Comparison of Carbon and Hi-Z Primary Collimators for Phase 2

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Motivation:

1. Reduce the number of single-diffractive protons lost in the dispersion suppressor.

2. Reduce the energy deposition in warm magnets and beam pipes near the primary collimators.

Outline

I. Choice of Tungsten

II. Conditions for SixTrack Runs

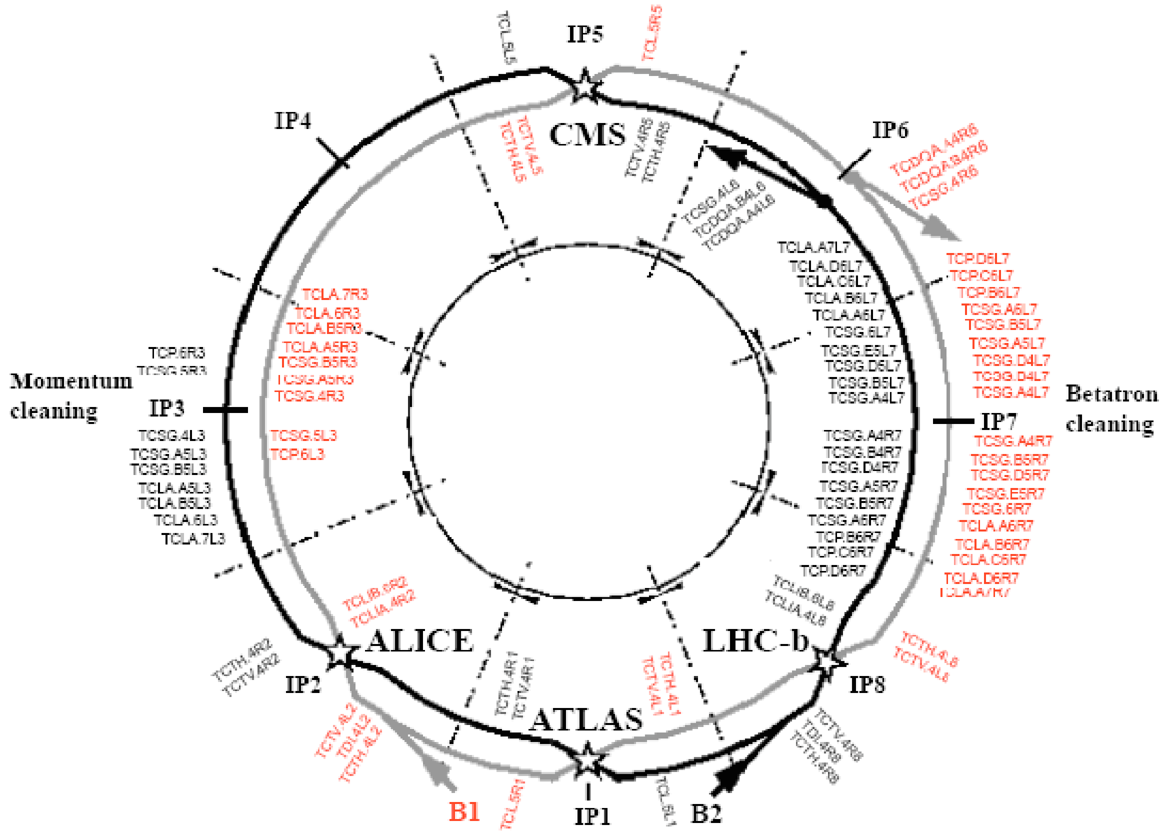
III. SixTrack/TURTLE Results
- Losses in the dispersion suppressor
- Local inefficiency
- Global inefficiency

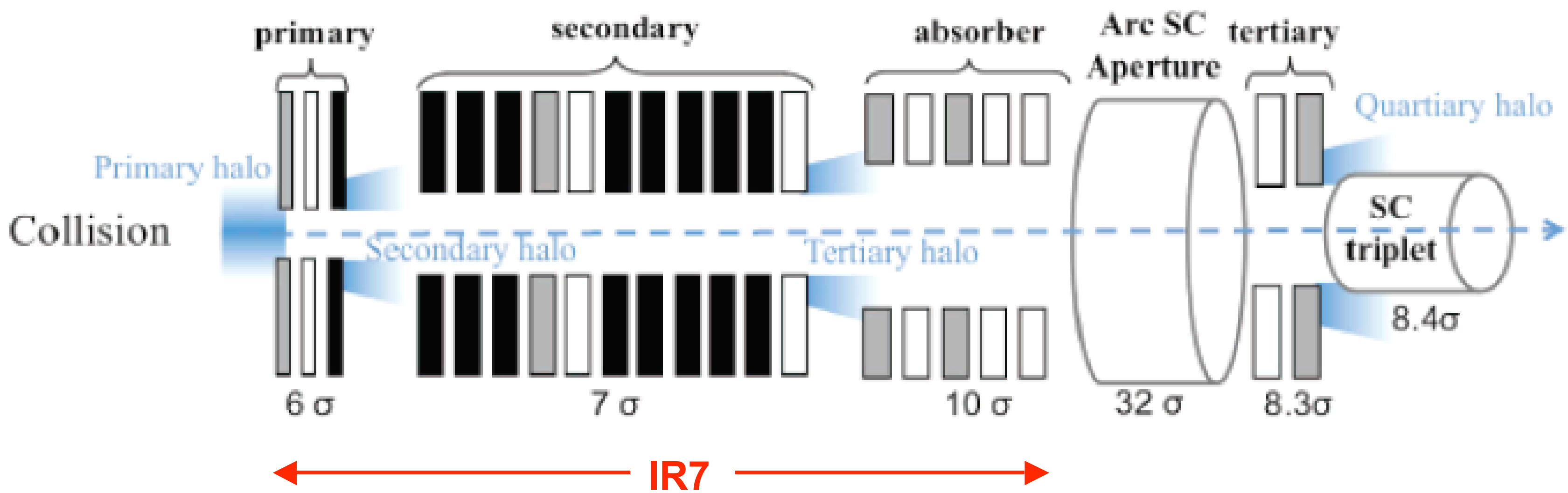
IV. Energy Loss in the IR7 Beam Line Elements

V. Energy Deposition in the Tungsten Radiator

VI. Summary

VII. Further Work


IP5
CMS
IP4
IP6
Momentum
cleaning
IP3
IP7
Betatron
cleaning
ALICE
IP2
LHC-b
IP8
ATLAS
IP1
B1
B2


primary
secondary
absorber
Arc SC
Aperture
tertiary
Primary halo
Quartiary halo
Collision
Secondary halo
Tertiary halo
SC
triplet
8.4σ
6 σ
7 σ
10 σ
32 σ
8.3σ
IR7

Choice of Tungsten as the Primary Collimator Material

1. Want to reduce the halo loss from nuclear interactions (and therefore the number of single-diffractives) and increase the halo loss from multiple coulomb scattering (MCS).

