New Possibilities in Physics of Quarkonia
24-25 September 2015

Prospects of quarkonium physics with the CMS experiment

Ilse Krätschmer* (HEPHY Vienna)
on behalf of the CMS Collaboration

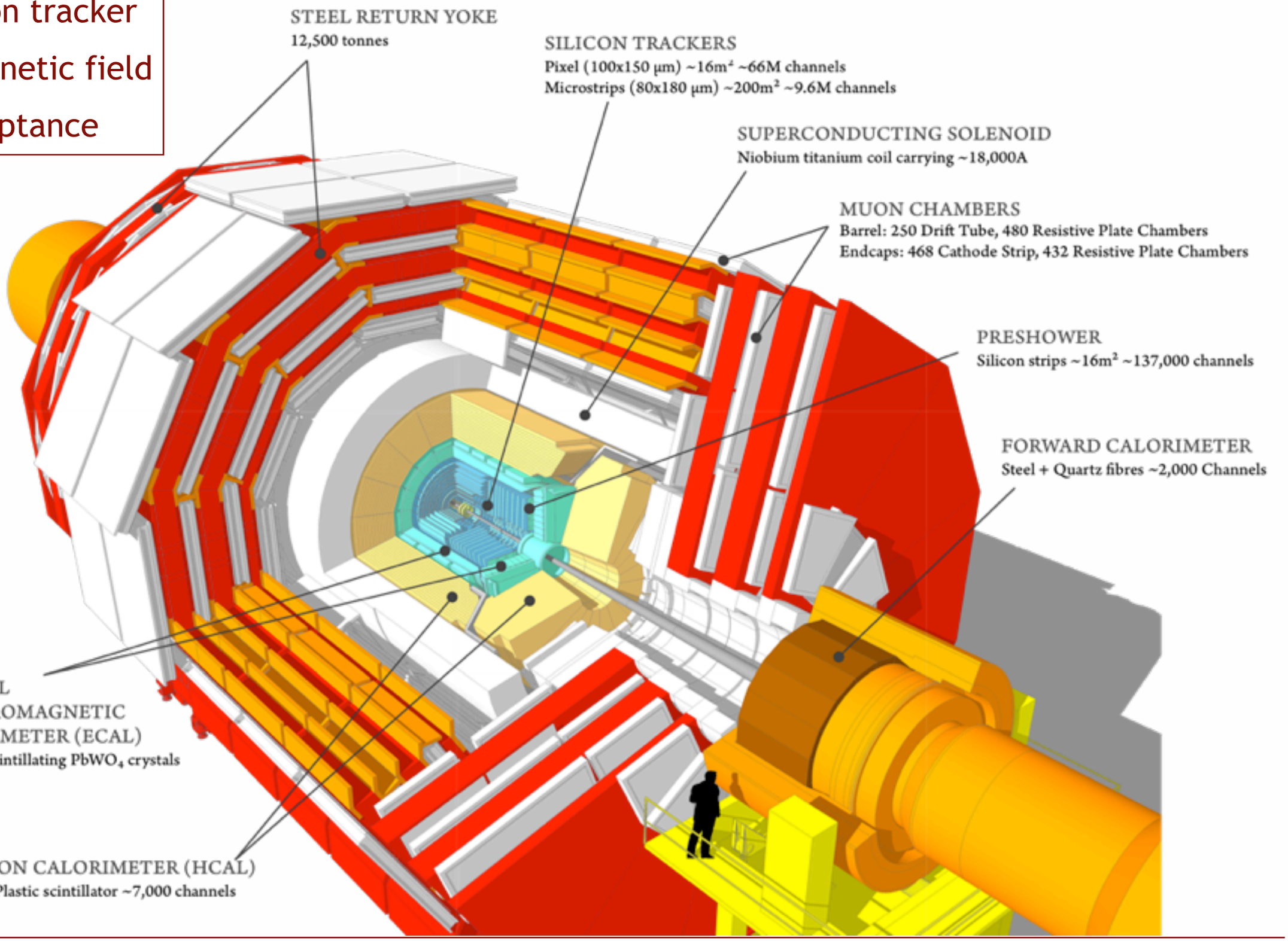
*supported by Austrian Science Fund (FWF): P28411

CMS is well suited for quarkonium studies

Large silicon tracker

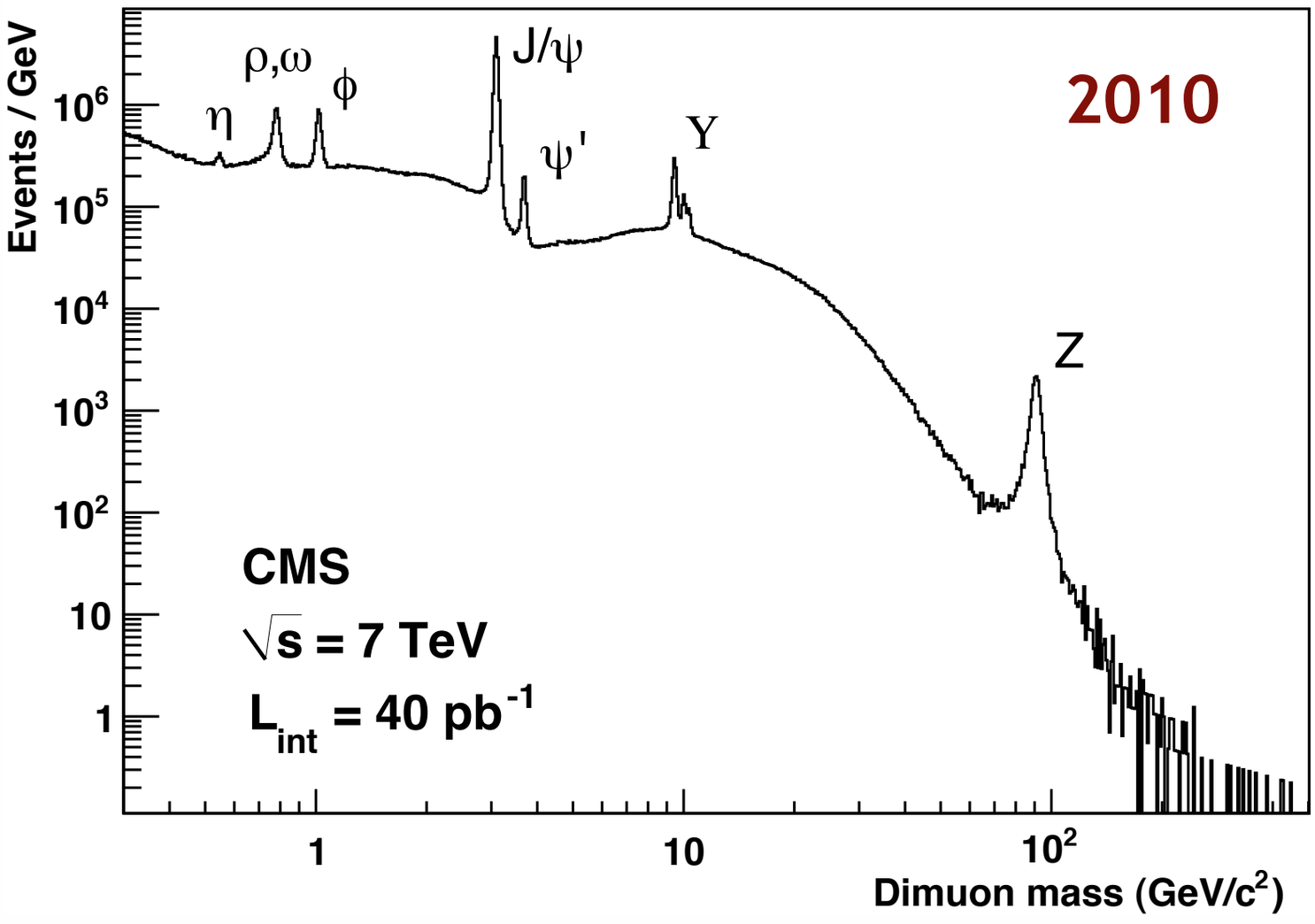
Strong magnetic field

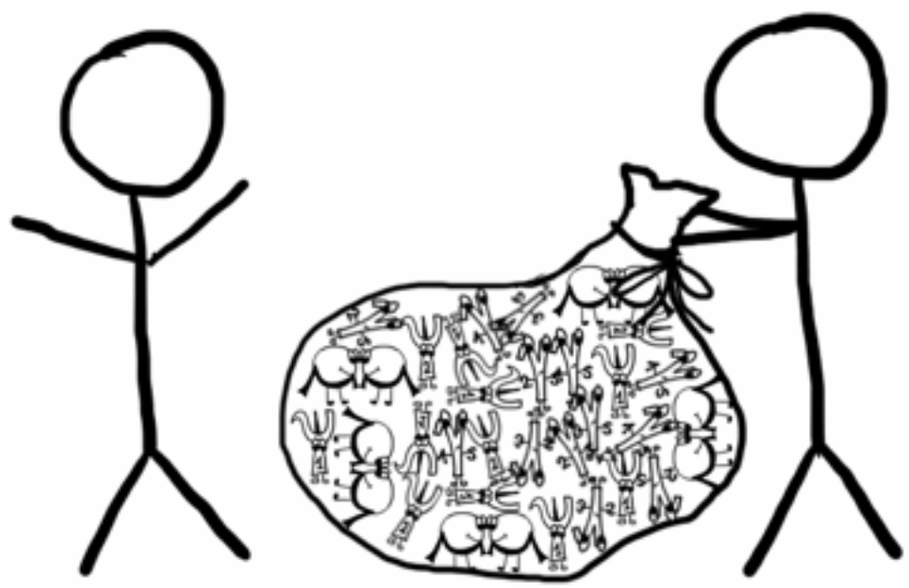
Broad acceptance



Dedicated trigger strategy

- Trigger requiring two muons
- Possible to collect a large number of events up to high transverse momentum, p_T
- High signal/background ratio

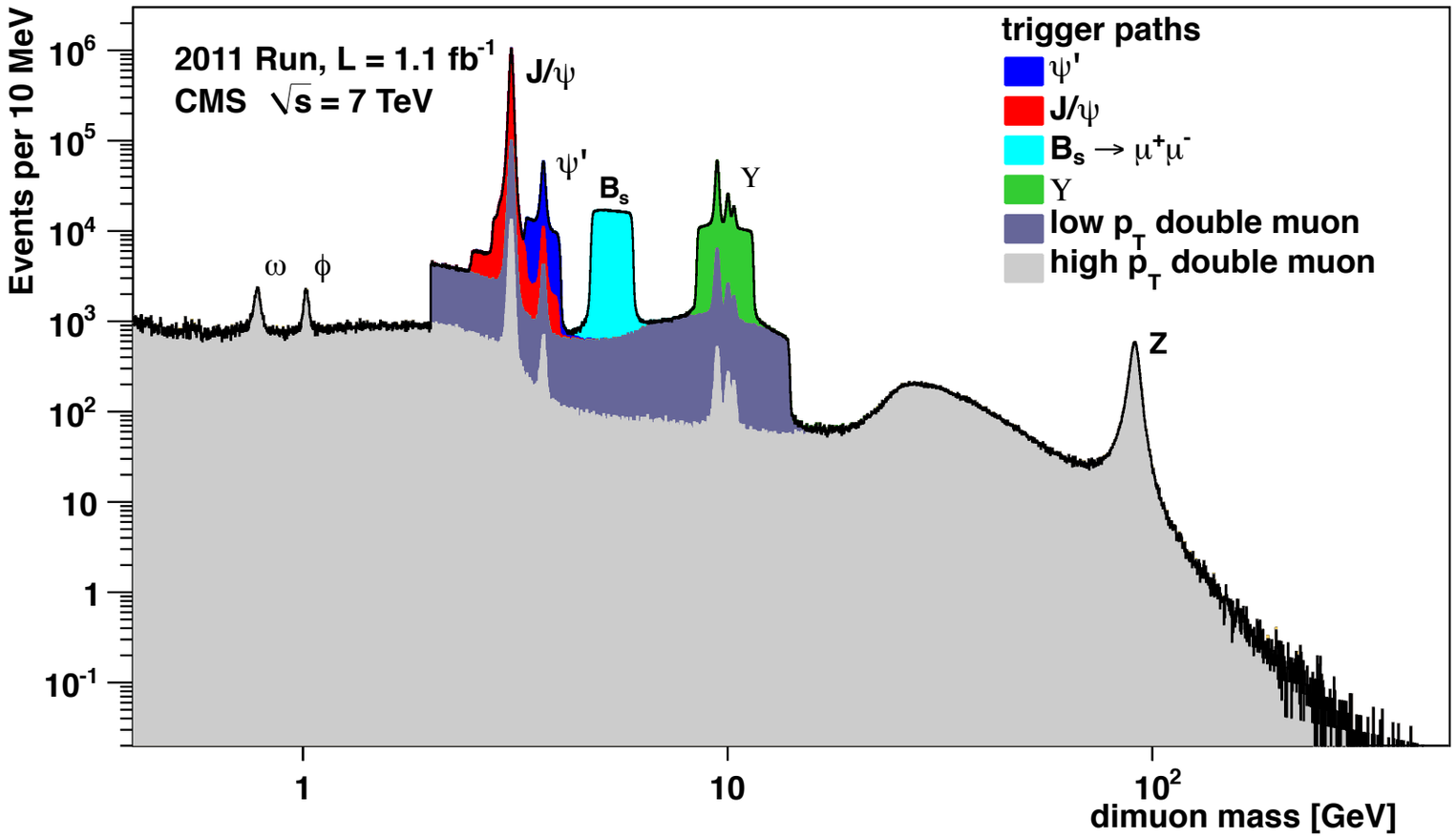


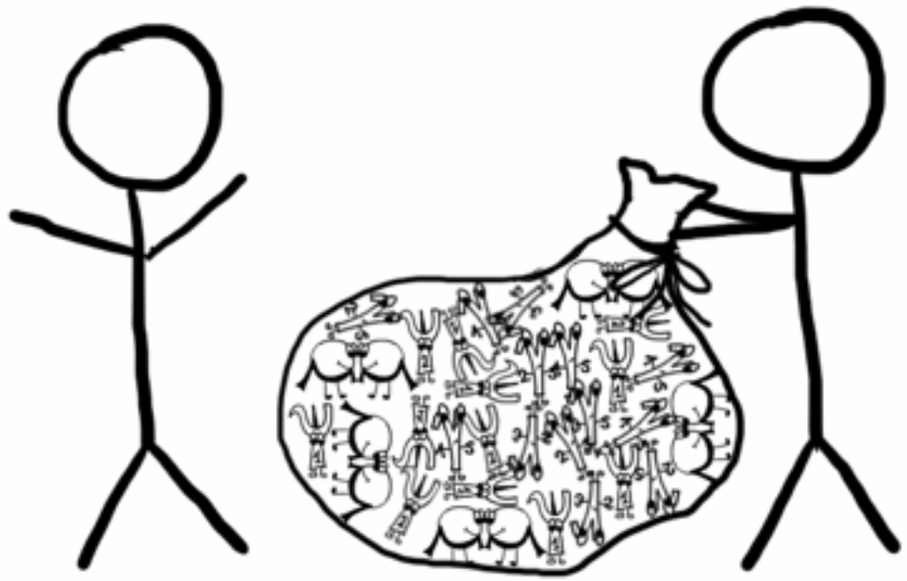


Dedicated trigger strategy

- Trigger requiring two muons coming from the same vertex
- Possible to collect a large number of events up to high transverse momentum, p_T
- High signal/background ratio

