Few ideas on Hadronic Physics at RHIC/LHC

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1. Λ from pp at ALICE and H dibaryon
2. Exotics from HIC
3. Crypto-exotics from HIC

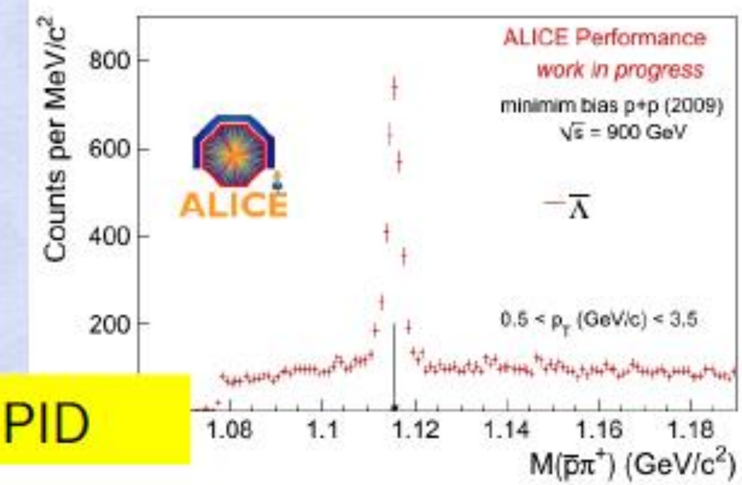
Acknowledgement: S. Cho, C.M. Ko, S. Yasui + ExHIC collaboration

Λ from p-p ALICE and the H dibaryon

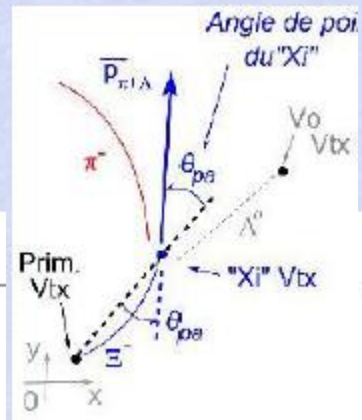
Satoshi Sano
Center for Nuclear Study (CNS) University of Tokyo

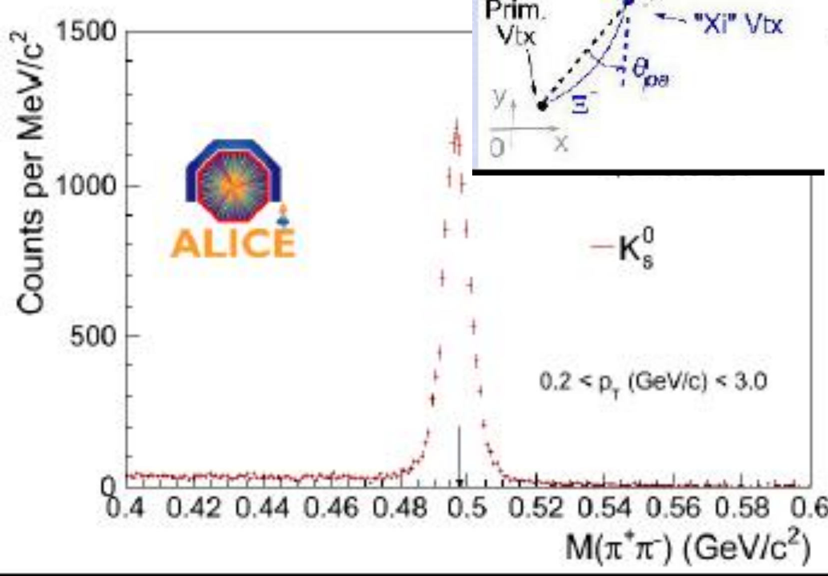
Invariant mass spectrum in 900 GeV p+p collisions(Ks^0,Λ)

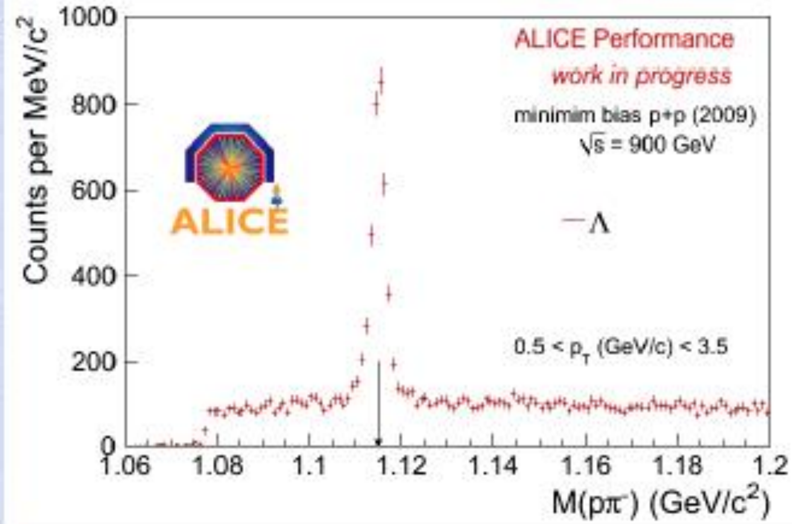
Ks^0 and Λ can be found well with V0 finder.



