Collimation in Booster: Experimental Results for Horizontal Plane

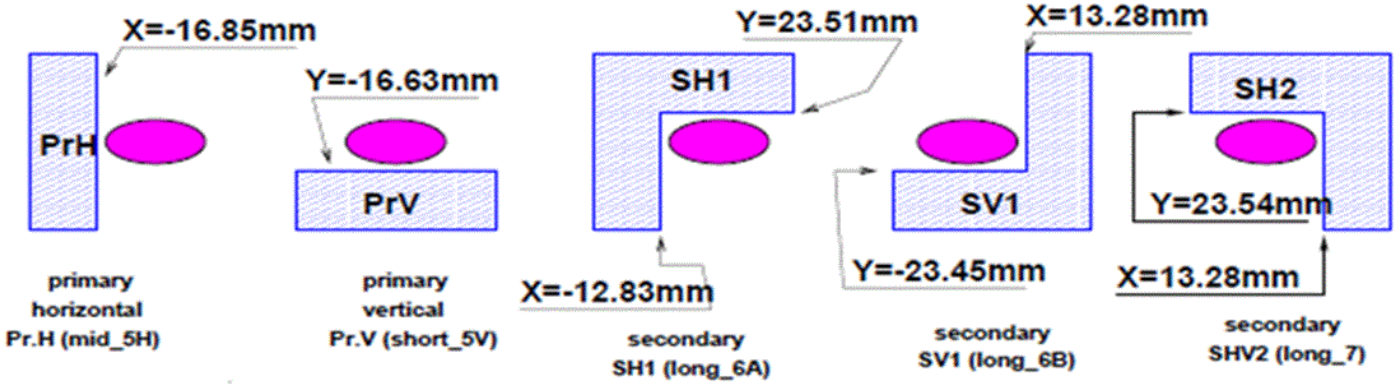
V.Kapin, R.J.Tesarek,
S.Chaurize, T.Sullivan, K.Triplett

PIP General Meeting, Wed, 19 Apr, 2017

Some previous reports & talks

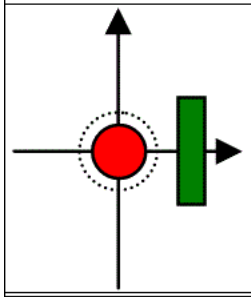
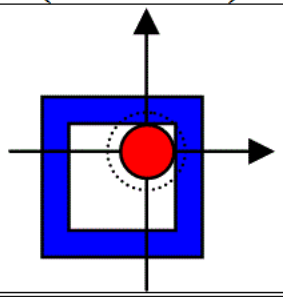
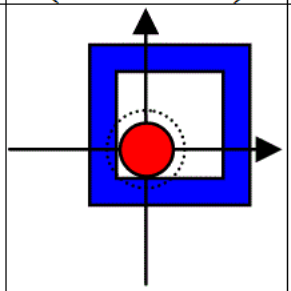
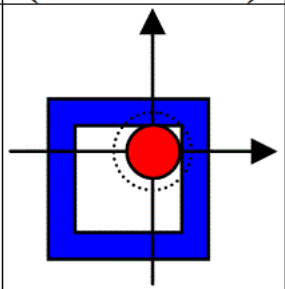
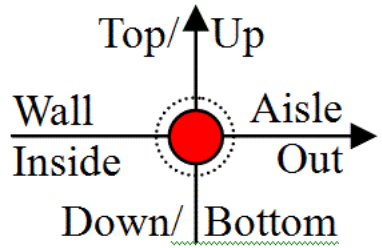
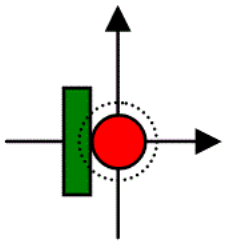
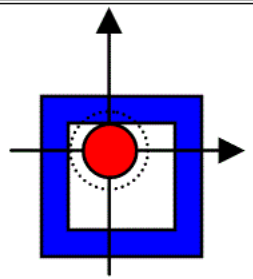
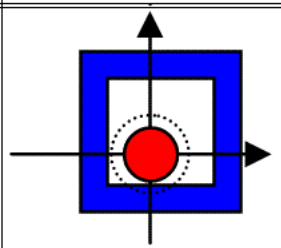
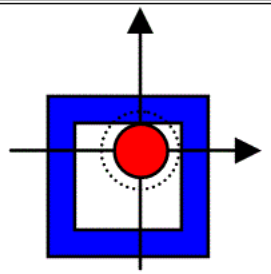
- V.Kapin, “A proposal for upgrade of Booster collimation system”, PIP meeting 22-Feb-2017, Beams-doc-5340-v1
- V.Kapin, “Booster Collimation: 2-stage vs 1-stage”, PIP meeting 24-Aug-2016, Beams-doc-5222-v2 (incl. Exp. Results for **Vertical** Plane)
- V.V.Kapin, V.A.Lebedev, N.V.Mokhov, S.I.Striganov, I.S.Tropin, “Numerical Simulations of Collimation Efficiency for Beam Collimation System in the Fermilab Booster”, NAPAC-2016, Chicago, paper WEPOA20. (Pre-release at “vrws.de/napac2016”)
- V.Kapin, S.Chaurize, N.Mokhov, W.Pellico, M.Slabaugh, T.Sullivan, R.J.Tesarek, K.Triplett, “Experimental Studies of Beam Collimation System in the Fermilab Booster”, paper WEPOA18, Ibid
  (incl. Exp. Results for **Vertical** Plane)

Horizontal Collim. Study on 2-Mar-2017



2004 design by A.Drozdin – Sec.Colls touch beam in both planes

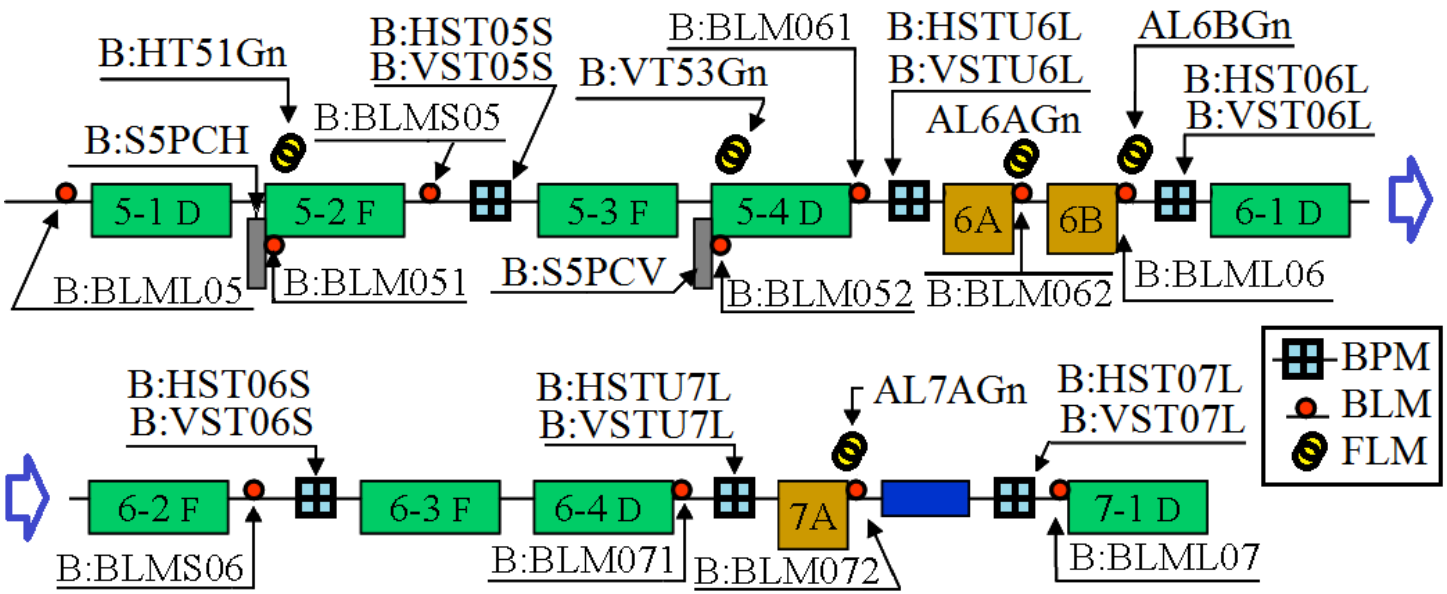
Collimation schemes used during the beam study:

	H-Prim	Col1=L6A (SHCOL1)	Col2=L6B (SVCOL1)	Col3=L7A (SHVCOL2)	Comments
Initial positions of collimators = 1SC:					
Final positions of Collimators =Hor. 2SC (Vert 1SC):					2004 A.D.'s design for 2-stage hor. collimation modified as following: *Col2 from opposite side - enhancing Col1*

1SC=Single Stage Collimation; 2SC=Two Stage Collimation

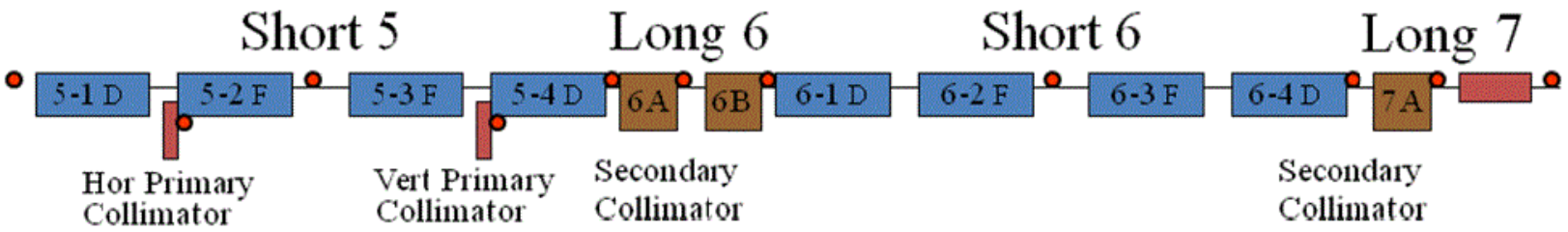
Detectors & ACNET applications & post-proc. codes

Coll. motion:
B109 & B110



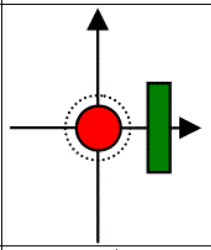
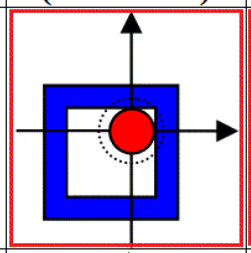
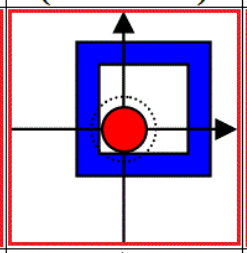
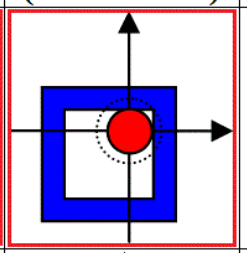
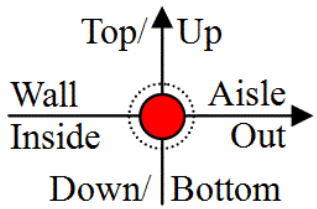
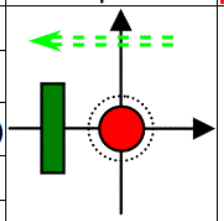
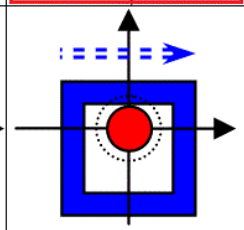
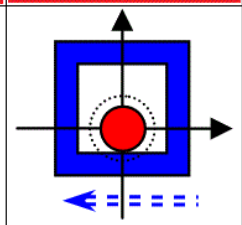
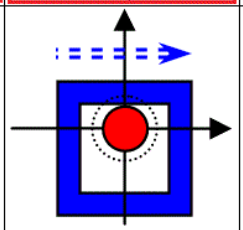
B:BOOEFF; CHG1; CHG2	Beam transm. efficiency; Inj/Extraction beam charge
B38 Beam orbits	save data => postproc. code: x & x' at collimators
D43 save-list	BLM data recorder for off-line usage via D44
FLM signals	on-line for Collimator tuning; off-line via D44
B88 "frac.trip point"	"PrintScreen" (on-line) & Data export (off-line)
A'la "B88"	Exe (on-line) for reading BLM data to reproduce B88 plots
B136 BLMs signal within Boo-cycle	Save data => postproc. Code: check bad signals; e.g. averaging over cycle => compare with B88-plots, etc.
D44	Off-line plotting of recorded parameters (pos; BLMs; FLMs)

Transverse collimator positions (1of3)



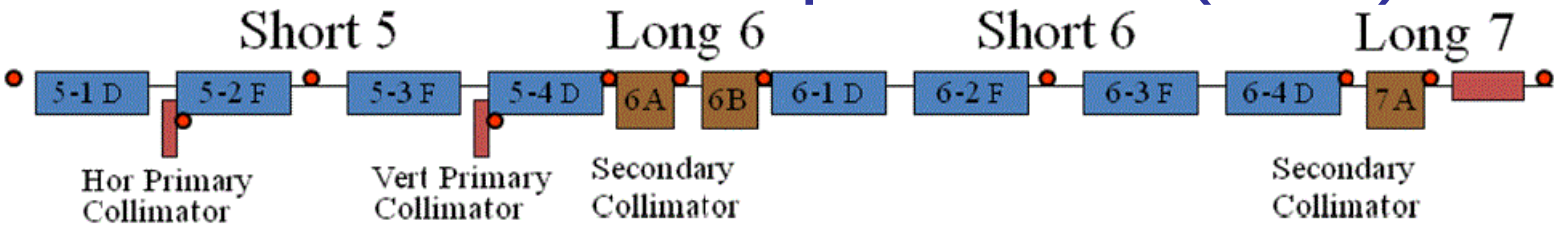
Steps 1÷4b of total 14

Actual Study Steps & points of time

No	time	Step No&name	H-Prim	Col1=L6A (SHCOL1)	Col2=L6B (SVCOL1)	Col3=L7A (SHVCOL2)	Comments
1	A	Record BLM/BPM/ColPos (110325.xls/*_kap03_01n.txt) at usual col-positions (1-stage used in 2016)					
2	A1	move **Col2** to garage (->W)					move all SecCols to garage; STOP BEAM for Hprim motion); **4=1SC with 1 sec.col.! 4b=all SC - garage!**
3		move **Col3** to garage (->A)					
4	B	rec. **BLM/BPM** (111822/041)					
4a	B1	move **Hprim** to Wall-garage					
4b	C	move **Col1** to garage (->A)					

