A Search for the LHCb Pentaquark in $J/\psi$
Photo-production at Hall C
(for the $J/\psi$-007 Collaboration)

Burcu Duran

Hall C Winter Collaboration Meeting
January 29, 2019
Discovery of the LHCb charmed (charming!) "pentaquark"

$P_c$

Observation of $J/\psi p$ Resonances Consistent with Pentaquark States in $\Lambda_c^0 \to J/\psi K^- p$ Decays - LHCb Collaboration (Aaij, Roel et al.)

Cited by: 666 records

.. of which self-citations: 82 records

Co-cited with: 25593 records

666 citations since 2015!
LHCb charmed (charming!) "pentaquark" $P_c$

2 $P_c$ states needed to describe the results

- **narrow**: $P_c(4450)$, width: $\sim 39$ MeV
- **broad**: $P_c(4380)$, width: $\sim 205$ MeV

Spin/parity either:

- $5/2^+$, $3/2^-$ (most likely)
- $5/2^-$, $3/2^+$
- $3/2^-$, $5/2^+$

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Charmed "pentaquark" in Photo-production

- Common Interpretations for LHCb observations

- $P_{c}$ states

- Alternative: Kinematic enhancements through Anomalous Triangle Singularity (ATS)

- The photo-production is an ideal tool to distinguish between the explanations

- if $P_{c}$ states are real states, should also be created in photo-production

- kinematic enhancement through ATS not possible

- $P_{c}(4450)$ creates narrow peak around $E_{\gamma} = 10.1$ GeV

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- Common Interpretations for LHCb observations
  - LHCb: True resonant "Pentaquark" $P_c$ states
Charmed "pentaquark" in Photo-production

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Charmed "pentaquark" in Photo-production

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$J/\psi$ Photo-production: Current Data Status

- Measured in many experiments at high $W_{\gamma p}$
  - Dominated by $t$ channel 2-gluon exchange
- Almost no data in threshold region
Unpublished GLUEX data from Lubomir Pentchev’s slide
**Resonant $J/\psi$ Production through $P_c$ Decay**

- Cross section depends on coupling to $(J/\psi p)$ channel
- $J/\psi$ angular distribution depends on $P_c$ spin/parity

Pentaquark Search with E12-16-007 Experiment in Hall C

- **Experimental Setup (PAC)**
  - 11 GeV beam energy
  - 50 µA
  - 9% copper radiator
  - LH2 15 cm target
  - total 10% RL

- **Experimental Setup (NEW)**
  - 10.6 GeV beam energy
  - 70 µA
  - 9% copper radiator
  - LH2 10 cm target
  - total 10% RL
**E12-16-007 SETTINGS**

- **Signal \( (P_c) \) Setting:**
  - minimizes accidentals and maximizes S/B
  - **HMS:** 4.6 GeV, 16.4°
  - **SHMS:** 4.3 GeV, 30°

- **t channel (BG) Setting 1:**
  - low \( E_\gamma \), low \( t \)
  - precise determination of the \( t \) channel background
  - **HMS:** 4.95 GeV, 19.1°
  - **SHMS:** 4.835 GeV, 17°

- **t channel (BG) Setting 2:**
  - high \( E_\gamma \), low \( t \)
  - precise determination of the \( t \) channel background
  - **HMS:** 4.08 GeV, 19.9°
  - **SHMS:** 3.5 GeV, 20.1°

Photon Energy Reconstruction

Initial photon energy can be unambiguously reconstructed from the reconstructed $J/\psi$ momentum and energy

- **Assumptions**
  - proton target at rest
  - photon beam along the z axis
  - proton and $J/\psi$ are the two final state particles

\[
E_\gamma = \frac{M_\psi^2 - 2E_J M_P}{2(E_\psi - M_P - P_\psi \cos \theta_\psi)}
\]
Projected results for "background" setting 1
low $E_{\gamma}$, low $t$
Projected results for "background" setting 2
high $E_\gamma$, low $t$

