Meson Spectroscopy Analysis of New and Exotic States: Search for and study of light exotic mesons, Strangeonia and charmonia

Vincent MATHIEU
Universidad de Barcelona
Complutense Universidad de Madrid

York - September 2021
Outline

Groups:

U Glasgow, UC Madrid, U Barcelona, 
U Bonn, GSI, U Bochum, TU Munich, 
INFN Catania, Ferrara and Torino

Outline:

Conventional mesons: 
strangeonia and charmonia

Light exotic mesons: 
hybrid mesons and glueballs

Heavy exotic mesons: XYZ
Light Exotic Mesons, Charmonium and Strangeonium

“Exotic” in the quark model sense meson different from $q\bar{q}$

identification through quantum numbers, decay modes, and/or analysis
Discovery Exotic Mesons

Design and build detectors
Collect data
Build observables
Fit data
Extract pole position,
...

Lattice QCD,
Constituent Models,
Effective Field Theories,
...

Experiments Tools

Interpretation

Theory

Discovery Exotic Mesons

Design and build detectors
Collect data
Build observables
Fit data
Extract pole position,
...

Lattice QCD,
Constituent Models,
Effective Field Theories,
...

Experiments Tools

Interpretation

Theory
Conventional mesons: strangeonia

First time measurement of transverse momentum distributions for charged K*(892) in inelastic pp collisions at $\sqrt{s} = 5.02, 8, 13$ TeV.

Consistent with previous measurements of neutral K*(892) production

Transverse momentum distribution not very well described by event generators

Ongoing: Multiplicity dependence of charged K*(892) in pp collisions at $\sqrt{s} = 13$ TeV
Conventional mesons

ALICE publications on meson resonances production

« Production of light-flavor hadrons in pp collisions at $\sqrt{s} = 7 \text{ and } 13 \text{ TeV }$, EPJC81 (2021) 256

«Unveiling the strong interaction among hadrons at the LHC», Nature 588 (2020) 232

« Production of $\omega$ mesons in pp collisions at $\sqrt{s} = 7 \text{ TeV }$, EPJC80 (2020) 1130

«$K^*(892)^0$ and $\phi(1020)$ production at mid-rapidity in pp collisions at $\sqrt{s} = 8 \text{ TeV }$, PRC 102 (2020) 024912

«Multiplicity dependence of $K^*(892)^0$ and $\phi(1020)$ production in pp collisions at $\sqrt{s} = 13 \text{ TeV }$, PLB 807 (2020) 135501

«Evidence of rescattering effect in Pb-Pb collisions at the LHC through production of $K^*(892)^0$ and $\phi(1020)$ mesons», PLB 802 (2020) 135225
Conventional mesons: charmonia

**INFN-Ferrara** Ongoing analysis:

Inclusive measurement of $h_c(1P)$ in the $\psi(2S)$ decay

- **Up to January 2020:**
  - Event and track selection validation (done)
  - Systematic uncertainty studies finalised (done)

- **From January 2020 - up to now:**
  - BESIII internal document released
  - Internal review started
  - Paper draft ready and in review

- **PLANS:**
  - Finish the internal review
  - Submission to journal by the end of 2021/ beginning of 2022

Slide by I. Garzia
Conventional mesons: charmonia

**University of Barcelona**

Montaña et al PRD102 (2020) 096020

Properties of open-charm mesons ($D, D_s, D^*, D_s^*$) in a bath of light mesons at temperatures below $T_c$ using effective field theories

Ground states and excited states decrease their mass and acquire width at temperatures $< 150$ MeV

Application: Euclidean correlators and transports coef.

Montaña et al EPJA56 (2020) 294

Torres-Rincon et al arXiv:2106.01156
Various cases studied:

- $\Lambda(1405)$ in $K^*\Sigma\pi$ triangle
- $a_0(1420)$ in $K^*K\bar{K}$ triangle
- $X(3872)$ in $D^*D\bar{D}$ triangle
- Deuteron in $\Delta p\pi$ triangle
Light hybrid mesons: Experimental efforts

Non-resonant (Deck) mechanisms contributes to all waves

Exotic wave sensitive to number of waves included (88 @COMPASS)

Deck explain most of the $J^{PC} = 4^{-+}$ and $6^{-+}$ waves

Important results for CLAS and GlueX collaboration
**Light hybrid mesons: Experimental efforts**

