Central diffractive studies with protons

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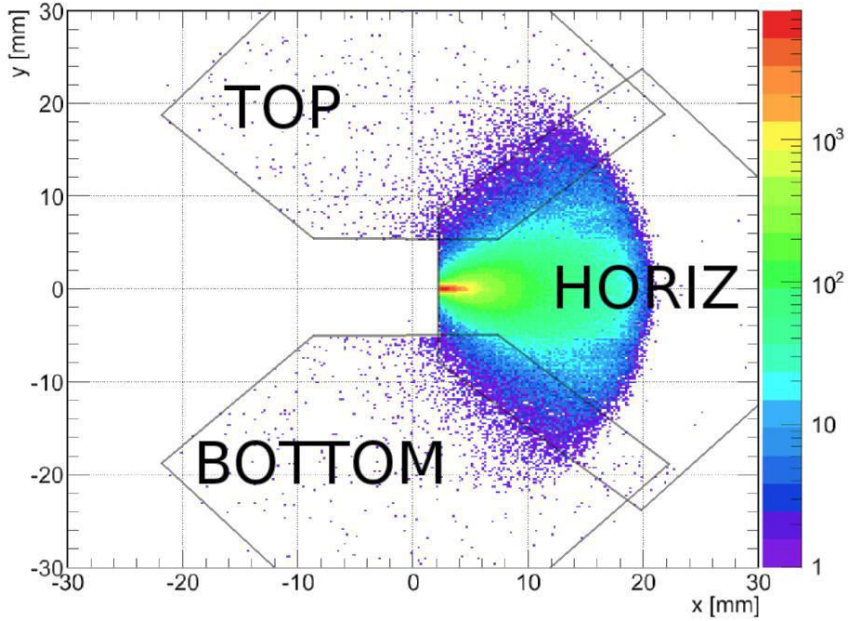
Cracow workshop

- low mass CD exclusive states
- missing mass topology in CD events
- CD exclusive jets

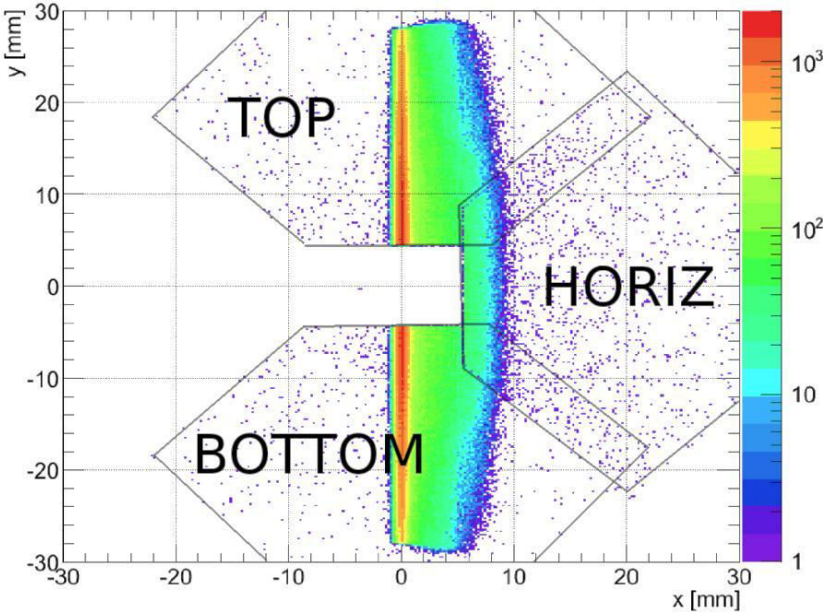
Analysis demonstrated on data from combined CMS-TOTEM runs in July 2012 at $\sqrt{s}$ = 8 TeV !!

Different LHC Optics

Standard low β^* (μ = 30 – 50):



Special high β^* (μ = 0.05 – 0.5):



