研究大型强子对撞机上低质量多轻子末态的一些物理可能性

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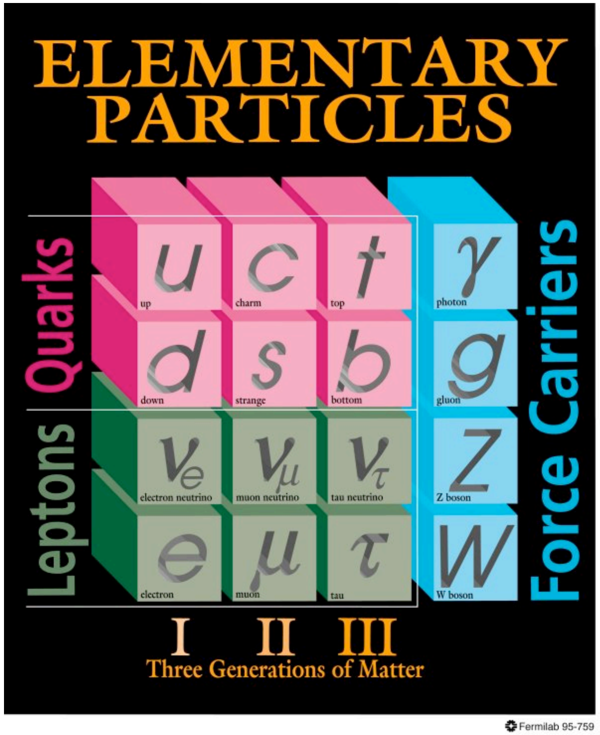
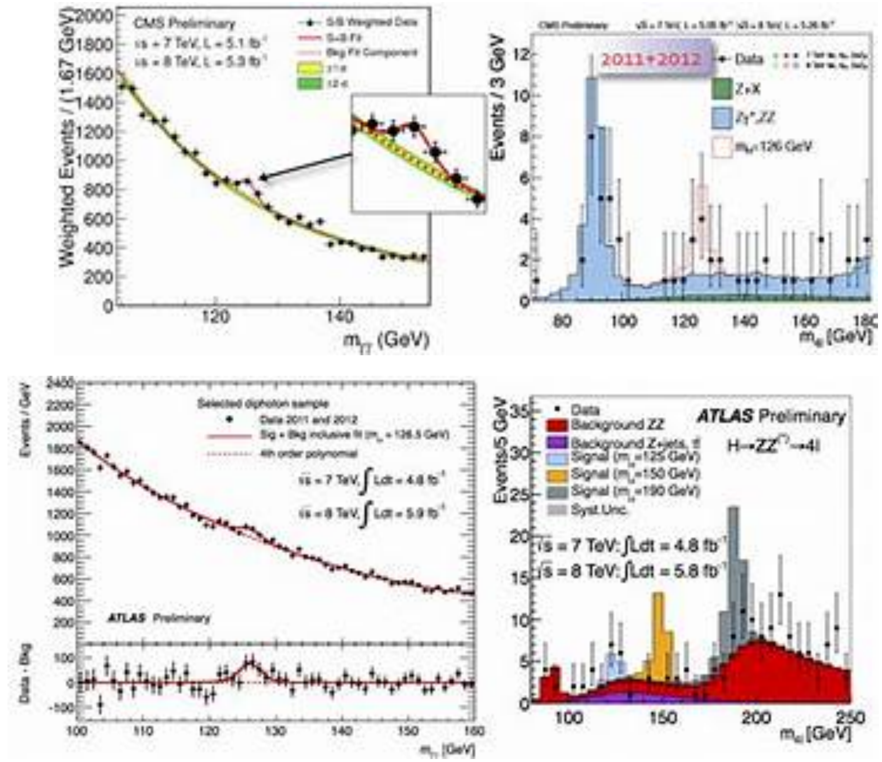
南京师范大学

第六届XYZ研讨会, 一月十一号, 二零零零年

What else after the discovery of Higgs?



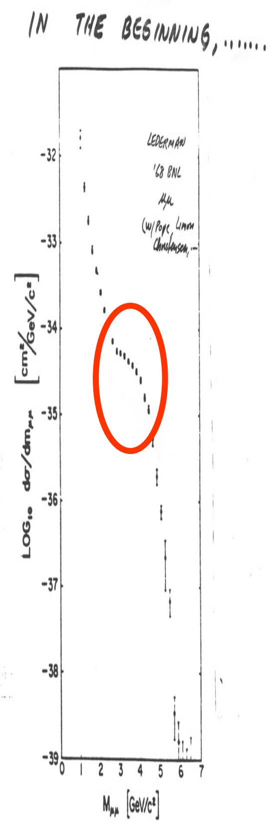


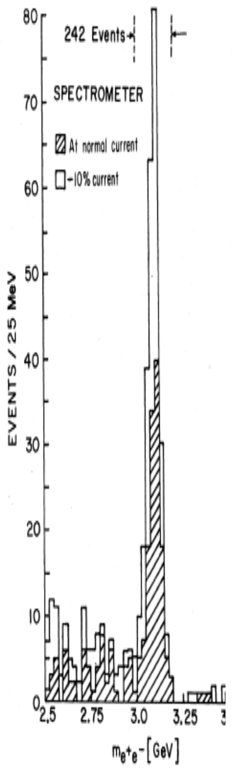
Any new fundamental particles?
Any new format matter with building blocks?

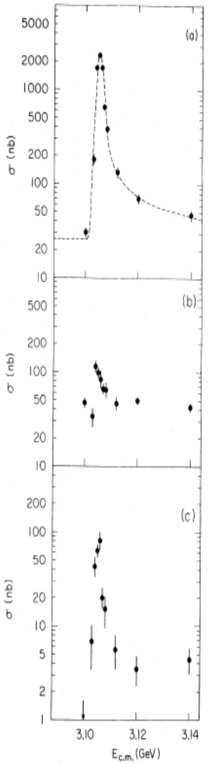
Historic discoveries with leptonic decays

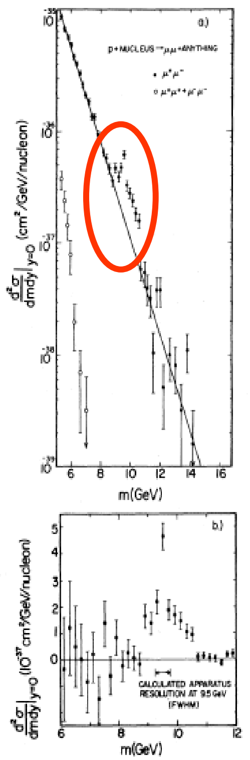
Milestones with leptonic decays

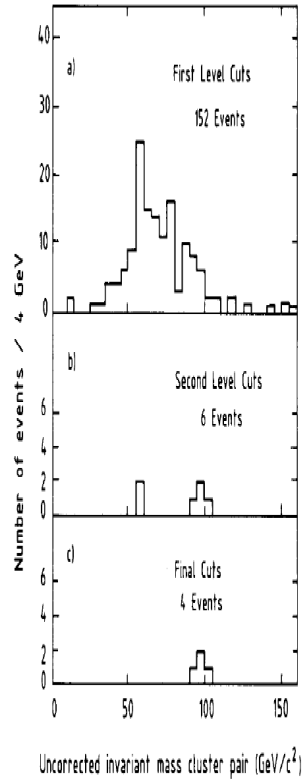
J/ψ ($c\bar{c}$) ***ϒ ($b\bar{b}$)*** ***Z*** ***Higgs***

