

CMS与奇特强子

易凯

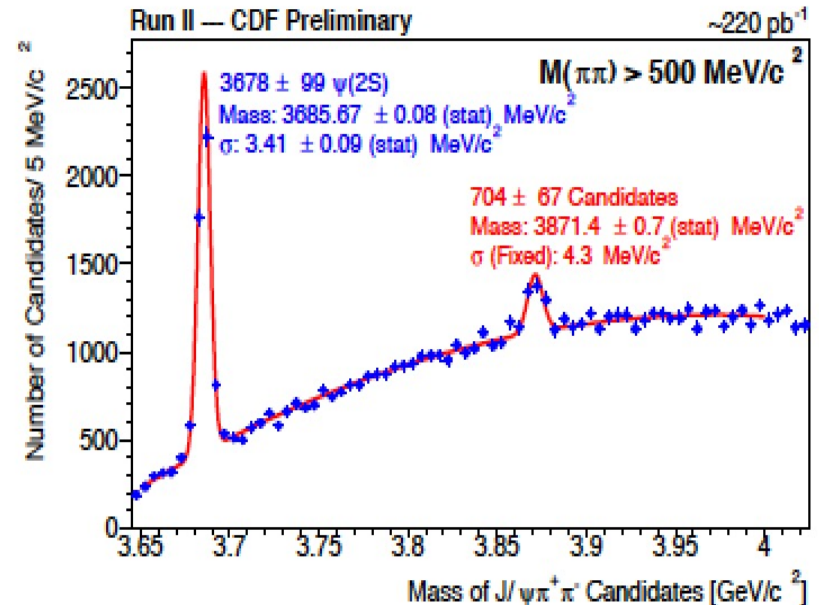
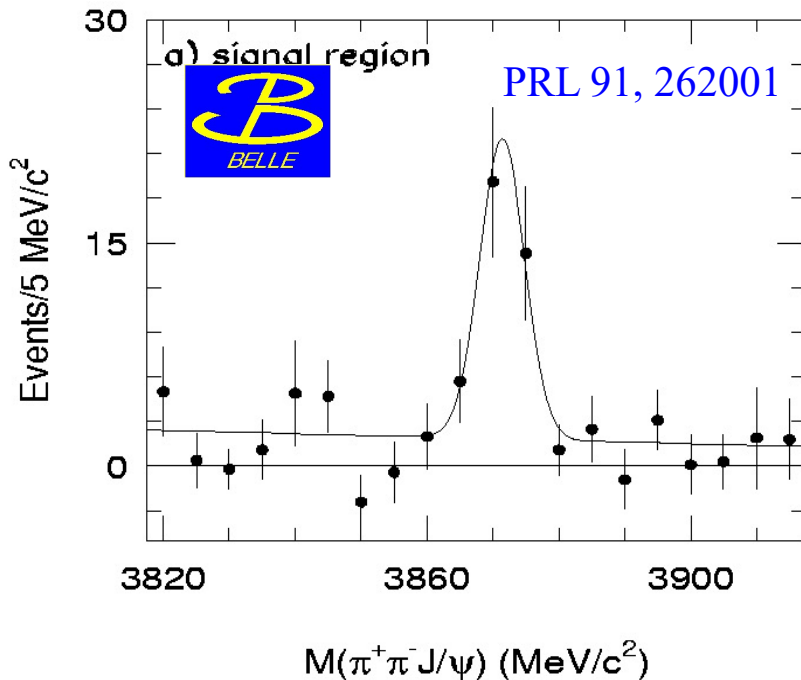
南京师范大学&清华大学

第二届强子与重味物理理论与实验联合研讨会, 3.27, 2021

山色横倾遮不住，萃英山下好读书！



X(3872) (Belle)--2003



2017 Laureates



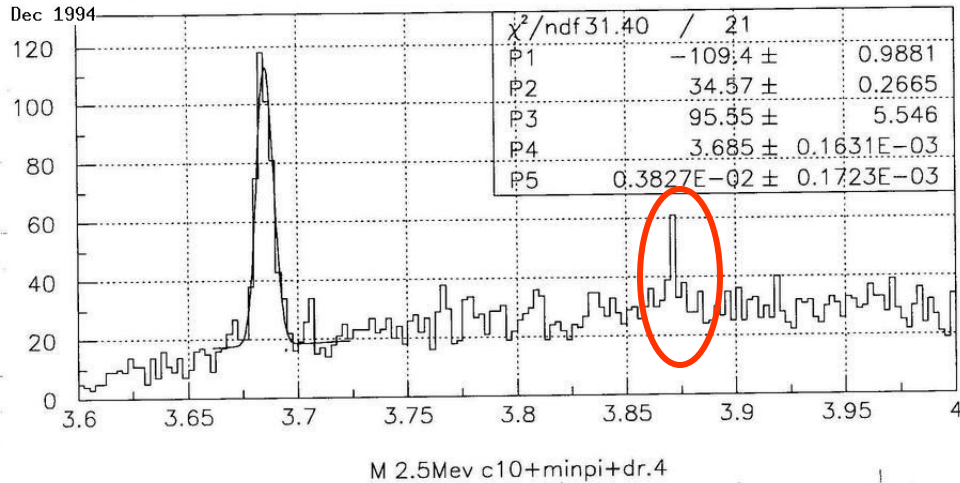
“...The X(3872) was discovered by Dr. Sookyung Choi and Dr. Stephen Olsen with their colleagues in the Belle experiment among the final states of the decay of B mesons. The X(3872) was confirmed by seven other experimental groups thereafter and is the first example of a new type of XYZ meson and the most well-established state among them. ...”

重味奇特强子浪潮的起点，强子对撞机直接贡献

2017 Korean Ho-Am Science Prize

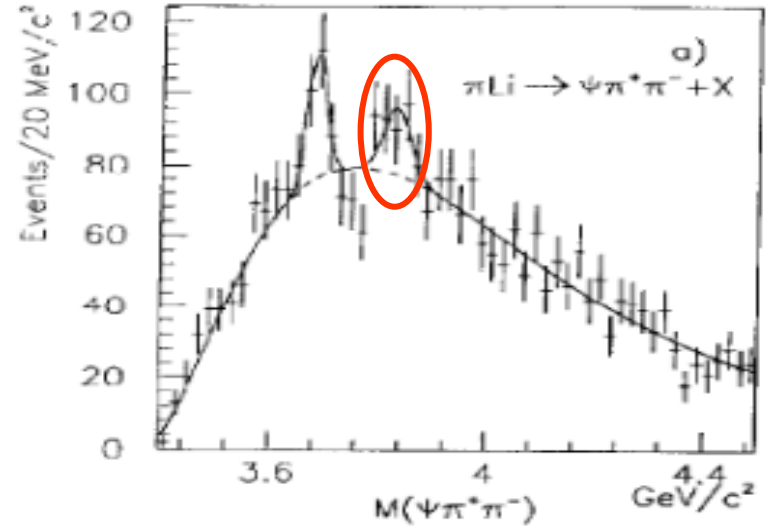
Hints before the discovery of $X(3872) \rightarrow J/\psi \pi^+ \pi^-$

CDF internal, 1994

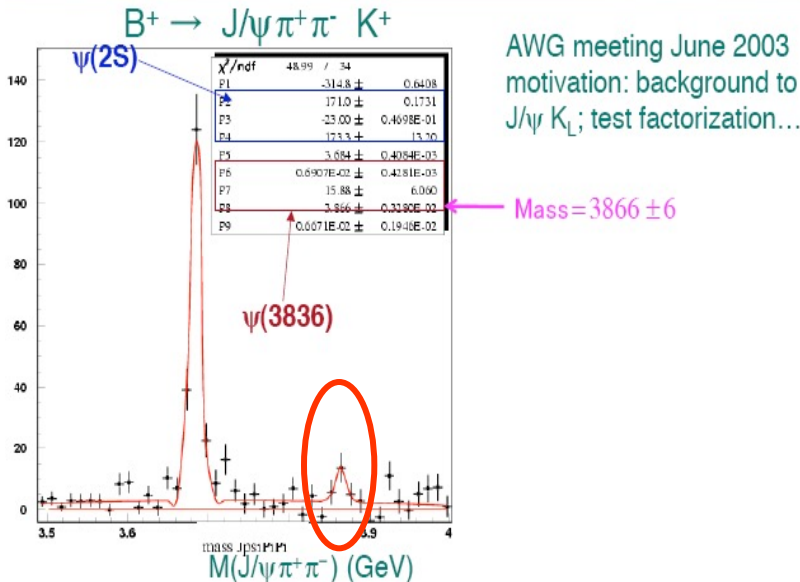


E705, PRD 50, 4258 (1994)

*E705 saw $\psi(3836) (2^-)$ in 1994, 3.836 ± 0.013 GeV
PRL 115 011803, PRL 111 032001*



