Performance studies of large-area triple-GEM prototypes for future upgrades of the CMS forward muon system

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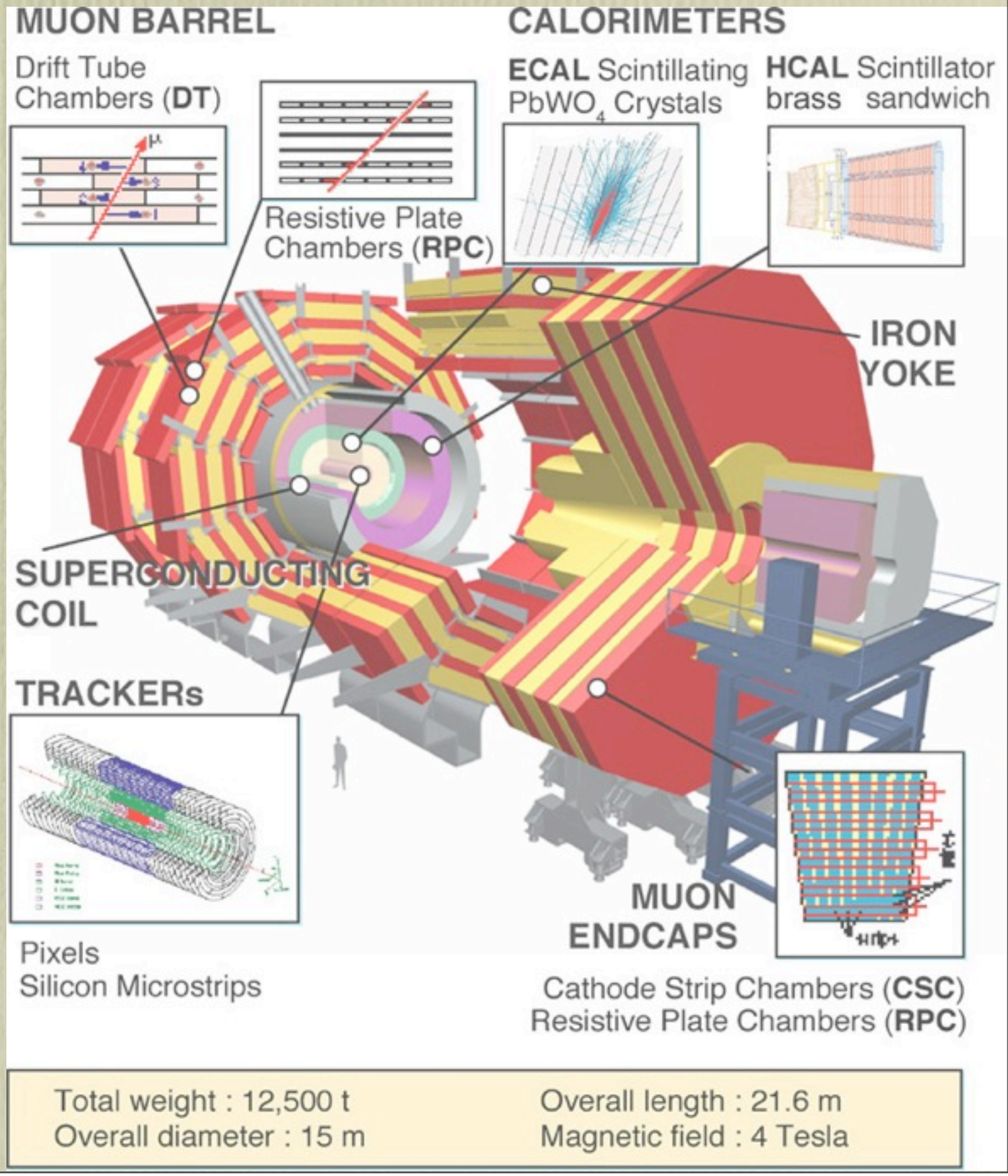
- *CMS Muon system upgrade scenario*
- *GEMs construction first steps*
- *Simulation studies*
- *Trigger performance*
- *Physics reach*

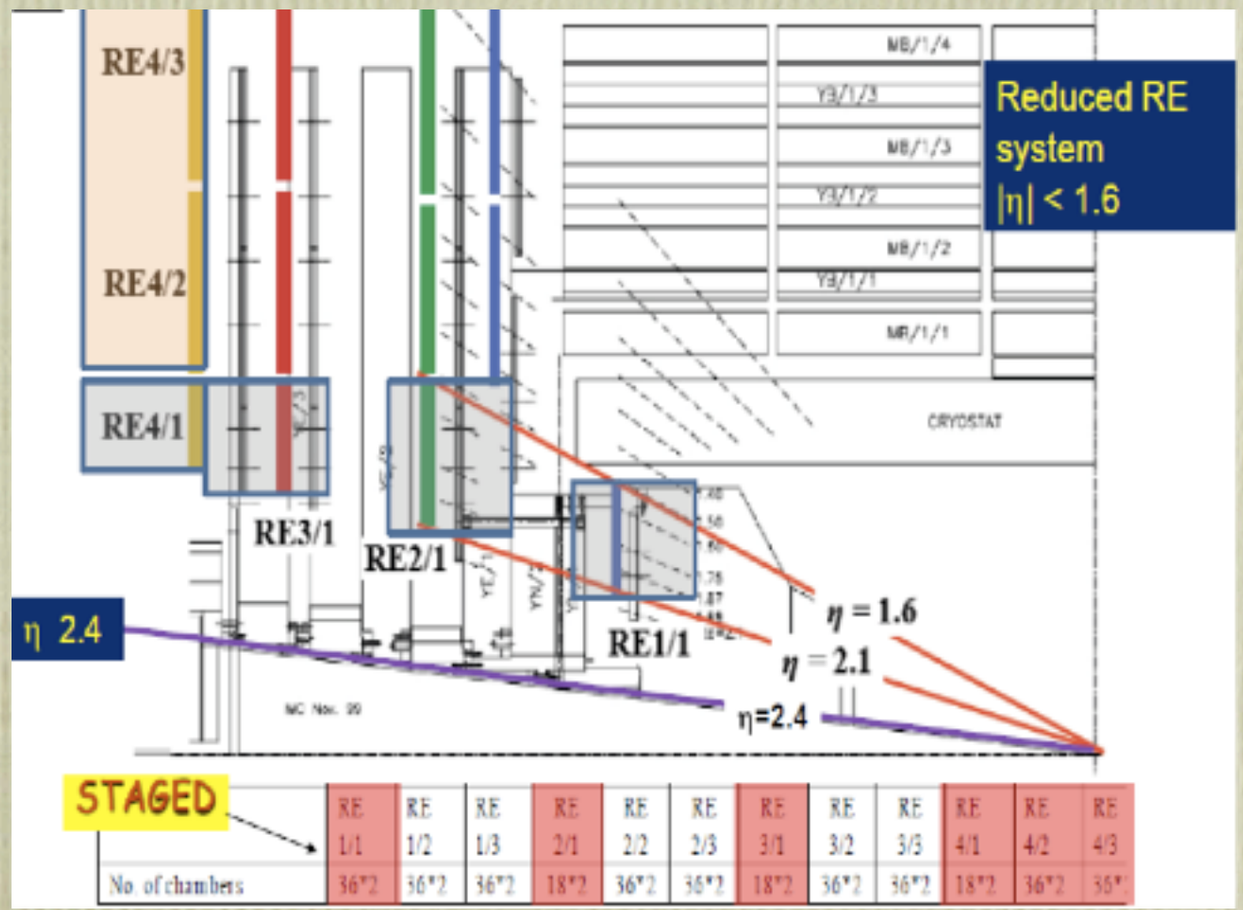
Compact Muon Solenoid

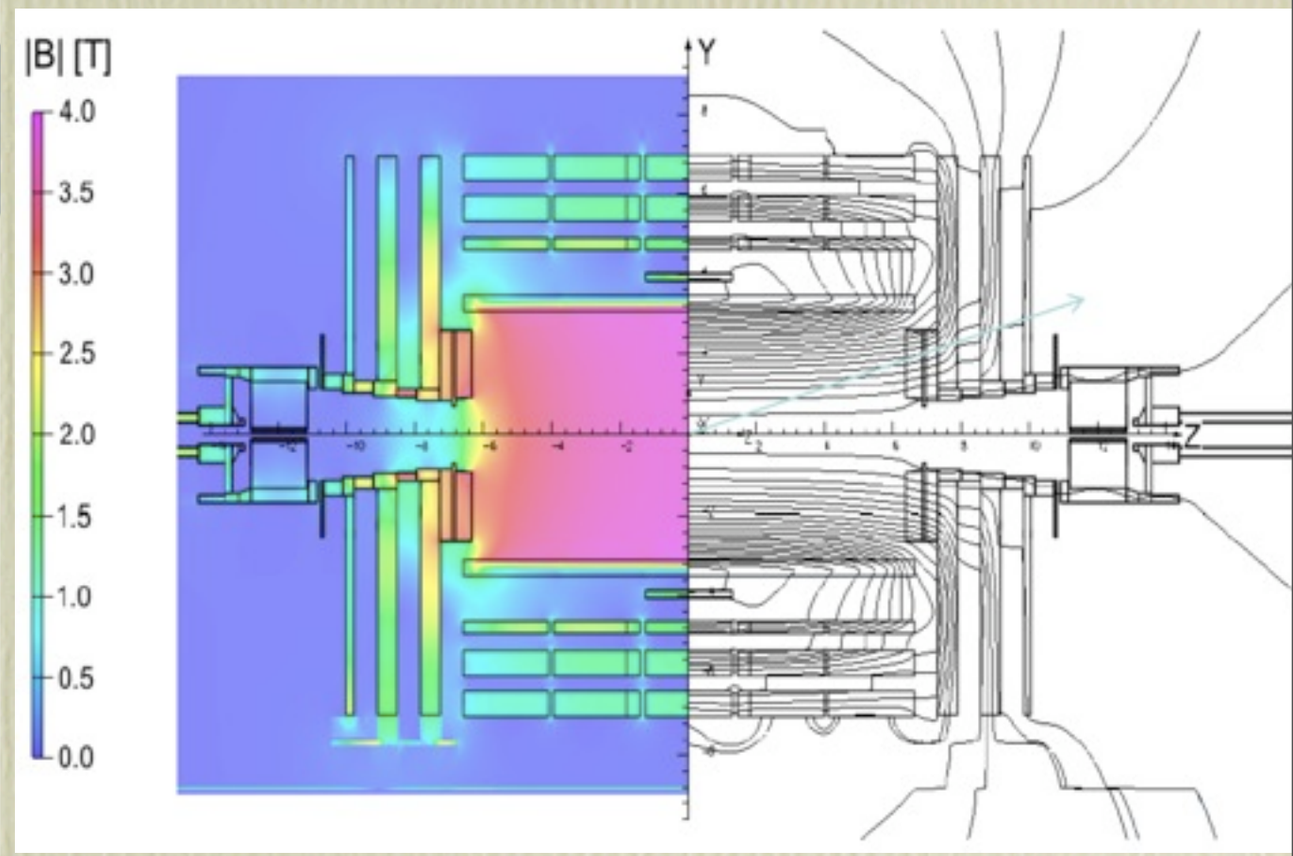
- *Gaseous detectors for the muon system*
  - *Tracking detectors - o(100 μm) spatial resolution*
    - *Drift Tubes (DT) in barrel*
    - *Cathode Strips Chambers (CSC) in endcaps*
  - *Trigger detector - o(ns) time resolution*
    - *Resistive Plate Chambers (RPC) in both region*