ξ > ~3 % protons in **horizontal** RP

|t| > ~0.01 GeV^2 protons (@ any ξ) in **vertical** RP

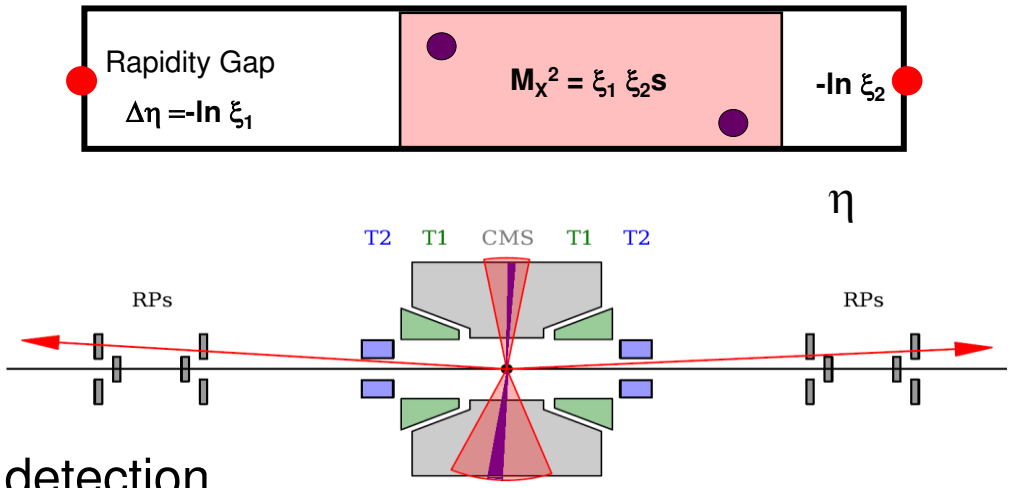
low cross-section processes (hard diffraction) – continuous running

high cross-section processes – short dedicated runs with optimized conditions

~ 10^{34} cm^{-2} s^{-1} ← $\mathcal{L} \propto \frac{1}{\beta^*}$ → **~$10^{28\text{-}32}$ cm^{-2} s^{-1}**

Studies on-going to implement β^* = 90 m with 1000 bunches, pileup ~0.05-0.5; $\mathcal{L}$ ~$10^{31\text{-}32}$ cm^2 s^{-1} →1-10 pb^{-1}/day

Central diffraction: CMS+TOTEM



Large η-coverage:

- CMS: $-5.5<\eta<5.5$
- T1: $3.1 < |\eta| < 4.7$
- T2: $5.3 < |\eta| < 6.5$
- FSC: $6 < |\eta| < 8$

Double-arm proton detection

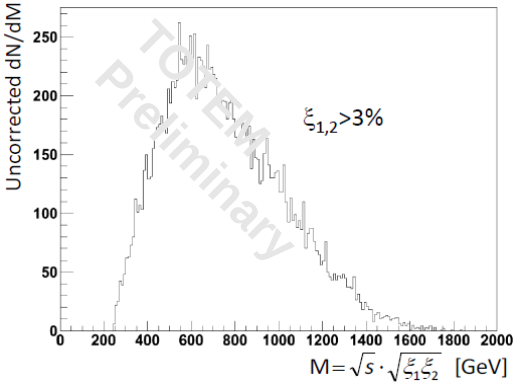
Prediction of mass to be seen in central from reconstructed protons: $M^2 = s\,\xi_1\xi_2$

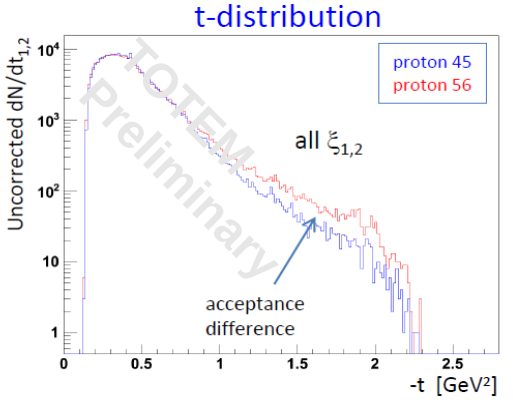
Comparison of forward and central system: M(pp) =? M(central), $p_{T,z}$(pp) =? $p_{T,z}$(central), protons from same vertex as central system?

Prediction of central particle flow topology from proton ξ's (rapidity gaps): $\Delta\eta_{1,2} = -\ln\xi_{1,2}$

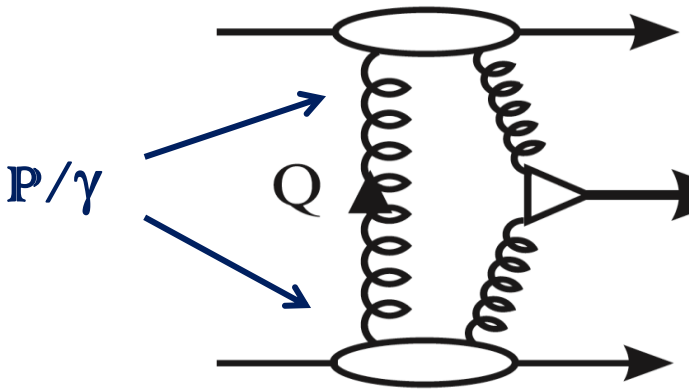
Masses upto 2 TeV with pp survival!

