Mionowy układ wyzwalania detektora BAC albo historia pewnego kalorymetru

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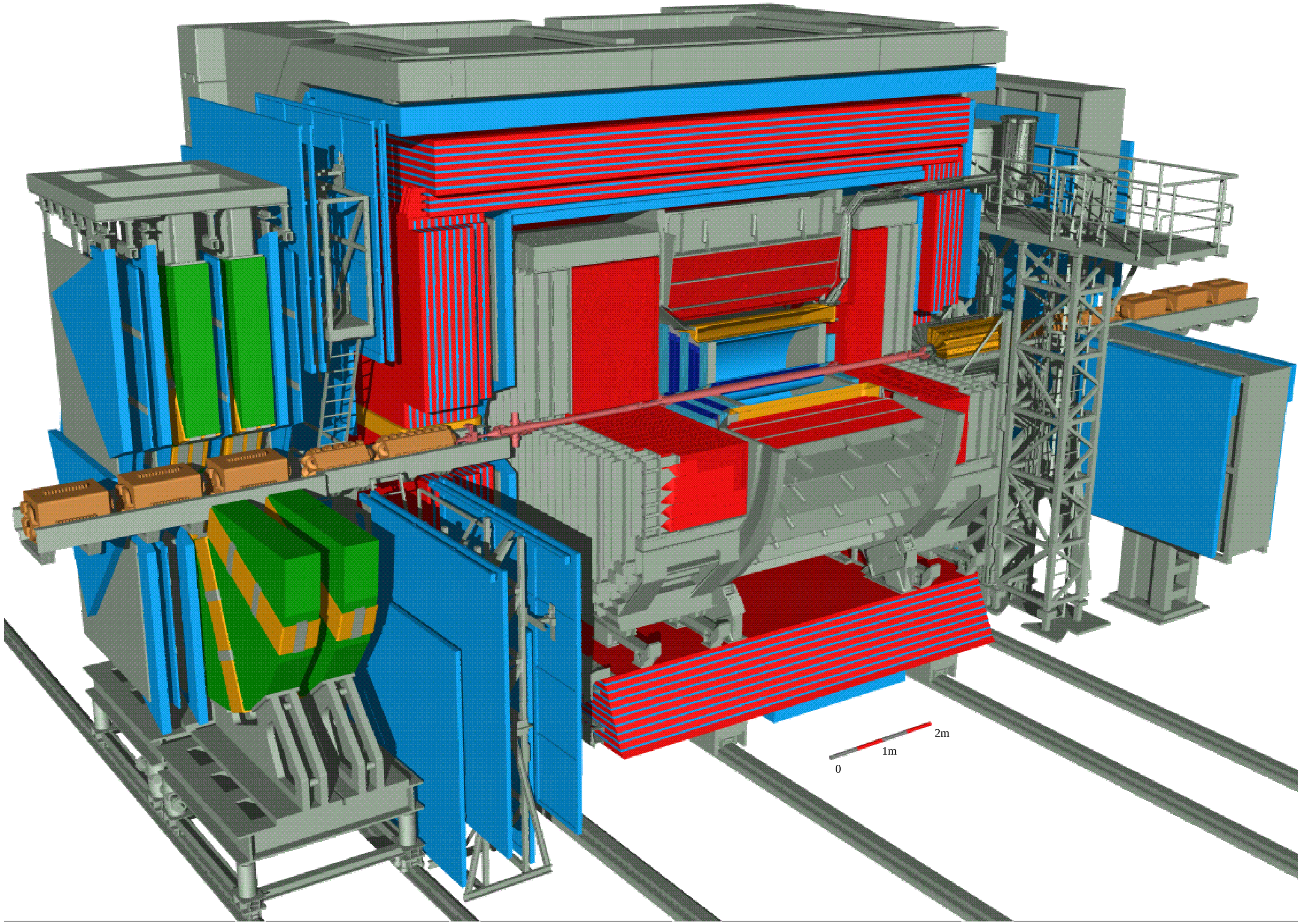
Seminarium Fizyki Wysokich Energii, Warszawa, 26 maja 2006

Plan

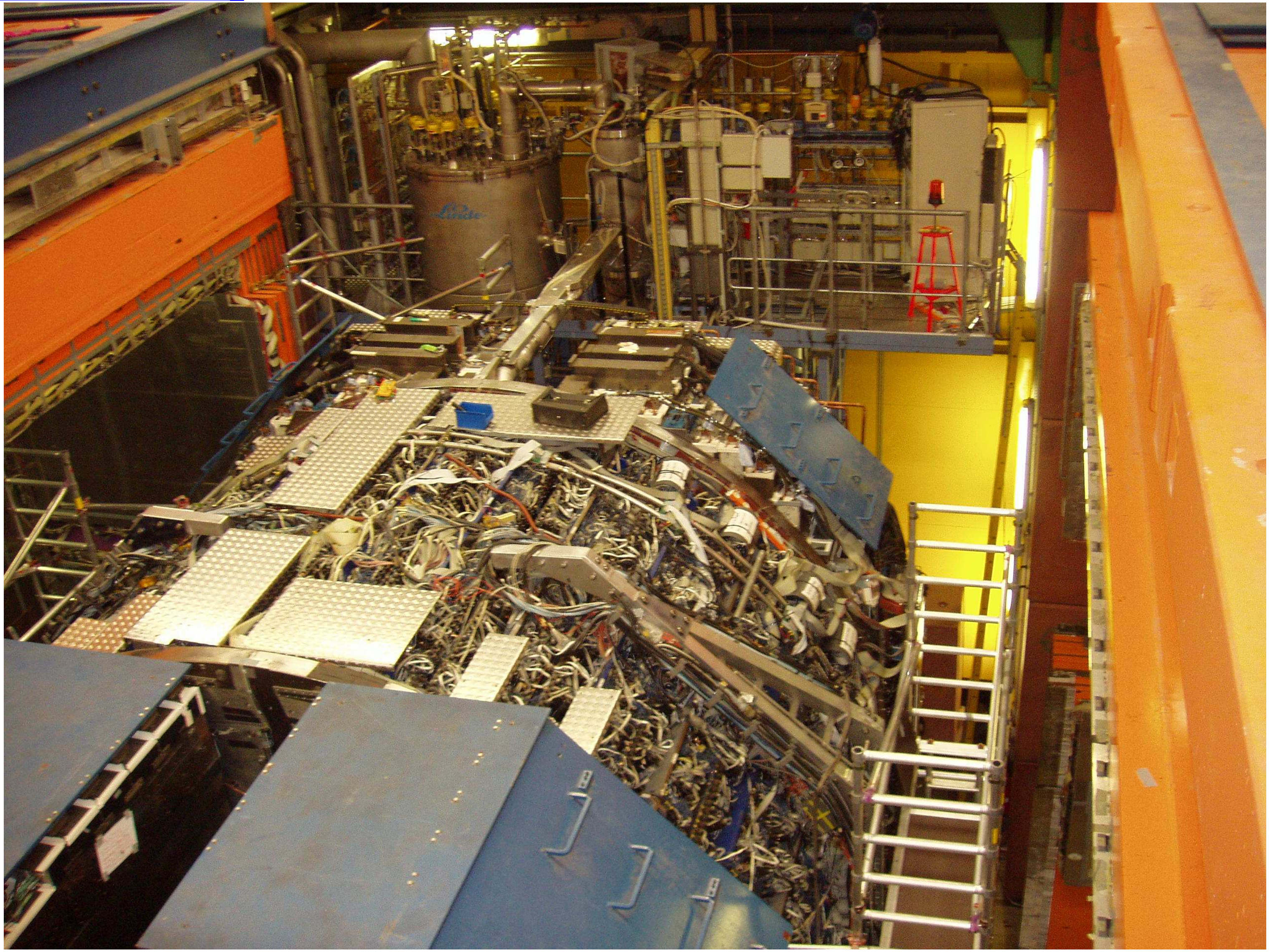
- ♦ Budowa detektora BAC
- ♦ BAC jako kalorymetr
- ♦ BAC jako detektor mionowy
- ♦ Remont kapitalny (*shutdown* 2000/1)
- ♦ *Trigger* mionowy detektora BAC
  - Pierwszy stopień układu wyzwalania
  - Drugi stopień układu wyzwalania
  - Trzeci stopień układu wyzwalania
- ♦ Diagnostyka detektora BAC
- ♦ Analiza działania, pierwsze dane
- ♦ Podsumowanie (plus szczypta historii)

The ZEUS Detector at HERA



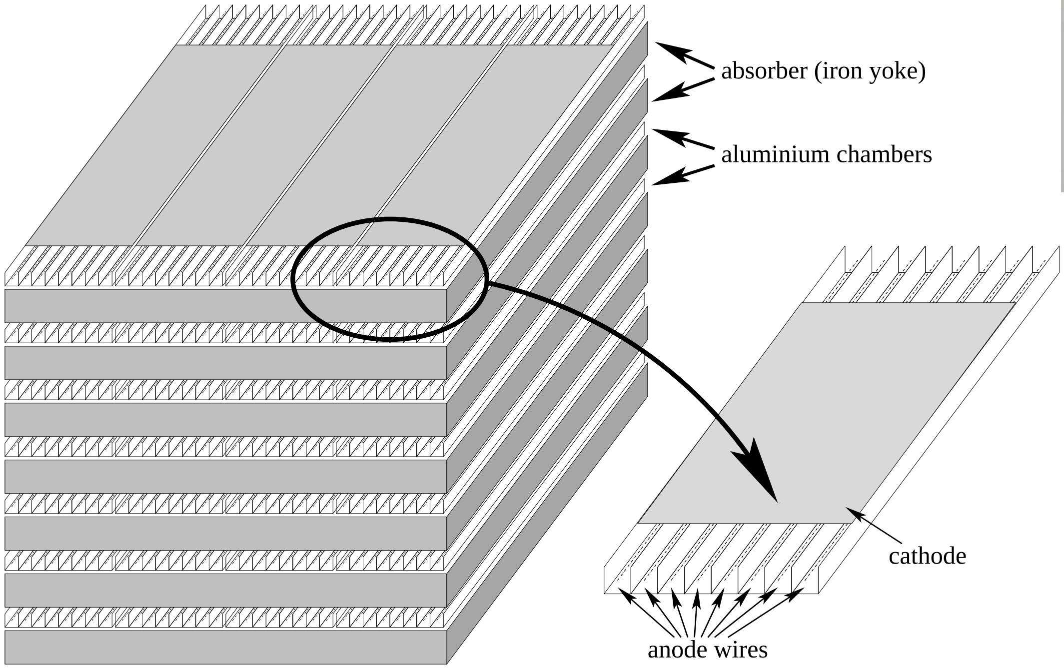
- MVD,CTD,UCAL,BRMUON,FMUON,BAC,VETO WALL,...

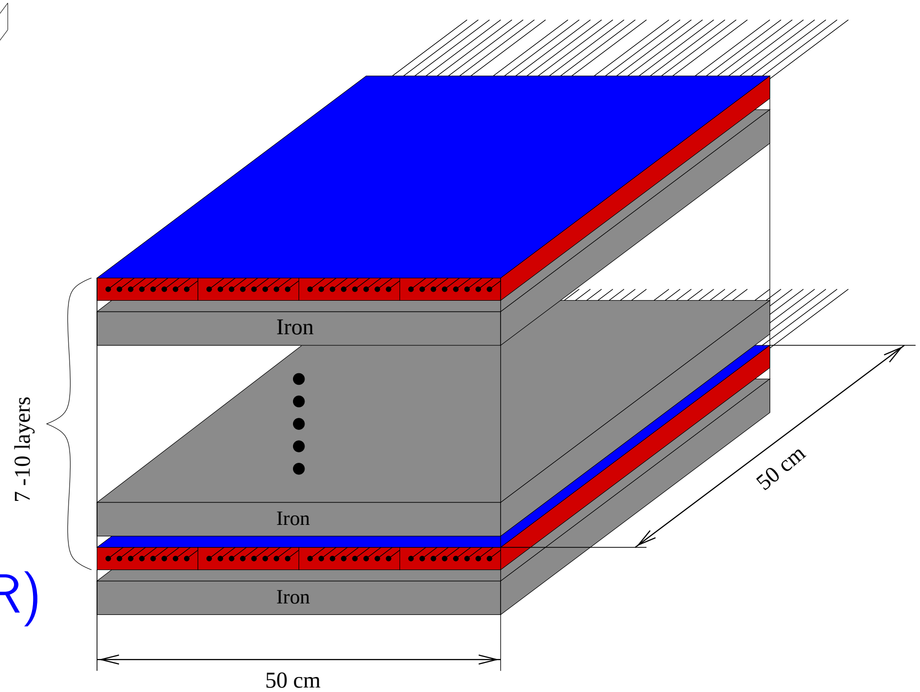
The ZEUS Detector



- ZEUS as it is after 15 years...

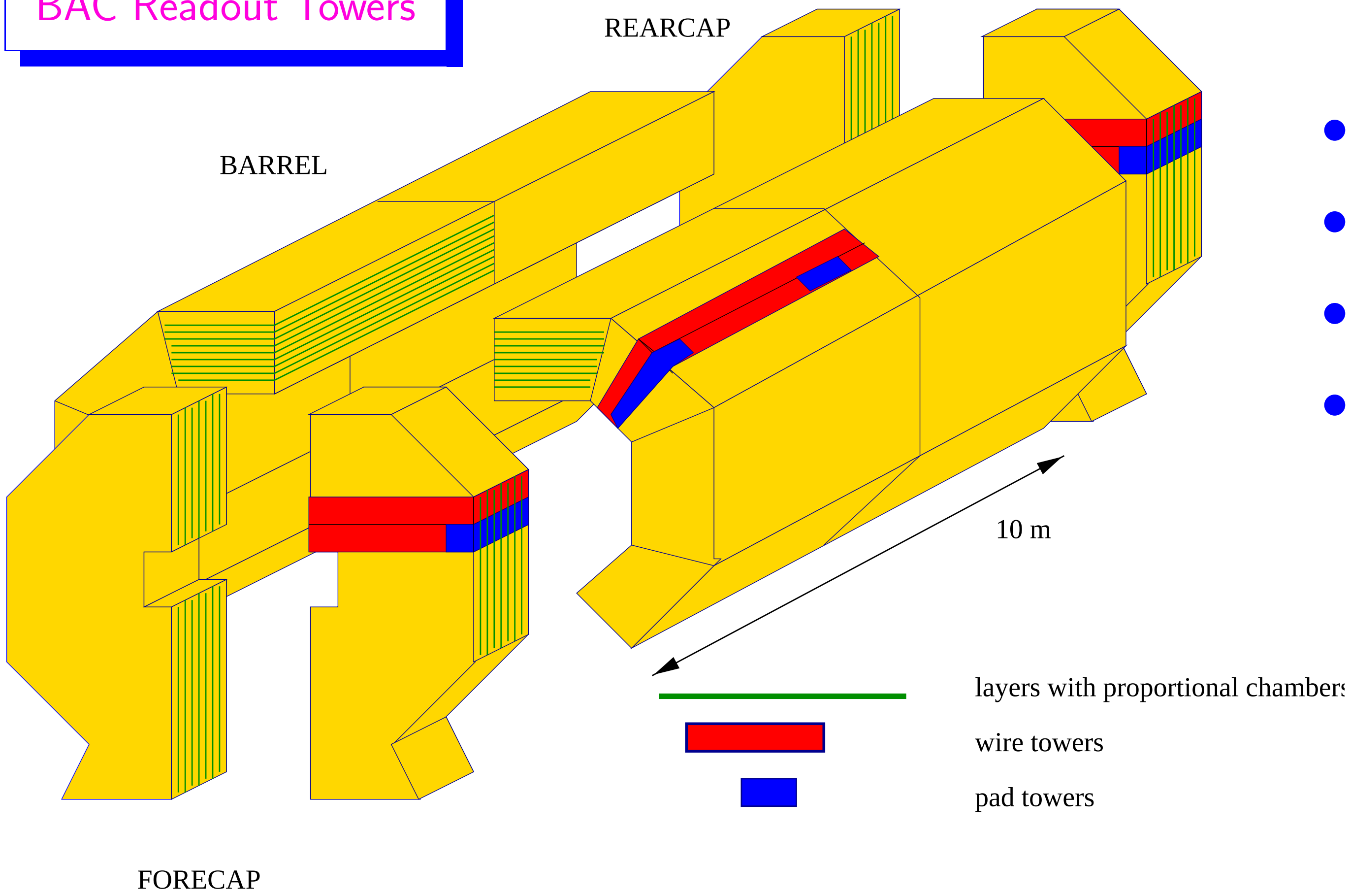
BAC chambers and towers structure





- sampling calorimeter (10/9/7 Layers: F/B/R)
- $Ar + 13\%\, CO_2$, $HV = 1875\, V$
- Readout from anodes (wires) and cathodes (pads)
- Pad Tower: $50{*}50{*}100\, cm^3$, Wire Towers: $500{*}50{*}100\, cm^3$

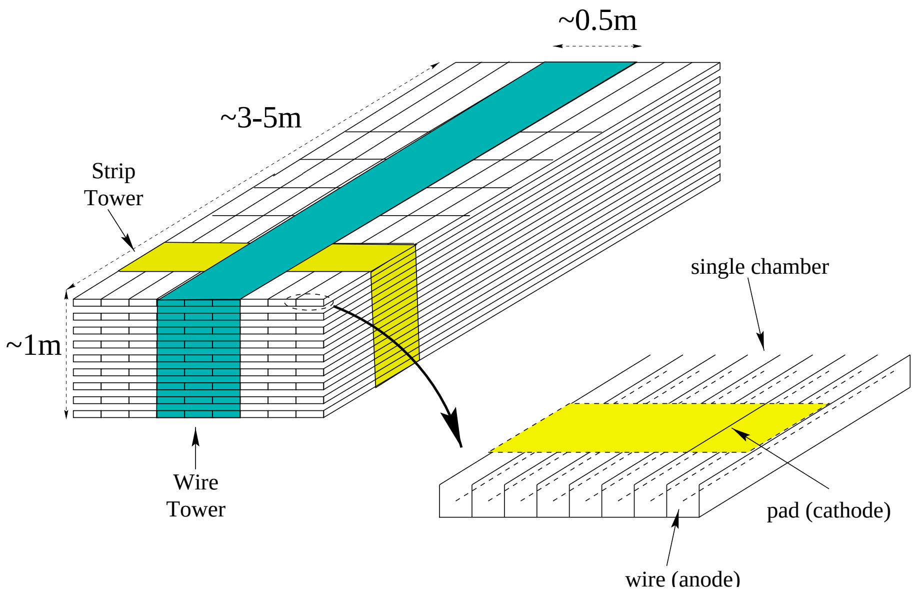
BAC Readout Towers

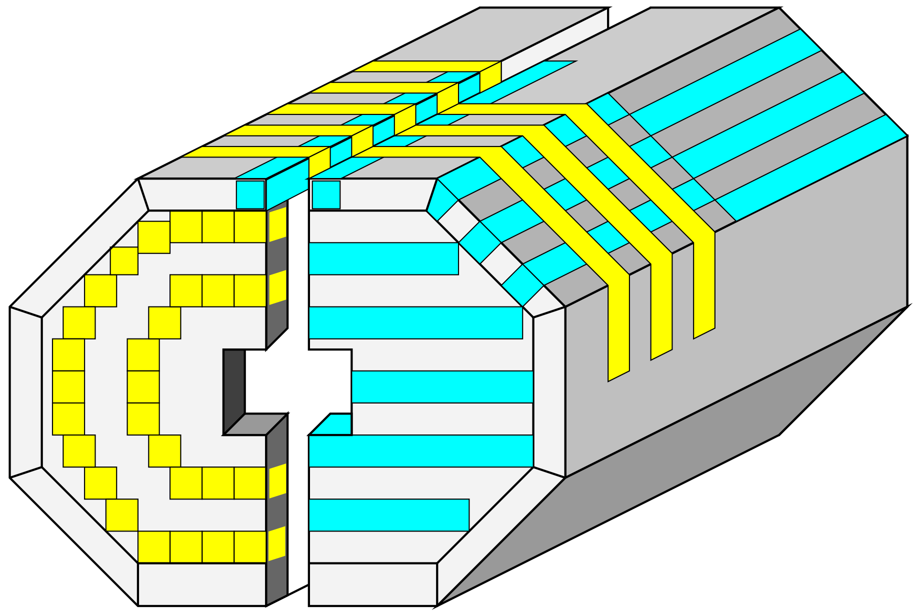


- 178 Wire Towers
- 133 Strip Towers
- 1600 Pad Towers
- $\sim 40\,000$ wires

- Proportional aluminium gas chambers inserted into iron yoke gaps $(4\,000\,m^2)$
- Wires in Barrel along z-axis, in Endcaps horizontal (along y-axis)
- 13 TRIGGER AREAS: 4 in Endcaps, 8 in Barrel (N/S,F/R,Up/Down) + Bottom

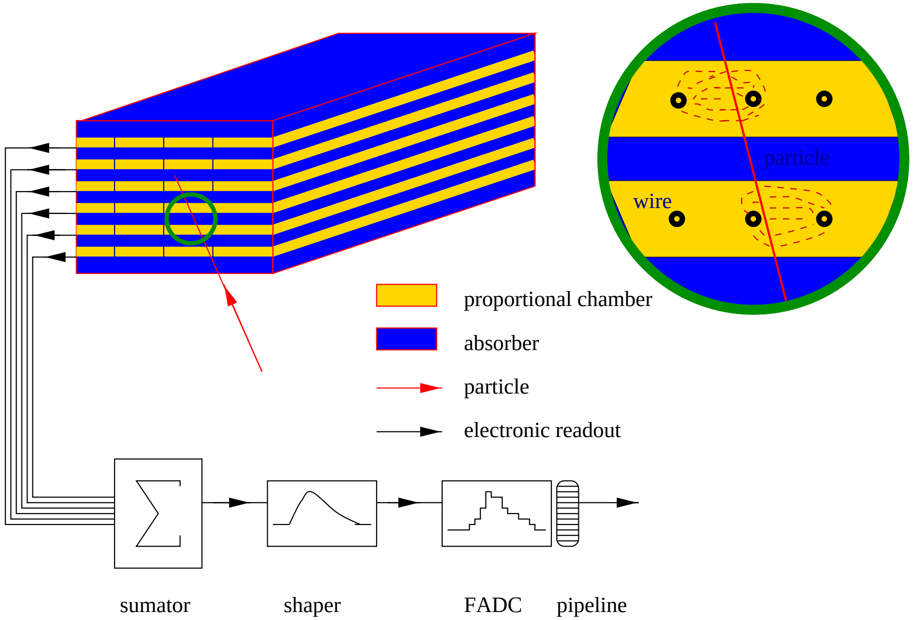
BAC Strip Towers





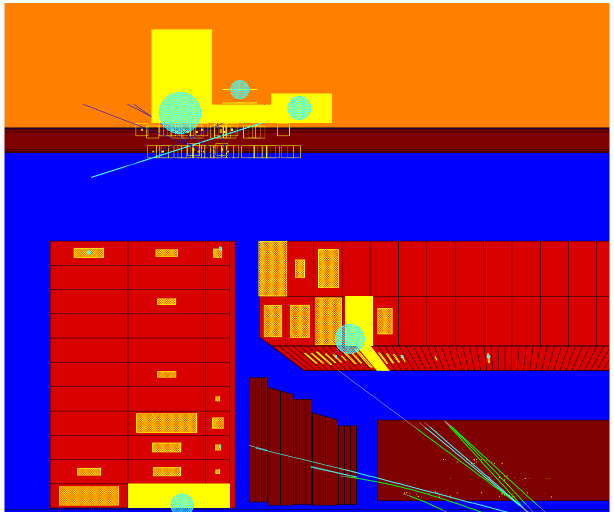
- Strips are constructed using neighbour pad towers
- In Barrel: Strip towers are perpendicular to wire towers
- In Endcaps: Strips are formed in semi-circles around beam-pipe

