The NA62 Liquid Krypton Electromagnetic Calorimeter Level 0 Trigger

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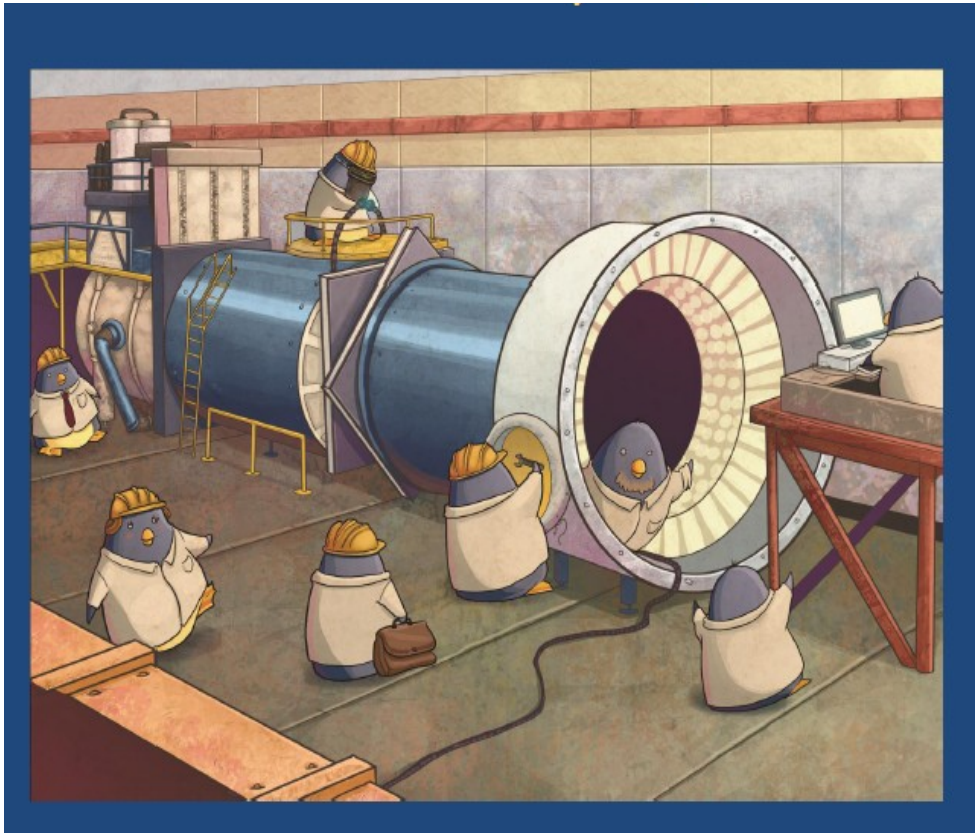
Outlook



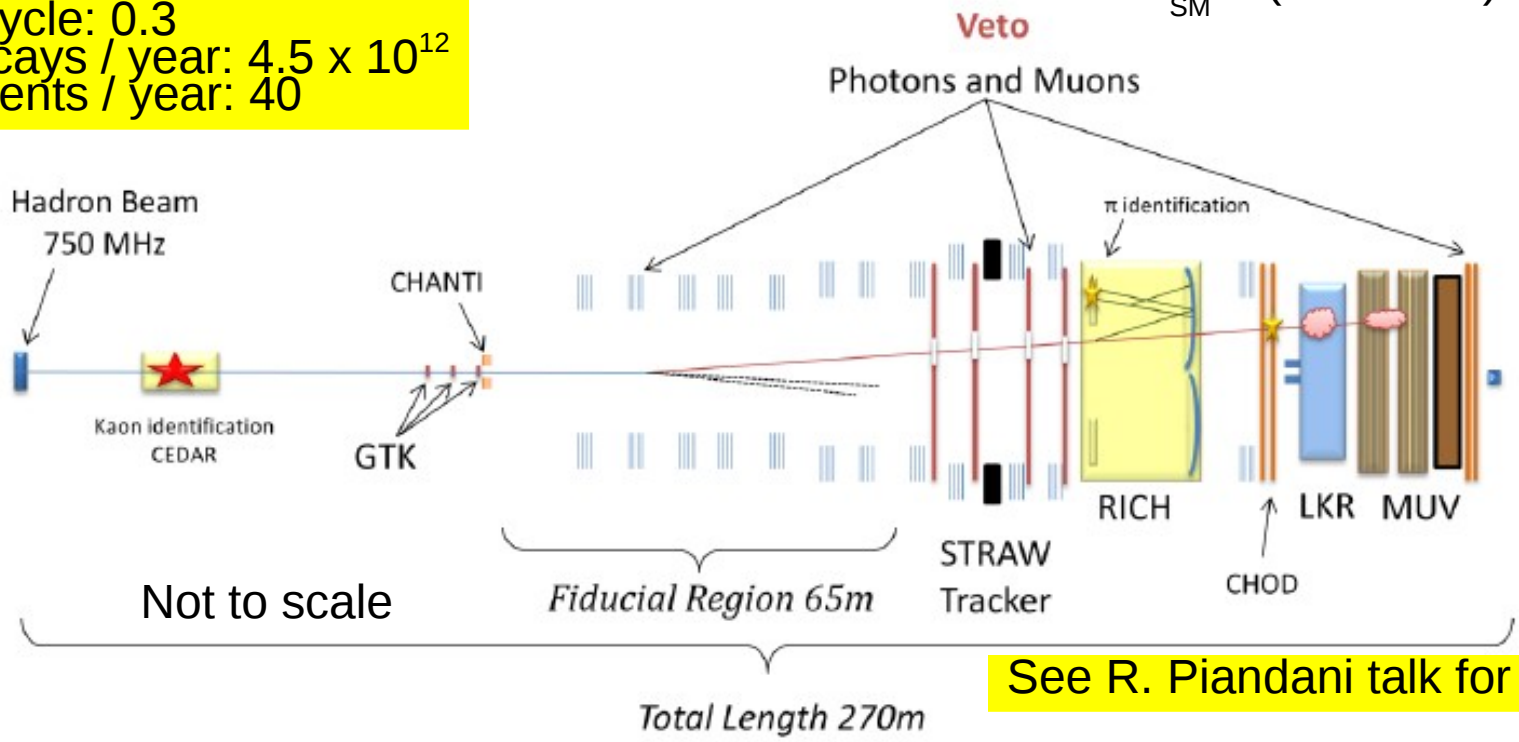
- The NA62 experiment
- The TDAQ system
- The LKr electromagnetic calorimeter
- The Lkr L0 trigger processor
- Conclusions

The NA62 experiment at CERN SPS

Inst p rate / eff: 1.1 x 10^{12}
Momentum: 75 GeV/c
Duty cycle: 0.3
K+ decays / year: 4.5 x 10^{12}
SM events / year: 40

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$

$BR_{SM} = (8.5 \pm 0.7) \times 10^{-11}$

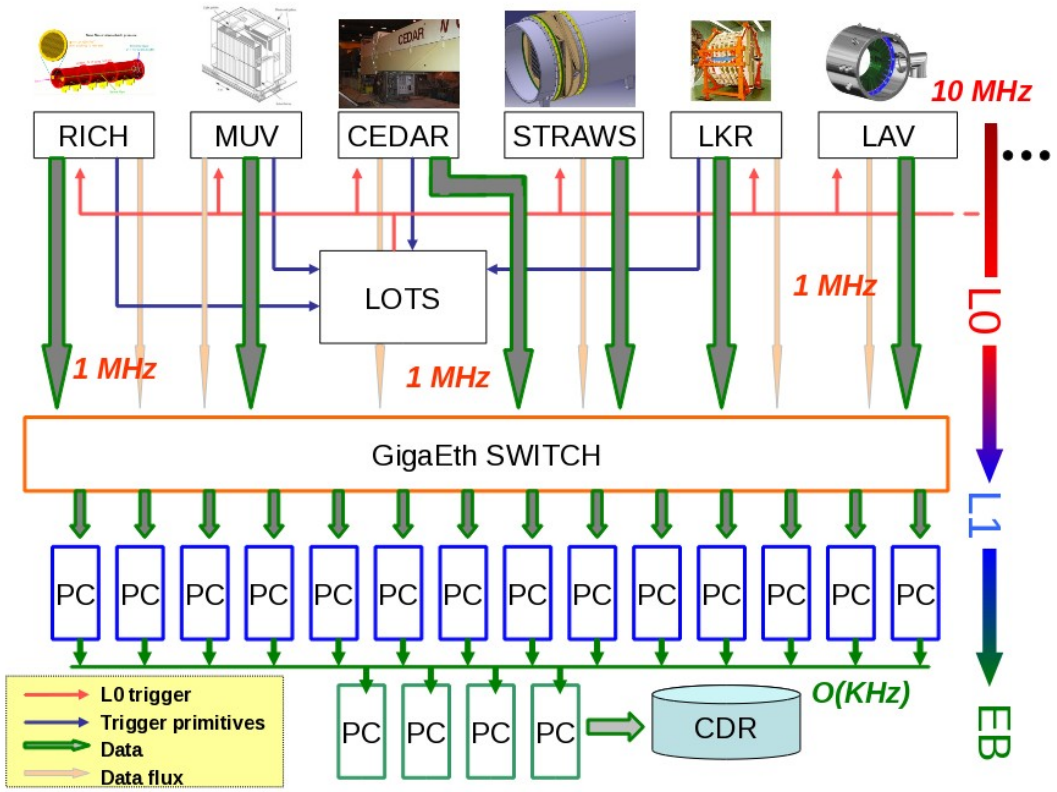


See R. Piandani talk for details

In flight kaon decay technique: K tagging (CEDAR)
Kinematical rejection: K^+ momentum (GTK) and π^+ momentum (magnetic spectrometer)
Particle ID and veto: γ veto(LKr, LAV, SAR), π/μ separation (muon detector and RICH), multi-track event veto (straw tracker)