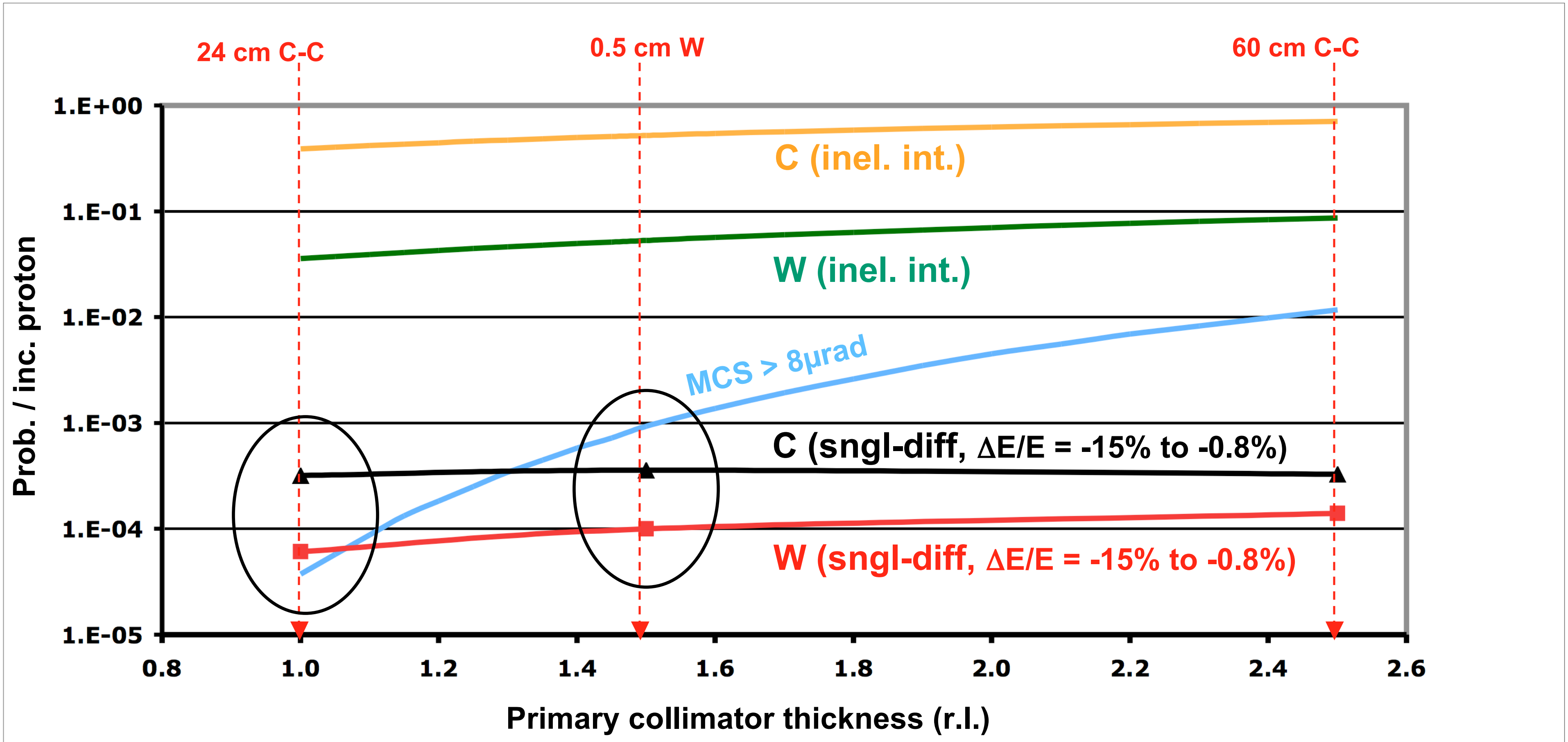
2. Since MCS scales as $1/\sqrt{\ }$ radiation length, for a given thickness material, want to minimize the ratio (R) of radiation length to nuclear interaction length, i.e. the opposite of the Phase 1 philosophy.

3. For C-C, R ≈ 24cm/48cm = 0.5; and for W, R = 0.35cm/9.6cm = 0.036

4. Tungsten probably doesn’t need water cooling and will not be damaged as long as t < 3-4 RL.

Probability of Various Interactions/Incident Proton

Single pass through TCPH (FLUKA)



Note:

On-momentum protons which scatter more than 8 μrad in the horizontal plane hit the secondary collimators, otherwise they go around the ring again.

Based on the large ratio of MCS > 8 μrad to sngl-diff and the desire to keep the nuclear interactions as small as possible, choose 1.5 r.l. (0.525 cm) tungsten.

Conditions for SixTrack Runs:

a) 7 TeV, V6_500 optics, low beta, beam 1, sextupoles on, "perfect" machine.

b) Halo on TCPH, jaws parallel, 4 x 10^{11} loss rate unless otherwise specified.

c) Halo dE/E = 0.

