Data acquisition system of TeraHz detectors & Optical powered Beam Loss Monitors

N.Smale for the accelerator team, IPQ, IMS and IPE

Institute for Synchrotron Radiation

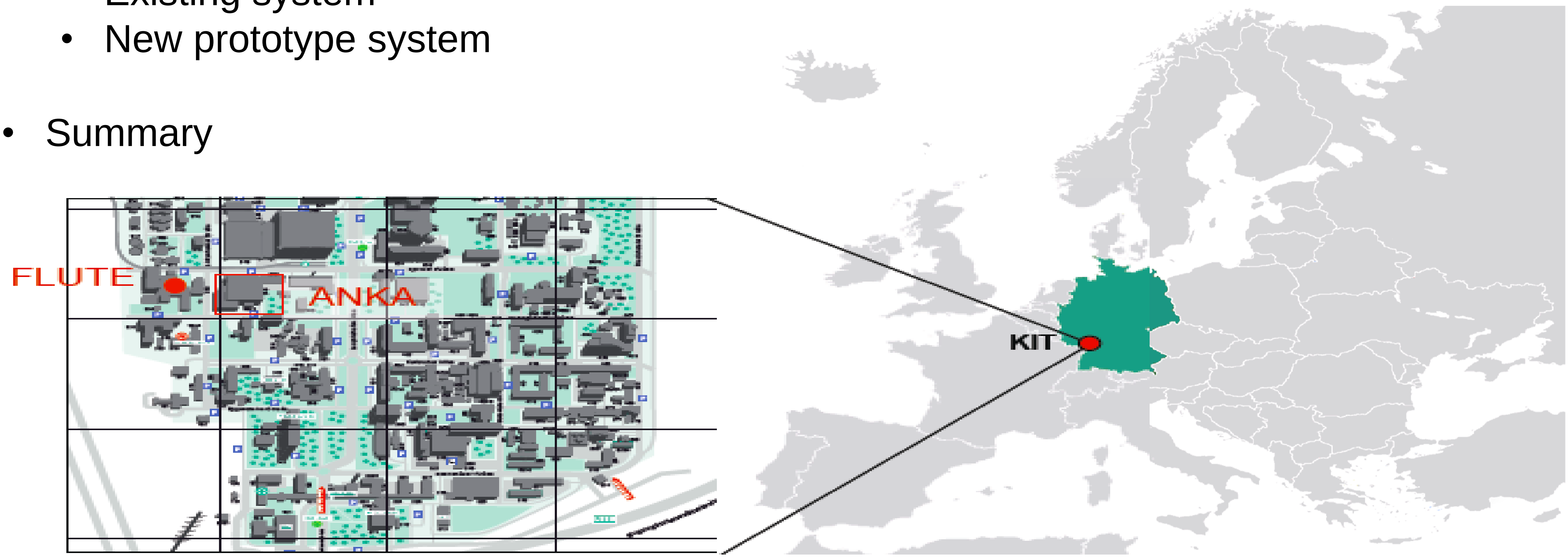
Outline

- Introduction to KIT
  - Very brief overview of ANKA and FLUTE Diagnostics

- DAQ of THz detectors
  - Detectors at ANKA and in-house DAQ unit

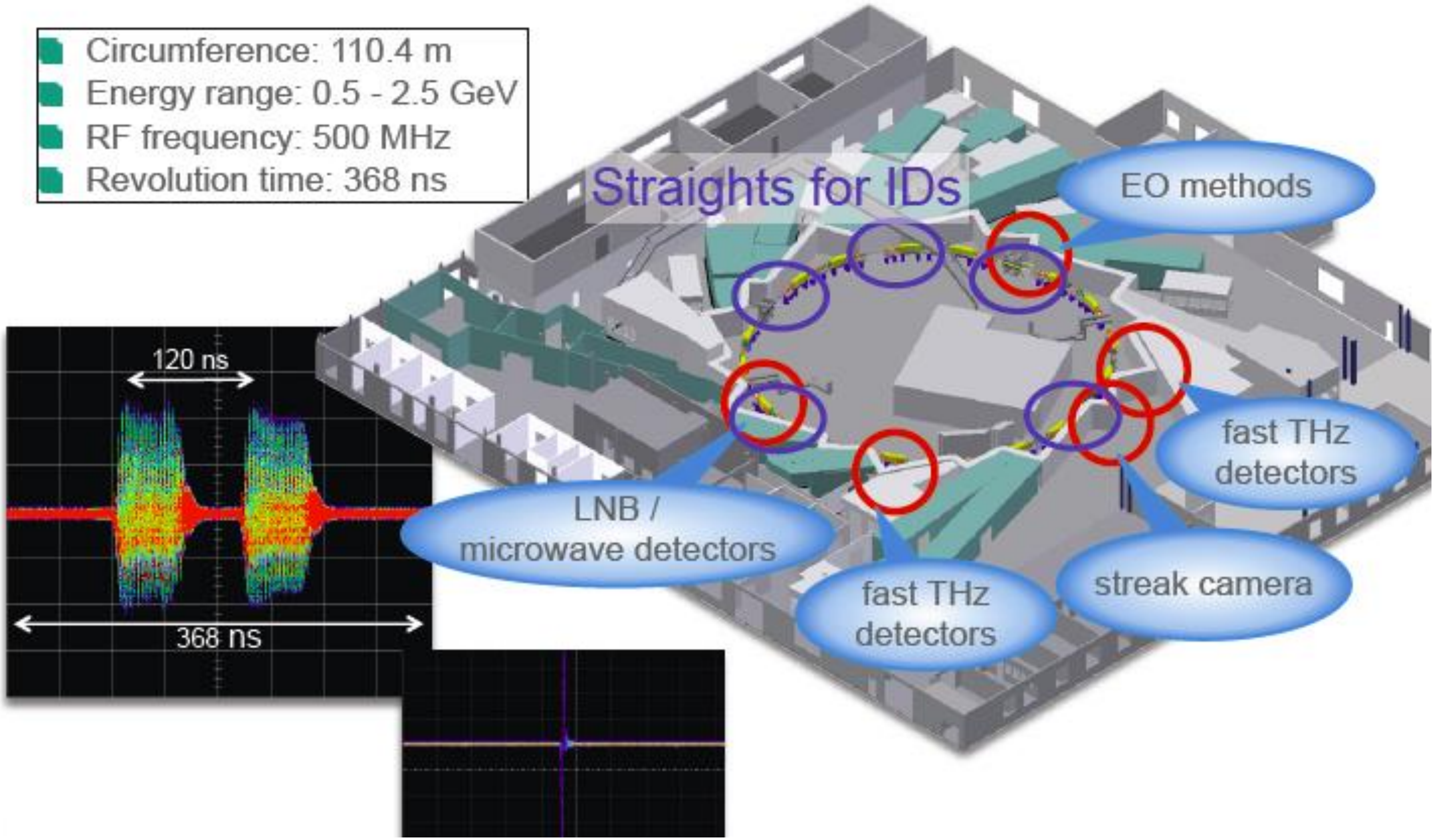
- Optial powered BLM
  - Motivation for a power over optic Beam Loss
  - Existing system
  - New prototype system

- Summary



The ANKA synchrotron radiation facility

- Circumference: 110.4 m
- Energy range: 0.5 - 2.5 GeV
- RF frequency: 500 MHz
- Revolution time: 368 ns



DAQ of THz detectors

The development of both THz detectors and DAQ systems is a collaboration of KIT institutes

KIT (Karlsruhe Institute of Technology, Helmholtz)

IPE: M. Caselle, S. Cilingaryan, A. Kopmann, M. Schleicher, M. Vogelgesang, M. Weber

IMS: J. Raasch, S. Wuensch, M. Siegel

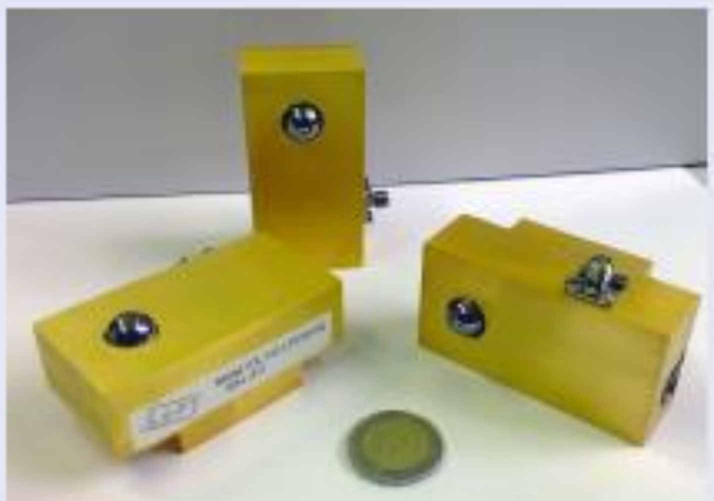
LAS – ANKA: M. Brosi, V. Judin, A.-S. Müller, N. J. Smale, J. Steinmann, N. Hiller, V. Judin

Slides courtesy of Michele Caselle IPE and Miriam Brosi.

THz detectors

Advanced Compound Semiconductor Technologies GmbH

Quasi-optical broadband detector



room temperature

response time <200ps

50 GHz up to 1 THz

based on schottky diode

ACST (acst.de)

DLR Berlin

A. D. Semenov et al., IRMMW-THz 2009

Hot Electron Bolometer (NbN)

cryogenic (LHe)

response time <165ps

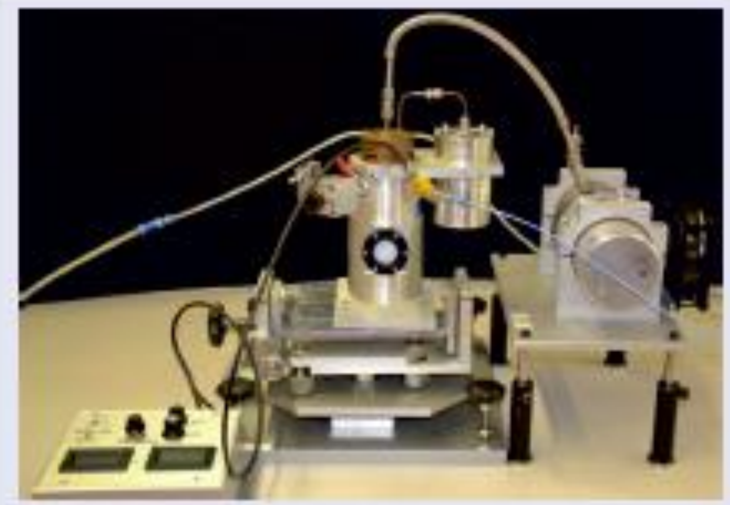
200 GHz up to 4 THz

high sensitivity

KIT Karlsruhe

P. Thoma et al., Appl. Phys. Lett. 101 (2012) 142601

YBCO detector



cryogenic (LN2)

response time <15ps

30 GHz up to 2.5 THz

(KIT - IMS)

