PETERSBURG NUCLEAR PHYSICS INSTITUTE NAMED BY B.P. KONSTANTINOV
OF NATIONAL RESEARCH CENTRE «KURCHATOV INSTITUTE»

Crystal technology at PNPI

Yury M. Ivanov and Yury A. Gavrikov

HiLumi LHC - Crystal Collimation Day, CERN

October 19, 2018

Crystal facility were founded to support basic researches at PNPI

Facility founders:

Yu.P.Platonov - fine mechanics and astronomic optics

A.I.Smirnov - particle masses, beam focusing with crystals

O.I.Sumbaev – quasi-mosaic (QM) effect, volume capture (VC) effect

Bent quartz crystals to measure particle masses

Crystals 1x120x120 mm^3, QM cuts

Bending 5 meters

Best measurement up to now

Best measurement up to now

PHYSICAL REVIEW D 98, 030001 (2018)

REVIEW OF PARTICLE PHYSICS

$K^{\pm}$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	CHG	COMMENT
493.677 ±0.016 OUR FIT	Error includes scale factor of 2.8.			
493.677 ±0.013 OUR AVERAGE	Error includes scale factor of 2.4. See the ideogram below.			
493.696 ±0.007	[1] DENISOV 91	CNTR	−	Kaonic atoms
493.636 ±0.011	[2] GALL 88	CNTR	−	Kaonic atoms
493.640 ±0.054	LUM 81	CNTR	−	Kaonic atoms
493.670 ±0.029	BARKOV 79	EMUL	±	$e^+e^- \to K^+K^-$
493.657 ±0.020	[2] CHENG 75	CNTR	−	Kaonic atoms
493.691 ±0.040	BACKENSTO...73	CNTR	−	Kaonic atoms
• • • We do not use the following data for averages, fits, limits, etc. • • •				
493.631 ±0.007	GALL 88	CNTR	−	K^-Pb (9→ 8)
493.675 ±0.026	GALL 88	CNTR	−	K^-Pb (11→ 10)
493.709 ±0.073	GALL 88	CNTR	−	K^-W (9→ 8)
493.806 ±0.095	GALL 88	CNTR	−	K^-W (11→ 10)
493.640 ±0.022 ±0.008	[3] CHENG 75	CNTR	−	K^-Pb (9→ 8)
493.658 ±0.019 ±0.012	[3] CHENG 75	CNTR	−	K^-Pb (10→ 9)
493.638 ±0.035 ±0.016	[3] CHENG 75	CNTR	−	K^-Pb (11→ 10)
493.753 ±0.042 ±0.021	[3] CHENG 75	CNTR	−	K^-Pb (12→ 11)
493.742 ±0.081 ±0.027	[3] CHENG 75	CNTR	−	K^-Pb (13→ 12)

Σ^- MASS

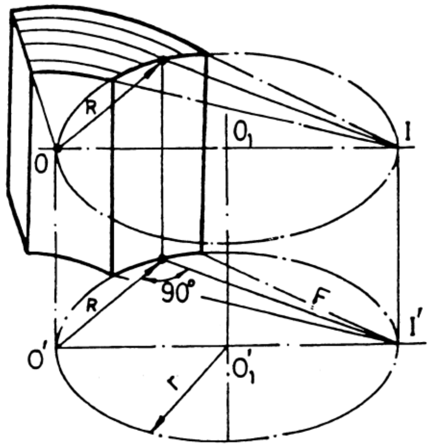
The fit uses Σ^+, Σ^0, Σ^-, and Λ mass and mass-difference measurements.

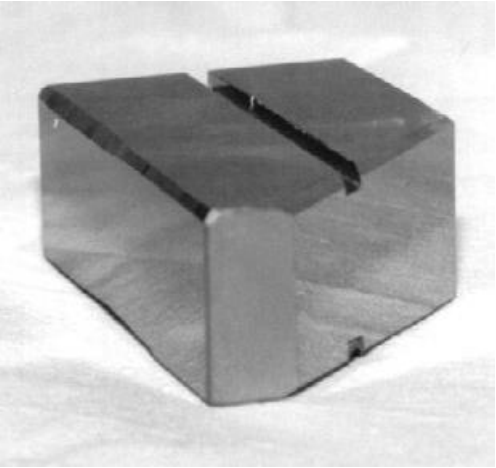
VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
1197.449±0.030 OUR FIT		Error includes scale factor of 1.2.		
1197.45 ±0.04 OUR AVERAGE		Error includes scale factor of 1.2.		
1197.417±0.040		GUREV 93	SPEC	Σ^-C atom, crystal diff.
1197.532±0.057		GALL 88	CNTR	Σ^-Pb, Σ^-W atoms
1197.43 ±0.08	3000	SCHMIDT 65	HBC	See note with Λ mass
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1197.24 ±0.15		[1] DUGAN 75	CNTR	Exotic atoms

[1] GALL 88 concludes that the DUGAN 75 mass needs to be reevaluated.

