Observation of the X(3872) with the CMS experiment

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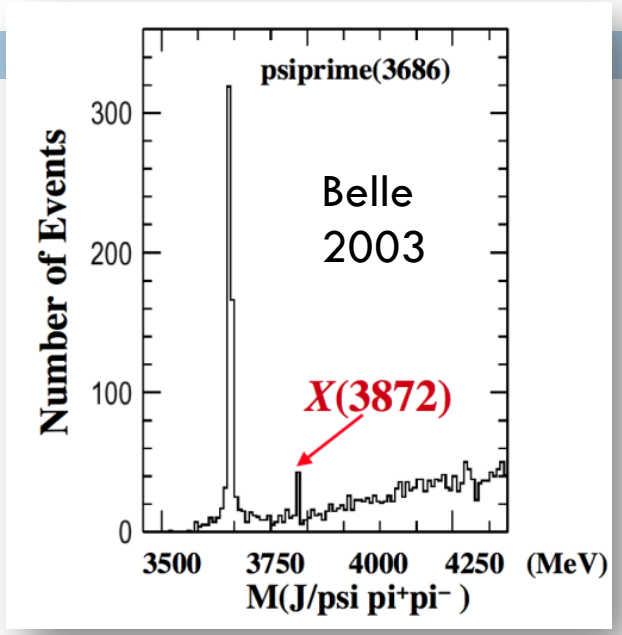
The X(3872) state

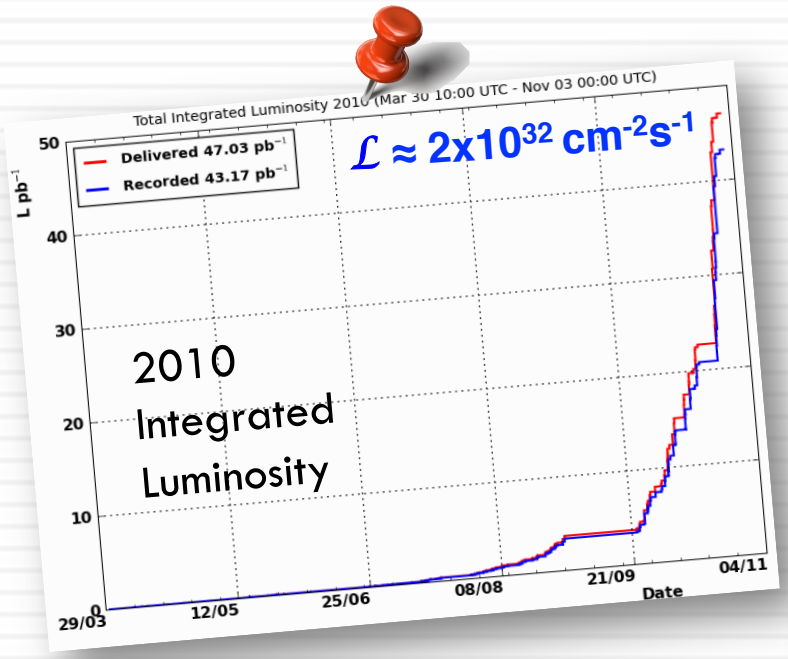
- Many open questions since the discovery of this unexpected charmonium state
- Mass consistent with the location of the $D^0\overline{D}^{*0}$ threshold at 3871.81 ± 0.36 MeV

