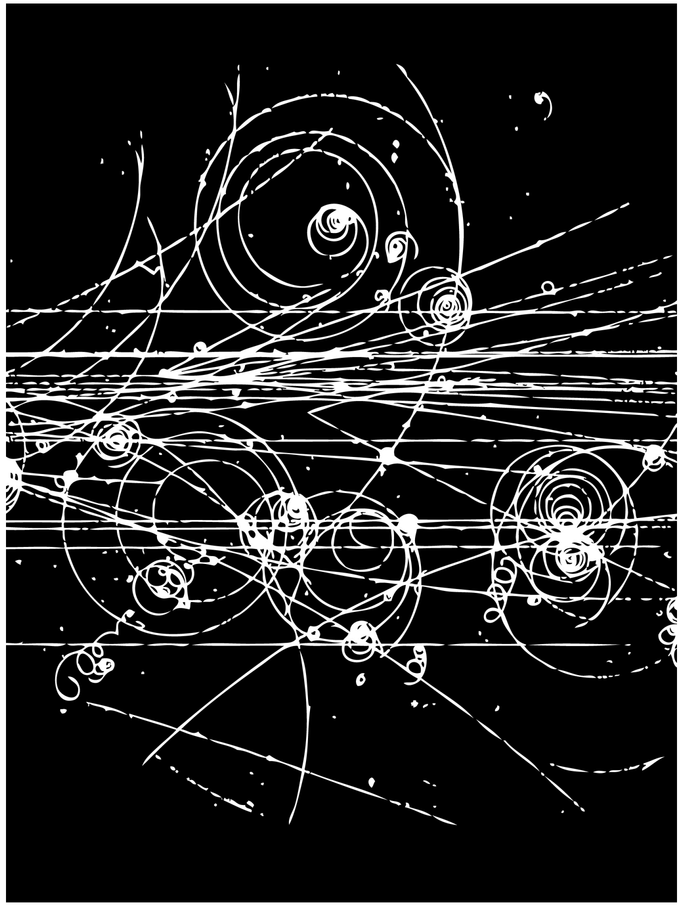
Hadron Spectroscopy



Stephen Lars Olsen
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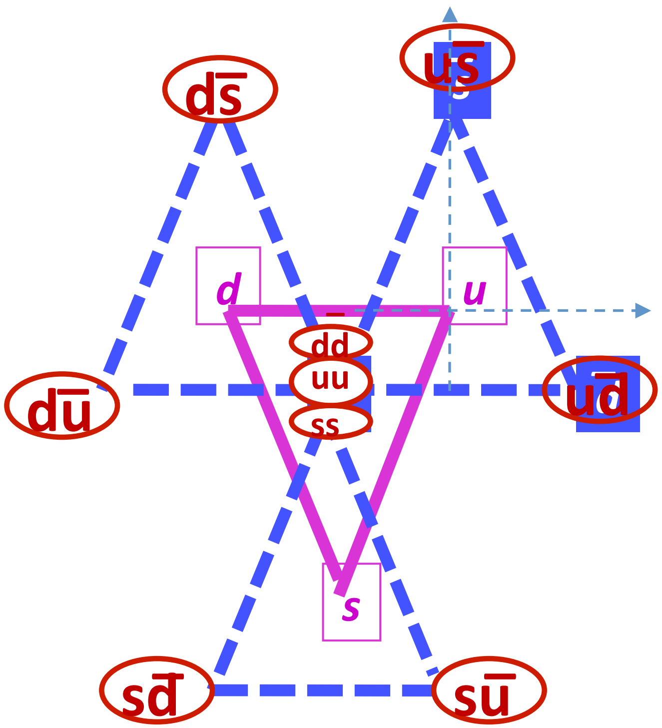
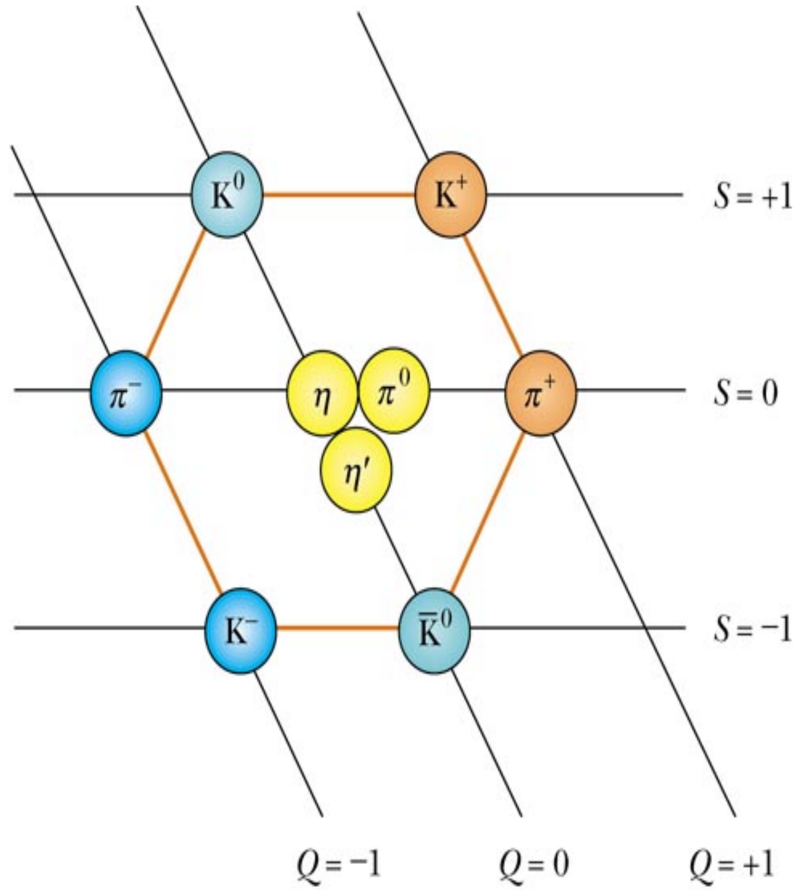
University of the Chinese Academy of Science

UCAS Physics-department, June 20 – July 6, 2014

Lecture 3: Successes and failures of the quark model.

Make mesons from quark-antiquark

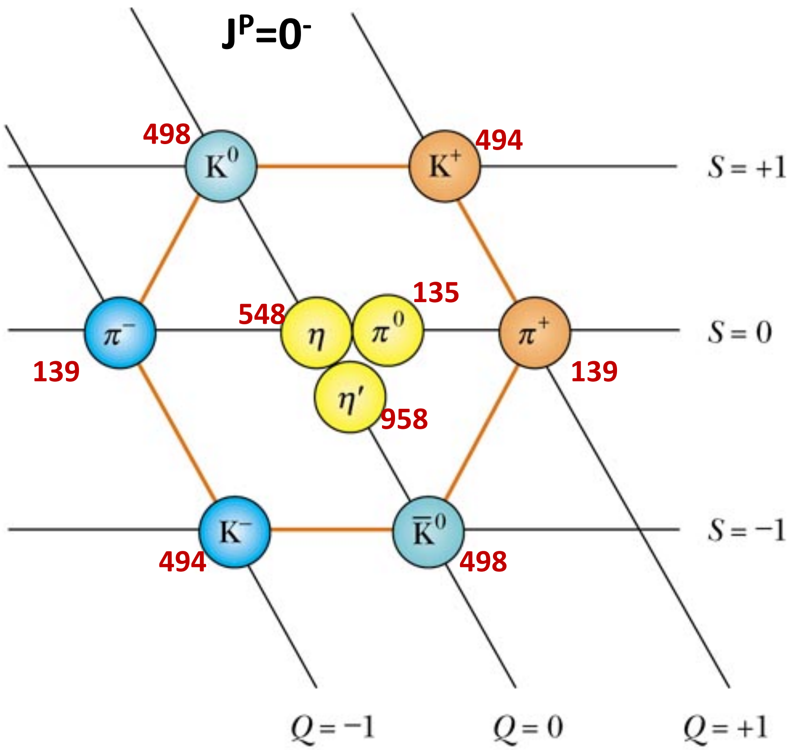


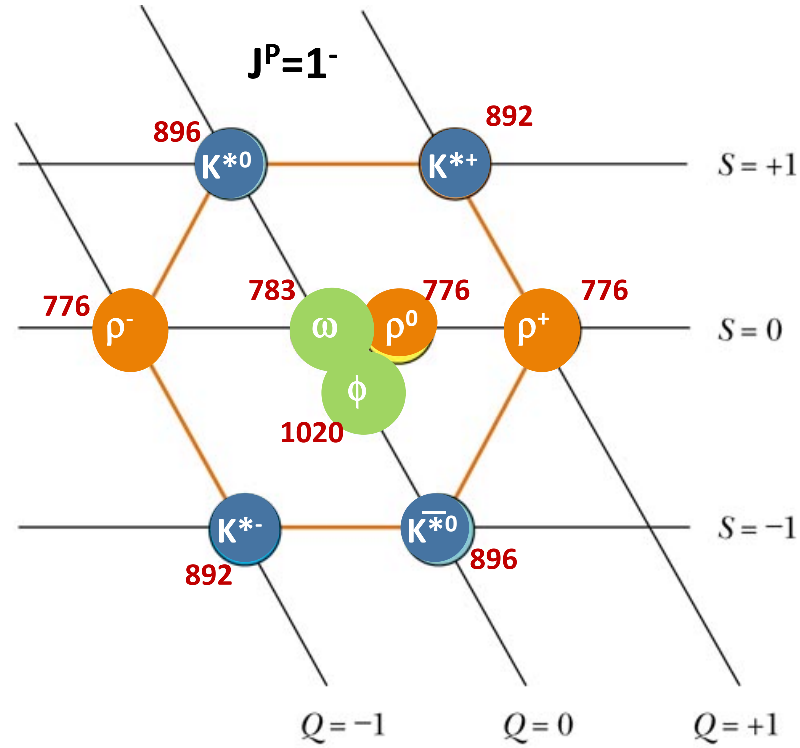


Q=electric-charge (=I_z+Y/2)

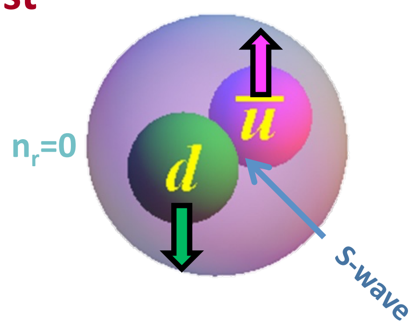
9 states: $$3 \otimes \overline{3} = 1 \oplus 8$$ SU(3) singlet + SU(3) octet

Ground state mesons

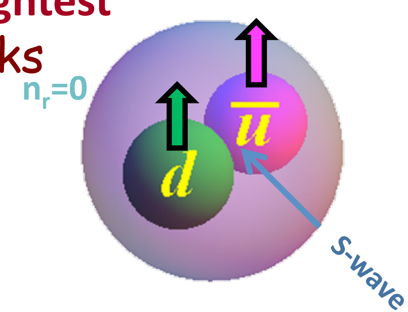




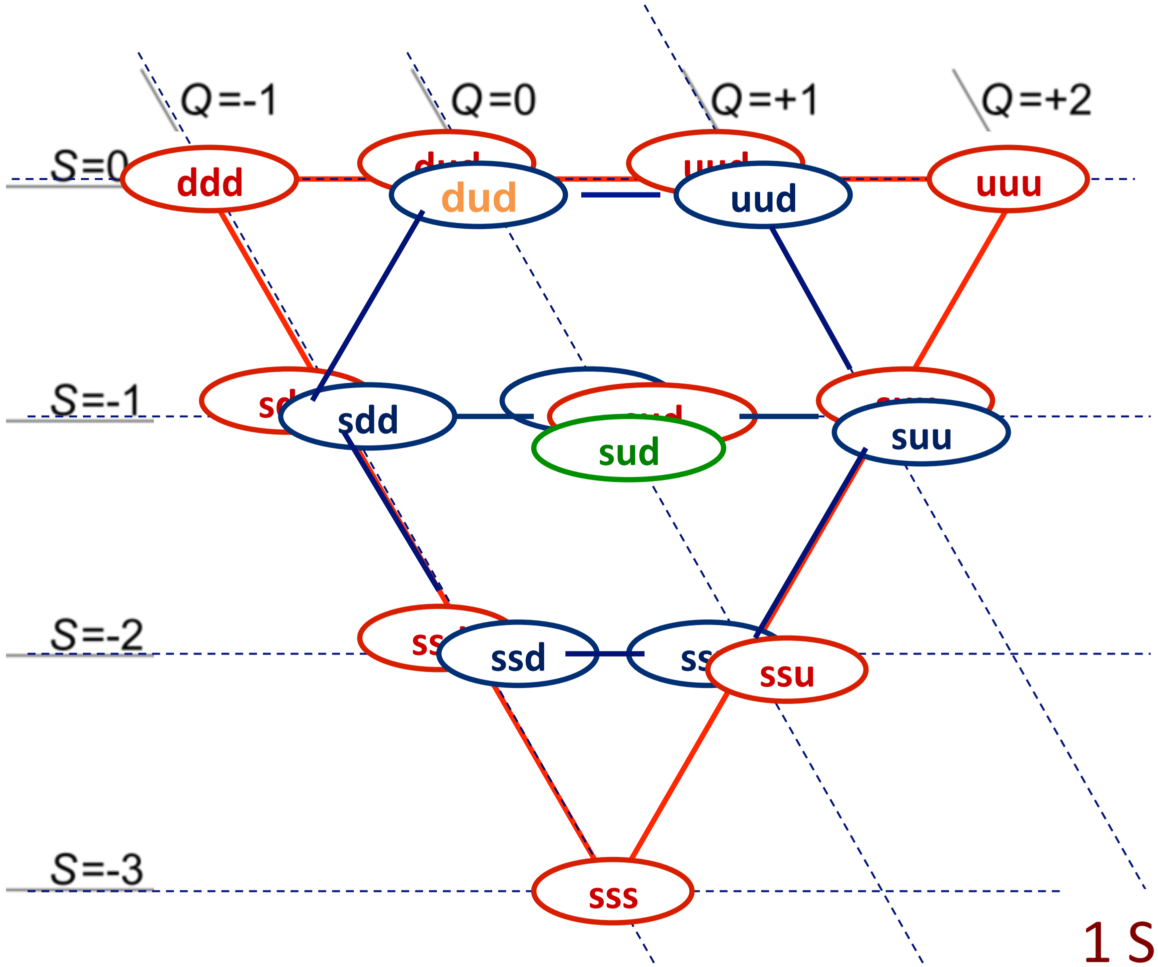
(π^+,π^0,π^-)=lightest
no s-quarks



(ρ^+,ρ^0,ρ^-)=lightest
no s-quarks



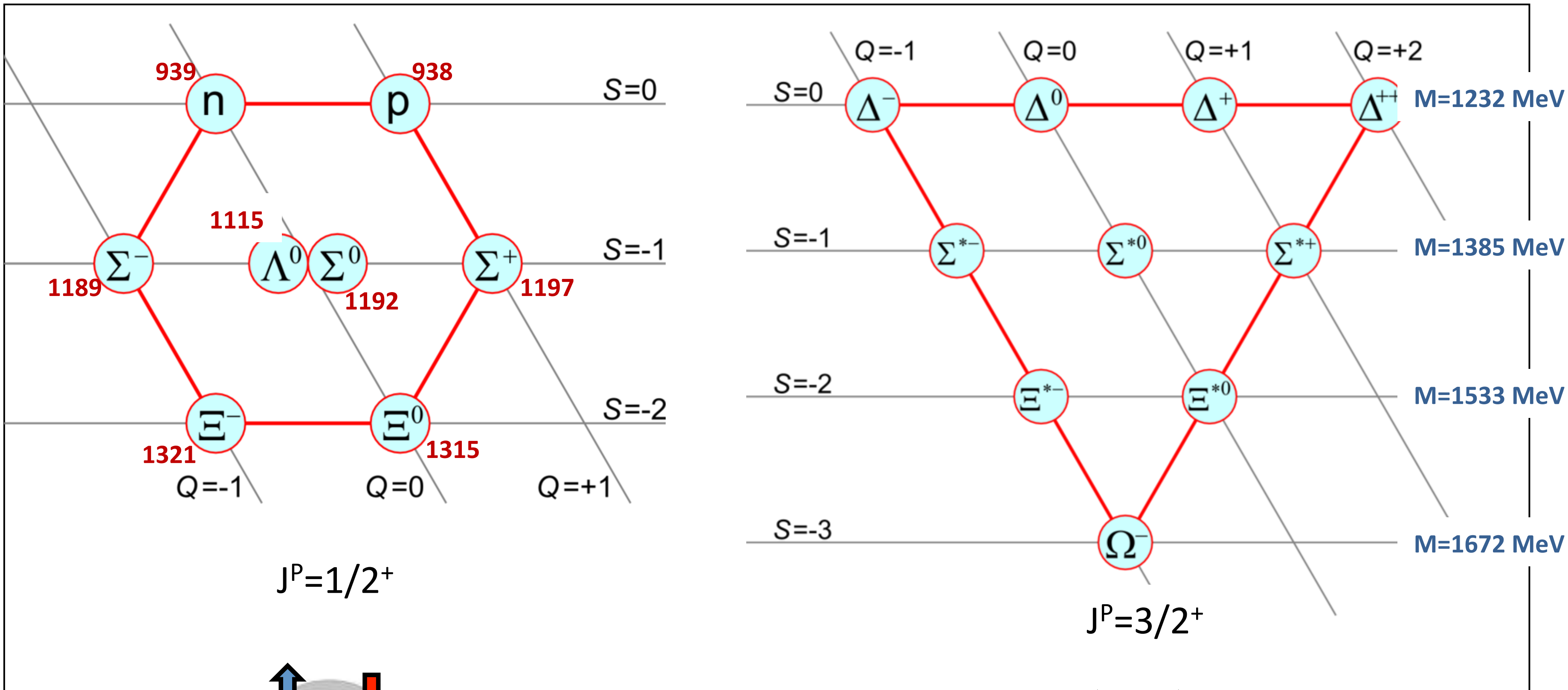
Baryons = qqq

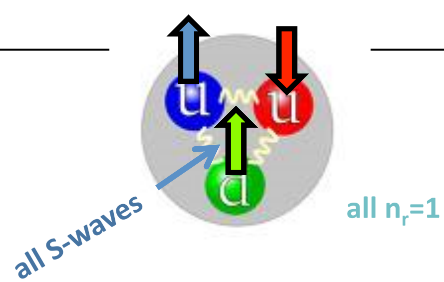


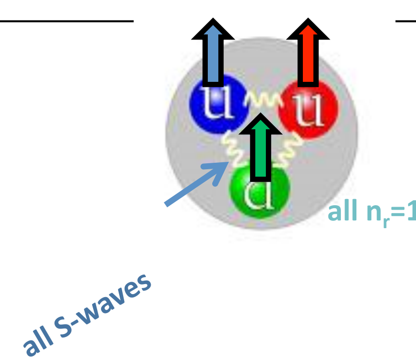
27 states: $3 \otimes 3 \otimes 3 = 1 \oplus 8 \oplus 8 \oplus 10$

1 SU(3) decuplet
+2 SU(3) octets
+1 SU(3) singet

Ground state Baryons

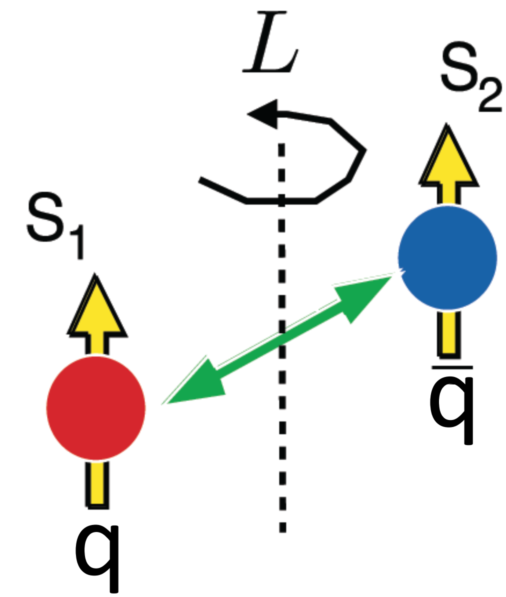






How about excited mesons & baryons?

J^{PC} quantum numbers of $q\bar{q}$ mesons



$\vec{S} = \vec{S}_1 + \vec{S}_2$

$\vec{J} = \vec{L} + \vec{S}$

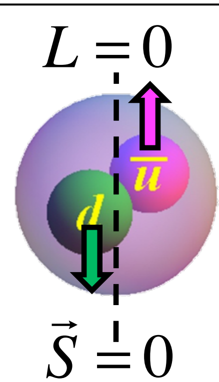
$P = (-1)^{L+1}$

$C = (-1)^{L+S}$ ← if q & $\bar{q}$ are the same flavor

+radial excitations

pseudoscalars

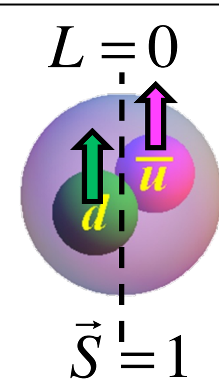
π, η, K, η'



$J^P = 0^-$

vectors

ρ, ω, K^*, ϕ



$J^P = 1^-$

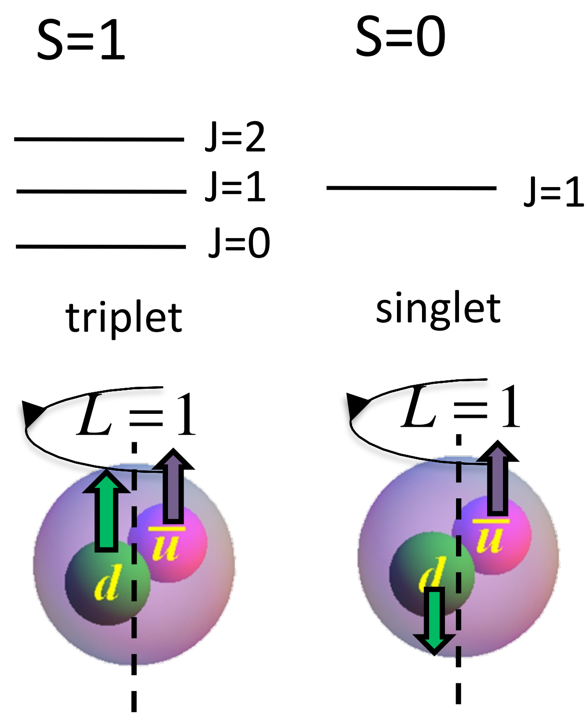
What about P-wave mesons?