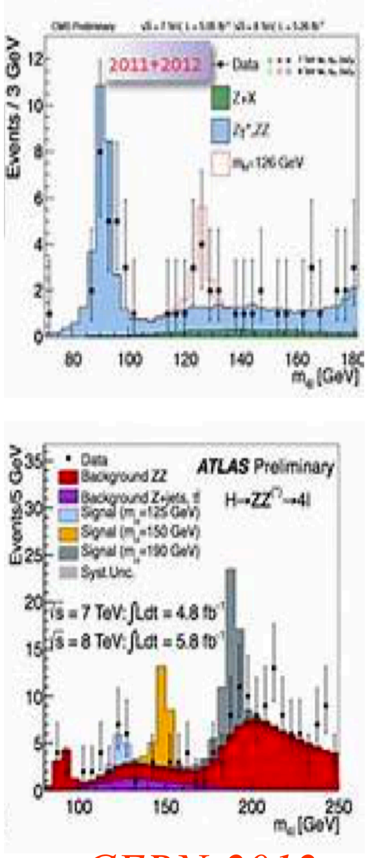








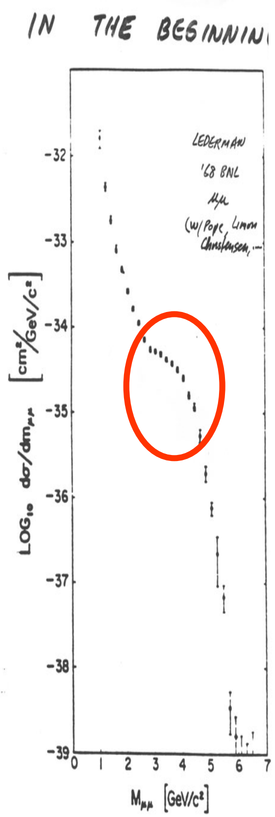




BNL-1968 *BNL-1974* *SLAC-1974* *FNAL-1977* *CERN-1983* *CERN-2012*

It is very beneficial for leptonic decays due to their clean signatures, however, anything can happen even so.

Oops-Leon



BNL-1968

Volume 56B, number 5 PHYSICS LETTERS 26 May 1975

OBSERVATION OF HIGH MASS ELECTRON-POSITRON PAIRS PRODUCED IN PROTON-PROTON COLLISIONS AT THE CERN ISR

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The Rockefeller University[3], N.Y., USA

M. BANNER, J.B. CHÈZE, J.L. HAMEL, H. KASHA[4], J.P. PANSART, G. SMADJA, J. TEIGER, H. ZACCONE and A. ZYLBERSTEJN
CEN, Saclay, France

Received 22 April 1975

In an experiment performed at the CERN Intersecting Storage Rings (ISR), 11 e^+e^- pairs of high invariant mass value (> 2.5 GeV/c^2) have been observed. Of these events, 9 can be interpreted as arising from the reaction $p+p \to J(3.1)$ + anything. The cross-section for this reaction is estimated and compared with the result obtained at lower centre-of-mass energies.

Volume 56B, number 5 PHYSICS LE

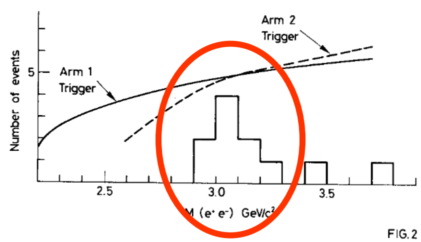


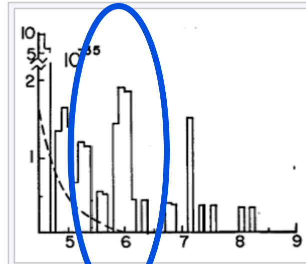
Fig. 2. Invariant mass distribution for the observed e^+e^- pairs. The curves represent the shapes of the acceptance, as a function of the e^+e^- invariant mass value, for the Arm 1 and Arm 2 triggers, respectively.

cluded that the 11 e^+e^- pairs are genuine and correspond to the occurrence of reaction (1).

The invariant mass of each pair was calculated using the momenta of the particles as measured in the magnetic spectrometers. The distribution of invariant

CERN ISR-1975

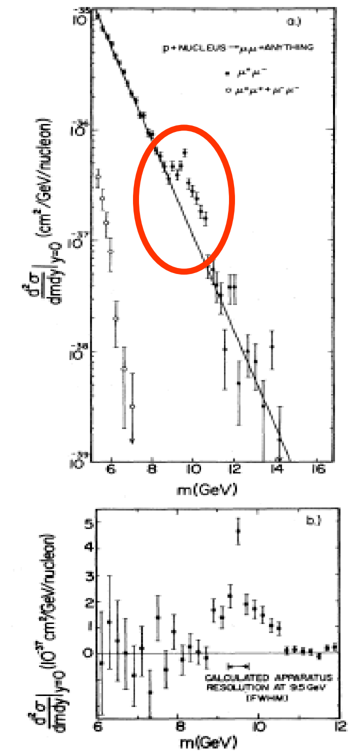
ops-Leon is the name given by article physicists to what was hought to be a new subatomic article "discovered" at Fermilab in 976. The E288 experiment team, a roup of physicists led by Leon ederman who worked on the E288 article detector, announced that a article with a mass of about 6.0 GeV, which decayed into an electron and a ositron, was being produced by the Fermilab particle accelerator.[1] The particle's initial name was the greek letter Upsilon (ϒ). After taking further data, the group discovered that this particle did not actually exist, and the "discovery" was named "Oops-Leon" as a pun on the original name and the first name of the E288 collaboration leader.[2]



A plot counting the rate of production of electron–positron pairs as a function of invariant mass (in GeV). The apparent peak around 6 GeV was initially identified as a new particle,[1] but named **Oops-Leon** when it turned out not to exist.

The original publication was based on an apparent peak (resonance) in a histogram of the invariant mass of electron-positron pairs produced by protons colliding with a stationary beryllium target, implying the existence of a particle with a mass of 6 GeV which was being produced and decaying into two leptons. An analysis showed that there was "less than one chance in fifty" that the apparent resonance was simply the result of a coincidence.[1] Subsequent data collected by the same experiment in 1977 revealed that the resonance had been such a coincidence after all.[2] However, a new resonance at 9.5 GeV was discovered using the same basic logic and greater statistical certainty,[3] and the name was reused (see Upsilon particle).