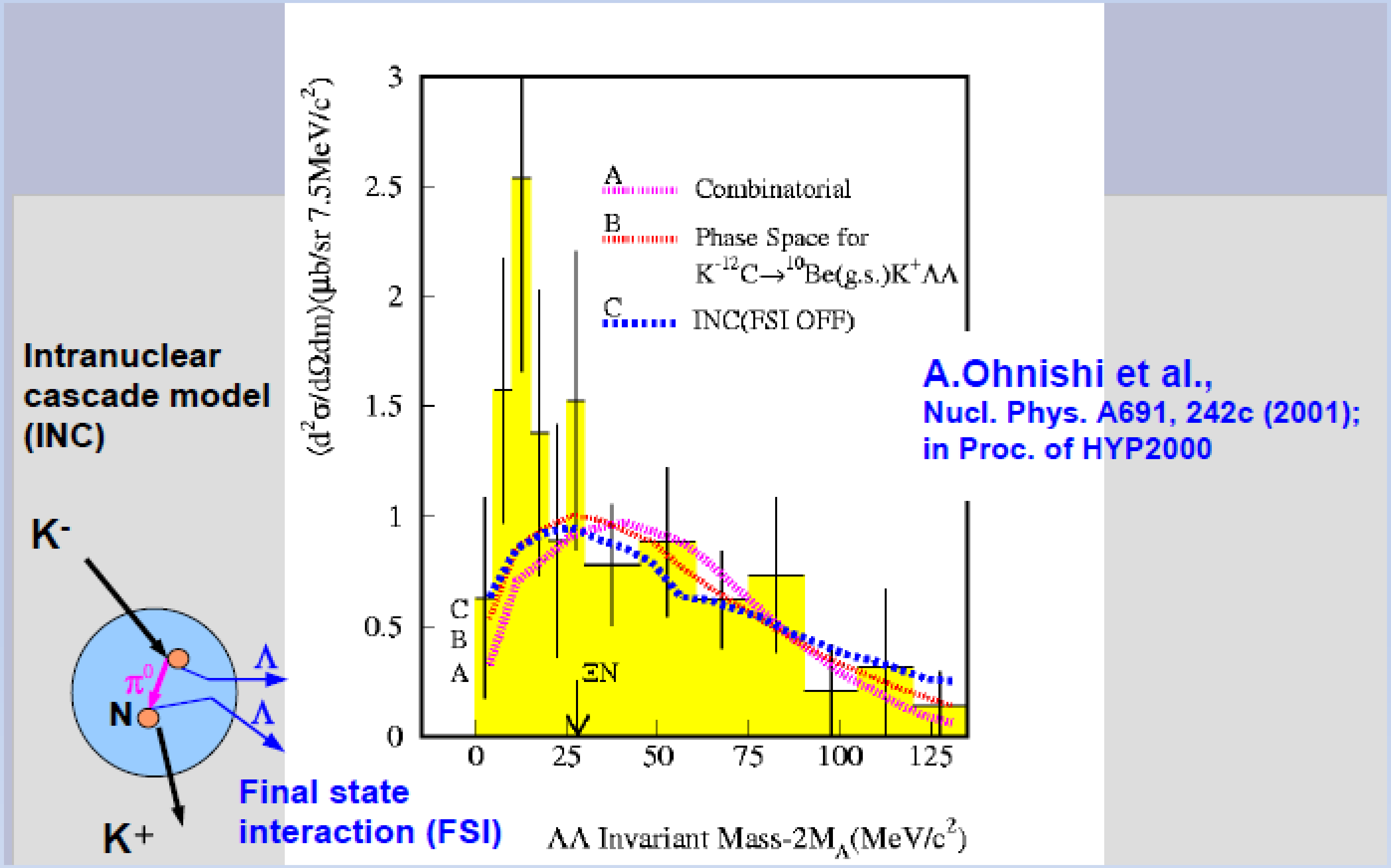
No PID





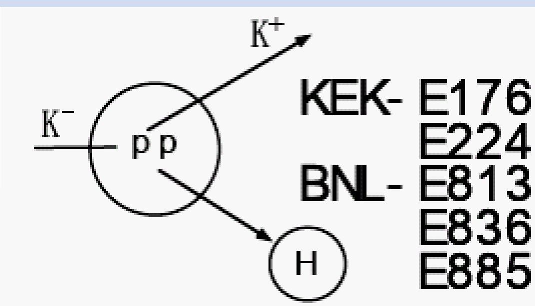


ΛΛ measurement at KEK (안정근 E224, E522)



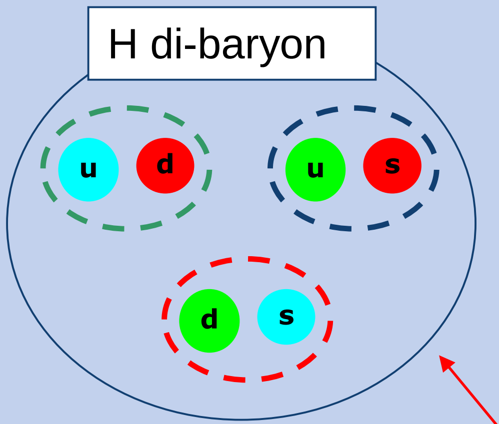
→ A continued search for H-dibaryon

(K. Imai …)



H -dibaryon Jaffe 77

0^+



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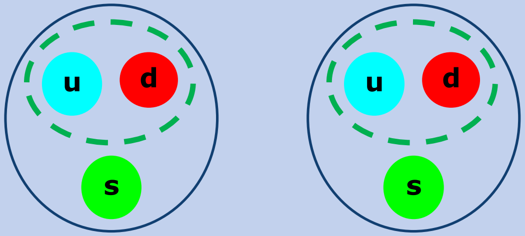


$$V_{qq} \rightarrow -\frac{3}{4}\frac{C_B}{m_u^2} \qquad -\frac{3}{4}\frac{C_B}{m_u^2}$$

2SC Phase

$$V_{qq} = -\frac{3}{4}\frac{C_B}{m_u^2} - \frac{3}{4}\frac{C_B}{m_u m_s} - \frac{3}{4}\frac{C_B}{m_d m_s}$$

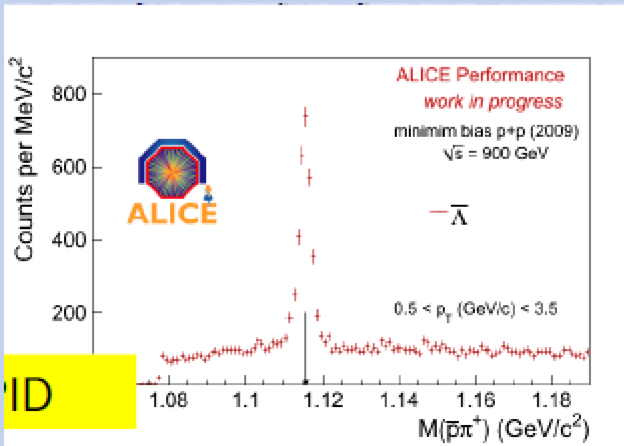
CFL Phase of color superconductivity ?

H Binding = –29 MeV + Instanton repulsion (M. Oka)

H di-baryon → could be bound

→ unfortunately not found in so far

Expectations for H and ΛΛ production in Pb Pb collision at LHC

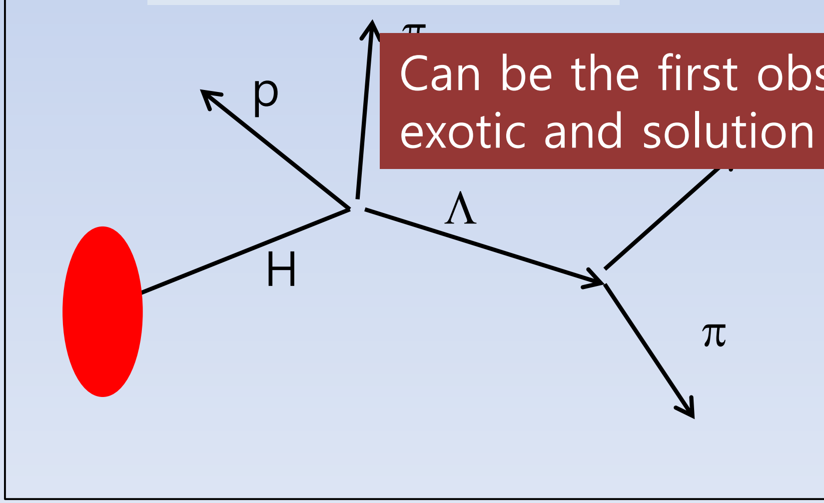


N_{part} Pb+Pb: X 100

Stat : H/ Λ = 10^{-2}

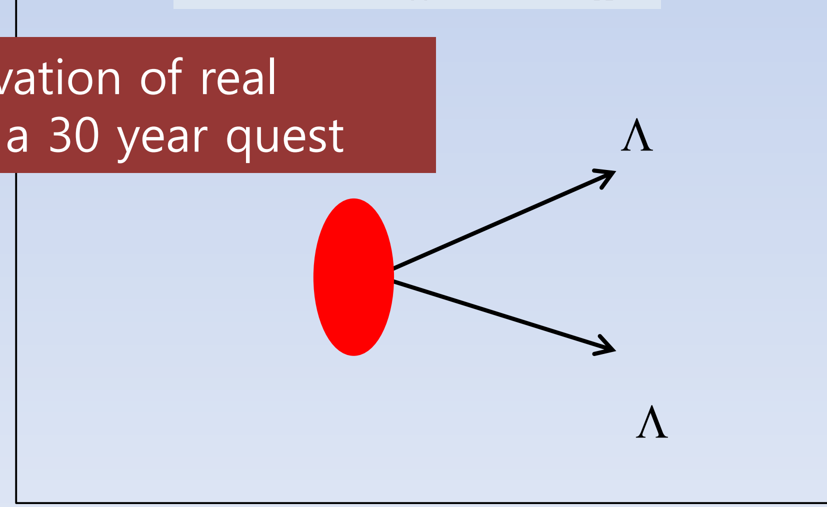
More than
100 H dibaryon

- If $m_H < 2\, m_\Lambda$



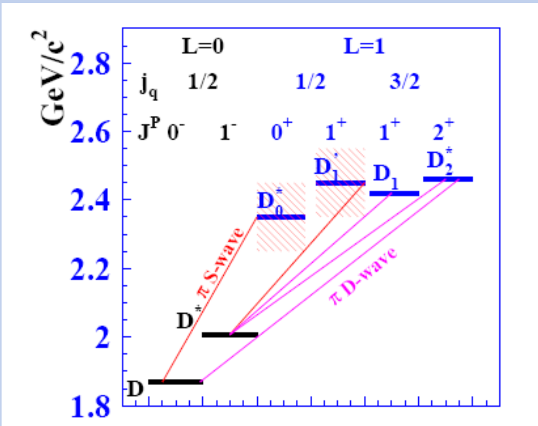
Can be the first observation of real exotic and solution to a 30 year quest

