MICE Step IV Lattice Optimization using GA

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and also

Cherenkov Light Yield

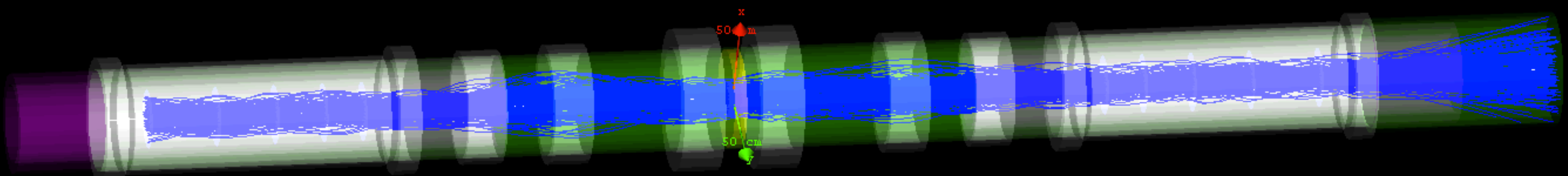
Outline

- Methodology of GA optimizations
- Results for Step IV lattice design
  - M1D off only
    - Minimum B_z of 2 T in the trackers;
    - Minimum B_z of 2.8 T in the trackers;
  - M1D and M2D both off
- Current Ckov light yield
- Discussion

Motivation

- MICE Step IV goals – demonstrate material physics properties
  - Measurement of the muon Multiple Coulomb Scattering (MCS) and energy loss in the materials;
  - Measurement of the transverse normalized emittance ($\varepsilon_\perp$) reduction
- In the absence of M1 coil downstream (M1D)
  - Lack of optics matching power;
  - Measurement of the MCS and energy loss are largely unaffected;
  - Can we still demonstrate $\varepsilon_\perp$ reduction?
  - Need: New lattice designs for all the run modes, which should have:
    - Decent transmission (good acceptance)
    - Maximized $\varepsilon_\perp$ reduction between the reference planes with minimum $\varepsilon_\perp$ growth, especially in the SSD.

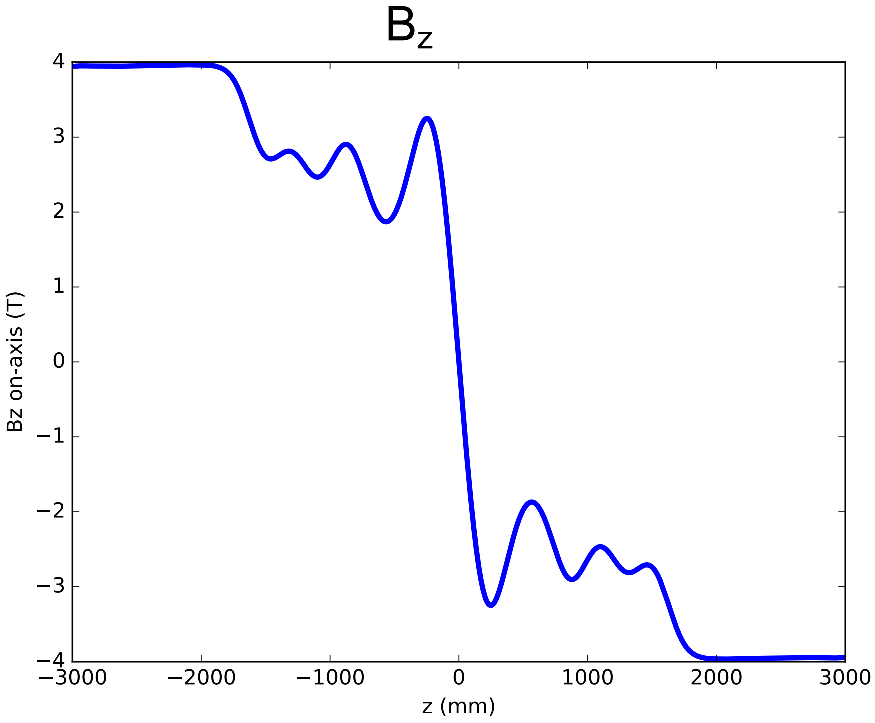
Simulation setup – G4Beamline

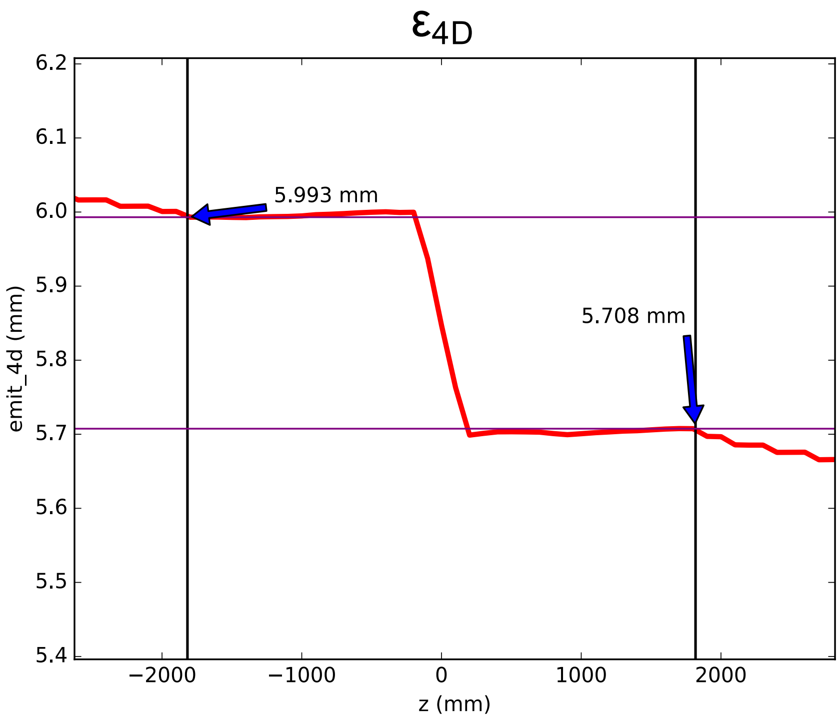


G4BL GUI multi-event display

- Geometry ID 70 of MICE Step IV cooling channel
- Materials in channel to match MAUS as accurately as possible:
  - SciFi tracker planes (2 mm Polystyrene each), 65 mm LiH absorber;
  - TOF2 at the end of the channel (+4200 mm from the absorber);
  - Beam pipe to kill particles hitting it (r=258 mm);
- Monte Carlo initial particle ensemble matched to the solenoid longitudinal field B_z
  - Beam starts at z=-3000 mm from the absorber (upstream tracker).
- G4BL chosen for its MPI feature and speed on the cluster

