

PAUL SCHERRER INSTITUT



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International Beam Instrumentation Conference



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CMOS based Beam Loss Monitor at SLS

TUOB02 - 14.09.2021

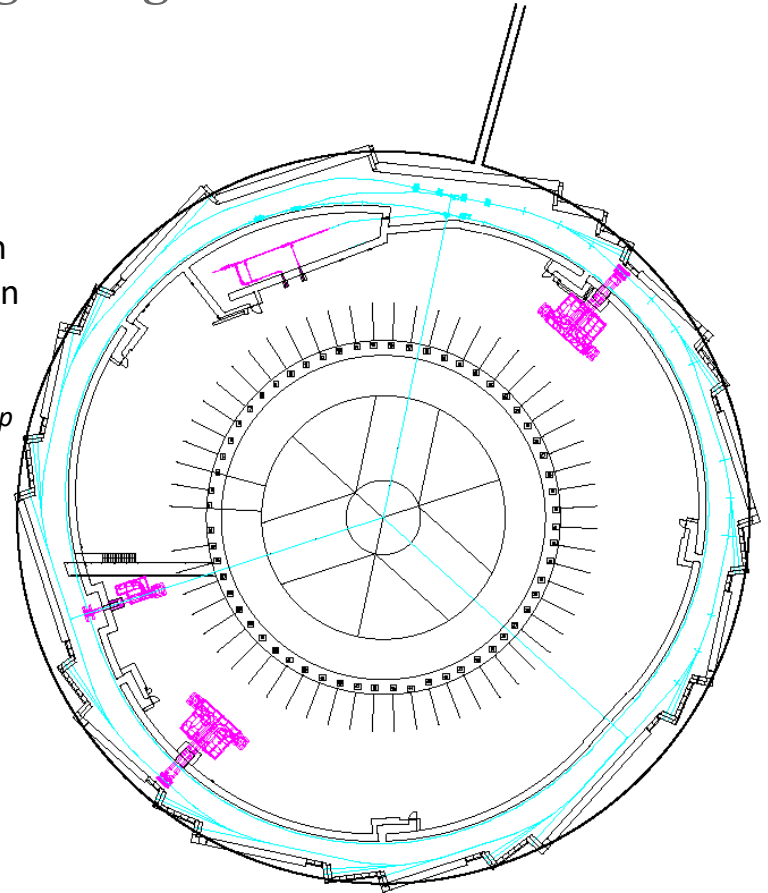
Requirements

- From the booster extraction point, down the storage ring injection straight and around the storage ring
- Detect low charge on-axis injection losses
- Provide loss patterns around the storage ring
- Loss measurements to determine beam lifetime and injection efficiency
 - Slow losses:
Usually confined to hot spots (collimators, scraper, ...). Depend on the beam size and population of the buckets. Time scale of the order of seconds.
 - Fast losses:
Related to accidental effects or events such as injection or beam dump. These losses can be distributed all around the machine. Time scale of the order of the single bunch or single turn.
- Protection of Insertion Devices
- Possibility of [software] interface to machine interlocks

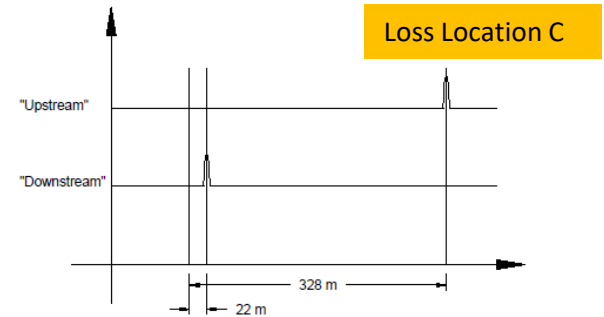
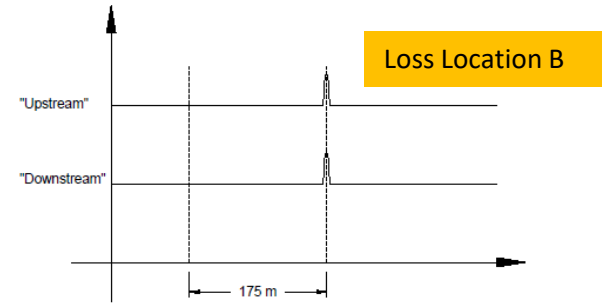
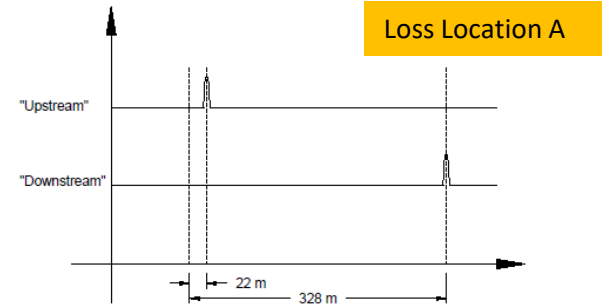
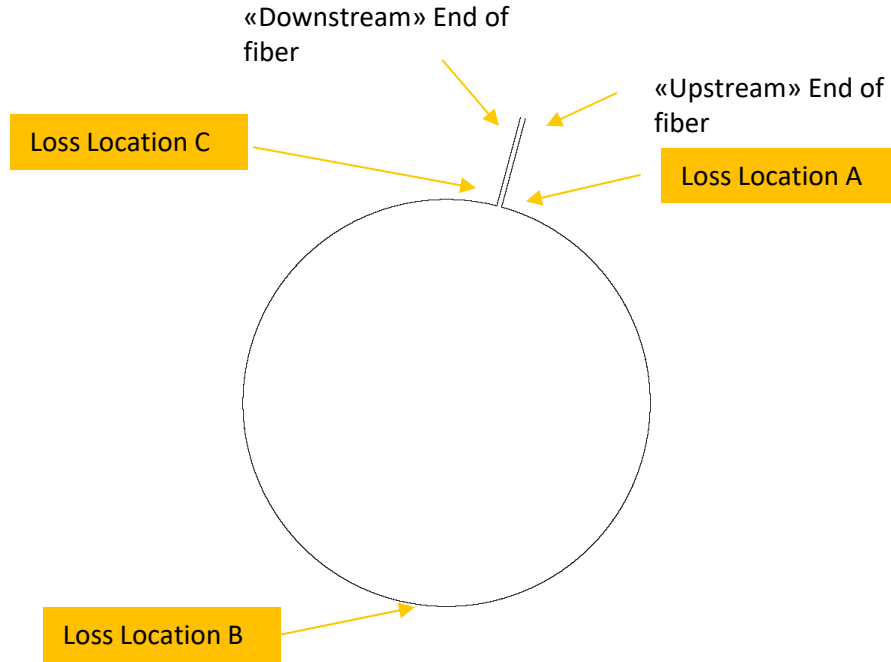
Long fiber around the Storage Ring

