The RHIC polarized H^- ion source

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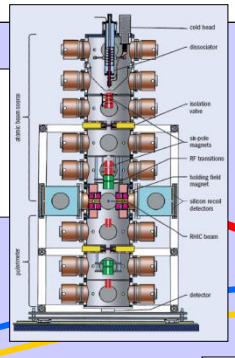
- Polarized beams in RHIC accelerator complex
- High-intensity polarized H^- ion source
- Polarized beams in Run-2015
- Summary

Polarization facilities at RHIC

$L_{max} = 1.6 \times 10^{32}\ s^{-1}cm^{-2}$ $50 < \sqrt{s} < 510$ GeV

Absolute $\vec{H}$-jet polarimeter



RHIC pC "CNI" polarimeters

RHIC

PHENIX

STAR

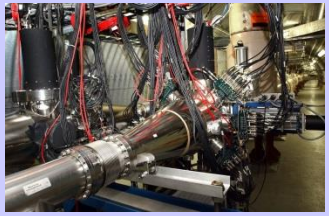
Siberian Snakes

Pol. H^- ion source

Spin Rotators

LINAC

AGS, 24GeV



AGS pC "CNI" polarimeter

200 MeV polarimeter

BOOSTER, 2.5 GeV

RHIC Polarized beam in Run 2013-15

OPPIS → 1.0 mA x 300us→$18 \cdot 10^{11}$ polarized H^- /pulse.

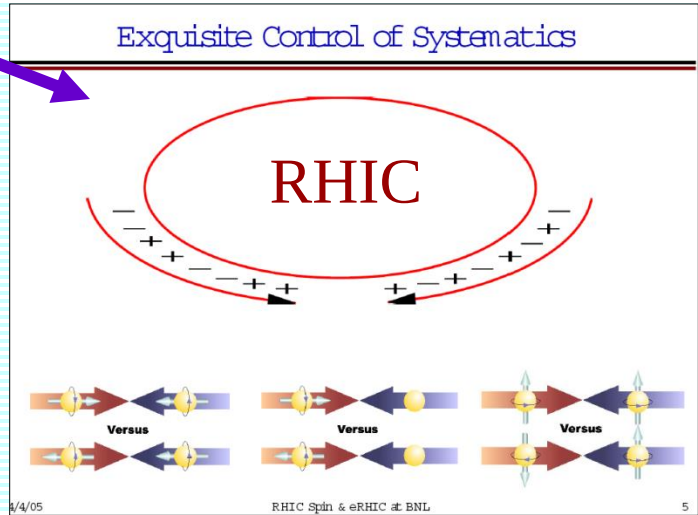
LINAC → $9.0 \cdot 10^{11}$ polarized H^- /pulse at 200 MeV routinely in Run-15

Booster → $(2.5\text{-}3.0) \cdot 10^{11}$ protons /pulse at 2.3 GeV

AGS → $(2.0\text{-}3.0) \cdot 10^{11}$ p/bunch

~$1.8 \cdot 10^{11}$ p/bunch, P~60-65% at 100 GeV
P ~ 58% at 255 GeV

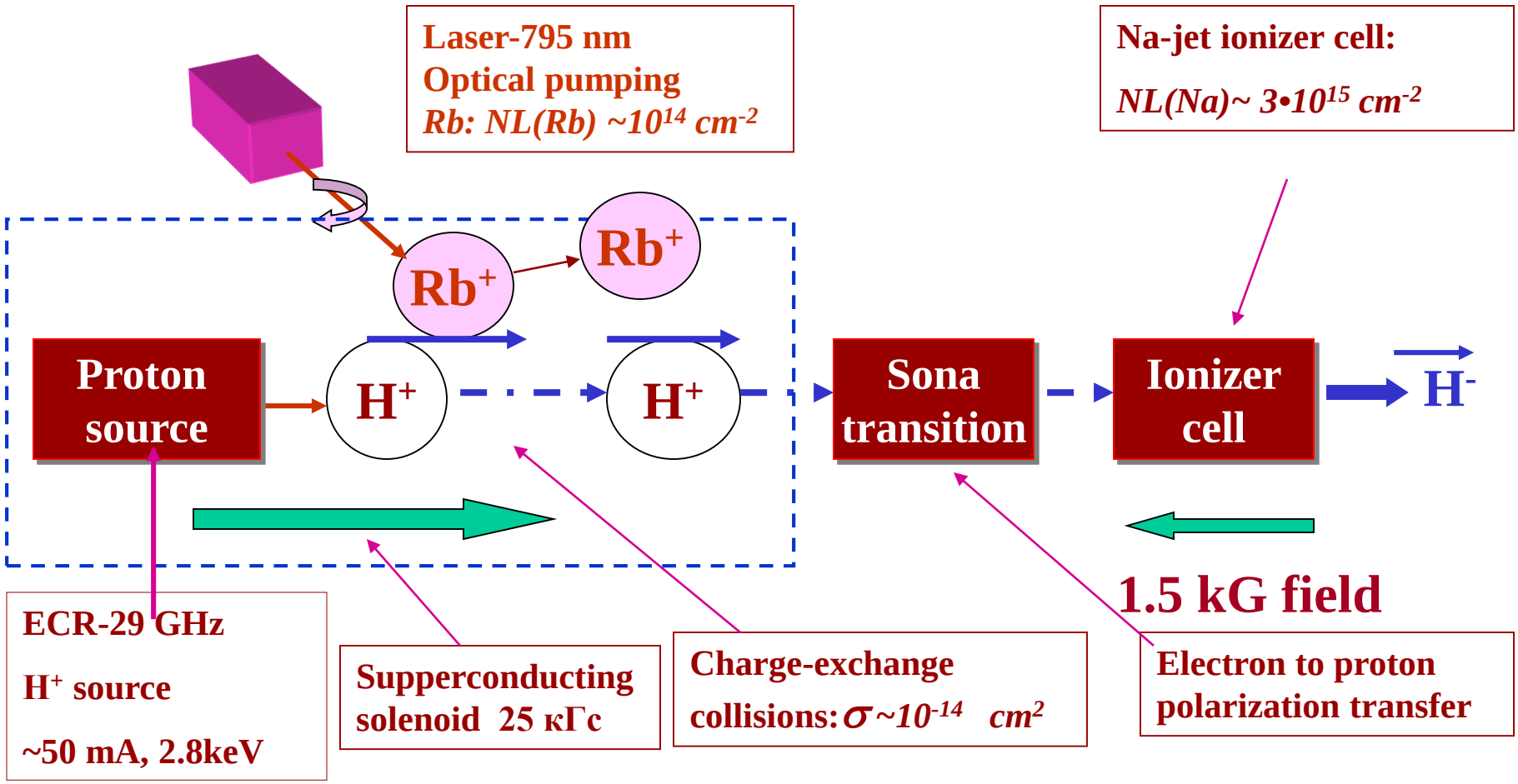
It is expected, that use of Electron Lens will allow increase of the bunch intensity to ~$2.5 \cdot 10^{11}$ p/bunch.



The RHIC OPPIS upgrade with atomic hydrogen injector, Run-2013-15

BNL - BINP, Novosibisk, INR, Moscow- collaboration

SPIN -TRANSFER POLARIZATION IN PROTON-Rb COLLISIONS

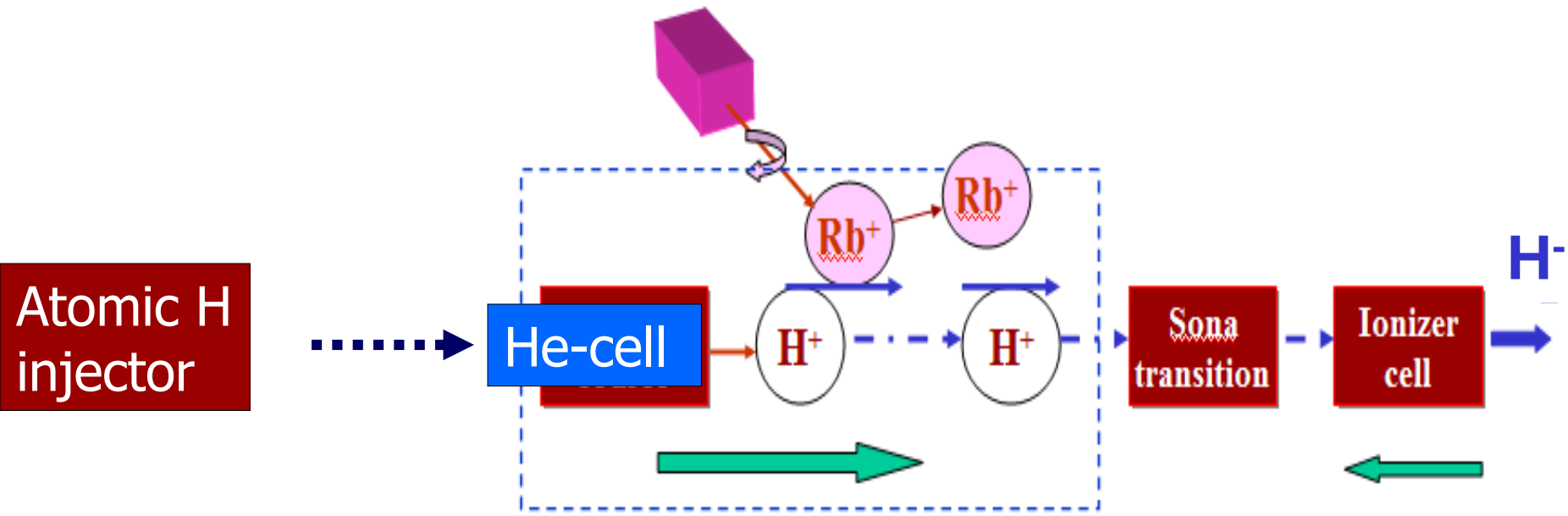


Laser beam is a primary source of angular momentum:

10 W (795 nm) ⟹ $4 \cdot 10^{19}$ hν/sec ⟹ 2 A, H^0 equivalent intensity.

New generation OPPIS with atomic H^0 injector

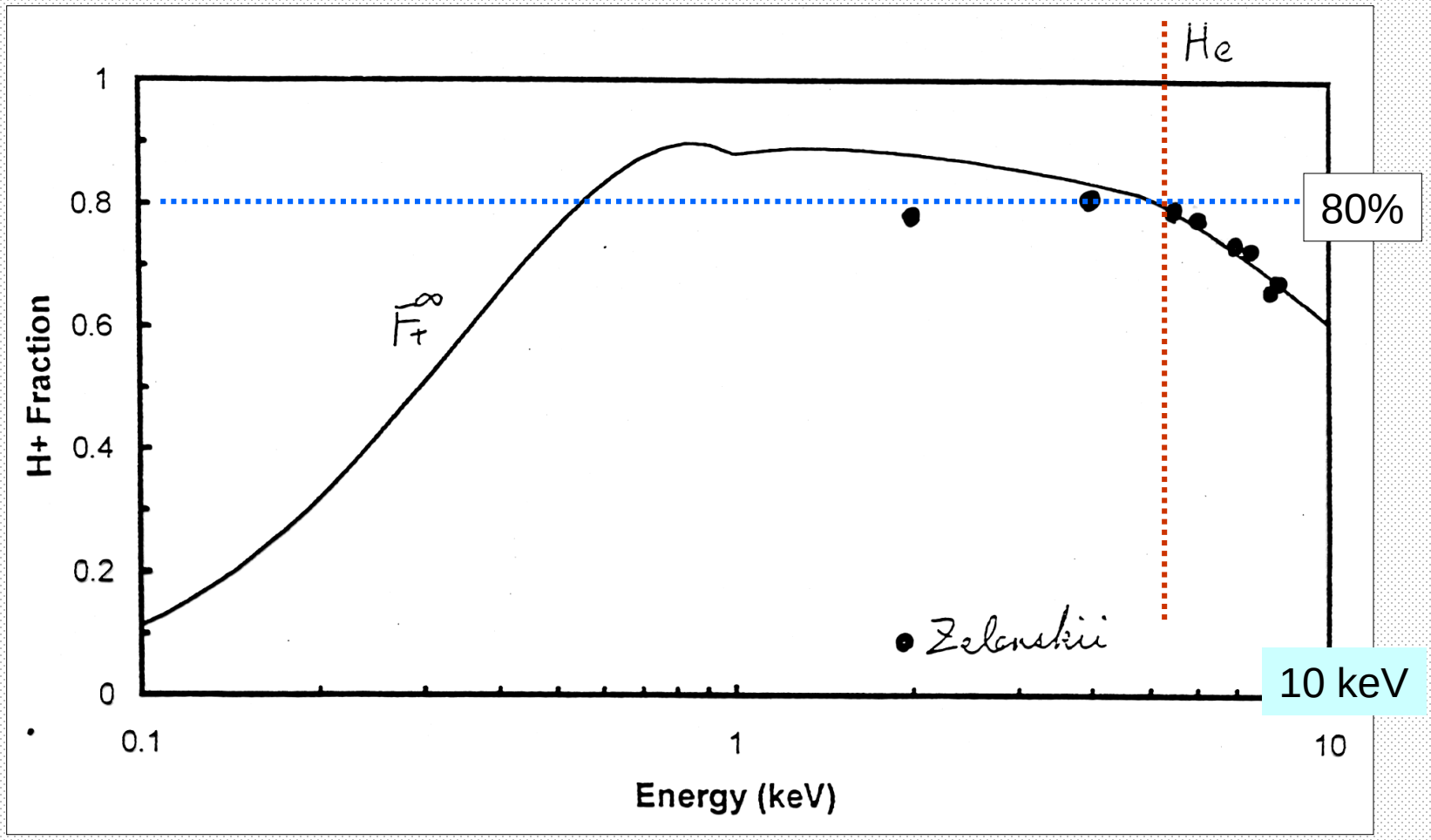
High-brightness proton beam inside strong 2.5 T solenoid field produced by atomic H beam ionization in the He-gas ionizer cell



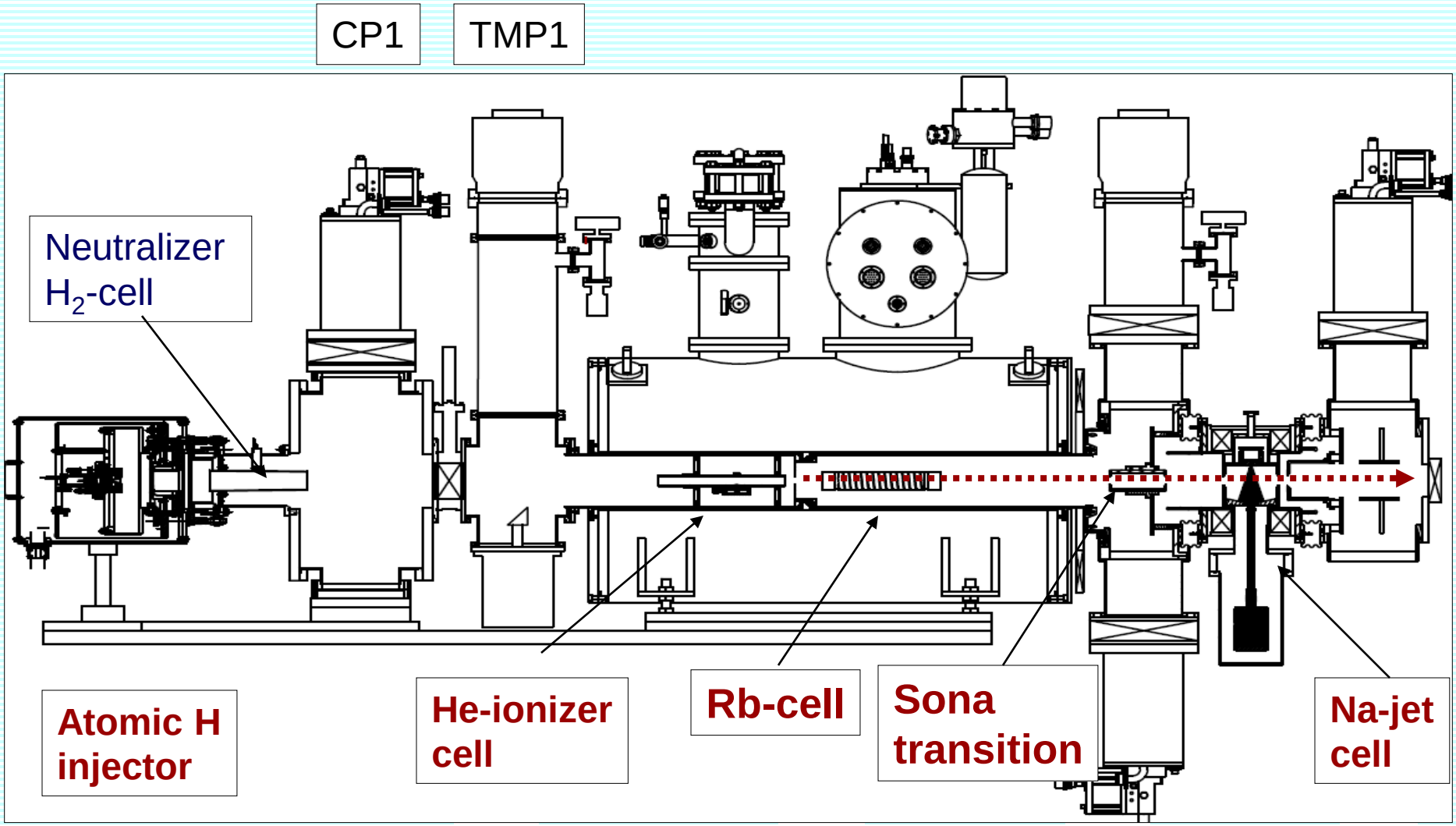
The proton beam intensity is about 1.0 A !

