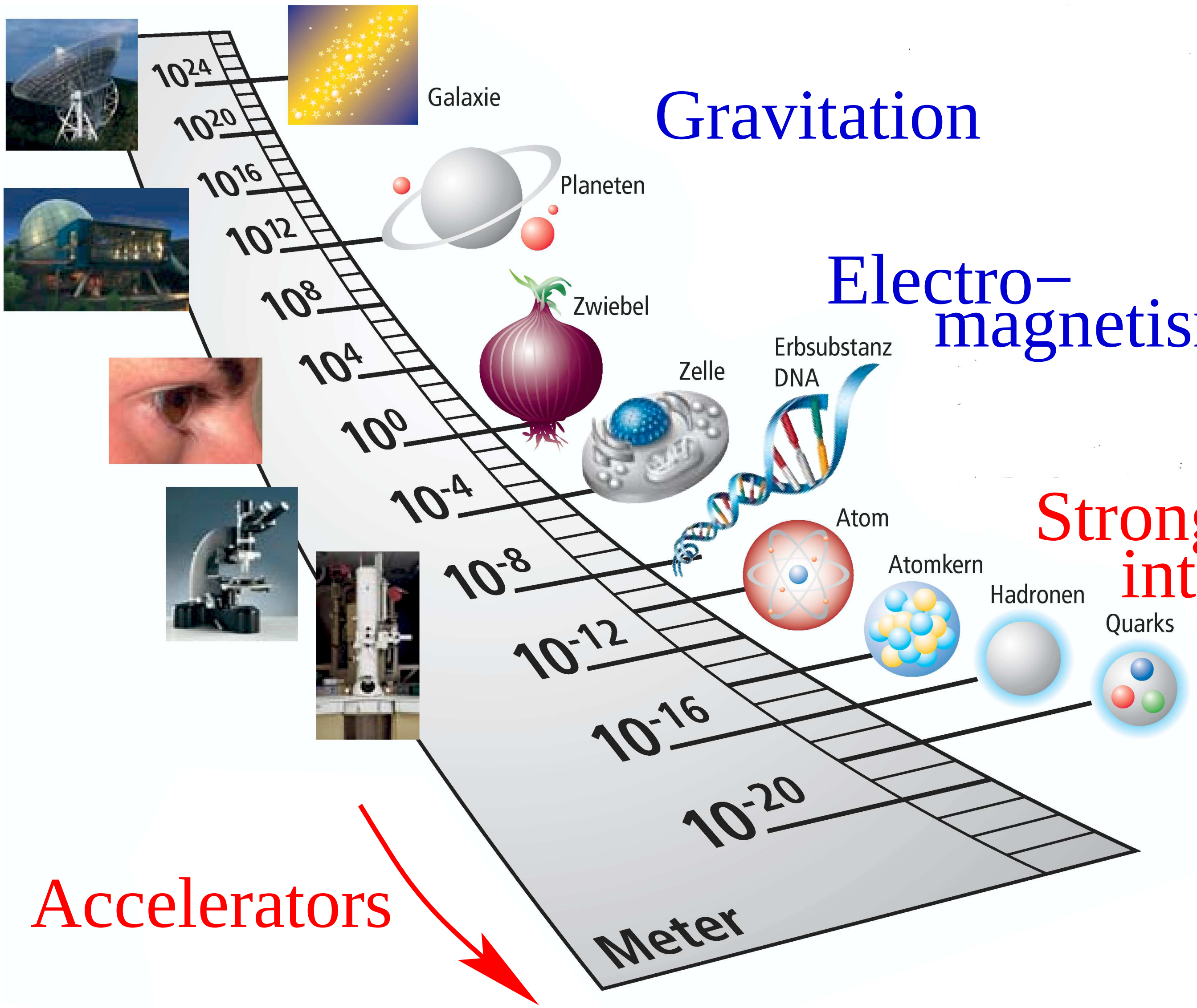
The XYZ-states - a new particle zoo?

Christoph Hanhart

Forschungszentrum Jülich

The fundamental interactions



Gravitation

Electro–magnetism

Strong–interactions

in addition:

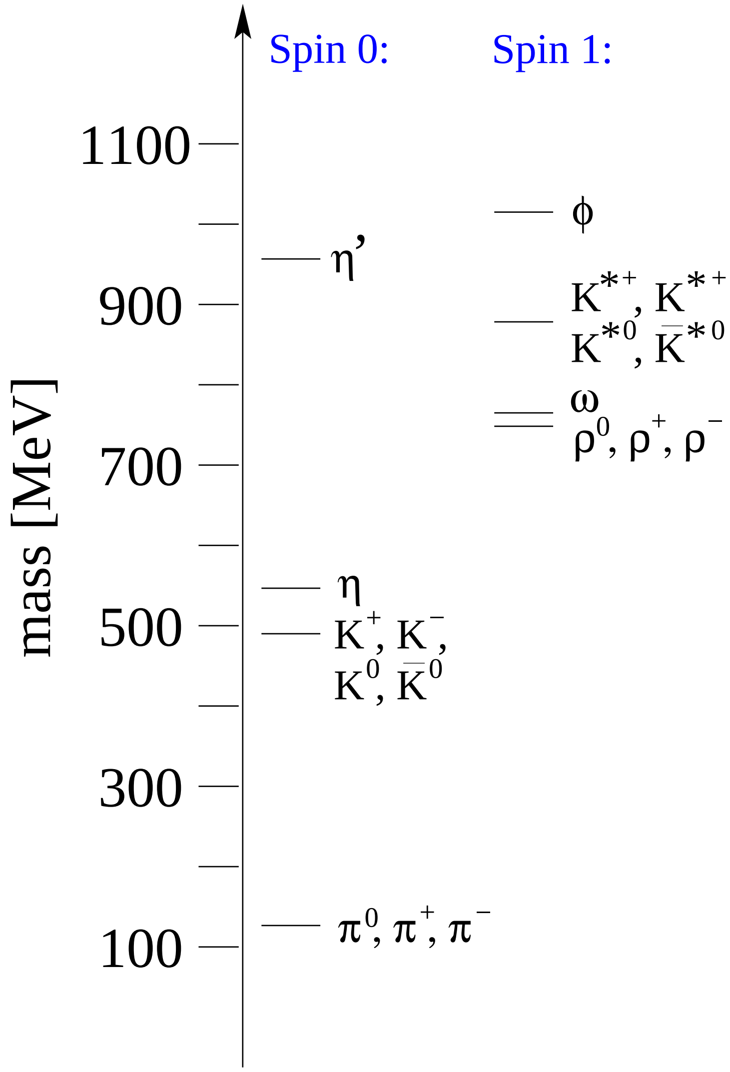
weak–interaction

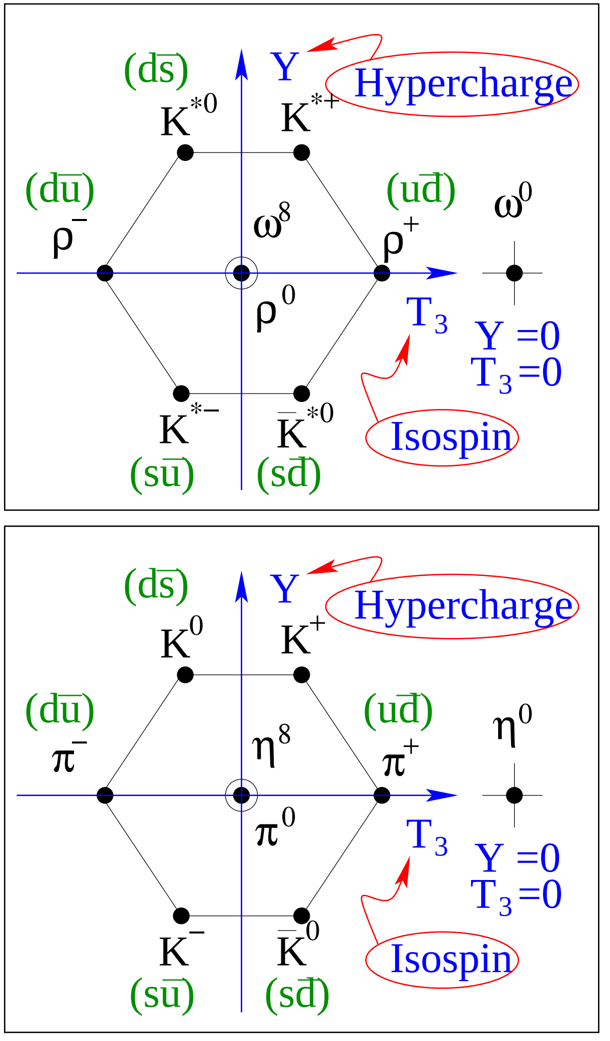
Accelerators

The Quarkmodel: Mesons ($\bar{q}q$)

Gell–Mann; Ne'emann; Zweig (1964)

The three lightest quarks (u, d, s) tame the particle zoo

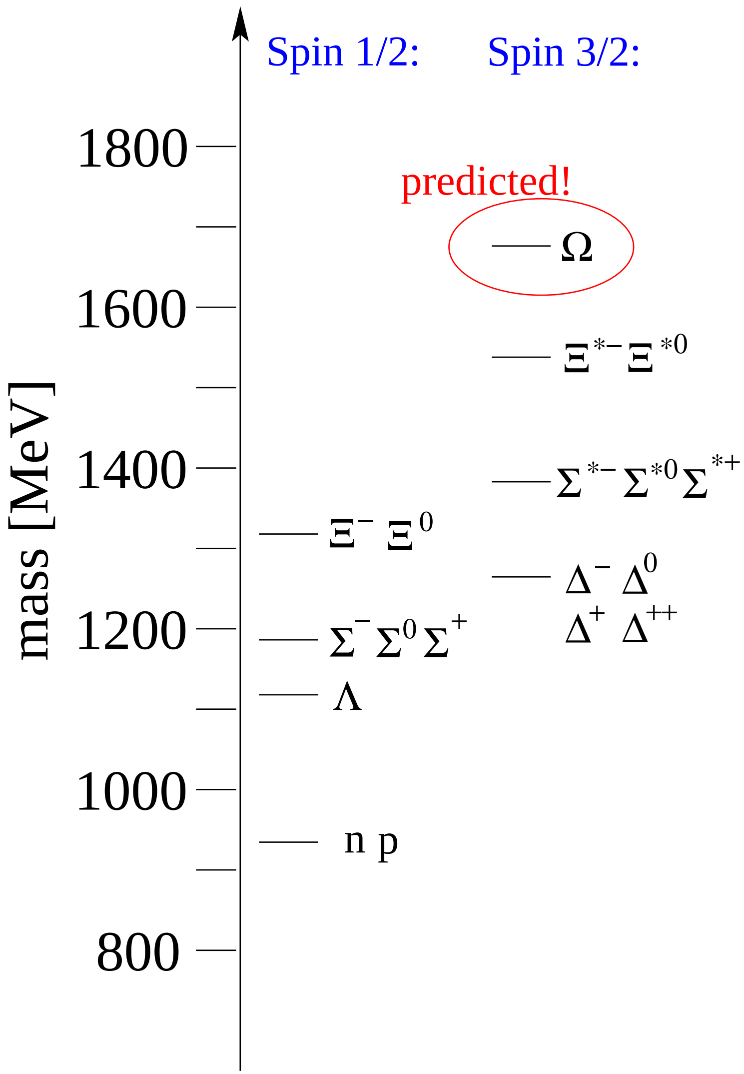


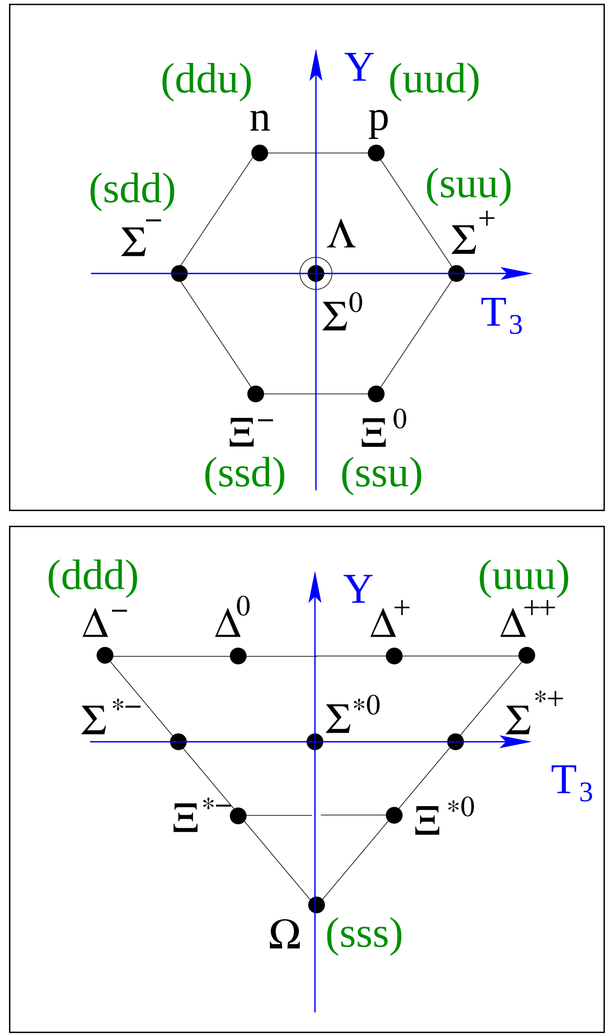


The Quarkmodel: Baryons (qqq)

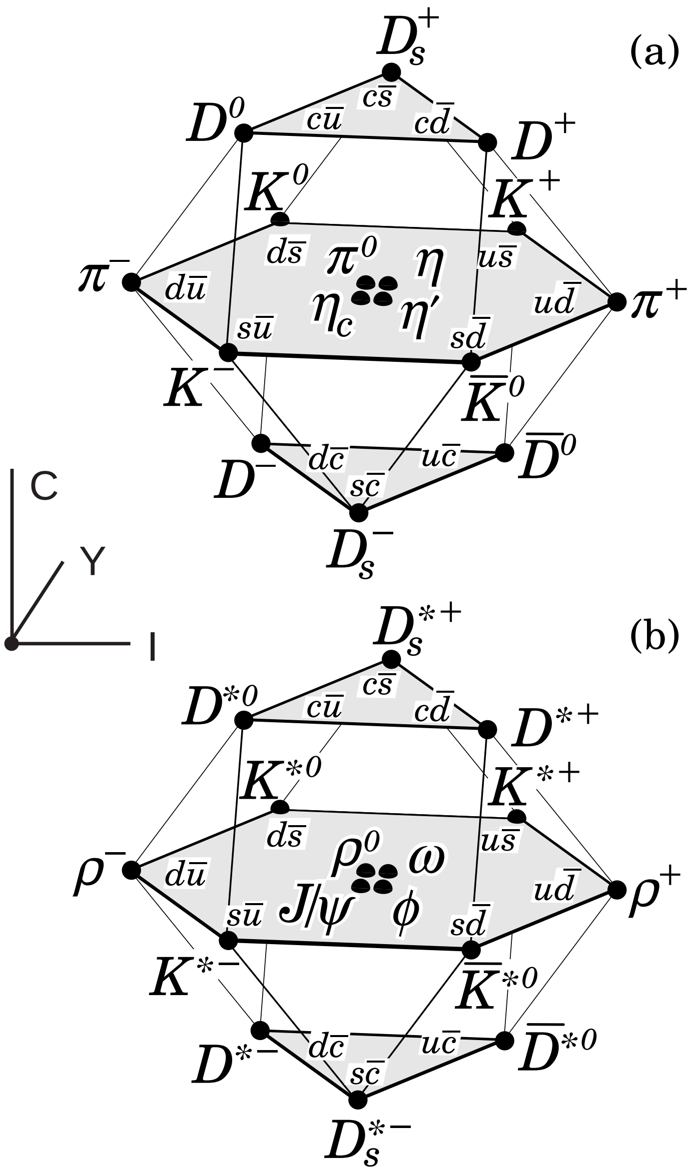
Gell–Mann; Ne’emann; Zweig (1964)

