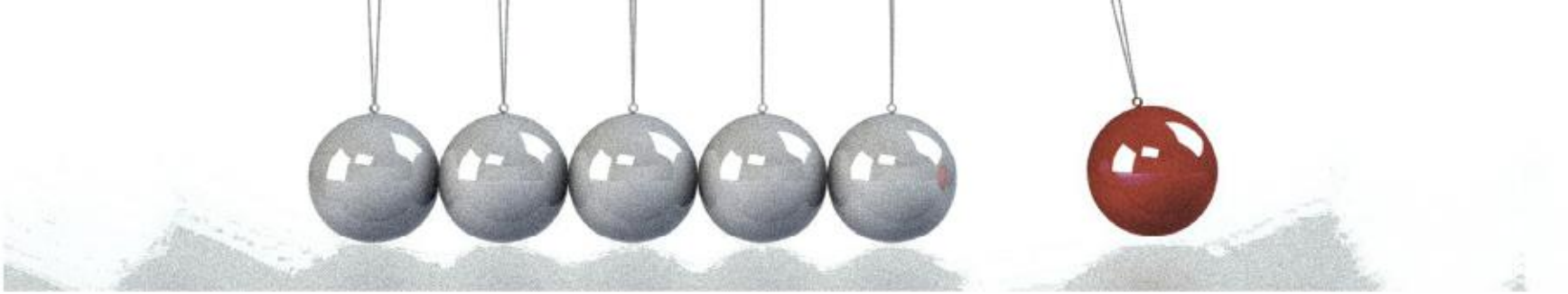

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First irradiation tests of the RCU2

