Multiquark Resonances

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based on 1603.07667 (PLB) with A. Esposito (Columbia U.) and A. Pilloni (JLab)

CHARGED EXOTIC RESONANCES

BES III, BELLE (2013)

$e^+e^- \to \gamma\, Y(4.26)$

$\hookrightarrow \pi^+ Z_c^-(3.9)$

$\hookrightarrow \pi^- J/\psi$

$I^G J^{PC} = 1^+ 1^{+-}$, $\Gamma \sim 50$ MeV

another decay modes of Y's

$Y(4.26) \to \gamma\, X(3.872)$

$\hookrightarrow D D^*$

$J/\psi\, \pi^+ \pi^-$

$J/\psi\, \pi^+ \pi^- \pi^0$

Z_c IS A 4-QUARK RESONANCE

$c \bar{c} d \bar{u}$

courtesy of A Pilloni

Charged $Z_c(3900)$

$$G = G_\pi C_{J/\psi} = \\ = -1(-1) = +1$$

$$P = +1 \ (S - \text{wave})$$

$$\Rightarrow Z_c^0 \text{ has } J^{PC} = 1^{+-}$$

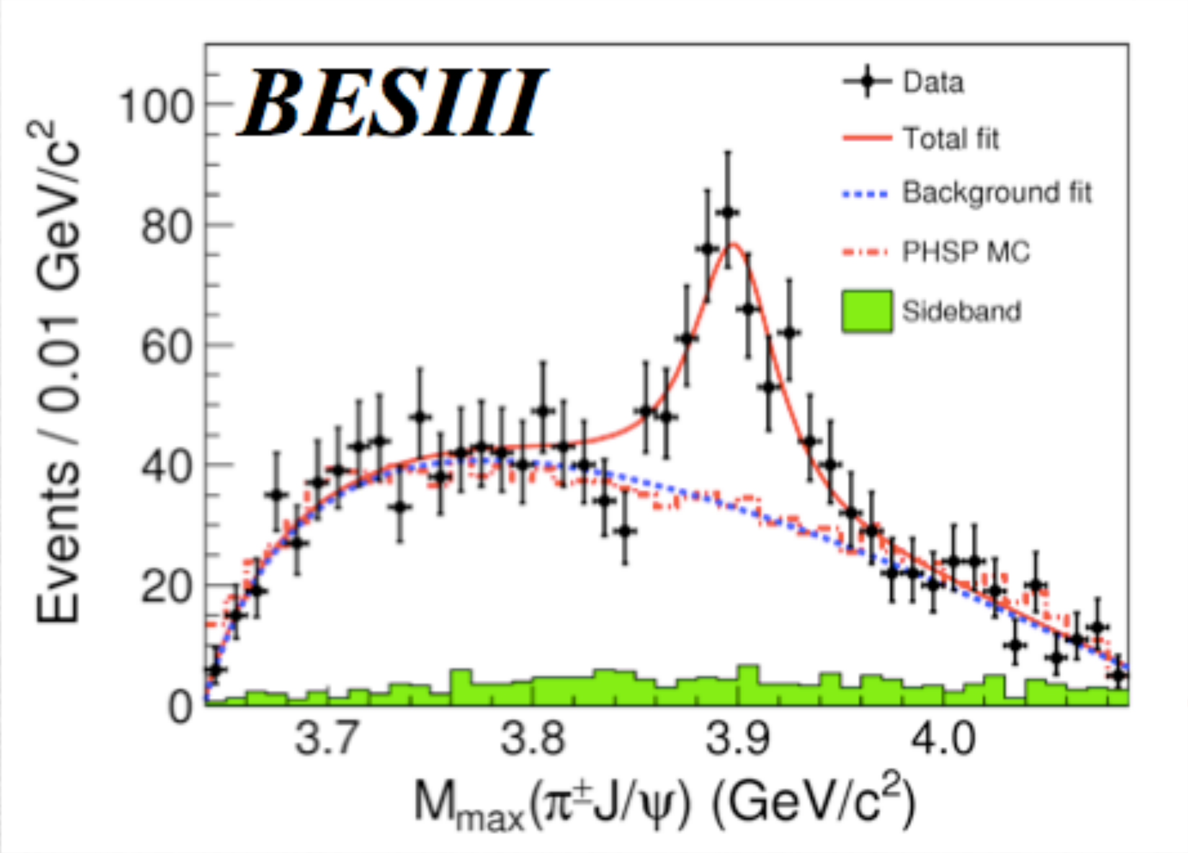
$$I^G J^{PC} = 1^+ 1^{+-}$$

Found in $Y(4260) \to Z_c^\pm(3900)\,\pi^\mp \to J/\psi\,\pi^\pm\,\pi^\mp$

Exotic charged charmonium-like state!

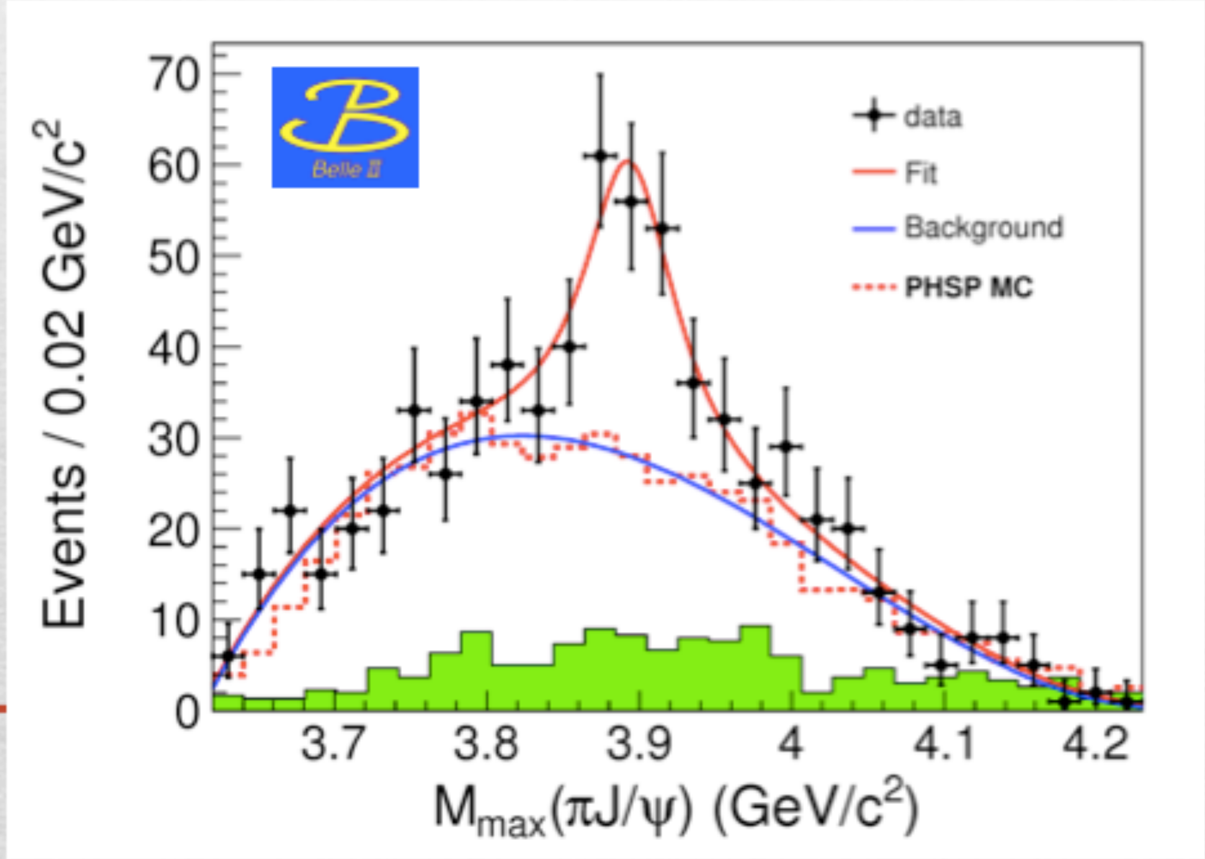
BESIII, arXiv:1303.5949

$$M = 3899.0 \pm 3.6 \pm 4.9 \text{ MeV}$$
$$\Gamma = 46 \pm 10 \pm 20 \text{ MeV}$$



Belle, arXiv:1304.0121

$$M = 3894.5 \pm 6.6 \pm 4.5 \text{ MeV}$$
$$\Gamma = 63 \pm 24 \pm 26 \text{ MeV}$$

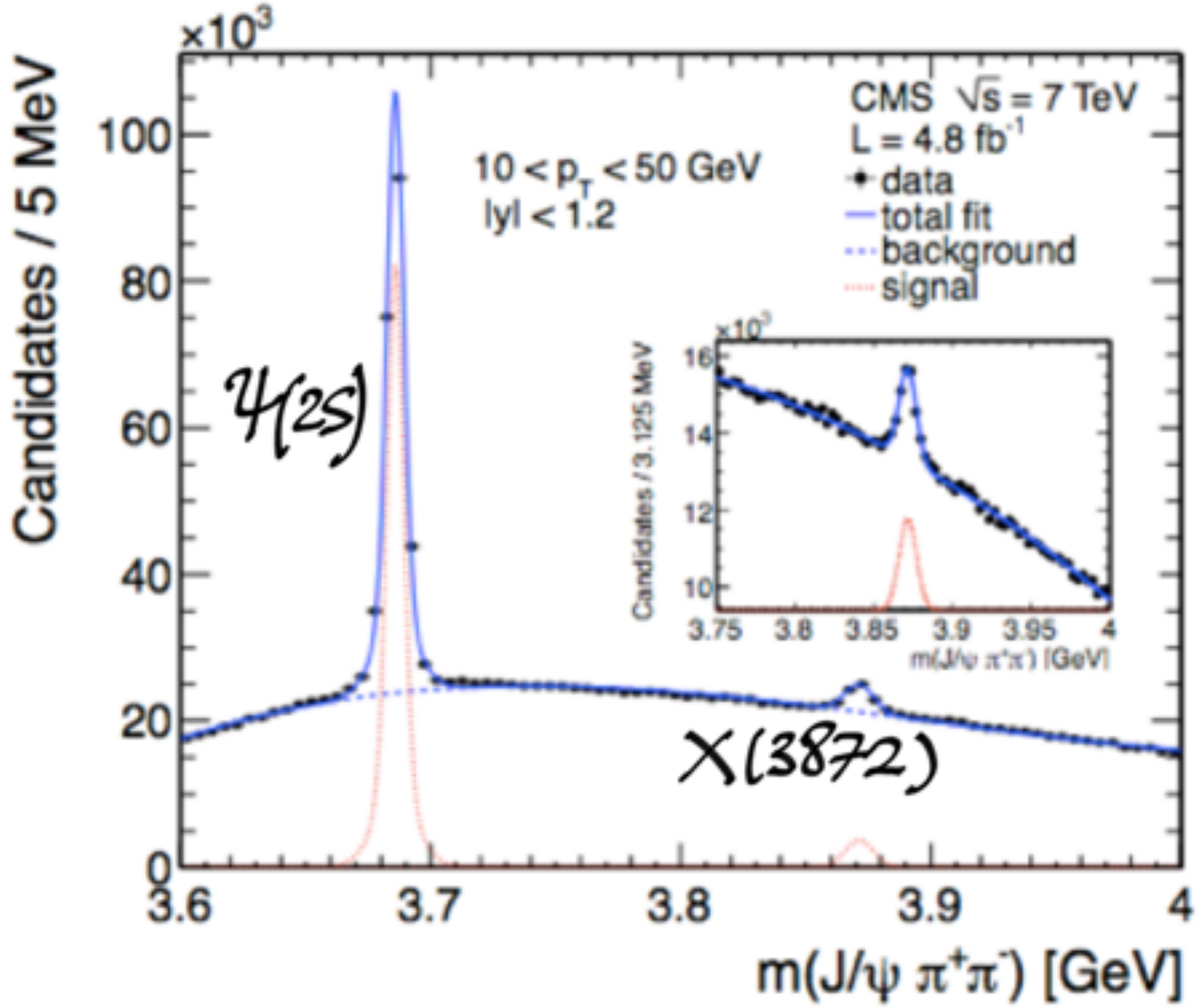


X(3872)

DISCOVERED BY BELLE IN 2003
CONFIRMED BY BaBar, DØ, CDF, CMS, LHCb & ATLAS!

4 $pp \to X(3872)$ @CMS — 4 Measurement of the cross section ratio

PROMPT PRODUCTION



high $p_\perp$

Figure 1: The $J/\psi\pi^+\pi^-$ invariant-mass spectrum for $10 < p_T < 50$ GeV and $|y| < 1.2$. The lines represent the signal-plus-background fits (solid), the background-only (dashed), and the signal-only (dotted) components. The inset shows an enlargement of the X(3872) mass region.

EXOTIC RESONANCES

— $X^0(3872)$ 1^{++}

No charged partners observed: $X^{\pm}$?
Isospin violations: $X \to \psi\rho / X \to \psi\omega \sim 1$
Very narrow $\Gamma < 1$ MeV
Almost degenerate w/ $\bar{D}^0 D^{*0}$ & $\psi\rho$

— $Z_c^{0,\pm}(3900)$, $Z_c'^{\pm}(4020)$ 1^{+-}

Charged & neutral!
The lowest is very close in mass to X^0

— $Z_b(10610)$, $Z_b(10650)$ 1^{+-}

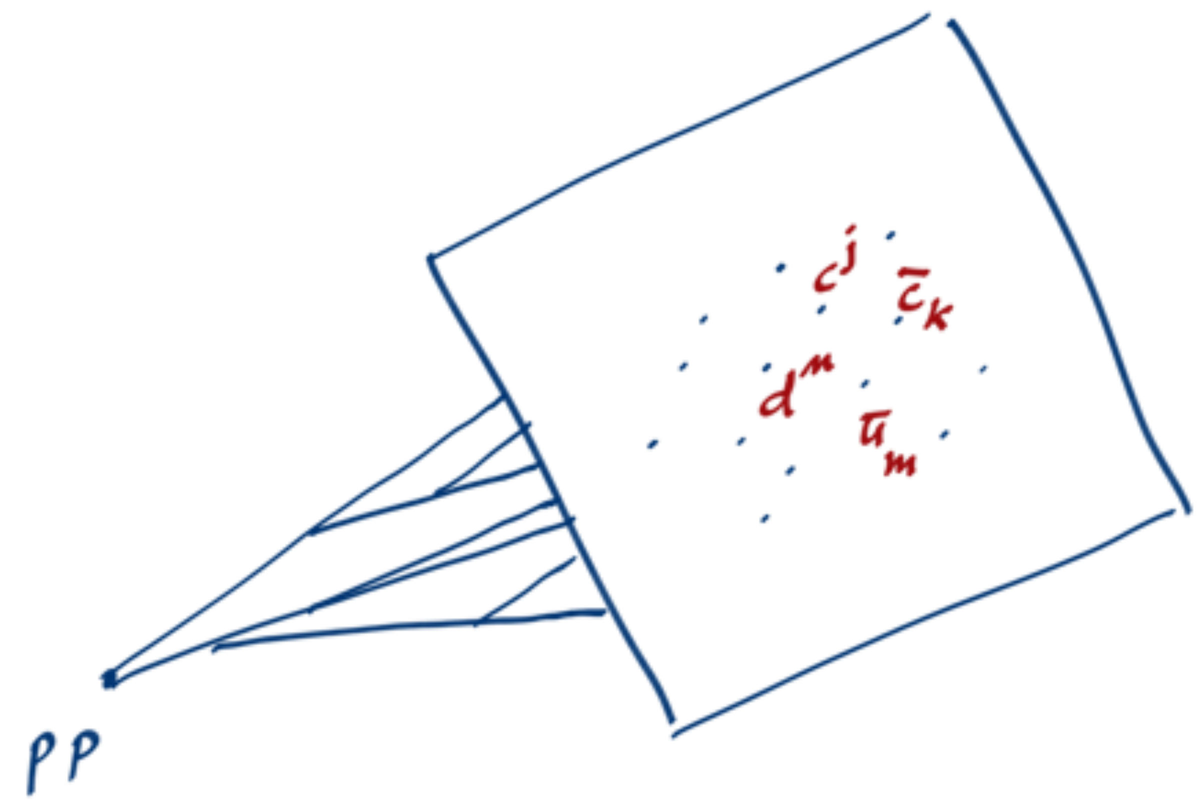
There is no $X_b^0(\simeq 10600)$

— $X^0(4140)$ 1^{++}

Together w/ $X(4274)$, $X(4500)$, $X(4700)$ recently observed by LHCb.

