Diffractive physics at ALICE,LHC.

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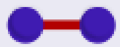
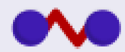
Physics motivation – Mesons not allowed by CQM

- Constituent Quark Model (CQM)
  - Goes back over 40 years to Gell-Mann and Zweig
  - Constituent quarks: Quasi particles with additional effective mass due to interac tion with gluon field.
- Mesons in constituent quark model
  - Color-singlet $|q\bar{q}\rangle$ states, groups into $\mathrm{SU}(N)_{flavour}$ multiplets
  - Table of mesons with quantum numbers

ℓ	S	J	$P=(-1)^{1+\ell}$	I	$G=(-1)^{I+\ell+S}$	$C=(-1)^{\ell+S}$	$I^G J^{PC}$	nomenclature
0	0	0	−1	0	+1	+1	0^+0^{-+}	η
0	0	0	−1	1	−1	+1	1^-0^{-+}	π
0	1	1	−1	0	−1	−1	0^-1^{--}	ω
0	1	1	−1	1	+1	−1	1^+1^{--}	ρ
1	1	0	+1	0	+1	+1	0^+0^{++}	f_0
1	1	0	+1	1	−1	+1	1^-0^{++}	a_0
1	0	1	+1	0	−1	−1	0^-1^{++}	h_1
1	0	1	+1	1	+1	−1	1^+1^{+-}	b_1
1	1	1	+1	0	+1	+1	0^+1^{++}	f_1
1	1	1	+1	1	−1	+1	1^-1^{++}	a_1
1	1	2	+1	0	+1	+1	0^+2^{++}	f_2
1	1	2	+1	1	−1	+1	1^-2^{++}	a_2
2	0	2	−1	0	+1	+1	0^+2^{-+}	η_2
2	0	2	−1	1	−1	+1	1^-2^{-+}	π_2

  - Not allowed J^{PC} with CQM mesons : $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}$, …(spin-exotic)

Purposes of this study

- Finding states beyond Constituent Quark Model (CQM)
  - Physical mesons = linear superposition of all allowed basis states: $|q\bar{q}\rangle, |q\bar{q}g\rangle, |gg\rangle, |q^2\bar{q}^2\rangle, \ldots$
  - Quarkonia  $|q\bar{q}\rangle$
  - Tetra-quarks : is not my sight  $|q^2\bar{q}^2\rangle$
  - Hybrids : The first purpose of this study  $|q\bar{q}g\rangle$
  - Glueballs : The second purpose  $|gg\rangle$

Hybrids $|q\bar{q}g\rangle$

- Resonances with excited glue and quarks.
- Angular momentum of glue component → **all J^{PC} possible**
- Lightest predicted hybrid : **spin-exotic $J^{PC} = 1^{-+}$**
  - ✓ Mass 1.3 to 2.2 GeV/c^2
  - ✓ Experimental candidates **$\pi_1(1400, 1500, 2000)$ controversial**

Purposes of this study

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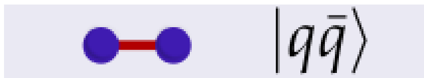
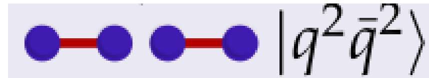
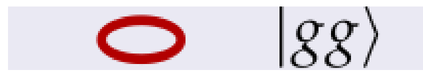
  - Quarkonia 

  - Tetra-quarks : is not my sight 

  - Hybrids : The first purpose of this study 

  - Glueballs : The second purpose 

Glueballs $|gg\rangle$

- Bound states consisting purely of gluons
- Lightest predicted glueball : ordinary $J^{PC} = 0^{++}$
  - ✓ **Will strongly mix with nearby conventional $J^{PC} = 0^{++}$**
  - ✓ Mass 1.5 to 2.0 GeV/c^2
  - ✓ Experimental candidate $f_0(1500)$; glueball interpretation disputed

Systems for the study?

- Gluon-rich environment is needed
  - Gluons play a key role for Hybrids & glueballs
  - More possibility to search them with gluon-rich environment

→Centrally diffracted system(CD)

- Central diffraction system
  - **Central diffraction system is caused by two ℙ(pomeron) exchange**

    → **Pomeron is also quasi-particle(at least {gg}(first order) in and around proton)**

    → Gluon-rich environment

    → More possible to find a glueball and hybrid
  - The best thing is we can **exclude many quarkonia from the system**

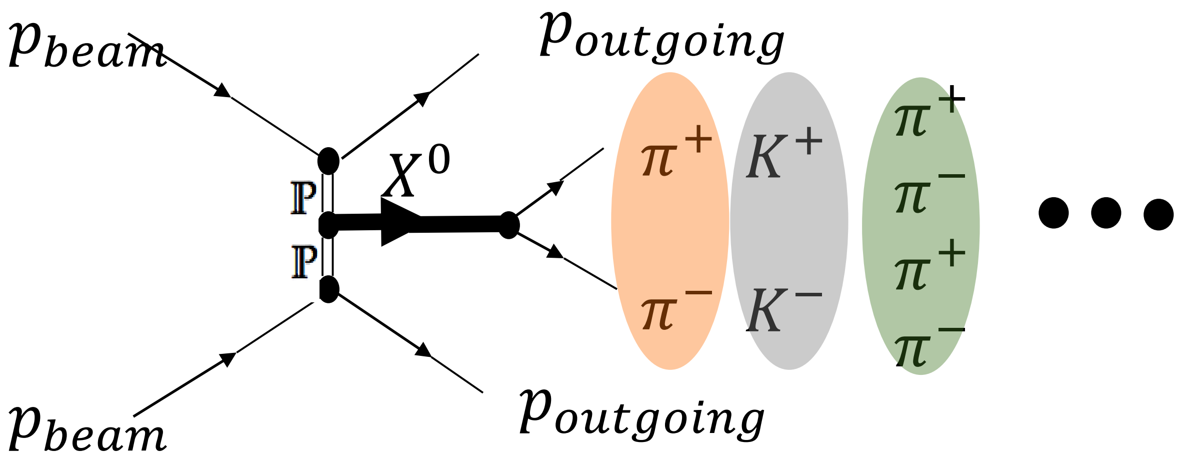
    → J^{PC} =even^{++}(J^{PC}) states are only possible with two ℙ exchange.

