Performance of TOTEM in run II

K. Österberg,
Department of Physics,
University of Helsinki & Helsinki Institute of Physics

on behalf of
TOTEM collaboration

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UNIVERSITY OF HELSINKI

HELSINKI INSTITUTE OF PHYSICS

- Commisioning & first 13 TeV data
- TOTEM consolidation & upgrade
- Run II physics perspectives

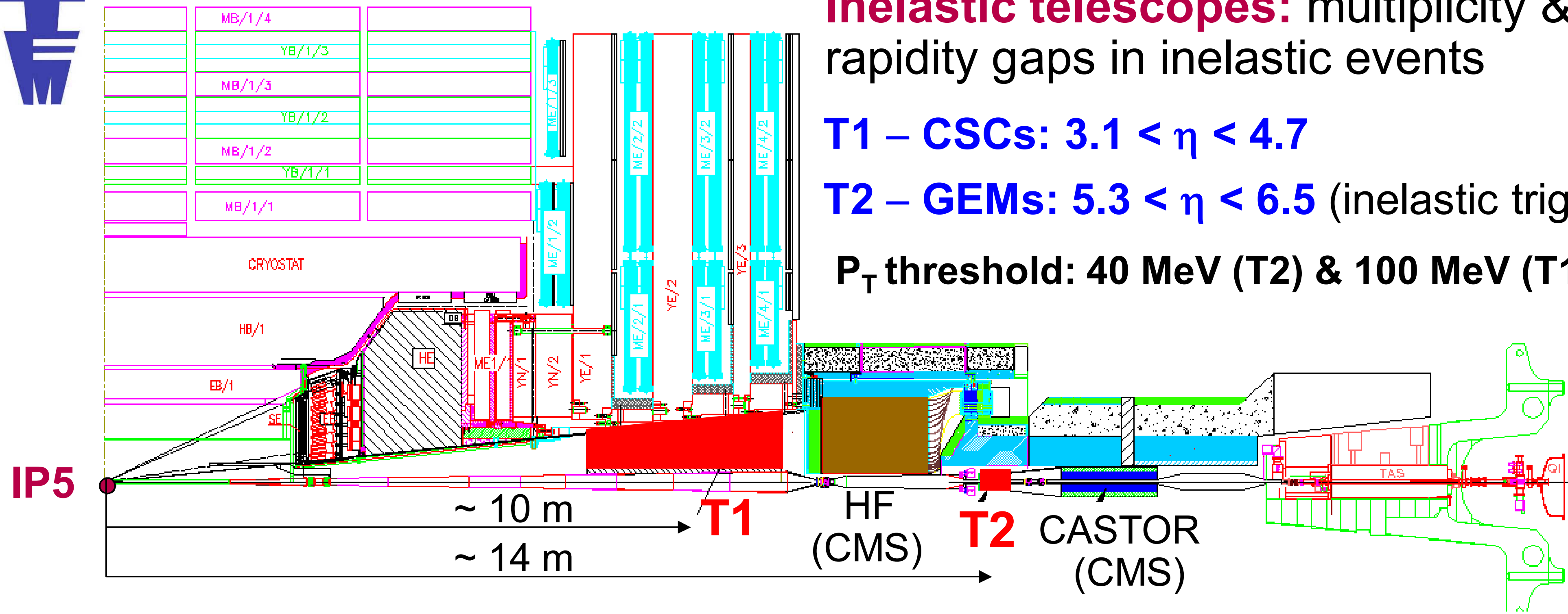
Experimental apparatus @ LHC IP5

Inelastic telescopes: multiplicity & rapidity gaps in inelastic events

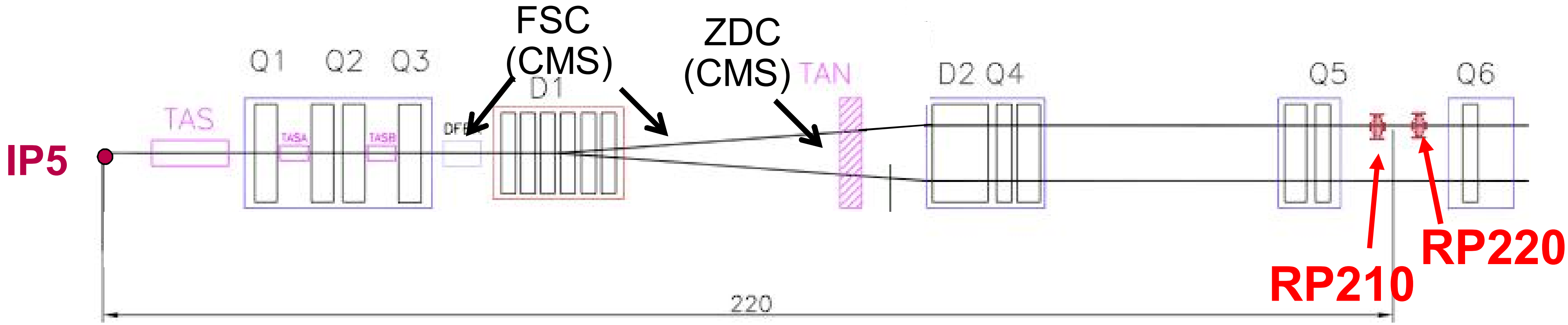
T1 – CSCs: $3.1 < \eta < 4.7$

T2 – GEMs: $5.3 < \eta < 6.5$ (inelastic trigger)

P_T threshold: 40 MeV (T2) & 100 MeV (T1)



Roman Pots – Si μstrip sensors: elastic & diffractive protons (proton trigger)



Consolidation & upgrade: RP relocation, DAQ upgrade, new RPs, timing & Si sensors

Experimental apparatus @ LHC IP5

Inelastic telescopes: multiplicity & rapidity gap

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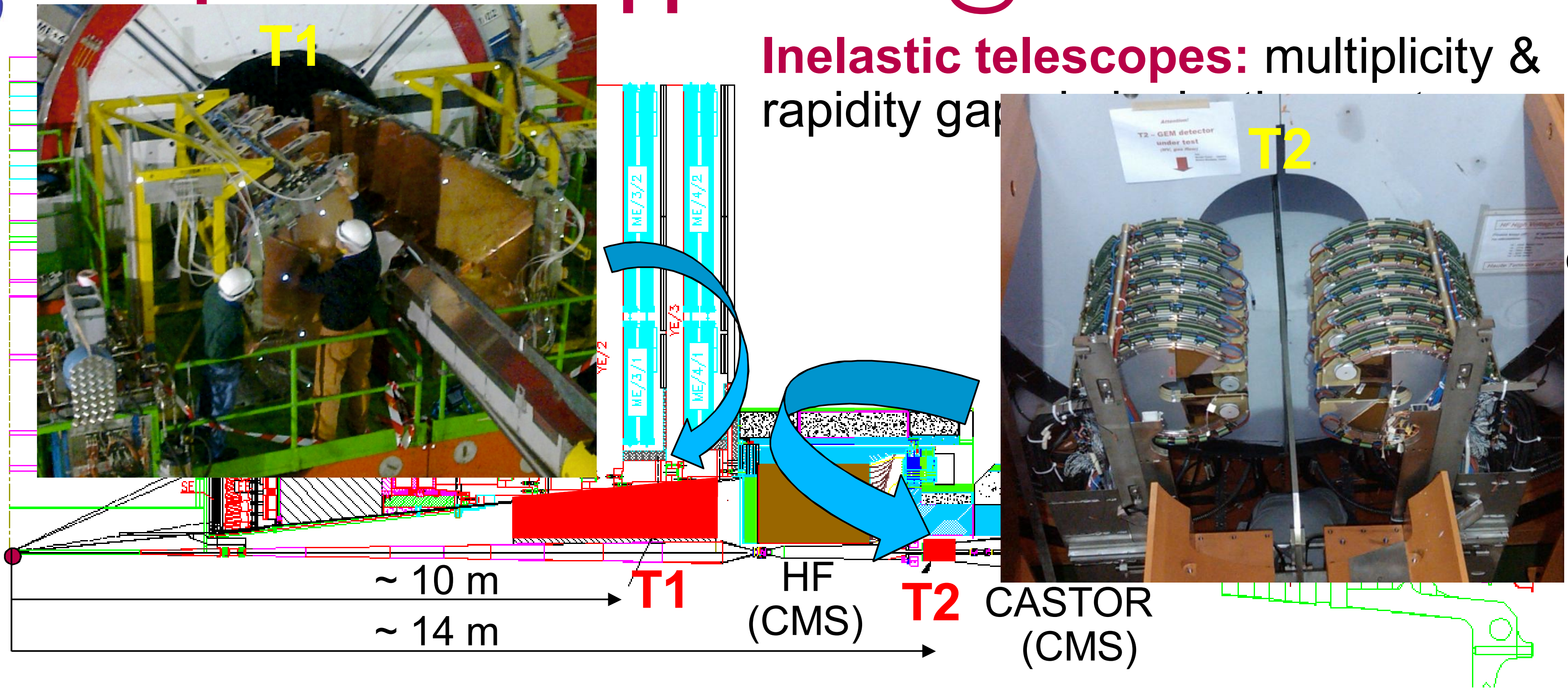
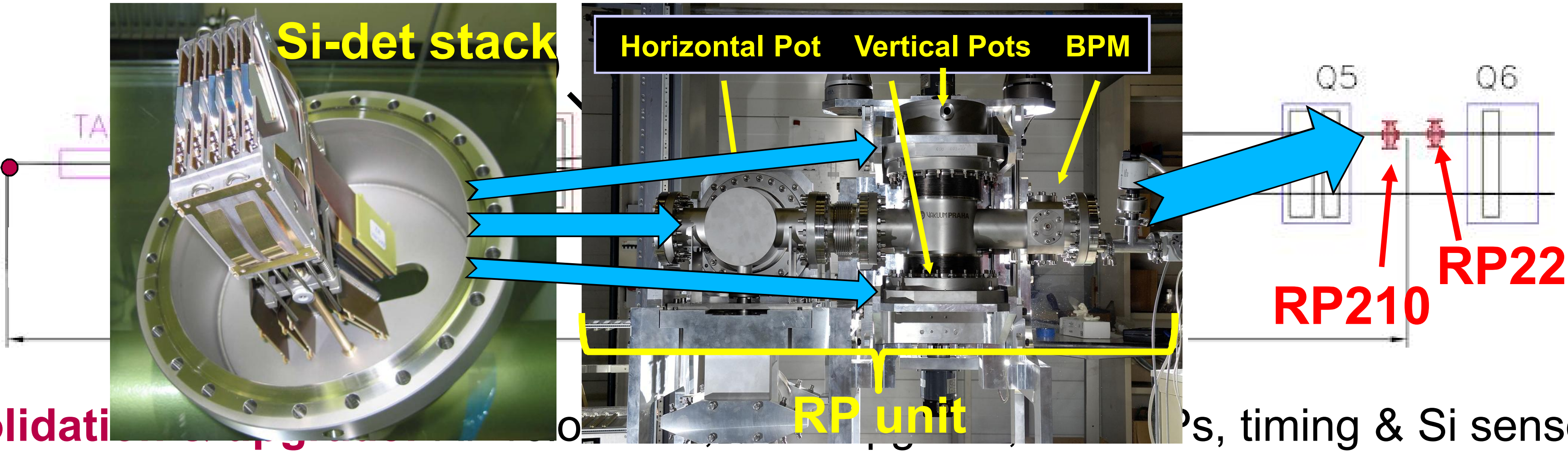


