CNGS Proton Beam Commissioning

1. Proton beam line
2. Beam commissioning preparation
3. Results from commissioning

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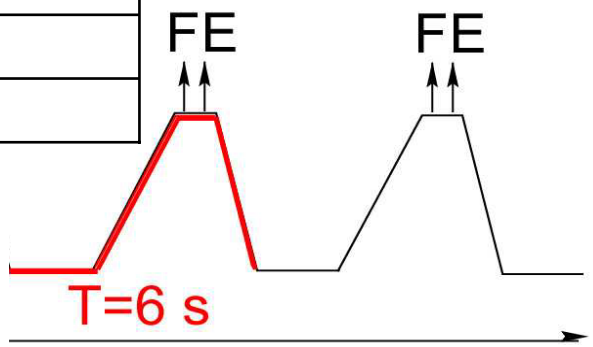
for CNGS commissioning team

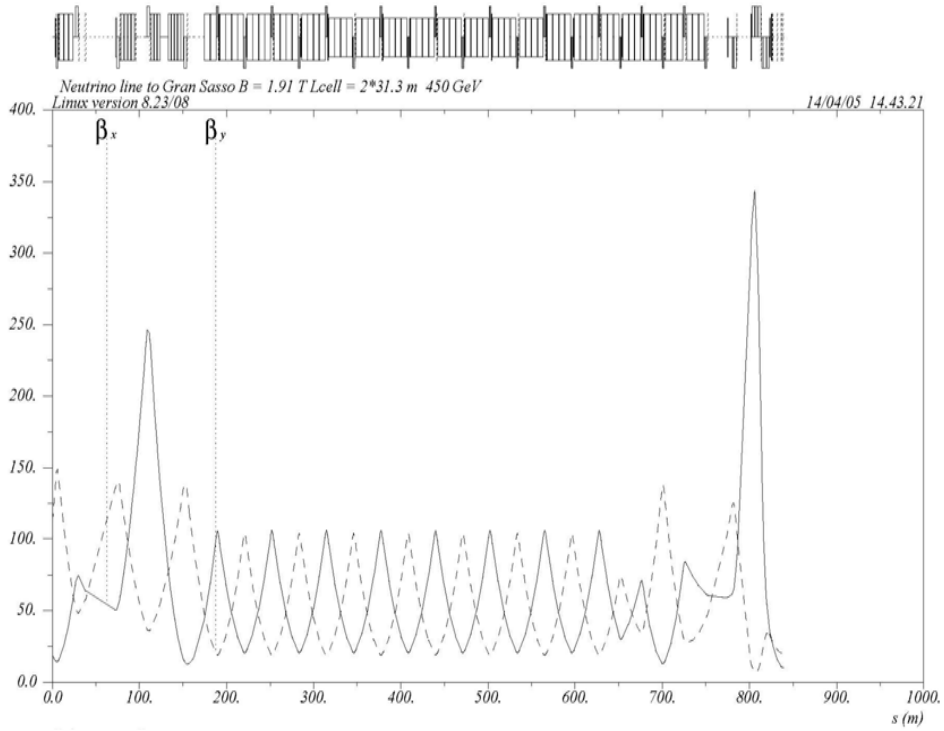
1. Proton beam line

Beam parameters	Nominal CNGS beam
Nominal energy [GeV]	400
Normalized emittance [μm]	H=12 V=7
Emittance [μm]	H=0.028 V= 0.016
Momentum spread Δp/p	0.07 % +/- 20%
# extractions per cycle	2 separated by 50 ms
Batch length [μs]	10.5
# of bunches per pulse	2100
Intensity per extraction [10^{13} p]	2.4
Bunch length [ns] (4σ)	2
Bunch spacing [ns]	5
Beta at focus [m]	hor.: 10 ; ver.: 20
Beam sizes at 400 GeV [mm]	0.5 mm
Beam divergence [mrad]	hor.: 0.05; ver.: 0.03

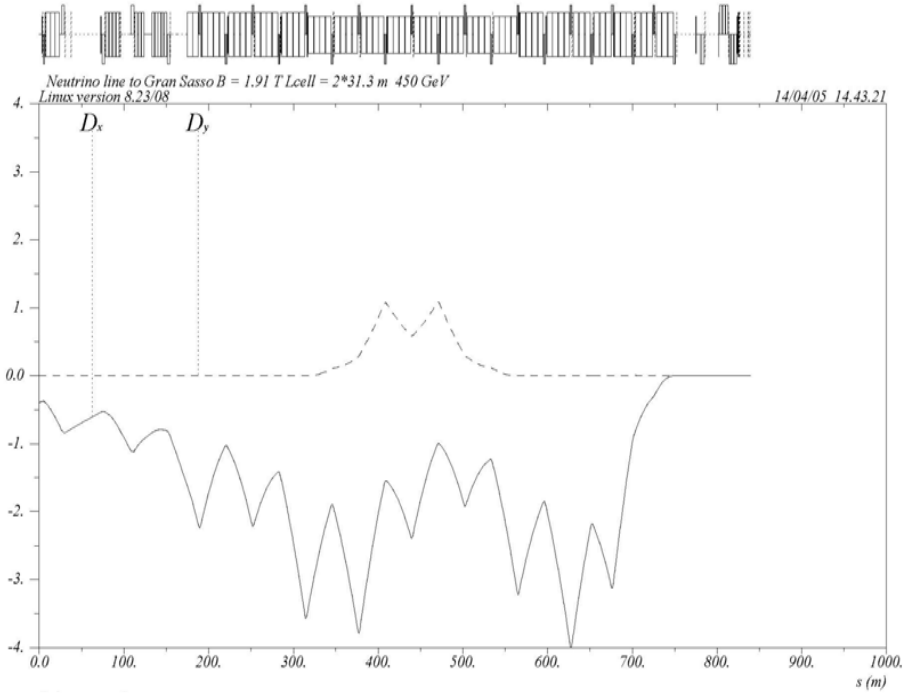
Upgrade phase: 3.5 10^{13} p



Optics at Target



Beta functions



Dispersion

New transfer line magnets

MBG 73 magnets (78 ordered)

Nominal field : 1.7 T @ 400 GeV

Magnetic length : 6.3 m

Gap height 37 mm

QTG 20 magnets (23 ordered)

Magnetic aperture : 45 mm

Nominal gradient 40 T/m, 2.2 m

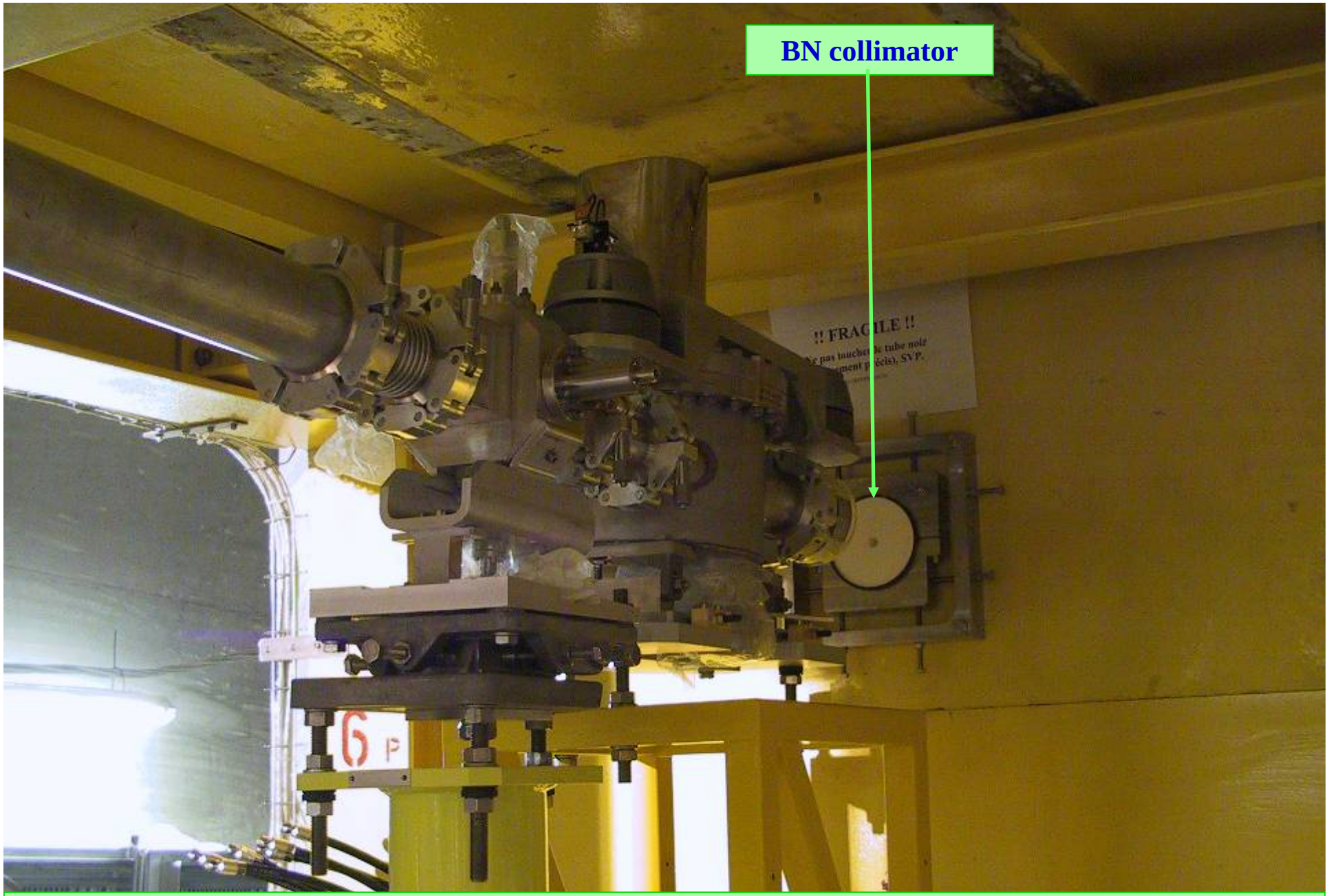
MDG 12 magnets (17 ordered)

Gap height : 45 mm

Bending angle 80 µrad

Overall length: 700mm

Final focusing onto the target (recuperated magnets)



Proton beam: last beam position / beam profile monitors upstream of the target station collimator and shielding