- ACAD drawing of the ring, with symbolic circle (frying pan shape) representing the 350m length of fiber optic
- Straight lines representing the two ends of the fiber which are brought out of the tunnel to the measurement location

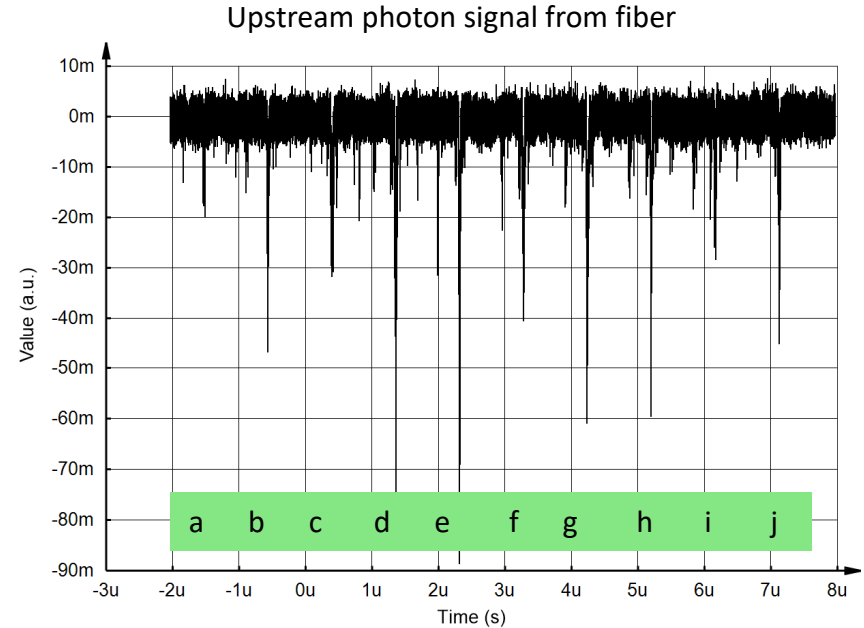
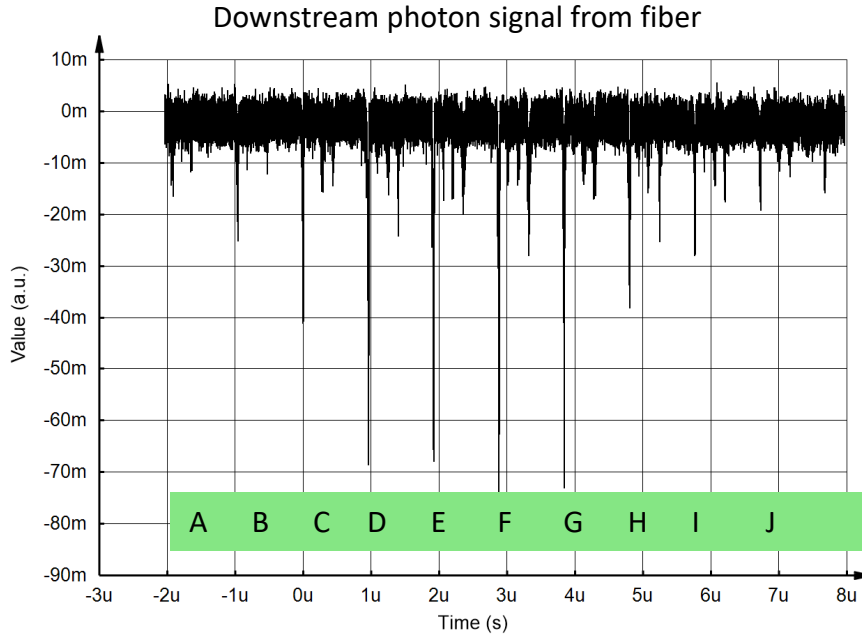
Thanks to Chris Gough for his collaboration and generosity, and Jonas Kallestrup for losing the beam on demand.



