

# $K_L$ and Muon Trigger in the Belle II Experiment



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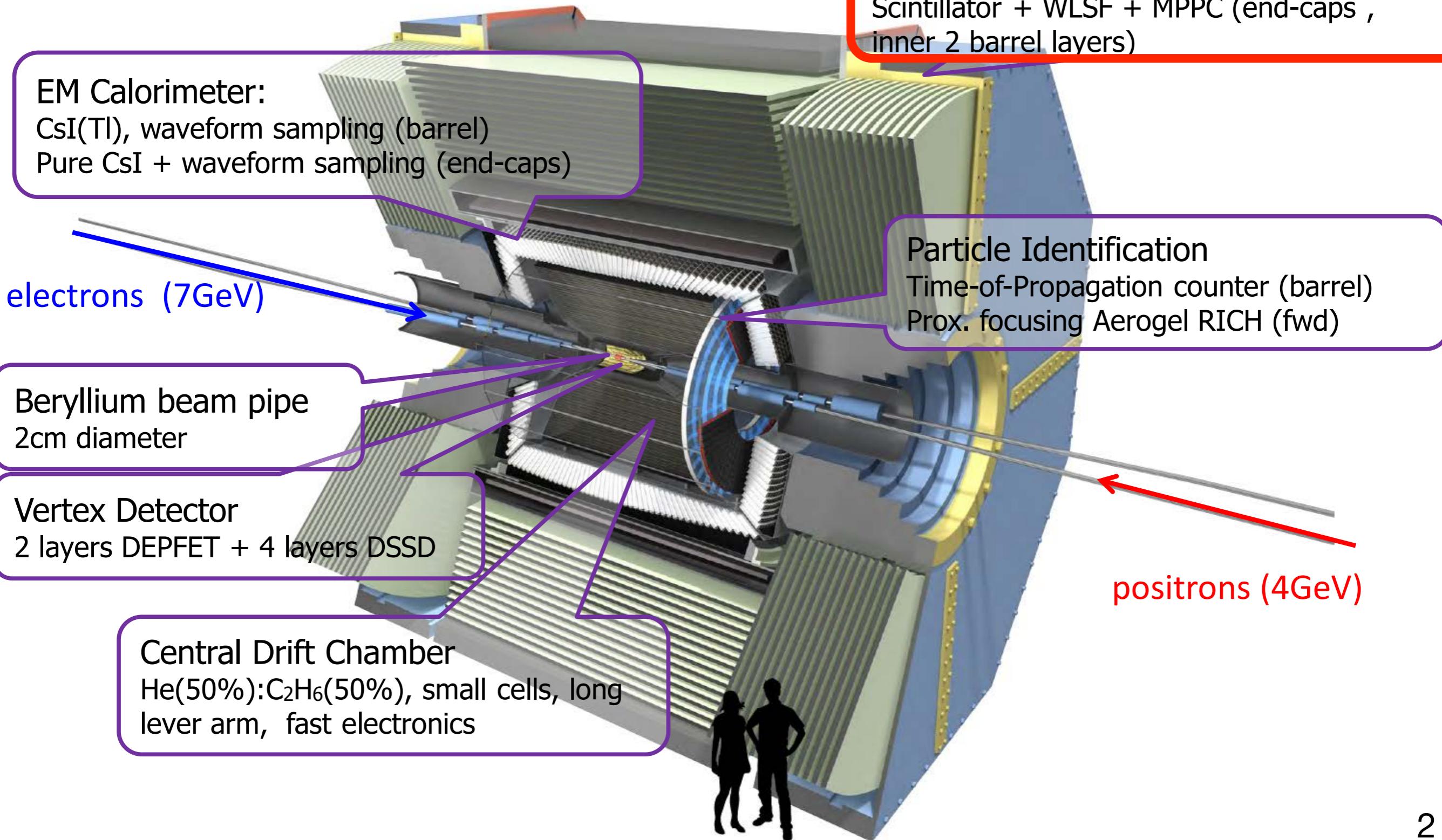
*on behalf of the Belle II Collaboration*



CHEP 2013, Amsterdam



# Belle II Detector



# Vital statistics at the design luminosity of $L = 8 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

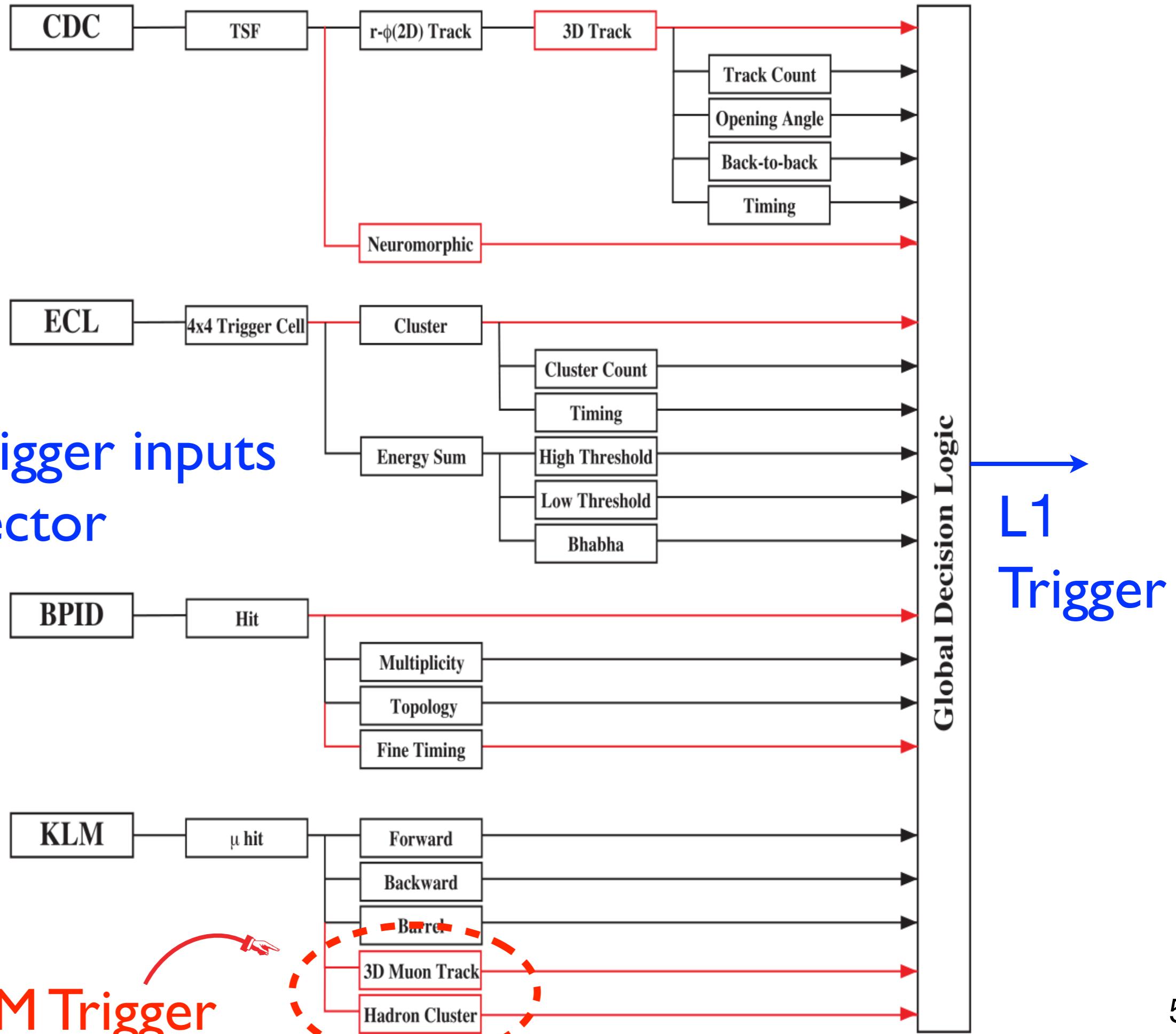
- ✓ Beam collision frequency  $\sim 508 \text{ MHz}$   
 $\Rightarrow$  bunch separation  $\sim 2 \text{ ns}$
- ✓ Separation between physics events  $\sim 25000$  bunches  
 $\sim 50 \mu\text{s}$
- ✓ Good physics rate  $\sim 20 \text{ kHz}$  (*see next slide*)
- ✓ L1 trigger peak rate  $\sim 30\text{kHz}$  (*not much junk!*)
- ✓ L1 latency =  $5 \mu\text{s}$
- ✓ Minimum time between triggers  $\sim 2 \text{ ns}$
- ✓ Data reduction:  $80 \text{ TByte/s} \rightarrow 60 \text{ GByte/s}$
- ✓ L1 efficiency for  $\Upsilon(4S)$  events  $\sim 100\%$

