Optical Diagnostics

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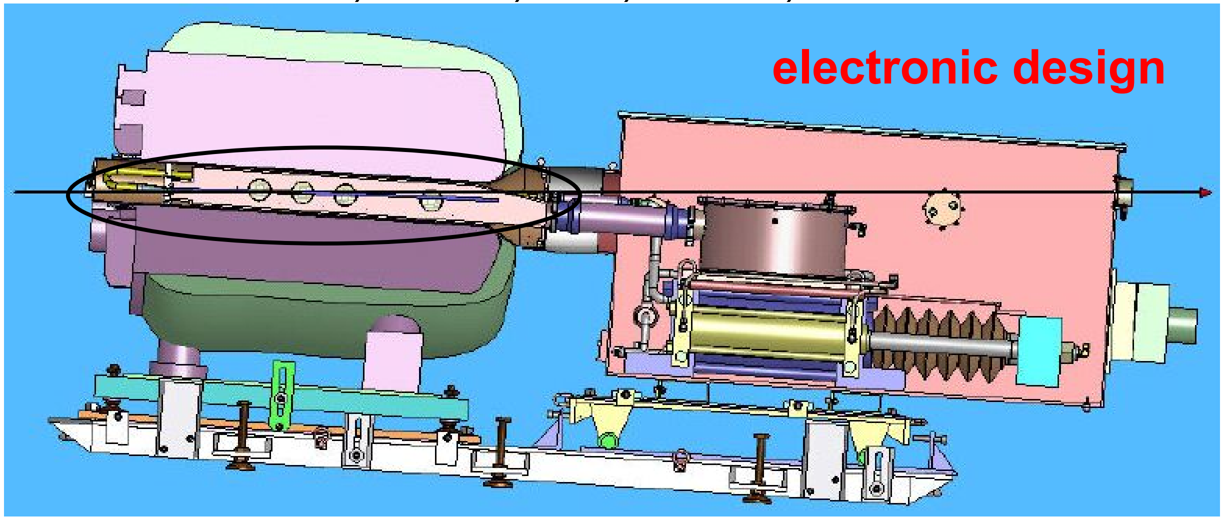
(Feb. 2, 2008)

Princeton, ORNL, MIT, CERN, and BNL

Design and construct a high-speed optical camera system, perform image collection and data analysis

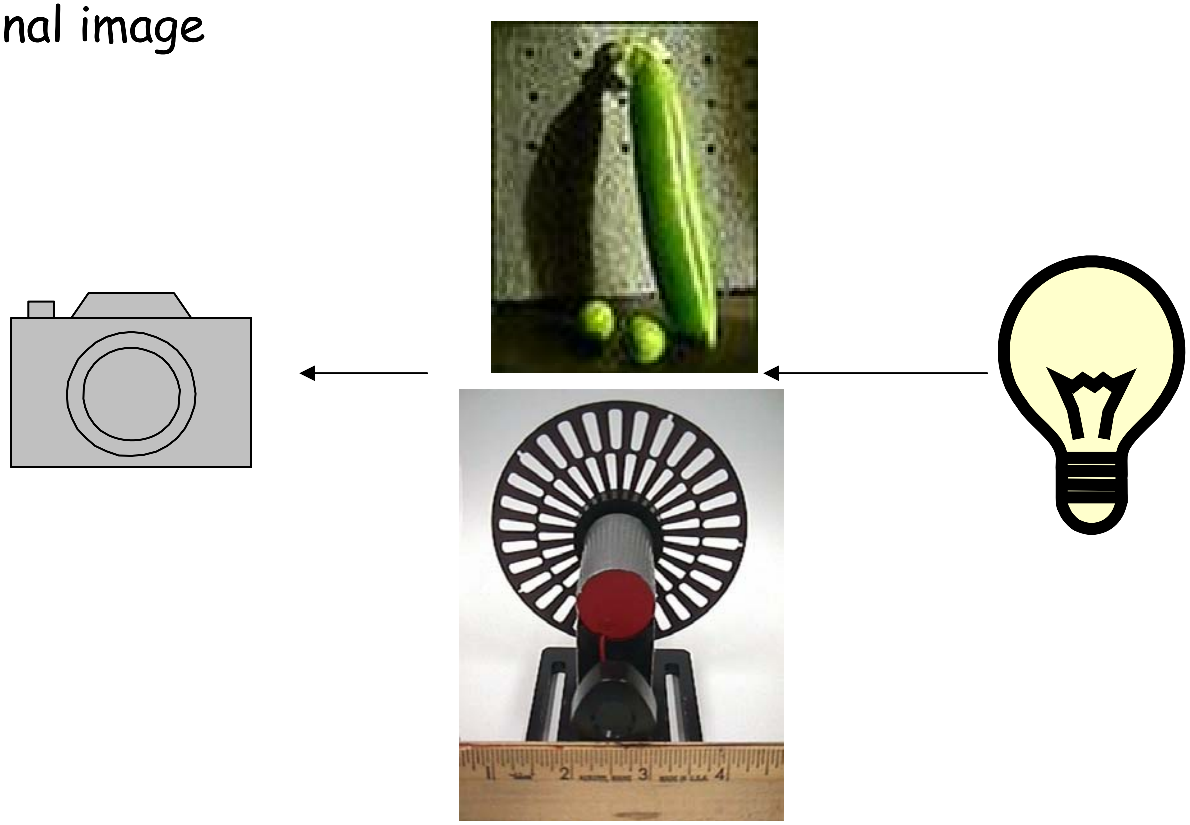


- tight environment
- high radiation area
- non-serviceable area
- passive optical components
- image transmit through flexible coherent imaging fiber bundles

Optical diagnostic tool:

high-speed camera to fast record transient phenomena

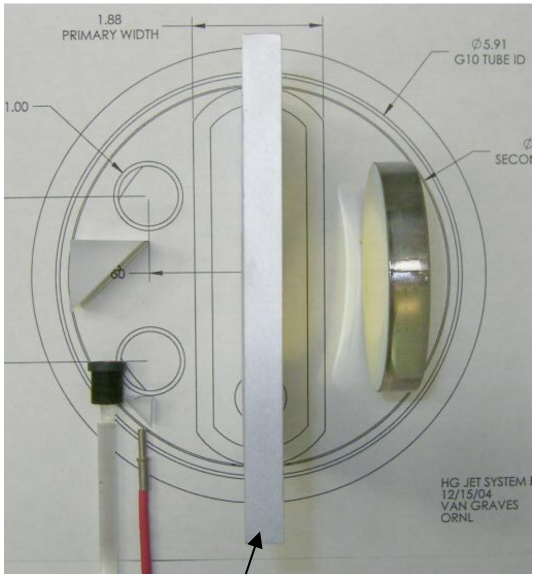
- back illuminated laser shadow photography technique
- freeze the image of events using high speed camera (up to 1 μs/frame)
- synchronized arrival of short laser light pulses illuminate onto the target
- the motion of the target after proton impact is freezed by high intensity short (150 ns) laser pulses
- 2-dimensional image



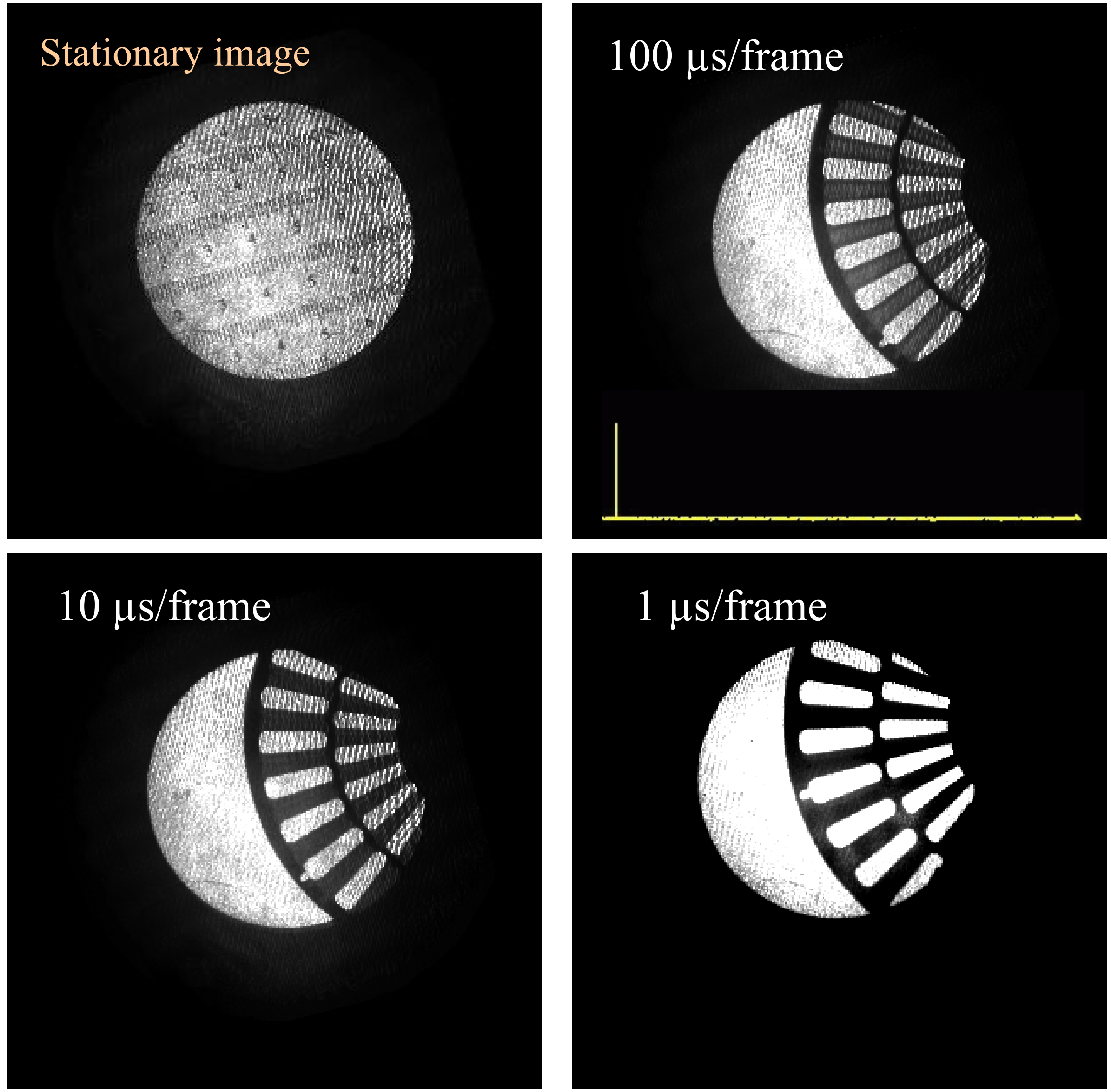
Optical Diagnostics

An optical chopper in motion @ 4 kHz

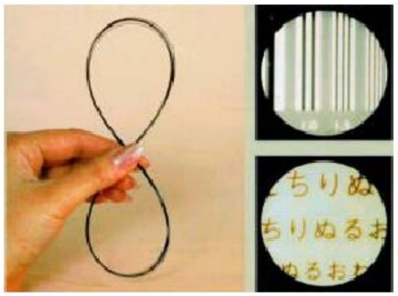
BROOKHAVEN NATIONAL LABORATORY
Instrumentation Division Ultrafast Laser Laboratory



Velocity @ ~40 m/s



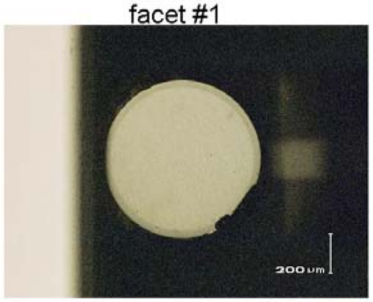
Flexible coherent imaging fiber: Sumitomo (employed in our setup)



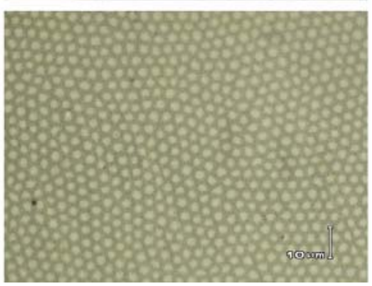
IGN-08/30 sample
0.3-meter
30,000 pixels

facet #1

50x



800x



TP03105B

SEI **Product Lineup**

Rad-hard to 1 Mrad

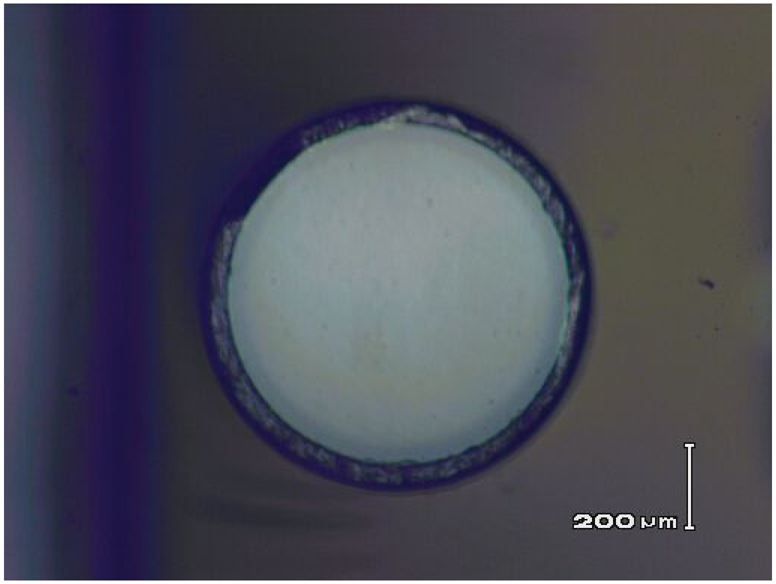
	IGN-02/03	IGN-028/06	IGN-035/06	IGN-037/10	IGN-05/10	IGN-08/30	IGN-15/30	IGN-20/50
Number of picture elements	3,000	6,000	6,000	10,000	10,000	30,000	30,000	50,000
Jacketing diameter (um)	200	280	350	370	500	800	1,500	2,000
Picture elements area diameter (um)	180	252	315	333	450	720	1,350	1,800
Coating diameter (Primary) (um)	250	340	420	450	590	960	1,900	2,400
Coating diameter (Secondary) (um)	---	---	---	---	---	---	2,500	3,000
Circularity	>= 0.93							
Core material	GeO2 Containing Silica							
Cladding material	F Containing Silica						Pure Silica	
Coating material	Silicone						Silicone + PFA	
Numerical aperture	0.35						0.30	
Lattice defect (%)	<= 0.1							
Allowable bending radius (mm)	10	15	15	20	25	40	75	100
Allowable max temp. (C)	150							

SUMITOMO ELECTRIC

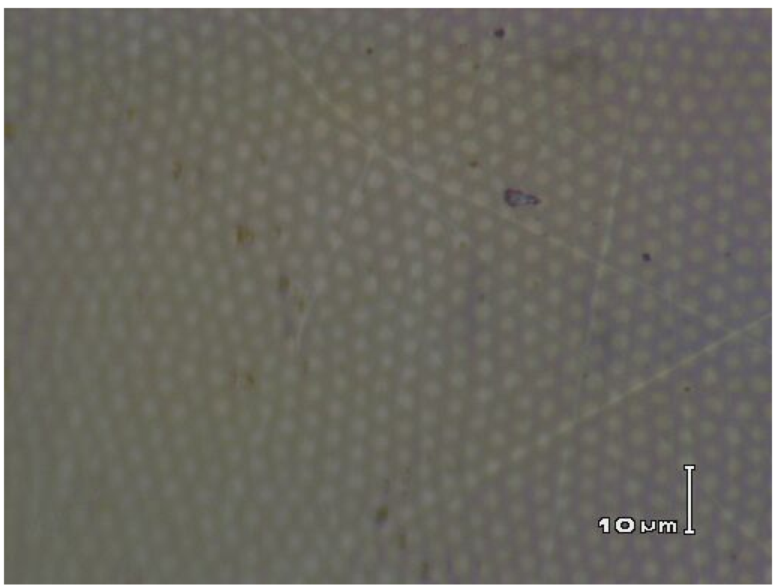
	IGN-08/30	IGN-15/30	IGN-20/50
Cost per foot	**$78**	**$158**	**$305**
Cost in 10 meter	**$2574**	**$5214**	**$10065**
Total cost for 4 fibers (40 meter)	**$10.3k**	**$20.8k**	**$40.3k**

Sumitomo IGN08/30 imaging fiber – 20-meter long

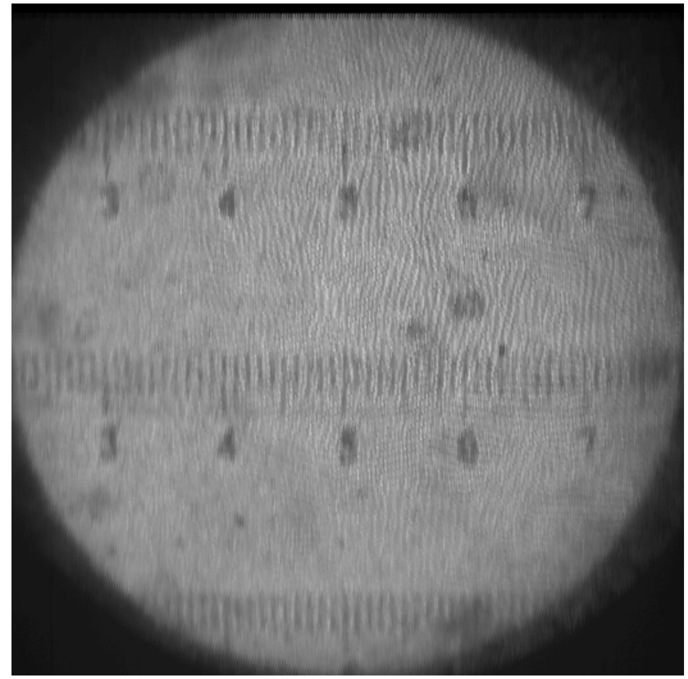
50 x



800 x

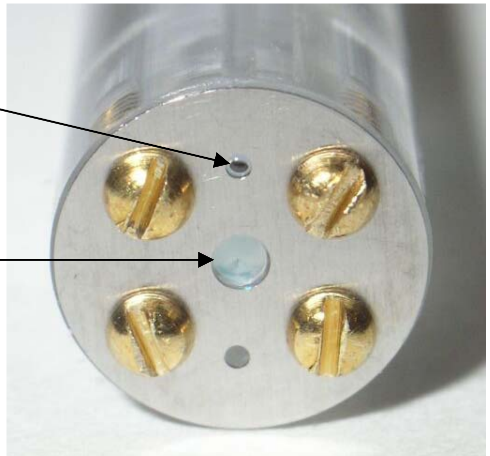


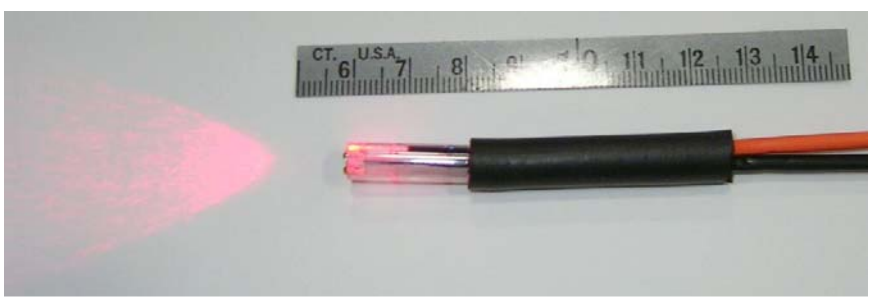
NIR 100 μs/frame static image



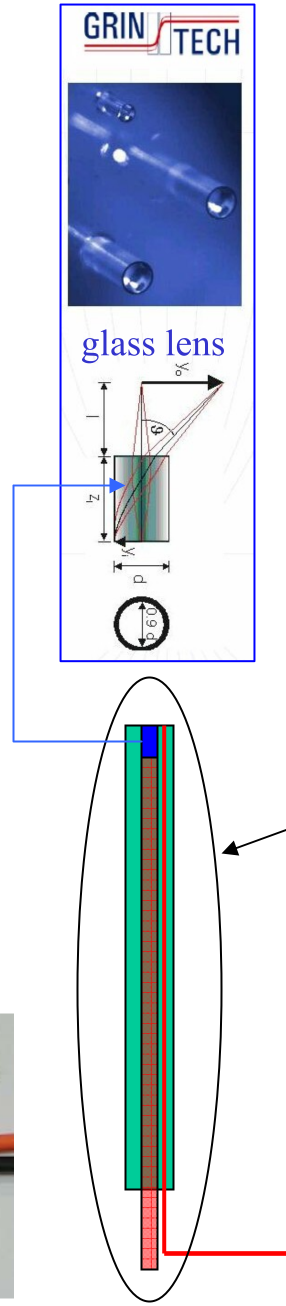
Pixelation artefact:
image superimposition of a honeycomb pattern

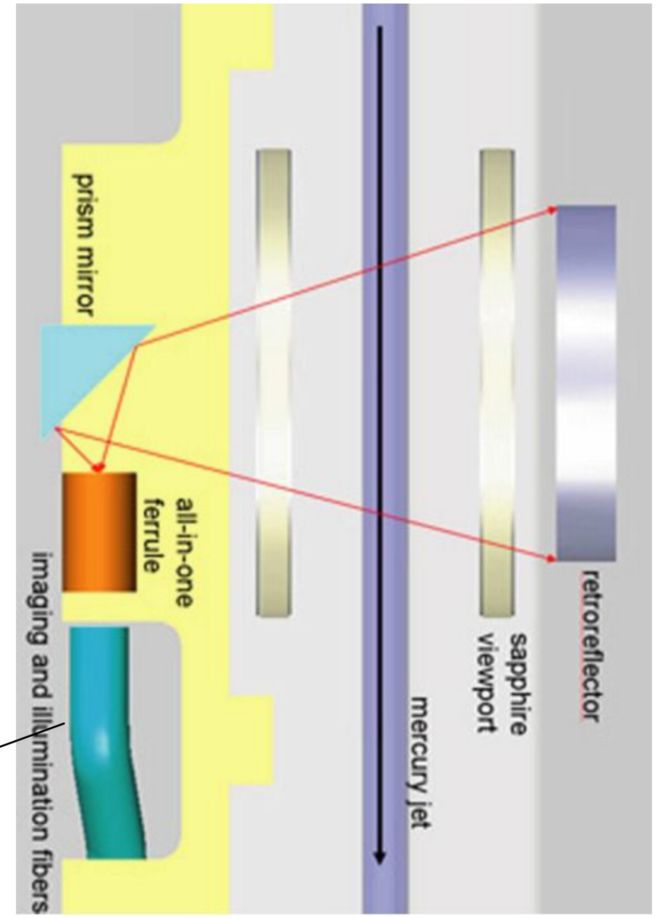
All-in-one optical setup





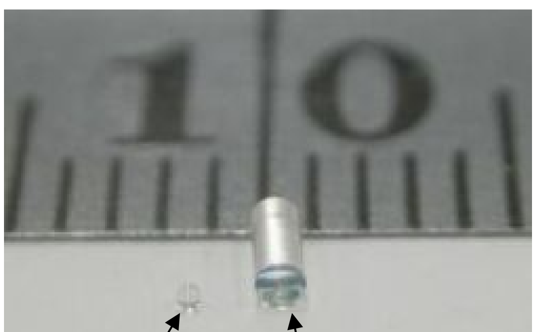
d=0.5 mm sapphire ball lens, increase the NA of illumination to Φ ~ 45 degree





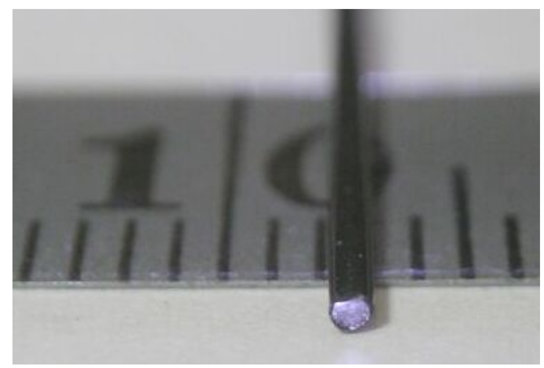
Grin objective lens
fiber holder
illumination fiber
imaging fiber, D=1 mm

<u>All-in-one – 10 meter long imaging and illuminating fibers</u>



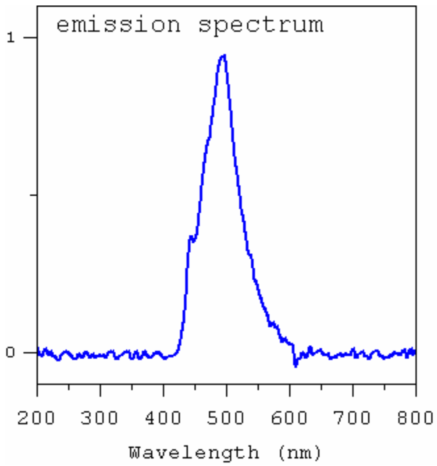
sapphire ball lens

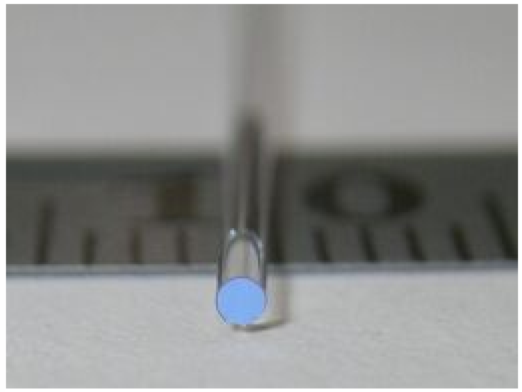
Grin objective lens



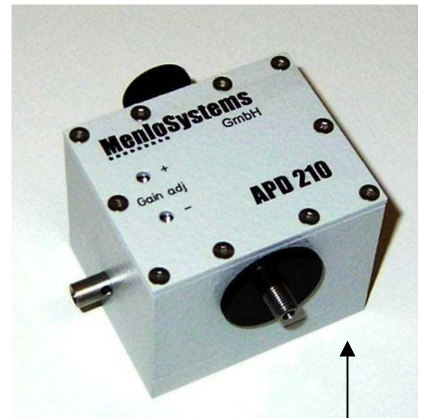
imaging fiber, D=1 mm

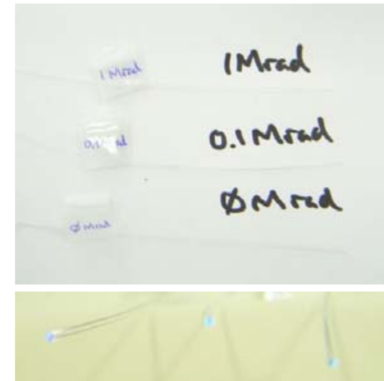
Scintillating fiber channel #0

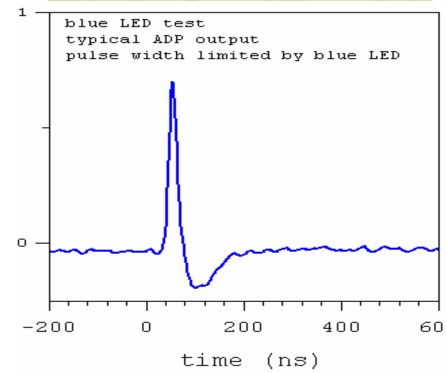




Avalanche photodiode





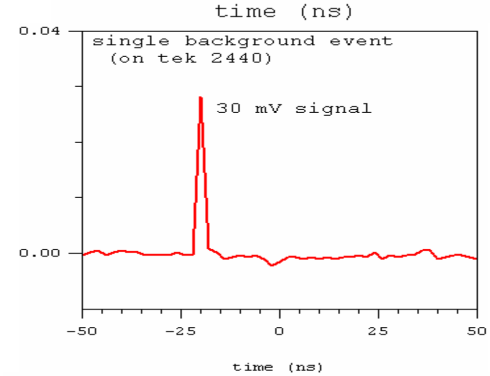


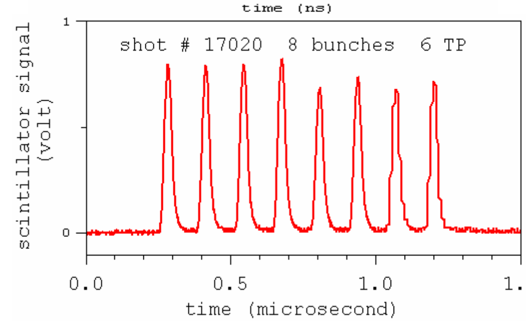
γ

2 meter long, 1-mm diameter
blue emission scintillating fiber

12 meter long, 1-mm diameter
BFH37-1000 fiber

blue T=0.77





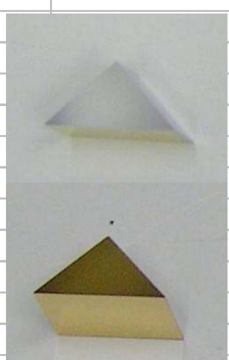
Radiation resistance of optical components

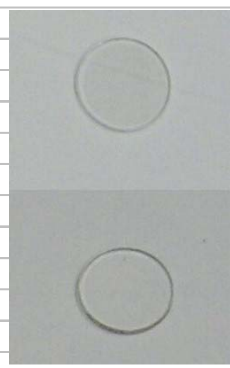
Source #1: CERN proton beam: 1.4 GeV, 5x10^15 protons, 320 krad, equivalent to 40 pulses of 24 GEV proton

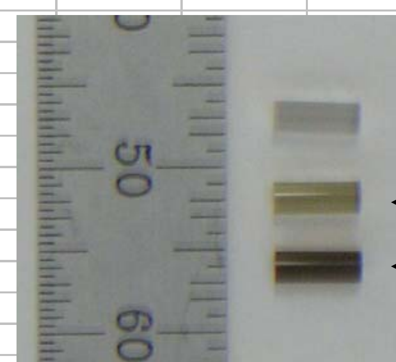
Source #2: BNL Co60: 30 krad & 3 Mrad equivalent to 3.7 & ~370 pulses of 24 GeV proton

measurements wavelength ~ 800 nm

		radiation	equivalent	NIR (~800nm)		
		source	proton pulse			
item #	**components**			**before**	**after**	**results**
1	gold mirror reflector	#1	40	0.910	0.920	no change
2	1-mm thick sapphire window (& ball lens)	#1	40	0.863	0.867	no change
3	5-meter multimode low-OH fiber	#1	40	1.000	1.020	no change
4	30-cm long Sumitomo imaging fiber	#1	40	0.670	0.710	no change
5	Grin objective lens, 2.43 mm long	#2	~4	0.900	0.860	T=95%
5	Grin objective lens, 2.43 mm long	#2	370	0.900	0.657	T=73%







CCD cameras

SMD 64KIM camera
CCD size: 13.4 x 13.4 mm
Pixels: 960x960
Single frame: 240x240 pixels
57,600 picture elements
Frame rate: 16 frames up to 1 μs/frame
Full well capacity: 220,000 e^-
ADC: 12-bit
Quantum Efficiency: 18%

