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# Collimation

Valery Kapin

Workshop on Booster Performance and Enhancements
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# Activities & acknowlegments to people involved

1) Booster Collimator Hardware & Control (motion tests):
   *Charles Briegel, Salah Chaurize, Mike Coburn,*
   *Vladimir Sidorov, Matt Slabaugh, Todd Sullivan,*
   *Rick Tesarek*

2) Support for Beam Dynamics Simulations:
   *Valeri Lebedev, Nikolai Mokhov,*
   *Igor Rakhno, Sergei Striganov, Igor Tropin*

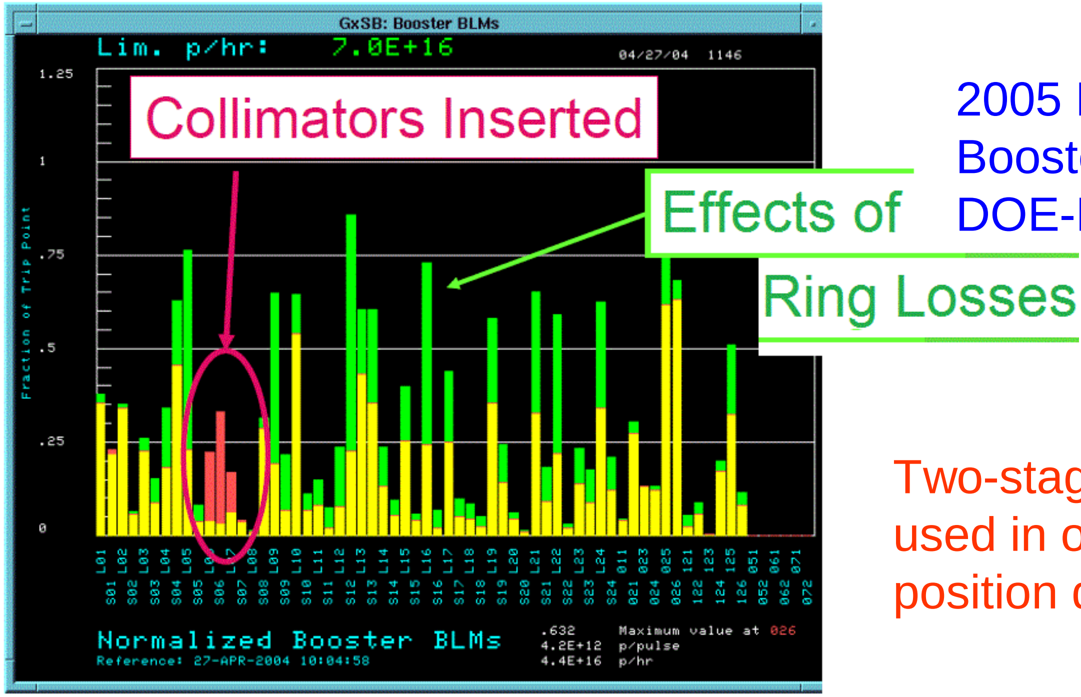
3) Support for task managments:
   *Bill Pellico and Cheng-Yang Tan*

# 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*




March 29 - 31, 2005 DOE Review of Tevatron Operations at FNAL 10

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”)

# Principle scheme of 2-stage collimation system

Collimation system must redistribute losses to dedicated “secondary” collimators

Usual “1-stage” collimation produces uncontrolled out-scattered protons => “2-stage” scheme

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

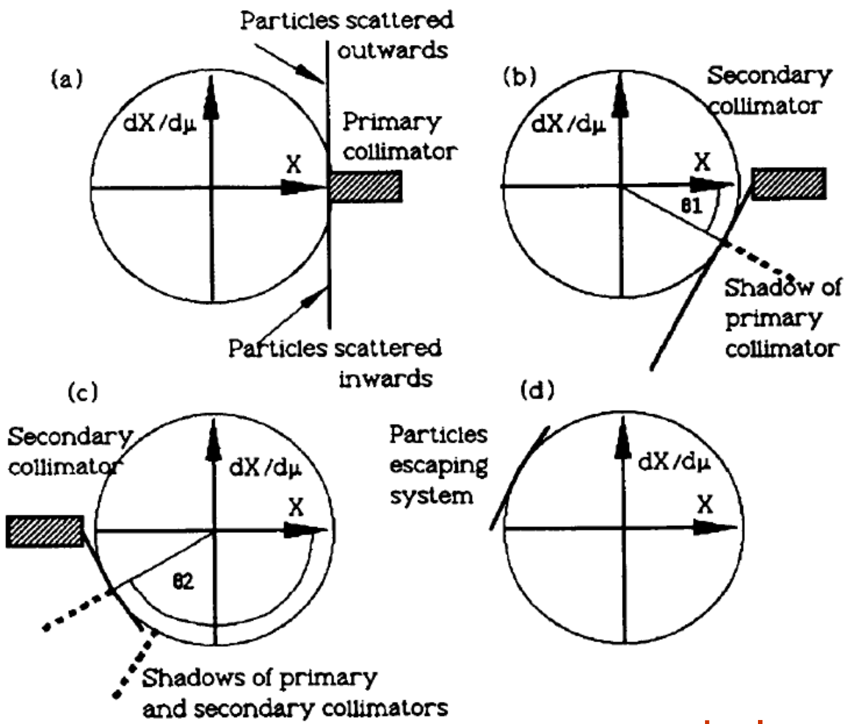



Fig. 11 Main features of a collimation system

The primary collimator is followed by two secondary collimators set at optimized phases for intercepting the scattered particles.

Simulations steps (as with STRUCT):

- ❖Generate **part. distribution** on edge of Prim-Collimator (halo-particles)
- ❖**Scattering** in material of thin P-Coll
- ❖**(Non-linear) Tracking** scattered parts
- ❖Collect **lost particles** on Sec-Colls and other magnet **apertures**

halo particles => large amplitudes =>
Correct treatment non-linear dynamics => ~MADX

# Collimator placements in booster

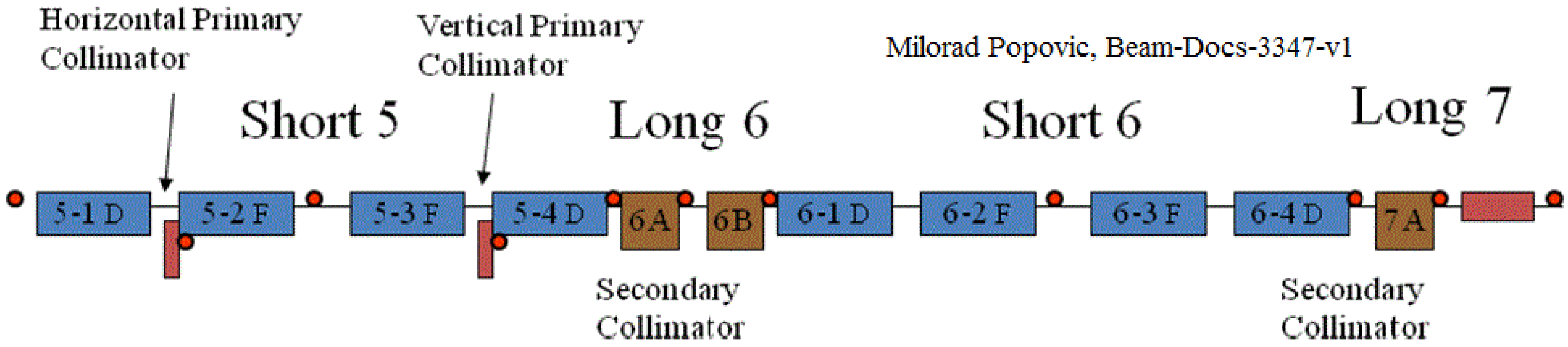
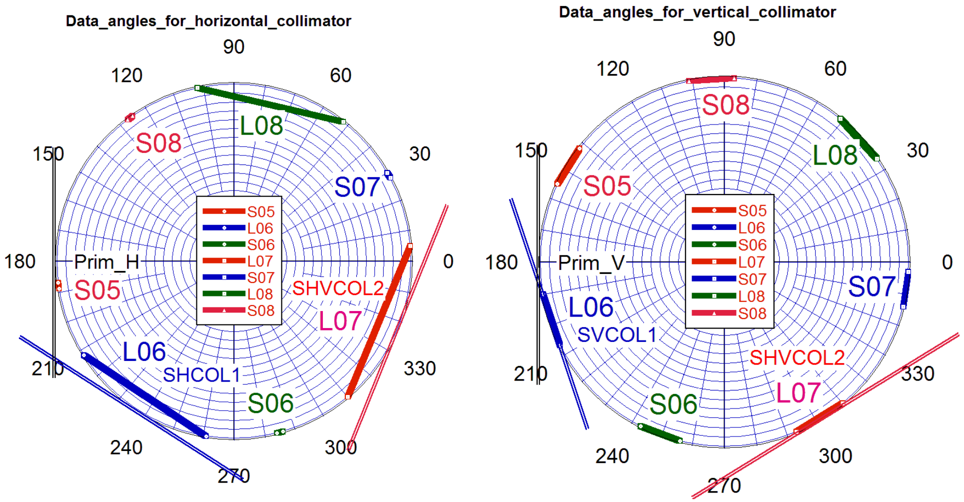



Figure 1. Blue boxes represent the main magnets; collimators are represented by brown boxes.