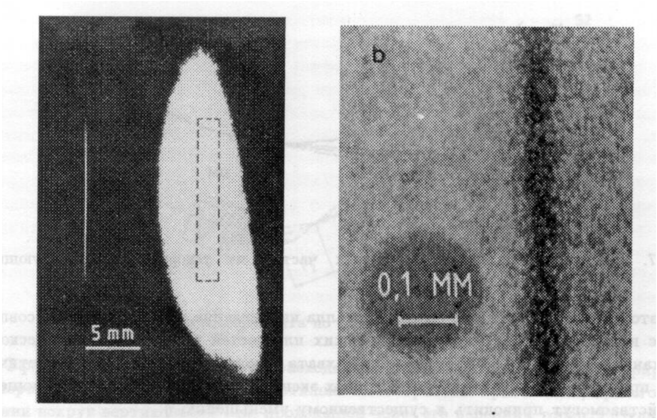
Bent silicon focusing crystals

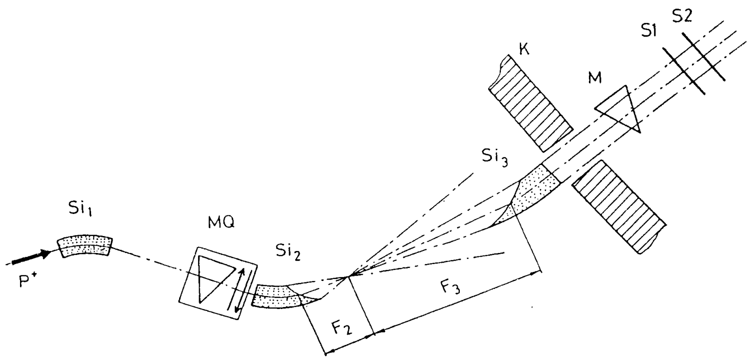
A.I.Smirnov





Experiments at U-70





$F^2 = 4r^2 - R^2$

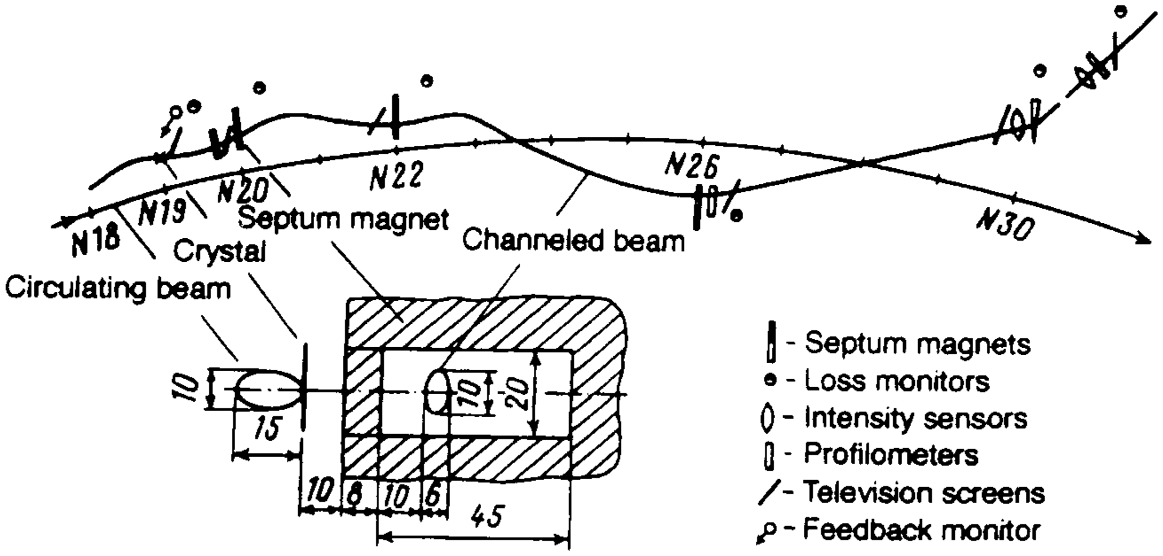
F - focal distance

R - bending radius of the crystal

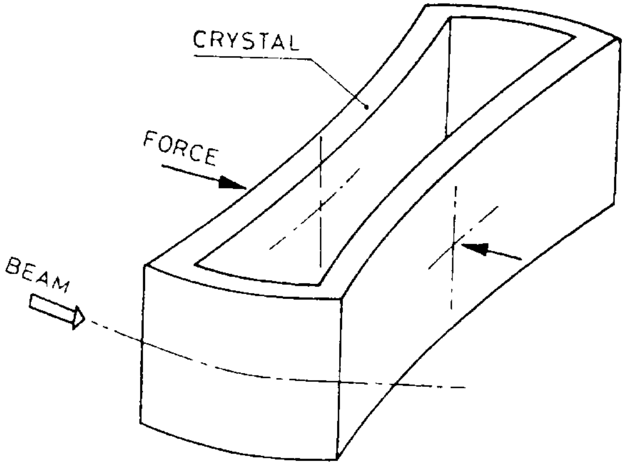
r - radius of the exit crystal face

Short bent silicon crystals for multi-pass extraction of proton beam from U-70

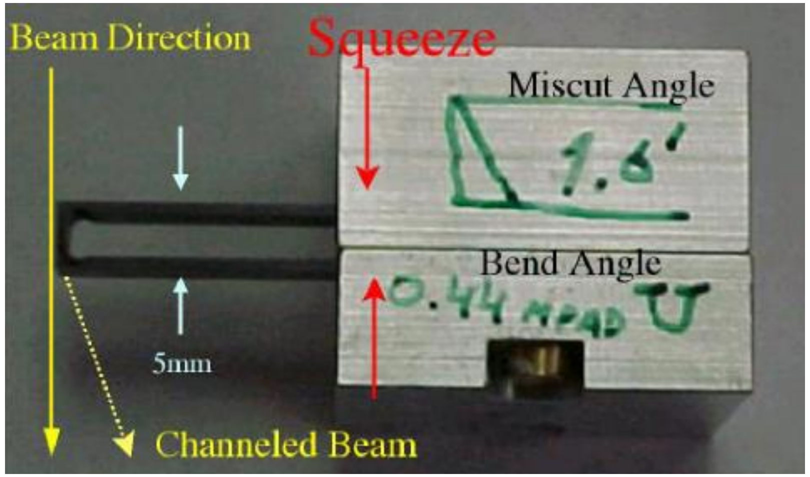
- Bent crystal to deflect beam into septum aperture
- Magnet system to extract beam



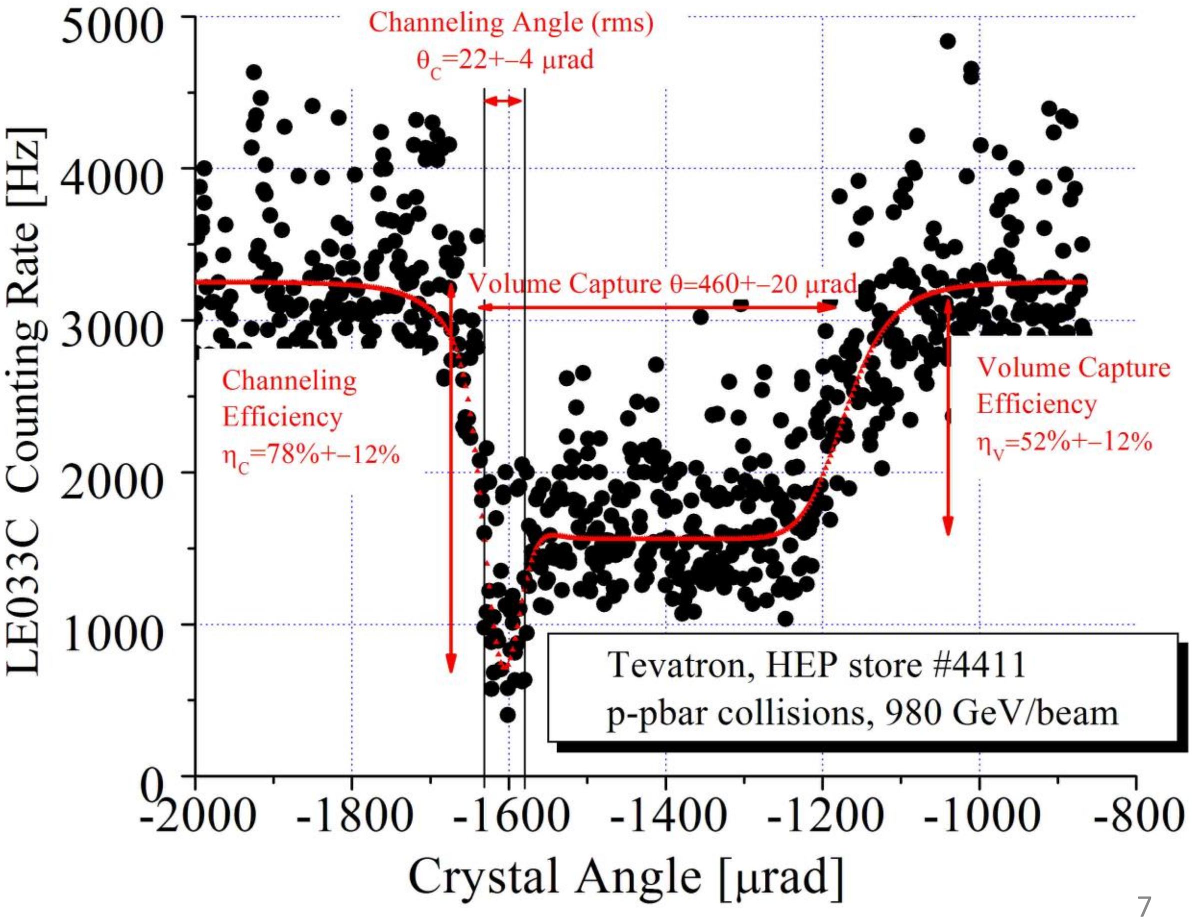
Bent silicon O-crystals. Beam extraction at U-70.



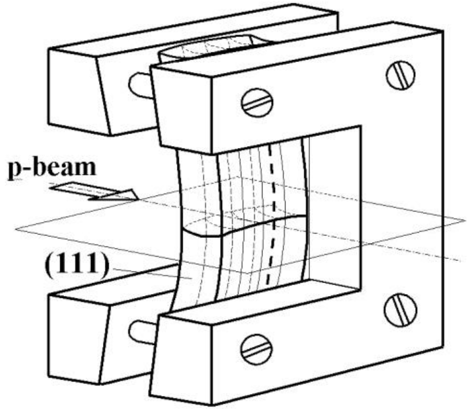
Bent silicon O-crystals. Collimation at RHIC and Tevatron.