BaBar internal, 2003



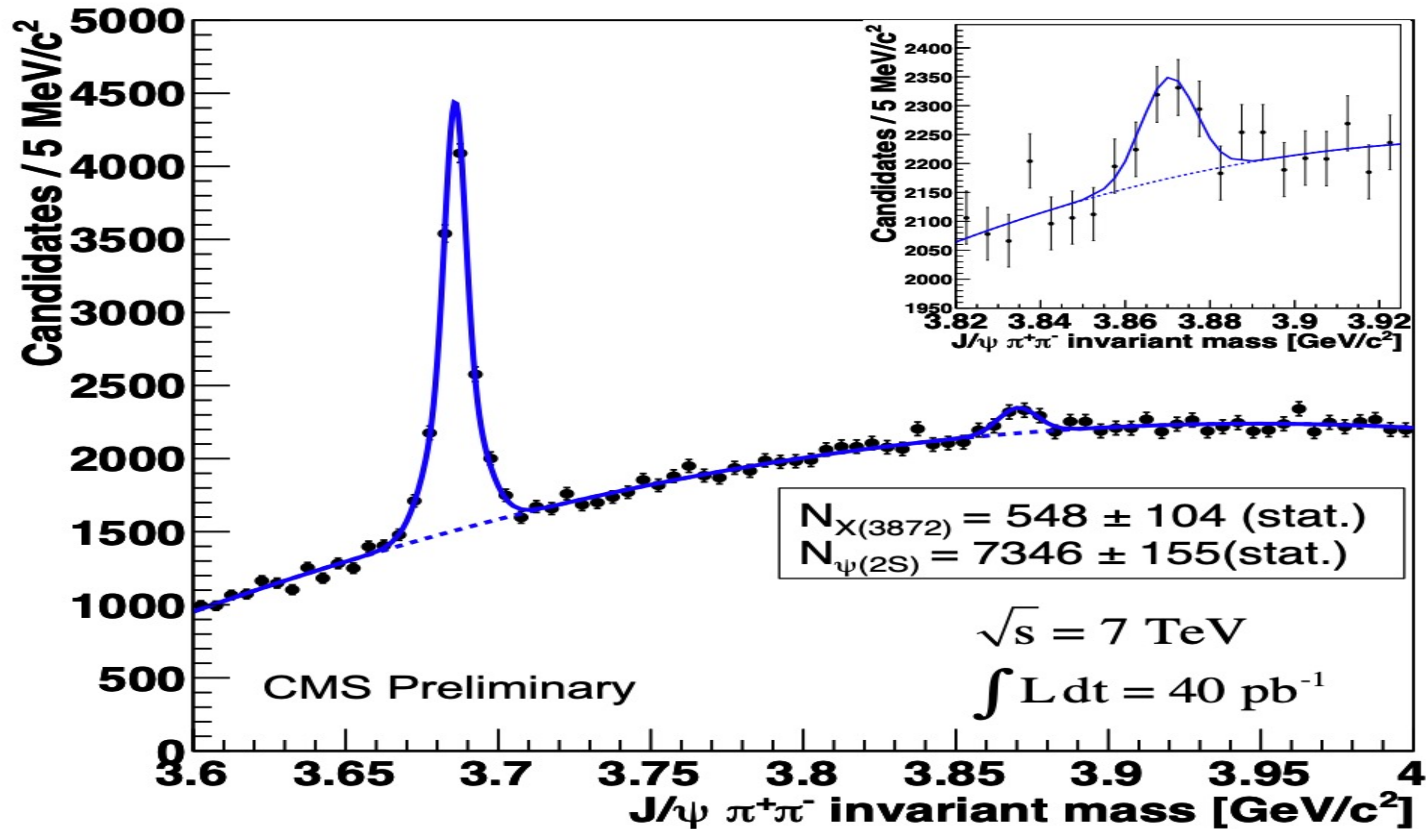
*CDF saw a hint in 1994, unpublished
BaBar saw a hint in 2003, unpublished*

Both CDF and Babar spotted hints of $X(3872)$ before its discovery!

起点可能更早来到，世界上没有如果...

*From BaBar B-Factory Symposium (C. Hearty)
<http://www-conf.slac.stanford.edu/b-factory-symposium/talks.asp>*

X(3872) at CMS--2010



$$R = \frac{\sigma(pp \rightarrow X(3872) + \text{anything}) \times BR(X(3872) \rightarrow J/\psi \pi^+ \pi^-)}{\sigma(pp \rightarrow \psi(2S) + \text{anything}) \times BR(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-)} \quad R = 0.087 \pm 0.017(\text{stat.}) \pm 0.009(\text{syst.})$$

The first LHC experiment re-discovered X(3872), CMS PAS BPH-10-018

X(3872) at CMS--2011



J/ψ π⁺ π⁻ Mass Distribution

Fit:

Unbinned maximum likelihood fit.
J/ψ mass fixed to the PDG value.

Fit results:

ψ(2S) Voigtian:

$\mu = 3685.90 \pm 0.02$ MeV
 $\sigma = 3.2 \pm 0.1$ MeV
 $\gamma = 0.00283 \pm 0.00005$
 $N = 72594 \pm 518$

X(3872) Gaussian:

$\mu = 3871.5 \pm 0.5$ MeV
 $\sigma = 6.1 \pm 0.4$ MeV
 $N = 5303 \pm 341$

Chebyshev Polynomial:

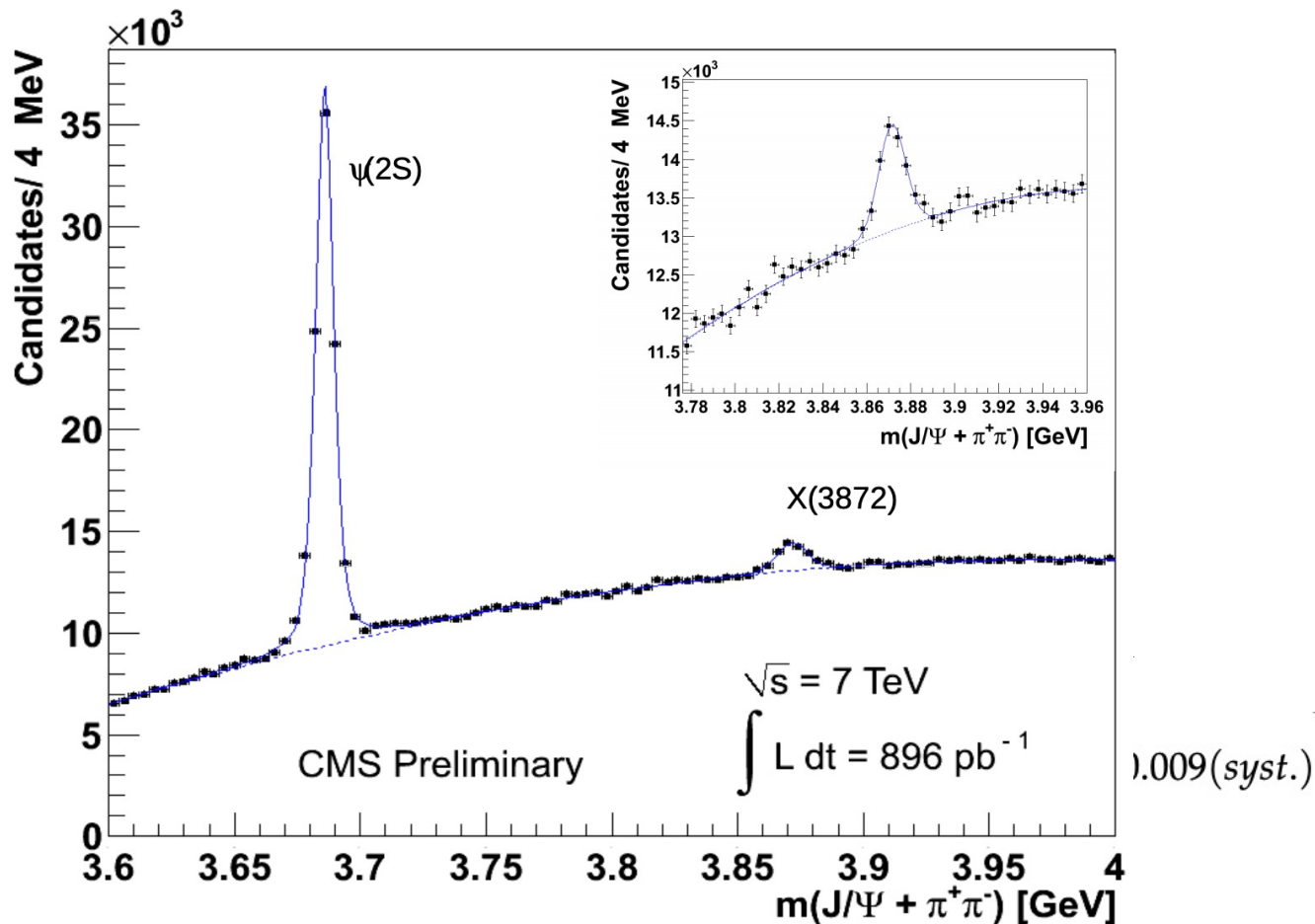
$c1 = 0.321 \pm 0.002$
 $c2 = -0.091 \pm 0.002$

R =

$\chi^2/\text{ndf} = 0.99$

PDG mass values:

