Physics of TOTEM joint special high β* runs with CMS

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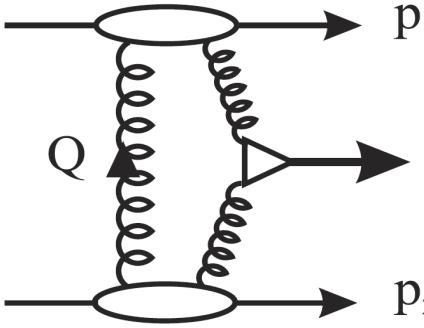
LHCC special forward proton session

18.11.2014

Preliminary analysis of all physics channels presented performed on the available common CMS-TOTEM $\beta^* = 90$ m data set at $\sqrt{s} = 8$ TeV (double RP trigger: ~ 3 nb^{-1}, lepton+jets: ~ 50 nb^{-1})

(Exclusive) central diffraction



p_1 (ξ_1) $M^2 = \xi_1\ \xi_2\ s$

X at rapidity y_X gg collider

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

also $\gamma\gamma$ fusion & γPomeron fusion

- exchange of colour singlets with vacuum quantum numbers
  $\Rightarrow$ selection rules for system X: $J^{PC} = 0^{++}, 2^{++}, \ldots$
- <u>with double-arm proton detection</u>

  $\beta^* = 90$ m runs: all M(pp), $\mu \sim 0.1$ - 0.5 $\Rightarrow$ 0.15-6 pb^{-1}/day this talk

  low β^* runs: M(pp) > ~ 250 GeV, $\mu \sim 25$ - 50 $\Rightarrow$ O(fb^{-1}/day) Varela's talk
- 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 : $\Delta\eta_{1,2} = -\ln\xi_{1,2}$

Glueballs: motivation

CD: x ~ 10^{-3} - 10^{-4} gluons $\Rightarrow$ pure gluon pair $\Rightarrow$ M_X ~1-4 GeV

Pomeron $\approx$ colourless gluon pair/ladder $\Rightarrow$ Pomeron fusion likely to produce glueballs

- $f_0(1500)$ & $f_0(1710)$ 0^{++} glueball candidates
- Lattice QCD [1]: m(0^{++}) glueball ~ 1700 ($\pm$ 100) MeV $\Rightarrow$ favours $f_0(1710)$
- Show glueball mass hierarchy (uu, dd, ss, gg) $\Rightarrow$ precise branching ratios (Br)

Open questions:

- $f_0(1500)$ mass, yields, decay channels and Br's well measured, $f_0(1710)$ not
- Previous measurements (WA102 and predecessors) disfavoured $f_0(1710)$, claiming Br($f_0(1710) \rightarrow K^+K^-$) > Br($f_0(1710) \rightarrow \pi^+\pi^-$) & no $f_0(1710) \rightarrow \rho^0\rho^0$
- Observation & measurement of $f_0(1710) \rightarrow \rho^0\rho^0$ + new measurements of Br($f_0(1710) \rightarrow K^+K^-$) and Br($f_0(1710) \rightarrow \pi^+\pi^-$) would bring new knowledge

Limitations previous experiments:

- Limited invariant mass / final state reach or lack of purity/mass resolution
- Experiment [2]capable of stuyding 4π final states assumed $f_0(1710)$ to be f_2

[1] Y. Chen et al., PRD73 (2006) 014516; C. J. Morningstar et al., PRD60 (1999) 034509.

[2] A. Breakstone et al., Z. Phys. C58 (1993) 251.