The TDAQ System

12 sub-detectors, ~ 80000 channels, 25 GB/s raw data



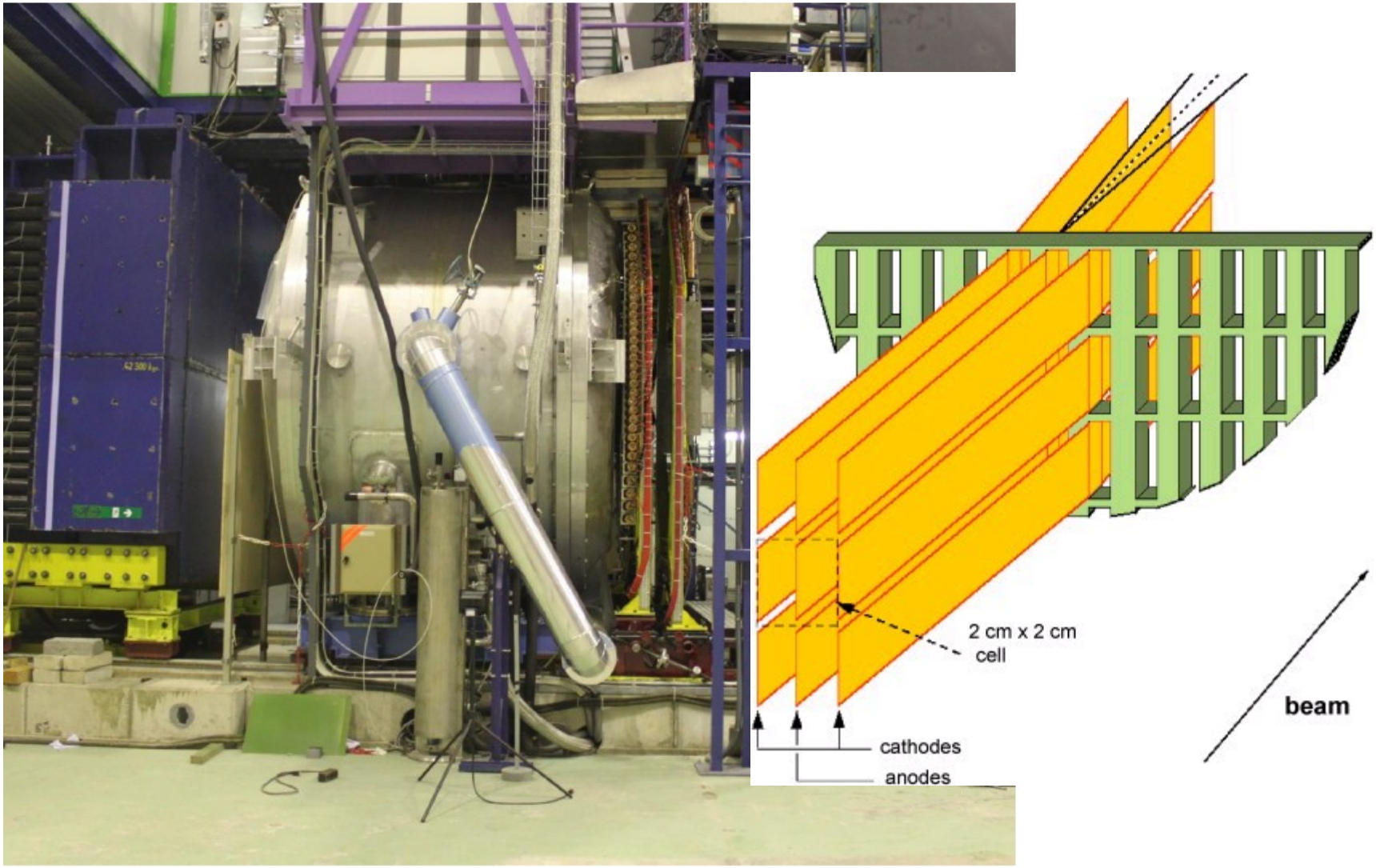
L0 hardware trigger based on few sub-detectors: after L0 data readout from the FE electronics to dedicated PCs (for most sub-detectors); max output rate 1 MHz, max total latency 1 ms

L1 software trigger executed independently by each sub-detector using data stored on dedicated PCs; max output rate 100 kHz, max total latency 1 s

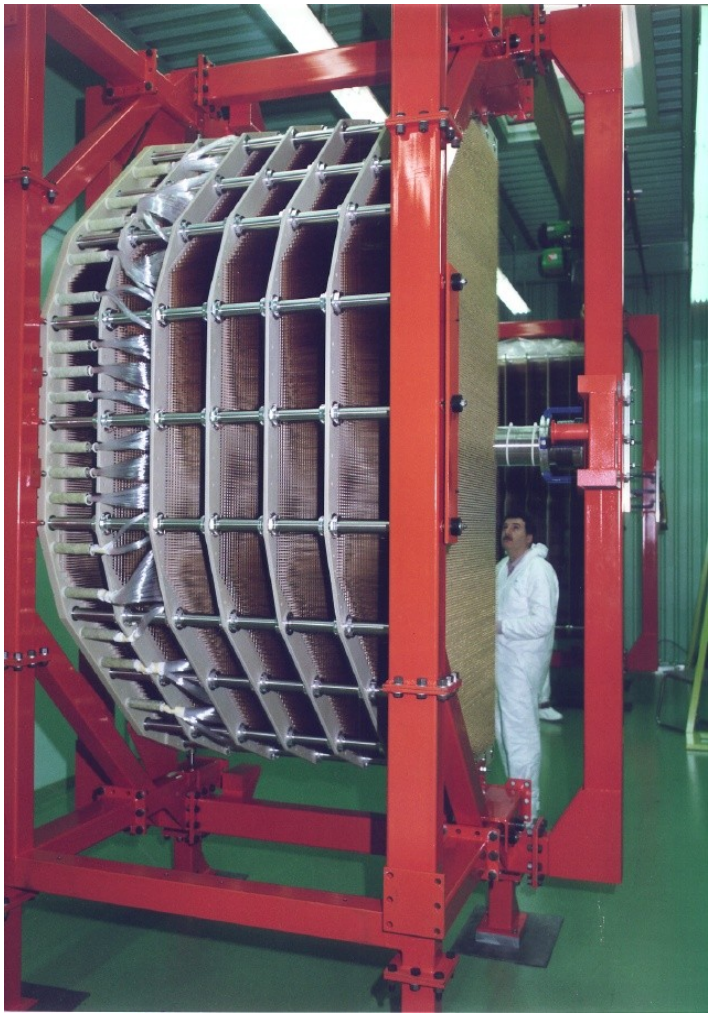
L2 software trigger based on assembled and partially reconstructed events; max output rate O(15 kHz), max total latency spill period

$$L0 = RICH * \overline{LKR} * \overline{MUV}$$

The NA48 Liquid Krypton electromagnetic calorimeter



The NA48 Liquid Krypton electromagnetic calorimeter



13248 channels
27 X_0

$$\frac{\sigma_E}{E} = \frac{0.032}{\sqrt{E}} \oplus \frac{0.09}{E} \oplus 0.0042$$

$$\sigma_{X,Y} = \frac{0.42}{\sqrt{E}} \oplus 0.06$$

$$\sigma_t = \frac{2.5}{\sqrt{E}}.$$ (GeV, cm and ns)

