



# Glueballs/low mass resonances in CEP at LHC

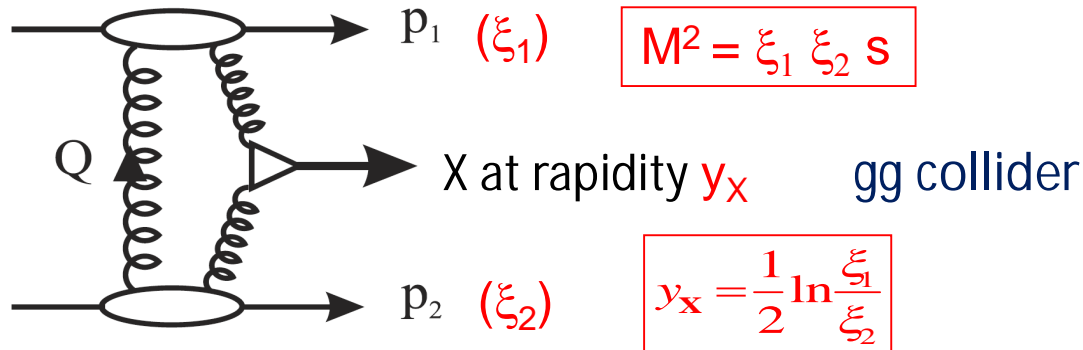
K. Österberg  
LHC Forward Physics and Diffraction WG  
meeting

17.12.2014

Preliminary analysis of all physics channels presented  
performed on the CMS-TOTEM  $\beta^* = 90$  m double RP  
triggered data set of  $\sim 3 \text{ nb}^{-1}$  at  $\sqrt{s} = 8 \text{ TeV}$



## (Exclusive) central diffraction



also  $\gamma\gamma$  fusion &  
 $\gamma$ Pomeron fusion

- > exchange of colour singlets with vacuum quantum numbers  
 $\Rightarrow$  selection rules for system  $X$ :  $J^{PC} = 0^{++}, 2^{++}, \dots$
- > with double-arm proton detection  
 $\beta^* = 90$  m runs: all  $M(pp)$ ,  $\mu \sim 0.1 - 0.5 \Rightarrow 0.15-6 \text{ pb}^{-1}/\text{day}$   
 $\text{low } \beta^* \text{ runs: } M(pp) > \sim 250 \text{ GeV}, \mu \sim 25 - 50 \Rightarrow O(\text{fb}^{-1}/\text{day})$
- > Comparison of prediction from forward to central system:  
 $M(pp) = ? M(\text{central}), p_{T,z}(pp) = ? p_{T,z}(\text{central}), \text{vertex}(pp) = ? \text{vertex}(\text{central})$
- > prediction of rapidity gaps from proton x's :  $\Delta\eta_{1,2} = -\ln\xi_{1,2}$



# Glueballs: motivation

CD:  $x \sim 10^{-3} - 10^{-4}$  gluons  $\Rightarrow$  pure gluon pair  $\Rightarrow M_x \sim 1-4$  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  $\sim 1700 (\pm 100)$  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  $\text{Br}(f_0(1710) \rightarrow K^+K^-) > \text{Br}(f_0(1710) \rightarrow \pi^+\pi^-)$  & no  $f_0(1710) \rightarrow \rho^0\rho^0$
- Observation & measurement of  $f_0(1710) \rightarrow \rho^0\rho^0$  + new measurements of  $\text{Br}(f_0(1710) \rightarrow K^+K^-)$  and  $\text{Br}(f_0(1710) \rightarrow \pi^+\pi^-)$  would bring new knowledge

## Limitations previous experiments:

- Limited invariant mass / final state reach or lack of purity/mass resolution
- Experiment [2] capable of studying  $4\pi$  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.