The three lightest quarks (u, d, s) tame the particle zoo





Adding Charm



About the strong interaction:

→ Matter: 6 Quarks; Field: 8 Gluons

→ There are three charges red, green, blue → Quantum Chromo Dynamics

→ Gluon–fields carry charge

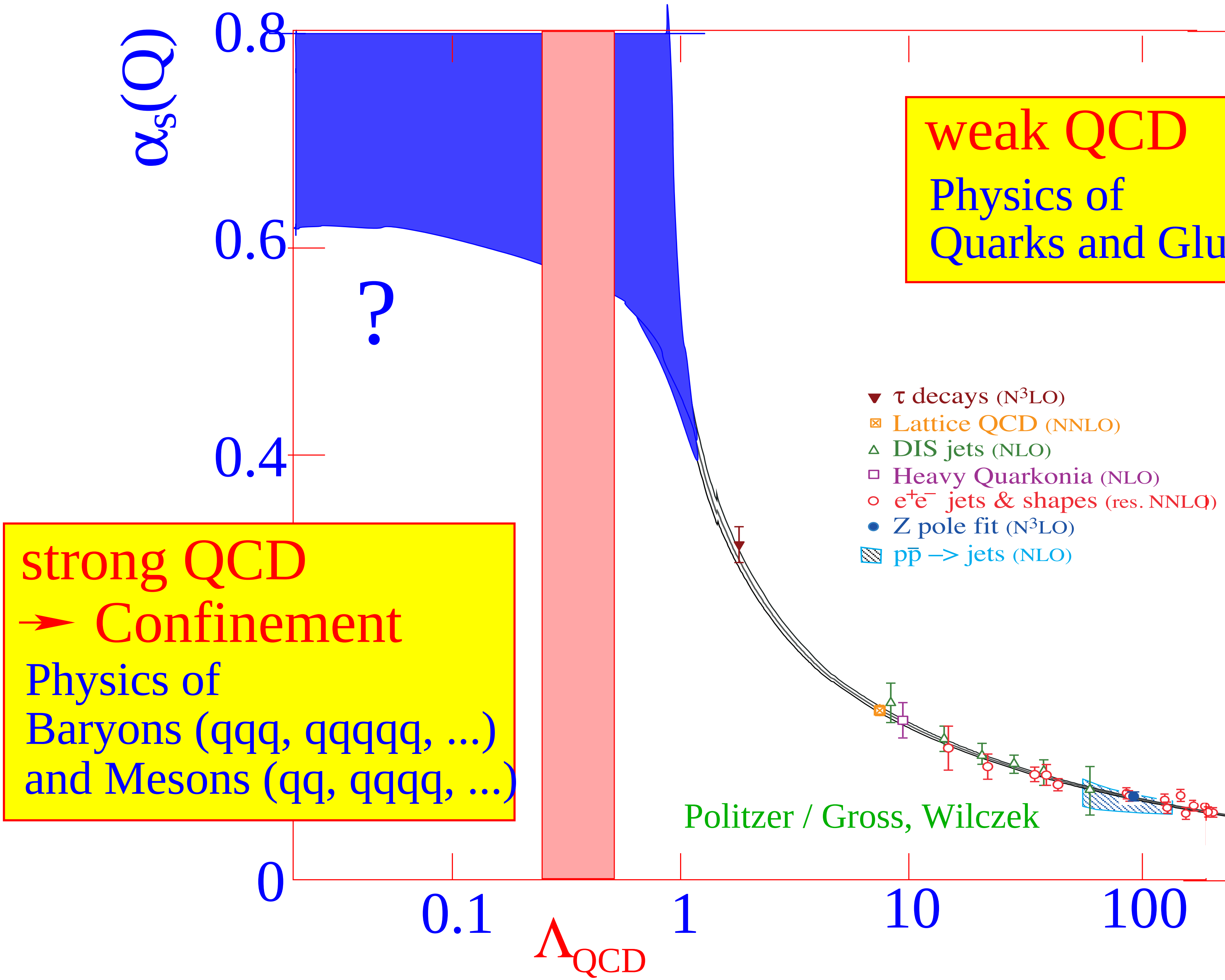
Nambu; Fritzsch, Gell–Mann;
Minkowski, Leutwyler