- **COMPASS**  
  **T. U. Munich**  
  Isobar formalism for $\tau^- \rightarrow 3\pi\nu_\tau$  
  Krinner and Paul, arXiv:2107.04295

Ongoing analyses @CLAS and GlueX:  
**Search for $\pi_1(1500)$ signal in $\eta^{(')}\pi$ and $3\pi$ final states**

- **U. Glasgow, INFN-Genova, etc**

- **U. Glasgow**  
  More details in Pauli’s talk

Joint effort with phenomenologists (JPAC, …)
Light hybrid mesons: Phenomenology

Forward-backward asymmetry related to the existence of (exotic) P-wave

JPAC, EPJC81 (2021) 647

More details in Szczepaniak's talk

Asymmetry originating mainly from \((a_2, f_2/P) \neq (f_2, f_2/P)\)

and from \((P, P)\) in \(\eta'\pi\)

Forward

Backward

Backward
Review by Llanes-Estrada (UC Madrid), **EPJ Special Topics 230 (2021) 1575**

Fit of $J/\psi \to \gamma \pi^0 \pi^0, \gamma K_S^0 K_S^0$ multipole, **Rodas, Pilloni et al (JPAC) in preparation**

4 scalar states:
- $f_0(1500)$
- $f_0(1710)$
- $f_0(2020)$
- $f_0(2330)$

No $f_0(1370)$
BESIII - New analysis started recently: $e^+e^- \rightarrow Y(4660) \rightarrow Z_c(4430)\pm \pi^\pm \rightarrow \psi(2S)\pi^+\pi^-$

- Zc(4430) observed first by Belle Collaboration and confirmed by LHCb
- In 2020/2021, BESIII took new data up to 4.9 GeV
  - we plan to search for Zc(4430) in BesIII by means of this new data set ($\sqrt{s}>4.6$ GeV BESIII datasets, about 5 fb$^{-1}$) and to study possible connection with the nearby Y(4660) resonance
  - Up to now:
    - Study the analysis feasibility (done) ==> for BR > 5% we expect to see the signal
    - start of the analysis: signal MC production done (resonant and non resonant)
    - Event and track selection almost complete (only additional checks are ongoing)

- Plans (from Autumn 2021):
  - Evaluation of background contributions
    - Study of inclusive Monte Carlo
  - Look at the data

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PRL112,222002
Plans for new analyses (with BESIII data)

• New analyses planned by our group for the next years:
  • Search for $X(1835)$ in $J\psi \to \omega X(1835)$, $X(1835) \to \eta' \pi^+ \pi^-$ hadronic decays
    • improve the analysis published on PRD99,071101 (published on April 2019) with the full $J\psi$ statistics collected by BESIII in the 2018 and 2019 (10 billion of $J\psi$ data)
  • BR measurement of $J\psi \to \phi \eta' \pi^+ \pi^-$, and search for $X(1835)$ into $\eta' \pi^+ \pi^-$ invariant mass spectra (ongoing inside BESIII Collaboration)
  • Study of the rare decay $h_c \to e^+ e^- \eta_c$ with 2.7 billion of $\psi(2S)$ data collected by BESIII: feasibility studies started in September 2021

Conferences:
• SIF 2020, SIF 2021, EPS

Papers:
• One paper in preparation (it will be submitted in the next days to MDPI-Special issue “High Energy Physics: Standard Model Predictions and Observation of New States”)
• One review on XYZ states to be published in Review of Physics
Exotic candidates

- $Z_c(3900)^\pm$
- $Z_c(4020)^\pm$

Extraction of partner reactions

- $e^+e^- \rightarrow J/\psi\pi^+\pi^-$
- $e^+e^- \rightarrow h_c(1P)\pi^+\pi^-$

No signal, upper limits (UL) given

**TABLE II.** Observed cross section $\sigma$ and upper limits (ULs) for the reaction $e^+e^- \rightarrow \eta_c\eta\pi^+\pi^-$ at the five center-of-mass energies.

