Experience with Hera-B triggering

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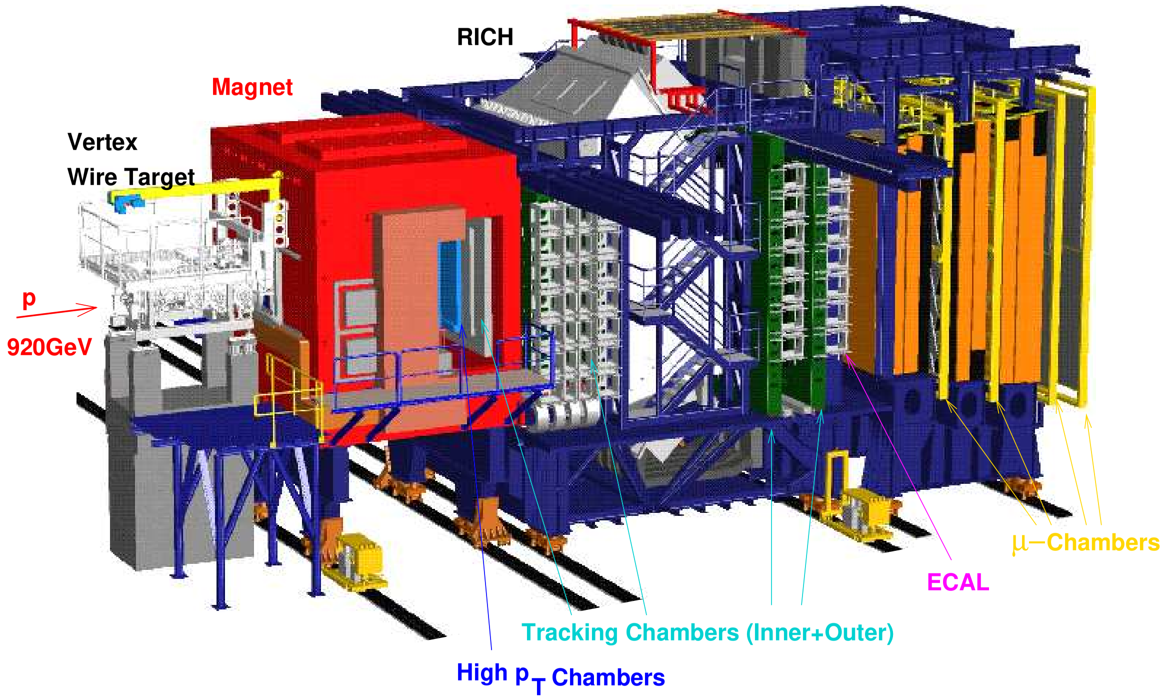
Sea of Galilee, September 14, 2000
Beauty-2000

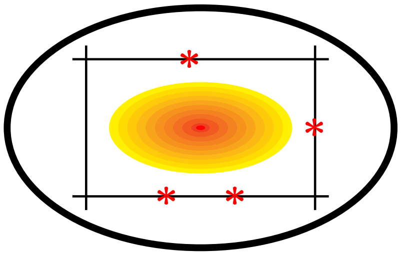
- Review of the Hera-B Trigger concept
- J/ψ production in year 2000 run
- First Level Trigger commissioning
- Full Trigger-chain commissioning
- Conclusions and prospects

The Hera-B experiment



Dedicated B-physics experiment at DESY

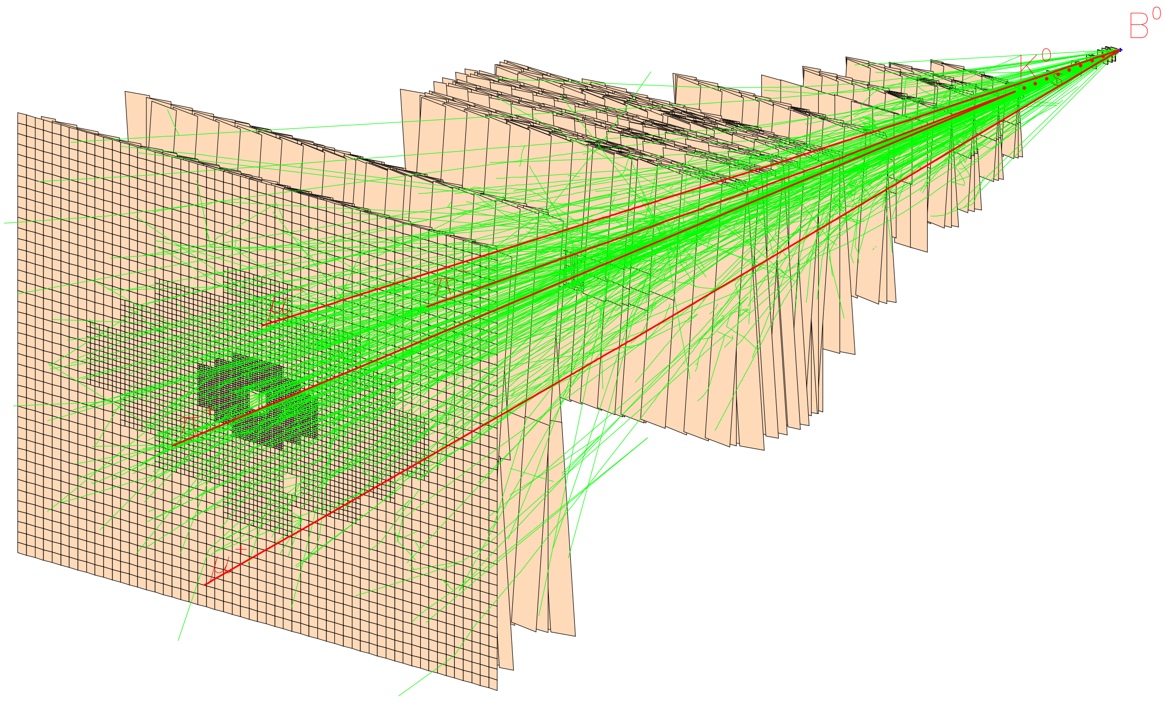
- pN interactions in HERA proton beam:



- Bunch frequency 10 MHz
- Interaction rate $\leq$ 40 MHz $\Longleftrightarrow$ $\leq 5\ pN$ inter. per BX
- p(920 GeV) $+ N$(target) $\rightarrow b\bar{b} + X$
- $\sigma_{b\bar{b}}/\sigma_{inel} \approx 10^{-6} \Longrightarrow b\bar{b}$ prod. $\approx$ 40 Hz

The Hera-B Trigger Challenge

$\Rightarrow$ Typical MC event with $B^0 \to J/\psi\, K_s^0$ decay and 5 minimum-bias interactions :

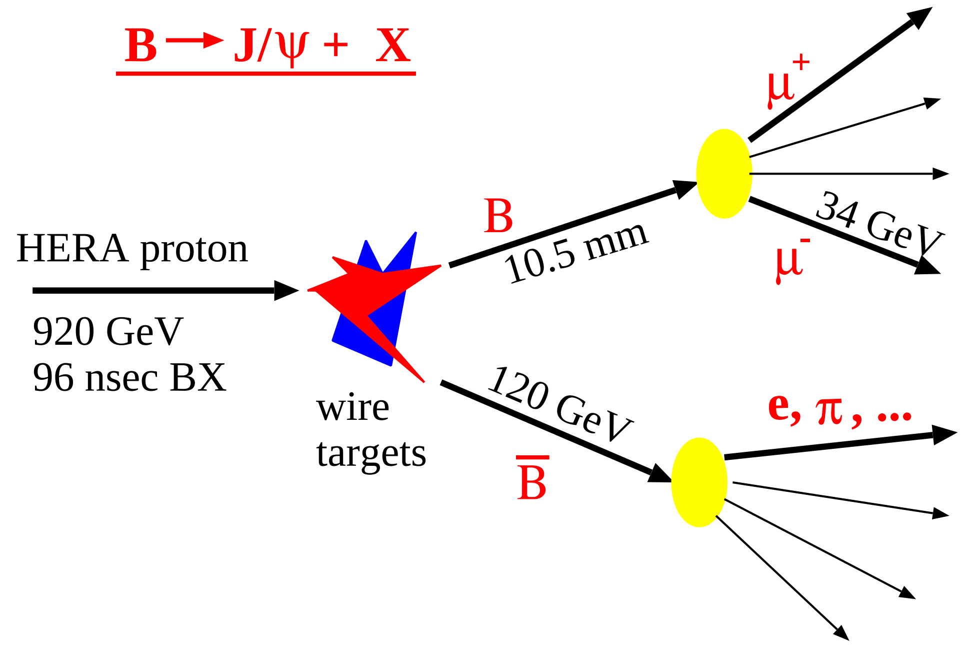


❖ High interaction rates	$\leq$ 40 MHz
❖ Low Signal/Background	$\approx 10^{-9} - 10^{-11}$
❖ Large number of <tracks/event>	≈ 150
❖ High occupancies	$\leq 20\%$
❖ Large number of detector channels	$\approx 600K$

$\Rightarrow$ need:
- efficient, highly selective trigger
- high bandwidth, low latency data acqu. system