Hydrogen atomic beam ionization efficiency in the He- cell

$$H^0 + He \rightarrow H^+ + He + e$$

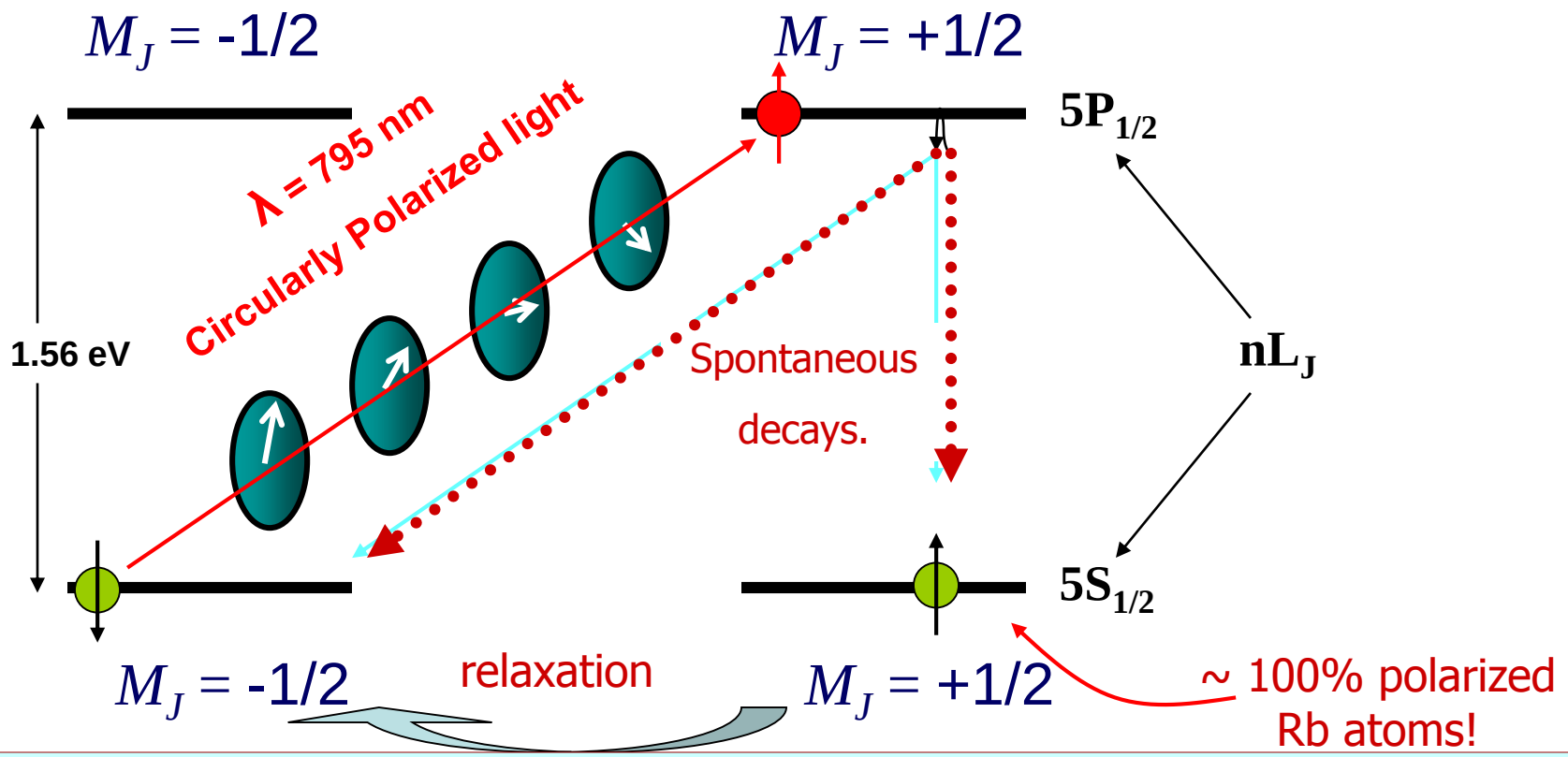


New OPPIS with atomic H^0 injector layout, 2013



$H^+ \rightarrow H2 \xrightarrow{H^0} He \xrightarrow{H^+} Rb \xrightarrow{H^0} Na \xrightarrow{H^-}$

Optical Pumping polarization technique

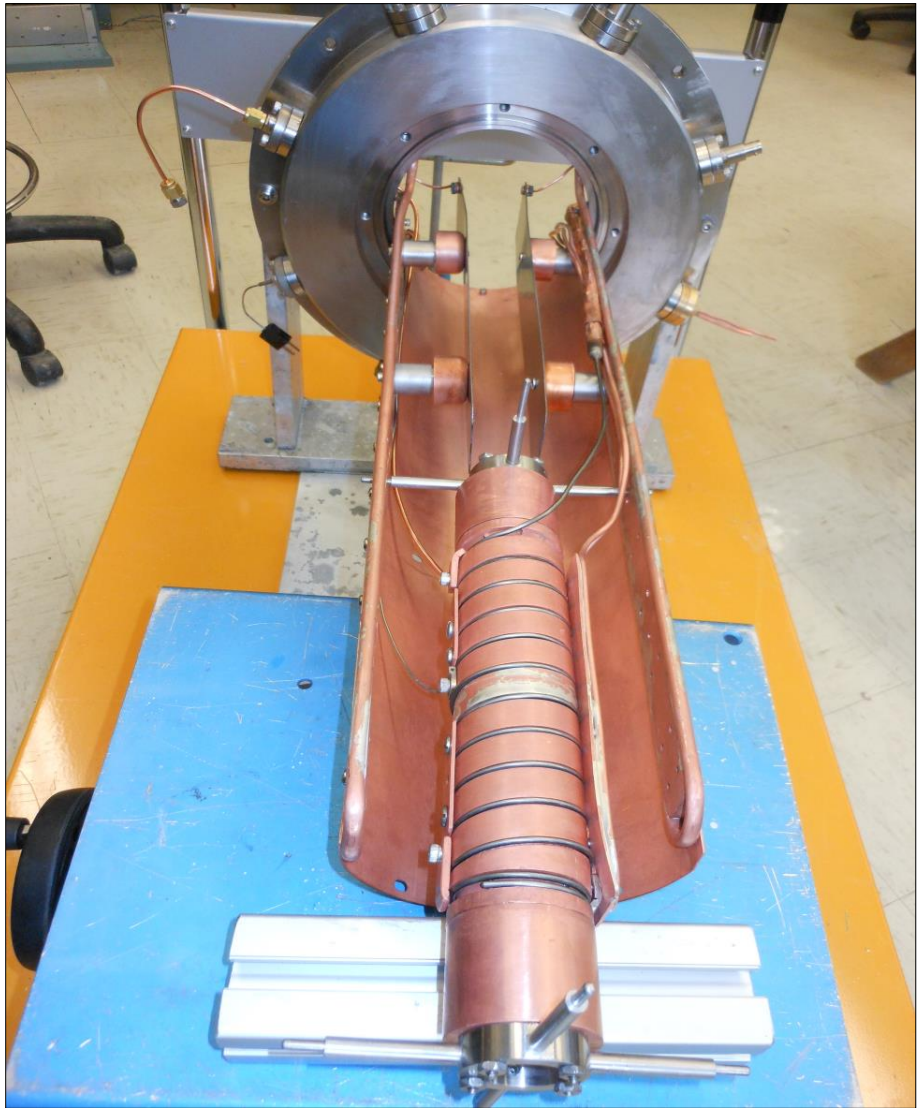


Laser beam is a powerful primary source of angular momentum:

10 W (795 nm) → $4 \cdot 10^{19}$ hν/sec → 2 A, H^0 equivalent intensity.

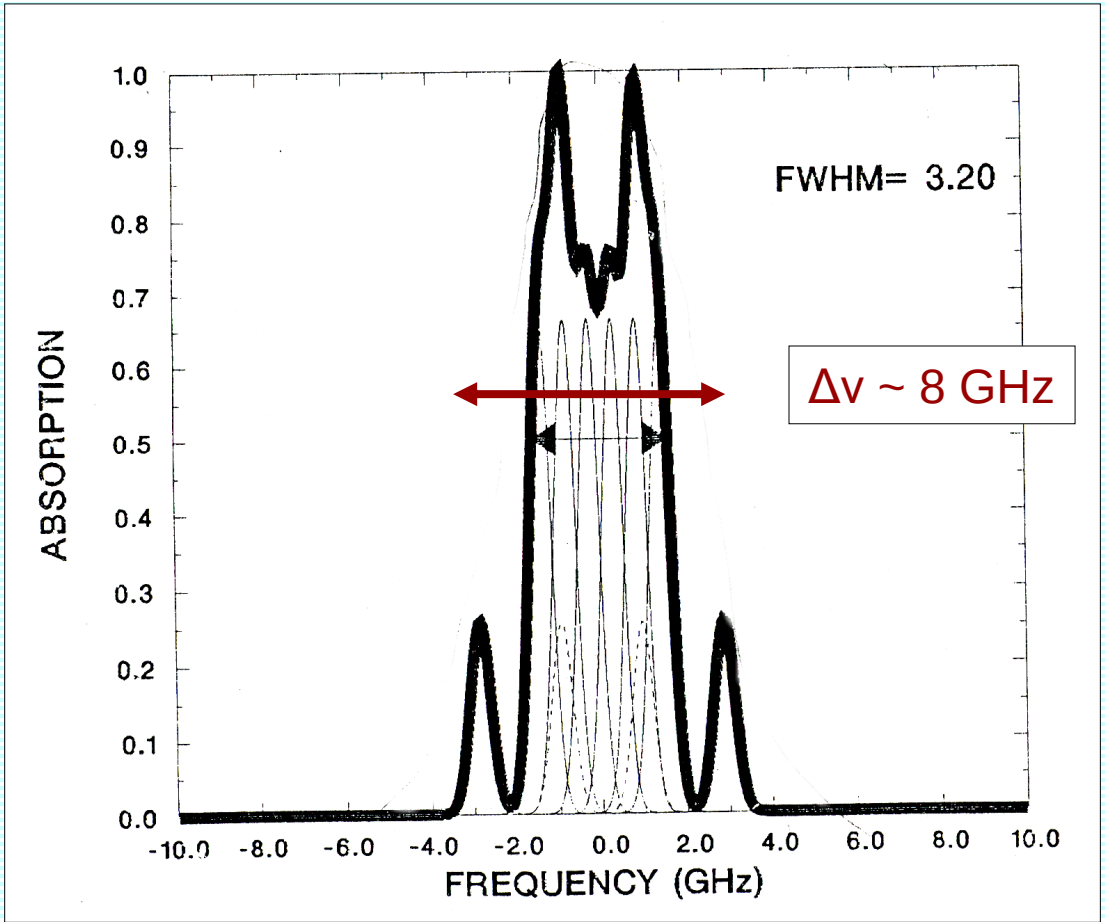
Feasibility of Multi-ampere polarized beams.

Rb –cell preparation for the Run-2017, higher 6.0 kV deflecting plate voltage.

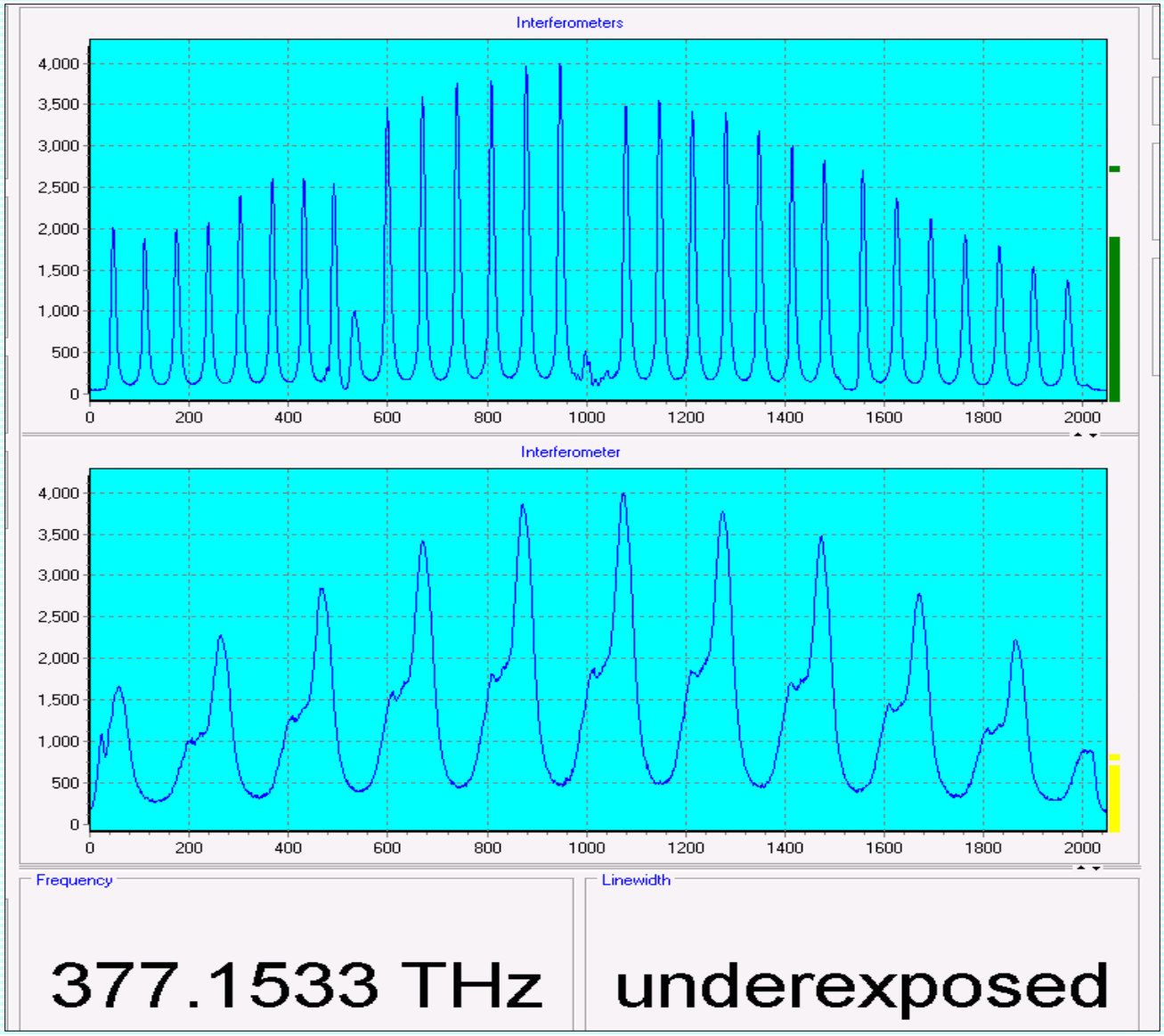


Optical pumping of Rb-85 (72.7%), Rb-87(27.8%) natural mixture..

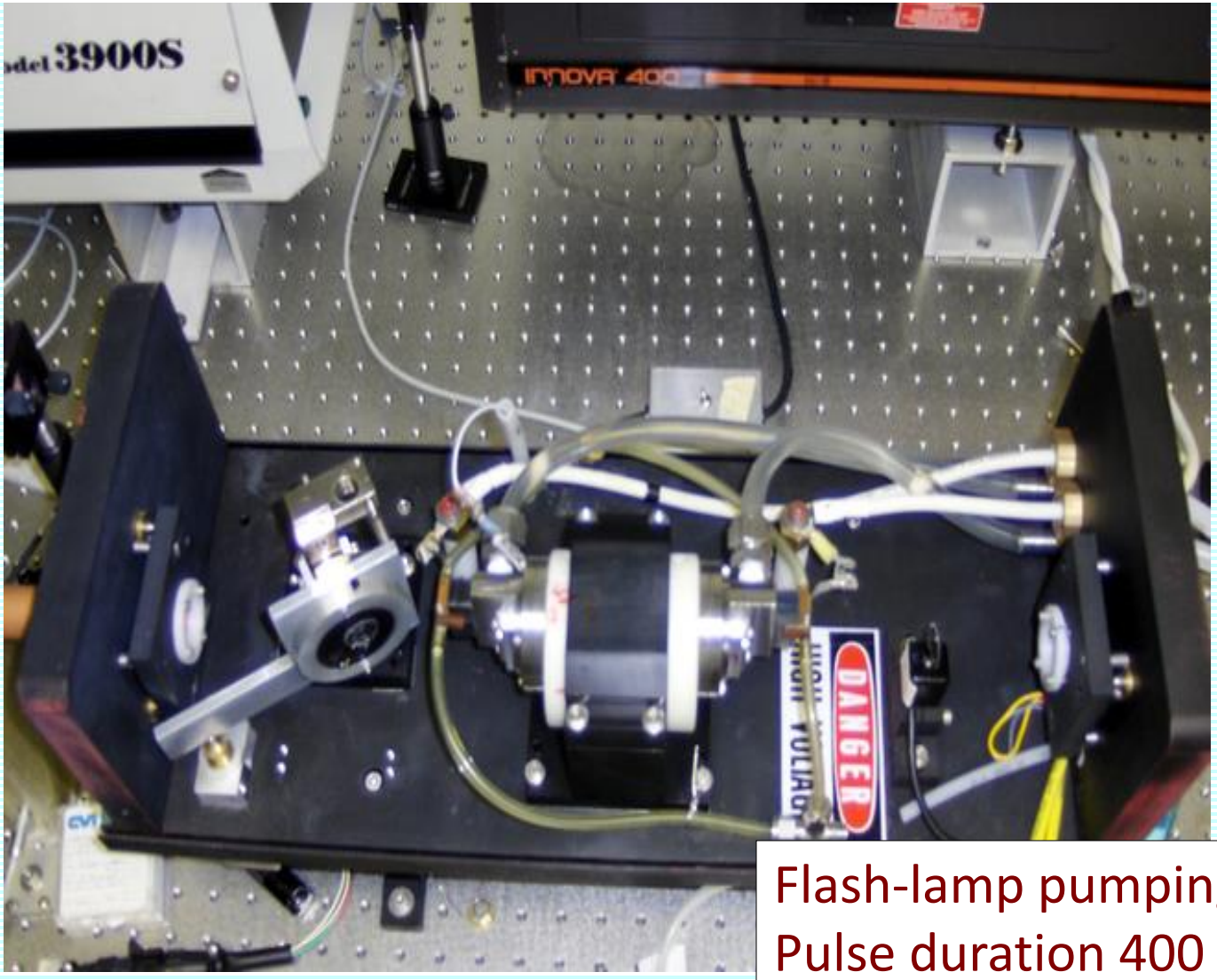
Effective width of Rb 85-87 natural mixture including hyperfine Splitting and Doppler broadening is ~ 3.2 GHz



Problems with laser line-width control



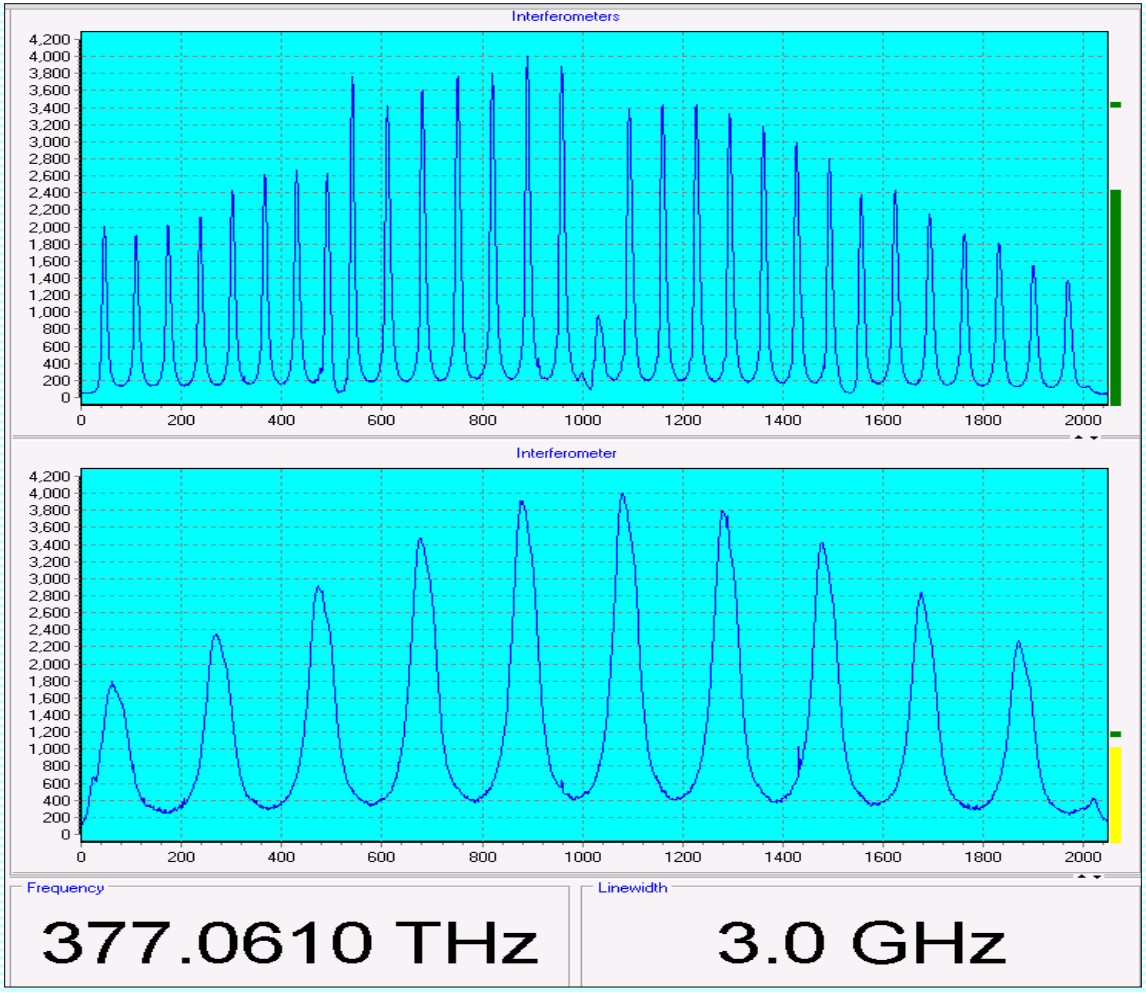
Ti:LISAF tunable laser for Rb optical pumping at 795 nm.