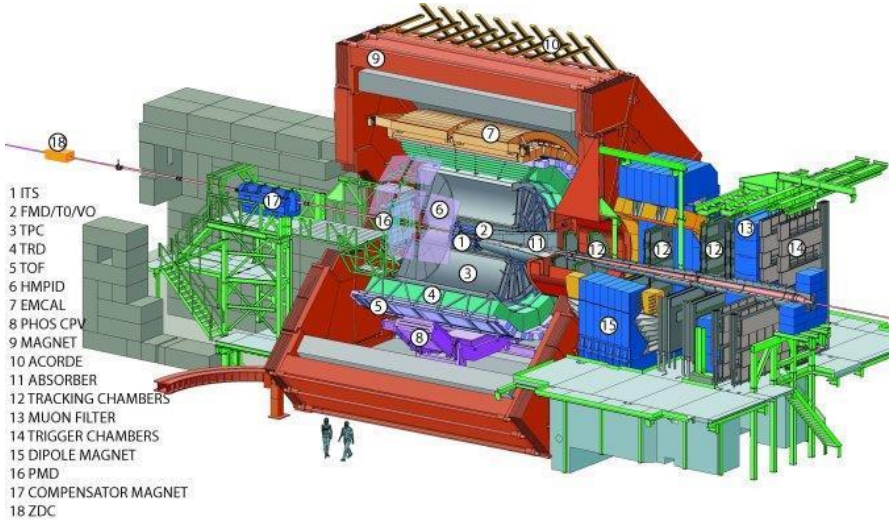
Chengxin Zhao

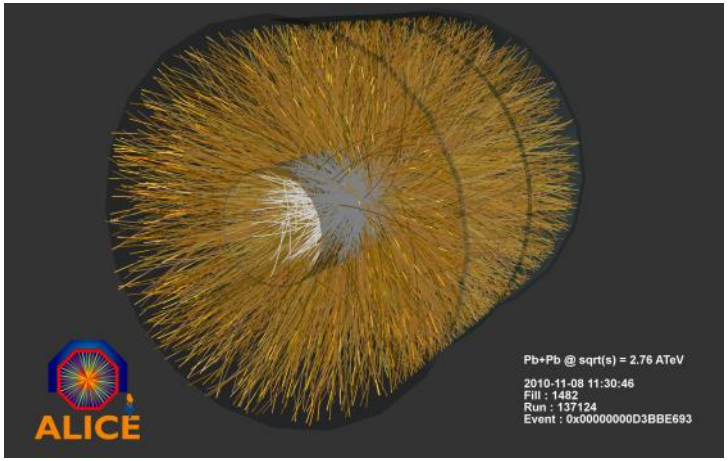
University of Oslo, Norway

On behalf of the ALICE TPC collaboration

ALICE TPC Detector

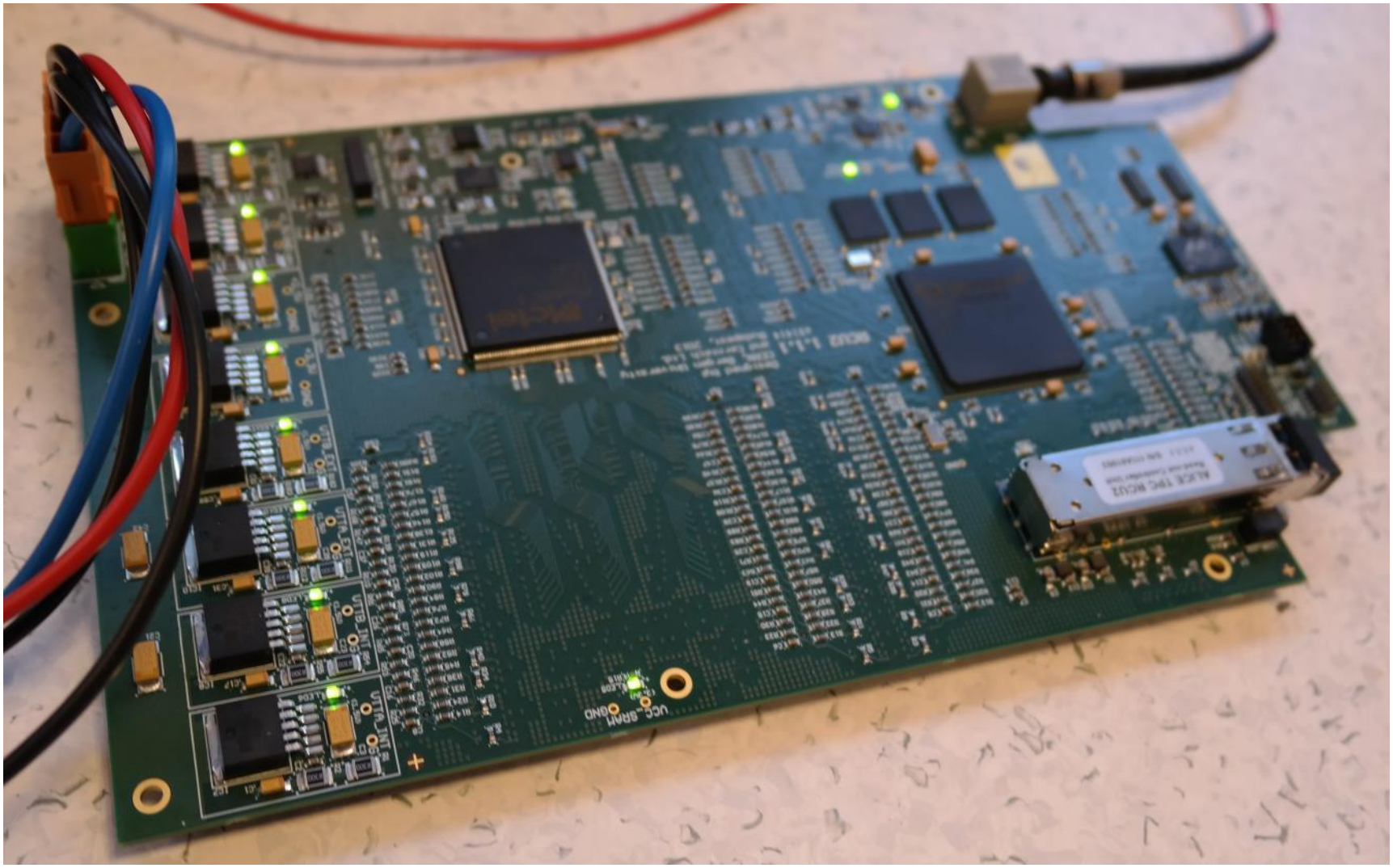
- The Time Projection Chamber (TPC) is the main tracking detector in ALICE
- There are about ~600000 detector pads divided between the two end-plates.
- The events are controlled and readout by complex readout electronics mounted on the end-plates.
  - 4356 Front End Cards
  - 216 Readout Control Units
- In *Run 2* the event rate and event size will increase:
  - *Higher readout speed needed!*
  - *Better radiation tolerance needed!*
- The answer: *The RCU2*





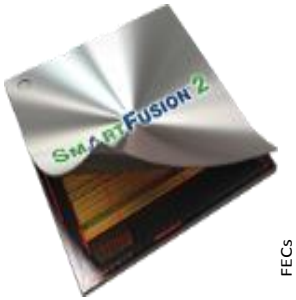
Low multiplicity event from Run 1
High multiplicity event is completely crowded
Run 2 will have even *higher* multiplicity