Roman Pots – Si μstrip sensors: elastic & diffractive protons (proton trigger)

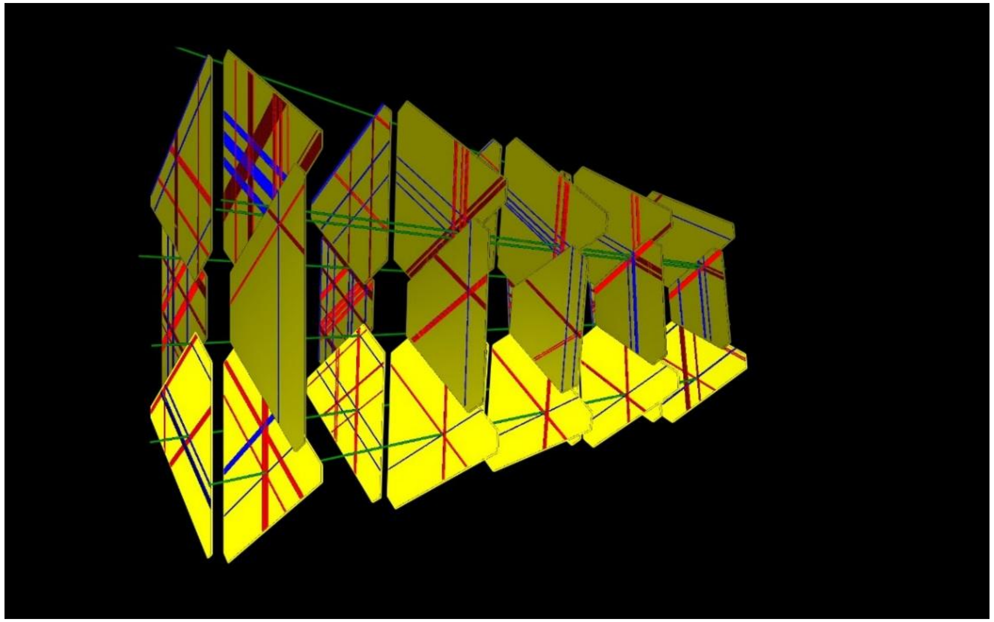


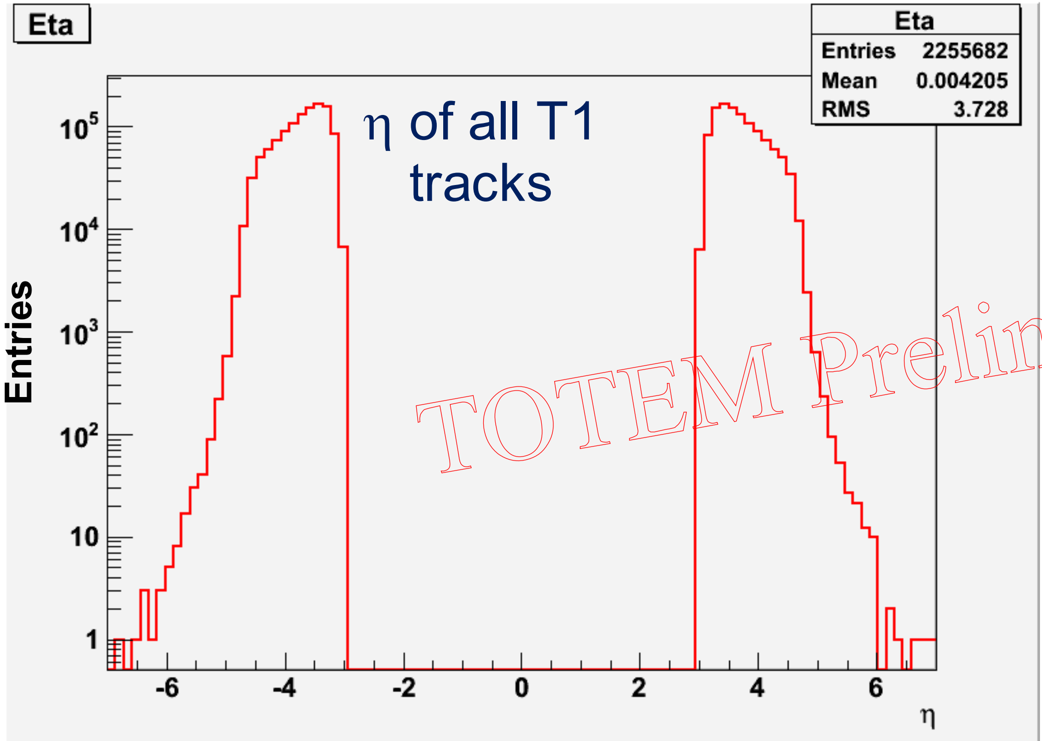
Consolidati o Ps, timing & Si sensors

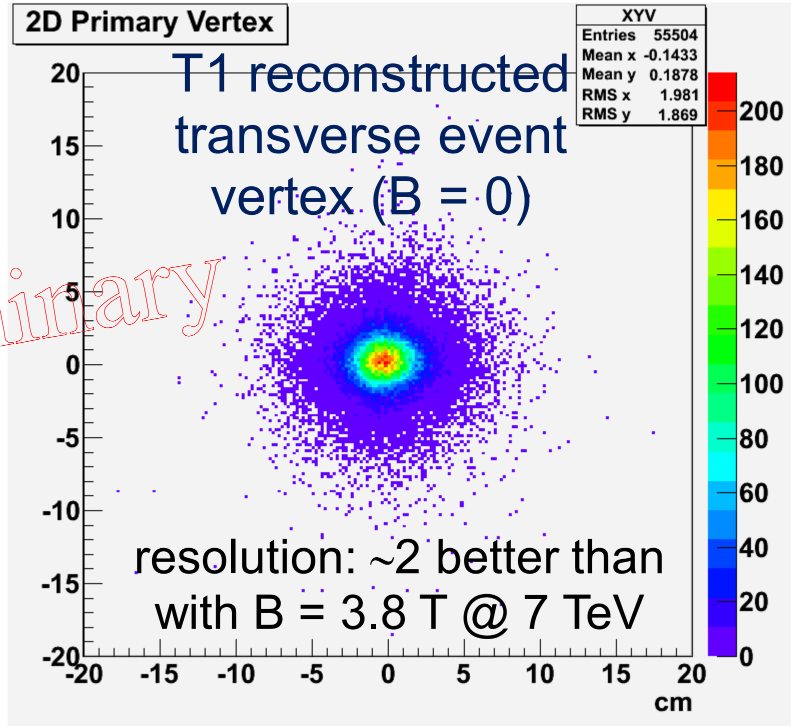
T1 telescope

- Reinstalled & commissioned.
- Fully operational.
- Tracking performance & efficiency (at least) as in Run I

Performance plots from LHCf run ($\mu \sim 0.003$) without CMS B field

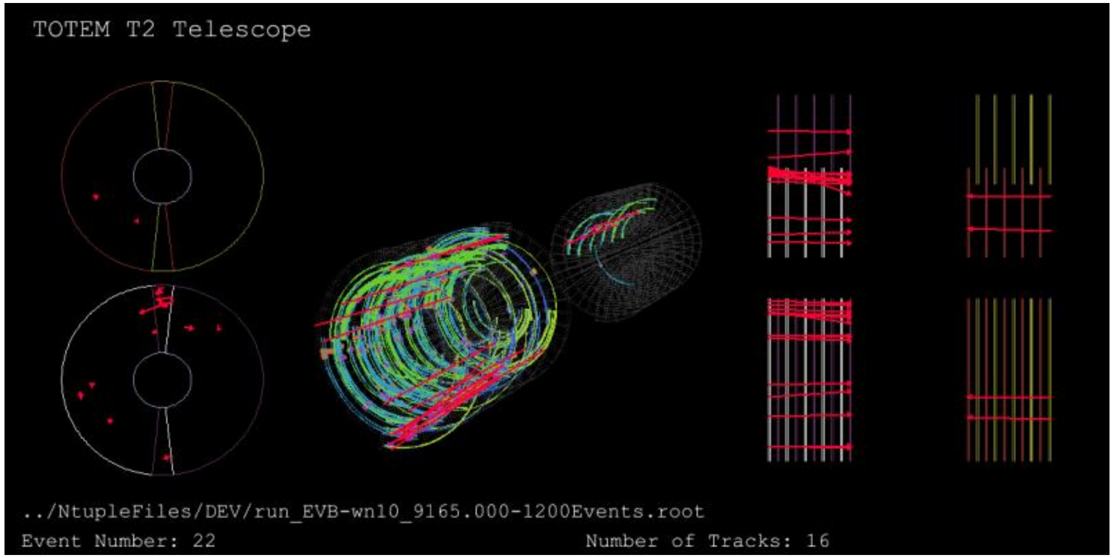




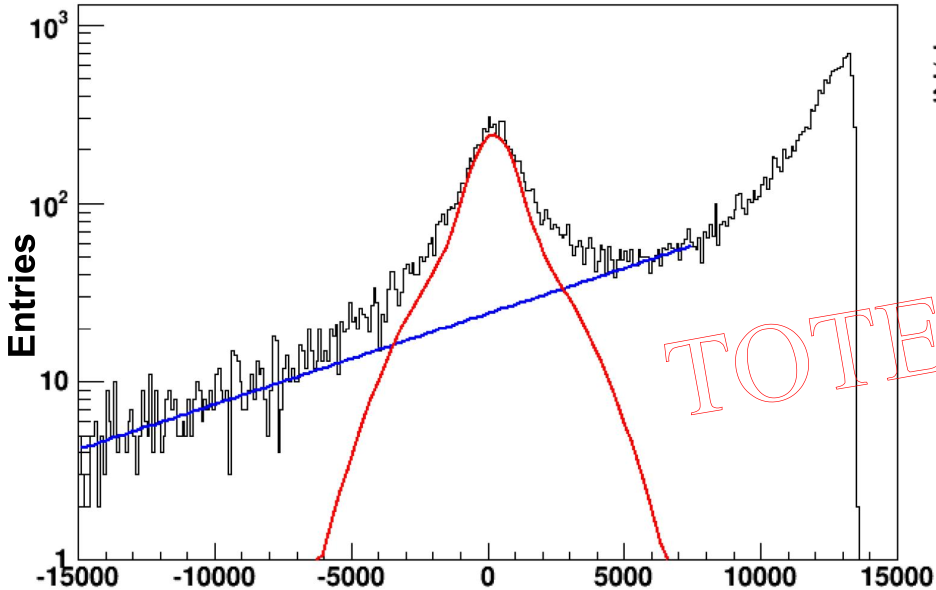


T2 telescope

- Reinstalled & commissioned.
- Similar efficiency & tracking performance as in Run I
- 3 out of 4 half-arms operational (missing half-arm ≤ 1 % effect on measurements)