HADRONIZATION OF EXOTIC RESONANCES

All should be searched in prompt pp collisions at LHC



The relative motion must be compatible with the formation of a compact tetraquark

$$\epsilon_{ijn}\, c^j d^n \; \epsilon^{ikm}\, \bar{c}_k\, \bar{u}_m$$

(Virial theorem $\bar{T}\,(=-\bar{E}) = \frac{1}{2} m_c \alpha_s^2 (2m_c) \approx 50\,\mathrm{MeV}$)

Diquarks

$$[cq]_i = \epsilon_{ijk}\, \bar{c}^j_c \gamma_5 q^k \equiv \epsilon_{ijk} (c^j)^T C \gamma_5 q^k \qquad J^P = 0^+$$

$$C = -\sigma^2 \otimes \tau^1$$
$$\gamma_5 = \mathbb{1} \otimes \tau^1$$

$$[cq]_i = \epsilon_{ijk} (c^j)^T C \vec{\gamma} q^k \qquad J^P = 1^+$$

$$[cq]_i = \epsilon_{ijk} (c^j)^T \sigma^2 q^k \qquad \text{NR-formalism.}$$

$$[cq]_i^\lambda = \epsilon_{ijk} (c^j)^T \sigma^2 \sigma^\lambda q^k$$

A light-light diquark w/ $S=0$ has to be ANTISYMMETRIC in flavor space

$$[qq]_i = \epsilon_{ijk}\, \epsilon^{ab} (q^{aj})^T C \gamma_5 q^{bk} \qquad \text{w/ two flavors}$$

$$[qq]_i^a = \epsilon_{ijk}\, \epsilon^{abc} (q^{bj})^T C \gamma_5 q^{ck} \equiv \zeta_i^a \qquad \text{w/ three flavors}$$

$$\Phi^{ab} \equiv (\zeta^a_{Li})^* (\zeta^{bi}_R)$$

$$\Phi \xrightarrow{SU(3)_L \times SU(3)_R} V_R \Phi V_L^\dagger \qquad \text{like quark condensate}$$

DIQUARKS

$$d^{S,A} = q^{\alpha}\,\Gamma\, q'^{\beta} \pm q^{\beta}\,\Gamma\, q'^{\alpha}$$

BUILD NEW HADRONS WITH

$$S \begin{cases} q \mapsto \bar{d}^{A} \\ \bar{q} \mapsto d^{A} \end{cases}$$

$$\bar{q}\bar{q}\bar{q} \xmapsto{S} d^{A}\bar{q}\bar{q} \rightarrow d^{A}\bar{d}^{A}$$

$d^{A}\bar{d}^{A}$: TETRAQUARK (charged & neutral!)

$d^{A}\bar{q}\bar{q} \rightarrow d^{A}d^{A}\bar{q}$: PENTAQUARK

$d^{A}\bar{q}\bar{q} \rightarrow d^{A}d^{A}d^{A}$: DIBARYON $(B=2)$

'HADRONIZATION STATE'

Superposition with unknown coefficients

$$\Psi = [cd]_s[\bar{c}\bar{u}]_{s'} + \psi\pi^- + \psi'\pi^- + \eta_c\rho + \bar{D}D^* + \bar{D}^*\bar{D}^*$$

$$= \Psi_d + \sum_i \Psi_{m_i}$$

$$\Psi = \Psi_Q + \Psi_P = Q\Psi + P\Psi$$

$Q + P = \mathbb{1}$ & $Q \cdot P = PQ = 0$

$$H\Psi = E\Psi \quad \begin{cases} (E - H_{PP})\Psi_P = H_{PQ}\Psi_Q \\ (E - H_{QQ})\Psi_Q = H_{QP}\Psi_P \end{cases}$$

$$H_{PP} = H_0 + V_1$$
$$H_{QQ} = H_0 + V_2$$

& $(E - H_{PP} - V_I)\Psi_P = 0$

EFFECTIVE INT. IN THE P SPACE ($P \to Q \to P$)

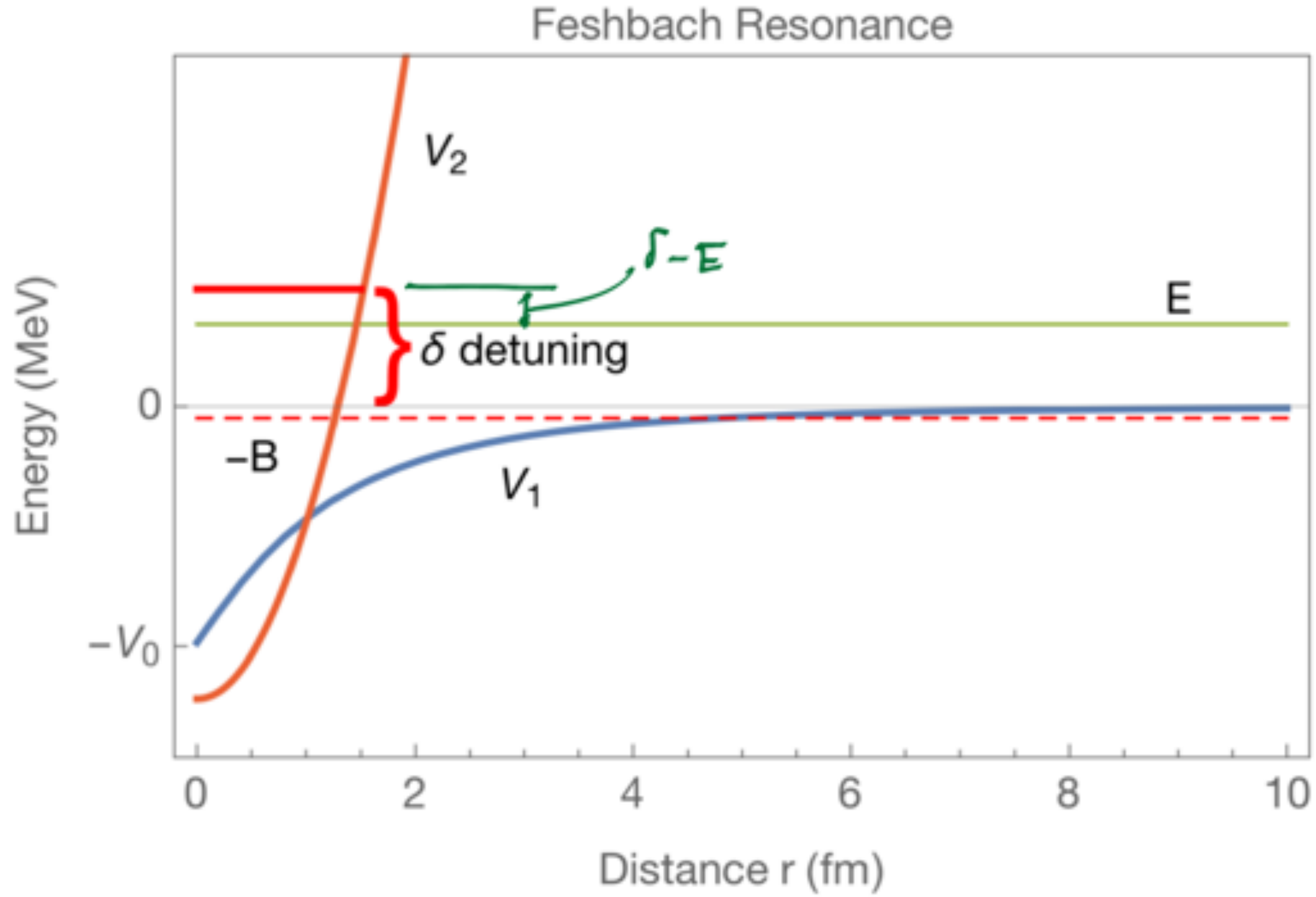
$$V_I = H_{PQ}\frac{1}{E - H_{QQ} + i\epsilon}H_{QP}$$

16/05/16

3 / 15

4qLund

OPEN & CLOSED CHANNELS



Because of V_I the scattering length in P is

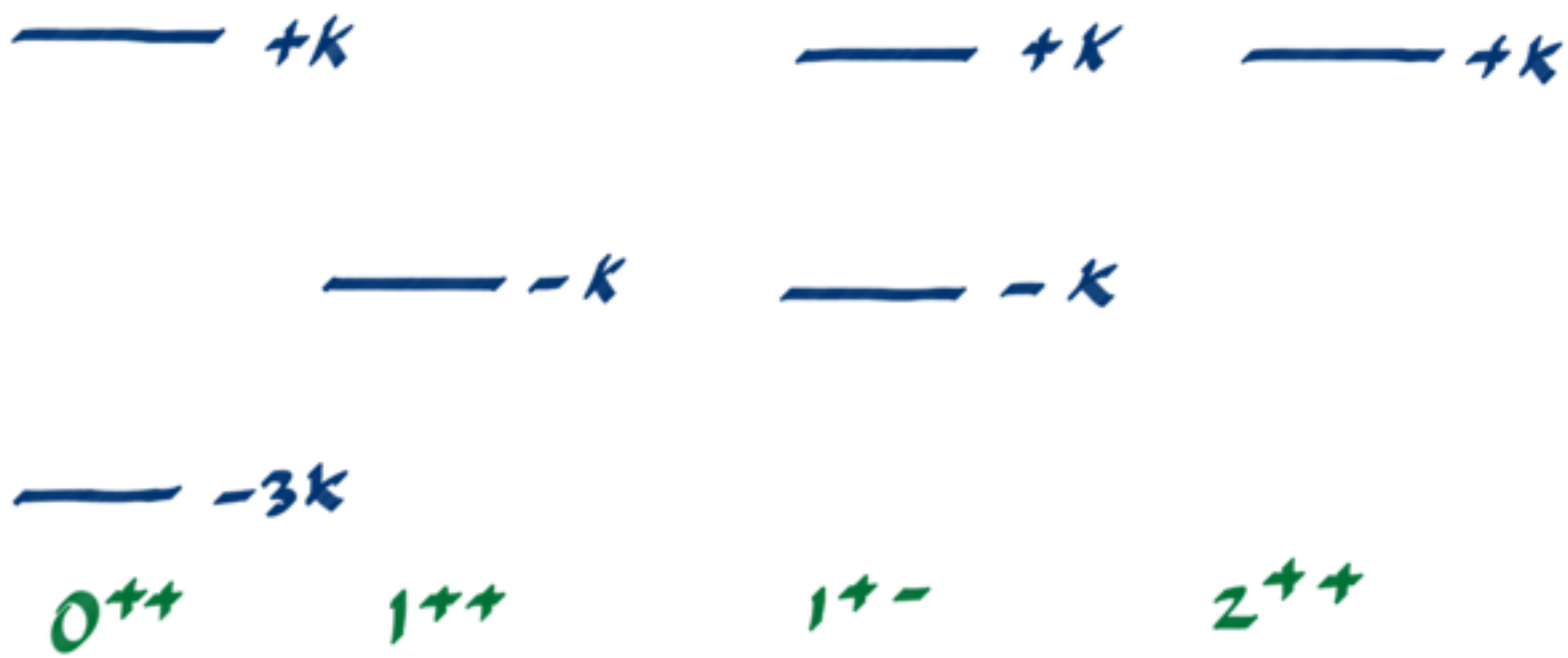
$$a = a_p - c \, \frac{|\langle \Psi_n | H_{QP} \Psi_\alpha \rangle|^2}{E_n - E_\alpha + i\epsilon} \qquad (c>0)$$

$$\equiv \left(1 - \frac{x}{\delta - E + i\epsilon}\right) a_p$$

DIQUARKONIUM MASSES (Q-SPACE)

$$H \approx 2k\left(\vec{S}_Q \cdot \vec{S}_q + \vec{S}_{\bar{Q}} \cdot \vec{S}_{\bar{q}}\right)$$

The spectrum is as follows



DIQUARKONIUM MASSES (Q-SPACE)

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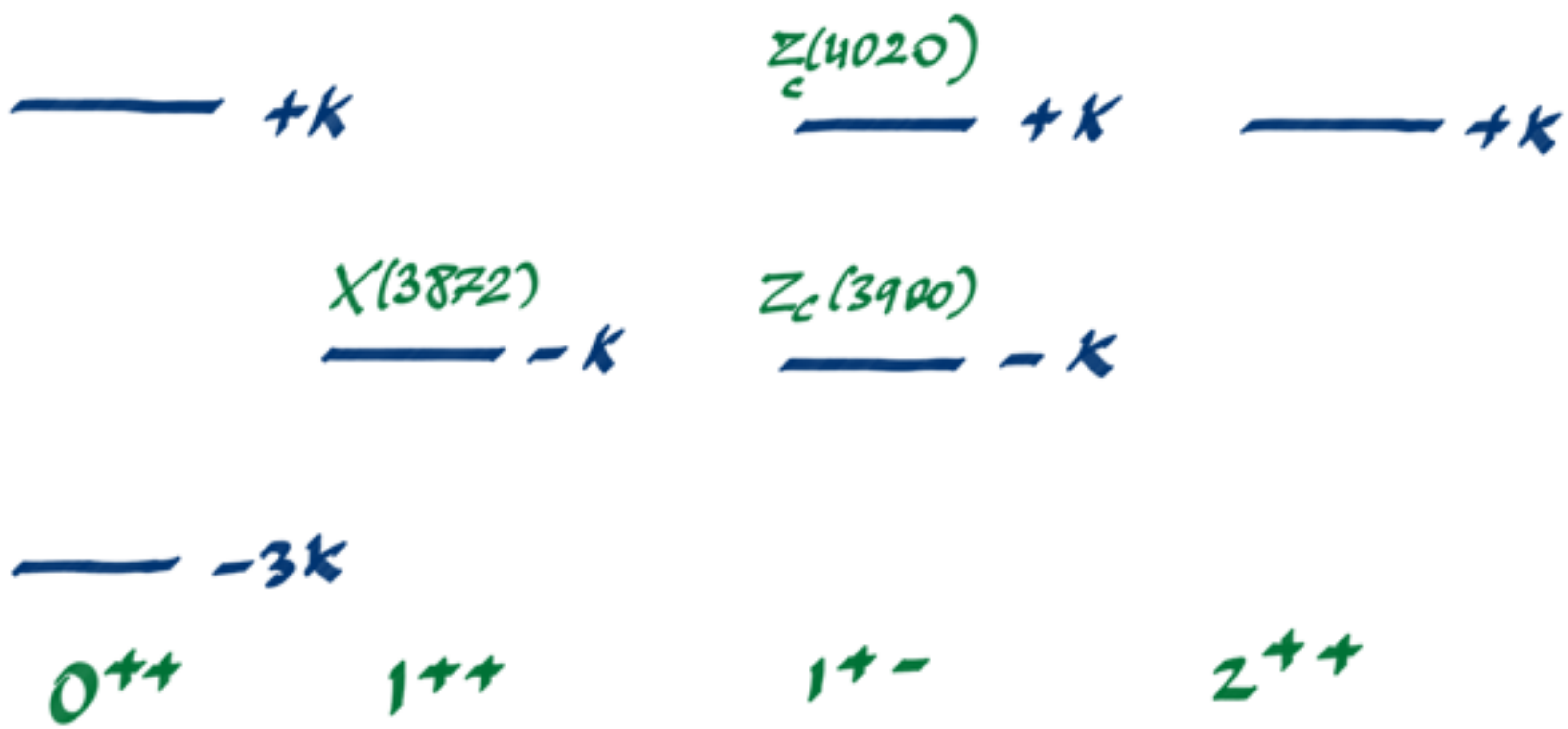
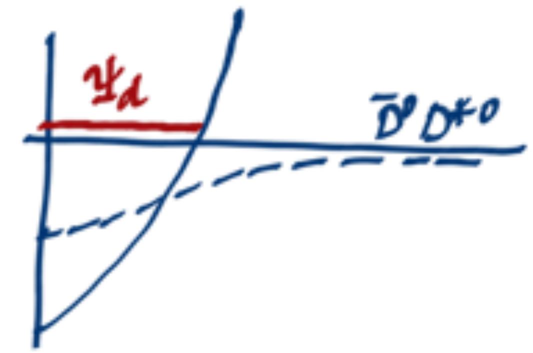
The spectrum is as follows