FNAL-1976



FNAL-1977

A range lacking of experimental data

e^+e^- cross section as a function of energy

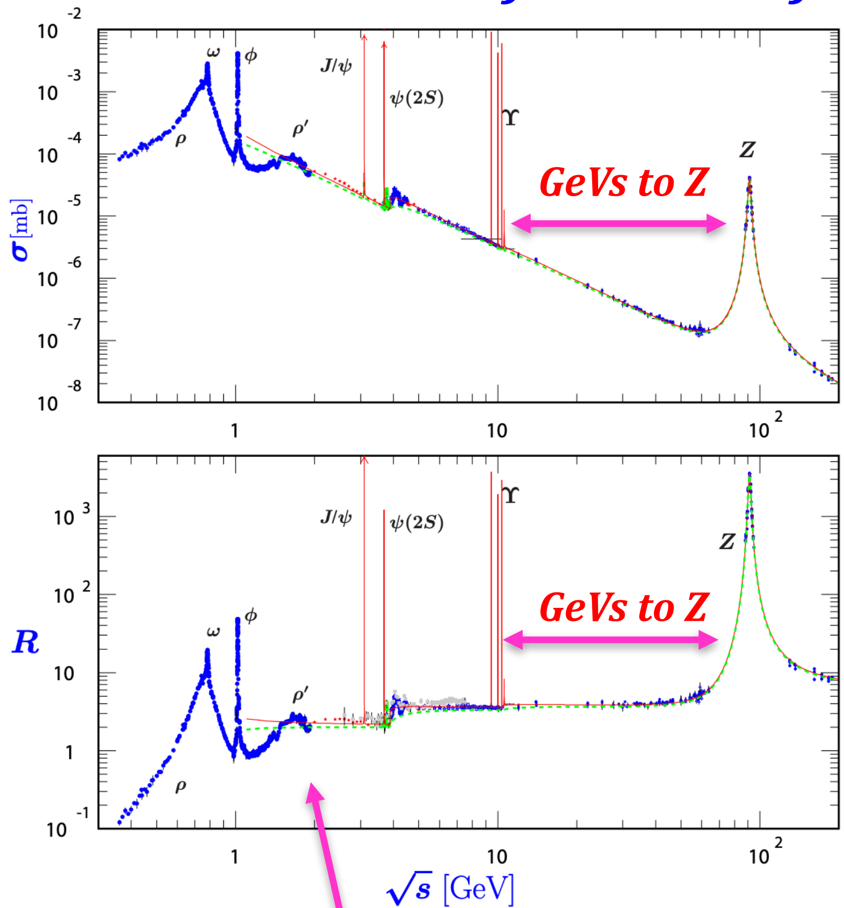


Figure 51.2: World data on the total cross section of $e^+e^- \to hadrons$ and the ratio $R(s) = \sigma(e^+e^- \to hadrons, s)/\sigma(e^+e^- \to \mu^+\mu^-, s)$. $\sigma(e^+e^- \to hadrons, s)$ is the experimental cross section corrected for initial state radiation and electron-positron vertex loops, $\sigma(e^+e^- \to \mu^+\mu^-, s) = 4\pi\alpha^2(s)/3s$. Data errors are total below 2 GeV and statistical above 2 GeV. The curves are an educative guide: the broken one (green) is a naive quark-parton model prediction, and the solid one (red) is 3-loop pQCD prediction (see "Quantum Chromodynamics" section of this *Review*, Eq. (9.7) or, for more details, K. G. Chetyrkin *et al.*, Nucl. Phys. **B586**, 56 (2000) (Erratum *ibid.* **B634**, 413 (2002)). Breit-Wigner

A) Lack of e^+e^- experimental data from GeVs to Z mass

B) Constraint of various physics models in this range is loose

A new window for unknown by LHC (Leptonic searches)

m_Z=90 GeV

BES made significant contributions to this range

never fully explored (GeVs-Z mass)
Multiple-lepton final states

http://arxiv.org/abs/hep-ph/0312114

Experiment	E_{cm} [GeV]
* ADONE-MEA	2.23
BEPC-BES	2.0 - 4.8
BEPC-BES	2.6 - 5.0
* SPEAR-SMAG †	2.4 - 5.0
* SPEAR-SMAG+LGW	3.598 - 3.886
SPEAR-Crystal Ball	3.670 - 4.496
SPEAR-Crystal Ball	5.0 - 7.4
SLAC-MARK-II	3.670 - 3.872
DORIS-DASP	3.6025 - 5.1950
DORIS-II-LENA	7.440 - 9.415
* DORIS-II-ARGUS	9.360
DORIS-II-Crystal Ball	9.39 - 9.46
* DORIS-II-DHHM	9.45 - 10.04
DORIS-II-DASP	9.51
VEPP-4-MD1	7.30 - 10.29
CESR-CUSB	10.43 - 11.09
CESR-CLEO	10.49
CESR-CLEO ††	10.60 - 11.20
CESR-CLEO II	10.52
DORIS/PETRA-PLUTO	3.6 - 30.8
* PETRA-TASSO	12.0 - 41.4
* PETRA-TASSO	12.00 - 31.25
* PETRA-TASSO	14.03 - 43.70
PETRA-TASSO	41.45 - 44.20
PETRA-JADE	12.00 - 46.47
PETRA-MARK-J	12.00 - 46.47
* PETRA-MARK-J	31.57
* PETRA-MARK-J	34.85
PETRA-CELLO	14.0 - 46.6
PEP-MAC	29.0
* PEP-MARK-II	29.0
* TRISTAN-AMY	50.0 - 61.4
* TRISTAN-TOPAZ	50.0 - 61.4
* TRISTAN-TOPAZ	57.77
* TRISTAN-TOPAZ	57.37 - 59.84
* TRISTAN-VENUS	50.0 - 52.0
* TRISTAN-VENUS	63.6 - 64.0

A) Not enough energy (associated production)

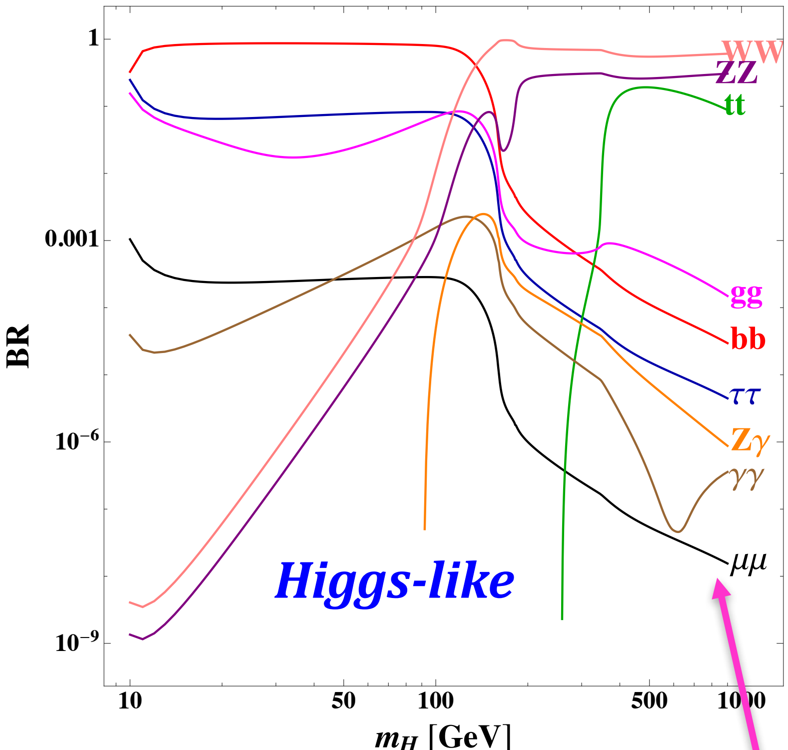
B) Not enough data

C) Opportunity comes with LHC
Enough energy and luminosity

D) Rich physics motivation + curiosity,
BSM—new scalar, Higgs-like,…
QCD—new dynamics, 4b states,…
anything else unexpected?

