

Operation of a Multi-strip Crystal Collimator in the Fermilab Tevatron

Tevatron T-980 Experiment

FNAL, SLAC, CERN, PNPI, IHEP, INFN

Dean Still

Channeling 2010 , Ferrara, Italy

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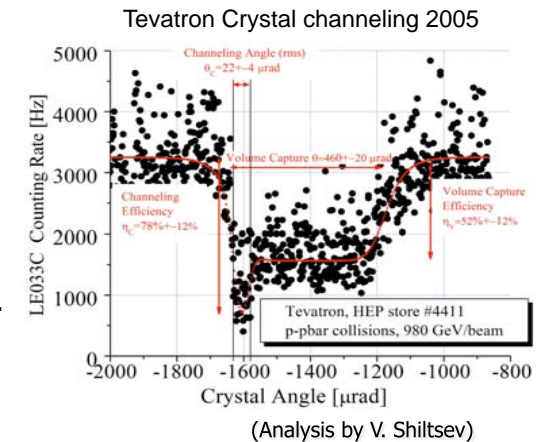
Outlook

- Brief History of T-980 Results and Motivation
- Multi-strip Measurements
- Results
- Future Plans and Summary

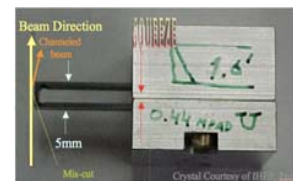
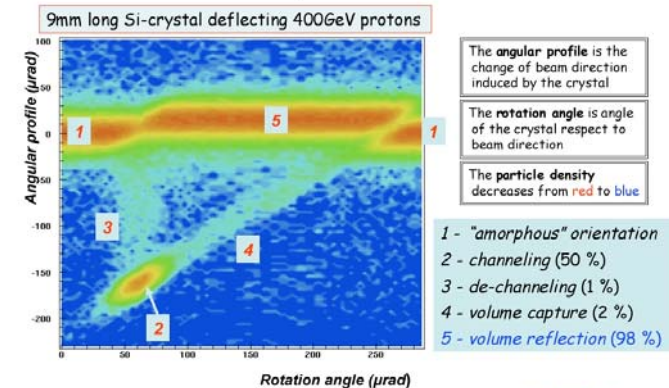


Brief History & Motivation for using Multi-Strip Crystals

- ✓ Since 2005, FNAL (T-980) has only used 1 crystal.
(O-shape O-BNL-02) with large miscut 1.6mrad
- ✓ In 2005, Tevatron demonstrated channeling at 980GeV and demonstrated that proton halo loss at CDF IP could be reduced by factor of 2 as predicted.
- ✓ In 2009, Crystal collimation was used during Tevatron collider stores
 - A successful automatic insertion test of crystal has been achieved.
 - A reduction of ring losses was reproducibly observed along with local loss effects on the collimator due to crystal channeling.
 - No adverse effects were found.
- ✓ In 2006, CERN RD22 demonstrated beautifully in H8 the 5 main effects in bent crystals which one is Volume Reflection (VR).
- ✓ **Some differences between CH and VR is the angular acceptance:**
 - Channeling (CH) <math>< 10 \mu\text{rad}</math>
 - Vol-reflection (VR) $\sim 100 \mu\text{rad}$
 - VR has high **efficiency**.
 - But VR the smaller angle



Angular beam profile as a function of the crystal orientation



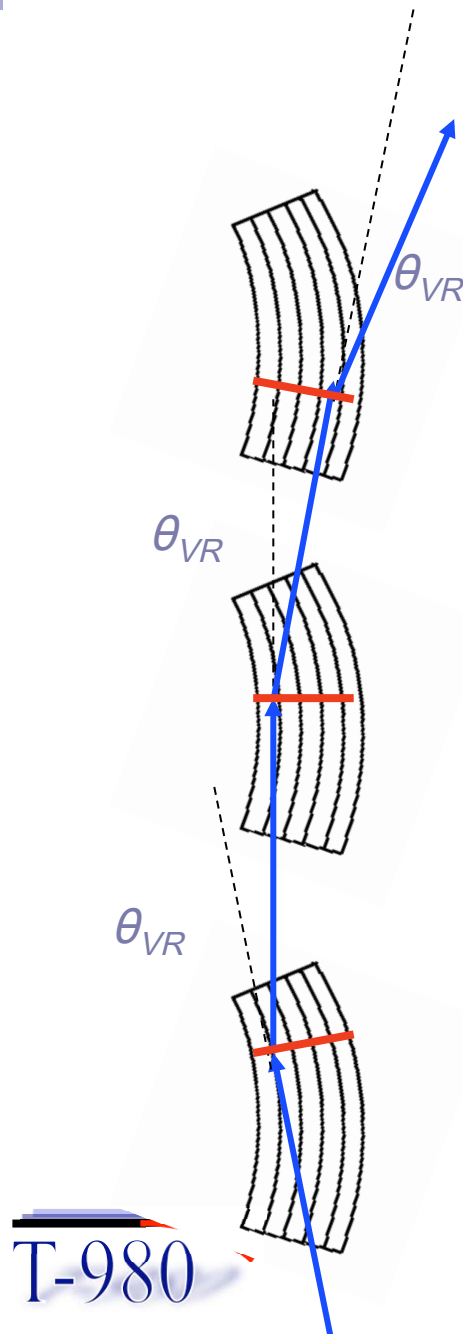


The concept of multiple VR

Repeated VRs in an array of parallel crystals results in larger deflection, e.g. at $E=1$ TeV:

One crystal $\theta_{VR} = 8\mu rad$; $\theta_{bend} = 200\mu rad$

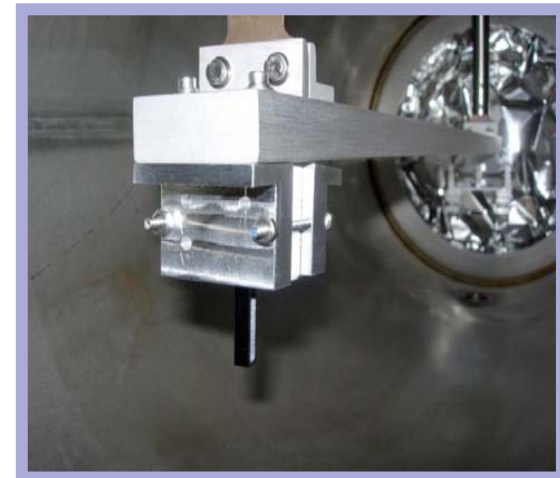
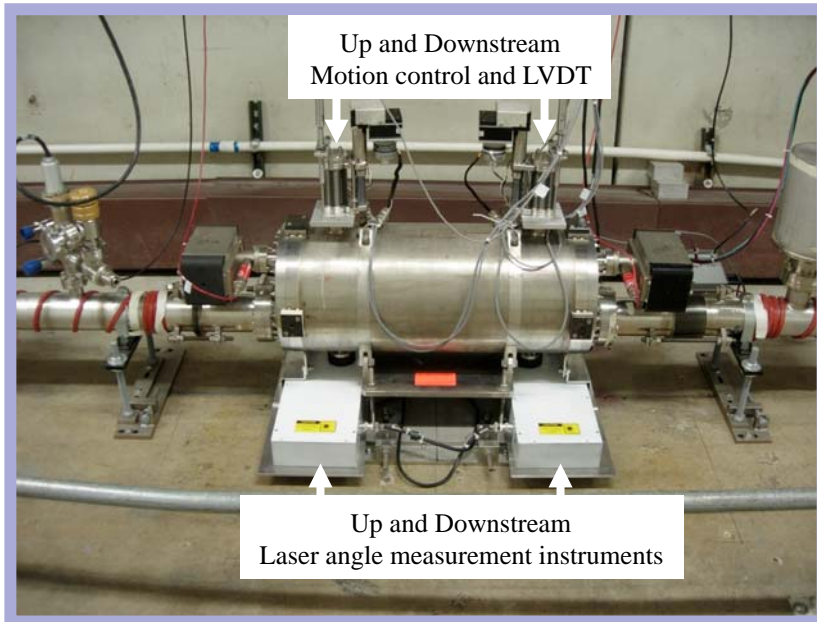
8 crystals $\theta_{VR} = 8 \times 8 = 64\mu rad$





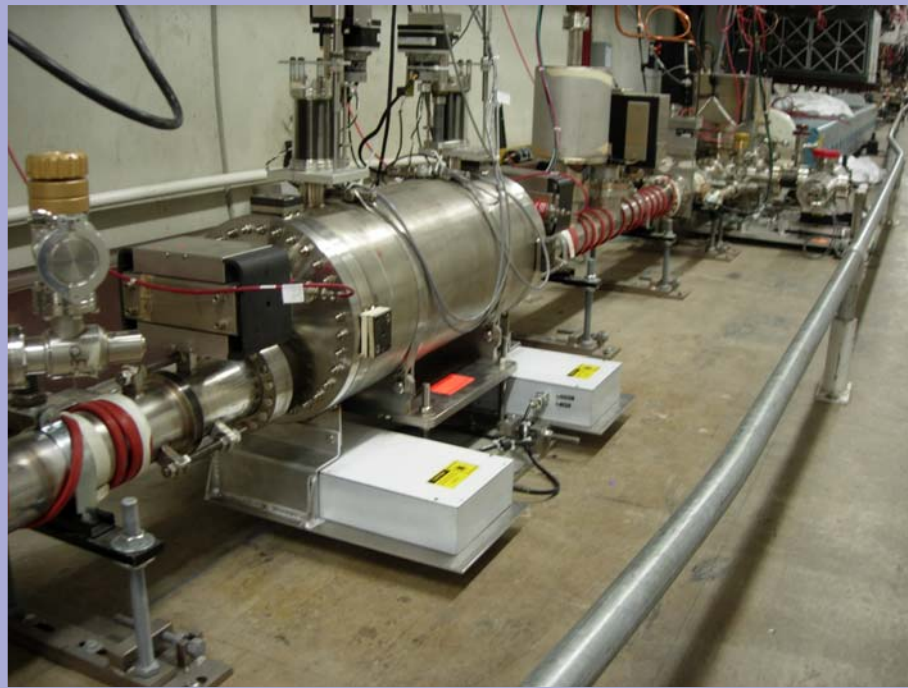
The T980 Experiment Hardware:

- Since Tevatron is deeply committed to Collider run II, it is difficult to access or change T980 hardware.
- Wanted more options to study more crystals and 2 plane crystal collimation.
- January 2009 IHEP built T-980 a vertical goniometer of push-pull type that could house 2 crystals

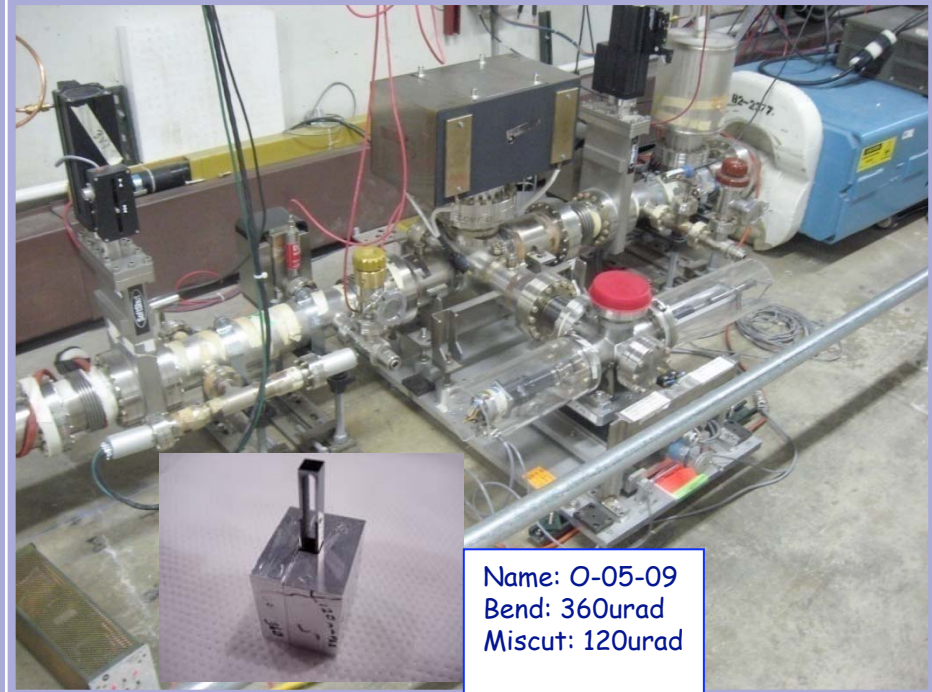




Goniometer Installations over Summer 09 Shutdown



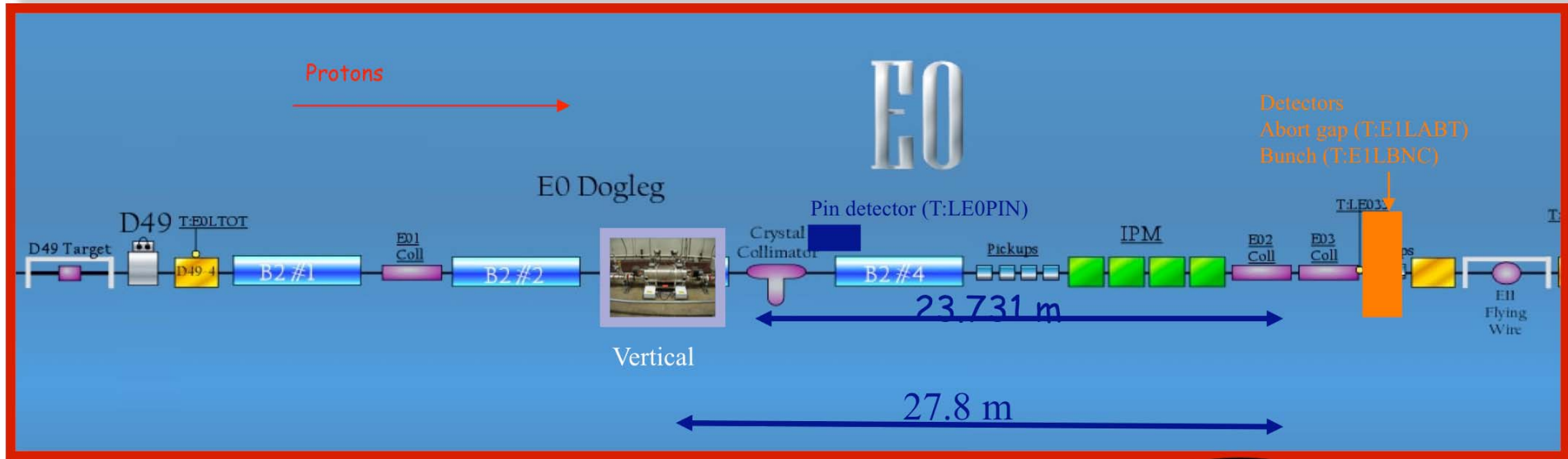
Newly built and installed (Summer 2009) Vertical goniometer at E0. It is ~ 4m upstream of the Hor. one. Ver. goniometer houses old **O-shaped crystal** (reversed for negative miscut) and **multi-strip crystal**.



Modified horizontal goniometer. Replaced old large-miscut angle O-shaped crystal with **new small miscut O-shaped** during Summer 2009.

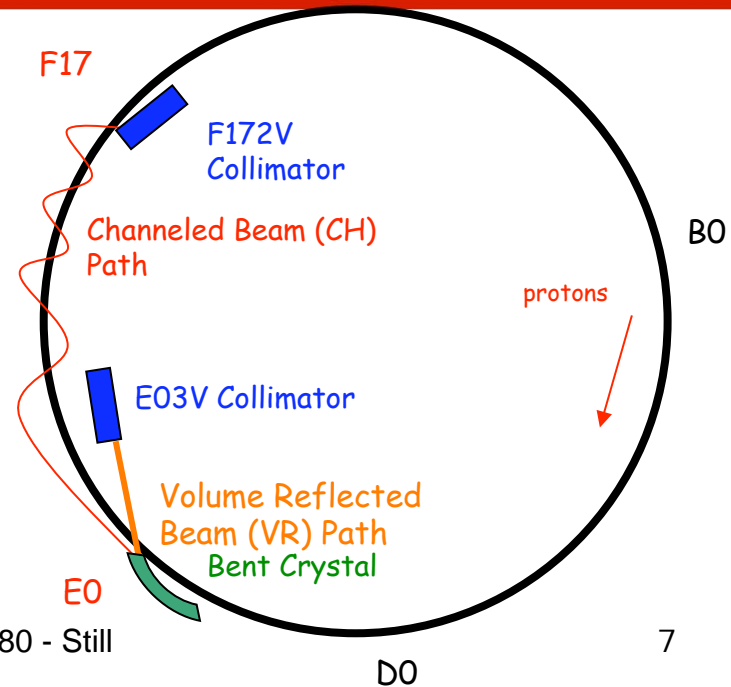


T980 Setup in Tevatron E0 for 2009-2010



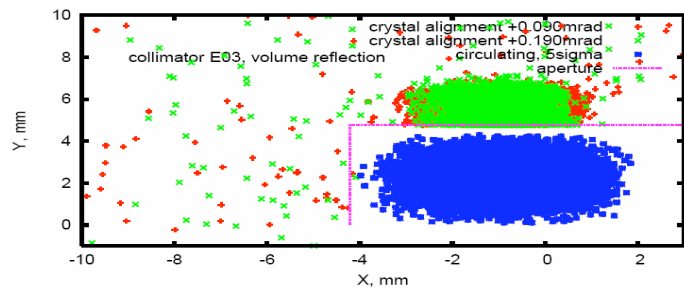
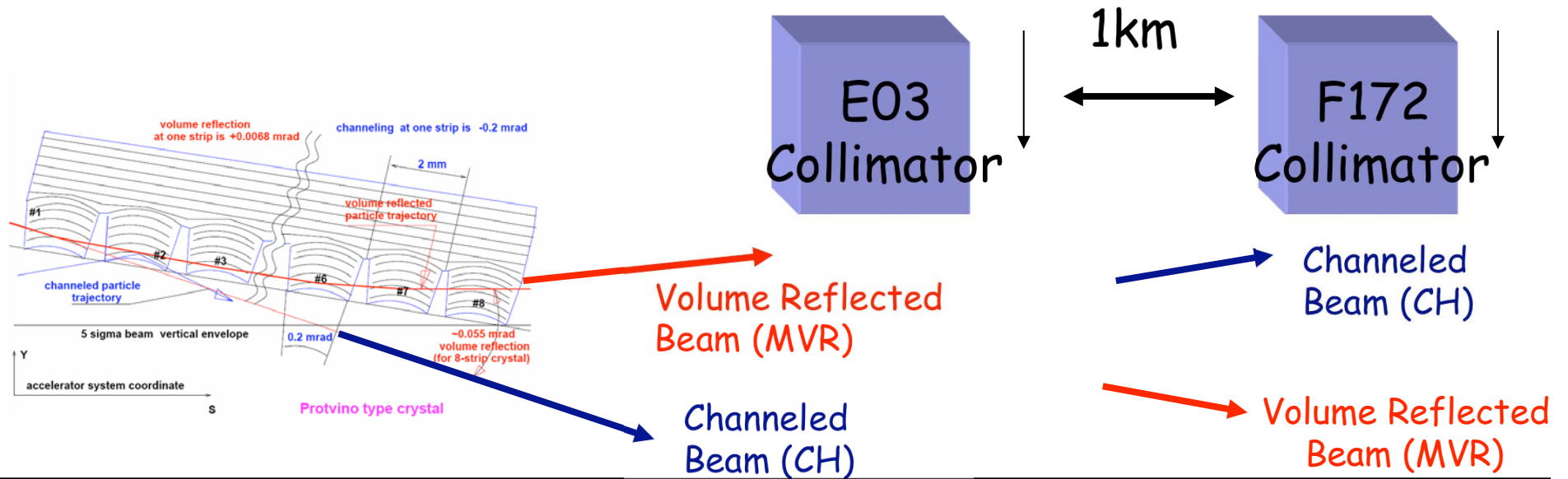
E0 expanded region