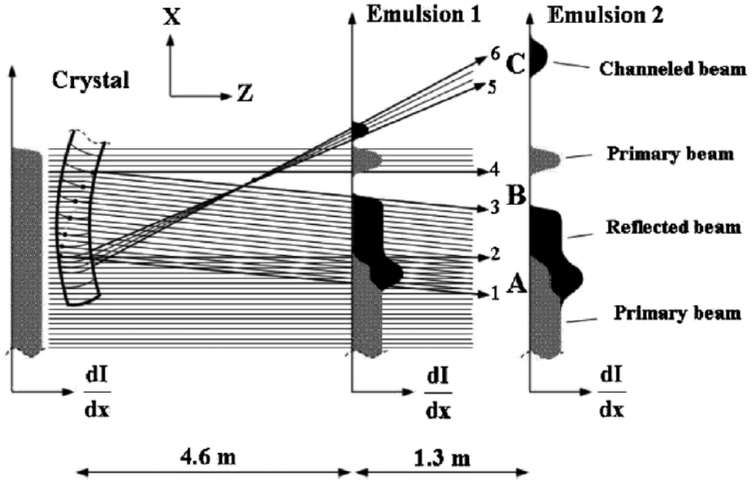


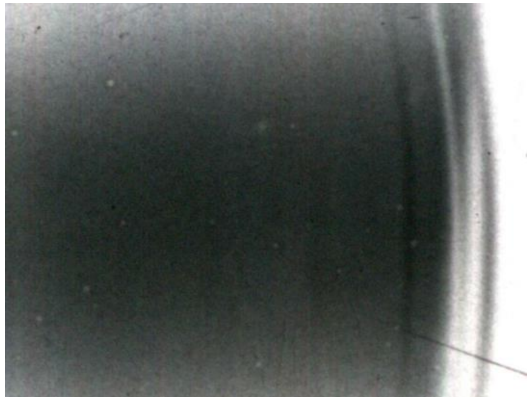
1 TeV Channeling, October 5, 2005



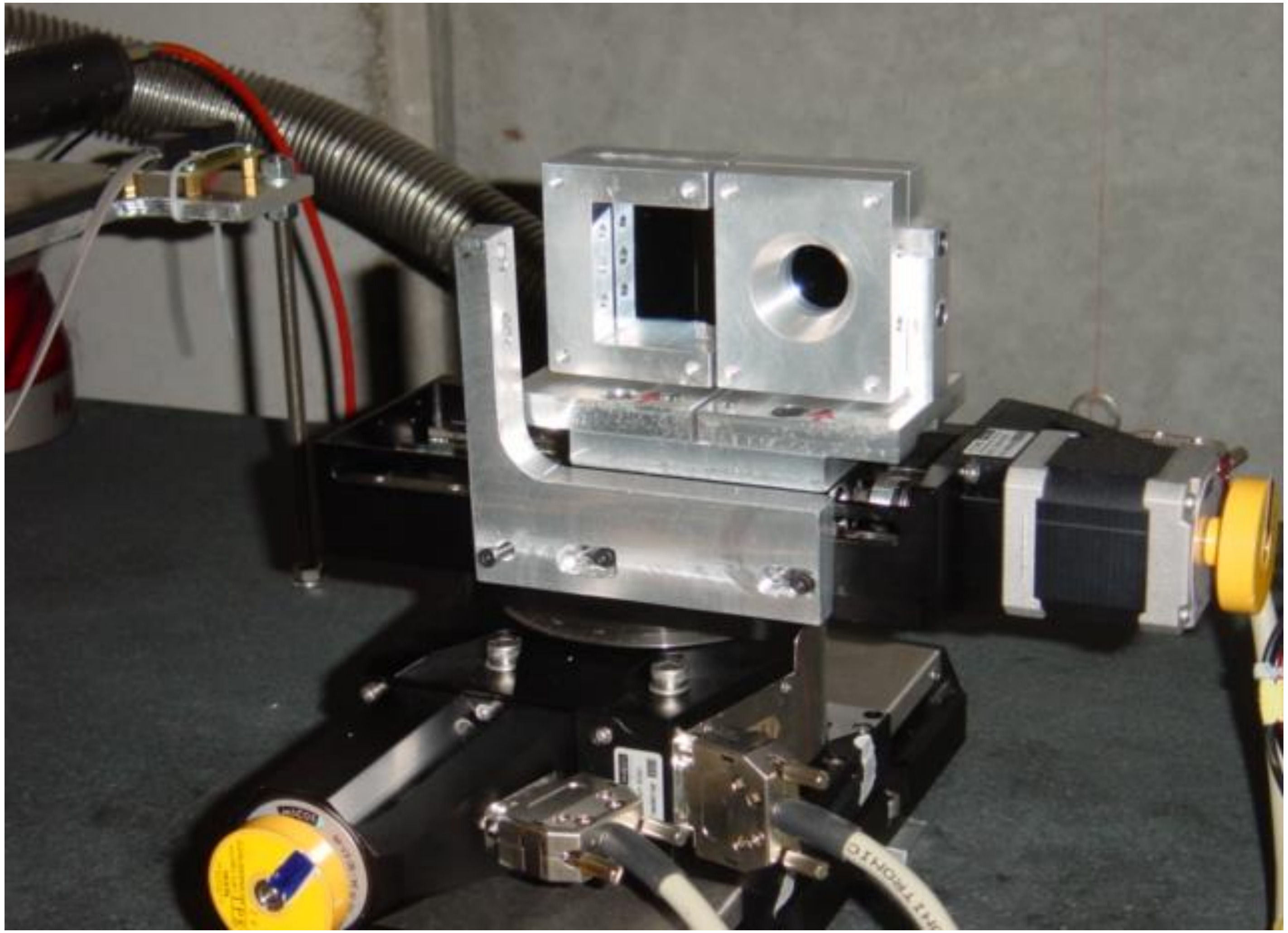
Silicon crystals with Quasi-Mosaic (QM) bending. First observation of Volume Reflection (VR) effect at U-70.







Silicon crystals with Quasi-Mosaic (QM) bending. The H8RD22 and UA9 studies at CERN. Feasibility of crystal collimation.



QM1 and QM2 crystals at H8, 2006

LHC-type Quasimosaic crystals tested in 2015 - 2017

QMP52 – installed into LHC in February, 2017
changed for ACP76 in February, 2018

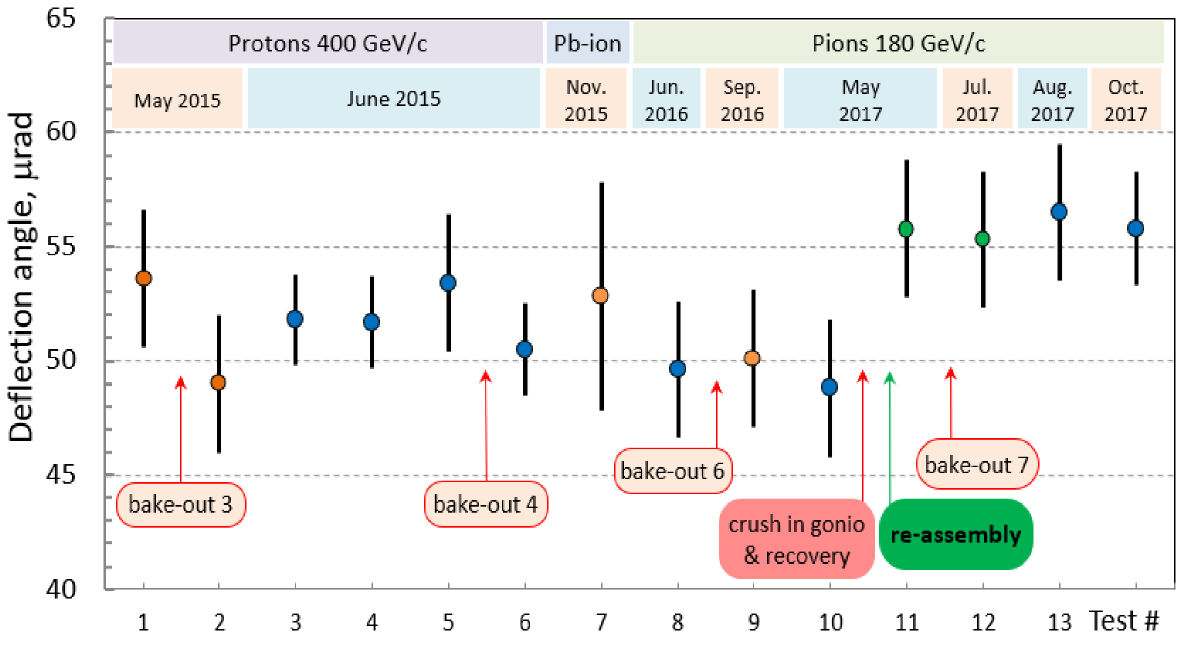
QMP53 – installed into LHC in February, 2017

