Baryon Spectroscopy at COMPASS

HK 8.4

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for the COMPASS collaboration

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DPG-Frühjahrstagung Frankfurt
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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

COMPASS

Introduction

Why study baryons?

- 3-quark bound states
  $\Rightarrow$ excellent probe to study QCD
- baryon spectrum only poorly known
  - many states with $*$ or $**$ in PDG listings
  - many missing states

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How to study baryons?

- π**N** scattering
  - no new data available
  - still dominates PDG listings
- γ**N** scattering
  - MAMI, ELSA
- J/ψ decays
  - BESIII
- **NN** scattering
  - HADES
  - **COMPASS**

Introduction

What do we measure at COMPASS?

- 2009 data taking
- 190 GeV/c proton beam on liquid hydrogen target
- diffractive dissociation
- Different channels investigated:
  - $\mathbf{pp} \longrightarrow \mathbf{p_f}\pi^+\pi^-\mathbf{p}_{\text{recoil}}$
  - $\mathbf{pp} \longrightarrow \mathbf{p_f}\mathbf{K}^+\mathbf{K}^-\mathbf{p}_{\text{recoil}}$
  - $\mathbf{pp} \longrightarrow \mathbf{p_f}\pi^0\pi^0\mathbf{p}_{\text{recoil}}$
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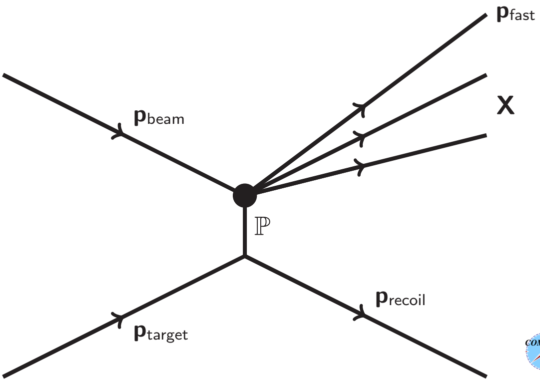

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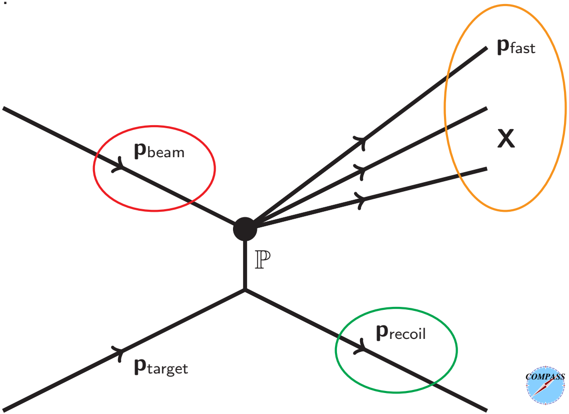

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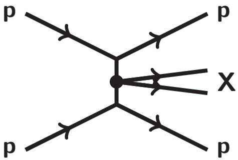
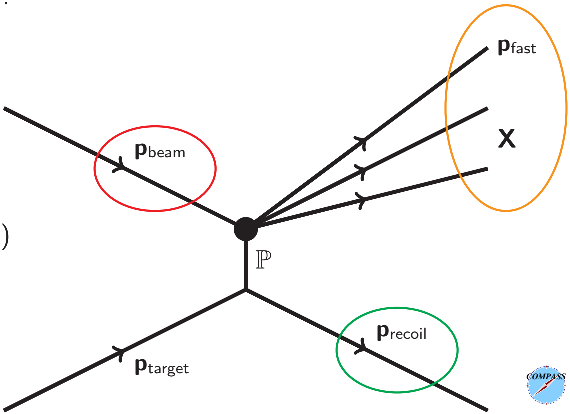
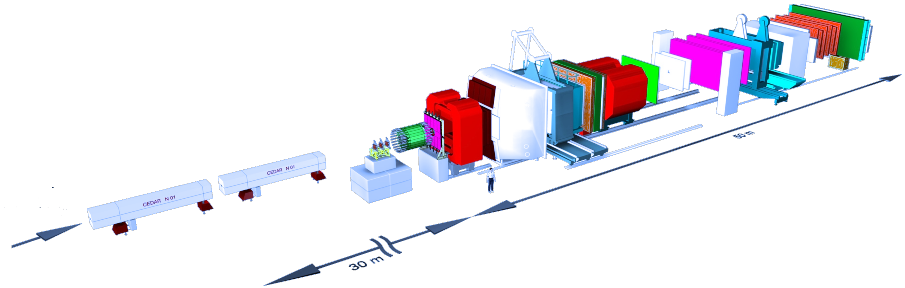
Central Production (HK 47.5)