2011





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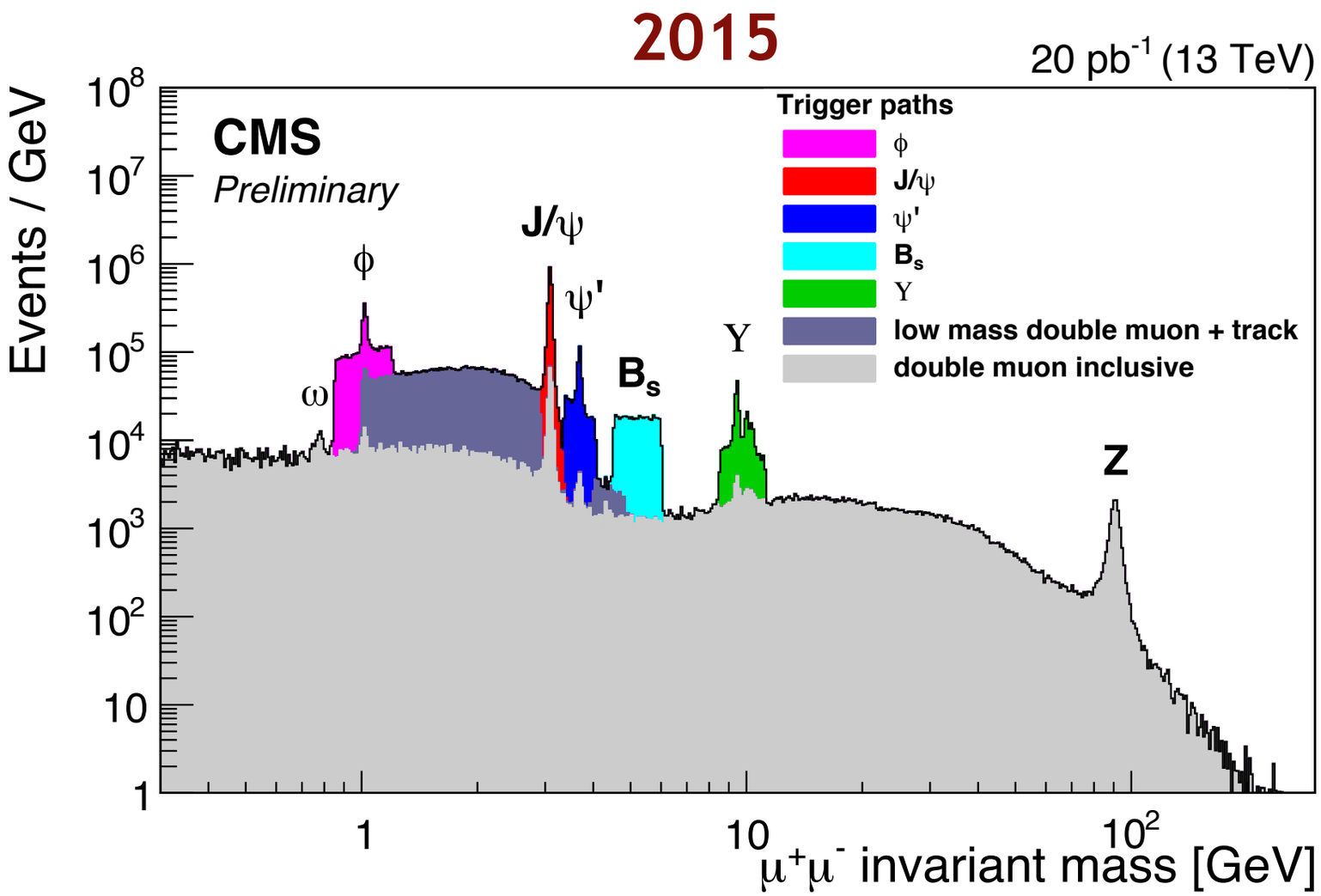
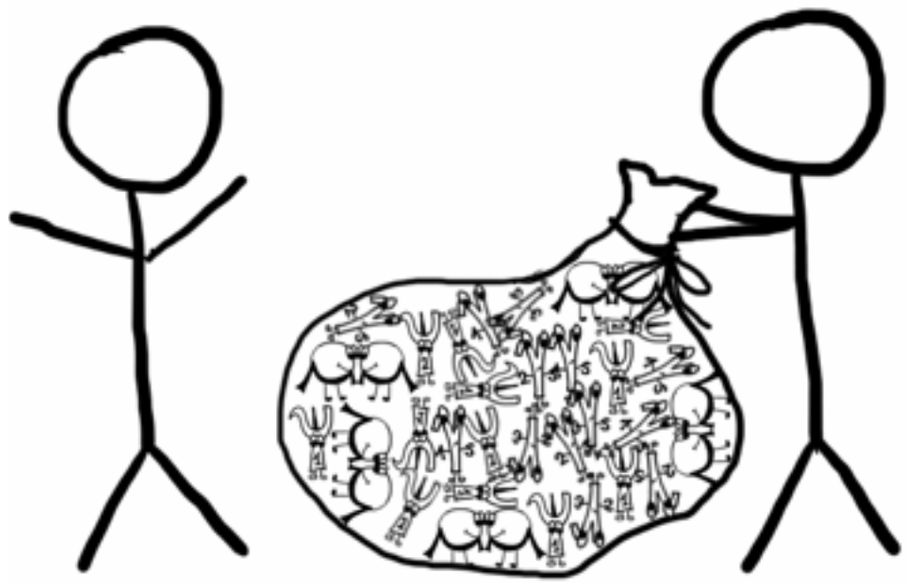
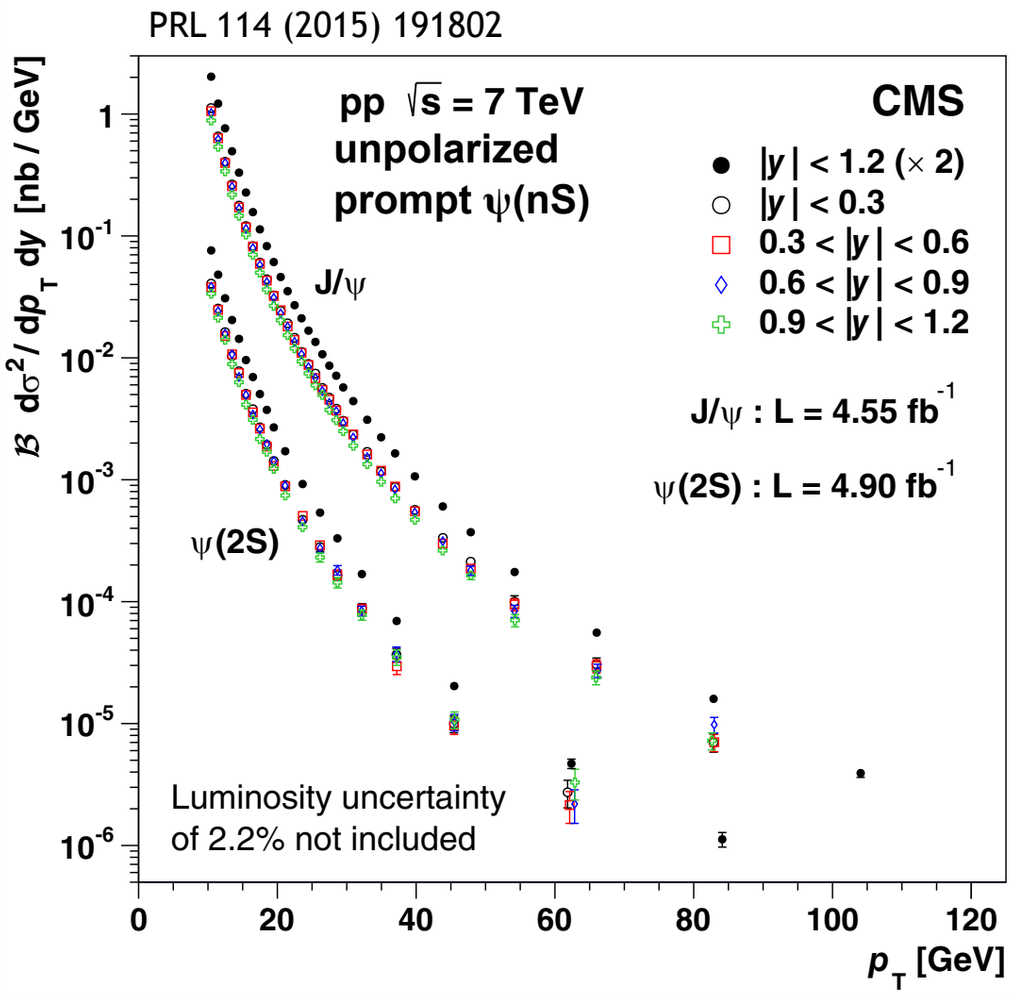
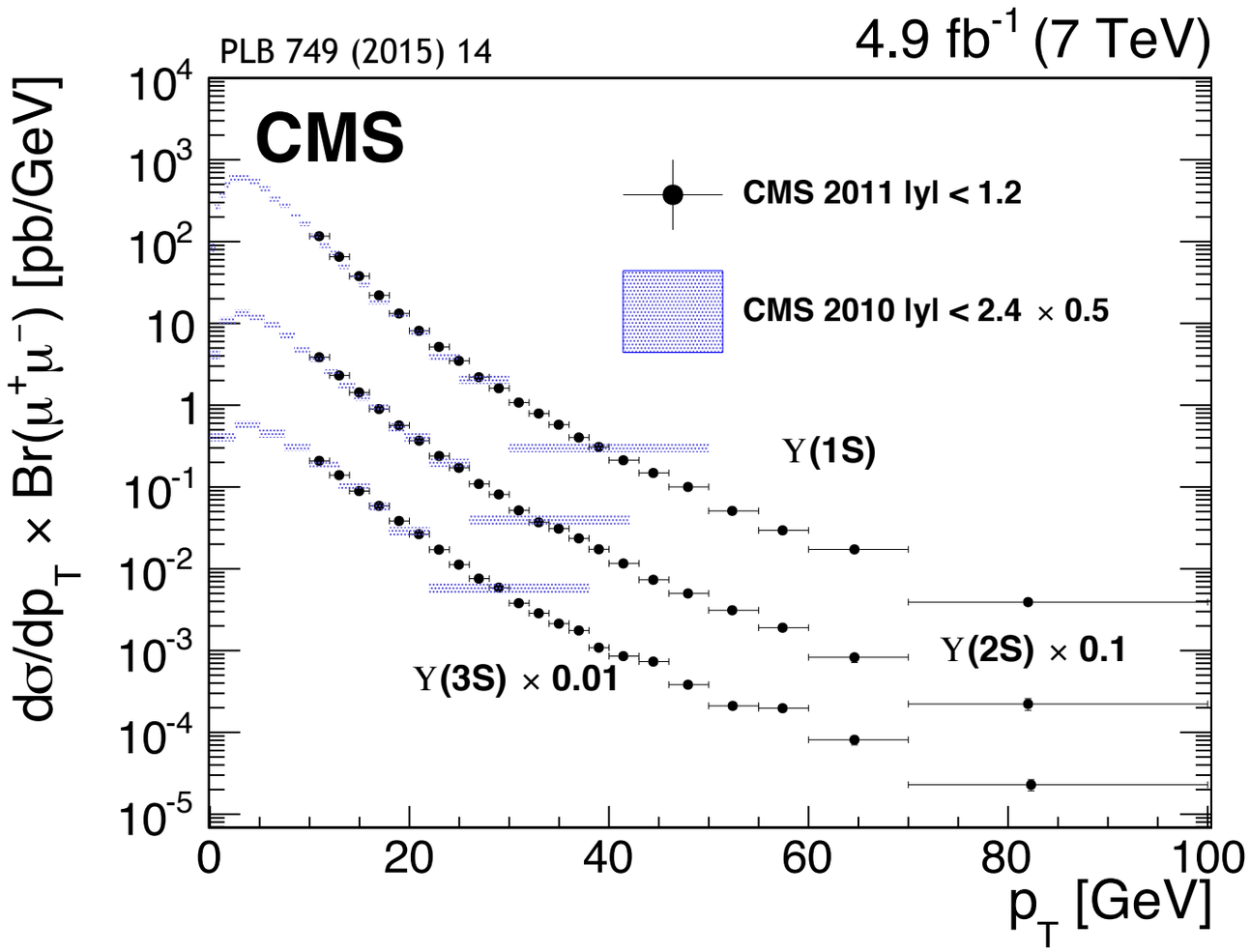