    → Thus many quantum states cannot survive in CD system

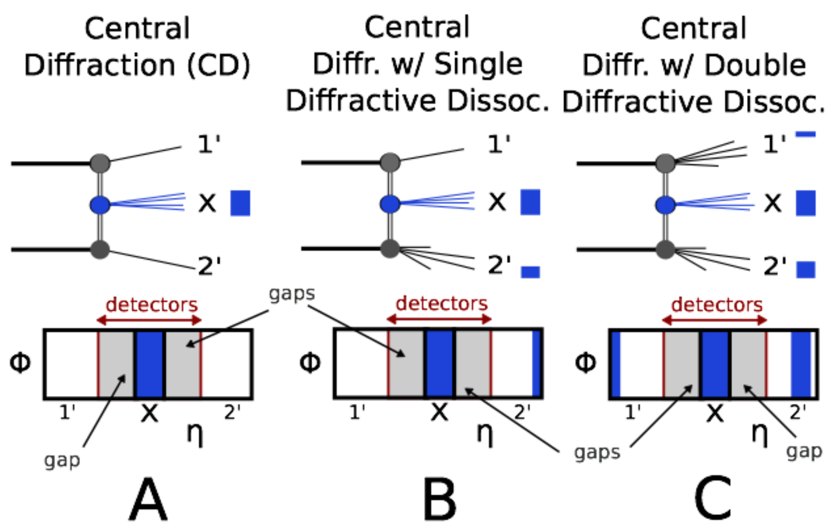
    → We can search glueballs or hybrids without backgrounds

Central diffraction and double-gap topology

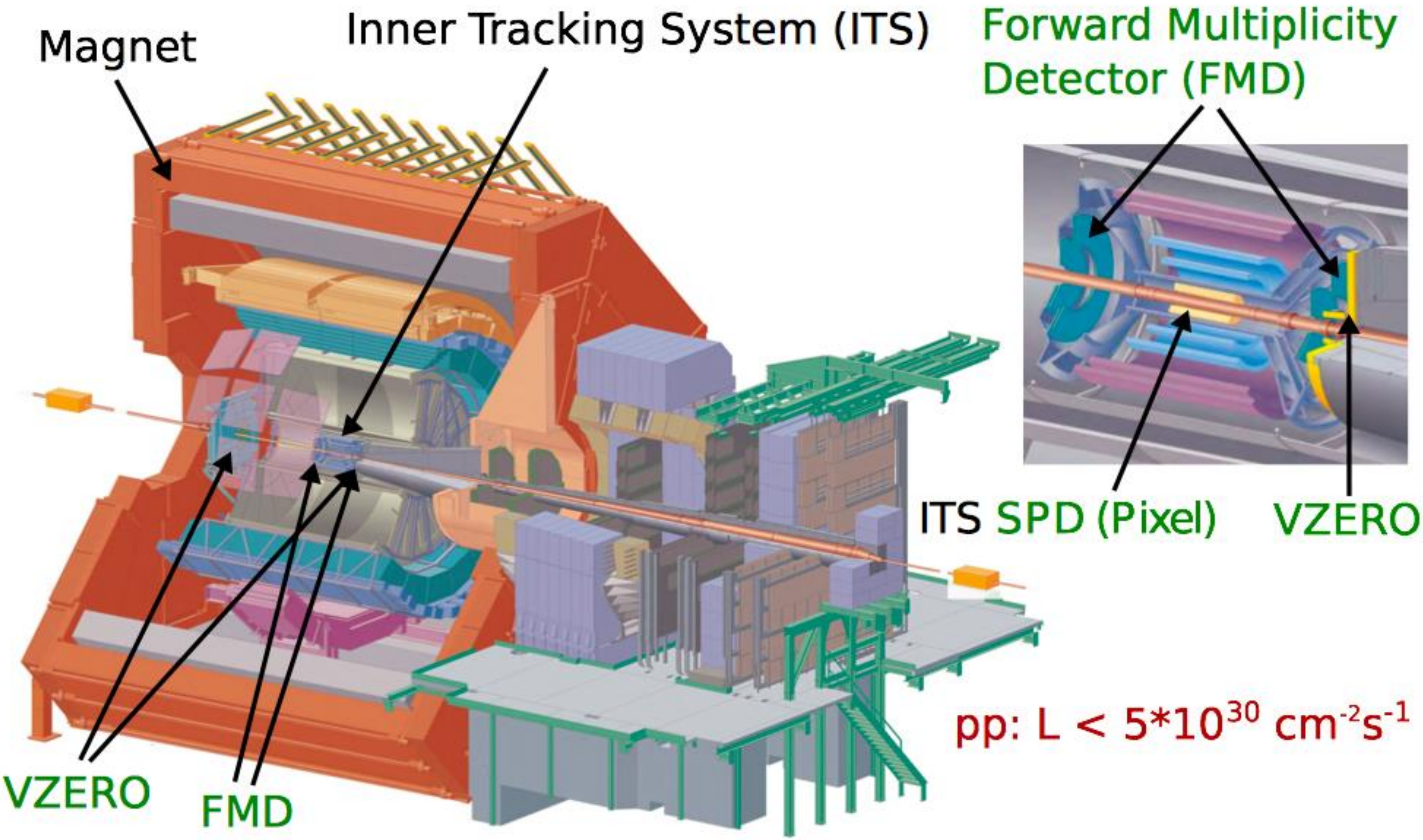
- Schematic view of the Central Diffraction (double $\mathbb{P}$ exchange)



- Of particular interest is double-gap topology as filter for central diff(CD)