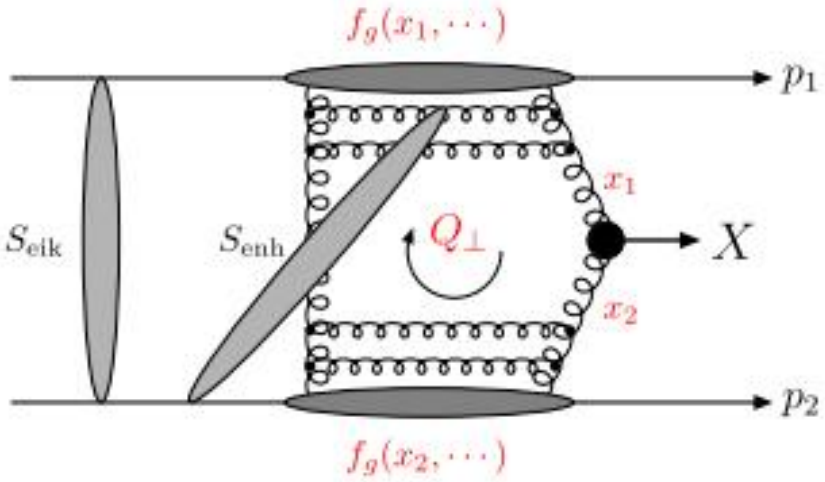
Glueballs: CMS-TOTEM

unique characteristics of LHC+TOTEM+CMS:

- LHC $\sqrt{s}$ such that 1-10 GeV masses CD produced with x ~ 10^{-3} - 10^{-4} gluons ensuring pure gluonic exchange (no valence quark component)
- Both protons measured and tagged by TOTEM
- CMS-TOTEM effectively selects/cuts with high purity (vertexing) in required x range.
- CMS tracker reconstructs 4 charged particle invariant mass with σ(M) ~ 20-30 MeV:

(with sufficient statistics effects of close resonances accounted for without partial-wave techniques)

X = $\pi^+\pi^-$, K^+K^-, $\rho^0\rho^0$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$…



Event selections & analysis:

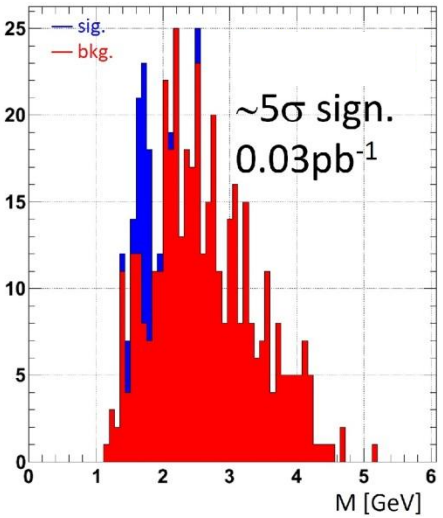
- double arm RP trigger
- nh$^+$ nh$^-$ only central states (n = 1 - 3)
- pT(pp) = pT(central) (within resolution)
- horizontal vertex for pp (assuming ξ_{pp} ~ 0)
- π/K identification using CMS tracker dE/dx (π/K uniquely identified if p ≤ 1.20/1.05 GeV)
- spin determination from decay angles

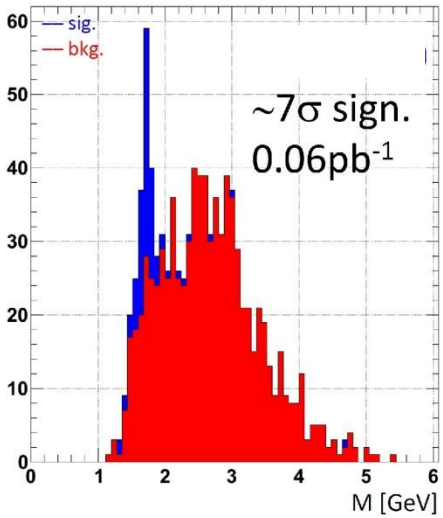
Glueballs: decay characterisation

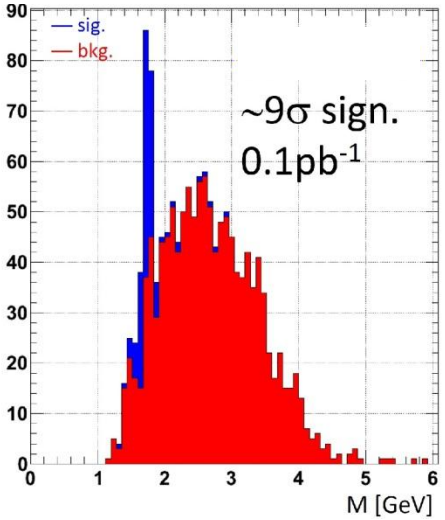
Analysis of available common CMS-TOTEM data set (L = 3 nb^{-1} of double arm RP trigger) show sensitivity to $f_0(1710) \rightarrow \rho^0\rho^0$.