FastVision (1,2)
CCD size: 15.4 x 12.3 mm
Pixels: 1280x1024
Single frame: FPGA programable
1.3 M picture elements
Frame rate: 500/s @ full resolution
500k/s @ 1x1280
Responsivity: ~1000 LSB/lux-sec
ADC: 10-bit
Quantum Efficiency: 10%

CERN Olympus Encore PCI 8000S
CCD size: 1/3 inch
Pixels: 650x500
4 kHz recording rate
25 us electronic shutter

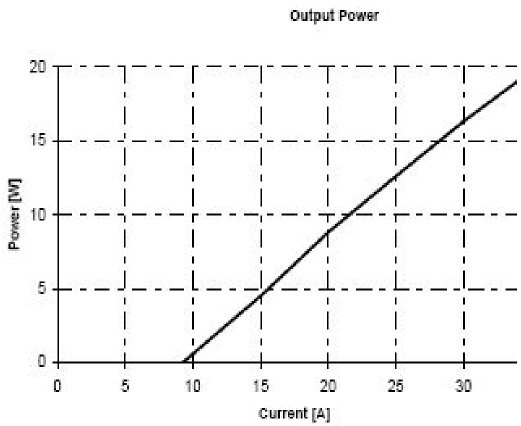
Laser sources

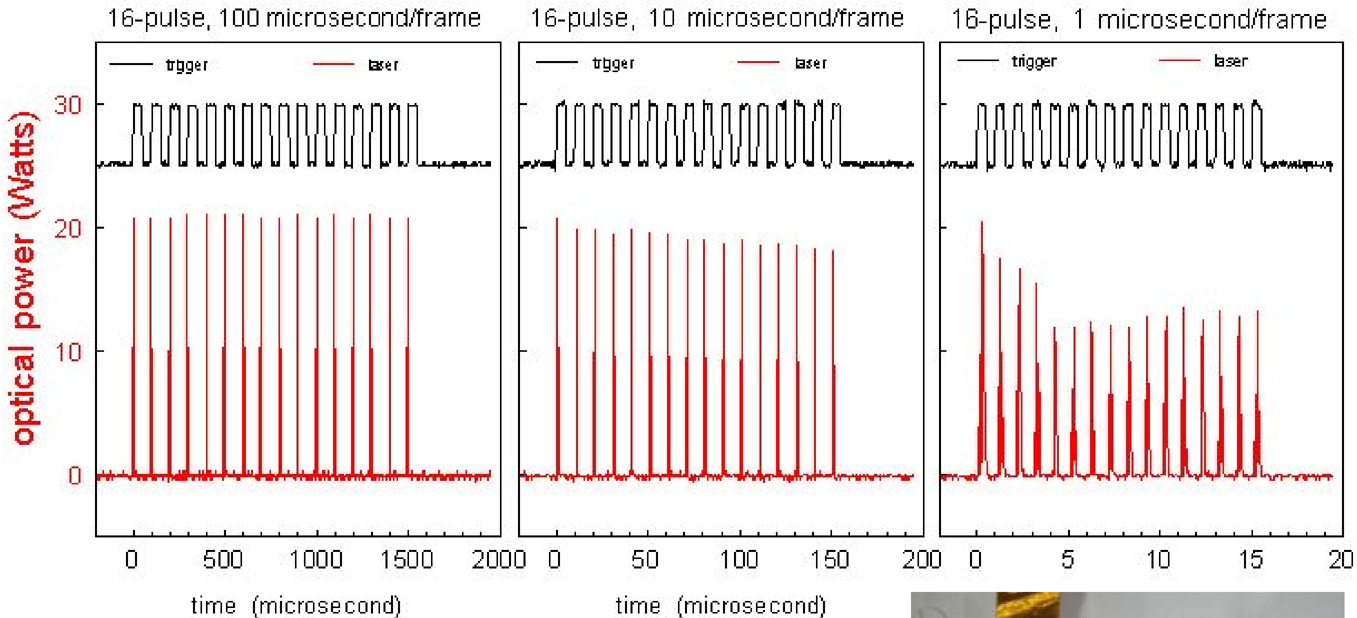
pulse with Avtech pulser

BrightSolutions
SOLUZIONI LASER INNOVATIVE

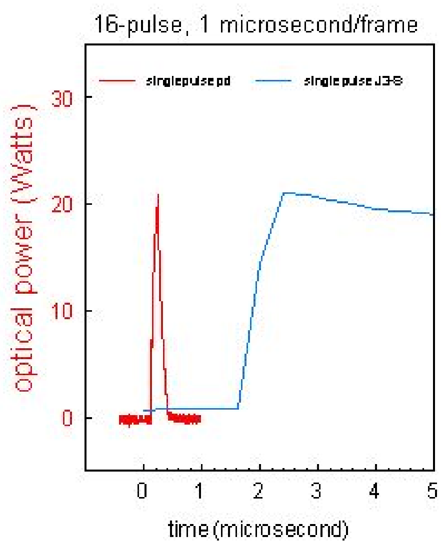
BDL20-808-F6

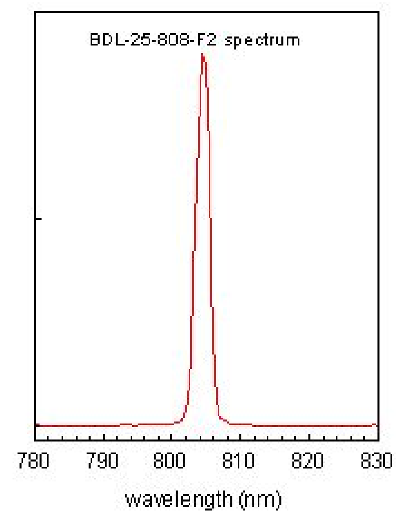
s/n: 05091745





Parameter	Value	Unit
Temperature	25	°C
Rated power	20	W
Current at rated power	35.38	A
Maximum current	41.63	A
Threshold current	9.2	A
Center wavelegth	808.6	nm
Linewidth FWHM	2.64	nm



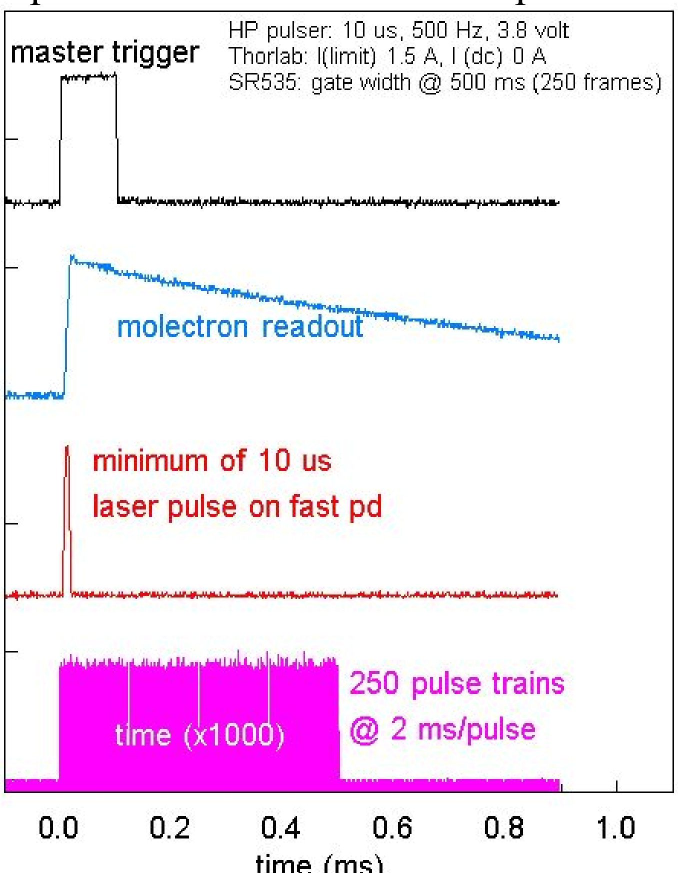


min. pulse width ~150 ns

Laser sources

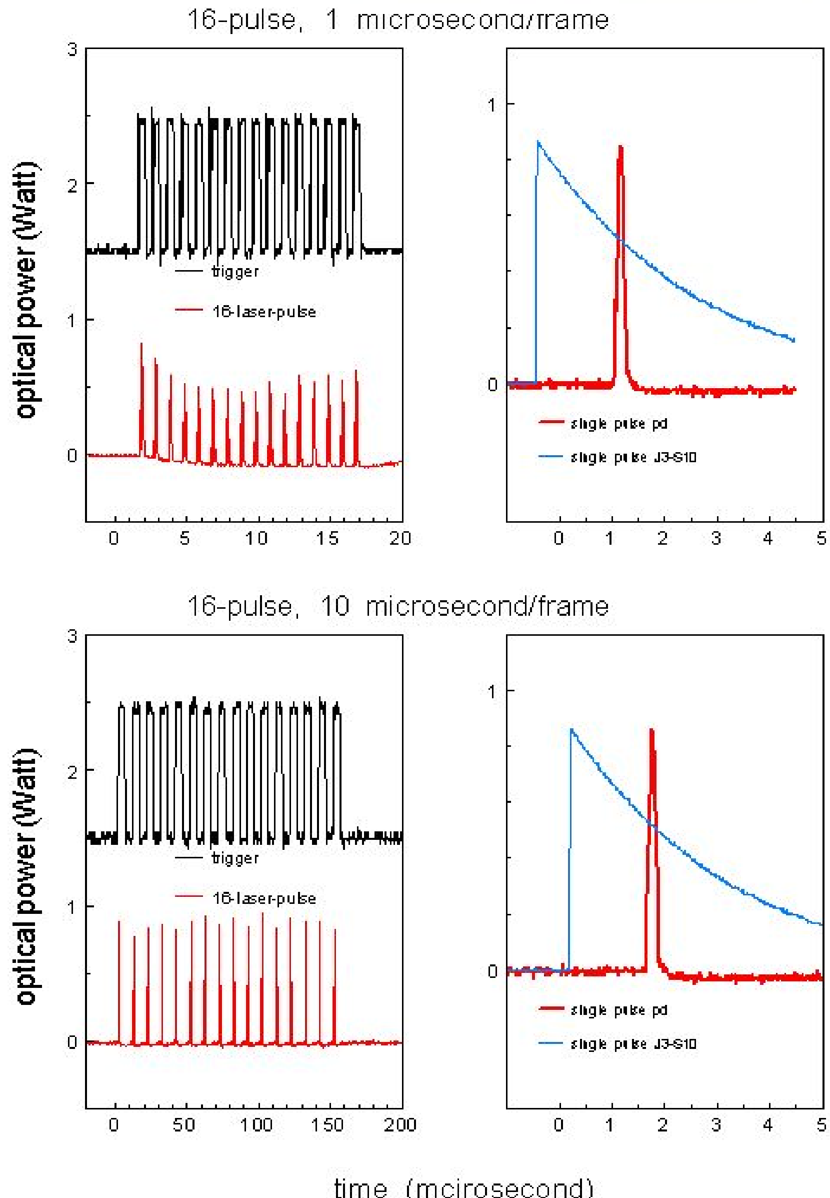
JDS Uniphase
Laser diode, SDL-2300-L2
Power = 1 Watts
I_{th}= 0.3 Amp
λ -= 850 nm

pulse with ThorLab/DG535 pulser



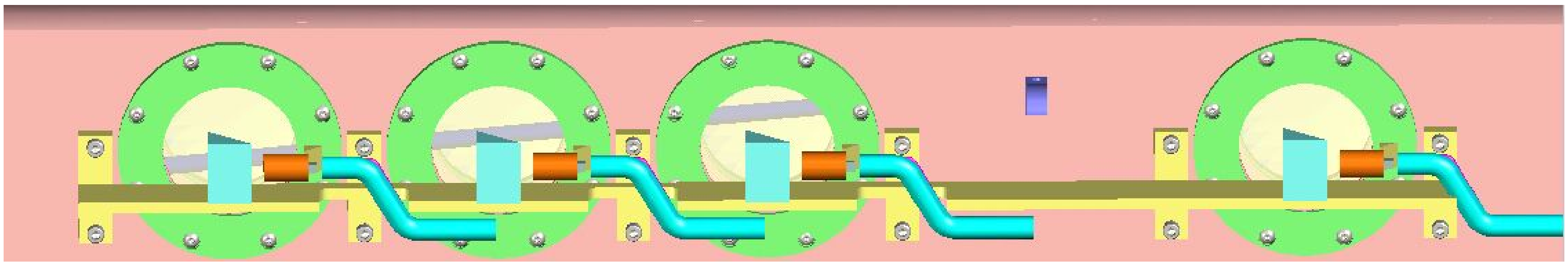
min. pulse width ~10 μs

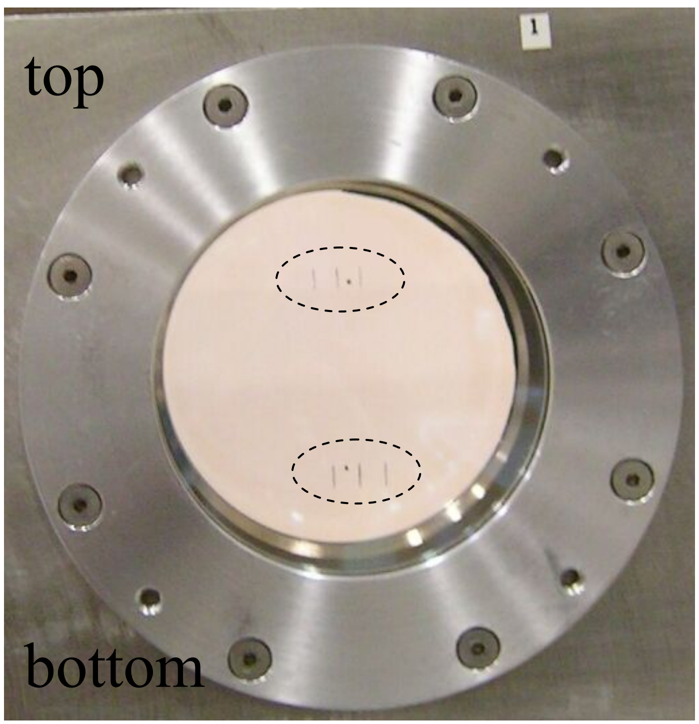
pulse with Avtech pulser

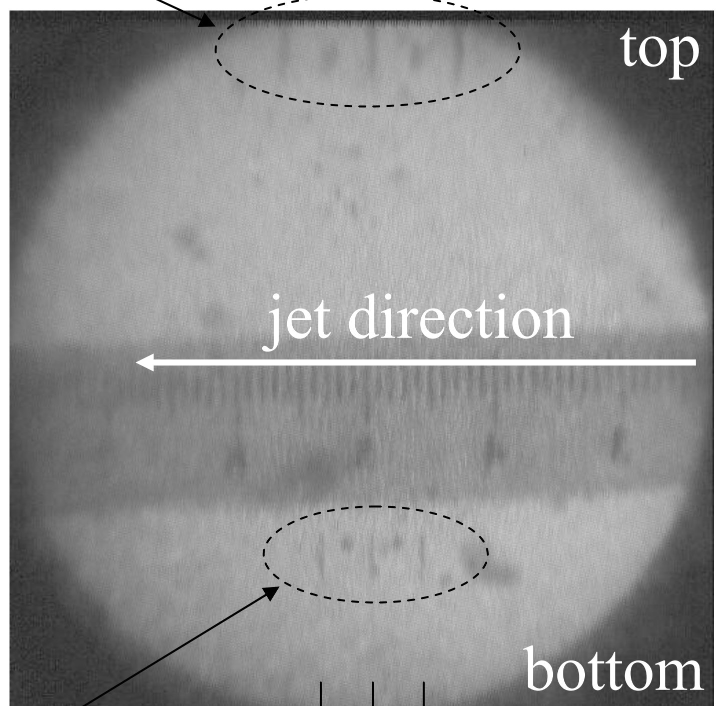


min. pulse width ~150 ns

Optical Diagnostics – viewport identification

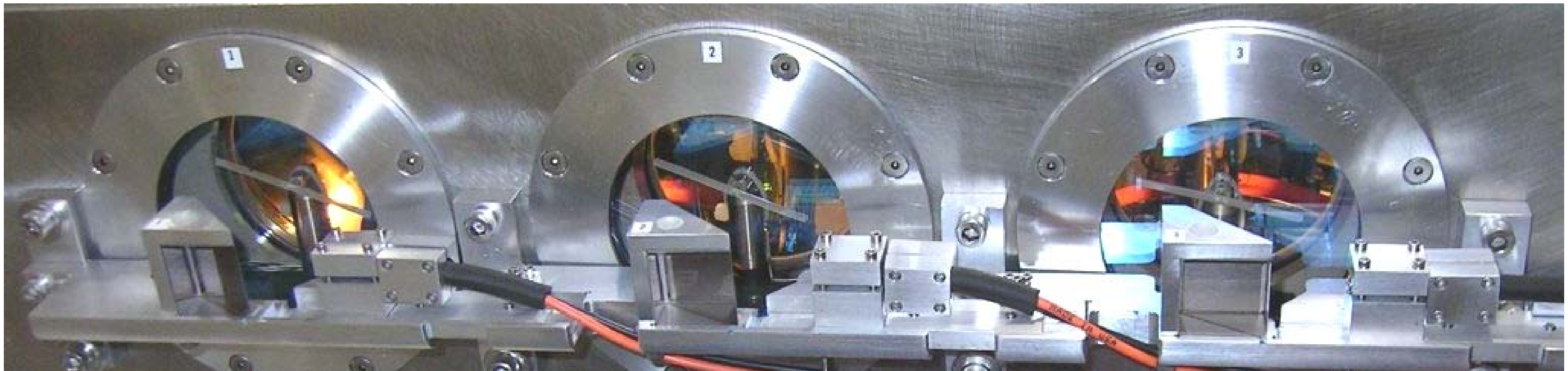


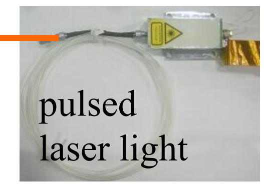




Optical Diagnostics – complete setup

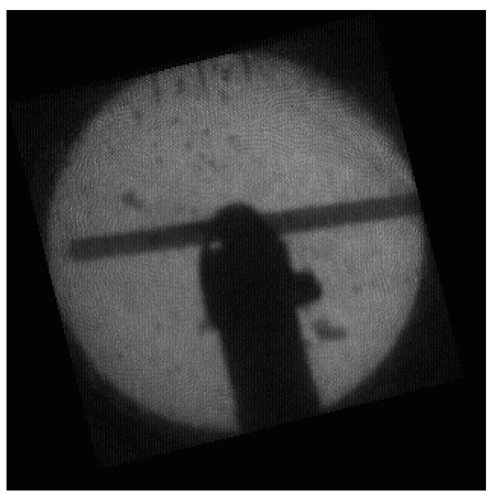
Optical Diagnostics on SS Primary





cw NIR light
conventional video camera
30 frame/sec, 1sec. movie

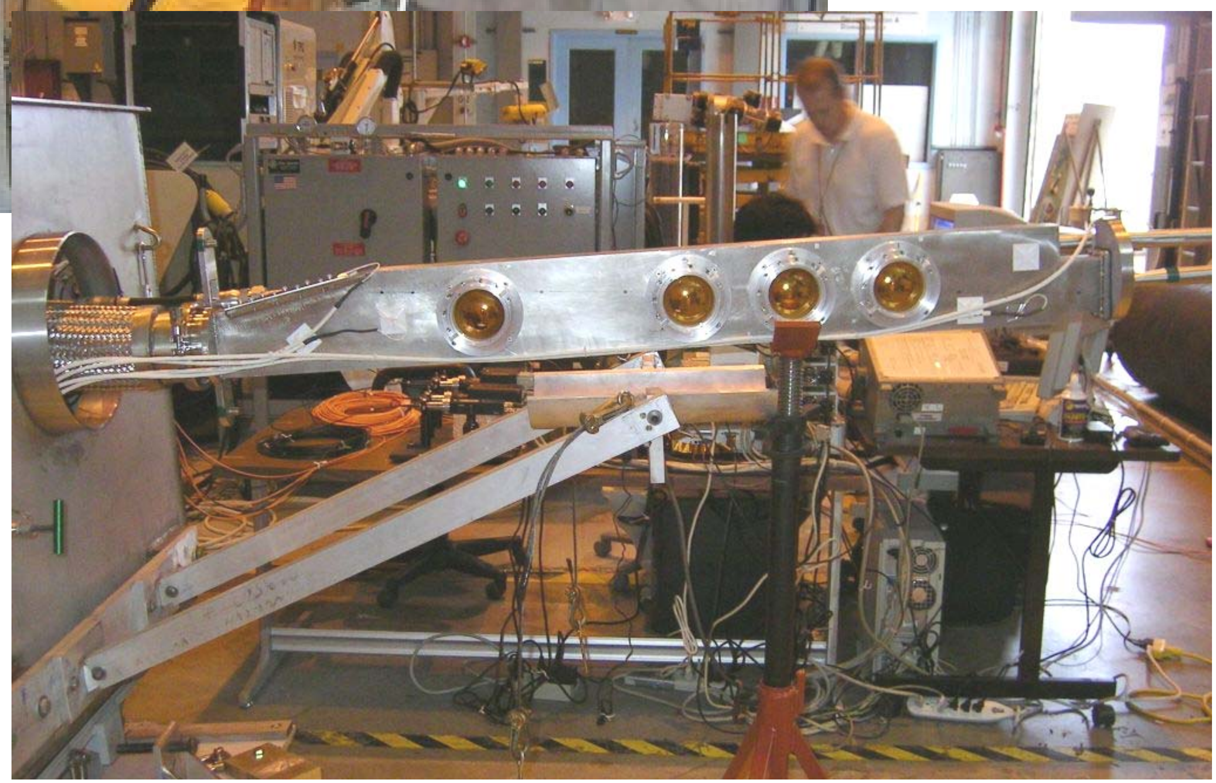
pulsed NIR light
SMD camera
80 us/frame, 16 frames



pulsed NIR light
FastVision camera
2 ms/frame, 250 frames
(only 16 frames showing)

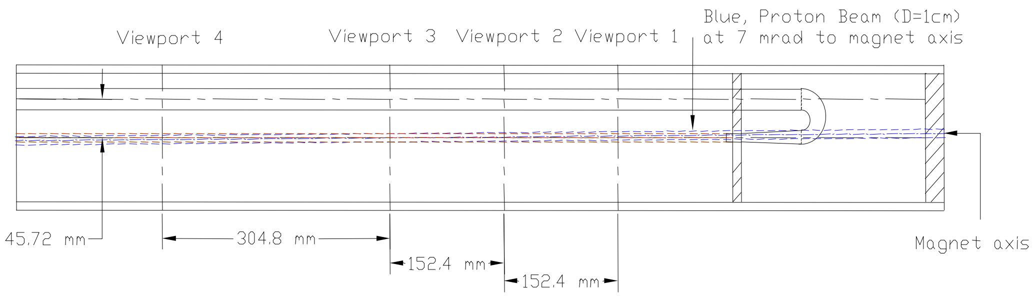
1st runs of water jet at ORNL on Nov. 28, 2006

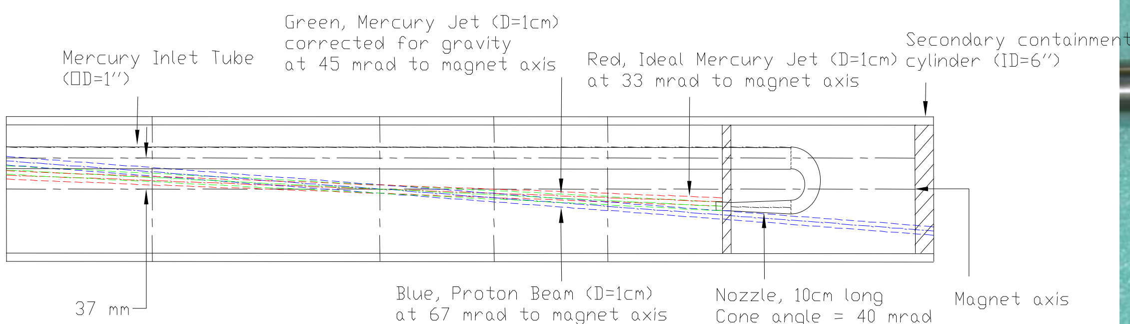
nozzles A, B, & C



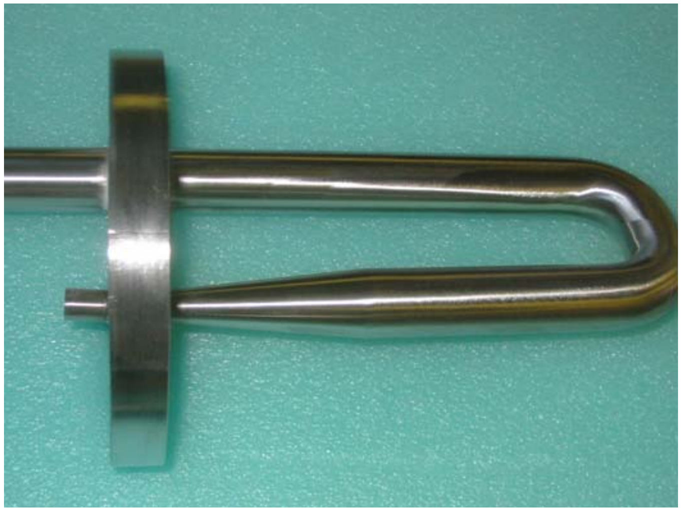
Nozzle Configuration

A : Reduction after 180 degree bend with 44 mrad angle with respect to magnet axis.
B : Reduction before 180 degree bend with 44 mrad angle with respect to magnet axis.
C : Reduction after 180 degree bend, but straight nozzle with no tilted angle with respect to magnet axis.
D : Nozzle A is reamed through the nozzle flange.

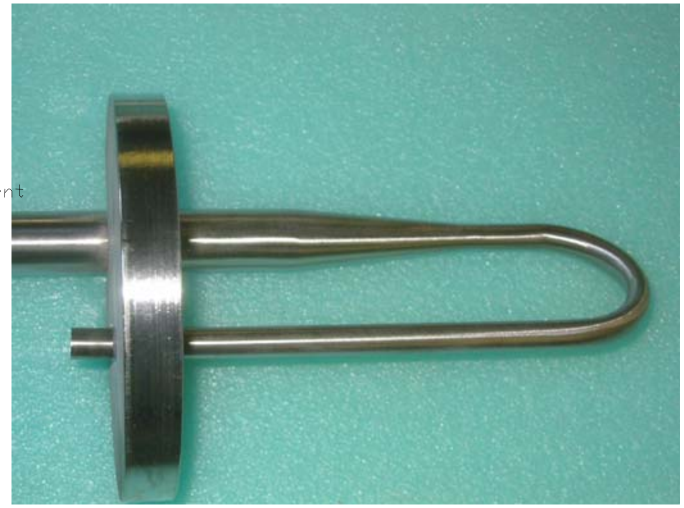




Nozzle A

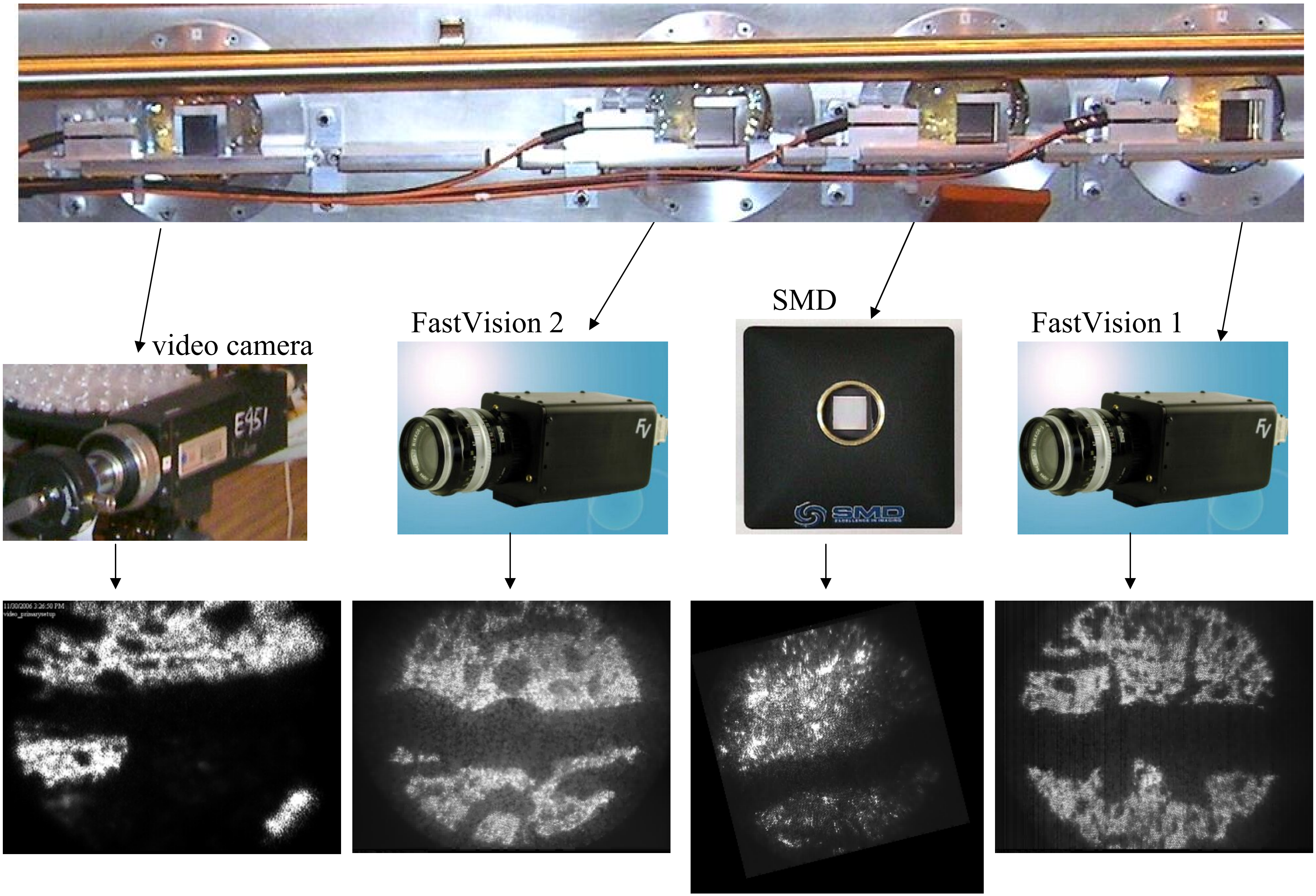


Nozzle B



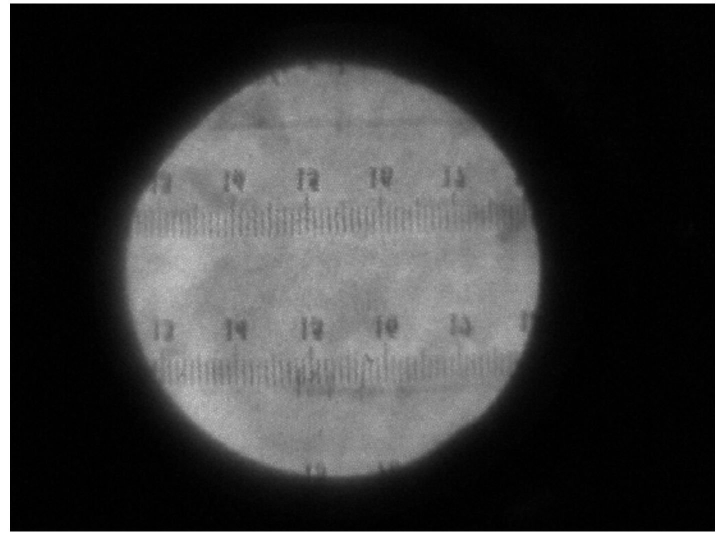
Nozzle C shows stable shape and uniform velocity.