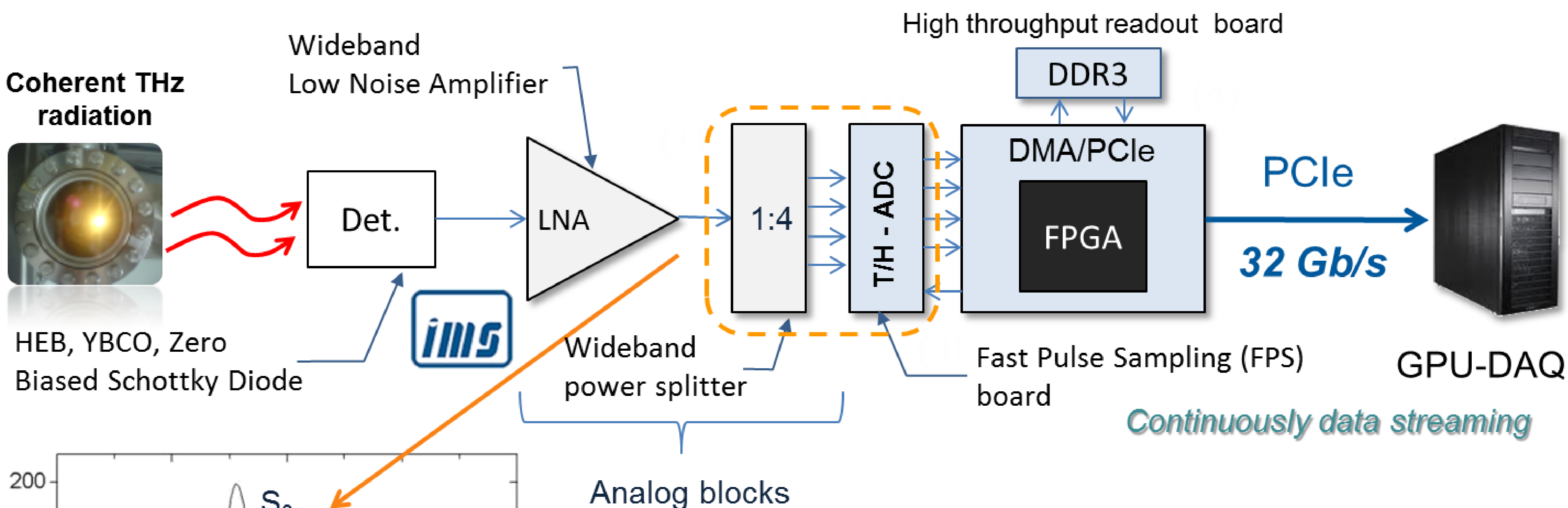
J. Raasch [1]

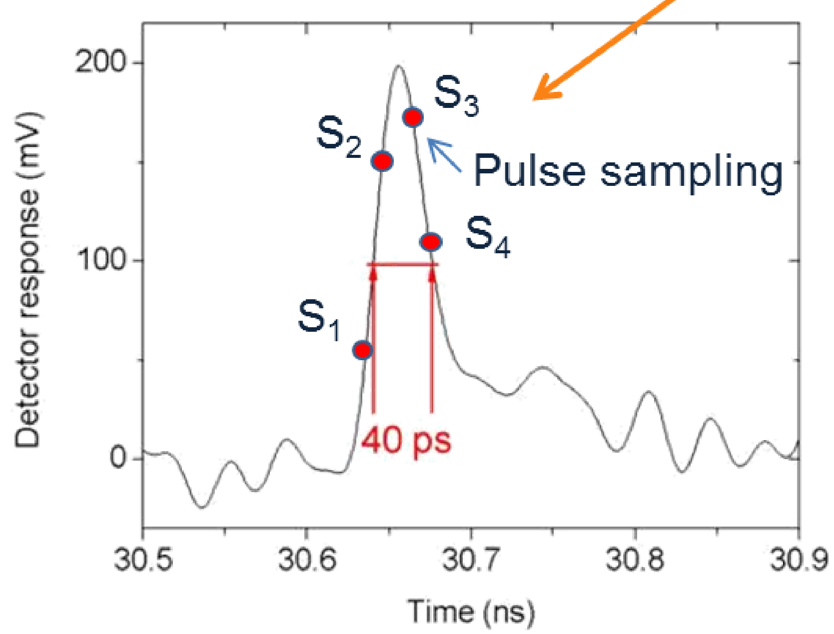
- Resolve intensity of each bunch (minimal bunch spacing 2 ns)

[1] Thoma, P.; Raasch, J.; et al.; IEEE Trans. Appl. Supercond., vol.23, no.3, pp.2400206,2400206, June 2013

CSR – Readout system and requirements

- *Incoming pulse @ 500MHz (ANKA RF system)*
- Turn-to-turn & bunch-to-bunch CRS measurements (minutes/hours)
- *Wideband DC- 50/60 GHz*



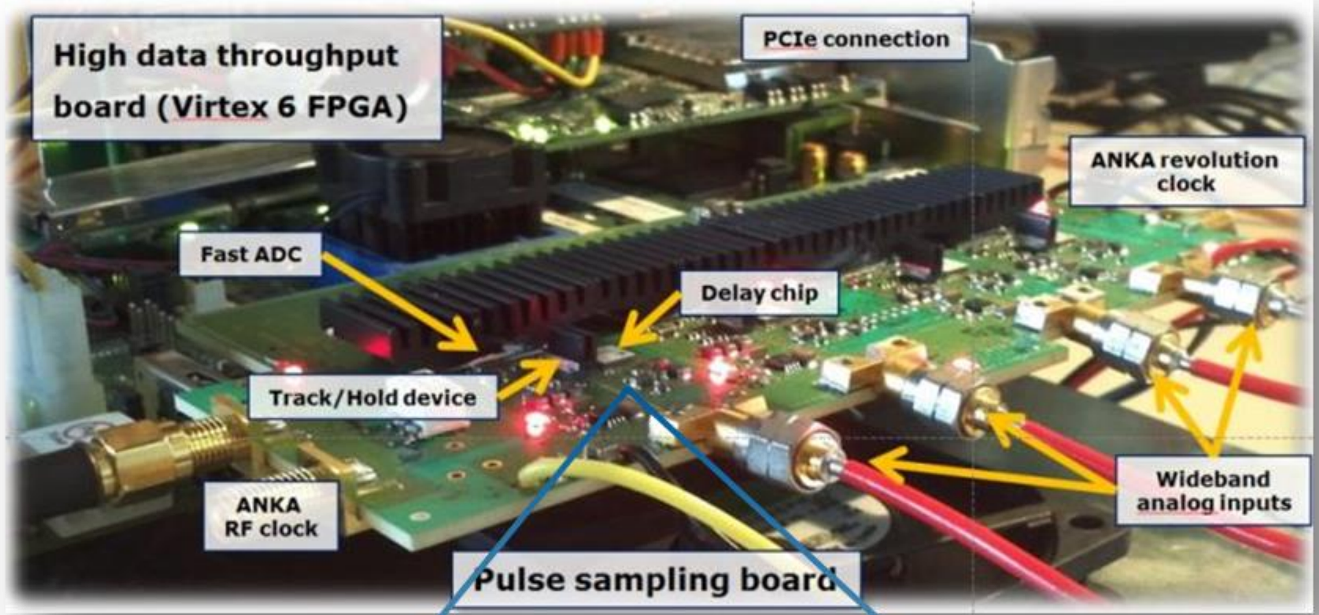


1. Sampling each incoming pulse with 4 samples (min. sampling time of 3 psec)

2. Data transfer to high-end GPU (Graphics Processing Units)

3. Pulse reconstruction and peak amplitude + peak time measurements (GPU)

Fast Pulse Sampling board (FPS board)



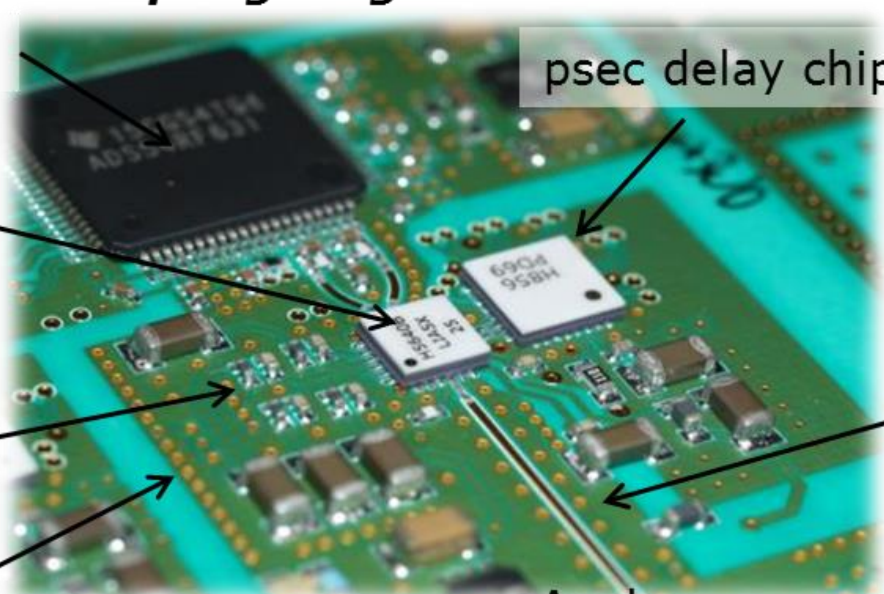
Performance:

✓ Minimum sampling time: 3 psec → >300GS/s

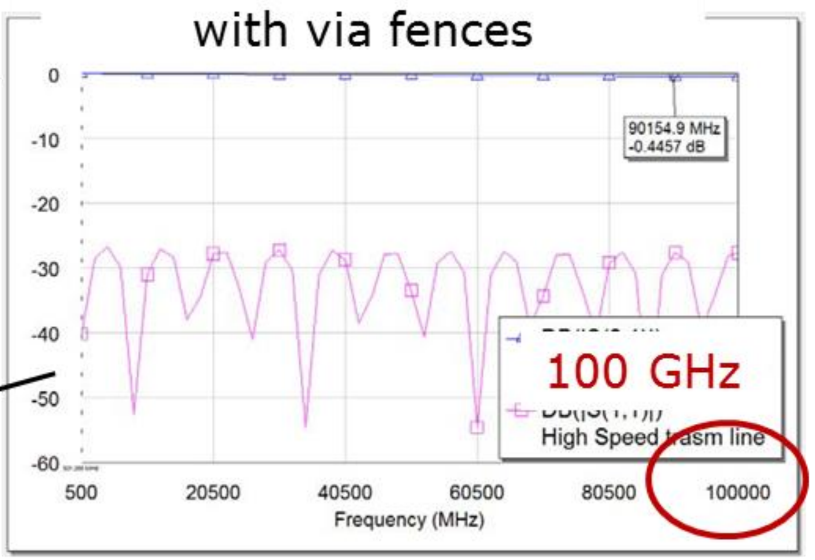
✓ 12 bit ADC resolution

✓ Configurable for the readout of up to 4 ultra-fast detectors in parallel

Sampling stage

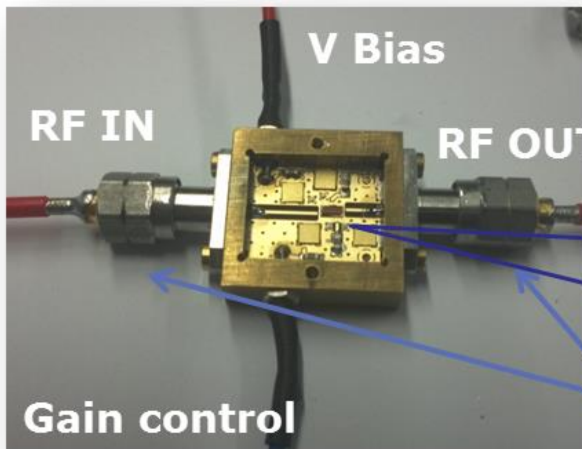


Wideband CPW trans. line with via fences

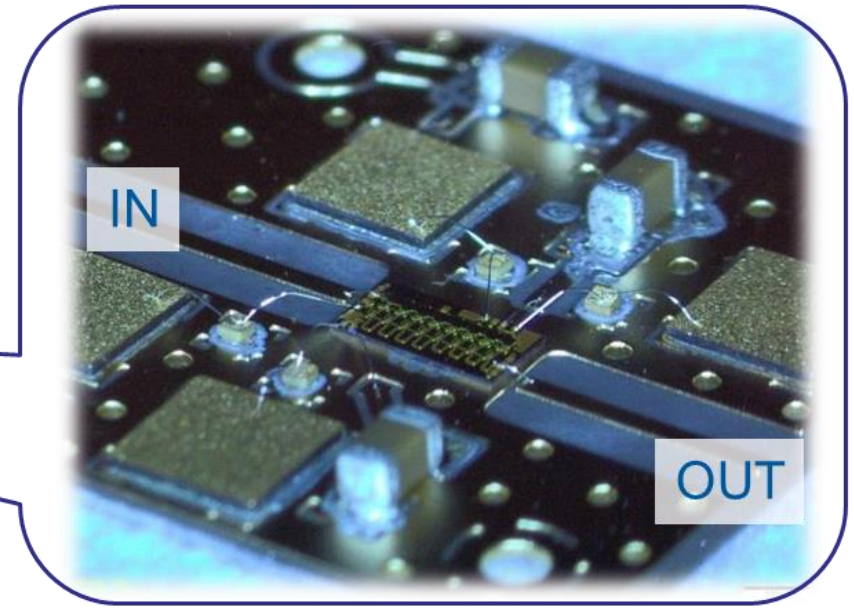


Wideband LNA (Low Noise Amplifier) & power splitter

Wideband LNA

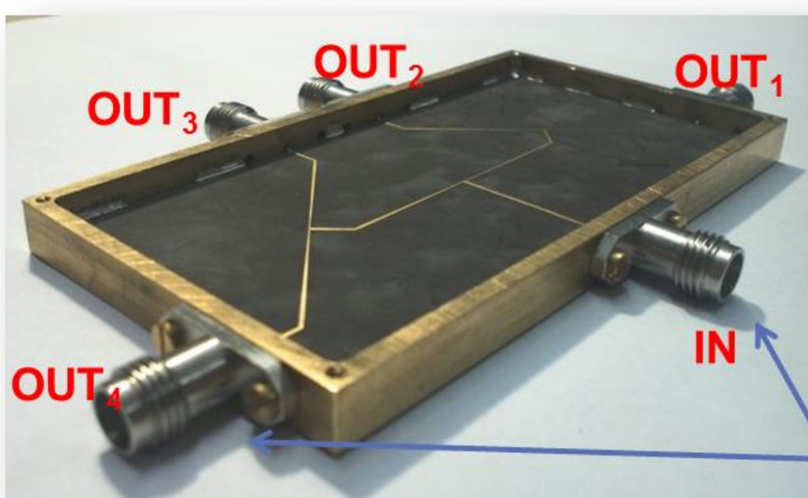


High-freq.
V-connectors

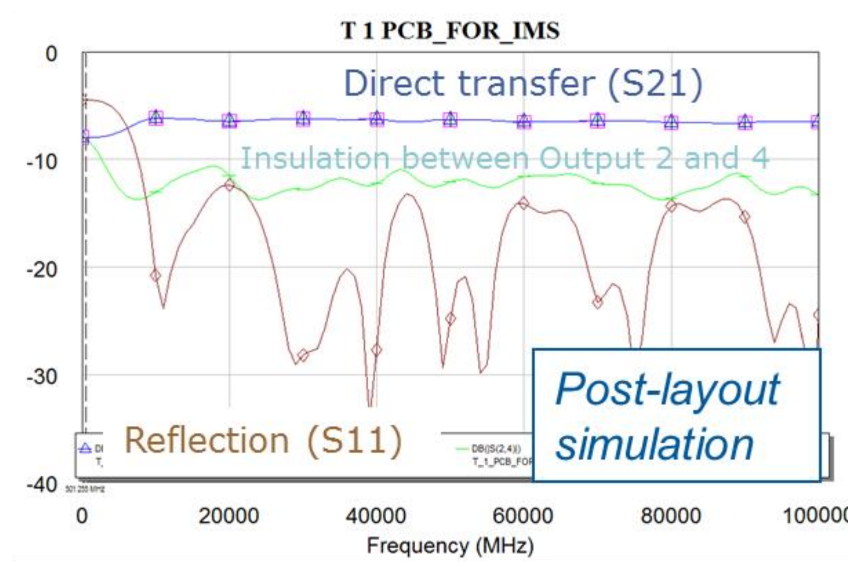


MCM-D technology, new PCB materials for microwave/RF design, MMIC based on GaAs technology. **Flat gain: 12 dB, from DC -48 GHz**