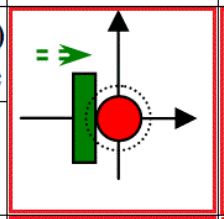
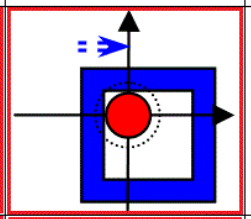
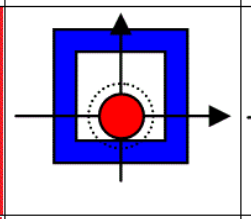
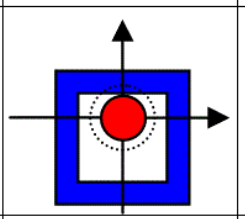
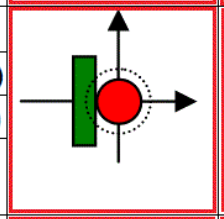
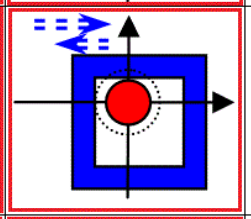
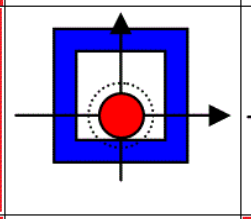
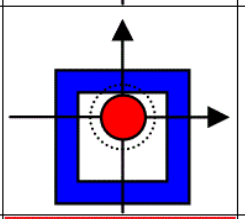
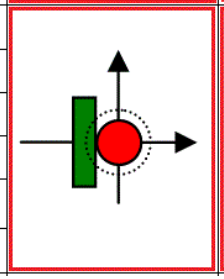
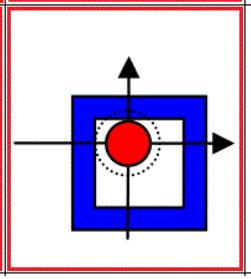
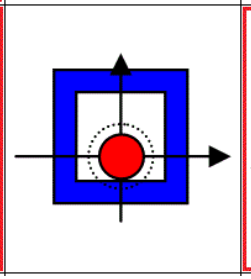
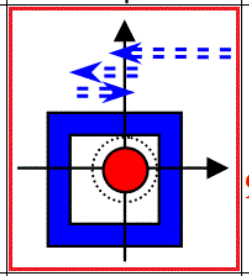
Hor. Collim. Study => move collimators only in horizontal plane

Transverse collimator positions (2of3)



Steps 4c÷9c of total 14

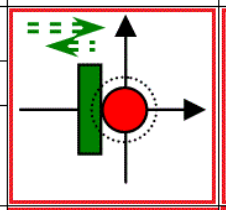
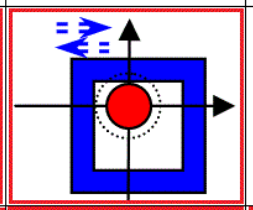
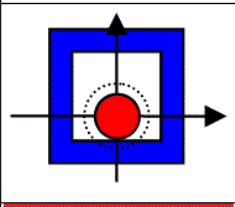
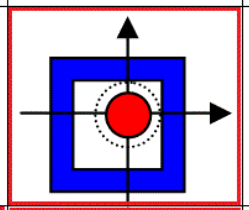
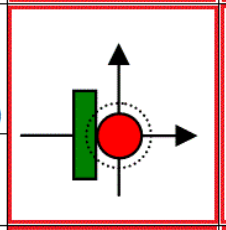
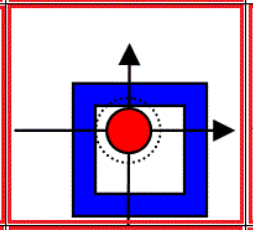
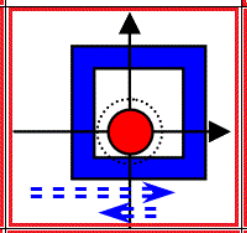
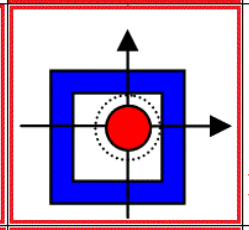
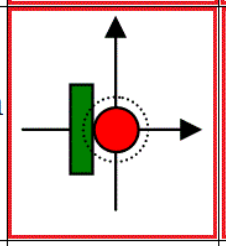
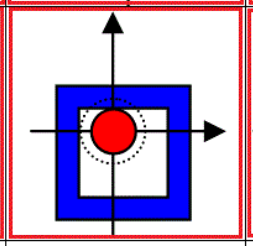
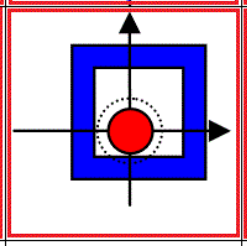
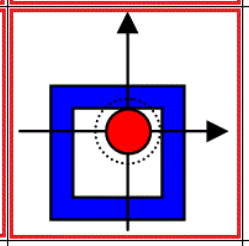
Actual Study Steps & points of time

No	time	Step No&name	H-Prim	Col1=L6A	Col2=L6B	Col3=L7A	Comments
4c	C1	continue move **Col1** (->Aisle) to touch beam from Wall-side					setup the major sec. collimator (=COL1) to touch beam and then optimize H-prim
5	C2	move **Hprim** (->Aisle) to touch beam from Wall-side					
6:	C3	re-optimize **Col1**:					**"6b=7"= 2SC with single major Sec. coll. (Col1)** (7: 116313/07n)
6a		adjust **Col1** to beam (->Aisle)					
6b		retract **Col1** from beam(->W)					
7	D	Record **BLM/BPM**					
8a	D1	move **Col3** to beam (->Wall)					(8b:117504/08n) retract to ->A δx =+1mm=~40mils **9c=2SC with 2 sec.col.!** (9c:118348.xls/09n)
8b	D2	Record **BLM/BPM**					
9:		Optimize **Col3** at beam core					
9a		**Col3** further in beam (->W)					
9b		retract **Col3** from beam(->A)					
9c	E	Record **BLM/BPM**					

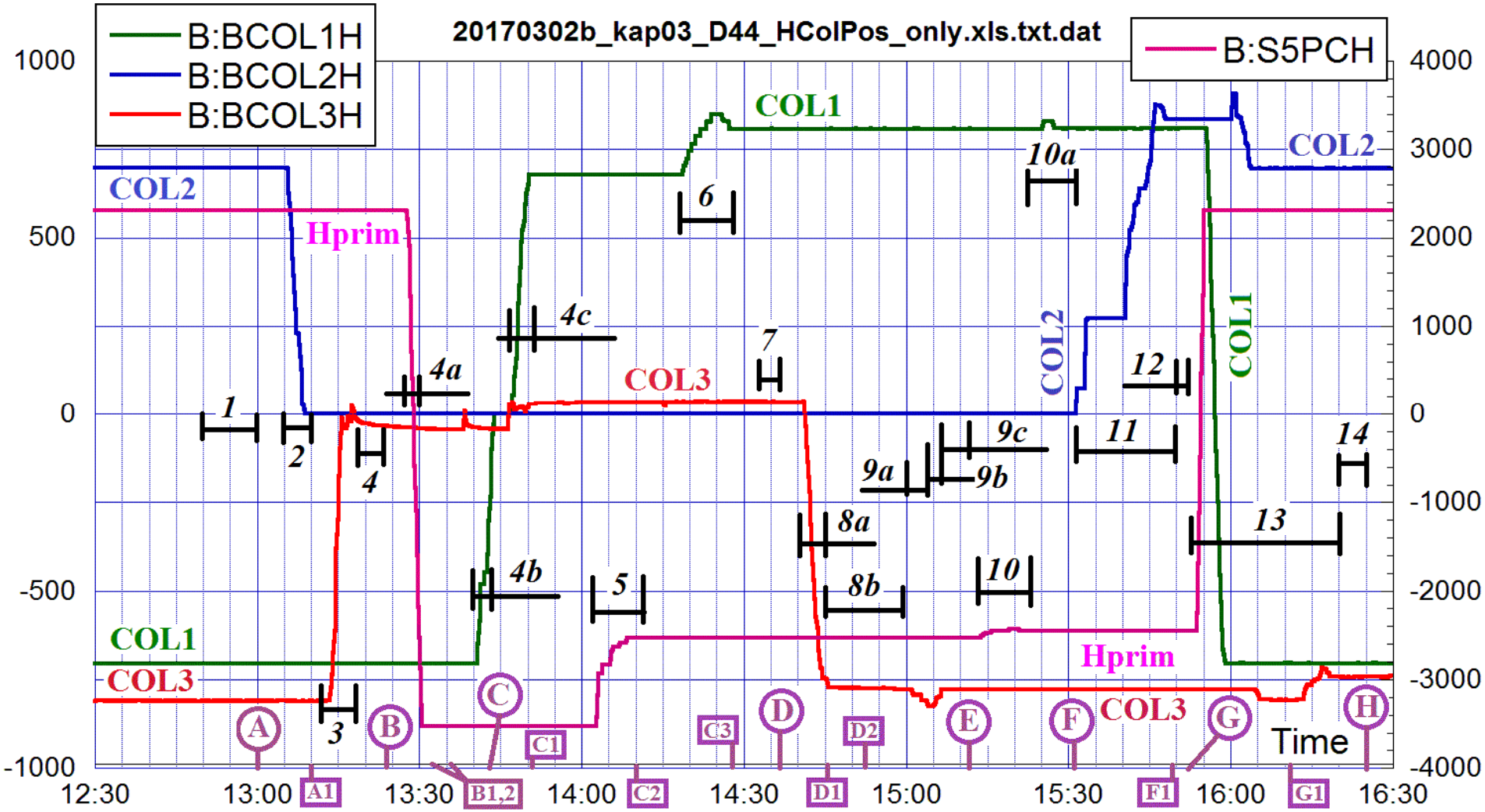
Transverse collimator positions (3of3)

Steps 10÷14 of total 14

Actual Study Steps & points of time

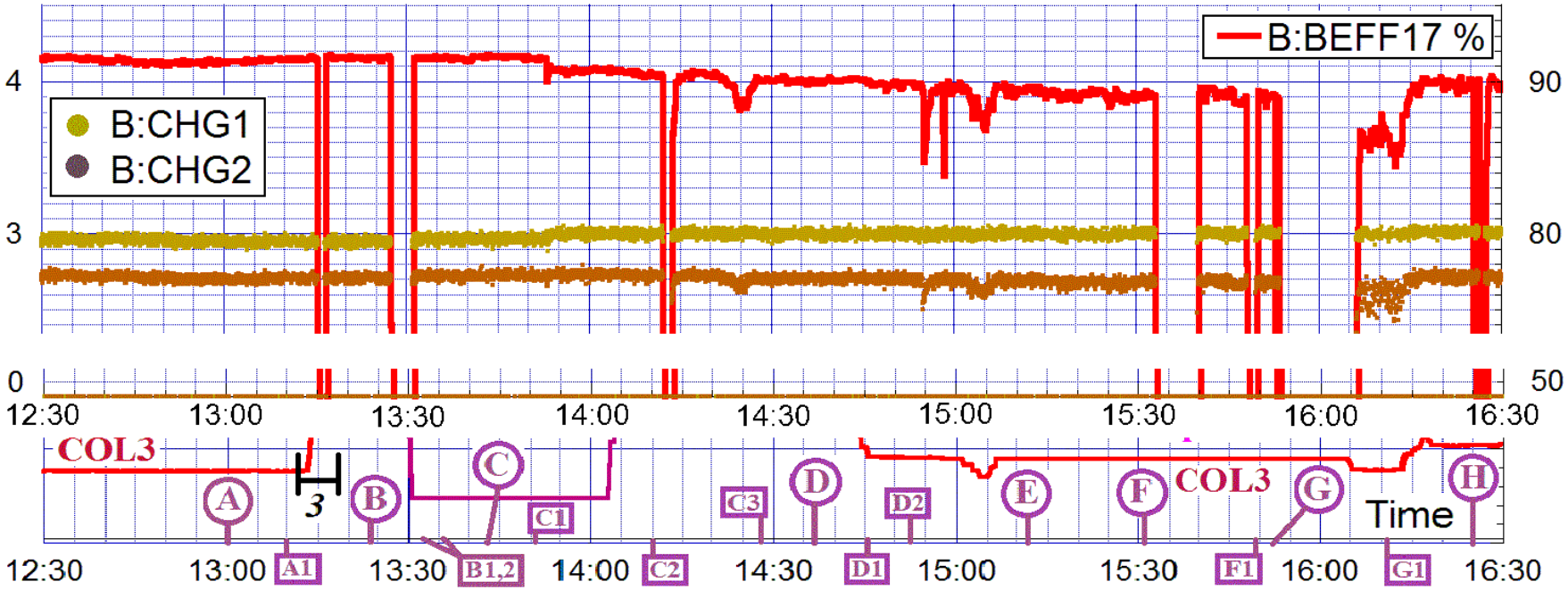
No	time	Step No&name	H-Prim	Col1=L6A	Col2=L6B	Col3=L7A	Comments
10		re-optimize (play) **Hprim**					**10a=re-optimized 2SC with 2 sec.col.!**
10 a		re-optimize (play with) **Col1**					
	F	Record **BLM/BPM** (_11590.xls/*_10An.txt)					
11	F1	"Surround" beam by **Col2**: move to touch beam (->A) then retract from beam (->W)					after approach Col2 to beam retract it by δx =+1mm=40mils; **12=2SC with 3 sec.col.!**
12	G	Record **BLM/BPM** (_120882.xls/*_12n.txt)					
For info		final positions for horizontal 2-stage collimation (while keeping 1SC in vertical plane)					2004 A.D.'s design for 2-stage hor. collimation modified as following: *Col2 from opposite side - enhancing Col1*
13	G1	Return **all collims** to ini. 1SC: a)H_{prim} b)Col1 c)Col2 d)Col3	move to Aisle garage BEAM STOP	move to Wall touch beam from outside	small move into beam (->Wall)	small move to (Wall|Aisle)	14: *_122709.xls/ _14n.txt
14	H	Record BLM/BPM					

