"Booster Collimators Update"

Valery Kapin

PIP General Meeting, Wed, Feb 17, 2016

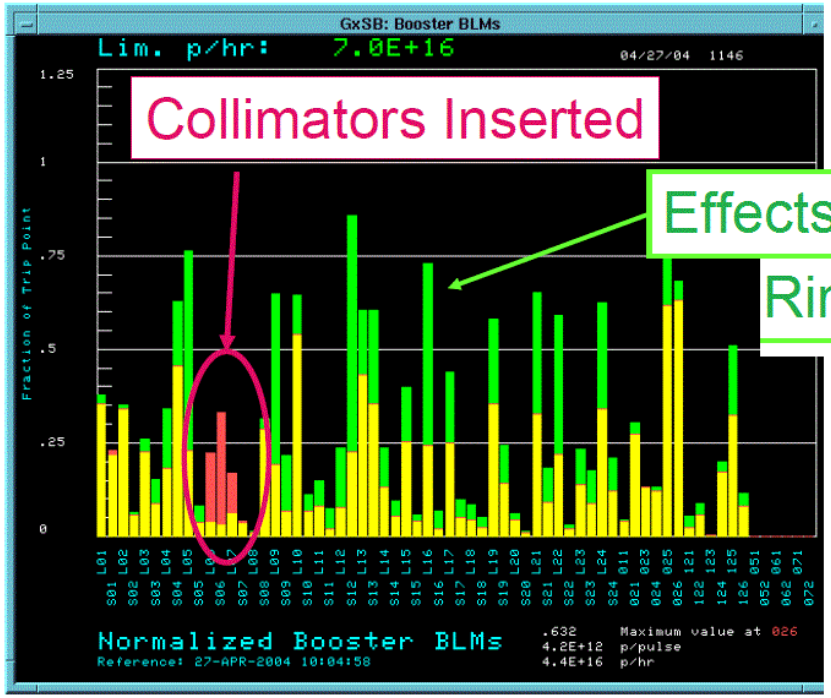
Activities & acknowlegments to people involved

- 1) Booster Collimator Hardware & Control (motion tests):
  Charles Briegel, Salah Chaurize, Mike Coburn,
  Vladimir Sidorov, Matt Slabaugh, Todd Sullivan,
  Kent Triplett, Rick Tesarek
- 2) Support for Beam Dynamics Simulations:
  Valeri Lebedev, Nikolai Mokhov, Yuri Alexahin,
  Igor Rakhno, Sergei Striganov, Igor Tropin
- 3) Support for task managments:
  Bill Pellico and Cheng-Yang Tan

2-stage collimation system of FNAL booster

Two stage collimation system for booster designed and installed in 2004.

Design ~2001-03 with STRUCT & MARS codes by A.Drozhdin & N.Mokhov:
Optimal primary foils at 400 MeV: tungstem 0.003mm (or graphite 0.15mm) Beams-doc-3734.



Instead 0.381 mm copper foil was installed

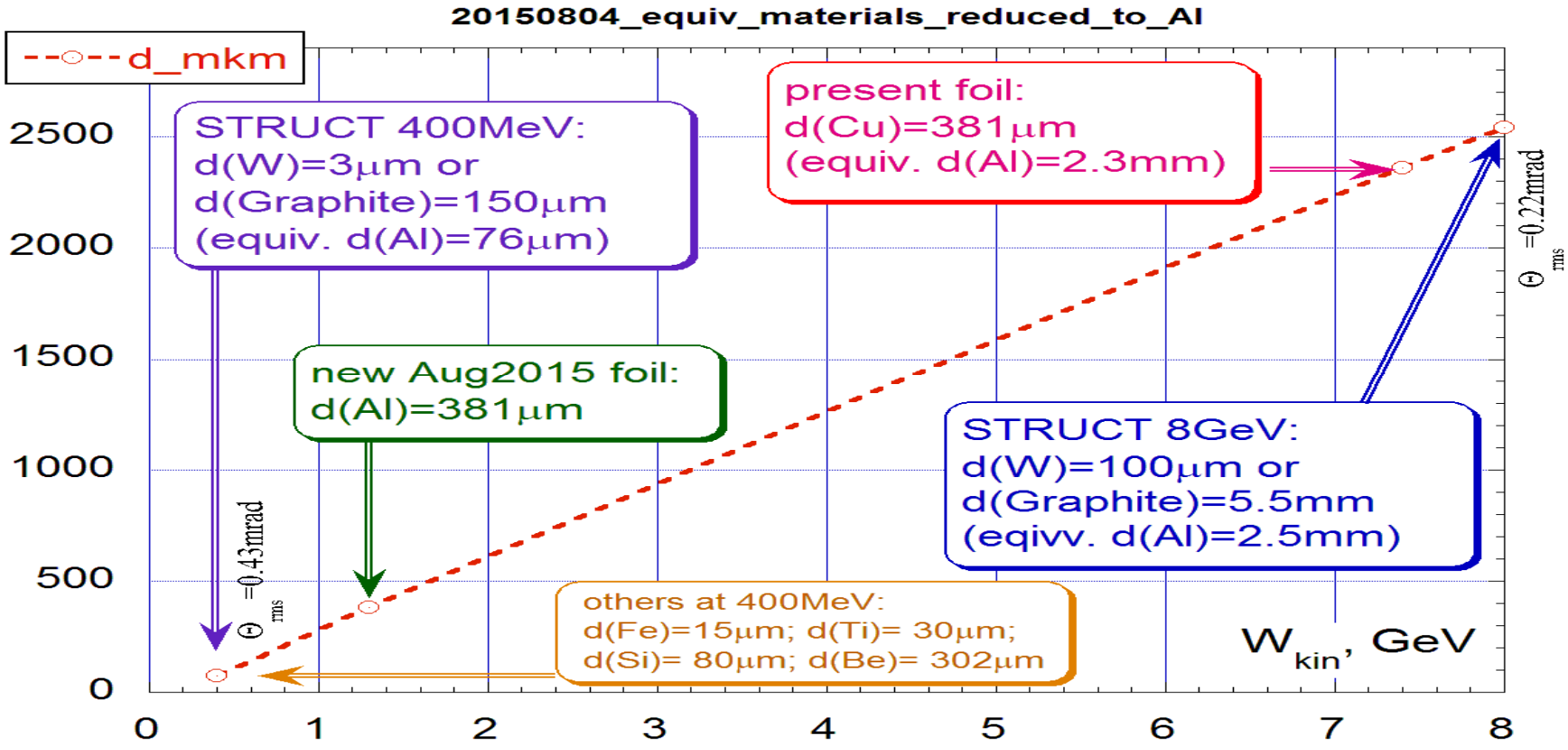
2005 Pellico & Sullivan
Booster Collimation
DOE-Review

Two-stage collimation was tested but is not used in operations (variable beam size and position due to e.g. “momentum cogging”)

Task started in 2014: optimal thickness of primary coll.

- MADX code has been modified to include proton interactions with thin primary collimators (Prim-Colls) plus out-scattering from secondary collimators (MARS model by Tropin & Rakhno)
- Dependence of collimation efficiency on thickness of Cu Prim-Colls at injection energy (400MeV) within thickness range {0; 381um} has been simulated. It is quite smooth.
- Collimation efficiency grows up with the number of turns (simulated up to 100) under simulation approach that all accelerator parameters are constant (is it a case of booster ?)
- Optimal thickness of Prim-Colls for Cu is ~50um (or thinner) to reduce losses of scattered protons in magnet apertures and pipes between primary and secondary collimators.
- ~50 mkm is much less of existing 381 um (0.015") Cu foil for both hor. and vert. primaries
- Original STRUCT's calculations at 400 MeV corresponds to equivalent Cu foils of ~12um

Primary thickness for ~2004 “STRUCT” design & Equiv. materials



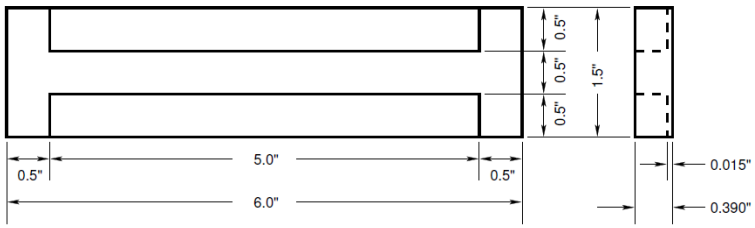
RMS scattering angle

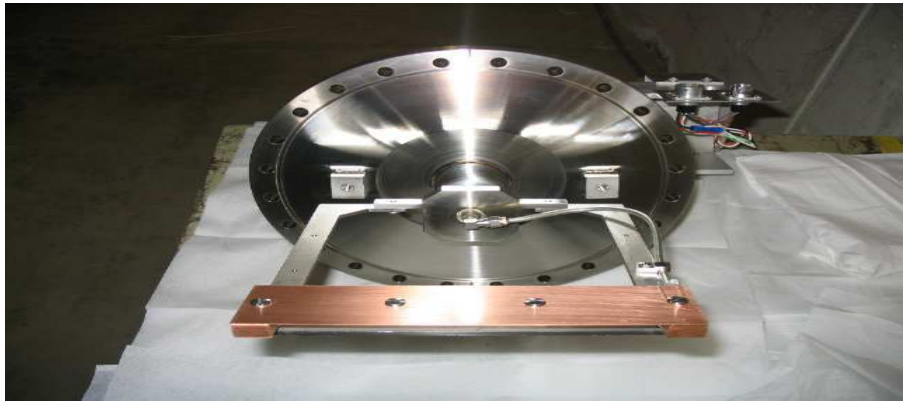
$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p}\, z\, \sqrt{x/X_0}\left[1 + 0.038 \ln(x/X_0)\right]$$

$$x[\mathrm{g/cm^2}] = \rho[\mathrm{g/cm^3}] \cdot d[\mathrm{cm}]$$

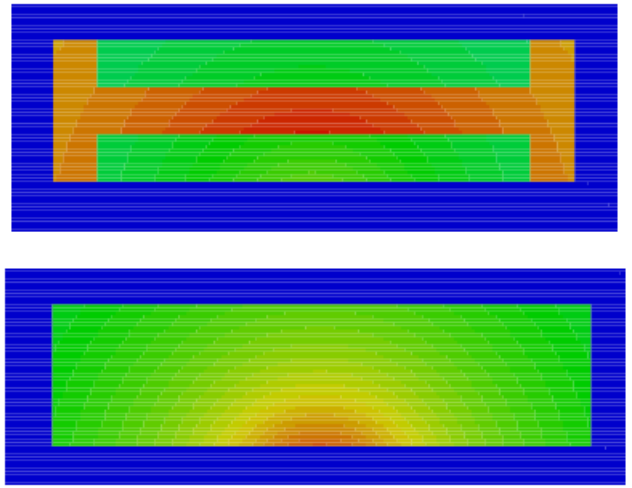
New aluminium Prim-Colls - Installed on 2-Feb-2016

2005: Cu primary heat sink with signal cable (+ceramic ins.)