F17 expanded region

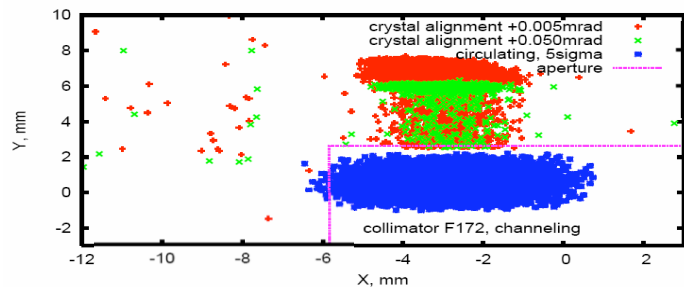




Vertical Multi-Strip Orientation



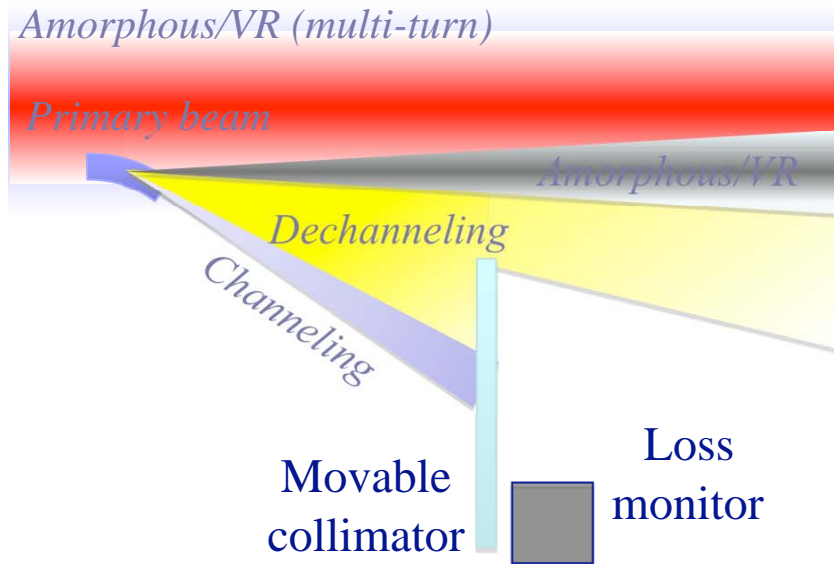
Volume Reflected beam (MVR) at E03 Collimator
Core



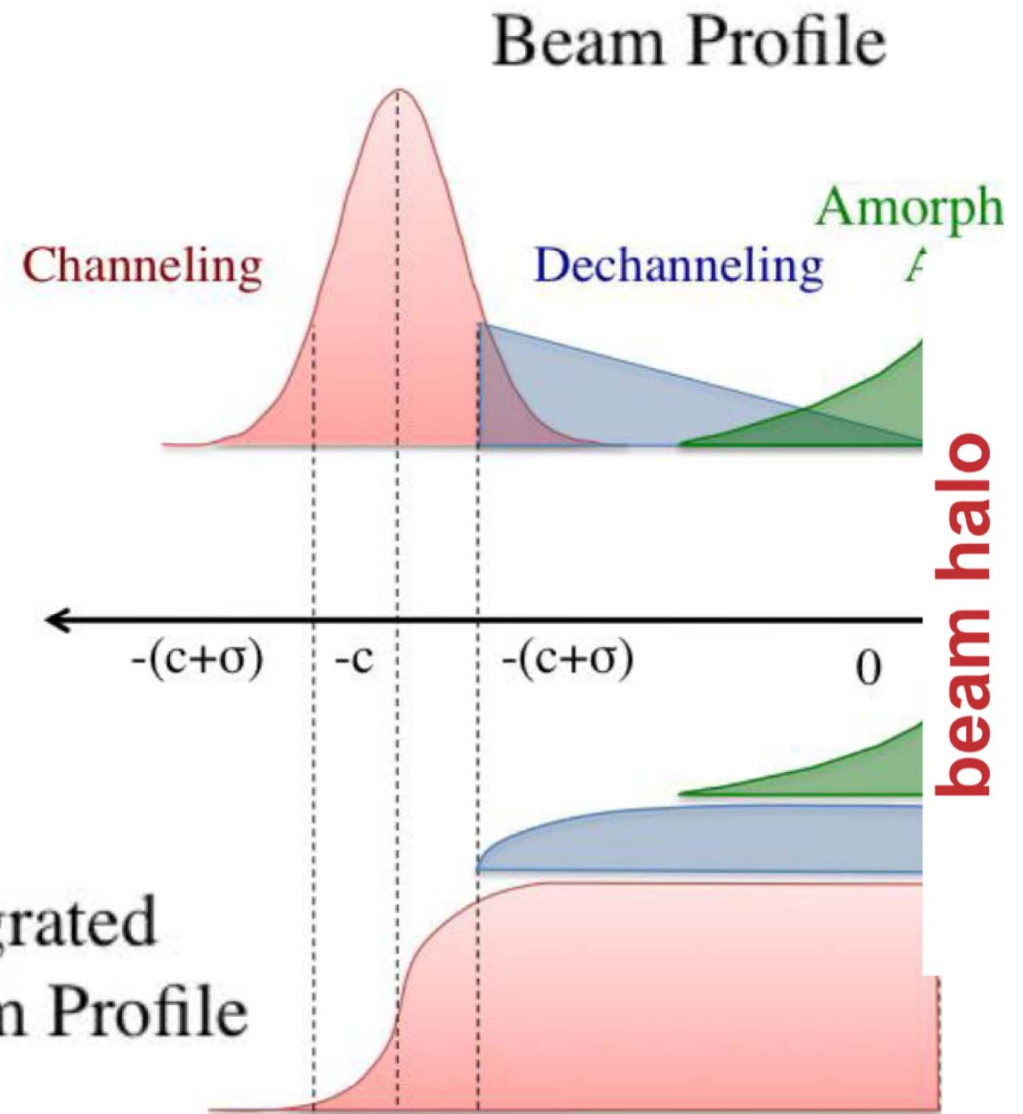
Channeled Beam (CH) at F172 Collimator
Core



Collimator Scans of Extracted Beams



- Move collimator into the beam halo
- Vary crystal angle to observe CH/VR beam
- Observe the losses vs collimator X position (indicates intensity)