RCU2

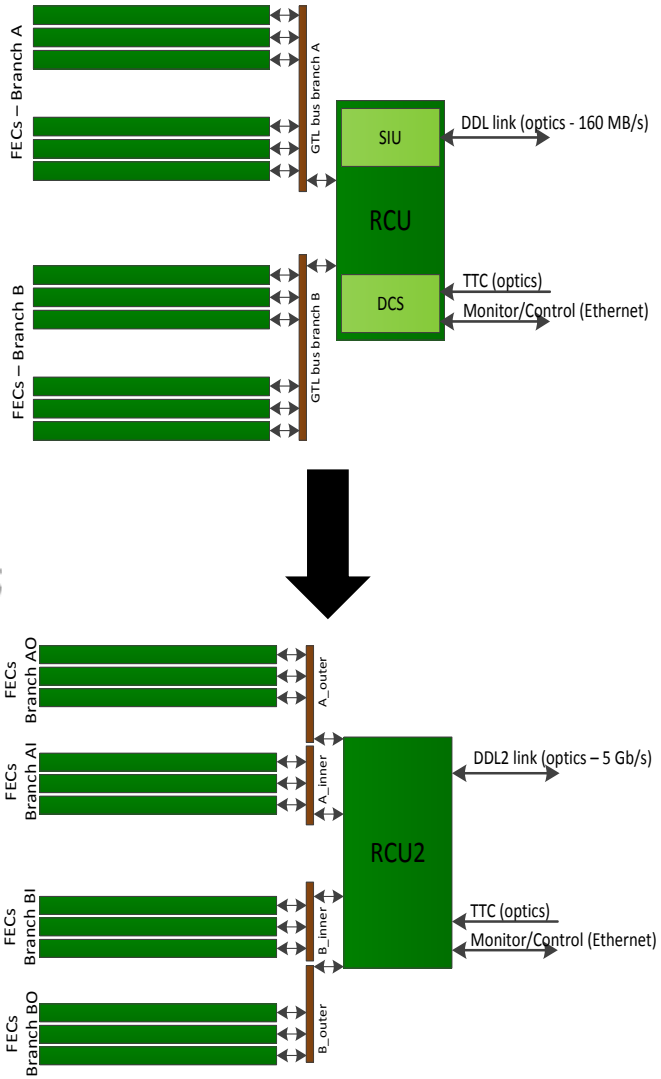


RCU2 - A «simple» upgrade

- We split a «slow» multidrop parallell bus
  - Doubles the speed!
- We upgrade the Readout Control Unit!
  - SoC FPGA: Microsemi SmartFusion2
  - New technology – Faster, bigger and better in radiation!
    - First flash-based FPGA to include high speed SERDES!
    - SEU immune
    - SECDED on interfaces
    - SEU resistant latches
    - …



- On paper the SmartFusion2 looks promising!
- Still we need to do irradiation campaigns
  - To qualify the SF2
  - To qualify components



RCU2 Irradiation Campaigns

- Irradiation Campaigns @ TSL Uppsala
  170 MeV Protons
  - 5th – 8th May 2014, Main objectives:
    - Microsemi Smartfusion 2:
      - Single Event Latchup
      - PLLs
      - Dose tests
      - Single Event Upsets/transients in logic elements
    - TTC interface w/custom CDR
    - DDL2 interface Optical Transceiver and SF2 SERDES
  - 11th – 12th June 2014, Main Objectives:
    - Different optical receivers for TTC
    - TTC interface with Analog Devices ADN2814
    - Microsemi Smartfusion 2:
      - Single Event Latchup @ different core voltages
      - Dose tests

- Irradiation Campaigns @ OSL[2]
  Prototype testing prior to TSL
  25 MeV Protons
  - November, Main objectives:
    - Component testing for RCU2
  - April, Main objectives:
    - Component testing for RCU2
    - Microsemi SmartFusion 2:
      - Internal SRAM tests

- Irradiation Campaigns @ NPI Rez[3]
  35 MeV Protons
  - 10th – 12th Sept. Main Objectives:
    - TTC interface with TTCrx and PDLD Optical Receiver
    - Microsemi Smartfusion 2:
      - Dose tests

[1]Theo Svedberg Laboratory
[2]Oslo Cyclotron Laboratory
[3]Nuclear Physics Institute