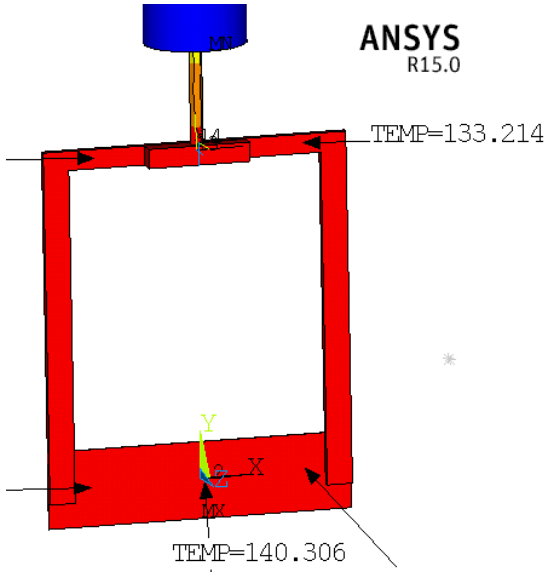


Oct.2015 New simplified primary assembly (just Al plate without any ceramic insulators): R.J. Tesarek et al, Beams-Doc-5983, November 4, 2015.



Aver.deposited beam power is reduced 30 times

From abstract: … a candidate primary collimator design of a uniform aluminum foil with a uniform thickness of 381 um. … the steady state temperature of the collimator under nominal beam conditions to be at or below 140 C (absorb <4.6W).



Beam study: starting a detailed plan for beam study (by Rick)

Work at stable beam conditions ~2-4 hours:

- a) Record LVDT positions of all collimators
- b) Record losses for booster everywhere (~loss distribution plot by B88)
- c) Booster operation conditions NO MI BEAM (event 17)
- d) move all collimators out (garage positions)
- e) move Vert-Prim untill it "touches" the beam (detect with FLM)
- f) back off it by "small" steps
- g) Repeat e, f with "main" secondary vertical collimators (e.g. COL2 & COL3 in 2004-design)
- h) repeat (as necessary) with "supplementary" secondary collimators (e.g. COL1 in 2004-design)
- i) Record losses for booster everywhere (~loss distribution plot by B88)
- j) Return collimators to original locations (e.g. existing 1-stage configuration)
- k) evaluate data

2-stage Collimation: from Collider to Synchrotron

- Energy variation (but fixed foil thickess)
- Beam size & closed orbit (co) vary during cycle

Bryant, in CERN Acc. School (1992), p.174

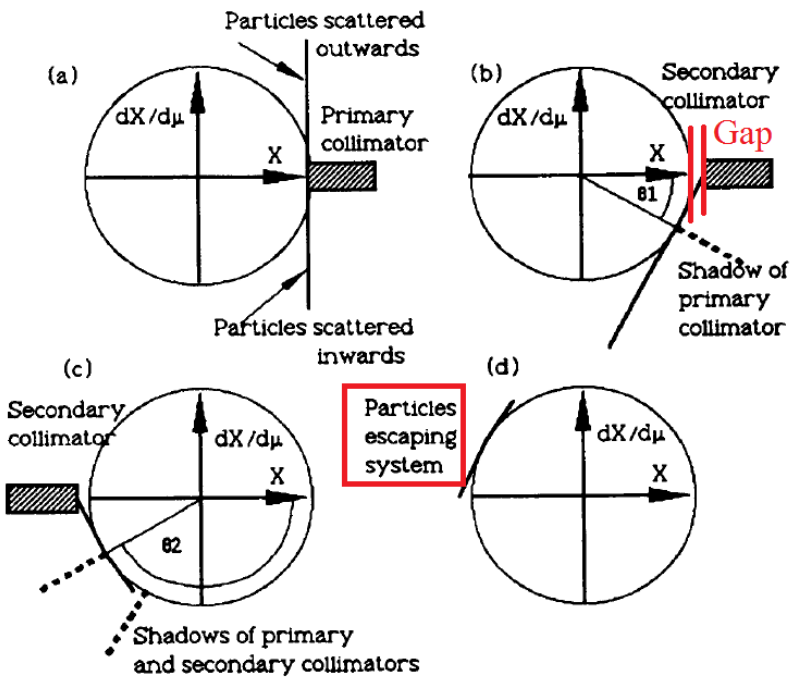


Fig. 11 Main features of a collimation system

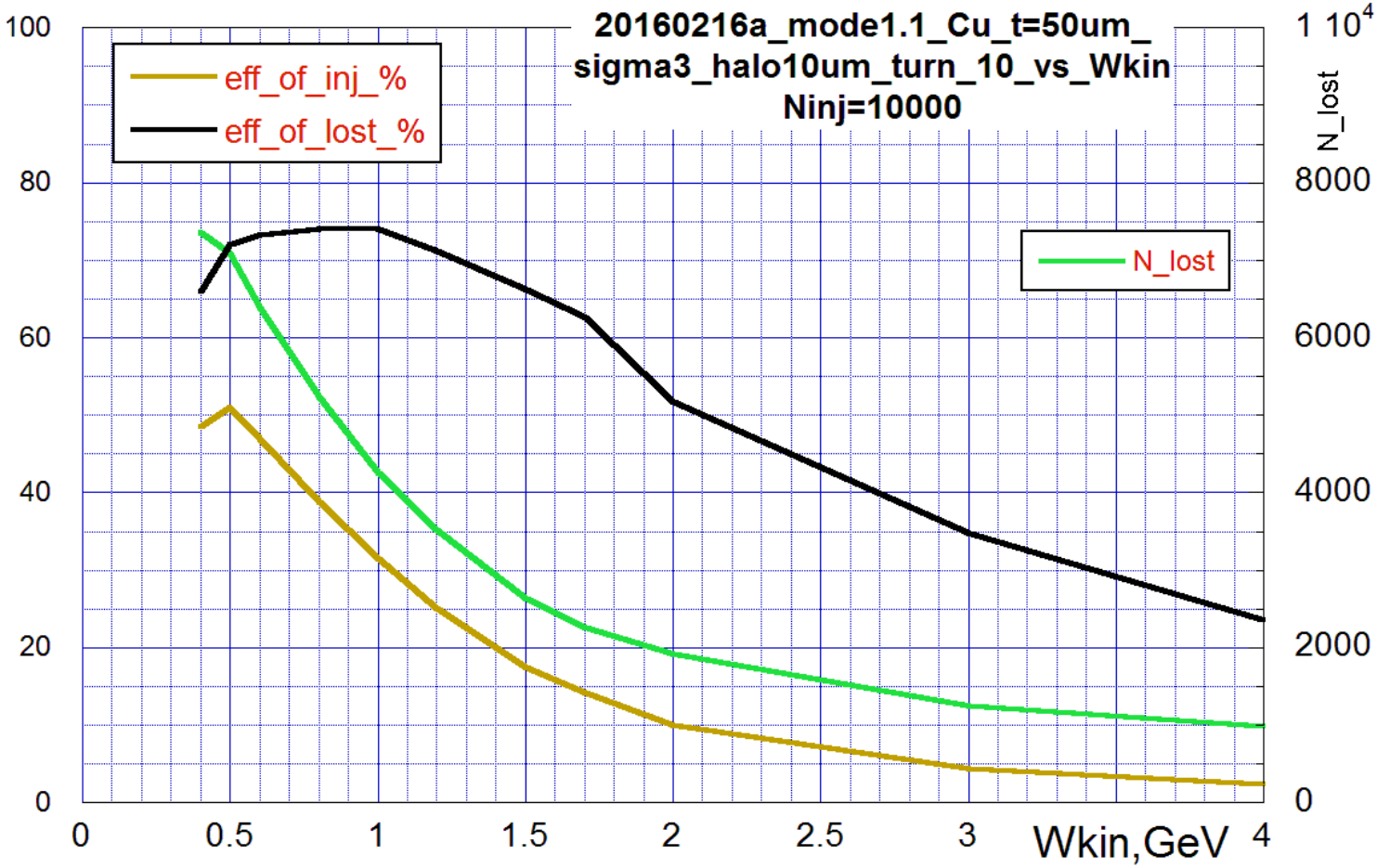
Normalized Coordinates:
Center oscillate (C.O) =>
There is gap
(Nikolai recommends for colliders ~2mm)