$\psi(2S) = 3686.09 \pm 0.04$ MeV
 $X(3872) = 3871.57 \pm 0.25$ MeV



Contact: cms-pkg-conveners.hbk@cern.ch

X(3872) at CMS--2013

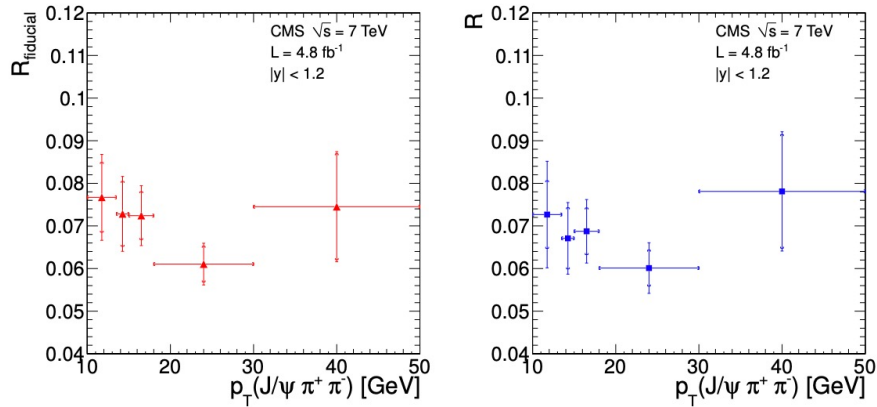
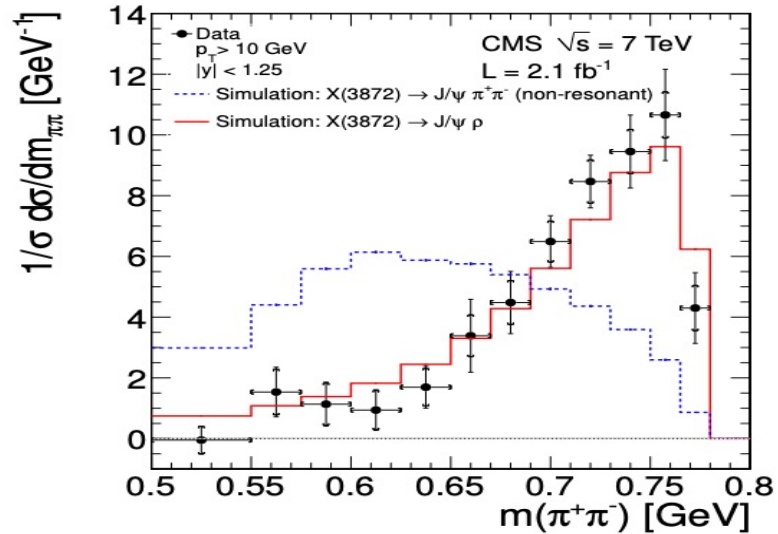
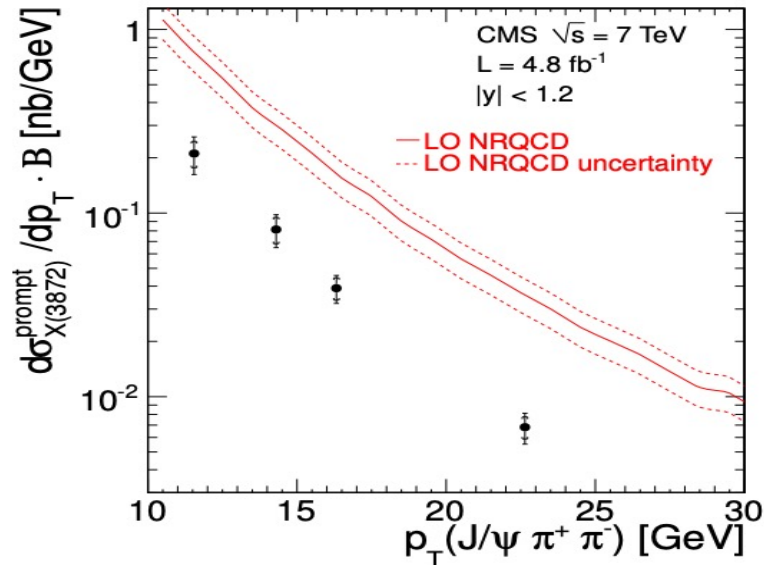
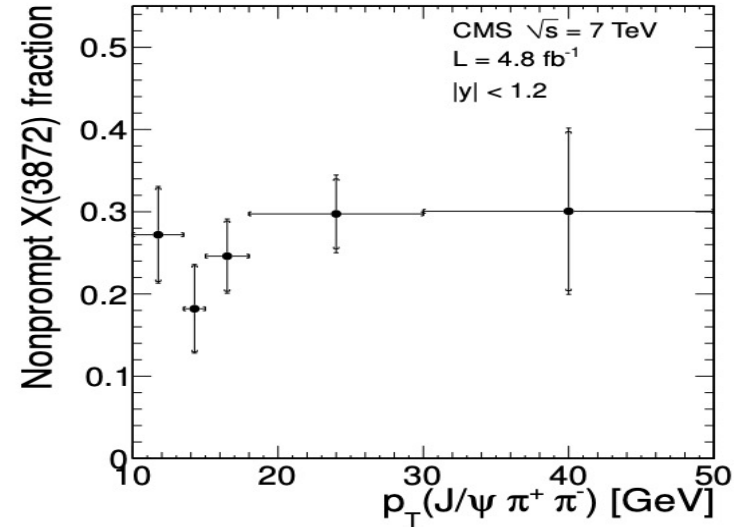
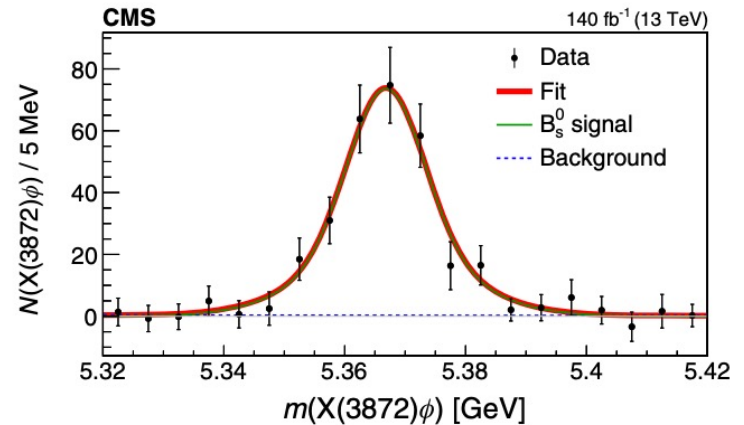
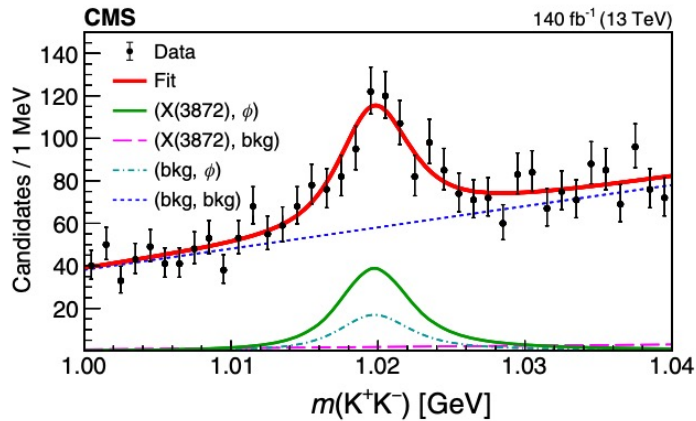
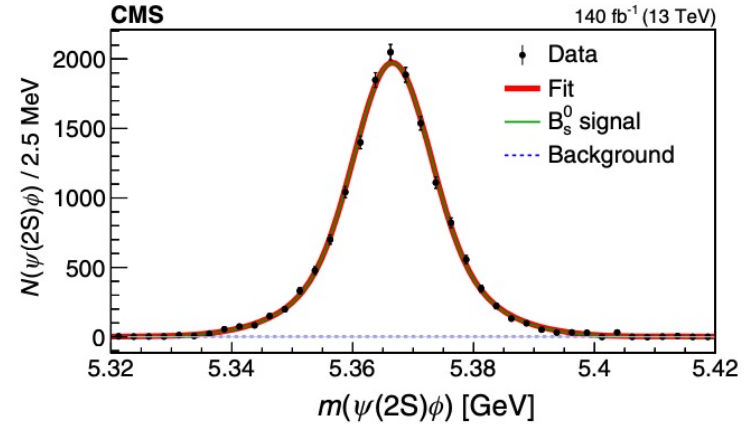
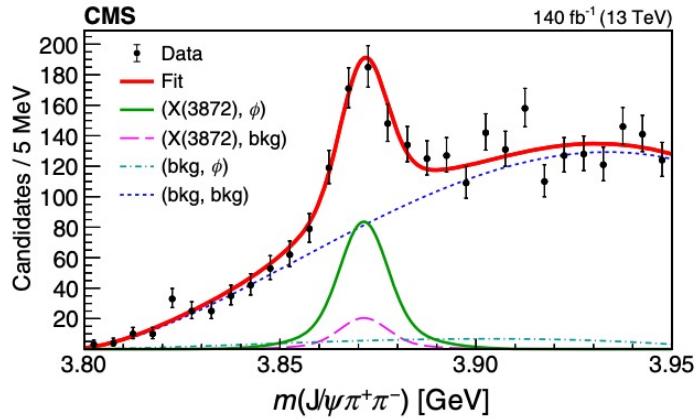


Figure 3. Ratios of the X(3872) and $\psi(2S)$ cross sections times branching fractions, without (R_{fiducial} , left) and with (R , right) acceptance corrections for the muon and pion pairs, as a function of p_T . The inner error bars indicate the statistical uncertainty and the outer error bars represent the total uncertainty. The data points are placed at the centre of each p_T bin.