The COMPASS Experiment

- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
- Located at SPS at CERN



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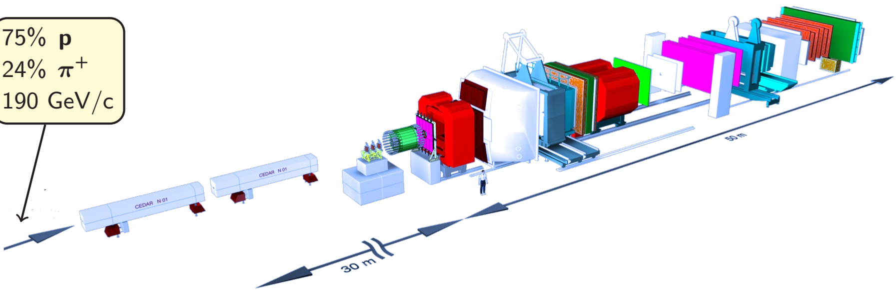
75% **p**
24% π^+
190 GeV/c



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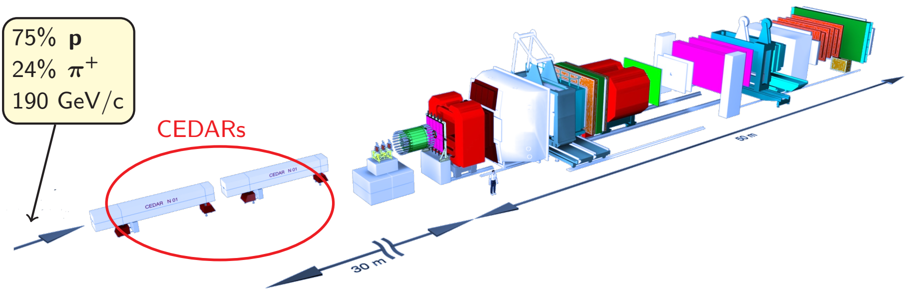

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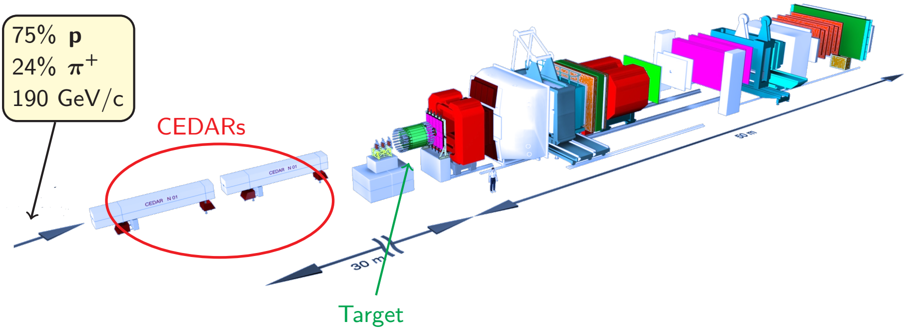

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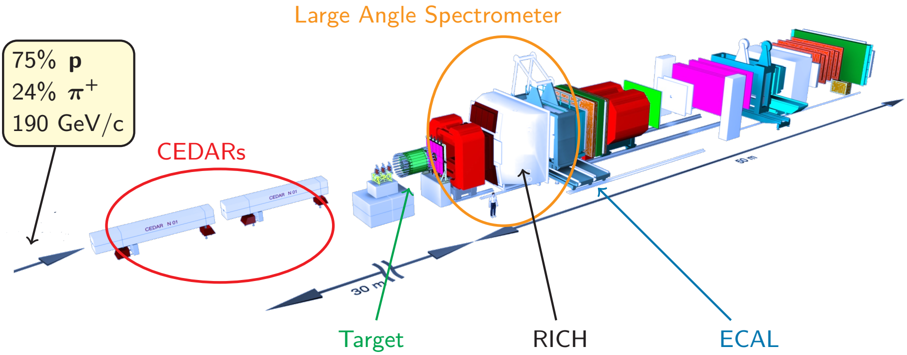