1st runs of water jet at ORNL on Nov. 28, 2006



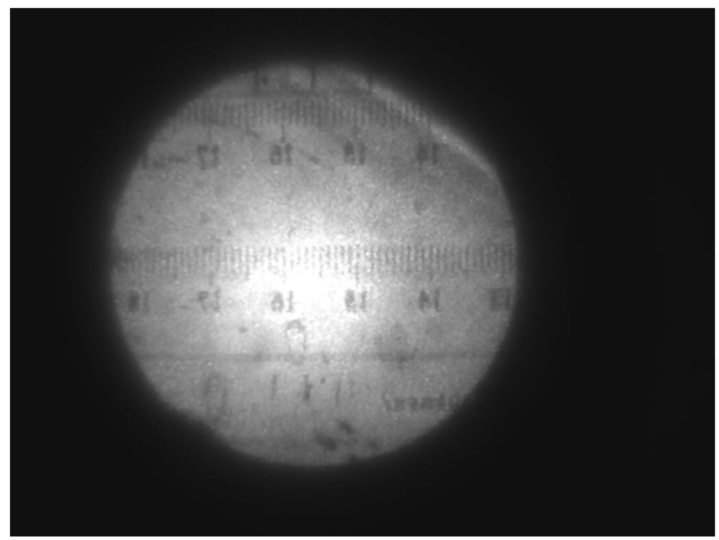
imaging/illuminating fibers #5 replaced on viewport #4 - 7 meter long Jan. 24, 2007

(imaging fiber broke on 11-30-2006 @ORNL)



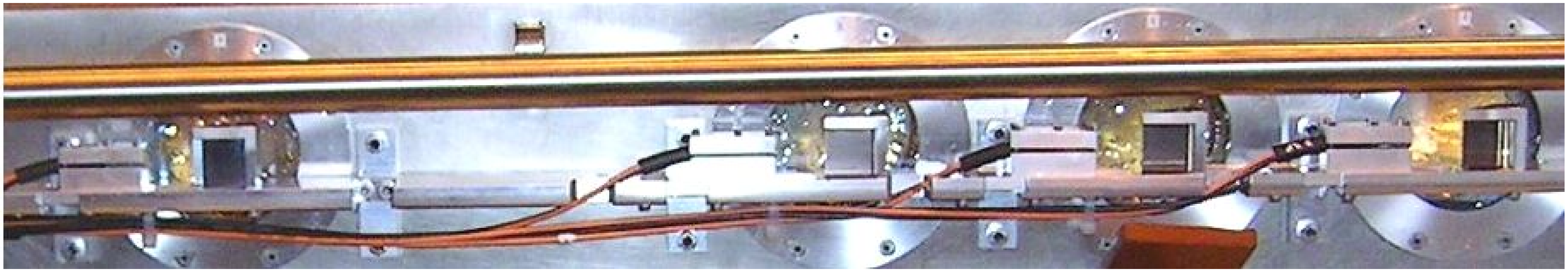
backup imaging/illuminating fiber #6 - 8.5 meter long

(after repairing imaging fiber broke on 11-30-2006 @ORNL) Feb. 12, 2007



Window cleaning after water jet test @ ORNL, Jan 24, 2007

before



after

Window cleaning prior to Hg injection Feb 12, 2007

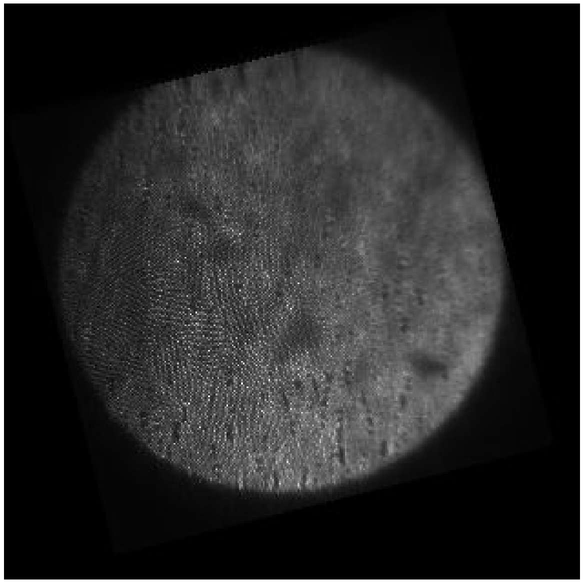
Viewport #2 SMD camera

705 lbs (320 kg, 23.7 liters) of Hg loaded

Feb. 8

1st cleaning

max ~10-bit bright level

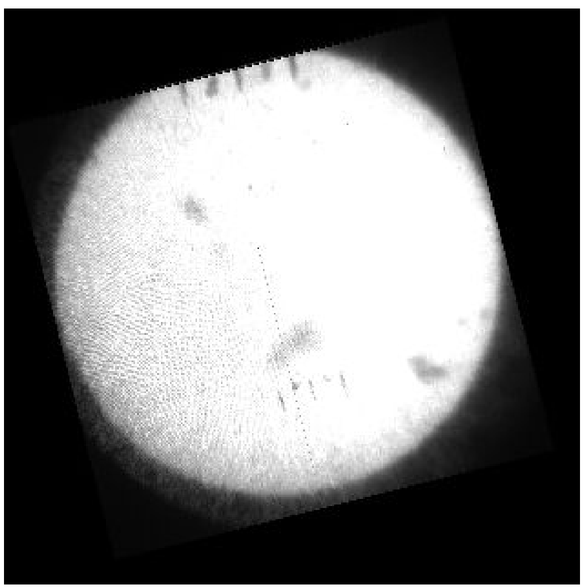


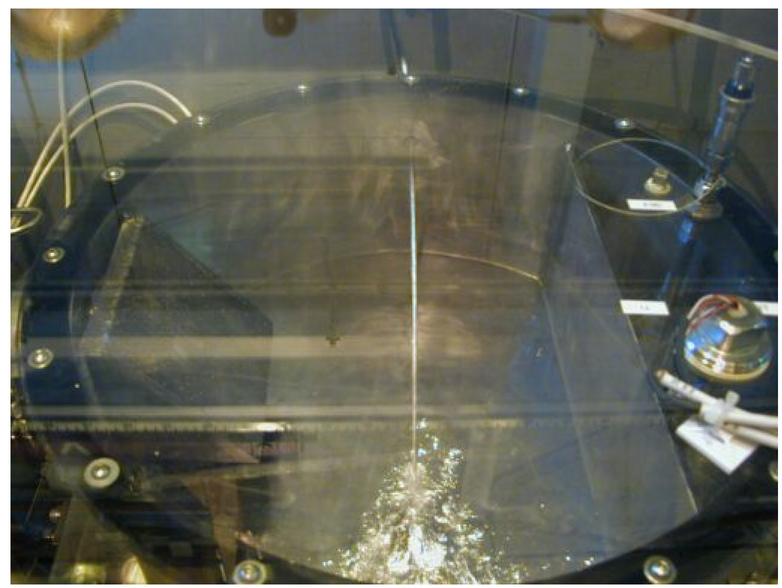
Feb. 10

much improved

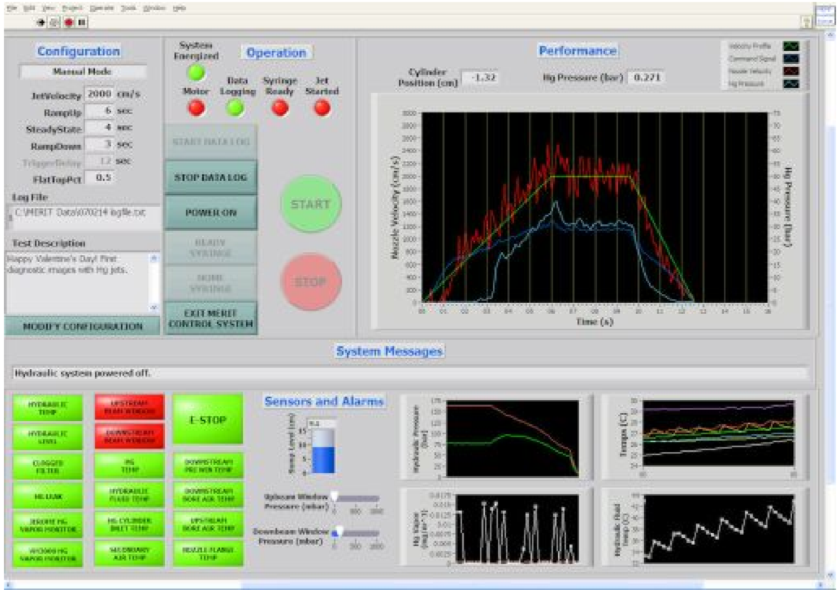
2nd cleaning

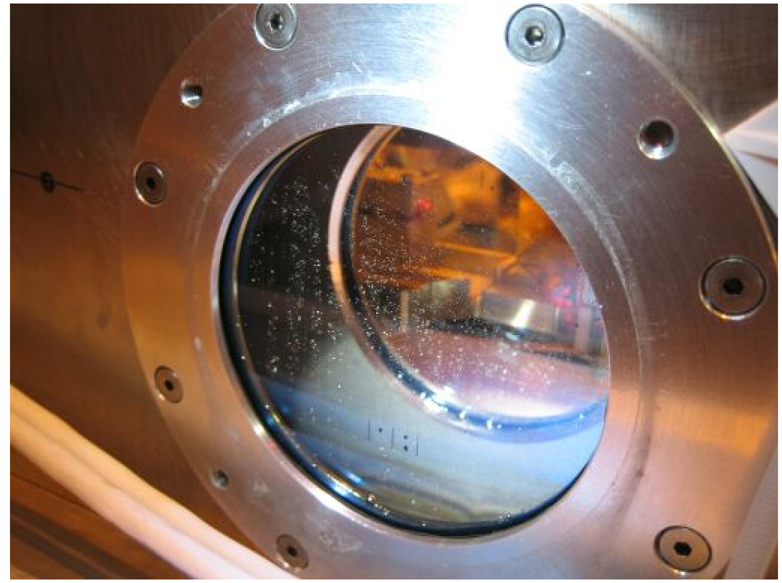
max ~12-bit bright level





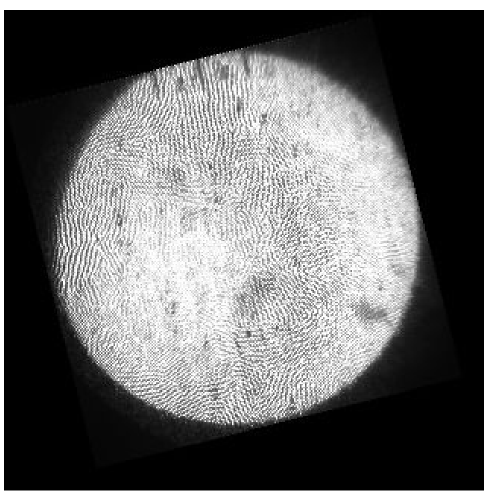
1st Hg jet runs on Feb 14, 2007 @ ORNL – wetting of viewports



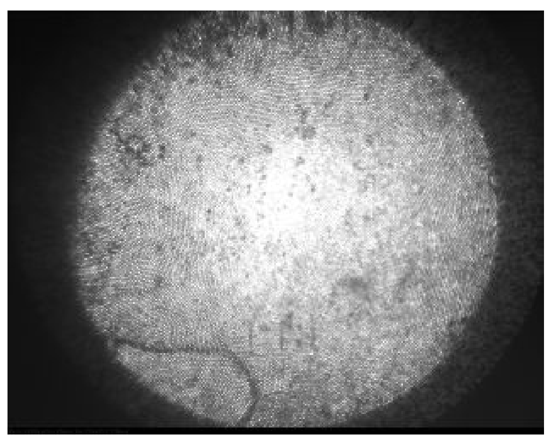


Hg droplets adhere on viewports
size varies from 0.1 mm to 0.5 mm

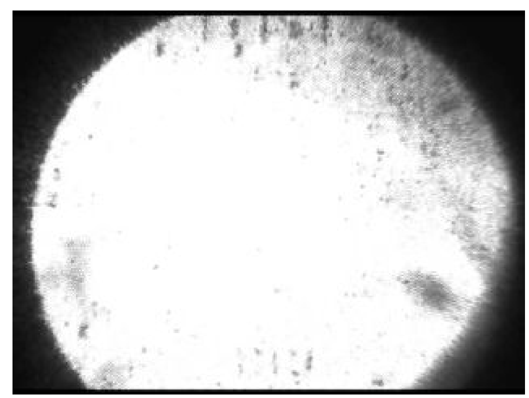
viewport #2



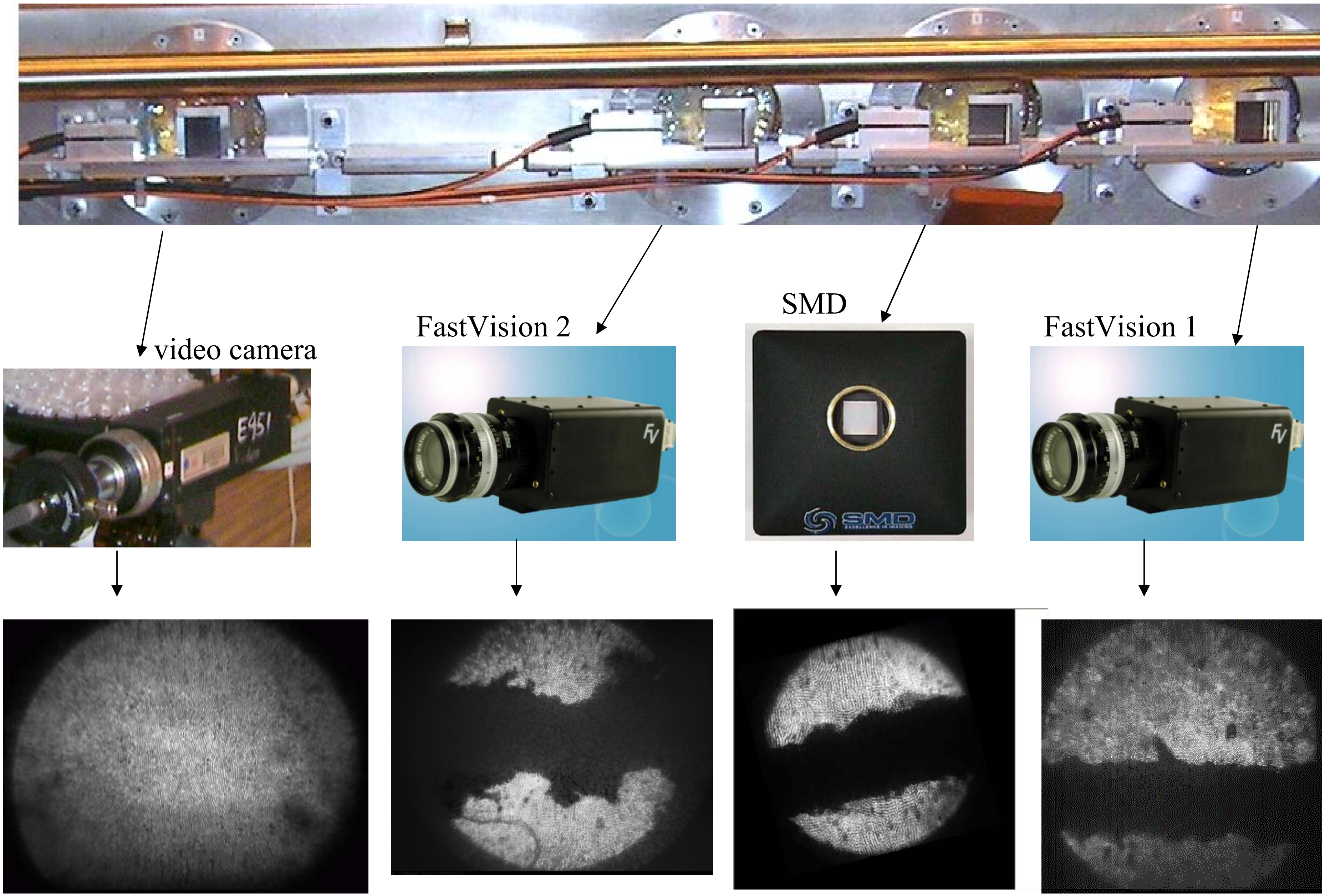
viewport #3



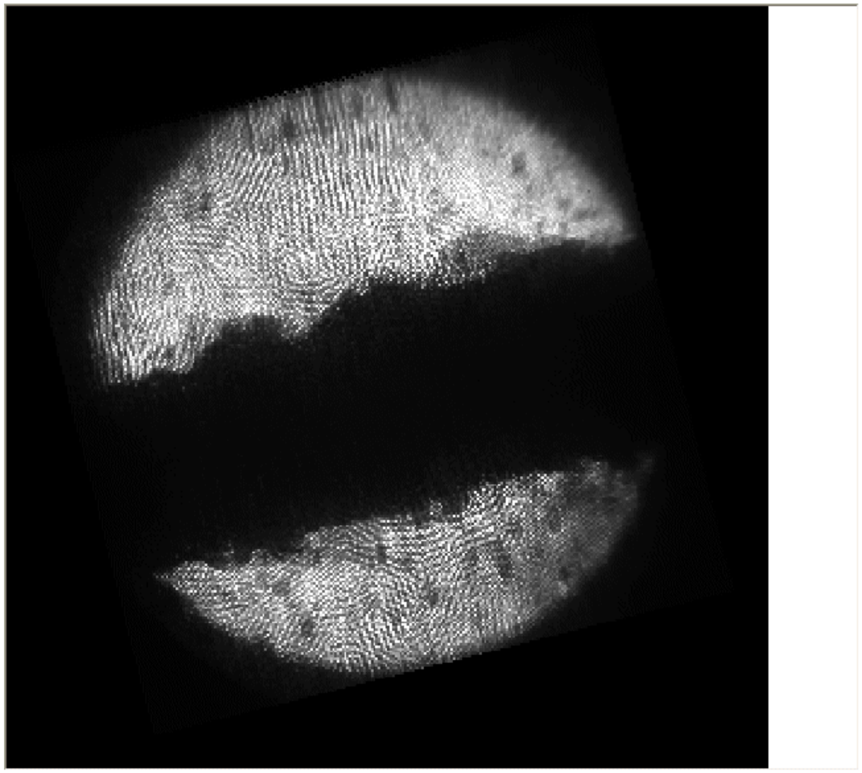
viewport #4



1st Hg jet runs on Feb 14, 2007 @ ORNL

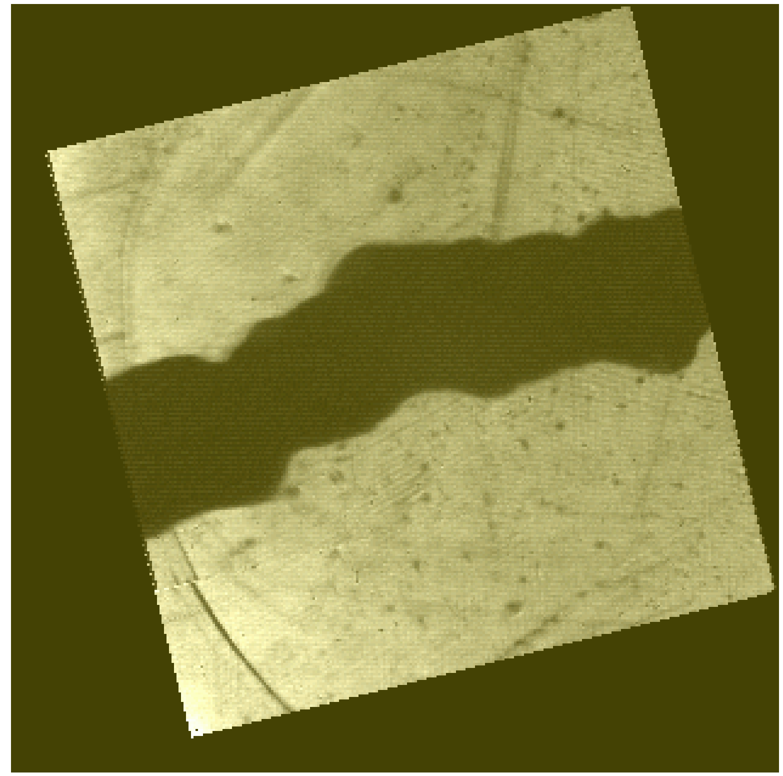


1st Hg jet runs on Feb 14, 2007 @ ORNL



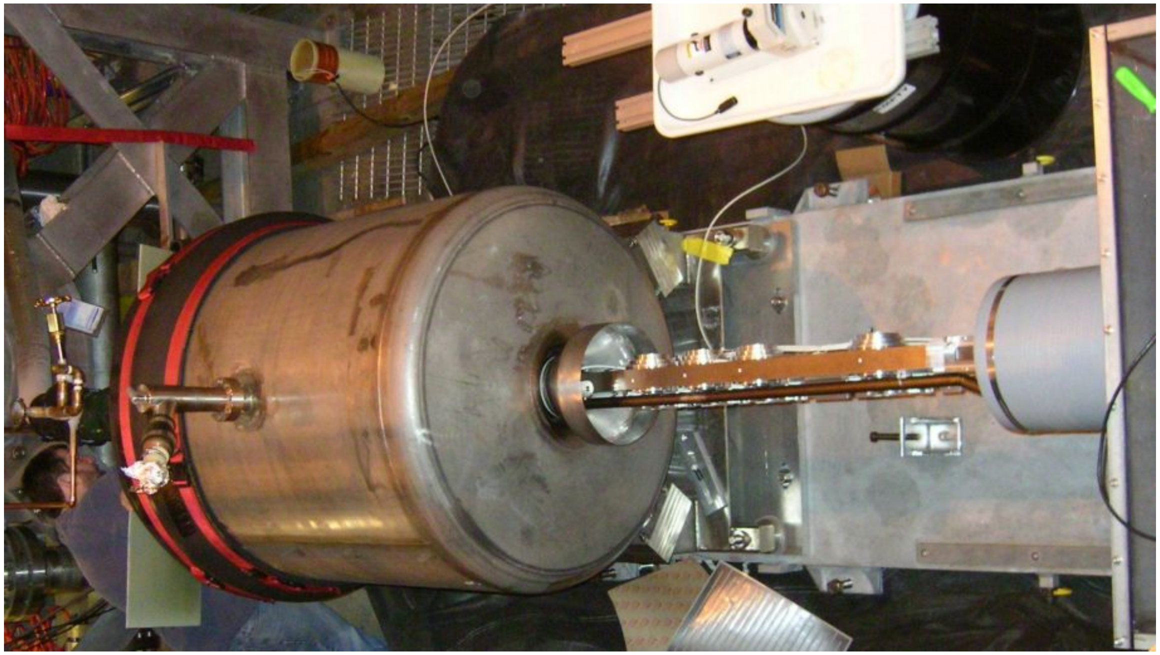
Hg core diameter ~17-23 mm
Jet velocity 22 m/s
FOV 5.5 cm @ center
Camera SMD 50 μs/frame
Viewport #2
Hg_20ms.gif

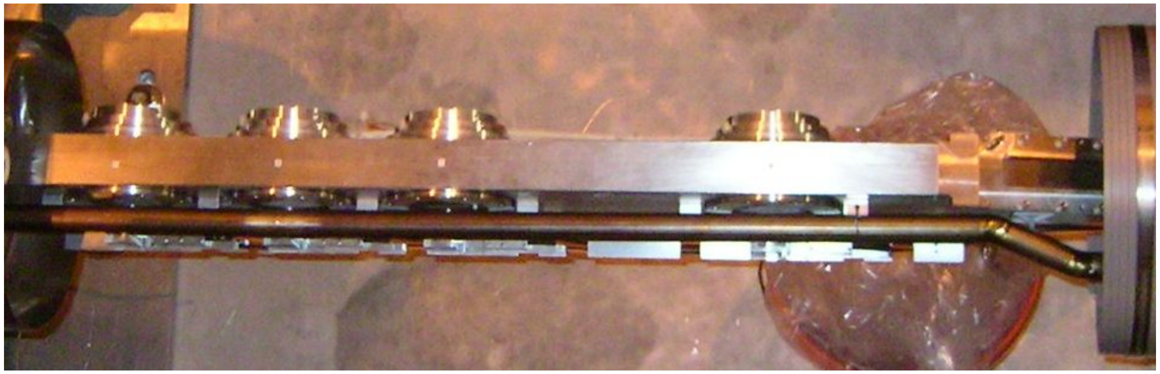
E951 Hg jet runs on April 27, 2001 @ BNL - AGS



Hg core diameter ~10 mm
Jet velocity 3 m/s
FOV 4.2 cm x 4.2 cm
Camera SMD 100 μs/frame
24 GeV proton @ .8 TP
Jet-4-27-01-15-movie.gif

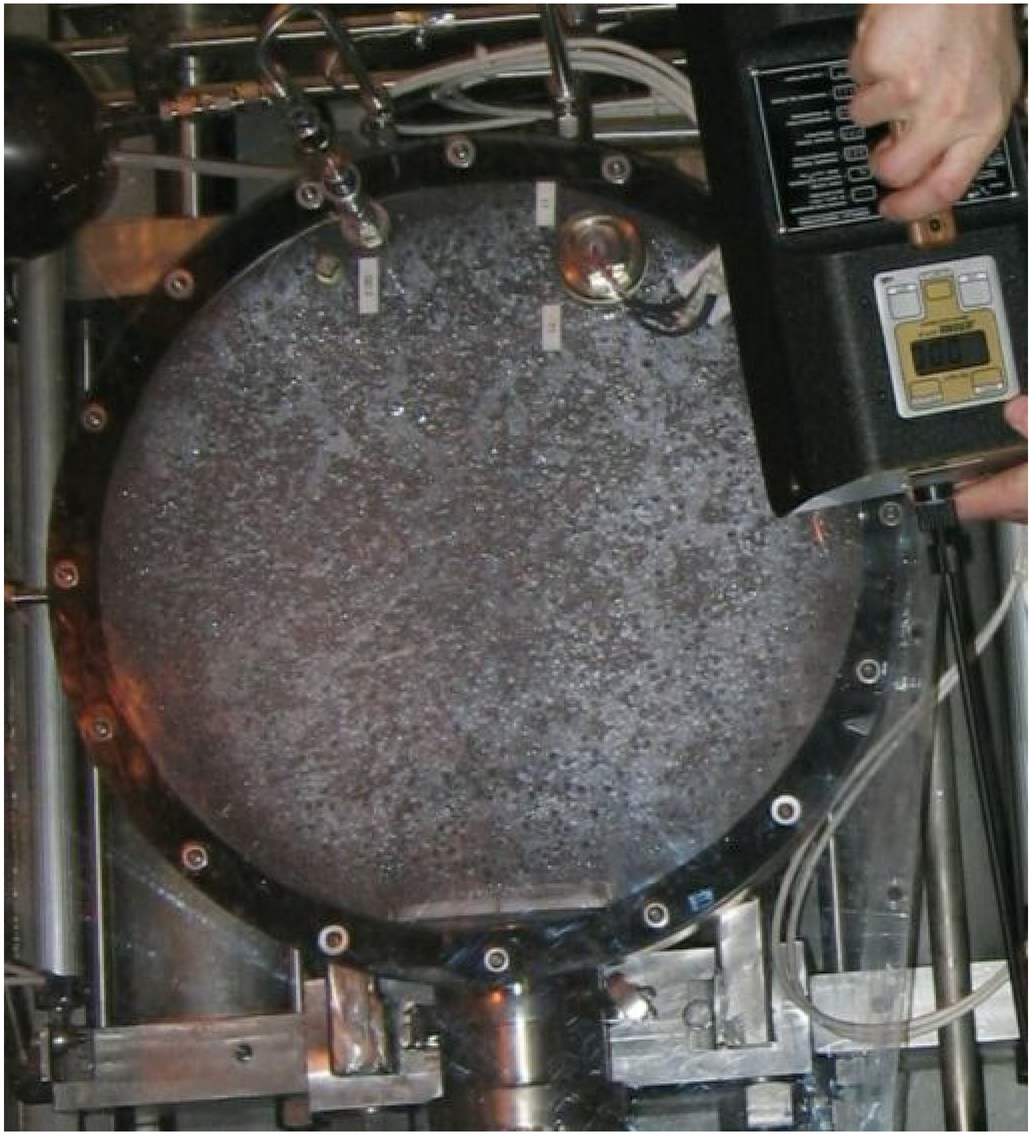
Hg jet runs with 15T magnet on March 1, 2007 @ MIT