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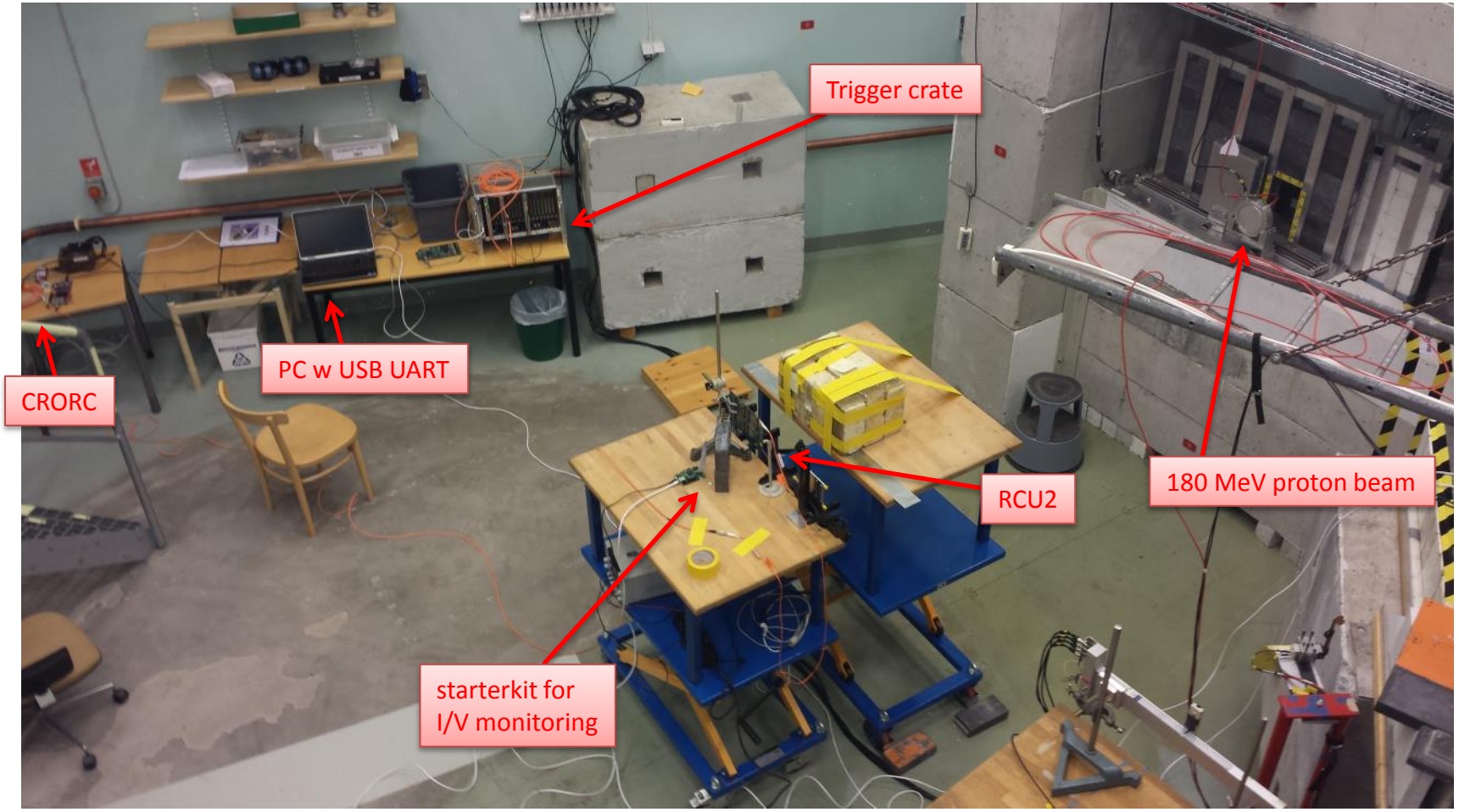
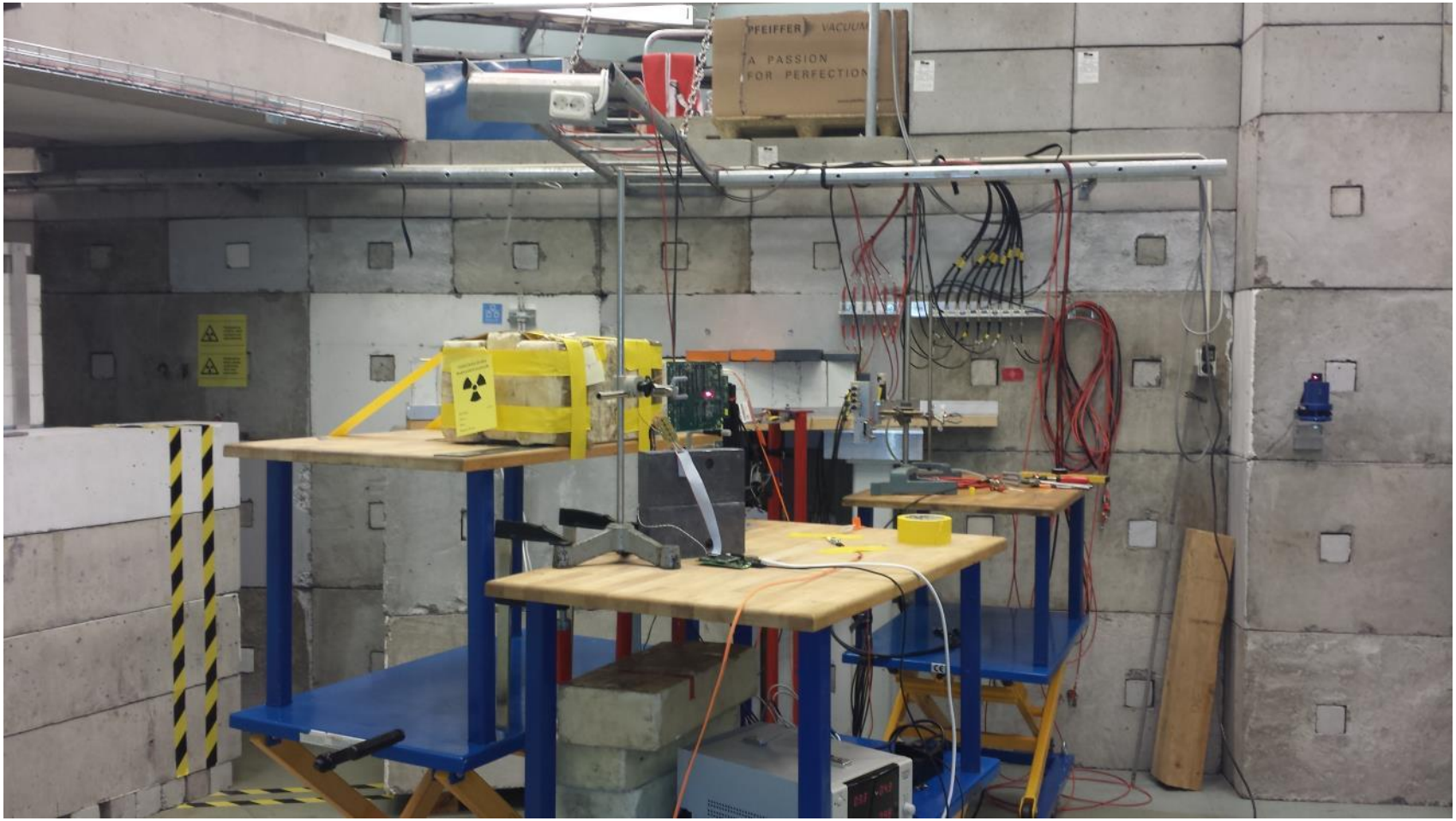
ALICE
A JOURNEY OF DISCOVERY

