Observation of Structures in the $J/\psi\phi$ from $B^+ \to J/\psi\phi K^+$ Decay at CMS

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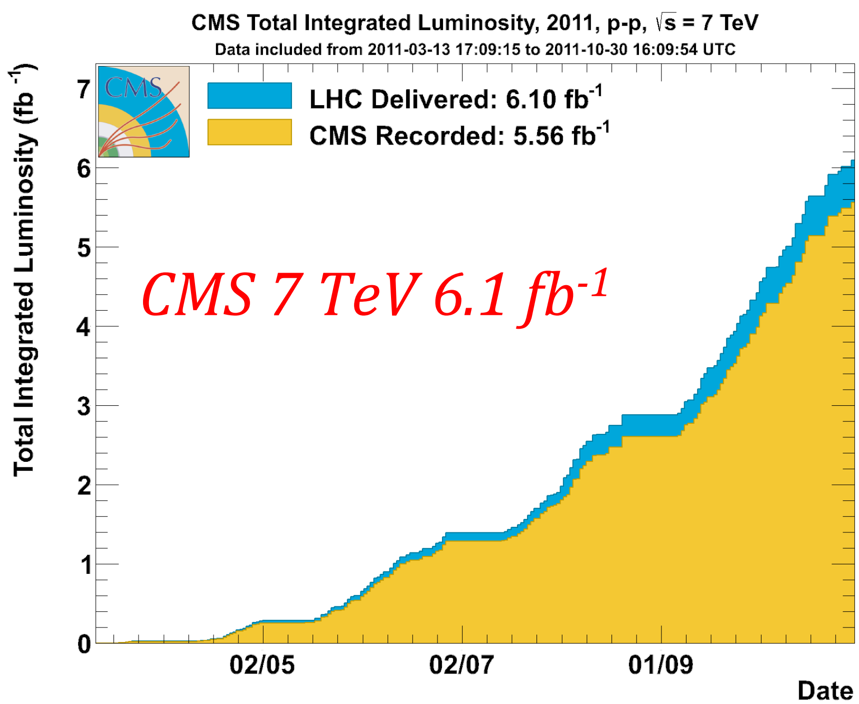
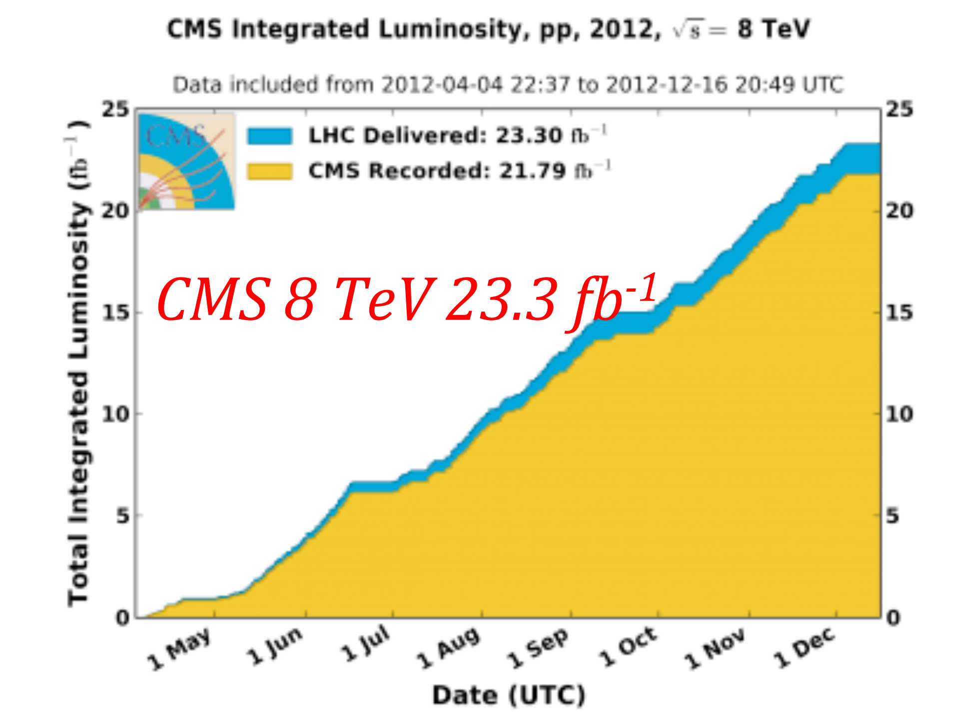
BNL Particle Physics Seminar, Feb 7, 2013

CMS & LHC





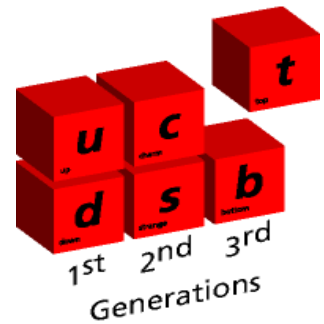
- *LHC yields large amounts of data at the world's* ***highest*** *energy*
- *Besides confirmation of the SM (i.e. Higgs), enormous opportunities to search for new phenomena in high-pt &* ***low-pt*** *regimes*

This talk focuses on a new phenomena in low-pt QCD (2011, 7 TeV)

Outline

- *Introduction & motivation*
- *Y(4140)➔J/Ψϕ? CDF vs LHCb*
- *CMS detector and trigger*
- *CMS searches of structures in J/Ψϕ*
- *Observation of two structures in J/Ψϕ @CMS*
- *Comparison & implications*
- *Summary*

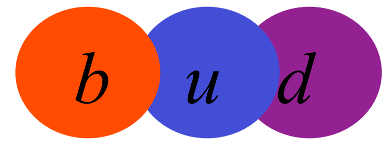
Quark Model



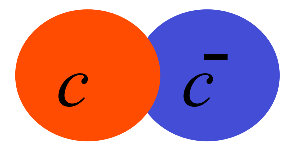
- *The birth of quark model (M. Gell-Mann & G. Zweig): M. Gell-Mann, Phys. Lett. 8, 214 (1964)*

- *All (known) hadrons are bound states of quarks*

    - *Baryons: (qqq)*



    - *Mesons: $(q\bar{q})$*
      quarkonia: $(s\bar{s})$, $(c\bar{c})$ $(b\bar{b})$ (hidden)



- *J/ψ establishes the quark model, $\Upsilon(1S)$ further confirms it*

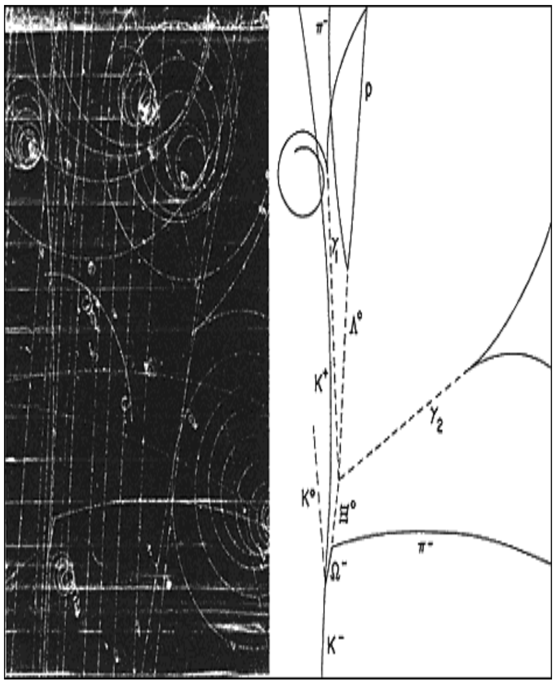
- *Gell-Mann also suggested exotic states $(qq\bar{q}\bar{q})$, $(qqq\bar{q}\bar{q})$ at the birth of quark model, but evidence has never been solidly established*

Interest in exotics ***revitalized*** *by the discovered charmonium-like states despite almost a decade, still mysterious!*

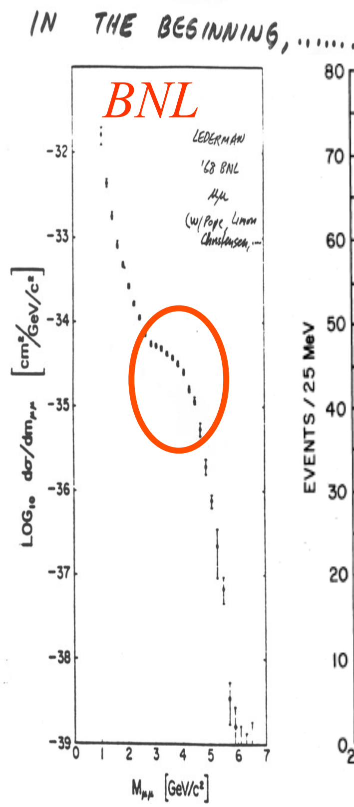
From strange to bottom discovery

Ω^- discovery | *J/ψ ($\bar{c}c$) discovery* | *ϒ ($\bar{b}b$) discovery*

BNL



1964



1968

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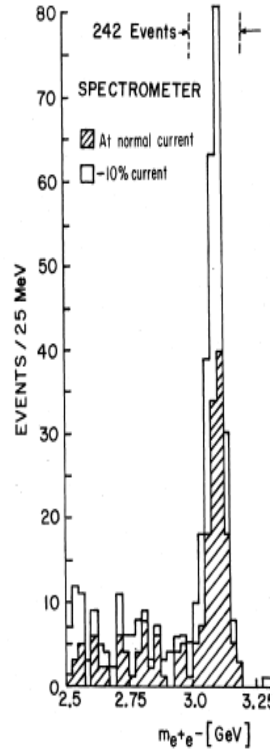
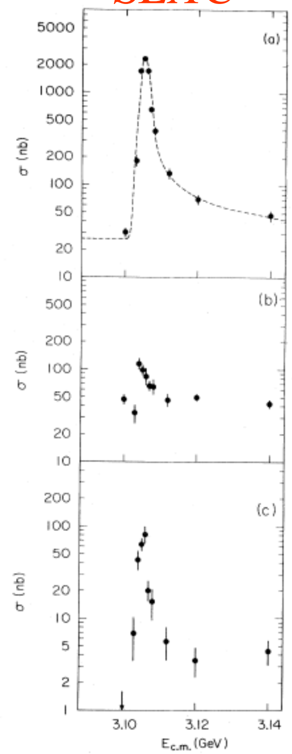


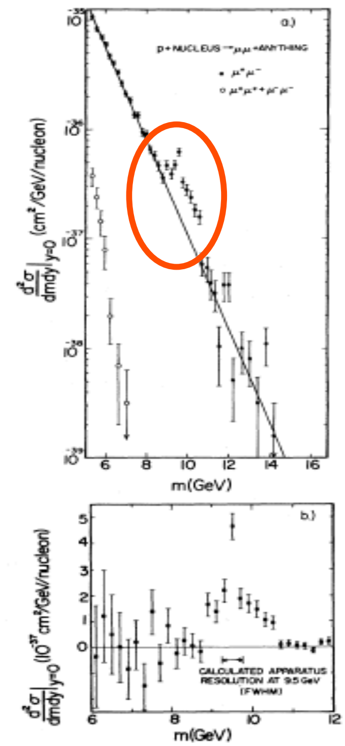
1974

SLAC



1974

FNAL



1977

Heavy flavor quarkonium spectroscopy helped turn quarks into a reality!

What we can learn more from quarkonium(-like) spectroscopy?

Charmonium ($c\bar{c}$) Potential Model (Cornell Model)

- *simple QCD-inspired phenomenological potential :*

$$V(r) = -\frac{\kappa}{r} + \frac{r}{a^2}, \quad \kappa = 0.61, m_c = 1.84\,\text{GeV}, \text{a} = 2.38\,\text{GeV}^{-1}$$

- ***non-relativistic*** *(charm quark is "heavy" compared to binding energy)*

- *quark confinement (increases linearly with separation)*

- *extendable to include spin-dependent terms, relativistic corrections, etc.*

- *Lattice QCD provides calculation of the masses and widths*

Eichten et. al., PRD 17, 3090 (1978)
Godfrey & Isgur, PRD 32, 189 (1985)
Barnes et. al., PRD 72, 054026 (2005

Charmonium States

Notation:

$^{2S+1}[L]_J$

L=S,P,D (0,1,2)
(No cand. *with* L>=3)

J = L+S

$S(q\bar{q})$ = 0 or 1

Parity: **P = (-1)$^{L+1}$**

Charge conjugation eigen*vales:* **C=(-1)$^{L+S}$**

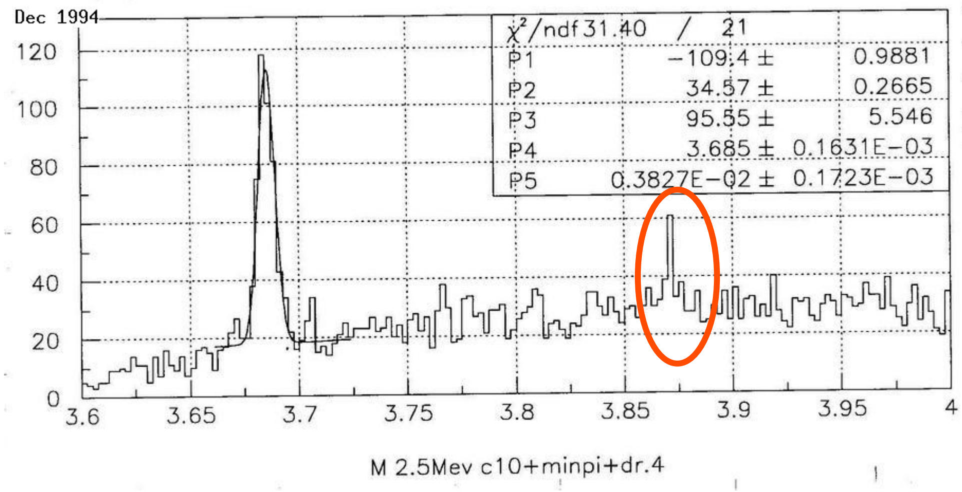
***N**: Radial Quantum Numbers*

Quantum numbers				Name	Mass (MeV/c²)	width(MeV)
N	L	J^{PC}	$N^{2S+1}L_J$			
1	0	0^{-+}	1^1S_0	**η_c(1S)**	2980.4±1.2	26.7±3
1	0	1^{--}	1^3S_1	**J/ψ**	3096.916±0.011	93.2±0.02 $\times 10^{-3}$
1	1	0^{++}	1^3P_0	**χ_{c0} (1P)**	3414.75±0.31	10.2±0.7
1	1	1^{++}	1^3P_1	**χ_{c1}(1P)**	3510.66±0.07	0.89±0.05
1	1	2^{++}	1^3P_2	**χ_{c2}(1P)**	3556.20±0.09	2.03±0.12
1	1	1^{+-}	1^1P_1	**h_c(1P)**	3525.93±0.27	<1
1	2	1^{--}	1^3D_1	**ψ(3770)**	3772.92±0.35	27.3±1.0
2	0	0^{-+}	2^1S_0	**η_c(2S)**	3637±4	14±7
2	0	1^{--}	2^3S_1	**ψ(2S)**	3686.09±0.04	317±9 $\times 10^{-3}$
2	1	2^{++}	2^3P_2	**χ_{c2}(2P)**	3929±5	29±10
3	0	1^{--}	3^3S_1	**ψ(4040)**	4039±1	80±10
2	2	1^{--}	2^3D_1	**ψ(4160)**	4153±3	103±8
4	0	1^{--}	4^3S_1	**ψ(4415)**	4421±4	62±20

These states work well with charmonium model, until the appearance of X(3872)

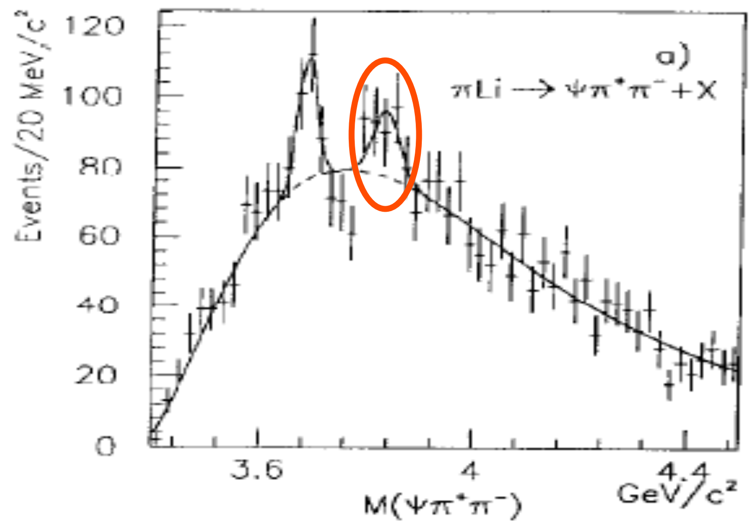
Hints before the discovery of X(3872)→J/$\psi\pi^+\pi^-$

CDF internal, 1994

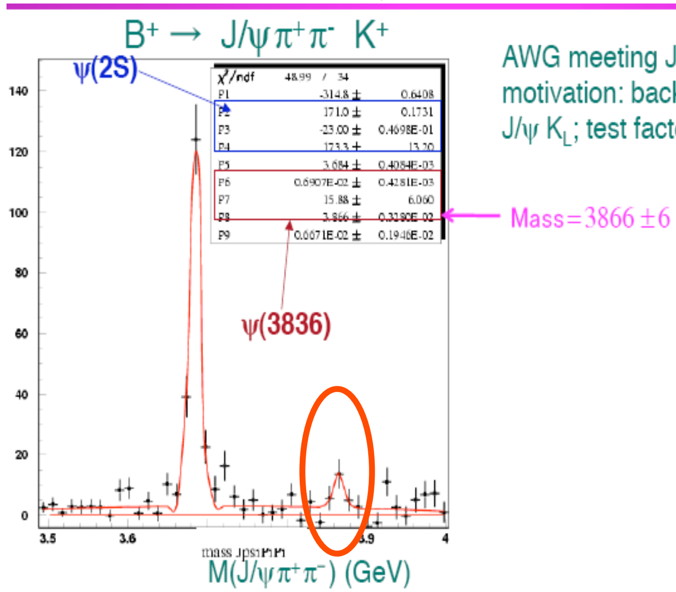


E705, PRD 50, 4258 (1994)

E705 claimed ψ(3836) in 1994



BaBar internal, 2003



AWG meeting June 2003
motivation: background to
J/ψ K_L; test factorization…

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

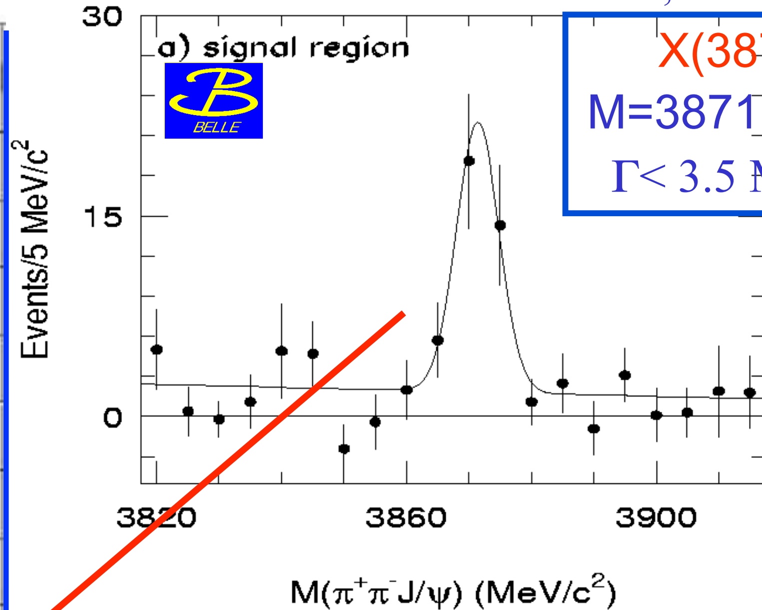
Both CDF and Babar spotted hints of X(3872) before its discovery!