- If $m_H > 2\, m_\Lambda$



Exotics from HIC

SHL, S. Yasui :	EPJC 64 283 (09)
SHL, S. Yasui, W. Liu, CM.Ko :	EPJC 54 259 (08)
S. Cho et al.	arXiv:1011.0852



Babar: $D_{SJ}(2317)$ 0+

Puzzle in Constituent Quark Model(2400)

1. D0 K+ (2358) threshold effect
2. Chiral partner of (0^- 1^-)
3. Tetraquark

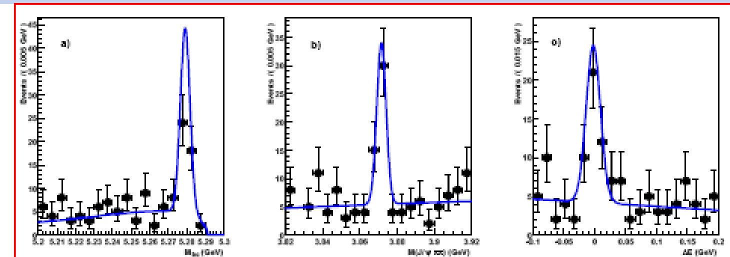


FIG. 17: X(3872) in the $J/\psi\pi^+\pi^-$ channel from Ref. [150].

Molecule ?

D0	D*	D1
1864	2007	2420

D0+$\bar{D}$*	D*+$\bar{D}$*	D+$\bar{D}$1	D1+$\bar{D}$*
3871	4014	4284	4427

X(3872) , Y(4260),

Z(4430) → $\psi'\pi$

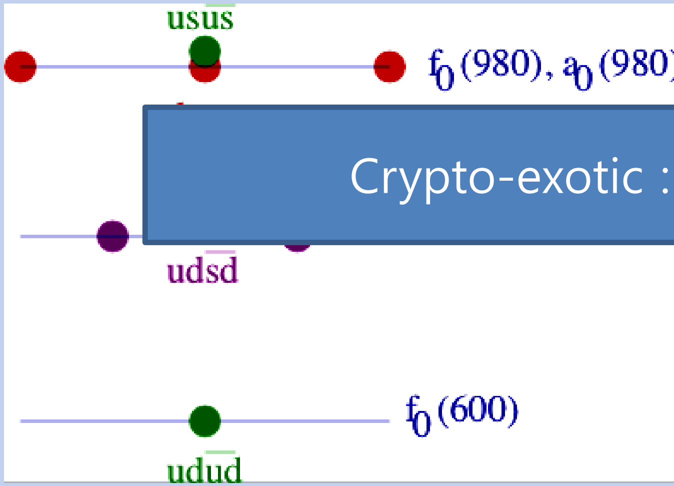
Z(4051),Z(4248)→ $\chi_{c1}\pi$

Must contain $c\bar{c}$?

Tetraquark ?

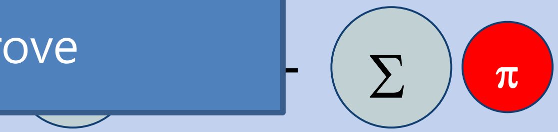
Previous Work on Multiquark hadrons - Light quark sector

Scalar tetraquark (Jaffe 76)

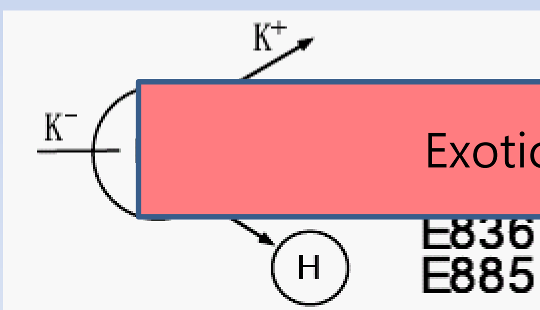


Crypto-exotic : difficult to prove

Λ(1405) (Weise, Oset, Jido, Sekihara..)

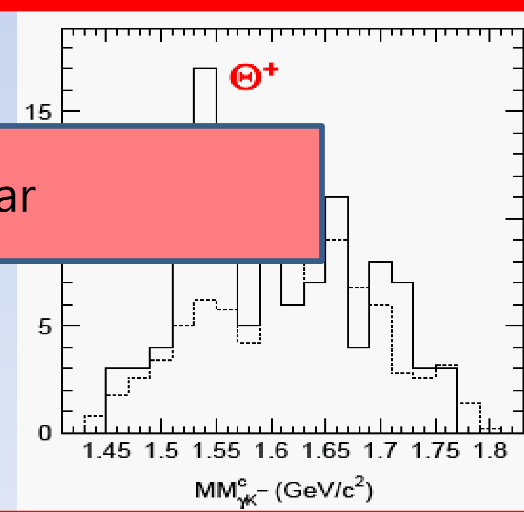


Search for H dibaryon



Exotic : Not found so far

Search for Θ+ pentaquark

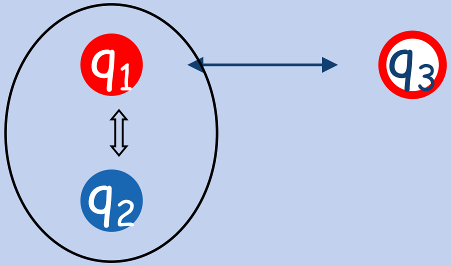


Multiquark configuration:

- Diquark attracation vs quark-antiquark

$$V_{qq} = C_M \vec{s}_1 \cdot \vec{s}_3 \frac{1}{m_1 m_3}$$

$$V_{q\bar{q}} = C_B \vec{s}_1 \cdot \vec{s}_2 \frac{1}{m_1 m_2}$$



$$C_M \approx 3 \times C_B$$

$$\text{make} \quad m_3 \rangle\rangle\, 3 \times m_2$$

- diquark picture: Yasui, Ko, Liu, Lee,.. (EJP08,EJP09)

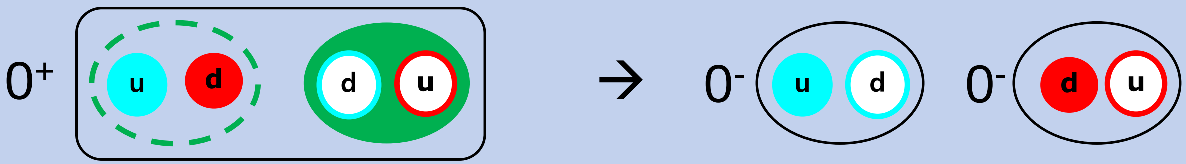
	Type of diquark and its q-q binding		
S=C=0	(ud) → A		
S=-1, $m_s=5/3m_u$	(us) → 3/5 A	(ds) → 3/5 A	
C=1, $m_c=5m_u$	(uc) → 1/5 A	(dc) → 1/5 A	(sc) → 3/25 A