Fabry-Perot etalon

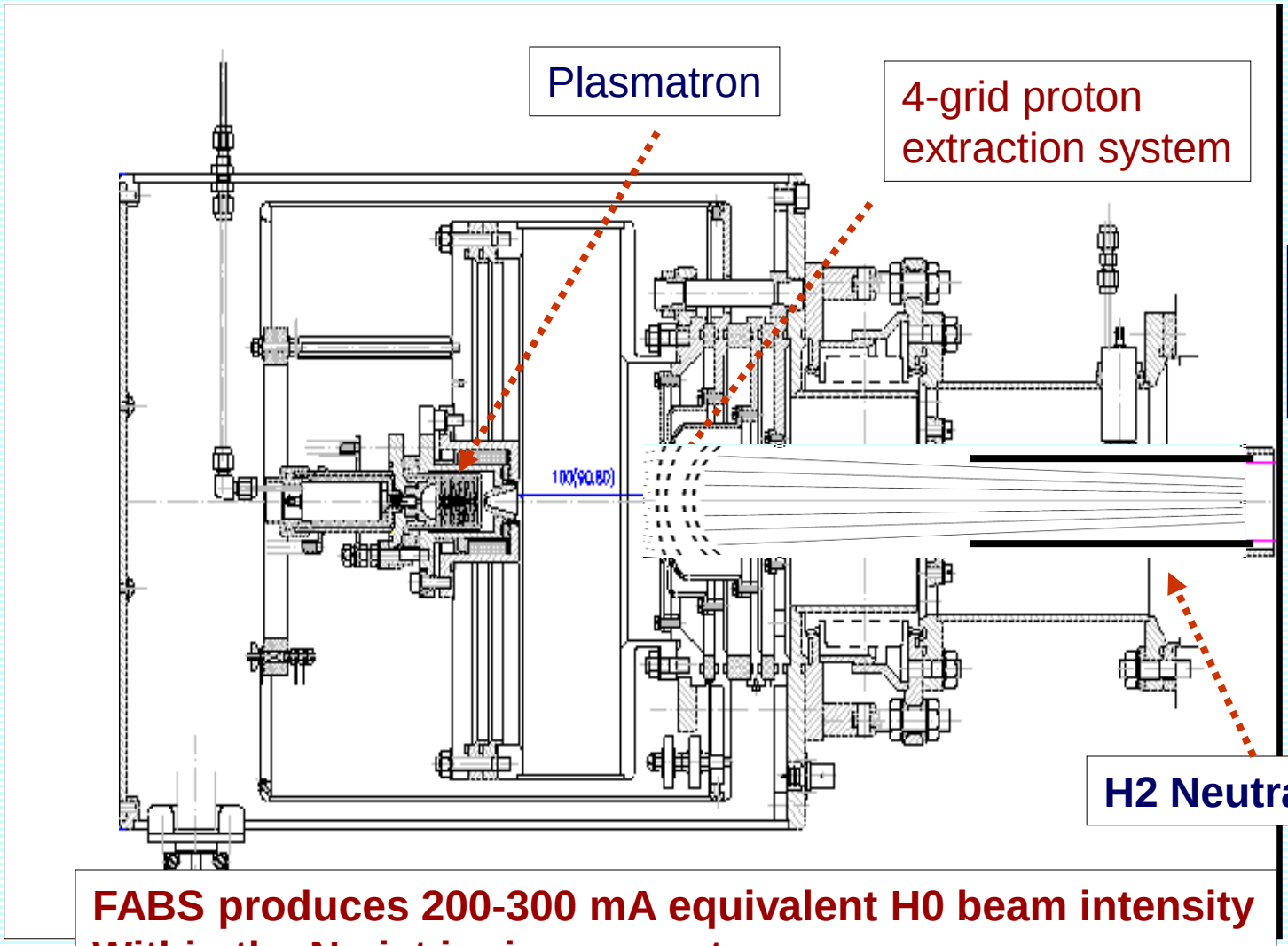
Flash-lamp pumping.
Pulse duration 400 us

Laser wavelength and Line-width control



Laser spectra with two intra-cavity Fabry-Perot etalons

"Fast Atomic Beam Source", BINP, Novosibirsk, 2012



FABS produces 200-300 mA equivalent H0 beam intensity Within the Na-jet ionizer acceptance.

FABS 4-grid spherical Ion Optical System

1820 holes , 1.0 mm in diameter

3-5 A of proton beam At 6-10 keV energy

8 keV, L=230cm, I-3.4 A, April 26, 2012

$I(r) = I_0 \exp(-r^2/\delta r^2)$, $I_0 = 3.2A$

$\delta r^2 = \delta a \cdot L^2 + a^2 \cdot (L/F - 1)^2$

δr-radius at intensity 1/e

L - distance to profile detector

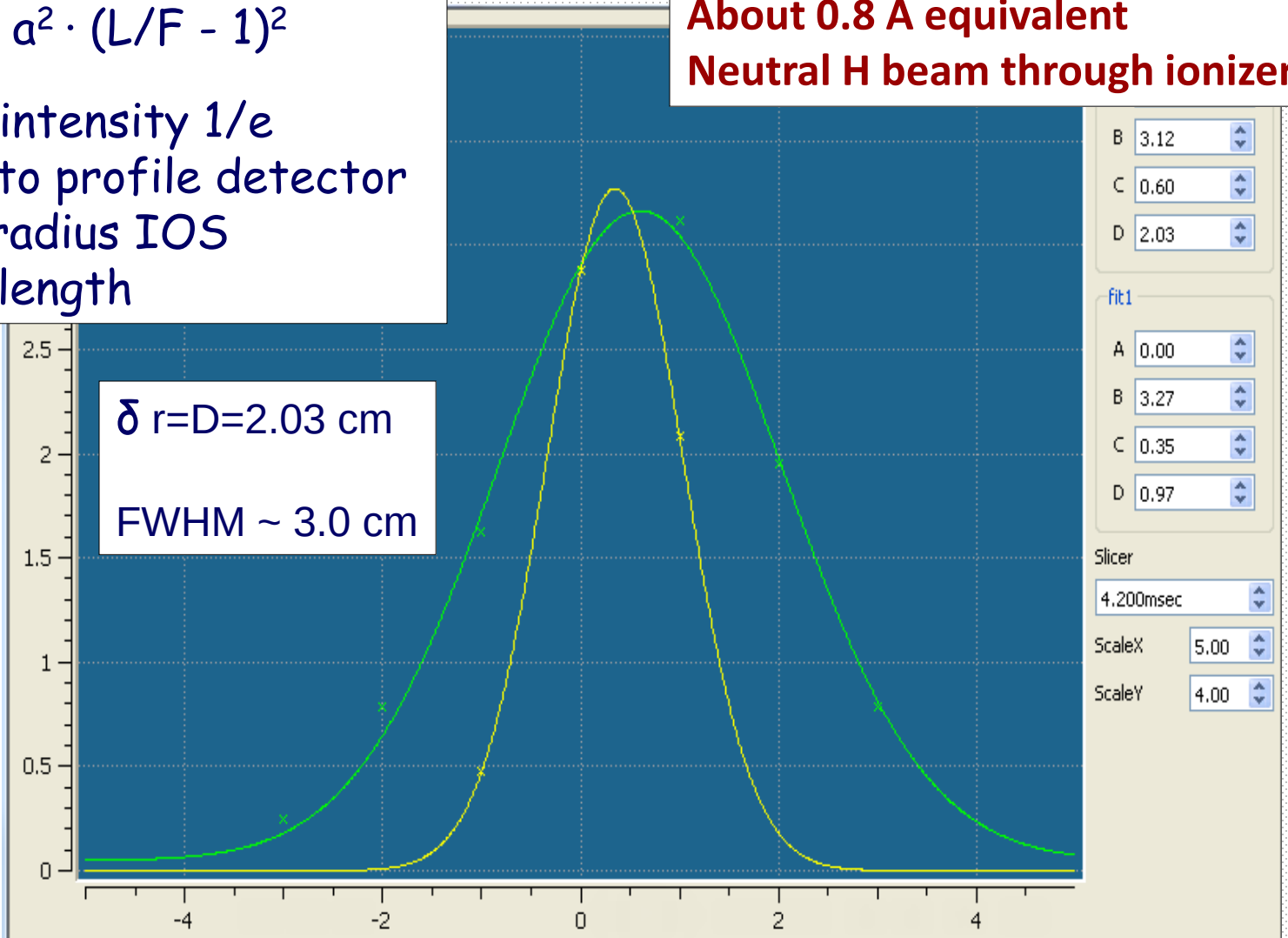
A =2.5 cm - radius IOS

F – focusing length

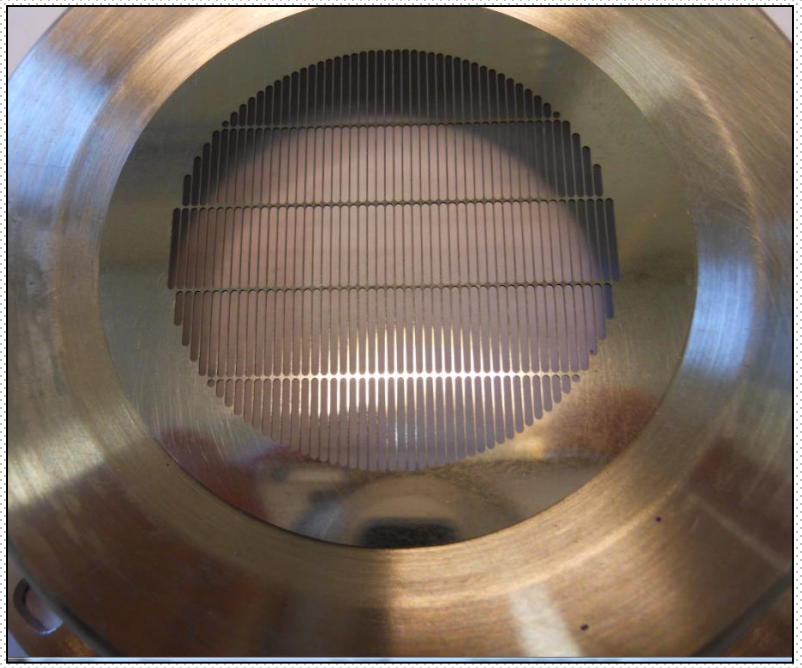
3.4 A total current

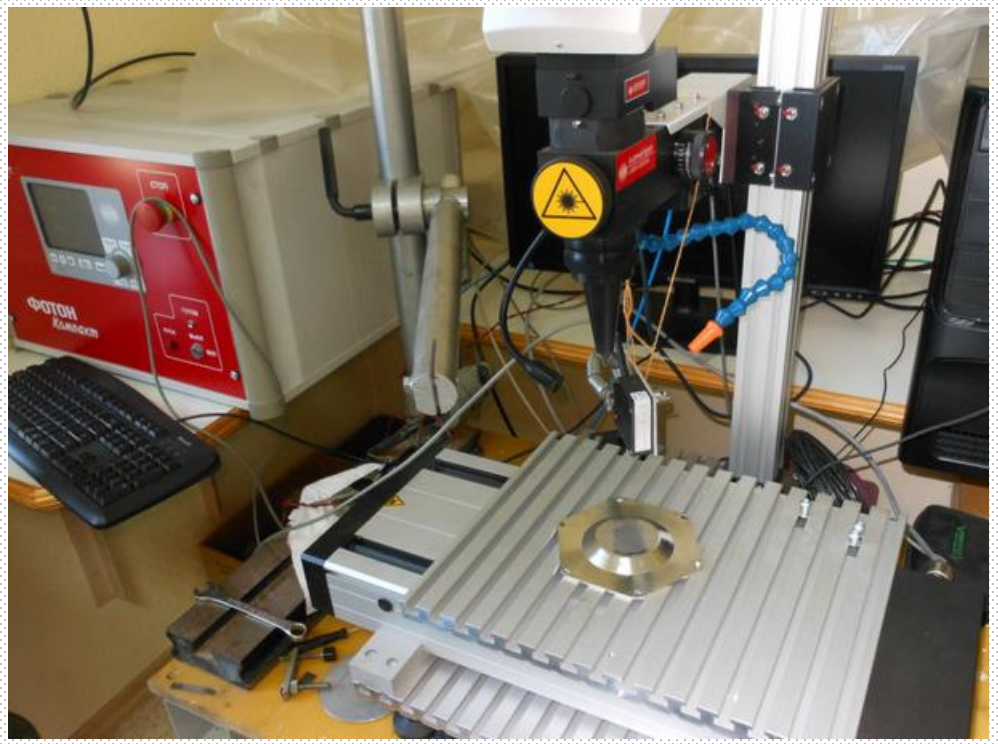
About 0.8 A equivalent

Neutral H beam through ionizer.



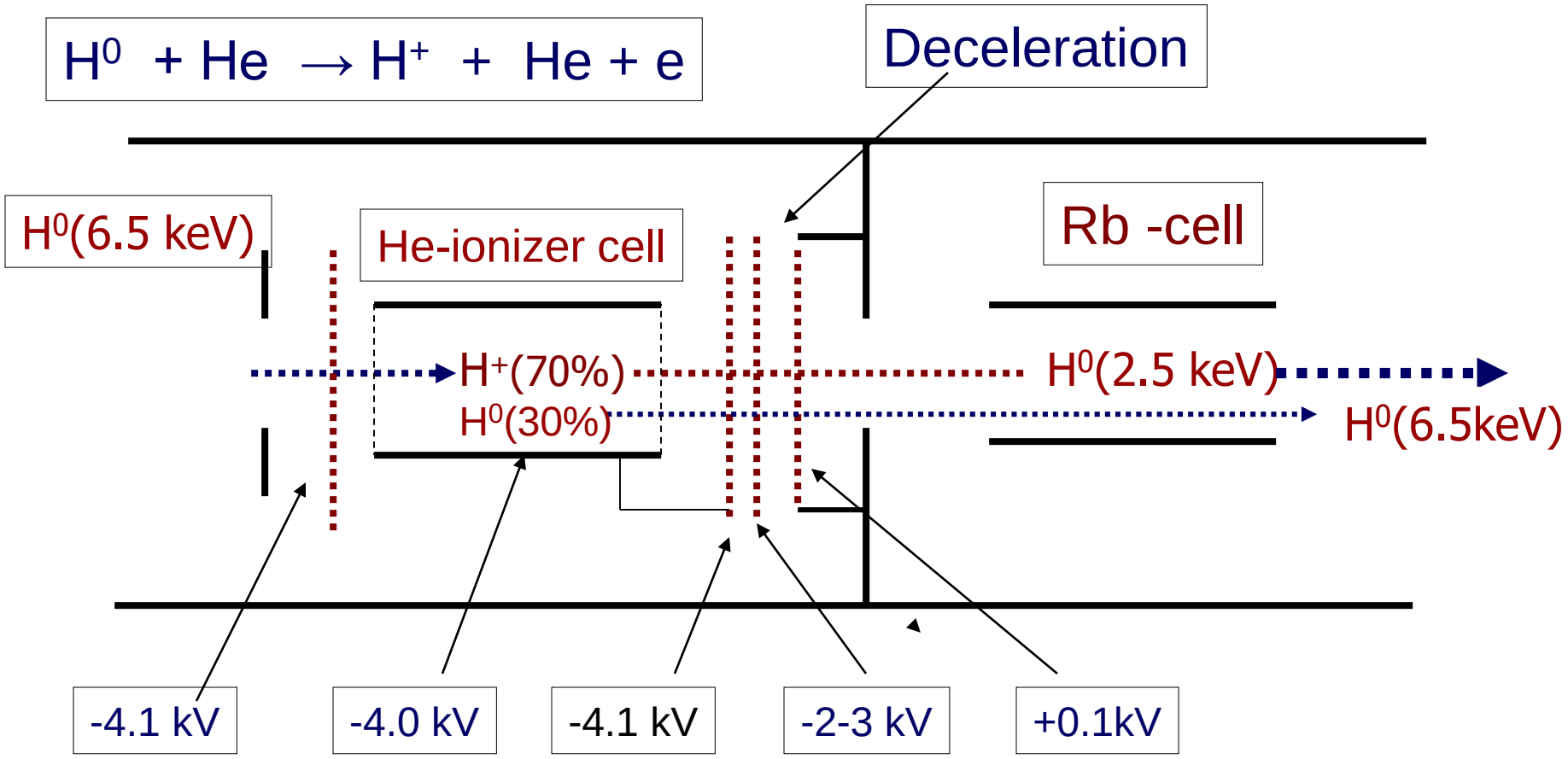
New slit-type IOS grid for higher brightness beam formation, for Run-2017



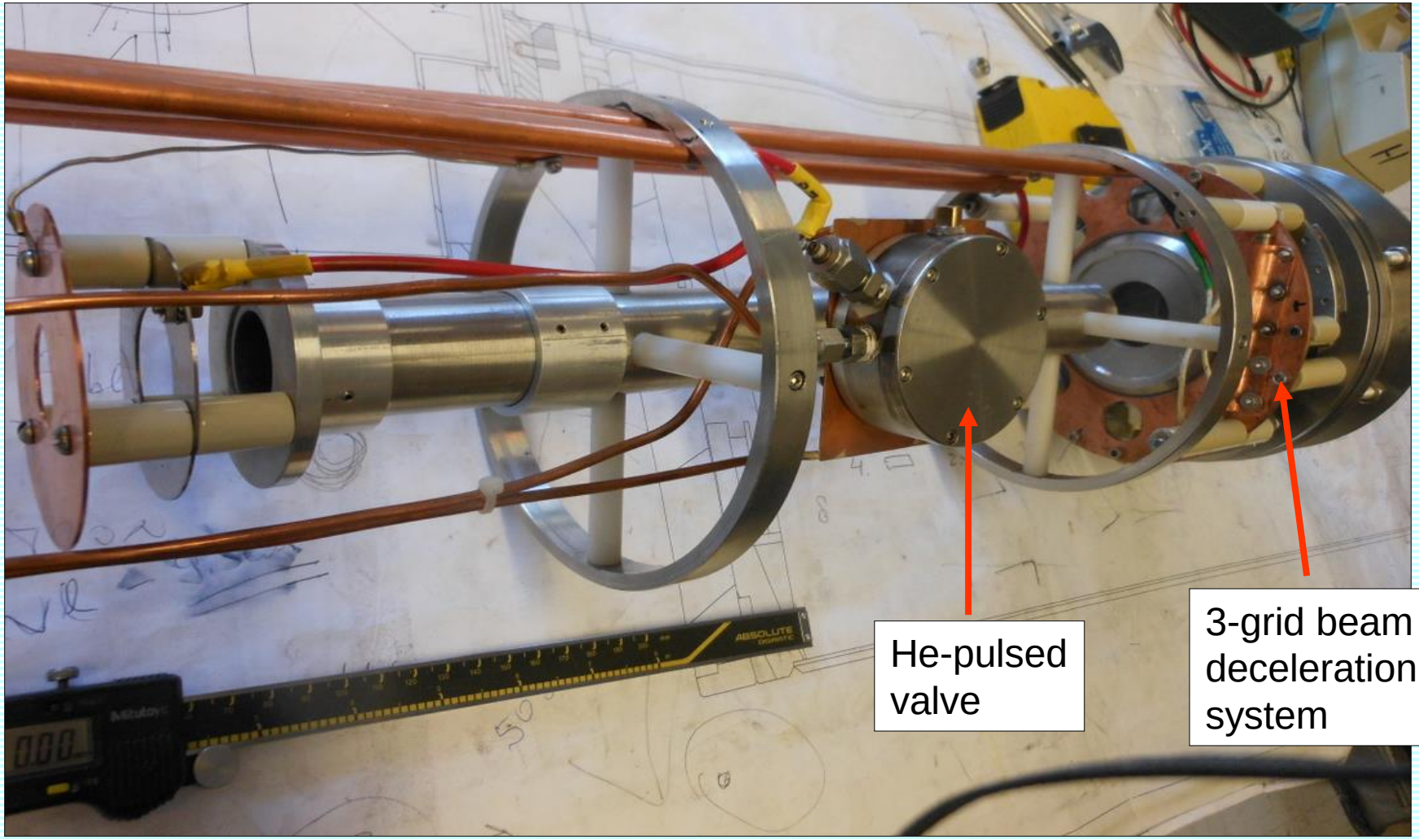


Grid assembly facilities at BINP, Novosibirsk

Residual un-polarized H^0 beam component suppression by the energy separation



He-ionizer cell and 3-grid energy separation system.

