CMS与奇特强子

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第七届XYZ粒子研讨会, 5.15, 2021

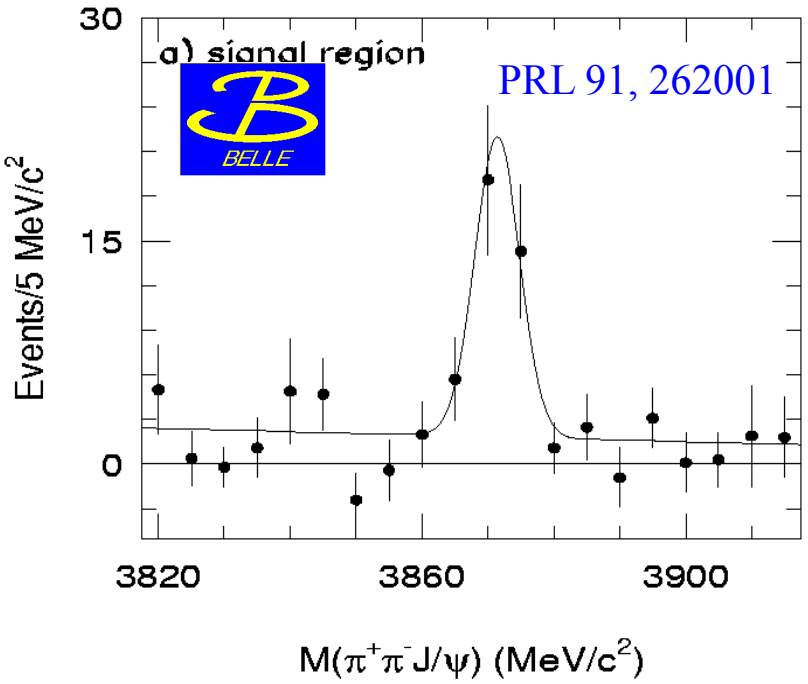
XYZ“困惑”—个人观点

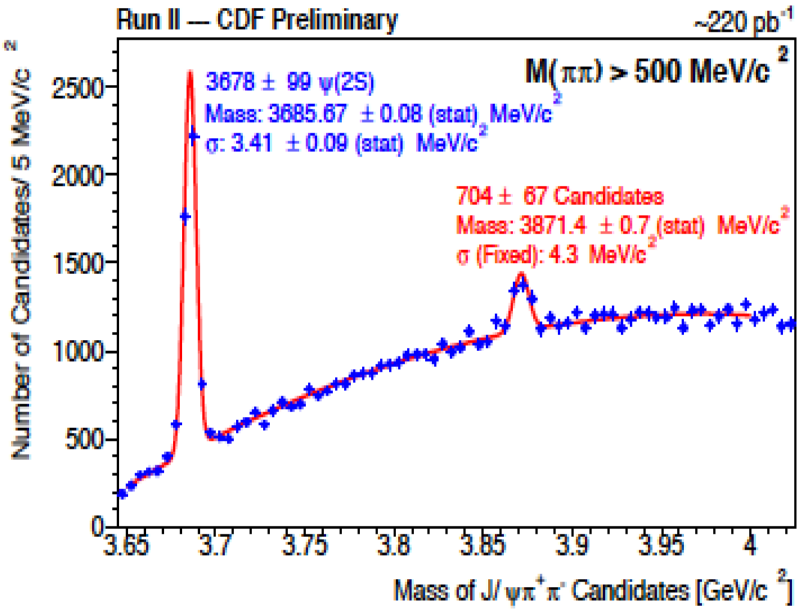
- 我们已发现几十个XYZ例子：
  --大部分粒子质量在某种阈值附近，稍微大一点，有较宽的宽度
  --部分粒子带有电荷，有别于夸克偶素(quarkonium)
  --多种解释：分子态，四夸克态等共振态类型
  阈值行为的某种形态(不能排除)
  --X(3872)很窄，阈值或阈值之下，不能排除粲偶素(ccbar)的可能

- 如何在实验上更进一步?
  --能否找到不在阈值附近的态？阈值之下或之上
  --能否找到窄的粒子态?
  --能否在全重味有更多的收获?
  --能否更有效的与理论合作?

- 理论与实验从来没有离开过

X(3872) (Belle)--2003





2017 Laureates

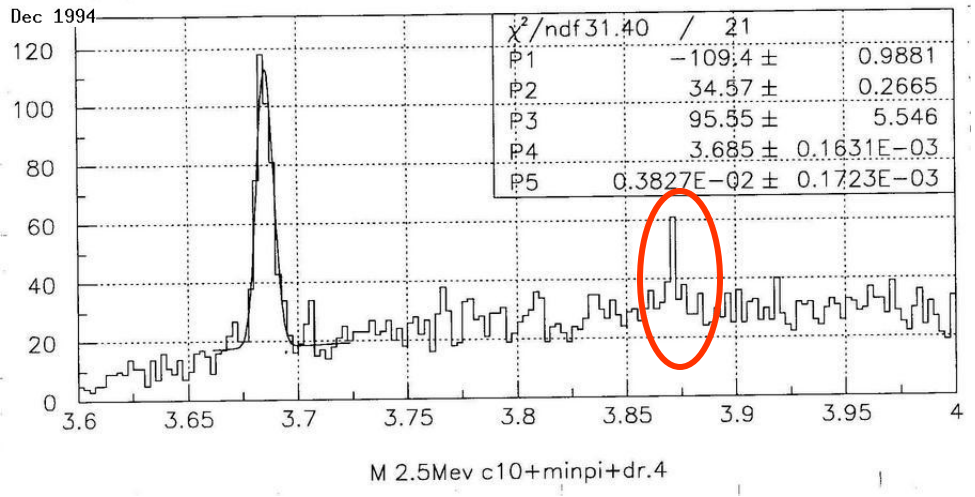
"…The X(3872) was discovered by Dr. Sookyung Choi and Dr. Stephen Olsen with their colleagues in the Belle experiment among the final states of the decay of B mesons. The X(3872) was confirmed by seven other experimental groups thereafter and is the first example of a new type of XYZ meson and the most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

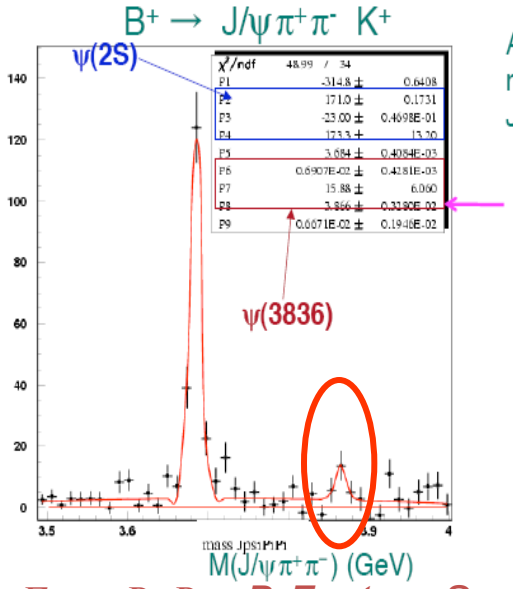
2017 Korean Ho-Am Science Prize

Hints before the discovery of X(3872)→J/ψπ⁺π⁻

CDF internal, 1994



BaBar internal, 2003

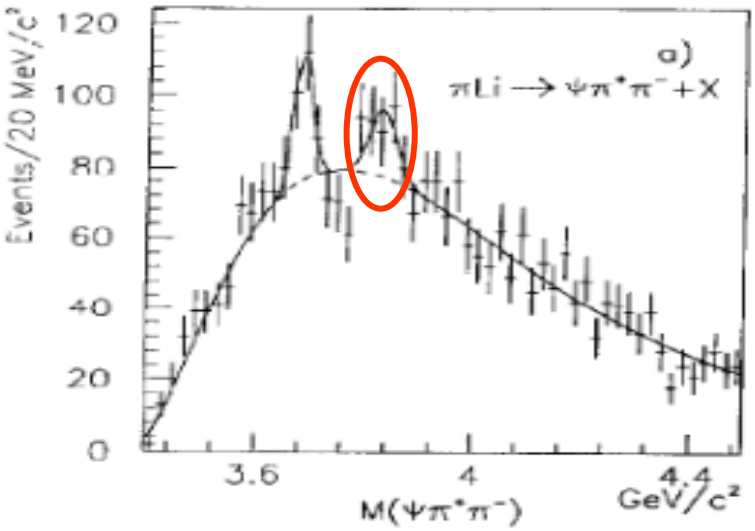


AWG meeting June 2003
motivation: background to $J/\psi K_L$; test factorization…