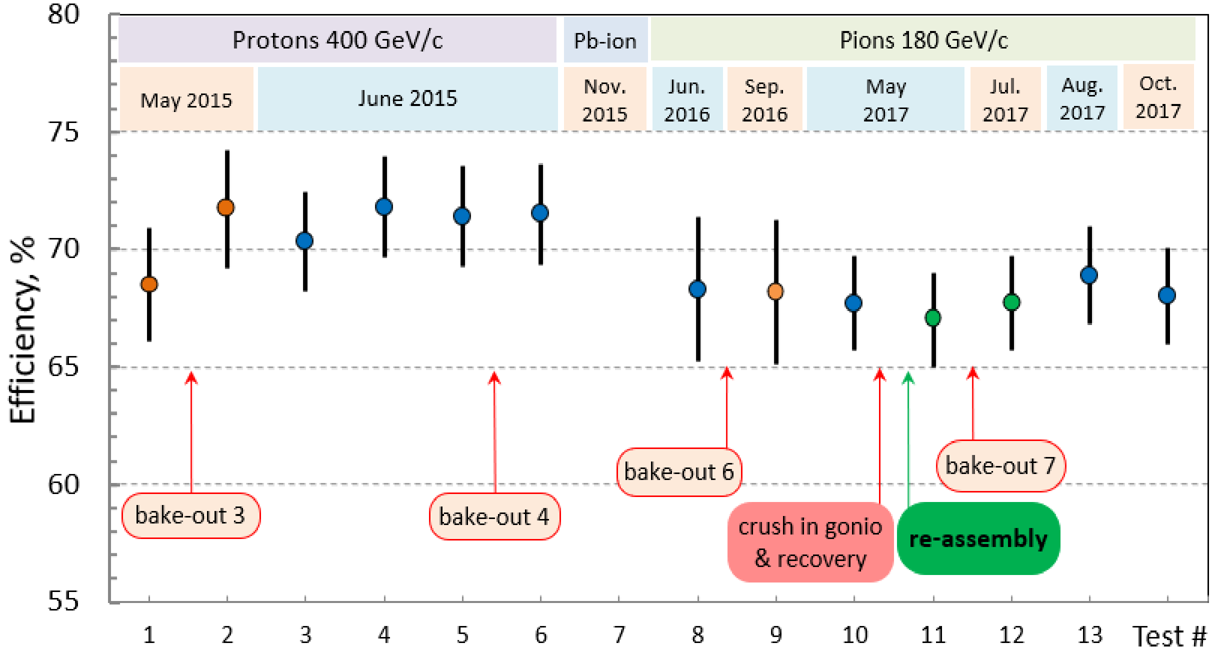
	Crystal	Runs	Deflection angle, urad ± 1 urad	Efficiency, % ±3 mm Y pos. cut ±8 urad X ang. cut		Torsion urad/mm ± 1 urad/mm	Stability at 250 °C
				Protons 400 GeV/c	Pions 180 GeV/c		
QM QuasiMosaic	QMP46	2018-2017	56	71	68	0	OK
	QMP54	2015-2017	56	70	68	0	OK
	QMP52	2015-2016	55	70	65	0	OK
	QMP53	2015-2016	55	69	66	0	OK

Stability of QMP46 in time and after bake-out at 250 °C

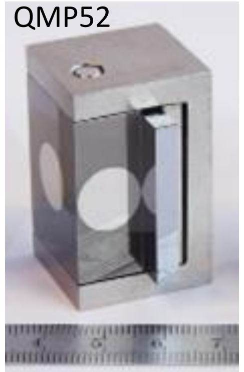
- The stability of QMP46 was confirmed with 4 bake-outs at 250°C
- The stability in time is confirmed during period 2015-2017

- Crystal was experienced a crash inside of LHC goniometer while motion tested
- Crystal was successfully restored and confirmed stability of parameters