Realistic trigger crucial for μ > ~0.5 (see Valentina's talk)





Exclusive central diffraction



$M^2 = \xi_1 \xi_2 s$

gg collider !

$$y_X = \frac{1}{2} \ln \frac{\xi_1}{\xi_2}$$

exchange of colour singlets with vacuum quantum numbers
$\Rightarrow$ Selection rules for system X: $J^{PC} = 0^{++}, 2^{++}$

X = $\pi\pi$, KK, $\rho\rho$, $\eta\eta$, χ_{c0}, χ_{cb}, jets, ? (unknown)….

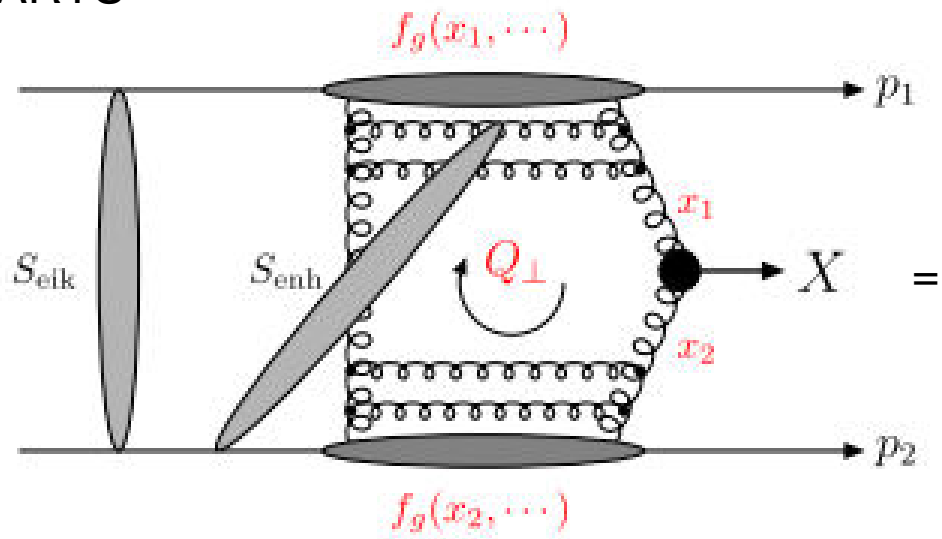
$\beta^* = 90 - 0.5$ m
$\mu = 0.05 - 50$

M = $\pi\pi$ threshold – ~ 2 TeV,
σ = O(μb) – O(fb)

Flexibility !

Low mass CD exclusive states

KHARYS



= ππ, KK, ρρ, ηη...

pp → p + di-meson + p events: ππ threshold – O(10 GeV)
events with RP double arm + charged particles in CMS tracker

p/K/p identification using CMS tracker dE/dx

masses reconstructed from charged particles in CMS tracker with excellent resolution

reconstruct decay chains (for example ρ → ππ)

study low mass resonance production in CED: gluon-rich resonances?

small / large pT(pp) ⇒ parallel / diagonal pomeron topologies

Low mass CD exclusive states

REF: public CMS-TOTEM result before finalization of yellow report ?

What has been measured @ 8 TeV

β^*=90m: 3 bunches, $\mu \sim 0.05$, $L_{int} \sim 0.8$ nb^{-1}
Trigger: RP double arm

nh^+ nh^- only central states (n = 1 - 4)
pT(pp) = pT(central) (within resolution)
π/K/p identification using CMS tracker dE/dx
Statistics limited!

Cuts:

- Vertex ≤ 1 (suppress pileup)
- $\xi \sim 0$ (at 3σ) protons (enhance exclusivity)
- RP vertex (suppress pileup)
- T1 and T2 gaps (enforce low-ξ & suppress MB pileup)
- charge balance (suppress incomplete reconstruction)

Challenges:

- RP double arm trigger rate for 1k bunches
- partial rapidity gap coverage
[T1, T2, Castor, FSC....]
- background (low pile-up)
σ(x vertex [RP]) ~ 10 μm resolve pileup in RP
- limited pT range for dE/dx identification
- n > 2 combinatorics becomes problematic
- missed neutrals/very low pT tracks
…

Run Scenario:

- β^*=90m
Low pileup (1k bunches & low μ (~ 0.05))
Improved with timing in vertical RPs

Missing mass topology in CD events

CD: gg collisions upto 2 TeV with known initial state

Can some ”new physics” have escaped detection in standard searches?
And what if that new physics includes ”missing momentum/mass” signature?