For [cq][$\bar{c}\bar{q}'$] diquarkonia

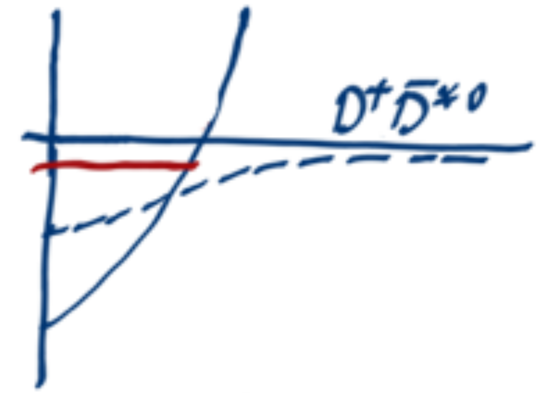


DIQUARKONIA & MOLECULES

'CLOSED' SPACE Q	'OPEN' SPACE P
$\Psi_d(X_d^0) \equiv [cd]_0[\bar{c}\bar{d}]_1 + [cd]_1[\bar{c}\bar{d}]_0$ $\sim(\bar{D}^{*-}D^{+} - D^{*+}\bar{D}^{-}) + i\,\psi\wedge\rho^0 - i\,\psi\wedge\omega$ $\Psi_d(X_u^0)$ not $\perp$ to ψ_m $\rightarrow$ I violation $\Psi_d(X^+) \sim (D^+\bar{D}^{*0} - \bar{D}^0 D^{*+}) - i\,\psi\wedge\rho^+$, not $\perp$	$\Psi_m \sim \bar{D}^0 D^{*0}$  $\Psi_m \sim D^+\bar{D}^{*0} \vee \bar{D}^0 D^{*+}$
$\Psi_d(Z_c^+) \sim \eta_c\rho^+ - \psi\pi^+ - i\,\bar{D}^{*0}\wedge D^{*+}$ $M(Z_c^+) > M(D^+\bar{D}^{*0}) \longrightarrow$ yes Z^+	$\Psi_m \sim \bar{D}^0\, D^{*0}$
$\Psi_d(Z_c'^+) \sim \eta_c\rho^+ + \psi\pi^+ - \bar{D}^0 D^{*+} + D^+\bar{D}^{*0}$ $M(Z_c'^+) > M(D^{*+}\bar{D}^{*0}) \longrightarrow$ yes Z'^+	$\Psi_m \sim D^{*0}\,\bar{D}^{*0}$

SAME FOR Z_b RESONANCES BUT $M(X_b^0)$ IS ESTIMATED $<$ $M(\bar{B}^0 B^{*0})$
(deduced from the splitting $Z_c - X$)

DIQUARKONIA & MOLECULES

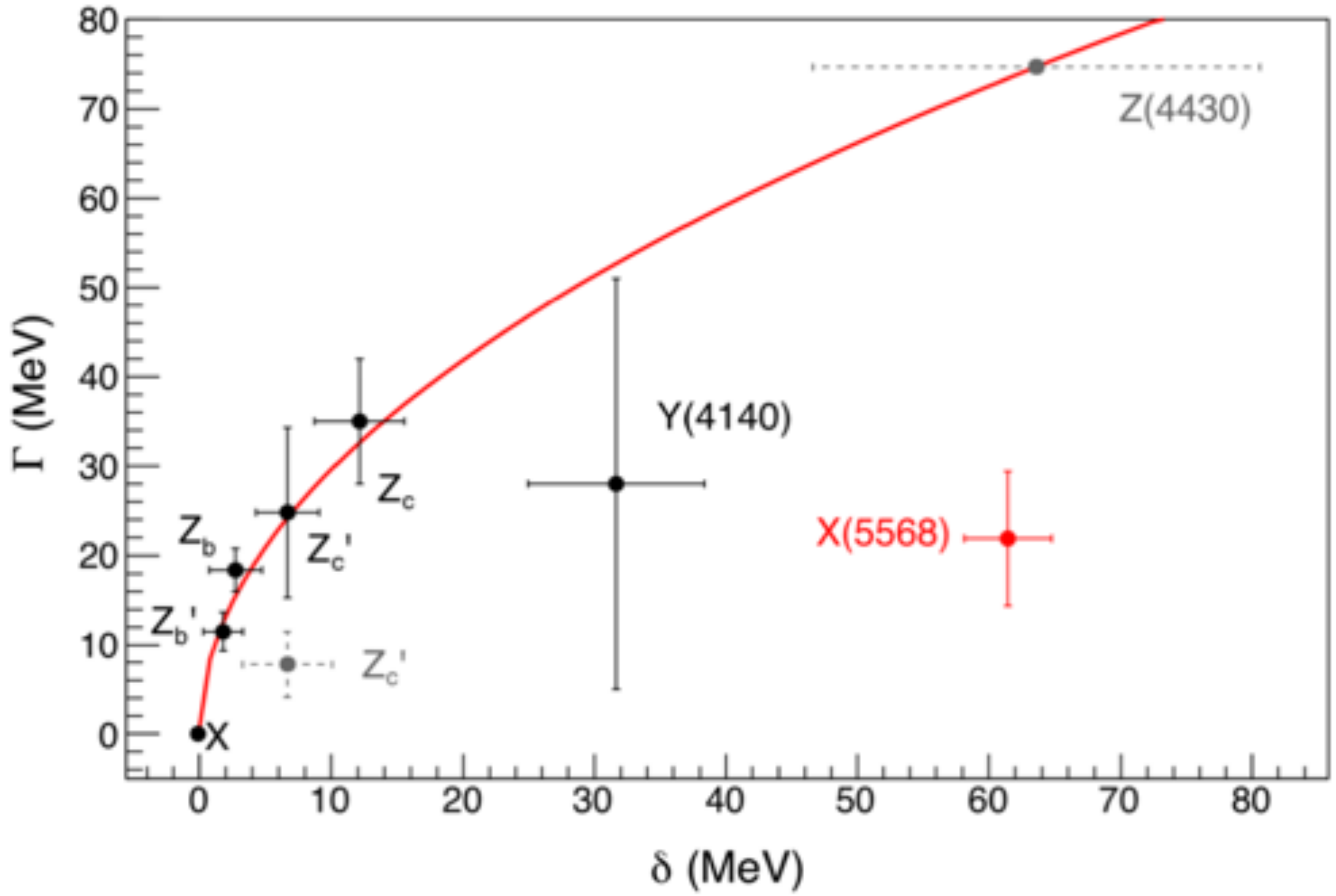
'CLOSED' SPACE Q	'OPEN' SPACE P
$\Psi_d(X_d^0) \equiv [cd]_0[\bar{c}\bar{d}]_1 + [cd]_1[\bar{c}\bar{d}]_0$ $\sim (\bar{D}^{*-}D^{+} - D^{*+}\bar{D}^{-}) + i\,\psi\wedge\rho^0 - i\,\psi\wedge\omega$ $\Psi_d(X_u^0)$ not $\perp$ to ψ_m $\rightarrow$ I violation $\Psi_d(X^+) \sim (D^+\bar{D}^{*0} - \bar{D}^0 D^{*+}) - i\,\psi\wedge\rho^+$, not $\perp$	$\Psi_m \sim \bar{D}^0 D^{*0}$  $\Psi_m \sim D^+\bar{D}^{*0} \vee \bar{D}^0 D^{*+}$
$\Psi_d(Z_c^+) \sim \eta_c\rho^+ - \psi\pi^+ - i\,\bar{D}^{*0}\wedge D^{*+}$ $M(Z_c^+) > M(D^+\bar{D}^{*0}) \rightarrow$ yes Z^+	$\Psi_m \sim \bar{D}^0 D^{*0}$
$\Psi_d(Z_c'^+) \sim \eta_c\rho^+ + \psi\pi^+ - \bar{D}^0 D^{*+} + D^+\bar{D}^{*0}$ $M(Z_c'^+) > M(D^{*+}\bar{D}^{*0}) \rightarrow$ yes Z'^+	$\Psi_m \sim D^{*0}\bar{D}^{*0}$

SAME FOR Z_b RESONANCES BUT $M(X_b^0)$ IS ESTIMATED $<$ $M(\bar{B}^0 B^{*0})$
(deduced from the splitting $Z_c - X$)

TOTAL WIDTHS

N.B. δ (detuning) = distance of the level in Q from the CLOSEST molecular threshold from BELOW.

$$\Gamma \sim (2m)^{1/2} \, |\varkappa a_p| \sqrt{\delta}$$



X(5568) claimed by D0 in $B_s^0 \pi^+$ in FEB 2016

A. ESPOSITO, A. PILLONI, ADP 1603.07667 (PLB)

TOTAL WIDTHS

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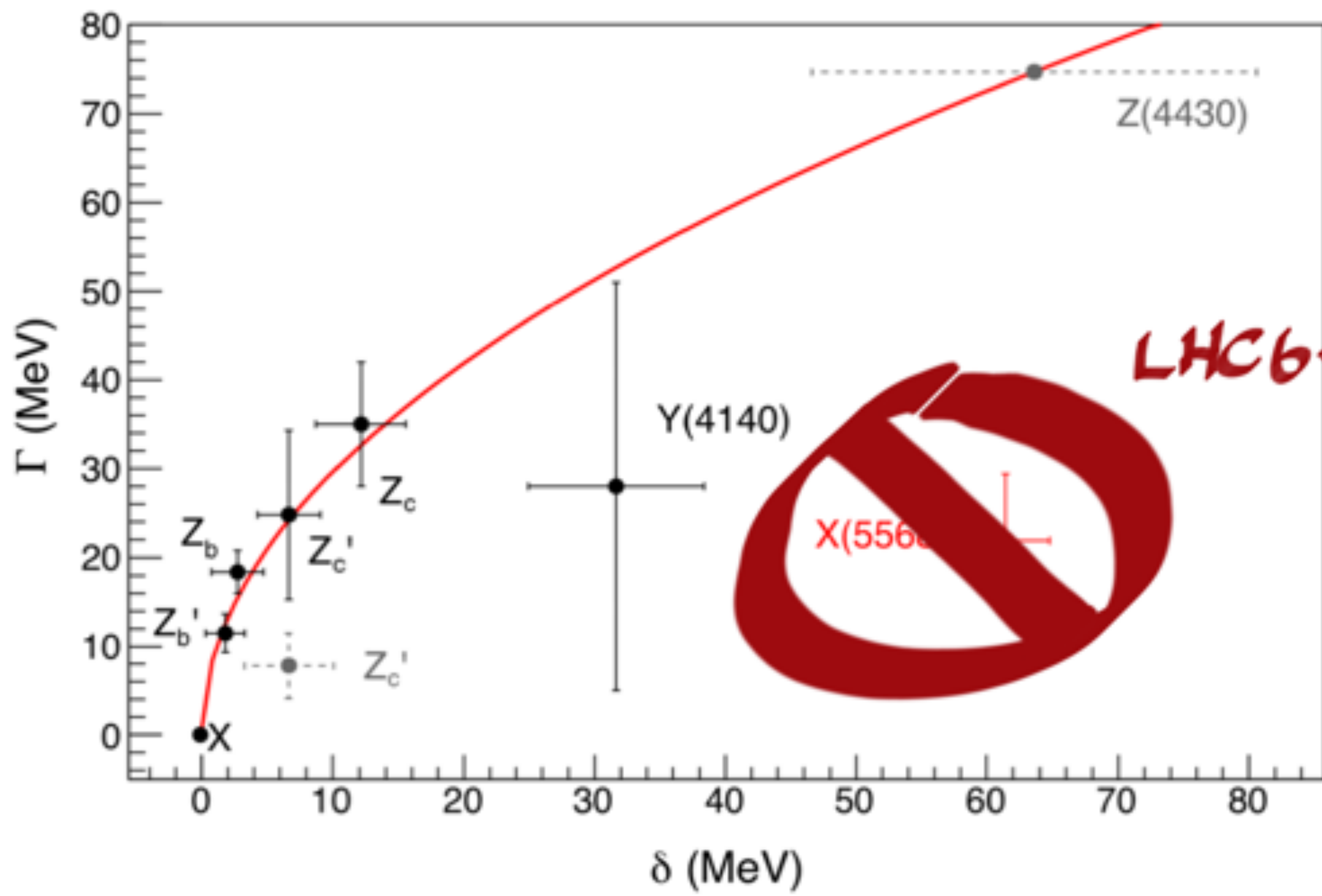
$0 < \delta < E_{max} < \bar{T}$ in $[Qq][\bar{Q}\bar{q}]$