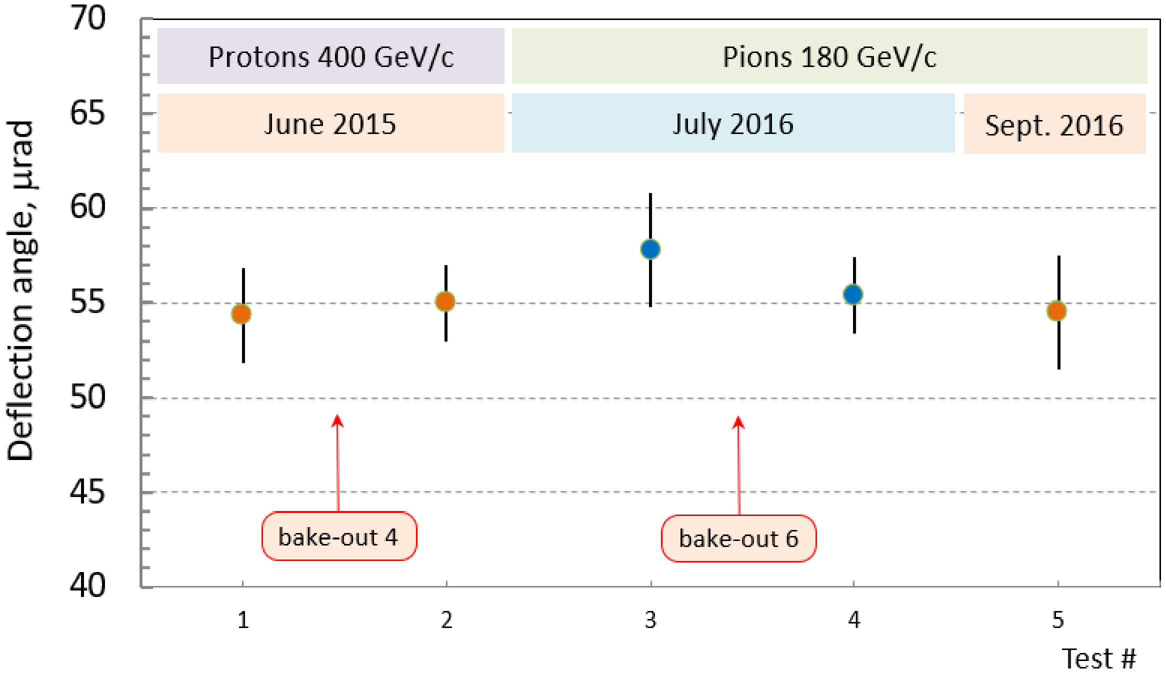


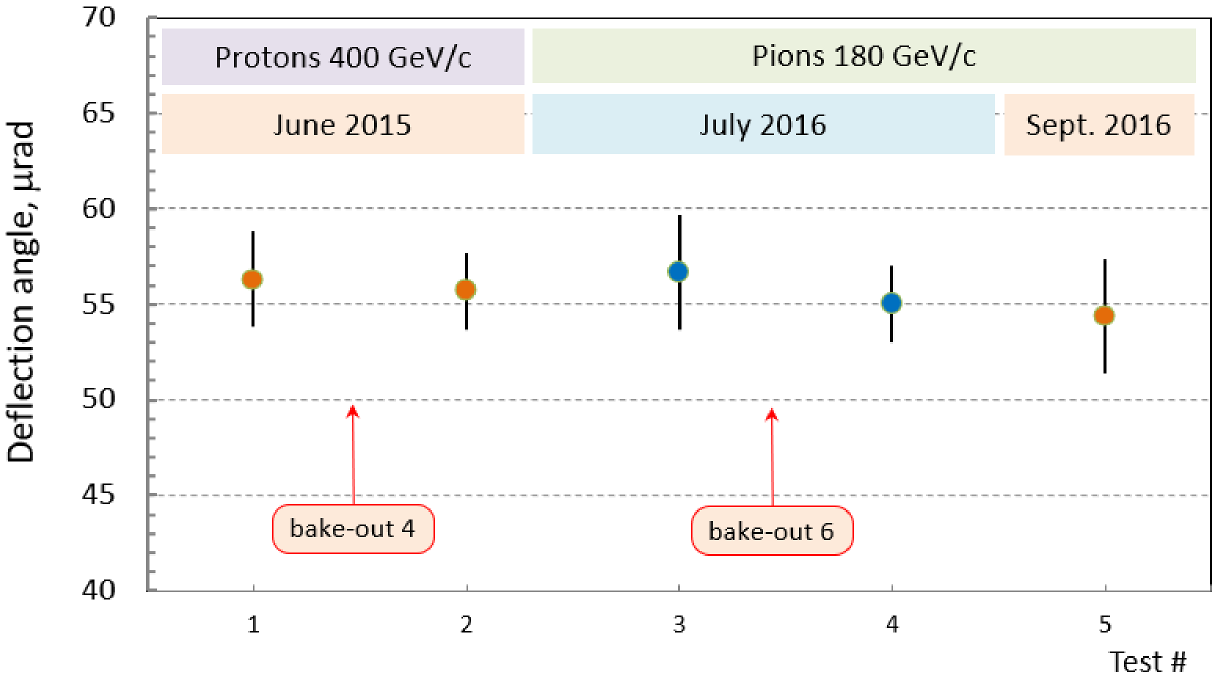


Stability of QMP52,QMP53 in time and after bake-out at 250 °C



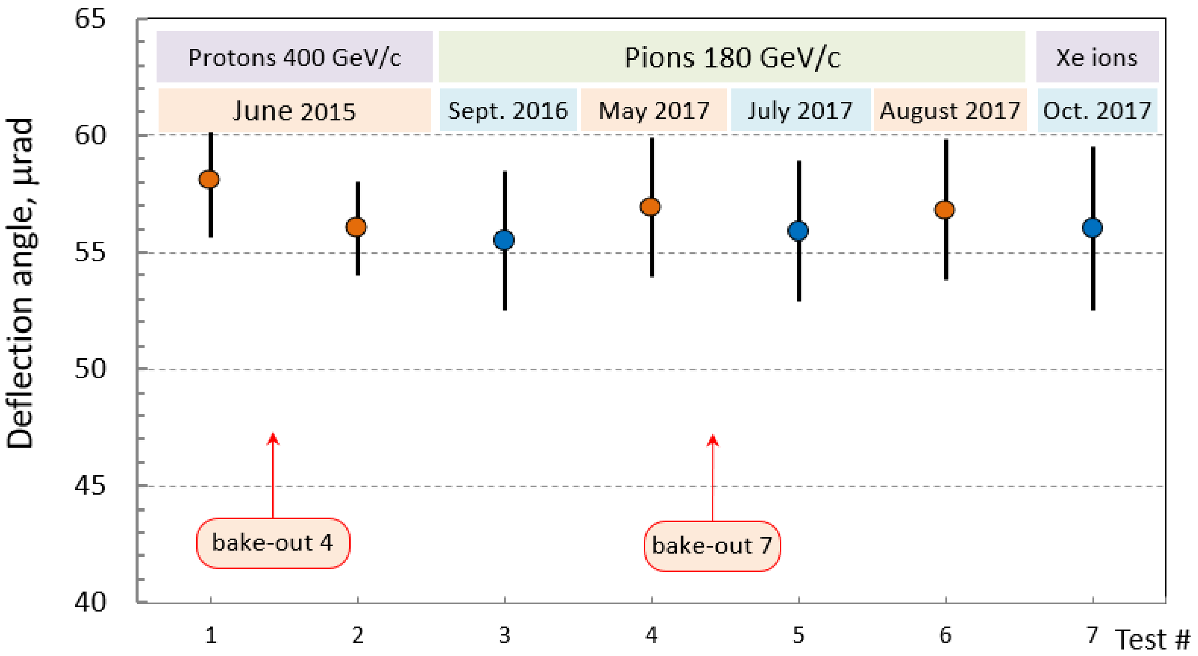
- The stability of QMP52, QMP53 was confirmed with 2 bake-outs at 250°C
- The stability in time is confirmed during period 2015-2016
- Both crystals were installed in LHC

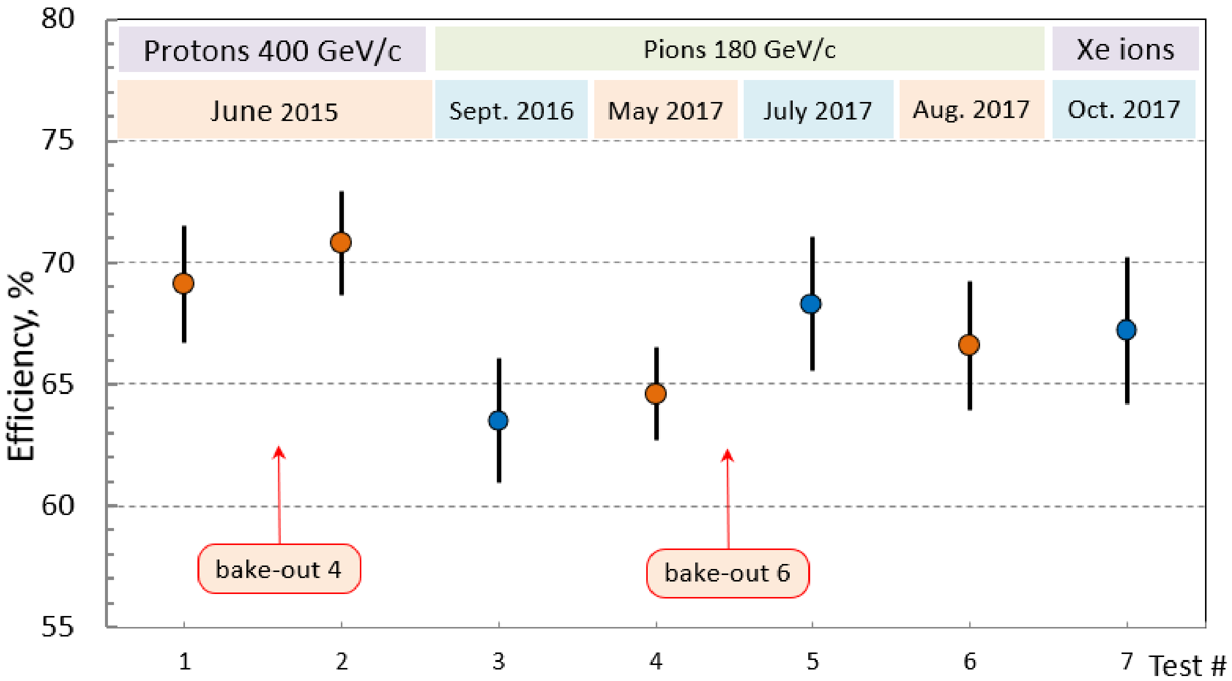




Stability of QMP54 in time and after bake-out at 250 °C

- The stability of QMP54 was confirmed with 2 bake-outs at 250°C
- The stability in time is confirmed during period 2015-2017