**Restrictions for design:**

Not optimal phase advances;

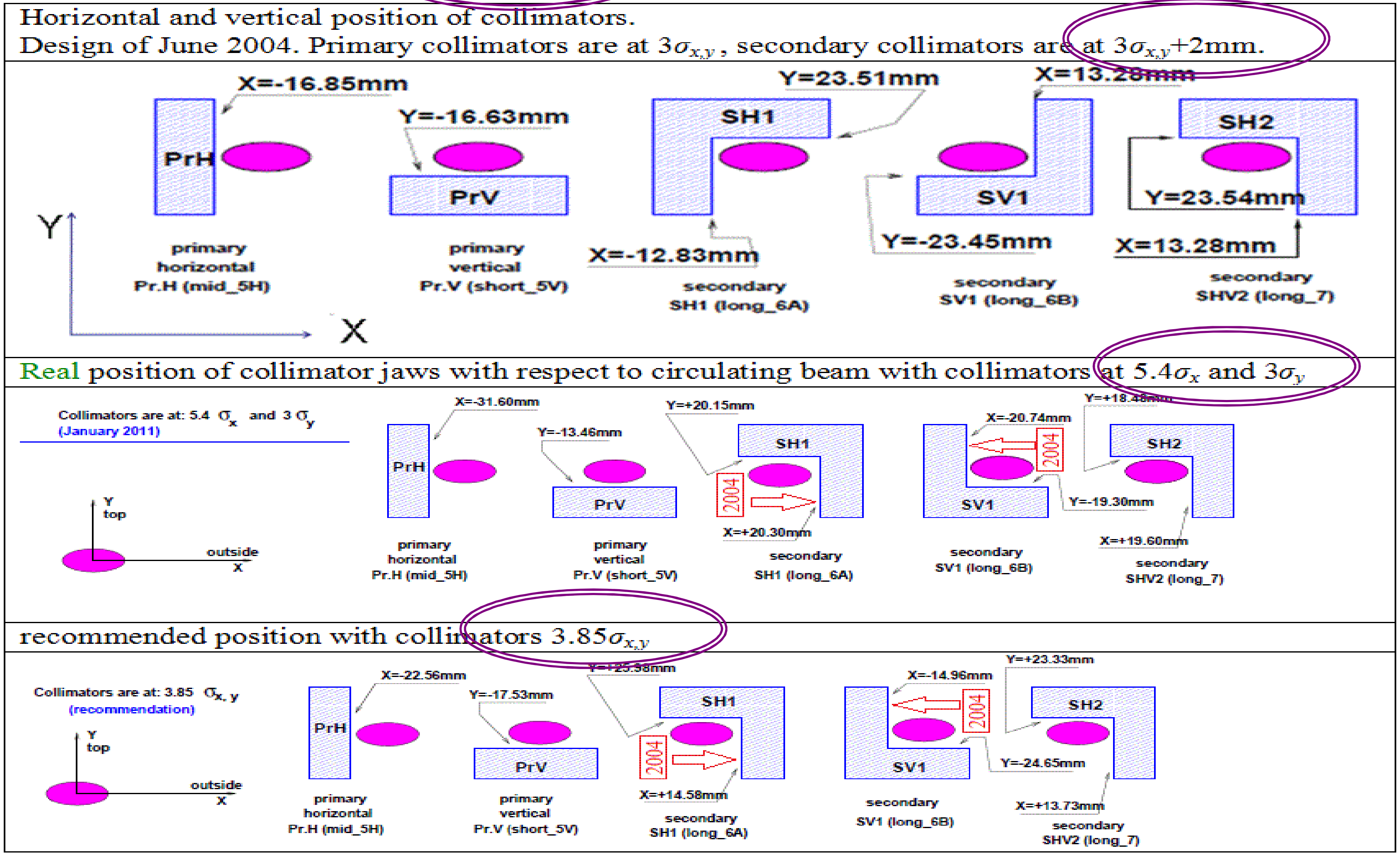
Small magnet & RFcav apertures;

Bending magnets in coll system;

Variable beam parameters during accelerator cycle

# Collimation system transverse layouts by A.Drozhdin

**Table. from Ref.1 "pap_coll-2011_new.pdf"**



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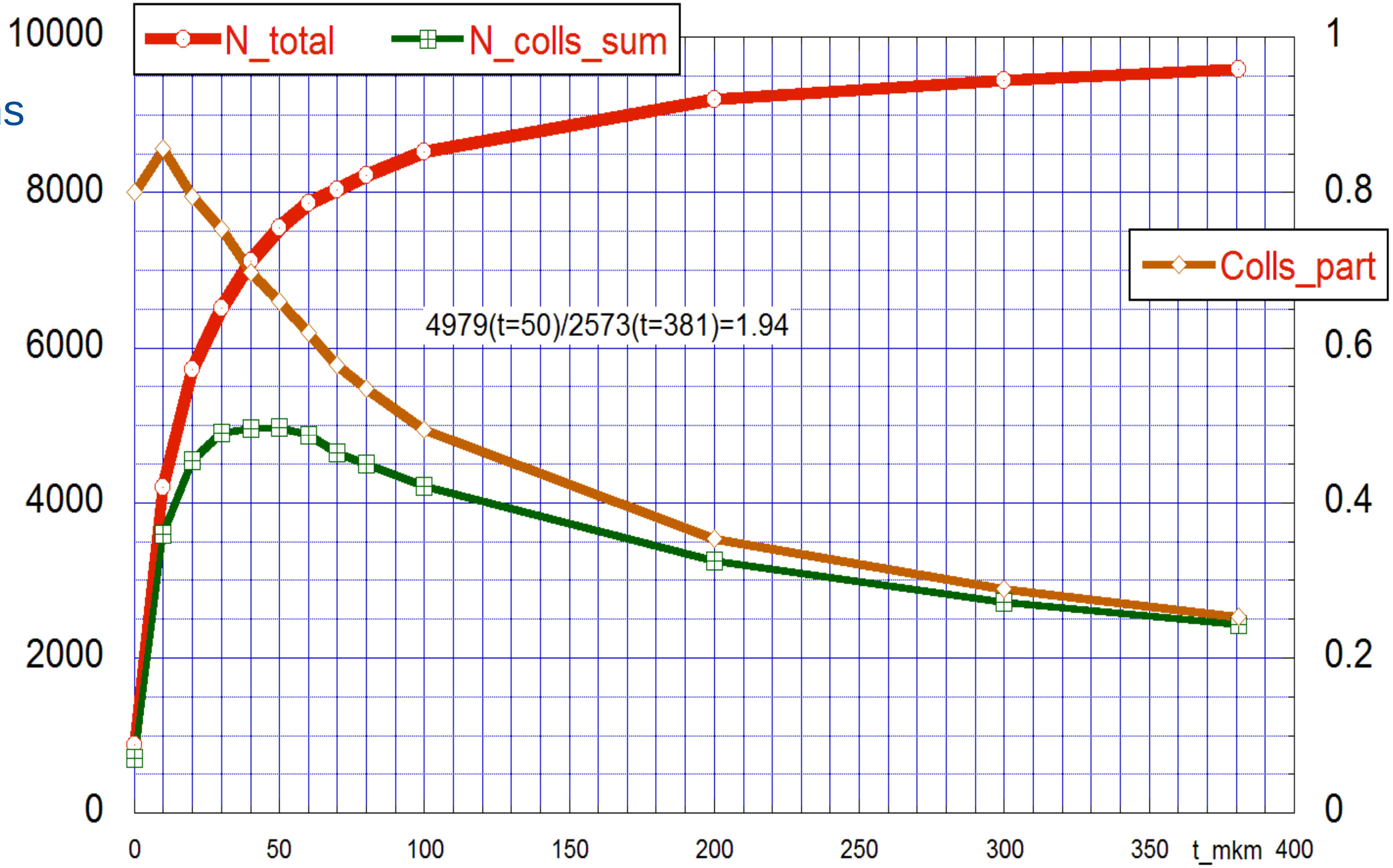
# Task started in 2014: optimal thickness of primary coll.