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

X(3872)--2003

PRL 91, 262001

$N^{2S+1}L_J$	J^{PC}	$u\bar{d}, u\bar{u}, d\bar{d}$ $I=1$	$u\bar{u}, d\bar{d}, s\bar{s}$ $I=0$	$c\bar{c}$ $I=0$
$1\,^1S_0$	0^{-+}	π	η, η'	$\eta_c(1S)$
$1\,^3S_1$	1^{--}	ρ	ω, ϕ	$J/\psi(1S)$
$1\,^1P_1$	1^{+-}	$b_1(1235)$	$h_1(1170), h_1(1380)$	$h_c(1P)$
$1\,^3P_0$	0^{++}	$a_0(1450)^*$	$f_0(1370)^*, f_0(1710)^*$	$\chi_{c0}(1P)$
$1\,^3P_1$	1^{++}	$a_1(1260)$	$f_1(1285), f_1(1420)$	$\chi_{c1}(1P)$
$1\,^3P_2$	2^{++}	$a_2(1320)$	$f_2(1270), f_2'(1525)$	$\chi_{c2}(1P)$
$1\,^1D_2$	2^{-+}	$\pi_2(1670)$	$\eta_2(1645), \eta_2(1870)$	
$1\,^3D_1$	1^{--}	$\rho(1700)$	$\omega(1650)$	$\psi(3770)$
$1\,^3D_2$	2^{--}			??
$1\,^3D_3$	3^{--}	$\rho_3(1690)$	$\omega_3(1670), \phi_3(1850)$	
$1\,^3F_4$	4^{++}	$a_4(2040)$	$f_4(2050), f_4(2220)$	
$2\,^1S_0$	0^{-+}	$\pi(1300)$	$\eta(1295), \eta(1440)$	$\eta_c(2S)$
$2\,^3S_1$	1^{--}	$\rho(1450)$	$\omega(1420), \phi(1680)$	$\psi(2S)$
$2\,^3P_2$	2^{++}	$a_2(1700)$	$f_2(1950), f_2(2010)$	
$3\,^1S_0$	0^{-+}	$\pi(1800)$	$\eta(1760)$	



$X(3872) \to J/\psi\pi^+\pi^-$
M=3871.8±0.7±0.4 MeV
Γ< 3.5 MeV @ 90% CL

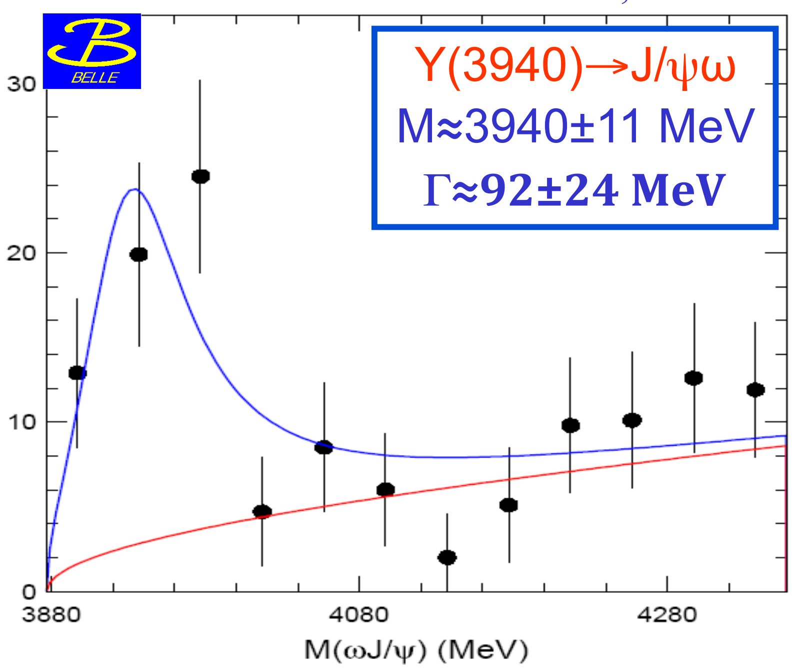
(Problematic) features

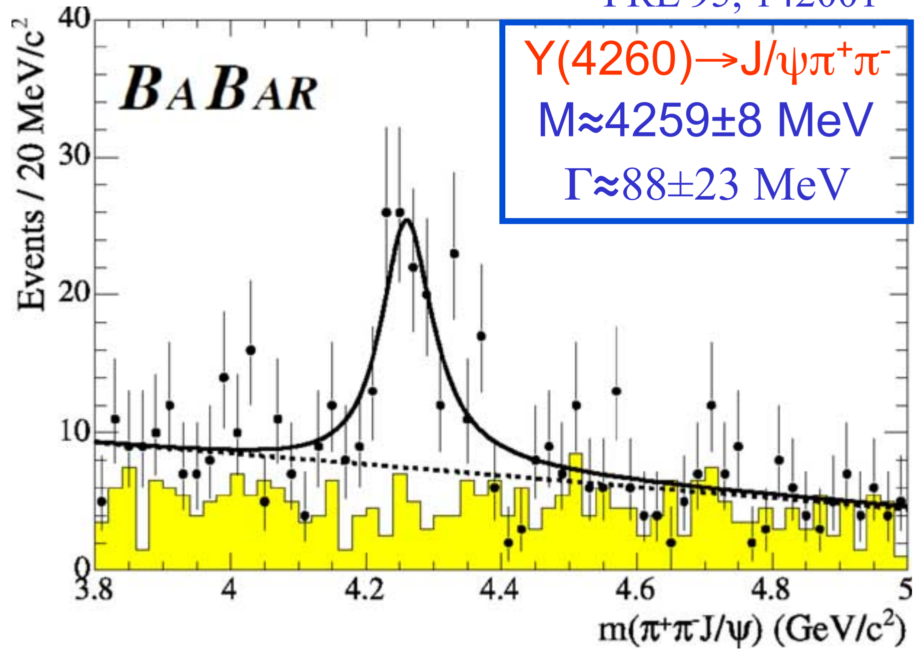
mass ~70 MeV > 1^3D_2 charmonium, J^{PC} = 1^{++} or 2^{-+}
$M(\pi^+\pi^-)$ peaks as a ρ, C=+, isospin=1 (charmonium--0)
Decays to $J/\Psi\gamma$ & $\Psi'\gamma$, suppressed for 2^{-+}

Mass close to DD, molecule is speculated*
No charged partners observed, tetra-quark?
similar rate as charmoniums at hadron colliders.
mixture of a DD molecule and the 2^3P_1 charmonium?*

First particle challenging charmonium model, revitalized exotic meson study

$Y(3940) \rightarrow J/\psi\omega$, $Y(4260) \rightarrow J\psi\pi^+\pi^-$--2005



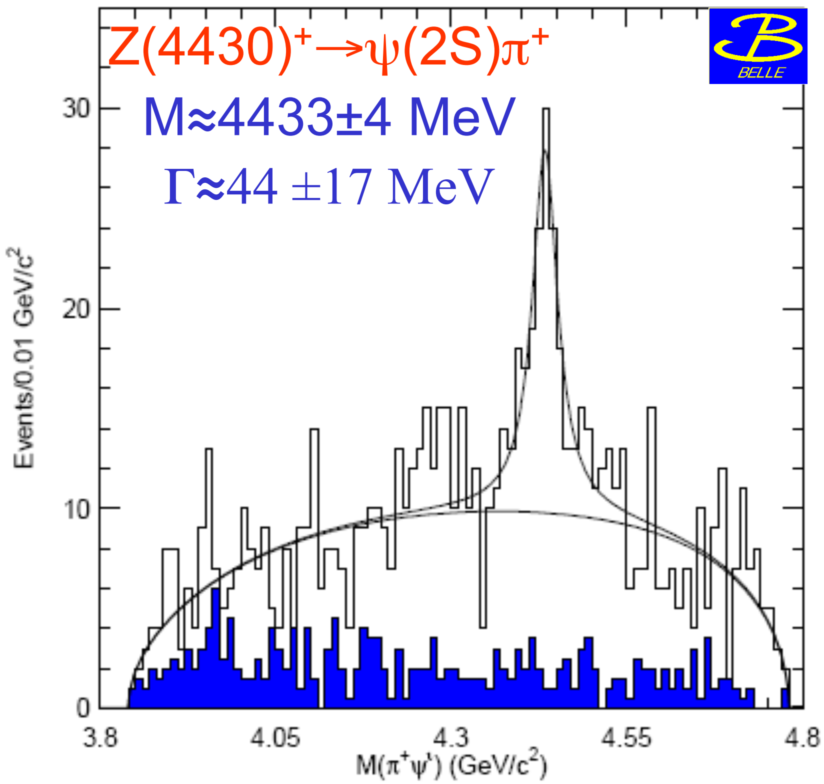


Above $D\bar{D}$ & $D\bar{D}^*$ threshold,
Tiny branching fraction expected
New mass and width from BaBar:
$M \approx 3919.1^{+3.8}_{-3.4} \pm 2.0$, $\Gamma \approx 31^{+10}_{-8} \pm 5$ MeV
arXiv:1012.0074 [hep-ex]
at the $J/\psi\omega$ threshold ***?***

Well above $D\bar{D}$ & $D\bar{D}^*$ threshold,
Tiny branching fraction expected
$J^{PC}=1^{--}$, plus Y(4350), Y(4660)
too many 1^{--} ?

$Z(4430)^+ \to \psi(2S)\pi^+$--2008

PRL 100, 142001



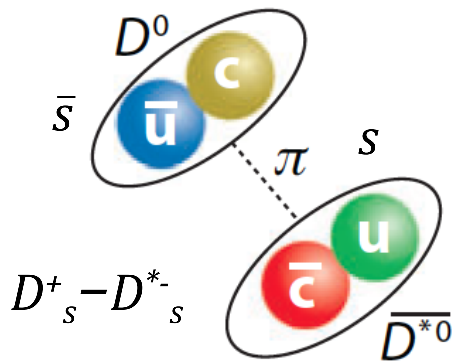
The first charged charmonium-like state, a smoking gun if confirmed

Babar disagrees with Belle

Many more new states…
They do not fit into charmonium expectation
Has been extended to bottomonium system

Beyond $(q\bar{q})$ mesons: exotic mesons?

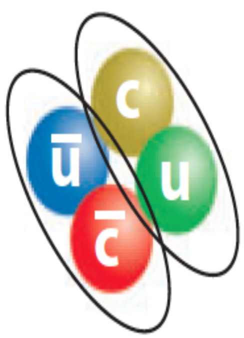
Exotic Models-I



D^0–$\overline{D}^{*0}$ "molecule"

<u>***Molecular***</u>

*Loosely bound state of a pair of mesons. The dominant binding mechanism should be **pion exchange**. Being weakly bound the mesons tend to decay as if they were free*



Diquark–diantiquark

<u>***Tetraquark***</u>

Bound state of four quarks, i.e. $\boldsymbol{qq\bar{q}\bar{q}}$ *in which the quarks group into color triplet scalar or vector clusters*

Strong decays proceed via rearrangement processes

Distinctive features of multi-quark picture with respect to charmonium:

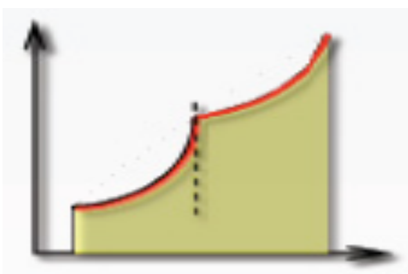
- *prediction of many new states*
- *possible existence of states with non-zero charge, strangeness or both*

Exotic Models-II

Charmonium hybrids

States with excited gluonic degrees of freedom;
exotic $J^{PC}=0^{+-}, 1^{-+}, 2^{+-}$... not allowed for charmonium.
Smoking gun for exotic states.

Lattice QCD for 1^{-+}: $m \sim 4.3\pm0.05$ GeV (C. Thomas)



Threshold, cusp, or coupled-channel effect giving a cross section enhancement which may not correspond to resonance production at all

Hadro-charmonium

Light hadrons bounded by van der Waal's force to a charmonium core in the case where the light hadron is a highly excited resonance.

We know something is going on even though we do not know exactly what!
New kind(s) of spectroscopy with complex binding forces?

How about ***$J/\psi\phi$ system?*** *(threshold @4.116 GeV, VV, C=+)*
(cc) with a mass above 4.116 GeV, expect tiny branching fraction to $J/\Psi\phi$.

Charmonium hybrid → $J/\psi\phi$?

PRD 57, 5653 (1998)
F. Close et al

J^{PC}	Open charm	Hidden charm
0^{+-}	Quantum numbers forbid $D^{(*)}D^{(*)}$	$J/\psi\{f_{\{0,1,2\}},(\pi\pi)_S\}$ $h_c\eta;\ \eta_c h_1$ $\chi_{c0}\omega$ $\chi_{c\{1,2\}}\{\omega,h_1,\gamma\}$
0^{--}	D^*D	$h_c(\pi\pi)_S$ $J/\psi\{f_{\{1,2\}},\eta^{(\prime)}\}$ $\chi_{c0}h_1;\ \eta_c\{\omega,\phi\}$ $\chi_{c\{1,2\}}\{\omega,h_1,\gamma\}$
1^{-+}	$D^*D,\ D^*D^*$	$\chi_{c\{0,1,2\}}(\pi\pi)_S$ $\eta_c\{f_{\{1,2\}},\eta^{(\prime)}\}$ $\chi_{c\{1,2\}}\eta$ $\{h_c,J/\psi\}\{\omega,h_1,\phi,\gamma\}$
2^{+-}	$D^*D,\ D^*D^*$	$\{h_c,J/\psi\}\{f_{\{0,1,2\}},(\pi\pi)_S\}$ $\{h_c,J/\psi\}\eta^{(\prime)}$ $\{\eta_c,\chi_{c\{0,1,2\}}\}\{\omega,h_1,\phi,\gamma\}$

Accessible at CMS

Considered to be the ground exotic state, mass prediction from 3.9 to 5.3 GeV
Most recent Lattice QCD calculation: 4.3 ±0.05 GeV

Multi-quark states → $J/\psi\phi$?

J^{PC}	M(MeV)	Decay Channel
0^{++}	3834	-
0^{++}	3927	$J/\psi\ \omega$
0^{-+}	4277(+15)	$J/\psi\ \phi$, $J/\psi\ \omega$, $D_s^{*+} D_s^{*-}$
0^{-+}	4312(+30)	$J/\psi\ \phi$, $J/\psi\ \omega$, $D_s^{*+} D_s^{*-}$
0^{--}	4297(-5)	$\psi\ \eta(\eta')$, $D_s^{+} D_s^{*-}$
1^{++}	3890	$J/\psi\ \omega$
1^{+-}	3870	$J/\psi\ \eta$
1^{+-}	3905	$J/\psi\ \eta$
1^{-+}	4321(+15)	$J/\psi\ \omega$, $J/\psi\ \phi$
1^{-+}	4356 (+30)	$J/\psi\ \omega$, $J/\psi\ \phi$
1^{--}	4330	$\psi\ \eta(\eta')$, $D_s^{(*)+} D_s^{(*)-}$; $J/\psi\ f_0(980)$
1^{--}	4341(-5)	$\psi\ \eta(\eta')$, $D_s^{(*)+} D_s^{(*)-}$; $J/\psi\ f_0(980)$
1^{--}	4390(+40)	$\psi\ \eta(\eta')$, $D_s^{(*)+} D_s^{(*)-}$; $J/\psi\ f_0(980)$
1^{--}	4289(-41)	$\psi\ \eta(\eta')$, $D_s^{(*)+} D_s^{(*)-}$; $J/\psi\ f_0(980)$

← *arXiv:0902.2803*
N. V. Drenska et al

$J/\psi\phi$ *is well motivated!*

How to search?

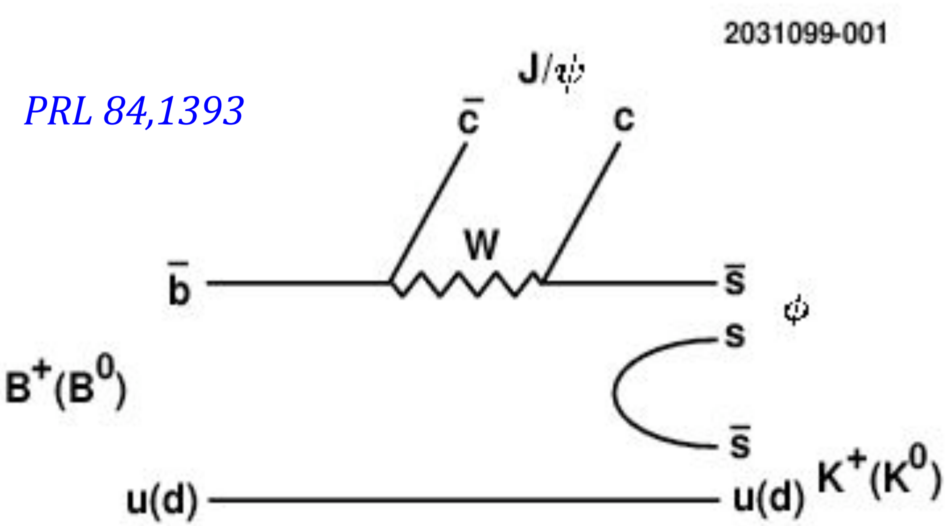
Inclusive? Challenge!

Through B decays!

Search structures ➔J/ψϕ through B decays

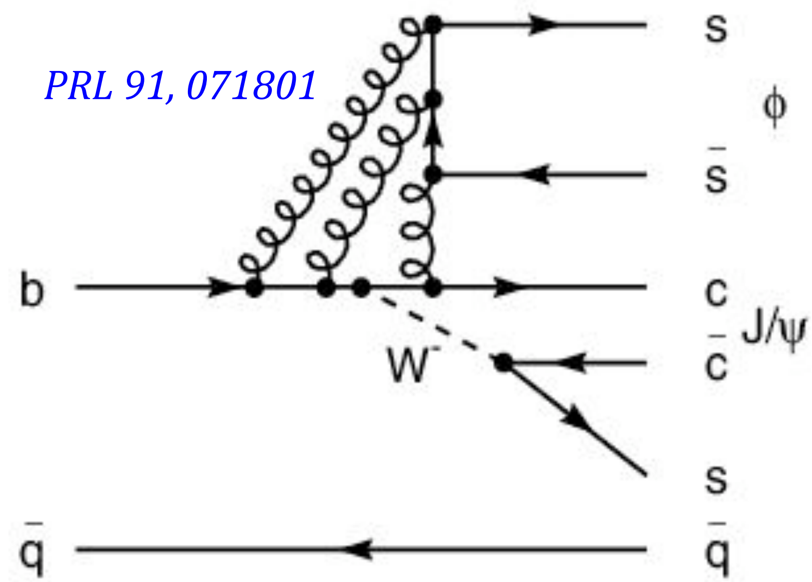
- *Experimentally attractive to search through clean B→J/ψϕK channel*
  -- taking advantage of B lifetime and narrow B mass window
  -- B➔J/ψϕK is OZI suppressed, so low rate from phase space decays
  -- constrained phase space favor forming of two-body structures.

PRL 84,1393



vacuum polarization

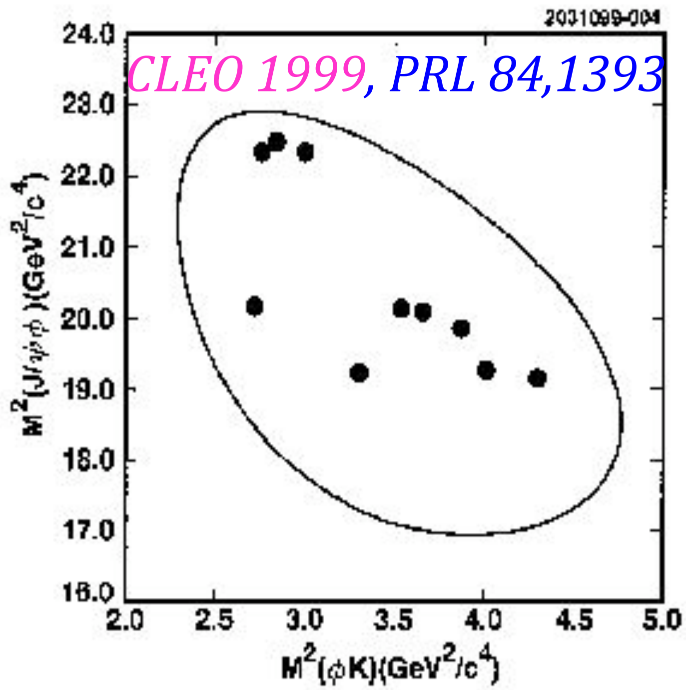
PRL 91, 071801



gluon coupling

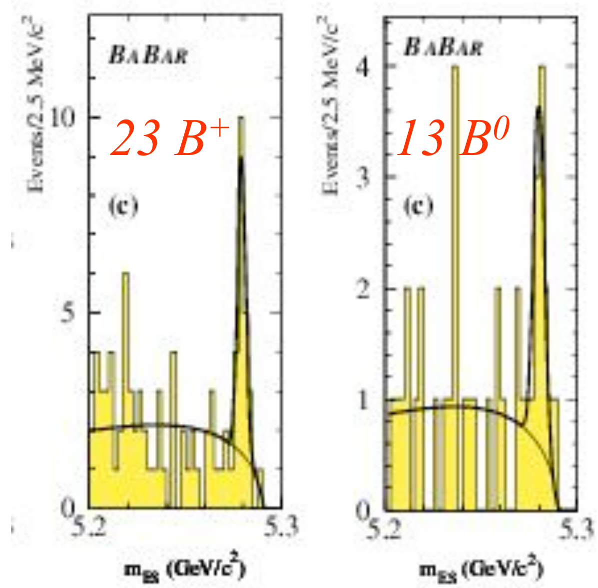
The status before Original CDF Report

- *The **status** through $B \to J/\psi\phi K$:*



$J/\psi \to \mu\mu$ and ee, 10 B^+ and B^0

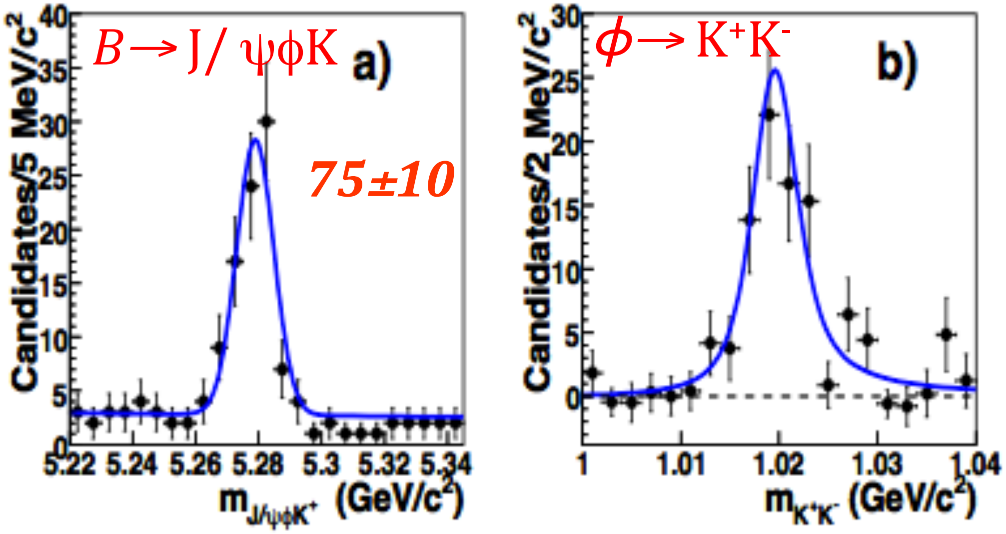
BaBar 2003, PRL 91, 071801



$J/\psi \to \mu\mu$ and ee

- *statistically limited, no structures reported*

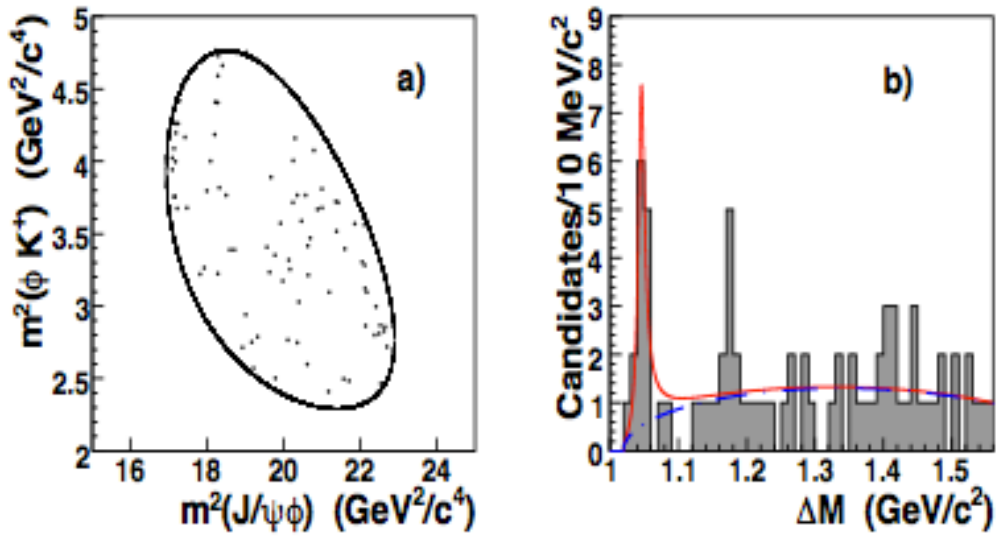
First Report by CDF w/ 2.7 fb^{-1} (2009)



