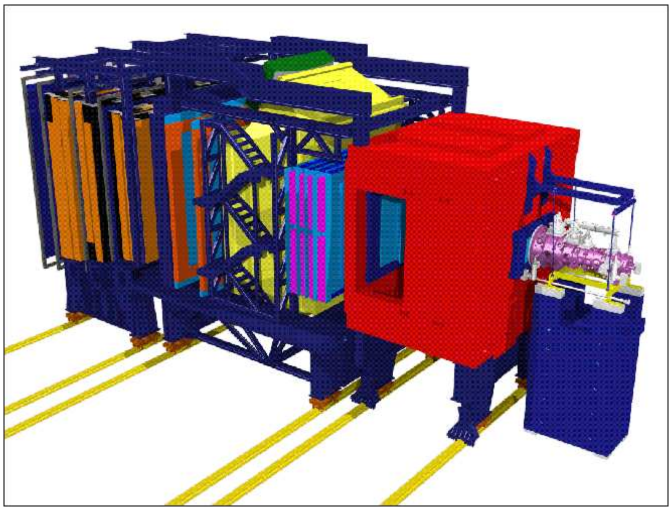
MARCO BRUSCHI

I.N.F.N BOLOGNA

HERA B BOLOGNA

STATO DELLA PARTECIPAZIONE

AD HERA–B



Assemblea Scientifica
Sezione di INFN di BOLOGNA
26 Giugno 1997

OUTLOOK

THE HERA−B FLT SYSTEM

THE ELECTROMAGNETIC CALORIMETER (ECAL)

THE PRETRIGGER SYSTEM

THE READOUT SYSTEM

EXPERIMENTAL RESULTS

SUMMARY

The goals

- CP VIOLATION in the B system
  - Gold Channel : $B^o \rightarrow J/\psi\ K_S$
  - Other Channels (e.g. $B^o \rightarrow J/\psi\ K^*$)
  - J/ψ decay mode: e^+e^- , $\mu^+\mu^-$

- B - PHYSICS
  - B_S mass, lifetime, oscillation
  - Rare B decays
  - Other

- LEPTONIC (tagging and semileptonic decays)

  DI-LEPTONIC TRIGGER (J/ψ)

  HIGH-PT TRIGGER

  ELECTROMAGNETIC CALORIMETER

  MUON CHAMBERS

  PAD CHAMBERS

Principle Goals of HERA–B :

C̸P in: $B \rightarrow J/\psi K_S^0$, with $J/\psi \rightarrow l^+ l^-$ and $K_S^0 \rightarrow \pi^+\pi^-$

B_S mixing in: $B_S \rightarrow D_S^{(*)} l \nu$, $(b \rightarrow l X)$

Some Other Goals:

C̸P in: $B \rightarrow \pi^+\pi^-$

"B physics:" $B \rightarrow J/\psi + X$, with $J/\psi \rightarrow l^+ l^-$

$B^0 \rightarrow l^+ l^-$

$B \rightarrow l^+ l^- + X$

$B^0 \rightarrow K^+ \pi^-$

$B \rightarrow l + X$, $(b \rightarrow l X)$

$B \rightarrow h + X$, $(b \rightarrow h X)$

The gold-plated decay: $B^0 \to J/\psi\, K^0_S$

$$\mathbf{Br(B^0 \to J/\psi\, K^0_S \to \mu^+\mu^-\pi^+\pi^-) \approx 10^{-5}}$$

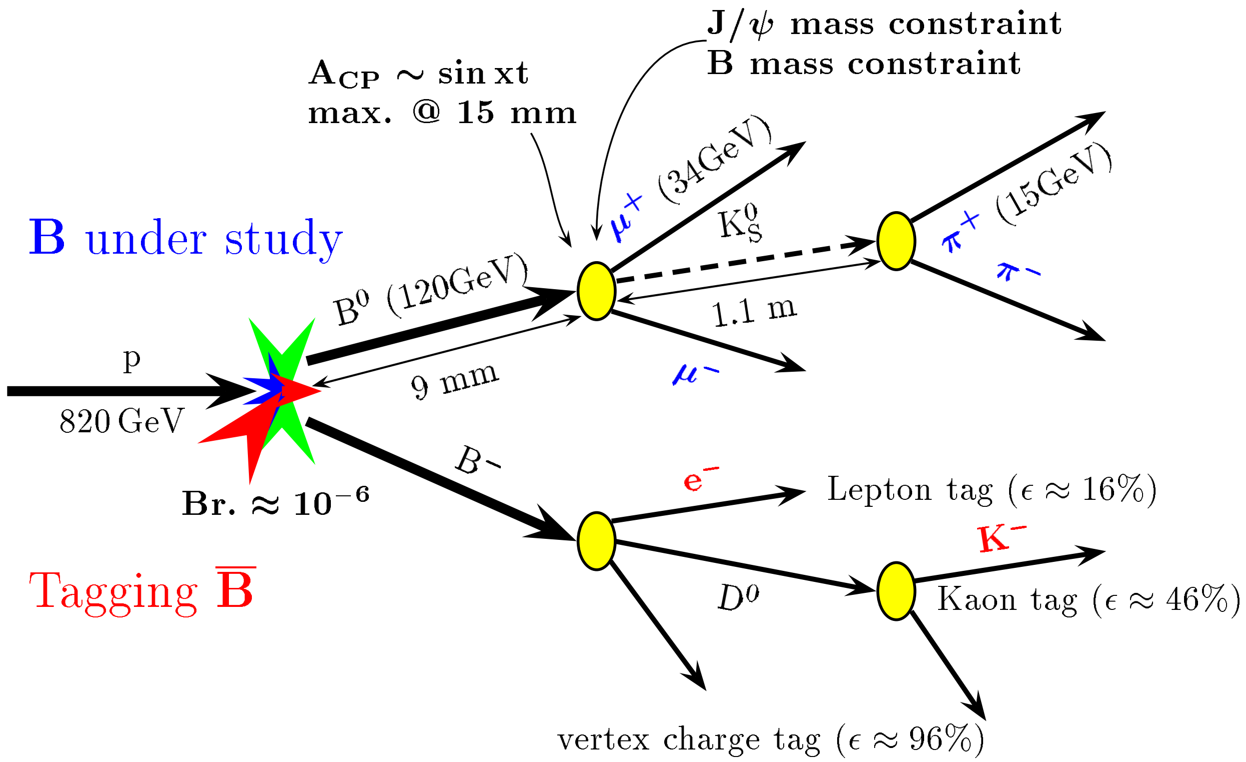


Table 1: *Estimate of the number of reconstructed $B^0 \to J/\psi K_S$ after a running time of 10^7 s at an interaction rate of 40 MHz using a Cu target, and the resulting statistical precision of the measurement of $\sin(2\beta)$ after tagging. The results are shown for three different values of the $b\bar{b}$ cross section per nucleon.*

$\sigma_{b\bar{b}}$	6 nb	12 nb	17 nb
σ_{inel}	13 mb	13 mb	13 mb
$\sigma_{b\bar{b}}/\sigma_{inel}$	$4.6 \cdot 10^{-7}$	$9.2 \cdot 10^{-7}$	$1.3 \cdot 10^{-6}$
trigger rate	40 MHz	40 MHz	40 MHz
bb rate	18 Hz	37 Hz	52 Hz
fraction of detected $B^0 \to J/\psi K_S^0$	$4.2 \cdot 10^{-6}$	$4.2 \cdot 10^{-6}$	$4.2 \cdot 10^{-6}$
# $J/\psi K_S^0$ per 10^7 s	$\approx$ 700	$\approx$ 1400	$\approx$ 2000
statistical factor	2.3	2.3	2.3
tagging power P_{tag}	0.31	0.31	0.31
$\Delta \sin(2\beta)$ after 10^7 s	**0.18**	**0.13**	**0.11**

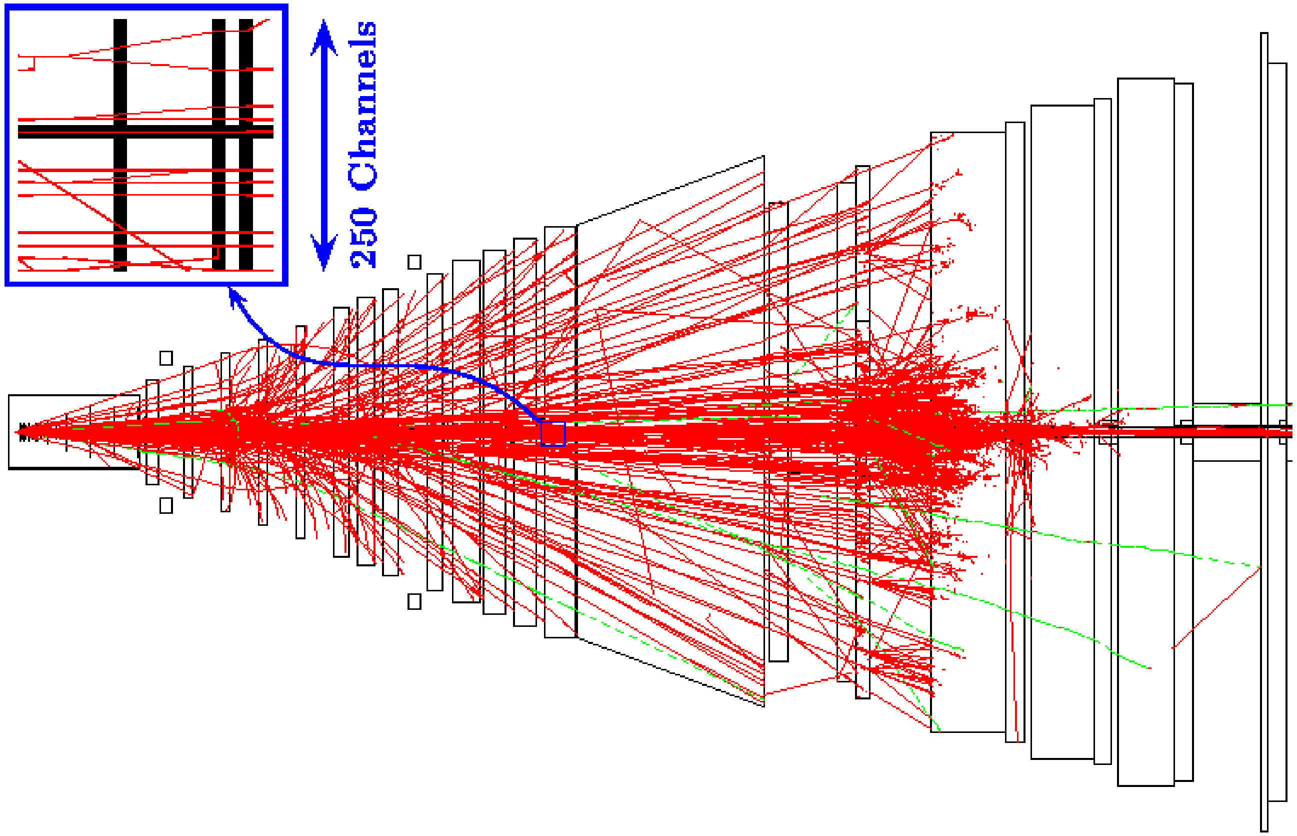
1

Operating Environment:

• Signal / Background in the range of	$\mathbf{10^{-9}}$ **to** $\mathbf{10^{-11}}$
• Rate for production of interesting Signals	$\mathbf{\ll 1\,Hz}$
• Bunch Crossing rate	**10 MHz**
• <# of interactions per Bunch Crossing (event)>	**4**
• <# of tracks per event>	**200**
• Occupancy up to	**20%**

A "typical event" consisting of 4 interactions

60 primary tracks **200 tracks before ECAL**



Multi-Level Trigger Scheme

Level	Used parts	# of channels	Input rate	Algorithm	Time	Gain
						10 MHz
1	part of tracking, ECAL,MUON	100 k	150 GB/s	pattern recognition; track, J/ψ reconst.	12 μs	200
						50 kHz
2	Tracking; Silicon	400 k	1.8 GB/s	Magnet tracking; Trackfit; part. ID; Vertexing	5-50 ms	25
						2 kHz
3	all	600 k	140 MB/s	match information global fit	100 ms	20
						100 Hz
4	all	600 k	7 MB/s	Complete reconstruction	2 s	-

FLT information

channel#	part.ID	tracking	occup.	roads	occup.
Muon	9k	23k	$< 1\%$	$2 \cdot 10^6$	10^{-6}
ECAL	6k($\times$7 bit)	-	100%		
p_T	20k	-	10-20%		
Outer	-	43k	10-20%	$20 \cdot 10^6$	$5 \cdot 10^{-6}$
Inner	-	18k	10-20%	$12 \cdot 10^6$	$3 \cdot 10^{-6}$
total	71k	84k		$34 \cdot 10^6$	
FLT					
"tracks"					
# of μ	2/BX			0.5/BX	
# of e	5/BX			2/BX	
# of h	3/BX			1/BX	
total	10/BX			3.5/BX	

Outline of the FLT strategy

Identify lepton in MUON or ECAL

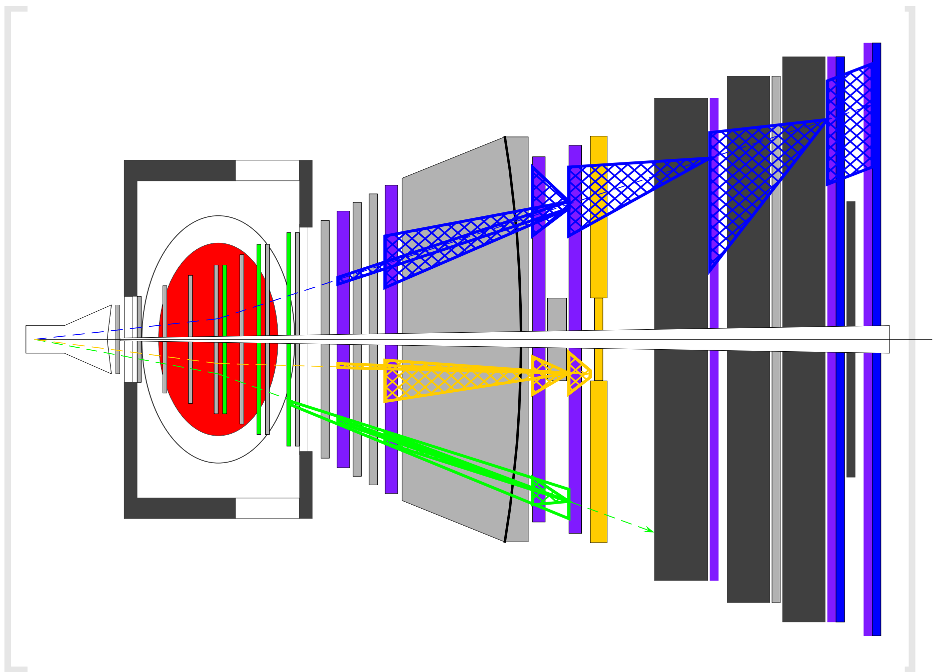
⟶ track seed

follow track from back to front in TRACKING

⟶ Kalman filtering

calculate track parameters using a VERTEX constraint, apply cuts and calculate invariant mass of track pairs

⟶ trigger decision



The FLT Problem

is the scan of 34 million roads using 150 kbit information to find 3.5 tracks $\boxed{\text{in } 12\,\mu\text{s}}$.

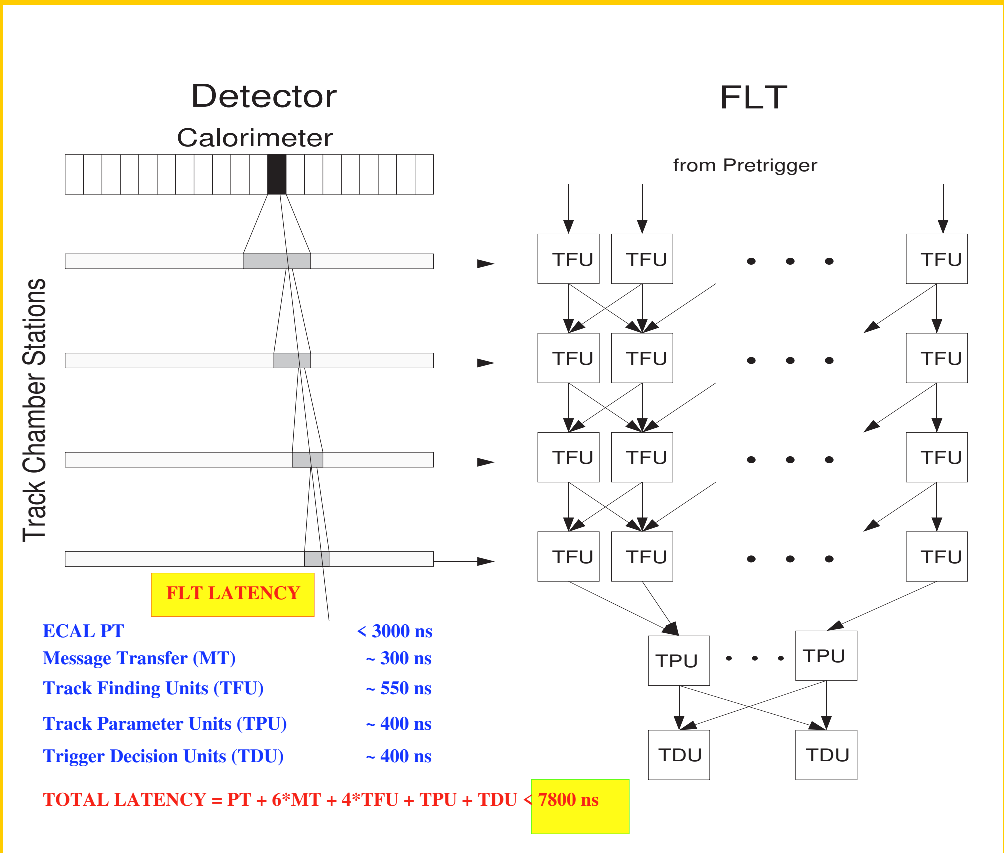
The FLT Concept

is iterative pattern recognition á la Kalman Filter.

The FLT implementation

are asynchronous parallel process pipelines where each process pipeline step acts only on data local to the process pipeline step.

Realization in hardware



- Data are kept local
- "Processes" ≡ messages are moved to the data
- Processing is purely data driven
- All units operate asynchron

General Triggers

Triggers are selective! no open triggers like in e^+e^- experiments but triggers for decay classes! The triggers are very flexible →introduce cuts for desired classes at any time.