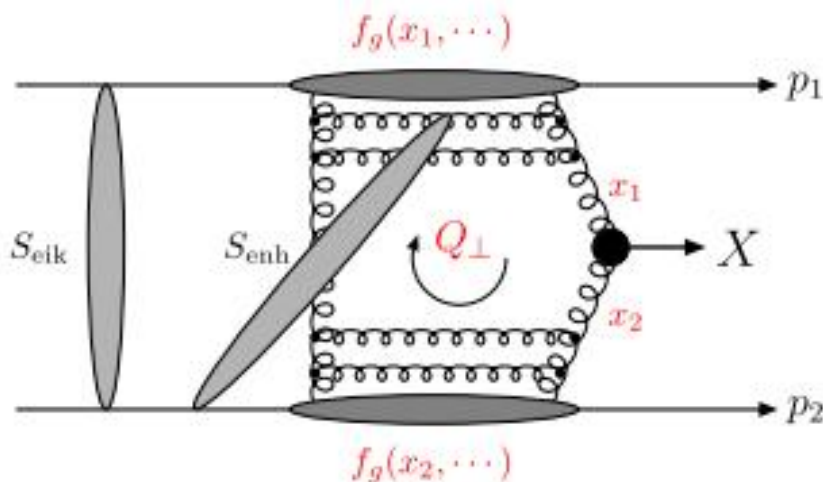


# Glueballs: CMS-TOTEM

unique characteristics of LHC+TOTEM+CMS:

- LHC  $\sqrt{s}$  such that 1-10 GeV masses CD produced with  $x \sim 10^{-3} - 10^{-4}$  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  $\sigma(M) \sim 20-30$  MeV:  
(with sufficient statistics effects of close resonances accounted for without partial-wave techniques)

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



Event selections & analysis:

- double arm RP trigger
- $nh^+ nh^-$  only central states ( $n = 1 - 3$ )
- $p_T(pp) = p_T(\text{central})$  (within resolution)
- horizontal vertex for pp (assuming  $\xi_p \sim 0$ )
- Possible extra selections: T1 & T2 veto
- $\pi/K$  identification using CMS tracker  $dE/dx$  ( $\pi/K$  uniquely identified if  $p \leq 1.20/1.05$  GeV)
- spin determination from decay angles

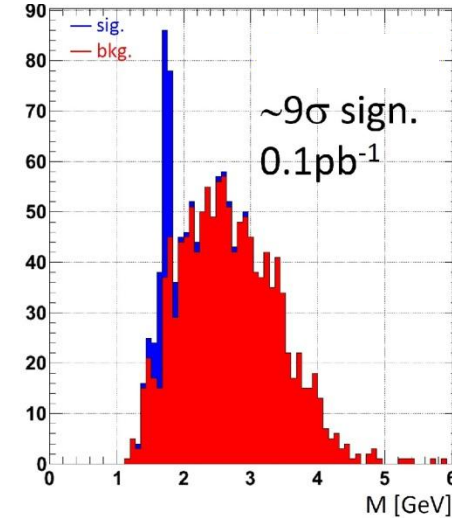
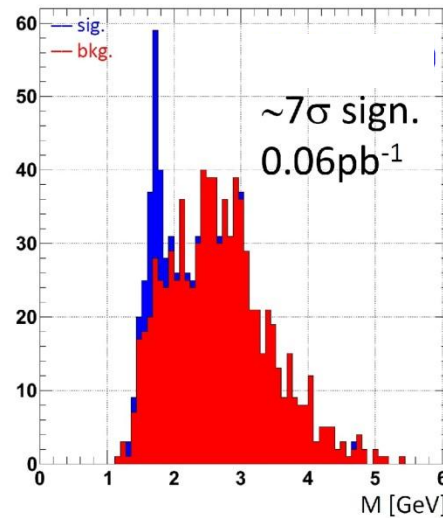
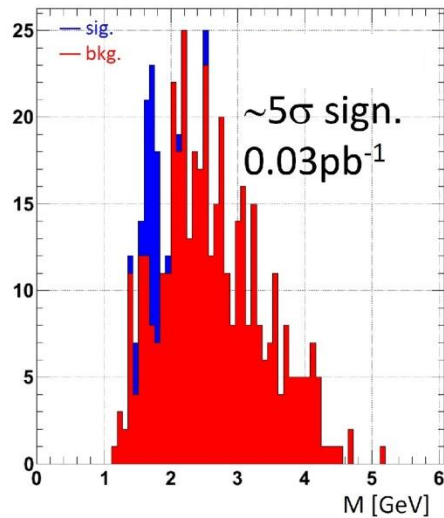


# Glueballs: decay characterisation

Analysis of available common CMS-TOTEM data set ( $L = 3 \text{ nb}^{-1}$  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

