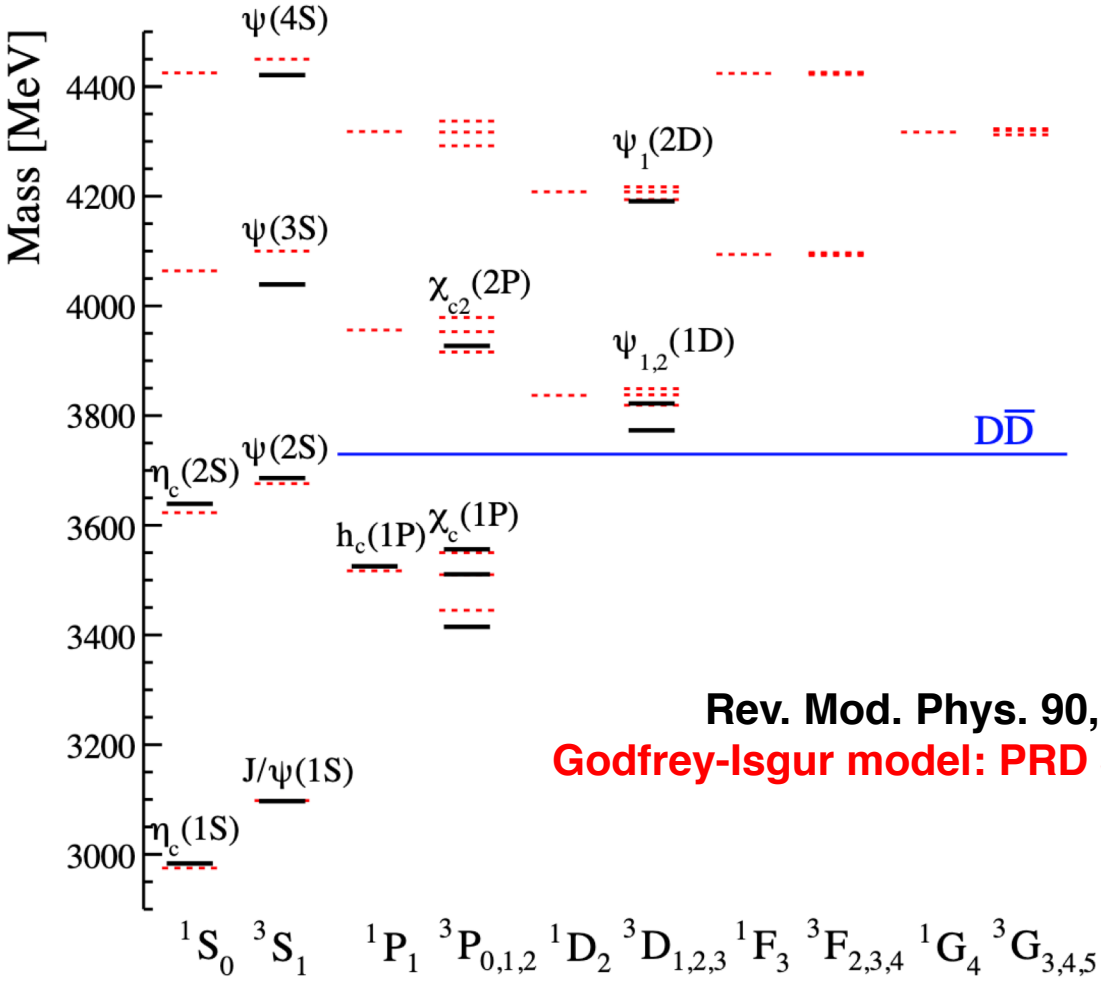
$\chi_{c1}(3872)$ production in pp with particle multiplicity

Andrii Usachov
on behalf of the LHCb collaboration

Intro: charmonium spectroscopy



Rev. Mod. Phys. 90, 15003 (2018)

Godfrey-Isgur model: PRD 32 (1985) 189

- Well described by potential models
- More precise studies from lattice QCD

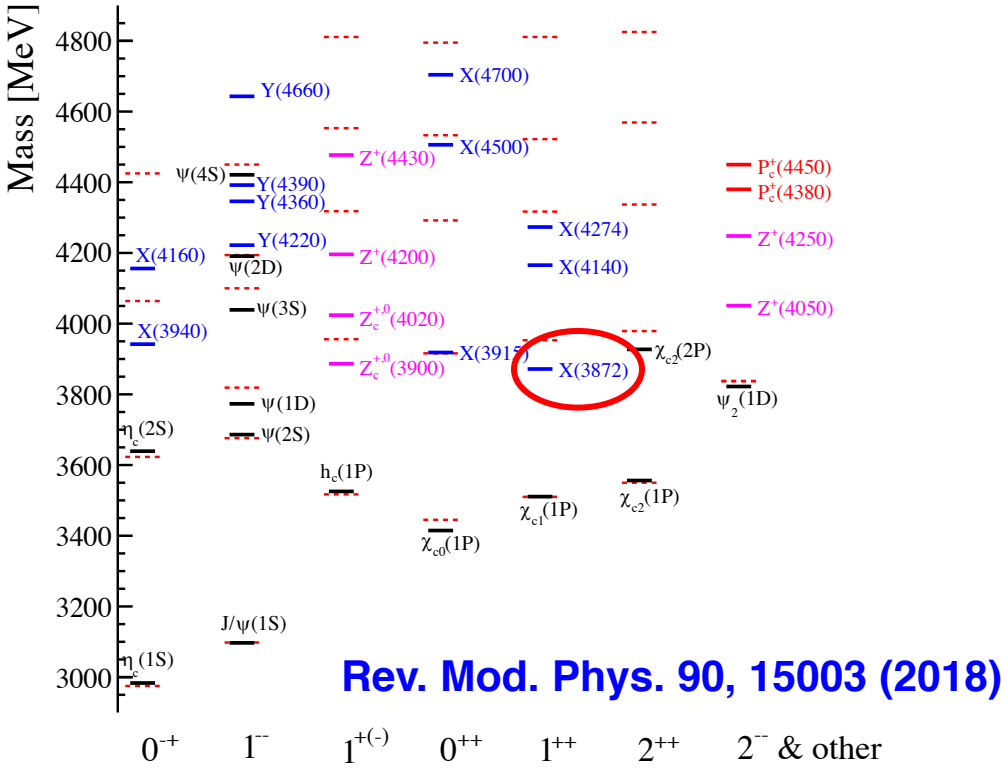
* see talk by Zhiyu Xiang for LHCb results on conventional quarkonia