$$A = \frac{3}{4}\frac{C_B}{m_u^2} = 145 \ \text{MeV}$$

Exotics 1: Tetra-quark - configurations

❖ 2- light quark 2-light anitquark configuration

Scalar - Tetraquark $\qquad$ π Meson $\qquad$ π Meson

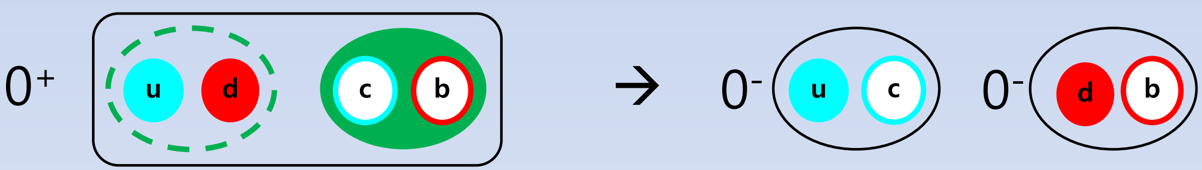


$$V_{2\times qq} = -\frac{3}{4}\frac{C_B}{m_u^2} - \frac{3}{4}\frac{C_B}{m_u^2} \qquad 2\times V_{q\bar{q}} = -\frac{3}{4}\frac{C_M}{m_u^2} - \frac{3}{4}\frac{C_M}{m_u^2}$$

since $C_M > C_B$

$\rightarrow$ not bound

❖ 2- light quark **2-heavy** anitquark configuration



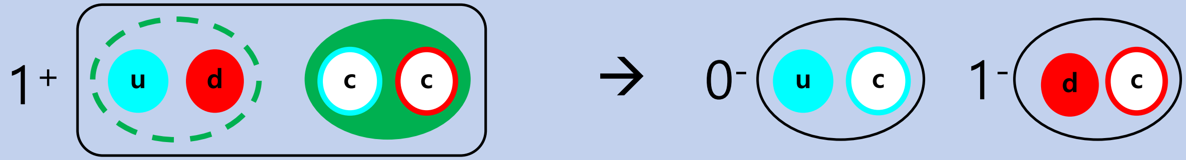
$$-\frac{3}{4}\frac{C_B}{m_u^2} - \frac{3}{4}\frac{C_B}{m_c m_b} \qquad -\frac{3}{4}\frac{C_M}{m_u m_c} - \frac{3}{4}\frac{C_M}{m_u m_b}$$

Binding of T_{cb}^0

$\rightarrow$ -21.25 MeV

$T_{cb}^0/D > O(10^{-5})$ at LHC

❖ Axial meson Tcc 2- light quark **2-heavy** anitquark



$$-\frac{3}{4}\frac{C_B}{m_u^2} \quad +\frac{1}{4}\frac{C_B}{m_c^2} \qquad -\frac{3}{4}\frac{C_M}{m_u m_c} \quad +\frac{1}{4}\frac{C_M}{m_u m_c}$$

Binding of T^1_{cc} $\rightarrow 79.3\,\mathrm{MeV}$

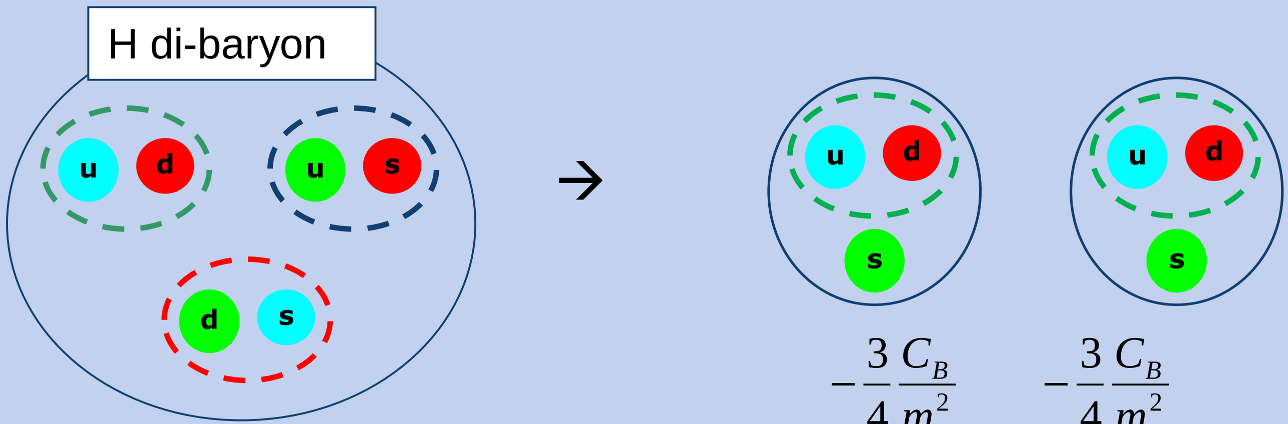
$$\mathrm{T}^1_{cc}(\mathrm{ud}\bar{\mathrm{c}}\bar{\mathrm{c}}) \rightarrow (D^{*-} + \overline{D}^0) \rightarrow D^{*-} K^+ \pi^-$$

$T_{cc}/D > O(10^{-4})$ at LHC

➢ Vertex detector: FAIR 10^4 D^0 /month, LHC 10^5 D^0/month

Why Di-bayron

0^+



$$-\frac{3}{4}\frac{C_B}{m_u^2} \qquad -2\times\frac{3}{4}\frac{C_B}{m_u m_s}$$

$$-\frac{3}{4}\frac{C_B}{m_u^2} \qquad -\frac{3}{4}\frac{C_B}{m_u^2}$$

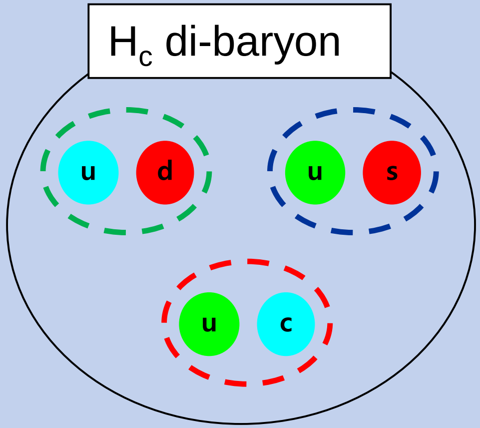
H Binding = –29 MeV + Instanton repulsion (M. Oka)

H di-baryon → could be bound

→ unfortunately not found in so far

A new Di-baryon : Hc

0^+



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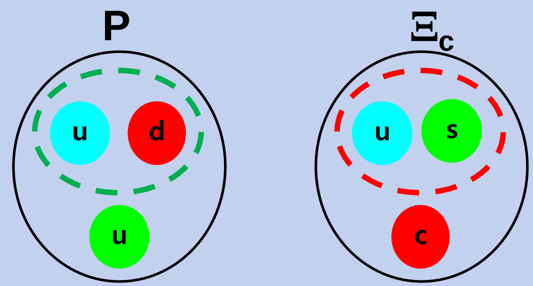


$$V_{qq} = -\frac{3}{4}\frac{C_B}{m_u^2} \qquad -\frac{3}{4}\frac{C_B}{m_u m_s}$$

Binding of H_c
$\rightarrow$ 29 MeV

$$V_{qq} = -\frac{3}{4}\frac{C_B}{m_u^2} \qquad -\frac{3}{4}\frac{C_B}{m_u m_s} \qquad -\frac{3}{4}\frac{C_B}{m_u m_c}$$

$$\mathrm{H_c(udusuc)} \rightarrow (\Lambda_c^+ + \Sigma^+) \rightarrow pK^-\pi^+ + p\pi^0$$

$$\rightarrow (p + \Xi_c^+) \rightarrow p + \Lambda K^-\pi^+\pi^+$$

H_c/D > $O(10^{-3})$ at LHC

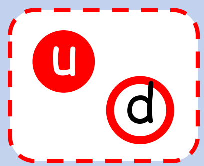
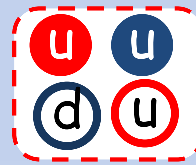
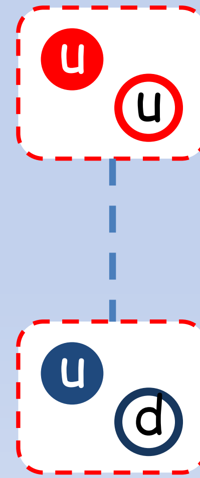
➢ Vertex detector: FAIR 10^4 D^0 /month, LHC 10^5 D^0/month

Crypto Exotics from HIC

(Multiquark configurations)