$$L = 1$$

$$S = 0,1$$

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

$$\vec{J} = \vec{L} + \vec{S}$$



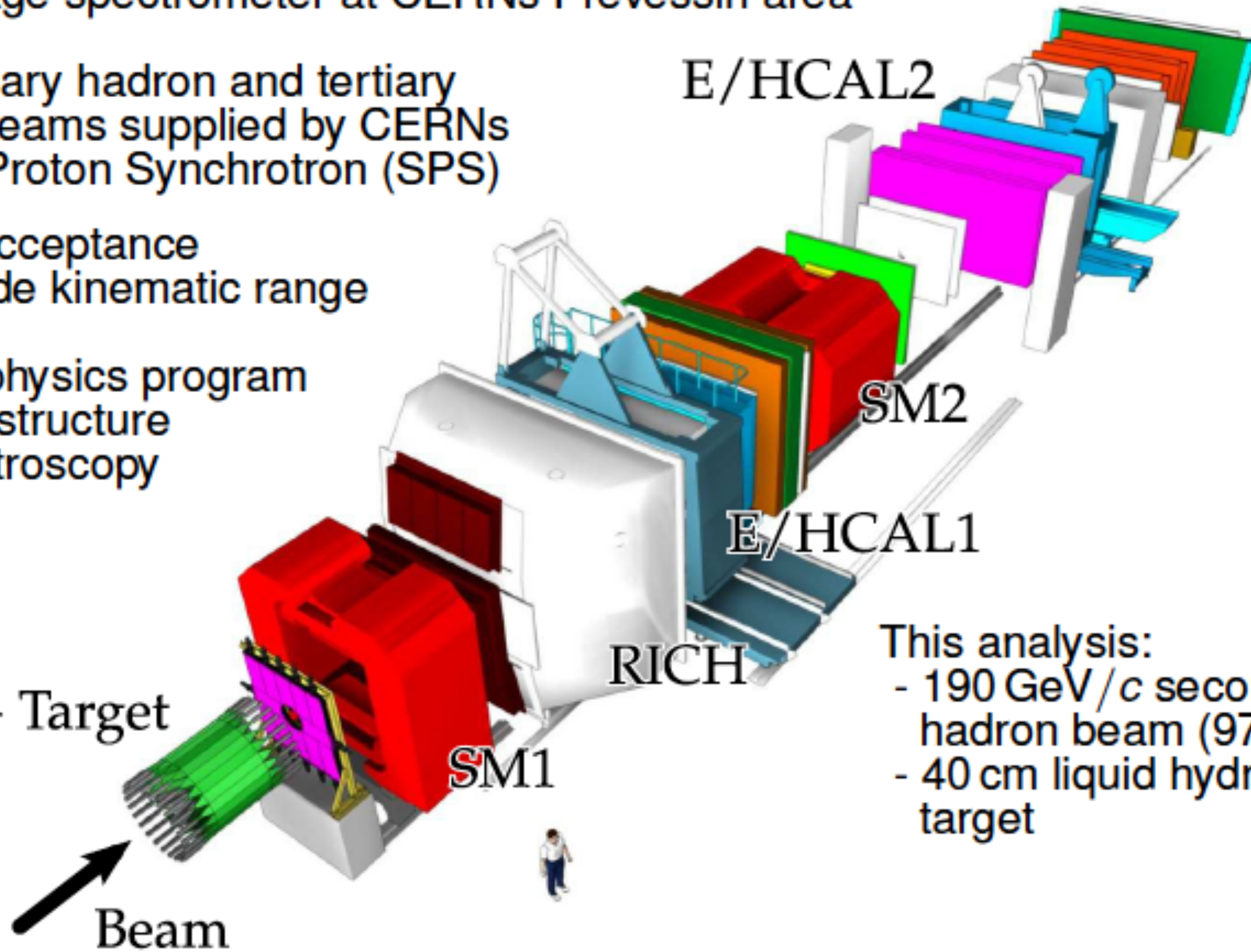
COMPASS Experiment at CERN

Two-stage spectrometer at CERNs Prévessin area

Secondary hadron and tertiary
muon beams supplied by CERNs
Super Proton Synchrotron (SPS)

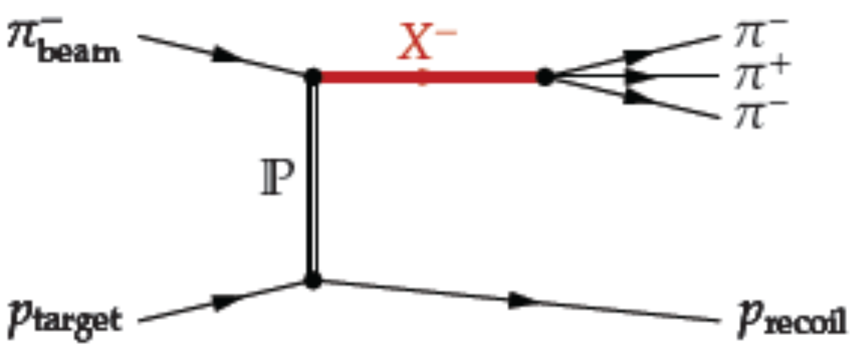
Good acceptance
over wide kinematic range

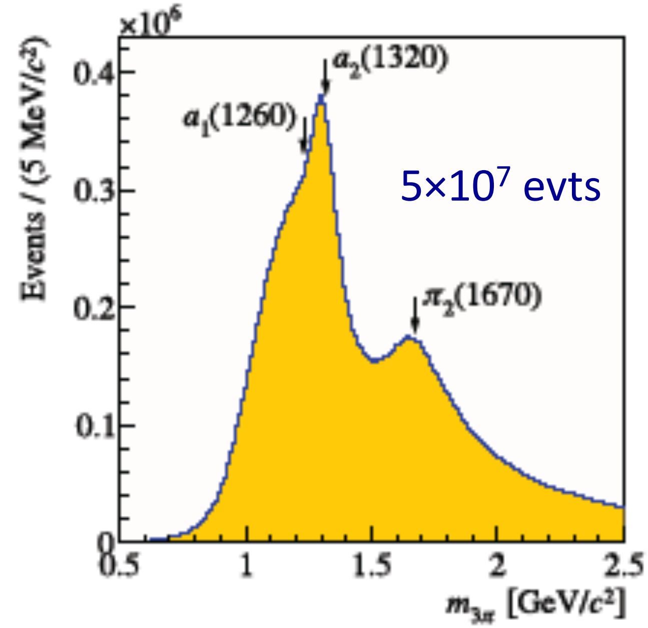
Broad physics program
- Spin-structure
- Spectroscopy



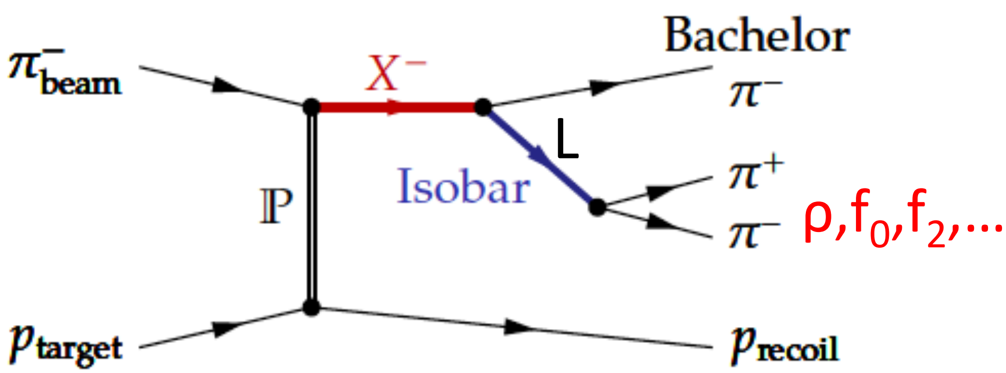
This analysis:
- 190 GeV/c secondary hadron beam (97% π^-)
- 40 cm liquid hydrogen target

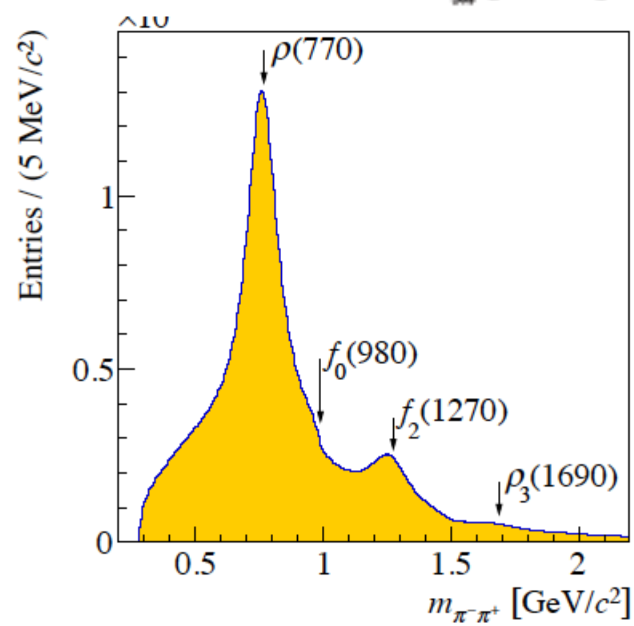
P-wave mesons via $\pi^- p \rightarrow \pi^+\pi^-\pi^- p$





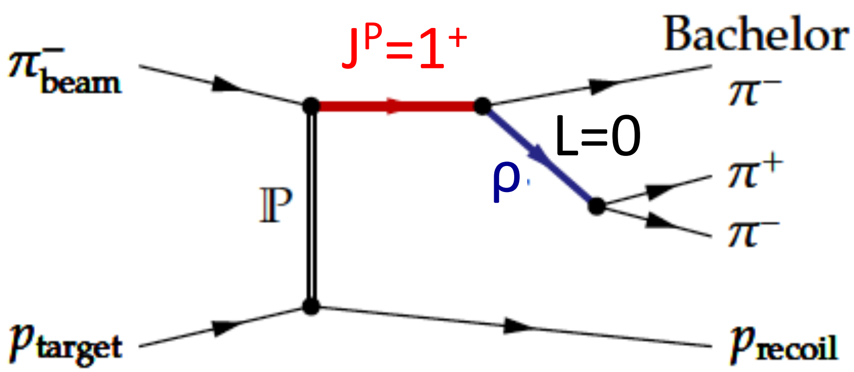
Mostly 2-body process

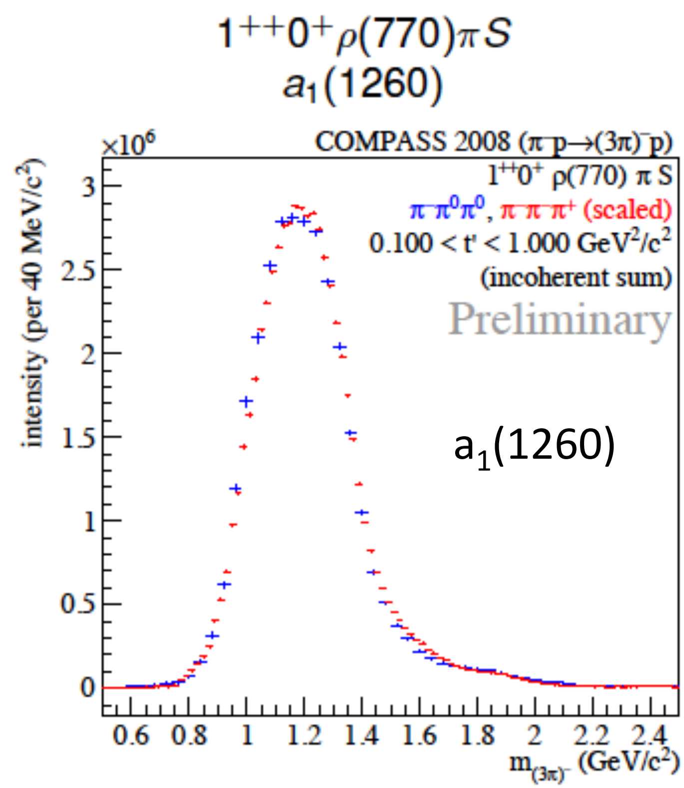




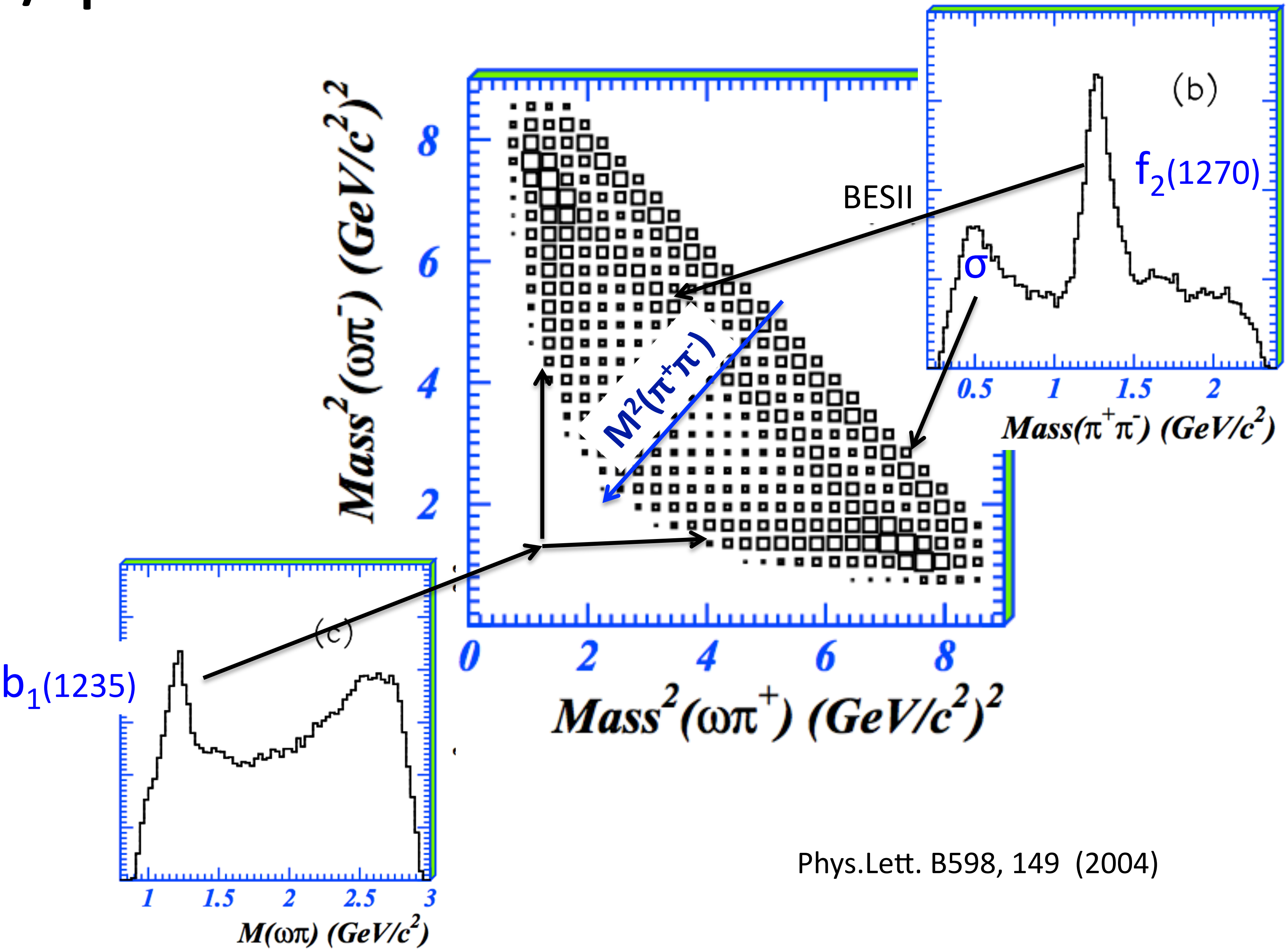
Phys.Rev.Lett. 115,082001 (2015)

The $J^P=1^+$ $a_1(1260) \rightarrow \pi^- \rho^0$ meson



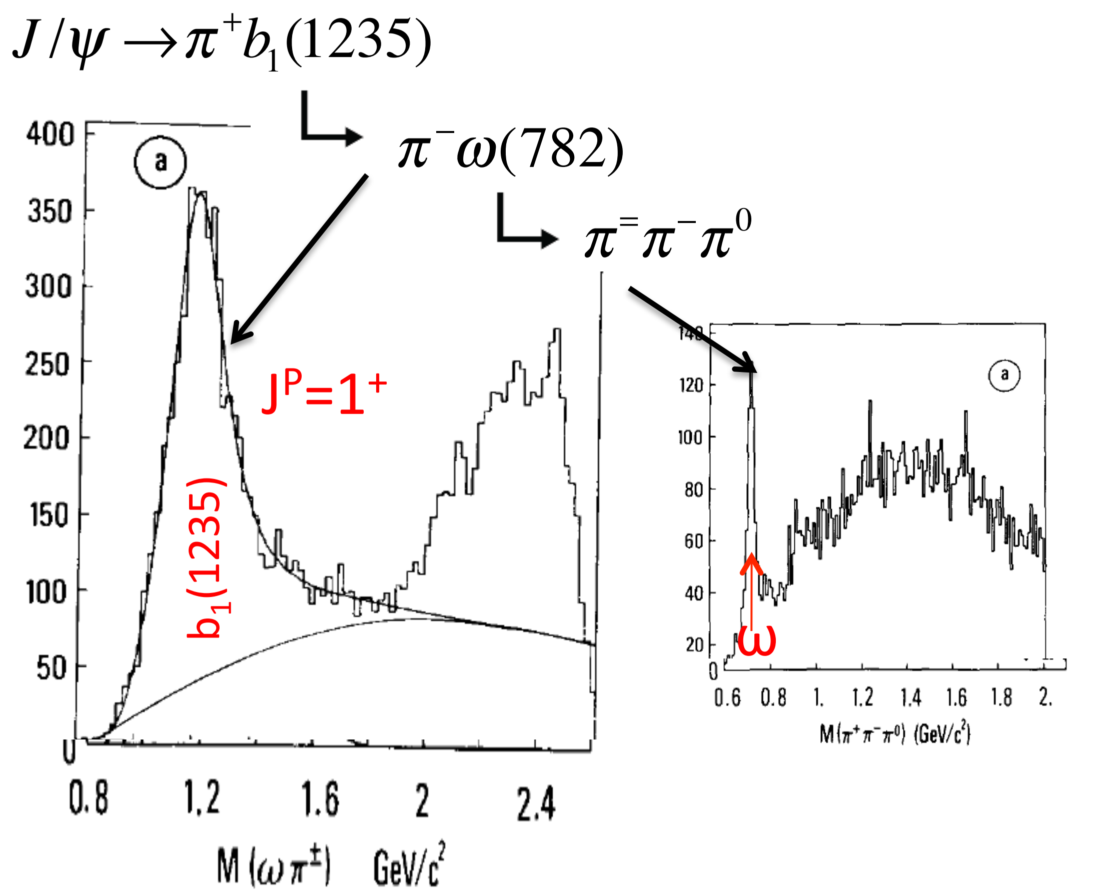


J/ψ→$\pi^+\pi^-\omega$ from BESII



Phys.Lett. B598, 149 (2004)

The $J^P=1^+$ $b_1(1235) \rightarrow \pi^-\omega$ meson



Nuclear Physics B320 (1989) 1–19

Difference between a_1(1260) & b_1(1235)

both have $J^P=1^+$; both have Ispin=1

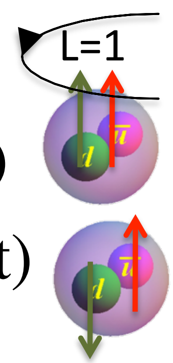
$$\begin{array}{l} a_1(1260) \rightarrow \pi\rho \rightarrow 3\pi \\ b_1(1235) \rightarrow \pi\omega \rightarrow 4\pi \end{array} \Rightarrow G(n\pi) = (-1)^n \Rightarrow \begin{array}{l} G(a_1(1260)) = (-1)^3 = -1 \\ G(b_1(1235)) = (-1)^4 = +1 \end{array}$$

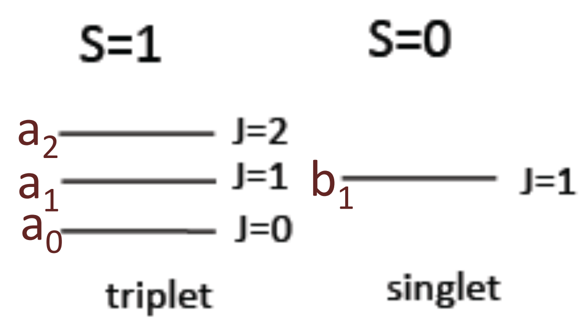
C-parity of I_3=0 neutral meson

=-1 for I=1

$$G(X) = C_{X^0} e^{i\pi I_2} \Rightarrow \begin{array}{l} C(a_1(1260)^0) = +1 \\ C(b_1(1235)^0) = -1 \end{array}$$

$$C = (-1)^{L+S} \Rightarrow \begin{array}{l} a_1(1260):\ S=1\ \text{(triplet)} \\ b_1(1235):\ S=0\ \text{(singlet)} \end{array}$$





Other 1⁺ mesons from BESII

$f_1(1285)$ and $\eta(1420)$

$I= 0; J^P=1^+$ $I= 0; J^P=0^-$

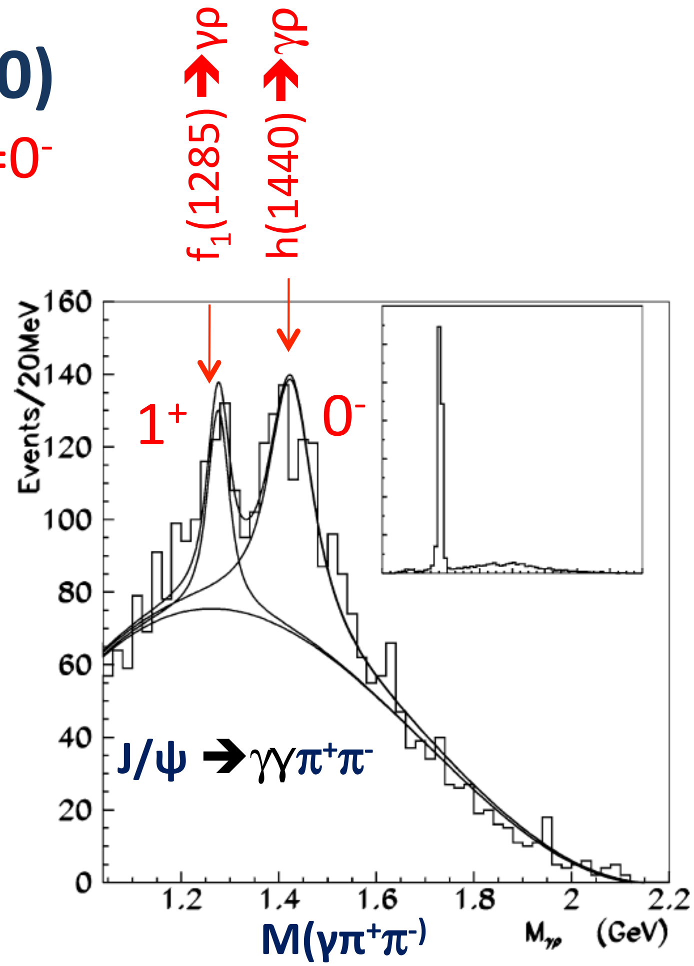


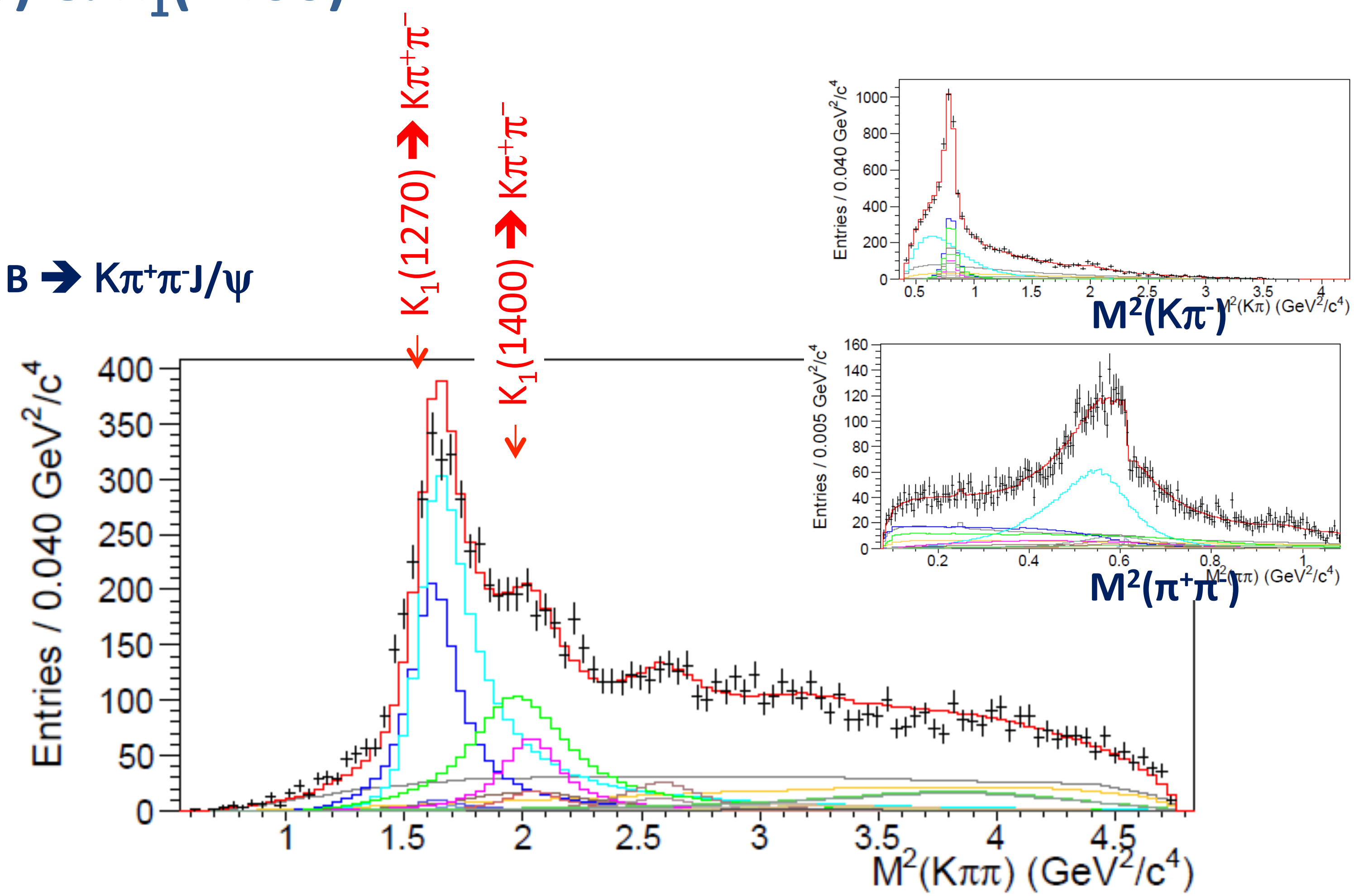
Fig. 2. The $\gamma\rho$ invariant mass distribution. The insert shows the full mass scale where the $\eta(958)$ is clearly observed.