Simulation setup – G4Beamline (cont'd)





Nominal 200 MeV/c flip mode;
Transmission = 98% with δp/p in ± 5%
4.9% emit. Reduction between ref. planes
G4BL is consistent with MAUS results – both Geant4 based

Optimization setup – GA

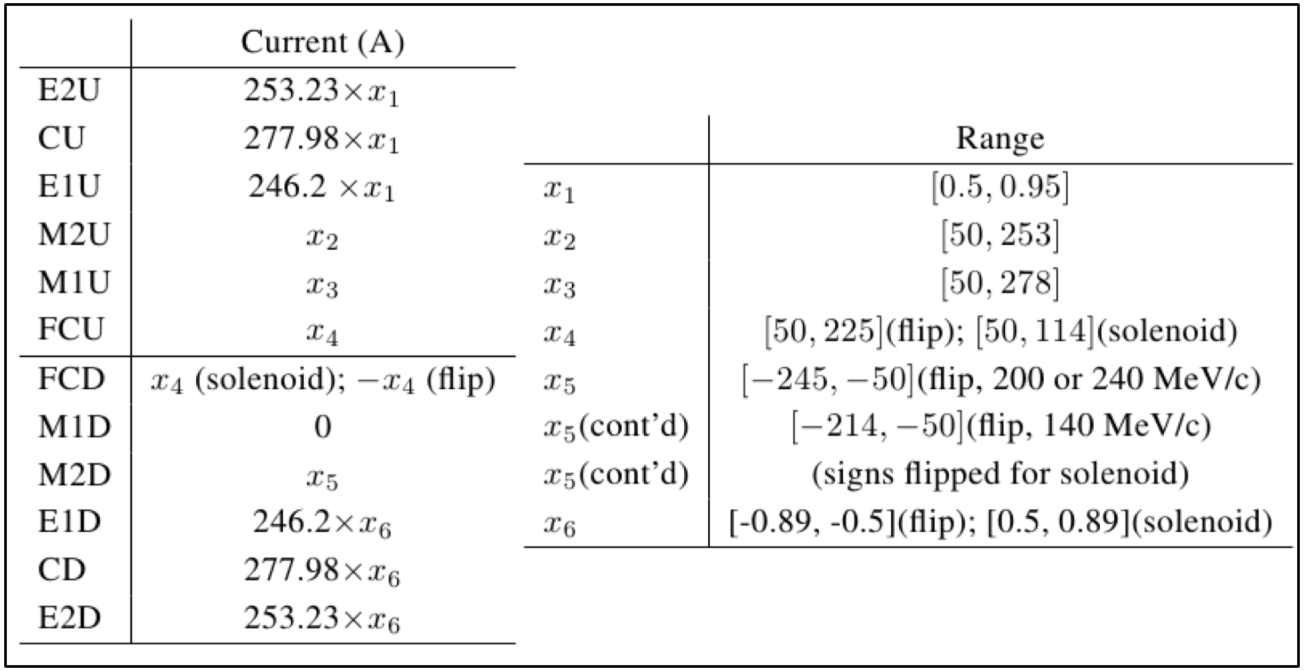
- Single Objective Genetic Algorithm (SOGA):
  - Searches the parameter space thoroughly and finds the global optimum; The more variables, the more powerful;
- Objective function:

$$F = T^2\left[(\epsilon_{ref,u} - \epsilon_{ref,d})/\epsilon_{ref,u} + (\epsilon_{bound,u} - \epsilon_{bound,d})/\epsilon_{bound,u}\right]$$

  - T: Transmission. T^2 guarantees a good transmission and avoids bias from scraping particles with strong MCS
  - $\varepsilon_{ref,u}$, $\varepsilon_{ref,d}$: Transverse normalized emittance at the reference planes (±1800 mm from the absorber). The first term is what we measure;
  - $\varepsilon_{bound,u}$, $\varepsilon_{bound,d}$: Transverse normalized emittance at the boundaries of the upstream and downstream tracker (± 3000 mm). The second term guarantees a regulated emittance in the trackers (especially downstream).

Optimization setup – GA (for our case)

- A few more details:
  - Optimization variables (and their ranges) and the corresponding coil current:

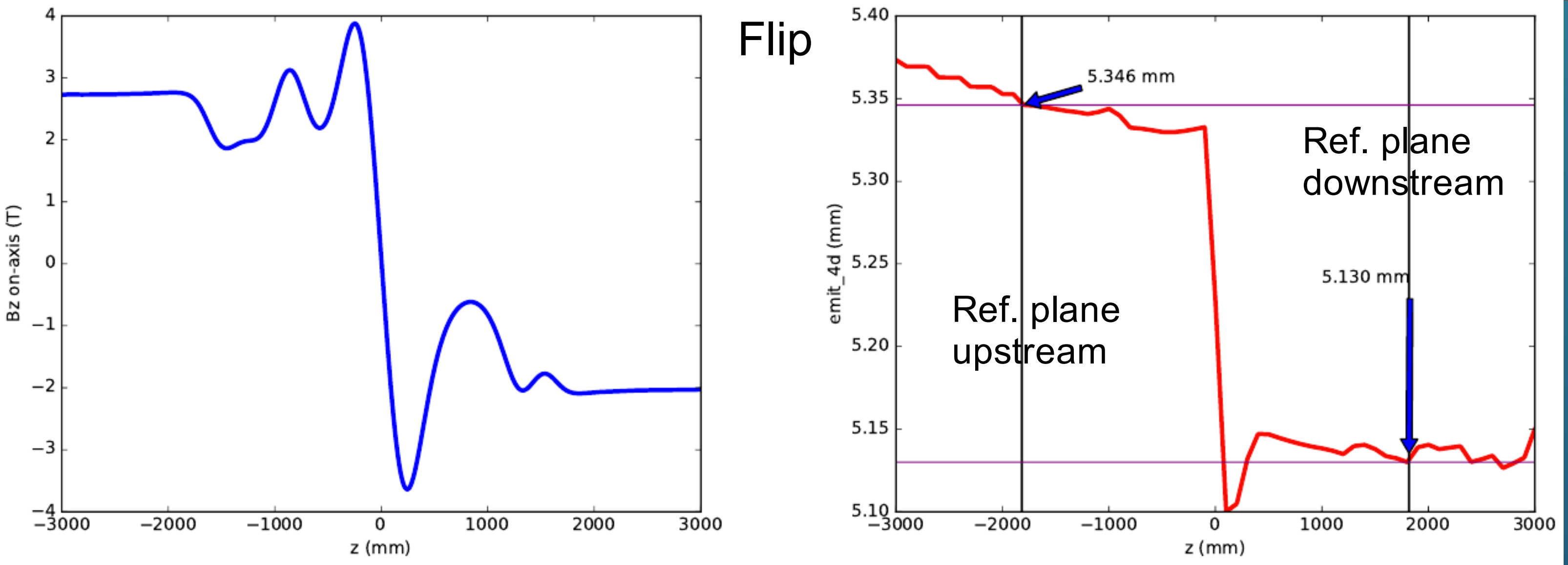


	Current (A)
E2U	$253.23\times x_1$
CU	$277.98\times x_1$
E1U	$246.2\ \times x_1$
M2U	x_2
M1U	x_3
FCU	x_4
FCD	x_4 (solenoid); $-x_4$ (flip)
M1D	0
M2D	x_5
E1D	$246.2\times x_6$
CD	$277.98\times x_6$
E2D	$253.23\times x_6$