Detailed measurements, JHEP 04 (2013) 154

X(3872) at CMS--2020



$$R \equiv \frac{\mathcal{B}[B_s^0 \rightarrow X(3872)\phi] \mathcal{B}[X(3872) \rightarrow J/\psi\pi^+\pi^-]}{\mathcal{B}[B_s^0 \rightarrow \psi(2S)\phi] \mathcal{B}[\psi(2S) \rightarrow J/\psi\pi^+\pi^-]}$$

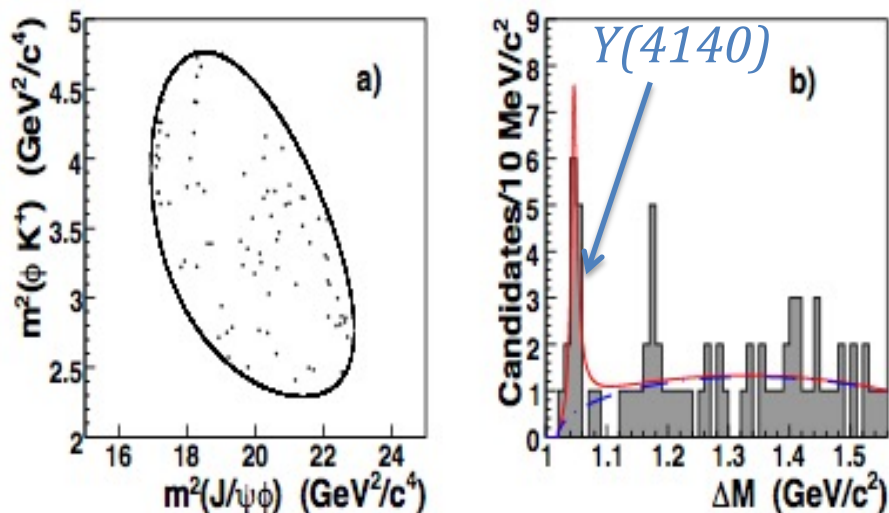
$$= \frac{N[B_s^0 \rightarrow X(3872)\phi]}{N[B_s^0 \rightarrow \psi(2S)\phi]} \frac{\epsilon_{B_s^0 \rightarrow \psi(2S)\phi}}{\epsilon_{B_s^0 \rightarrow X(3872)\phi}}$$

$$R = [2.21 \pm 0.29(\text{stat}) \pm 0.17(\text{syst})]\%$$

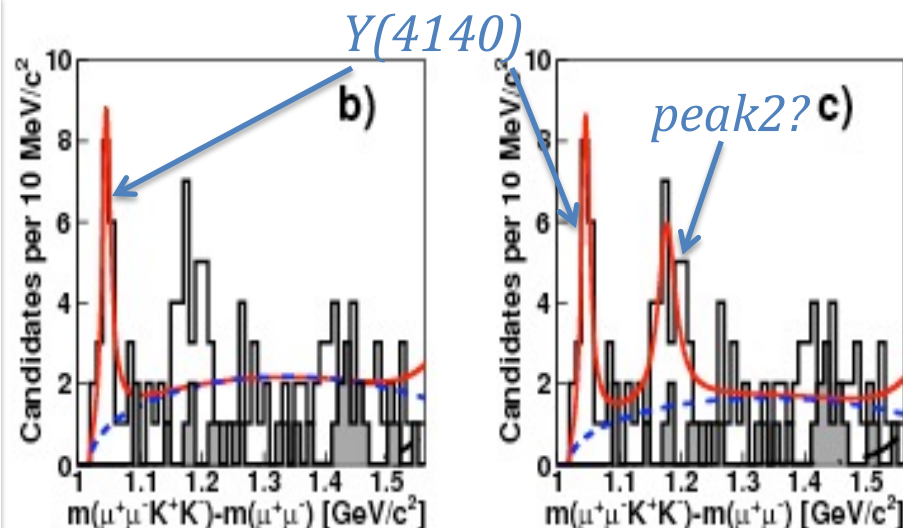
$B_s \rightarrow X(3872)\phi$, PRL 125 152001 (2020)

The Story of $Y(4140)$ —CDF(2009-10)

CDF—PRL102:242002 (2009)



Mod.Phys.Lett. A32 (2017) no.26, 1750139



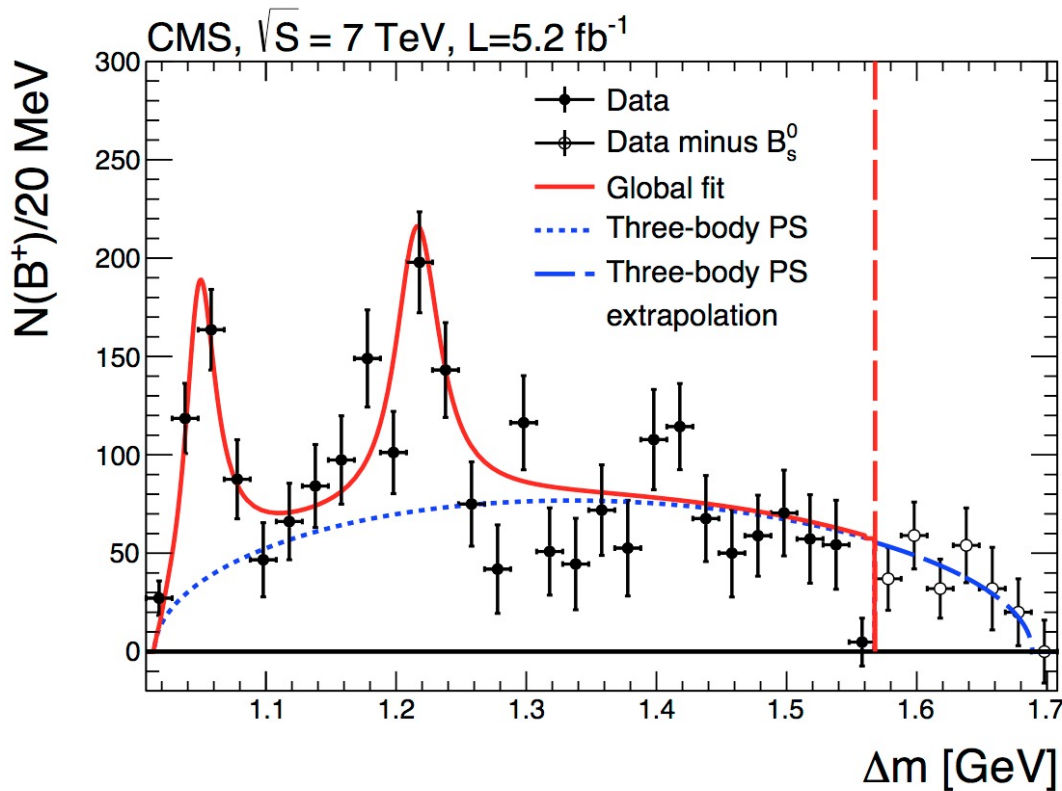
$X(4140)$ (renamed), mass-4.14 GeV, width—15 MeV

This is the first unexpected particle discovered by Tevatron!

Possible second state: mass—4.27 GeV, width—30 MeV

Experienced a long road for confirmation!

Result from CMS (2011-2014)



PLB 734 261 (2014)

