IRTG Seminar

Free-Streaming Readout Chain of the CBM Time of Flight Wall

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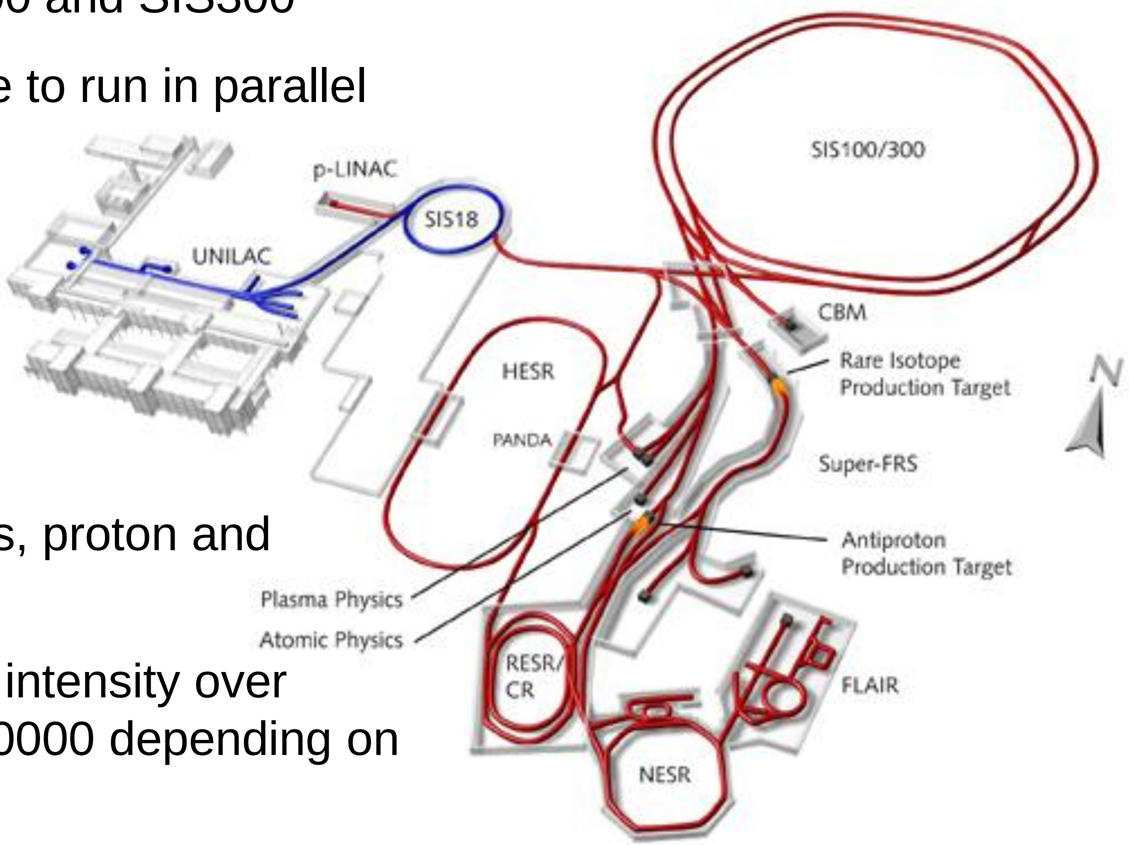
1. FAIR, CBM and the Time of Flight wall
2. ToF wall electronics
3. Free-Streaming readout
4. GSI & Heidelberg readout chain
5. Beam tests

Conclusion & Outlook

1.1 FAIR

Facility for Antiproton and Ions Research

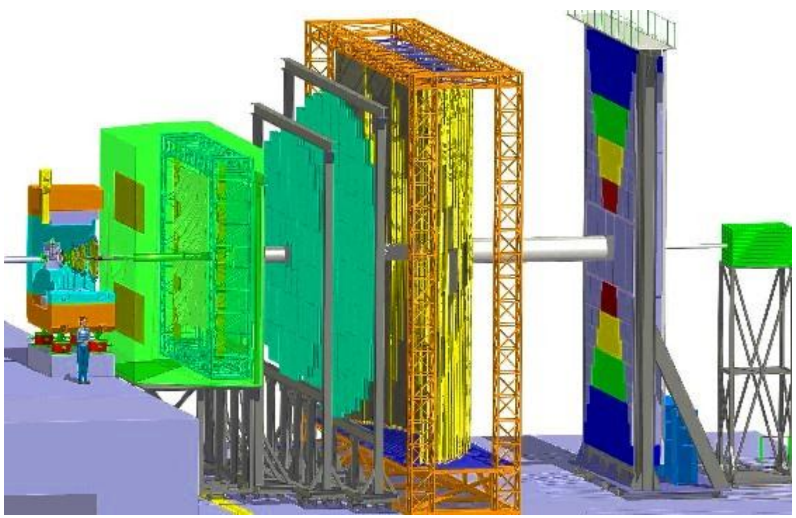
- Use part of the existing GSI facility
- Two new synchrotron: SIS100 and SIS300
- 4 groups of experiments able to run in parallel
    - APPA
    - CBM/HADES
    - PANDA
    - NUSTAR
- Heavy Ions, Radioactive Ions, proton and cooled antiproton beams
- Big improvement in terms of intensity over existing facility (factor 100-10000 depending on beam)