# Cross Sections and Level 1 Trigger rate at the design luminosity of $L = 8 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Physics Process	Cross Section (nb)	Rate (Hz)	<b>IEEE Trans Nucl Sci 58, 1807 (2011)</b>
$\Upsilon(4S) \rightarrow B\bar{B}$	1.2	960	
$e^+e^- \rightarrow \text{continuum}$	2.8	2200	
$e^+e^- \rightarrow \mu^+\mu^-$	0.8	640	
$e^+e^- \rightarrow \tau^+\tau^-$	0.8	640	
Bhabha ( $\theta_{\text{lab}} \geq 17^\circ$ )	44	350 <sup>a</sup>	
$\gamma\gamma$ ( $\theta_{\text{lab}} \geq 17^\circ$ )	2.4	19 <sup>b</sup>	
two-photon processes <sup>b</sup>	$\sim 80$	$\sim 15000$	
Total	$\sim 130$	$\sim 20000$	

<sup>a</sup> The rate is prescaled by a factor of 100.

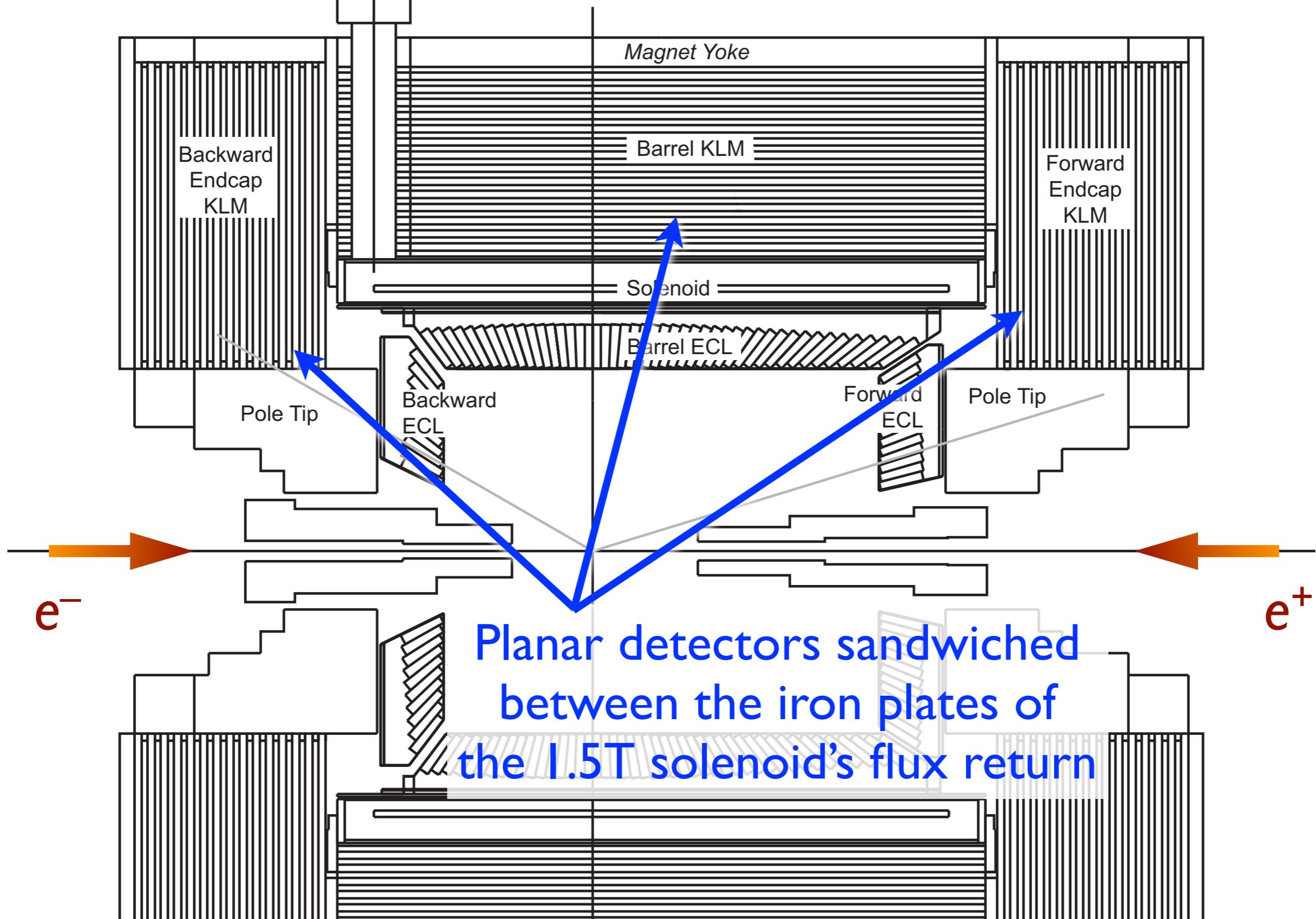
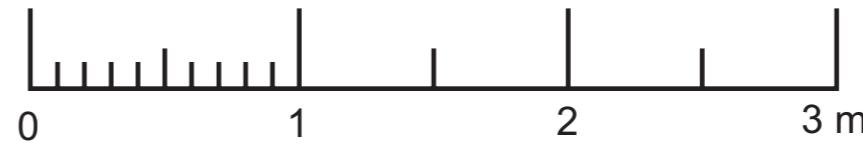
<sup>b</sup>  $\theta_{\text{lab}} \geq 17^\circ$ ,  $p_t \geq 0.1 \text{ GeV}/c$