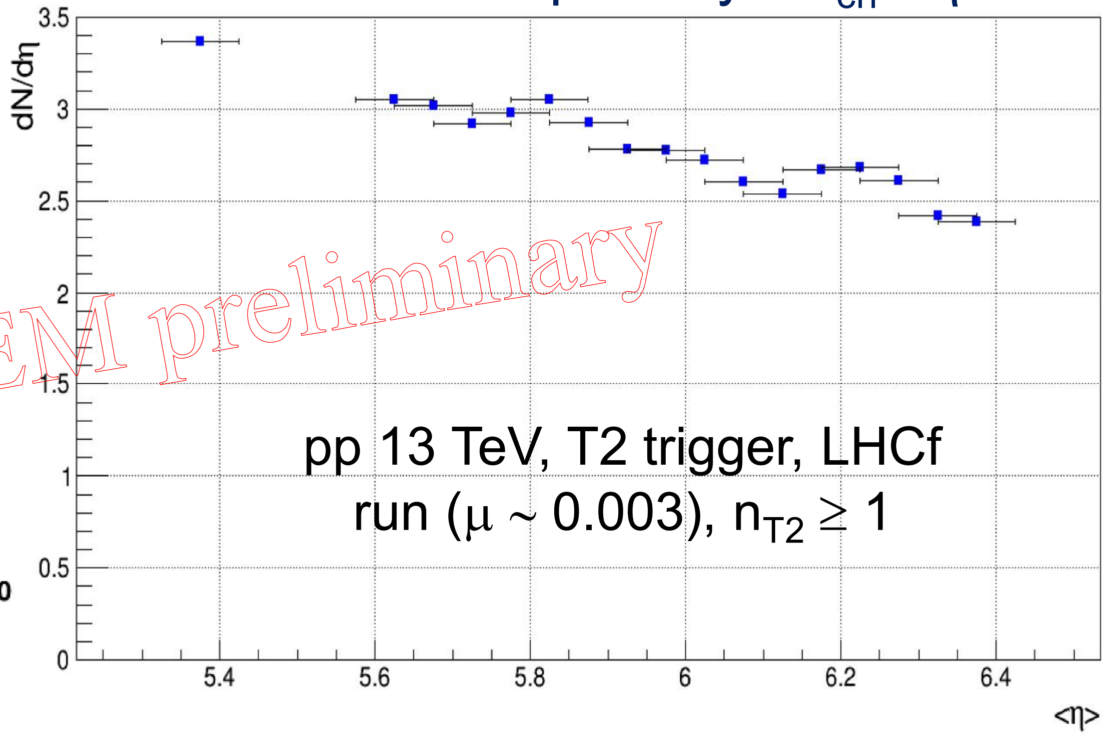


Primary/secondary separation



identical method as in Eur. Phys. J. C 74 (2014) 3053

Uncorrected primary $dN_{ch}/d\eta$

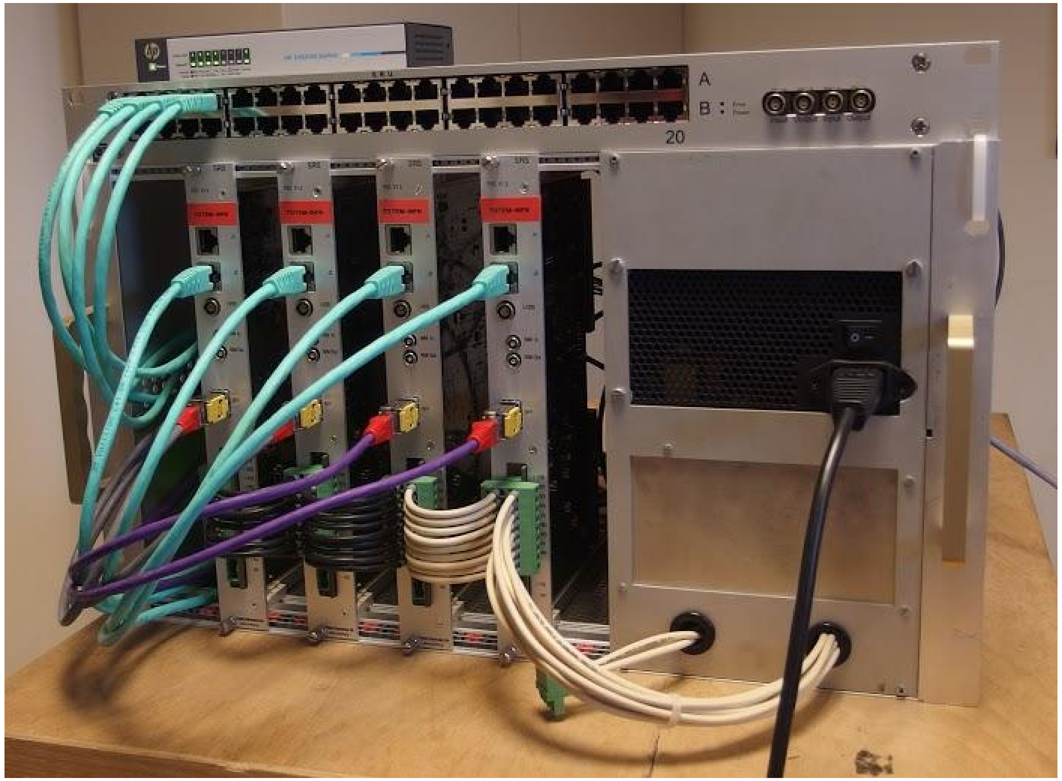


DAQ consolidation

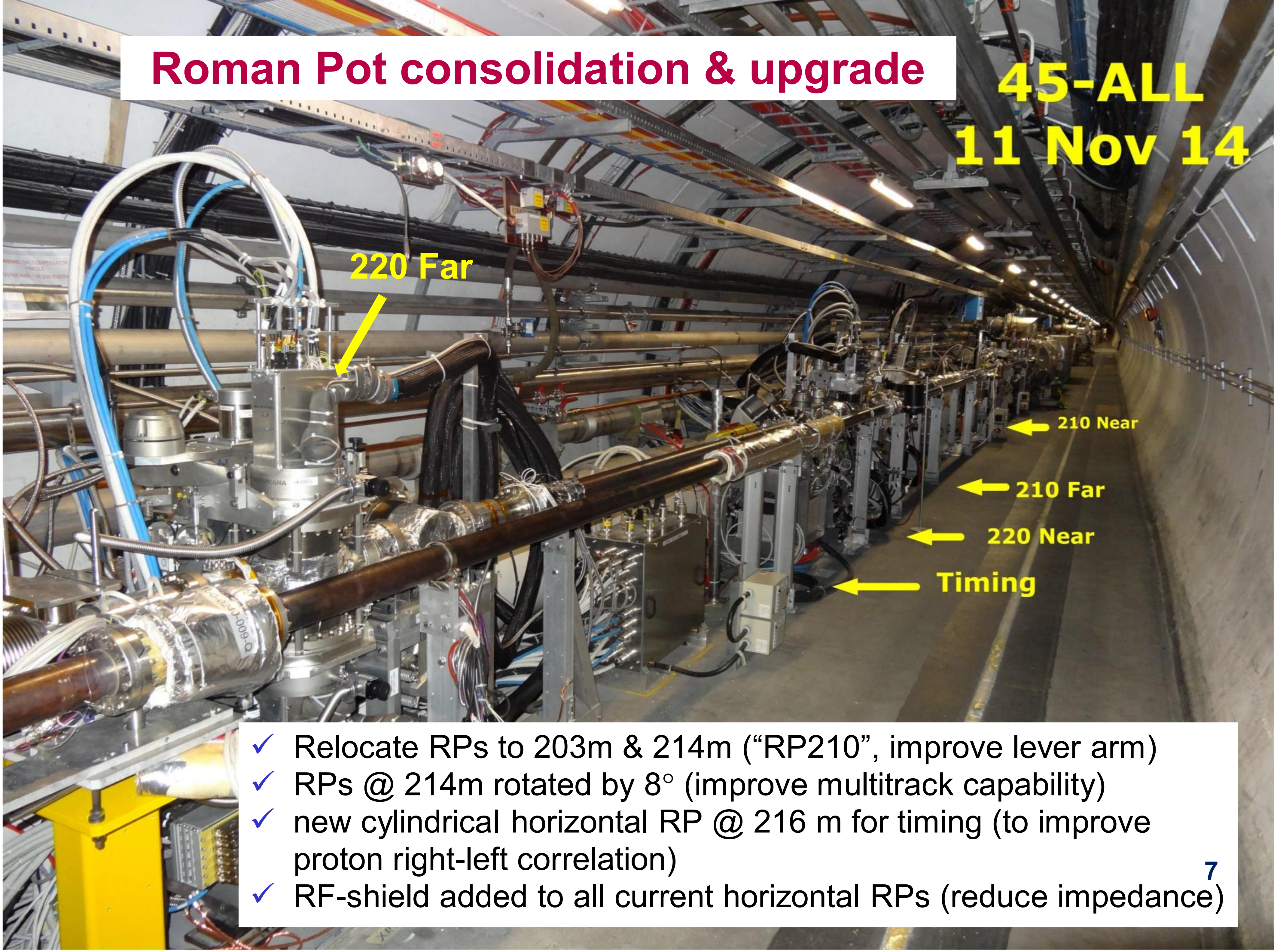
- Replacement of VME back-end with Ethernet 1Gb links, using RD51 FrontEnd Concentrator (FEC) cards
- Full compatibility with CMS DAQ & LHC TTC
- Fully commissioning done in last weeks VdM run
- 25kHz trigger rate measured: factor 25 w.r.t. RunI DAQ