	Range
x_1	$[0.5, 0.95]$
x_2	$[50, 253]$
x_3	$[50, 278]$
x_4	$[50, 225]$(flip); $[50, 114]$(solenoid)
x_5	$[-245, -50]$(flip, 200 or 240 MeV/c)
x_5(cont'd)	$[-214, -50]$(flip, 140 MeV/c)
x_5(cont'd)	(signs flipped for solenoid)
x_6	[-0.89, -0.5](flip); [0.5, 0.89](solenoid)

  - Investigated both flip and solenoid modes at all three momentum: 140, 200 and 240 MeV/c

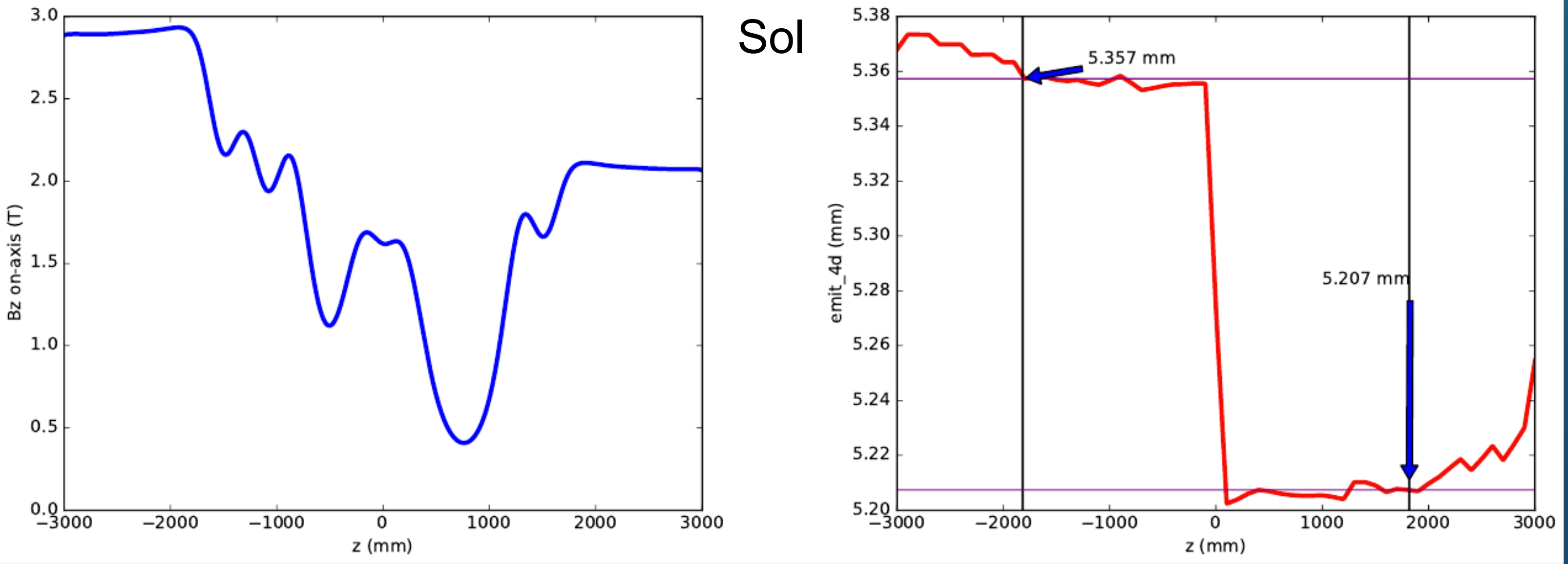
Optimization result – 200 MeV/c



Flip

4 % reduction in $\varepsilon_\perp$

Transmission: 93%