Mass = 3866 ±6

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

E705, PRD 50, 4258 (1994)
E705 saw ψ(3836) (2^{-+}) in 1994, 3.836 ±0.013 GeV
PRL 115 011803, PRL 111 032001

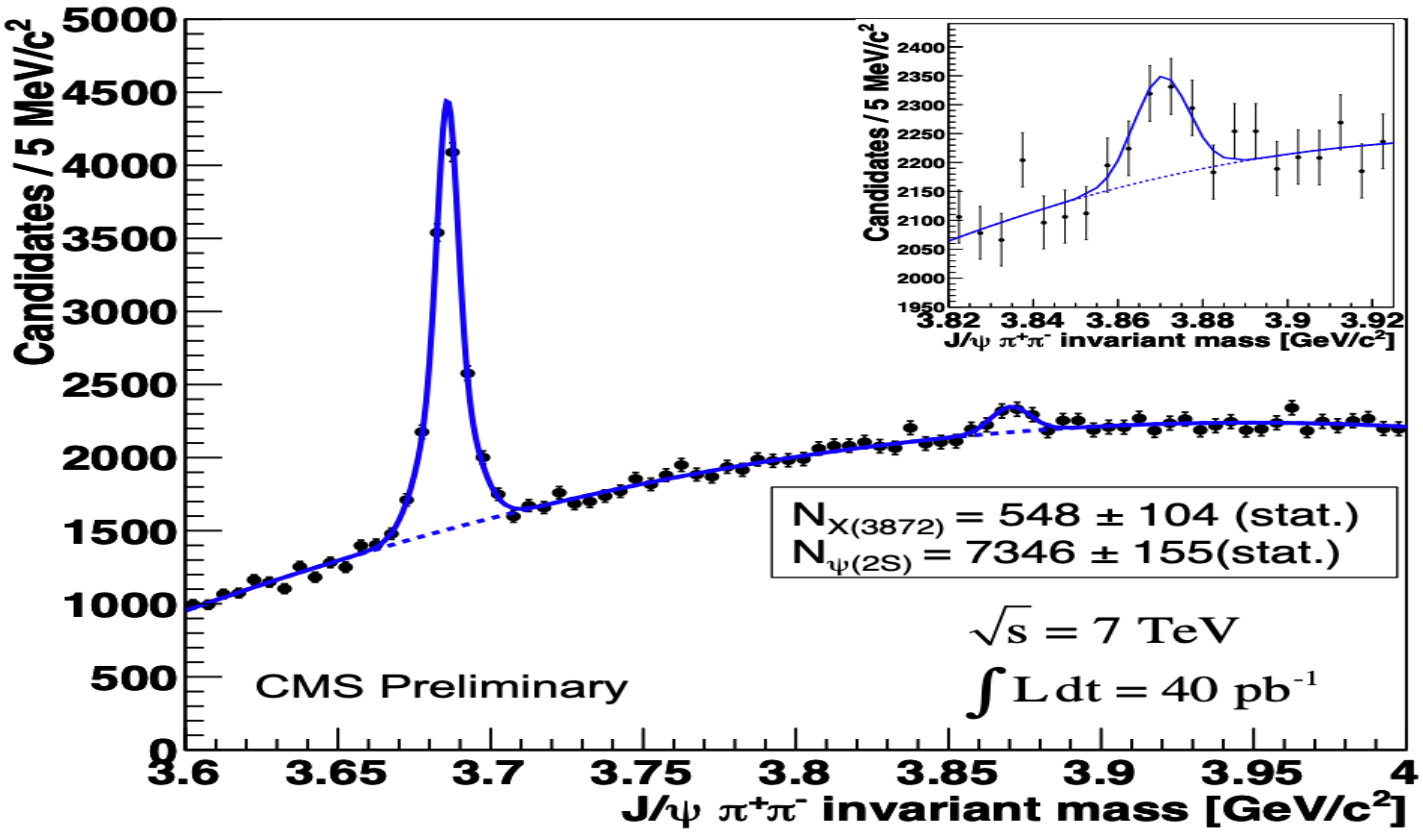


***CDF saw a hint in 1994**, unpublished*
BaBar saw a hint in 2003, unpublished

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…

X(3872) at CMS--2010



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

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

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:

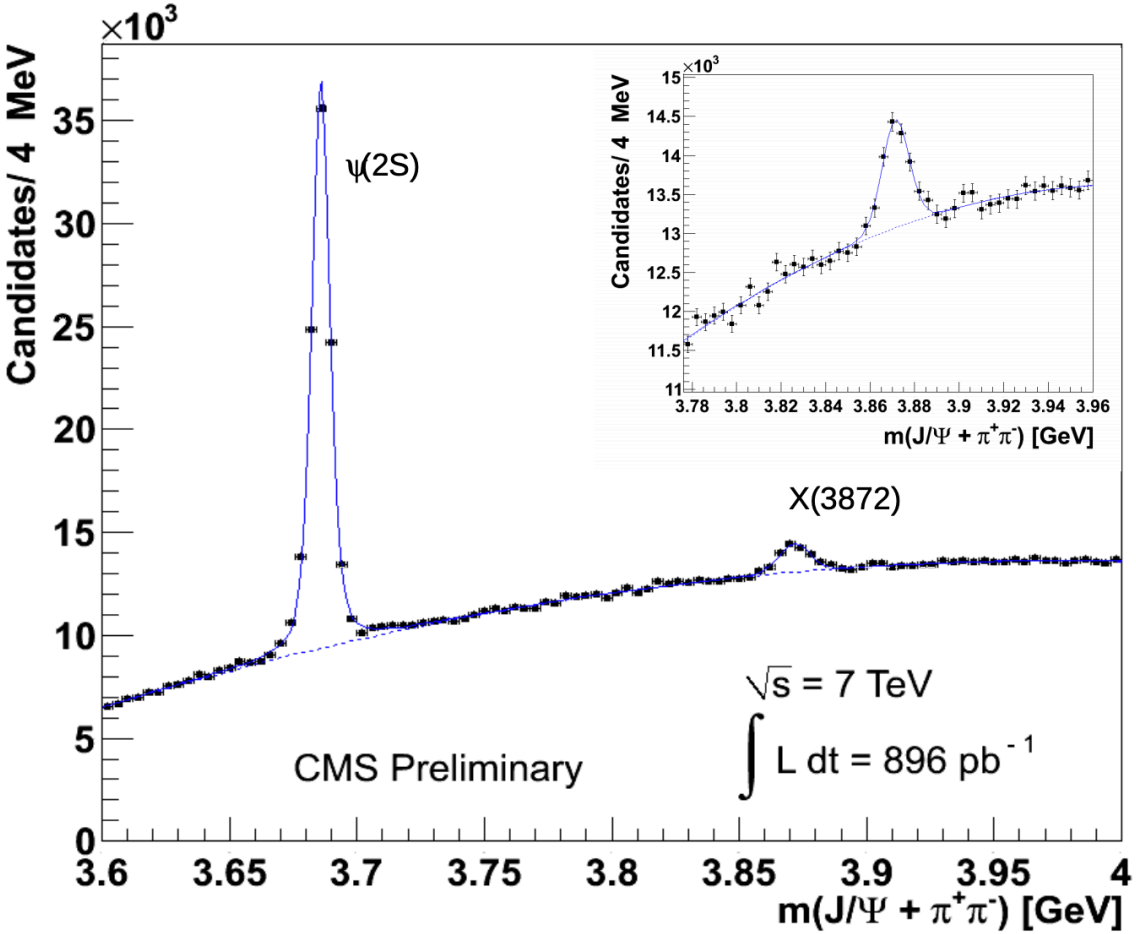
ψ(2S) Voigtian:
μ = 3685.90 ± 0.02 MeV
σ = 3.2 ± 0.1 MeV
γ = 0.00283 ± 0.00005
N = 72594 ± 518