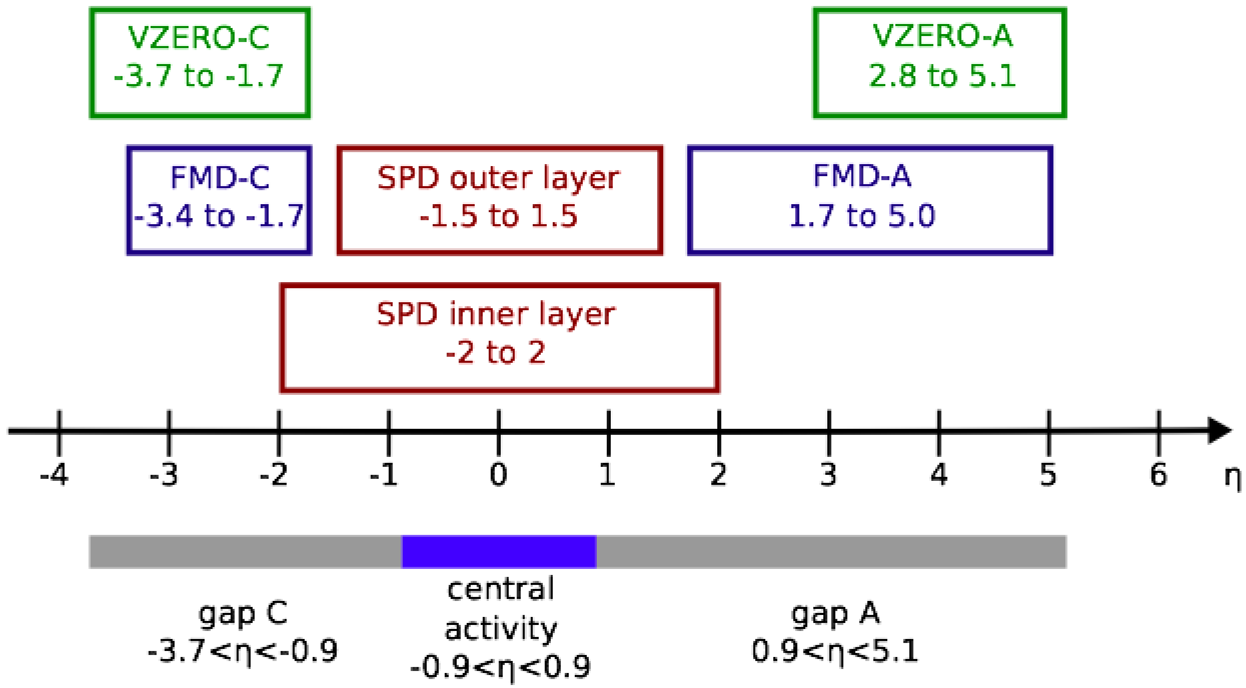


A Large Ion Collider Experiment



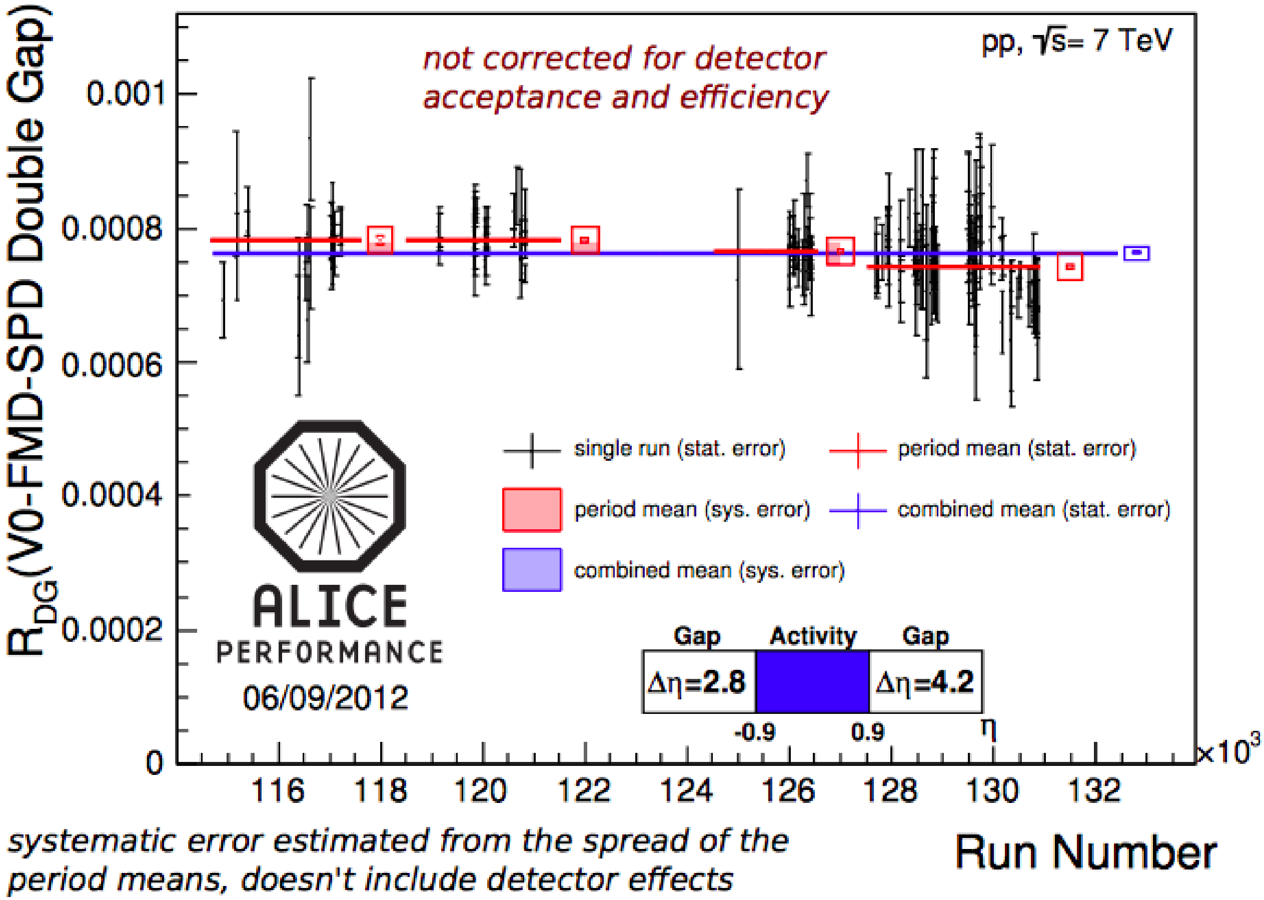
pp: L < $5*10^{30}$ $cm^{-2}s^{-1}$

Double-Gap topology in ALICE



- Selection criteria for the double-gap topology
  - Activity in the central barrel ($-0.9<\eta<0.9$) → detector : SPD
  - Two gaps (no activity) outside of central barrel
    - A-side : $0.9<\eta<5.1$, C-side : $-3.7<\eta<-0.9$