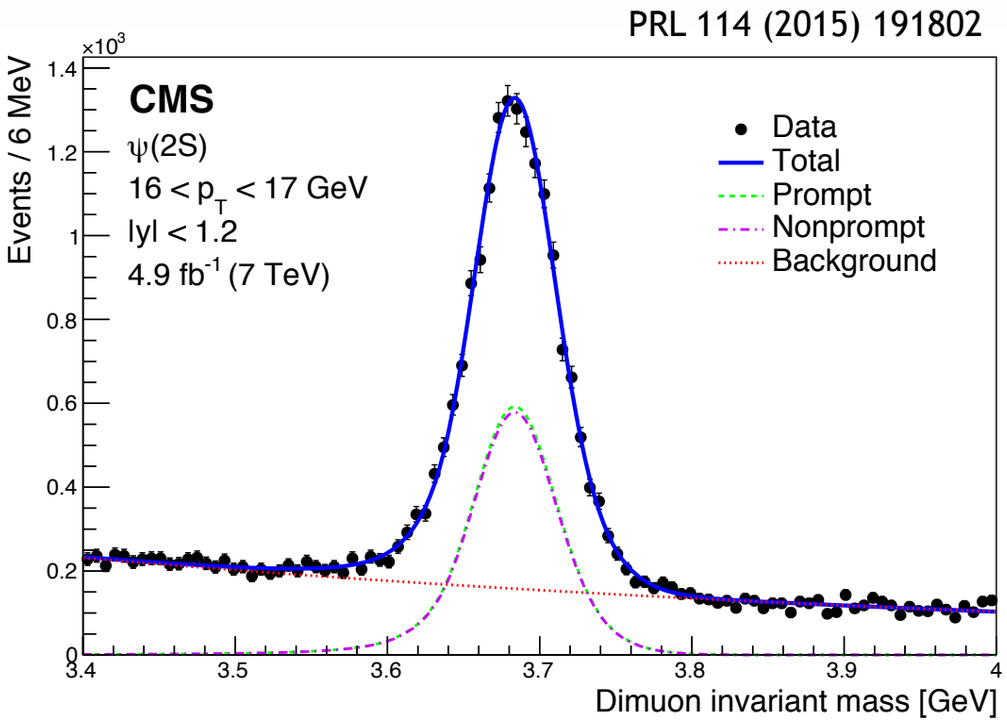


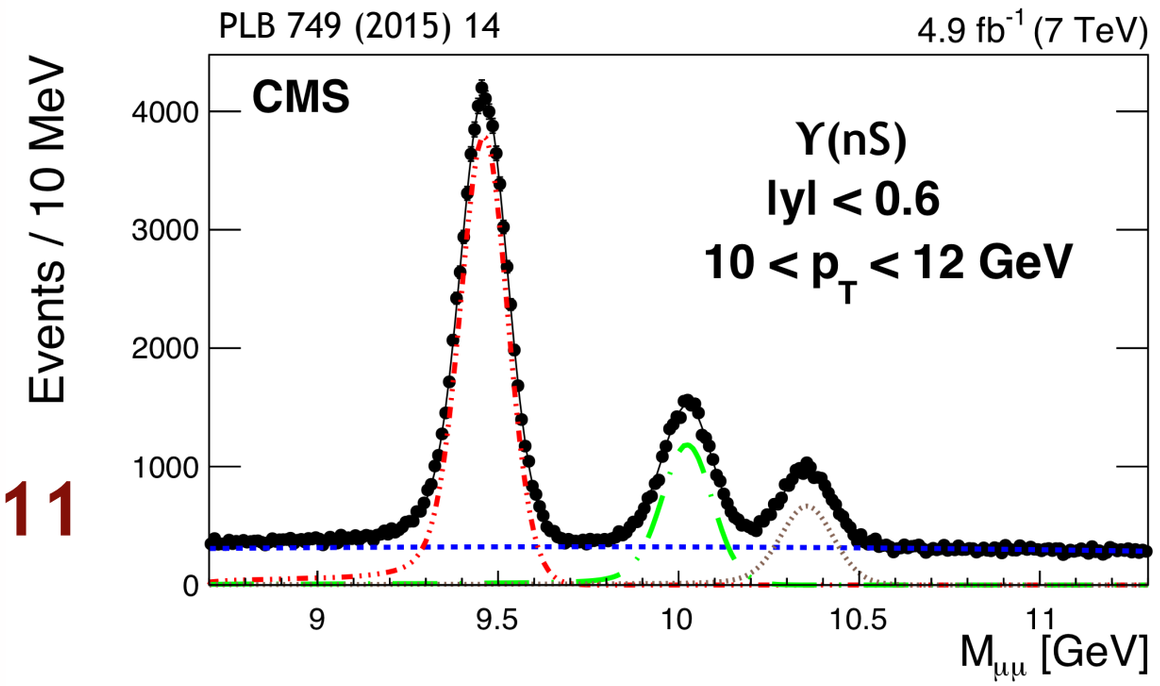
High p_T coverage



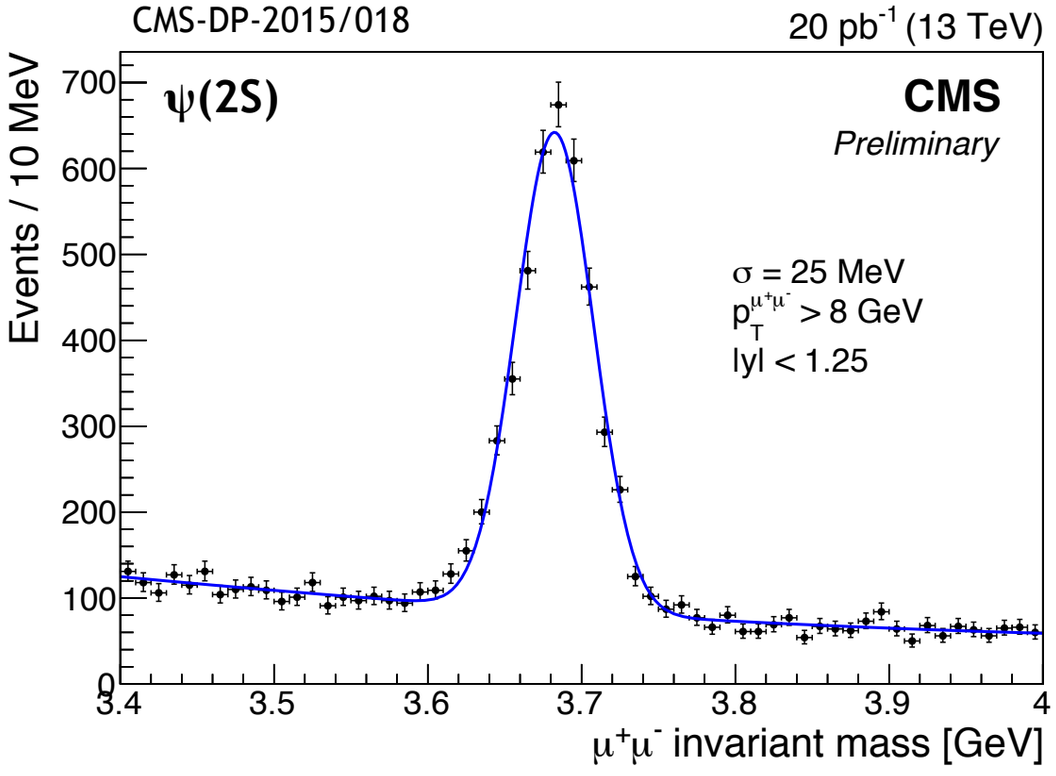


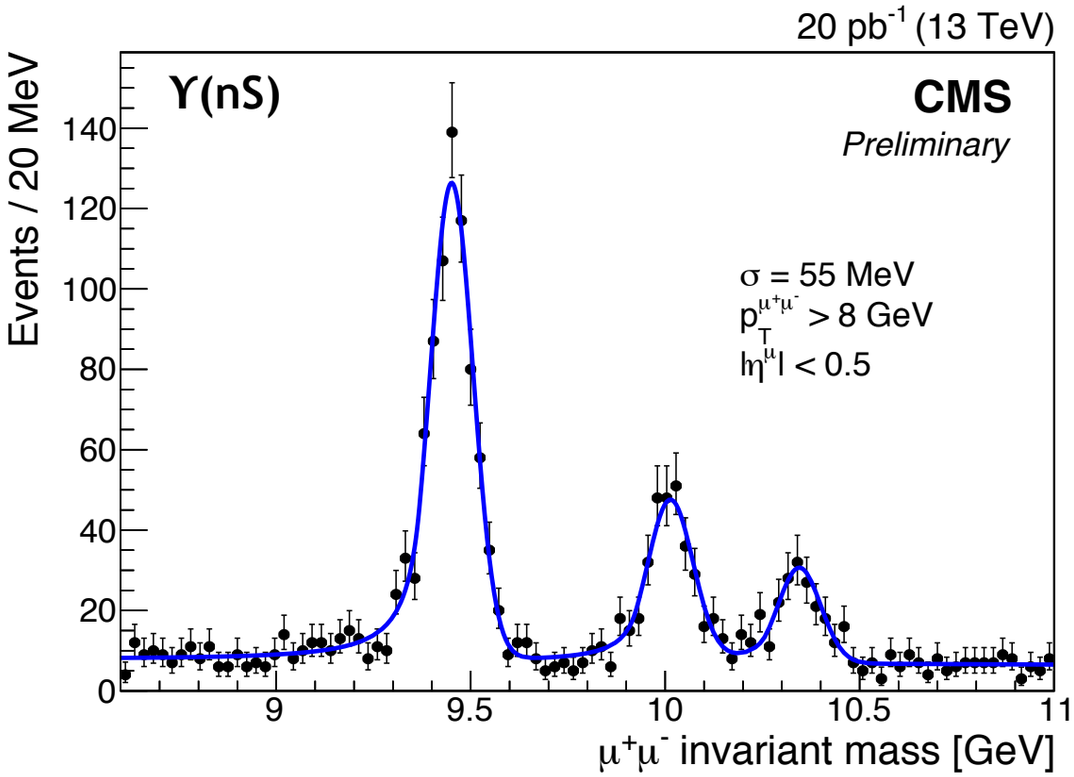
Excellent dimuon mass resolution





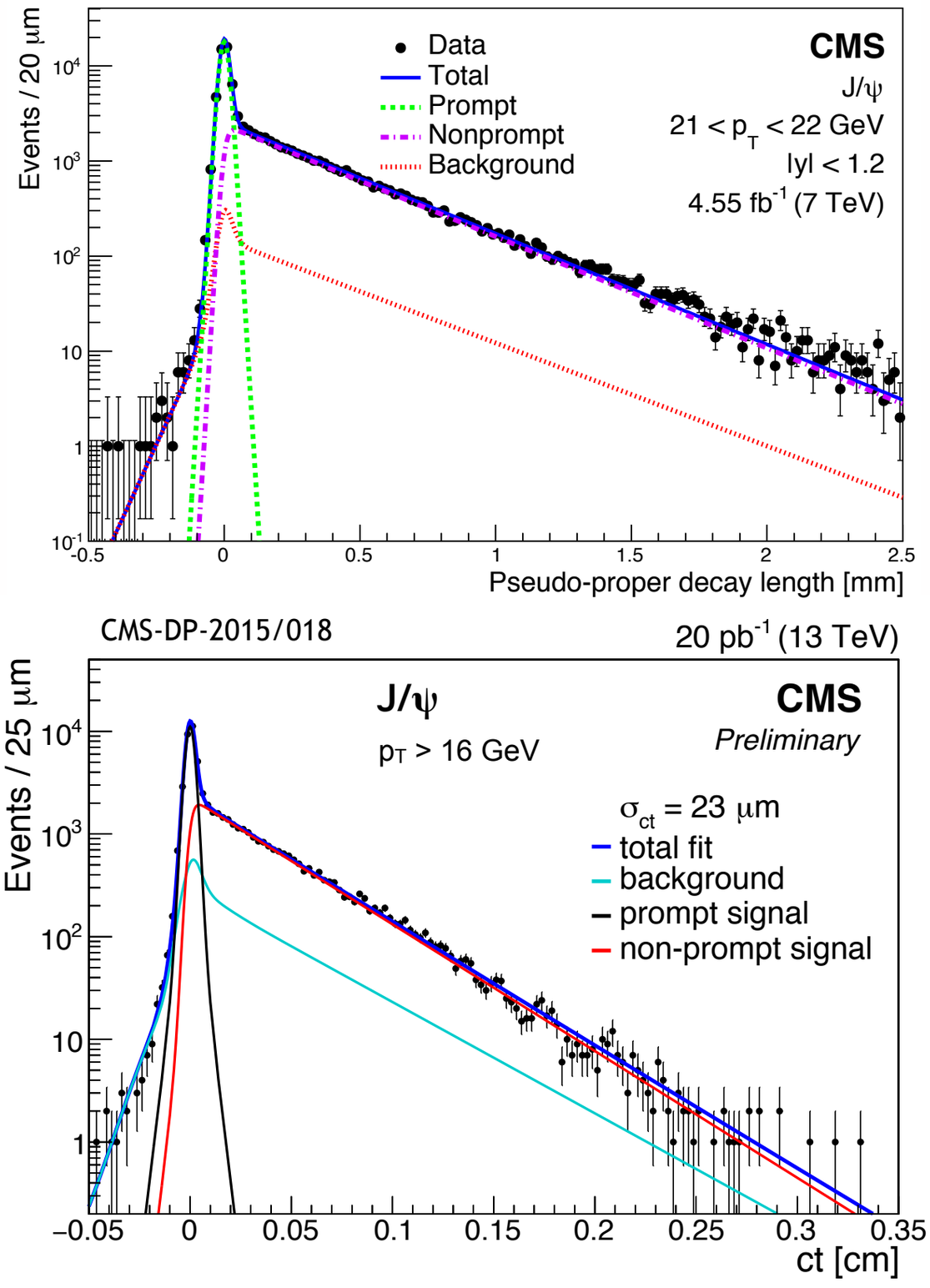
2011





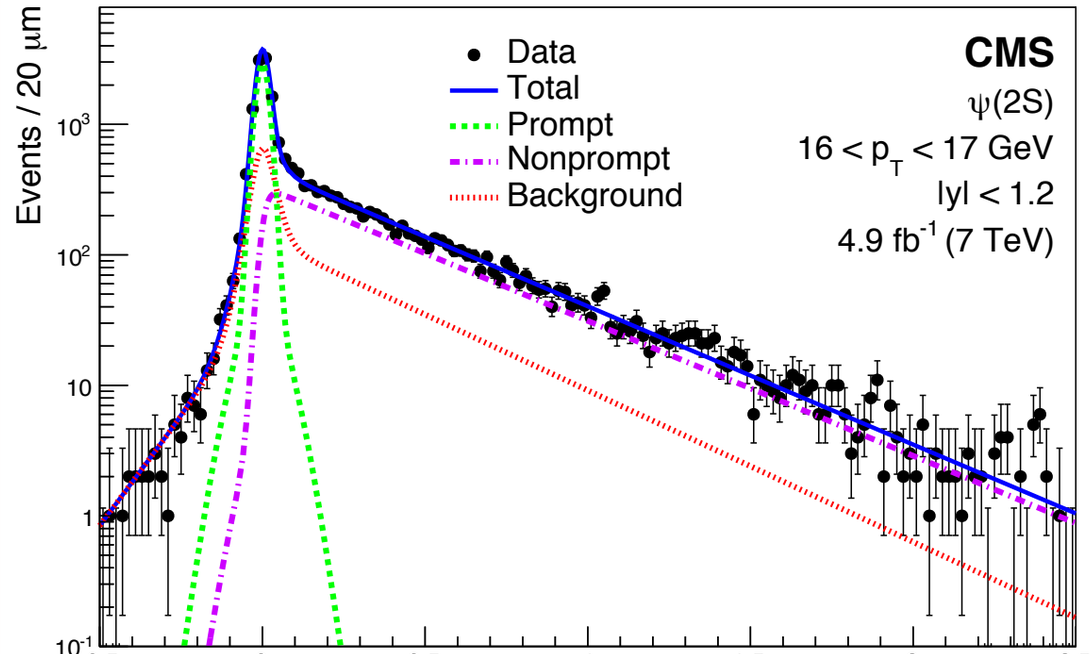
2015

Excellent decay length resolution



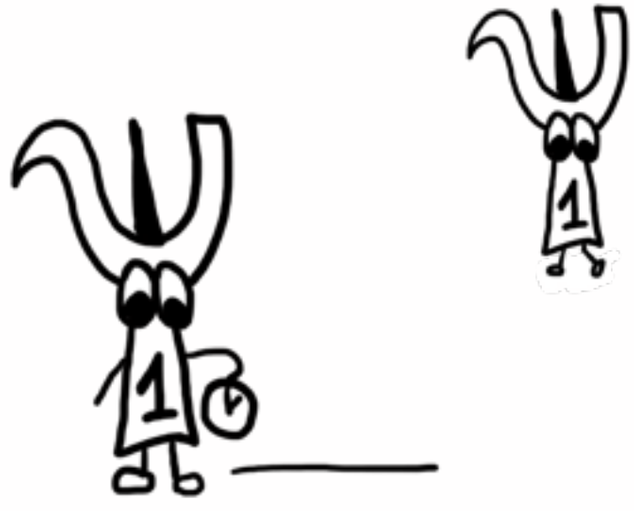
2011

PRL 114 (2015) 191802



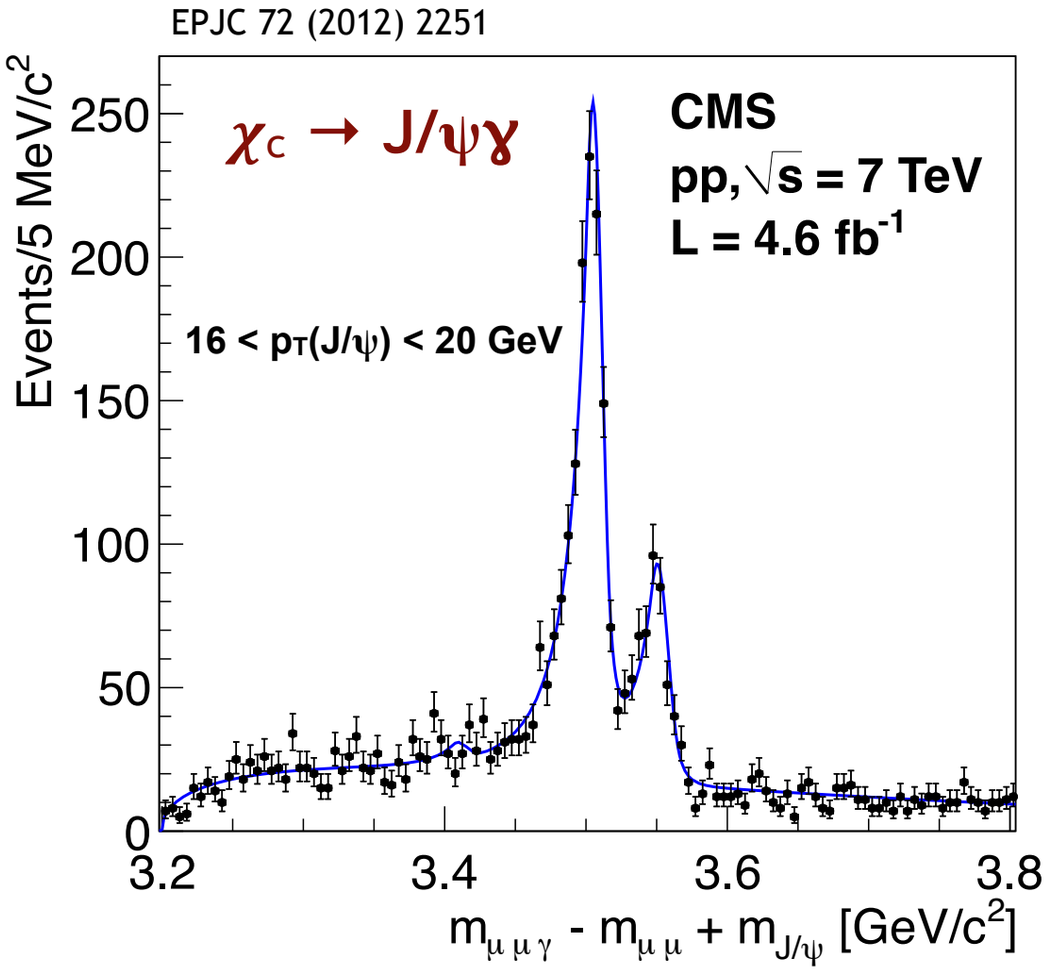
2015

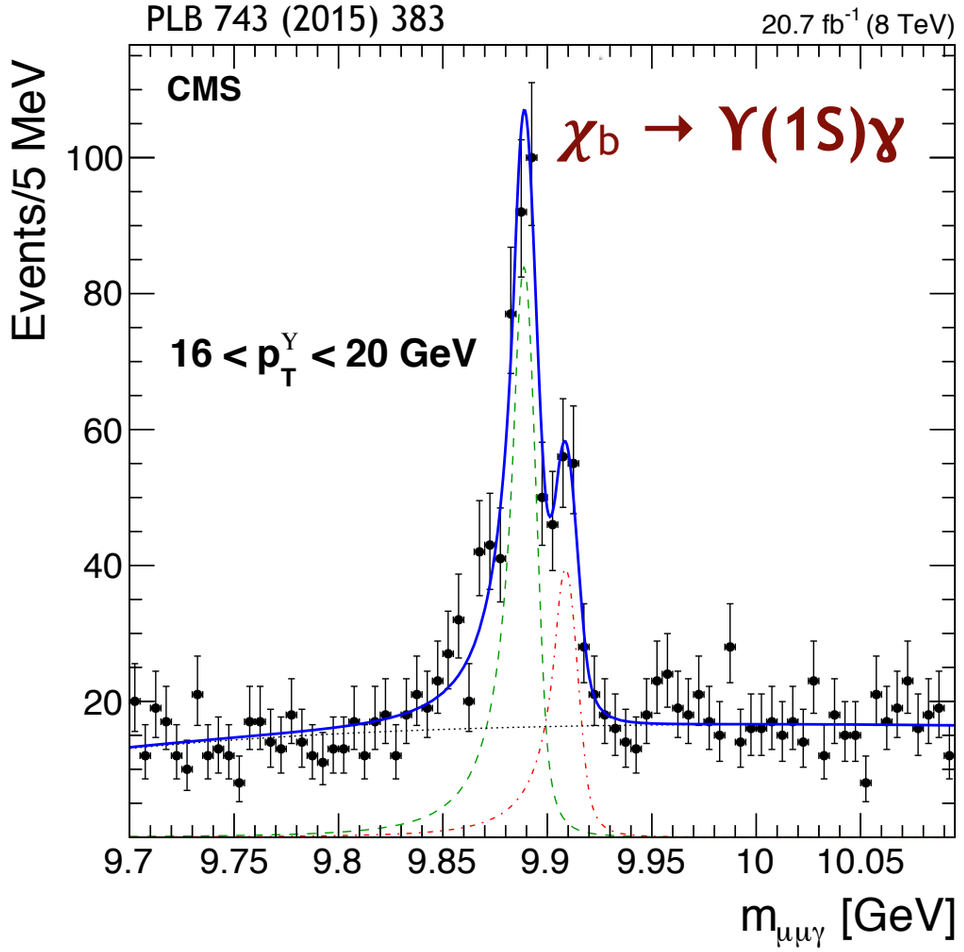
- Allows us to distinguish prompt and non prompt events



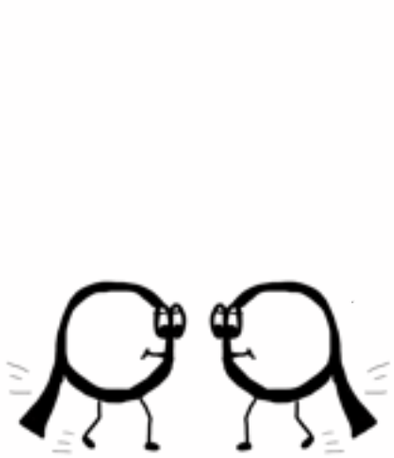
Excellent χ mass resolution

- Detection via radiative decays using converted photons
- e^+e^- tracking provides mass resolution needed to resolve the χ states
- Photons have ~1% probability to convert and be reconstructed in the silicon tracker





Timeline



Run I

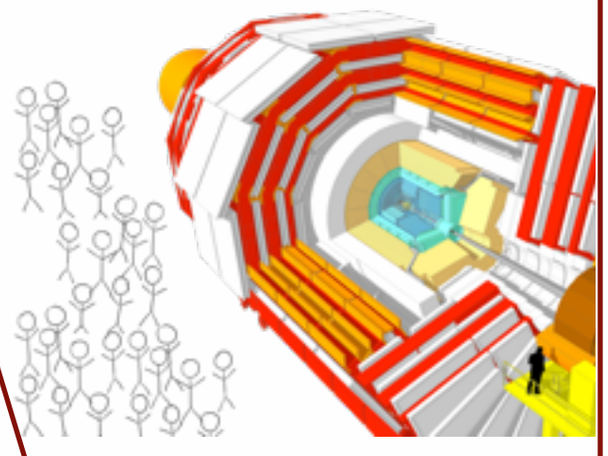
Long shutdown I

Run II

2010	2011	2012	2013	2014	2015
$\sqrt{s}$ = 7 TeV L_{int} = 37 pb^{-1}	7 TeV 5 fb^{-1}	8 TeV 20 fb^{-1}	Upgrades: 4th muon chamber improved track reconstruction cold operation of tracker ...		13 TeV 2-3 fb^{-1} (expected for 2015)

# signal events	
J/ψ	4.7M
ψ(2S)	317k
Υ(1S)	413k
Υ(2S)	152k
Υ(3S)	111k
χ_{c1}(1P)	8k
χ_{c2}(1P)	3.5k
X(3872)	10.5k

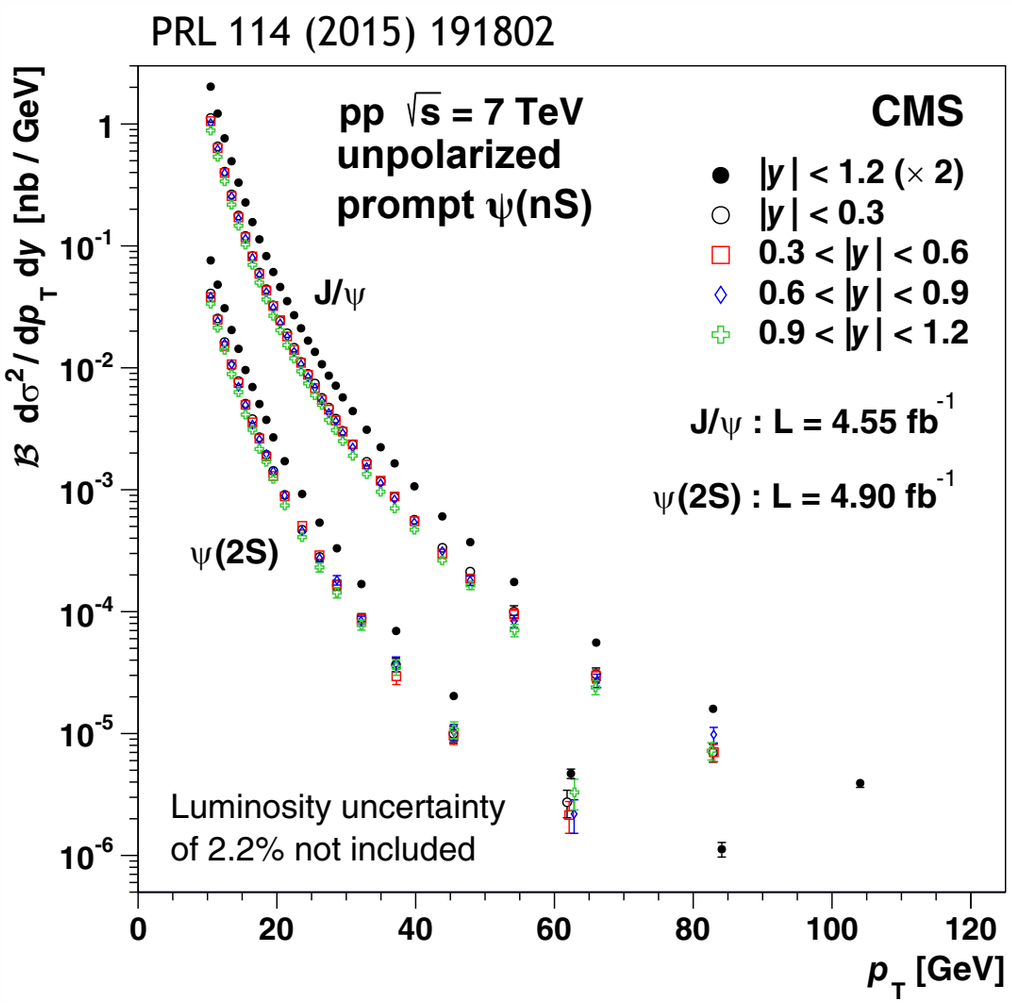
# signal events	
χ_{b1}(1P)	1.9k
χ_{b2}(1P)	1k

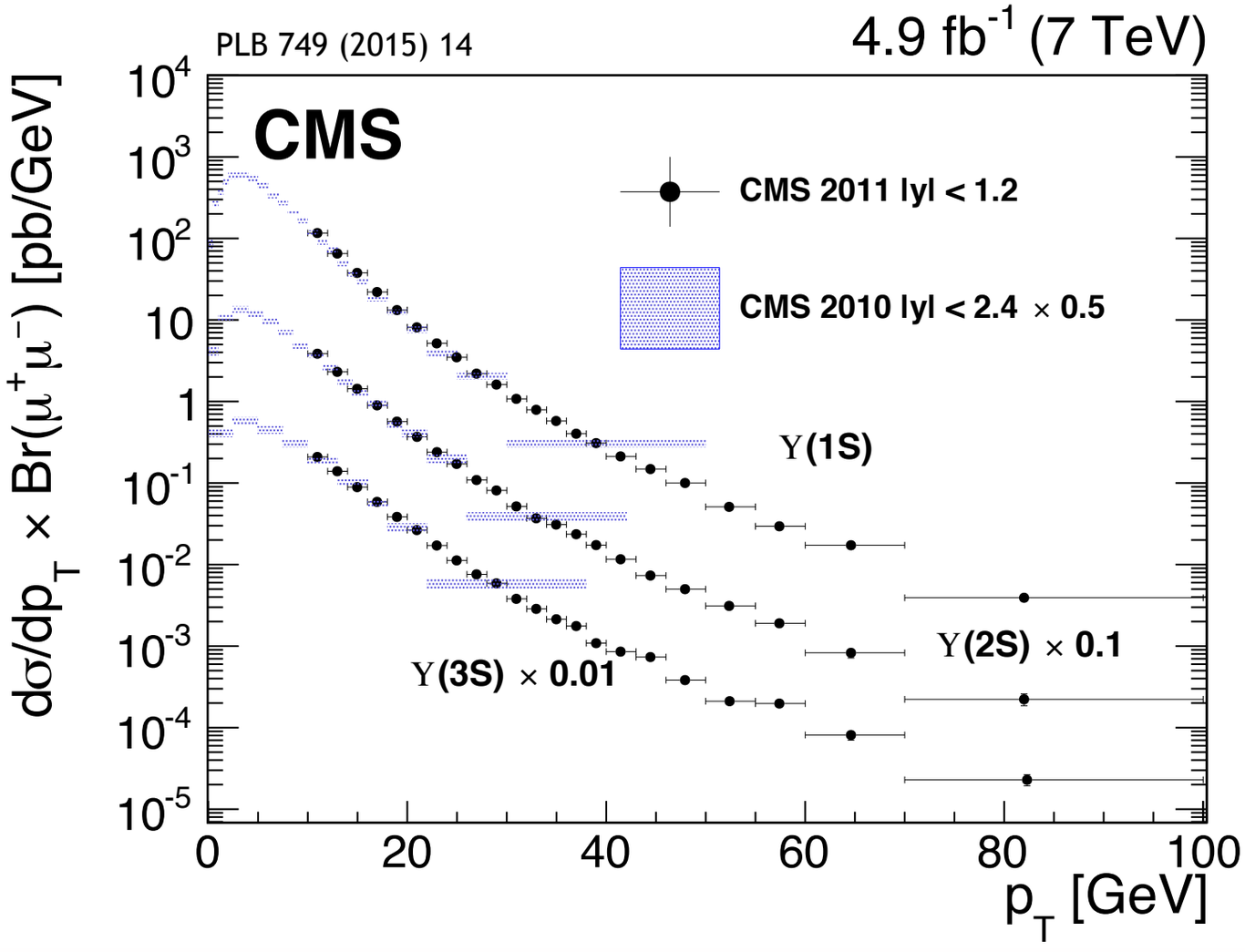


High luminosity of run I compensates for higher energy in run II so far

Run I: S-wave quarkonia

- S-wave quarkonia are experimentally easily accessible through dimuon decay
- Cross sections and polarizations of all five S-wave quarkonium states measured as function of p_T and rapidity, |y|
- Cross sections with early run II data coming soon





