Efficiency of Two-Stage Collimation System

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Betatron Collimators in IR7

name	ds[m]	angle[degree]	L[m]	b_y[m]	a_y	dy_y[degree]
TCP.D6L7.B1	**0.00**	**90.01**	**0.02**	**76.66**	**-1.10**	**0.00**
TCP.C6L7.B1	**2.00**	**0.00**	**0.02**	**81.10**	**-1.15**	**1.42**
TCP.B6L7.B1	**4.00**	**126.91**	**0.02**	**85.76**	**-1.21**	**2.77**
TCSG.B6L7.B1	39.49	41.37	1.00	206.15	-2.21	17.99
TCSG.A6L7.B1	43.49	141.12	1.00	224.18	-2.32	19.04
TCSG.B5L7.B1	102.72	143.47	1.00	165.99	2.67	31.81
TCSG.A5L7.B1	106.72	40.68	1.00	145.63	2.48	33.28
TCSG.D4L7.B1	128.05	**90.01**	1.00	69.37	0.90	45.94
TCSG.B4L7.B1	197.98	0.00	1.00	133.15	-1.25	101.94
TCSG.A4L7.B1	201.98	134.59	1.00	143.50	-1.33	103.63
TCSG.A4R7.B1	205.98	46.30	1.00	154.47	-1.40	105.19
TCSG.B5R7.B1	254.72	141.52	1.00	267.98	-2.36	117.65
TCSG.D5R7.B1	313.23	51.39	1.00	158.25	2.92	128.97
TCSG.E5R7.B1	317.23	130.46	1.00	135.70	2.68	130.53
TCSG.6R7.B1	351.84	0.52	1.00	46.42	0.02	160.12

Definition of Efficiency

Ralph's

For a given normalized aperture a_c, the efficiency is

$$h_c(a_c) = \frac{1}{N}\sum_{i=1}^{N} H(A_r - a_c)$$

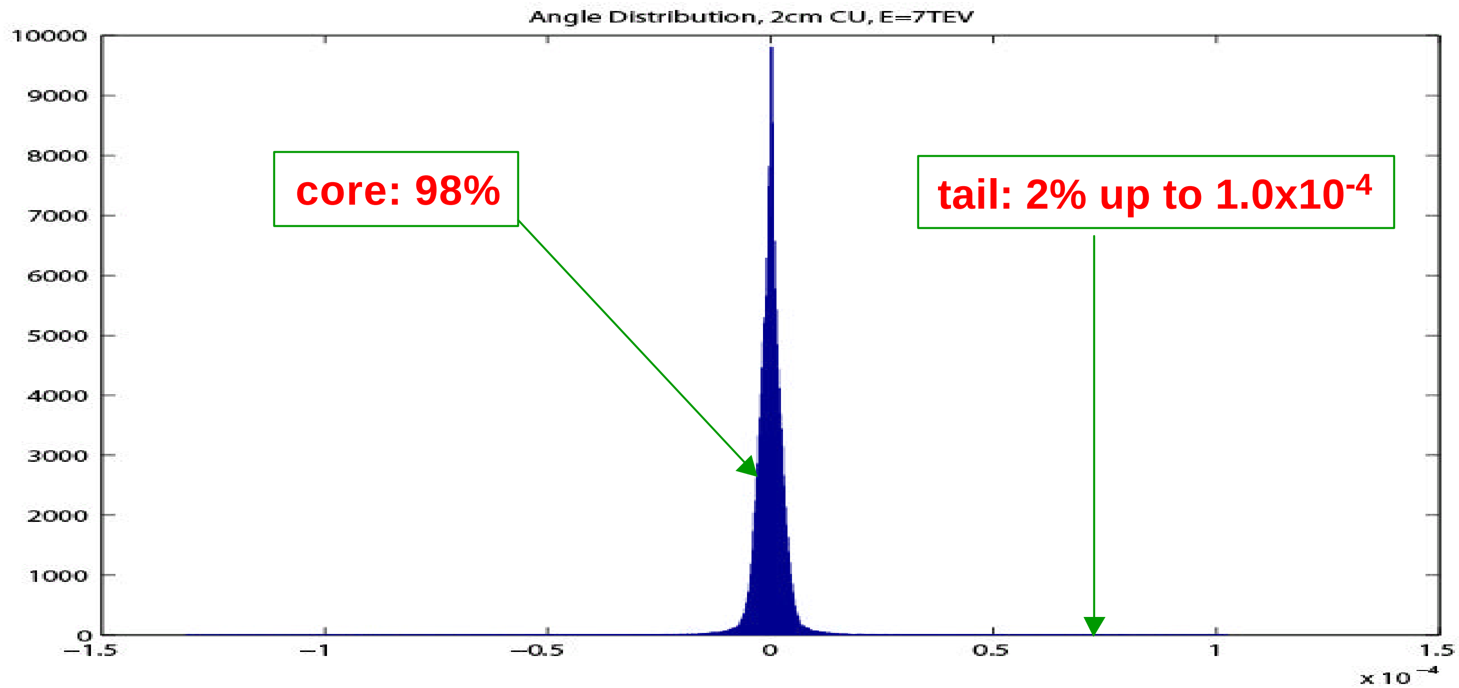
- N is # of particles impacting at the collimators
- H(x) is the Heaviside step function

$$A_r = \sqrt{A_x^2 + A_y^2},$$

$$A_x = \sqrt{\left(\frac{x}{\sqrt{e_x b_x}}\right)^2 + \left(\frac{a_x x + b_x p_x}{\sqrt{e_x b_x}}\right)^2}$$