Coll. Positions (D44) with study steps & points of time



A, B, D-H are points of time with <u>full set</u> of measurements (B38; B136; B88);
A1, B1, B2, etc. – additional points for some interesting states (only B88)

Beam Intensity Fluctuations During Study

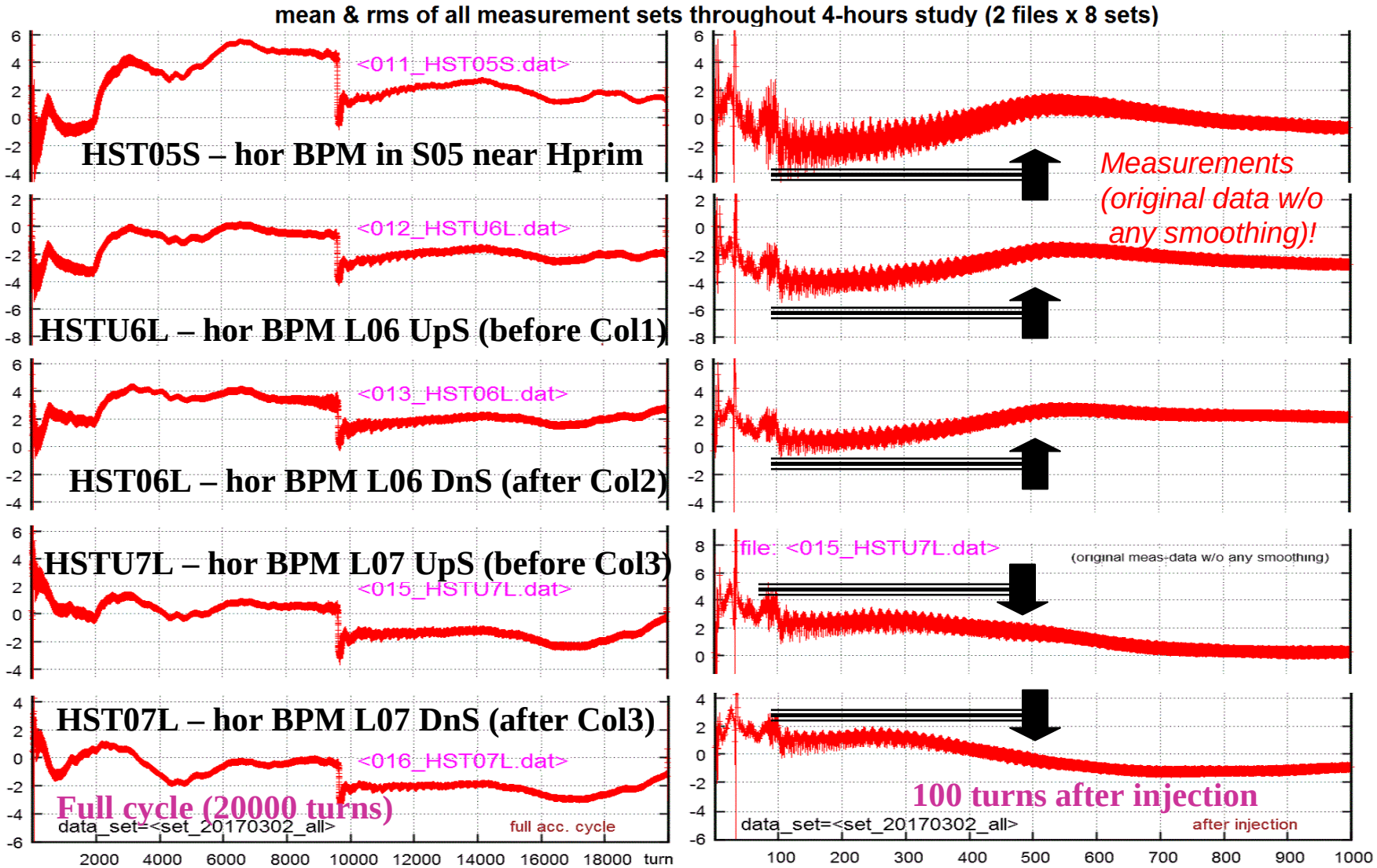


Let's exclude "additional" points D2, F1 and G1 due to efficiency drop around them

A - usual 1SC (routinely ~2016)	C3 - COL1 is re-optimized => **"2SC with single sec. col."**
A1 - COL2 in GRG (garage)	D - (=C3) **"2SC with single sec. col."**
B - COL3 in GRG	D1 - COL3 at beam aisle-side => **"2SC with two sec.col."**
B1 - Hprim in Wall-GRG	E - COL3 is re-optimized => **"2SC with 2 sec.col. re-opt"**
C - COL1 in GRG (all hor. GRG)	F - Hpr & COL1 re-opt. => **"2SC with 2 sec.col., all re-opt"**
C1 - COL1 at beam Wall-side	G - COL2 at beam W-side => **"2SC with 3 sec. cols"**
C2 - Hprim at beam Wall-side	H - back to initial 1SC (=A)

B38 post-proc.: orbits at Hor-BPMs (periods 5-7)

At study start: *special C.O. bumps ~after injection (by Todd & Salah)*

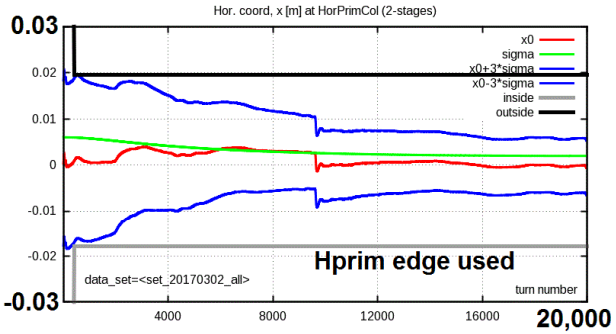


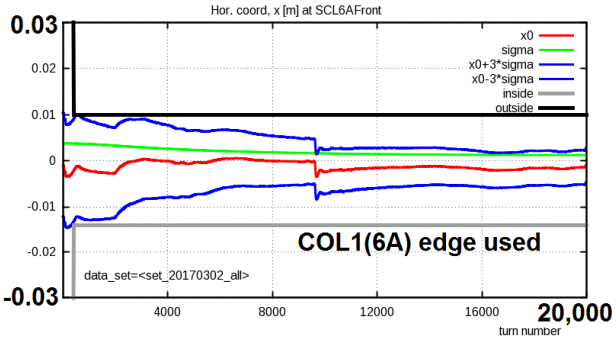
Beam orbits are stable (~±1mm) throughout all study steps!

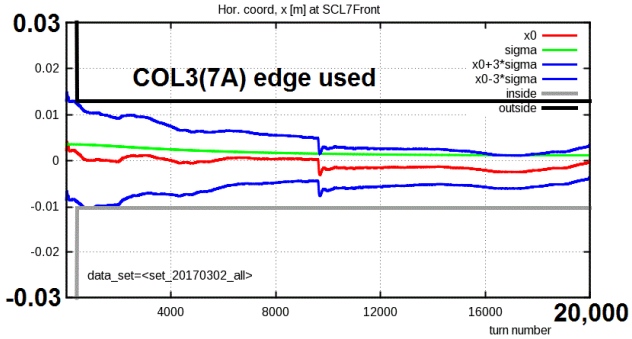
B38 post-proc: “restored” orbits at Collimators

1) Using ideal linear matrices orbits at nearest BPMs have been traced to the fronts of all collimators: Hprim, COL1(6A), COL2(6B), COL3(7A);
2) 3σ-envelopes has been added to orbits;
3) X-positions of collimator edges are defined by max&min of envelope curves

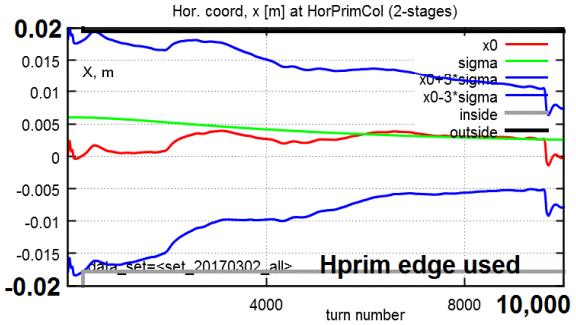
Full 20,000-turn cycle



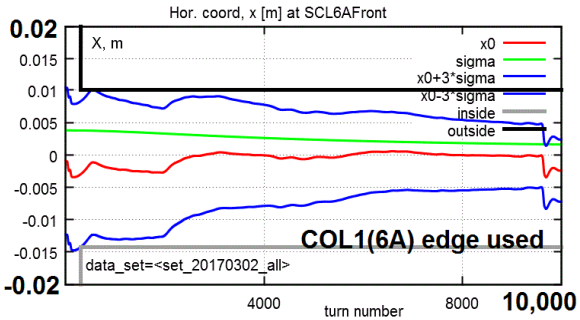




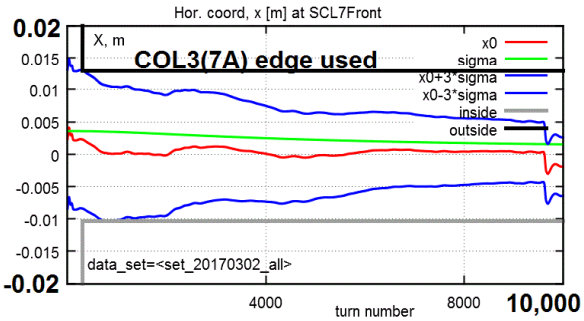
First half of cycle (10,000 turns)



Hprim



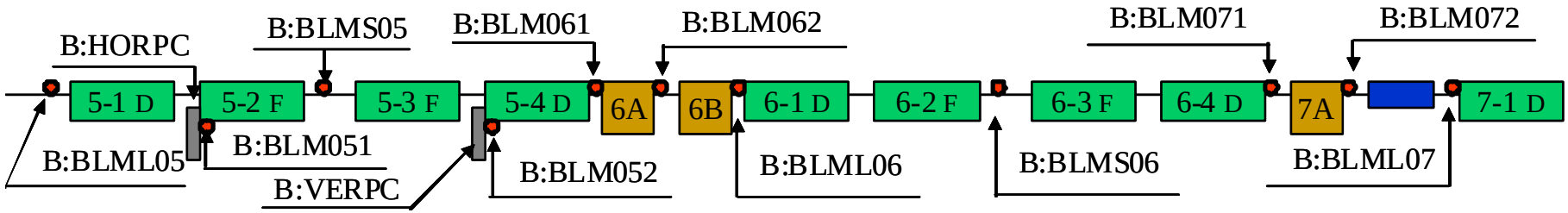
COL1(~COL2)

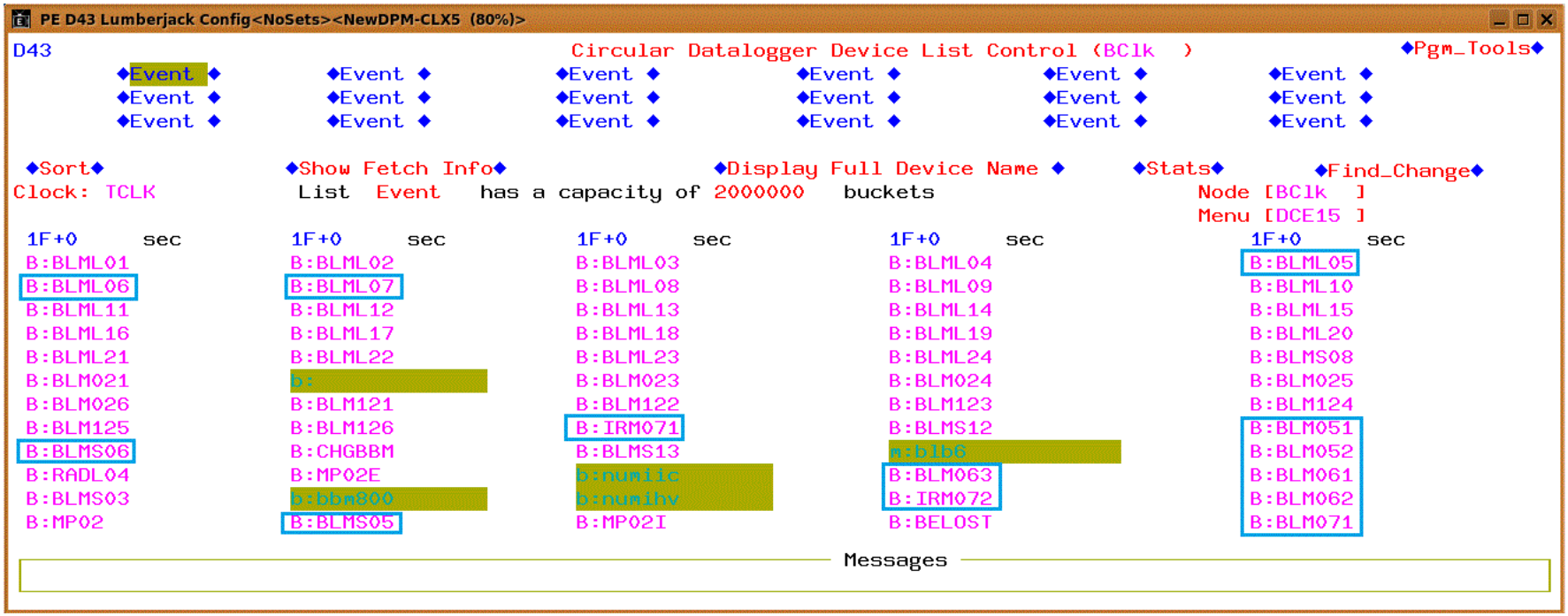


COL3

Note: 3σ - beam envelopes assuming an ideal damping as 1/βγ

D43 save-list: BLM data recorded





For collimation tests – all “collimation” BLMs must be on D43 page !