Level 1 Trigger inputs  
from detector

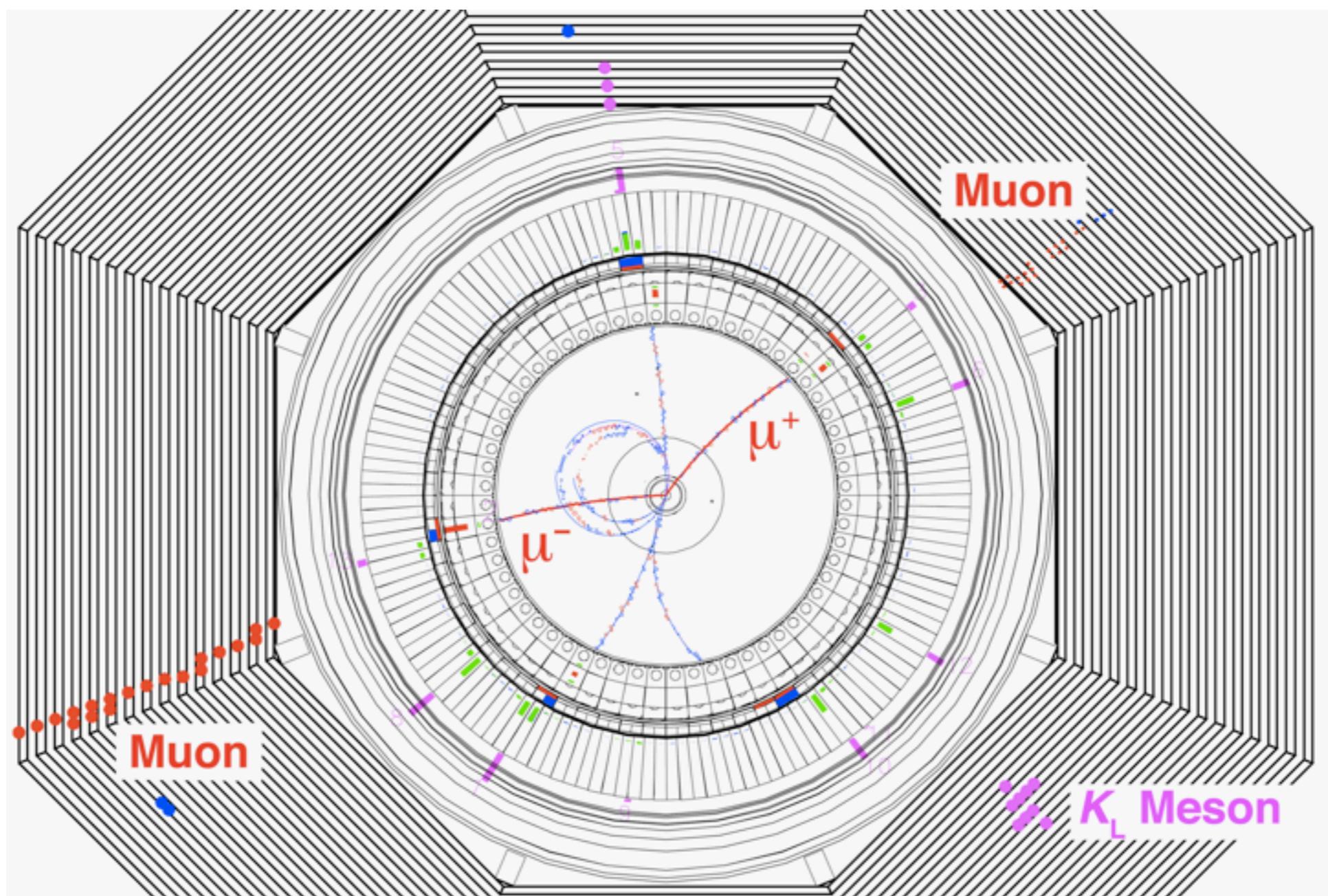
KLM Trigger

# Belle II $K_L$ -Muon (KLM) Detector

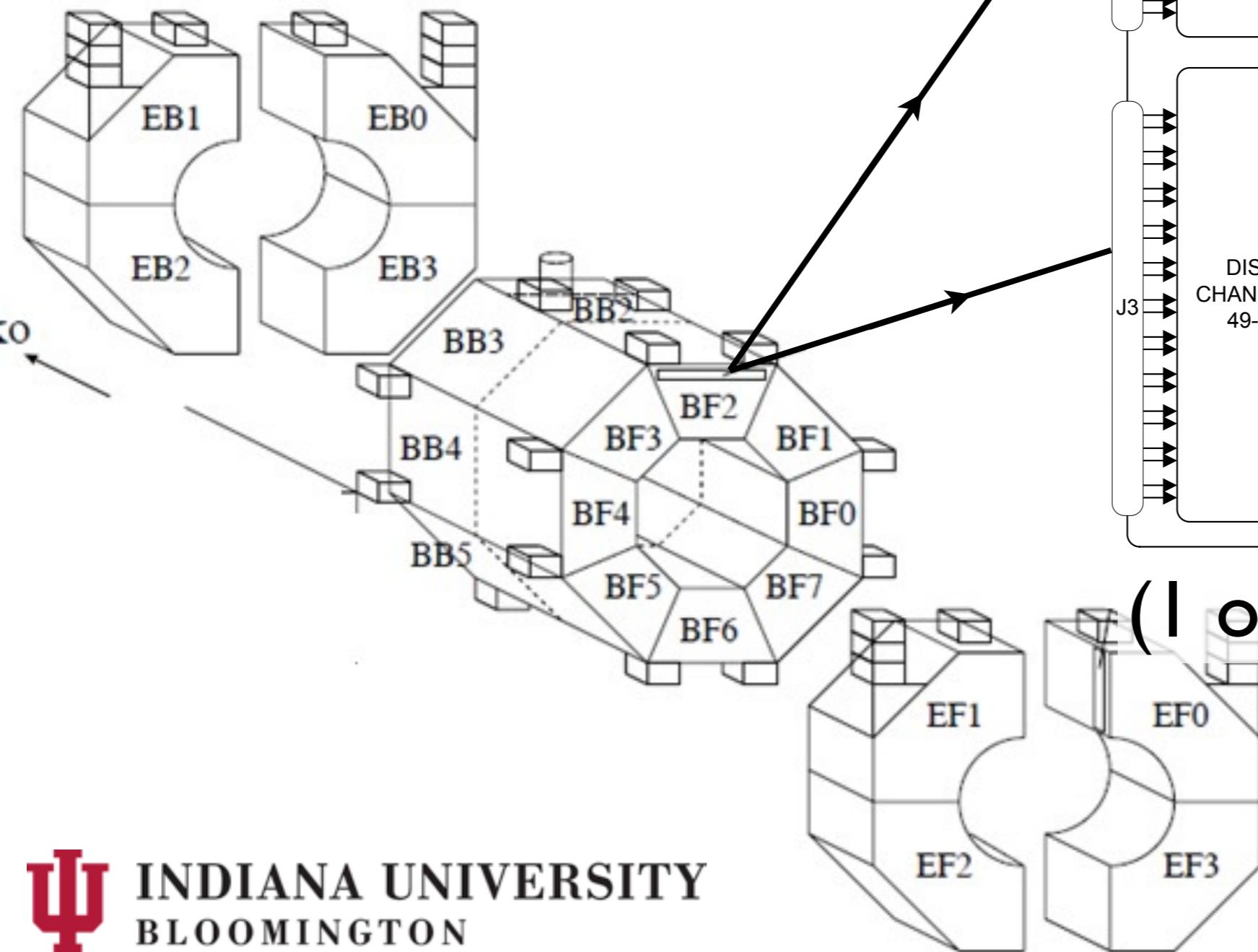


# Trigger on $K_L$ mesons and muons ( $\approx 1$ per event)

$B^0 \rightarrow J/\psi K_L$  event  
 $\mu^+ \mu^-$