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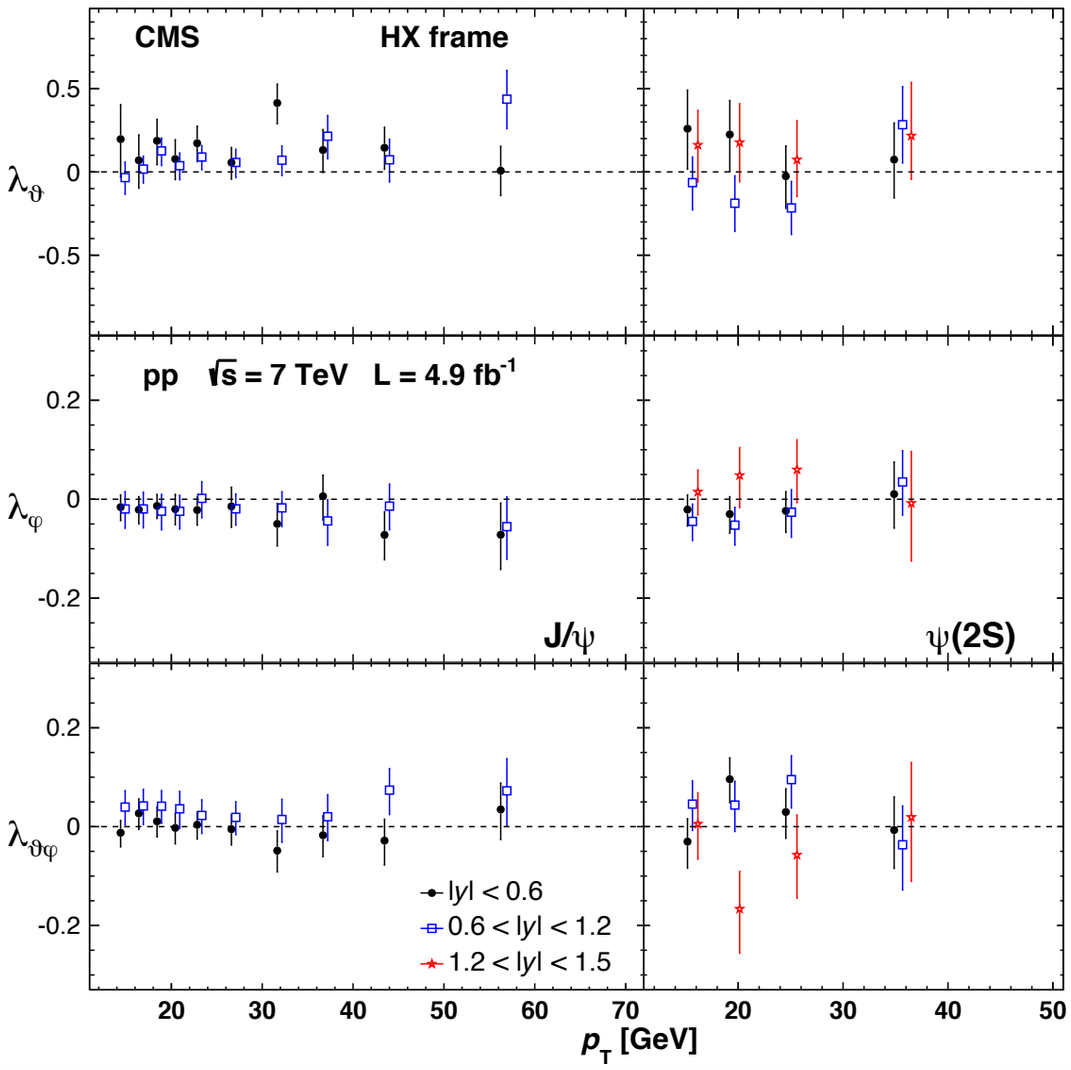
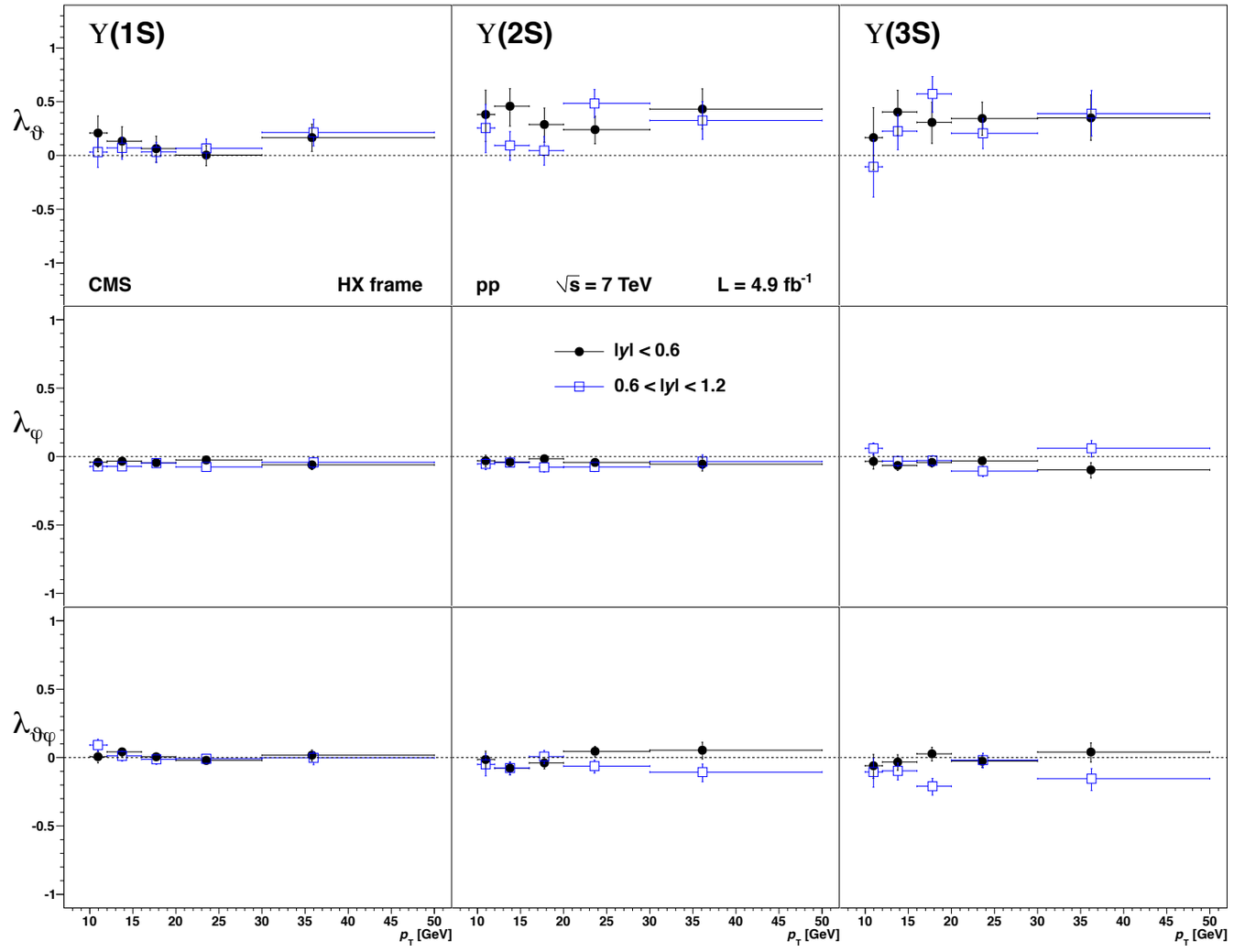
PLB 727 (2013) 381



PRL 110 (2013) 081802

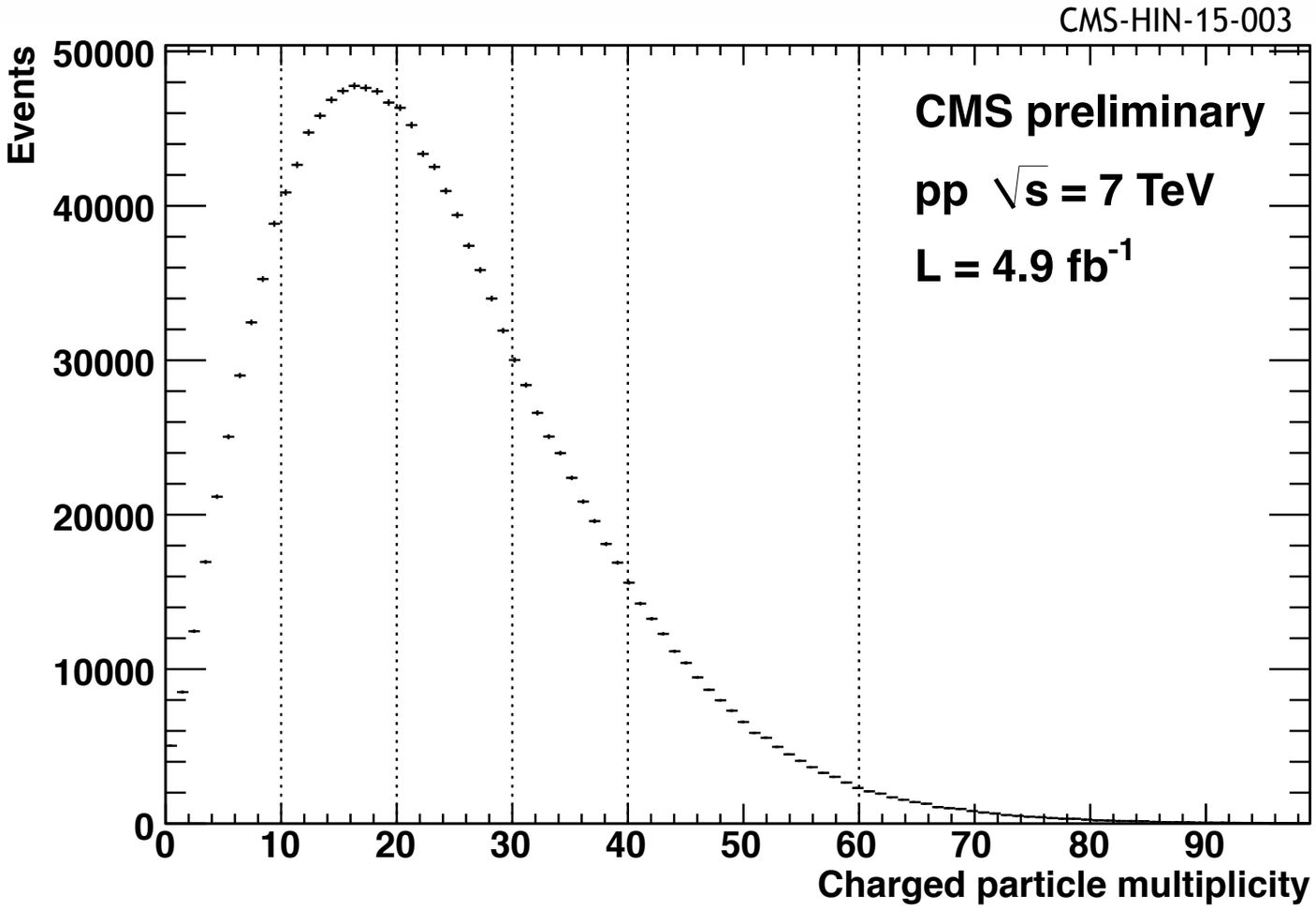


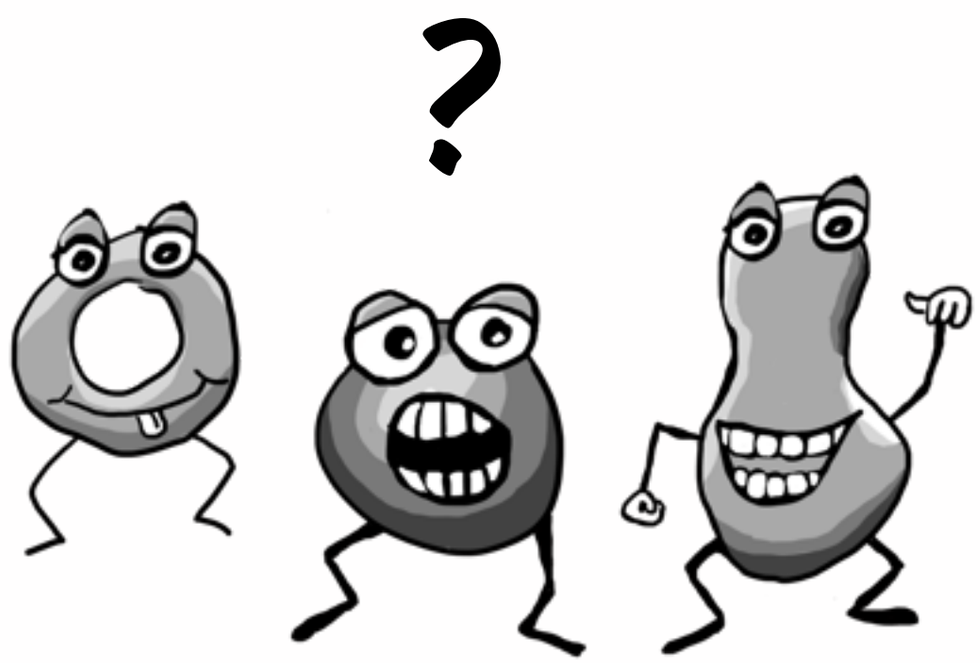
Υ(nS) polarization vs charged particle multiplicity N_{ch}

- First step towards testing the universality (process independence) of LDMEs

➡ Extend measurement to pPb and PbPb collisions

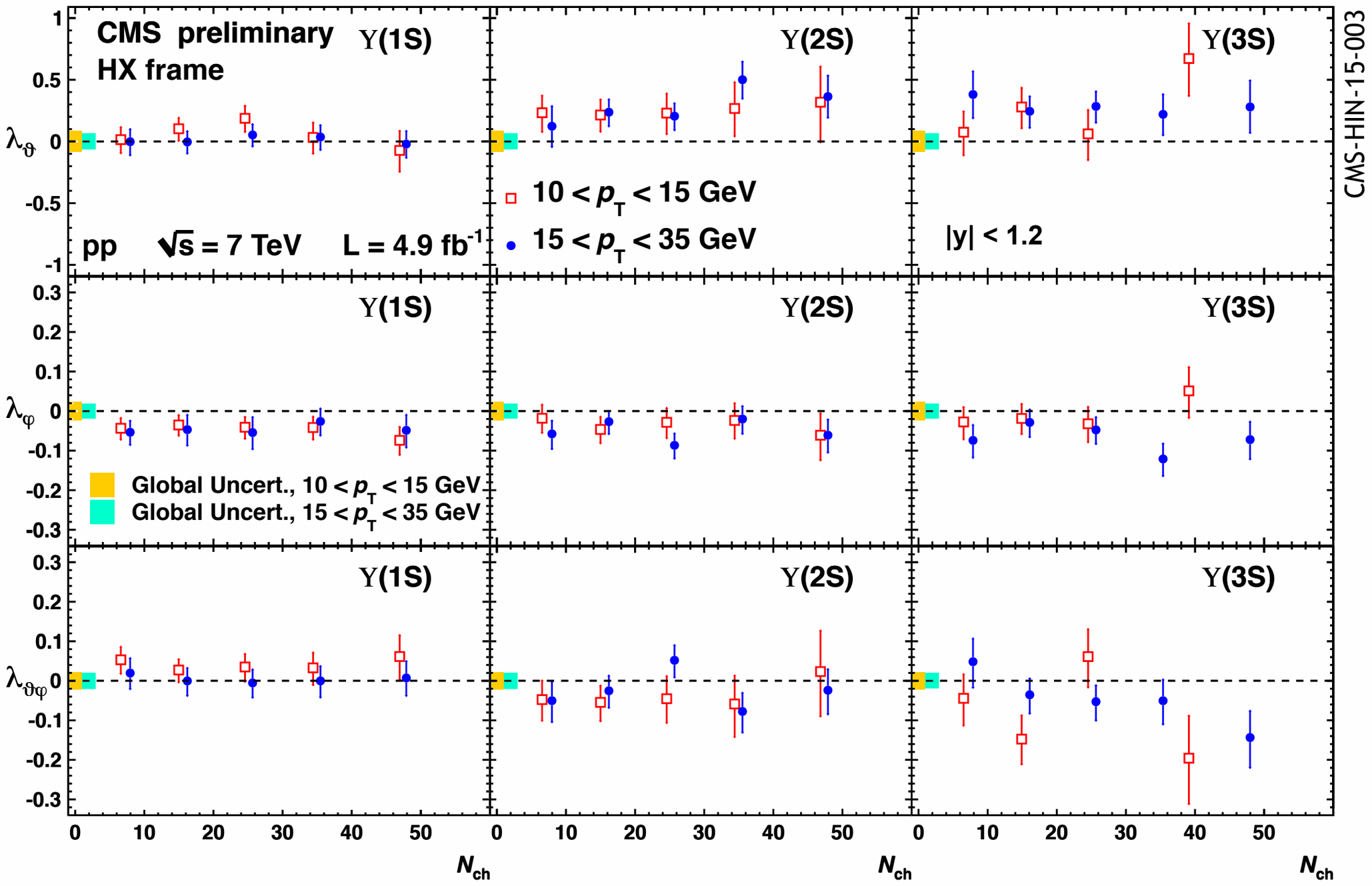
- N_{Ch} = sum of "high purity" tracks with p_T > 500 MeV weighted by likelihood that track belongs to primary vertex, excluding the two muons





