A digital calorimetric trigger for the COMPASS experiment at CERN

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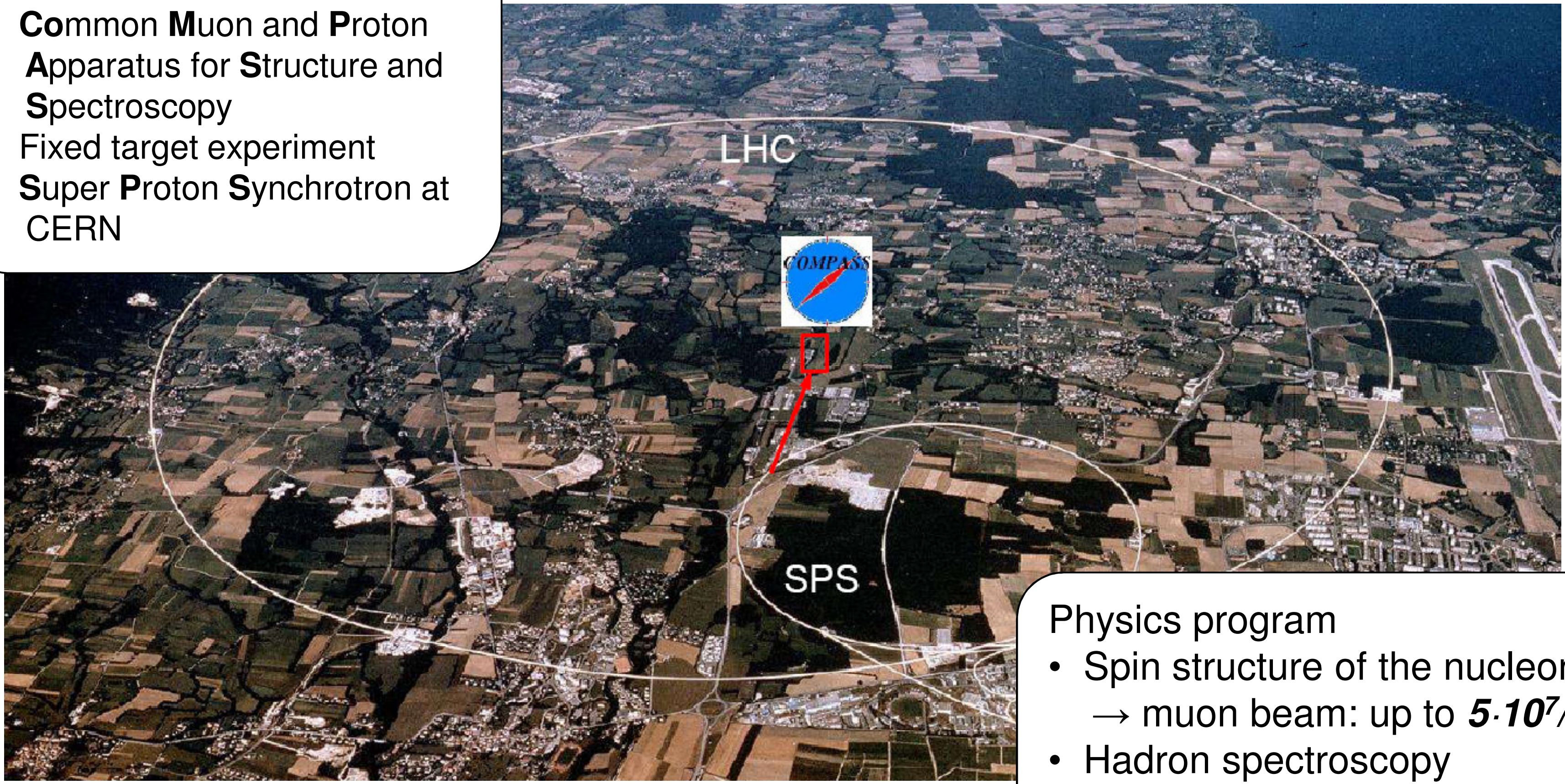
Overview

- The COMPASS experiment at CERN
- Motivation
- The electromagnetic calorimeter of COMPASS
- Digital contra analog trigger
- Trigger concept
- Trigger implementation
- Monitoring of the calorimetric trigger
- Conclusion/Outline

The COMPASS experiment at CERN

Overview
- **Co**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
- Fixed target experiment
- **S**uper **P**roton **S**ynchrotron at CERN



Physics program
- Spin structure of the nucleon
  → muon beam: up to ***5·10^7/s***
- Hadron spectroscopy
  → hadron beam: up to ***5·10^6/s***

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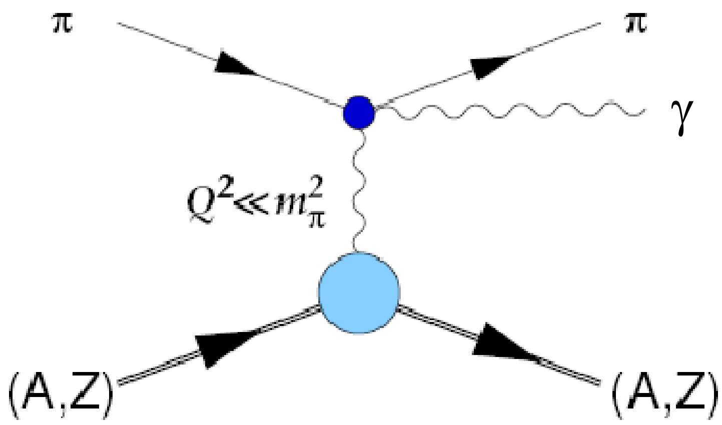
The COMPASS Experiment at CERN

Setup:
- Two-stage magnetic spectrometer
- Data taking since 2002

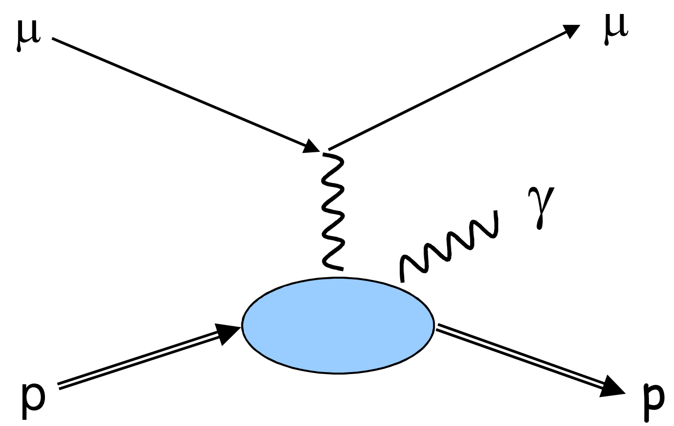
Detectors
- Tracking:
  → Silicon, GEM, SciFi, MicroMegas, MWPC, DC, …
- Calorimetry:
  → ECAL, HCAL
- PID:
  → RICH, μWall