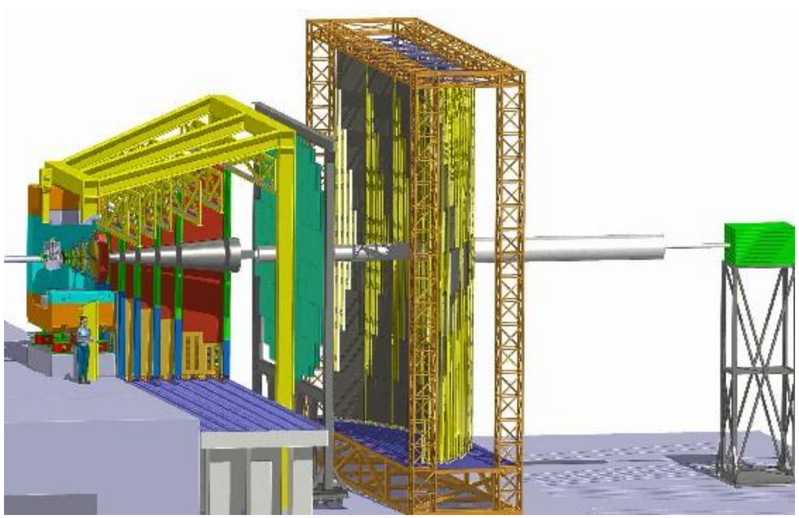
1.2 CBM

Compressed Baryonic Matter

- Investigation of the properties of strongly interacting matter under extreme conditions
- Au beams up to 35 AGeV (11 AGeV) with SIS300 (SIS100), typical being 25 AGeV
- Proton beams up to 89 GeV (29 GeV)
- High statistics measurement of rare probes
- Interaction rates up to 10MHz in Au+Au collisions => Free-streaming readout!!!!



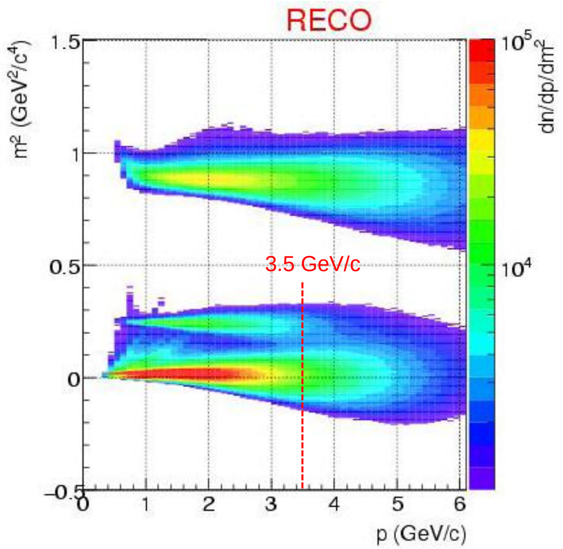
Standard setup



Muon setup

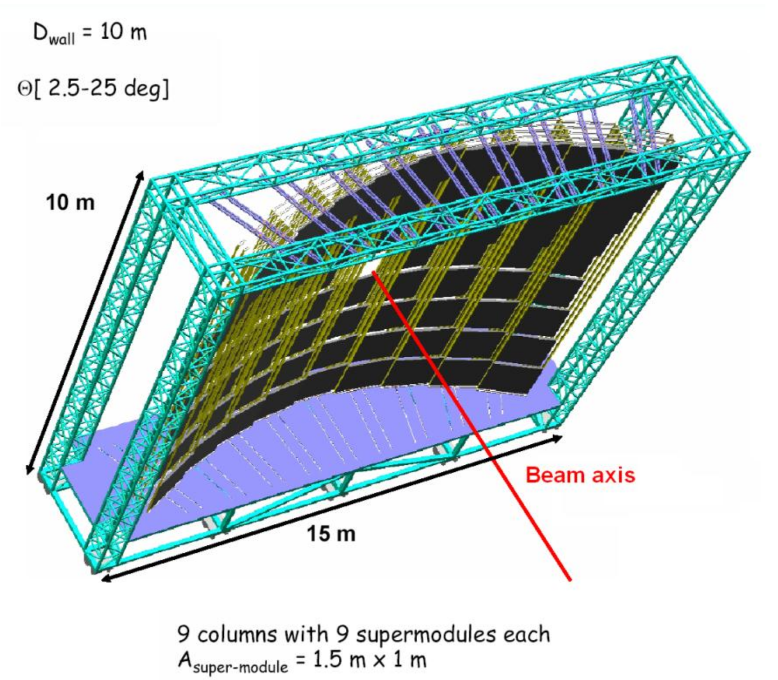
1.3 The Time of Flight wall (ToF)

- Provides charged hadron identification to CBM
- Based on Multi-gaps Resistive Plate Chambers (MRPC)
- Full time resolution σ_T = 80ps needed for Kaons/Pions separation up to 3.5 GeV/c
- Between 70k and 120k electronic channels
- Rate capability from 0.5 kHz/cm² to 25 kHz/cm²
- Polar angular range 2.5° – 25°
- Efficiency > 95 %
- Multi-hit capability



m² versus momentum distribution for reconstructed tracks, simulation, Au+Au @25 AGeV