PRL 102:242002, 2009

Purity ~80% in B^+ region

Nice ϕ shape



Dalitz plot $\Delta M = m(\mu^+\mu^- K^+ K^-) - m(\mu^+\mu^-)$

Near threshold peak, called Y(4140)

Significance: ~4σ

Yield =14±5

M= 4143.0 ± 2.9 (stat)± 1.2 (syst) MeV

Γ = $11.7^{+8.3}_{-5.0}$ (stat) ± 3.7(syst) MeV

Not likely to be charonium:

High mass w/ narrow width

Reflection in Three-body Decays

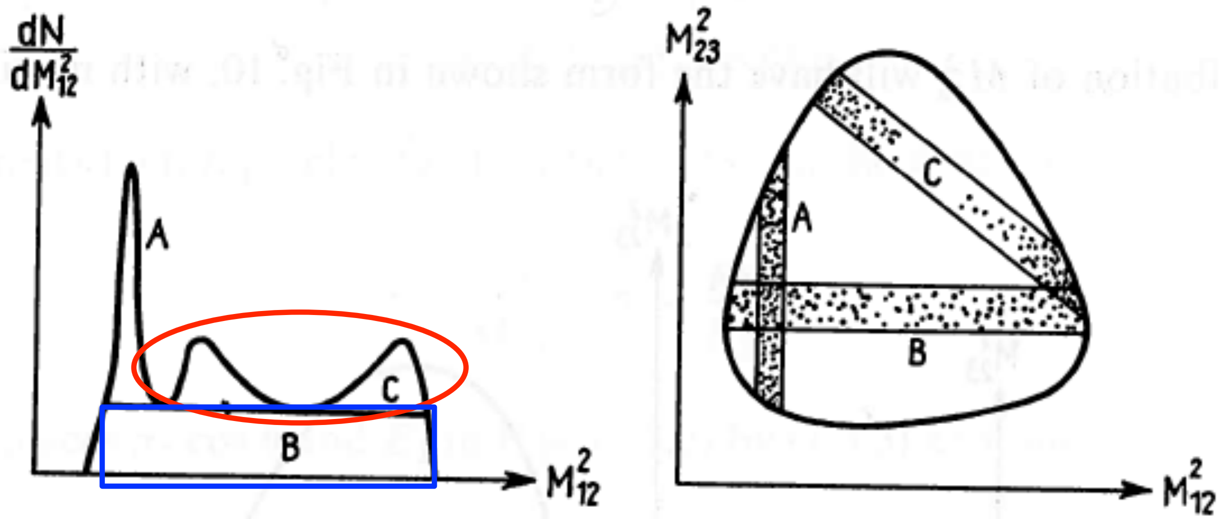


Fig. 11

Three resonances:
A ➔ M_{12}
B ➔ M_{23}
C ➔ M_{13}

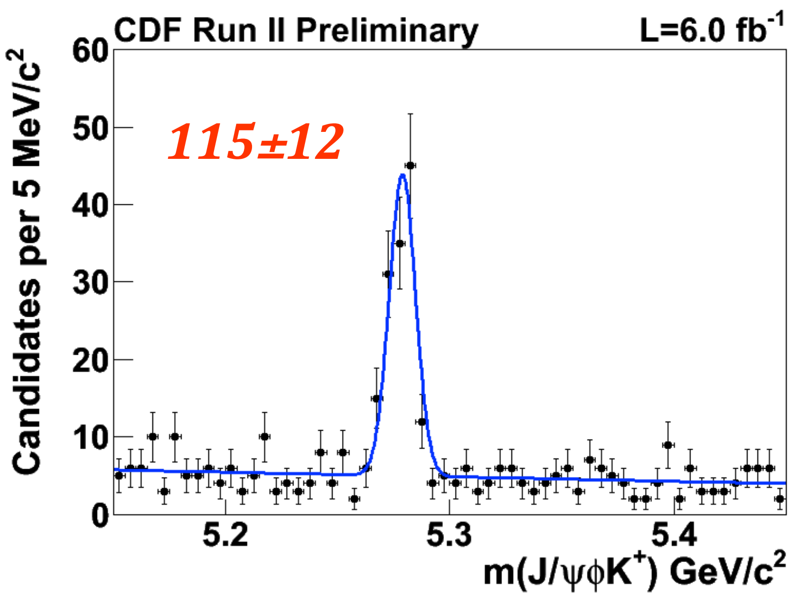
Example: ρ^+, N^{*++}, N^{*+} in
$\pi^+ + p \rightarrow \pi^+ + \pi^0 + p$

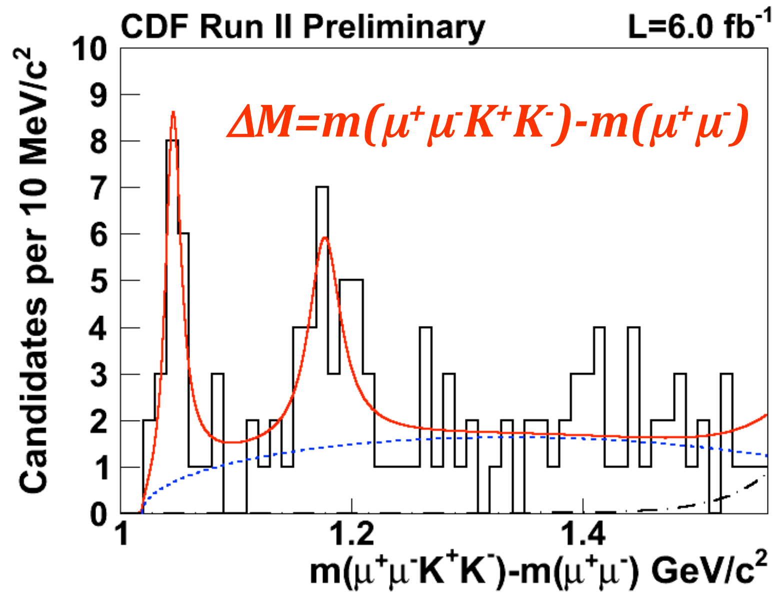
Depending on J^{PC}, B & C can be structure-less or structures in M_{12}. In this example, B shows flat distribution in M_{12} and C shows up two structures in M_{12}.

There are no established resonances in m(ϕK^+) (possible hint for K_1 & K_2) and m($J/\Psi K^+$), CDF was limited by statistics and state:

"We find no evidence for any other structure in the φK^+ and $J/\psi K^+$ spectrum; the only structure [i.e. $K_2(1770)$] that has been claimed in the φK^+ spectrum by previous experiments is too broad to alter our analysis" *Re-visit later.*

Update from CDF w/ 6.0 fb^{-1} (2010)





arXiv:1101.6058 [hep-ex]

$Yield_1$ =19±6; >5σ

M_1= $4143.4^{+2.9}_{-3.0}$ (stat)± 0.6 (syst) MeV

Γ_1 = $15.3^{+10.4}_{-6.1}$ (stat) ± 2.5(syst) MeV

$Yield_2$ =22±8; 3.1σ

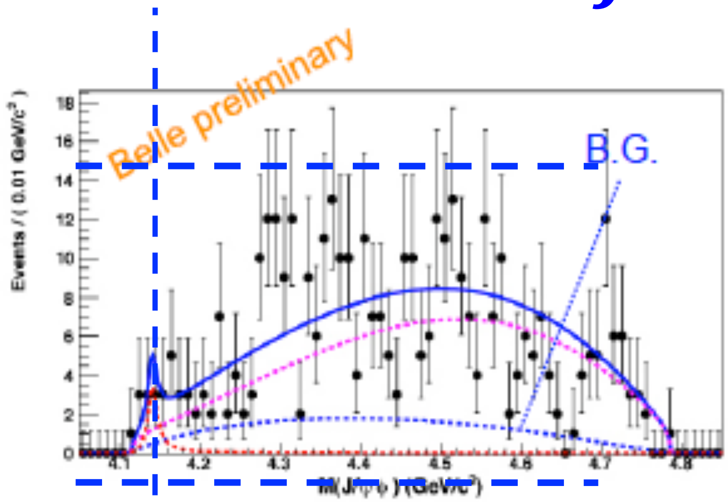
M_2= $4277.4^{+8.4}_{-6.7}$ (stat)± 1.9 (syst) MeV

Γ_2= $32.3.7^{+21.9}_{-15.3}$ (stat) ± 7.6(syst) MeV

χ^2/dof between old and new Δm is 7.2/3, p-value=6.5% w/ four regions

$$\frac{\mathcal{B}(B^+\to Y(4140)K^+, Y(4140)\to J/\psi\phi)}{\mathcal{B}(B^+\to J/\psi\phi K^+)} = 0.149 \pm 0.039(\mathrm{stat}) \pm 0.034(\mathrm{syst})$$

Belle: Confirm or Refute? (2009, 2010)

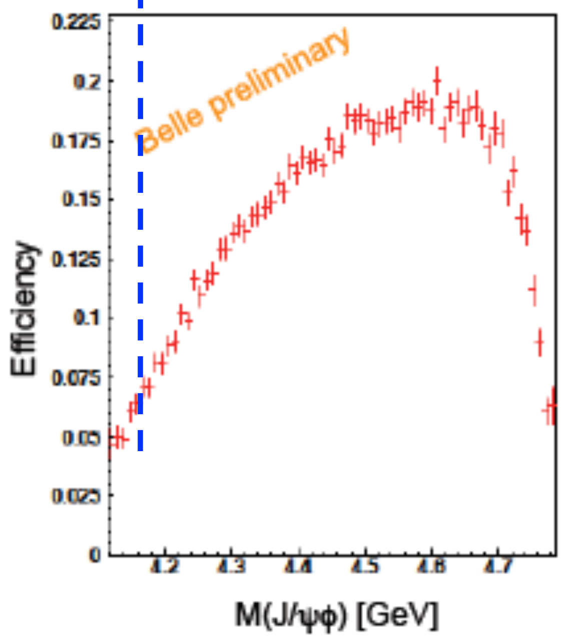


Y(4140): 7.5 +4.9/-4.4events
Statistical significance: 1.9σ
Signal could not be identified.

Summary

- *B factories suffer from low pt track efficiency*
- *Belle cannot confirm or deny the existence of Y(4140)*
- *Tevatron edge over B factories:*
  Low p_T kaons are boosted from B momentum

no verdict from Babar

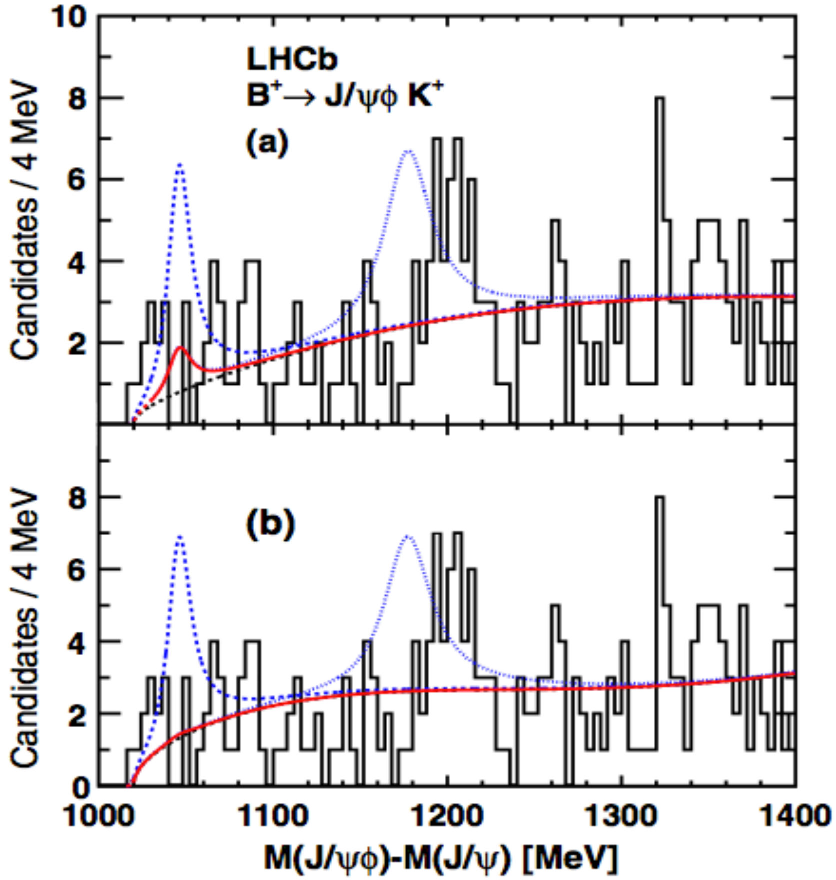


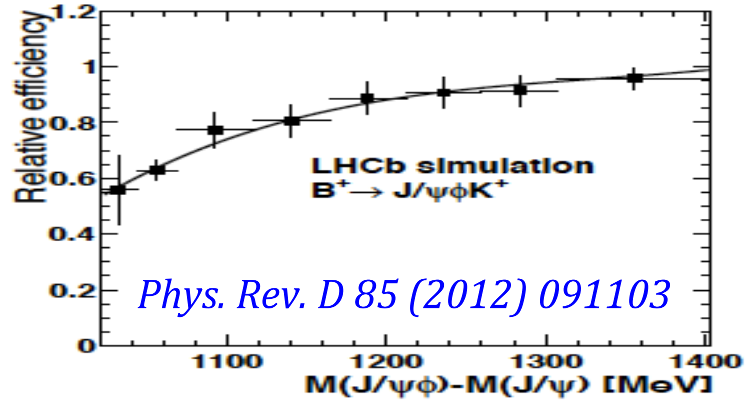
Note: CDF and Belle do not contradict each other.
In Belle, B meson at rest on ϒ(4S) rest frame, Kaon momentum from φ decay is low, especially just above J/ψφ threshold
→ lower reconstruction efficiency.

Kenkichi Miyabayashi
(Nara Women's Univ.)
2010 May QWG7

QWG 2010

LHC_b: Contests CDF Report (2011)





LHC_b confirms neither structure(s)

2.4σ disagreement with CDF measurement @90% CL:

$$\frac{\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi\,\phi)}{\mathcal{B}(B^+ \to J/\psi\,\phi K^+)} < 0.07.$$

$$\frac{\mathcal{B}(B^+ \to X(4274)K^+) \times \mathcal{B}(X(4274) \to J/\psi\,\phi)}{\mathcal{B}(B^+ \to J/\psi\,\phi K^+)} < 0.08$$

LHCb Versus CDF: Two Punches In The Face!

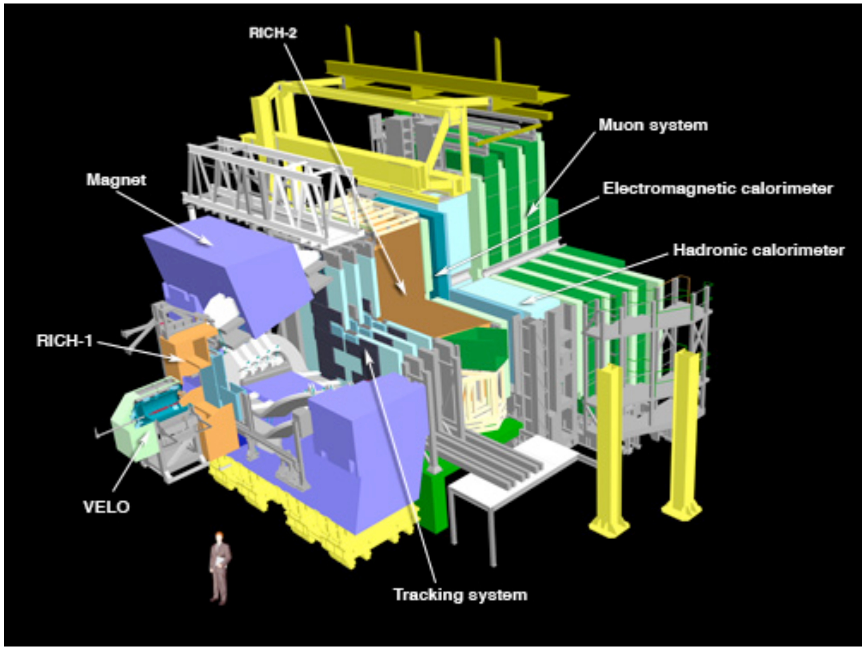
By Tommaso Dorigo | July 27th 2011 05:48 AM | 10 comments | Print | E-mail | Track

The first is the tentative observation ofa new hadron, called

Y(4140), a bump observed in the invariant mass of pairs of

result. Note that, as reported in the figure, if the CDF signal were as estimated by CDF, LHCb would have been able to fit 39+-9+-6 events. The Y(4140) is on very shaky ground at the moment, and the new PDG will likely change its status in the particle zoo... This is punch number 1.

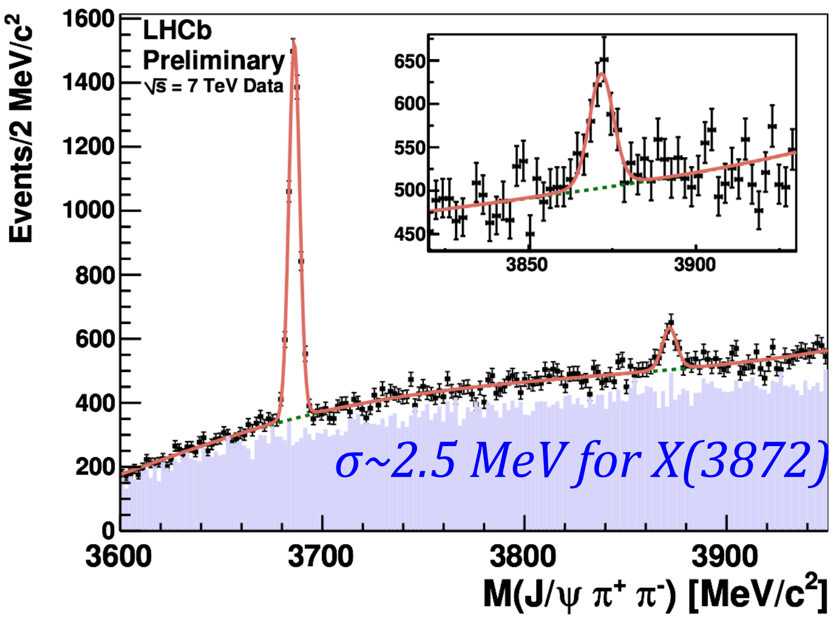
LHC$_b$: Contests CDF Report (2011)



LHCb is specifically designed to select Bottom/charm/exotic-quarkonium particles and the products of their decays

Excellent lepton and hadron Identification

Excellent mass resolution
~2.5 MeV for X(3872) decays

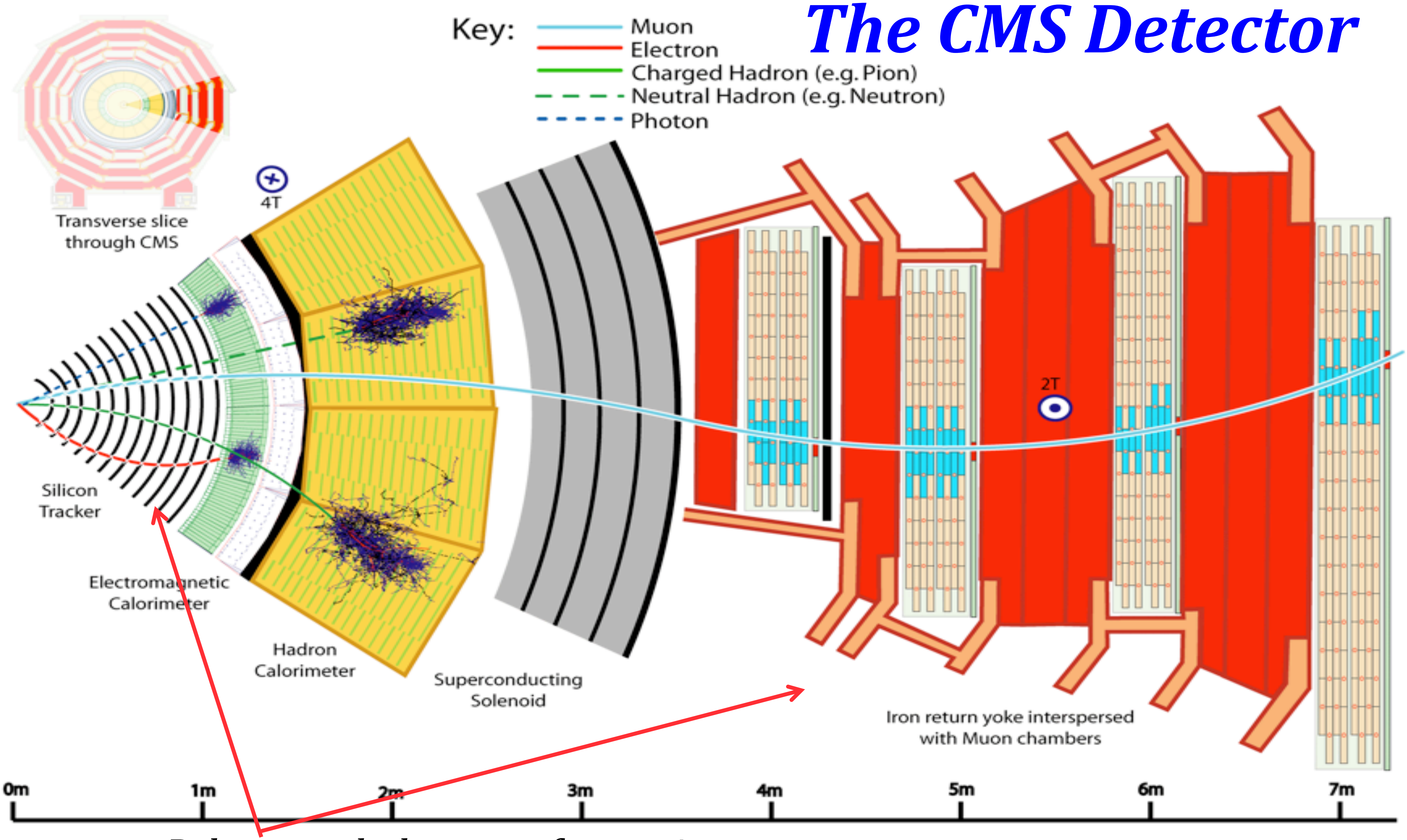


BUT LHCb did not confirm the existence of Y(4140). A serious challenge!