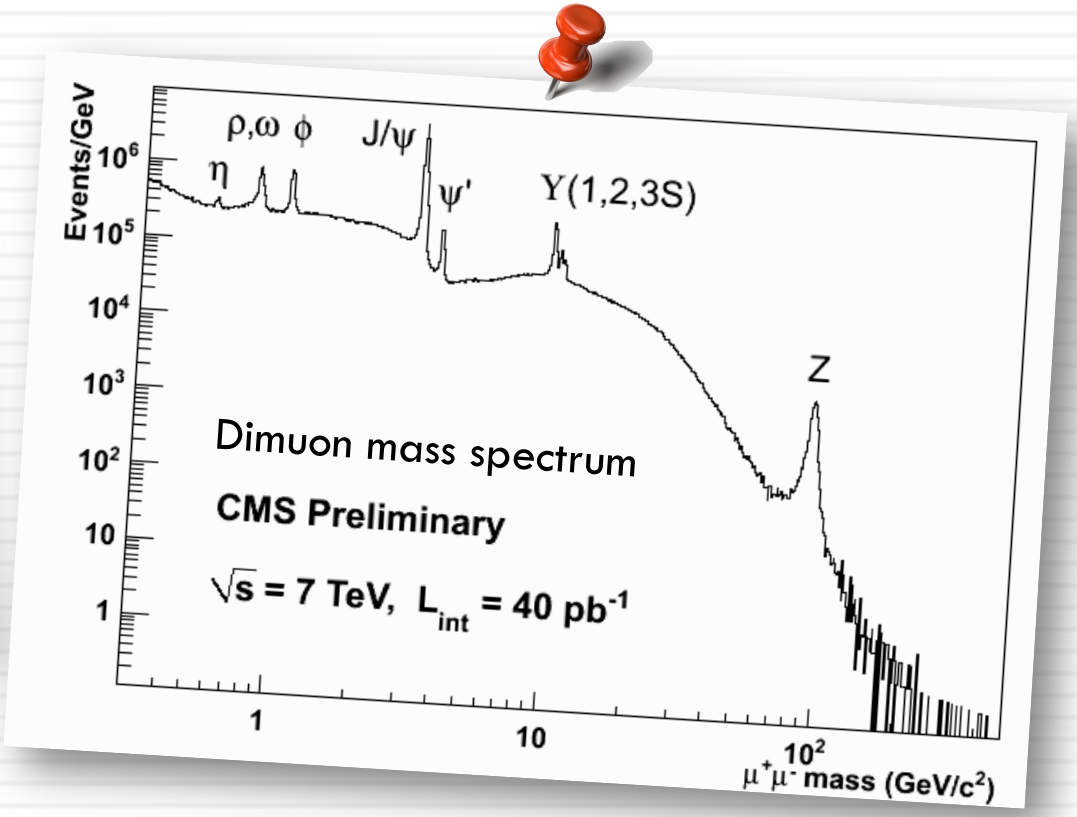
Molecular state of two D mesons?



- Hadron collider experiments can also provide interesting information (cf. CDF)
- LHC allows us to perform studies in a new energy regime
- NRQCD predictions exist for the X(3872) cross section at LHC energies

2010 Data Analysis (~40 pb^{-1})





Objectives

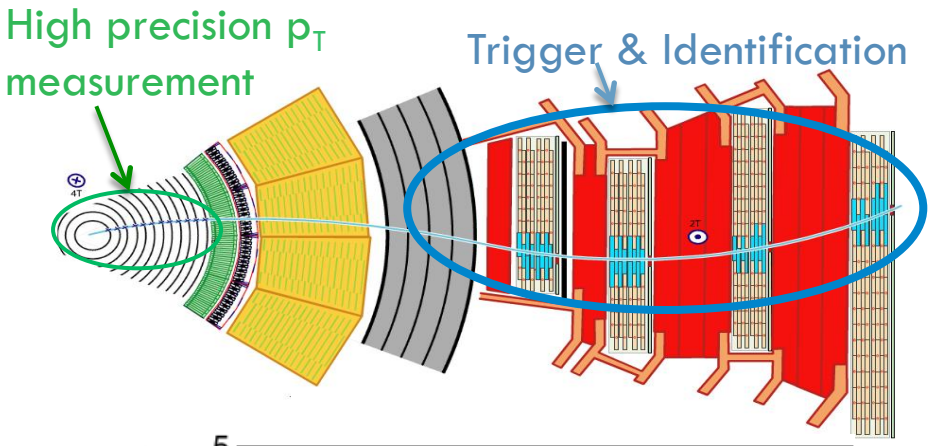
- Establish a clear X(3872) signal using the 2010 CMS data

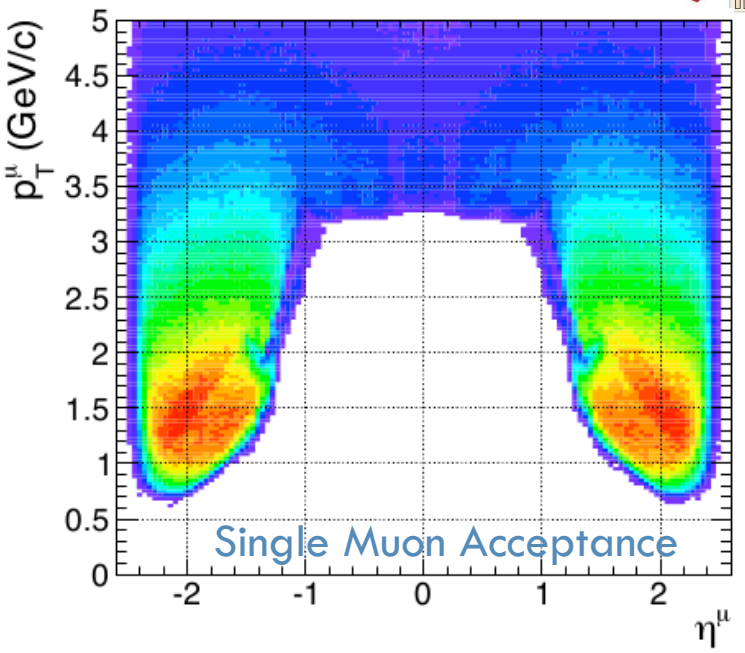
- Measure the inclusive cross section ratio w.r.t. the $\psi(2S)$ signal in the same decay channel, $J/\psi\,\pi^+\pi^-$, with subsequent decay of the J/ψ to two muons