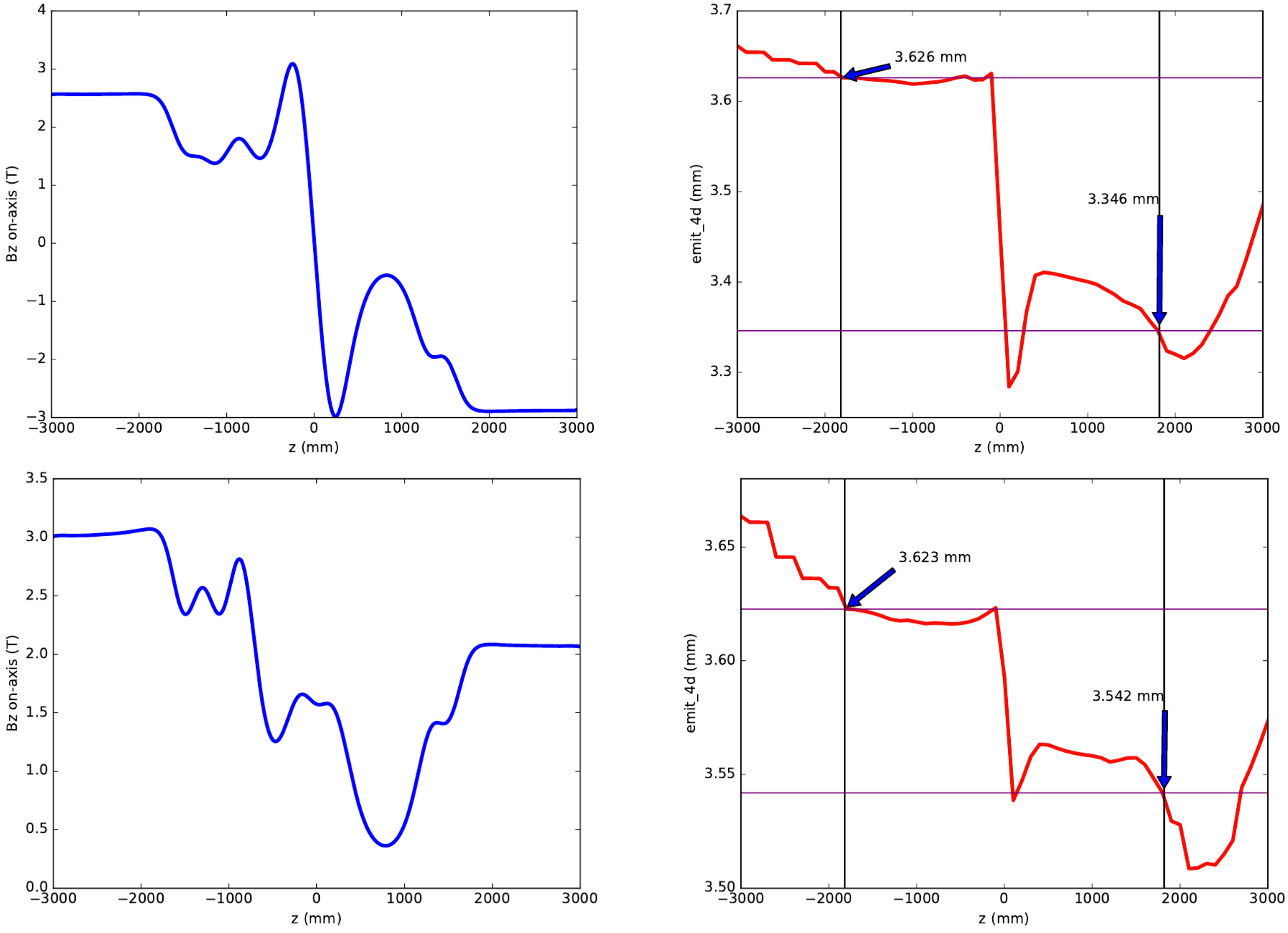


Sol

2.8 % reduction in $\varepsilon_\perp$

Transmission: 92%

Optimization result – 140 MeV/c

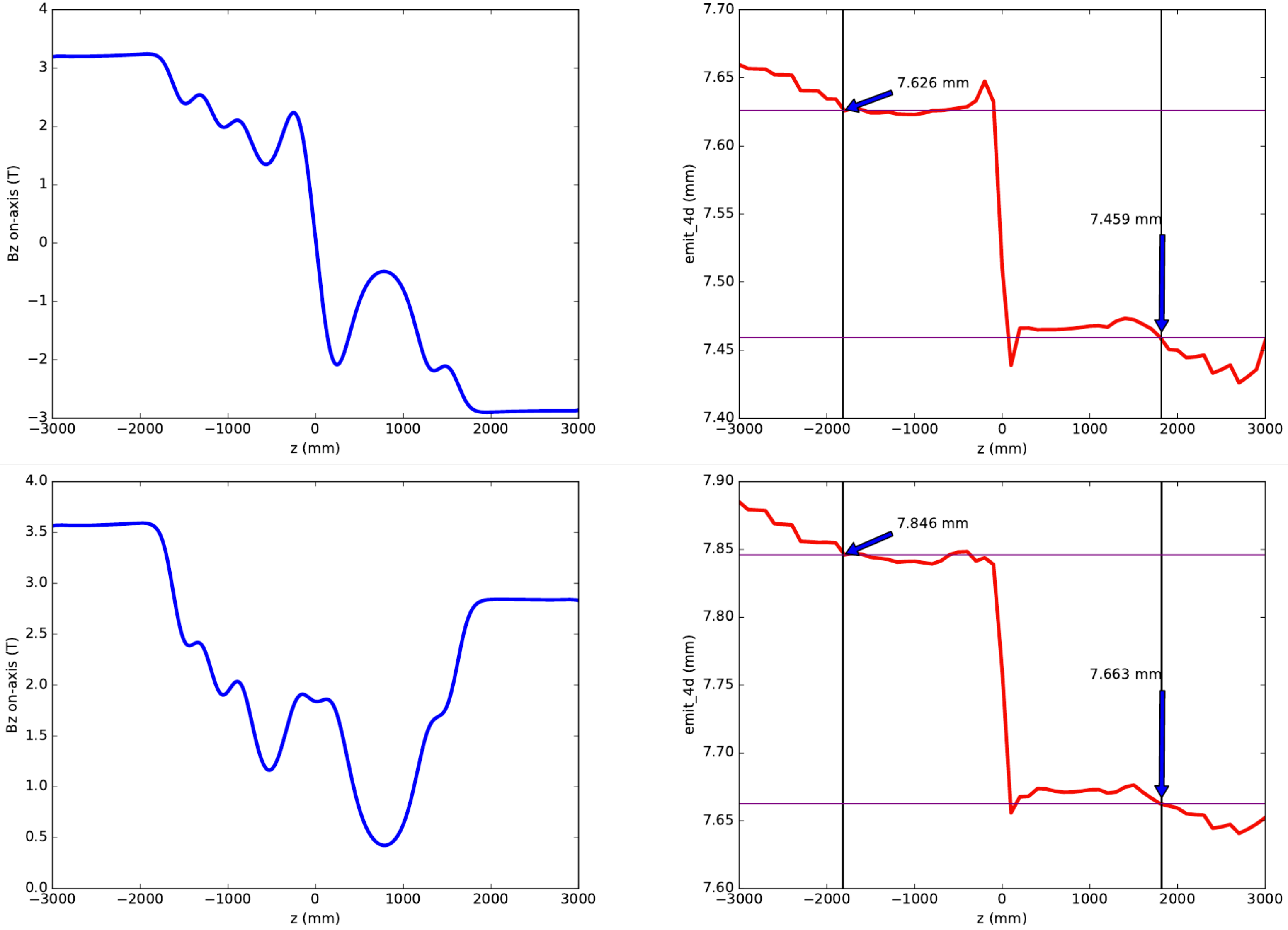


140 MeV/c
flip
T=93%
$\varepsilon_\perp$ reduction:
7.7%

140 MeV/c
Sol
T=91%
$\varepsilon_\perp$ reduction:
2.2%

Left: flip mode; right: solenoid mode

Optimization result – 240 MeV/c



240 MeV/c
flip
T=90%
$\varepsilon_\perp$ reduction:
2.2%

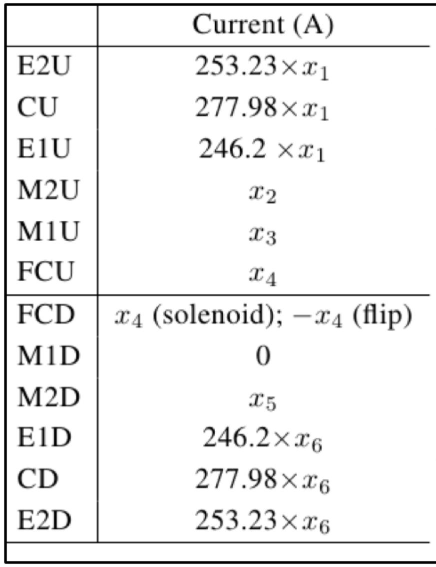
240 MeV/c
Sol
T=90%
$\varepsilon_\perp$ reduction:
2.1%