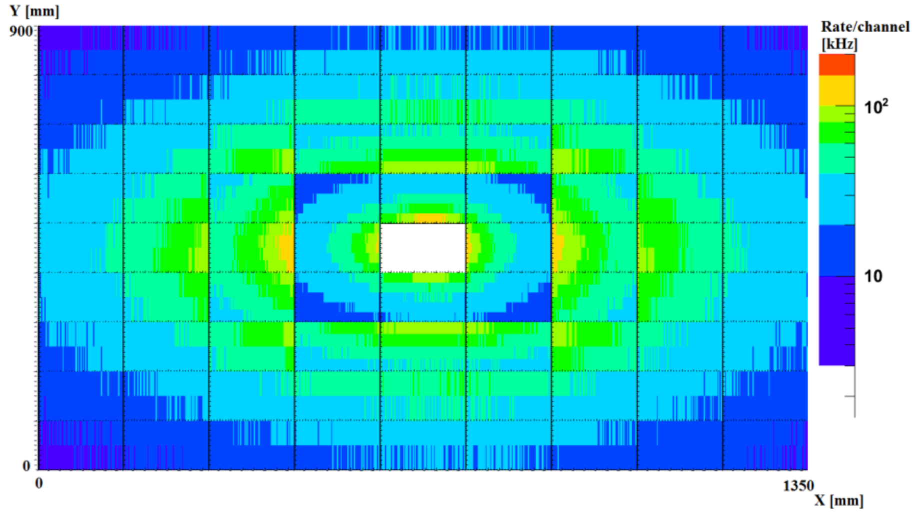
From the CBM Physics Book

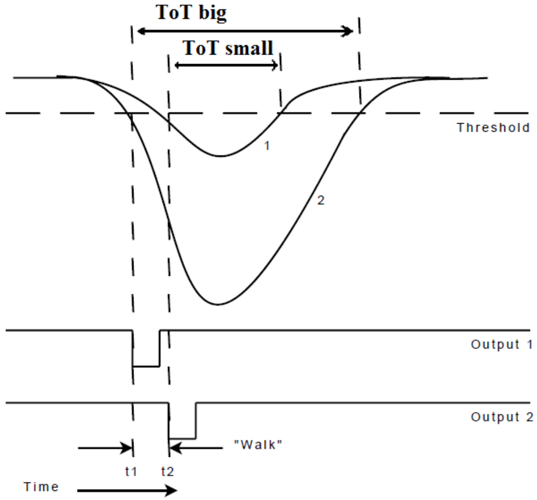


2. ToF wall electronics: requirements

- Time resolution: 40ps or better
- Up to 200 kHz per electronic channel (Channel area ~ 6 – 50 cm^2)
- Time Over Threshold (ToT) capability
- Free-streaming readout
- Double hit capability better than 10ns, if possible better than 5ns
- Low price! (between 70k and 120k channels)

Mean Rate per channel,
Au+Au @ 25AGev,
10MHz interaction rate,
Simulation by A. Kiseleva





3.1 Free-Streaming readout: Advantages

Free-streaming?

- No trigger fed back to the detector electronic
- All data are read out in parallel and sent to an online event selector located in a processing farm a few hundreds meter away
- Event selector reconstruct partial events in time slices (tracks, vertices, PID)
- If conditions for selection are there, extract all matching data (time slice, geometry) from the data stream for archiving

Advantages:

- No need to buffer data close to detectors to allow trigger building
- No need to feed back a trigger signal to all detector systems
- No common dead time => for each sub-system, dependent on its output bandwidth, no bottle-neck sub-system

3.2 Free-Streaming readout: Time measurement

General challenges:

- Synchronization of many sub-systems
- No common dead-time => how to get maximal number of events with full apparatus working?
- High sensitivity to noise/oscillations: a single channel can saturate the readout
- Strict time ordering of data needed at last when extracting data from stream

Challenges specific to time measurement:

- 1 Hit = 2 timing information => rising and falling edge have to be properly associated to generate the ToT(width) and select good hits
- The information used for ordering/selection is the same used later for physics
- The synchronization of all TDCs in our sub-system has to be done at ps level

3.3 Free-Streaming readout: Solutions

- Two clock systems synchronized:

  $\Rightarrow$ A general CBM readout clock, based on known technology, sent to all sub-systems via optical connection

  $\Rightarrow$ A Clock System for the ToF detector generating

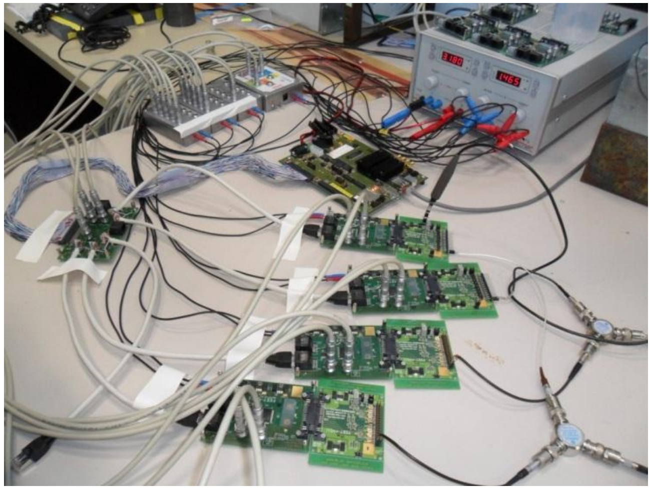
    1) Main timing clock of the ToF wall locked on CBM clock

    2) A regular synchronization signal on coincidences with the CBM clock
- Hit building at Front-end chip level (Time from rising edge + ToT from edges difference)
- Some regular “dead-time” period sent to all problematic sub-systems to give them time to empty their buffers
- Control of the Thresholds for individual channels allow to “kill” oscillating channels

4.1 GSI & HD system: ToF wall electronics Options

- Pre-Amplifier and Discriminator
  - ⇒ NINO (CERN)
  - ⇒ <u>PADI (GSI)</u>
- Free-streaming TDC
  - ⇒ <u>GET4 (GSI)</u>
  - ⇒ New version of HPTDC (CERN?)
  - ⇒ TDC based on radiation-hard FPGA designs (GSI, USTC China, …)
- Readout
  - ⇒ <u>ROC, based on SYSCORE boards</u> (KIP-HD/FIAS) , later updated with pre-processing (PI-HD)
  - ⇒ ROC + a new board dedicated to pre-processing later in the readout chain