CMS forward muon system

- *Cathode Strip Chambers (CSC) fully cover 1.2<|η|<2.4; good spatial resolution in η & ϕ: segments for trigger and reconstruction*
- *Resistive Plate Chambers (RPC) cover |η|<1.6; strips length along η, have o(cm) spatial resolution in ϕ*
  - *good time resolution: hits used in trigger for correct BX ID and resolving ambiguities*

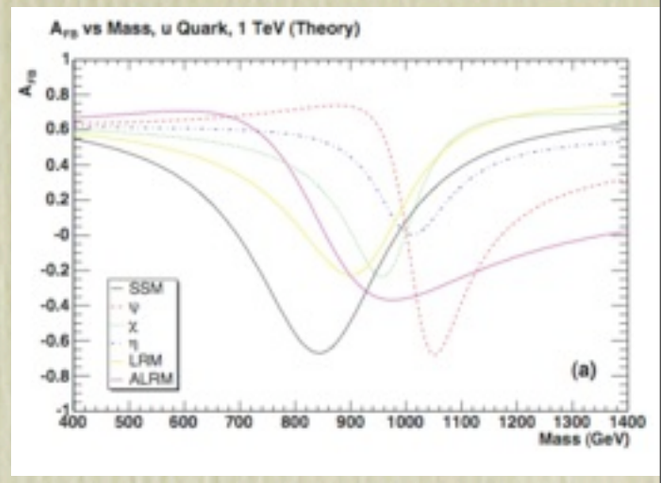


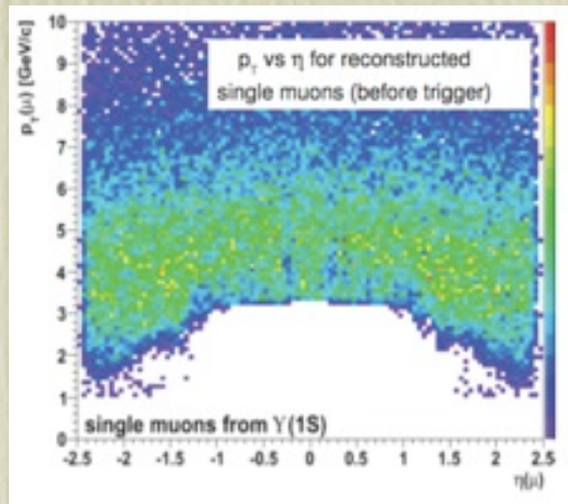


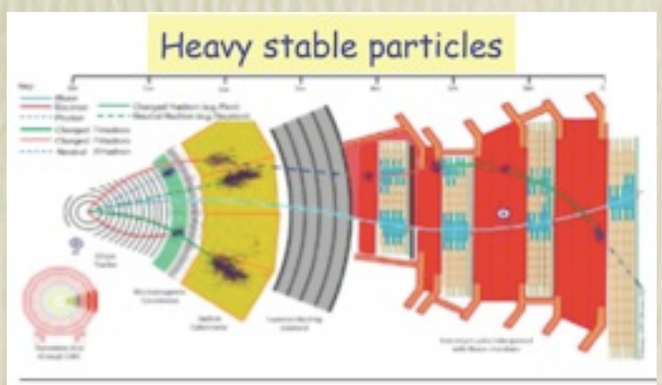
- *Original project foresaw a redundant muon system with RPC to cover |η|<2.1*
  - *current RPC system to |η|<1.6 (budget cuts, high-rate might have been too much)*
  - *redundancy's missing in the most critical zone: high-rate and high-density radiation and lower magnetic field*
- *RPC system upgrade (up to |η|<2.1) required to keep up with LHC future environments*

Physics for high-eta regions

- *Upgrade foreseen by ~2020: ~3000 fb^{-1} will be already collected by then*
- *Standard Model precision measurement:*
  - *high-η Z production for backward-forward asymmetry studies (important for PDF)*
  - *precise measurements of electroweak processes where barrel is not enough (low-p_T J/ψ, Υ)*
- *Exotica (aka whatever new physics at 7-8 TeV mass scale):*
  - *Heavy-resonances (with possible multi-leptons signatures)*
  - *New Heavy Stable Charged Particle which may need precision timing*
  - *May produce very high-p_T muons (hundreds of GeV/c up to… who knows?)*
- *Muons wide acceptance and robust triggering become even more crucial for a "Compact Muon Solenoid"*

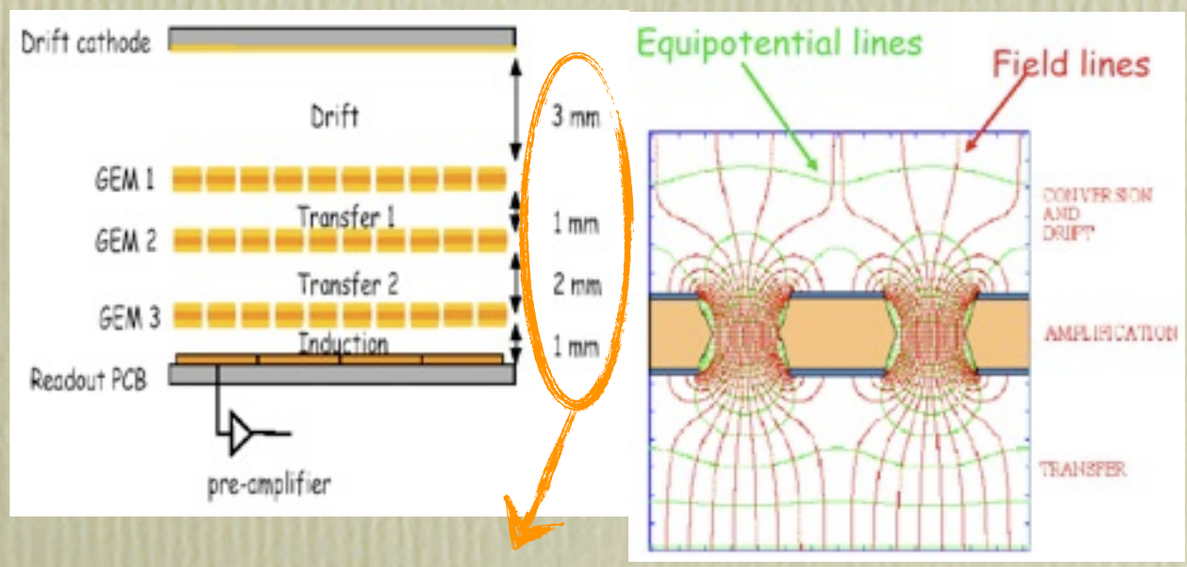






Multi Pattern Gaseous Detectors (MPGD) for upgrade

- *Rate capability ≳ 10^5 Hz/mm² ⇒ 10 MHz/cm²*
- *Spatial resolution ~100 μm ($\theta_{track} < 45^o$)*
- *Good double track resolution*
- *Time resolution ~ 4-5 ns*
- *High efficiency (typically over 98%)*
- *Non-flammable gases (Ar, CO2)*
- *Can be readout along η as well*
  - *improvement in rate capability from using η measurement in trigger*