$\Rightarrow$   **$0.06 \text{ pb}^{-1}$  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  $f_0(1500)$ ) + an additional factor 2 considering backgrounds from other exclusive non-resonant production & adjacent  $f_2$  states ( $f_2(1640)$  &  $f_2(1810)$ )

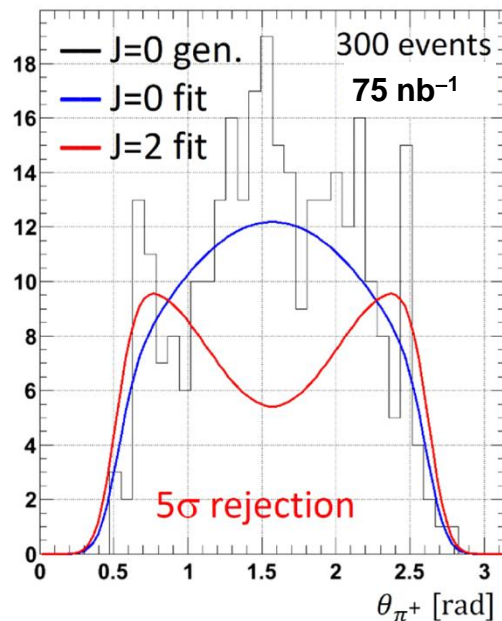
$\Rightarrow$   **$1.0 \text{ pb}^{-1}$  needed for  $f_0(1710)$  decay characterisation**



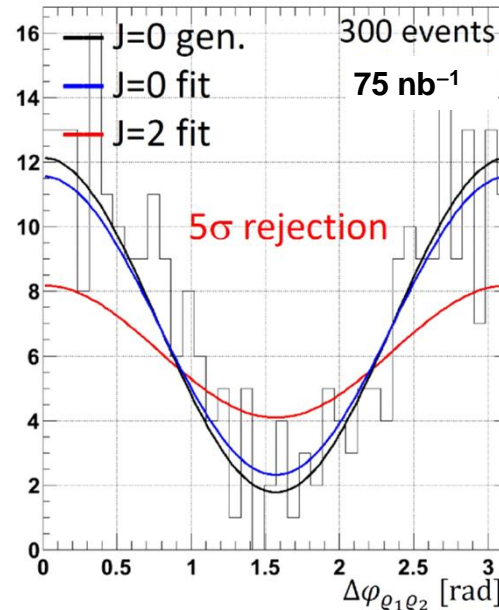
# Glueballs: spin analysis

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

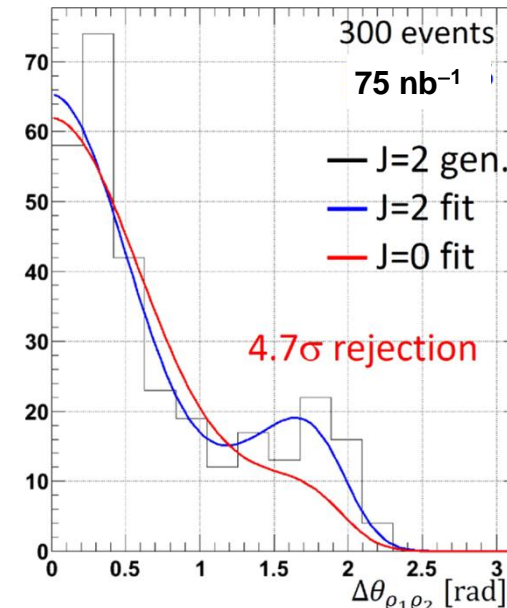
- Angular correlations between leading protons
- $\rho \rightarrow \pi^+ \pi^-$  distributions
- Angular correlations between 2 pairs of  $\pi^+ \pi^-$



polar angle  $\theta_{\pi^+}$  of the  $\pi^+ \pi^-$  pair with the  $\rho$  candidate at  $\eta > 0$



azimuth and polar angle difference between 2 pairs of  $\pi^+ \pi^-$  ( $\Delta\phi_{\rho_1 \rho_2}$ ,  $\Delta\theta_{\rho_1 \rho_2}$ )