$$R = \frac{\sigma(pp \to X(3872) + anything)BR(X(3872) \to J/\psi\pi^+\pi^-)}{\sigma(pp \to \psi(2S) + anything)BR(\psi(2S) \to J/\psi\pi^+\pi^-)}$$

Particle Reconstruction in CMS

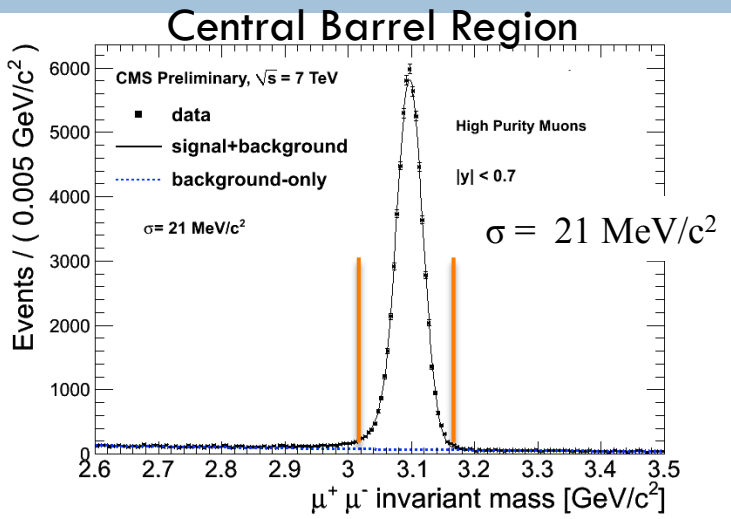
- Silicon Tracker:
  - Pixels: 2-3 layers
  - Strips: 10-12 layers
  - Good p_T resolution ~1%
  - Good vertex and impact parameter resolution
- Muon System
  - 3 types of gaseous detectors
  - Acceptance (p_T dependent) in $|\eta| < 2.4$
  - Highly efficient muon trigger and identification
- Muon tracks matched to silicon tracker tracks for improved momentum resolution
- Data collected with a double-muon trigger kept without additional p_T requirements





Candidates selection

- J/ψ reconstructed by combination of two opposite-charge good quality muons
  - ~1 million events in 2010
  - Selected in mass windows determined by the detector resolution (changes with rapidity)