LHCb few weeks later

X(5568) claimed by D0 in $B_s^0 \pi^+$ in FEB 2016

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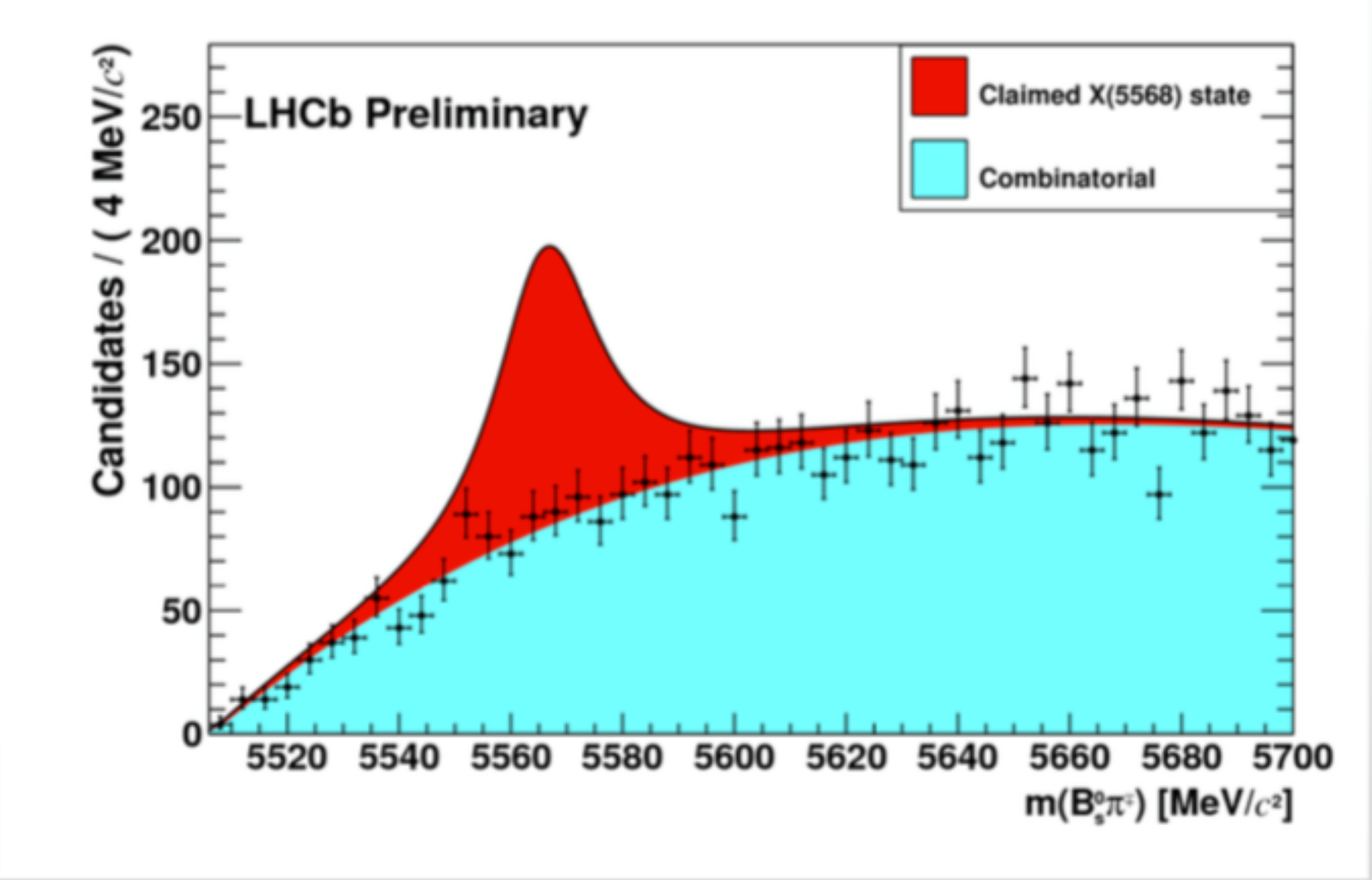
JUST FOR CURIOSITY...

LHCb-CONF-2016-004

If $\rho_X^{\mathrm{LHCb}} = \rho_X^{\mathrm{D\emptyset}} = 8.6\%$, how would the X(5568) signal look like?

(Both modes combined: $p_T(B_s) > 10$ GeV/c)



DIQUARKONIUM & $X_b(5568)$

$$M_{Z'_b} - M_{Z_b} = 2k_{bq}$$

$$M_{Z'_b} + M_{Z_b} = 4 m_{[bq]}$$

$$M(X_b[\bar{b}\bar{q}][sq]) = m_{[bq]} + m_{[sq]} + 2k_{bq}\,\vec{S}_{\bar{b}}\cdot\vec{S}_{\bar{q}} + 2k_{sq}\,\vec{S}_s\cdot\vec{S}_q$$

both diquarks w/ $S=0$
0^{++}

$$= m_{[bq]} - 3/2\,k_{bq} + \underbrace{(m_{[sq]} - 3/2\,k_{sq})}_{m_{a_0}/2}$$

$$\simeq \underline{5771\ \text{MeV}}$$

- Too large detuning δ wrt $B_s\pi$ threshold ($\delta > E_{max}$)
- Very close to BK threshold. If underestimated by a few MeVs, a resonance might appear just above the BK (same quark content).

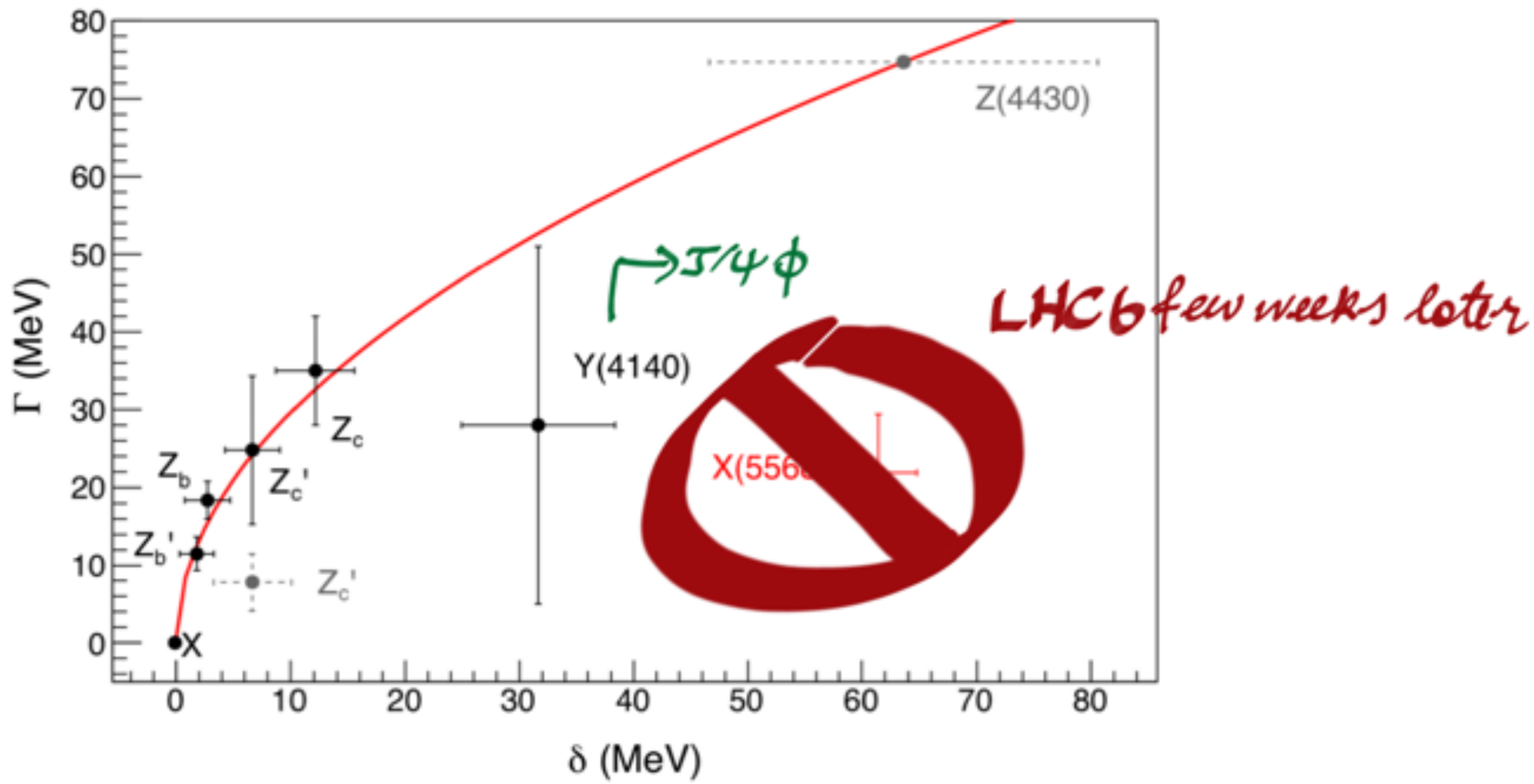
SEARCH IN BK^+!

TOTAL WIDTHS

N.B. δ (detuning) = distance of the level in Q from the CLOSEST molecular threshold from BELOW.

$$\Gamma \sim (2m)^{1/2}\, |\varkappa a_p|\, \sqrt{\delta}$$

$0 < \delta < E_{max} < T$ in $[Qq][\bar{Q}\bar{q}]$



$$\Psi_d(X(4140)) \sim \bar{D}_s^{*-} D_s^{+} - D_s^{*+} \bar{D}_s^{-} + i\, \psi \wedge \phi$$

Ψ_m might be taken orthogonal but there will be no single threshold dominance: <u>δ from the lower $\bar{D}_s^{*-} D_s^{+}$</u>

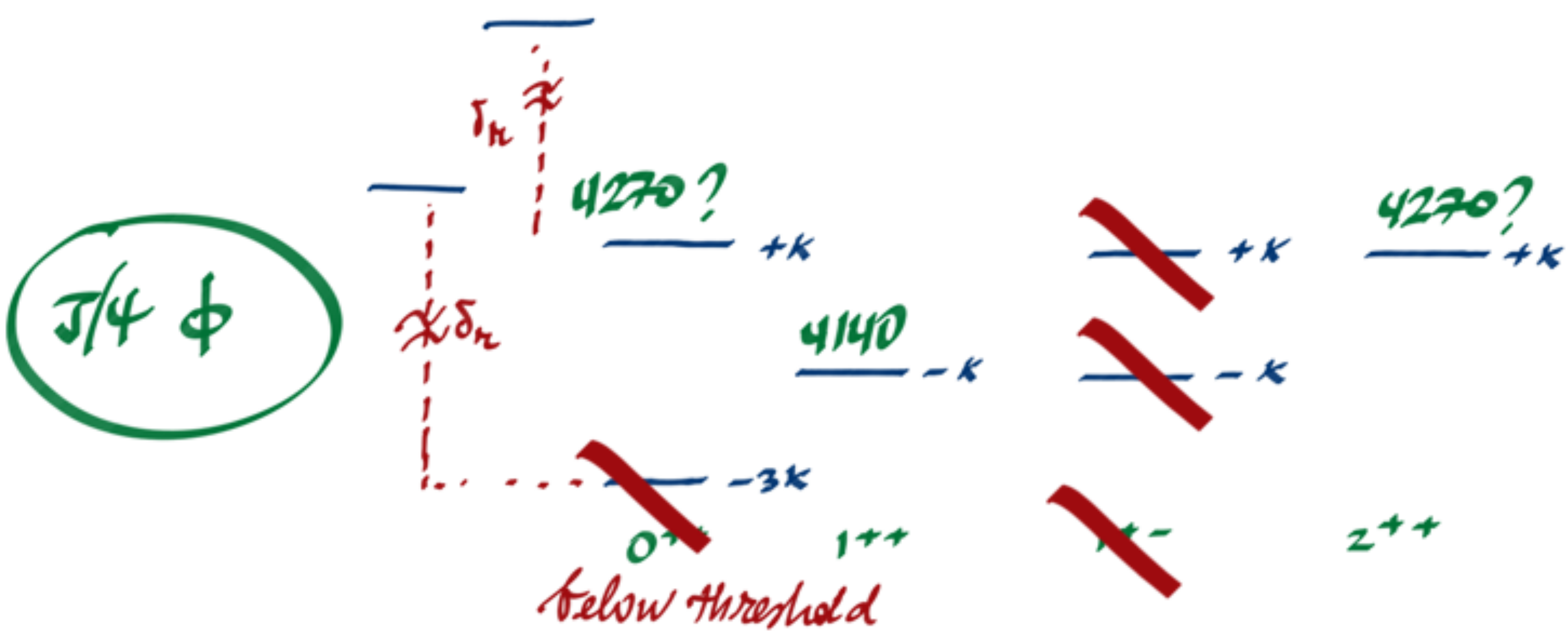
X(4140), X(4274), X(4500), X(4700)

as from LHCb @ Blois (see S. Stone)

28 Recontres de Blois, June 2, 2016

$$X(4140) = [cs]_0[\bar{c}\bar{s}]_1 + [cs]_1[\bar{c}\bar{s}]_0$$

X(4140)	1^{++}	$2m_{[cs]} - K$
X(4270)	$0^{++} \vee 2^{++}$	$2m_{[cs]} + K$
X(4500)	0^{++}	$2m_{[cs]} - 3K + \delta_r$
X(4700)	0^{++}	$2m_{[cs]} + K + \delta_r$



X(4140), X(4274), X(4500), X(4700)

as from LHCb @ BLOIS (see S. Stone)

$$X(4140) = [cs]_0[\bar{c}\bar{s}]_1 + [cs]_1[\bar{c}\bar{s}]_0$$

X(4140)	1^{++}	$2m_{[cs]} - k$	4146	
X(4270)	$0^{++} \vee 2^{++}$	$2m_{[cs]} + k$	4273	(MeV)
X(4500)	0^{++}	$2m_{[cs]} - 3k + \delta_r$	4506	
X(4700)	0^{++}	$2m_{[cs]} + k + \delta_r$	4704	

with $m_{[cs]} = 2100$ MeV

$k_{cs} = 54$ MeV

$\delta_r = 460$ MeV

N.B. $m_{[cs]} = m_{[cq]} + \underbrace{(m_s - m_q)}_{120\text{ MeV from }\underline{10}\text{ of }SU(3)} \simeq 2100$ MeV

