RPC PAC muon trigger of the CMS detector

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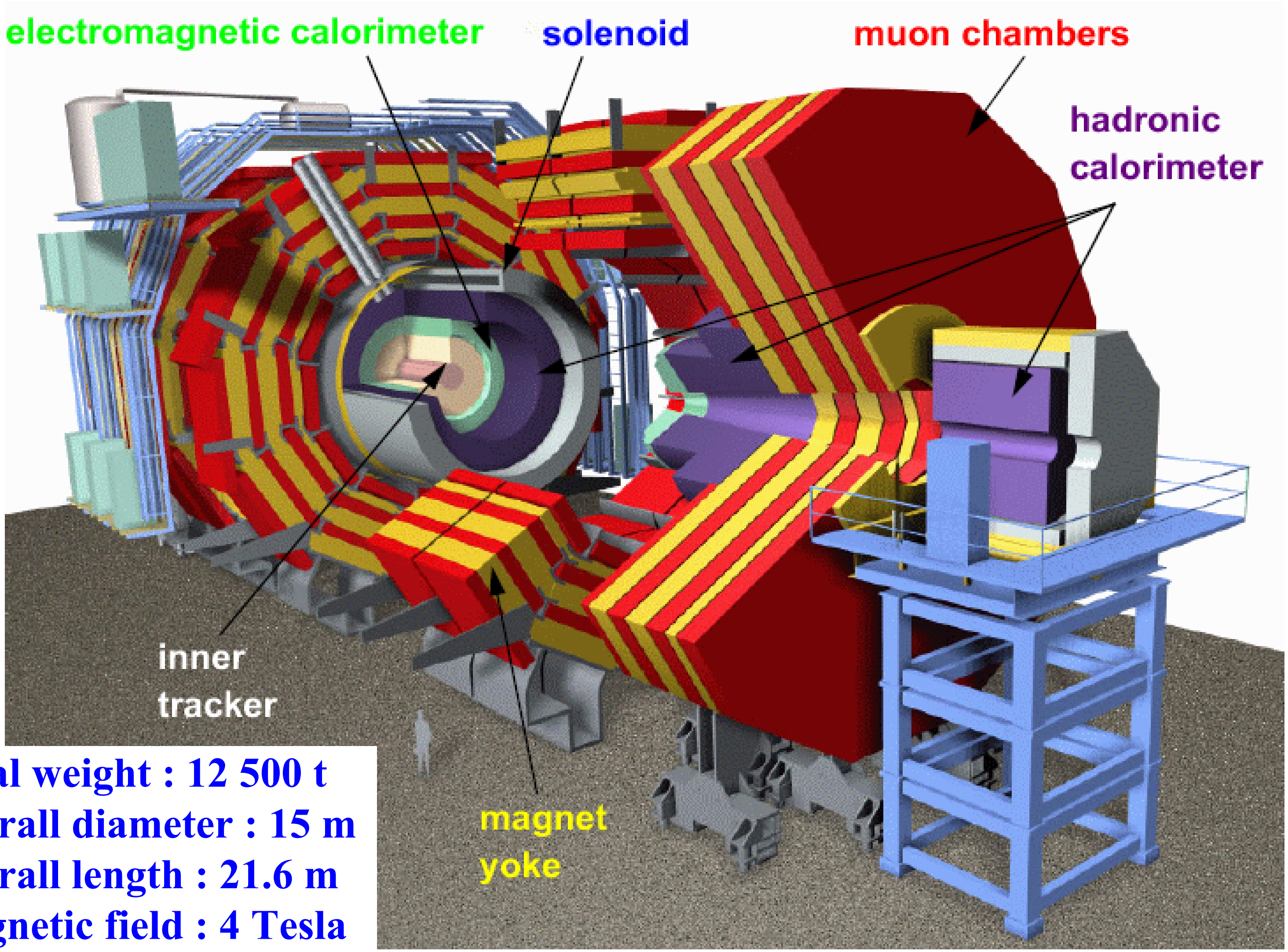
Physics at Future Colliders, January 11, 2006

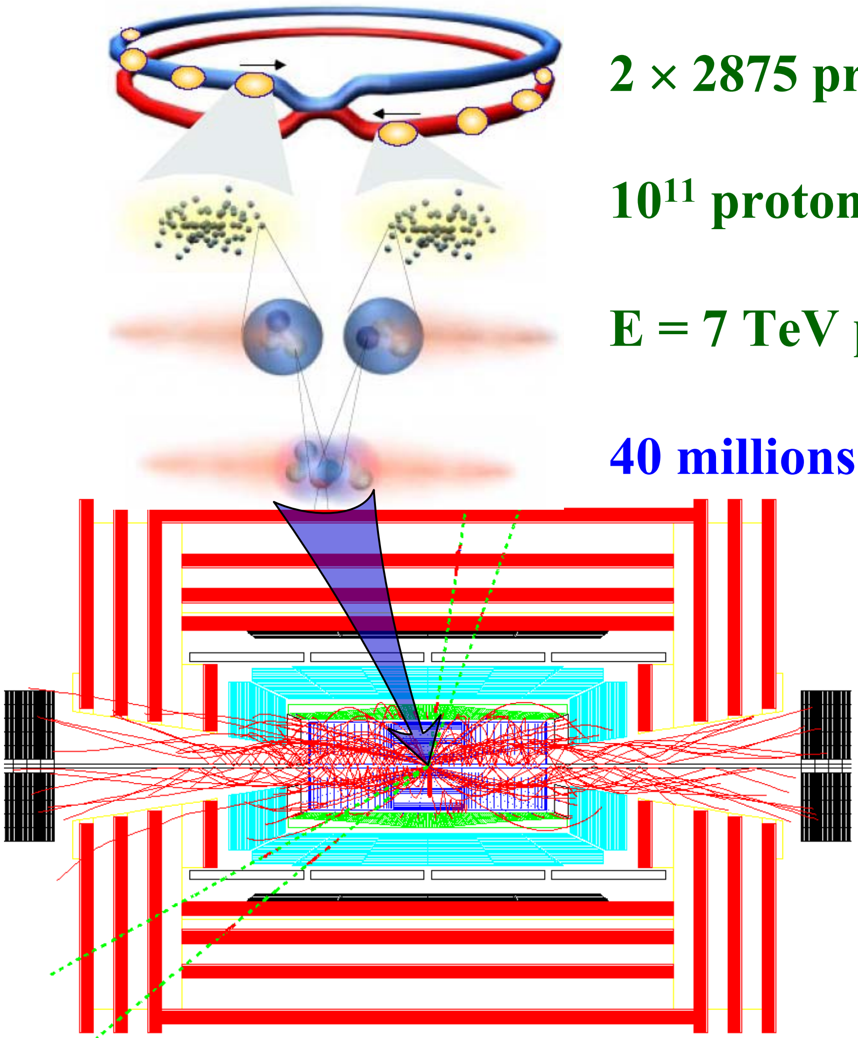
CMS - Compact Muon Solenoid



Total weight : 12 500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

Need for trigger

LHC



2 × 2875 proton bunches

10^{11} protons / bunch

E = 7 TeV per proton

40 millions of bunch crossing /s

~ 20 proton-proton interactions each **25 ns**,

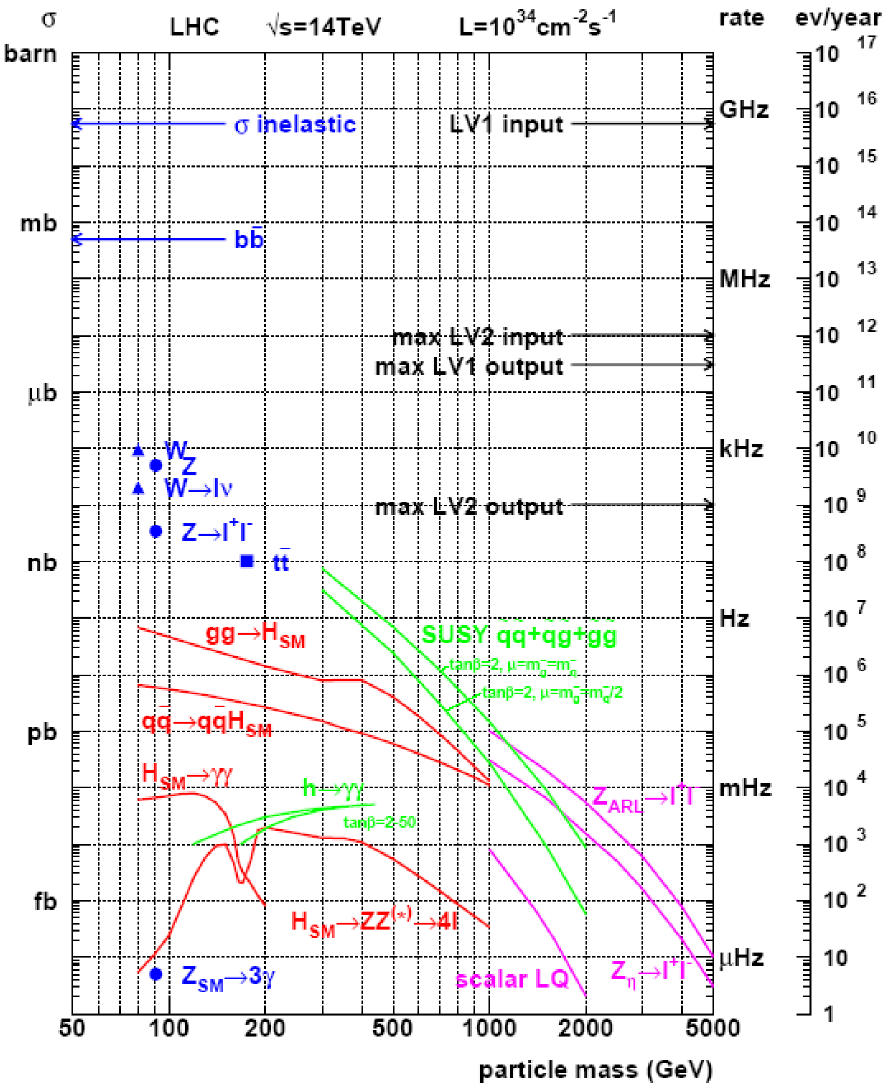
resulting in hundredths of particles

Detector response **~1 MByte** of data
(after zero suppression)