BES Collaboration / Physics Letters B 594 (2004) 47–53

1^+ mesons with |S|=1

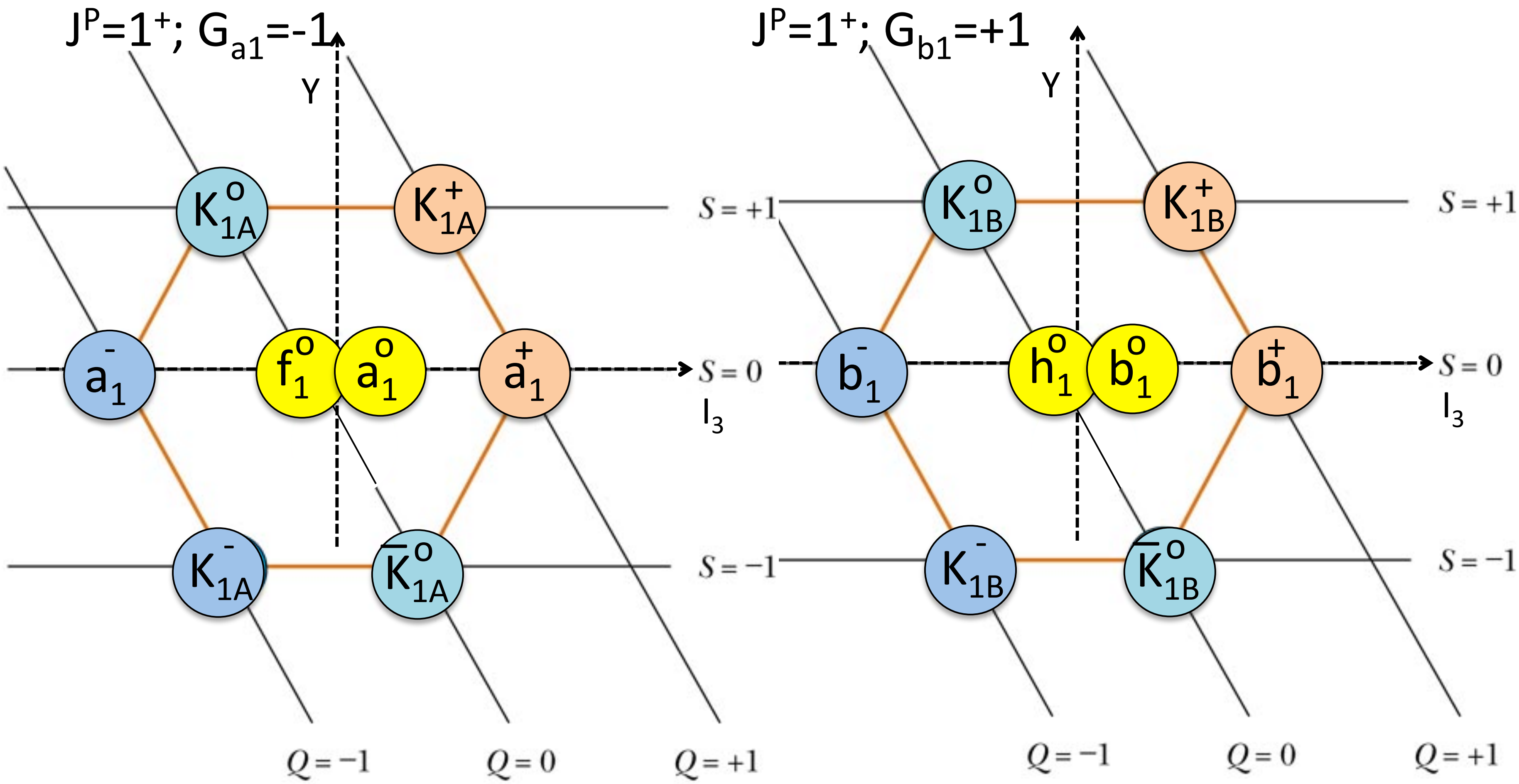
$K_1(1270) = \cos q_K\, K_{1A} + \sin q_K\, K_{1B}$
$K_1(1400) = \cos q_K\, K_{1B} - \sin q_K\, K_{1A}$

The $K_1(1270)$ & $K_1(1400)$



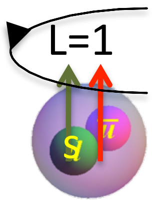
H. Guler et al. (Belle) PRD 83, 032005 (2011)

Axial Vector ($J^P=1^+$) octets

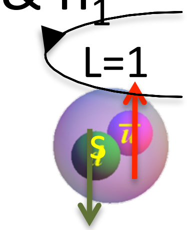


What are the K_{1A} and K_{1B} mesons?

The K_{1A} mesons are the |S|=1 octet partners of the a_1 & f_1



The K_{1B} mesons are the |S|=1 octet partners of the b_1 & h_1



these differ by C- and G-parity

➔ C- and G-parity do not apply to strange mesons

➔ only SU(3) quantum numbers distinguish K_{1A} from K_{1B}, but SU(3) is badly broken

➔ K_{1A} and K_{1B} mix

$$\begin{pmatrix} K_1(1400) \\ K_2(1270) \end{pmatrix} = \begin{pmatrix} \cos\theta_K & -\sin\theta_K \\ \sin\theta_K & \cos\theta_K \end{pmatrix} \begin{pmatrix} K_{1A} \\ K_{1B} \end{pmatrix},$$

some model-dependent analysis of K_{1A} & K1B masses and decay widths estimate the "strange axial-vector mixing angle, θ_K, to be:

$$\theta_K \approx 60^o$$

see, e.g., Eur. Phys. J A28,369 (2006)

$K_1(1270)$ and $K_1(1400)$

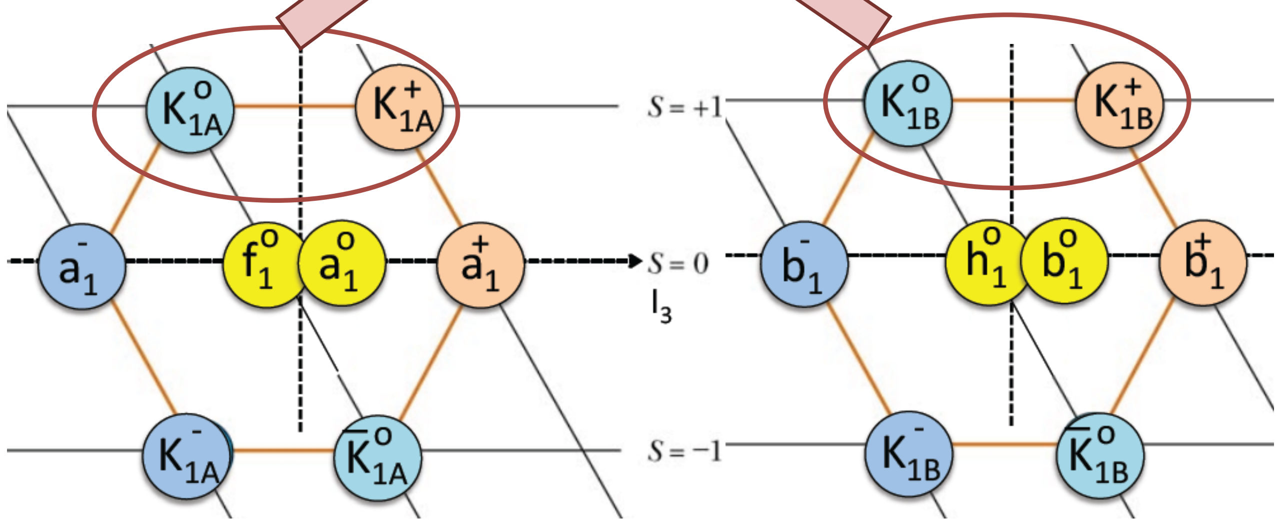
$K_1(1400)$ decays

$K^*(892)\pi$	(94 ±6) %
$K\rho$	(3.0±3.0) %
$K f_0(1370)$	(2.0±2.0) %
$K\omega$	(1.0±1.0) %

$K_1(1270)$ decays

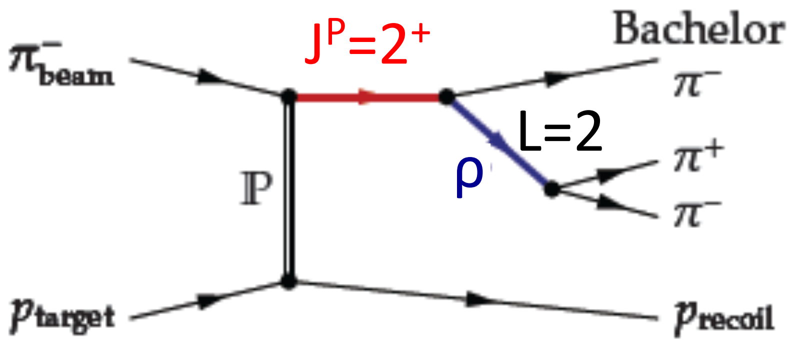
Γ_1	$K\rho$	(42 ±6) %
Γ_2	$K_0^*(1430)\pi$	(28 ±4) %
Γ_3	$K^*(892)\pi$	(16 ±5) %
Γ_4	$K\omega$	(11.0±2.0) %

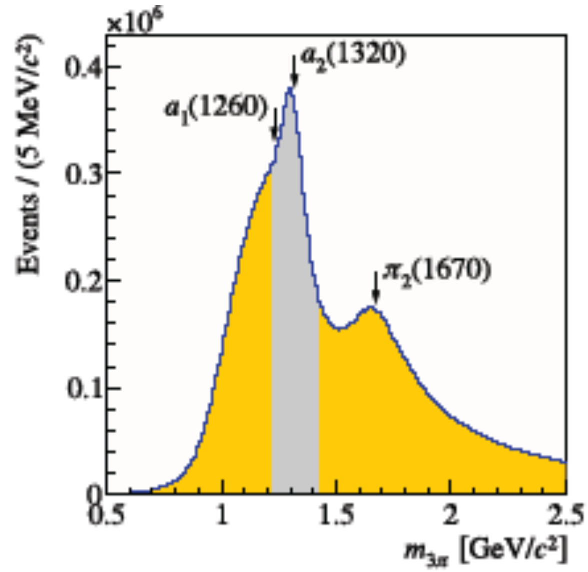
$$\begin{pmatrix}K_1(1400)\\ K_2(1270)\end{pmatrix} = \begin{pmatrix}\cos\theta_K & -\sin\theta_K\\ \sin\theta_K & \cos\theta_K\end{pmatrix}\begin{pmatrix}K_{1A}\\ K_{1B}\end{pmatrix},$$

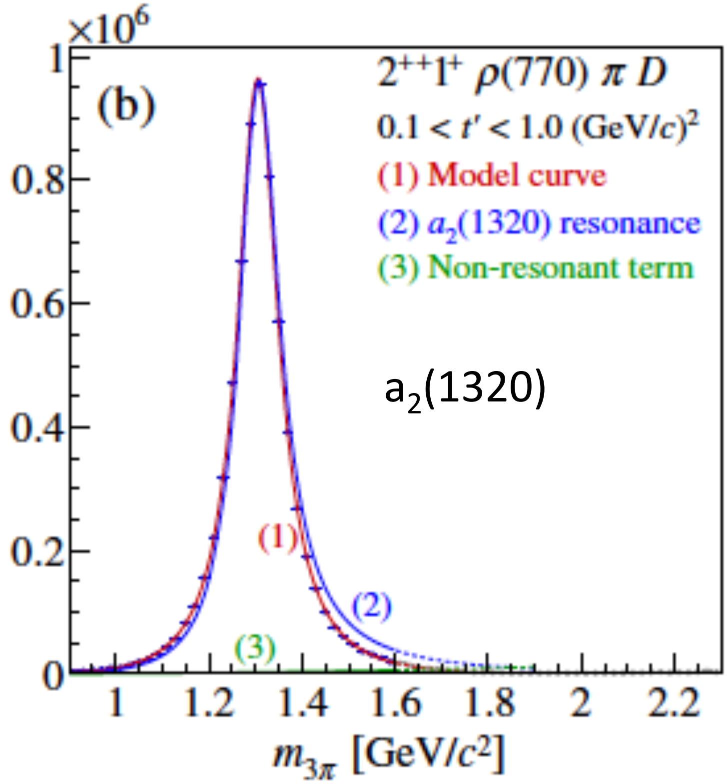


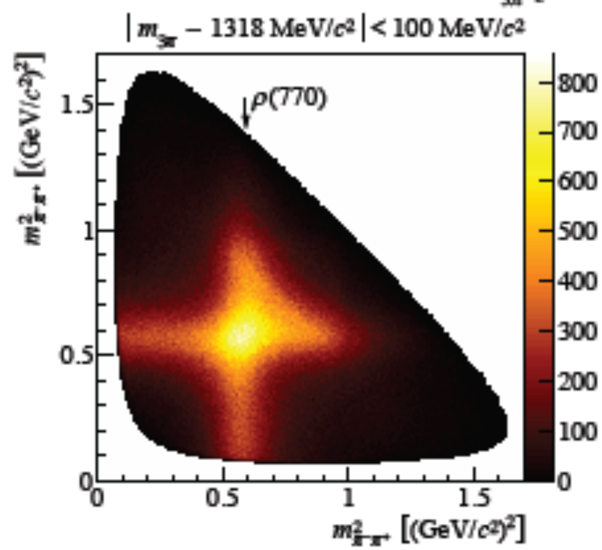
the J=0 and J=2 SU(3) partners of the $a_1(1270)$ octet

The $J^P=2^+$ $a_2(1320)\rightarrow\pi^-\rho^0$ meson

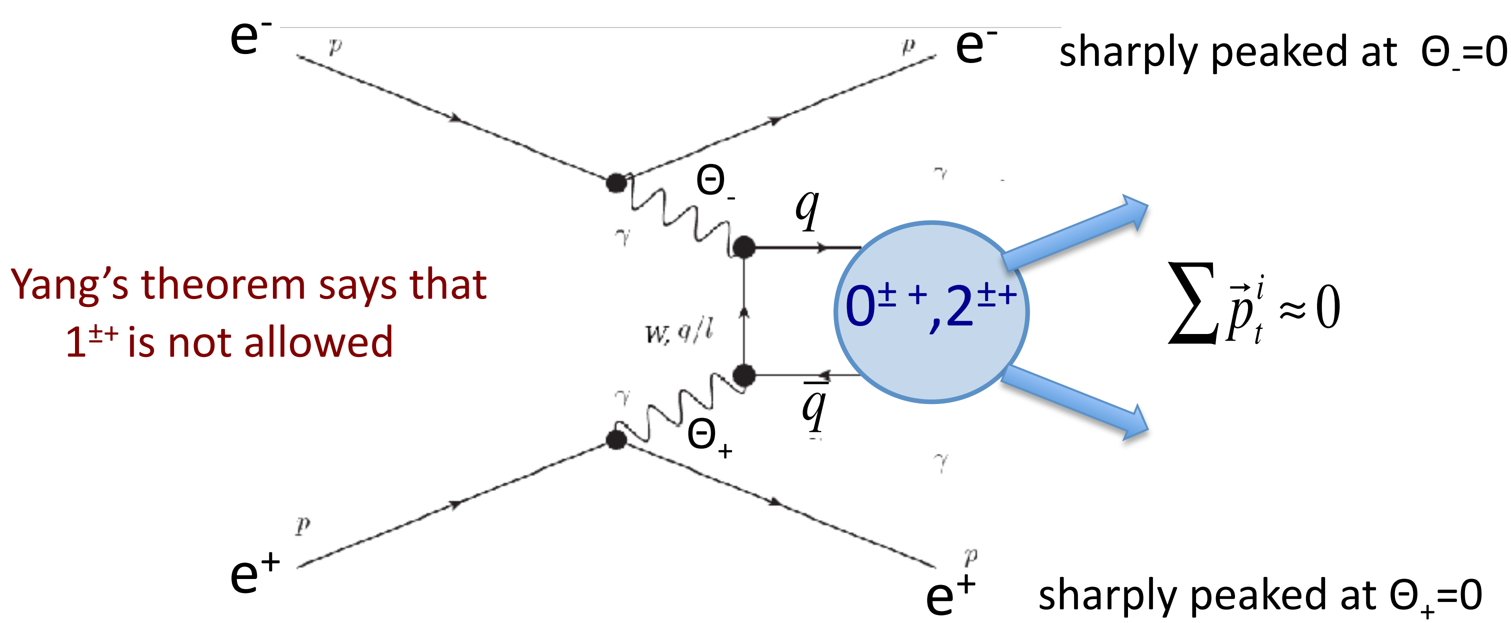








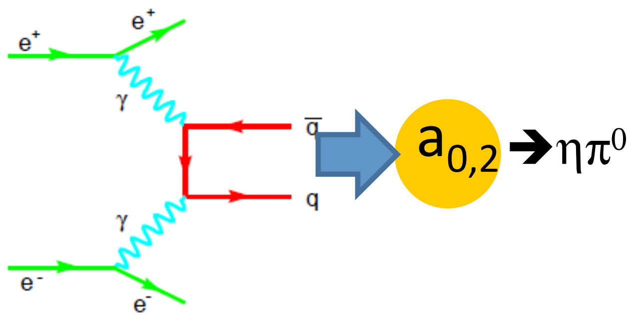
two-photon reactions

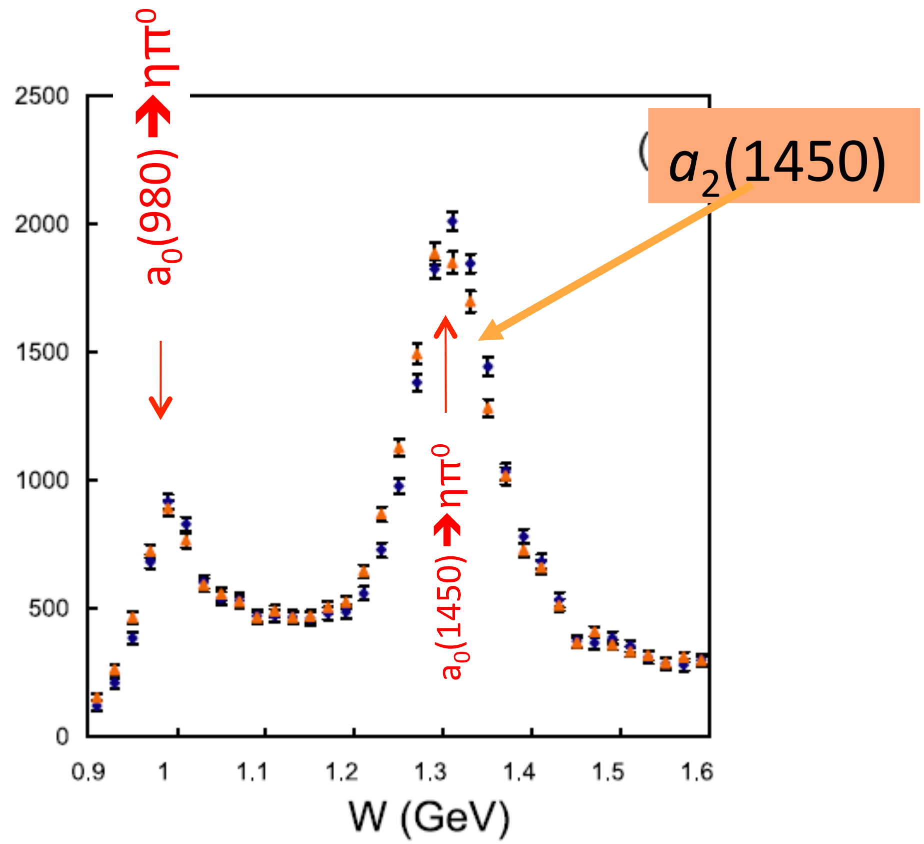


For almost "real" photons, Θ_- and $\Theta_+ \approx 0$, the scattered e^- and e^+ are very forward and remain in the beam pipe. The produced particles have a net transverse momentum of zero. production of 0^{++} and 2^{++} is favored although 0^{-+} and 2^{-+} are also allowed.