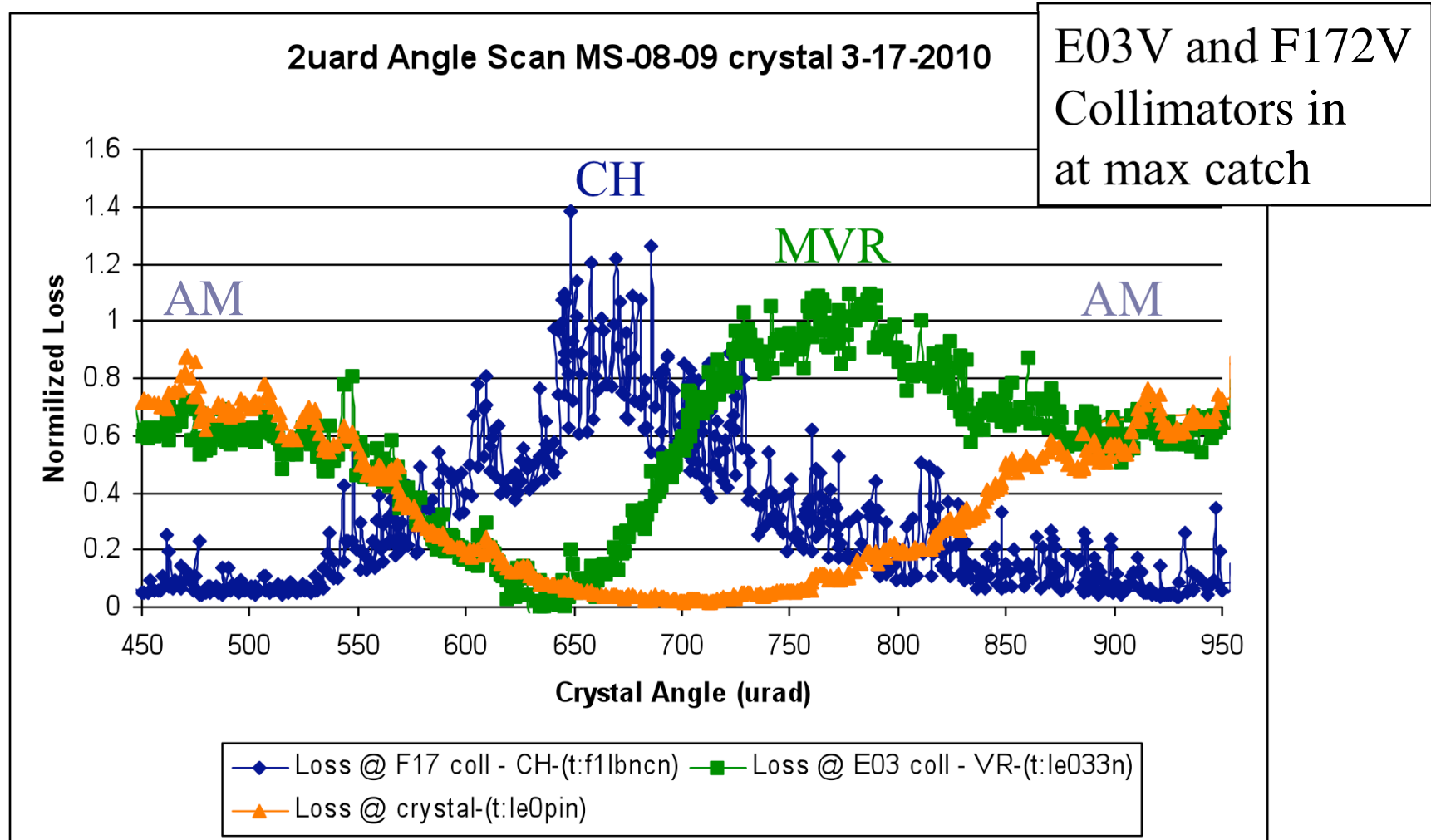


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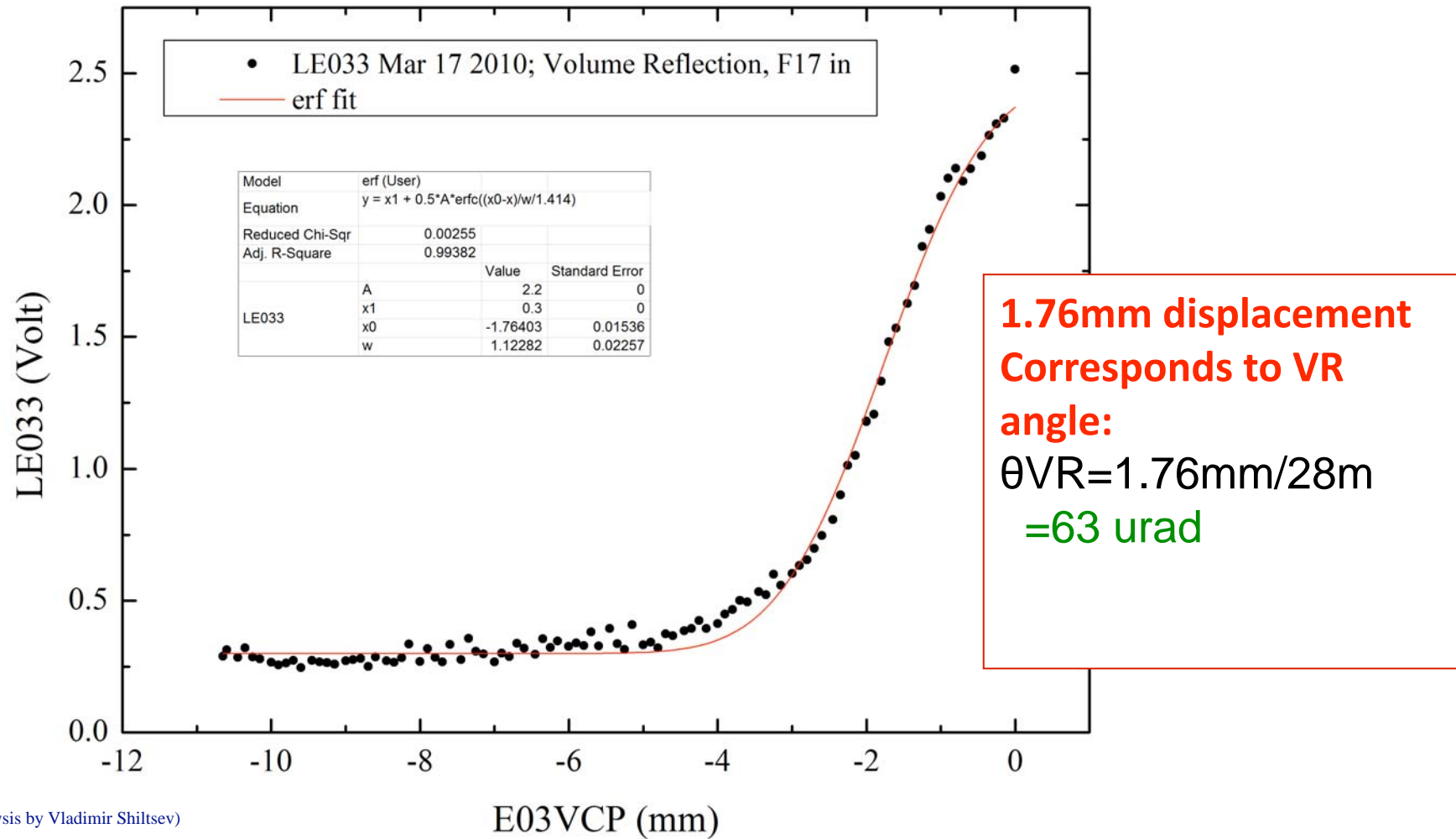


Vertical Multi-strip Angular scan



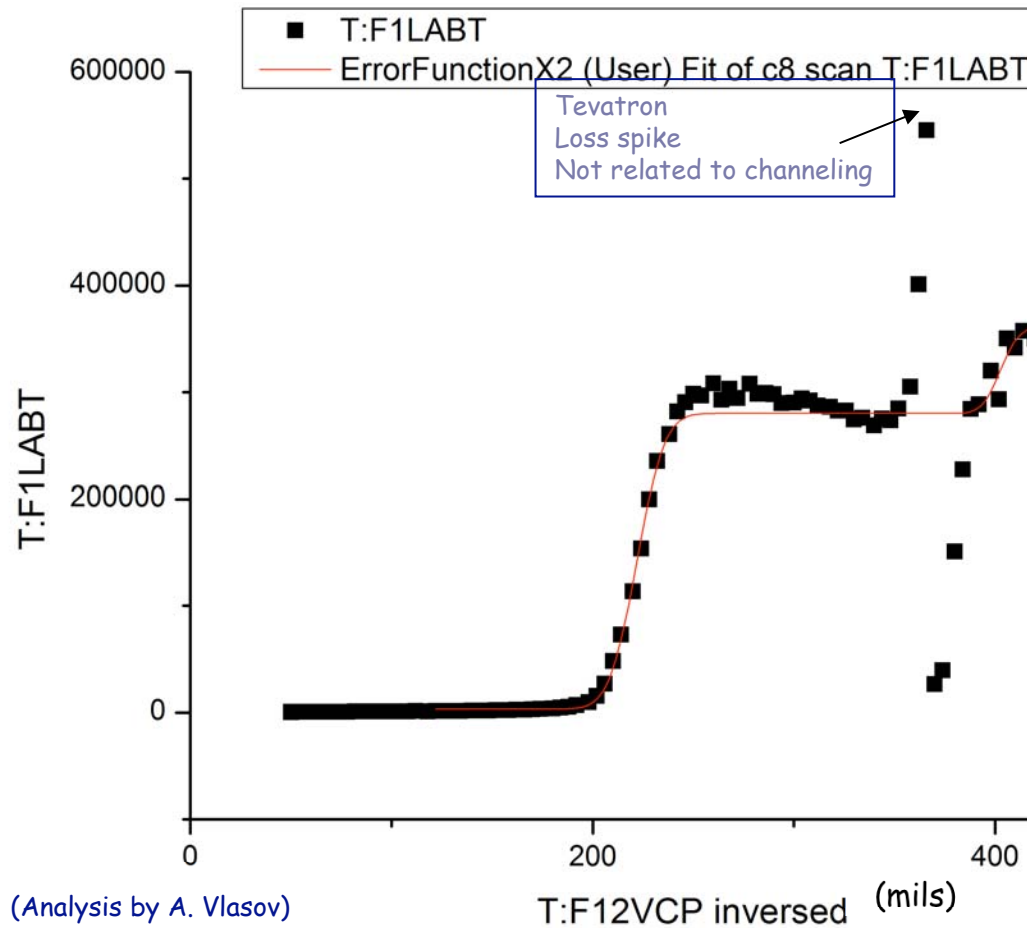


E03V Collimator Scan with Crystal at VR angle





F172V Collimator Scan with Crystal at CH angle



(Analysis by A. Vlasov)

	A	B	C	D
1	Model	ErrorFunctionX2 (User)		
2	Equation	$y = y0 + A1/2 * (\text{erf}((x-xc1)/w1/\text{sqrt}(2)) + 1) + A2/2 * (\text{erf}((x-xc2)/w2/\text{sqrt}(2)) + 1)$		
3	Reduced Chi-Sqr	3,60576E9		
4	Adj. R-Square	0,82812		
5			Value	Standard Error
6	A1	276612,9424	17837,62466	
7	A2	80400,97533	29262,62564	
8	y0	3445,40217	14135,20006	
9	T:F1LABT	xc1	221,94543	3,10533
10		xc2	402,677	8,94663
11		w1	10,84337	4,29996
12		w2	7,1561	12,59536