Particles escape due to the gap

Scattering angle reduces with energy growth => system loss efficient only at some range of energies

a)Popovic Beam-Whacker => HD motor
b) V.Lebedev "septum" with V-variation
c) Single stage

Collimation efficiency vs energy

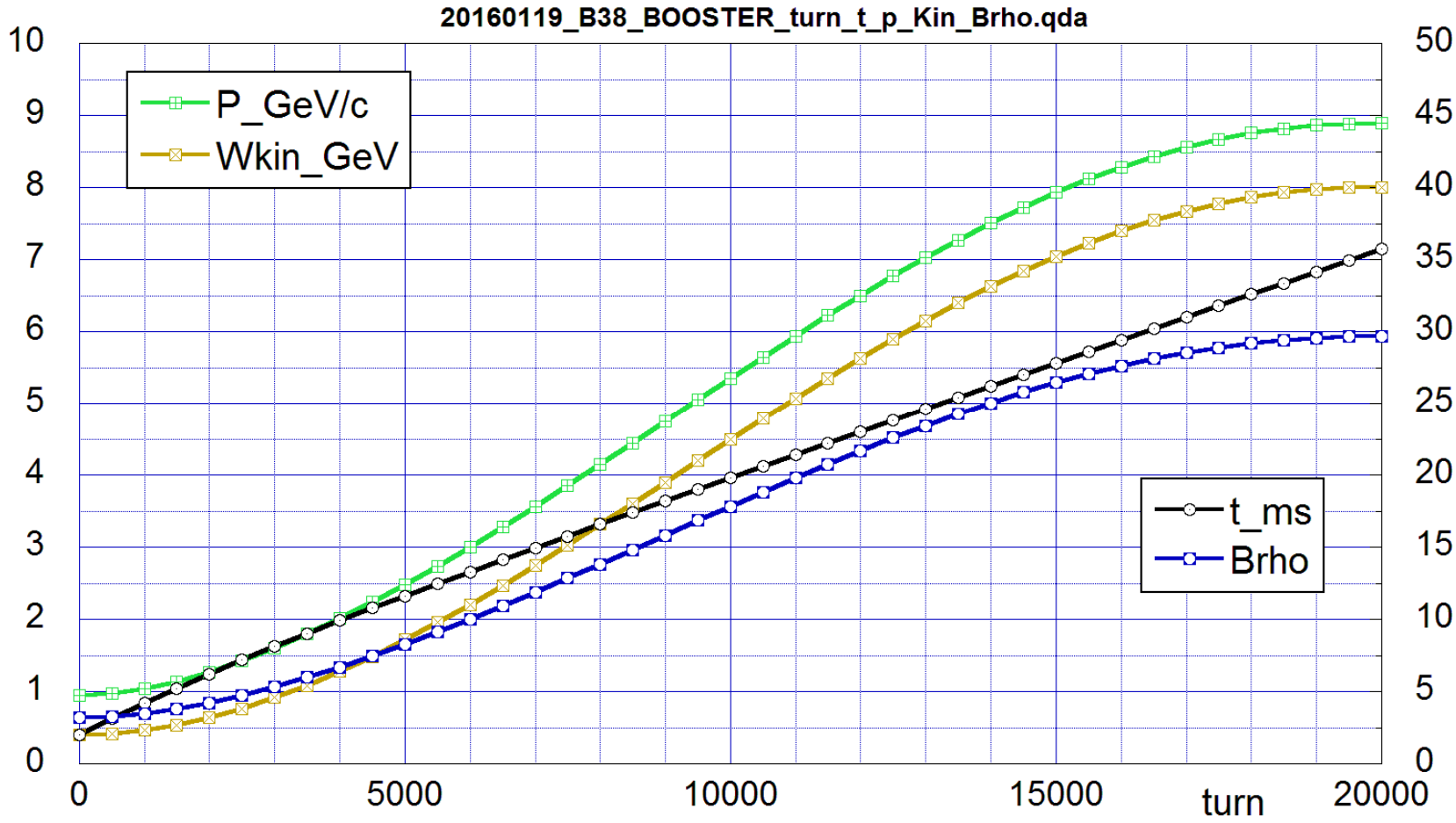


Efficiency <coll.loss>/<total losses>

Efficiency > 60% for 0.4-1.8 GeV

Efficiency <coll.loss>/<injected>
(Many particles with unknown fate => 0.4-0.7GeV)

Booster Wkin vs turns



Calculator in B38 application

0.4-2GeV => 0-5000 turns =>
“good” collimation possible at 300-5000

1-stage eff. also depends on C.O.

M. Seidel The Proton Collimation System of HERA DESY 94-103 June 1994 Dissertation

2. 3. 3 Simulation Results

In this chapter we present simulations made with a single collimator jaw. Tracking simulations of the complete system are presented in chapter 3. The most obvious result is the strong dependence of the absorption efficiency (and also the rms-deflection angle) on the angular alignment of the jaw (see also [SE192]). If the jaw is misaligned as depicted in Fig. 2.15 the effective collimator length is reduced.

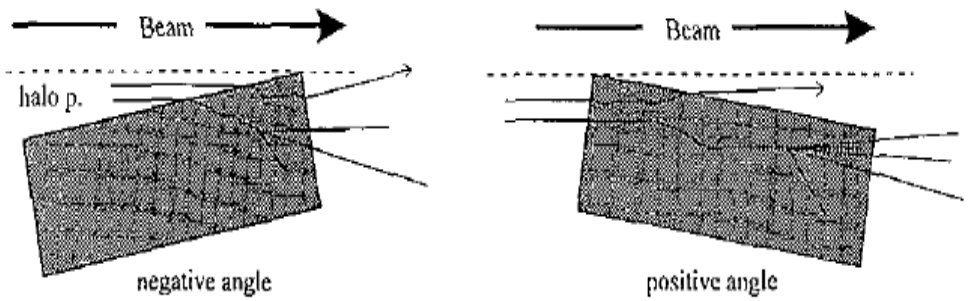
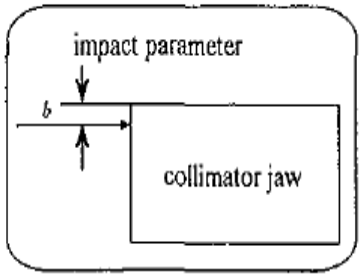


Fig. 2.15: Reduction of the effective jaw length due to angular misalignment.



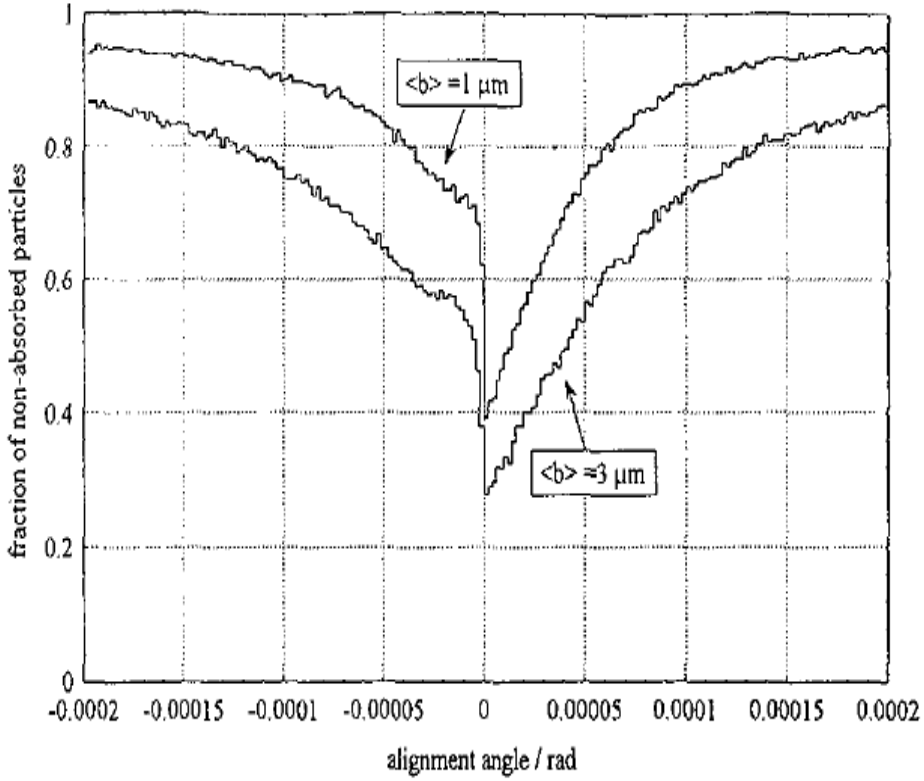


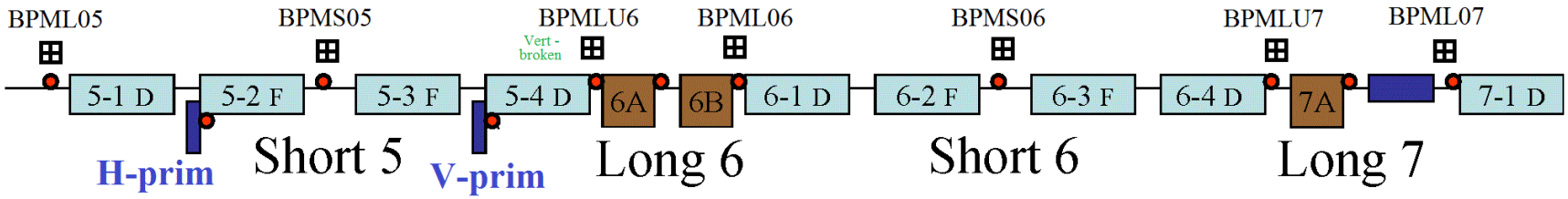
Fig. 2.16: The out-scattering probability as a function of alignment angle for two different exponential impact parameter distributions.