$a_0(980)$ and $a_0(1450)$ ➔ $\eta\pi$

$\gamma\gamma$➔$\eta\pi^0$ Belle

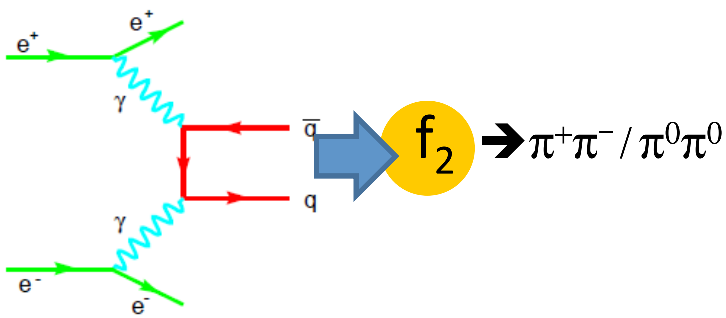


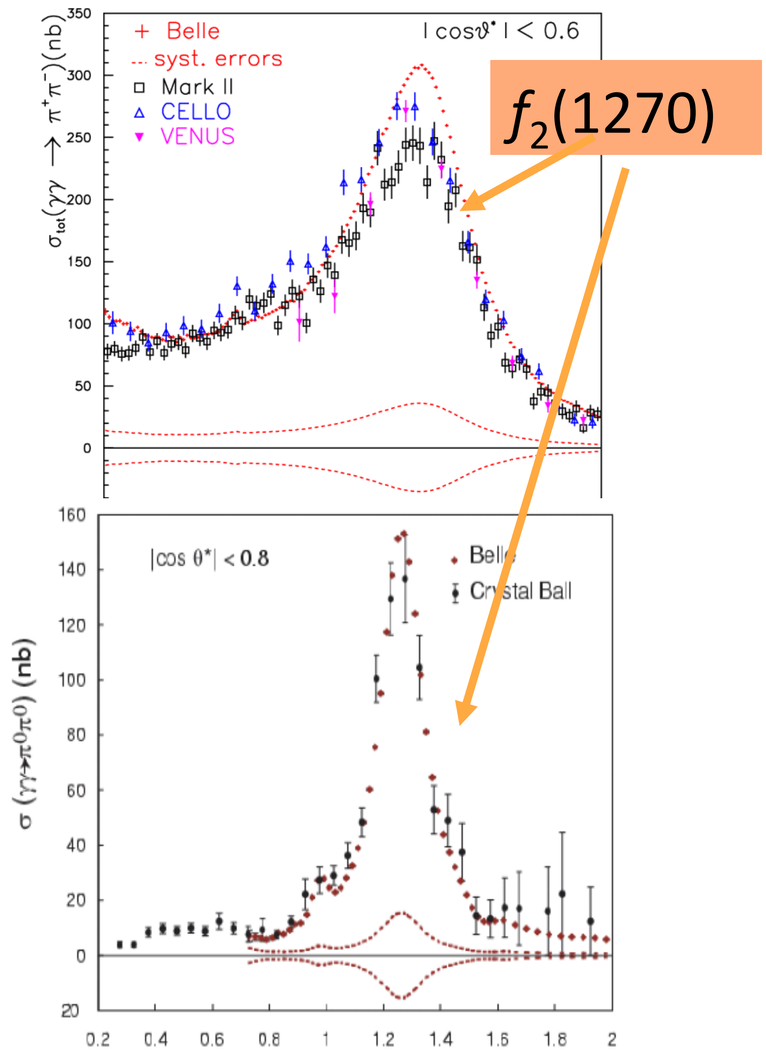


PHYSICAL REVIEW D **80,** 032001 (2009)

$\gamma\gamma \rightarrow f_2(1270) \rightarrow \pi^+\pi^- / \pi^0\pi^0$

$\gamma\gamma \rightarrow \pi^+\pi^- / \pi^0\pi^0$ at Belle



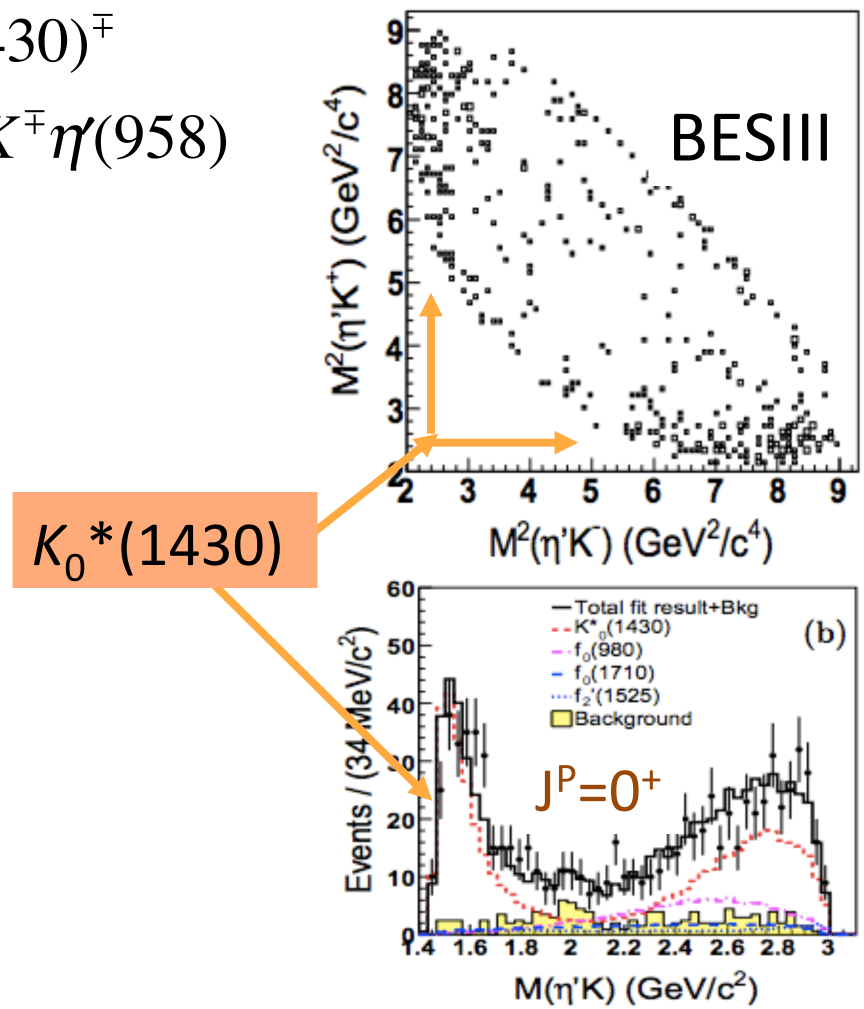


$K_0^*(1430)^\pm \to K^\pm \eta'(958)$

$J/\psi \to \gamma\chi_{c1}(1P)$

└→ $K^\pm K_0^*(1430)^\mp$

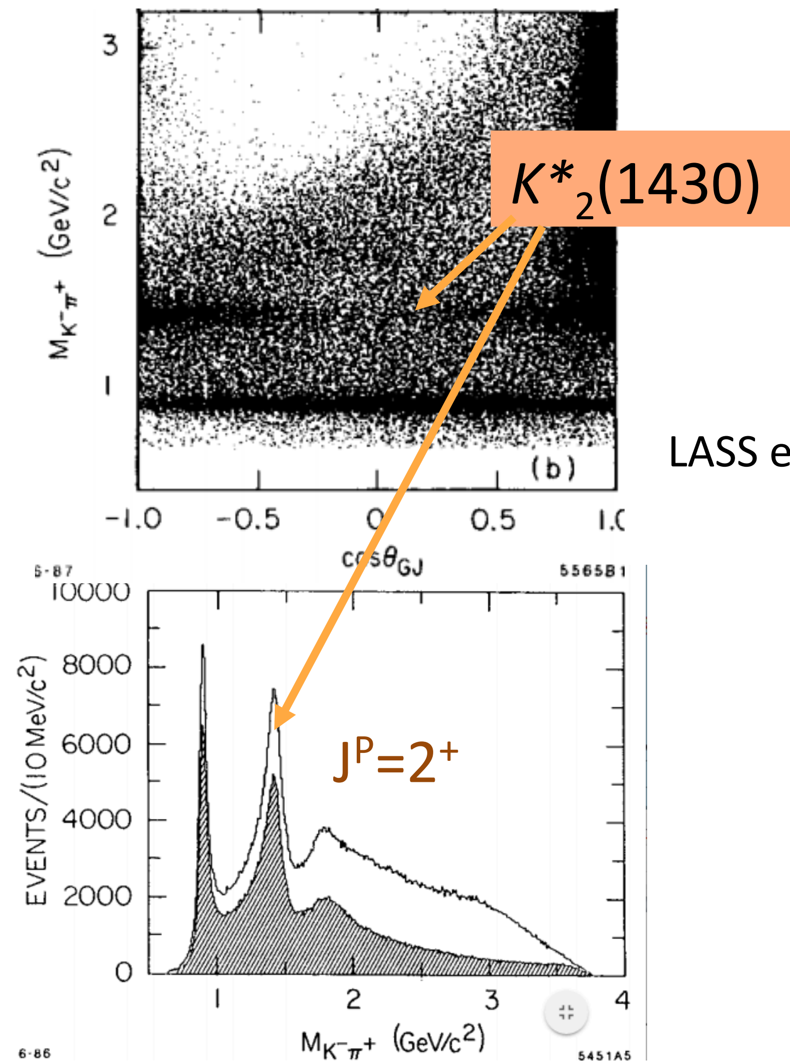
└→ $K^\mp \eta'(958)$



Phys.Rev. D89, 074030 (2014)

$K_2^*(1430) \rightarrow K\pi$

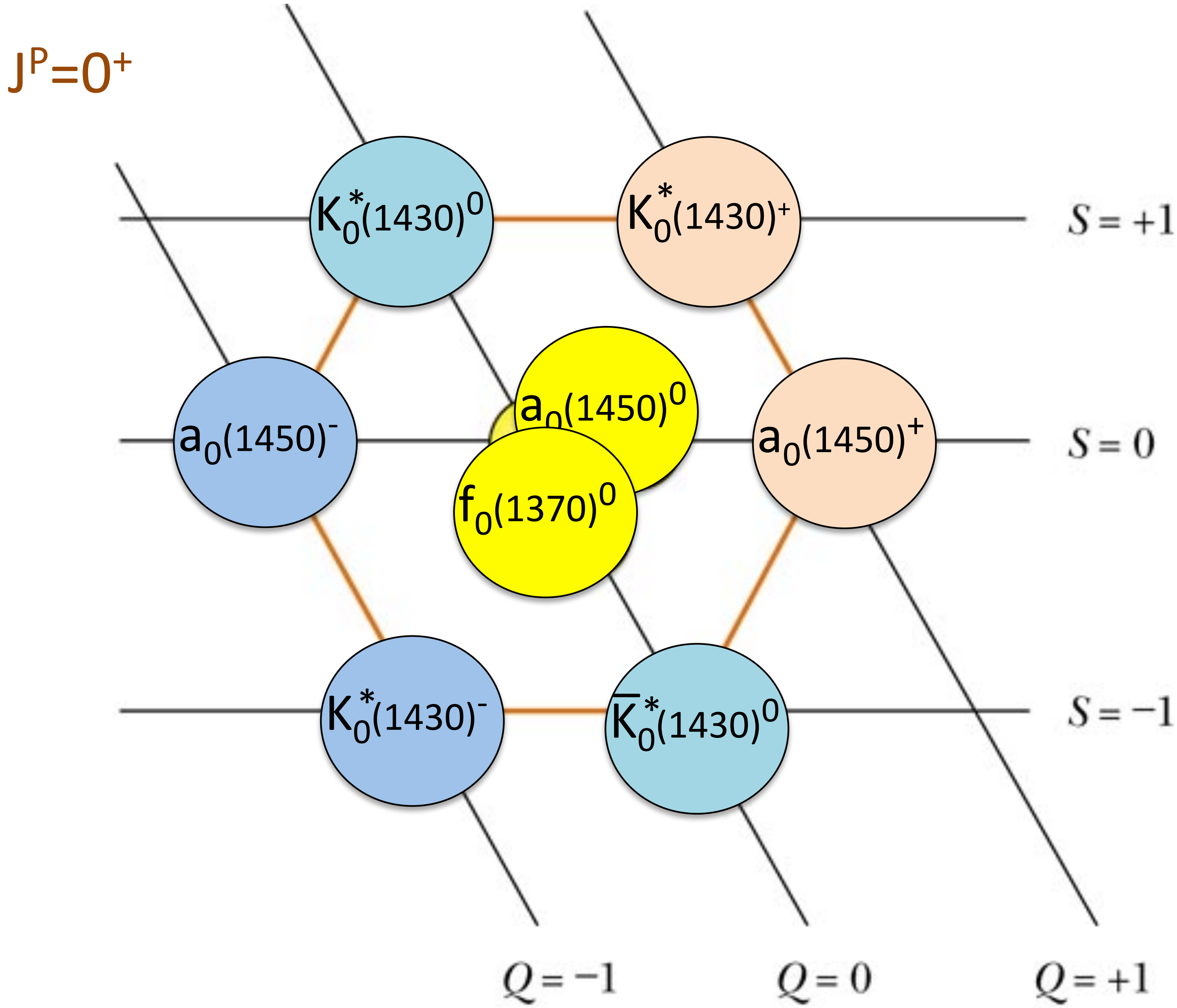
$$\gamma p \rightarrow K^{\pm} K_2^*(1430)^{\mp} p$$
$$\hookrightarrow K^{\mp}\pi^0$$



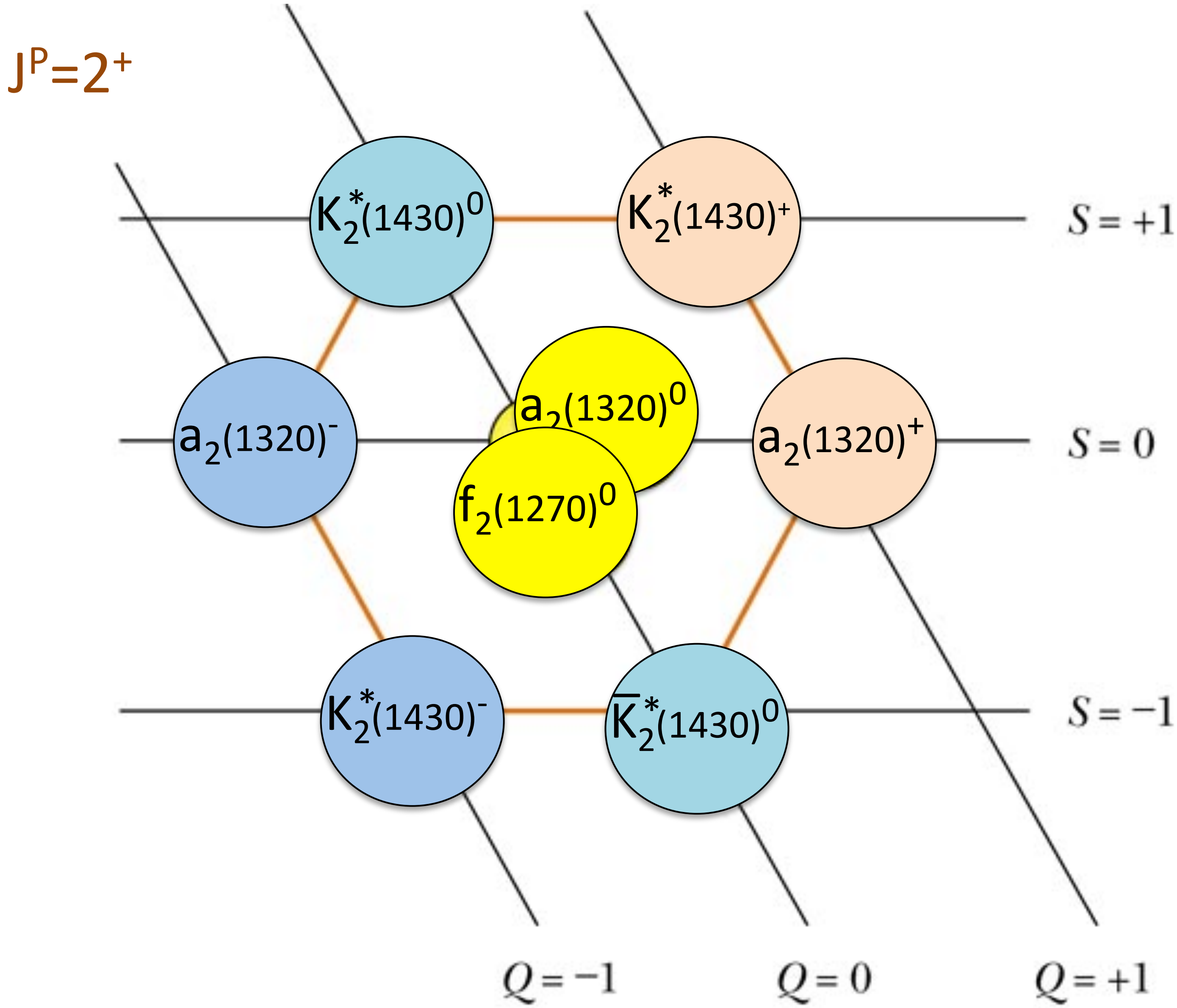
LASS expt (at SLAC)

Nucl.Phys. B296, 493 (1988)

The scalar P-wave octet

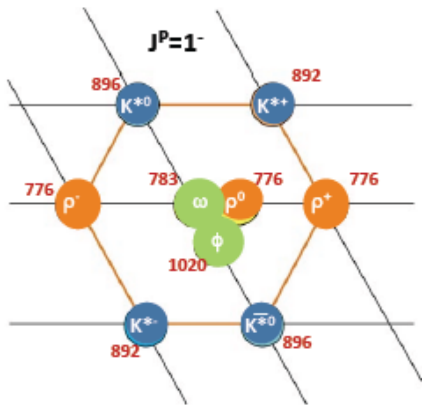


The tensor P-wave octet

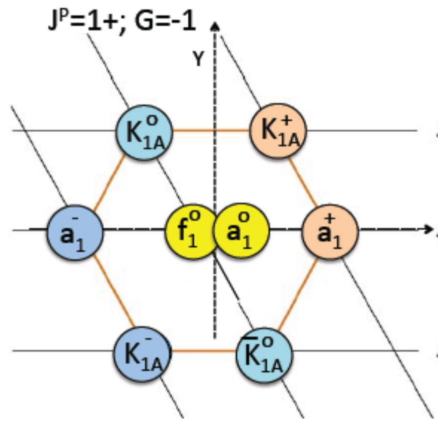


Some features of the P-wave states

S-Wave



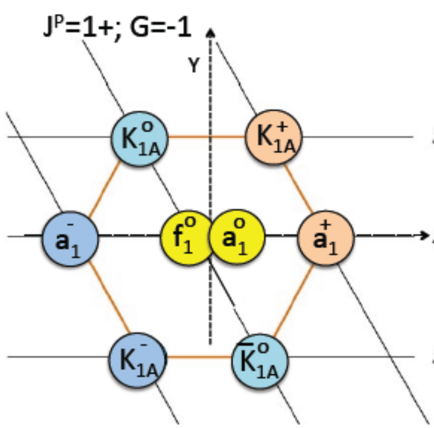
P-Wave



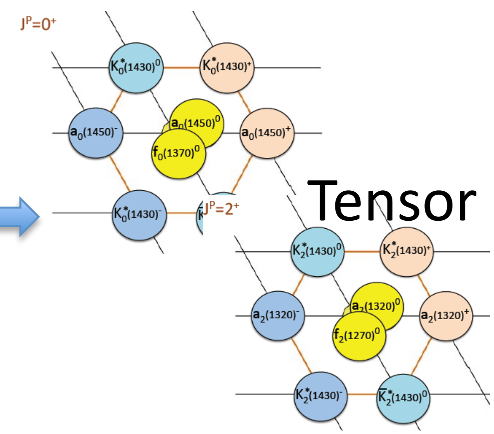
ΔM ≈ +400~500 MeV

S→P costs about 500MeV

Axial Vector

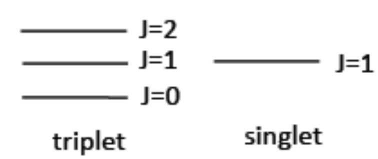


Scalar



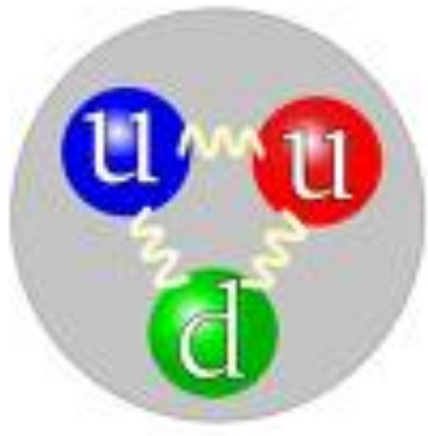
δM ≈ 100~200 MeV

S=1 S=0



splitting between same L states is ~100MeV

Excited baryons



$$\text{QM: } E = (2(n_r - 1) + L + 3/2)\hbar\omega$$

radial excitation has 2× the energy from addition of one unit of L

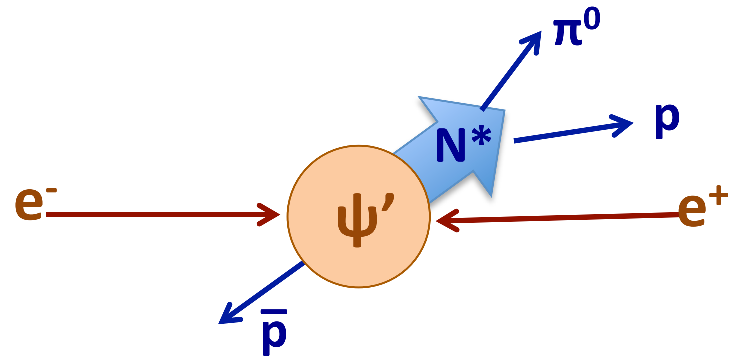
$\psi'(3686) \rightarrow \bar{p}p\pi^0$ at BESIII