Study signal + non-resonant $\rho^0\rho^0$ background (DIME MC[1]) using parametrisation of CMS tracker performance

$\Rightarrow$ **0.06 pb^{-1} needed for $f_0(1710)$ observation**







Glueball analysis also requires measurement of $f_0(1710) \rightarrow K^+K^-$ (no candidates in available data). Assuming a typical branching ratio range of a factor 10 (similar range as for $f_0(1500)$)

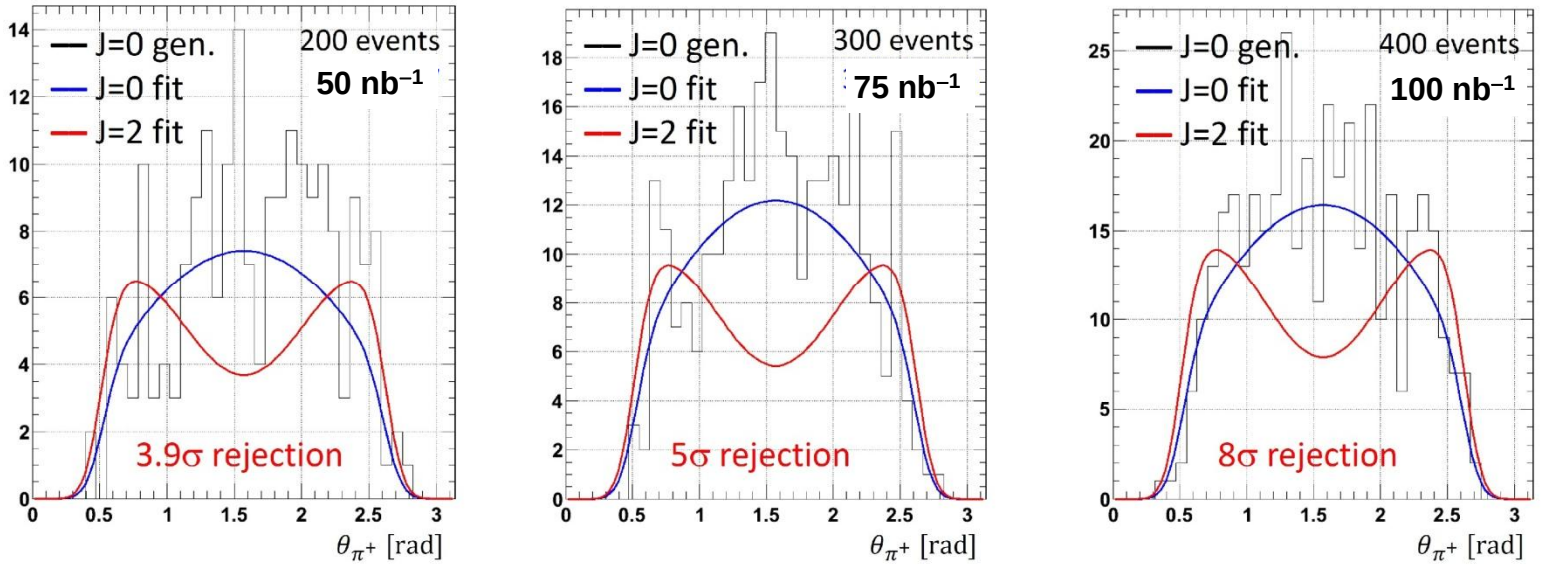
$\Rightarrow$ **0.6 pb^{-1} needed for $f_0(1710)$ decay characterisation**

Glueballs: spin analysis

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 $\eta > 0$ (signal only)



Similar requirement ($L \geq 75$ nb^{-1}) imposed for azimuth and polar angle difference between 2 pairs of $\pi^+\pi^-$ ($\Delta\phi_{\rho1\rho2}$, $\Delta\theta_{\rho1\rho2}$)

Background from non-resonant $2(\pi^+\pi^-)$, $\rho\pi^+\pi^-$ & $\rho\rho$ final states & close by f_2 resonances (that partially overlap) not included