Trigger	$B \to lX$	$bb \to llX$	$b \to lc \to llX$	$cc \to llX$	$B_S \to D_S \pi$
J/ψ	-	11	2.8	0.05	0
Di - lepton	-	18	1.7	0.01	0
1 lepton	3.5	7	4.6	0	0
2 hadron	-	?	?	?	0.03
FLT all	3.5	24	8.4	0.06	0.03

- high p_T hadron pretrigger allows also $B^0 \to \pi^+\pi^-$ decays to trigger $\eta_{FLT} = 0.30$ (850 reconstructed decays/year $\to \delta \sin 2\alpha \approx 0.14$)
- The semileptonic B triggers and also mixed hadron/lepton triggers allow for a B_S mixing study: $\eta_{FLT} = 0.24$ ($\to \delta X_S = 17$)
- high p_T photon pretrigger allows also $B^0 \to K\gamma$ decays to trigger $\eta_{FLT} = 0.10$ (10 reconstructed decays/year)

Ghosts

Decomposition of accepted events:

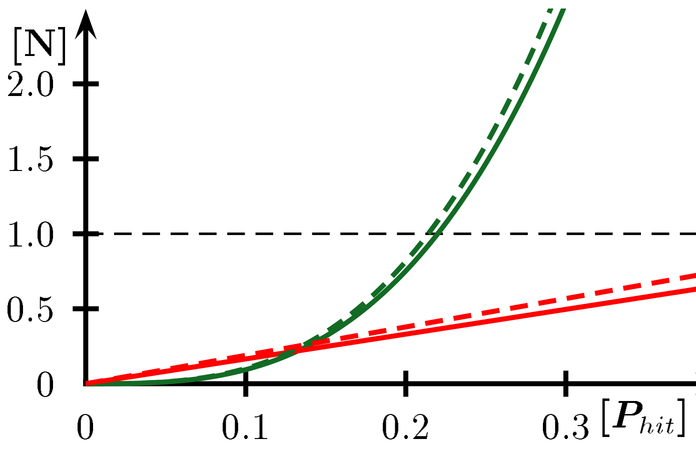
ghost tracks	45%
events with at least 1 ghost track	70%

Kinds of "ghost" points:

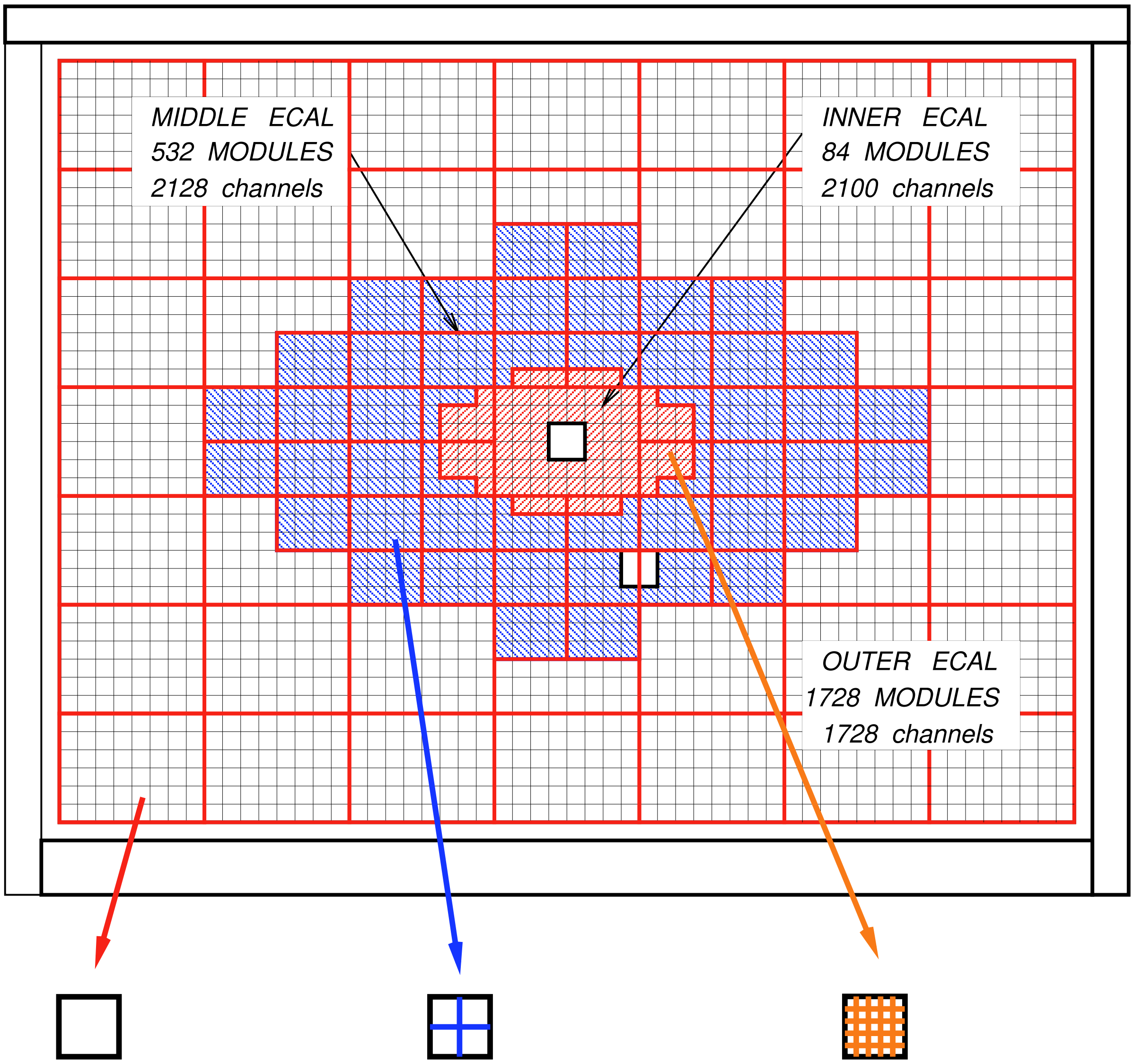
Combinatorics	∼(# of points in ROI)·(occupancy)^3
Ghost track	∼(area of ROI) · (hit-density)

41% of the tracks have a ghost point

For the mean ROI size in the hottest area of TC2:
MSGCs (solid line, 94 out of 234 points)
OT (dashed line, 107 out of 234 points)



THE ELECTROMAGNETIC CALORIMETER



OCCUPANCY ~ 10 %

SHASHLIK CALORIMETER

PRETRIGGER CANDIDATES

HADRON/ ELECTRON SEPARATION

ENERGY MEASUREMENTS

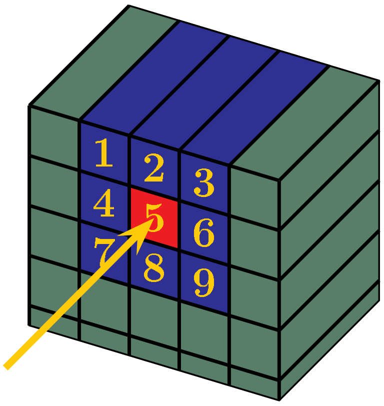
DEPTH : 20 – 23 X_0

PM – CW

Calorimeter Towers (of the 3 types) tested on beam@ DESY and CERN

- Energy Resolution
- Non uniformity of response

do agree with design specs



track seeds are produced by pretrigger units

Electron track seeds:

$$E_{th} = K_{Trig} \cdot \left(\frac{1}{R} + \frac{1}{x^2+|y^3|}\right)$$

$E_{\Sigma} > E_{th}$ $\quad E_5 > E_{th}/2$

mean # of seeds: 2/BX

# of channels: 6000

E energy of track:

$$(\sigma E)/E = \left(17/\sqrt{E} \oplus 1.6\right)\%$$

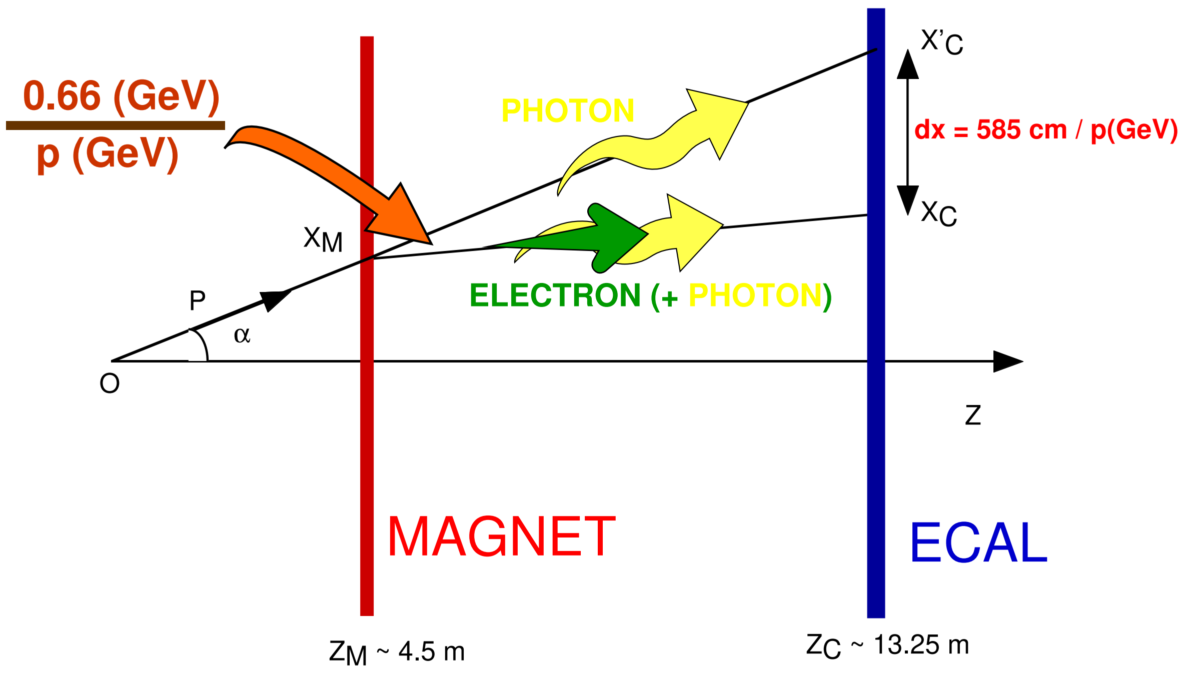
x using corrected center-of-gravity for row:

$$x = x_0 + A \cdot \arctan\left(B \cdot \sum_{i=4,5,6} (x_i \cdot E_i) \,/ \sum_{i=4,5,6} E_i\right)$$

y using corrected center-of-gravity for column:

$$y = y_0 + C \cdot \arctan\left(D \cdot \sum_{i=2,5,8} (y_i \cdot E_i) \,/ \sum_{i=2,5,8} E_i\right)$$