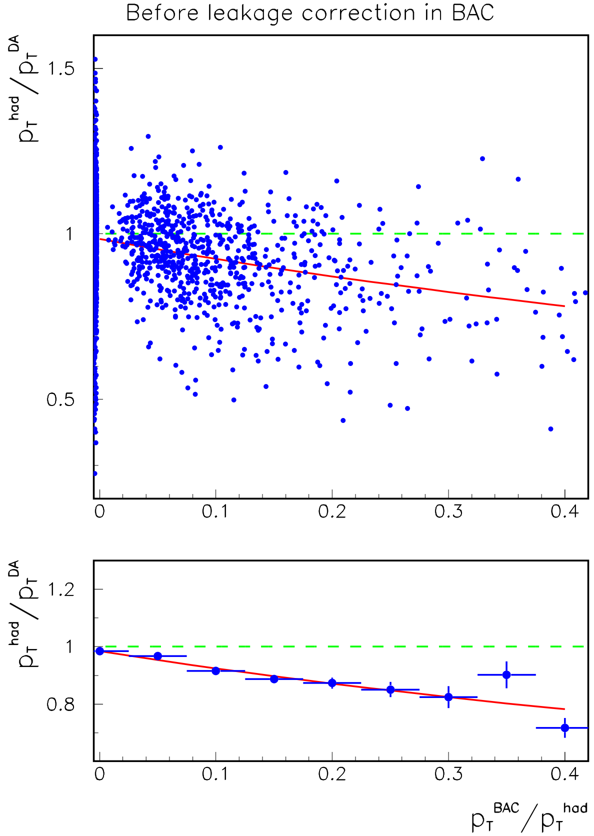
BAC energy readout

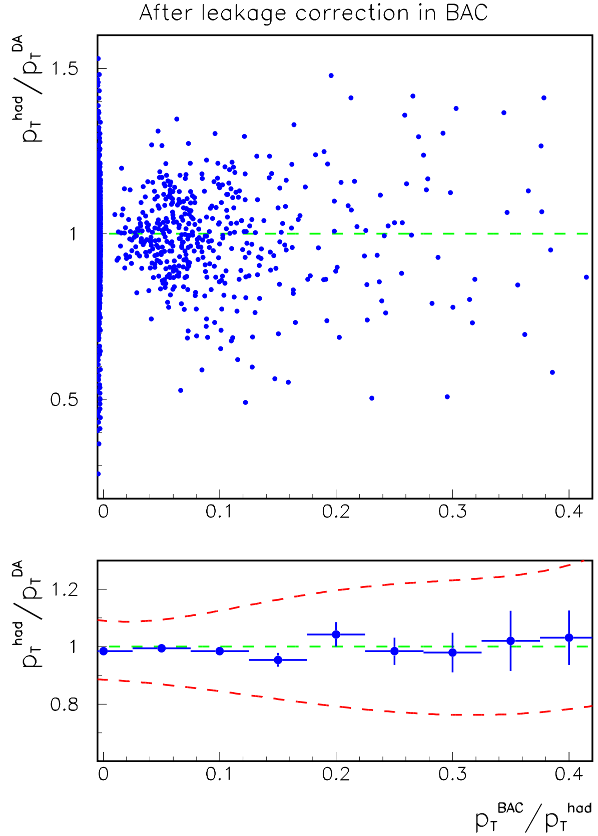


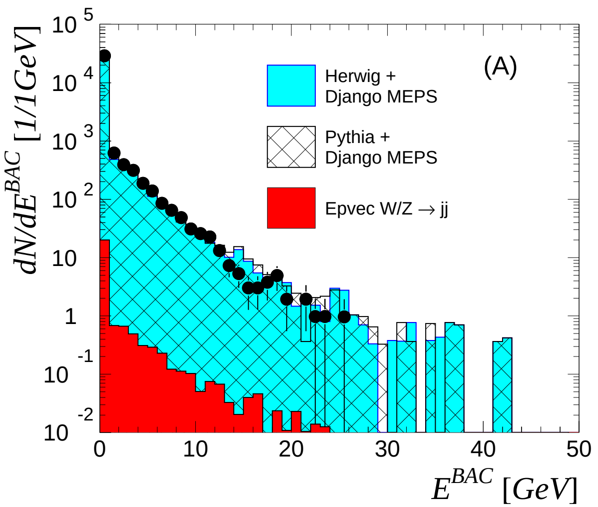
- preamplfication, sum over tower
- shaper (charge $\longrightarrow$ amplitude)
- Flash Analog to Digital converter ($10\,MHz$ FADC)
- pipeline (FLT buffer)
- DPM memory (SLT buffer)

BAC as a hadron calorimeter: intercalibration with CAL



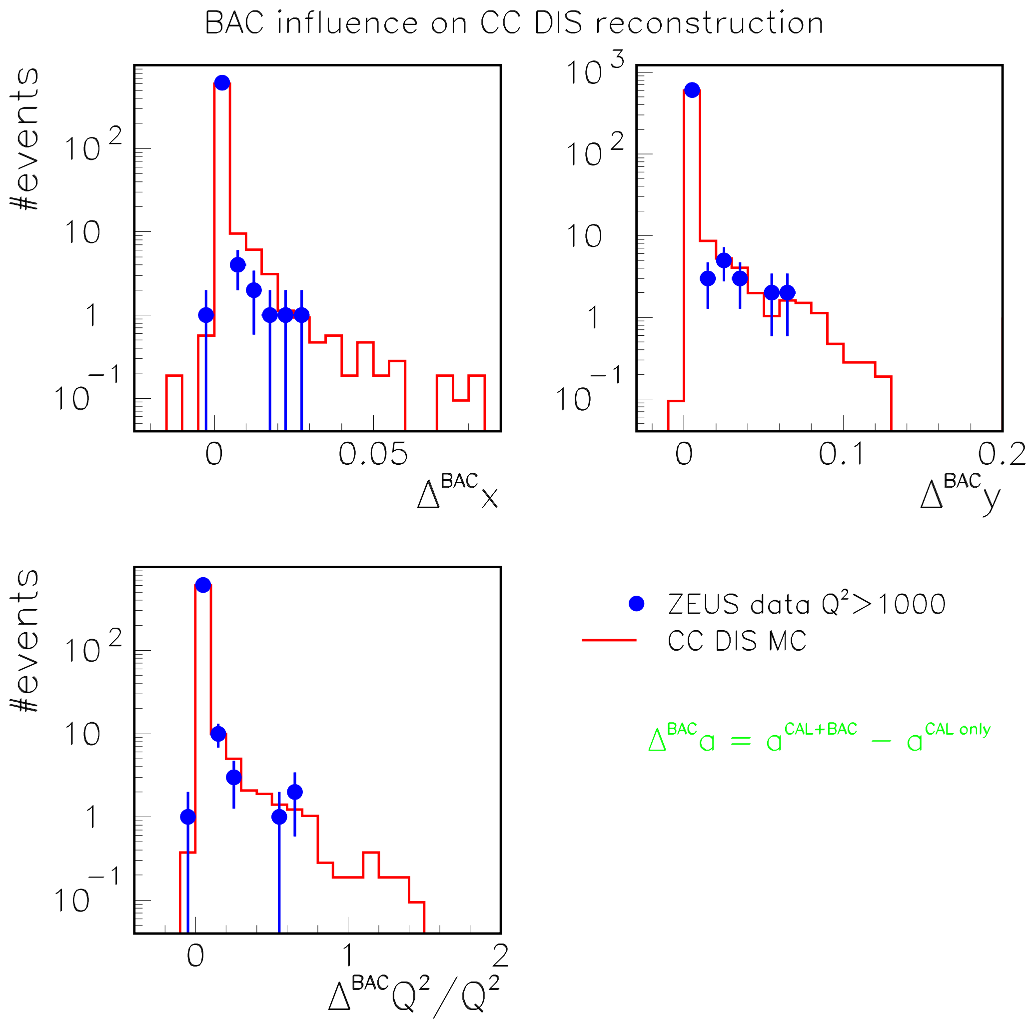






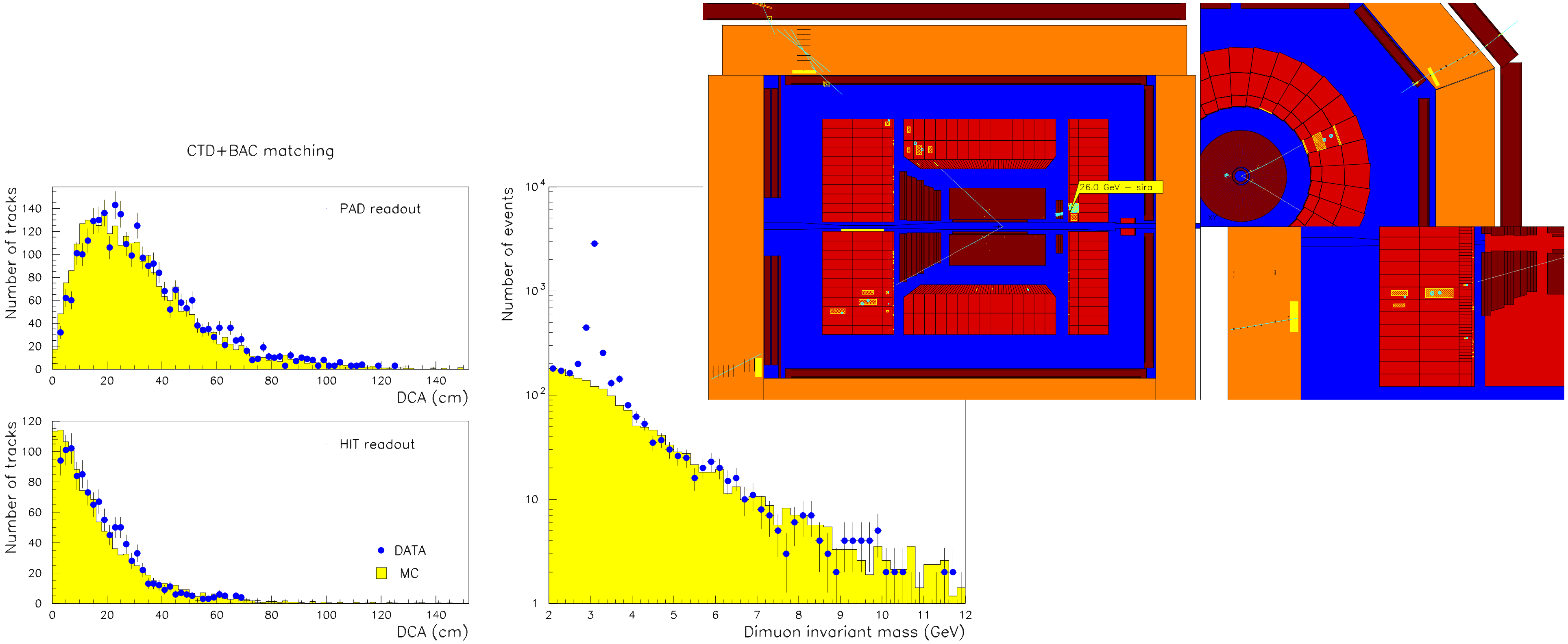
- hadron energy correction using BAC
- BAC energy shape after intercalibration with CAL

BAC corrections for x, y, Q^2



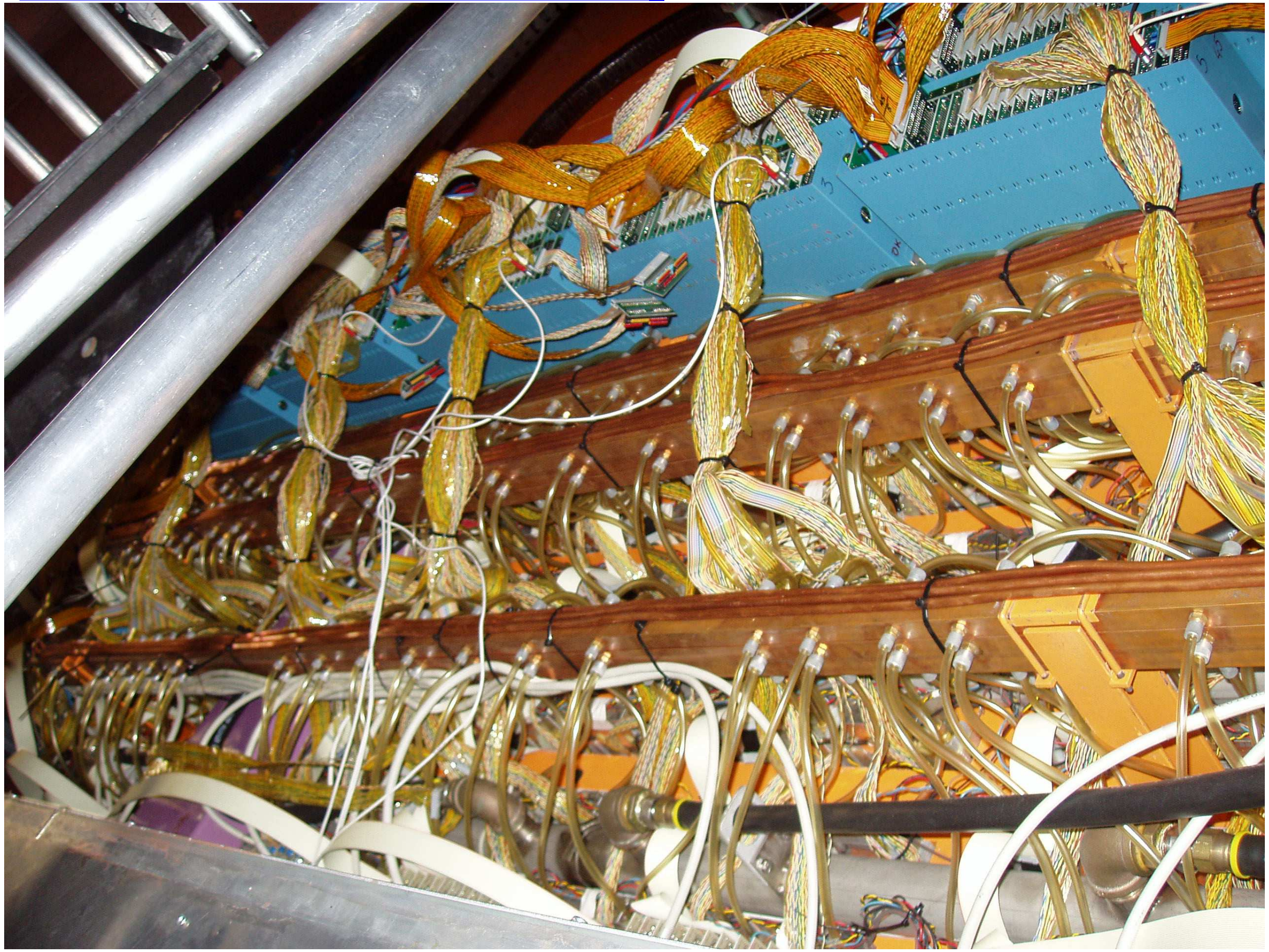
- BAC impact on the reconstruction of the kinematics variables
- for CC/NC DIS selection only about 1 - 3% events 'affected' (BAC $E_T > 1\,GeV$)

BAC as a muon detector



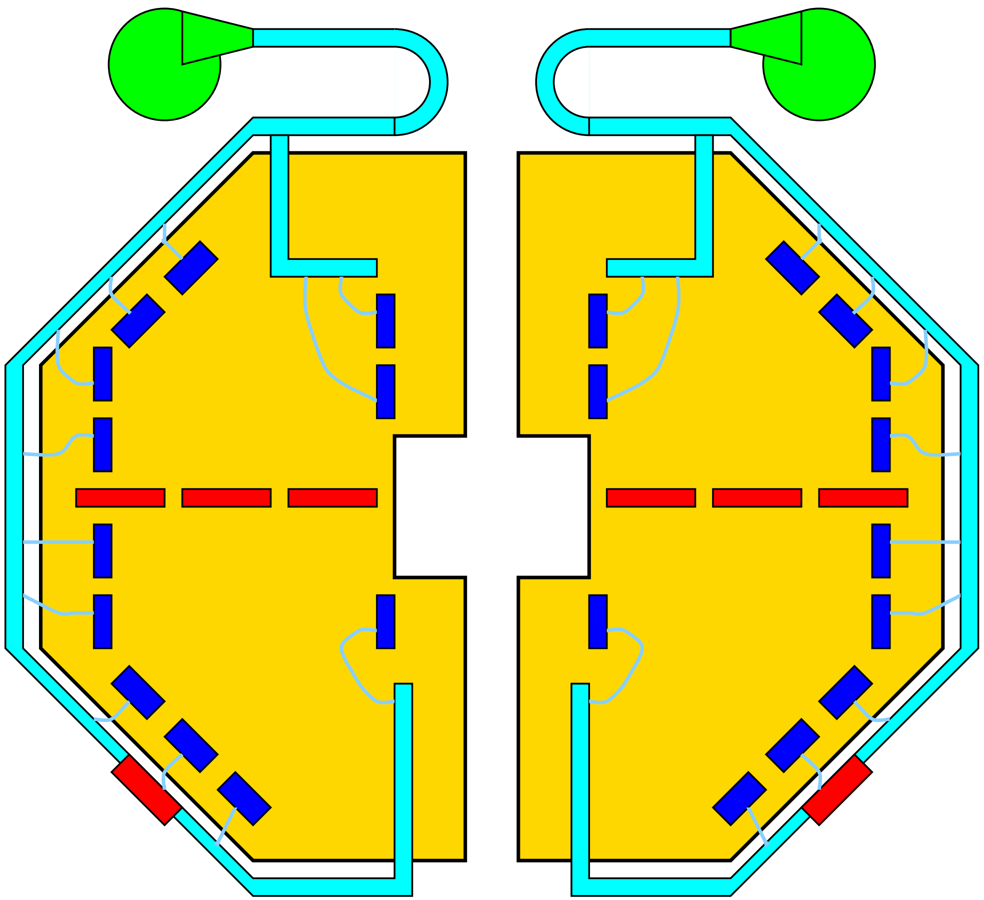
- Position (HIT) readout fully installed in 1997/98
- Di-muon analysis: J/ψ, ψ' and Bethe-Heitler

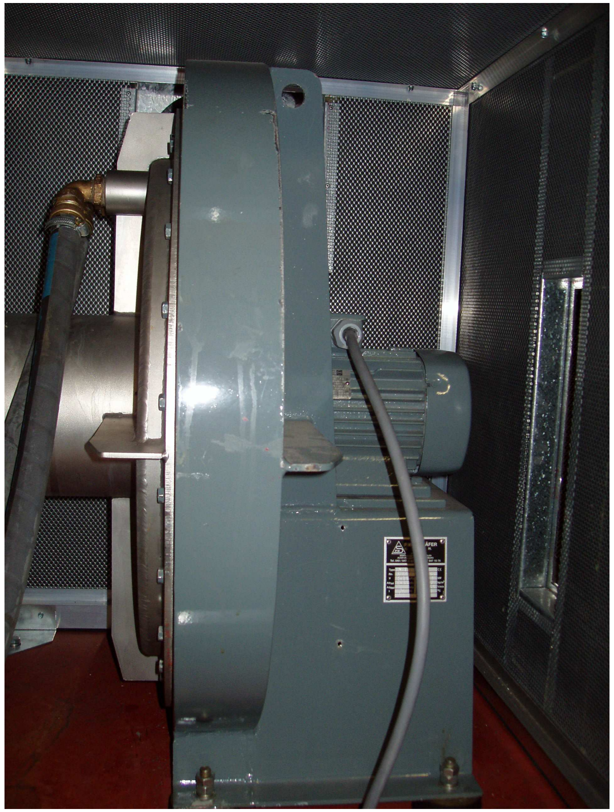
BAC Position readout: HITBOXES



- Position readout and pattern recognition for muon trigger
- 2 or 3 HITBOXES connected to each wire tower (356 HITBOXES on BAC)

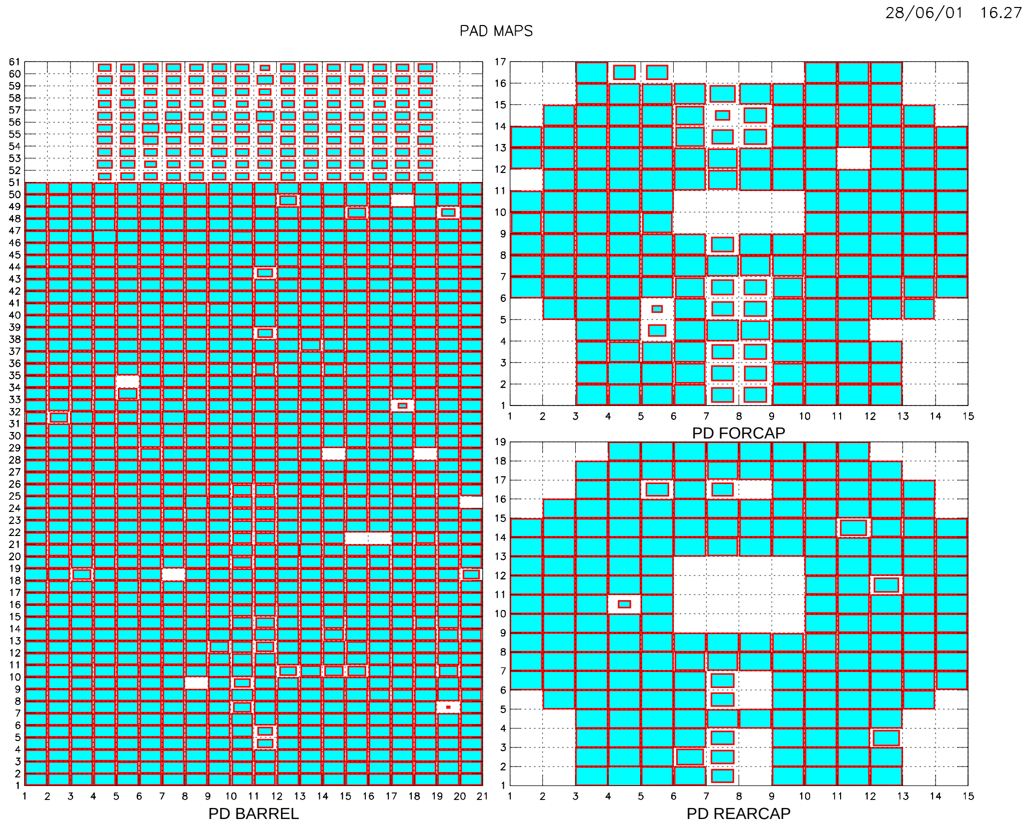
HITBOXES cooling, LV upgrade

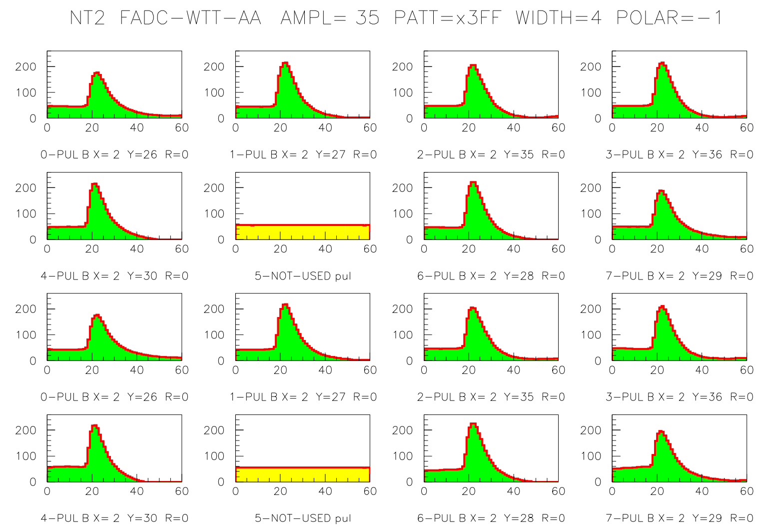




- Full scale prototype using PVC pipes
- Water cooling of air, $\sim 5\, l/min$ volume exchange for each hitbox
- 40 new $8\,V/50\,A$ Power Supplies, panels for fuses, better back-planes

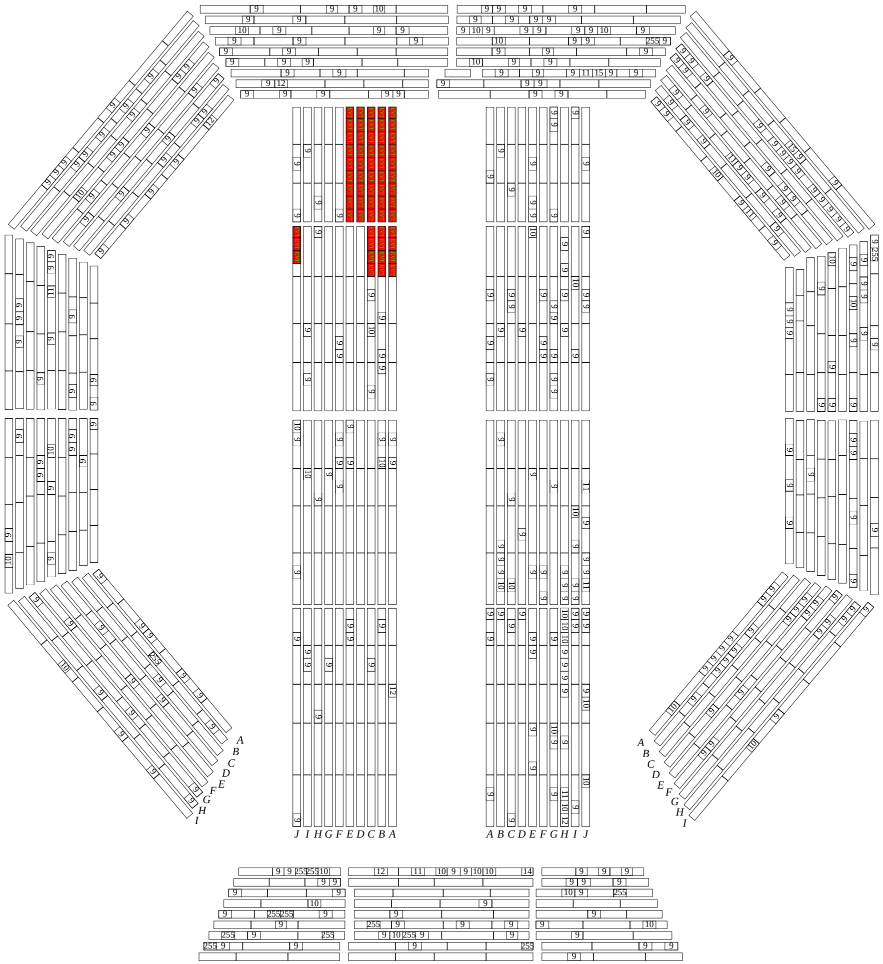
PULSER: charge injection

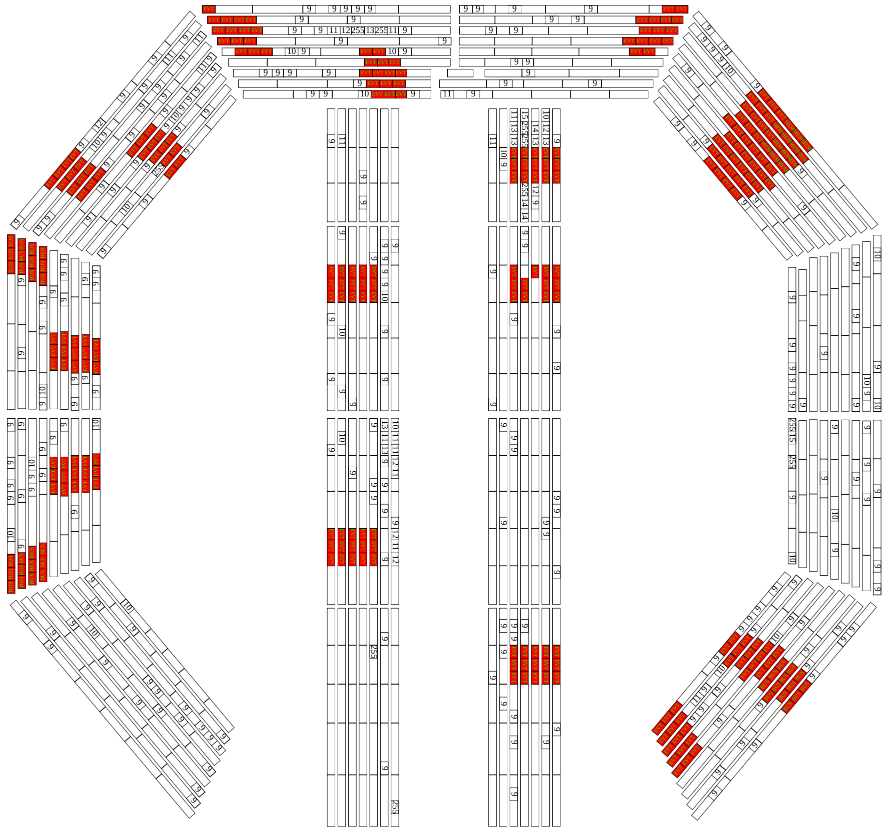




- charge injection for cathodes/pads and wires
- for each plane programmable amplitude and signal width