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

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

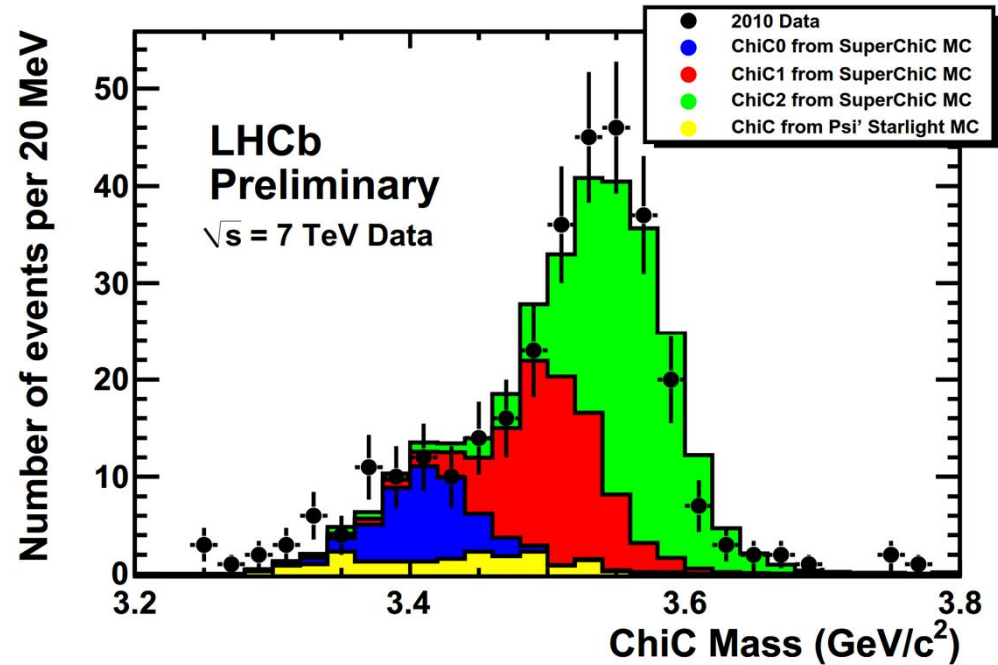
$\Rightarrow$   **$\sim 5 \text{ pb}^{-1}$  needed for  $f_0(1710)$  spin characterisation**



# Exclusive $\chi_c$ : previous measurements

$x \sim 10^{-3} - 10^{-4}$  gluons  $\Rightarrow$  charmonium states  $\Rightarrow$  perturbative QCD applicable

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



Comparison with Durham model prediction (arXiv:1405.0018):

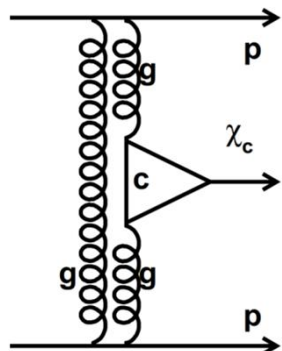
	$\sigma(pp \rightarrow pp(J/\psi + \gamma))$ LHCb (pb)	SuperCHIC prediction (pb)
$\chi_{c0}$	$9.3 \pm 4.5$	14
$\chi_{c1}$	$16.4 \pm 7.1$	10
$\chi_{c2}$	$28 \pm 12.3$	3

uncertainty in predictions:  $\times 2-3$

discrepancy ?