→ Charged particles confined

→ ~~Only established structures: qqq (baryons) and $\bar{q}q$ (mesons)~~

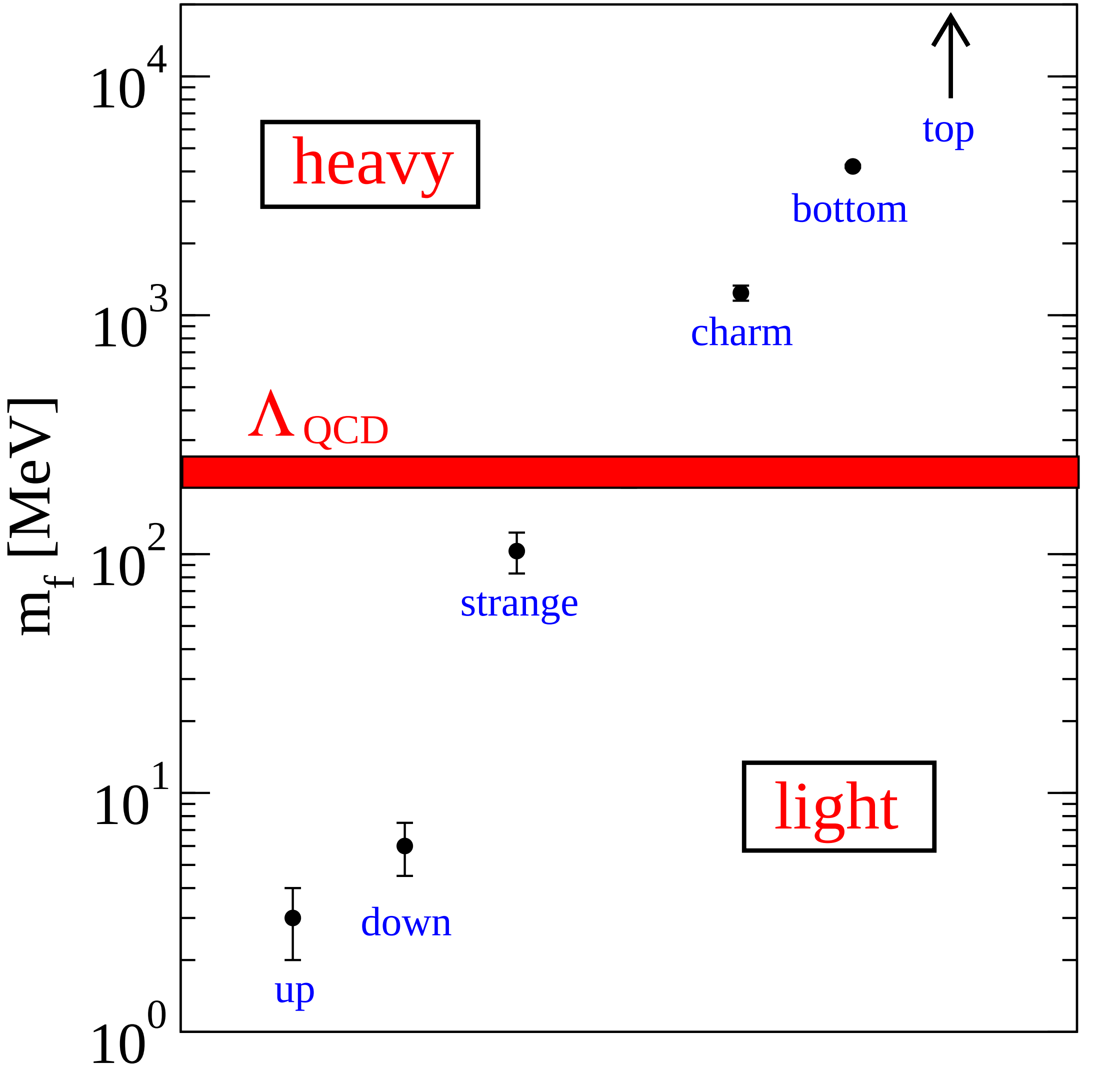
NO LONGER TRUE

The two faces of QCD



Quarkmasses

Quarkmasses (in $\overline{\mathrm{MS}}$ at μ=2 GeV)



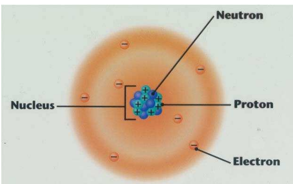
Particle Data Group (2008)

Expect very different phenomena for light (u,d,s) and heavy (c,b) quarks

- What are the spectra?
- What structures are there?
- Role of gluons?

Origin of hadron masses

M = sum of individual masses = $\Sigma_i m_i$



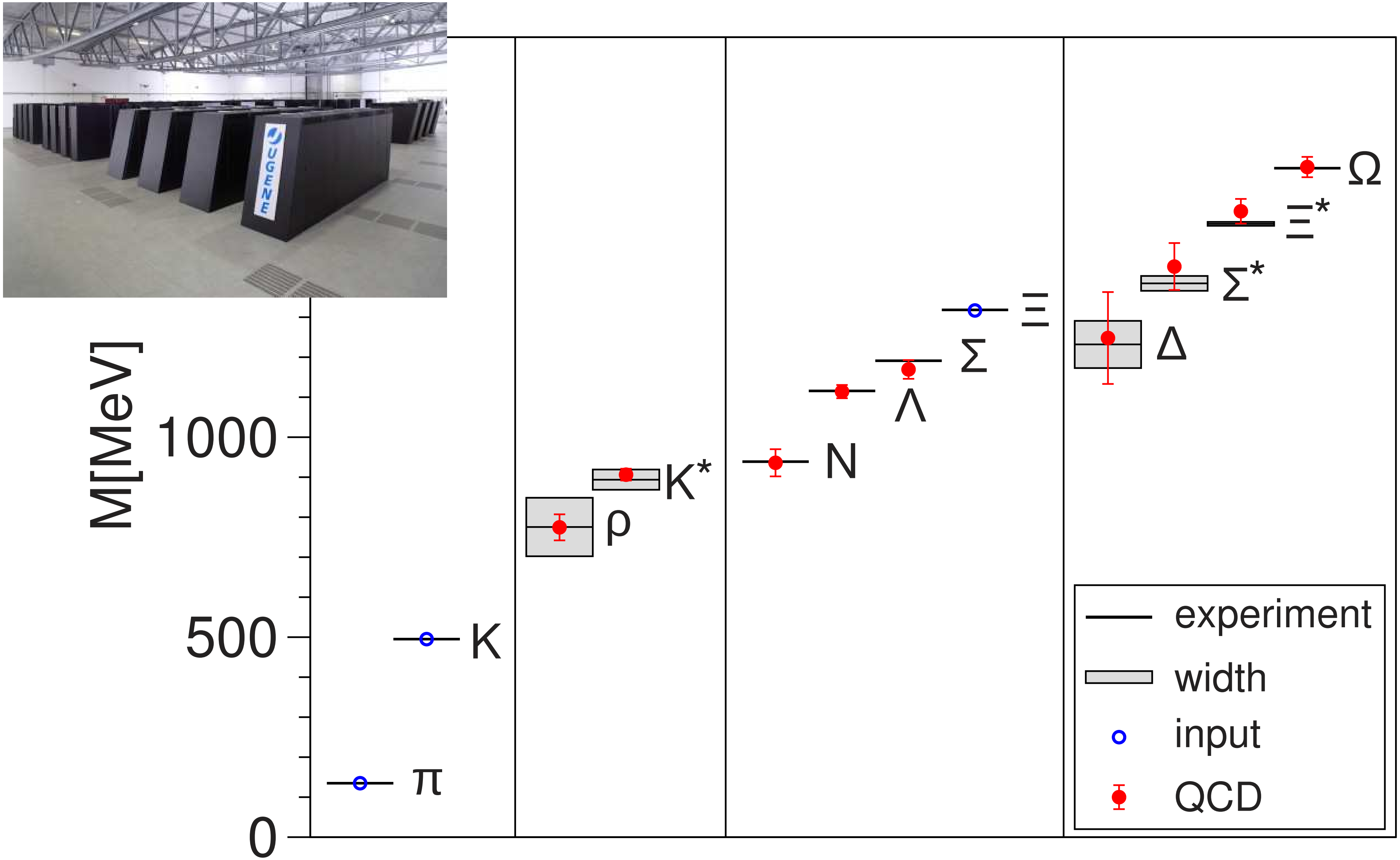
$$\text{M}_{\text{Atom}} = (\Sigma_i m_i) \times \left(1 - \text{const.} \times 10^{-8}\right)$$
$$\text{M}_{\text{Kern}} = (\Sigma_i m_i) \times \left(1 - \text{const.}' \times 10^{-3}\right)$$