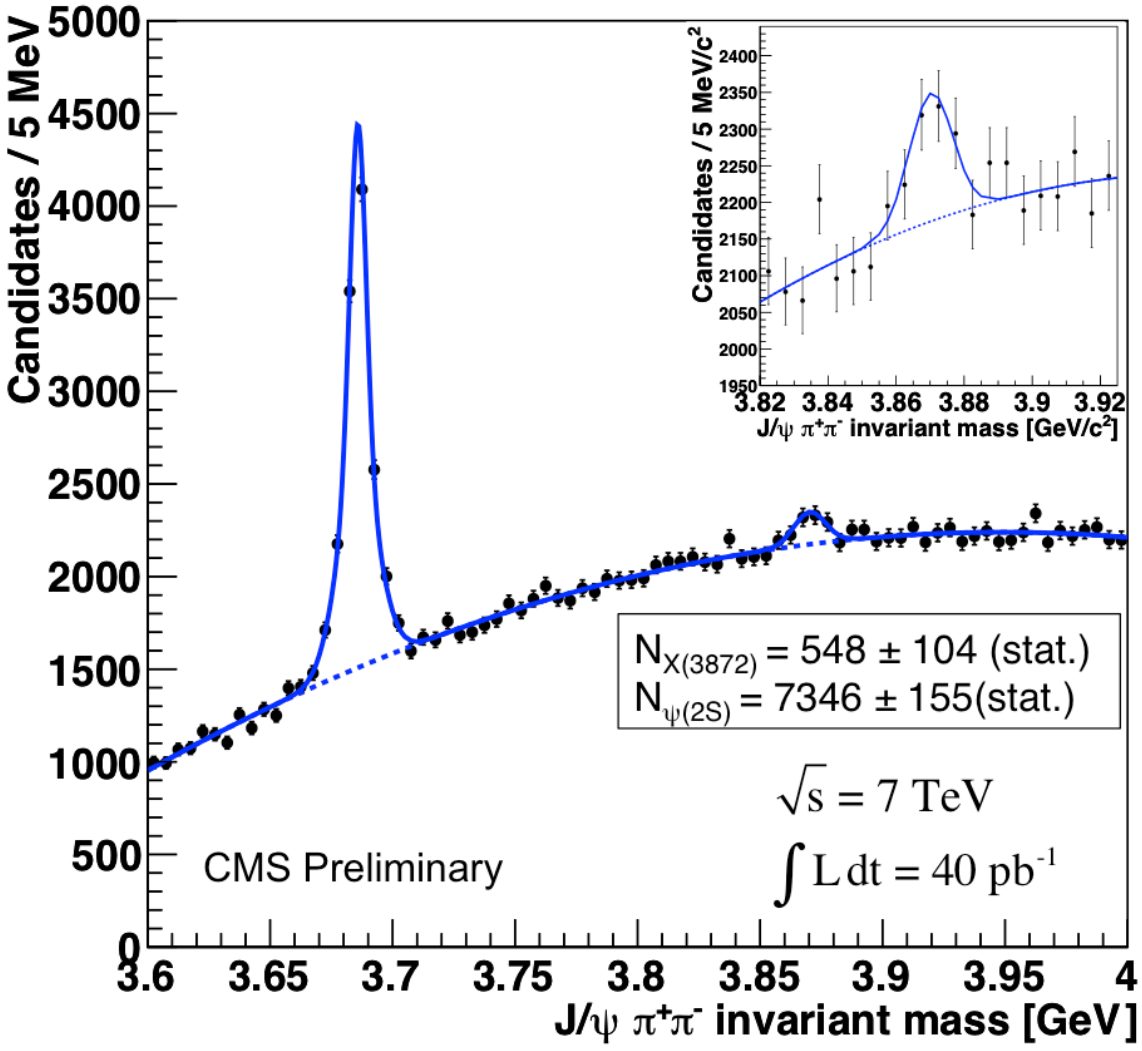


- Select pairs of good quality opposite-charge tracks in a cone of $\Delta R = 0.7$ around the J/ψ direction
- Four-track vertex fit, with the the $\mu^+\mu^-$ invariant mass set to the PDG J/ψ mass
- Keep all candidates with vertex fit prob > 1% and in the mass range 3.6–4.0 GeV
- **Kinematic region: $p_T(X) > 8$ GeV and $|y(X)| < 2.2$**

2010 J/ψ $\pi^+\pi^-$ Mass Spectrum

- Unbinned log-likelihood fit
- Fit results:
  - $m_{\Psi(2S)} = 3685.9 \pm 0.1$ MeV
  - $\sigma_{1\,\Psi(2S)} = 8.1 \pm 0.6$ MeV
  - $\sigma_{2\,\Psi(2S)} = 3.3 \pm 0.3$ MeV
  - $m_{X(3872)} = 3870.2 \pm 1.9$ MeV
  - $\sigma_{X(3872)} = 6.3 \pm 1.3$ MeV

- Compatible with PDG masses:
  - $m_{\Psi(2S)} = 3686.09 \pm 0.04$ MeV
  - $m_{X(3872)} = 3871.56 \pm 1.9$ MeV



Measurement of the σ×BR ratio

① Extract from the J/ψ $\pi^+\pi^-$ invariant mass spectrum the ψ(2S) and X(3872) yields

② Calculate the ratio

$$R = \frac{\sigma(pp \to X(3872)+anything) \times BR(X(3872) \to J/\psi\ \pi\pi)}{\sigma(pp \to \psi(2S)+anything) \times BR(\psi(2S) \to J/\psi\ \pi\pi)} = \frac{N_{X(3872)}}{N_{\psi(2S)}} / C$$

③ Extract the correction factor C from MC studies

$$C = \frac{A_{J/\psi}(X) \cdot \varepsilon_{J/\psi}(X) \cdot A_{\pi\pi}(X) \cdot \varepsilon_{\pi\pi}(X)}{A_{J/\psi}(\psi') \cdot \varepsilon_{J/\psi}(\psi') \cdot A_{\pi\pi}(\psi') \cdot \varepsilon_{\pi\pi}(\psi')}$$

- Pythia 6 used for X(3872) MC, setting mass of χ_{c1} ($J^{PC}=1^{++}$) to 3.872 GeV
- Both particles assumed unpolarized and decayed with EvtGen
- Combined prompt and non-prompt samples, assuming 30% non-prompt fraction