Hardware (HitBoxes): Typical number of dead channels after 2001

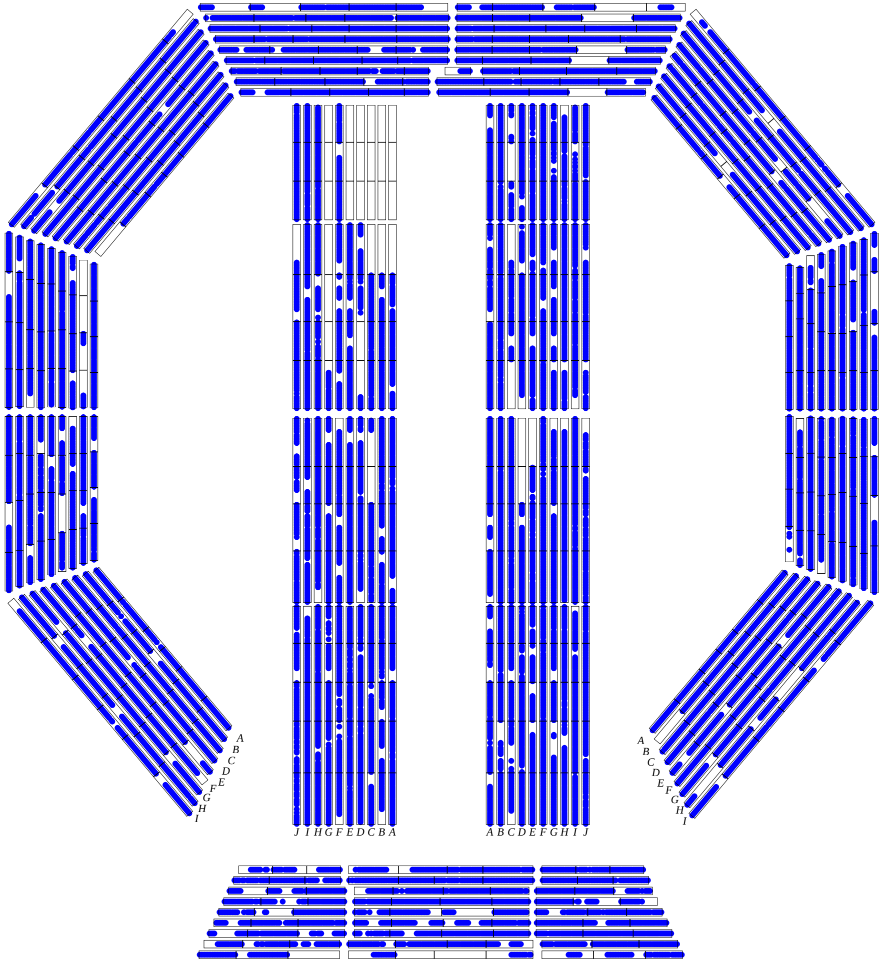


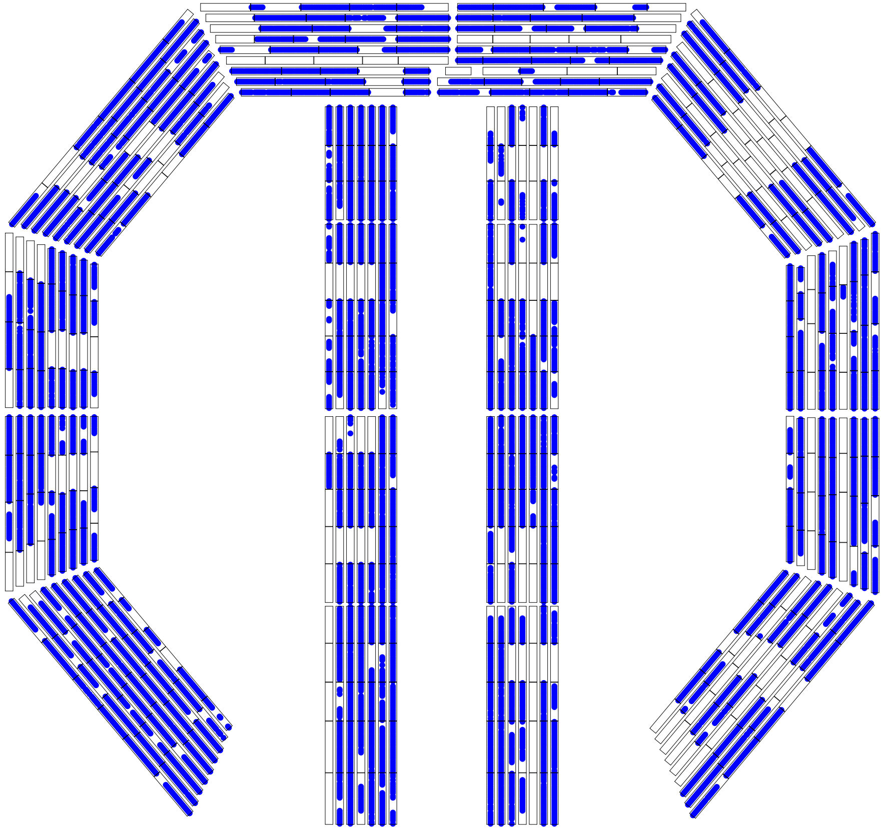


- READOUT: 97 % Forward, 85 % Rear
- TRIGGER: 93 % Forward, 72 % Rear

- Forward and Rear (not reachable) dead HITBOXES
- in total 8 % out of 356 HitBoxes are dead

New Diagnostic Tool: Muon "tomography": overlayed 200k single muons

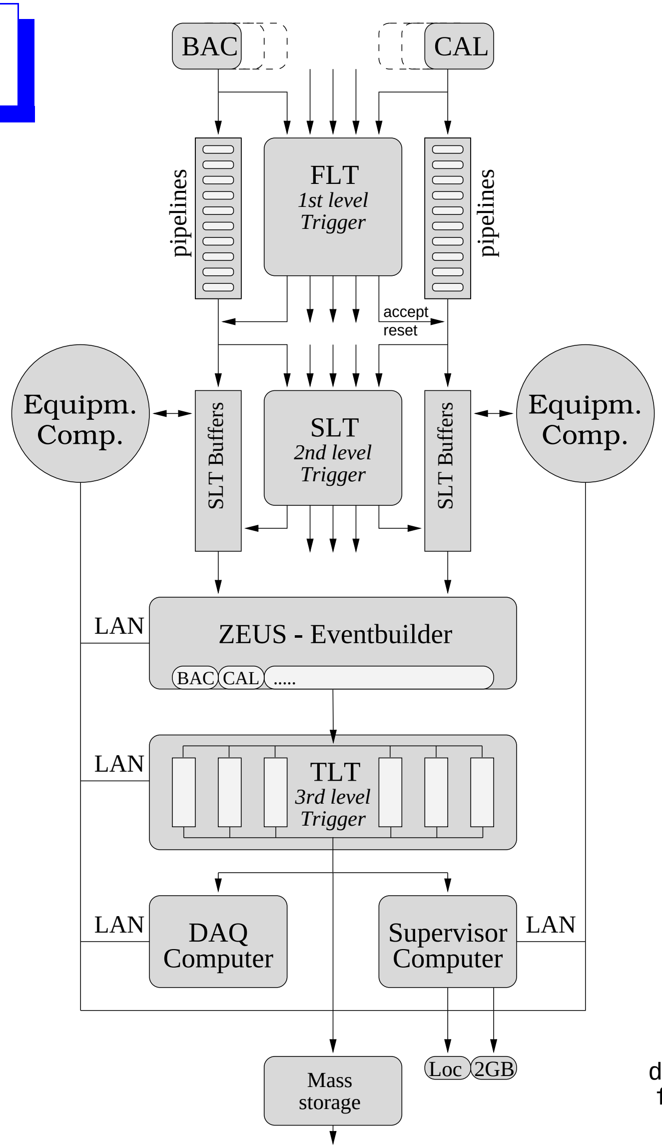




- most comprehensive test: LV, HV, gas, readout and trigger electronics
- cross-check for Slow-Control

- No HV in Rear North Barrel 2 Layers
- No LV in parts of Rearcap Layers

ZEUS Trigger Scheme



ZEUS readout components
data input rate 10 MHz

5 us pipelines
and local FLT

rate accepted by
Global FLT 1 kHz

pipelined local SLT
local equipment computers

rate accepted by
Global SLT 100 Hz

Event builder
collecting subevents
formatting

TLT
farm of Linux workstations

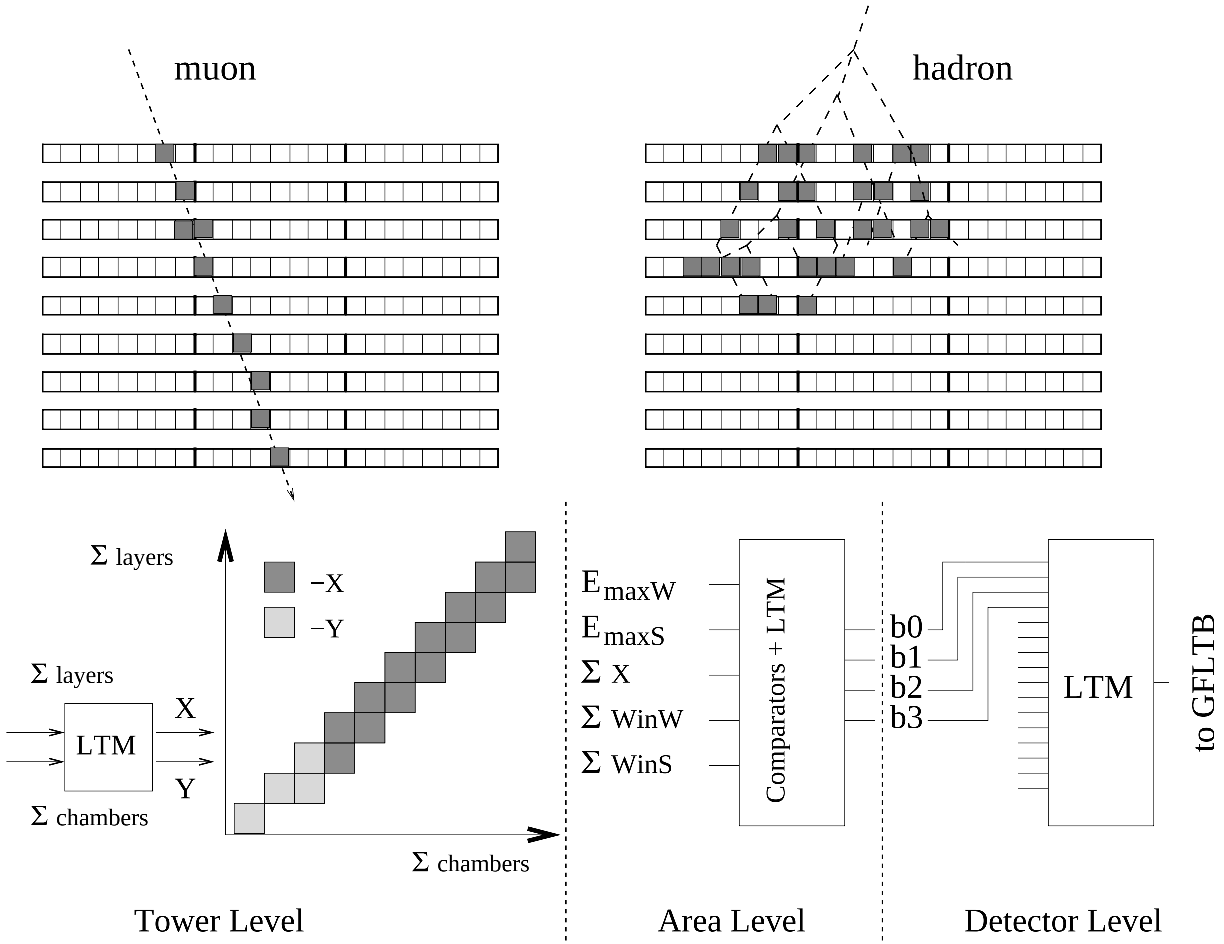
rate accepted by
TLT ~5 Hz

expert supervision
Run Control
Data Quality Monitoring

data transfer to main storage
facility (~0.5-1 MByte/sec.)

- 3 Level Trigger: FLT - fifo pipelines, SLT - DPM memory, TLT: software

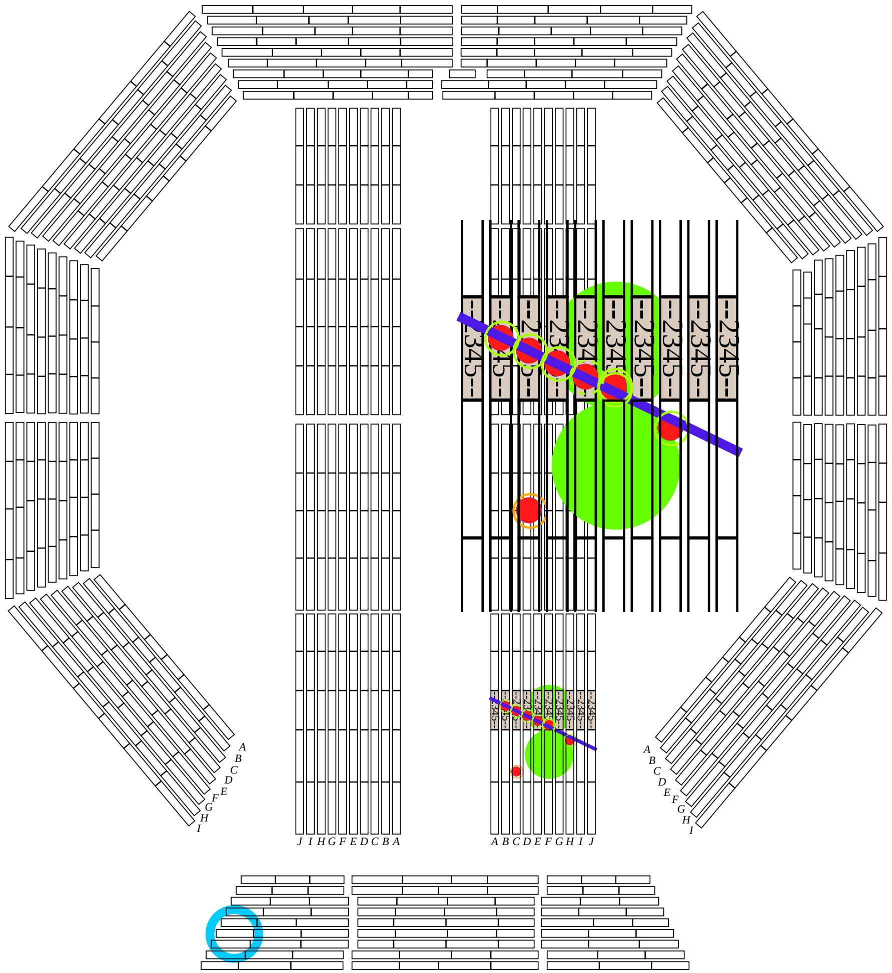
BAC Muon Trigger Algorithm: Basic Idea

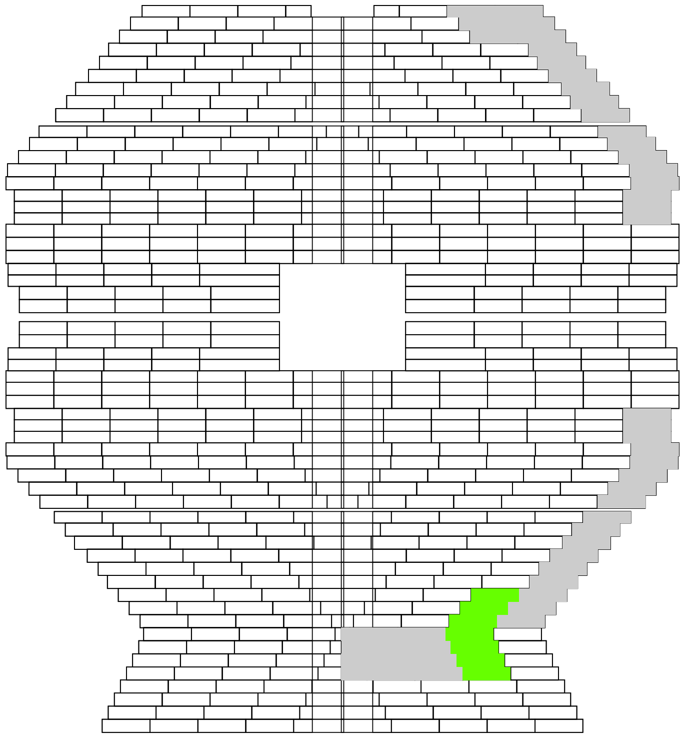


- fast pattern recognition in wire towers
- counting $\Sigma\, chambers$ and $\Sigma\, layers$
- LTM memory to classify events
- flexible fillings possible for each tower

- BAC muon trigger logic on Tower, Area and Detector Level
- For "good"/quite towers: $(N_{layers} >= 3, N_{chambers} >= 3)$

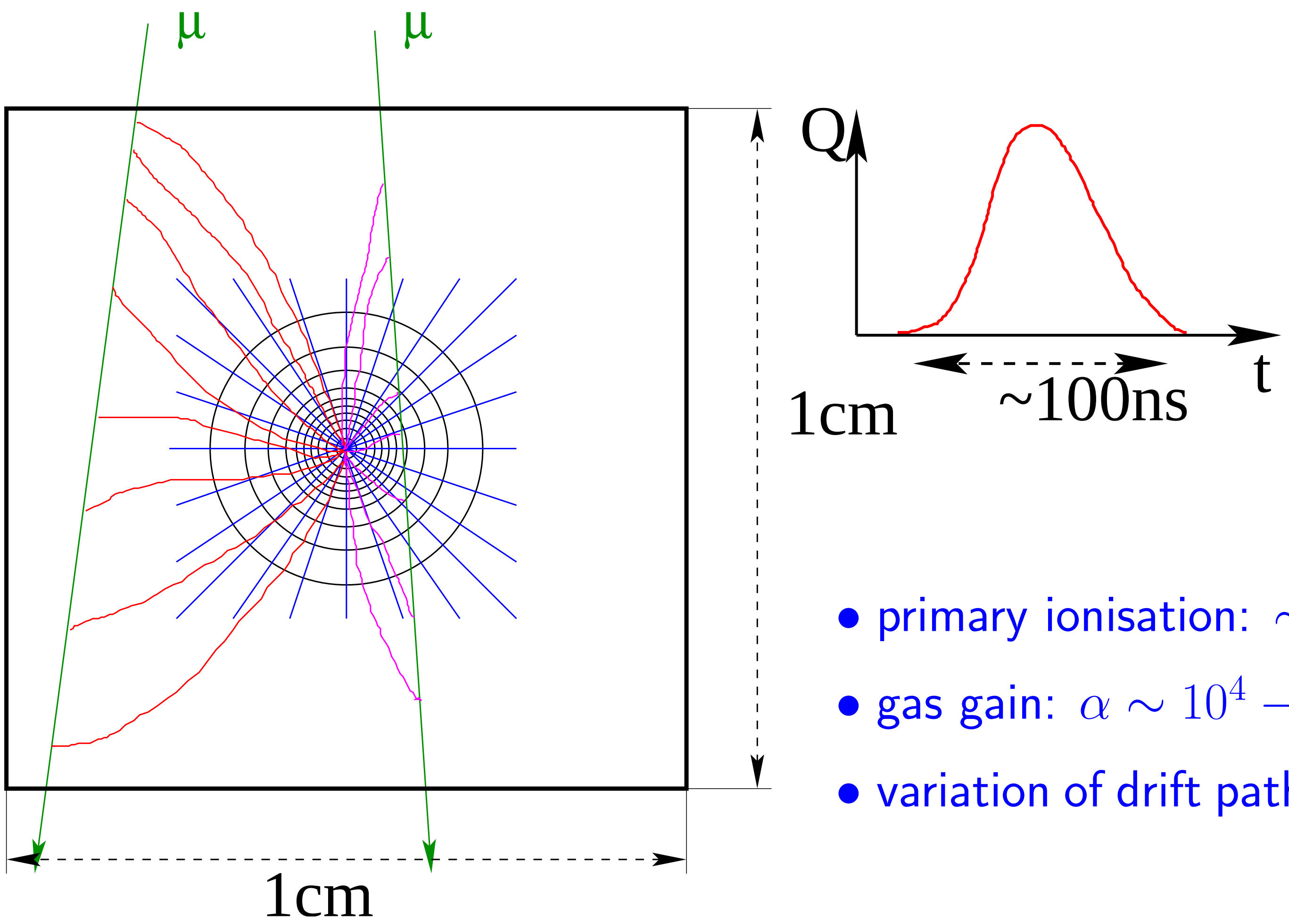
BAC ForeCap: coincidence with Strips





- cross-section perpendicular and along wires shown
- veto on first two inner rings around the beam-pipe

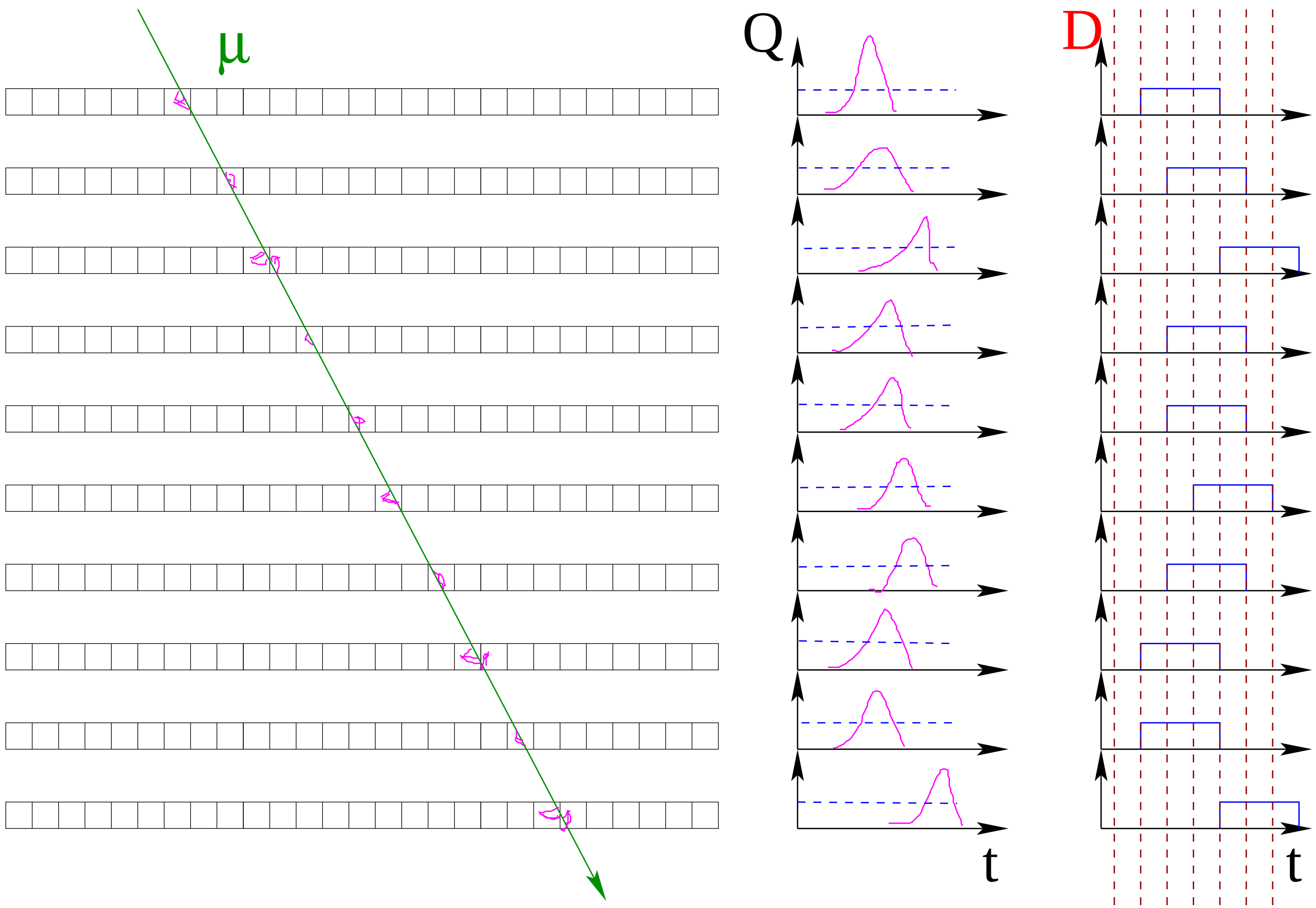
Drift Time Problem: single BAC cell



- primary ionisation: $\sim 50\, pairs\, e^{-} Ar^{+} / 1\, cm$
- gas gain: $\alpha \sim 10^4 - 10^5$
- variation of drift paths/times and signal shape