- **MADX code** has been modified to include **proton interactions with thin primary collimators** (Prim-Colls), while out-scattering from secondary collimators is neglected
- **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**

# MADX (w/o out-scattering): horizontal collimation for 2004-design

After 10 turns




Maximum N_colls_sum at 50um (within 30-60um)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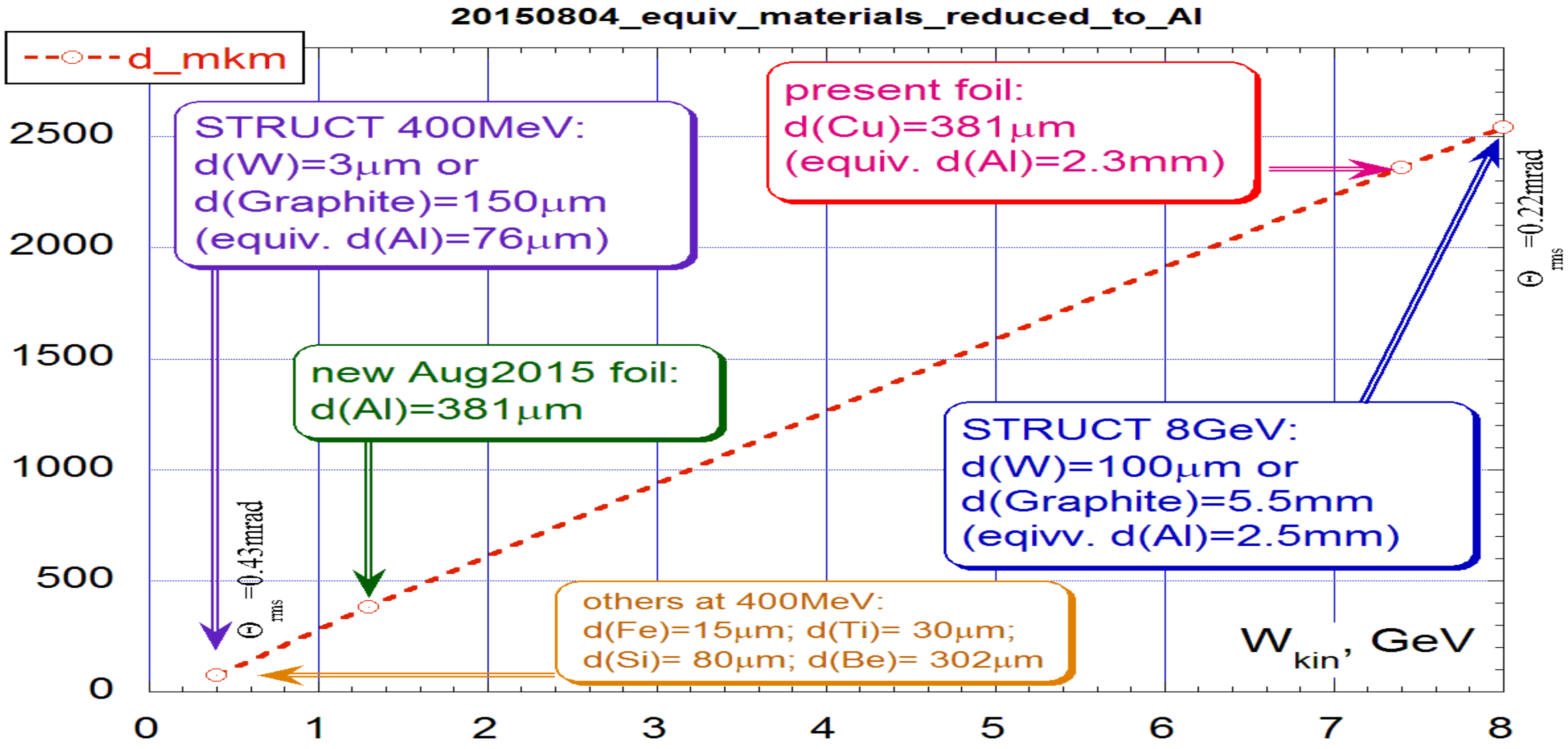
# Primary thickness for ~2004 “STRUCT” design & Equiv. materials

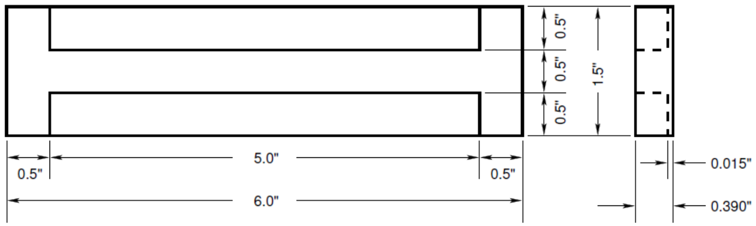


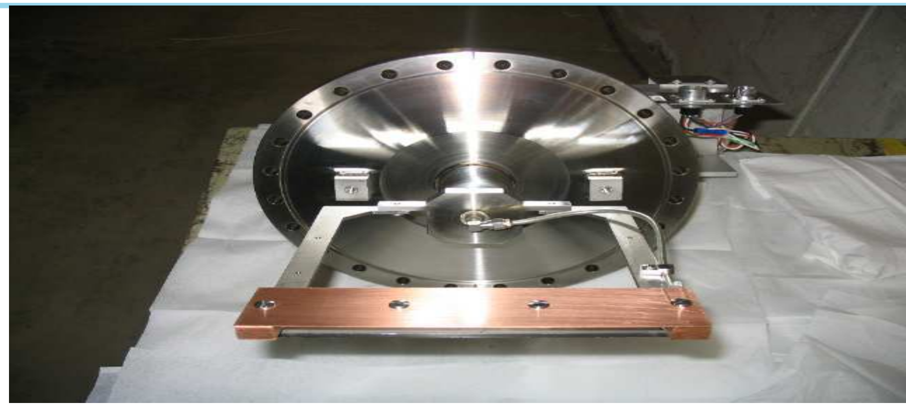

## RMS scattering angle

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p}\, z\, \sqrt{x/X_0}\left[1 + 0.038 \ln(x/X_0)\right] \qquad x[\mathrm{g/cm^2}] = \rho[\mathrm{g/cm^3}] \cdot d[\mathrm{cm}]$$

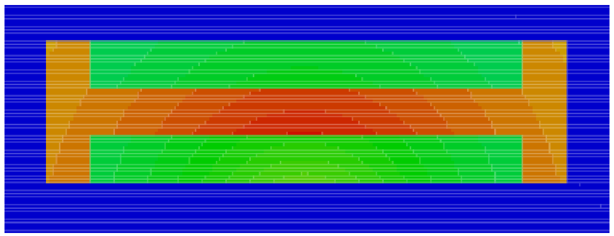
# New aluminium Prim-Colls

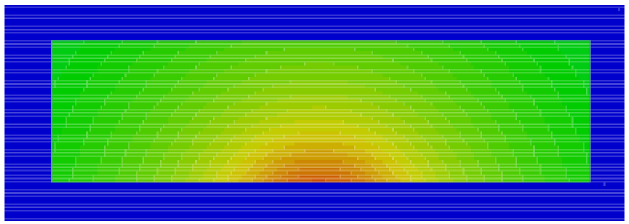
2005: Cu primary heat sink with
signal cable (+ceramic ins.)



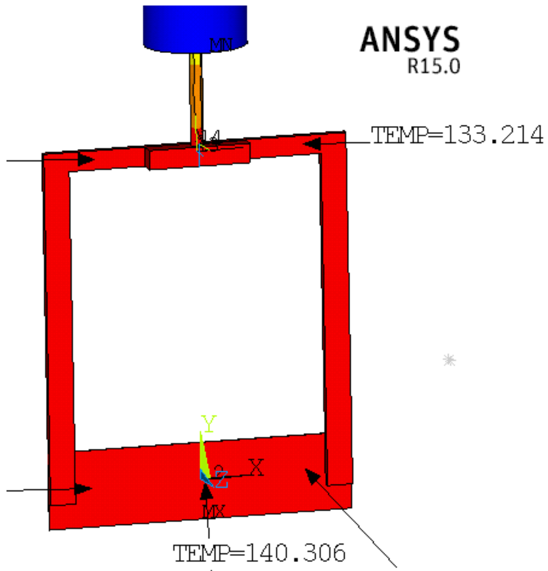
Oct.2015 New simplified primary assembly (just Al plate without any ceramic insulators):
R.J. Tesarek et al, Beams-Doc-5983, November 4, 2015.