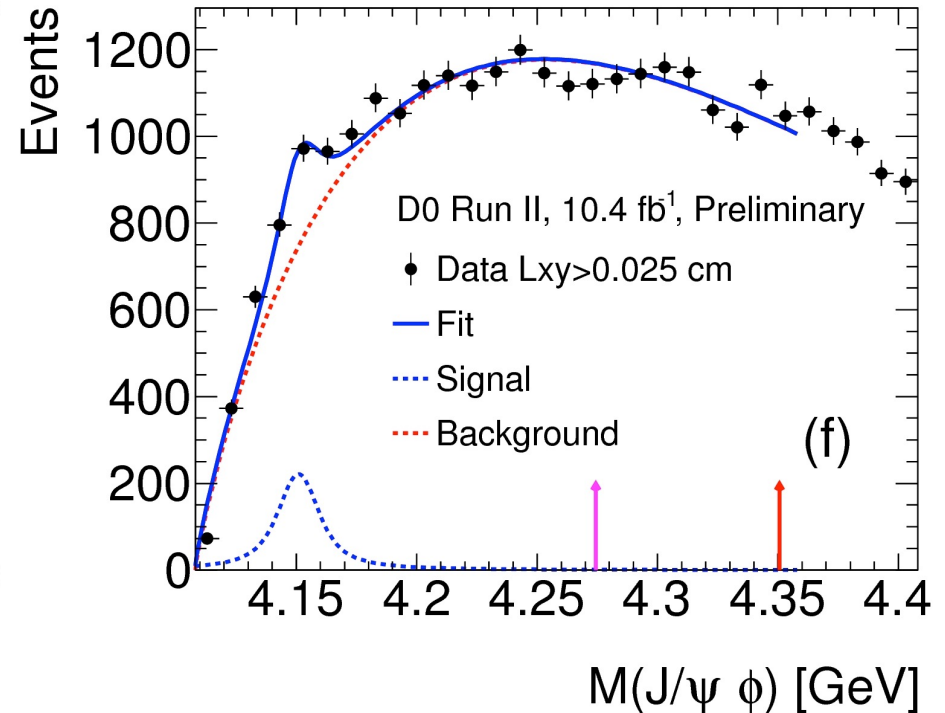
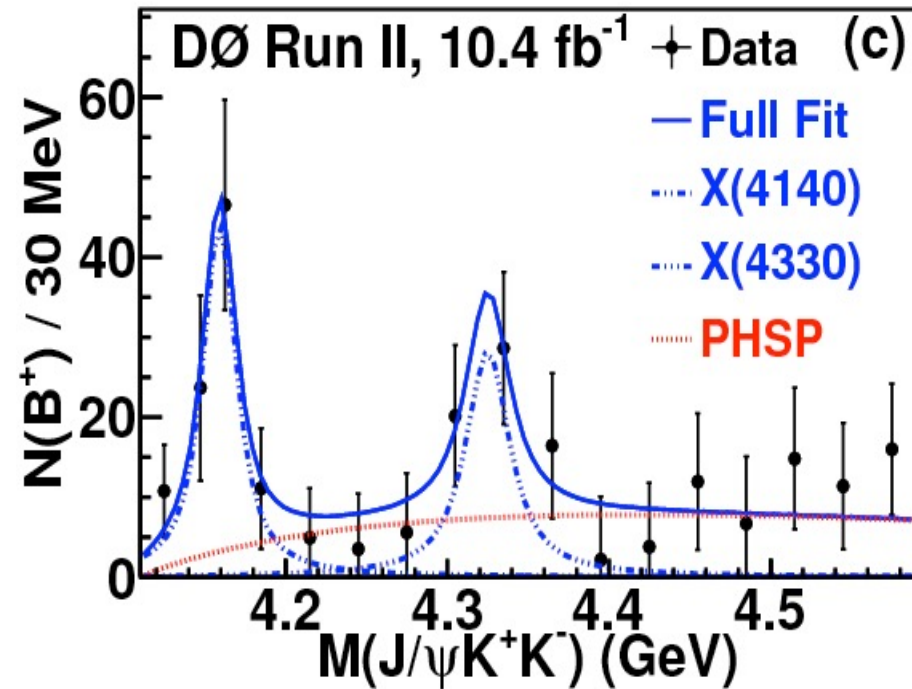
*Collaborated with Asli Yetkin
(previous Iowa student)*

- ▶ *significance greater than 5σ , confirms the existence of $Y(4140)$ for the first time from another experiment*
- ▶ *evidence for a second structure in the same mass spectrum*

$Y(4140)$ @ $D0$ (2013-2015)

PRD 89, 012004 (2014)

PRL 115(2015) no. 23, 232001

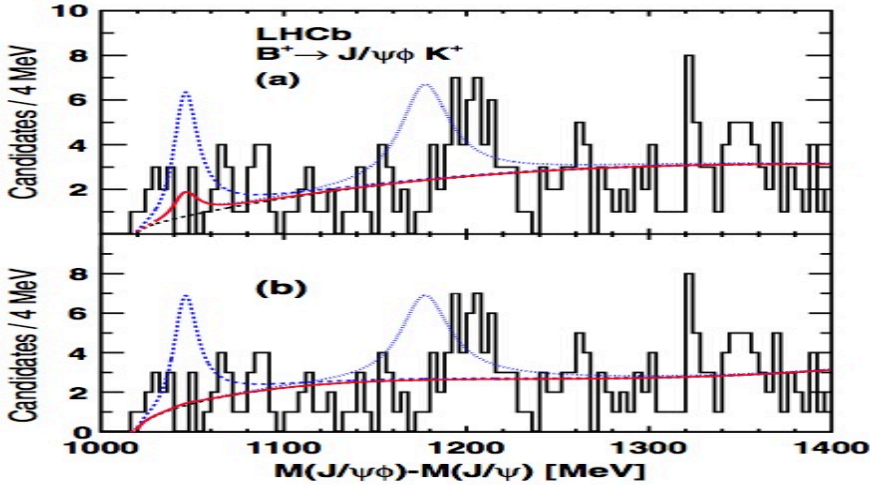


D0 provides 2nd independent confirmation of $Y(4140)$ (3.1σ)

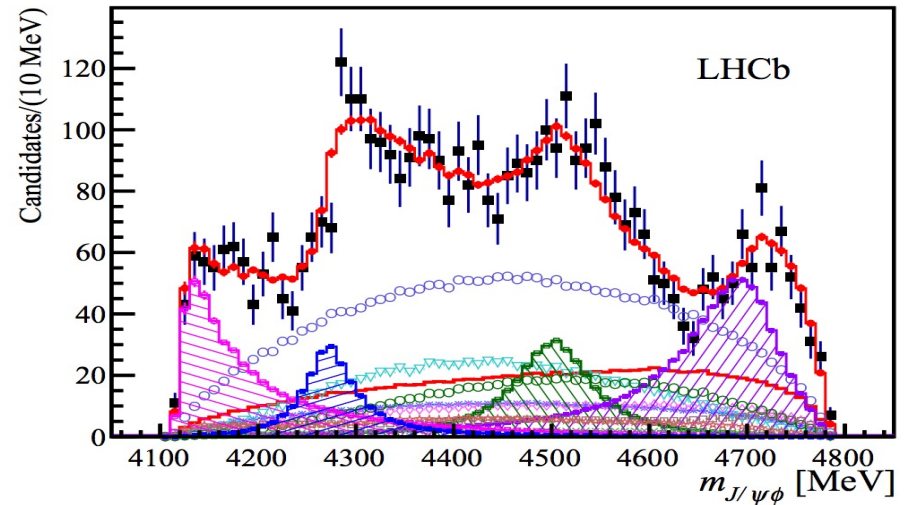
Later D0 confirmed the $Y(4140)$ using the inclusive channel (5σ)