2. Commissioning plans

CNGS COMMISSIONING GOALS			
GOAL	**PARAMETERS**	**Beam instrumentation**	**Commissioning Goal**
1	Proton beam parameters on target	Proton beam intensity monitor BFCT412425	Intensity : 2.4 E13 per extraction or maximum available from injectors
		Proton beam profile monitor BTVG412445	Beam sizes : 0.45 mm < $\sigma_{x,y}$ < 0.7 mm for nominal target unit
		Proton beam position monitor at BPKG412449	Proton beam position stability better than +/- 0.5 mm (upper value)
2	Proton beam direction on target	Proton beam positon monitors BPG412424 and BPG412444	Proton beam direction established within better than 0.2mr of the known direction to Gran Sasso detectors
3	Proton beam position along TT41	Proton beam positon monitors along TT41	Trajectory excursion less than +/- 4 mm
5	Muon detector parameters	Muon monitors in TNM41 and TNM42	Intensity per proton and Profile within xx% (TBA by SBWG) of simulated values
6	Proton beam losses	Beam loss monitors	No more than 1E-3 at extraction. None along TT41 beam line
7	Proton beam tails	Proton beam profile monitors	tbd

Plans for week 28

	Intensity per extraction	Extractions #	Intensity per 18 s cycle	duration [hours]	Total protons	Period	TED	Target	Horn	Reflector
commissioning low intensity on TED	2.00E+11	1	2.00E+11	6	2.40E+14	week 22 DAY1	IN	OUT	OFF	OFF
commissioning low intensity on TED	2.00E+11	2	4.00E+11	1	8.00E+13	week 22 DAY1	IN	OUT	OFF	OFF
commissioning low intensity TT41	2.00E+11	1	2.00E+11	8	3.20E+14	week 22 DAY2	OUT	OUT	OFF	OFF
commissioning low intensity TT41	2.00E+11	1	2.00E+11	8	3.20E+14	week 22 DAY3	OUT	OUT	OFF	OFF
commissioning low intensity TT41	2.00E+11	2	4.00E+11	2	1.60E+14	week 22 DAY3	OUT	OUT	OFF	OFF
commissioning secondary beam	2.00E+11	1	2.00E+11	8	3.20E+14	week 22 DAY4	OUT	IN	OFF	OFF
commissioning secondary beam	2.00E+11	2	4.00E+11	2	1.60E+14	week 22 DAY4	OUT	IN	OFF	OFF
commissioning secondary beam	2.00E+11	1	2.00E+11	8	3.20E+14	week 22 DAY5	OUT	IN	ON/OFF	ON/OFF
commissioning secondary beam	2.00E+11	2	4.00E+11	2	1.60E+14	week 22 DAY5	OUT	IN	ON/OFF	ON/OFF
commissioning low intensity on TED	1.00E+12	1	1.00E+12	1	2.00E+14	week 22 DAY5	IN	IN	OFF	OFF
commissioning low intensity on TED	1.00E+12	2	2.00E+12	0.25	1.00E+14	week 22 DAY5	IN	IN	OFF	OFF
re-establish low intensity TT41 + secondary beam	1.00E+12	1	1.00E+12	2	4.00E+14	week 22 DAY5	IN	IN	OFF	OFF

Upper limit of total protons sets to 2 10^{16} for week 28

Plans for week 30

	Intensity per extraction	Extractions #	Intensity per 18 s cycle	duration [hours]	Total protons	Period	TED	Target	Horn	Reflector
re-establish low intensity on TED	1.00E+12	1	1.00E+12	0.5	1.00E+14	week 25 DAY1	IN	IN	OFF	OFF
re-establish low intensity on TED	1.00E+12	2	2.00E+12	0.5	2.00E+14	week 25 DAY1	IN	IN	OFF	OFF
re-establish low intensity TT41 + secondary beam	1.00E+12	1	1.00E+12	4	8.00E+14	week 25 DAY1	OUT	IN	ON	ON
more beam studies at low intensity TT41 + secondary beam	1.00E+12	1	1.00E+12	8	1.60E+15	week 25 DAY2	OUT	IN	ON	ON
re-establish low intensity TT41 + secondary beam	1.00E+12	2	2.00E+12	1	4.00E+14	week 25 DAY2	OUT	IN	ON	ON
commissioning medium intensity on TED	6.00E+12	1	6.00E+12	2	2.40E+15	week 25 DAY3	IN	IN	OFF	OFF
commissioning medium intensity on TED	6.00E+12	2	1.20E+13	0.5	1.20E+15	week 25 DAY3	IN	IN	OFF	OFF
commissioning medium intensity TT41+ secondary beam	6.00E+12	1	6.00E+12	8	9.60E+15	week 22 DAY3	OUT	IN	ON/OFF	ON/OFF
commissioning medium intensity TT41 + secondary beam	6.00E+12	2	1.20E+13	5	1.20E+16	week 25 DAY4	OUT	IN	ON/OFF	ON/OFF

Upper limit of total protons sets to 3 10^{16} for week 30

Plans for week 33

	Intensity per extraction	Extractions #	Intensity per 18 s cycle	duration [hours]	Total protons	Period	TED	Target	Horn	Reflector
re-establish low intensity on TED	1.00E+12	1	1.00E+12	0.5	1.00E+14	week 27 DAY1	IN	IN	OFF	OFF
re-establish low intensity on TED	1.00E+12	2	2.00E+12	0.25	1.00E+14	week 27 DAY1	IN	IN	OFF	OFF
re-establish / run low intensity TT41 + secondary beam	1.00E+12	1	1.00E+12	8	1.60E+15	week 27 DAY1	OUT	IN	ON	ON
re-establish medium intensity on TED	6.00E+12	1	6.00E+12	0.25	3.00E+14	week 27 DAY2	IN	IN	OFF	OFF
re-establish / run medium intensity TT41 + secondary beam	6.00E+12	1	6.00E+12	6	7.20E+15	week 27 DAY2	OUT	IN	ON	ON
commissioning high intensity on TED	1.00E+13	1	1.00E+13	1	2.00E+15	week 27 DAY2	IN	IN	OFF	OFF
commissioning high intensity on TED	1.00E+13	2	2.00E+13	0.5	2.00E+15	week 27 DAY2	IN	IN	OFF	OFF
commissioning high intensity in TT41 + secondary beam	1.00E+13	1	1.00E+13	6	1.20E+16	week 27 DAY3	OUT	IN	ON	ON
commissioning and runhigh intensity in TT41 + secondary beam	1.00E+13	2	2.00E+13	6	2.40E+16	week 27 DAY4	OUT	IN	ON	ON

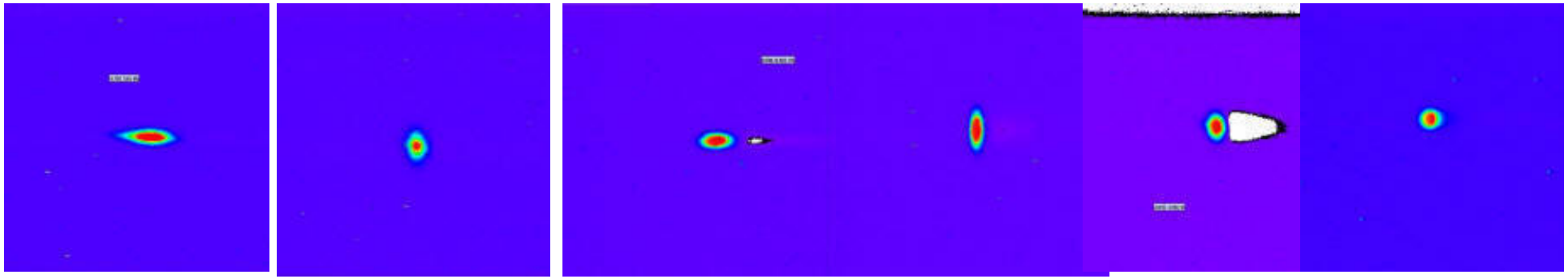
Upper limit of total protons sets to 5 10^{16} for week 33

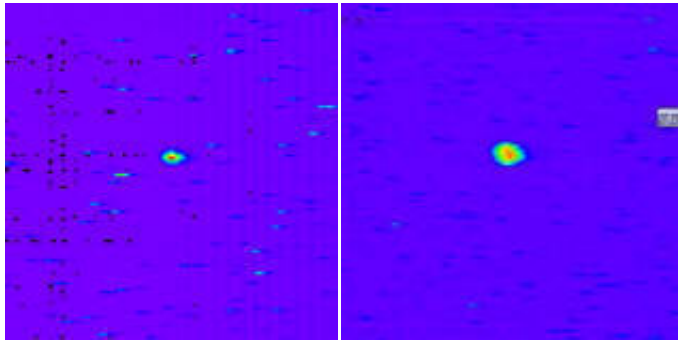
3. Commissioning results

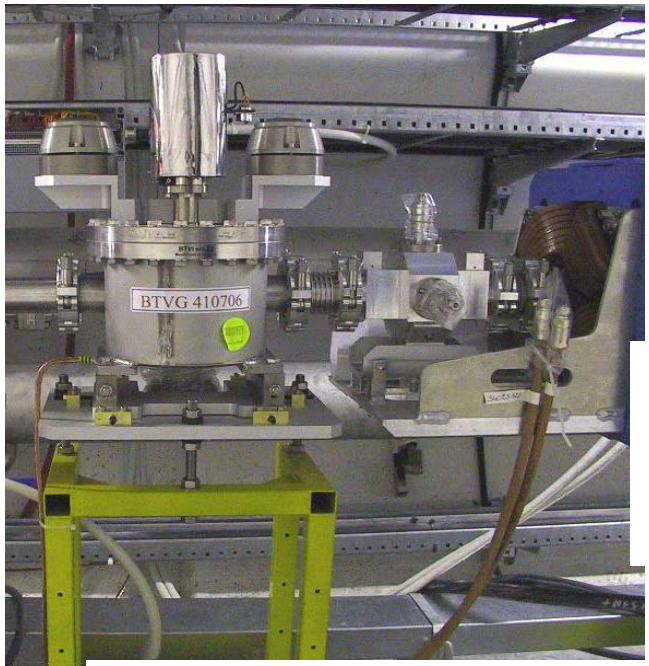
Importance of complete Hardware commissioning and dry runs
(like if beam but without beam)

Proton beam line screens

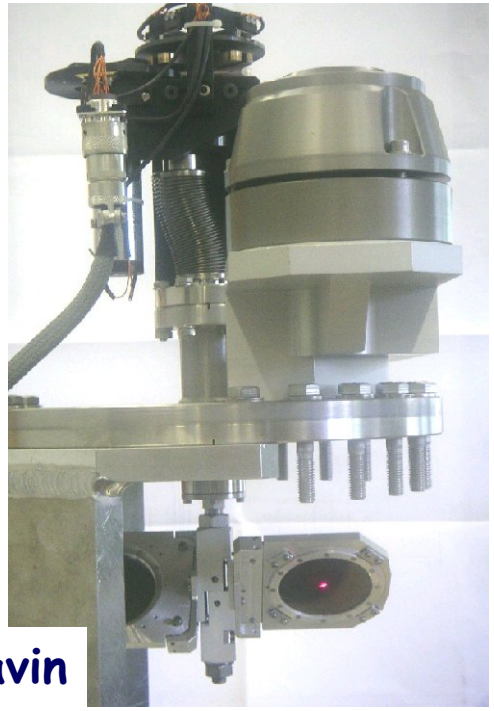
1st shot down proton beam line: beam is already well centered on screens