    - Detectors : VZERO, FMD, SPD requiring no activity(no tracks and signals)

Double-Gap fraction

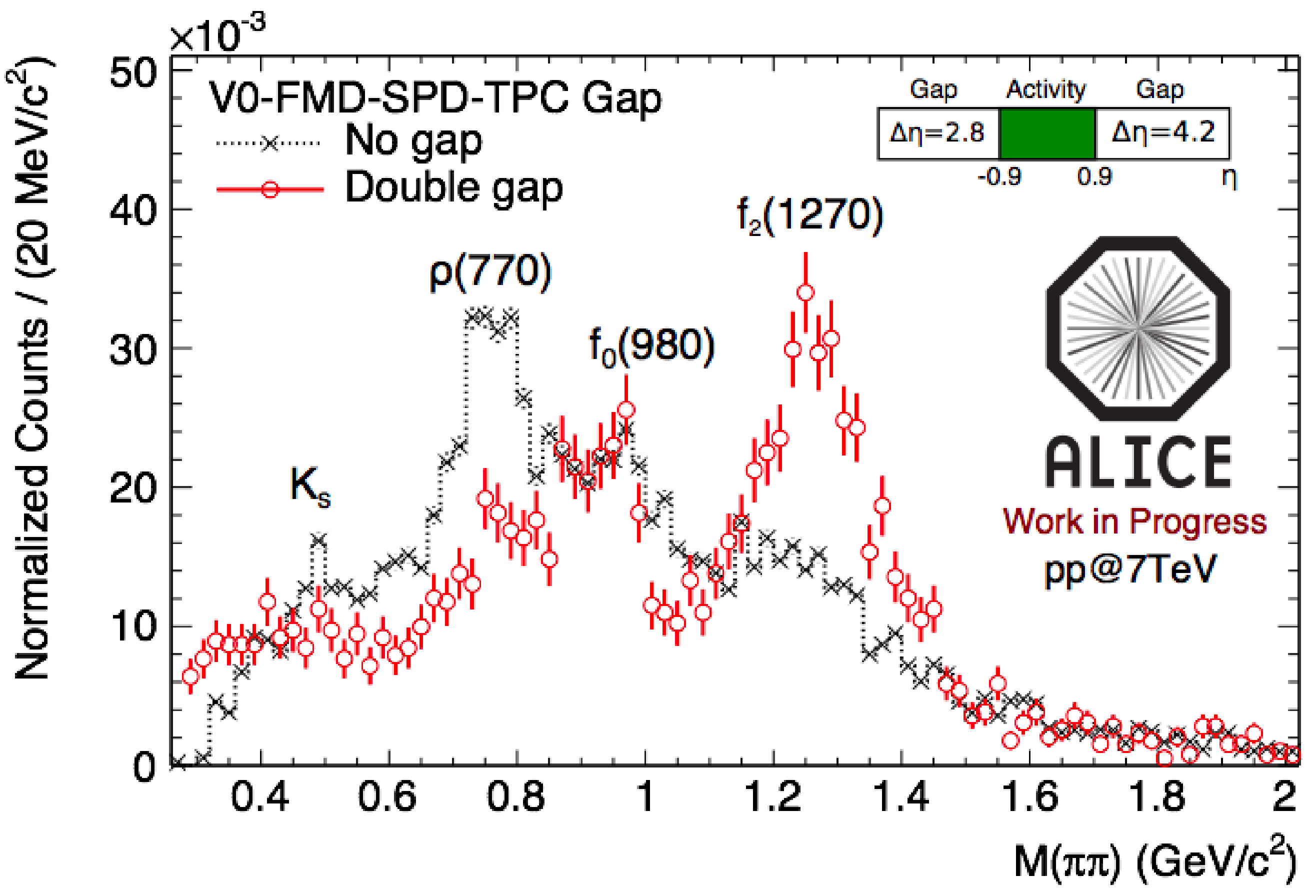


- $R_{DG}(2.8, \pm 0.9, 4.2) = \frac{N_{DG}}{N_{MB}} = (7.63 \pm 0.02_{stat} \pm 0.87_{sys}) \times 10^{-4}$
  - Uniform behavior at ALICE, stable with various run-periods.

Are we correctly taking CD events by DG topology?

