Booster Collimation: 2-stage vs 1-stage

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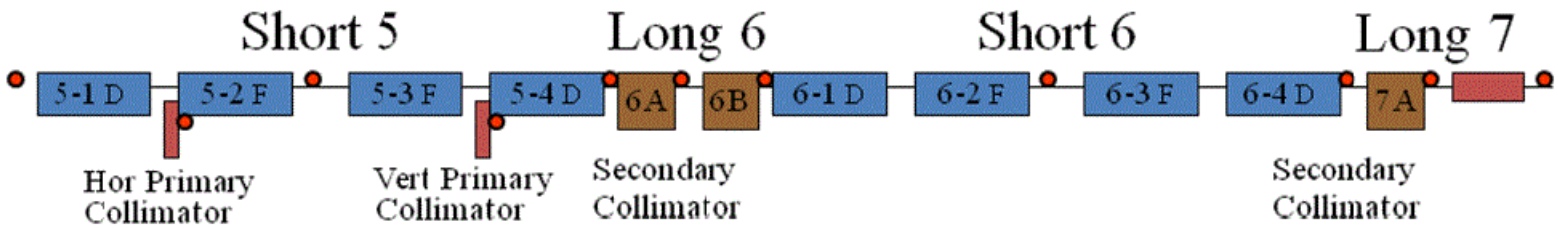
Activities & acknowlegments to people involved

- 1) Booster Collimator Hardware & Control (motion tests) and Beam Studies:
  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, Sergei Striganov, Igor Tropin
- 3) Support for task managments and planning:
  Bill Pellico and Cheng-Yang Tan

Booster collimation activity and status



History

- 2-stage coll. system for booster designed & installed in 2004. Optimal primary foils at 400 MeV: 0.003mm W by "STRUCT+MARS" (or ~ 0.015mm Cu). *Instead 0.381 mm (thick!) Cu foil was installed*
- 2-stage collimation is not used in operations (due to variable beam size and positions < ~2014)

Programming & Simulations

- New MADX+MARS bundle for booster: proton interactions with PrCol & outscattering from Sec. Colls
- Calculated Coll. Efficiency < 60% (low & ~1-stage); Opt. foil ~50um for Cu. => 400um Al - installed
- Tools for post-processing of beam orbits (B38), BLMs (B136 & "a'la B88") have been developed

Beam study (in vertical plane)

- **Objective**: to understand if 2-stage coll. is better than existing 1-stage collimation
- Initial study of 2-st. collimation at low intensity: stable beam orbits (B38); BLMs are not timed relatively to one another (~300us), strange plots for some BLMs; Beam near detection thresholds for FastLMs;
- Analysis of BLM data: 2-stage vert. collimation works (fraction of p scattered by PrColl then lost on SecColL6A), but not optimized yet
- Second study: vertical collimation under full intensity (14-turns) done **on 29/Jun/2016. Presented here**.

Hardware repair & support

- Two broken BPM (upstream vert. in L06 & upstream hor. In L07) – were repaired before 2016 shutdown
- Sec. collimators motion: maintaining plan for summer shutdown (by Matt) - to sample the oil the from one of the collimator gearboxes & at least visually check the condition; to purchase a spare gearbox
- Some issues for BLMs data (B136) should be resolved (for future studies)

Objective: to understand if 2-stage collimation is better than existing 1-stage collimation

Why such task exists:

- There are **plans to increase Booster intensity**:
  PIP => 4.3E12 ppBc (15Hz) and further (~50%) to 6.5E12
- Present PIP efficiency: 92% (for 4.3E12) drops to 90% (for 5.3E12), and => <89% (for 6.5E12). **Losses are increased with intensity**!
- To remain at our present activation levels Booster needs to operate at around 95% efficiency (by **"beam physics" improvements**)
- **Improved collimation** potentially may help to **facilitate this task**
- Booster has installed a 2-stage collimation (2SC) consisting of 2 primary & 3 secondary colls. **Only 1-stage** (1SC) **is used now**.
- **Exp. capabilities of 1SC** are known (small improvements possible)
- Potentially well-designed **2SC can be better of 1SC**. However, it was **never demonstrated for booster**. (Due to non-optimal foils?)
- Our task to **compare 2SC and 1SC** and understand if 2SC can be useful for a booster intensity upgrade.

Design principles for 2SC in synchrotrons: are they well established and proved ?

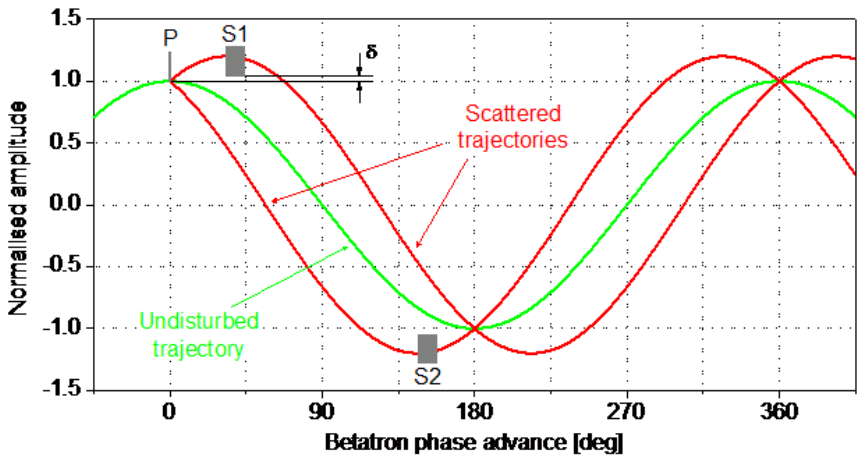
- Classical 2-stage collimation (2SC) designed in 2004 for **booster synchrotron** has been never applied for **synchrotrons** (var Energy & C.O.) by that time (SNS & JAERI were built later).
- **Design principles** have been **directly transferred** from Tevatron 2SC (collider with constant energy and stable beam orbits)
- Booster 2SC has been implemented into already **existing machine** installing collimators **in available spaces** between small-aperture magnets
- 2SC is effective within **narrow region of synchrotron circle** (e.g. injection)
- There is **no reliable & comprehensive simulations** comparing 2SC with single stage collimation (1SC) **for booster**. Automatically better ?
- 2SC systems at JAERI & SNS were designed for **new machines** (Disp=0)
- JAERI (RCS) **in similar way** with STRUCT (later re-simulated with ORBIT). Used in operations; but no comprehensive data published (why?). Later additional collimators were installed at H-minus injection area.
- SNS **does not use installed 2SC** (not needed due to large apertures). published beam study results did not show positive effects from 2SC
- RAL uses set of many thin and thick collimators (**not a classical 2SC**)
- SNS,RCS,RAL use thicker prim-colls (tanks to larger apertures) => larger rms scattering angles => larger impact params. => smaller out-scattering

2SC as an improvement of 1SC

Usual “1-stage” collimation produces **uncontrolled out-scattered protons**
=> “2-stage” scheme (icreasing impact parameter on sec.colls)

From Ivan Strasik (GSI) 2014 talks

- Primary collimator (thin foil) – scattering of the halo particles
- Secondary collimators (bulky blocks) – absorption of the scattered particles



- Particles have small impact parameter on the primary collimator
- The impact parameter on the secondary collimator is enlarged due to scattering

Very robust concept and well established in many accelerators.

[Ref] M. Seidel, DESY Report, 94-103, (1994)
[Ref] T. Trenkler and J.B. Jeanneret, Particle Accelerators 50, 287 (1995)
[Ref] J.B. Jeanneret, Phys. Rev. ST Accel. Beams 1, 081001 (1998)

1SC efficiency depends on several params.

1SC depends on impact parameter & angular alignment of jaw

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

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.

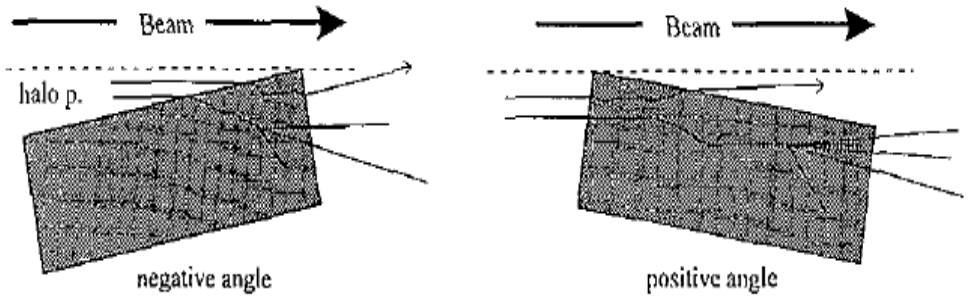
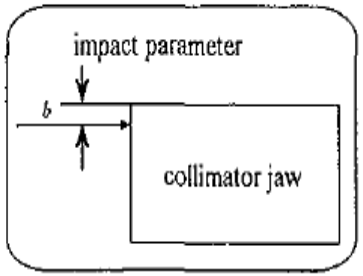


Fig. 2.15: Reduction of the effective jaw length due to angular misalignment.



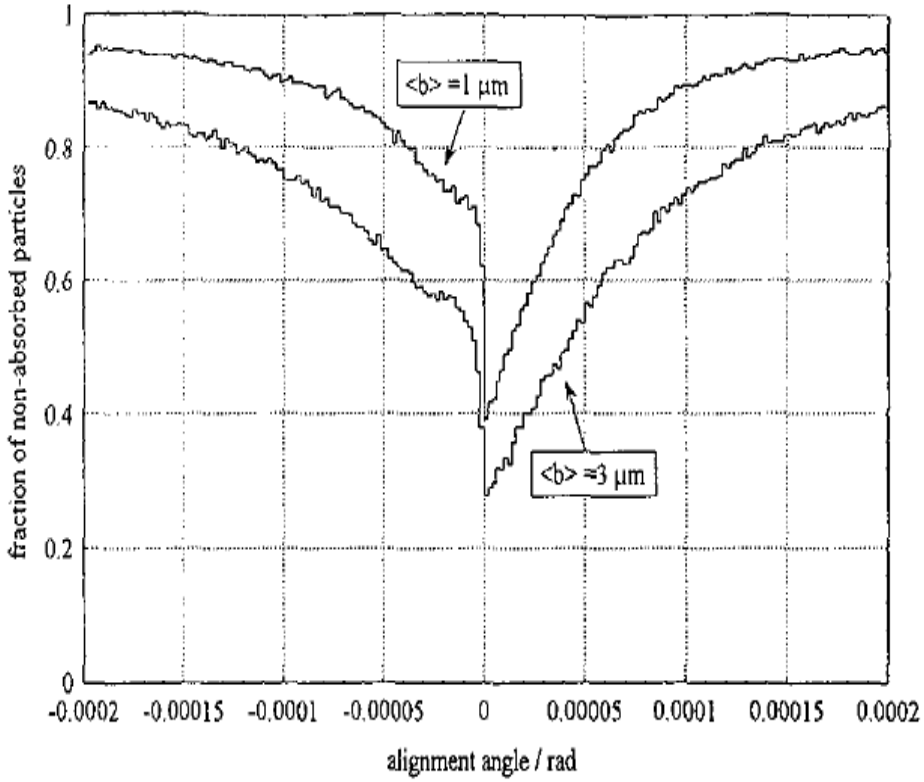


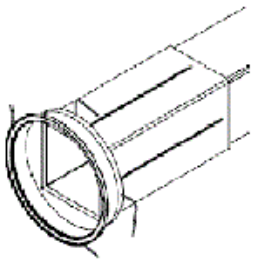
Fig. 2.16: The out-scattering probability as a function of alignment angle for two different exponential impact parameter distributions.

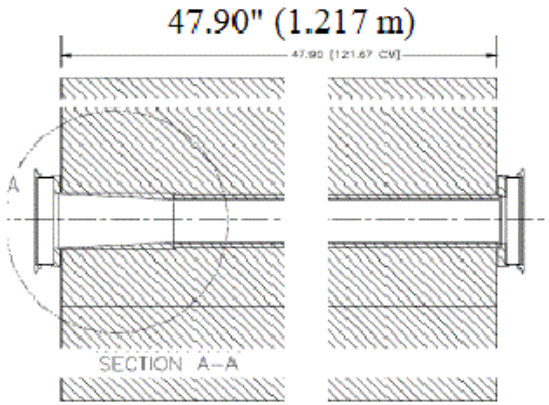
Collimation efficiency may also depend on particular features of **jaw configuration** of secondary. collimators

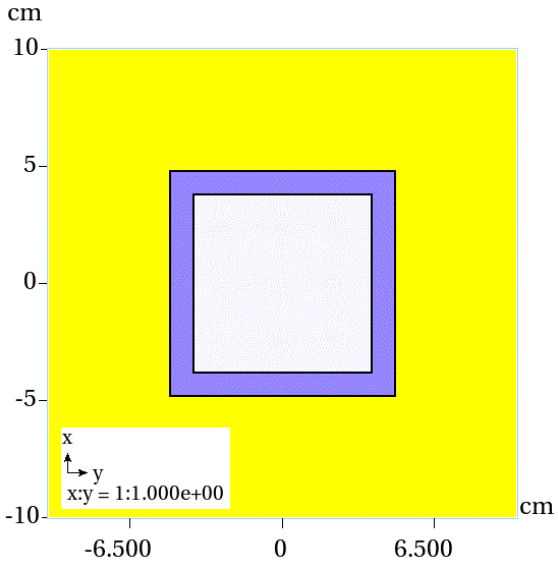
Simulations with MARS model for secondary collimators

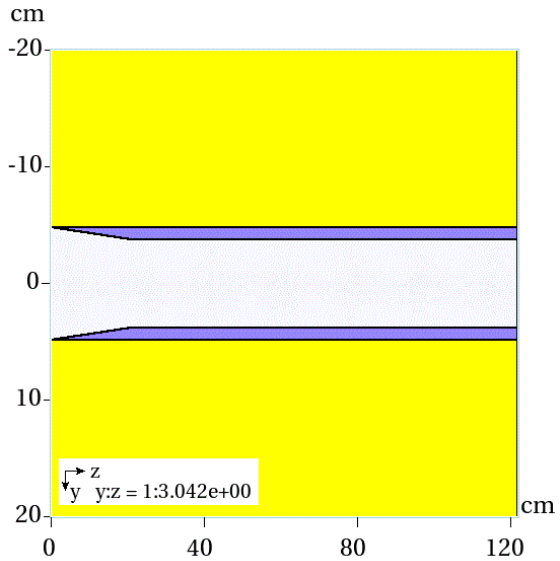
Model created and supported by I. Tropin & N.Mokhov; Interface with “STRUCT” coordinate system (x,x’,y,y’,p); Model is centered on ref. orbit.

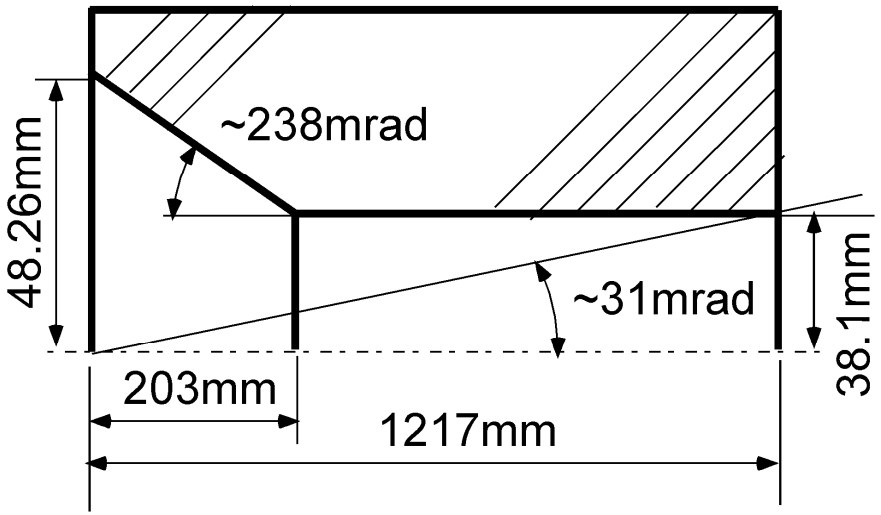
Original drawings;
MARS visualization;
relevant sizes & angles







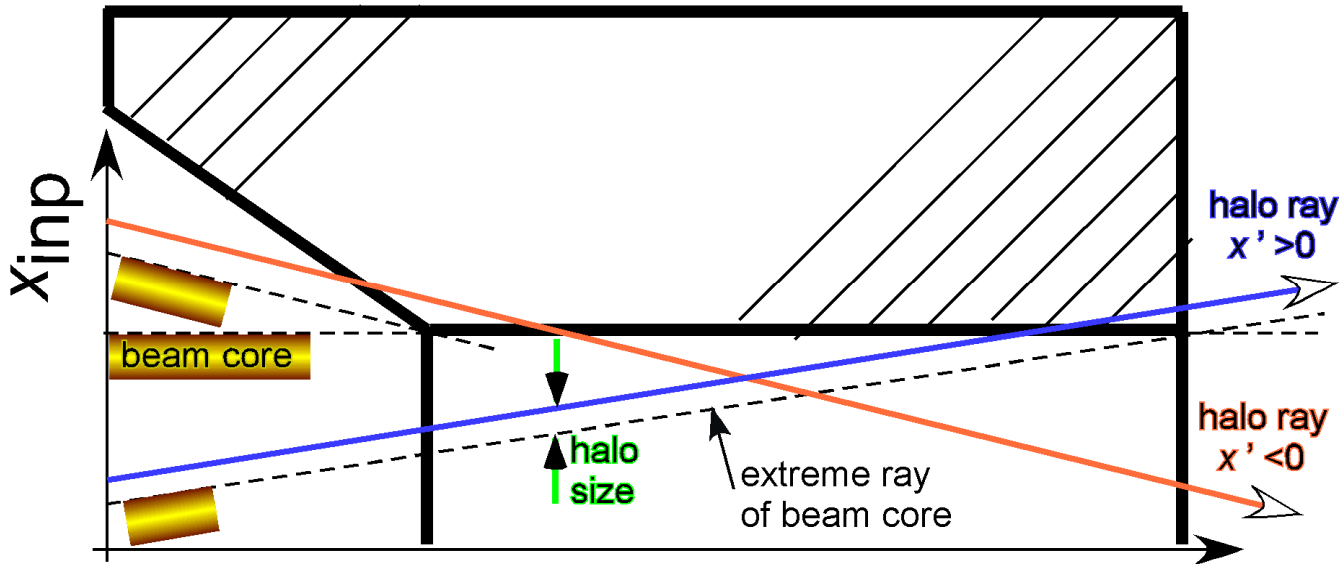


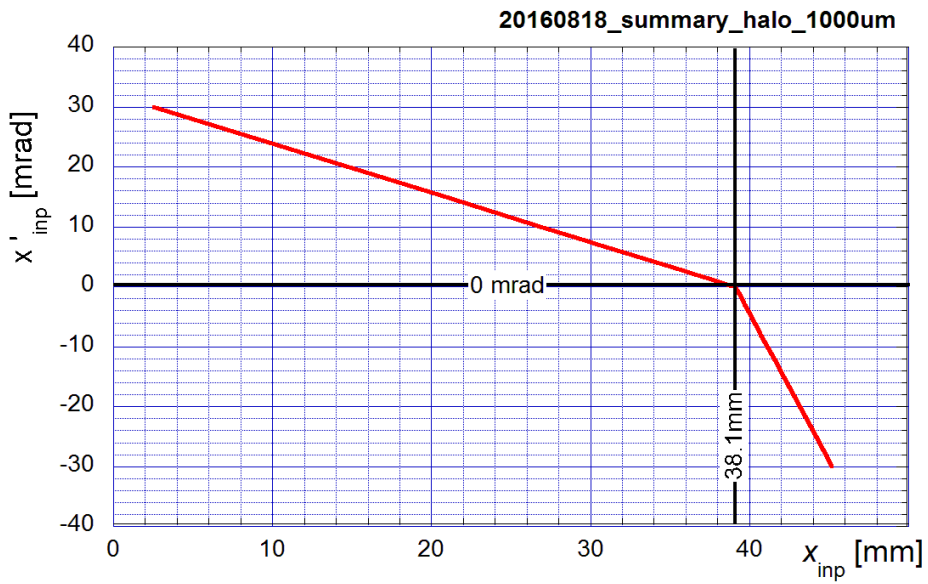


1SC: simulation scheme

halo ray (10^4 protons with identical coords); dependence on slope x'=dx/dz [mrad] at given halo sizes