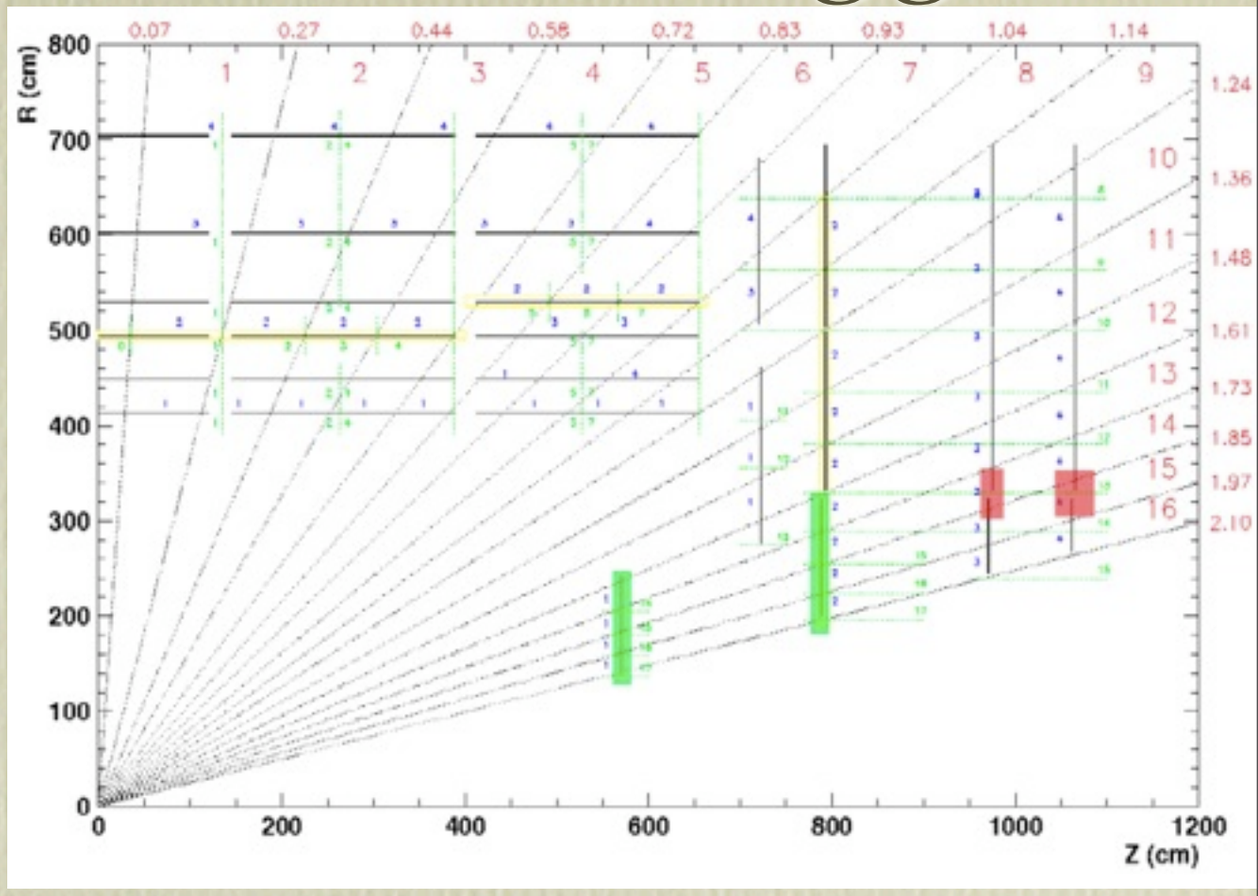
3/1/2/1 GEM

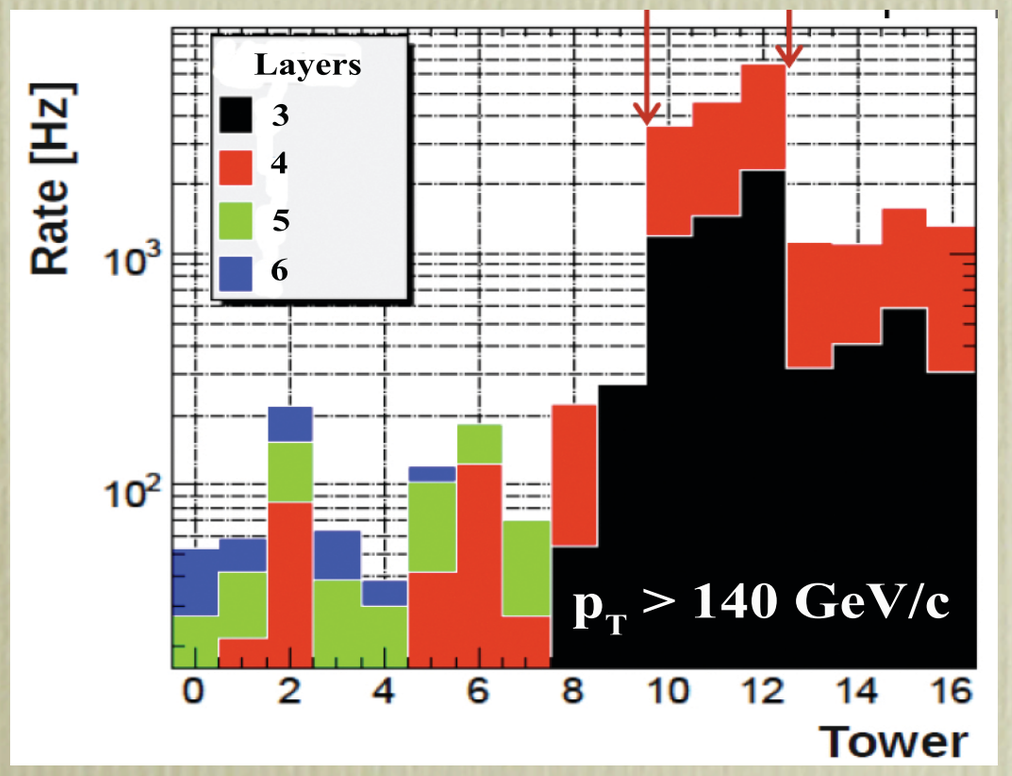
RPC Region	Rates Hz/cm² LHC (10^{34} cm²/s)	High Luminosity LHC 2.3 x LHC	(10^{35}cm²/s) Phase II SLHC ??
RB	30	Few 100	kHz (tbc)
RE 1, 2, 3,4 η < 1.6	30	Few 100	kHz (tbc)
Expected Charge in 10 years	0.05 C/cm²	0.15 C/cm²	~ C/cm²
RE 1,2,3,4 η > 1.6	kHz	Few kHz	Few 10s kHz
Total Expected Charge in 10 years	~ C/cm²	few C/cm²	Few 10s C/cm²

- *Timing comparable to RPCs; improvements in*
  - *spatial resolution*
  - *radiation-hardness*
- *Cost sustainable for going to large areas chambers (o(1) m²)*
- *Already used in some HEP experiments (COMPASS, LHCb, TOTEM)*
- *Activities within RD51 framework*

Including MPGD into RPC trigger

- *RPC PAttern Comparator (PAC) compares muon hits (same BX) with preloaded patterns*
  - *at least 3 stations fired*
  - *within projective η towers*
  - *p_T assignment w.r.t. patterns*

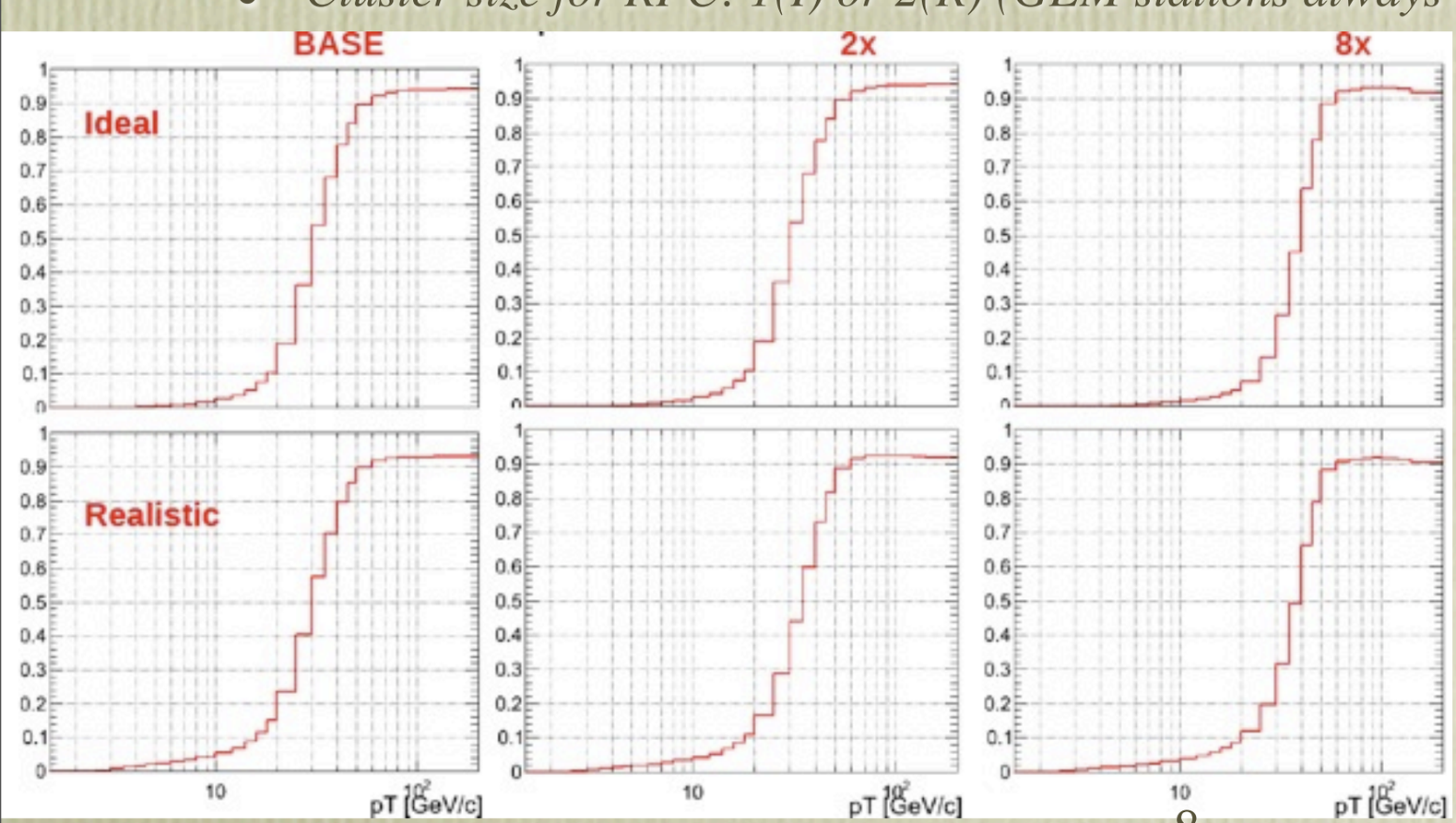




- *as p_T precision depends on spatial granularity along ϕ, improved spatial resolution*
  - *sharpens turn-on curve*
  - *contributes to rate lowering*

Trigger simulation set-up

- *Disclaimer: only spatial resolution has been considered relevant for preliminary performance studies on trigger and tracking*
  - *simulation relies on "RPC-like" chambers with different spatial resolutions*
- *Single muon samples with 3 different resolutions referred wrt RPC strips number as are reported in CMS Technical Design Report (TDR):*
  - *x1 - x2 - x8*
- *Ideal (I) and realistic (R) conditions for RPC chambers:*
  - *Efficiency: 100%(I) or 95%(R)*
  - *Cluster size for RPC: 1(I) or 2(R) (GEM stations always cs=1)*

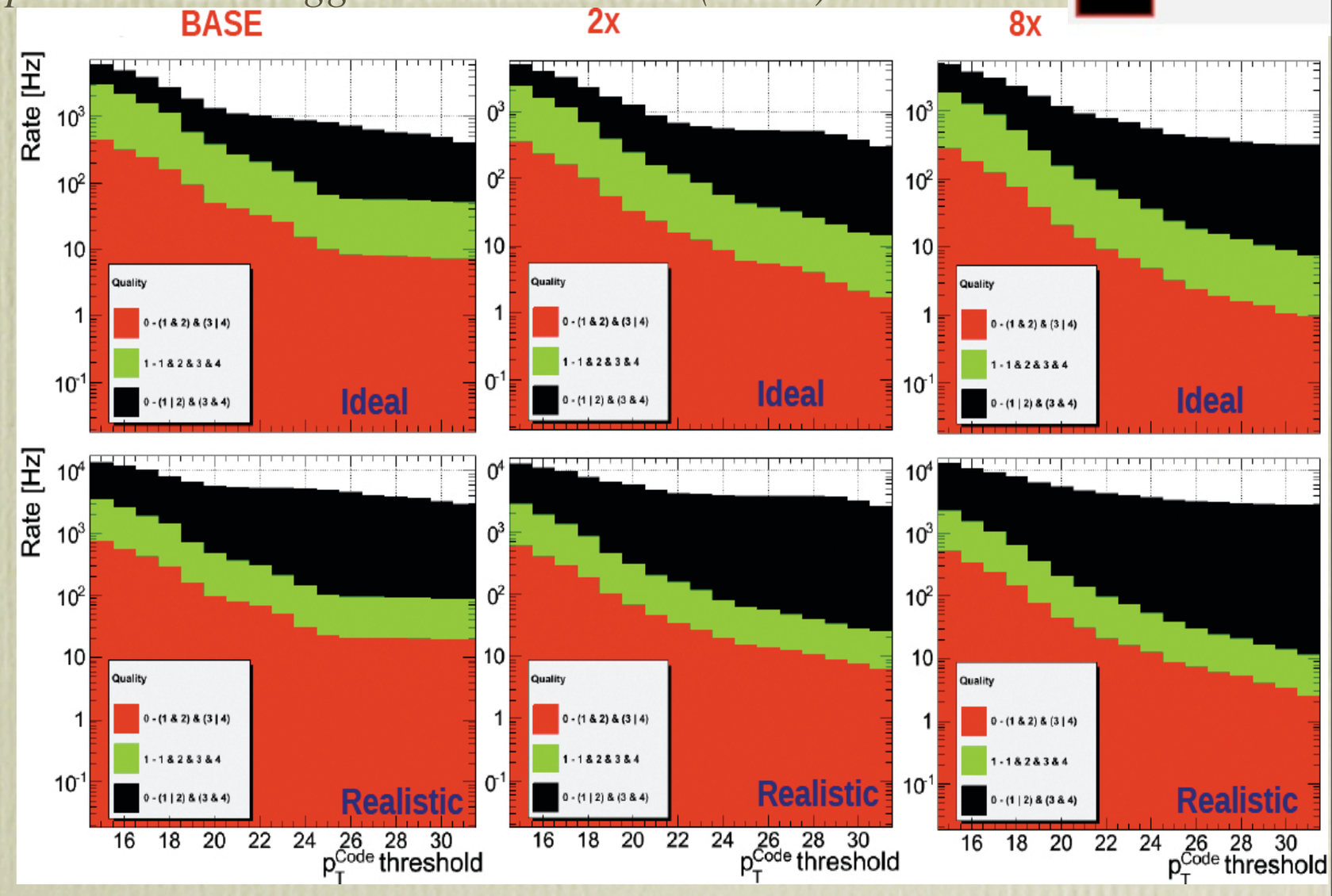


- *Trigger turn-on curves for PAC p_T > 50 GeV/c*
- *Steeper step slope as resolution increases*
- *Larger tails in realistic case*