Look in CD events (pp) with missing momentum/mass with respect to initial pp state
M(particle flow + missing momentum) ≤ M(pp)

Also M(pp) in CD @ LHC >> $\sqrt{s}_{LEP,max}$, hence more energy to create “new physics”

Dark matter:

prefered models: WIMP 100 GeV – 2 TeV $\Rightarrow$ σ’s small (~ fb or smaller), high lumi

alternative models (asymmetric): M_{DM} could be as low as 5 GeV,
$\sigma(pp \rightarrow p + X\ DM + p) = ?$

Other scenarios?

Missing mass topology in CD events

REF: LHC Seminar- TOTEM Physics program, analysis and results- H. Niewiadomski

What has been measured @ 8 TeV

β^*=90m: 3 (112) bunches, $\mu \sim 0.05$, $L_{int} \sim 0.8$ (43) nb^{-1}
Trigger: RP double arm (central jets (pT>25))
M(particle flow + missing momentum) ≤ M(pp)

particles violating ξ-predicted gaps $\Delta\eta_{1,2}$
→ No candidates in dijet sample

escaping-mass candidates (p(particle flow) ≠ p(pp))
Additional particles NOT observed in forward detectors where allowed/required by ξ-predicted gaps
→ Few candidates with $\Delta M \geq 400$ GeV
Additional particles required (but NOT observed) in forward detectors forbidden by ξ-predicted gaps → No candidates

Cuts:
- Vertex ≤ 1
- RP near edge area removed (background suppression)
- RP top-top/bot-bot topology
- $\xi > 1.5\% \Rightarrow$ M(pp) > 120 GeV (better resolution)
- FSC empty (suppress background)

Challenges:

- RP double arm trigger rate for 1k bunches
- background (beam halo, pile-up, N*)
- partial rapidity gap coverage [T1, T2, Castor, FSC....]
- detector inefficiencies/cracks

…

Run Scenario:

- β^*=90m
1k bunches & $\mu \sim 0.05$-0.5
ZDC for n/pi0 detection
improvement with timing in vertical RPs
....

- Low β^*:
M(pp) acceptance > 400-500 GeV
forward detector veto not applicable
.....

feasible?

CD exclusive jets

cross-sections, 3j/2j ratio, gluon jet studies

CDF Observed X = JJ at $\sqrt{s}$ = 1.96 TeV to E_T = 30 GeV

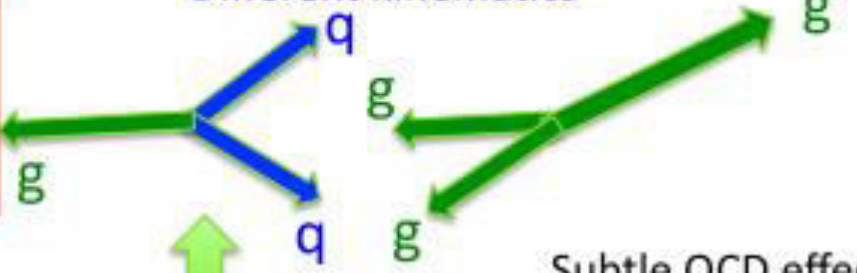
At LEP: e+e- → Z → 2 jets (q-qbar) or 3 jets (q-qbar-g)

At LHC: IP + IP → 2 jets (g-g) or 3 jets (q-qbar-g) OR (g-g-g)

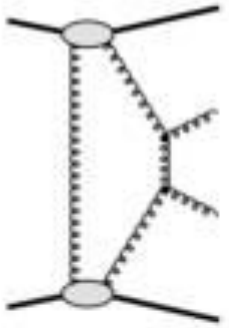
Different kinematics

99% of exclusive dijets are g-g (unique) 1% are b-bbar
→ uu, dd, ss, cc suppressed by $[m(q)/m(JJ)]^2$ (Durham theory gp)

Democratic so 1/5 each quark type:
20% b-bbar 20% c-cbar, ...