X(3872) Gaussian:
μ = 3871.5 ± 0.5 MeV
σ = 6.1 ± 0.4 MeV
N = 5303 ± 341

Chebychev Polynomial:
c1 = 0.321 ± 0.002
c2 = -0.091 ± 0.002

χ^2/ndf = 0.99

PDG mass values:
ψ(2S) = 3686.09 ± 0.04 MeV
X(3872) = 3871.57 ± 0.25 MeV



$R =$ $).009(syst.)$

The first LHC experiment re-discovered X(3872), CMS DP 2011/009

X(3872) at CMS--2013

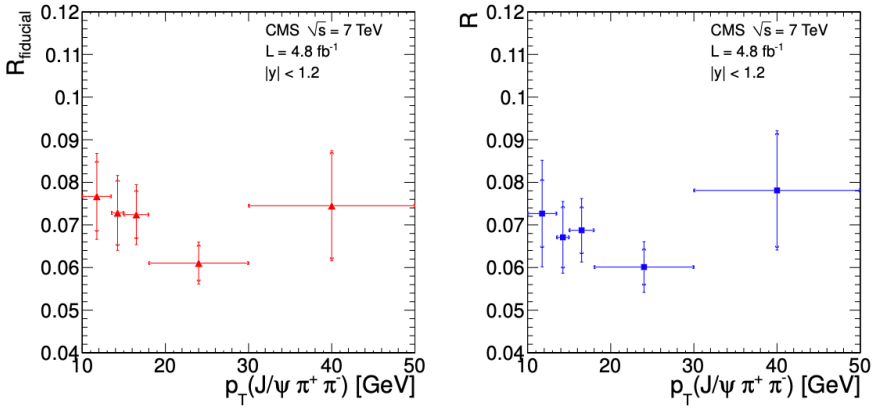
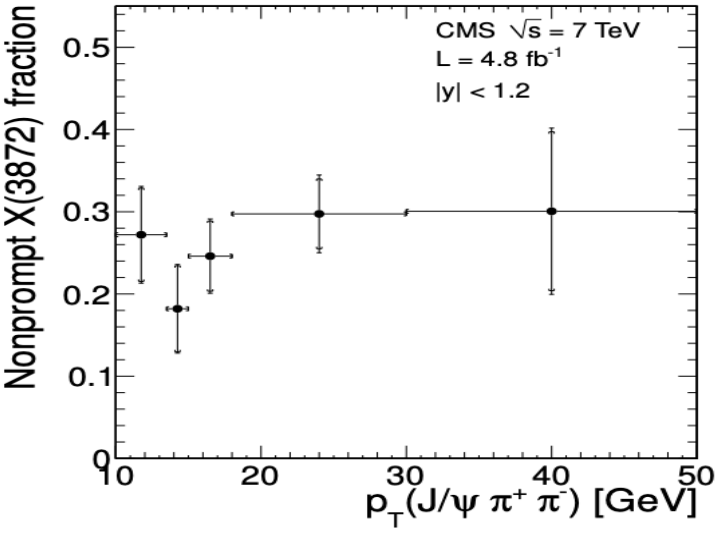
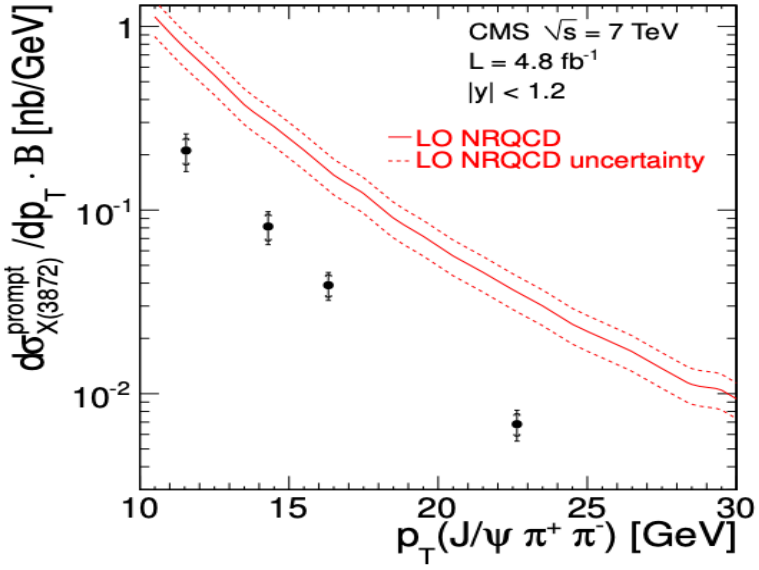
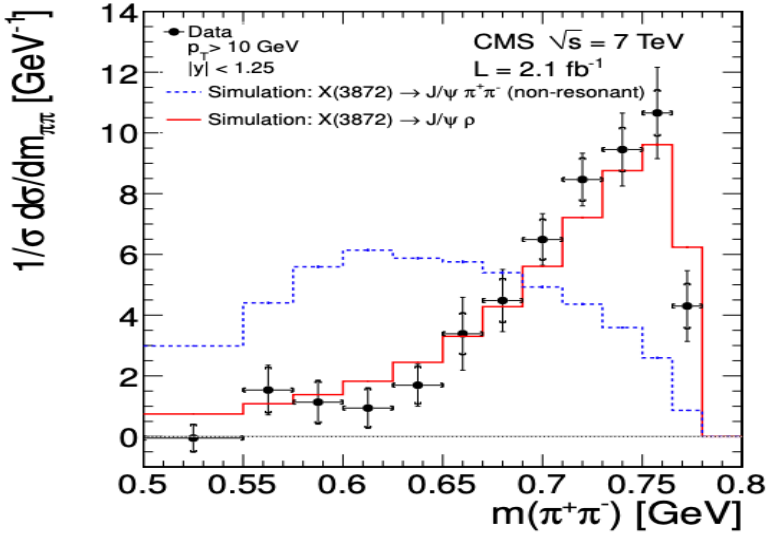


Figure 3. Ratios of the X(3872) and $\psi(2S)$ cross sections times branching fractions, without ($R_{\rm fiducial}$, left) and with (R, right) acceptance corrections for the muon and pion pairs, as a function of $p_{\rm T}$. The inner error bars indicate the statistical uncertainty and the outer error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

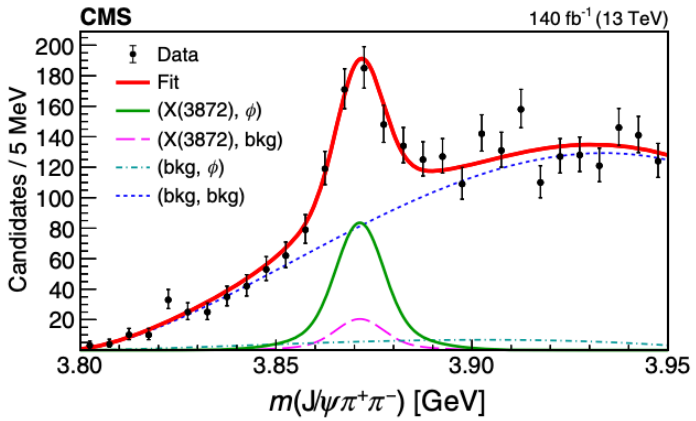


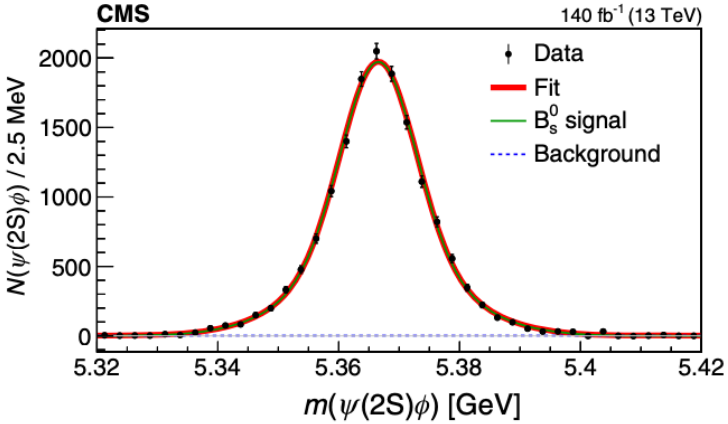


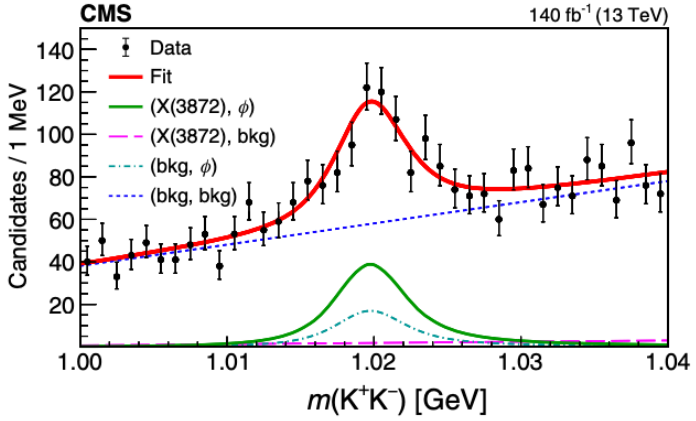


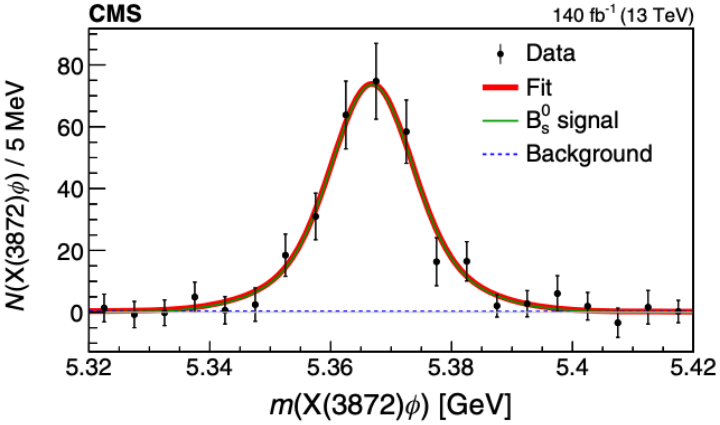
Detailed measurements, JHEP 04 (2013) 154