Note: modern (>2005) collimators have similar "tapers" at both front & back jaws





For **x'>0** beam hits **back** jaw

For **x'<0** beam hits **front** jaw

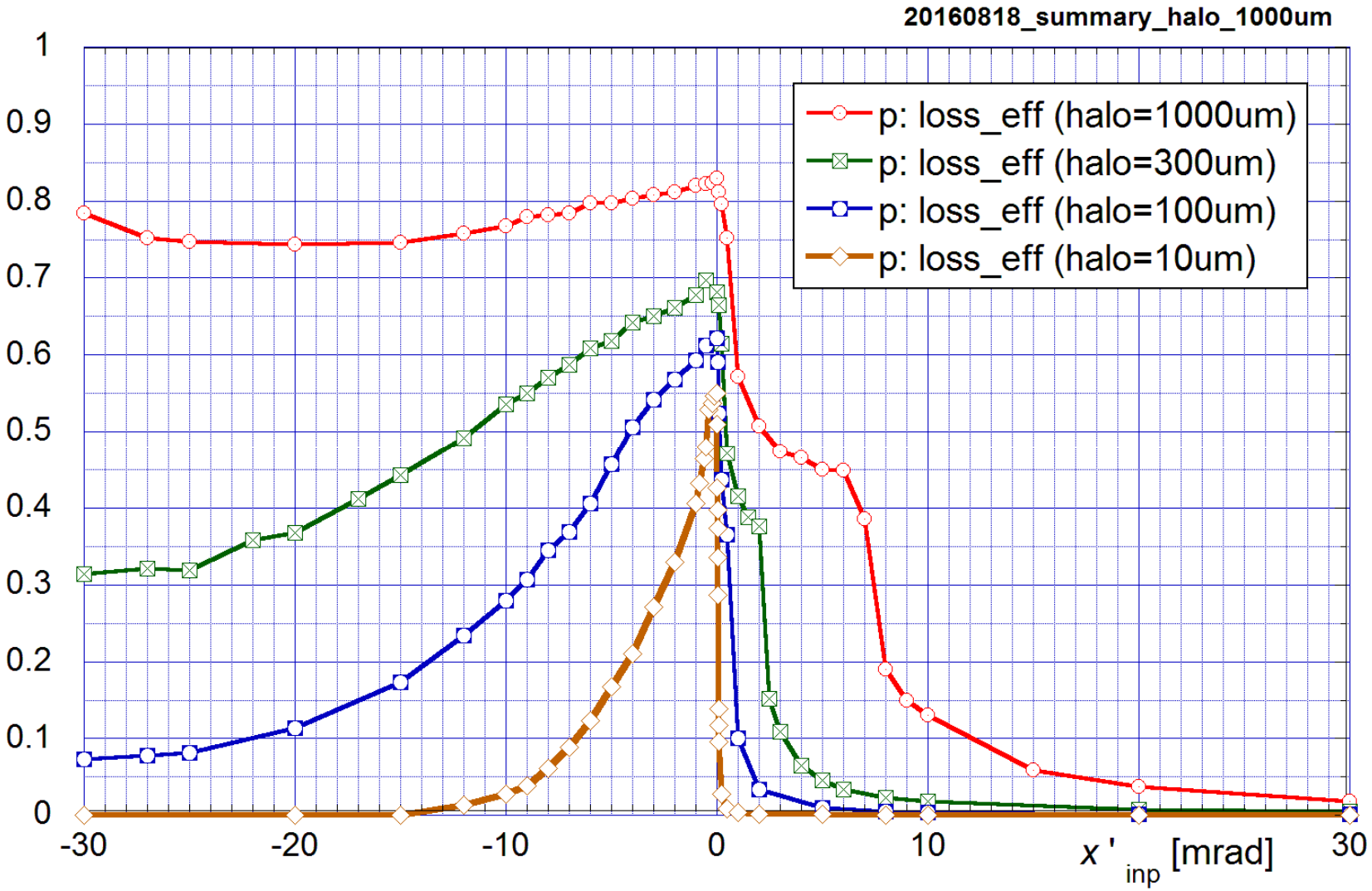
Condition:

beam core touches jaw w/o losses

Left: Relation between input x' & x for a given halo size (here 1mm)

1SC simulation: eff. vs x' at diff. impact parameters

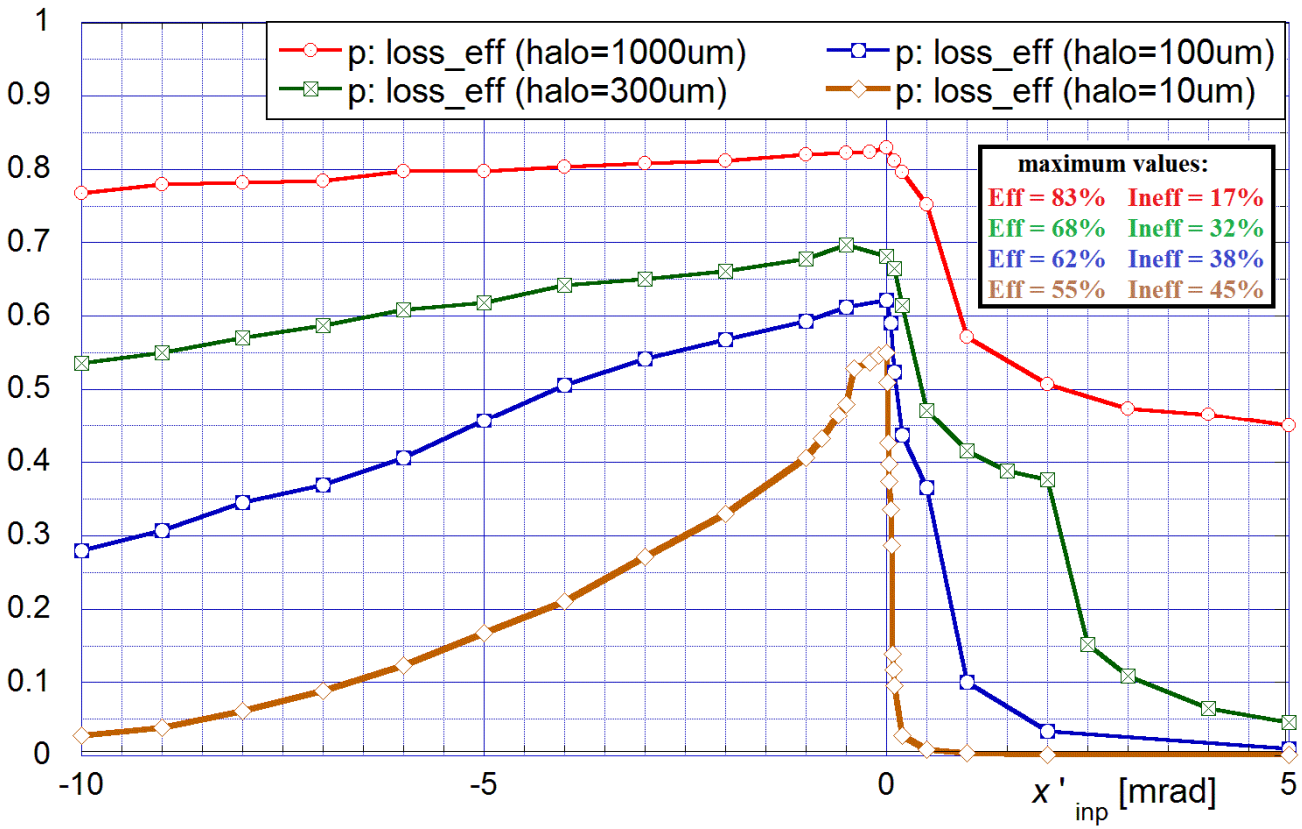
"1SC Eff."=(N protons lost in collimator)/(N=10^4 parts in incident beam)



Imaginary goal-values for 2SC

Assuming that 2SC can reduce (collimator related) losses of 1SC by **50 %:**

Halo [um]	1SC Ineff	2SC Ineff	2SC Eff
10	45 %	45*0.5 ~23 %	(1-0.22)=77 %
100	38 %	38*0.5 =19 %	(1-0.19)=81 %
300	32 %	32*0.5 =16 %	(1-0.16)=84 %
1000	17 %	17*0.5 ~ 9 %	(1-0.09)=91 %



Need to evaluate "Halo per turn"= Impact param.

Collimator related losses ~ Inefficency:

Let's define "1SC Inefficiency" = (1- Eff.)~ (N_outscat/N incident)

Ways for “halo” evaluations

1) Numerical simulations (e.g. Synergya code) can help to evaluate minimum values of beam halo. It is more adequte for rings with constant parameters.

(A. Macridin & V. Lebedev did some evaluations. Details are not published)

Actual “Halo-growth rates” in synchrotrons (with var. params) should be **higher** due to many real effects (variations of orbit, energy, misalighnments, mismatching etc.)

2) Indirect experimental evaluations (feasible ?) using the dependence Eff=(x’)
It suggests Efficiency drop (say 20 %) within: a) 1.5mrad, if halo ~10um;
b) 4mrad, if halo ~100um; c) 10mrad, if halo ~300um; d) none, if halo > 1mm

Aperture Restrictions, e.g. Long 6 collimators:

Distance between COL1 front and COL2 back L=4m

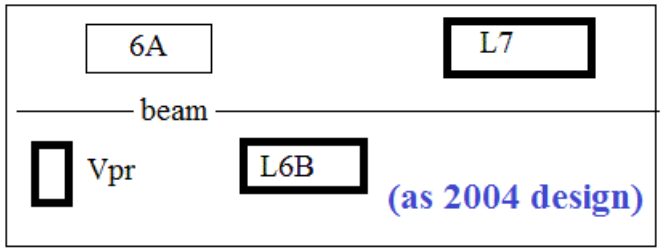
Max beam core sizes (~5sigma) = 19mm/32mm (H/V); Collimator a=38mm

Max angle x’=2*(38-19)/4 < 9 mrad; y’=2*(38-32)/4<3mrad;

May be possible to evaluate for hor. plane x’, if the halo rate within or > 100um ?

Todd: regular change of x’ with dX(BPM)=+-2mm =>4mm/5m <1mrad

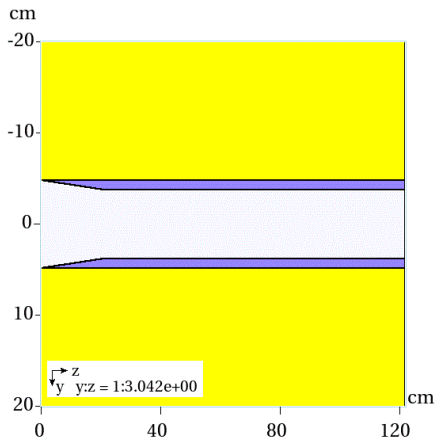
Simulation of 2SC in vert. plane



My conventions for Boo **2SC setup** (1.*=hor; 2.*=ver)

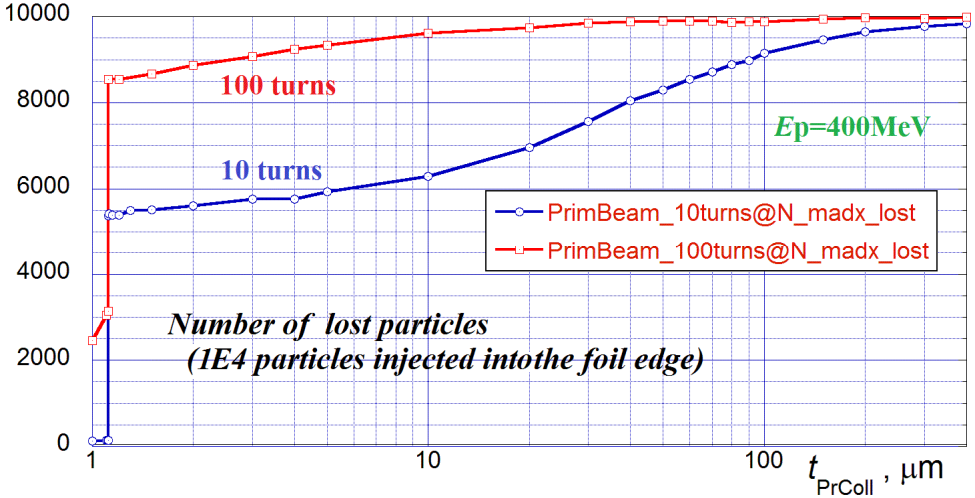
- Mode 2.1) **"2004-design"** COL {Vp,1,2,3}={-;"0";-;+}, where "+/-"=top/bottom, 0 - garage
  if **V-prim** on **bottom** beam edge (mode2.1), then:
  a) only **COL3(L7)** has mu>90deg, it must come from opposite (**top**) edge;
  b) both COL1&COL2 can be used for mu<90deg, but larger mu-preferable (large delta-gap) and free COL1 for Mode=1.*. Then, **COL2** should be set on the side of V-prim (**bottom**)
  1c) if "b"=OK, then **COL1** should be in garage (or at least not on the bottom). It may be set at **top** with a large gap from beam edge to avoid direct beam interception (as for 1-stage scheme)

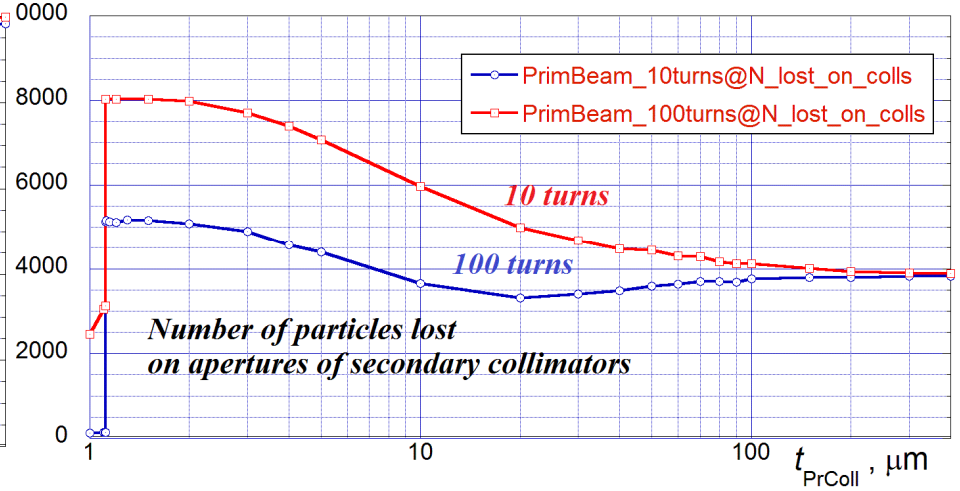
One MARS model for 3 identical sec-colls.
Model is centered on ref. orbit.
Transverse shifts simulated via shift of input and output particle coordinates



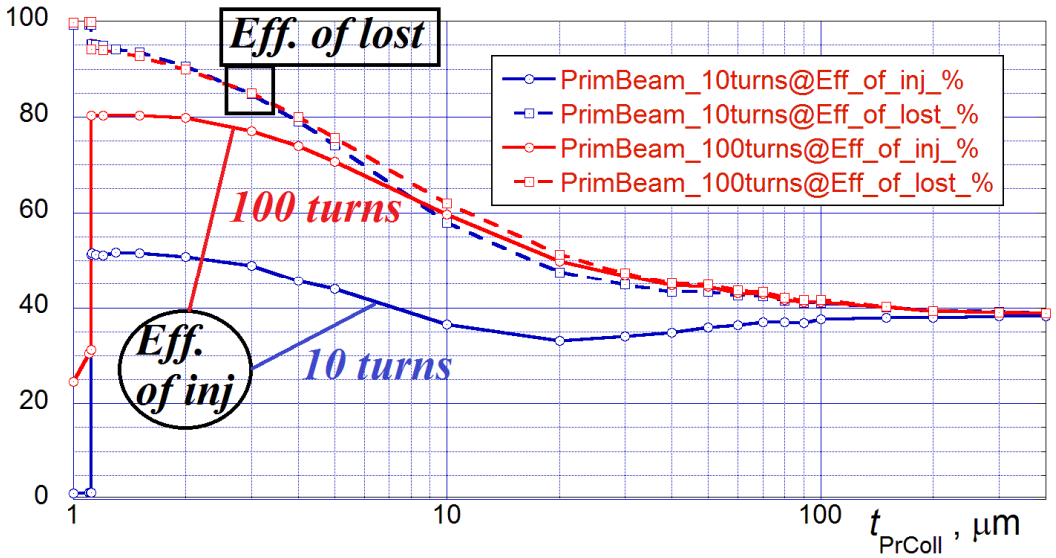
Steps:
a) MADX multi-turn tracking with usual losses on apertures ;
b) protons lost on collimators collected at collimator fronts;
c) that protons are re-tracked throughout sec-colls with MARS;
d) Out-scattered protons are collected at sec-coll ends are tracked again by MADX

a) MADX tracking (losses on apertures) vs t-foil





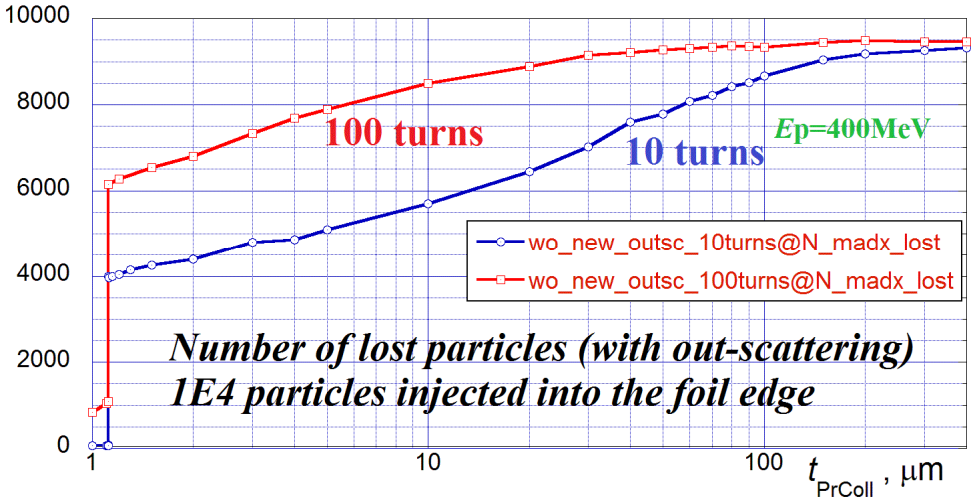
Efficiency definitions: a) "Eff. of lost" = (N lost on colls) / (N total lost on the ring);
b) "Eff. of inj" = (N lost on colls) / (N injected on foil = 1E4)

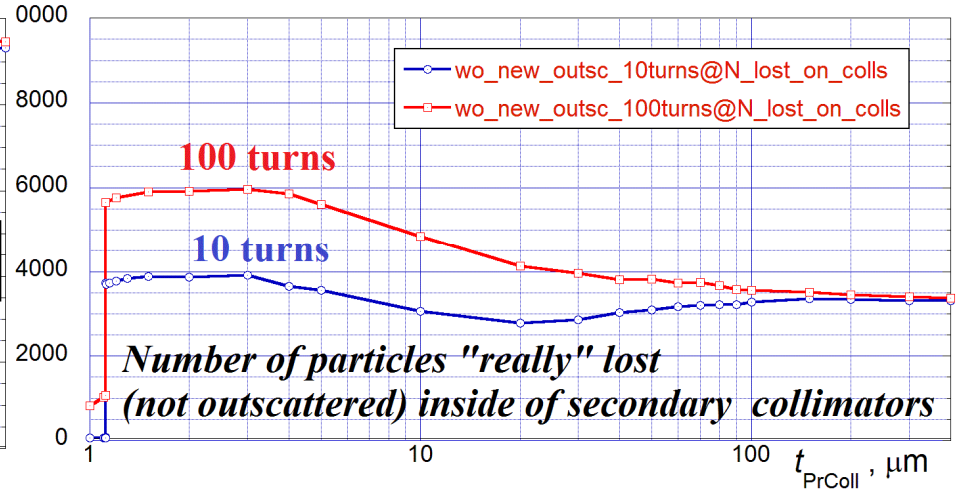


Def. a): "no worry" about particles which were not lost in simulations. In reality they will spread & lost around ring due to their worsen 6D-coordinates after interaction with the primary foil

Idea of 2SC is to insert prim. foil and catch most of scattered protons (say >90%) by sec. collimators => Use def. b) "Eff. of injected" !!!

c) MARS re-track “lost” p in Sec.colls (out-scattering!)