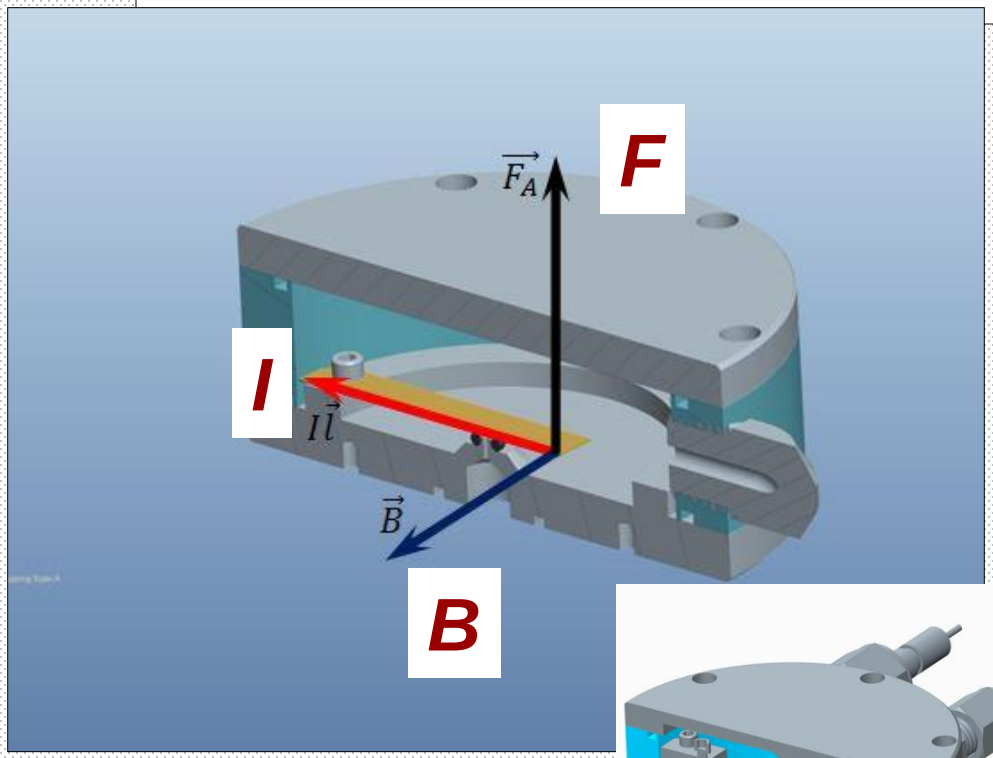


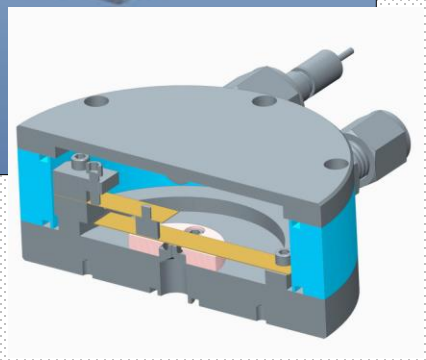
"Electro-magnetic" valve operation principle.

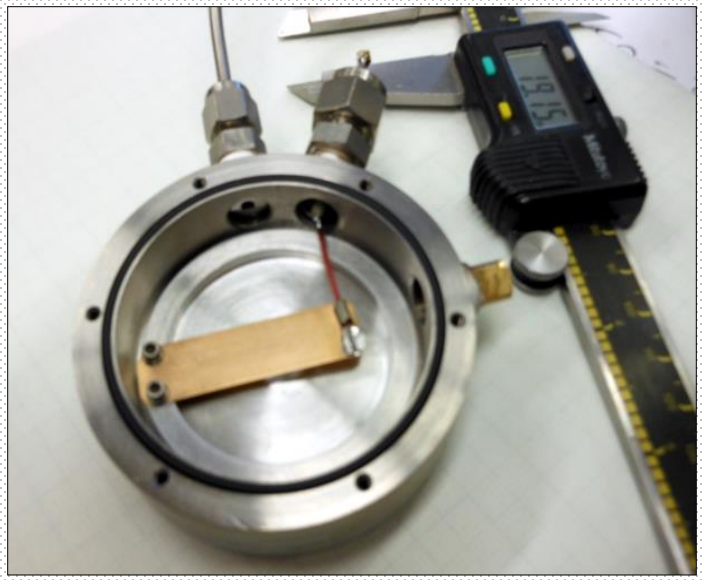
Force to the conducting plate in the (high ~ 3 T) magnetic field.

$$d\overrightarrow{F_A} = I[d\vec{l}\,\vec{B}]$$

For I=100 A, L=5 cm, F=15 N).

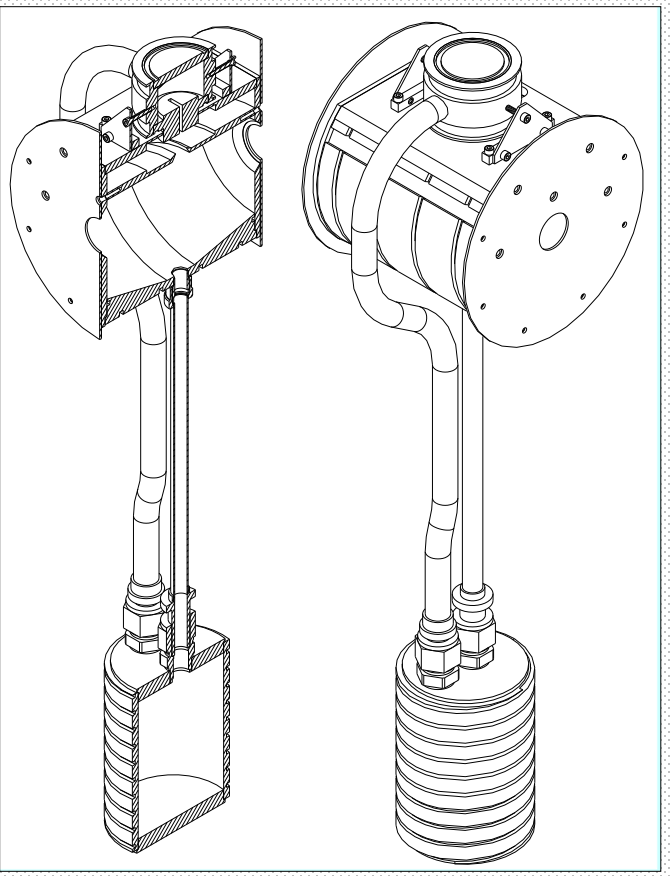


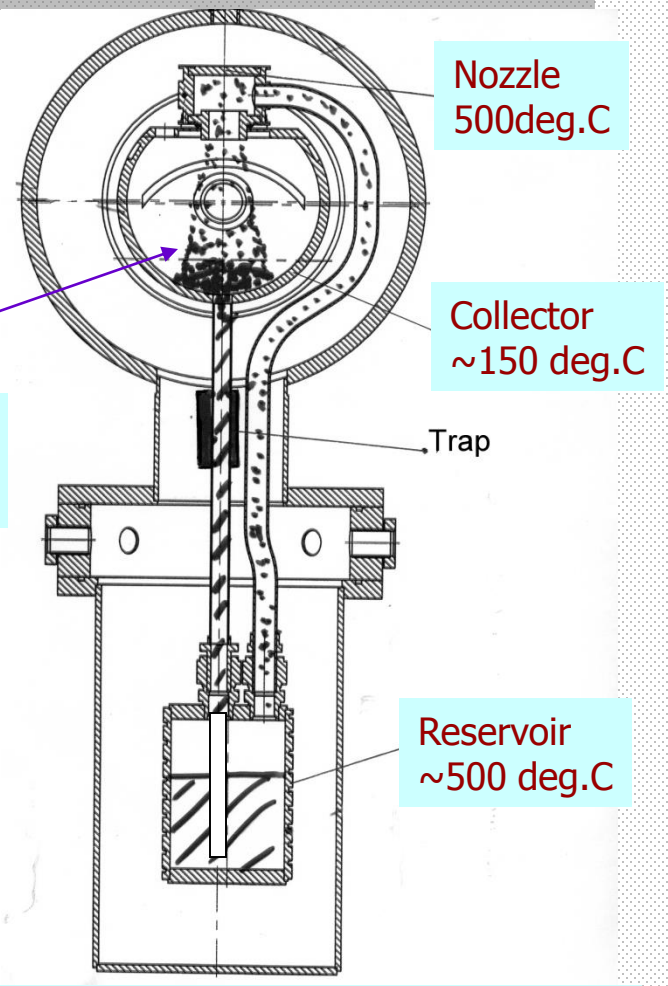




Sodium-jet ionizer cell

Transversal vapor flow in the N-jet cell.
Reduces sodium vapor losses for 3-4 orders of magnitude, which allow the cell aperture increase up to 3.0 cm .

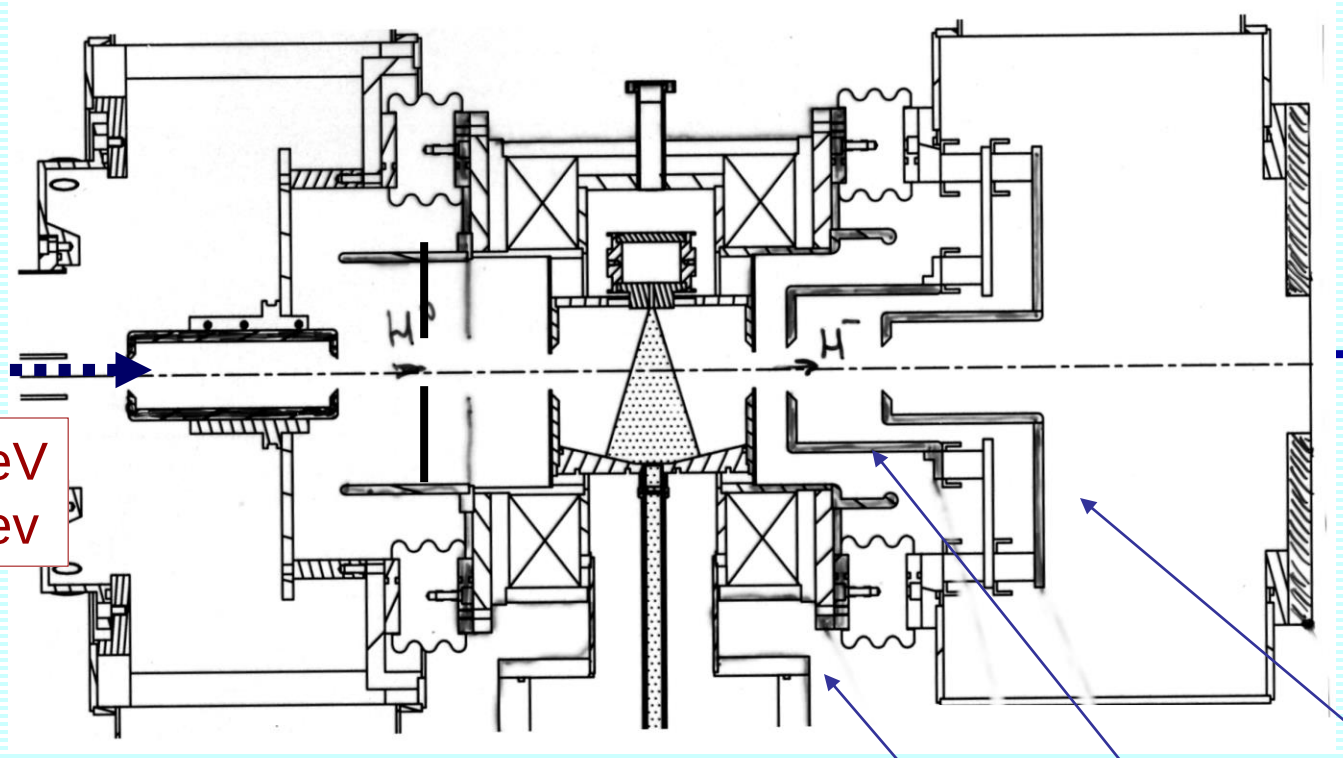




NL ~$2 \cdot 10^{15}$ atoms/cm^2
L ~ 2-3 cm

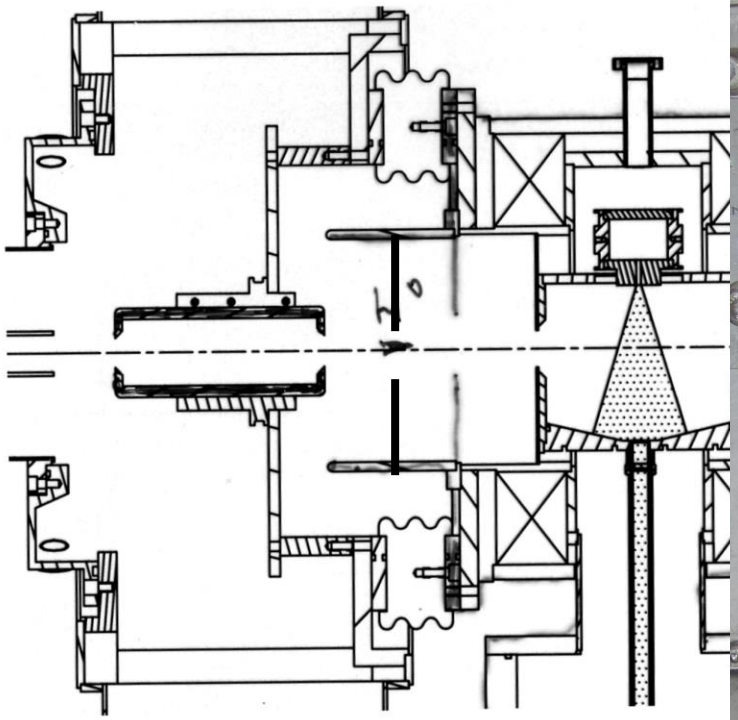
Reservoir– operational temperature. Tres. ~500 °C.
Nozzle – Tn ~500 °C.
Collector- Na-vapor condensation: Tcoll.~120°C
Trap- return line. T ~ 120 – 180 °C.

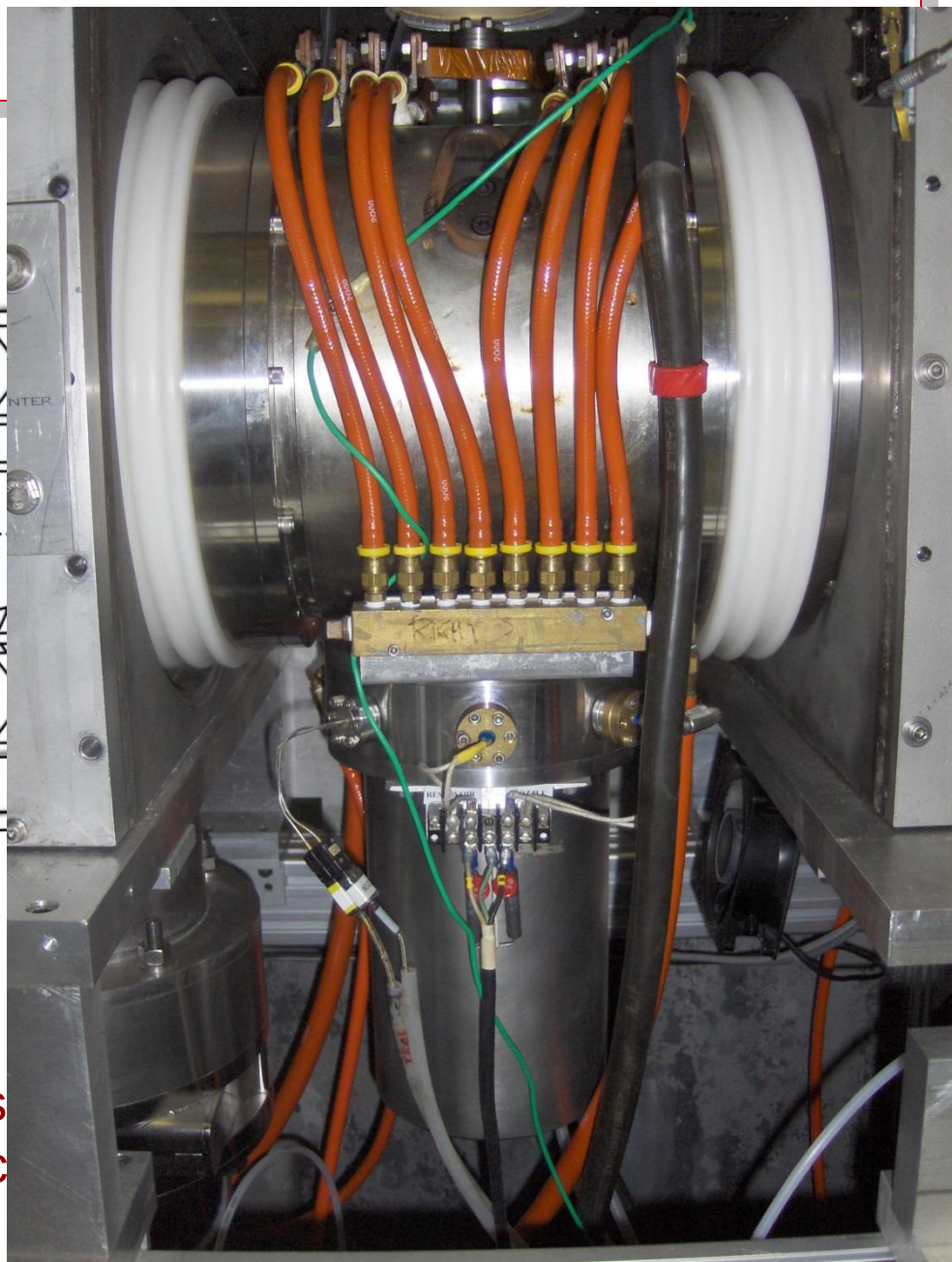
H^- beam acceleration to 35 keV at the exit of Na-jet ionizer cell



Na-jet cell is isolated and biased to – 32 keV. The H^- beam is accelerated in a two-stage acceleration system.