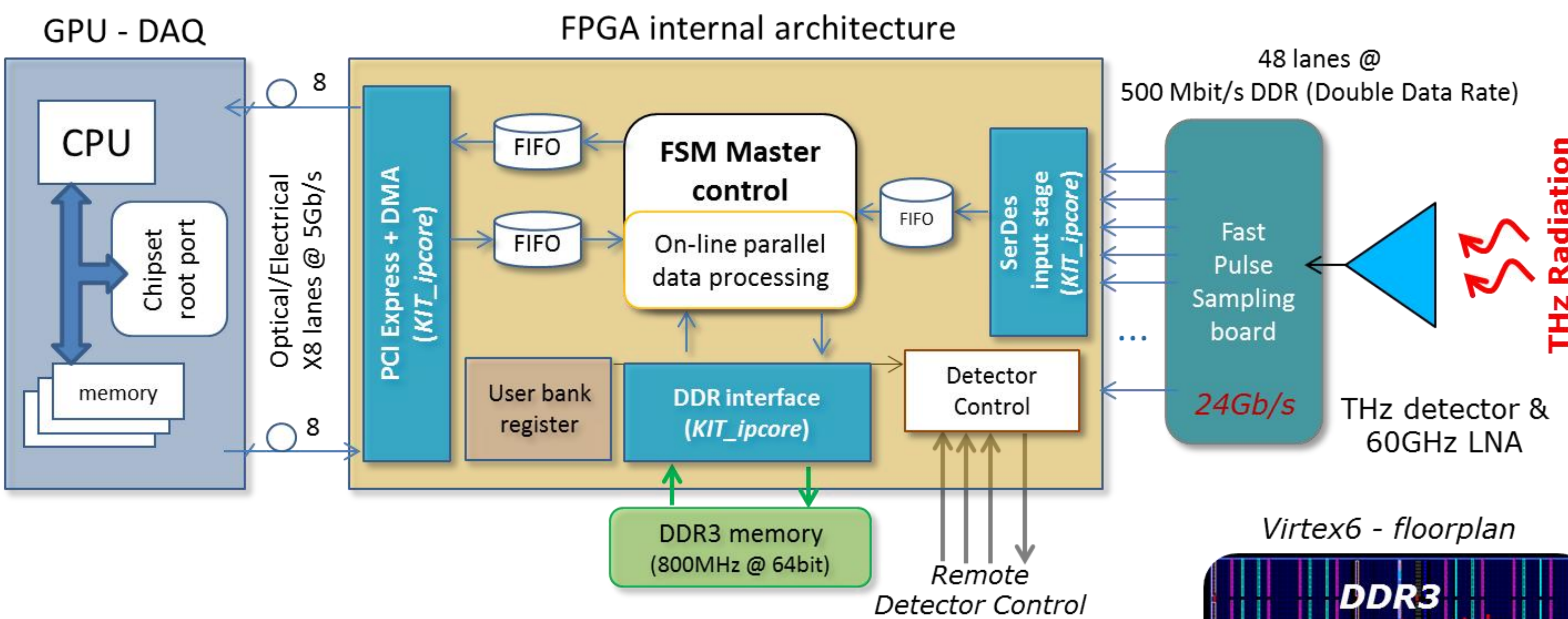
Wideband power splitter



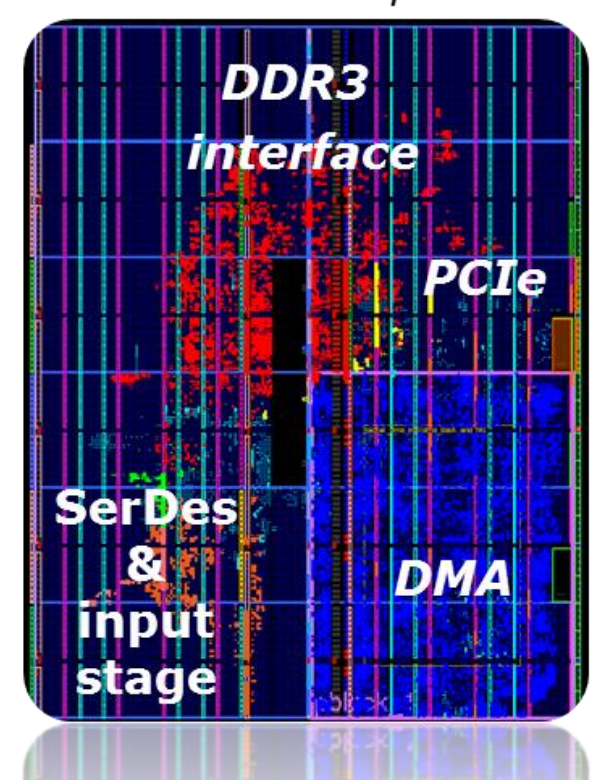
High-freq.
V-connectors



High-throughput FPGA architecture

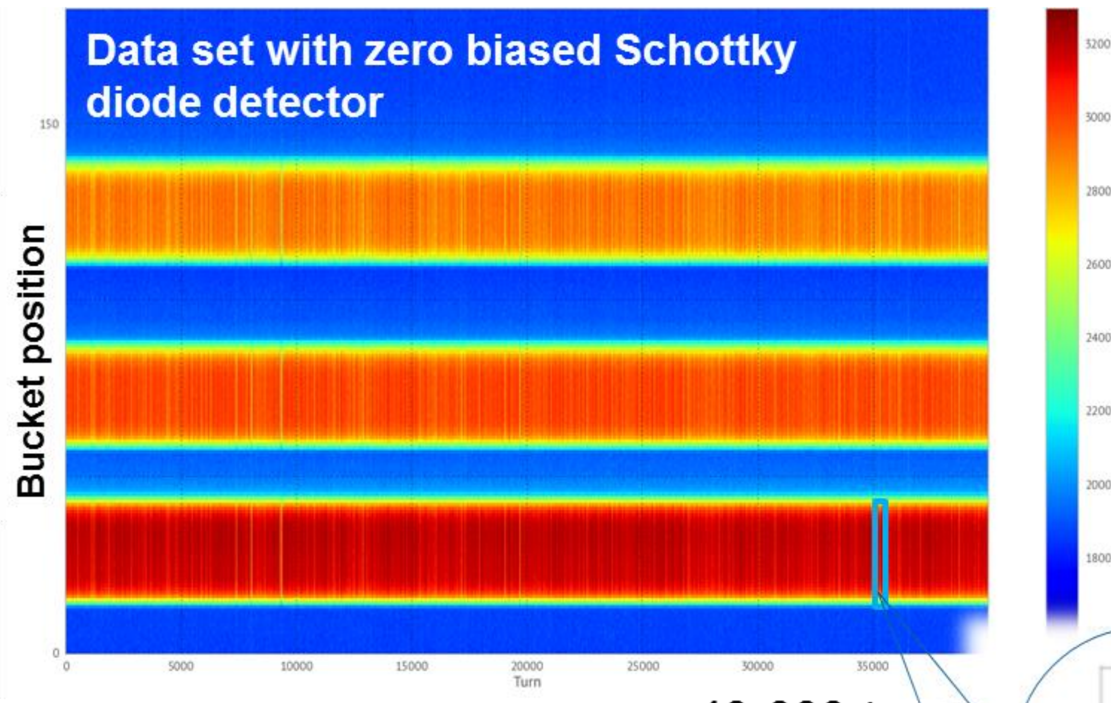


Virtex6 - floorplan



- ✓ PCIe-Bus Master DMA readout architecture operating @ 32Gb/s [with 8 lanes PCIe @ Gen2] → DMA detals
- ✓ Multi-port high speed DDR3 interface @ 51Gb/s
- ✓ PCI Express/DMA Linux 32-64 bits driver
- ✓ Integration in the parallel GPU computing framework

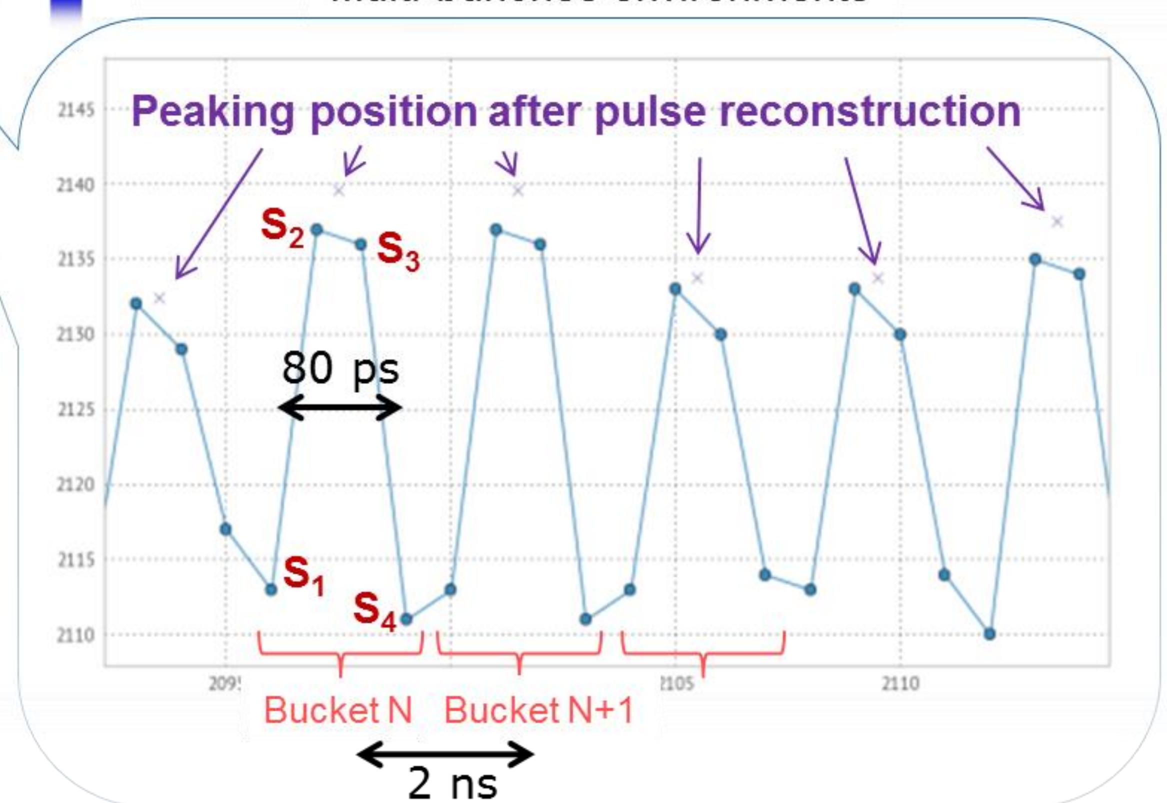
Real-time GPU data analysis



Turn-to-turn & bunch-to-bunch - long observation time.

- Graphic User Interface
- Board control & calibration routines

Multi-bunches environments



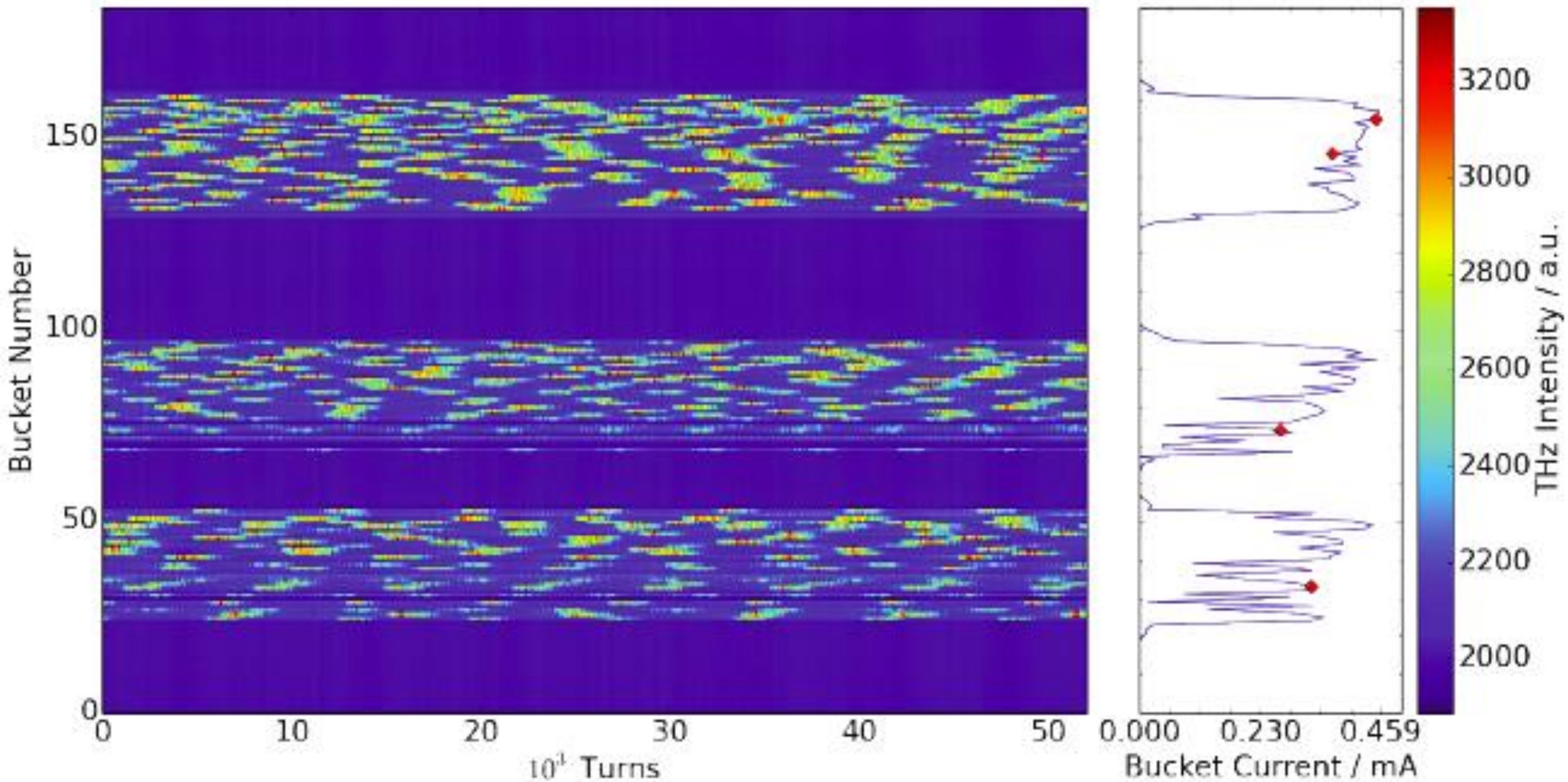
Real-time GPUs data analysis

- Fast pulse reconstruction with "Gaussian shape" by GPU
- Fast real-time FFT both amplitude & time oscillations
- Histograms (buckets, turn, etc..)
- ..

Fast-Readout Results

Courtesy of M. Brosi.