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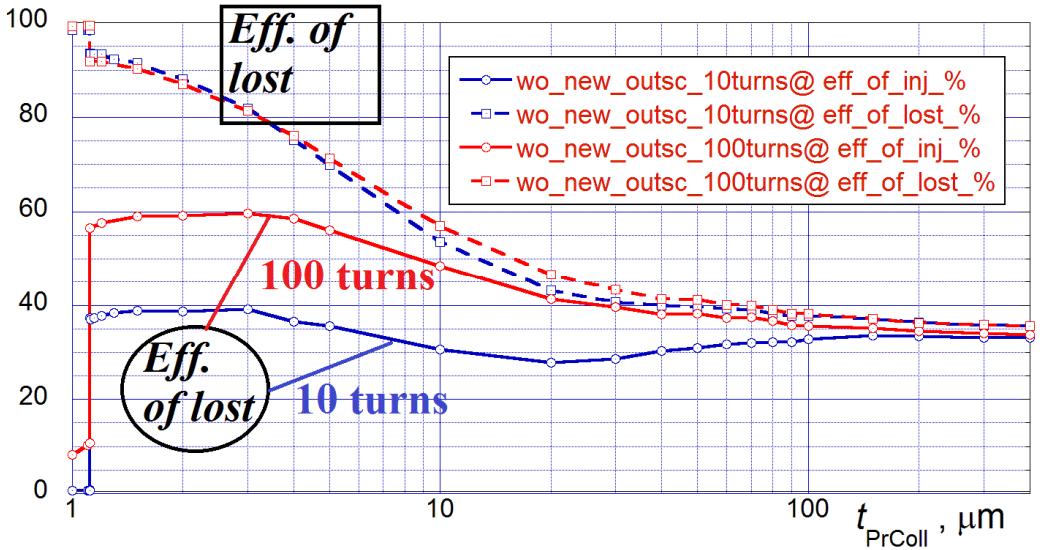
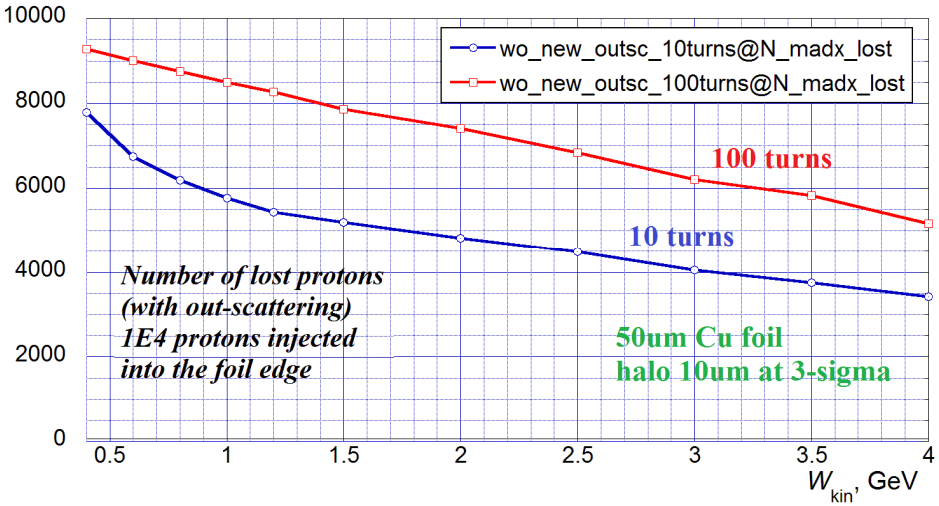


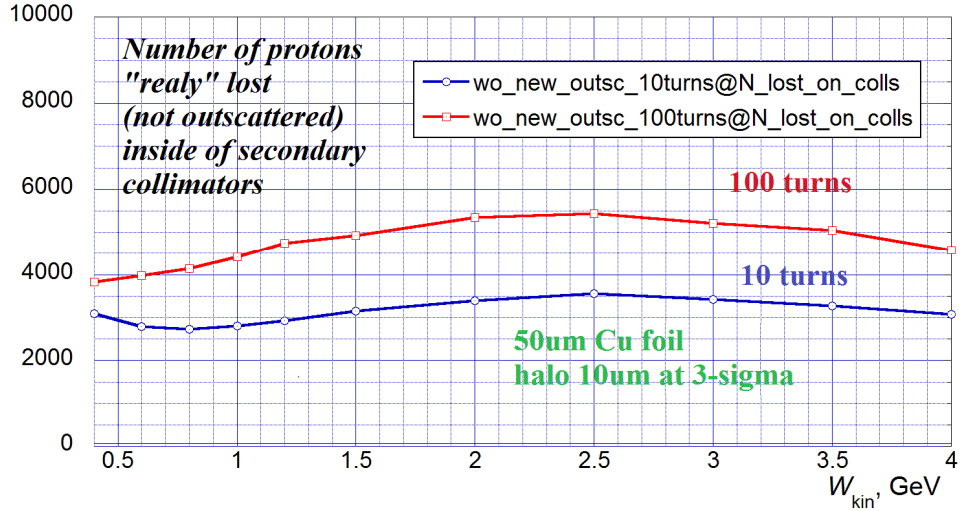
Def. a): very optimistic efficiency for ultra-thin; what about the fortune of not-lost (& out-of-control) >4000 particles with worsen 6D-coordinates by foil ?

“Eff. of injected”
b): max 60% for ultra-thin ~3um Cu
40% for new 380um Al (~50um Cu)

“Foil will find its optimum energy”
or much thinner foil => Be !(???)

Eff. Vs Energy for new 380um Al (~50um Cu)





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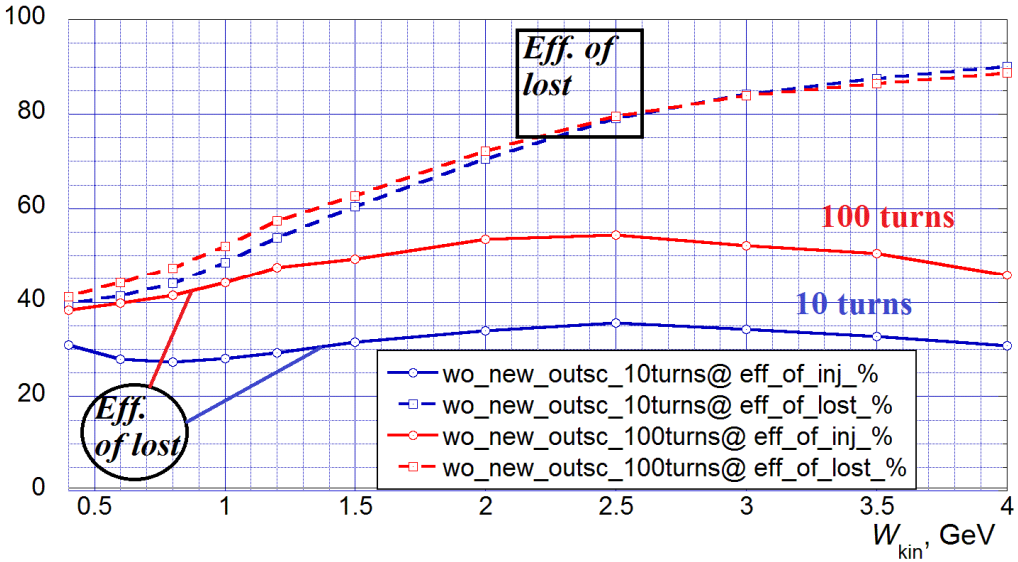


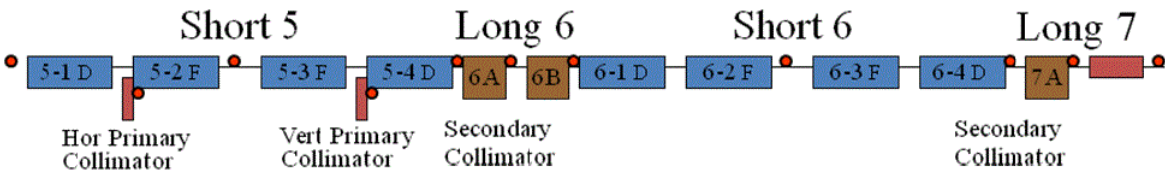
Def. a): efficiency increased with Wkin

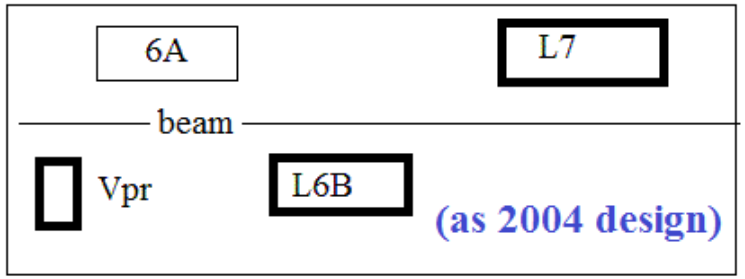
"Foil found optimal Wkin" ~ 2.5GeV
With "Eff. of injected" max 60%

At injection "Eff of inj" ~40%

Even optimal efficiency 60% is ~ the same as 55% 1SC (halo ~ 10um) !!!

29-Jun-2016 Beam study: Vert 2SC

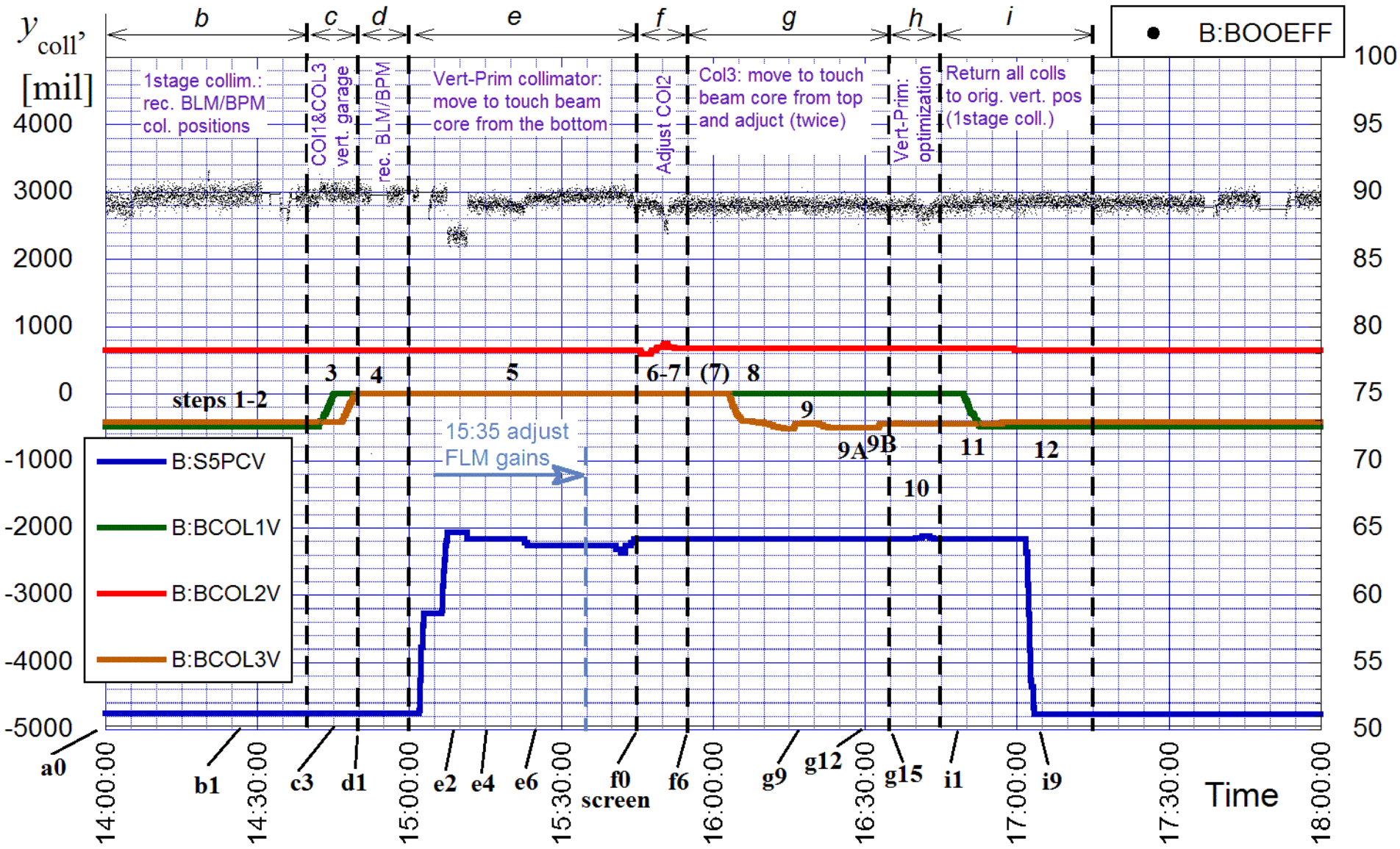




Actual Study Steps & time intervals

1-2	*b*	*Record BLMs, BPMs Coll-pos*	8	*g*	Move Col3-L7 toward to beam (DN) to touch beam core
3a	*c*	Move Col1-L6A vert. garage	9	*g*	Adjust Col3-L7 to beam core & move away (UP) ~2mm
3b	*c*	Move Col3-L7 vert. garage	9A	*g*	Adjust Col3-L7 again
4	*d*	*Record BLMs & BPMs*	9A	*g*	*Record BLMs & BPMs*
5	*e*	Move Vprim to touch beam core from bottom	9B	*g*	Move Col3-L7 (UP) from beam core ~2mm
6	*f*	Move Col2-L6B away from beam (DN)	10	*h*	Play with Vprim position
7	*f*	Adjust Col2-L6B to beam core & move away (DN) ~2mm	11	*I*	Return all Colls to 1SC: Col1-L6A; Col3-L7; Col2-L6B; Vprim
(7)	*g*	*Record BLMs & BPMs*	12	*i*	*Record BLMs & BPMs*

Time intervals & (corrected) plan steps

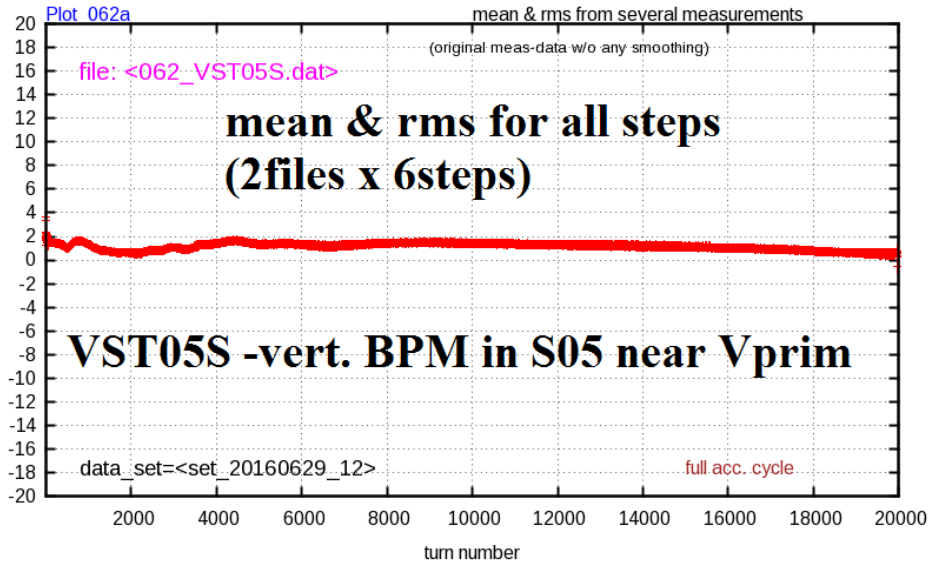


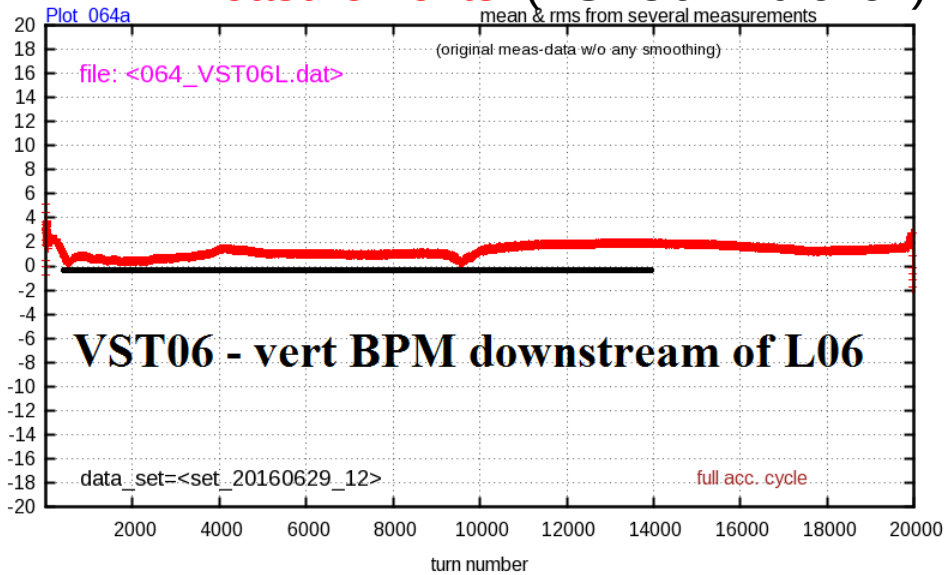
ACNET applications used & post-proc .code