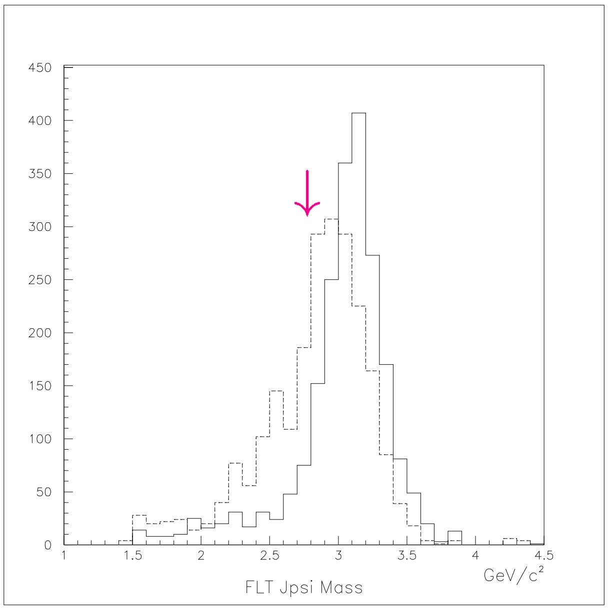
THE BREMSSTRAHLUNG RECOVERY



- The method provides a safety margin for the FLT

→

- dashed line : no brem. recovery
- solid line : with brem. recovery



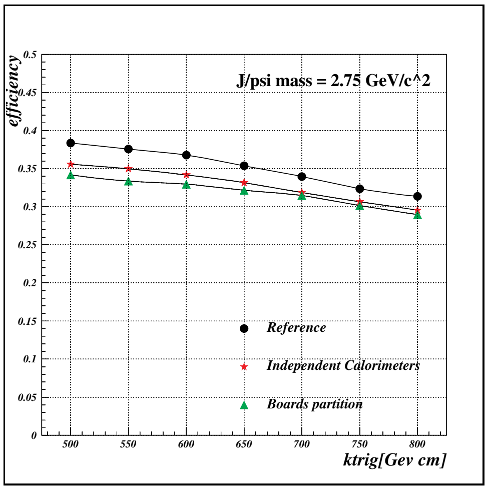
PT HARDWARE REALIZATION

- BORDER SIGNAL RECOVERY BETWEEN NEIGHBOURING BOARDS

- BREMSSTRAHLUNG RECOVERY : ONLY BETWEEN TWO CLOSE BOARDS (1 BOARD HANDLES 10 TOWERS IN THE NON BENDING PLANE)

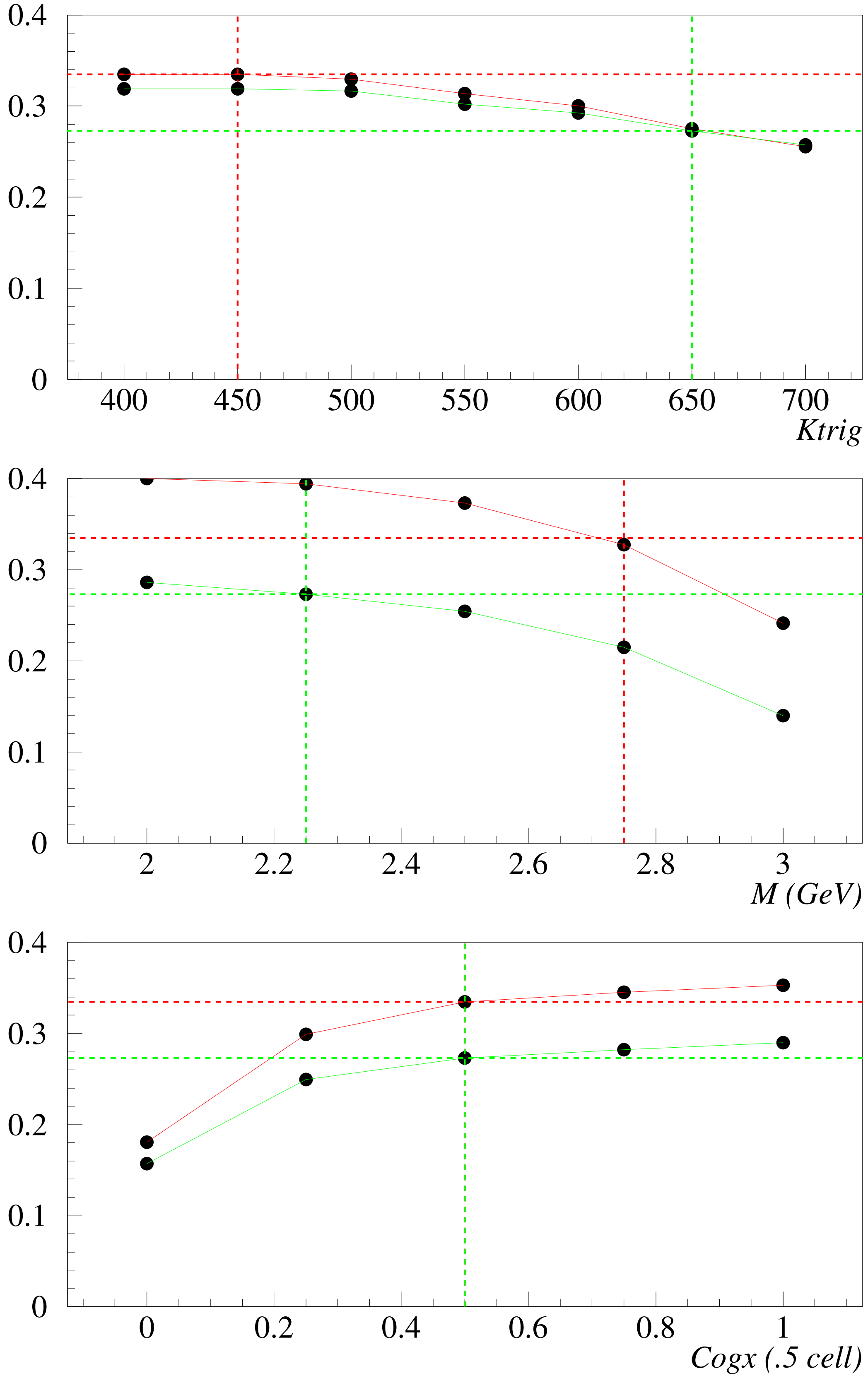
- INDEPENDENT CALORIMETERS

- DIGITAL COMPRESSION (7 BIT OUT OF 12 + 1 BIT OF FLAG) OF ABSOLUTELY CALIBRATED ENERGY DATA FROM READOUT LUT

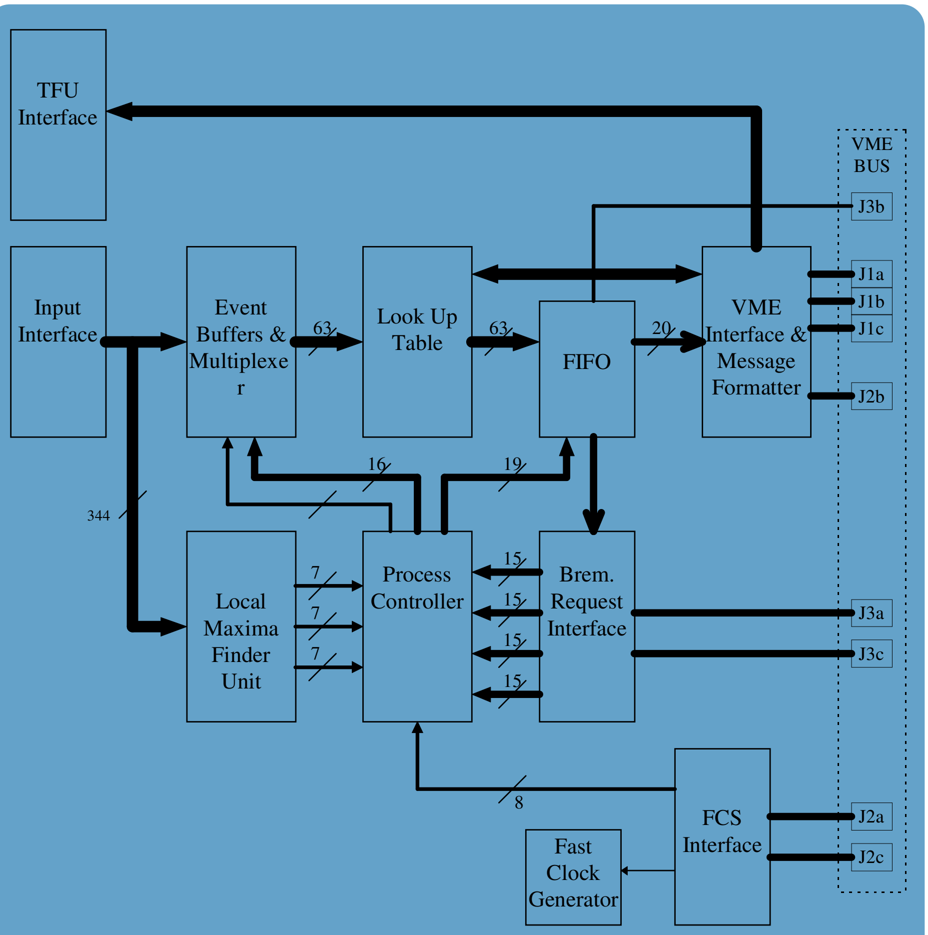


Phys. Quant.	Energy (GeV)	Cell Coord.	PT recon.	RO recon.
P TOT (GeV)	20	c.c	19.6 ± 1.0	19.6 ± 0.7
x_{COG} (c.u)	20	q.c	0.06 ± 0.02	0.06 ± 0.01
d_{brem} (c.u)	20	q.c	13.4 ± 0.7	13.3 ± 0.5