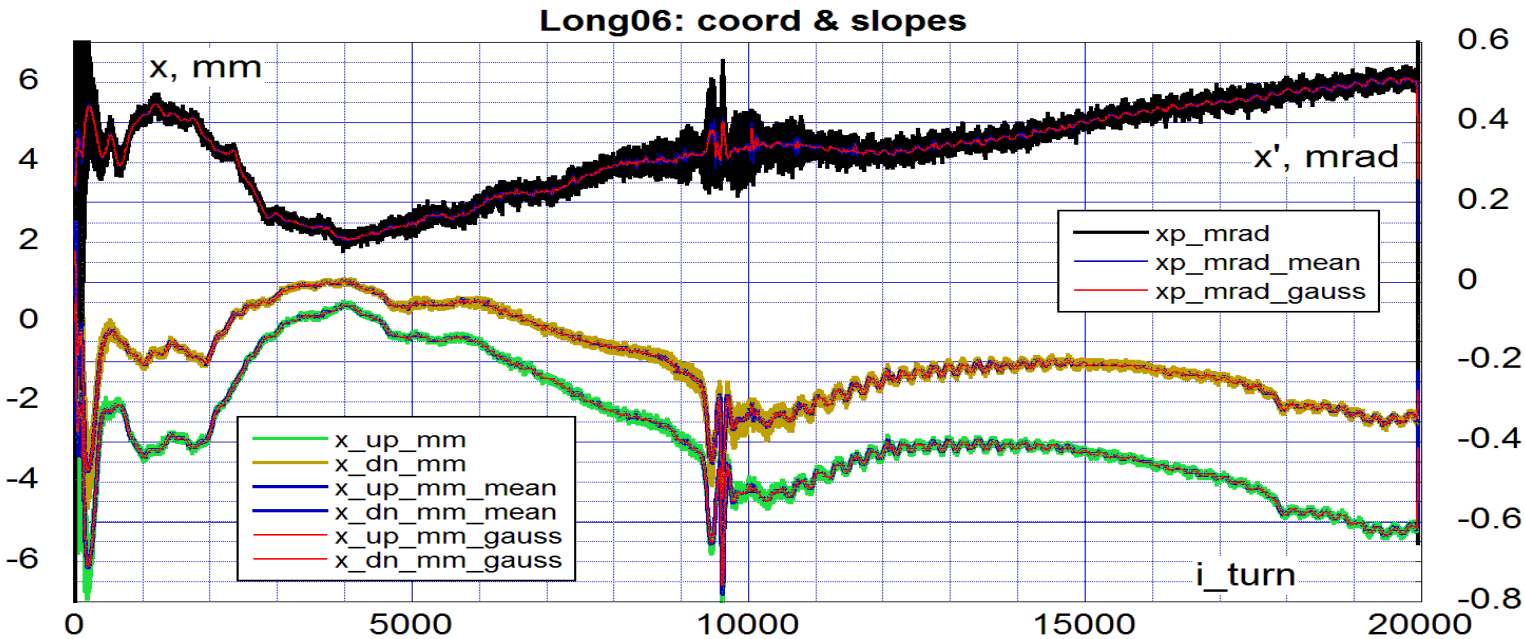
Single-stage collimation:

M. Seidel: Out-scattering reduces to 0.4 within [+-0.05mrad]

Misalignments can be partly cured with CO steering (?)

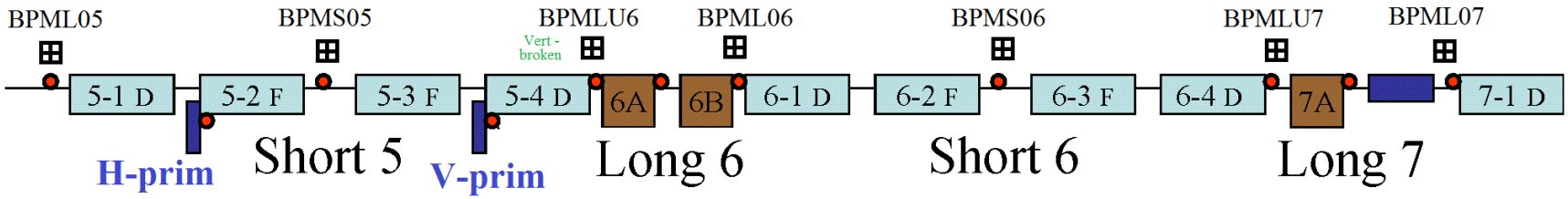
Study on CO in vicinity of colls

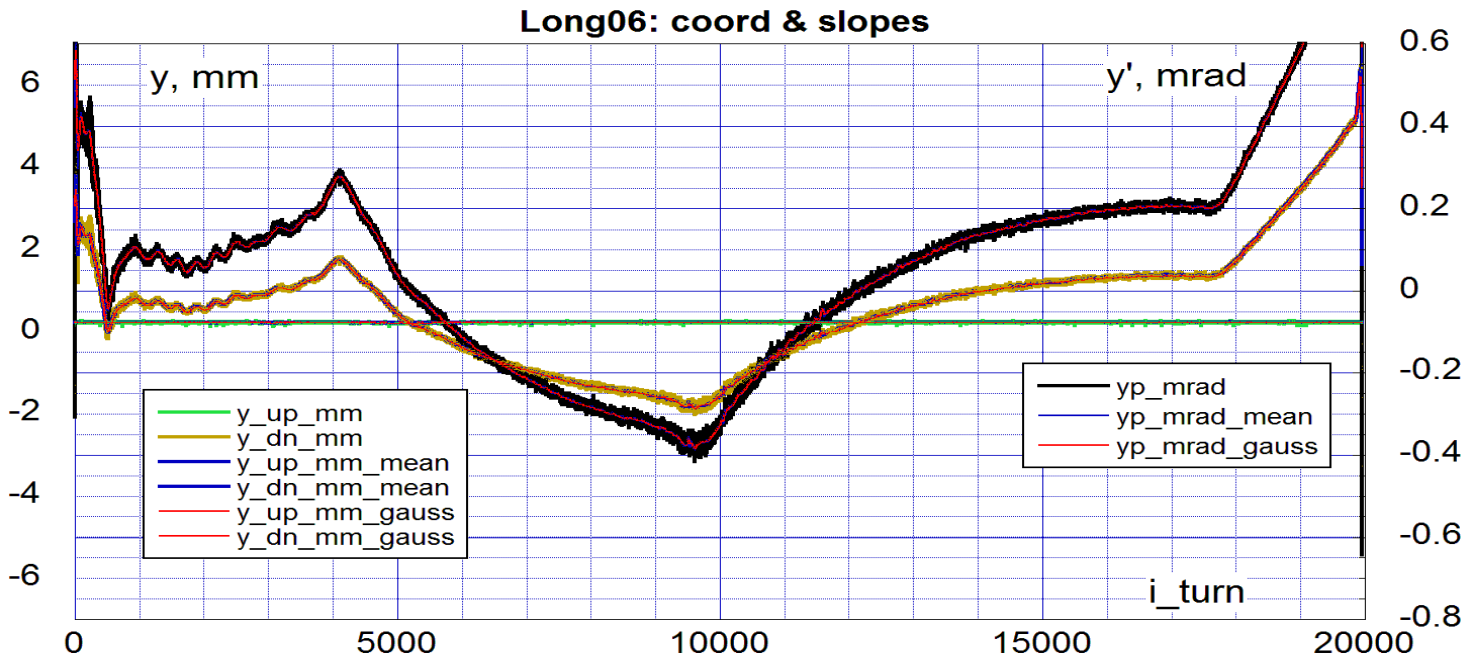




BPMs data taken from B38 (thanks to K.T.):
Noisy BPM signals has been averaged (arithm. & Gaussian) (thanks to Y.A.)