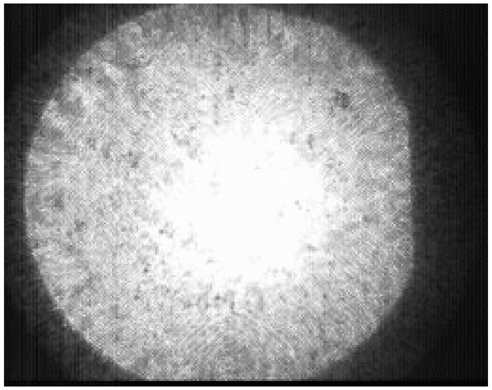


Hg jet runs with 15T magnet on March 2, 2007 @ MIT

water condensation inside the primary – viewports got foggy



- primary was purged with dry nitrogen
- heaters installed on primary



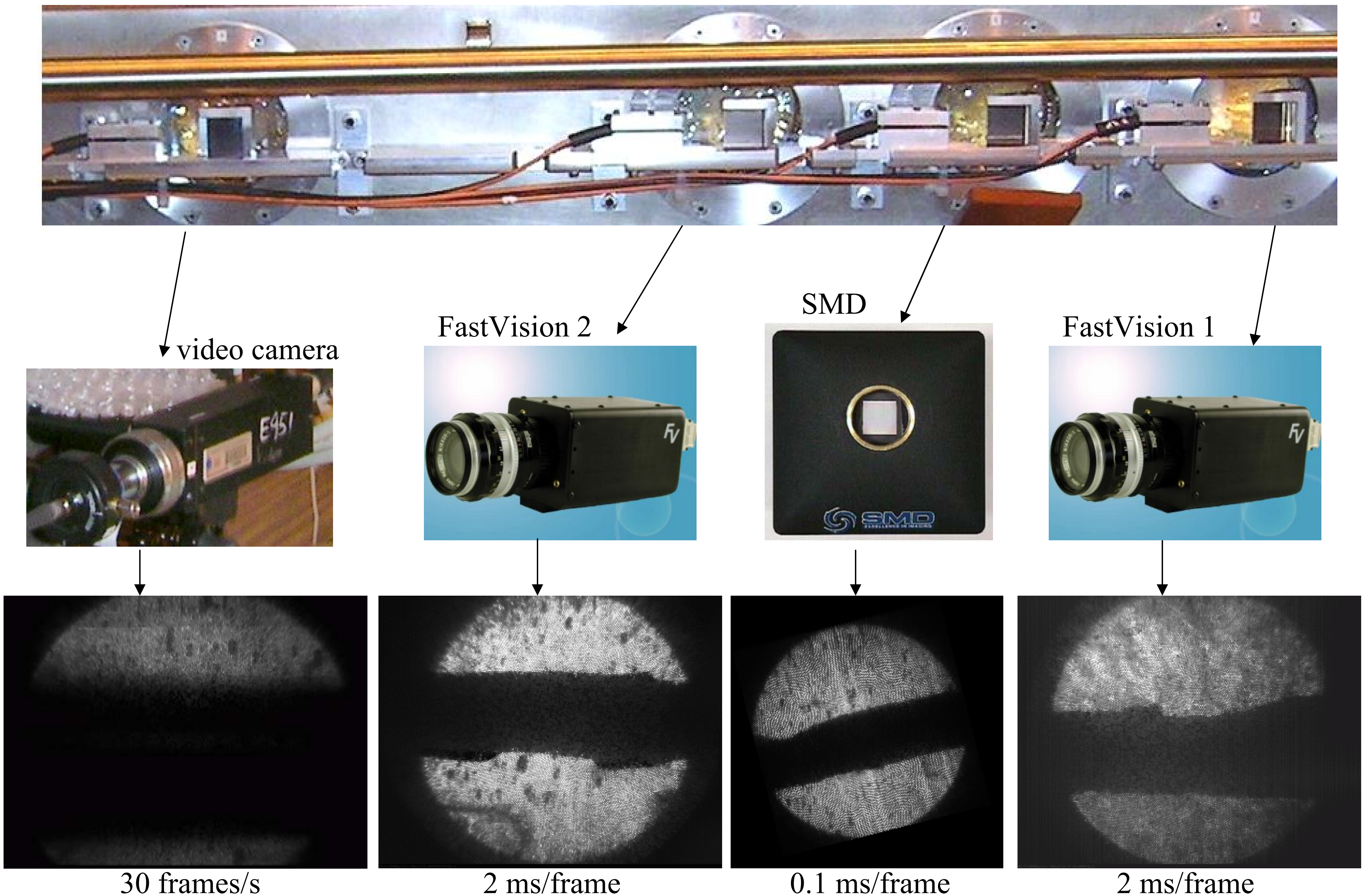
gradual fogging of viewport

lunar eclipse on March 3 , 2007

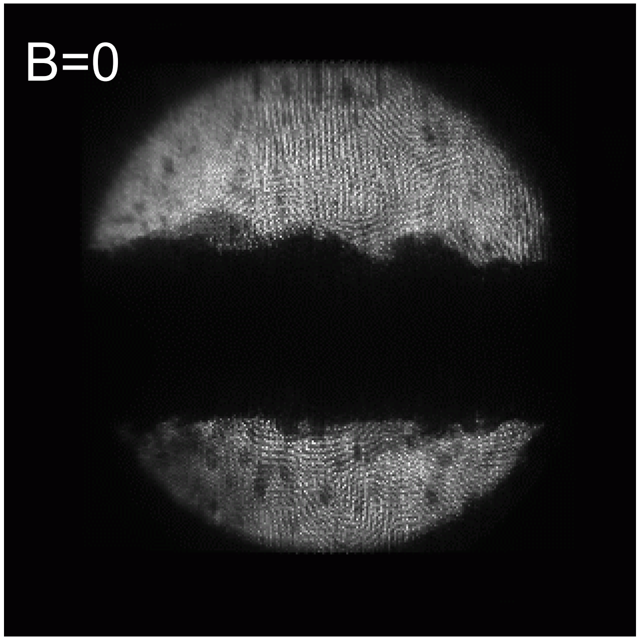
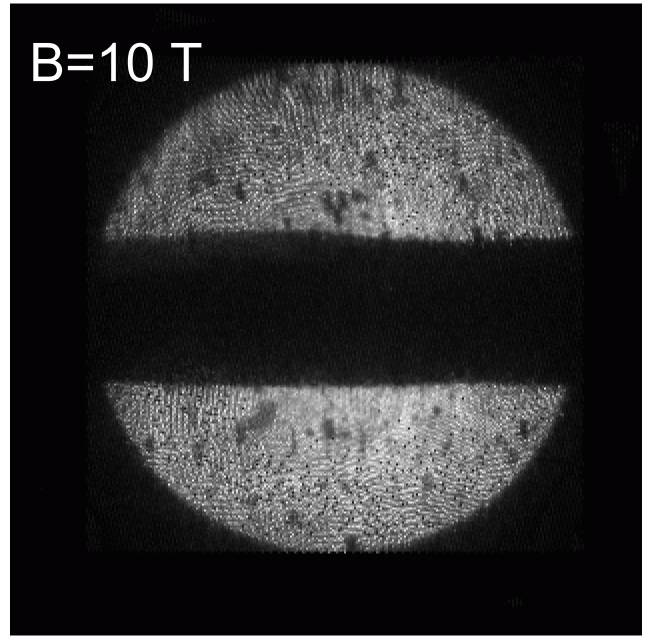
Hg jet runs with 15T magnet on March 1, 2007 @ MIT

heaters installed on the primary and on the snout

1st Hg jet runs with 15T magnet on March 3, 2007 @ MIT



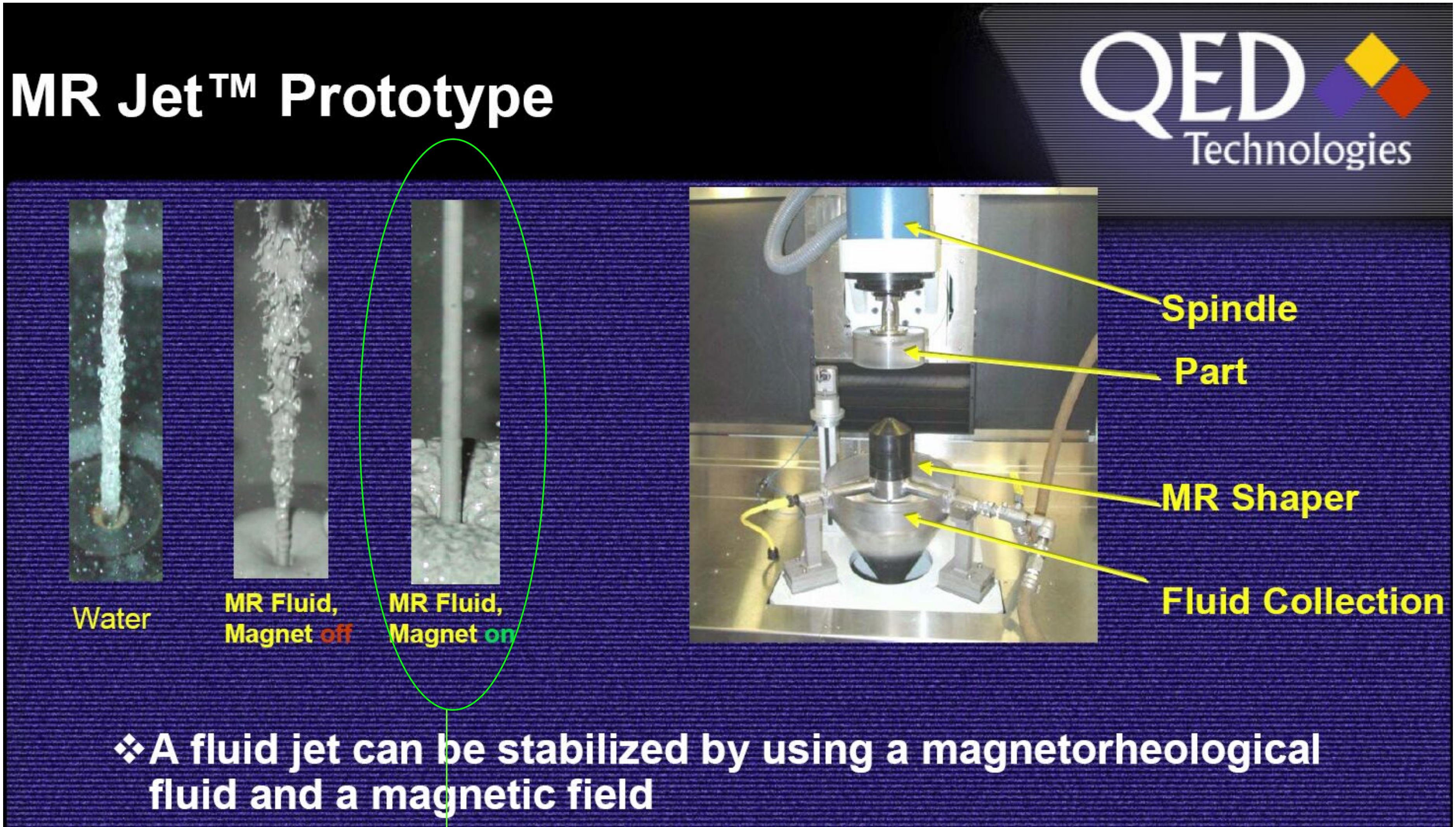
20 m/s Hg jet, 7 Tesla magnetic field

1st Hg jet run Feb 14, 2007 @ ORNL	1st Hg jet run with pulsed solenoid March 3, 2007 @ MIT
	
Hg core diameter ~17-23 mm Jet velocity 22 m/s FOV 5.5 cm @ center Camera SMD 50 μs/frame Viewport #2 Hg_20ms.gif	Hg core diameter ~14-16 mm Jet velocity ~19.4 m/s Magnetic field 10 Tesla FOV 5.5 cm @ center Camera SMD 100 μs/frame

- ***Hg jet clearly stabilized in the core of the pulsed solenoid***

Magnetorheological jet (MR Jet) finishing technology

Kordonski, et. al., J. of Fluids Eng., V128, 20-25, 2006

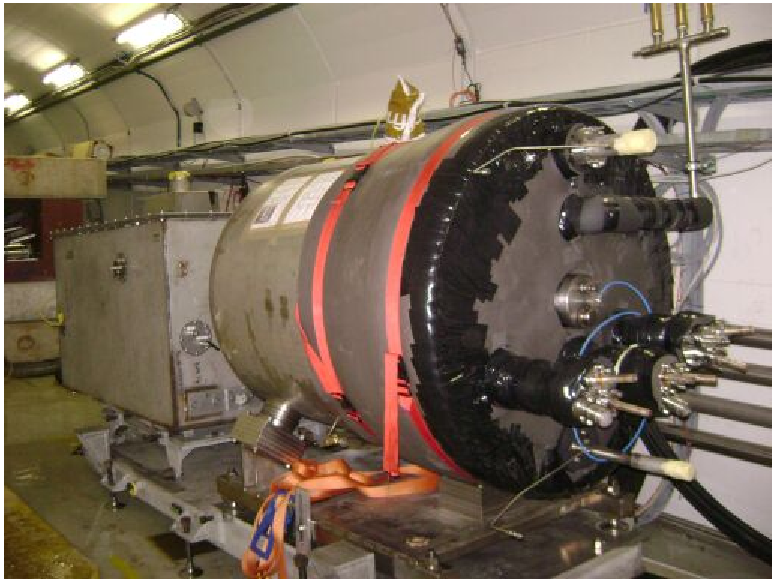


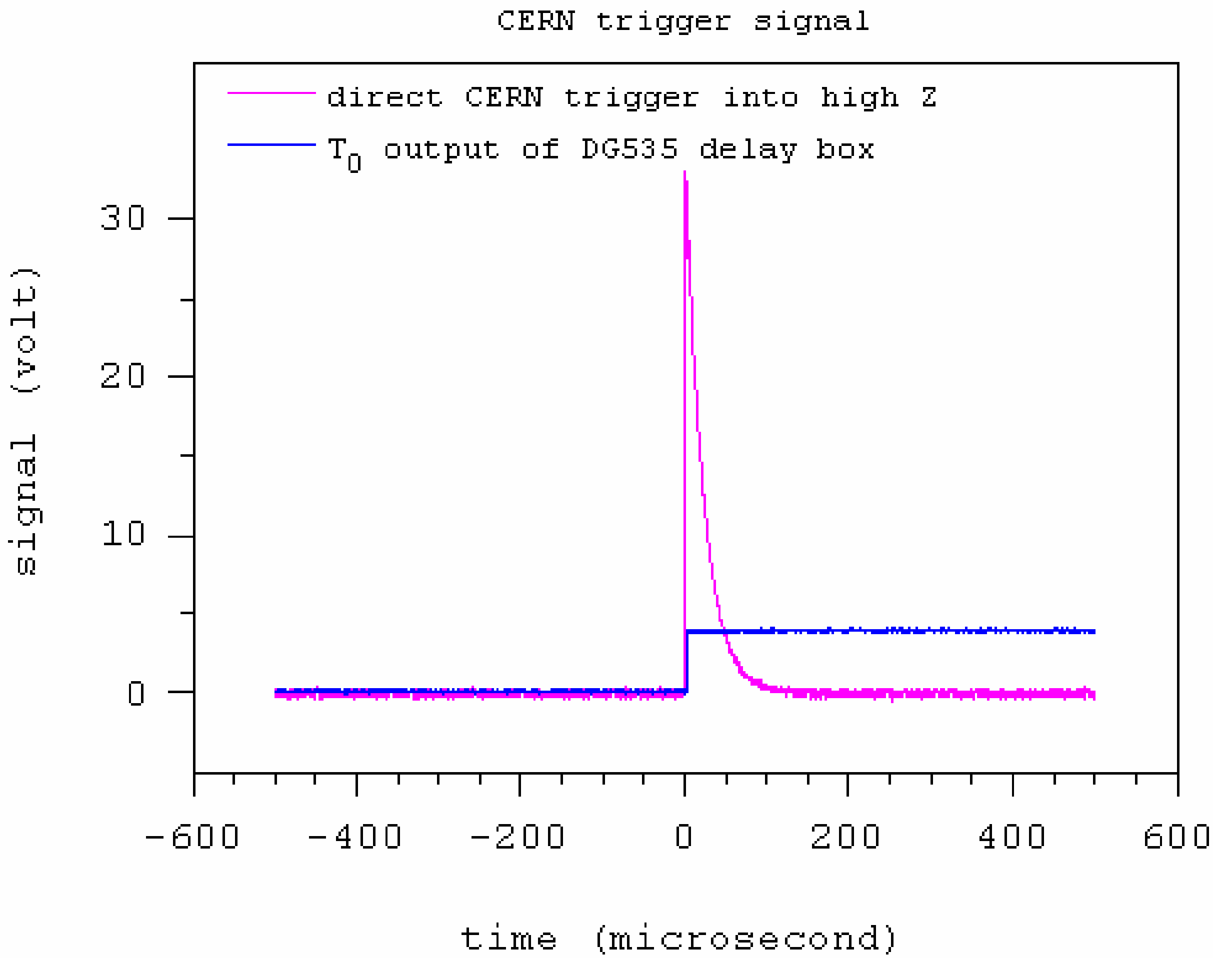
Free jet of magnetic fluid	
Nozzle diameter:	2 mm
Jet velocity	30 m/s
Column length	~40 cm
Magnetic field strength:	not known, apparently applied only on the nozzle but not during jet propagation

Magnet and Mercury System Arrive at CERN 16 May 2007

Snout Fell 10 cm
Rubber Collar Stretched by ~ 5 cm.
¿Damage to the Primary Containment?

Fiberoptics Connected, 18 June, 2007



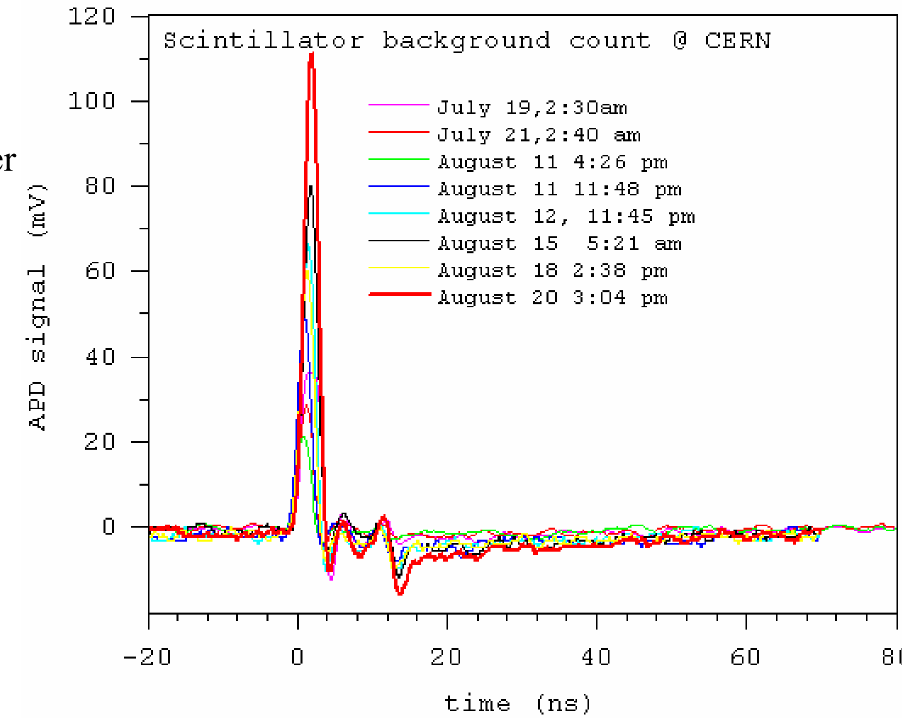

CERN trigger signal
direct CERN trigger into high Z
T0 output of DG535 delay box
signal (volt)
time (microsecond)
30
20
10
0
-600
-400
-200
0
200
400
600

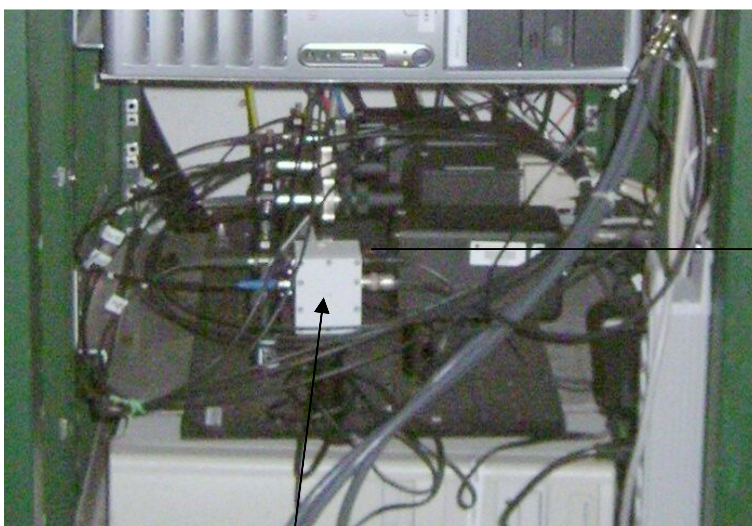
Scintillating fiber channel #0 – CERN background count, July – August 2007

Monitor/control at BNL via RDC to CERN

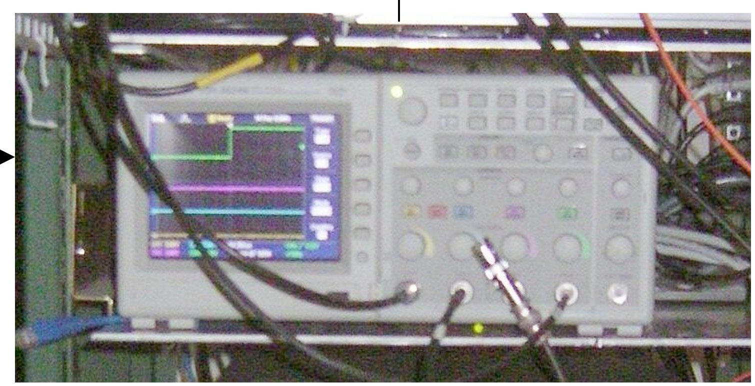
2 meter long, 1-mm diameter blue emission scintillating fiber

12 meter long, 1-mm diameter BFH37-1000 fiber

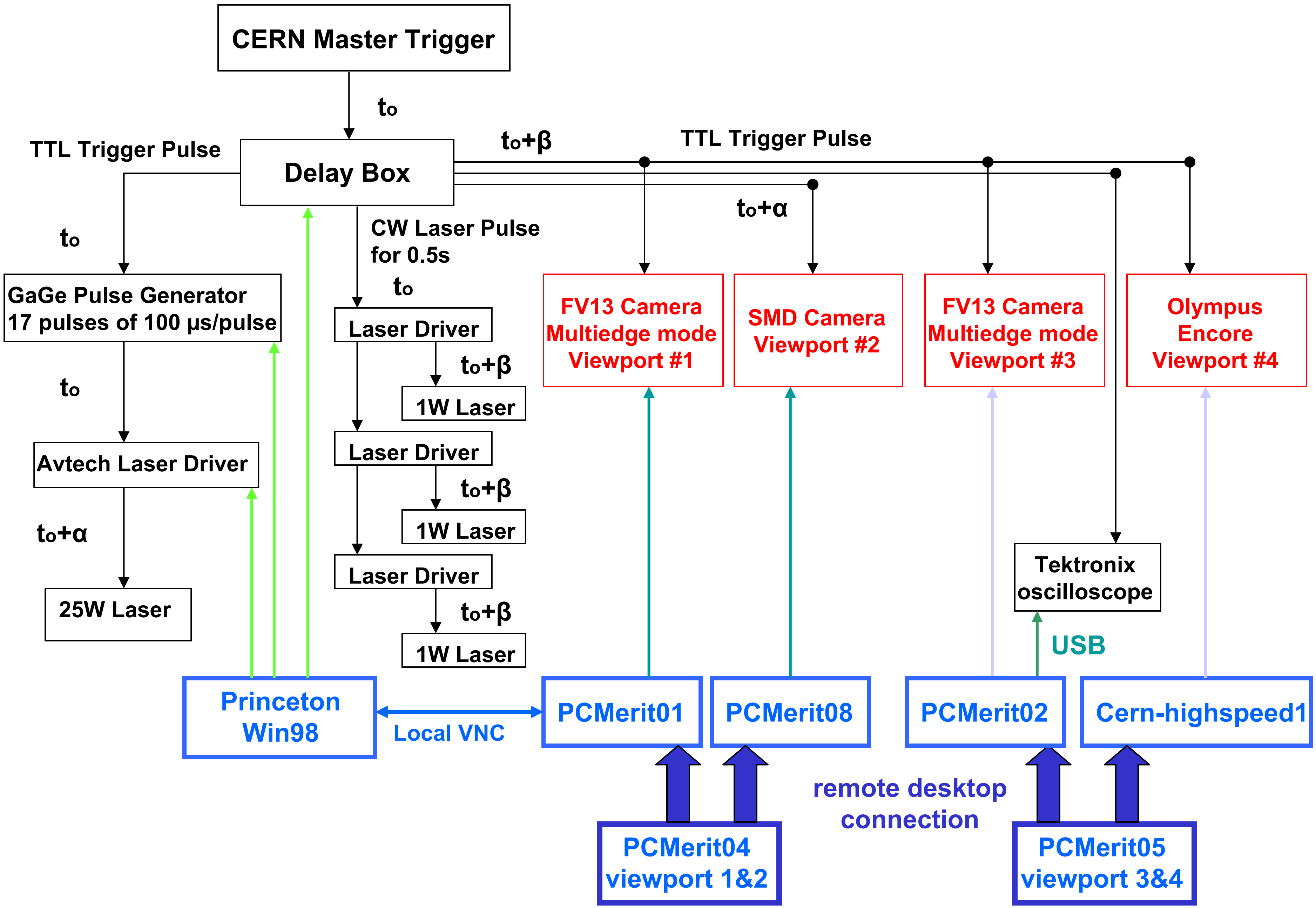




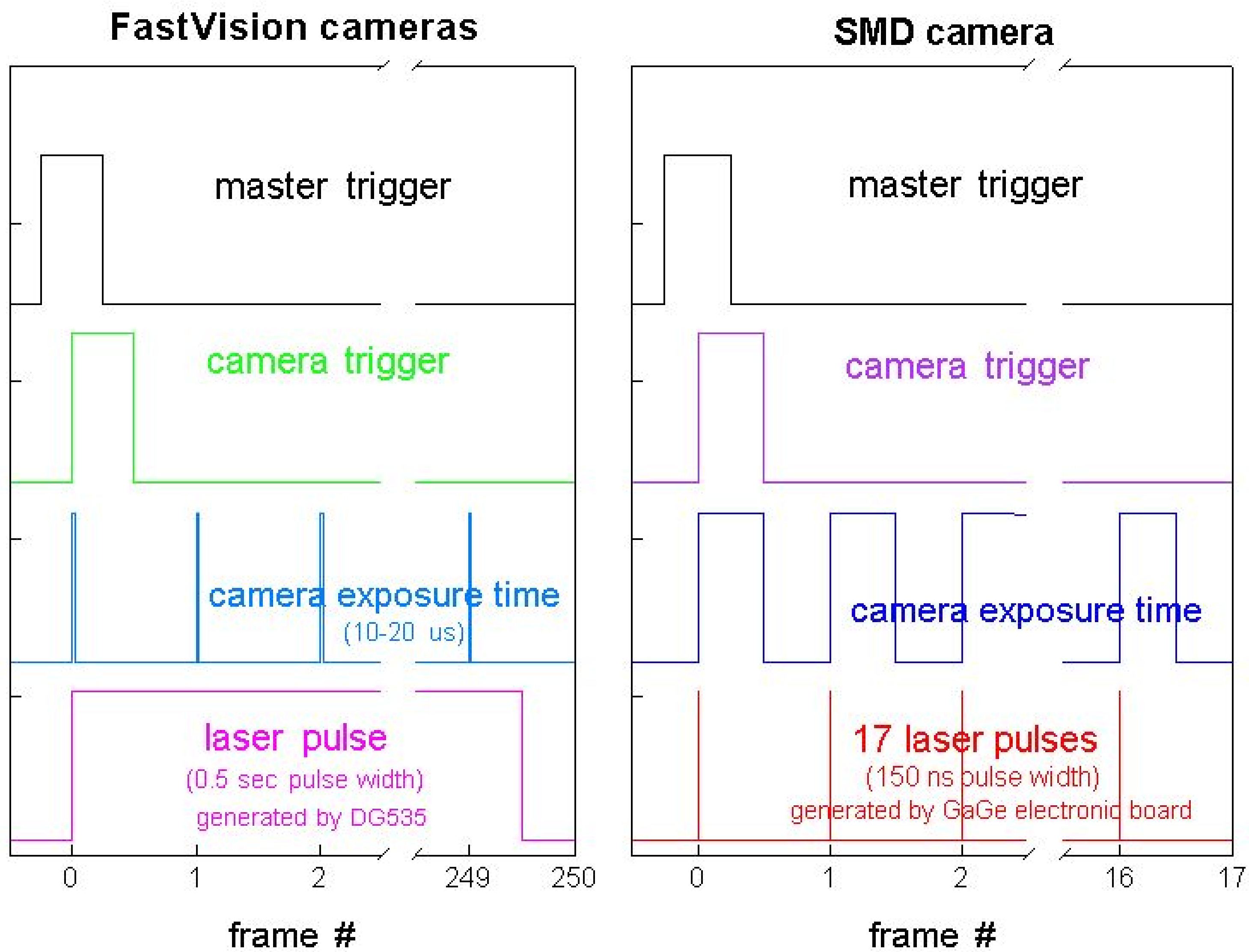
Avalanche photodiode



Triggering Diagram of Camera in Optical Diagnostics @ CERN



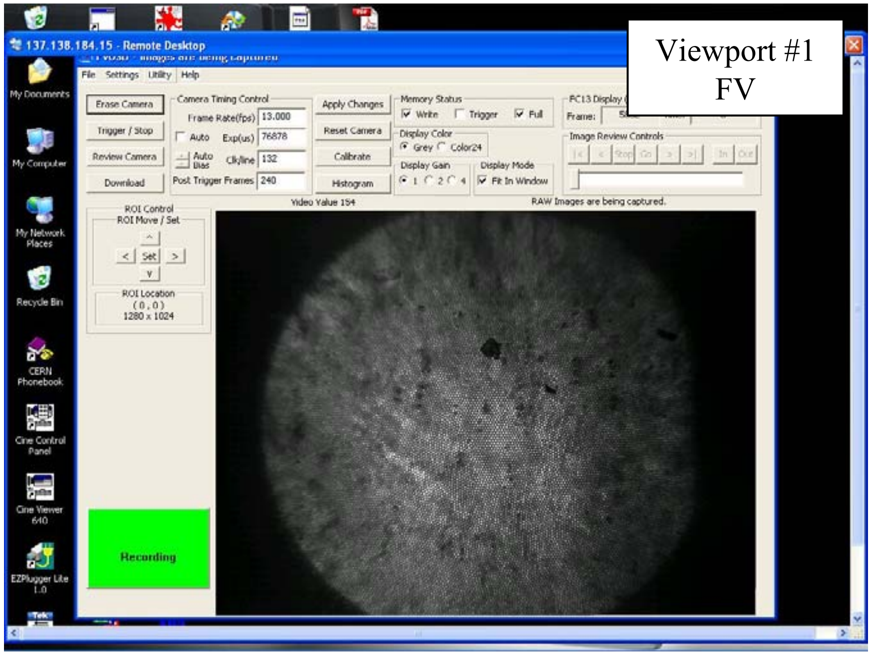
Trigger pulse sequence for FastVision & SMD Cameras