A result from a 3rd experiment is important!

For instance, CMS?

The CMS Detector

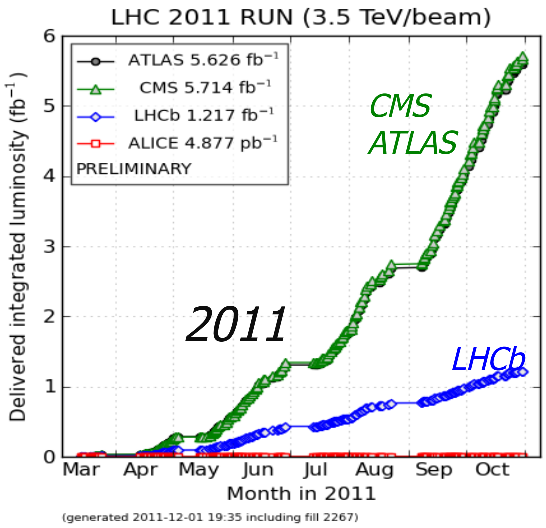


Relevant sub-detectors for exotic meson

CMS Detector Performance

Excellent muon/silicon detectors for quarkonium:

- *Muon system*
  - *High-purity muon identification*
  - *Good dimuon mass resolution ($\Delta m/m \sim 0.6\%$ for J/Ψ)*
- *Silicon Tracking detector*
  - *excellent track momentum resolution ($\Delta p_T/p_T \sim 1\%$)*
  - *excellent vertex reconstruction and impact parameter resolution*



LHC luminosity and CMS trigger:

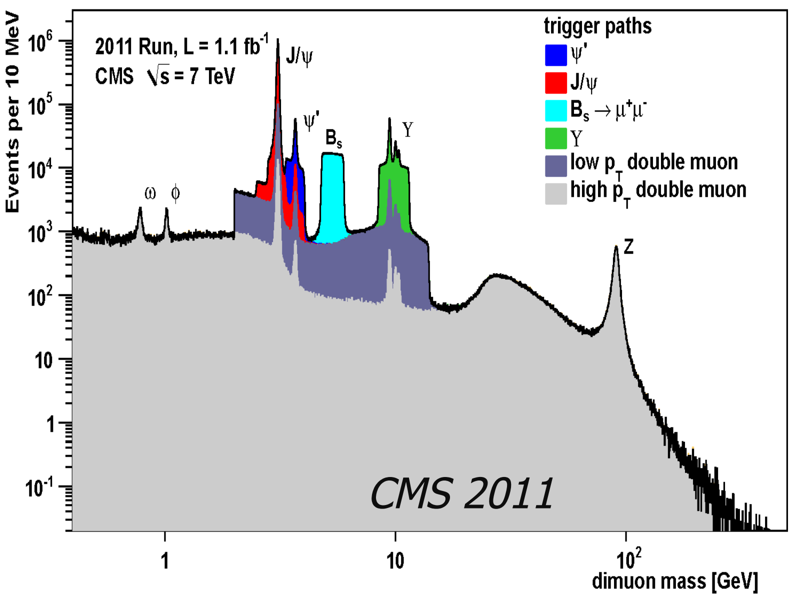
- *collect data at increasing instantaneous luminosity*
  - *about 5fb⁻¹ from 2011 data at √s=7 TeV*

    (used for this analysis)
- *Triggers are essential ingredients*
  - *Special trigger for different analysis*

    For this analysis:

    displaced dimuon vertex &

    minimum (di)muon transverse momentum

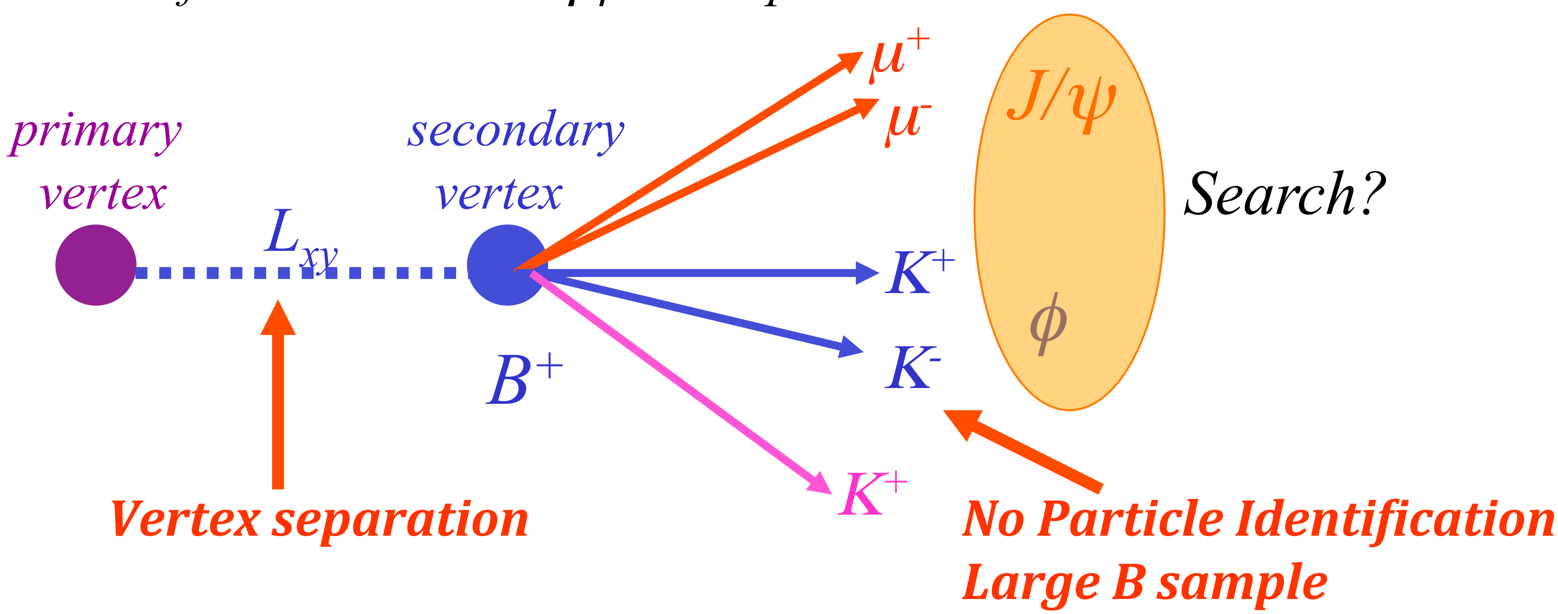


J/Ψφ analysis strategy (CMS 2012)

- *I) Reconstruct B^+ as:*

$$B^+ \to J/\psi\phi\, K^+$$
$$J/\psi \to \mu^+\mu^-$$
$$\phi \to K^+K^-$$

- *II) Search for structure in $J/\psi\phi$ mass spectrum inside B^+ mass window*



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH11026

CMS: BPH-11-026

Event Selections (CMS 2012)

--$|\eta|$ for all tracks <=2.4

--probability(χ^2) for J/ψ vertex fit>10%, probability(χ^2) for B^+ vertex fit>1%

--p_T(kaon track)>1 GeV

--J/ψ vertex flight length significance >=3

&

Dataset A: $p_T(J/\psi)$>7 GeV [first part of the run w/ low lumi, pileup]

Dataset B: $p_T(J/\psi)$>7 GeV & both muon p_T>4 GeV

[second part of the run w/ high lumi, pileup]

--mass window:

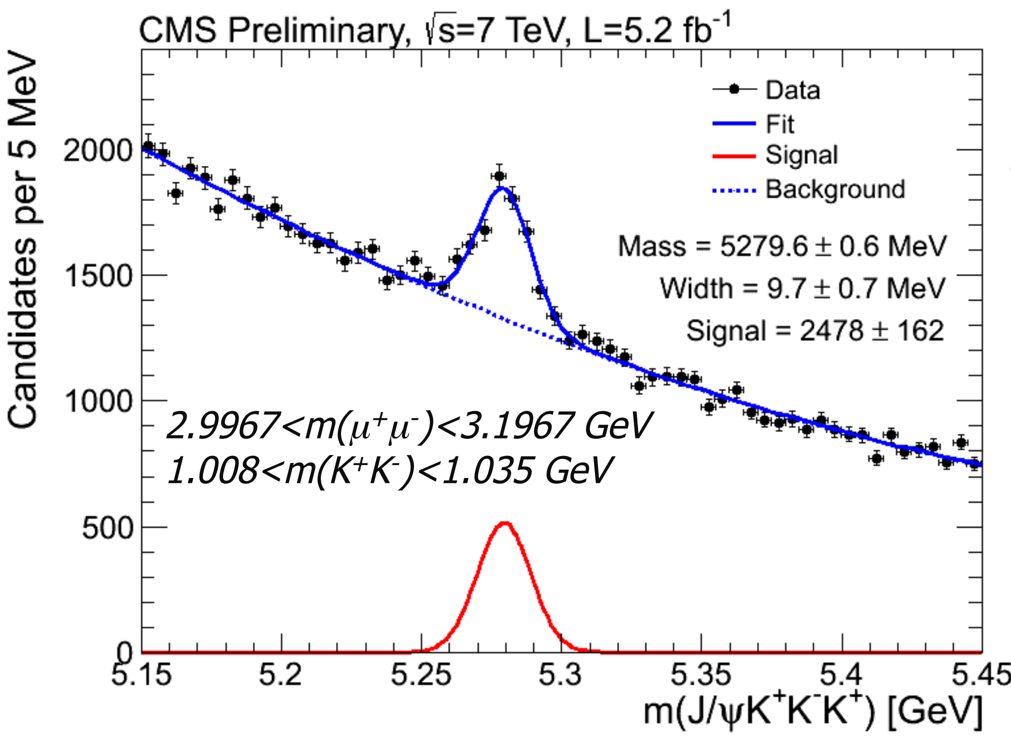
J/ψ (±150 MeV) and ϕ in [1.008, 1.035] GeV (Breit-Wigner shape)

constraint $\mu^+\mu^-$ to J/ψ PDG mass value

Requirements are not optimized to be unbiased, confirm trigger requirements

The B Signal (CMS 2012)

$B^+ \rightarrow J/\psi\phi K^+$ decay



Signal PDF: Gaussian

Background PDF:
2nd-order Chebyshev polynomial

Mass: consistent with PDG value

Width: consistent with simulation

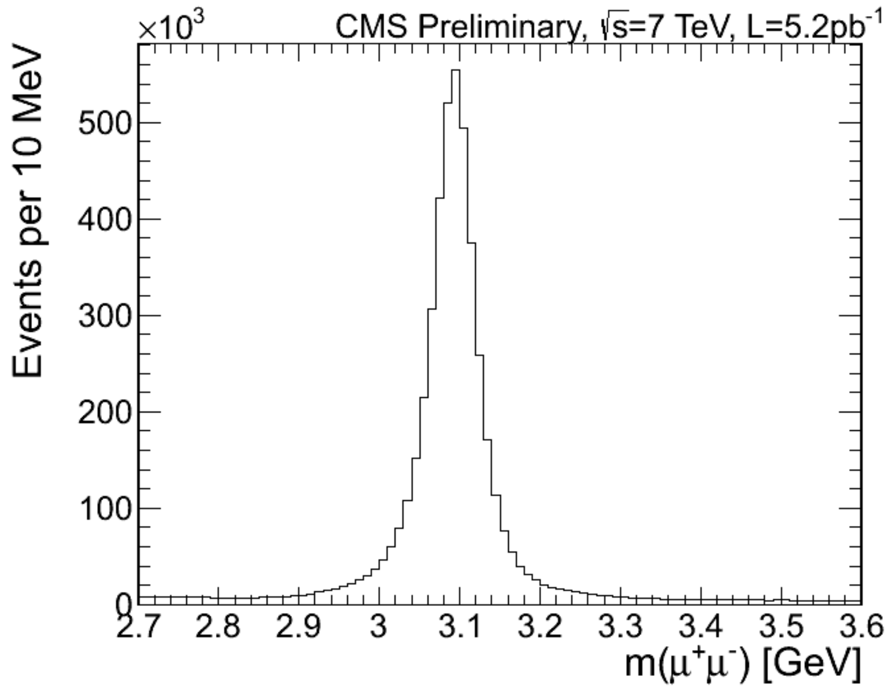
two (K^+K^-) combinations, only keep $m(K^+K^-)_{min}$ as ϕ candidate, <2% from another combination based on MC

Largest $B^+ \rightarrow J/\psi\phi K^+$ sample collected in the world to date

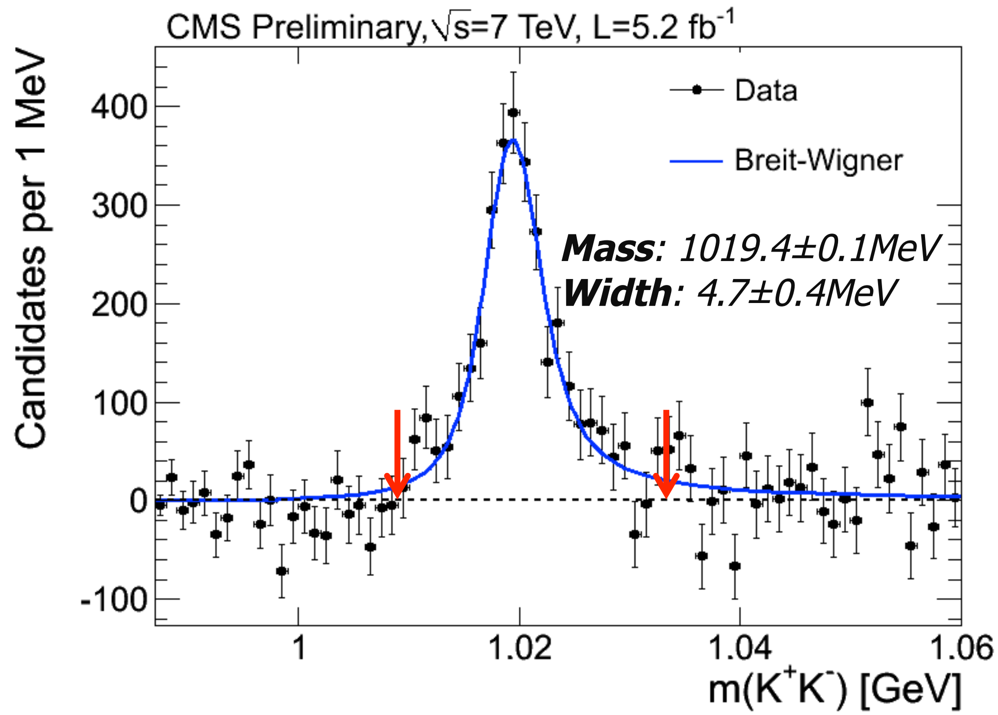
~20 times CDF statistics (115±12); ~7.2X LHCb statistics (346±20)

J/Ψ and ϕ Signal (CMS 2012)

$m(\mu^+\mu^-)$ before forming the B signal

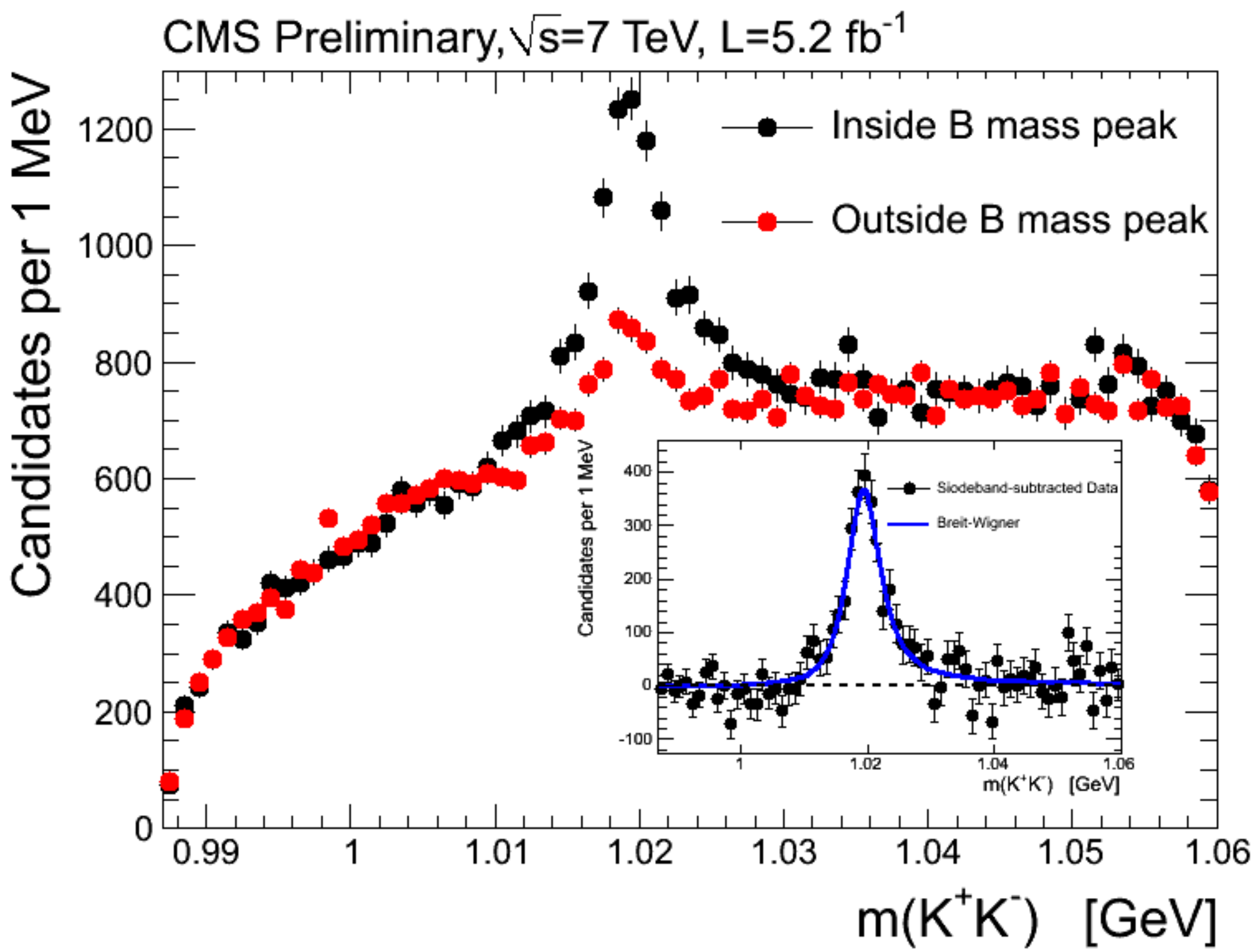


The B^+ sideband subtracted $m(K^+K^-)$ where $m(J/\psi\phi K^+)$ is within $\pm 3\sigma$ of $m(B^+)$



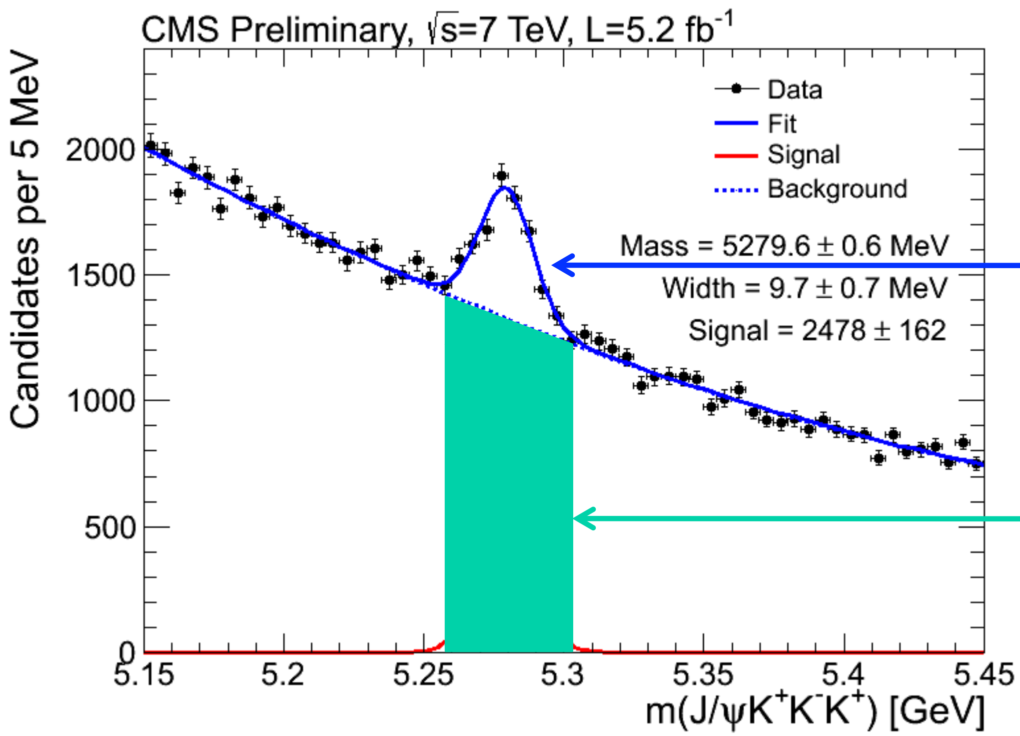
- *A clear and clean J/Ψ signal*
- *Nice ϕ lineshape, consistent with PDG parameters*
- *$B(J/\Psi\phi K^+)$ dominates after ϕ mass restriction*