Intro: exotic hadron spectroscopy

- Exotic hadron candidates in charmonium region: experimentally observed states that don't fit into charmonium picture

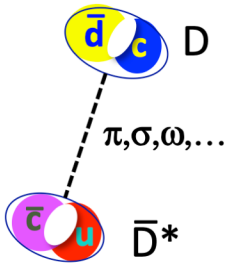
=>more than 20 charmonium-like states observed

* for more results on exotic states see talk by Daniel Johnson



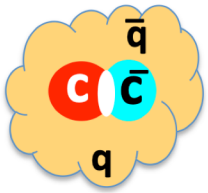
Rev. Mod. Phys. 90, 15003 (2018)

Possible interpretations

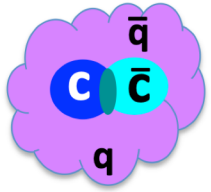


meson-antimeson molecule

compact tetraquark



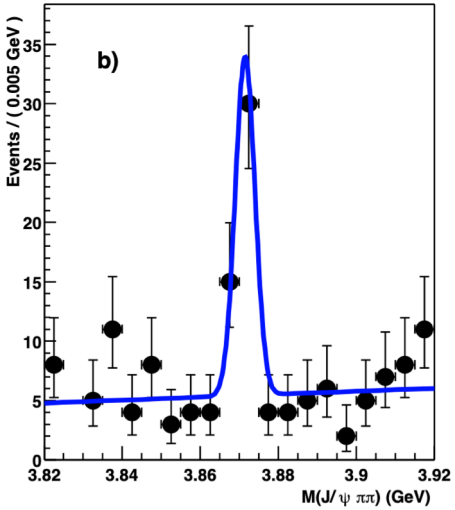
hadrocharmonium



adjoint charmonium

$\chi_{c1}(3872)$ or former X(3872)

- Firstly observed in $J/\psi\pi\pi$ spectrum by Belle in 2003
  PRL 91, 262001



- Followed by measurements at BaBar, CDF, and LHC experiments
  => exotic hadron candidate

- Very narrow (unlikely to many other exotic states)
  => disfavors charmonium interpretation

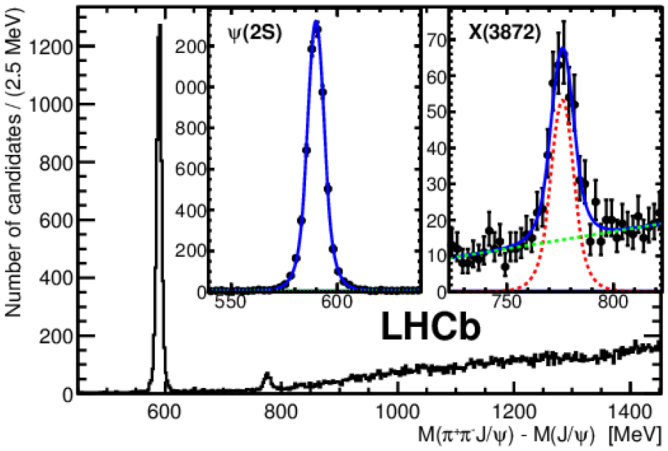
- Close to DD^* threshold $M_{\chi_{c1}(3872)} - (M_{D^0} + M_{\bar{D}^{*0}}) = 0.01 \pm 0.27\,\mathrm{MeV}/c^2$

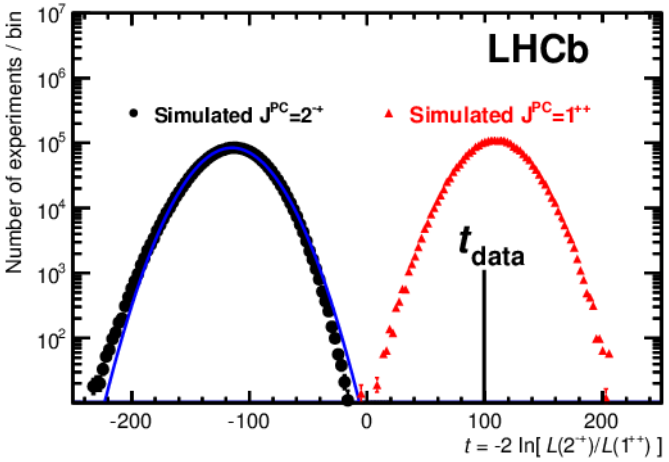
  => possible interpretation: weakly bound state - hadron molecule
  * other models: compact tetraquark, mixed state, *ccg* hybrid, etc.

- **Nature of $\chi_{c1}(3872)$ to be understood**

LHCb contribution: spectroscopy and decays

- $J^{PC} = 1^{++}$ established by LHCb [PRL 110, 222001] [PRD 92, 011102]





The last alternative - $J^{PC} = 2^{-+}$ rejected at 8.4σ level

- Precise line-shape measurement **(new)** arXiv:2005.13419
  * for more details see talk by Daniel Johnson

- Measurements/searches of $\chi_{c1}(3872)$ decays.
  Particularly, evidence of $X(3872) \to \psi(2S)\gamma$ decay Nucl.Phys. B886, 665-680

$$\frac{\mathcal{B}(\mathrm{X}(3872) \to \psi(2\mathrm{S})\gamma)}{\mathcal{B}(\mathrm{X}(3872) \to \mathrm{J}/\psi\gamma)} = 2.46 \pm 0.64 \pm 0.29$$ → rejects pure molecular model

- Study/discoveries of b-hadron decays to $\chi_{c1}(3872)$
  * for recent results on b-hadron decays to charmonia see talk by Peilian Li