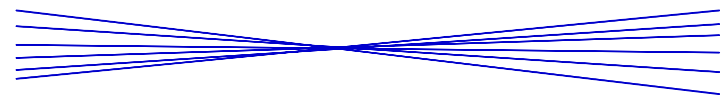
⇒ 4 × 10^{13} Bytes (4000 GB) / s

<u>Not possible to record!!!</u>

Need for trigger (2)



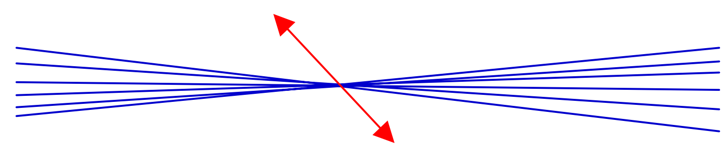
But most of events is not very interesting (classical physic)



Signature: low transverse momentum (p_T)

We are looking for **very rare events** in which **heavy particles** were produced

Decay into high energy objects (hardronic jets, leptons, photons)



Signature: high transverse momentum (p_T)

CMS/LHC Trigger Physics

Standard model Higgs (high luminosity)
- H (80 GeV) → γ γ
- H (120 GeV) → Z Z* (4 leptons)
- H (>500 GeV) → leptons (+ ν's)
- H (< $2M_W$ Associated t or W or Z) → b b (lepton + X)

SUSY Higgs (low luminosity)
- (standard model Higgs like channels)
- h, H, A → τ τ (lepton + X) or → μμ
- A → Z h ; h → bb (lepton + X)
- p p → t t X; t → H^+ b; H^+ → τ μ; t → lepton + X; τ → X

SUSY sparticle searches (low luminosity)
- MSSM sparticle → LSP (Missing E_t) + n jets
- MSSM sparticle → Same sign dileptons + X

Other new particles
- Z' → dileptons
- Leptoquarks: dileptons

Top physics (low luminosity)
- t → lepton + X
- t → multijets

Bottom physics (low luminosity)
- b → lepton + X
- b → ψk_s (leptons + X)

QCD
- Low luminosity 100 GeV jets
- High luminosity 200 GeV jets

⇒

L1 Trigger objects requirements:

- **High luminosity (10^{34} $cm^{-2}s^{-1}$):**

  e/γ (30 GeV), ee/γγ (15 GeV)

  μ (20 GeV), μμ (5 GeV)

  missing E_T (100 GeV),

  jets (200 GeV)

- **Low luminosity (10^{33} $cm^{-2}s^{-1}$):**

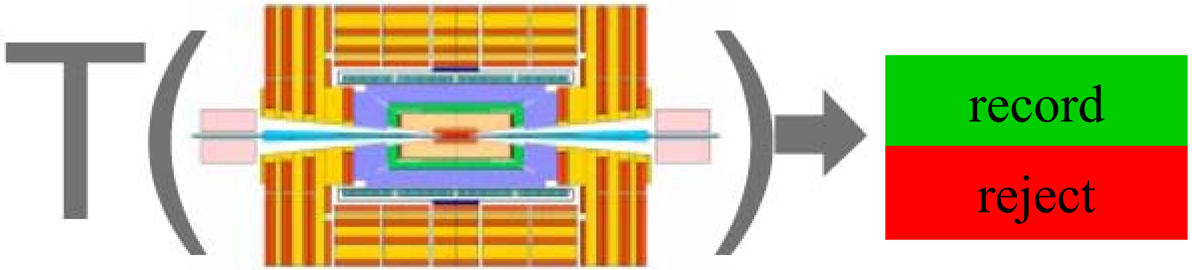
  e/γ (15 GeV), ee/γγ (10 GeV)

  μ (14 GeV), μμ (3 GeV)

  missing Et (50 GeV)

  jets (100 GeV)

Trigger System



Evaluates the data of every event

and decides whether

record the event data to the mass storage

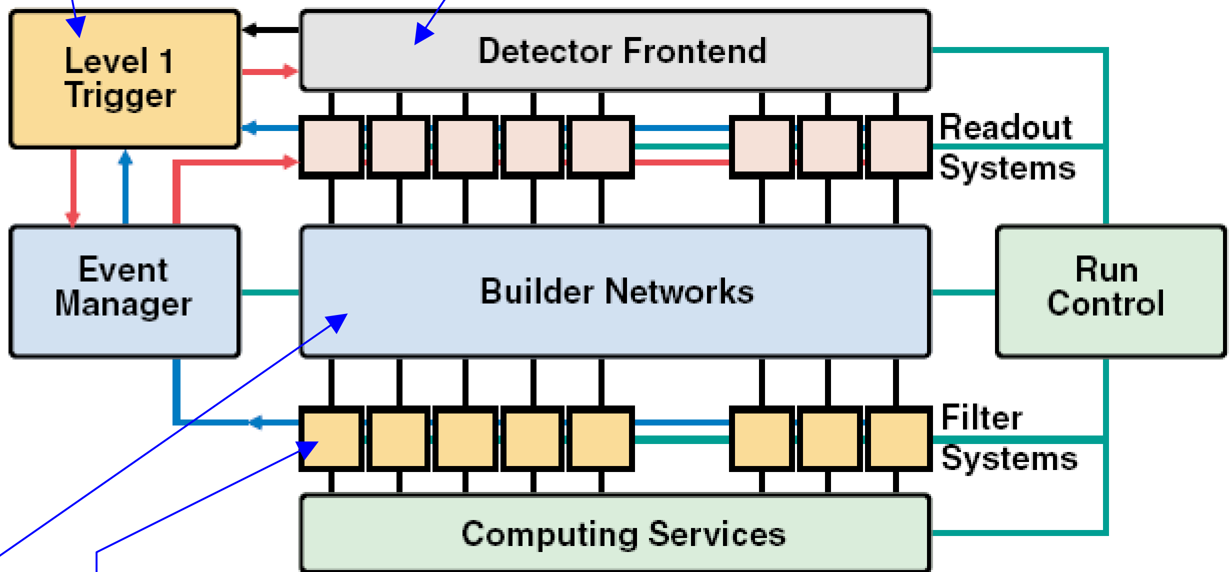
or reject it

CMS Trigger and Data Acquisition System

Level 1 Trigger
- Custom electronic @ 40 MHz
- every event is analyzed
- ⇒ pipeline processing – total latency 3.2 μs, including ~2 μs for data transmission

Output ≤ 100 kHz

Readout buffers
128 event deep = 3.2 μs

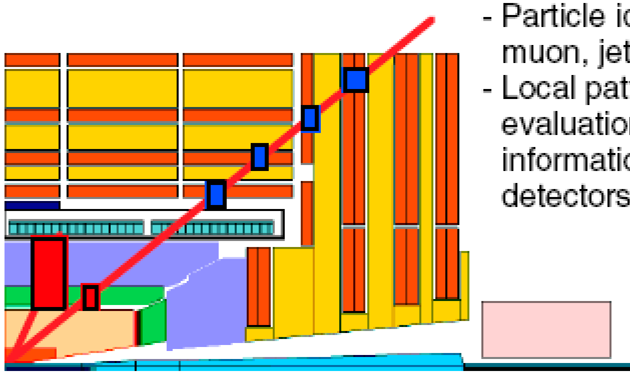


Event Builder
- switching network (512 to 512 ports)
- total throughput of approximately 500 Gbit/s

High level triggers
- Farm of ~1000 commercial PCs running data selection algorithms – effectively on-line data analysis
- Reduces rate from 100 kHz **to 100 Hz,** for storage on tape

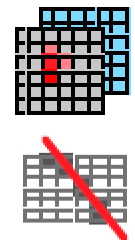
CMS Trigger overview

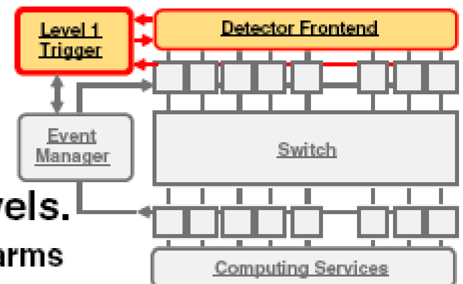
40 MHz



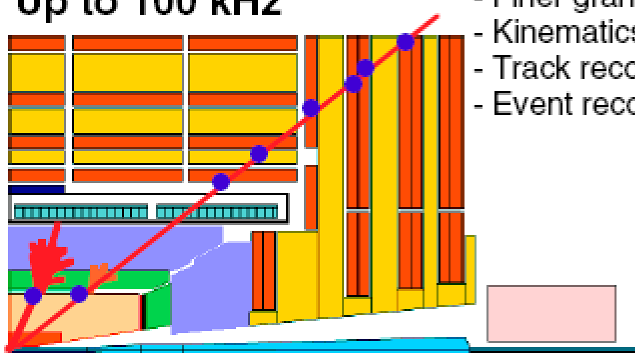
Level-1. **Specialized processors**

- Particle identification: high p_T electron, muon, jets, missing E_T
- Local pattern recognition and energy evaluation on prompt macro-granular information from calorimeter and muon detectors





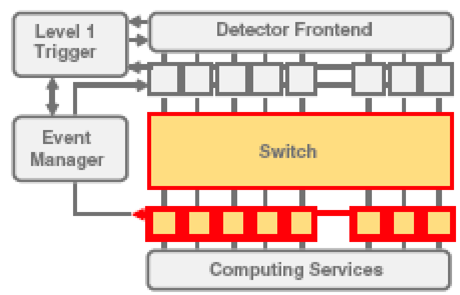
Up to 100 kHz



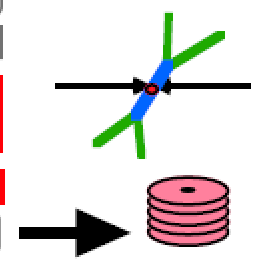
High trigger levels.