Frame-dependent results in the HX frame

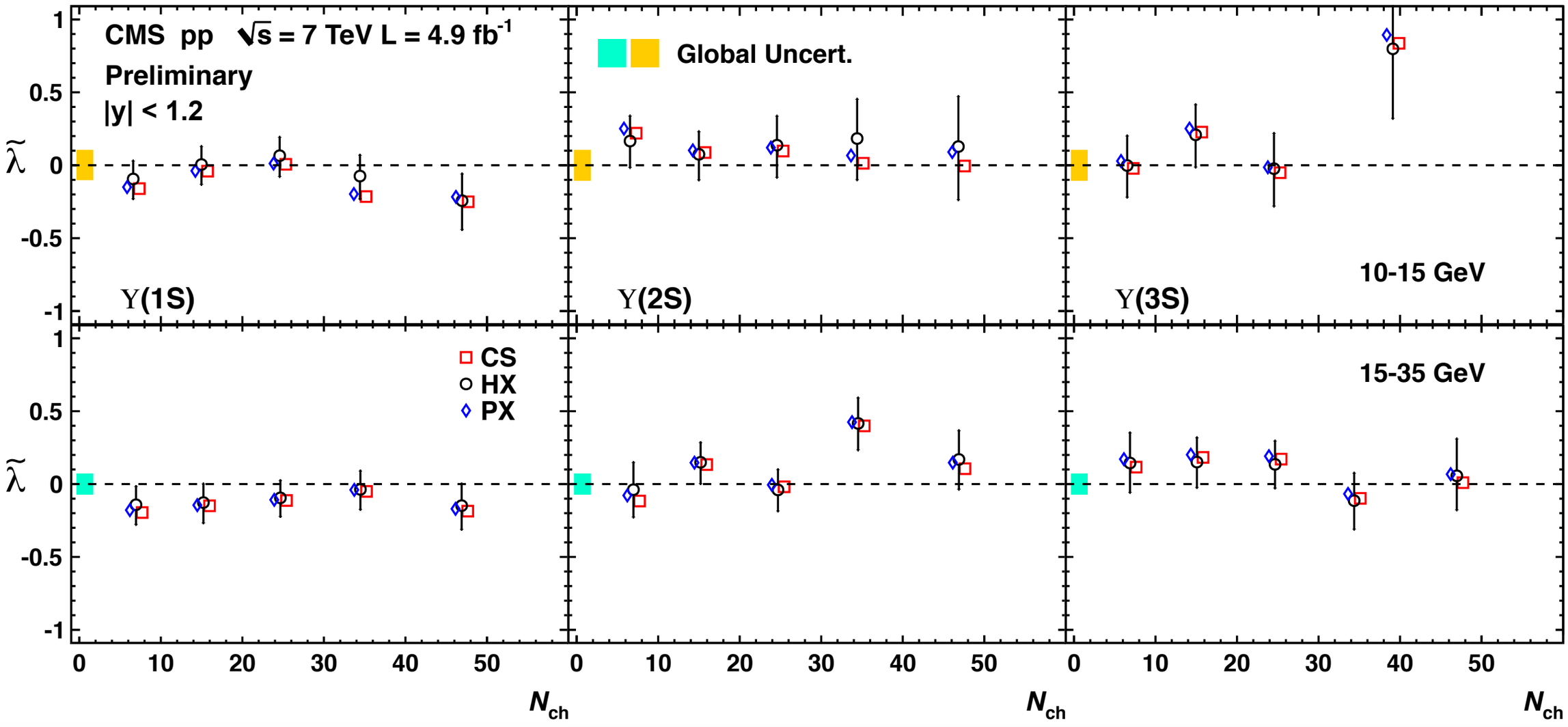
Polarization does not change significantly as function of N_{ch}



Frame-independent results

- Good agreement in the 3 reference frames
- No hints of systematic problems

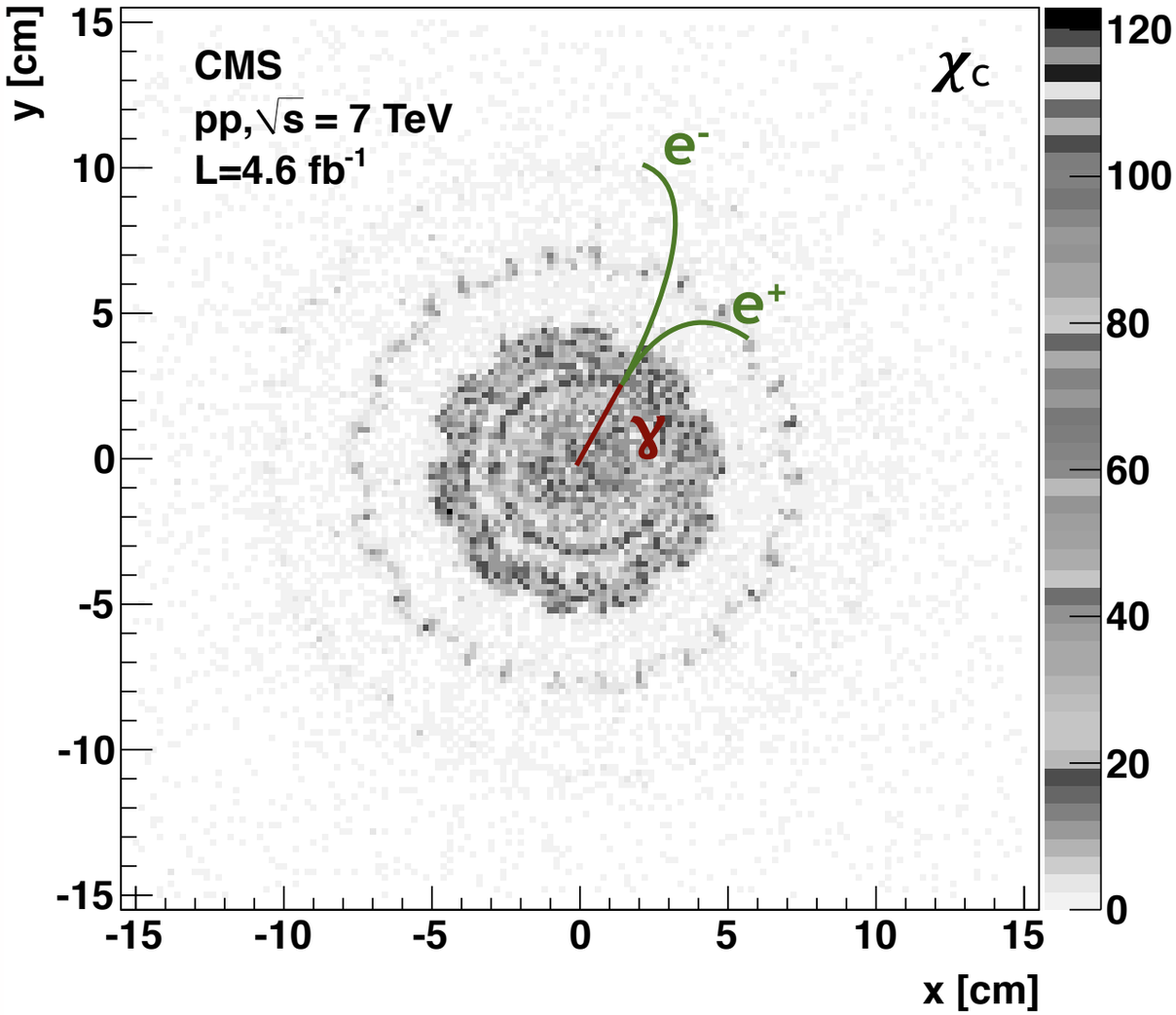
CMS-HIN-15-003



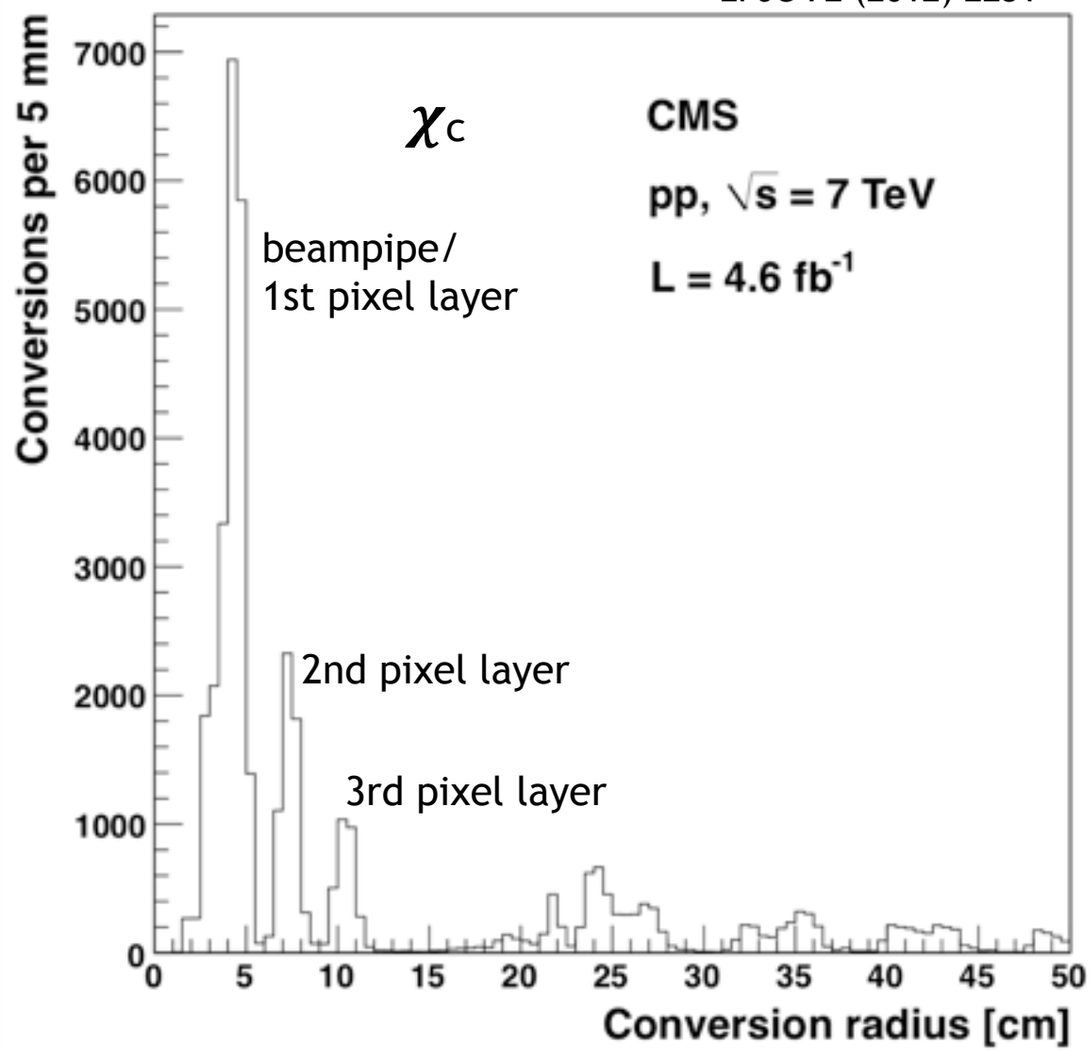
Run I: P-wave quarkonia

- Detection through radiative decays using converted photons

$$\chi_c \rightarrow J/\psi\gamma$$
$$\chi_b(1P) \rightarrow \Upsilon(1S)\gamma$$



EPJC 72 (2012) 2251

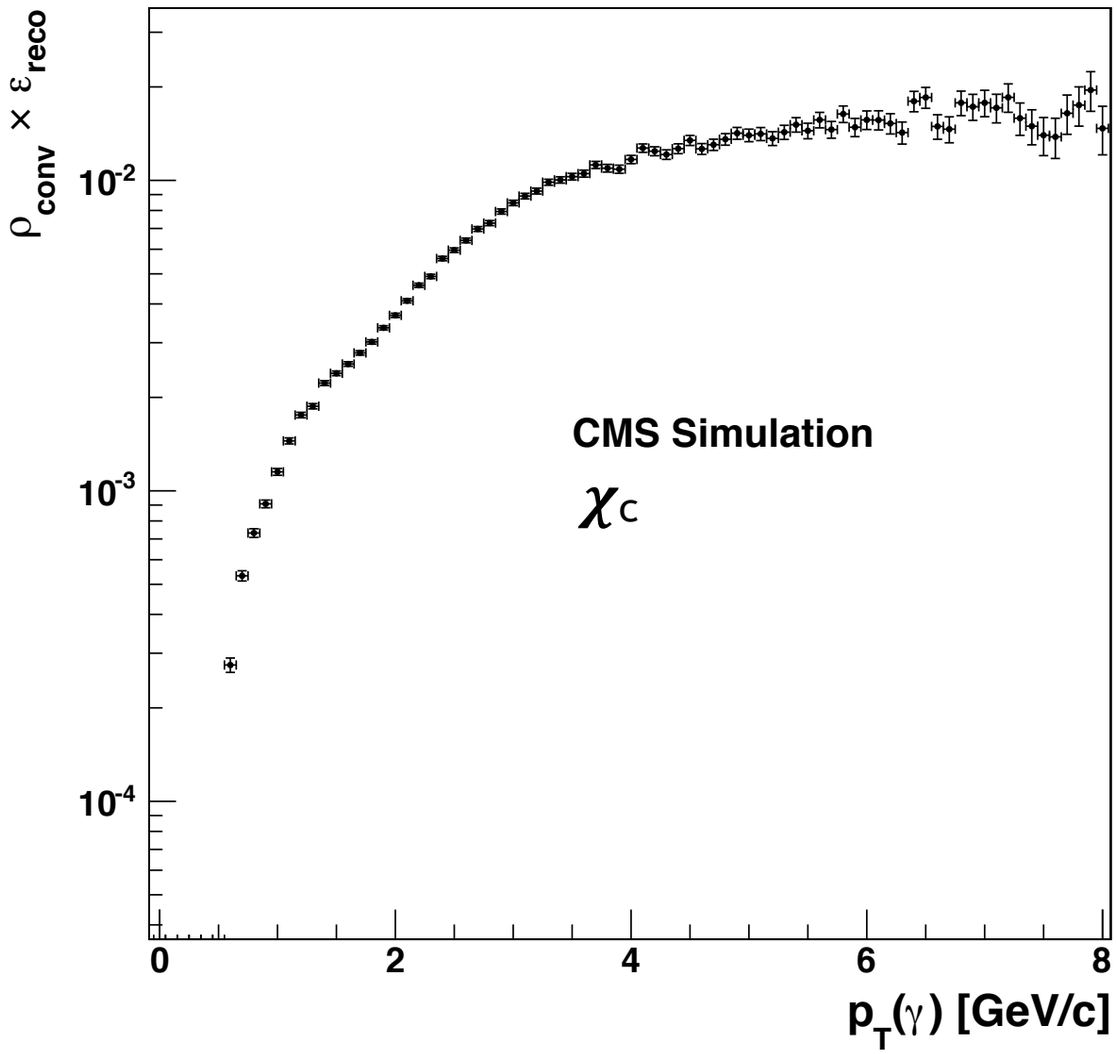


Run I: P-wave quarkonia

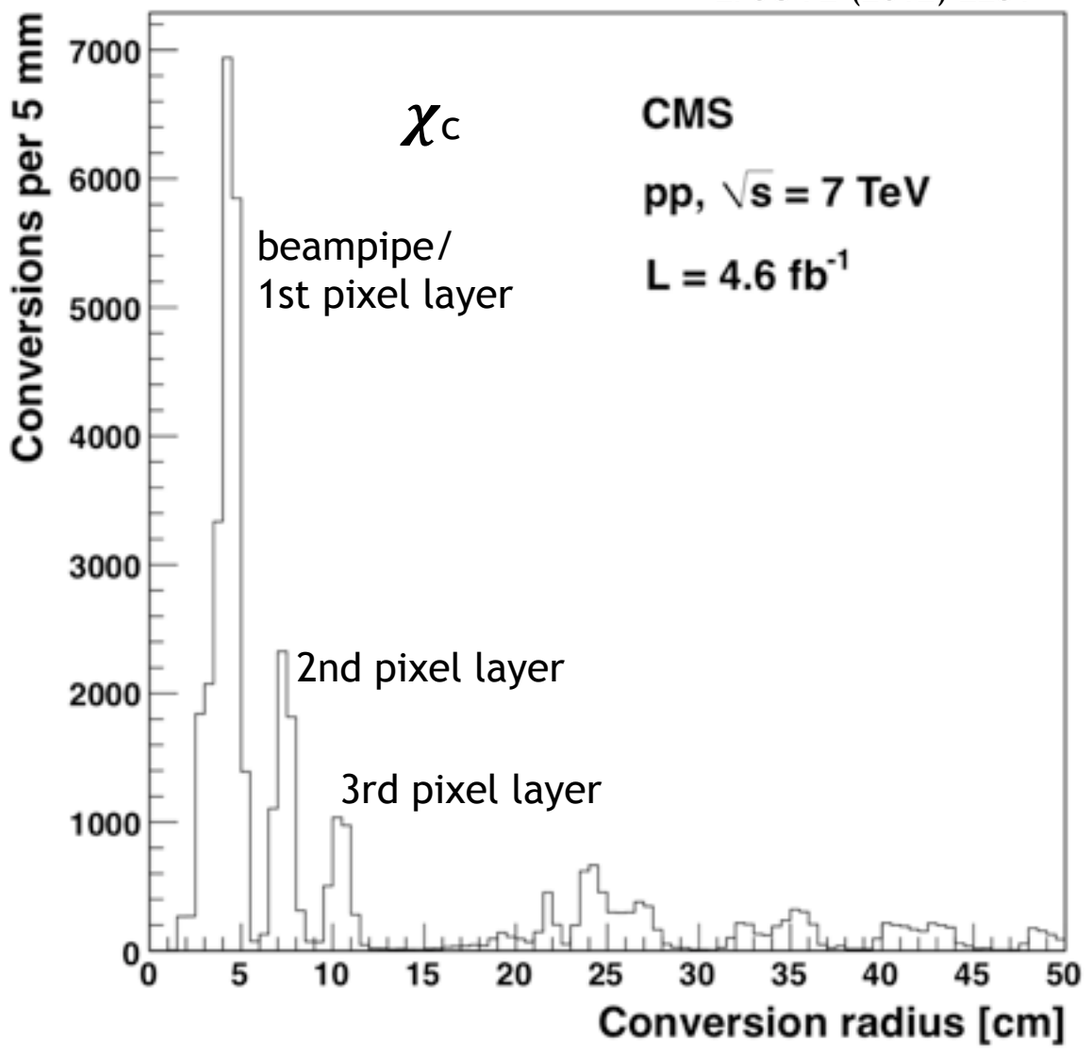
- Detection through radiative decays using converted photons

$$\chi_c \rightarrow J/\psi\gamma$$
$$\chi_b(1P) \rightarrow \Upsilon(1S)\gamma$$