$\chi_{c1}(3872)$ prompt production

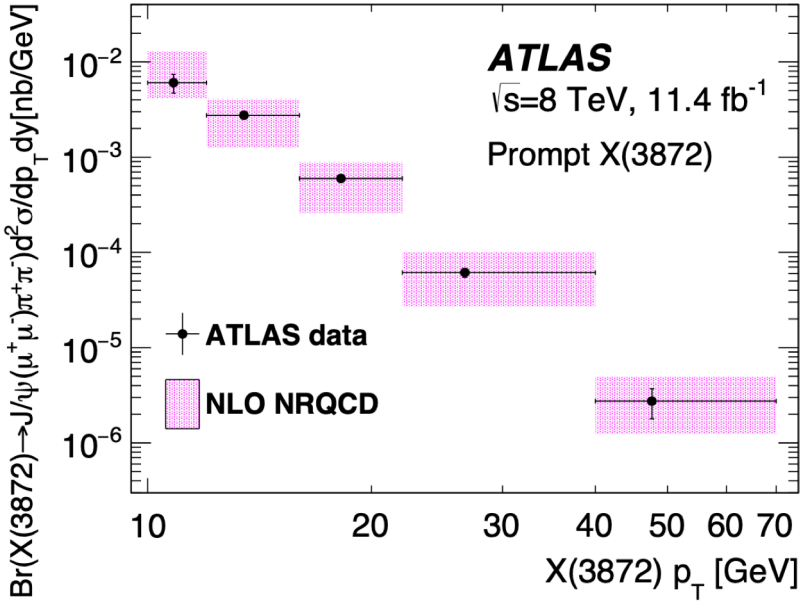
- First prompt production measurement in pp at LHCb EPJC 72, 1972

$$\sigma(pp \to X(3872) + \text{anything})\,\mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) = 5.4 \pm 1.3\,(\text{stat}) \pm 0.8\,(\text{syst})\,\text{nb}$$

$$at\ \sqrt{s} = 7\ TeV$$

=> Differential production cross-section to be measured

- Recent prompt production measurement by ATLAS JHEP 01 (2017) 117



=> Prediction: $\chi_{c1}(3872)$ modelled as a mixture of $\chi_{c1}(2P)$ and *DD molecule**

arXiv:1304.6710

$\chi_{c1}(3872)$ production in-medium

- Nature of $\chi_{c1}(3872)$ can be studied by exploring in-medium effects:
  - **Dependence on event multiplicity in pp collisions (this talk)**
  - Nuclear modification factors in heavy-ion or pA collisions

- Promptly produced quark pairs can dissociate due to **interactions with surrounding medium**
  ** for heavy-ion results see talks by Guilia Manca and Jiayin Sun*

- In-medium effects expected to be enhanced if $\chi_{c1}(3872)$ has large radius compared to charmonium system
  **weakly bound molecular state is expected to have radius about 7fm*

  => powerful test when comparing the effects wrt to ones observed for charmonium states, e.g. $\psi(2S)$

Measurement of $\chi_{c1}(3872)$ production in pp with particle multiplicity

LHCb-CONF-2019-005

LHCb-CONF-2019-005
November 13, 2019

Multiplicity-dependent modification of $\chi_{c1}(3872)$ and $\psi(2S)$ production in pp collisions at $\sqrt{s} = 8$ TeV

LHCb collaboration[†]