4.2 GSI & HD system: Overview



- Clock System: CLOSY2 board and distribution tree (GSI)
- Pre- amplifier and discriminator: PADI III (GSI)
- Free-running digitizer: GET4 (GSI)
- ReadOut Controller: ROC-FEET firmware loaded on the SYSCORE FPGA board, (KIP/ZITI)
- DAQ: DABC software (GSI)
- Monitoring & Analysis: GO4 framework, (GSI)

4.3 GSI & HD system: Front-end ASICs

Pre-amplifier and discriminator = PADI

- 4 channels
- Fully differential design
- Impedance matching with strip RPCs
- 1-100mV signals standard operating range

Free-streaming digitizer = GET4

- 4 input channels, corresponding to 8 timing channels (1 per edge)
- 50 ps bin size for 25ps resolution (RMS, with pulser)
- Free streaming readout via a serial link
- Synchronization error detection
- 3.2ns double hit minimal capability (in reality double edge capability)
- Insure all data inside a reference period are sent before reference message

4.4 GSI & HD system: Readout

<u>ROC-FEET</u>

- Modular firmware specifically designed for ToF, with Ethernet or Optical readout

<u>Readout softwares</u>

- DAQ = DABC software

  ⇒ Next generation DAQ at GSI/FAIR

  ⇒ Compatible with both triggered and free-streaming systems

  ⇒ Provide dedicated libraries for the readout of ROC systems

- Monitoring: GO4 framework, used for both online and offline analysis

  ⇒ Based on ROOT

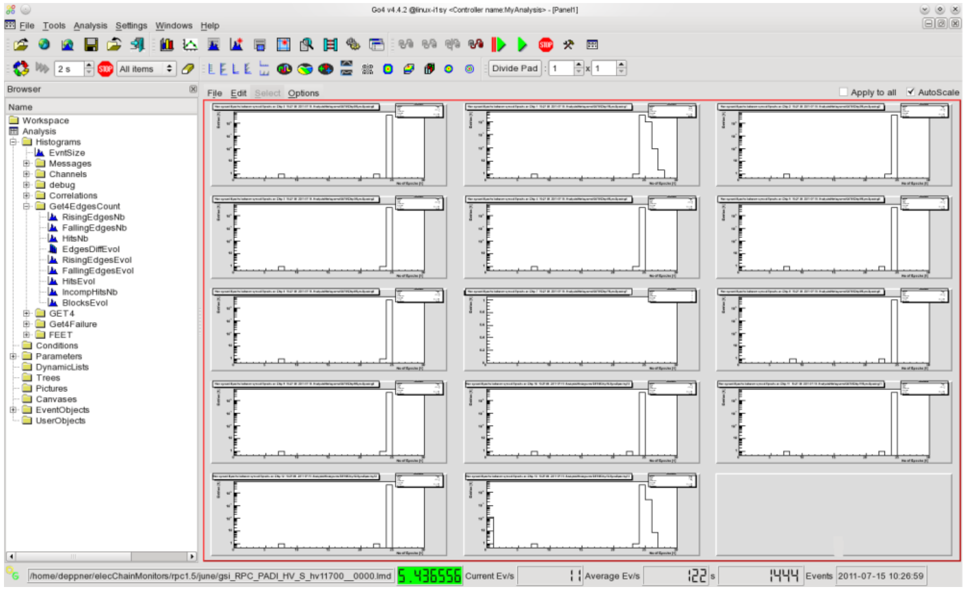
  ⇒ Provide a graphic interface

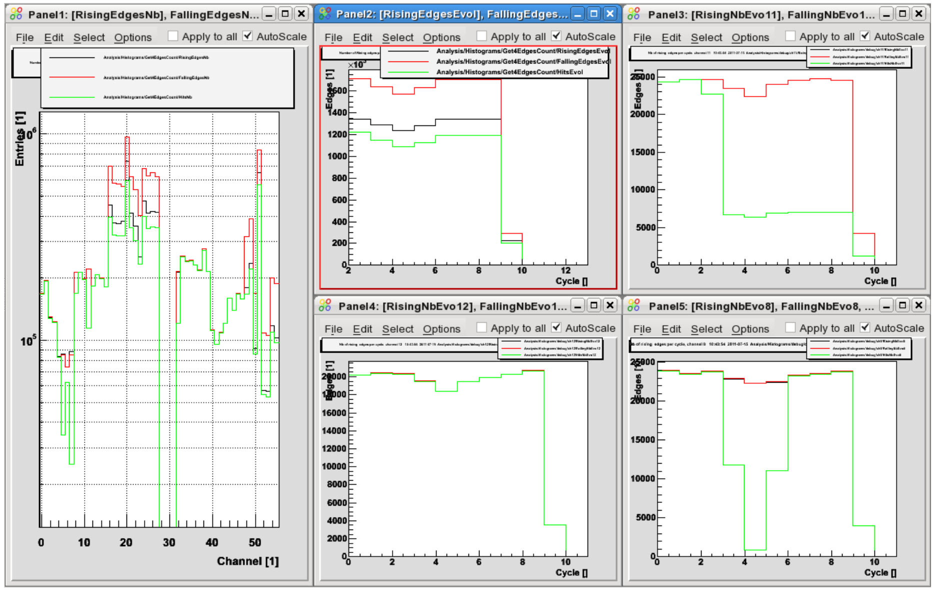
  ⇒ Provide an easy access for the user to free-streaming data messages when combined to DABC