$Y(4140)$ @LHCb--from 0 to $10+\sigma$

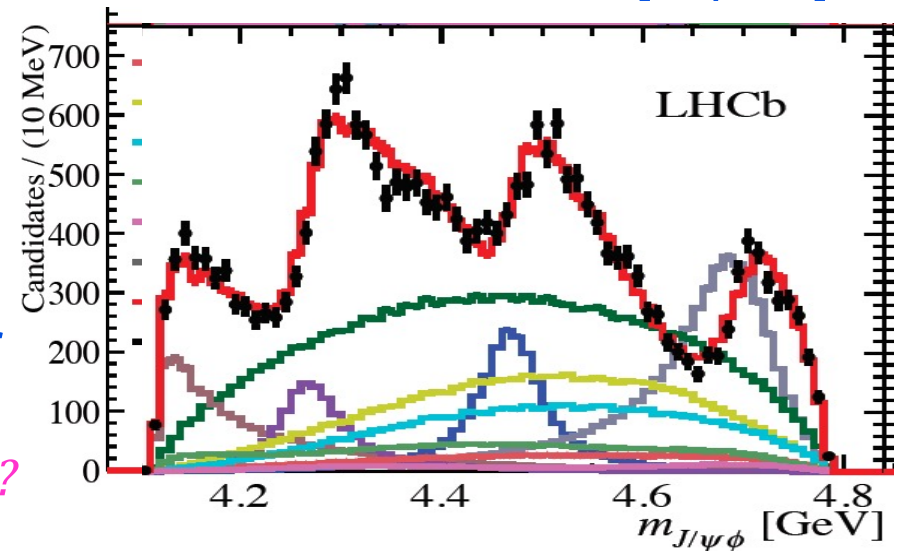
Phys. Rev. D85 (2012) 091103



PRL 118 (2017) no.2, 022003



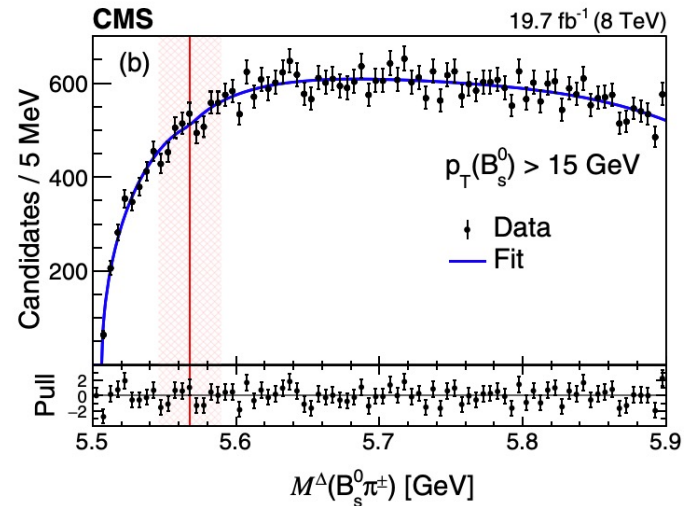
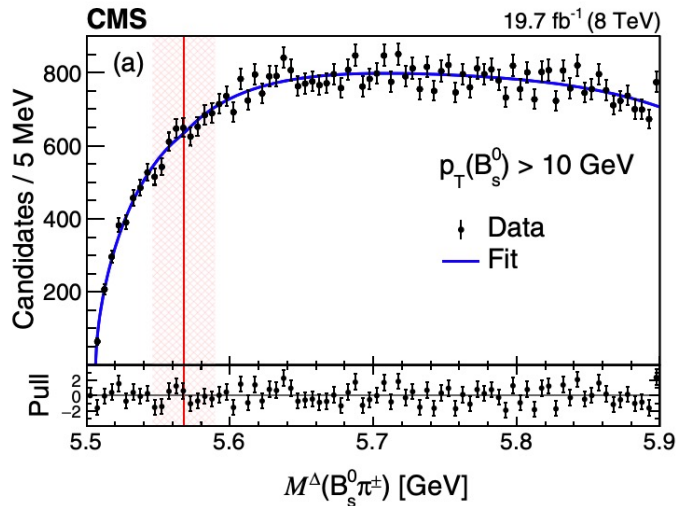
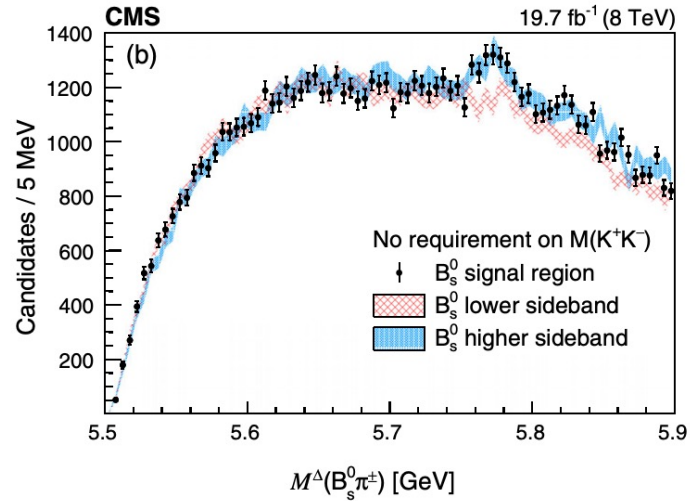
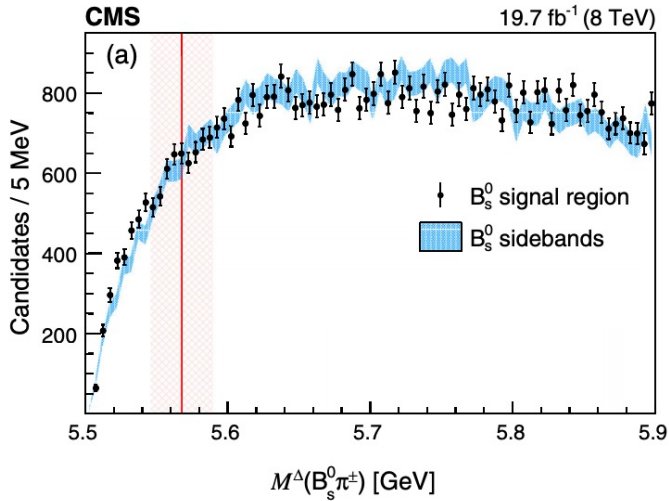
[arXiv:2103.01803v1 \[hep-ex\]](https://arxiv.org/abs/2103.01803v1)



- ▶ *LHCb data evolved unexpectedly*
- ▶ *$0 \rightarrow 10+\sigma$ with amplitude analysis*
- ▶ *Width much wider than others*
- ▶ *Many other peaks. Extraordinary results need extraordinary scrutiny*
- ▶ *CMS/Belle II/? confirm using same PWA?*

X(5568) @CMS

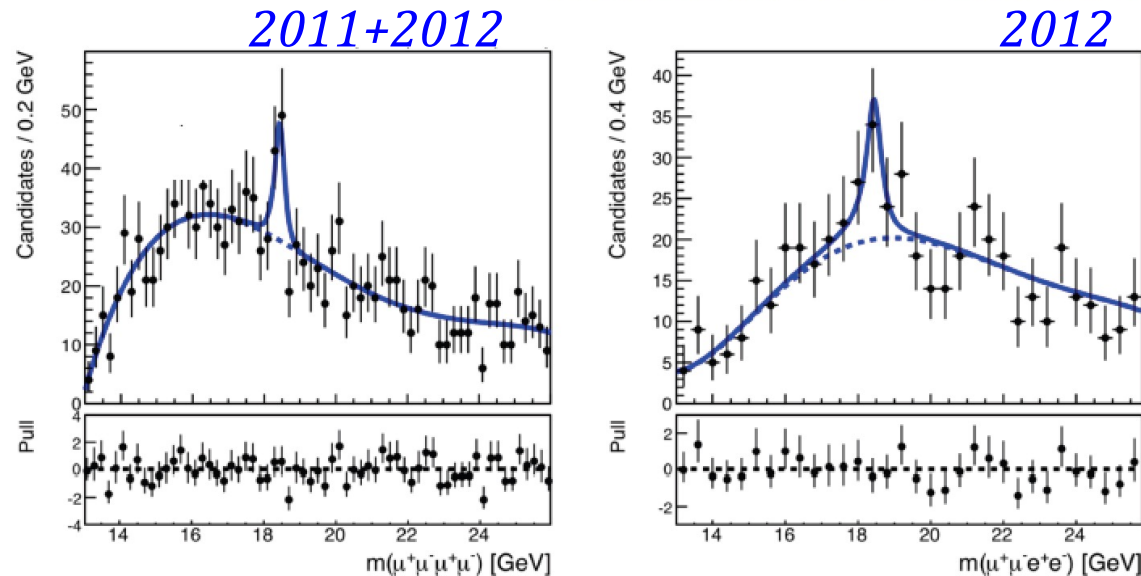
PRL 120 (2018), 202005



► CMS could not confirm X(5568)

Something interesting in CMS data

Combined Result



- Do a simultaneous fit to both channels, with fixed signal shapes but floating mass value.

- **Best mass : 18.4 ± 0.1 (stat.) ± 0.2 (syst.) GeV**

- **Local Significance: 4.86σ ($p_{\text{value}} = 5.8 \times 10^{-7}$)**

- In order to calculate global significance, Look-Elsewhere-Effect must be taken into account. Lots of toy MC generations are required, not an efficient method.
- Global significance is calculated using Gross-Vitells method which is used in Higgs discovery.

[Eur.Phys.J.C70:525-530,2010](http://arxiv.org/abs/1003.5454)

- **The returned global significance was 3.6σ .**

12

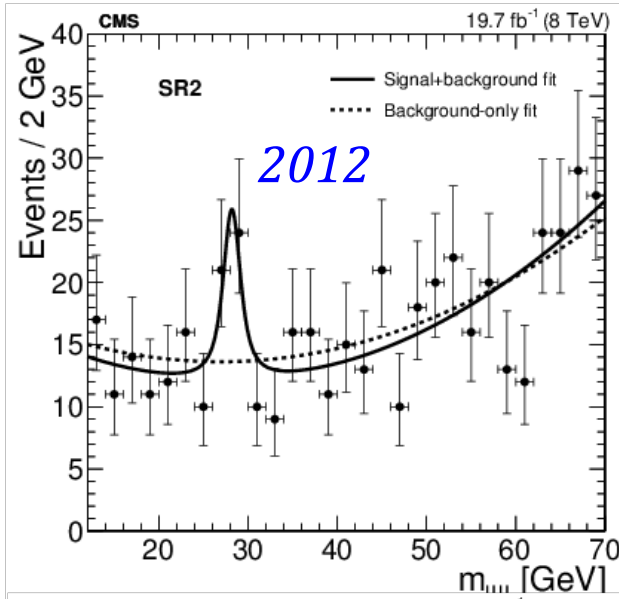
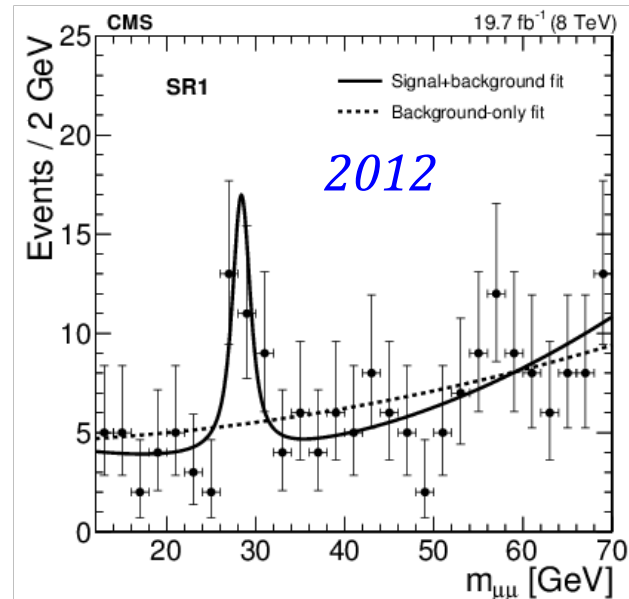
Taken from: <http://meetings.aps.org/Meeting/APR18/Session/U09.6>

How about the full run II data and future data?