Please note: once a particle reaches the aperture a_c in any turns, it is counted. Each particle only is counted one or zero.

Multiple Coulomb Scattering



Fermi distribution (core):

$$P(y, p_y \mid z) = \frac{2\sqrt{3}}{p z^2 w^2} \exp[-\frac{4}{w^2}(\frac{p_y^2}{z} - 3\frac{y p_y}{z^2} + 3\frac{y^2}{z^3})],$$

$$w^2 = (\frac{E_s}{b c p})^2 \frac{1}{L_R}, E_s = \sqrt{\frac{4p}{a}} m_e c^2 = 21.2 Mev,$$

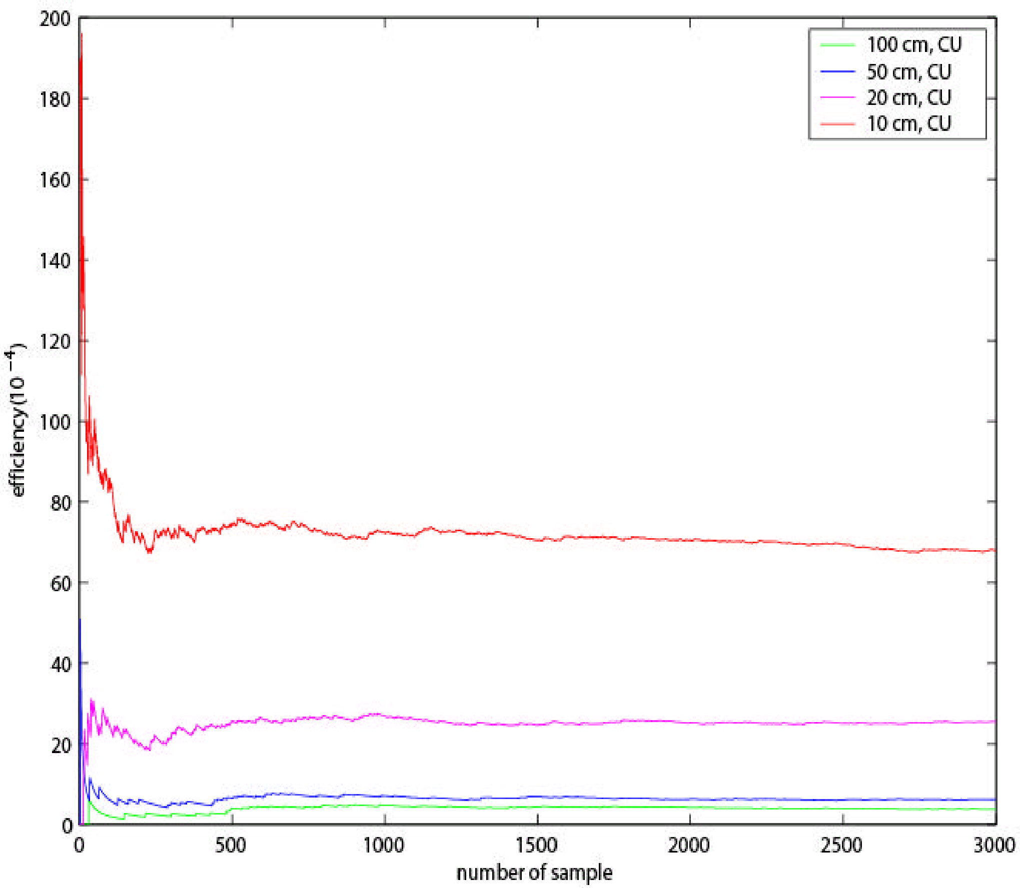
$$\sqrt{< p_y^2 >} = \sqrt{z/2}\, w$$

Simulation:
core rms: 2.49×10^{-6}
with a cut: 1.0×10^{-5}.
Theory:
core rms: 2.53×10^{-6}