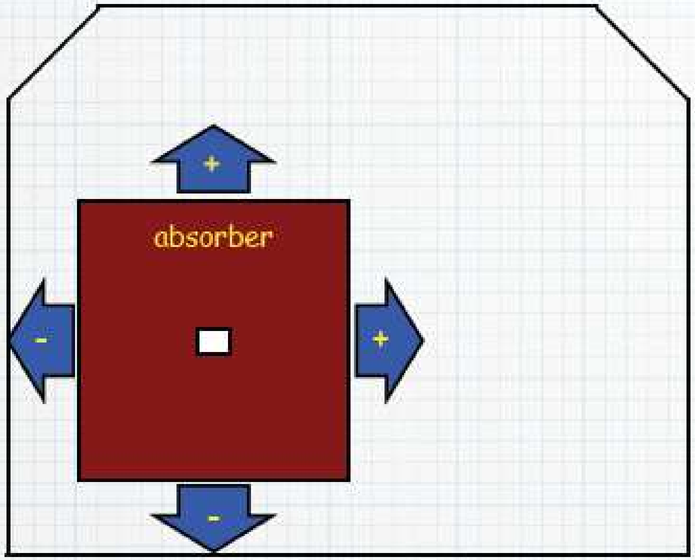


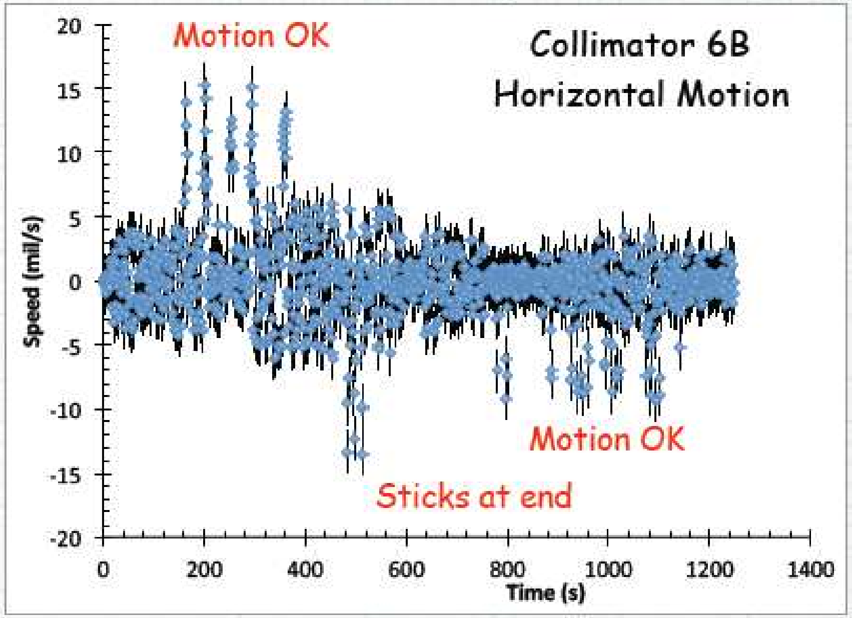
Aver.deposited beam power is reduced 30 times

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).



# Sec. collimators motion: reliability (courtesy R.Tesarek)




Motion Reliability Tests:

- Move absorber multiple times
- Check that device moved correctly

➡ Found collimators move more reliably at slower speed.

✓ Updated program to move all absorbers at "reliable" speed.

✓ 4mil/s (H) 9 mil/s(V) (C.Briegel)

Needs further study (summer shutdown)

## "Reliable" Speeds

| Collimator | Vert. speed (mil/s) | Horiz speed (mil/s) |
|---|---|---|
| 6A | 4.5 | 12 |
| 6B | 4.5 | 9 |
| 7 | 4 | 11 |

# Sec. collimators motion: Horizontal Backlash Calibration

**Program Corrects for Backlash:**

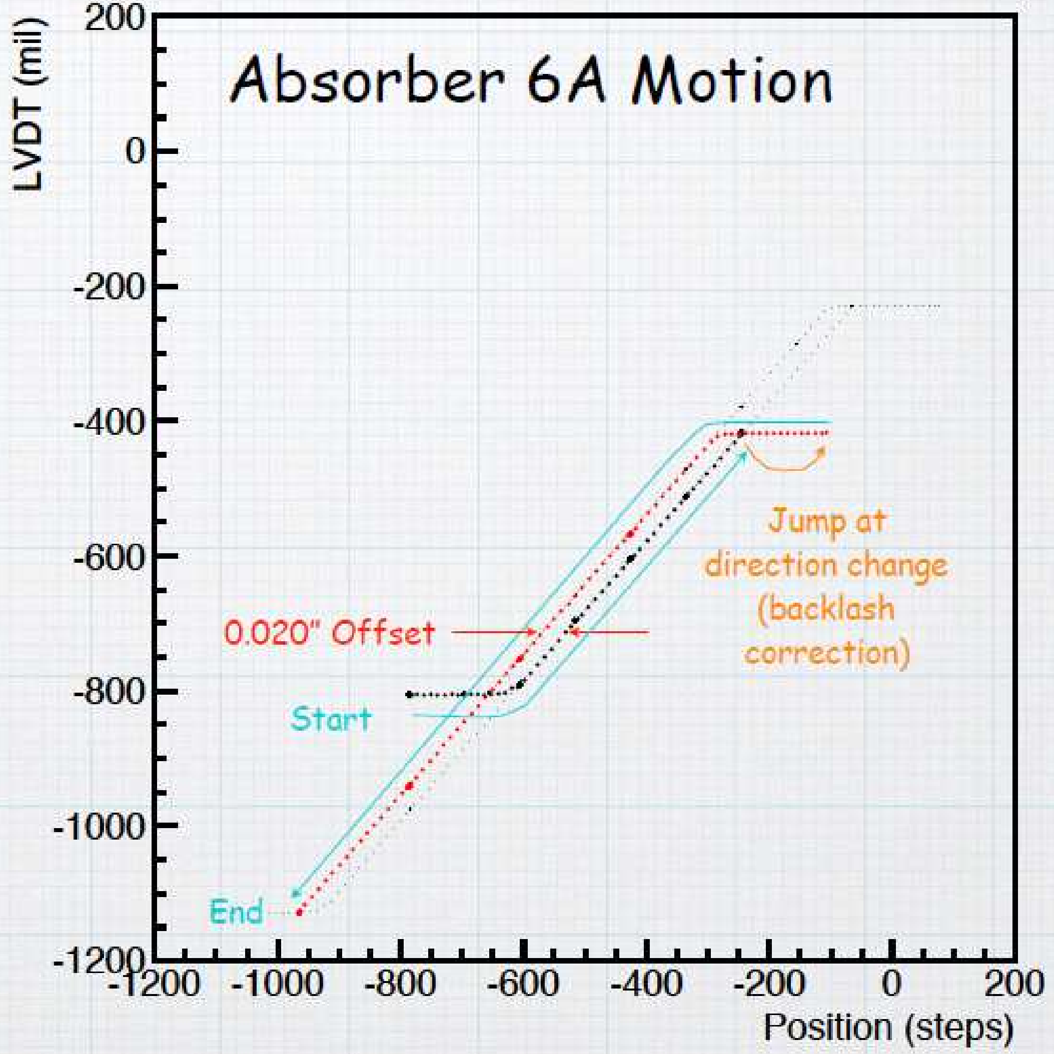
- Correction observed too small
- Data to make new correction
- Confirm correction

➡ 6B found to be "slipping"

➡ Can correct to 0.020" (no better)

Additional studies needed next shutdown

| Collimator | Backlash Correction |
|---|---|
| 6A | +0.020" |
| 6B | Slipping |
| 7 | +0.043" |



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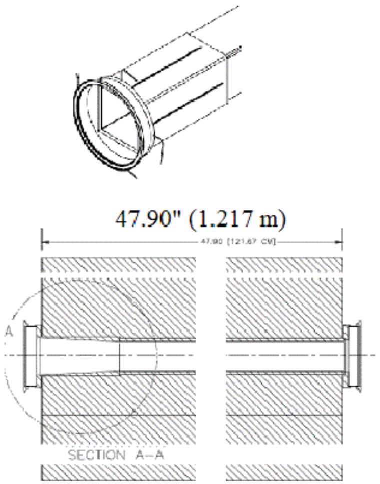
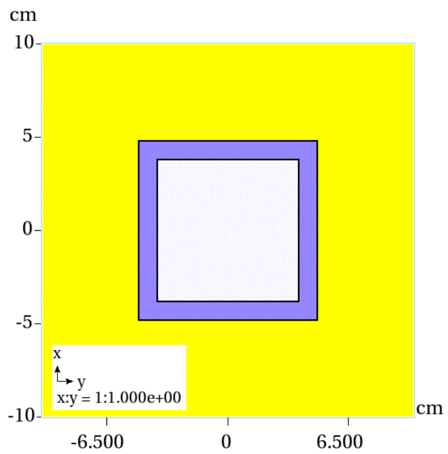
# New simulations: upgraded model