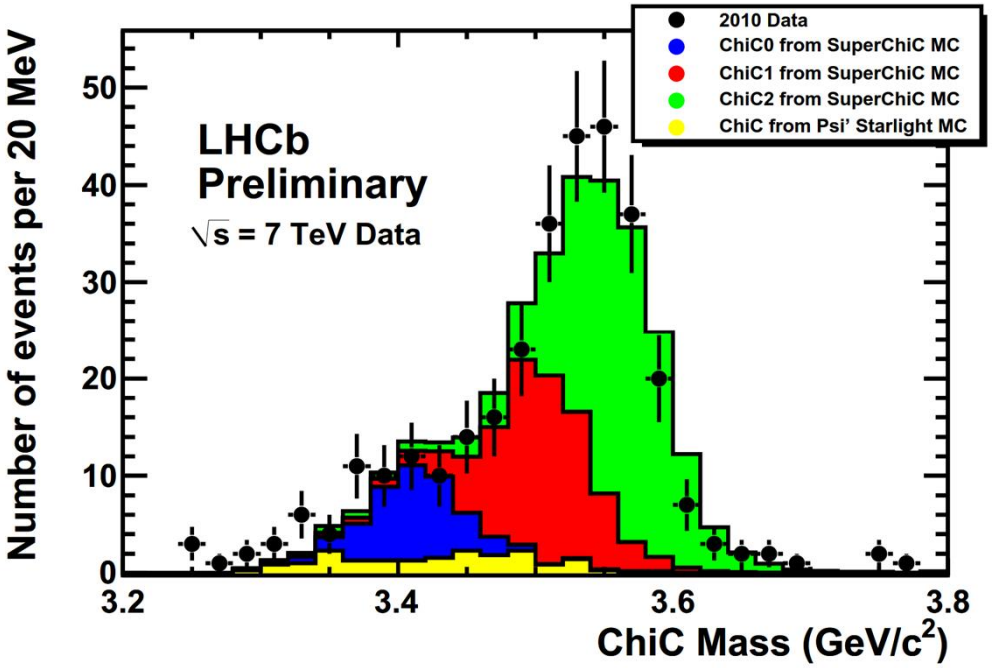
$\Rightarrow$ require spin analysis in mass bins ΔM ($\Delta M \leq 40$ MeV needed).

$\Rightarrow$ **~5 pb^{-1} needed for $f_0(1710)$ spin characterisation**

Exclusive χ_c: previous measurements

x ~ 10^{-3} - 10^{-4} gluons ⇒ charmonium states ⇒ perturbative QCD applicable

All existing observations (LHCb & CDF) based on rapidity gap tagging & $\chi_c \to J/\psi\,(\to\mu^+\mu^-)\,\gamma$ final state ⇒ significant proton dissociation background (~ 40 % estimate in case of LHCb from pT spectrum) & mass separation limited.



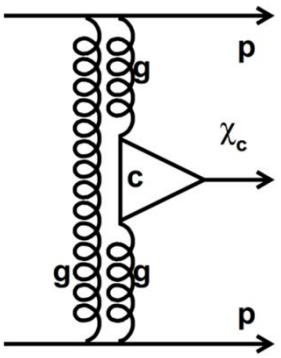
Comparison with Durham model prediction (arXiv:1405.0018):

	$\sigma(pp \to pp(J/\psi+\gamma))$ LHCb (pb)	SuperCHIC prediction (pb)
χ_{c0}	9.3 ± 4.5	14
χ_{c1}	16.4 ± 7.1	10
χ_{c2}	28 ± 12.3	3

discrepancy ?