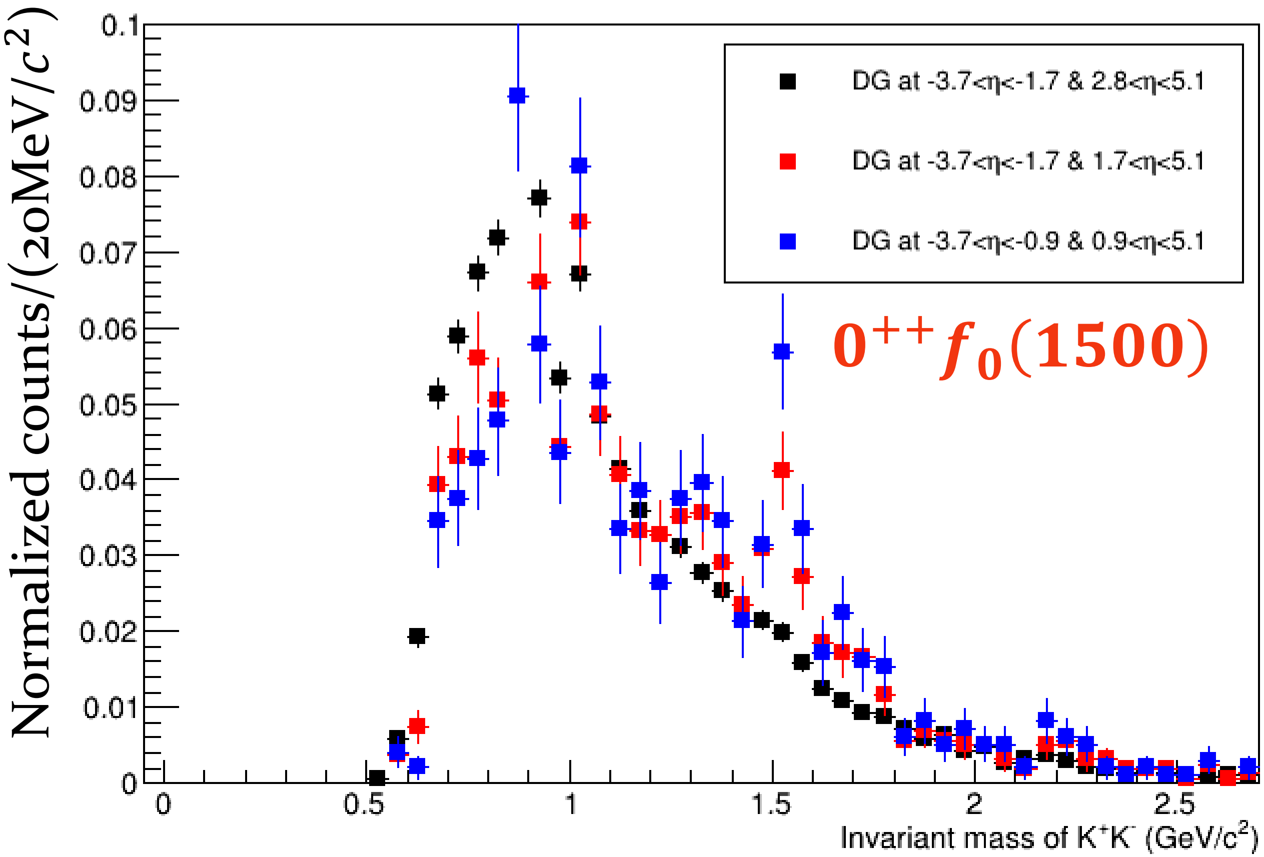
- CD (two IP exchange) system confines quantum numbers
  - Double IP exchange only allows quantum numbers, $J^{PC} = even^{++}(0^{++}, 2^{++}, \dots)$
  - With double-gap condition

→ $1^{--}\rho_0(770)$ was restricted, $0^{++}f_0(980)$ and $2^{++}f_2(1270)$ appear significantly



Results $X^0 \to K^+K^-$

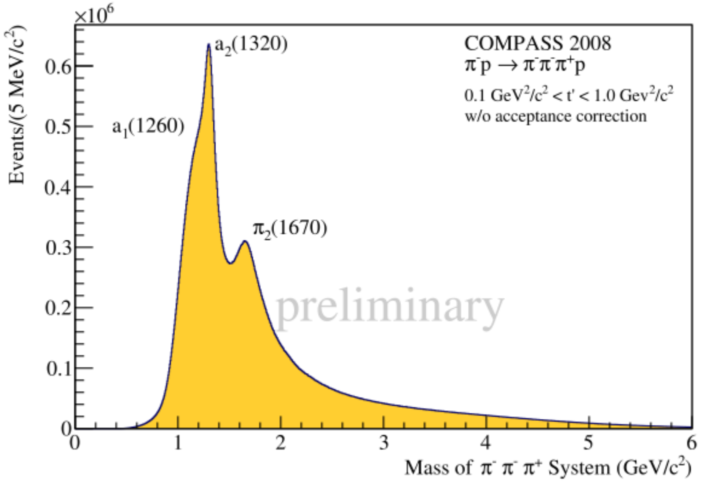
- Full statistics at 7TeV
- Clear $f_0(1500)(gluball\ candidate) or\ f_2'(1525)\ and\ f_0(1710)$
  - Need to study about J=o and p and c=+ (by partial wave fit)
- $f_2(1270), f_0(1370)$ also can be seen however cannot be distinguished.