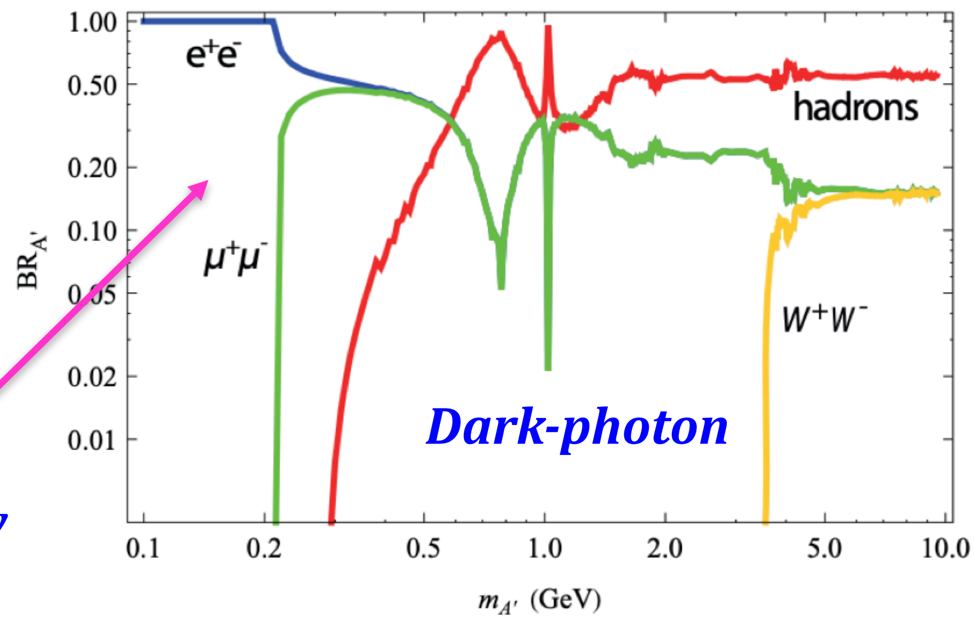
m_Z=90 GeV

Motivation—Beyond Standard Model



Higgs-like

Many models exist in this region

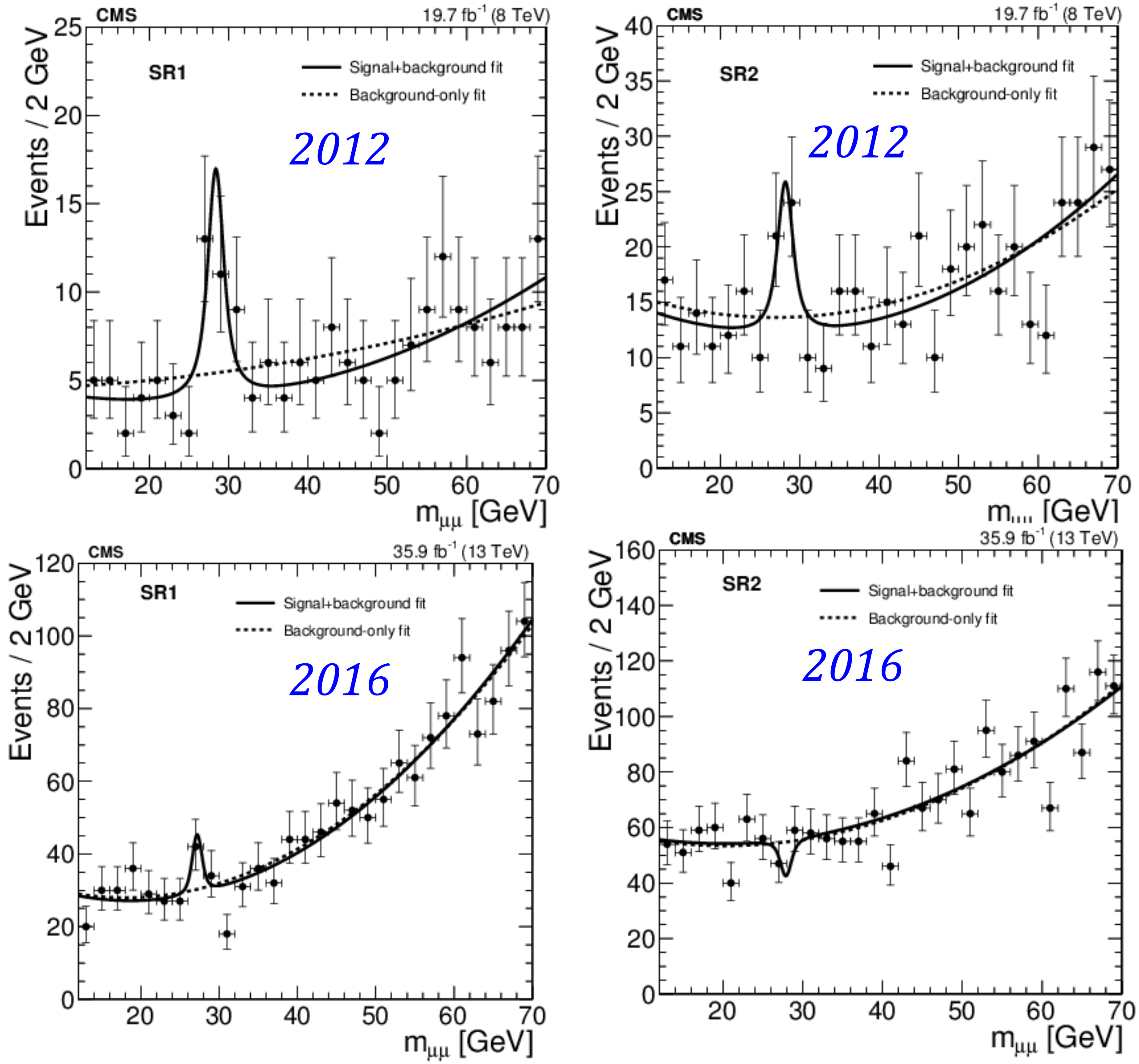


Dark-photon

Leptonic decays can be significant signatures experimentally to identify

Dimuon result from CMS

arXiv:1808.01890 [hep-ex]
accepted by JHEP



ATLAS does not see
Same sensitivity?