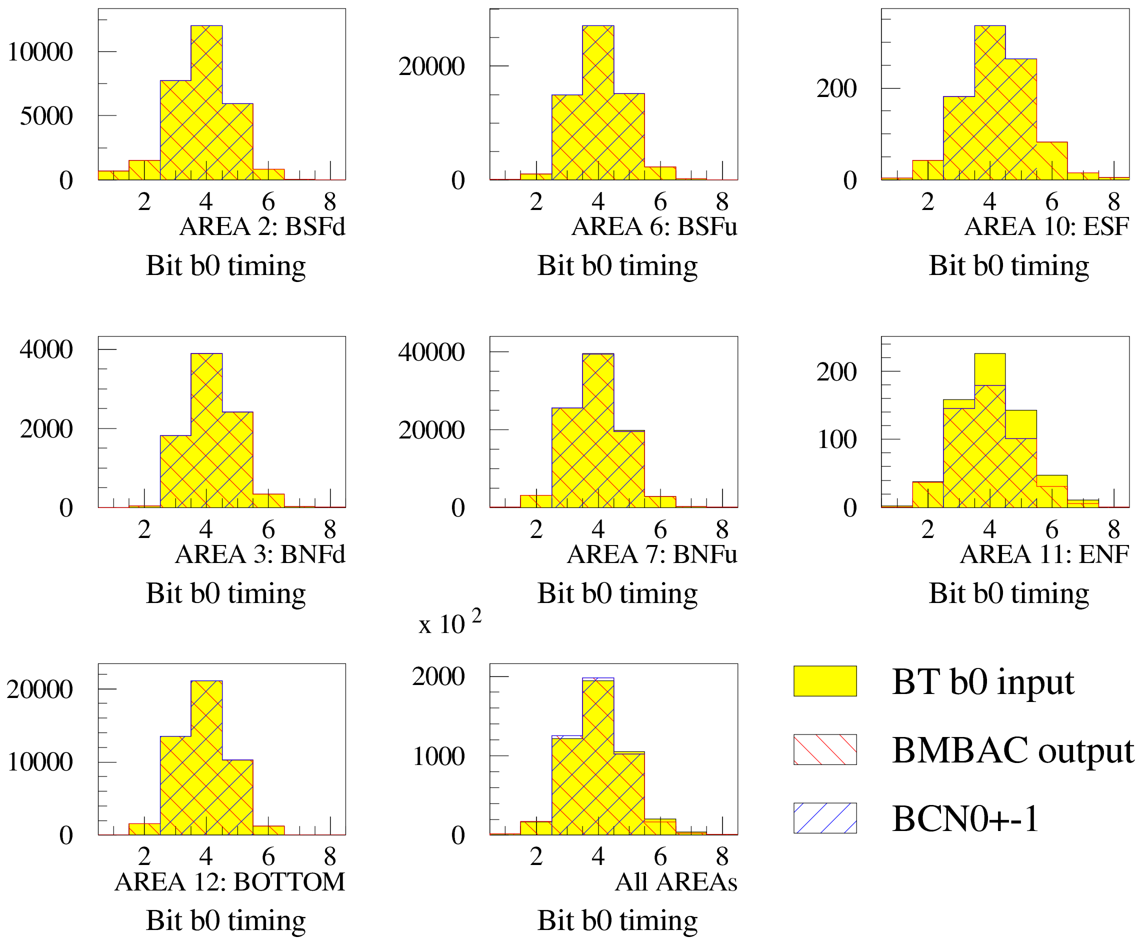
- $Ar + 13\% CO_2$ mixture @ $\sim 1800\, V$, wire diameter $\phi = 50\, \mu m$, field $\vec{E} \sim \frac{1}{\rho} \vec{e}_\rho$
- drift velocity: $v_{drift} \sim 1\, cm/100\, ns$

Drift Time Problem: Wire Tower



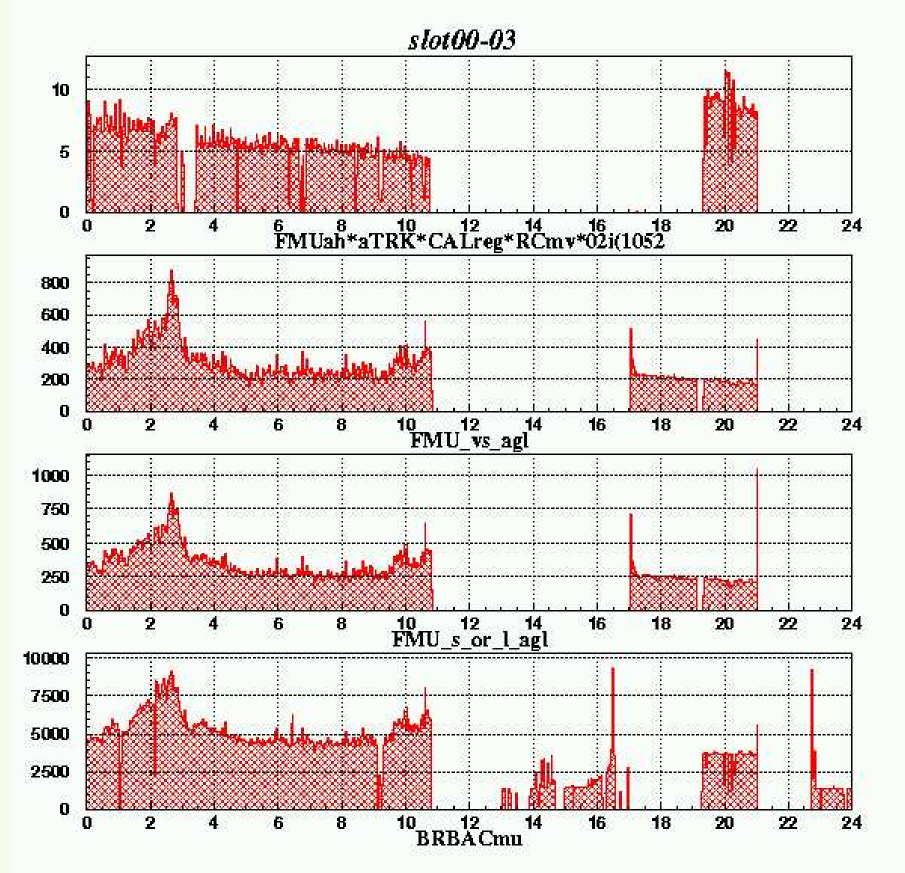
- amplitude discrimination in comparators (programmable threshold)
- digital signal is extended for 3 consecutive HERA clocks to reduce jitter effect
- $N_{layers}, N_{chambers}$ are calculated for each clock

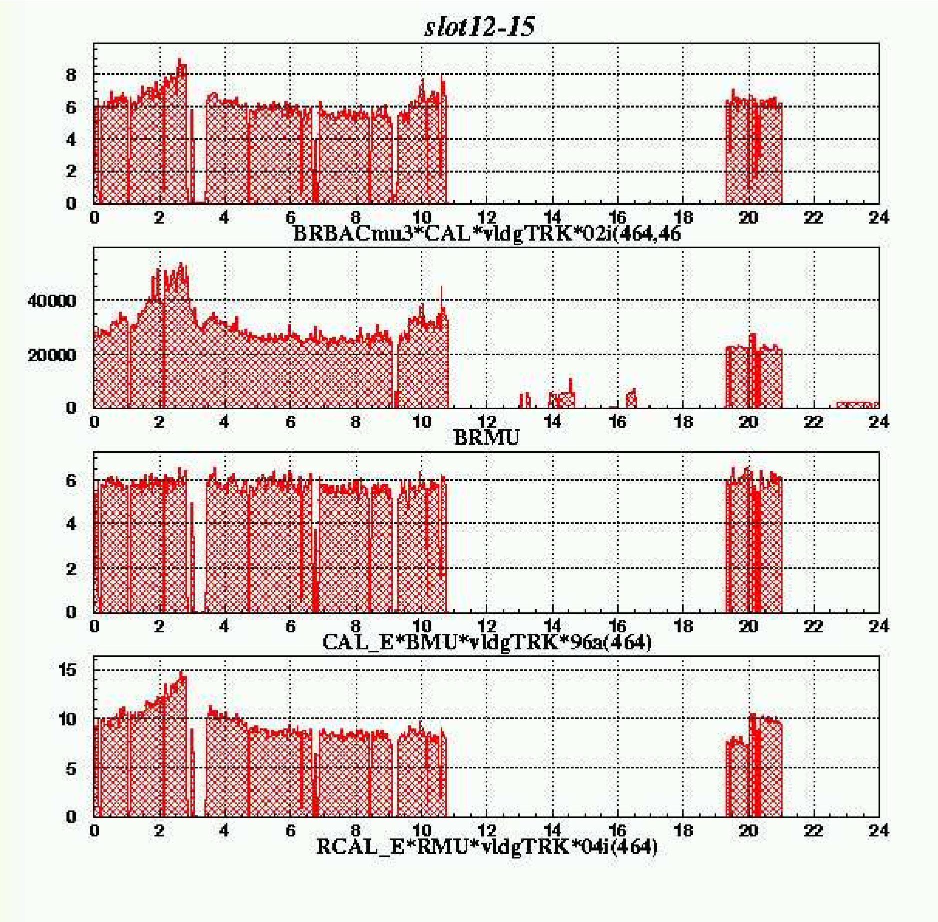
BAC Trigger timings for selected Areas



- Timing distribution of BAC muon trigger
- Each muon bit is extended for 2 consecutive HERA clocks
- Some irreducible jitter due to the drift time in gas ($\sim 100\, ns/1\, cm$)

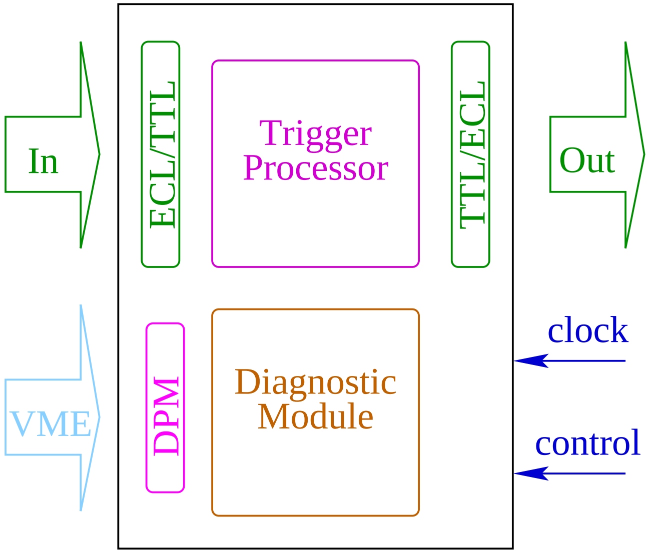
BAC FLT: rate of Physics Trigger slots

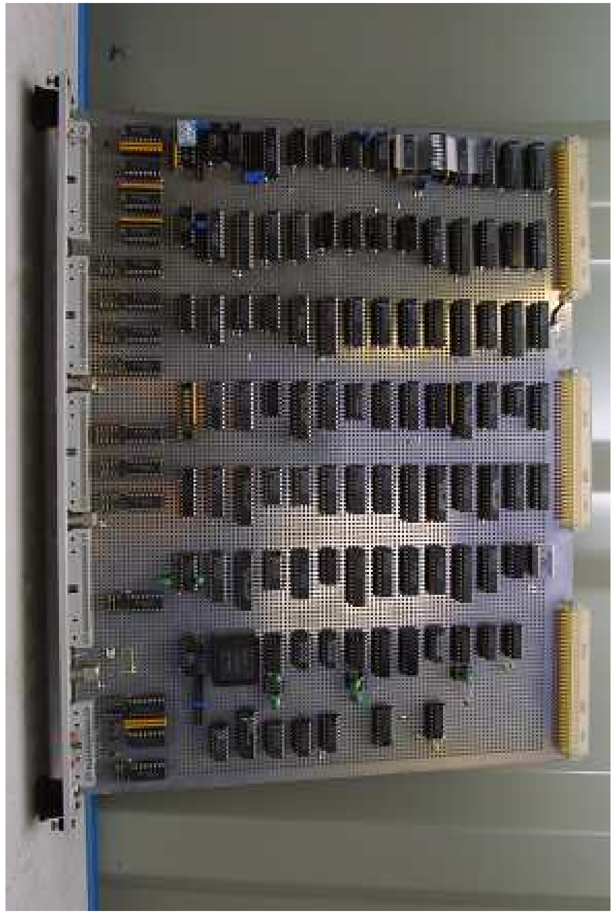




- FLT12: BRBAC*CAL*vldgTRK*Bg_v; FLT05: FBAC*HAC*gTRK*Et*Bg_v
- Good correlation with other muon detectors (BRMUO, FMUON)
- Stable rate $\sim 5 - 15\, Hz$ (Physics), $\sim 5 - 15\, kHz$ (BAC alone)

BAC Trigger Hardware implementation

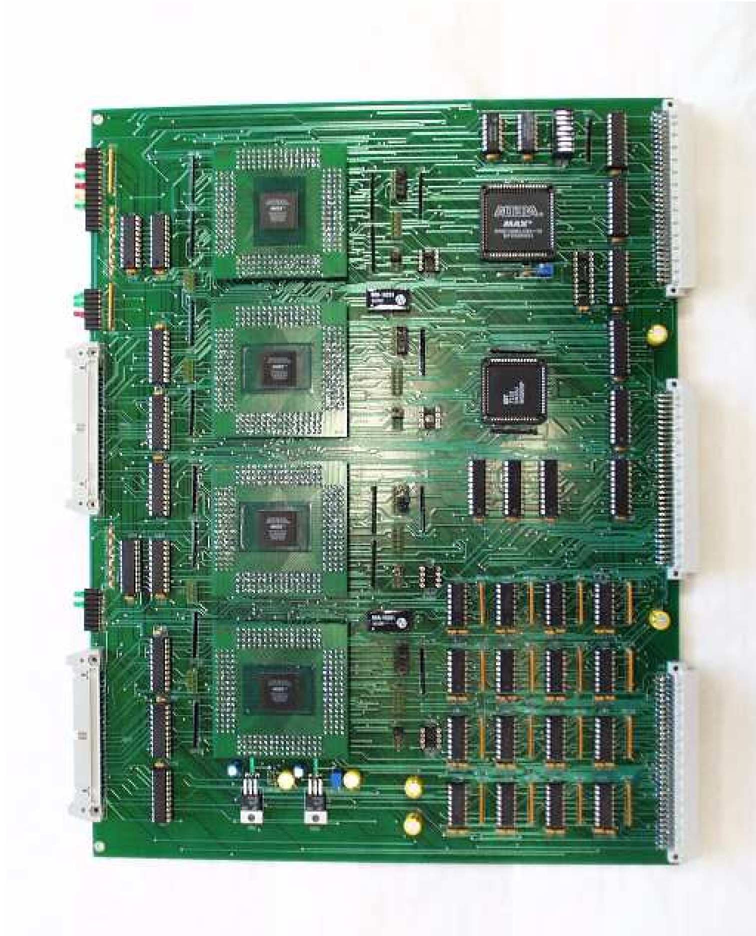




- universal FPGA/ALTERA borads
- programmable in VHDL language, flexible !

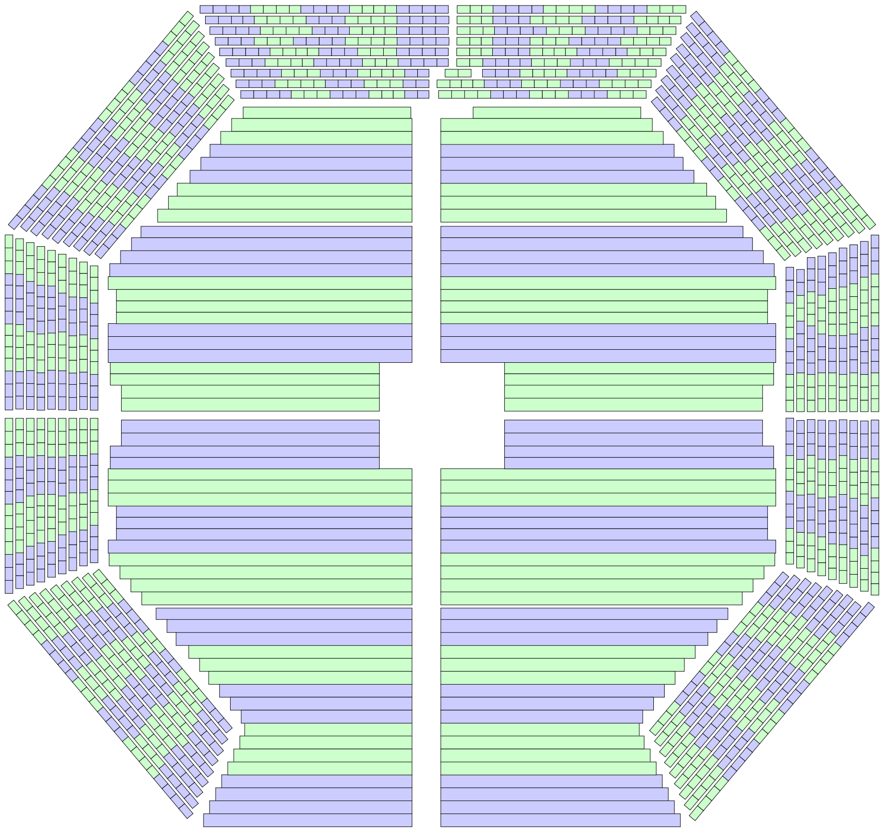
BAC Trigger Hardware implementation

- 162 XY Boards in HITBOXes
- 7 XY-RECEIVER boards
- 4 ADDER boards
- 2 RACE boards
- 2 MUON BITS boards
- central boards:
  - EMBAC (Energy Main)
  - RMBAC (Race Main)
  - BMBAC (muon BITS Main)
  - GFLT board interface



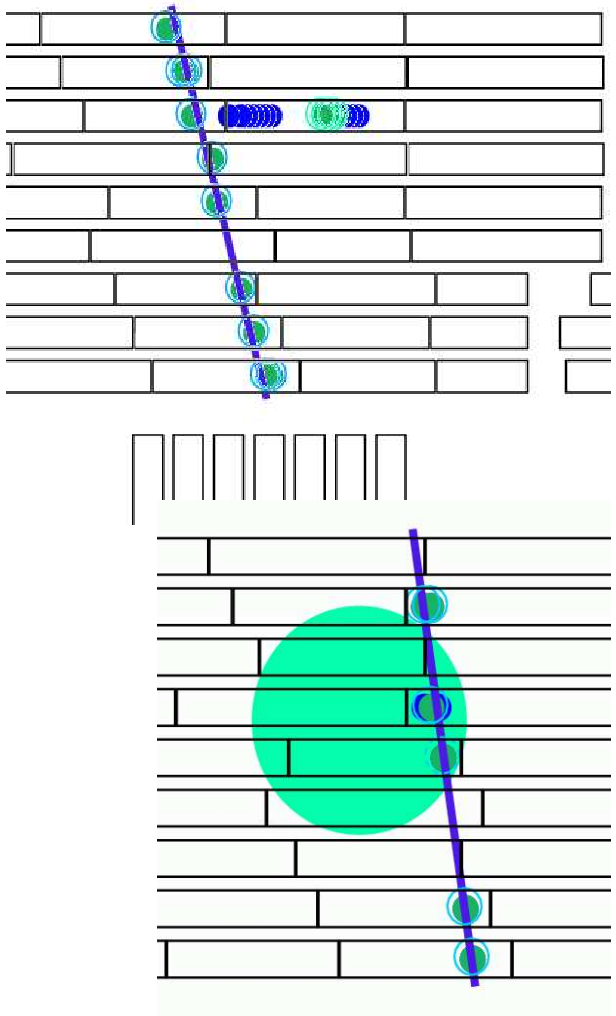
Printed boards (6 layers printing, 9 U hight) produced in Warsaw (ITR – *Instytut Tele- i Radiotechniczny*).

BAC Second Level Trigger (SLT)



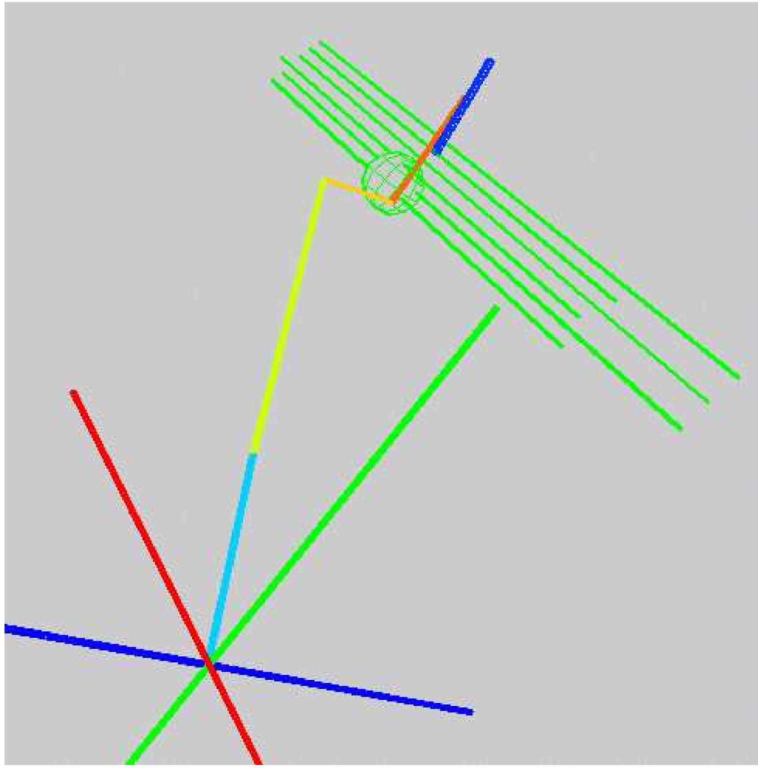
- On FLT BAC provides 13 bits of muon information for 13 Areas: (BNFU, BNFD, BNRU, BNRD, BSFU, BSFD, BSRU, BSRD, ENF, ESF, ENR, ESR, BOTT)
- On SLT this information can be refined by providing the list of "active" towers (or positions $\sim 50\,cm$ resolution)
- DPM Redout of XY-REC boards with SLT rate possible (few words only)
- Unfortunately not enough CPU on SLT available (track matching)...
- FLT bits are forwarded plus veto/clean-up cuts added (vertex and good timing "up-down")

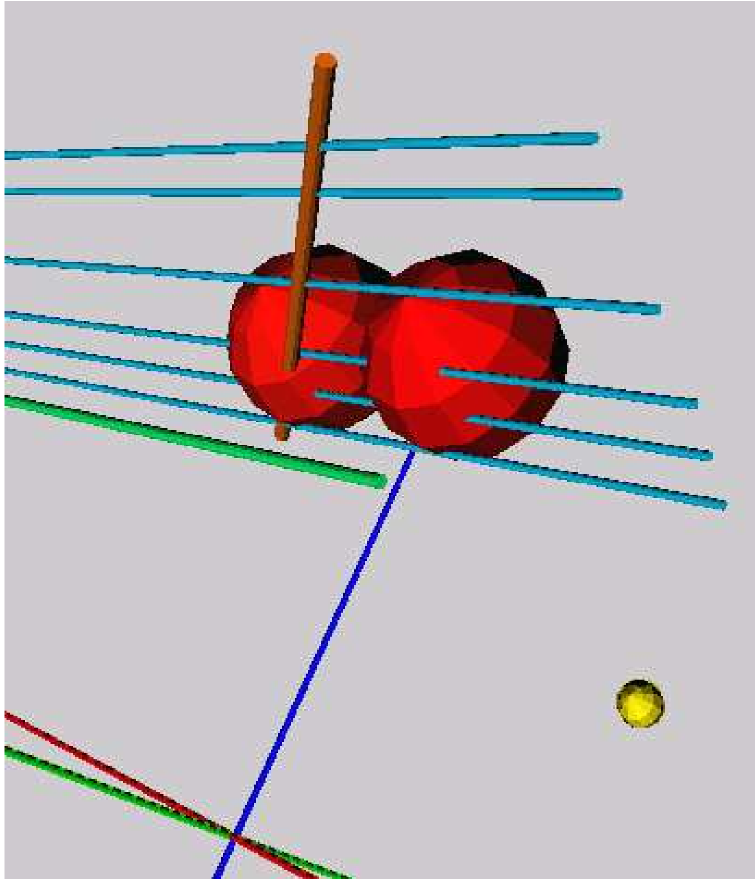
BAC TLT: New 3D Algorithm

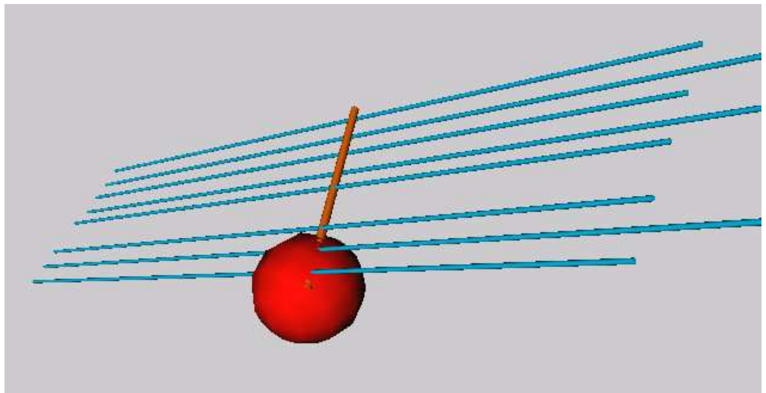


- Extracting of PAD and HITS raw data to local tables
- Noise suppression (blue full circles)
- Angular clustering of wires (open circles)
- Evaluation of cluster quality
- Straight line fit to good clusters (3 and more layers, etc...), no iterative fit
- 3D coordinate from pads associated with wire cluster (if exist) (green big circle)
- matching to CTD tracks (extrapolated from "at CAL" end point)
- in addition: PAD ONLY muons from compact mip-like pad clusters matched to CTD tracks
- Output: number of muons, positions (x,y,z) and directions.