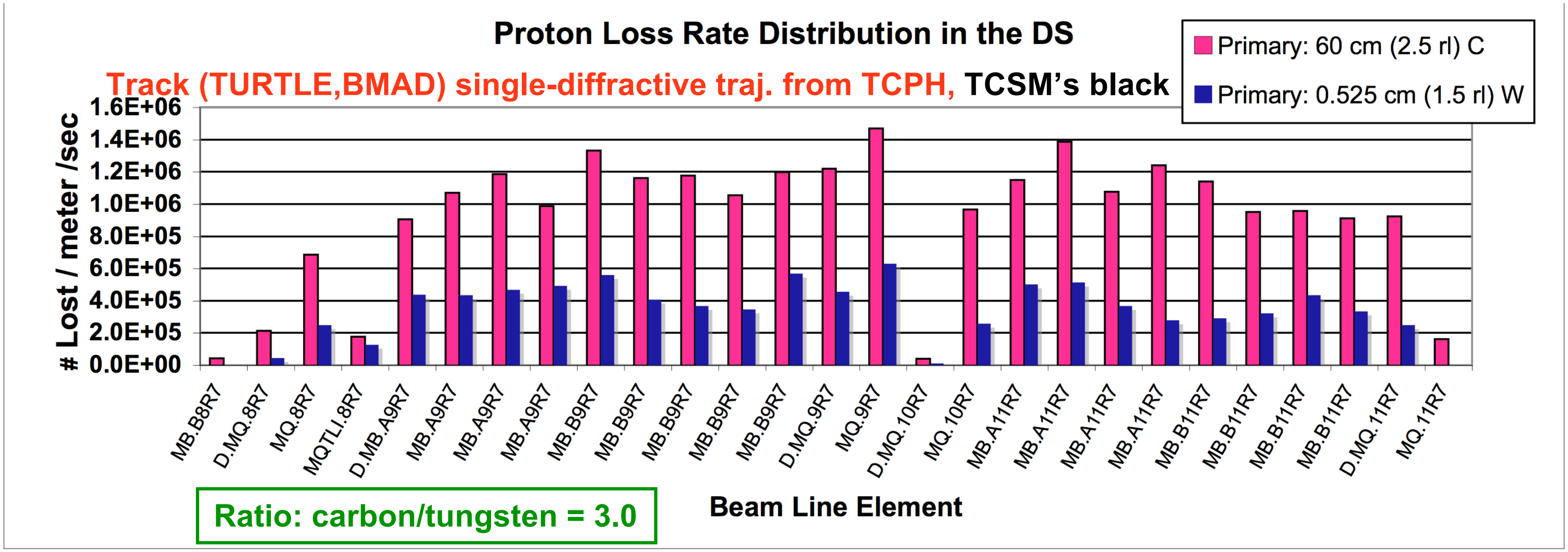
d) Collimator settings:

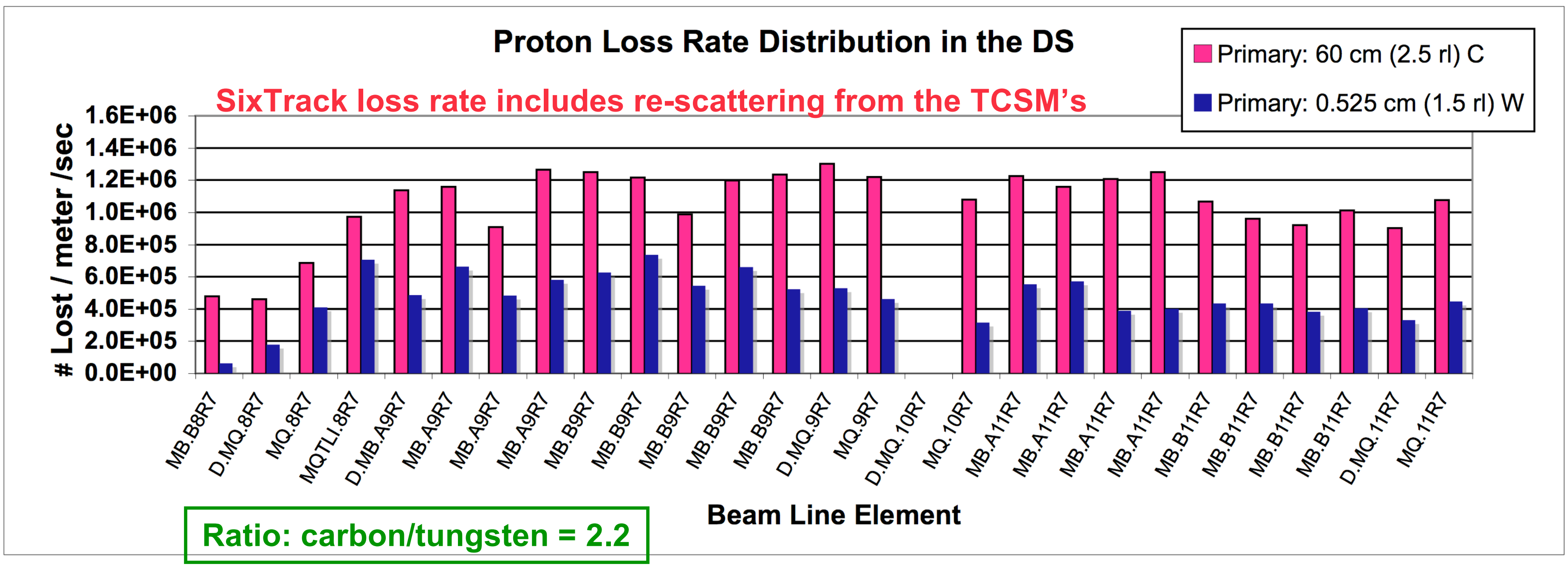
primaries @ 6 sigma, carbon or tungsten
secondaries @ 7 sigma, copper
absorbers @ 10 sigma, tungsten
tertiaries @ 8.3 sigma, tungsten

e) In addition to the usual SixTrack and aperture model output, SixTrack also provided:

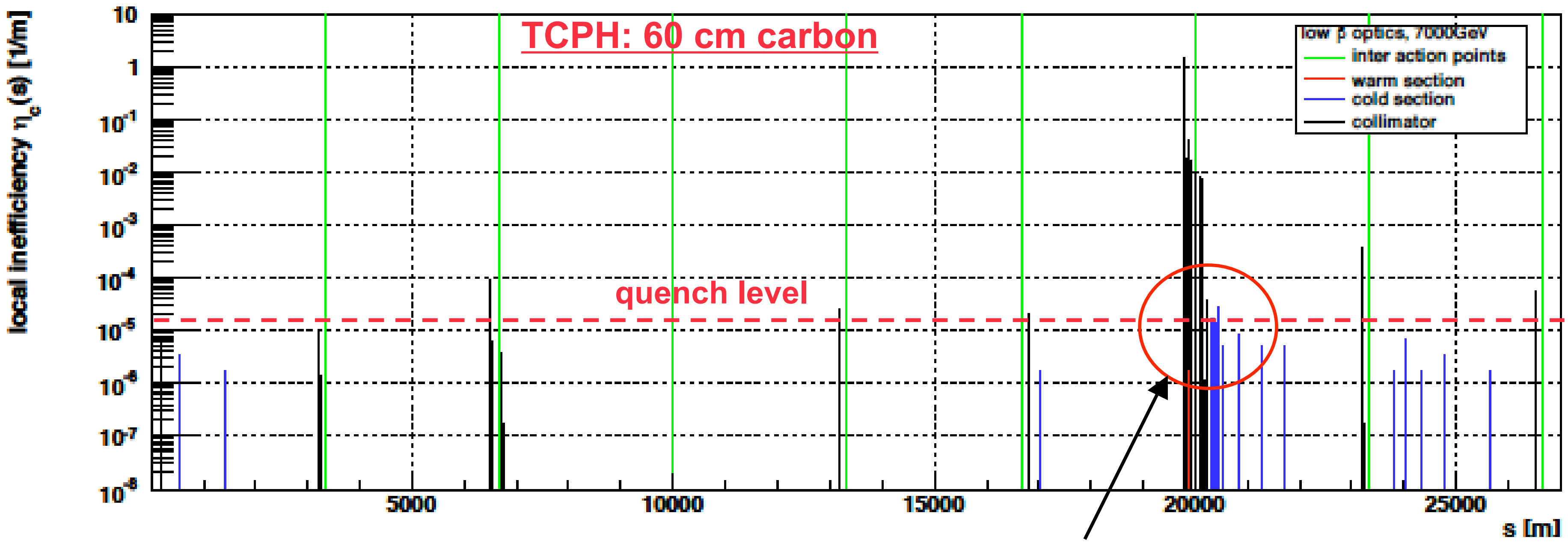
1. Trajectories of all single-diffractive protons just down beam from TCPH. These can be used by other optics programs to check losses around the ring and especially in the DS. They can also be used to compare S.D. production with FLUKA.

2. Trajectories of all single-diffractive protons which reach the beginning of the DS (also useful for checking SixTrack optics).


Proton Loss Rate Distribution in the DS
Track (TURTLE,BMAD) single-diffractive traj. from TCPH, TCSM's black
Primary: 60 cm (2.5 rl) C
Primary: 0.525 cm (1.5 rl) W
Lost / meter /sec
1.6E+06
1.4E+06
1.2E+06
1.0E+06
8.0E+05
6.0E+05
4.0E+05
2.0E+05
0.0E+00
MB.B8R7
D.MQ.8R7
MQ.8R7
MQTLI.8R7
D.MB.A9R7
MB.A9R7
MB.A9R7
MB.A9R7
MB.B9R7
MB.B9R7
MB.B9R7
MB.B9R7
MB.B9R7
D.MQ.9R7
MQ.9R7
D.MQ.10R7
MQ.10R7
MB.A11R7
MB.A11R7
MB.A11R7
MB.A11R7
MB.B11R7
MB.B11R7
MB.B11R7
MB.B11R7
D.MQ.11R7
MQ.11R7
Beam Line Element
Ratio: carbon/tungsten = 3.0


Proton Loss Rate Distribution in the DS
SixTrack loss rate includes re-scattering from the TCSM's
Primary: 60 cm (2.5 rl) C
Primary: 0.525 cm (1.5 rl) W
Lost / meter /sec
1.6E+06
1.4E+06
1.2E+06
1.0E+06
8.0E+05
6.0E+05
4.0E+05
2.0E+05
0.0E+00
MB.B8R7
D.MQ.8R7
MQ.8R7
MQTLI.8R7
D.MB.A9R7
MB.A9R7
MB.A9R7
MB.A9R7
MB.B9R7
MB.B9R7
MB.B9R7
MB.B9R7
MB.B9R7
D.MQ.9R7
MQ.9R7
D.MQ.10R7
MQ.10R7
MB.A11R7
MB.A11R7
MB.A11R7
MB.A11R7
MB.B11R7
MB.B11R7
MB.B11R7
MB.B11R7
D.MQ.11R7
MQ.11R7
Beam Line Element
Ratio: carbon/tungsten = 2.2