- Conversion probability times reconstruction efficiency is at the 1% level



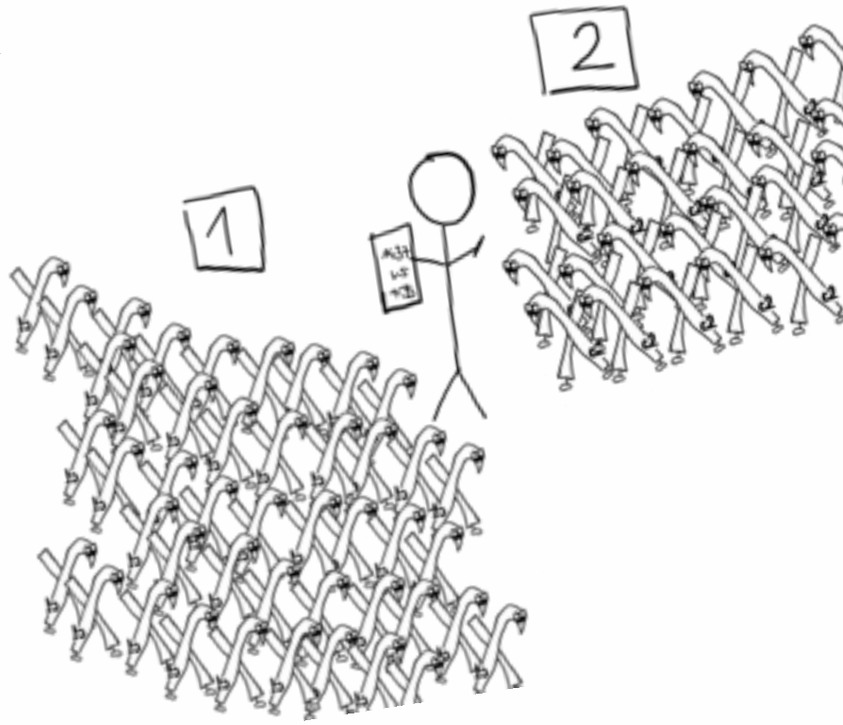
EPJC 72 (2012) 2251



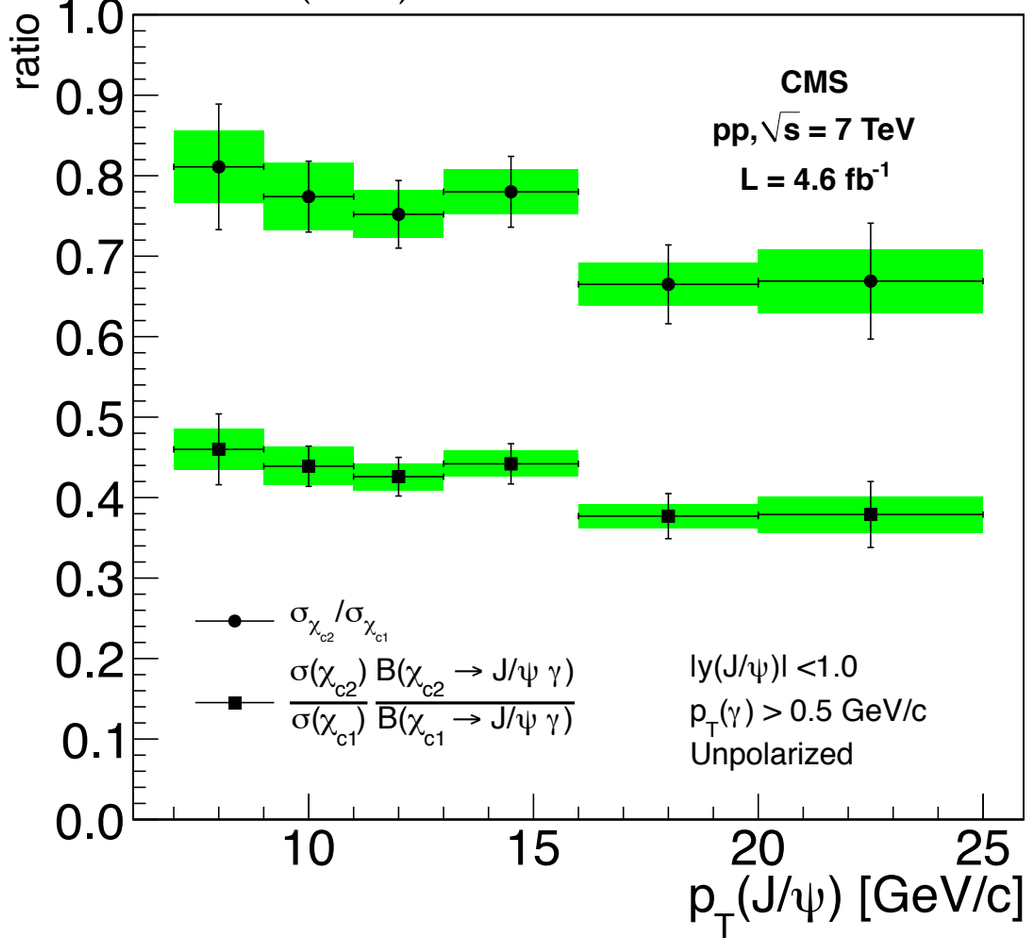
Run I: P-wave quarkonia

- Photon reconstruction efficiency associated with a large systematic uncertainty that cancels in ratio measurements

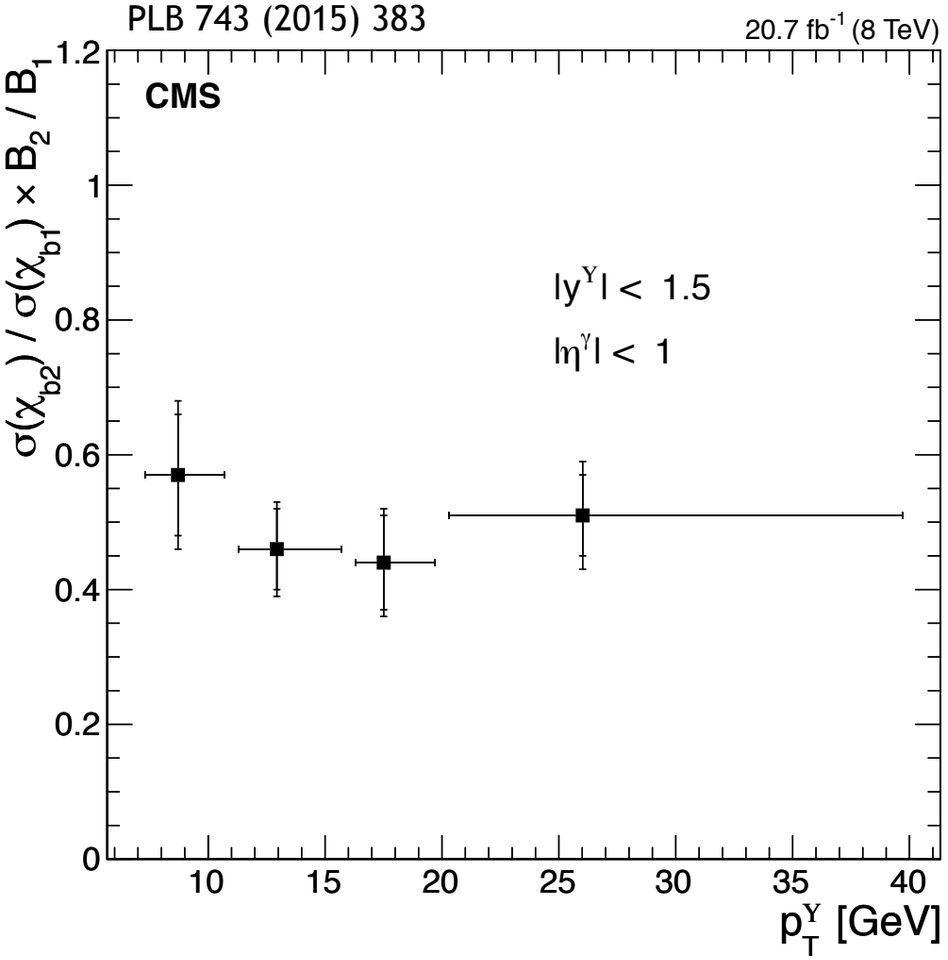
➡ CMS currently limited to measurements of ratios of cross sections of prompt $\chi_{c2}(1P)/\chi_{c1}(1P)$ and $\chi_{b2}(1P)/\chi_{b1}(1P)$



EPJC 72 (2012) 2251

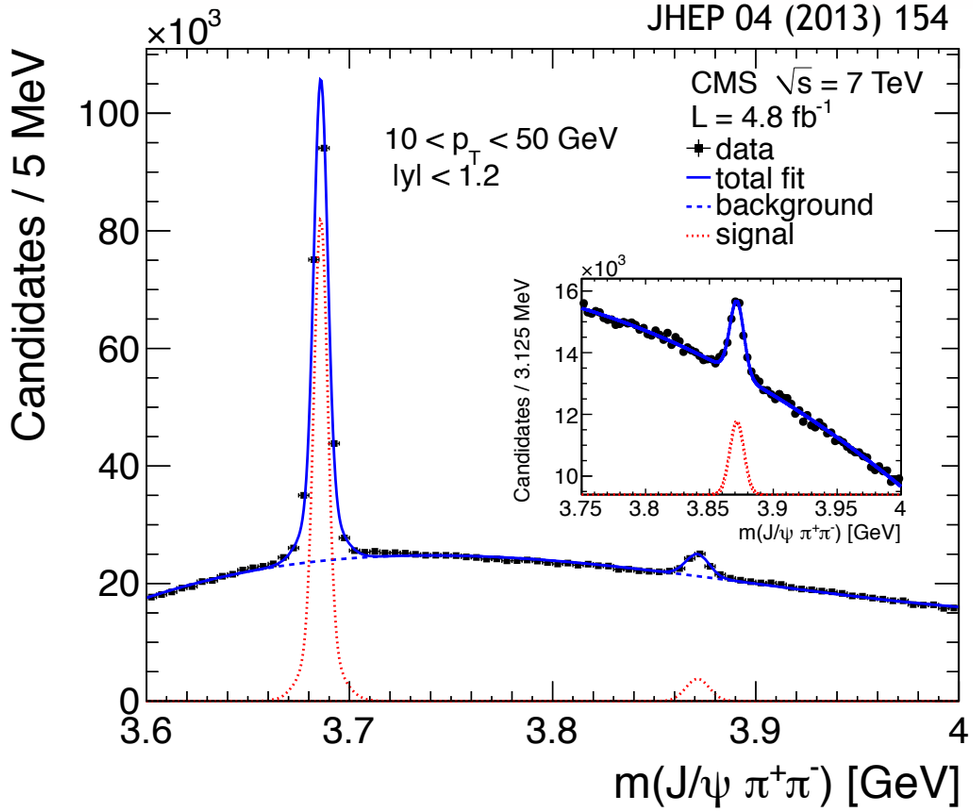


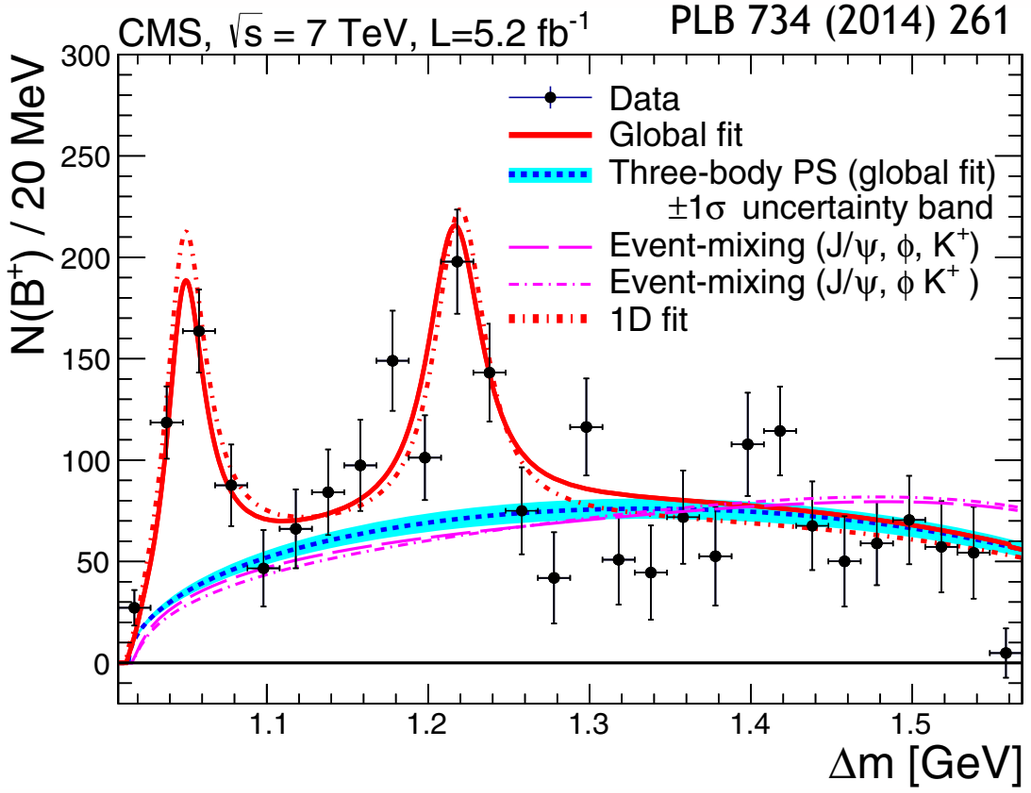
PLB 743 (2015) 383



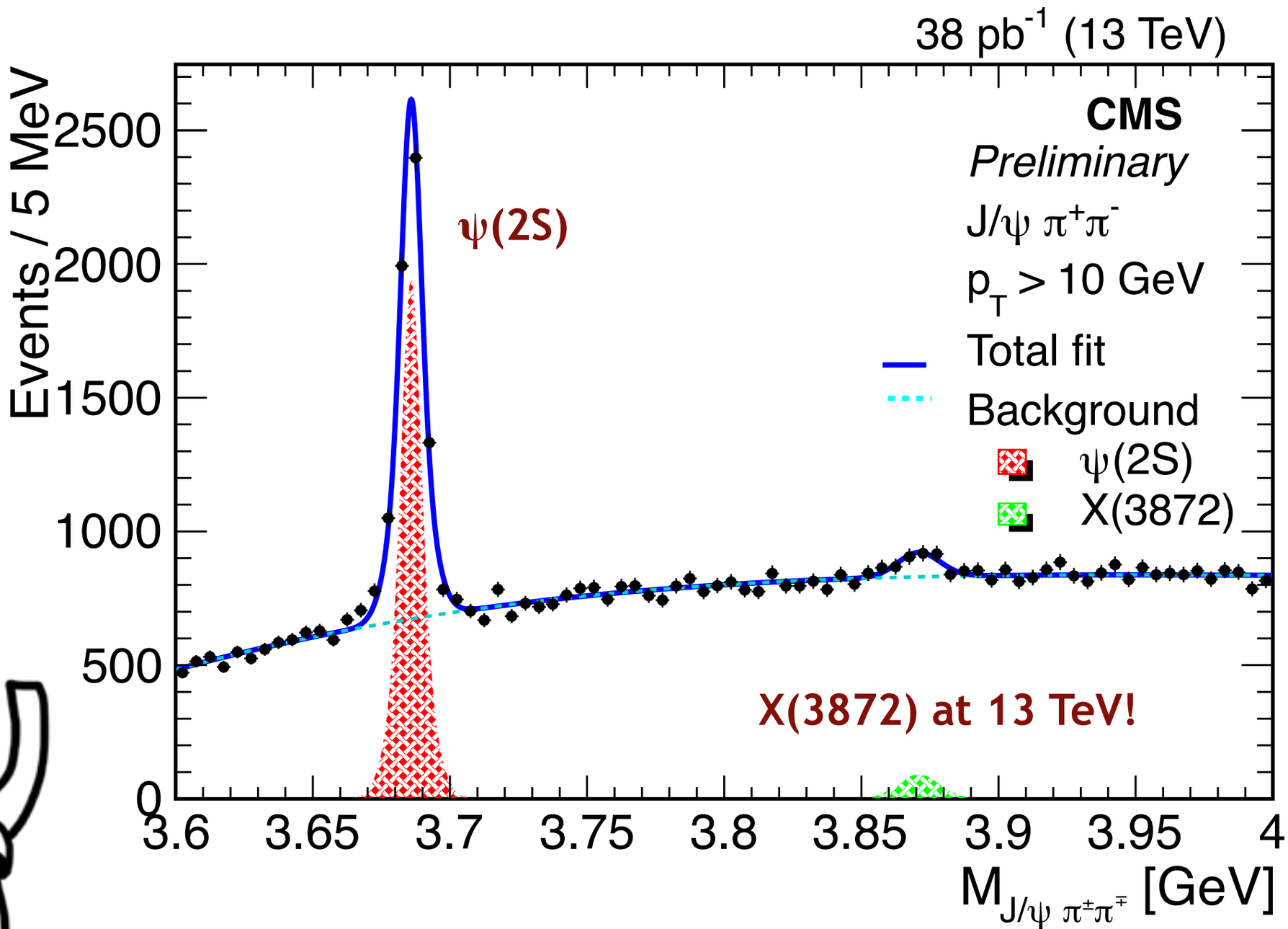
Run I: Exotic quarkonia

- Prompt X(3872) cross section:
  - Ratio of inclusive cross section times branching fraction of X(3872) and ψ(2S)
  - Fraction of X(3872) originating from B decays
- Search for X_b in Υ(1S)$\pi\pi$ spectrum
- Y(4140): One of two peaking structures in $B^+ \rightarrow J/\psi + \phi + K^+$ spectrum





Run II: Exotic quarkonia

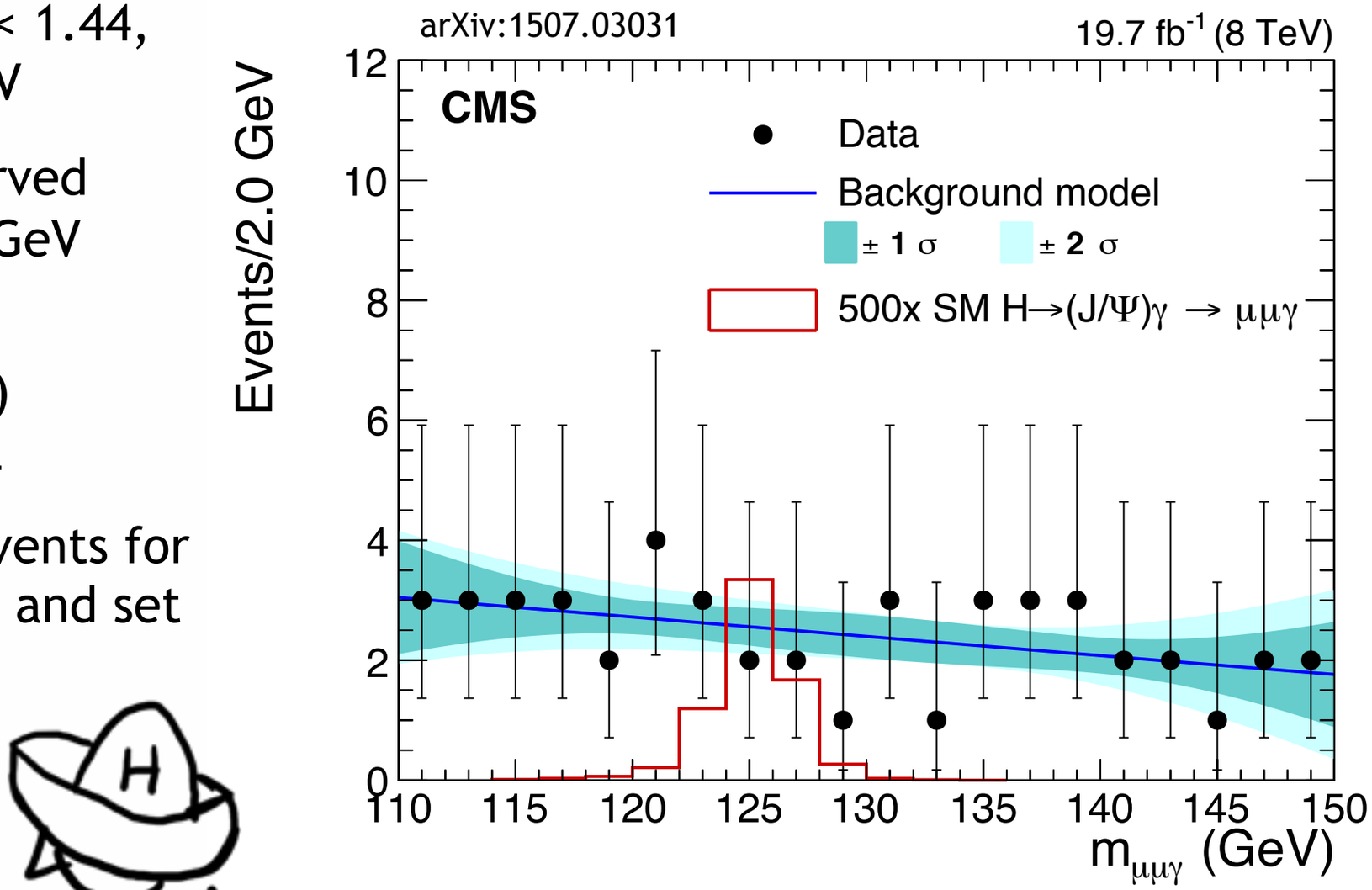


Run I: Higgs to J/ψ + photon

- Measured in the context of $H \to \gamma^*\gamma \to ll\gamma$ with 19.7 fb^{-1} at $\sqrt{s}$ = 8 TeV
- Trigger requires a muon and a photon, both with p_T > 22 GeV
- Isolated leading muon with p_T > 23 GeV, subleading muon with p_T > 4 GeV
- $p_T(\mu\mu)$ and $p_T(\gamma)$ > 40 GeV optimized for background rejection
- $|\eta(\mu)| < 2.4$, $|\eta(\gamma)| < 1.44$, $2.9 < m(\mu\mu) < 3.3$ GeV
- 12 $J/\psi\gamma$ events observed for $120 < m_{\mu\mu\gamma} < 130$ GeV