The principle

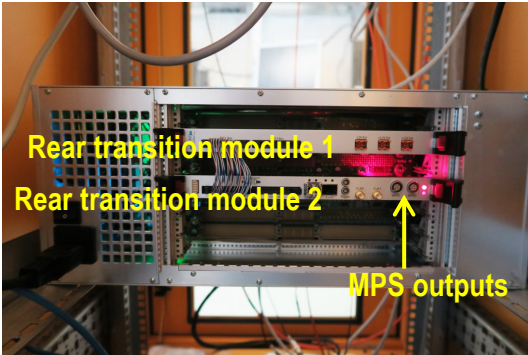
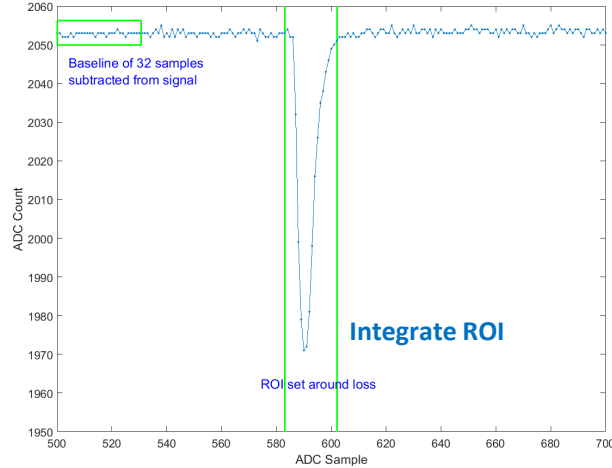
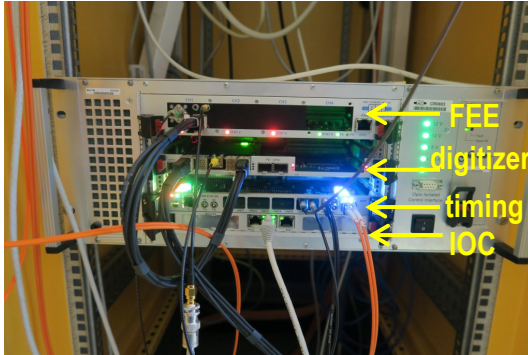
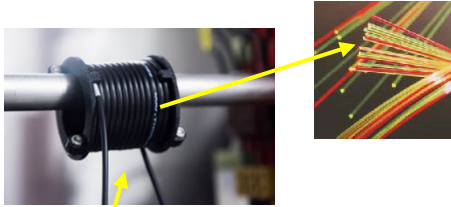


Loss of almost single bunch using RF phase inversion for beam dump

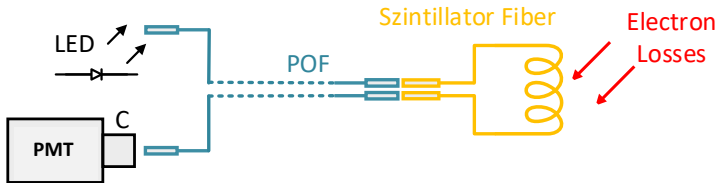
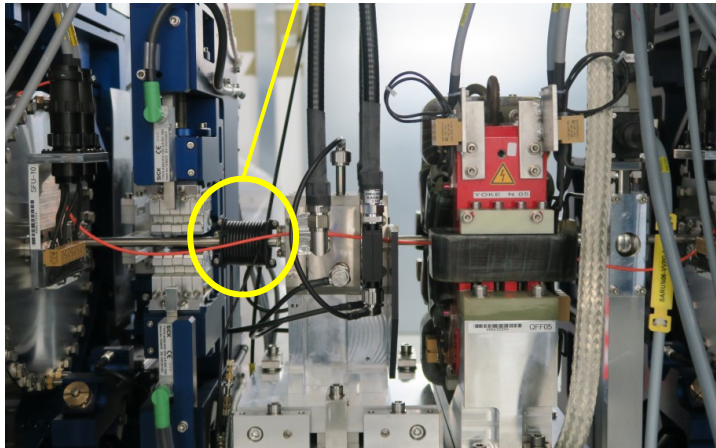


Surprise ! Reproducible single location of loss...but where?

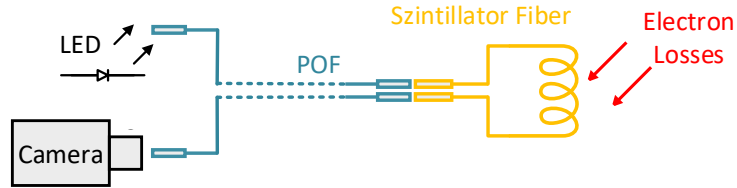
Loss Monitors for the SwissFEL



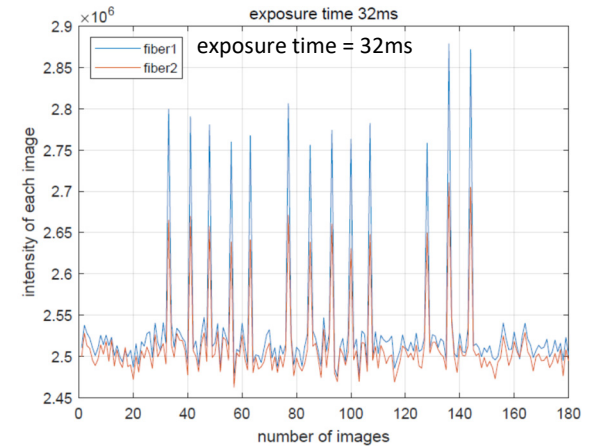
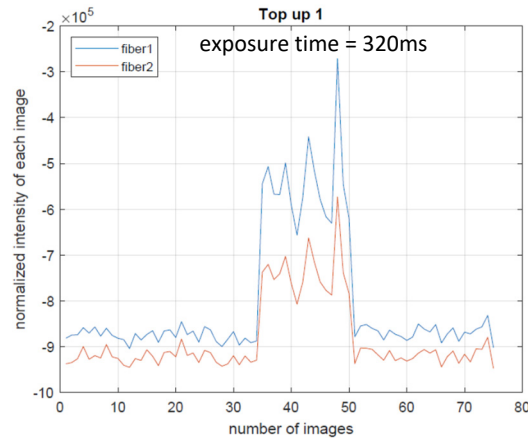
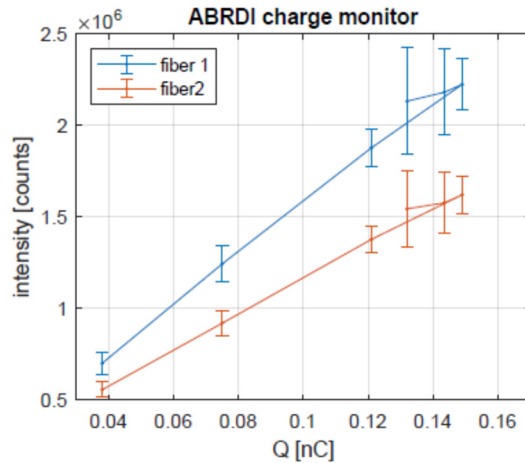
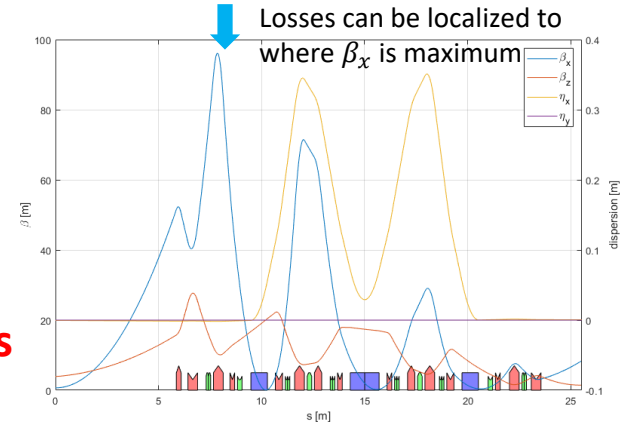
- Connects to machine protection system
- Calculations performed at 100Hz, independent of beam repetition rate