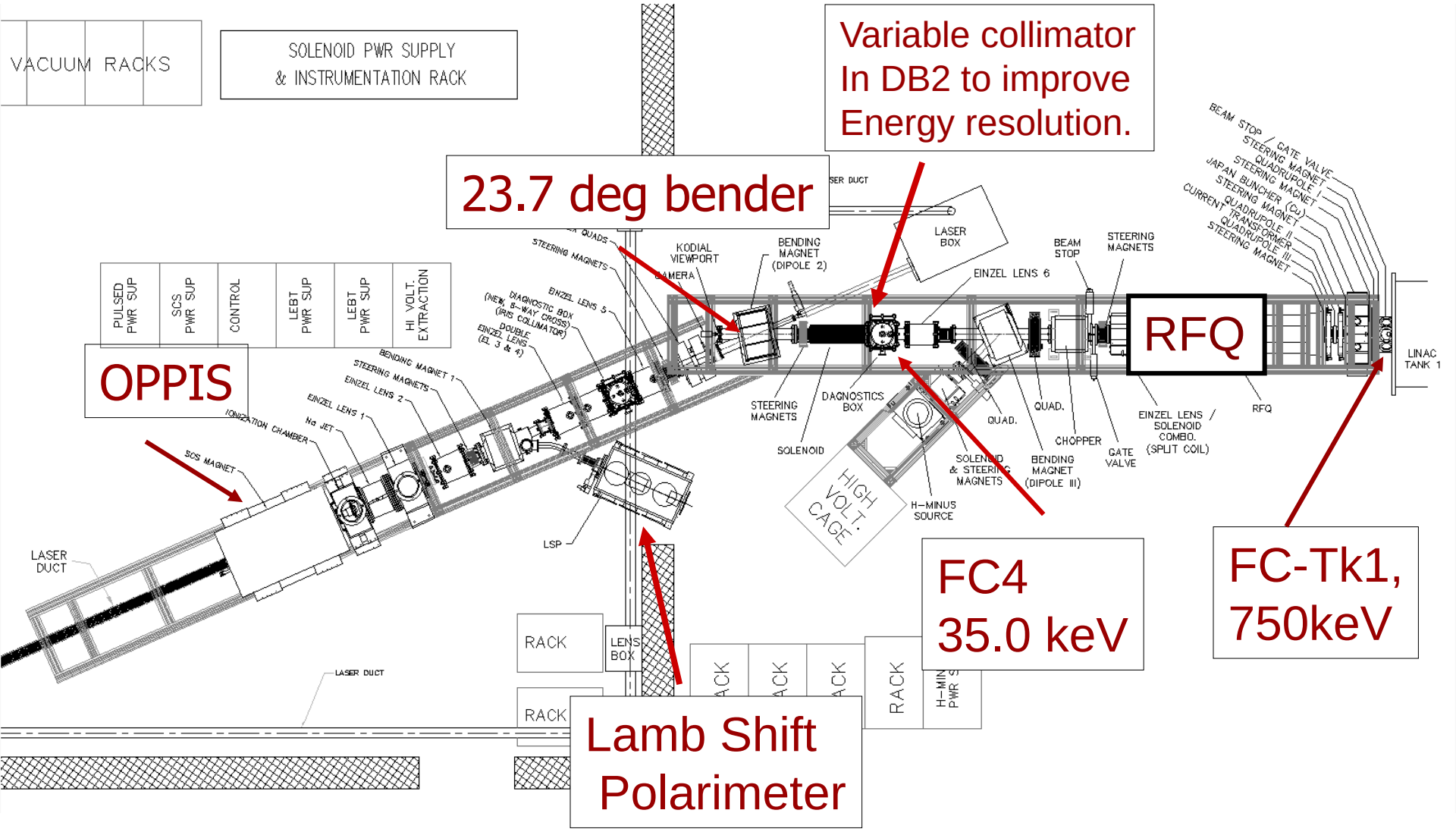
H^- beam acceleration to 35 keV at the exit of Na-jet



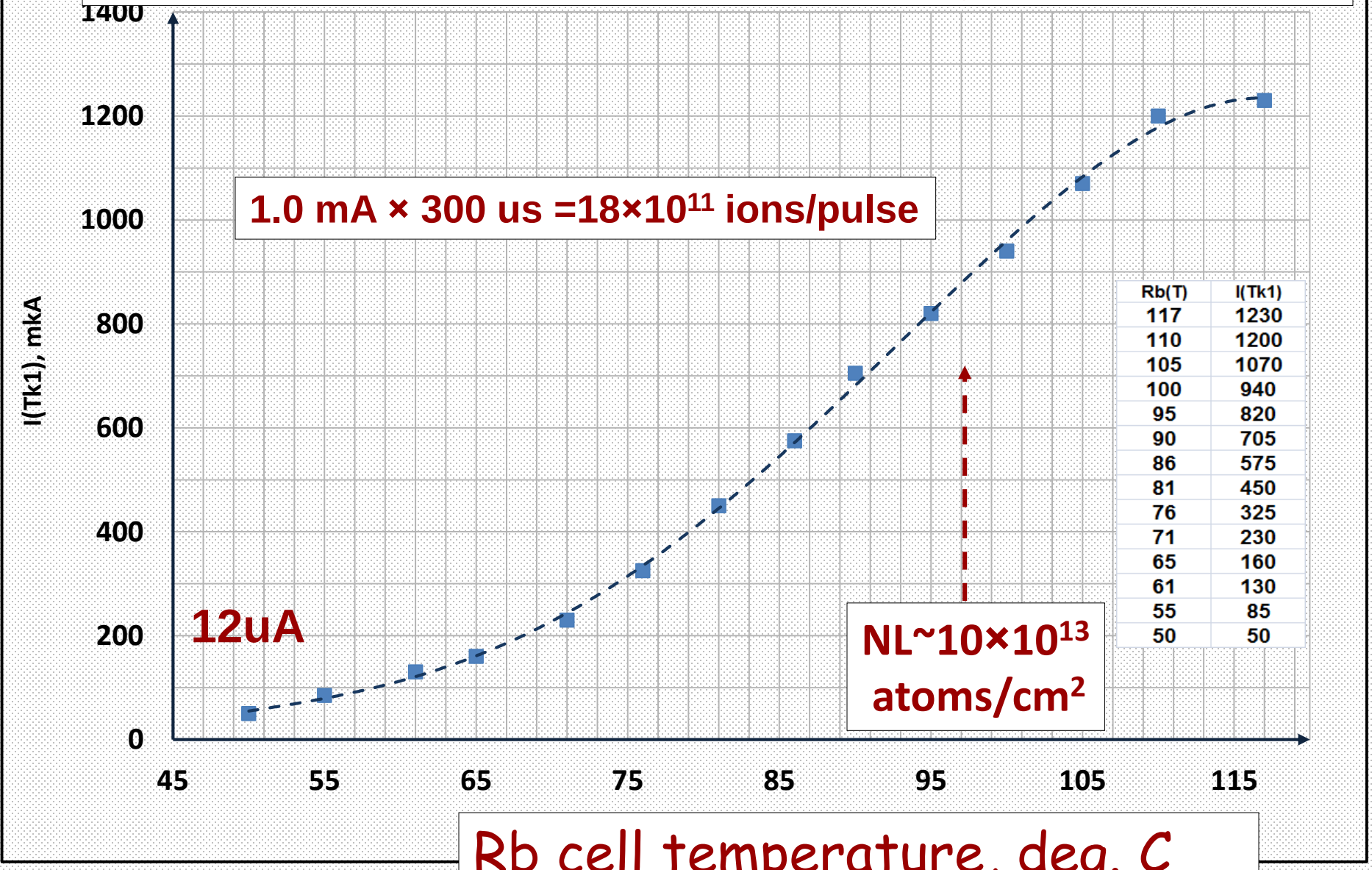


Na-jet cell is isolated and bias
accelerated in a two-stage ac

Low Energy Beam Transport line.

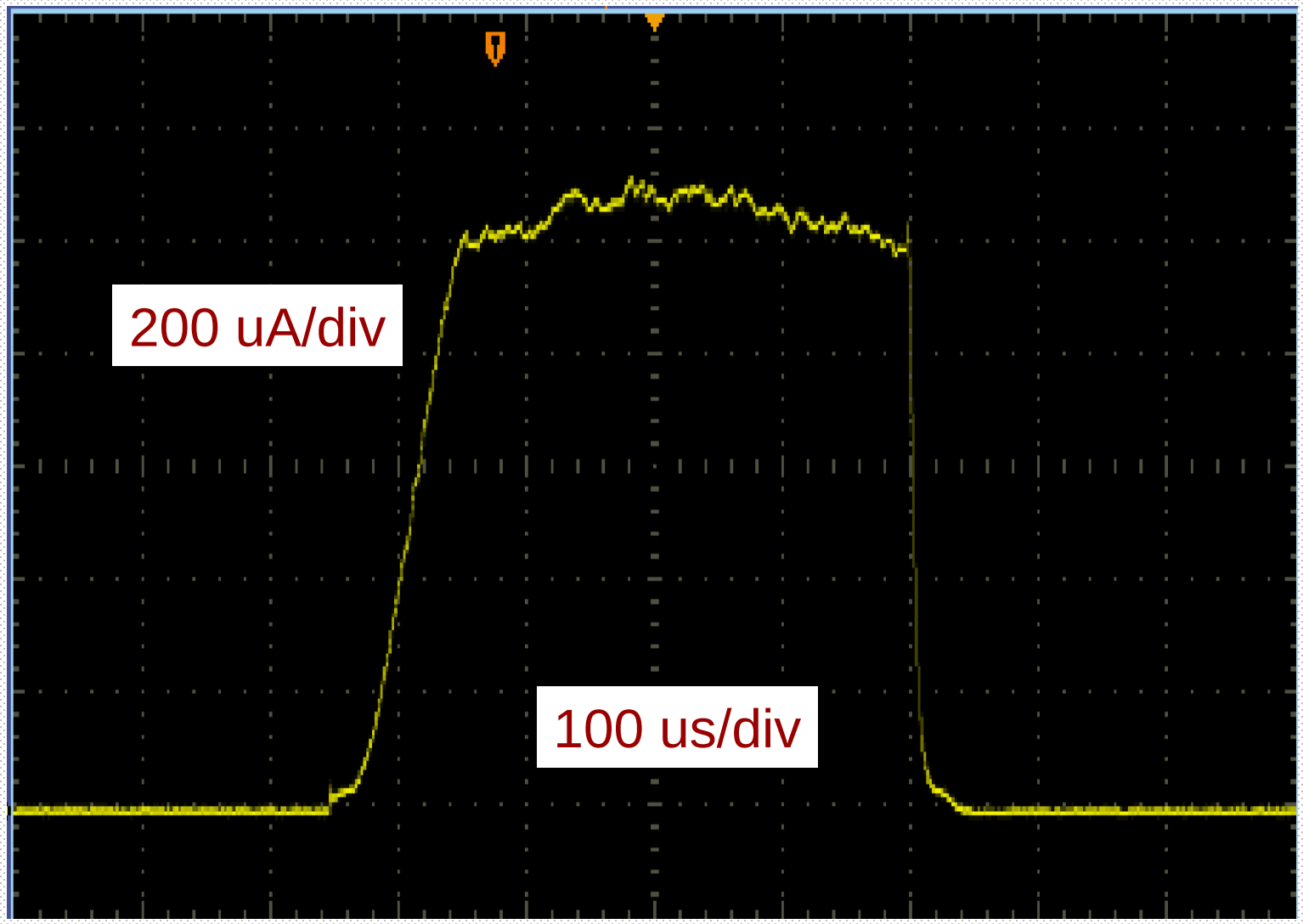


Polarized H⁻ current at 750 keV energy (after RFQ) vs. Rb-cell temperature

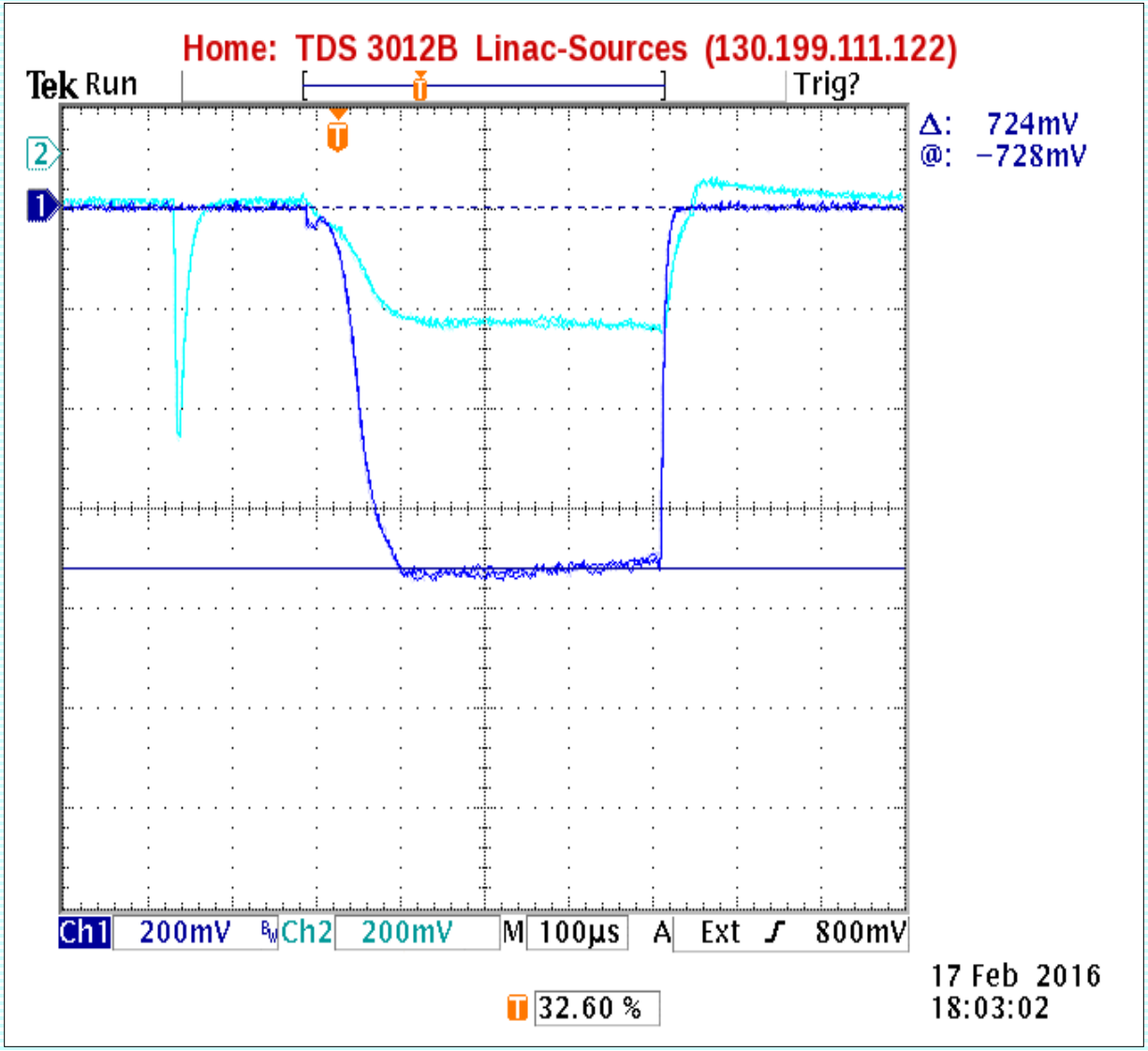


Rb(T)	I(Tk1)
117	1230
110	1200
105	1070
100	940
95	820
90	705
86	575
81	450
76	325
71	230
65	160
61	130
55	85
50	50

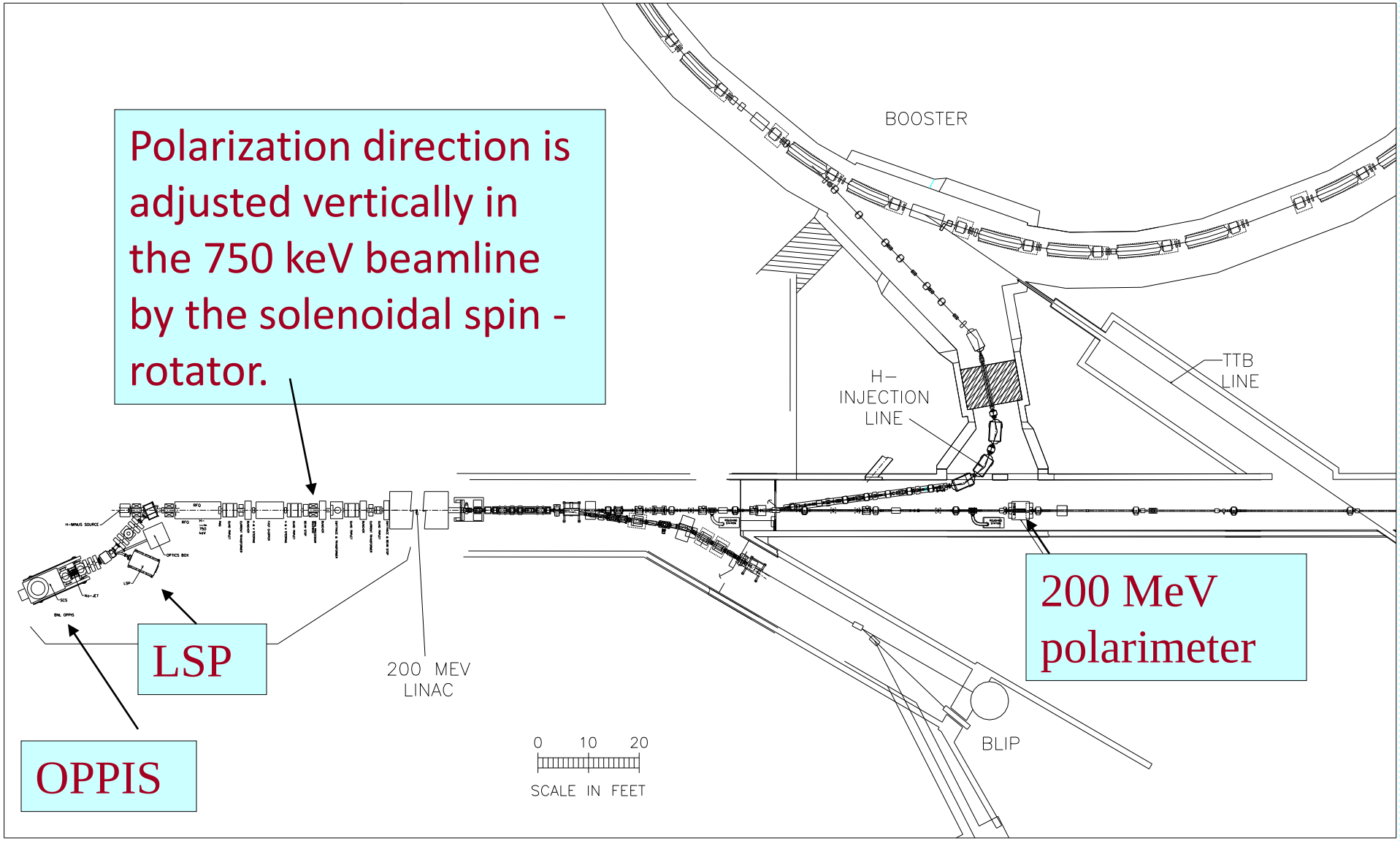
Polarized H^- current-1.05 mA, after RFQ 750 keV Rb-98°



Febr. 17, 2016. 750 uA polarized current out of the Linac



Polarized injector, 200 MeV linac and injection lines.