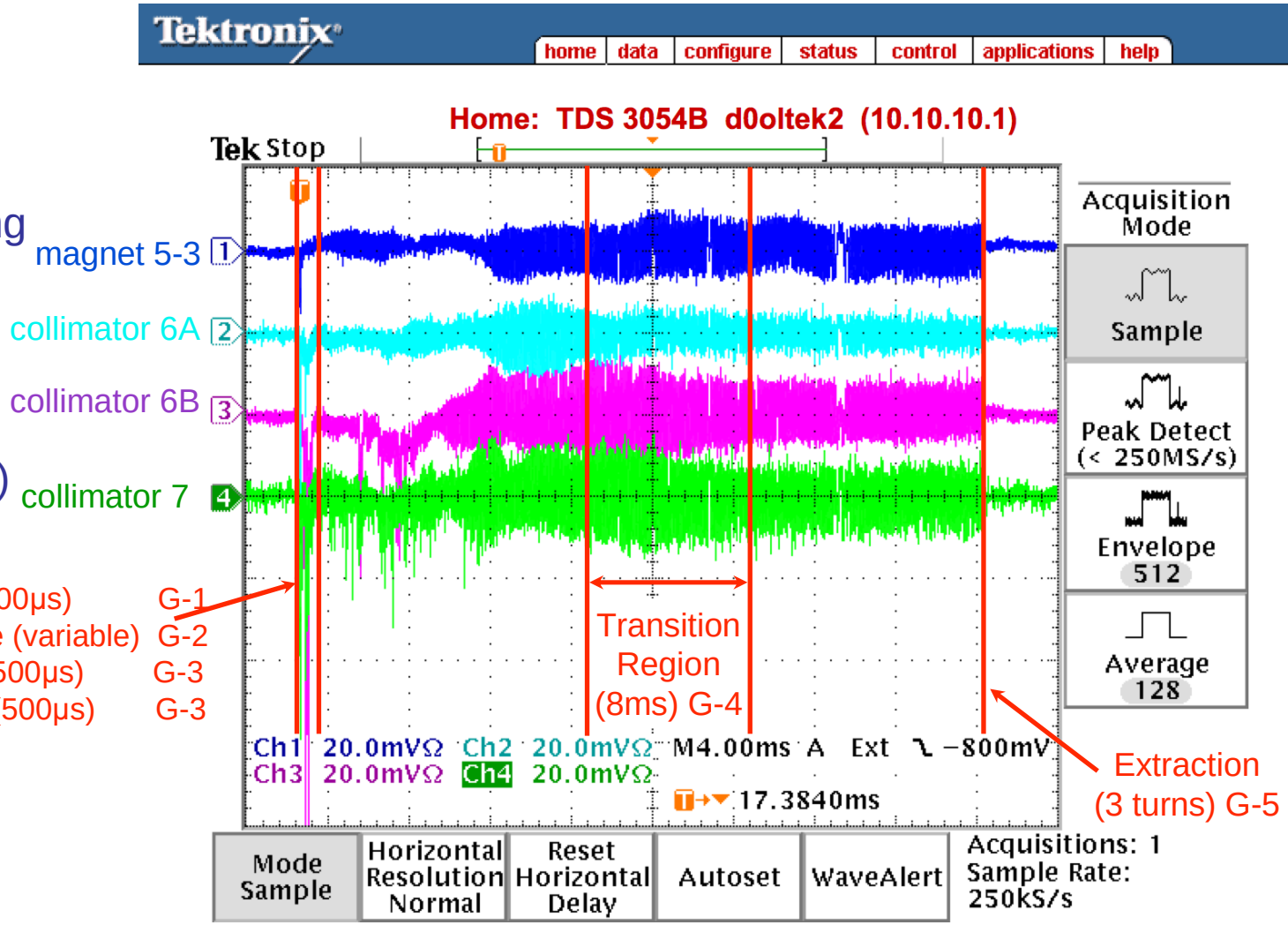
BLM allows 3 time scales:

1) B88-bar plot >1min (many Boo-cycles);

2) B136 averaging 1 Boo-cycle; 3) B136 within cycle (separate inj, notch, etc.)

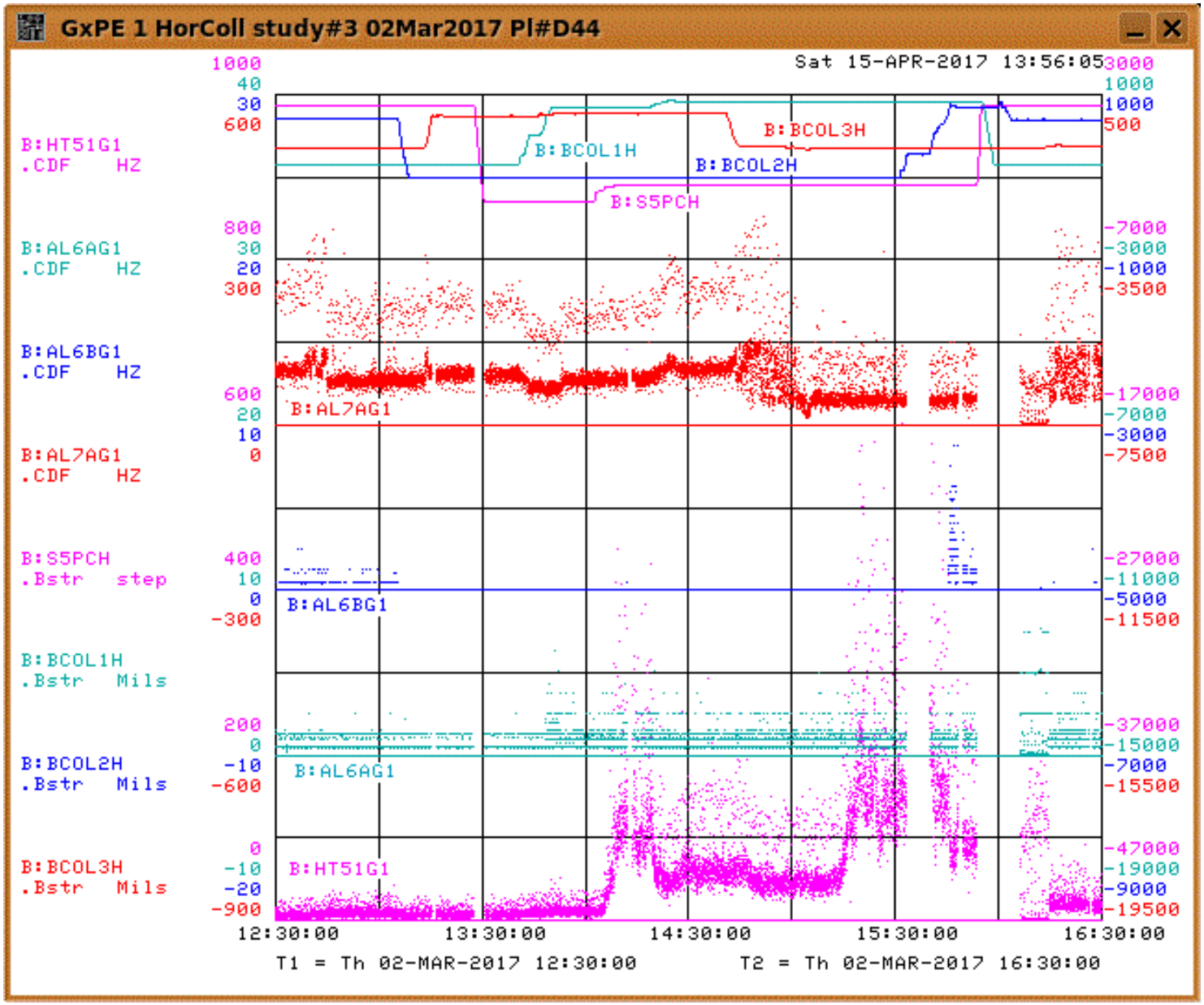
Booster losses: FLM for full booster cycle

Rick's FLMs (**Fast** Loss Monitors) provide ***new*** opportunities for high resolution (ns) loss monitoring and in specific windows During Booster cycle (ACNET variables)



For collimation tuning FLMs gate G-1 (Injection) is used !

Typical screens for tunings with FLMs

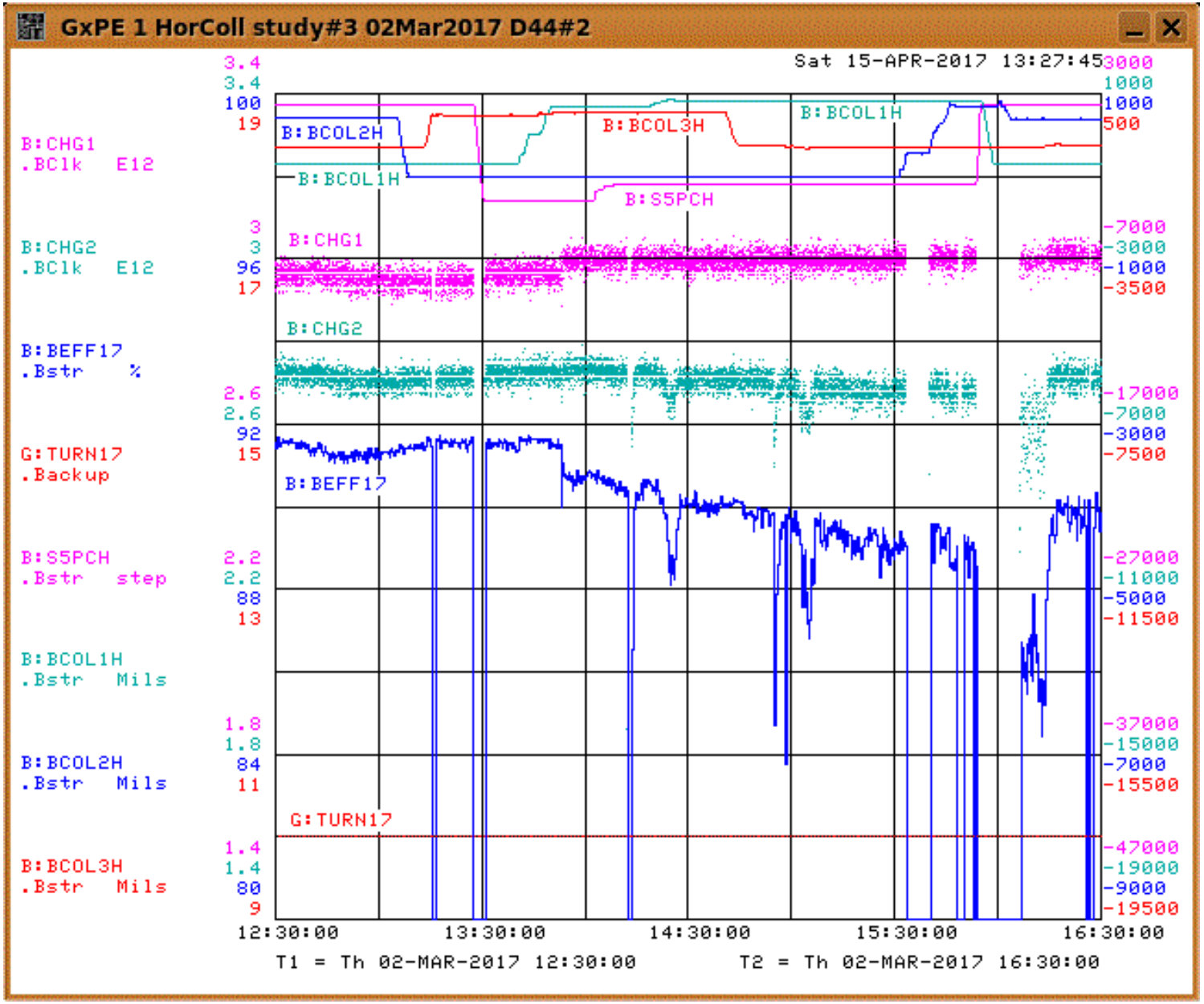


Restored
With D44:
VT53G1
AL6AG1
AL6BG1
AL7AG1

&

Hprim
COL1
COL2
COL3

General parameters controlled during study



Restored with D44:

CHG1

CHG2

BEFF17

TURN17

&

Hprim

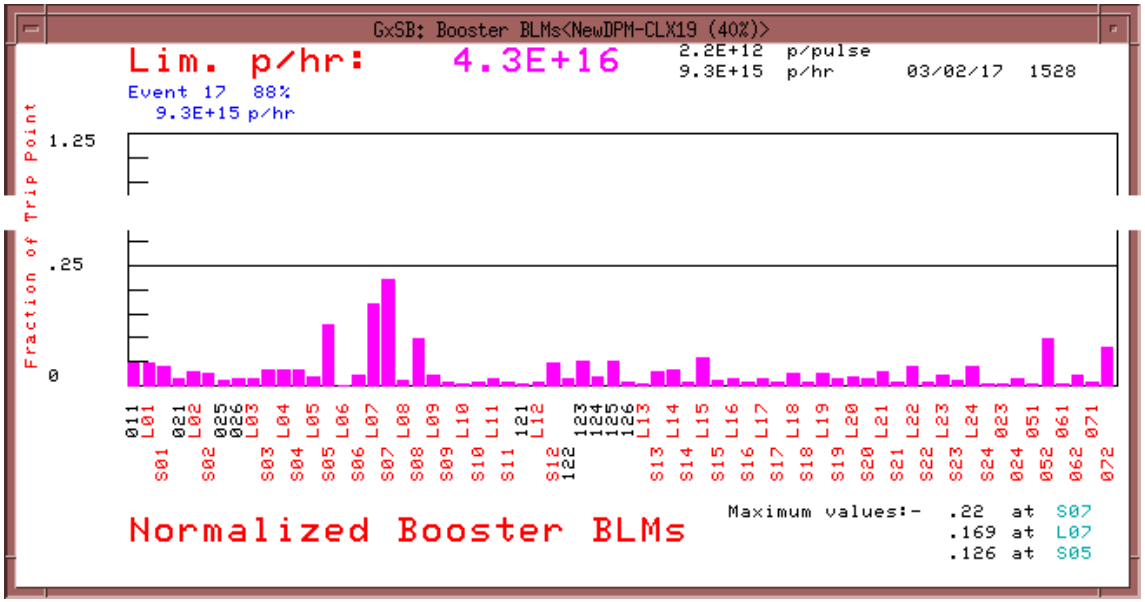
COL1

COL2

COL3

TURN17=10

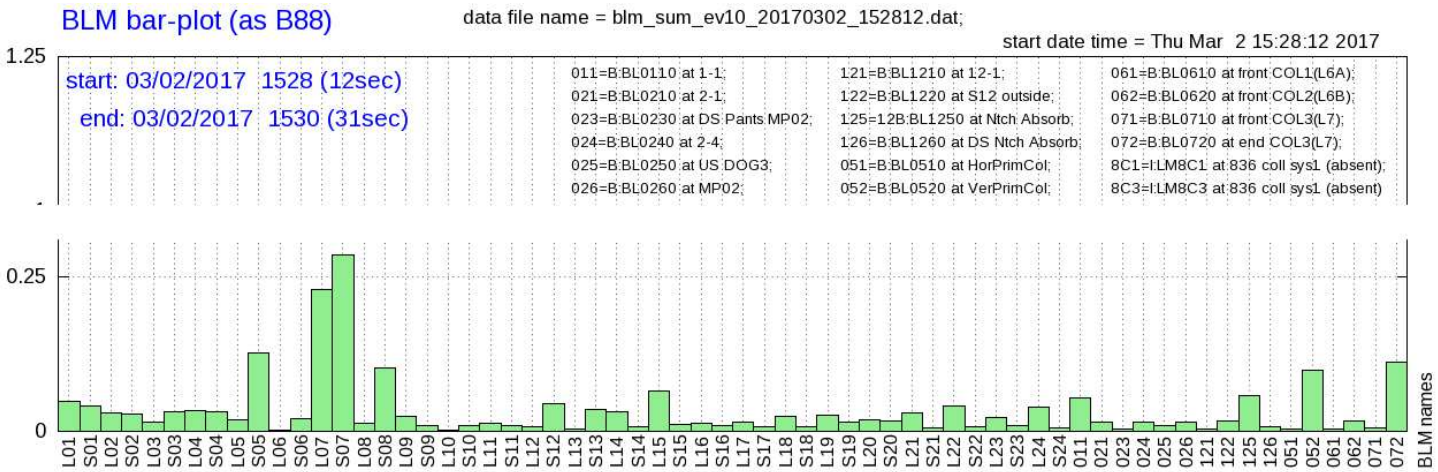
B88 for comparison losses at study steps