4.4 GSI & HD system: Monitoring

Monitoring

- Synchronization messages of the TDC chips
- Counts of rising/falling edges & matched hits per channel





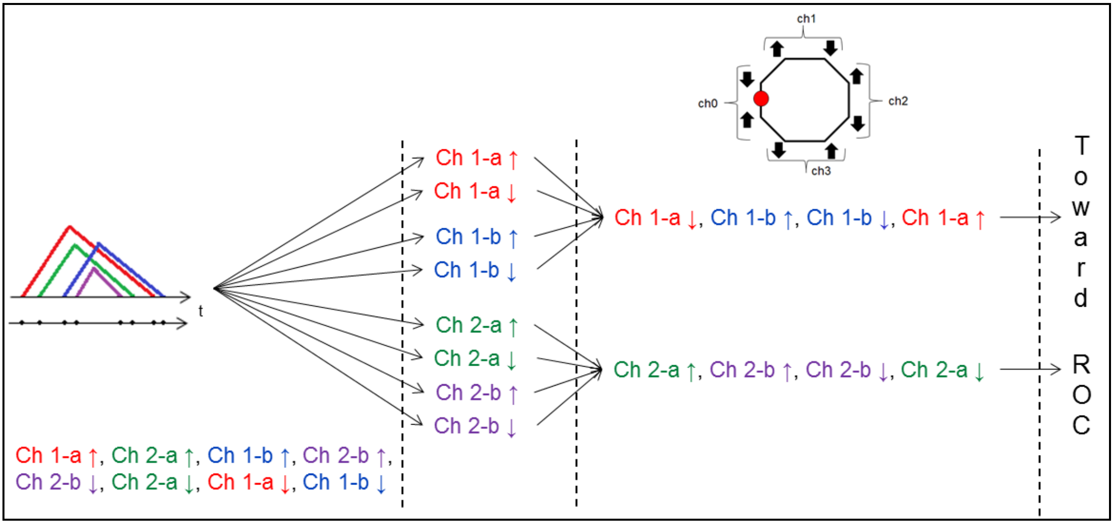
Synchronization check:
there should always be the same number of reference messages between 2 synchronization

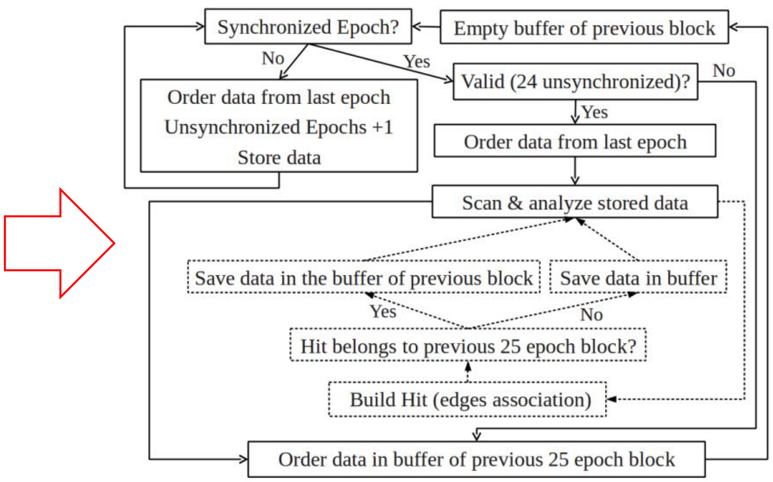
Matching check:
For working channel,
Rising edge Nb = Falling Edge Nb = Matched hits Nb

4.4 GSI & HD system: Analysis

<u>Analysis</u>

- Cleaning, time ordering and hit building:
  - ⇒ Rejecting data in time period were synchronization failed
  - ⇒ Time mixing by parallel/serial readout, example: channels to chip





  - ⇒ Hits on top of reference messages: need buffering
- Event selection, Timing analysis and Timing corrections (Walk, Non linearity)

5.1 Beam tests: Overview

Lab pulser results (2010)	**σ[ps]**
chip level (chan to chan)	36.94
PCB level (chip to chip)	38.94
PCB-PCB level	40.22