X(3872) at CMS--2020









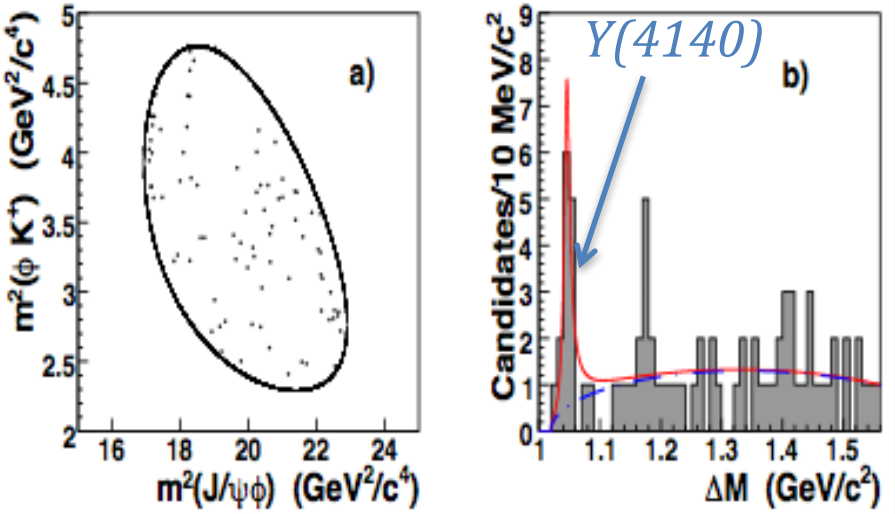
$$R \equiv \frac{\mathcal{B}[B_s^0 \to X(3872)\phi]\mathcal{B}[X(3872) \to J/\psi\pi^+\pi^-]}{\mathcal{B}[B_s^0 \to \psi(2S)\phi]\mathcal{B}[\psi(2S) \to J/\psi\pi^+\pi^-]}$$
$$= \frac{N[B_s^0 \to X(3872)\phi]}{N[B_s^0 \to \psi(2S)\phi]} \frac{\epsilon_{B_s^0 \to \psi(2S)\phi}}{\epsilon_{B_s^0 \to X(3872)\phi}}.$$

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

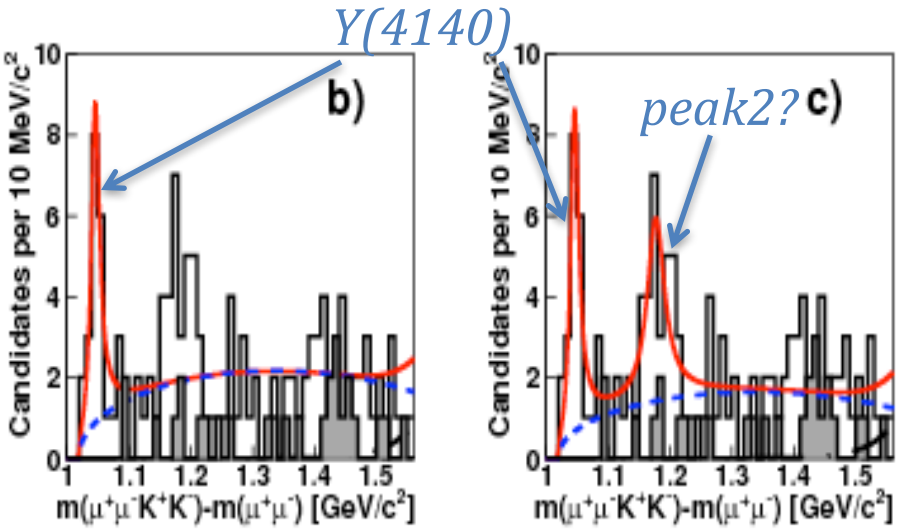
Bs→X(3872)ϕ, PRL 125 152001 (2020)

The Story of Y(4140)—CDF(2009-10)

CDF—PRL102:242002 (2009)



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

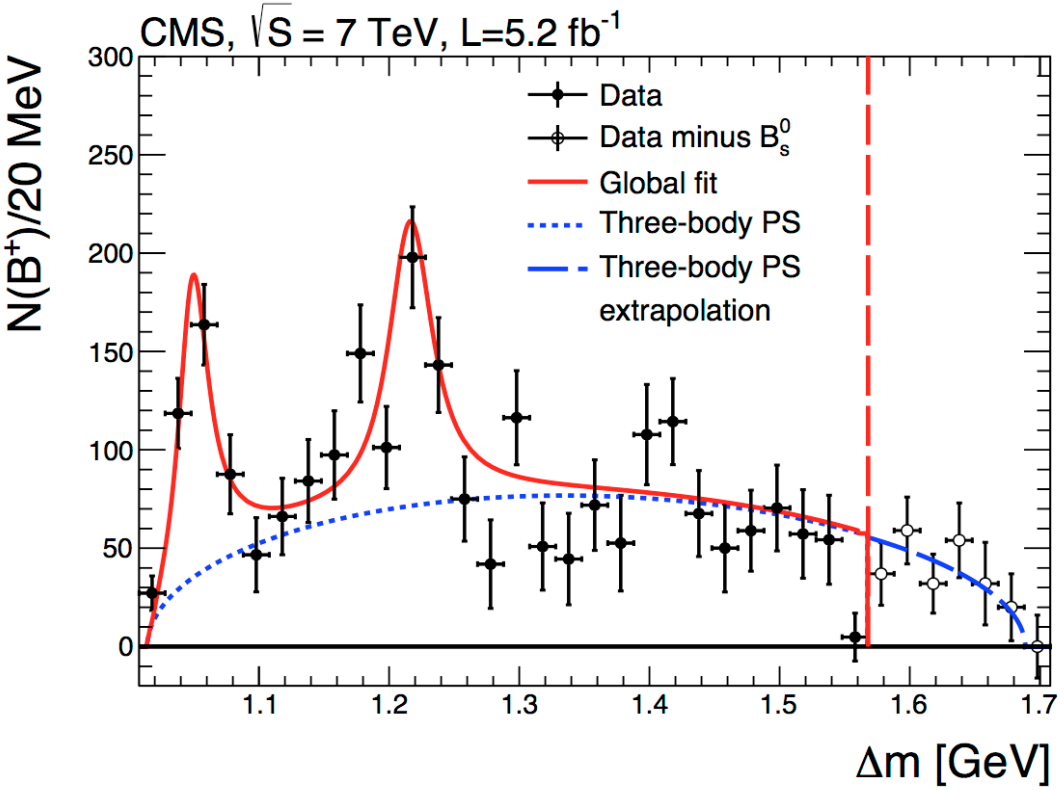


X(4140) (renamed), mass-4.14 GeV, width—15 MeV

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)



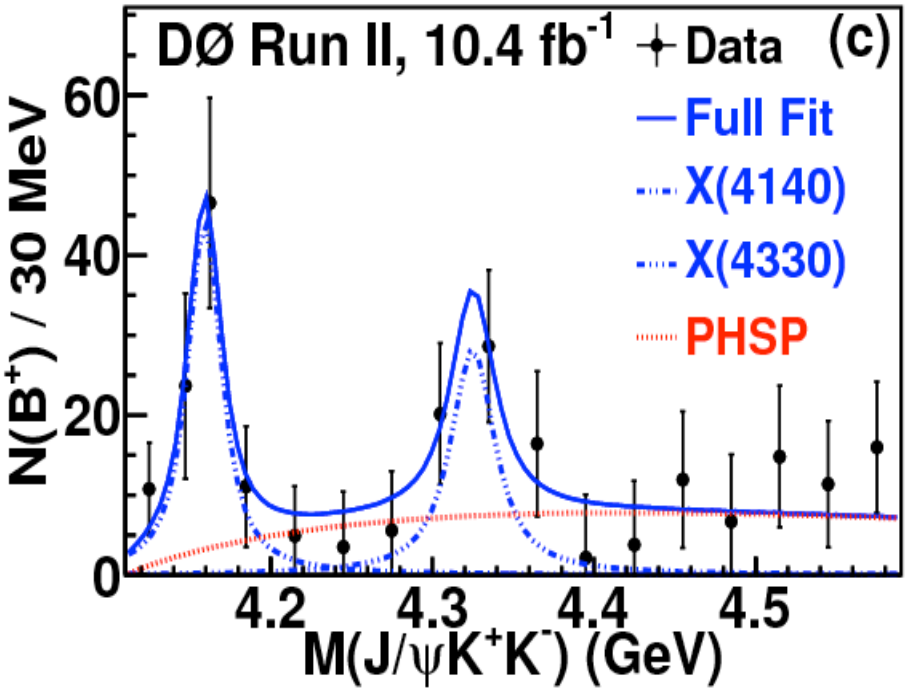
PLB 734 261 (2014)