LHC-type Anticlastic crystals tested in October 2017 – September 2018

TCP76 TCP77

ACP79 ACP80 ACP84 ACP85 ACP86

- **TCP76 – installed into LHC in February, 2018**

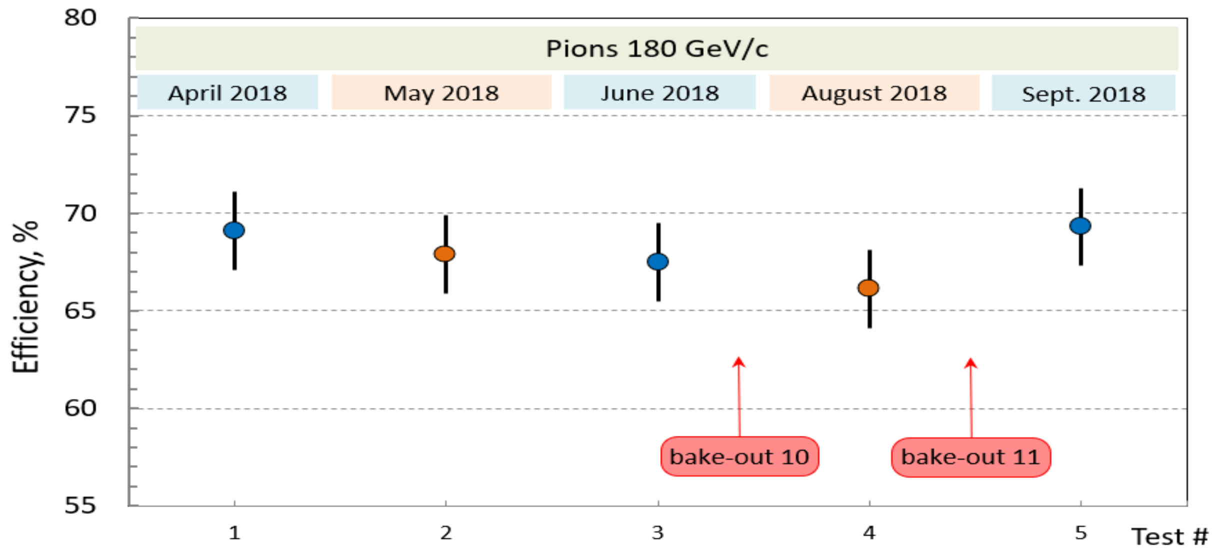
	Crystal	Runs	Deflection angle, urad ± 1 urad	Efficiency, % ±3 mm Y pos. cut ±8 urad X ang. cut	Torsion urad/mm ± 1 urad/mm	Stability at 250 °C
				Pions 180 GeV/c		
ACP AntiClastic PNPI crystal	TCP76	Oct.-Dec. 2017	50 ±2	70	0	OK
	TCP77	Oct.2017-May 2018	50	70	5	OK
	ACP79	April-May 2018	49	69	0	OK
	ACP80	Sept. 2018	57	67	0	OK
	ACP84	Aug.-Sept. 2018	52	68	0	OK
	ACP85	Aug.-Sept. 2018	49	68	0	OK
	ACP86	Aug.-Sept. 2018	56	66	0	OK

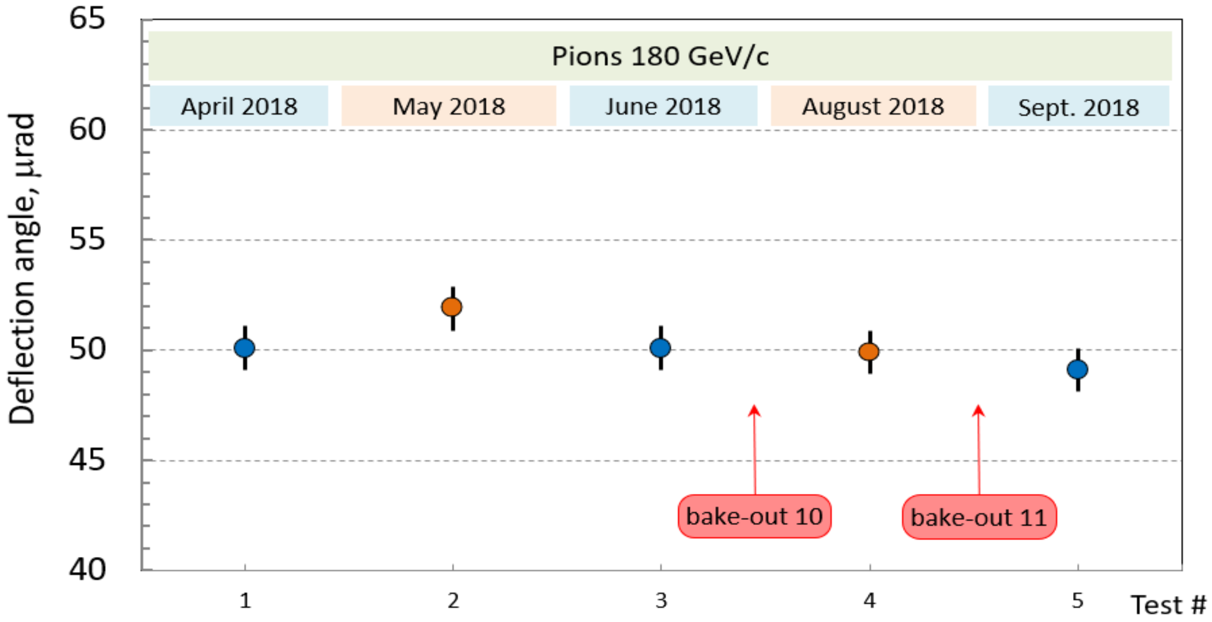
Stability of TCP79 in time and after bake-out at 250 °C

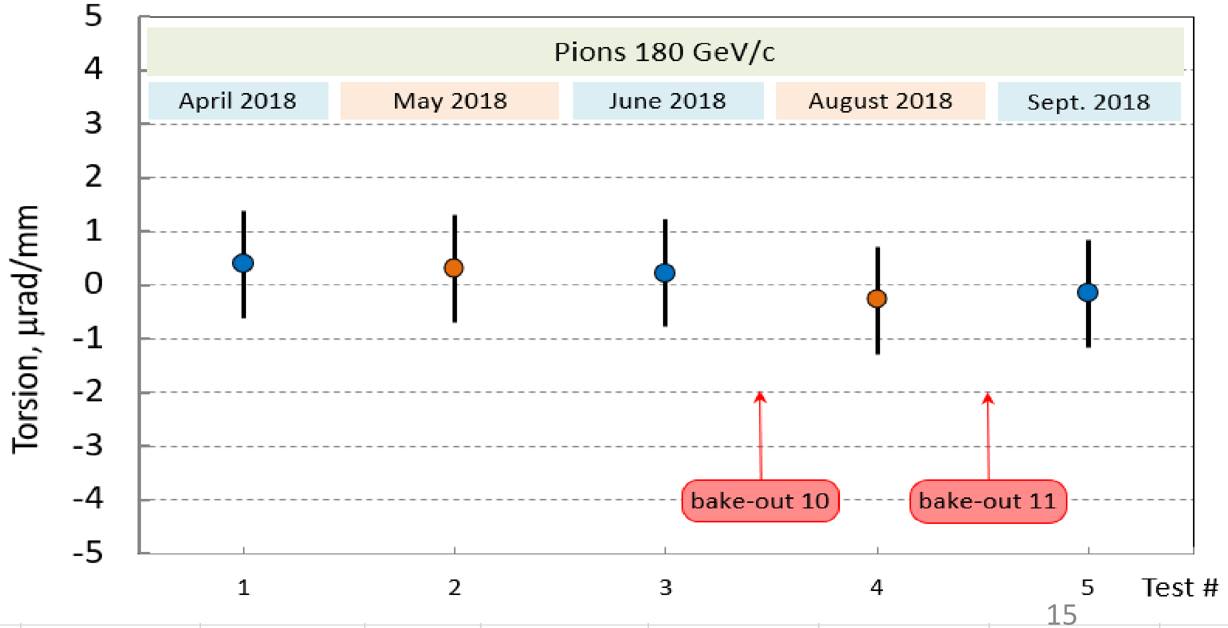
- The stability of TCP79 was confirmed with 2 bake-outs at 250°C