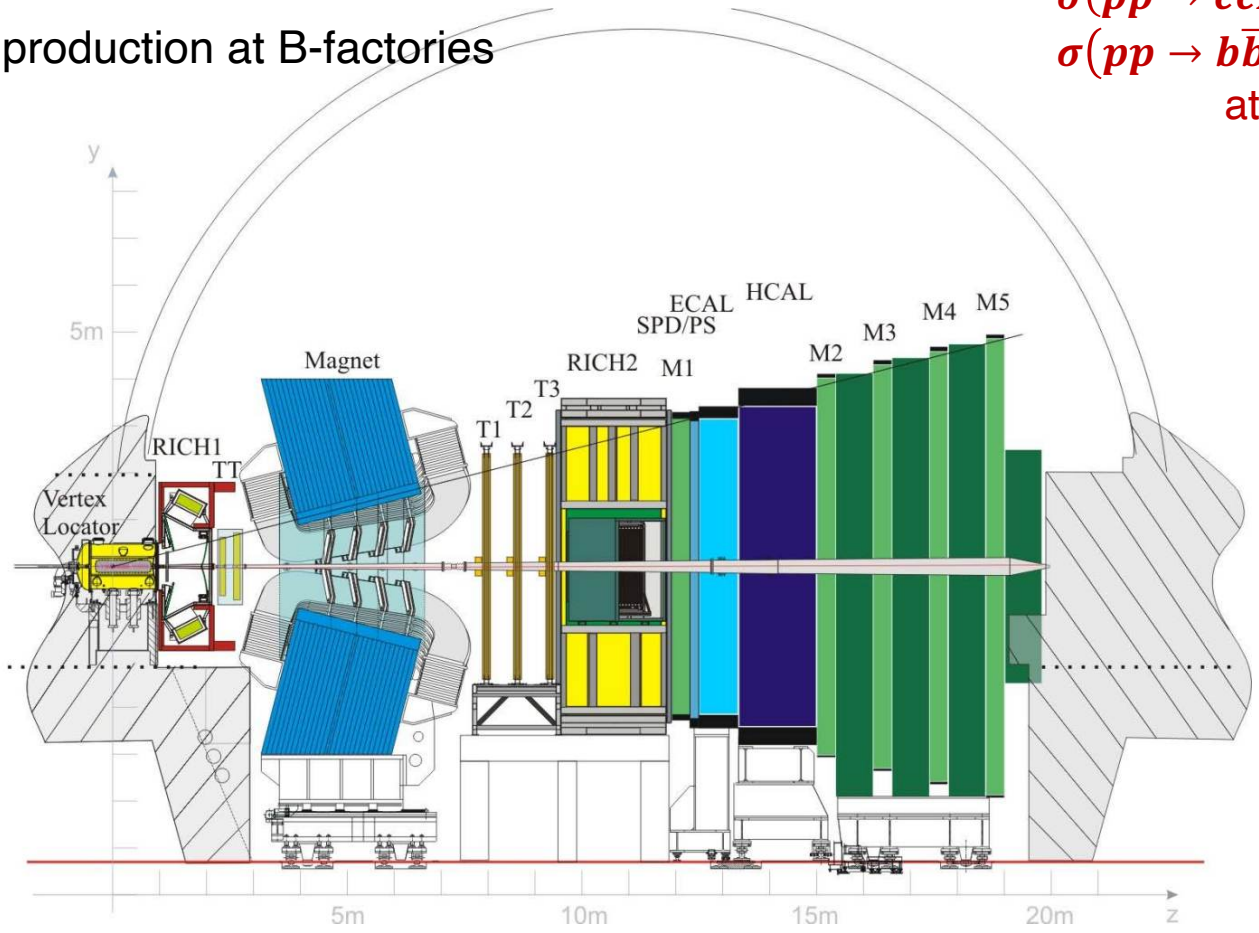
LHCb detector

IJMPA 30, 1530022
JINST 3, S08005

- Single-arm spectrometer designed for beauty and charm physics in forward region
- Large heavy quarks production cross-section compared to B-factories

$\sigma(pp \to c\bar{c}X) \sim 2.4\ mb$
$\sigma(pp \to b\bar{b}X) \sim 0.5\ mb$
at $\sqrt{s} = 13$ TeV

- No prompt production at B-factories



LHCb detector

IJMPA 30, 1530022
JINST 3, S08005

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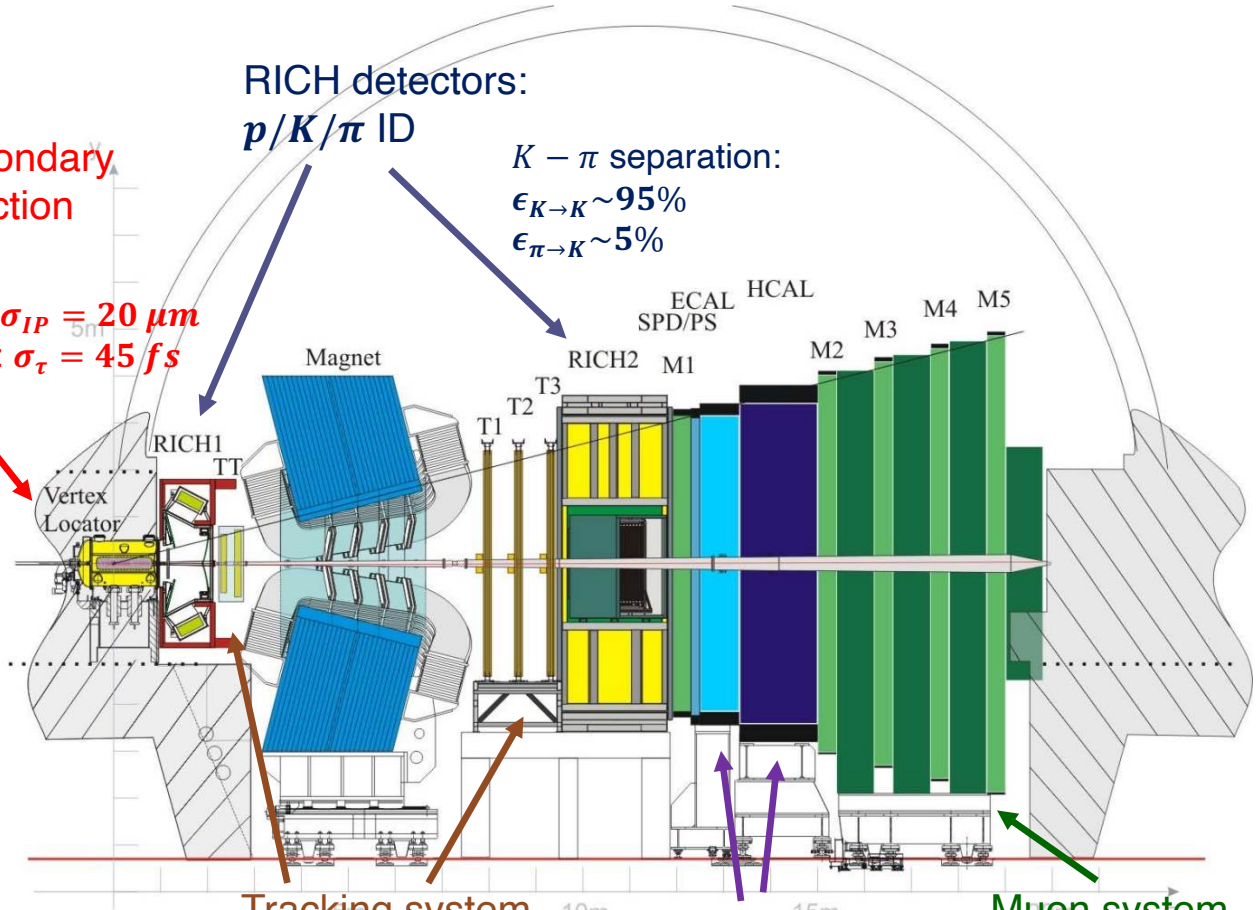
VErtex LOcator:
Primary and secondary vertex reconstruction

Resolution:
Impact parameter : $\sigma_{IP} = 20\ \mu m$
Lifetime : $\sigma_\tau = 45\ fs$