Copper as the Material of Secondary Collimators for Phase-II

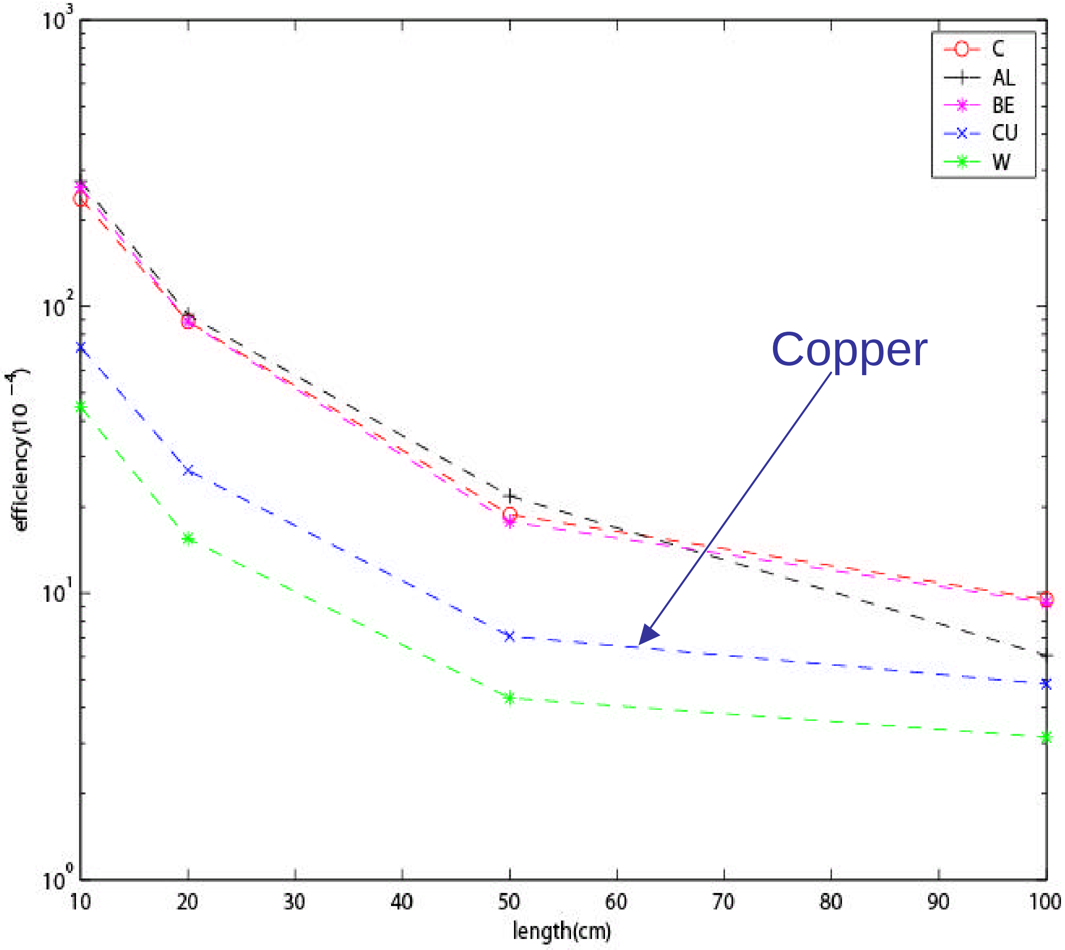
- Collision energy 7 Tev and collision lattice
- Primary collimators at 6σ and secondary ones at 7σ.
- Initial beam: 6.003(0.0015) in vertical plane

ν_x=64.31, ν_y=59.32, ε_x=ε_y=0.5nm-rad



Simulated using code: SixtrackwColl updated and supported by Guillaume Robert-Demolaize at CERN

Study of Material for Secondary Collimators



Heavy material is more effective in terms of efficiency of the system. So copper is chosen because its high thermal conductivity.