On-going:

- Studies of on-line hardware algorithms:
  - Data-reduction
  - Filtration based on on-line reconstruction
- Further improvements of DAQ rate capabilities excepted for next special run (October 2015)
- Integration with the CMS DAQ



Roman Pot consolidation & upgrade



- ✓ Relocate RPs to 203m & 214m (“RP210”, improve lever arm)
- ✓ RPs @ 214m rotated by 8° (improve multitrack capability)
- ✓ new cylindrical horizontal RP @ 216 m for timing (to improve proton right-left correlation)
- ✓ RF-shield added to all current horizontal RPs (reduce impedance)

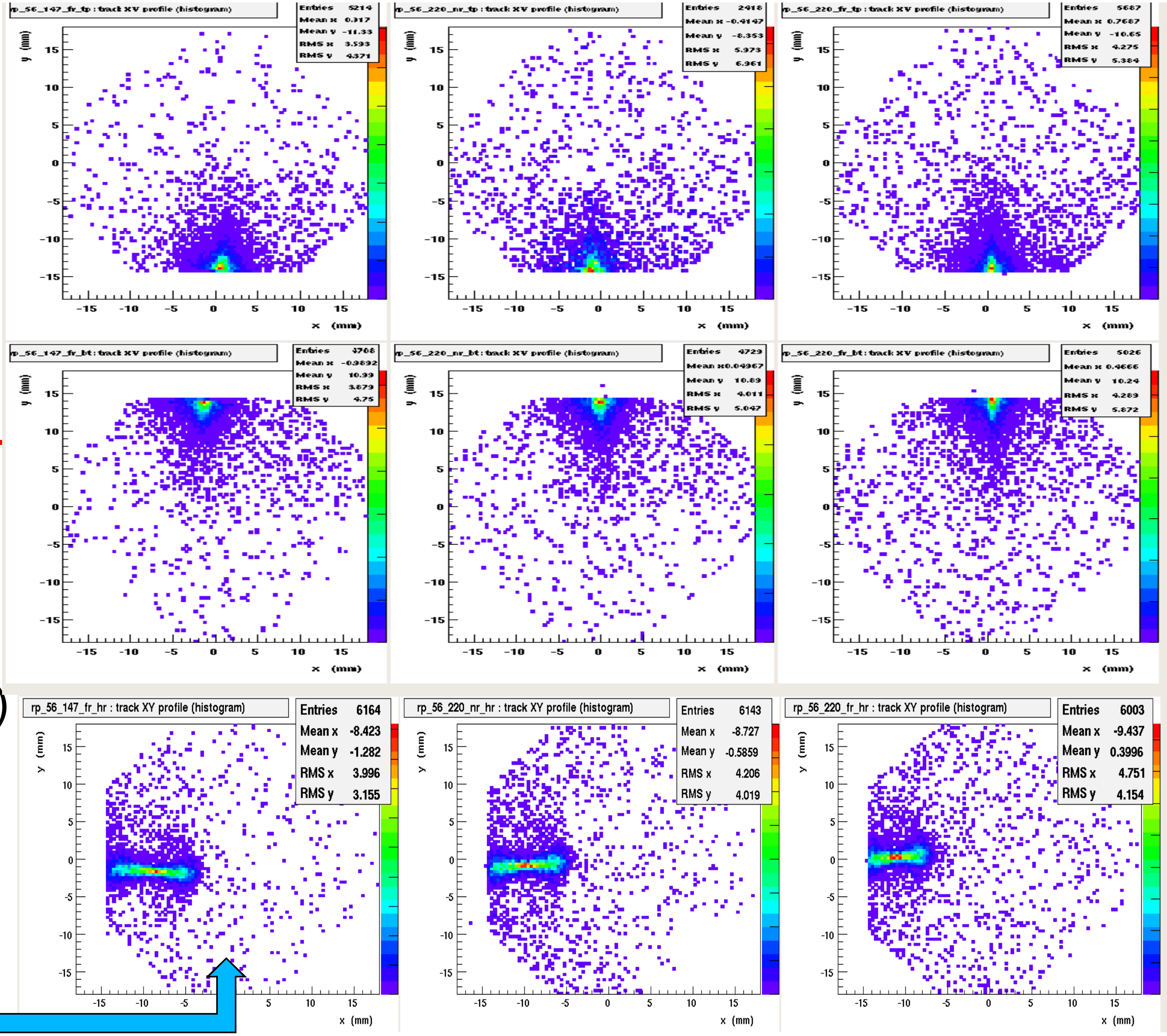
RP performance

RP hit profiles in 56 arm

RP Si-μstrip detectors reinstalled & commissioned.

Plots from VdM run (β^* = 19 m, RP@12$\sigma_{beam,T}$)

56 RP210 far | 56 RP220 near | 56 RP220 far



top

t

ξ

bottom

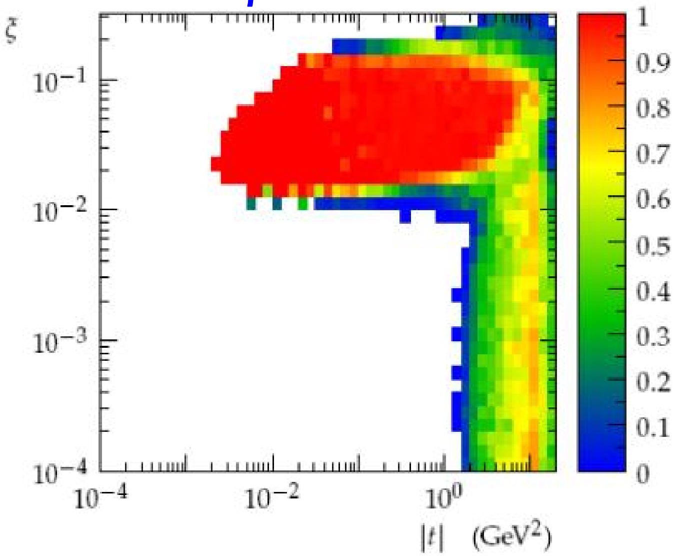
horizontal

new rotated RP@214m

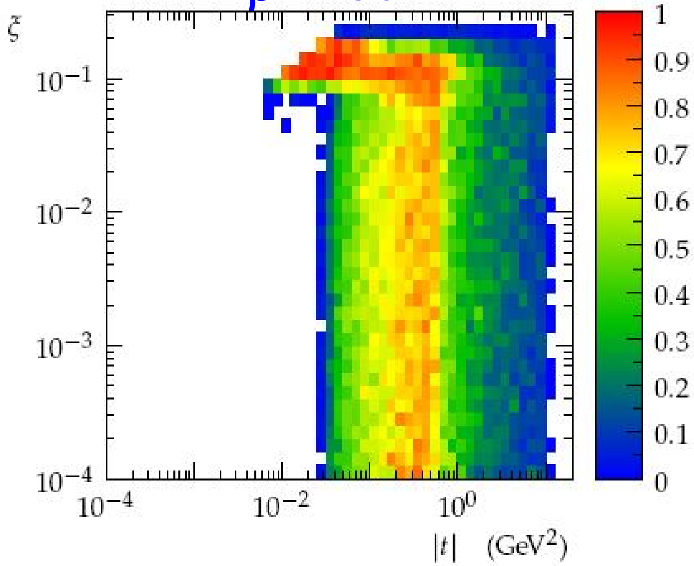
LHC Optics & proton acceptance

$t \approx -p^2\theta^2$: four-momentum transfer squared; $\xi = \Delta p/p$: fractional momentum loss

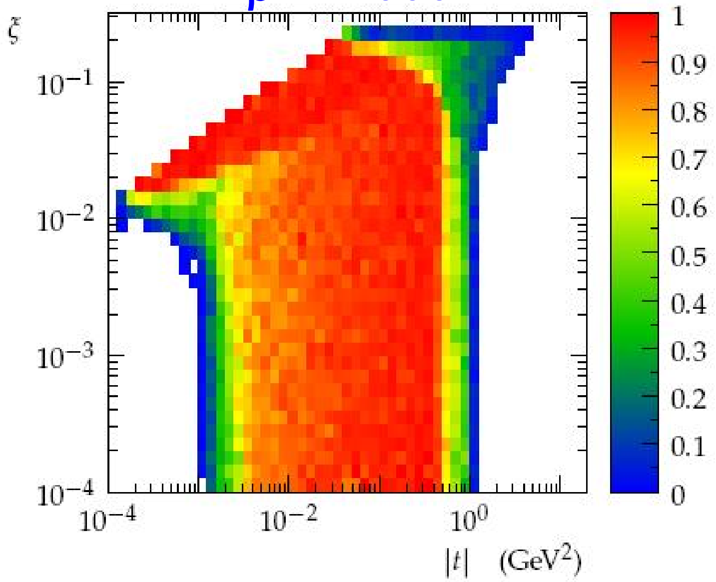
β* = 0.55 m



β* = 90 m



β* = 1000 m



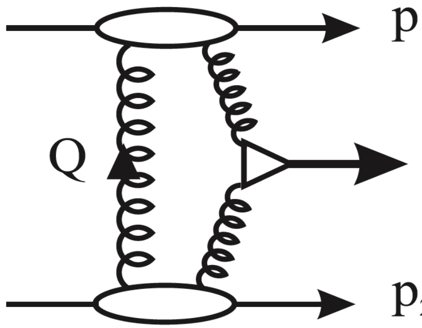
> 10^{33} cm^{-2} s^{-1} ← $\mathcal{L} \propto \frac{1}{\beta^*}$ → ~10^{27} cm^{-2} s^{-1}