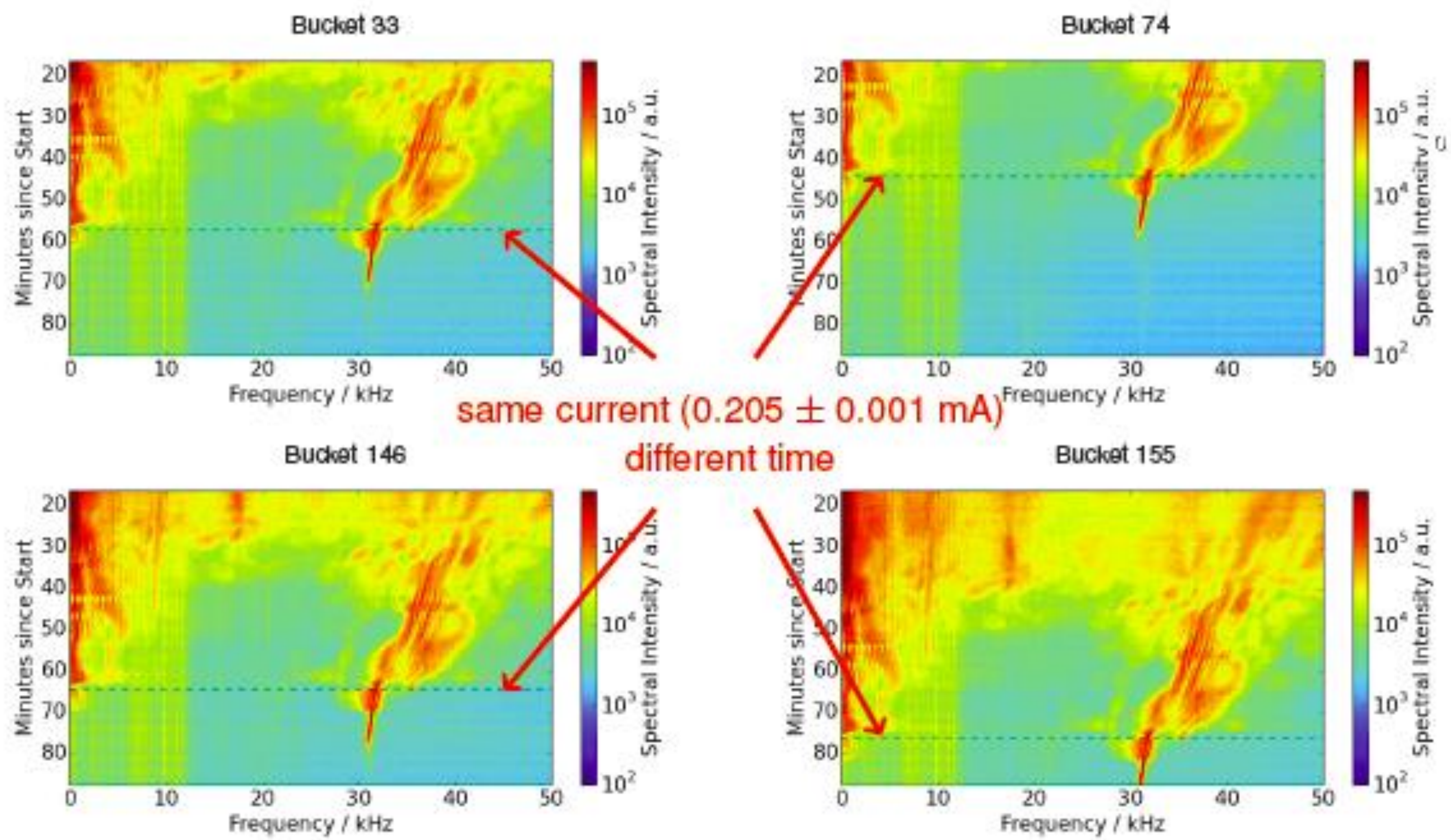
Simultaneous monitored intensity of all buckets over turns detected with Schottky diode and DAQ board.

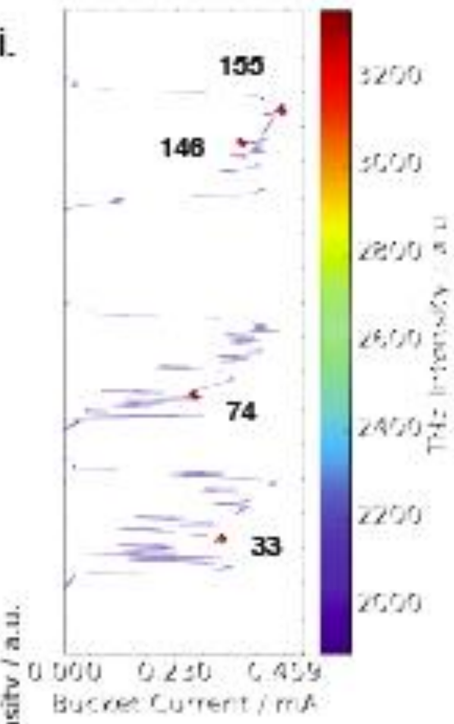


Courtesy of M. Brosi.

FFT of time domain signals
➜ spectrograms for different bunches

Do all bunches show a similar behavior for same bunch currents?





Optical powered Beam Loss Monitors

The development of Optical powered Beam Loss Monitors is a collaboration of KIT institutes

KIT (Karlsruhe Institute of Technology, Helmholtz)

LAS – ANKA: A.-S. Müller, N. J. Smale, E. Hertle

IPQ: K Worms, J Maurer, C Klamouris, F Wegh

IPE: M Balzer, M. Weber

PILOT STUDY

Optical powered Beam Loss Monitors

Motivation

The KIT institute IPQ had successfully developed a power-over optic industrial solution for wind turbine sensors. They then had a small start-up fund to look for innovative ideas using this technology.

The well known Bergoz BLM was in the right power range and the ANKA Bergoz BLM system was in need of renovation.

The Goal

- Very compact form size to allow many more detection points.
- A BLM that could act as a detector for low hits and a BLM at high hits.
- To give turn-by-turn counts, angular information and time of event.
- A system to indicate the magnitude of the single turn loss.
- A system that was EMC robust.

Optical powered Beam Loss Monitors

Requirements

All of the old reasons regarding beam safety, which can be said to be fast losses:

- In linear accelerators to achieve a high transfer efficiency
- In storage rings to achieve a high lifetime and injection efficiency
- In accelerators which use superconducting magnets to avoid quenching
- In all accelerators to limit the radiation damage to material
- In all accelerators to limit the radiation exposure of the personnel

The power over optic BLM/detector could offer further advantages.

Miniature device can offer more coverage. Can make a 3D detector at several points. Relevant aspects are the location of loss as well as the time frame, amount of losses and their direction.

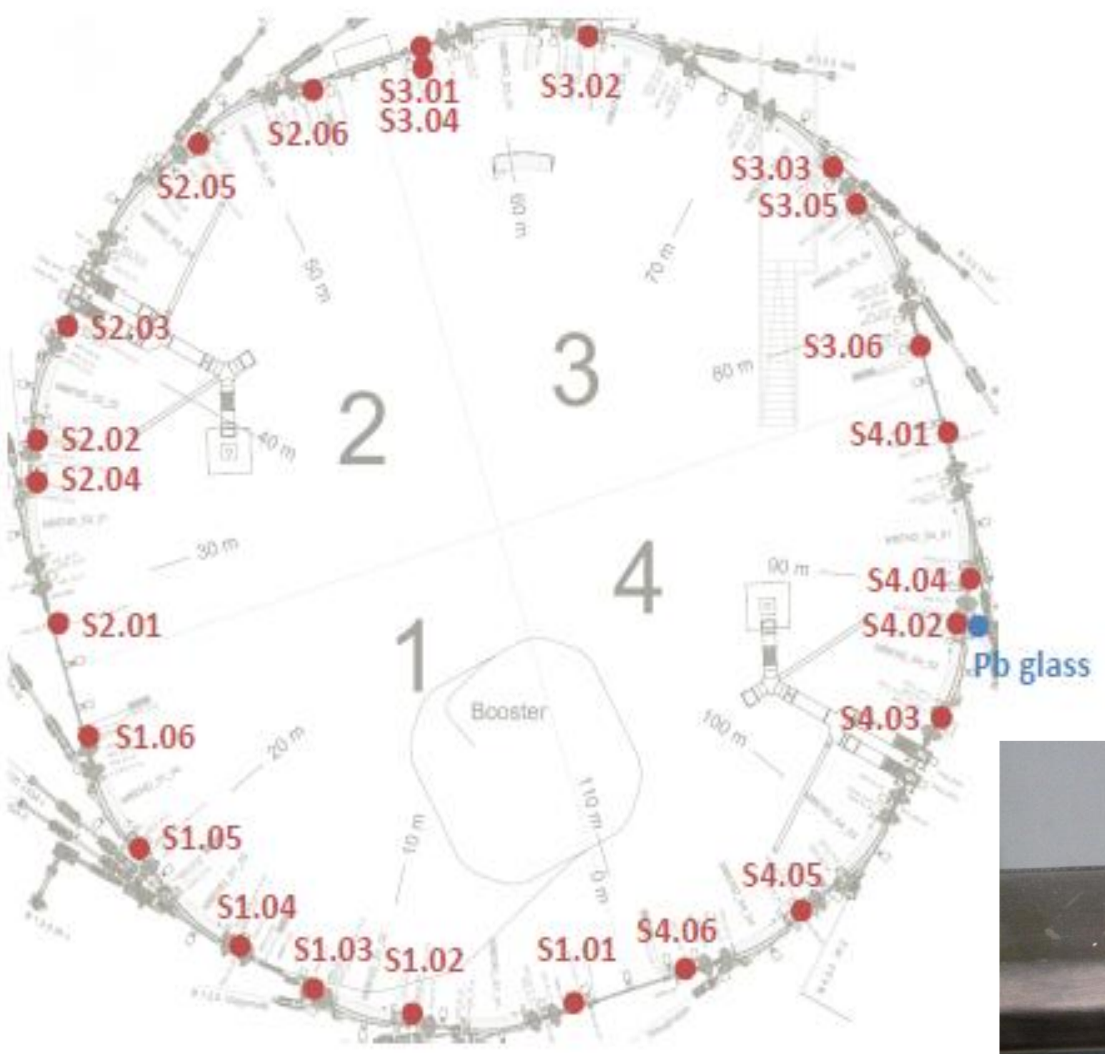
Injection losses would be interesting. Grabbing the loss turn by turn will help in understanding the cause of the loss.