$$\text{M}_{\text{Hadron}} = \sigma(\Sigma_i m_i) + E_{\text{field}}/c^2$$

for light quarks: $E_{\text{field}}/c^2 \gg \sigma(\Sigma_i m_i)$

for heavy quarks: $E_{\text{field}}/c^2 \ll \sigma(\Sigma_i m_i)$

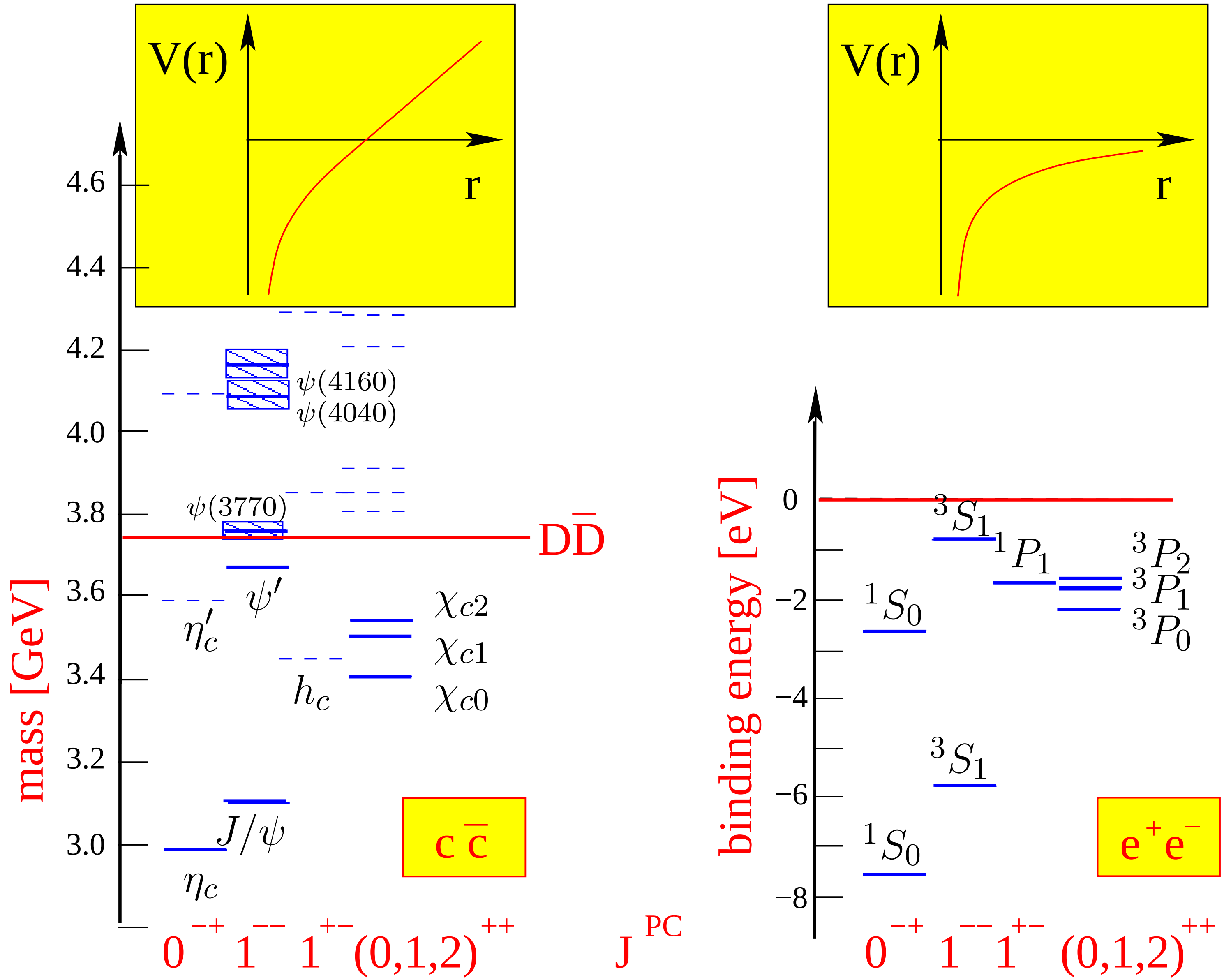
Direct evaluation



1 MeV $\simeq\ 2 \times 10^{-30}$ kg

Charmonium before 2002

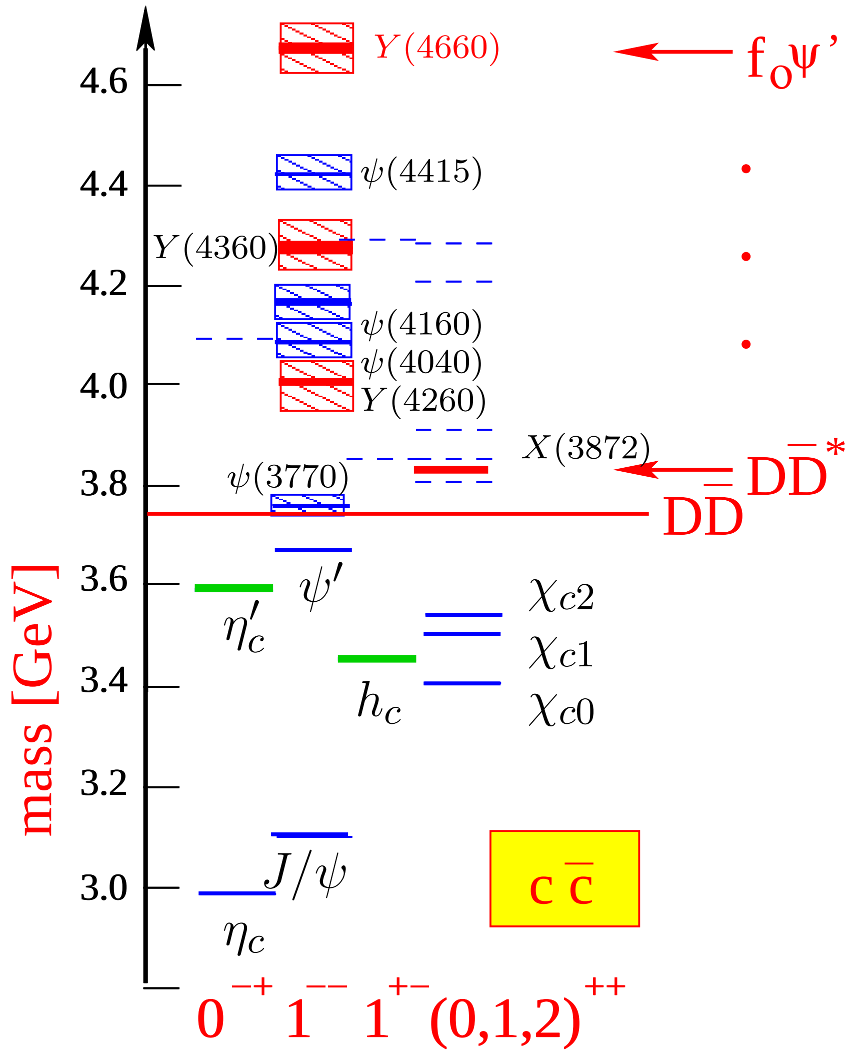
Quark-Model: Eichten et al. (1978)



Charmonium after 2002

Quark-Model: Eichten et al. (1978)

A new particle Zoo!



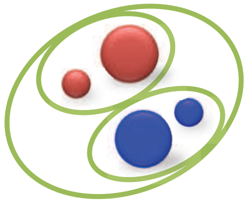
→ missing low lying states found

→ Above the $\bar{D}D$ threshold:

- ▷ Many new states
- ▷ incompatible with quark model in mass and properties

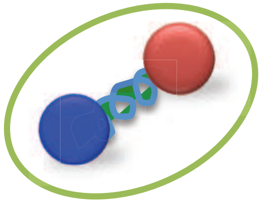
What are they?