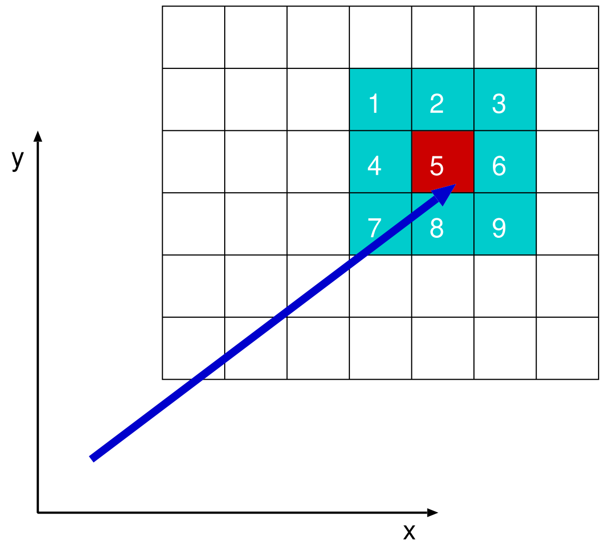
Multi-level Trigger design

$\Rightarrow$ trigger on high-pt leptons or hadrons, for example:

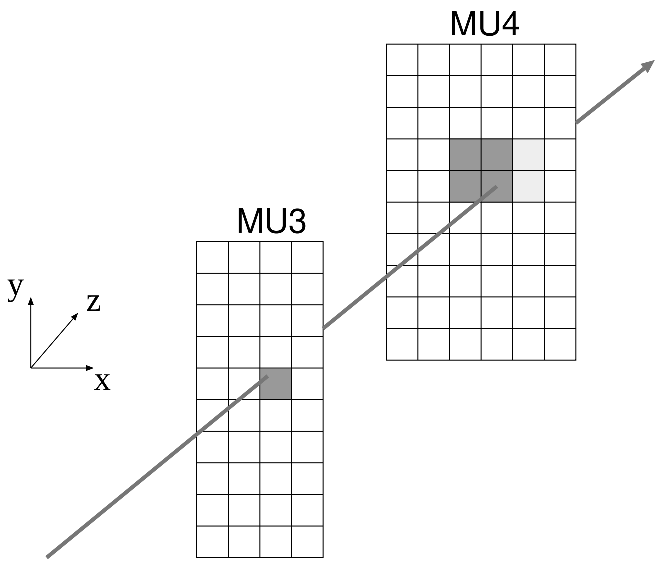


- Pre-trigger (latency 300nsec): Define Regions-of-interest (RoI) from Muon detector, ECAL, or coincid. in 3 Pad Chambers in Magnet (high-pt)
- Level 1 (latency 10μsec , red. 200):
  RoIs $\longrightarrow$ tracks behind magnet
- Level 2 (latency 3msec, red. 100):
  Refine tracks, $\longrightarrow$ VDS, vertex
- Level 3 (latency 100msec, red. 10):
  Full Silicon reconstruction, non-RoI secondaries
- Level 4 (latency 4sec , red. 2.5):
  Full Event reconstruction

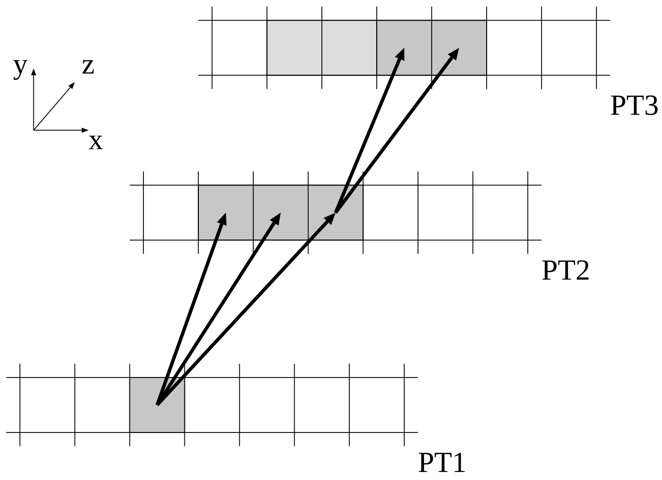
RoI definition



ECAL pre-trigger
(e.g. $J/\psi \rightarrow e^+e^-$
or hard-γ)

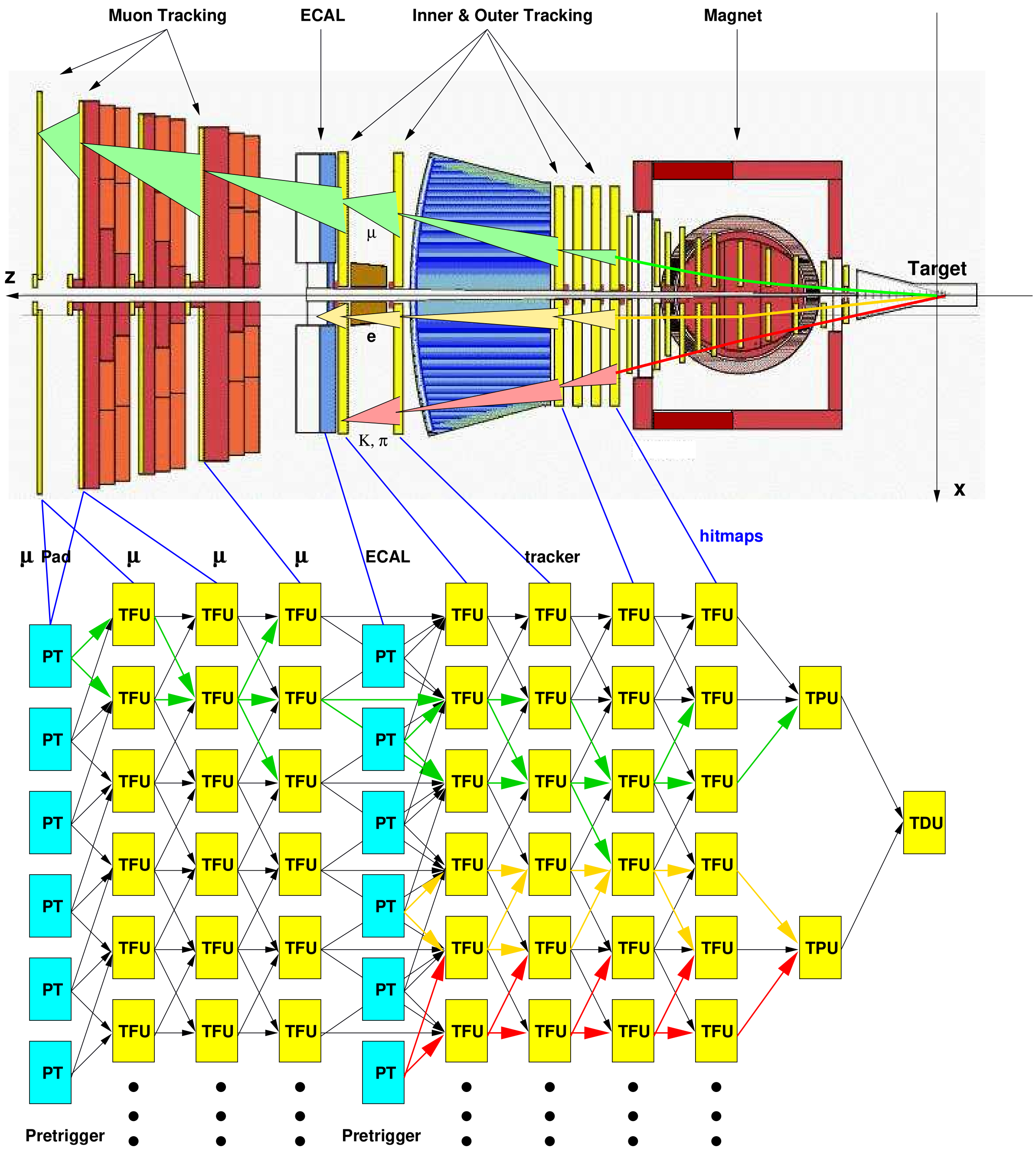


MUON pre-trigger
(e.g. $J/\psi \rightarrow \mu^+\mu^-$)



High-pt pre-trigger
(e.g. B $\rightarrow \pi^+\pi^-$)

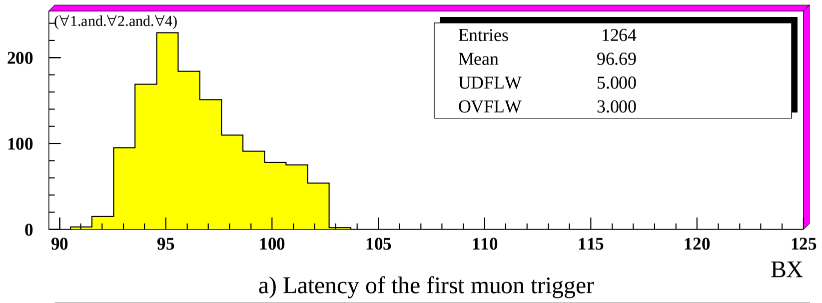
The First Level Trigger concept



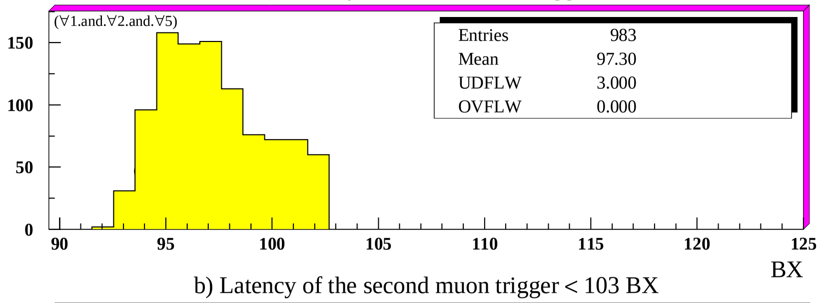
Important First Level Trigger characteristics