If true, can be a breakthrough in QCD, or even something more exciting

Dimuon result from CMS

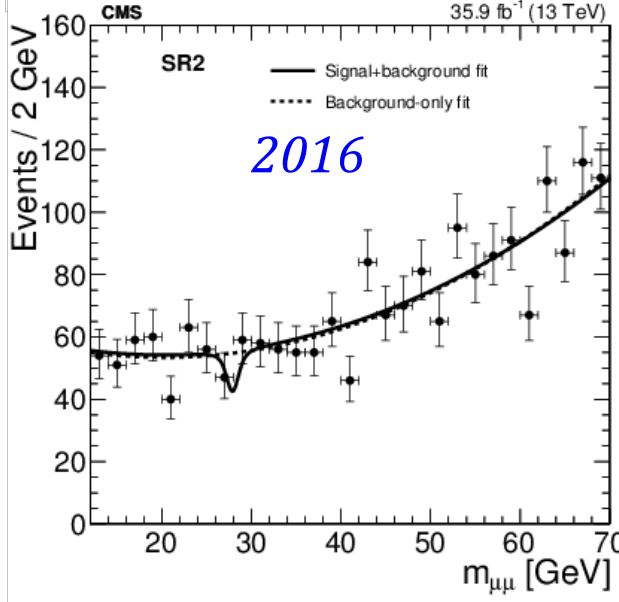
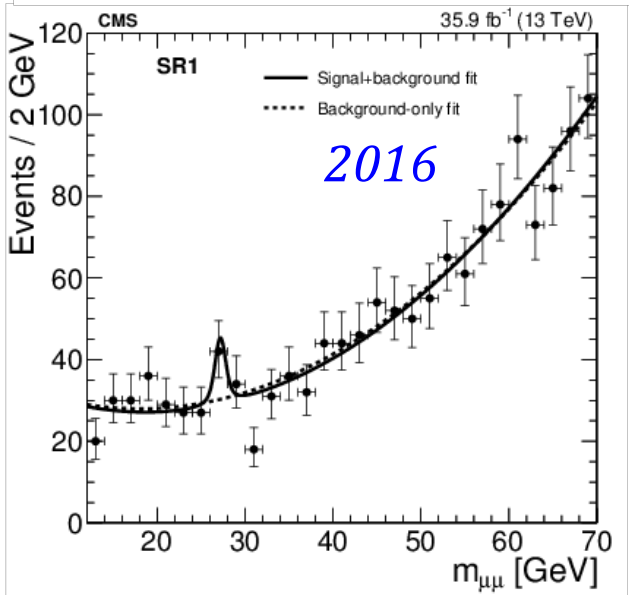
[arXiv:1808.01890](https://arxiv.org/abs/1808.01890) [hep-ex]
accepted by JHEP



*ATLAS does not see
Same sensitivity?*

How about 2017?

How about 2018?

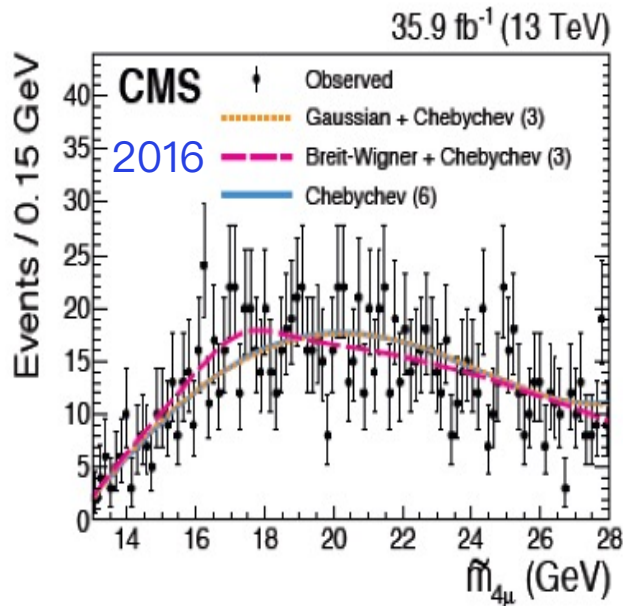
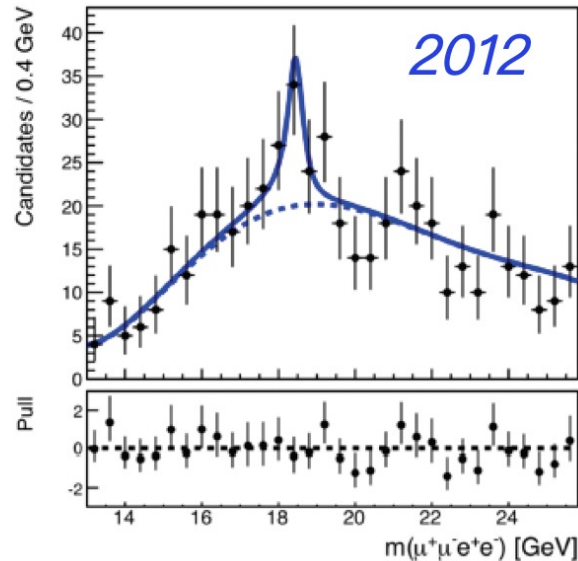
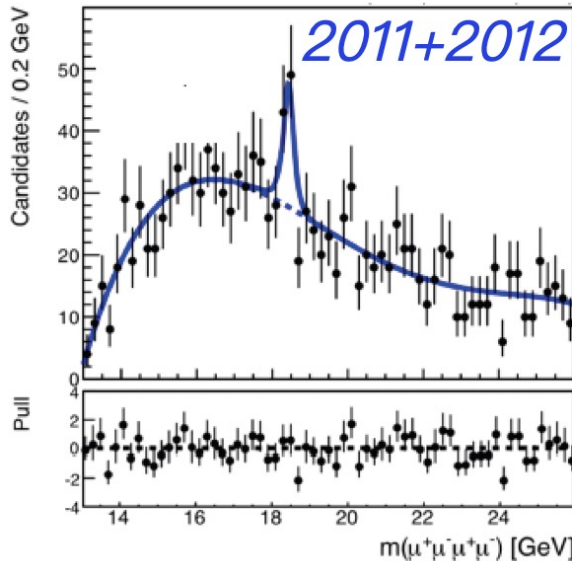


If true → BSM

An exploration in the low mass region at LHC

What is going on?

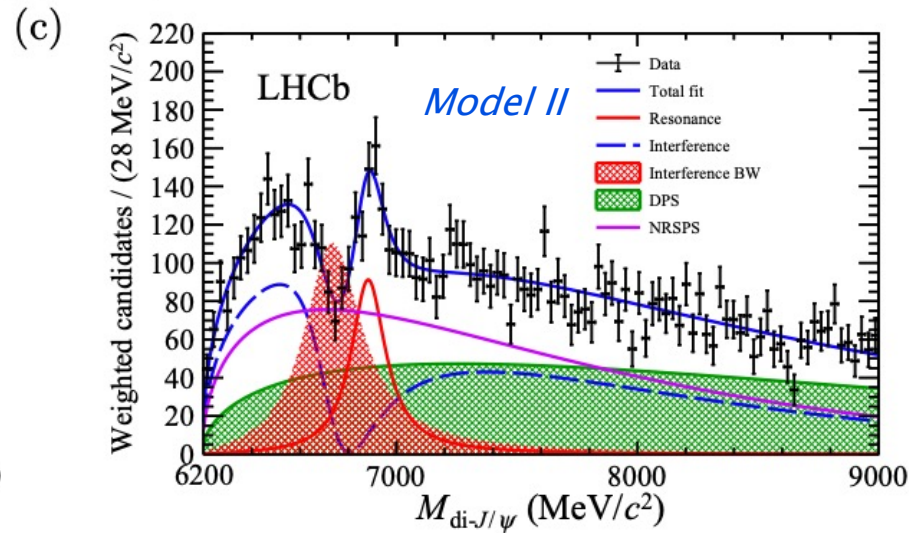
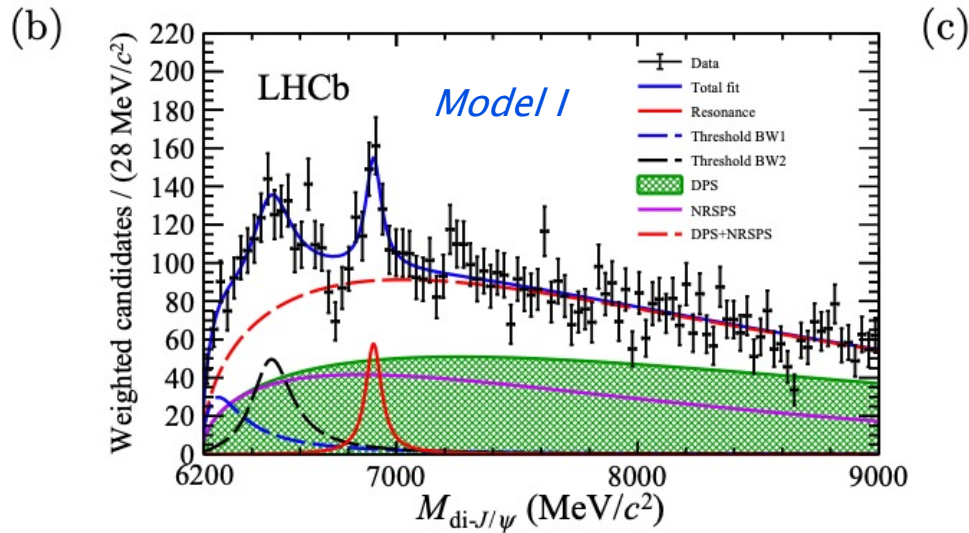
<http://meetings.aps.org/Meeting/APR18/Session/U09.6>