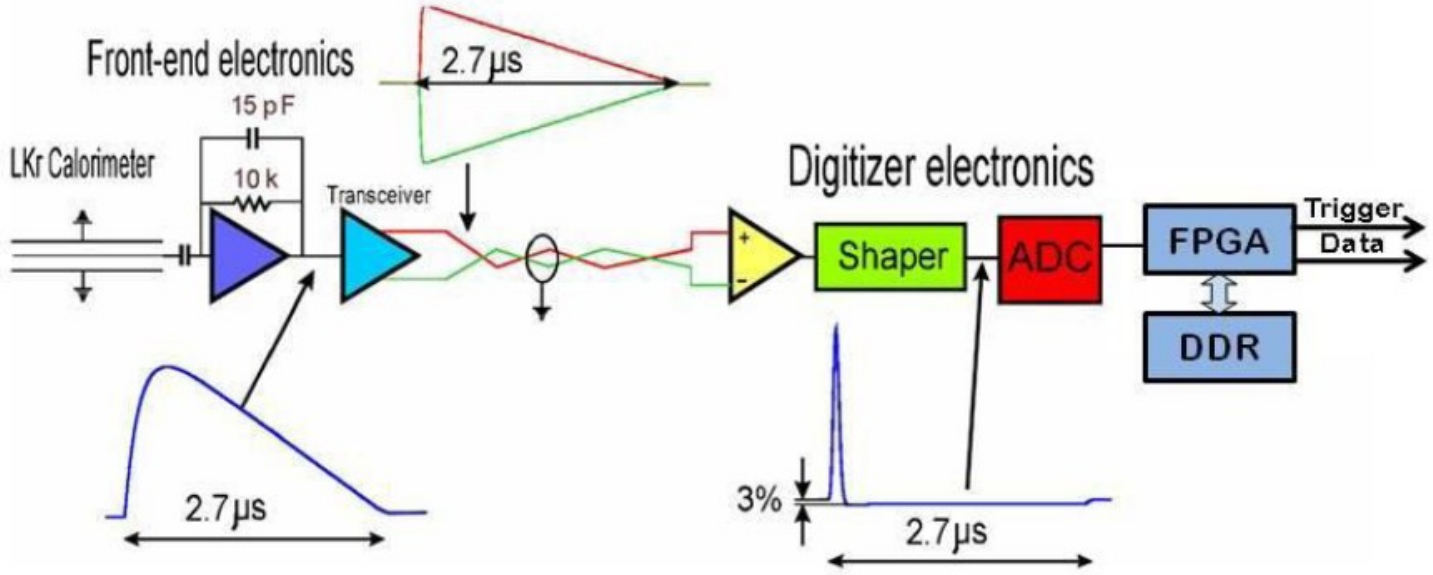
Photon veto in the angular decay region 1-8.5 mrad

For $K^+ \rightarrow \pi^+ \pi^0$ decays in the decay fiducial region and for $E_\pi < 35$ GeV 80% of the photons are in the Lkr acceptance

Inefficiency < 10^{-5} for $E_\gamma > 10$ GeV

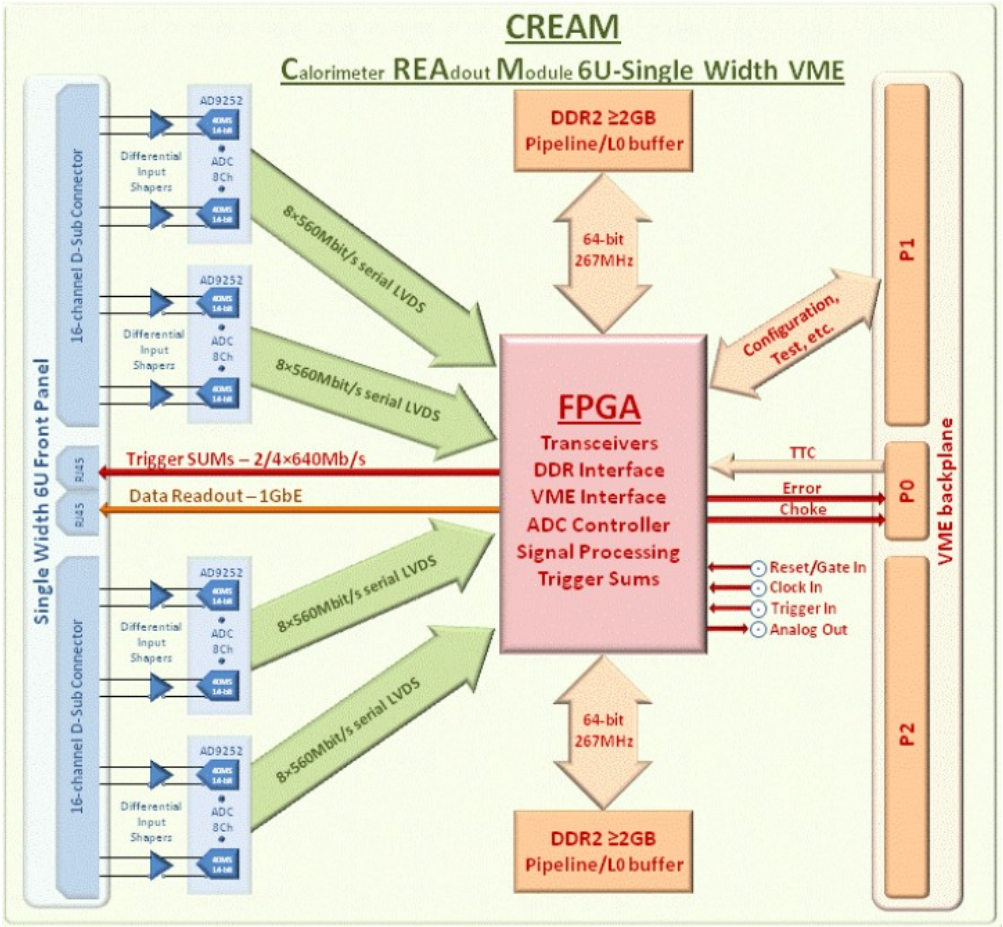
Not zero-suppressed readout

The LKr calorimeter readout chain



Cold preamplifier in the liquid krypton
Transceivers on the cryostat feed-trough
Digitizer and trigger electronics changed

The LKr calorimeter readout module

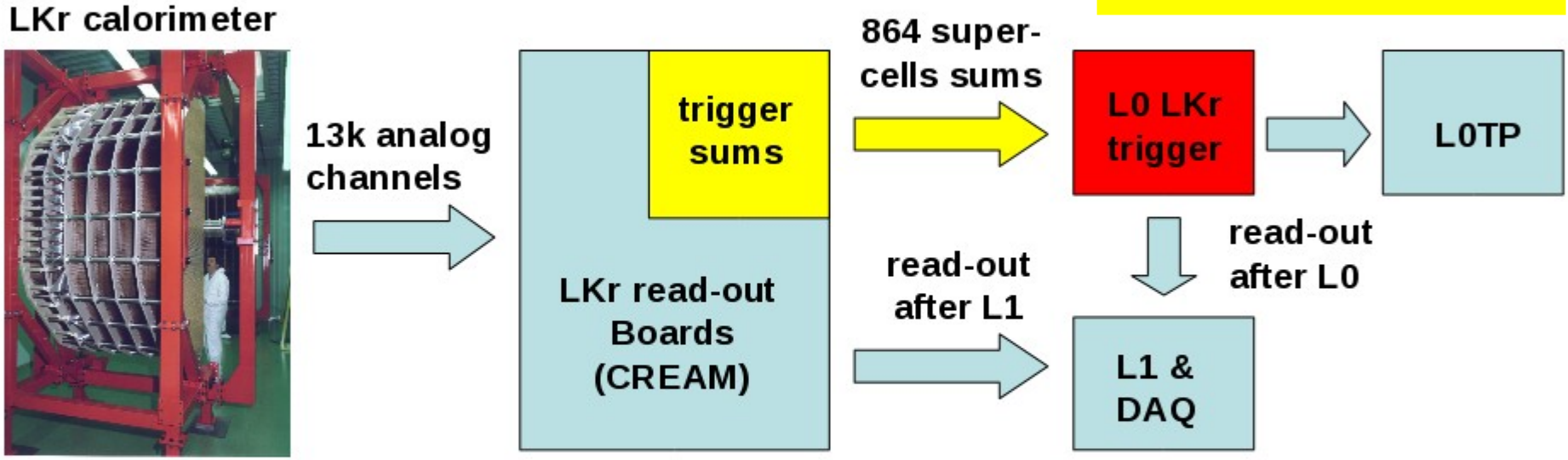


The "old" NA48 digitizer boards no longer suitable for NA62: max readout rate too low (10 kHz)