Motivation

- Reactions producing a hard photon



Primakoff



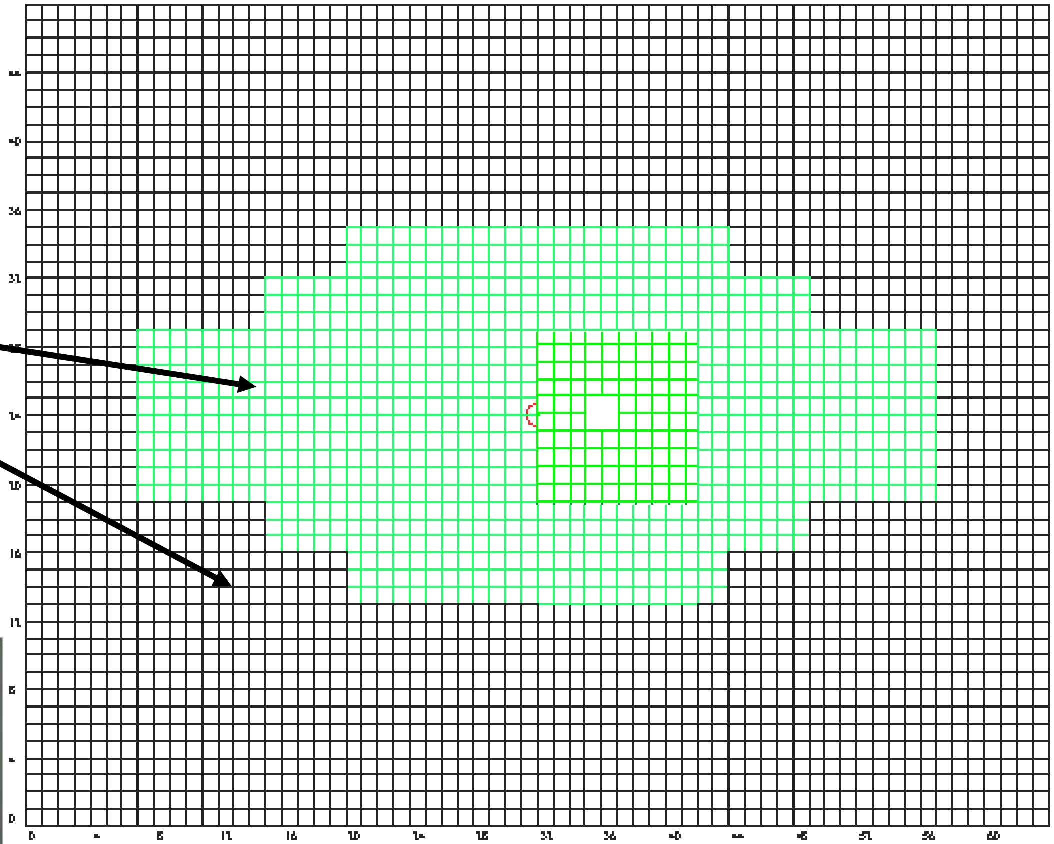
DVCS

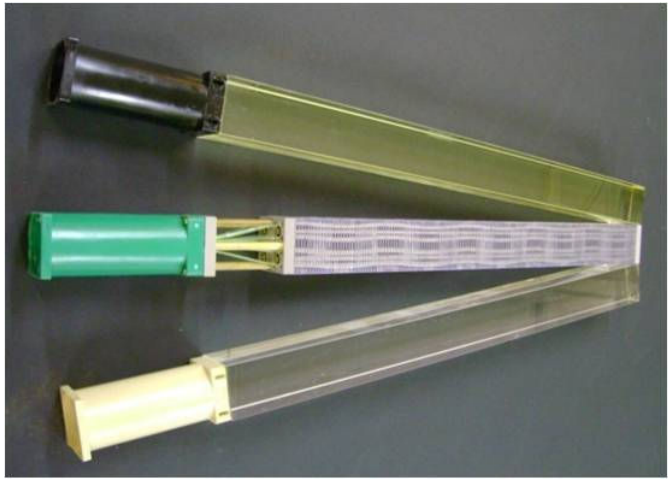
Deeply virtual Compton scattering

$\Rightarrow$ Trigger on electromagnetic calorimeter (ECAL)

ECAL2

- Size: ***2.44m×1.83m***
- 3068 Cells (***64×48 - 2×2***):
  - 860 Shashlik modules
  - 2208 GAMS modules
- 3072 Channels read out by Mezzanine Sampling ADC (MSADC)