KHARYS,
see Luciens talk



Subtle QCD effects:
No gluon radiation (Sudakov)
No other parton collisions
Test spin rule Jz = 0
Interplay of pQCD and npQCD
Distant relation to elastic scattering

Low β^*: M(pp) acceptance > 400-500 GeV
$\Rightarrow$ σ's small (fb), need high lumi

High β^*: see all M(pp) but ΔM(pp) ~ O(10's GeV)
with 1k bunches & μ ~ 0.5 can reach L_{int} ~ O(5-10 pb^{-1}/day) !!
σ (M(pp) > 75 GeV) = ~0.2 nb @ s = 13 TeV (KHARYS)

CD exclusive jets

REF: LHC Seminar- TOTEM Physics program, analysis and results- H. Niewiadomski
CMS-DP-2013-004

What has been measured @ 8 TeV

β^*=90m: 112 bunches, $\mu \sim 0.05$, $L_{int} \sim 43nb^{-1}$
Trigger on central jets (pT>25)
Forward & central consistent (within resolution)
M(particle Flow) = M(pp)
p(particle Flow) = p(pp)
→ Few candidates; none M(jj) =M(pp)
Lack of statistics!

Cuts:
- Vertex ≤ 1
- RP near edge area removed (background suppression)
- RP top-top/bot-bot topology
- $\xi > 1.5\% \Rightarrow$ M(pp) > 120 GeV (better resolution)
- FSC empty (suppress background)

Challenges:

- trigger rate for 1k bunches & $\mu \sim 1$
- limited M(pp) resolution at lower M
- background (beam halo, pile-up)
- acceptance corrections due to correlations (theta*_x and xi)

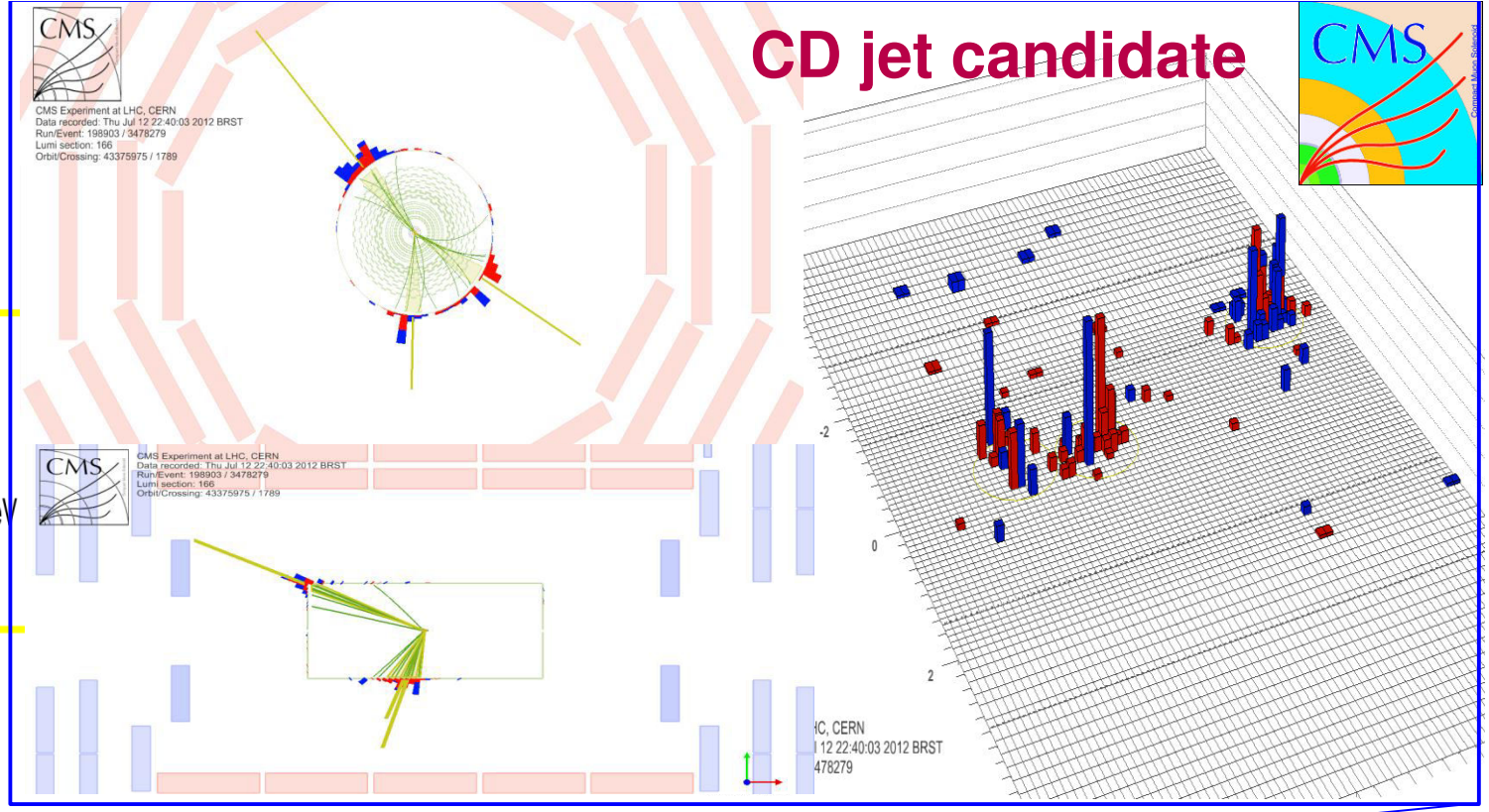
…

Run Scenario:

- β^*=90m
1k bunches & $\mu \sim 0.5$ / $\mu \sim 0.05$ longer run time
1st option improved by timing in vertical RPs
2nd option better for having a low jet pT threshold
....

- Low β^*:
M(pp) acceptance > 400-500 GeV
pile-up an issue
high pT cut on jets
.....

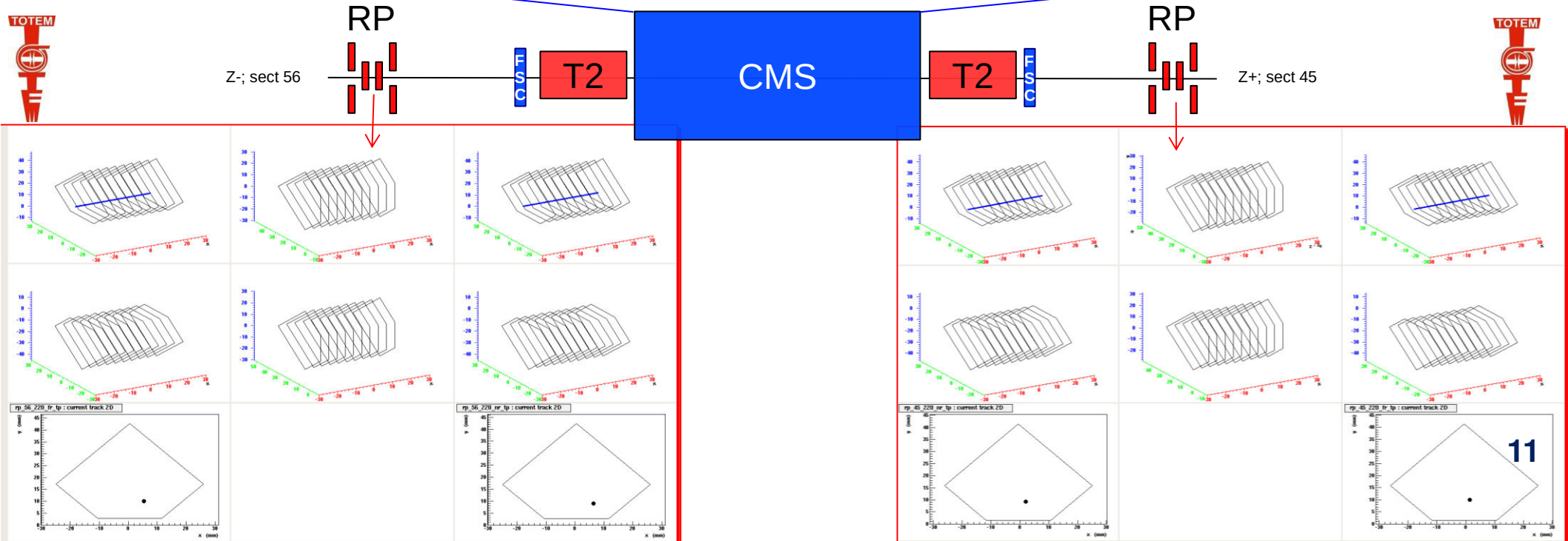
CD jet candidate



CMS + TOTEM 90m β*
Run/Event 198903/3478279
Jets E_T = 65,45,27 GeV

MM(pp) = 244 GeV; M(CMS) = 219 GeV
Σp_T(CMS) = 3.4 GeV
FSC empty both sides

M(pp) = 244 GeV
≈ M(central)
ξ_1 = 0.1 ξ_2= 0.01



Plans for yellow report contributions

Low mass CD exclusive states (low lumi only):
Brief description of the results obtained during LHC-RUN-I
(or description of analysis strategy)

Estimate of performances at higher energies including most suitable running scenario

Missing mass topology in CD events (low lumi & high lumi):
Description of analysis strategy and summarize prospects/predictions

Estimate of performances at higher energies including most suitable running scenario