B88 “Fraction of trip points”: “PrintScreen” (on-line) & Data export (off-line)

Examples for “F-point: time=15:28”s

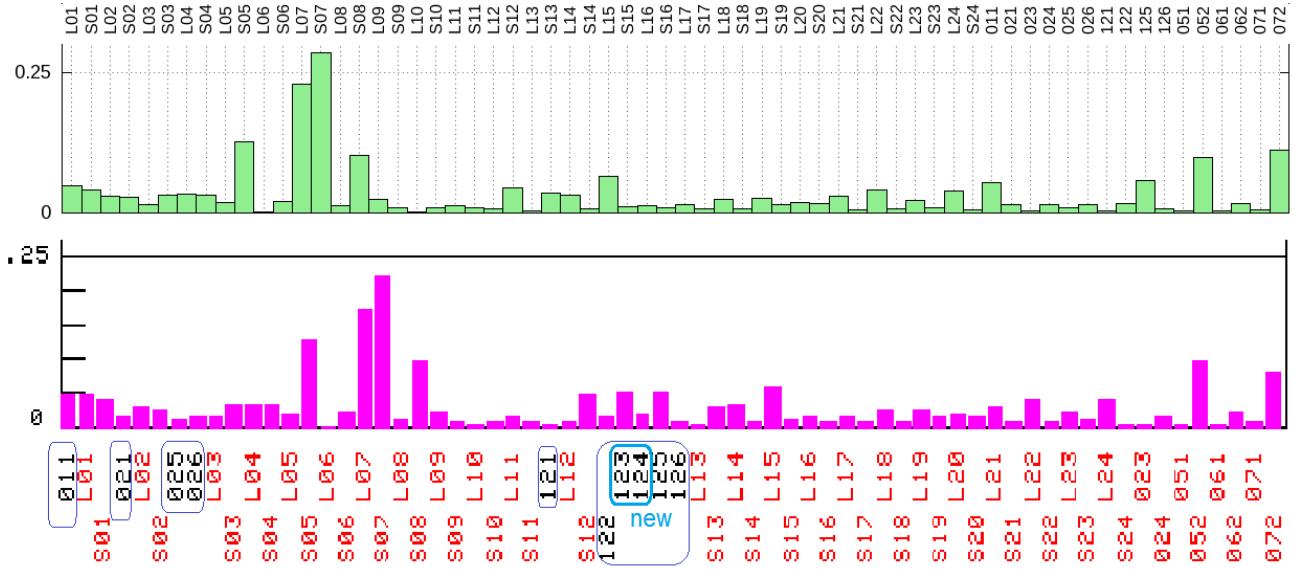
“B88” Linux-exe (on-line): directly reads BLM data to reproduce B88 plots (~1.5min)



for **numerical comparisons;**

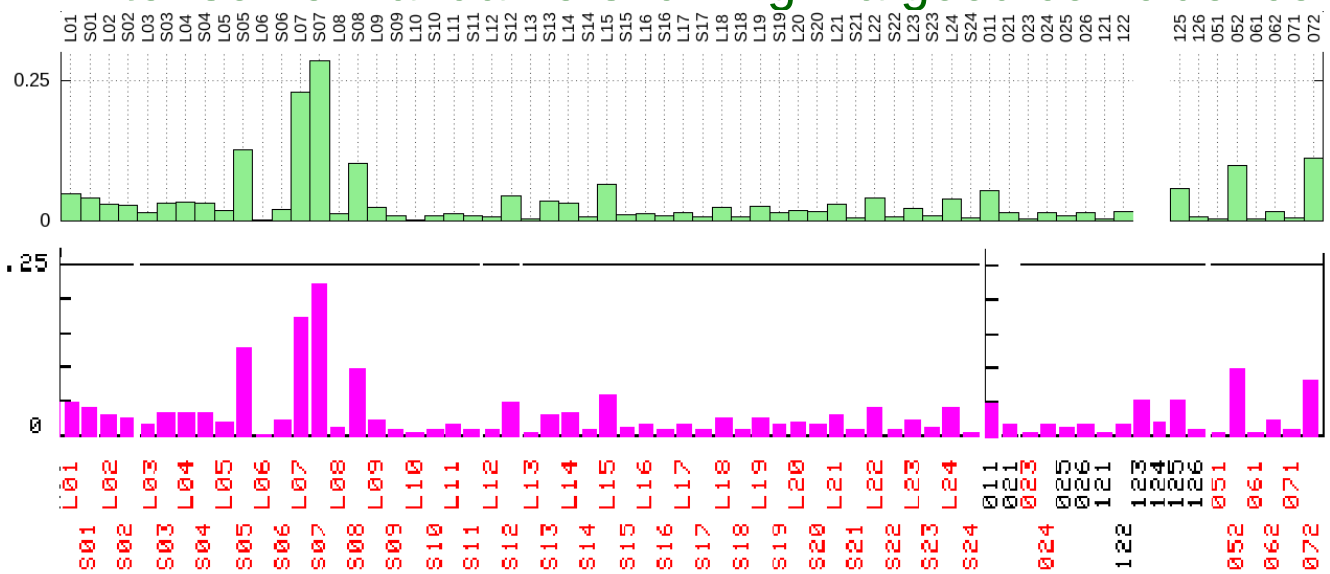
duplicates B88 data export (did not worked sometime ago)

Cross-check of coincidence for “B88” plots



Visually difficult:
BLM sequence
is shuffled time-to-time
(e.g.
since last summer)
&
new BLMs were
inserted (“123”,”124”)

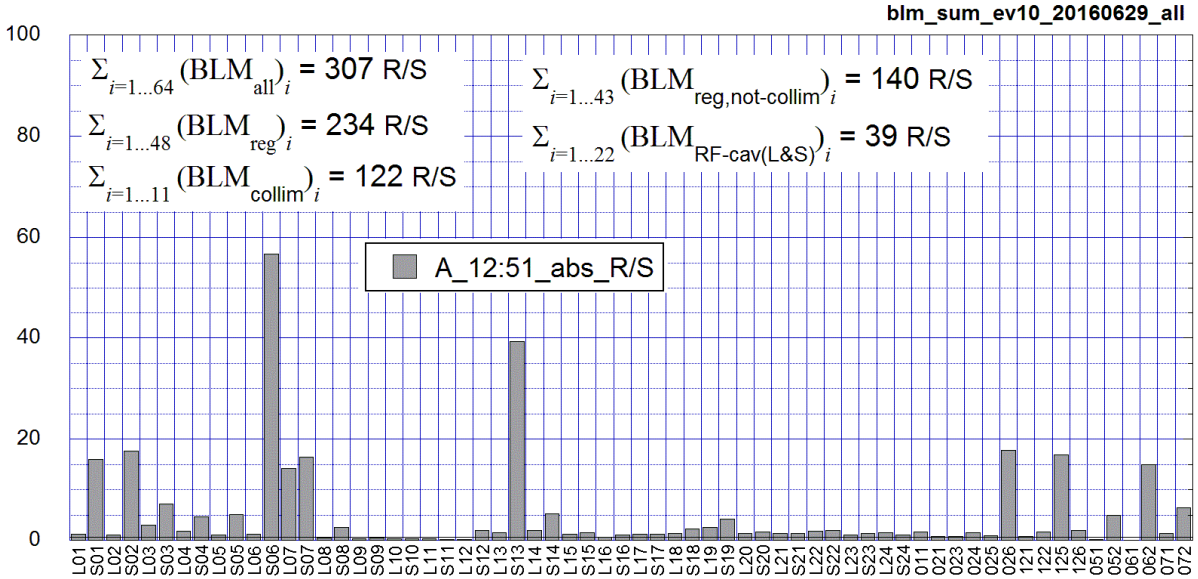
After some manual re-shuffling – a good coincidence:

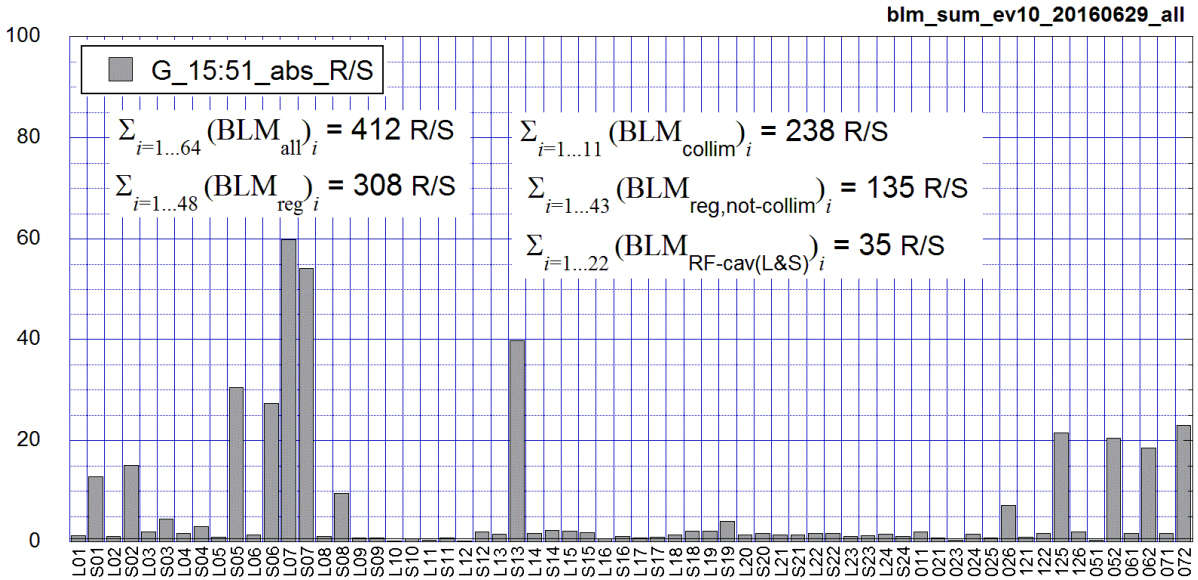


Here, examples for
“F-point: time=15:28”
(2SC-2, re-opt)

Here, the “summer” ordering for BLMs will be used for A’la “B88”-plts

Compare “B88” for points A=1SC-3 & G=2SC-3





5 type of sums introduced:

1) *All 64 BLMs*
2) *48 regular BLMS (L & S)*
3) *11 Collim. Area BLMs (regular + 051,…072)*
4) *43 reg. w/o 5 coll.reg (S05÷S07)*
5) *22 rf-cavity area (L & S)*

Compare two points of time:

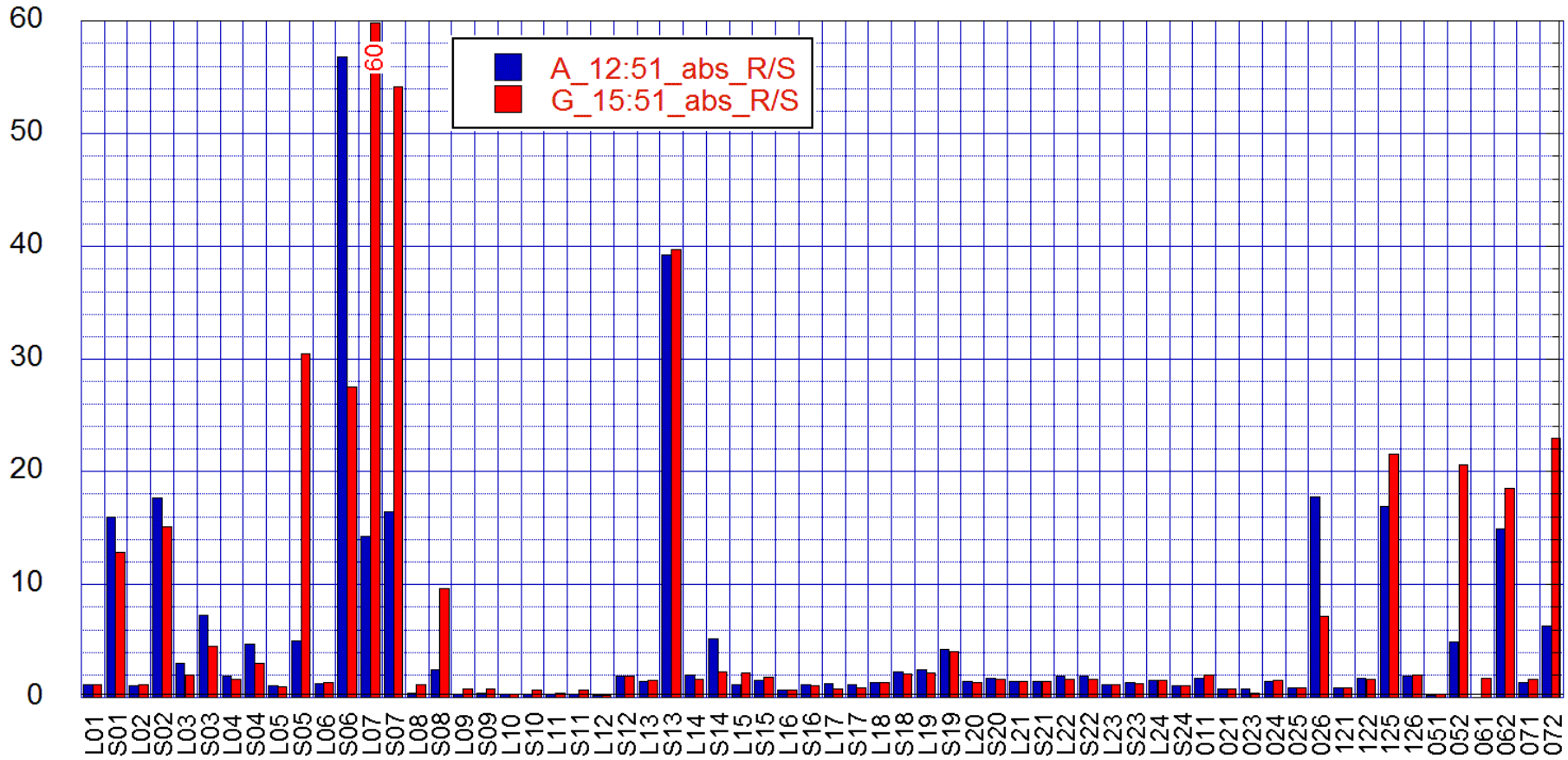
“A” – initial coll. Config. With single-stage (w/o prim.) collimation with 3 sec. collimators used (1SC-3)

“G” – one of “optimal” two-stage collimation using 3 secondary collimators (2SC-3)

Visual comparison difficult !