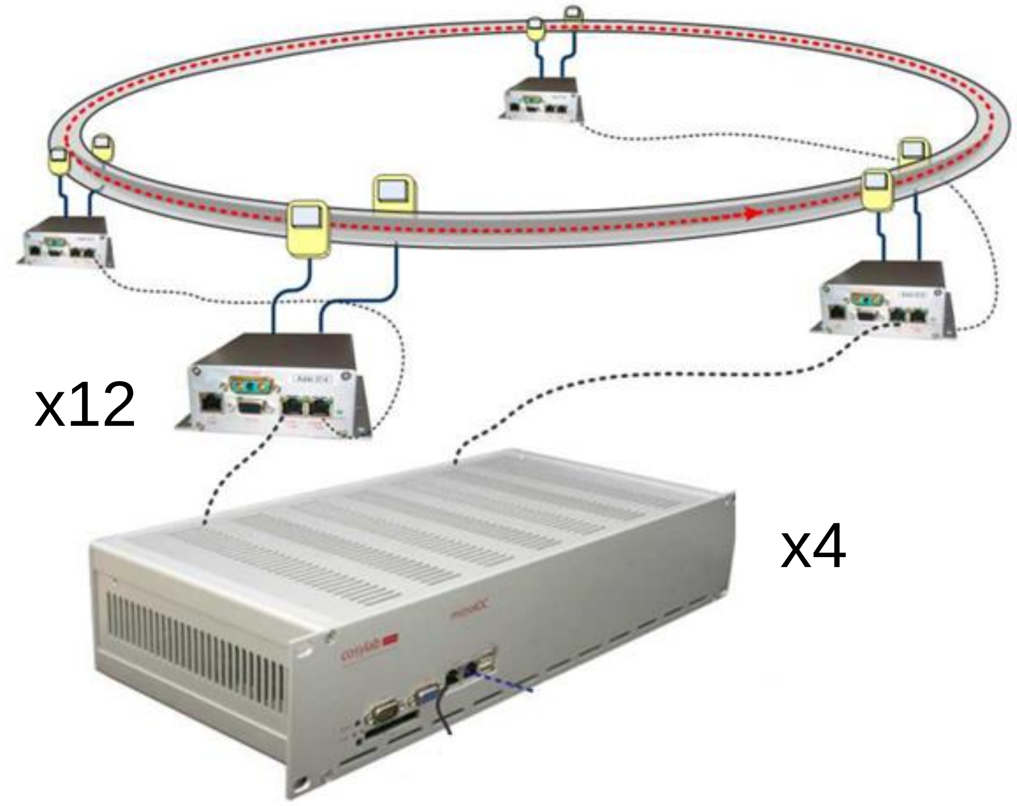
No longer a binary system but an analogue system that will give magnitude information.

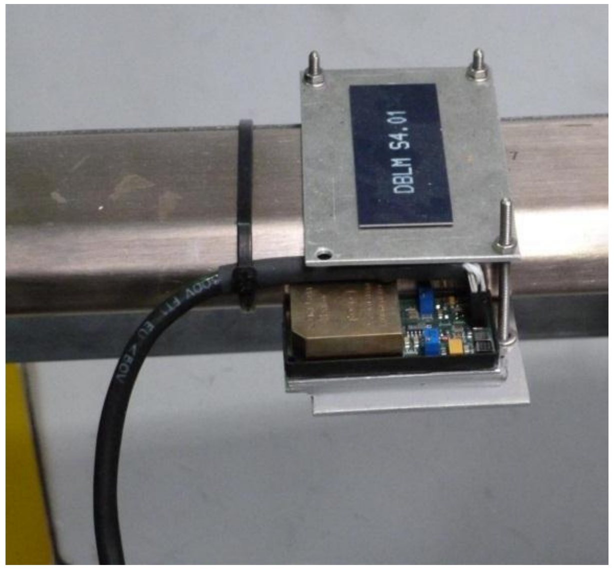
Example of something to capture:

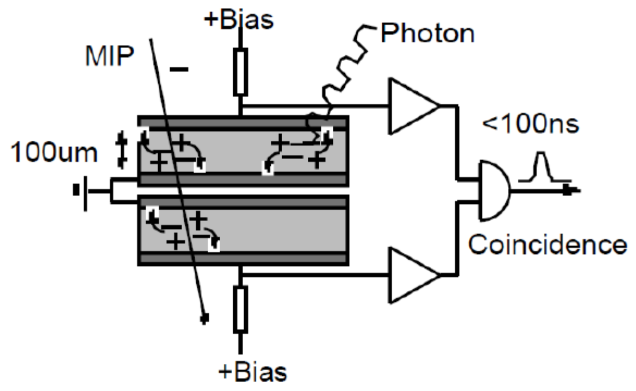
A trip on the RF system, for example, leads to a very fast beam loss due to a lack of RF voltage. The electrons permanently lose 0.1% of their energy per turn and are therefore lost, at the most, after about 100 turns or 36 µs.

Existing system suffers from low resolution (24 points), large form size, 1 second readout, binary and 1 second integral.









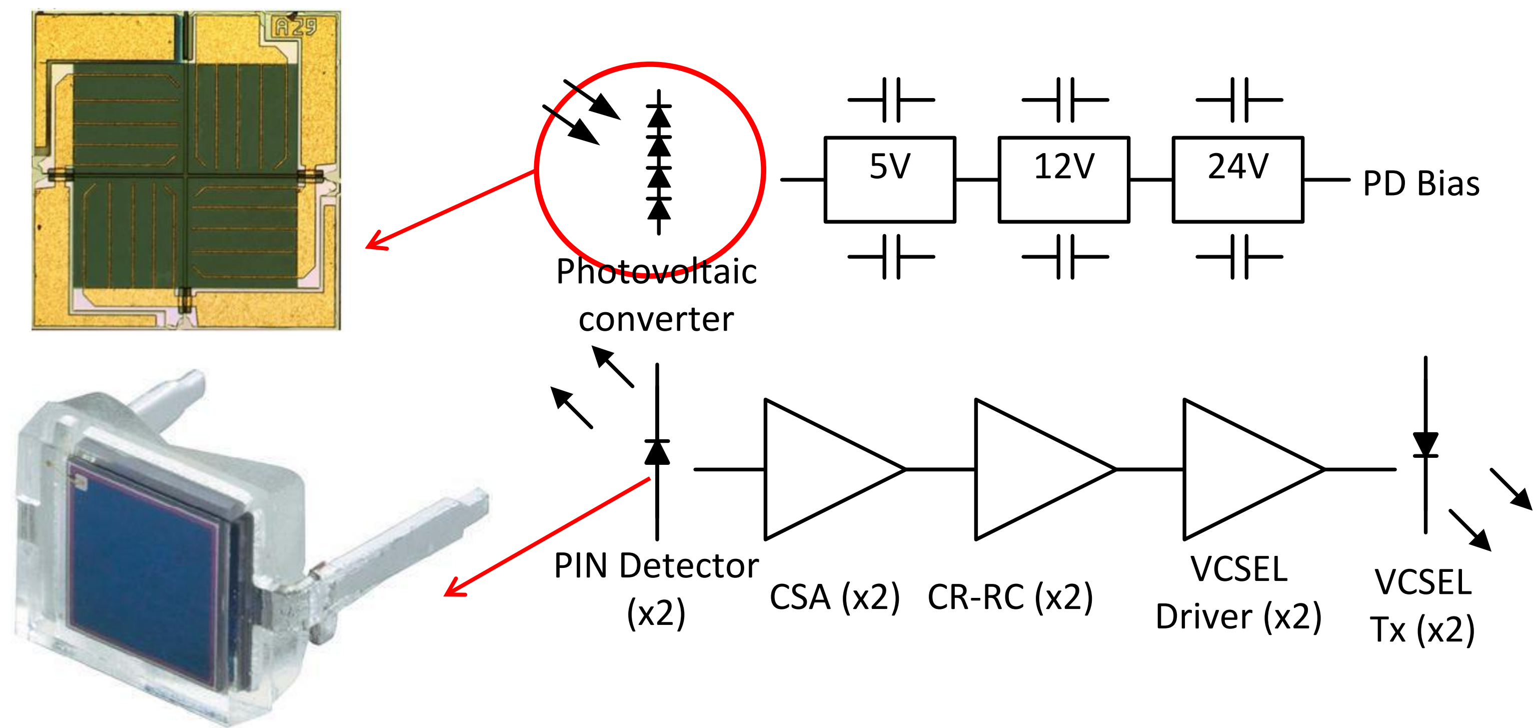
x24 (detector length = 7cm)

New system, turn-by-turn measurements, analogue readout, small form size, possibility to have more detector points and more 3D information.

All lasers are in one small box located outside of the SR. A fibre bundle distributes power to multiple detectors.

Fibre bundle

Laser source FPGA processing	Power converter Diode detector



BPW34BS 7.45mm2

Detector: P-I-N Photodiode made from Si, 300um width

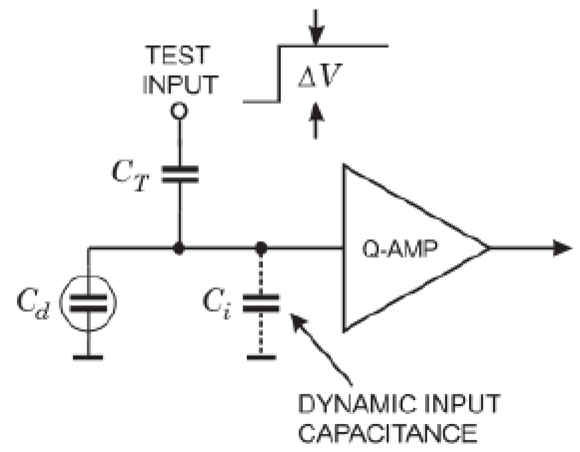
A single lost electron will produce 11k electrons due to ionisation.

Frontend amp

Karlsruhe Institute of Technology

The Bergoz system uses a trans-impedance amp for a frontend; which is suitable for a binary system.

The new system uses the standard charge-sensitive amplifier which is pulse shaped to give indication of the magnitude of loss.