![Graphs showing distributions of $E_\gamma$ and $t$ for different settings.](image)

**Labels:**
- Counts
- $E_\gamma$ (GeV)
- $t$ (GeV$^2$)

**Legend:**
- 1-channel J/$\Psi$
- $P_3/2$ (5.0% coupling)
- $P_5/2$ (5.0% coupling)
- sum
- 1.0 day estimate (1129 counts)
- 1.0 day estimate (1103 counts)
Projected results for "signal" setting

![Graph 1: Counts vs. $E_\gamma$ (GeV)](image1)

- t-channel $J/\Psi$
- $P_c$ 3/2- (5.0% coupling)
- $P_c$ 5/2+ (5.0% coupling)
- sum
- 8.0 day estimate (866 counts)

![Graph 2: Counts vs. $t$ (GeV$^2$)](image2)

- t-channel $J/\Psi$
- $P_c$ 3/2- (5.0% coupling)
- $P_c$ 5/2+ (5.0% coupling)
- sum
- 8.0 day estimate (865 counts)
Impact on $J/\psi$ World Data

![Graph showing the impact on $J/\psi$ world data with various settings and measurements.](image-url)
Sensitivity for Discovery

- $\Delta$-log-likelihood formalism

- $5\sigma$ discovery sensitivity can be reached starting from 1.3%
Hall C Bremsstrahlung Radiator (Jan. 2019)

- Link to water-cooled radiator operating procedure TGT-PROC-19-001:
  - Copy of

- Just upstream of target scattering chamber
- Water-cooled
- Upper (=home) & Lower limit switches
- Stepper motor controlled
- No motion FSD for radiator
  - Can move in/out of beam while beam is on after calling MCC
- But there is an FSD on water flow

Jan 18, 2019

Bremsstrahlung Radiator

Greg Smith’s slide
E12-16-007 Experiment: Radiator for photon beam

Setup & GUI

Spare
Primary
HOME=OUT

Greg Smith’s slide
**Particle Identification**

- **HMS Momentum Settings**
  - 4.6 GeV, 4.95 GeV, 4.08 GeV

- **SHMS Momentum Settings**
  - 4.835 GeV, 4.3 GeV, 3.5 GeV

- **PID for HMS:**
  - HMS Cherenkov + Calorimeter

- **PID for SHMS**
  - SHMS Noble Gas Cherenkov + Calorimeter
Summary

High impact experiment

- true nature of the LHCb "pentaquark" $P_c$
- Strong sensitivity to the coupling 1.3%
- Contribution to the knowledge of the threshold region of the $J/\psi$ photo-production (absolute cross section)
A Search for the LHCb Charmed Pentaquark in Photo-Production

The LHCb experiment found very strong evidence for a charmed pentaquark.

The first collaboration meeting for the J/ψ-007 experiment took place on October 26, 2018 at Jefferson Lab.

Interested to know more about the collaboration? Want to contact the spokesperson? Interested to join the
A Search for the LHCb Charmed Pentaquark in Photo-Production

PLEASE SIGN UP FORhifts!
Background: Inelastic $t$ Channel $\gamma p \rightarrow J/\psi p\pi$

- Threshold at 9 GeV
- Reconstructed photon energy $E_{rc}$ is 1 GeV too low
- Contribution to the $8 \text{ GeV} < E_{rc} < 9.7 \text{ GeV}$ range for a photon end-point energy of 10.7 GeV
  - not an issue for the Pc(4450) ($E_{rc} > 9.7\text{GeV}$)!

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Background: single electron/pion tracks

- Electron rate estimated using CTEQ5, cross checked with F1F209
- Positron rate estimated using EPC combined with a background program from E94-010
- Contribution to the coincidence rate < 10^{-5} Hz
- Pion rates estimated using Wiser
  - Assuming a pion rejection > 103 from the Cherenkov + Calorimeter coincidence rate \sim 10^{-5} Hz
Resolution

reconstructed $J/\psi$ mass: $\sigma = 5$ MeV

from Sylvester Joosten's slide