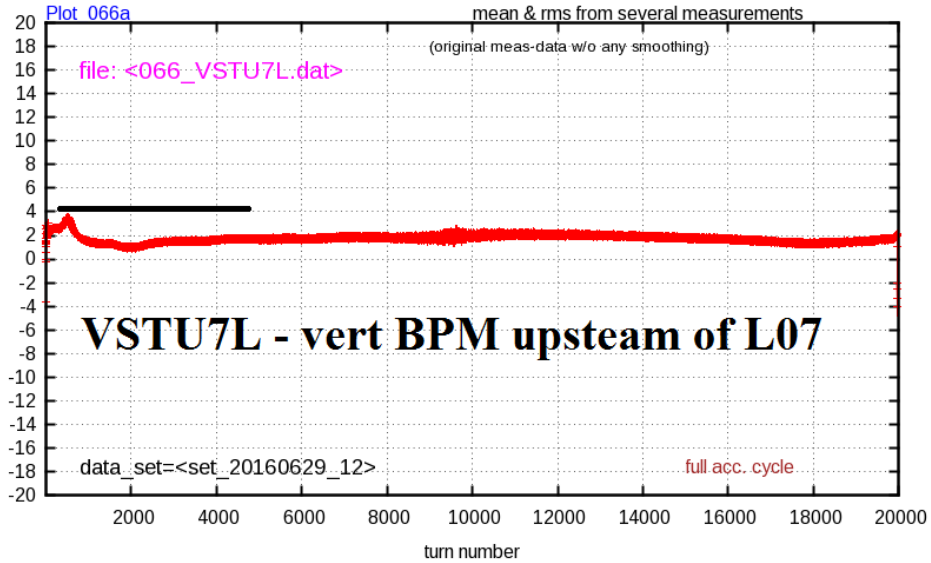
B:BEFF17	Beam transmission efficiency control
B38 Beam orbits	save data => postproc. code: x & x' at collimators
D43 save-list	BLM data recorder for off-line usage via D44
FLM signals	on-line for Collimator tuning; off-line via D44
B88 "frac.trip point"	Data export does not work => only "PrintScreen"
A'la "B88"	Exe for reading BLM data to reproduce B88 plots
B136 BLMs signal within Boo-cycle	Save data => postproc. Code: check bad signals; averaging over cycle => compare with B88-plots
D44	Off-line plotting of recorded parameters

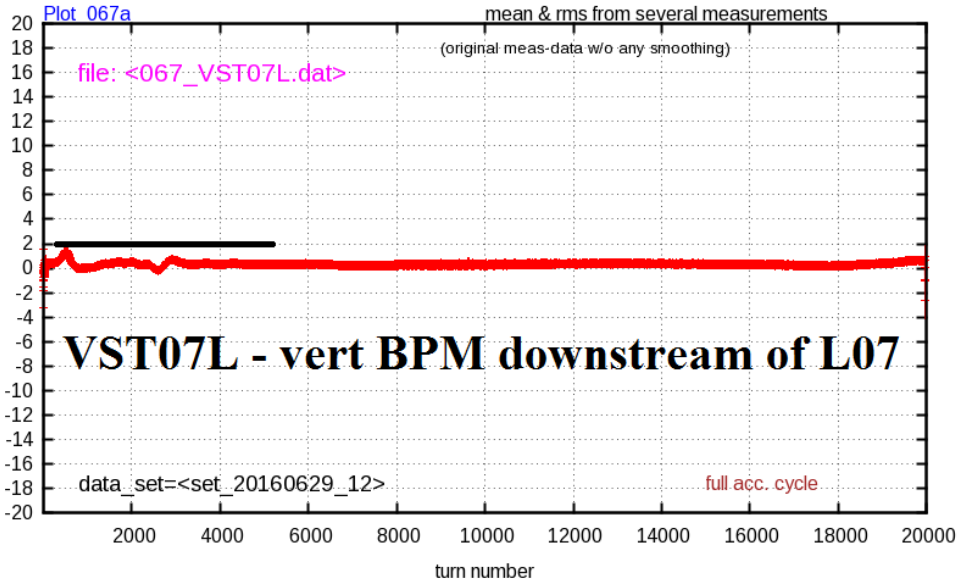
B38 post-processing: Vert-BPM in S05; L06; L07

Measurements! (VSTU6L - broken)



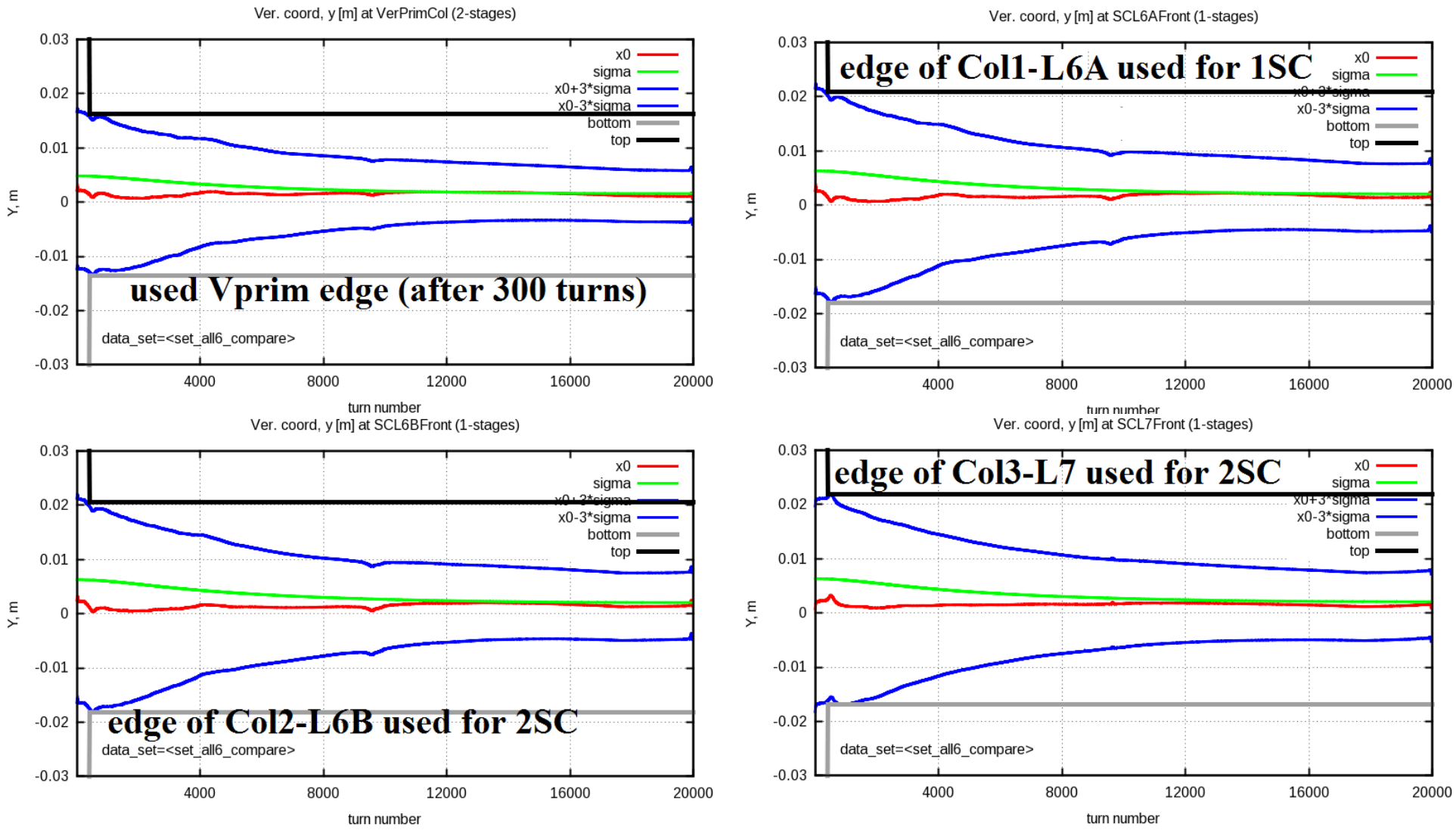






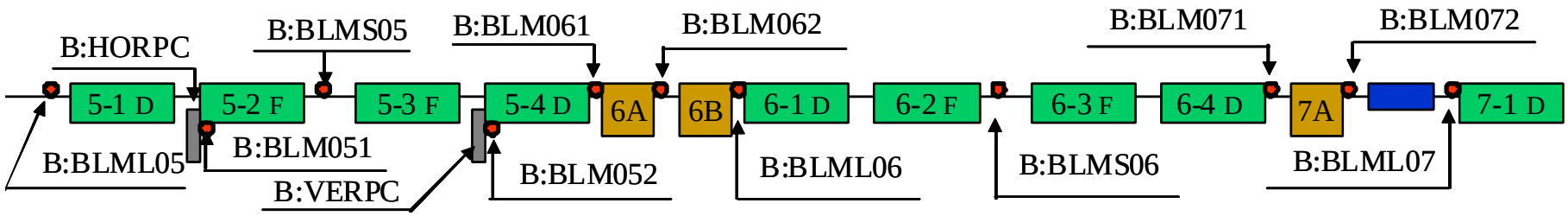
Beam orbit are stable during all steps of study !

B38 post-processing: orbits at Vert-collimators



Specially arranged bumps of 3-sigma envelops (by Todd)

D43 save-list: BLM data recorded



PB D43 Lumberjack Config<NoSets><NewDPM-CLX22 (0%)> 14-Jun-2016 16:00

D43 Circular Datalogger Device List Control (BClk) ◆Pgm_Tools◆

◆Event ◆ ◆Event ◆ ◆Event ◆ ◆Event ◆ ◆Event ◆ ◆Event ◆
◆Event ◆ ◆Event ◆ ◆Event ◆ ◆Event ◆ ◆Event ◆ ◆Event ◆
◆Event ◆ ◆Event ◆ ◆Event ◆ ◆Event ◆ ◆Event ◆ ◆Event ◆

◆Sort◆ ◆Show Fetch Info◆ ◆Display Full Device Name ◆ ◆Stats◆ ◆Find_Change◆

List Event has a capacity of 2000000 buckets

Node [BClk]
Menu [DCE15]

1F+0 sec	1F+0 sec	1F+0 sec	1F+0 sec	1F+0 sec
B:BLML01	B:BLML02	B:BLML03	B:BLML04	B:BLML05
B:BLML06	B:BLML07	B:BLML08	B:BLML09	B:BLML10
B:BLML11	B:BLML12	B:BLML13	B:BLML14	B:BLML15
B:BLML16	B:BLML17	B:BLML18	B:BLML19	B:BLML20
B:BLML21	B:BLML22	B:BLML23	B:BLML24	B:BLMS08
B:BLM021	b:	B:BLM023	B:BLM024	B:BLM025
B:BLM026	B:BLM121	B:BLM122	B:BLM123	B:BLM124
B:BLM125	B:BLM126		B:BLMS12	B:BLM051
B:BLMS06	B:CHGBBM	m:blb5	m:blb6	B:BLM052
B:RADL04	B:MP02E	b:numiic	B:BLM063	B:BLM061
B:BLMS03	b:bbm800	b:numihv	B:IRM072	B:BLM062
B:MP02	B:BLMS05	B:MP02I	B:BELOST	B:BLM071

◆Write_List_to_File◆ ◆Insert◆ ◆Reinitialize_Lumberjack◆

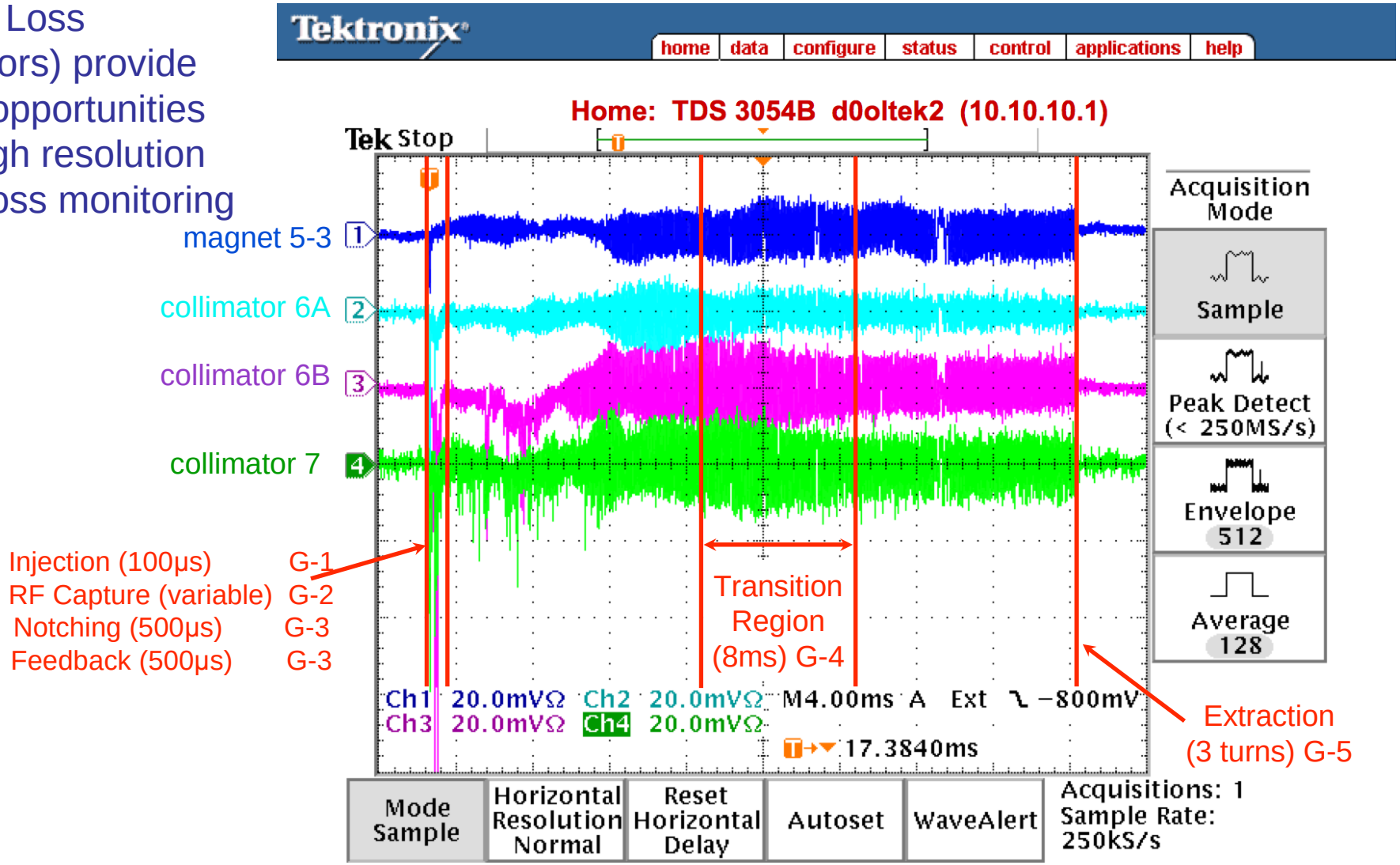
Restart: Tue Jun 14 14:17:22 Since: Sat Mar 5 02:01:33

Find ◆Devices◆< >
in ◆Lumberjack◆<All > Show ◆Active Devices◆ Property ◆All ◆

Messages

Booster losses: FLM for full booster cycle

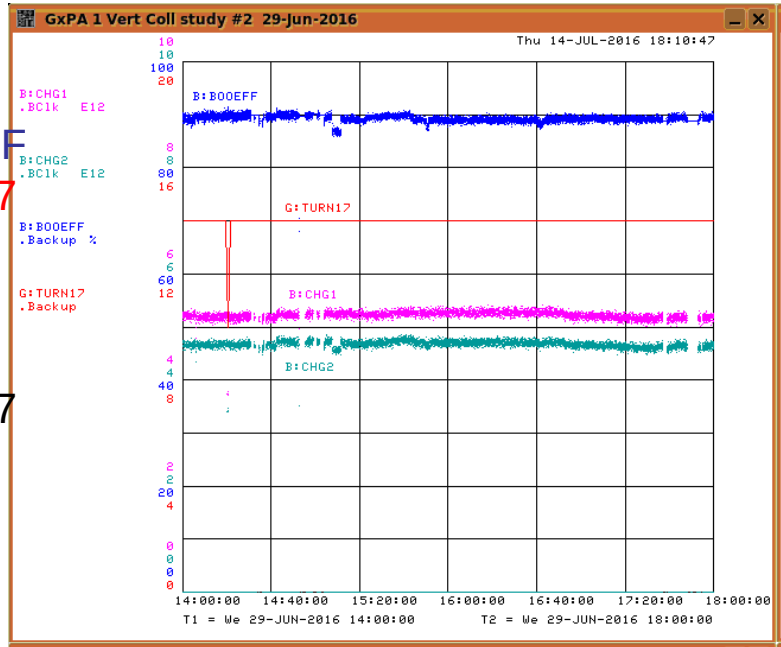
Rick's FLMs (**Fast** Loss Monitors) provide ***new*** opportunities for high resolution (ns) loss monitoring

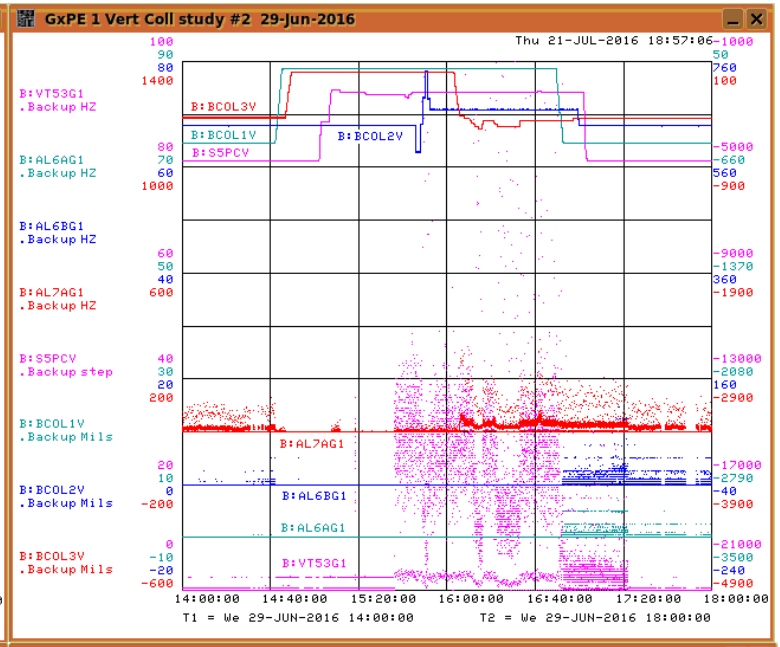


Typical screens for tunings with FLMs (2-6pm)