CREAM: Calorimeter REAdout Module
Developed at CERN
6U VME 64x card
32 channels digitizer
14 bit ADC @ 40 MHz
On board latency memory
Max readout rate 1 MHz
Trigger sums (2x8 or 4x4 Lkr tiles) for the LKr/L0 trigger
Transmitted to the Lkr/L0 trigger over cat5 ethernet cables

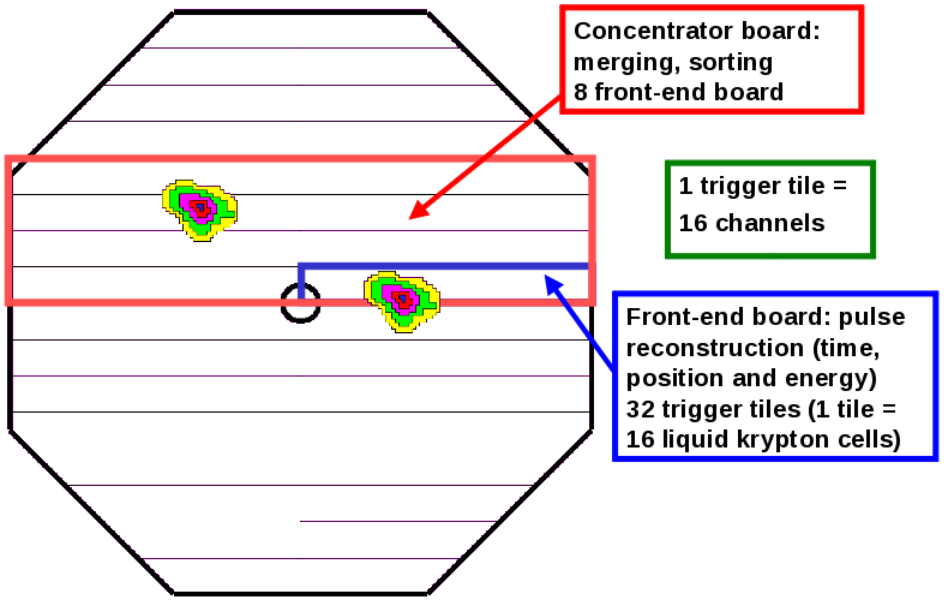
The liquid krypton calorimeter L0 trigger

Inst. hit rate: 30 MHz
Time resolution: ~1.5 ns
Latency < 100 us



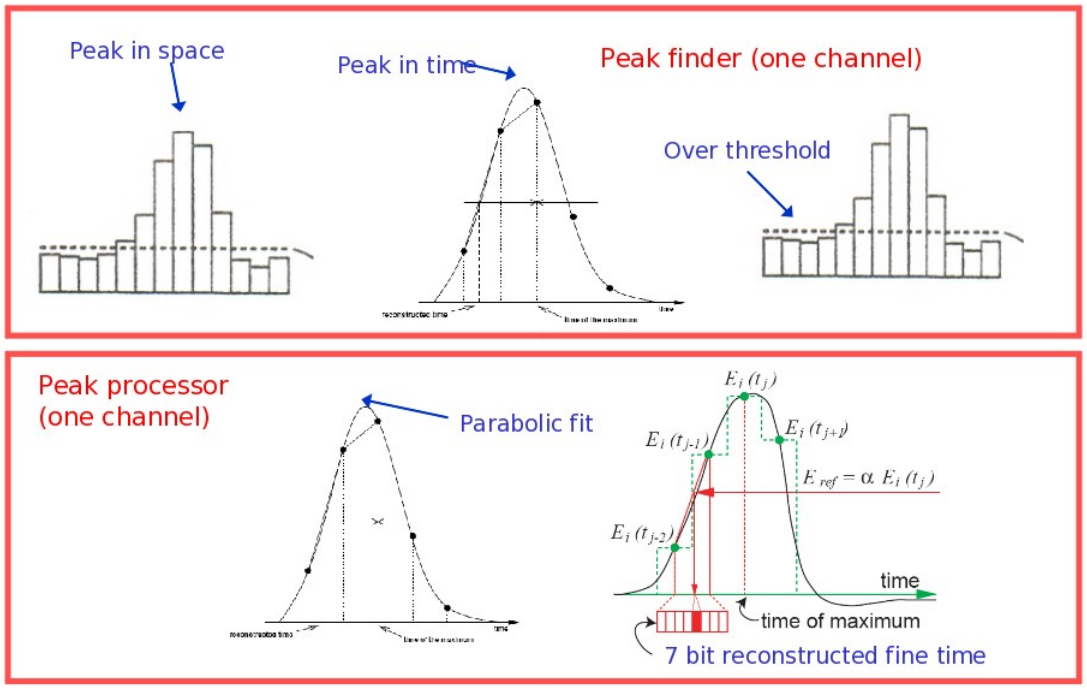
- Pixel based trigger processor with 2x8 or 4x4 calorimeter cell tiles
- Identifies electromagnetic clusters in the calorimeter and prepares a time-ordered list of reconstructed clusters (time, position and energy) for the L0 Trigger Processor
- Low granularity readout independent from CREAM full granularity readout
- Fast readout for L1 software triggers and/or Region of Interest for the Lkr full granularity readout at L1

Lkr L0 trigger algorithm



- 1 D + 1 D pixel based algorithm
- Calorimeter divided in slices parallel to the x axis
- Front-End boards (28): peaks in space and time indipendently searched in each slice: digital constand fraction discriminator + linear interpolator for fine timing
- Concentrator boards (7 + 1): peaks close in space and time merged and assigned to the same electromagnetic cluster

Peak reconstruction



Preliminary non optimized version of the peak reconstruction algorithm can reconstruct a peak every 62.5 ns on a rather old FPGA → maximum acceptable peak rate 16 MHz

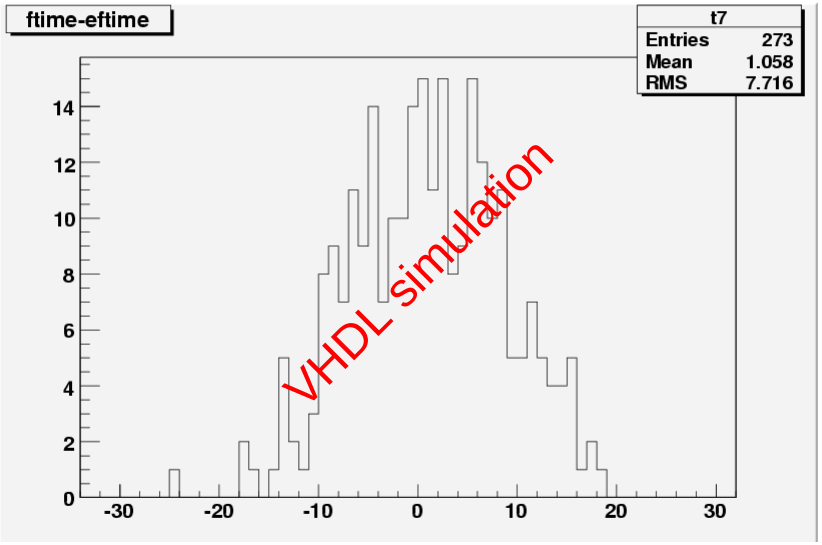
Digital Constant Fraction Discr

Peak search in parallel for all input tiles

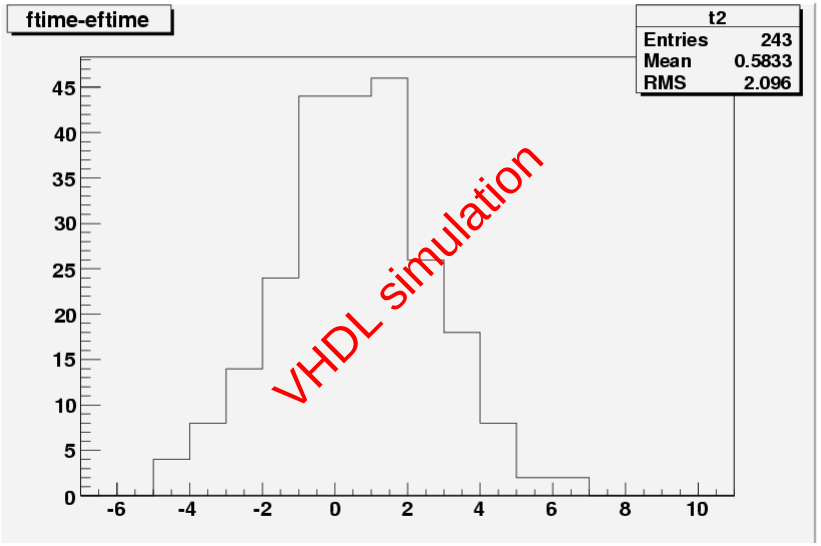
- Peak in space: $E_{i-1}[n] < E_i[n]$ AND $E_i[n] > E_{i+1}[n]$, E ADC count, i tile number, n sample number
- Peak in time: $E_i[n-2] < E_i[n-1] < E_i[n]$ AND $E_i[n] > E_i[n+1]$
- Threshold check: $E_i[n] > E_{th}$
- Parabolic interpolation in time around maximum
- Linear interpolation in energy between samples n-2 and n-1