<table>
<thead>
<tr>
<th>$E_{\text{c.m.}}$ [GeV]</th>
<th>$\sigma$ [pb]</th>
<th>UL after all correction [pb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.23</td>
<td>$-5.39^{+3.15}_{-2.83}$</td>
<td>6.2</td>
</tr>
<tr>
<td>4.26</td>
<td>$-0.98^{+4.11}_{-3.53}$</td>
<td>10.8</td>
</tr>
<tr>
<td>4.36</td>
<td>$8.59^{+6.72}_{-6.03}$</td>
<td>27.6</td>
</tr>
<tr>
<td>4.42</td>
<td>$3.07^{+5.36}_{-5.12}$</td>
<td>22.6</td>
</tr>
<tr>
<td>4.60</td>
<td>$3.16^{+6.91}_{-6.51}$</td>
<td>23.7</td>
</tr>
</tbody>
</table>
Heavy exotic mesons

U. Bonn  LHCb, PRD102 (2020) 092005

Study of the $X(3872) \equiv \chi_{c1}(3872)$ lineshape in pp and pole position extraction

$$m_{\chi_{c1}(3872)} = 3871.695 \pm 0.067 \pm 0.068 \pm 0.010 \text{ MeV}.$$  

$$\Gamma_{BW} = 1.39 \pm 0.24 \pm 0.10 \text{ MeV}$$

Experimental efforts in XYZ spectroscopy @GSI

More details in Glötzen’s talk
EIC Yellow Report, arXiv:2103.05419

JPAC, PRD102 (2020) 1107

Cross section estimation by JPAC

Implementation in event generator (ElSpectro) by D. Glazier (U. Glasgow)

\[ J^{\text{PAC}} \]

\[ \sigma(\gamma p \rightarrow Xp) \simeq 10 \text{ fb} \]

More details in Steven’s talk

More details in Pilloni's talk and in Szczepaniak's talk

Centre-of-mass energy

Renormalization of S-wave quarkonium wavefunctions at the origin, *JHEP*12 (2020) 065

P-wave quarkonium wavefunctions at the origin in the $\overline{\text{MS}}$ scheme, arXiv:2106.15514

Lattice gauge theory computation of the static force, arXiv:2106.01794

Inclusive production of heavy quarkonia in pNRQCD, *PRL*126 (2021) 082003 and *JHEP*09 (2021) 032

Inclusive production of heavy quarkonia in pNRQCD, *PRL*126 (2021) 082003 and *JHEP*09 (2021) 032

Heavy exotic mesons: (p)NRQCD

**TU Munich:** Brambila, Chung, Vairo (and collaborators)

$\overline{\text{MS}}$ renormalization of S-wave quarkonium wavefunctions at the origin, *JHEP*11 (2020) 130

Lattice gauge theory computation of the static force, arXiv:2106.01794

Inclusive production of heavy quarkonia in pNRQCD, *PRL*126 (2021) 082003 and *JHEP*09 (2021) 032

Barcelona: Soto and Tarrús Castellà

Nonrelativistic effective field theory for heavy exotic hadrons, *PRD*102 (2020) 014012
Conclusions

New developments since January 2020 in the network

U Glasgow, UC Madrid, U Barcelona, U Bonn, GSI, U Bochum, TU Munich, INFN Catania, Ferrara and Torino

Theory
Tools
Analyses

This network has member in

ALICE
COMPASS
BESIII
clas
GlueX
LHCb
RHIC

Citations Experiment
## Summary

### New developments since June 2019 in the network

<table>
<thead>
<tr>
<th>Theory</th>
<th>Tools</th>
<th>Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectra and decays of light and heavy hybrids from EFT and pNRQCD</td>
<td>Moments of photoproduction of 2 pseudo scalar mesons</td>
<td>( K^{*}(982) ) and ( \Omega(2012) ) with ALICE</td>
</tr>
<tr>
<td></td>
<td>Kinematics for 3-body decays</td>
<td>Test of pQCD in ( pp ) with BESIII</td>
</tr>
<tr>
<td></td>
<td>Webpages with codes</td>
<td>Pentaquark search in ( \Lambda_c ) decay with BESIII</td>
</tr>
<tr>
<td></td>
<td>Particle ID with Machine L.</td>
<td>( Z_c(4430)^+ ) and ( X(1835) ) search with BESIII</td>
</tr>
</tbody>
</table>