RICH detectors:
$p/K/\pi$ ID

$K-\pi$ separation:
$\epsilon_{K\to K}$~95%
$\epsilon_{\pi\to K}$~5%



Tracking system

Calorimeters:
e/γ/π^0 ID

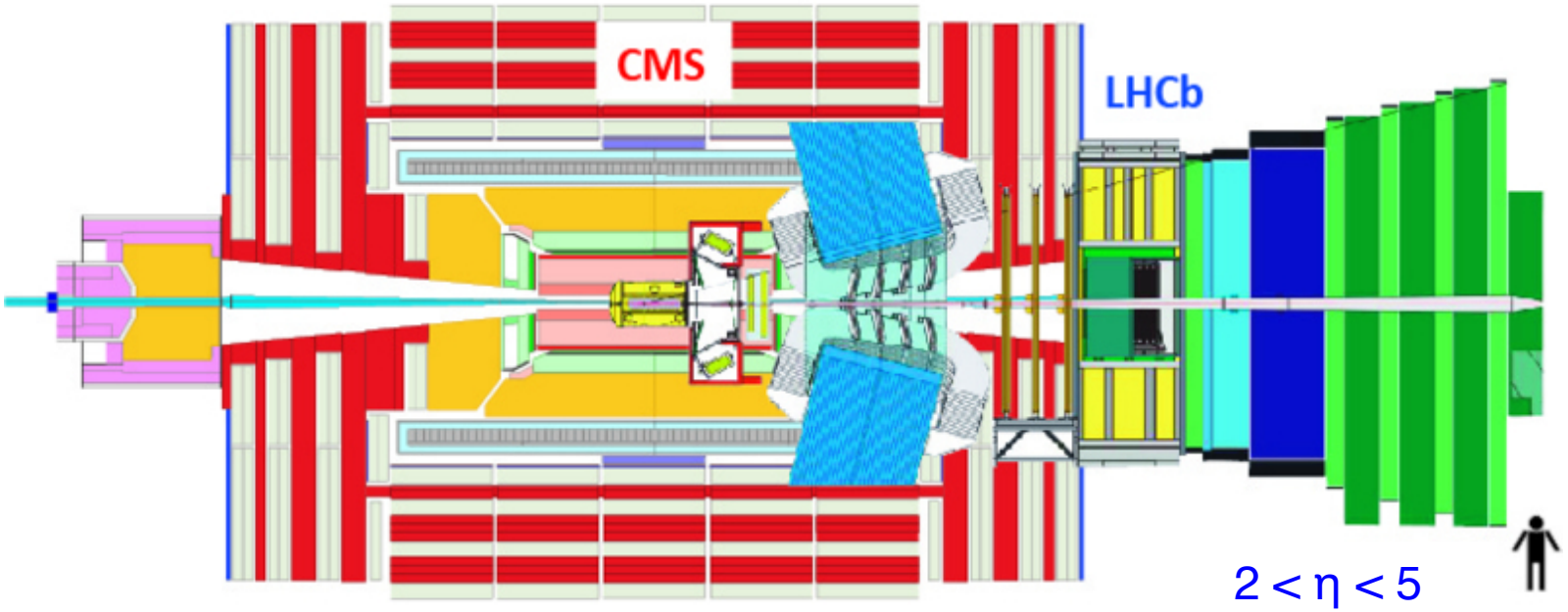
Muon system

$\epsilon_{\mu\to\mu}$~97%
$\epsilon_{\pi\to\mu}$~1 − 3%

- Precise vertex reconstruction with VELO
- Powerful charged hadrons ID by RICH detectors

LHCb detector

IJMPA 30, 1530022
JINST 3, S08005



- Coverage complementary to ALICE, ATLAS and CMS in p_{T} and η
- Comparable b-quark production cross-section in much smaller solid angle
- Large trigger bandwidth for b-physics
- Limited instantaneous luminosity

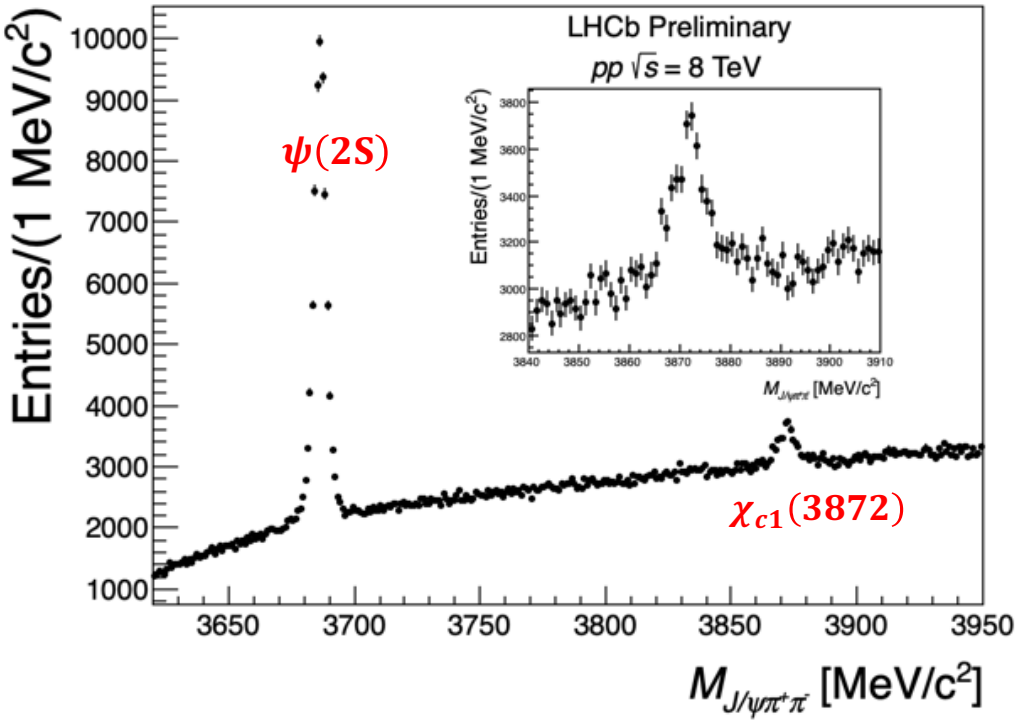
Data analysis

LHCb-CONF-2019-005

- Data sample: $2.0\ fb^{-1}$ collected at $\sqrt{s} = 8\ TeV$
- Signal channel: $\boldsymbol{\chi_{c1}(3872) \to (J/\psi \to \mu\mu)(\rho \to \pi\pi)}$
- $\boldsymbol{\psi(2S) \to (J/\psi \to \mu\mu)\pi\pi}$ used as normalization

- Data selection:

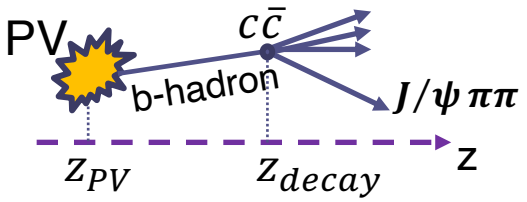
  $\boldsymbol{J/\psi \to \mu\mu}$ candidates are combined with two pions identified by RICH
- Kinematic refit constraints
  - $\boldsymbol{M(\mu\mu)}$ mass to $\boldsymbol{J/\psi}$ mass from PDG
  - to have same origin vertex for all four tracks