Network and CPU farms

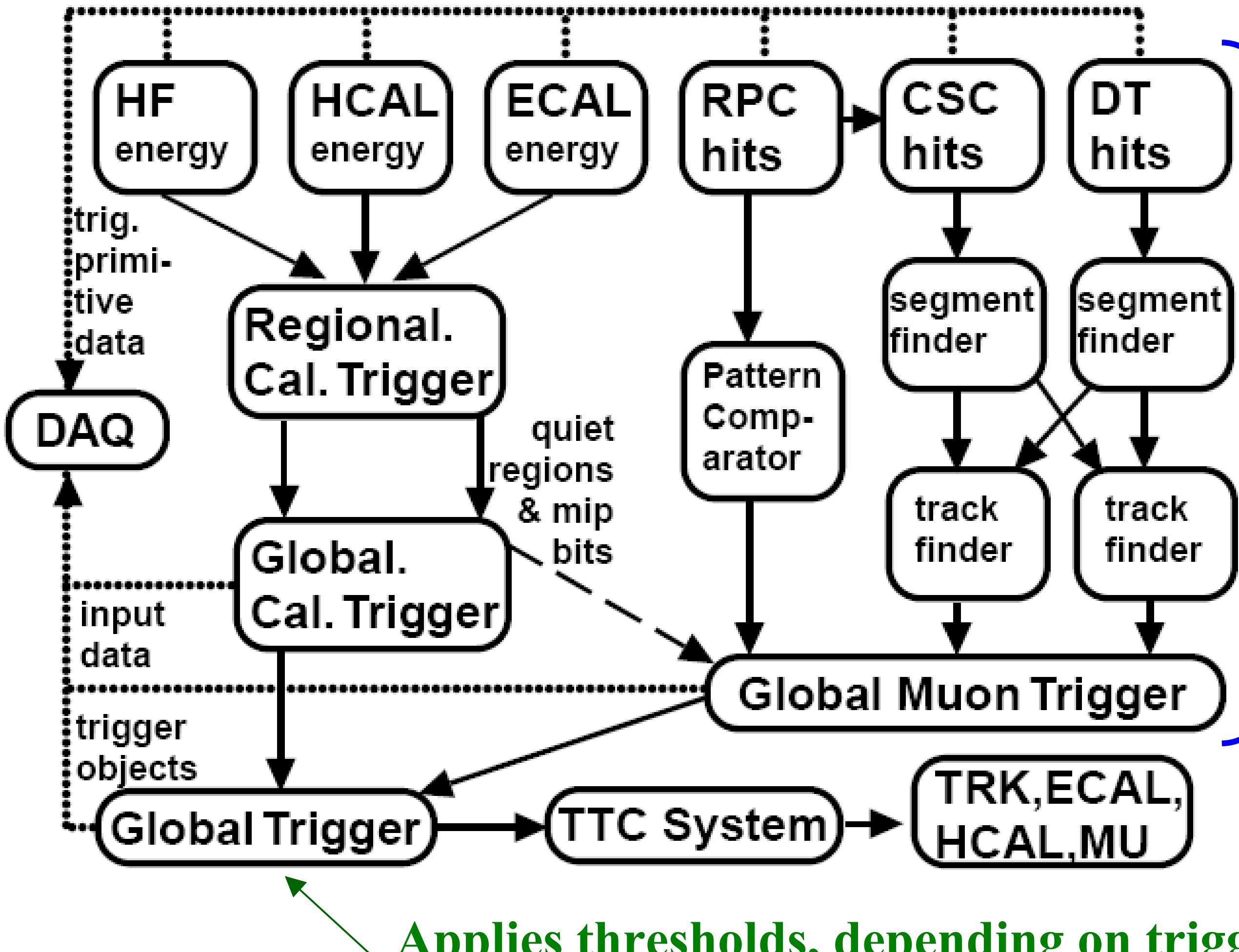
- Clean particle signature
- Finer granularity precise measurement
- Kinematics. effective mass cuts & event topology
- Track reconstruction and detector matching
- Event reconstruction and analysis



≈ 100 Hz



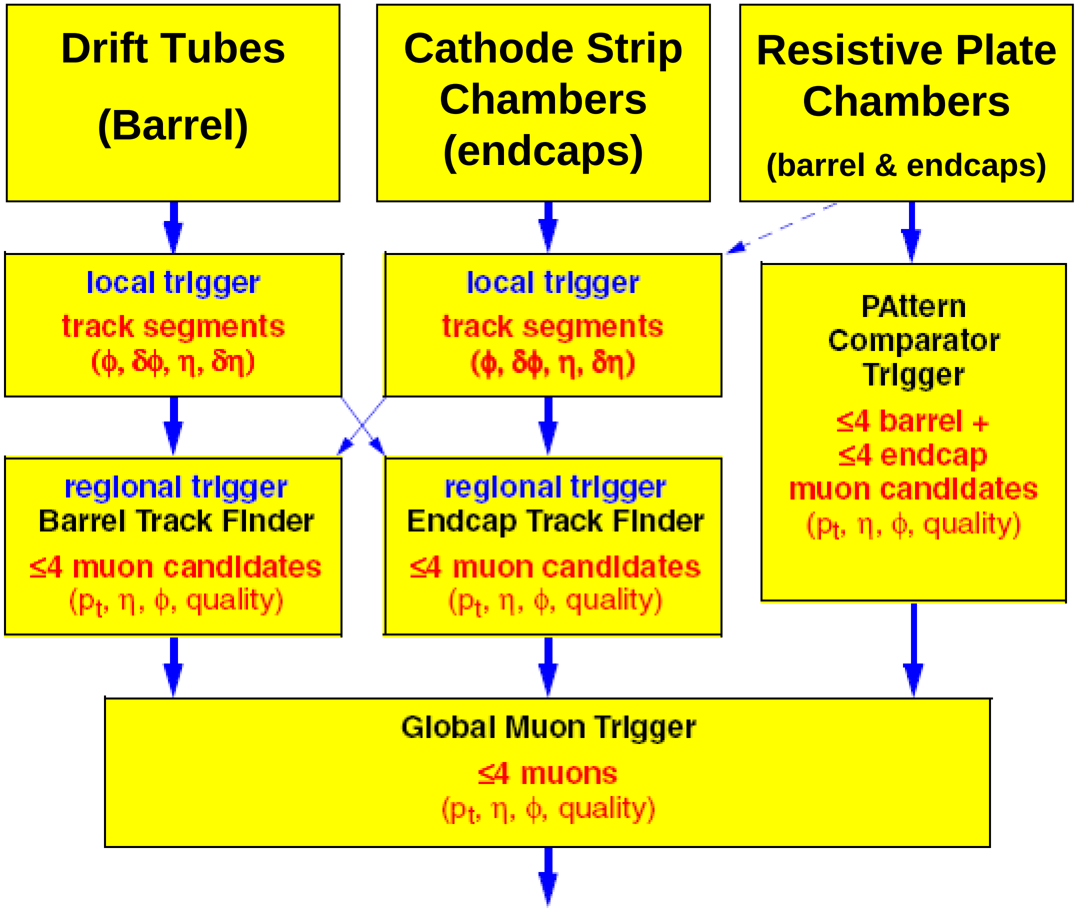
Overview of Level 1 Trigger



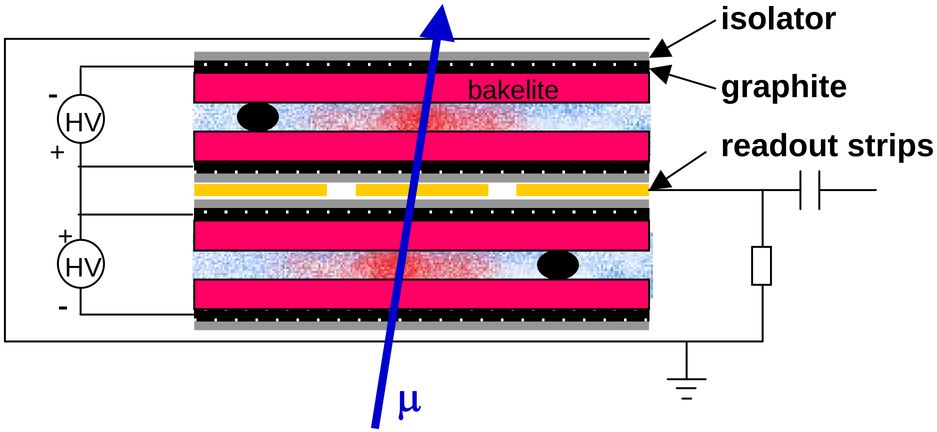
Trigger subsystems
search for trigger objects,
rank them and sort

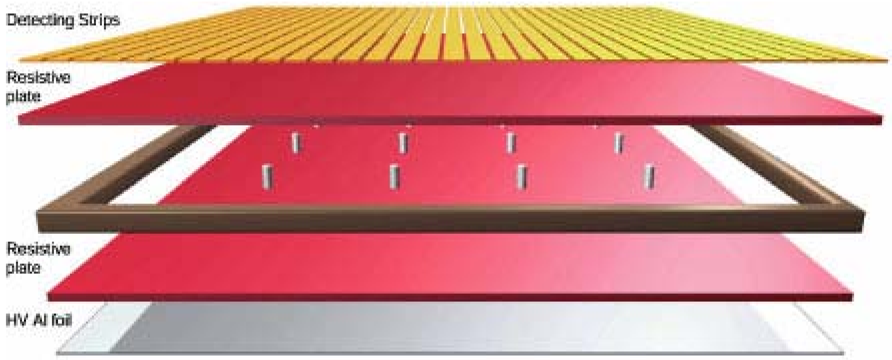
Applies thresholds, depending on trigger objects localization and coincidence