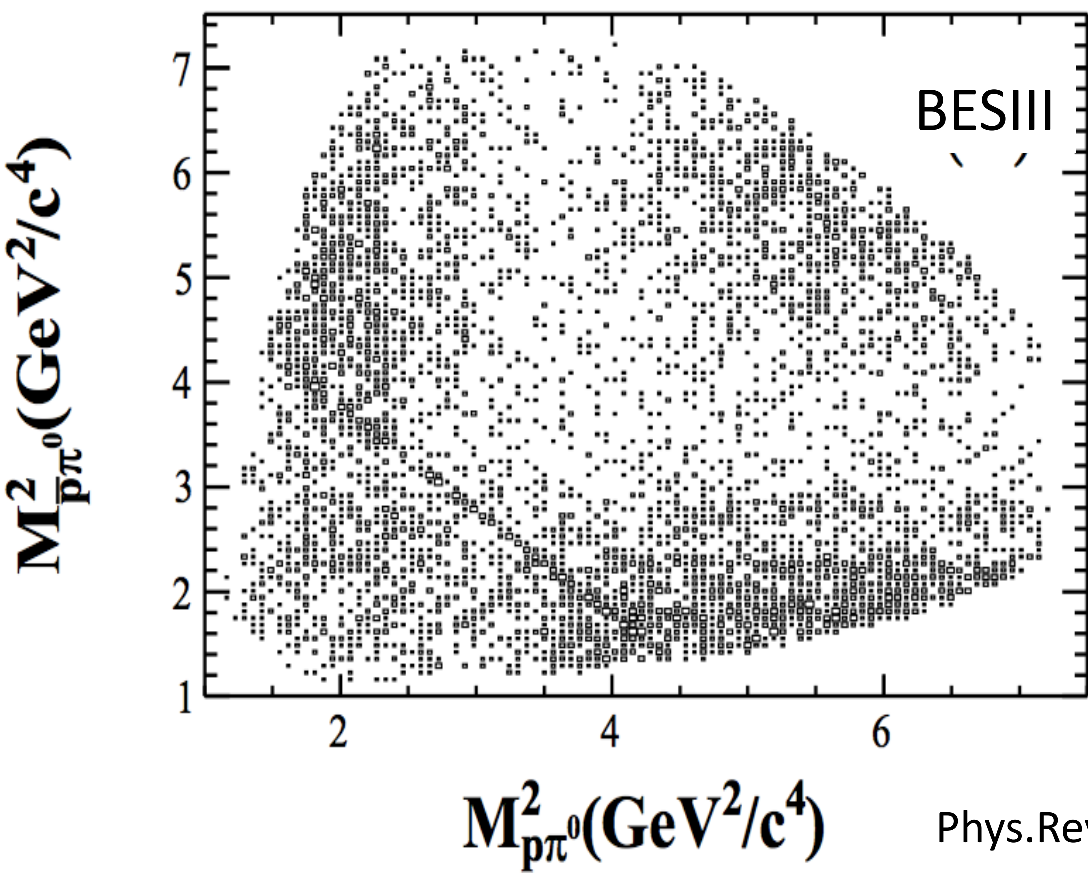
Ispin=½ filter

$\psi' \rightarrow \bar{p}\ N^*$

I=0 I=½

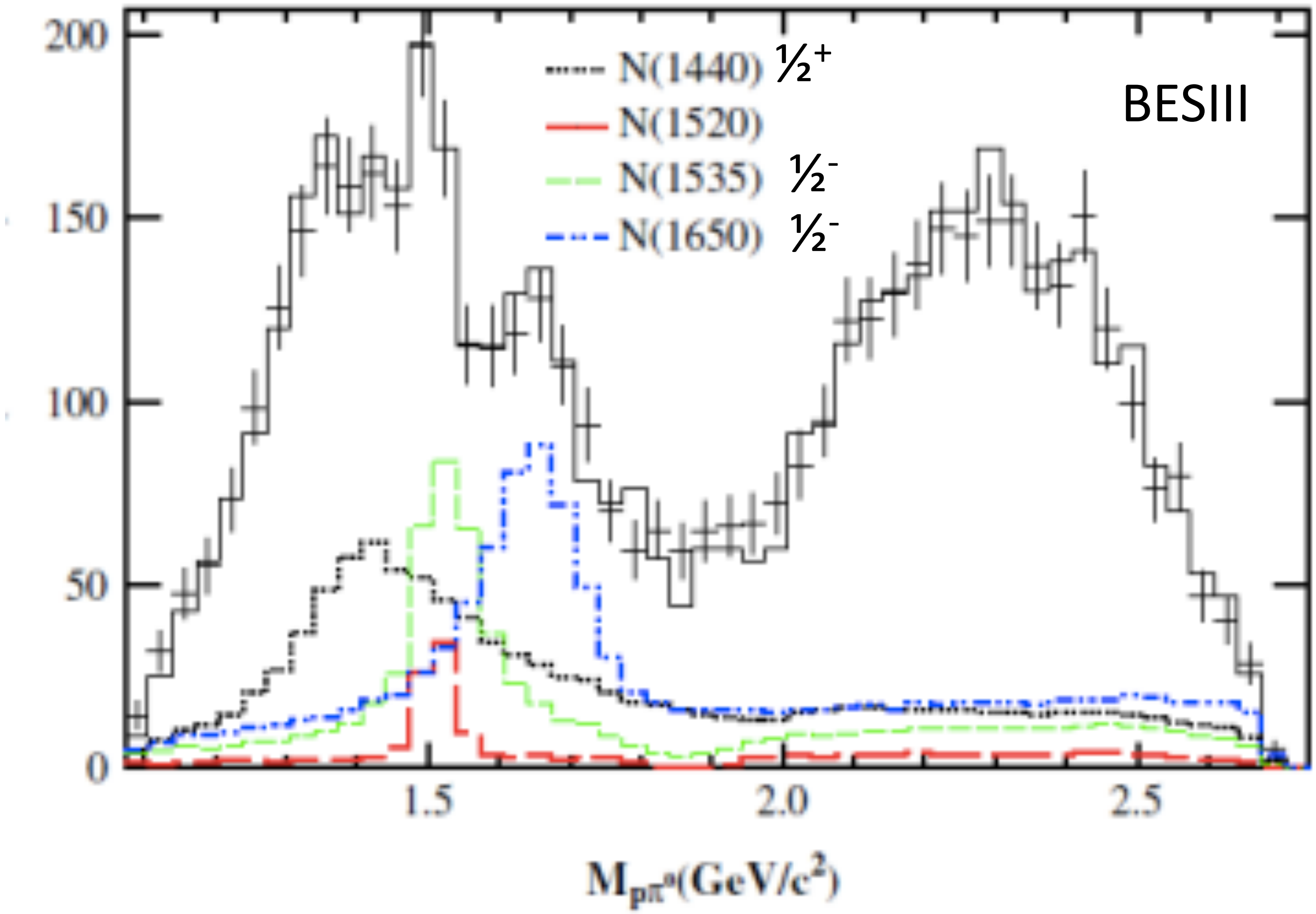
I(N*) must be ½



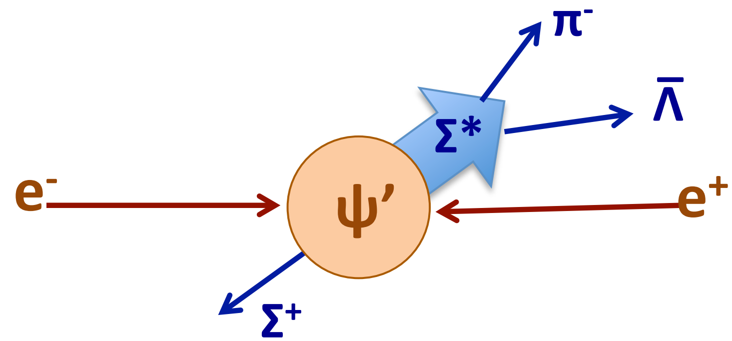


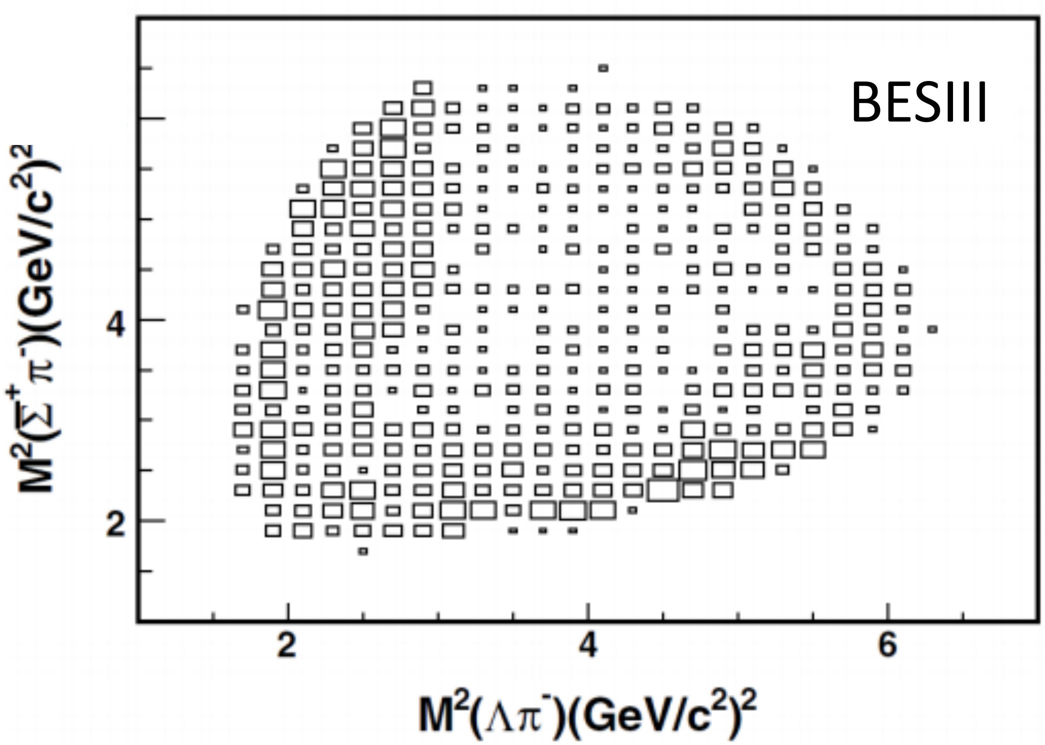
Phys.Rev.Lett. 110, 02001 (2013)

Excited nucleon states



$\psi'(3686) \rightarrow \bar{\Lambda}\Sigma^+\pi^-$ at BESIII

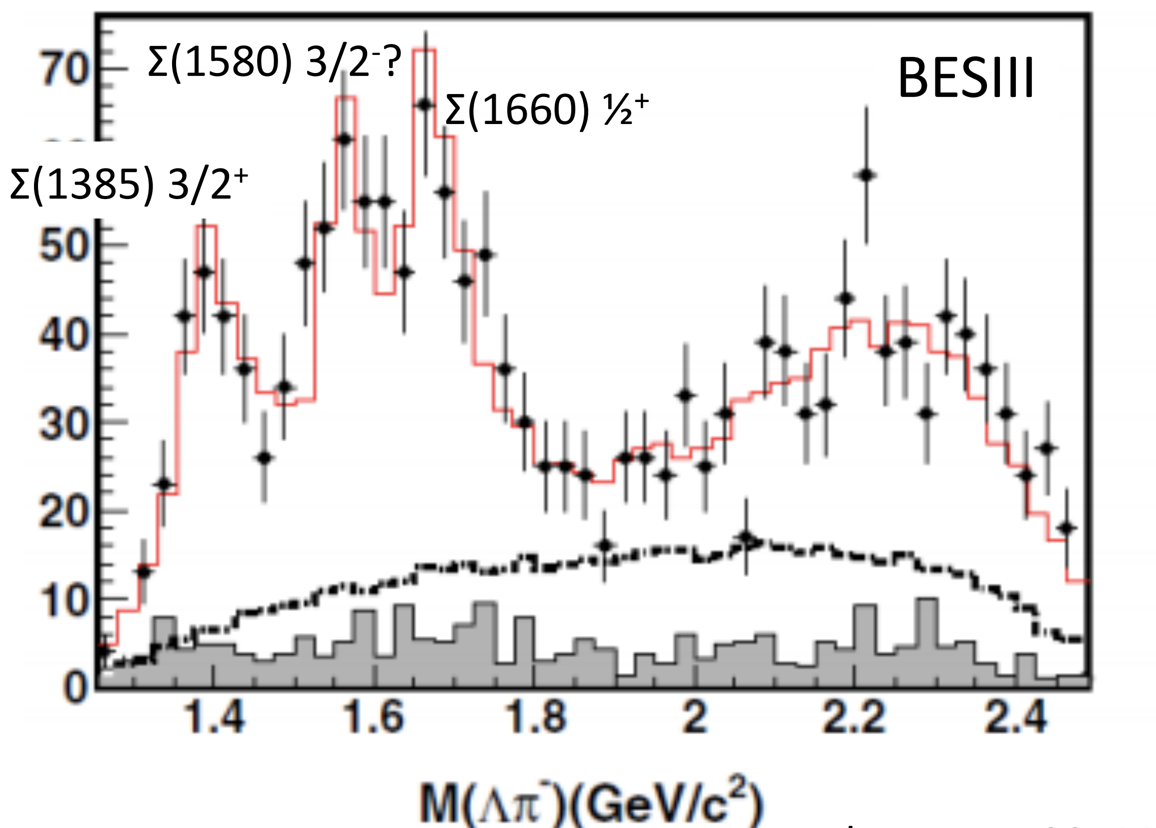




Phys.Rev. D88, 112007 (2013)

Excited Σ states

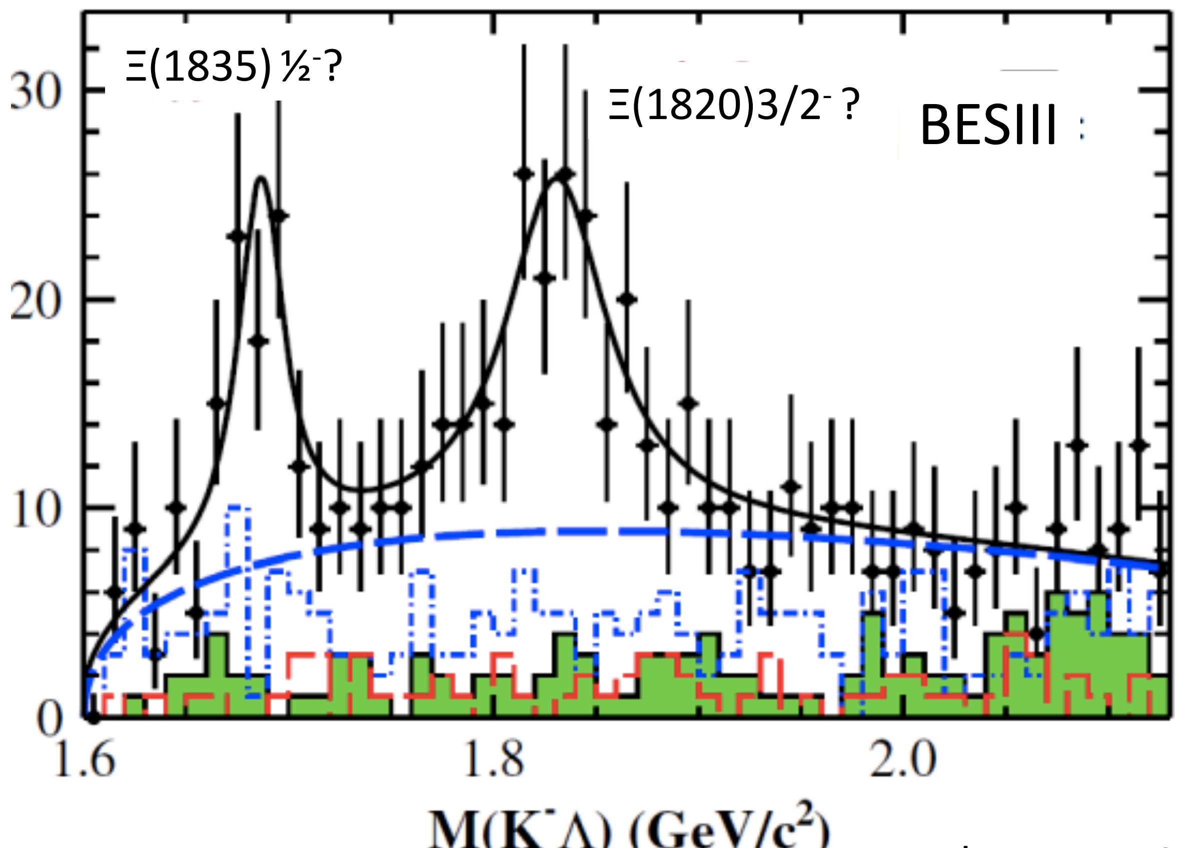
$$\psi' \to \Sigma^+ \overline{\Sigma}^*$$
$$\hookrightarrow \overline{\Lambda}\pi^-$$



Phys.Rev. D88, 112007 (2013)

exicited Ξ states

$$\psi' \rightarrow \overline{\Xi}^{+}\Xi^{*-}$$
$$\quad\quad\quad\quad \hookrightarrow K^{-}\Lambda$$

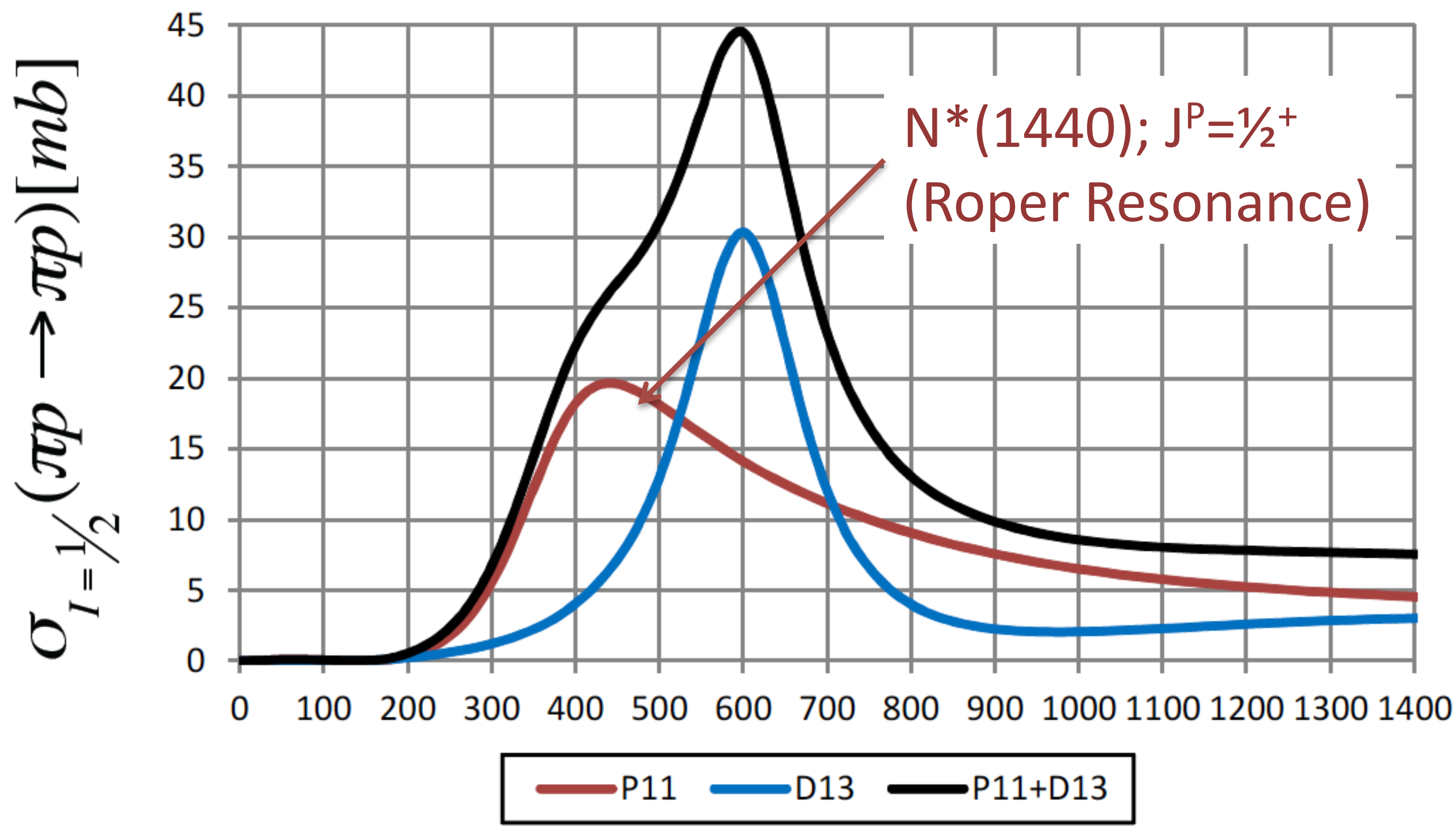


Phys.Rev. D91, 092006 (2015)

Problems with excited Baryons

1st excited nucleon (I=½) state

-- The “Roper” resonance --

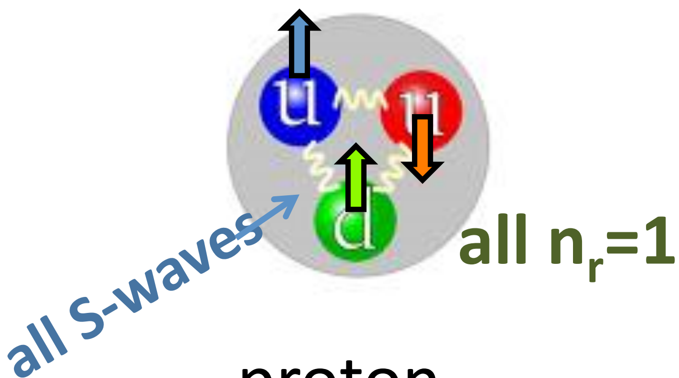


L. David Roper’s
MIT PhD Thesis
in 1964

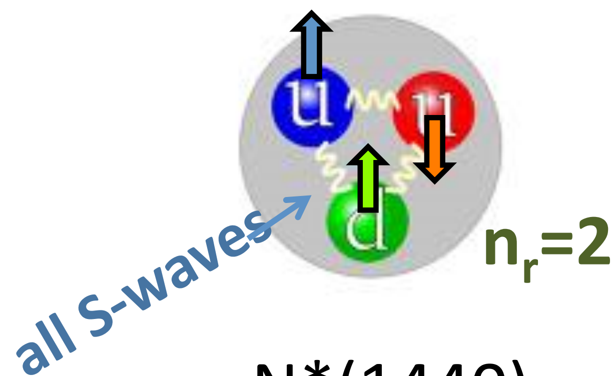
L. D. Roper PRL 12, 340 (1964)

N*(1440) in the qqq model

N*(1440); $J^P=½^+$ ➔ same spin-parity as proton



proton



N*(1440)

Minimal excitation that conserves J^P : n_r=0 → n_r=1

1st excited Λ predicted in 1959

--pre SU(3); pre quarks--

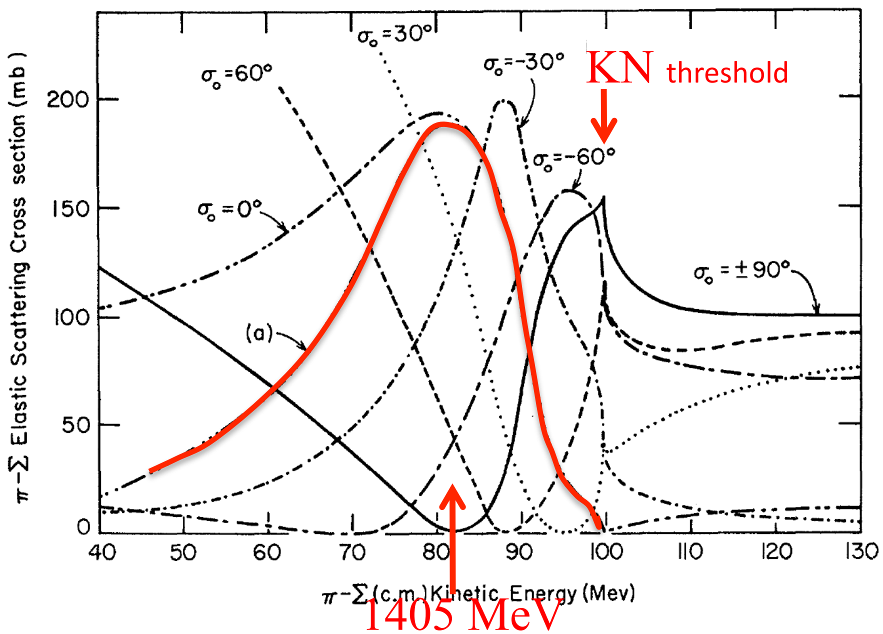
1959!!

VOLUME 2, NUMBER 10 pg 425 PHYSICAL REVIEW LETTERS MAY 15, 1959

POSSIBLE RESONANT STATE IN PION-HYPERON SCATTERING*

R. H. Dalitz and S. F. Tuan
Enrico Fermi Institute for Nuclear Studies and Department of Physics,
University of Chicago, Chicago, Illinois
(Received April 27, 1959)

Analytic continuation of KN data → below KN threshold



Predicted a πΣ resonance @ 1405

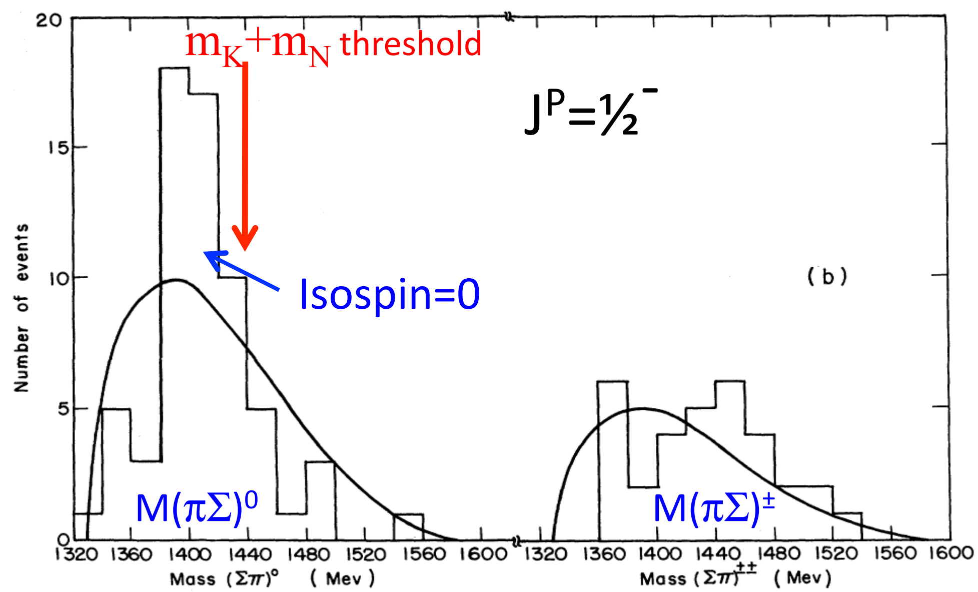
$\Lambda(1405)$ discovered in 1961

VOLUME 6, NUMBER 12 pg 698 PHYSICAL REVIEW LETTERS JUNE 15, 1961

STUDY OF RESONANCES OF THE Σ-π SYSTEM*

Margaret H. Alston, Luis W. Alvarez, Philippe Eberhard,† Myron L. Good,‡
William Graziano, Harold K. Ticho,‖ and Stanley G. Wojcicki
Lawrence Radiation Laboratory and Department of Physics, University of California, Berkeley, California
(Received May 8, 1961; revised manuscript received May 31, 1961)

$$K^- + p \rightarrow \Sigma^+ + \pi^- + \pi^- + \pi^+,$$
$$K^- + p \rightarrow \Sigma^- + \pi^+ + \pi^+ + \pi^-,$$
$$K^- + p \rightarrow \Sigma^0 + \pi^0 + \pi^+ + \pi^-.$$

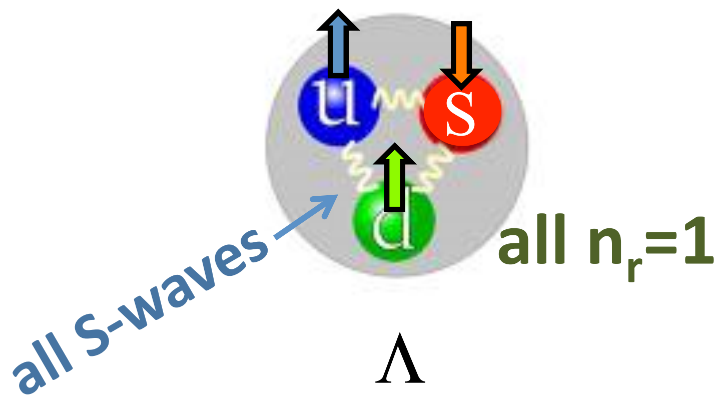


its peak corresponds to a mass of 1405 Mev, and its full width at half maximum is about 20 Mev after unfolding experimental errors.