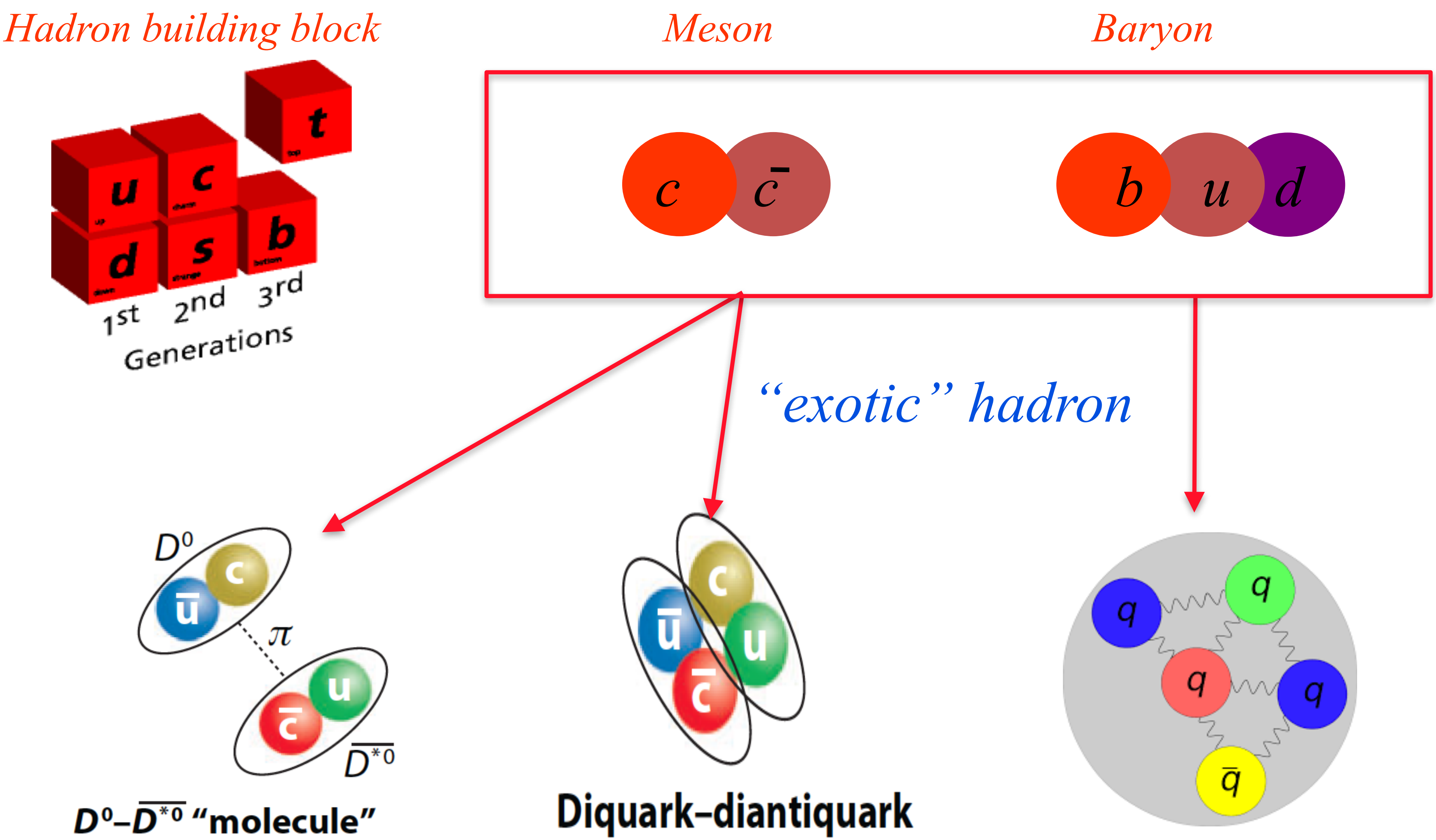
How about 2017 ?

How about 2018?

If true → BSM

An exploration in the low mass region at LHC

Motivation--Quark model



Two possible extensions of meson to tetra-quark states

Focus of today's object, revitalized by X(3872) (2003)

Possible penta-quark state

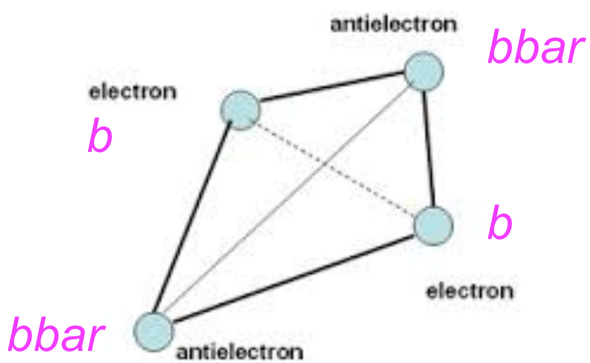
Motivation—heavy tetra-quark states

- ***Heavy-quark tetra-quark states--****PRD 86, 034004(2012)*

$b\bar{b}b\bar{b}$ open to 4-lepton final states through upsilon pair

$$
\begin{aligned}
0^{++\prime}: &\quad M = 18.754\,\mathrm{GeV}, &\quad M - M_{\mathrm{th}} = -544.\,\mathrm{MeV},\\
1^{+-\prime}: &\quad M = 18.808\,\mathrm{GeV}, &\quad M - M_{\mathrm{th}} = -490.\,\mathrm{MeV},\\
2^{++}: &\quad M = 18.916\,\mathrm{GeV}, &\quad M - M_{\mathrm{th}} = -382.\,\mathrm{MeV}.
\end{aligned}
$$

positronium molecule analog:



cccc--Kuang-Ta Chao

12 FERMILAB-Pub-80/70-THY

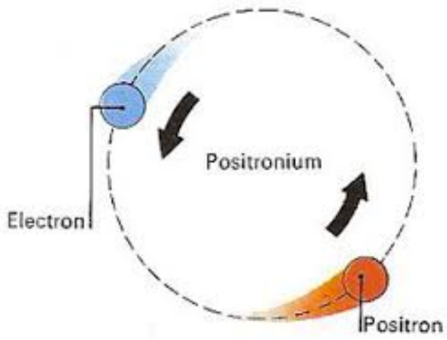
Table I(a). The quantum numbers and masses for the $(cc)_{\underline{3}}^{*} - (\overline{cc})_{\underline{3}}$ states (without spin-dependent forces between two clusters)

L	S	J^{PC}	Mass (GeV)
1	0	1^{--}	6.55
	1	0^{-+}, 1^{-+}, 2^{-+}	
	2	1^{--}, 2^{--}, 3^{--}	
2	0	2^{++}	6.78
	1	1^{+-}, 2^{+-}, 3^{+-}	
	2	0^{++}, 1^{++}, 2^{++}, 3^{++}, 4^{++}	
3	0	3^{--}	6.98
	1	2^{-+}, 3^{-+}, 4^{-+}	
	2	1^{--}, 2^{--}, 3^{--}, 4^{--}, 5^{--}	

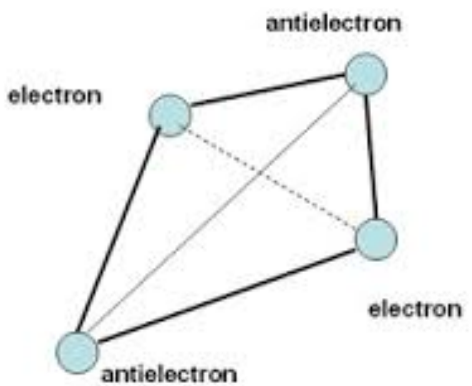
Will be a breakthrough for exotic mesons if established, and reveal potential new dynamics

Molecule structures from electrons

Positronium (1951)



positronium molecule (2007)



Vol 449|13 September 2007|doi:10.1038/nature06094 nature

Nature letter LETTERS

The production of molecular positronium

D. B. Cassidy[1] & A. P. Mills Jr[1]

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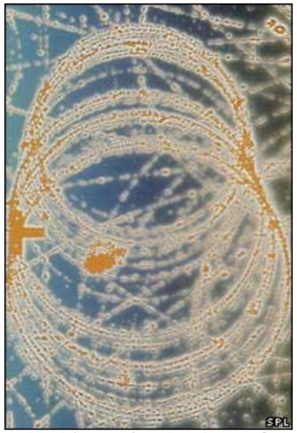
Mirror particles form new matter

By Jonathan Fildes
Science and technology reporter, BBC News

Fragile particles rarely seen in our Universe have been merged with ordinary electrons to make a new form of matter.