Systematic uncertainties

- Background parameterization and signal extraction **5.3%**
- Variation of the X(3872) and ψ(2S) non-prompt fraction in 30% ± 20% **6.0%**
- Lack of knowledge of the X(3872) production mechanism **3.5%**
  - Study of the effect of changes in the X(3872) p_T shape
- Uncertainty due to limited statistics in MC samples **1.8%**
- Uncertainty on the pion tracking efficiency **4.0%**
  - Data-driven cross check comparing the yields in the decay channels ψ(2S) → J/ψ $\pi^+\pi^-$ and ψ(2S) → $\mu^+\mu^-$, corrected for
    - branching ratios (PDG)
    - acceptances and efficiencies of J/ψ and ψ(2S) decaying into two muons

Total systematic uncertainty: 10%

Cross section ratio

- The measurement of the ratio of cross sections

$$R = \frac{\sigma(pp \to X(3872) + anything)BR(X(3872) \to J/\psi\pi^+\pi^-)}{\sigma(pp \to \psi(2S) + anything)BR(\psi(2S) \to J/\psi\pi^+\pi^-)}$$

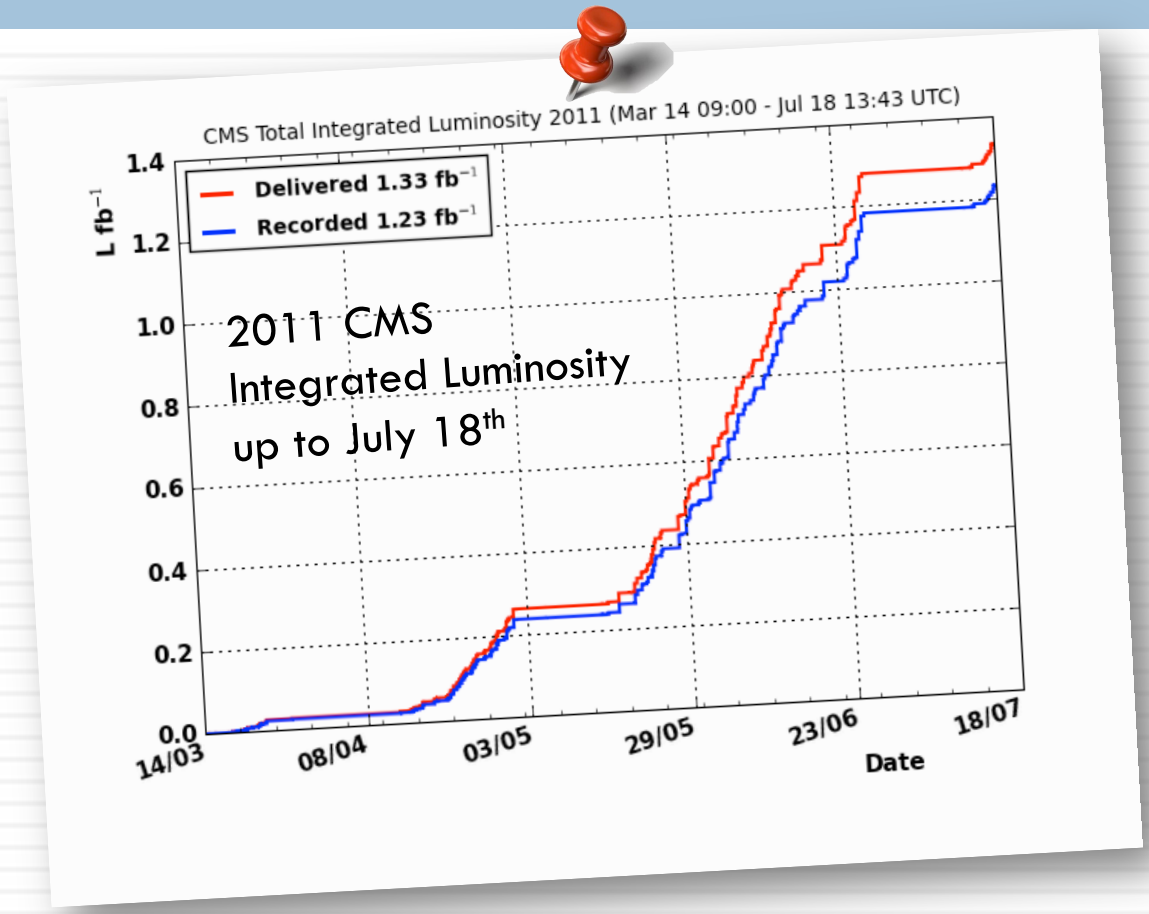
gives:

$$\mathbf{R = 0.087 \pm 0.017\ (stat.) \pm 0.009\ (syst.)}$$

in the fiducial range $p_t(X) > 8$ GeV and $|y(X)| < 2.2$

- More details in the CMS "Physics Analysis Summary" BPH-10-018: **http://cms-physics.web.cern.ch/cms-physics/public/BPH-10-018-pas.pdf**