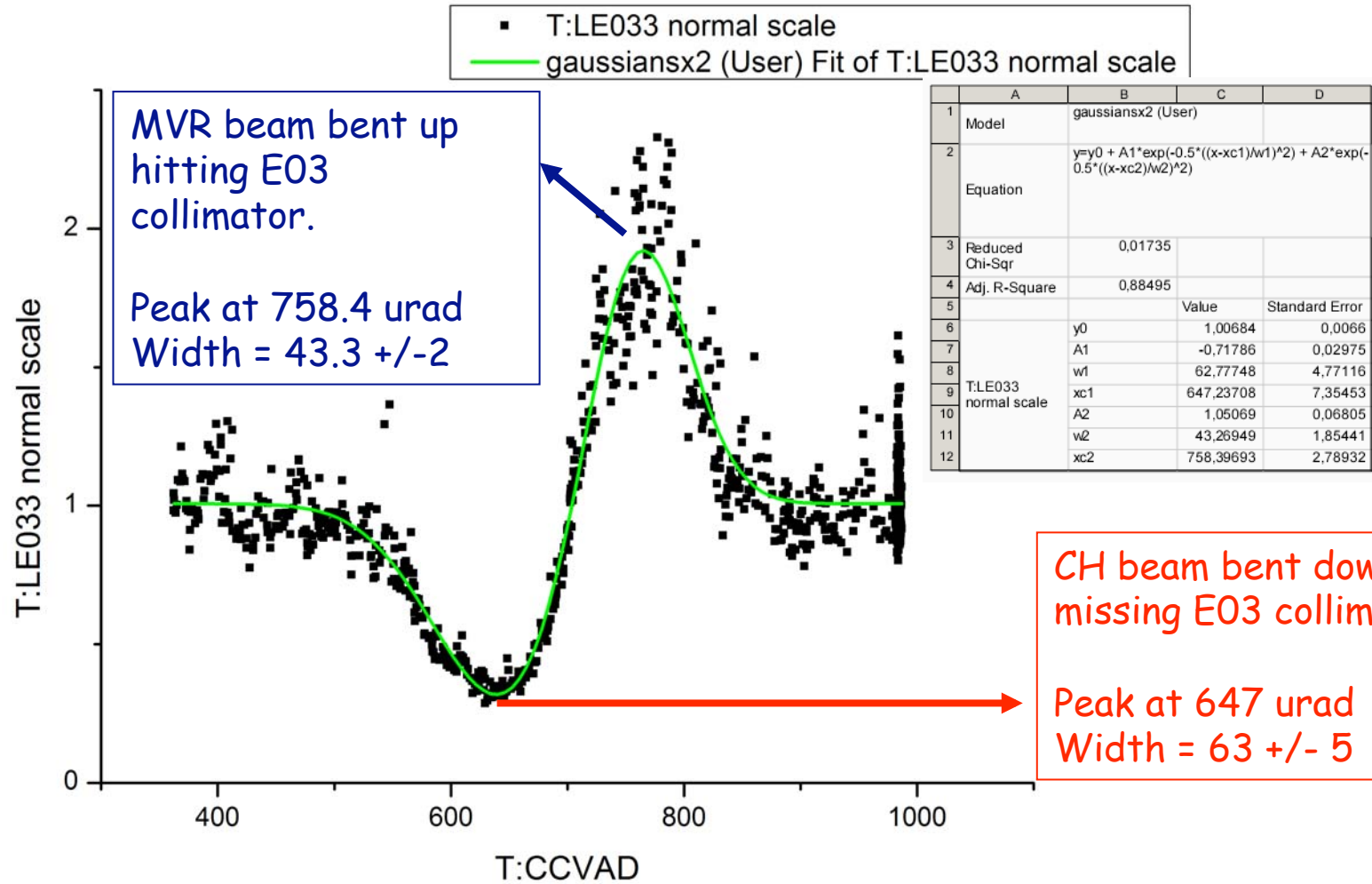
449-222mils/40mils/mm
= 5.7 mm displacement
from core for Channeled
beam.

$\theta_{CH} = 186 \text{ urad}$

Specified $\theta_{CH} = 200 \text{ urad}$

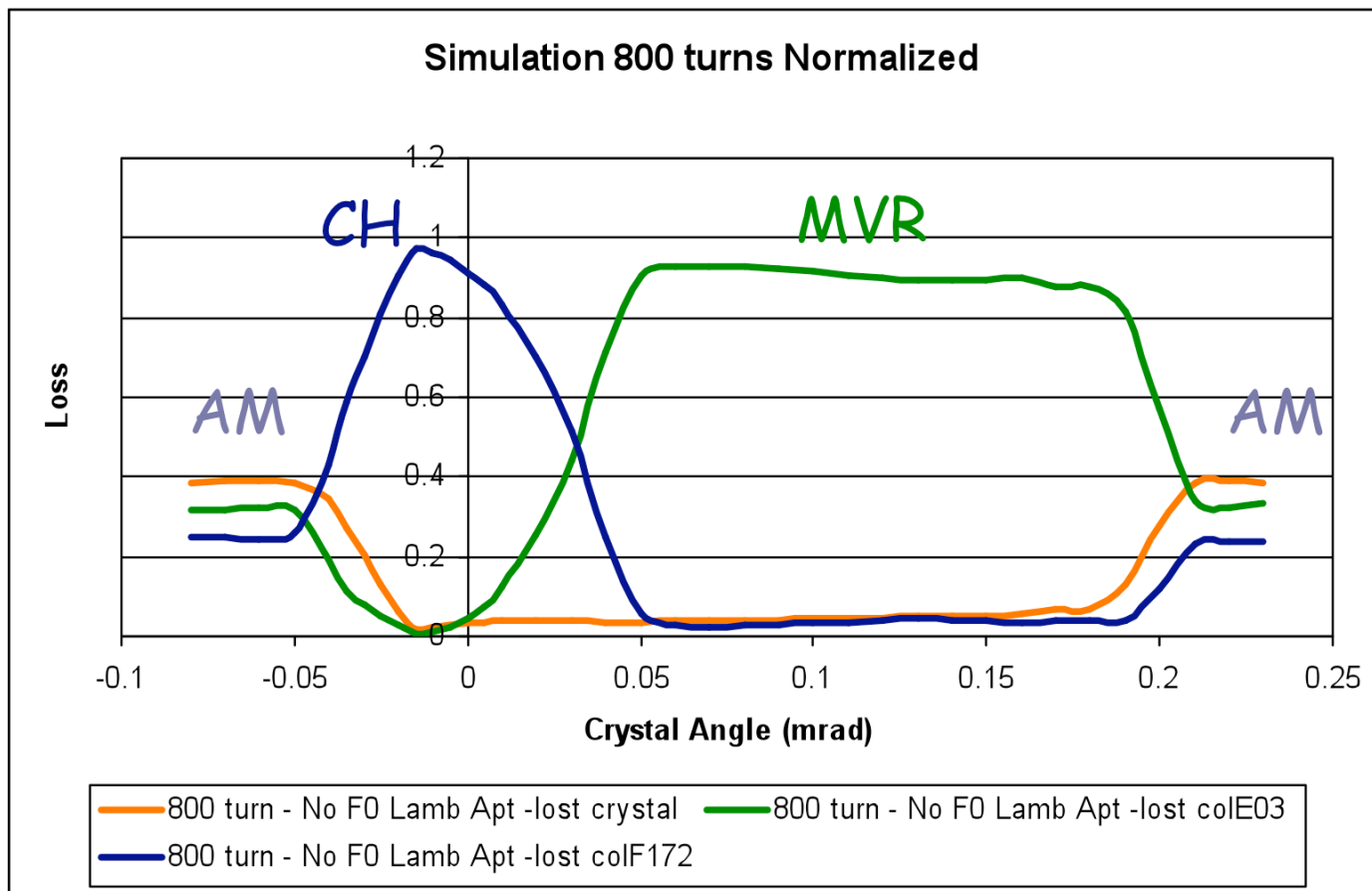


Angle Scan Depicting CH & MVR beam on loss monitor downstream of E03 collimator





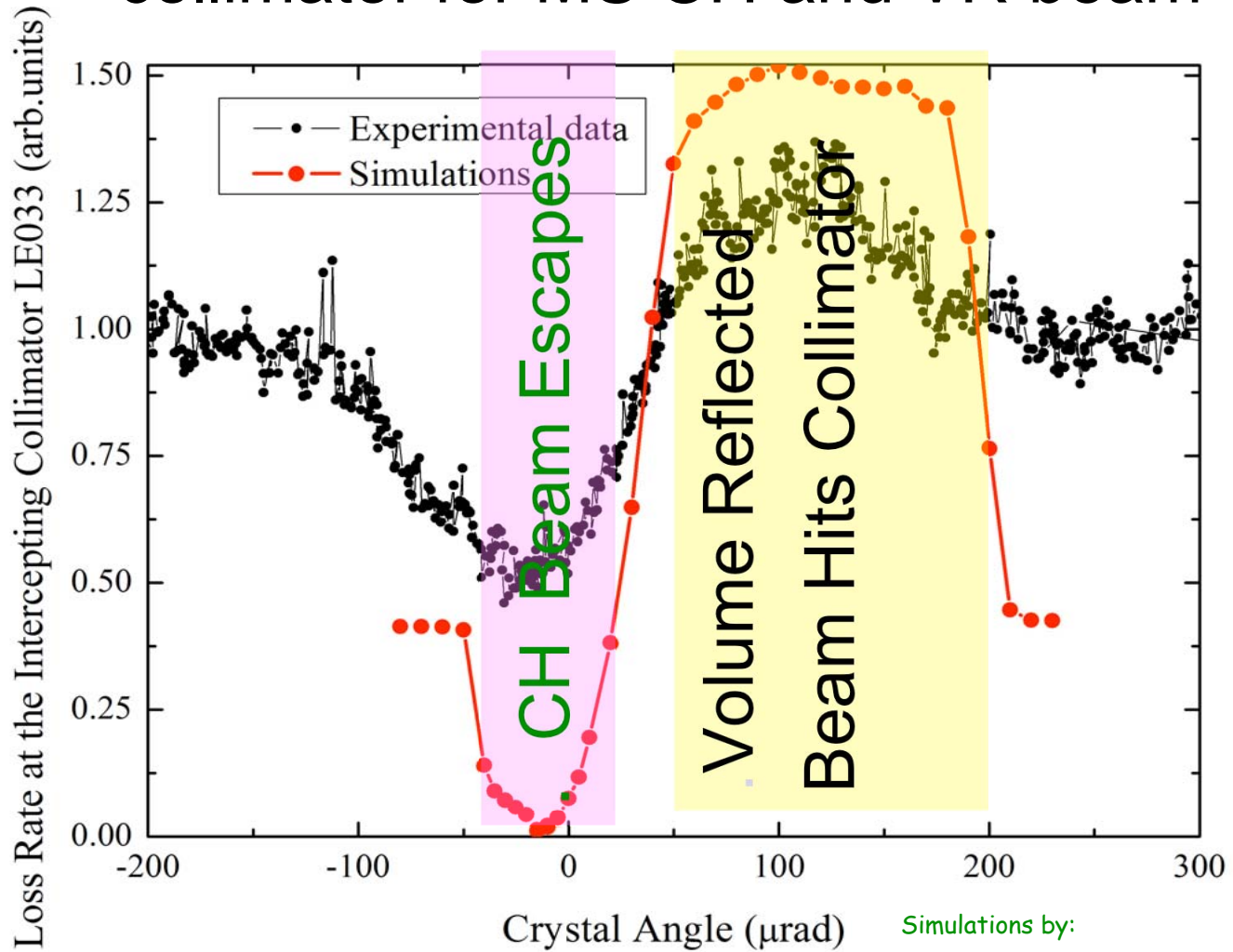
Simulations for 8 strip Multi-strip (MS-08-09)