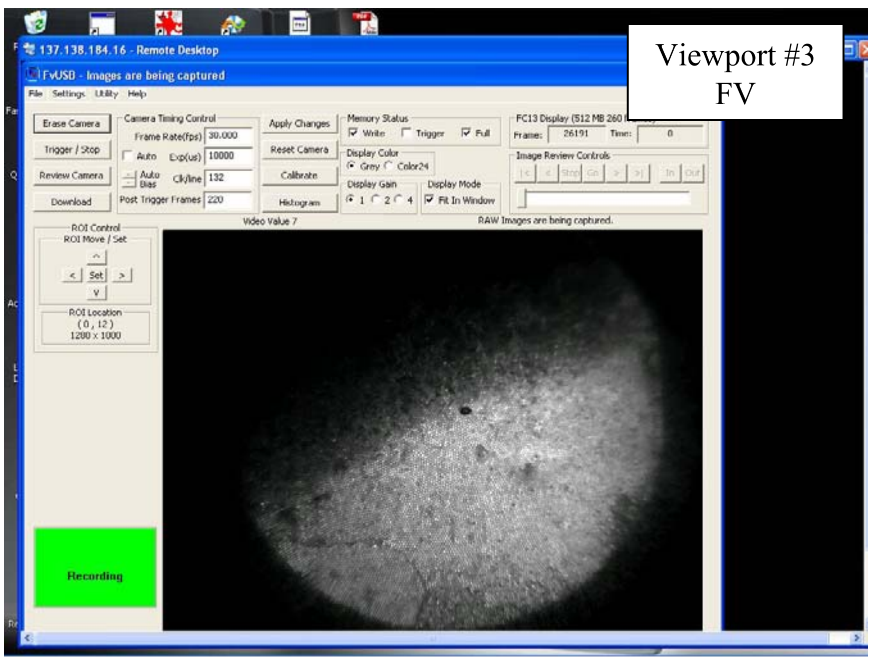


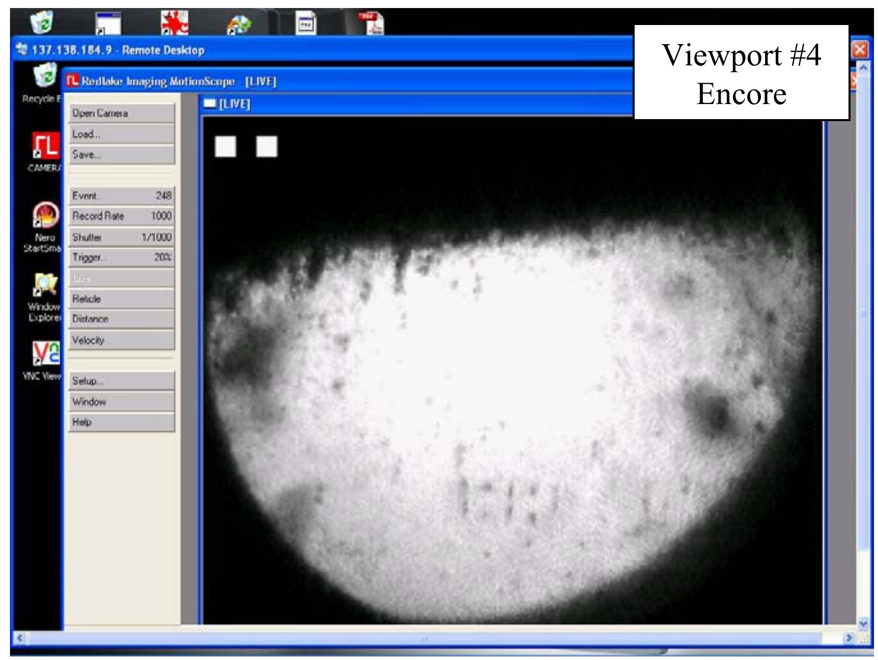
typical 2 ms/frame
total of 256 frames

typical 0.1 ms/frame
total of 16 frames

More problems discovered after all cameras are up and running: SMD camera not good, optics shifted







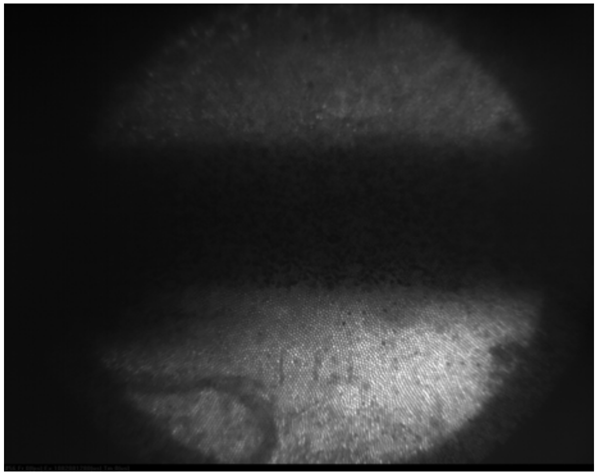
Hg Jet Run at CERN (August 29, 2007)

After pulling snout out to re-align optics

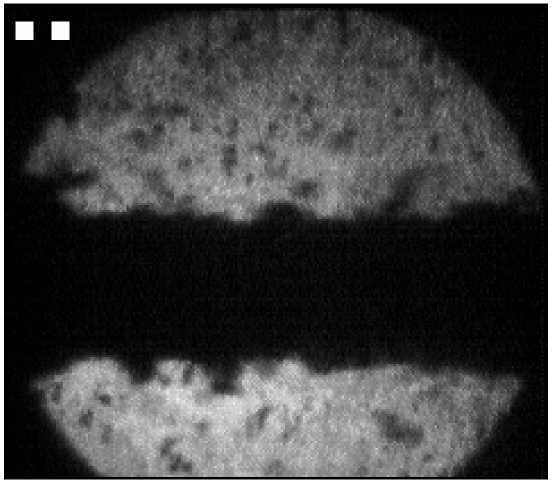
Optics
–Primary optics aligned
–View port images confirmed
–Remote Controls confirmed

20m/s jet

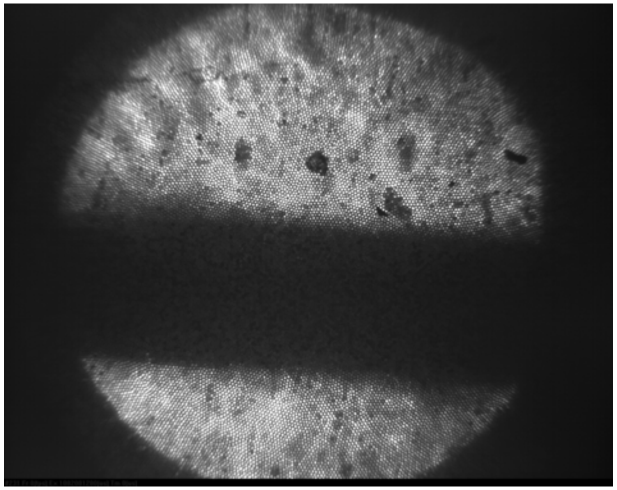
Viewport #3, FV camera



Viewport #2, CERN camera



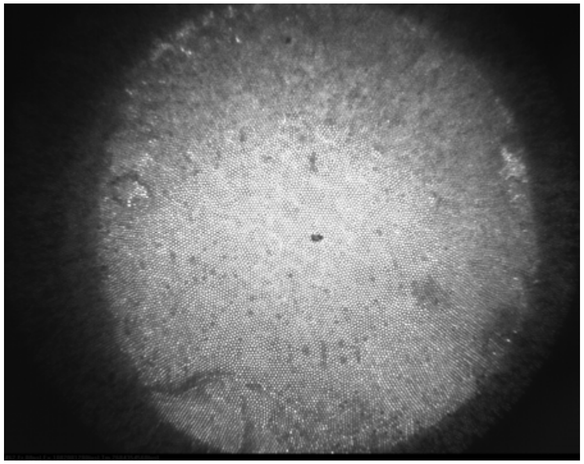
Viewport #1, FV camera

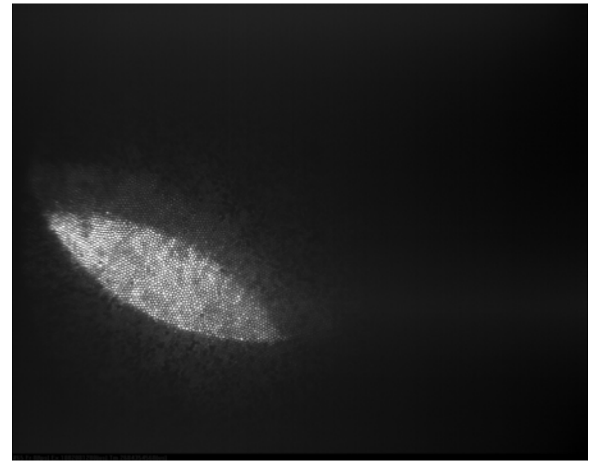


Heater overheat in the snout (Sept. 10-11, 2007)

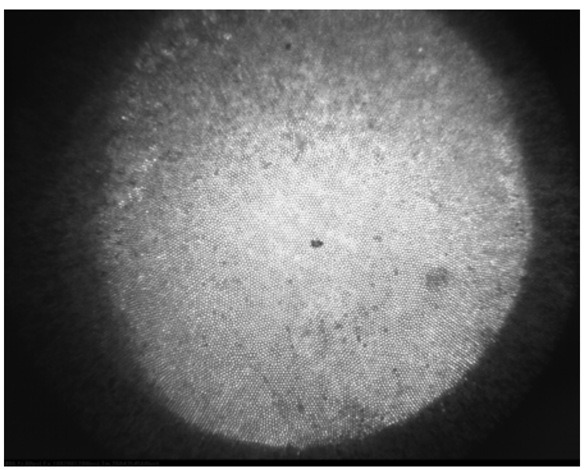
Viewport #3 | **Viewport #2** | **Viewport #1**

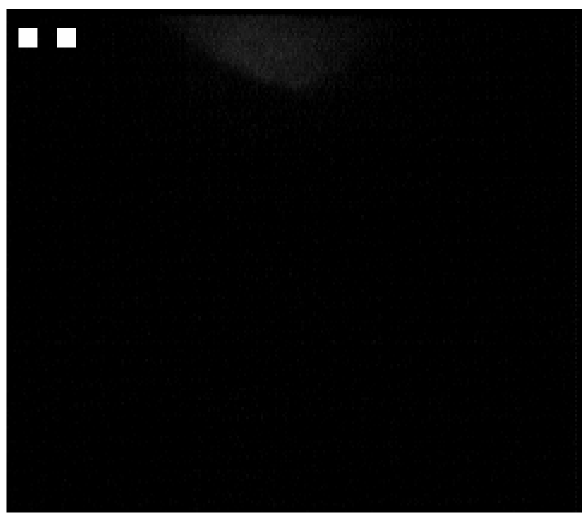
2007, September 10, 3:20 pm

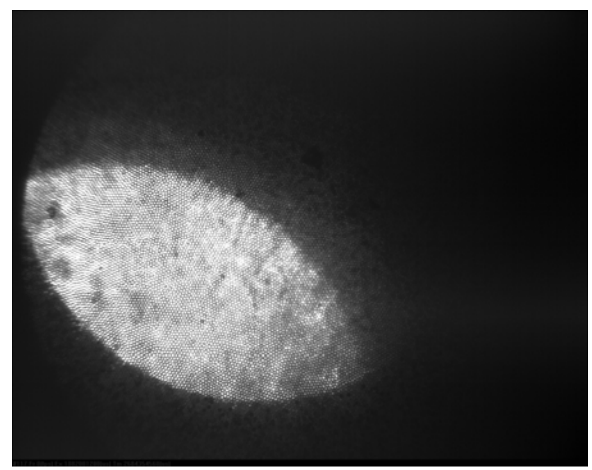




2007, September 11, 11:20 AM

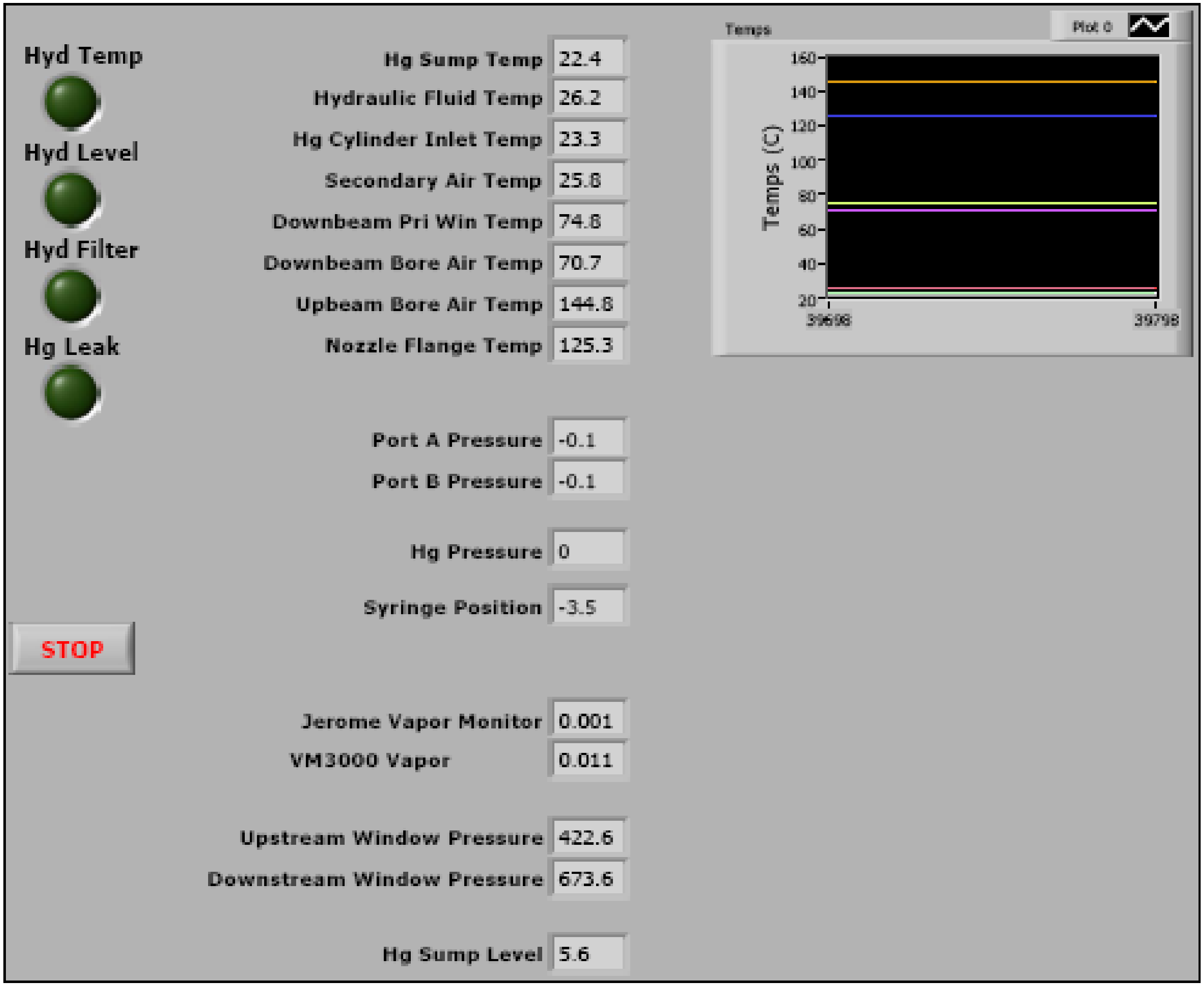






Heater overheat in the snout cont.   (Sept. 10-11, 2007)

MERIT Read Sensors.vi
C:\MERIT Data\MERIT Control System\MERIT Read Sensors.vi
Last modified on 8/29/2007 at 4:11 PM
Printed on 9/11/2007 at 11:46 AM

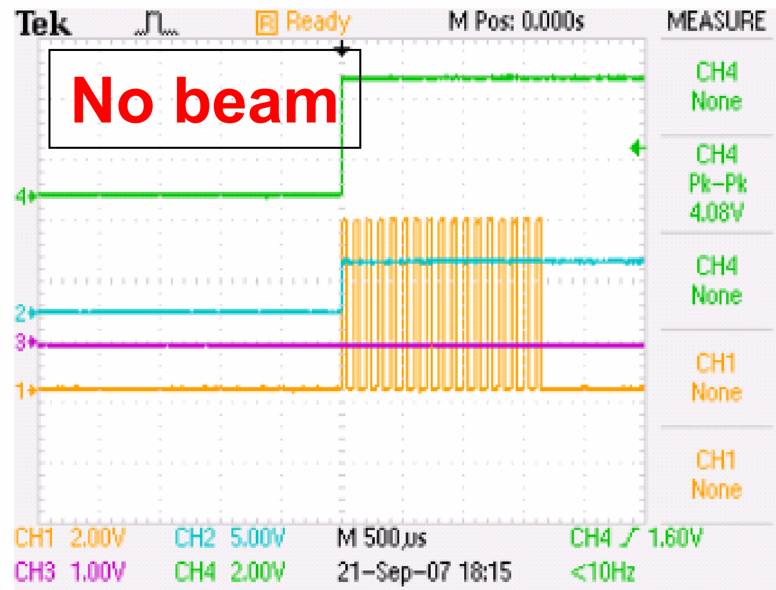


Sept 21, 2007
5 shots of proton beam fired
beam size ~ 4 mm

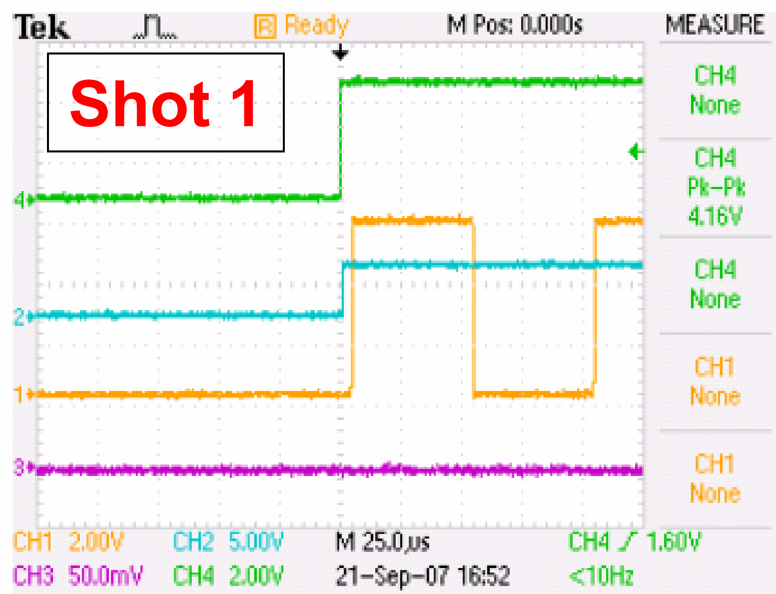
CH1 : AvTech LD pulse input, B
CH2 : SMD trigger, A
CH3 : Scintillating fiber
CH4 : Master trigger, To

Scintillating signal collected by Avalanche photodiode

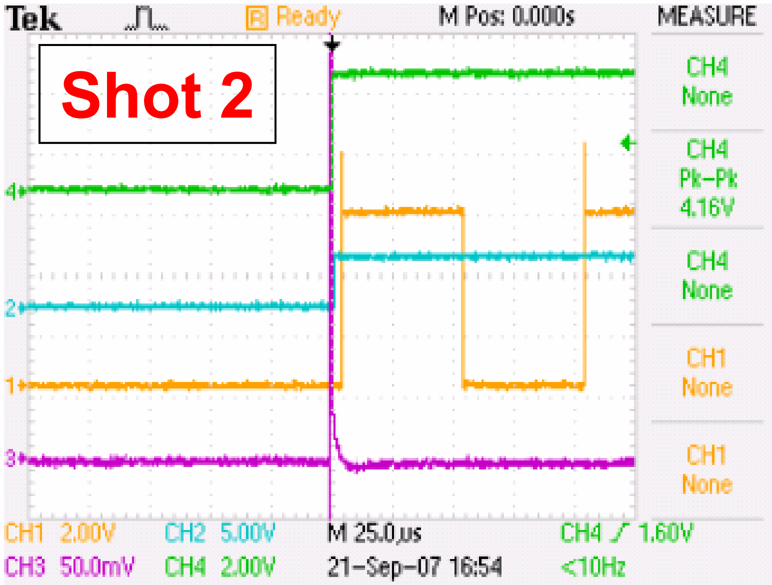
All system response successfully to the 5 shots of proton beams



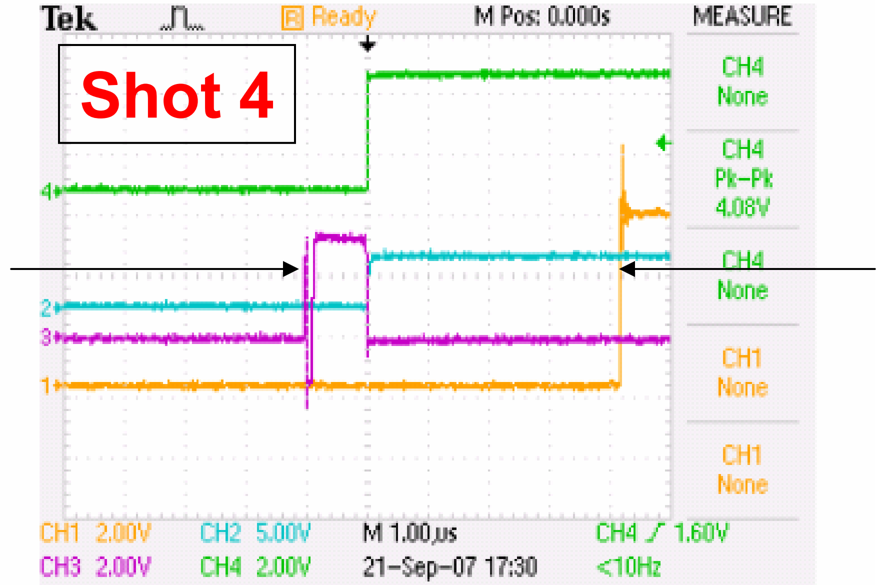
TDS 2024B - 5:14:19 PM 9/21/2007



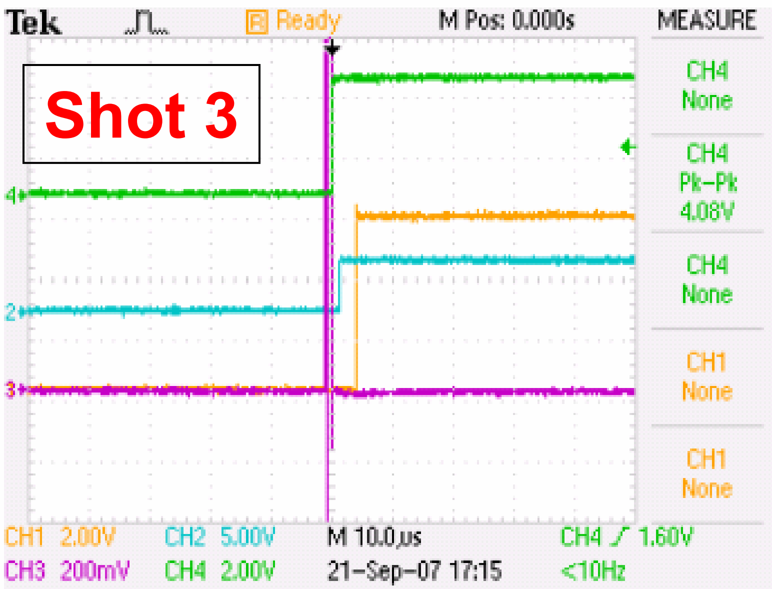
TDS 2024B - 3:50:59 PM 9/21/2007



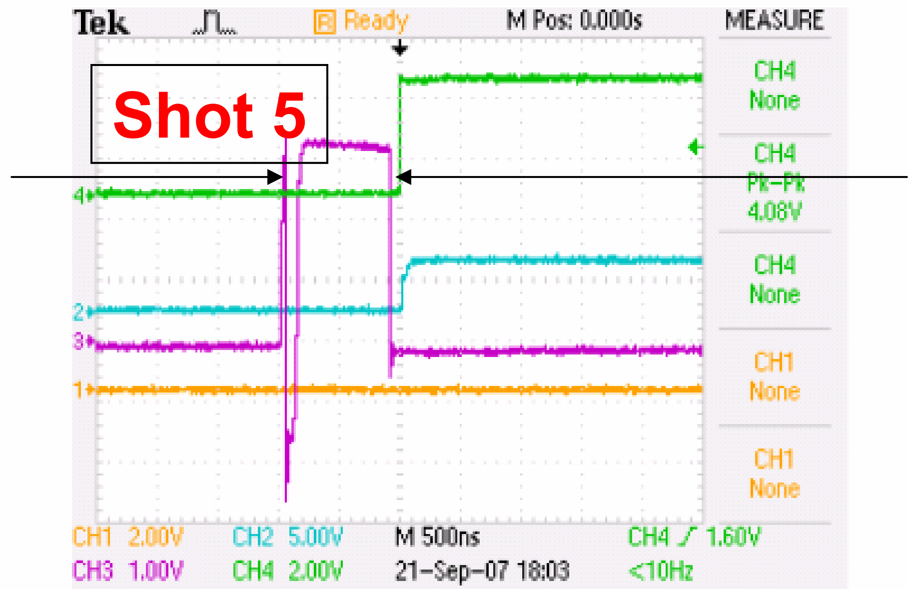
TDS 2024B - 3:53:37 PM 9/21/2007



TDS 2024B - 4:29:05 PM 9/21/2007



TDS 2024B - 4:14:11 PM 9/21/2007



TDS 2024B - 5:02:28 PM 9/21/2007

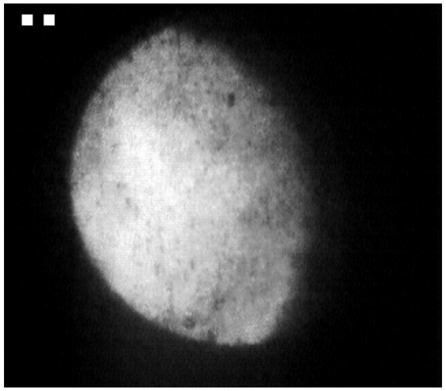
Proton beam arrives ~1 µs earlier than the CERN trigger

~5 µs earlier than SMD camera trigger

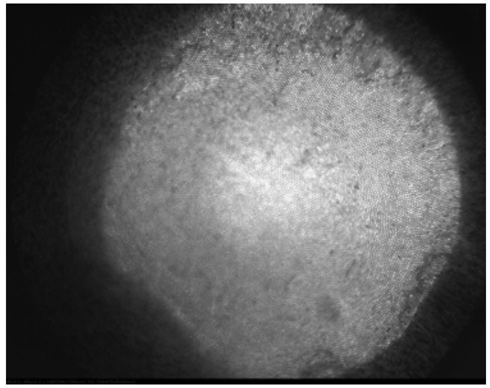
Oct 8, 2007, 2.5 hrs access to replace V#2 optical head and V#1 reflector

Primary : 26 C Secondary : 21 C

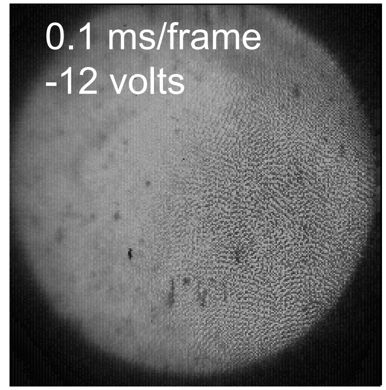
Viewport 4



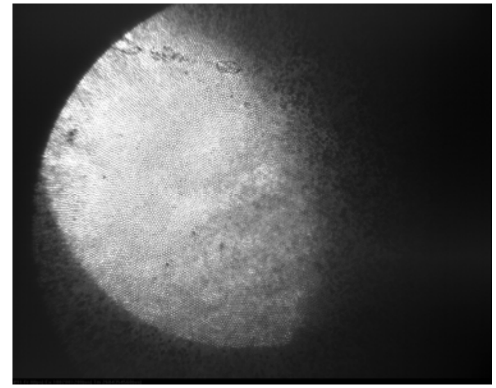
Viewport 3



Viewport 2

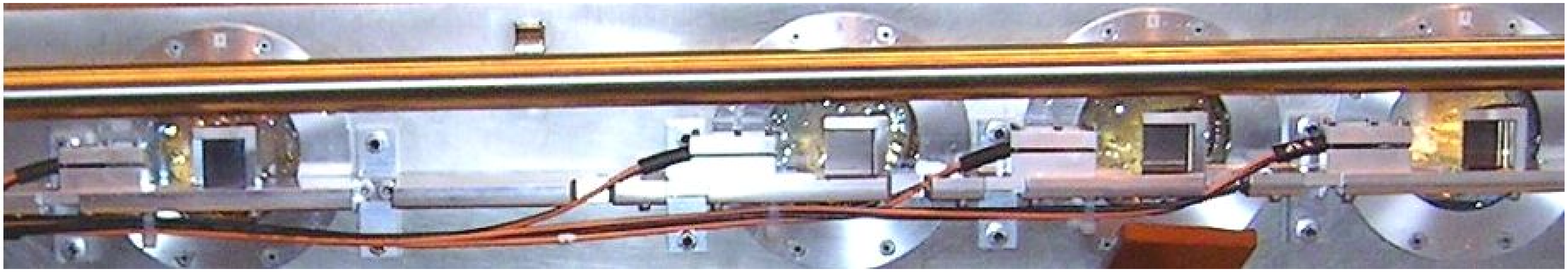


Viewport 1



puncture made for passage of
replacement optics head

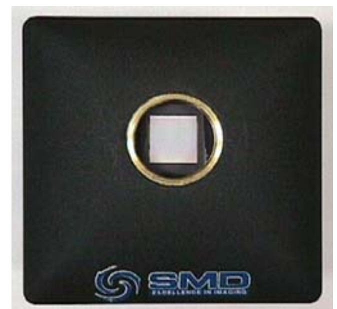
Oct 22, 2007 CERN 15 m/s mercury jet   0 T field



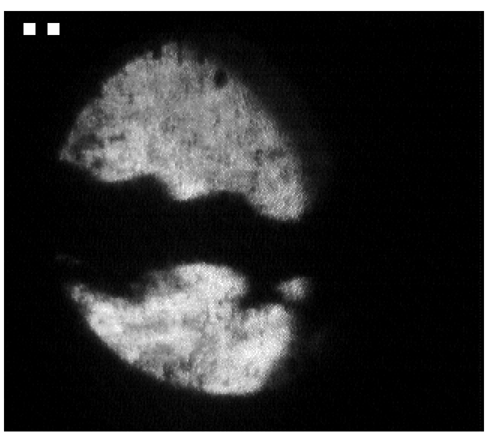
Olympus
Encore Camera
2 ms frame rate
100 μs exposure

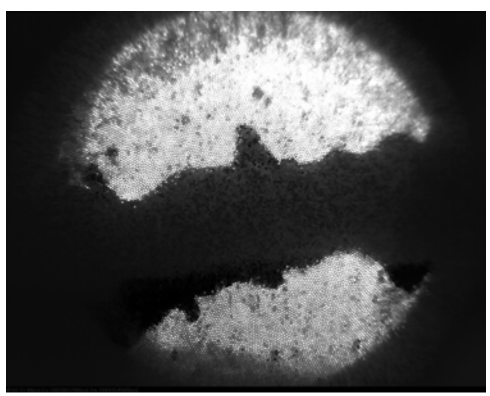
Viewport 3
FV Camera
2 ms frame rate
10 μs exposure

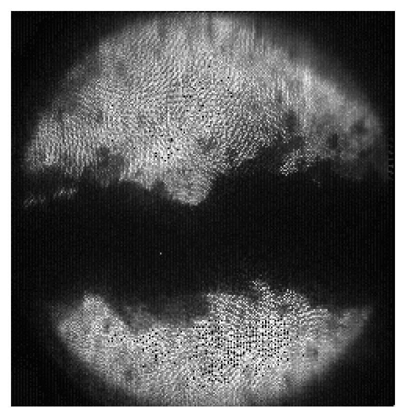
Viewport 2
SMD Camera
0.1 ms frame rate
0.15 μs exposure