- The stability in time is confirmed during April-September 2018

ACP79



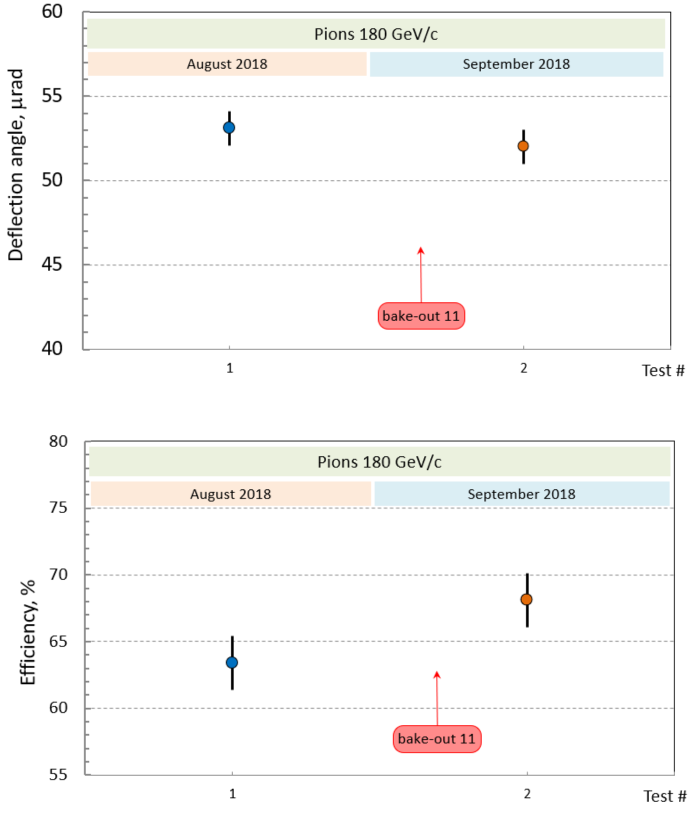




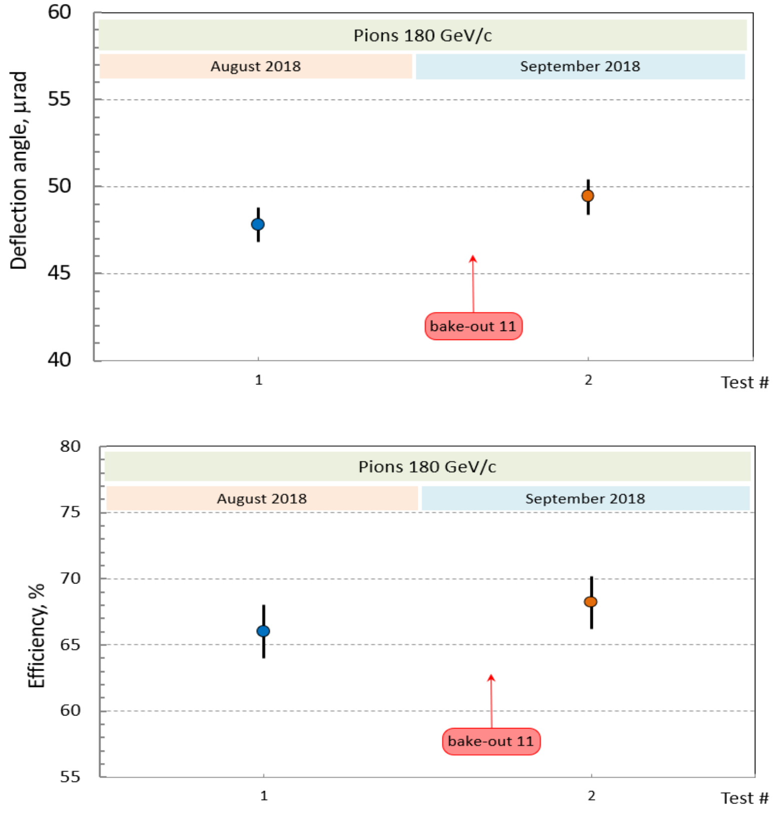
Stability in time and after bake-out at 250 °C

- The stability of ACP84, ACP85, APC86 was confirmed with 1 bake-out at 250°C during August-September 2018