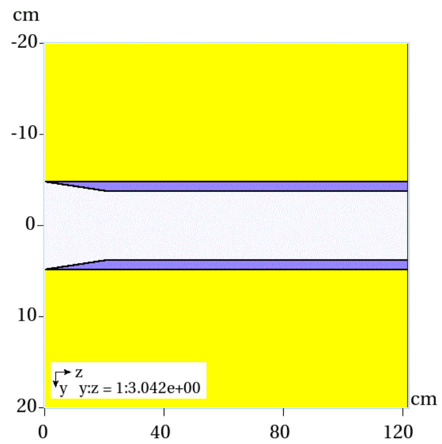
- General idea by V.Lebedev & N.Mokhov
- A new simulation approach including **out-scattering in Sec-Colls** is under development for a correct **comparison of two-stage and one-stage collimation** in the booster.
- The proton interactions with Sec-Colls are simulated by MARS (Mokhov's group) and used by MADX tracker as black-boxes.
- Calulations for different collimator layouts (2004-design; 2011 Drozhdin “real” configuration; and find optimal one)
- Plans: simulations for different beam sigma and halo sizes
- Optional: Optimizations for existing single-stage scheme

## New simulations: Mars model for booster secondary collimators

The model of sec. collimator was created by I. Tropin & I.Rakhno.
Interface with “STRUCT” coordinate system (x,x’,y,y’,p)



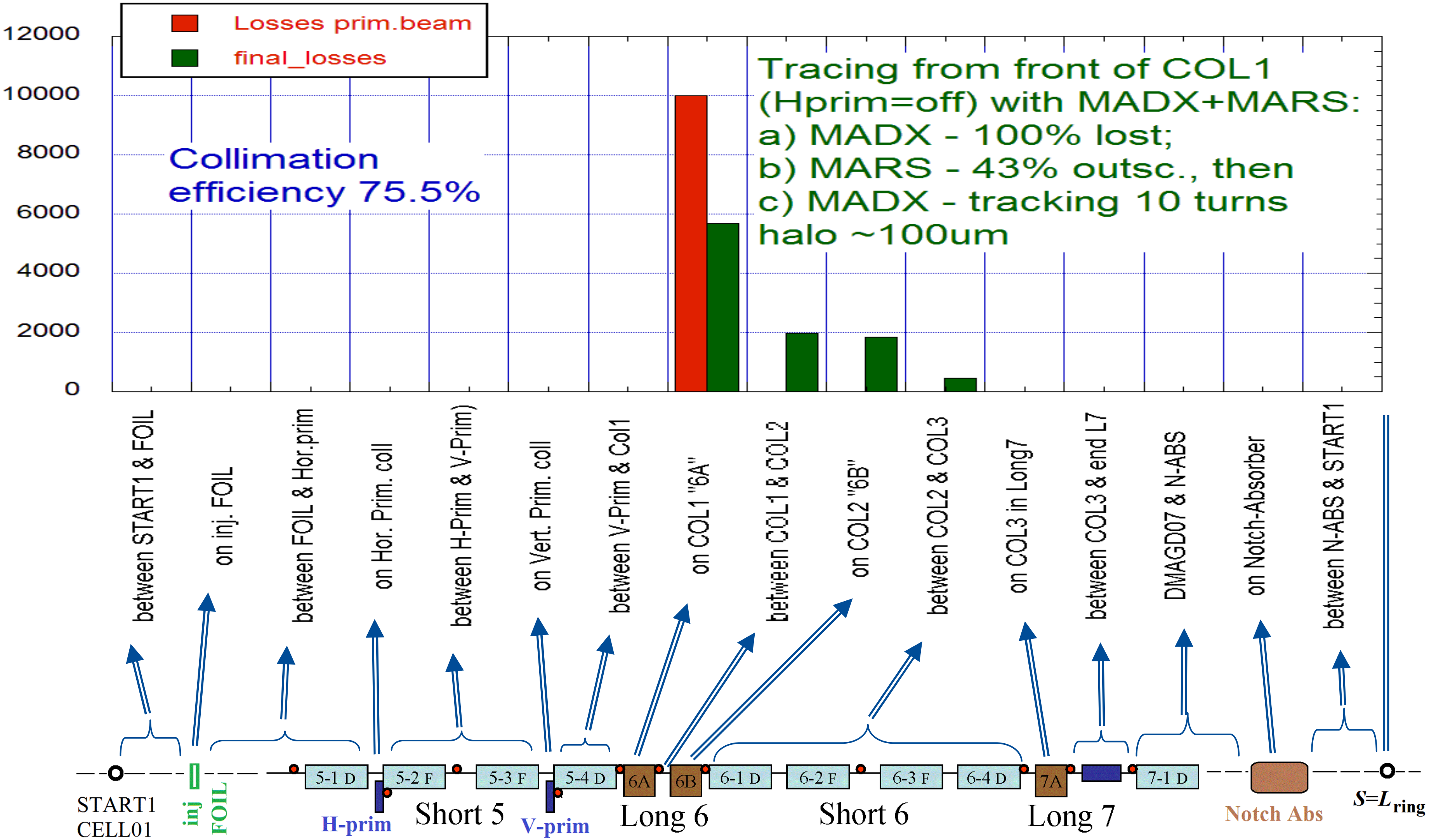



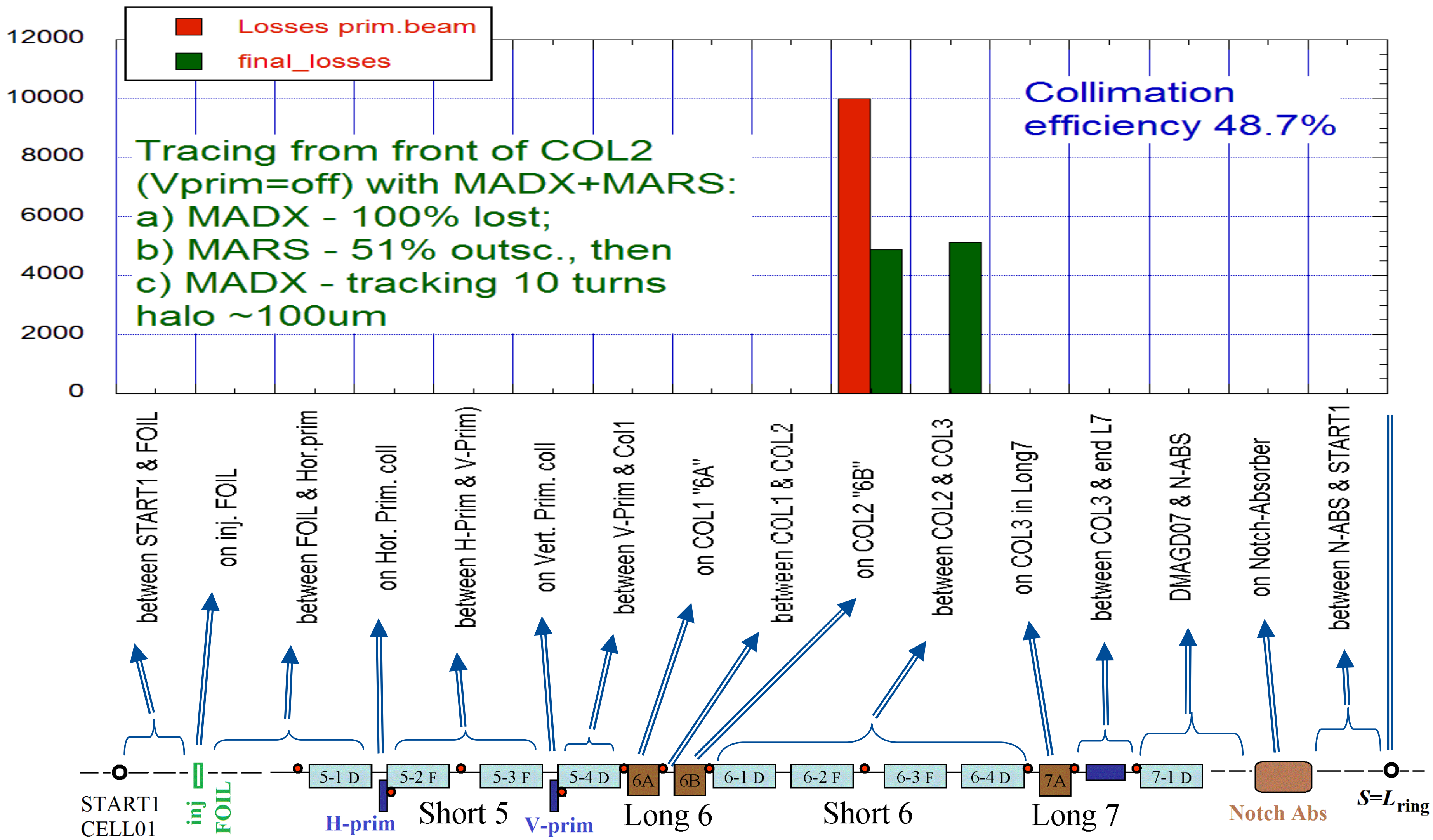

*One model for 3 identical sec-colls. Model is centered on ref. orbit.*
*Transverse shifts simulated via shift of input and output particle coordinates*