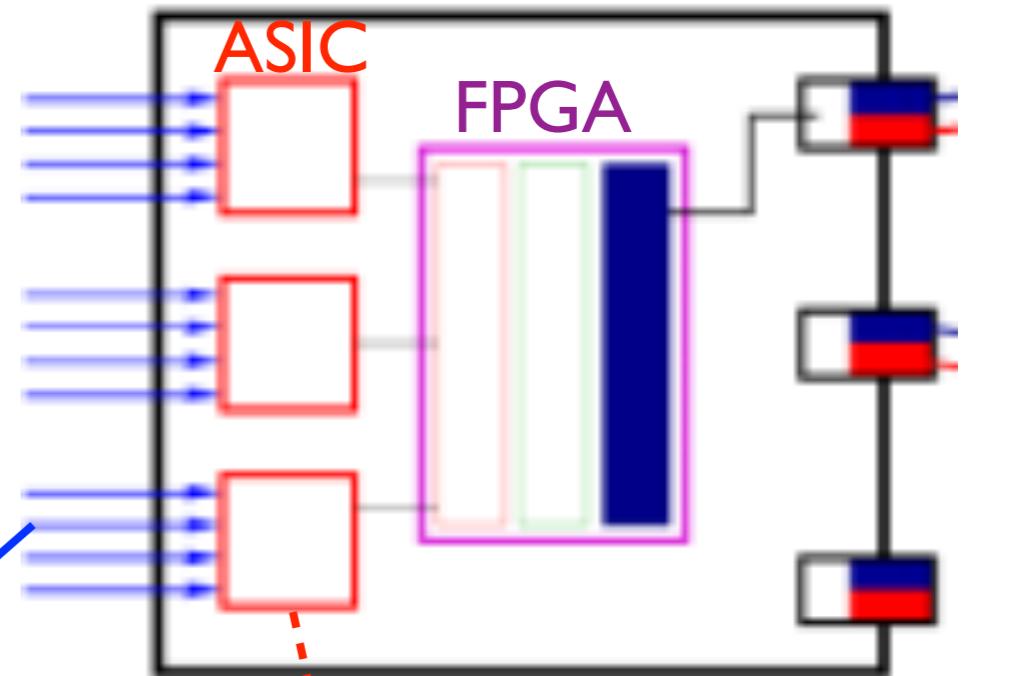
# Barrel $K_L$ -Muon (KLM) data flow for RPCs



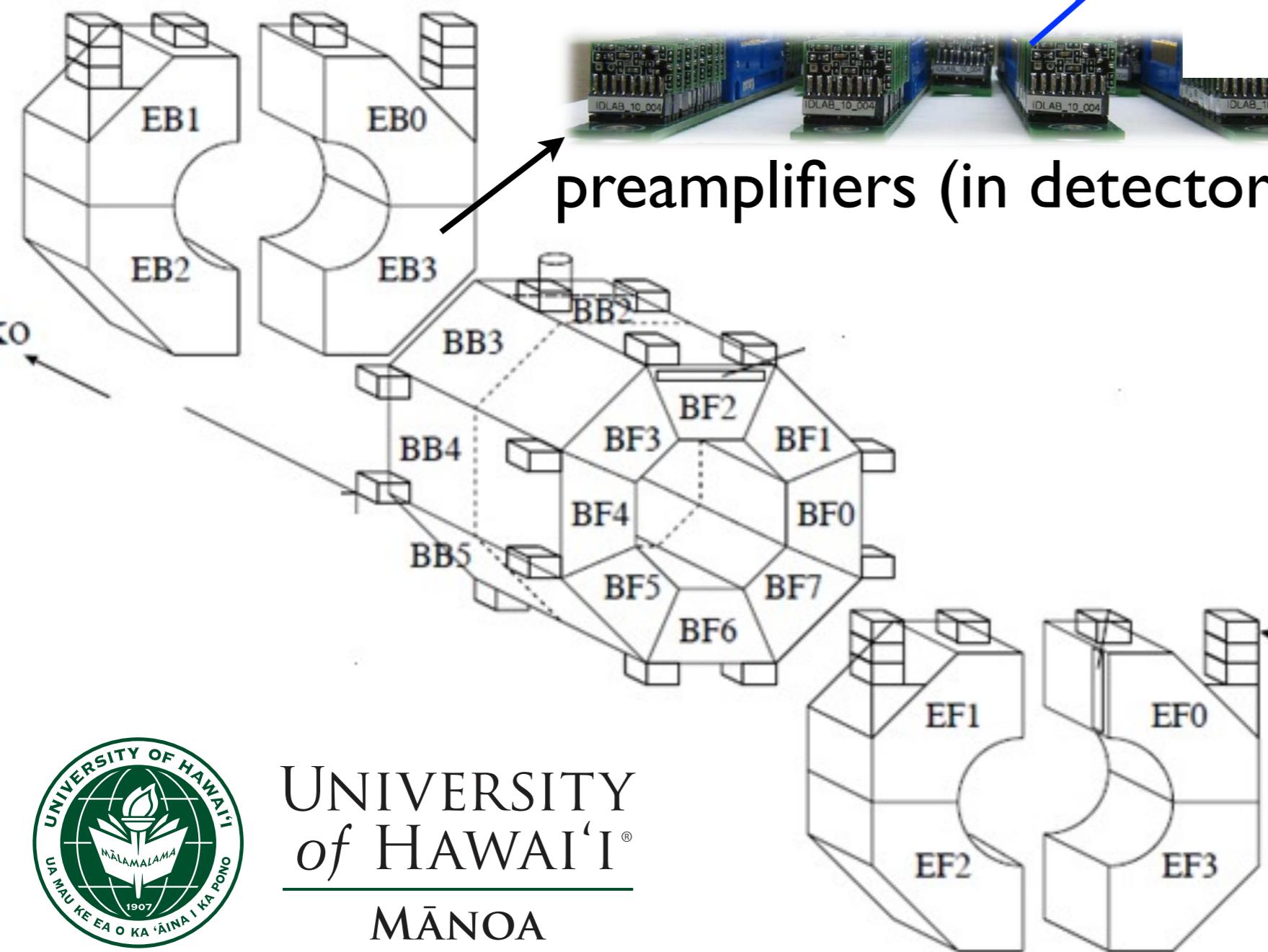
(1 of 1 3x8x2)



# Endcap $K_L$ -Muon (KLM) data flow for scintillators



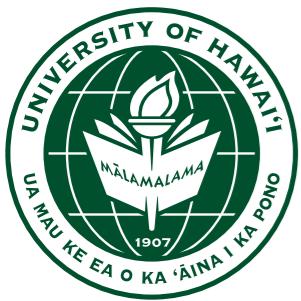
(1 of 14x4x2)



preamplifiers (in detector)