uncertainty in predictions: × 2-3

Exclusive χ_c : CMS-TOTEM

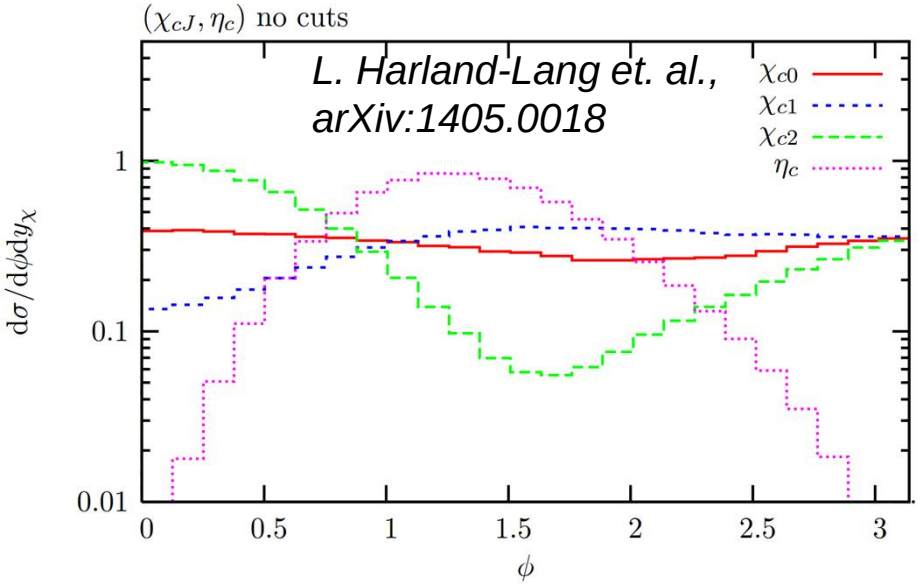


SuperChic predictions $\sqrt{s}$ = 13 TeV (Durham model):

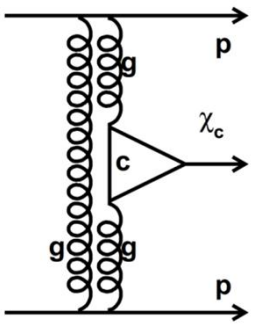
	J/ψ (→ $\mu^+\mu^-$)γ	2($\pi^+\pi^-$)	3($\pi^+\pi^-$)	$\pi^+\pi^-K^+K^-$
χ_{c0} :	264 pb	**7.6 nb**	**4.1 nb**	**6.0 nb**
χ_{c1} :	166 pb	61 pb	46 pb	45 pb
χ_{c2} :	53 pb	49 pb	38 pb	40 pb

χ_c selection identical to glueball analysis except $\Gamma\chi$ « σ(M) ~ 30 MeV.
In ~5 pb^{-1} (at least) **χ_{c0} with good statistics in 3 decay different modes(!)**,
maybe even χ_{c2} (if LHCb measurement right!)

~5 pb^{-1} would allow unique measurement of ϕ, azimuthal angular correlations between leading protons, **for χ_{c0} & test models!**



Exclusive J/ψ



SuperChic predictions $\sqrt{s}$ = 13 TeV (Durham model):

	$\mu^+\mu^-$	$2(\pi^+\pi^-)$	$3(\pi^+\pi^-)$	$\pi^+\pi^-K^+K^-$
J/ψ :	5.35 nb	320 pb	390 pb	592 pb

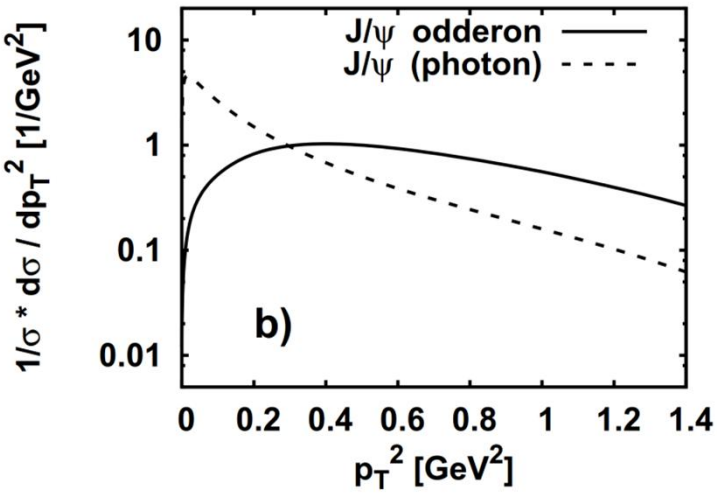
agrees with Starlight prediction within ~ 10 %

J/ψ selection identical to glueball analysis except $\Gamma_{J/\psi}$ « σ(M) ~ 30 MeV,
for $\mu^+\mu^-$ final state also double RP arm trigger & μ id used only when available
In ~5 pb^{-1} J/ψ with good statistics in several decay modes(!)

Previously measured by CDF, LHCb & ALICE with rapidity gap tags.