Peak reconstruction

40 MHz sampling: 100 ps/bin
1/40 full scale pulse + noise + jitter → 700 ps RMS

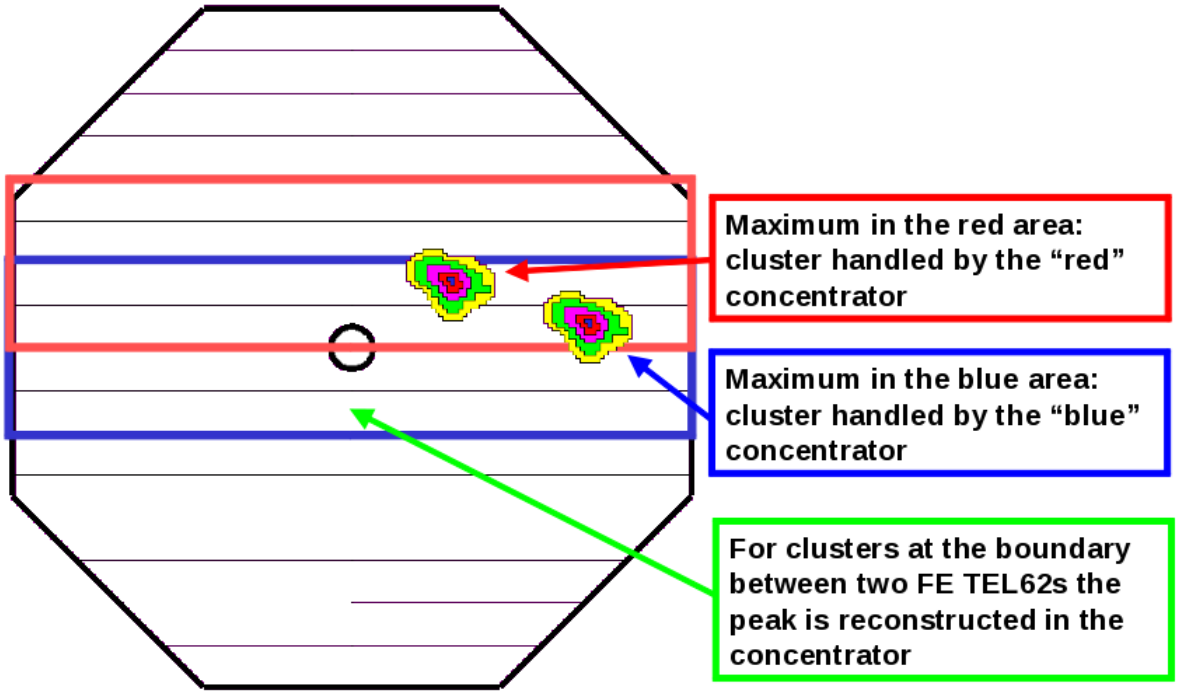


80 MHz sampling: 50 ps/bin
full scale pulse → 100 ps RMS



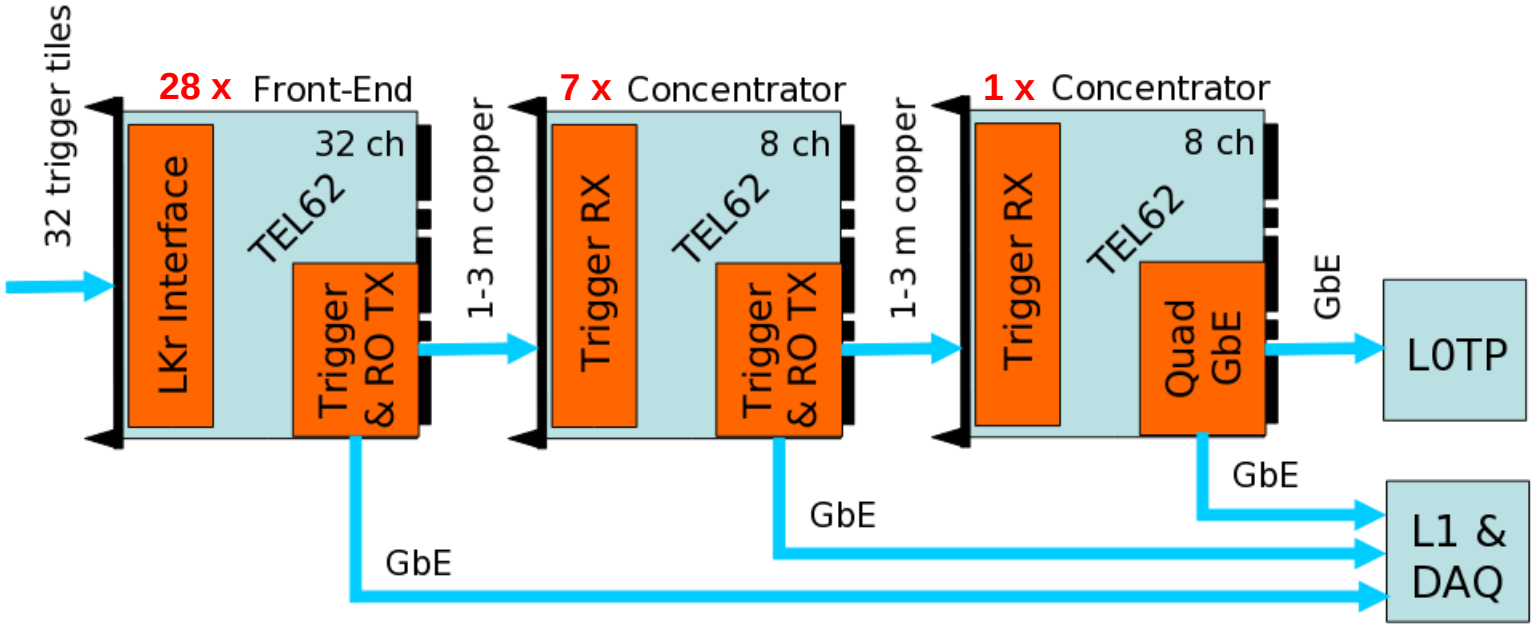
VHDL simulations with simple test functions to check the peak time reconstruction algorithm

Overlap handling in the Concentrators



- Each cluster is fully contained in a single Concentrator
- The area covered by a Concentrator is divided in an inner and an outer region
- Only clusters with the energy maximum along the vertical axis in the inner region of the Concentrator are managed by the Concentrator, to avoid double counting