*Steps: a) MADX multiturn tracking; b) protons lost on collimators collected at collimator fronts; c) that protons are re-tracked throughout sec-colls with MARS; d) Out-scattered protons are collected at sec-coll ends are tracked again by MADX*

# Example of 1 stage horizontal collimation on COL1



# Example of 1 stage vertical collimation on COL2



# Efficiency(%) of 1 stage collimation vs sigma & halo-width

Horizontal collimation on COL1
(Convergent beam envelope)

| | 3sigma | 4sigma |
|---|---|---|
| 10um | 69.86 | 65.13 |
| 100um | 75.48 | 76.40 |
| 1000um | 81.93 | 81.61 |

Vertical collimation on COL2
(Divergent beam envelope)

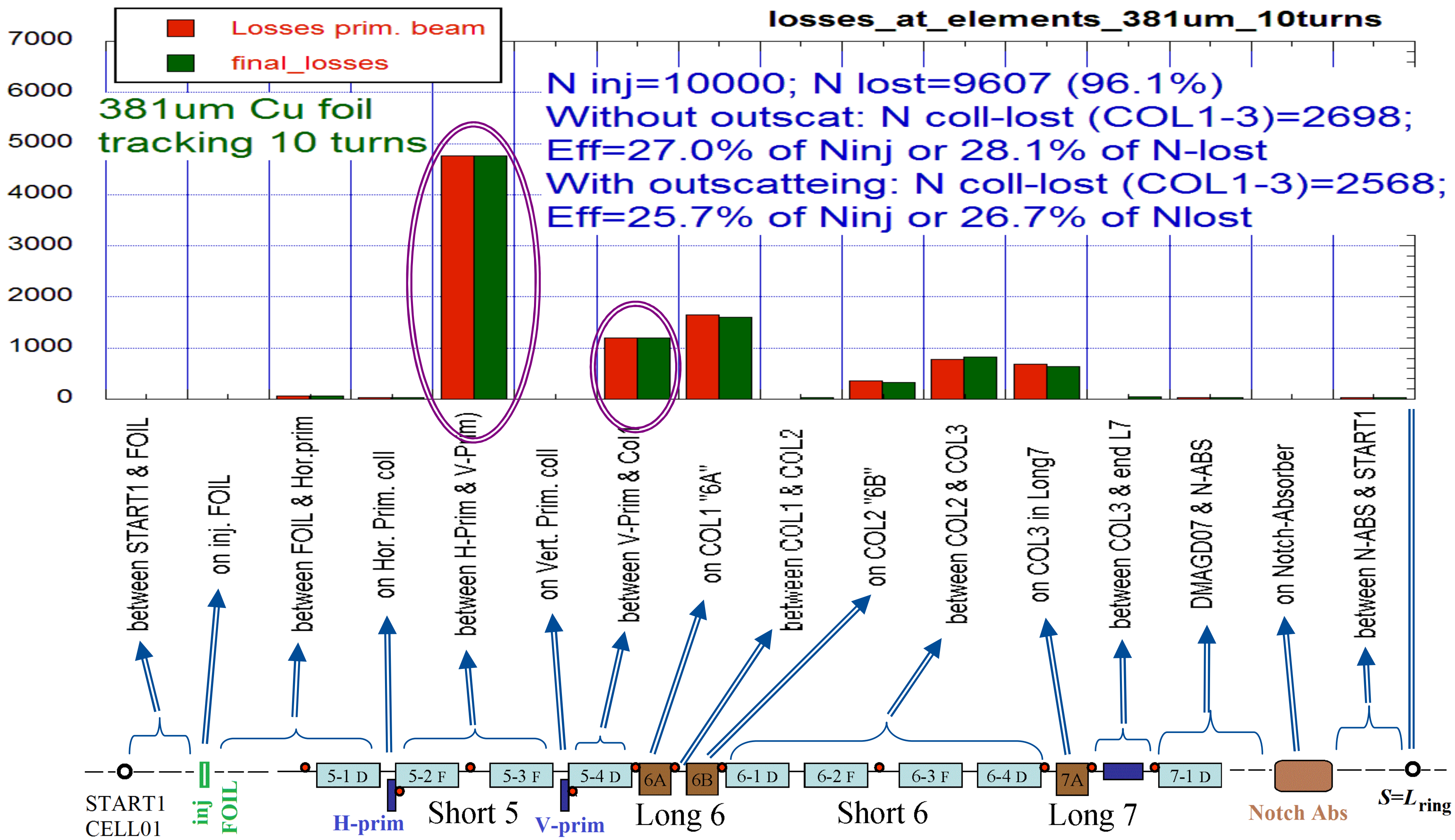
| | 3sigma | 4sigma |
|---|---|---|
| 10um | 24.14 | 21.18 |
| 100um | 48.71 | 46.05 |
| 1000um | 68.04 | 67.45 |

1-stage collimation dependence on:

- **Twiss alpha** – higher absorption for convergent beam
- higher beam **halo width** => higher impact parameter
- **Beam sigma** is not critical within 3-4 for booster