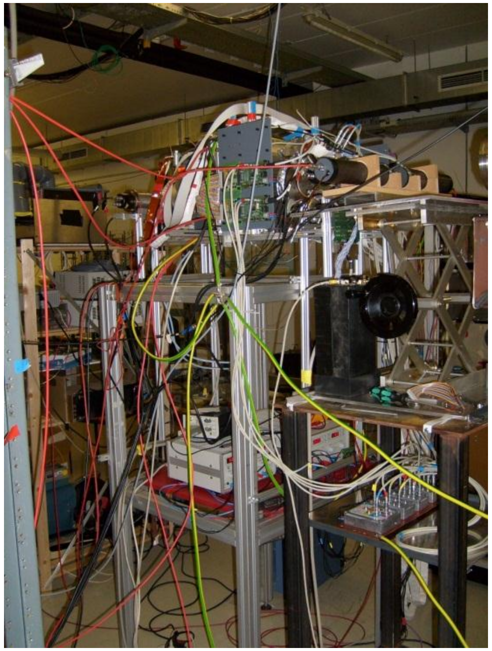
COSY in Jülich, November 2010

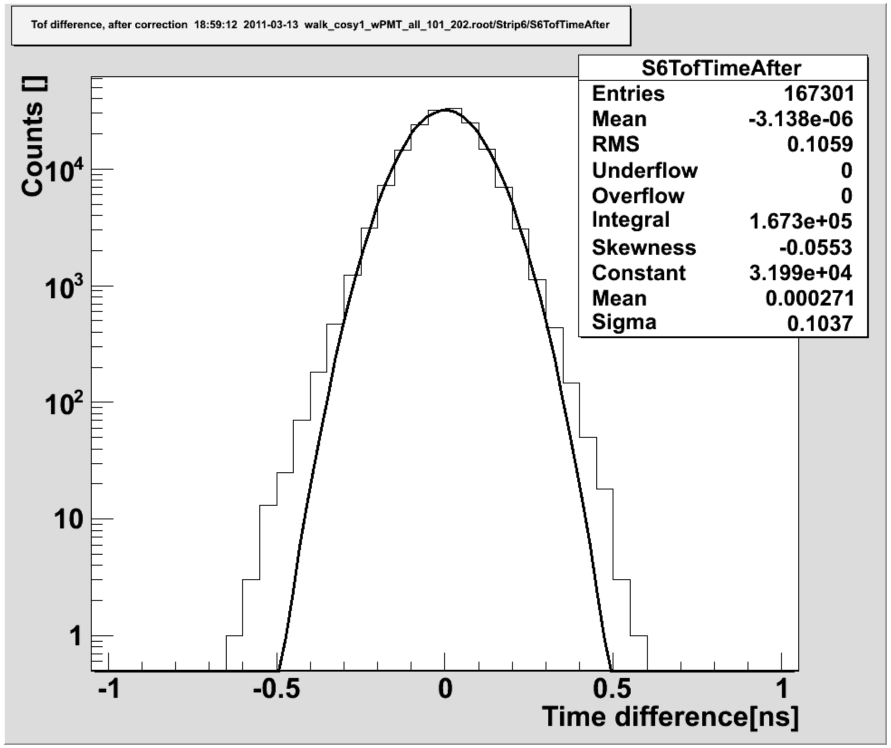
- 24 channels equipped: 8 double sided RPC strips and 4 reference plastic scintillators with 2 photomultipliers each
- ~6 hours of data taking
- Proton beam with variable rate

Behind FOPI @ GSI in Darmstadt, June 2011

- 32 channels equipped: 12 double sided RPC strips and 4 reference plastic scintillators with 2 photomultipliers each
- π^- beam, counter placed directly in beam

5.2 Beam tests: COSY in November 2010

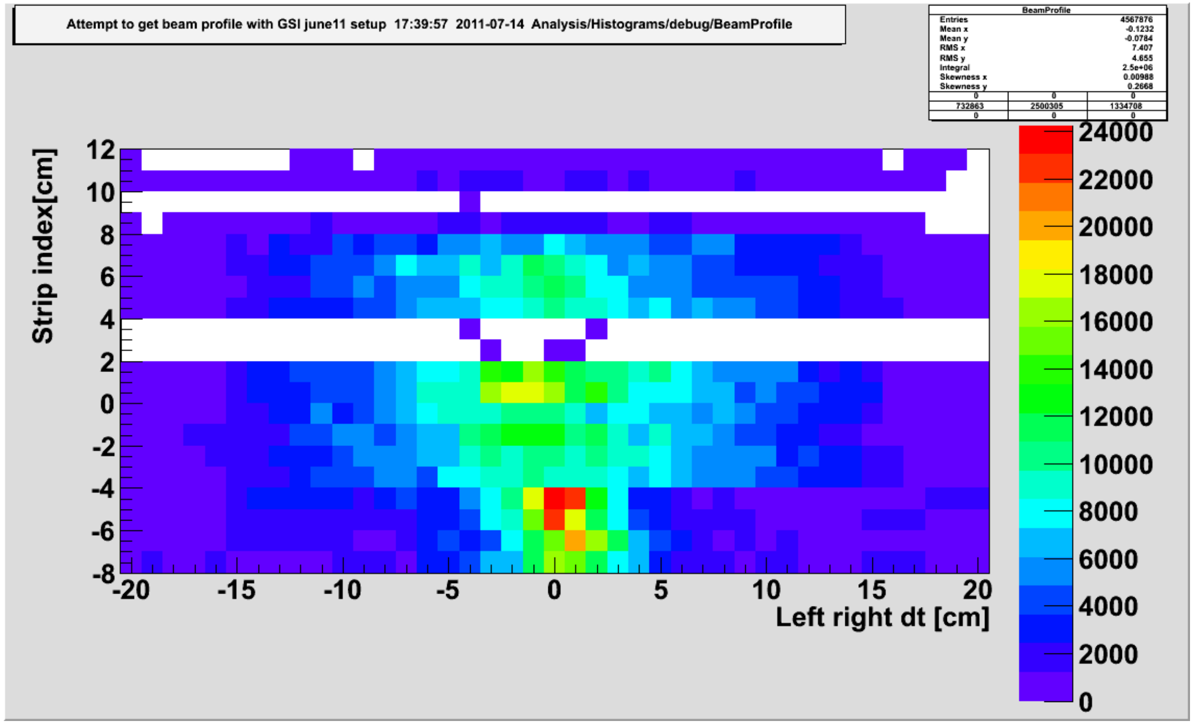




- First data with full system over long time
- Detector was not at nominal parameters
- Lot of crashes for the TDC chips, not seen during data taking => data from only 1 RPC strip could be used
- Performance worse than with triggered system, but still in same order: 104ps

5.3 Beam tests: GSI in June 2011

- Detectors was a real size prototype developed by Ingo Deppner
- We could see the beam spot online
- Lots of oscillations => led to almost constant TDC crashes (shifted channels)
- Analysis now ongoing to recover data and evaluate timing performances
  1) Recover shifts
  2) Find best reference
  3) Build events
  4) Time performance