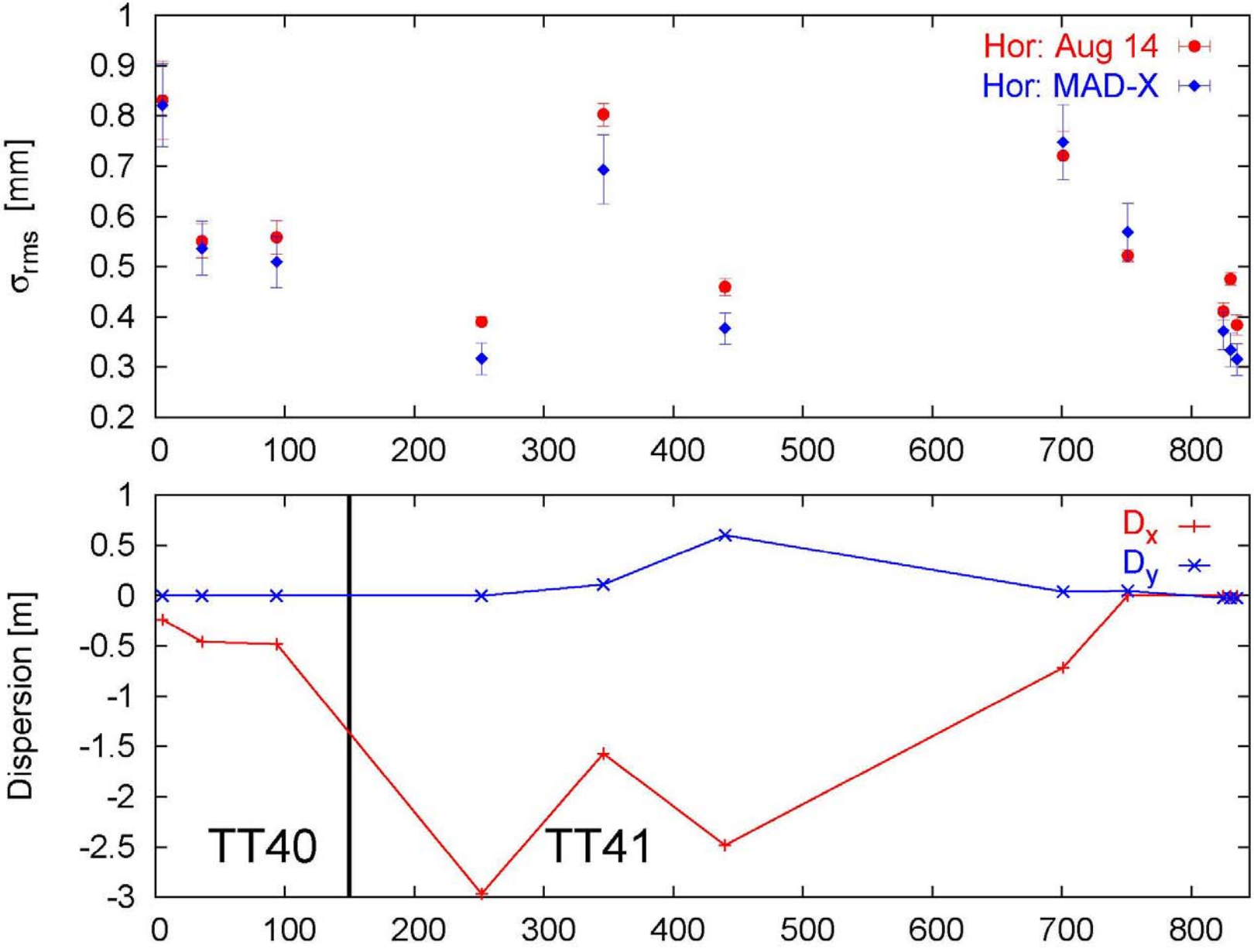


8 profile monitors
Optical Transition Radiation screens:
75 μm carbon
12 μm titanium screens



performance of all profile monitors discussed by E. Bravin

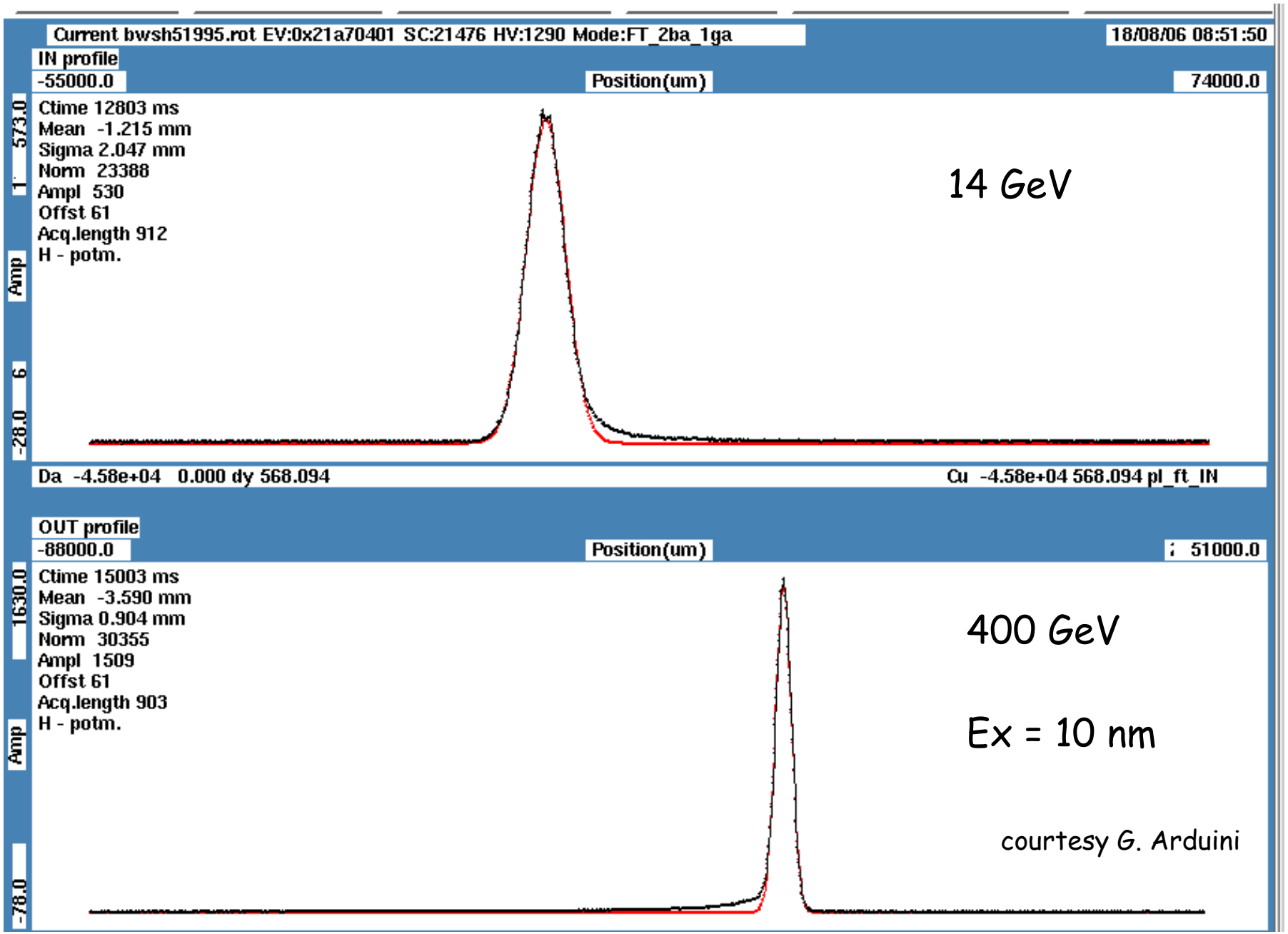
Beam sizes checks along transfer line: example of H plane