First Look at 2011 Data



Challenges and Opportunities in 2011

- Higher instantaneous luminosity:
  - Tighter triggers due to limited bandwidth
    - Dimuon trigger cuts: $p_T > 7$ GeV, $|y| < 1.25$, $2.95 < M < 3.25$ GeV
    - New candidate fiducial region $p_T(X) > 9$ GeV and $|y(X)| < 1.25$
  - Pileup: 7-8 collisions per bunch crossing

- Higher integrated luminosity:
  - Larger event samples:
    - Tighter offline cuts to improve the the signal significance
    - Move to a p_T-differential cross section ratio measurement

2011 J/ψ $\pi^+\pi^-$ Mass Spectrum

- Unbinned log-likelihood fit: $\chi^2/ndf = 0.99$

- Fit results:

$m_{\Psi(2S)} = 3685.90 \pm 0.02$ MeV

$\sigma_{\Psi(2S)} = 3.2 \pm 0.1$ MeV

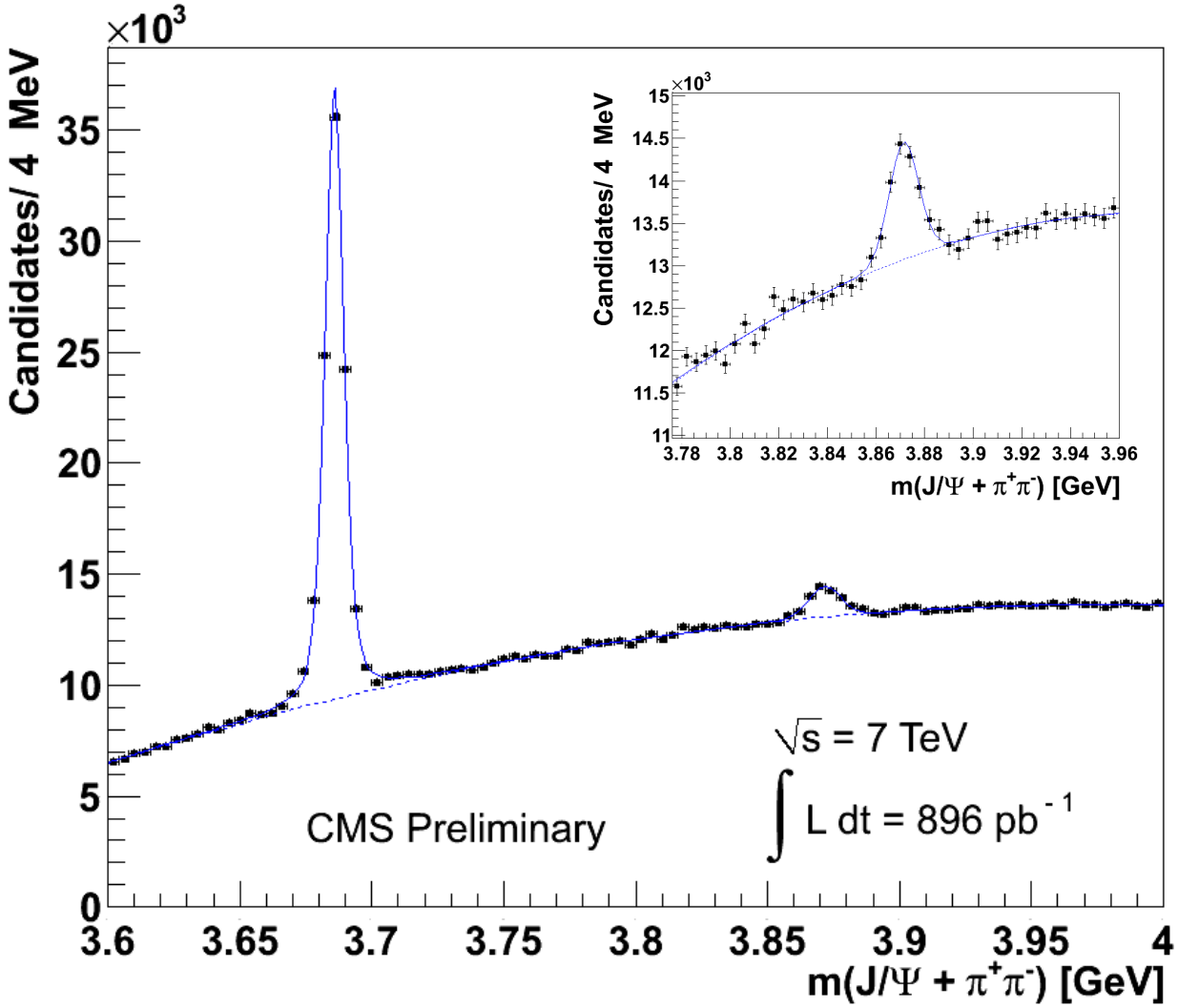
$\gamma_{\Psi(2S)} = 0.00283 \pm 0.00005$