Collaborated with Asli Yetkin *(previous Iowa student)*

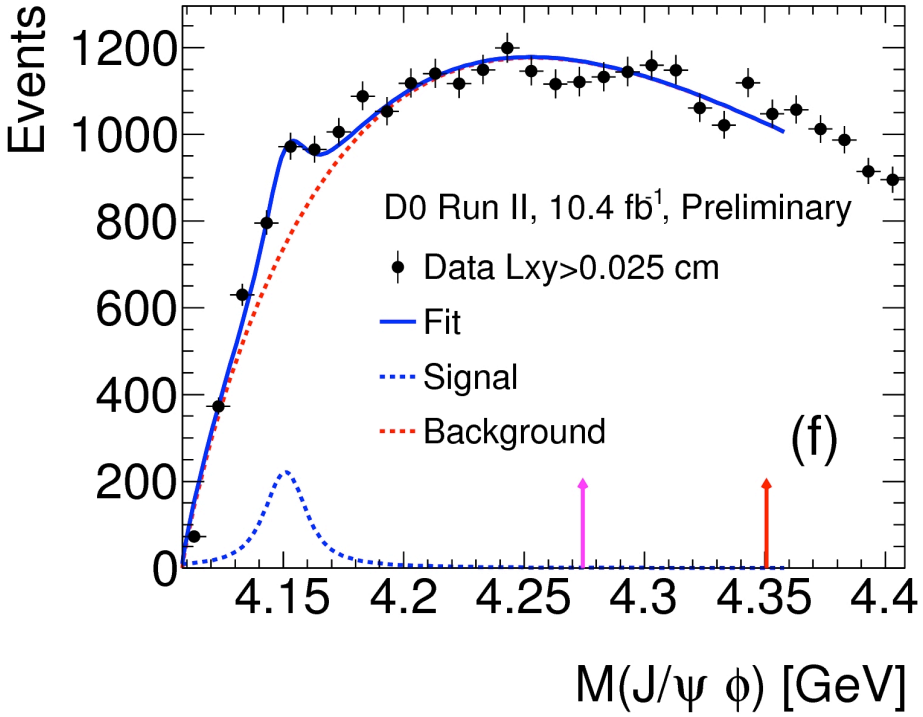
- *significance greater than 5σ, confirms the existence of Y(4140) for the first time from another experiment*
- *evidence for a second structure in the same mass spectrum*

Y(4140) @ D0 (2013-2015)

PRD 89, 012004 (2014)



PRL 115(2015) no. 23, 232001

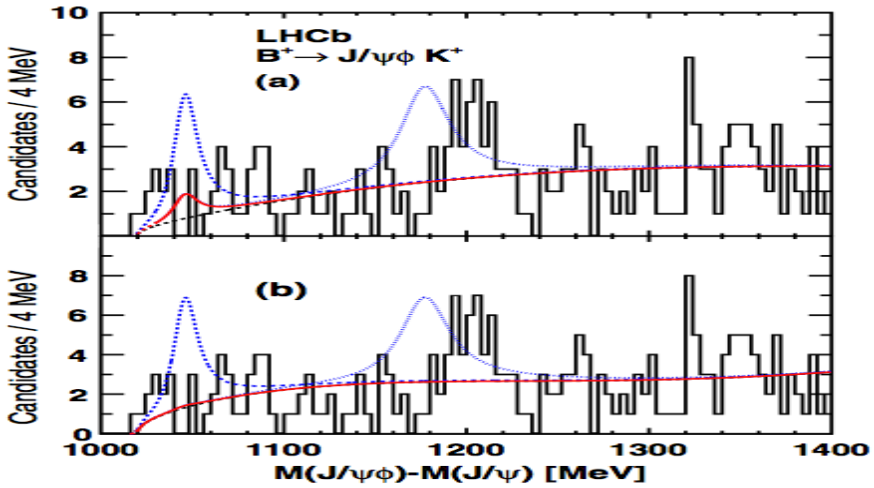


D0 provides 2nd independent confirmation of Y(4140) (3.1σ)

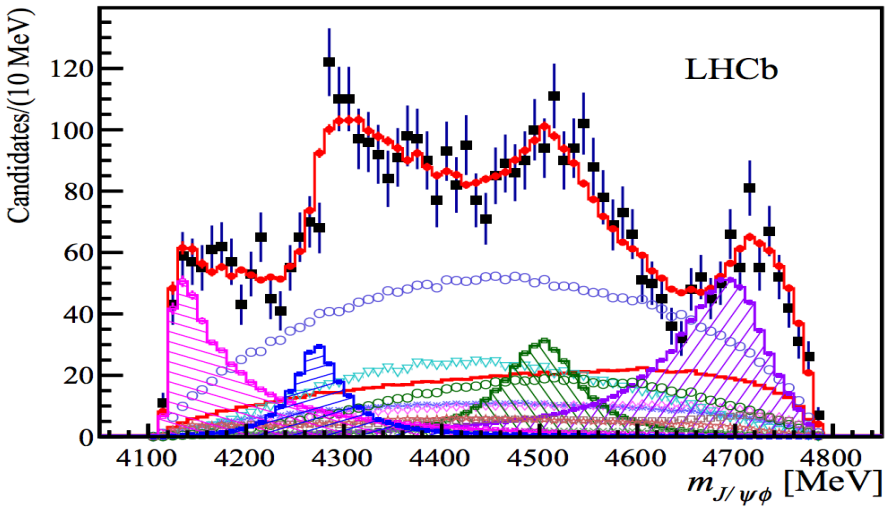
Later D0 confirmed the Y(4140) using the inclusive channel (5σ)

Y(4140) @LHCb--from 0 to 10+σ

Phys. Rev. D85 (2012) 091103

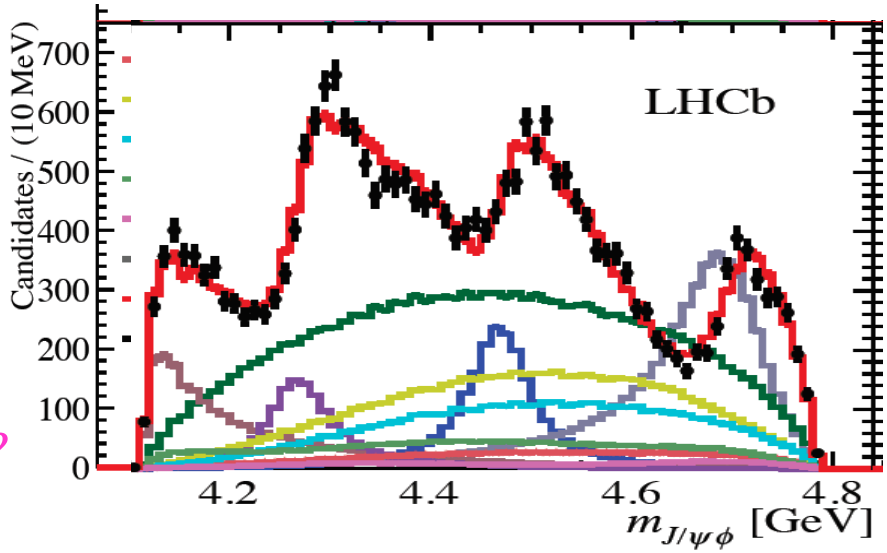


PRL 118 (2017) no.2, 022003



- *LHCb data evolved unexpectedly*
- *0→10+**σ** with amplitude analysis*
- *Width much wider than others*