*Efficiency in range 25-80%; Possible optimization by yaw & pitch angles*

# Loss distributions with present 381um Cu foil (*10turns*)



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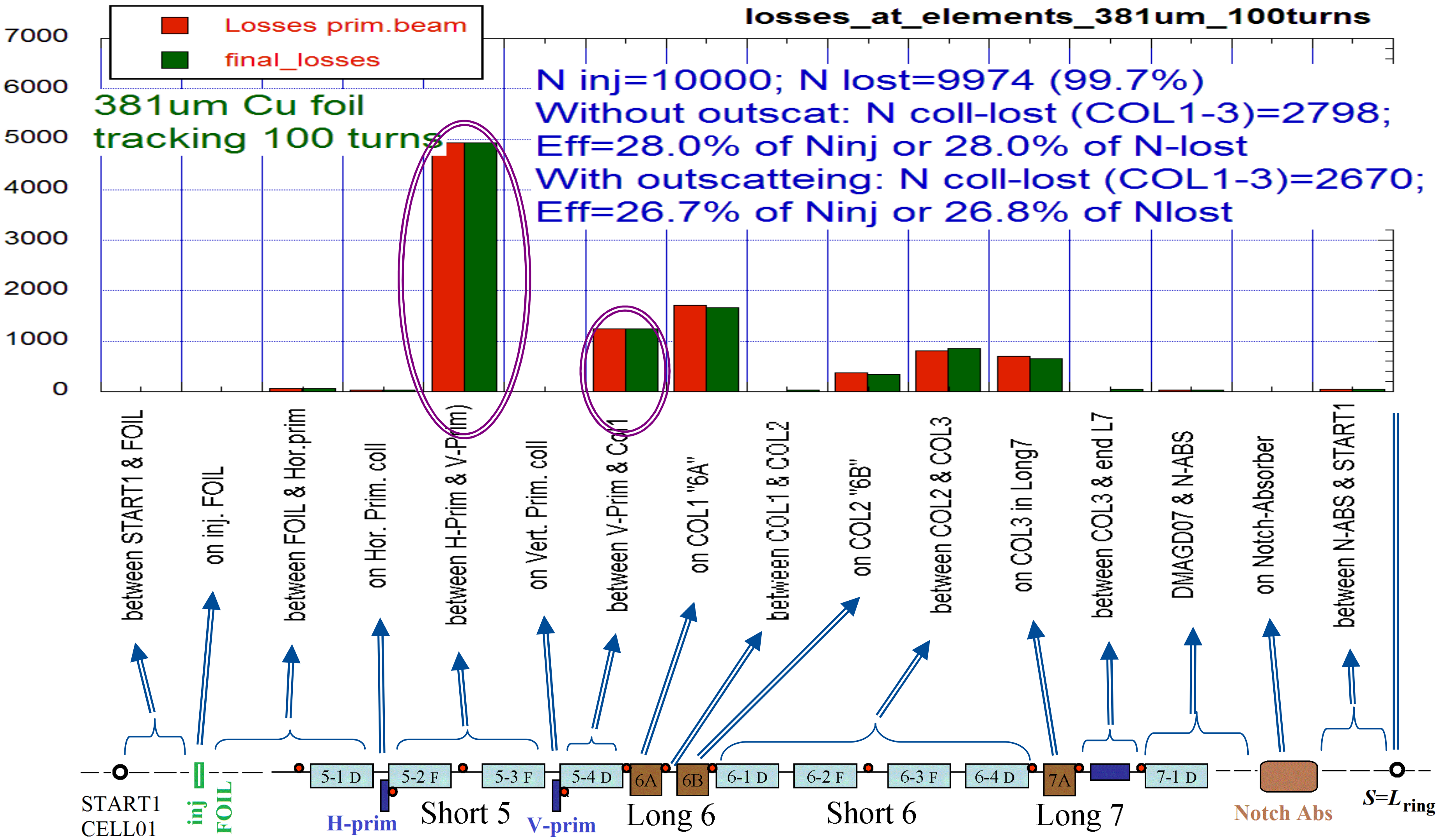
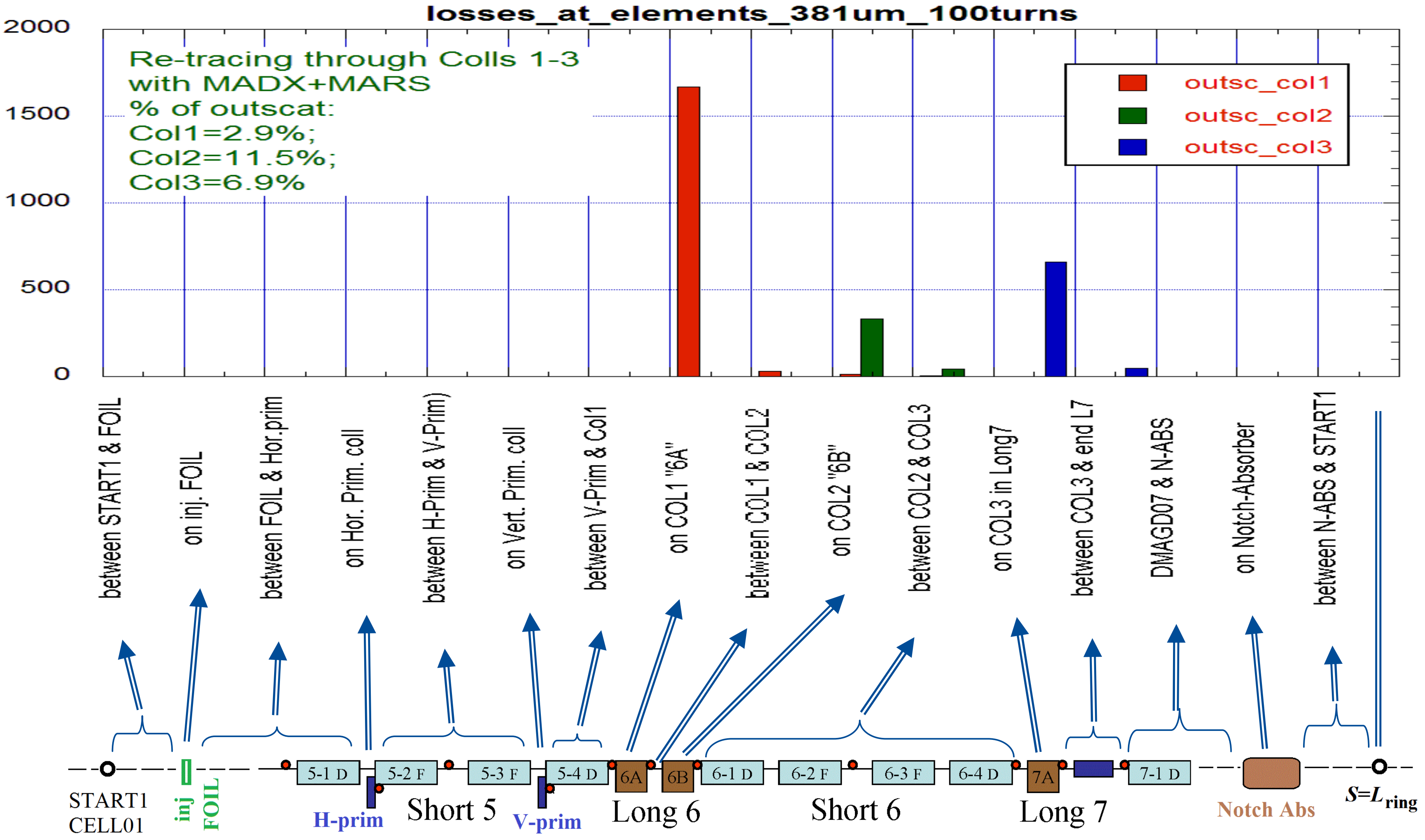
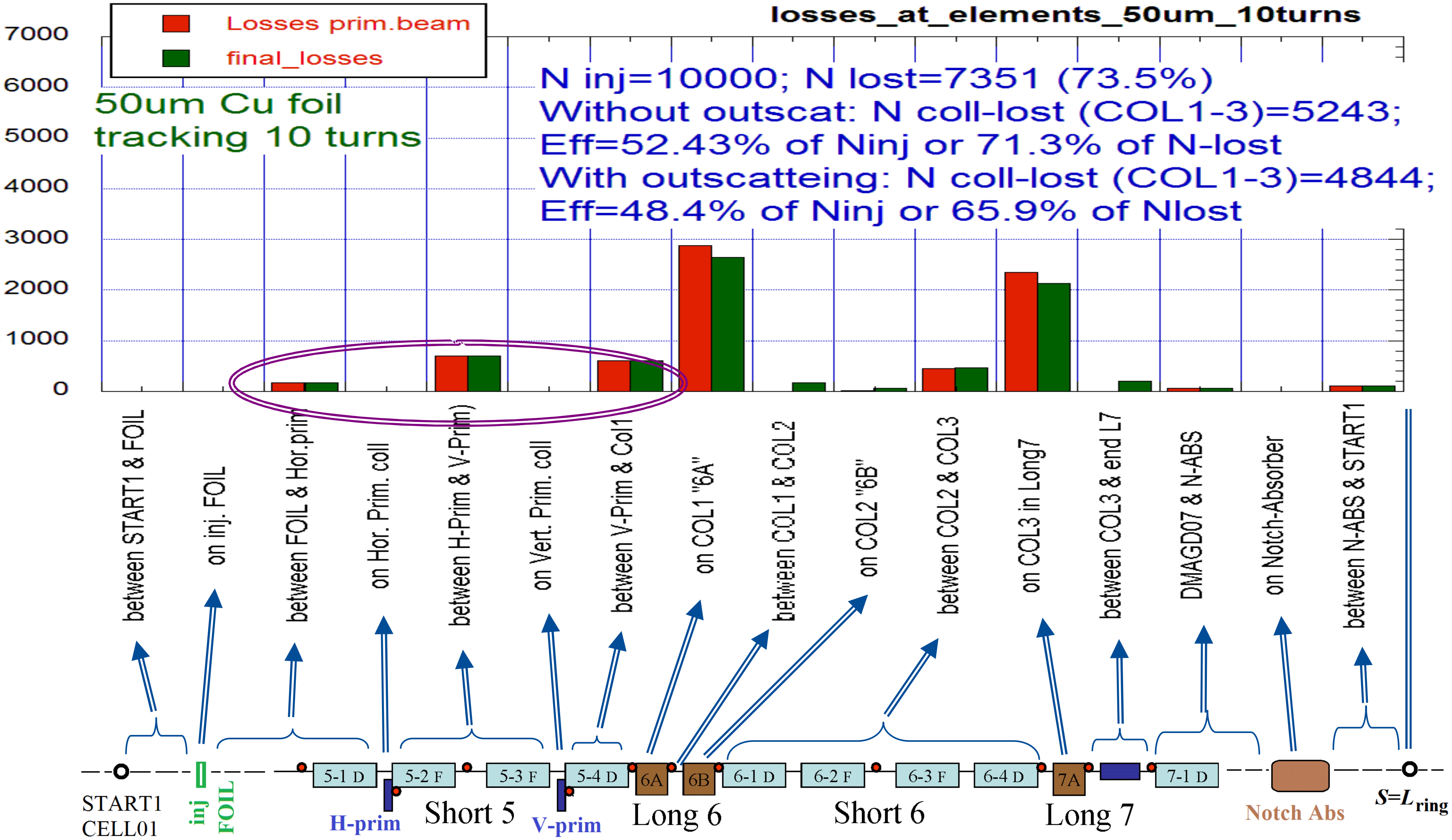