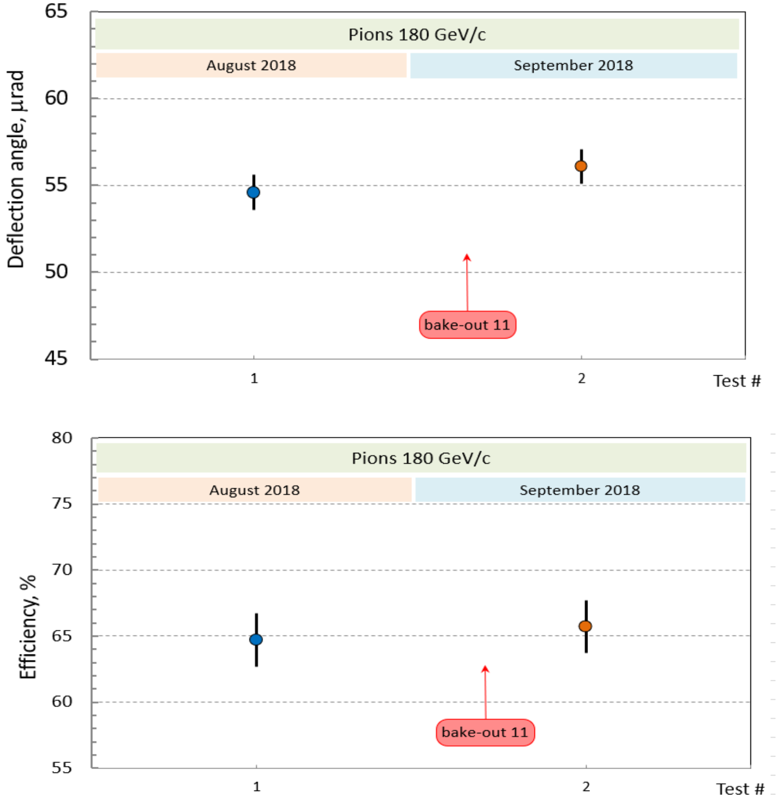
ACP84



ACP85

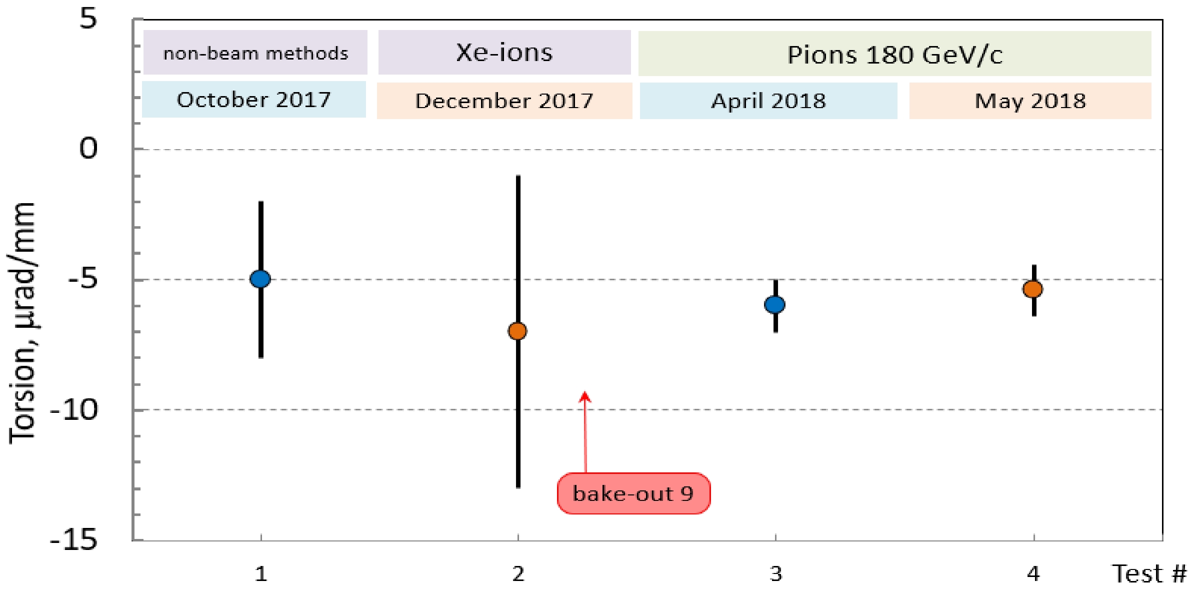


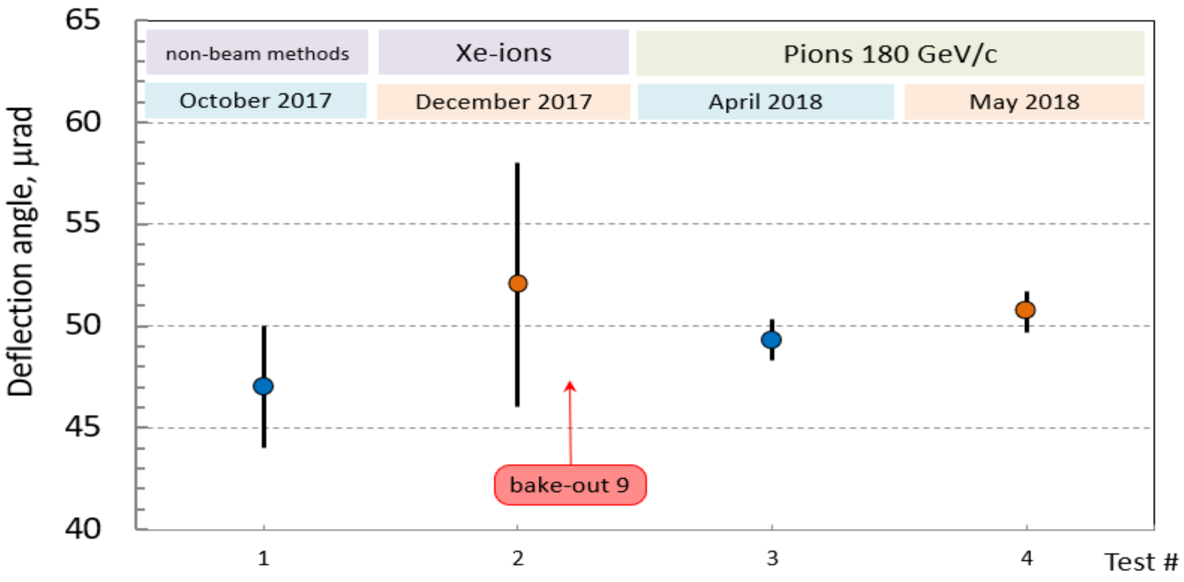
ACP86

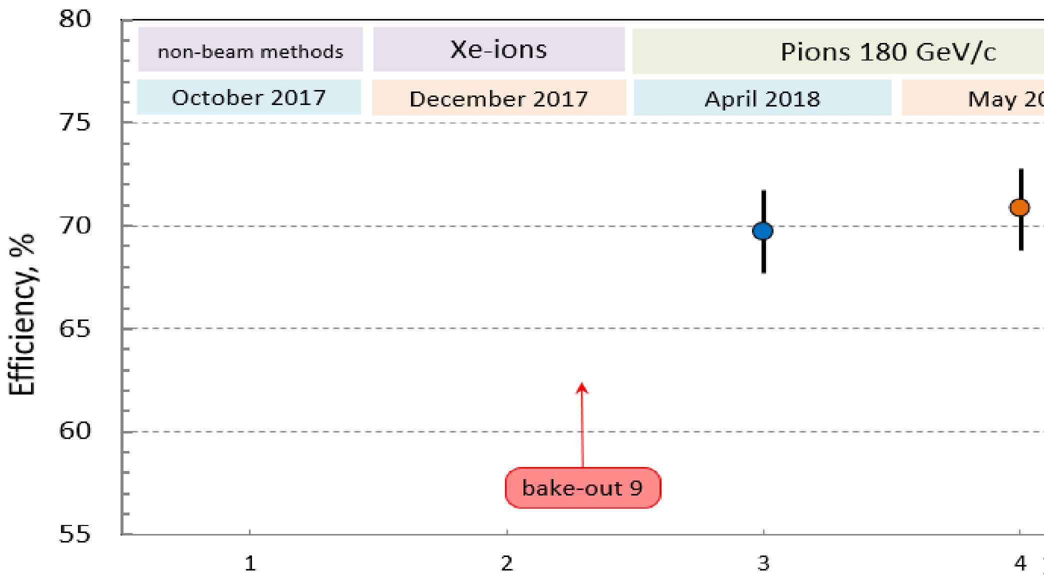


Stability of TCP77 in time and after bake-out at 250 °C

- Despite non-zero torsion TCP77 was tested with Xe-ion and pion beam in H8 for stability study







Production Review with Alessandro Masi in 2017

Crystal orienting with X-rays

Crystal cutting

Grinding

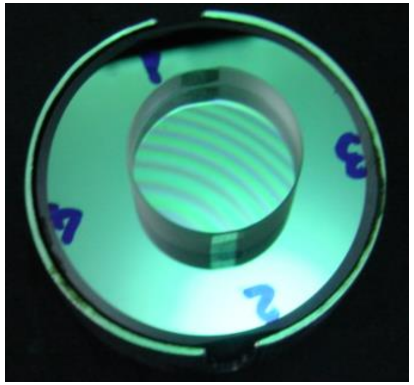
Polishing

Titanium holder production

Visual check

Surface check

Shape check



Production Review with Alessandro Masi in 2017

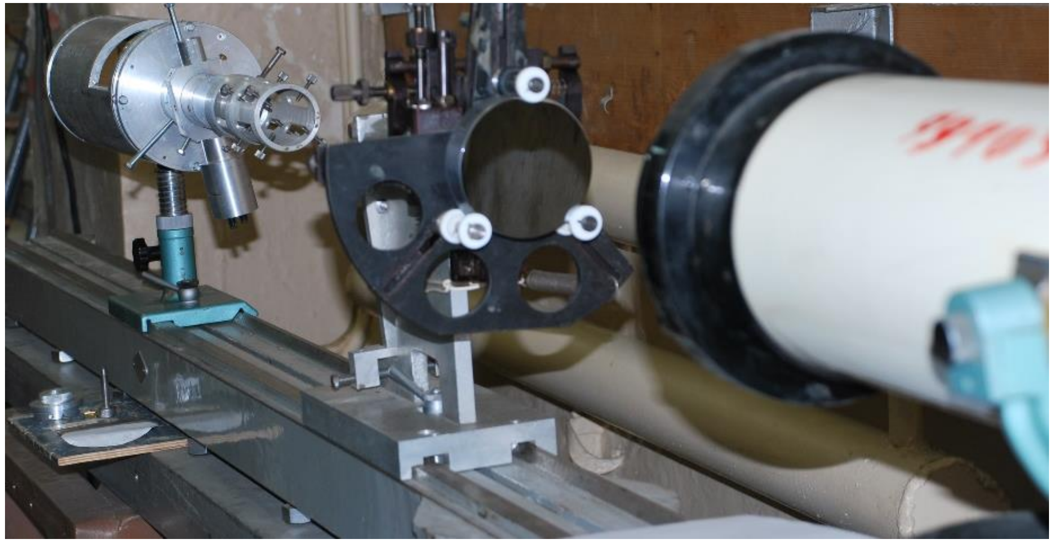
Angle_between_crystal_faces check

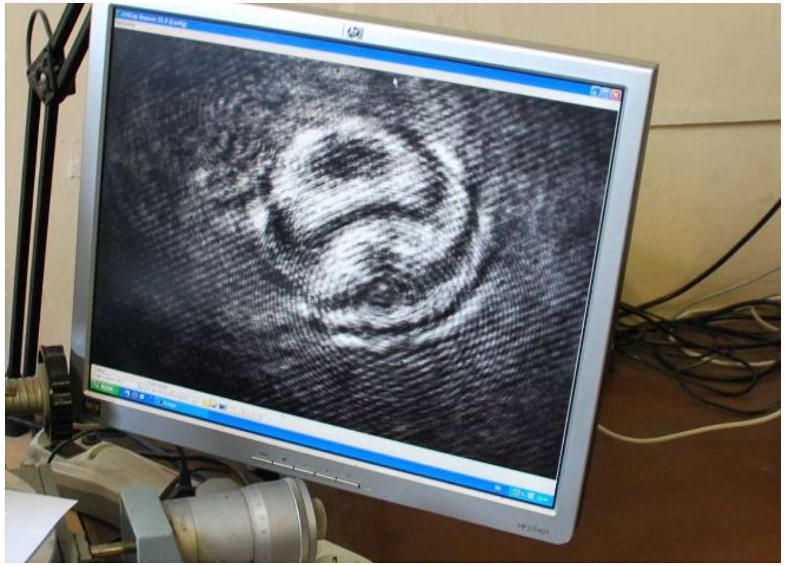
Production Review with Alessandro Masi in 2017

Miscut check

Production Review with Alessandro Masi in 2017

Flatness check





Production Review with Alessandro Masi in 2017

X-test station

Thank you for attention !