Conclusion

1) CBM readout will be free-streaming to allow for high rates
2) Free-streaming is a challenge, especially for time measure
3) ToF full readout chain 1st time put into operation in Nov 2010
4) First free streaming data recorded for our sub-detector
    - Allowed to get first timing performances
    - Allowed to identify some problems in current electronics
5) System is highly sensible to oscillations
6) Analysis software of free-streaming data under development

Outlook

1) Optical readout of our system
2) Test with different real size RPC prototypes
3) Next beam time at end of the year with software/hardware workarounds to finally get stable TDC operation
4) Same beam time will be used to test operation with readout of another sub-system (Silicon Tracker System)
5) New version of chain components under development

Thank you for your attention

Many thanks for their help to:

Pr. Norbert Herrmann, Ingo Deppner, Jochen Frühauf, Sebastian Manz,

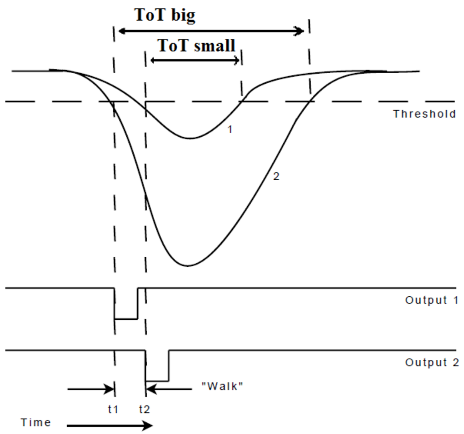
Mircea Ciobanu, Harald Deppe, Holger Flemming, Mladen Kis, Karlsten Koch, Serguey Linev, Walter F.J. Müller

And to all other people involved in the development of the readout chain components

Bundesministerium für Bildung und Forschung

SEVENTH FRAMEWORK PROGRAMME

Backup 1: Walk, charge and ToT



- Time measure is also dependent on the signal rising time => also on its size
- This effect can be corrected by measuring the integral charge of the signal or its height, but high cost per channel
- To reduce cost per channel, a solution is to use the width information instead of the charge
  - ⇒ It can be measured by the same kind of TDC as the time signal, by measuring both edges of the discriminated signal
  - ⇒ It needs a specifically designed pre-amplifier/discriminator to insure the quality of the measure

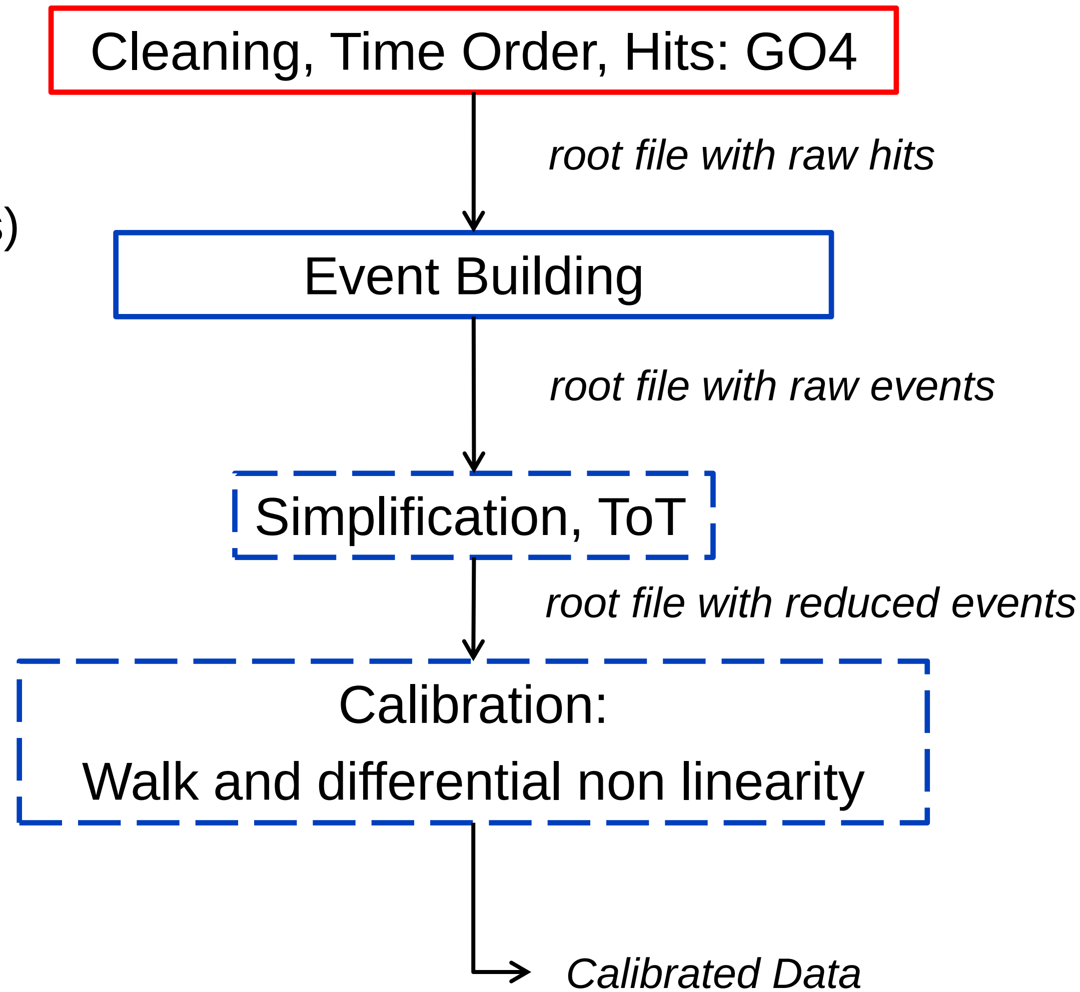
Backup 2: Resolution and time corrections