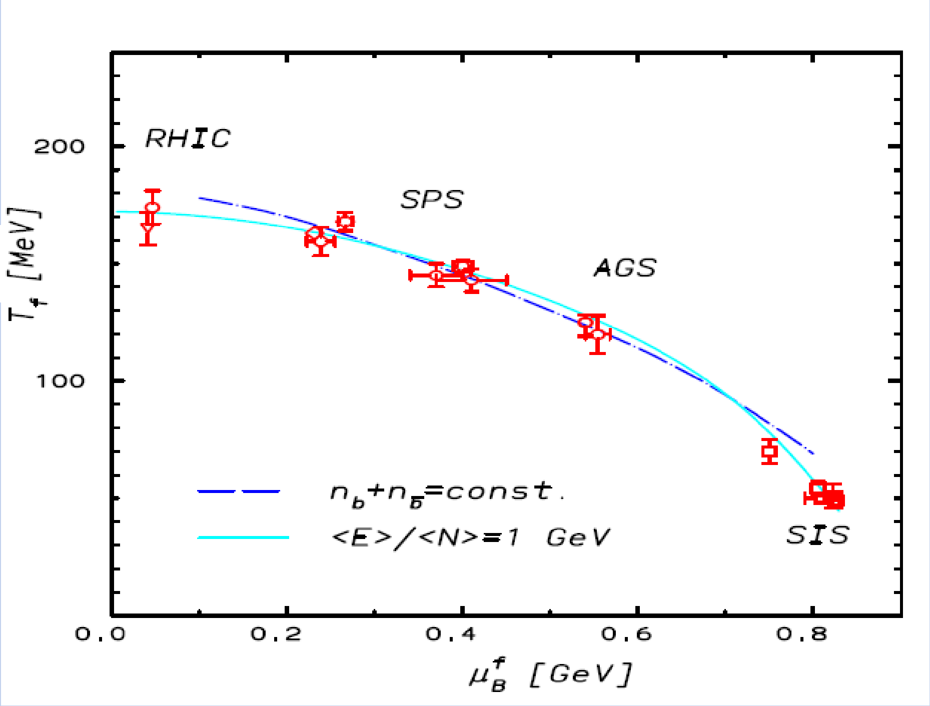
S. Cho (ExHIC collaboration) arXiv:1011.0852

Normal meson, Tetraquark and Molecule

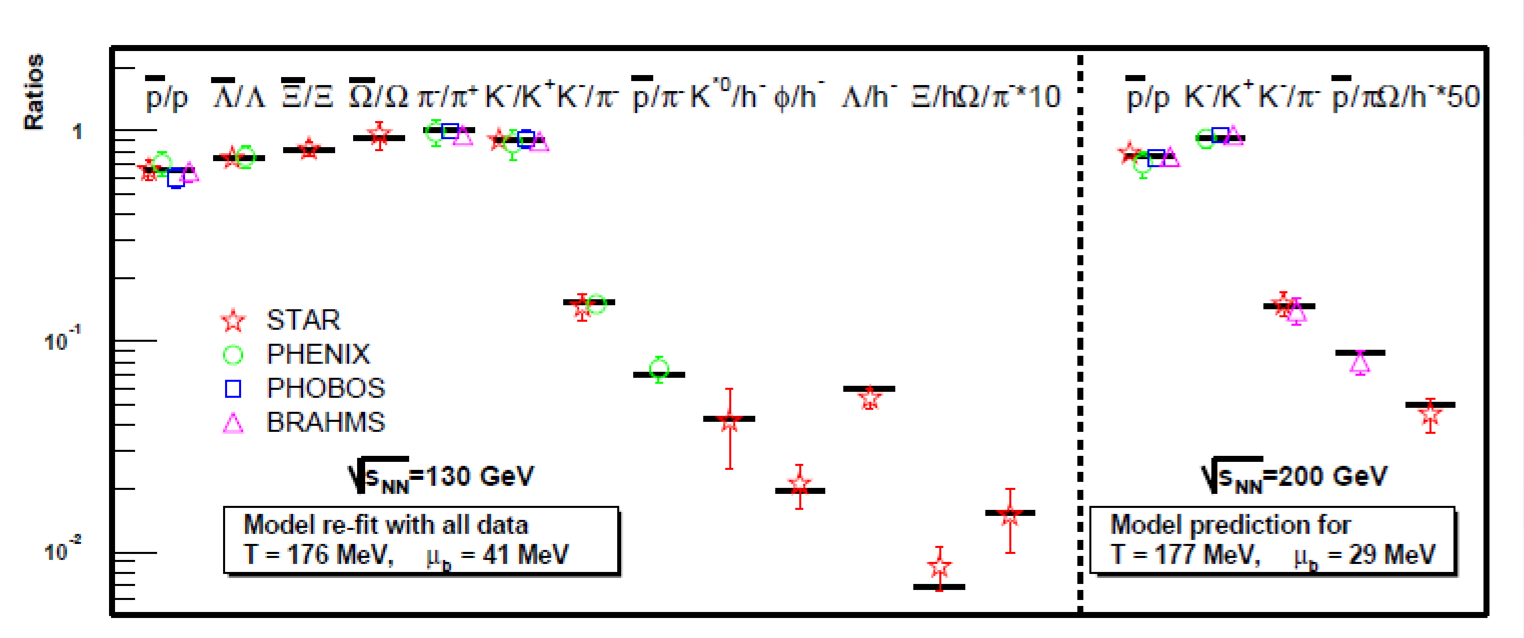
	Normal meson	Tetraquark	Molecule
Geometrical configuration			
Flavor quantum number	u$\underline{d}$	u$\underline{d}$	u$\underline{d}$

Statistical Model

Freezeout points



Normal hadron yields



Coalescence model : for things with structures

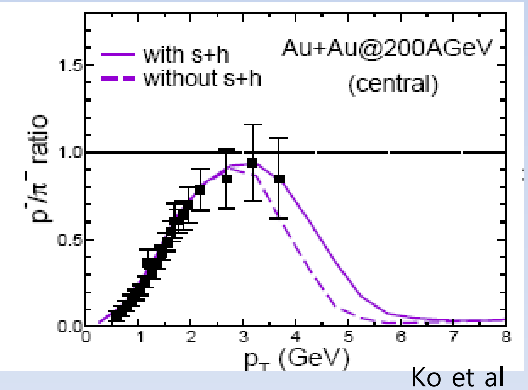
Coalescence model = Statistical model + overlap

$$\frac{dN_H}{d^2P_T} = g_H \int \prod_{i=1}^{n} \frac{p_i \cdot d\sigma_i d^3\mathbf{p}_i}{(2\pi)^3 E_i} f_q(x_i, p_i) f_H(x_1..x_n; p_1..p_n)\, \delta^{(2)}\left(P_T - \sum_{i=1}^{n} p_{T,i}\right)$$

Suppression of p-wave resonance
(Muller and Kadana En'yo)

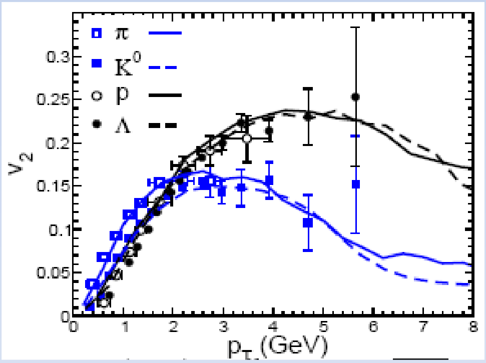
$$(\Lambda^*(1520)/\Lambda)_{Au-Au} \Big/ (\Lambda^*(1520)/\Lambda)_{p-p} < 1$$