The ϕ Signal (CMS 2012)



- *w/o hadron PID, we still see a clear ϕ signal inside B mass peak*

Various Components (CMS 2012)



Two big components:

$B^+ \rightarrow J/\Psi \phi K^+$

Random combinatory background
(need to be subtracted, next slide)

Possible components for $B^+ \rightarrow J/\Psi \phi K^+$ final state (ignoring interference):

1. *Phase space events: 3-body decay: $B^+ \rightarrow$ $J/\Psi \phi K^+$*
2. *Possible structures in $m(J/\Psi \phi)$: $B^+ \rightarrow XK^+$, $X \rightarrow J/\Psi \phi$ $\rightarrow$ $J/\Psi \phi K^+$*
3. *Possible structures in $m(J/\Psi K^+)$: $B^+ \rightarrow X\phi$, $X \rightarrow J/\Psi K^+$ $\rightarrow$ $J/\Psi \phi K^+$*
4. *Possible structures in $m(\phi K^+)$: $B^+ \rightarrow XJ/\Psi$, $X \rightarrow \phi K^+$ $\rightarrow$ $J/\Psi \phi K^+$*

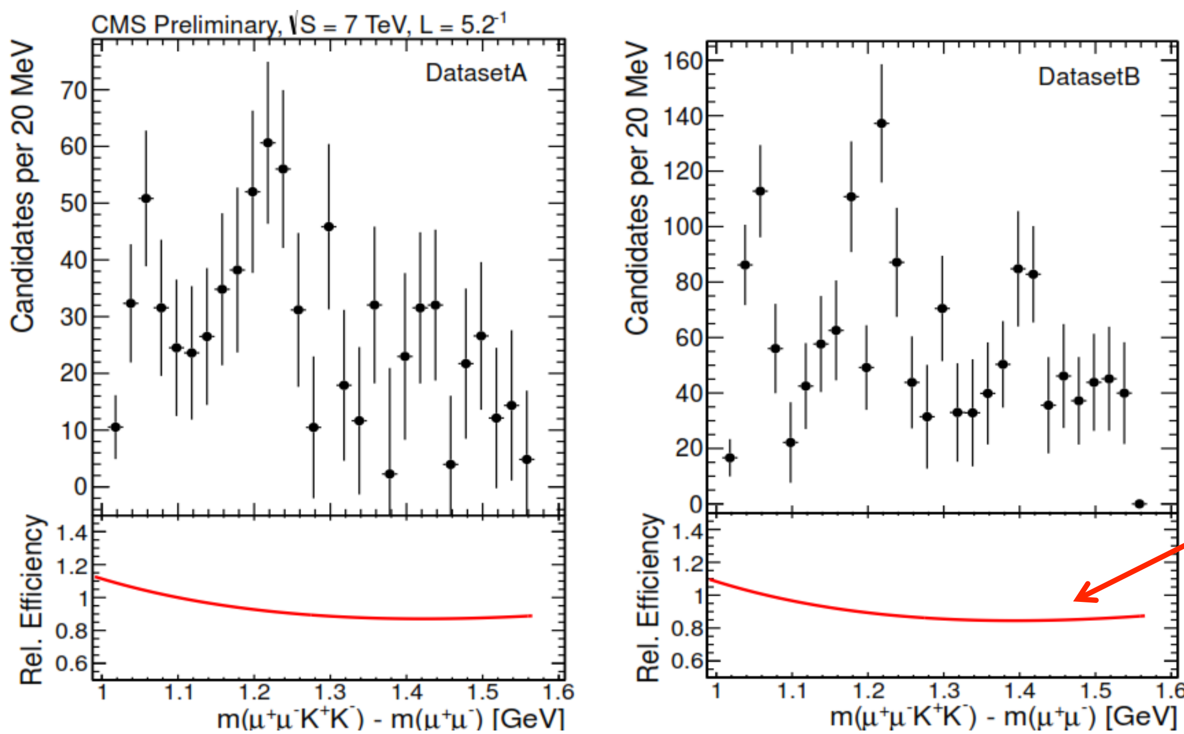
We need to sort out each component

$J/\psi\phi$ Invariant Mass Spectrum(CMS 2012)

- The mass difference $\Delta m = m(\mu^+\mu^-K^+K^-) - m(\mu^+\mu^-)$ is used

- Extracting the Δm spectrum
  - Divide the dataset into the 20 MeV Δm bins
  - Extract the number of B events for each Δm by fitting the $J/\psi\phi K$ spectrum
    - Means fixed to the PDG B mass
    - RMS fixed to the signal MC values
  - Plot the B yield as a function of Δm

$p_T(J/\psi)>7GeV$ | $p_T(J/\psi)>7GeV$ & $p_T(\mu)>4GeV$



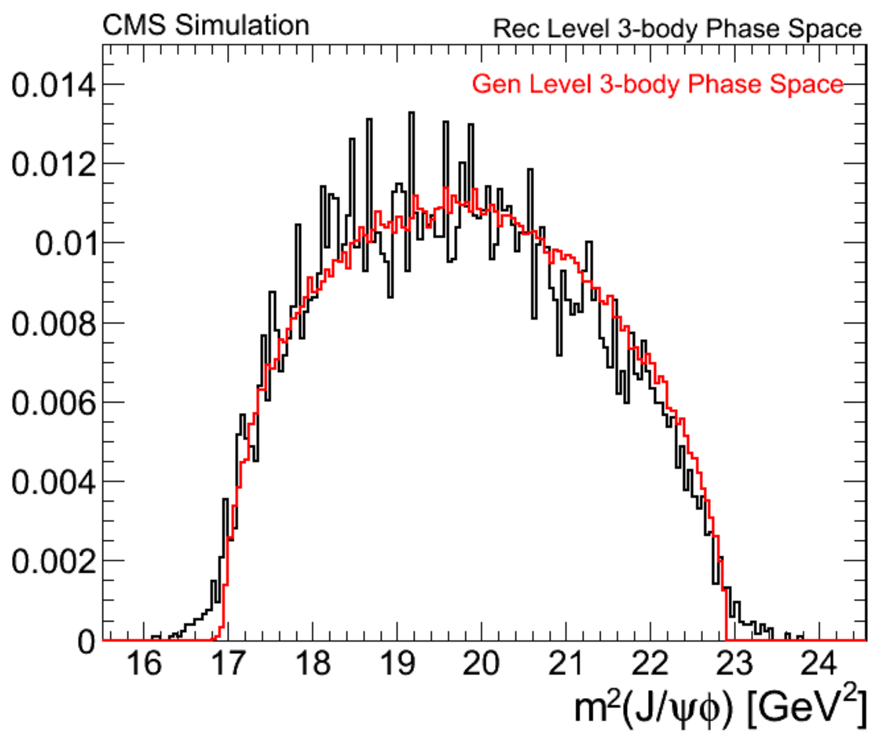
We cut-off Δm>1.568 GeV Region to avoid background From $B_s \rightarrow \psi'\phi$, $\psi' \rightarrow J/\psi\pi\pi$

correct the spectrum by efficiency before fitting

Relative efficiency over Δm : approx. flat

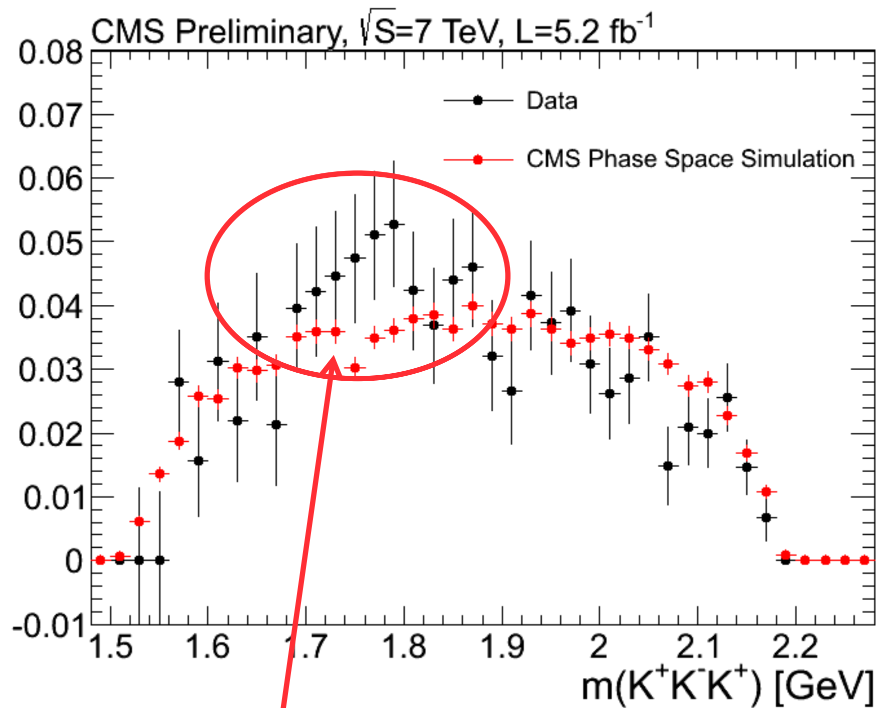
Background Shape Studies (CMS 2012)

The phase space Dalitz projection on $m^2(J/\psi\phi)$
generated events (red)
Vs
reconstructed events (black)



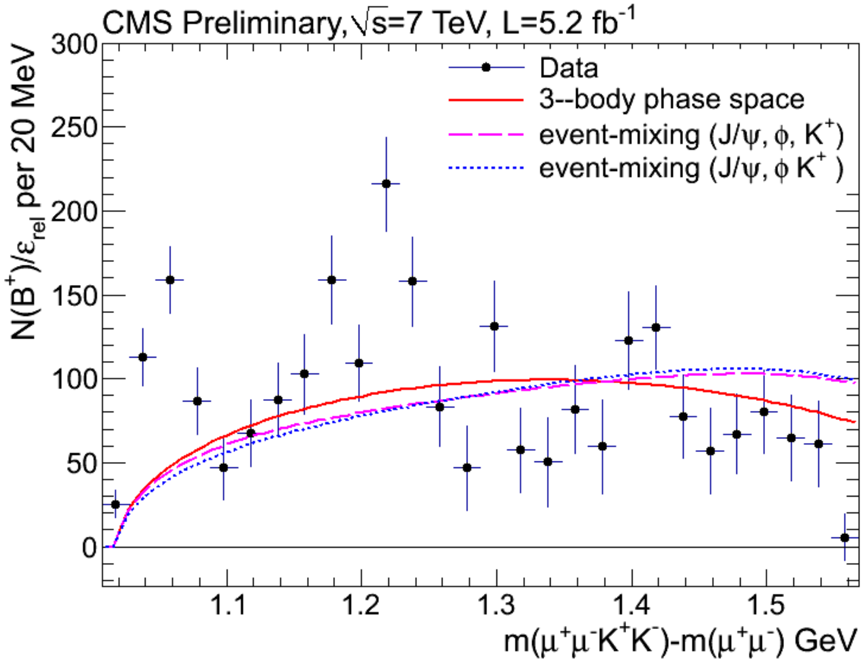
CMS detector does not produce peaks
Also imply relative flat efficiency

Sideband subtracted KKK mass
Phase Space MC (red)
Vs
data (black)



Possible $K_2(1770)$, $K_2(1820)$?
Does it effect Δm?

Background Shape Studies(CMS 2012)



Event mixing to study the Δm shape

--J/Ψ, ϕ, K^+ from different event

--ϕ, K^+ from the same event, J/Ψ from different event. This is to get the impact on Δm from possible ϕK^+ resonances

Require the $J/\Psi\phi K^+$ mass around B mass

Event-mixing Δm shapes are slightly distorted compared to three-body phase space

However, the possible effect is on high Δm region and the three-body phase space shape is more conservative at low Δm region where the two structures are observed.

Preliminary ϕK^+ Resonances Studies (CMS 2012)

- *Generated simple Dalitz plot for (ϕK^+) resonances. No similar structures seen in $m(J/\Psi\phi)$ from reflections.*
- *No evidence of structures or deviation from phase space background shape found in $m(\phi K^+)$ mass distribution after removing the two structures in $m(J/\Psi\phi)$ in the data*
- *No evidence for $m(J/\Psi K^+)$ so far*
- *Possible interference ? Could affect lineshape parameters, no big signal*
- *A full amplitude analysis is desirable, limited by statistics and high non-B combinatoric background*

T. Armstrong et al. / PWA of the $K^-\Phi$ system

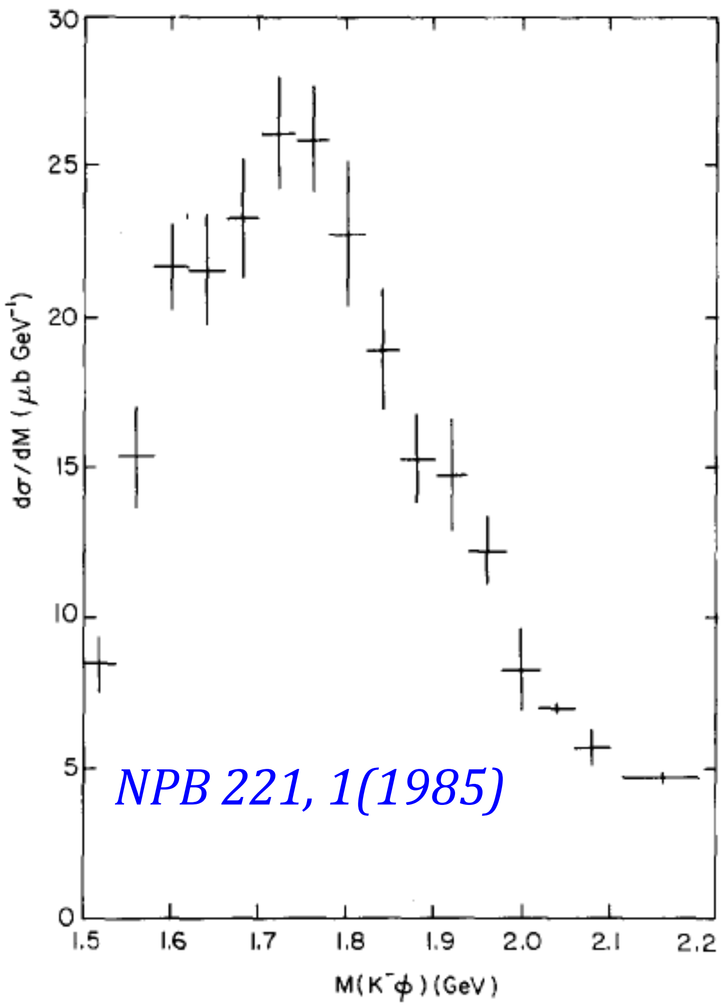


Fig. 7. Corrected $K^-\Phi$ mass spectrum for $t' < 0.8$ GeV^2.

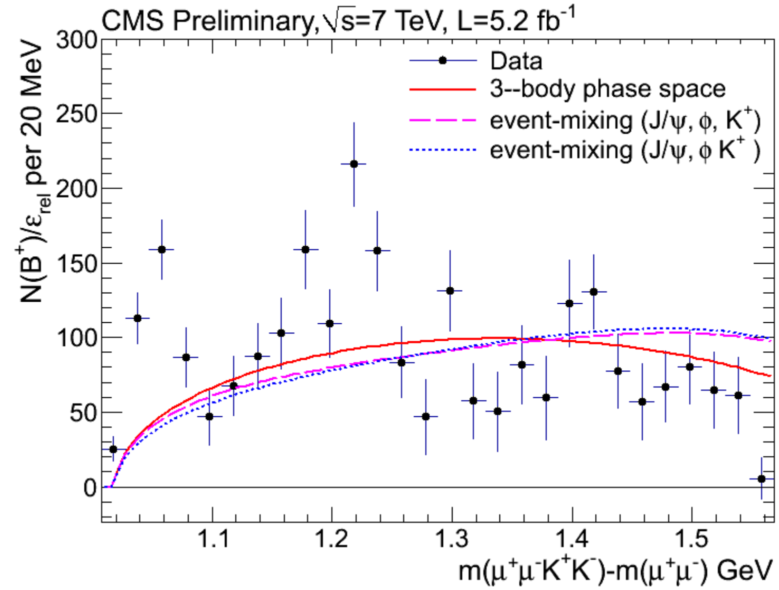
Null- and Signal-hypothesis Fits

	Mass (MeV)	Signal Yield
First Peak	1051.5 ± 2.0	355 ± 46
Second Peak	1220.0 ± 3.0	445 ± 83

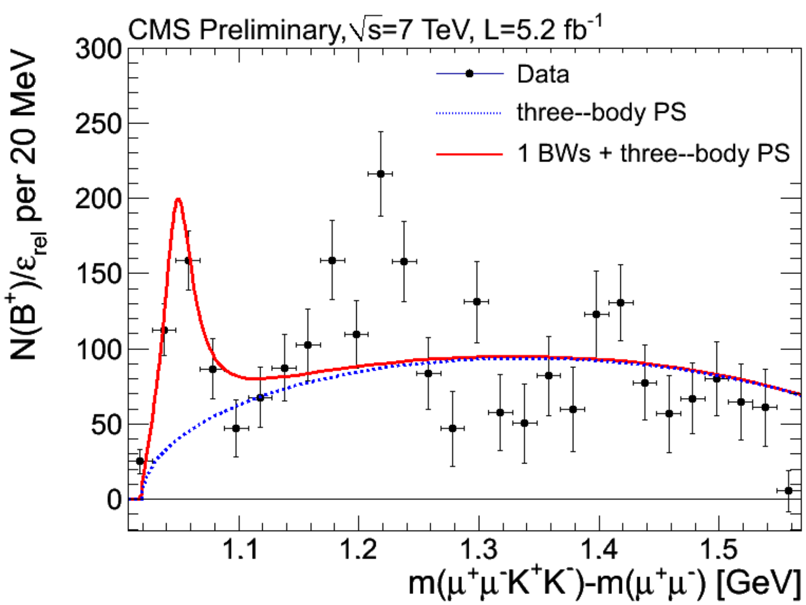
Background: 3-body phase space
Signal: S-wave relativistic Breit-Wigner functions convolved with a Gaussian resolution function

Significance: >5σ for 1st peak
evidence for 2nd peak

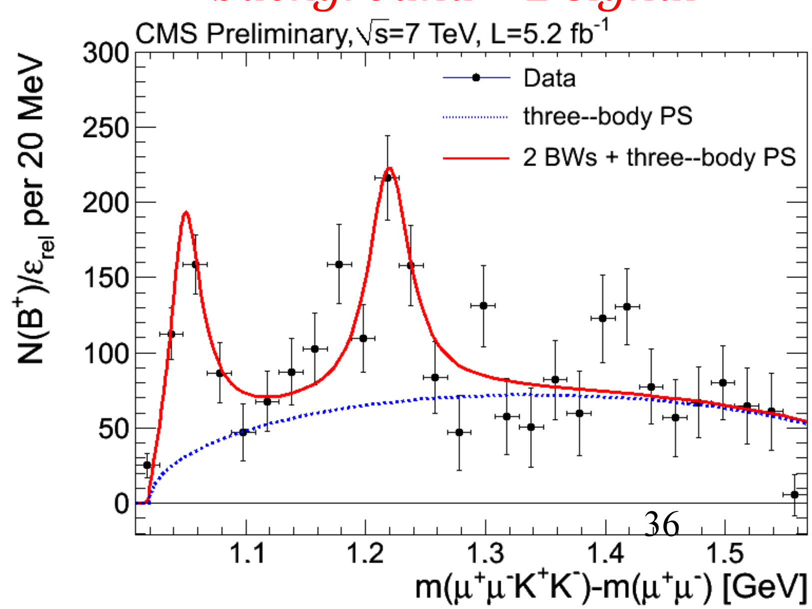
background only hypothesis



background + 1 signal



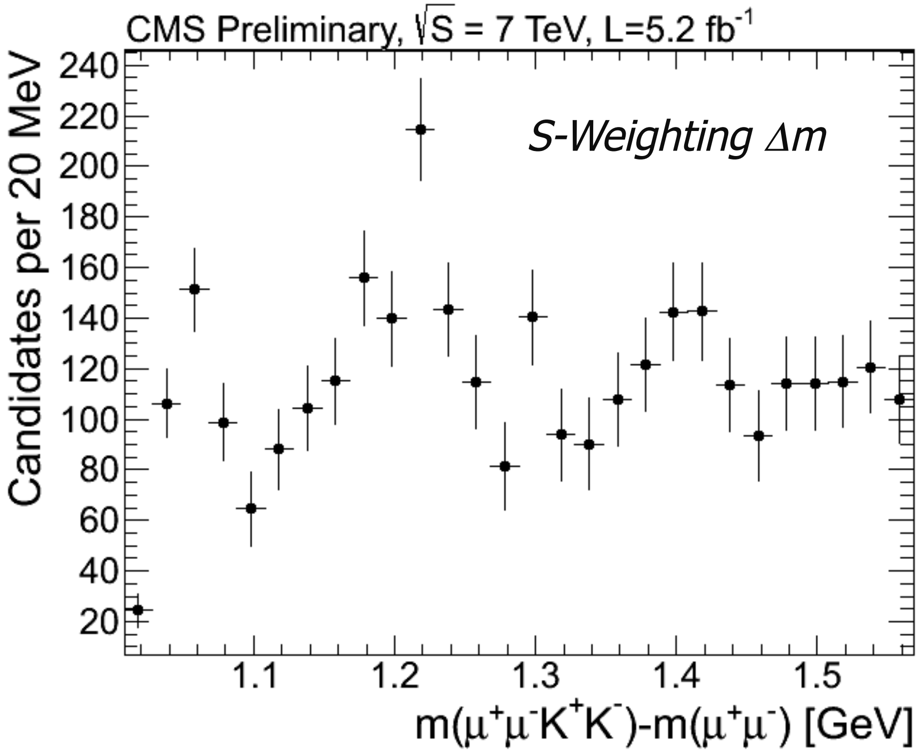
background + 2 signal



Robust Checks

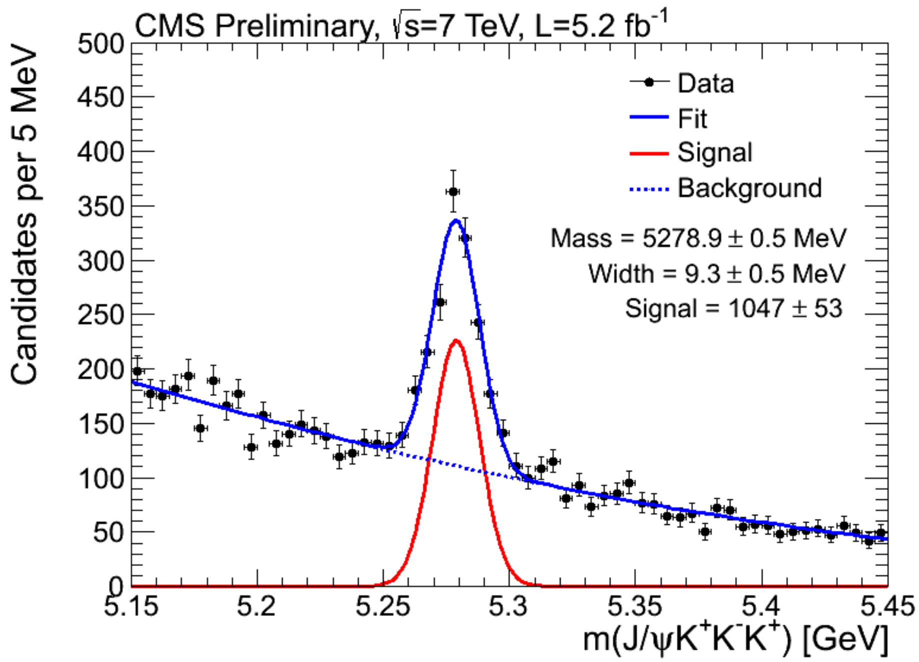
- *Many checks to investigate the robustness of the two structures*
  - *Variations on selection cuts, different background and signal shapes, different Δm binning…*
  - *Different Background-subtraction technique: sPlot*