D44:
BOOEFF
TURN17
CHG1
CHG2

TURN17
=14

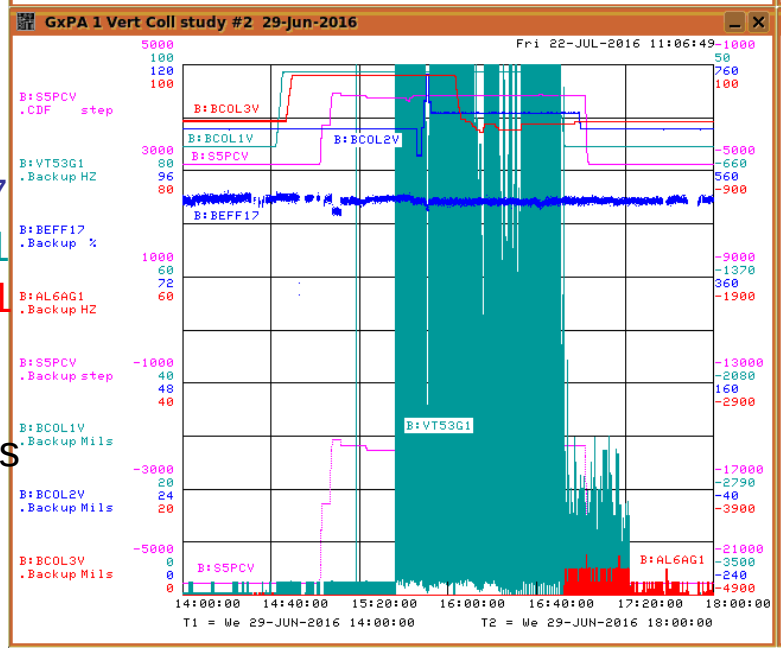


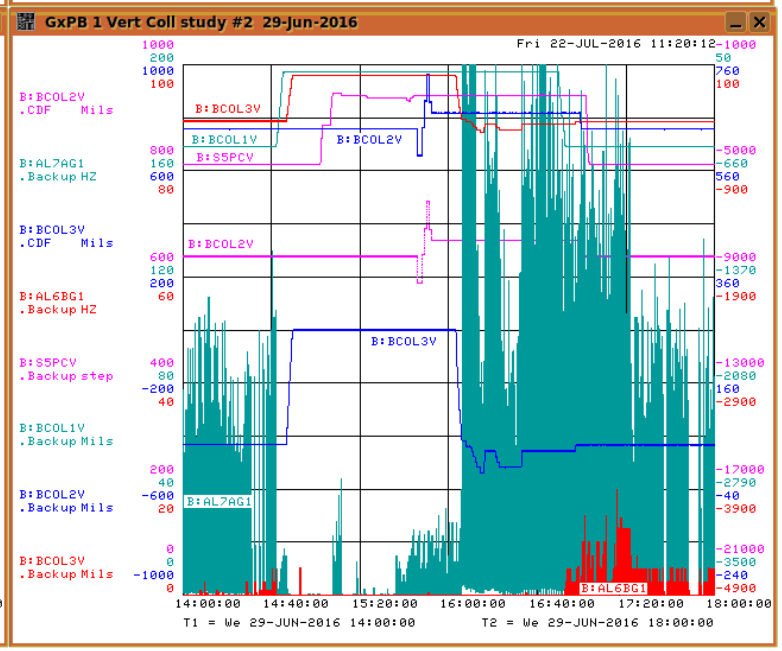


D44:
VT53G1
AL6AG1
AL6BG1
AL7AG1
&
Coll.
positions

D44:

BEFF17
VT53G1
AL6AG1
&
Coll.
positions





D44:

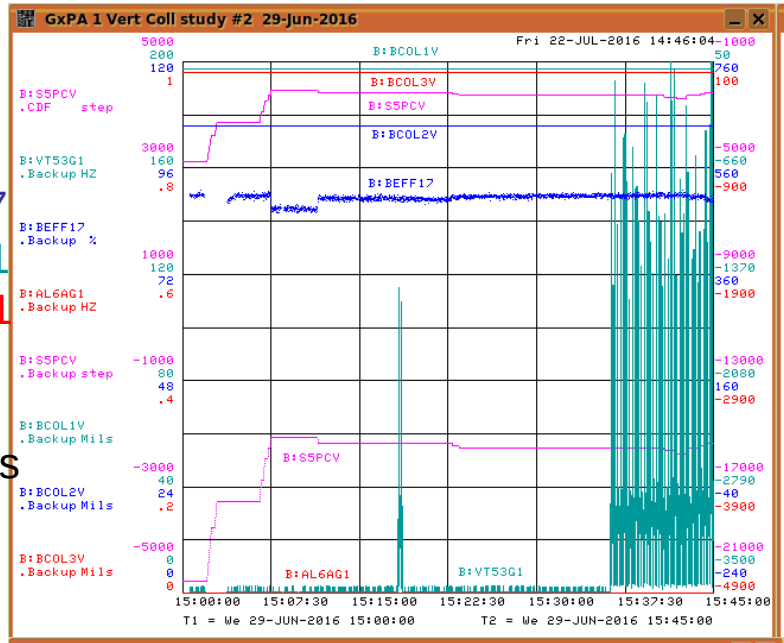
AL7AG1
AL6BG1

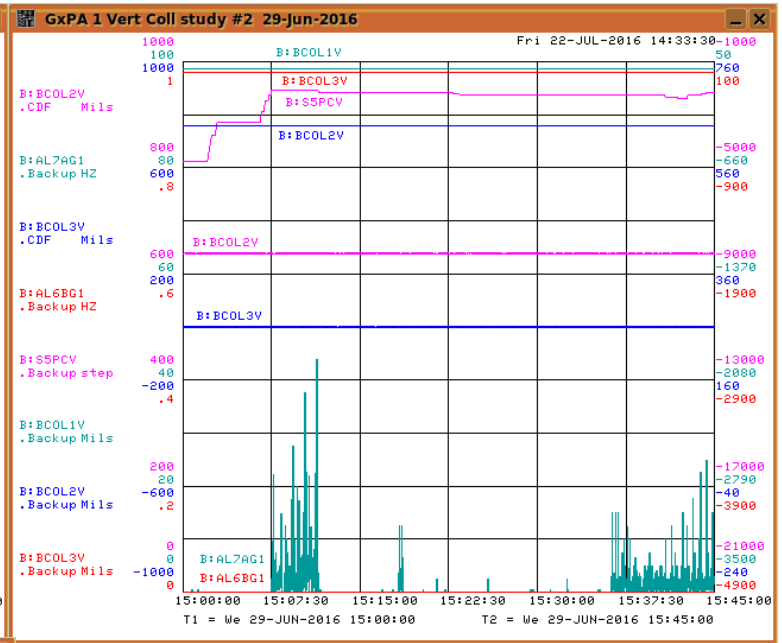
&
Coll.
positions

Tuning Vprim: “e”-interval (15:00-15:45)

D44:

BEFF17
VT53G1
AL6AG1
&
Coll. positions



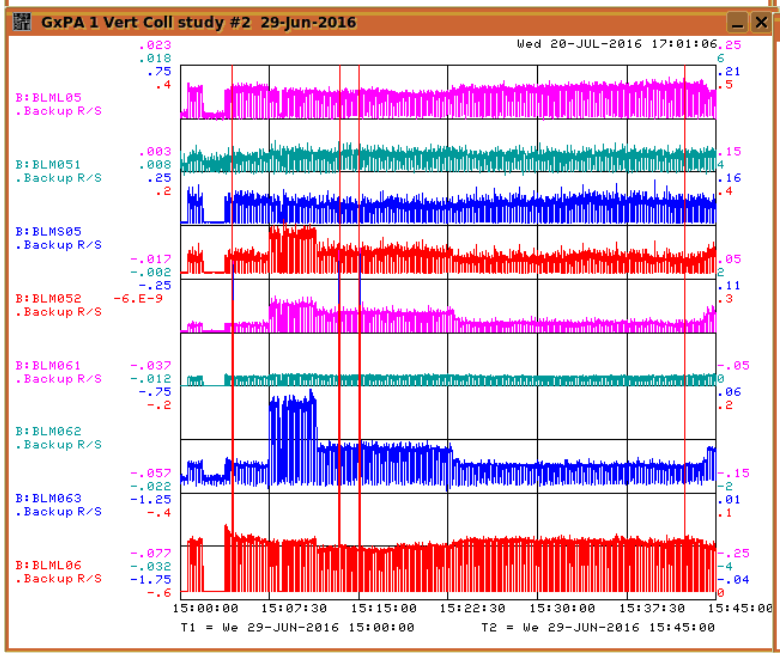


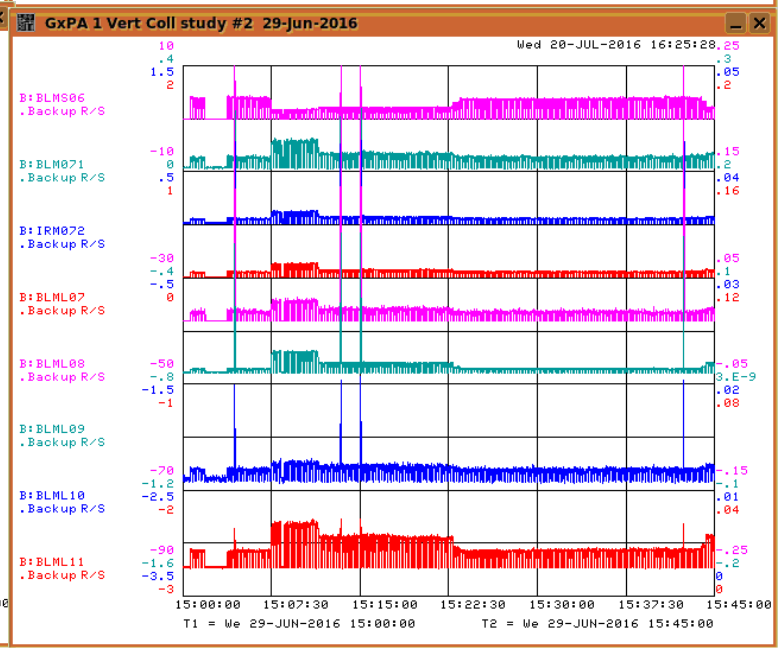
D44:

AL7AG1
AL6BG1

&
Coll. positions

BLMs
In D43
list:
L05,
051,
S05
052,
061
062
063
L06



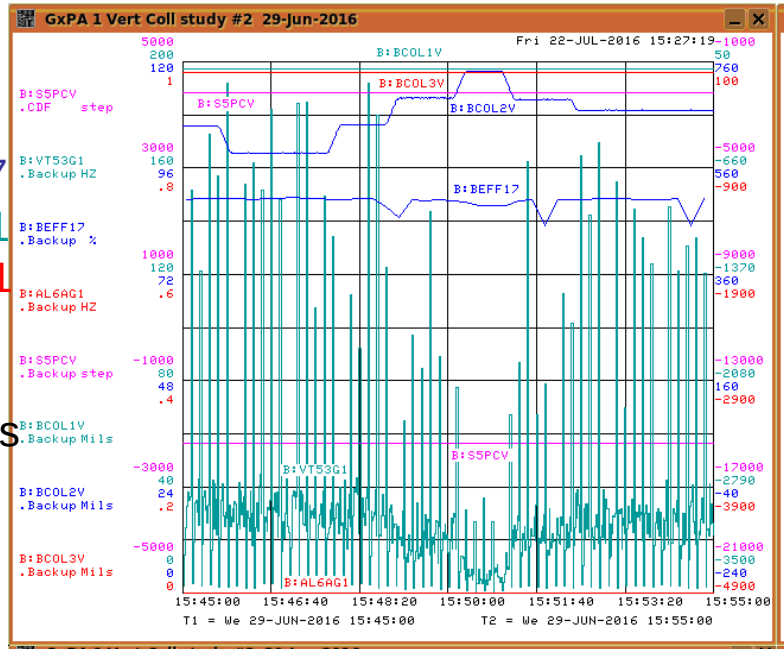


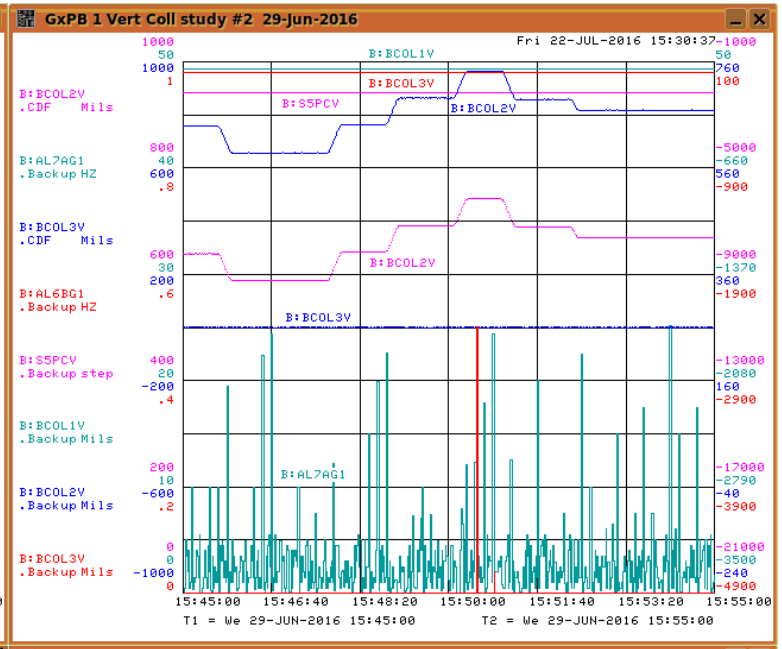
BLMs
In D43
list:
S06,
071,
072,
L07
L08
L09
L10
L11

Tuning Col2-L6B: “f”-interval (15:45-15:55)

D44:

BEFF17
VT53G1
AL6AG1
&
Coll. positions



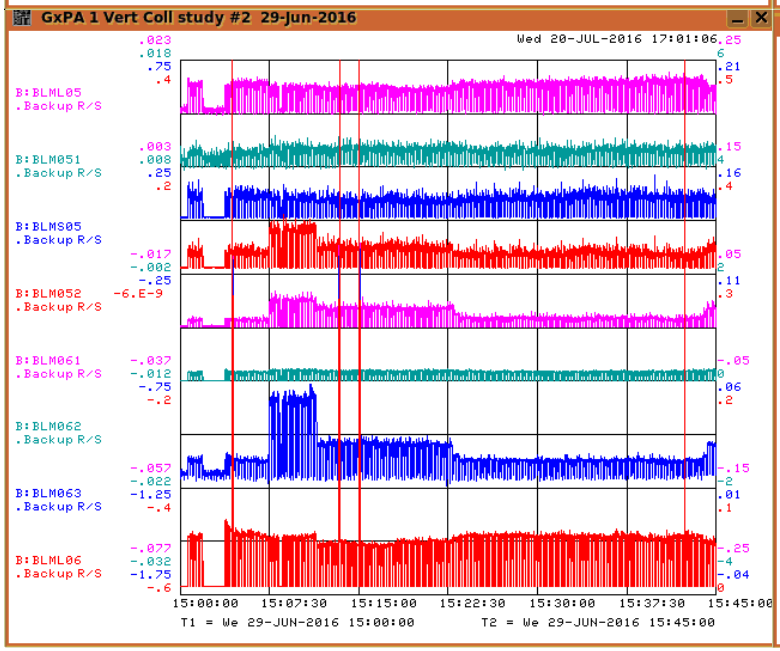


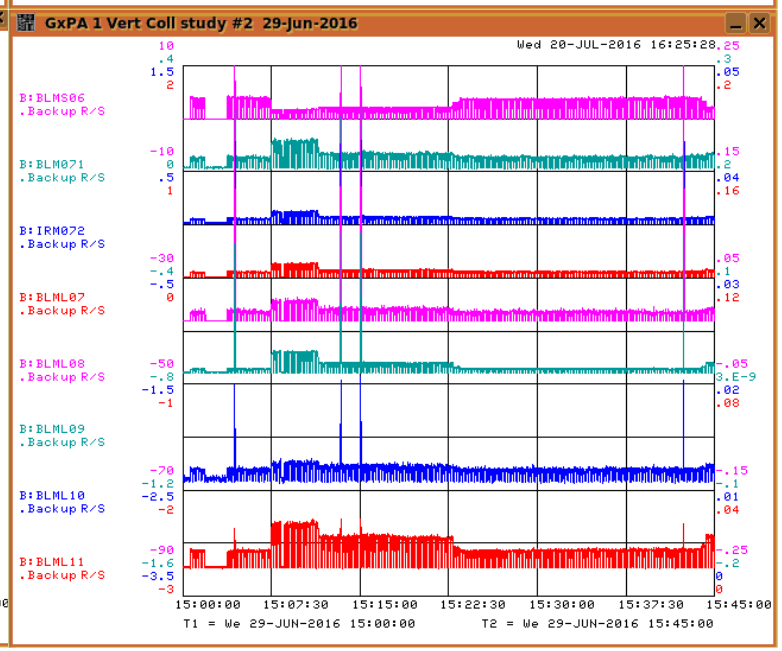
D44:

AL7AG1
AL6BG1

&
Coll. positions

BLMs
In D43
list:
L05,
051,
S05
052,
061
062
063
L06



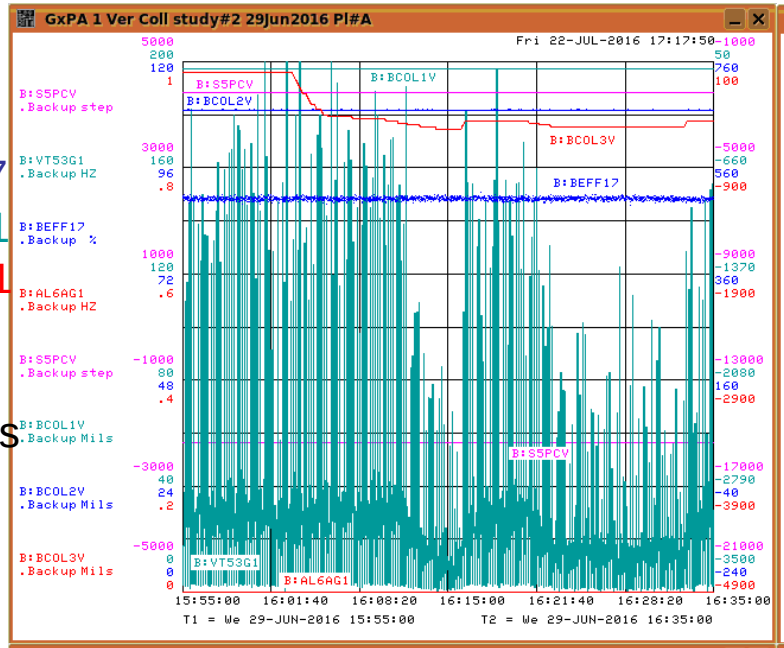


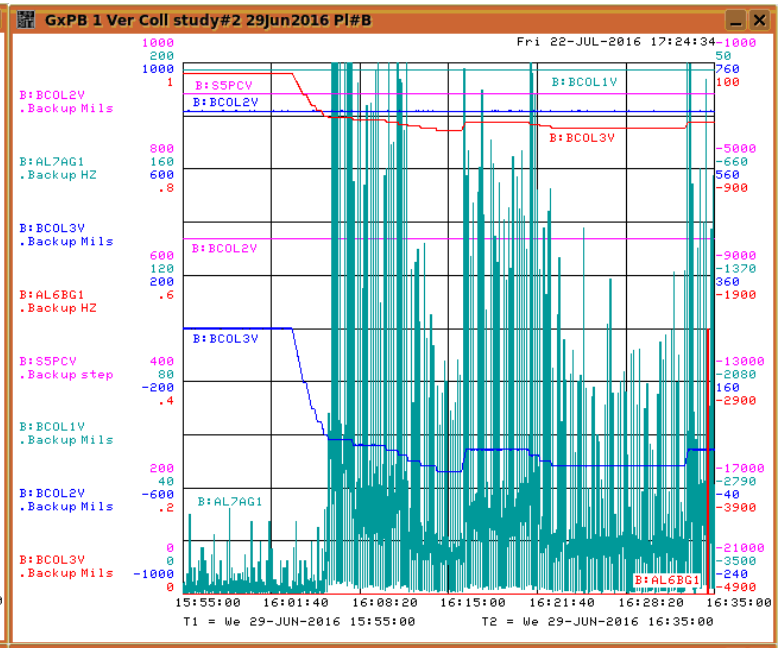
BLMs
In D43
list:
S06,
071,
072,
L07
L08
L09
L10
L11

Tuning Col3-L7A: “g”-interval (15:55-16:35)

D44:

BEFF17
VT53G1
AL6AG1
&
Coll. positions



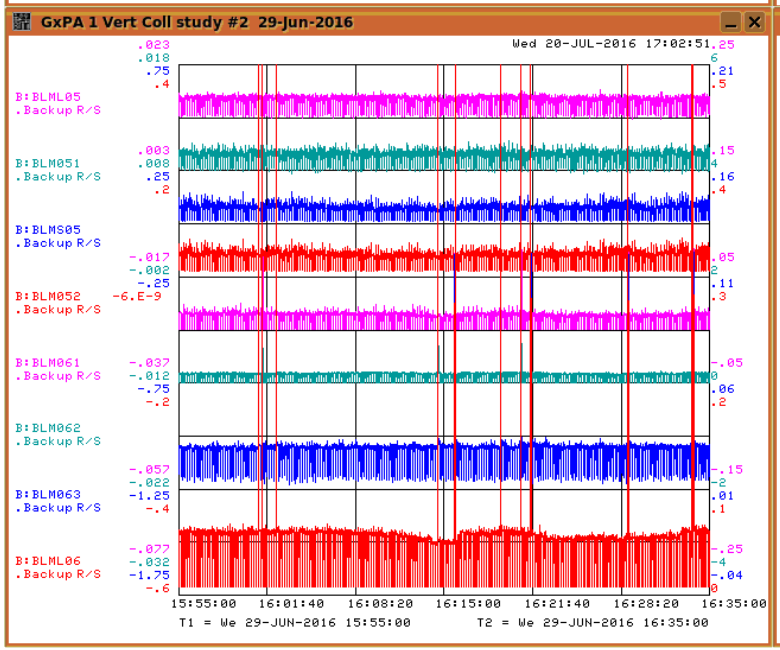


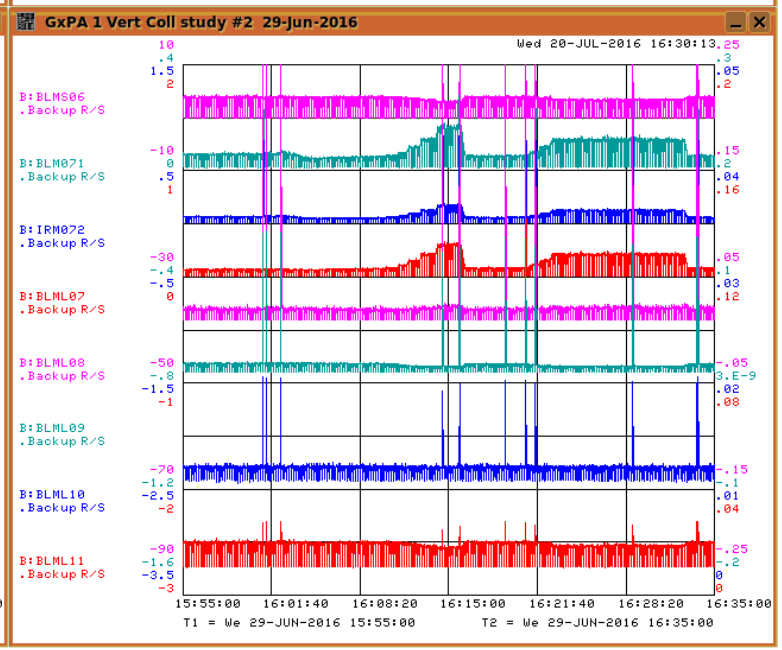
D44:

AL7AG1
AL6BG1

&
Coll. positions

BLMs
In D43
list:
L05,
051,
S05
052,
061
062
063
L06



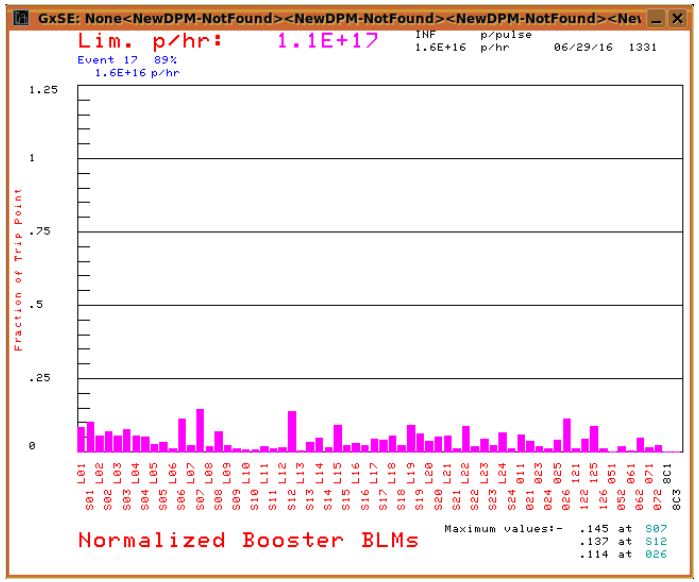


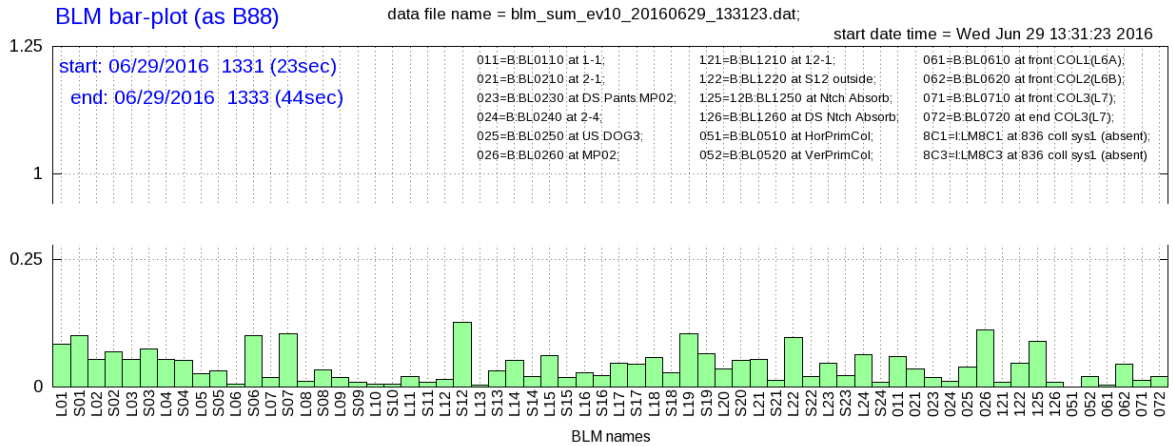
BLMs
In D43
list:
S06,
071,
072,
L07
L08
L09
L10
L11

Plot “Frac. trip point” B88

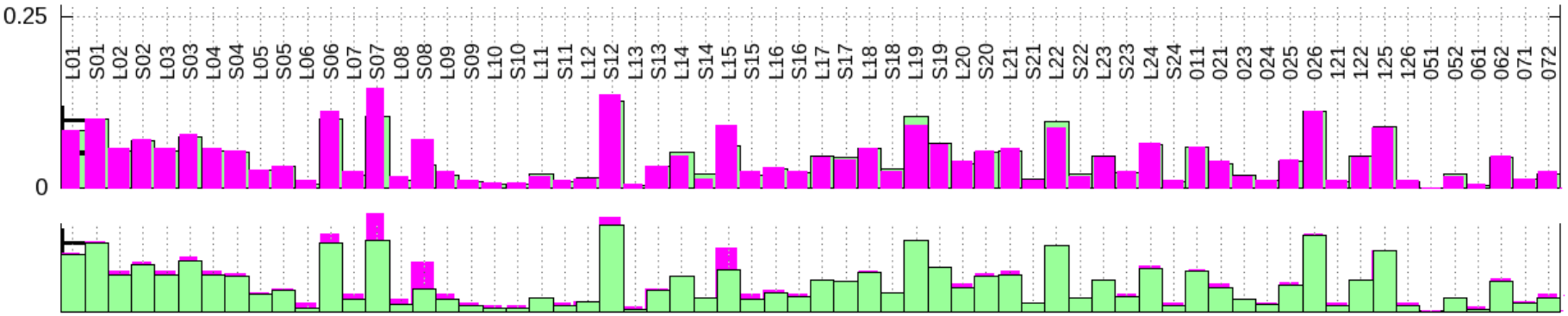
B88 Data export does not work => only “PrintScreen” (snapshots)
Data of B136 recommended by Kent

a’la “B88”: for **numerical comparisons** of loss-patterns I wrote code for linux. It reads BLM data to reproduce B88 plots (~1.5min)



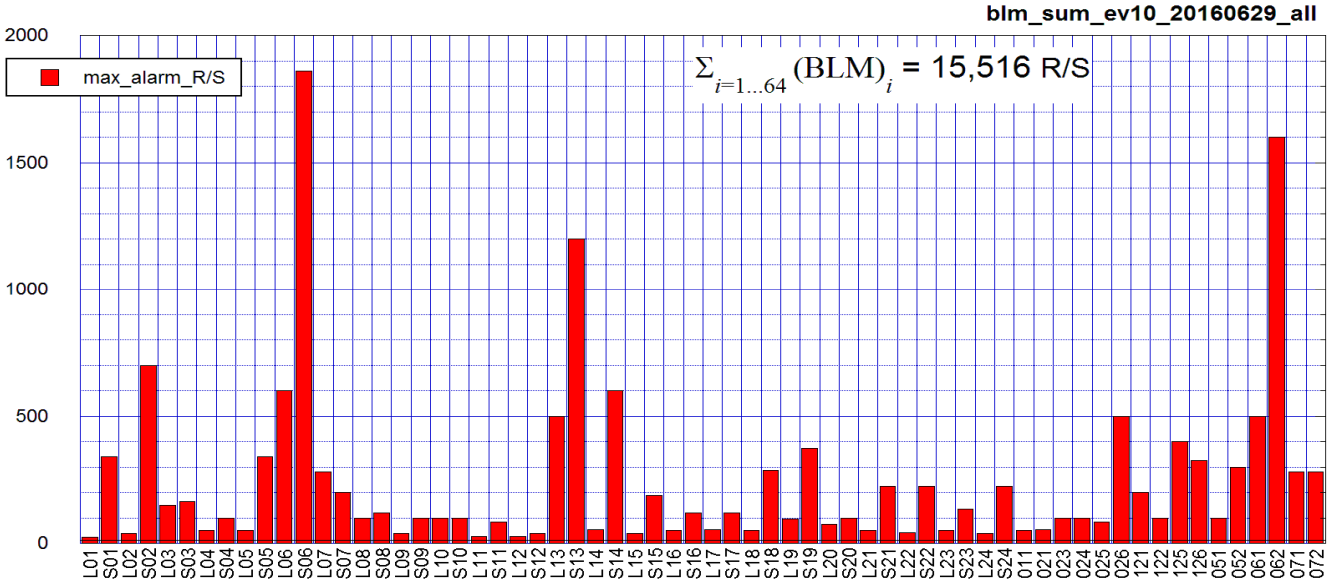


Check coincidence by overlapping:



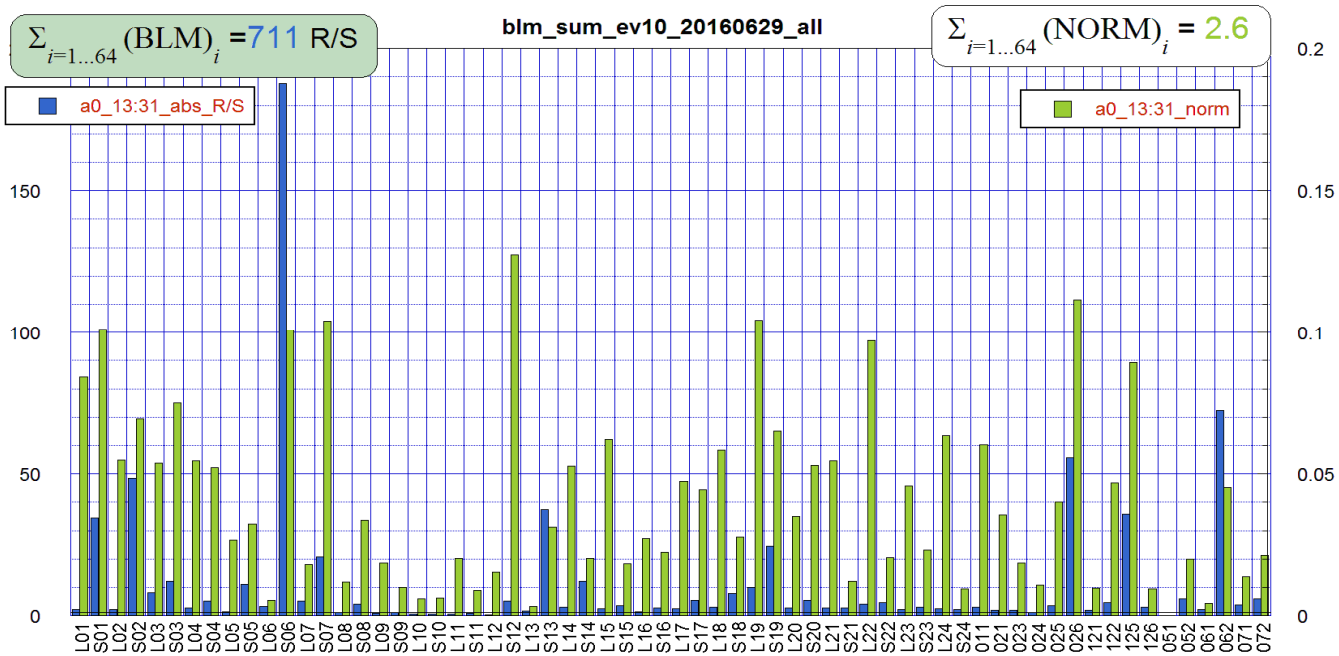
Data used to create “a’la B88” tripping plots

Absolute Alarm (trip) values

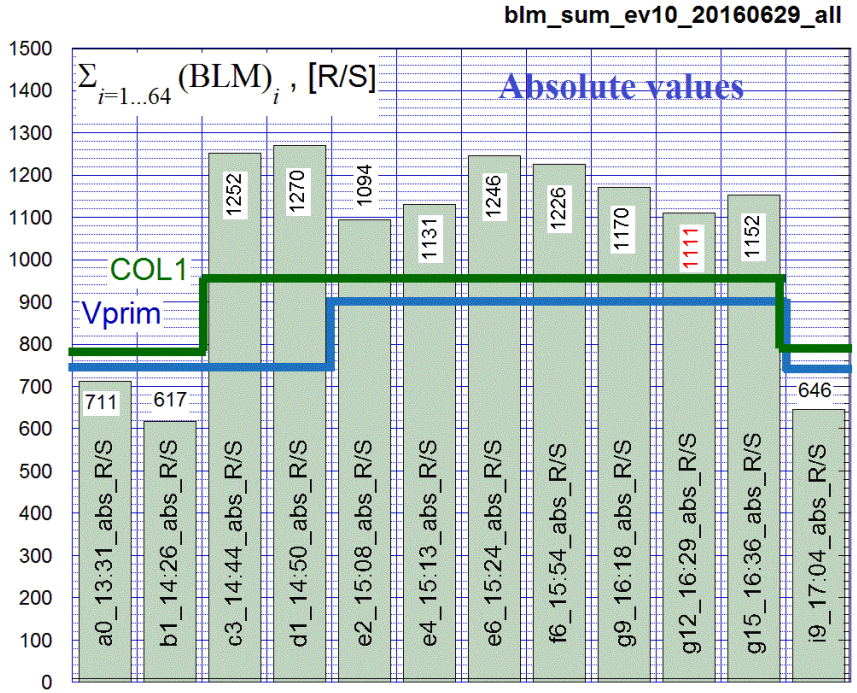


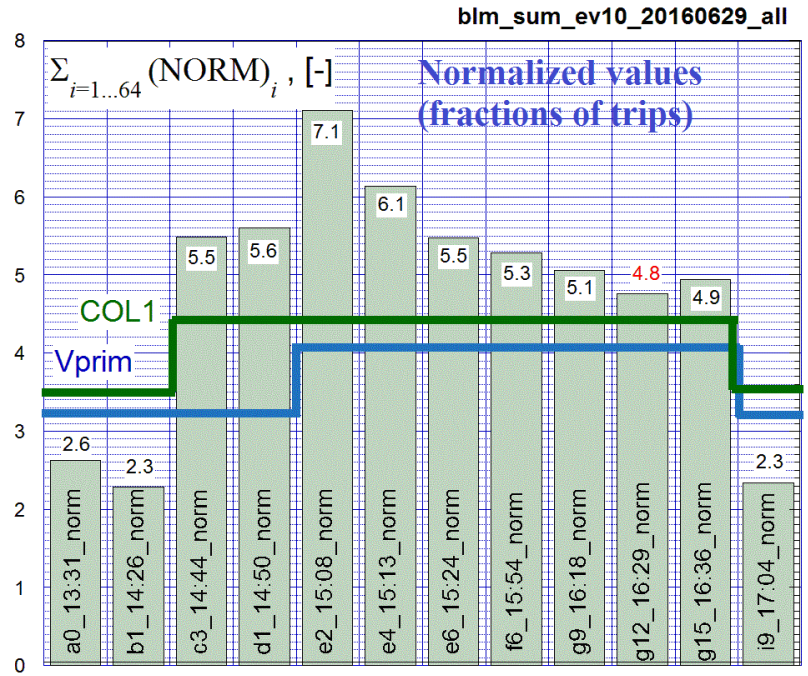
Distributions for absolute and normalized (fractions of trip) values looks very different

Sum of all (or part) Available !