BAC TLT: some 3D examples of reconstructed muons

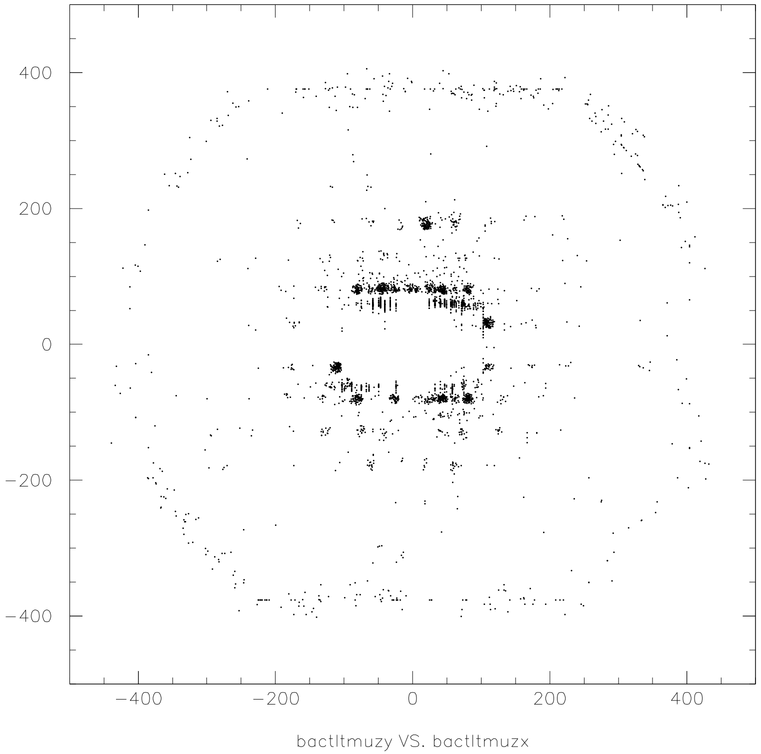


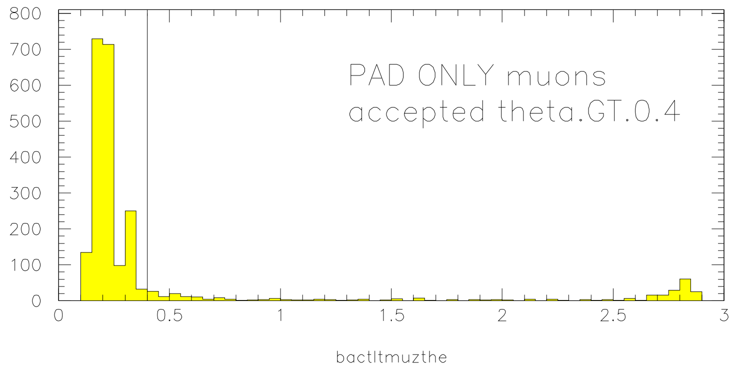


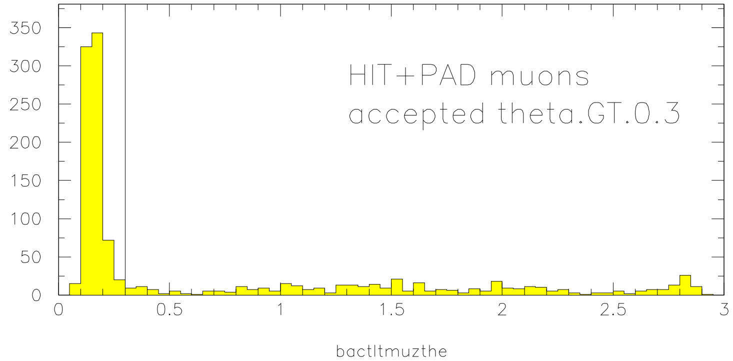


- light blue - CTD track
- yellow - extrapolated line to BAC
- orange - DCA to BAC cluster
- red - fitted muon (BAC TLT)
- blue - MuBAC (off-line algorithm)

PHYSICS runs: typical distribution of reconstructed muons







- "fake" muons close to beam-pine in FBAC (hadrons, p-remnant) rejected by extra cut on $\theta > \theta_{min}$
- still some COSMIC in BARREL can be suppressed by back-to-back cut or by coincidence with other components in physics filters
- some HALO muons in Rearcap

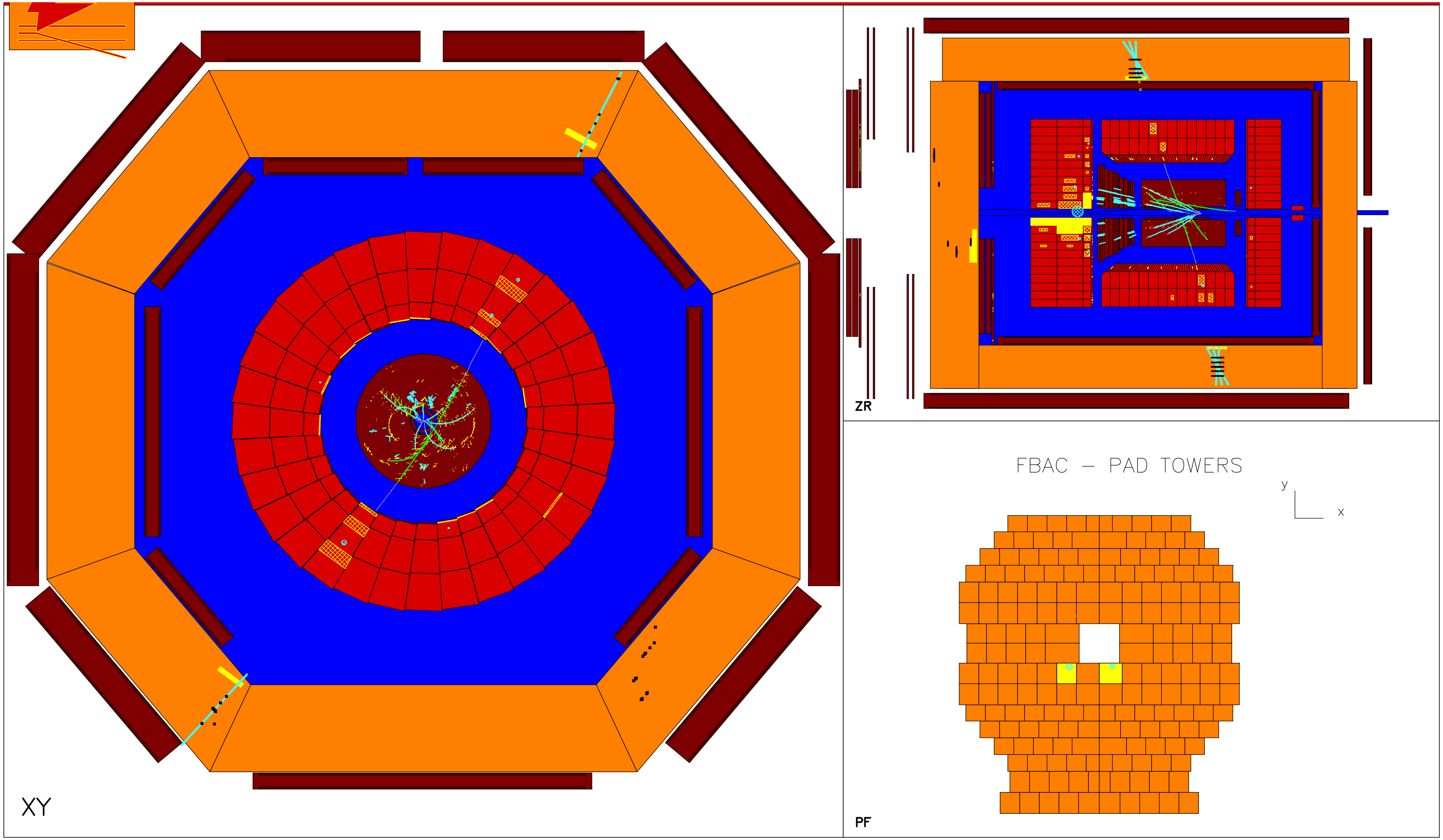
BAC TLT anti-COSMIC cuts

- BAC COSMIC MUON "HARD":
  - 2 BAC muon segments
  - both matched to good CTD tracks ($p_T > 1.5$)
  - in back-to-back configuration
- BAC COSMIC MUON "SOFT":
  - 1 or 2 BAC muon segment(s)
  - only 1 matched to good CTD track ($p_T > 1.5$)
  - $N_{trk} <= 3$ (low multiplicity event)
  - any other track in back-to-back configuration to the BAC matched track

HARD COSMIC muons can also overlay physics events
SOFT COSMIC muons: to reject stopping COSMIC muons
and/or COSMIC events with BAC inefficiency

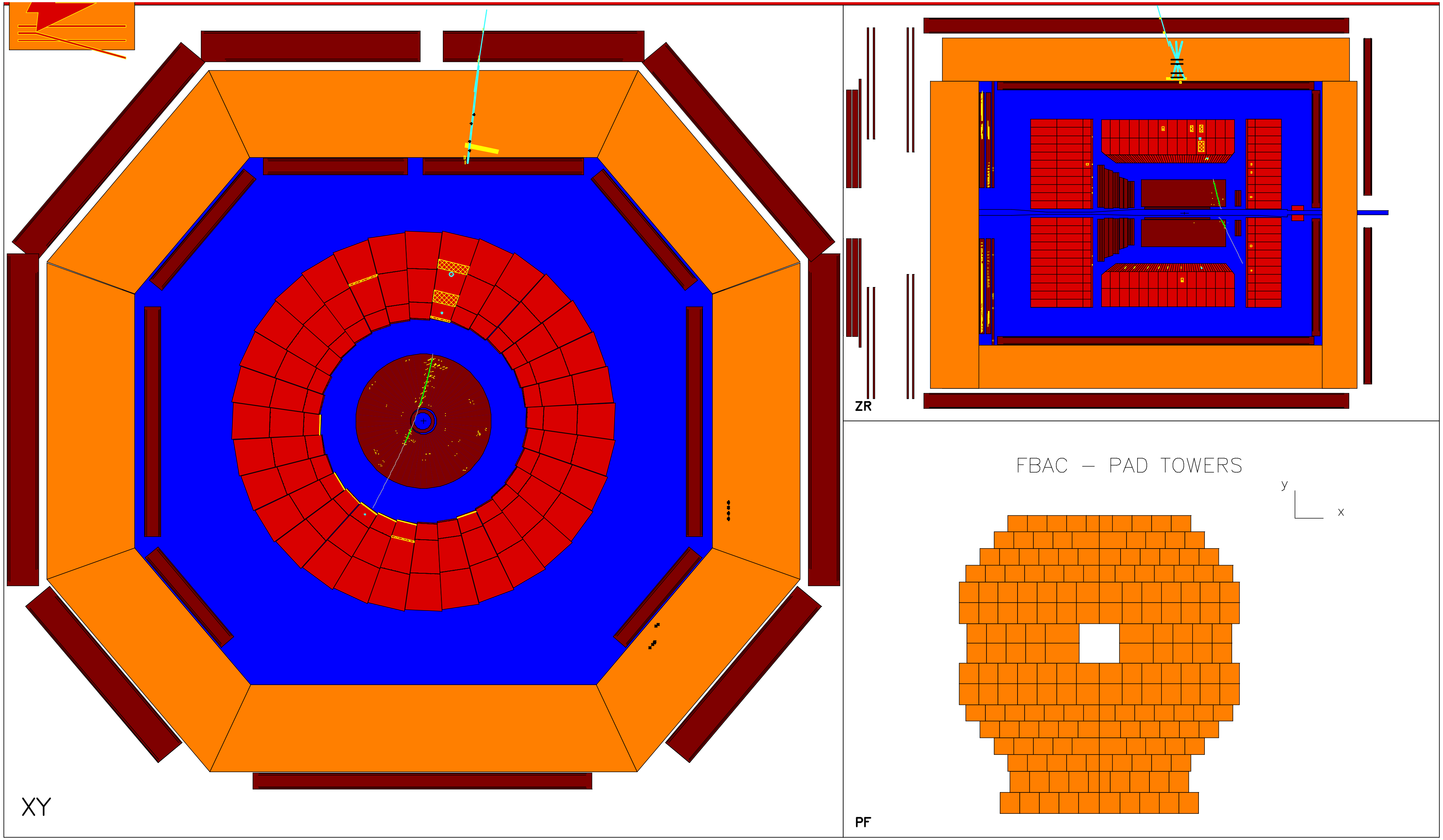
BAC TLT COSMIC reduction

BAC COSMIC HARD MUON overlayed with Physics event

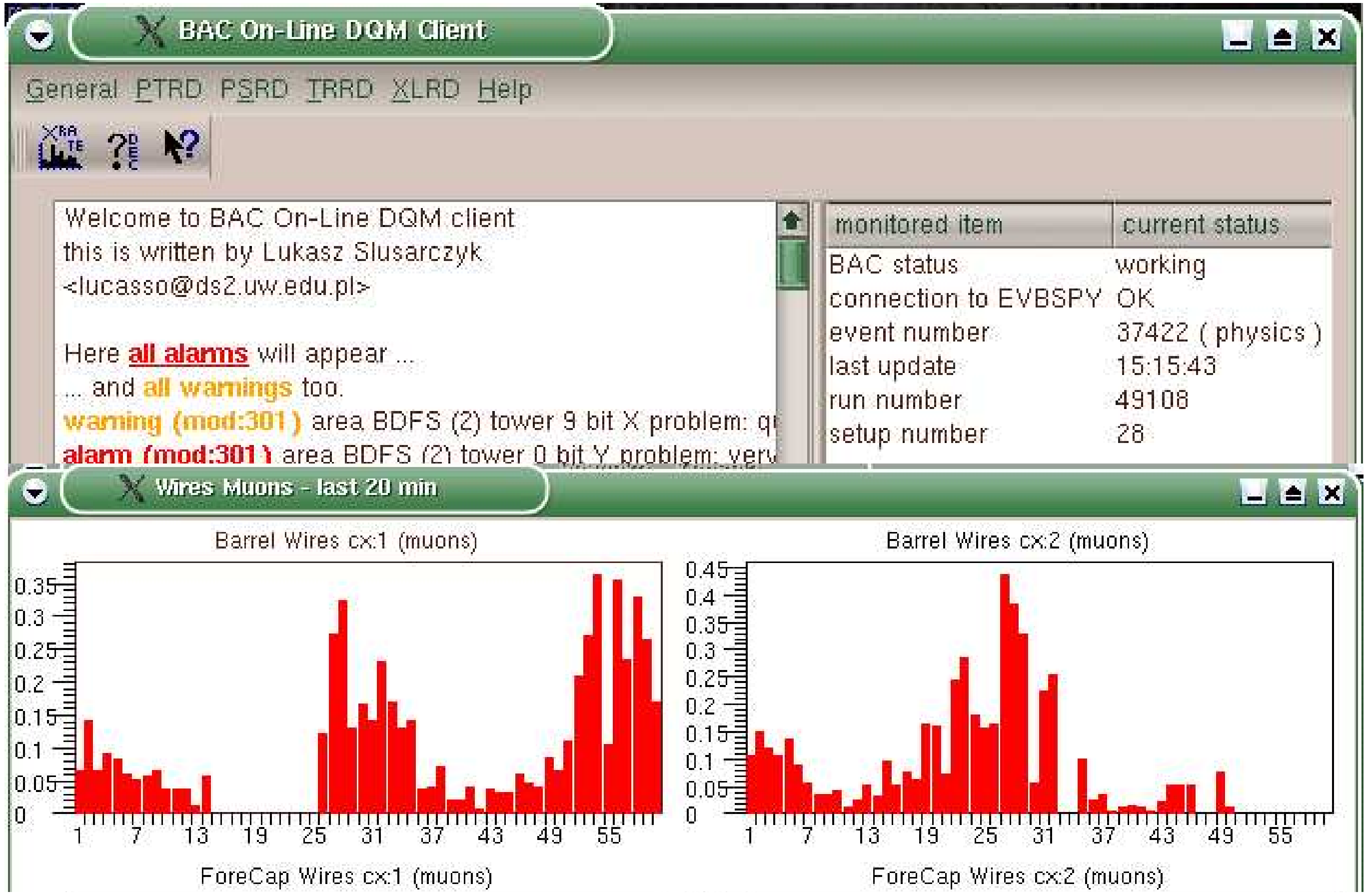


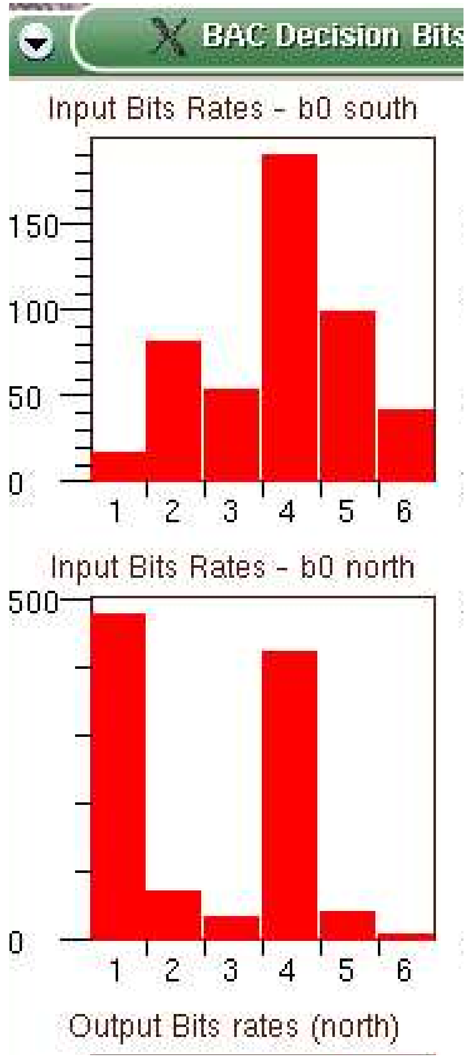
BAC TLT COSMIC reduction

BAC COSMIC SOFT MUON



BAC On-line DQM

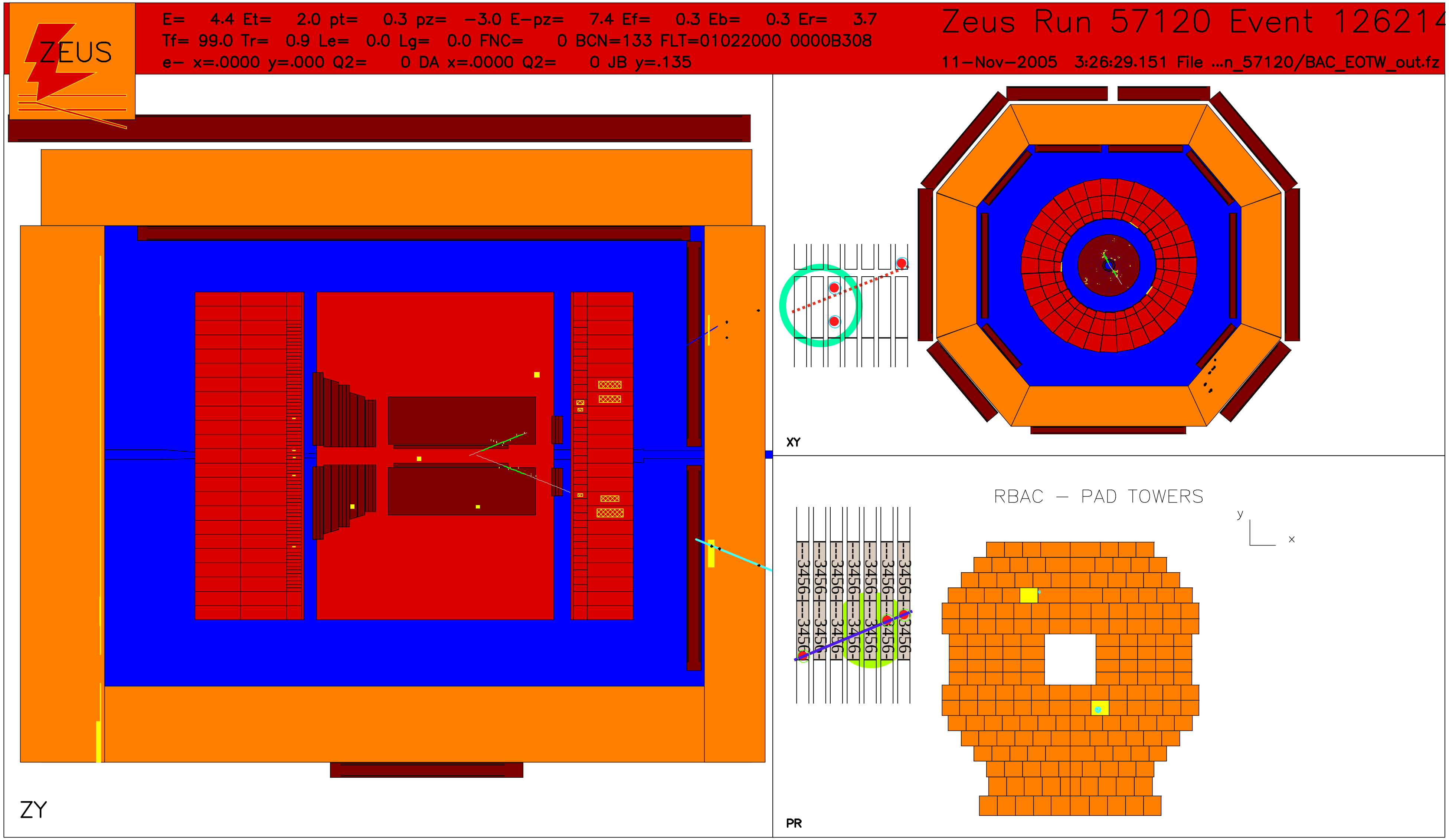




- TCP-IP client-server application, data from Event Builder
- fast monitoring of BAC trigger rates for EACH tower, area, etc...
- interfaced to Global ZEUS on-line automatic DQM
- daily remote control of detector performance