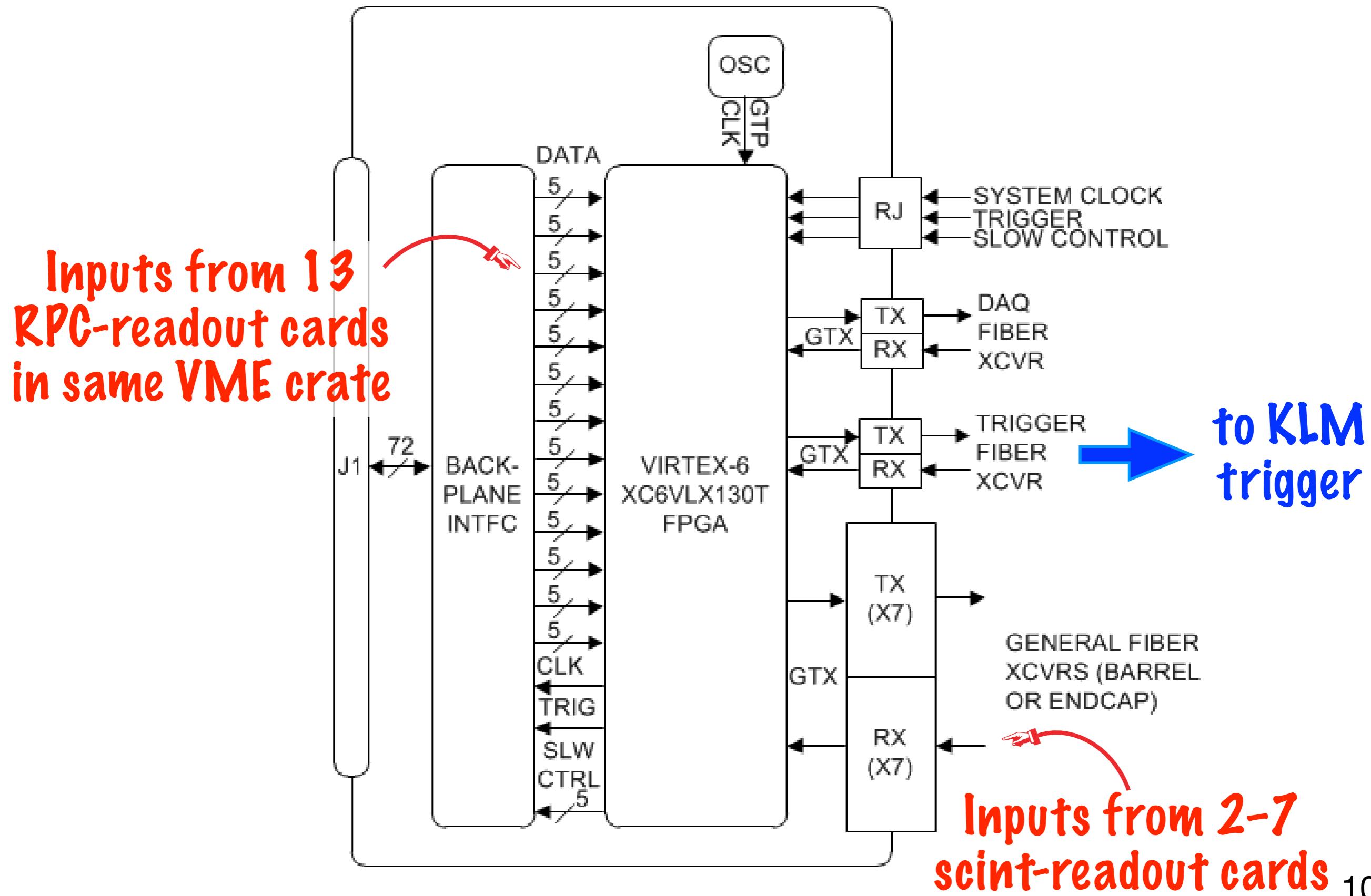


(1 of 10)



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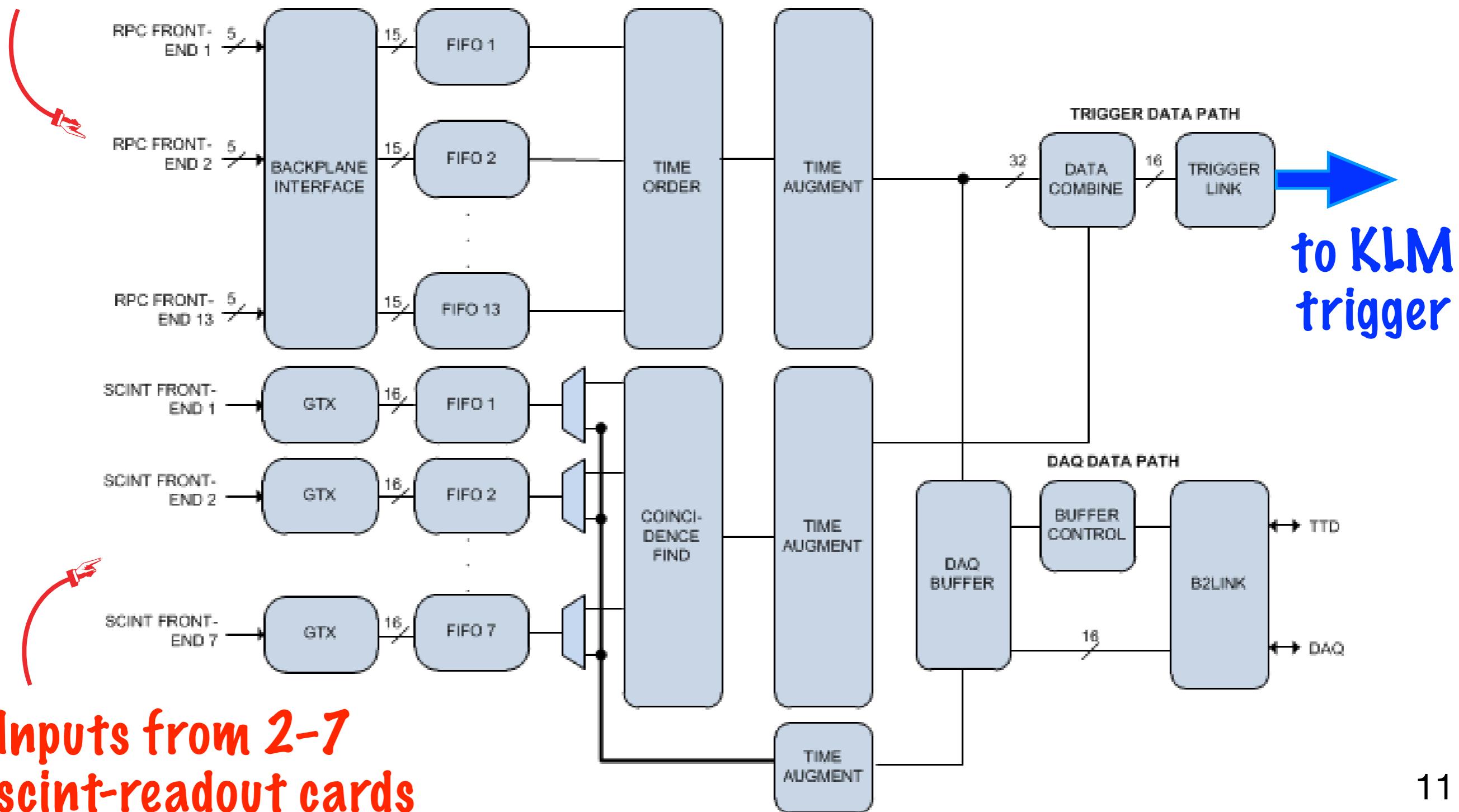
# Data concentrator card (1 of 32)