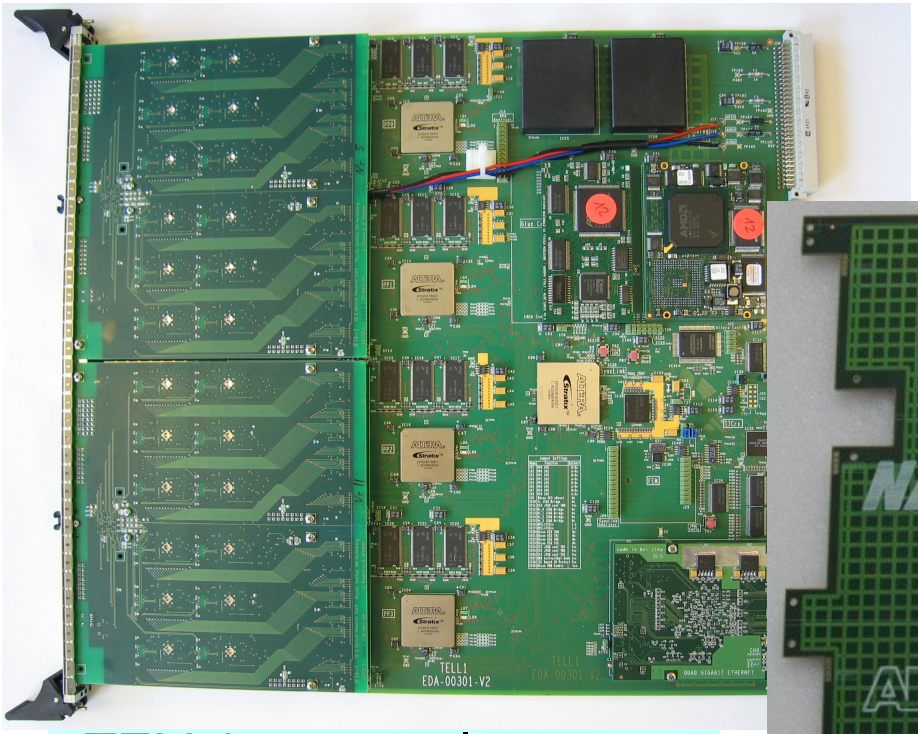
Lkr L0 trigger implementation

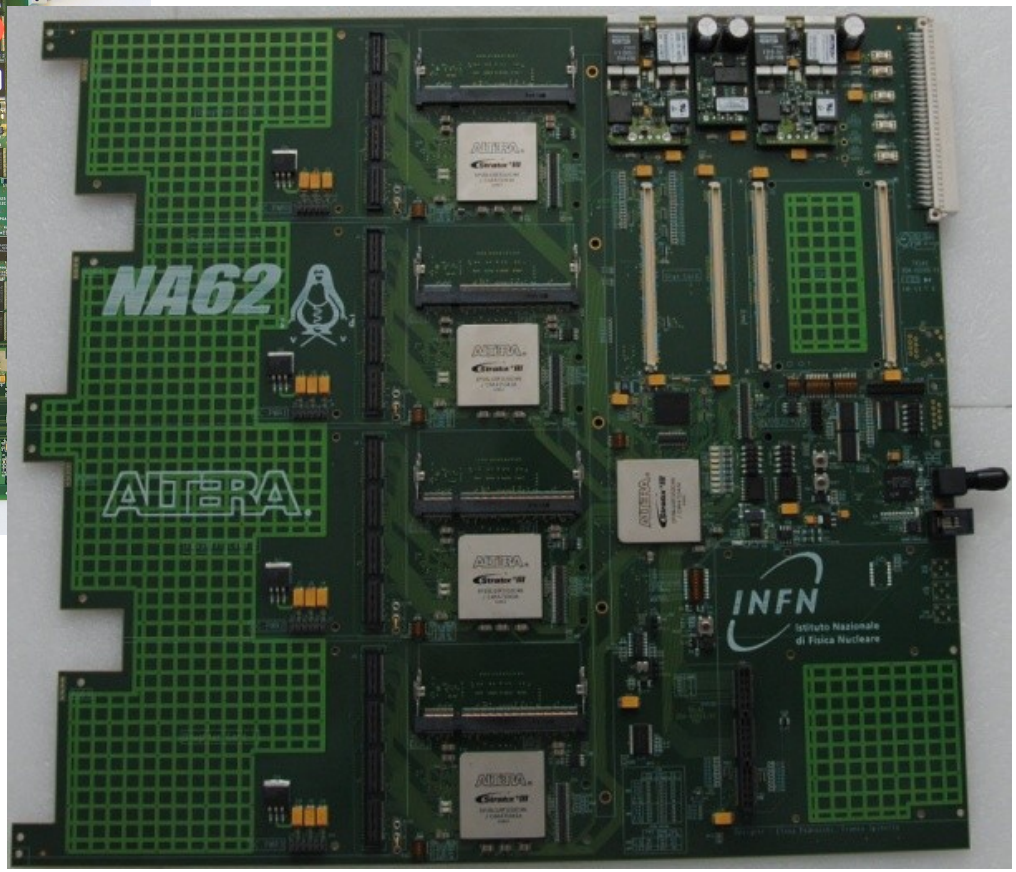


- 36 9U TEL62 electronics modules + 108 dedicated mezzanines
- 3 9U crates
- 864 input channels (tiles), 16 bit @ 40 MHz per tile from the calorimeter readout modules (CREAM) over cat 5 Ethernet cables
- 1 trigger output channel (Gbit Ethernet) to the L0 Trigger Processor
- 28 raw data + 7 reconstructed clusters readout channels to L1 and DAQ
- Less than 100 μs output latency

The motherboard: from TELL1 to TEL62

TEL62: new general purpose trigger and data acquisition board developed ar INFN Pisa for the NA62 experiment

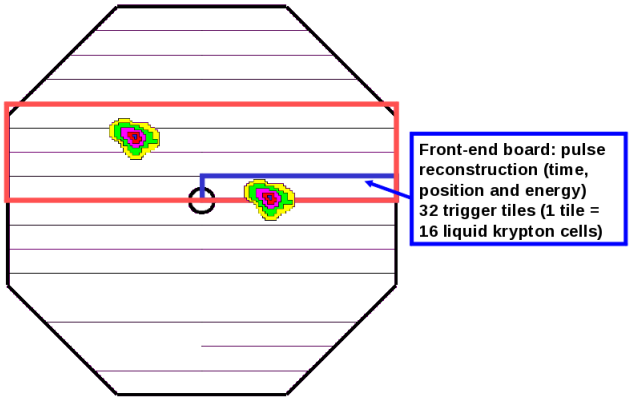


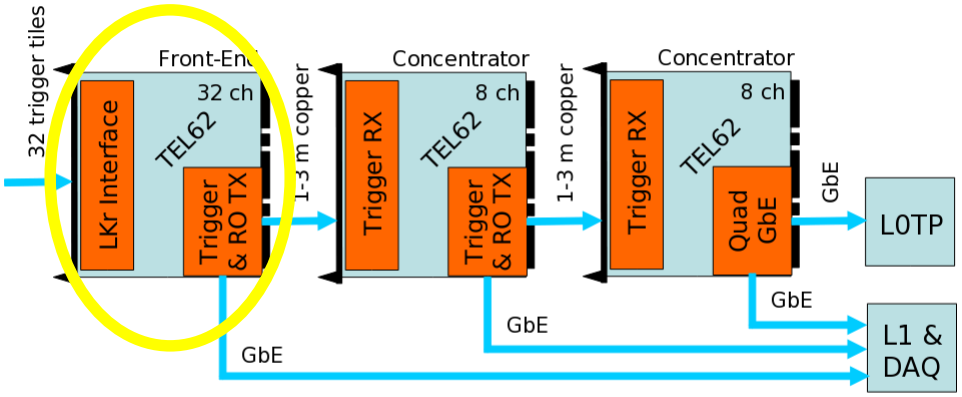


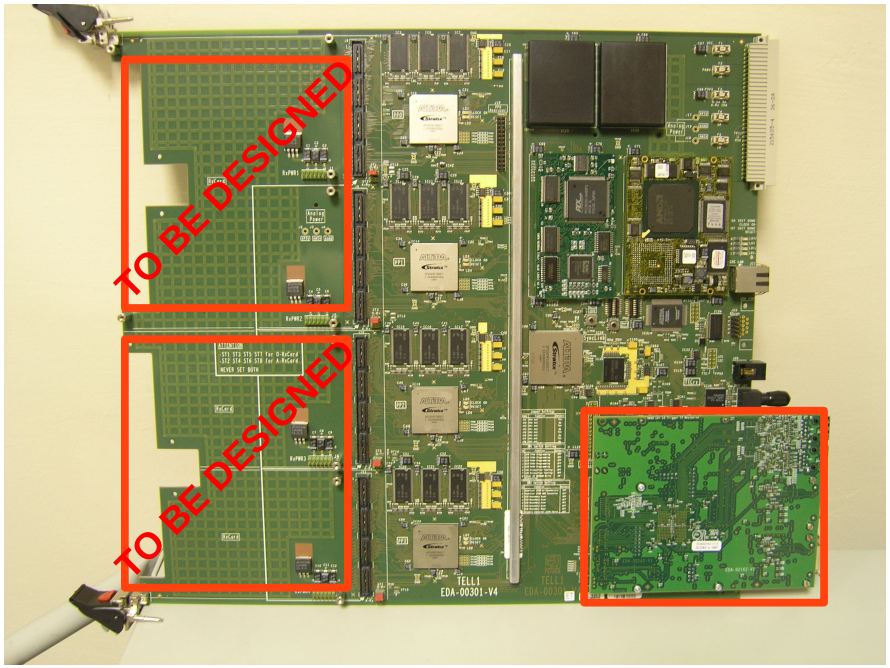
TELL1: general purpose data acquisition board developed at EPFL for the LHCb experiment

9U, 2-4 input mezzanine cards, 4+1 large FPGAs, credit card PC, 4 Gbit ethernet output