Prompt and b-decays components

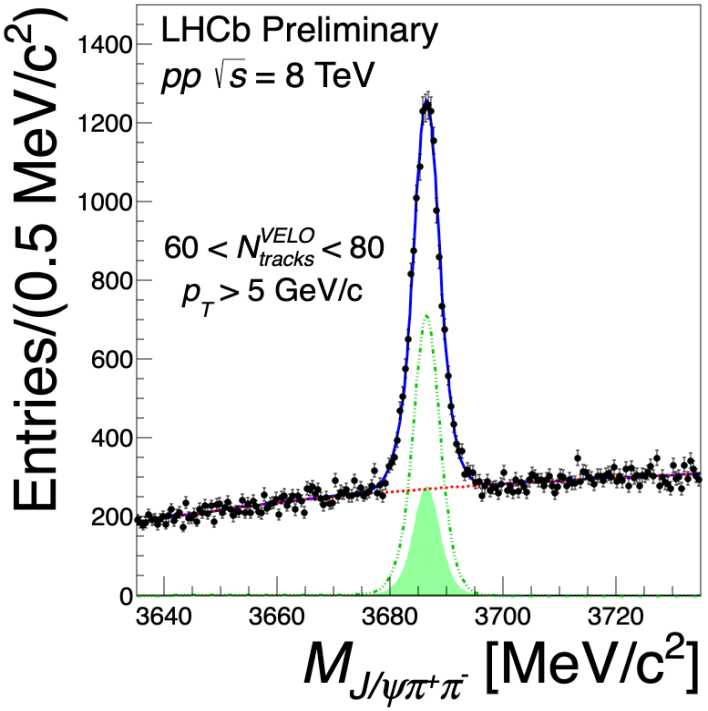
- Separated using pseudo-proper lifetime t_z

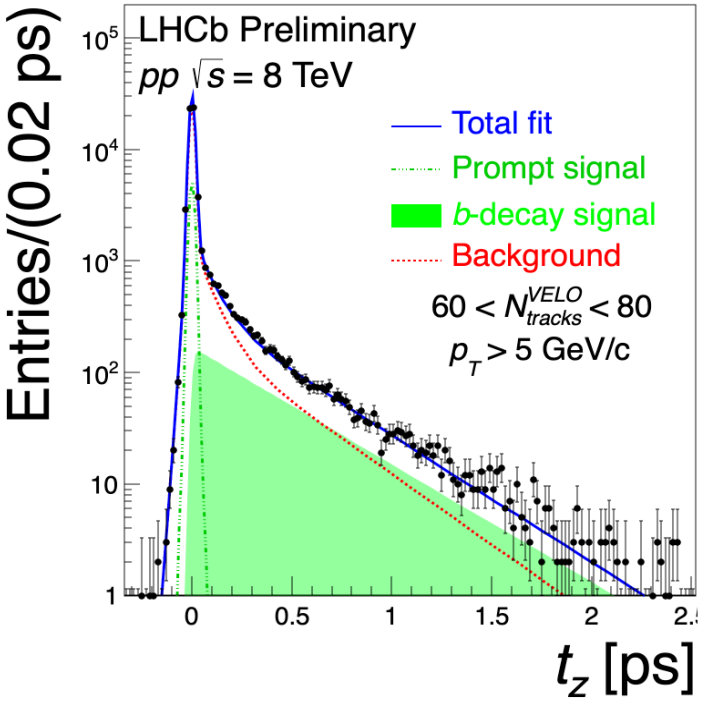
$$t_z = \frac{(z_{\text{decay}} - z_{\text{PV}})M}{p_z}$$



- Simultaneous fit to invariant mass and t_z performed

- Ratio of $\chi_{c1}(3872)/\,\psi(2S)$ extracted in bins of N_{tracks}^{VELO} - proxy to event multiplicity

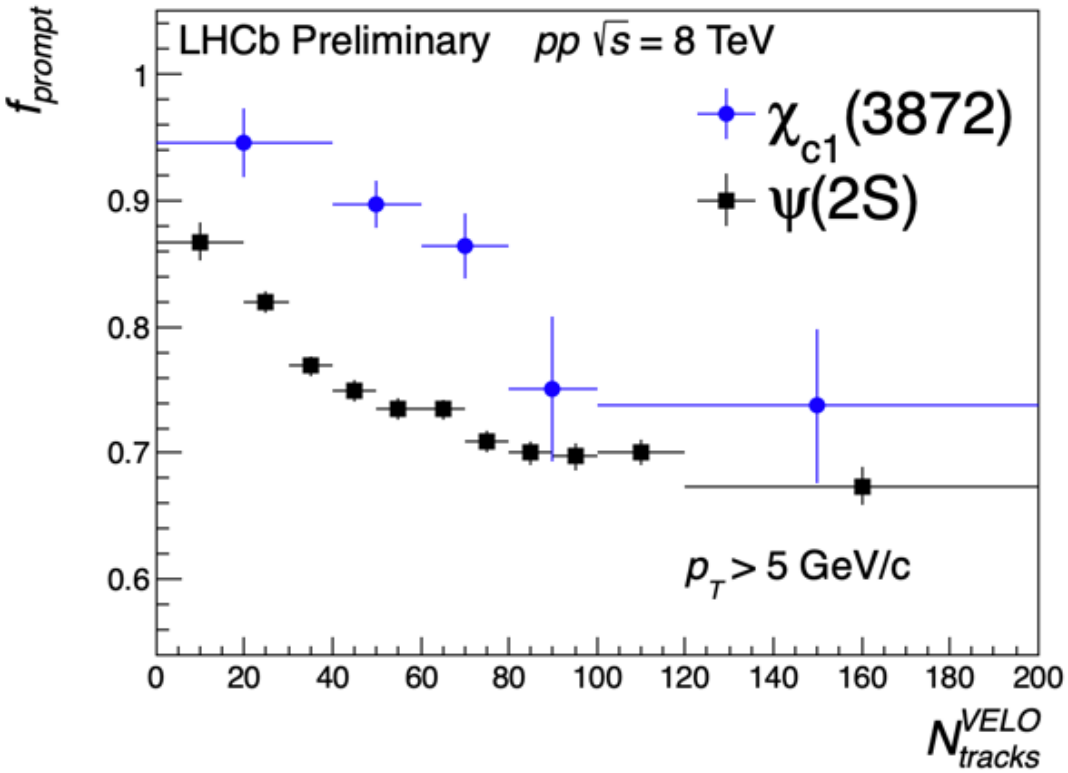




Prompt production fraction

LHCb-CONF-2019-005

- Defined as $f_{prompt} = \frac{N_{prompt}}{N_{prompt} + N_{b-decays}}$ - studied in bins of N_{tracks}^{VELO}