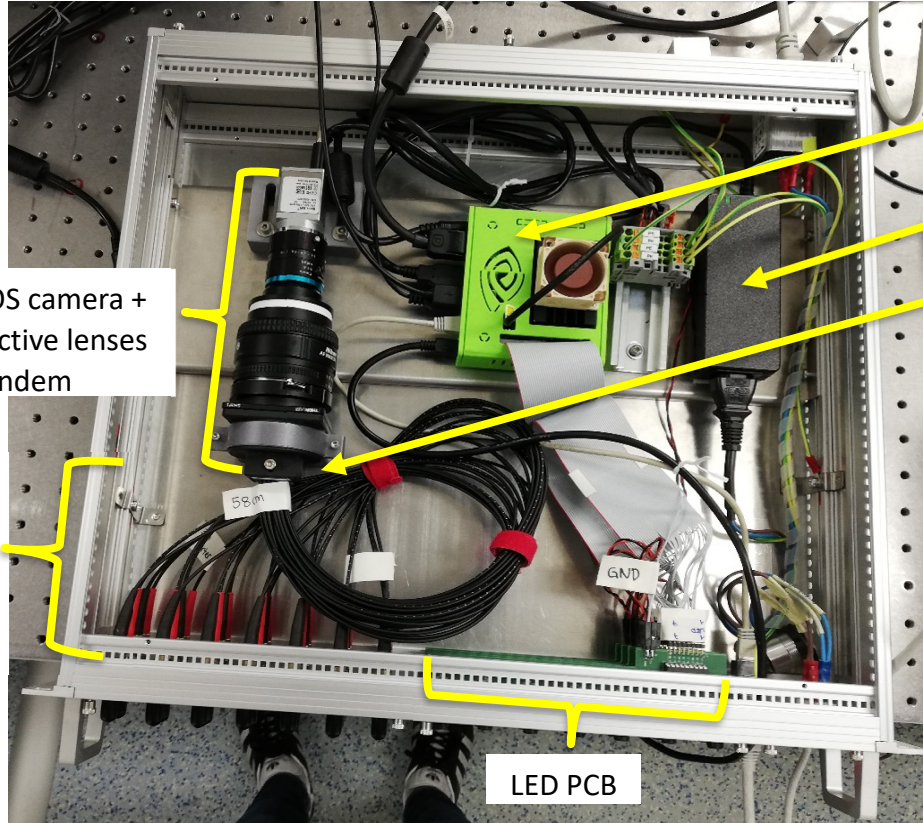
Proof of principle



Cannot detect turn-by-turn losses



CMOS based Beam Loss Monitor



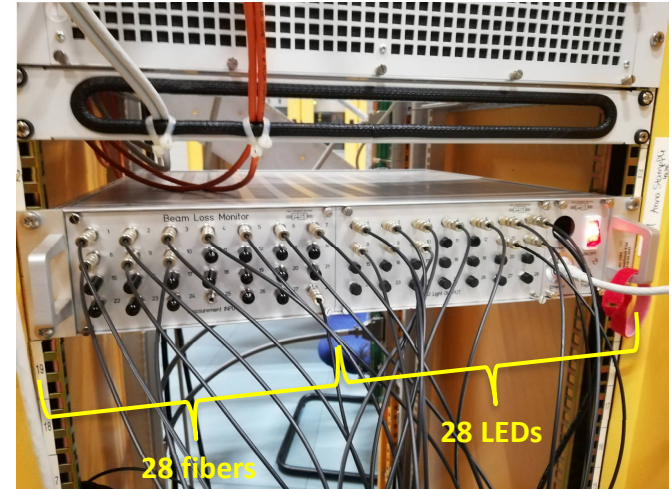
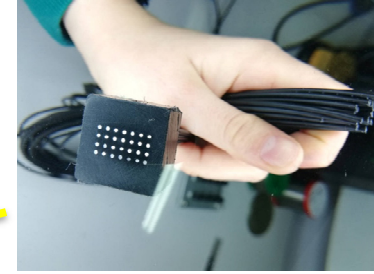
CMOS camera +
objective lenses
in tandem