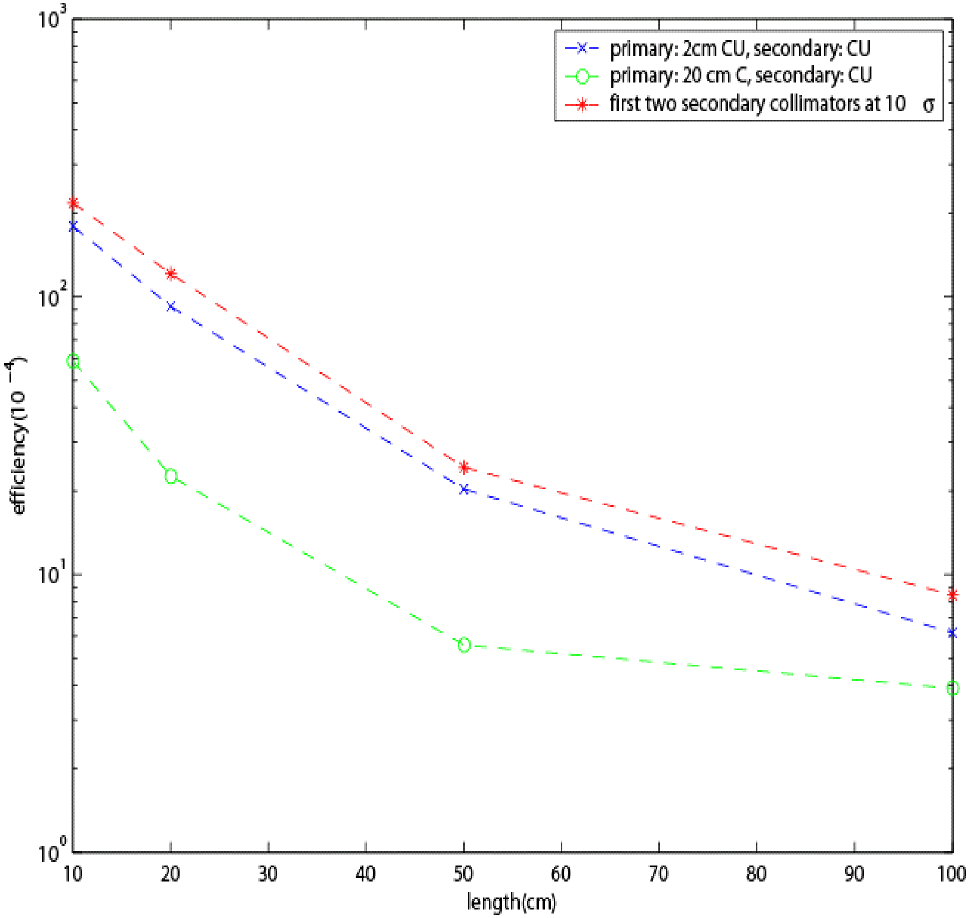
Length should be about 1 meter.

Achievable efficiency is about 3.5×10^{-4} at 10 σ.

Similar result was obtained by Ralph Aβmann

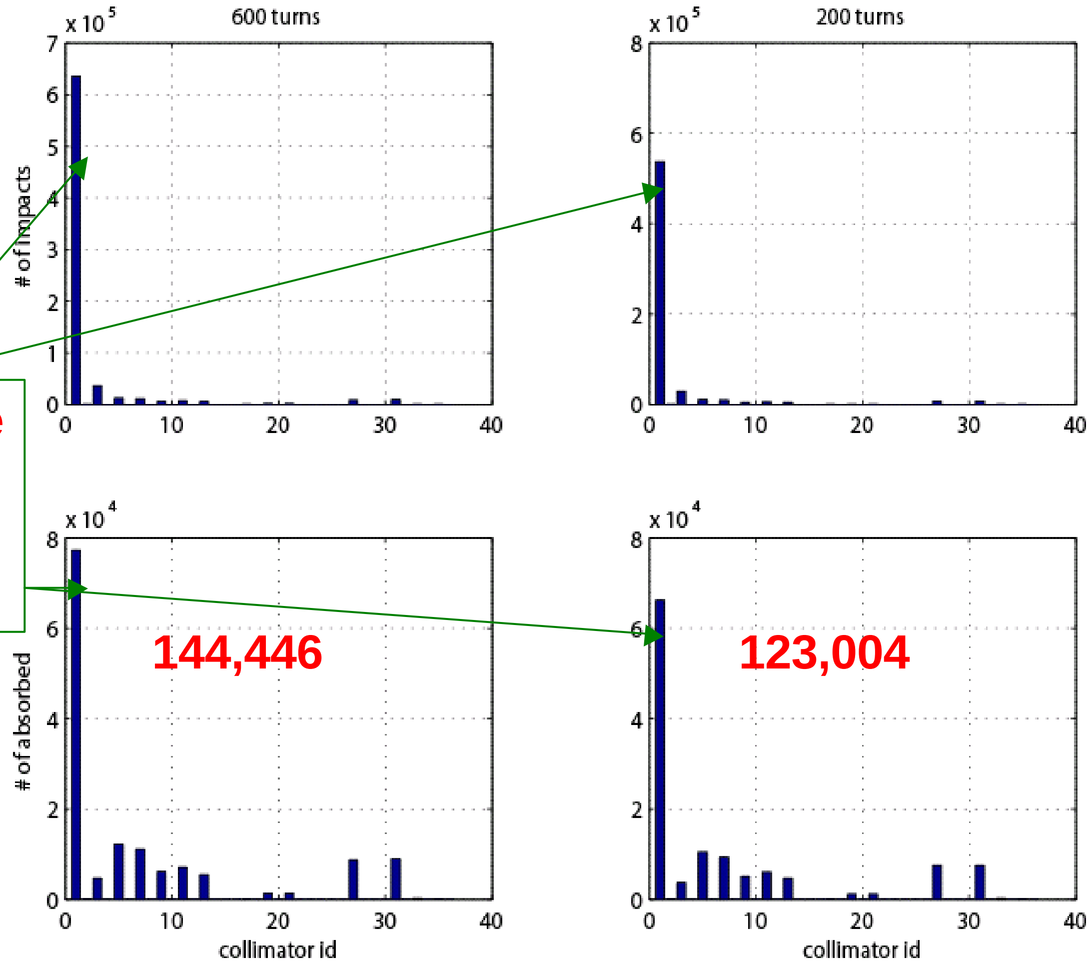
Study of Primary Collimators

- 2 cm copper primary collimators are less efficient than 20 cm carbon
- Why?