- Controversial so far
- 2017&2018 data to be analyzed
- Run III data to be collected
- Do not know how CMS data evolves

$X(6900)$ @LHCb

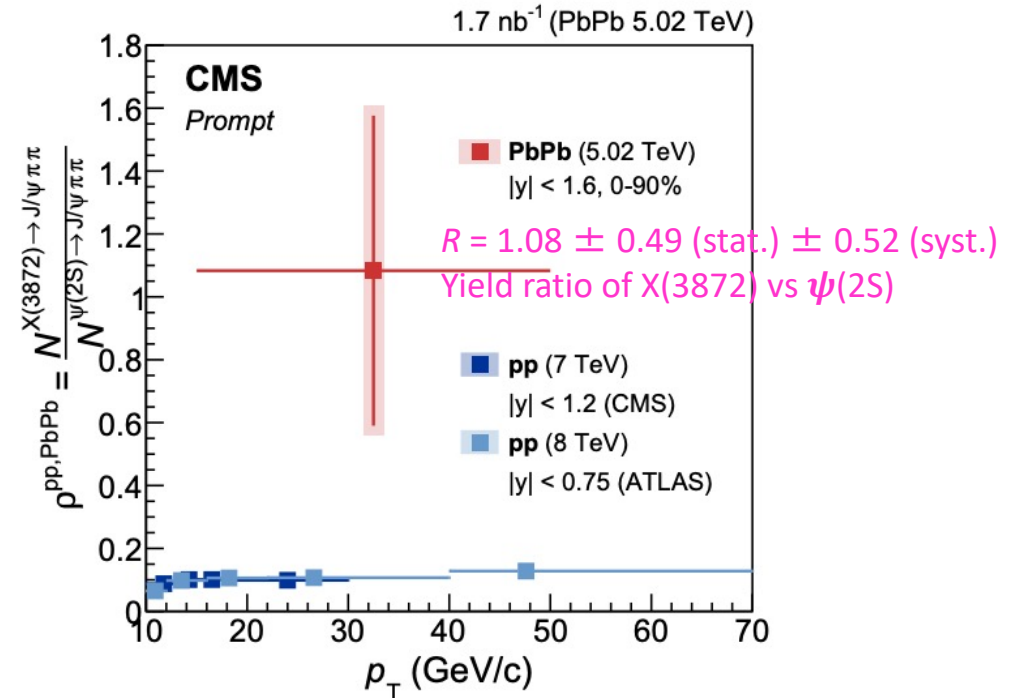
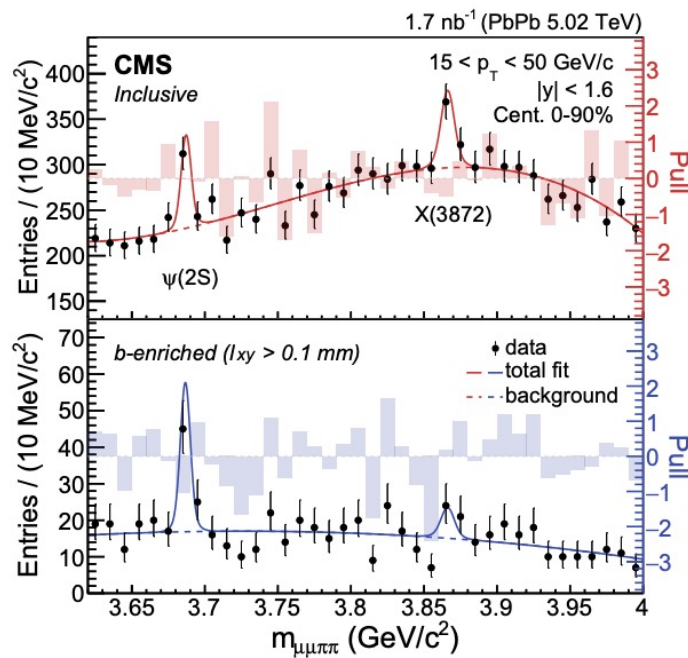
Science Bulletin 65 (2020) 1983



- Caused new wave, especially in China
- Unclear what it is
- Scream for “confirmation”
- CMS/ATLAS?

X(3872) @CMS PbPb

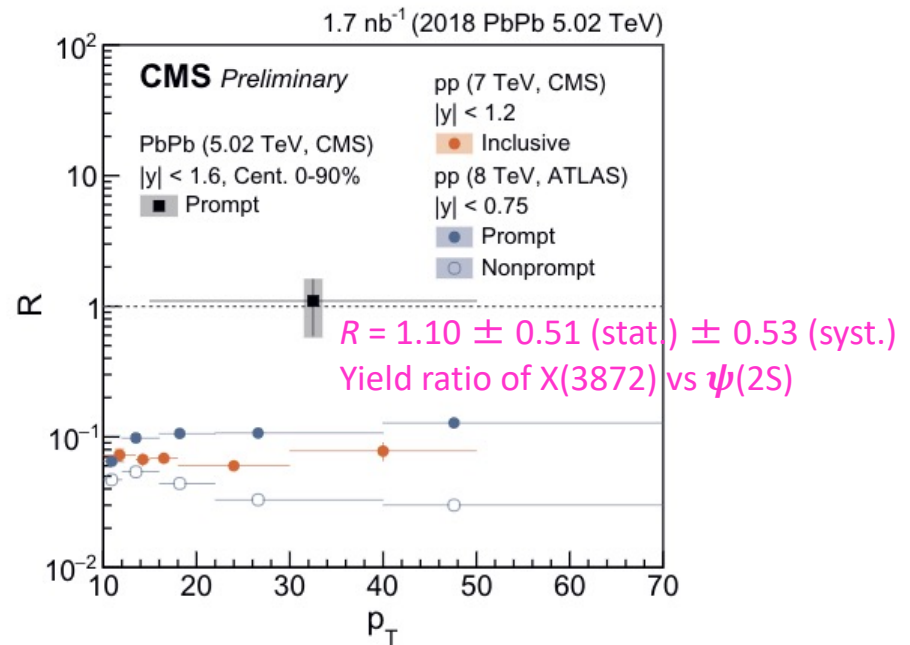
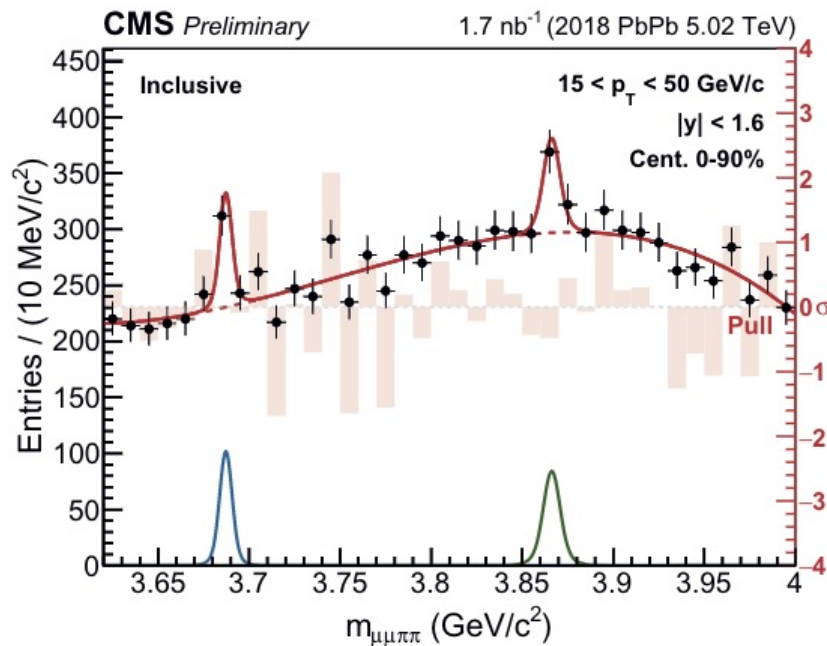
arXiv:2102.13048v1 [hep-ex]



- Large R is observed in PbPb data; prompt dominate
- [X\(6900\) @PbPb? arXiv:2009.10319 \[hep-ph\]](#)
- CMS is the best place to look for:
vs ALICE/ATLAS/LHCb, BNL experiments

$X(3872)$ @CMS PbPb

Nuclear Physics Volume 1005, January 2021, 121781



- Large R is observed in PbPb data
- [X\(6900\) @PbPb? arXiv:2009.10319 \[hep-ph\]](https://arxiv.org/abs/2009.10319)
- CMS is the best place to look for:
vs ALICE/ATLAS/LHCb, BNL experiments

总结和讨论

- 粒子物理领域对CMS有所期待
- CMS中国组目前处于前沿
 - 近期可望取得一些结果
 - 后期展望前景明亮，低动量轻子CMS有优势
 - 触发至关重要
 - 期待更多理论指导
- 可望扩展至重粒子领域

谢谢!