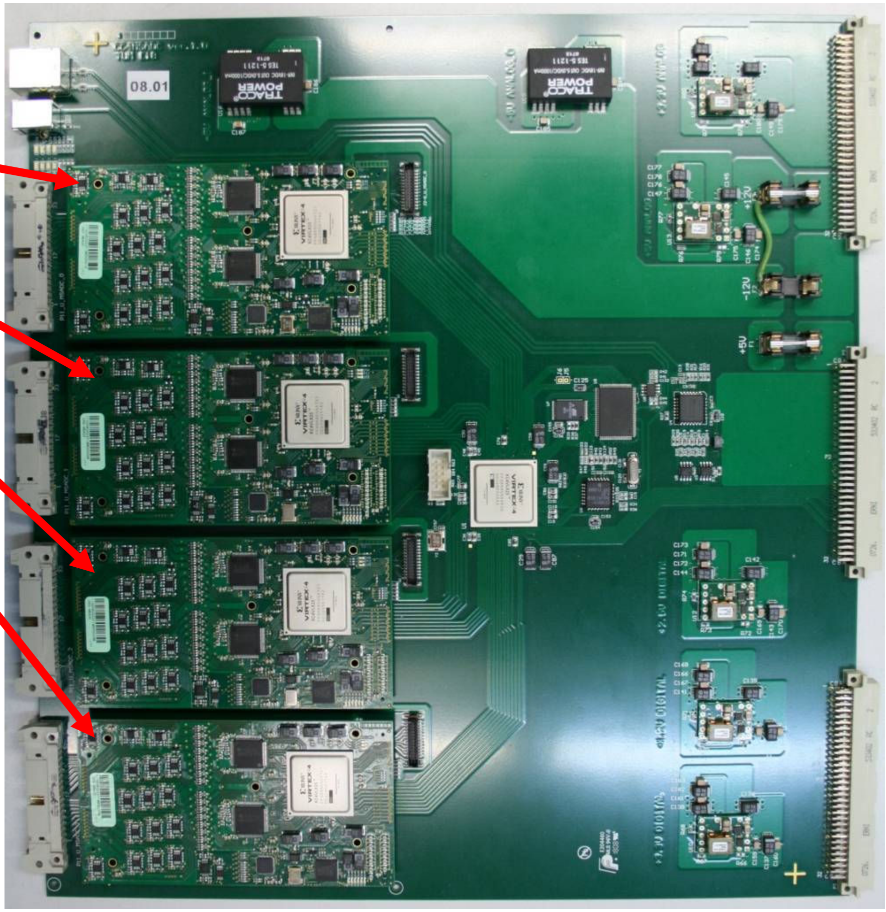




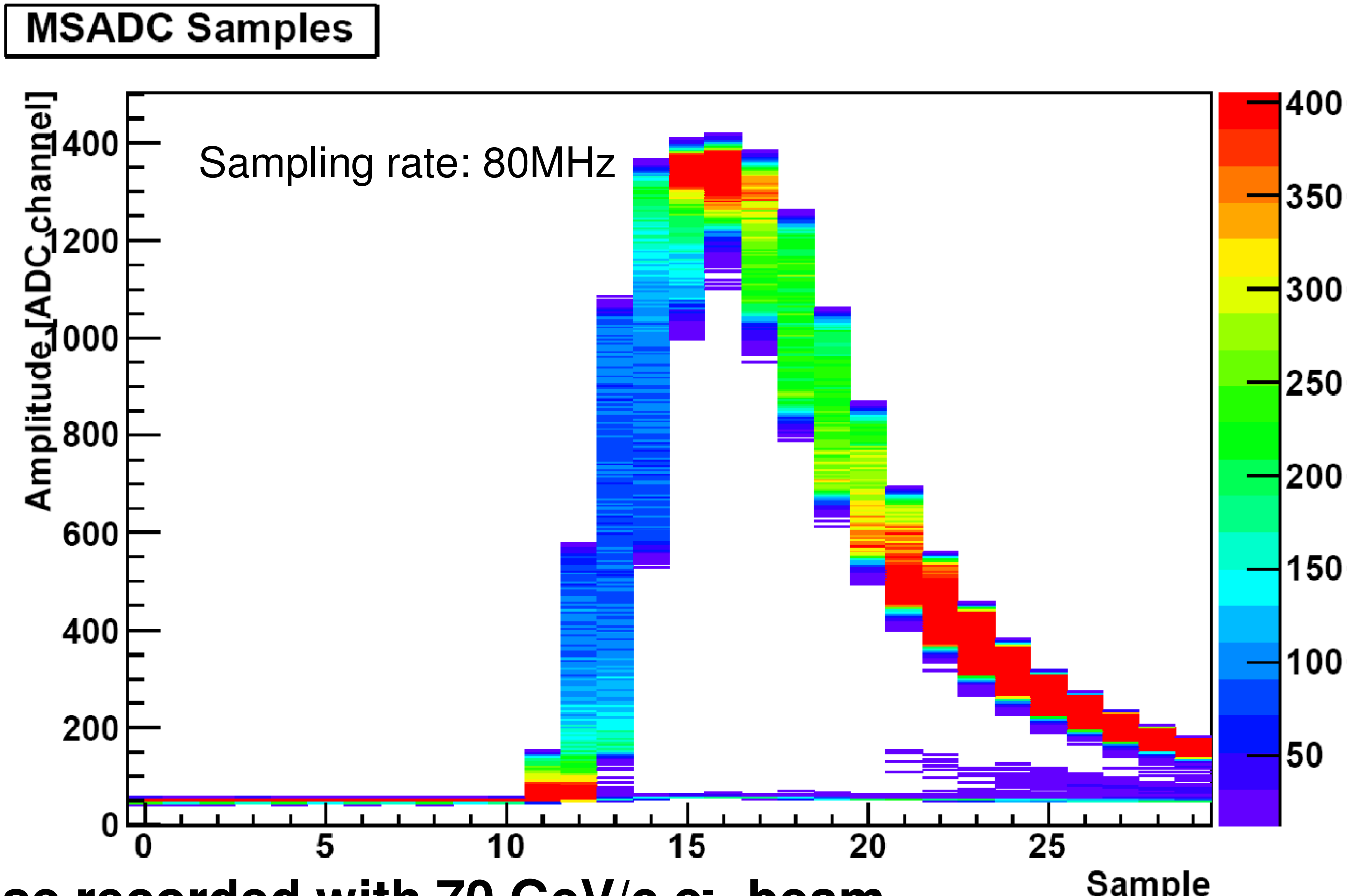
12 bit SADC architecture

- Mezzanine SADC
  - 16/32 channels
  - 12 bit
  - 80/40 MHz
  - Virtex4
- CC4MSADC
  - Virtex4
  - USB
  - HotLink
  - TCS receiver
  - Power supplies

  - **4 MSADC cards**
  - **64 channels**
  - **12 bit**
  - **80 MHz**



Mezzanine sampling ADC



Pulse recorded with 70 GeV/c e^- -beam

Comparison of digital and analog trigger implementation

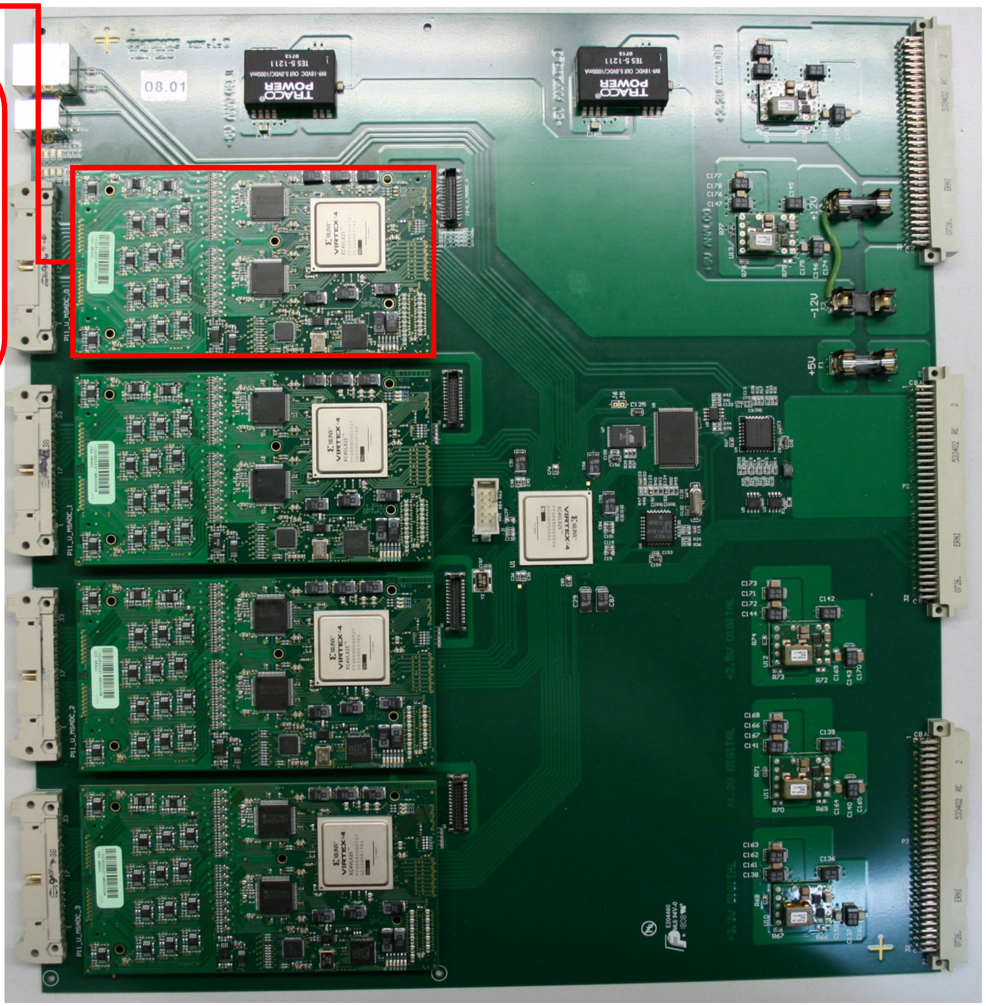
- Advantages of a digital trigger
  - More complex trigger logic achievable
    - Improved noise suppression
    - Amplitude normalization
    - Geometry (multi geometry settings possible)
  - Flexible settings (programmable)
    - Timing of channels
    - Thresholds
    - Calibrations
  - Better access in offline analysis
    - Monte Carlo
    - Trigger decision
  - High integration
    - Integrated into the readout system

Trigger concept

- Energy summation over all included calorimeter channels
  - 2009: 16×16 central channels
  - Future: Extend to all 3068 channels of the calorimeter
- Trigger on events using a threshold on the total energy sum
  - Currently aimed at 20-40GeV (190GeV beam energy)
- On channel level:
  - Signal detection/zero suppression (constant fraction algorithm)
  - Time calculation and latency adjustment
  - Energy calibration
- Implementation:
  - Pipeline algorithm for FPGA (on MSADCs)
  - Parallel to readout logic on same FPGAs

Hardware overview

- Mezzanine Card:
  - Channel level:
    - Signal detection/zero suppression
    - Time extraction
    - Energy conversion
  - Sum over 16 Channels



Channel level computation

- Pedestal subtraction
  - Pedestals updated upon each spill
- Constant fraction discriminator plus threshold
  - Signal detection/zero suppression
  - Time calculation
  - Amplitude extraction
  - Configurable

Signal Time extraction

- Constant fraction discriminator

  B[i] = kA[i] – A[i+N]

- Coarse Time :

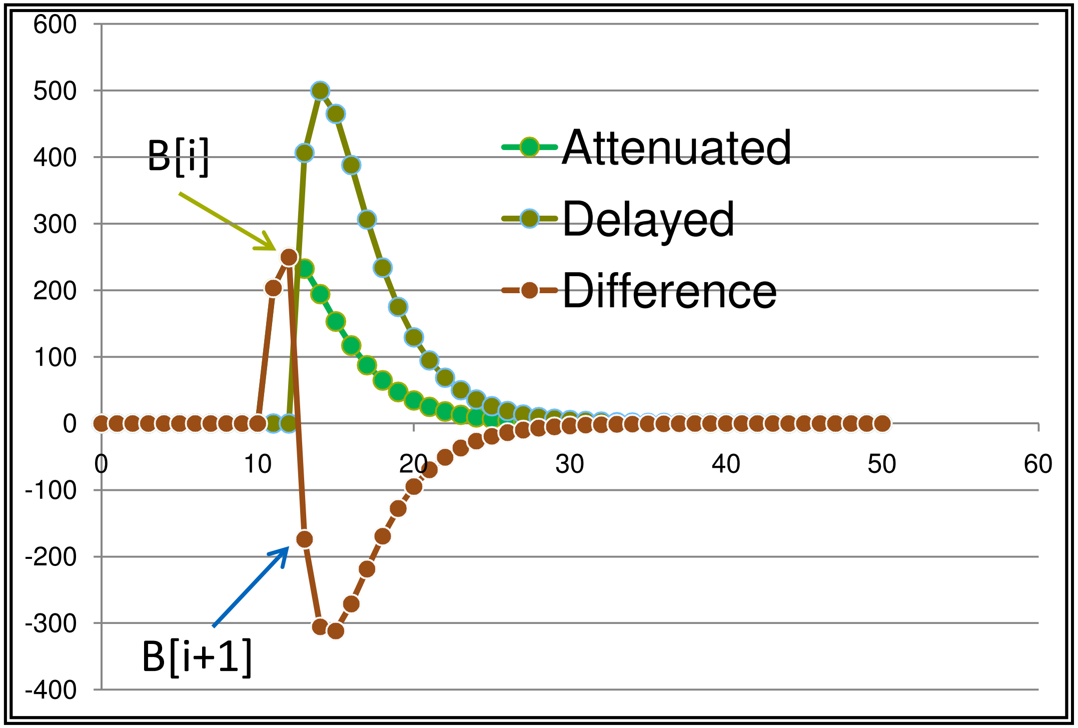
  B[i] > 0 & B[i+1]≤ 0

- Fine Time :

  dt = B[i]/(B[i] - B[i+1])