$N_{\Psi(2S)} = 72\,594 \pm 518$

$m_{X(3872)} = 3871.5 \pm 0.5$ MeV

$\sigma_{X(3872)} = 6.1 \pm 0.4$ MeV

$N_{X(3872)} = 5303 \pm 341$

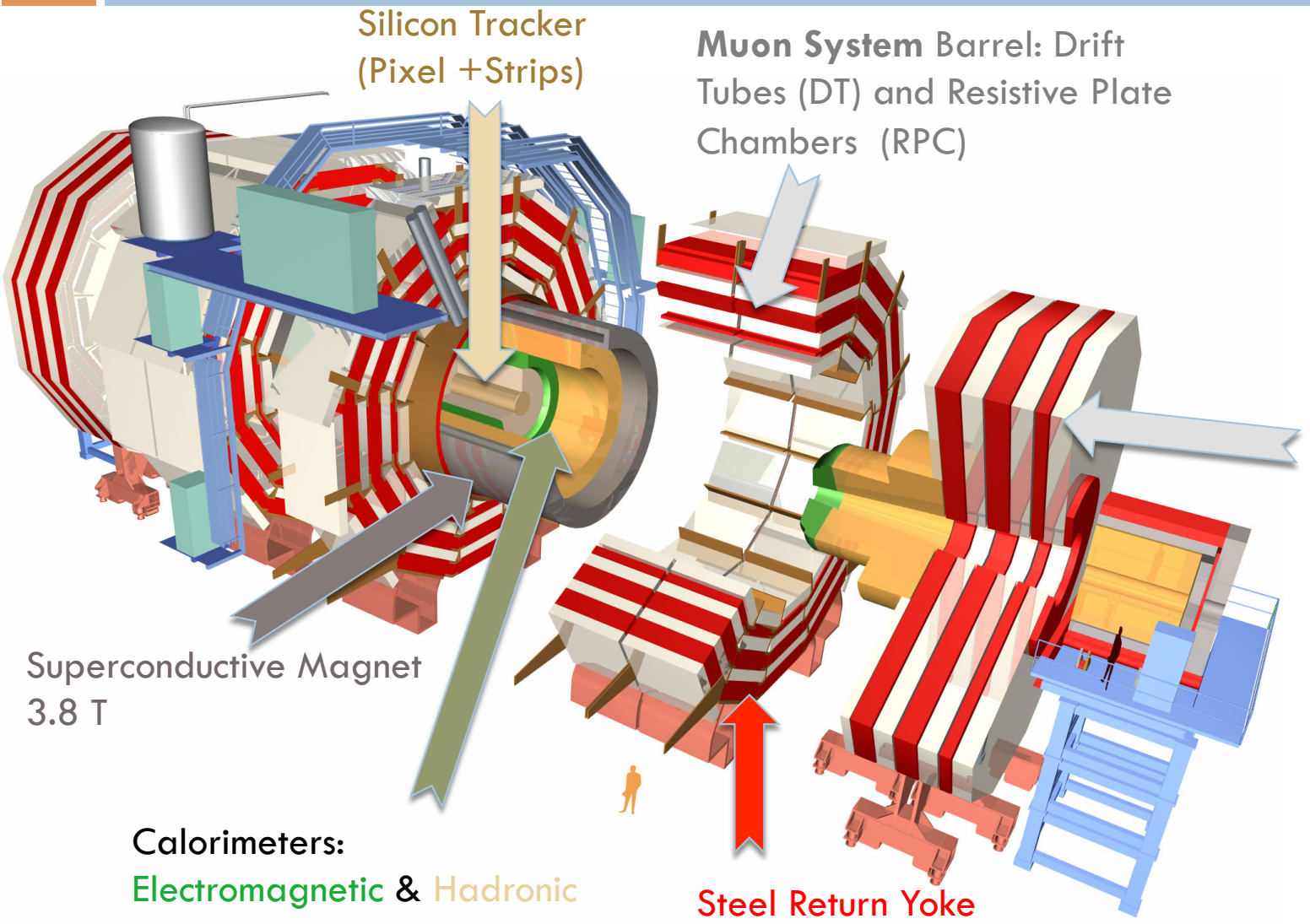


Summary and outlook

- Using the 2010 data, CMS observed a clear X(3872) peak and evaluated the inclusive cross section ratio w.r.t. the Ψ(2S) in the decay channel $J/\psi\ \pi^+\pi^-$
- In 2011 we already collected 10 times more X(3872) events reducing the statistical uncertainty from 20% to 6%
- We will measure the p_T-differential cross-section ratio, the non-prompt fraction and the X(3872) mass