### Other developments in Task 3.1 missing? (LHCb from Neubert?)

- Pentaquark search
- \( Z_c(4430)^+ \) and \( X(1835) \) search

Don’t hesitate to contact me
BACKUP SLIDES
Vincent Mathieu  
TAHSP  
Task 3.1 Light exotic, stangeonium, charmonium

Coordinator: Nora Brambilla (talk at 16:45 and collaborator Hee Sok Chung at 17:45)

Brambilla, Lai, Segovia, Castella and Vairo
PRD101 (2020) 054040

Spectra of exotic charmonium derived from pNRQCD with spin-depend force included
Coordinator: Francesco Giacosa (talk tomorrow at 14:45)

Eshraim, Fischer, Giacosa and Parganlija
EPJ Plus 135 (2020) 945

Linear Sigma Model extended with hybrid mesons

\[ \mathcal{L}_{eLSM,1}^{\text{hybrid-linear}} = i2\lambda_1^{hyb} G \{ \text{Tr} \left[ \Pi_\mu^{hyb} \left[ P, B^\mu \right] \right] + \text{Tr} \left[ \Pi_\mu^{hyb} \left[ V_E^\mu, S \right] \right] \}
+ 2\lambda_1^{hyb} G \{ \text{Tr} \left[ B_\mu^{hyb} \left\{ P, V_E^\mu \right\} \right] + \text{Tr} \left[ B_\mu^{hyb} \left\{ B^\mu, S \right\} \right] \}. \]

\[ \pi_1 \rightarrow b_1 \pi, \ldots \]

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Mass [MeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \pi_1^{hyb} )</td>
<td>1660 [input using ( \pi_1(1600) ) [9]]</td>
</tr>
<tr>
<td>( \eta_1^{hyb} )</td>
<td>1660</td>
</tr>
<tr>
<td>( \eta_1^{hyb, S} )</td>
<td>1751</td>
</tr>
<tr>
<td>( K_1^{hyb} )</td>
<td>1707</td>
</tr>
<tr>
<td>( b_1^{hyb} )</td>
<td>2000 [input set as an estimate]</td>
</tr>
<tr>
<td>( h_1^{hyb, N,B} )</td>
<td>2000</td>
</tr>
<tr>
<td>( K_1^{hyb, B} )</td>
<td>2063</td>
</tr>
<tr>
<td>( h_1^{hyb, S,B} )</td>
<td>2126</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Gamma_{\pi_1^{hyb} \rightarrow \pi \eta^{'}} / \Gamma_{\pi_1^{hyb} \rightarrow \pi \eta} )</td>
<td>12.7</td>
</tr>
<tr>
<td>( \Gamma_{K_1^{hyb} \rightarrow K \eta} / \Gamma_{\pi_1^{hyb} \rightarrow \pi \eta} )</td>
<td>0.69</td>
</tr>
<tr>
<td>( \Gamma_{K_1^{hyb} \rightarrow K \eta^{'}} / \Gamma_{\pi_1^{hyb} \rightarrow \pi \eta} )</td>
<td>5.3</td>
</tr>
<tr>
<td>( \Gamma_{\eta_1^{hyb, N} \rightarrow \eta \eta^{'}} / \Gamma_{\pi_1^{hyb} \rightarrow \pi \eta} )</td>
<td>2.2</td>
</tr>
<tr>
<td>( \Gamma_{\eta_1^{hyb, S} \rightarrow \eta \eta^{'}} / \Gamma_{\pi_1^{hyb} \rightarrow \pi \eta} )</td>
<td>1.57</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Gamma_{K_1^{hyb} \rightarrow K h_1(1170)} / \Gamma_{\pi_1^{hyb} \rightarrow \pi b_1} )</td>
<td>0.050</td>
</tr>
<tr>
<td>( \Gamma_{b_1^{hyb} \rightarrow \pi \omega(1650)} / \Gamma_{\pi_1^{hyb} \rightarrow \pi b_1} )</td>
<td>0.065</td>
</tr>
<tr>
<td>( \Gamma_{K_1^{hyb} \rightarrow \pi K^*(1680)} / \Gamma_{\pi_1^{hyb} \rightarrow \pi b_1} )</td>
<td>0.19</td>
</tr>
<tr>
<td>( \Gamma_{h_1^{hyb} \rightarrow \pi \rho(1700)} / \Gamma_{\pi_1^{hyb} \rightarrow \pi b_1} )</td>
<td>0.16</td>
</tr>
</tbody>
</table>
Estimation of XYZ Cross Sections @EIC