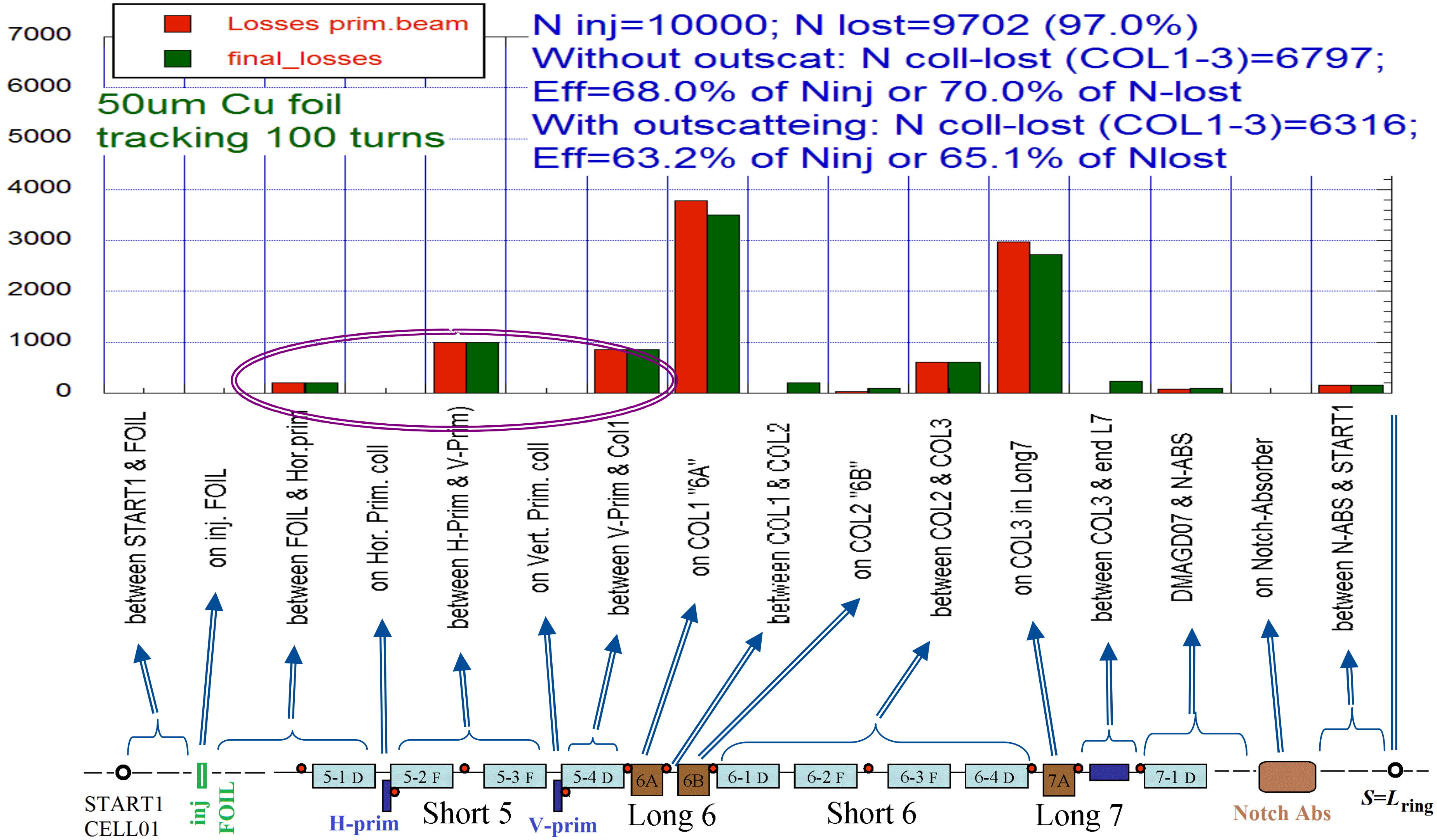
# Losses on collimators redistributed with outscattering (381um Cu foil)



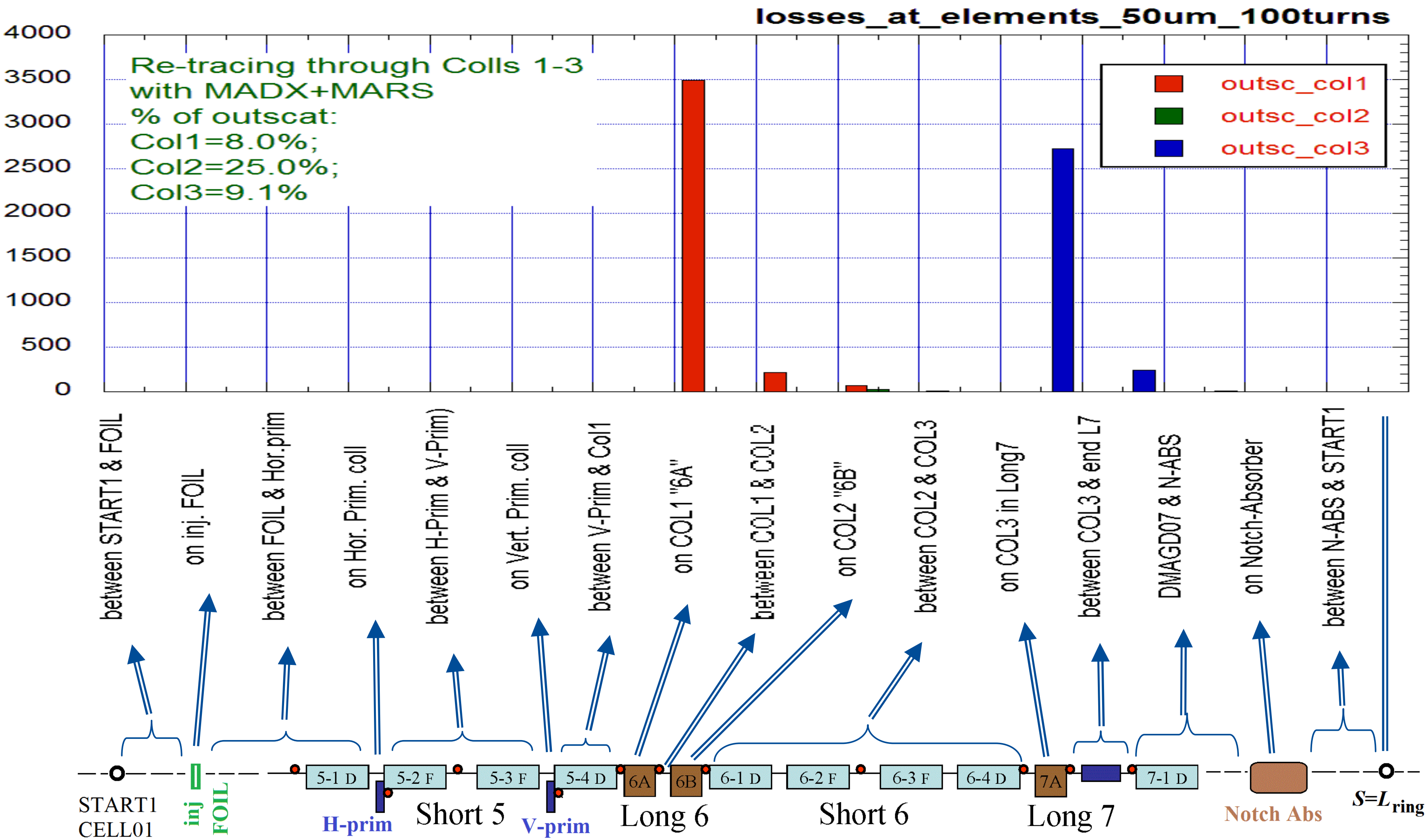
# Loss distributions with new 381um Al "50um Cu" foil (*10turns*)



# Loss distributions with new Al “50um Cu” foil (*100turns*)



# Losses on collimators redistributed with outscattering (new Al 381um foil)



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# Efficiency(%) of 2 stage collimation vs sigma & halo-width & turns

## Horizontal collimation with new Al “50um Cu” foil at 10/100 turns

| | 3sigma | | 4sigma | |
|---|---|---|---|---|
| halo | % of injected | % of lost | % of injected | % of lost |
| 10um | 48 / 63 | 66 / 65 | 41 / 55 | 59 / 57 |
| 100um | 48 / 64 | 66 / 65 | 42 / 57 | 59 / 58 |
| 1000um | 51 / 65 | 67 / 65 | 44 / 58 | 60 / 58 |

2-stage collimation dependence on:

- Efficiency <coll.loss>/<total losses> ~ const vs N_turns
- Efficiency <coll.loss>/<injected> increases with N_turns
- Efficiency decreases for larger beam sigma
- Weak dependency of halo width (?)

# Plans for near future

- Matt made drawings for new Al foil and its "fork " holder: fabricated and ready for alignment measurements and installation of both(?) primaries in vacuum  (a future >8hrs shutdown)
- "Easy" replacement of prim. plate (Al: 0.015"->0.005" -> ? mm-Be)
- Beam tests could be started afterwards (~Dec. 2015)
- Simulations plans (see above) include comparison with 1-stage colls
- Due to many concerns (collimation in synchrotron, not storage/collider ring) : review of collimation systems on similar proton synchrotrons (J-PARC, SNS, ISIS, ?) to work out possible alternative solutions, if present booster two-stage collimations is failing.
- Considering alternative collimations schemes (e.g. a'la "septum" suggested by V.Lebedev)

# Supporting slide

# Sec. collimators motion: 6B Horizontal motion

**6B-H: Same program as previous slides:**

- Move 0.090" steps toward aisle for ~0.45" total (OK)

➡Attempted move 0.180" steps toward wall (failed)

- Moved 0.020" steps toward wall back to original position
- Time sequence indicated by arrows

➡Jump in ACNET data at direction change

➡Slope different for different directions