Diffraction:
ξ > ~0.03, low cross-section processes (hard diffraction)
Elastic scattering: large |t|

Diffraction: all ξ if |t| > ~ 0.04 GeV^2, soft & semi-hard diffraction
Elastic scattering: low to mid |t|
Total cross-Section

Elastic scattering: very low |t|, Coulomb-Nuclear Interference
Total cross-Section

(Exclusive) central diffraction



p_1 (ξ_1) $M_X^2 = \xi_1 \xi_2 s$

also $\gamma\gamma$ fusion &
γPomeron fusion

X at rapidity y_X **gg collider**

p_2 (ξ_2) $y_X = \frac{1}{2}\ln\frac{\xi_1}{\xi_2}$

- exchange of colour singlets with vacuum quantum numbers
  $\Rightarrow$ selection rules for system X: $J^{PC} = 0^{++}, 2^{++}, \ldots$
- with double-arm proton detection
  β^* = 90 m runs: all M_X, $\mu \sim 0.1 - 0.5$ $\Rightarrow$ 0.15-6 pb^{-1}/day
  low β^* runs: $M_X > \sim 250$ GeV, $\mu \sim 25 - 50$ $\Rightarrow$ O(fb^{-1}/day)
- Comparison of prediction from forward to central system:

M(pp) =? M(central), $p_{T,z}$(pp) =? $p_{T,z}$(central), vertex(pp) =? vertex(central)

- prediction of rapidity gaps from proton x's : $\Delta\eta_{1,2} = -\ln\xi_{1,2}$

Examples:

- Glueball studies
- Exclusive charmonium production: O(10 pb – 10 nb)
- Low mass exclusive dijets (p^T_{jet} > 30 GeV: $\sigma_{visible}$ ~100 pb)
- Searches for missing mass signals of O(pb) e.g. SUSY searches
- High mass exclusive diboson & dijets: O(0.01 –10 fb) standard high lumi runs

(first four: special medium lumi runs)

Vertex reconstruction by time measurement

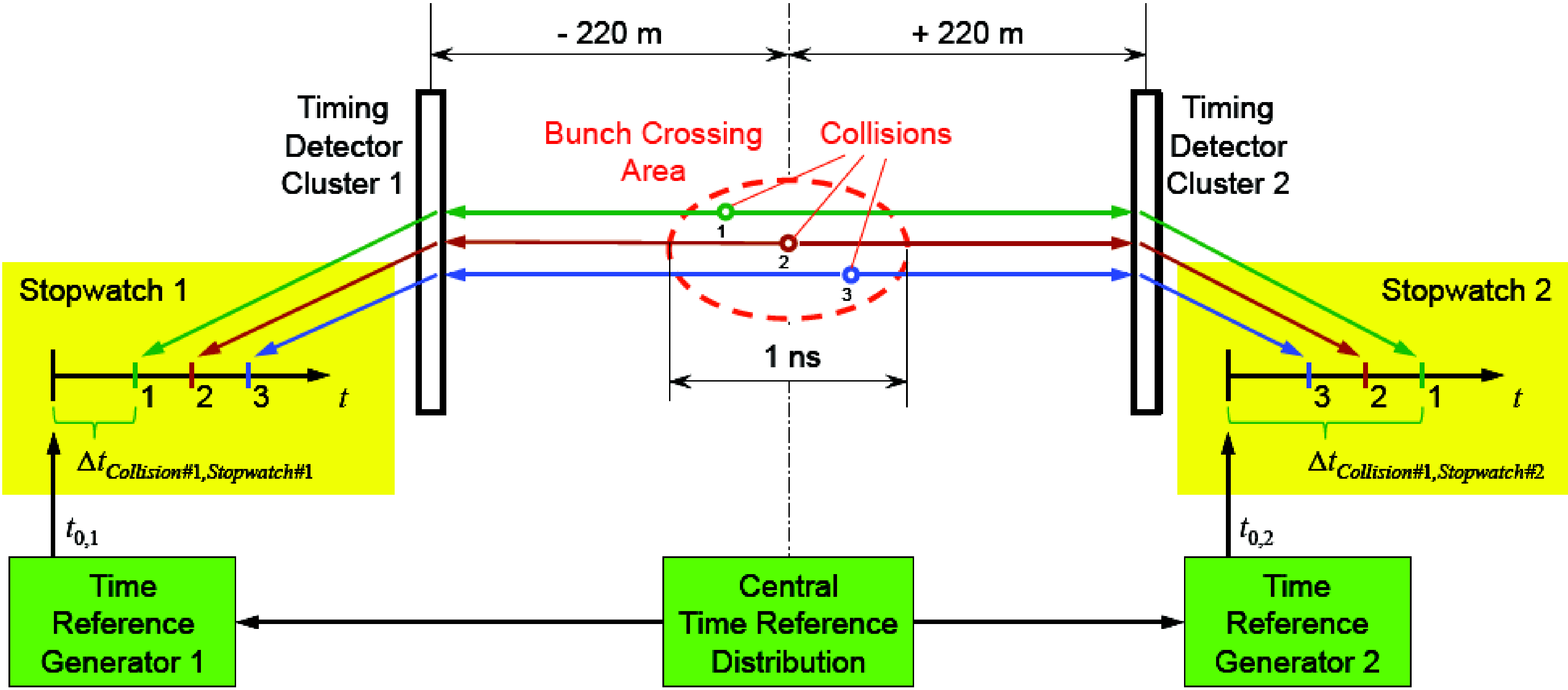
Pileup problem:

High luminosity → multiple events in 1 bunch collision !

– CMS tracker can separate multiple vertices longitudinally

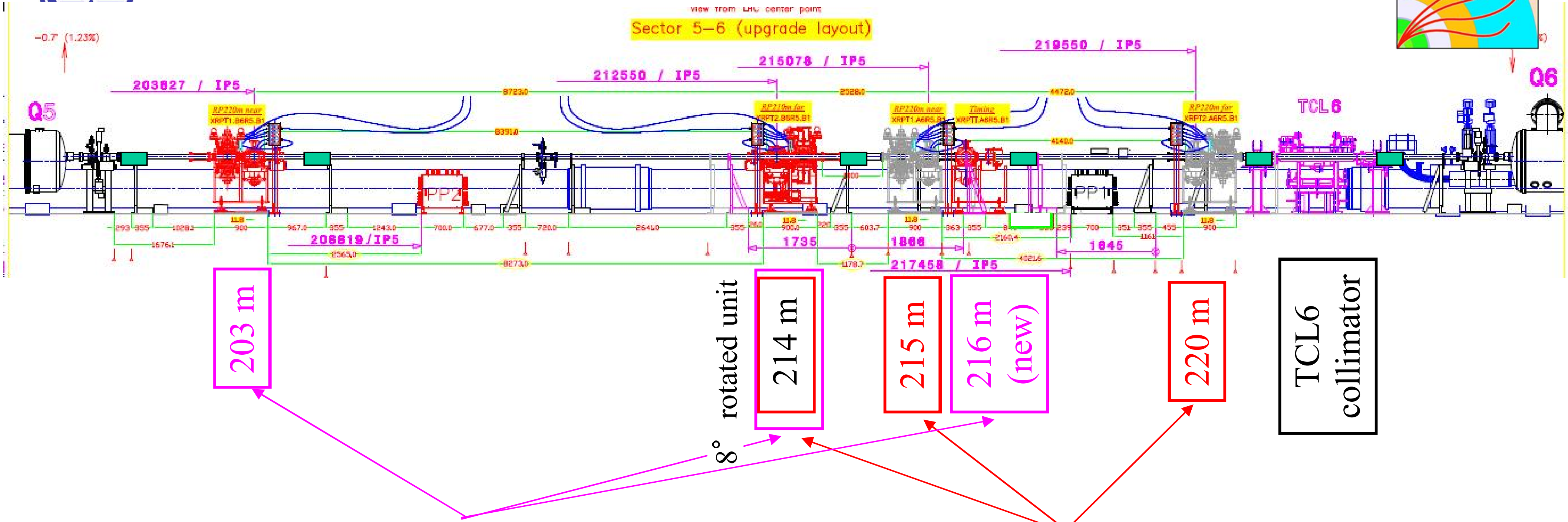
– leading proton tracks have angles in μrad range → insufficient vertex precision

– for double-arm events (CD) reconstruct vertex from time-of-flight difference



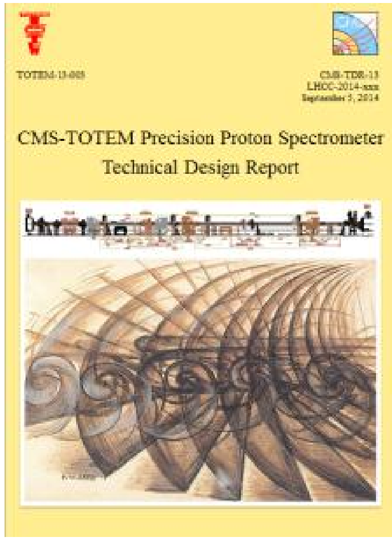
$$\text{Position of Collision} \sim \Delta t_{Collision\#1,Stopwatch\#1} - \Delta t_{Collision\#1,Stopwatch\#2}$$

Roman Pot upgrades



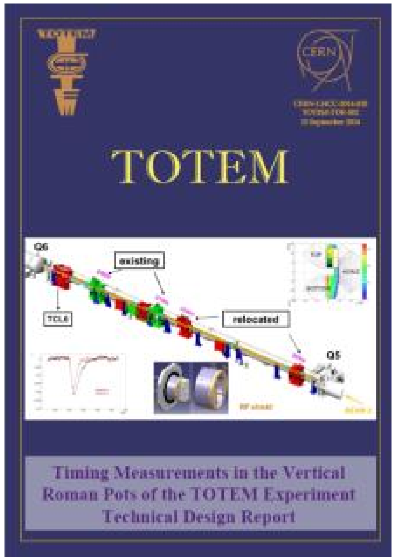
low β* (< 1 m), high lumi, standard runs, M_X > 250 GeV

high β* (19 m, 90 m, > 1 km), low – medium lumi, special runs, all M_X



CMS-TOTEM Precision Proton Spectrometer (CT-PPS)