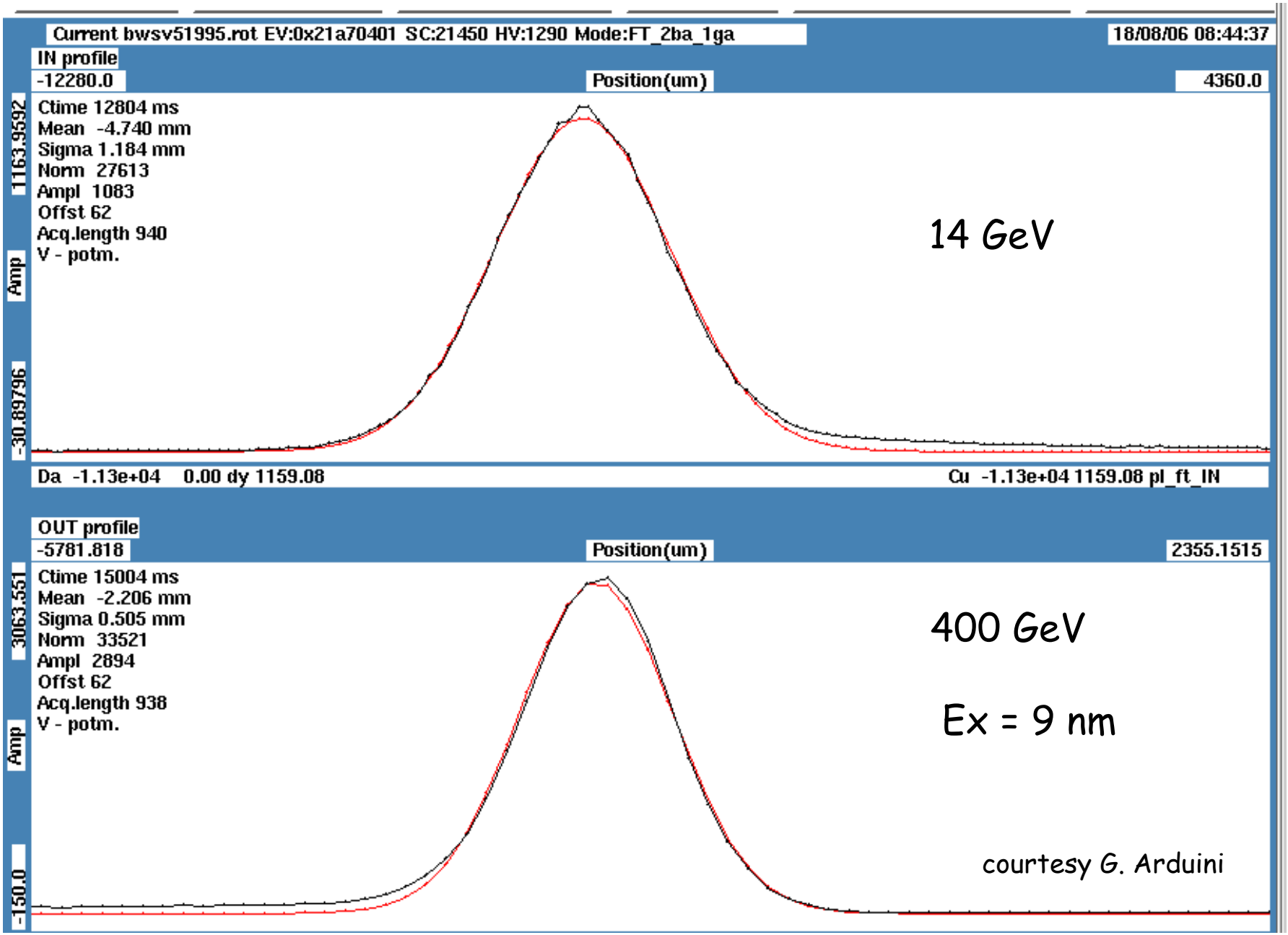
Further discussed by E. Bravin

courtesy R. Calaga – T. Pieloni

Emittance measurement, 1.E13 protons per extraction, H plane



Emittance measurement, 1.E13 protons per extraction, V plane

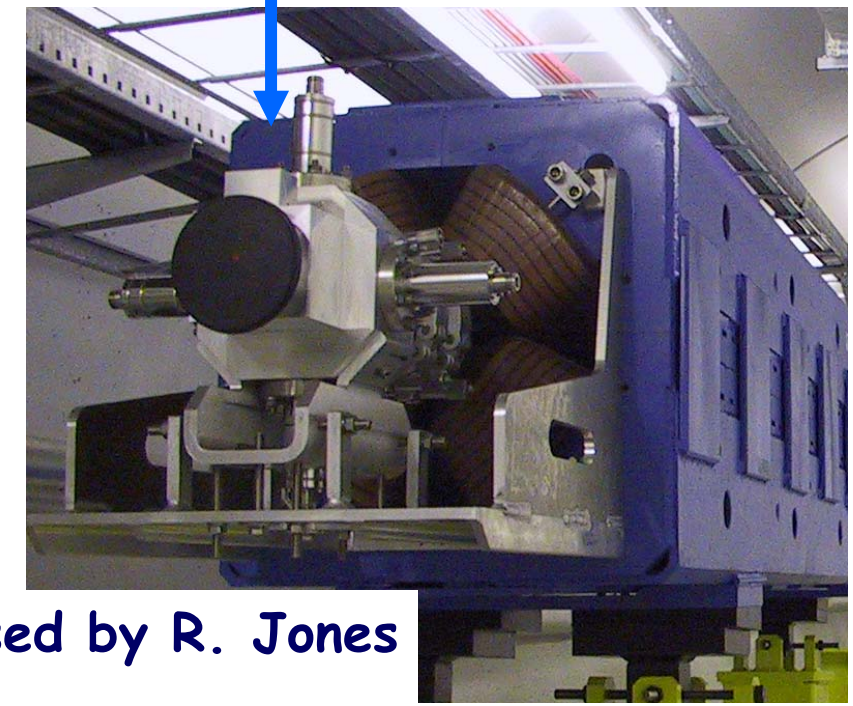


Beam position monitors

2 batch lengths

- 2μs, for I~2E11
  Trigger at 1μs, 400ns gate
- 10.5μs for I>2E12
  Trigger at 1μs, 8μs gate
  or trigger at 2μs, 400ns gate

18 Button Electrode
in proton beam line
60mm Aperture

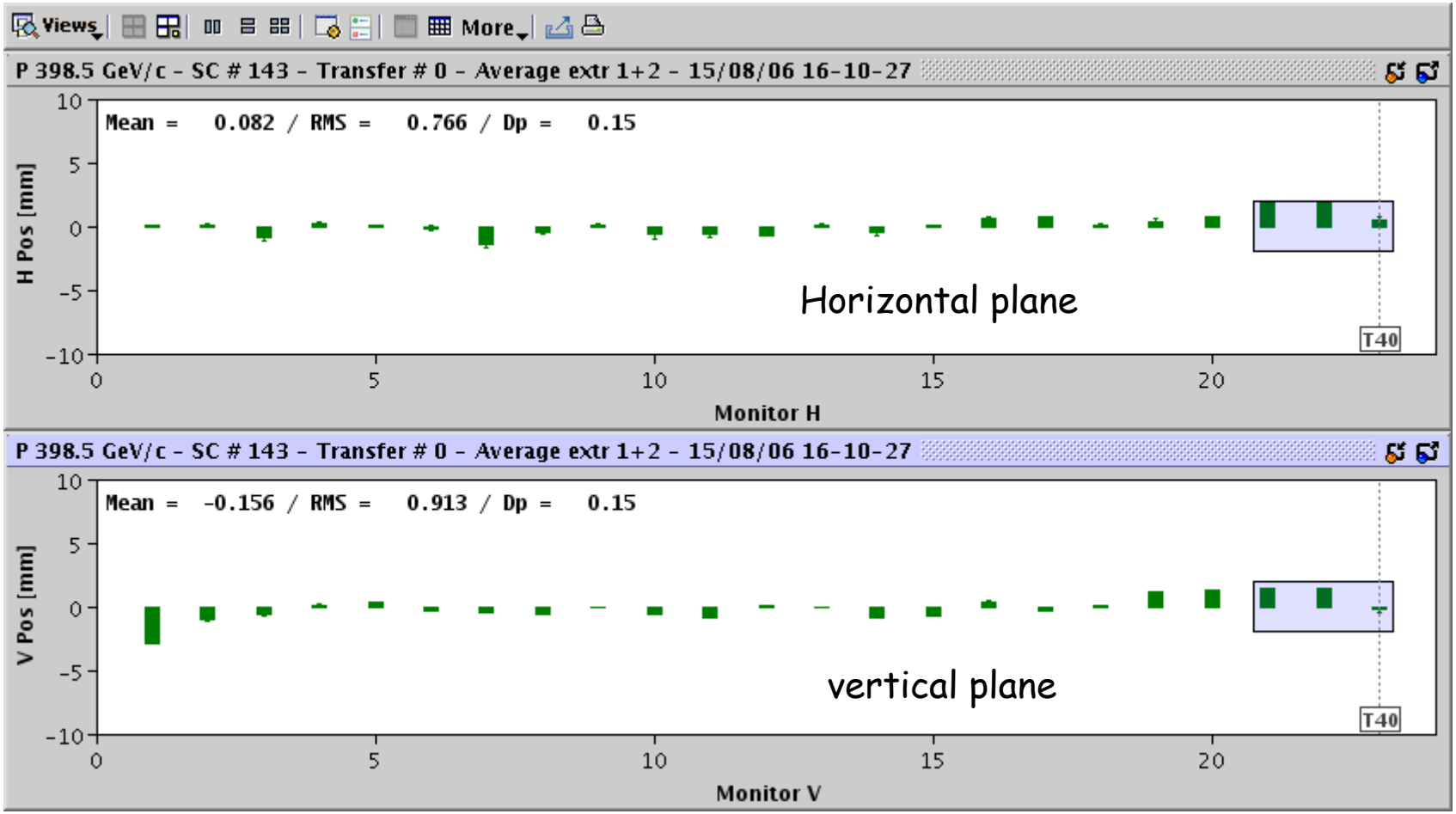


System is very sensitive
to batch structure and intensity.
However for nominal beam
parameters, system is reliable.