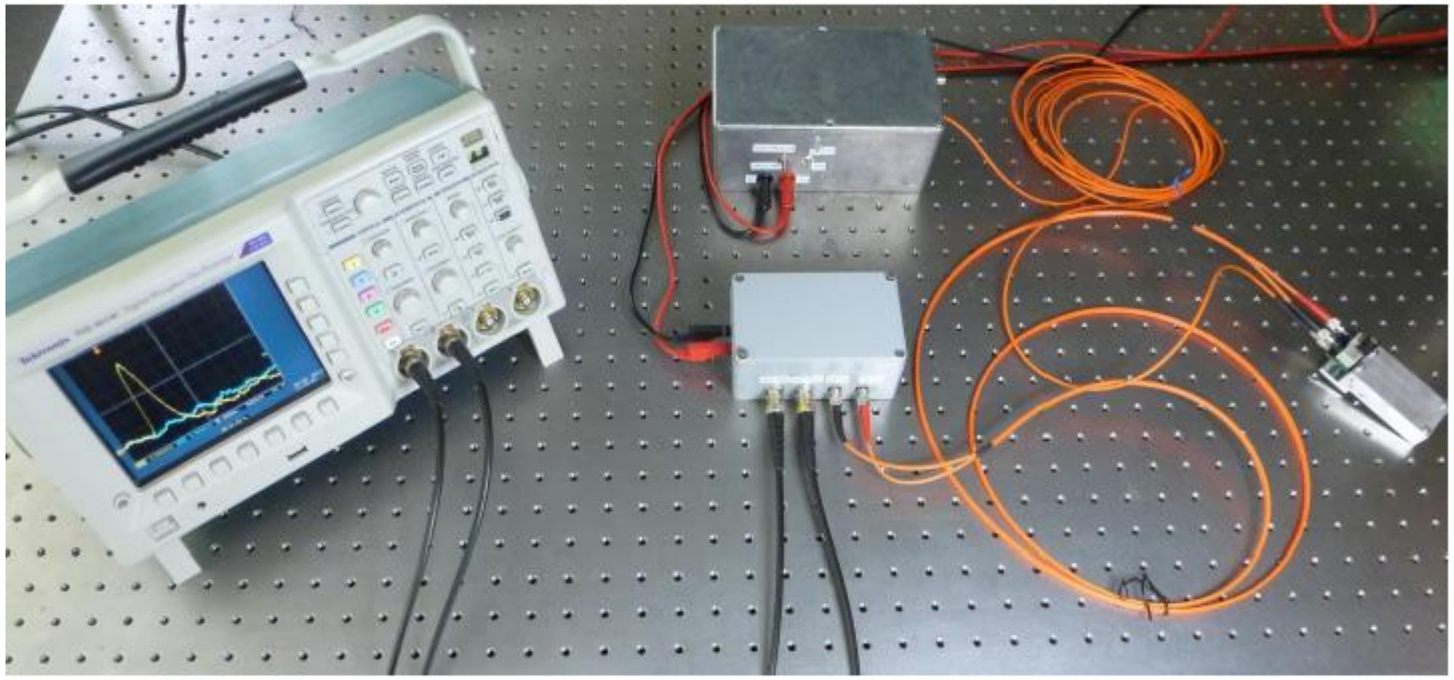
$$Q_T = \frac{C_T}{1+\frac{C_T}{C_i+C_d}} \cdot \Delta V \approx C_T\left(1-\frac{C_T}{C_i+C_d}\right)\Delta V$$

Spieler Semiconductor Detector Systems

2mV @ C_T=1pF provide charge of 11k electrons

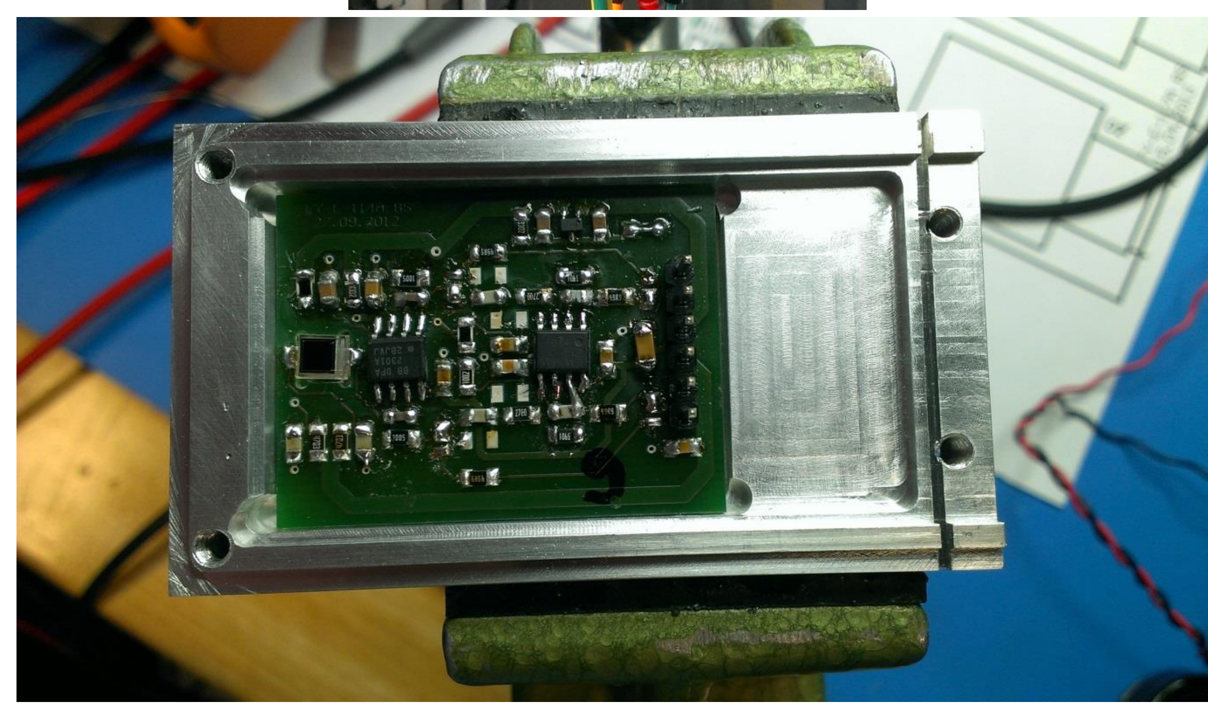
For each detector there are two diodes for coincidence detection. However, raw data from each diode is read out to a remote central station over optic. Here the analogue data is processed to determine coincidence, time and magnitude.

The power over optic BLM/detector Prototype



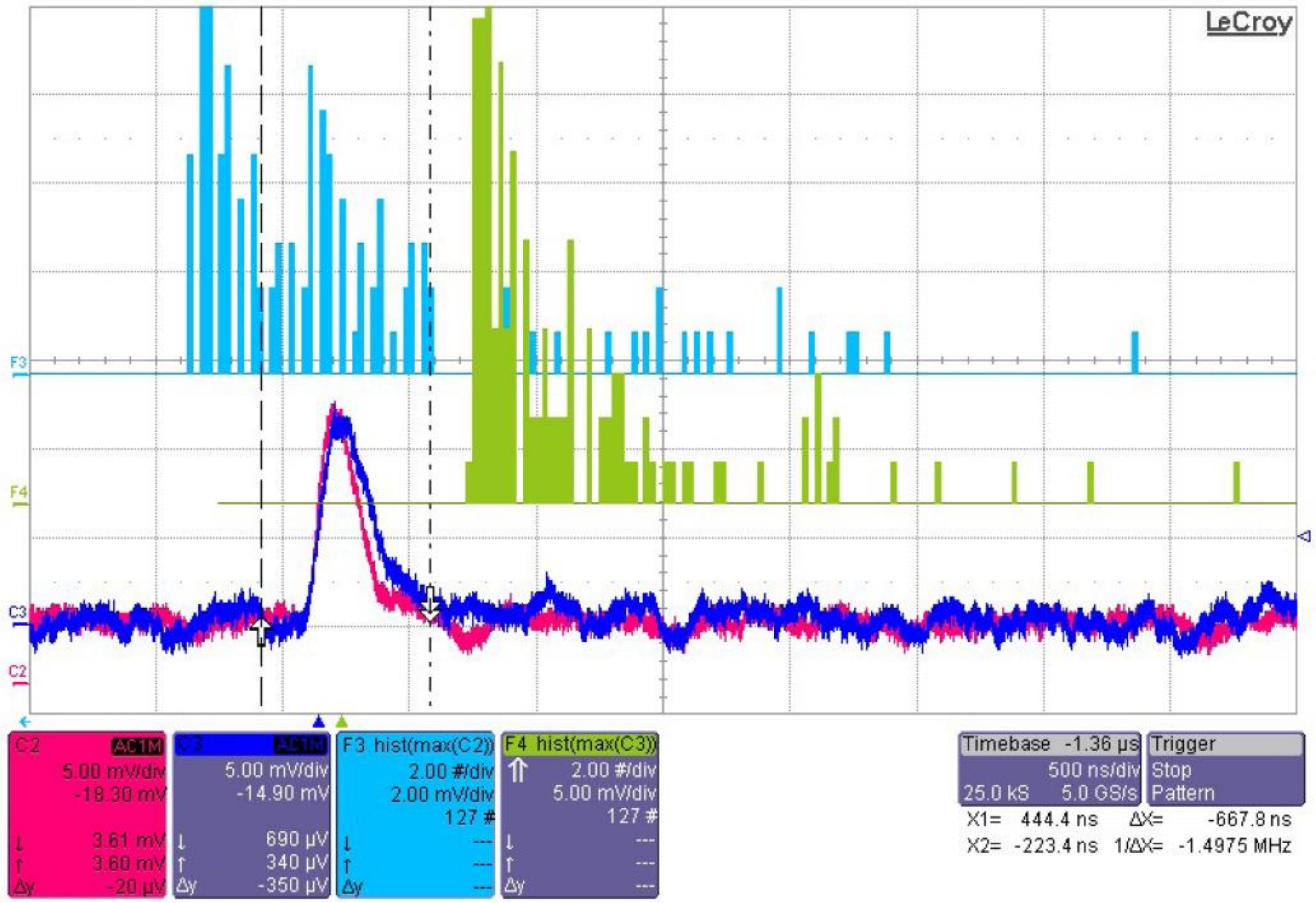
Power budget for one fibre is 500mW
Prototype BLM power 140mW
Tests were done with a BPW34BS diode 7.5mm2,

CSA ASIC chip maybe 10mW/ch



First SR results, just dipping the toe in the water.

Machine parameter: 124mA, 2.5GeV and 20 hours life time.



Scope triggered for coincedence. Pulse shape looks good, Ch1 =9mV/MIP, Ch2 = 6mV/MIP for mean over 1 hour. Coincedence hits were less than 1/ per minute, which is reasonable and compares to the existing Bergoz system.

First SR results, just dipping the toe in the water.