Unpacking using GO4:

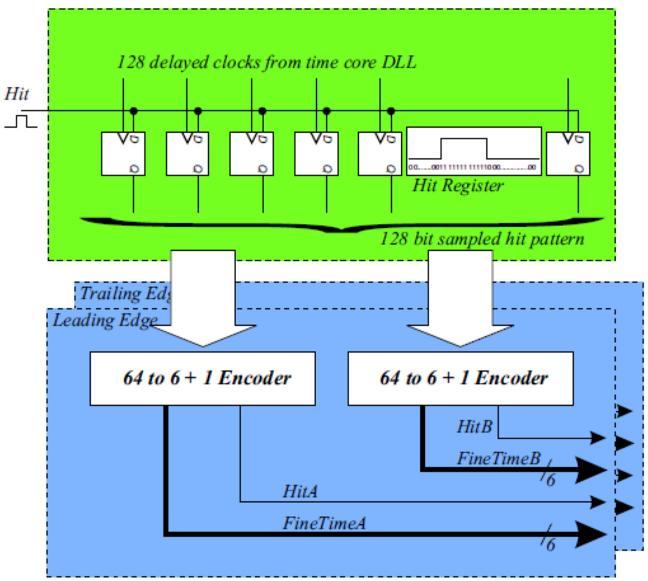
- Checking data synchronization
- Ordering data messages (edges)
- Building hits
- Ordering hits

Analysis using ROOT scripts:

- Building events from channel coincidences and external reference signal
- ToT & event structure
- Correction and analysis
- Calibration scripts tested first on triggered data



Backup 3: Double hit ↔ Double edges



	ToT b	ToT a
Signal		
Register	0 0 0 0 0 0… 0 1 1 1 1 1	1 1 0 0 1 1… 1 1 1 0 0 0
Leading encoder		La
Trailing Encoder	Tb	Ta
Time Order:	?? < La < Ta < Tb < ?	

	ToT b	ToT a
Signal		
Register	0 0 1 1 1 1… 1 1 0 0 1 1	1 1 1 1 1 1… 1 1 1 0 0 0
Leading encoder	Lb	La
Trailing Encoder	Ta	
Time Order:	?? < La < Ta < Lb < ?	

Backup 4: Solutions to problems seen at GSI

Main sources of unusable data in this system is an overloaded buffer:

⇒ Each timing block has its own buffer

⇒ Synchronization messages should be protected but this backfired

⇒ Lead to stuck slot in buffer, increasing next crash probability

Workarounds to test:

⇒ Reset signal sent to all chips by the DAQ at regular intervals (software)

⇒ Reset signal sent to all chips by the DAQ during "spill-off" period (software)

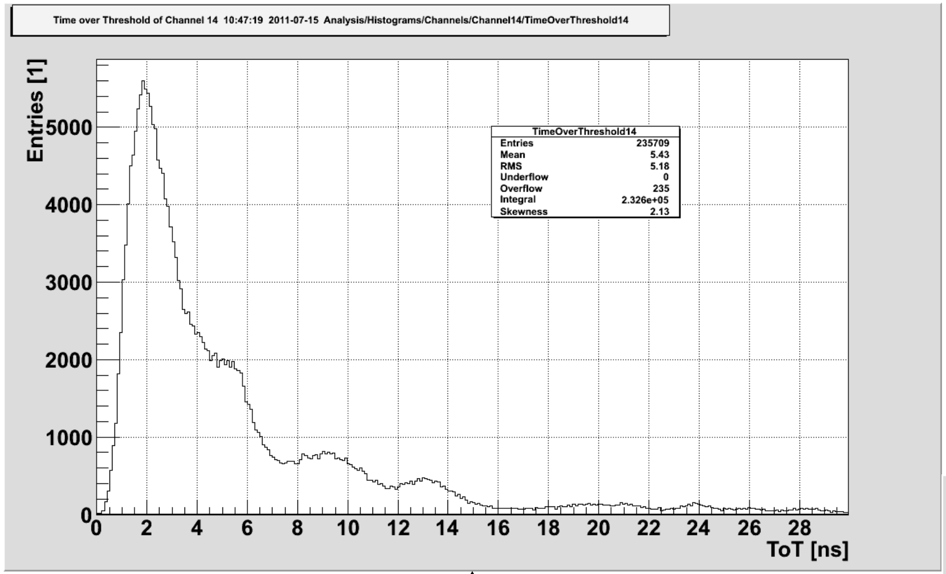
⇒ Reset signal sent to all chips by the ROC at regular intervals (hardware)

⇒ Reset signal sent to all chips by the ROC on reception of a pulse in auxiliary input (hardware)

Backup 5: Goals and Additions planned to the setup for next beam time

- Optical readout => should decrease grounding problems from computers
- Slow control
  - High Voltage => detector condition
  - Low Voltage => front-end and readout condition
  - Gas
  - Temperature => for detector test with warming
- Test of synchronization scheme
  - More channels => synchronization between 2 ToF ROCs
  - Silicon detectors => synchronization with other sub-systems

Backup 6: A few online time plots



Raw Left-Right time difference for strip 9

=> Width around 3ns, corresponding to length of a RPC strip

Raw ToT spectra channel 14

=> mean around 2 ns as expected for RPC signal