Left: flip mode; right: solenoid mode

Optimization result - Continued

- Variable values corresponding to the previous results:

variable	flip, 140	flip, 200	flip, 240	sole, 140	sole, 200	sole, 240
x_1	0.64	0.68	0.80	0.75	0.72	0.89
x_2	116.40	150.40	251.62	241.14	219.81	222.69
x_3	133.01	253.18	150.98	225.42	162.66	146.06
x_4	181.21	222.94	126.80	53.52	55.95	64.09
x_5	-205.95	-242.47	-244.00	147.05	205.66	161.48
x_6	-0.71	-0.5	-0.70	0.51	0.51	0.70
$\Delta\epsilon/\epsilon_i$	-7.7%	-4.0%	-2.2%	-2.2%	-2.8%	-2.3%
T	93%	93%	90%	91%	92%	90%

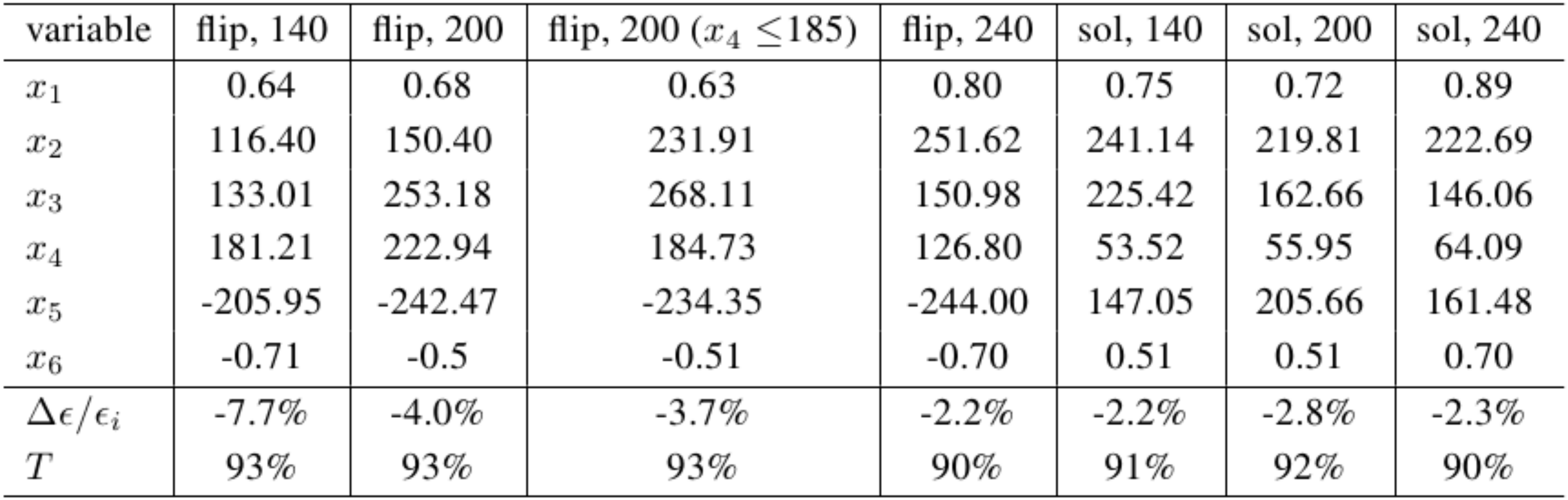


	Current (A)
E2U	$253.23\times x_1$
CU	$277.98\times x_1$
E1U	$246.2\ \times x_1$
M2U	x_2
M1U	x_3
FCU	x_4
FCD	x_4 (solenoid); $-x_4$ (flip)
M1D	0
M2D	x_5
E1D	$246.2\times x_6$
CD	$277.98\times x_6$
E2D	$253.23\times x_6$

- In each run mode, we are able to deliver an ensemble of particles that can be cooled in the MICE Step IV lattice, with at least 90% transmission to the TOF2 without M1D. In most of them, the normalized transverse emit. reduction is more than 3%;

You may have noticed that

- AFC module with LiH can not run above 185 A.