Performance of position monitors discussed by R. Jones

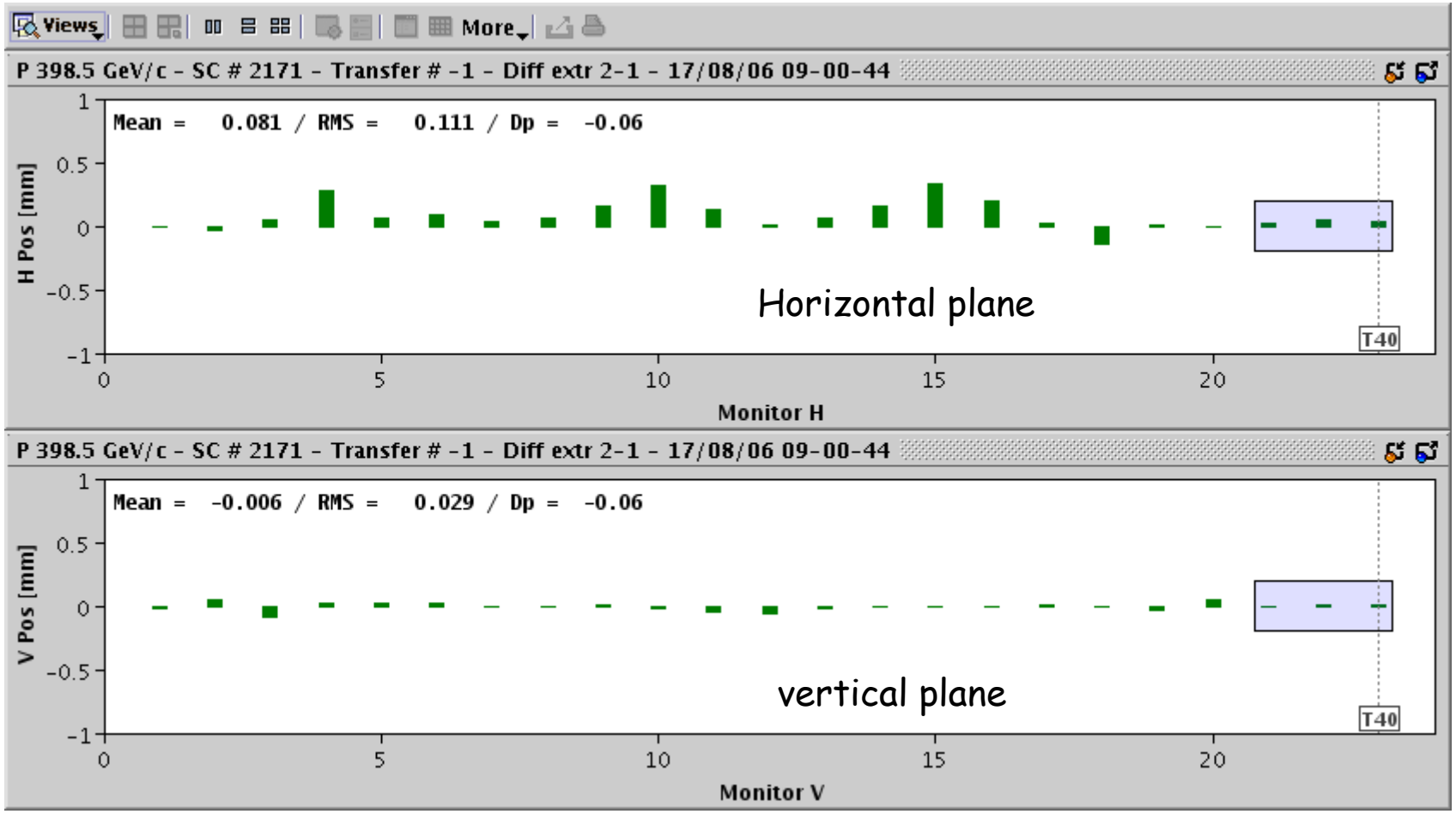
Trajectory along beam line

2 extractions. 1E13 protons per batch



Trajectory difference between the 2 extractions on BPGs

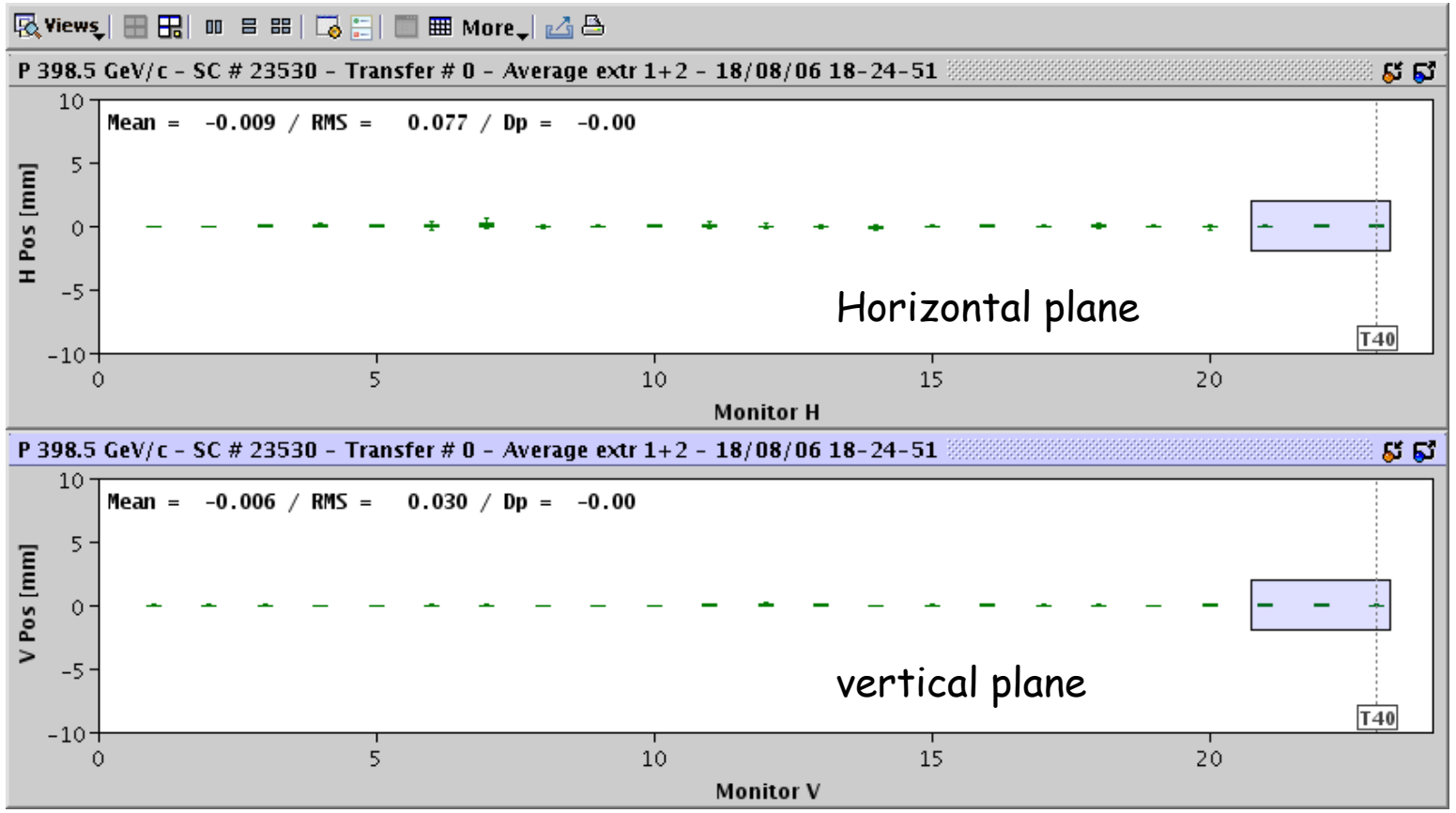
energy difference of 6 ^ 10-5



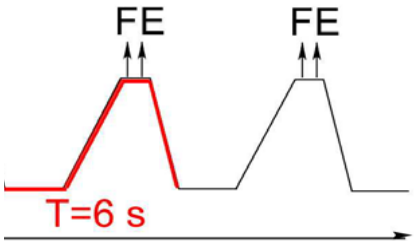
Interpolation to Target Elements

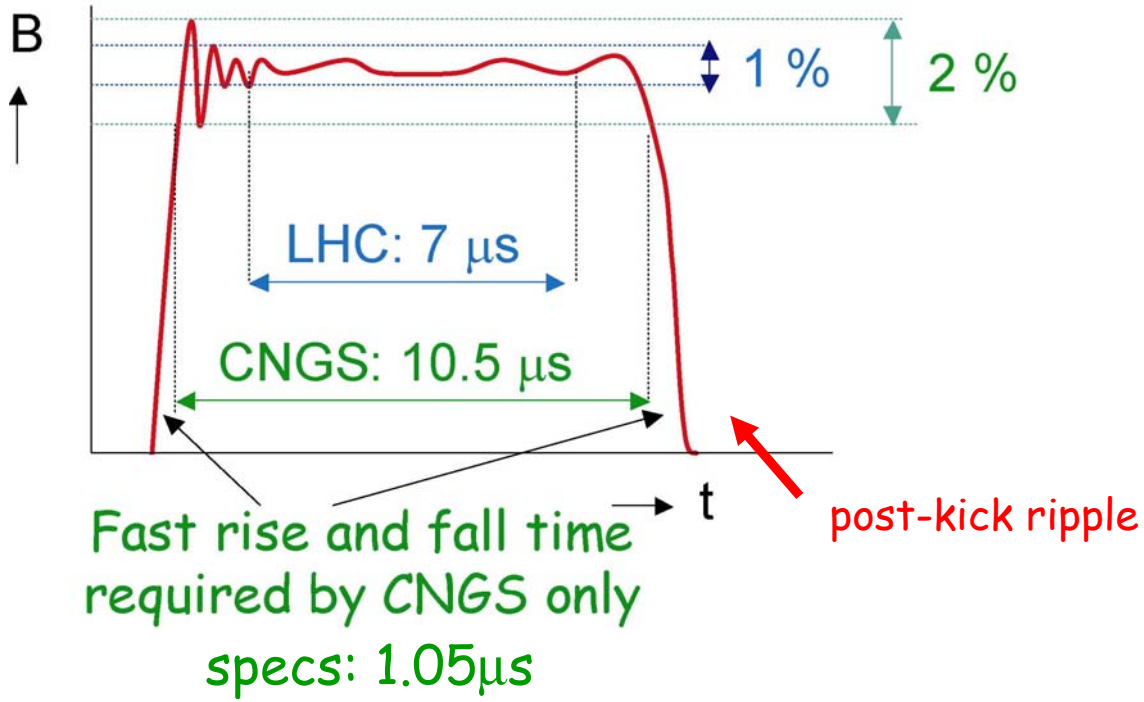
Target	Type	Corr.	X	X' [urad]	Y	Y' [urad]	Show	History
T40	Left-Left	☑	0.002	-5.76	-0.012	-13.43	☐	☐

Beam position stability onto the target over 3 first days: ~50 μm rms



Main contributor to horizontal ripple: SPS injection kicker





Beam stability onto target proves that kickers are well within specification in terms of ripples.

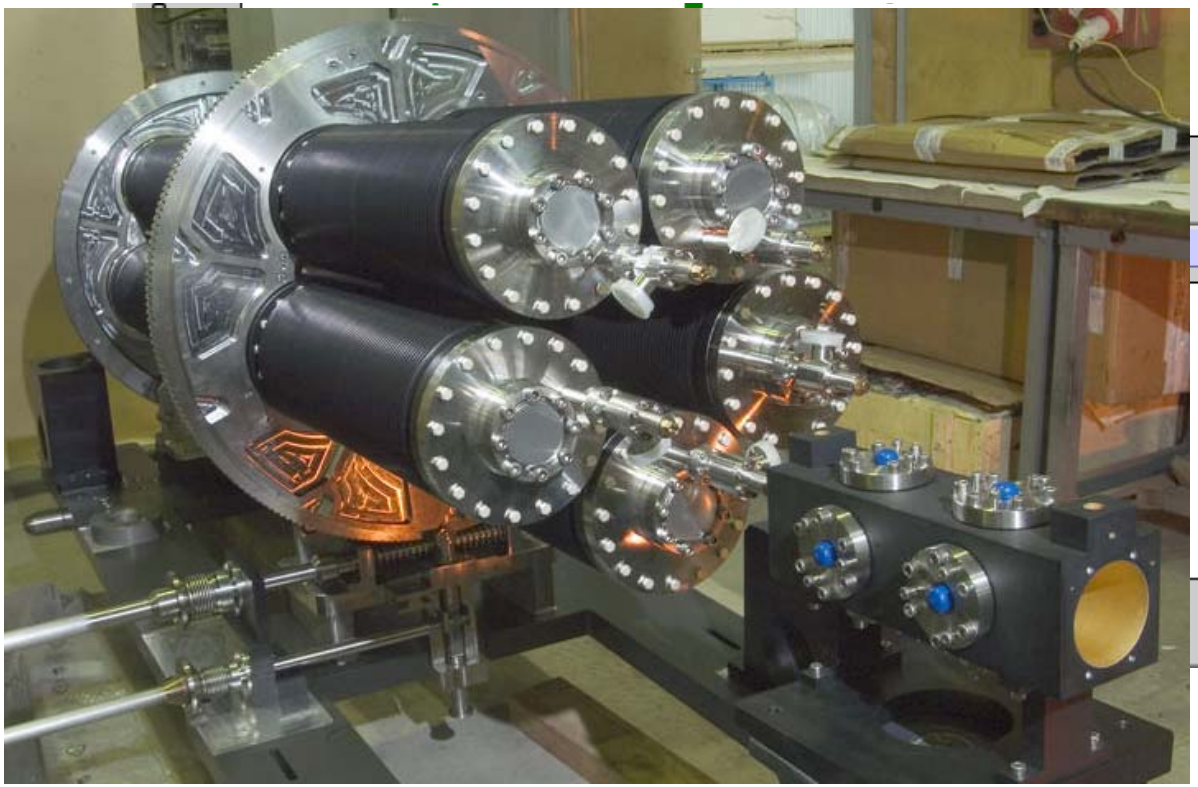
More on the kickers specification by V. Kain