Irradiation Testing @ TSL



Irradiation Testing @ TSL



Test results

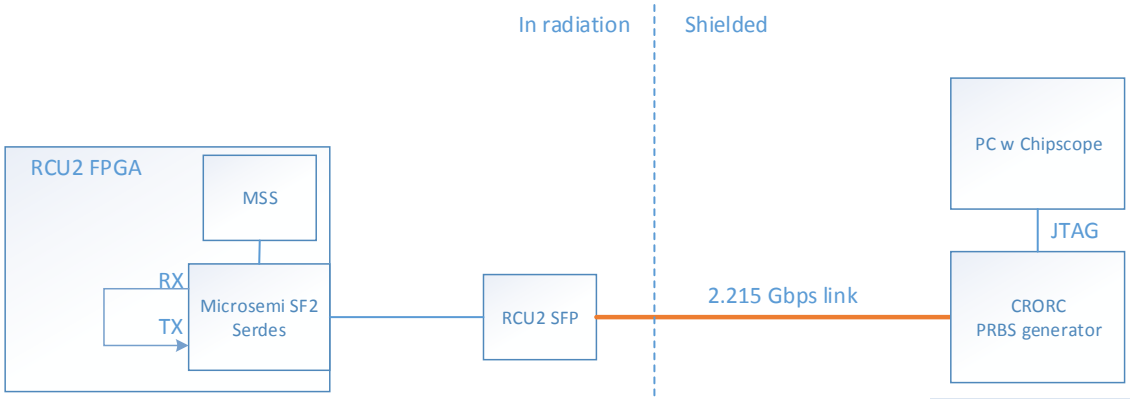
- The focus in this presentation are:
  - SmartFusion 2 test results
  - TTC interface and DDL2 interface test results

- Test Results from component testing are not presented
  - However – we did not see any major problems with any of the components we tested

- The test results are presented as follows:
  - Cross Section for the different tests have been calculated
  - MTBF (worst case) for run 2 has been calculated:
    - >20MeV Hadrons: 3.4 kHz/cm2 *
    - 216 RCUs

* Preliminary number for Run 2 inner partitions.