Trigger rates

- *Rates of trigger candidates built up with 2 GEM (2-GEM cands') no more flat at high p_T thresholds (red and green) due to better momentum assignment and no clusters:*
  - *~3-4x rate drop for 2xTDR resolution*
  - *~8-9x rate drop for 8xTDR resolution*
- *Realistic cluster size raises up the 1-GEM trigger candidates rate (black)*

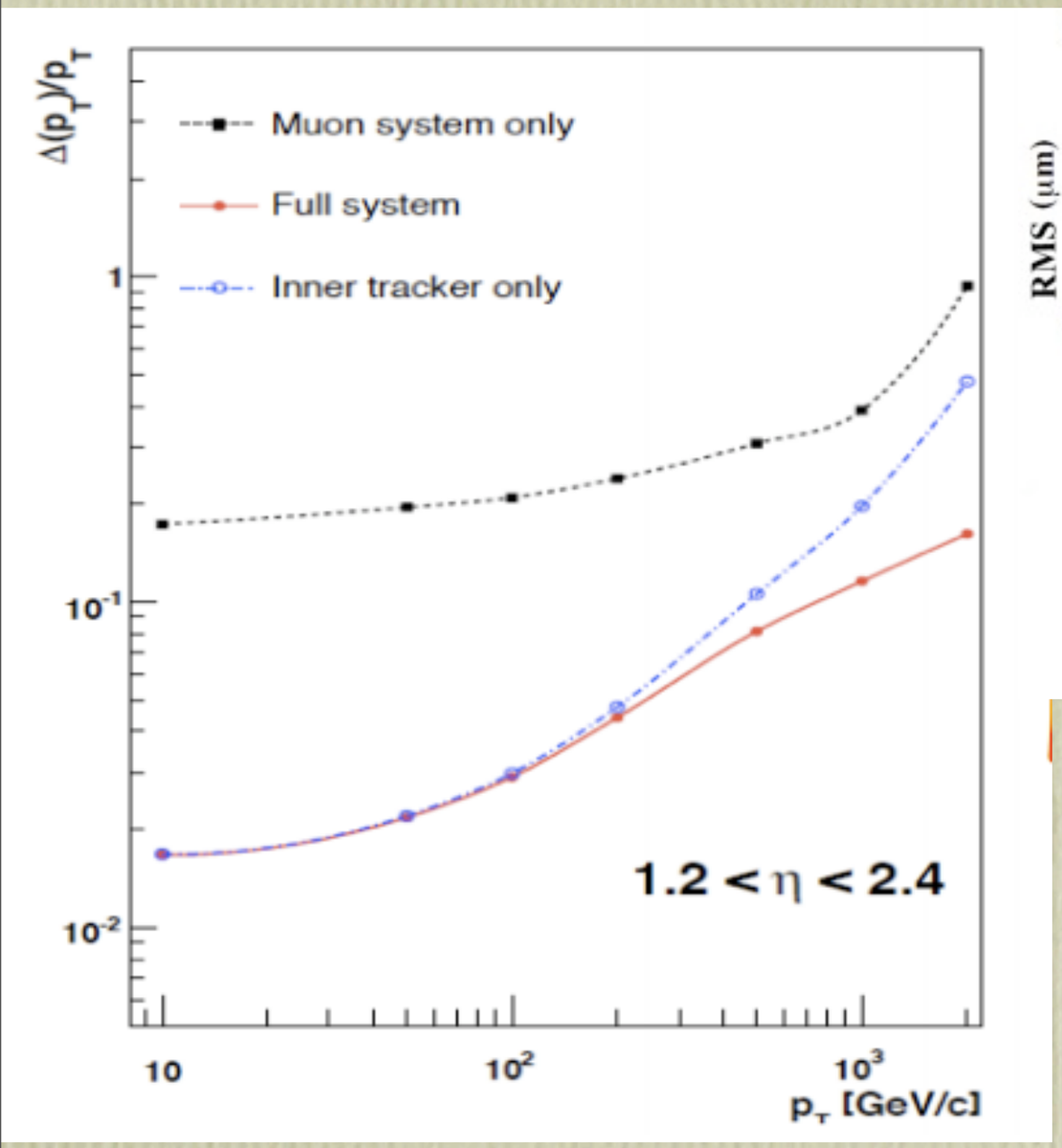
- *High-p_T trigger rate benefits from MPGDs*
- *Just slight decrease for lower pT, as bending is more enhanced*
  - *1-GEM candidates suppression may be a choice*

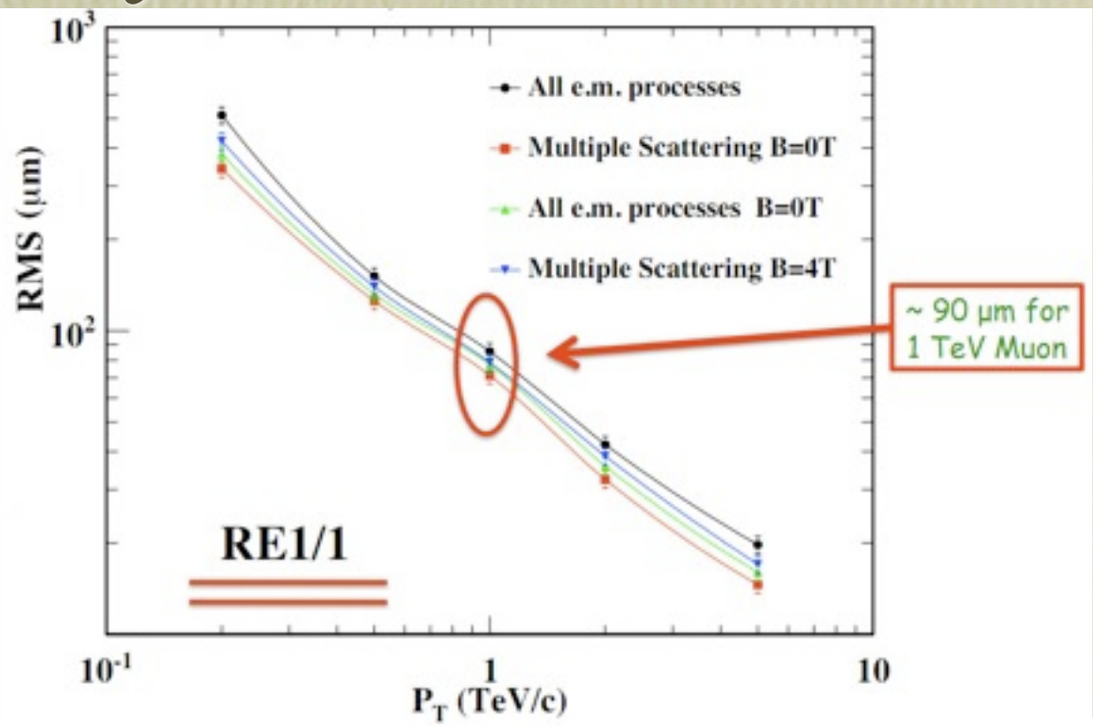


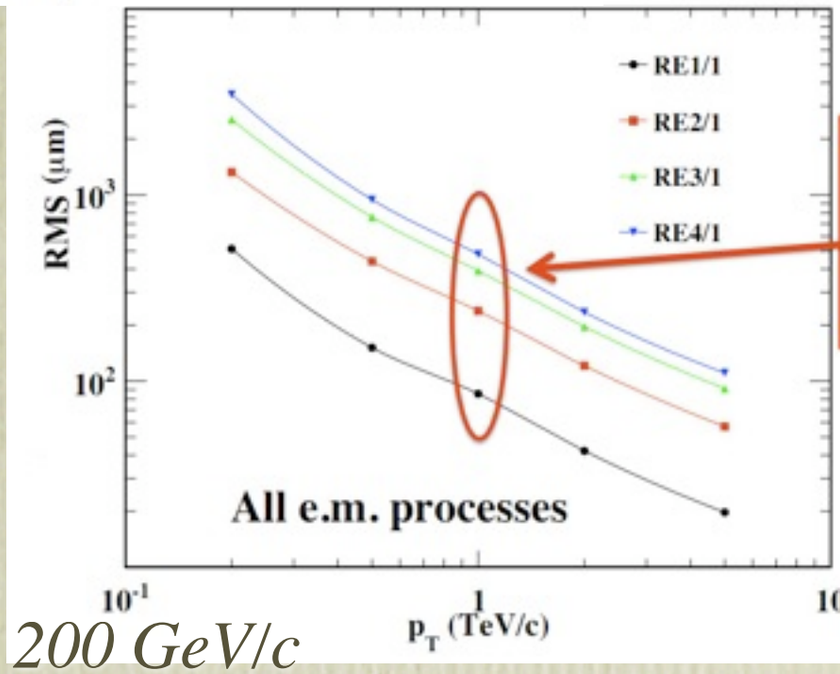
Studies on tracking performance

- *Single muon samples*
  - *p_T = 200, 500, 1000, 2000, 5000 GeV/c*
  - *$|\eta|>1.6$; uniform in ϕ*
- *RPC system with high eta chambers with point resolution given by*
  - *TDR, TDRx2, TDRx4, ... ,TDRx64, TDRx128 strips*