Quartz sensors for Timing & pixel sensors for tracking in horizontal RPs



Timing Measurements in the Vertical Roman Pots of the TOTEM Experiment

Thin diamond sensors in vertical RPs

Low β* RP insertions

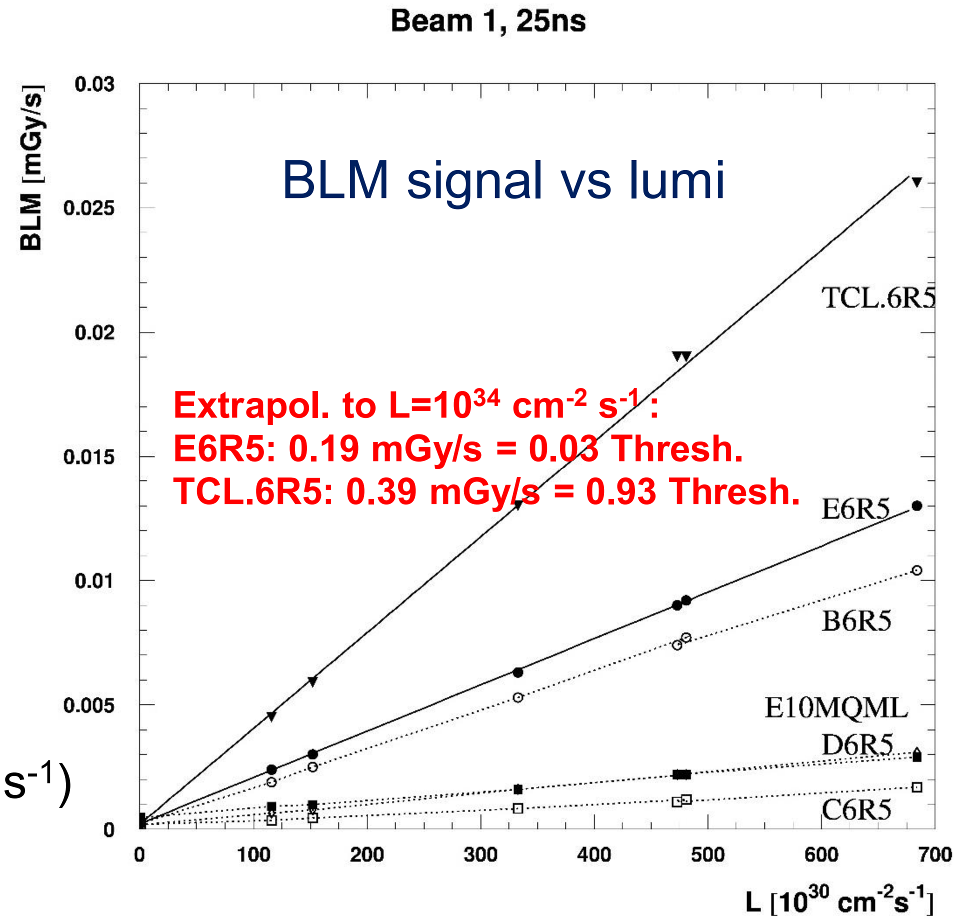
Final goal: Establish insertions for physics in regular fills from 2016

Experience from 2012:

- Collision debris showers from IP ⇒ beam dump due to BLMs
- Impedance heating combined with outgassing

Technical Improvements during LS1

- New ferrite material & ferrite bake-out at 1000 ºC ⇒ less outgassing
- RF shields & cylindrical geometry for horizontal RPs ⇒ impedance reduction
- TCL6 to intercept showers from RPs



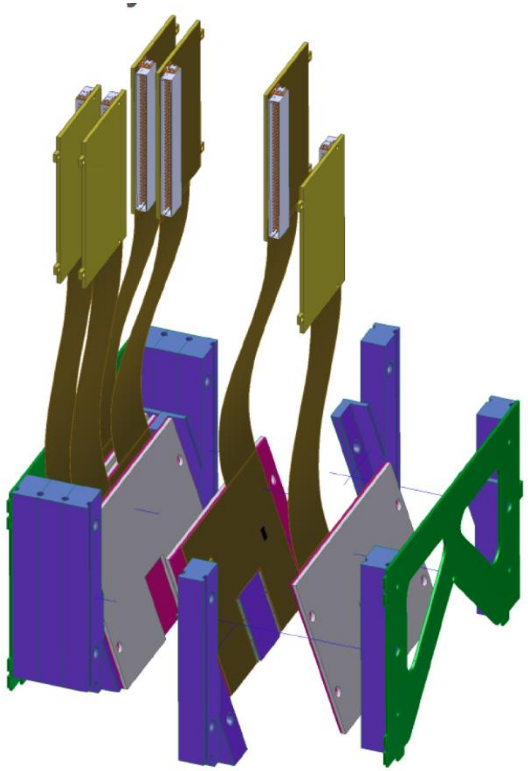
July: Beam-based alignment/loss maps at ~ $30\sigma_{beam,hor}$ & successful RP insertions in 50 ns intensity ramp-up (up to L ≈ 1.3 · 10^{33} cm^{-2} s^{-1})
August: RPs closer (~ $25\sigma_{beam,hor}$), final TCL configuration & successful RP insertions in 25 ns intensity ramp-up so far (up to L ≈ 0.7 · 10^{33} cm^{-2} s^{-1})

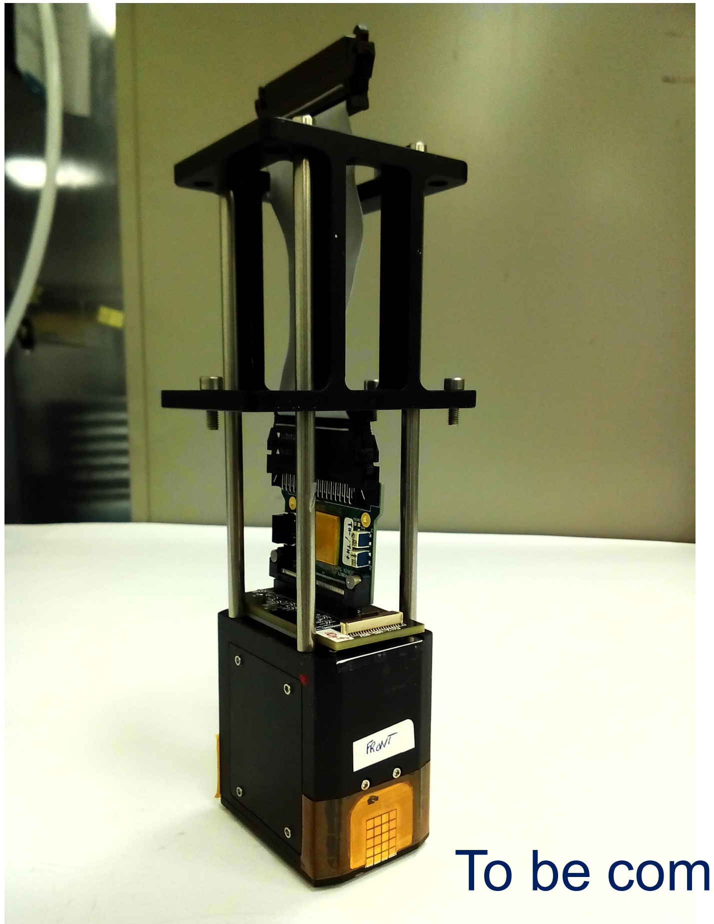
Main conclusion:
* Linearity of BLM response with lumi, proving debris-hypothesis for losses
* Extrapolation to L≈10^{34} cm^{-2} s^{-1} indicates no problem with BLM threshold for RPs

CT-PPS detectors

Tracking: 3D silicon sensors

• PSI46dig ROC, with same readout Phase I CMS pixel upgrade
• 6 detector planes per station
• 10 μm (position) & 1-2 μrad (angle)