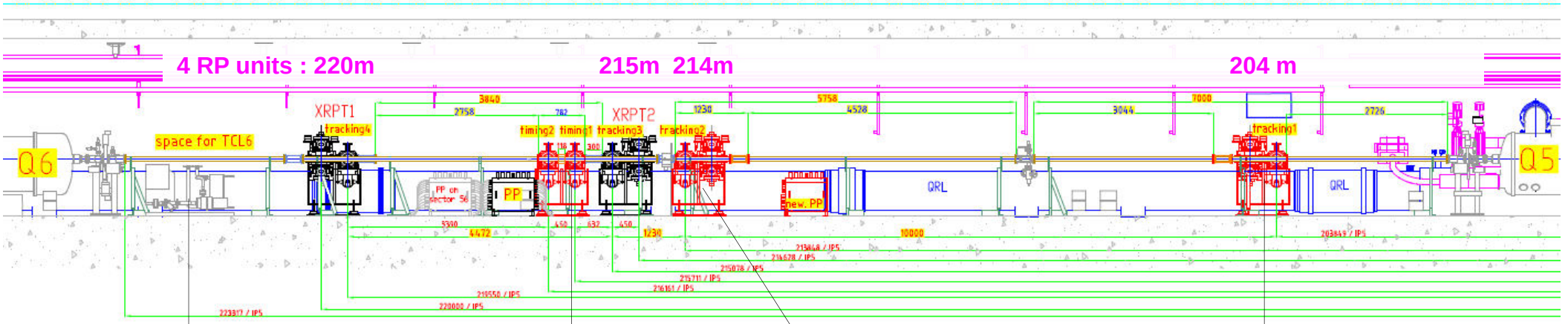
CD exclusive jets (low lumi & high lumi):
Full analysis description (one of the channels of common CMS-TOTEM studies) or description of analysis strategy plus summary of prospects

Estimate of performances at higher energies including most suitable running scenario

Backup

RP consolidation & upgrade summary

mechanics/infrastructure in LS1, timing sensors/replacement of Si strips later



Install collimator to protect Q6

Allow insertion of (horizontal) RPs closer to beam in high intensity scenario
→ **improved ξ acceptance**

Infrastructure to install 2 new horizontal pots

Cylindrical pots to host **timing detectors**

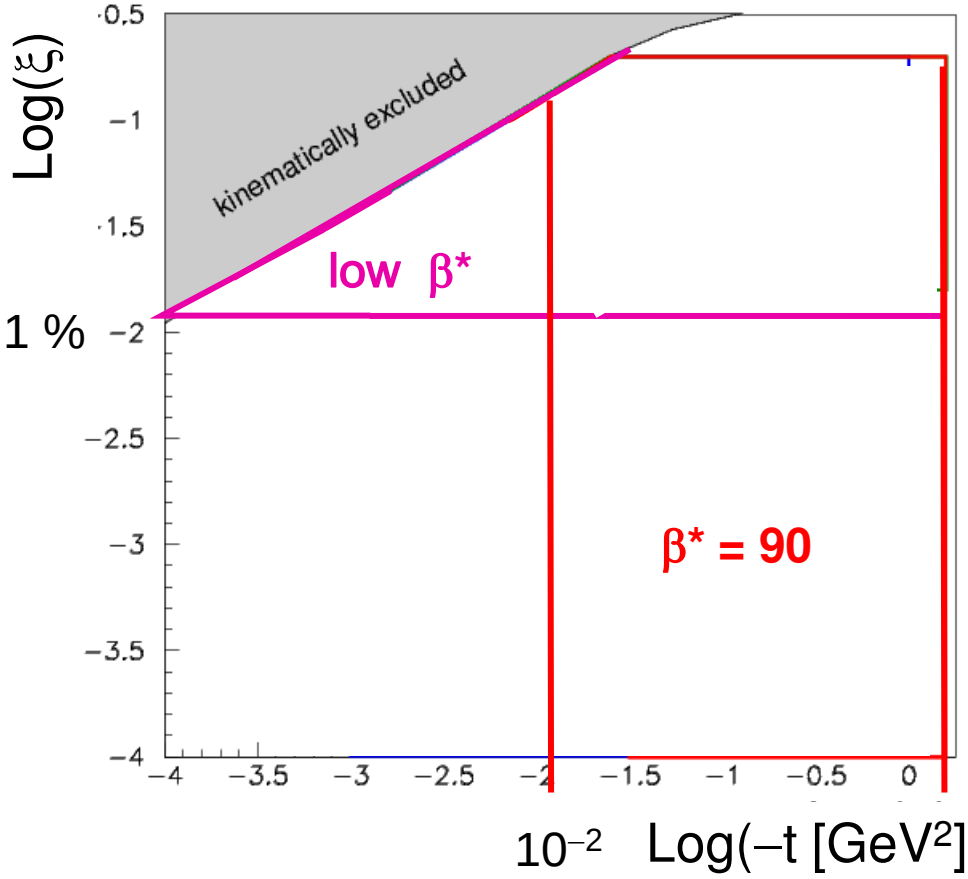
RP147 (fully equipped) relocated at 203-213 m 1 unit rotated by 8 degrees