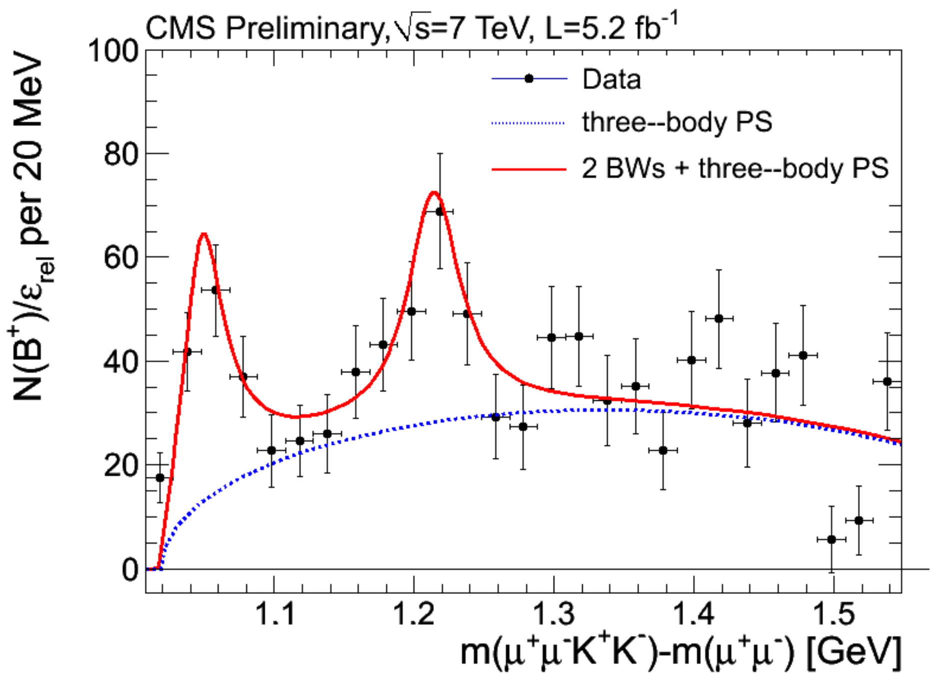
    sPlot is a technique of background-subtraction by weighting each event based on observed signal to background ratio.



Robust Checks

- *All main requirements are varied step by step to investigate possible bias*
- *Each sideband-subtracted Δm distribution is compared to the default one*
- *No indication of bias was found*
  one example with tighter cuts and purer B sample is shown below:
  keep ~40% B signal, reduce background by a factor of 12!

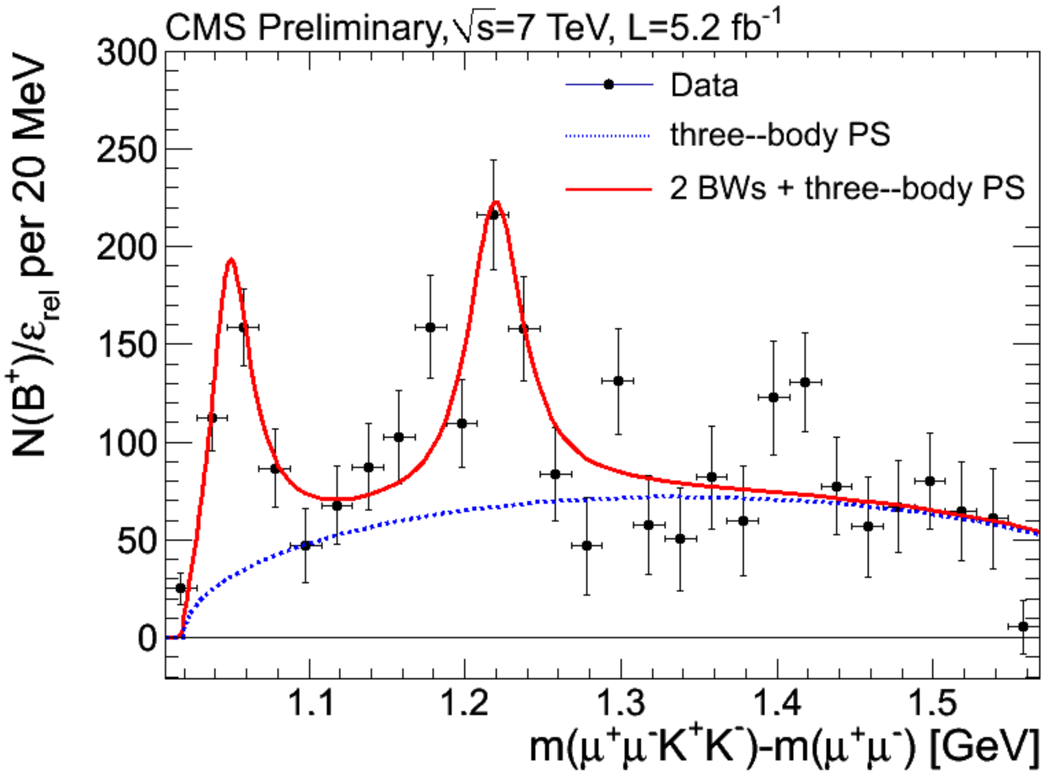




- *B purity ~60% within ±1.5σ of m(B^+)*
- *similar Δm spectrum*

Result

- *The efficiency-corrected* $\Delta m = m(\mu^+\mu^-K^+K^-) - m(\mu^+\mu^-)$



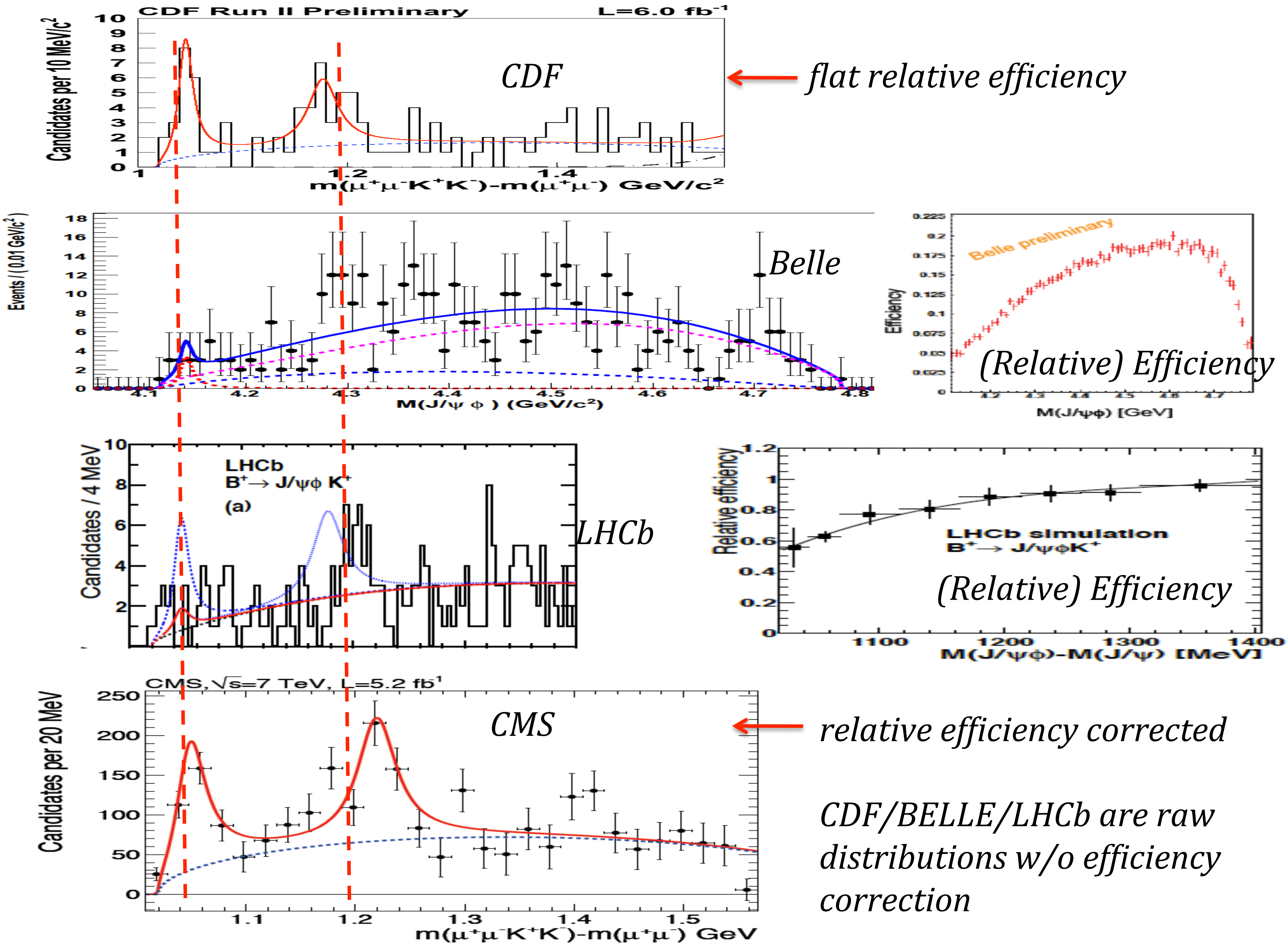
	Mass (MeV)	Signal Yield
First Peak	1051.5 ± 2.0	355 ± 46
Second Peak	1220.0 ± 3.0	445 ± 83

m_1= 4148.2±2.0(stat.)±4.6 (syst.) MeV
m_2= 4316.7±3.0(stat.)±7.3 (syst.) MeV

- *observed a* $J/\psi\phi$ *structure at 4148MeV with a significance greater than* 5σ *confirms the existence of Y(4140) for the first time from another experiment*

  CDF Y(4140): $m=4143.4^{+2.9}_{-3.0}$ *(stat) ± 0.6 (syst)*

- *evidence for a second structure at ~4317MeV in the same mass spectrum*

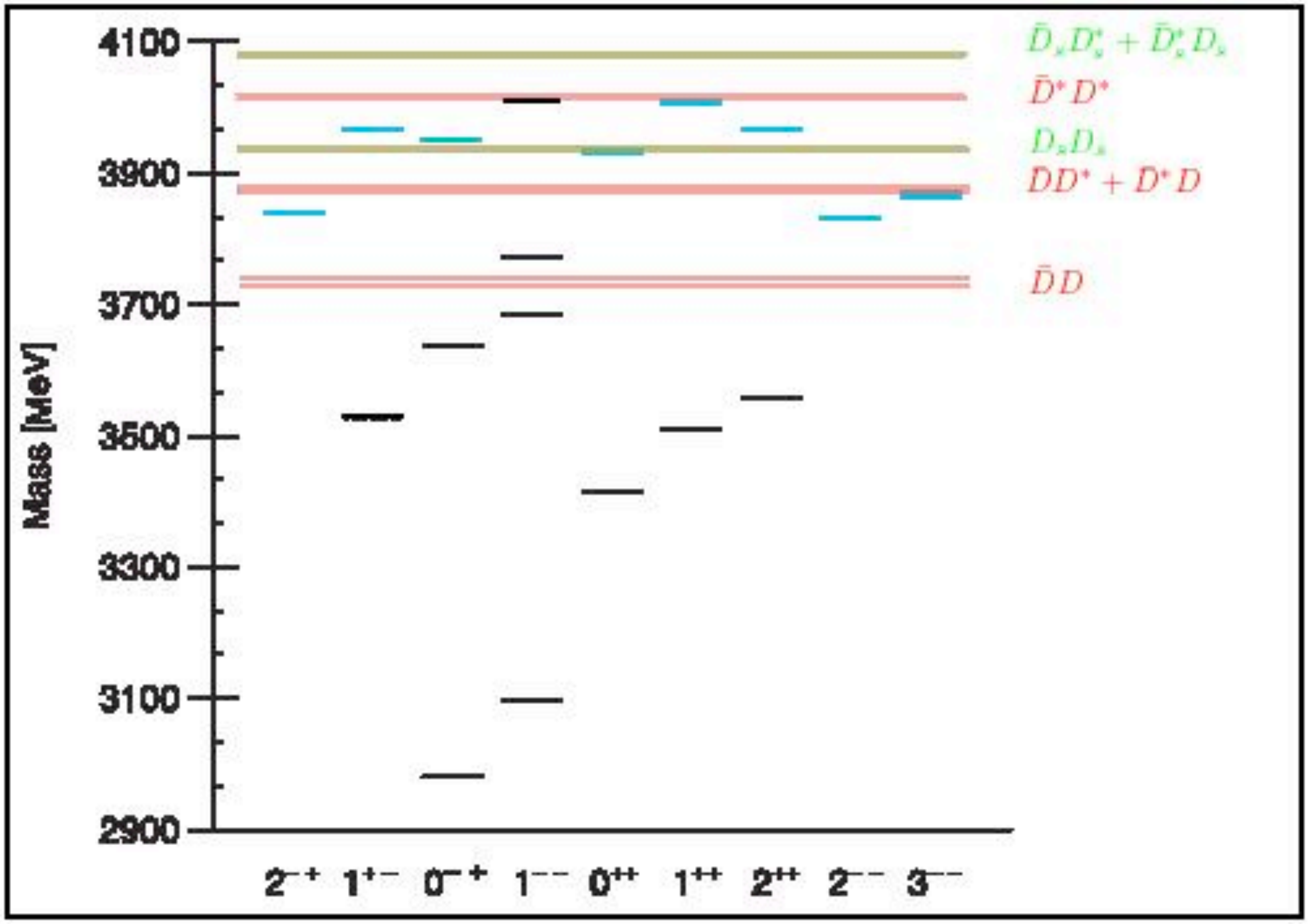

CDF Run II Preliminary
L=6.0 fb^{-1}
CDF
Candidates per 10 MeV/c^2
m($\mu^+\mu^-K^+K^-$)-m($\mu^+\mu^-$) GeV/c^2
flat relative efficiency
Belle
Events / (0.01 GeV/c^2)
M(J/ψ φ) (GeV/c^2)
Belle preliminary
Efficiency
M(J/ψφ) [GeV]
(Relative) Efficiency
LHCb
$B^+ \to J/\psi\phi K^+$
(a)
Candidates / 4 MeV
LHCb
Relative efficiency
LHCb simulation
$B^+ \to J/\psi\phi K^+$
(Relative) Efficiency
M(J/ψφ)-M(J/ψ) [MeV]
CMS, $\sqrt{s}$=7 TeV, L=5.2 fb^{-1}
CMS
Candidates per 20 MeV
m($\mu^+\mu^-K^+K^-$)-m($\mu^+\mu^-$) GeV
relative efficiency corrected
CDF/BELLE/LHCb are raw distributions w/o efficiency correction

What is it?

Charmonium Spectrum

2nd peak

Y(4140)



- *Well **above** charm pair threshold*
- *Expect **tiny** BF to $J/\psi\phi$*
- *Does **not** fit into charmonium*
- *Close $J/\psi\phi$ threshold like Y(3940)*
- *What is it? Molecule/ hybrid/threshold CUSP?*

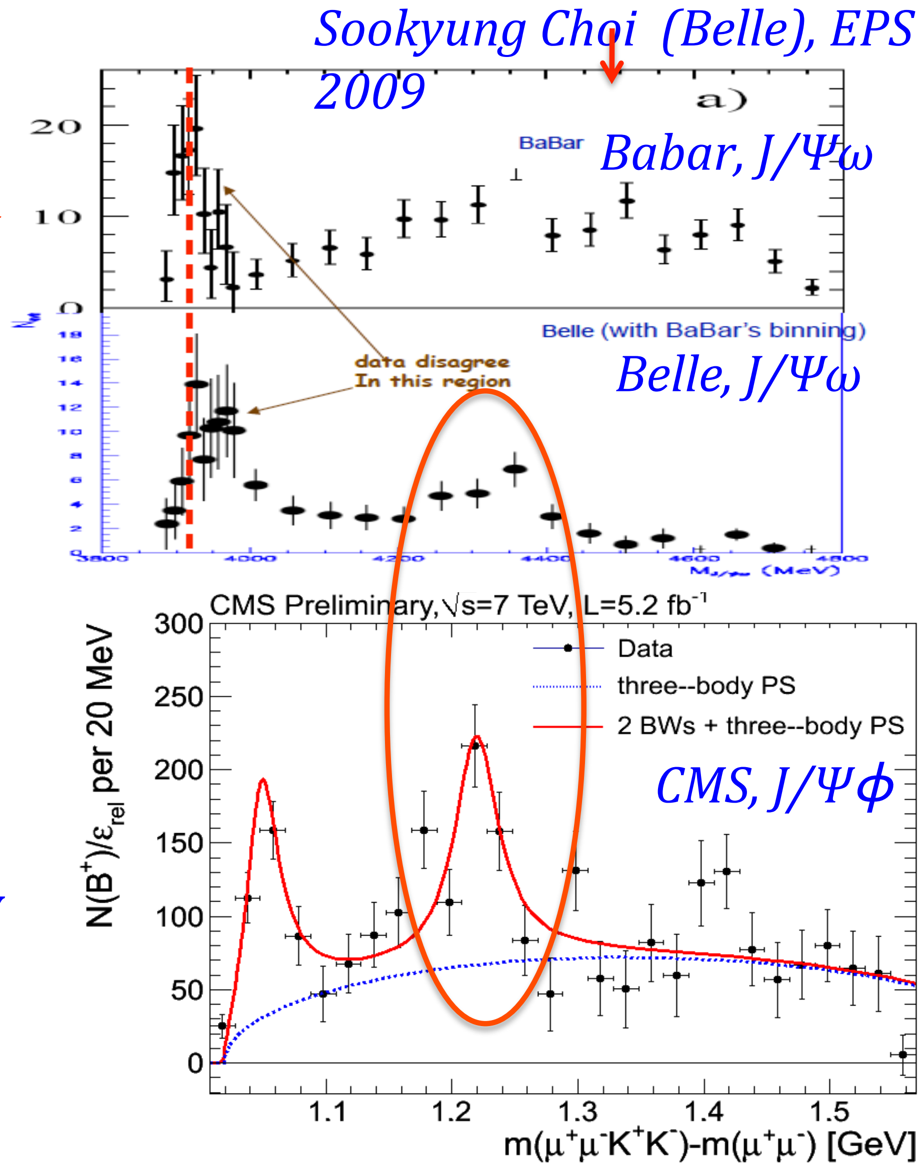
Possible Interpretation of the Structures?

http://indico.ifj.edu.pl/MaKaC/materialDisplay.py?contribId=832&sessionId=19&materialId=slides&confId=11 *(last page)*

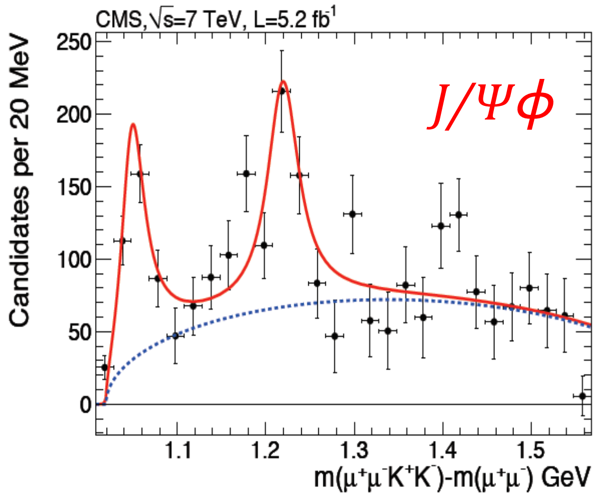
- *Possible J^{PC}: S-wave: 0^{++}, 1^{++}, 2^{++}*
  P-wave: 0^{-+}, 1^{-+}, 2^{-+}, 3^{-+}
- *Lattice QCD for 1^{-+} ($c\bar{c}g$): 4.3± 0.05 GeV*
- *M= 4316.7 ± 3.0(stat) ± 7.3(syst) MeV*
  (CMS 2nd structure)
- *Can the 2nd structure be 1^{-+} hybrid?*
  expect to see it in $J/\Psi\omega$ if so

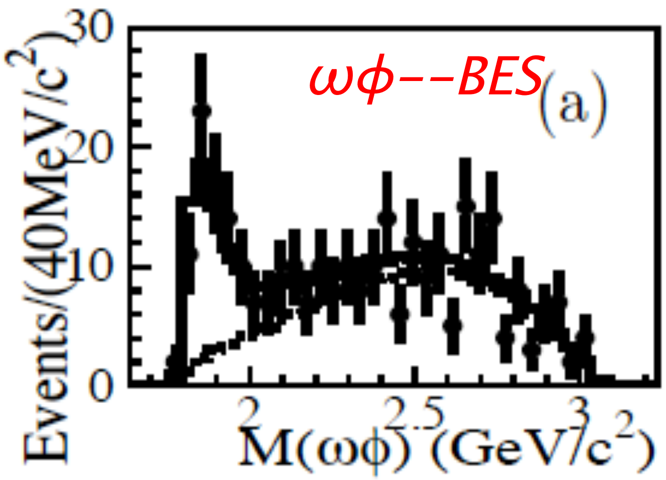
- ***What is the 1st structure? The same kind or it can be a different kind compared to the 2nd one?***
  Similar to Y(3940), both close to VV threshold? Same kind?