$$K_{cs} = K_{cq}\frac{m_q}{m_s} \simeq 45 \pm 3 \text{ MeV}$$

EXOTIC RESONANCES

— $X^0(3872)$ 1^{++}

No charged partners observed: $X^\pm$ ✓

Isospin violations: $X \to \psi\rho / X \to \psi\omega \sim 1$ ✓

Very narrow $\Gamma < 1$ MeV ✓

Almost degenerate w/ $\bar{D}^0 D^{*0}$ & $\psi\rho$ ← related

— $Z_c^{0,\pm}(3900)$, $Z_c'^{\pm}(4020)$ 1^{+-}

Charged & neutral! ✓

The lowest is very close in mass to X^0 ✓

— $Z_b(10610)$, $Z_b(10650)$ 1^{+-}

There is no $X_b^0(\simeq 10600)$ ✓

— $X^0(4140)$ 1^{++}

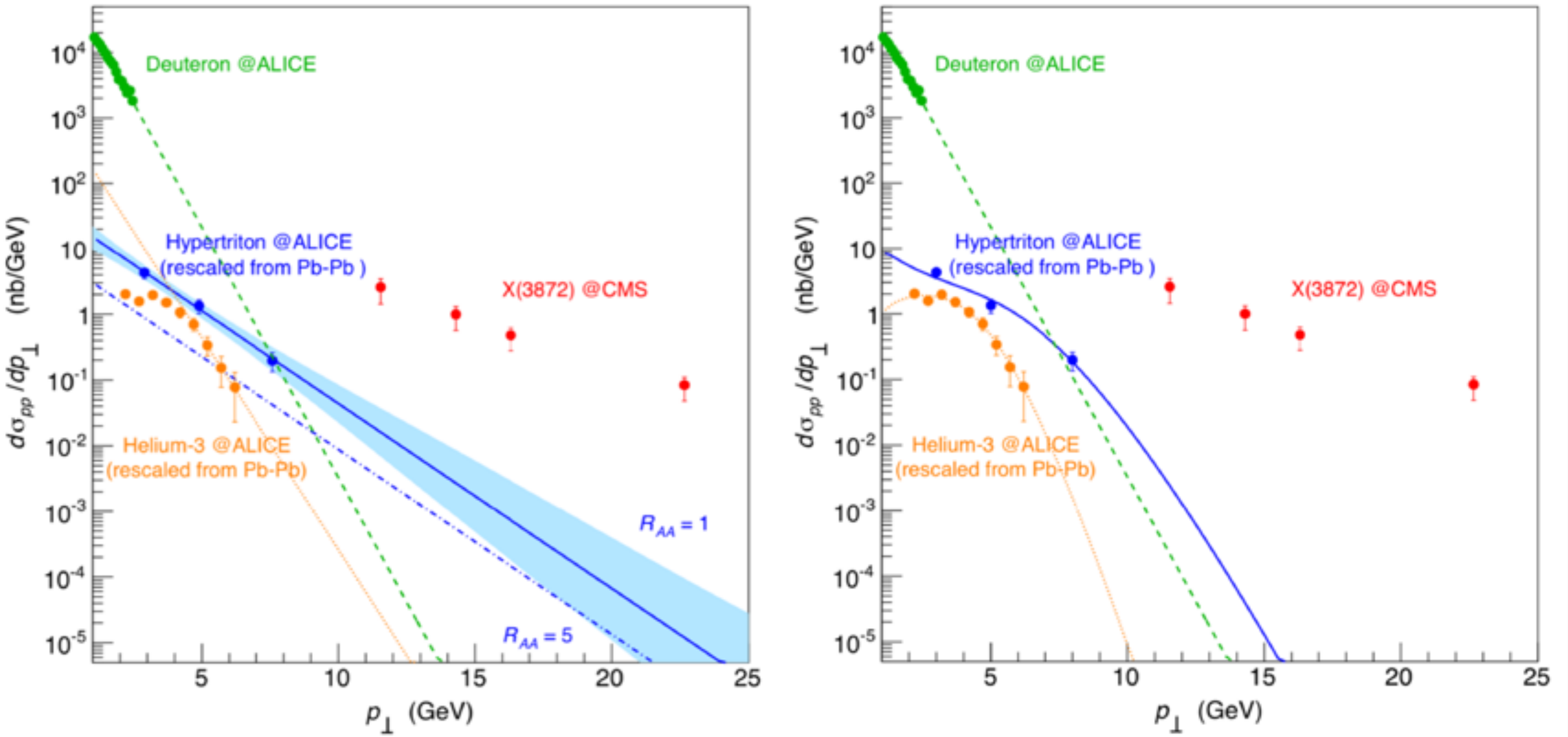
Together w/ $X(4274)$, $X(4500)$, $X(4700)$ ✓

recently observed by LHCb.

but: one of 1^{++} states is 0^{++} or 2^{++}.

DATA FROM ALICE

For those who think that we are observing only hadron molecules



Exponential fit – 'Blastwave' fit –

A Esposito et al. PRD 92 (2015) 034028

Pentaquarks

based on 1507.04980 (PLB) with L. Maiani and V. Riquer (Sapienza U.)

THE PENTAQUARK

Highly undesirable option for molecules (before discovery)
Perfect molecule (after discovery)

LHCb 2015

$$\Lambda_b(bud) \rightarrow K^- \mathbb{P}^+$$
$$\hookrightarrow J/\psi\, p$$

$$\mathbb{P}^+ = \bar{c}\, c\, u\, u\, d \Rightarrow \text{negative parity}$$

TWO STATES OBSERVED

$$J^P = 3/2^- \quad @ \quad 4380 \text{ MeV}$$

$$J^P = 5/2^+ \quad @ \quad 4550 \text{ MeV}$$

$L=0$ & $L=1$ Pentaquarks?

Note: Lower baryons have $P=+$ / pentaq. have $P=-$!
Lower mesons have $P=-$ / tetraq. have $P=+$

MASS DIFFERENCE

ISN'T $\Delta M = 170$ MeV too SMALL for one unit of L ?

($\Delta M = 300$ MeV for $\Lambda(1405) - \Lambda(1116)$)

On the other hand, from $\Sigma_c - \Lambda_c$ we find

$$M_{[qq']_{S=1}} - M_{[qq']_{S=0}} \simeq 200 \text{ MeV}$$

So

$$\mathbb{P}(3/2^-) = \bar{c}\,[cq]_{S=1}\,[q'q'']_{S=1} \text{ @ } L=0$$

$$\mathbb{P}(5/2^+) = \bar{c}\,[cq]_{S=1}\,[q'q'']_{S=0} \text{ @ } L=1$$

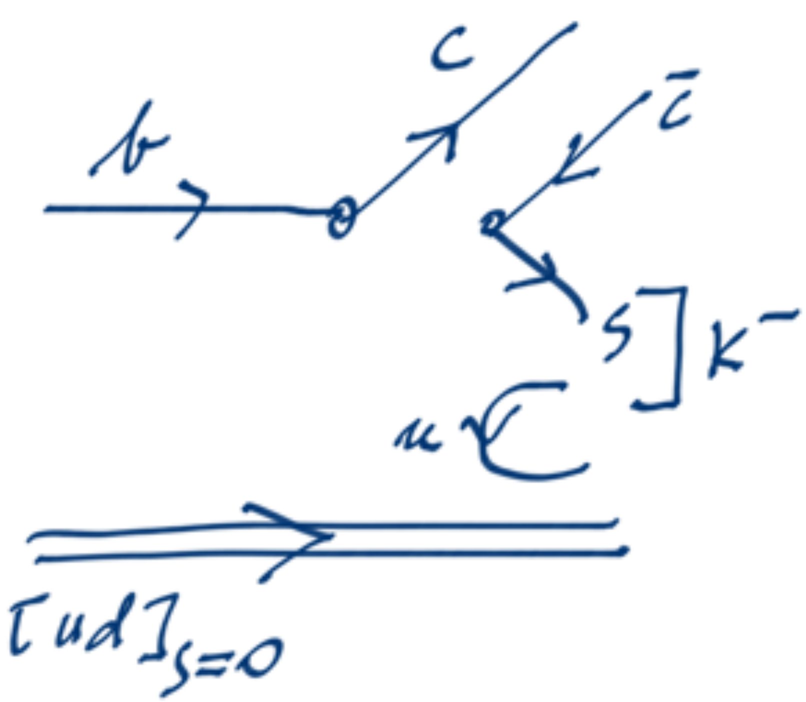
... combine diquark spin & orbital angular momentum -

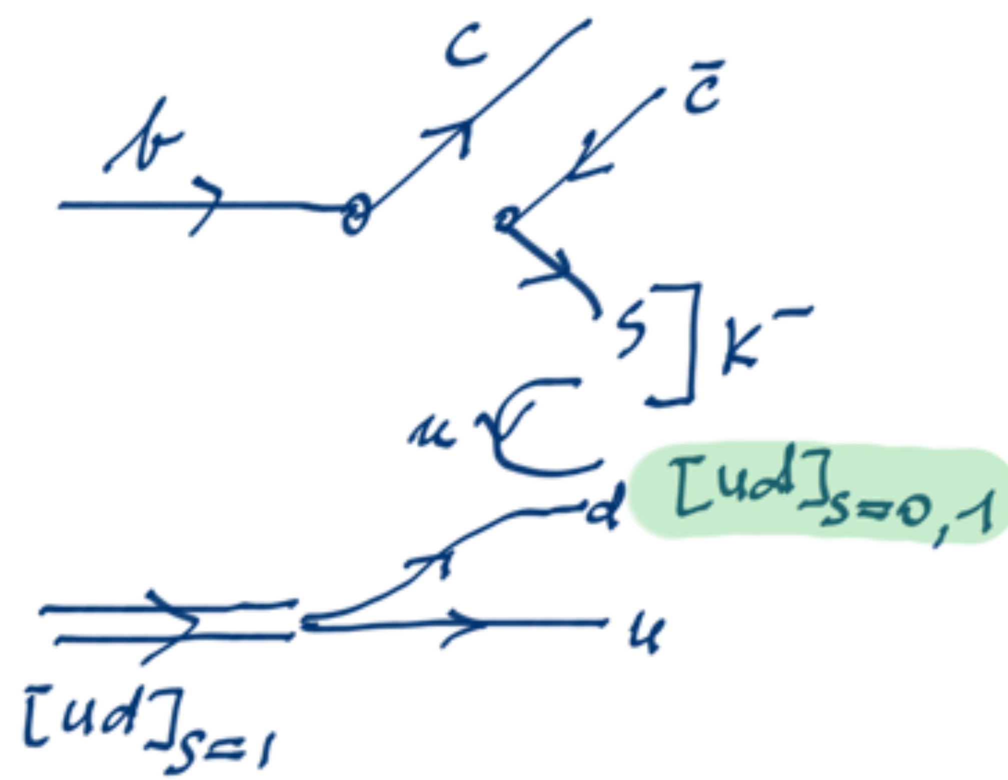
Other states ?

L Maiani, ADP, V Riquer, PRD 749 (2015) 289; PLB 750 (2015) 37

$\Lambda \to K^- P^+$

Λ_b baryon might contain a $[ud]_{S=0}$, "good" diquark.
But $P(3/2^-)$ should contain $[ud]_{S=1}$, whereas $P(5/2^+)$ has $[ud]_{S=0}$.





One can show that both pentaquarks have $S_{c\bar{c}} = 1$ so that HQ spin cons. allows decay into J/ψ.

L Maiani, ADP, V Riquer, PRD 749 (2015) 289; PLB 750 (2015) 37

Flavor

$$\langle \mathbb{P}, M \,|\, H_w(\Delta I=0, \Delta S=-1) \,|\, \Lambda_b \rangle$$

8_f $\qquad$ 3_f (from s,d,u) $\qquad$ $\bar{3}_f$ (from $[ud]$)

therefore $\mathbb{P}$ is either 8 or 10 (*)

We might expect

$$\Lambda_b \to \pi \, \mathbb{P}_{10}^{S=-1} \to \pi \, J/\psi \, \Sigma(1385)$$

$$\Lambda_b \to K \, \mathbb{P}_{10}^{S=-2} \to K \, J/\psi \, \Xi(1530)$$

or even

$$\Omega_b \to \phi \, \mathbb{P}_{10}^{S=-3} \to \phi \, J/\psi \, \Omega^-(1672)$$

(*) $\begin{cases} 8 \otimes 10 = 8 \oplus 10 \oplus 27 \oplus 35 \\ 8 \otimes 8 = 1 \oplus 8 \oplus 8 \oplus 10 \oplus \overline{10} \oplus 27 \end{cases}$

Tetraquarks in the 1/N expansion

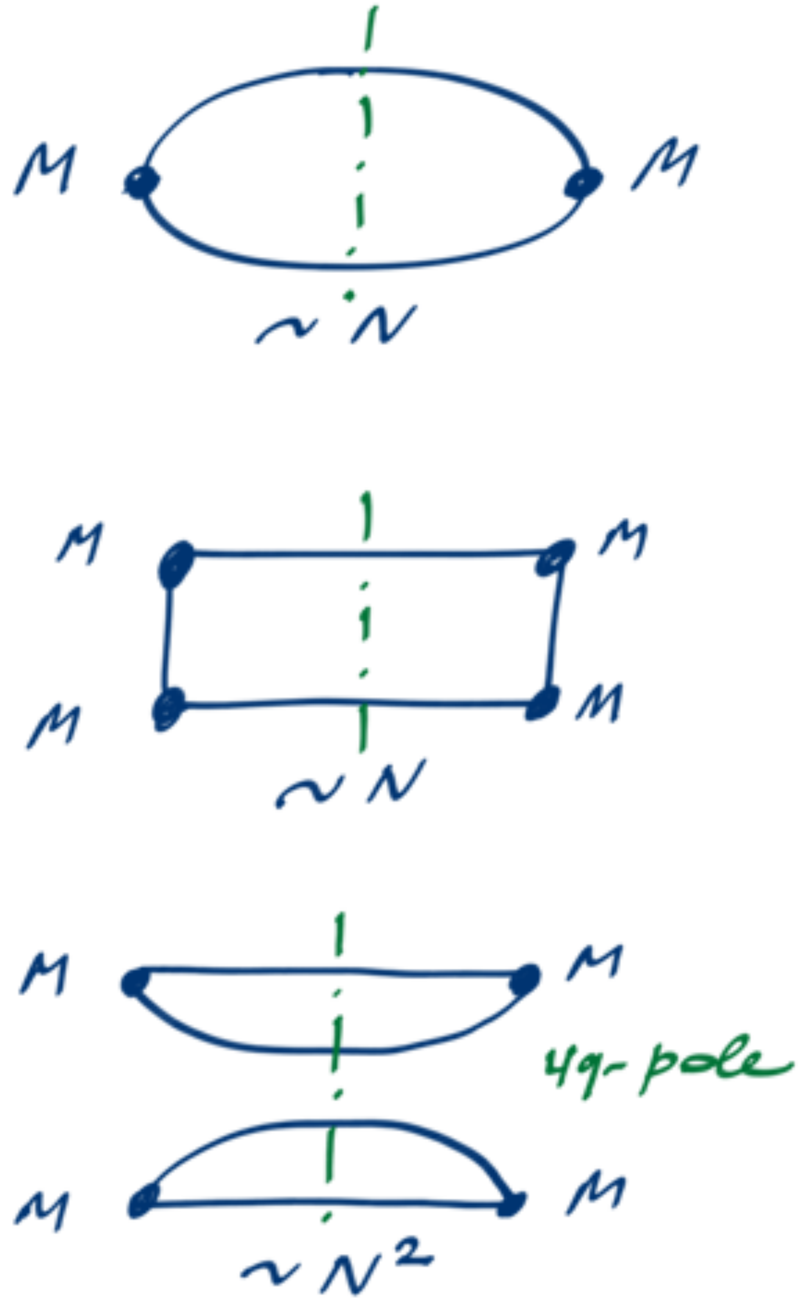
based on 1605.04839 (JHEP) with L. Maiani and V. Riquer