- triple coincidence required in 4 tracking stations $\Longleftrightarrow$ $\epsilon_{track} \sim (hit_{eff})^{12}$ ("or" in "double-layers")
- maximum latency of $10\mu s$ given by memory pipeline depth $\Longleftrightarrow$ currently $\sim 12\%$ of Muon trigger loss

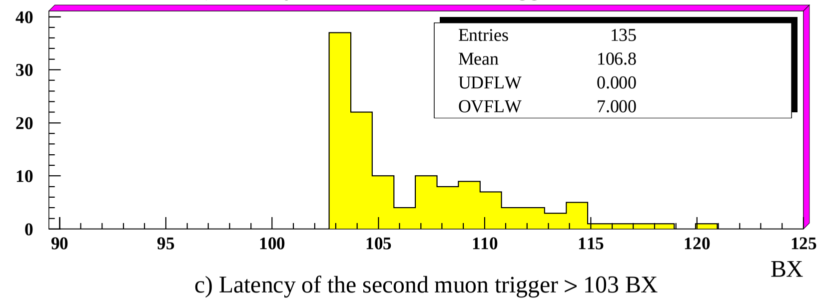
TDU behaviour checks



a) Latency of the first muon trigger



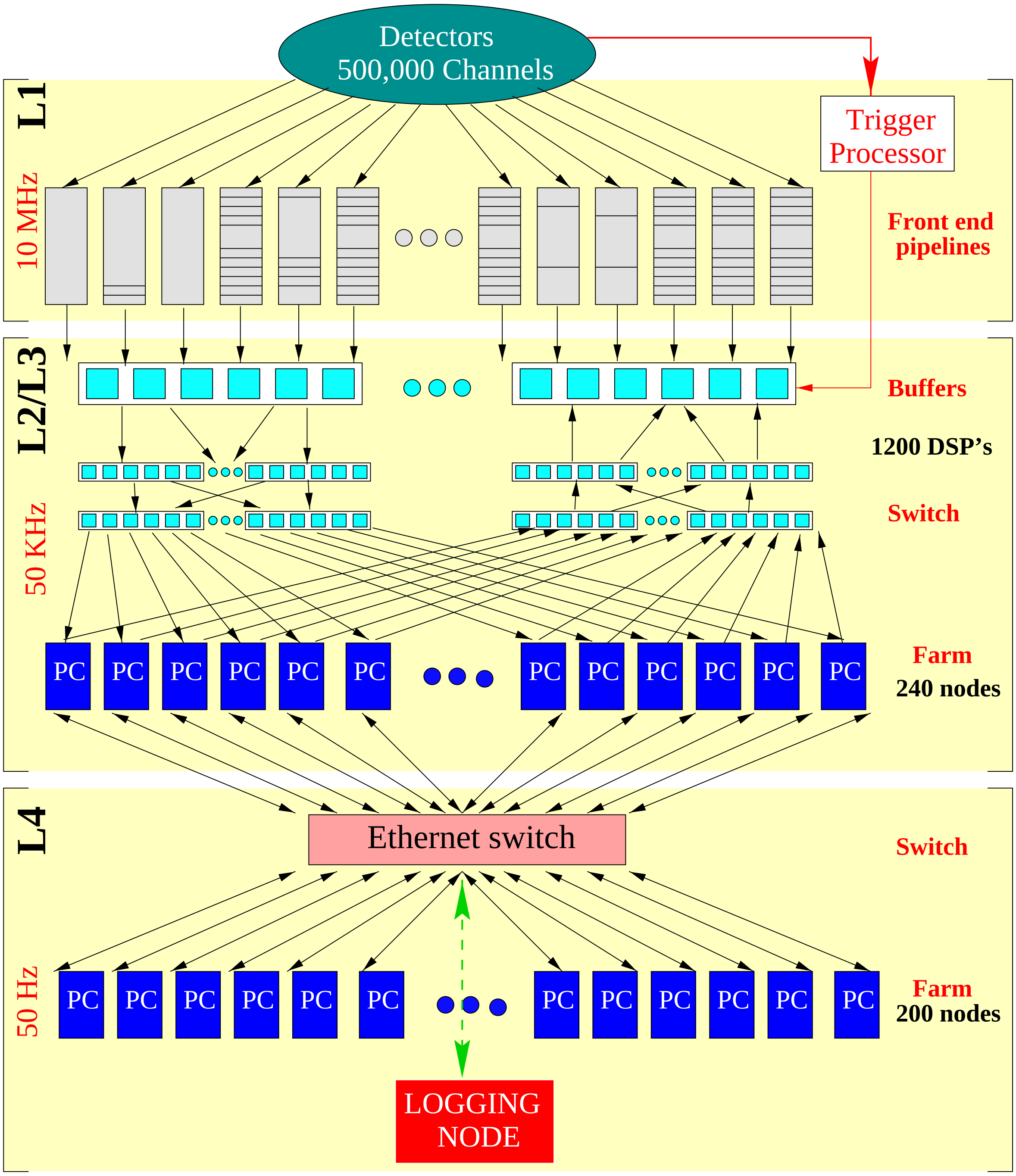
b) Latency of the second muon trigger < 103 BX



c) Latency of the second muon trigger > 103 BX

- maximum 50KHz output rate

Level 2 / DAQ architecture

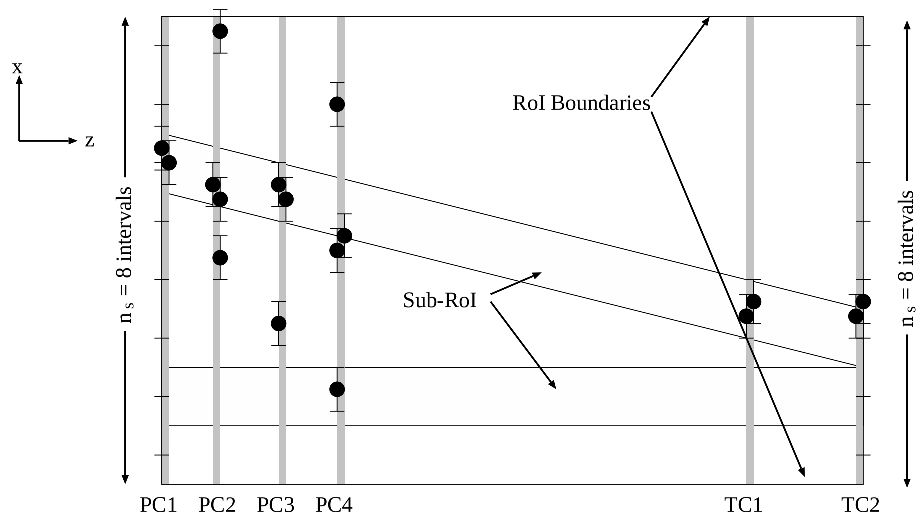


Level 2 Algorithm overview

Section	Functionality
Slicer	"Hough transform", x-layers behind magnet
Refitx	"Kalman filter" x-layers behind magnet
Refity	"Kalman filter" stereo layers behind magnet
L2Mag	transport through field; add hit, 1st SL
L2Sili	"Kalman filter" VDS
L2Vert	two-track vertexing

$\Rightarrow$ Full Level 2 chain running since <u>April 2000</u>

Slicer:

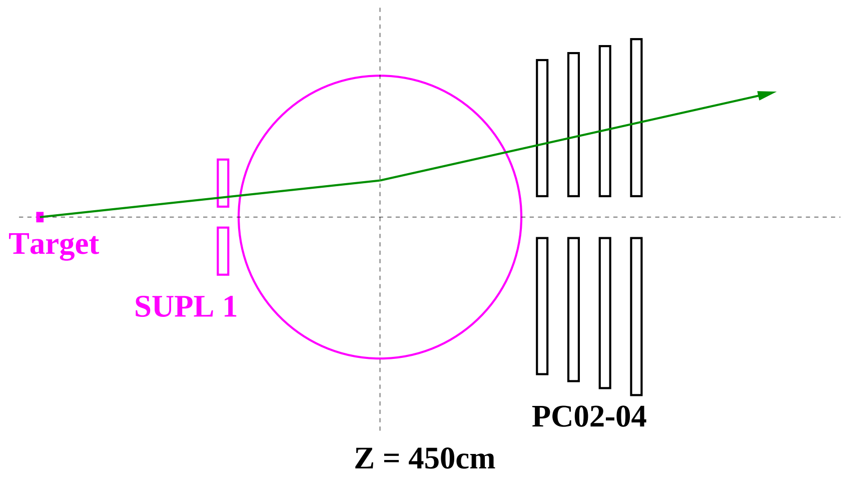


- Goal: Fast Ghost removal at Level 2 input
- Slice Level 1 RoI (X-view) into $n_s \times n_s$ sub-RoIs
- Require at least one hit in each "checked" super-layer
- Require minimum number of tot hits (max 18 layers)

RefitX and RefitY:

- Goal: Refine RoI's behind magnet
- Method: "Kalman filter"-like formalism in X and Y projections
- Cuts:
  - $\chi^2 \leq 10 * n$
  - $\leq$ 2 holes in series
  - "best" 5 sub-tracks kept
  - cut on $Q = N_{holes} + 0.05 \cdot \chi^2$

L2Magnet:



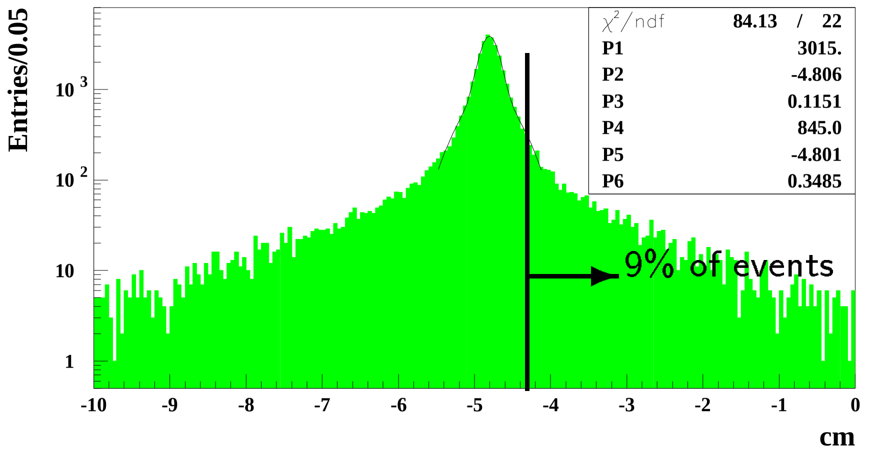
- Goal: Fast transport of RoI through magnet
- Look for hits in first super-layer and adjust RoI if hit found

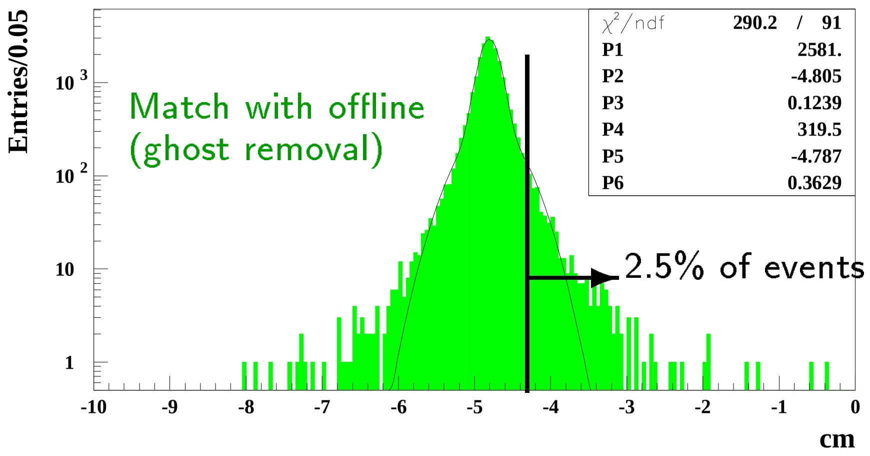
L2Sili:

- Goal: confirm RoI's in VDS
- Method:
  "Kalman filter"-like algorithm
- Cuts:
  - $\geq$ 3 hits in X,Y
  - $\geq$ 2 Super-planes-hits in X,Y

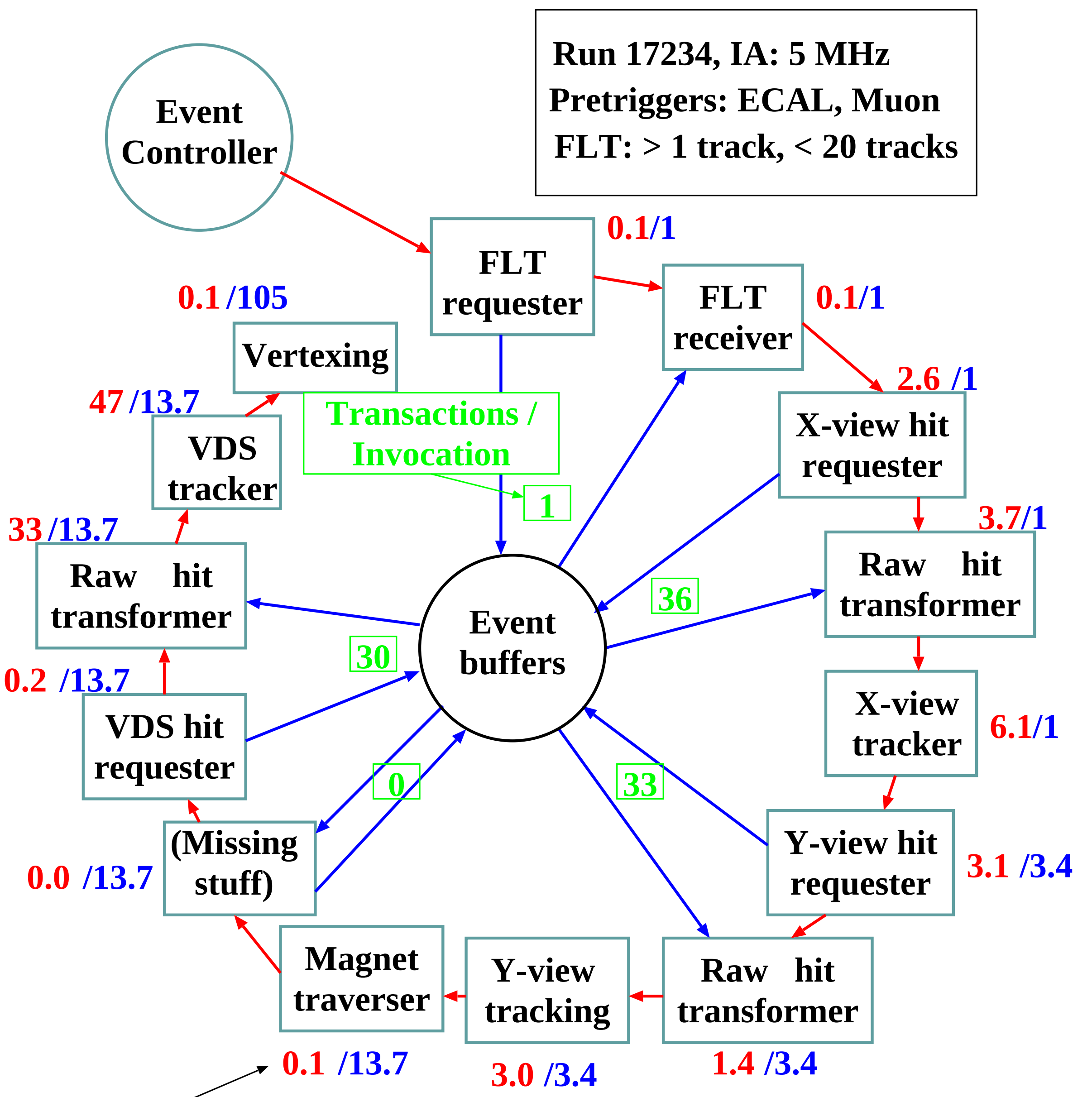
L2Vertex:

- Goal: Ensure that a pair of trigger tracks originate from the same wire, but are not fragmentation tracks.
- Methods:
  J/ψ trigger: Detached vertex of opposite charged particles
  General B trigger: Cut on impact parameter





Level 2 processing



(Execution time per invocation (ms) / Integrated rejection)

Totals: 19 ms per event / suppression: 105

Suppression/timing depend strongly on Level 1, ...

Level 3 and Level 4

LEVEL 3:

- Look for detached vertices using full vertex detector

LEVEL 4:

- online reconstruction
- event classification
- event selection
- data quality monitoring
- data for calibration and alignment
- re-processing

J/ψ production in year 2000 run

Trigger scheme:

- in parallel to Level 1 commissioning, use the remarkable flexibility of the Level 2 software to substitute Level 1 tracking with online ECAL/MUON reconstruction algorithms
- "transparent" TDU-mode allows to use ECAL/MUON pre-trigger information for Level 1 track-seeding

Running modes:

Type	Start	Trigger			Events
		Pre	Level 1	Level 2	$\cdot 10^{-6}$
Di-lepton	29 Apr	E	-	V	12
Di-lepton	15 Jun	E	-	OV	1
Di-lepton	28 Jun	Eμ	-	OV	3.7

Pre-triggers: E $\Rightarrow$ ECAL, μ $\Rightarrow$ Muon, H $\Rightarrow$ High-pt
Level 2:
O $\Rightarrow$ Outer tracker tracking
V $\Rightarrow$ Vertex detector tracking
X $\Rightarrow$ Vertex cuts

Limitations:

- CPU bound due to VDS tracking (E/V mode)
- dead-time due to ECAL reconstruction
- Pre-scaling (x 4) needed (Eμ/OV mode)

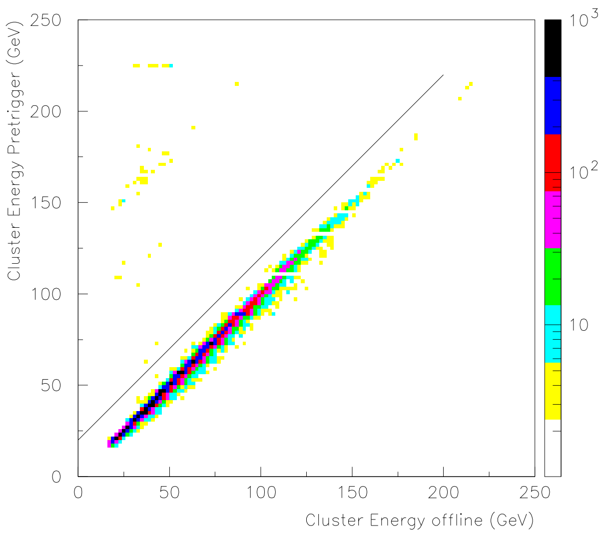
Level 2 input rate: $\sim$ 20KHz

Pre-triggers

e-Pre-trigger:
- working

$\rightarrow$ efficiency $\sim$ 96%

'Inner section - Run'17195



μ-Pre-trigger:
- operational since June (cathod pads of Muon chambers)