Antiparticles are the mirror image of ordinary particles

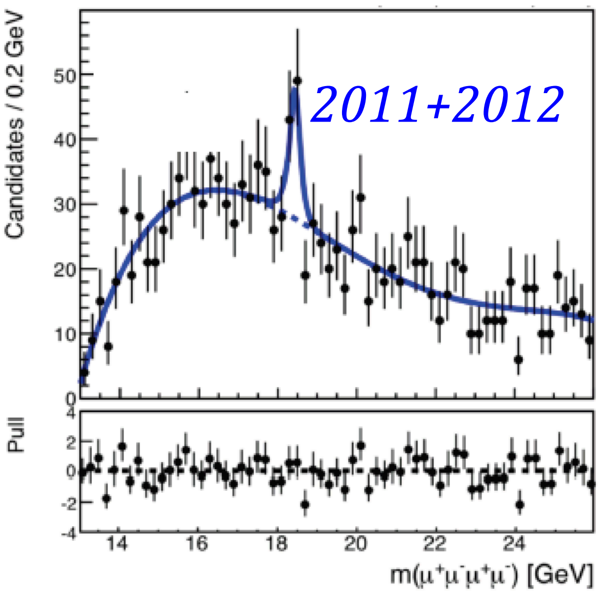
Di-positronium, as the new molecule is known, was predicted to exist in 1946 but has remained elusive to science.

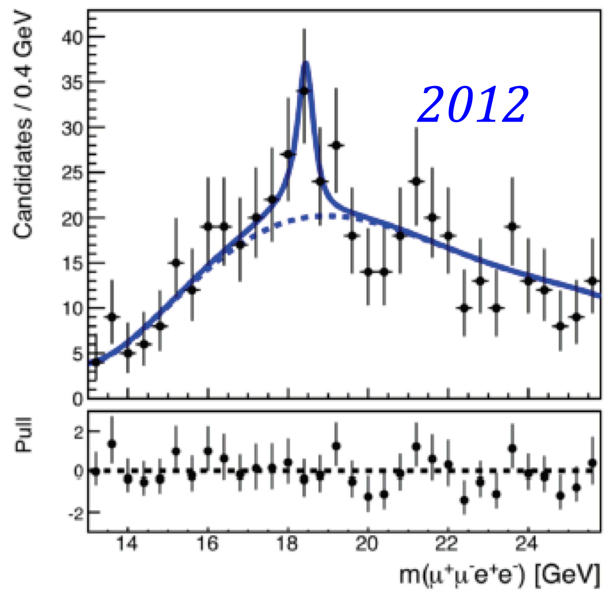
Now, a US team has created thousands of the molecules by merging electrons with their antimatter equivalent: positrons.

The discovery, reported in the journal Nature, is a key step in the creation of ultra-powerful lasers known as gamma-ray annihilation lasers.

Analog structures at quark level? i.e. (b bbar)+(b bbar)?
A potential place to study new multi-body dynamics at quark level

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 ($p\_value = 5.8 \times 10^{-7}$)

- 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

- The returned global significance was 3.6σ.

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

The LHC experiments

- *The LHCb experiment has excellent hadron PIDs, excellent lepton IDs, excellent mass resolutions. Comparing to ATLAS/CMS, limited by integrated luminosity and acceptance.*

- *ATLAS and CMS have excellent lepton IDs but do not have hadron PIDs, comparing to LHCb, ATLAS and CMS have edges on integrated luminosity and acceptance.*

- *What ATLAS and CMS can explore in this new window for unknown?*

Potential channels to explore

- $X \rightarrow J/\psi J/\psi \rightarrow l^+l^-l^+l^-$
- $X \rightarrow J/\psi l^+l^- \rightarrow l^+l^-l^+l^-$
- $X \rightarrow \psi(2S)\psi(2S)$, $J/\psi\psi(2S) \rightarrow l^+l^-l^+l^-$
- $X \rightarrow \psi(2S)l^+l^- \rightarrow l^+l^-l^+l^-$
- $X \rightarrow Y(nS)Y(nS)$, $Y(nS)\psi(nS) \rightarrow l^+l^-l^+l^-$
- $X \rightarrow Y(nS)l^+l^- \rightarrow l^+l^-l^+l^-$

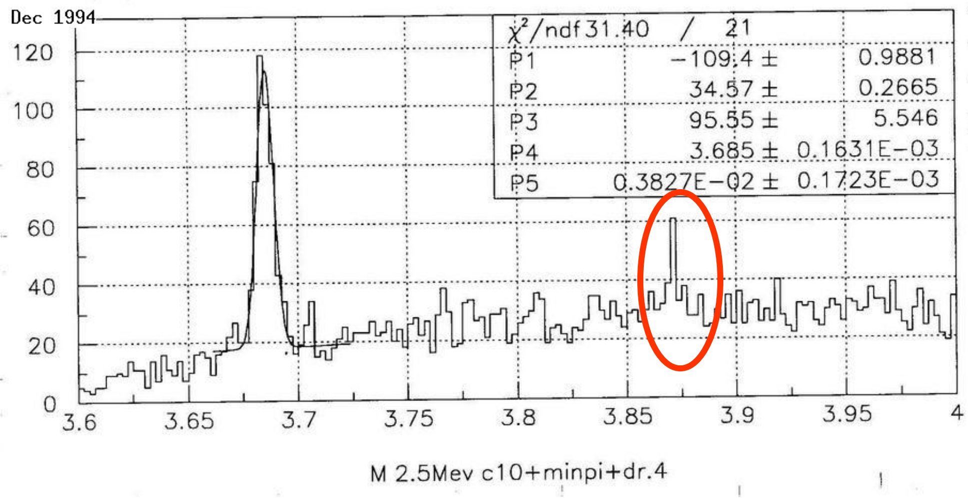
- $X \rightarrow J/\psi \boldsymbol{\phi} \rightarrow l^+l^-l^+l^-$
- $X \rightarrow Y(nS)\boldsymbol{\phi} \rightarrow l^+l^-l^+l^-$

- $X \rightarrow l^+l^-$, $\boldsymbol{\gamma\gamma}$ *(inclusive and associate production)*
- *Even more bizarre:* $X \rightarrow J/\psi J/\psi J/\psi \rightarrow l^+l^-l^+l^-l^+l^-$, …….