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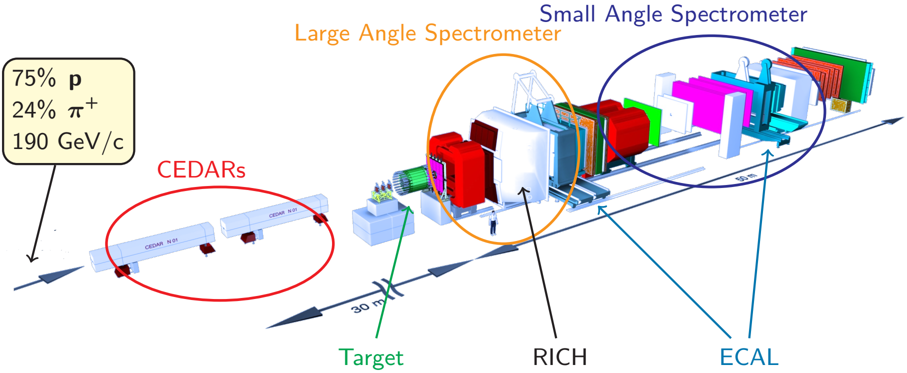

Event Selection

Basic Cuts

- minimum bias trigger
  - incoming beam + recoiling proton
- exactly 1 primary vertex reconstructed inside the target
- identified incoming proton
- 1 reconstructed recoil proton
- $\approx \mathbf{4 \times 10^9}$ events at this stage

Selection of π^0/η

- 1 outgoing charged particle with positive charge
- 2 ECAL clusters
  - Combined to a π^0 or η

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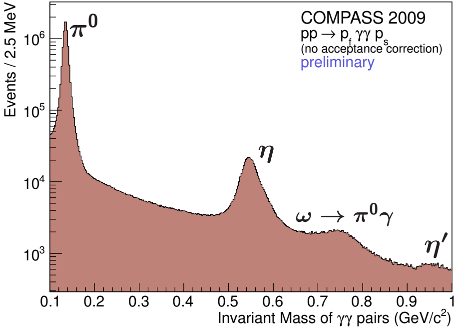

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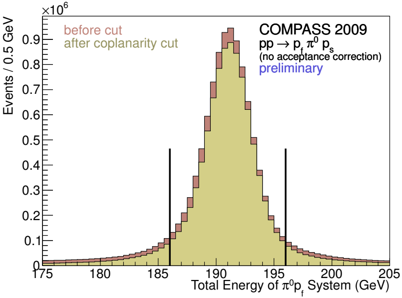
Event Selection

Exclusivity and Coplanarity

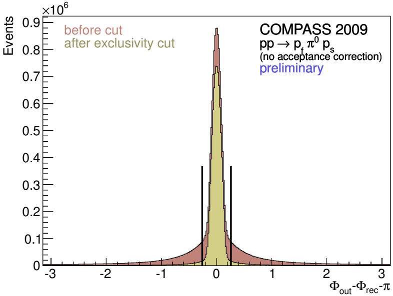
Exclusive events selected by 2 cuts:

- energy sum of outgoing system around peak value (exclusivity)
- azimuthal angles of outgoing system and recoil proton differ by π (coplanarity)

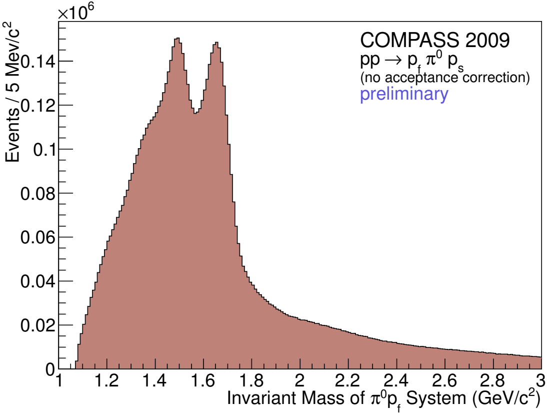
Exclusivity



Coplanarity

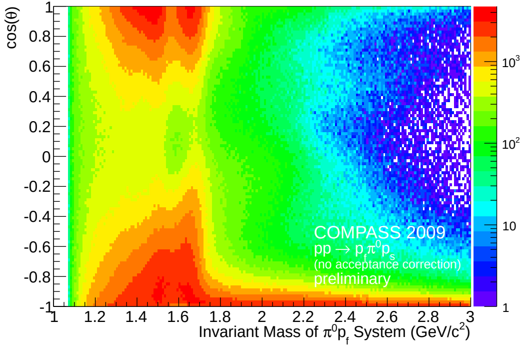


$pp \rightarrow p_f \pi^0 p_{recoil}$ – Invariant Mass



- nearly 9 million events
- no **Δ(1232)** visible
  ↔ no isospin transfer in Pomeron exchange
- peaks around **1500 MeV** and **1700 MeV**
  → several candidates
- steep drop after second peak
  → change of production mechanism?
  → have a look at angular dependece