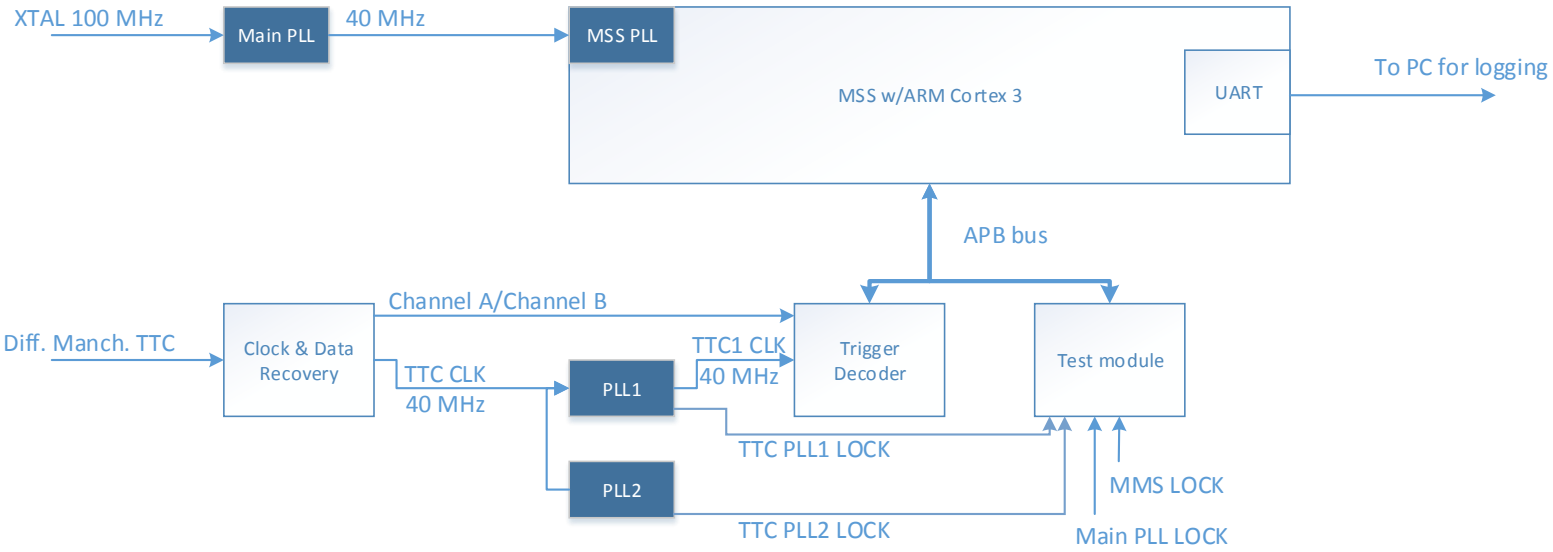
SF2 SERDES loopback



- Tested radiation tolerance of DDL2 link
- Irradiated SF2 and Optical transceiver
- Test: Xilinx IBERT 7 bit PRBS @ 2.125 Gbps was looped
- Three categories of errors:
  - (1) Bit errors, < 10^5
  - (2) Link down, self recover (typically after 2-5 seconds)
  - (3) Link down, power cycle needed
- Pause and recover scheme will handle situations when the link is down

	Smartfusion 2 irradiated	SFP irradiated
Total fluence	3.2E+11	3.6E+11
Total time	130 mins	45 mins
Cross-section (1)	5.0E-11 cm^2 *4 errors*	1.1E-11 cm^2 *3 errors*
MTBF Run 2 (1)	8 hrs	35 hrs
Cross-section (2)	1.6E-10 cm^2 *13 errors*	3.6E-12 cm^2 *1 error*
MTBF Run 2 (2)	2 hrs	106 hrs
Cross-section (3)	2.5E-11 cm^2 *2 errors*	7.2E-12 cm^2 *2 errors*
MTBF Run 2 (3)	15 hrs	53 hrs

TTC interface Test

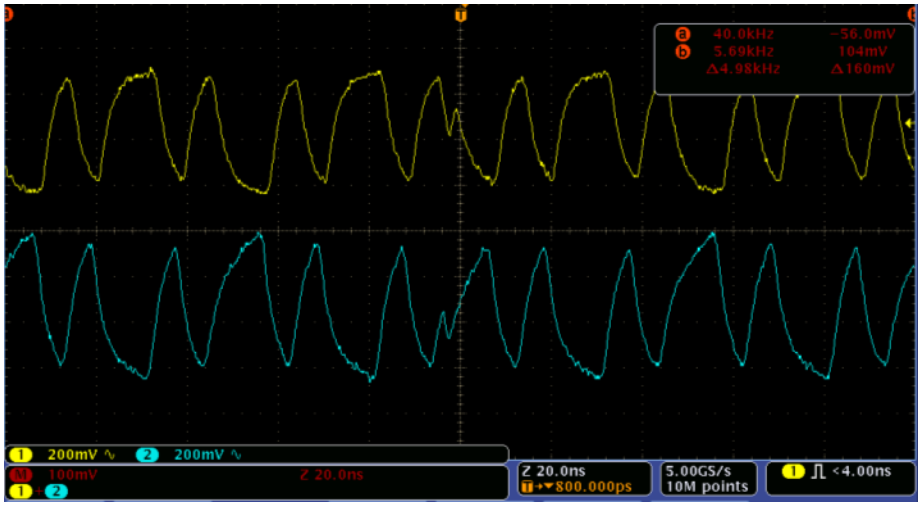


- Irradiated Optical Receiver, CDR and RCU2 Smartfusion2
- Tested three different solutions for Clock and Data Recovery (CDR)
  - (1) Custom CDR solution in FPGA[1]
  - (2) Analog Devices ADN2814
  - (3) TTCrx IC
- The input signal was generated by a Local Trigger Unit (LTU). Trigger rate 1Hz, 1kHz, 10kHz.

[1] Poster presentation: C. Torgersen et. Al. ”Clock and Data Recovery implementation and testing for the Readout Control Unit 2 in ALICE TPC”

TTC interface Test Results

- Following values were monitored:
  - Single/double hamming errors
    - TTC signal is hamming encoded
  - Errors in TTC data signal
  - Number of times the PLL that is clocked by the recovered TTC clock loses lock.
    - Other PLLs with different clocks monitored as references



- The most interesting was found to be the *TTC PLL loss of lock.*
  - The other errors were related to:
    - Number of times the clock was lost
    - Trigger rate (more data -- > more errors)
  - Very low number of data errors as long as the clock was OK.
  - Lead to system instability – self recover

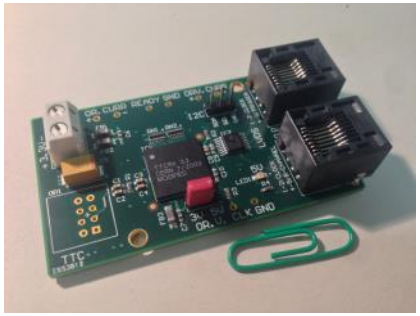
The oscilloscope shot shows a typical irradiation effect on the optical reciever in the TTC chain.