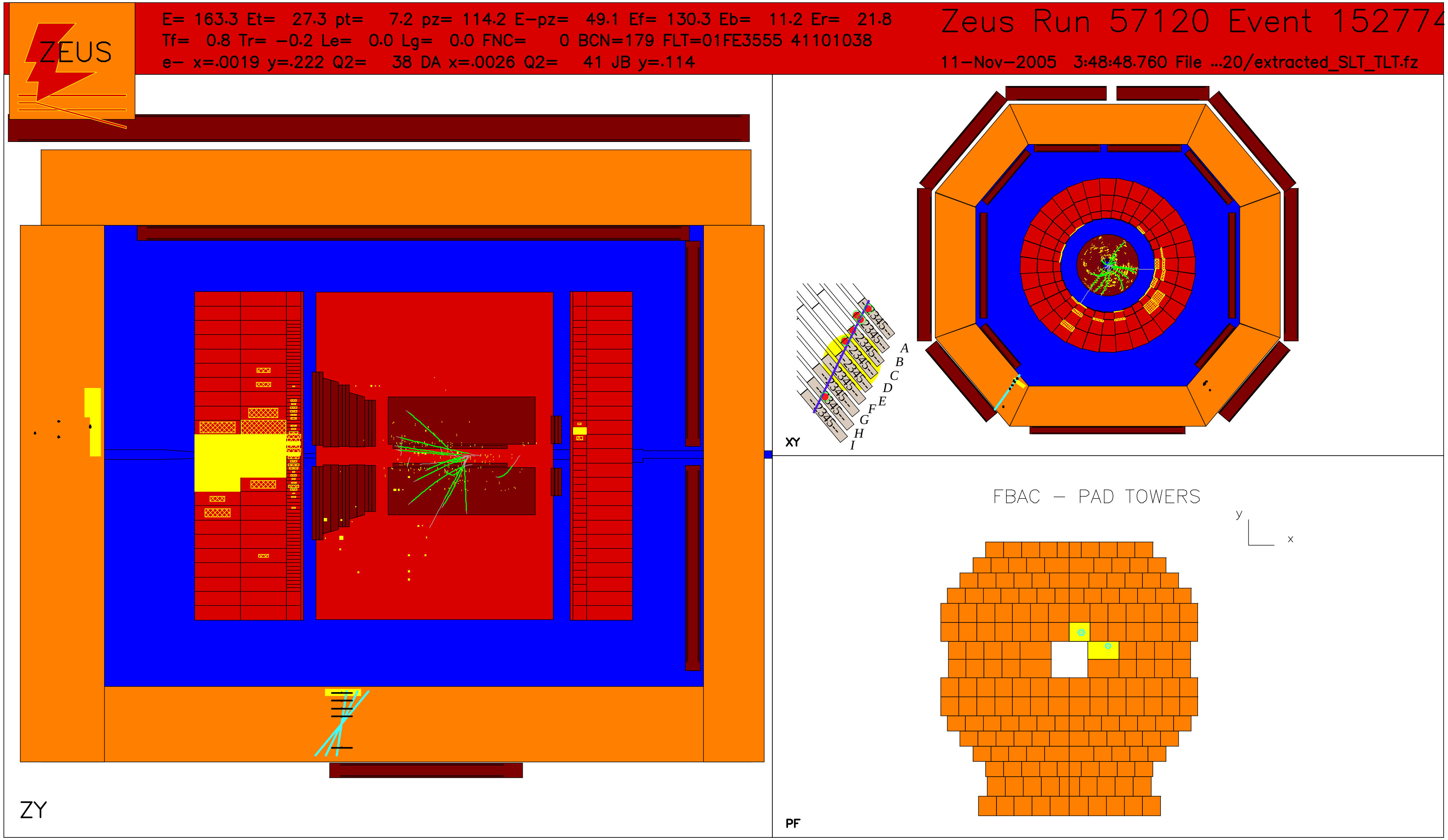
BAC TLT MUO slots: elastic J/Ψ

BAC FLT fired for lower muon, BAC TLT for both tracks



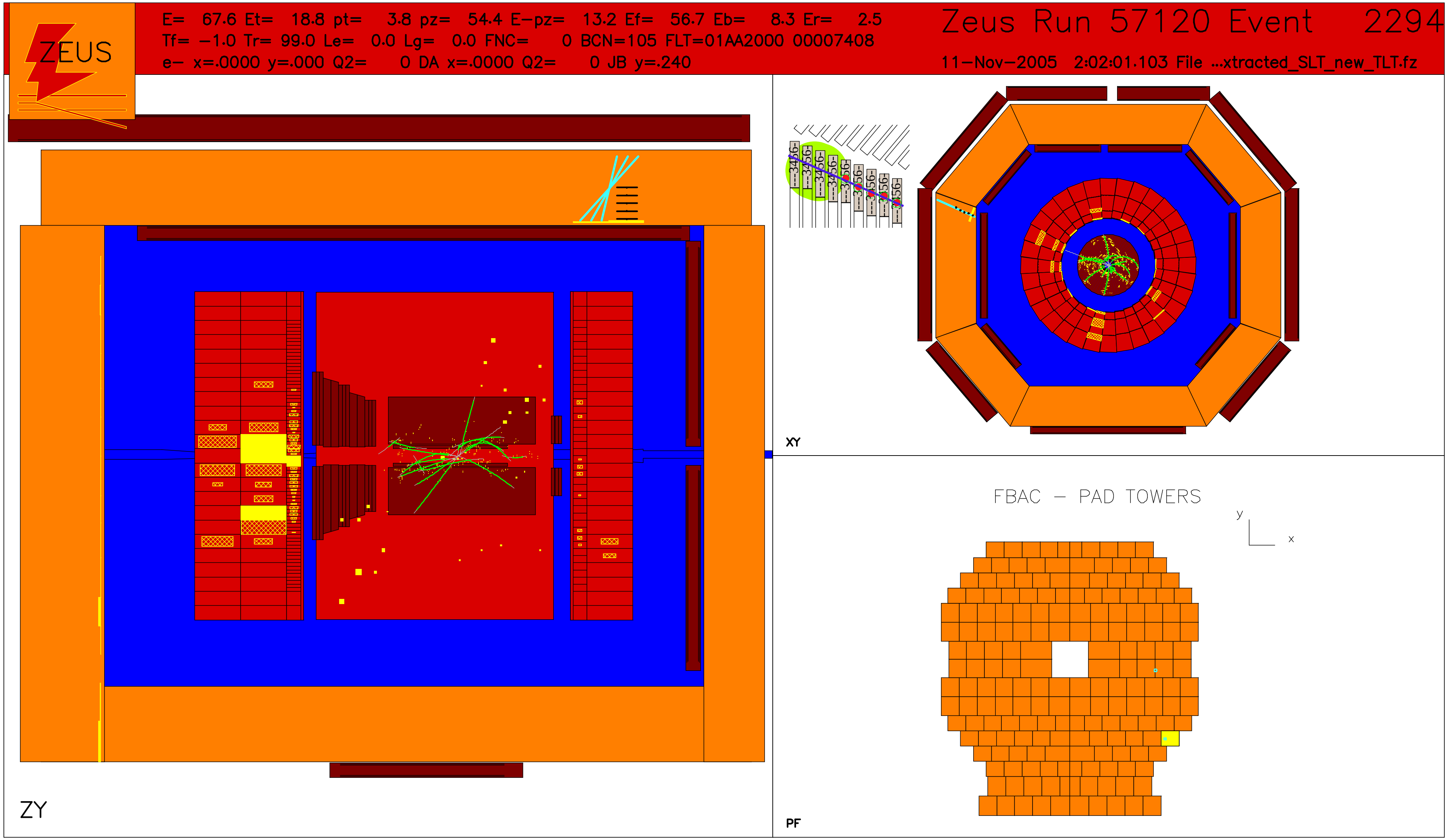
BAC TLT MUO slots: Low Q2 DIS with muon

BAC FLT and TLT fired for Muon in Barrel



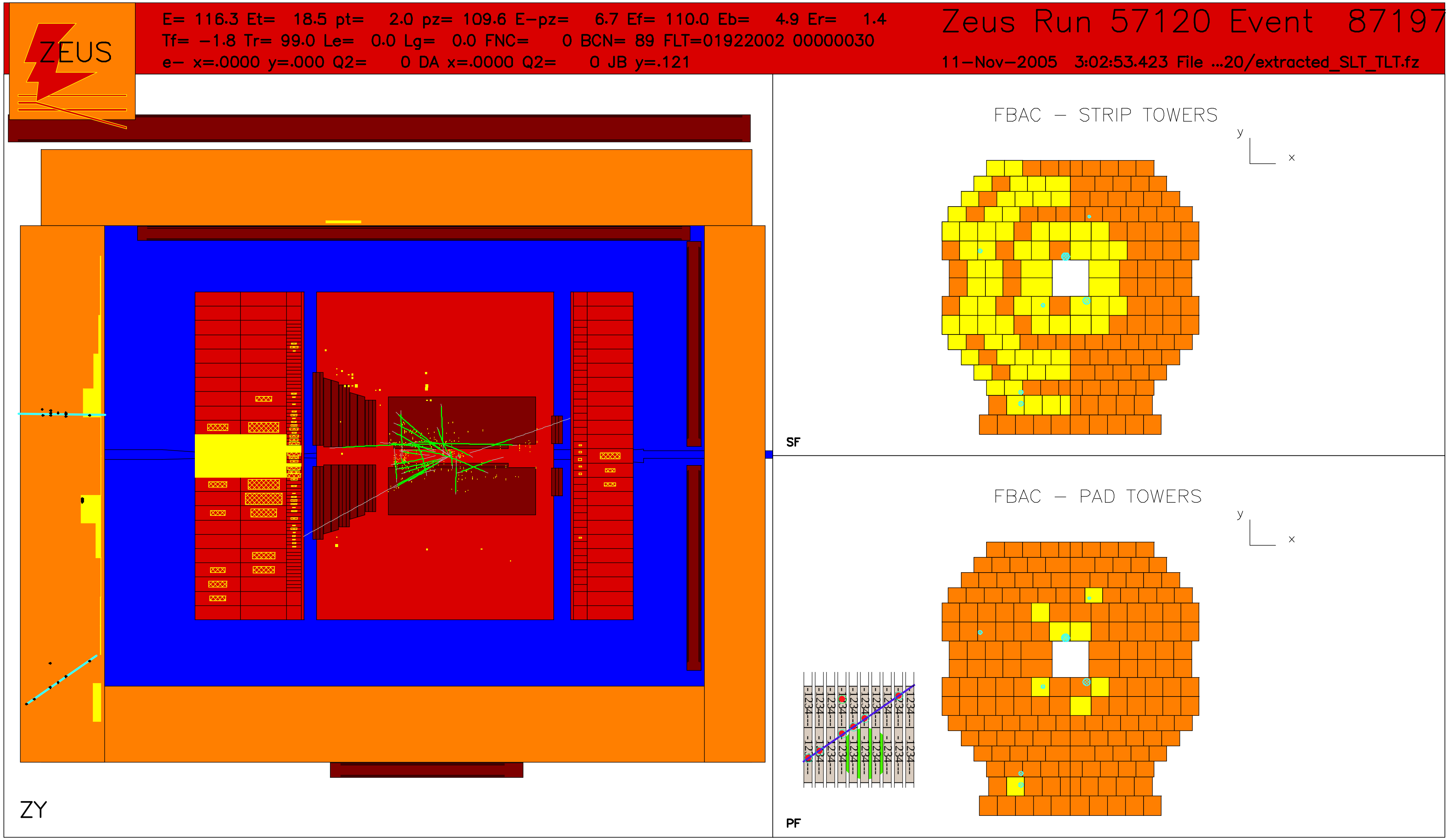
BAC TLT MUO slots: PHP with muon

BAC FLT and TLT fired for Muon in Barrel



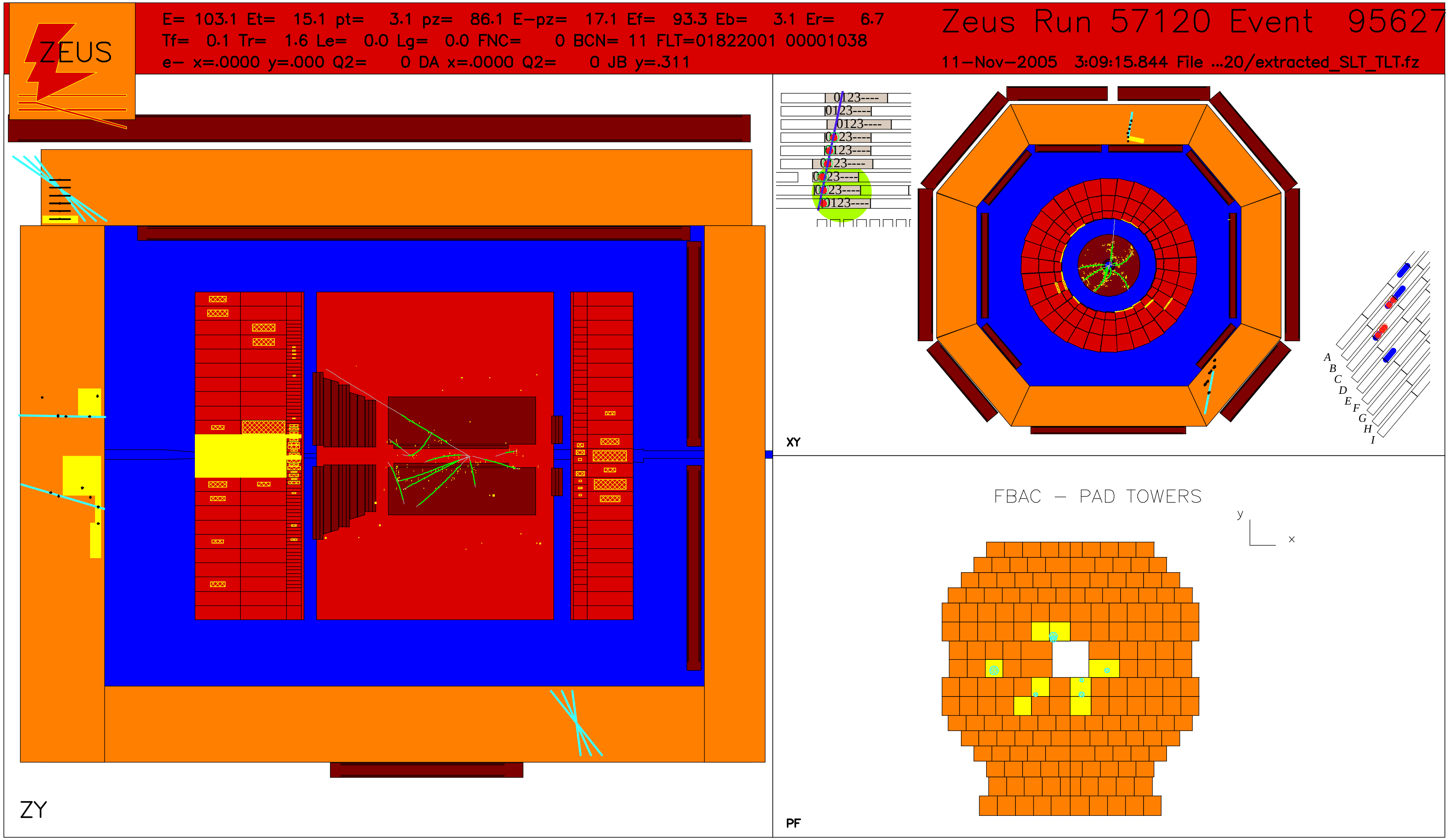
BAC TLT MUO slots: PHP with muon

BAC FLT and TLT fired for Muon in Forecap



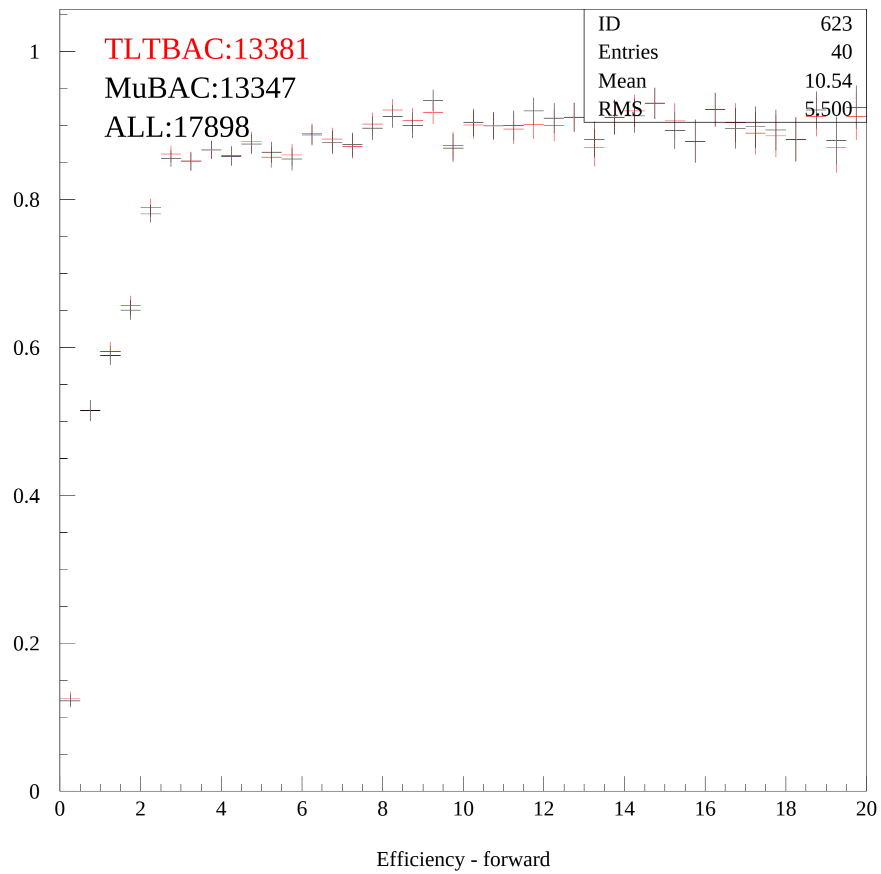
BAC TLT MUO slots: PHP with muon

BAC FLT and TLT fired for Muon in Barrel edge, noise in BNRD (not fitted by TLT !)

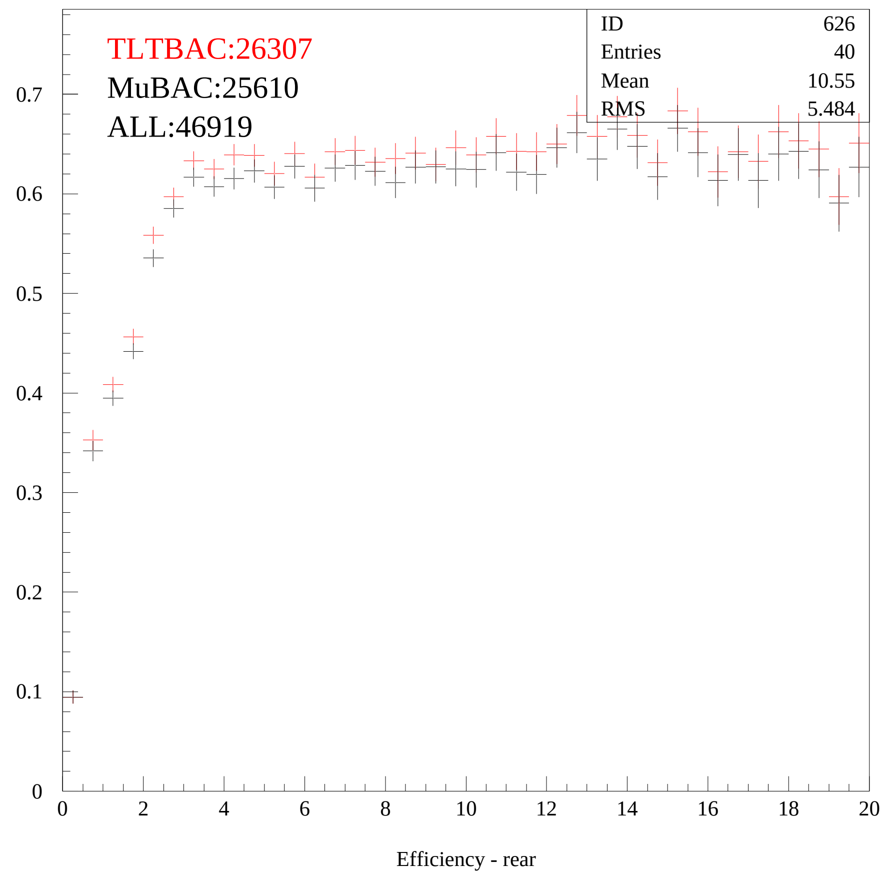


BAC TLT efficiencies (from COSMIC run)

eff: 59425 v:267 (μ in Forward half - HITs)

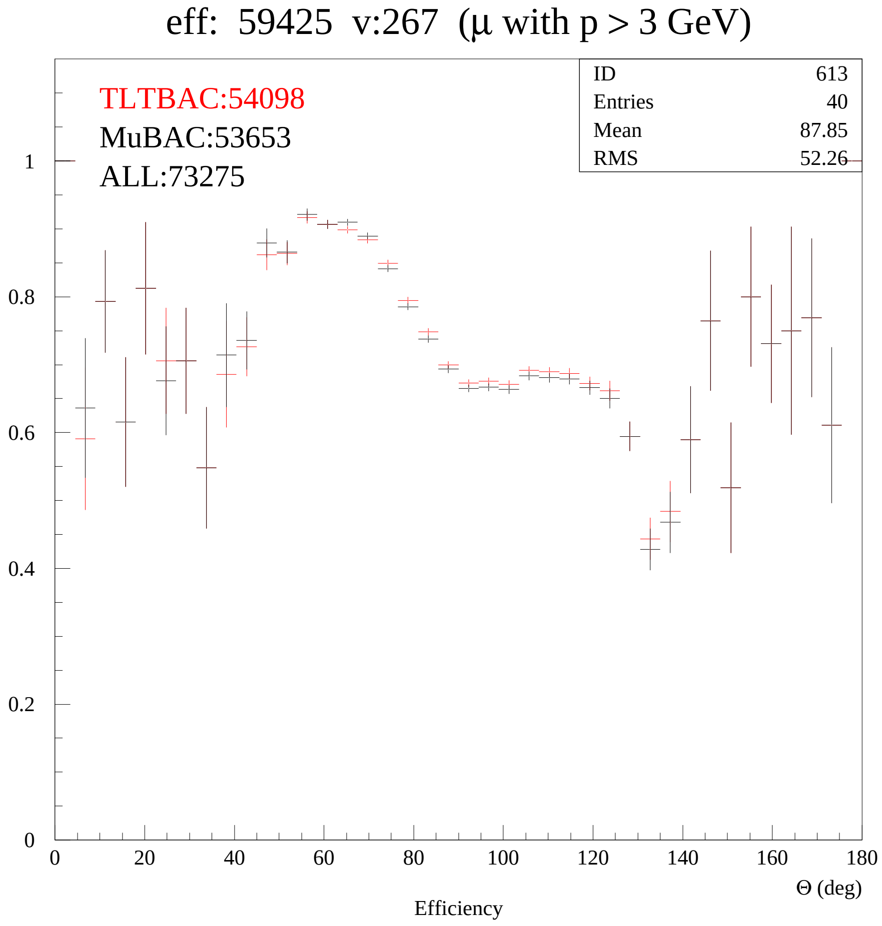


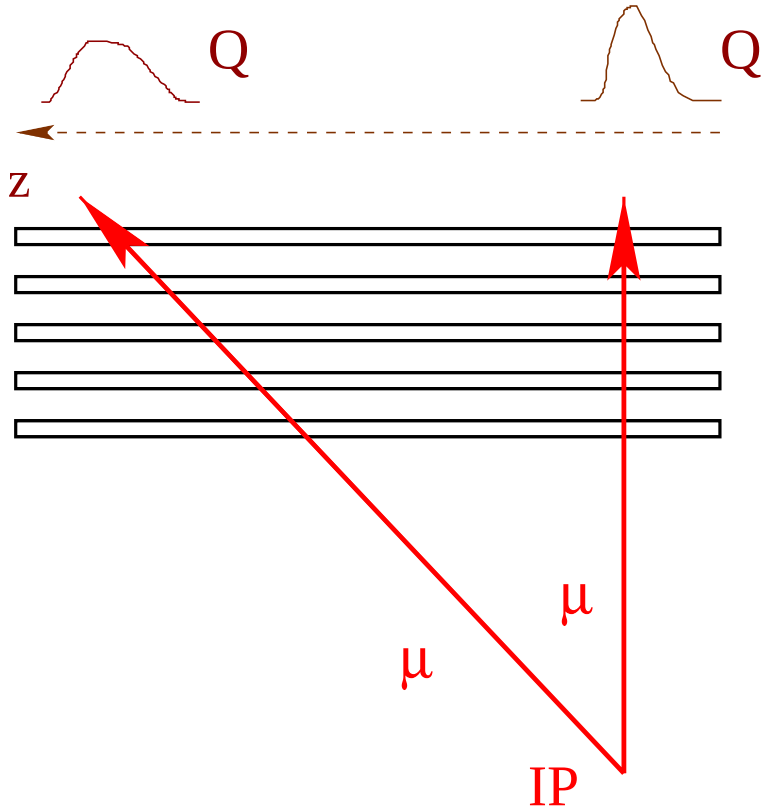
eff: 59425 v:267 (μ in Rear half - HITs)



- calculated w.r.t. the CTD tracks, (off-line MUBAC and BACTLT compared)
- trigger efficiency as a function of the muon momentum is plotted

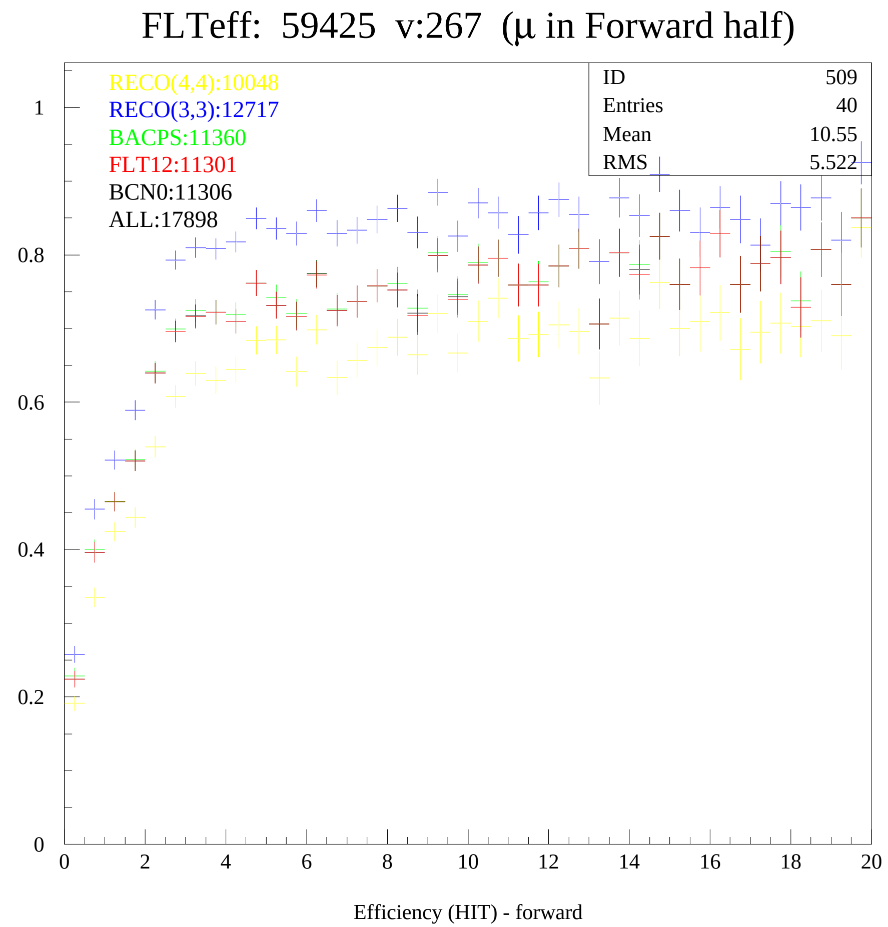
TLT Theta efficiency

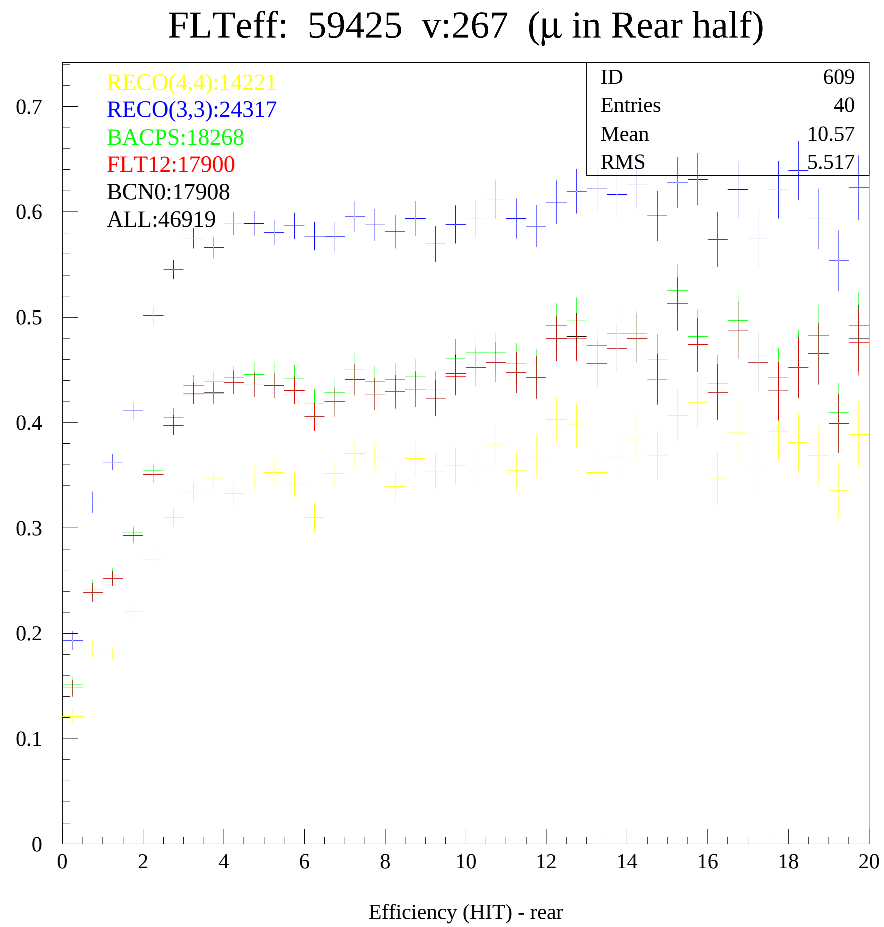




- convolution of two effects:
  - charge transport along the long wire and amplitude discrimination
  - primary ionisation (length of the gas path)