**JPAC collaboration**
Albaladejo, Hiller-Blin, Pilloni, Winney, Fernández-Ramírez, VM and Szczepaniak
PRD102 (2020) 114010

**Cross sections prediction for**

\[ \gamma p \rightarrow XYZ \]

\[ X(3872), X(8900), Y(4260) \]
\[ Z_c(3900)^+, Z_b(10610)^+, Z_b(10650)^+ \]
Formalism for Any Three-Body Decays

**JPAC collaboration**


Isobar parametrised in 2-body frame need to be boosted in the 3-body frame

All kinematical functions coded and available:

http://cgl.soic.indiana.edu/jpac/DalitzPlot.php

Applied to:

\[ \Lambda_c^+ \rightarrow pK^-\pi^+ \]
\[ \bar{B}^0 \rightarrow \psi K^-\pi^+ \]
\[ \Lambda_b^0 \rightarrow pK^-J/\psi \]
Moments of 2 Mesons Photoproduction

JPAC collaboration
VM, Albaladejo, Fernández-Ramírez, Jackura, Mikhasenko, Pilloni and Szczepaniak, PRD100 (2019) 054017

Formula to extract moments from angular distribution and their relation to partial waves

http://cgl.soic.indiana.edu/jpac/EtaPi_moments.php

New observable sensitive to exotic waves

Implemented in GlueX analyses \( \pi \eta, \pi \pi, \eta \eta \)
Double Regge Phenomenology

**JPAC collaboration**
Bibrzycki, Fernández-Ramírez, Mikhasenko, VM et al
work in progress

Fit COMPASS data with double Regge amplitudes

F/B asymmetry responsible for exotic odd waves
Websites

Event generator for XYZ@EIC

https://github.com/dglazier/elSpectro

Coordinator: Derek Glazier

JPAC Interactive webpage

https://ceem.indiana.edu/jpac

Coordinator: VM

Photoproduction:

1. High energy model for tensor meson photoproduction: $\gamma p \to T_p$ page
2. High energy model for $p_\gamma \to \eta_b p$ and di-meson moments: $\gamma p \to \eta_b p$ page
3. High energy model for $\gamma N \to \pi N$ constrained by FESR: $\gamma N \to \pi N$ page
4. High energy model for $\rho^0, \omega, \phi$ spin density matrix elements: $\gamma p \to V_p$ page
5. High energy model for $\eta'$ beam asymmetry photoproduction: $\gamma p \to \eta' p$ page
6. High energy model for $\eta$ photoproduction: $\gamma p \to \eta p$ page
7. High energy model for $\pi^0$ photoproduction: $\gamma p \to \pi^0 p$ page
8. Model for $J/\psi$ photoproduction $\gamma p \to J/\psi p$: unpolarized observables; polarized observables

Hadroproduction:

1. Pion-nucleon Scattering:
   - $\pi N \to \pi N$ amplitude page
   - Finite energy sum rules $\pi N \to \pi N$ FESR page
2. Kaon-nucleon scattering: $K N \to \bar{K} N$ page

Three-body Decay: Isobar decomposition and recoupling coefficients.

Light Meson Decay:

1. $\eta$ meson into three pions: $\eta \to 3\pi$ page
2. Vector meson into three pions: $\omega, \phi \to 3\pi$ page

Heavy Baryon Decay:

1. $\Lambda_b \to J/\psi p K^-$ and the $P_c(4312)^+\to P_c(4312)^+$ page
Coordinator: Angela Badalà

Measuring $p_T$ spectra of in different multiplicity bins of $K^*(982)^\pm \rightarrow \pi K$ in $pp$ at 13 TeV

Developing Machine Learning technique to identify resonances

Training on $K^*(892)^0 \rightarrow \pi K$ to improve recognition in $pb pb$ collisions

Future plan: applying on $\Omega(2012) \rightarrow \Xi K$ in $pp$ at 13 TeV
Matching pQCD with data

Investigation of the interference between hadronic and electromagnetic processes

proton-antiproton final states

$e^+e^- \rightarrow J/\psi \rightarrow p\bar{p}$ vs $e^+e^- \rightarrow p\bar{p}$