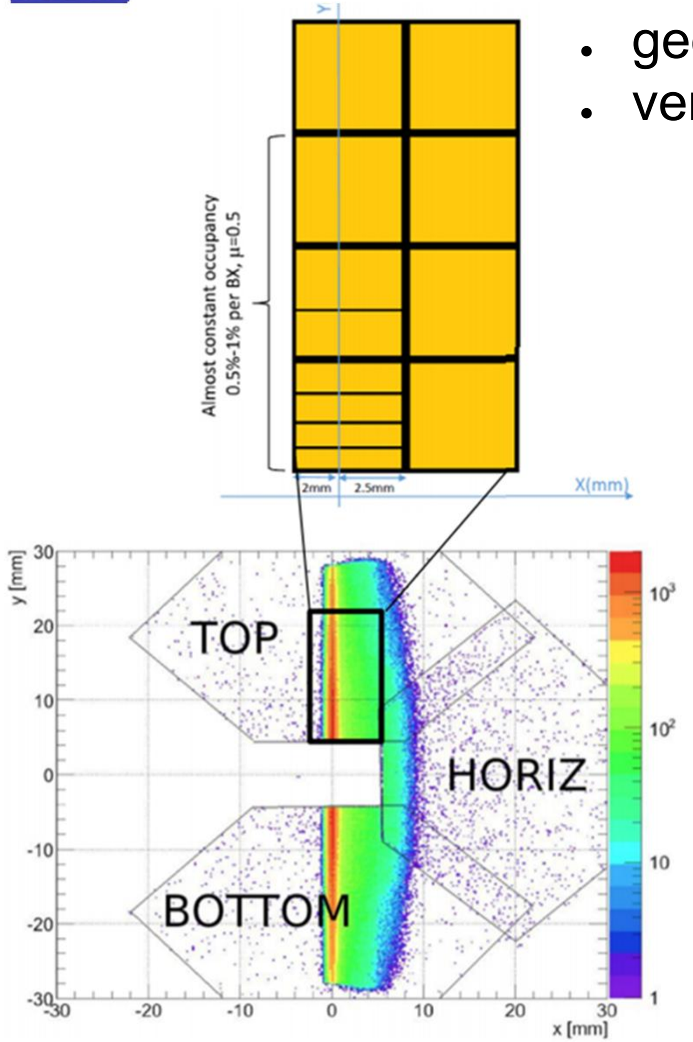
Timing baseline: Quartic detector

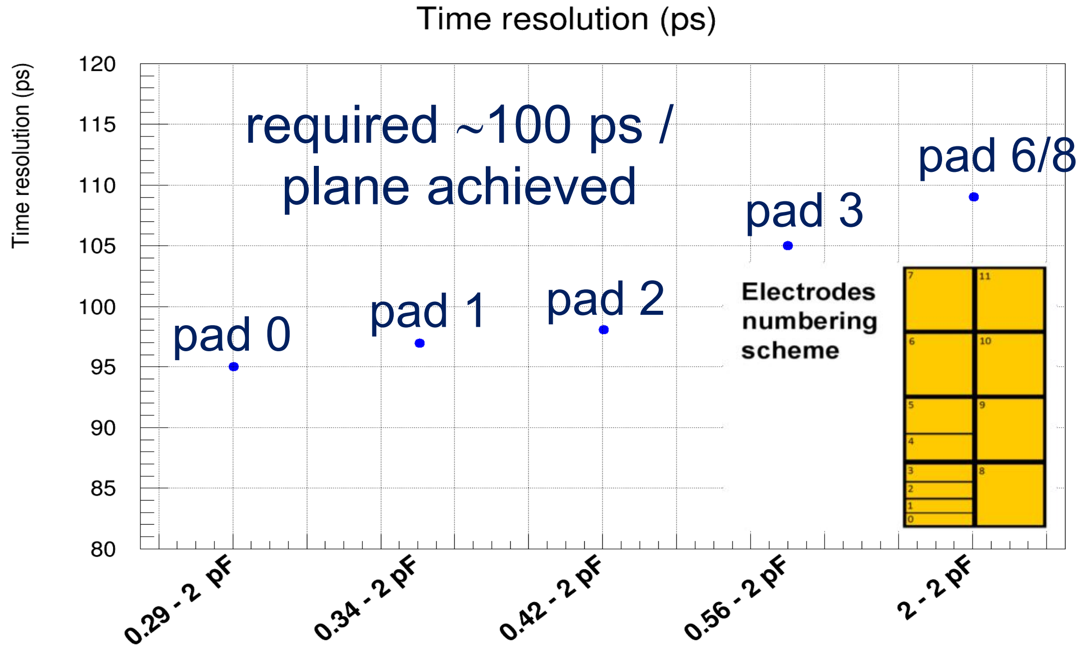
• 20 (4 x 5) quartz bars, 3 x 3mm^2, SiPM for light detection.
• 2 modules/RP unit
• In beam tests: σ(t) = 30 ps/module (~ 20 ps/RP unit)
• Currently modules tested in RPs with MIPs

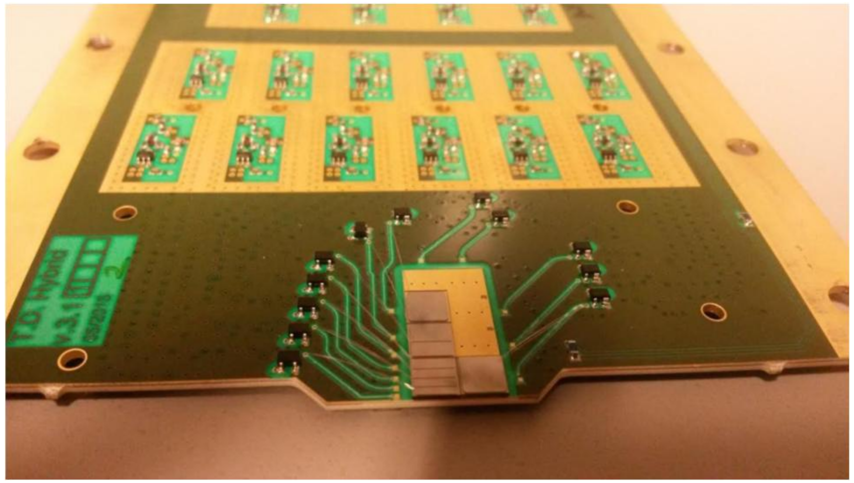
To be completed & installed in spring 2016

Diamond timing detectors

- geometry adjusted to track occupancy in β^* = 90m runs
- vertex z-position reconstruction resolution ~few cm







currently 2 completed planes being tested inside RPs with MIPs

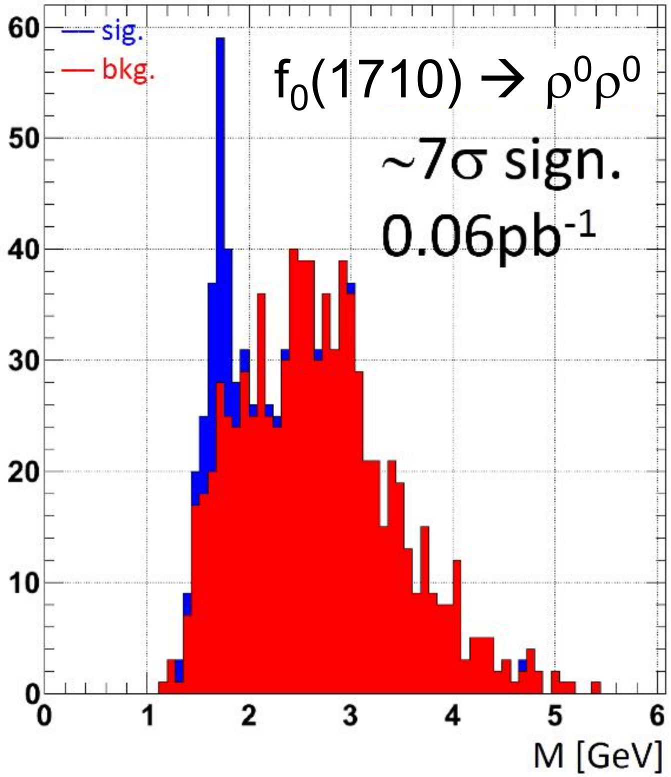
total 12 planes (each with 4 diamonds) to be completed & installed spring 2016

Glueball studies at $\beta^* = 90$ m

Pomeron ≈ colourless gluon pair/ladder ⇒ fusion likely to produce glueballs
CD@LHC: $x \sim 10^{-3} - 10^{-4}$ gluons ⇒ pure gluon pair ⇒ $M_X \sim 1 - 4$ GeV
Candidates for 0^{++} glueball: $f_0(1500)$ or $f_0(1710)$
Lattice QCD favours $f_0(1710)$

Decays and branching ratios of $f_0(1710)$ poorly explored (unlike $f_0(1500)$)
→ Goal: characterize $f_0(1710)$ and compare with known $f_0(1500)$

CMS+TOTEM data from 2012: ($\mathcal{L} = 3\ nb^{-1}$ of double arm RP trigger)
show sensitivity to $f_0(1710) \to \rho^0\rho^0 \to 4\pi^\pm$ (channel not yet reported in PDG)



- particle ID using CMS tracker dE/dx
- RP protons assure exclusivity ($p_{T,RP} \sim p_{T,tracker}$)
- $\sigma(M) \sim 20 - 30$ MeV

[common analysis note in progress]

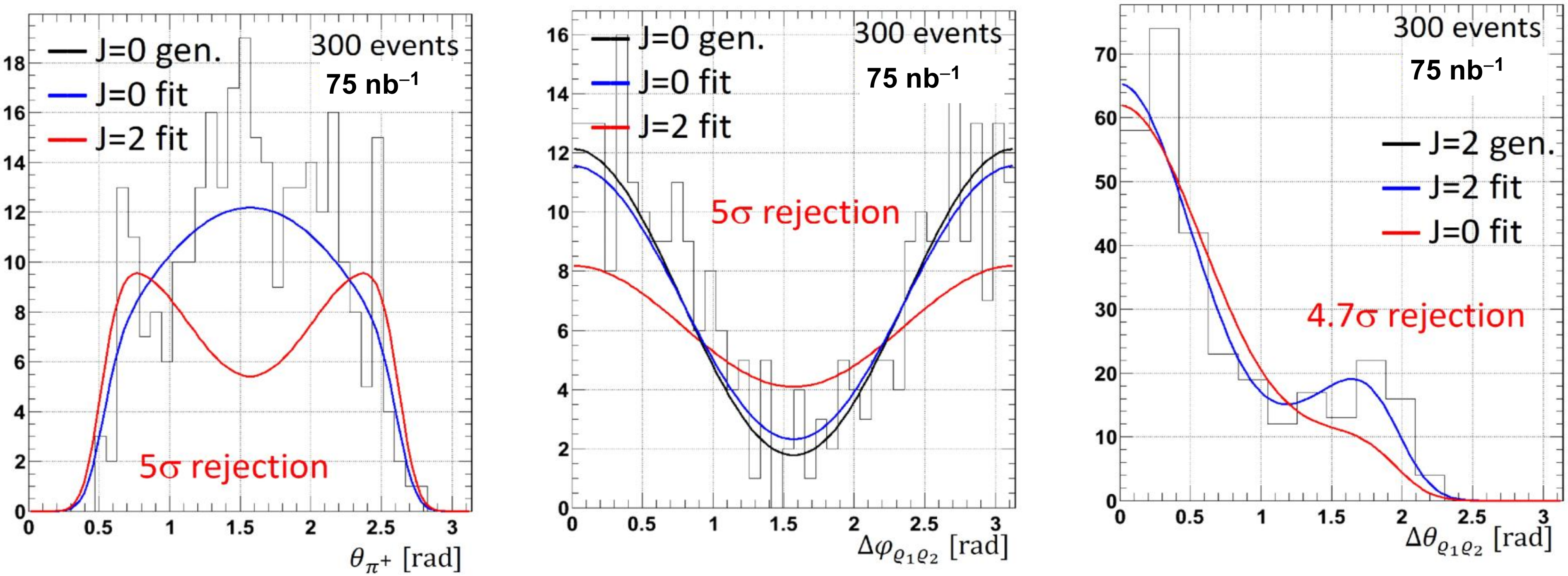
simulation of signal & non-resonant $\rho^0\rho^0$ background [DIME MC] with CMS tracker performance:

No $f_0(1710) \to K^+K^-$ candidate in available data
allow factor 10 for branching ratios ⇒
need ~1 pb^{-1} for decay characterization ⇒
~ 2 days of $\beta^* = 90$ m & $\mu = 0.1$ data (in 2015)

Glueball studies at $\beta^* = 90$ m

Spin analysis of $f_J(1710) \rightarrow \rho^0\rho^0 \rightarrow 2(\pi^+\pi^-)$ to determine J = 0 or 2:

- Angular correlations between leading protons
- $\rho \rightarrow \pi^+\pi^-$ distributions
- Angular correlations between 2 pairs of $\pi^+\pi^-$



polar angle θ_{π^+} of the $\pi^+\pi^-$ pair with the ρ candidate at $\eta > 0$

azimuth and polar angle difference between 2 pairs of $\pi^+\pi^-$ ($\Delta\phi_{\rho1\rho2}$, $\Delta\theta_{\rho1\rho2}$)