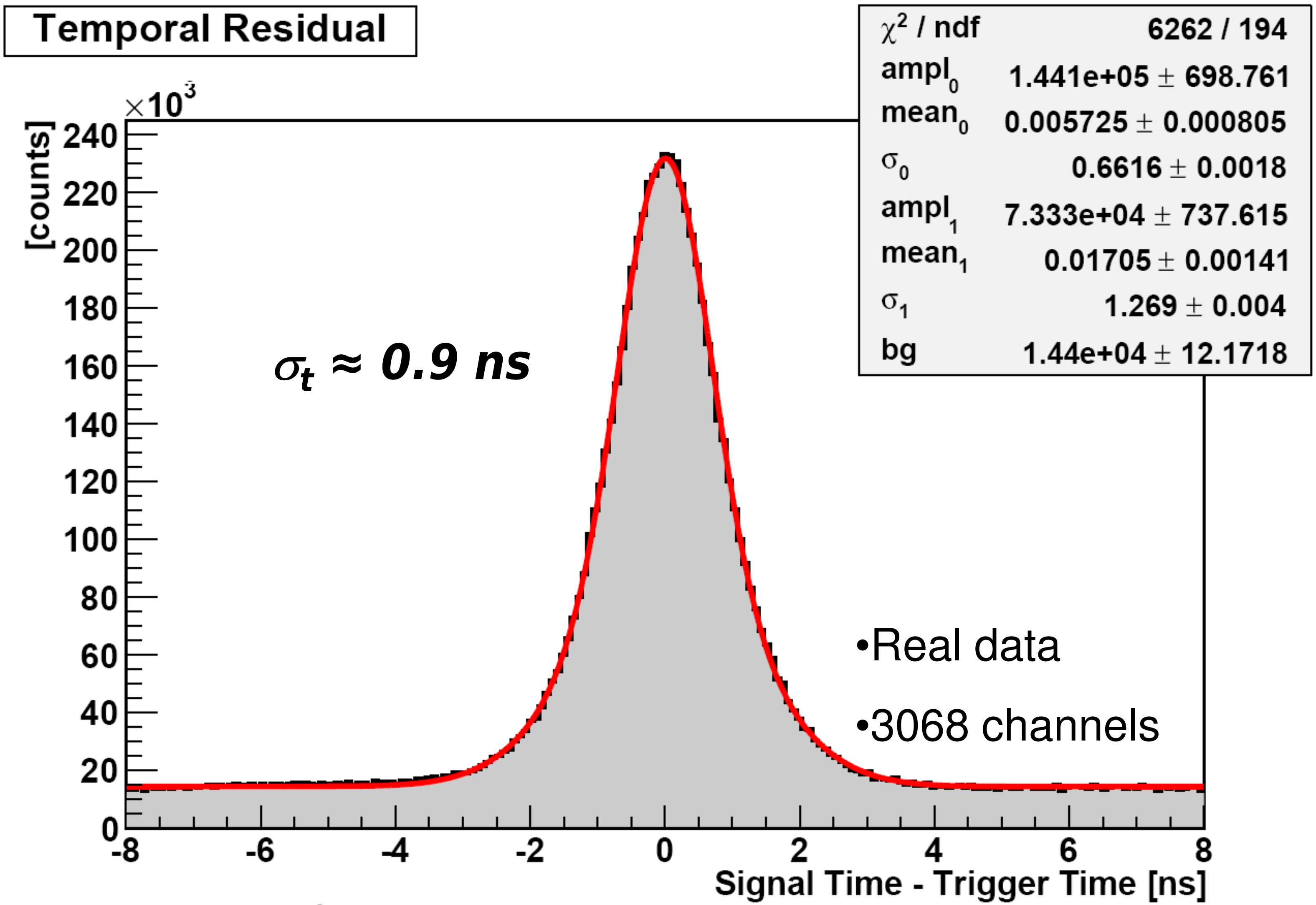
- Trigger if A[i+M] is over threshold

- A[i+M] taken as signal amplitude (if triggered)



Channel level computation

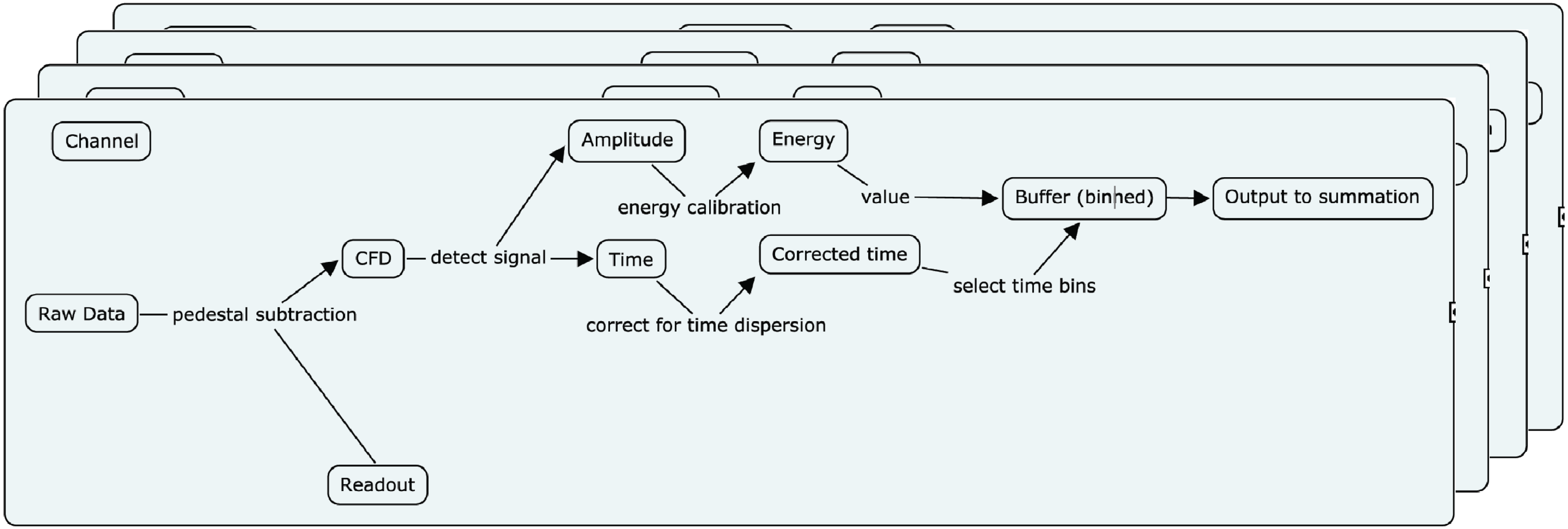
- Pedestal subtraction
  - Pedestal updated upon each spill
- Constant fraction discriminator plus threshold
  - Signal detection/zero suppression
  - Time calculation
  - Amplitude extraction
  - Configurable
- Energy calibration
  - Using energy calibrations for each individual channel
  - Continuously monitored (online data processing)
- Correct time dispersion of channels
  - Using time calibrations on channel base
  - Continuously monitored (online data processing)