Compare with double-bar “B88” (A & G)

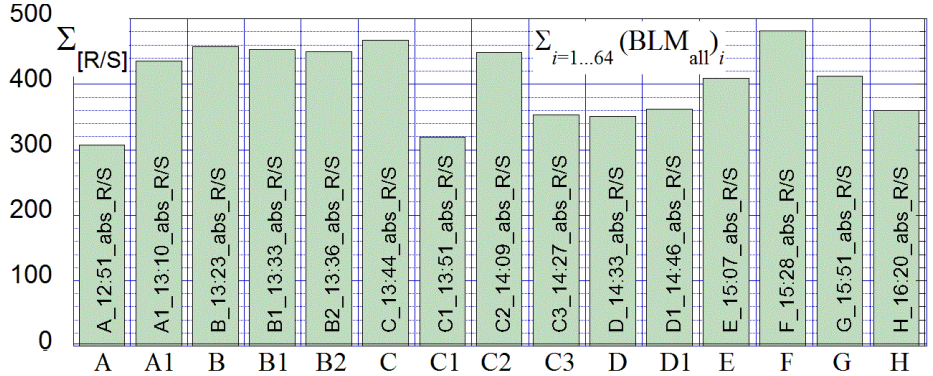
A=1SC-3 & G=2SC-3

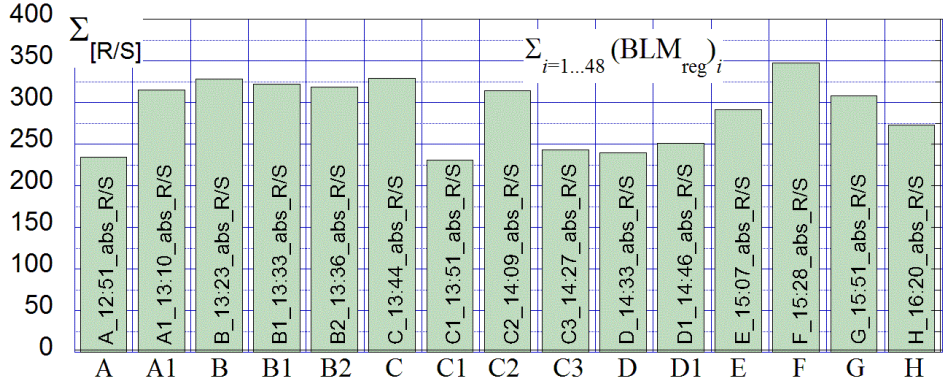


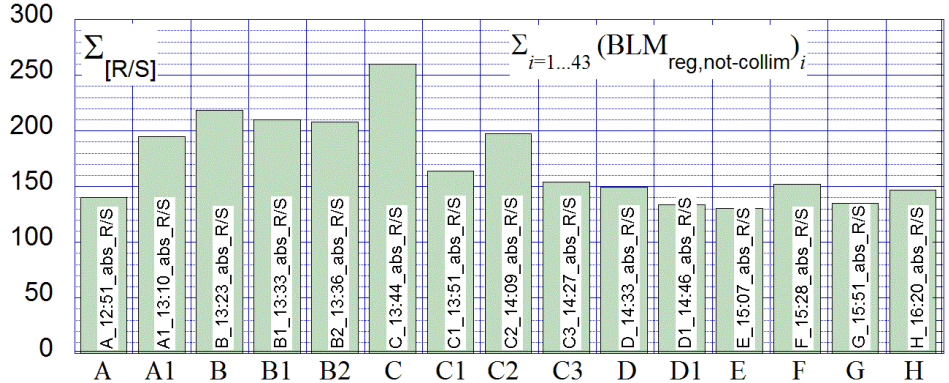
Some tiny loss reduction in RF-region (L14÷S24) can be seen !

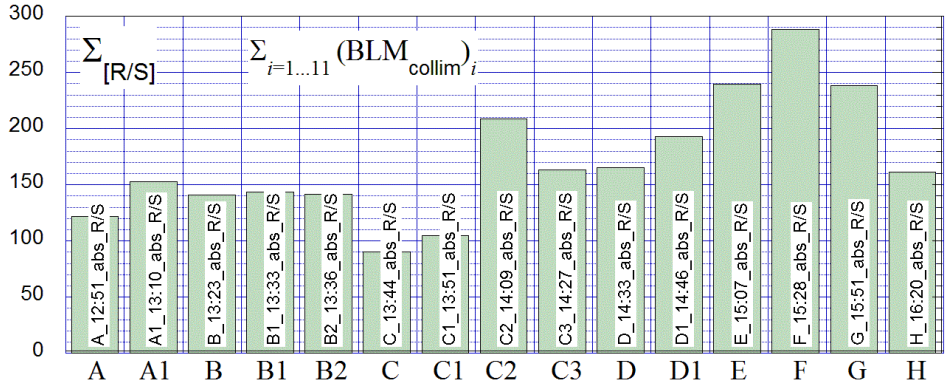
Sums of absolute BLM values

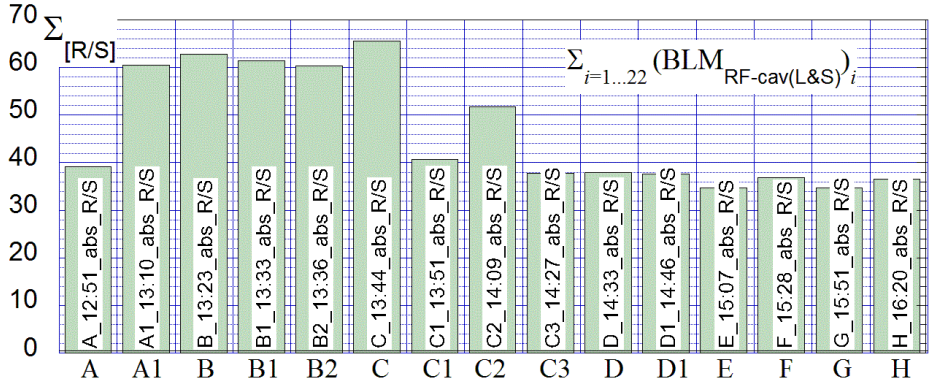
Compare <C3÷G> vs <A,H>:









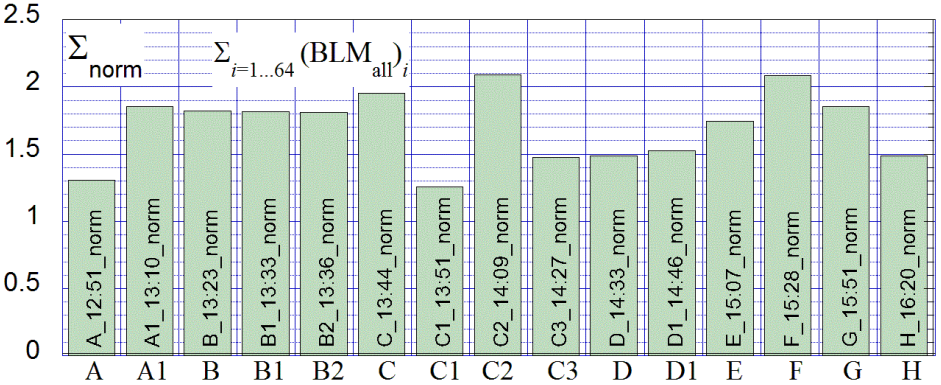


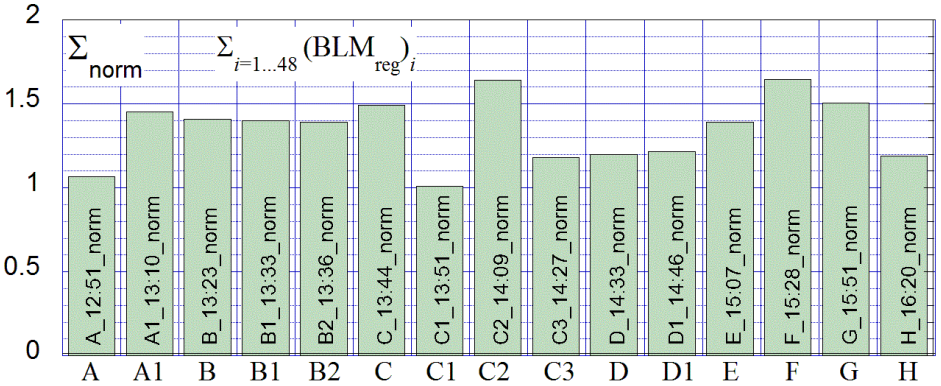
"1SC->2SC":
All sums become worse, except time points E & G for sums "43" & "22(RF)".

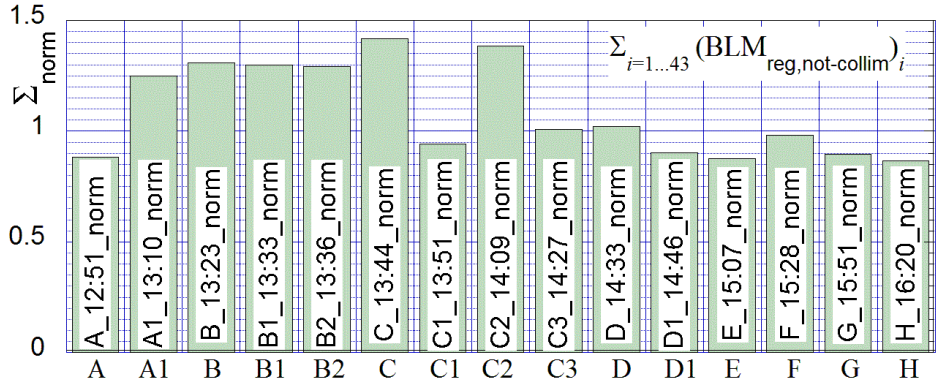
A - 1SC; C3 - **"1SC with single sec. col."**;
D - (=C3) **"1SC-1"**; D1 - **"2SC-2"**;
E - **"2SC-2, re-opt 7A"**; F - **"2SC-2, all re-opt"**; G - **"2SC-3"**; H - 1SC (=A)

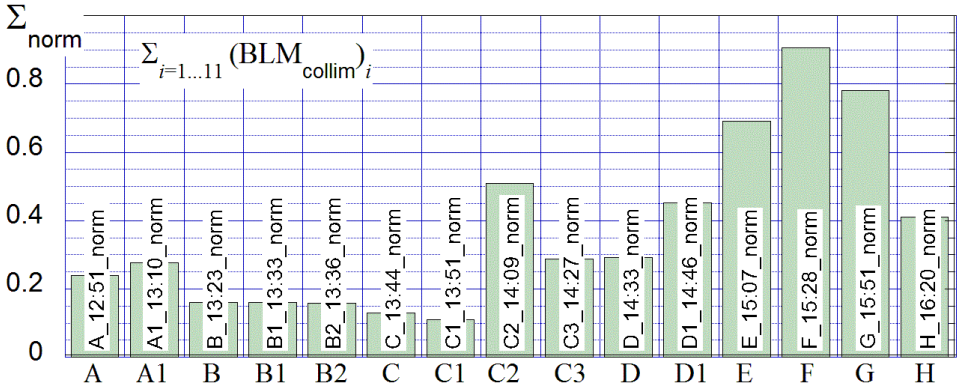
Sums of normalized (by trip values) BLM

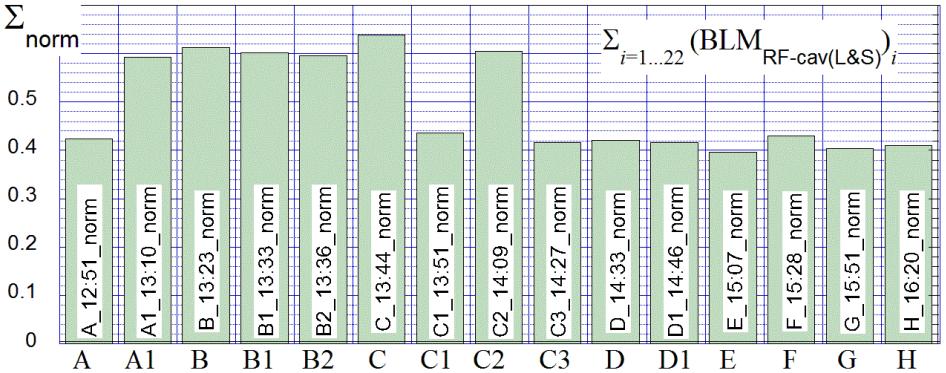
Compare <C3÷G> vs <A,H>:











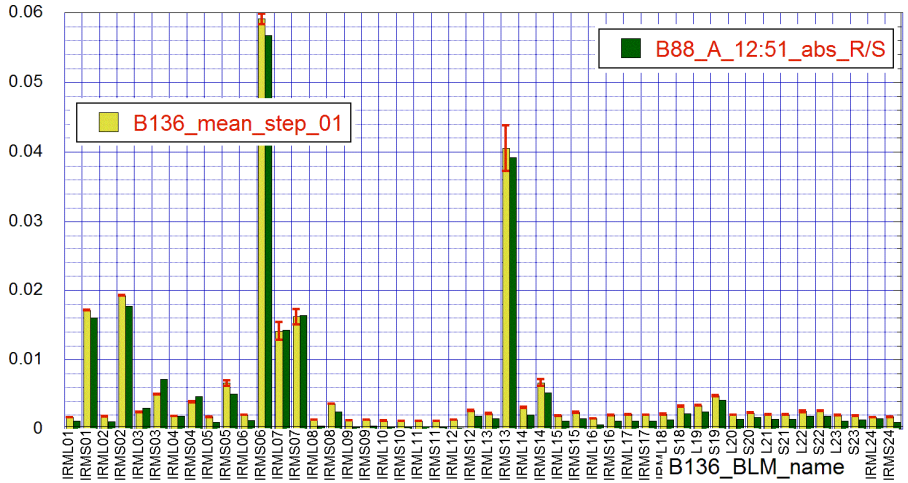
"1SC->2SC":
All sums become worse, except time points E & G for sum "22"(RF).