ECAL PT Efficiency



THE PRETRIGGER BOARD BLOCK DIAGRAM



Block diagram

Hera-B Clock (10.4 MHz) units

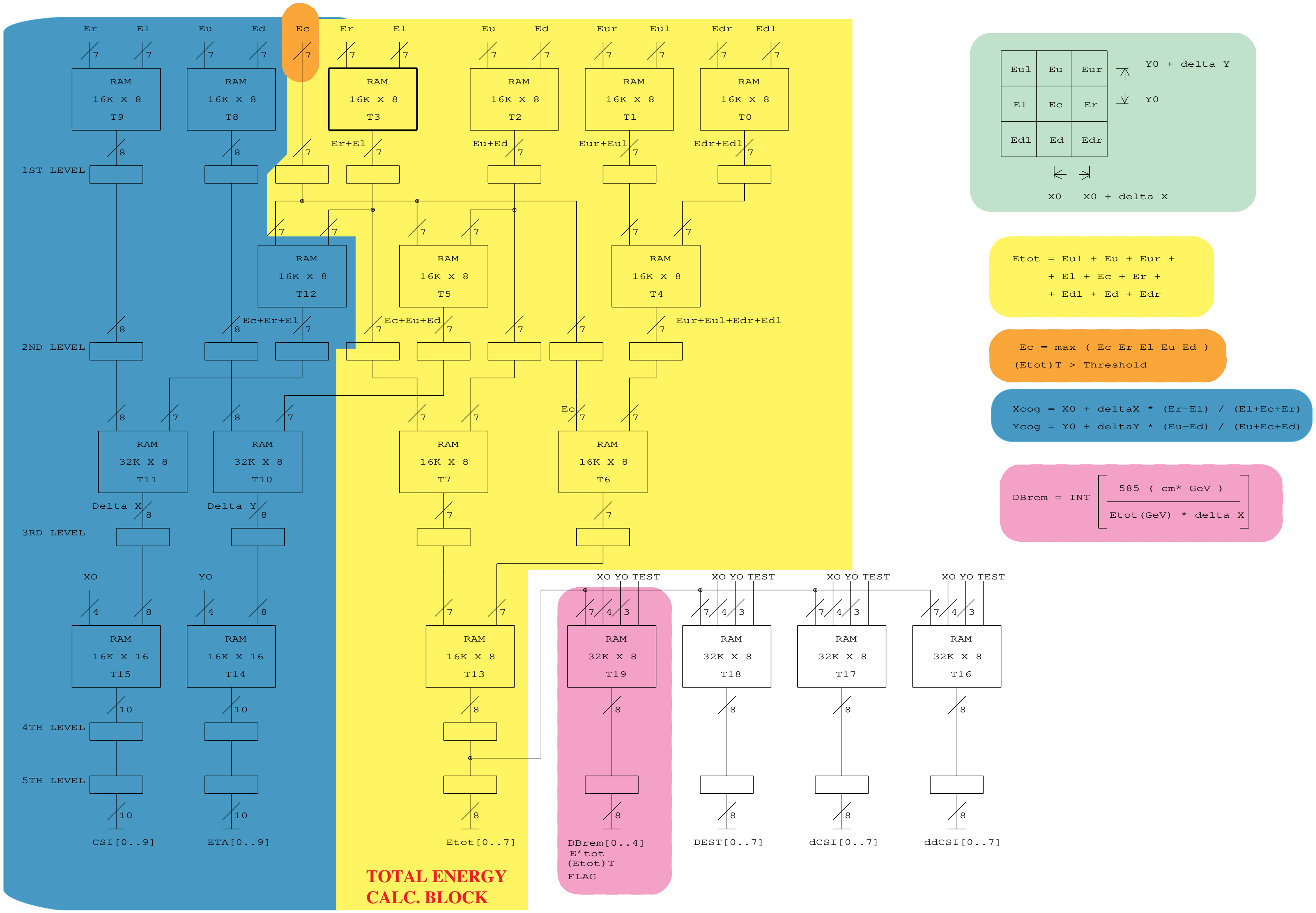
↓

1.00 Read out output
1.75 LMFU input + EBM input
2.00 LMFU data latched
3.25 Comparator outputs, within the LMFU
4.25 LMFU outputs the first data
5.25 ... second ...
6.25 ... third ...
4.75 Process Controller stores first data
7.25 BCN (Bunch Crossing Number) + SEL (Multiplexer Selections) extraction from the Process Controller
8.00 Extraction data from RAM in EBM
12.00 EBM Output and LUT input
13.25 LUT output (and DBREM output)
13.50 Brem. Request Interface output
-
-
- BREM. cycle (as LMFU output ---> LUT output) latency 9 BX
-
-
22.50 LUT output
23.50 Bus Request
24.50 Bus OK
25.50 MBUF output / MFVI (Message Formatter & VME Interf.) input
26.75 MFVI output message for the first data
27.75 ... second ...
28.75 ... third ...

Process time scale

M.B. - Elba '97

THE PRETRIGGER LUT DATA PROCESSING UNIT

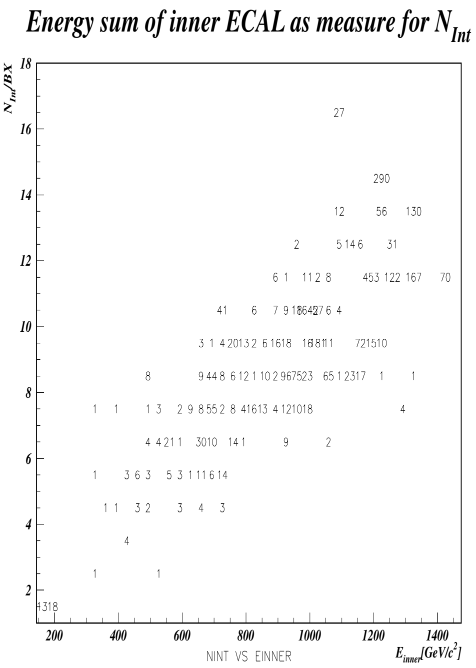


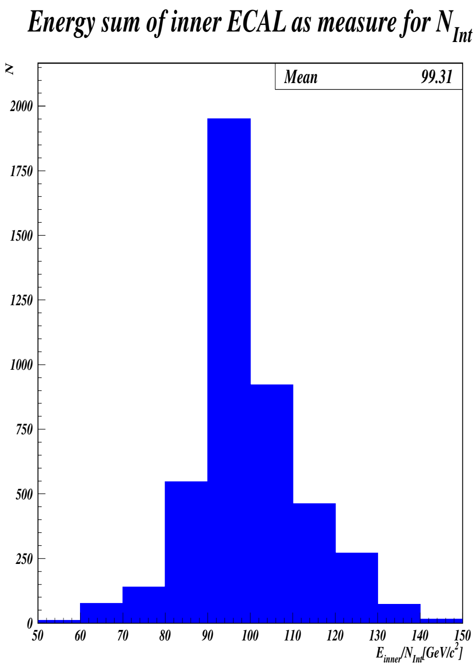
TOTAL PROCESSING TIME = 1. 25 HERA_B BX

Measurement of N_{int}

Use energy sum of inner calorimeter as measure for N_{int}, the number of Interactions !

This may be obtained fast
It is not noise sensitive
Allows to cut on the multiplicity!





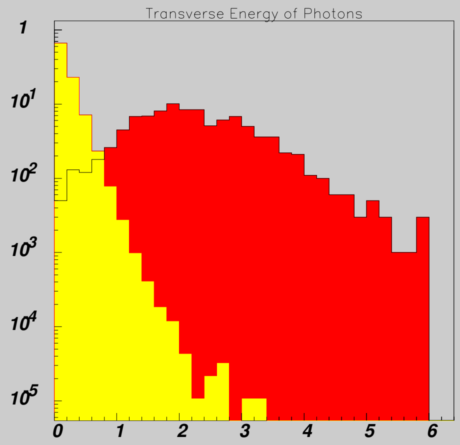
N_{int} versus $\sum E_{inner}$

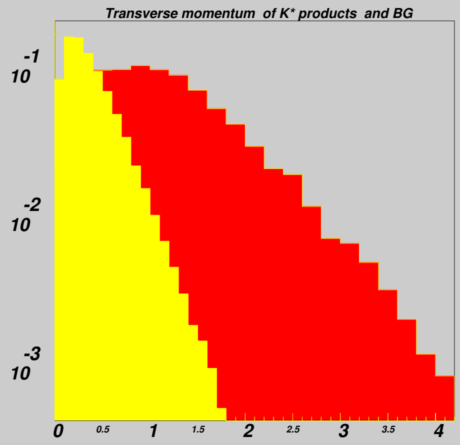
$N_{int} / \sum E_{inner}$

Photon Pretrigger

for: $B^0 \rightarrow K^{*0}\gamma$
$\quad\quad\quad\quad\quad\quad \hookrightarrow K^+ pi^-$

