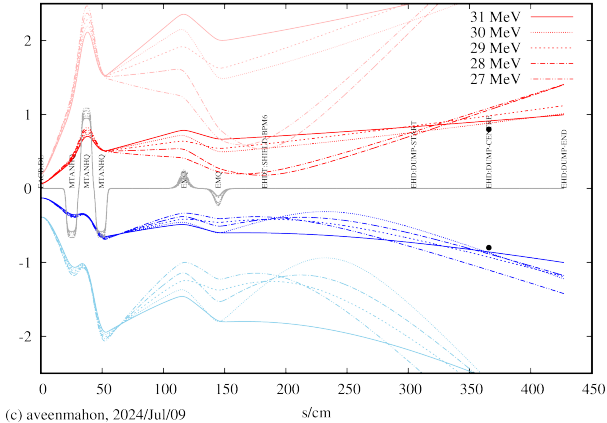


Requirement: 27-31 MeV range

Solution: lower PMQ strengths by ≈ 10% to accommodate for lower energy requirement.

New PMQ strengths:

- -0.55 T
- 0.9 T
- -0.55 T



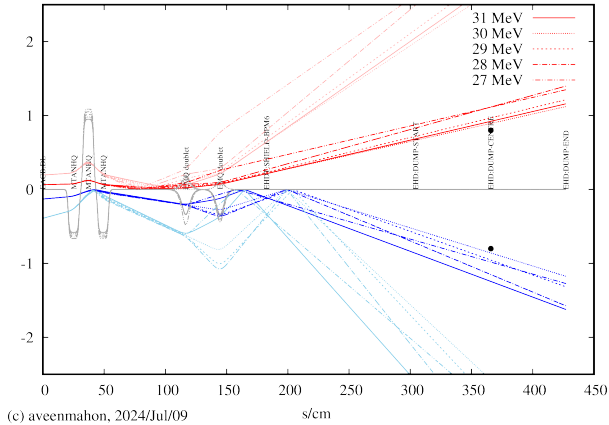
Requirement: 27-31 MeV range

Solution: lower PMQ strengths by ≈ 10% to accommodate for lower energy requirement.

New PMQ strengths:

- -0.55 T
- 0.9 T
- -0.55 T

Model also valid for regular operation (no target).



Other targets and energies:

Still unclear what the exact “ask” is...

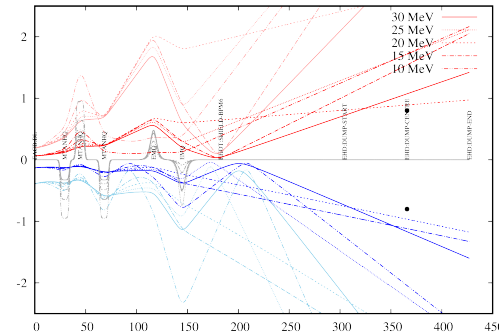
Angela has been checking the following:

- 1 μm Carbon target optics from 10-30 MeV
- 1 μm Ta target optics from 10-30 MeV

Aiming for a setup using either previously ordered 0.3 T PMQs or newer triplet.

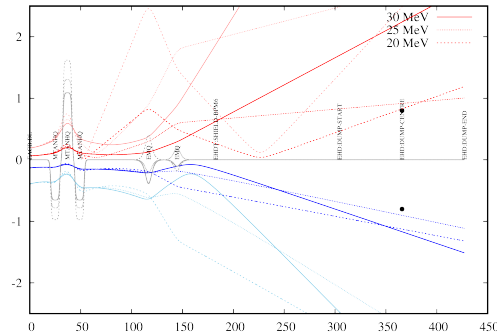
1 μm Carbon Target

0.3 T PMQs



(c) angelasabzevarigonzalez, 2024/Jul/09

Nominal PMQs



(c) angelasabzevarigonzalez, 2024/Jul/09

Scenario	x1 [cm]	x2 [cm]	x3 [cm]	x5 [cm]	x6 [cm]
0.3T PMQs	29.4369	44.6209	68.1042	116.717	144.716
Nominal PMQs	25.0069	37.0207	49.0346	116.716	144.715

Status

- Found solution for carbon target at all energies.
- Working on getting Ta scattering angles at lower energies.

Energy [MeV]	Material	0.3T PMQs	Nominal PMQs
10	C	✓	✗
10	Ta	tbd	tbd
15	C	✓	✗
15	Ta	tbd	tbd
20	C	✓	✓
20	Ta	tbd	tbd
25	C	✓	✓
25	Ta	tbd	tbd
30	C	✓	✓
30	Ta	✗	✓

Summary

- Agreement between TRANSOPTR, GEANT & FLUKA
- PMQs need to be lowered by $\approx 10\%$
- Solution for $1\,\mu\text{m}$ Carbon target down to 10 MeV

TRIUMF

Thank you
Merci

References I

R Baartman. Quadrupole shapes. *Physical Review Special Topics—Accelerators and Beams*, 15(7):074002, 2012.