P_T dependence of ratio



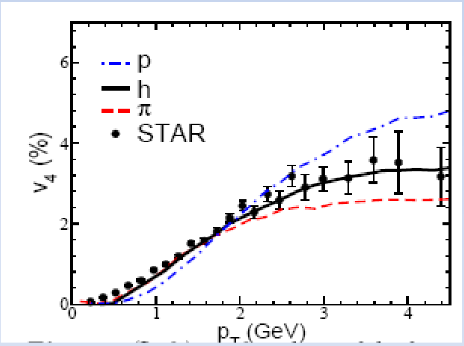
Ko et al

Quark number scaling of v2



Ko et al

v4



Ko et al

Production of multiquark states from HIC arXiv:1011.0852

Sungtae Cho,[1] Takenori Furumoto,[2,3] Tetsuo Hyodo,[4] Daisuke Jido,[2] Che Ming Ko,[5] Su Houng Lee,[2,1] Marina Nielsen,[6] Akira Ohnishi,[2] Takayasu Sekihara,[2,7] Shigehiro Yasui,[8] and Koichi Yazaki[2,3]

(ExHIC Collaboration)

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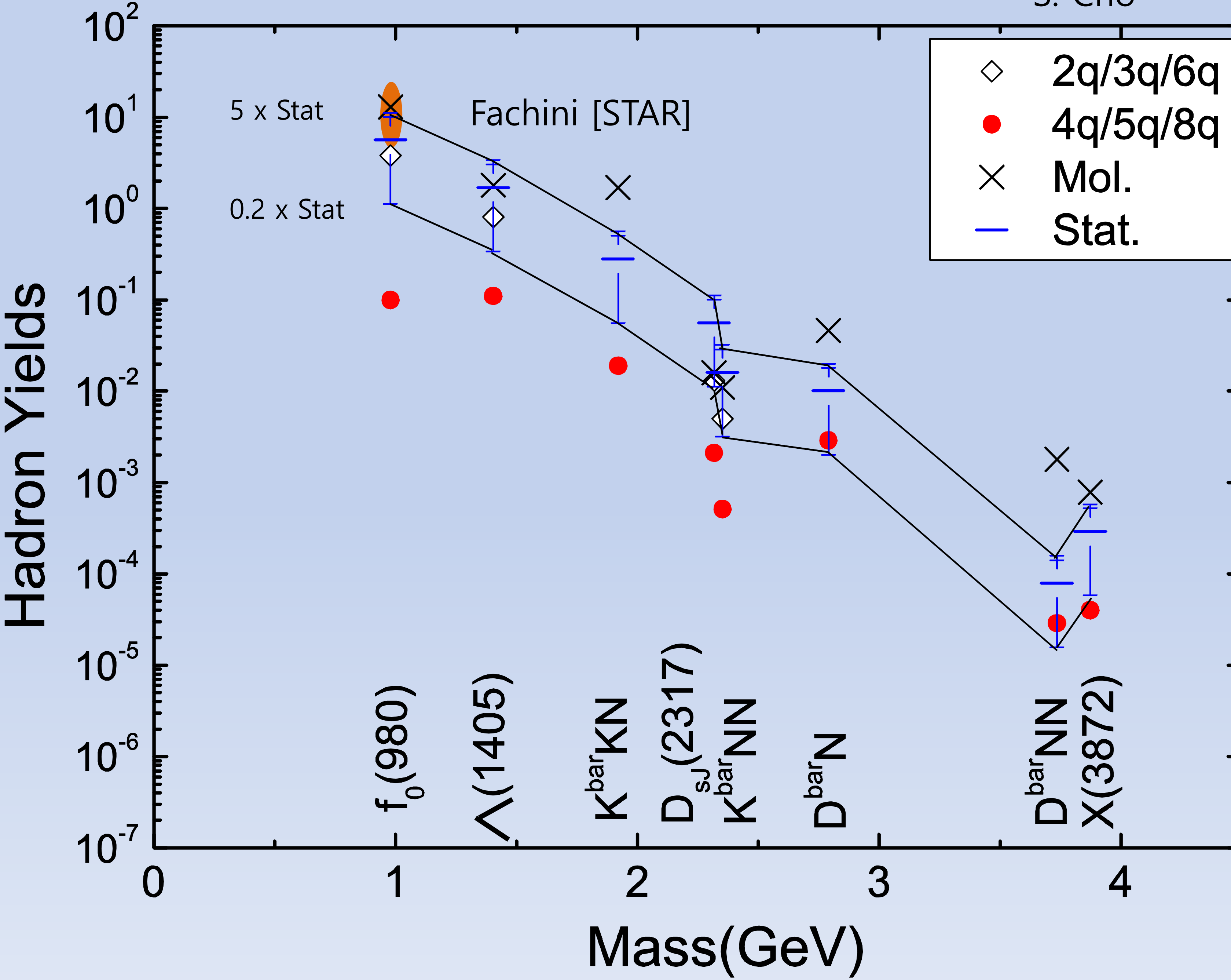
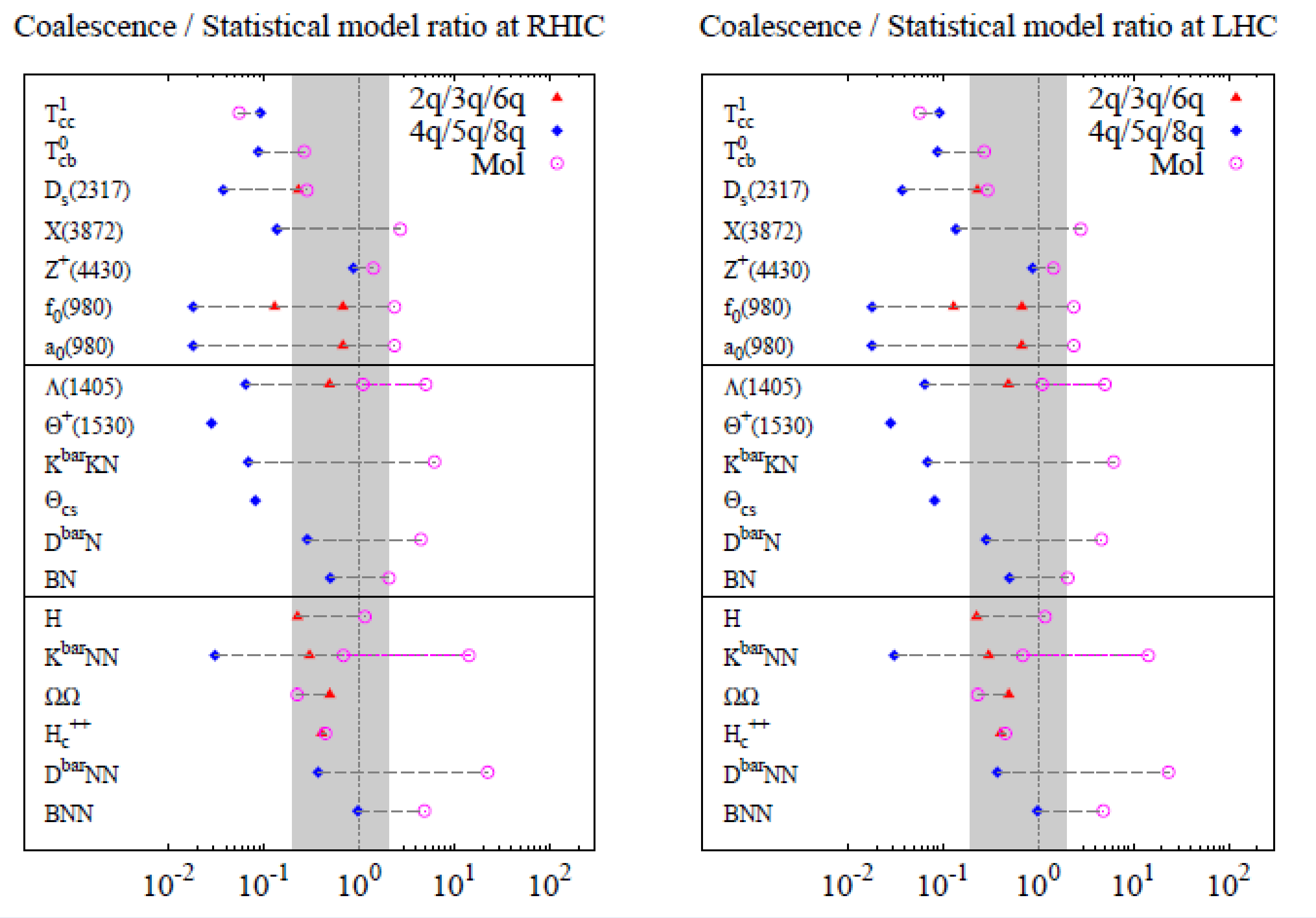
1. Determine Coalescence parameter to yields of normal hadrons at RHIC
2. Using the coalescence model, calculate the yields of multiquark candidates assuming they are **normal hadron**, **multiquark**, **molecule**