Simulations by:
S. Drozhdin with imbedded code from I. Yazynin

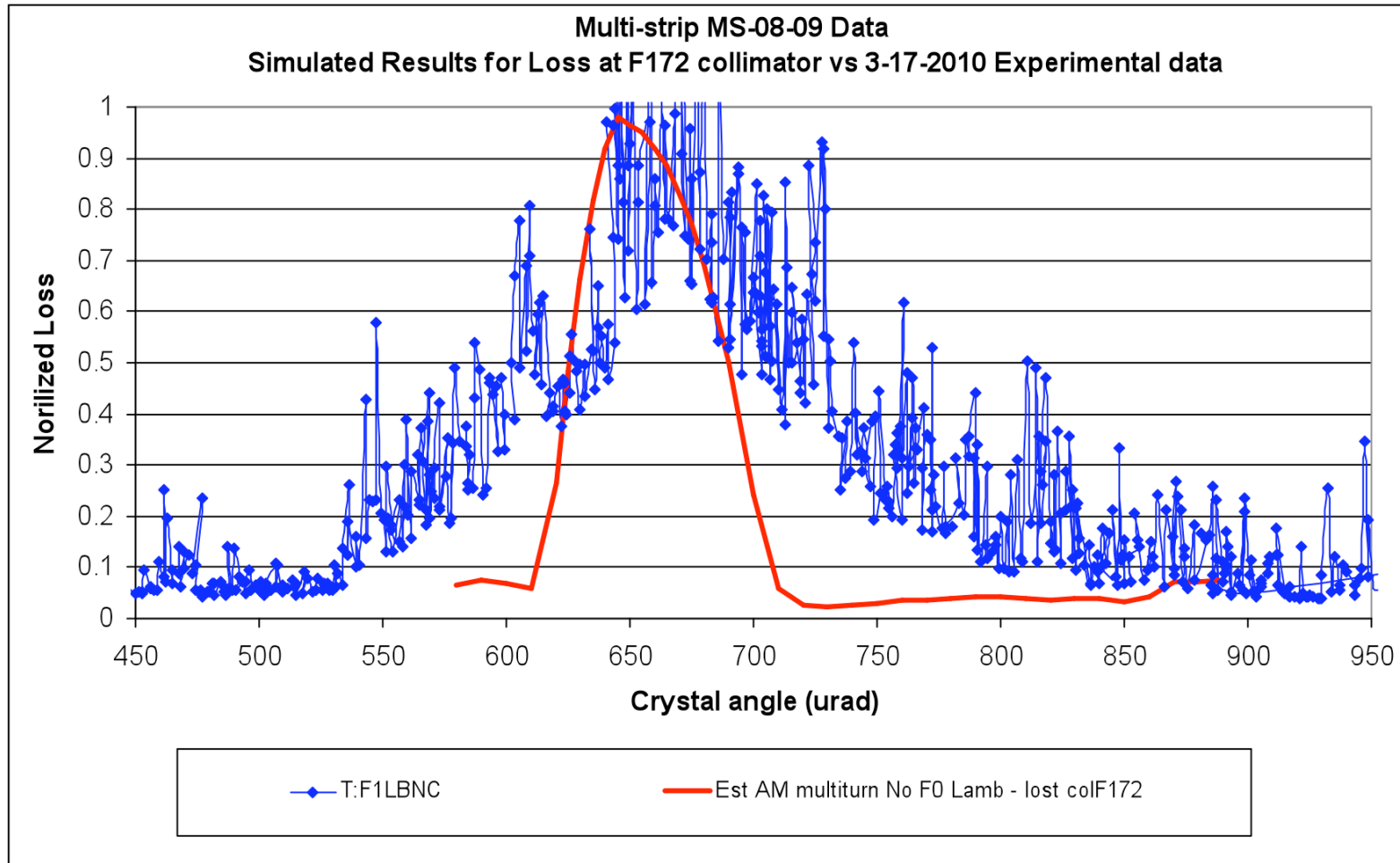


Experimental and simulated losses at E03 collimator for MS CH and VR beam





Experimental and simulated losses at F172 collimator for MS CH beam



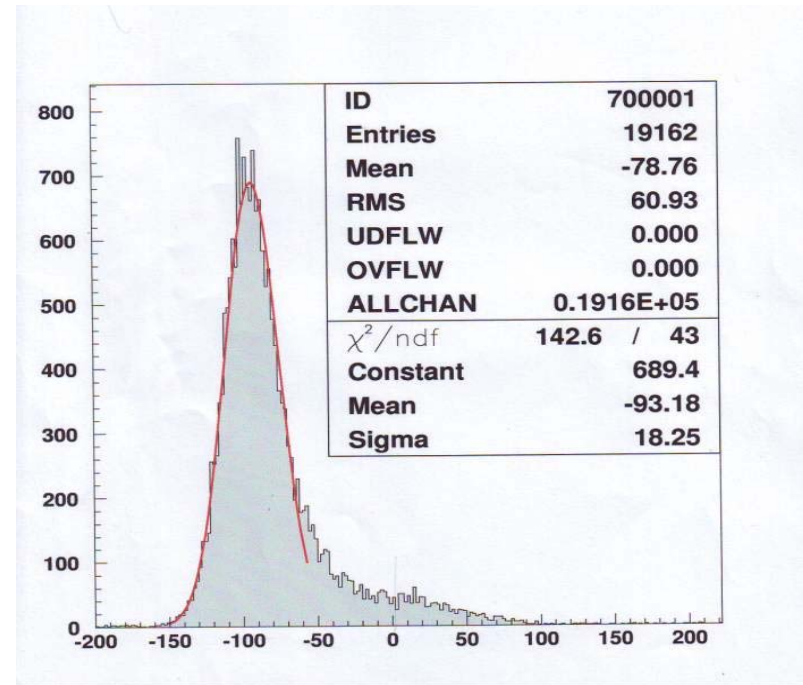
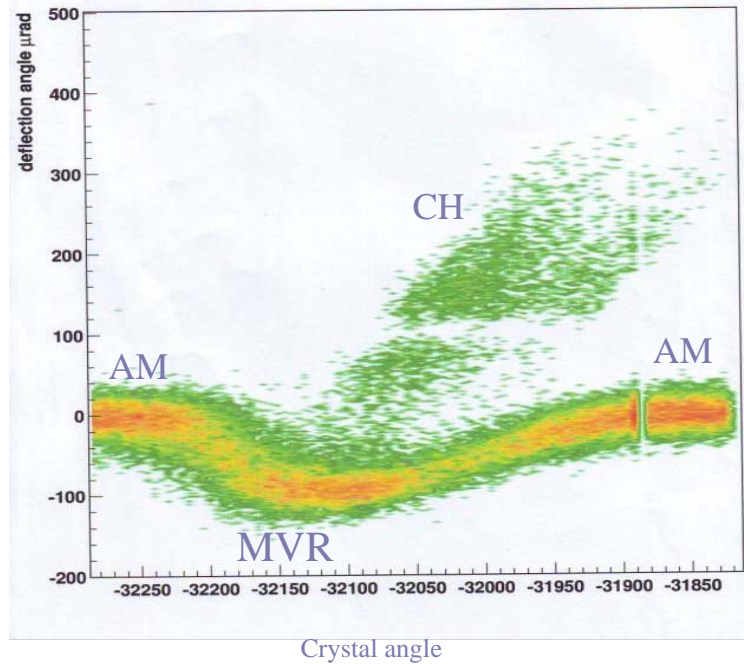
Simulations by:
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MS-08-09 Characterizations at Cern North Area RD22 H8, 400 GeV/C protons



Name: MS-08-09
Bend: 63urad (VR)
Bend: 200urad (CH)
8 strips





Comparison crystal **MVR** parameters for Multi-strip crystal MS-08-09

Specified VR angle = 64 urad (8 strips X 8urad/strip) Note: This is not a strictly defined angle

	MVR angle (by collimator scan) (μ rad)	MVR width (μ rad)	MVR displaced at E03V collimator (mm)	MVR efficiency (%)	Bend angle (by angle scan) (μ rad)	MVR peak (μ rad)
Measured	74.6 (+/- 7.5 stat) (+/- 1.6 instr)	36 (+/- 10 stat) (+/- 2.5 instr)	1.7 (+/- .6 (stat)) (+/- 1.6 instr)	83.5% (+/- 4 instr)	255 (+/- 28.3 stat) (+/- 6 inst)	767 (+/- 12.72 stat) (+/- 3 inst)
Simulated	64	43.3 (+/- 1.9)	1.61	-	-	758 (+/- 2.9)
SPS H8 Run Result	60* <small>* scaled by 1/sqrt(E)</small>	28.6* <small>* scaled by sqrt(E)</small>	-	-	300 (+/- 50)	-
Measured /Expected	SPS 1.24 Simulated 1.17	SPS 1.25 Simulated 0.83	Simulated 1.05	-	SPS 0.85	Simulated 1.01