Connection
to Camera

LED PCB

Jetson Nano

Power Supply

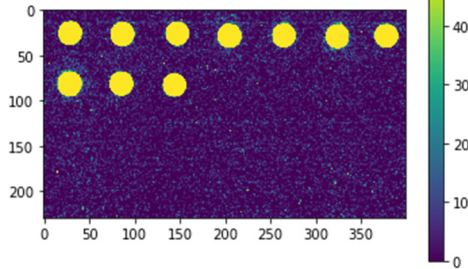


28 fibers

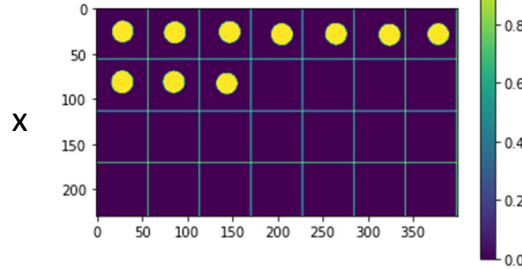
28 LEDs

Image Processing Step by Step

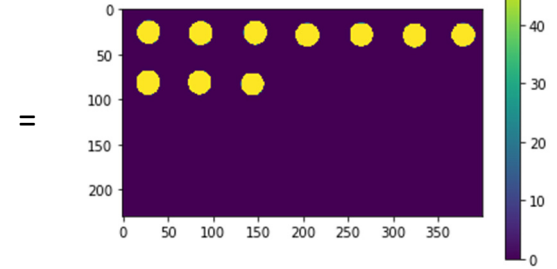
Camera image cut around fibers



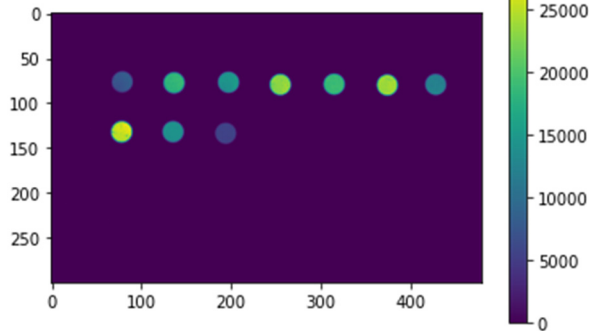
Create Bit Mask using LEDs



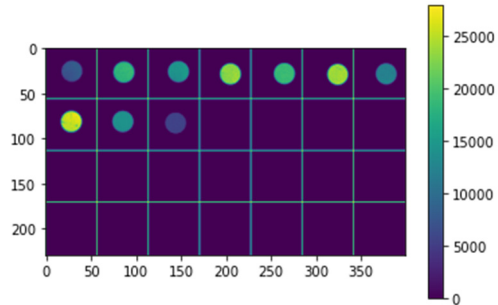
Fiber areas determined



From full camera image

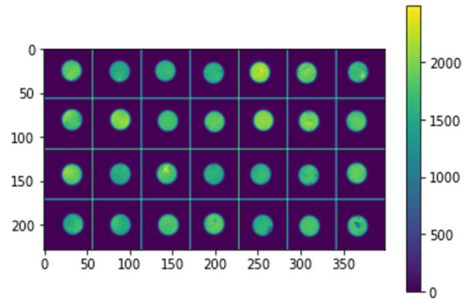


To loss values from each fiber

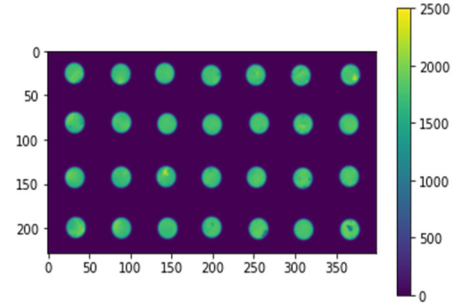


- Image divided into equal ROIs around fibers
- ROIs summed for tracking loss intensity

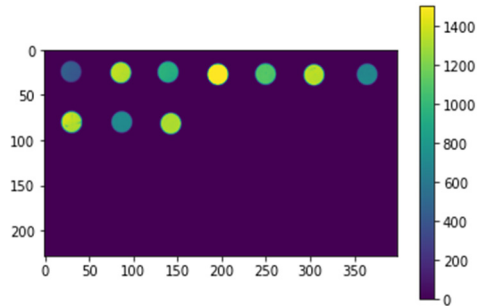
Calibration



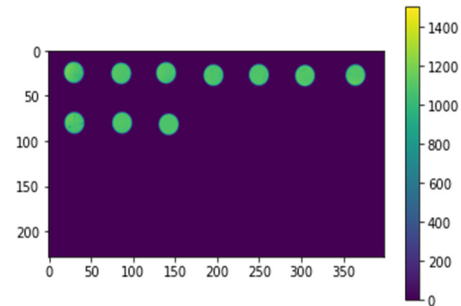
All LEDs ON (with calibration fiber)