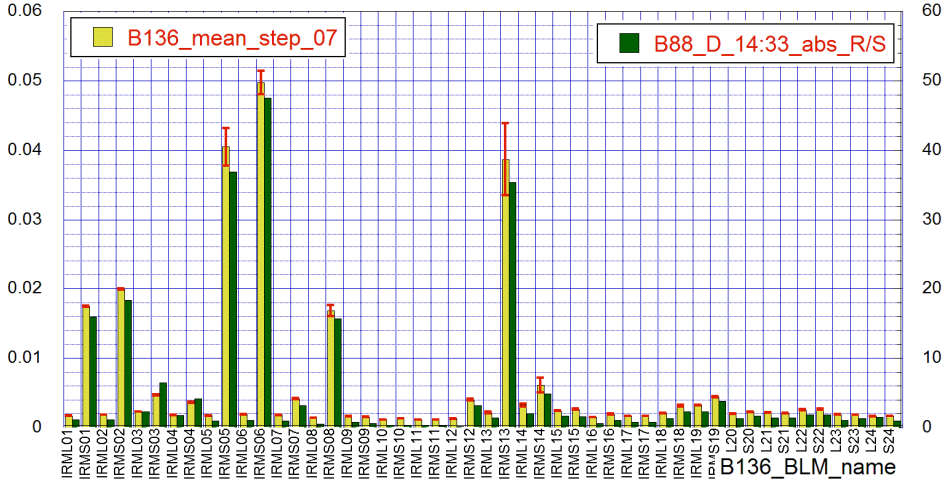
A - 1SC; C3 - **"1SC with single sec. col."**;
D - (=C3) **"1SC-1"**; D1 - **"2SC-2"**;
E - **"2SC-2, re-opt 7A"**; F - **"2SC-2, all re-opt"**; G - **"2SC-3"**; H - 1SC (=A)

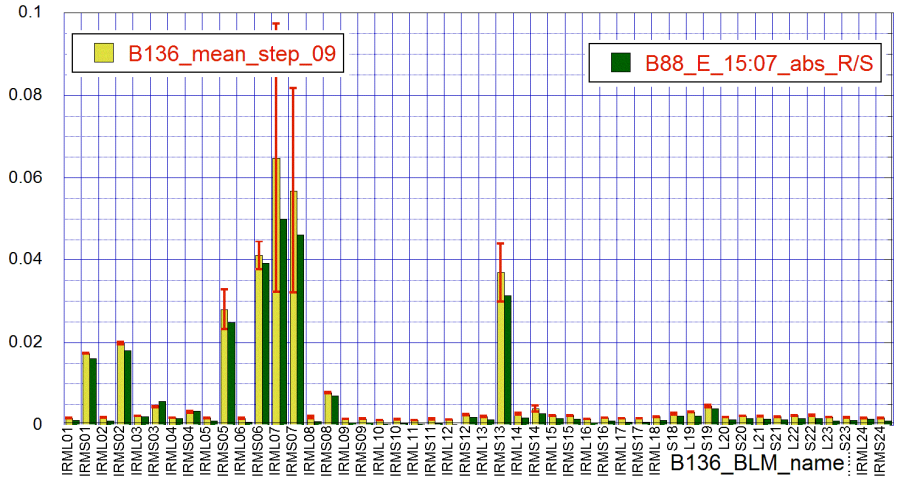
Cross-checking: B88-data vs B136-data

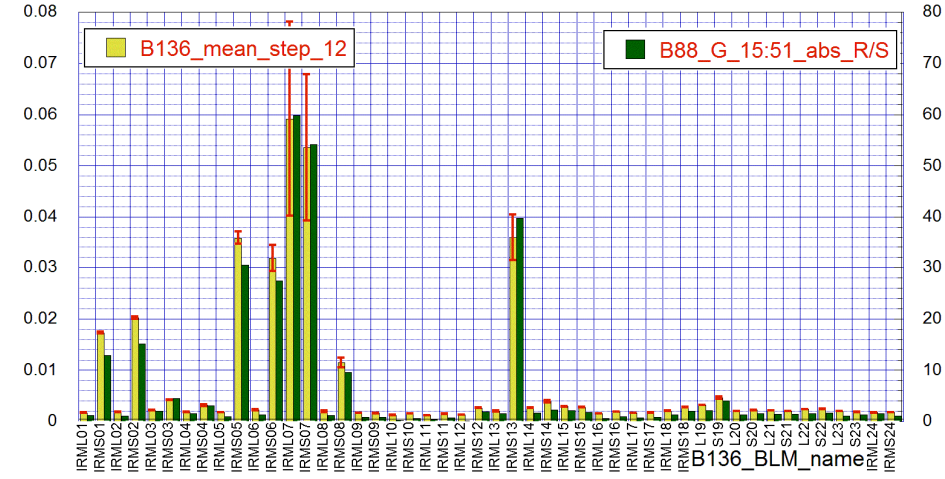
*Compare BLM bar plots by B88 (>1min) data and B136 (within **one Boo-cycle**)*

For “B136” – mean and rms of 5 measurements at every point of time



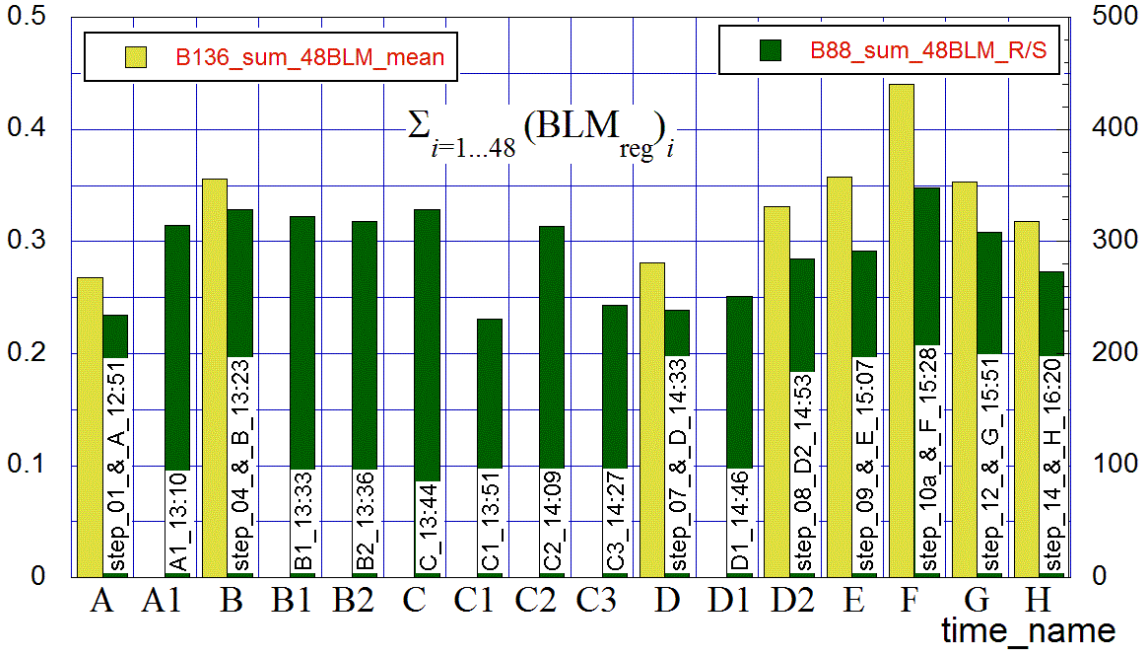


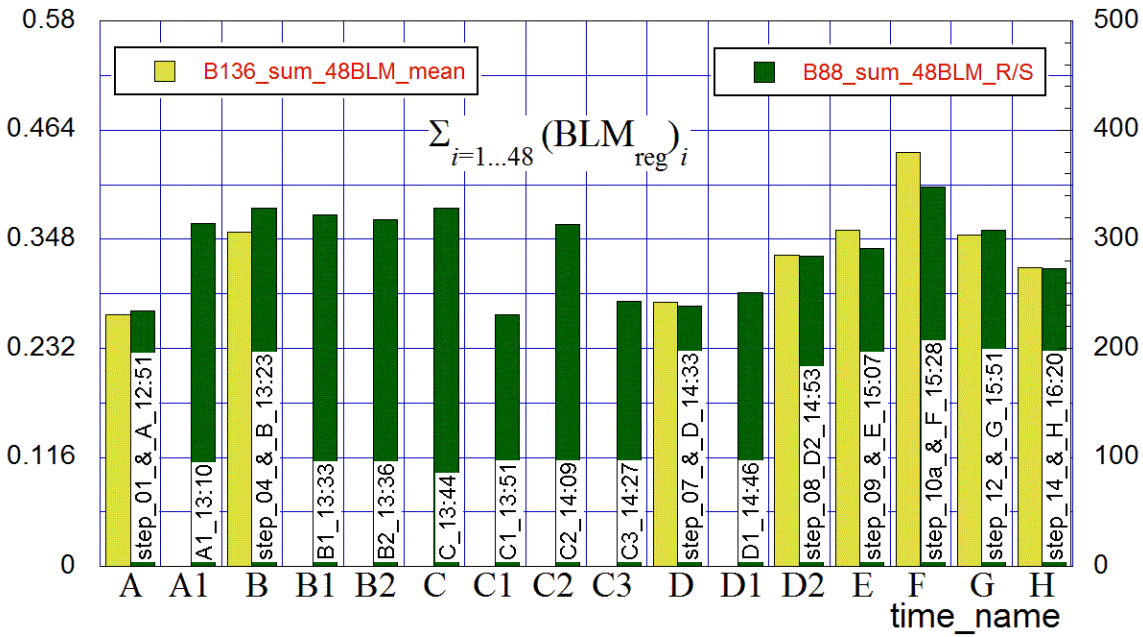




A - 1SC; D - **"1SC-1“; E - "2SC-2, re-opt 7A“; G - "2SC-3"**

Cross-checking: B88 vs B136 (“48-BLM” sums)





Compare BLM sums by B88 (>1min) & B136 (33ms)

For “B136” – mean values of 5 measurements at every time

Upper plot has scales 0.5 & 500 (coeff=1000)

Lower plot with 14%-adjusted scales 0.58 & 500 (coeff=862) - for easier comparison between points of time

B136 ~ the same ratios between point of time as B88 !

A - 1SC; D - (=C3) **"1SC-1“;**
D1 - **"2SC-2“;** E - **"2SC-2, re-opt 7A"**
F - **"2SC-2, all re-opt“;**
G - **"2SC-3“;** H - 1SC (=A)

Losses at Injection, Notch, Total (by R.J.T.)