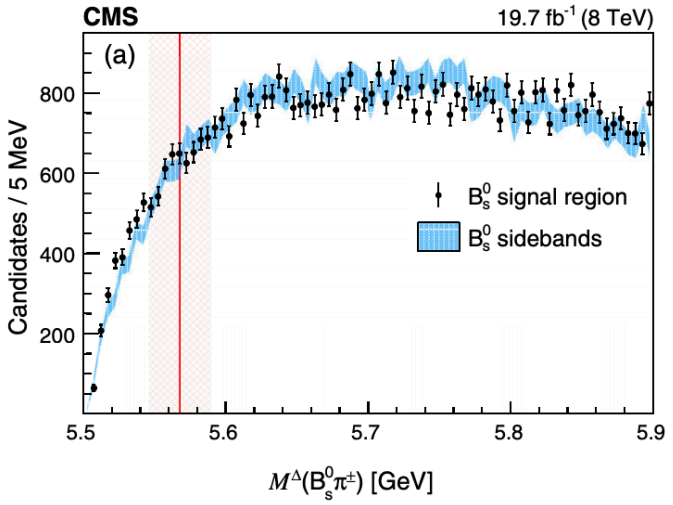
arXiv:2103.01803v1 [hep-ex]

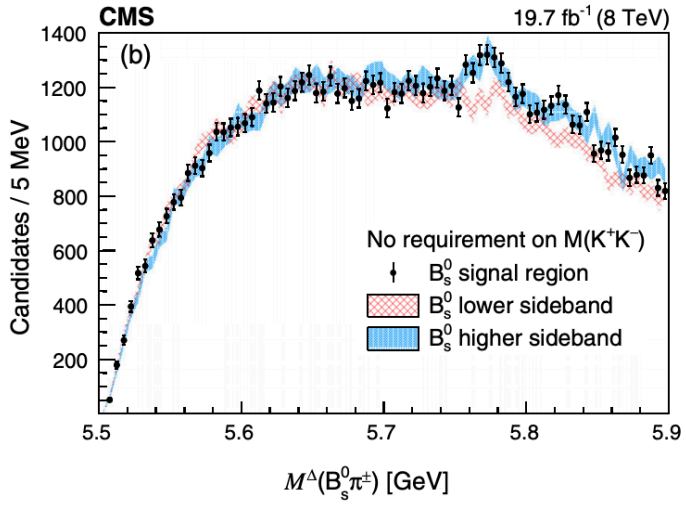


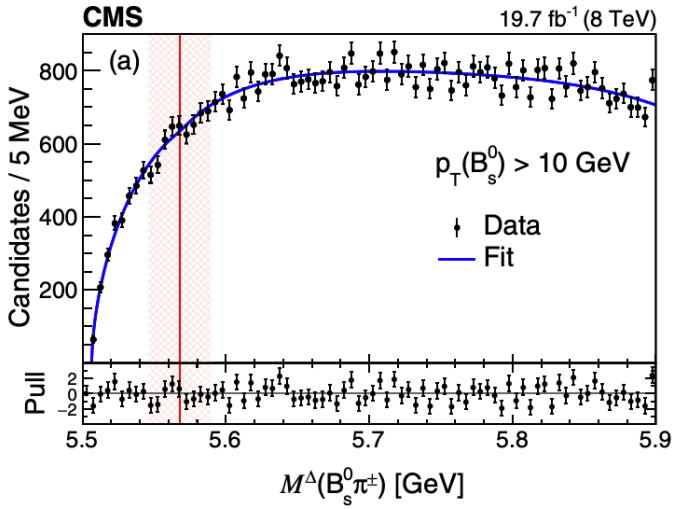
- *Many other peaks. Extraordinary results need extraordinary scrutiny*
- *CMS/Belle II/? confirm using same PWA?*
- *No charge, no isospin, heavy,"narrow"?...*

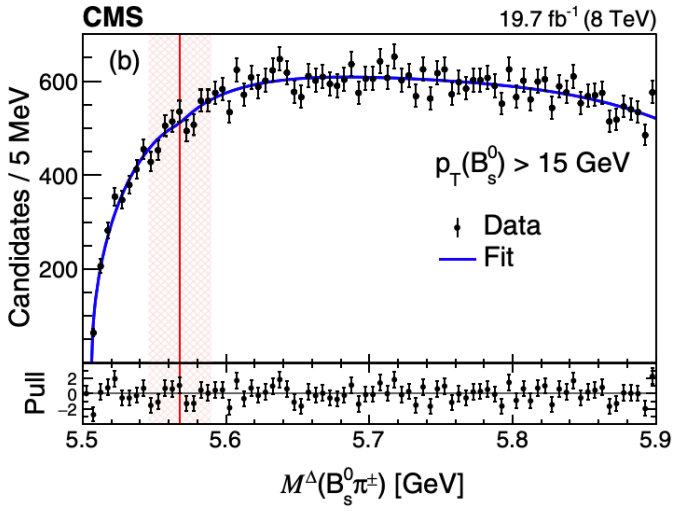
X(5568) @CMS

PRL 120 (2018), 202005







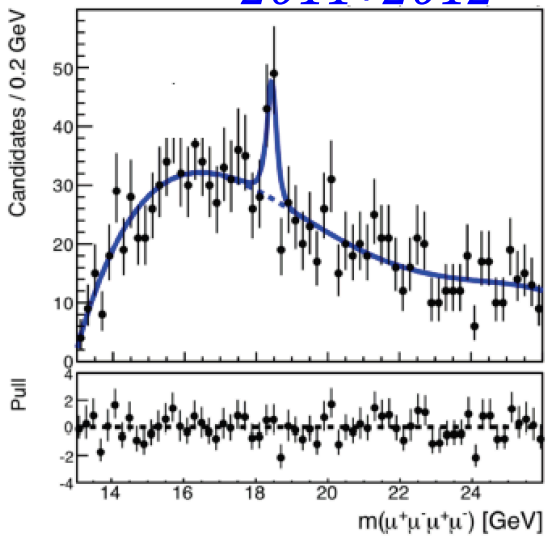


- *CMS could not confirm X(5568)*

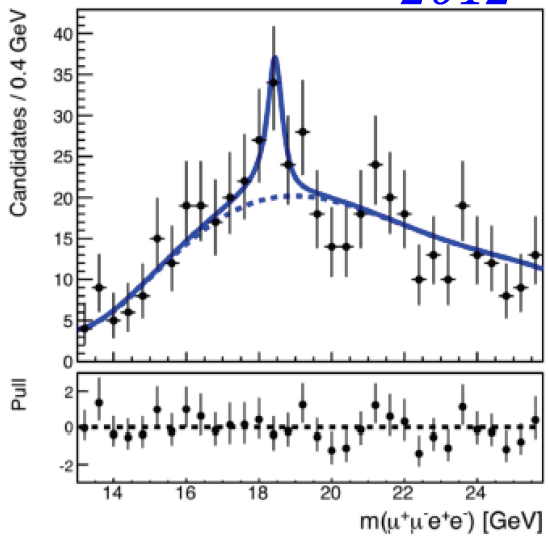
Something interesting in CMS data

Combined Result

2011+2012



2012



- 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_value = 5.8×10^{-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

- The returned global significance was 3.6σ.

12

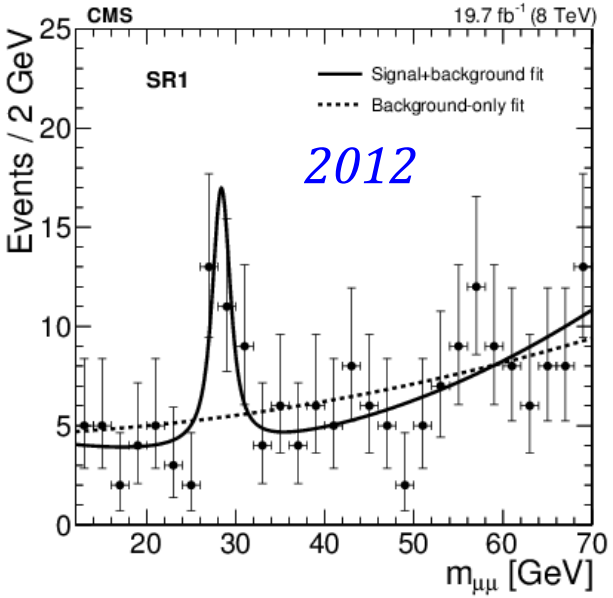
Taken from: http://meetings.aps.org/Meeting/APR18/Session/U09.6

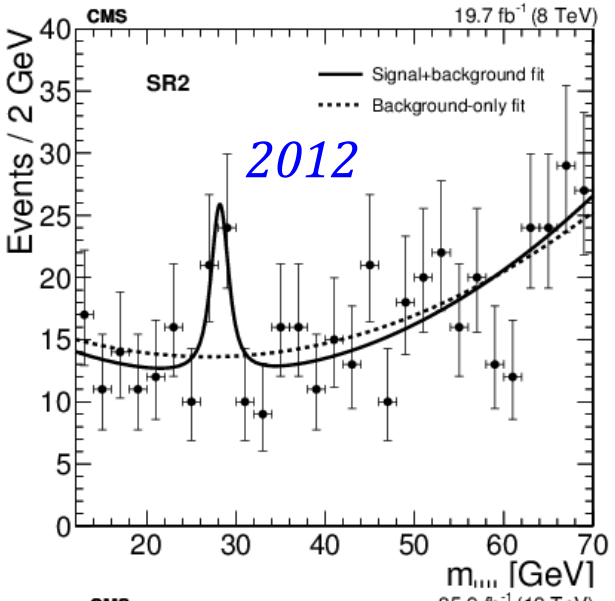
How about the full run II data and future data?