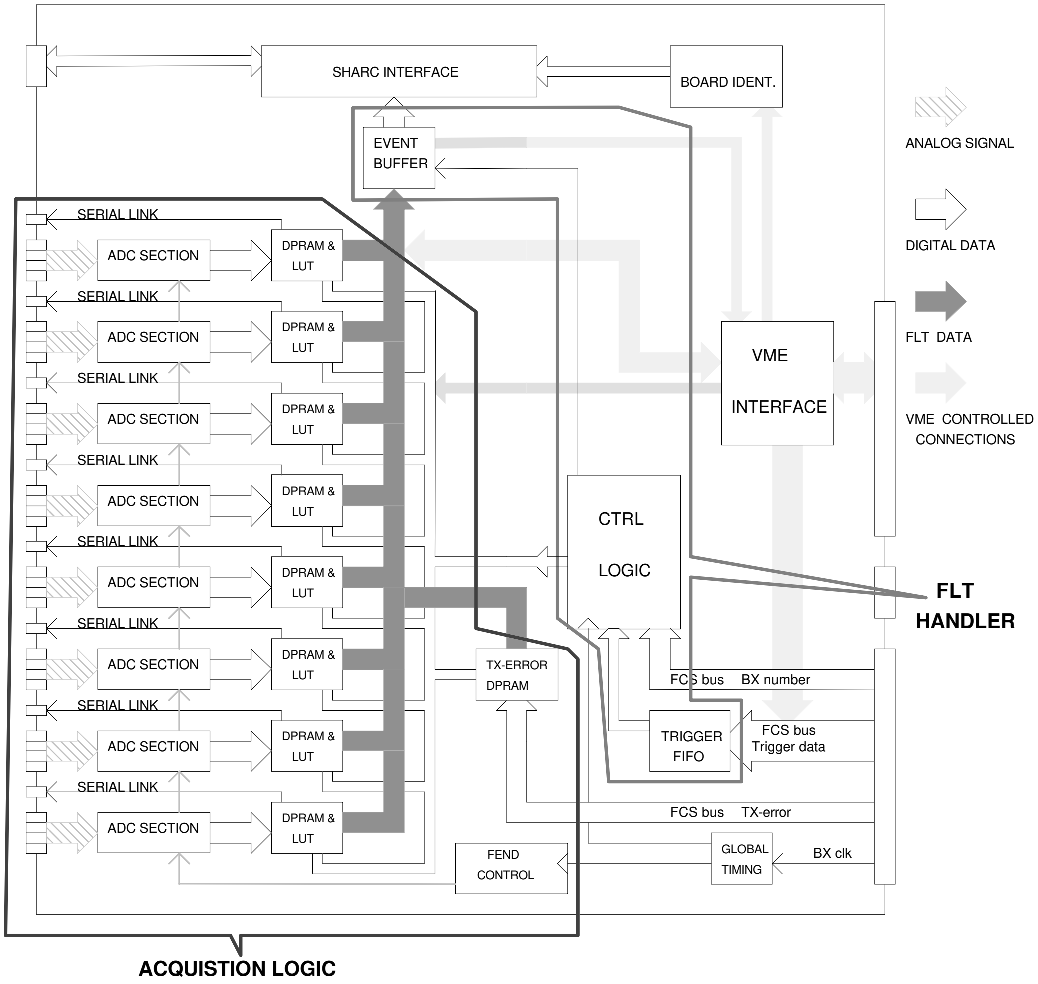
E_T of γ and inelastic BG	p_T of K, π and inelastic BG





- Cut on photon E_T larger then $3\,\mathrm{GeV}/c^2$
- Cut on hadron p_T at $1.5\,\mathrm{GeV/c}$
- rejection factor of 500
- efficiency of 10%

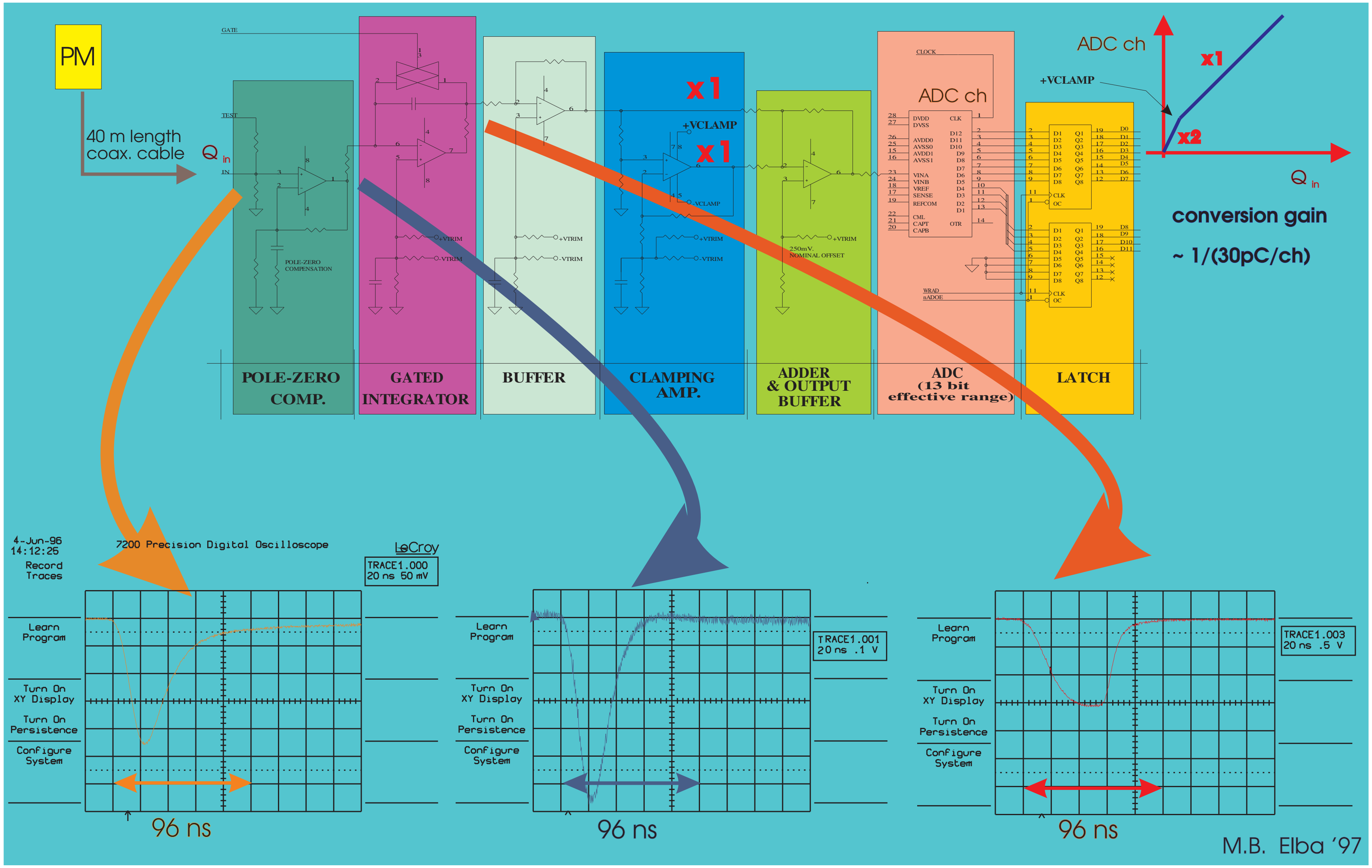
The Readout Board



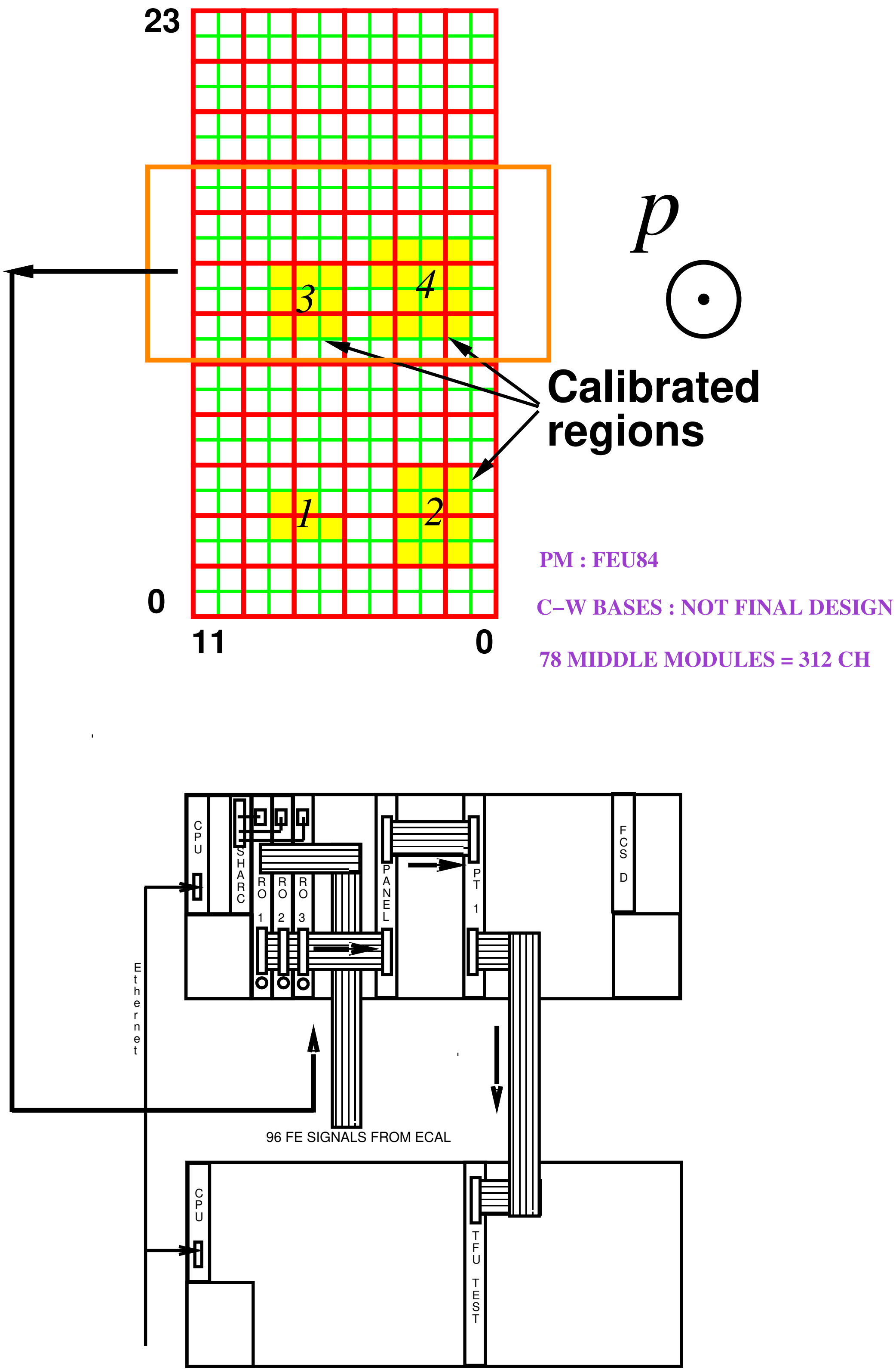
- The FCS system distributes the HERA-B clock (10.4 MHz) to all the detectors
- The DAQ system is based on SHARC processors (40 Mbyte/s)
- The ADC section card is a separate unit mounted on the 9U VME mother board (modular $\rightarrow$ usable in other systems !)
- The design foresees a full diagnostics of all the board components (analog and logic)
- The LUT provide calibrated data to the pretrigger by means of a serial sync. protocol

- Digital Pipeline 128 HERA-B BX deep
- ADC Latency 3.5 HERA-B BX clock
- ADC: 13-bit dynamic range with 12-bit resolution
- The board delivers also an analog sum output of 32 channels: very important: will give FAST INHIBIT on high multiplicity events to the HERA-B pretriggers !