# Data concentrator card (1 of 32)

## data flow

Inputs from 13 RPC-readout cards in same VME crate



# Universal Trigger Board with GTX daughter board and general IO board

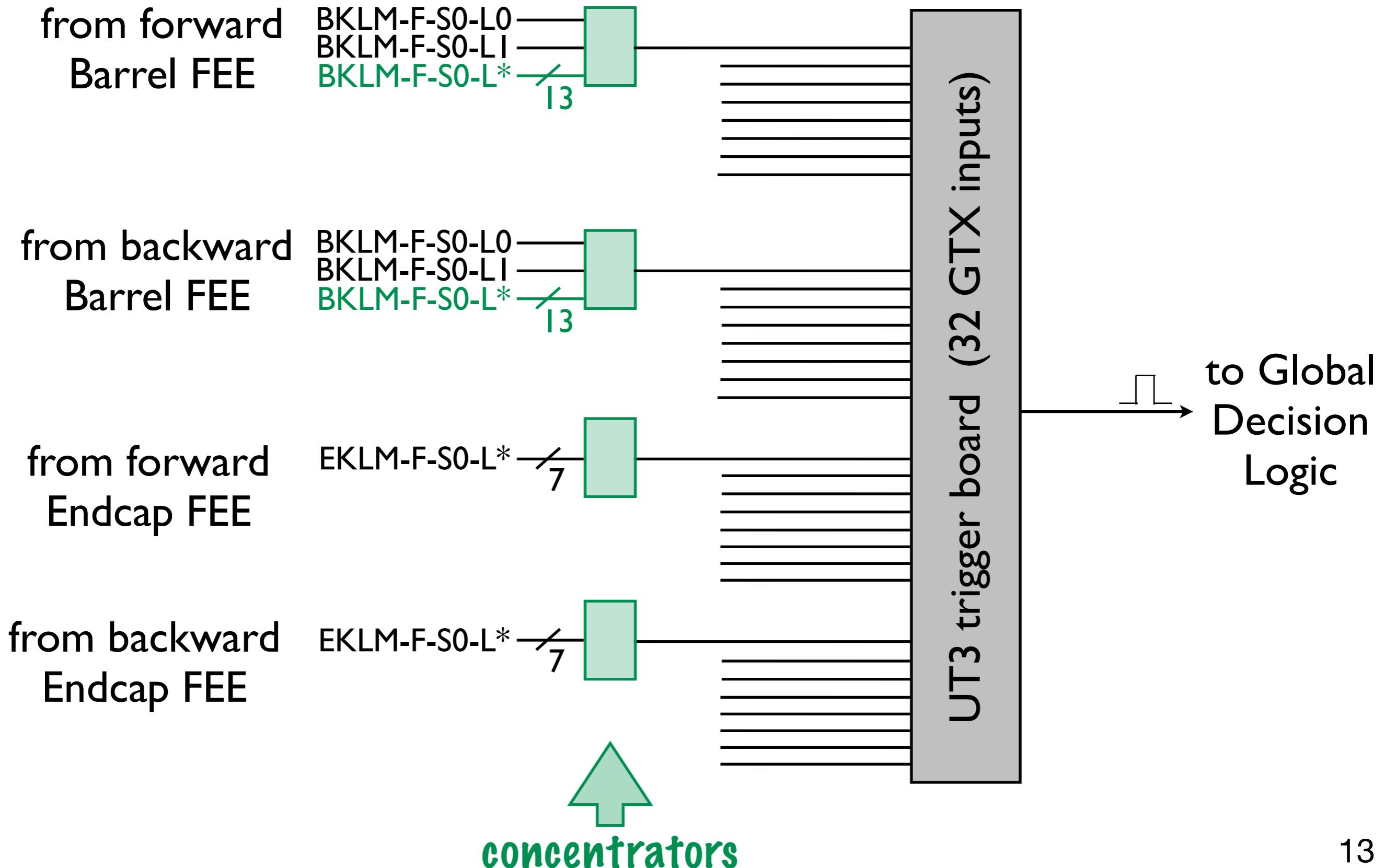
✓ FPGA = Virtex6 HXT

✓ Input/Output:

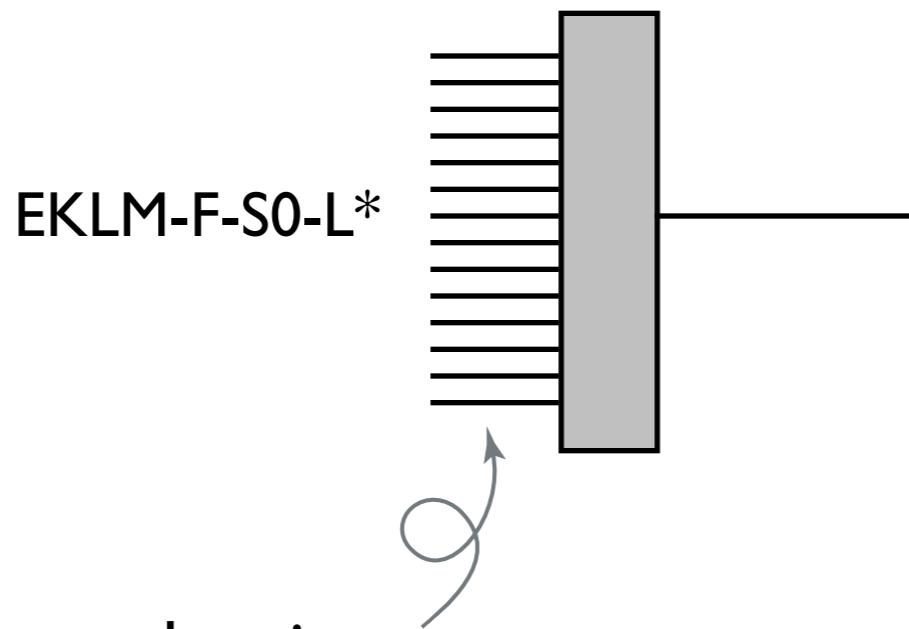
- Clock: 1 in, 3 out
- NIM: 10 in, 10 out
- 24 GTH (11 Gbps x 24)
- 40 GTX (6.25 Gbps x 40)
- LVDS: 32x2 in/out
- RJ45: 4 (for Belle2Link)



# KLM trigger finds muon tracks and $K_L$ clusters



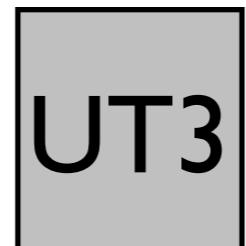
# Concentrator board passes only “good” hits to UT3



Each line delivers *x*- and *y*-view hits from one detector module

- An ***x*-view hit is passed only if the concentrator sees an in-time *y*-view hit in the same module**
- A ***y*-view hit is passed only if the concentrator sees an in-time *x*-view hit in the same module**
- All hits are time-ordered