Act actively and discover nature's secret as early as possible

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

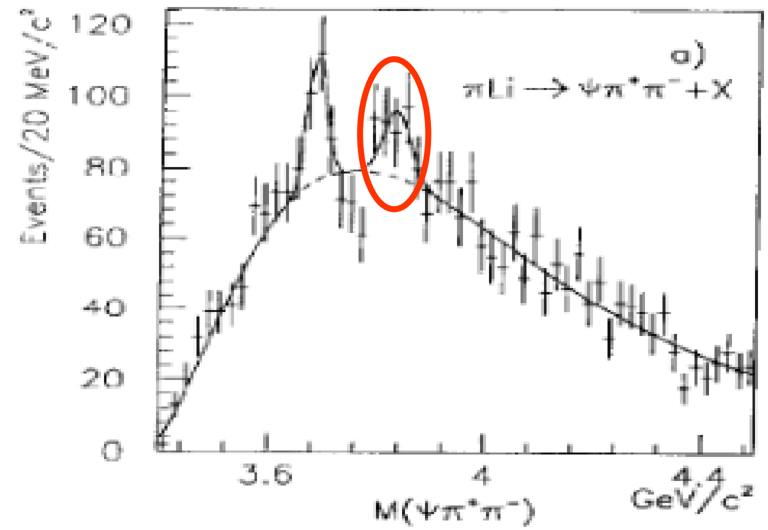
CDF internal, 1994



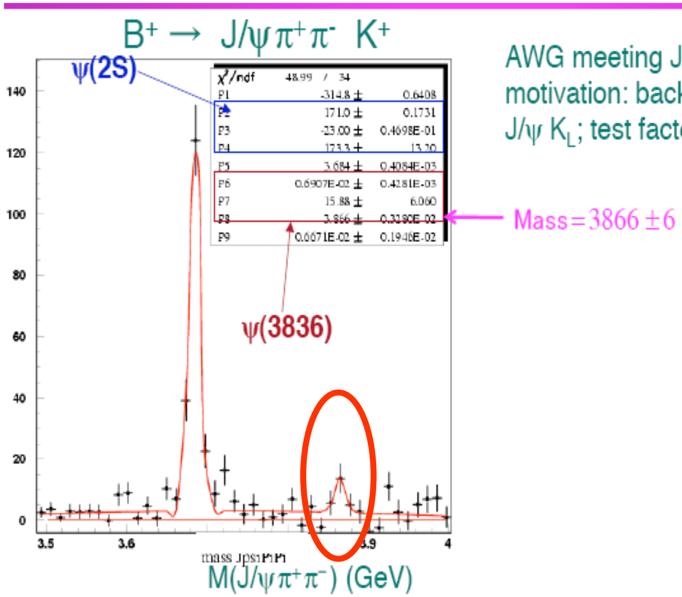
E705, PRD 50, 4258 (1994)

E705 saw $\psi(3836)$ (2^{--}) in 1994, 3.836 ± 0.013 GeV

PRL 115 011803, PRL 111 032001



BaBar internal, 2003



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

From BaBar B-Factory Symposium (C. Hearty)

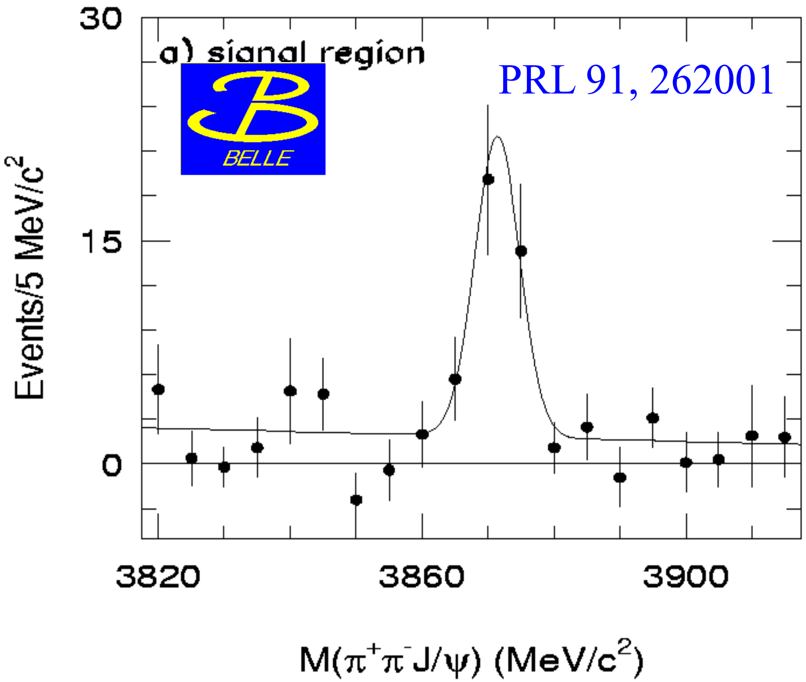
http://www-conf.slac.stanford.edu/b-factory-symposium/talks.asp

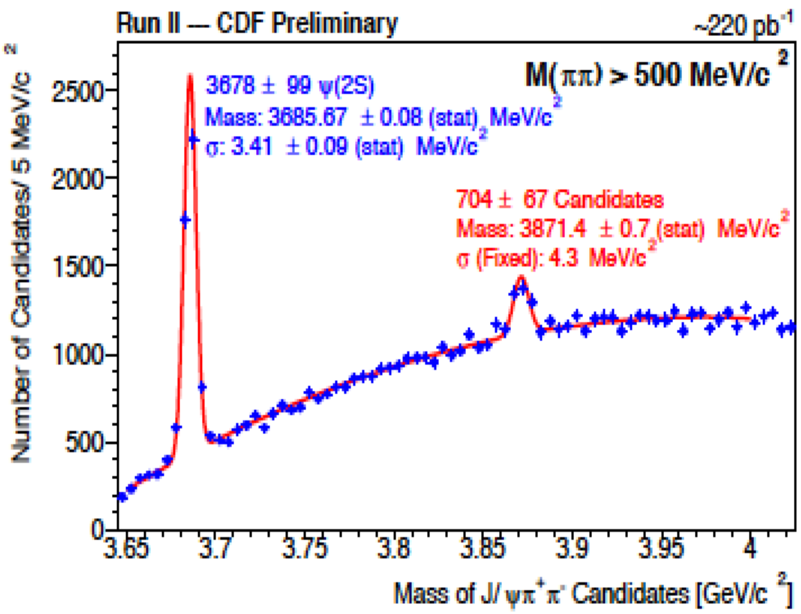
CDF saw a hint in 1994, unpublished

BaBar saw a hint in 2003, unpublished

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

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. …"

2017 Korean Ho-Am Science Prize

Summary

- *Rich BSM and QCD physics motivation for low mass multiple lepton final state*

- *This region has never been fully explored before*

- *Great opportunities at LHC*

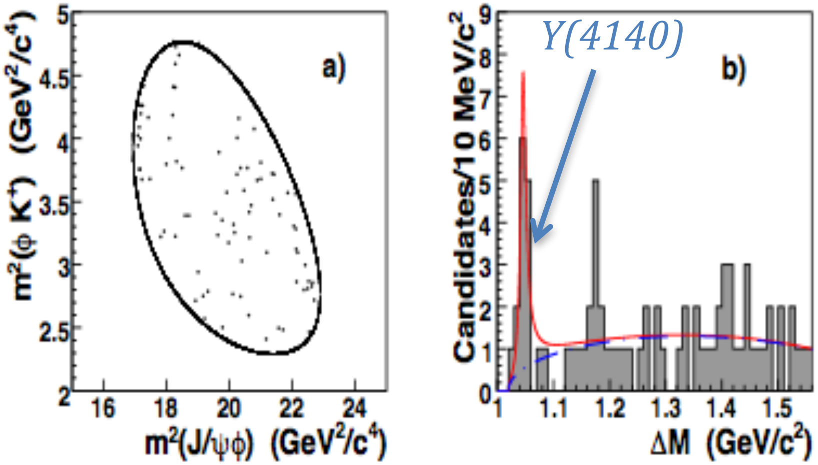
- *A new window for unknown*

Thank you! ☺

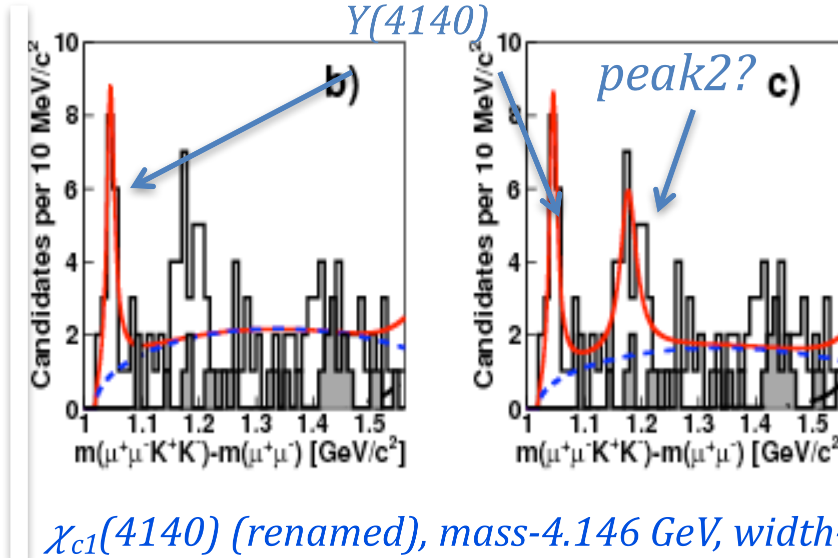
A XYZ project at Belle II

The history of Y(4140)—CDF (2009)—LHCb (2016)