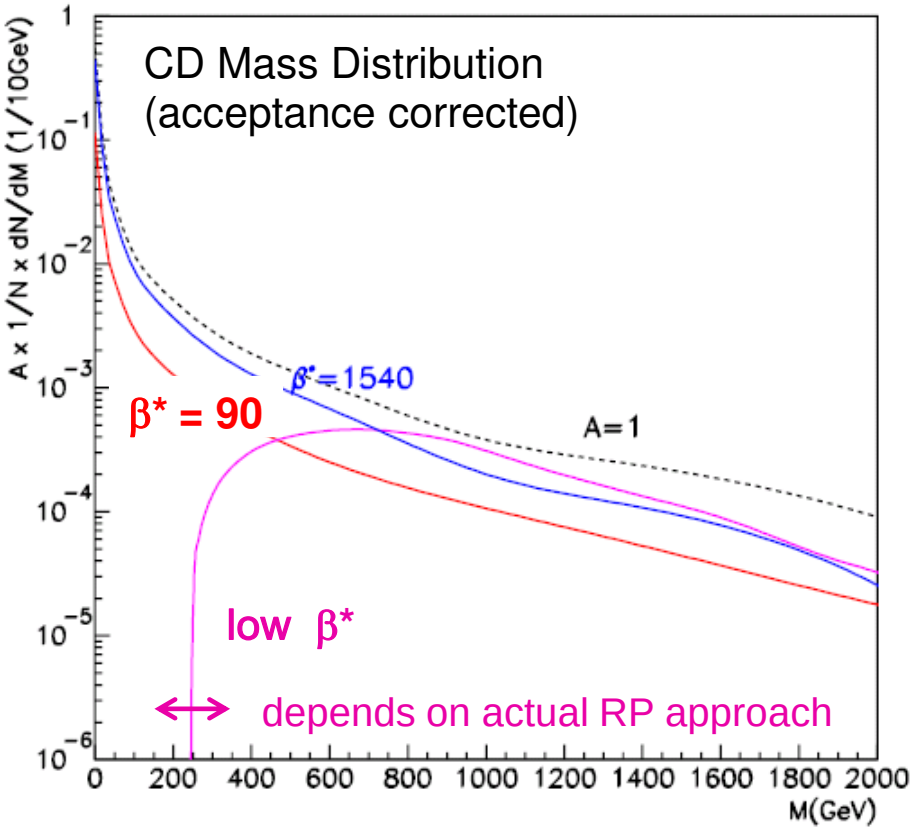
Long lever arm (~15m) **improves angular resolution** (until beam divergence limit)

Si-strip detectors rotated to **improve multitrack** event reconstruction (beam halo pileup, background)

- RP system will consist of 4 RP units/arm, each with 2 vertical + 1 horizontal pots equipped with 10 planes Si-strip detectors, with full trigger capability
- Extreme flexibility in using 4 units according to running scenario; possibility to dedicate pots to new **Si-pixel detectors** as well as to **timing detectors** with low material budget

Proton & CD mass acceptance





β^* [m]	$\sigma(\Theta_x^*)$ [μrad]	$\sigma(\Theta_y^*)$ [μrad]	$\sigma(t)$ [GeV^2]	$\sigma(\Phi^*)$ [rad]	$\sigma(\xi)$	$\sigma(M)$ [GeV]
90 (no vtx.)	17	2.3	$0.22\|t\|^{0.67}$	$0.075/\|t\|^{0.59}$	$0.003 \div 0.006$	$40 \div 200$
90 (w. vtx.)	5	2.3	$0.13\|t\|^{0.79}$	$0.026/\sqrt{\|t\|}$	0.0012	$10 \div 100$
0.55	$32 \div 35$	30	$0.45\sqrt{\|t\|}$	$0.23/\sqrt{\|t\|}$	$0.001 \div 0.007$	$(0.025 \div 0.03)M$

Exception: for very low $|\xi|$ can be neglected improving $\sigma(\theta_x^*) \approx 2.3$ μrad = beam divergence