Front-End







28 9U TEL62 boards with
- Lkr interface mezzanines
- Trigger & RO TX mezzanines

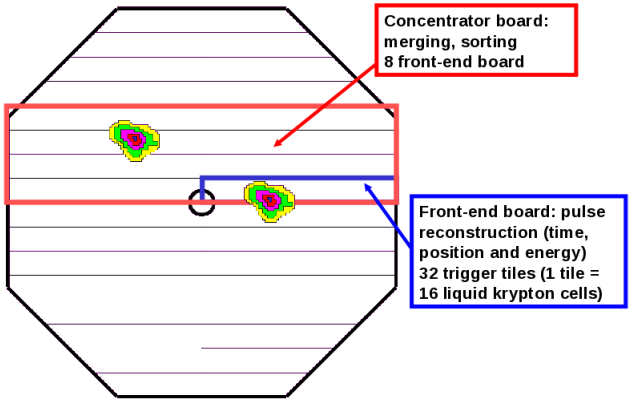
16 ethernet CAT5 input cables for 32 trigger tiles (16 bit @ 40 MHz per cable)

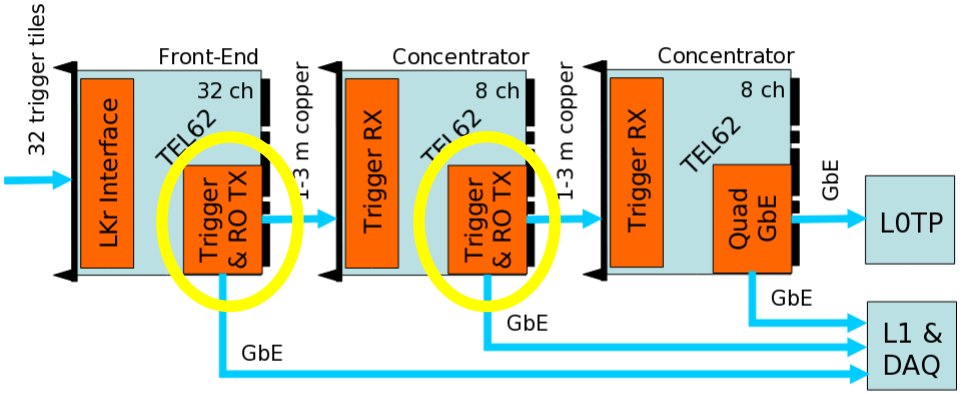
Peak reconstruction (energy, position and time)

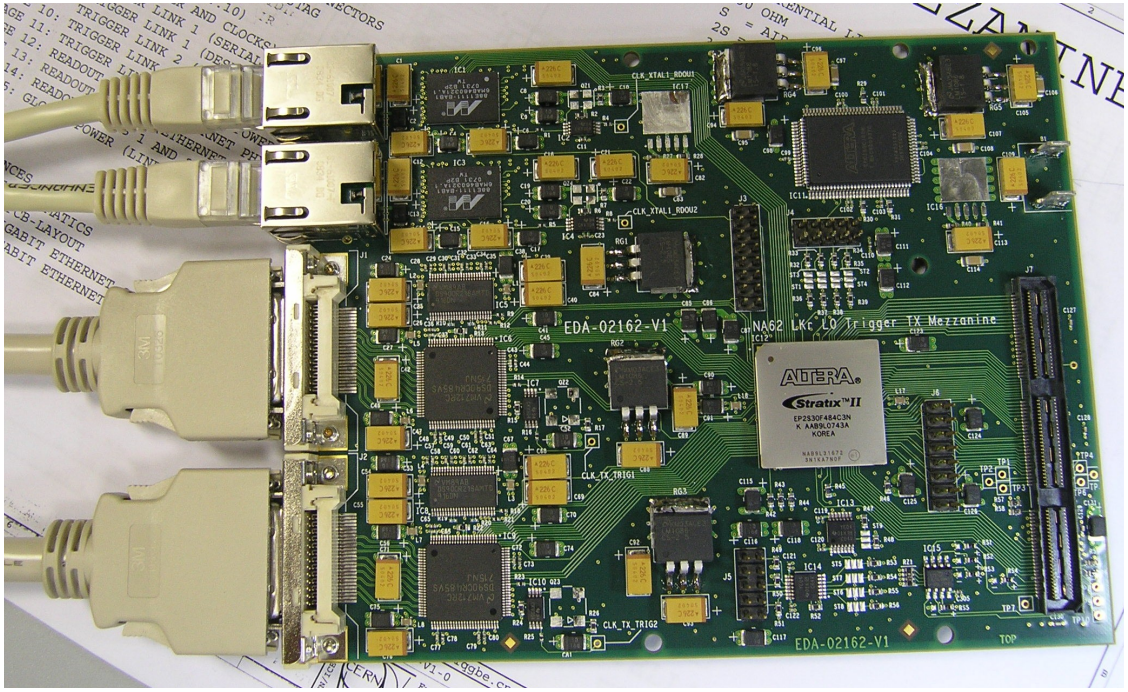
On board memory for L0 trigger latency

Readout of not zero suppressed Lkr raw data after L0 yes

Trigger and RO TX mezzanine





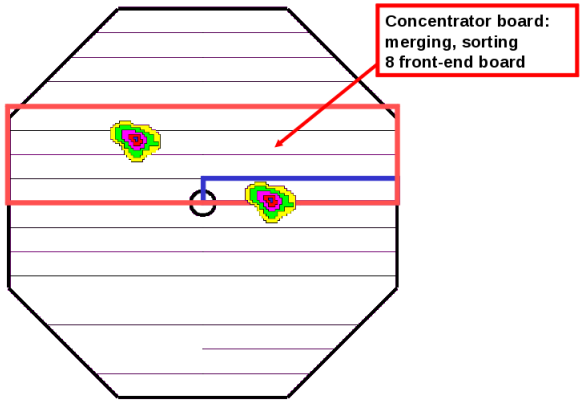


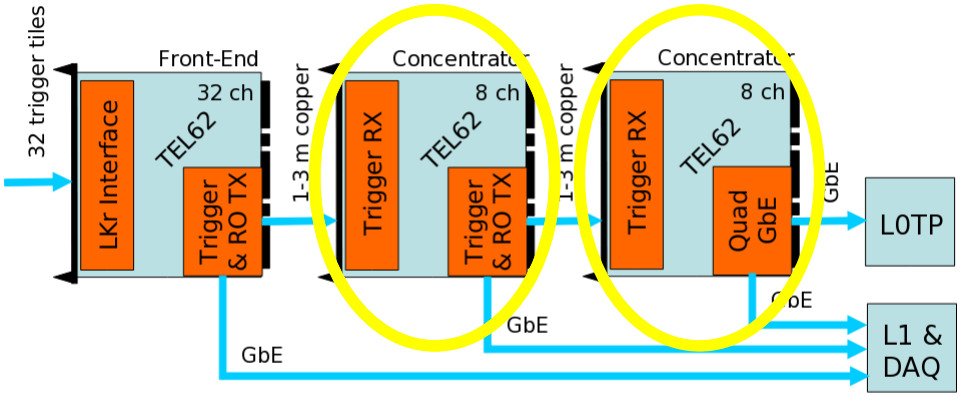
Transmits fast trigger data over a dedicated low latency trigger link (up to 4.8 Gbps)
Two trigger cables

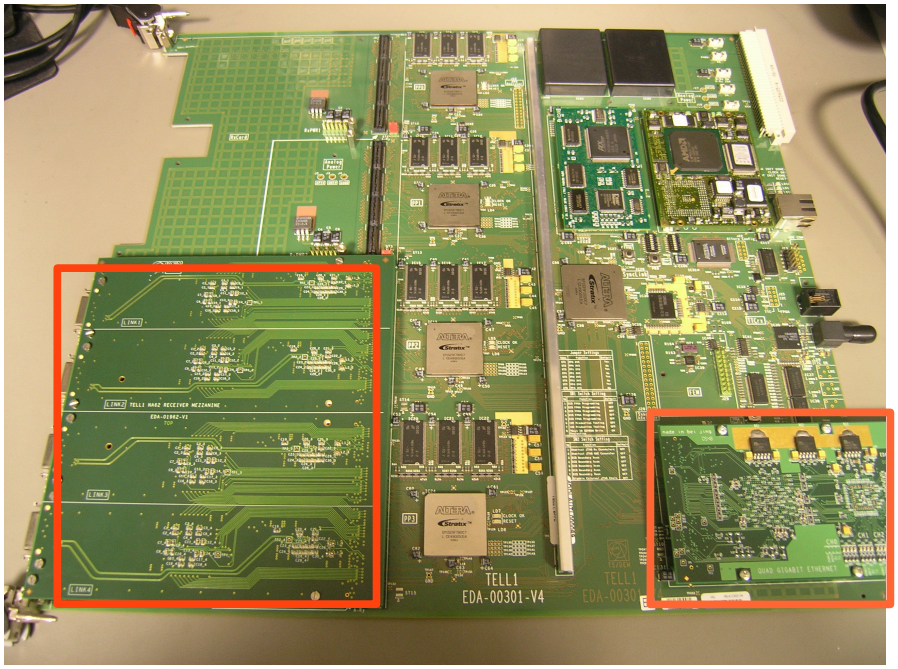
Performs readout over two Gbit Ethernet links