Several optical receivers (Avago HFBR-2316TZ , Truelight TRR-1B43-000, Ficer FTPDA-R155-ST , PD/LD PLD-2317TM) were tested in beam to find the most suitable one:

- PD/LD PLD2321 (CERNpinout) eventually selected
- Radiation sensitivity approx. the same – best signal quality.

TTC interface Testresults

	Custom CDR – *SF2 irradiated*	Custom CDR – *OR irradiated*	ADN2814 CDR – *ADN irradiated*	ADN2814 CDR – *OR irradiated*	*ADN2814 CDR – both ADN and OR irradiated*
Fluence	1,92E+11	1,00E+11	2,43E+10	2,35E+10	1,66E+11
Time	~126 mins	~73 mins	21 mins	138 mins	109 mins
Cross section TTC PLL Loss of Lock	1,04E-10 (20 errors)	6,07E-09 (607 errors)	3,70E-10 (9 errors)	2,55E-09 (60 errors)	3,24E-09 (538 errors)
MTBF Run2	3.6 hrs	0.06 hrs	1.0 hrs	0.15 hrs	0.12 hrs



- The results from the custom CDR solution as well as from the commercial CDR (ADN2814) was not satisfying
  - Neither of the solutions would behave well in radiation

- Only recently an existing batch of TTCrx ICs came to our attention:
  - Previously qualified and designed for radiation tolerance*
  - We immediately redesigned the trigger part for the RCU2 with the TTCrx
  - These were tested in Rez mid September**
  - No errors were seen @ 35 MeV protons (*tests are inconclusive*)

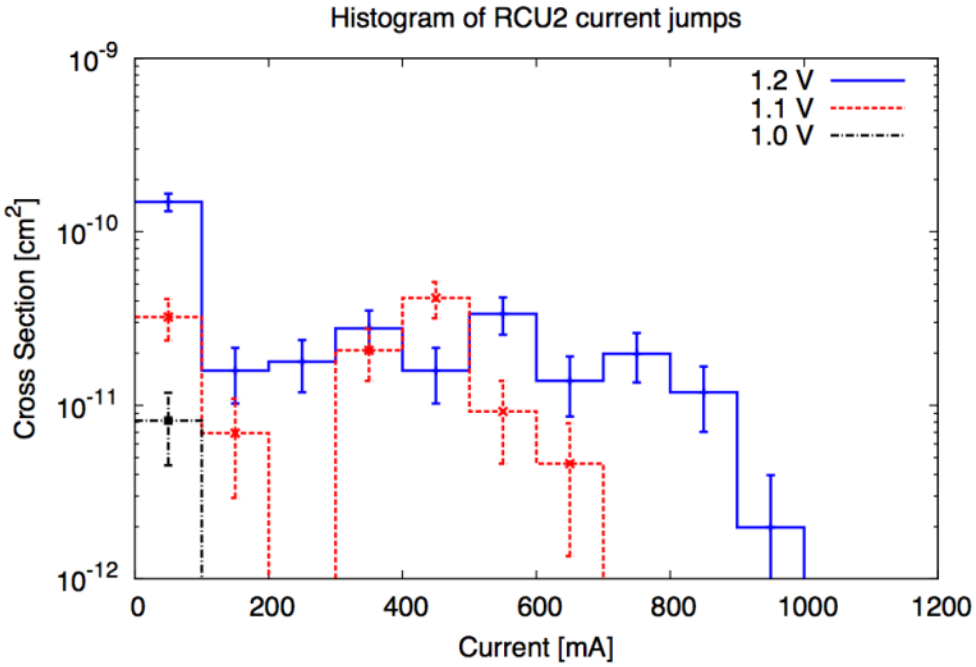
*Toifl et al:. Measurements of Radiation Effects on the Timing, Trigger and Control Receiver (TTCrx) ASIC

***Special thanks to Jozef Ferencei and co. at Rez – your help was really appreciated.*

SF2 Single Event Latch-up Test

- *Current consumption of SF2 core supply voltage monitored during irradiation*
- *Detected current jumps are most likely Single Event Latch-ups.*
  - *Removed by a power cycle*
  - *Current jumps also experienced by Microsemi and said to be non-destructive*
- Reduced core voltage => reduced rate of current jumps.
- Problem with 1.0V core voltage:
  - Timing properties change in design

	1.2V	1.1V	1.0V
Cross section [cm^2]	4.5e-10	8.2e-11	8.2e-12 *
MTBF run 2	0.8 hrs	4.6 hrs	46 hrs



Note: The single event latchups tolerance will be improved by Microsemi in their next batch. Expected by the end of the year.

** Improvement of ~50x compared to 1.2V*

SF2 dose tests

- Single event effects are a minor problem in flash based devices
  - Configuration elements are SEE immune
- Total Ionizing Dose (TID) is however of concern.
- At TSL, 4 SF2 FPGAs were irradiated up to several 10's of kRad and still fully functional.
- However, it was not possible to reprogram the FPGA after irradiation
- One SF2 FPGA was irradiated in steps of ~0.5 kRad and reprogramming failed after only **2.5 kRad**.