LEDs normalized to average LED intensity



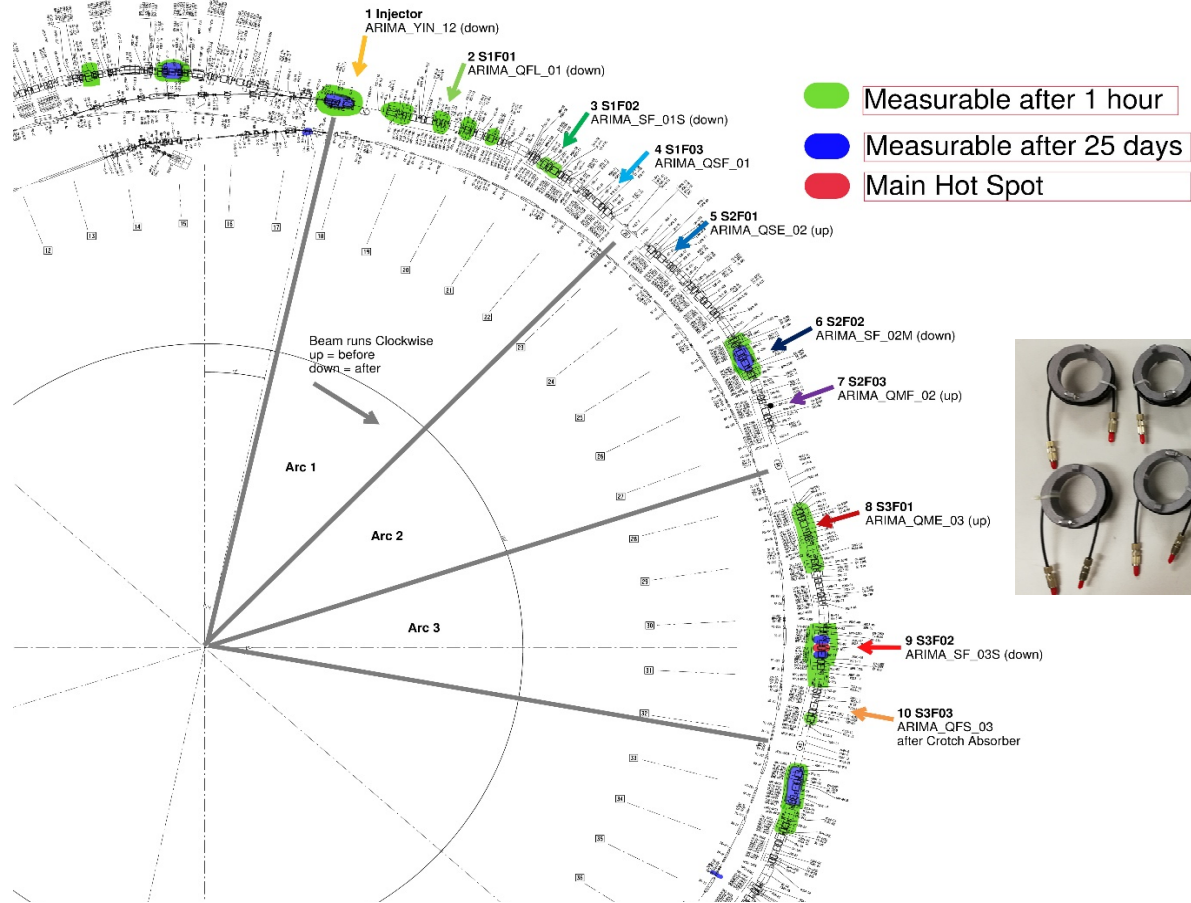
LED through (POF + Scintillator) fiber



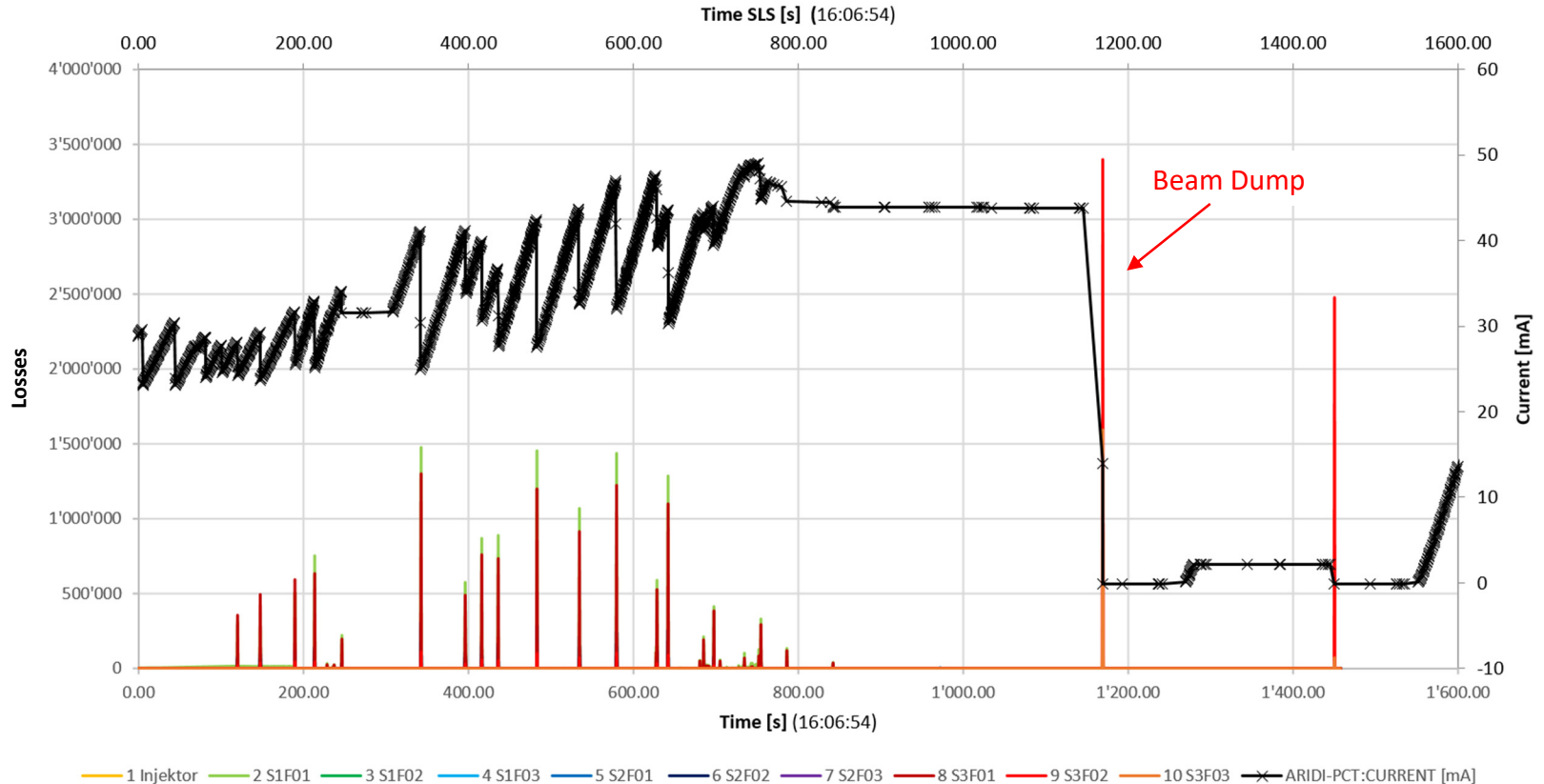
Fiber responses normalized to average fiber intensity