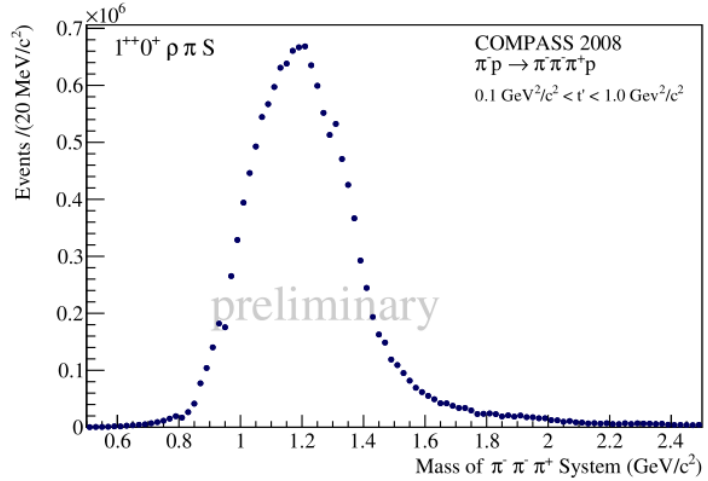
Stronger
Double-gap condition

COMPASS measurement for hybrid $1^{-+}(\pi_0(1600))$

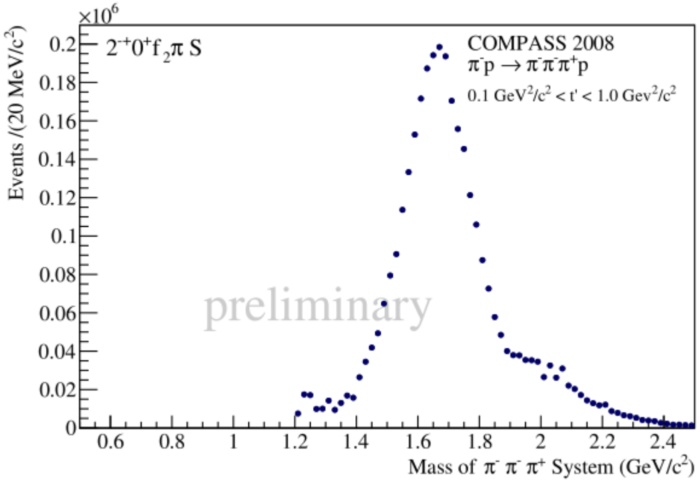
$\pi^-\pi^+\pi^-$ invariant mass spectrum