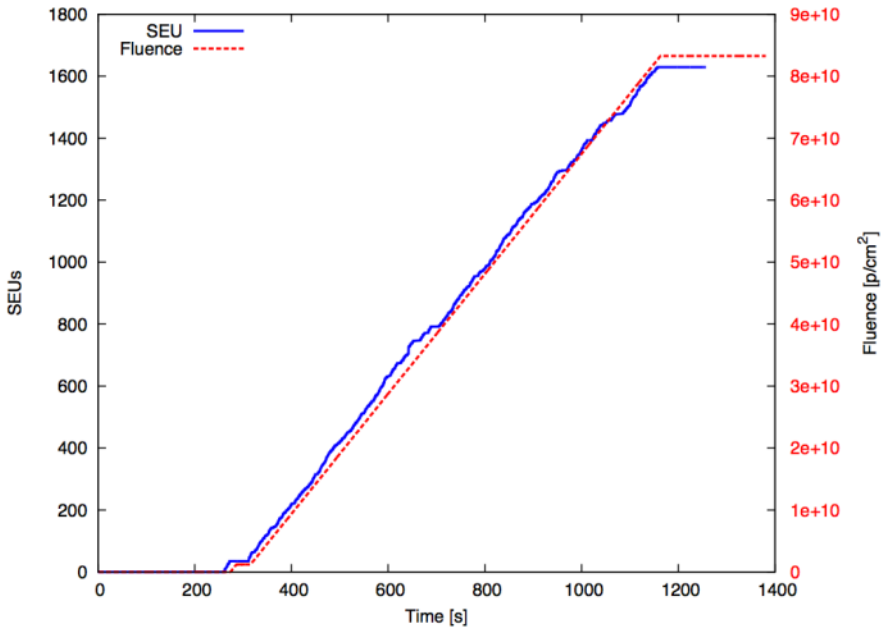
Sample	RCU2 – A	RCU2 – B	SK 1	SK 2
Dose [kRad]	38	19	14	18

SF2 SRAM Tests

- Smartfusion2 has two types of SRAM memory
  - Micro SRAM (~65kbits bits)
  - Large SRAM (~ 1.1 Mbits)

- Test were performed by:
  - a state machine reading/writing a checkboard pattern on the SRAM memories
  - Counting bitflips

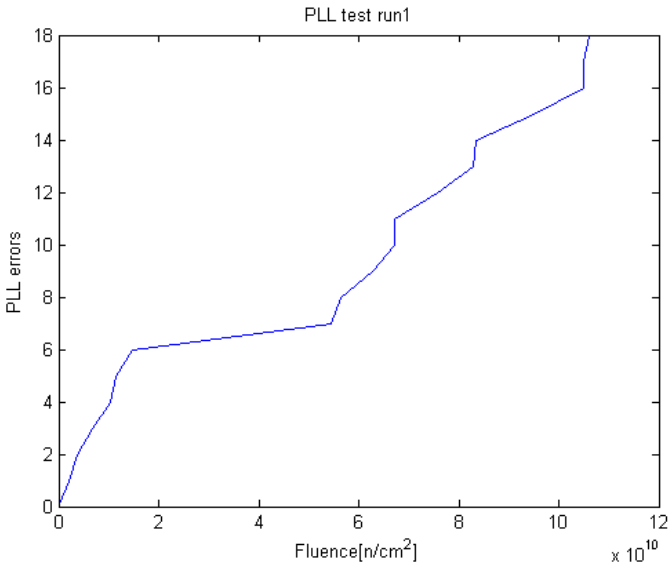
Example of SRAM test from TSL



	Large SRAM	Small SRAM
Cross section [cm^2/bit]	1.9 *10^{-14}	1.2 *10^{-14}
MTB SEU run 2	64 s	1731 s

SF2 PLL tests

- Monitored the PLL lock signal during irradation.
  - Dedicated tests on starterkits
- A total of 345 loss of lock experienced for a total fluence of 1.6 x 10^{12} p/cm^2.
  - The PLLs always regained lock after some microseconds
  - The clock output of PLL is still present without lock – but unstable/high jitter
- **CS: 2.2x 10^{-10} cm^2**
- **This is concerning**
  - **Special precautions must be taken during design (i.e. avoid PLL usage unless absolutely needed)**



	Fabric PLL
Cross section [cm^2]	2.2 *10^{-10}
MTBF run 2 *(using 1 PLL/RCU2)*	1.7 hrs

Conclusions

- Several irradiation campaigns have been set up for the RCU2
- They have revealed several problem areas on the RCU2 design
  - All of the radiation related problems have so far been dealt with
  - However, it has caused delays in the project
- The SmartFusion2 shows some unexpected limitations
  - Single Event Latch-ups
    - Reported to be corrected in next batch of SmartFusion2 devices
  - Fairly low dose before programming fails
  - PLLs fail at a discomforting high rate
- However - None of the issues above are regarded as a high reliability problem for the RCU2
  - Given that the PLL failure rate is compensated for during design

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Thanks for Listening

- RCU2 people *(in no particular order)*:

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