Local Inefficiency



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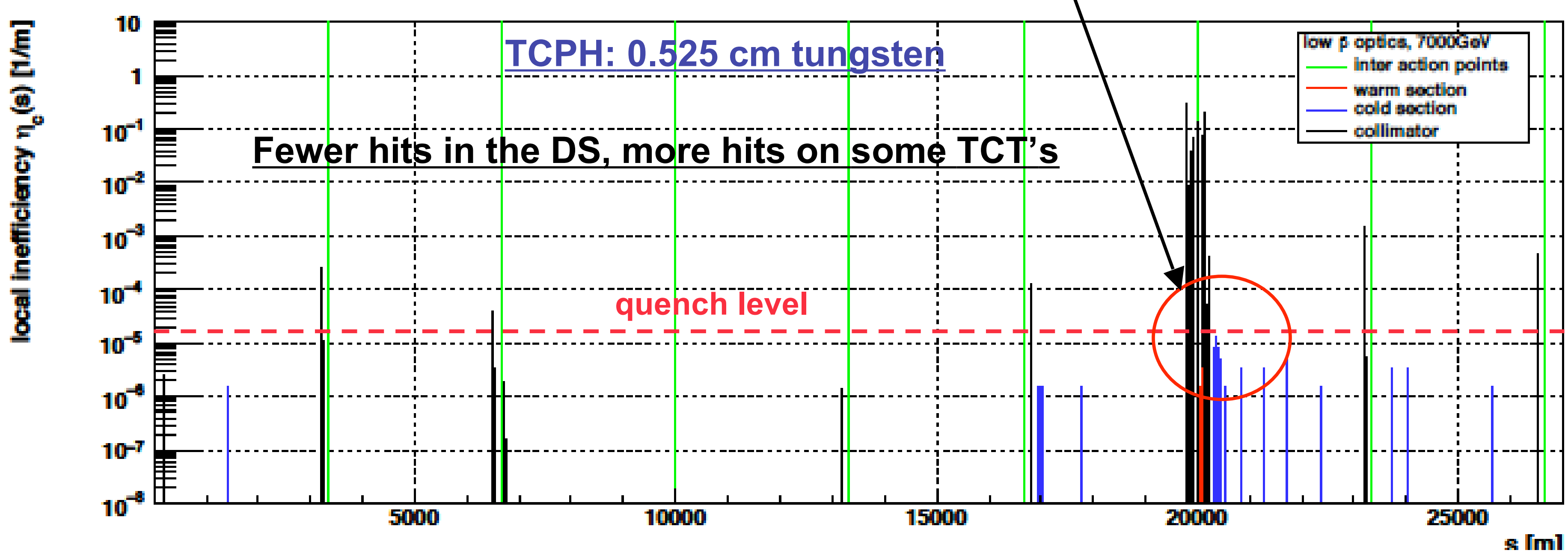
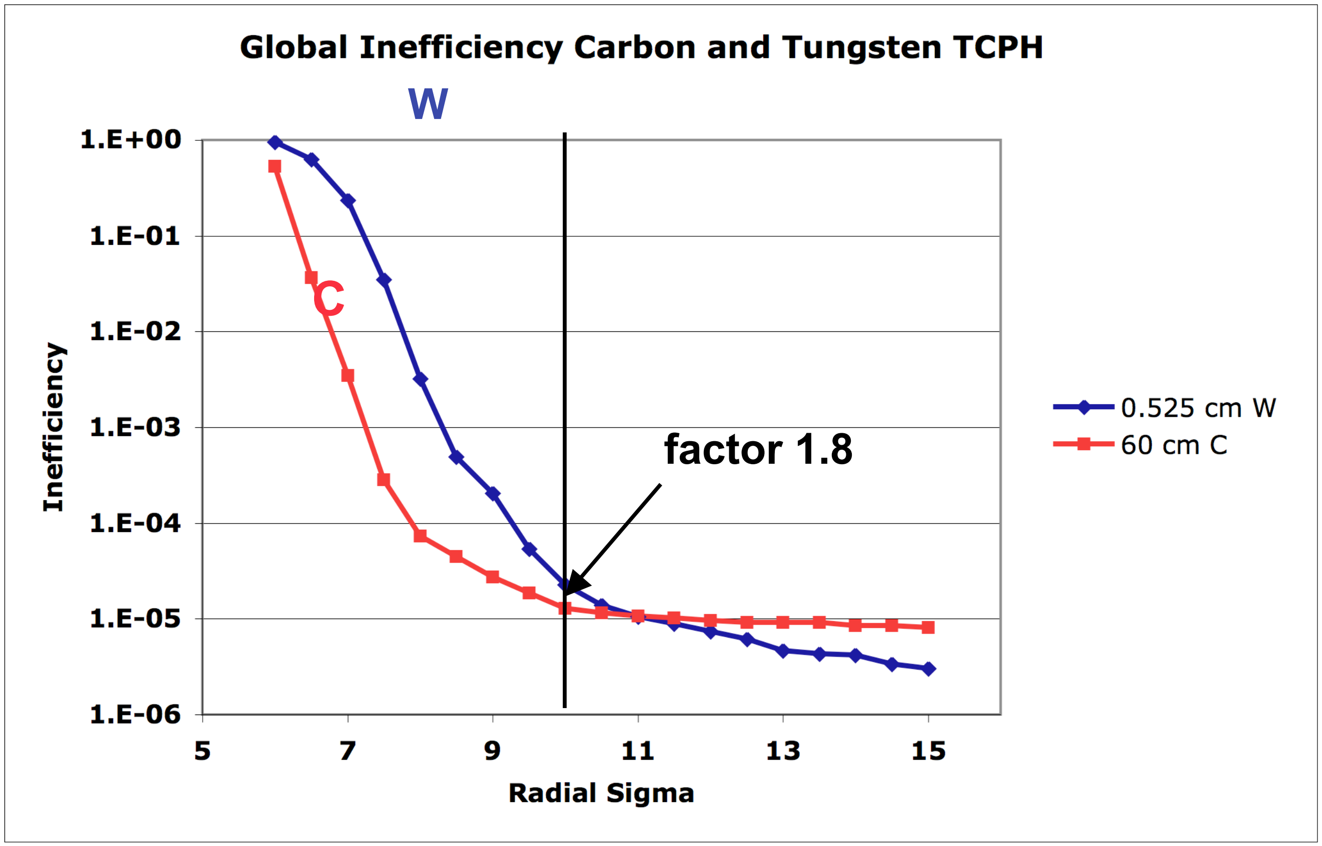