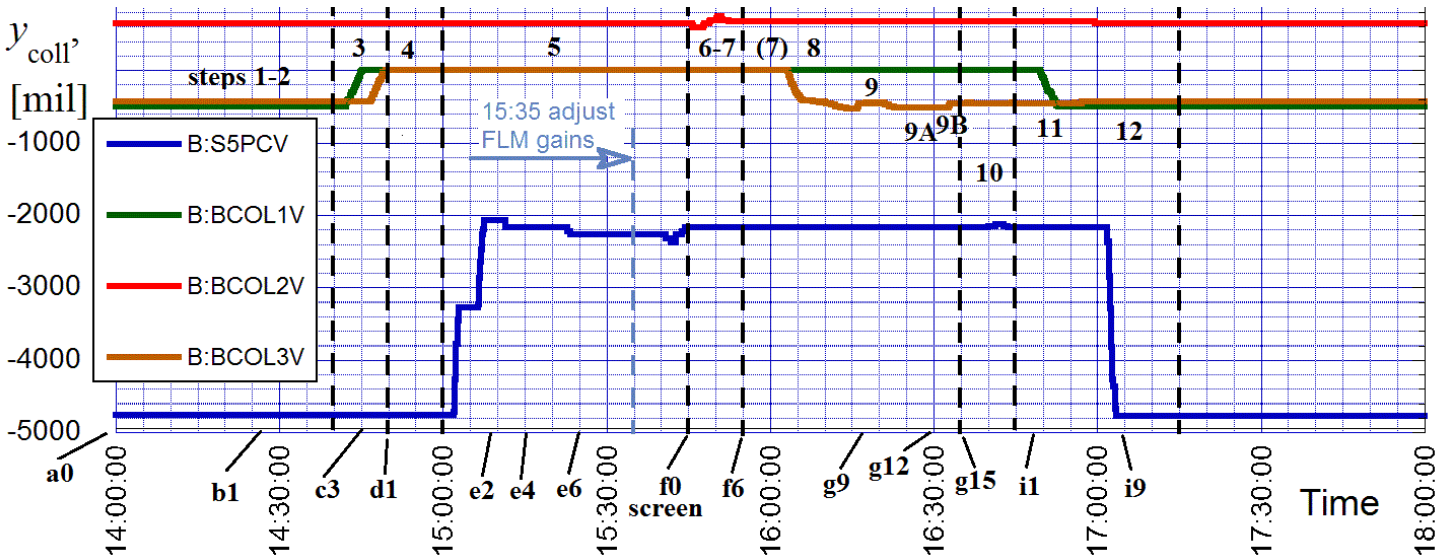
Loss distribution comparison





G12&b1: 1111/ 617 =1.8

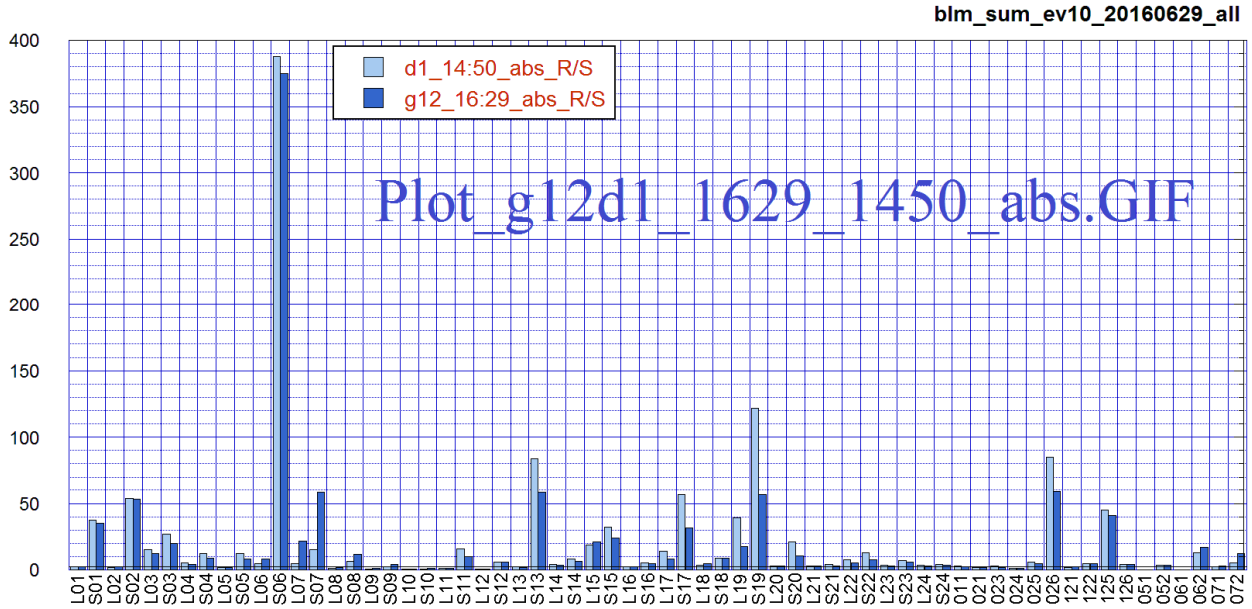
G12&d1: 1111/ 1270= 0.87

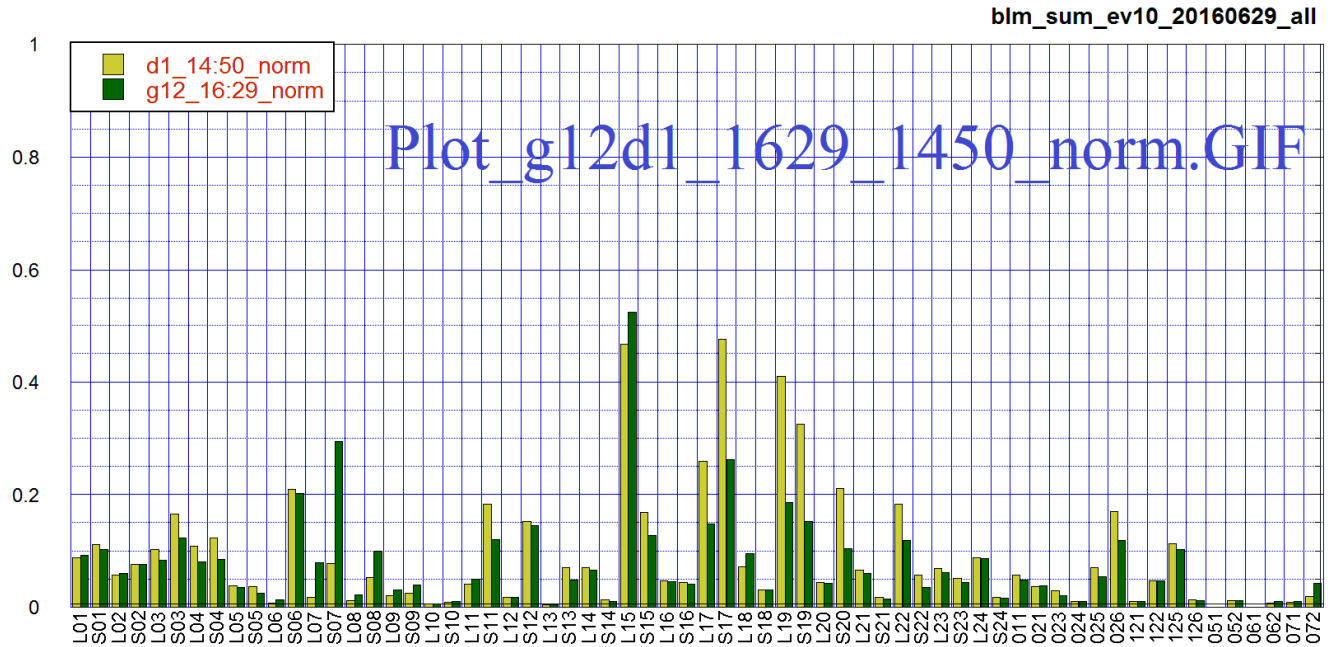


G12&b1: 4.8/2.3 =2.1

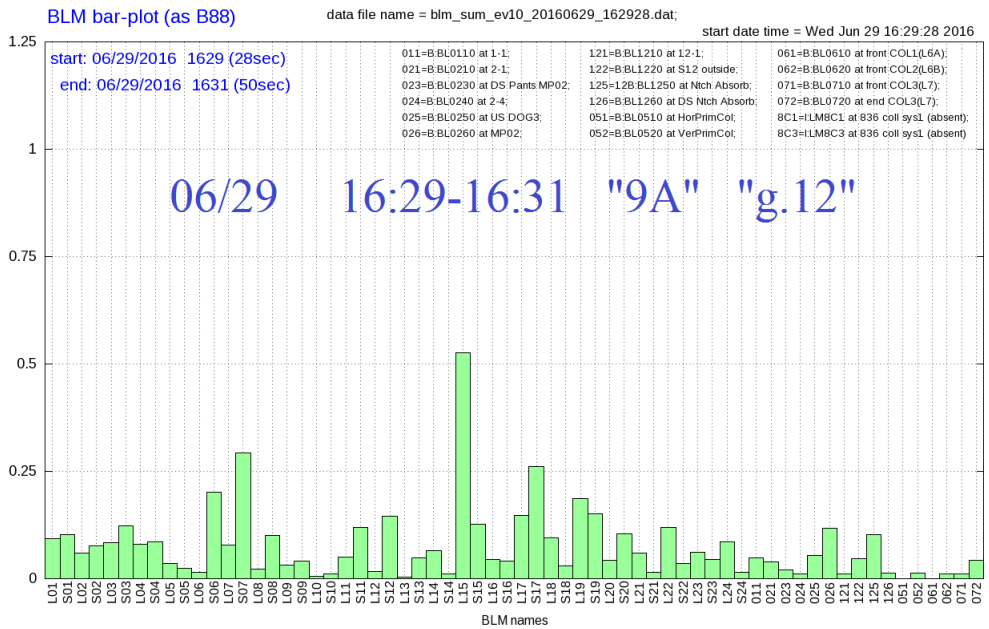
G12&d1: 4.8/5.6= 0.86

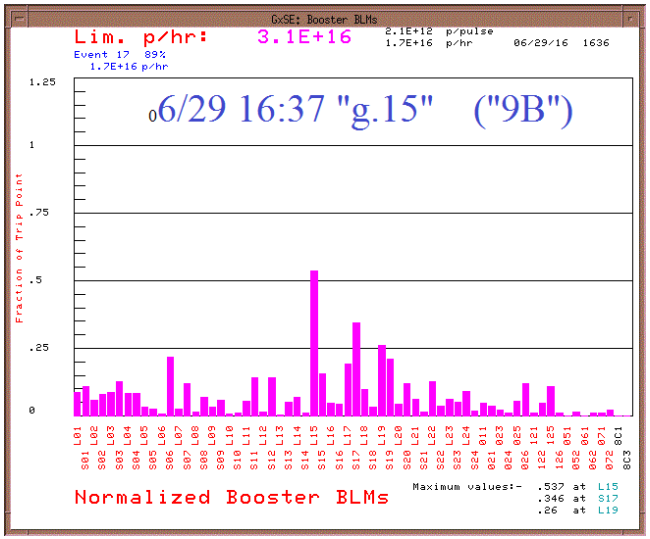
Plots for “local” optimization “g12 vs d1”

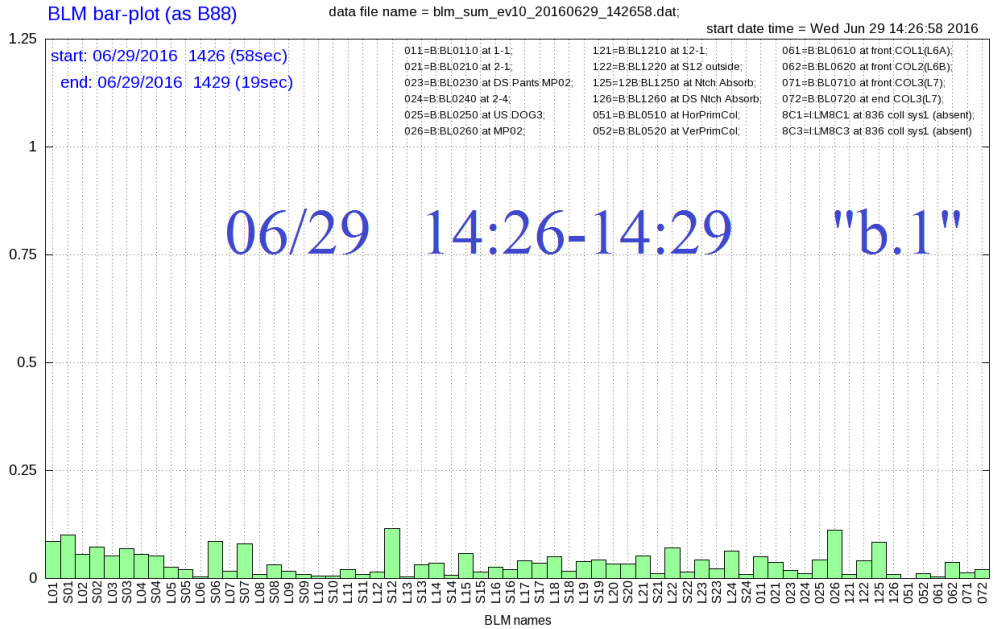


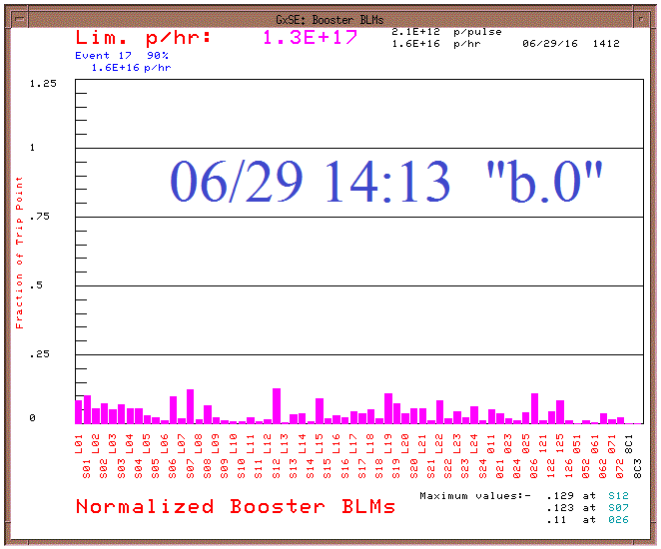


Comparison with initial "g12 vs b1"





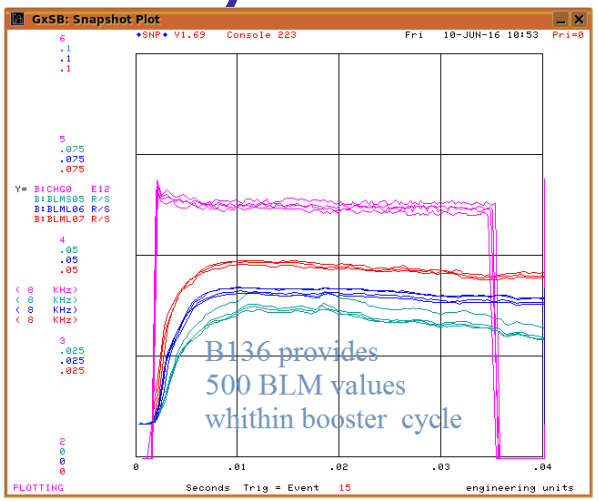


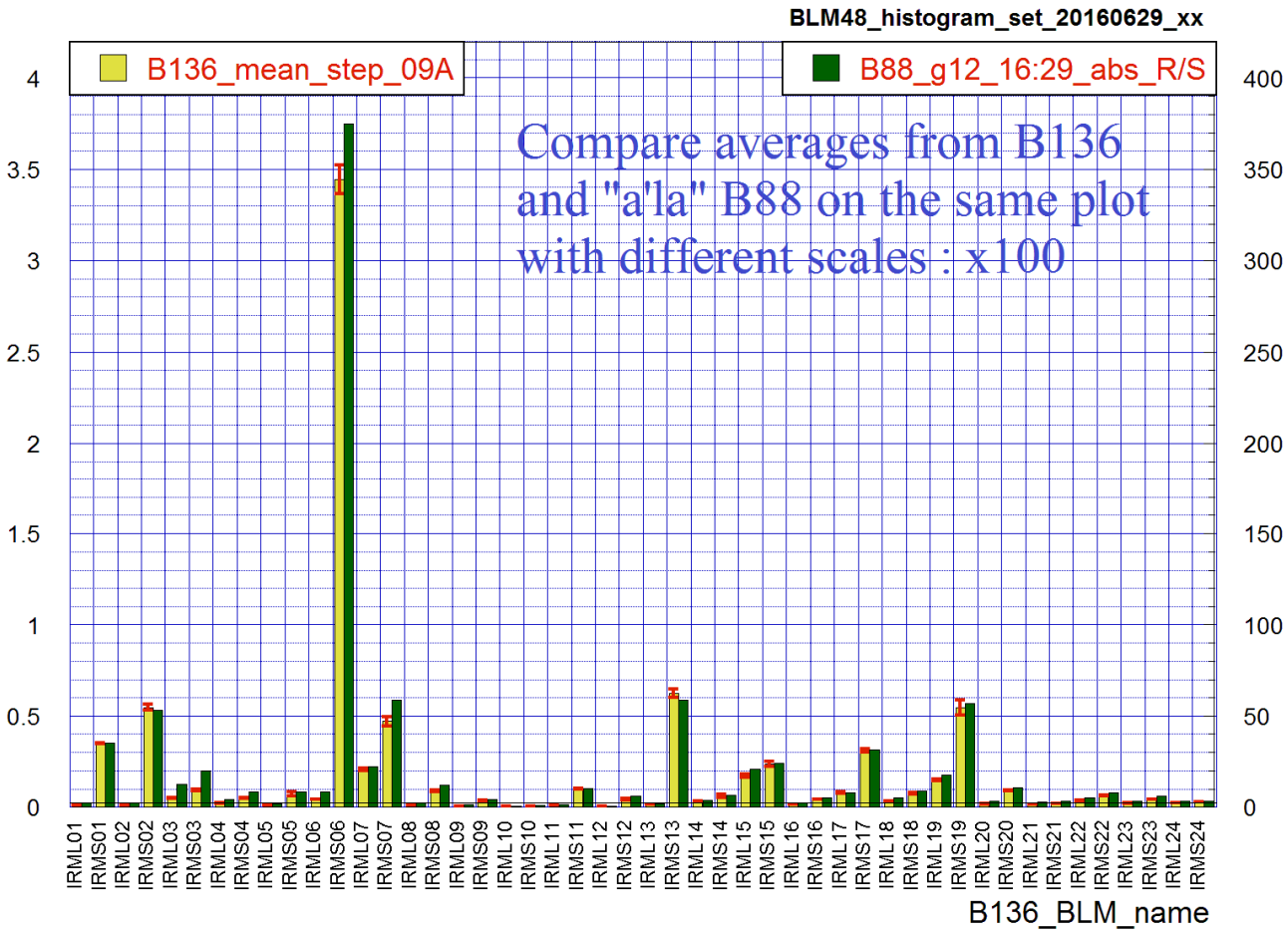


B136 BLMs signal within Boo-cycle

Save data => postproc. Code: check bad curves (see last presentation);

averaging over cycle => compare with “B88:-plots





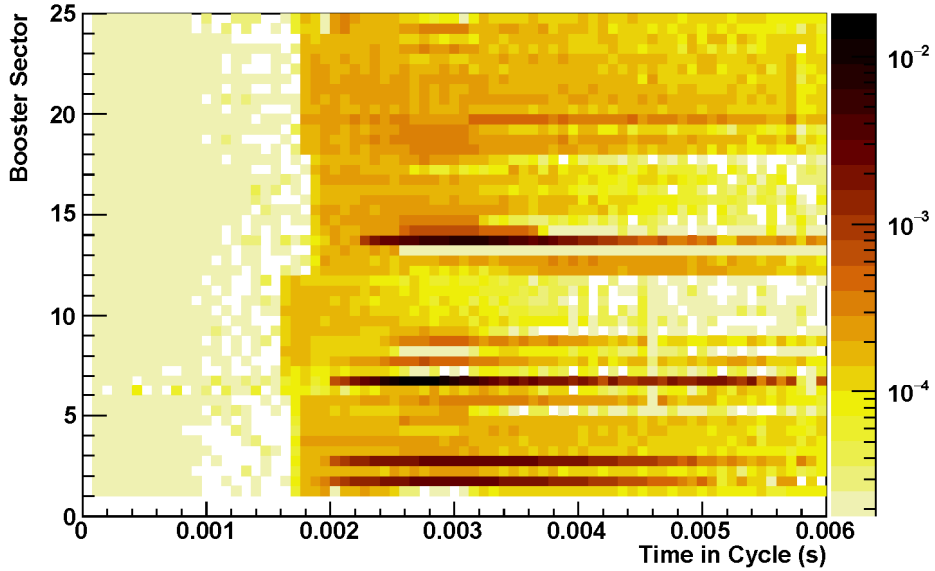
Very similar Results From B136 Averaging And “B88” plots

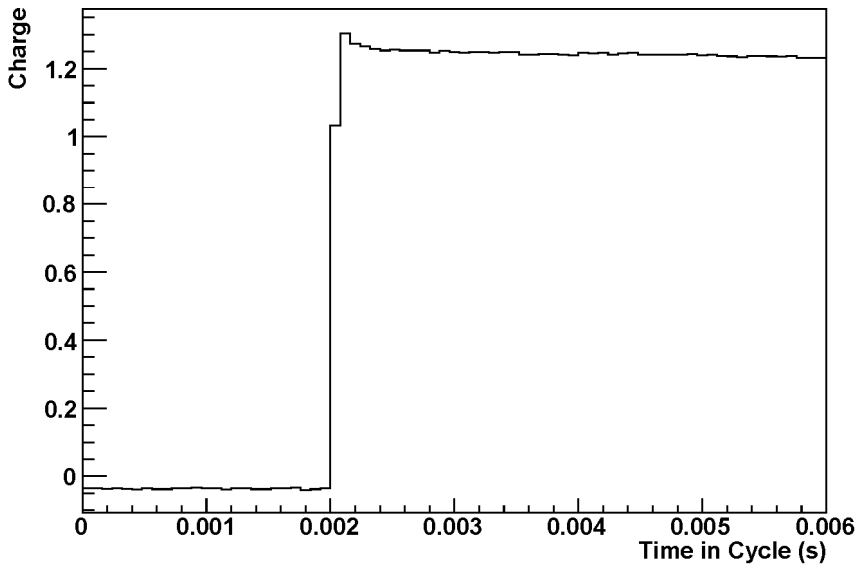
Conclusion

- Simulations: 2SC have ~ the same efficiency (max ~60%) as 1SC at halo 10um (55%)
- 1SC may have even larger actual efficiency (if halo higher)
- Present foil is still thicker of optimal one:
  change to Be-foil may help reach ~60% efficiency
- Preparing for beam study: all equipment ant & pos-proc code are ready for next studies
- 29-Jun study for Vert-plane demonstrated ~twice lower efficiency for 2SC vs 1SC
- Another study for V-plane can be done if “L6A<->L6B”
- Study for Hor-plane should be also schedule
- Analytical & simulation study to understand low efficiency of existing 2SC and suggestion of new collimation are planned to start

Additional slides

BLM data: “initial conditions” zoomed at injection





“initial conditions” = a standard collimator settings for 1-stage.