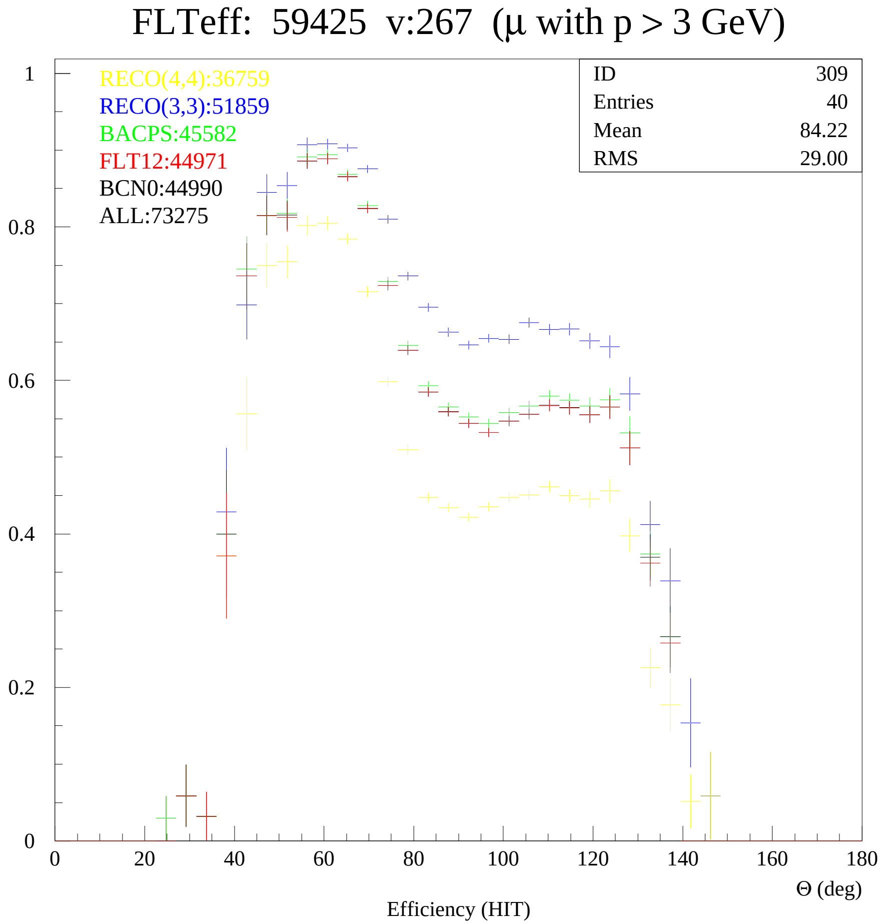
BAC FLT on-line efficiencies (from COSMIC run)

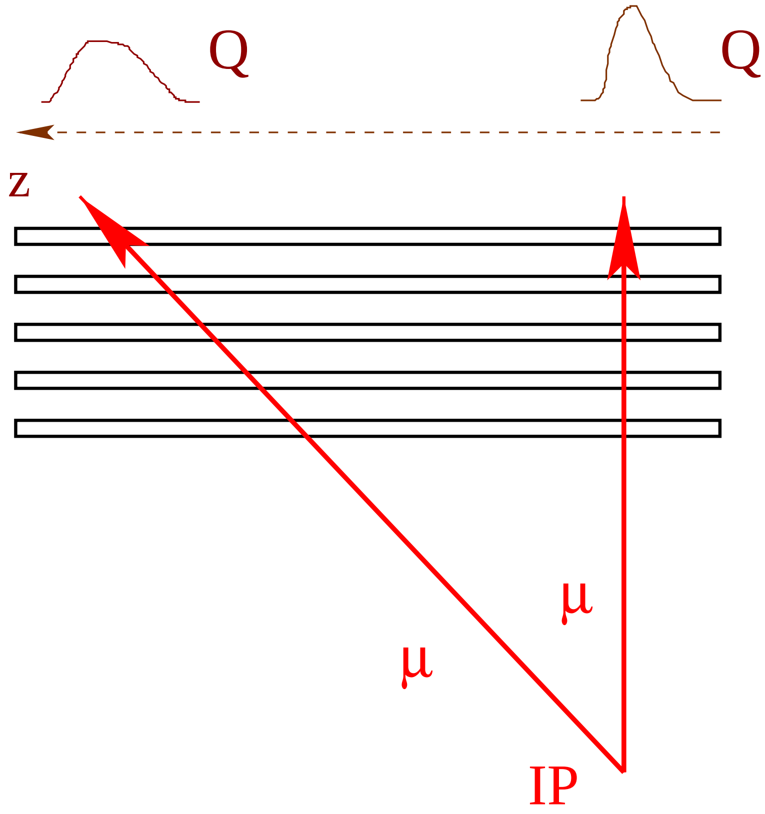




- calculated w.r.t. the FLT61 (BCAL-COSMIC-x*gTRK)
- trigger efficiency as a function of the muon momentum is plotted

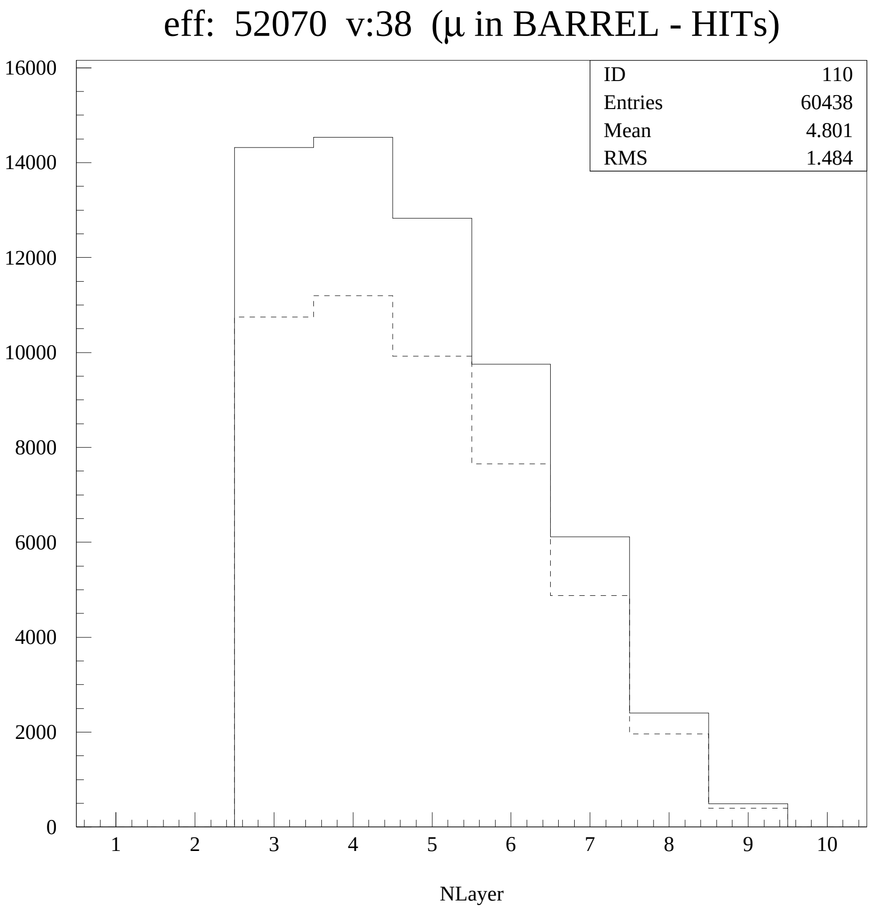
BAC FLT on-line Theta efficiency

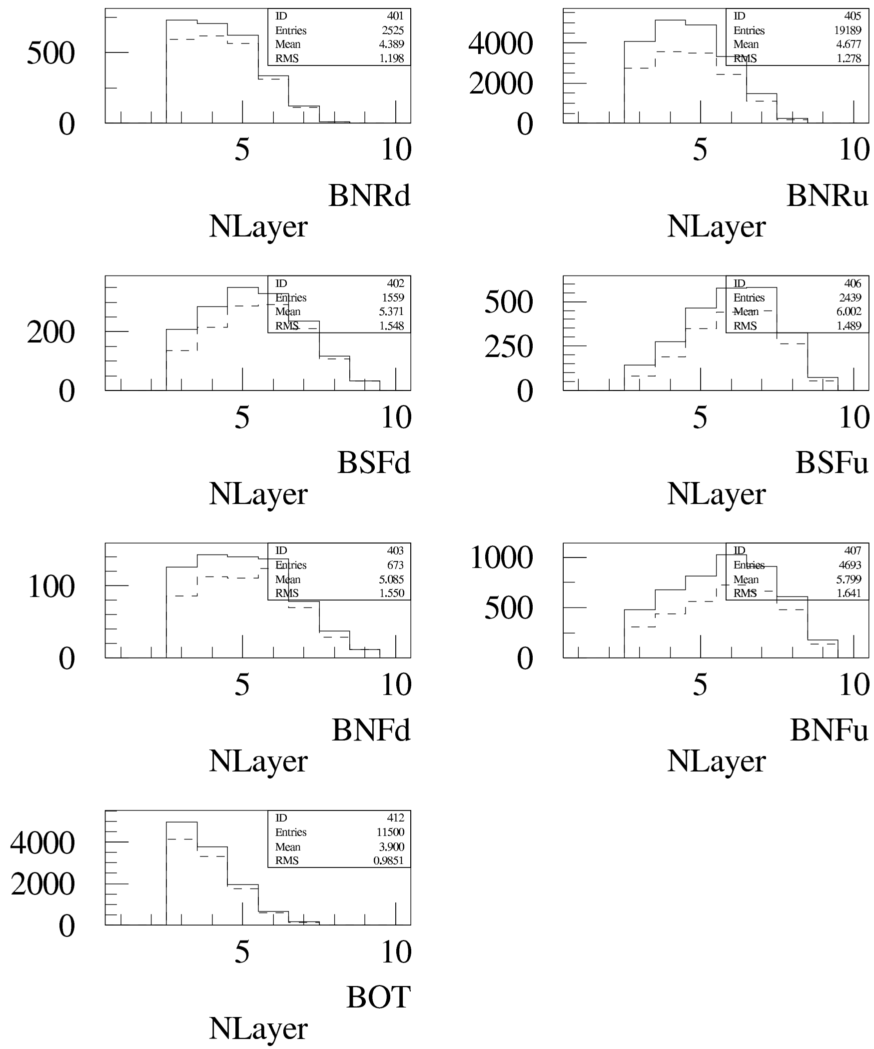




- convolution of two effects:
  - charge transport along the long wire and amplitude discrimination
  - primary ionisation (length of the gas path)
- theta dependence less pronounced for lower threshold $(N_{layers}, N_{chambers})$ (3,3)

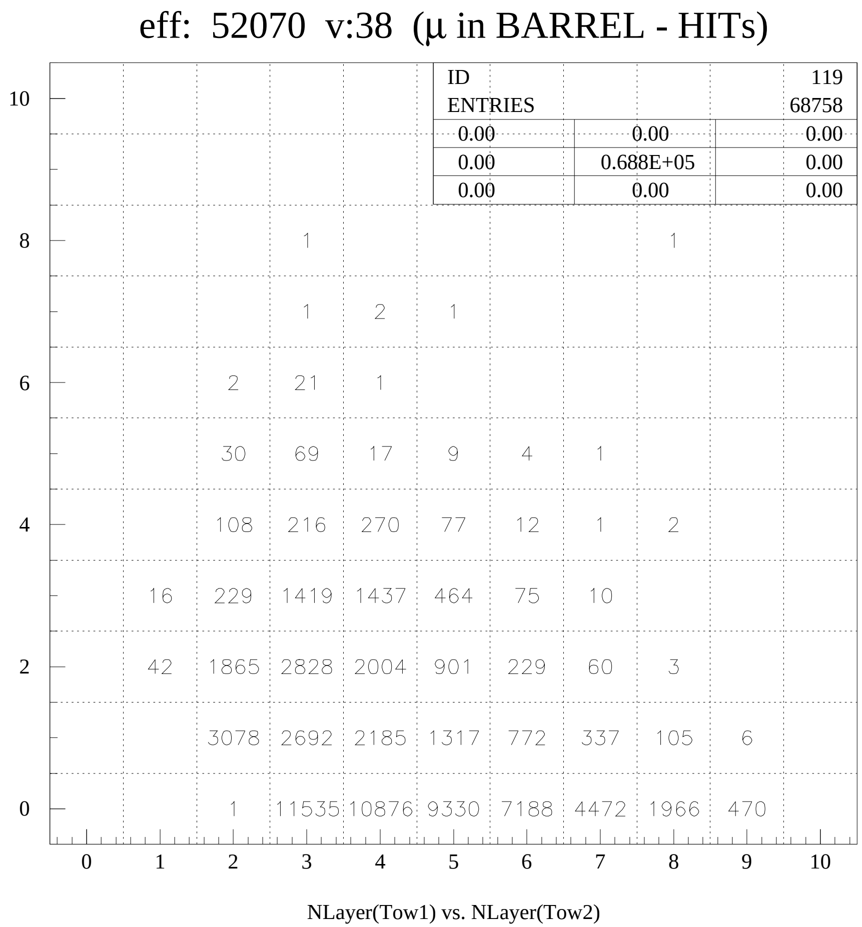
BAC layers multiplicity for muons

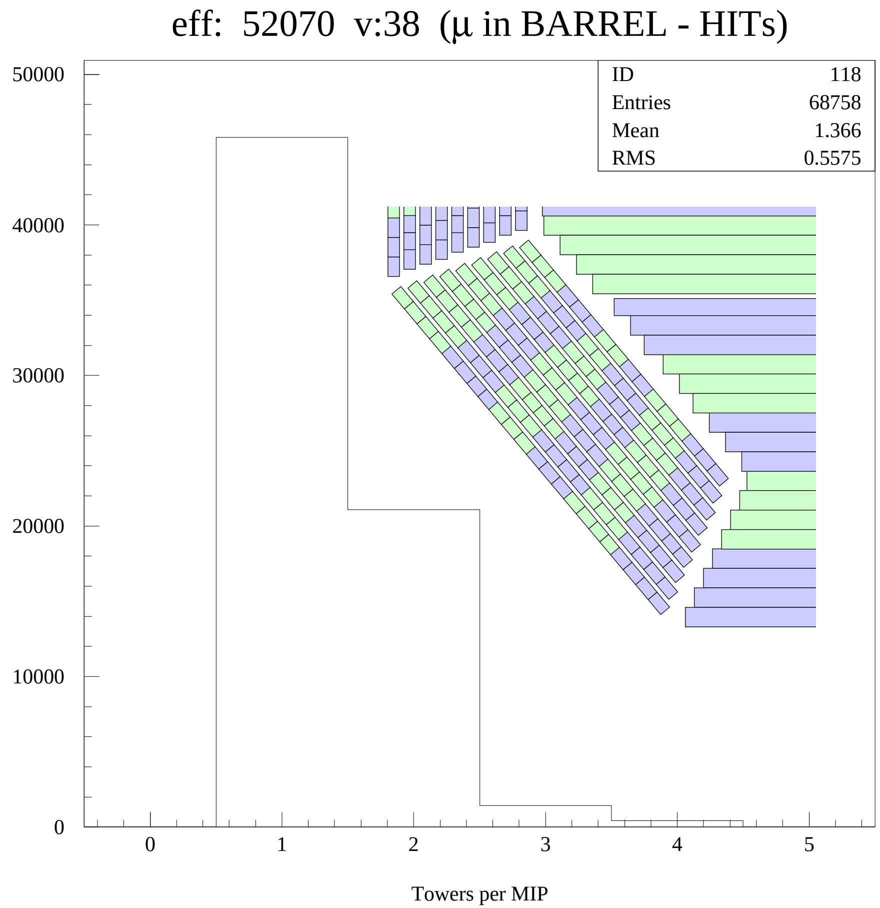




- All muons (solid) and muons with $p > 3\,GeV$ (dashed) plotted
- Small plots: breakdown for selected Areas

Layer multiplicity in neighbour towers





- Number of towers hit by single muon (right)
- Number of hits seen by neighbour towers ($N_1 >= N_2$) (left)
- Towers are not exactly “pointing” to IP in $r\phi$ plane

2006: $42\,pb^{-1}$ Elastic di-muon selection (basing on CTD and CAL)

- Ntrks $=$ Ntrvtx $= 2$
- $\Sigma\, charge = 0$
- $|Zvtx| < 50$ cm
- $N_{SL} \geq 3$
- $cos_{\mu+\mu^-} > -0.95$
- $DCA^{CTD-CALMIP} < 30$ cm
- ($p_1 \geq 3\,\mathrm{GeV}$ or $p_2 \geq 3\,\mathrm{GeV}$)
- $\frac{E_{emc}}{E_{tot}} < 0.8$ (for each track)

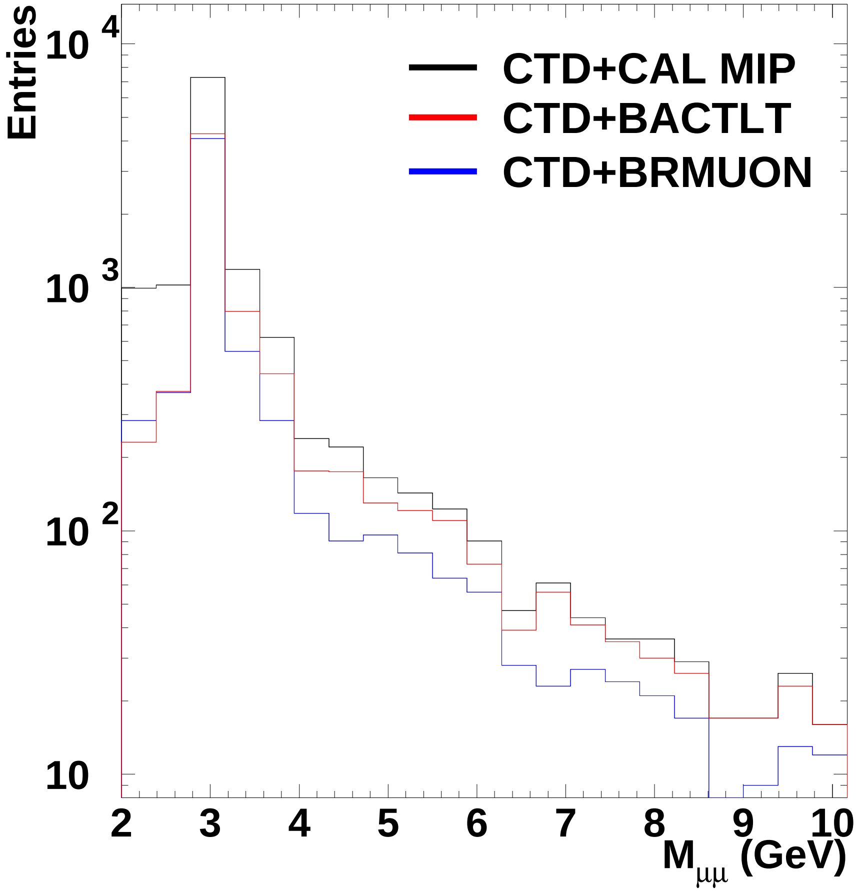
Selection of BAC TLT events

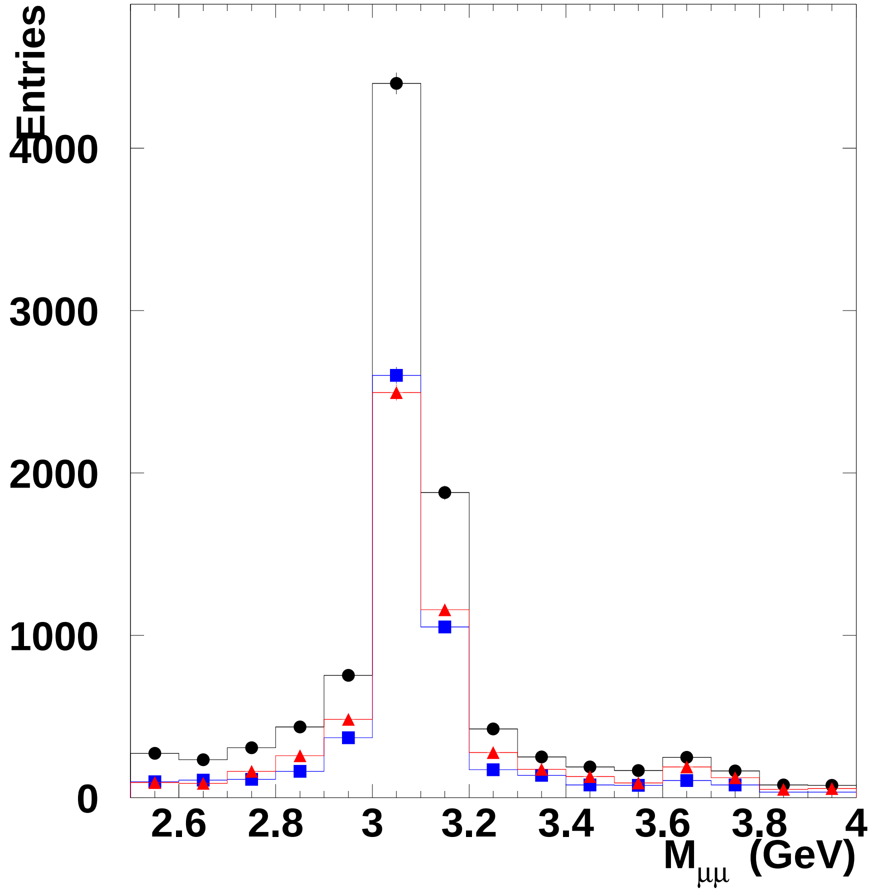
- TLT MUO 11 or TLT MUO 12

Number of selected events (inc. p_1, p_2 cut):

CTD and ...	**CAL MIP**	**BACTLT**	**BRMUON**
J/ψ	3168	2483	1321
BH ($M > 4\,\mathrm{GeV}$)	1280	1082	680

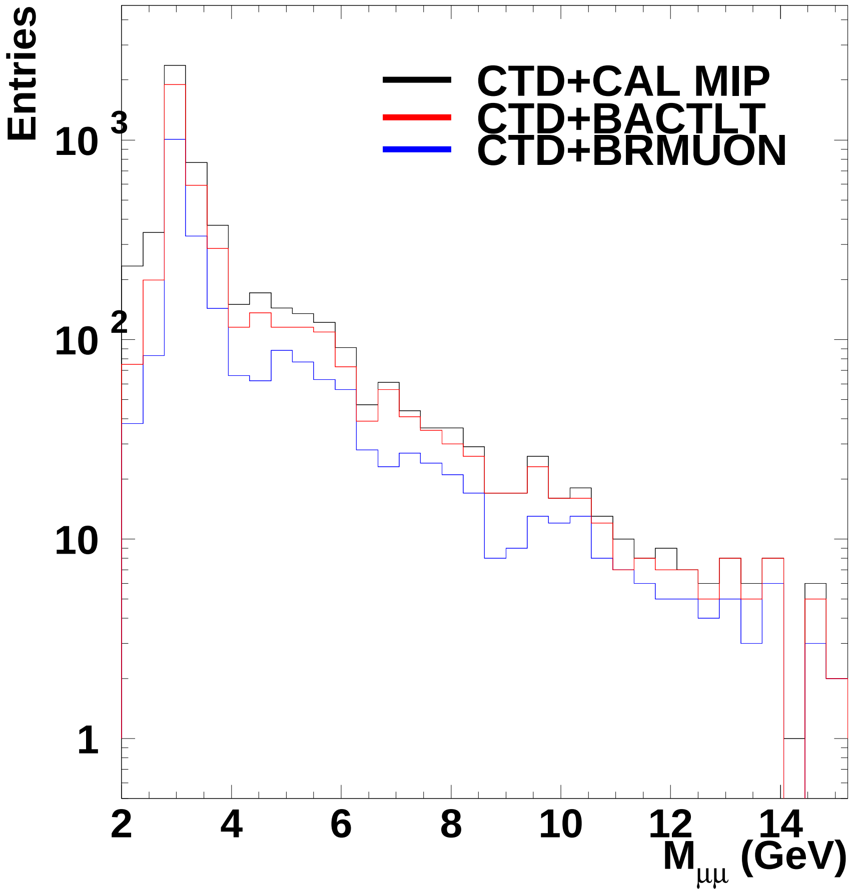
Invariant Mass inc. low momentum muons

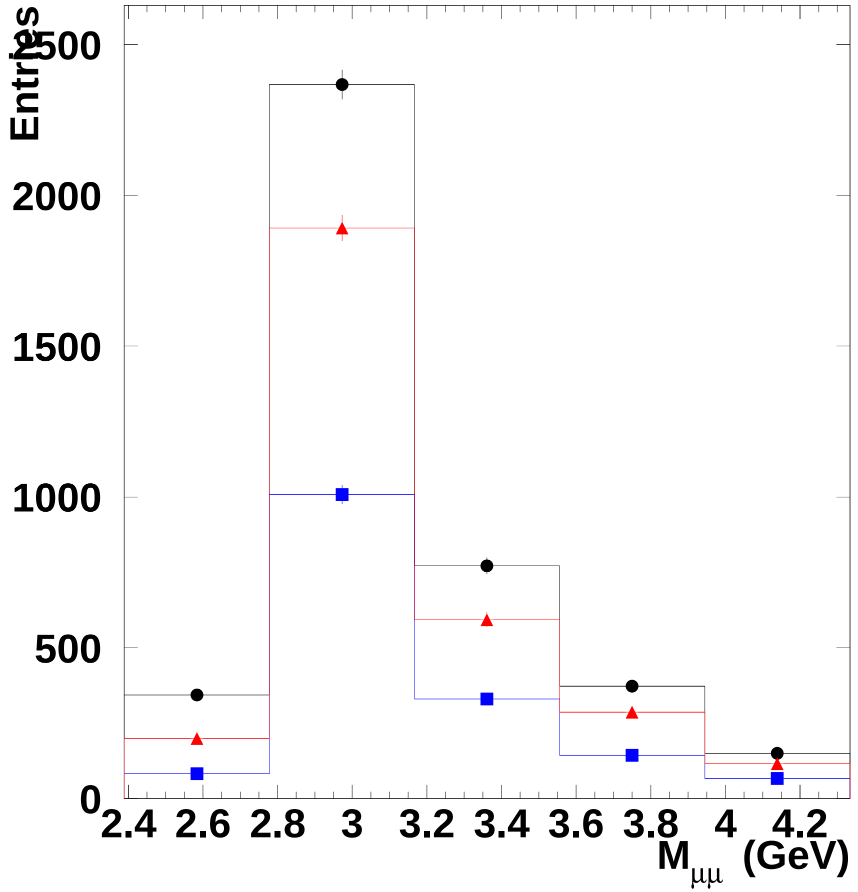




- Di-muon invariant mass spectrum and J/Ψ, Ψ' zoom
- Low momentum muons do not reach BAC...