- **Obvious decreasing trend** for both $\chi_{c1}(3872)$ and $\psi(2S)$
  => b-production events has naturally larger multiplicity than prompt
  => prompt production can be affected by in-medium effects
  (unlikely to affect production in b-decays)

Relative production cross-section

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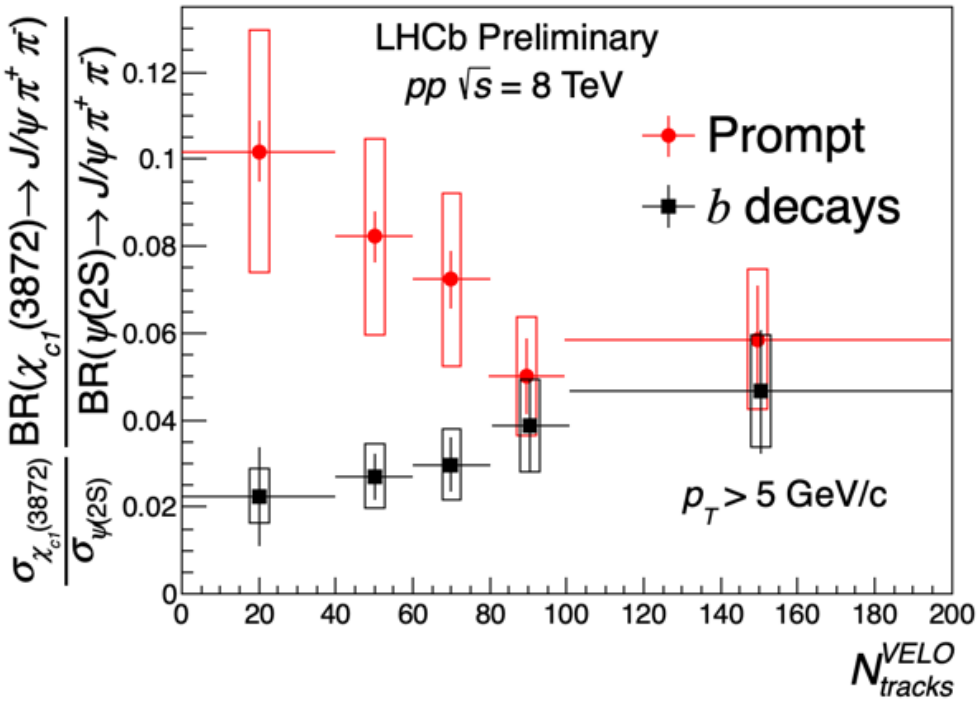
- Obtained as

$$\frac{\sigma_{\chi_{c1}(3872)}}{\sigma_{\psi(2S)}} \frac{\mathcal{B}[\chi_{c1}(3872) \to J/\psi\pi^+\pi^-]}{\mathcal{B}[\psi(2S) \to J/\psi\pi^+\pi^-]} = \frac{N_{\chi_{c1}(3872)}}{N_{\psi(2S)}} \frac{f^{\chi_{c1}(3872)}_{\text{prompt}}}{f^{\psi(2S)}_{\text{prompt}}} \frac{\varepsilon_{\psi(2S)}}{\varepsilon_{\chi_{c1}(3872)}}$$



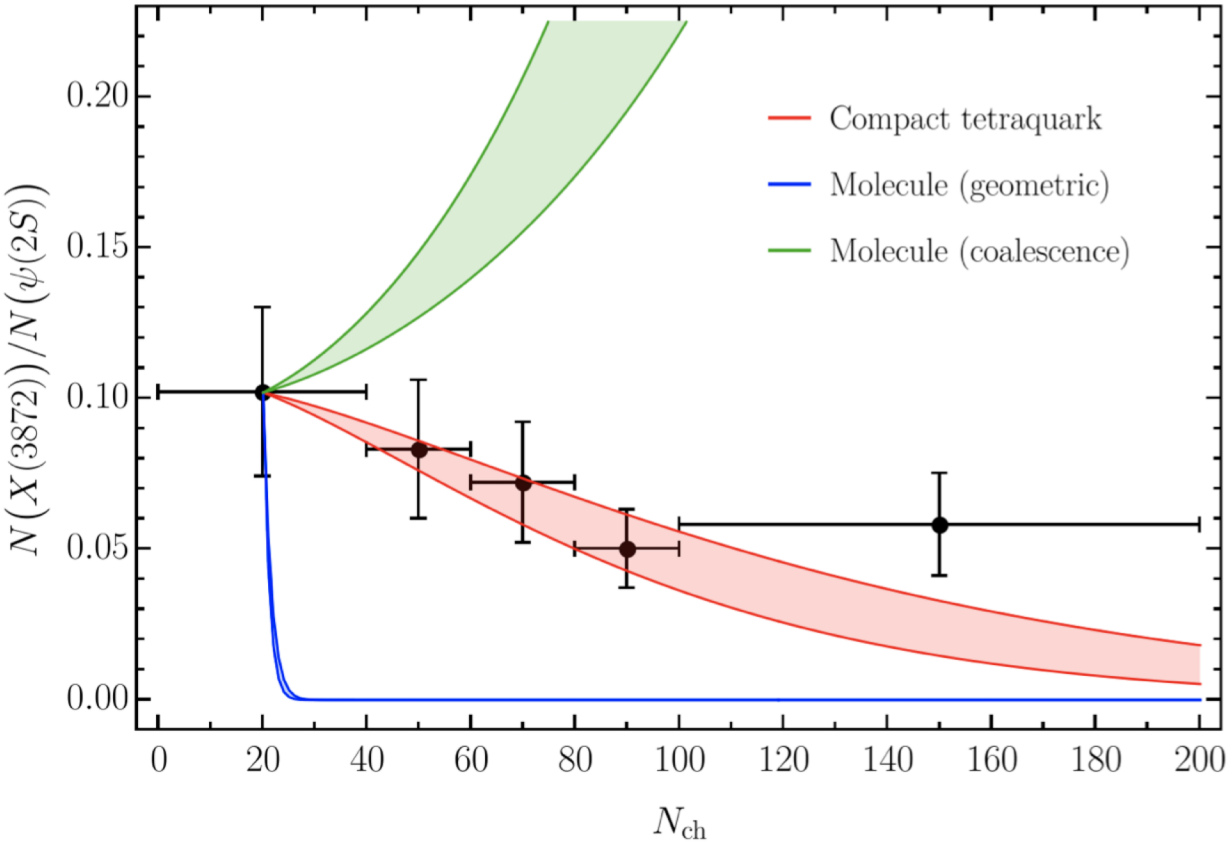
- systematics dominated, correlated between the bins
- would benefit from differential prompt production measurement