Boundary conditions

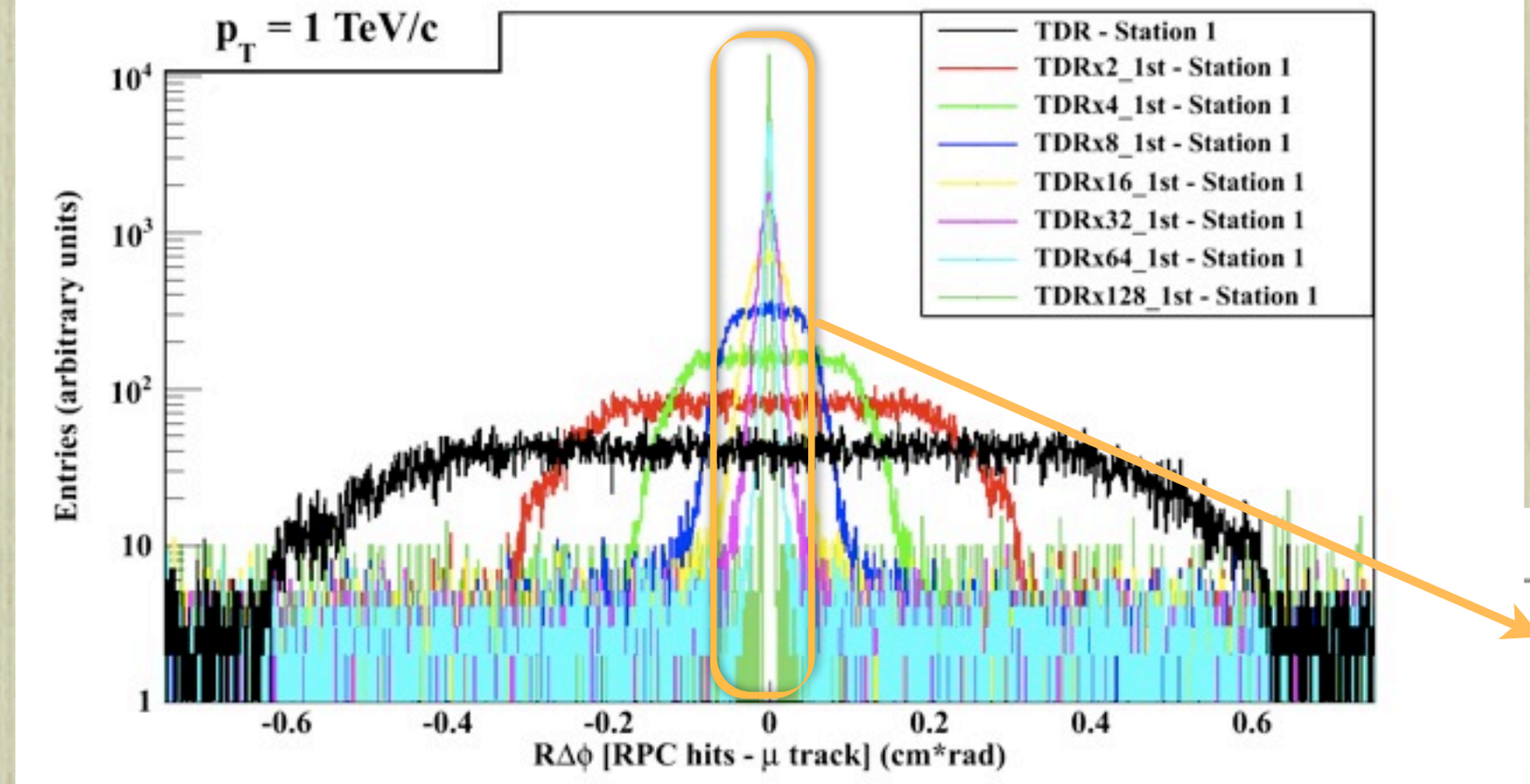


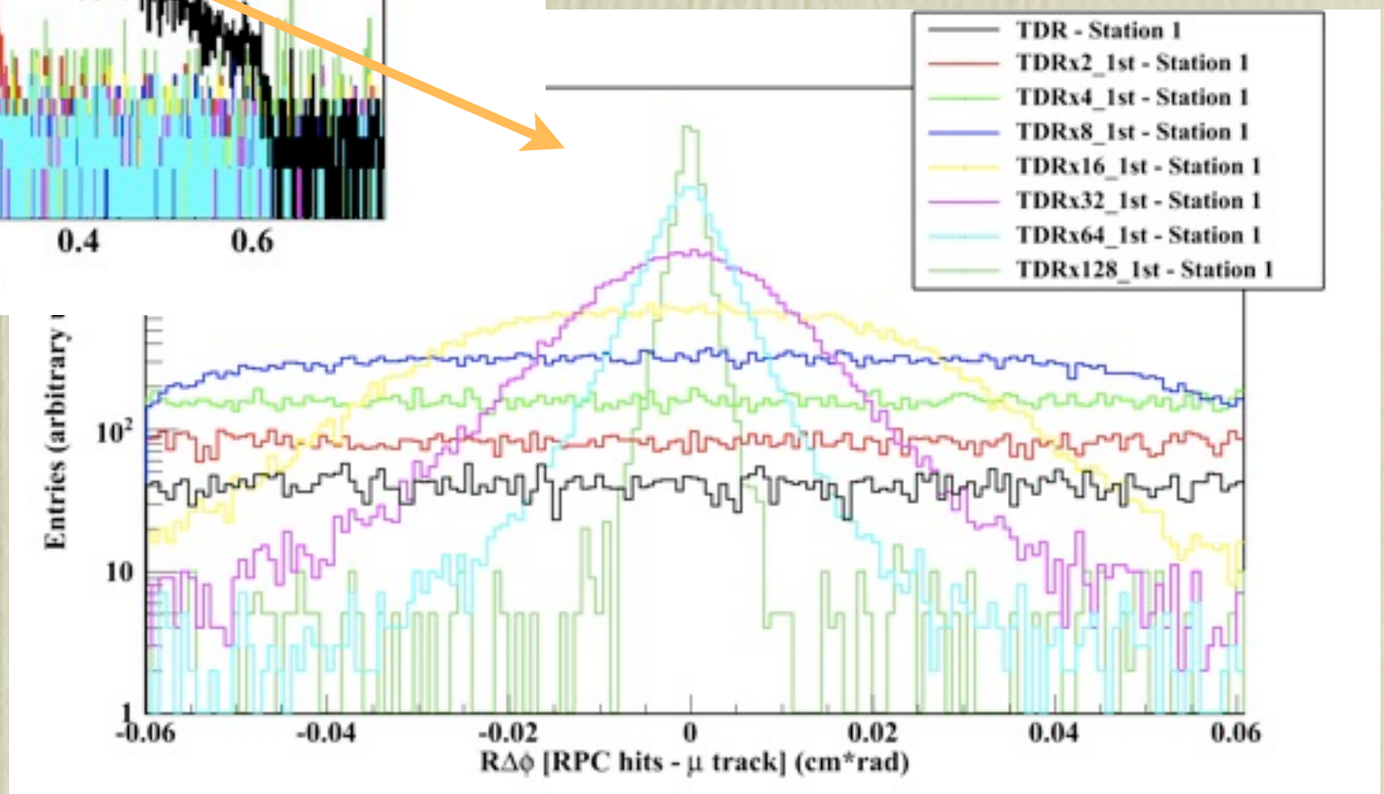




- *Muon system reconstruction start contributing from 200 GeV/c*
  - *At lower momenta contribution for acceptance and muon ID*
- *A 1 TeV muon interacting with detector material can't be resolved better than o(100) μm*