Lossless data compression of readout data from the Lkr calorimeter

Concentrator







7 + 1 9U TEL62 boards with

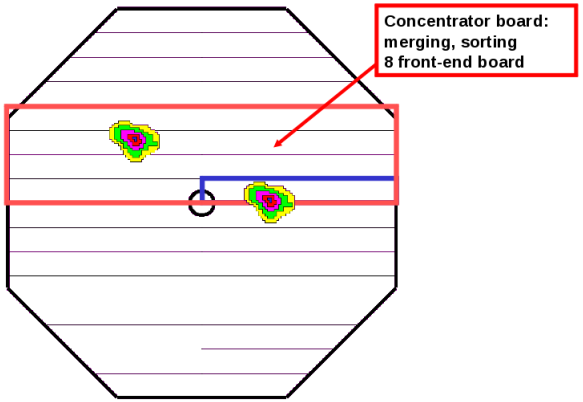
- Trigger RX mezzanines
- Trigger & RO TX mezzanines or Quad Gbit Ethernet

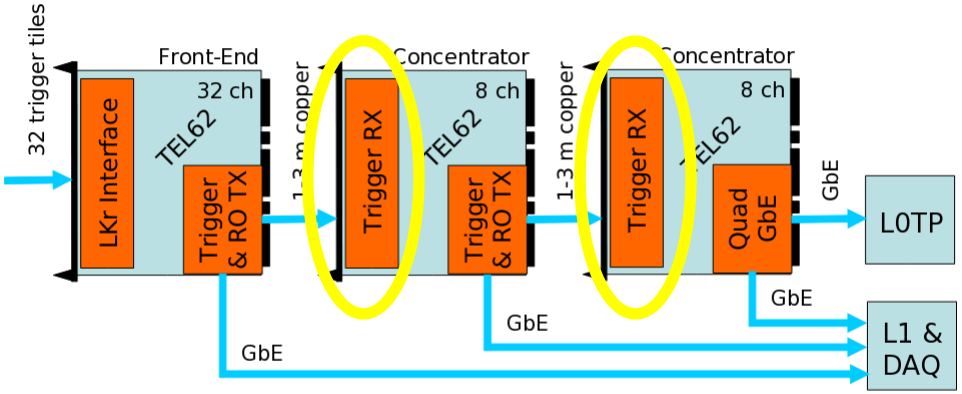
Combines peaks reconstructed by different FE boards in a single cluster, prepares a time-ordered list of trigger primitives, prepares Region of Interest for CREAM readout

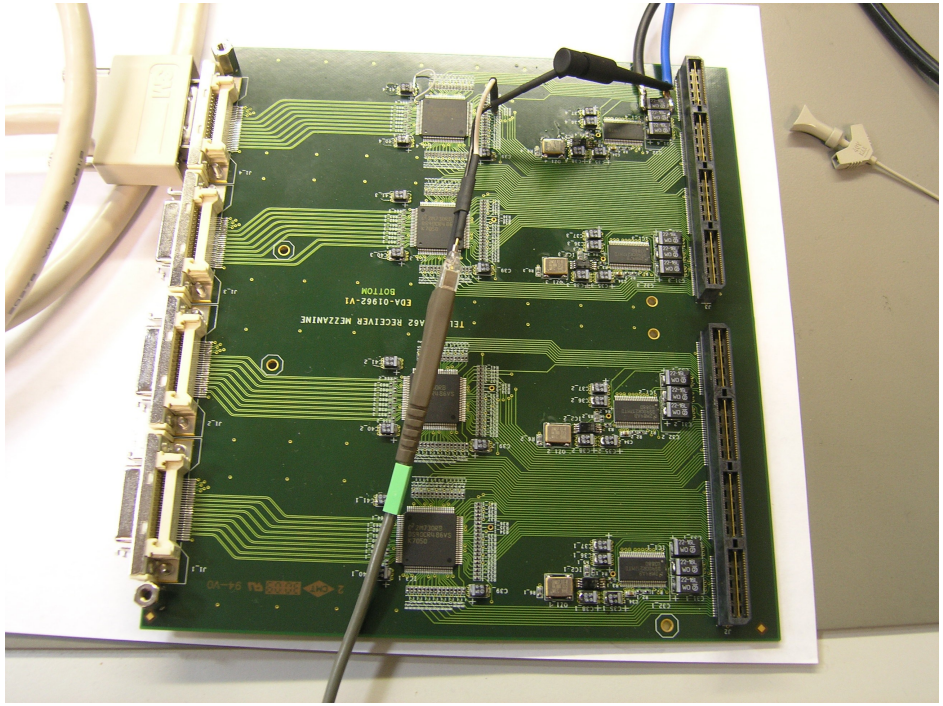
On board memory for L0 trigger latency

Readout of reconstructed clusters after L0 yes

Trigger RX mezzanine







Receives fast trigger data from a dedicated low latency trigger link (up to 4.8 Gbps)

Conclusions

A large parallel processor for the Liquid Krypton electromagnetic calorimeter ($K^+ \rightarrow \pi^+ \pi^0$ rejection) has been designed and is currently been assembled and tested

The main parameters driving the project are:
Instantaneous hit rate: 30 MHz
Time resolution: ~ 1.5 ns
Latency: < 100 μs

Not zero-suppressed readout (lossless data compression)
Region of Interest for the high granularity readout

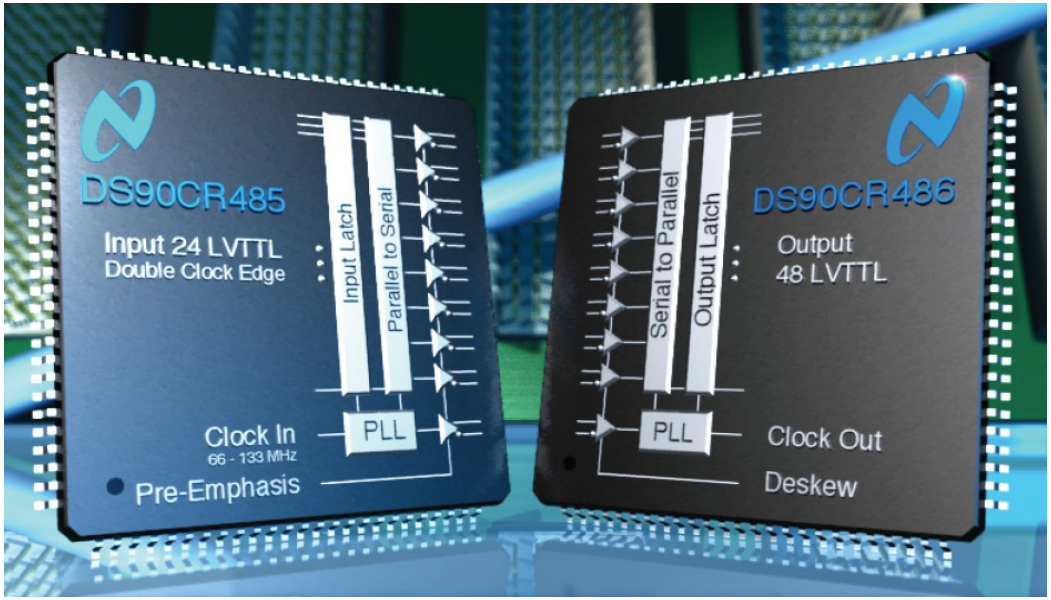
2012: technical run
2014-2015: physics

Backup

Lkr measured inefficiency

Energy	Inefficiency
$2 < E_\gamma < 3.5$ GeV	$(5.8 \pm 1.3)\times10^{-4}$
$3.5 < E_\gamma < 5$ GeV	$(1.6 \pm 0.4)\times10^{-4}$
$5 < E_\gamma < 7.5$ GeV	$(2.8 \pm 1.6)\times10^{-5}$
$7.5 < E_\gamma < 10$ GeV	$<2\times10^{-5}$
$E_\gamma > 10$ GeV	$<1\times10^{-5}$

High speed trigger link



National Semiconductors serializers/deserializers: up to 4.8 Gbps
Cameralink cable assembly individually shielded twisted pairs: 1-3 meters over copper