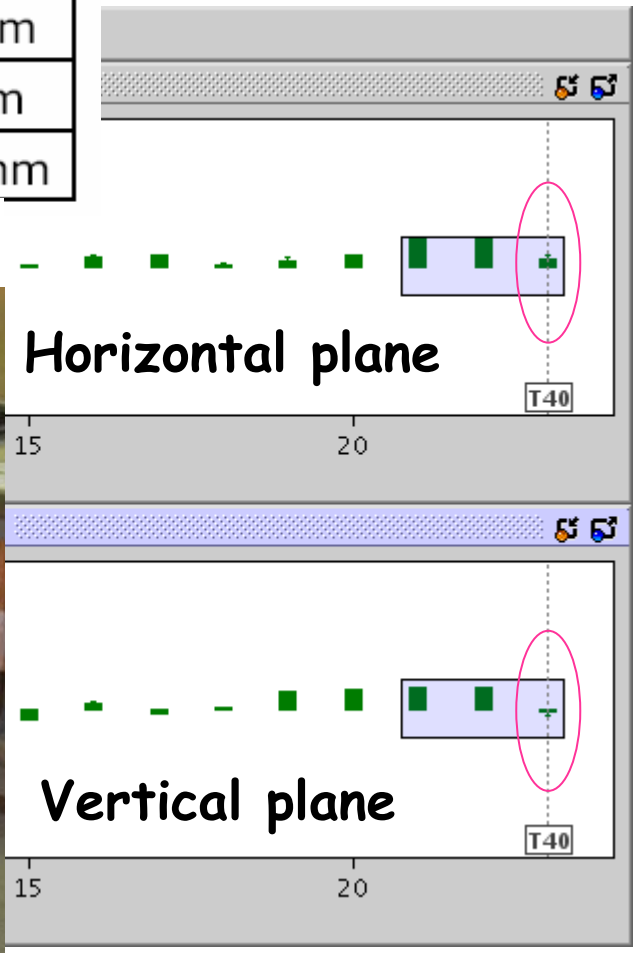
special beam position monitor on target table:
Stripline coupler Pick-up operated in air

error source	*rms uncertainty*	*tolerance*
BPM (global accuracy)	0.1 mm & ≤± 0.15 mm	± 0.2 mm & ≤± 0.3 mm
Alignment	0.10 mm	± 0.2 mm
Total	0.14 mm	≤± 0.35 mm