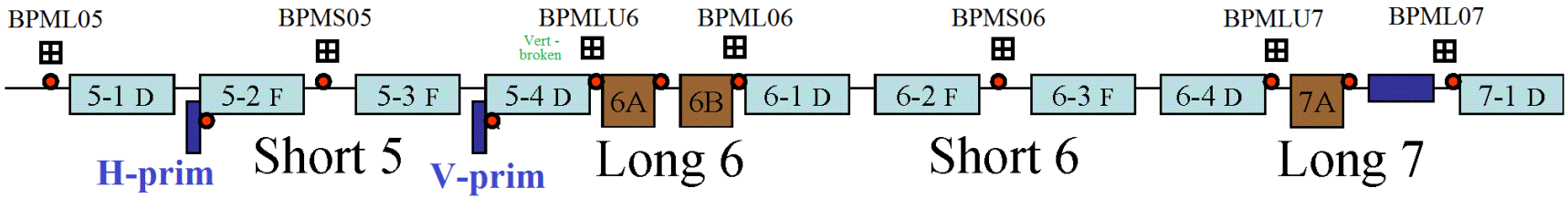
Study on CO in vicinity of colls

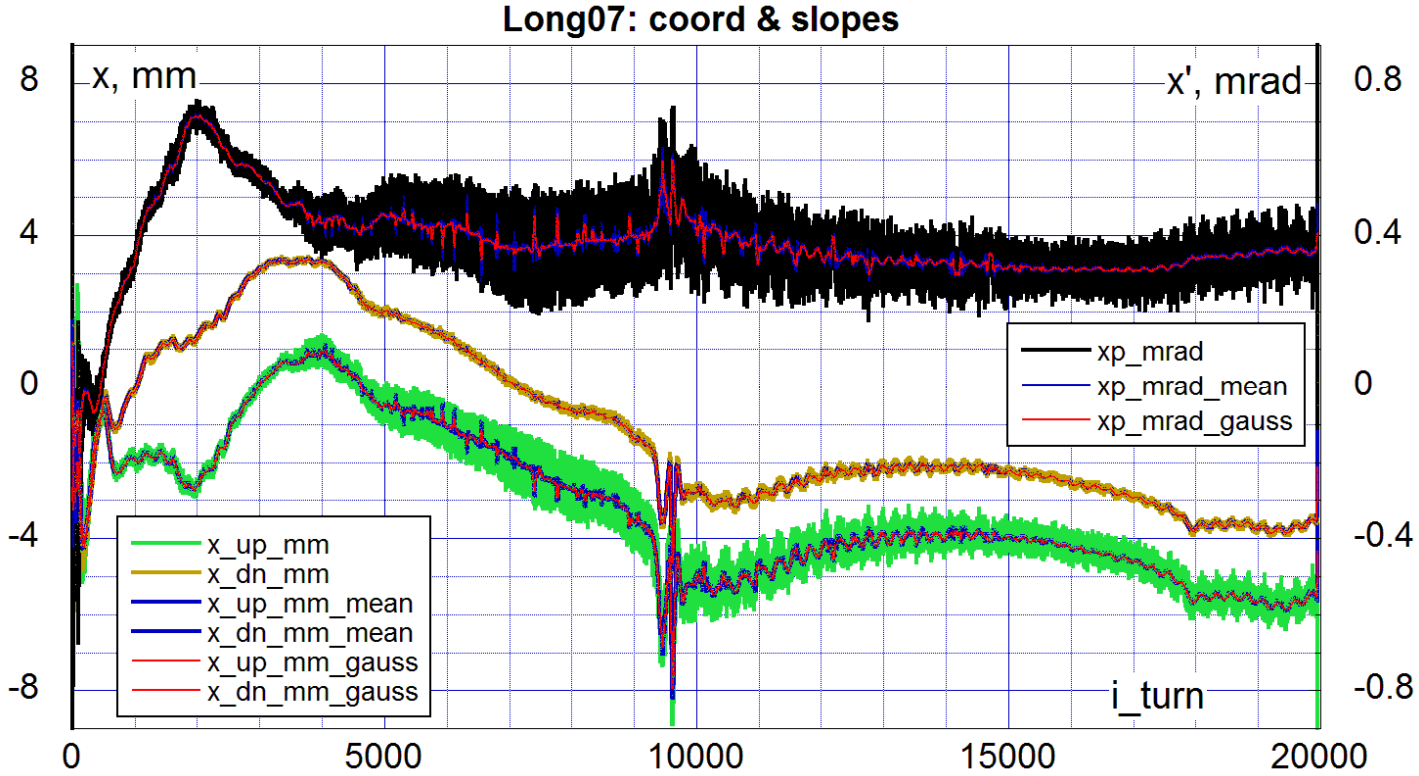




“Broken” BPMLU6(vert) has been restored via data processing
Using adjacent BPM signals (MADX matrices)

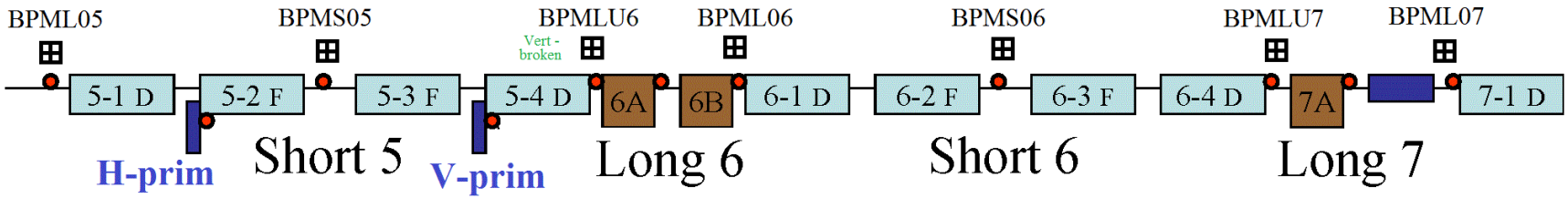
Study on CO in vicinity of colls

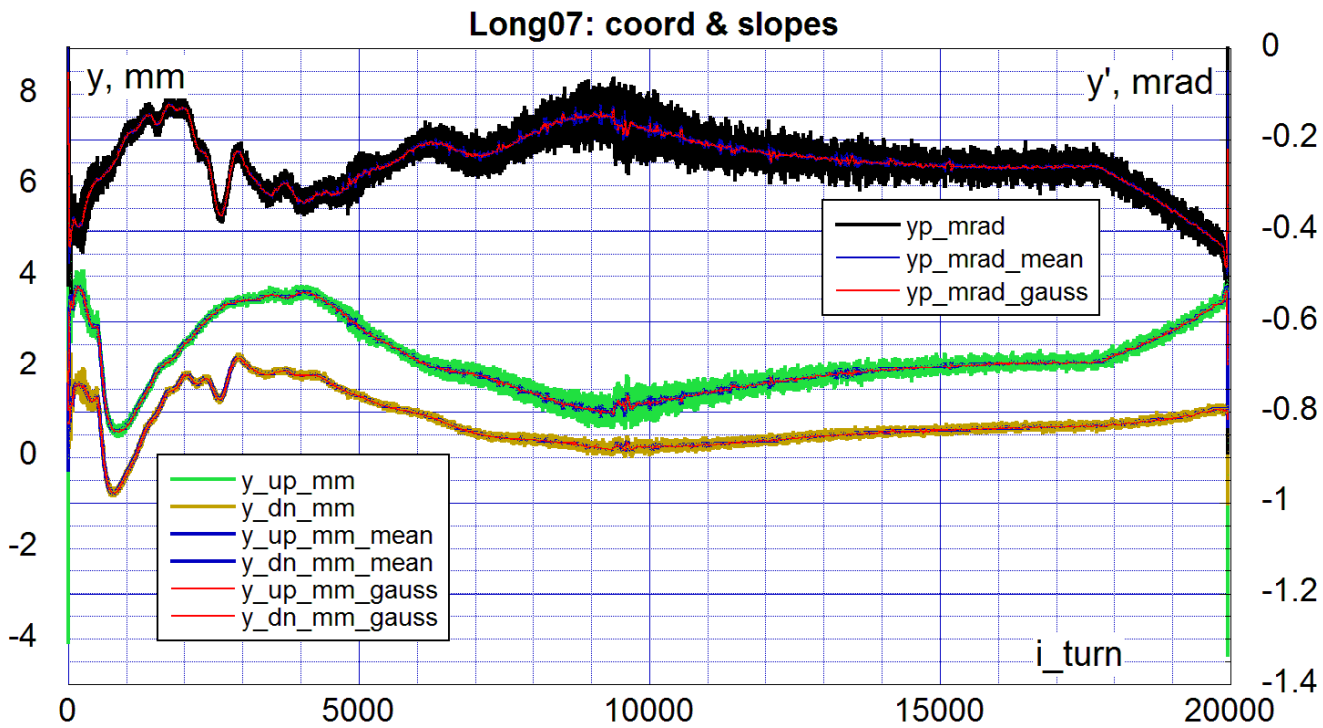




Large noise for X_up (BPMLU7-hor)

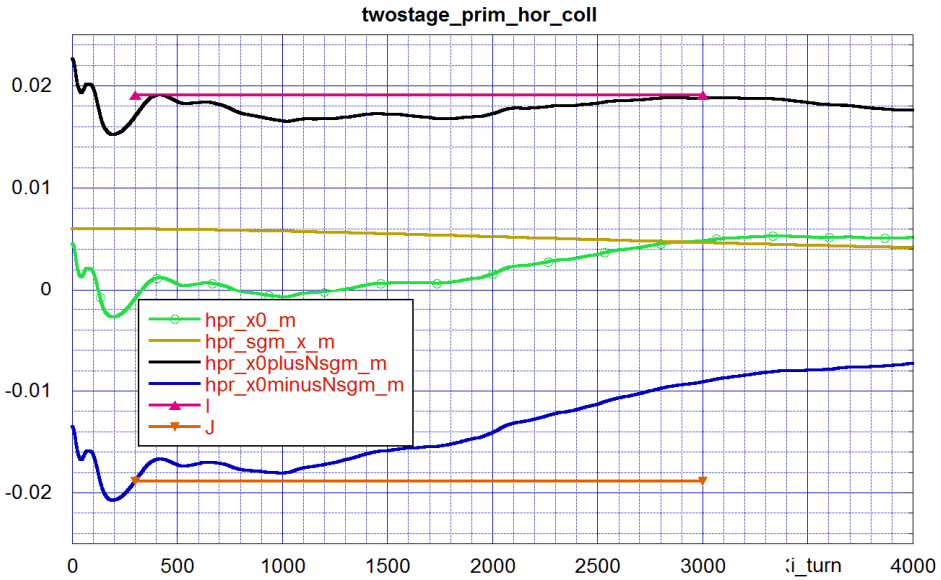
Study on CO in vicinity of colls

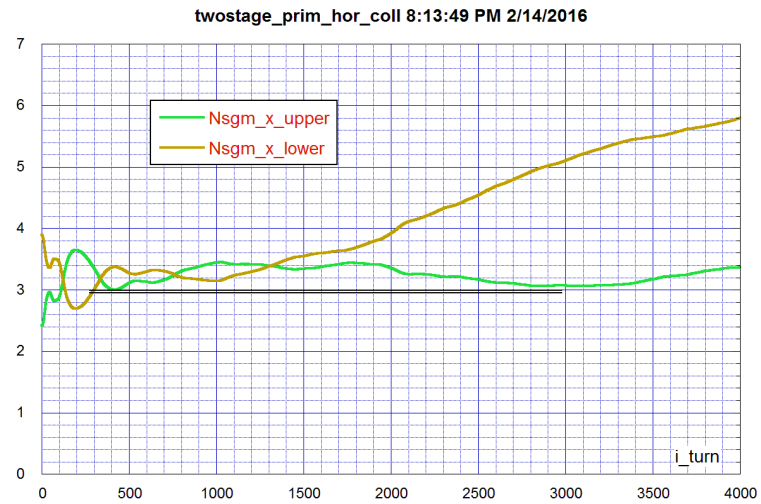




noise for y_up (BPMLU7-hor)