Comparison crystal **CH** parameters for Multi-strip crystal MS-08-09

Specified CH angle = 200 urad Note: This is not a strictly defined angle

	CH angle (by collimator scan) (μ rad)	CH width (μ rad)	CH displaced at F172 collimator	CH efficiency (%)	Bend angle (by angle scan) (μ rad)	CH peak (μ rad)
Measured	186 (+/- 3 instr)	59 (+/- 12.2stat) (+/- 3.2 instr)	5.6 (+/- 3 instr)	87.5 (+/- 13.6)	255 (+/- 28.3 (stat) (+/- 6 inst)	655.7 (+/- 10.0 stat) (+/- 3.3 inst)
Simulated	200	26 (+/- 5.7 stat) (+/- 1 inst)	6.1	-	192.8 (+/- 20)	658.5 (+/- 2.1 stat) (+/- 1.25 inst)
Measured /Expected	0.93	2.26	0.92	-	1.32	0.99



Comparison crystal CH parameters for O shaped crystal O-05-09

This crystal will be used in the horizontal plane for 2 plane
Crystal collimation.

	CH angle (by collimator scan) (μ rad)	CH width (μ rad)	CH displaced at E03H (mm)	CH Efficiency (%)	Bend angle (by angle scan) (μ rad)	CH peak (μ rad)
Measured	158.8 (+/- 22.8 stat) (+/- 1.2 instr)	16.2 (+/- 5.3stat) (+/- 1.5 instr)	3.8 (+/- .5 stat) (+/- 3 (instr)	79.57 (+/- 9.38)	280.4 (+/- 53.5 (stat) (+/- 100 inst)	-960.8 (+/- 9.1 stat) (+/- 1.5 inst)
Simulated	360	10.5 (+/- 1.1 stat) (+/- 1.0 inst)	8.5	-	192.8 (+/- 20)	-962.8 (+/- 1.6 stat) (+/- 1.0 inst)
Measured /Expected	.44	1.5	.45	-	1.45	.99

The CH angle being smaller is a consistent result with the other O-shaped crystal O-BNL-02 (300 μ rad/410 μ rad = .72 Meas/Exp). Thought that this was miscut related but O-05-09 miscut = 120 μ rad not 1600 μ rad like O-BNL-02.



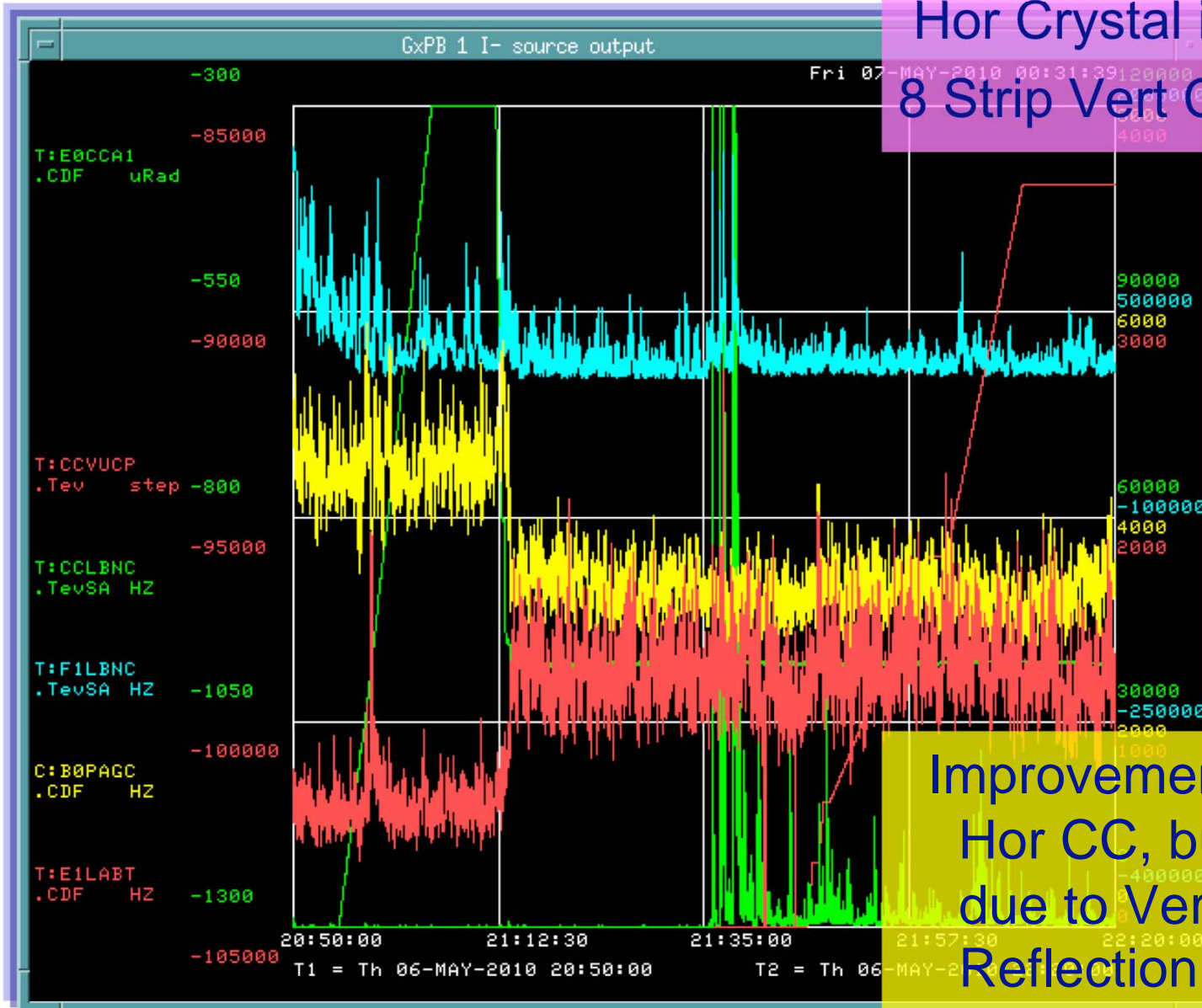
Comparison crystal VR parameters for O shape crystal O-05-09

	VR angle (by collimator scan) (μ rad)	VR width (μ rad)	VR peak (μ rad)	VR length (μ rad)	VR displaced at F172 collimator (mm)	VR Efficiency (%)
Measured	29.8 (+/- 3.3 stat) (+/- 1.6 instr)	33.5 (+/- 10 stat) (+/- 2.5 instr)	767 (+/- 12.72 stat) (+/- 3 inst)	154.7 (+/- 32 stat) (+/- 23 instr)	1.7 (+/- .2 stat) (+/- 1.6 instr)	71 (+/- 7.0 stat) (+/- 7.3 inst)
Simulated	16	-	-	100 (+/- 4)	0.93	-
Measured /Expected	1.86	-	-	-	1.8	-