Notes:

- Losses dominated by notch formation (3/83 RF buckets ~4%)
- Booster is ~92% efficient -> 1/2 losses from notch formation

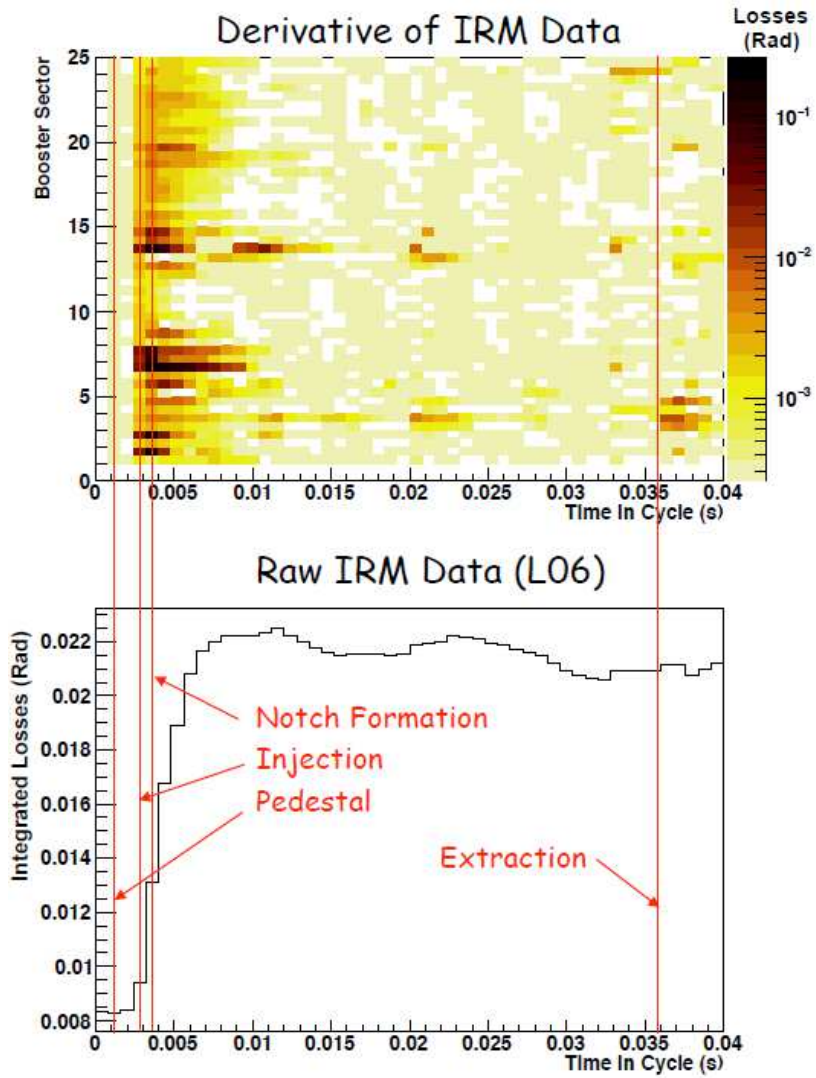
BLM vs Time Data:

- Data taken with 1/10 full BLM time resolution (barely adequate, oversight at time of study).
- Sampling phase allows separation of injection/notch formation.
- Collimation "optimized" at injection using fast loss monitors.
- Loss Definitions (following slide)

$L_{Injection} = IRM_{Injection} - IRM_{Pedestal}$

$L_{Notch} = IRM_{Notch} - IRM_{Injection}$

$L_{Total} = IRM_{Extraction} - IRM_{Pedestal}$

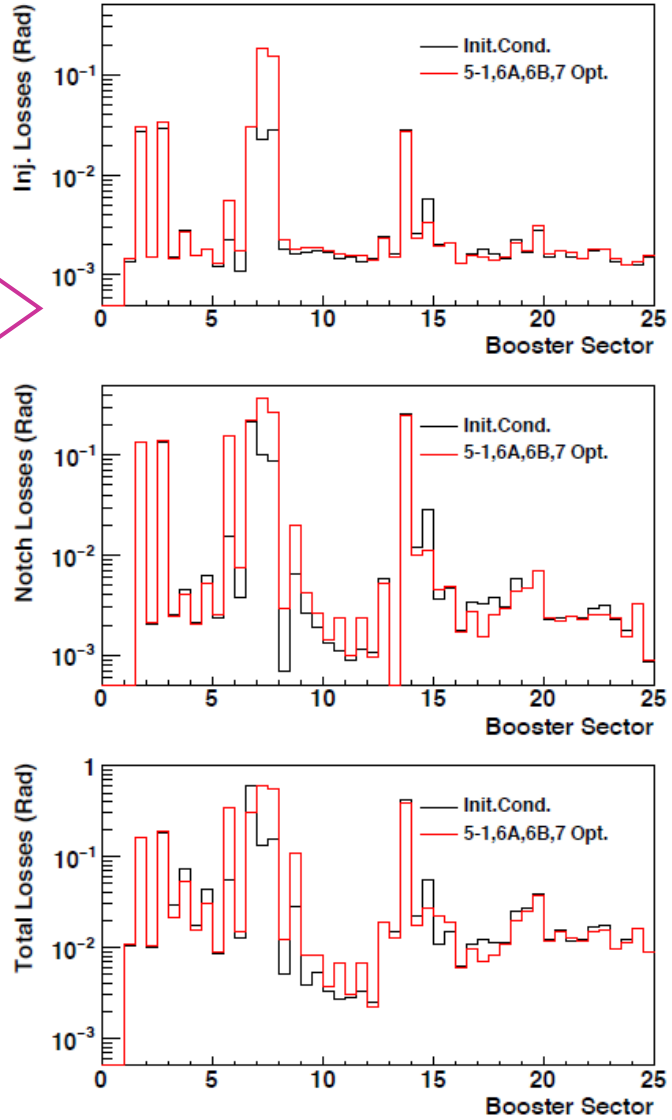


Note suppressed zero in raw IRM data

Losses at Injection, Notch, Total (by R.J.T.)

Optimizations (at injection):

- primary (5-1), 6A ("D")
- primary (5-1), 6A, 7 (3) ("E" & "F")
- primary (5-1), 6A, 6B, 7 ("G")



Observations:

- Only tiny improvement away from 2ndary collimators for *any* configuration
- Example losses to right

NOTES:

- Same scale for Inj, Notch losses
- Double scale for Total losses

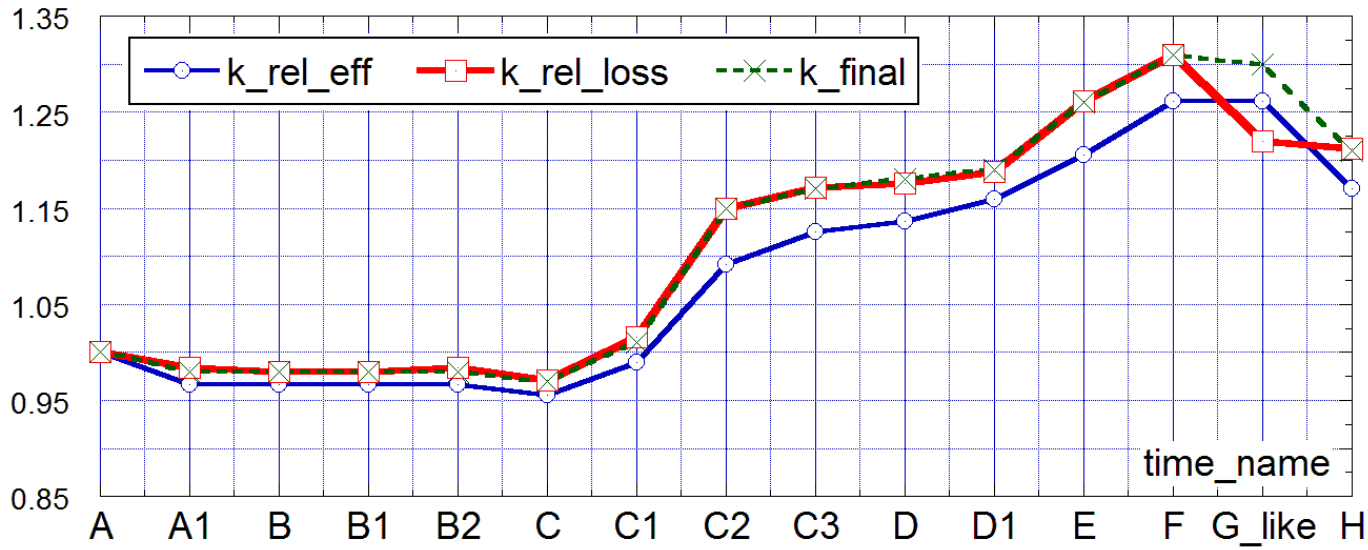
Search for improvements: EFF drops(?)

There are drops for BOOEFF (BEFF17), CHG1, CHG2 during study (see slides 9 &15)

Losses ~ δ_{chg} =CHG1-CHG2=CHG1*(1-CHG2/CHG1)=CHG1*(1-EFF)

Let's normalize BLM sums relatively initial point of time "A"
via the correction coeff. $k_{rel.loss}$(chg1,chg2)=δ_{chg}("x")/ δ_{chg}("A"),
which is a ratio of losses at time "x"to losses at "A" (here, δ_{chg}("A")=0.245

Alternatively, BOOEFF-dependent coeff $k_{rel.eff}$(eff)=[1-EFF("x")]/[1-EFF("A")]

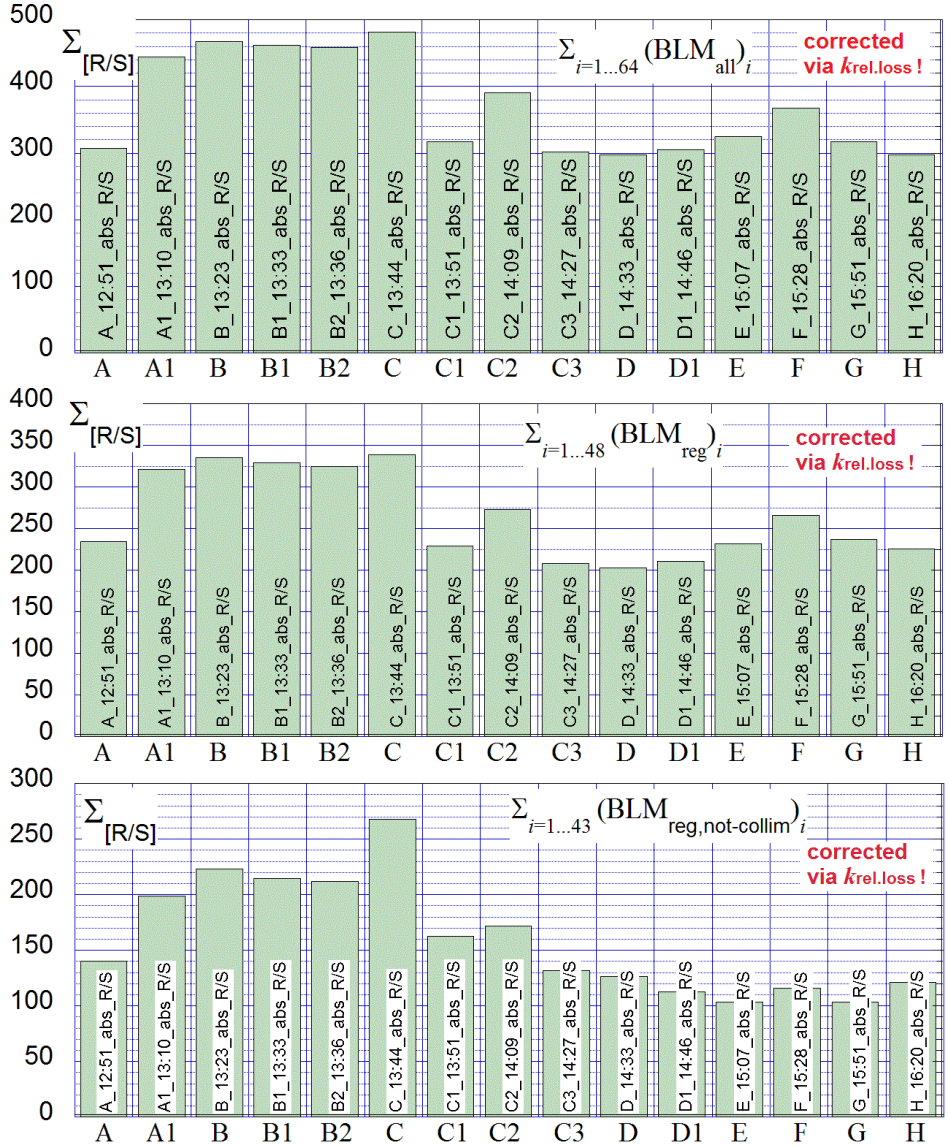


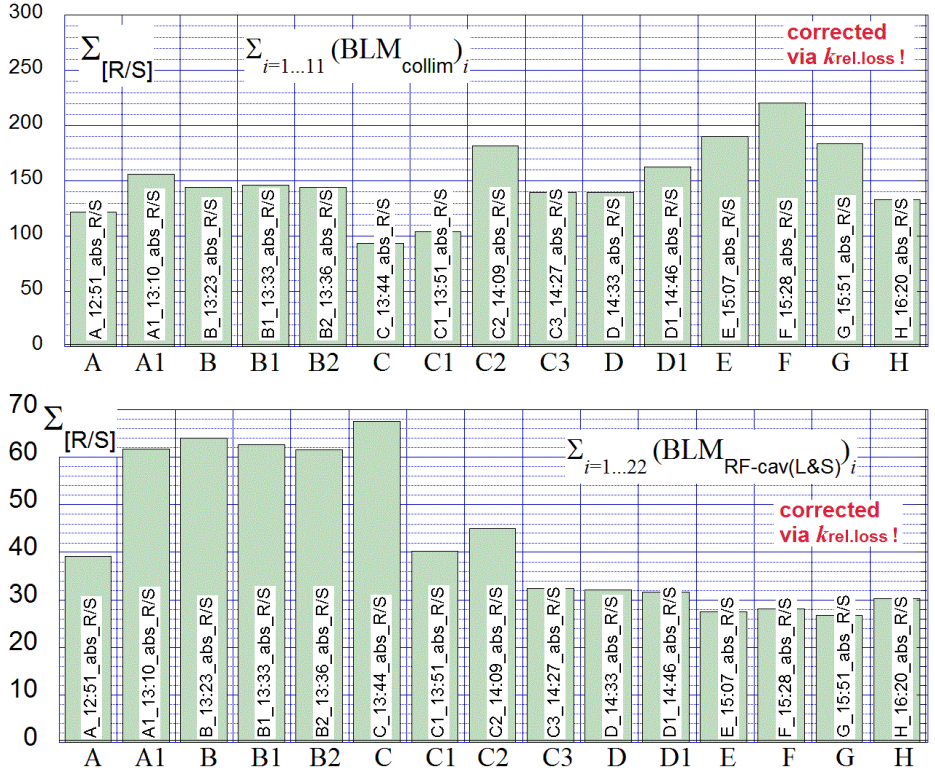
Let's use more favourable for 2SC coeff $k_{rel.eff}$ (final) !

(divide the above original sums on slide 21 by the coeff)

Corrected sums of absolute BLM values

Compare <C3÷G> vs <A,H>:





1)Correction => losses "A" ~ "H"

2) "1SC->2SC": all sums become worse, except D (sum"48"), E & G for sums "43" & "22(RF)" (<10%).

A - 1SC; C3 - **"1SC with single sec. col."**; D - (=C3) **"1SC-1"**; D1 - **"2SC-2"**; E - **"2SC-2, re-opt 7A"**; F - **"2SC-2, all re-opt"**; G - **"2SC-3"**; H - 1SC (=A)

Conclusion

- Several two-stage collimation (2SC) schemes in horizontal plane using one, two and three secondary collimators has been implemented during the collimation study on 2-Mar-2017
- BLM loss patterns around the Booster for 2SC have been compared to 1SC at 3 time scales (conclusions are consistent between them)
- Analysis demonstrated a worse collimation efficiency for 2SC vs 1SC
- Some tiny (<10%) reduction of losses has been detected over whole RF-area (periods 14-24) using some heuristical correction