Proposals



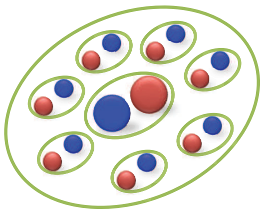
Tetraquark

$\rightarrow$ Compact object formed from (Qq) and $(\bar{Q}\bar{q})$



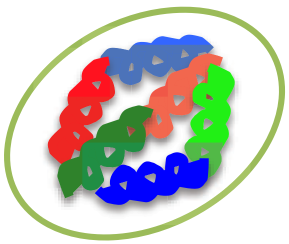
Hybrid

$\rightarrow$ Compact with active gluons and $\bar{Q}Q$



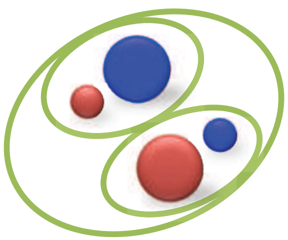
Hadro-Quarkonium

$\rightarrow$ Compact $(\bar{Q}Q)$ surrounded by light quarks



Glueball

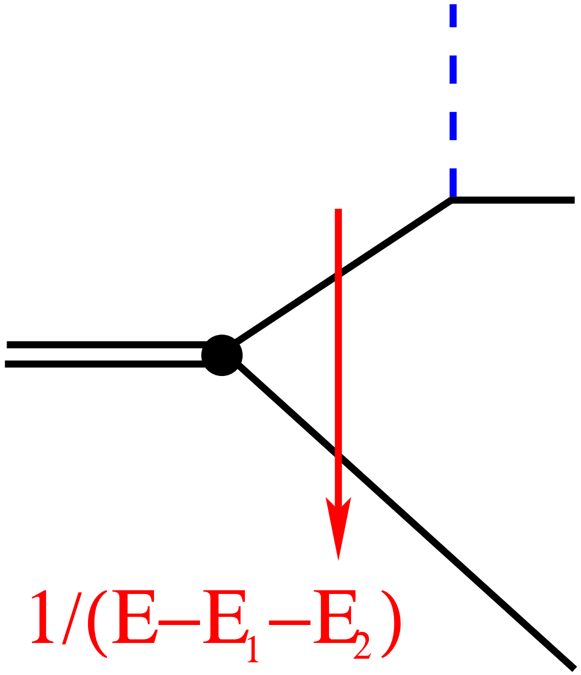
$\rightarrow$ Compact object just made off gluons



Hadronic-Molecule

$\rightarrow$ Extended object made of $(\bar{Q}q)$ and $(Q\bar{q})$

Size of a Molecule



with $E = M_{\rm Mol.}$ & $E_1 + E_2 = M_1 + M_2 + p^2/(2\mu)$

and $E_B = M_1 + M_2 - M_{\rm Mol.}$

$\longrightarrow p \sim \sqrt{2\mu E_B}$

$\longrightarrow$ size of the molecule, R, reads

$$R \sim 1/p \sim 1/\sqrt{2\mu E_B}$$

c.f. H-atom: $E_B = m_e\alpha^2/2; \mu = m_e \to a_0 = 1/(m_e\alpha)$

On the other hand: confinement radius $\ll$ 1 fm

Molecules extended for $(\hbar c)^2/(2\mu) \gtrsim E_B$

for $\mu \sim$ 1 GeV we need $E_B \sim 20$ MeV or smaller

then external probes couple predominantly via the constituents

Charged states

2012: Discovery of charged states that

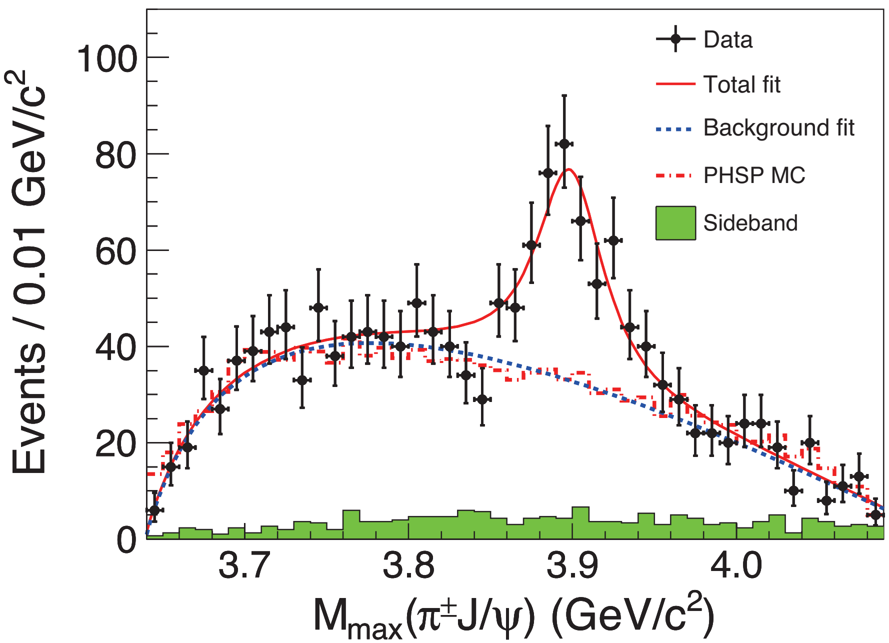
→ have masses in the quarkonium regime;