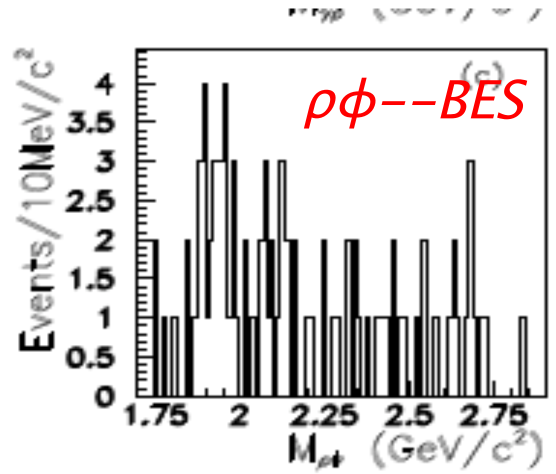
A topic to be investigated more



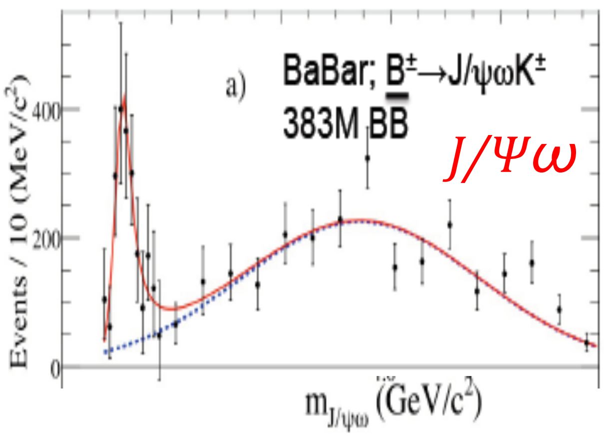
Mini Summary of near VV threshold behavior

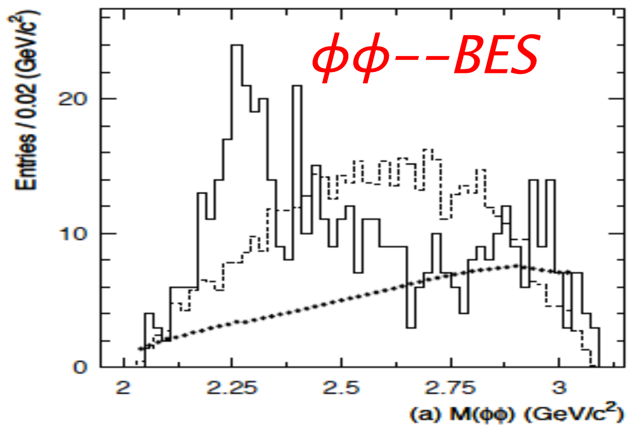


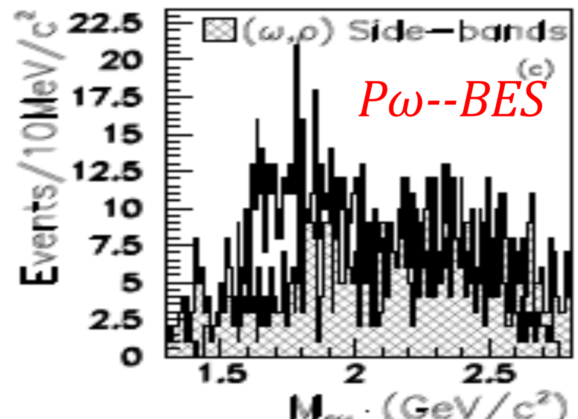




PRD 77, 012001(2008)





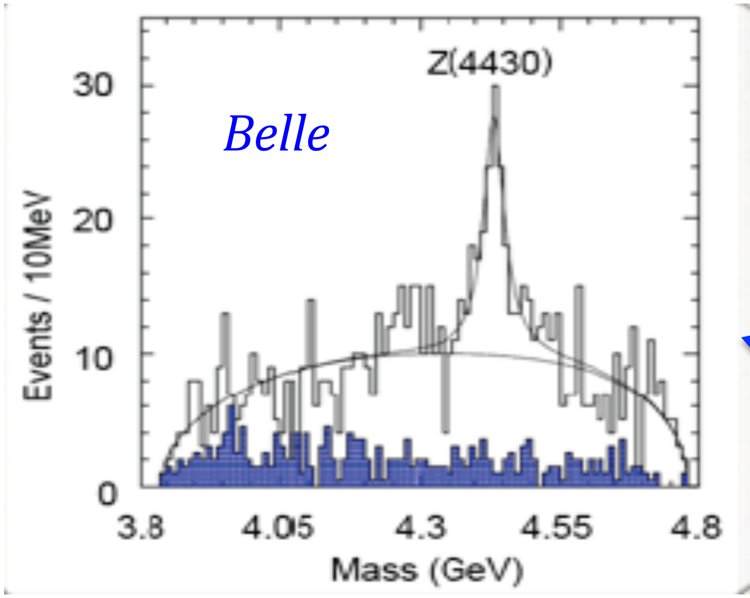


I(V,V)=0, observed near VV threshold enhancement, through (double) OZI suppressed process

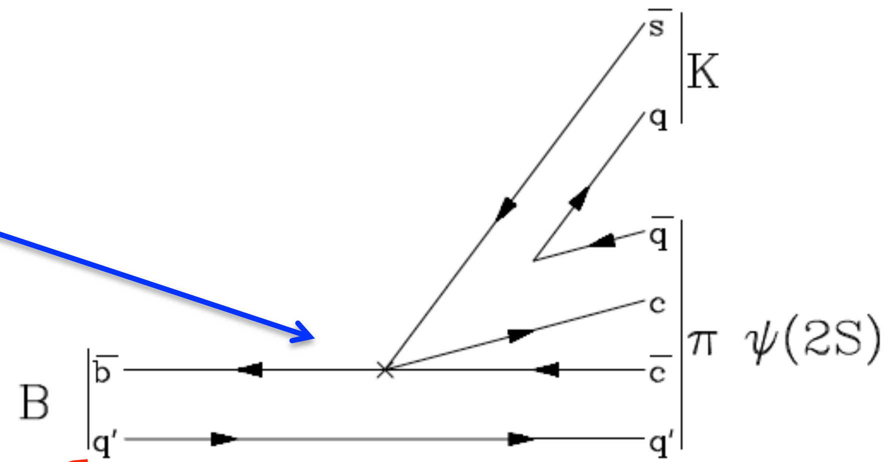
I(V)=1, no clear enhancement
Skip complicated ωω, ρρ

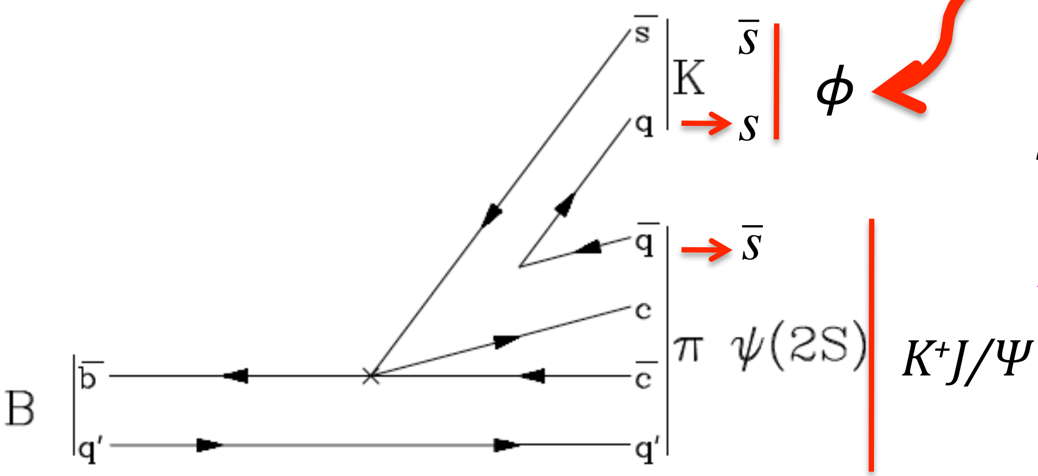
Observed near V(I=0)V (I=0) threshold enhancement. Strong decay. Above (qq'+q'q) threshold. What are they?

Search Possible Charged Exotics in $J/\Psi K^+$ Spectrum



arXiv: 0708.3496 [hep-ph], Jonathan Rosner
Mechanism to produce $Z^+(4430)$:
$B \rightarrow K Z^+(4430)$, $Z^+(4430) \rightarrow \Psi(2S)\pi^+$





Same mechanism, we can search for:

$B^+ \rightarrow \phi Z^+(xxxx)$, $Z^+(xxxx) \rightarrow J/\Psi K^+$

Summary

- *CMS observed two structures in the $J/\psi\phi$ spectrum at 4148 MeV and 4317MeV using 5.2 fb^{-1} of data at 7 TeV collision energy*

  m_1 = 4148.2 ± 2.0 (stat.) ± 4.6 (syst.) MeV (>5sigma)
  m_2 = 4316.7 ± 3.0 (stat.) ± 7.3 (syst.) MeV (>3sigma)

- *Confirm the existence of the Y(4140), consistent with CDF result*

  &

  find evidence for a second structure

- *Preliminary investigation find no evidence of reflection from $K_{1,2}$*

- *More to be expected with the large data sample (4X) from 2012*
  There are lots of mysteries in this system, it is trying to tell us something, may be something new! Stay tuned!

Backup

Exotic J^{PC}

- *For $q\bar{q}$ meson system, let **L** to be the orbital angular momentum.*
  *The meson spin **J** is given by |**L-S**|<**J**<|**L+S**|,*
  *where **S=0** (antiparallel quark spin) or **1** (parallel quark spin)*

- *The parity P and charge parity C of the meson system can be expressed as:*
  $P=(-1)^{L+1}$
  $C=(-1)^{L+S}$

- *In the configuration of* $P=(-1)^J$, ***S=1, CP=+1,*** $\Rightarrow$
  Exotic J^{PC} *(not allowed for $q\bar{q}$ meson):*
  $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$
  But exotic mesons can have these JPC due to additional degree of freedom.

- *Identify **exotic J^{PC}** is helpful to identify **exotic mesons***

Jet Reconstruction

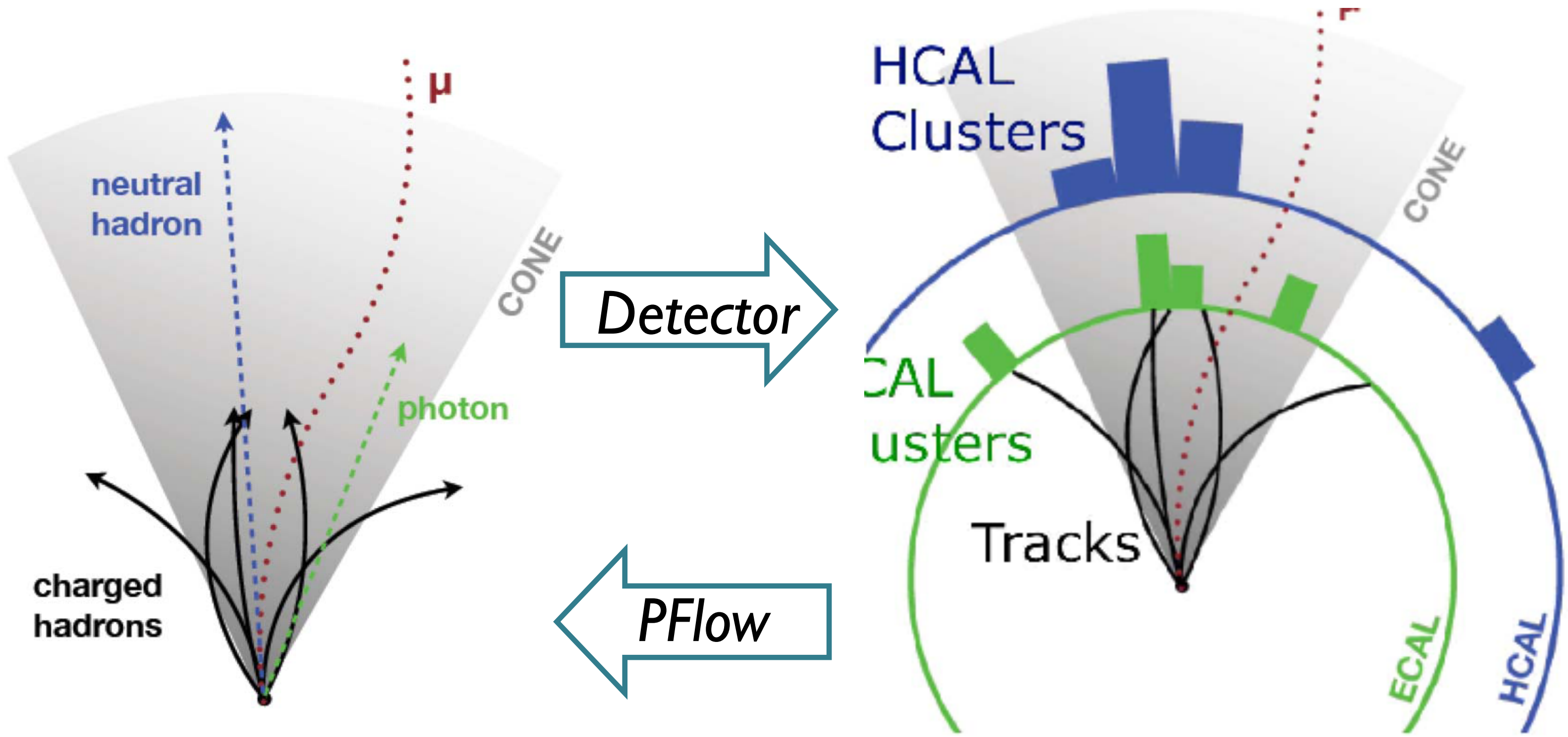
- *Anti-kt (AK) clustering algorithm with cone size of 0.5 (AK5) and 0.7 (AK7)*
  - *Infrared and collinear safe*
- *Jet types:*
  - *Calorimeter Jets:*

    Reconstructed from energy deposits in the ECAL and HCAL, grouped in projective calo towers
  - *Particle Flow (PF) Jets (Details in next slide):*

    Use all detector elements to reconstruct particles and cluster to jets.
  - *Fat Jets:*

    Clusters of AK5 PF Jets within radius of 1.1, optimize dijet resonance resolution by recombining FSR into the two leading jets
- *Jet energy corrections: using MC truth information and real data (i.e. γ+jet) for residual correction*
  - *Uncertainty on jet energy scale ~2%*
  - *Uncertainty on Jet energy resolution ~10%*
- *MET: negative of vector sum of transverse momenta of all particle*

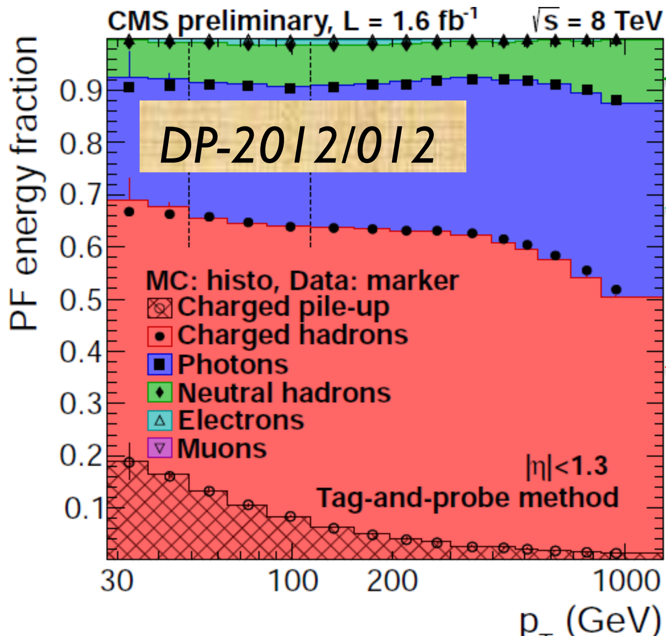
Particle Flow Jet

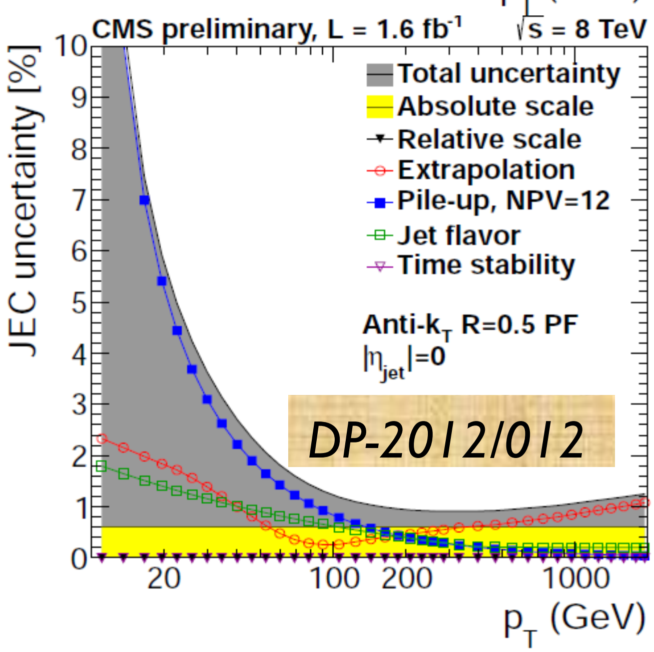


Particles

Clusters and tracks

Particle Flow Jet





HCAL: 120%/ √E + 6.9%

ECAL: ~1% /√E

Precise

Tracker $\sigma(p_T)/p_T$: 1-2% for 10 GeV track

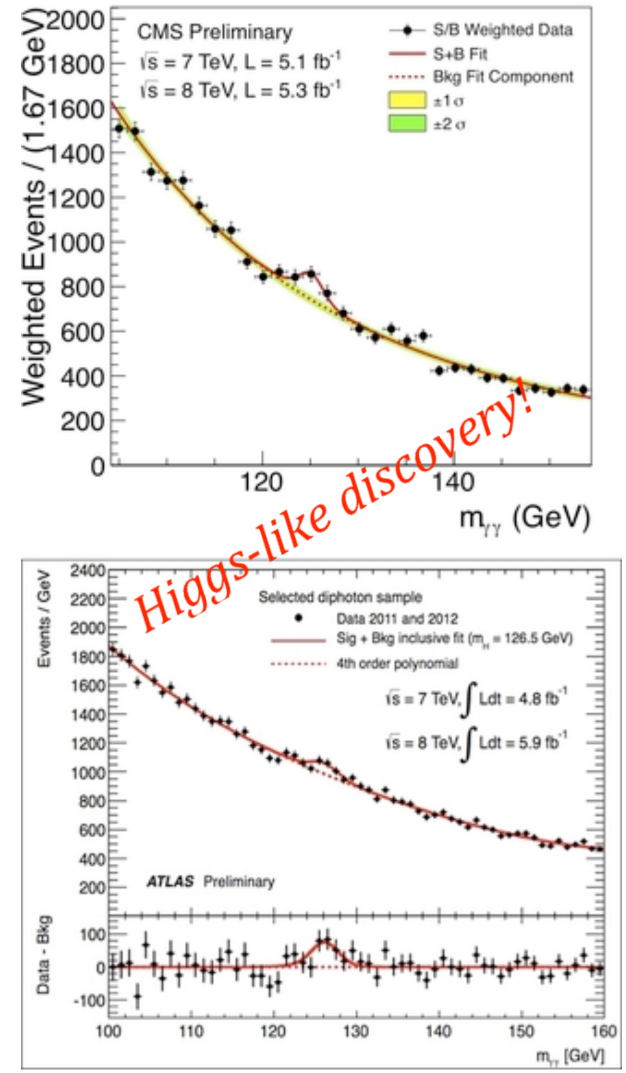
<10% for 100 GeV track

Precise

- *60% of pileup mitigation using charged hadrons attached to secondary tracks*
- *Remaining mitigation using jet area*

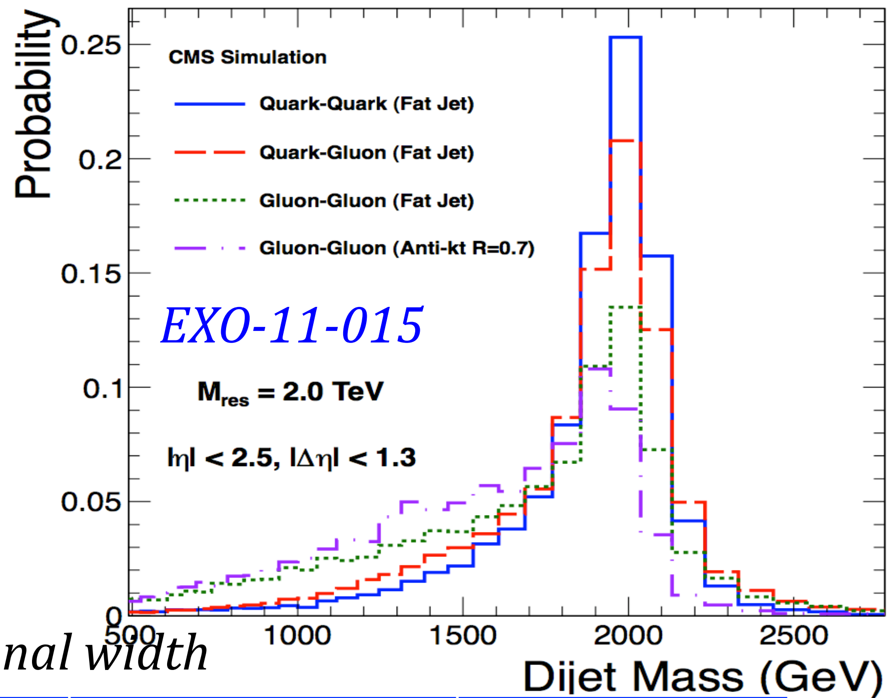
Motivation for NP

- *Why Search for "new" physics after the discovery of a "Higgs"-like particle?*
- *We have a hierarchy problem if this is the SM Higgs and it is so light. Possible solutions from "new" physics:*
  - *SUSY: R-parity conserved and violated scenarios*
  - *Warped Extra Dimension*
- *We expect new physics if this is not the SM Higgs:*
  - *Need to find out a "Higgs"-like mechanism*
  - *Strong Dynamics?*
- *Jets are copiously produced, with several orders of magnitude higher cross section than other processes. Jets are either part of searching signal or background. This talk focus on the searches with jet(s) in the final state*