Muon Trigger Overview



RPC - Resistive Plate Chambers

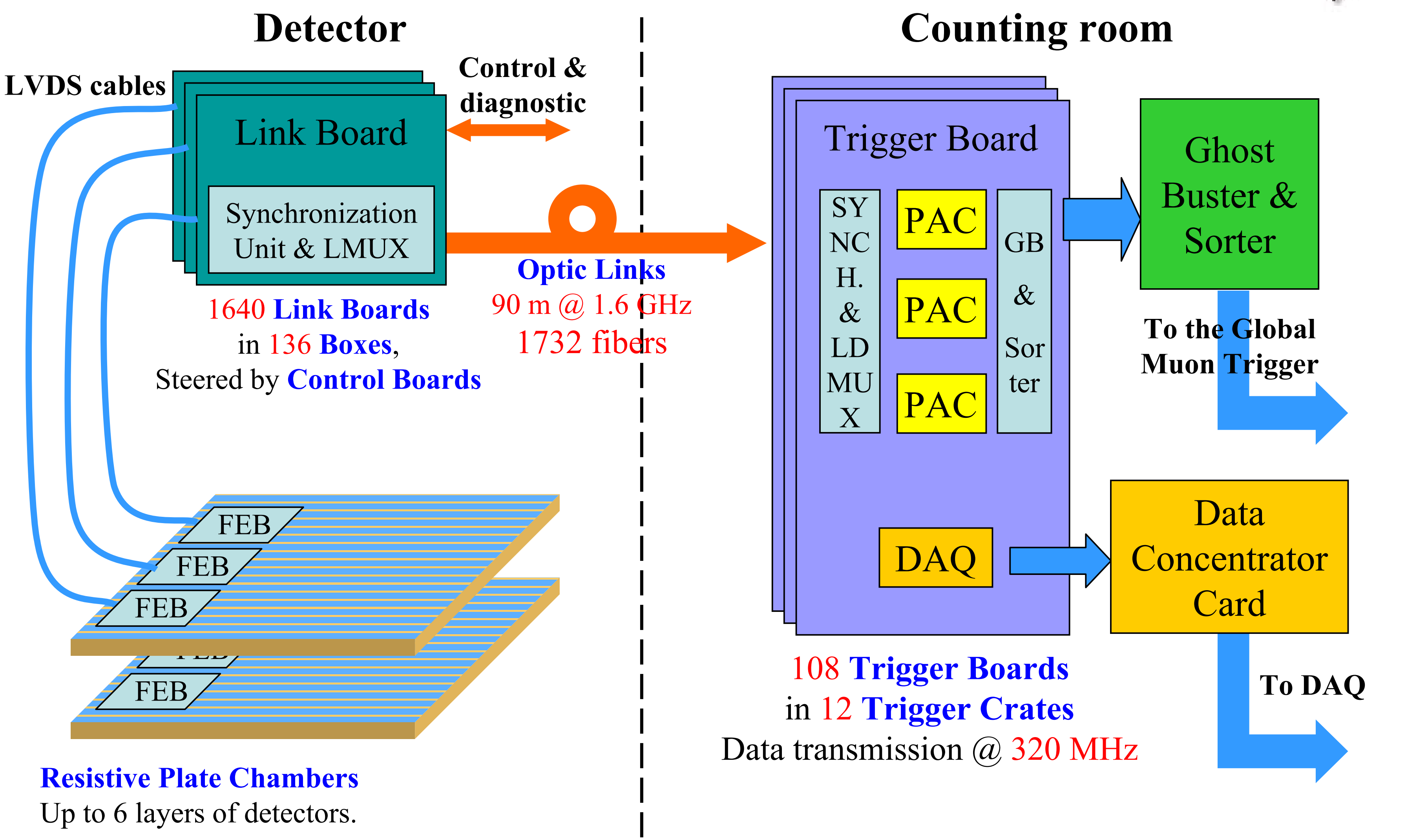




Gaseous, fast detectors, optimized for muons measurements

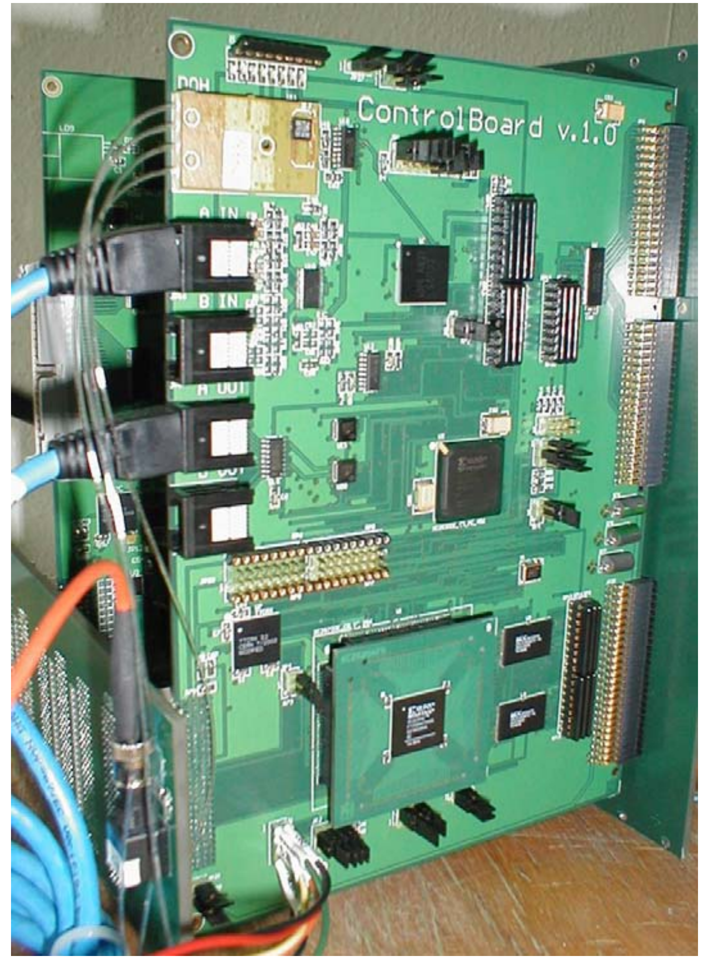
- Gas gap thickness: **2 mm**
- Readout Strips:
  pitch: 0.5 – 4 cm,
  length: 20 -100 cm
- High Voltage ~ **9.5 kV**
- Gas mixture: 96.2% $C_2H_2F_4$, 3.5% isoC_4H_{10}, 0.3% SF_6
- **Time resolution ~ 1 ns**
- **Efficiency > 95%**
- **Noise ~5 Hz cm²**

RPC PAC Muon Trigger overview



Preproduction versions of boards are tested now!

Trigger Board



Link Board and Trigger Board

Karol Buńkowski, Warsaw University

RPC PAC Muon Trigger

The system was proposed and designed by Warsaw CMS group

Participants:

Chambers:

Italy, CERN, Korea, Pakistan, China, Bulgaria

Electronic:

Poland (Warsaw), Italy, Finland

System complexity

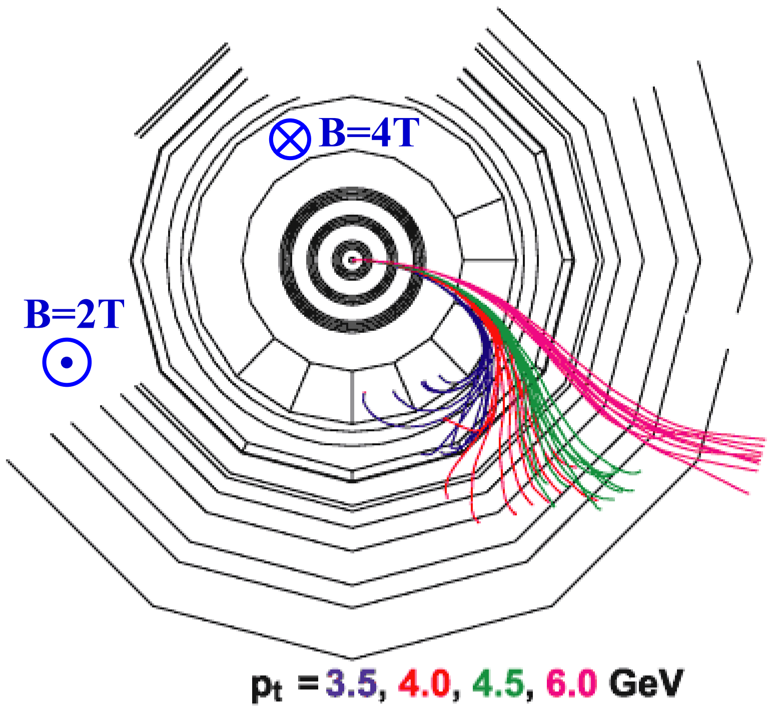
- 2000 chambers of different shape and construction
- 165 000 strips – 1 bit electronic channels
- ~15 types of electronic boards
- ~2 000 pieces of electronic boards
- Synchronous system, working @ 40 MHz
- Most boards programmable
- Most boards controlled by computers
- Kilometers of cables (electrical and optical)

Tasks overview

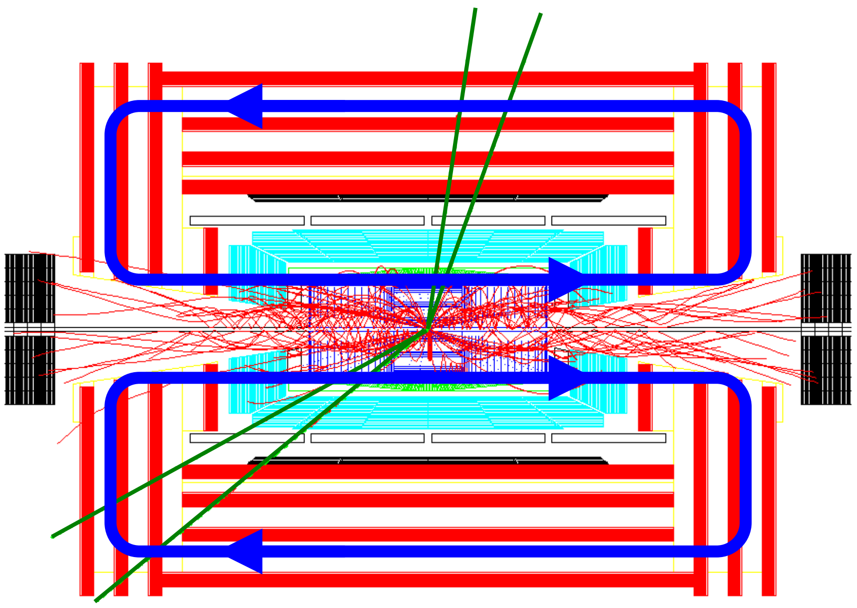
- Chambers production and tests
- Design, production and tests of electronic boards
- <u>Development and tests of FPGA firmware</u>
- Tests of radiation immunity of electronics components
- Configuration, control, monitoring and diagnostic:
  - distributed, multithread computer system
  - data bases: equipment, configuration, condition
  - real-time system performance analysis
- Synchronization: bunch crossing assignment, data stream alignment
- <u>Trigger algorithms development and optimization</u>
- <u>Trigger simulation</u>