Global Inefficiency

$$\eta_c(A_c) = \frac{N_p(A > A_c)}{N_{abs}}$$

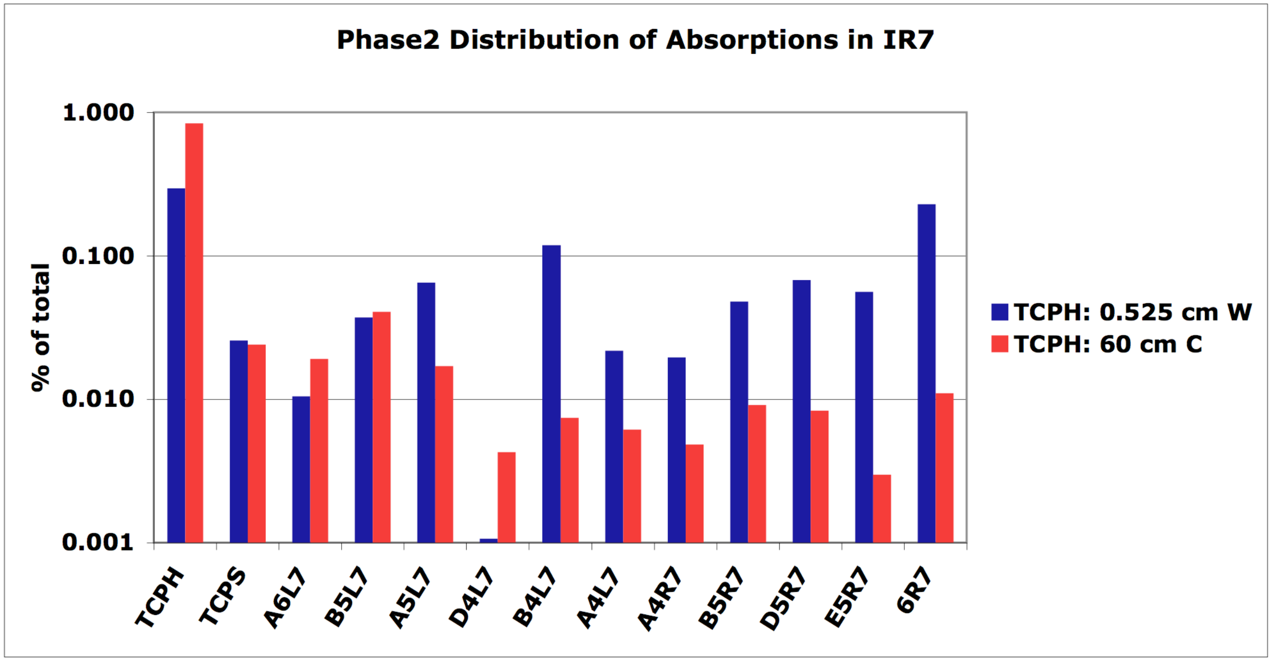


Global inefficiency about x2 worse for W @ 10σ

SixTrack Fractional Distribution of Inelastic Impacts on Phase 2 Collimators

(For Input to FLUKA)

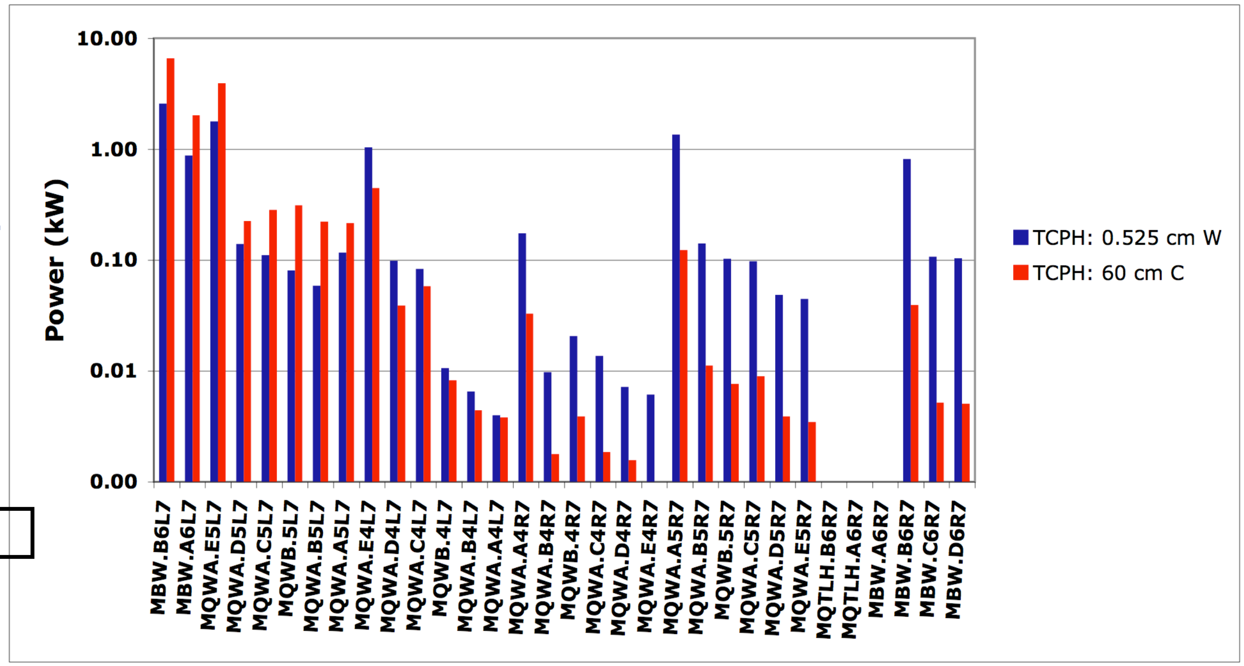
	TCPH 60 cm carbon	TCPH 0.525 cm tungsten
TCPH	0.845	0.297
TCPS	0.024	0.026
A6L7	0.019	0.011
B5L7	0.041	0.037
A5L7	0.017	0.065
D4L7	0.004	0.001
B4L7	0.007	0.119
A4L7	0.006	0.022
A4R7	0.005	0.020
B5R7	0.009	0.048
D5R7	0.008	0.068
E5R7	0.003	0.056
6R7	0.011	0.230
	1.00	1.00



Steady State Power Distribution on IR7 Magnets (SixTrack + FLUKA)

Quadrupoles	TCPH carbon	TCPH tungsten
MQWA.E5L7	3.94 kW	1.78 kW
MQWA.D5L7	0.23	0.14
MQWA.C5L7	0.29	0.11
MQWB.5L7	0.31	0.08
MQWA.B5L7	0.22	0.06
MQWA.A5L7	0.22	0.12
MQWA.E4L7	0.45	1.04
MQWA.D4L7	0.04	0.10
MQWA.C4L7	0.06	0.08
MQWB.4L7	0.01	0.01
MQWA.B4L7	0.004	0.01
MQWA.A4L7	0.004	0.004
MQWA.A4R7	0.03	0.18
MQWA.B4R7	0.002	0.01
MQWB.4R7	0.004	0.02
MQWA.C4R7	0.002	0.01
MQWA.D4R7	0.002	0.01
MQWA.E4R7	0.001	0.01
MQWA.A5R7	0.12	1.36
MQWA.B5R7	0.01	0.14
MQWB.5R7	0.01	0.10
MQWA.C5R7	0.001	0.10
MQWA.D5R7	0.004	0.05
MQWA.E5R7	0.003	0.04
MQTLH.B6R7	0.0001	0.0002
MQTLH.A6R7	0.00001	0.0001