Amplitude cut: 20 ADC channels ≈ 600 MeV

Implementation on Mezzanine card

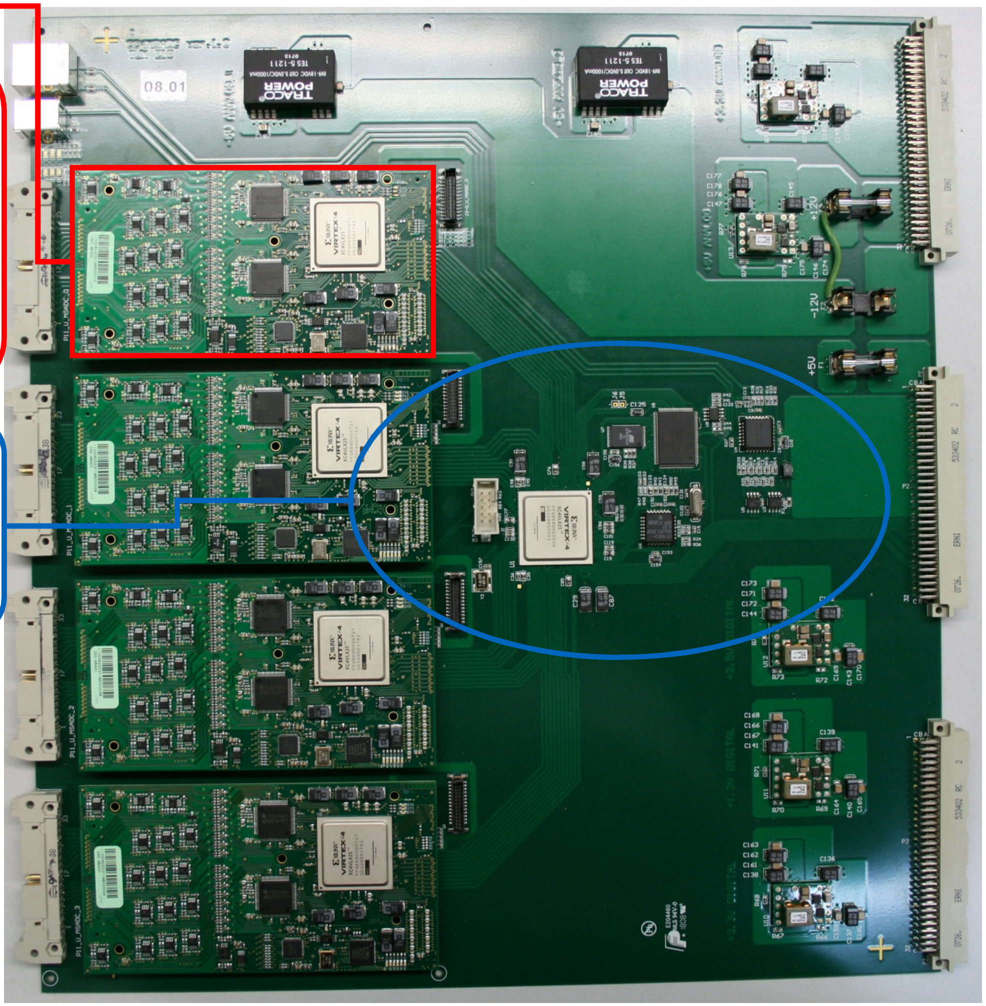
16 x



+ Sum 16

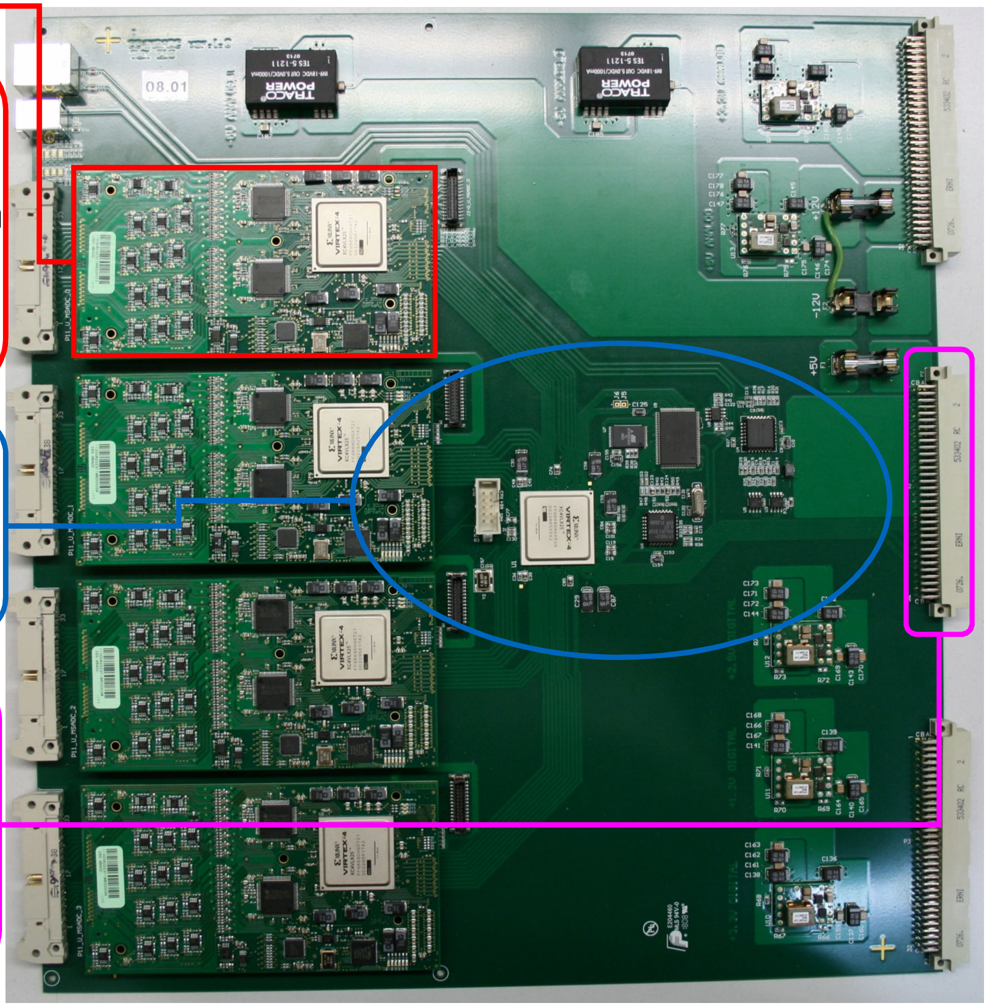
Hardware overview

- Mezzanine Card:
  - Channel level:
    - Signal detection/zero suppression
    - Time extraction
    - Energy conversion
  - Sum over 16 Channels
- VME module:
  - Sum over 64 Channels
  - Output to backplane