The top plot are the instantaneous losses (diff. between consecutive readings: R(i) - R(i-1)).

The bottom plot shows the beam current.

Some Issues:

1. The BLMs data are not timed relative to one another at about the 300us level (see backup slide).

It appears that there are two groups (sectors 1-12 and 13-24)

2. Loss information from specific BLMs looks strange (see top plot).

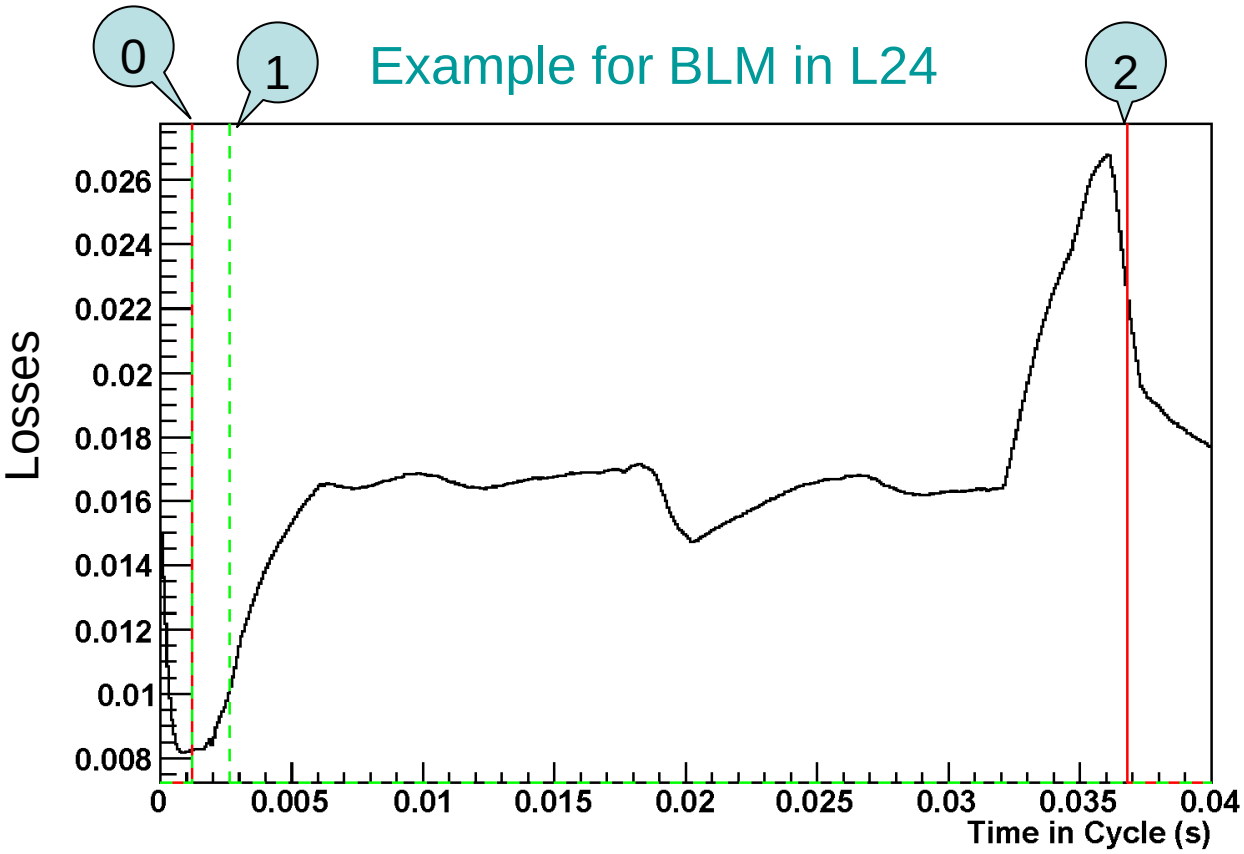
3. The beam current has a “negative pedestal” (see bottom plot).

BLM post-processing: definitions

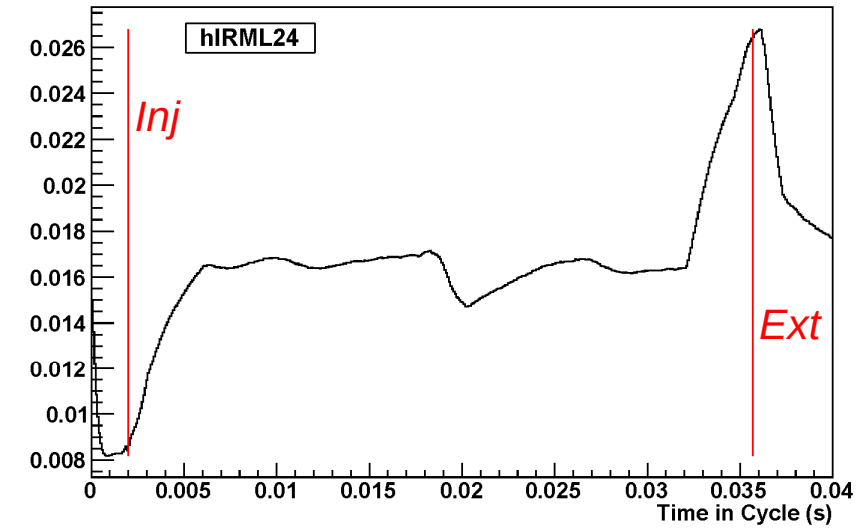
Booster Loss profiles (losses vs BLM number)

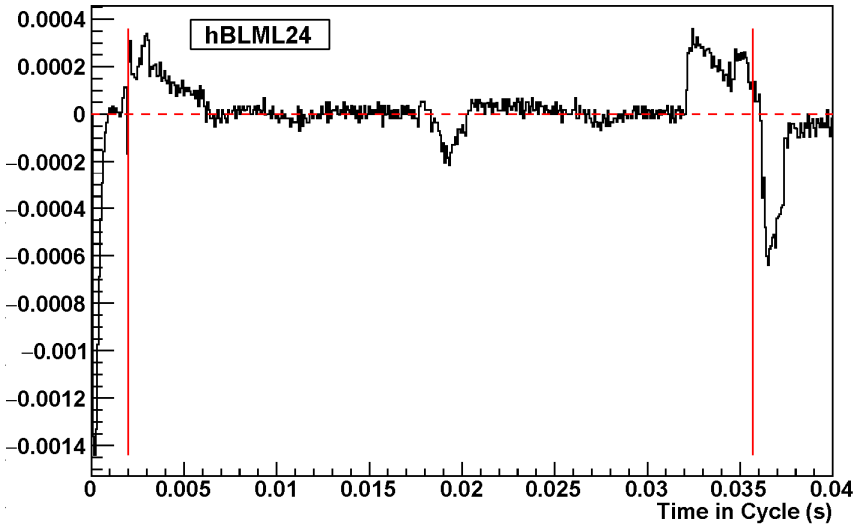
Inj. Losses = Loss(1) –Loss(0)

Tot. Losses = Loss(2) –Loss(0)



Example: BLM in L24



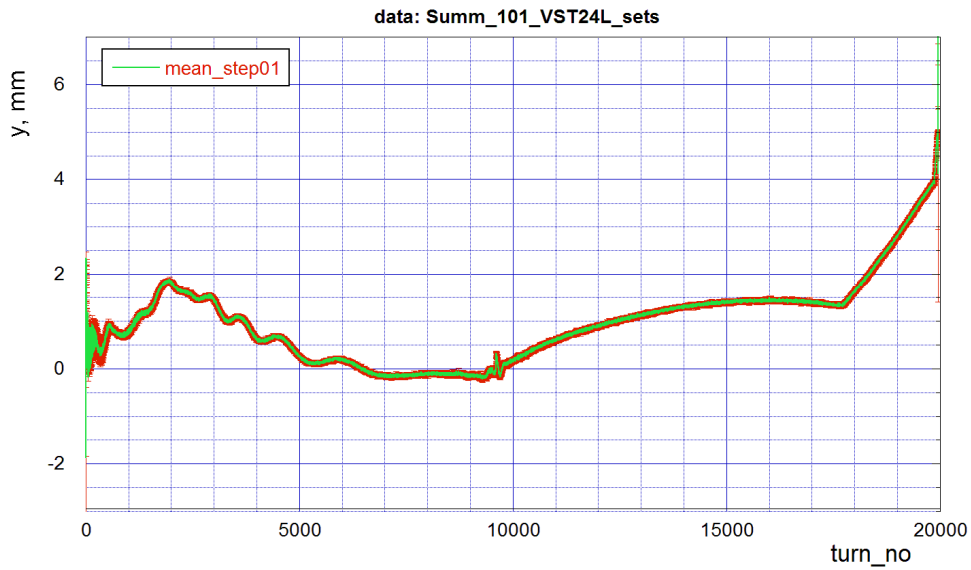


Integrated losses (top) and instantaneous losses (bottom).

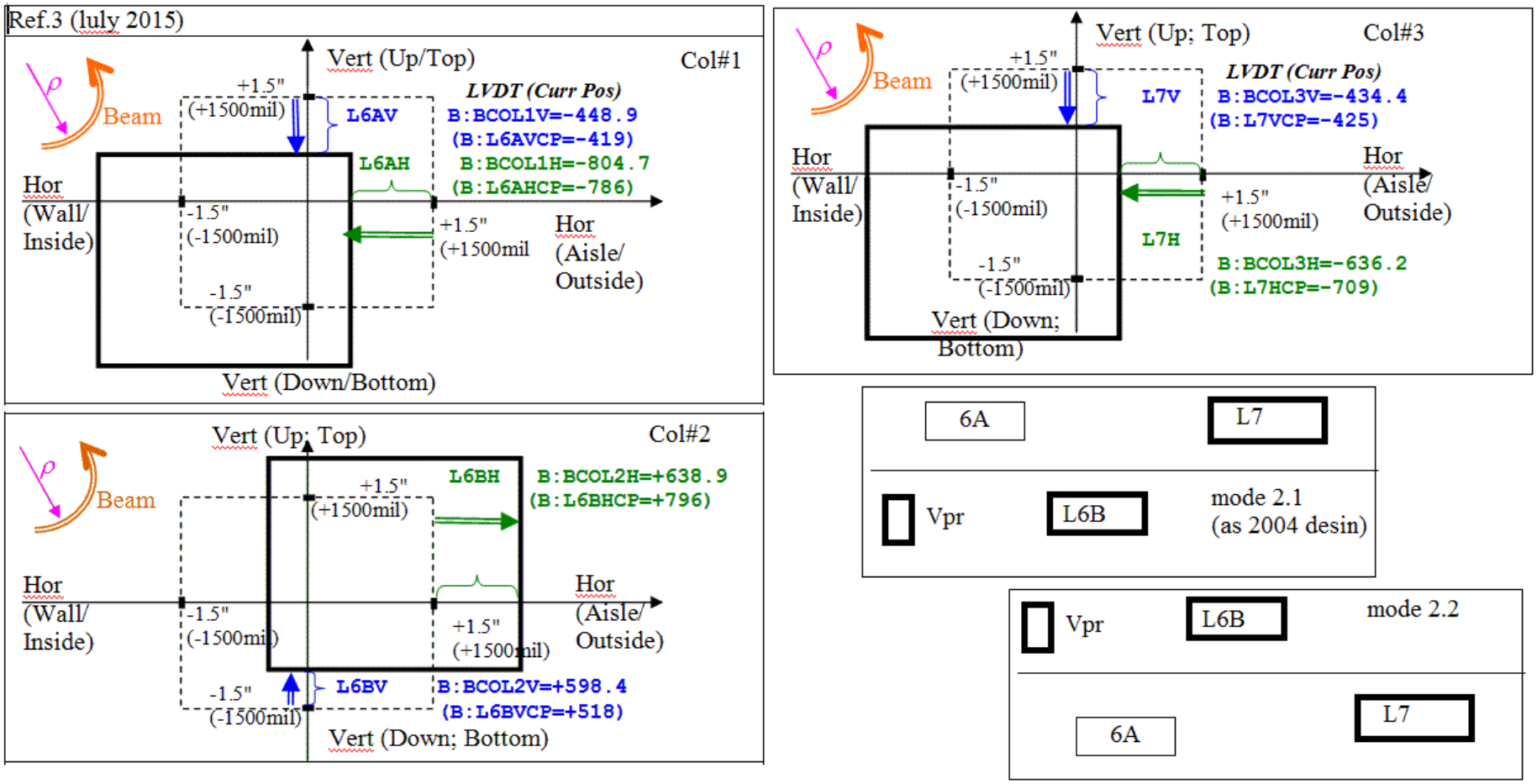
Red lines: injection & extraction

Issues:
fast drops of integrated losses
Negative values of differential (instantaneous) losses

Vert. orbit in L24



Connection Coll LVDT & modes



Principle scheme of 2-stage collimation system

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

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

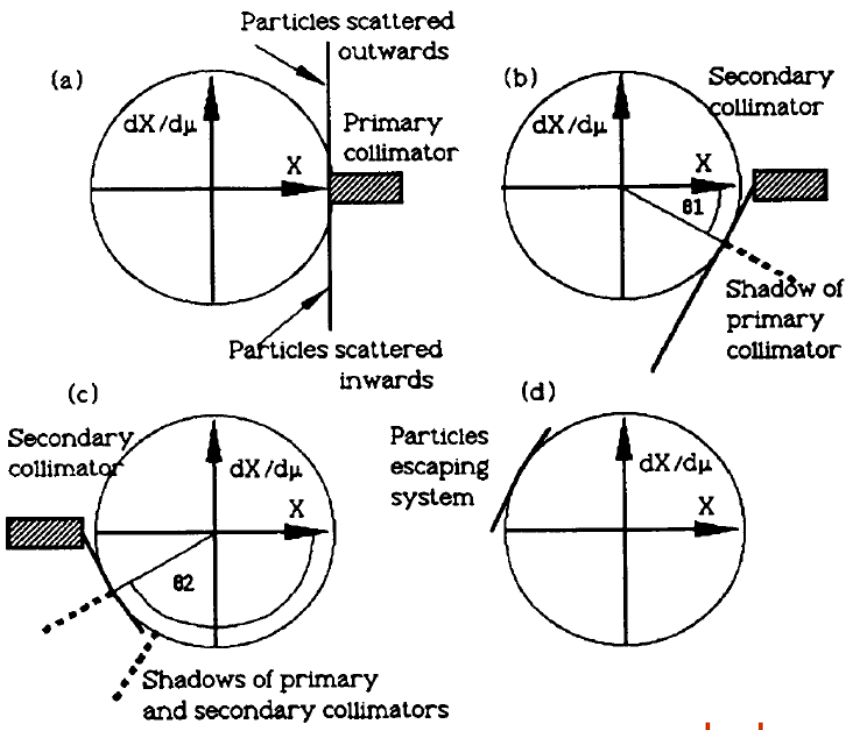


Fig. 11 Main features of a collimation system

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

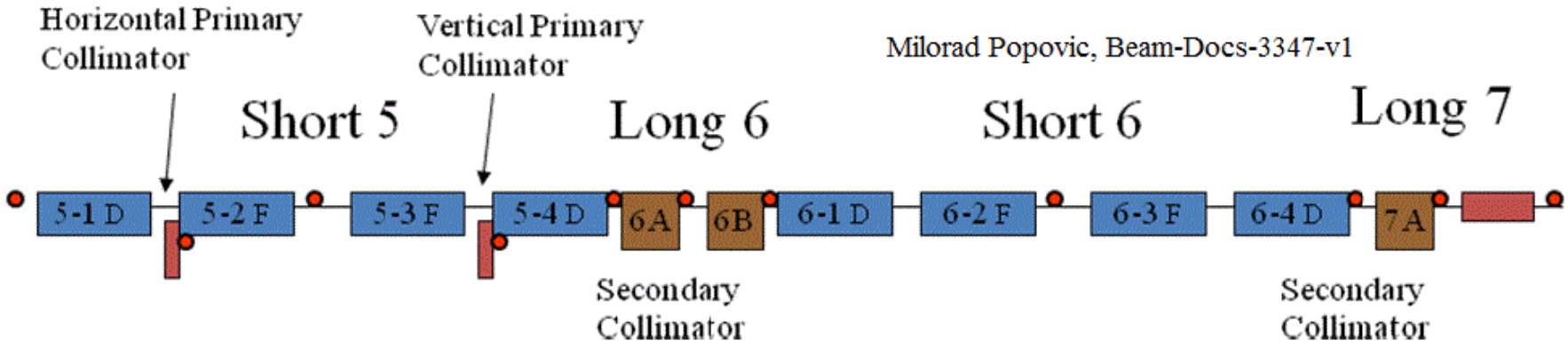
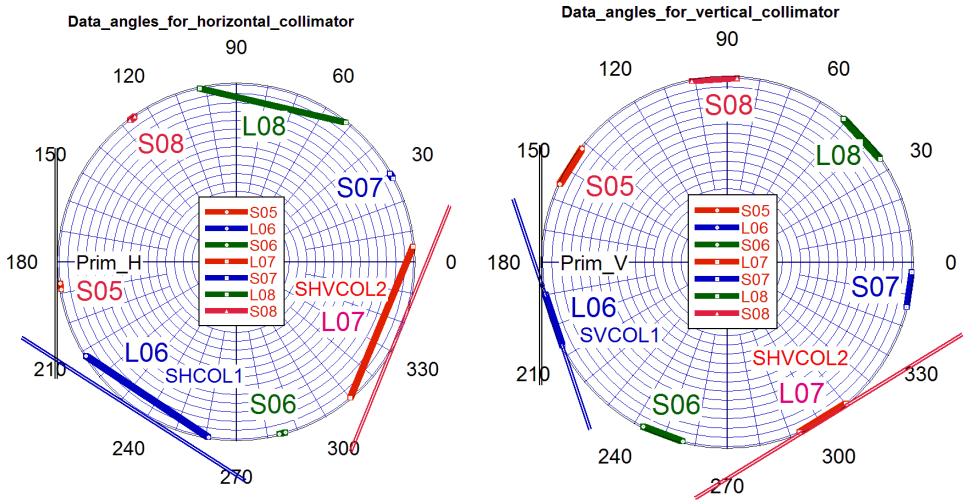


Figure 1. Blue boxes represent the main magnets; collimators are represented by brown boxes.



Restrictions for design:
Not optimal phase advances;
Small magnet apertures;
Bending magnets in coll system;
Variable beam parameters during accelerator cycle