THE GATED INTEGRATOR + ADC SECTION



ECAL READOUT AND PRETRIGGER TEST SETUP NOV. '96

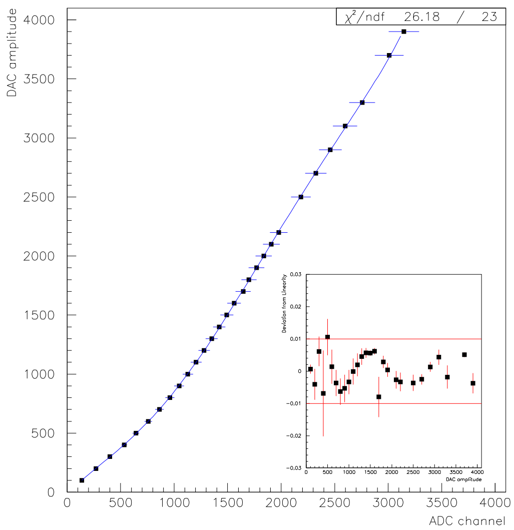


Results on The Readout System

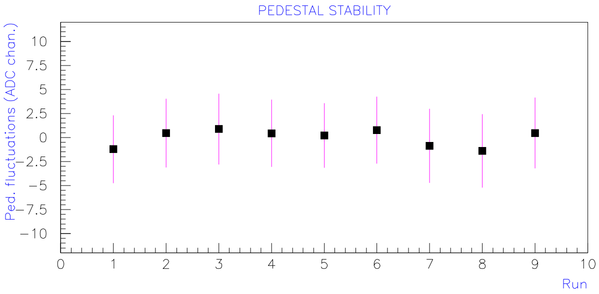
- The ADC chain intrinsic electronics noise is about 1.5 ch. (45 fC)

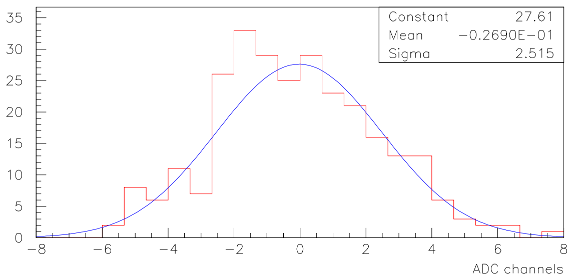
- The new PM bases electronics noise is about 1 ch (30 fC)

  The expected electronics noise is less than 2 ch (2.7 ch. in the NOV '96)



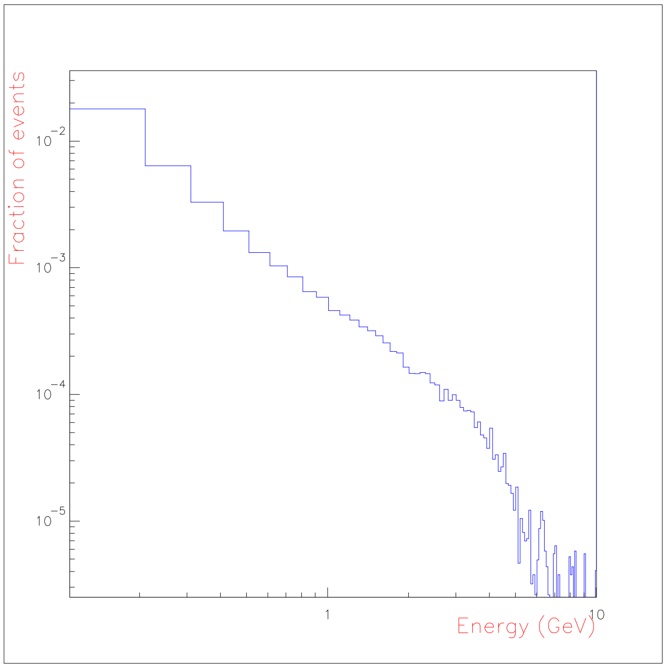
⟵ 96 ADC channels Transfer Function





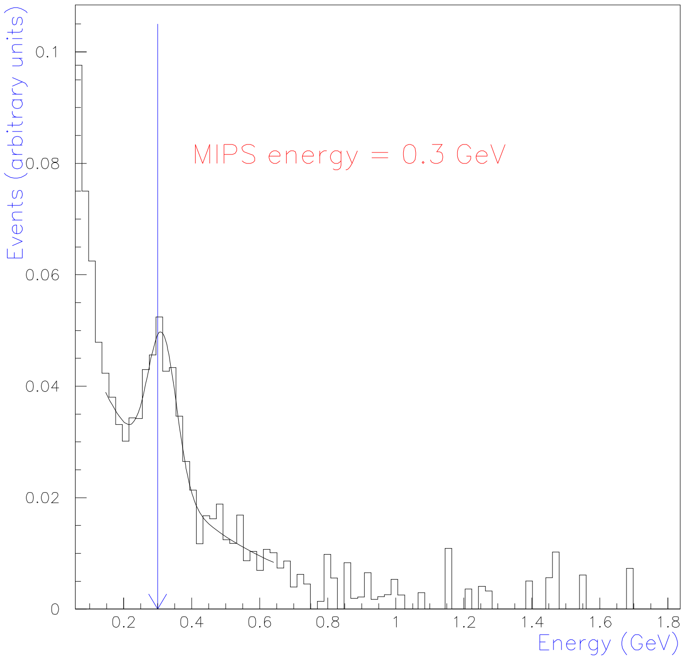
96 ADC channels pedestal stability (on ten days) ⟶

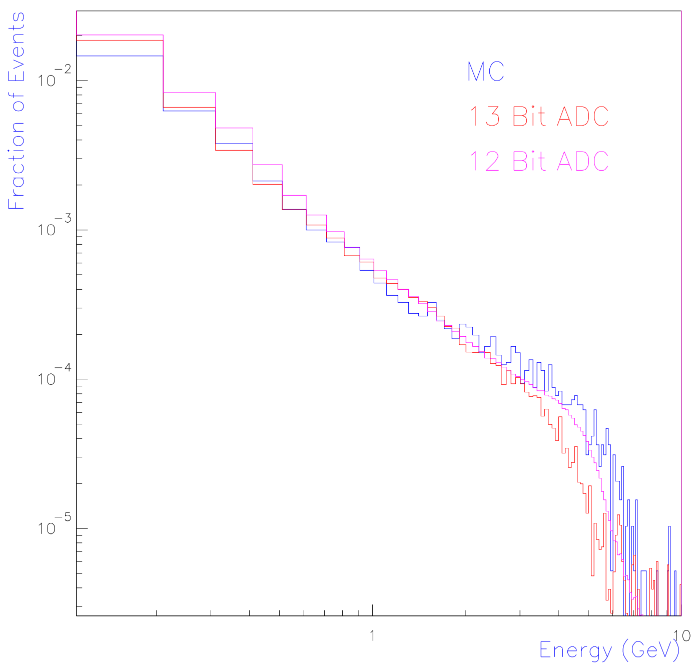
Results on The Readout System @ HERA-B

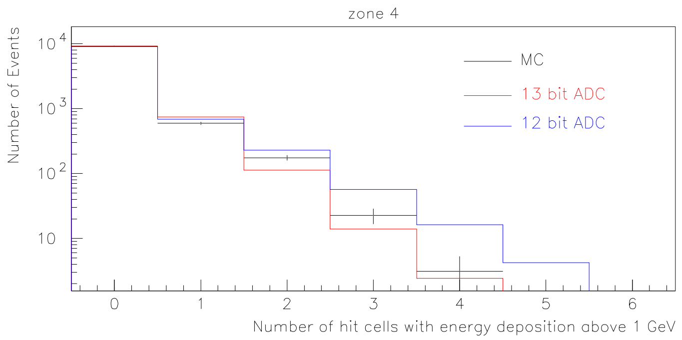


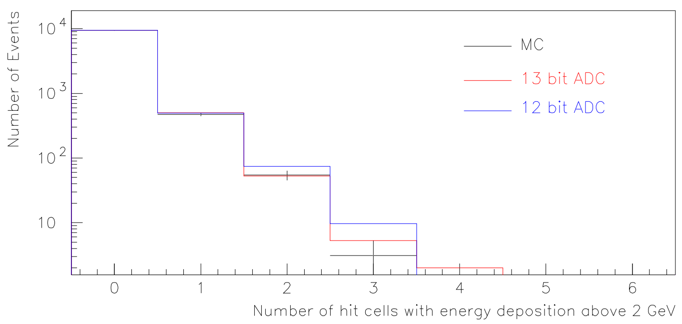
← "Differential" occupancy as a function of the energy deposited in a single tower