Dijet Resonances Search

- *Parton resonances decaying into dijets from various models*
- Search for 3 generic types of narrow dijet resonances
  - *qq,qg,gg resonances*
  - *U*sing fat jet in this *search*
  - *Fat jets shows better resolution due to more recovery of FSR*



Experimentally jet resolution dominates signal width

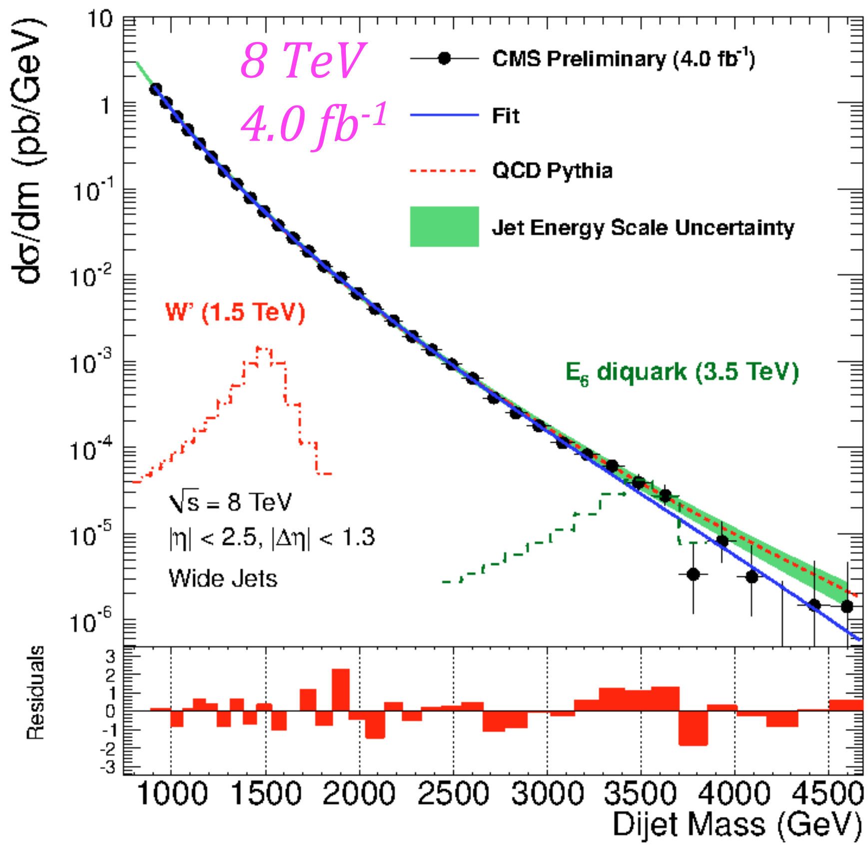
Models	X	Color	J^p	Γ/(2M)	Channel
Excited quark	q*	Triplet	$½^+$	0.02	qg
E_6 Diquark	D	Triplet	0^+	0.004	qq
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
RS Graviton	G	Singlet	2^+	0.01	qq, gg
Heavy W	W’	Singlet	1^-	0.01	$q\bar{q}$
Heavy Z	Z’	Singlet	1^-	0.01	$q\bar{q}$
String	S	Mixed	Mixed	0.003-0.037	qg, $q\bar{q}$,gg

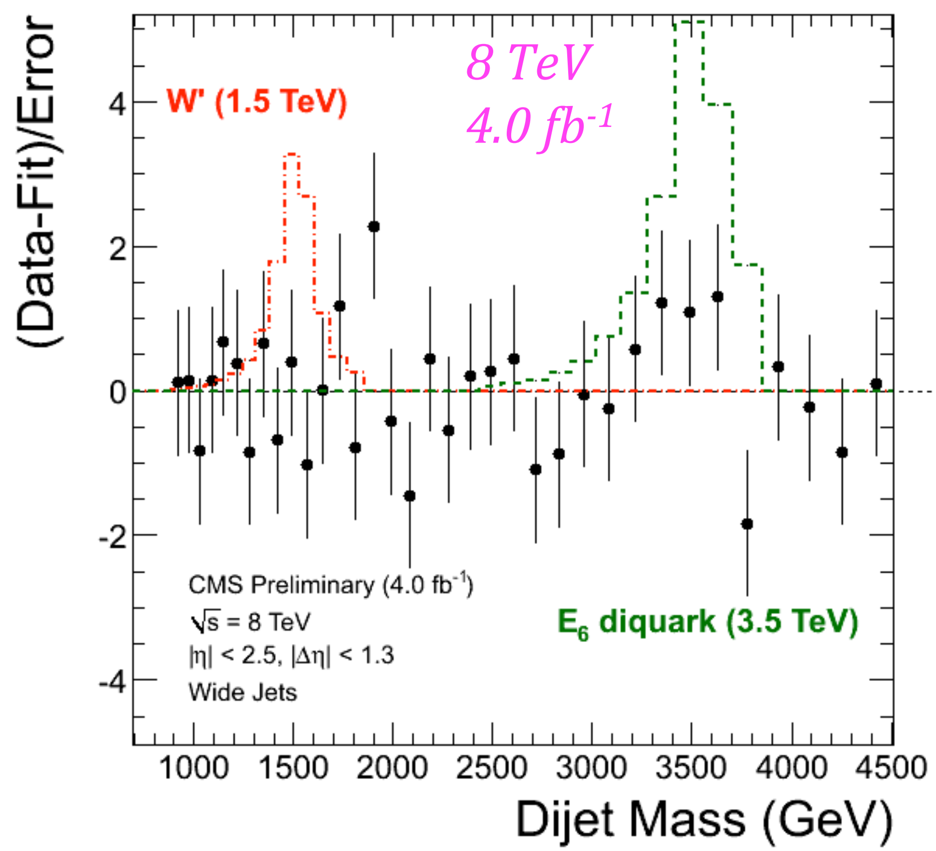
Dijet Resonances with 8 TeV

- *Fat PF Jet, |η|<2.5 & |Δη|<1.3*
- *Data are in good agreement with QCD*
- *Fit to a parameterization*
- *No evidence of new physics*

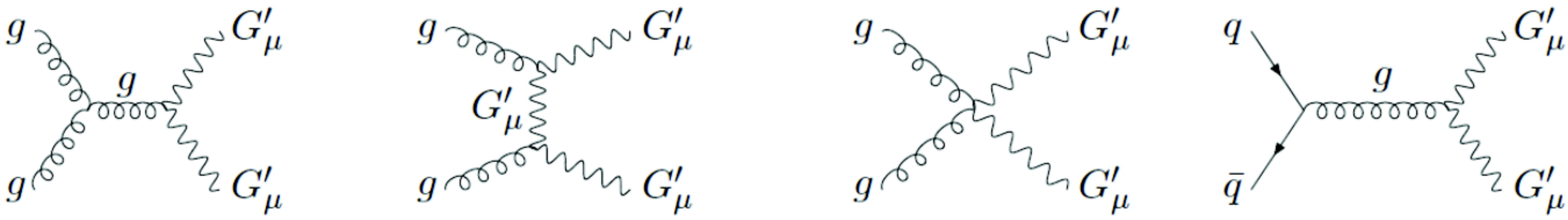
  8TeV EXO-12-016

$$\frac{d\sigma}{dm} = \frac{p_0 \cdot (1 - m/\sqrt{s})^{p_1}}{(m/\sqrt{s})^{p_2 + p_3 ln(m/\sqrt{s})}}$$





Paired Dijet Resonance Search (4-jets)



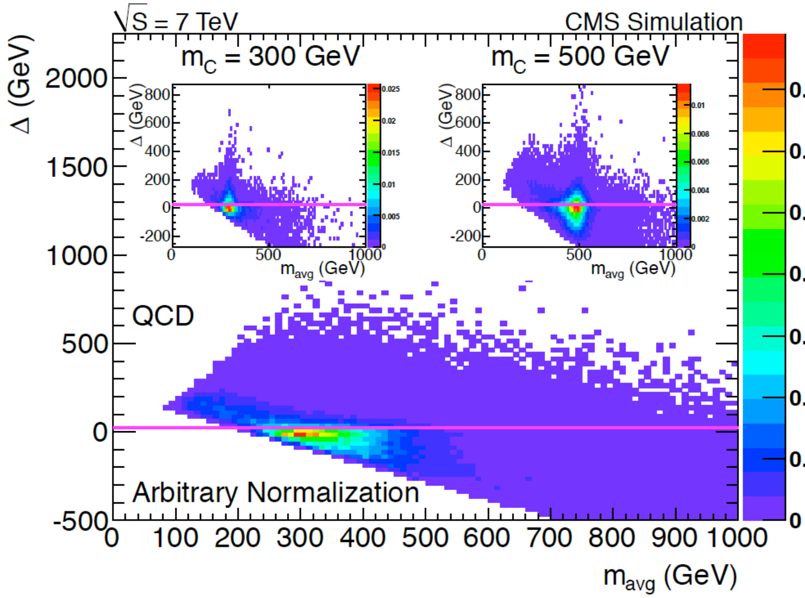
- *Benchmark model: pair produced colorons*

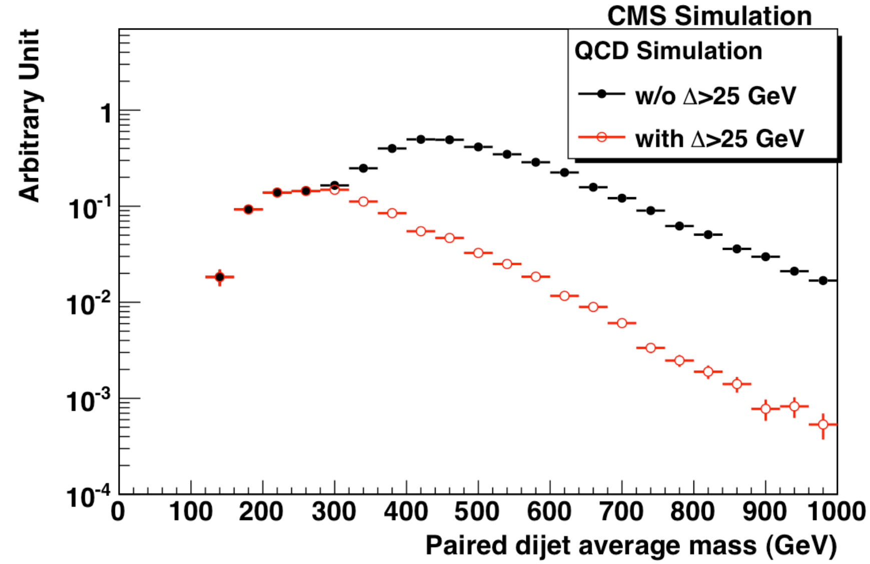
- *Require well separated central jets: all jet $|\eta|<2.5$, deltaR(j,j)>0.7*
- *≥ 4 jets with $p_T>150$ GeV, optimized for a generic coloron search*
- *3 pairs, examine average dijet mass of pairs—(m_{avg}), select the best matched pair —$\Delta m/m_{avg}<15\%$*
- *Diagonal cut to have a smooth falling background:*

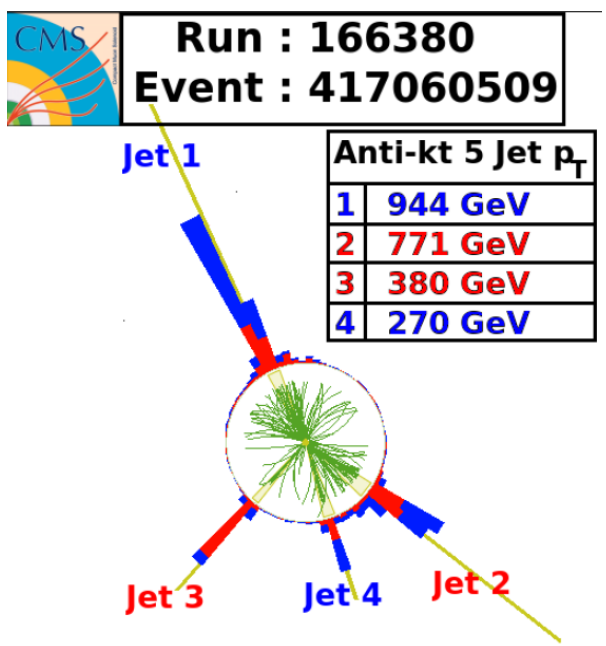
$\Delta=(p_{Ti} + p_{Tj} - m_{ij}) > 25$ GeV

7TeV EXO-11-016

Paired Dijet Resonance Search (4-jets)



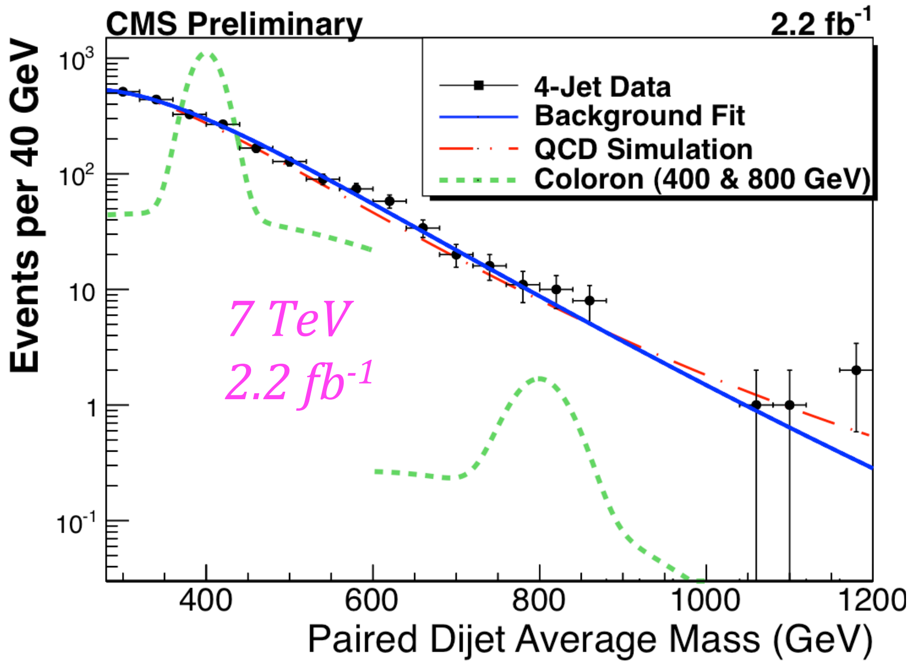


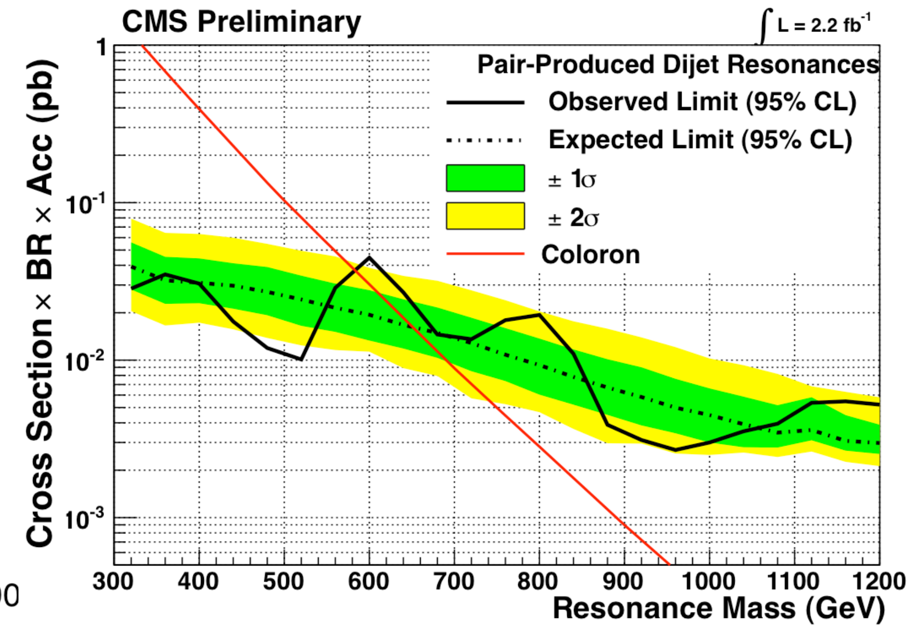


- *Δ > 25 GeV cut removes the second broad sructure and the dijet mass smoothly falling*

A typical paired dijet event

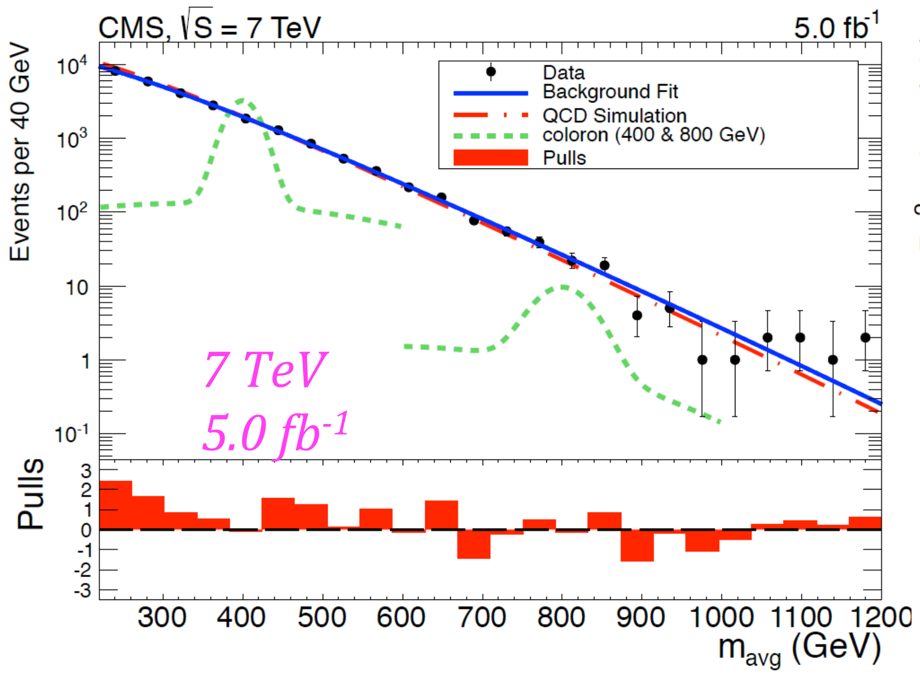
Paired Dijet Resonance Search (4-jets)

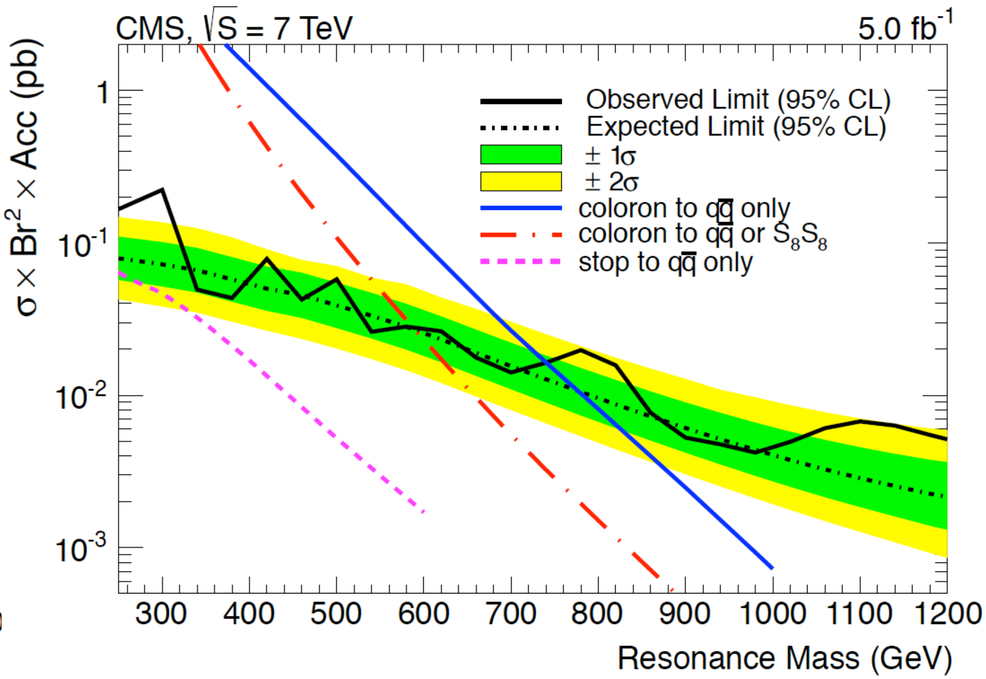




- *Well described by QCD MC and parameterization (same as in the dijet search)*
- *No evidence for new physics*
- *Exclude pair production of colorons with mass in [320, 560] GeV @95% CL*

Update w/ 2011 Full Dataset





Lowered jet p_T threshold to 110 GeV to be more sensitive to low mass stop production

- *Well described by QCD MC and parameterization (same as in the dijet search)*
- *No evidence for new physics*
- *Exclude pair production of colorons @95%: with mass in [250, 740] GeV assuming coloron decays to only to qqbar, or mass in [250, 580] GeV assuming competition from S_8*
- *Start to be sensitive to stop*

Summary for (paired)-Dijet Searches

- *CMS new physics searches using jets have been presented based on 2011 and 2012 data.*
- *No evidence for new physics yet.*
- *Data significantly constrain many models of new physics.*
- *Much more data in 2012 is quickly supersede 2011 results*
  - *~20 fb^{-1} on tape*
- *Ample space for discoveries.*

Stay tuned!