see G. Rossi and G. Veneziano 1605.04285 (JHEP) for an alternative approach

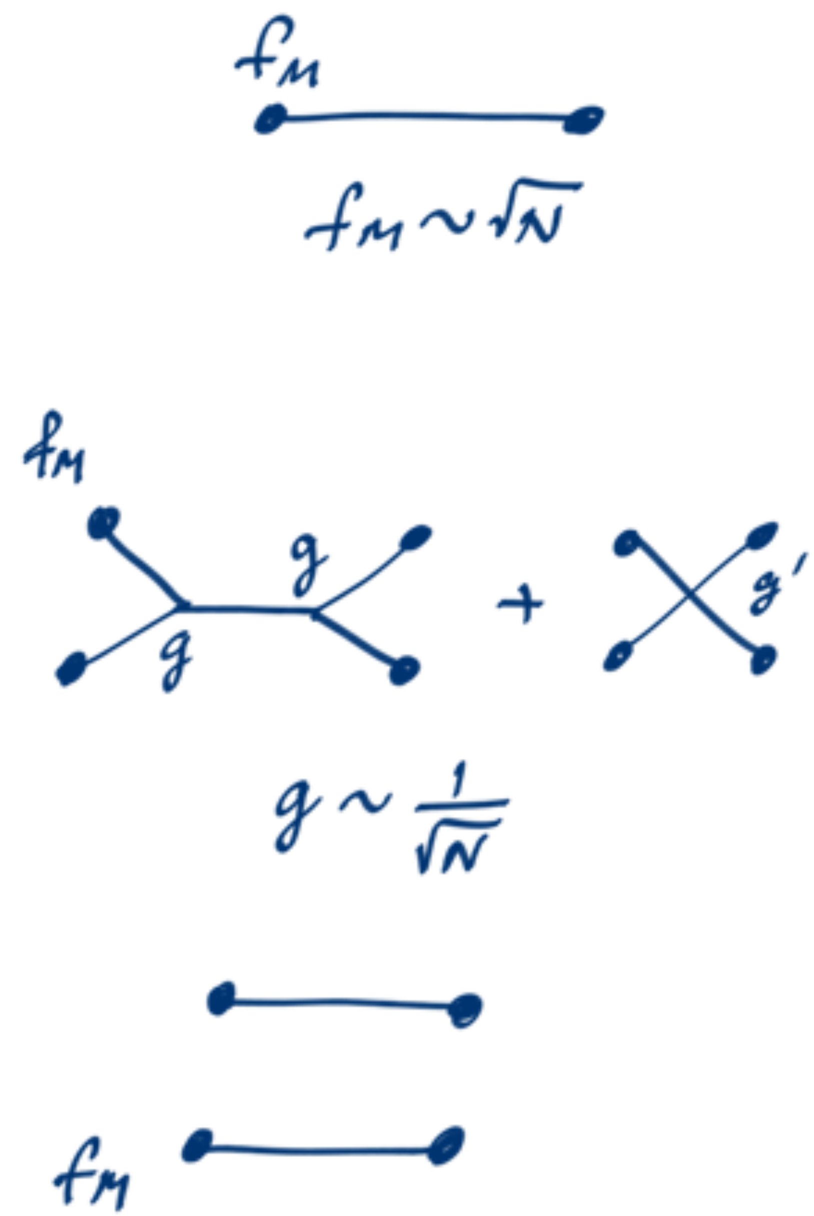
Large N - QCD & Tetraquarks

Reputation of tetraquarks obscured by some considerations by Witten and Coleman (Witten Nucl. Phys. B160 (1979))

Quark theory



Meson theory

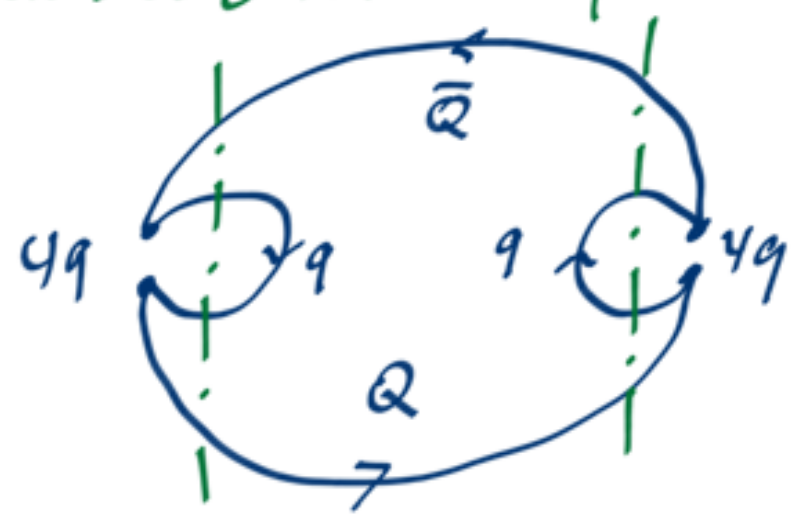


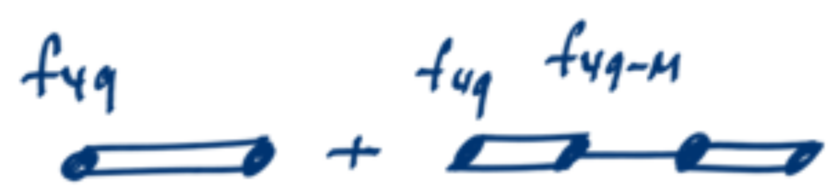
Large N - QCD & Tetraquarks

IF TETRAQUARKS DEVELOP A POLE, IT WILL BE IRRELEVANT IF THE RESIDUE IS OF ORDER $1/N$ WRT DISCONNECTED PARTS.
[S. Weinberg PRL 2013]

MOREOVER THE WIDTH $\Gamma_{4q} \sim 1/N$.

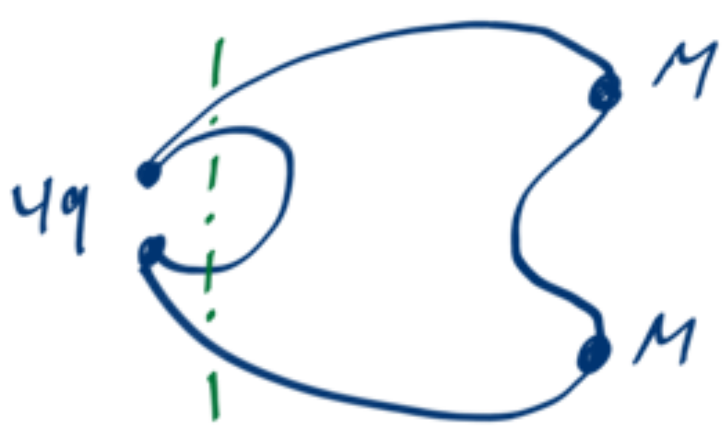
Consider the case of neutral tetraquarks

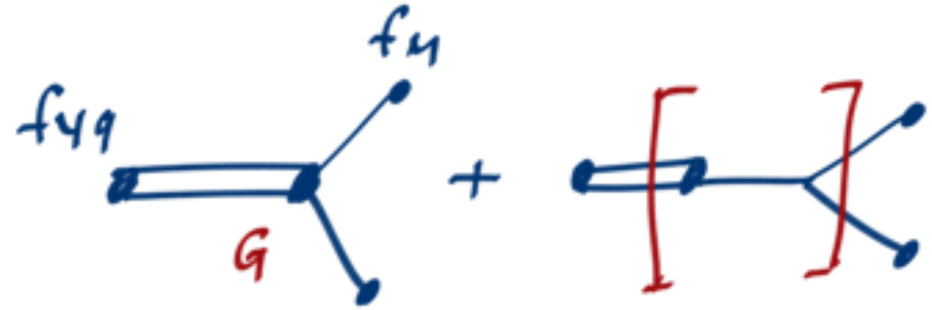




$f_{4q} \sim \sqrt{N}$

$f_{4q\text{-}M} \sim N^0$



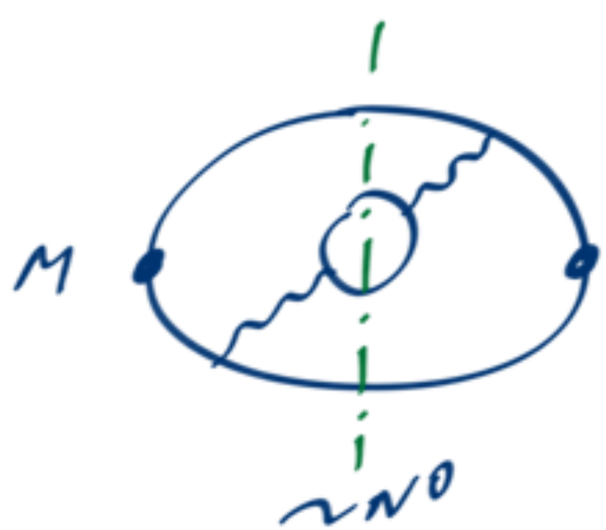


$G \sim \frac{1}{\sqrt{N}}$

$G \sim N^0 \cdot \frac{1}{\sqrt{N}}$

Large N - QCD & Tetraquarks

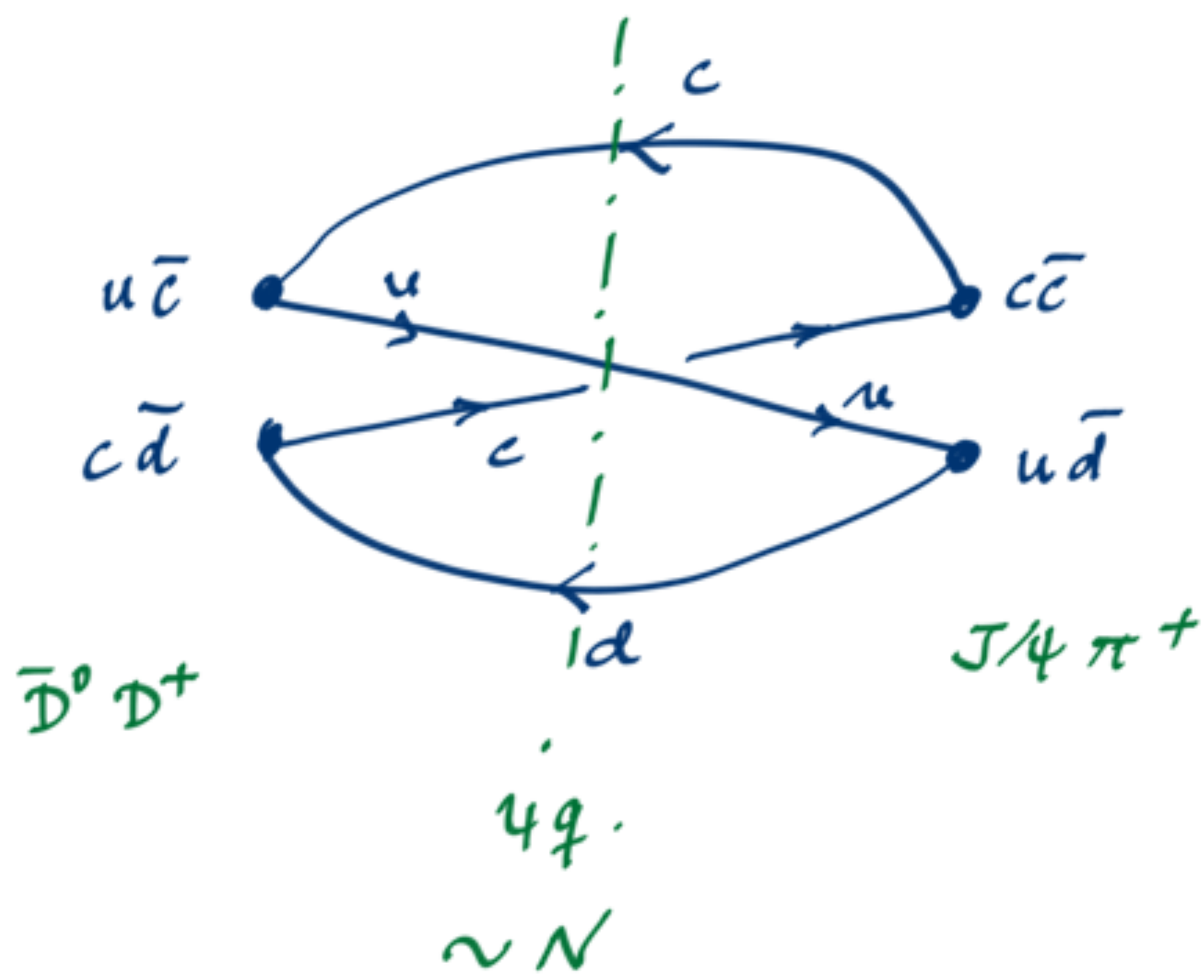
1. Aren't those cuts equivalently leading to Witten's argument?
2. Why the mixing should appear at a different N order in different diagrams?



$f_{M-4q} \sim \frac{1}{\sqrt{N}}$

Large N - QCD & Tetraquarks

Consider a charged tetraquark corrl. funct.

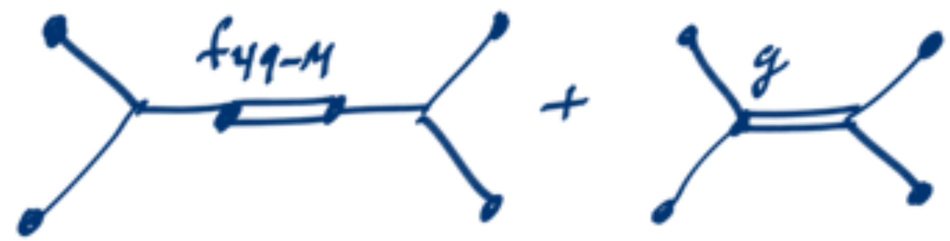


Can be 'untwisted': does it really contain a tetraquark pole?

ONE CAN SHOW THAT DIQUARKONIA GIVE THE RIGHT DESCRIPTION OF THE INTERMEDIATE 4q-STATE!