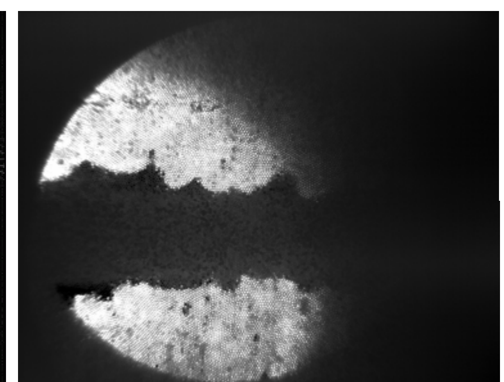


Viewport 1
FV Camera
2 ms frame rate
10 μs exposure

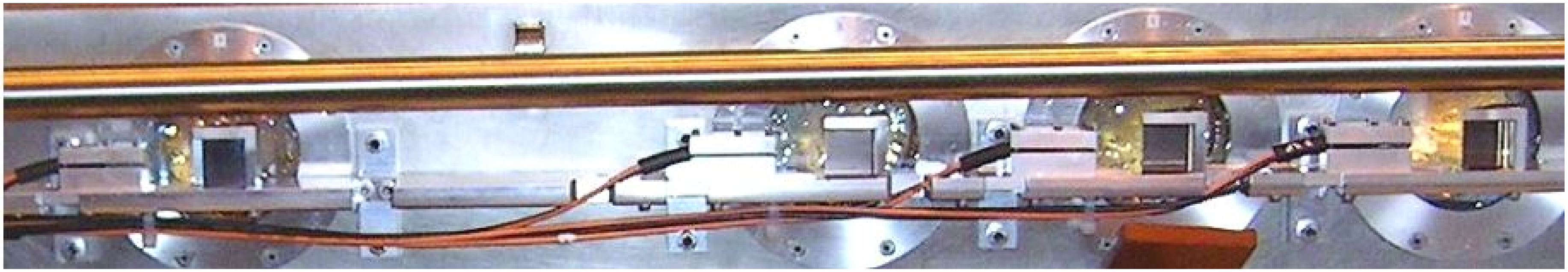








Oct 22, 2007 CERN 1st 15 m/s mercury jet 5 T field ~2500 A

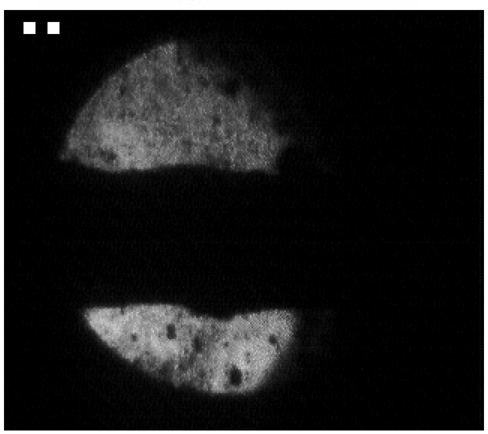


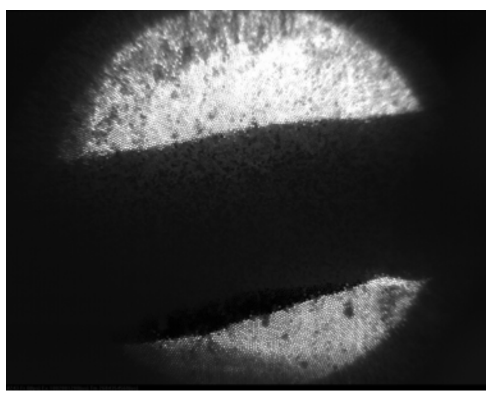
Olympus
Encore Camera
2 ms frame rate
100 μs exposure

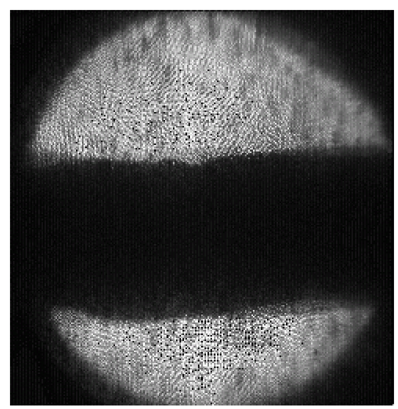
Viewport 3
FV Camera
2 ms frame rate
10 μs exposure

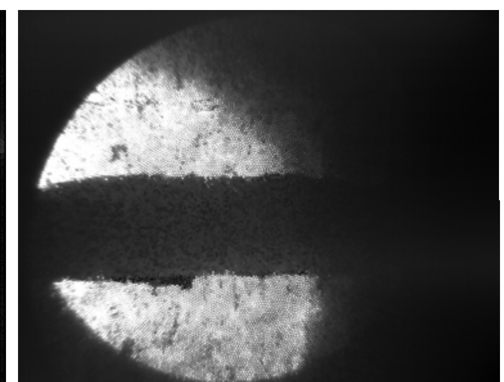
Viewport 2
SMD Camera
0.1 ms frame rate
0.15 μs exposure

Viewport 1
FV Camera
2 ms frame rate
10 μs exposure







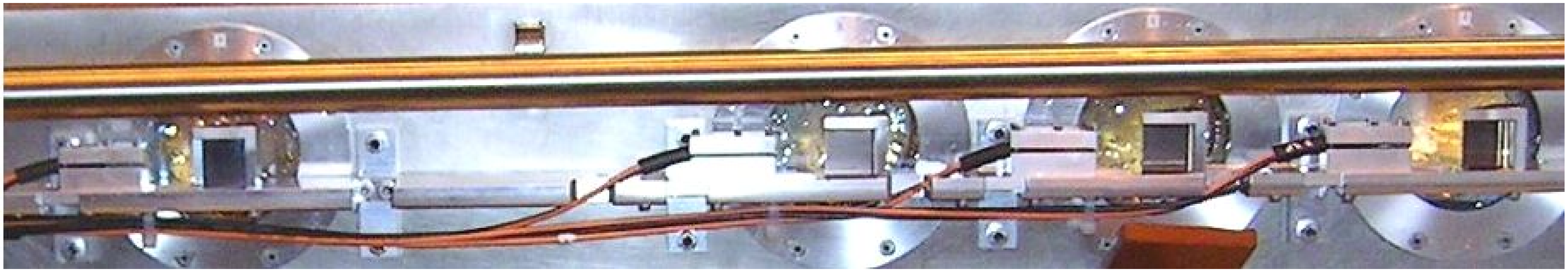


Stabilization of Hg jet by B field is again observed at CERN

Scintillating fiber channel #0

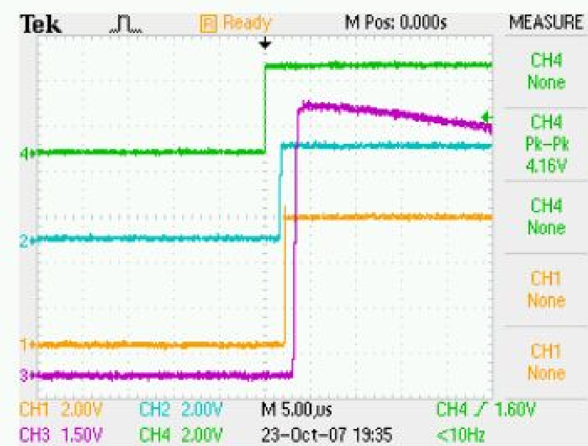
Oct. 23, 2007

Scintillating signal collected by 20 ns risetime photodiode (Thorlab DET110)



TDS 2024B - 5:42:27 PM 10/23/2007

TDS 2024B - 4:26:11 PM 10/23/2007

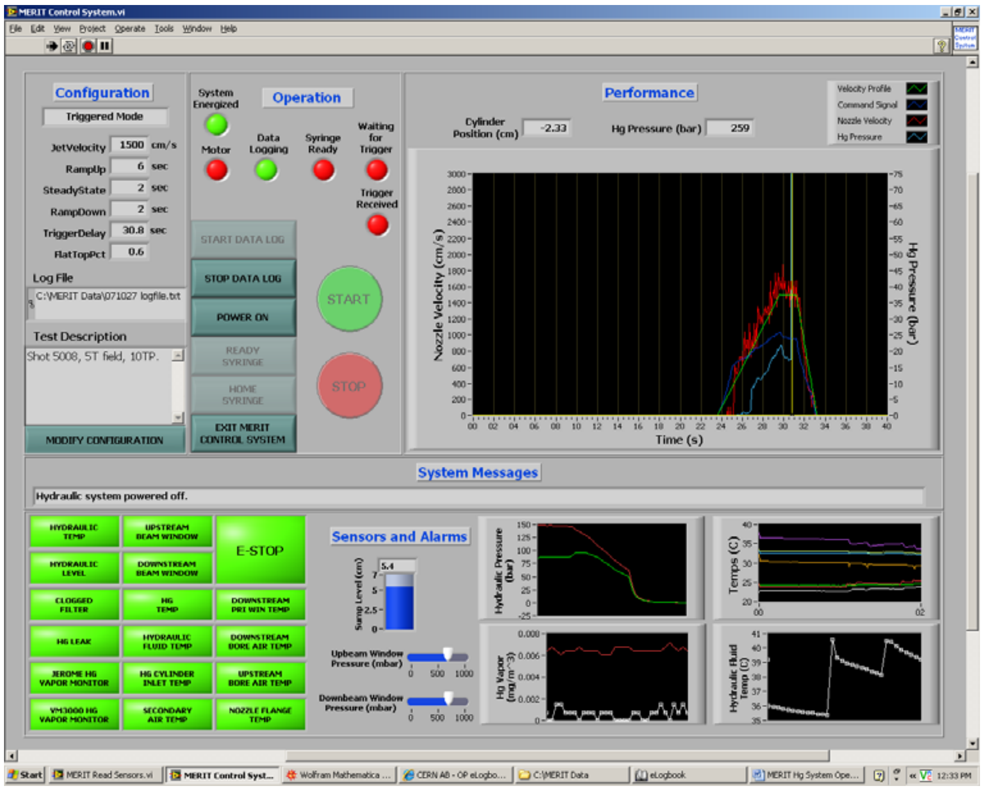


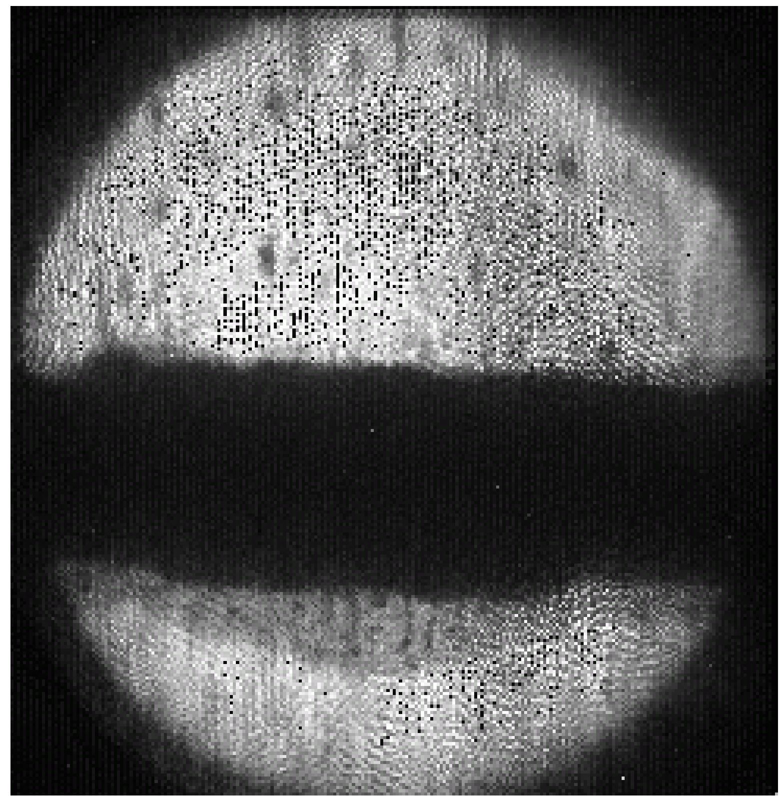
TDS 2024B - 6:34:05 PM 10/23/2007

Scintillator pulse height signal indicates beam intensity and beam position location

Oct 27, 2007 CERN 1st beam 2x10^{14} protons on target

Beam #5008 - 6A, 5T, 15 m/s, 10TP
Viewport #2 SMD camera 0.2 ms/frame, 0.15 μs exposure time



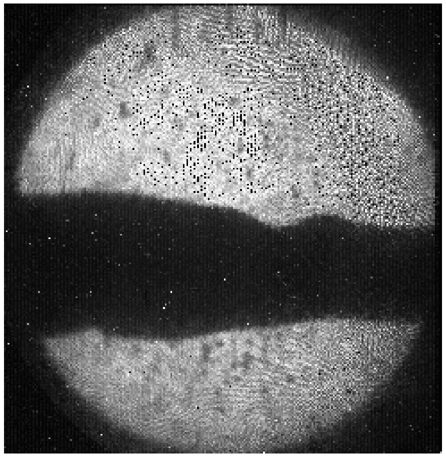


More proton beam on target

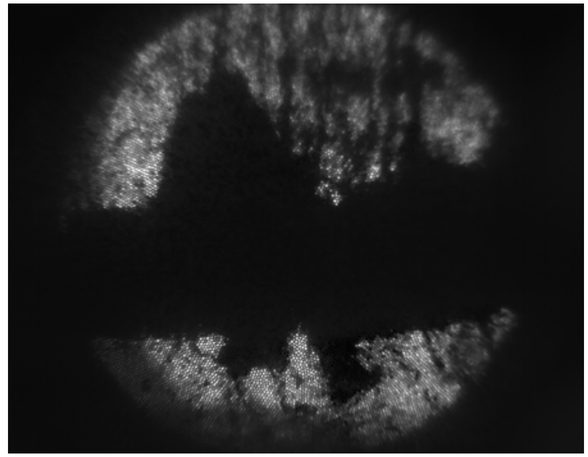
Oct 31, 2007 CERN

Beam # 8035
B=7T,V=15m/s
Pump 15TP
Probe 5TP
dT = 2.3μs

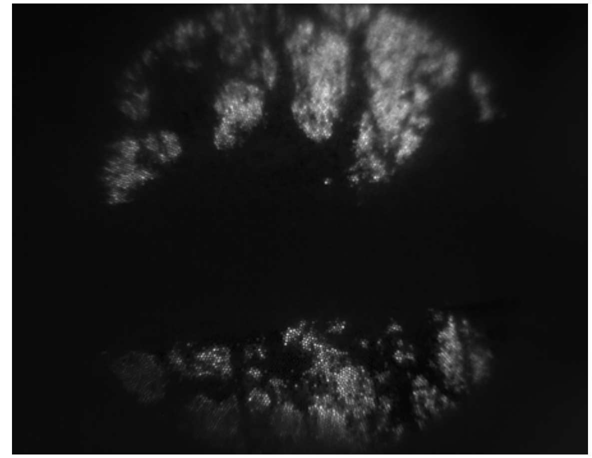
Viewport 2
100μm/frame, Total 1.6ms



Viewport 3
frame @ 6ms

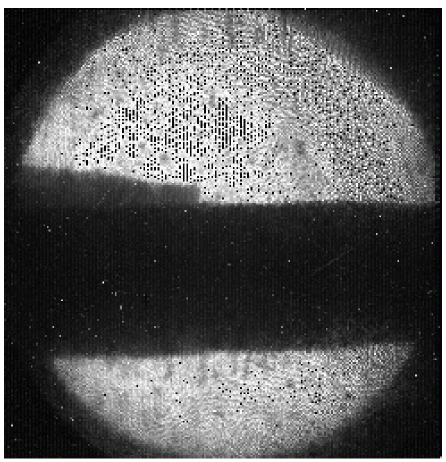


Viewport 3
frame @ 10ms

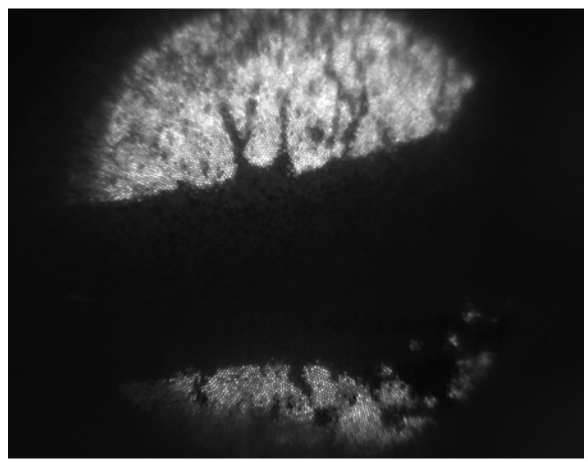


Beam # 8037
B=7T,V=15m/s
Pump 15TP
Probe 5TP
dT = 700μs

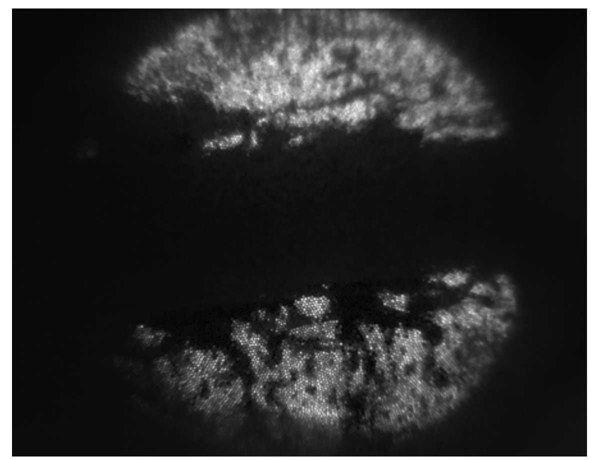
Viewport 2
100μm/frame, Total 1.6ms



Viewport 3
frame @ 12ms



Viewport 3
frame @ 16ms



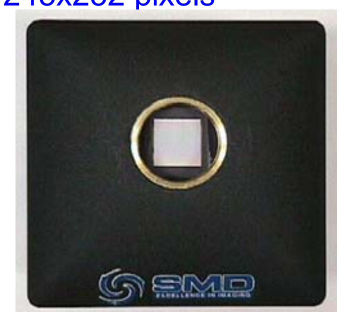
Nov 8, 2007 camera lens replaced to give 2000 fps with reduced imagine resolution

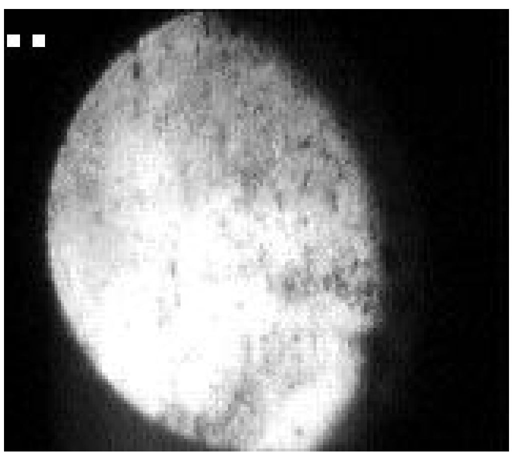
Viewport 4, Olympus
0.5 ms frame rate
33 µs exposure
160x140 pixels

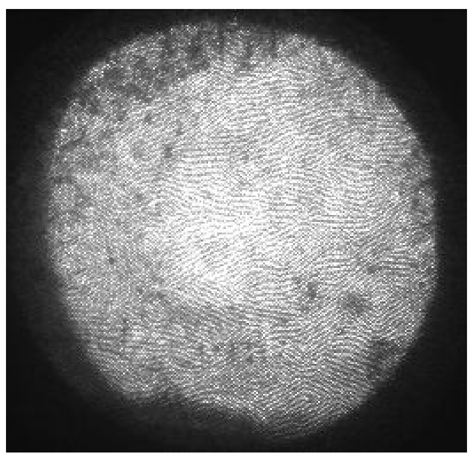
Viewport 3, FV Camera
0.5 ms frame rate
6 µs exposure
260x250 pixels

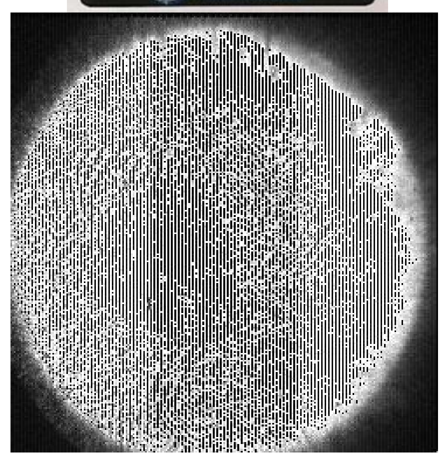
Viewport 2, SMD Camera
0.5 ms frame rate
0.15 µs exposure
245x252 pixels

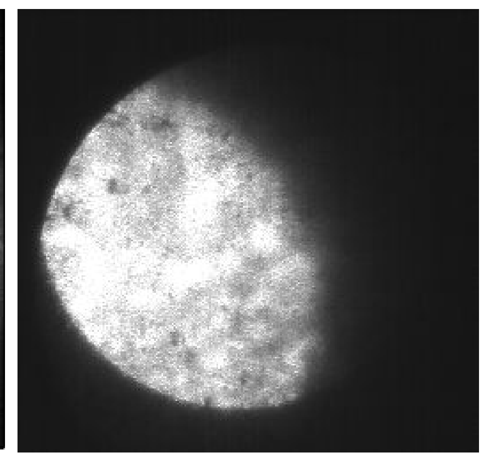
Viewport 1, FV Camera
0.5 ms frame rate
6 µs exposure
260x250 pixels



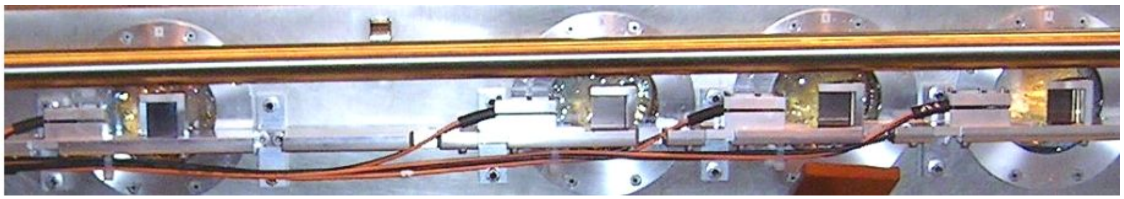


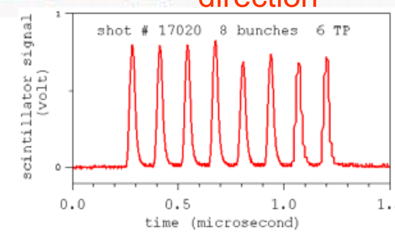






Nov 8-11, 2007 CERN proton beam run, all camera @ 2000 fps





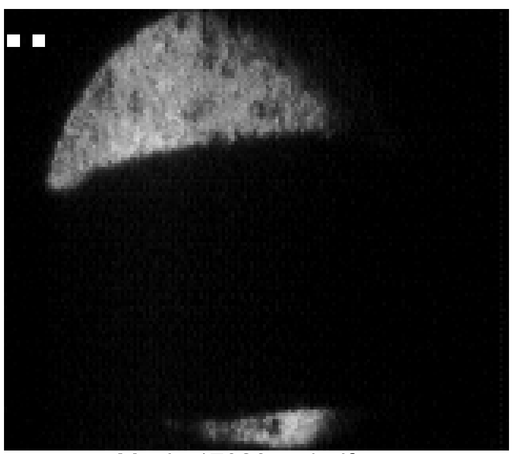
Viewport 4, Olympus
33 µs exposure
160x140 pixels

Viewport 3, FV Camera
6 µs exposure
260x250 pixels

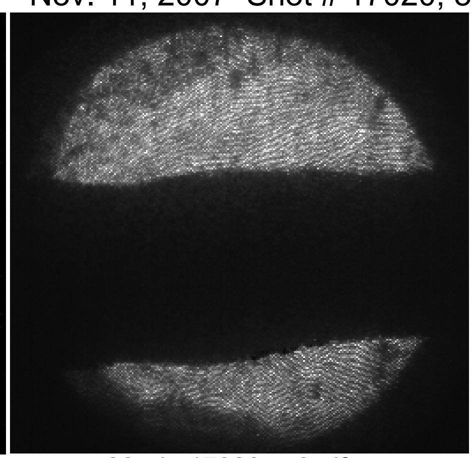
Viewport 2, SMD Camera
0.15 µs exposure
245x252 pixels

Viewport 1, FV Camera
6 µs exposure
260x250 pixels

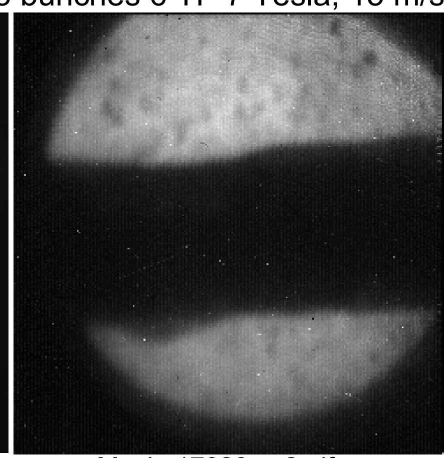
Nov. 11, 2007 Shot # 17020, 8 bunches 6 TP 7 Tesla, 15 m/s jet



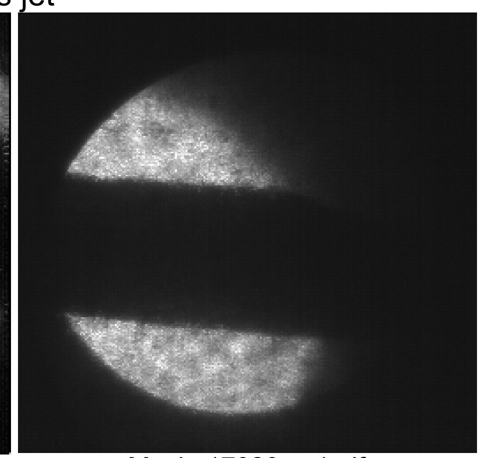
Movie 17020 vp4.gif



Movie 17020 vp3.gif



Movie 17020 vp2.gif

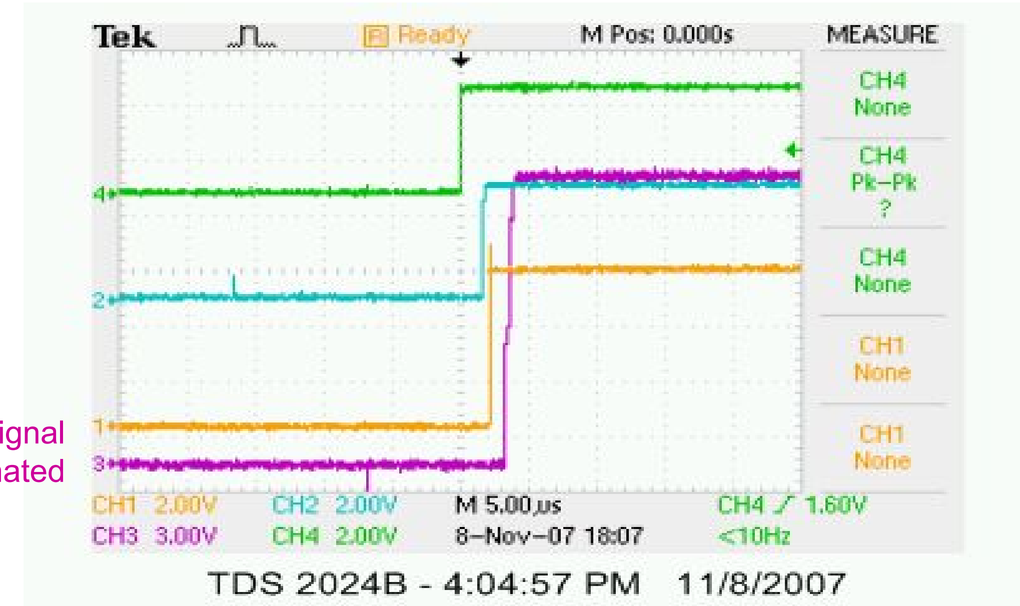


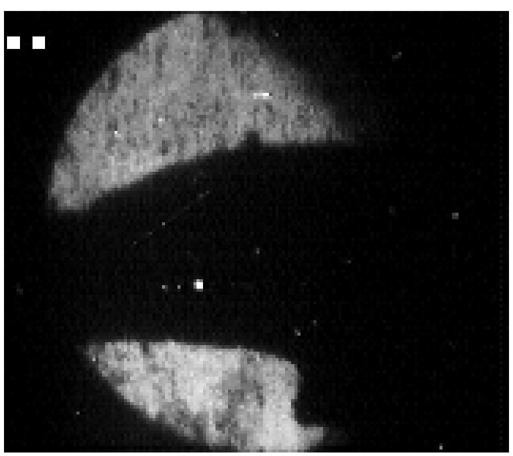
Movie 17020 vp1.gif

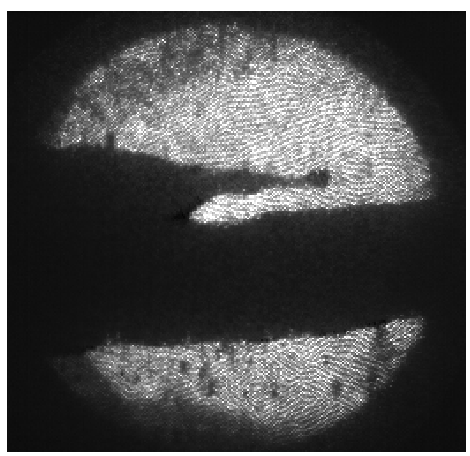
MORE CERN proton beam run @ @ 2000 fps

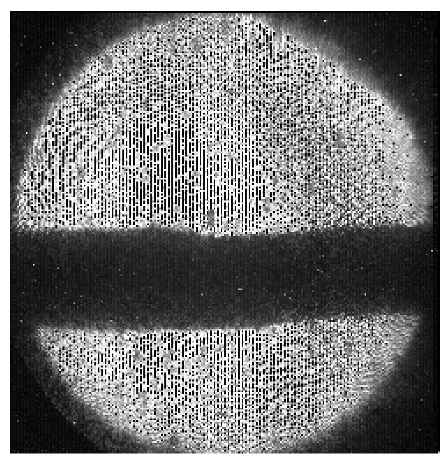
Shot # 14018
6+2 bunches
16 TP
5 Tesla
15 m/s jet