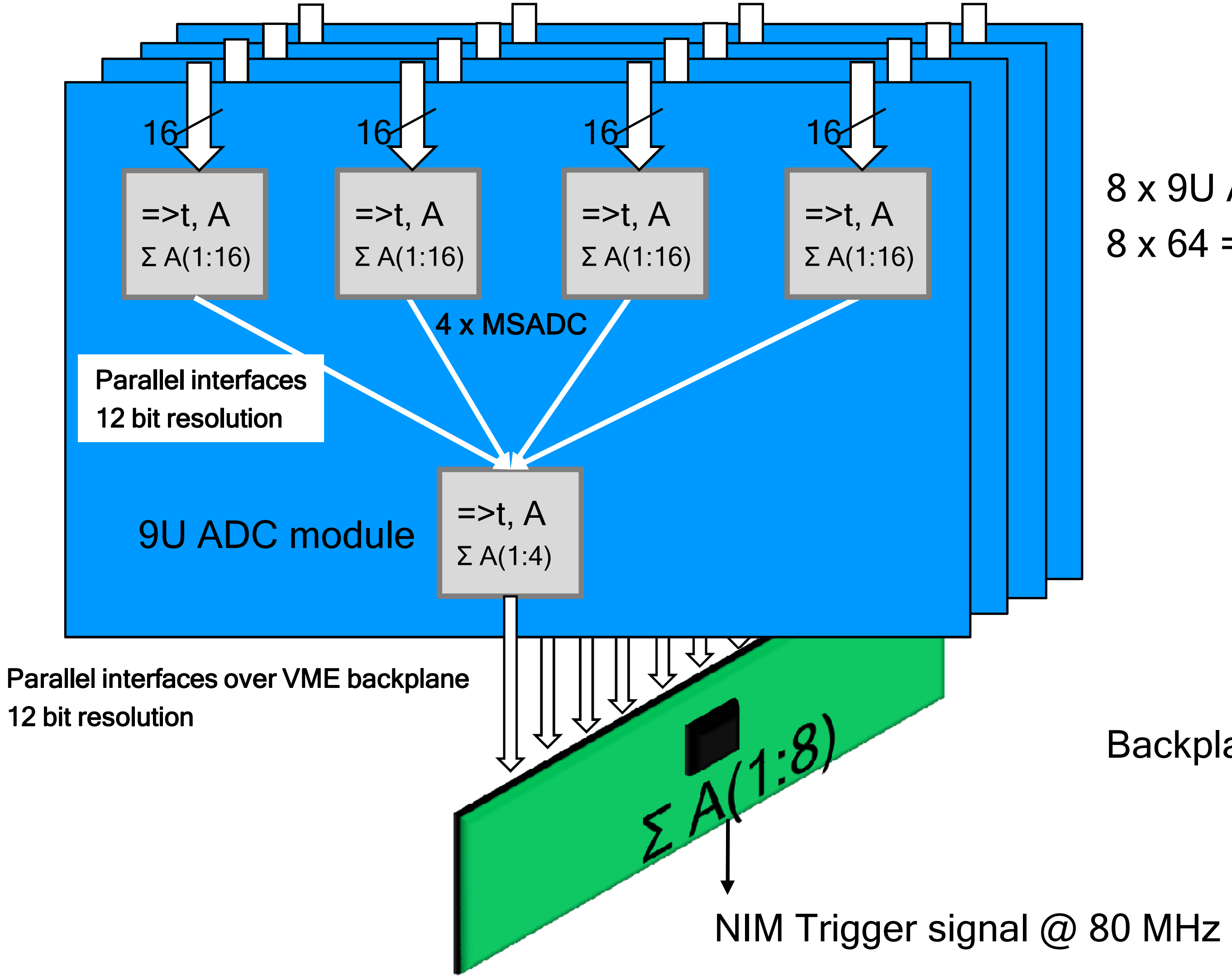


Hardware overview

- Mezzanine Card:
  - Channel level:
    - Signal detection/zero suppression
    - Time extraction
    - Energy conversion
  - Sum over 16 Channels
- VME module:
  - Sum over 64 Channels
  - Output to backplane
- Backplane summation cards
    - Final summation
    - Apply threshold (output NIM)
    - Extendable by interconnection



System architecture in 2009



8 x 9U ADC modules

8 x 64 = 512 channels

Backplane summation card

Monitoring

- Monitor and generate calibration constants continuously
  - Using online data processing (PC farm)
  - Monitor LED pulses to adjust energy calibrations
  - Extract timing of channels
  - Updated once per run (about 2h)
- Stored values in VME registers
  - Independent communication
  - Scaler (channel)
  - Current pedestals
  - Readout once per spill
- Hit Time and Amplitude added to corresponding event into data stream for online/offline analysis

Conclusion/Outlook

- Digital trigger logic on FPGA
  - Implemented on electronics developed for ECAL readout (12bit, 80MHz SADC)
  - Pipelined CFD based algorithm
  - Time resolution better than ***1ns***
  - Architecture scalable
  - Expected trigger rates for COMPASS ca. 25kHz@30GeV threshold (190GeV/c hadron beam)
- Schedule
  - Start of project mid December 2008
  - Test beam end of August 2009 (Analysis of data is currently ongoing)
  - First use in COMPASS foreseen for mid October 2009
- Upgrade options for future improvements
  - Include complete calorimeter (multiple summation ranges)
  - Clustering (improved noise suppression and energy calculation)

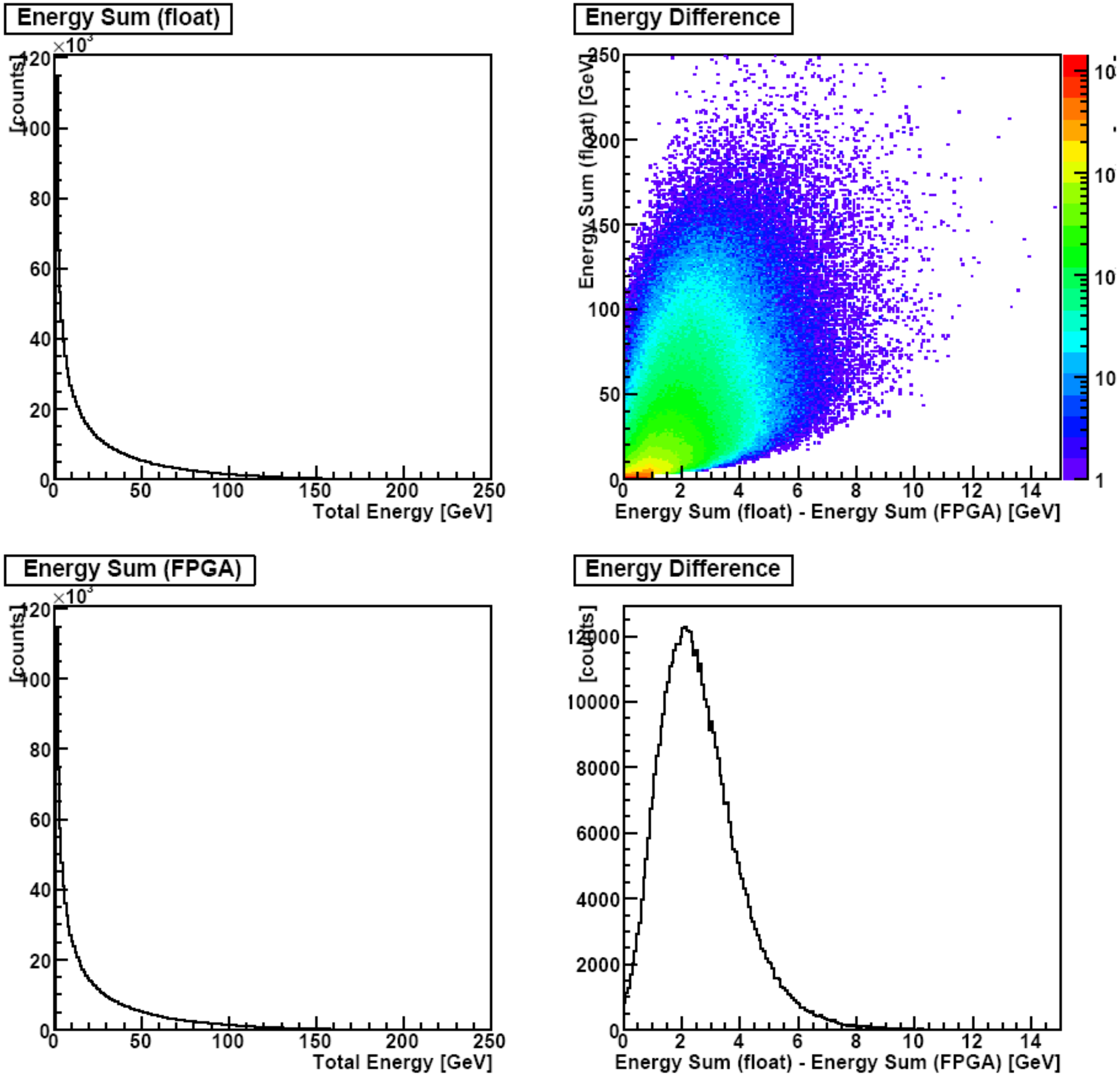
Thank you for your attention!

Expected Trigger-Rates for ECAL2 (no coincidence)

- Conditions:
  - Beam:
    - Intensity: ***≈5·10⁶/s***
    - Particles: π^-
    - Momentum: ***190GeV/c***
  - Target:
    - ***Cu 3.5 mm***
    - ***≈24%*** X_0
    - ***≈2.3%*** λ_I
- Rates from simulation:

Threshold	FULL (64x48)	16x16
20 GeV	85.1 kHz	40.7 kHz
25 GeV	60.5 kHz	32.0 kHz
30 GeV	36.7 kHz	25.6 kHz
35 GeV	28.6 kHz	21.0 kHz
40 GeV	22.9 kHz	17.3 kHz
60 GeV	10.2 kHz	8.4 kHz
80 GeV	5.0 kHz	4.3 kHz

Energy comparison between online (FPGA) and 'offline' (float)



Time constrains for trigger (estimation)

- Time of flight (Target to ECAL2): 115 ns
- Signal generation (Detection to ADC): 120 ns
- ADC digitalization: 200 ns
- Run time trigger signal to trigger barrack: 200 ns
- Trigger decision in FPGA clock cycles (@80MHz)
  - Channel computation: 1-3 (depends on implementation, might be combined with digitalization)
  - Delay to synchronize signals: 1-3 (foreseen, synchronizes most channels)
  - Mezzanine (Sum over 16 channels): 3 (might even be combined with earlier)
  - VME module (Sum over 64channels): 2
  - Sum over all channels: <=1

  $\Rightarrow$ $\approx 12 \cdot 12.5$ ns = 150 ns

$\Rightarrow$ Needed are **765 ns** to make decision. Currently there are about 500 ns to take a trigger decision. Increase to ***1 μs*** to be on the save side.