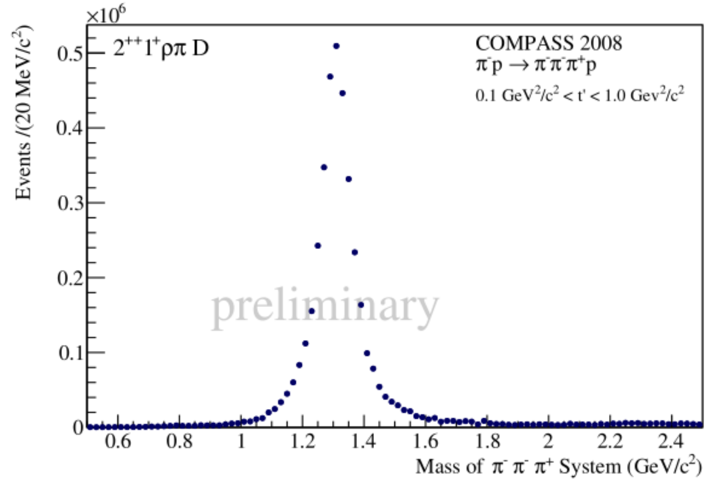
$1^{++}0^+[\rho\pi]S$: $a_1(1260)$



$2^{-+}0^+[f_2\pi]S$: $\pi_2(1670)$

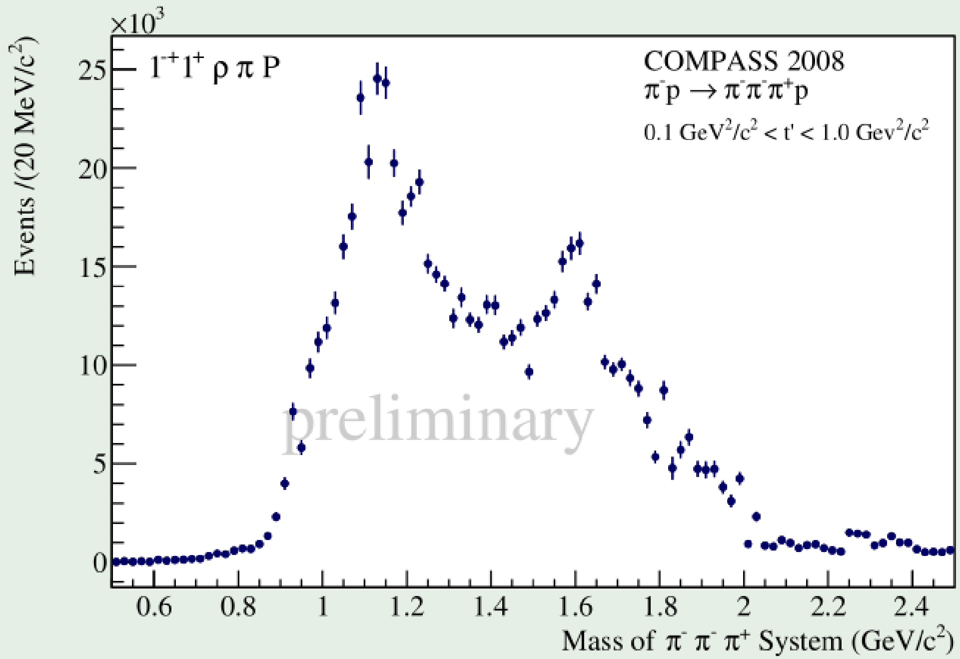


$2^{++}1^+[\rho\pi]D$: $a_2(1320)$



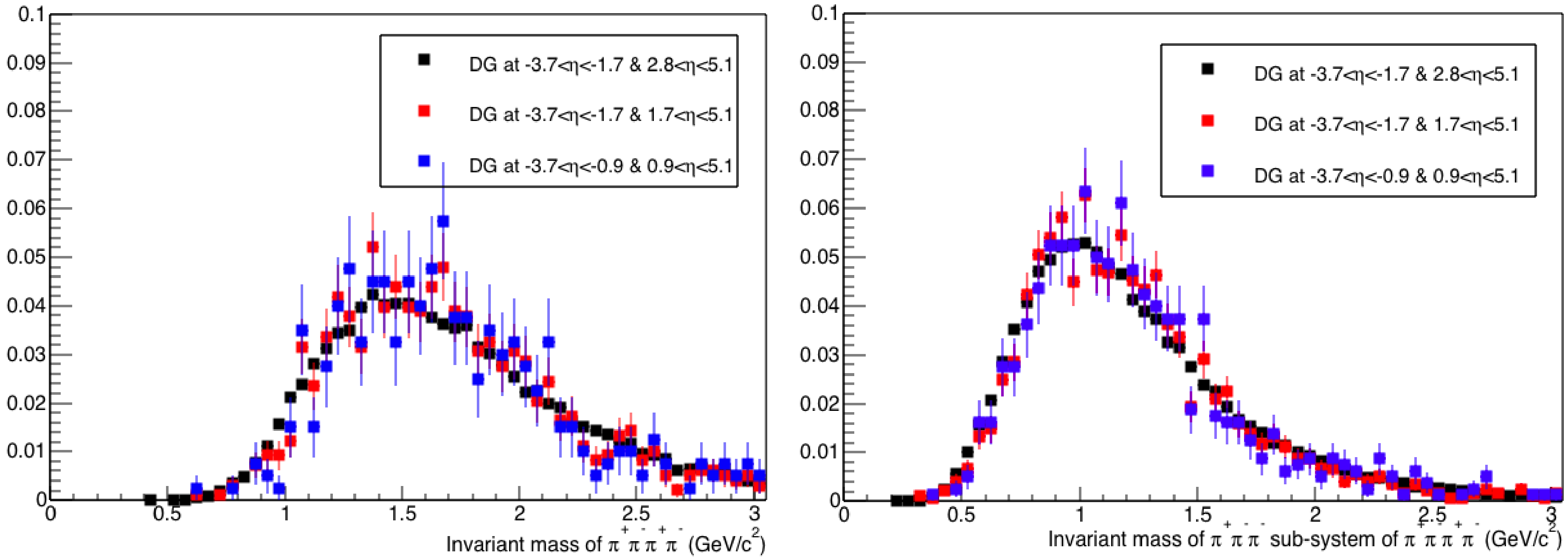
COMPASS measurement for hybrid $1^{-+}(\pi_0(1600))$

COMPASS



- 190 GeV/c π beam
- p target
- $50 \cdot 10^6$ events
- $0.1 < t' < 1.0$ $(\mathrm{GeV}/c)^2$
- Rank-2 fit with 53 waves

4 Pion events and 3 pion sub-system at ALICE



- We are expecting to find a hybrid 3 pion sub-system of 4 pion events fro m DG(1-+ →pi+pi-pi-)
- Developing "partial wave analysis" which was used for the COMPASS res ult in order to pull out signals from data
- Analysis are ongoing for glueball and hybrids.

Summary and promising points for the physics

- We found that we can choose central production by control of the doub le rapidity gap condition. ($f_0(980)$, $f_2(1270)$ showed up as we expected)
- Search for glueball& hybrids is ongoing. Remaining jobs are just “fitting”
- At RUN2(2015~) period, pp collisions with $\sqrt{s}$ =13 to 14 TeV are reserved . We expect that there would be more statistics with central production since cross-section of the double pomeron exchange goes up exponentia lly with energy.
- With the help of the forward new detectors, ADA & ADC, we can measu re the system more efficiently with extended pseudo-rapidity coverage
- ALICE has the capability to measure low p_T particles compared to other LHC experiment(ATLAS, CMS) which is very important for this study

→Promising subject for RUN2, RUN3 with ALICE

Residuals

Physics motivation

- Exotic meson : mesons which have quantum numbers not possible in the quark model
  - QCD suggests : in addition to mesons made by quarks, **new states** where colored gluons play an essential role.
  - New state 1 : "glueballs" resonating states purely made by gluons
  - New state 2 : "Hybrids" resonating states made by gluons and quarks.
  - This study : search for this glueballs or Hybrids
- Possible states by J^{PC} expression for the constituent model of $q\bar{q}$ mesons

$$0-+,\ 0++,\ 1--,\ 1+-,\ 1--,\ 2--,\ 2-+,\ 2++,\ 3--,\ 3+-,\ 3--,\ \cdots$$

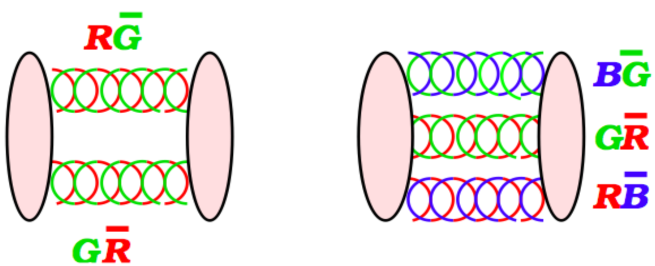
- Not possible states

$$0--,\ 0+-,\ 1-+,\ 2+-,\ 3-+,\ \cdots$$

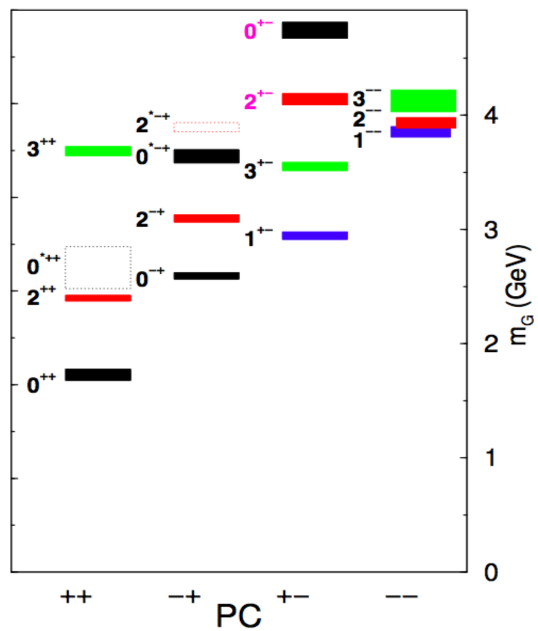
- The latter quantum numbers are known as "*explicitly exotic*". If this states are found, it implies that it should not be a normal $q\bar{q}$ meson