$\rightarrow$ cathod pad efficiency 70-90%

High-pt Pre-trigger:
- inner (gas pixel) chambers installed and commissioned:

$\rightarrow$ chamber efficiency $> 90\%$
- outer (straw) chambers commissioning ongoing

$\rightarrow$ transmission problems of pre-trigger electronics

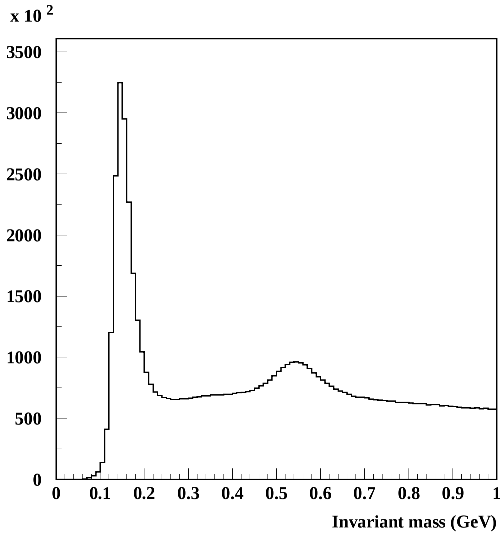
ECAL reconstruction in Level 2

- Two ECAL cluster with pt $>$ (1-1.2 GeV) in on-line CARE reconstruction.
- RoI definition:

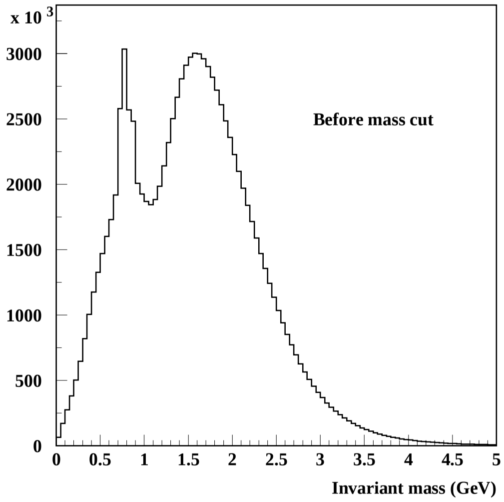
  ECAL: determined by ECAL cluster.

  PC1: determined using ECAL energy and position, target constraint and magnetic field.
- Consider only out-bender pairs with invariant mass larger than 2 GeV.

$\Rightarrow$ Seedings for Slicer/Refit or directly into L2Sili.

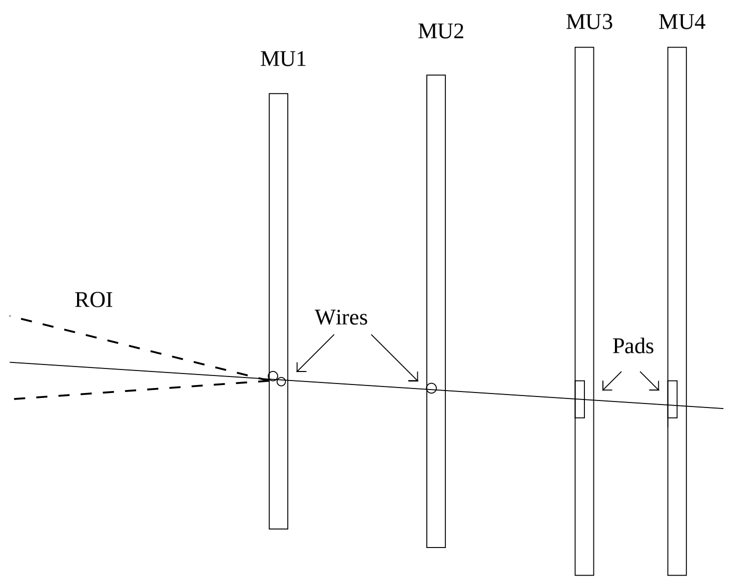


(all pairs)



(charged pairs only)

Muon reconstruction in Level 2



- Minimum distance of 50 cm required between pre-trigger coincidences (MU3 & MU4).
- Tracking through MU1 & MU2 (only x-view layers).
- RoI definition (2 possible charges):

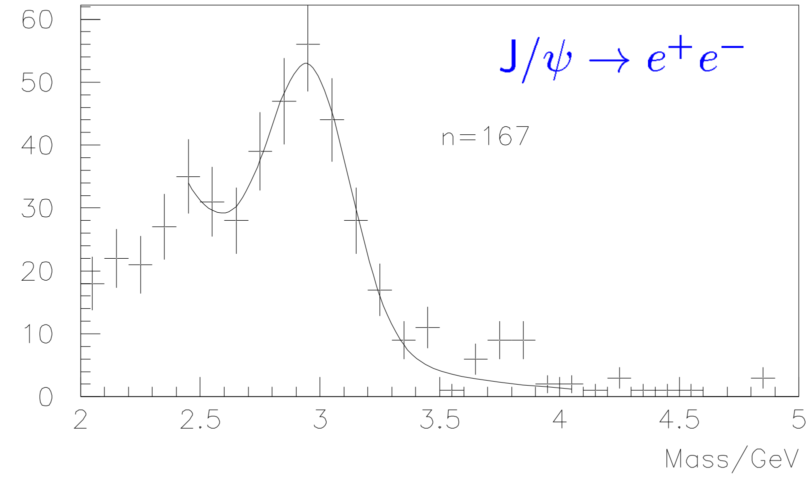
  MU1: x from MU1 and y from PADs (MU3).

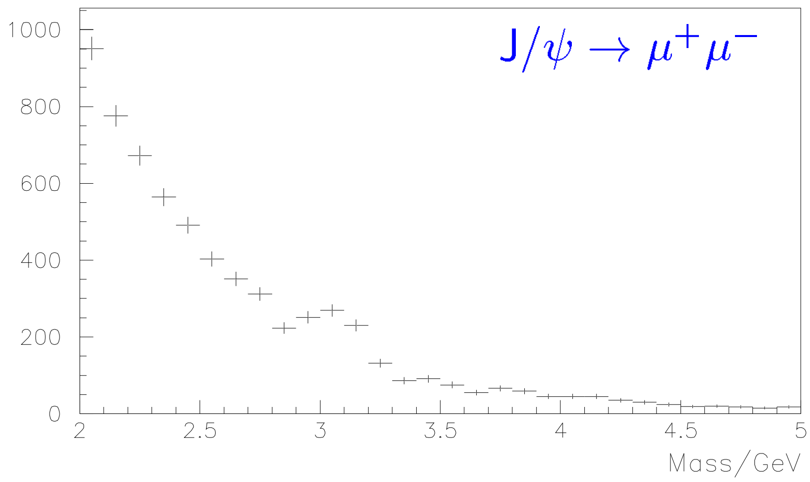
  PC1: setup with borders corresponding to 0.7 GeV $< p_t <$ 2.5 GeV using magnetic field and target constraint.

$\Rightarrow$ Large RoI's (up to 30cm in PC01) require refinement by Slicer/Refit before L2Sili processing.

Online J/ψ signals

$\Rightarrow$ Important achievement: online J/ψ





J/ψ efficiency compared to MC expectations

Running mode:

$\Rightarrow$ **Level 2 with ECAL, MUON, OTR** and **VDS**

Measured J/ψ Rates:

MUON channel: **200** $J/\psi/hour$

(real/live time $= 14\%$)

ELEC channel: **340** $J/\psi/hour$

(real/live time $= 54\%$)

	MC (%)	Data (%)
J/ψ $\rightarrow$mumu	1.2	0.7
J/ψ $\rightarrow$ee	2.8	1.2

$\Rightarrow$ the main contributions to the inefficiencies are the Geometry, the Pre-Triggers, the MUON reconstruction, the OTR

(Design eff including Level 1 is 60% for muons and 30% for electrons)

Second Level Trigger efficiencies

	Realistic OTR		Ideal OTR	
Algorithm	e^+e^-	$\mu^+\mu^-$	e^+e^-	$\mu^+\mu^-$
SLICER	0.99	0.99	1.00	1.00
REFIT-X	0.92	0.91	0.94	0.96
REFIT-Y	0.93	0.97	0.97	0.99
L2SILI	0.88	0.89	0.92	0.94
L2VERTEX	0.97	0.98	0.97	0.98
Overall SLT	0.72	0.76	0.81	0.88

$\rightarrow$ the simulation shows a 11% J/ψ efficiency drop between realistic and ideal MC

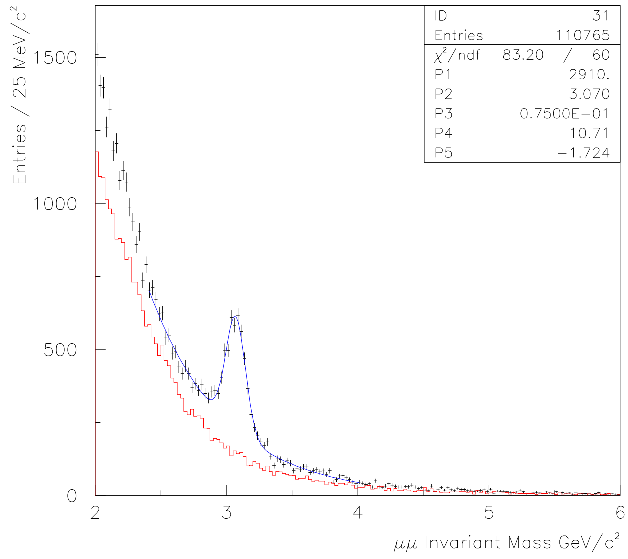
$\rightarrow$ but measurements on data showed Level 2 efficiency drops in the OTR up to 20%, due to unstable OTR detector quality conditions