$\Rightarrow$ Digital trigger achievable with current ECAL2 electronics!!!

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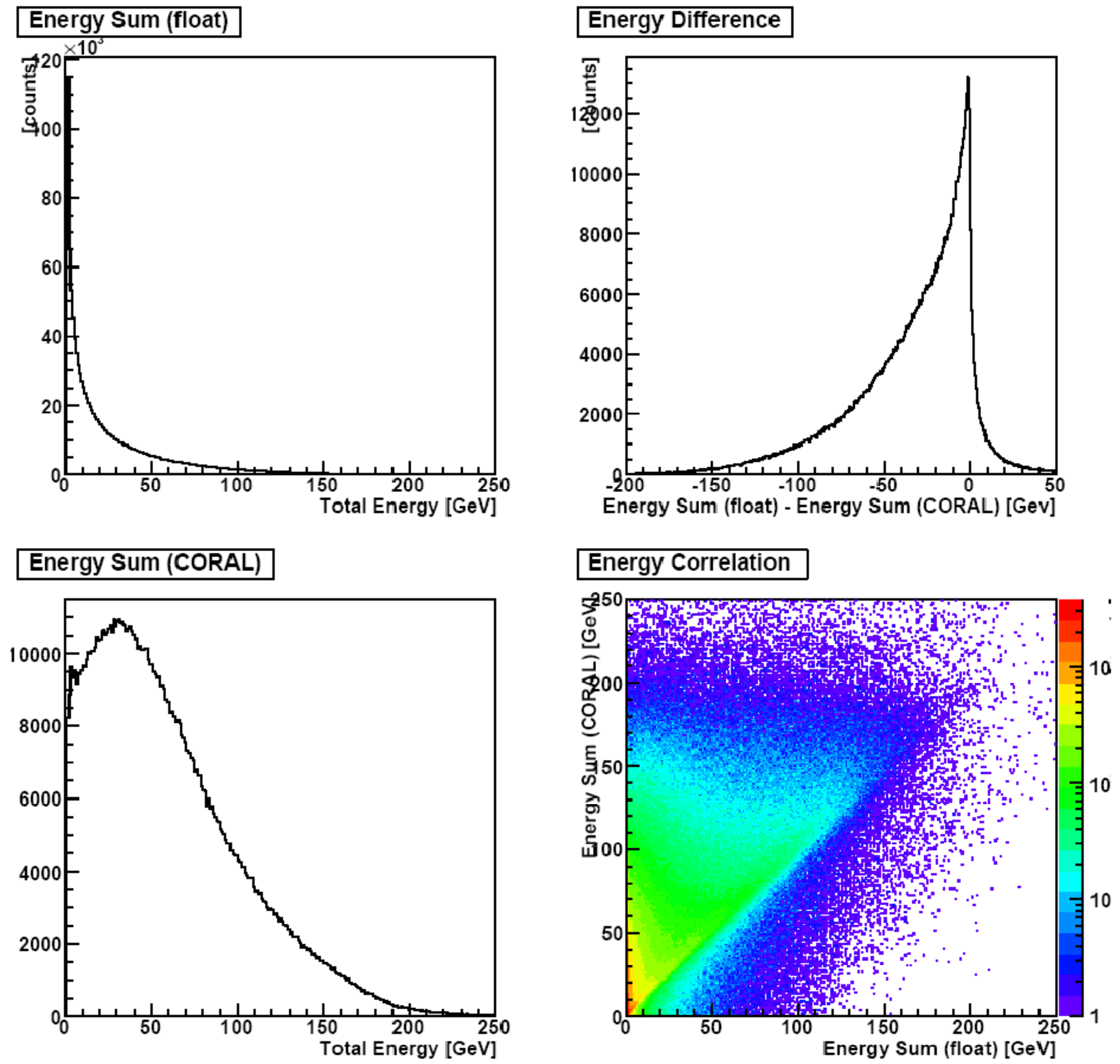
Energy studies

CORAL Cluster

Energy Threshold:

0.0 GeV



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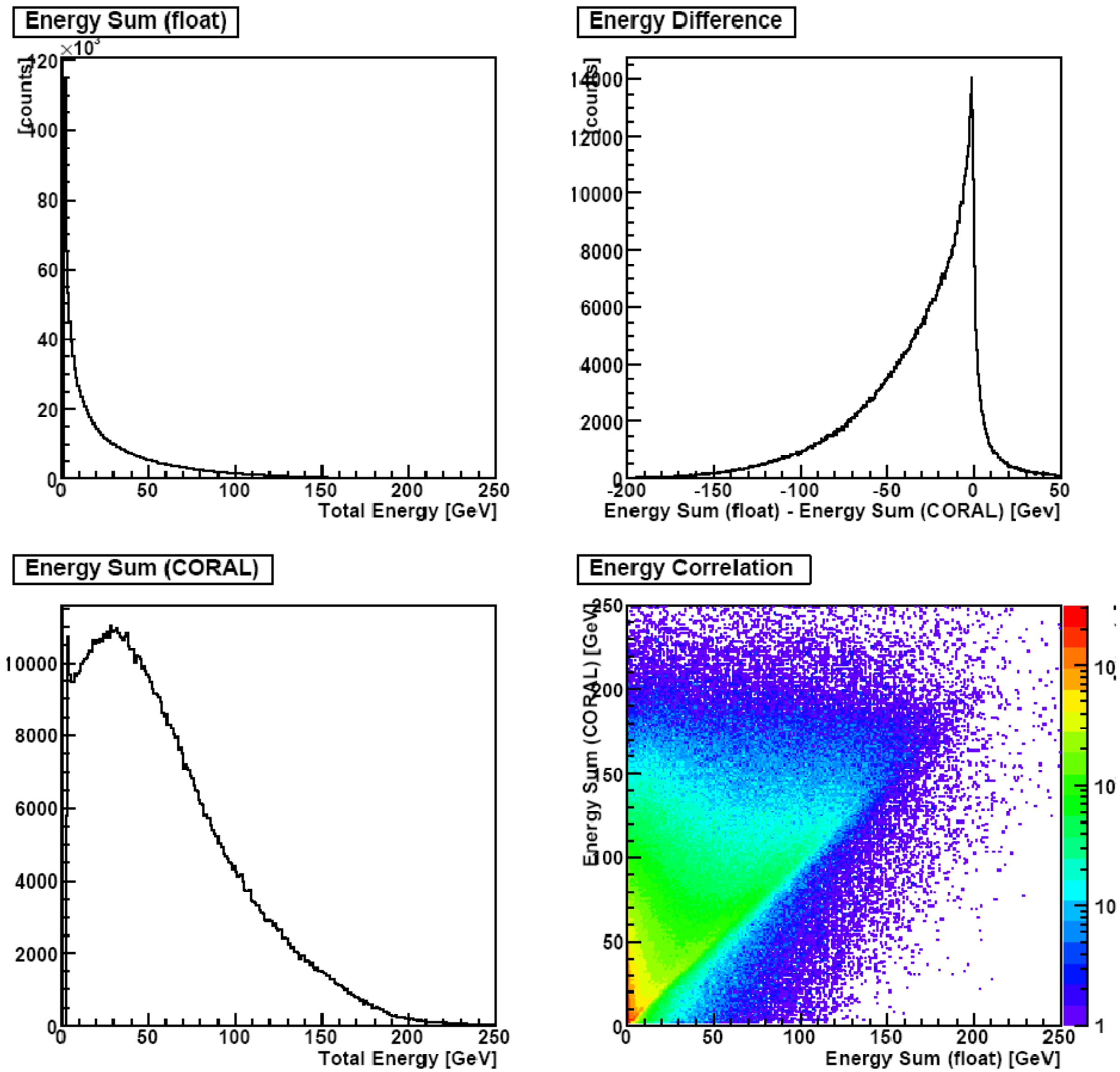
Energy studies