Prompt: stronger suppression of $\chi_{c1}(3872)$ relative to $\psi(2S)$ at high multiplicity
=> expected if $\chi_{c1}(3872)$ is weakly bound state (system with large radius)
* the slope is found to be 2.6σ different from zero

b-decays: no strong dependence on event multiplicity
=> consistent with ATLAS measurement JHEP 01 (2017) 117

Theory interpretation (new)

arXiv:2006.15044

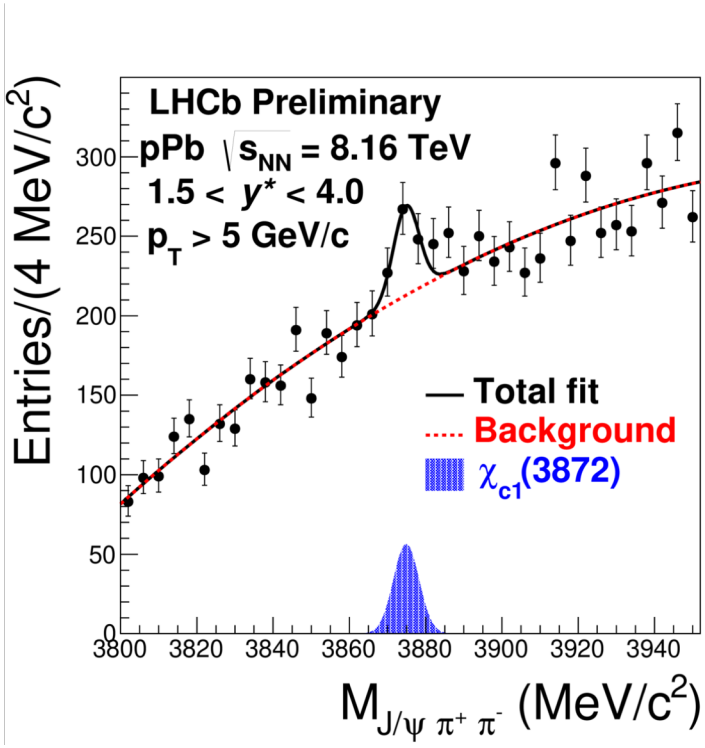


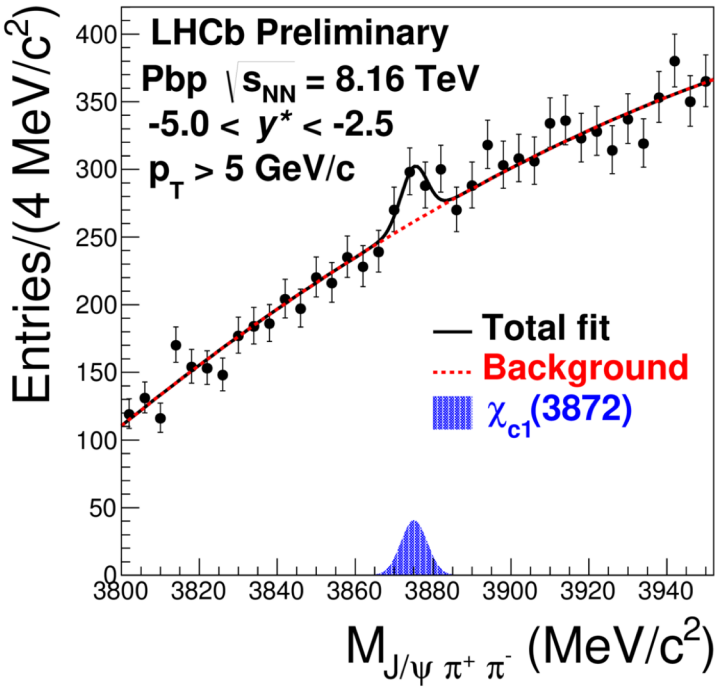
- Molecule dissociates immediately: sharp dependence predicted
- Tetraquark interpretation fits better to data points
- Detector effects to be understood

Towards production measurement in pPb and Pbp

LHCB-FIGURE-2019-019

- Clear signal from $\chi_{c1}(3872)$:





- Analysis ongoing
- Complementary to other LHC measurements

Summary

- The nature of $\chi_{c1}(3872)$ is important for understanding and testing QCD
- A rich program is devoted at LHCb to study its **spectroscopy, production and decays**
- The measurement of the $\chi_{c1}(3872)$ **production in pp with particle multiplicity** has been performed
- The results show that **prompt** $\chi_{c1}(3872)$ production is **more suppressed than** $\psi(2S)$ at high event multiplicities
  => helps to understand the nature of $\chi_{c1}(3872)$
  => suggests that $\chi_{c1}(3872)$ **is more weakly bound than** $\psi(2S)$
- More production measurements to come:
  - $\chi_{c1}(3872)$ production in pPb
  - updated $\chi_{c1}(3872)$ production in pp
  - **...**

Stay tuned