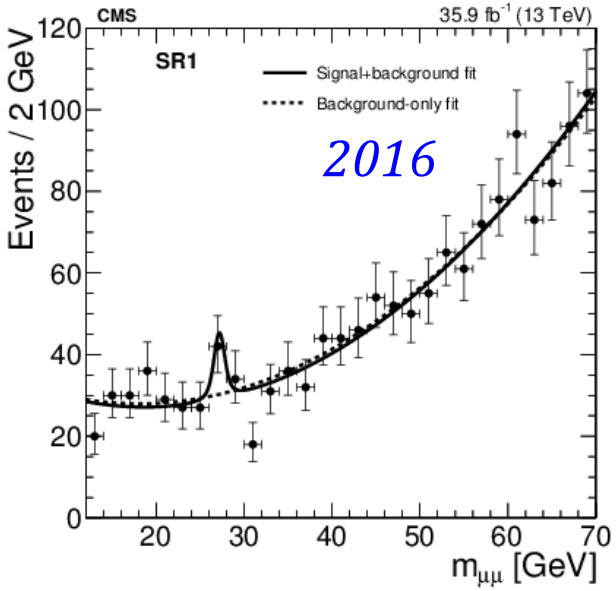
If true, can be a breakthrough in QCD , or even something more exciting

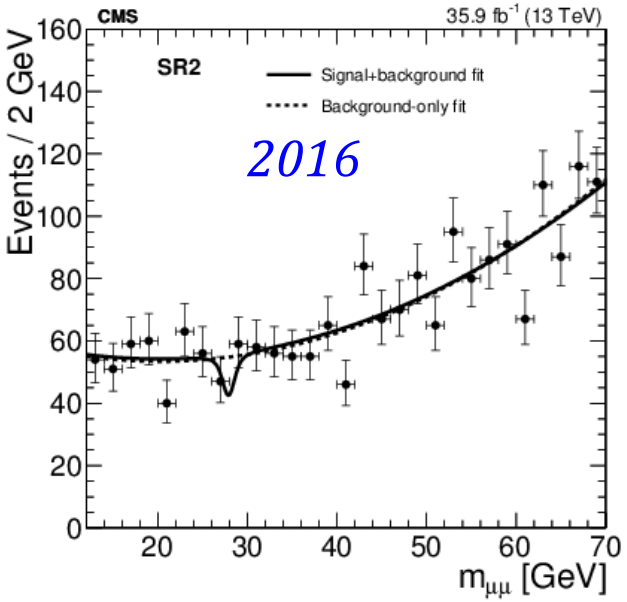
Dimuon result from CMS

arXiv:1808.01890 [hep-ex]
accepted by JHEP









ATLAS does not see
Same sensitivity?

How about 2017 ?

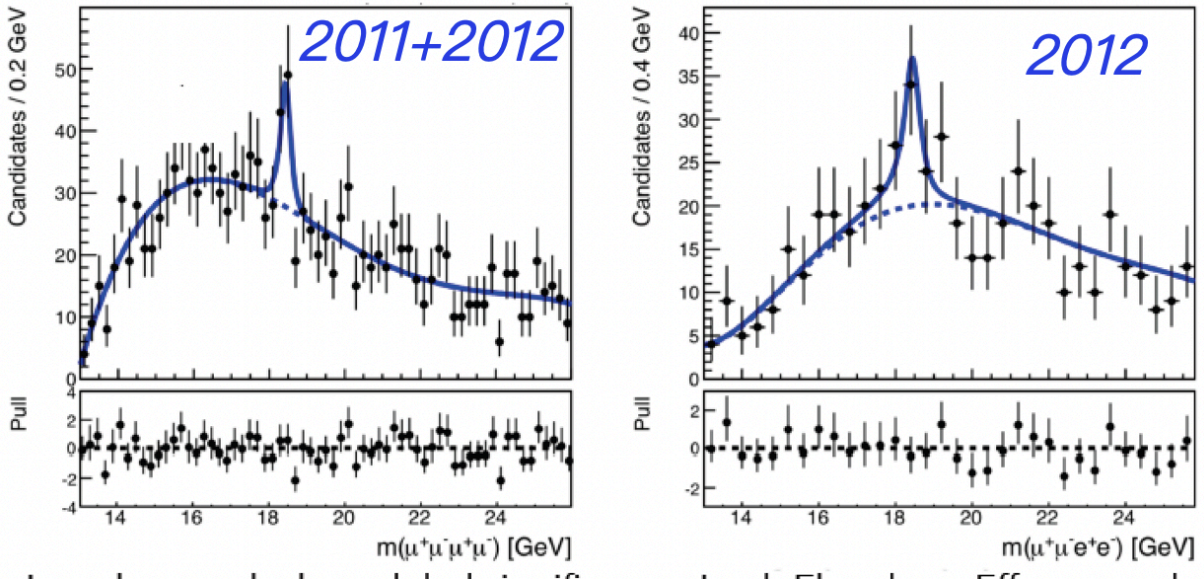
How about 2018?

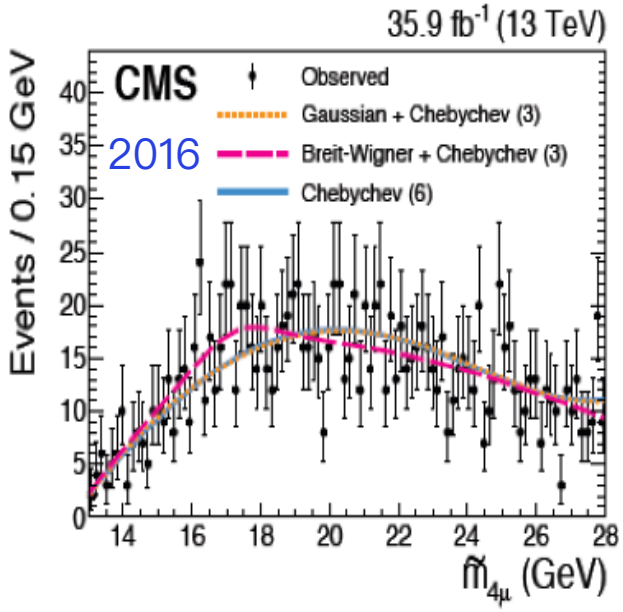
If true → BSM

An exploration in the low mass region at LHC

What is going on?

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

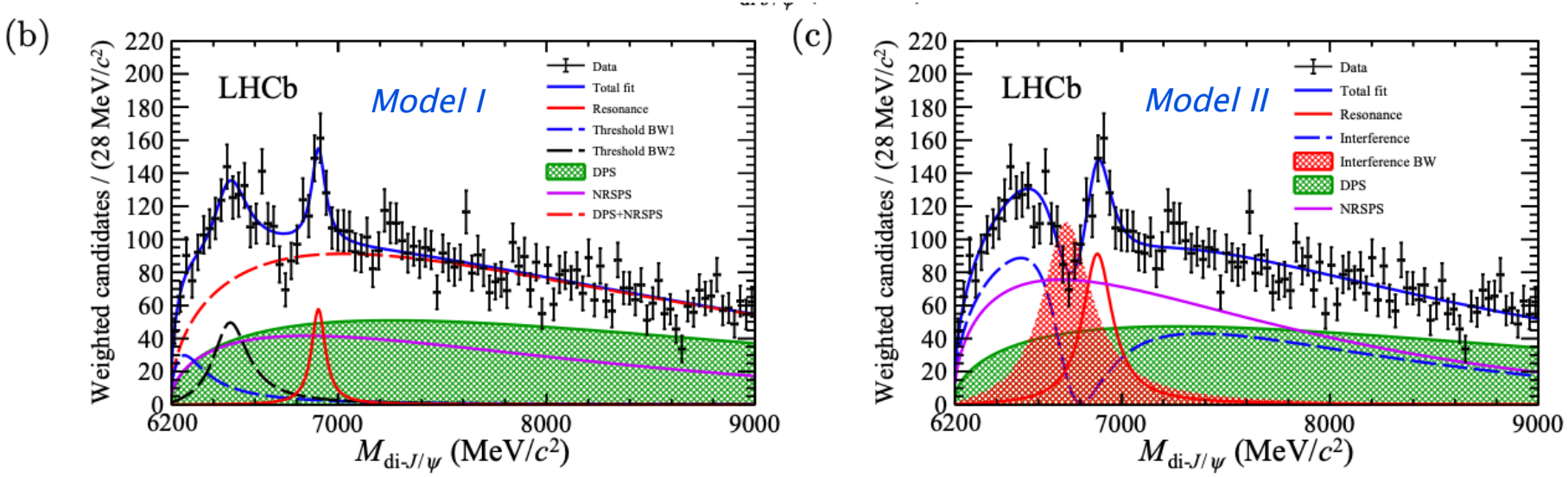




- Controversial so far
- 2017&2018 data to be analyzed
- Run III data to be collected
- Do not know how CMS data evolves