Proton-Carbon Elastic Scattering at 200 MeV.

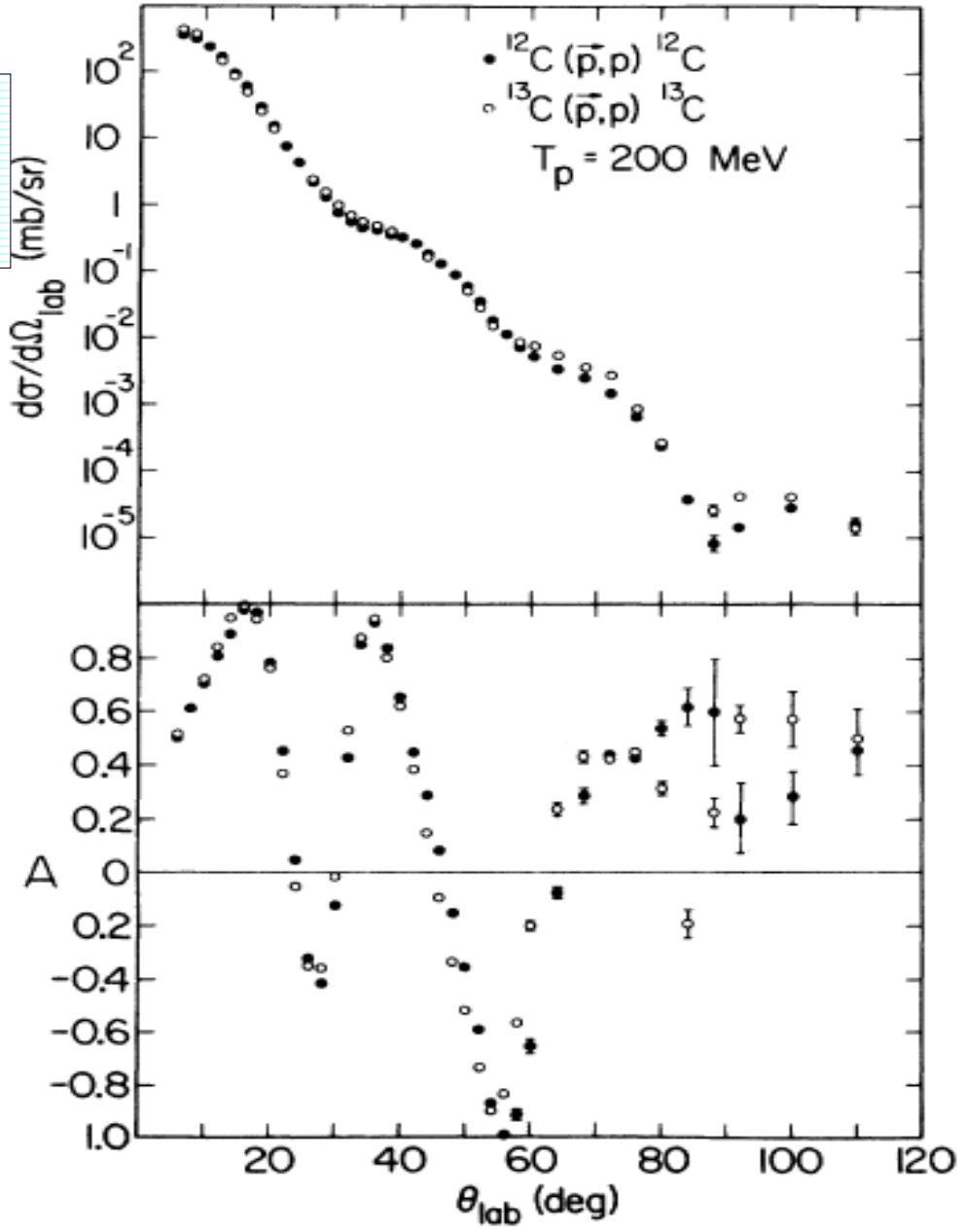
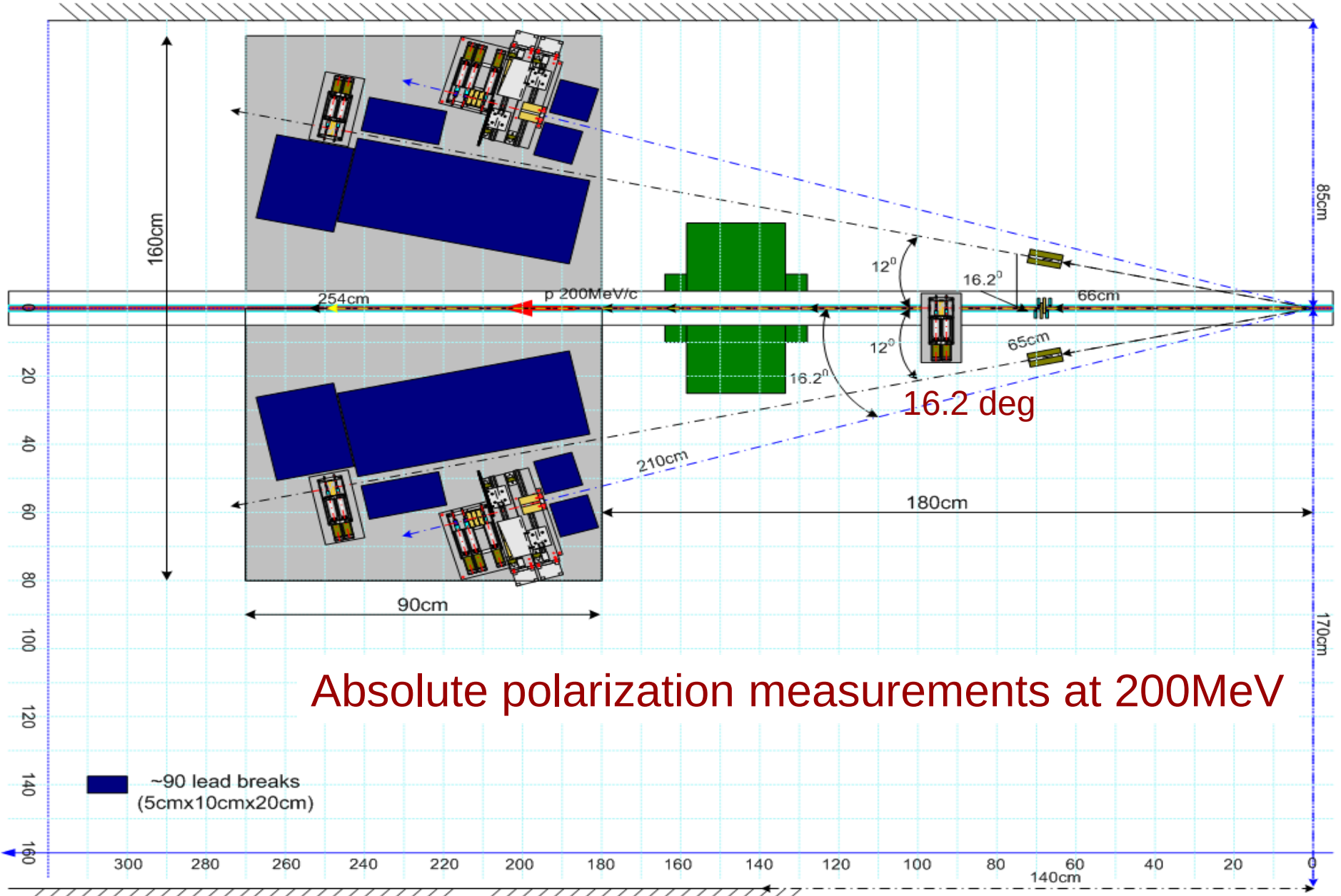
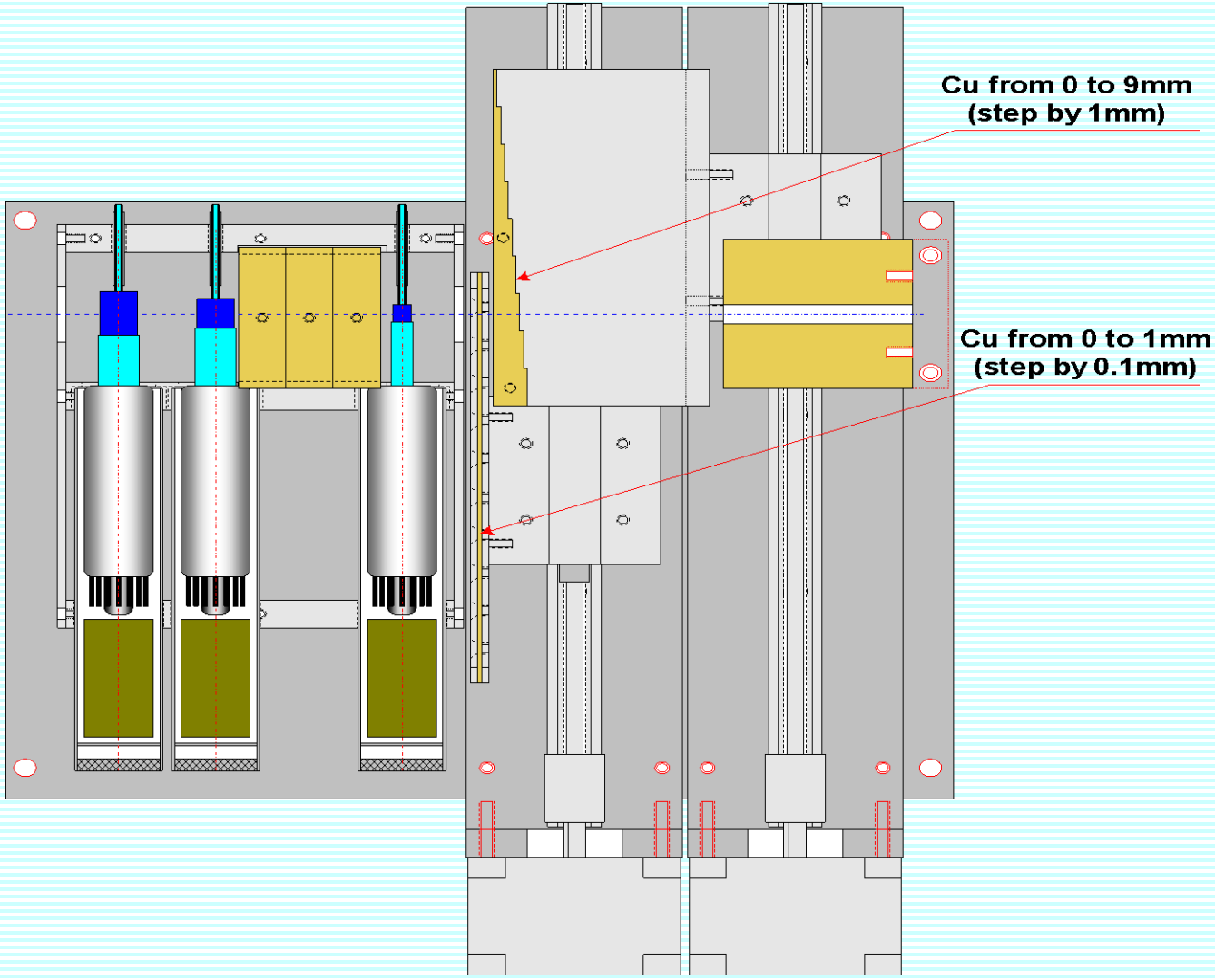


FIG. 1. Laboratory differential cross sections and analyzing powers, as a function of laboratory scattering angle, measured for 200 MeV polarized protons elastically scattered from ^{12}C and ^{13}C.

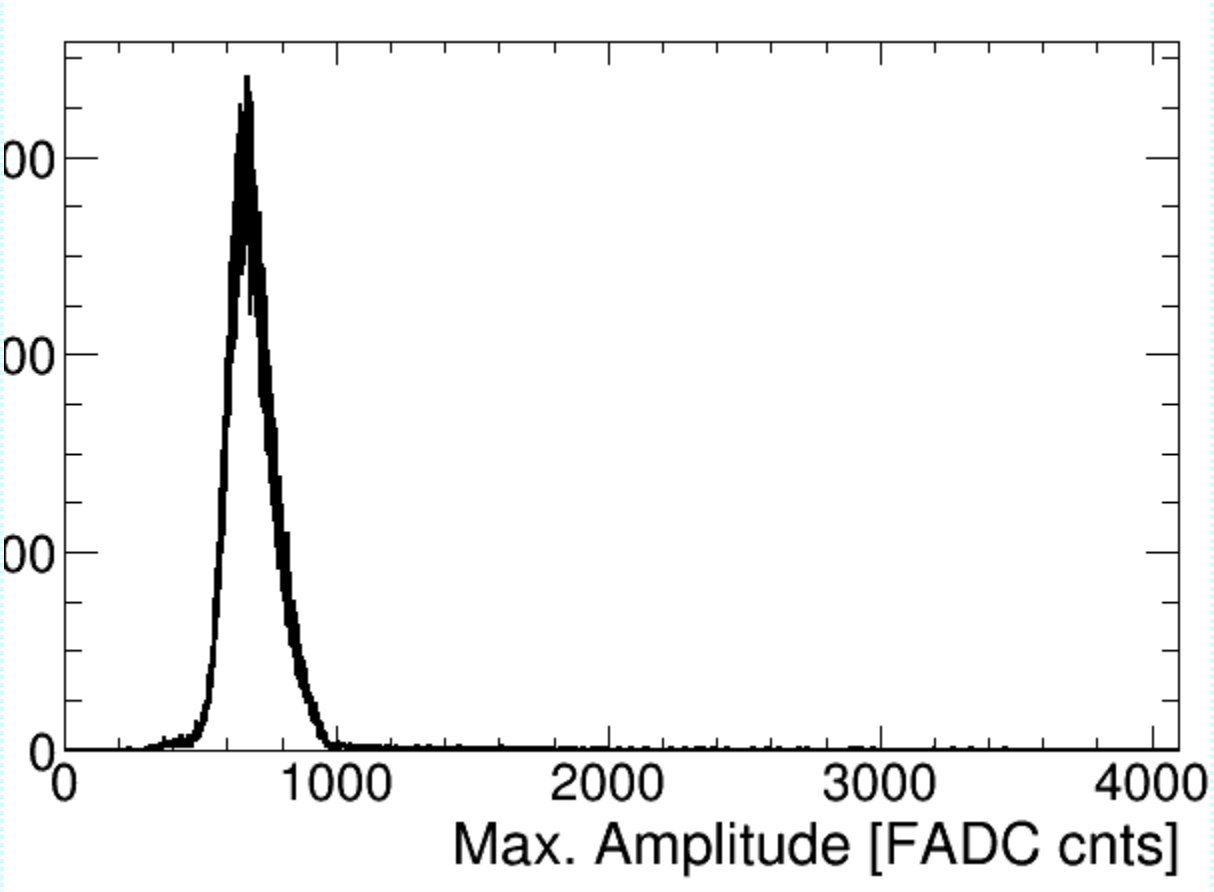
Layout of the 200 MeV proton polarimeter, (2010)



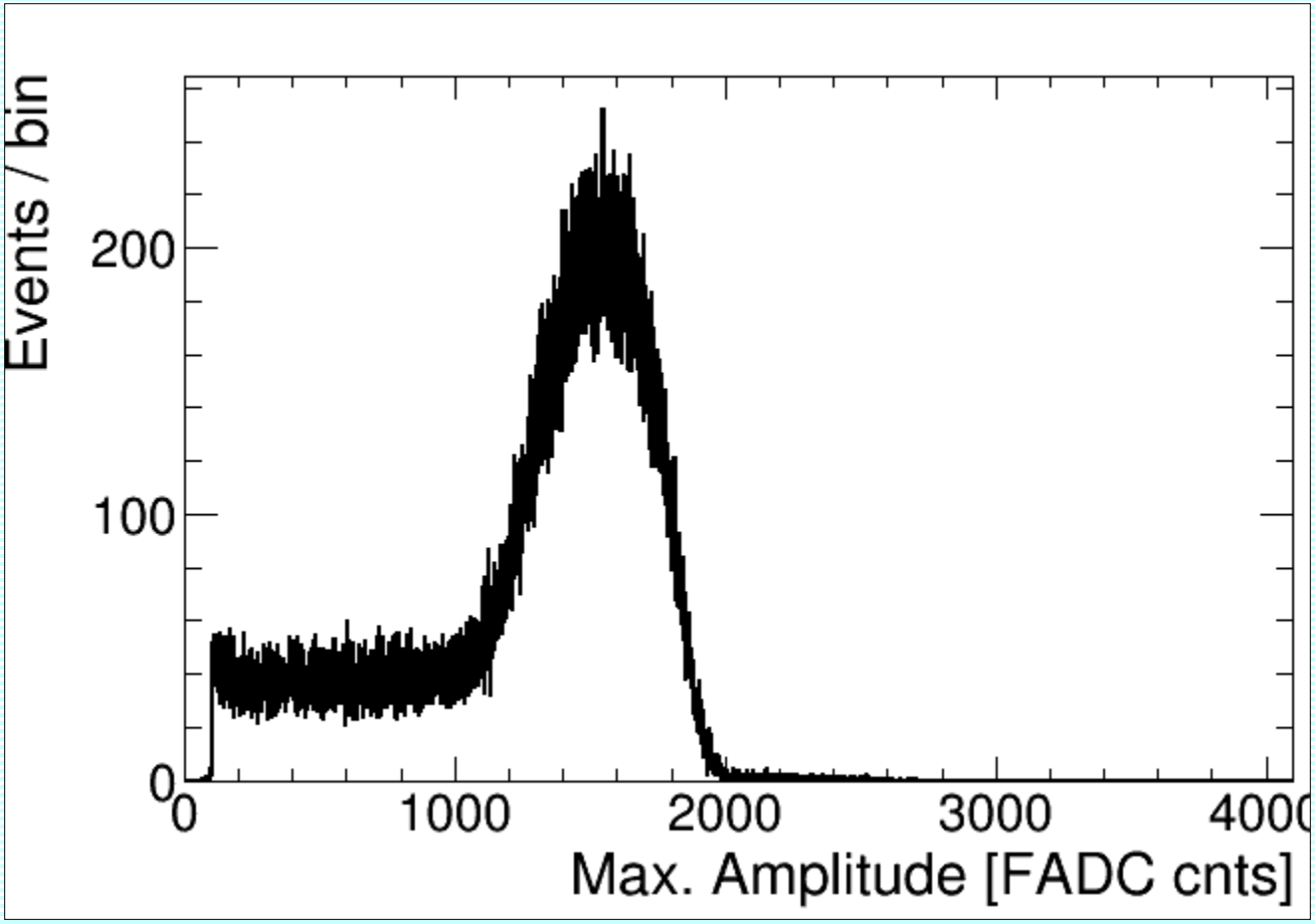
Detector and variable absorber setup for 200 MeV proton beam.