Glueballs in the exotic mesons

- Gluons
  - Because gluons carry color charge, it is possible to bind into color-singlet objects
  - The simplest glueballs are either two or three gluons confined together.
  - The best prediction of the glueball spectrum comes from the lattice QCD



Two and three gluons bound into color singlet glueballs

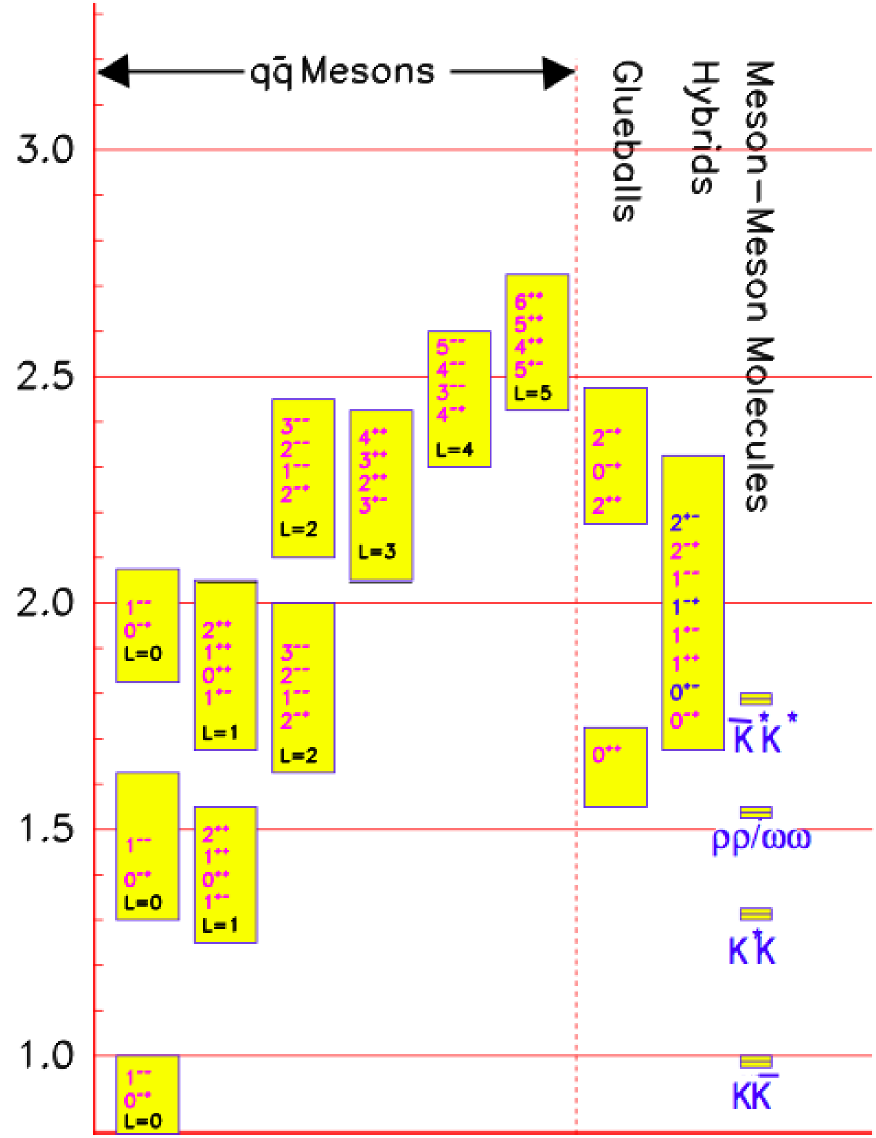


Glueball states which are predicted by L-QCD. The states described by black means that this states are also possible by $q\bar{q}$ meson. On the other hand, pink states are not possible by $q\bar{q}$

  - The lightest glueball is expected to have $J^{PC} = 0^{++}$ followed by a 2^{++} and then a 0^{-+}. Unfortunately all these 3 states are allowed for the normal meson[$q\bar{q}$]
  - The lightest glueball states with exotic are beyond $4GeV/c^2$. This exceeds our experimental mass regime.

Glueballs in this experiment

- By double-gap condition
  - $J^{PC} = even^{++}$ is only allowed
  - 0^{++} and 2^{++}
    - Two possible states of glueball
  - For 2^{++}, it is difficult to discriminate it from $q\bar{q}$ mesons
  - Target of this experiment
    - 0^{++} gluball



Mass independent partial wave fit

Components of the LogLikelihood function:

$$\ln L = \sum_{n=1}^{N_{\text{events}}} \ln \sum_{\epsilon} \sum_{i,j} \rho^{\epsilon}_{ij} \bar{\psi}^{\epsilon}_i(\tau_n) \bar{\psi}^{\epsilon}_j(\tau_n)^* - \sum_{\epsilon} \sum_{i,j} \rho^{\epsilon}_{ij} I A^{\epsilon}_{ij}$$

Decay amplitudes

Kinematics

Acceptance corrected
Phase space integral

Spin density matrix (fit parameters)

Coherent sum over waves

Incoherent sum over reflectivities

Production amplitudes → Spin density matrix:

$$\rho^{\epsilon}_{ij} = \sum_{r} T^{\epsilon}_{ir} T^{\epsilon *}_{jr}$$

Normalized decay amplitudes:

$$\bar{\psi}^{\epsilon}_i(\tau) = \frac{\psi^{\epsilon}_i(\tau)}{\sqrt{\int |\psi^{\epsilon}_i(\tau')|^2 \mathrm{d}\tau'}}$$

Phase space integrals (with acceptance):

$$IA^{\epsilon}_{ij} = \int \bar{\psi}^{\epsilon}_i(\tau_n) \bar{\psi}^{\epsilon}_j(\tau_n)^* Acc(\tau) \mathrm{d}\tau$$

$$Acc(\tau) = \begin{cases} 0 \\ 1 \end{cases}$$