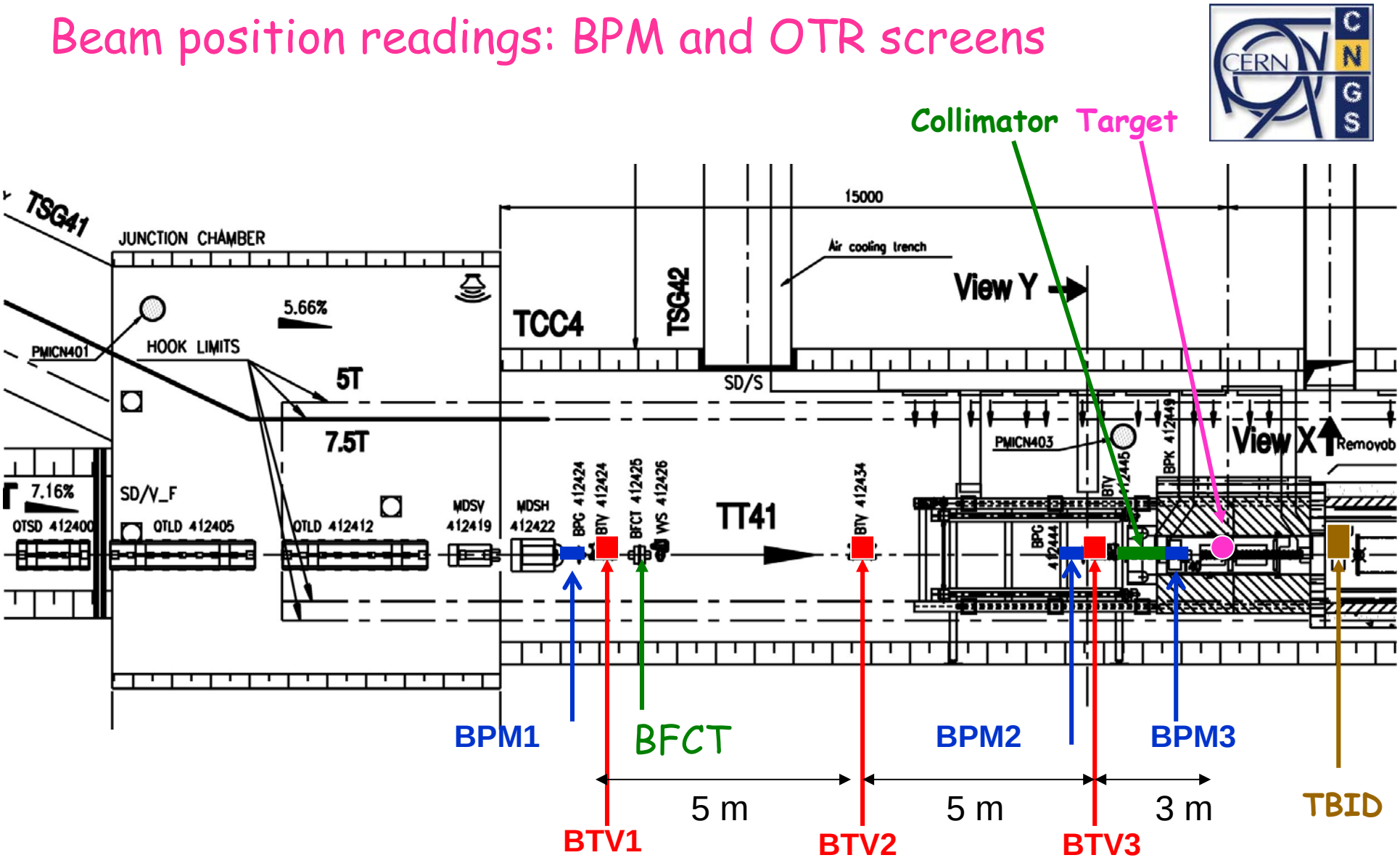
More on this coupler by R. Jones

-> very reliable position reading

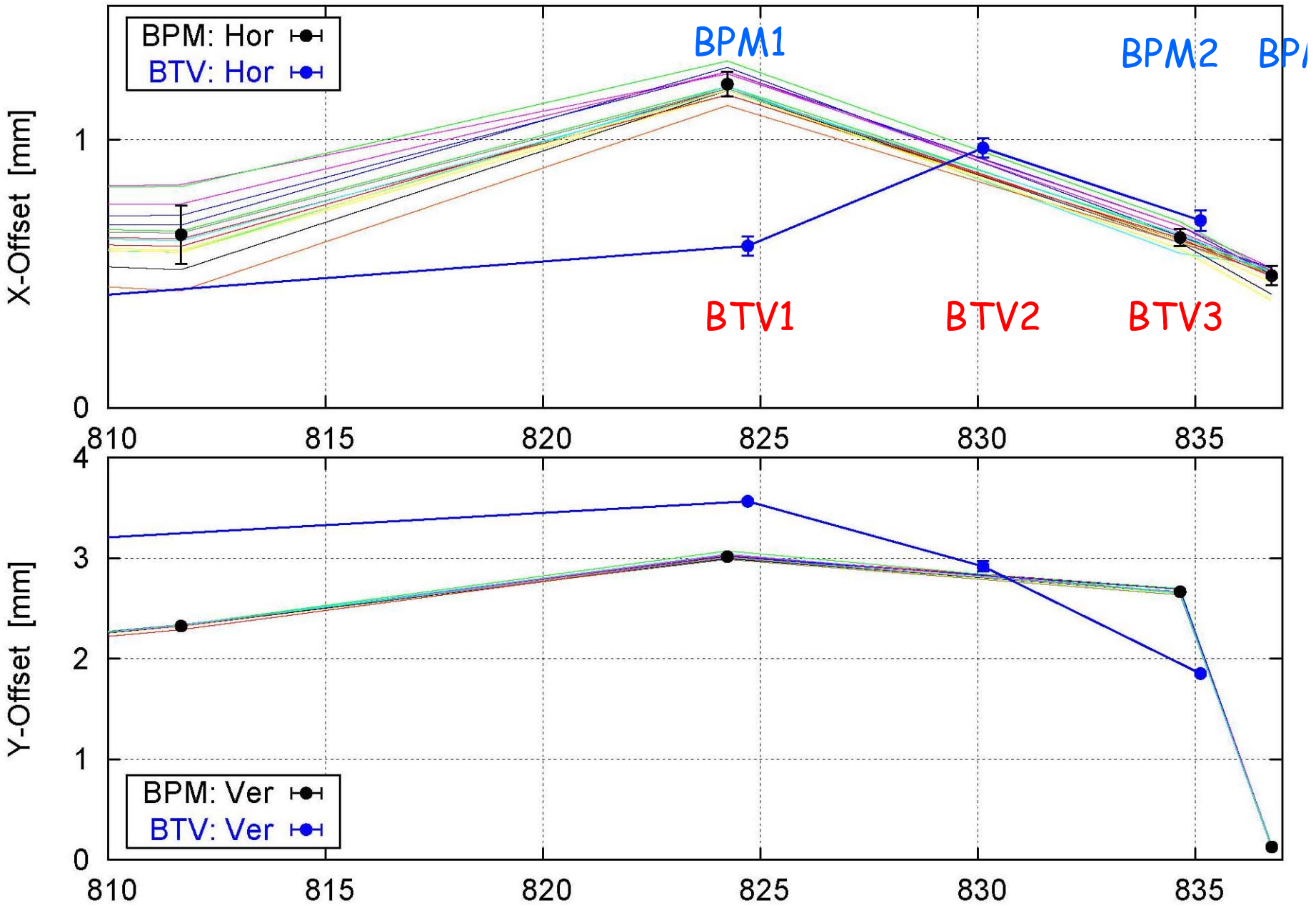




Beam position readings: BPM and OTR screens

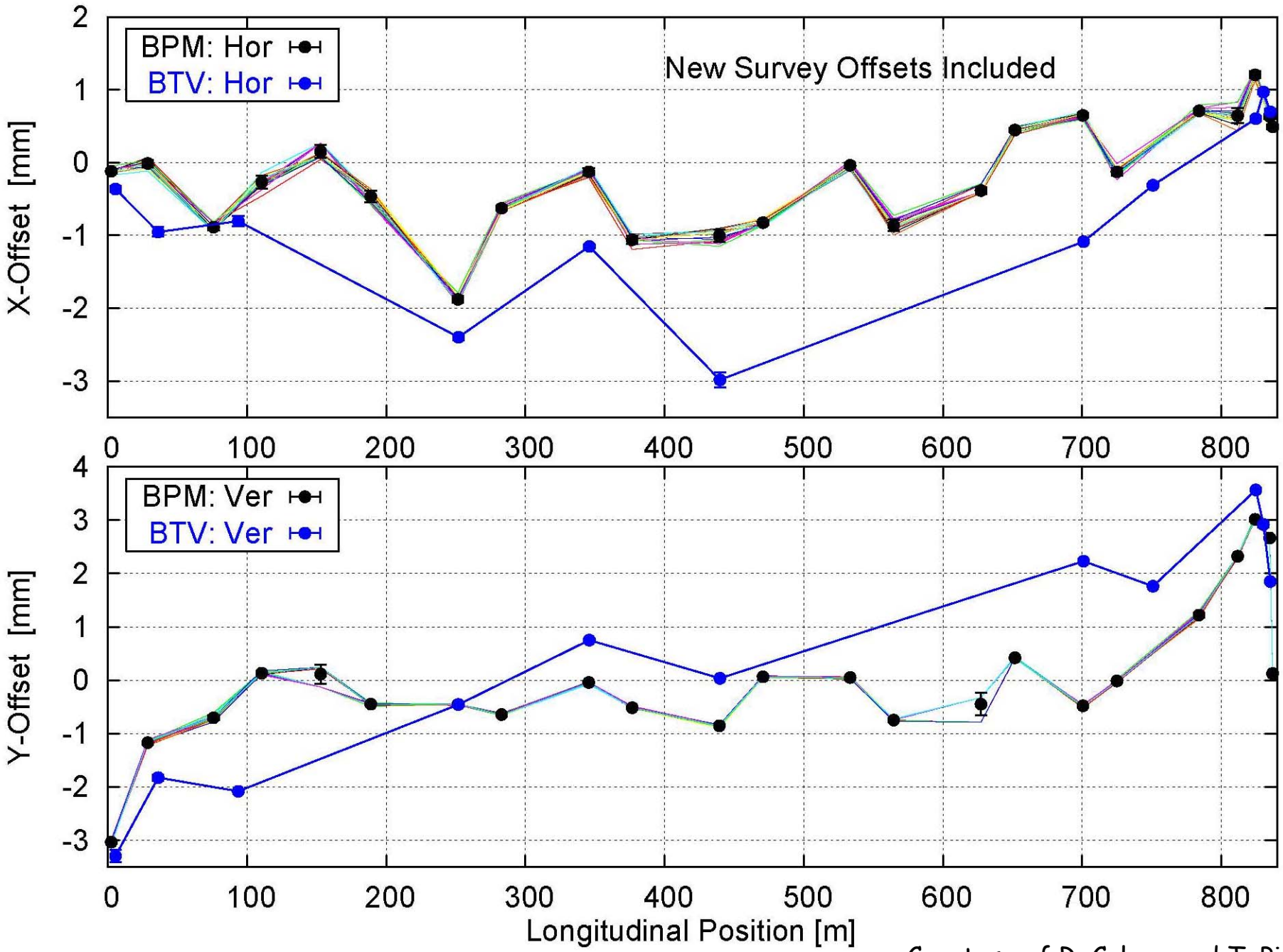


Last 20m of proton beam line



Further discussed by E. Bravin

Courtesy of R. Calaga and T. Pieloni



Courtesy of R. Calaga and T. Piel

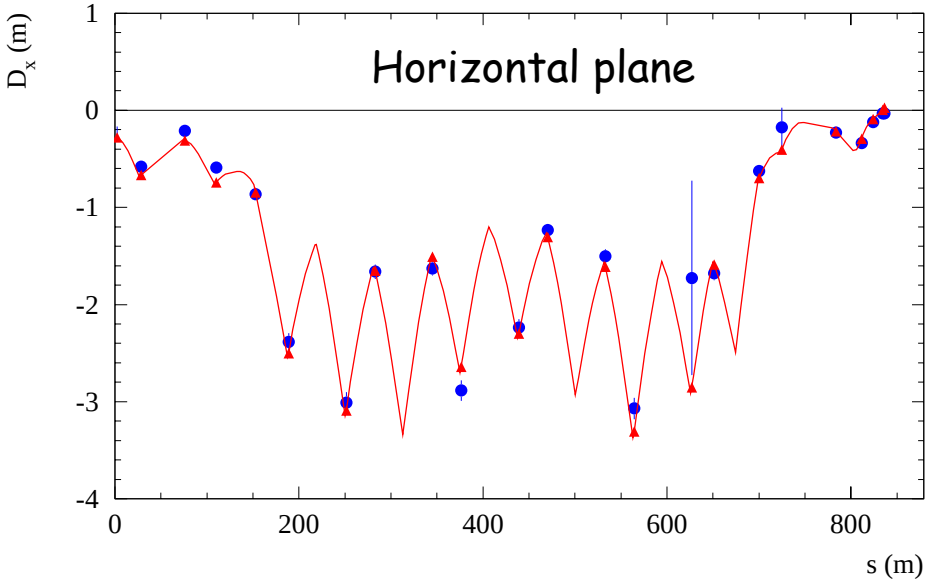
Further discussed by E. Bravin

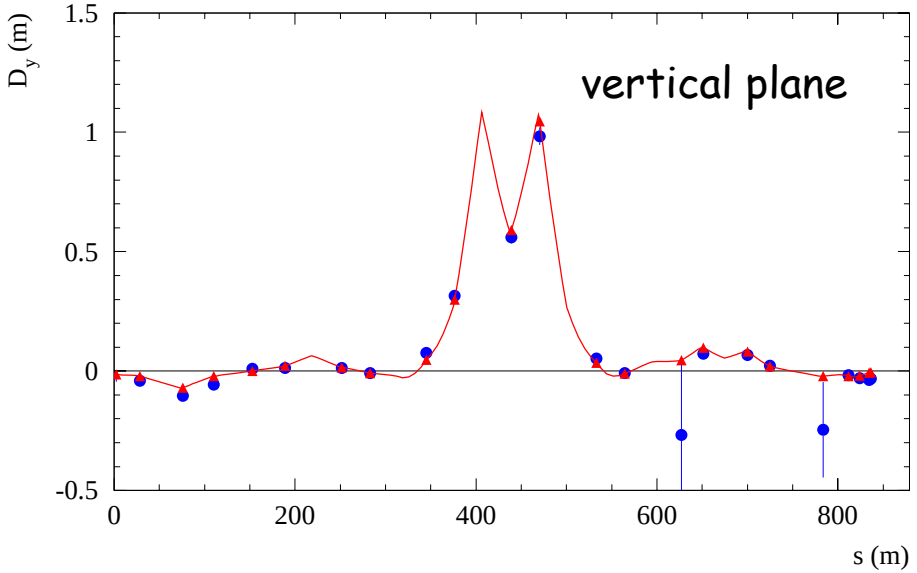
Optics checks

good agreement with theory

Beta beat of less than 10%

Dispersion measurements





courtesy J. Wenninger

Beam loss monitors along beam line

TT40: Screens IN and OUT of beam. Losses in mGray

Device : BLMITT40

Interlock Settings | Interlock Reset & Latch

BLMITT40

Values in milliGray | HW Settings Actions: Get, Set | Show Tes

BLM Name	Gain	Loss/Ex1	Loss/Ex
BLM400103	16	2.0948	0.3064
BLM400117	16	0.2850	0.0428
BLM400206	16	0.5557	0.1069
BLM400306	16	0.0143	0.0071
BLM400316	16	0.0071	0.0000
BLM400406	16	0.0000	0.0000

2 extractions, 1E13, no screens

Device : BLMITT40

Interlock Settings | Interlock Reset & Latch

BLMITT40

Values in milliGray | HW Settings Actions: Get, Set | ☑ Show Test & Setup Tools

BLM Name	Gain	Loss/Ex1	Loss/Ex2	Threshold
BLM400103	16	1.5675	4.3819	20.000
BLM400117	16	2.1731	2.6149	20.000
BLM400206	16	9.8895	10.7374	20.000
BLM400306	16	0.9761	1.0331	20.000
BLM400316	16	0.8479	0.9049	20.000
BLM400406	16	8.0299	8.2579	100.000

2 extractions, 1E13, with screens

Extraction channel studies discussed by V. Kain

TT41: ALL screens OUT, at the exception of the target one

Device : BLMICNGS

Interlock Settings | Interlock Reset & Latch

BLMICNGS

Values in milliGray

HW Settings Actions: Get | Set

Show Test & Setup Tools

BLM Name	Gain	Loss/Ex1	Loss/Ex2	Threshold
BL410024	16	0.0000	0.0000	25.000
BL410145	16	0.0499	0.0428	5.000
BL410307	16	0.0641	0.0641	5.000
BL410607	16	0.0855	0.0855	5.000
BL410707	16	0.0926	0.0926	5.000
BL410907	16	0.1069	0.1140	5.000
BL411107	16	0.2423	0.2494	5.000
BL411507	16	0.0000	0.0000	5.000
BL411807	16	0.0000	0.0000	5.000
BL411907	16	0.0000	0.0000	5.000
BL412007	16	0.0000	0.0000	5.000
BL412243	16	0.0214	0.0285	5.000
BL412445L	16	1.5461	1.5176	5.000
BL412445R	16	1.5889	1.5604	5.000
SPARE	16	0.0071	0.0000	5.000
SPARE	16	0.0000	0.0000	5.000
SPARE	16	0.0000	0.0000	5.000
SPARE	16	0.0000	0.0000	5.000
XGBL400002	16	1.6102	1.5889	10.000
XGBL400003	16	1.8311	1.8169	10.000
XGBL400094	16	6.0990	6.0135	10.000
XGBL400095	16	5.7784	5.7143	10.000