Summary of J/ψ 2000 yield

$J/\psi \to \mu^+\mu^-$

— unlike sign
— like sign

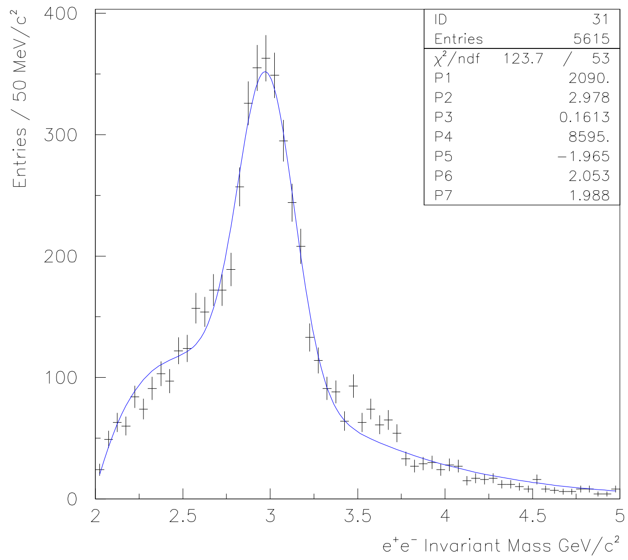
$\approx$ full sample
(total: 3000 J/ψ)



$J/\psi \to e^+e^-$

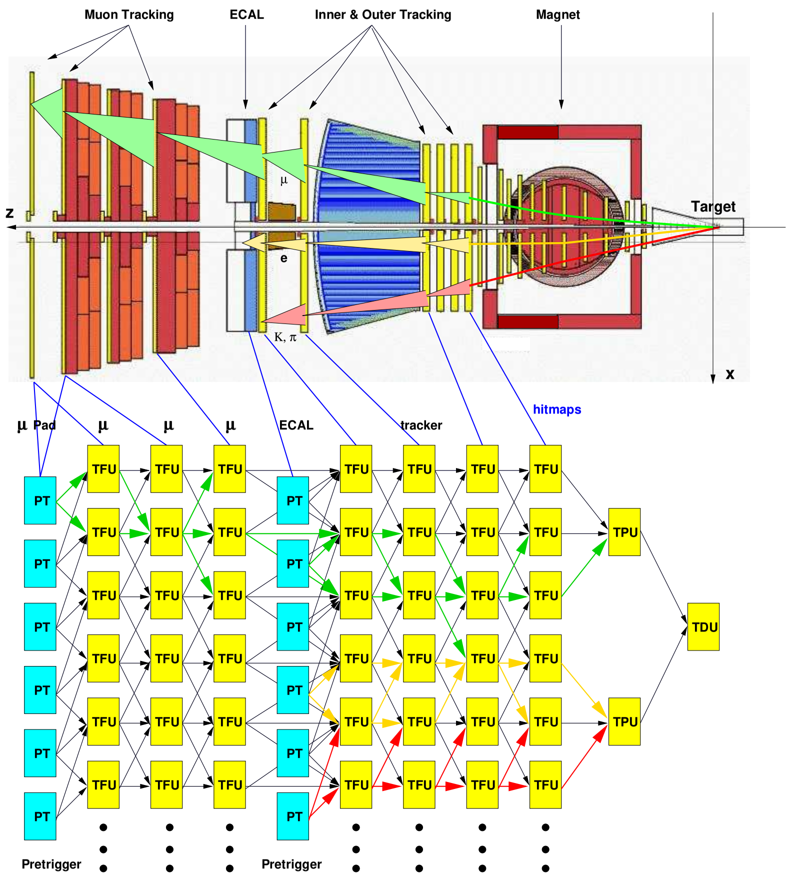
bremsstrahlung
for electron id

$\approx$ 1/2 sample
(full: 4000 events or
40,000 w/o brems req.

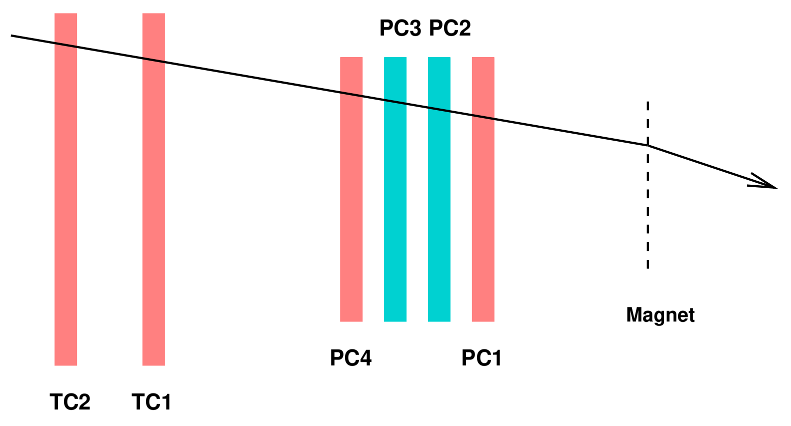


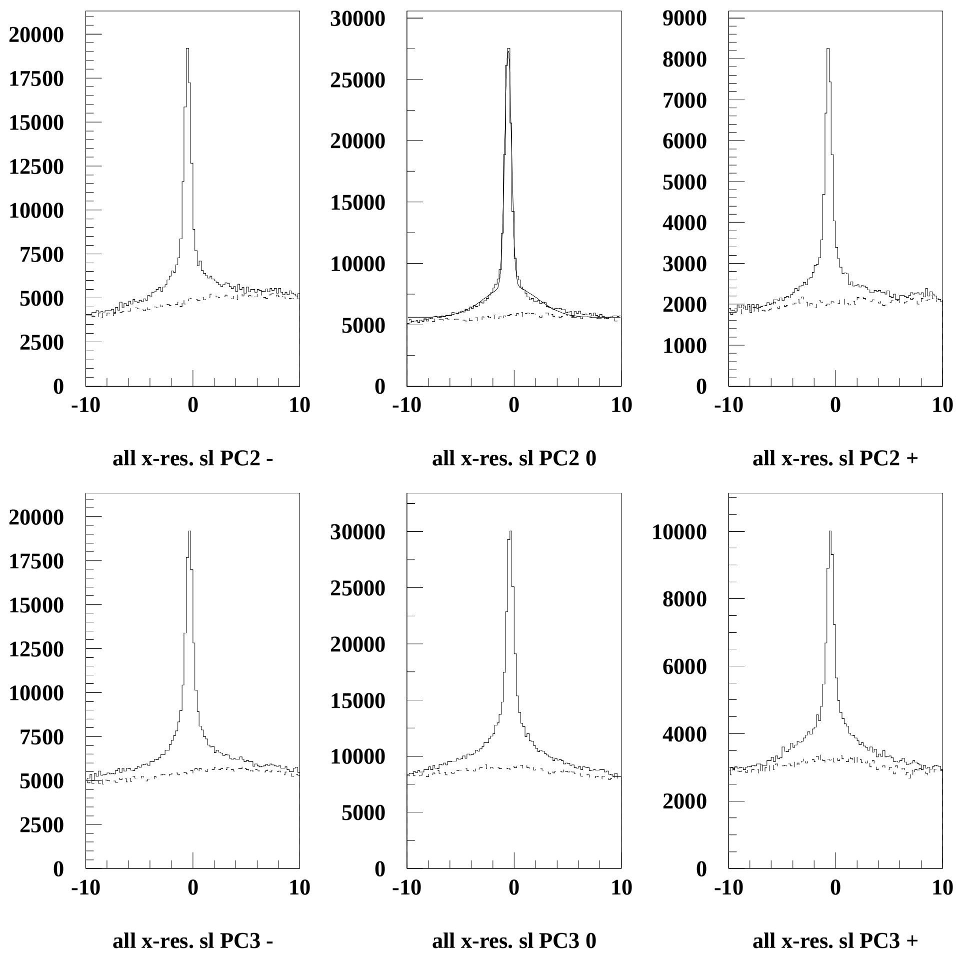
First Level Trigger commissioning

- hardware installation finalized in April 2000
  - 3 racks of electronics
  - 80 trigger processors
  - 200 Trigger Link Boards
  - 1000 optical fibers
- networking test (processors/messaging): performance at design specifications (track loss rate $\leq 4 \cdot 10^{-6}$)
- 1.5% of all detector channels non-functional $\Rightarrow$ reflects in tracking efficiency (83% efficiency / track)
- Trigger Decision Unit extensively debugged while running in "transparent mode" for J/ψ production



Level 1 residuals in non-trigger chambers





→ Level 1 tracks confirmed by unused chambers
track residuals: 3 mm (design 1.4 mm)