BACKUP

CMS Experiment



Factorization of C

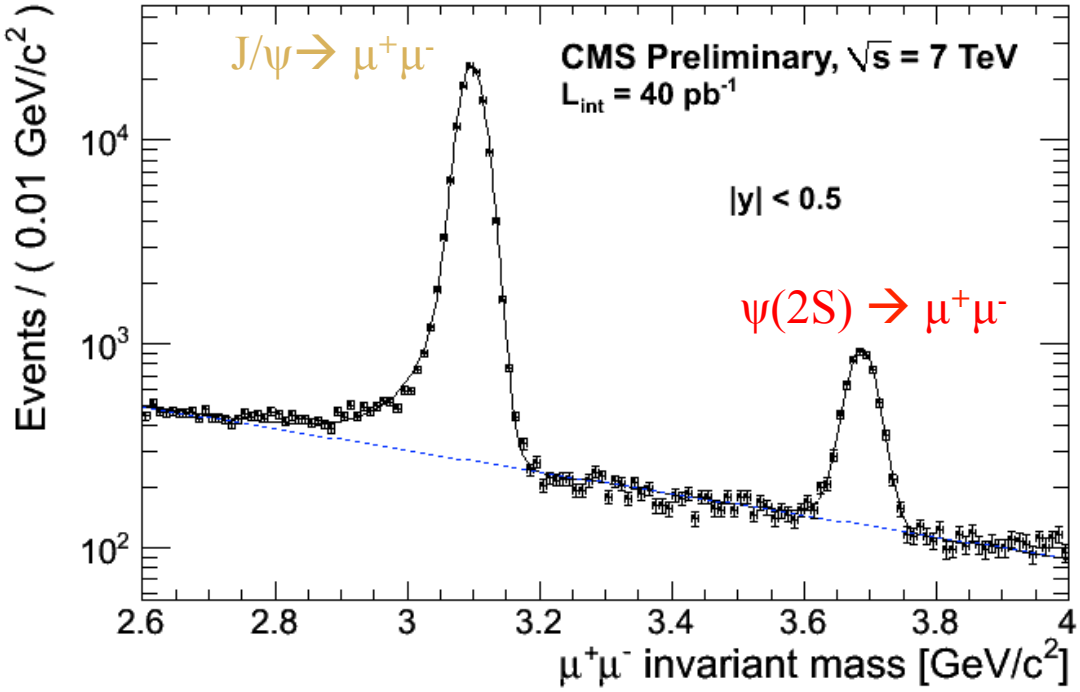
$$C = \frac{A_{J/\psi}(X) \cdot \varepsilon_{J/\psi}(X) \cdot A_{\pi\pi}(X) \cdot \varepsilon_{\pi\pi}(X)}{A_{J/\psi}(\psi') \cdot \varepsilon_{J/\psi}(\psi') \cdot A_{\pi\pi}(\psi') \cdot \varepsilon_{\pi\pi}(\psi')}$$

- Where the term are:
  - Acceptance of J/ψ ($A_{J/\psi}$)
    Fraction of all generated J/ψ with 2μ in acceptance region.
  - Efficiency of J/ψ ($\varepsilon_{J/\psi}$)
    Fraction of J/ψ with 2μ in acceptance region that are triggered and reconstructed.
  - Acceptance × Efficiency for pions ($A_{\pi\pi} \cdot \varepsilon_{\pi\pi}$)
    Fraction of X(3872) or ψ(2S), with a triggered and reconstructed J/ψ, passing the whole selection.
- C components are separately determined from X and ψ(2S) MC simulation for both prompt and non-prompt components.

Data driven evaluation $A_{\pi\pi}(\psi')\cdot\varepsilon_{\pi\pi}(\psi')$

- Check the value for $A_{\pi\pi}(\psi')\cdot\varepsilon_{\pi\pi}(\psi')$ comparing the decay channels $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ and $\psi(2S) \rightarrow \mu^+\mu^-$ in our fiducial region.

- Determine the number of
  - $\psi(2S)\rightarrow\mu^+\mu^-$
  - $\psi(2S) \rightarrow J/\psi\ \pi^+\pi^-$
- Correct the ratio for
  - branching ratios (PDG)
  - acceptances and efficiencies of J/ψ and $\psi(2S)$ decaying into two muons



- Result found to be perfectly consistent with the simulation