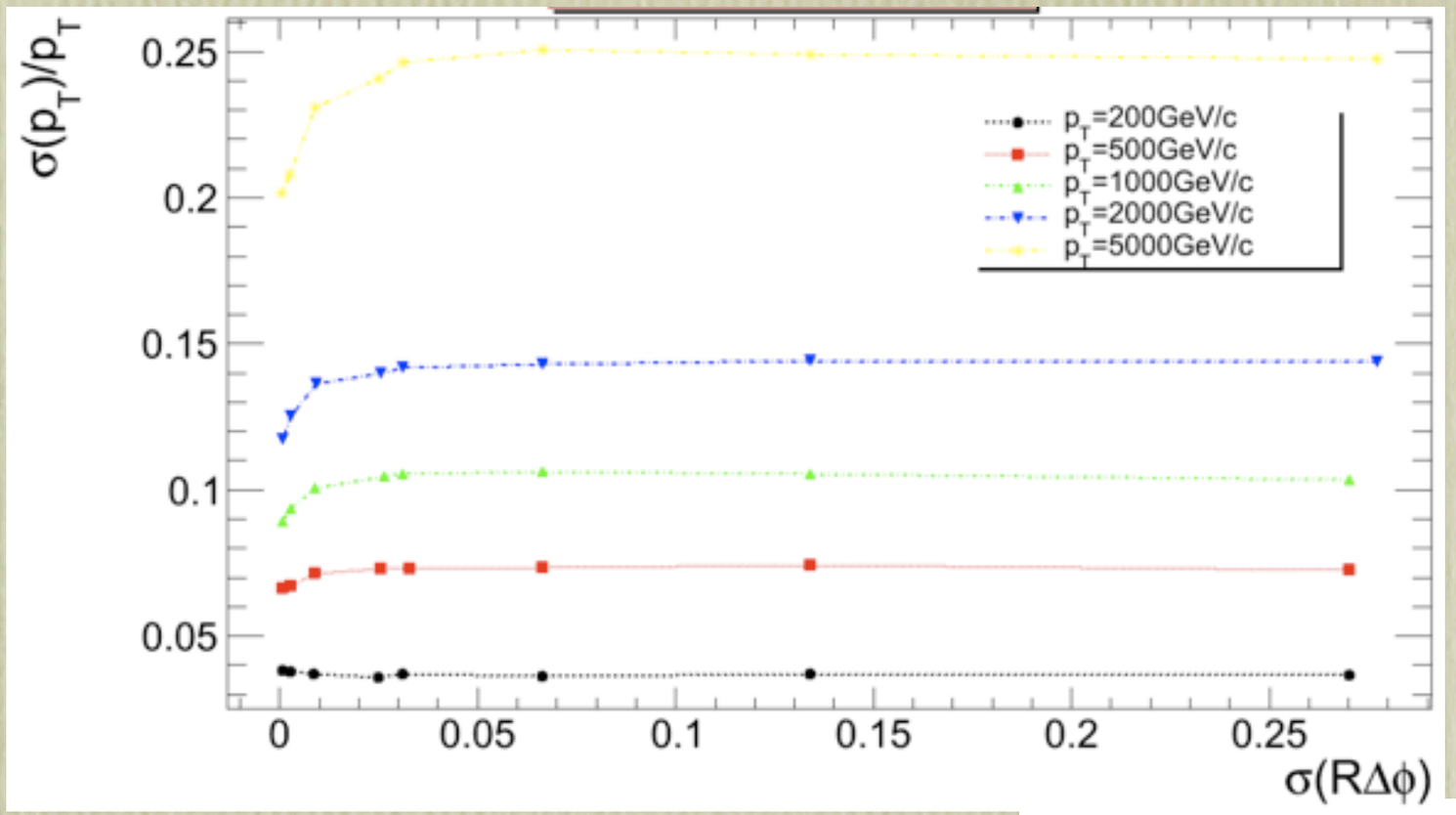
Point resolution





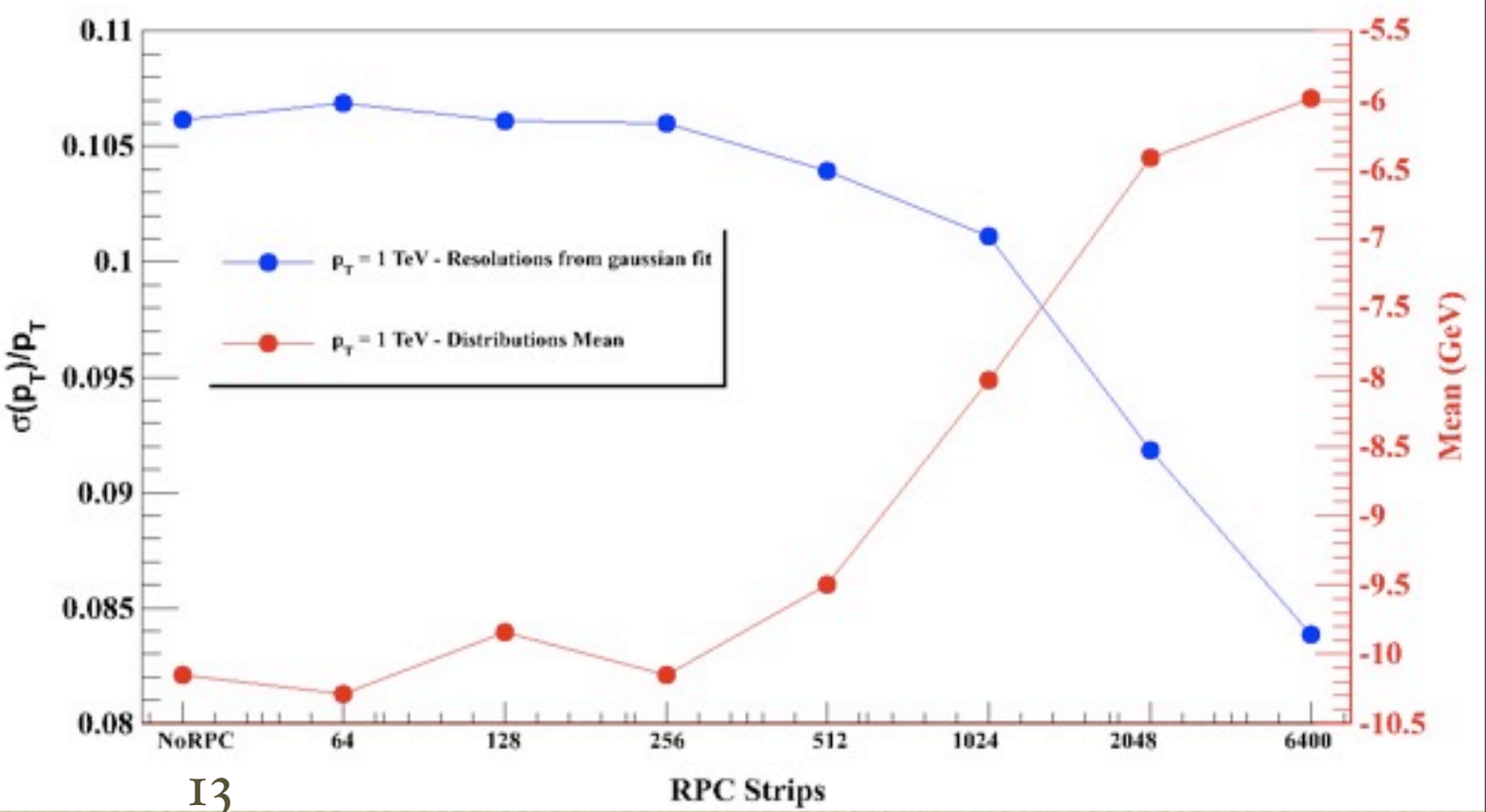
- *Strip pitch dominates resolution up to TDRx8*
- *Going further the e.m. effects begin to be appreciable*

Momentum resolution



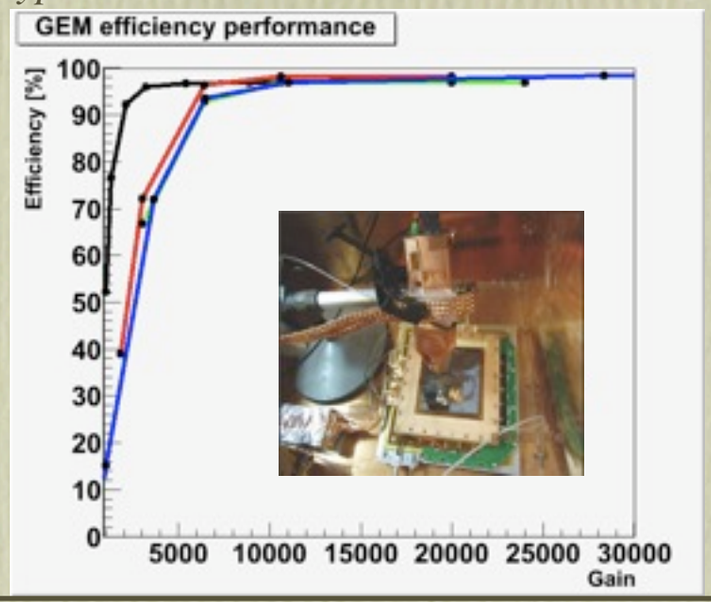
- *Momentum improves as strip pitch fades from spatial resolution*
- *Momentum value systematic bias reduced*
- *Improvement noticeable even with standard CMS muon reconstruction*

- *CAVEAT: results obtained with standard CMS muon reconstruction*
  - *Employs RPC hits just for resolving segment extrapolation ambiguities*
- *Real impact deserves to be evaluated by accounting for improved resolution in reconstruction algorithm*

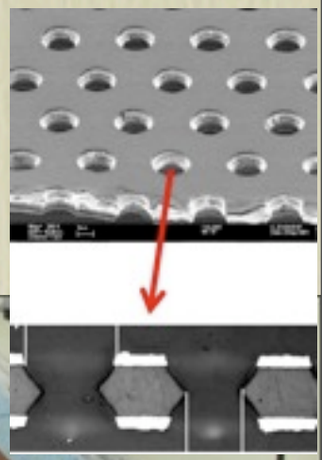


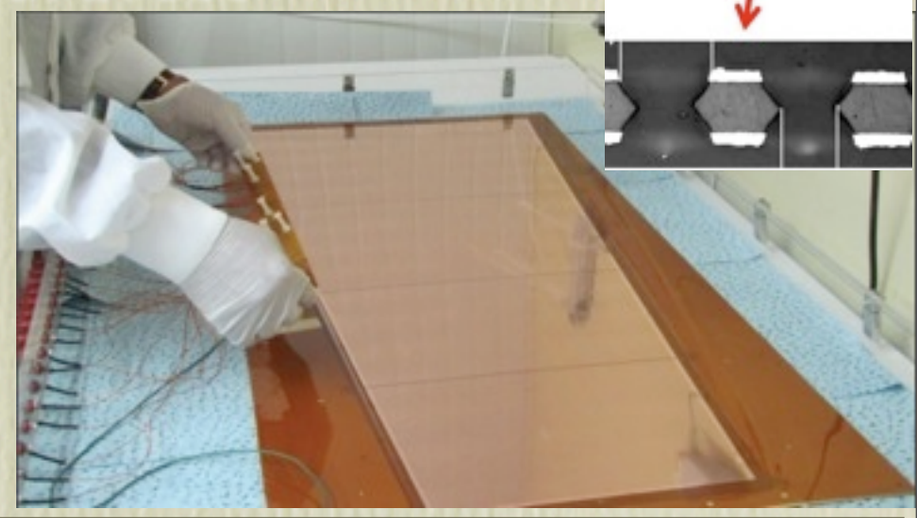
Experience & GEM prototypes growing...

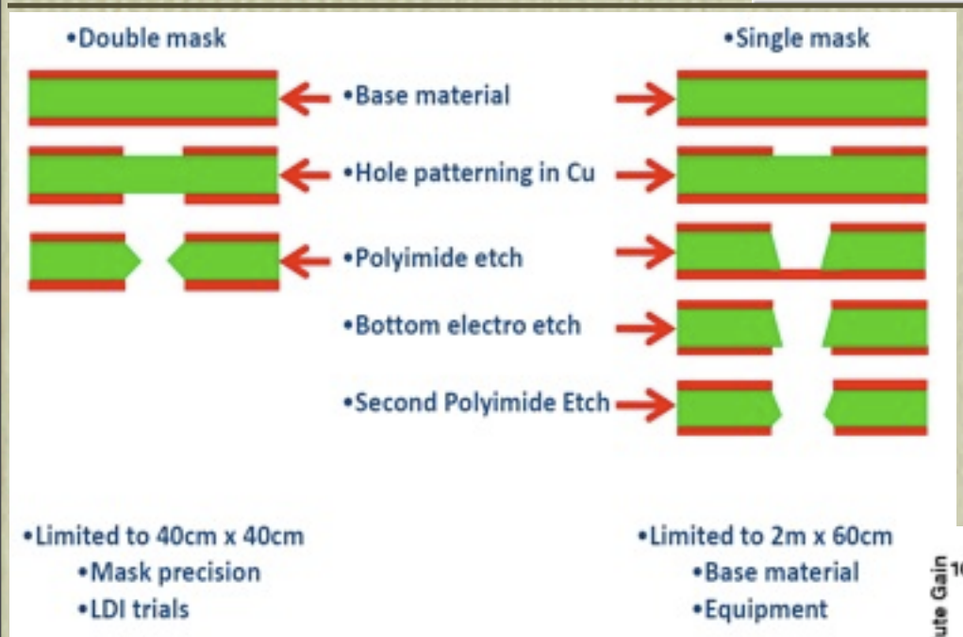
- *Small (10x10 cm²) size prototypes built*
  - *1D & 2D readout*
  - *256 or 512 channels*
  - *3/1/2/1 & 3/2/2/2*

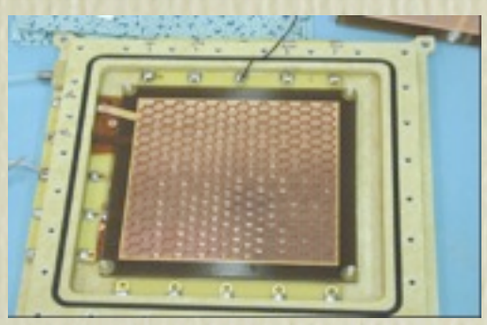


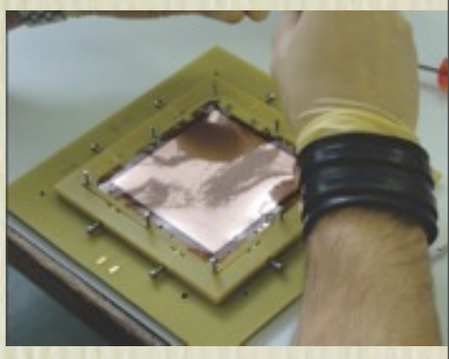
- *Full-size (1x0.6 m²) prototypes built*
  - *1D readout*
  - *1024 or 3072 channels*
  - *3/1/2/1 & 3/2/2/2*