Invariant Mass, high momentum muons





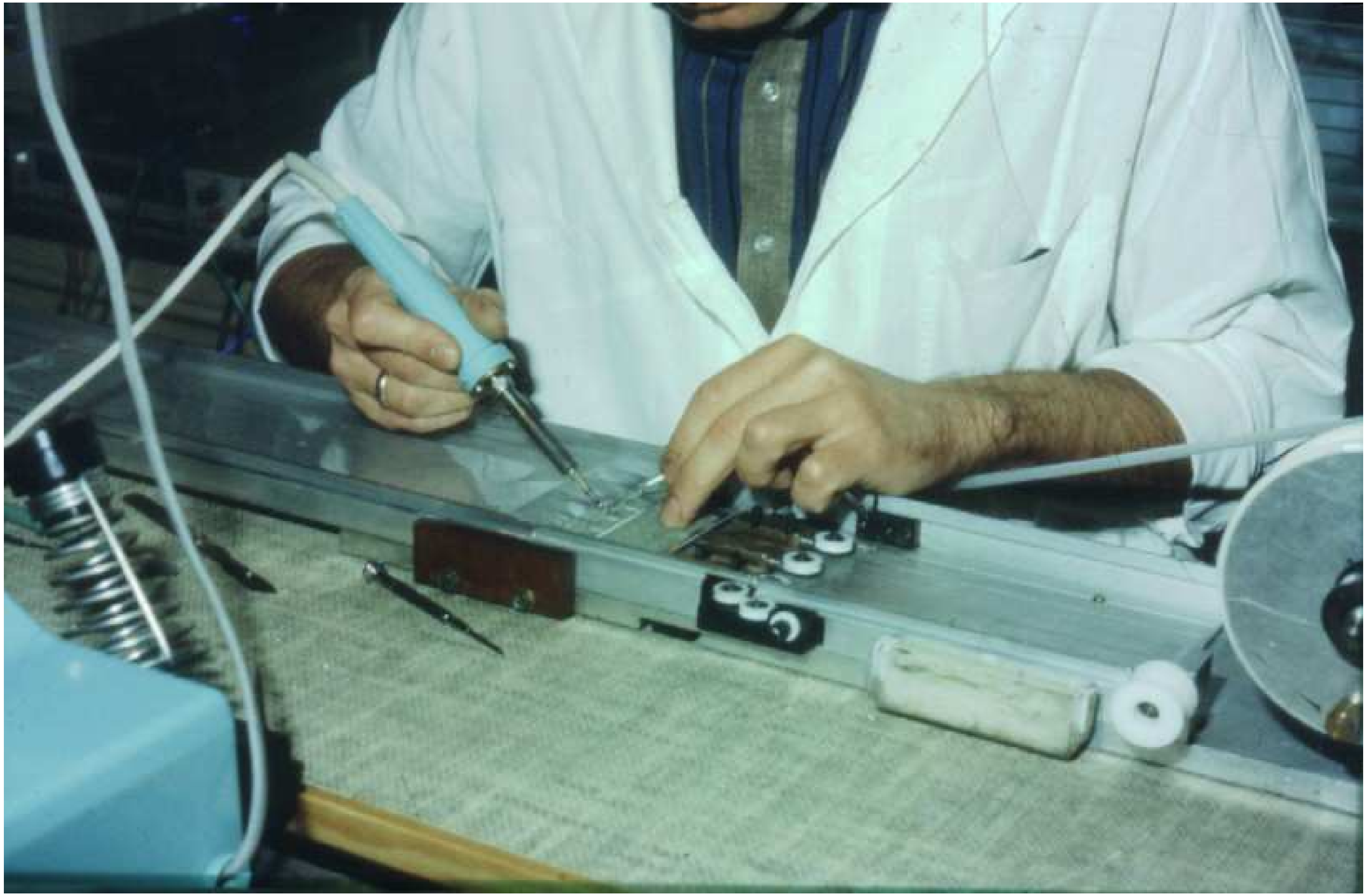
- Di-muon invariant mass spectrum (BH) and J/Ψ, Ψ' zoom
- additional cut: $p_1 > 3\,GeV$ OR $p_2 > 3\,GeV$

The biggest Polish HEP detector: 5500 chambers

- design, R&D
- tests of the prototype
- mass production
- validation/quality monitoring
- installation in ZEUS experimental hall
- electronics design and production (readout, trigger: ~ 200 boards, 18 VME crates)
- slow control (LV, HV, monitoring,...)
- gas system (60 m^3 $Ar + CO_2$)
- software: on-line, off-line
  - data acquisition
  - reconstruction
  - Monte Carlo simulation
- continuous 15 years support, servis, running... (on-site and remote experts)

BAC chambers assembling in Warsaw

Wires stretching



BAC prototype tests at CERN

Final tests in TASSO hall at DESY

Kraków AGH contribution

- Kazimierz Jeleń
- Tadeusz Kowalski
- Juliusz Zając
- Elżbieta Rulikowska-Zarębska
- Bogusław Bednarek
- Stefan Koperny
- Franciszek Jędrzejowski
- Wiesław Filipek
- Witold Machowski
- Andrzej Bolewski
- Mirosław Bobrowski
- Dorota Słonimska
- Karol Musiał
- Stanisław Cyganik
- Mieczysław Despet
- Andrzej Ochoński
- Wiesław Szymański
- Stanisław Sroka
- Andrzej Leszczyński
- Ryszard Tomasik
- Jan Jerzykowski
- Antoni Ostrowski
- Bogusław Prochal
- Mirosław Zimnoch
- Bartosz Mindur
- Marcin Deptuch

Warszawa UW, IPJ (+ Łódź), Politechnika Warszawska

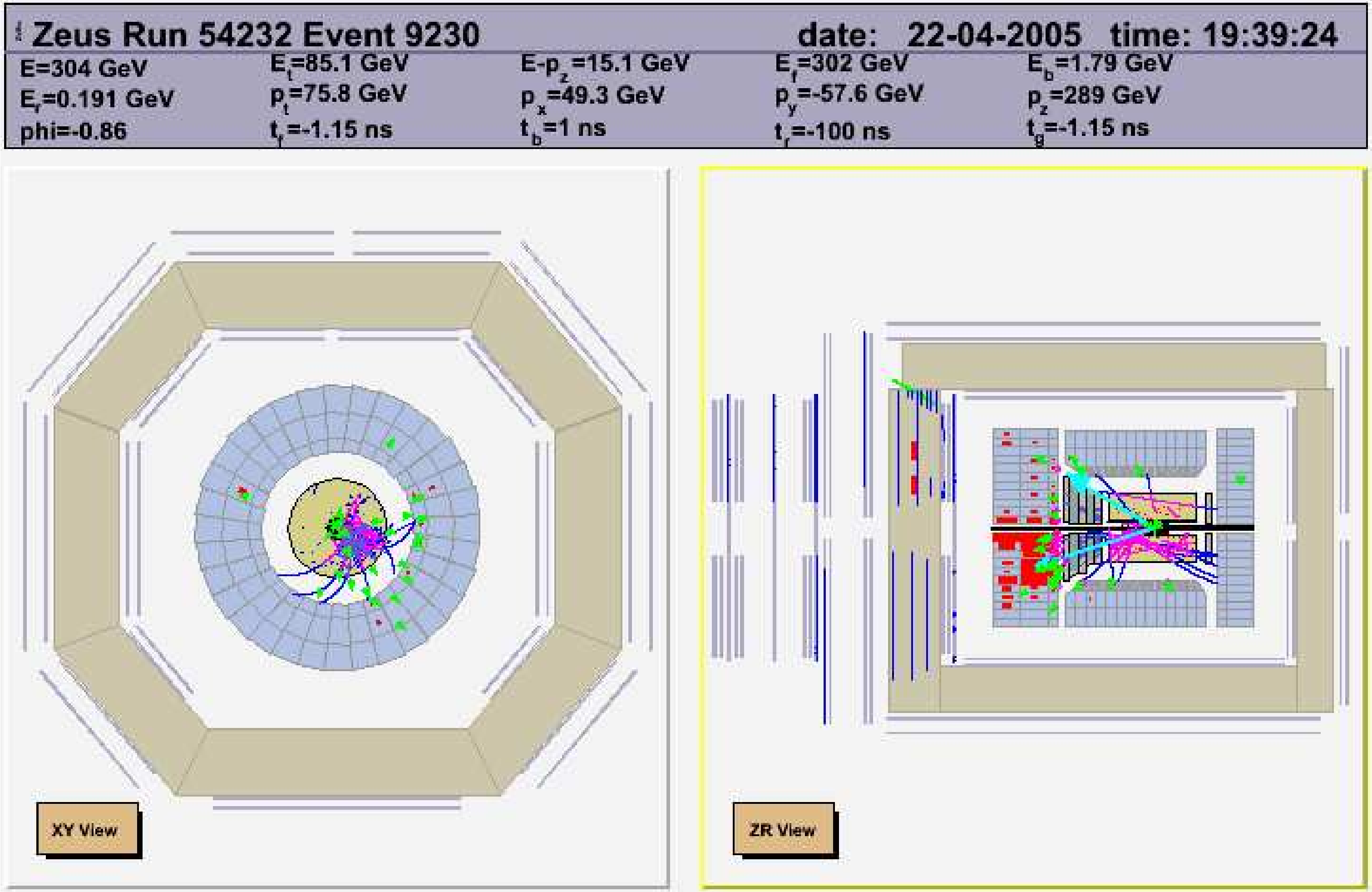
- Janusz Zakrzewski
- Roman Walczak
- Halina Abramowicz
- Roman Szwed
- Jecek Gajewski
- Michał Pawlak
- Ksawery Stojda
- Maciej Kudła
- Andrzej Derlicki
- Waldemar Kuśmierz
- Grzegorz Wrochna
- Andrzej Stopczyński
- Krzysztof Genser
- Dorota Genser
- (...)
- Marek Hamela
- Ryszard Dąbrowski
- Zdzisław Mazur
- Henryk Czyrkowski
- Wiesław Martynow
- Zbigniew Sałapa
- Krzysztof Kierzkowski
- Jarosław Milewski
- Michał Pietrusiński
- Marcin Gromisz
- Rafał Pietrak
- Maciej Krzyżanowski
- Krzsztof Muchorowski
- Michał Kasprzak
- Roman Karpiuk
- Jacek Ciborowski
- Filip Żarnecki
- Roman Nowak
- Marek Adamus
- Grzegorz Grzelak
- Paweł Pluciński
- Radomir Kupczak
- Krzysztof Poźniak
- Tomasz Jeżyński
- Marzena Gawor
- Grzegorz Bałuka
- (...)
- Radek Pawlak
- Marek Bukowy
- Jacek Pliszka
- Barbara Smalska
- Robert Ciesielski
- Jolanta Sztuk
- Justyna Ukleja
- Paweł Łużniak
- Łukasz Ślusarczyk
- Paweł Kuliński
- (...)

Podsumowanie

- BAC po 15 latch pracy nadal jest w bardzo dobrej formie:
  - znikome efekty starzeenia się komór
  - niska awaryjność elektroniki
- Pomyślne wdrożenie układu wyzwalania na 3 poziomach
- Wysoka efektywność układu wyzwalania BAC
- Problemy z serwisem tylnej części detektora
- Przed nami jeszcze ok. $200\,pb^{-1}$ (do lipca 2007) z aktywnym udziałem BAC'u

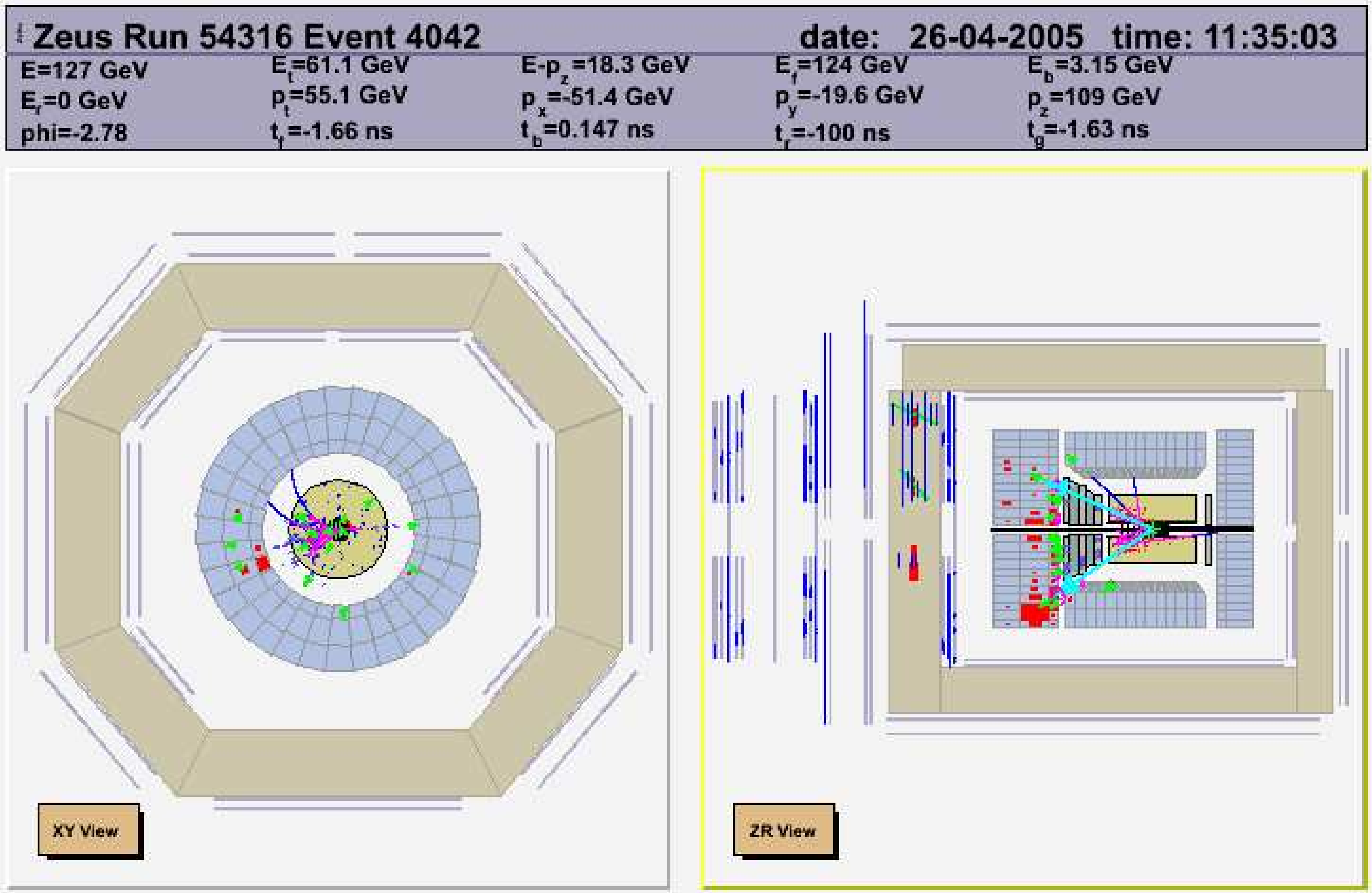
Paris: Rue du BAC :)

High p_T isolated muons



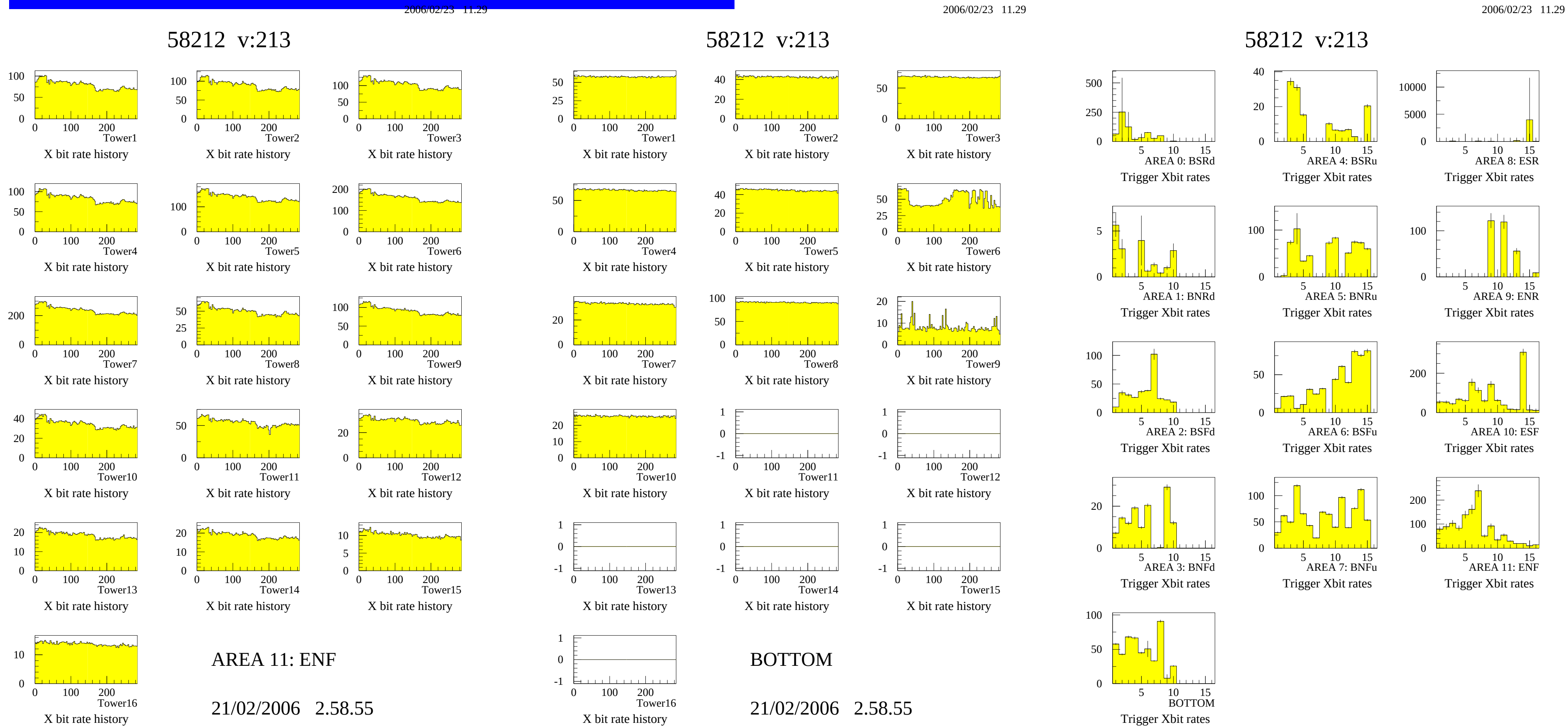
- $W \to \mu + \nu$ candidate ?

High p_T isolated muons



- $W \to \mu + \nu$ candidate ?

BAC diagnostic: generation of DAQ setup data



- Trigger rates vs. time for selected towers, mean rates for selected Areas
- BAC_DIAG: hardware tests, threshold tuning, setup data generation

BAC FLT/SLT/TLT Slots Definition

```
------------------------------------------------------------------
FLT_FBAC_only  : <-- control/monitoring slot
FLT_BRBAC_only : <-- control/monitoring slot
..................................................................

FLT_FBAC       : FBAC*HAC*gTRK*Et*Bg_v
FLT_BRBAC      : BRBAC*CAL*vldgTRK*Bg_v

SLT_FBAC       : FLT_FBAC*Vertex
SLT_BRBAC      : FLT_BRBAC*BARREL_Timing_up_down_OK

TLT_FBAC  ISO  : TLT_FBAC * CAL_MIP_match * CTD_match, p >2.0 GeV
TLT_BRBAC ISO  : TLT_BRBAC* CAL_MIP_match * CTD_match, pt>1.5 GeV

TLT_FBAC HI-PT : TLT_FBAC * CTD_match, p >4.0 GeV
TLT_BRBAC HI-PT: TLT_BRBAC* CTD_match, pt>4.0 GeV

TLT_DI-MUON    : 2 TLT_BAC muons, CTD match, m_inv>2.5 GeV
------------------------------------------------------------------
```

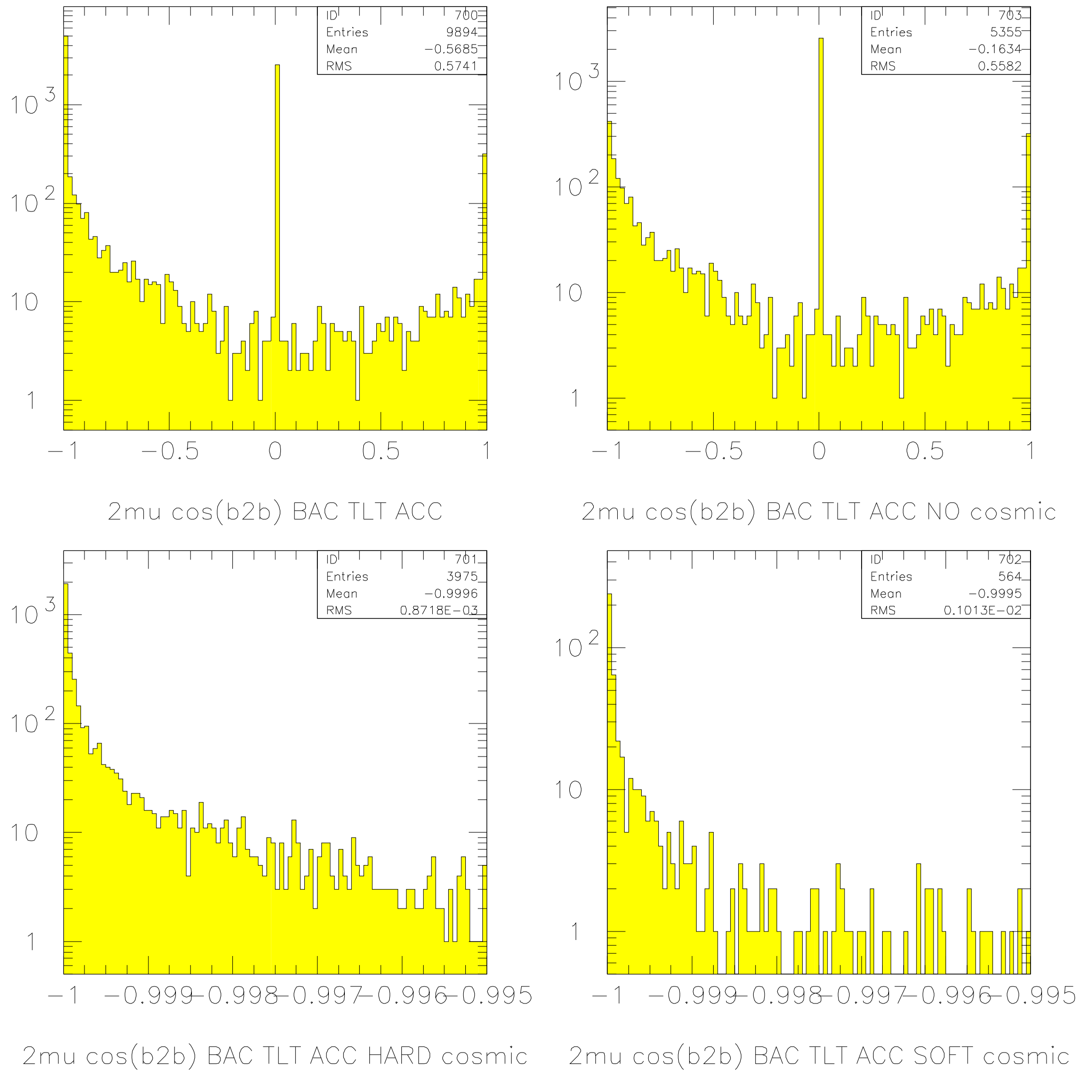
TLT Cross sections, number of events

```
------------------------------------------------
RUN 57120, L=401.84 nb^-1 N_TOT_EVT = 268254
------------------------------------------------
sig_tot = 667 nb

BAC TLT MUO11/12 online cross sections:

sig_BAC =  25 nb 3.7% of total (MUO slots)
sig_BAC =  17 nb 2.5% of total (Unique)
------------------------------------------------
NOTE: number before COSMIC rejection
```

BAC TLT ISO MUONS, anti-cosmic cuts run 57120



- $cos(back - to - back - angle)$ for all BAC TLT events (#evt. 9894)
- after cosmic rejection (#evt. 5355)
- $cos() = 0$ for single muon events
- zoom around $cos() = -1$ for HARD and SOFT COSMIC muons

BAC ISO MUON rate reduction by ∼50%