Scintillator signal
not 50-Ohm terminated

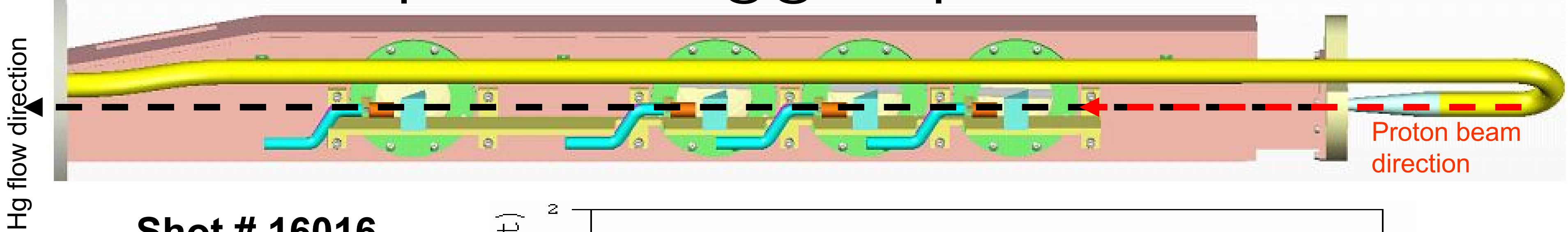




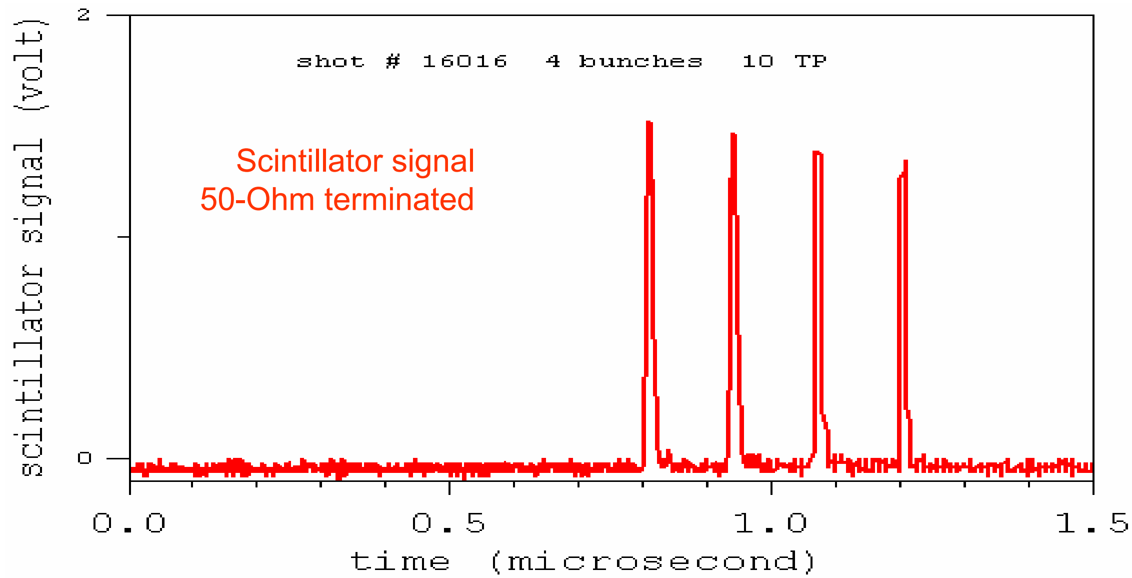


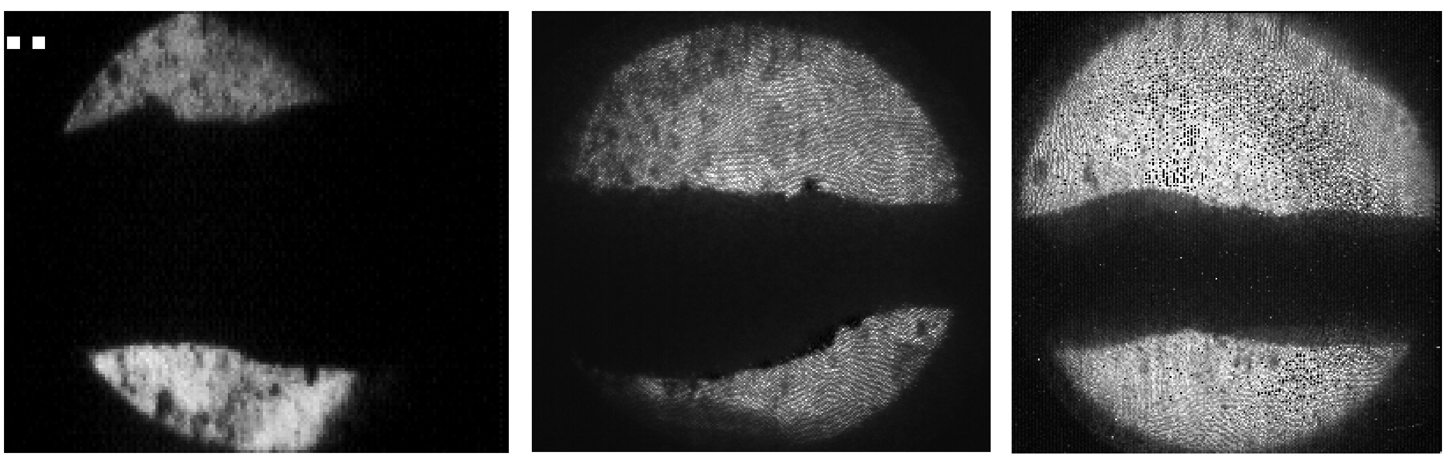


MORE CERN proton beam run @ @ 2000 fps

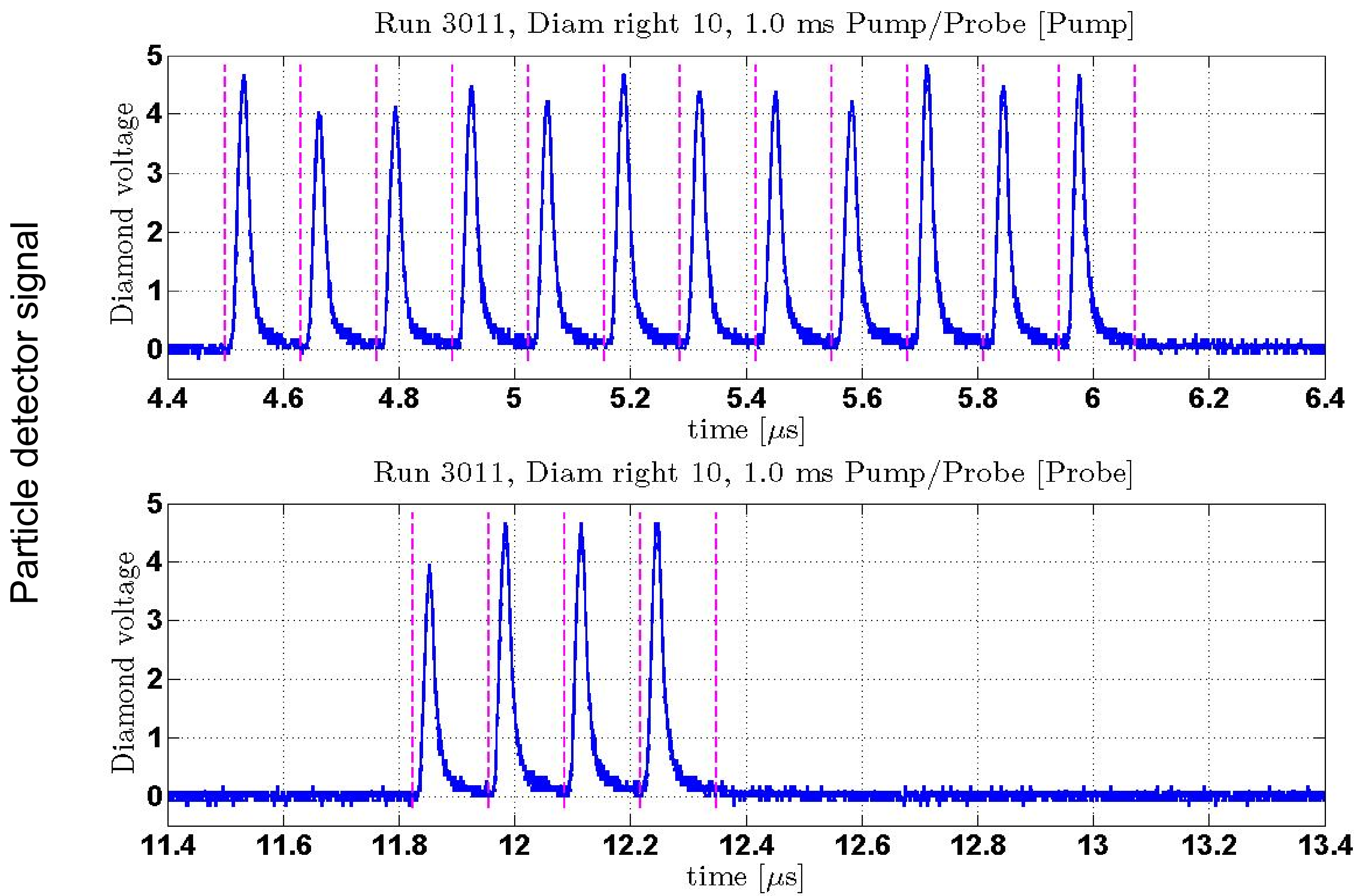


Shot # 16016
4 bunches
10 TP
5 Tesla
15 m/s jet



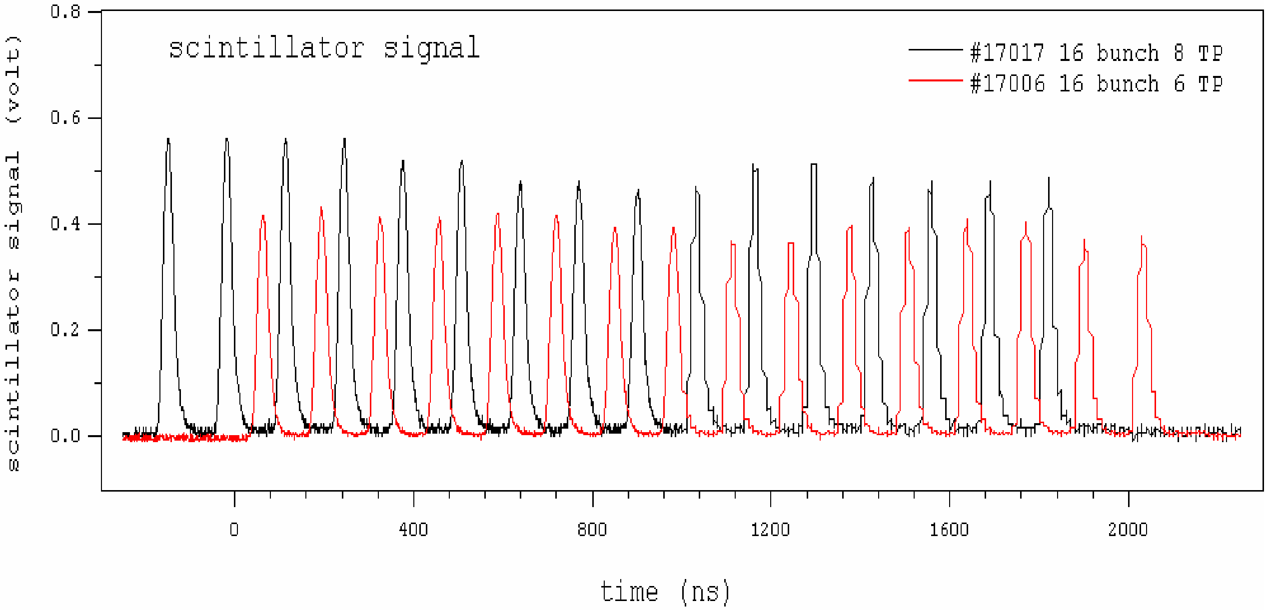


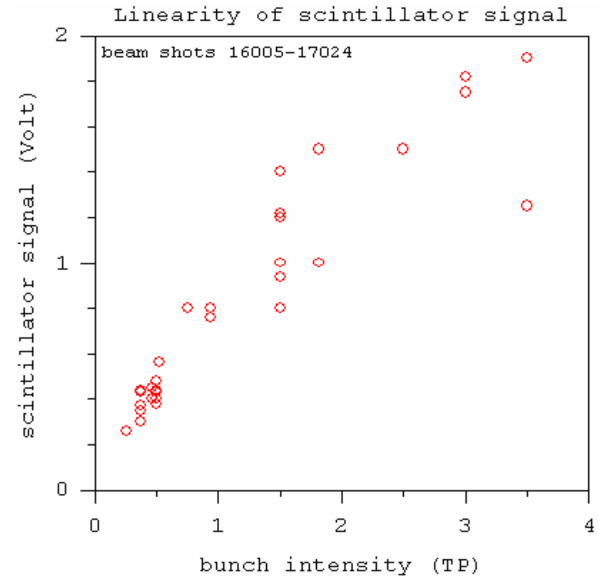
A 3TP Pump Pulse and a 1TP Probe Pulse with 1ms delay



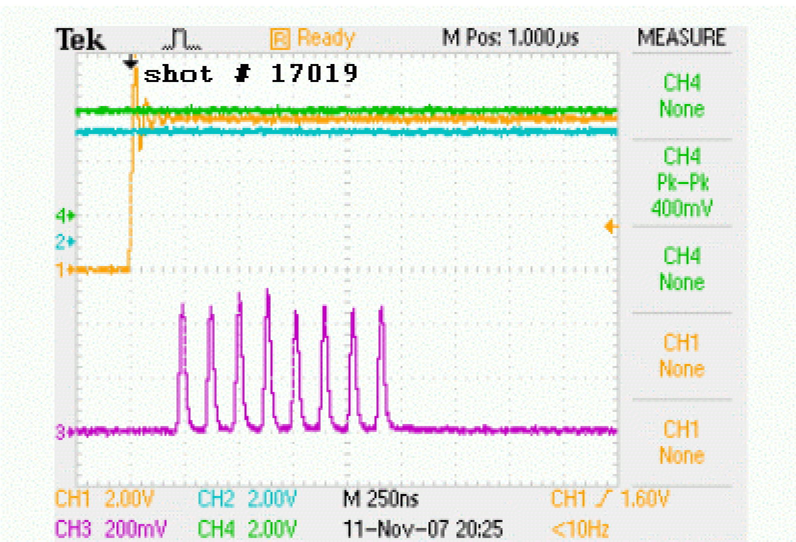
Optical scintillator detection signal - Channel 0

Scintillator signal indicated that : 1st 8 bunch has better timing resolution than the 2nd 8 bunch



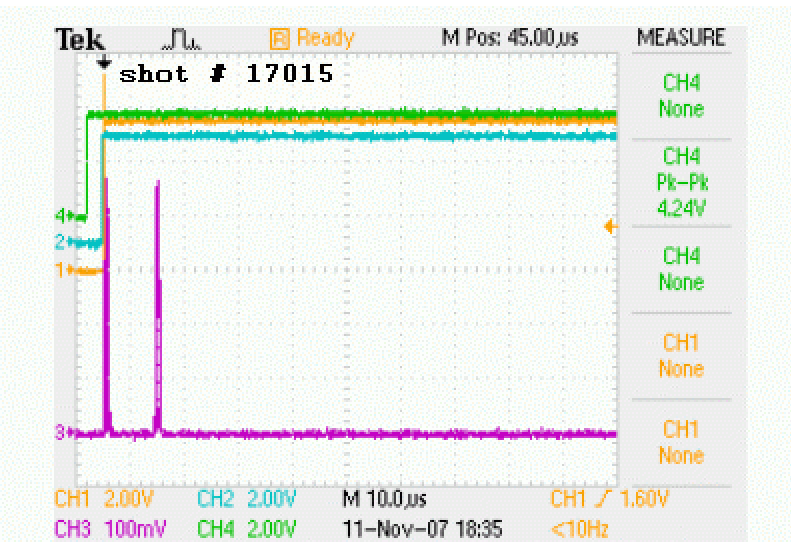


Various bunch intensities & bunch lengths



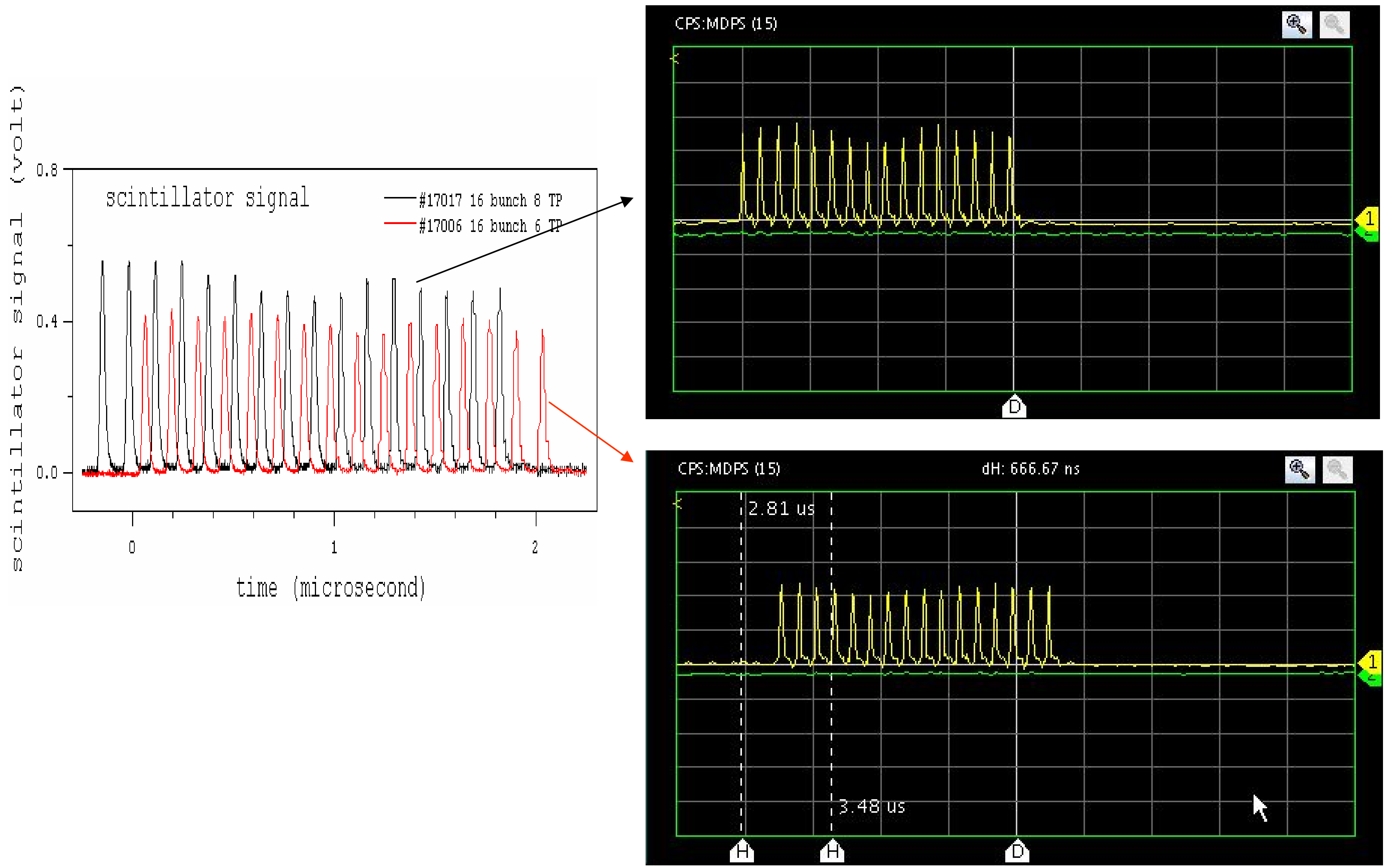
TDS 2024B - 6:22:51 PM 11/11/2007

various pump probe bunches



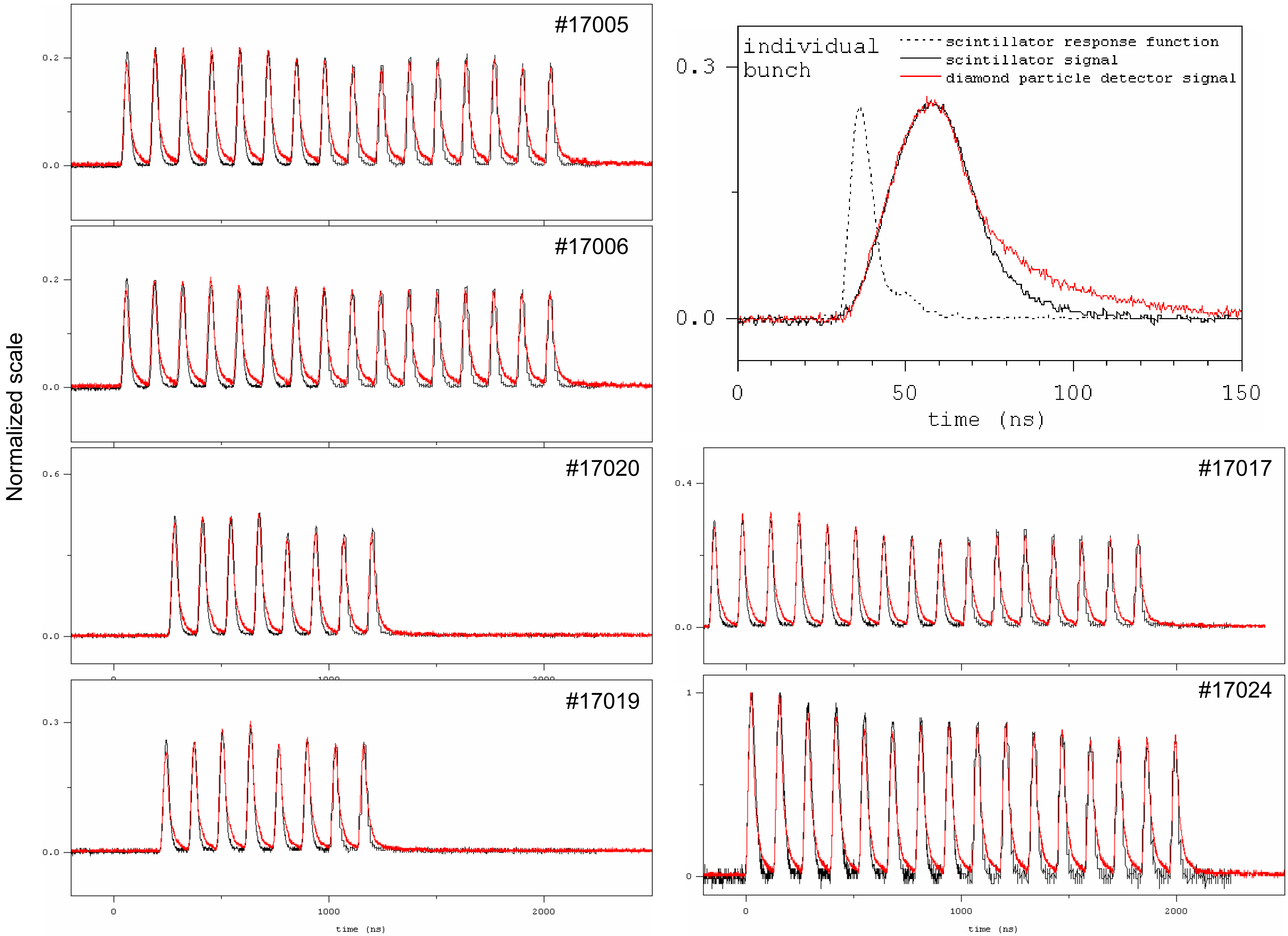
TDS 2024B - 4:33:27 PM 11/11/2007

Optical scintillator detection signal - Channel 0

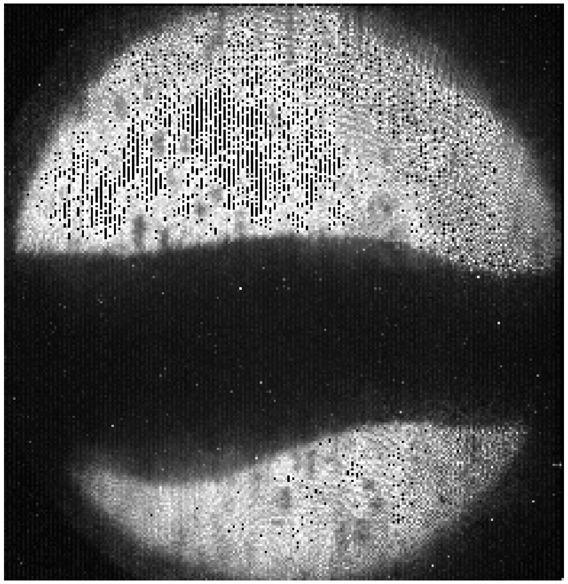


Correlation between scintillator & particle detector signal

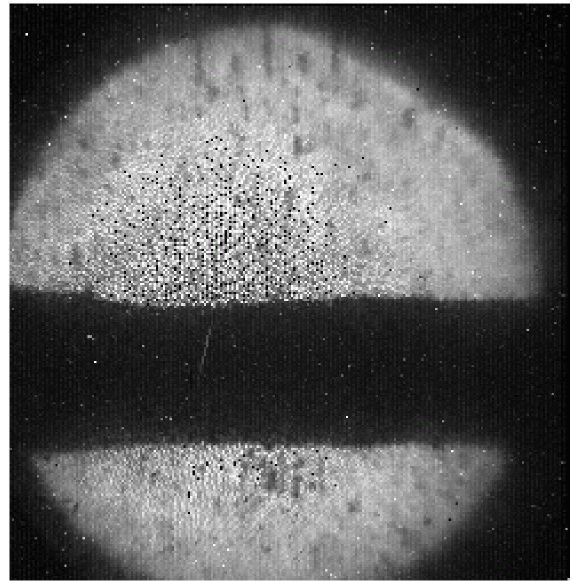
diamond left 20^{o}



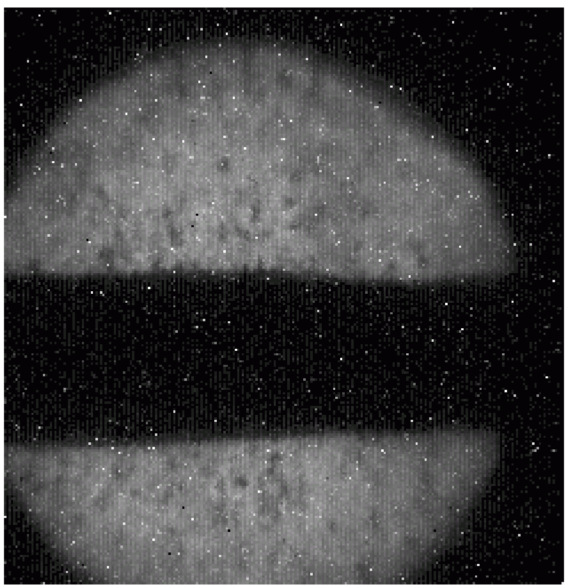
MORE CERN proton beam run, SMD Viewport #2



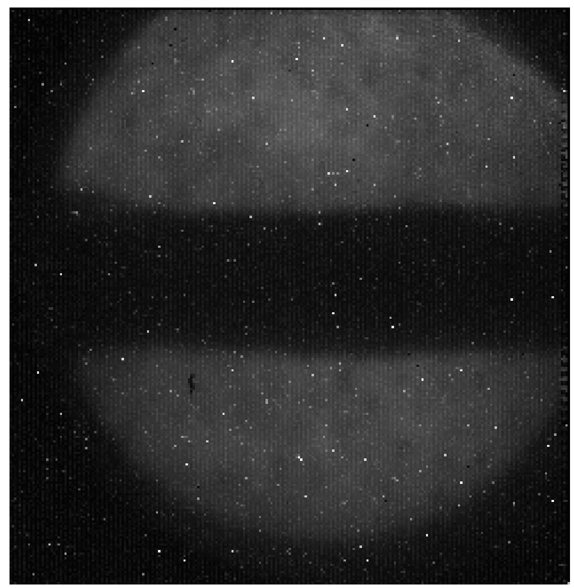
Shot # 6006
16 bunches
10 TP
5 Tesla
15 m/s jet
0.1 ms/frame



Shot # 11019
16 bunches
10 TP
10 Tesla
15 m/s jet
0.1 ms/frame

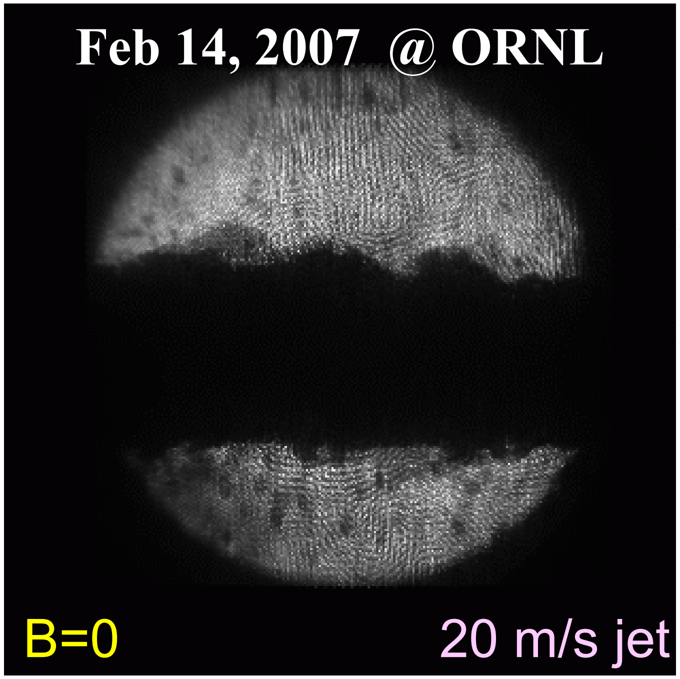


Shot # 12033
16 bunches
30 TP
15 Tesla
20 m/s jet
0.1 ms/frame

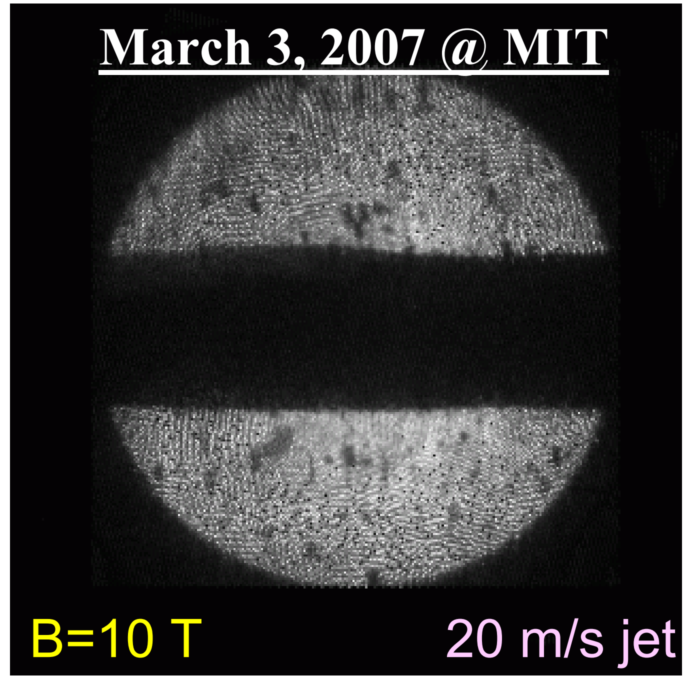


Shot # 17024
16 bunches
29 TP
10 Tesla
20 m/s jet
0.5 ms/frame

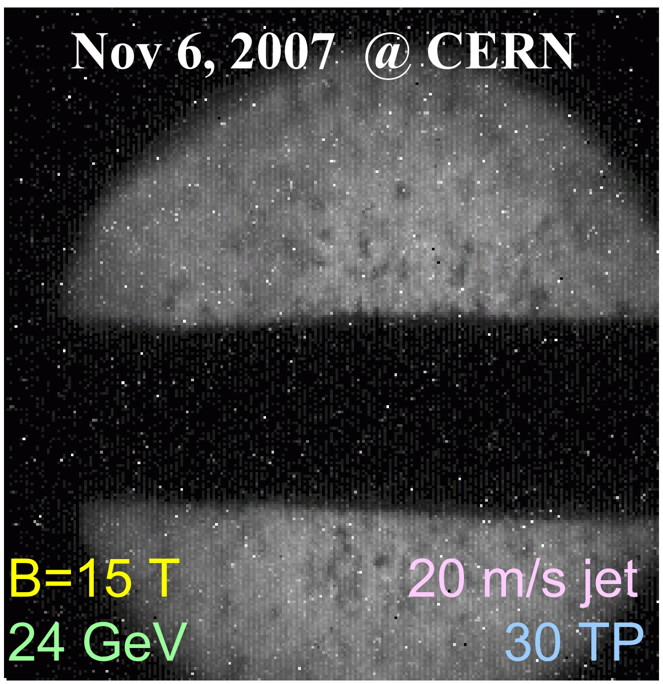
Merit Milestones



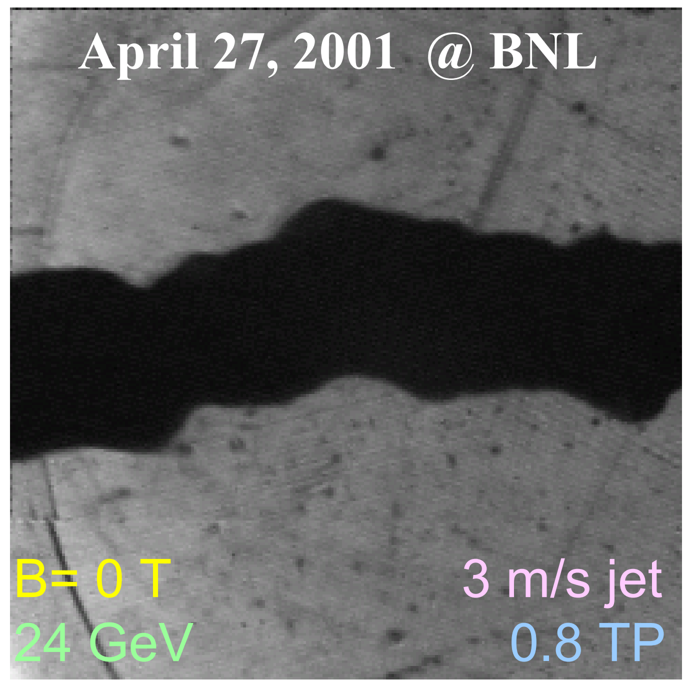
FOV 5.5 cm
50 µs/frame
0.15 µs exposure
Hg_20ms.gif