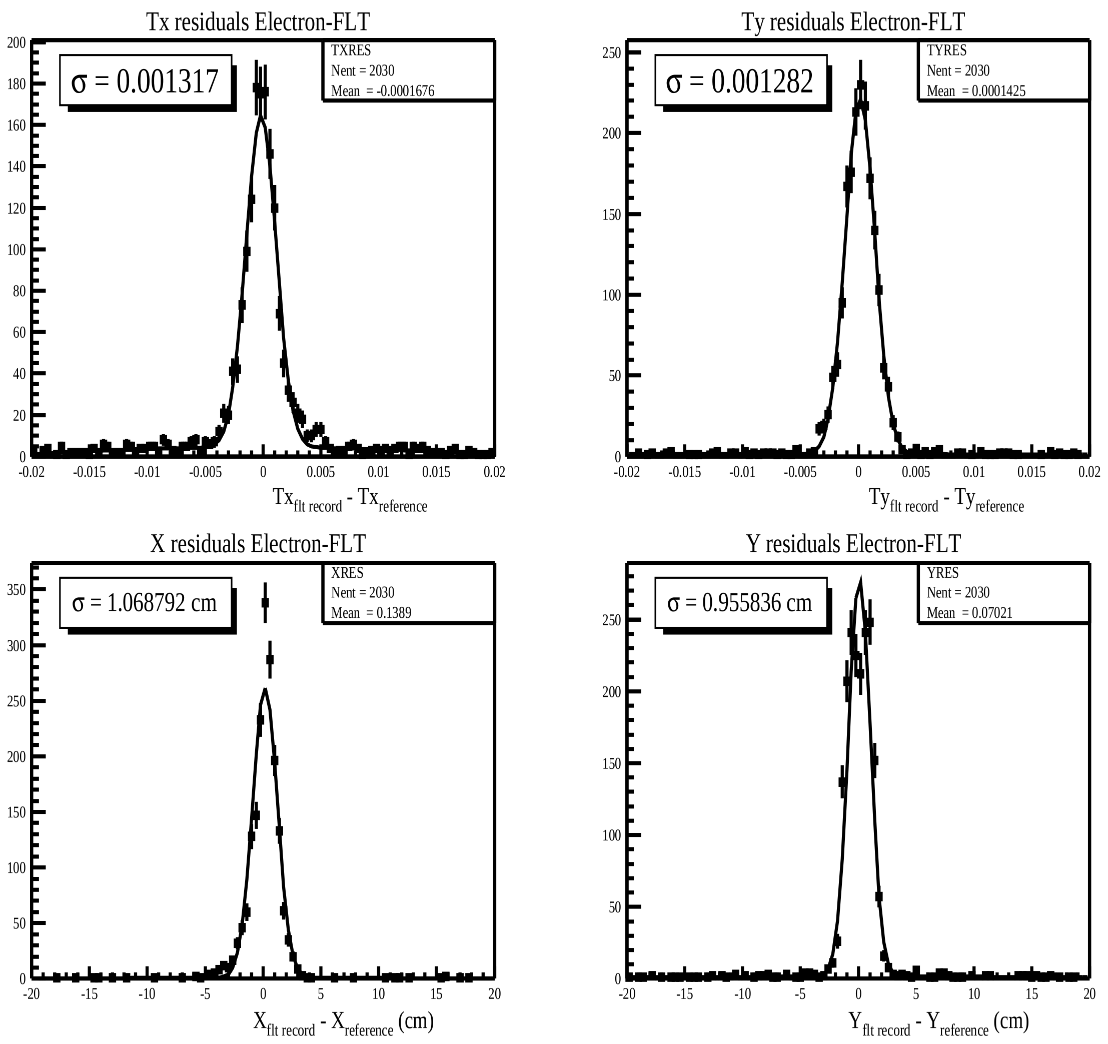
Level 1 tracking efficiency (Electron channel)

Data Sample:

Triggered with Level 2 (ECAL) (Level 1 in passive mode)

⇒ Off-line track selection using ECAL/RICH/VDS segments (well defined tracks without OTR bias)

⇒ efficiency measurement by matching with Level 1 RoI's



⇒ **60-70 % tracking efficiency**

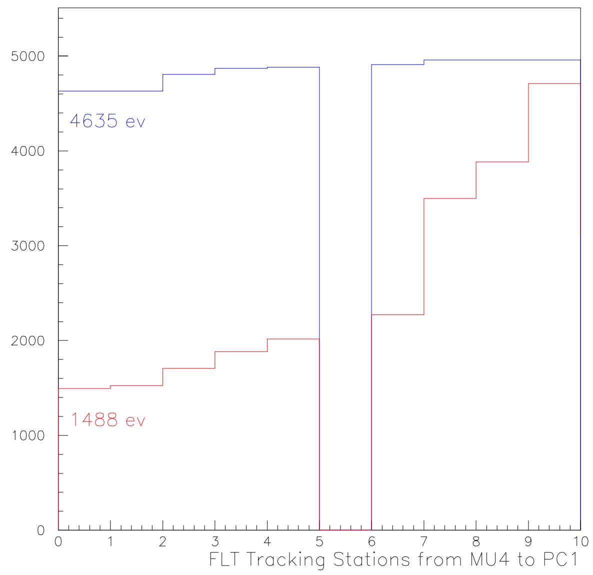
Level 1 tracking efficiency (Muon channel)

Data Sample:

Triggered with Level 2 (MUON)

"Hard" off-line selection of $J/\psi \to \mu^+\mu^-$ events

$\Rightarrow$ Apply Level 1 emulation



$\Rightarrow$ **32% tracking efficiency**

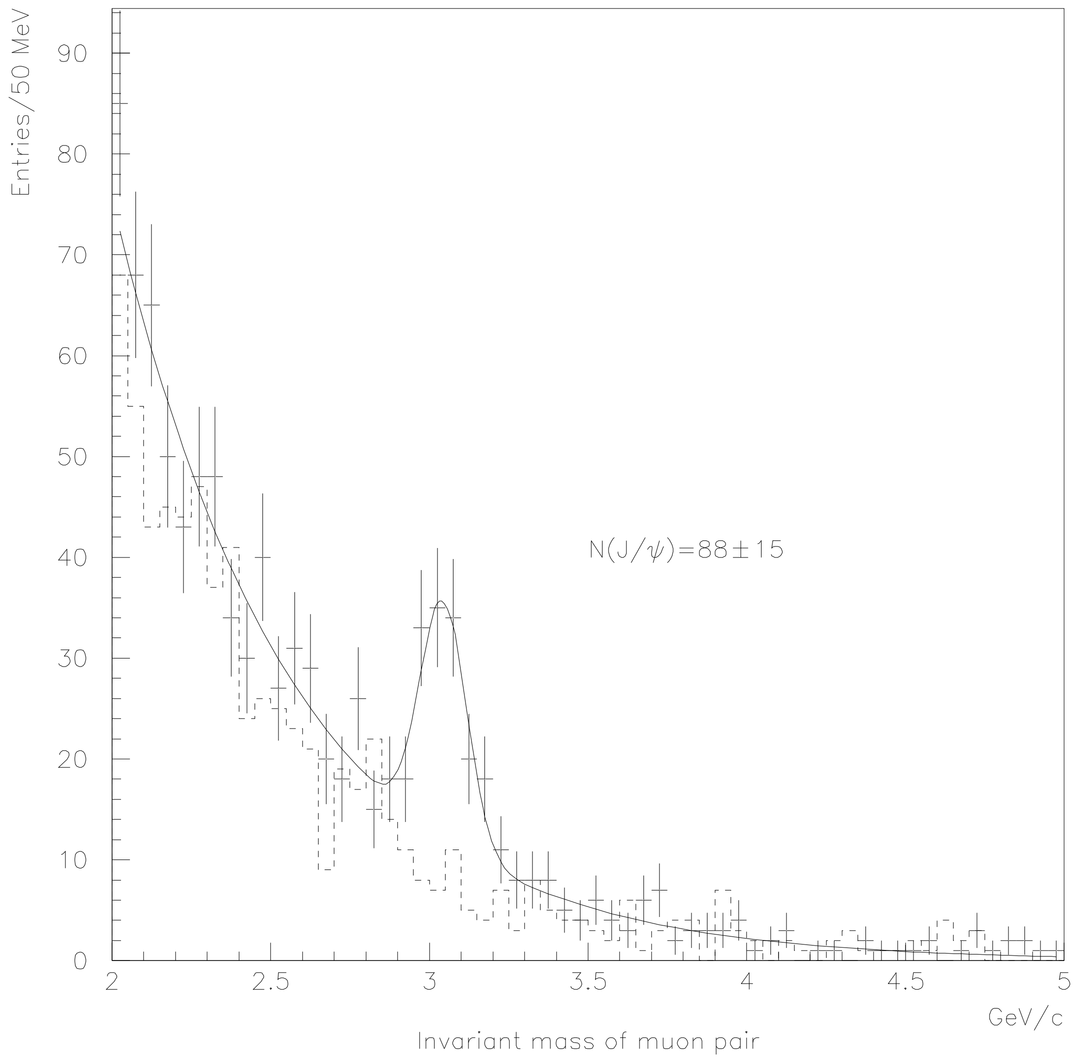
(0.7(OTR) x 0.46(MUON))

- Measured OTR tracking eff. compatible with MC prediction
- MUON tracking shows discrepancy with MC (x 1.6 lower)
  - low tube chamber efficiency in stereo views ?
  - intrinsic geometry feature of the chamber ?
  - ghost tracks in data sample ?