# Trigger algorithm finds 2D track(s) in each projection



for each endcap

## Decoder

- Deserialize hits
- Send hits in coincidence window to Finders

## $x-z$ Finder

- Assemble list(s) of  $x$ -view hits in each quadrant
- Geometry table

## $x-z$ Fitter

- Fit  $(z, x)$  hits in each list to get  $x_0$  at I.P.
- straight-line fit

## Decision

- Fire trigger if  $(x_0, y_0)$  is near I.P.
- range-dependent criterion

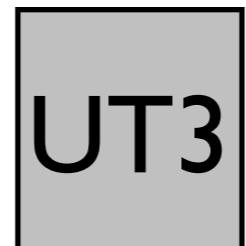
## $y-z$ Finder

- Assemble list(s) of  $y$ -view hits in each quadrant
- Geometry table

## $y-z$ Fitter

- Fit  $(z, y)$  hits in each list to get  $y_0$  at I.P.
- straight-line fit

# Trigger algorithm finds 2D track(s) in each projection



for barrel

## Decoder

- Deserialize hits
- Send hits in coincidence window to Finders

## $r-\phi$ Finder

- Assemble list(s) of  $\phi$ -view hits in each quadrant
- Geometry table

## $r-\phi$ Fitter

- Fit  $(r, \phi)$  hits in each list to get  $r_0$  at I.P.
- straight-line fit

## Decision

- Fire trigger if  $(r_0, z_0)$  is near I.P.
- range-dependent criterion

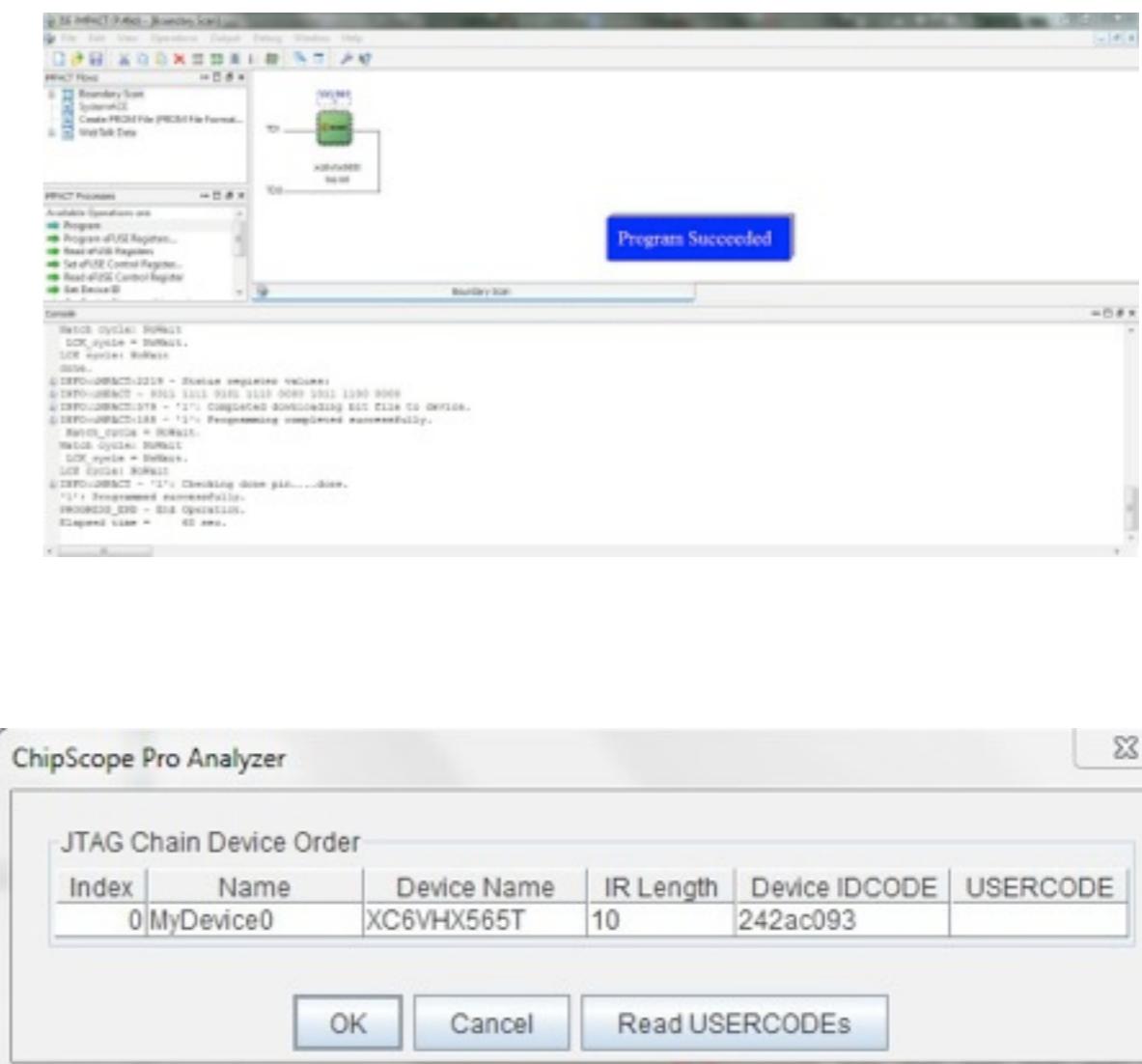
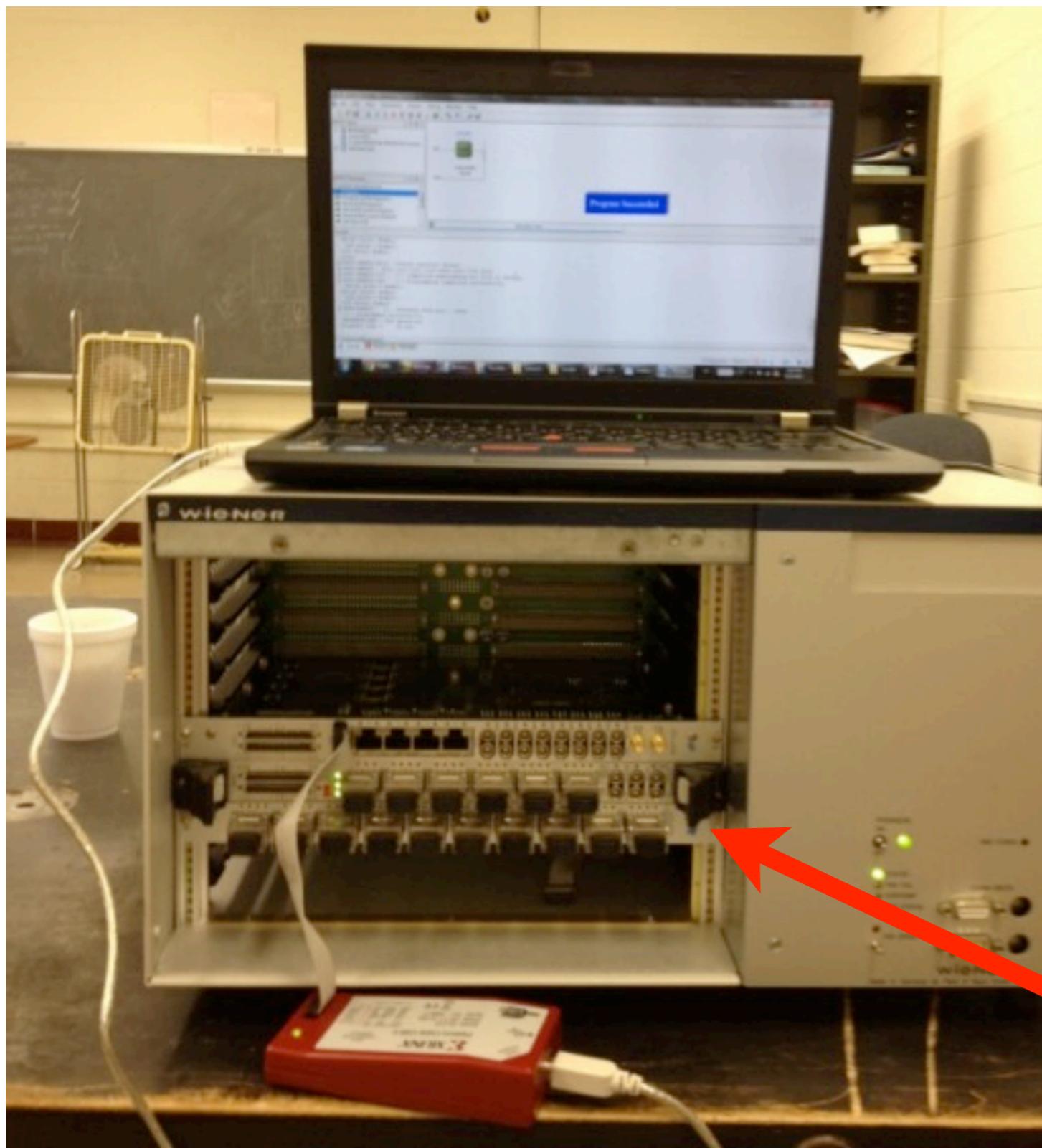
## $r-z$ Finder