ROOT implementation of fitting routine
M. Ablikim et al. PRD86 032014 (2012)

Theoretical prediction from
Baldini, Bini and Luppi
PLB404 (1997) 362
# BESIII Group in Ferrara

<table>
<thead>
<tr>
<th>Ferrara group</th>
<th>Position</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isabella Garzia</td>
<td>Researcher (UNIFE)</td>
<td>Coordinator/Analysis</td>
</tr>
<tr>
<td>Gianluigi Cibinotto</td>
<td>Researcher (INFN)</td>
<td>Coordinator/Analysis</td>
</tr>
<tr>
<td>Giulio Mezzadri</td>
<td>Postdoc</td>
<td>Analysis</td>
</tr>
<tr>
<td>Ilaria Balossino</td>
<td>Postdoc</td>
<td>Analysis</td>
</tr>
<tr>
<td>Marco Scodrigo</td>
<td>PhD student</td>
<td>Analysis</td>
</tr>
</tbody>
</table>
Search for hidden-strangeness pentaquark in $\Lambda_c$ decay at BESIII

- In 2014, BESIII has collected 567 pb$^{-1}$ close to $\Lambda_c\bar{\Lambda}_c$ production threshold (4.6 GeV)
  - The pentaquark is searched in the $p\phi$ invariant mass
  - The result is limited by statistic
  - No evidence of signal is found
  - PLANS: BESIII has collected new data between 4.6 to 4.7 GeV in 2020 — this analysis will be updated

Stimulated by LHCb and Belle observation, in BESIII we reached for a hidden-strangeness pentaquark in $\Lambda_c$ decay
Inclusive measurement of $hc$ in the $\psi(2S)$ decay

Ongoing analysis

- From April 2019:
  - Event and track selection validation
  - Systematic uncertainty studies finalised

- This year (2020):
  - BESIII internal document released
  - Internal review started

- PLANS:
  - Prepare the draft
  - Submission to journal (2021)
**BESIII Group in Ferrara**

**BESIII - New analysis started very recently:**
\[ e^+e^- \rightarrow Y(4660) \rightarrow Zc\text{-}/+(4430)pi\text{-}/+ \rightarrow \psi(2S)\pi\text{-}/+pi\text{-}/+ \]

- Zc(4430) observed first by Belle Collaboration and confirmed by LHCb
- In 2020, BESIII took new data up to 4.7 GeV
  - we plan to search for Zc(4430) in BesIII by means of this new data set and to study possible connection with the nearby Y(4660) resonance

**PLANS (from Autumn 2020):**
- start of the analysis: signal MC production ongoing (resonant and non resonant)
- Study the analysis feasibility
- Plan to have event selection cut by min winter 2020/2021
Plans for new analyses (with BESIII data)

- Two new analyses planned by our group for the next year:
  - Search for $X(1835)$ in $J\psi \rightarrow \omega X(1835)$, $X(1835) \rightarrow \eta'\pi^+\pi^-$ hadronic decays
  - Improve the analysis published on PRD99,071101 (published on April 2019) with the full $J\psi$ statistics collected by BESIII in the 2018 and 2019 (10 billion of $J\psi$ data)
  - BR measurement of $J\psi \rightarrow \phi \eta'\pi^+\pi^-$, and search for $X(1835)$ into $\eta'\pi^+\pi^-$ invariant mass spectra
Summary

New developments since June 2019 in the network

**Theory**
- Spectra and decays of light and heavy hybrids from EFT and pNRQCD

**Tools**
- Moments of photoproduction of 2 pseudo scalar mesons
- Kinematics for 3-body decays
- Webpages with codes
- Particle ID with Machine L.

**Analyses**
- $K^*(982)$ and $\Omega(2012)$ with ALICE
- Test of pQCD in $p\bar{p}$ with BESIII
- Pentaquark search in $\Lambda_c$ decay with BESIII
- $Z_c(4430)^+$ and $X(1835)$ search with BESIII

Other developments in Task 3.1 missing?
(LHCb from Neubert?)

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Meson Spectroscopy Analysis of New and Exotic States: Search for and study of light exotic mesons, Strangeonia and charmonia

Vincent MATHIEU
Universidad de Barcelona
Complutense Universidad de Madrid

York - September 2021