  $\Rightarrow$ under investigation

Full Trigger Chain commissioning

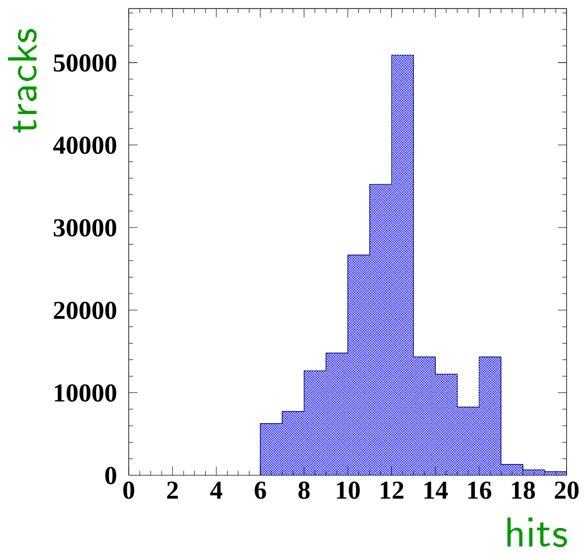
(1) Level 1 (1 trk) / Level 2 (Alone, 2 trks)



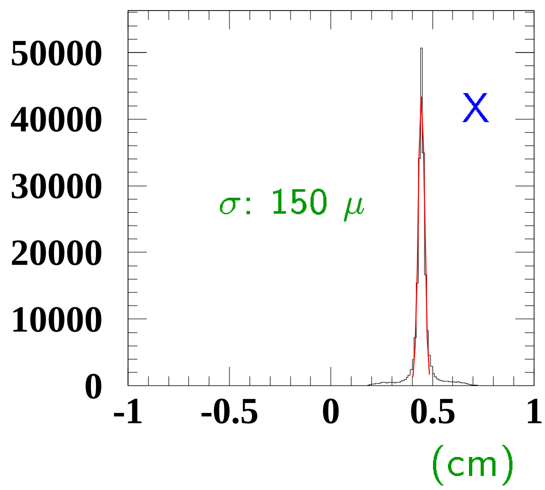
⇒ Ratio between measured J/ψ rate and rate from Level 2 (Alone) mode: **0.36**

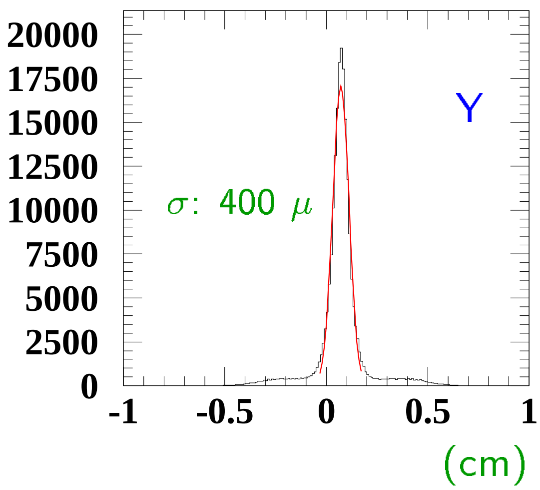
Silicon track quality seen in Level 2

Number of hits
on tracks
($\rightarrow$ most tracks traverse 3 S.L.)



Impact point on target plane





Single wire run, single μ trigger

Full Trigger Chain commissioning (ctnd)

Do we understand the observed J/ψ rate with Level 1 ?

$\Rightarrow$ need to apply a correction in the efficiencies seen by Level 2 between the 2 trigger modes: 0.96 (from MC)

$\Rightarrow$ extract the observed Level 1 single track efficiency on the J/ψ signal:

$$0.36 \times 0.96 = 1 - (1-\eta)^2 \Rightarrow \underline{\eta = \mathbf{0.19}}$$

$\Rightarrow$ comparison with expectations from single track MC :

$0.51 \times \epsilon_{real} = \underline{\mathbf{0.31}}$

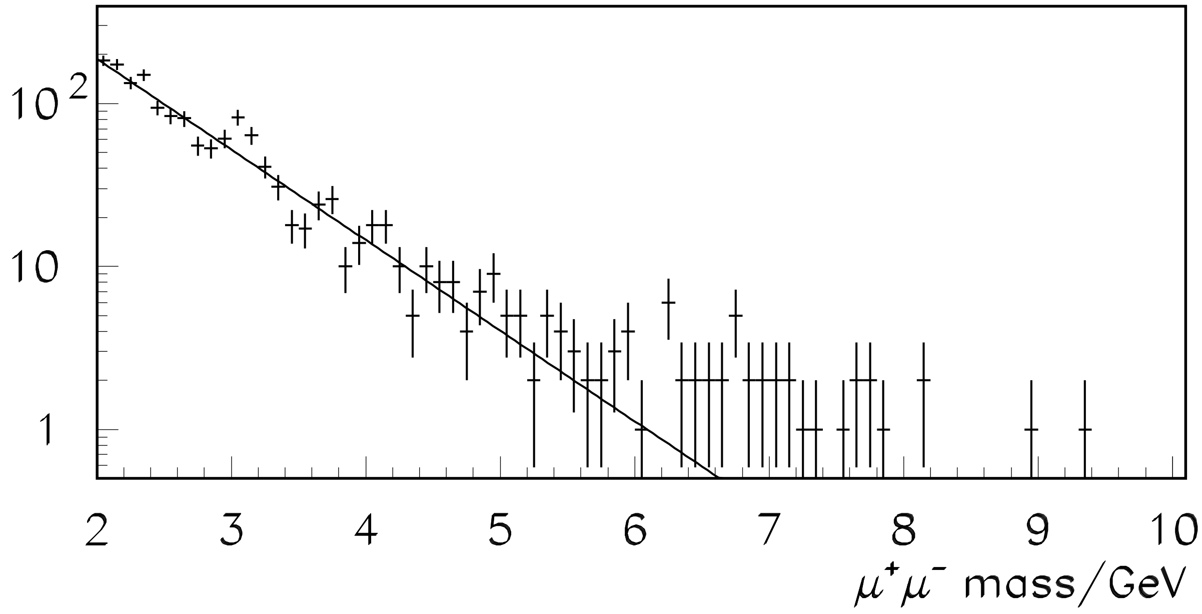
$\Rightarrow$ comparison with off-line Level 1 analysis on selected MUON tracks from J/ψ:

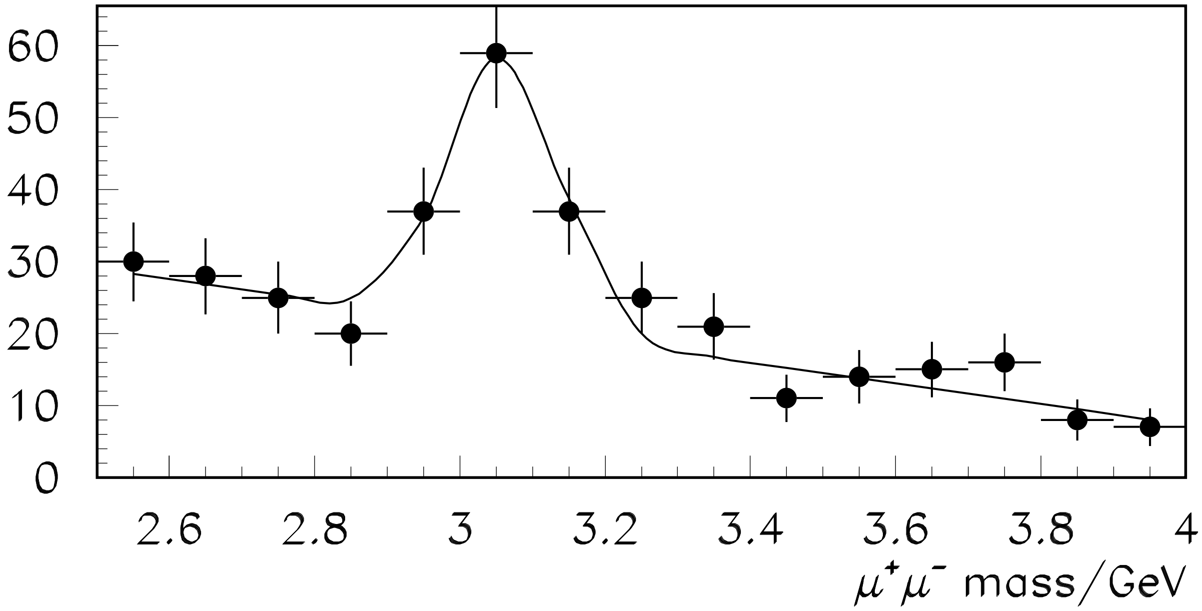
$$0.32 \times \epsilon_{real} \times \epsilon_{geo} = \underline{\mathbf{0.21}}$$

where $\epsilon_{real} = 0.7$ is a correction for known online inefficiencies.

Full Trigger Chain commissioning (ctnd)

(2) Level 1 (1 trk) / Level 2 (1 trk)





⇒ in this mode, Level 2 is using the Level 1 message as an input. J/ψ seen in the off-line reconstruction, efficiencies not yet understood, but encouraging result.

⇒ no J/ψ reconstructed so far in pair trigger mode.

Conclusions and Prospects

- Hera-B Trigger chain operational
- Level 2 efficiencies close to design
- No fundamental problems encountered in Level 1 hardware commissioning
- Level 1 efficiencies for
  - single electrons: 60-70%
  - single muons: 20%
- Overall J/ψ production still ≈ 2 orders of magnitude below design values; fields of improvements are
  - Pad efficiencies
  - OTR and MUON efficiencies
  - Level 1 latency
  - Geometrical acceptance (Inner tracker)

We have not yet concluded the commissioning of the First Level trigger. We are confident to get the system to design values for the next run.