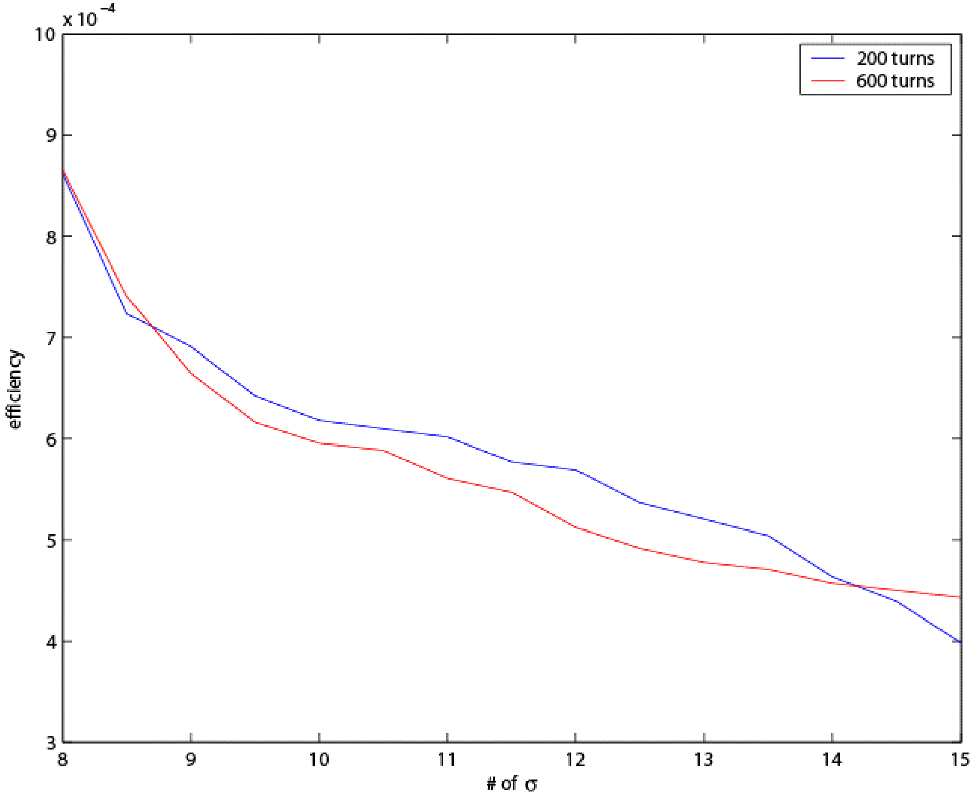
Loss Maps at Collimators

The difference Is mostly in the primary collimators.



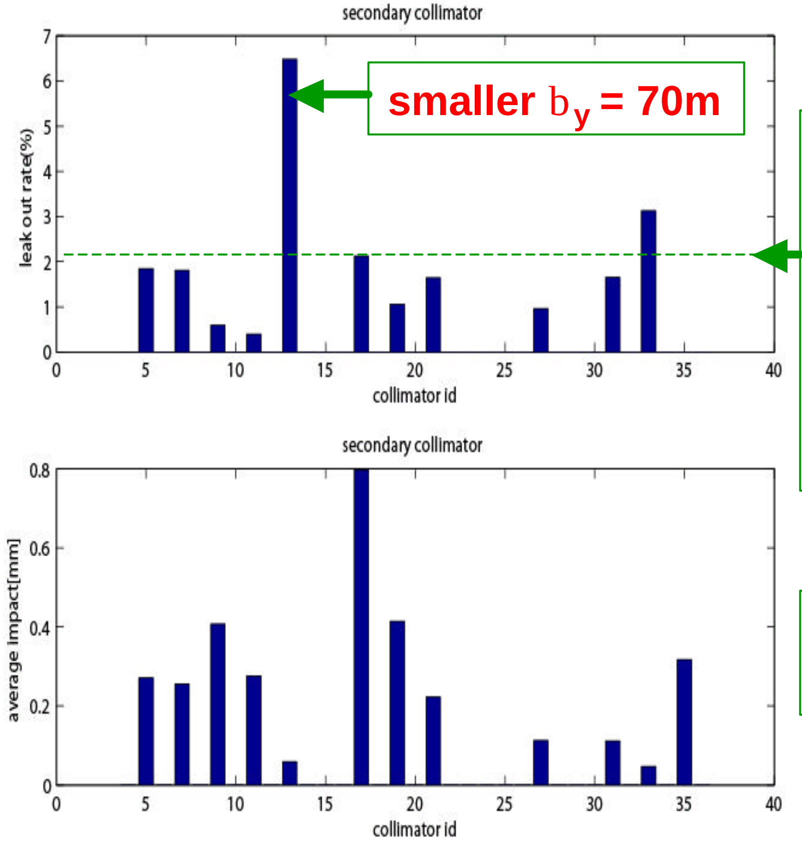
3000x64=192,000 particles tracked in the simulation.