Data processing for 2-Stage: H-prim





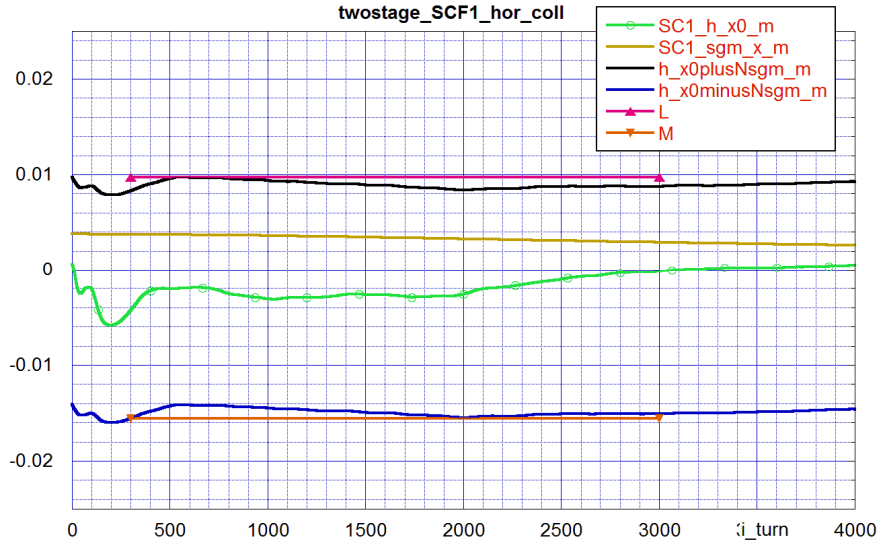
3-sigma - boundary between core and halo (to be collimated). Collimators can not intercept beam core (no beam losses!) We consider as example some range of turns (300-3000).
Emittance ~1/beta*gamma (or IPM measurements in a future)

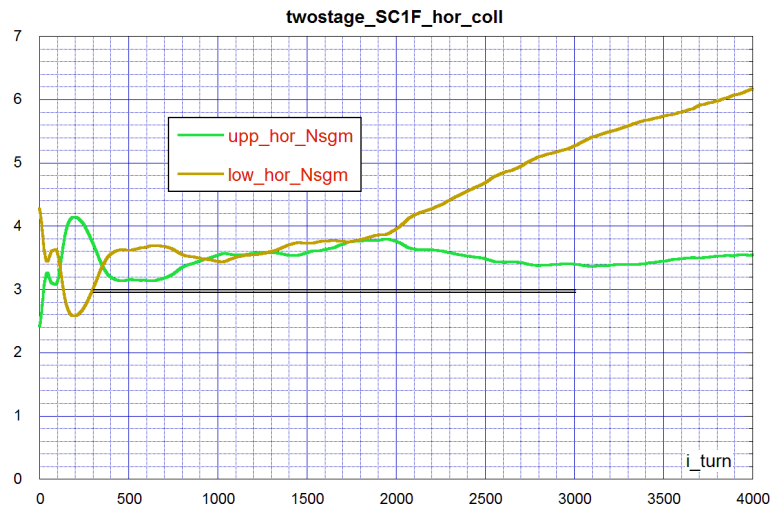
The left plot: At H-prim beam with design 3-sigma will oscillate due to CO oscillation.
3-sigma beam envelopes are shown in black and blue; green curve - is closed orbit (CO).

To avoid beam losses the 3-sigma beam core can not touch the Prim. collimator.
The minimal positions of PrC is defined by straight lines:
upper pink for aisle(out) and lower orange for wall (in) in boo tunnel.

The right plot: It shows actual N-sigmas=f(i_turn) at which the beam touches PrC at it setup positions.
Within the given turn range, N-sigmas are larger then the design values sigma=3 (black line).

Data processing for 2-Stage: SC1(L6A)H





gap=0.0014m (0.4sigma)

Left plot

Let's use N-sigmas=f(i_turn) at which the beam core touches PrimaryCol.

Secondary Collimator #1 (SC1) must not intercept the beam (core+some halo) given by the same N-sigmas=f(i_turn). The upper and lower boundaries of the N-sigmas beam envelope are shown by black and blue curves.

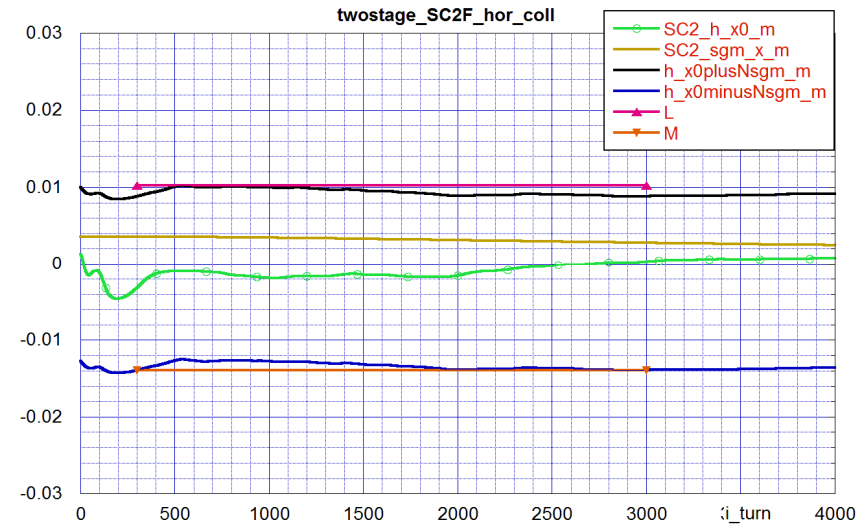
The direct interception of N-sigma beam by SC1 must be avoided (otherwise we get single-stage collimation).

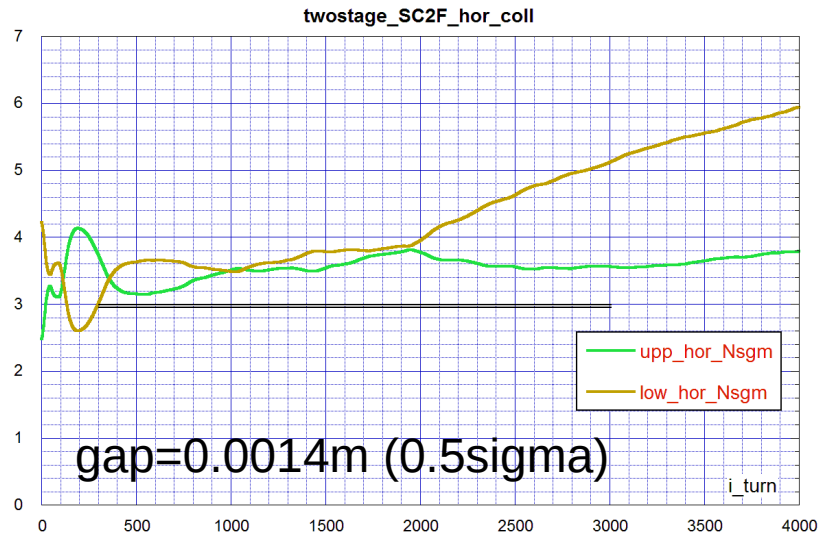
The pink and orange lines correspond to extreme aisle(out) and wall(in) positions of SC1. Since CO can randomly fluctuate cycle-by-cycle some additional "safety gap" should be added. In this analysis it is not used, but can be obtained later (several data sets).