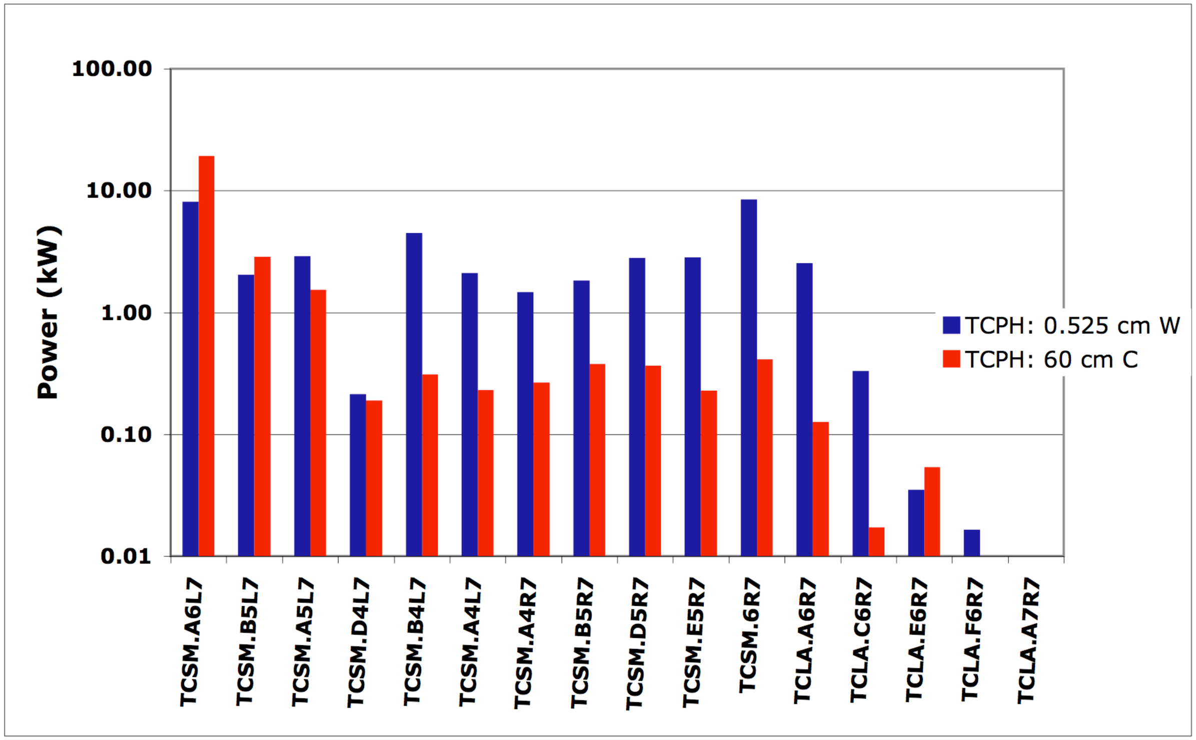
Dipoles	TCPH carbon	TCPH tungsten
MBW.B6L7	6.6 kW	2.6 kW
MBW.A6L7	2.0	0.9
MBW.B6R7	0.04	0.8
MBW.C6R7	0.005	0.11
MBW.D6R7	0.005	0.11



	carbon	tungsten
Total power, Quads + Dipoles	14.7 kW	10.1 kW

Steady State Power on IR7 Phase 2 Collimators and Absorbers (FLUKA)

Collimator	TCPH 60 cm carbon	TCPH 0.525 cm tungsten
TCSM.A6L7	19.4 kW	8.12 kW
TCSM.B5L7	2.89	2.04
TCSM.A5L7	1.54	2.90
TCSM.D4L7	0.19	0.21
TCSM.B4L7	0.31	4.53
TCSM.A4L7	0.23	2.12
TCSM.A4R7	0.27	1.48
TCSM.B5R7	0.38	1.84
TCSM.D5R7	0.37	2.82
TCSM.E5R7	0.23	2.84
TCSM.6R7	0.41	8.51
TCLA.A6R7	0.13	2.55
TCLA.C6R7	0.02	0.33
TCLA.E6R7	0.05	0.04
TCLA.F6R7	0.005	0.02
TCLA.A7R7	0.000	0.000
	26 kW	40 kW



LARP

Summary of Energy Loss in IR7 with 0.5 cm W Primary Collimators

1. The predominant halo loss occurs from multiple coulomb scattering in the primary collimators causing inelastic impacts in the secondary collimator system.

2. There are approximately a factor of three fewer inelastic impacts in the primary collimators resulting in a corresponding factor less radiation dose on the nearby warm magnets and beam pipes and 30% less total dose (14.7 kW => 10.1 kW) to quads and dipoles. The dose is also spread more uniformly in IR7.

3. There is a factor of 2.5 less energy loss (19.4 kW => 8.1 kW) on the first secondary collimator but 50% more energy (26 kW => 40 kW) is contained in the copper secondary collimators.

Energy Deposition in the 0.5 cm Tungsten Radiator

1. Would actually use tungsten with 25% rhenium - stronger, more ductile (from D. Walz).

2. Steady state (8 x 10^{10} p/sec) heating: 0.4 w each jaw (FLUKA).
   (Can be calculated simply from dE/dx but checked with FLUKA to get contribution from π^0 production (adds 40% to simple dE/dx).

3. Accident (9 x 10^{11} protons in 8 bunches) heating: $\Delta T \approx 1000$ ºC. W-Re melting point is 3200 ºC.
   As robust as carbon for accident

4. For a thin radiator the temperature rise in an accident is proportional to the number of bombarding protons, so it must be retracted during injection.

Is water-cooling necessary for the steady state running (0.4 w/jaw)?

Could three of these thin radiator assemblies be put into the 2 m space reserved for TCP.A6L7 (TCPS2)?