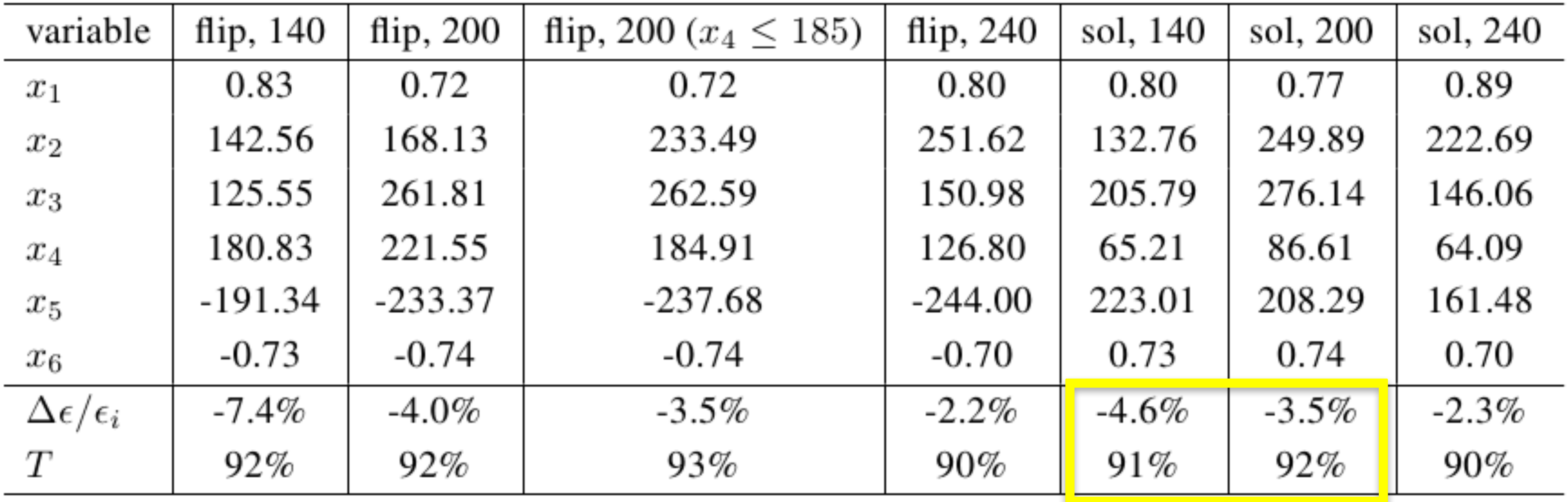


variable	flip, 140	flip, 200	flip, 200 ($x_4 \leq$185)	flip, 240	sol, 140	sol, 200	sol, 240
x_1	0.64	0.68	0.63	0.80	0.75	0.72	0.89
x_2	116.40	150.40	231.91	251.62	241.14	219.81	222.69
x_3	133.01	253.18	268.11	150.98	225.42	162.66	146.06
x_4	181.21	222.94	184.73	126.80	53.52	55.95	64.09
x_5	-205.95	-242.47	-234.35	-244.00	147.05	205.66	161.48
x_6	-0.71	-0.5	-0.51	-0.70	0.51	0.51	0.70
$\Delta\epsilon/\epsilon_i$	-7.7%	-4.0%	-3.7%	-2.2%	-2.2%	-2.8%	-2.3%
T	93%	93%	93%	90%	91%	92%	90%

From Flip, 200 with and without the constraint on FC current:
Performance not as good when constrained;
Showed a preference of higher FC current
Still doable

You may have worried that

- Tracker resolution becomes a problem with B_z~= 2T



variable	flip, 140	flip, 200	flip, 200 ($x_4 \leq 185$)	flip, 240	sol, 140	sol, 200	sol, 240
x_1	0.83	0.72	0.72	0.80	0.80	0.77	0.89
x_2	142.56	168.13	233.49	251.62	132.76	249.89	222.69
x_3	125.55	261.81	262.59	150.98	205.79	276.14	146.06
x_4	180.83	221.55	184.91	126.80	65.21	86.61	64.09
x_5	-191.34	-233.37	-237.68	-244.00	223.01	208.29	161.48
x_6	-0.73	-0.74	-0.74	-0.70	0.73	0.74	0.70
$\Delta\epsilon/\epsilon_i$	-7.4%	-4.0%	-3.5%	-2.2%	-4.6%	-3.5%	-2.3%
T	92%	92%	93%	90%	91%	92%	90%

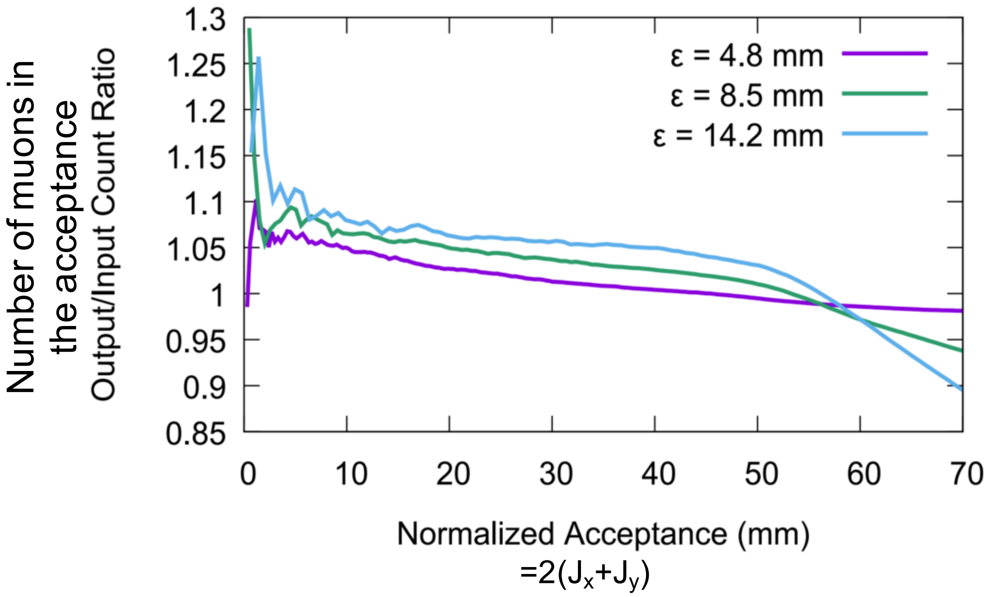
New constraint applied: minimum B_z in trackers = 2.8 T

Results slightly worse but still doable.

More emit. reduction between ref. planes but stronger emit. growth after ref. plane in SSD. Objective fitness was ~ same.

200 MeV/c flip mode – from the above-shown optimization result

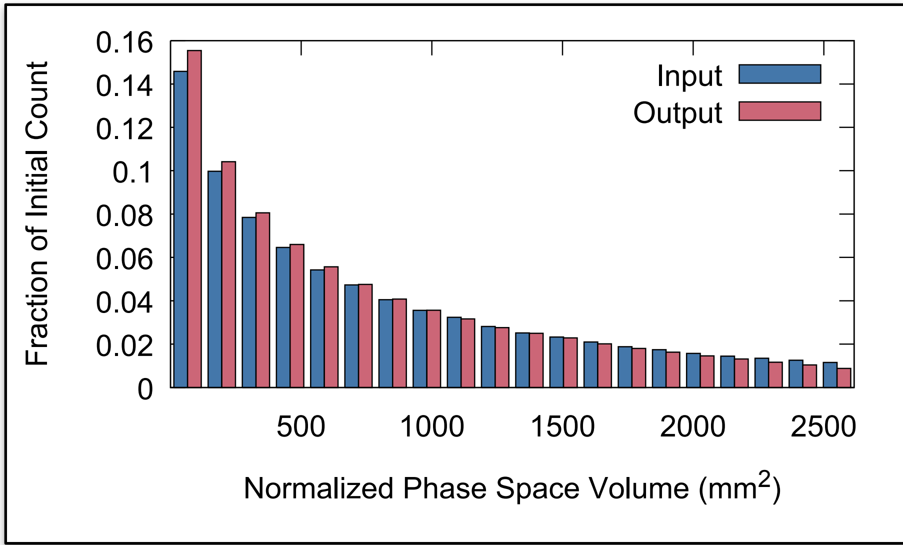
- Check the phase space density at the two ref. planes:



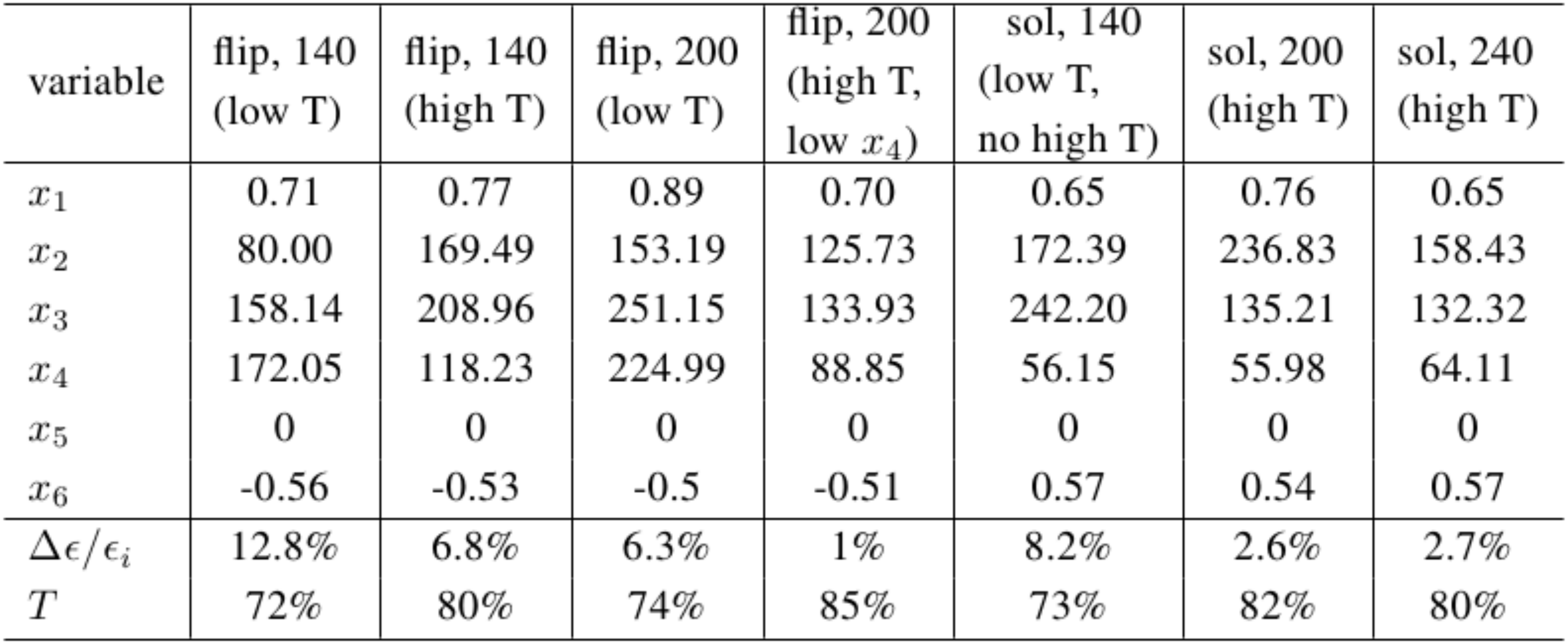
A ratio that is larger than 1 shows cooling in that acceptance;

Courtesy of J. Scott Berg, BNL.

Loss taken into account – not fooled by losing only muons with more MCS to reduce RMS normalized emit.



Optimization result – no M1D nor M2D



variable	flip, 140 (low T)	flip, 140 (high T)	flip, 200 (low T)	flip, 200 (high T, low x_4)	sol, 140 (low T, no high T)	sol, 200 (high T)	sol, 240 (high T)
x_1	0.71	0.77	0.89	0.70	0.65	0.76	0.65
x_2	80.00	169.49	153.19	125.73	172.39	236.83	158.43
x_3	158.14	208.96	251.15	133.93	242.20	135.21	132.32
x_4	172.05	118.23	224.99	88.85	56.15	55.98	64.11
x_5	0	0	0	0	0	0	0
x_6	-0.56	-0.53	-0.5	-0.51	0.57	0.54	0.57
$\Delta\epsilon/\epsilon_i$	12.8%	6.8%	6.3%	1%	8.2%	2.6%	2.7%
T	72%	80%	74%	85%	73%	82%	80%

It is possible but more difficult to pursue Step IV with M2D off:

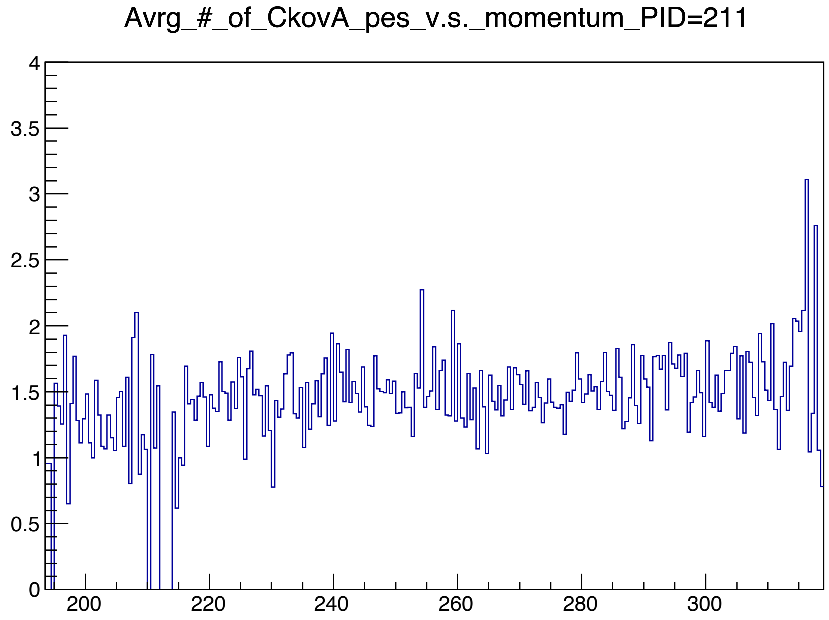
1. Requires (obviously) low ECE current downstream;
2. Challenges are data collection inefficiency and understanding the outcome from the big loss
3. More MC analyses are needed to be affirmative

Ckov Light Yield

Redone the analyses

- Previous: calculated the TOF based on the distance in the geometry
  - Approximation turned out to be not good enough
- Redo:
  - Use the electron TOF;
  - Consider that D1 and D2 select the same momentum, optics should be the same for pi, mu, e, therefore same path lengths