# Exclusive $\chi_c$ : CMS-TOTEM

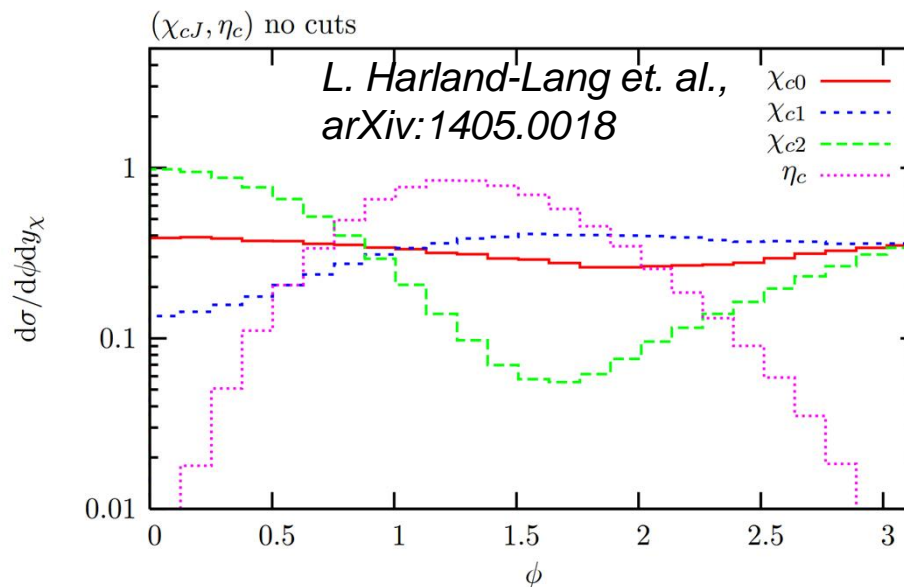


SuperChic predictions  $\sqrt{s} = 13$  TeV (Durham model):

	$J/\psi (\rightarrow \mu^+\mu^-)\gamma$	$2(\pi^+\pi^-)$	$3(\pi^+\pi^-)$	$\pi^+\pi^-K^+K^-$
$\chi_{c0}$ :	264 pb	<b>7.6 nb</b>	<b>4.1 nb</b>	<b>6.0 nb</b>
$\chi_{c1}$ :	166 pb	61 pb	46 pb	45 pb
$\chi_{c2}$ :	53 pb	49 pb	38 pb	40 pb

$\chi_c$  selection identical to glueball analysis except  $\Gamma_\chi \ll \sigma(M) \sim 30$  MeV.  
**In  $\sim 5$  pb $^{-1}$  (at least)  $\chi_{c0}$  with good statistics in 3 decay different modes(!),**  
 maybe even  $\chi_{c2}$  (if LHCb measurement right!)

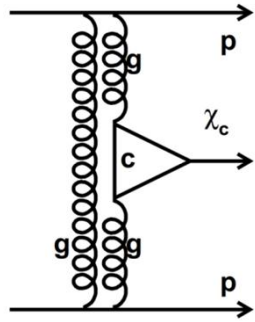
**$\sim 5$  pb $^{-1}$  would allow unique measurement of  $\phi$ , azimuthal angular correlations between leading protons, for  $\chi_{c0}$  & test models!**







# Exclusive J/ψ



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

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

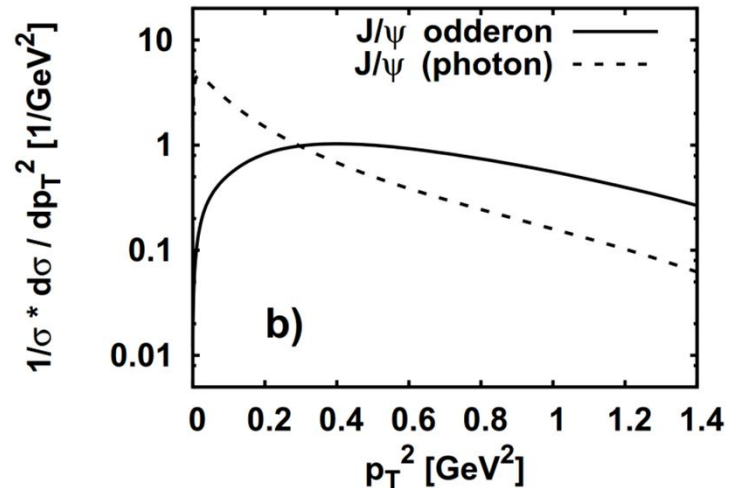
agrees with Starlight prediction within  $\sim 10\%$

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

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

**$\sim 5$  pb<sup>-1</sup> would allow unique measurement of proton  $\phi$  correlation & test models + measure spectrum for higher  $p_T$ 's for J/ψ to look for possible effects of the odderon**

L. Motyka, arXiv:0808.2216





## Conclusion

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

**With  $5 \text{ pb}^{-1}$  &  $\mu \sim 0.1$**

- (disap)prove glueball nature of  $f_0(1710)$
- measure exclusive  $\chi_c$  &  $J/\psi$  production (including proton azimuthal correlations)
- measure rapidity gap survival probability (in several SD process)
- ...

**May get  $1\text{-}2 \text{ pb}^{-1}$  at  $\beta^* = 90$  m &  $\mu \sim 0.1$  in 2015**