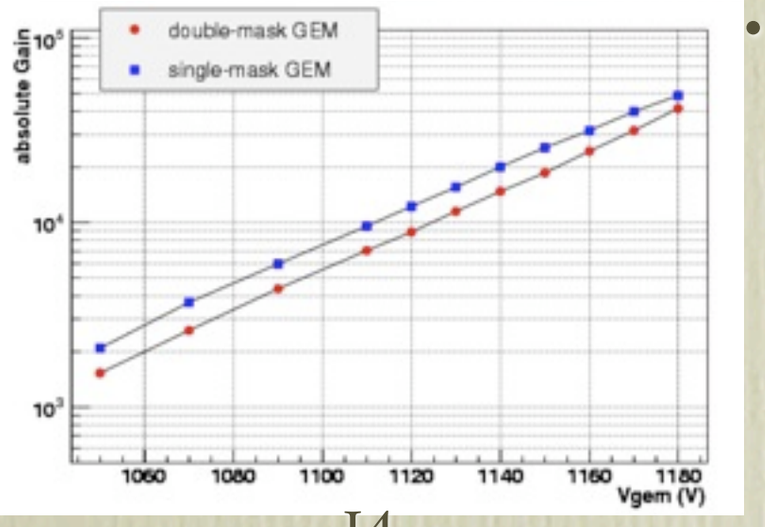






- *Stretching techniques*
  - *Honeycomb*
    - *different diameters configuration tested*
    - *larger diameters don't affect efficiency too much*
  - *Auto-stretching*
    - *new; proved promising for gain and operational stability*

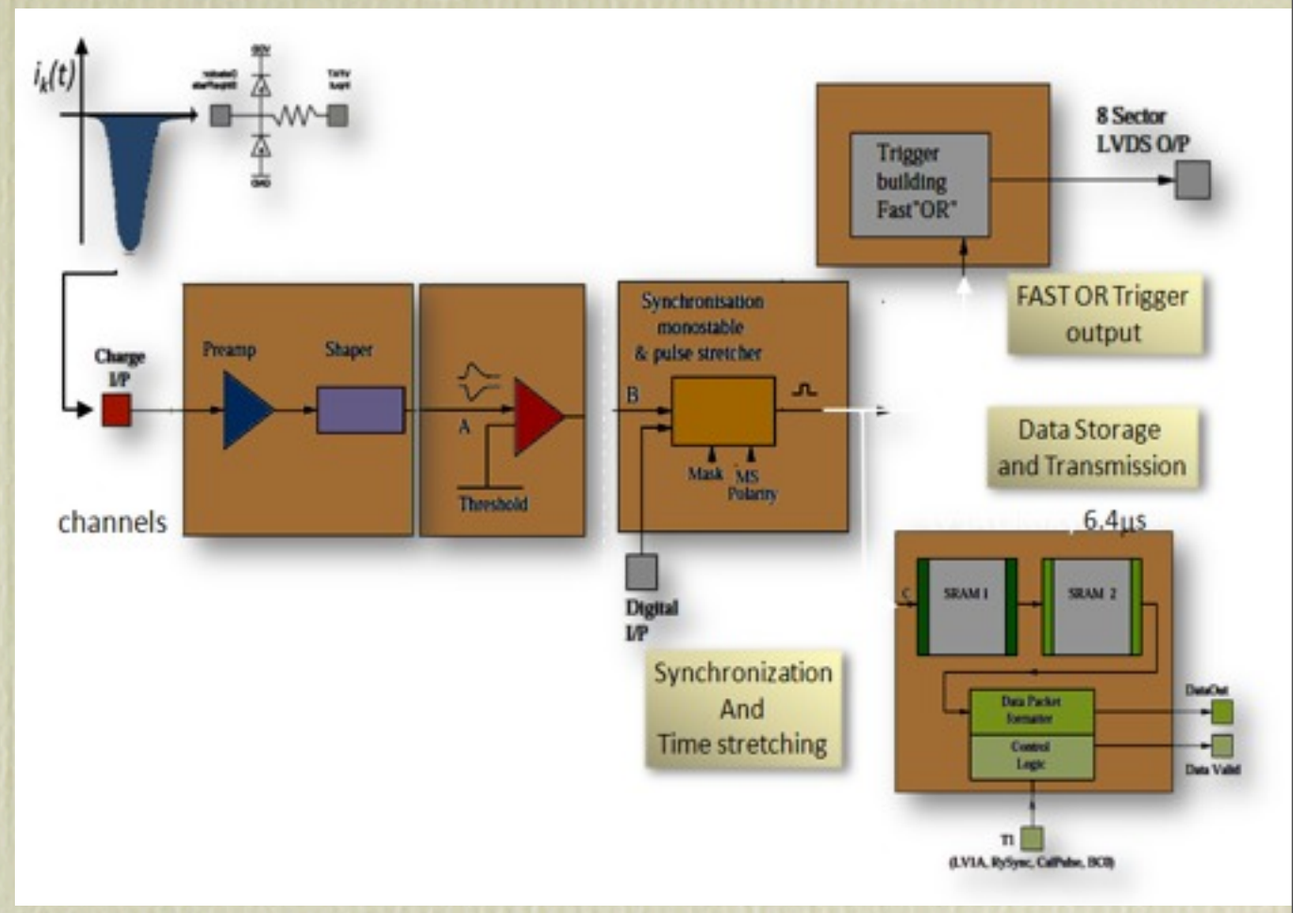
- *Ahead with new single-mask etching technology*
  - *inter-holes spacing: 50 ÷ 70 µm (inner ÷ outer)*
- *Better performance than traditional double-mask one:*
  - *100% alignment of GEM foils*
  - *suited for large sizes*

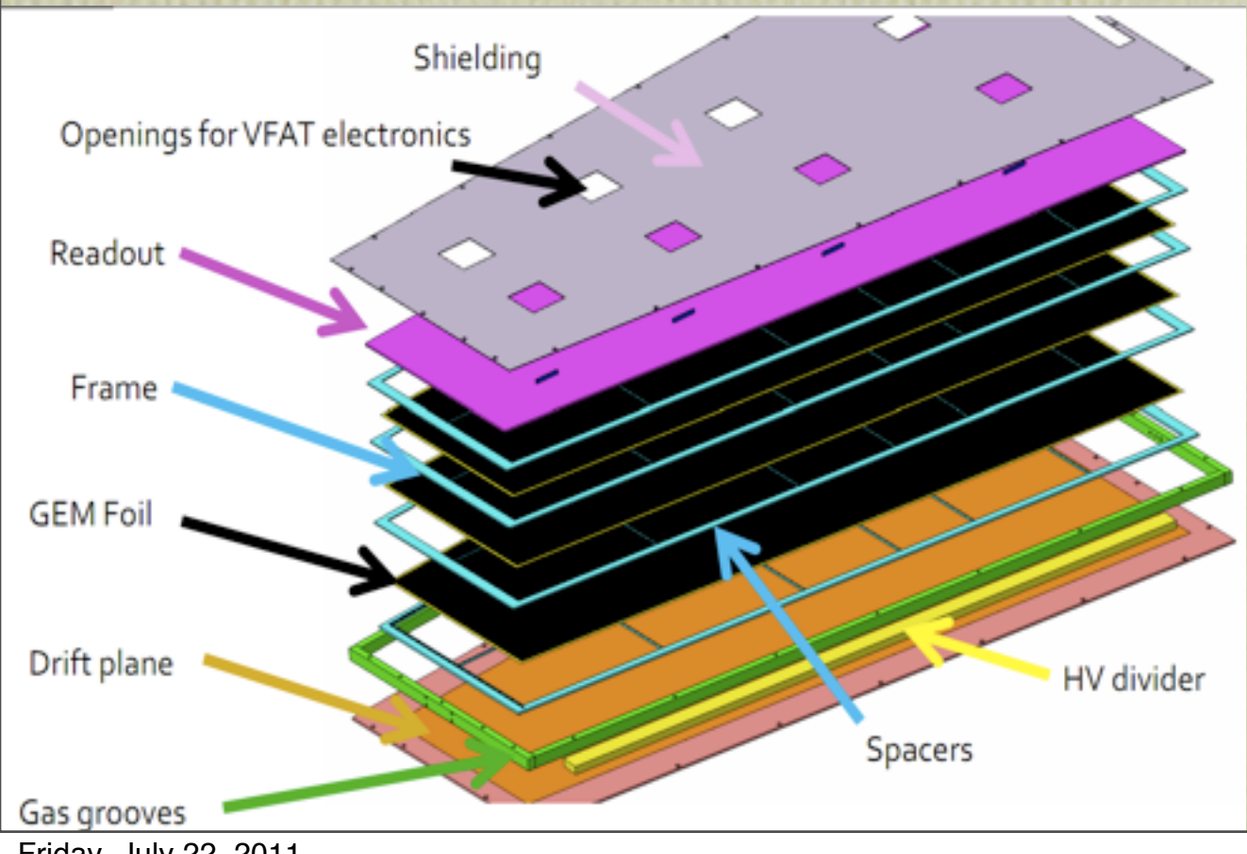


Electronics and latest prototype

Readout: VFAT chip (designed for TOTEM)

- *128 channels analog front-end*
- *binary output for each channel for tracking*
- *provides fast OR function on input channels for triggering*
- *adjustable thresholds, gain, signal polarity, integration time of analog input signals*
- *40 MHz clock signal sampling*