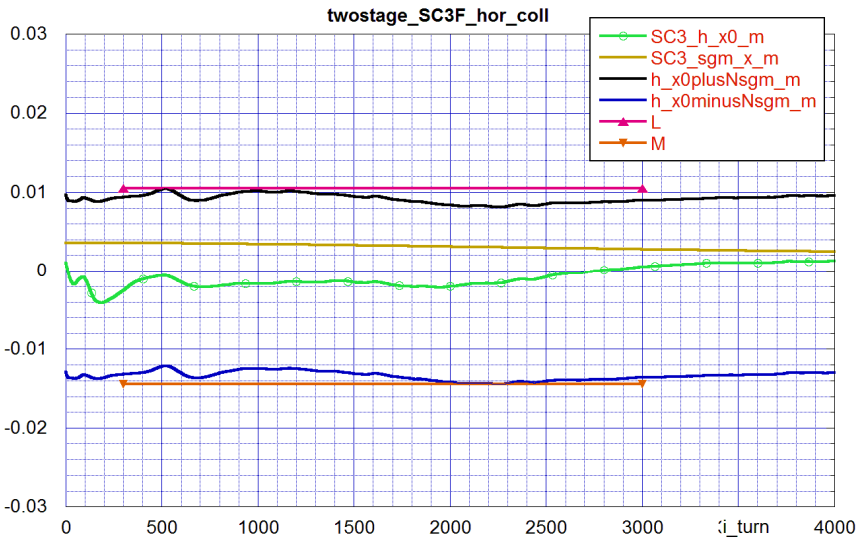
Right plot shows the beam N-sigmas at which the beam will touch SC1:

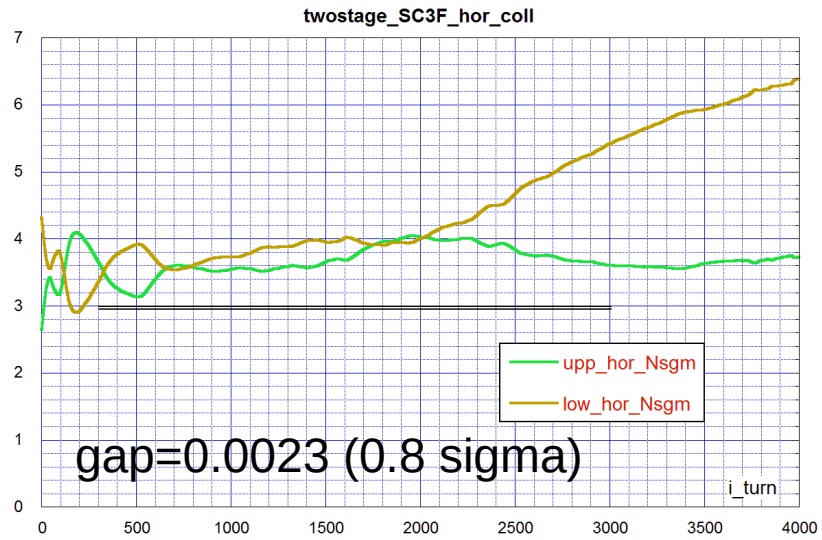
green(ailse); brown(wall)

2-Stage: SC2(L6B) & SC(L6C) Hor

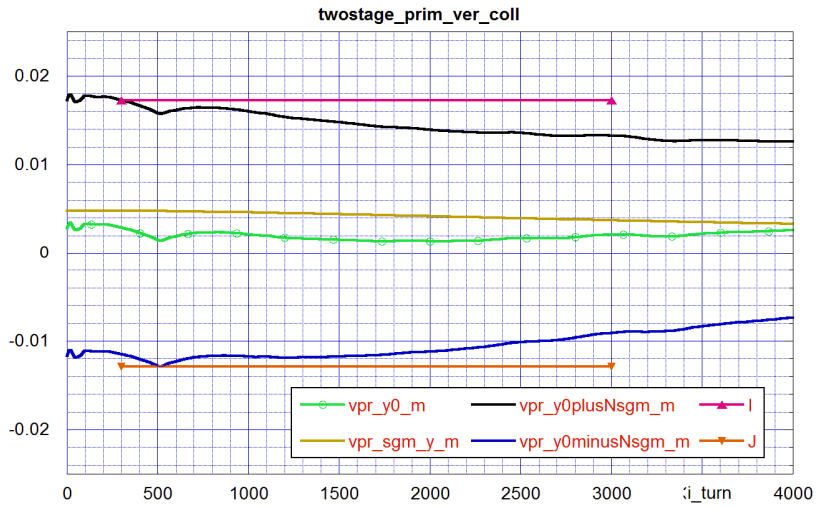


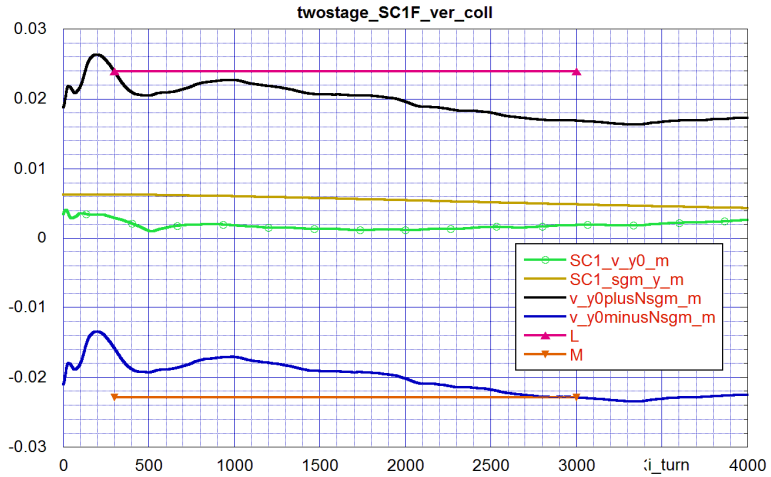




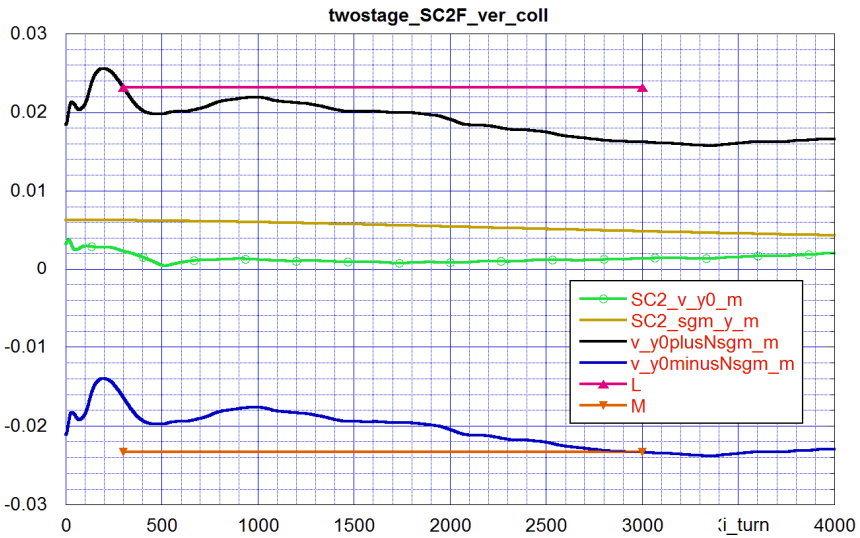


2-Stage: V-prim & SC1-3 Vertical

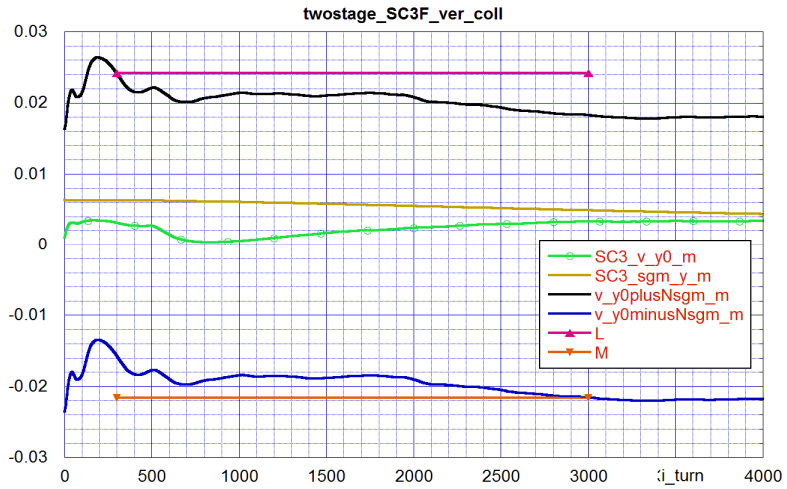




gap=0.0071m (1.4sigma)



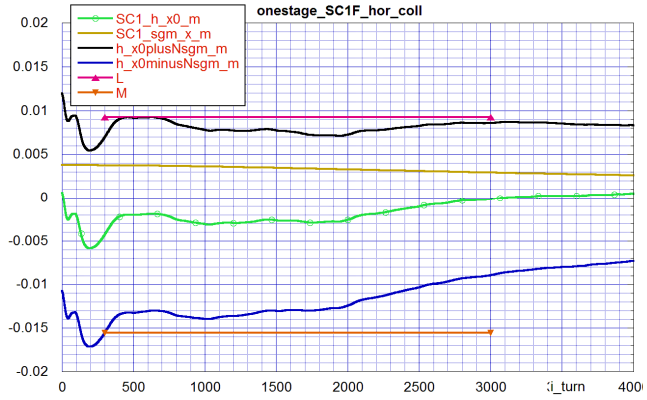
gap=0.007m (1.4sigma)



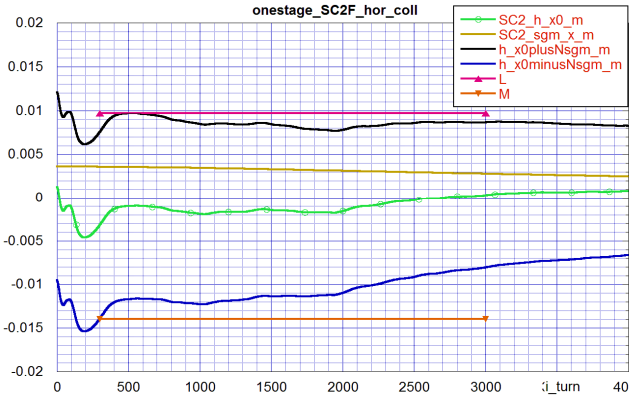
gap=0.0058 (1.2 sigma)