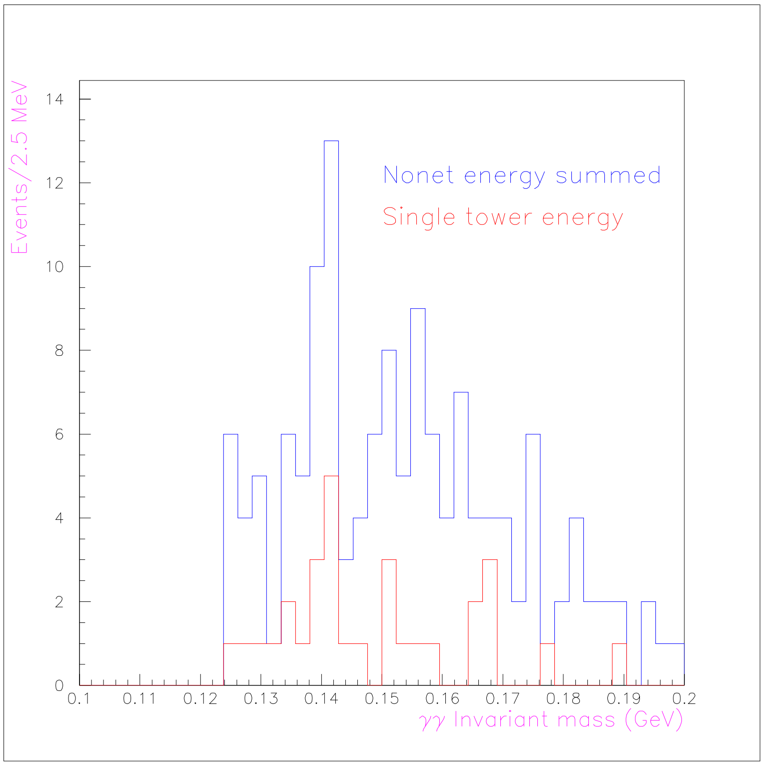
Single tower Energy Spectrum of MB events after the requirement of isolated cluster ⟶

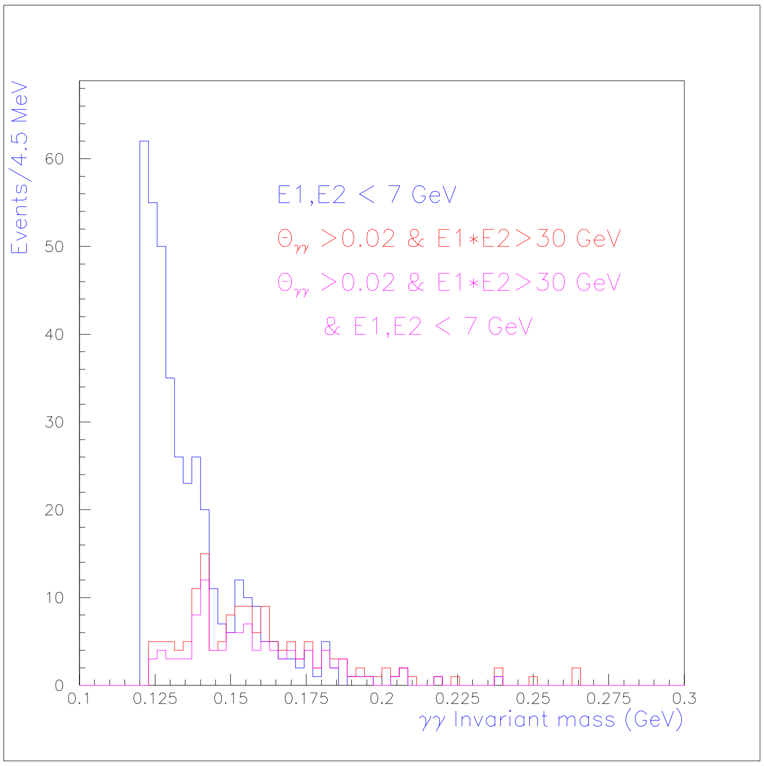


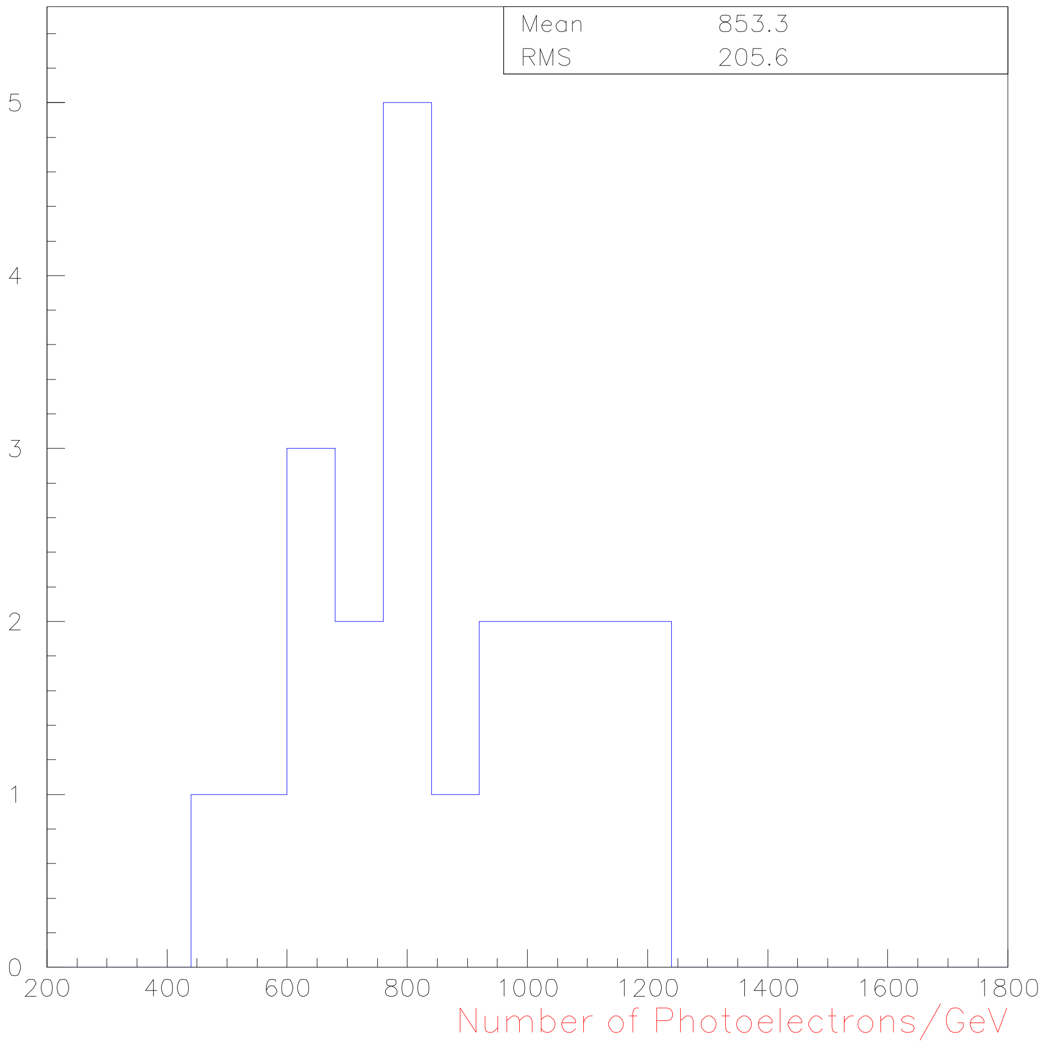

Fraction of Events
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1
10
Energy (GeV)
MC
13 Bit ADC
12 Bit ADC


zone 4
Number of Events
10^4
10^3
10^2
10
0
1
2
3
4
5
6
Number of hit cells with energy deposition above 1 GeV
MC
13 bit ADC
12 bit ADC


Number of Events
10^4
10^3
10^2
10
0
1
2
3
4
5
6
Number of hit cells with energy deposition above 2 GeV
MC
13 bit ADC
12 bit ADC


Events/2.5 MeV
14
12
10
8
6
4
2
0
0.1 0.11 0.12 0.13 0.14 0.15 0.16 0.17 0.18 0.19 0.2
γγ Invariant mass (GeV)
Nonet energy summed
Single tower energy


Events/4.5 MeV
60
50
40
30
20
10
0
0.1 0.125 0.15 0.175 0.2 0.225 0.25 0.275 0.3
γγ Invariant mass (GeV)
E1,E2 < 7 GeV
Θγγ >0.02 & E1*E2>30 GeV
Θγγ >0.02 & E1*E2>30 GeV
& E1,E2 < 7 GeV



Mean 853.3
RMS 205.6
0
1
2
3
4
5
200
400
600
800
1000
1200
1400
1600
1800
Number of Photoelectrons/GeV

ECAL PRETRIGGER TEST RESULTS

WHAT HAS BEEN TESTED

- KNOWN PATTERNS OF ENERGY WHERE SENT BY THE READOUT SYSTEM
- WE FED ON ONE PRETRIGGER BOARD 1 CANDIDATE PER BX
- THE PRETRIGGER MESSAGE BUILT WAS SENT TO THE TFU TEST BOARD
- THE DATA FLOW (@ 40 MHz) FROM THE PRETRIGGER BOARD TO THE TFU TEST BOARD WAS SUCCESFULL AND THE ENERGY OF THE CANDIDATE LIKE THE OTHER MESSAGE VARIABLES WERE CORRECTLY READ BY THE PROGRAM RUNNING ON THE CPU RESIDING IN THE TFU TEST BOARD

WHAT HAS NOT YET BEEN TESTED (NOT IMPLEMENTED IN THE FIRST PROTOTYPE)

1 – THE HANDLING OF MORE THAN ONE CANDIDATE PER BX

2 – THE BREMSSTRAHLUNG RECOVERY

3 – THE VME INTERFACE

THE CORRECT INTERFACING OF THE ECAL READOUT + PRETRIGGER SYSTEM TO THE HERA–B FLT HAS BEEN CHECKED !

THE SECOND PROTOTYPE RELEASE OF THE PRETRIGGER BOARD (READY INTO TWO MONTHS) WILL BE WITH POINTS 1–2–3 IMPLEMENTED

SUMMARY

- THE ECAL READOUT AND PRETRIGGER SYSTEM HAS BEEN DESCRIBED

- THE R&D STARTED ON MIDDLE '95

- THE FIRST PROTOTYPE BOARDS WERE AVAILABLE IN THE LATE '96

- THE TEST RESULTS (ON BEAM AND ON BENCH) ON THESE PROTOTYPES HAVE SHOWN GOOD PERFORMANCES

- THE SECOND RELEASE WILL BE READY IN THE MIDDLE OF THIS YEAR AND THE FINAL VERSION WILL BE READY FOR NEXT YEAR HERA-B RUN

- BOTH THE SYSTEMS DESIGNED ARE QUITE GENERAL AND ALLOW FOR FUTURE DEVELOPMENT