S. Cho

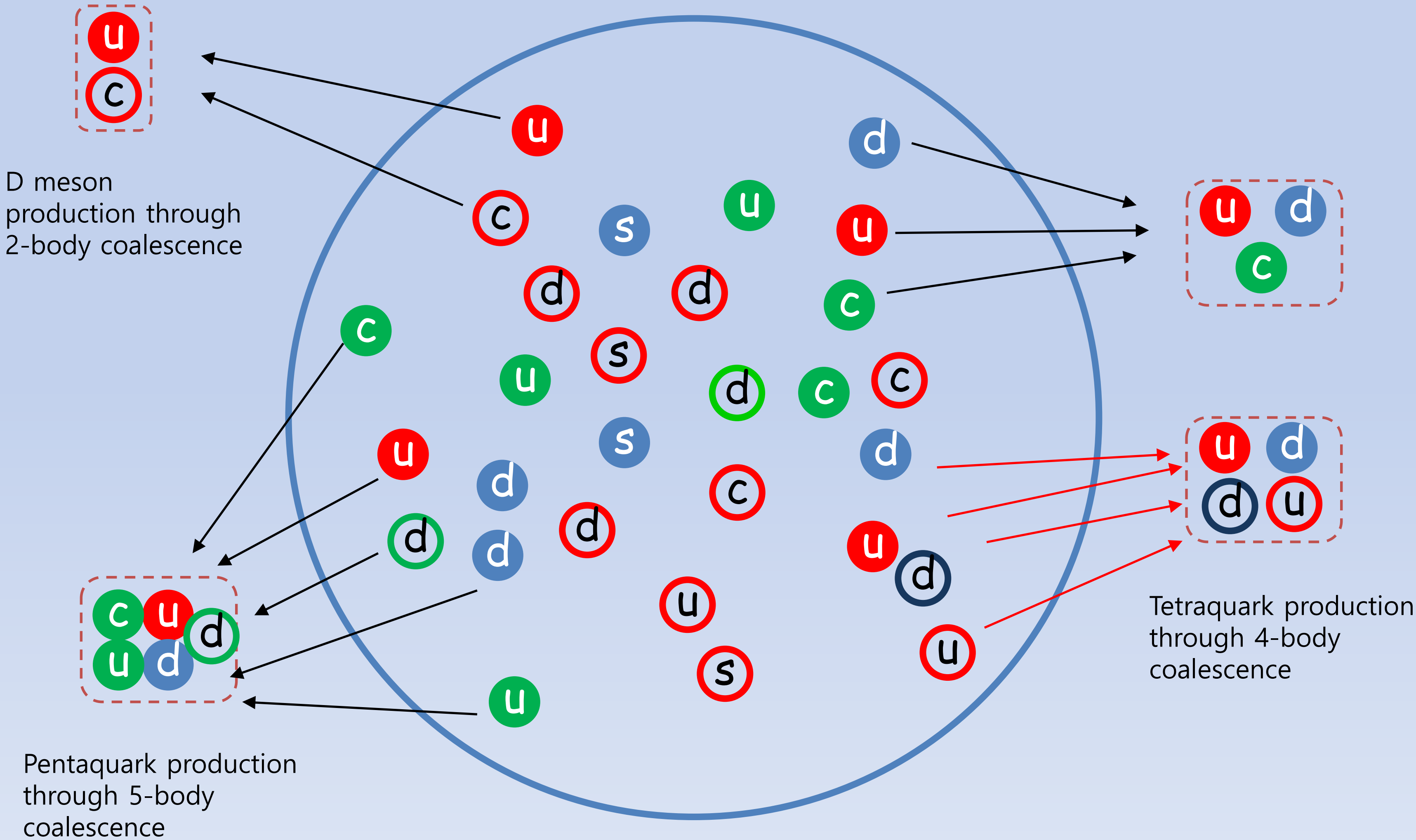


Hadron Yields
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
1
2
3
4
Mass(GeV)
5 x Stat
0.2 x Stat
Fachini [STAR]
2q/3q/6q
4q/5q/8q
Mol.
Stat.
$f_0(980)$
$\Lambda(1405)$
$K^{bar}KN$
$D_{sJ}(2317)$
$K^{bar}NN$
$D^{bar}N$
$D^{bar}NN$
X(3872)

Expectations at RHIC and LHC



Suppression of multi-quark states in HIC



Summary

1. One can search for H dibaryon from pp at LHC in ALICE and later from Pb Pb collisions→ end the 30 year old search.

2. One could also search for exotic multiquark states: Tcc, Hc, Θc

→ First step towards dense matter and phase diagram of QCD

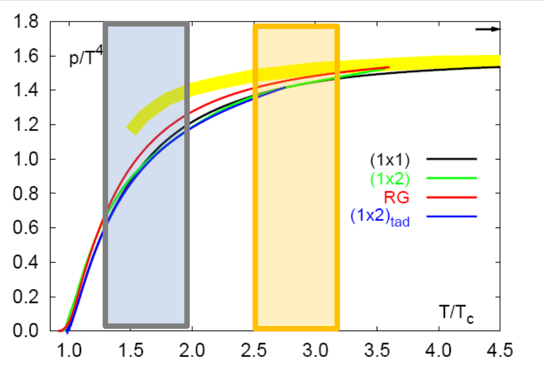
3. By measuring yields for crypto- exotic states one can identify multiquark configuration

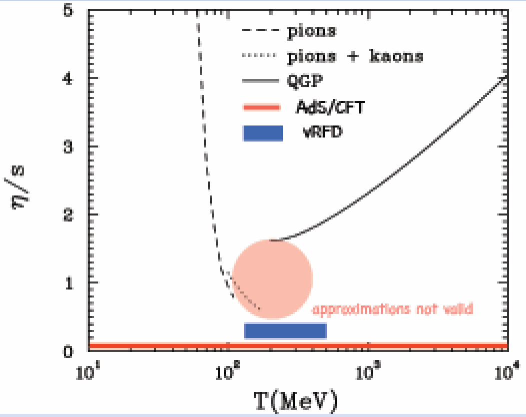
→ finally identify multiquark configuration

Back up slides

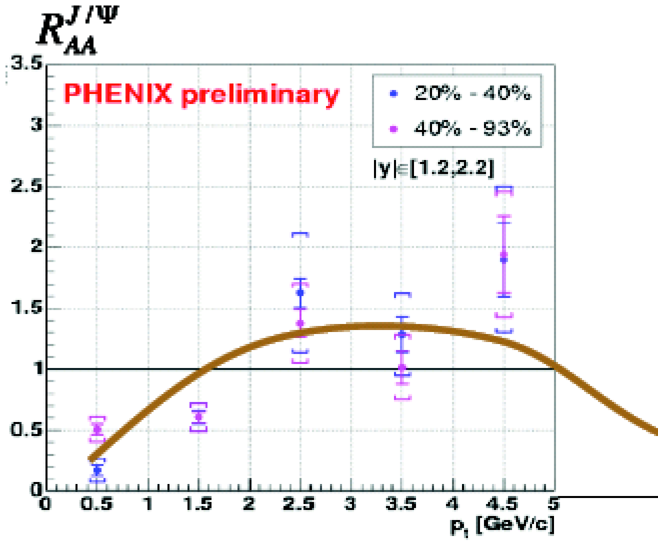
Running conditions at LHC

Collision system	$\sqrt{s_{NN}}$(TeV)	L_0 ($cm^{-2}s^{-1}$)	Run time (s/year)	σ_{geom} (b)
pp	14.0	10^{34} *	10^7	0.07
PbPb	5.5	10^{27}	10^6 **	7.7
pPb	8.8	10^{29}	10^6	1.9
ArAr	6.3	10^{29}	10^6	2.7