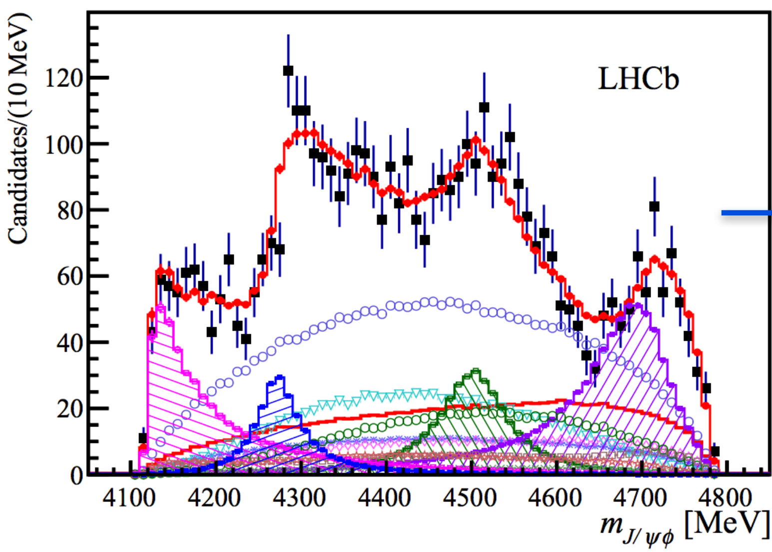
CDF—PRL102:242002 (2009)



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



χ_{c1}(4140) (renamed), mass-4.146 GeV, width—15 MeV
χ_{c1}(4274) (renamed), mass-4.274 GeV, width—32 MeV



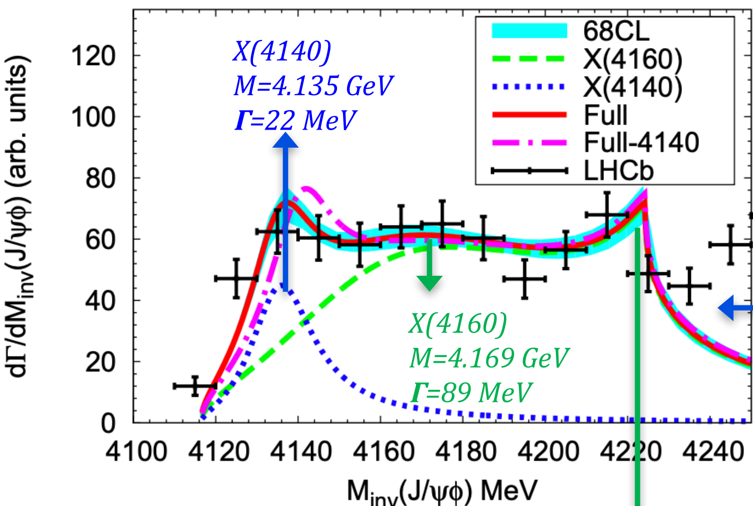
	significance	mass (MeV)	width (MeV)	
All $X(1^+)$				$16\pm3\ ^{+6}_{-2}$
$X(4140)$	8.4σ	$4146.5\pm4.5\ ^{+4.6}_{-2.8}$	$83\pm21\ ^{+21}_{-14}$	$13.0\pm3.2\ ^{+4.7}_{-2.0}$
ave.	Table 1	4147.1 ± 2.4	15.7 ± 6.3	
$X(4274)$	6.0σ	$4273.3\pm8.3\ ^{+17.2}_{-3.6}$	$56\pm11\ ^{+8}_{-11}$	$7.1\pm2.5\ ^{+3.5}_{-2.4}$
CDF	[26]	$4274.4\ ^{+8.4}_{-6.7}\pm1.9$	$32\ ^{+22}_{-15}\pm8$	
CMS	[23]	$4313.8\pm5.3\pm7.3$	$38\ ^{+30}_{-15}\pm16$	
All $X(0^+)$				$28\pm5\pm7$
$NR_{J/\psi\phi}$	6.4σ			$46\pm11\ ^{+11}_{-21}$
$X(4500)$	6.1σ	$4506\pm11\ ^{+12}_{-15}$	$92\pm21\ ^{+21}_{-20}$	$6.6\pm2.4\ ^{+3.5}_{-2.3}$
$X(4700)$	5.6σ	$4704\pm10\ ^{+14}_{-24}$	$120\pm31\ ^{+42}_{-33}$	$12\pm5\ ^{+9}_{-5}$

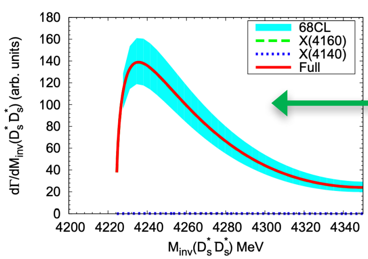
Four resonances were claimed by LHCb, three of them needs 5σ confirmation
X(4500) and X(4700) have no confirmation at all!

The history of Y(4140)—CDF (2009)—LHCb (2016)

$\chi_{c1}(4140)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
22^{+8}_{-7} OUR AVERAGE		Error includes scale factor of 1.3. See the ideogram below.			
$83 \pm 21 ^{+21}_{-14}$	4289	[1] AAIJ	17C	LHCB	$B^+ \to J/\psi \phi K^+$
$15.3^{+10.4}_{-6.1} \pm 2.5$	19	[2] AALTONEN	17	CDF	$B^+ \to J/\psi \phi K^+$
$16.3 \pm 5.6 \pm 11.4$	616	[3] ABAZOV	15M	D0	$p\overline{p} \to J/\psi \phi$ + anything
$20 \pm 13 ^{+3}_{-8}$	52	[4] ABAZOV	14A	D0	$B^+ \to J/\psi \phi K^+$
$28 ^{+15}_{-11} \pm 19$	0.3k	[5] CHATRCHYAN	14M	CMS	$B^+ \to J/\psi \phi K^+$





D_s^*-anti-D_s^* CUSP
at its threshold 4.22 GeV
Γ=89 MeV

Impact due to its J^{PC} and large width on the interpretation—The below-J/ψφ-threshold $D^{\pm}_s D^{*\mp}_s$ cusp may have an impact on the X(4140) structure" (PRL 118 (2017) no.2, 022003)

Other opinions on its large width (PRD 97 (2018) no.1, 014017)

The CDF one-dimensional fit to mass spectrum was criticized, and we can improve it using amplitude analysis this time

Can Belle II clarify it?