→ decay with $\bar{Q}$ und Q in the final state

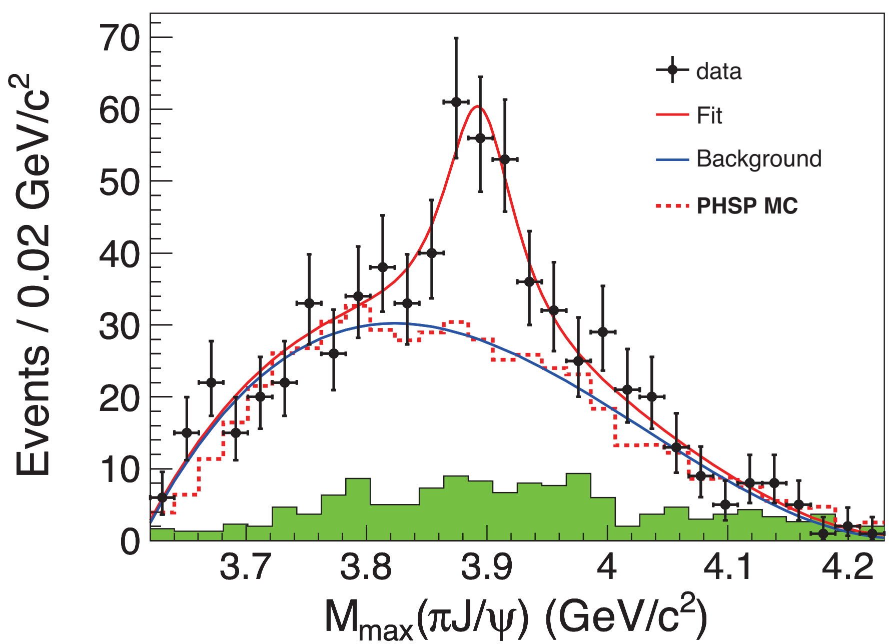
→ must contain at least 4 quarks

Example: $Z_c(3900)$ close to $\bar{D}D^*$ threshold

BES-III (China), 2013



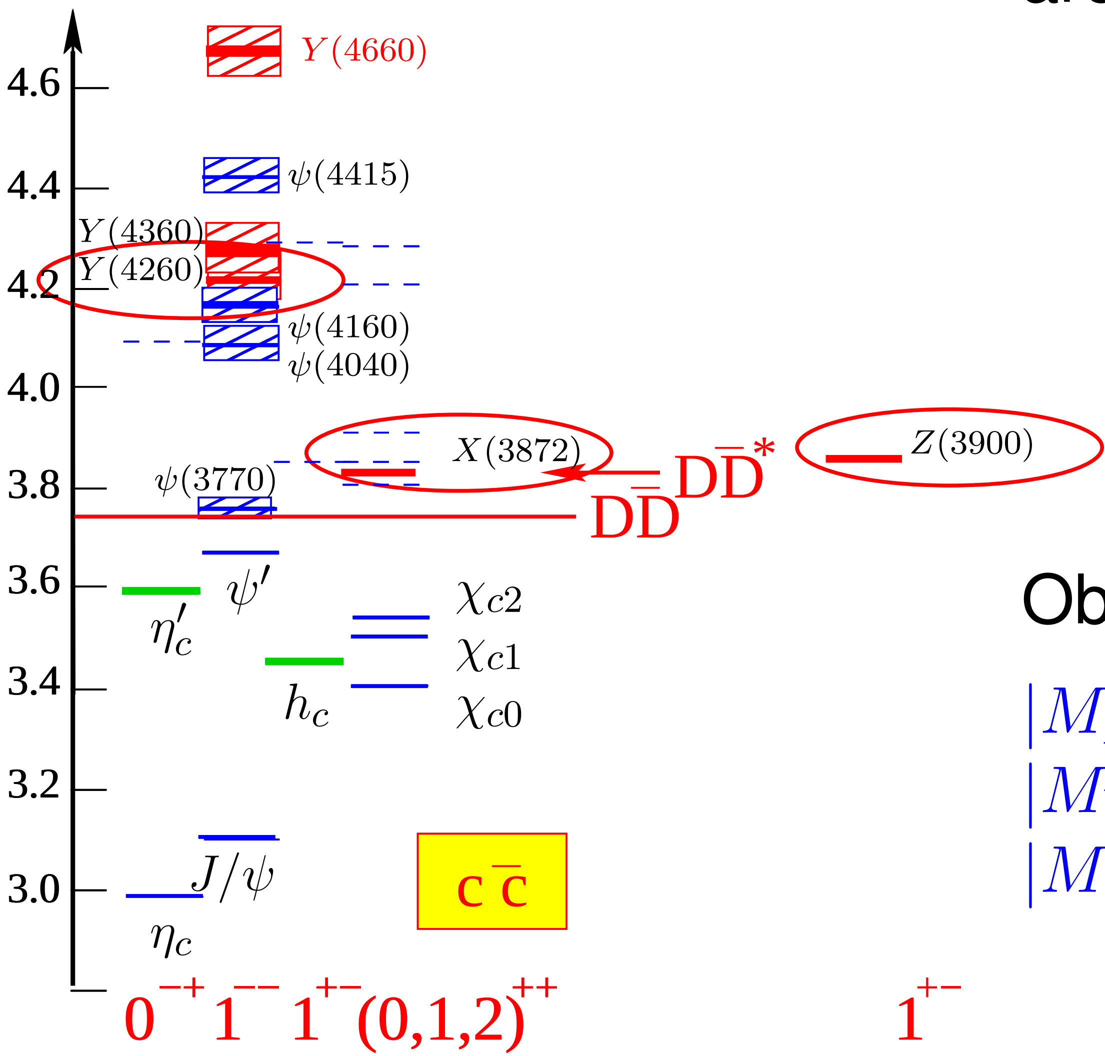
Belle (Japan), 2013



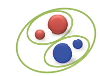
For the rest of the talk ...

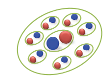
Quark-Model: Eichten et al. (1978)

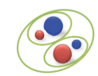
A new particle Zoo!



are these

tetraquarks, 

hadro-charmonia, 

molecules? 

Observation:

$|M_X - M_D - M_{D^*}| < 1$ MeV

$|M_Y - M_D - M_{D_1}| \simeq 30$ MeV

$|M_Z - M_D - M_{D^*}| < 20$ MeV

A possible scenario

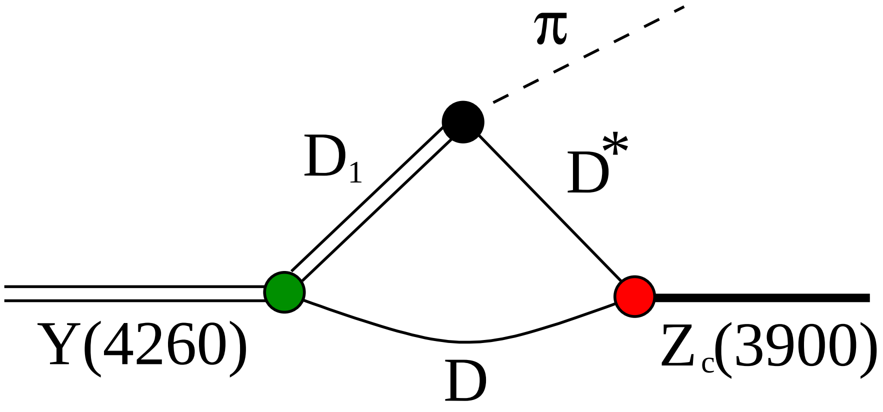
We proposed:

→ $Y(4260)$ is a $D_1(2420)\bar{D}$–molecule

→ $Z_c(3900)$ is a $D^*\bar{D}$ molecule

A molecule decays via its constituents

Within this picture Z_c was found in $Y(4260)$ decays since the decay $D_1 \to D\pi$ provides many D^*D pairs



Q. Wang, CH and Q. Zhao, Phys. Rev. Lett. 111 (2013) 132003

Consequences I

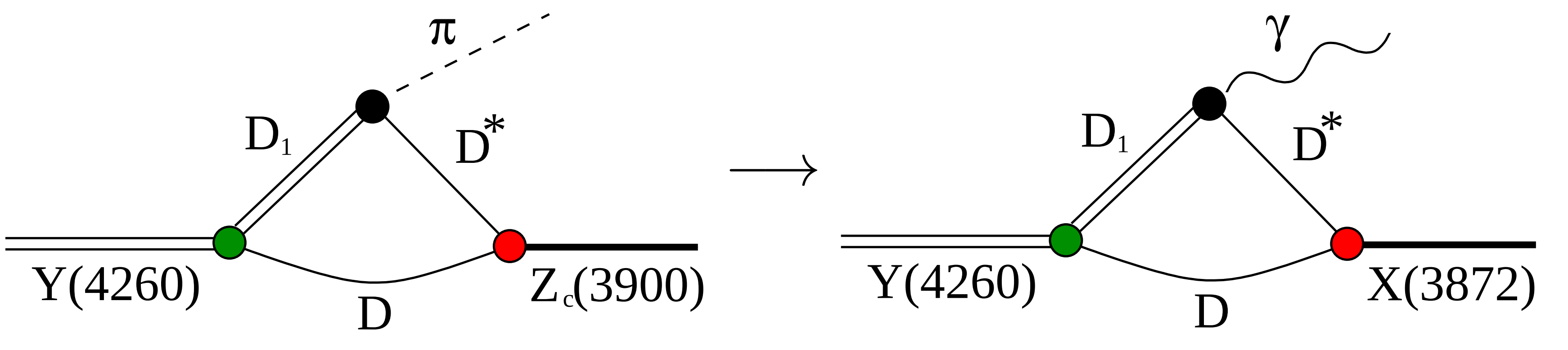
Thus we have:

$$Z_c^+ \sim D^{*+}\bar{D}^0\ ,\quad Z_c^0 \sim \frac{1}{\sqrt{2}}(D^{*+}D^- - D^{*0}\bar{D}^0)\ ,\quad Z_c^- \sim D^{*-}D^0$$