CNGS BLMs with double extraction 1 10^13

Device : BLMICNGS

Interlock Settings | Interlock Reset & Latch

BLMICNGS

Values in milliGray

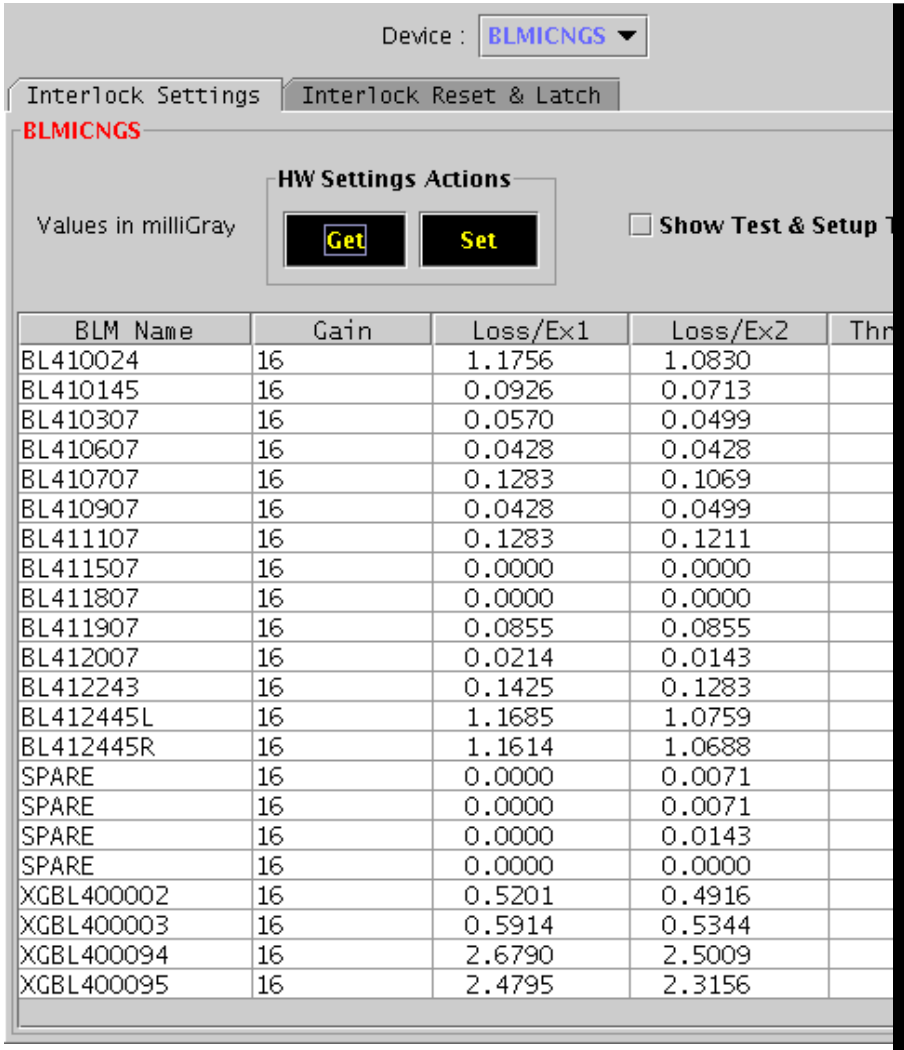
HW Settings Actions: Get | Set

Show Test & Setup Tools

BLM Name	Gain	Loss/Ex1	Loss/Ex2	Thres
BL410024	16	0.0000	0.0000	5
BL410145	16	0.0285	0.0143	5
BL410307	16	0.0143	0.0285	5
BL410607	16	0.0285	0.0285	5
BL410707	16	0.0285	0.0356	5
BL410907	16	0.0356	0.0428	5
BL411107	16	0.0926	0.0855	5
BL411507	16	0.0000	0.0143	5
BL411807	16	0.0000	0.0071	5
BL411907	16	0.0000	0.0000	5
BL412007	16	0.0071	0.0000	5
BL412243	16	0.0000	0.0000	5
BL412445L	16	0.3919	0.3990	5
BL412445R	16	0.3990	0.4204	5
SPARE	16	0.0071	0.0000	5
SPARE	16	0.0000	0.0000	5
SPARE	16	0.0000	0.0000	5
SPARE	16	0.0000	0.0000	5
XGBL400002	16	0.4418	0.4489	10
XGBL400003	16	0.5201	0.5130	10
XGBL400094	16	2.3370	2.3940	10
XGBL400095	16	2.1589	2.2159	10

CNGS BLMs with double extraction 6 10^12

TT41: All screens IN beam



Device : BLMICNGS

Interlock Settings | Interlock Reset & Latch

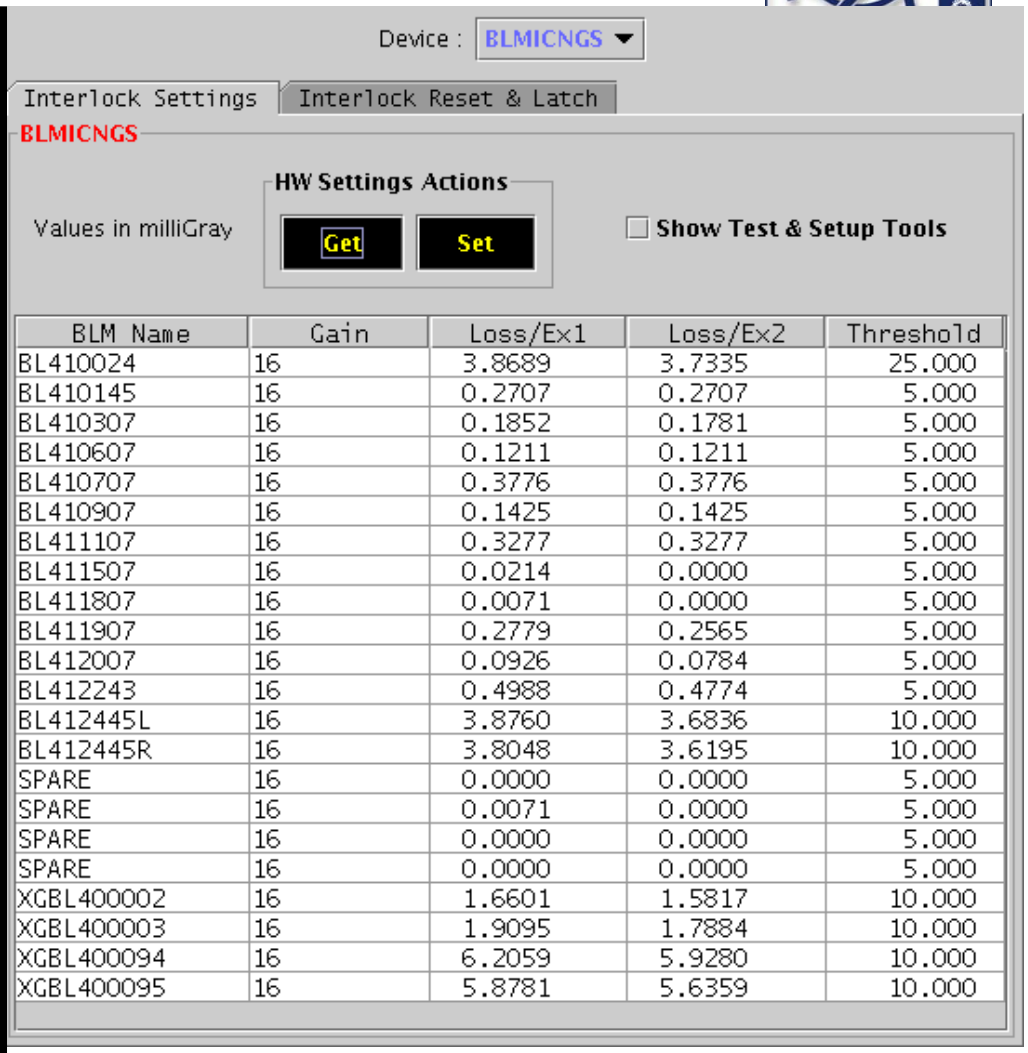
BLMICNGS

HW Settings Actions

Values in milliGray | Get | Set | Show Test & Setup T

BLM Name	Gain	Loss/Ex1	Loss/Ex2	Thr
BL410024	16	1.1756	1.0830	
BL410145	16	0.0926	0.0713	
BL410307	16	0.0570	0.0499	
BL410607	16	0.0428	0.0428	
BL410707	16	0.1283	0.1069	
BL410907	16	0.0428	0.0499	
BL411107	16	0.1283	0.1211	
BL411507	16	0.0000	0.0000	
BL411807	16	0.0000	0.0000	
BL411907	16	0.0855	0.0855	
BL412007	16	0.0214	0.0143	
BL412243	16	0.1425	0.1283	
BL412445L	16	1.1685	1.0759	
BL412445R	16	1.1614	1.0688	
SPARE	16	0.0000	0.0071	
SPARE	16	0.0000	0.0071	
SPARE	16	0.0000	0.0143	
SPARE	16	0.0000	0.0000	
XGBL400002	16	0.5201	0.4916	
XGBL400003	16	0.5914	0.5344	
XGBL400094	16	2.6790	2.5009	
XGBL400095	16	2.4795	2.3156	

CNGS BLMs with C screens, 6 10^12



Device : BLMICNGS

Interlock Settings | Interlock Reset & Latch

BLMICNGS

HW Settings Actions

Values in milliGray | Get | Set | Show Test & Setup Tools

BLM Name	Gain	Loss/Ex1	Loss/Ex2	Threshold
BL410024	16	3.8689	3.7335	25.000
BL410145	16	0.2707	0.2707	5.000
BL410307	16	0.1852	0.1781	5.000
BL410607	16	0.1211	0.1211	5.000
BL410707	16	0.3776	0.3776	5.000
BL410907	16	0.1425	0.1425	5.000
BL411107	16	0.3277	0.3277	5.000
BL411507	16	0.0214	0.0000	5.000
BL411807	16	0.0071	0.0000	5.000
BL411907	16	0.2779	0.2565	5.000
BL412007	16	0.0926	0.0784	5.000
BL412243	16	0.4988	0.4774	5.000
BL412445L	16	3.8760	3.6836	10.000
BL412445R	16	3.8048	3.6195	10.000
SPARE	16	0.0000	0.0000	5.000
SPARE	16	0.0071	0.0000	5.000
SPARE	16	0.0000	0.0000	5.000
SPARE	16	0.0000	0.0000	5.000
XGBL400002	16	1.6601	1.5817	10.000
XGBL400003	16	1.9095	1.7884	10.000
XGBL400094	16	6.2059	5.9280	10.000
XGBL400095	16	5.8781	5.6359	10.000

CNGS BLMs with C screens, 1 10^13

Learnt from commissioning

The commissioning stressed the importance of :

- detailed hardware commissioning
- complete "dry" commissioning (as if beam without beam)
- having screens along extraction channel and line for the first beam passages
- difficulties of precise survey with equipment completely embedded in shielding: survey involved in design phase, multiple surveys before beam
- save protons used during commissioning (ease access to tunnels)
- allocate time for operator training before going into physics

Conclusions

Proton beam line was successfully commissioned.
First shot down the line reached the target at about center
Beam is very stable and parameters are within specification

Thank you to all the colleagues from CERN and laboratories all over theworld who contributed to the project's success.