Magnetic filed configuration ⇒ RPC strips layout

R- φ plane (perpendicular to the beam line)



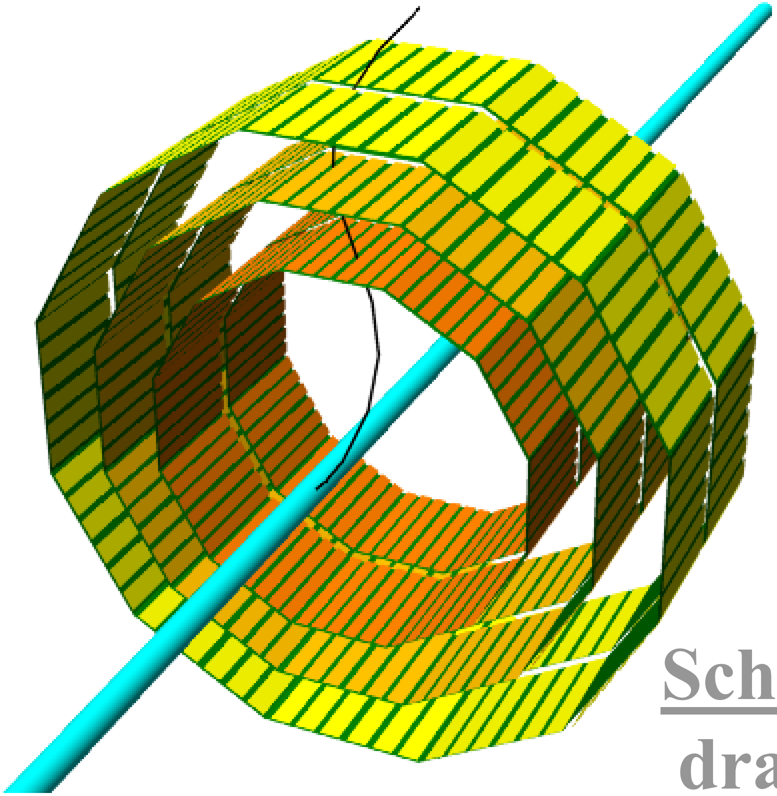
η plane (along the beam line)



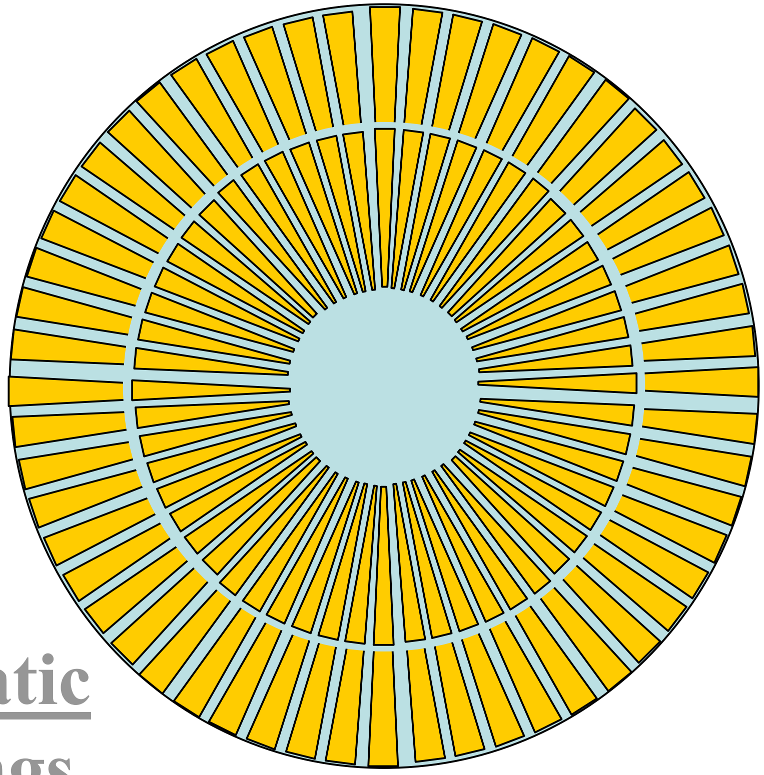
To measure the transverse momentum **R- φ** coordinate must be precisely determined

Magnetic filed configuration
⇒ RPC strips layout

Barrel Wheels



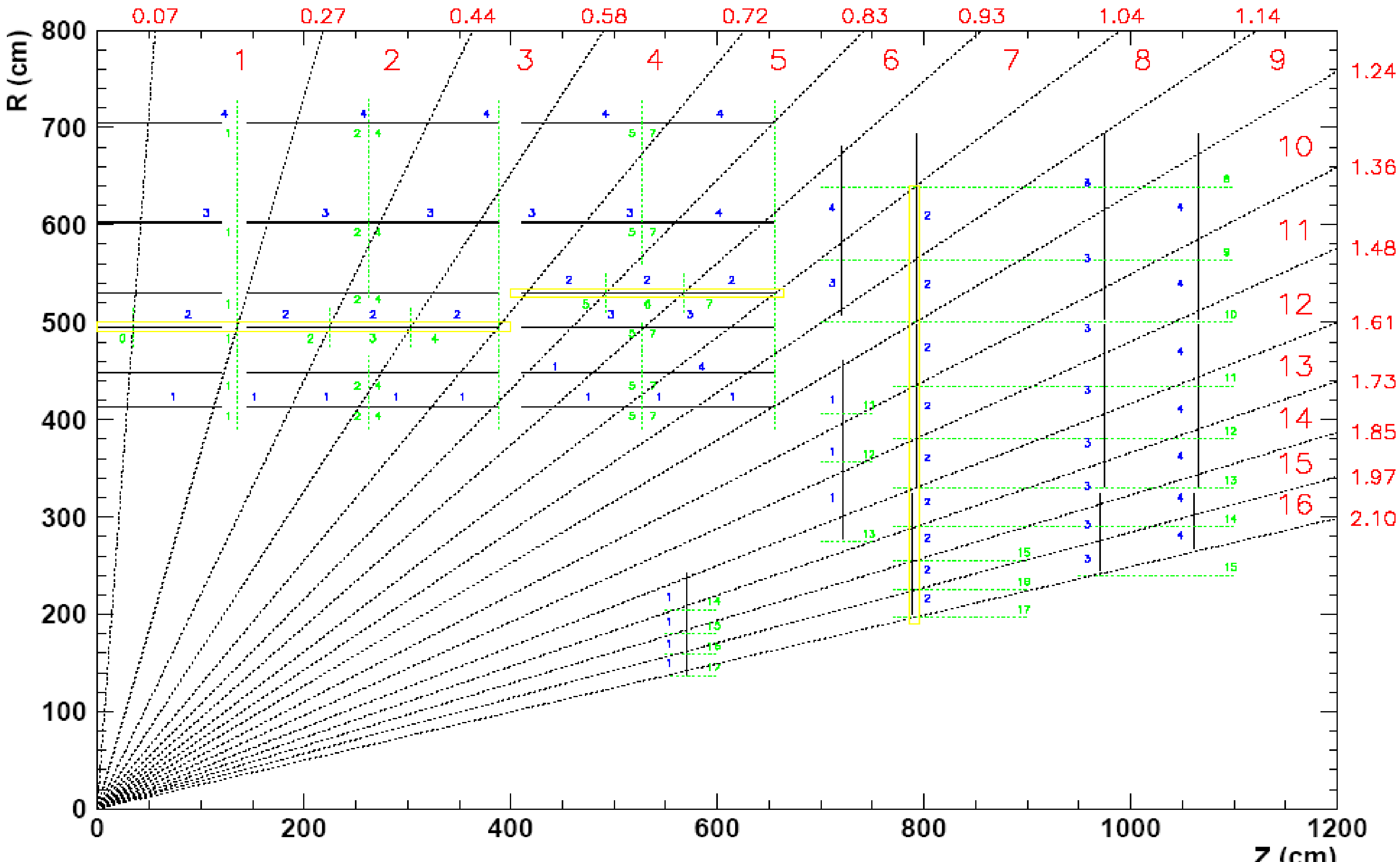
Endcap Disc



Schematic drawings

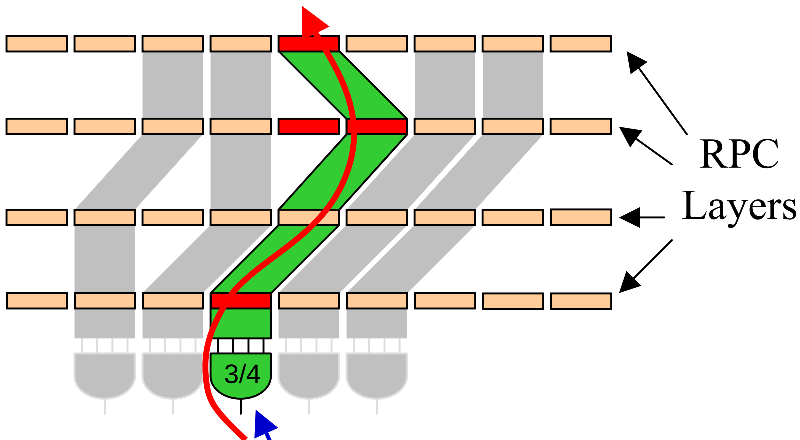
1152 strips in each layer (disc) ⇒ one strip = 0.3125°

RPC Strips η segmentation



RPC Trigger Algorithm: Pattern Comparator (PAC)

Chamber signals are compared to predefined patterns of muon tracks



Required coincidence of hits layers:

- Barrel: **6/6** or **5/6** or **4/6** or **3/4inner** layers
- Endcap: **4/4** or **3/4** layers