The procedure is to move the scraper in and then take samples for 2 mins

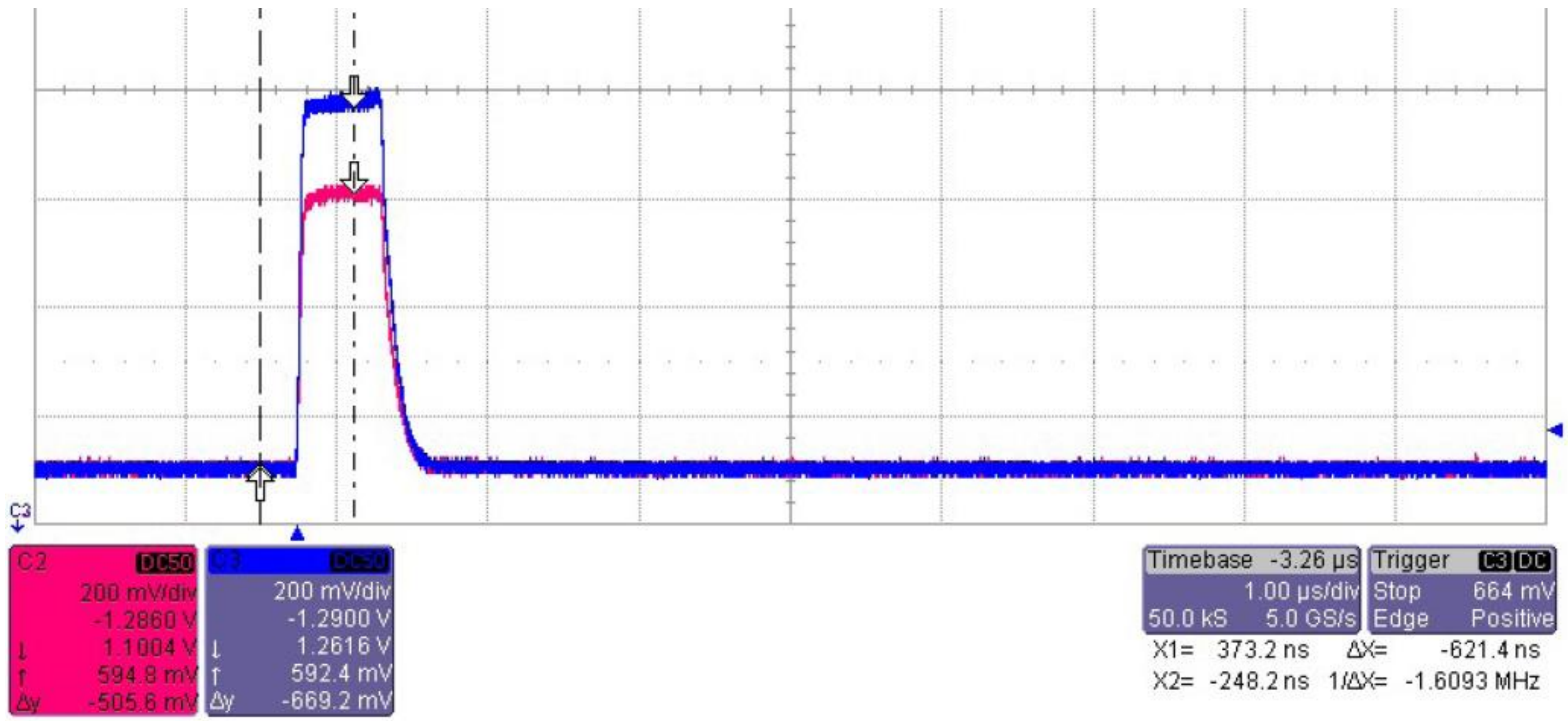
SR current	Loss mA/5s	Scraper	Histogram	Bergoz	Difference
116	0.009	5	127	204	77.166667
116	0.01	4.5	198	229	31.166667
115.8	0.011	4	267	296	28.833333
115.06	0.012	3.5	335	379	44.166667
114.7	0.014	3	464	488	23.5
114.1	0.016	2.5	653	729	76.166667
113.2	0.022	2	984	1108	124.33333
112.1	0.033	1.5	312	1021	708.83333
110.7	0.047	1.3	438	1421	982.83333
108	0.08	1	685	2688	2002.5
107	0.135	0.8	964	6063	5098.5
102	0.253	0.6	621	8515	7893.5833
84	0.303	0.5	522	10702	10180.083

← Up until this point things look o.k

It looks like the system is saturating at SR=112.1. The histograms showed a max peak of 50mV, which is less then saturation of 500mV, but the stats are very poor.

First SR results, just dipping the toe in the water.

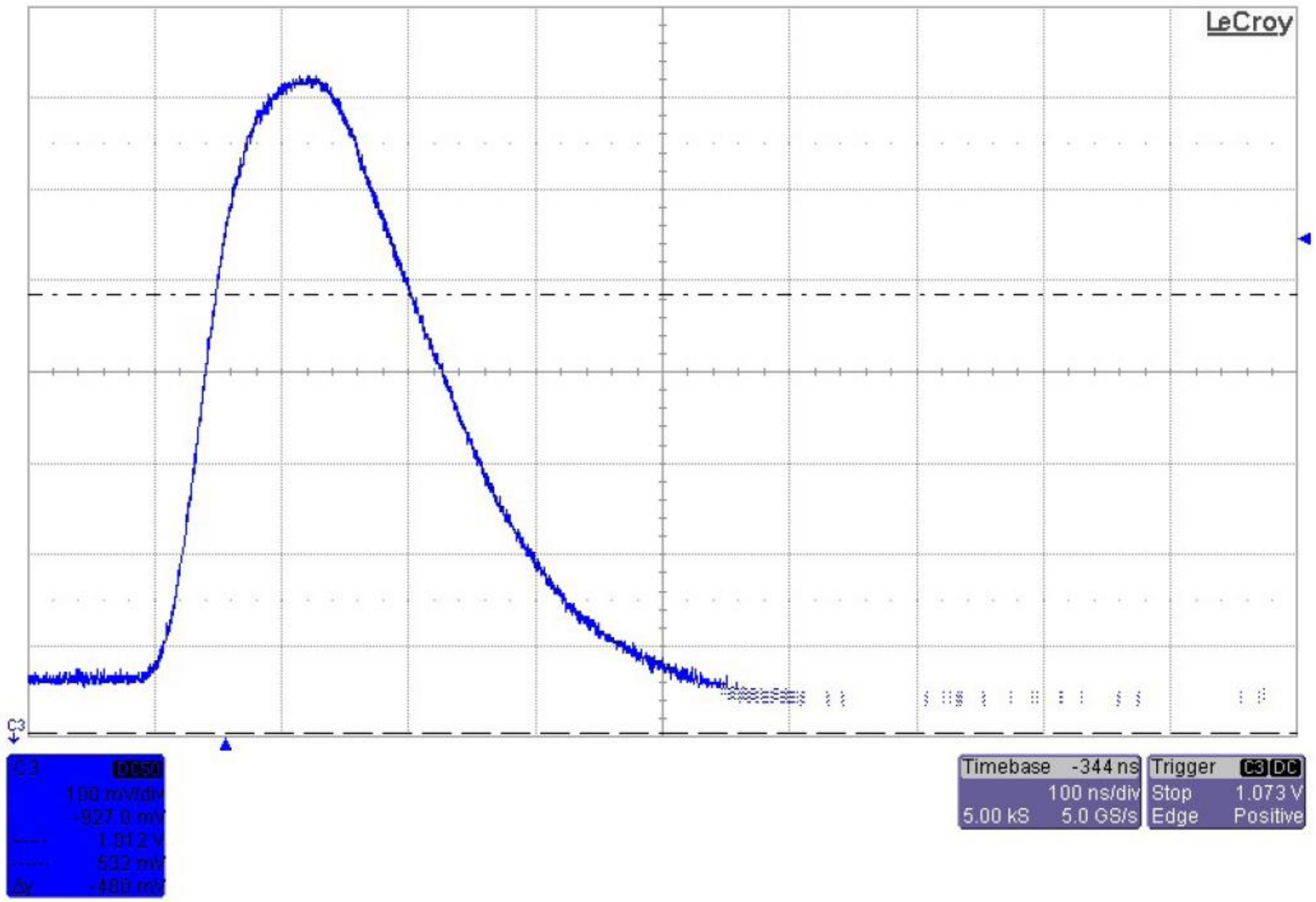
Saturation captured during beam dump.



Saturation for diode1=500mV/9mV=55 electrons (not 50mV)
Saturation for diode2=700mV/6mV=116 electrons
Diode two has twice the dynamic rage as diode1 ??
Saturation time 621ns

First SR results, just dipping the toe in the water.

Large pulse captured during injection



Pk to Pk approx =650mV=108-e
Typ rise time=72ns
Typ fall time=486ns (need to think about pile up)

First SR results, just dipping the toe in the water.

Comparison against bench tests

	Bench Test	SR Test
Voltage/MIP [mV]	4	6
Pulse Return to 20% [ns]	320	486
CSA Pile up rate [MIPS/s]	142	
Saturation [MIPS]	200	116

Not perfect, but for a first couple hour test not bad. Could come down to biasing.

Summary

Fast Pulse Sampling board (FPS board)

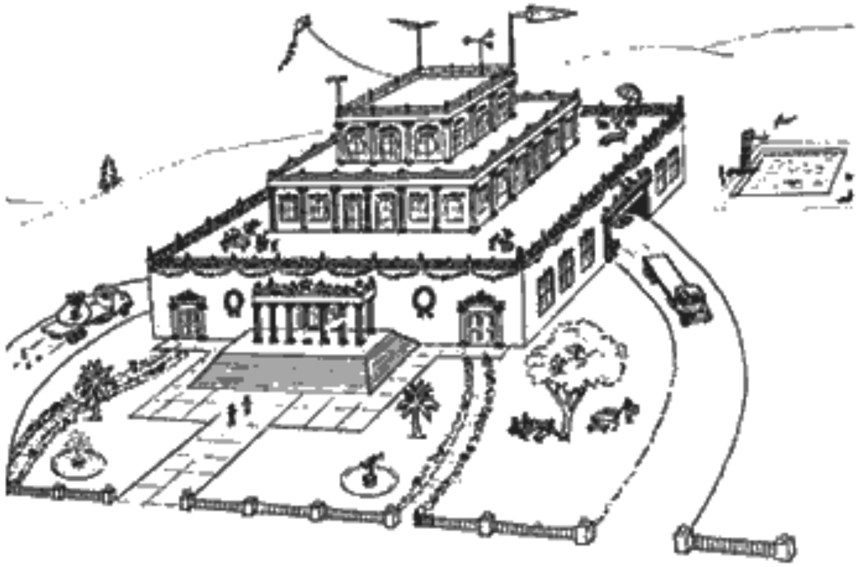
- FPS is in operation at the ANKA SR
- Next steps are to add on board signal processing and improve the front end.

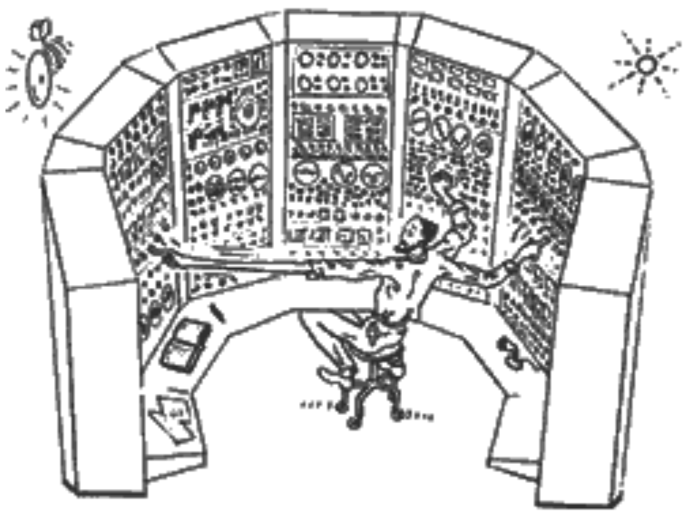
Power over optic BLM

- A pilot system has been developed and responds appropriately to electron losses.

- A good physics case now needs to be laid out to determine the true advantages of 3D, analogue, and high resolution; or other uses.

Thank you for your attention





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