Efficiency as Function of Aperture



At which aperture? What is the aperture of the SC magnets?

Leak out from Secondary Collimators



For 15cm of interaction length of copper, 2% leakage gives an effective length of 60cm compared with the actual length of 100cm. That implies that there are significant protons scattered through the edge of the collimators due to the angular divergence.

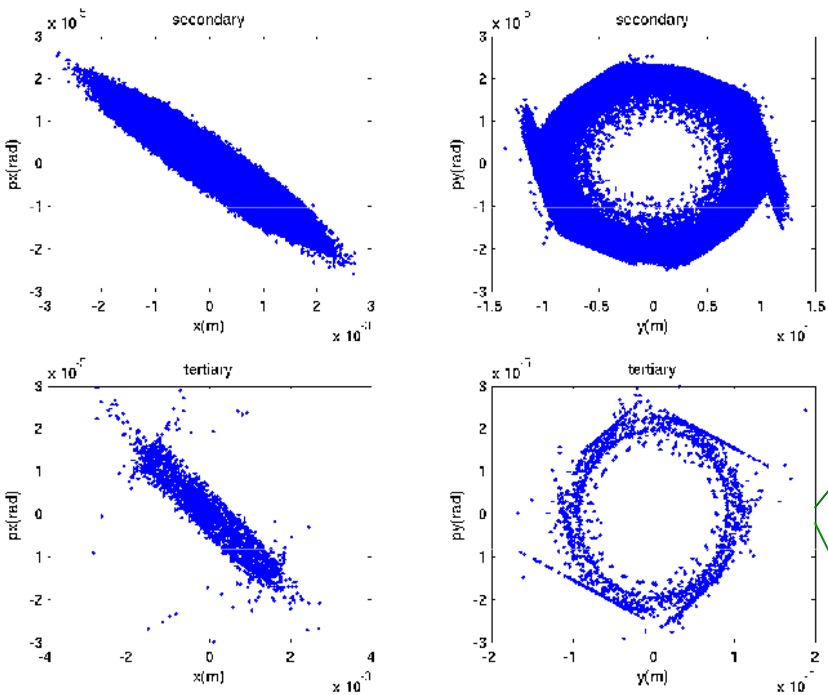
Total number of proton leaked out is 1155 out of 144,446 absorbed.

How Particles Escaped Collimation System?