➡ Upper limit on $BR(H \to J/\psi\gamma \to \mu\mu\gamma) < 1.5 \times 10^{-3}$ at 95% CL

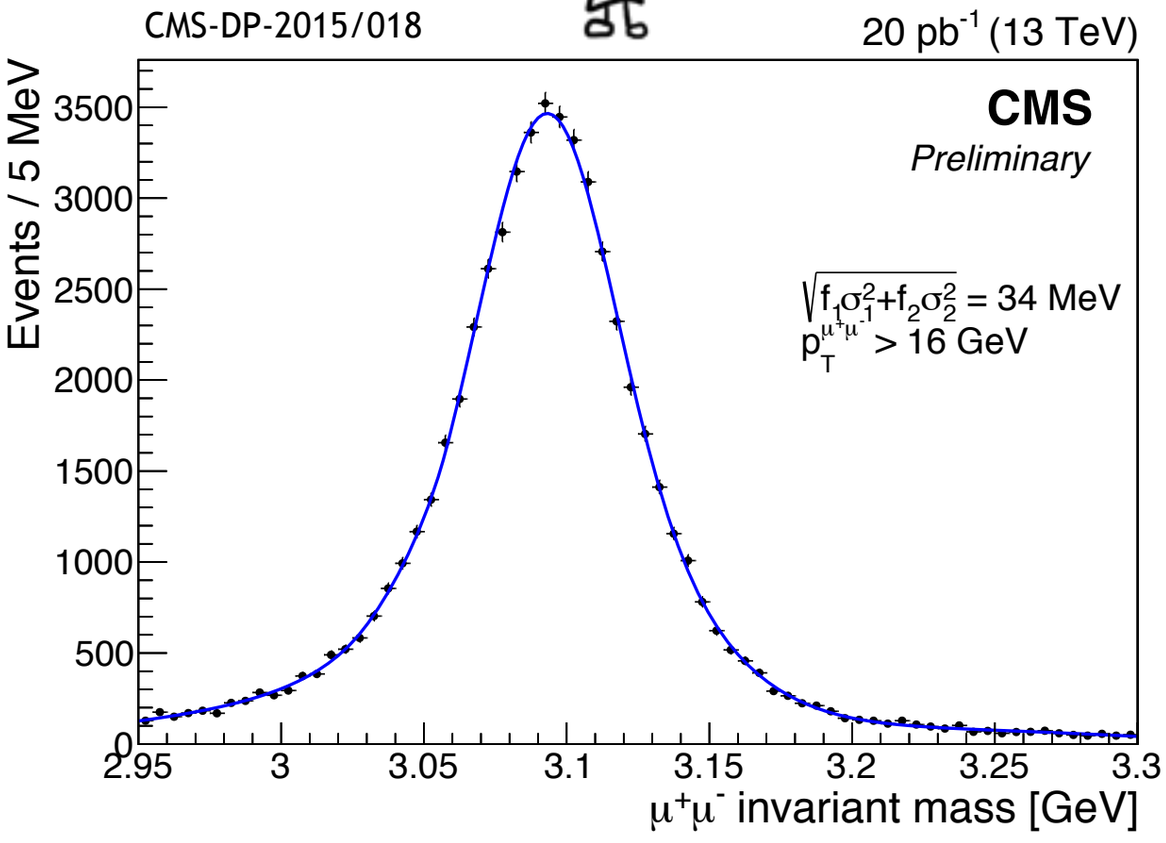
➡ ATLAS detected 20 events for $115 < m_{\mu\mu\gamma} < 135$ GeV and set same upper limit

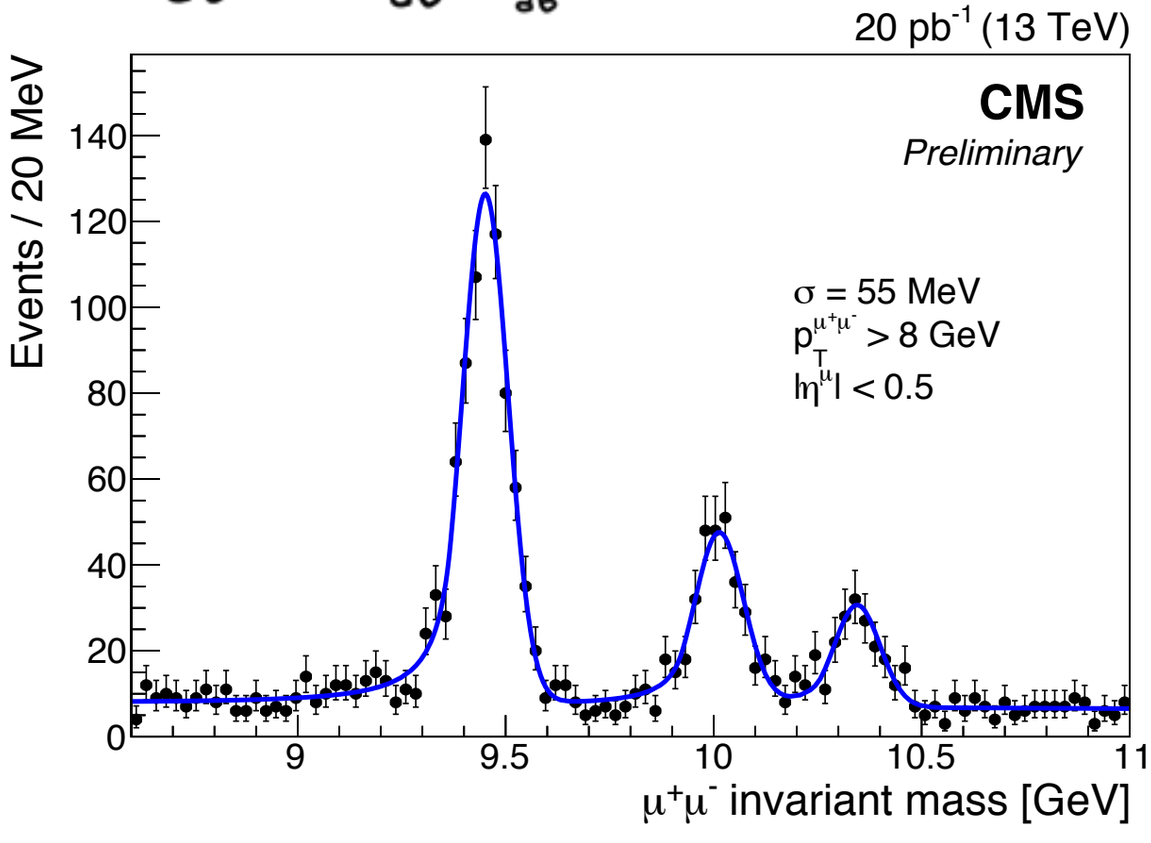


Future prospects:
Plenty of possibilities and dreams …
… but restricted by manpower limitations and reality

Future prospects: S-wave quarkonia

- Cross section measurements with 2015 data at $\sqrt{s}$ = 13 TeV coming soon
- Extend polarization measurements as function of N_{ch} to pPb and PbPb collisions to test universality of the LDMEs
- Extend pT reach of existing cross section and polarization analyses

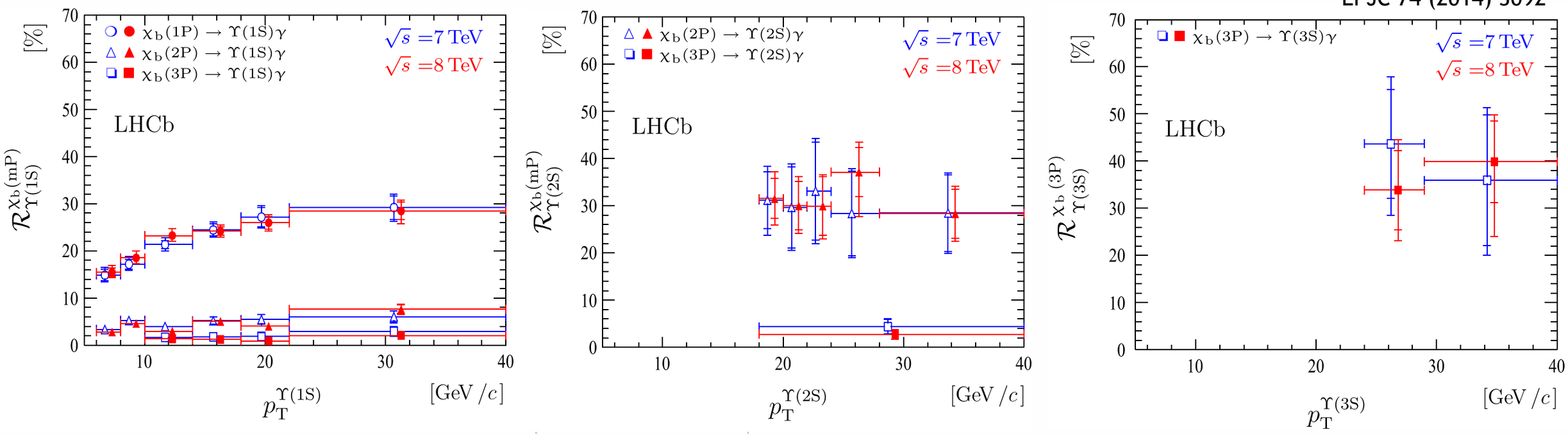


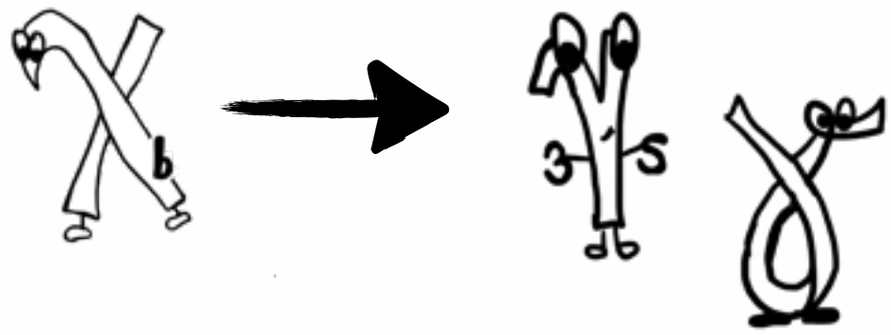


Future prospects: P-wave quarkonia

- Absolute cross sections and feed-down fractions
- Experimental challenge: determining photon efficiencies using $B^+ \to J/\psi + K^+$ and $B^+ \to \chi_{c1} + K^+ \to J/\psi + \gamma + K^+$

EPJC 74 (2014) 3092

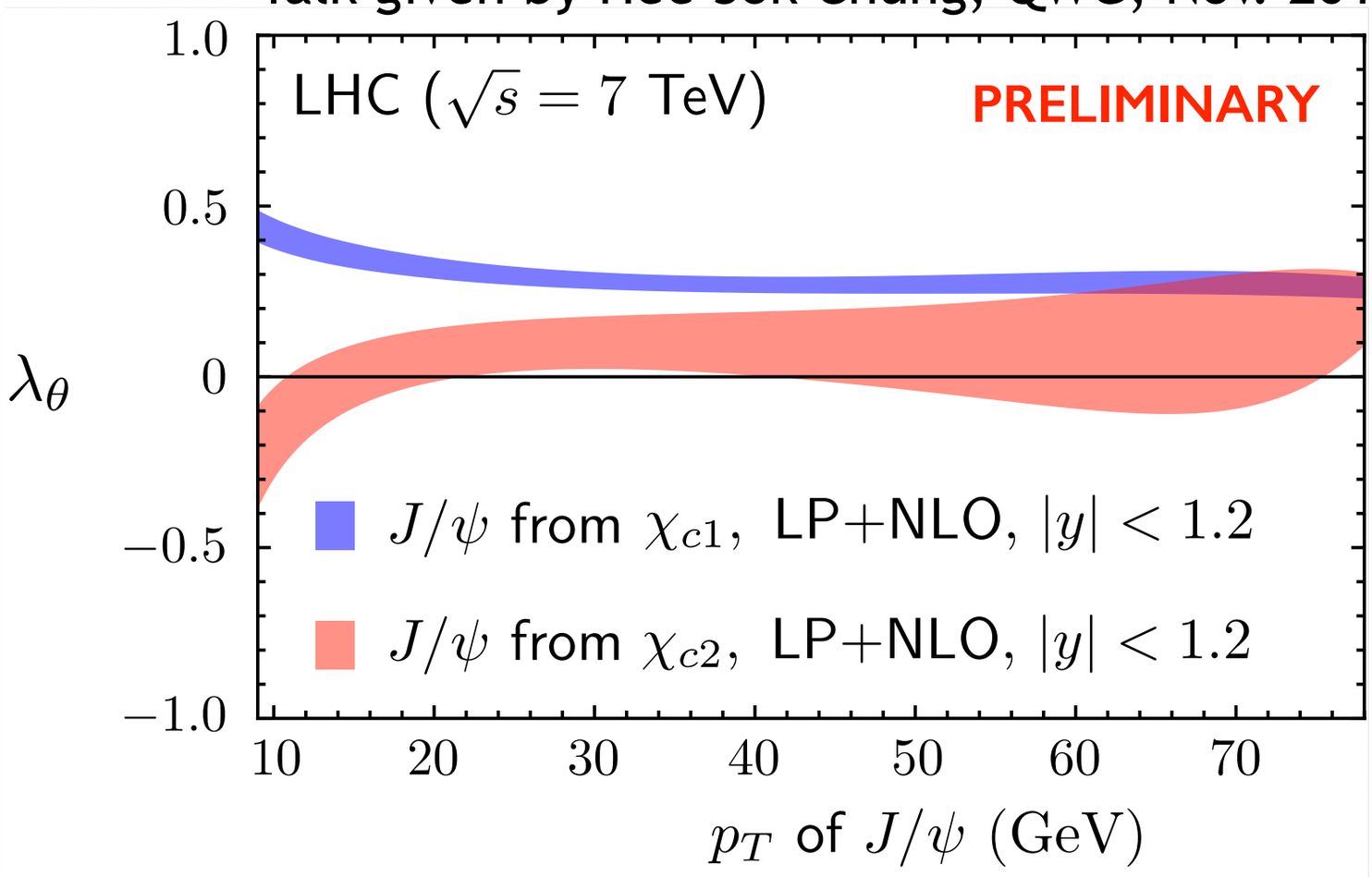


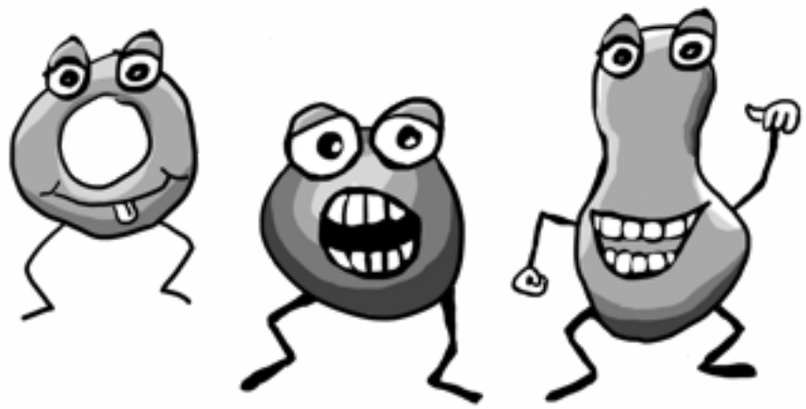


Future prospects: P-wave quarkonia

- χ_c and χ_b(1P) polarizations:
  - Measurement through the angular distributions of J/ψ and Υ(1S) decaying into two muons (P. Faccioli, et al. PRD 83 (2011) 096001)
  - Help to constrain LDMEs
  - Crucial to understand polarization of S-wave quarkonium states

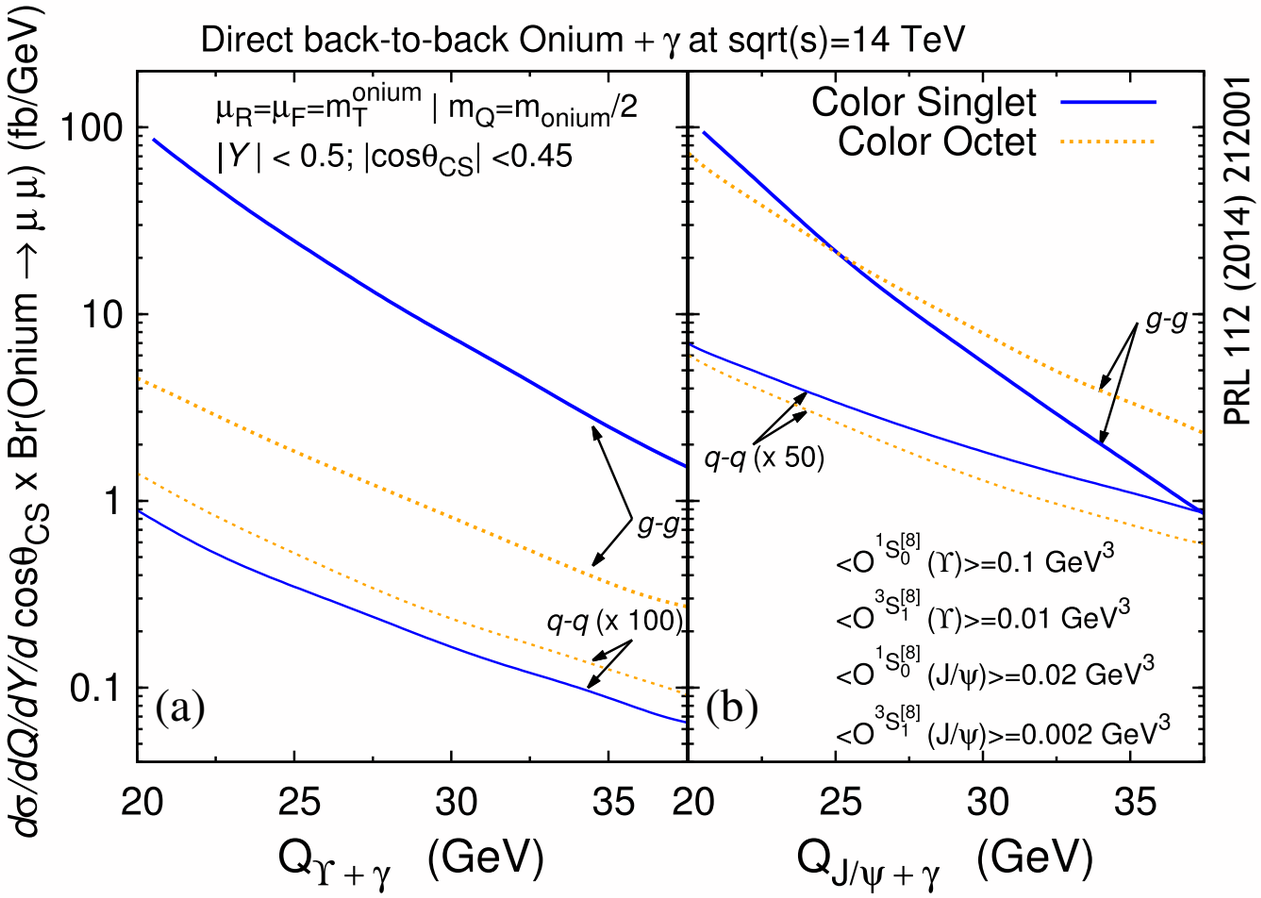
Talk given by Hee Sok Chung, QWG, Nov. 2014