If we assume in addition, that $X(3872)$ is a D^*D molecule with

$$X \sim \frac{1}{\sqrt{2}}(D^{*+}D^- + D^{*0}\bar{D}^0)$$

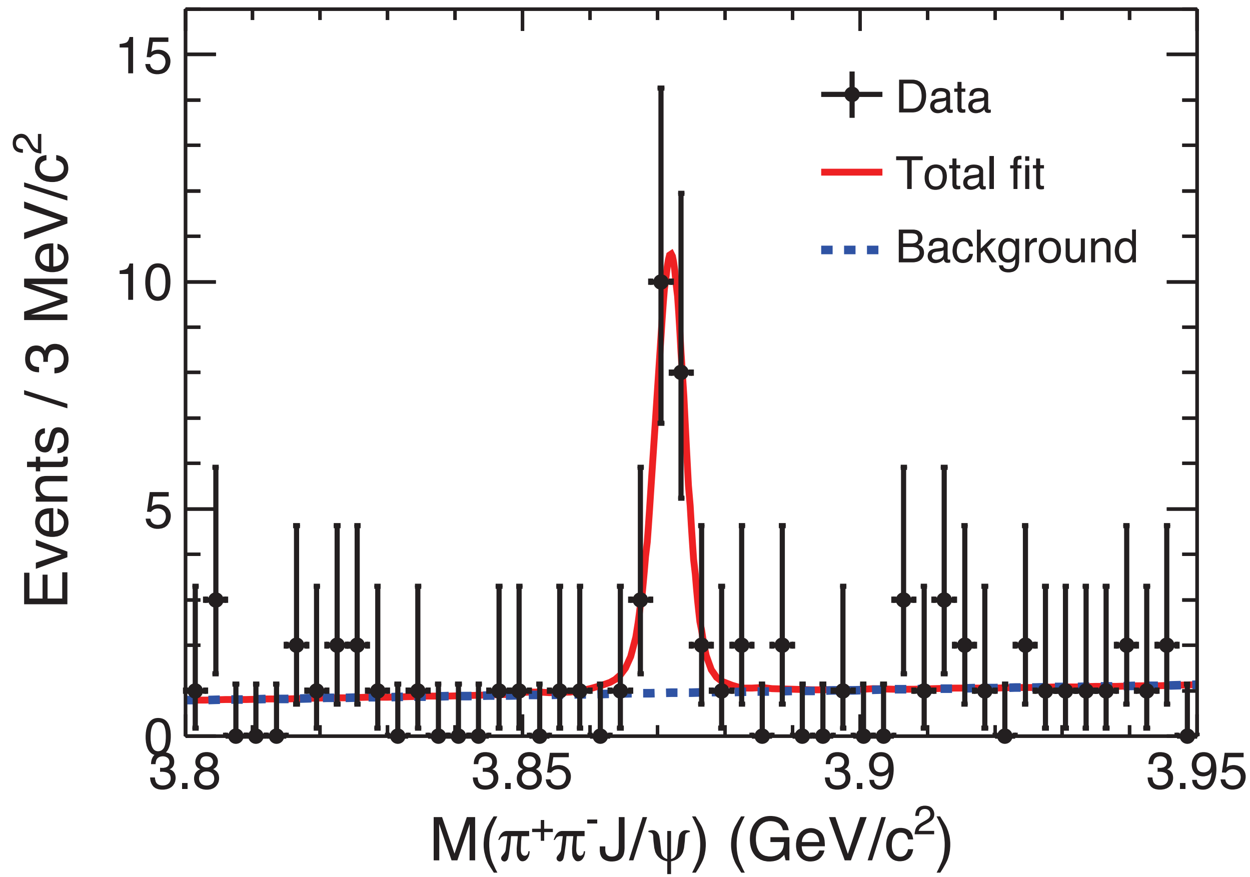
then there must be $Y(4260) \to \gamma X(3872)$



F.-K. Guo et al., Phys.Lett. B725 (2013) 127-133

and indeed ...

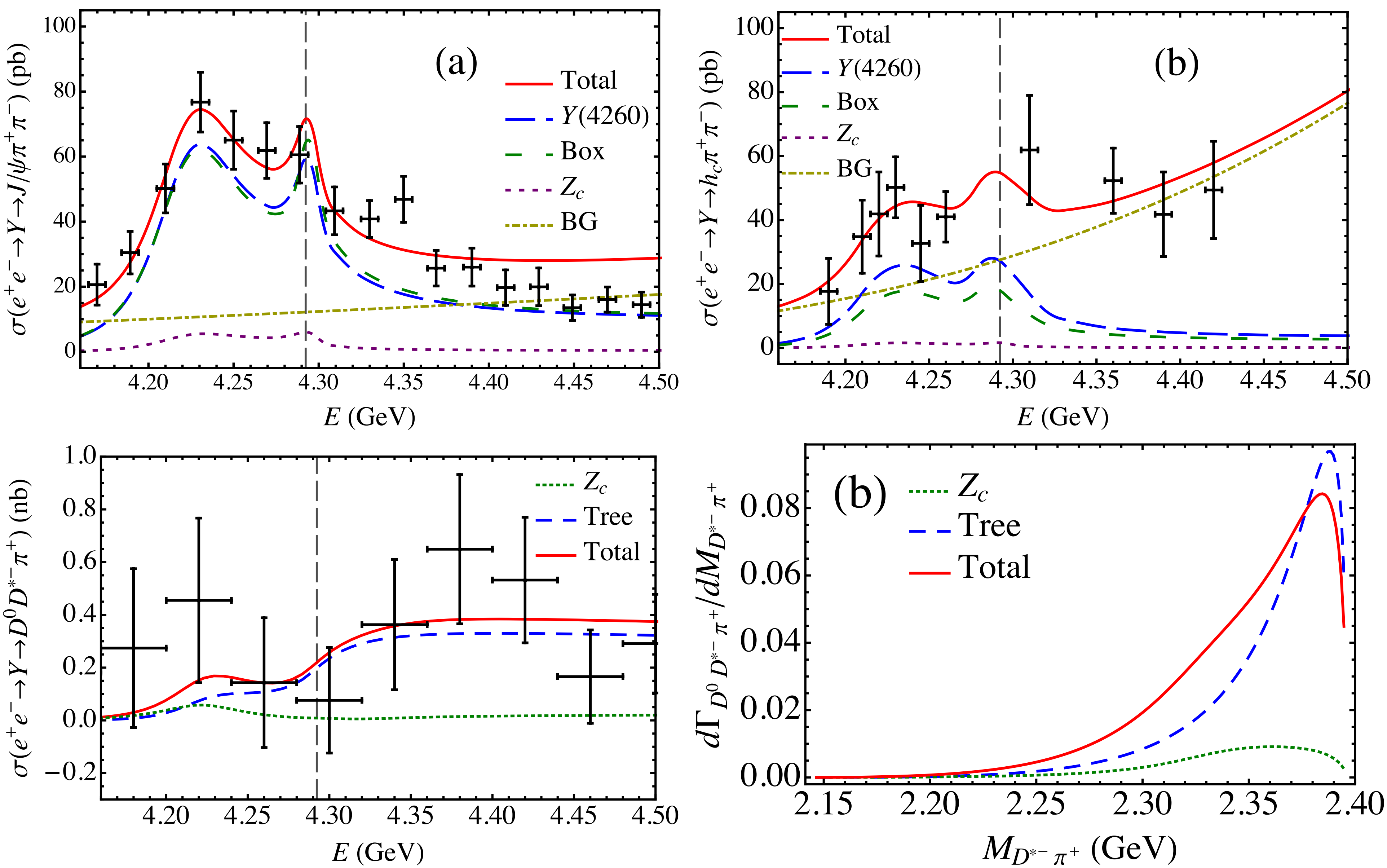
BES-III data for $Y(4260) \to \gamma X(3872) \to \gamma[\pi\pi J/\psi]$



arXiv:1310.4101

provides a strong support for the hypothesis

Consequences II ...



M. Cleven et al., arXiv:1310.2190 [hep-ph].

Summary

Various experiments (will be) looking for systems with charm

- BABAR (USA – data taking finished)
- Belle (Japan)
- BES-III (China)
- LHCb (CERN)
- PANDA (FAIR, Germany; after 2018)

together with the expected developments of theoretical tools

There are exciting times to come!

stay tuned!