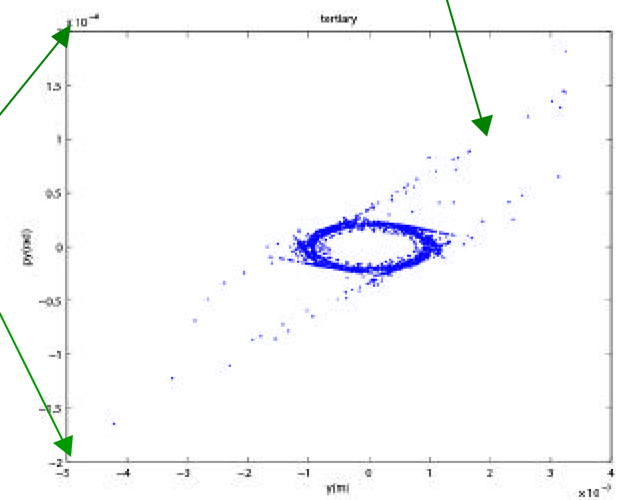
Horizontal **Vertical**

Secondary

Tertiary

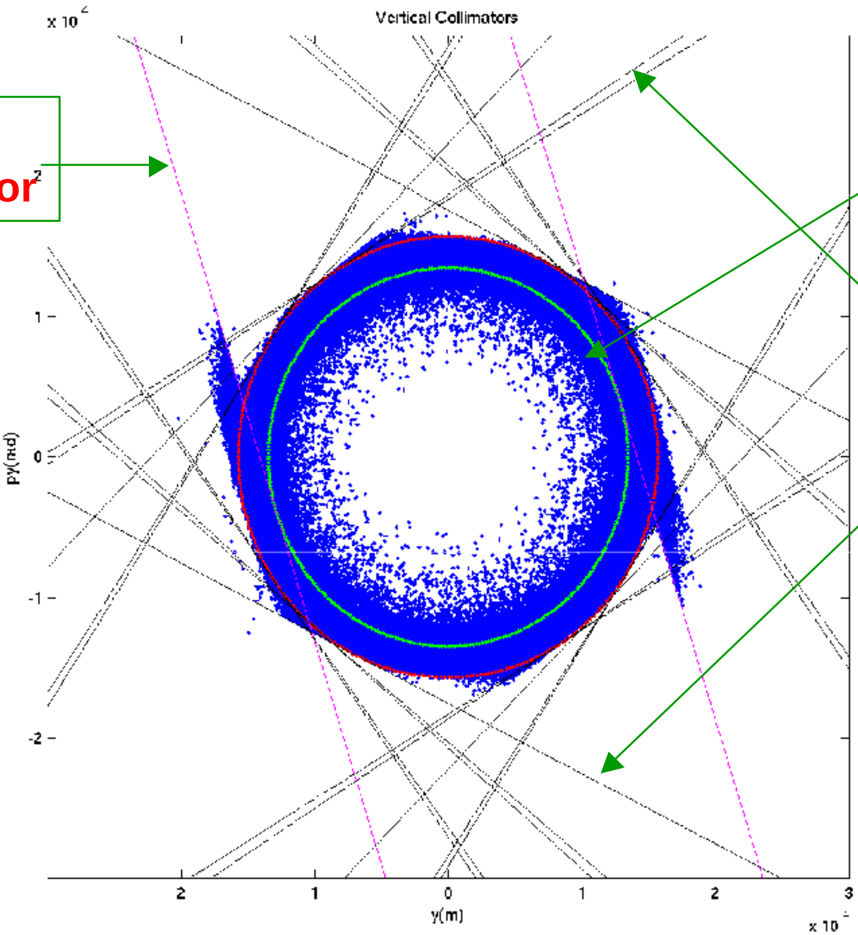


Route to large aperture



Vertical & Skew Collimators

Primary collimator

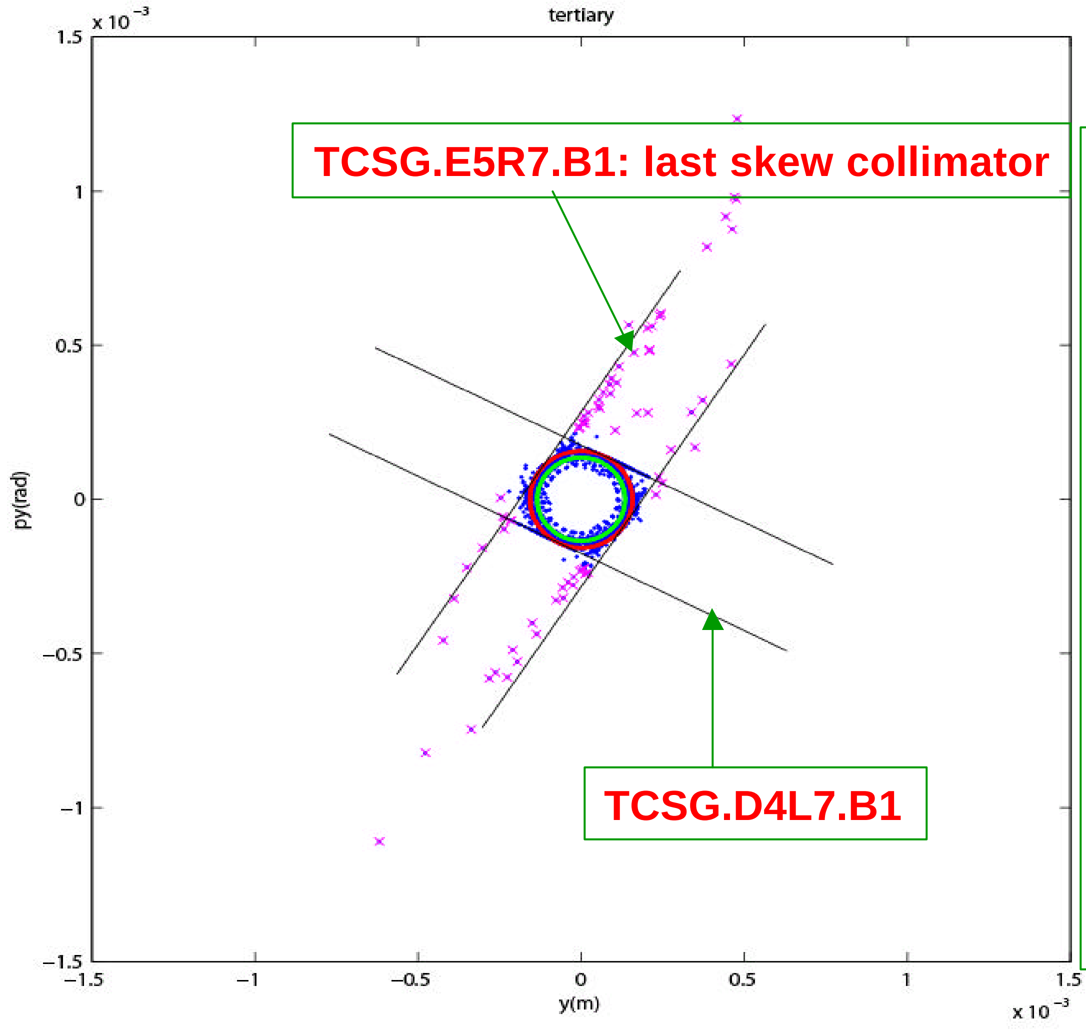


Secondary halo in normalized phase space at the end of collimation system

Collimators are projected to The end of collimation system

This is an independent check of the simulation code, since the collimators are plotted according to the lattice functions calculated using MAD.

Tertiary Halo: Particles Escaped from the Secondary Collimators



Number of particles beyond 10s is 73, which is consistent with the efficiency calculation: 73/144446 = 5x10^{-4}.

Tertiary halo at large amplitude is generated by the large-angle Coulomb scattering in the last collimator.