Ready for Beam

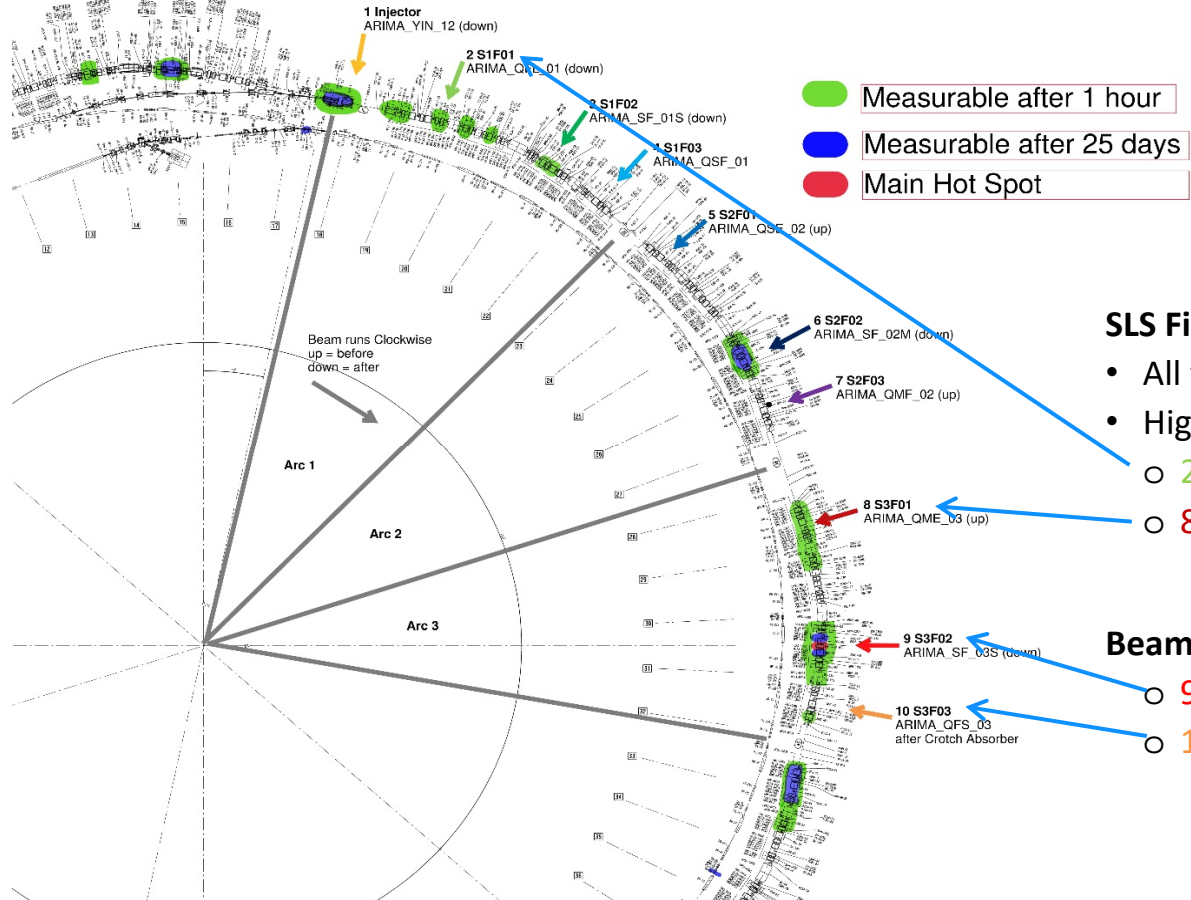
Position of the scintillator coils in SLS



Problems filling the SLS Storage Ring



Hotspot located



SLS Filling:

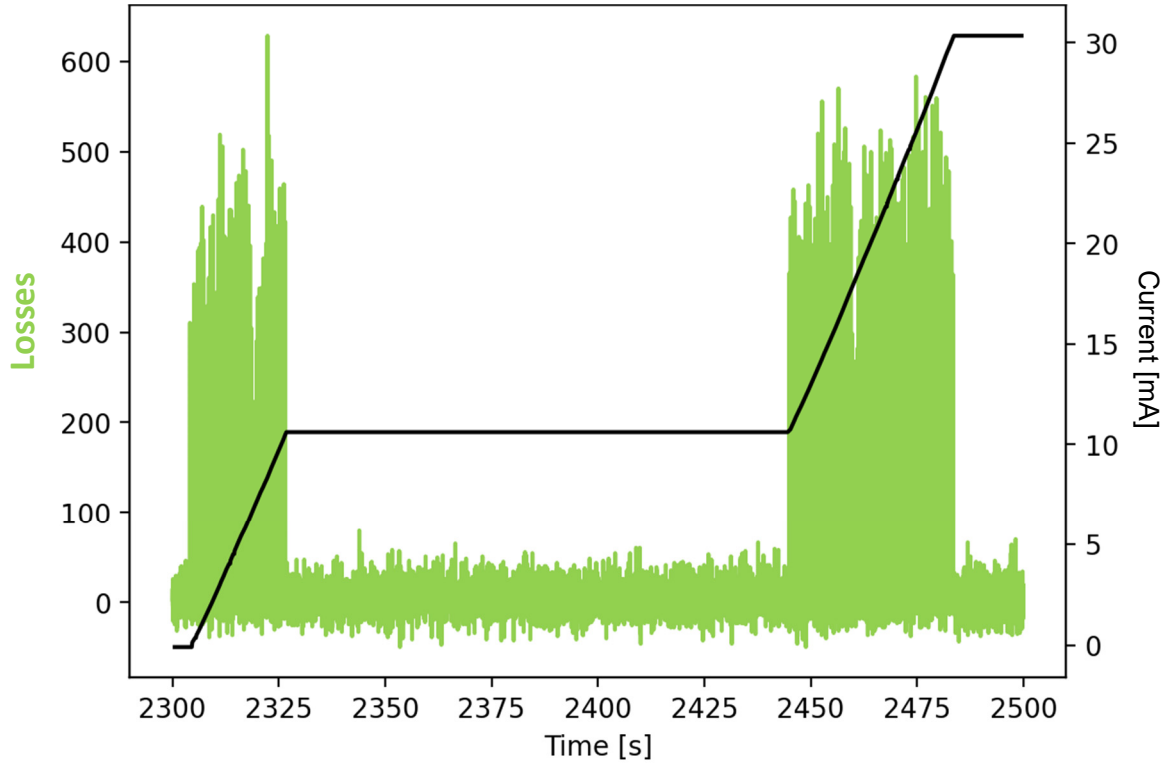
- All fibers detect losses
- Highest Losses seen by