Fit pattern gives track's **transverse momentum (p_T)** and **sign**

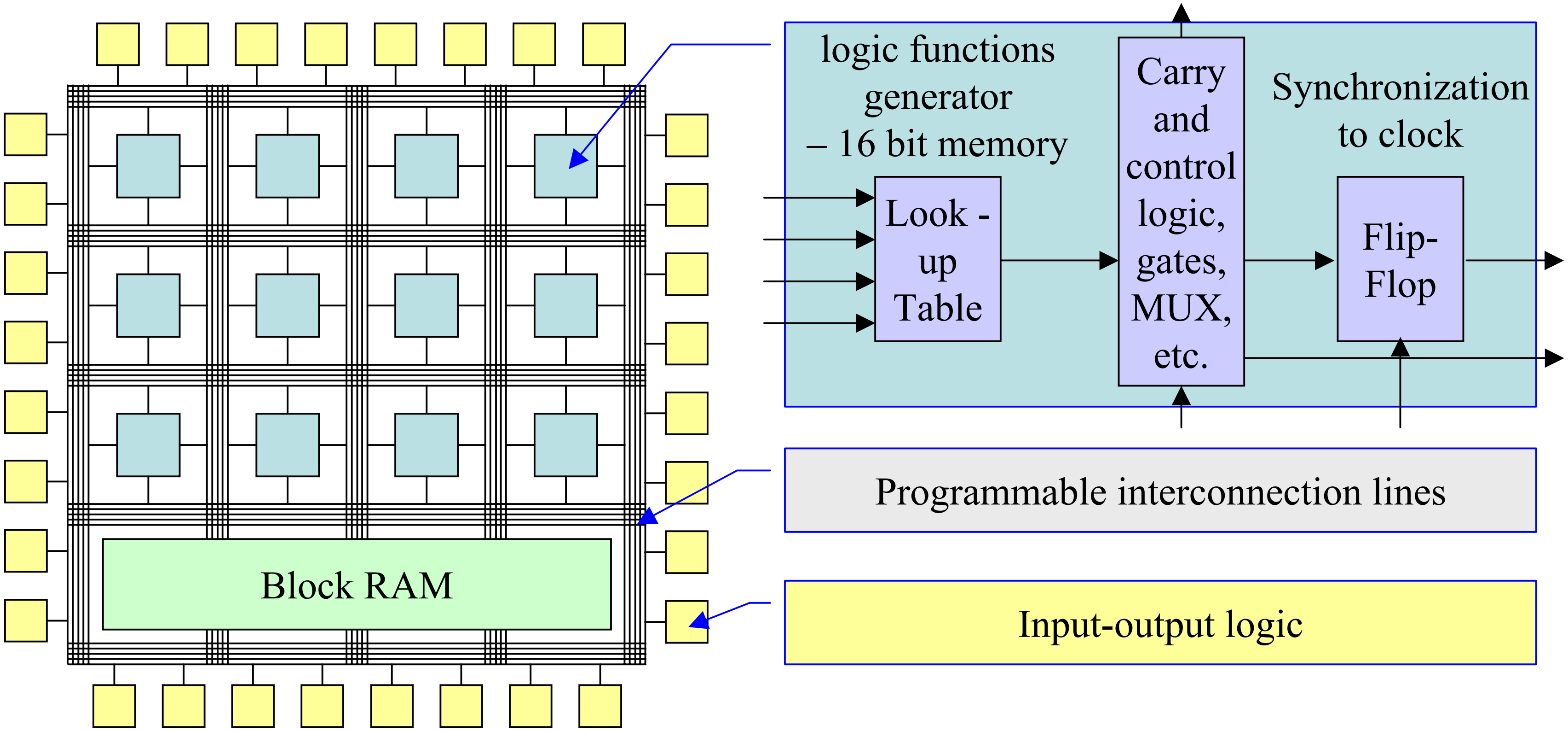
Level of coincidence defines the reconstruction **quality**

In case of algorithm for **6 layers**
22 AND functions have to be detected
for every pattern!

⇒ Very complicated logic

FPGA technology overview

Field Programmable Gate Array – programmable chip



FPGA technology overview

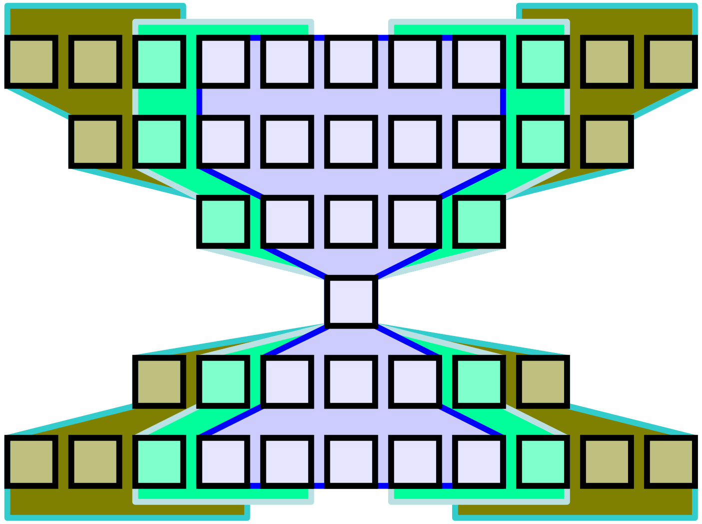
Modern FPGA e.g. **Altera Stratix II** (EP2**S90**F1020C3):

- 72 768 LUTs
- 4.5M of RAM bits (in block of different sizes)
- 902 user I/O pins
- DSP blocks (Digital Signal Processing), embedded multipliers

The logic is programmed in **VHDL** (Very High Speed Integrated Circuits Hardware Description Language)