Summary

In Phase 2 with an 0.5 cm tungsten primary collimator (compared to 60 cm carbon):

I. SixTrack has shown that cold losses in the dispersion suppressor are 2.2 times smaller.

II. The radiation dose is a factor of 3 smaller in nearby warm magnets.

III. The energy deposition in the 1st secondary collimator, TCSM.A6L7, is 2.5 times smaller.

IV. Losses on tertiary collimators in IR8, IR1, and IR2 are 2 to 5 times larger, (IR3 and IR5 are lower) - needs more study.

V. The global inefficiency is 1.8 times higher - needs more study.

VI. The jaws of a thin W radiator receive a small steady state power and easily survive a full 8-bunch kicker mis-fire accident.

Further Work

1. SixTrack run with halo on TCPV and TCPS.

2. SixTrack run with another tungsten thickness.

3. Simulate an ion beam on a tungsten primary to compare with carbon.

4. Try this in IR3.

5. Preliminary engineering to see if three small tungsten collimators can fit into a single 2m tank.

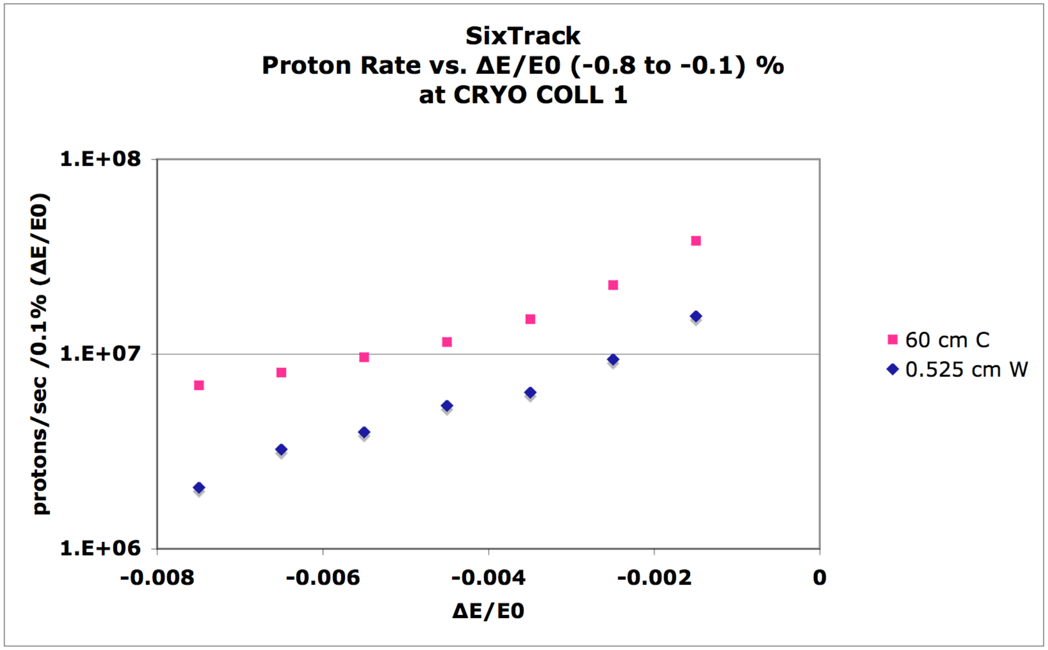
6. Study the effect of more hits on some of the TCT's.

7. For tungsten, compare single diffractive production in SixTrack and FLUKA - mostly finished - no time to report here.

8. Simulate residual activation of tungsten primary and compare with existing carbon primary (including the copper cooling plate).

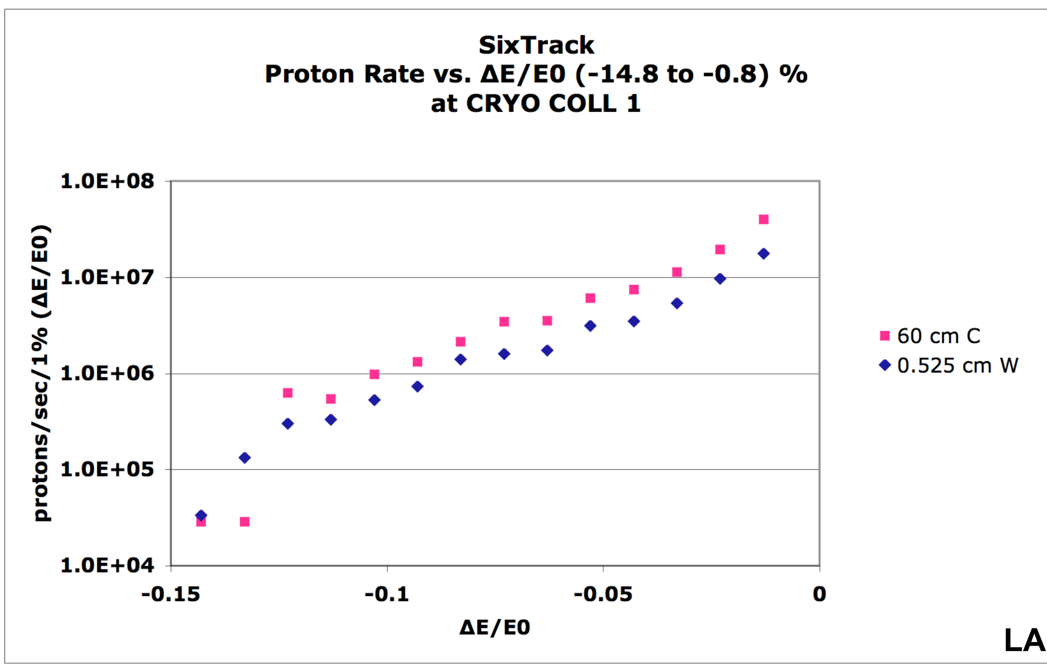
Backup Slides

Rate of Single-diffractive Protons at the Entrance to the Dispersion Suppressor



This group are lost on collimators in the ring

There are 2-3 times more S.D.'s with a carbon primary compared to a tungsten primary



This group are lost in the dispersion suppressor

Proton Inelastic Rate on the IR7 Collimators and Absorbers

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SixTrack runs:

TCPH: 0.525 cm tungsten
TCPH: 60 cm carbon