~5 pb^{-1} would allow unique measurement of proton ϕ correlation & test models + measure **spectrum for higher pT's for J/ψ** to look for possible effects of the **odderon**

L. Motyka, arXiv:0808.2216



SD processes

Single diffractive processes: study rapidity gap survival probability
Triggered using CMS lepton & jet triggers
Visible σ estimate at √s = 13 TeV (both proton + central object)

CMS PAS FSQ-14-001, TOTEM-NOTE-2014-002

- J/ψ production (POMPYT): $\mu^+\mu^-$
  $3.05 < M_{\mu\mu} < 3.15$ GeV,

5 pb^{-1}: 1540±45 events

- W production (POMWIG): $\mu^\pm/e^\pm$
  ($p_T > 20$ GeV), $60 < M_T < 110$ GeV

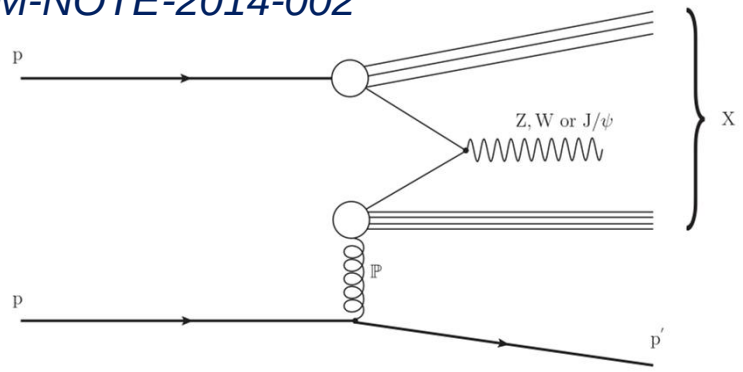
5 pb^{-1}: 170±5 events

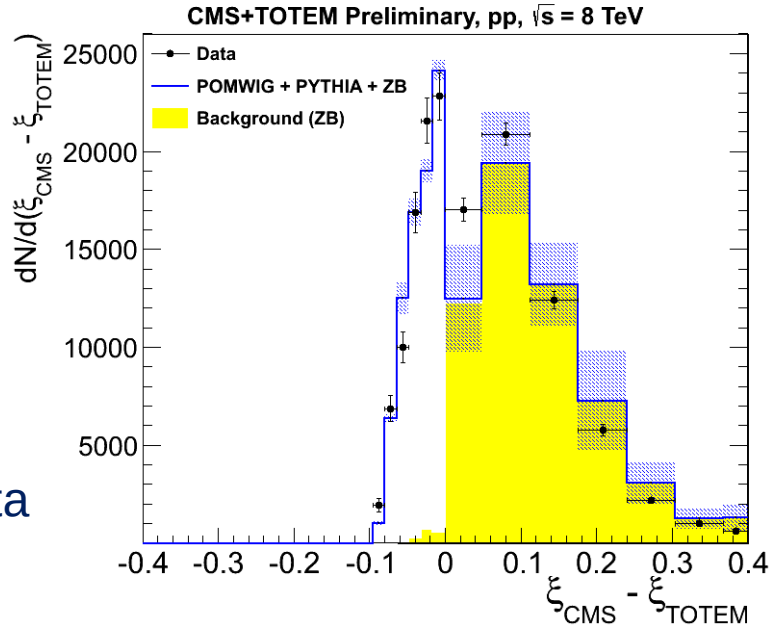
- Z production (POMWIG): $\mu^+\mu^-/e^+e^-$,
  ($p_T > 20$ GeV), $60 < M_{ll} < 110$ GeV

5 pb^{-1}: 15±1 events

- SD jet production: $p_{T,jet} > 30$ GeV

5 pb^{-1}: O(100k) events





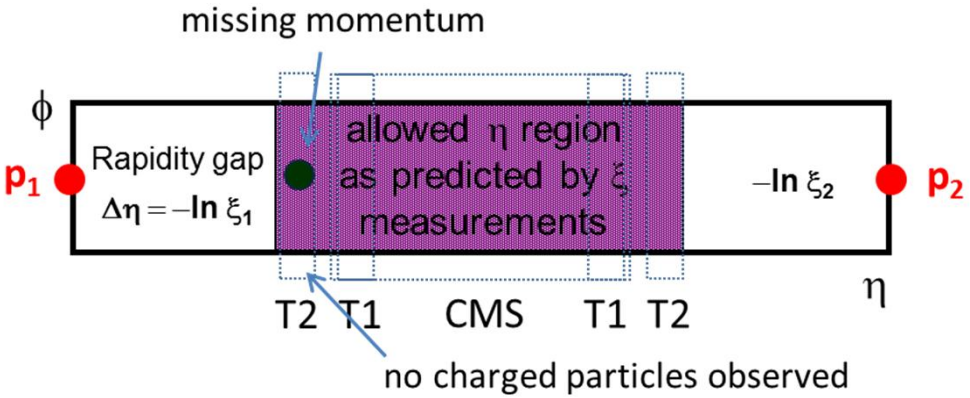
Background removal demonstrated on common CMS+TOTEM β* = 90 m data at √s = 8 TeV (SD dijets)