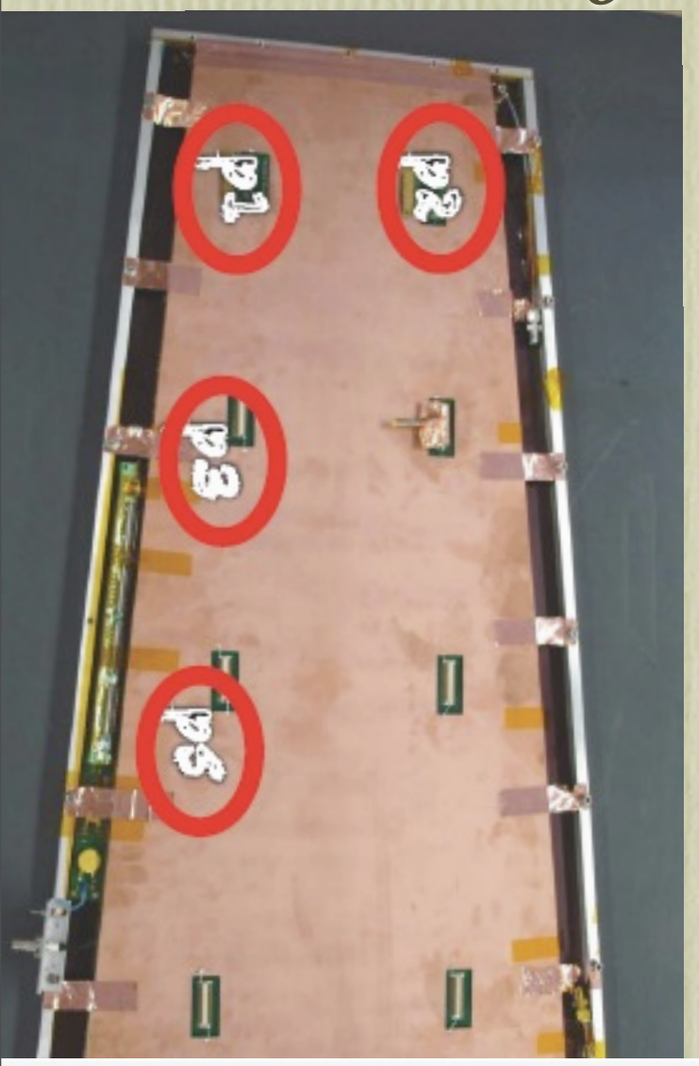




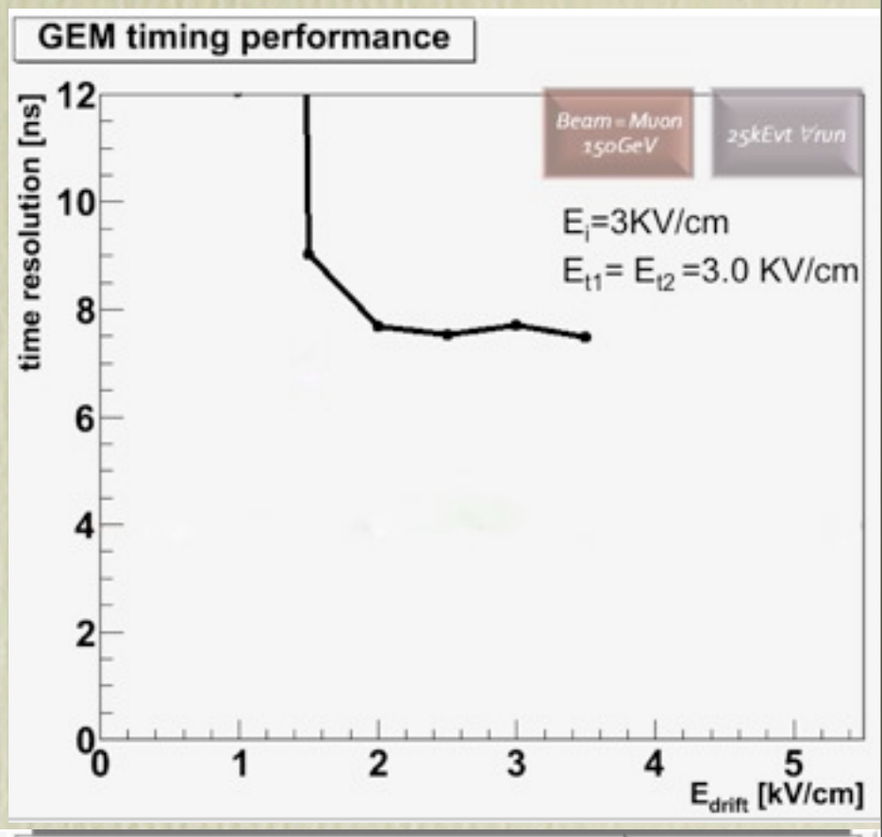
GEM1/1 II (3/1/2/1)

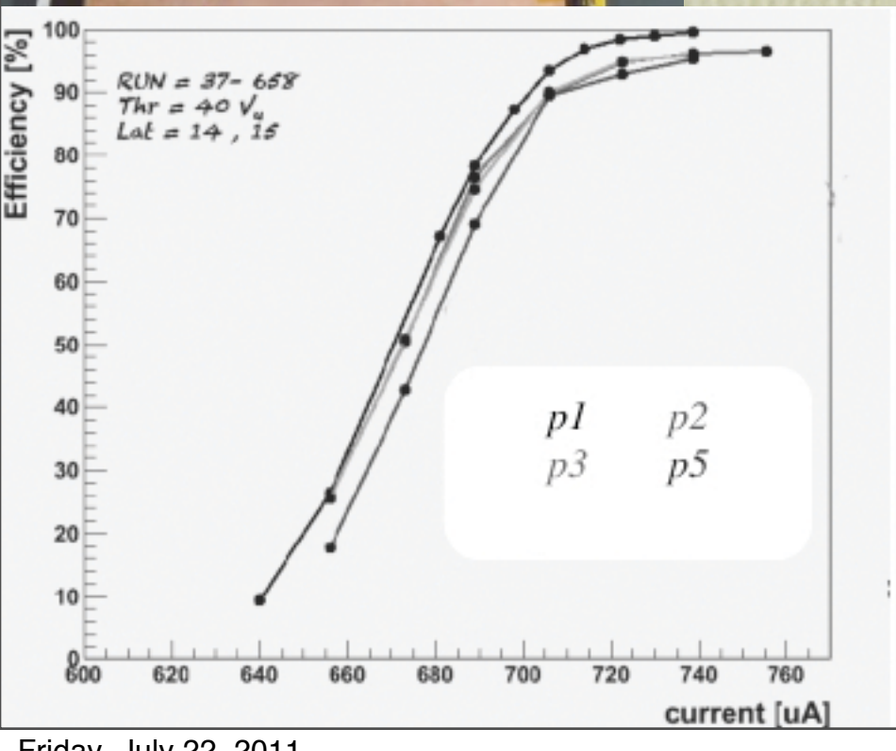
- *active area: 990x(220-445) mm²*
- *3072 channels (1D readout)*
- *Strip pitch = 0.8 mm*
- *Several gas mixtures employed (flowing at 5 l/h):*
  - *Ar/CO_2 (70/30, 90/10)*
  - *$Ar/CO_2/CF_4$ (45/15/40, 60/20/20)*
- *Tested in June 2011 (results currently being processed…)*

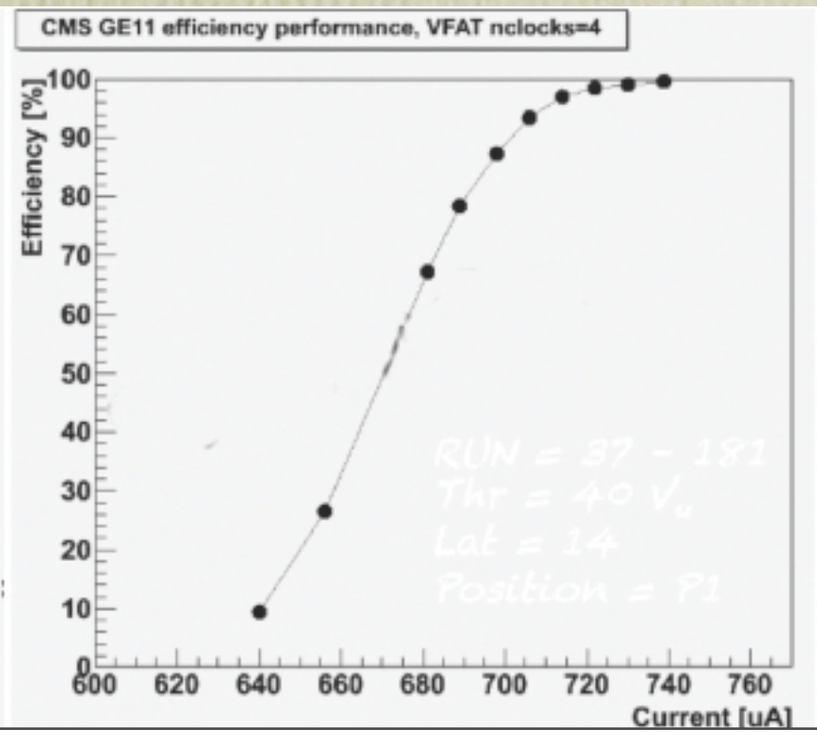
Results from October 2010 test beam

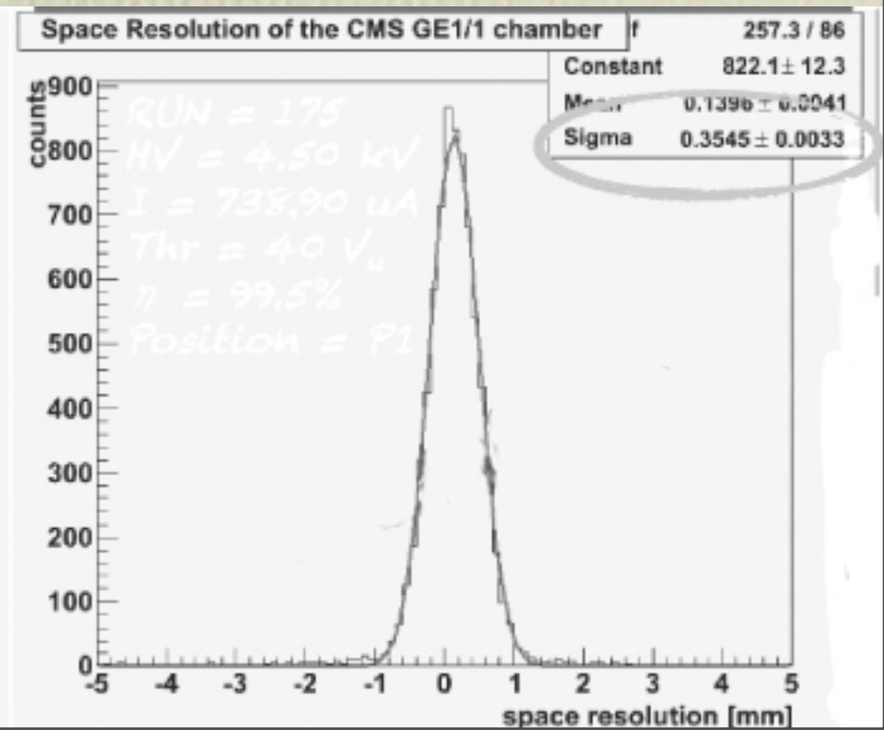


- *Muon beam from pions: 650 runs over p_i detector surfaces*
  - *3/2/2/2 with Ar/CO_2 (70/30)*
  - *in each p_i a VFAT chip is allocated reading out the chamber behavior regions which in CMS will be at different η coordinates and then exposed to different rates of radiation*
  - *HV scan 3.9 ÷ 4.5 kV*
- *Test beam held on June/July 2011 with 3/1/2/1 - $Ar/CO_2/CF_4$ chambers*









Conclusions

- *Trigger*
  - *Evidence for better control of trigger rate (for candidates built-up from 2 GEM stations)*
- *Tracking*
  - *Results suggests tracking improvements for muons can be achieved*
- *Prototypes building*
  - *Application of new techniques improving detector assembling and performance*
  - *Acquiring knowledge to build excellent performance detectors*

Future plans

- *DETECTOR*
  - *Processing of June/July 2011 test beam data with latest prototypes is ongoing*
  - *Construction test of 30x30 cm² prototype with new mechanics for get rid of thermal stretching*
    - *study feasibility on large scale detector*
- *TRACKING*
  - *Switch to GEM geometry simulations*
  - *Study muon reconstruction rescue in case of CSC ME1/1 off*
  - *Studies with real physics cases:*
    - *low-pT forward muon from b-jets*
    - *multi-leptons signatures from high energy scale hard processes*
- *TRIGGER*
  - *Simulation studies basically done*
  - *Future activities are going to be focused on choosing the most suited electronics for triggering*