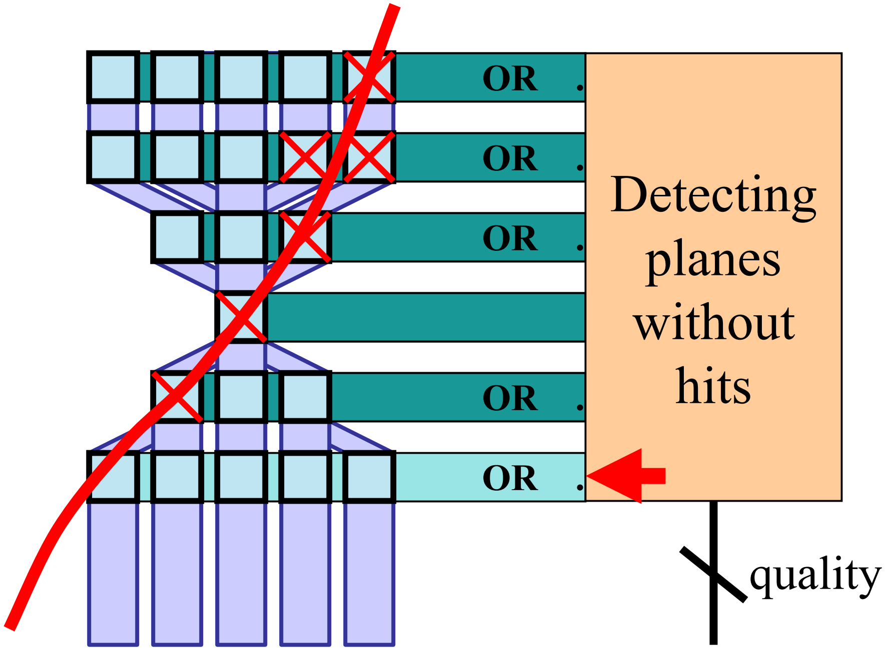
Improved PAC Algorithm - I

1. Patterns with the same p_{Tcode} and sign are grouped together



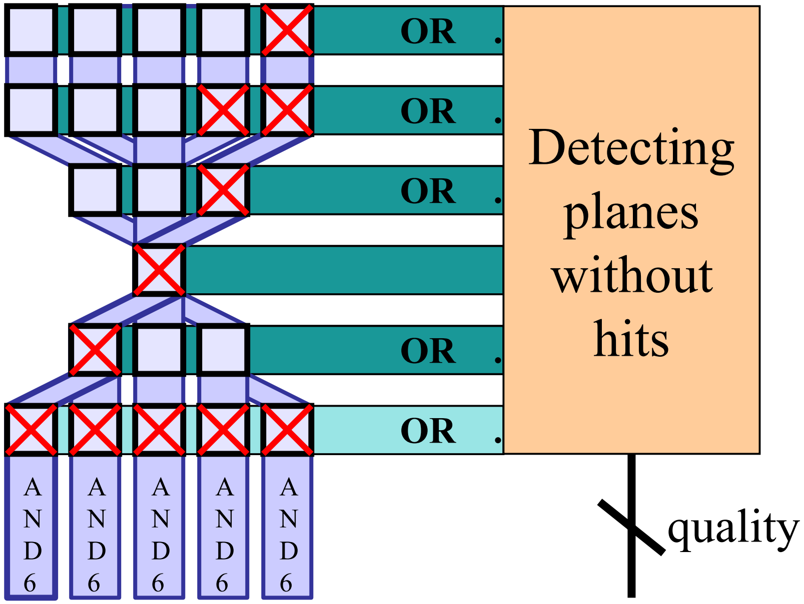
Improved PAC Algorithm - II

2. Detect planes without hits for every patterns group



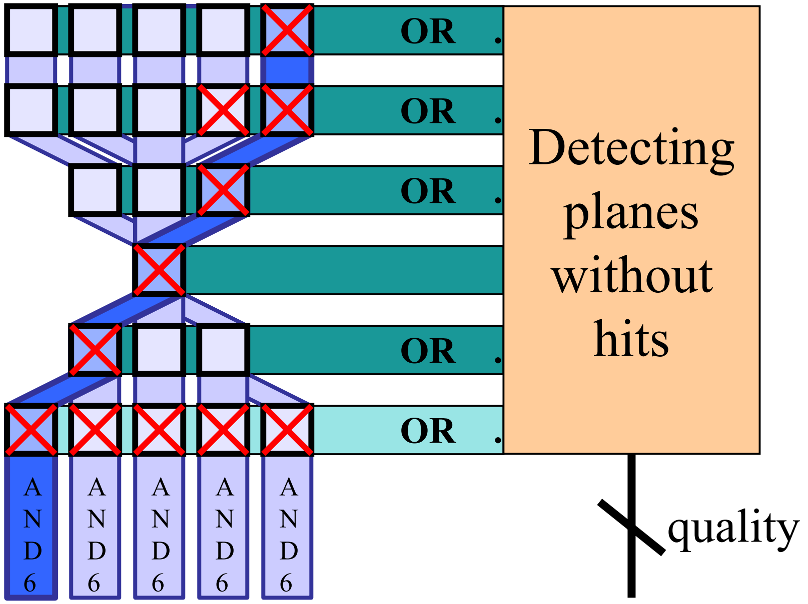
Improved PAC Algorithm - III

3. If there was no hit in one or two planes, set all strips of these planes to 1



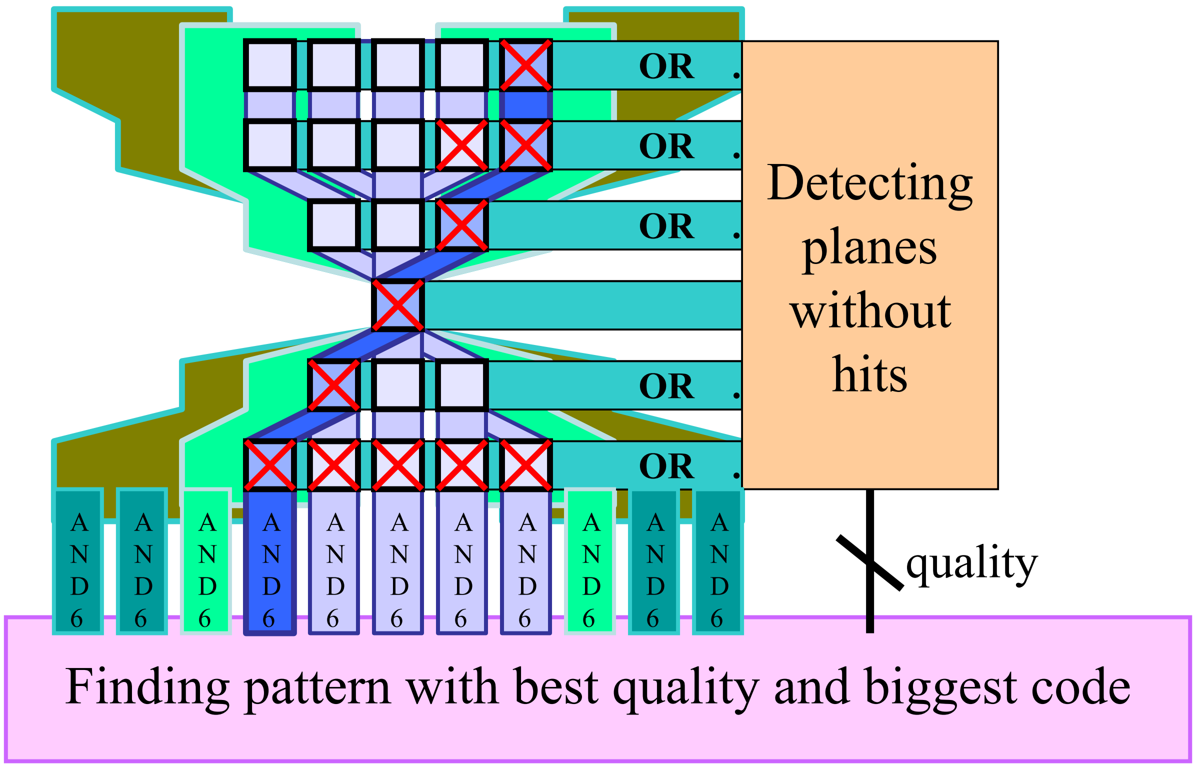
Improved PAC Algorithm - IV

4. For every pattern the coincidence of 6 planes is required



Improved PAC Algorithm - V

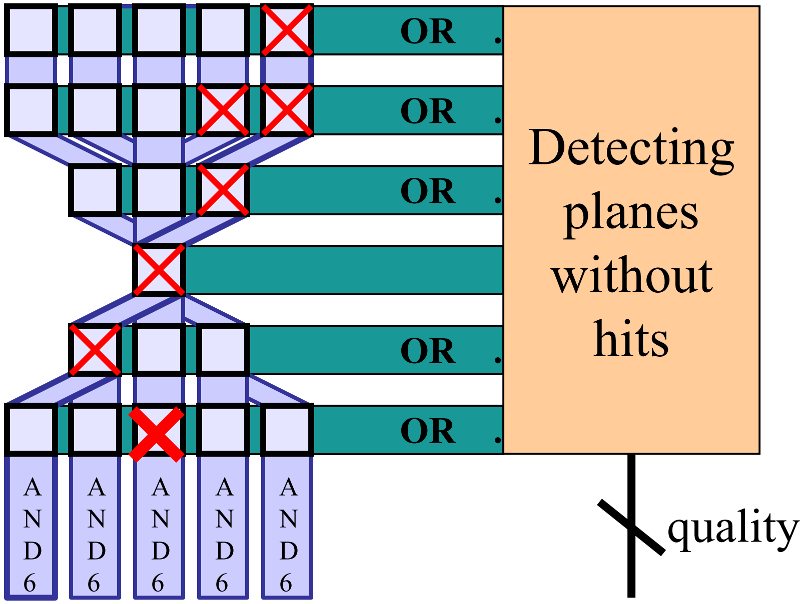
5. Sort the found tracks candidates



Improved PAC Algorithm - VI

Note: muon hits not fit to any patterns or noise hit occurred in plane without muon hit

None pattern fits to hits



Small loss in efficiency and small increase of ghost rate

Pac Chip Implementation in FPGA

One PAC chip (1of 396 in whole system):

- Pattern Comparator algorithm
- Input data decompression and synchronization
- Data distribution to PAC units

Implemented in parameterized VHDL code, including configuration file defining

- PAC units inputs,
- quality definition
- and patterns

Compilation results for PAC chip from Tower 0 containing 14 252 patterns defined on 6 planes:

Device: **Altera Stratix II** EP2**S90**F1020C3 – 72 768 LUTs :

- **LUTs Used: 42 064 (57 %)**
- Frequency > 45 MHz
- Compilation Time ~ 2 hours

RPC PAC trigger performance

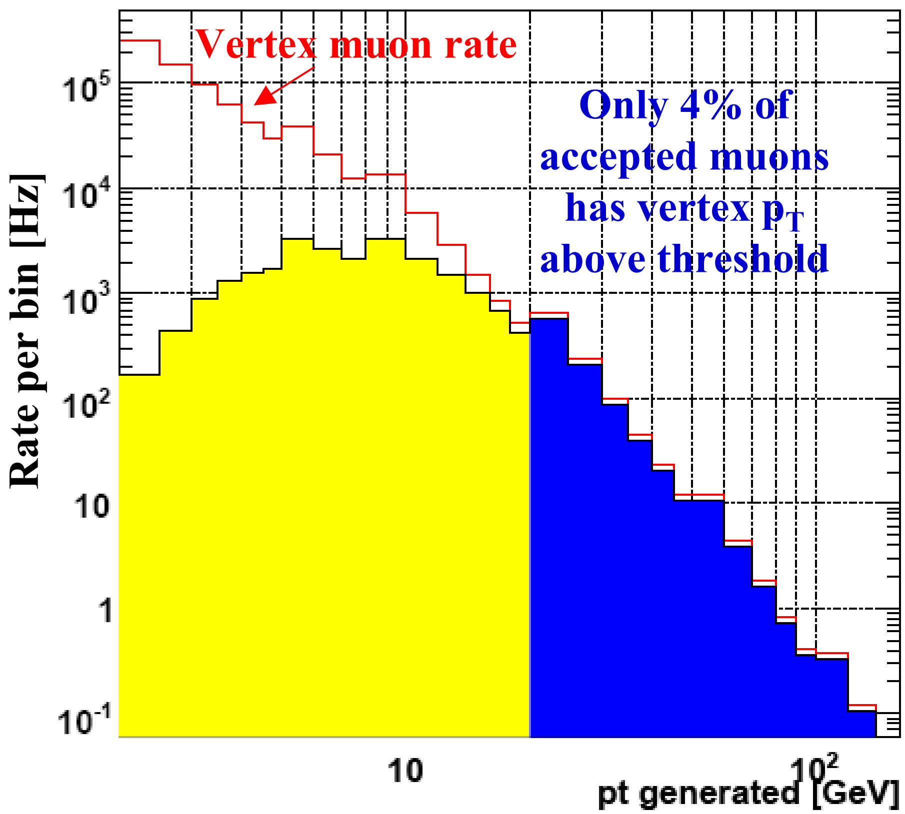
L1 Trigger requirements:

- Find as many as possible of trigger objects ⇒ Maximization of efficiency above threshold
- Keep output rate below required level

In case of RPC PAC trigger these requirements are realized by:

- During patterns generation (from the simulated tracks) the value of p_T is assigned to patterns in a way assuring > 90% efficiency
- PAC algorithm selects the pattern with best quality and highest p_T

Muons reconstructed with p_T > 20 GeV



Caution: bin size varies!

Trigger performance simulation - strategy and conditions

What we are mostly interested in?:

- Trigger efficiency (especially for high p_T muons)
- Trigger rate vs. p_T threshold
- False triggers and ghosts rate

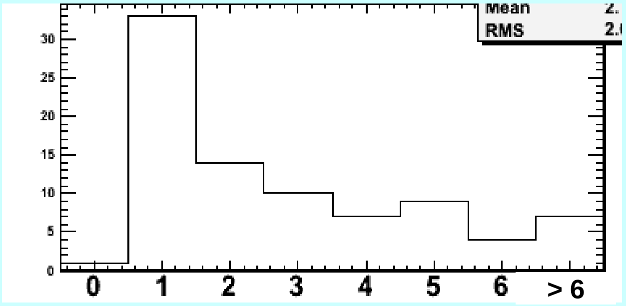
⇓

Muon sample:

- single muons originating from vertex,
- flat distribution in p_T (for rate studies p_T spectrum re-weighted with rate parameterization)
- flat distribution in η
- 1.83 millions of events (positive and negative muons),