FOV 5.5 cm
100 µs/frame
0.15 µs exposure



FOV 5.5 cm
100 µs/frame
0.15 µs exposure
shot # 12033
Movie12033vp2.gif



FOV 4.2x4.2 cm
100 µs/frame
0.15 µs exposure
Jet 4-27-01-15.gif
Proton beam size
~3 mm FWHM

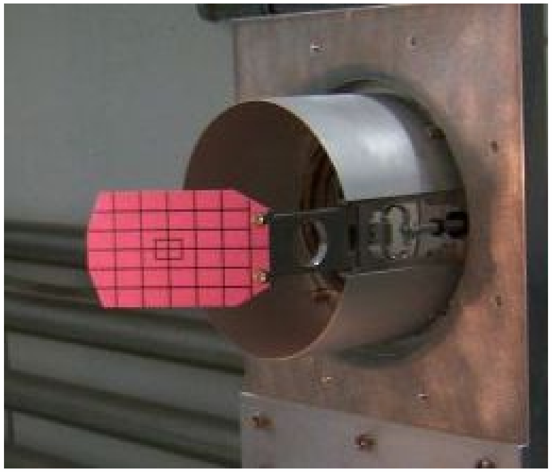
First Beam August 24

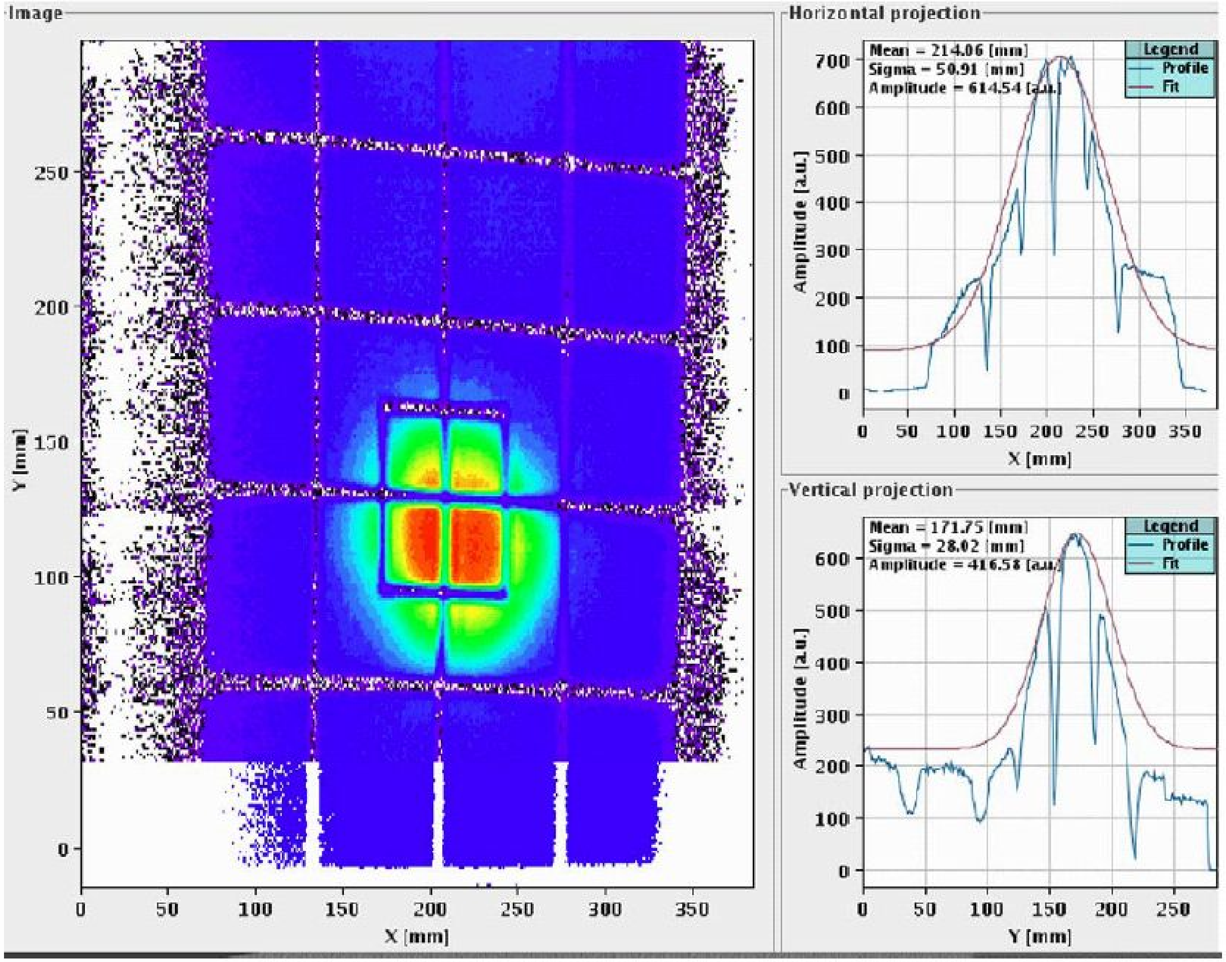
14 GeV

2 10^{11} ppp

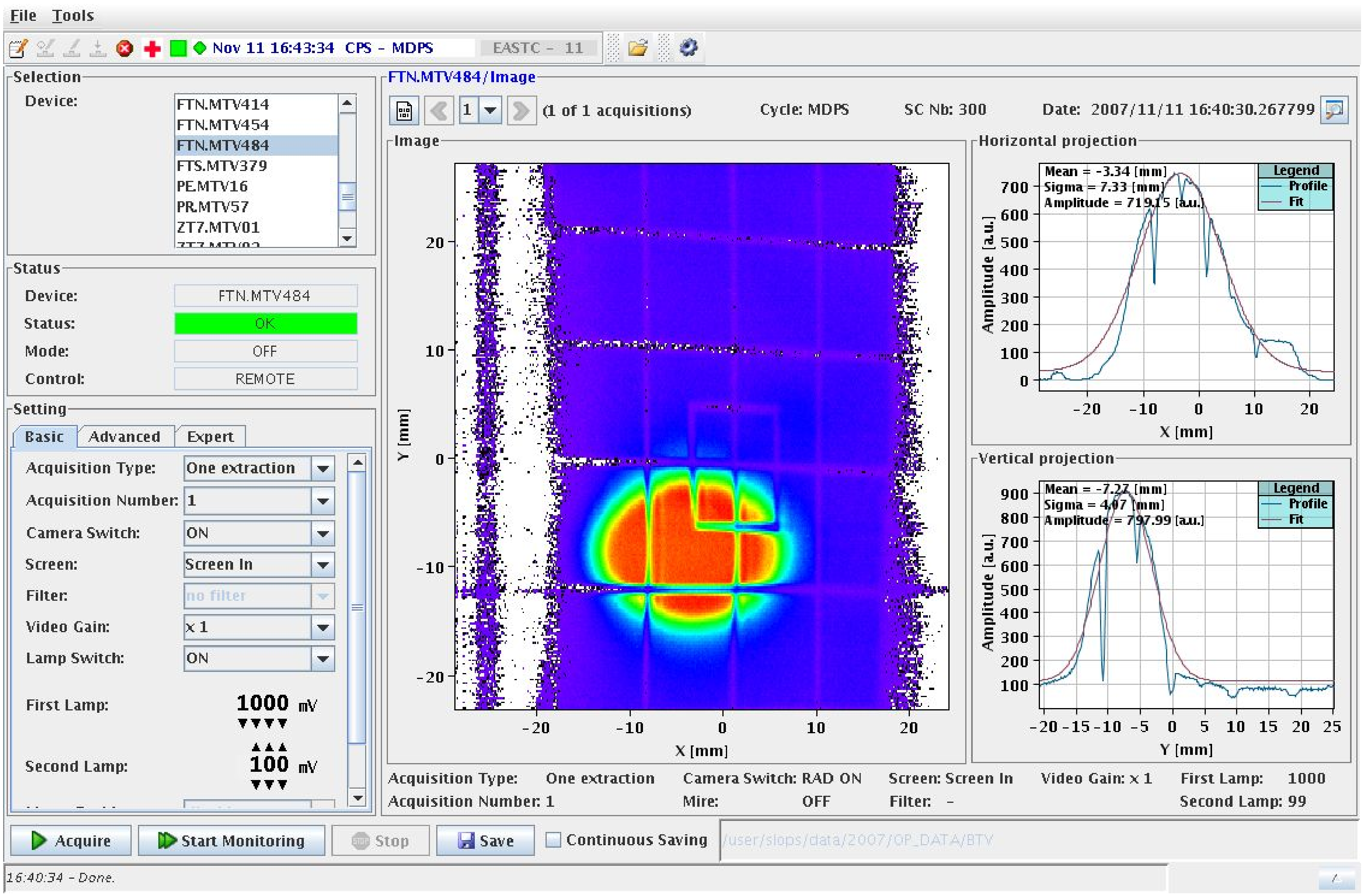
σ_x (rms) 7mm

σ_x (rms) 4mm



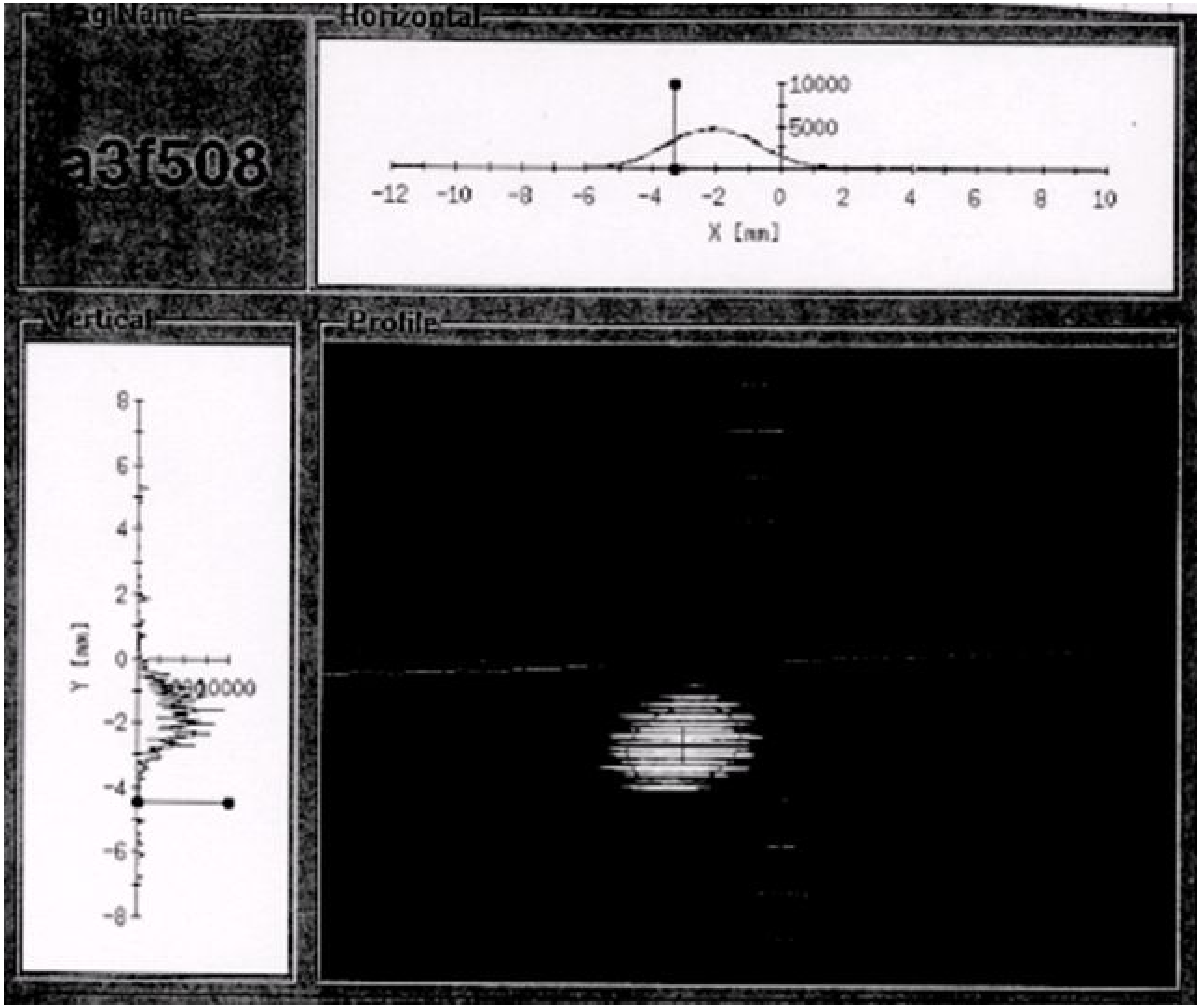


Nov. 2007 CERN
Shot #17016 beam profile: 24 GeV, 8+8 bunch, 7.4 TP



FWHM ~ 15 mm

April 2001 BNL AGS E951 beam profile: 24 GeV



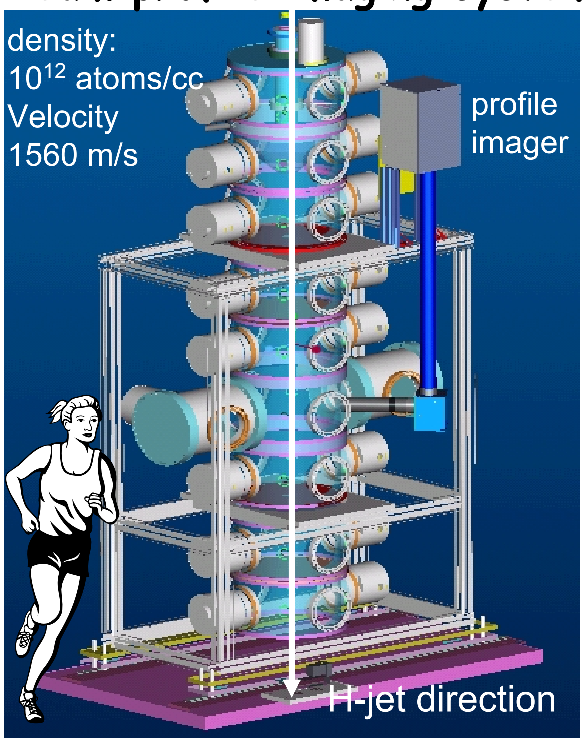
FWHM ~ 3 mm

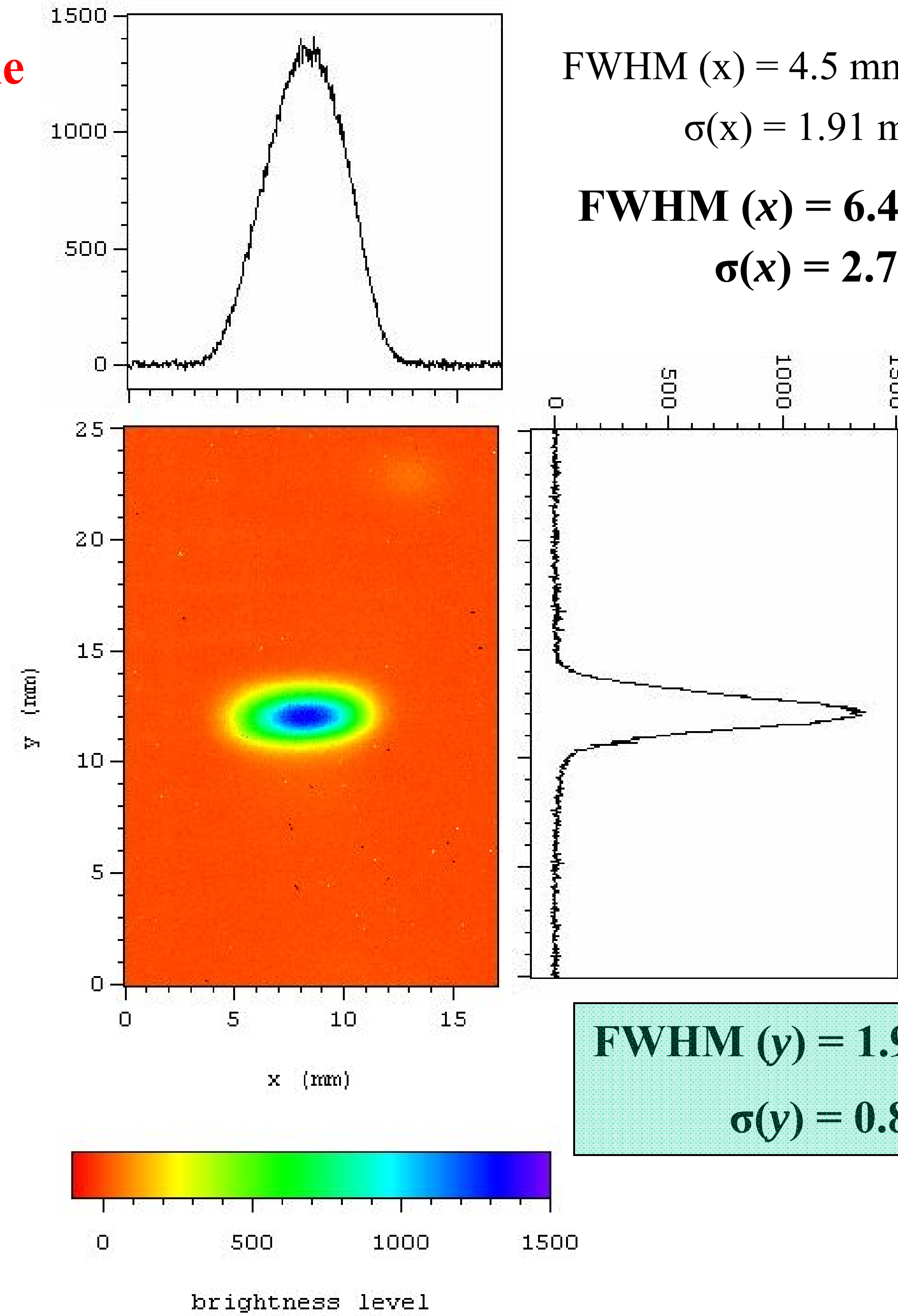
May 2006 BNL RHIC
100 GeV proton beam profile

RHIC Yellow beam profile after 656 nm red filter

Data of Feb. 28, 2006
10×10^{11} protons

RHIC H-jet beam profile imaging system





FWHM (x) = 4.5 mm
σ(x) = 1.91 mm

FWHM (x) = 6.4 mm
σ(x) = 2.7 mm } **H-jet**

FWHM (y) = 1.9 mm
σ(y) = 0.8 mm } **RHIC beam**

Oct – Nov, 2007 CERN beam runs

• radiation issues lead to malfunction of several pc in TT2 tunnel

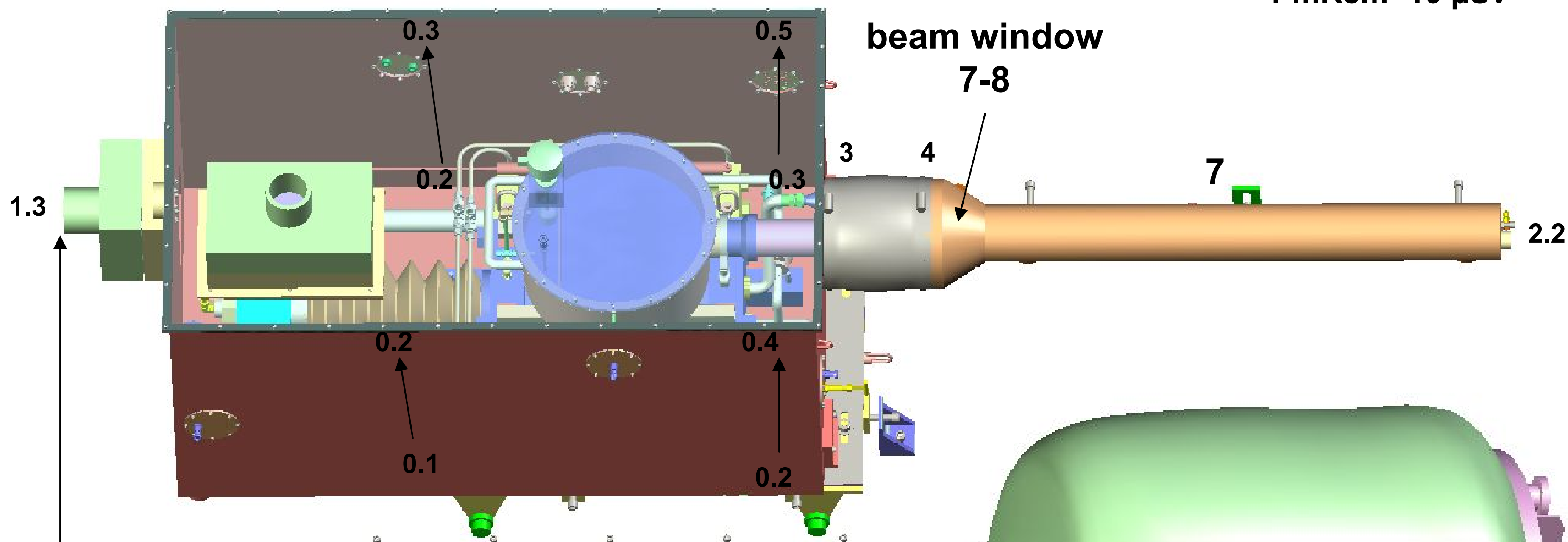
• camera clearly suffering radiation damage, loss of various pixels, particularly noticeable in the first few image frames at the arrival of the proton beam. However, they appear to recover right after proton beam passage. It is speculate that most radiation damage are caused by neutrons.

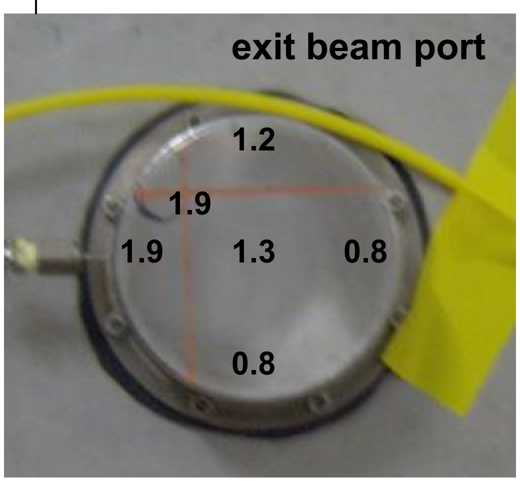
• SMD camera, or mostly framegrabbler board suffer transient radiation malfunction, losing half image frames, but it recovers in subsequence beam shots.

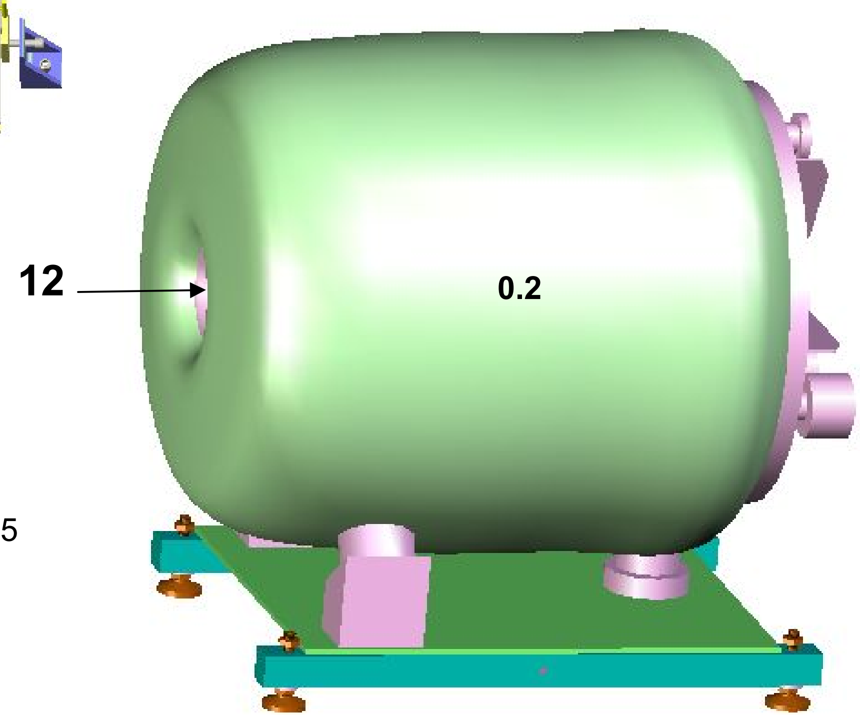
Feb 6, 2008 Decommission @ CERN
Radiation reading at the vicinity of the sub-tank and the solenoid   (Gamma-scout)

unit of mRem/hr

1 mRem=10 μSv







Geneva background 0.015

TT2A tunnel 0.04

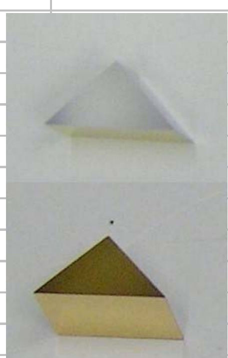
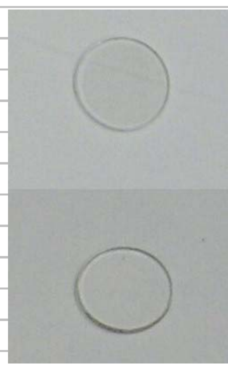
TT2 tunnel 0.02

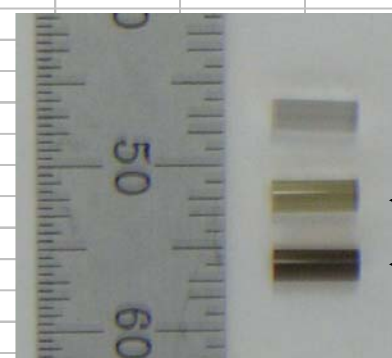
Beam dump 12-15

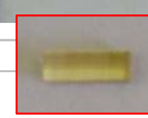
Radiation resistance of optical components

Source #1: CERN proton beam: 1.4 GeV, 5x10^15 protons, 320 krad, equivalent to 40 pulses of 24 GEV proton
Source #2: BNL Co60: 30 krad & 3 Mrad equivalent to 3.7 & ~370 pulses of 24 GeV proton
measurements wavelength ~ 800 nm

		radiation source	equivalent proton pulse	NIR (~800nm)		
item #	components			before	after	results
1	gold mirror reflector	#1	40	0.910	0.920	no change
2	1-mm thick sapphire window (& ball lens)	#1	40	0.863	0.867	no change
3	5-meter multimode low-OH fiber	#1	40	1.000	1.020	no change
4	30-cm long Sumitomo imaging fiber	#1	40	0.670	0.710	no change
5	Grin objective lens, 2.43 mm long	#2	~4	0.900	0.860	T=95%
5	Grin objective lens, 2.43 mm long	#2	370	0.900	0.657	T=73%



Merit completed
Feb 4 , 2008

Summary

- four 10-meter long imaging fibers assembled on SS primary
- SS primary are pressure tight (20 psi)
- dynamic image collection on all viewports were tested
- dismount and remounting optical base plate requires little or no realignment
- camera ↔ viewport are interchangeable, but the FOV all viewports are fixed – 55 mm

- Nov 20, 2006 - optics delivered to ORNL
- Nov 28, 2006 - water jet test @ ORNL started
- Feb 14, 2007 - Hg jet run completed @ ORNL
- March 3, 2007 - Hg jet run and 15T pulsed solenoid test completed @ MIT
- May 11, 2007 – Optics set up in the control room at CERN
- May 16, 2007 – remote control of all optical diagnostics equipment/PC from BNL achieved
- June 18, 2007 – fiberoptics installed and connected in TT2 tunnel, but no cameras are running, pc problem
- July 12, 2007 – all cameras are up and running, bad SMD camera discovered & misalignment in the snout discovered
- Aug 29, 2007 – pull out snout, optics realigned
- Sept 11, 2007 – heater on, snout overheat, problem with optics
- Sept 23, 2007 – SMD camera back online
- Oct 15, 2007 – replace channel #2 optical head, channel #1 retroreflector, all 4 camera running, optics not perfect!
- Oct 22, 2007 – 1st 15 m/s jet 5 T field
- Oct 27, 2007 – 1st 15 m/s jet 5 T field interact with 10 TP proton beam
- Nov 8, 2007 – camera lens replaced to give 2000 fps on all cameras, more pump-probe experiments
- Nov 11, 2007 – Merit experiment successfully completed, total of 406 beam shots from Oct 23 to Nov 11.

- Channel #0 - scintillating fiber, trigger confirmation, and proton intensity measurement
- Channel #1 - 1st viewport, old FastVision camera
- Channel #2 - 2nd viewport, SMD camera with new frame grabber
- Channel #3 - 3rd viewport, new FastVision camera
- Channel #4 - 4th viewport, Olympus Encore