CORAL Cluster

Energy Threshold:

2.5 GeV

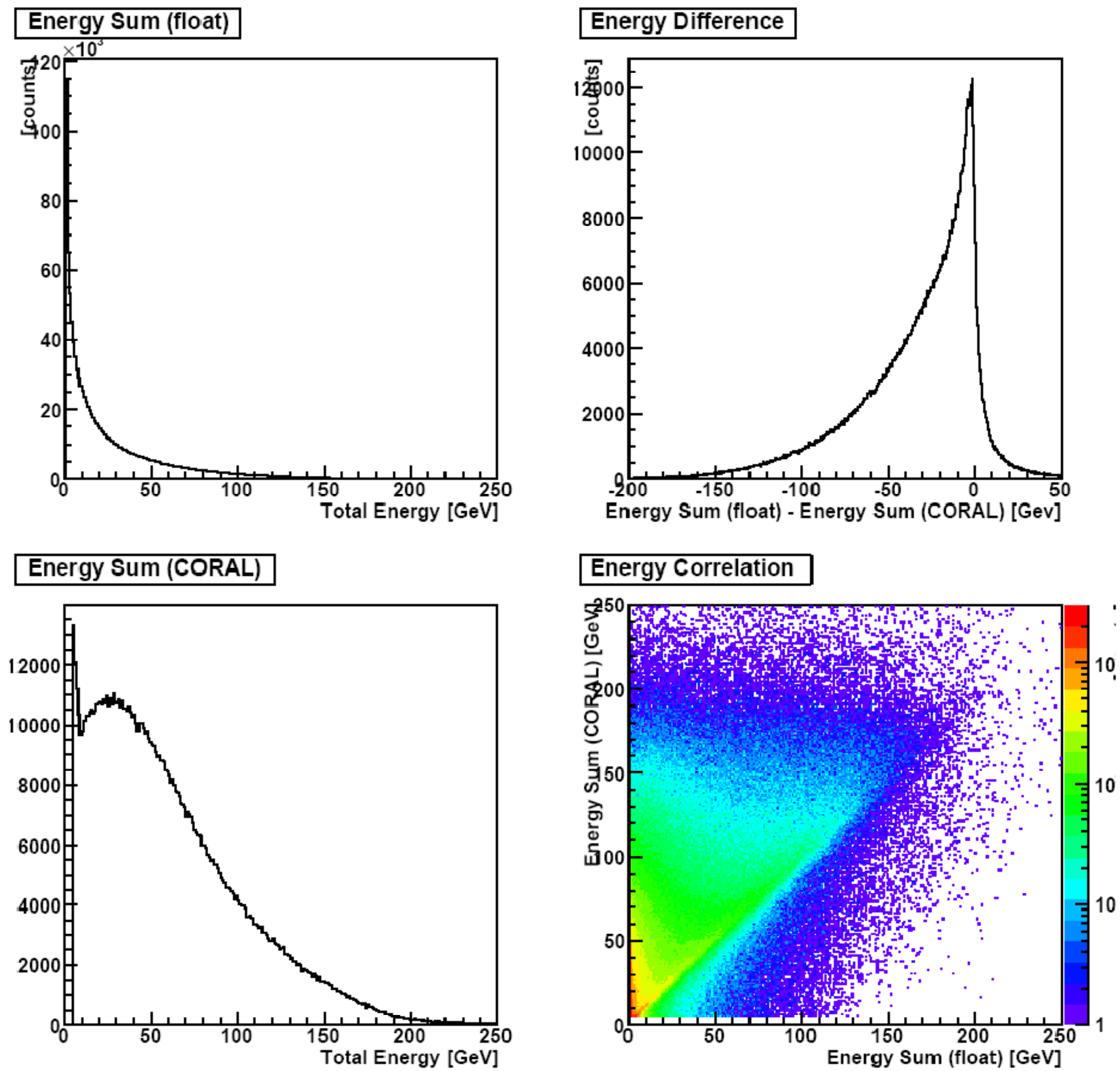


Energy studies

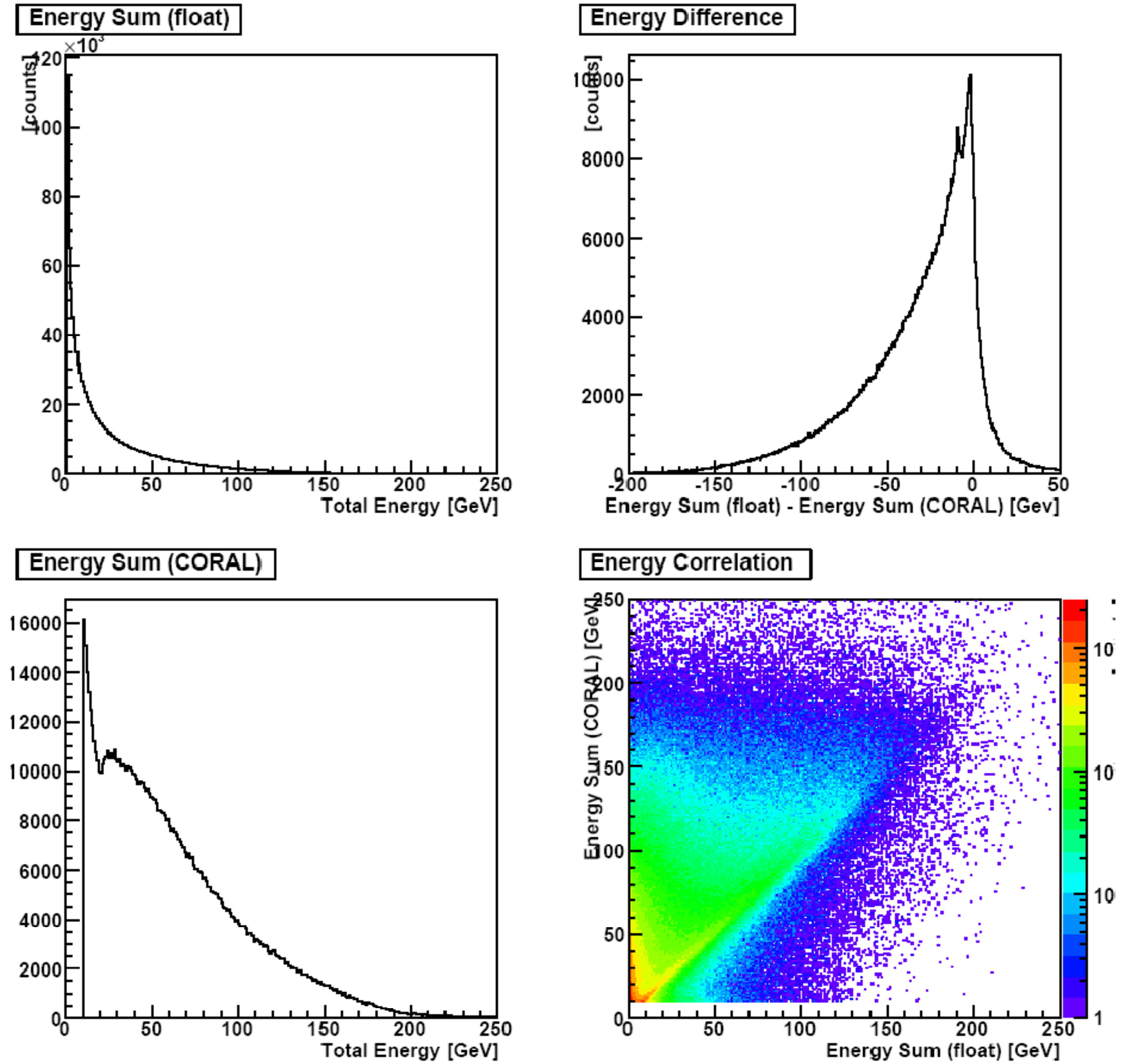
CORAL Cluster

Energy Threshold:

5.0 GeV



Energy studies



CORAL Cluster

Energy Threshold:

10.0 GeV