Simulation conditions

- Luminosity: 10^{34}
- Cluster size distribution

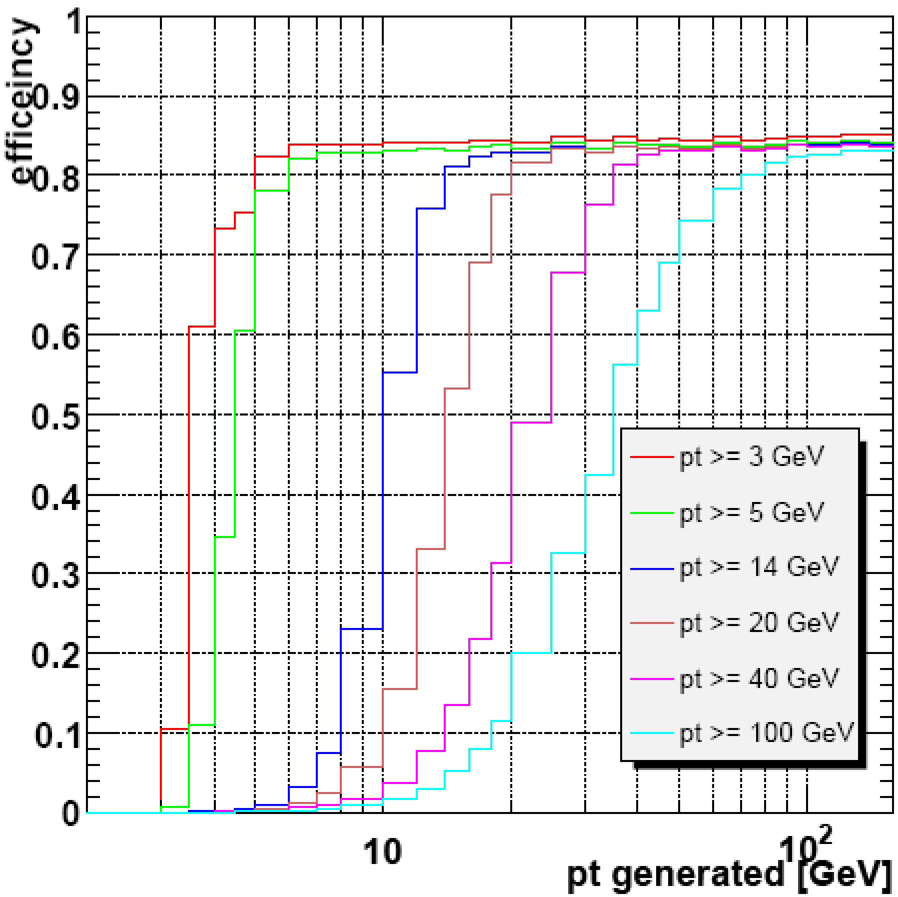


- Chambers noise 5 Hz/cm2
- Chambers efficiency 95%
- Neutron background: nominal level × 0.6

Trigger efficiency curves

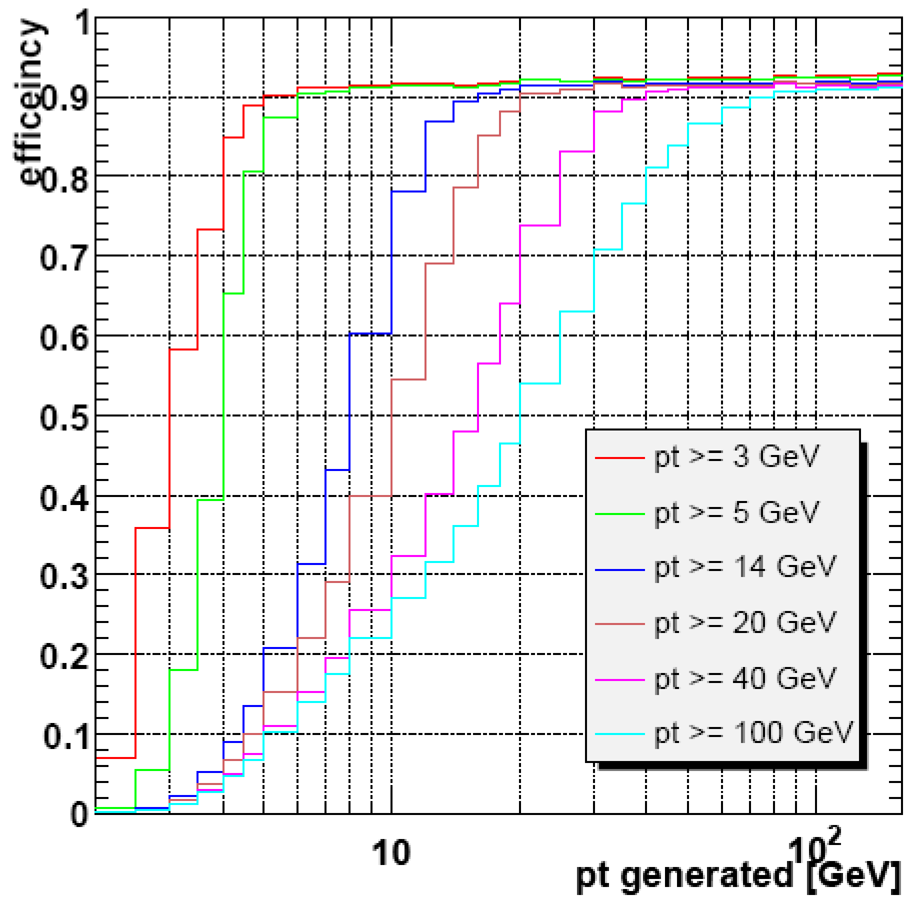
Barrel region

(η < 0.93, trigger tower 0-6)

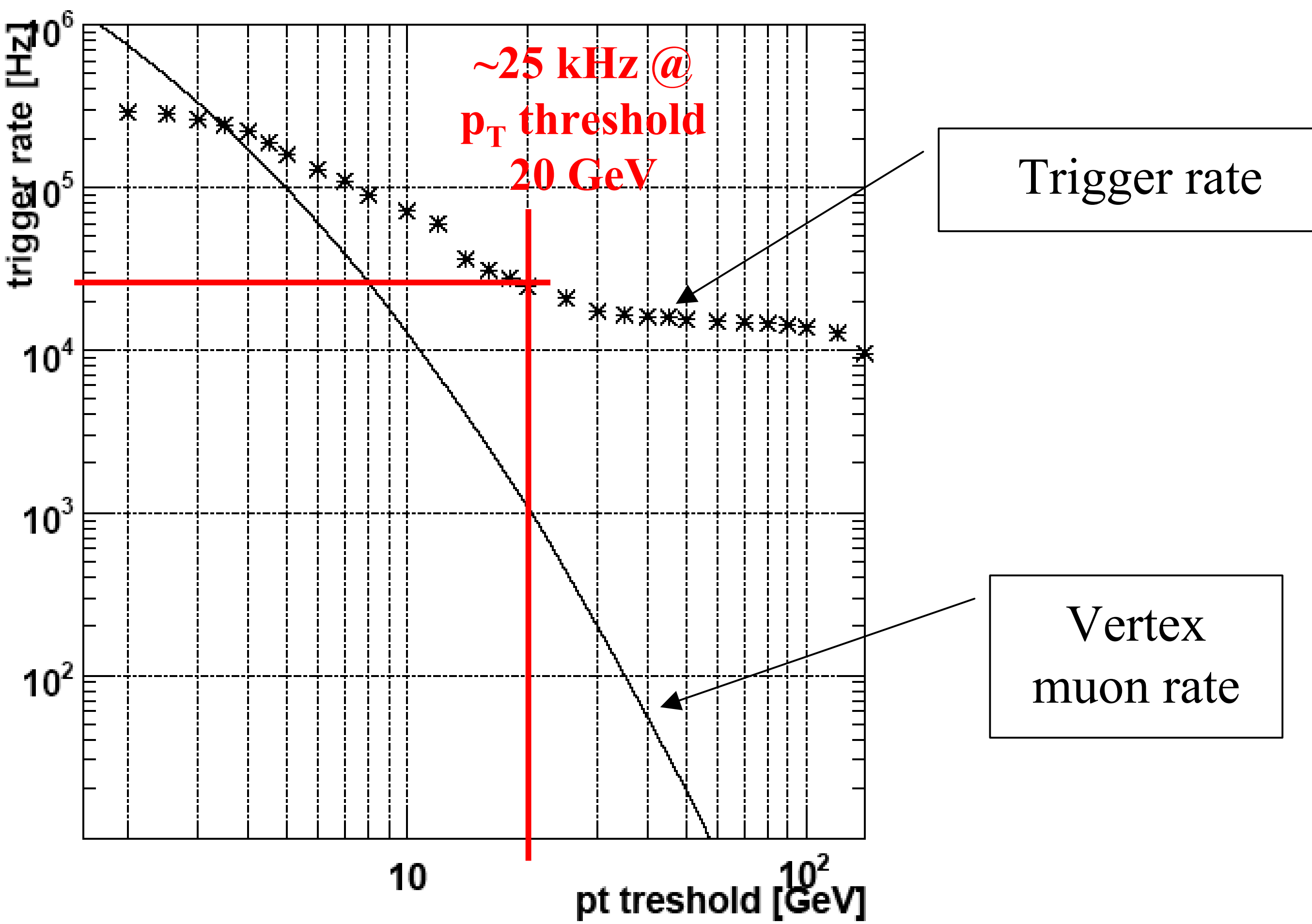


Endcap region

(0.93 < η < 2.1, trigger tower 7-6)



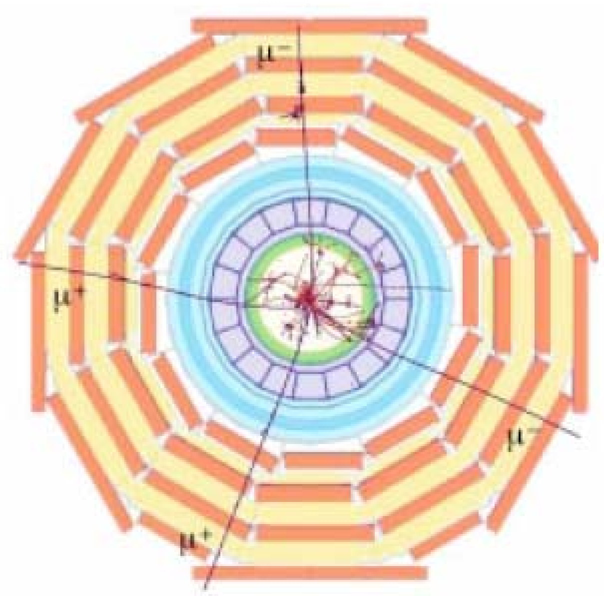
Trigger Rate (whole detector)



Conclusions

LHC and CMS (including RPC PAC trigger) should start working on the first half of 2007…

Then maybe we will find the event with 4 high-energy muons…



indicates, that we are observing HIGGS!