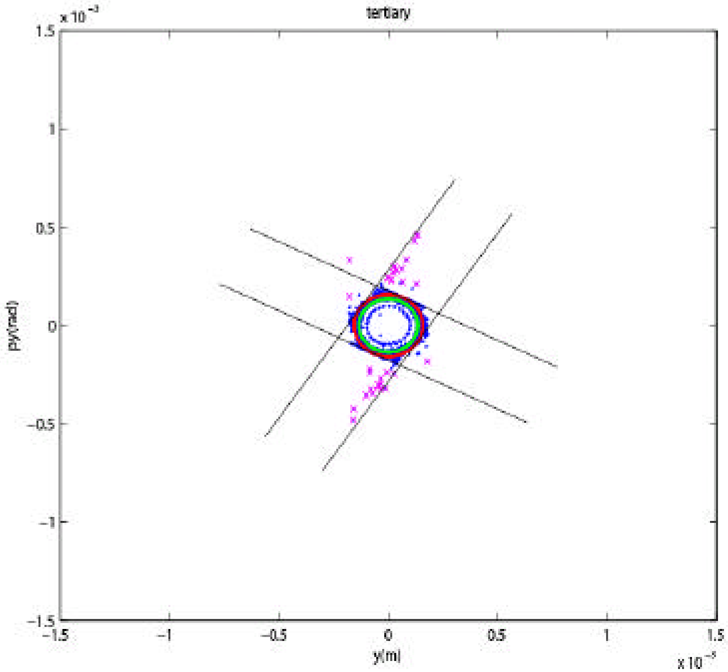
If we add a tertiary collimator at 8s in the same phase as the collimator: TCSG.D4L7.B1 after the secondary collimators, the efficiency should be better than 1x10^{-4}.

Important Components Contributed to the Efficiency of Collimation System

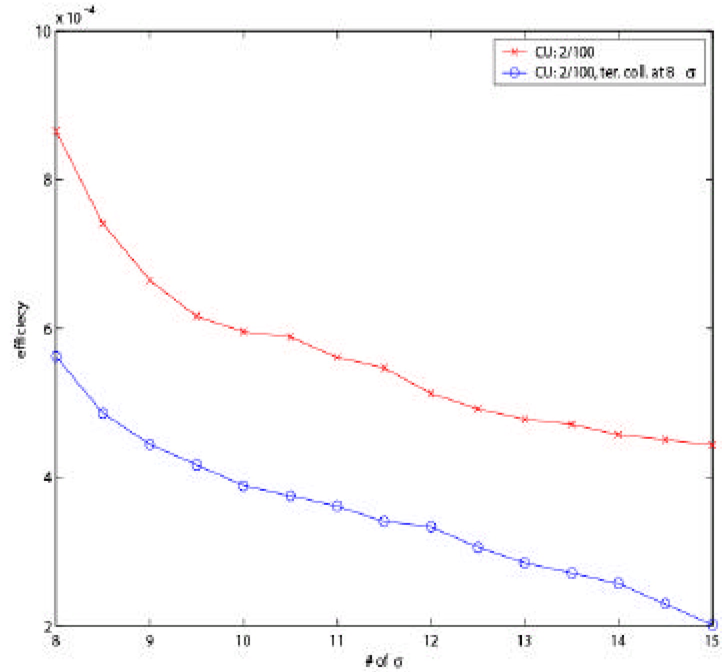
- Leakage from the secondary collimator
  - interaction length of collimator
  - angular divergence, α, β functions
- Large-angle Coulomb scattering in the last collimator
  - add tertiary collimator
  - use W for the last collimator

Add One Tertiary Collimator(8σ) at the End of Collimation System

Tertiary Halo



Efficiency



Efficiency is down from 6x10^{-4} to 4x10^{-4} at 10s. It can be improved further if a better phase is chosen.