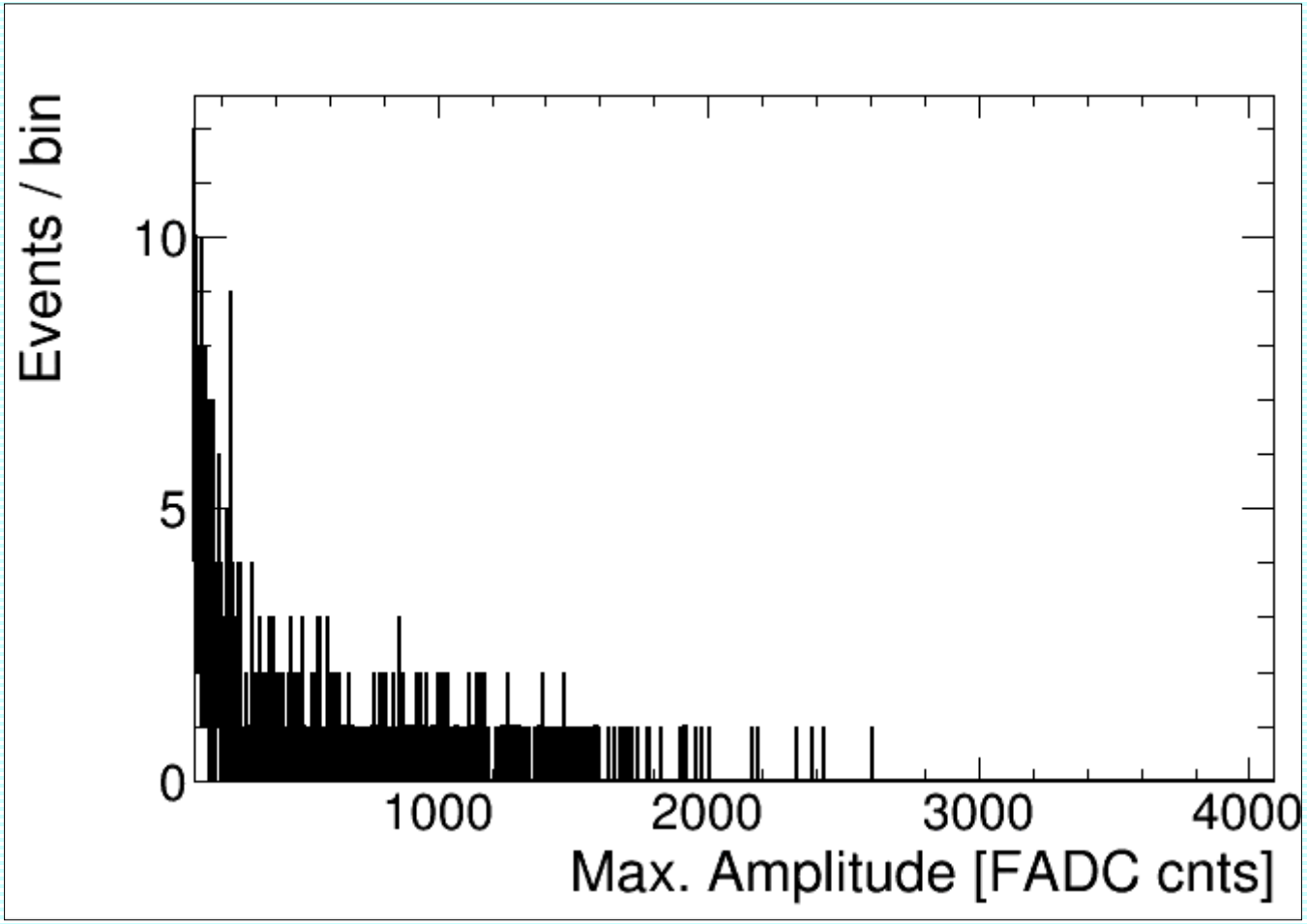
Signal amplitude distribution in the first detector



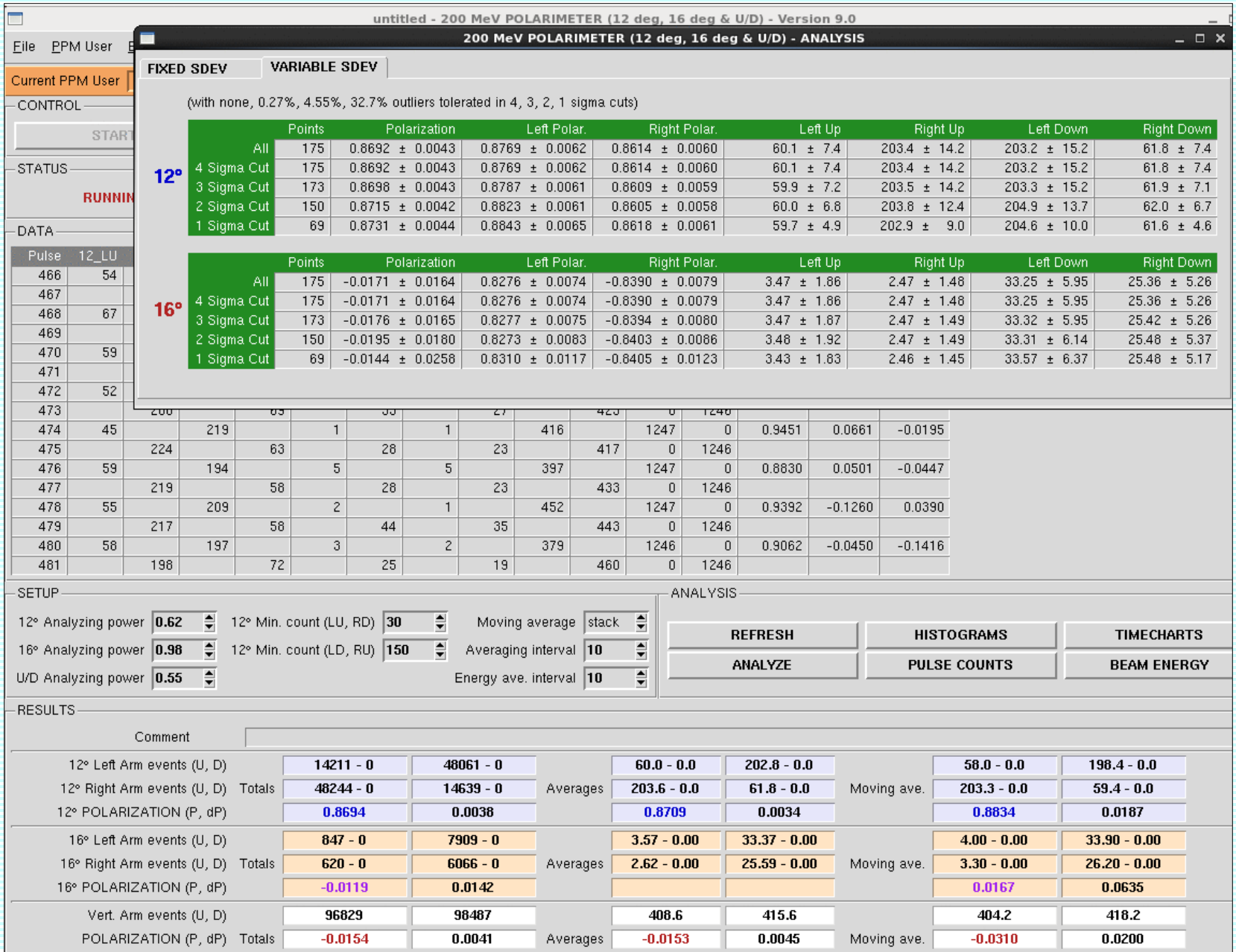
Signal amplitude distribution in the 2-nd detector



Signal amplitude distribution in the 3-rd detector



84.5% polarization was measured using WFD.



untitled - 200 MeV POLARIMETER (12 deg, 16 deg & U/D) - Version 9.0

File PPM User

Current PPM User

CONTROL

START

STATUS

RUNNIN

DATA

200 MeV POLARIMETER (12 deg, 16 deg & U/D) - ANALYSIS

FIXED SDEV | VARIABLE SDEV

(with none, 0.27%, 4.55%, 32.7% outliers tolerated in 4, 3, 2, 1 sigma cuts)

		Points	Polarization	Left Polar.	Right Polar.	Left Up	Right Up	Left Down	Right Down
12°	All	175	0.8692 ± 0.0043	0.8769 ± 0.0062	0.8614 ± 0.0060	60.1 ± 7.4	203.4 ± 14.2	203.2 ± 15.2	61.8 ± 7.4
	4 Sigma Cut	175	0.8692 ± 0.0043	0.8769 ± 0.0062	0.8614 ± 0.0060	60.1 ± 7.4	203.4 ± 14.2	203.2 ± 15.2	61.8 ± 7.4
	3 Sigma Cut	173	0.8698 ± 0.0043	0.8787 ± 0.0061	0.8609 ± 0.0059	59.9 ± 7.2	203.5 ± 14.2	203.3 ± 15.2	61.9 ± 7.1
	2 Sigma Cut	150	0.8715 ± 0.0042	0.8823 ± 0.0061	0.8605 ± 0.0058	60.0 ± 6.8	203.8 ± 12.4	204.9 ± 13.7	62.0 ± 6.7
	1 Sigma Cut	69	0.8731 ± 0.0044	0.8843 ± 0.0065	0.8618 ± 0.0061	59.7 ± 4.9	202.9 ± 9.0	204.6 ± 10.0	61.6 ± 4.6

		Points	Polarization	Left Polar.	Right Polar.	Left Up	Right Up	Left Down	Right Down
16°	All	175	-0.0171 ± 0.0164	0.8276 ± 0.0074	-0.8390 ± 0.0079	3.47 ± 1.86	2.47 ± 1.48	33.25 ± 5.95	25.36 ± 5.26
	4 Sigma Cut	175	-0.0171 ± 0.0164	0.8276 ± 0.0074	-0.8390 ± 0.0079	3.47 ± 1.86	2.47 ± 1.48	33.25 ± 5.95	25.36 ± 5.26
	3 Sigma Cut	173	-0.0176 ± 0.0165	0.8277 ± 0.0075	-0.8394 ± 0.0080	3.47 ± 1.87	2.47 ± 1.49	33.32 ± 5.95	25.42 ± 5.26
	2 Sigma Cut	150	-0.0195 ± 0.0180	0.8273 ± 0.0083	-0.8403 ± 0.0086	3.48 ± 1.92	2.47 ± 1.49	33.31 ± 6.14	25.48 ± 5.37
	1 Sigma Cut	69	-0.0144 ± 0.0258	0.8310 ± 0.0117	-0.8405 ± 0.0123	3.43 ± 1.83	2.46 ± 1.45	33.57 ± 6.37	25.48 ± 5.17

Pulse	12_LU														
466	54														
467															
468	67														
469															
470	59														
471															
472	52														
473															
474	45		219		1		1		416		1247	0	0.9451	0.0661	-0.0195
475		224		63		28		23		417	0	1246			
476	59		194		5		5		397		1247	0	0.8830	0.0501	-0.0447
477		219		58		28		23		433	0	1246			
478	55		209		2		1		452		1247	0	0.9392	-0.1260	0.0390
479		217		58		44		35		443	0	1246			
480	58		197		3		2		379		1246	0	0.9062	-0.0450	-0.1416
481		198		72		25		19		460	0	1246			

SETUP

12° Analyzing power 0.62 | 12° Min. count (LU, RD) 30 | Moving average stack

16° Analyzing power 0.98 | 12° Min. count (LD, RU) 150 | Averaging interval 10

U/D Analyzing power 0.55 | Energy ave. interval 10

ANALYSIS

REFRESH | HISTOGRAMS | TIMECHARTS

ANALYZE | PULSE COUNTS | BEAM ENERGY

RESULTS

Comment

12° Left Arm events (U, D)		14211 - 0	48061 - 0		60.0 - 0.0	202.8 - 0.0		58.0 - 0.0	198.4 - 0.0
12° Right Arm events (U, D)	Totals	48244 - 0	14639 - 0	Averages	203.6 - 0.0	61.8 - 0.0	Moving ave.	203.3 - 0.0	59.4 - 0.0
12° POLARIZATION (P, dP)		0.8694	0.0038		0.8709	0.0034		0.8834	0.0187
16° Left Arm events (U, D)		847 - 0	7909 - 0		3.57 - 0.00	33.37 - 0.00		4.00 - 0.00	33.90 - 0.00
16° Right Arm events (U, D)	Totals	620 - 0	6066 - 0	Averages	2.62 - 0.00	25.59 - 0.00	Moving ave.	3.30 - 0.00	26.20 - 0.00
16° POLARIZATION (P, dP)		-0.0119	0.0142					0.0167	0.0635
Vert. Arm events (U, D)		96829	98487		408.6	415.6		404.2	418.2
POLARIZATION (P, dP)	Totals	-0.0154	0.0041	Averages	-0.0153	0.0045	Moving ave.	-0.0310	0.0200

84.5% polarization was measured using WFD.

		Points	Polarization	Left Polar.	Right Polar.	Left Up	Right Up	Left Down	Right Down
12°	All	6	0.8563 ± 0.0209	0.8558 ± 0.0281	0.8568 ± 0.0309	49.3 ± 4.3	170.3 ± 14.4	160.8 ± 13.1	52.1 ± 5.2
	4 Sigma Cut	6	0.8563 ± 0.0209	0.8558 ± 0.0281	0.8568 ± 0.0309	49.3 ± 4.3	170.3 ± 14.4	160.8 ± 13.1	52.1 ± 5.2
	3 Sigma Cut	6	0.8563 ± 0.0209	0.8558 ± 0.0281	0.8568 ± 0.0309	49.3 ± 4.3	170.3 ± 14.4	160.8 ± 13.1	52.1 ± 5.2
	2 Sigma Cut	6	0.8563 ± 0.0209	0.8558 ± 0.0281	0.8568 ± 0.0309	49.3 ± 4.3	170.3 ± 14.4	160.8 ± 13.1	52.1 ± 5.2
	1 Sigma Cut	6	0.8563 ± 0.0209	0.8558 ± 0.0281	0.8568 ± 0.0309	49.3 ± 4.3	170.3 ± 14.4	160.8 ± 13.1	52.1 ± 5.2

		Points	Polarization	Left Polar.	Right Polar.	Left Up	Right Up	Left Down	Right Down
16°	All	6	0.8517 ± 0.0181	0.8529 ± 0.0169	0.8505 ± 0.0321	0.55 ± 0.14	7.32 ± 0.57	6.51 ± 0.79	0.63 ± 0.33
	4 Sigma Cut	6	0.8517 ± 0.0181	0.8529 ± 0.0169	0.8505 ± 0.0321	0.55 ± 0.14	7.32 ± 0.57	6.51 ± 0.79	0.63 ± 0.33
	3 Sigma Cut	6	0.8517 ± 0.0181	0.8529 ± 0.0169	0.8505 ± 0.0321	0.55 ± 0.14	7.32 ± 0.57	6.51 ± 0.79	0.63 ± 0.33
	2 Sigma Cut	6	0.8517 ± 0.0181	0.8529 ± 0.0169	0.8505 ± 0.0321	0.55 ± 0.14	7.32 ± 0.57	6.51 ± 0.79	0.63 ± 0.33
	1 Sigma Cut	6	0.8517 ± 0.0181	0.8529 ± 0.0169	0.8505 ± 0.0321	0.55 ± 0.14	7.32 ± 0.57	6.51 ± 0.79	0.63 ± 0.33

CONTROL

STATUS

DATA

Pulse	12														
106															
107															
108															
109															
110															
111															
112															
113		183		41		10		1		729	0	1335			
114	36		153		0		7		776		1335	0	1.0166	1.0101	0.0568
115		135		44											
116	53		171		0										
117		143		38											
118	46		179		2										
119		156		51		5		0		755	0	1336			
120	44		157		0		8		771		1335	0	0.8634	1.0101	0.0191
121		159		45		5		0		736	0	1335			

Polarization at 200 MeV -85.2%

SETUP

12° Analyzing power	0.62	12° Min. count (LU, RD)	20	Moving average	stack
16° Analyzing power	0.99	12° Min. count (LD, RU)	99	Averaging interval	10
U/D Analyzing power	0.55			Energy ave. interval	10

ANALYSIS

REFRESH	HISTOGRAMS	TIMECHARTS
ANALYZE	PULSE COUNTS	BEAM ENERGY

RESULTS

Comment

12° Left Arm events (U, D)		2966 - 7	9664 - 15		49.4 - 0.1	161.1 - 0.2		47.8 - 0.1	157.8 - 0.3
12° Right Arm events (U, D)	Totals	10229 - 12	3135 - 7	Averages	170.5 - 0.2	52.2 - 0.1	Moving ave.	159.4 - 0.4	49.9 - 0.2
12° POLARIZATION (P, dP)		0.8563	0.0085		0.8576	0.0092		0.8539	0.0213
16° Left Arm events (U, D)		35 - 0	406 - 3		0.58 - 0.00	6.77 - 0.05		0.60 - 0.00	6.40 - 0.20
16° Right Arm events (U, D)	Totals	445 - 1	38 - 0	Averages	7.42 - 0.02	0.63 - 0.00	Moving ave.	6.20 - 0.00	0.60 - 0.00
16° POLARIZATION (P, dP)		0.8498	0.0180					0.8318	0.0491

Source intensity and polarization.

- Reliable long-term ·operation of the source was demonstrated.
- Very high suppression of un-polarized beam component was demonstrated.
- Small beam emittance (after collimation for energy separation) and high transmission to 200 MeV.