Missing mass & momentum events

new physics that escaped standard searches
(e.g. due to special Pomeron coupling)?

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

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



with $p_{central}$ (particle flow) ≠ p_{pp} & $M_{central}$ (particle flow + $p_{missing}$) ≤ M_{pp} events with $p_{missing}$ in the instrumented region (& requiring $|\eta| > 6.5$ to be forbidden by $\xi_{1,2}$ measurements)

- search for missing mass in $100 < M_{missing} < 600$ GeV at 13 TeV
  some candidates with missing mass up to 400 GeV found but
  limited statistics doesn't allow accurate modeling of background

Missing mass & momentum events

Topology not used previously for searches at LHC or Tevatron ($\sqrt{\hat{s}} \geq \sqrt{s_{LEP}}$)

$L_{int} \approx 100\ pb^{-1}$ allows to search for processes with O(pb) cross section

E.g. standard gluino/squark searches insensitive to $(m_{gluino/squark} - m_{LSP}) \leq$ 30-40 GeV despite O(1000 pb) cross-section in 150-250 GeV mass range
$\Rightarrow$ rely on monojet searches for exclusion

Inclusive (=non-exclusive) diffractive cross-section might be O(pb) $\Rightarrow$

$pp \rightarrow p + X + p$ with large missing p_T and jets

CMS-TOTEM could check current exclusion limits on $(m_{gluino/squark} - m_{LSP})$ for gluinos/squarks in 150-250 GeV mass range the without tight cuts on the momentum of the jets and fully explore the $(m_{gluino/squark} - m_{LSP}) \leq$ 40 GeV range

Exclusive jet production

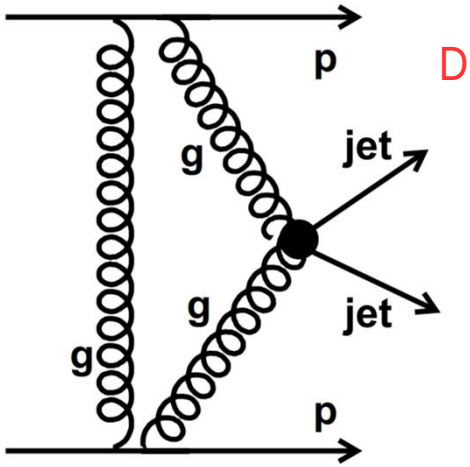
- $J_z = 0$ selection rule: $gg \to q\bar{q}, b\bar{b}$ suppressed by a factor 10^2-10^3
- unique possibility to observe enhanced gluon jets at LHC

  $\Rightarrow$ clean probe of properties of gluon jets (multiplicity, particle correlations...).
- cross-sections extremely sensitive to important & subtle QCD effects:

  - generalized gluon PDFs, rapidity gap survival probabilities, "Sudakov" factors.
- test model predictions:

  - study proton azimuthal correlations & 3-jet topologies

  Durham model: $gg \to gq\bar{q}$ (more Mercedes-like) & $gg \to ggg$ (more "back-to-back").



Durham model predictions for CMS-TOTEM selection:

Central: $|\eta_j| < 4.4$, $|p_\perp^j| > 30$ GeV (jets)

Protons: $|p_\perp^y| > 0.1$ GeV, $p_{1\perp}^y * p_{2\perp}^y > 0$

$\Rightarrow \sigma(gg) \approx 100$ pb

L.Harland-Lang at LHC Working Group on Forward Physics and Diffraction, Trento'14