1st Attempt of 2 Plane Crystal Collimation

Hor Crystal in Channeling
8 Strip Vert Crystal in VR



Improvement seen due to
Hor CC, but very little
due to Vert MS Volume
Reflection

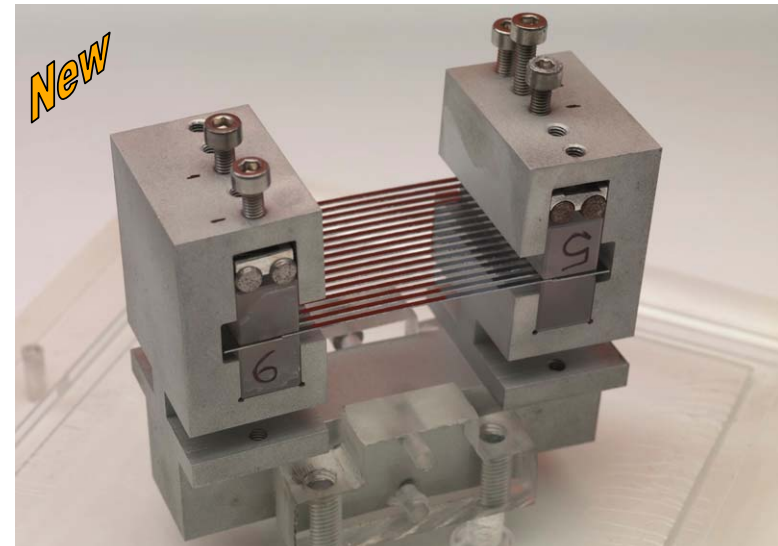
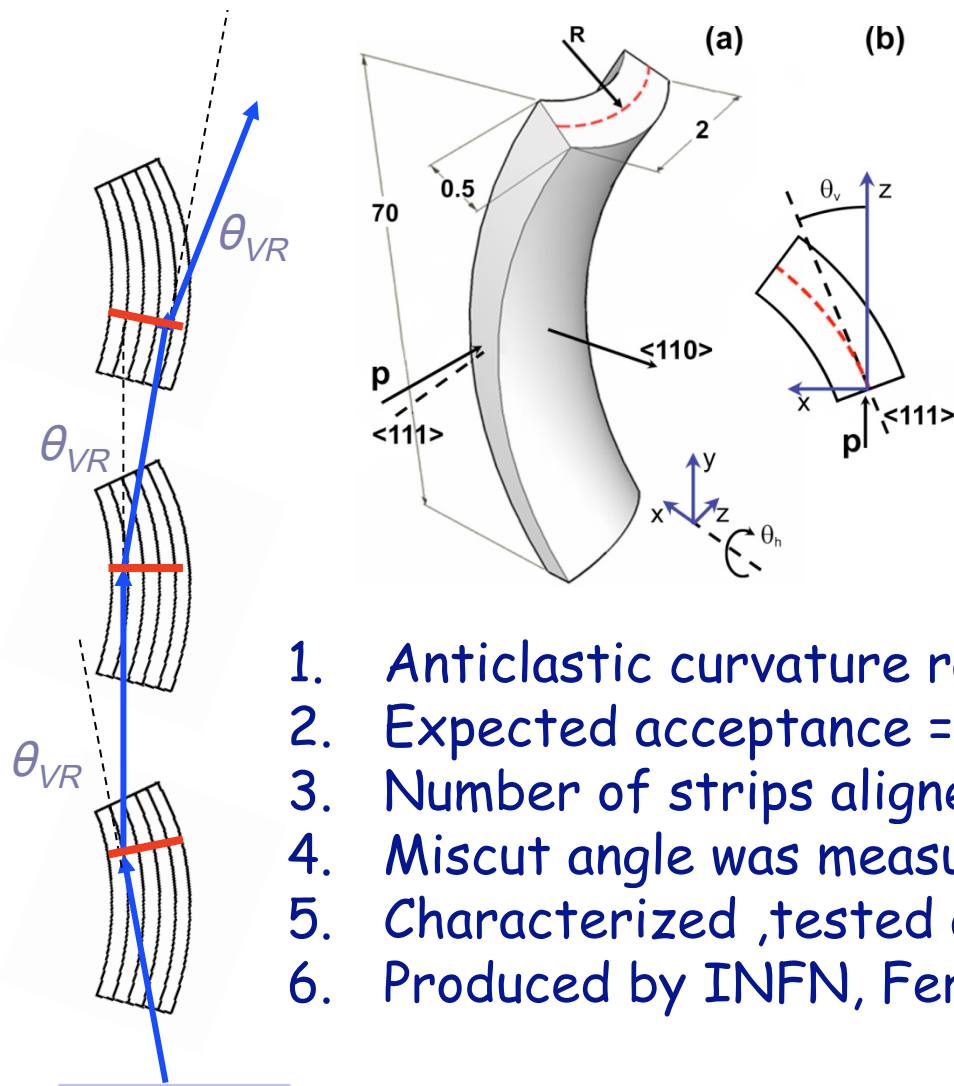


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New Ferrara Multi-Strip Crystal

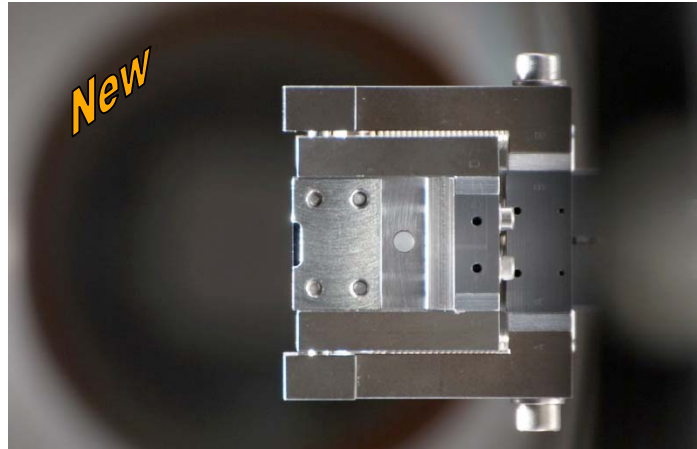


Multi-strip silicon crystal (16 strips) (MS-16-10)

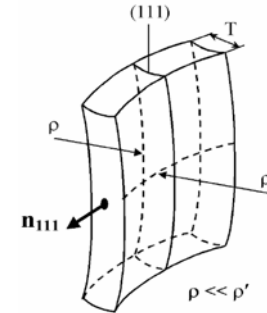
1. Anticlastic curvature radius = 4.2 m
2. Expected acceptance = 80 μrad
3. Number of strips aligned/used = 13
4. Miscut angle was measured as 600 μrad
5. Characterized, tested and installed in vertical goniometer
6. Produced by INFN, Ferrara V. Guidi



New PNPI Quasi-Mosaic Crystal



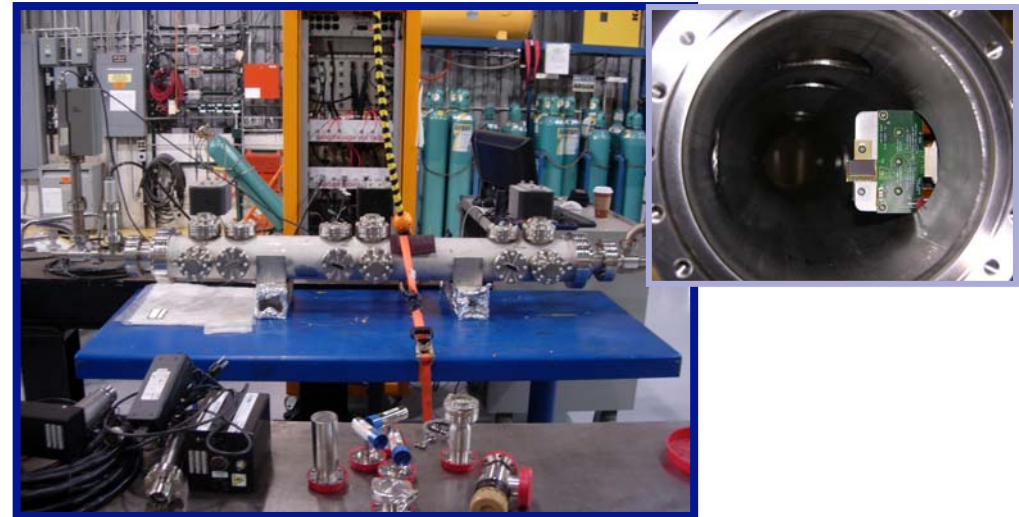
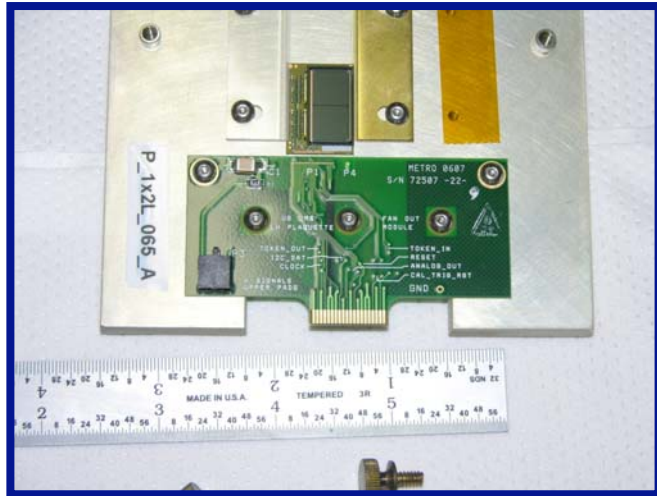
Quasi Mosaic (QM-01-10)



1. 2-mm thick, 120- μ rad bending,
2. miscut angle 50 μ rad
3. Opening in bending device 2x10 mm²
4. Characterized, tested and installed in the vertical goniometer.
5. Produced by PNPI Y. Ivanov



Pixel Telescope Detector



- Multi-chip modules are of CMS forward pixel production.
- 1x2 cm² with a sensitive area 0.8x1.6 cm².
- Pixel size 100x150 μm², **resolution 7-8 μm.**

- Building 2 detectors
 - 1 installed in front of E03 collimator
 - 1 installed in front of F172 collimator
- Consists of 3 telescoping pixels per plane.
- Problems vacuum certifying pixel boards due to baking temperatures.
- Should install ~ December 2010



Near Future Plans:

Beam studies will begin Oct 2010:

1. Characterize both crystal parameters with beam.
2. Demonstrate 2 plane crystal collimation for both crystals
 - MS Vertical VR & O shape Horizontal CH
 - QM Vertical CH & O shape Horizontal CH
3. Once the pixel is installed, gather data for the above studies.



Proposal for Post-Run II Studies

1. Detailed investigation of the principal crystal collimation issues in dedicated collider stores in controllable conditions with crystals and beam diagnostics tuned in 2010-2011.
2. 6-8 weeks interlaced with other accelerator studies, focusing on LHC-related questions introduced earlier.
3. Re-arrangement of E0 for pbar runs after the end of Run II (1 week).
4. Antiproton beam studies in 2 or 3 pbar only stores.



SUMMARY

- T-980 incorporated new crystals, goniometers and instrumentation to conduct beam studies for 2010 to provide options to study more crystals and also 2 plane crystal collimation.
- First results obtained for vertical plane 8 strip multi-strip crystal are encouraging with consistent values for MVR angle and width compared to SPS H8 run and simulations.
- Also results for new horizontal plane 360 urad bend O-05-09 crystal have been obtained with CH angle less at .44 of expected. This result is more consistent with previous O-shape O-BNL-02 and appears not to be related to miscut angle. Collimator scans were also conducted with different impact parameters small (nm) and large (10micron) with no difference in displacement.
- First attempt at 2 plane crystal collimation had limited success. Main problems stemmed from wrong initial angular set point for the horizontal crystal.
- 2 new crystals (Quasi-Mosaic & 16 strip Multistrip) are installed in the Tevatron which beam studies will begin in Oct 2010 to study 2 plane crystal collimation.
- 2 new pixel telescoping detectors are being built with installation hopeful for Dec 2010.
- A post-Run II period would provide a unique possibility for even deeper, controllable, dedicated studies of several key issues of the program with addition of antiproton channeling. Time period for the post Run II is still unclear.