Distinction from neighbouring resonances & non-resonant background: spin analysis in mass bins $\leq$ 40 MeV $\Rightarrow$ **needs ~5 pb^{-1}**

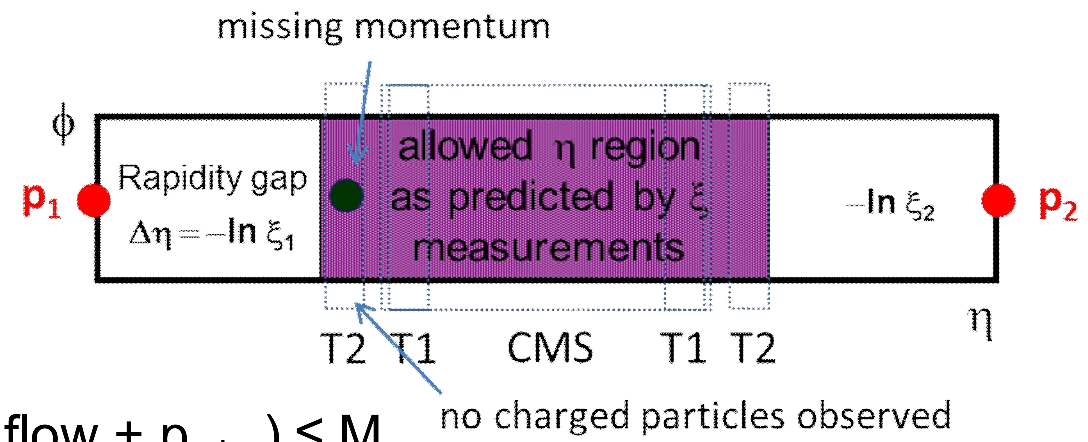
Missing mass & momentum

new physics that escaped standard searches

(e.g. due to special Pomeron coupling)?

preliminary search for performed on existing data samples (~0.05 pb^{-1})

- several topologies examined for predicted rapidity gap violations (no signal found)



- $M_{central}$ (particle flow + p_{miss}) ≤ M_{pp}
- $p_{central}$ (particle flow) ≠ p_{pp}
- p_{miss} pointing in the instrumented region
- $|\eta| > 6.5$ to be forbidden by $\xi_{1,2}$ measurements (optional)

search for missing mass in $150 < M_{miss} < 1000$ GeV at $\sqrt{s} = 13$ TeV

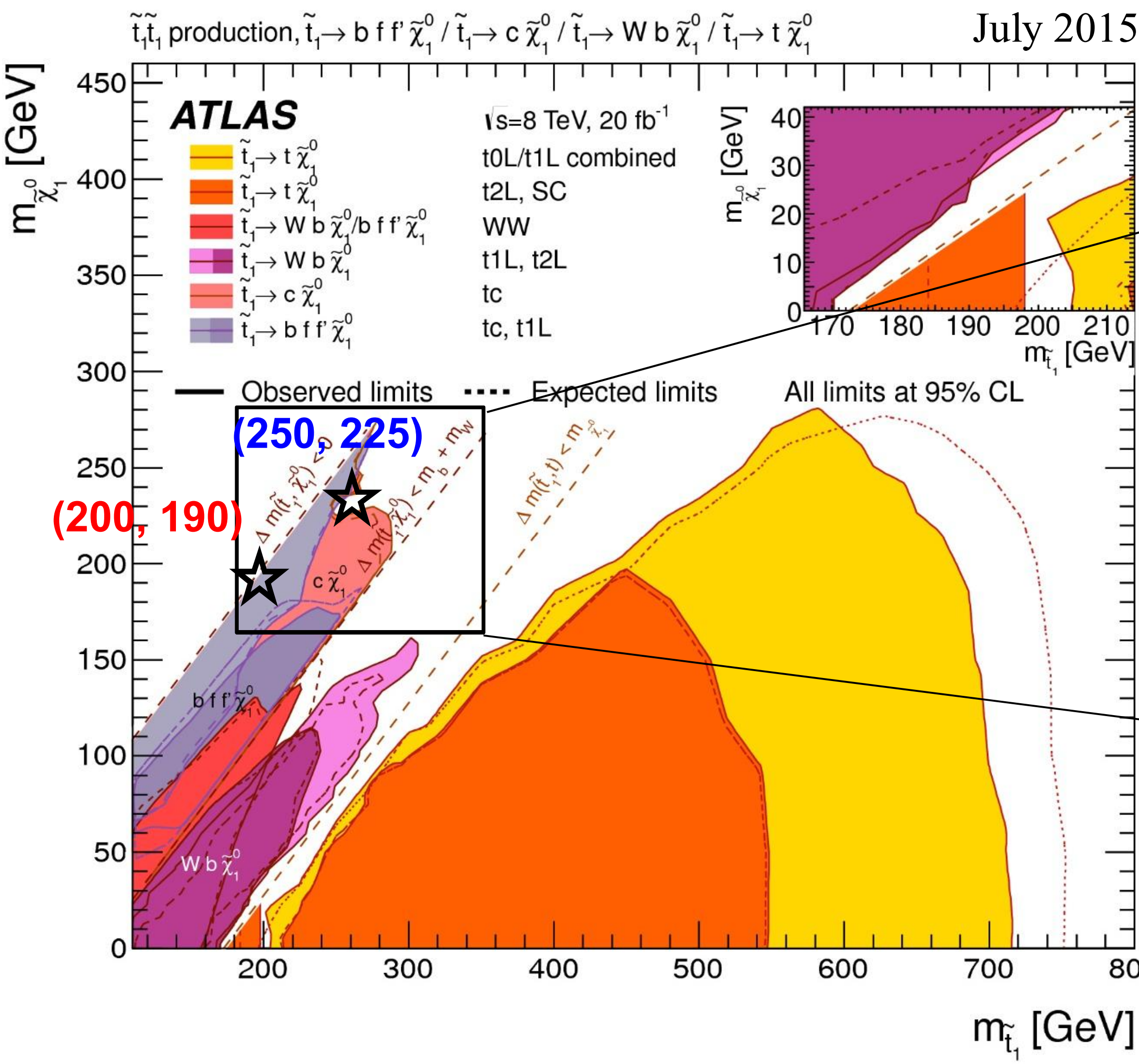
- O(100) pb^{-1} allows searches for O(pb) cross section processes ⇒ ~ few weeks of $\beta^* = 90$ m & $\mu = 0.5$ data (requires timing, in 2016)

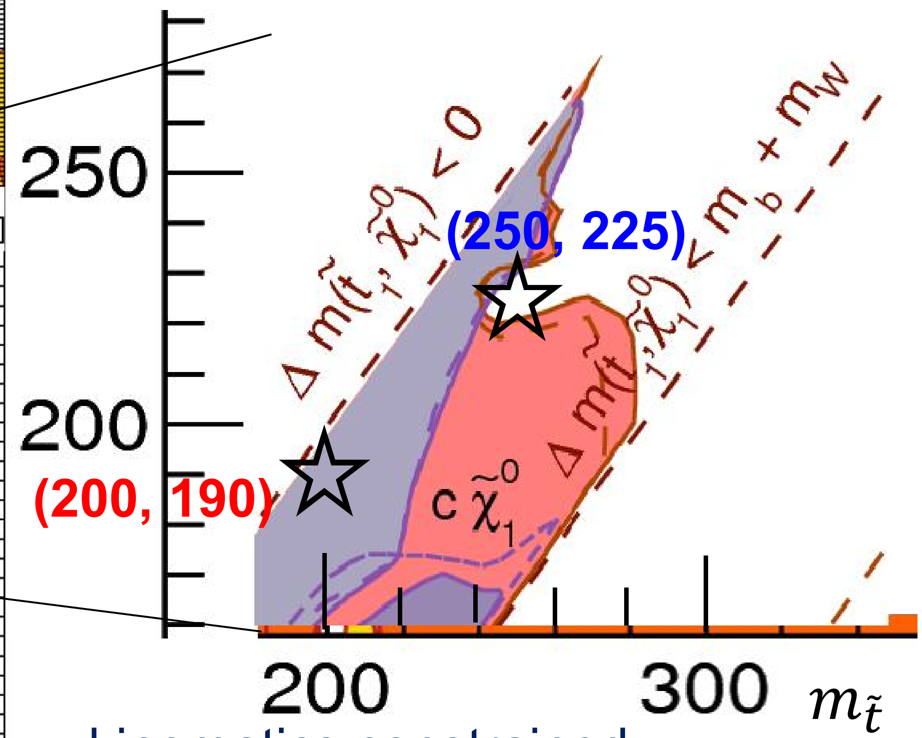
Missing mass & momentum: hidden SUSY example

Standard ATLAS/CMS $\tilde{q}$ searches insensitive to $m_{\tilde{q}} - m_{\tilde{\chi}_0} \leq$ 30-40 GeV.

$\sigma(pp \rightarrow p + X\tilde{q}\bar{\tilde{q}} + p) \approx O(pb)$? $\Rightarrow$ discovery with O(100 pb^{-1}) β^* = 90 m data?

characterized by **large M_{miss}** (= $M_{pp} - M_{CMS}$) & **$\vec{p}_{miss}$ in instrumented region**





Test case: $\tilde{t}\bar{\tilde{t}}$ pair production with fpmc

- ✓ kinematics constrained
- ✓ good M_{miss} resolution
- ✓ less background
- ✓ no ISR q or final state l required
- ✓ lower cross-section & luminosity

Summary

Many physics results published using Run I data,
More physics results being finalized
⇒ see H. Saarikko's talk in SM – QCD3 session just after lunch

All system commissioned & performing well !
Low β^* RP insertions progressing successfully !

2015:

- LHCf & Van der Meer runs (β^* = 19 m): moderate pileup (μ = 0.003 – 0.5) dN/dη, SD & CD jets
- Dedicated run (~2 days) at β^* = 90 m: ~1 pb^{-1} of data for glueball studies
- Completing & installing diamond & CT-PPS sensors for 2016 runs

2016:

- Dedicated run (~ few weeks) at β^* = 90m with timing detectors: $\mu \sim 0.5$
- Runs at β^* ~ 2500m for further studies of Coulomb-nuclear interference
- Regular low β^* running with CT-PPS