X(6900) @LHCb

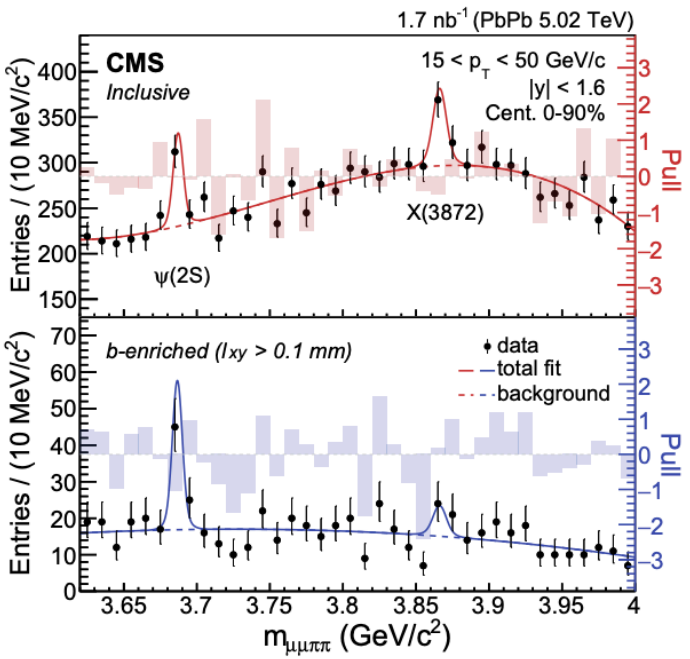
Science Bulletin 65 (2020) 1983

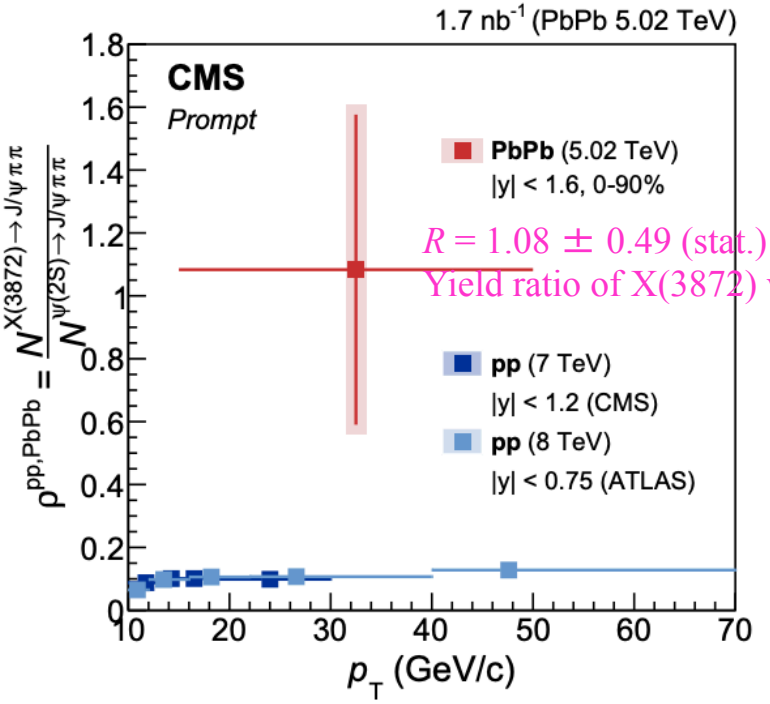


- Caused new wave, especially in China
- Unclear what it is
- Scream for “confirmation”
- CMS/ATLAS?

X(3872) @CMS PbPb

arXiv:2102.13048v1 [hep-ex]

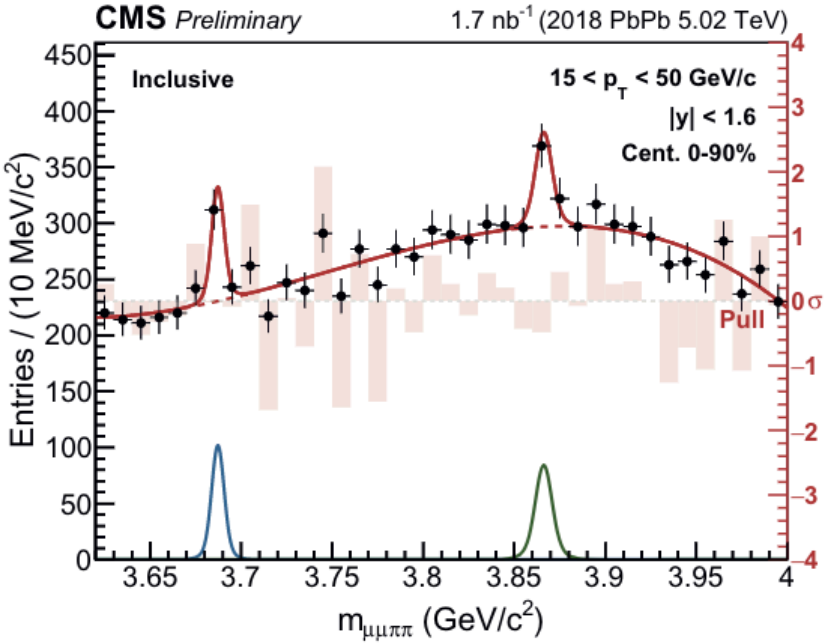


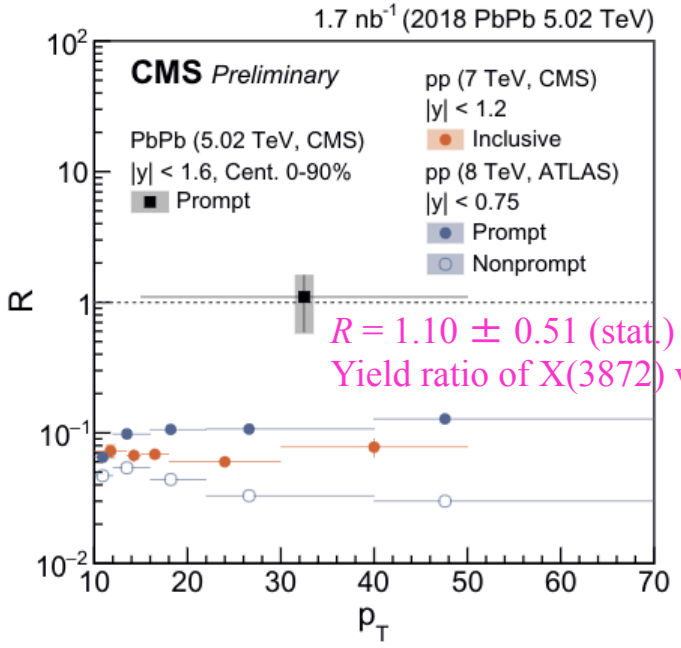


- Large R is observed in PbPb data; prompt dominate
- *X(6900) @PbPb? arXiv:2009.10319* ***[hep-ph]***
- CMS is the best place to look for:
  vs ALICE/ATLAS/LHCb, BNL experiments

X(3872) @CMS PbPb

Nuclear Physics Volume 1005, January 2021, 121781





$R = 1.10 \pm 0.51$ (stat.) $\pm$ 0.53 (syst.)
Yield ratio of X(3872) vs ψ(2S)

- Large R is observed in PbPb data
- *X(6900) @PbPb? arXiv:2009.10319* ***[hep-ph]***
- 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
- 欢迎大家11月到南京指导!

谢谢!

Backup