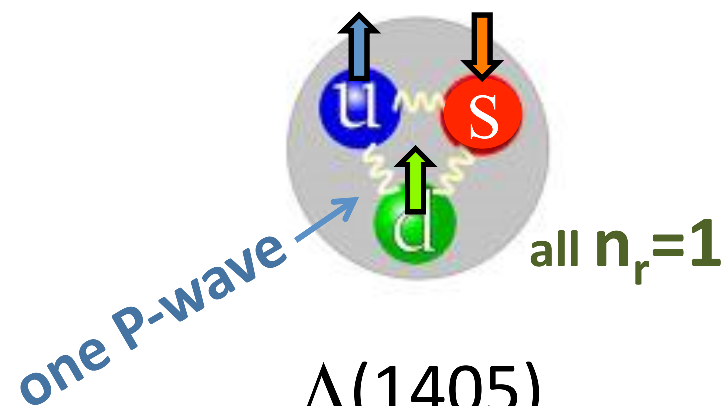
[9]R. Dalitz and S. F. Tuan, Phys. Rev. Letters 2, 425 (1959).

Λ(1405) in the qqq model

Λ(1405); J^P=½$^-$ ➔ same spin, *opposite*-parity as Λ



Λ



Λ(1405)

Minimal excitation that conserves J^P: L=0 → L=1

Λ(1405) discovered in 1961

VOLUME 6, NUMBER 12 pg 698 PHYSICAL REVIEW LETTERS JUNE 15, 1961

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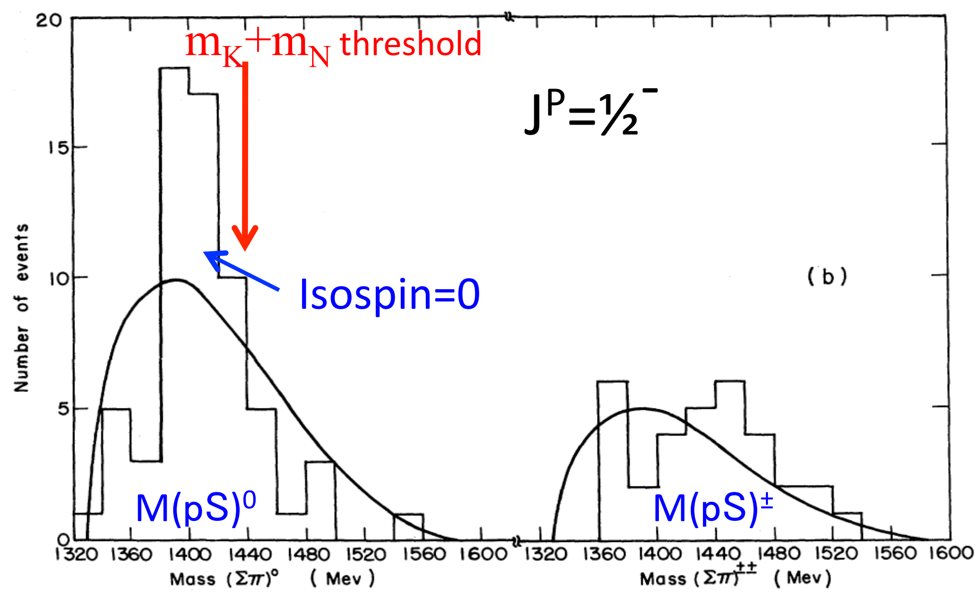

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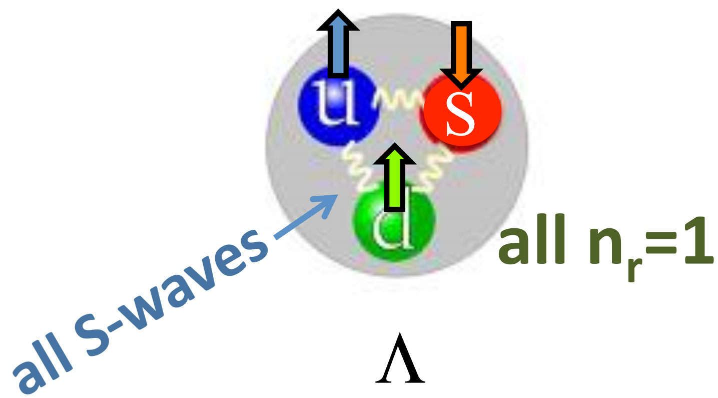
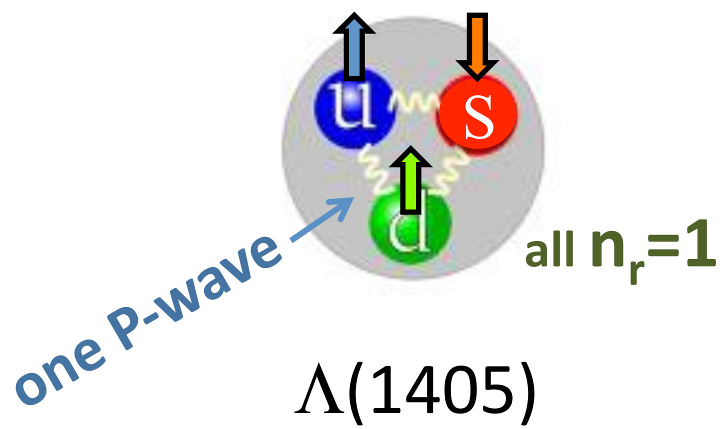
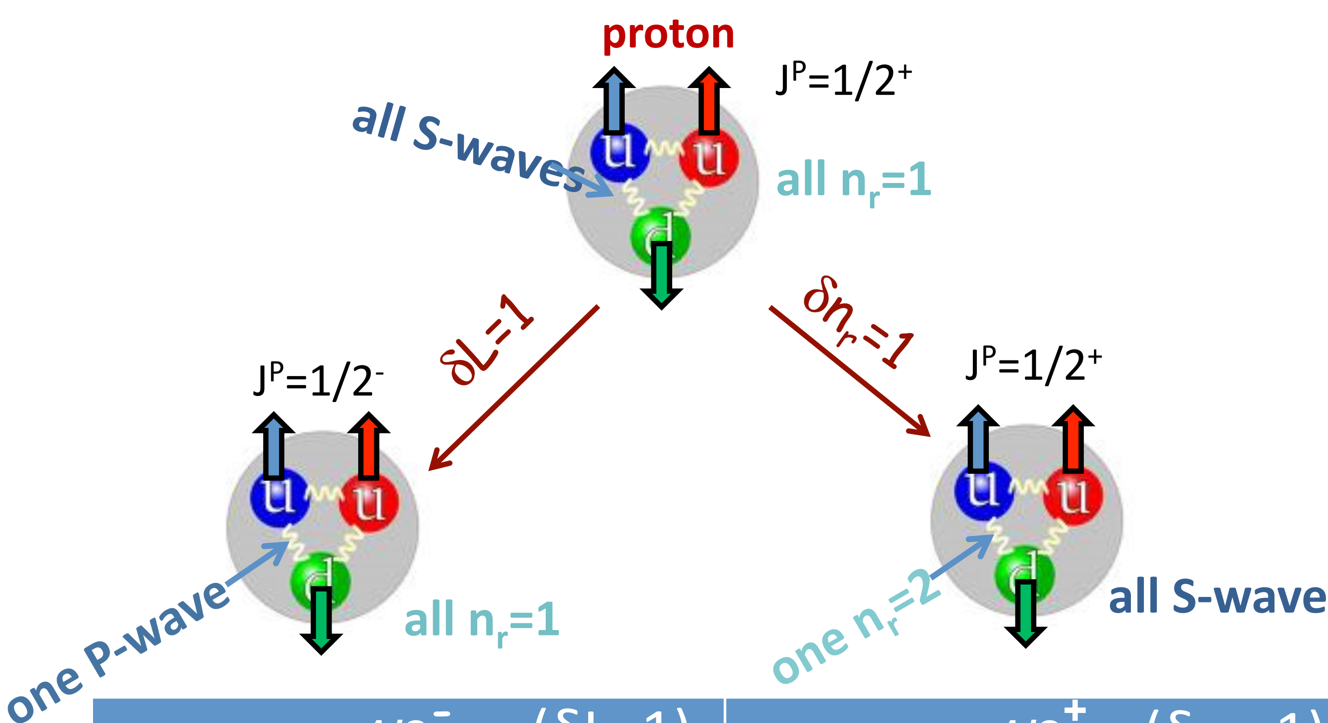




Minimal excitation that conserves J^P: L=0 → L=1

excited baryon octets?

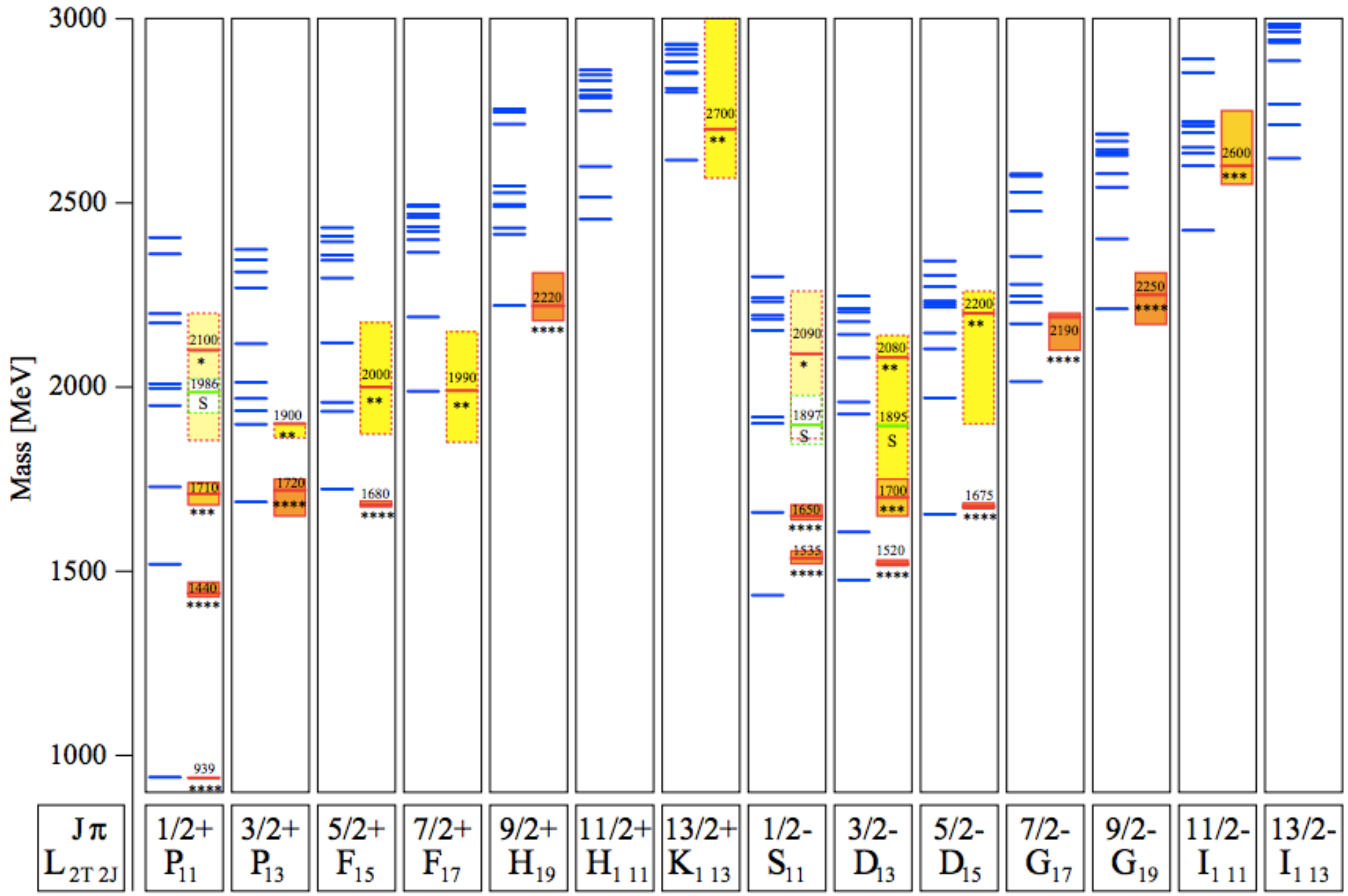


	$1/2^-$ (δL=1)		$1/2^+$ (δn_r=1)	
ΔE=595 MeV	N*(1535)	???	N*(1440)	ΔE=500 MeV
	Λ(1405) ???		Λ(1620)	
	Σ(1580) ???		Σ(1660)	
	Ξ(?)		Ξ(?)	

ΔE for δn_r=1 should be 2x ΔE for δL=1

“Missing” baryon states

Eur.Phys.J. A!0, 395 (2010)



Predicted I=1/2, S=0 states

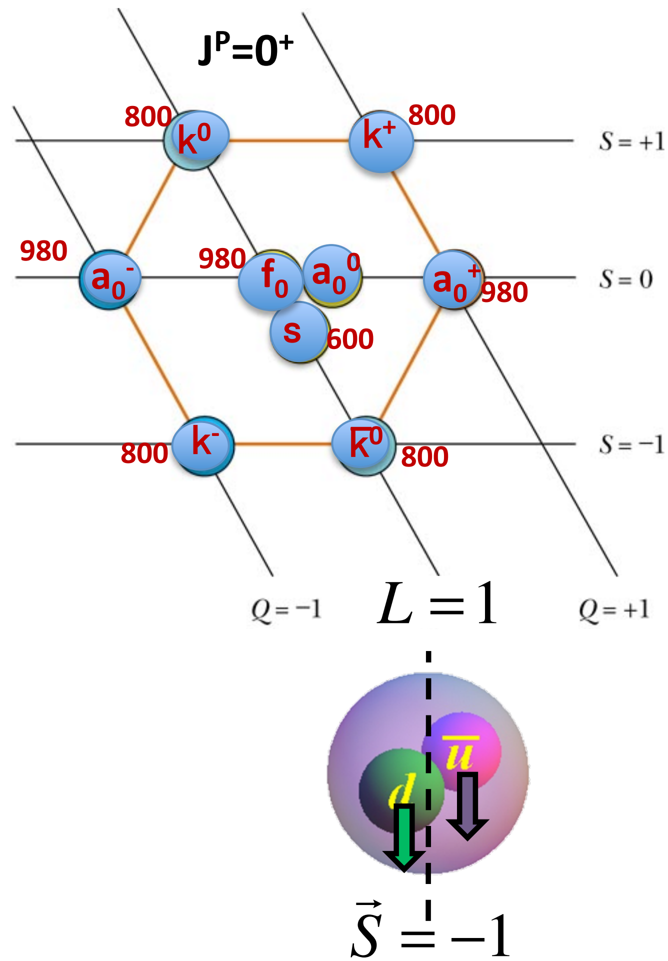
Observed: uncertainty

*** quality

Problems with mesons

problem with low-mass scalar mesons

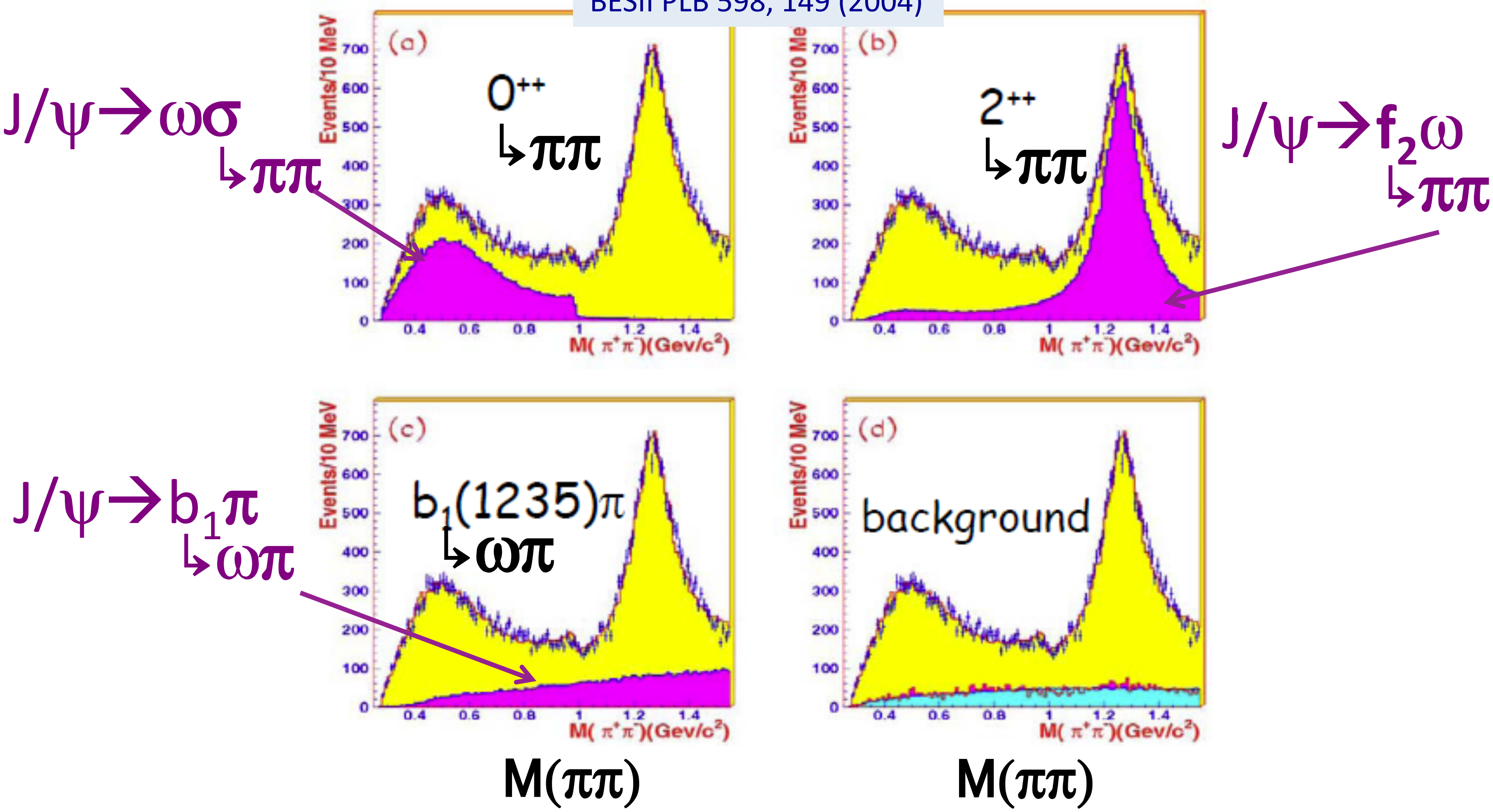
the “light” scalar-meson nonet



The $f_0(600)$ (the "σ")

From a Partial Wave Analysis of $J/y \to \omega\pi^+\pi^-$

BESII PLB 598, 149 (2004)

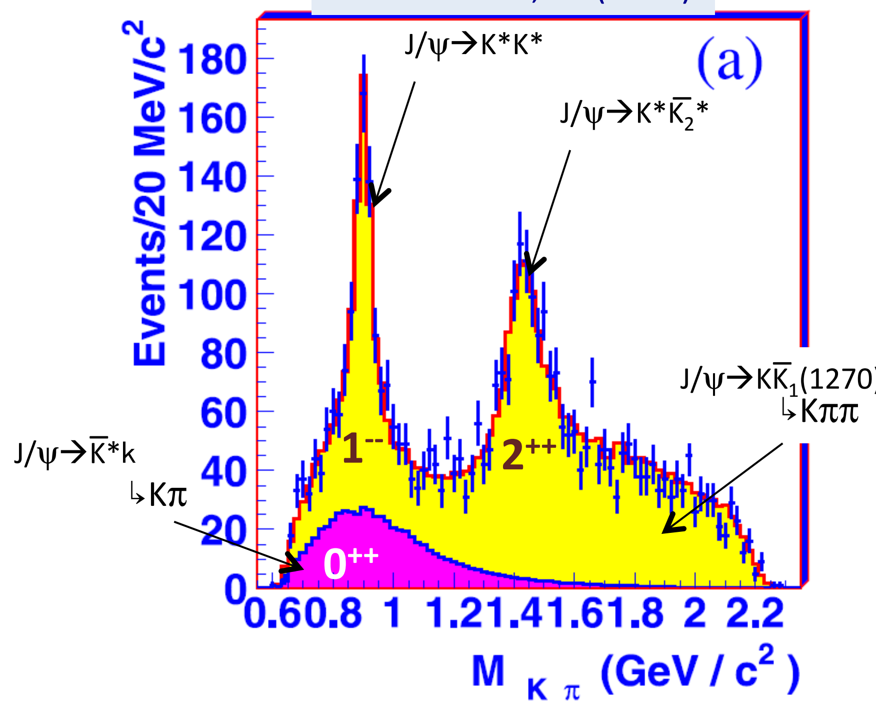


σ pole position: (541±39) – i(252±42) MeV

$K_0(800)^{\pm}$ (the "$\kappa^{\pm}$")

From a Partial Wave Analysis of $J/\psi \rightarrow K^+\pi^0 K_S \pi^-$
with either $M(K^+\pi^0)$ or $M(K_S\pi^-) = M(K^{*\pm}) \pm 80$ MeV

BESII PLB 693, 88 (2010)



κ pole position: $(849 \pm 77^{+18}_{-14}) - i(256 \pm 40^{+46}_{-22})$ MeV

$Bf(J/\psi \rightarrow K^{*+}\kappa^-) = 10 \pm 3 \times 10^{-4}$

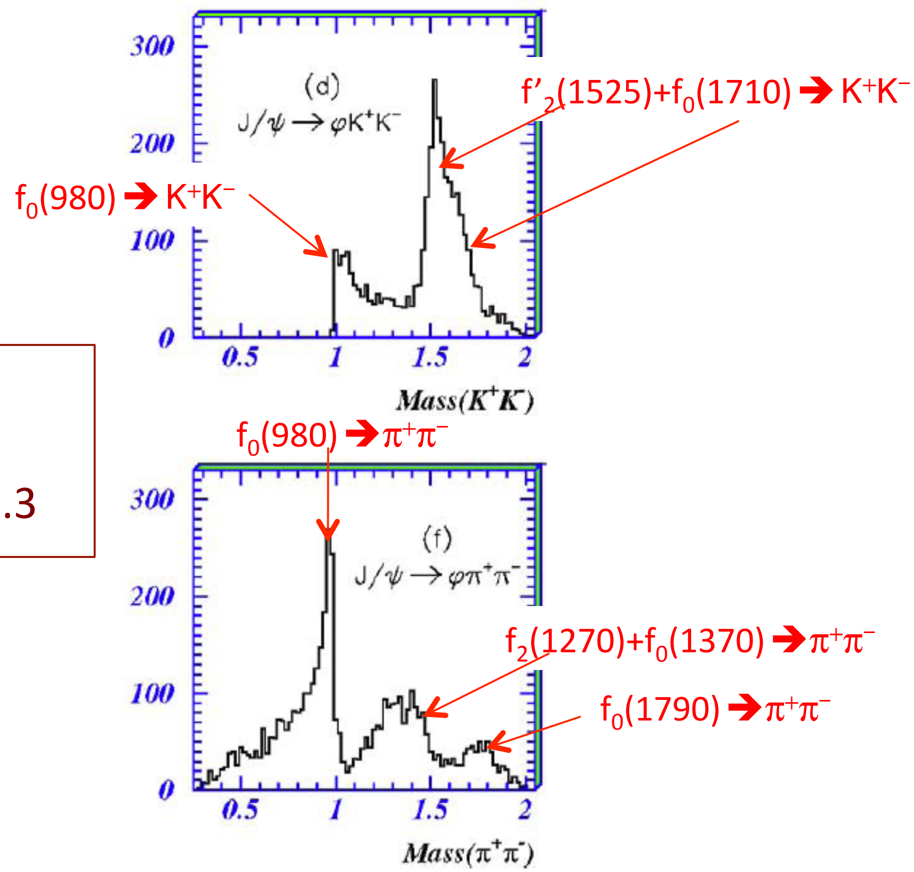
Signals for $f_0(980) \rightarrow \pi\pi$ & $\rightarrow K^+K^-$