Large N - QCD & Tetraquarks

$\sim \frac{1}{N^2} \left(= \frac{N}{(\sqrt{N})^6}\right)$

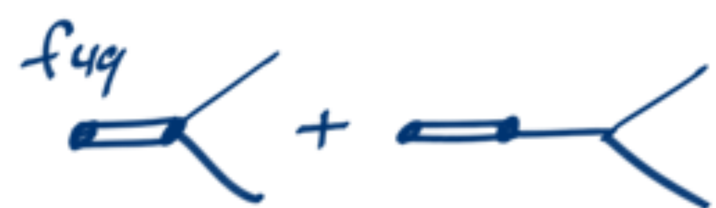


$g \sim \frac{1}{N^2}$

$f_{4q-M} \sim \frac{1}{N\sqrt{N}}$

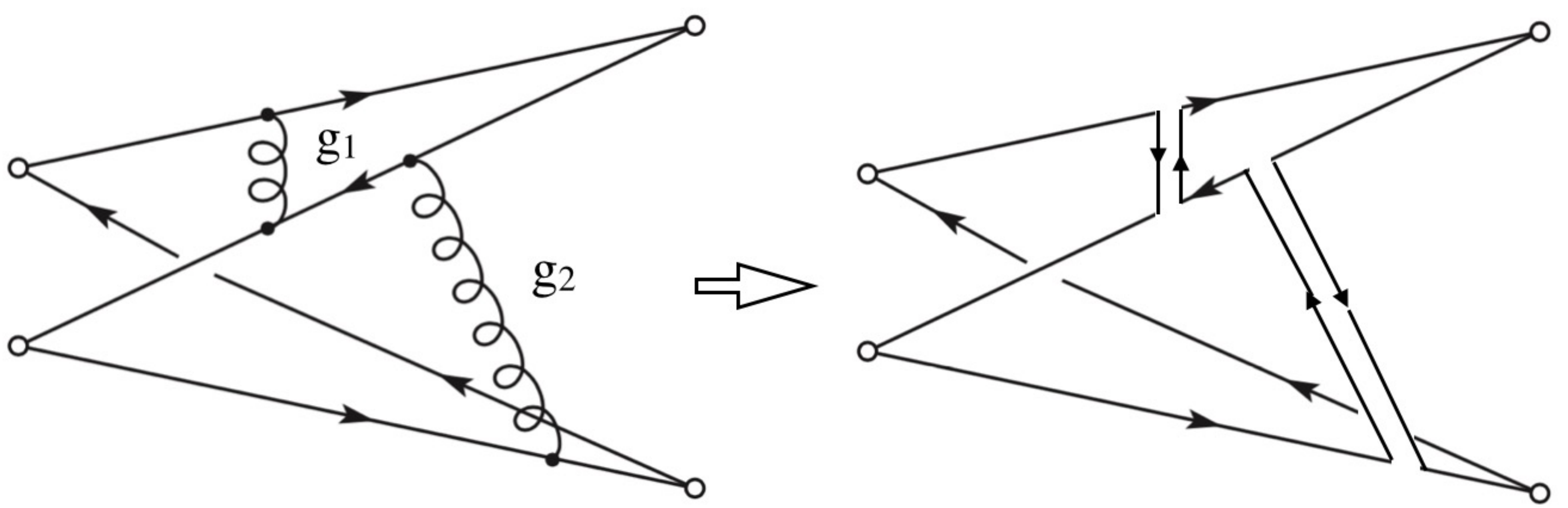
$\sim \frac{1}{N^2}$

$\sim \frac{1}{N} \left(= \frac{N}{(\sqrt{N})^4}\right)$



$f_{4q} \sim N^0$

Non-planar diagrams

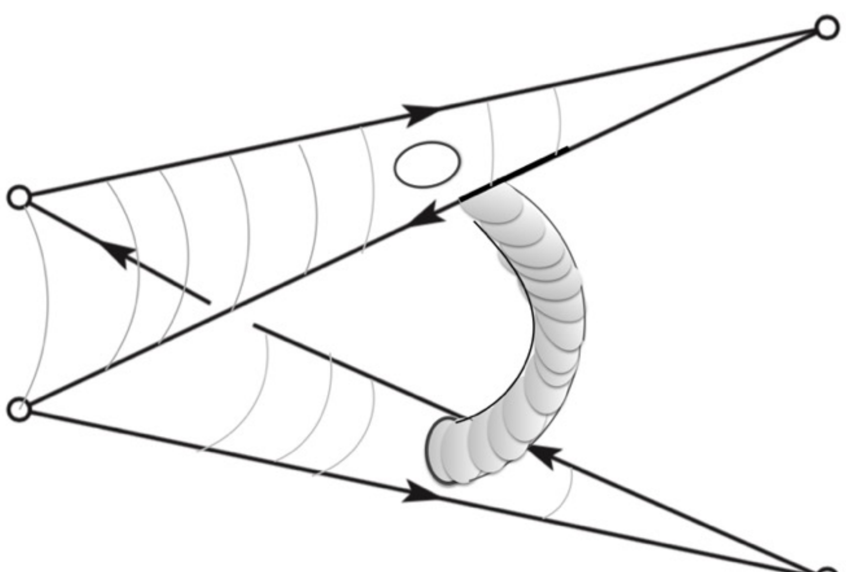


(a)

Non-planar gluons produce the interaction needed to make the color singlet bilinear to merge into a tetraquark.

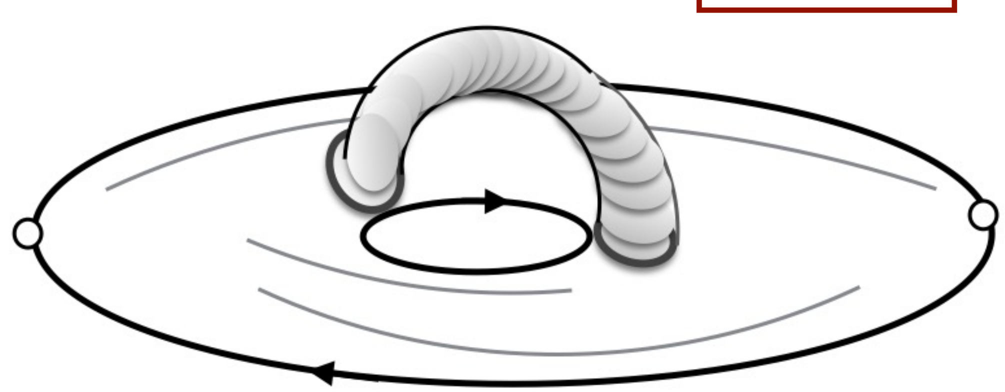
$$f^2_{4q-\text{charged}} \sim \frac{1}{N}$$

$$f_{4q} \cdot g \cdot \sqrt{N}\sqrt{N} \sim \frac{1}{N} \Rightarrow \boxed{g \sim \frac{1}{N\sqrt{N}}}$$



$$N^{2-L-2H} = N^{2-1-2} = 1/N$$

(b)



(c)

SUMMARY

About 20 (exotic) resonances have been discovered

1. Some have complete I-multiplets, some do not
2. Most of them close to M-M thresholds (above!)
3. Diquarks predict charged states & pentaquarks – But need complete I-multiplets – Several quantum numbers predicted $0^{--}, 2^{++}$...
4. Very similar problems with loosely bound molecules –

– A FESHBACH PHENOMENON AT WORK IN STRONG INTERACTIONS?

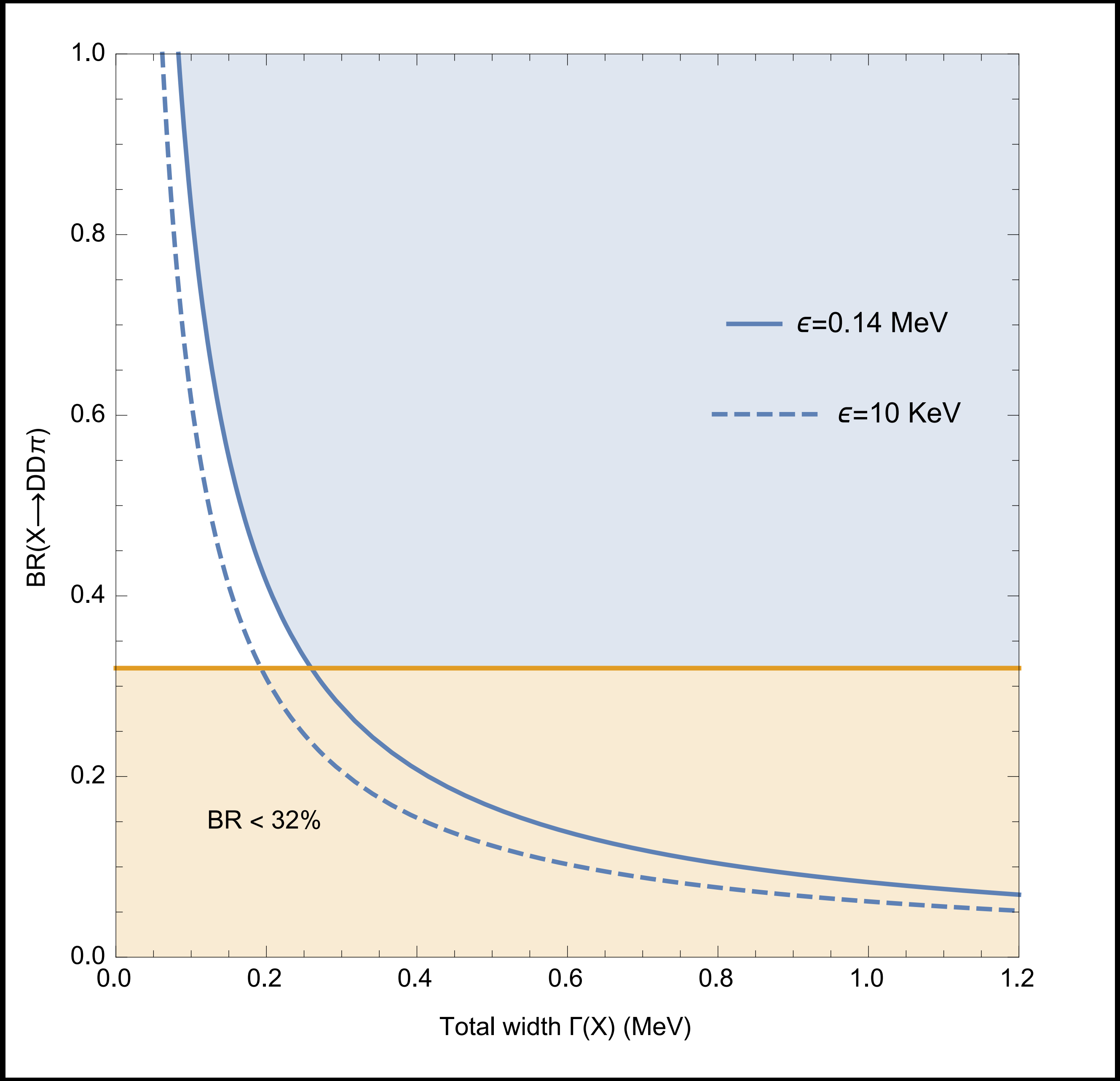
Combining diquarkonia predictions and threshold positions, a new picture might emerge –

Backup

Binding energy and decay rates

$$B \simeq \frac{G^4}{512\,\pi^2}\frac{m^5}{(m_a m_b)^4}$$

$$\mathcal{B}(X\to DD\pi)\cdot\Gamma(X)\sim G^2\sim\sqrt{B}$$



ADP
1505.03083 PLB

CHARGED RESONANCES

LHCb 2014 confirms BELLE 2007 (& disproves Babar 2007)

$$B \longrightarrow K^+ Z^-(4430)$$

$$\hookrightarrow \psi(2S)\pi^-$$

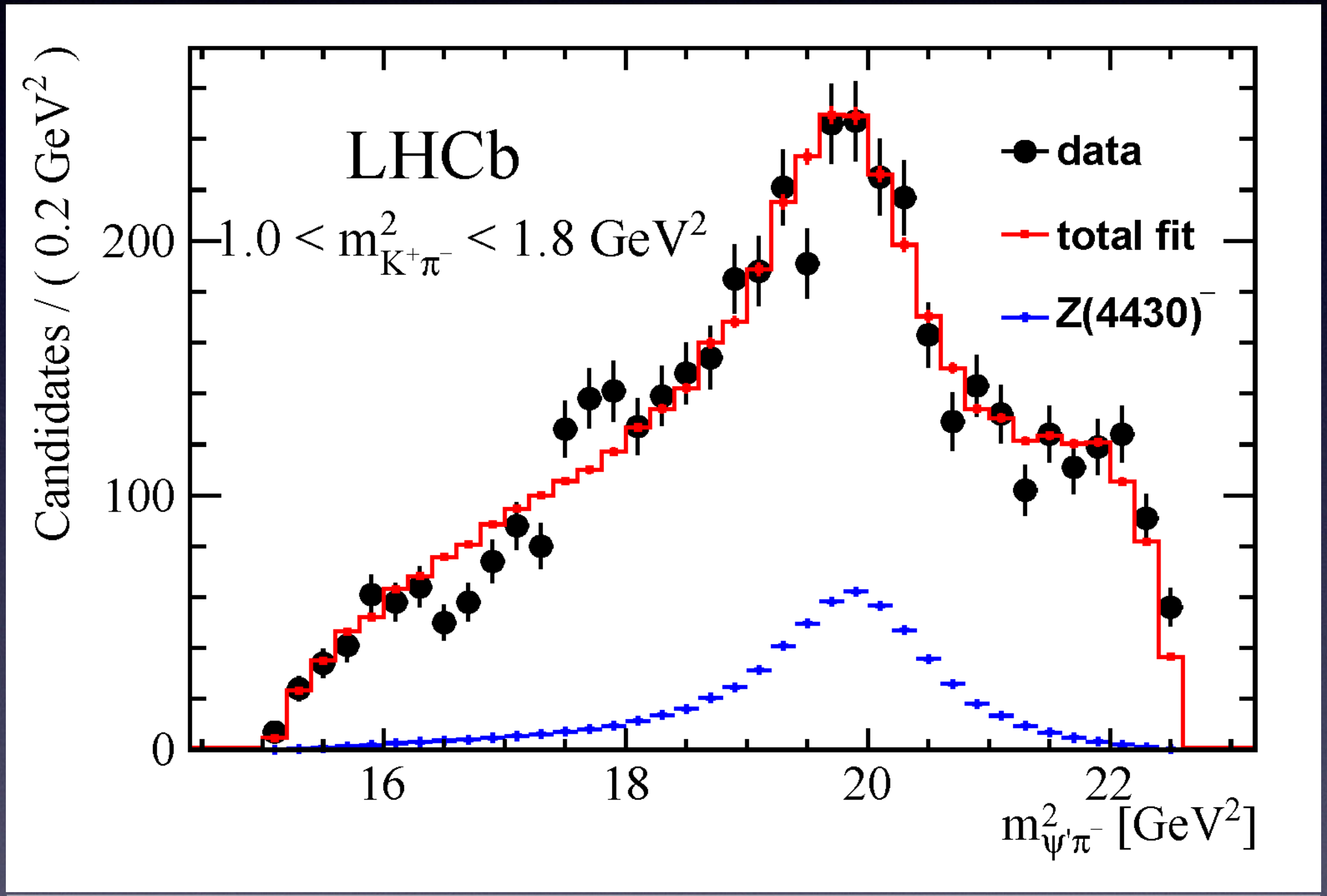
0708.3997 "A CRUCIAL CONSEQUENCE OF Z^- IS A CHARGED STATE IN $J/\psi\, \pi^\pm$ AT 3880 MeV" (Z^- is its radial excitation)

$$M(\psi(2S)) - M(\psi) \simeq M(Z(4430)) - M(Z(3880))$$

BES III FOUND $Z_c(3900)$ IN 2013.

CHARGED RESONANCES HAVE NOT (YET?) BEEN SEARCHED/OBSERVED IN PP PROMPT COLLISIONS.