Future prospects: Associated quarkonium production

- Quarkonium in association with a jet, Z/W boson, photon …
- Isolated photon back to back with Υ
  - Cross section is about 50 fb/GeV at $p_T(\Upsilon\gamma)$ = 20 GeV for $\sqrt{s}$ = 7 TeV, $|y| < 0.5$, $|\cos\vartheta_{CS}| < 0.45$, $p_T(\Upsilon) > 7$ GeV, $p_T(\gamma) > 7$ GeV
    (W. J. den Dunnen, et al. PRL 112 (2014) 212001)



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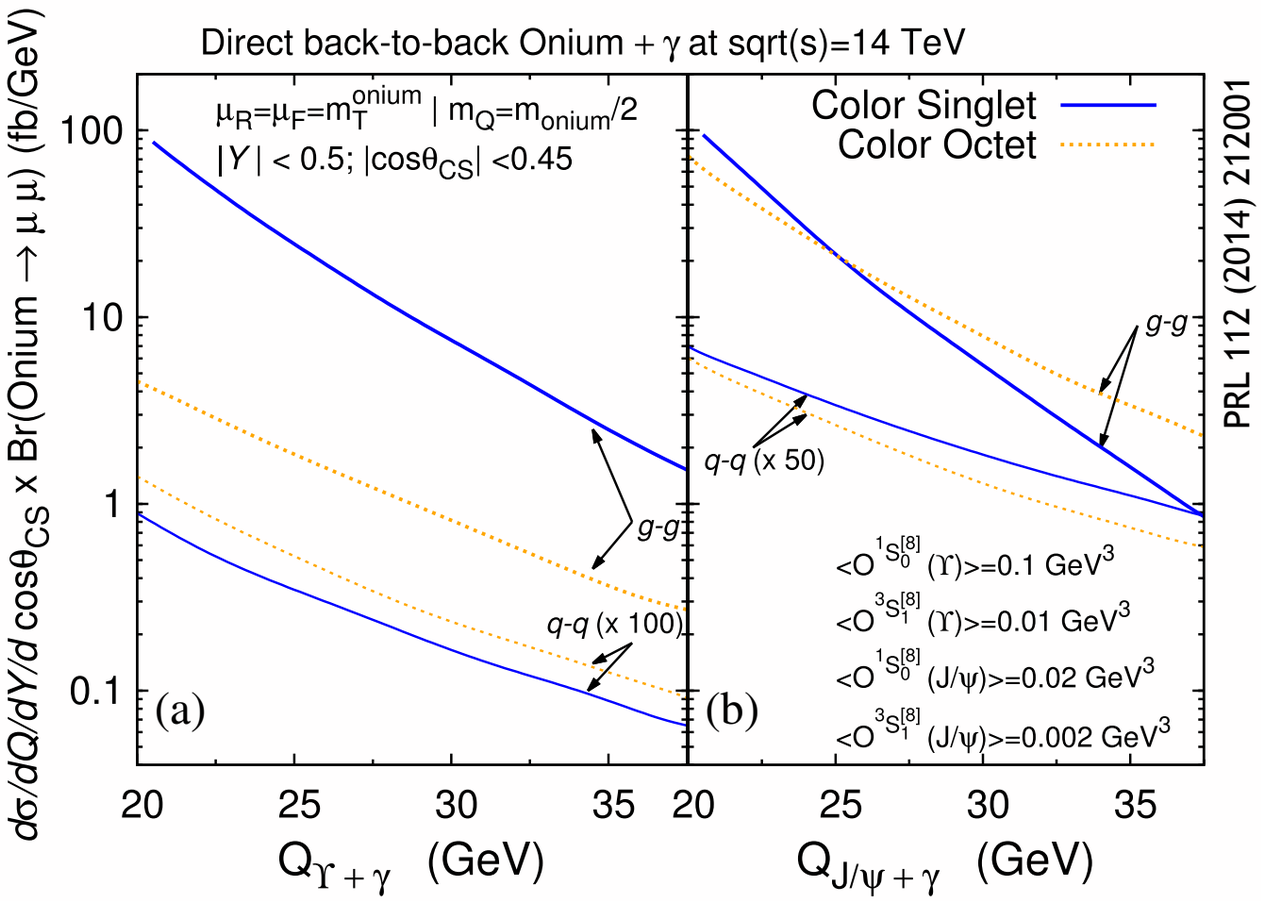
    (W. J. den Dunnen, et al. PRL 112 (2014) 212001)
  - CMS collected 20.7 fb^{-1} at $\sqrt{s} = 8$ TeV
  - Dimuon trigger in Υ mass window with $p_T(\mu\mu) > 7$ GeV



Future prospects: Associated quarkonium production

- Quarkonium in association with a jet, Z/W boson, photon …
- Isolated photon back to back with Υ
  - Cross section is about 50 fb/GeV at $p_T(\Upsilon\gamma) = 20$ GeV for $\sqrt{s} = 7$ TeV, $|y| < 0.5$, $|\cos\vartheta_{CS}| < 0.45$, $p_T(\Upsilon) > 7$ GeV, $p_T(\gamma) > 7$ GeV
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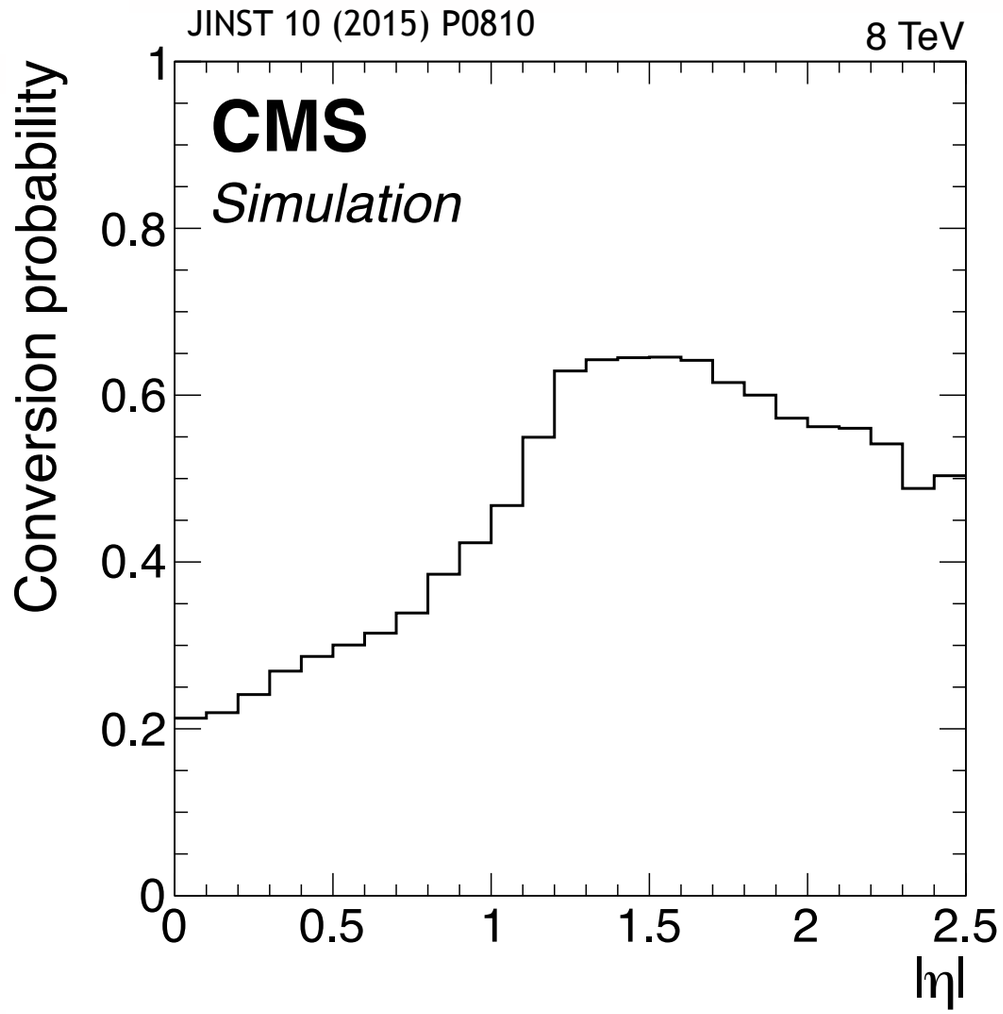

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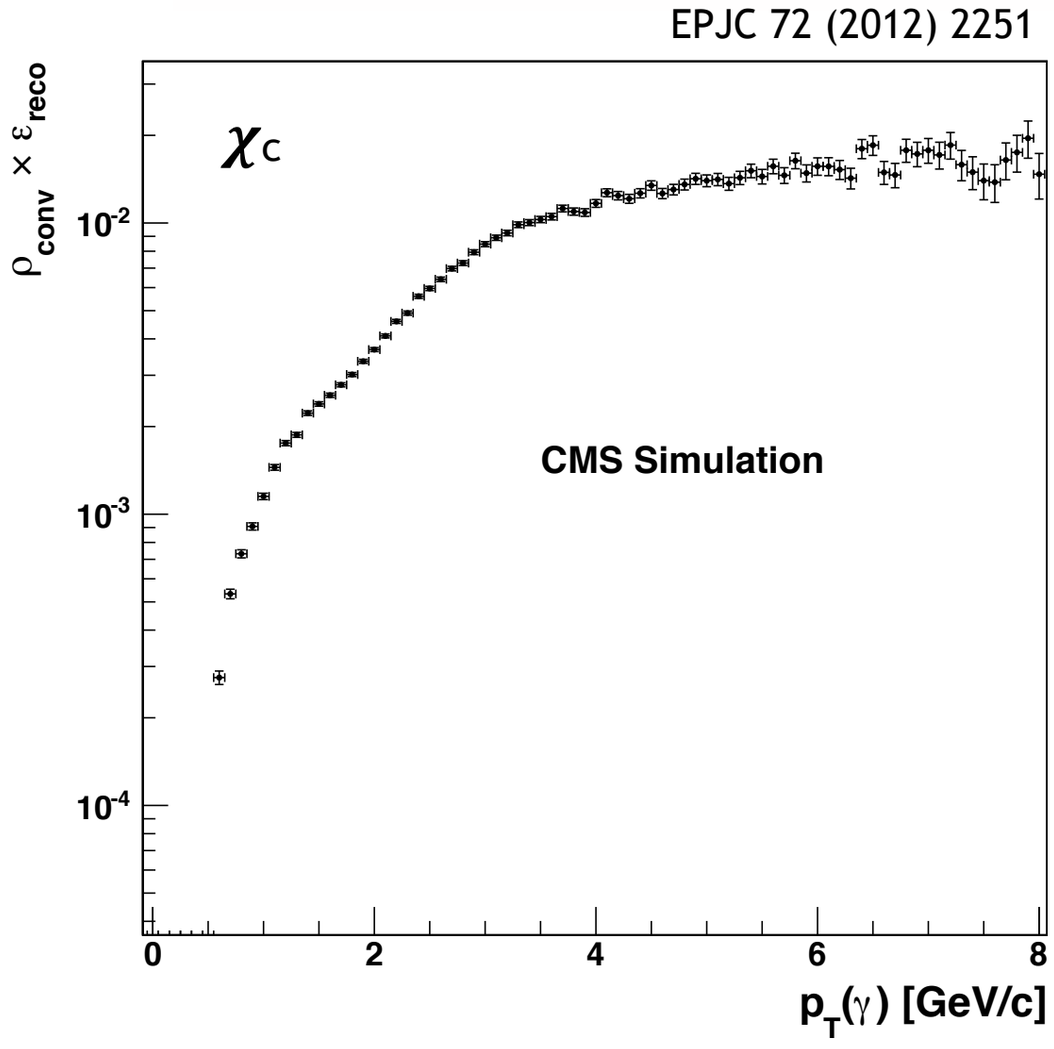
EPJC 72 (2012) 2251



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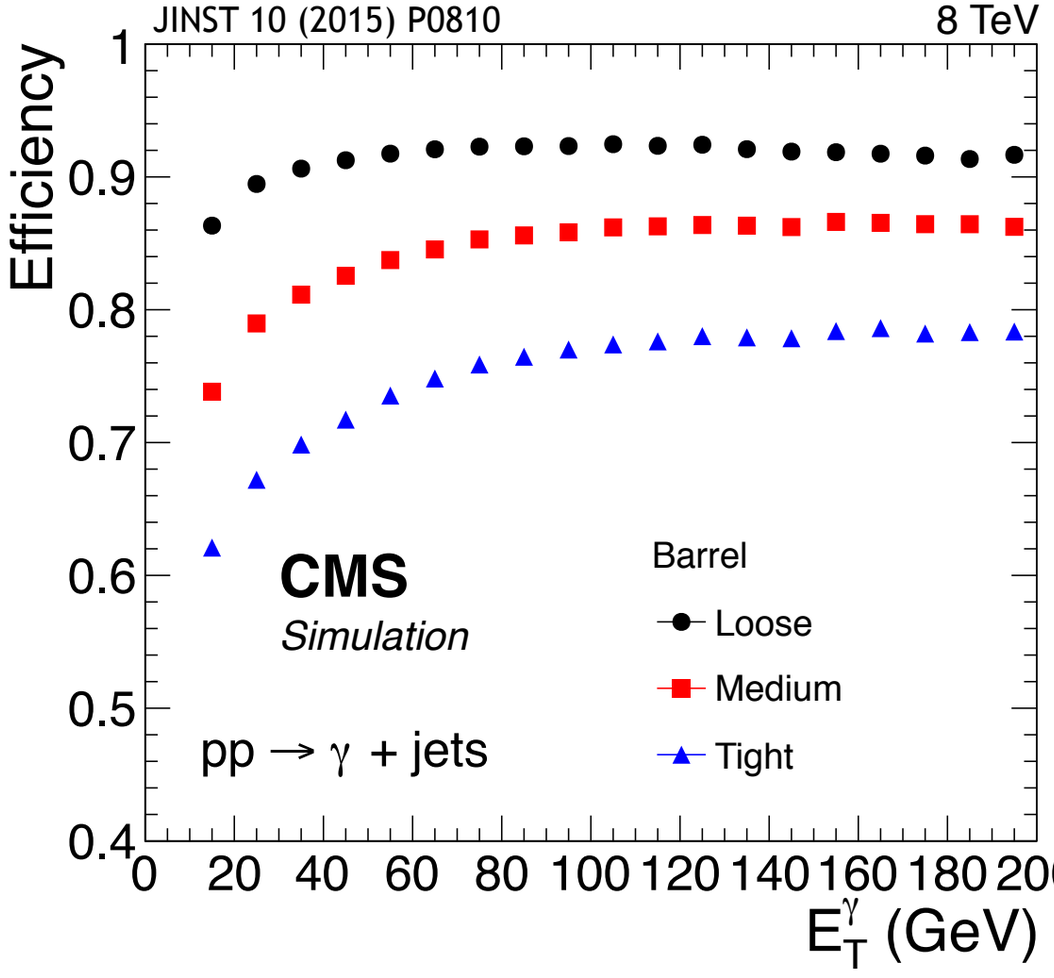

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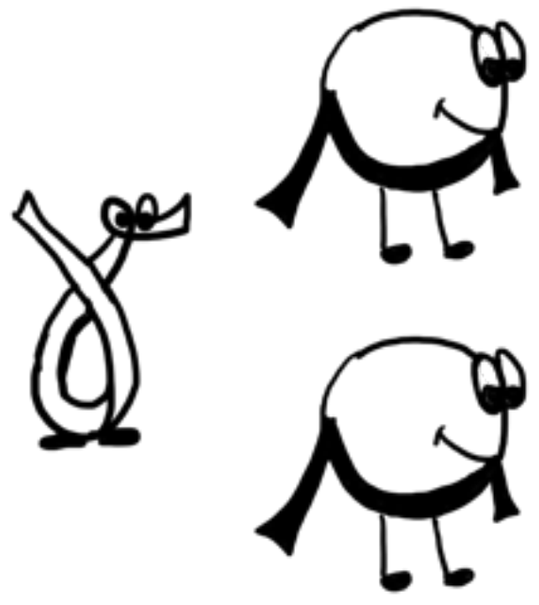
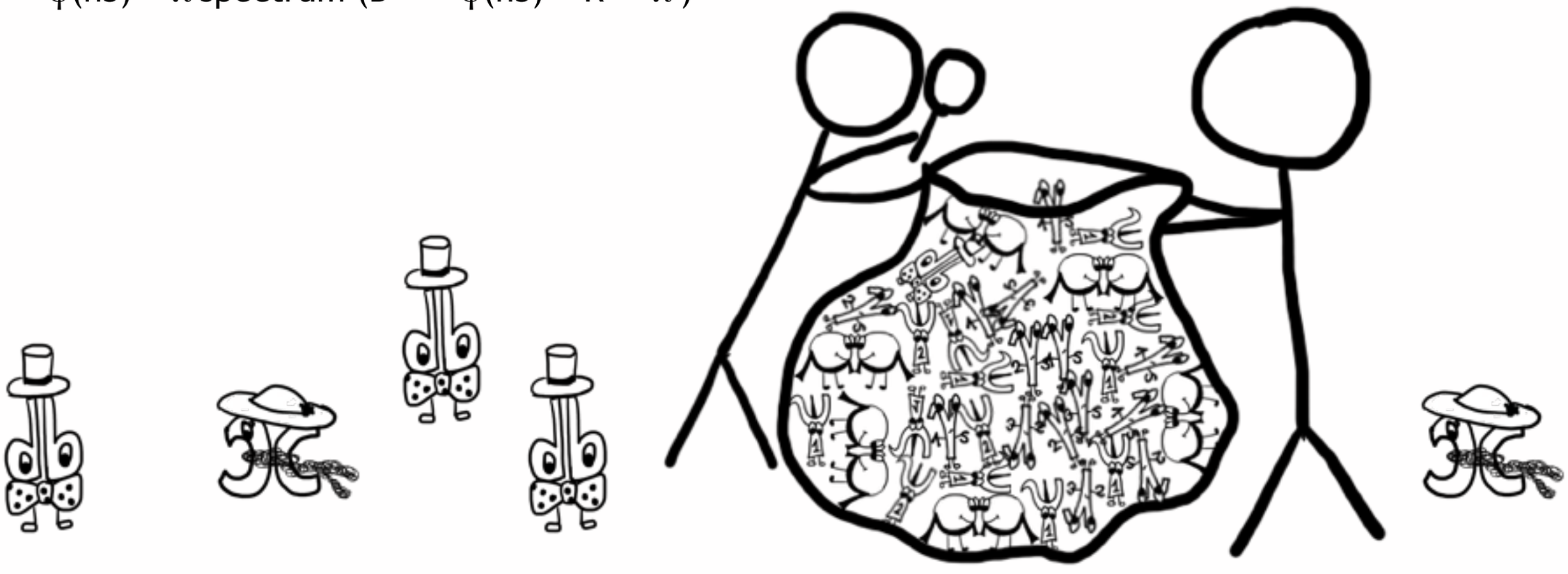
  - ➡ About 700 events expected to be seen in the CMS detector



Future prospects: Exotic quarkonia

- Search for new structures and resonances
  - ψ(nS) or Υ(nS) plus one or two π's
  - χ_c ($\rightarrow$ J/ψ + γ) + π
  - double J/ψ and Υ(1S) spectrum
- Study the nature of structures in the
  - J/ψ + ϕ spectrum ($B^+ \rightarrow$ J/ψ + ϕ + K^+, $B^0 \rightarrow$ J/ψ + ϕ + K^0_s)
  - ψ(nS) + π spectrum ($B^0 \rightarrow \psi$(nS) + $K^+ + \pi^-$)



Conclusions

CMS

- is well suited for quarkonium physics
- has done many interesting, high impact measurements in the past
- has the capability to do many interesting analyses with quarkonia
- will continue to do high quality research in quarkonium physics