1-Stage: SC1-3 Hor & Vert

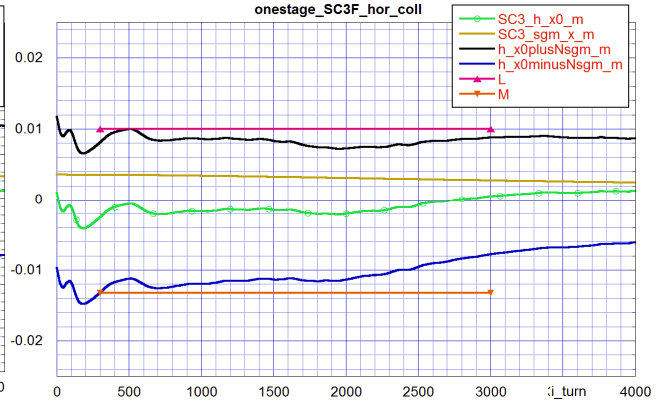
Horizontal:



gap=+0.02m(0.65sigma); -0.066(-2.3sigma)

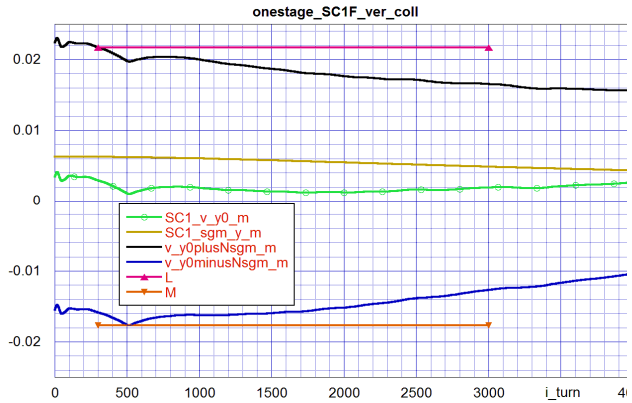


+0.002m (0.65sigma); -0.006m(-2.1sigma)

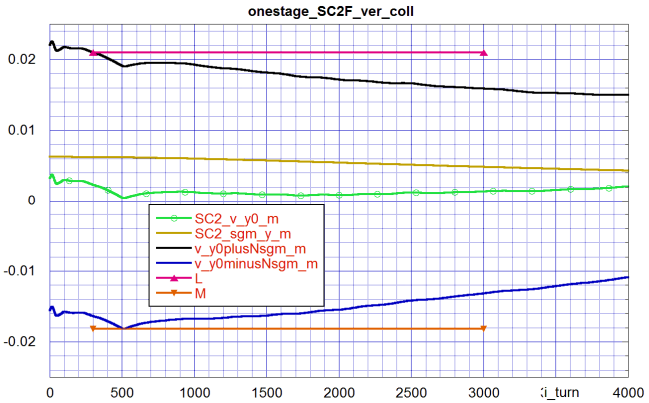


+0.0028 (0.9 sigma); -0.0054(-2.0sigma)

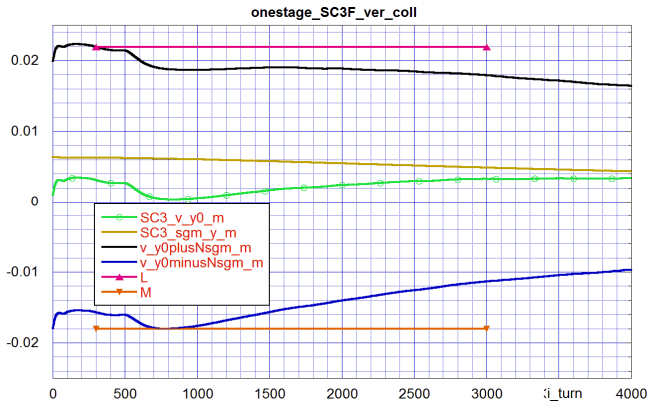
Vertical:



gap=+0.052m(1.1sigma); -0.050(-1.0sigma)



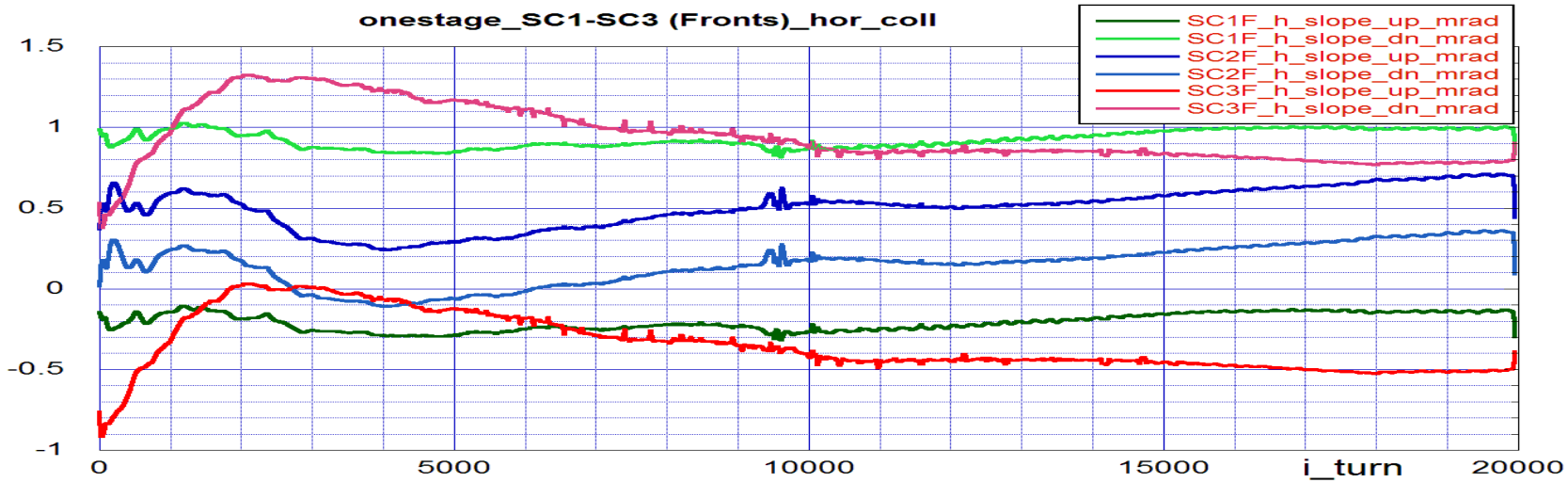
+0.005m (1.1sigma); -0.005m(-1.0sigma)



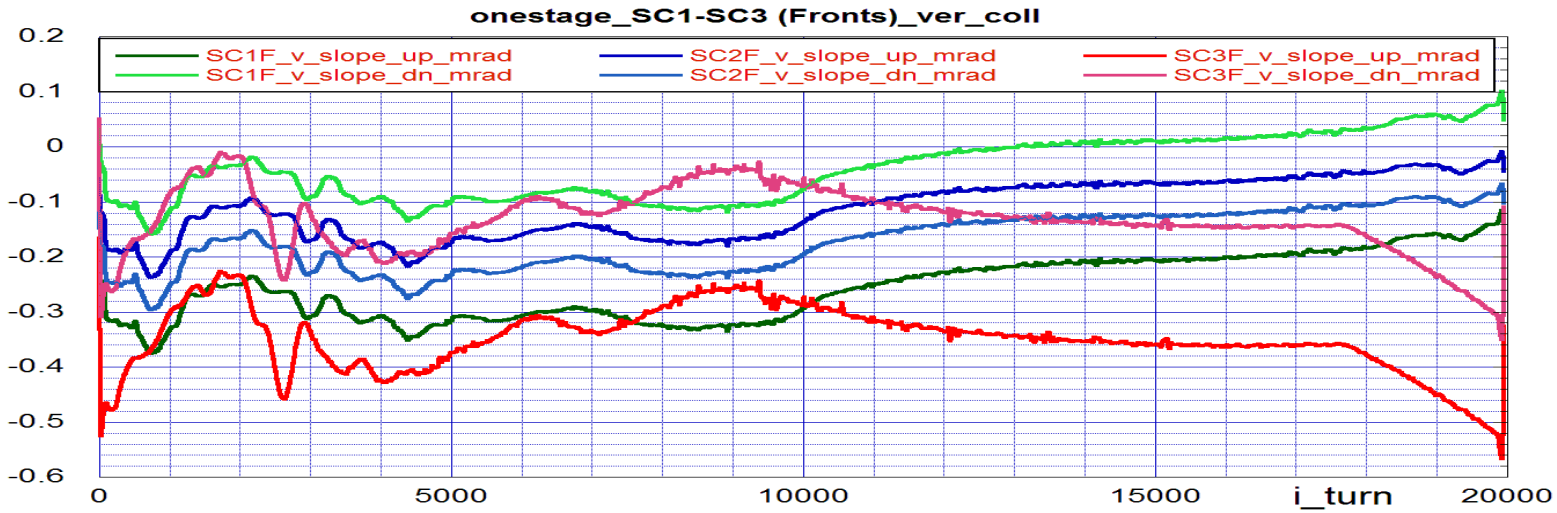
+0.004m (0.8 sigma); -0.007m(-1.4sigma)

1-Stage: Slopes of beam envelopes (Angles!)

Horizontal:



Vertical:



Slopes at phase-space point where beam-halo touches a collimator jaw

Conclusion

- Collimation hardware is ready for beam studies
- Detailed plan will be worked out (Rick, Todd, VK + help&advises from other people involved)
- With my BPM data processing the current C.O. position, gaps between SC & beam and halo angle (for 1-stage colls) can be understood and controlled (also used in simulations, if needed)
- Collimator maintaining plan for next summer shutdown (Matt - to sample the oil the from one of the collimator gearboxes, and at least visually check the condition; to purchase a spare gearbox to have on hand)