- 2 S1F01
- 8 S3F01

Beam Dump:

- 9 S3F02 → Main Hot Spot
- 10 S3F03

Injection losses on S1Fo1: Filling the SLS



EPICS Integration and GUI

Acquire Bit Mask

run, when Camera connected, but not measuring

acquire new BitMask set Exposure Time: 25um

▲▲▲▲▲ 1 2 0 Threshold
▼▼▼▼▼

current BitMask

2021-07-02_16-21-11_CEST

Bit Mask (sliced and mirrored, right Nr.1 left Nr.7)

Min: 0 Max: 2 Auto: x/y/z: 0 U/s (Mono,caLONG)

Saturation (without Dark and Calibration Factor)

	2	3
1	1805895	
2	1887795	
3	1859130	
4	1871415	
5	1859130	
6	1867320	
7	1826370	
8	1969695	
9	1879605	
10	1773135	
11	0	
12	0	
13	0	
14	0	
15	0	
16	0	

Acquire Dark Image

run, when Camera connected, but not measuring

acquire new Dark

Parameters of current Dark

2021-07-02_16-22-24_CEST

32000 us Exposure Time

sliced Dark Image

Min: 0 Max: Auto: x/y/z: 0 U/s (Mono,caDOUBLE)

DarkA			DarkA with BitMask		
	2	3		2	3
1	989.80		1	125.72	
2	813.29		2	115.29	
3	766.29		3	106.01	
4	810.79		4	115.77	
5	870.22		5	115.59	
6	893.61		6	132.33	
7	951.48		7	123.10	
8	929.68		8	135.09	
9	813.05		9	120.82	
10	690.68		10	80.96	
11	793.76		11	0.00	
12	775.17		12	0.00	
13	837.06		13	0.00	
14	896.27		14	0.00	
15	901.96		15	0.00	
16	805.29		16	0.00	
17	736.19		17	0.00	
18	834.92		18	0.00	
19	801.85		19	0.00	
20	913.42		20	0.00	
21	887.10		21	0.00	
22	1139.25		22	0.00	
23	966.87		23	0.00	
24	862.35		24	0.00	
25	958.77		25	0.00	
26	984.44		26	0.00	
27	1062.15		27	0.00	
28	1022.22		28	0.00	

BLM_GUI.ui

connect Camera
 measure
 LED all

Warning & Alarms

LOSS

1	2
1	5.7
2	-1.5
3	-0.0
4	-1.0
5	-8.8
6	1.8
7	-9.9
8	-9.9
9	-0.6
10	4.5
11	0.0
12	0.0
13	0.0
14	0.0
15	0.0
16	0.0
17	0.0
18	0.0
19	0.0
20	0.0
21	0.0
22	0.0
23	0.0
24	0.0
25	0.0
26	0.0
27	0.0
28	0.0

Camera Image Camera Settings LED Measurement

use BitMask
 subtract Dark
 use Calibration Factor
 save to csv

32000 us Exposure Time

29761 us Measurement Time (for Image Processing)

if Time <= Exposure Time: every Image is analyzed

▲▲▲▲▲ Measurement Delay [sec] (added to the Time)
▼▼▼▼▼

acquire Bit Mask
acquire Dark

measured Losses

Warning & Alarms for Losses

30 sec 5 min 1 h

800
600
400
200
0
-200
-400
-600
-800

10:48:52 10:58:52 11:08:52 11:18:52 11:28:52 11:38:52

ARIDI-BLM01:LOSS1 ARIDI-BLM01:LOSS2
ARIDI-BLM01:LOSS3 ARIDI-BLM01:LOSS4

200
100
0
-50

10:48:56 10:58:56 11:08:56 11:18:56 11:28:56 11:38:56

ARIDI-BLM01:LOSS5 ARIDI-BLM01:LOSS6
ARIDI-BLM01:LOSS7

150
100
50
0
-50

10:49:01 10:59:01 11:09:01 11:19:01 11:29:01 11:39:01

ARIDI-BLM01:LOSS8 ARIDI-BLM01:LOSS9
ARIDI-BLM01:LOSS10

400
300
200
100
0

10:56:56 11:06:56 11:16:56 11:26:56 11:36:56 11:46:56

ARIDI-PCT:CURRENT

- CMOS based BLM is good for surveillance of slow losses
- Can also be used in the Booster-to-Ring transfer line
- Not for turn-by-turn loss detection
- System is inexpensive ($\sim 3250\text{CHF}/\text{box} = \sim 117\text{CHF}/\text{channel}$, fibers included)
- To be tested in SLS at the Undulator exit for sensitivity and further improvement
- Cover the entire SLS with these loss monitors for further exploration

Many, many thanks to

- Jonas Kallestrup
- Anik Stark
- Markus Baldinger
- Renata Krempaska
- Michael Boege
- Chris Gough