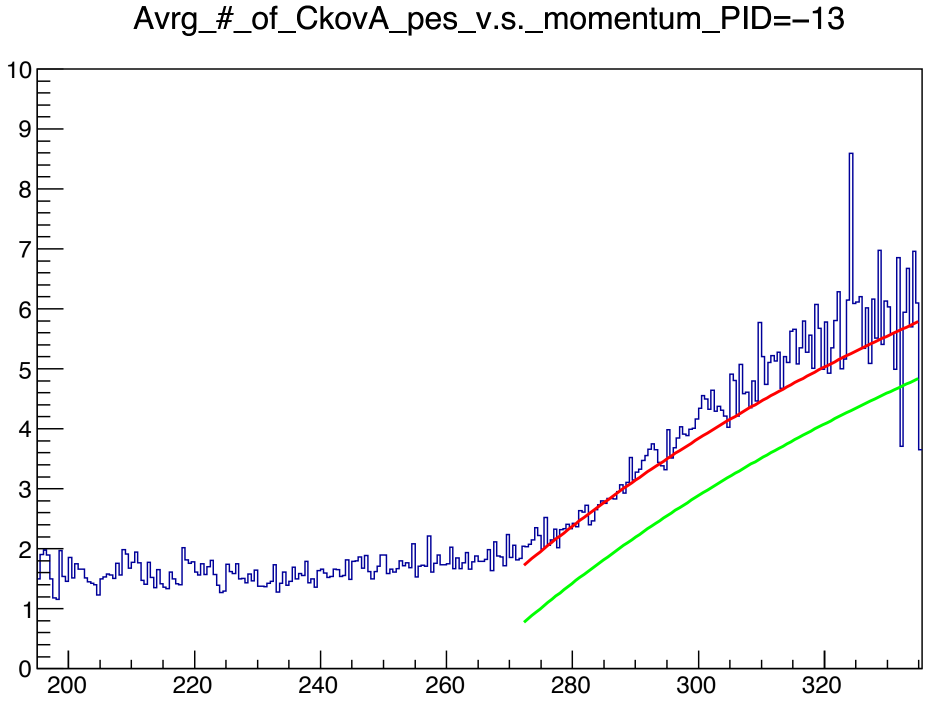
Ckov A



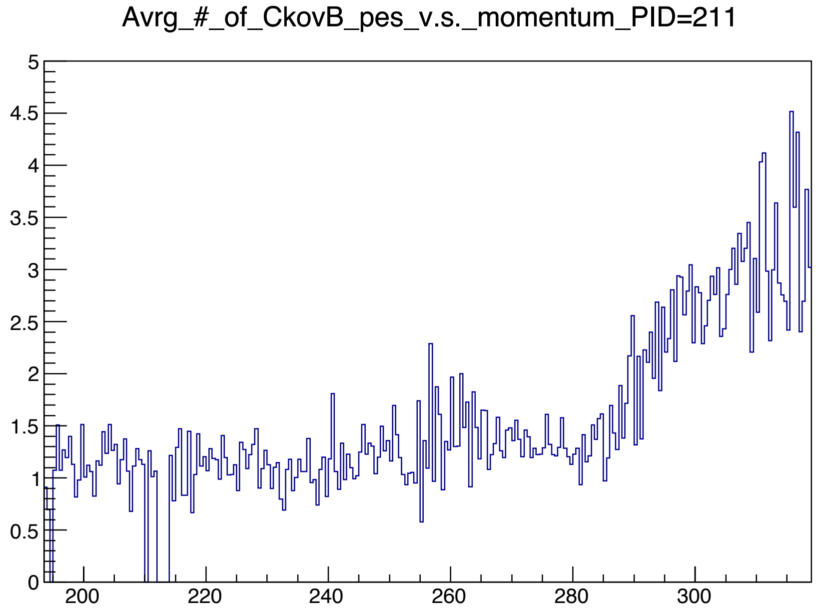
Note 473:
367.9 MeV/c for pions;
280.5 MeV/c for muons, but from the formula should be around 272 MeV/c, which was consistent with the scan;

Compare with the light yield formula in note 473: $f = 0.75 + 12 \times [1 - (272/p)^2]$

Background light yield was observed to be higher: (Red: f+0.95)

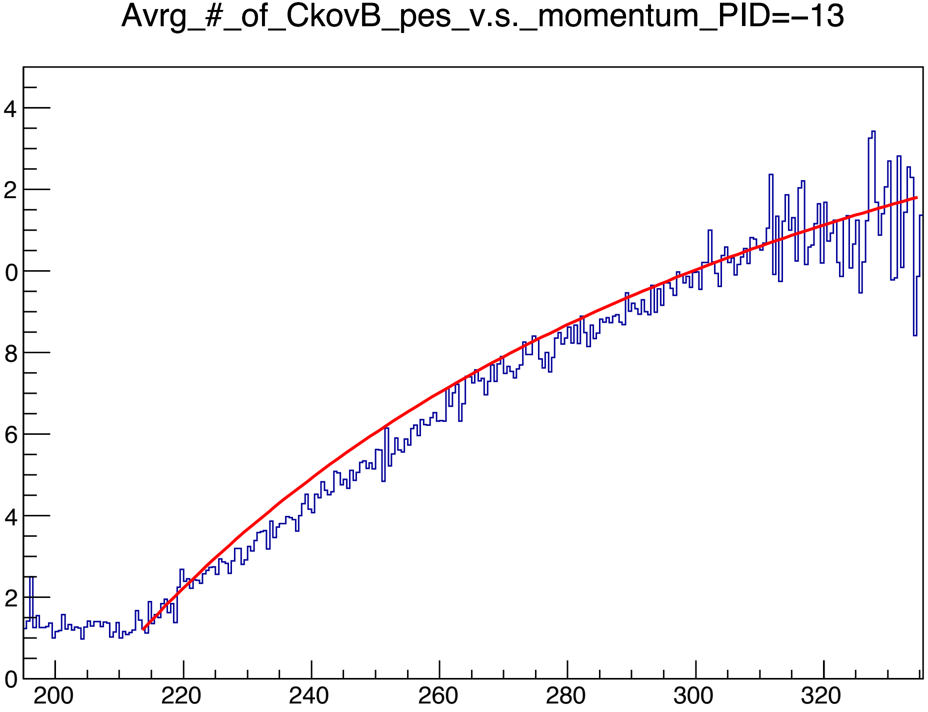


Ckov B



Compare with the light yield formula in note 473: $f = 1.1 + 18 \times [1 - (213/p)^2]$

Consistent results



Note 473:
285.8 MeV/c for pions;
217.9 MeV/c for muons;

Lack of data and action

- Lack of data at high momentum;
- Lack of pion data
  - For the last Ckov scan runs, DS was fixed and was running as a high current;
  - If we could get some pion runs to fill the data we probably could see the Ckov A turns on at higher momentum
- Waiting for a designated but short momentum scan run.