- LHC determines J/Psi production up to p_T = 20 GeV



Previous works on Tcc :

Z. Zouzou, B. Silverstre-Brac, C. Gilgnooux, J Richard (86), D. Janc, M. Rosina (04), Y. Cui, S. L. Zhu (07)

QCD sum rules: F Navarra, M. Nielsen, SHLee, PLB 649, 166 (2007)

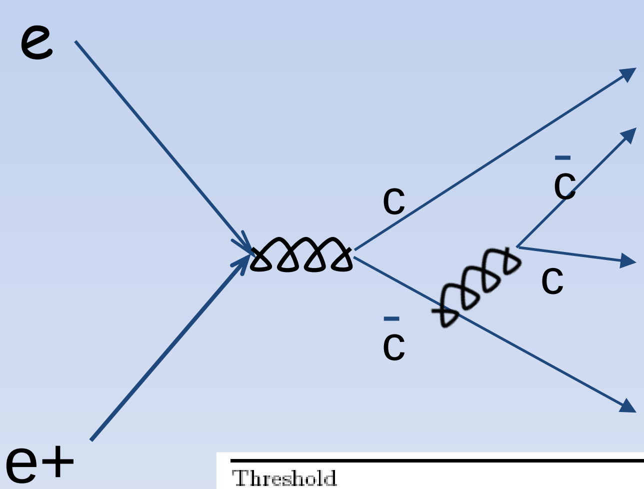
simple diquark: SHL, S. Yasui, W.Liu, C Ko EPJ C54, 259 (2008), SHL, S. Yasui: EPJ C (09)

Can look for 1^+ (Tcc)

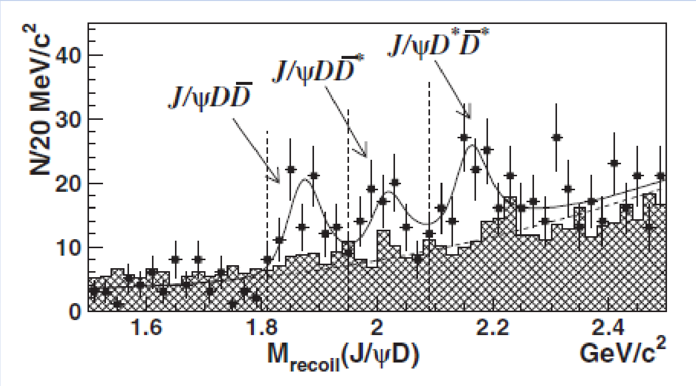
Belle: PRL 98, 082001 (07)

e+ e- → J/y + X(3904)

→ $\underline{D}$ D*



T_{cc} (3800)



Threshold	Decay mode	Lifetime
$M_{T_{cc}} > M_{D^*} + M_D$	$D^{*-}\bar{D}^0$	hadronic decay
$2M_D + M_\pi < M_{T_{cc}} < M_{D^*} + M_D$	$\bar{D}^0\bar{D}^0\pi^-$	hadronic decay
$M_{T_{cc}} < 2M_D + M_\pi$	$D^{*-}K^+\pi^-$, $D^{*-}K^+\pi^+\pi^-\pi^-$	0.41×10^{-12} s

SHL, S Yasui, W Liu, C Ko (08)

Production ratios for predicted Multiquarks

- Θ_c production at RHIC and LHC

$\Theta_c/D > 0.74 \times 10^{-4}$

$\Theta_c/D_s > 0.23 \times 10^{-3}$

TABLE IX: Possible decay modes of Θ_{cs}.

threshold	decay mode	lifetime
$M_{\Theta_{cs}} > M_N + M_{D_s}$	pD_s^-	hadronic decay
$M_\Lambda + M_D < M_{\Theta_{cs}} < M_N + M_{D_s}$	$\Lambda \bar{D}^0$	hadronic decay
	ΛD^-	hadronic decay
$M_{\Theta_{cs}} < M_\Lambda + M_D$	$\Lambda K^+\pi^-$, $\Lambda K^+\pi^+\pi^-\pi^-$	0.41×10^{-12} sec.
	$\Lambda K^+\pi^-\pi^-$	1.0×10^{-12} sec.

- H_c production at RHIC and LHC

$H_c/D > 0.8 \times 10^{-4}$

$H_c/D_s > 0.25 \times 10^{-3}$

$$H_c(\text{udusuc}) \rightarrow (\Lambda_c^+ + \Sigma^+) \rightarrow pK^-\pi^+ + p\pi^0$$

$$\rightarrow (p + \Xi_c^+) \rightarrow p + \Lambda K^-\pi^+\pi^+$$

- T_{cc} production

$T_{cc}/D > 0.34 \times 10^{-4}$ RHIC

$> 0.8 \times 10^{-4}$ LHC

threshold	decay mode	lifetime
$M_{T_{cc}} > M_{D^*} + M_D$	$D^{*-}\bar{D}^0$	hadronic decay
$2M_D + M_\pi < M_{T_{cc}} < M_{D^*} + M_D$	$\bar{D}^0\bar{D}^0\pi^-$	hadronic decay
$M_{T_{cc}} < 2M_D + M_\pi$	$D^{*-}K^+\pi^-$, $D^{*-}K^+\pi^+\pi^-\pi^-$	0.41×10^{-12} sec.

Pariticle	m (MeV)	g	I	$J\pi$	$2q/3q/6q$	$4q/5q/8q$	Mol.	$\omega_{\rm Mol.}$ (MeV)	decay mode
$D_s(2317)$	2317	1	0	0+	$c\bar{s}$ ($L=1$)	$q\bar{q}c\bar{s}$	DK	273(B)	$D_s\pi$ (strong decay)
$X(3872)$	3872	3	0	1+	-	$q\bar{q}c\bar{c}$	$\bar{D}\bar{D}^*$	3.6(B)	$J/\psi\pi\pi$ (strong decay)
$f_0(980)$	980	1	0	0+	$q\bar{q}$ ($L=1$)	$q\bar{q}s\bar{s}$	$\bar{K}K$	67.8(B)	$\pi\pi$ (strong decay)
$a_0(980)$	980	3	1	0+	$q\bar{q}$ ($L=1$)	$q\bar{q}s\bar{s}$	$\bar{K}K$	67.8(B)	$\eta\pi$ (strong decay)
$\Lambda(1405)$	1405	2	0	1/2−	qqs ($L=1$)	$qqqs\bar{q}$	$\bar{K}N$	20.5(R)−174(B)	$\pi\Sigma$ (strong decay)
$\bar{K}KN$	1920	4	1/2	1/2+	−	$qqqs\bar{s}$ ($L=1$)	$\bar{K}KN$	42(R)	$K\pi\Sigma$, $\pi\eta N$ (strong decay)
$\bar{D}N$	2790	2	0	1/2−	-	$qqqq\bar{c}$	$\bar{D}N$	6.48(R)	$K^+\pi^-\pi^- + p$
$\bar{K}NN$	2352	2	1/2	0−	$qqqqqs$ ($L=1$)	$qqqqqq\,s\bar{q}$	$\bar{K}NN$	20.5(T)-174(T)	ΛN (strong decay)
$\bar{D}NN$	3734	2	1/2	0−	-	$qqqqqq\,q\bar{c}$	$\bar{D}NN$	6.48(T)	$K^+\pi^- + d$, $K^+\pi^-\pi^- + p + p$

Recent data from RHIC

N^{coal}/N^{stat}