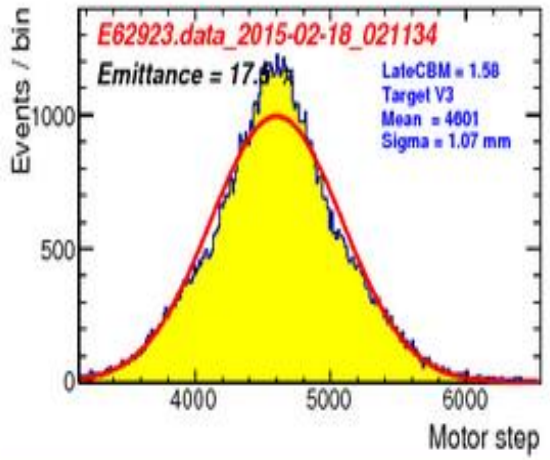
Rb-cell thickness-NL	4.5	5.5	7.5	10.4
Linac Current, μA	500	560	680	750
Booster Input $\times 10^{11}$	9.0	10.0	12.2	13.5
Pol. %, at 200 MeV	84	83	80.5	78

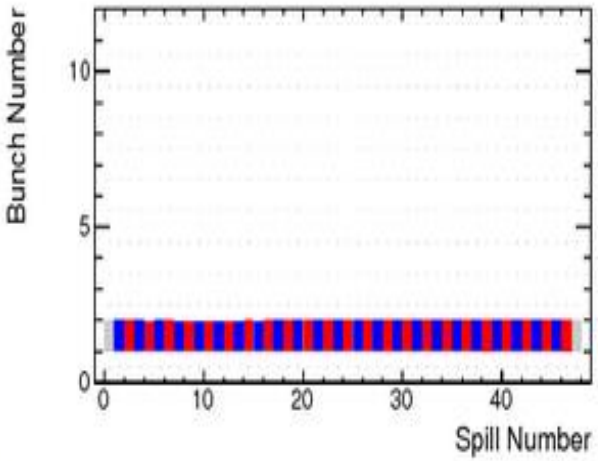
Rb-cell thickness ,NL $\times 10^{13}$ atoms/cm^2

Polarization in AGS, 23 GeV

Wed Feb 18 02:12:26 2015 Wed Feb 18 02:15:34 2015

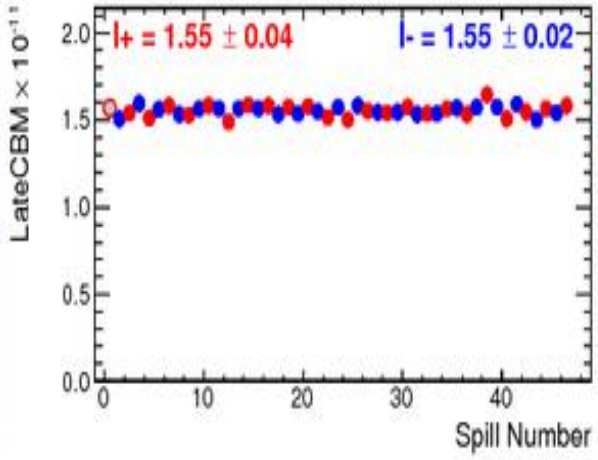
Run 62923 V3 I=1.55 Stat=38.9 (41.0) P = 74.3 ± 2.2%



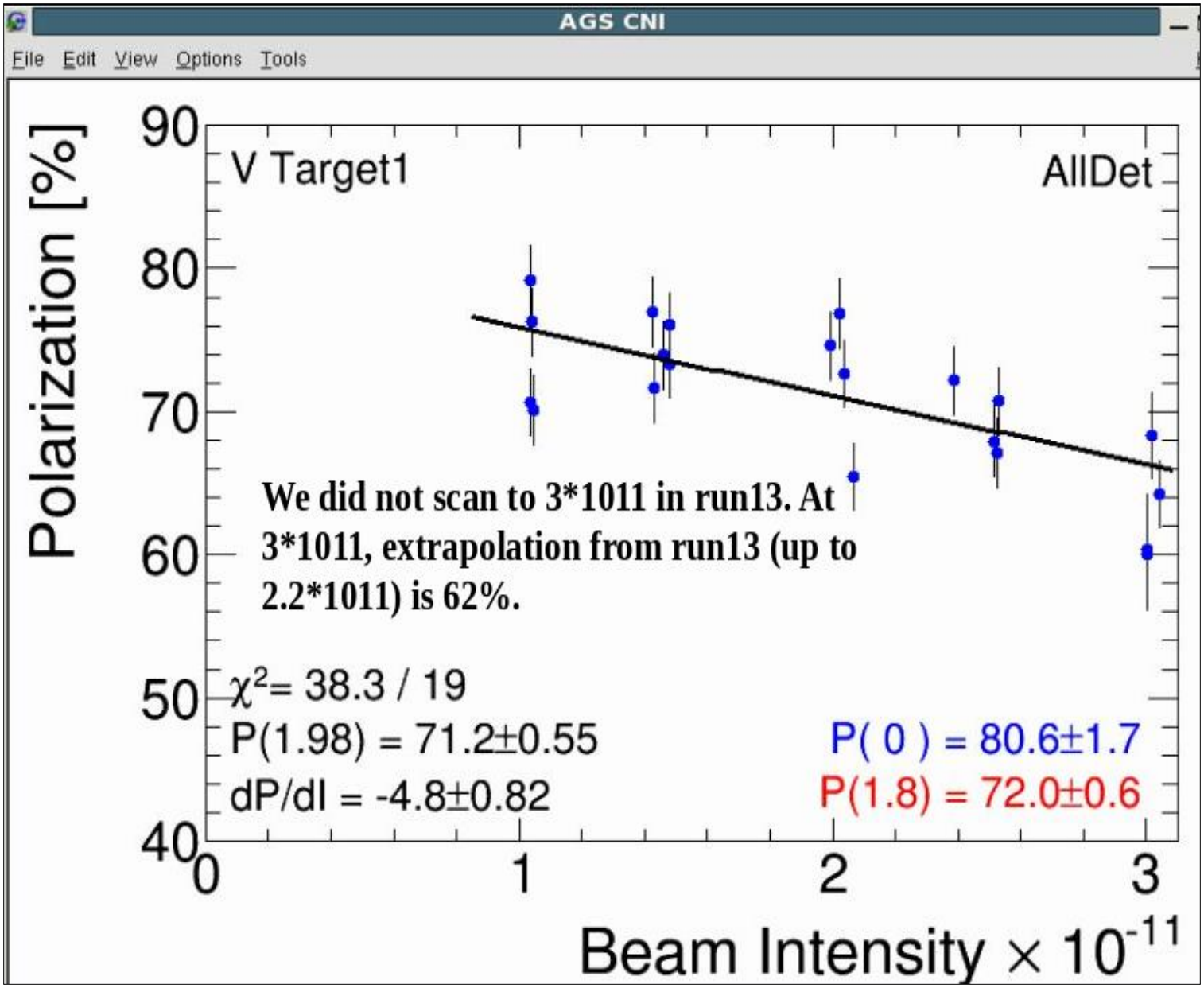


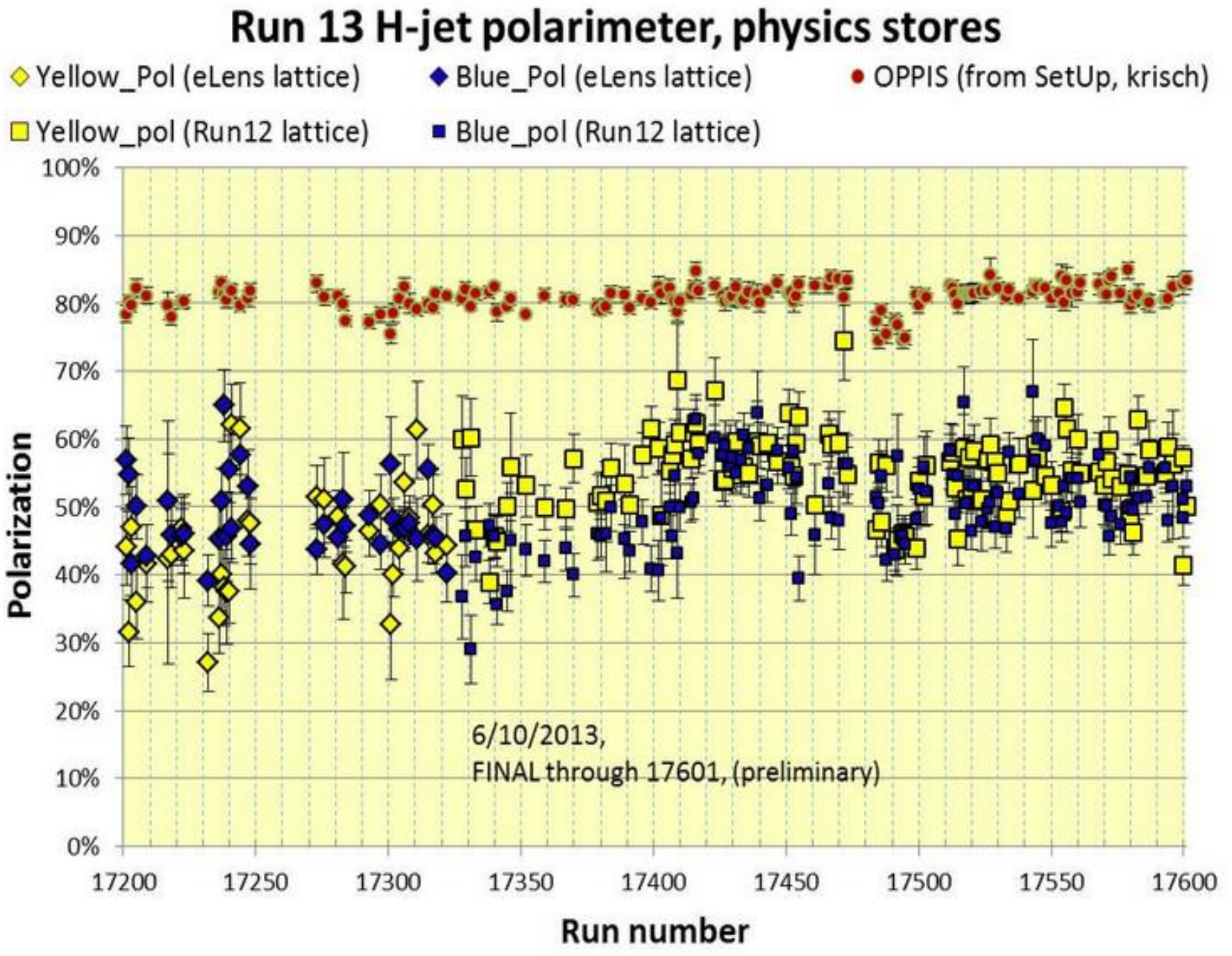
Detectors	Stat.	Polar.	(no corr.)
All	19.3	74.3 ±2.2	(70.6±2.2)
90deg	6.6	75.5 ±3.1	(71.7±3.1)
90degUp	6.6	75.5 ±3.1	(71.7±3.1)
90degDn			
45deg	12.7	73.0 ±3.1	(69.4±3.2)
45degUp	6.2	72.8 ±4.5	(69.2±4.6)
45degDn	6.5	73.2 ±4.4	(69.6±4.5)

Det.Mask=0xFF R.C.=1.00

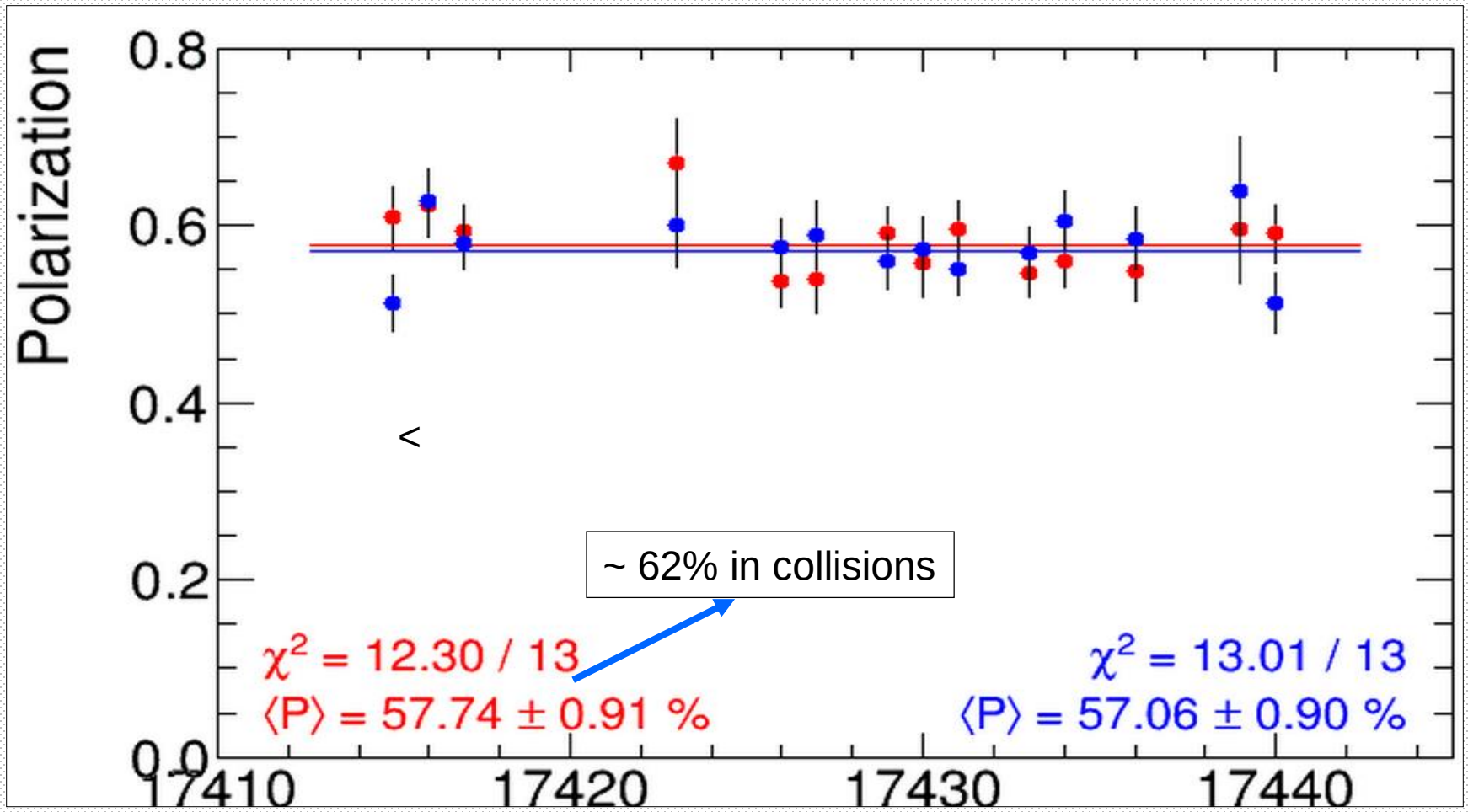


AGS polarization vs. beam intensity



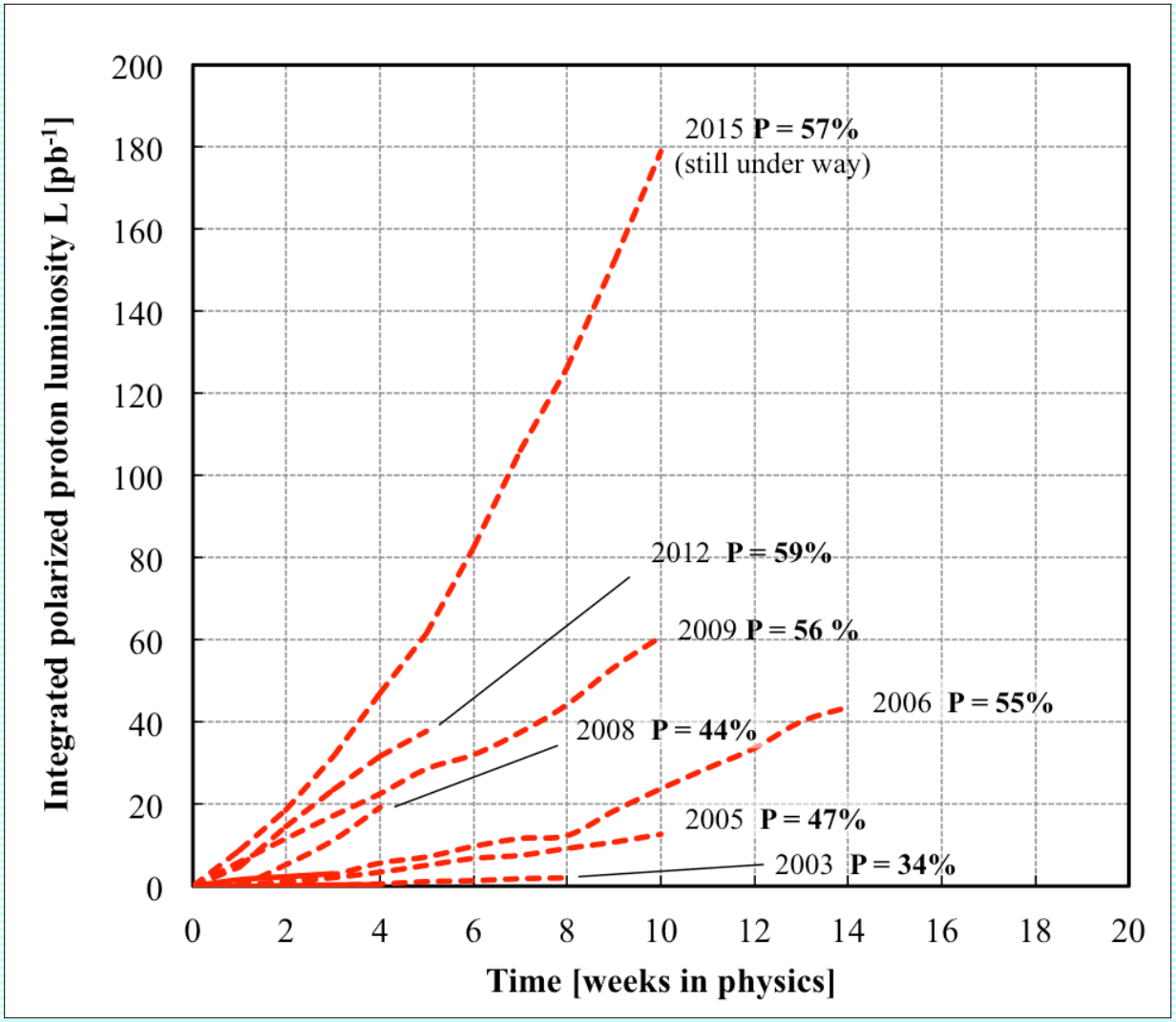

Run 13 H-jet polarimeter, physics stores
Yellow_Pol (eLens lattice)
Blue_Pol (eLens lattice)
OPPIS (from SetUp, krisch)
Yellow_pol (Run12 lattice)
Blue_pol (Run12 lattice)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Polarization
6/10/2013,
FINAL through 17601, (preliminary)
17200
17250
17300
17350
17400
17450
17500
17550
17600
Run number

Polarization measurements at 255 GeV in H-jet polarimeter, Run-2013.



Polarized p-p, p-Au and p-Al collisions at 100 GeV.

p-p high- luminosity operation in Run 2015 at 100 GeV.



Summary

- A number of improvements were implemented in 2016 and preparation for the next polarized Run-2017 in RHIC.
- Atomic injector stability was improved after pulsed valve upgrades. A new IOS is under development.
- Laser wavelength and line-width control was improved with two etalon operation.
- Sodium – jet ionizer reliability was improved with the new connector coupling for the hot Na-vapor and Na-metal.
- A lot of measurements at 200 MeV. Discovery of the Linac tune for the small beam emittance.
- New measurements in 200 MeV absolute elastic polarimeter with the Wave Form Digitizers.