- Assemble list(s) of  $z$ -view hits in each quadrant
- Geometry table

## $r-z$ Fitter

- Fit  $(r, z)$  hits in each list to get  $z_0$  at I.P.
- straight-line fit

# Trigger hardware setup w/Xilinx software environment



KLM Universal  
Trigger Module

# KLM Trigger algorithm: simulation environment on PC

The screenshot shows the ISE Project Navigator interface with the following details:

- Project Name:** C:\layerfitting\layerfitting
- File Type:** XISE Project
- Editor View:** Design (Implementation)
- Code Editor Content:** A portion of the Verilog code for the `layerfitting_tb.v` testbench. The code includes logic for calculating delta values and fitting results for x, y, and z layers.

```
224     .clk(clk),
225     .delta(deltay),
226     .length(tracklength),
227     .reset(rst)
228   );
229
230
231 //get delta of z-layer fitting
232 GetDelta delta_z (
233   .sum(finalsumz),
234   .sumsqr(finalsumz2),
235   .clk(clk),
236   .delta(deltaz),
237   .length(tracklength),
238   .reset(rst)
239 );
240
241
242 //x-layer fitting
243 GetFittingResult x_fitting(
244   .clk(clk),
245   .delta(deltax),
246   .sum(finalsumx),
247   .sumsqr(finalsumx2),
248   .sumlayer(finalsumlayer),
249   .sumsumlayer(finalsumxlayer),
250   .intercept(ax),
251   .gradient(bx),
```

- Toolbars:** Standard ISE toolbars for File, Edit, View, Project, Source, Process, Tools, Window, Layout, Help.
- Bottom Navigation:** Buttons for Start, Design, Files, Libraries, and tabs for Design Summary, layerfitting.v\*, GetFittingResult.v, layerfitting\_tb.v, and GetLsPosition.v.

# KLM Trigger algorithm synthesis: resource utilization

Minimum period: **2.476ns** (Maximum Frequency: **403.877MHz**)

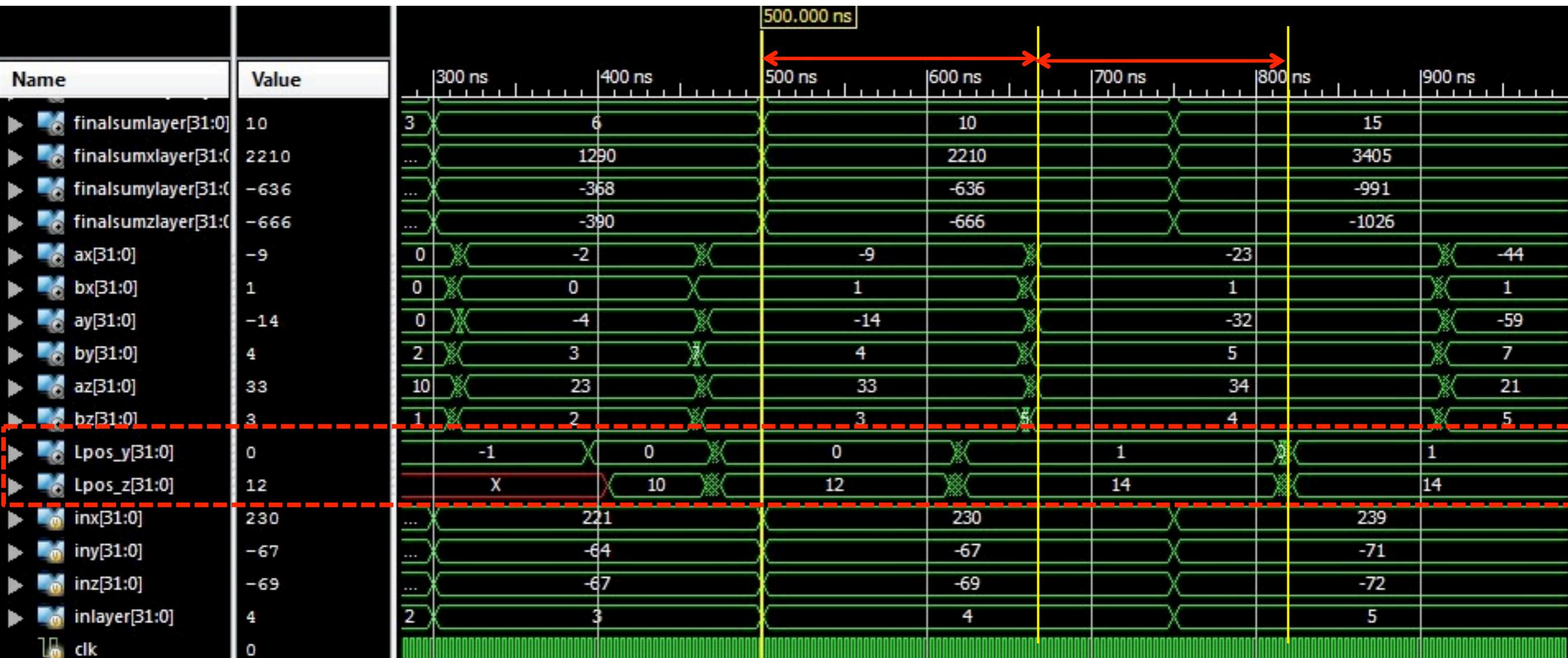
Minimum input arrival time before clock: 40.713ns

Maximum output required time after clock: 0.777ns

Logic Utilization	Used	Available	Utilization
Number of Slice Registers	41209	708480	5%
Number of Slice LUTs	16653	354240	4%
Number of fully used LUT-FF pairs	14555	43307	33%
Number of bonded IOBs	193	720	26%
Number of BUFG/BUFGCTRLs	1	32	3%
Number of DSP48E1s	69	864	7%

# ChipScope Pro time analysis of track-finding algorithm

~0.3 μs  
43 clock cycles      38 clock cycles



Input data are available

Deltas are available

L0s are available

# Summary

- Muon track-finding algorithm has been implemented in the Belle II Universal Trigger Board (*with ChipScope debugger*)
- Both 1D projections of each track are found in well under 1  $\mu\text{s}$  (trigger system's upper limit is 3  $\mu\text{s}$ )
- $K_L$  cluster-finding algorithm is in development
- To come:
  - ★ test algorithm robustness in the presence of neutron background (=noise hits), cosmics, multiple tracks and clusters (2013-2014)
  - ★ offline C++ version of KLM trigger simulator (2014)
  - ★ implement full end-to-end test with all hardware (2014)