$Z(4430)^-$ at LHCb | April 2014



$$B \to K^+(\psi(2S)\pi^-)_{J^{PG}=1^{++}}$$

Signal: 13.9 σ
Other assignments ruled out at 9.7σ

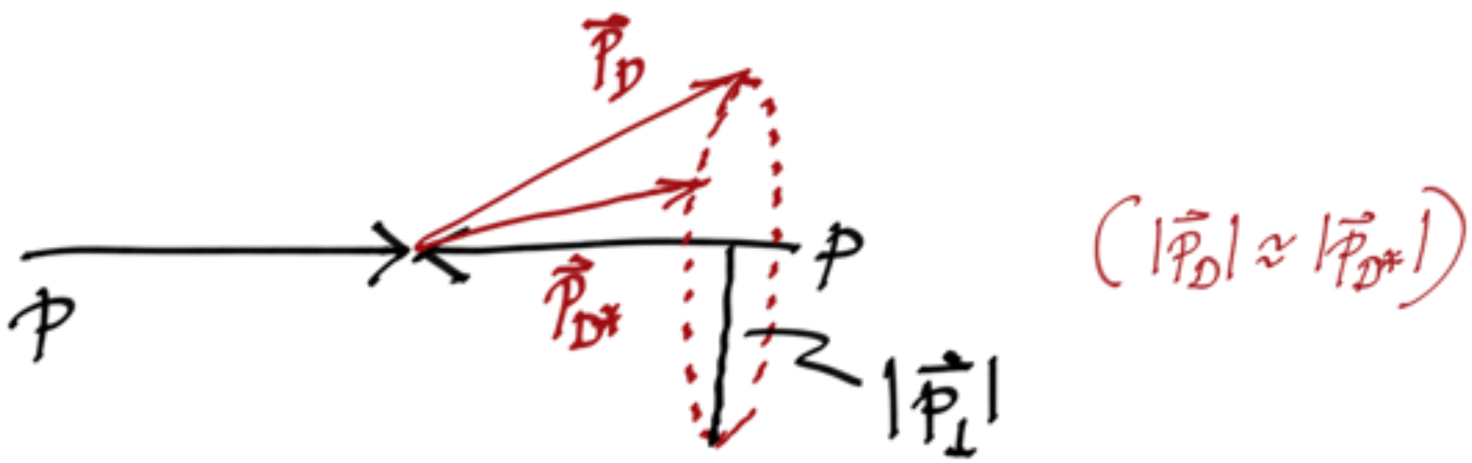
First observed by BELLE in 2007 and not confirmed by BaBar at that time

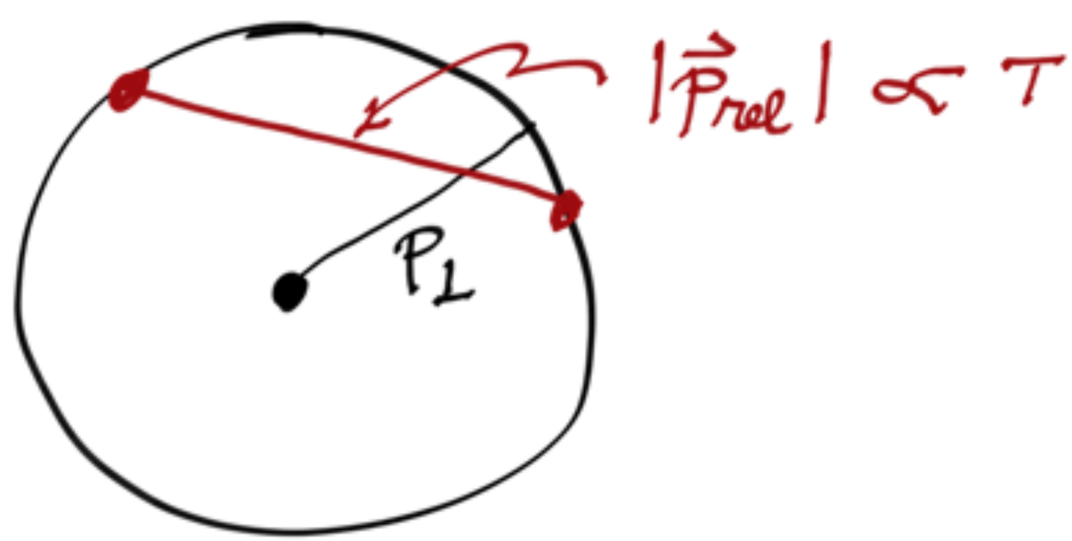
A $D^0 D^{*0}$ MOLECULE?

The previous arguments rely on $T \simeq 0$

What is T (barycentric energy of DD^* after subtraction of rest masses)

in pp collisions at LHC with HIGH $p_\perp$ CUTS?





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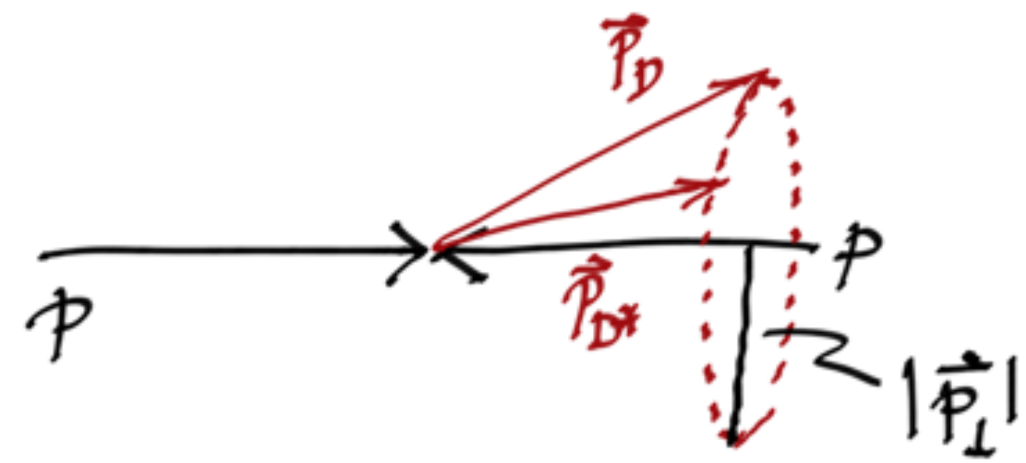
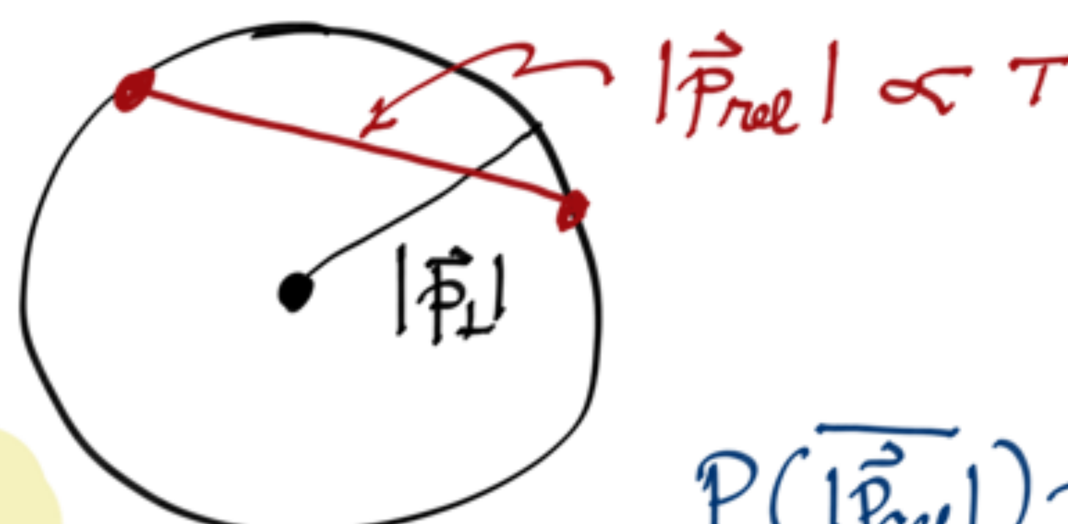


$(|\vec{p}_D| \simeq |\vec{p}_{D^*}|)$

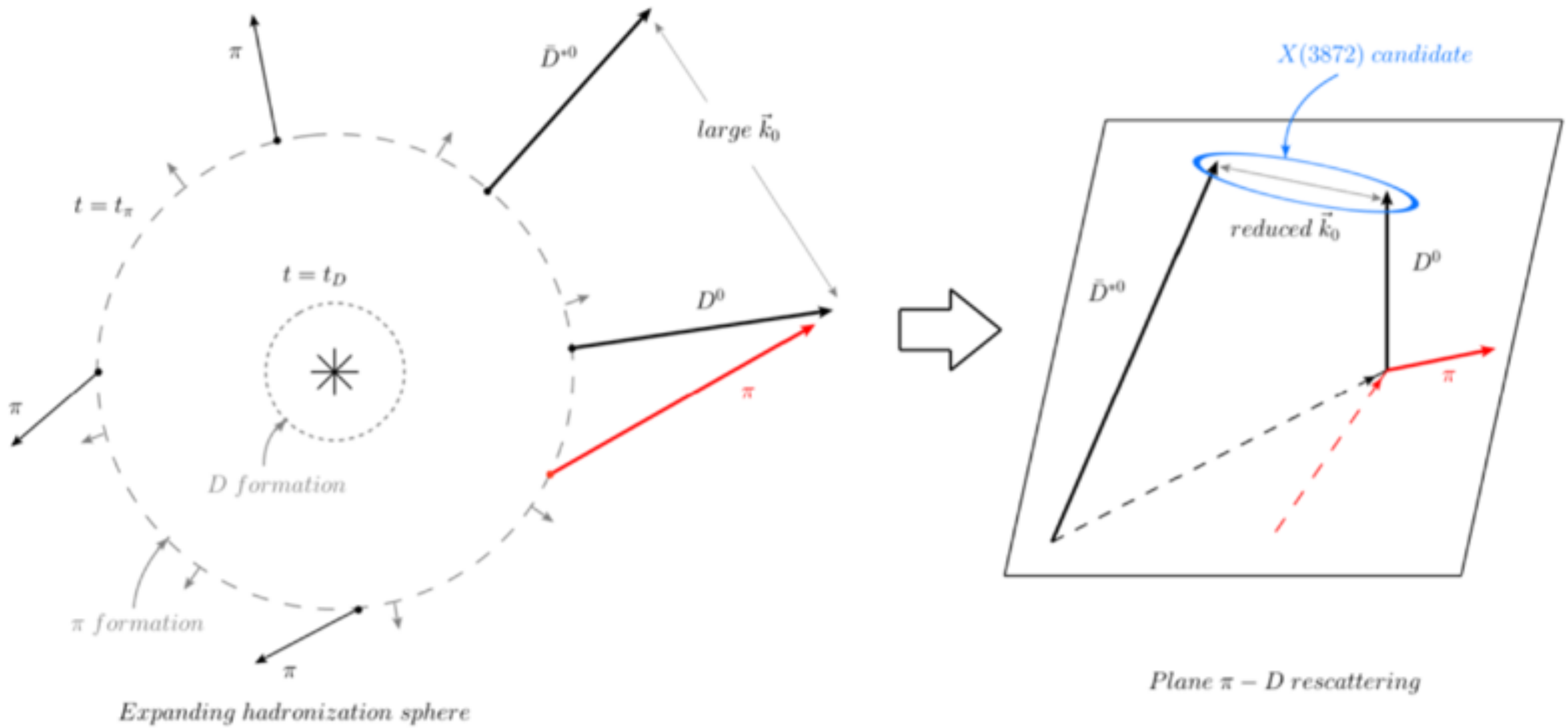
$$\overline{|\vec{p}_{rel}|} = 1.27\,|\vec{p}_\perp|$$



$$P(|\vec{p}_{rel}|) = \frac{1/\pi}{\sqrt{|\vec{p}_\perp|^2 - (|\vec{p}_{rel}|/2)^2}}$$

$$P(\overline{|\vec{p}_{rel}|}) \sim 40\%$$

RESCATTERINGS ?



Expanding hadronization sphere

(a)

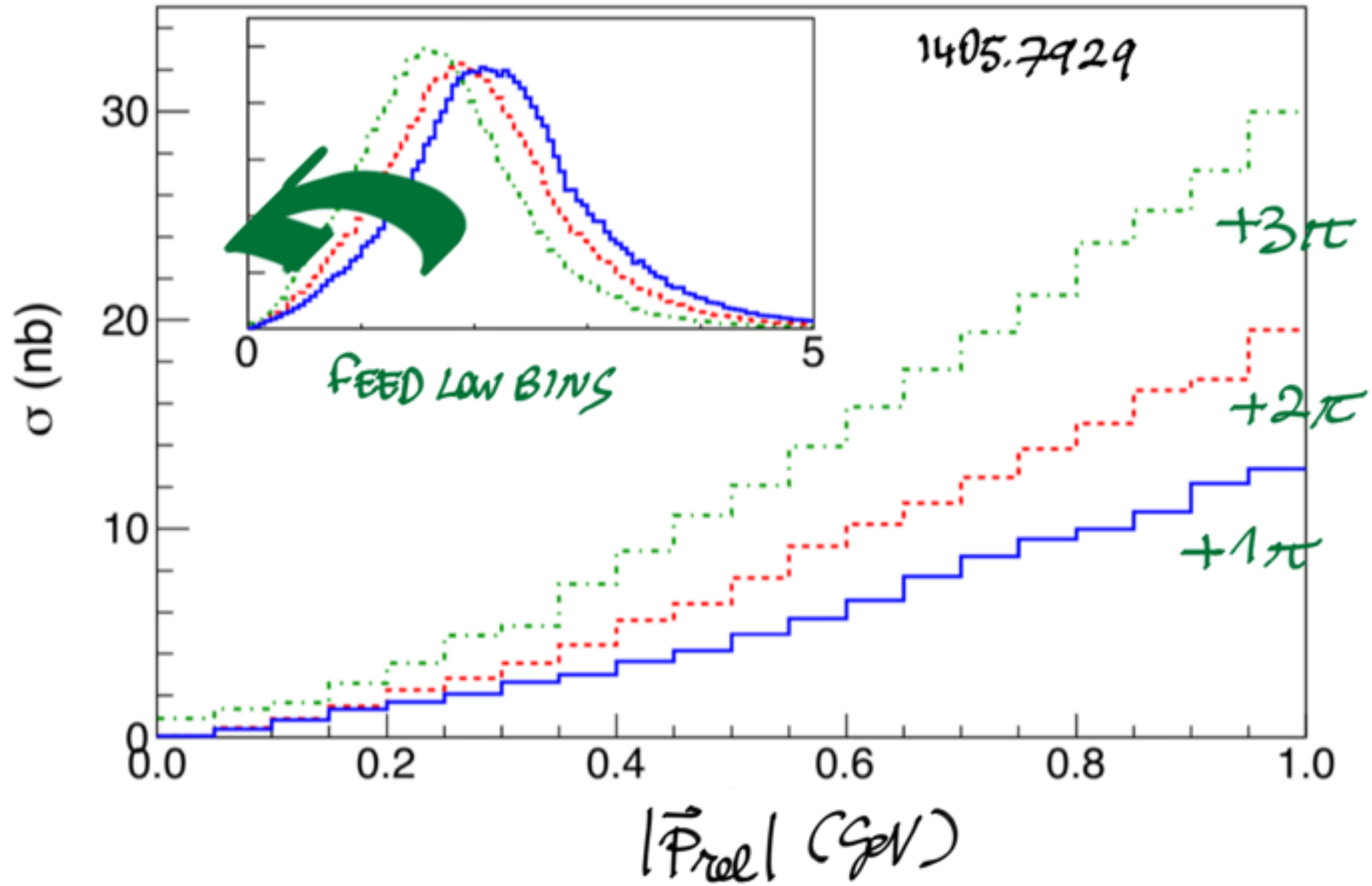
Plane π − D rescattering

(b)

RESCATTERINGS WITH HADRONS (π) MIGHT HELP TO DECREASE $|\vec{k}_{rel}|$ IN THE DD^* PAIR

A Esposito et al. J.Mod.Phys. 4 (2013) 1569
A Guerrieri et al. PRD 90 (2014) 034003
C Bignamini et al PRL 103 (2009) 162001

RESCATTERINGS ?



- THE MOST PROBABLE DD* CONFIGURATIONS HAVE HIGH |$\vec{P}_{rel}$|
- THIS IS MORE AND MORE VISIBLE INCREASING THE CUT IN |$\vec{P}_\perp$|
- THE FEED-DOWN OBTAINED BY RESCATTERING ON 1,2,3 π IS NEGLIGIBLE.