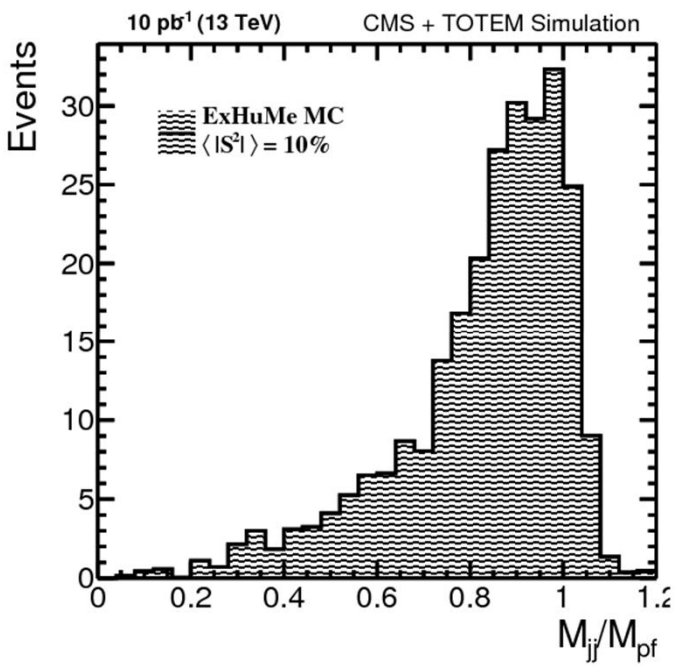
$L_{int} \approx 100$ pb^{-1}: pure exclusive jet sample (~ 10k) with $M_X \geq 60$ GeV

Expected S: B >> 1 (with timing detectors at $\mu \sim 0.5$)

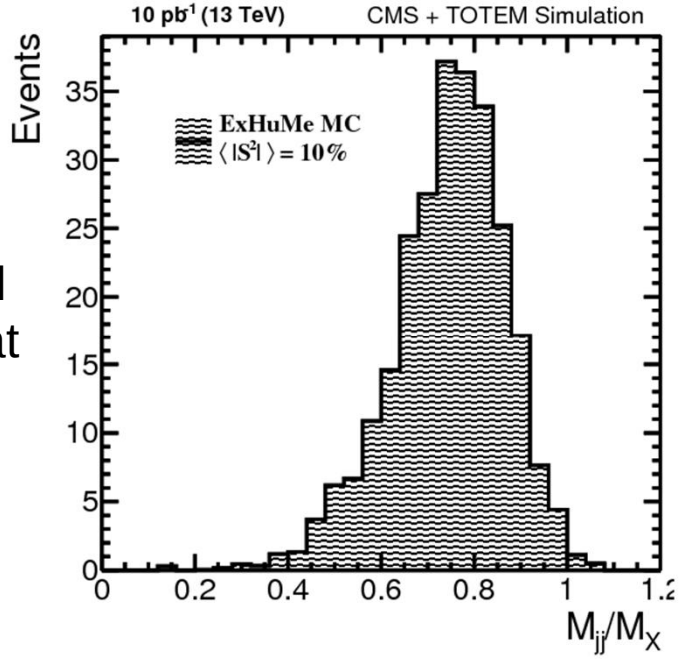
Exclusive jet production

- Full analysis performed at $\mu \sim 25$ for CT-PPS (low β^*) $\Rightarrow$ S:B $\approx$ 1:3
- Visible cross-section estimated for $\beta^* = 90$ m at $\mu \sim 1$

CMS PAS FSQ-14-001, TOTEM-NOTE-2014-002



Exclusive dijet signal centered at $M_{jj}/M_{pf} \sim 1$ $M_{jj}/M_X \sim 1$



- Preliminary analysis on common CMS-TOTEM $\beta^* = 90$ m data at $\sqrt{s} = 8$ TeV confirmed methods for pileup rejection (e.g. horizontal RP vertex cut for SD*SD+QCD dijet & Δy_{RP} for elastic+QCD dijet)

Conclusion

CMS-TOTEM can at $\beta^* = 90$ m

With 5 pb^{-1} & $\mu \sim 0.1$ (1 week in 2015)

- (disap)prove glueball nature of $f_0(1710)$
- measure exclusive χ_c & J/ψ production (including proton azimuthal correlations)
- measure rapidity gap survival probability (in several SD process)
- search for production exclusive mass states
- …

With 100 pb^{-1} & $\mu \sim 0.5$ (~1 week in 2016)

- search for O(pb) missing mass signals
- study exclusive jet production
- study quark content of the Pomeron
- …