Resonances in $J/\psi \rightarrow \phi\pi^+\pi^-$ and ϕK^+K^-

BESII PLB 607, 243 (2005)

strong $f_0(980)$ coupling to $K\bar{K}$

$$\frac{g_{KK}}{g_{\pi\pi}} = 4.2 \pm 0.3$$



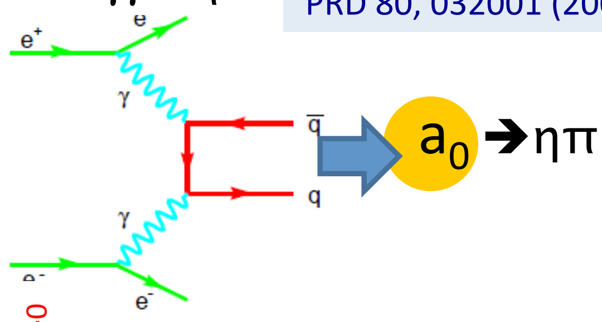
$Bf(J/\psi \rightarrow \phi f_0(980) = 0.32 \pm 0.09 \times 10^{-3}$

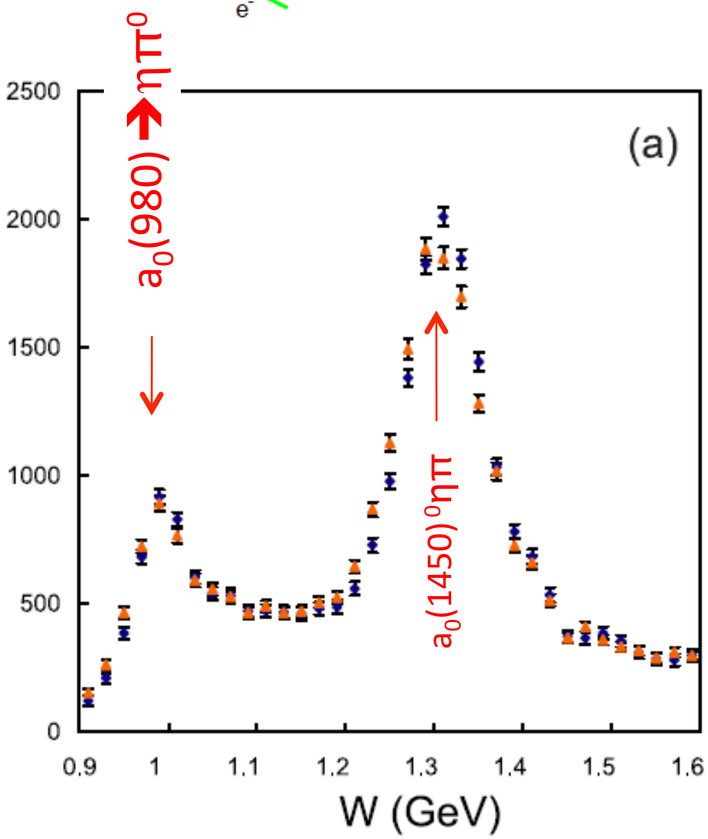
Signal for $a_0(980) \rightarrow \eta\pi$

Signal for $a_0(980) \rightarrow K^+K^-$

Belle Collab:
PRD 80, 032001 (2009)

$\gamma\gamma \rightarrow \eta\pi^0$

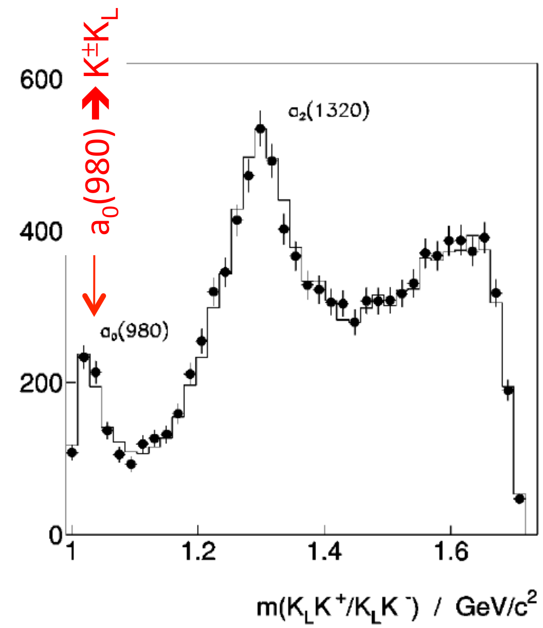


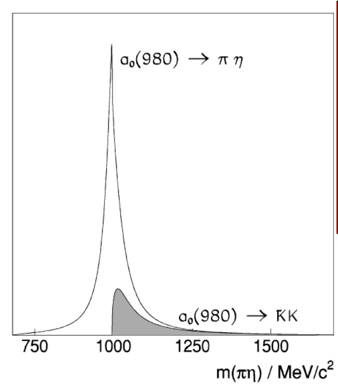


PHYSICAL REVIEW D **80**, 032001 (2009)

$\bar{p}p$ ANNIHILATION AT REST INTO $K_L K^{\pm} \pi^{\mp}$

Crystal Barrel Collab: PRD 57, 3860 (1998)

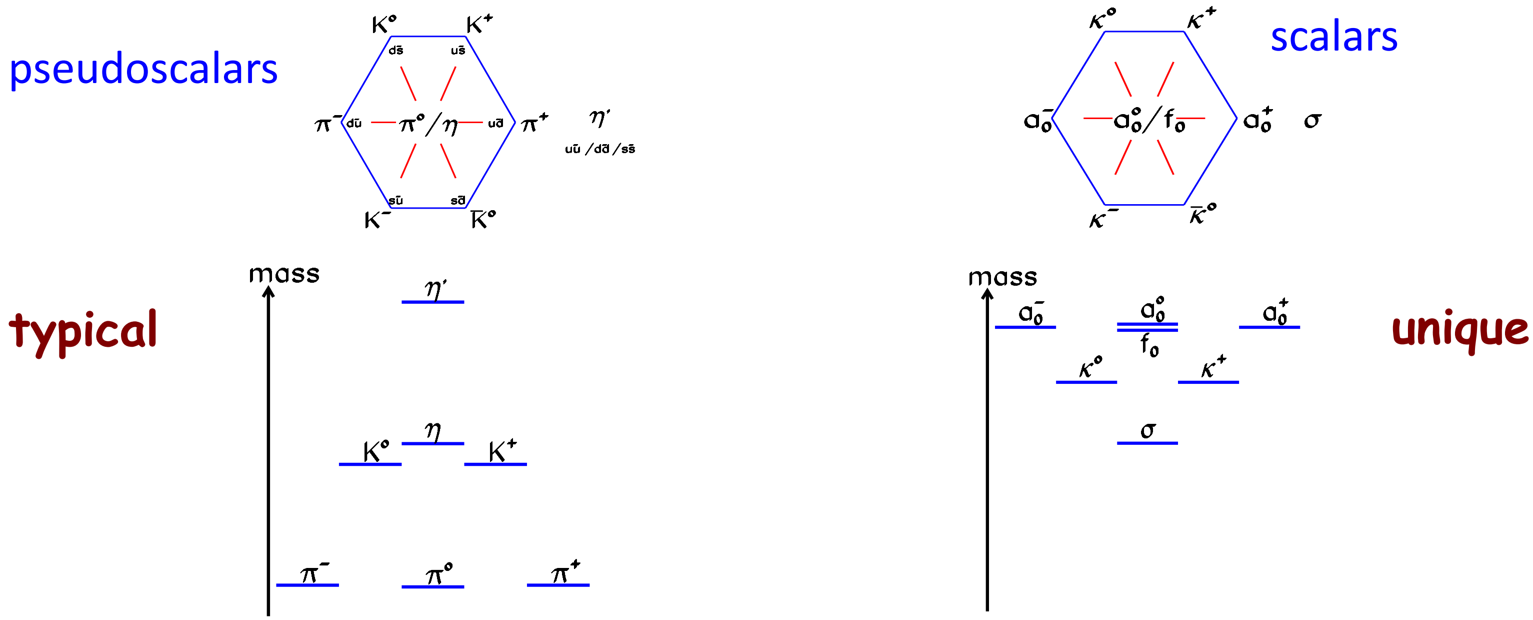




strong $a_0(980)$ coupling to KK

$$\frac{g_{KK}}{g_{\eta\pi}} = 1.03 \pm 0.14$$

light scalar nonet masses are inverted

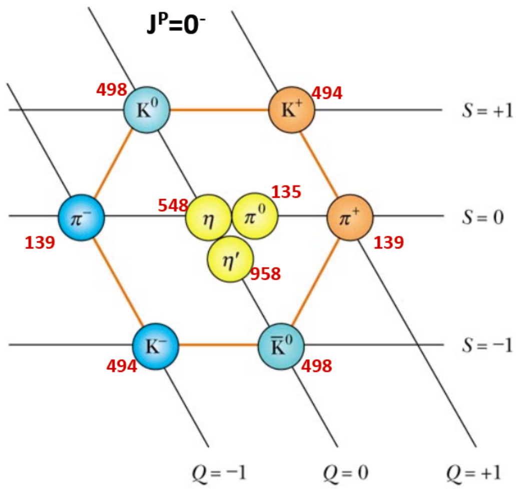


Also:

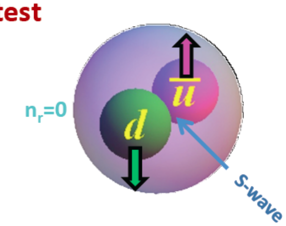
- No “light” $J^P=1^+$ and 2^{++} partner nonets in the same mass range.
- In $q\bar{q}$ meson nonets, the I=1 mesons have no s-quarks and are the lightest. However, the $a_0(980)$ I=1 mesons are the nonet’s heaviest.
- The $a_0(980)$ triplet has strong couplings to $K\bar{K}$.
- $m(f_0(980)) \sim m(a_0(980))$ implies “ideal” mixing & ***small*** s-quark content in $f_0(980)$.
- strong $K\bar{K}$ couplings of the $a_0(980)$ & $f_0(980)$ violate OZI-rule for $q\bar{q}$ mesons

Problems with mesons = $q\bar{q}$ model

pseudoscalars

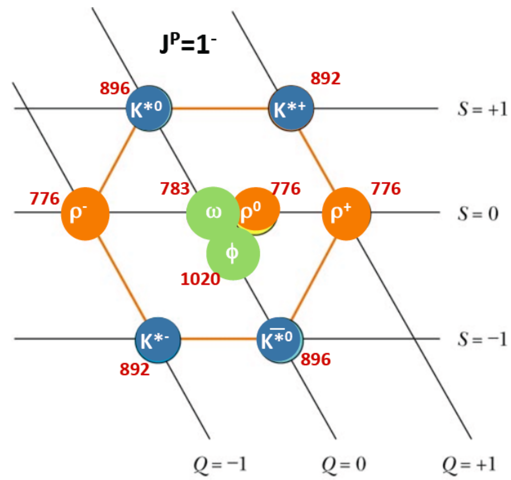


(π⁺,π⁰,π⁻)=lightest

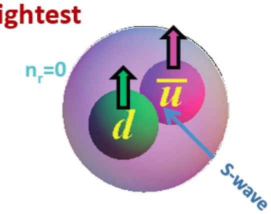


OK

vectors

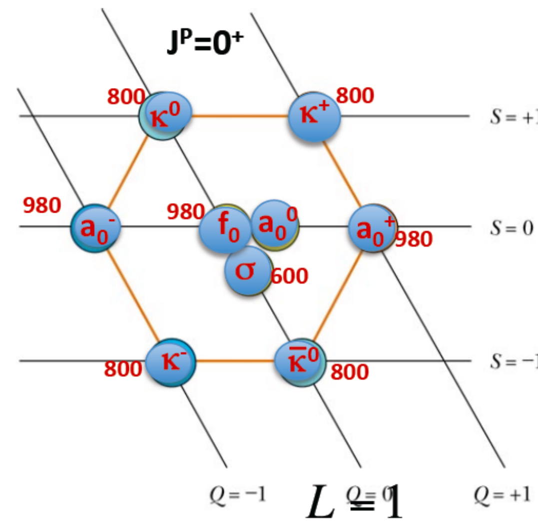


(ρ⁺,ρ⁰,ρ⁻)=lightest

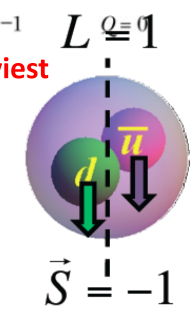


OK

scalars



(a_0^+,a_0^0,a_0^-)=heaviest



NG!

Some fundamental problems with the quark model:

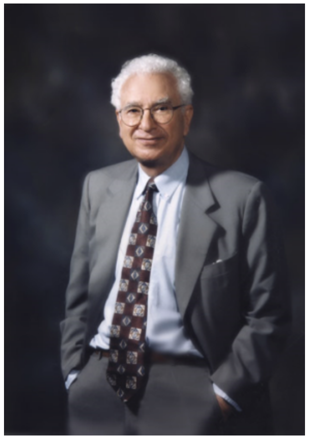
- Individual quarks are not seen

- why only qqq and $q\bar{q}$ combinations?

- violation of spin-statistics theorem?

Are quarks real objects?
or just mathematical mnemonics?

助记符



Are quarks actually real objects?" Gell-Mann asked. "My experimental friends are making a search for them in all sorts of places -- in high-energy cosmic ray reactions and elsewhere. A quark, being fractionally charged, cannot decay into anything but a fractionally charged object because of the conservation law of electric charge. Finally, you get to the lowest state that is fractionally charged, and it can't decay. So if real quarks exist, there is an absolutely stable quark. Therefore, if any were ever made, some are lying around the earth."
But since no one has yet found a quark, Gell-Mann concluded that we must face the likelihood that quarks are not real.

The Nobel Prize in Physics 1969

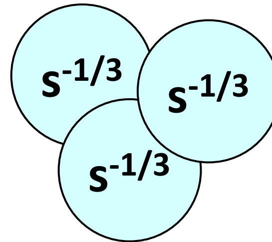
"for his contributions and discoveries concerning the classification of elementary particles and their interactions"

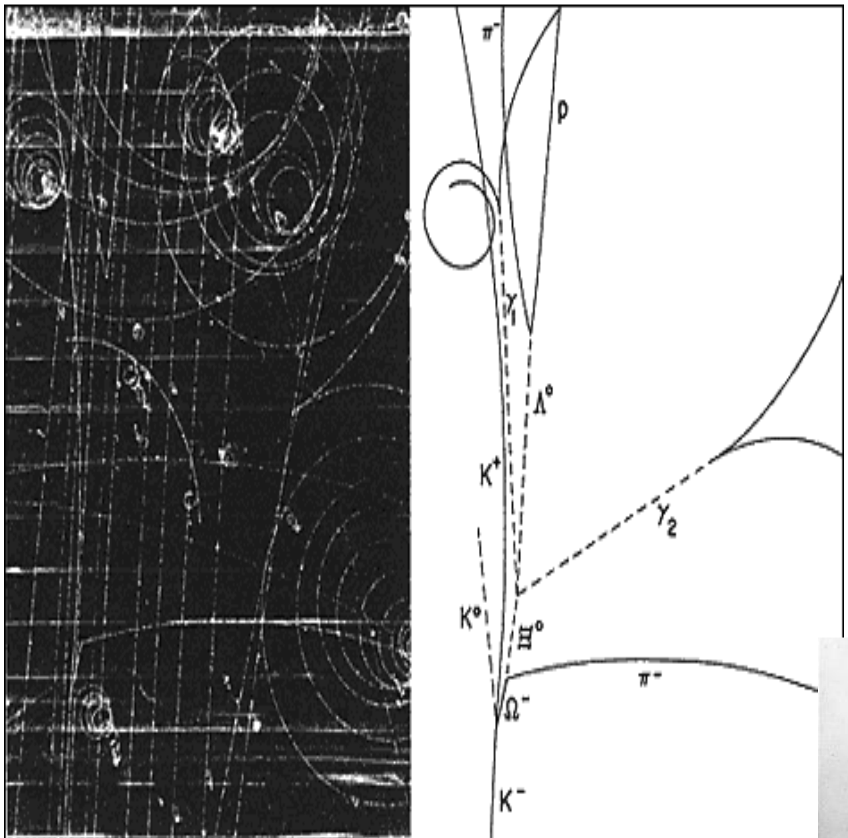
Nobel citation:

This classification of the elementary particles and their interaction discovered by Gell-Mann has turned out to applicable to all strongly interacting particles found later and these are practically all particles discovered after 1953. His discovery is therefore fundamental in elementary particle physics.

No mention of quarks; no prizes for Zweig, Sakata, or Fermi-Yang.

Ω^{-}





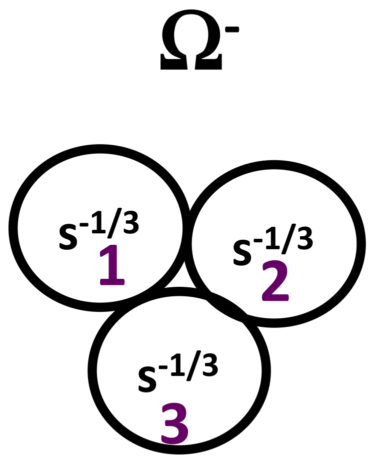
three s-quarks
in the same
quantum state

Das ist verboten!!

The strong interaction "charge" of each quark comes in 3 different varieties

Y. Nambu

M.-Y. Han



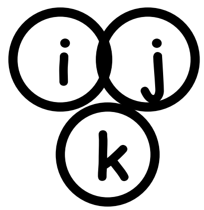
the 3 $s^{-1/3}$ quarks in the Ω^- have different strong charges & evade Pauli

Attractive configurations

Baryons:

$\varepsilon_{ijk}\, e_i e_j e_k$

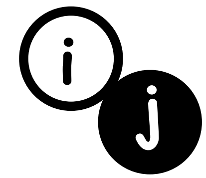
$\varepsilon_{ijk} = 1$ for $i \neq j \neq k$
$= 0$ otherwise



Mesons:

$\delta_{ij}\, e_i\, \bar{e}_j$

$\delta_{ij} = 1$ for $i = j$
$= 0$ otherwise



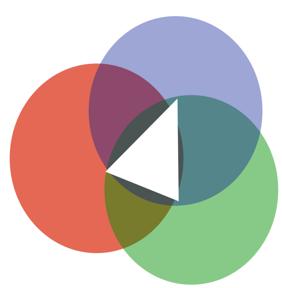
same as the rules for combining colors to get white:

add 3 primary colors   **or**   **add color+complementary color**

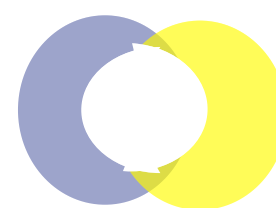
quarks: $e_i e_j e_k$ → color charges

antiquarks: $\bar{e}_i\ \bar{e}_j\ \bar{e}_k$ → anticolor charges

$\varepsilon_{ijk}\, e_i e_j e_k$

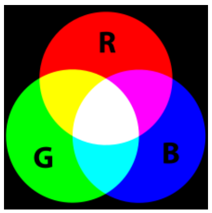


$\delta_{ij}\, e_i\, \bar{e}_j$

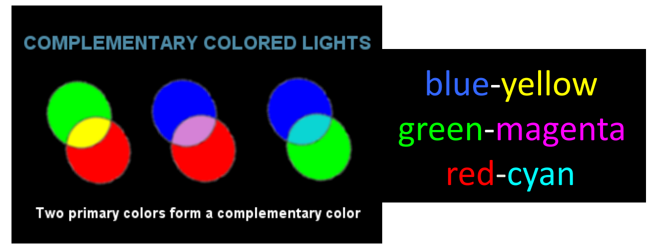


QPM Superseded by QCD in the 1970s: observed particles are color singlets

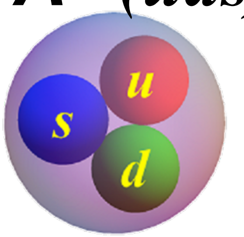
3 primary colors → **white**



color + complementary **color** → **white**

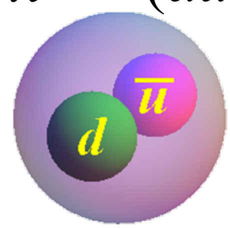


$$\Lambda = (uds)$$



Baryons are red-blue-green triplets

$$\pi^- = (d\bar{u})$$

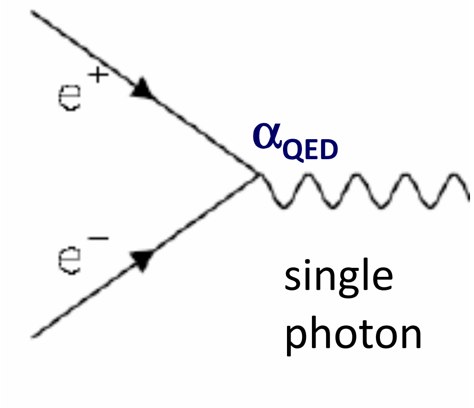


Mesons are color-anticolorpairs

A few remarks about QCD

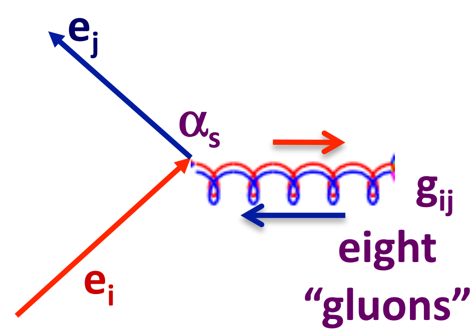
Quantum Chromodynamics

QED: scalar charge e



Non-Abelian extension of QED

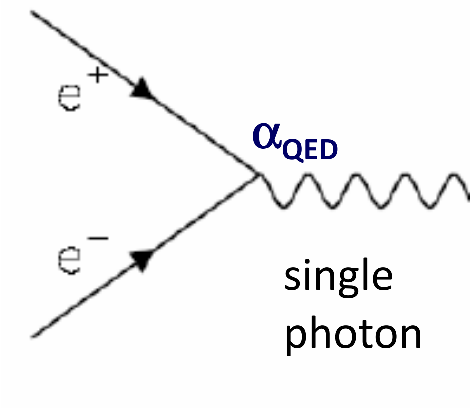
QCD triplet charge: $\begin{pmatrix} e_r \\ e_b \\ e_g \end{pmatrix}$



Quantum Chromodynamics

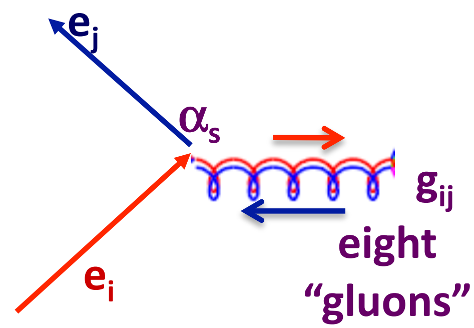
$$\begin{pmatrix} e_r \\ e_b \\ e_g \end{pmatrix}$$

QED: scalar charge e



Non-Abelian extension of QED

QCD triplet charge:



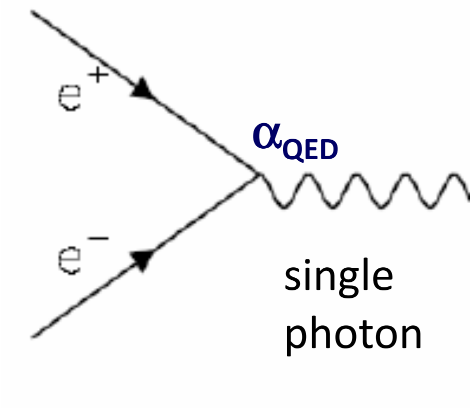
QED gauge transform

$$\vec{\nabla} \rightarrow \vec{\nabla} + i\, e\, \vec{A}$$

1 vector field (photon)

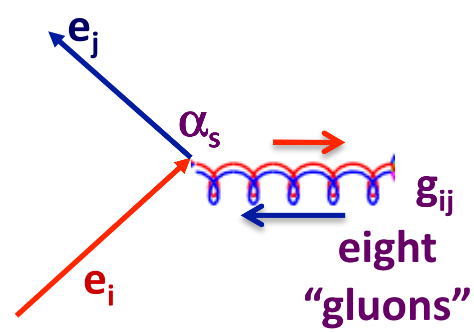
Quantum Chromodynamics

QED: scalar charge e



Non-Abelian extension of QED

QCD triplet charge: $\begin{pmatrix} e_r \\ e_b \\ e_g \end{pmatrix}$



QED gauge transform

$$\vec{\nabla} \rightarrow \vec{\nabla} + i\, e\, \vec{A}$$

1 vector field (photon)

QCD gauge transform

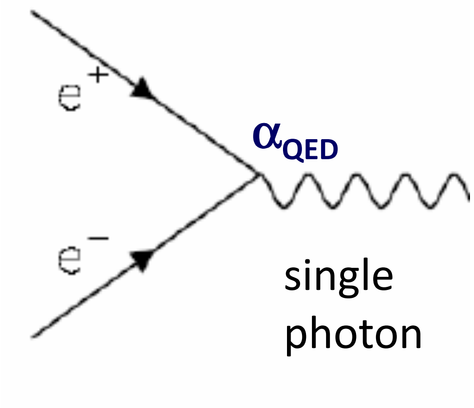
$$\vec{\nabla} \rightarrow \vec{\nabla} + i\, \alpha_s \lambda_i\, \vec{G}_i$$

eight 3x3 SU(3) matrices

8 vector fields (gluons)

Quantum Chromodynamics

QED: scalar charge e



Non-Abelian extension of QED

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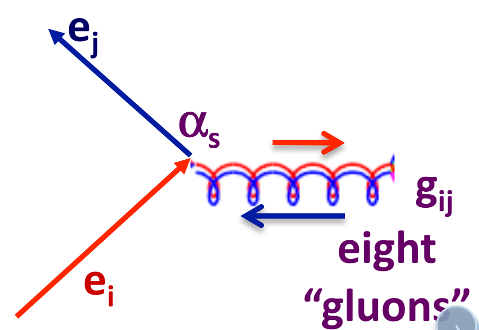


QED gauge transform

$$\vec{\nabla} \to \vec{\nabla} + i\, e\, \vec{A}$$

1 vector field (photon)

QED photons are electrically neutral

QCD gauge transform

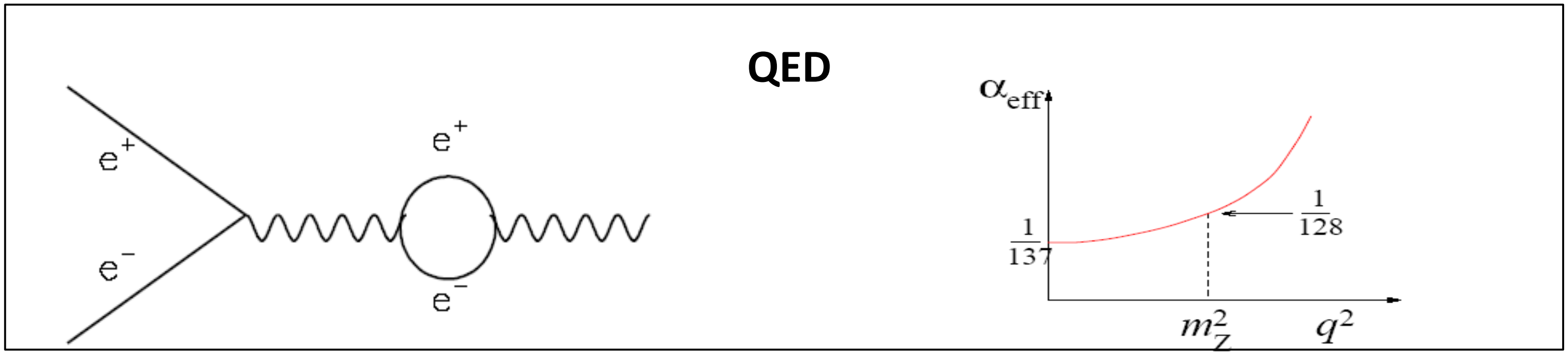
$$\vec{\nabla} \to \vec{\nabla} + i\, \alpha_s \lambda_i \vec{G}_i$$

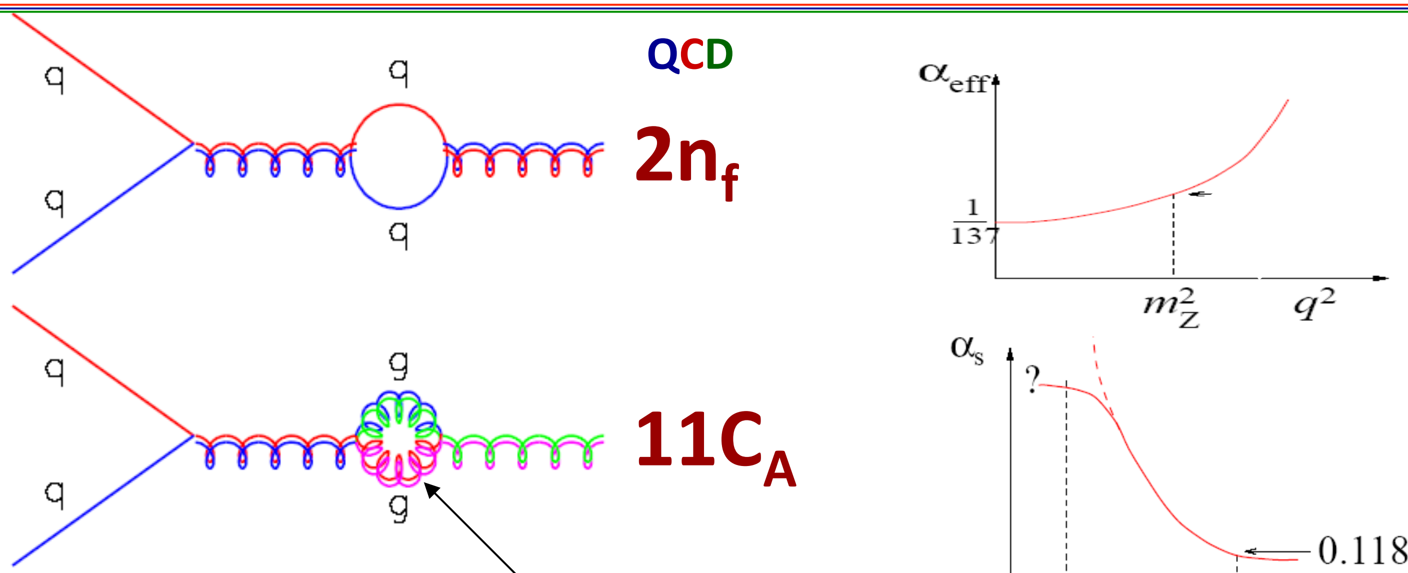
eight 3x3 SU(3) matrices

8 vector fields (gluons)

QCD gluons have color charges

Vacuum polarization QED *vs* QCD





in QCD: C_A=3, & this dominates

α_s increases with distance

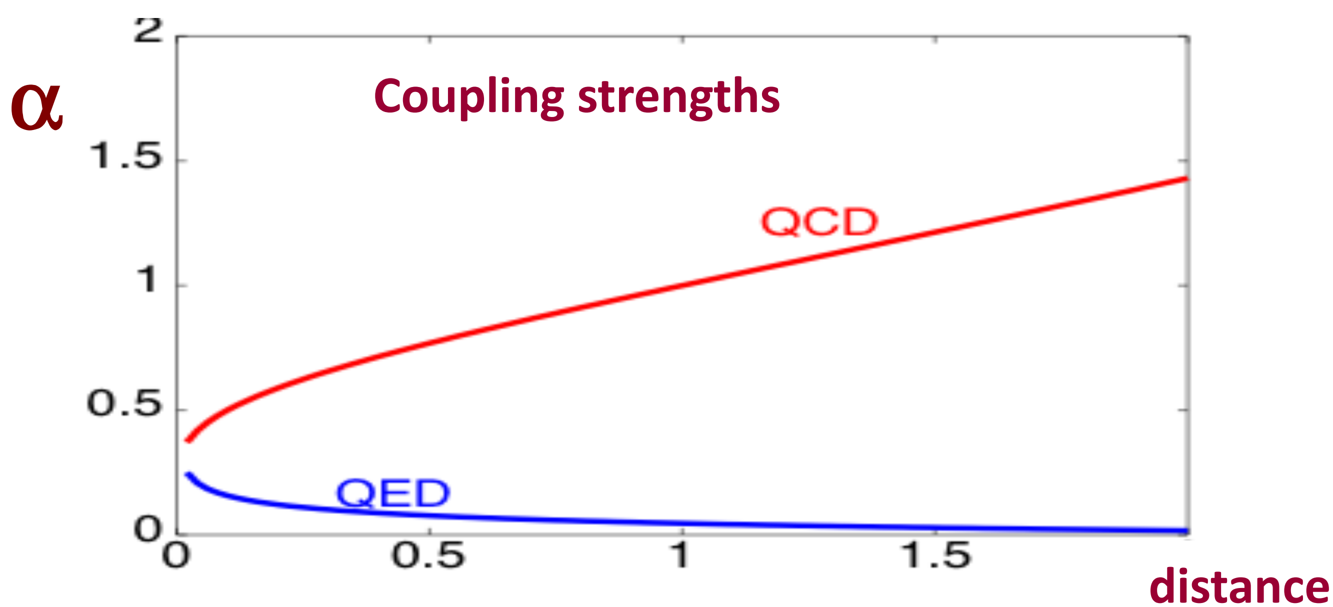
QED: photons have no charge

coupling decreases at large distances

QCD: gluons carry color charges

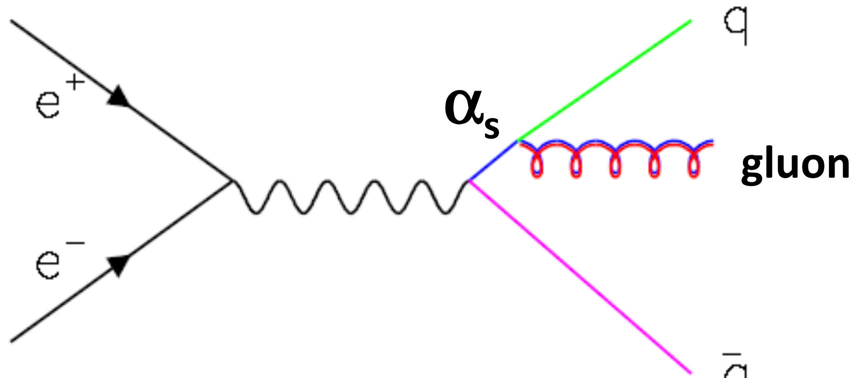
gluons interact with each other

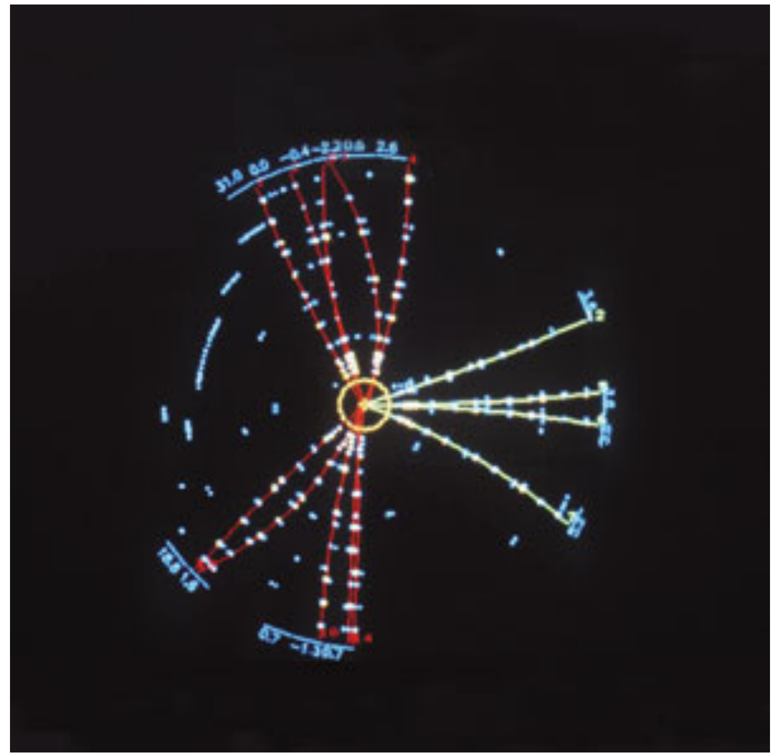
coupling increases at large distances



Test QCD with 3-jet events

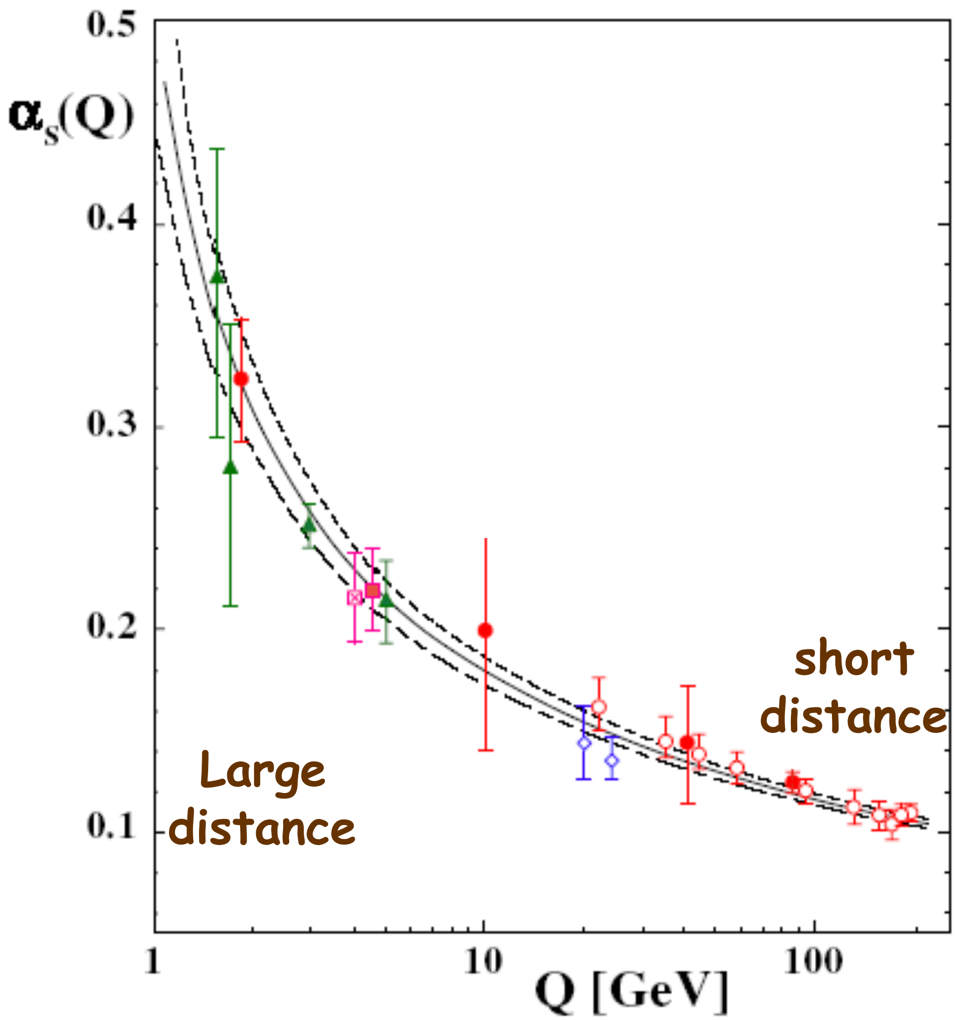
(& deep inelastic scattering)



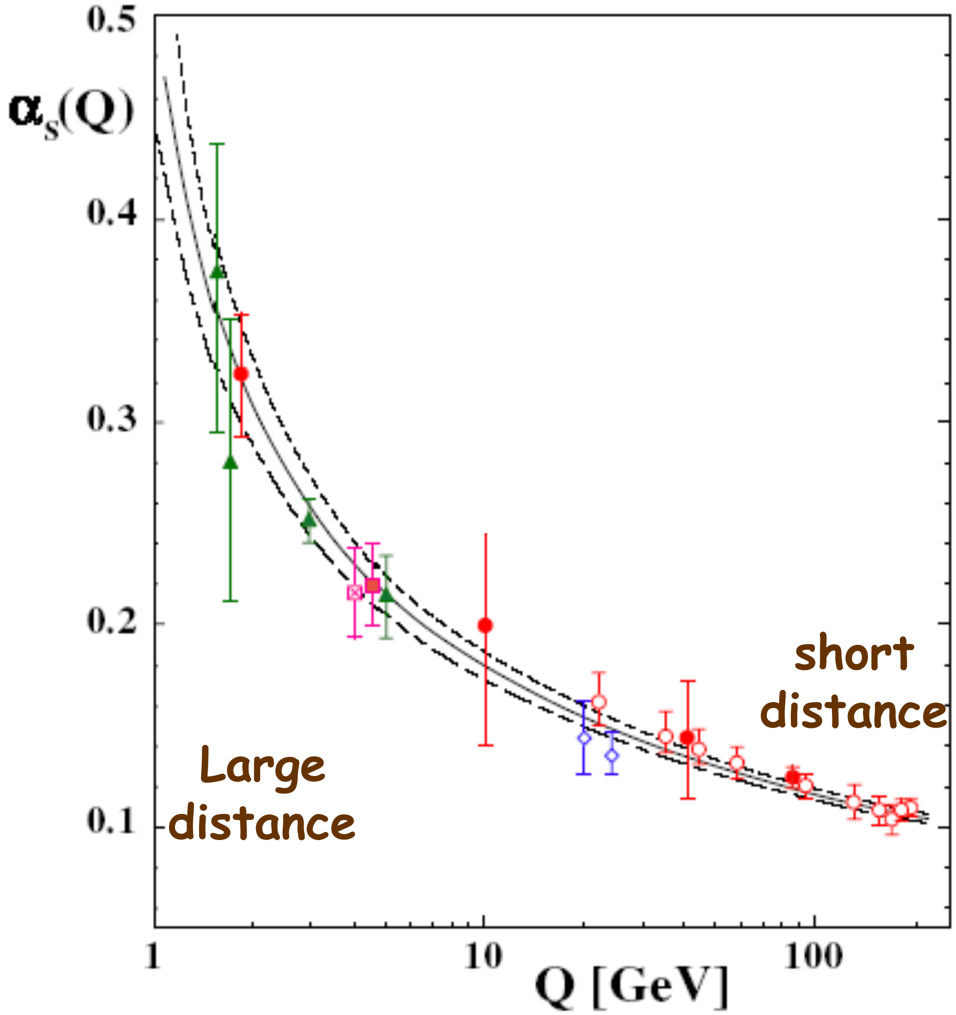


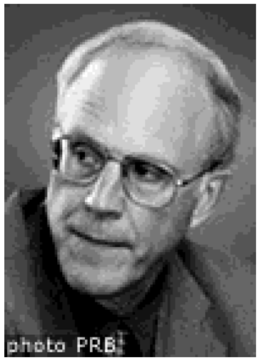
rate for 3-jet events should decrease with E_{cm}

“running” α_s

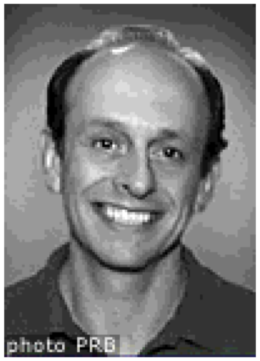


“running” α_s

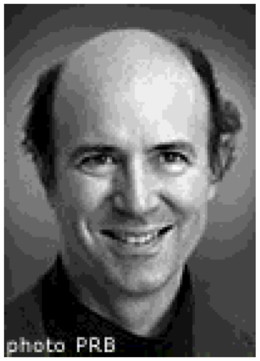




David J. Gross



H. David Politzer



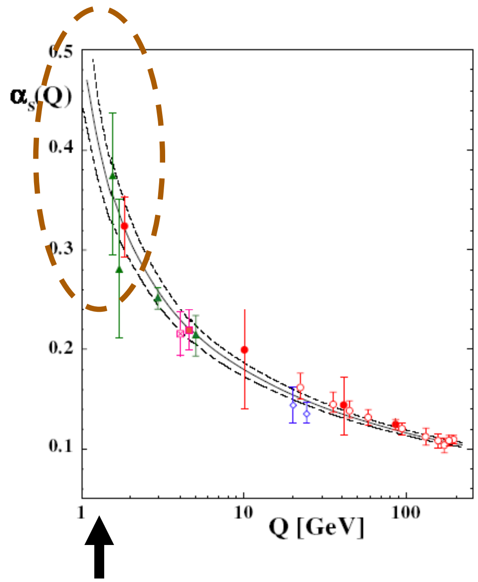
Frank Wilczek

2004 Nobel prize

The QCD particle spectrum hasn't been computed from 1st principles

Quark-binding into hadrons occurs here ($Q \approx m_p \approx 140$ MeV)

$\alpha_s(m_p) \sim 0.5$



perturbation theory can't be used

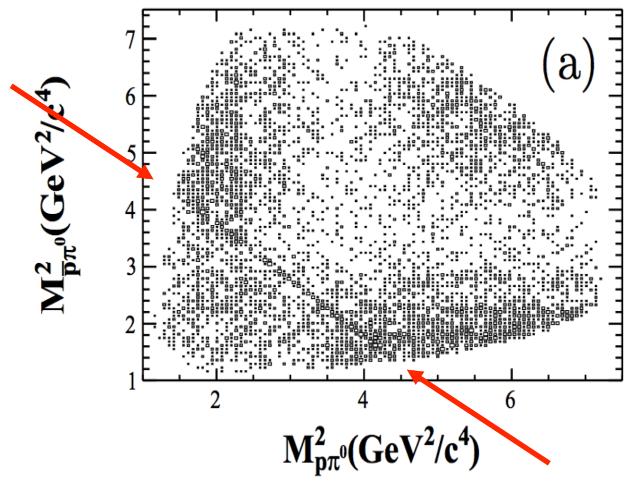
Theorists make "QCD-motivated" models that must be tested by experiment

Summary (lecture 3)

- The $q\bar{q}$=mesons and qqq=baryon prescriptions work well for the lowest-lying mesons & baryons, but fail otherwise
  - the mass hierarchy of the lowest-lying scalar mesons is opposite to expectations for $q\bar{q}$=mesons
  - The masses of the N*(1440), the 1st excited state of the nucleon, and the Λ(1405), the lowest excited sate of the Λ, disagree with QM predictions for qqq=baryons
- The quark model seriously violates the Pauli Principle
- Quark model is superseded by Quantum ChromoDynamics
- Quarks come in 3 colors; color force is mediated by 8 gluons

Discussion/HW items

The BESIII $\psi' \rightarrow pp\overline{\pi 0}$ Dalitz plot at the right has a narrow diagonal band of events as indicated by red arrows. What do you think caused this?



The Λ(1405) was seen via its Λ(1405)→Σπ decay mode, but is not seen in Λ(1405)→Λπ] decays. Why?

The $a_0(980)$ decays to ηπ, but not ππ, why is $a_0(980)\rightarrow\pi\pi$ a suppressed decay?