$pp \to p_f \pi^0 p_{recoil}$ – Polar Angle of π^0

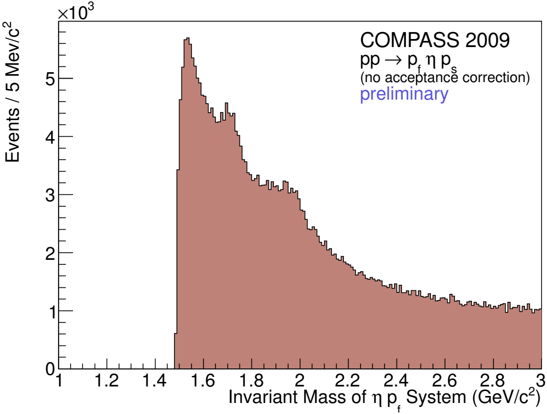


- Rich structures in region of peaks (< **1800 MeV**)
- Change in angular distribution above this region (π^0 goes "backwards")

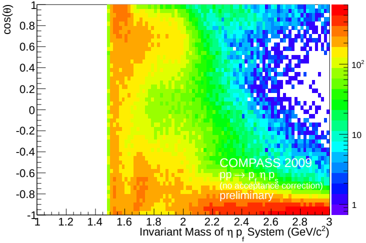
Gottfried-Jackson Frame

- Rest frame of $\mathbf{p_f \pi^0}$; z-axis: along beam direction
- y-axis: orthogonal to production plane (beam $\times$ $\mathbf{p_f \pi^0}$)

$pp \to p_f \eta p_{recoil}$



- some structures visible
- similar effect as in $\pi^0 p$ for higher masses
- more than 400 million events



Towards a Partial Wave Analysis

- Do not describe the full process
- Only investigate two-body decay into $\mathbf{p}\boldsymbol{\pi}^{\mathbf{0}}$
- Fit in bins of the invariant $\mathbf{p}\boldsymbol{\pi}^{\mathbf{0}}$ mass

Intensity (fit function)

$$\mathcal{I} = \sum_{\epsilon} \sum_{\lambda} \left| \sum_{k} T_k^{\epsilon} A_k^{\epsilon,\lambda}(\theta, \phi; m_{p\pi^0}) \right|^2$$

with (complex) strength $\mathbf{T_k}$, reflectivity $\epsilon = \pm \mathbf{i}$, proton helicity $\boldsymbol{\lambda} = \pm\frac{1}{2}$

Partial Wave Amplitude

$$A_k^{\epsilon,\lambda}(\theta, \phi; m_{p\pi^0}) = \sqrt{2L+1}(L\ 0, \tfrac{1}{2}\ \lambda | J\ M) D_{M\lambda}^{J,\epsilon\ *}(\phi, \theta, 0) F_L(q)$$

with Blatt-Weisskopf barrier factor $\mathbf{F_L(q)}$

Towards a Partial Wave Analysis

Wigner D-function in reflectivity basis

$$\mathbf{D}^{\mathbf{J},\epsilon}_{\mathbf{M}\lambda}(\phi,\theta,0) = \chi(\mathbf{M})\left[\mathbf{D}^{\mathbf{J}}_{\mathbf{M}\lambda}(\phi,\theta,0) - \epsilon\eta(-1)^{\mathbf{J}-\mathbf{M}}\mathbf{D}^{\mathbf{J}}_{-\mathbf{M}\lambda}(\phi,\theta,0)\right]$$

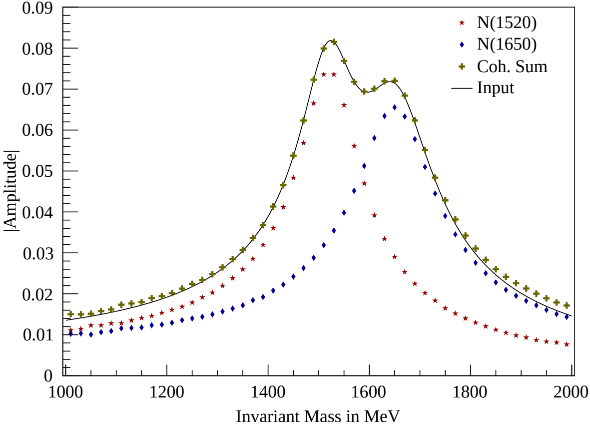
mit

$$\chi(\mathbf{M}) = \begin{cases} \frac{1}{\sqrt{2}} & \mathbf{M} > 0 \\ \frac{1}{2} & \mathbf{M} = 0 \quad \text{(not possible for baryons)} \\ 0 & \mathbf{M} < 0 \end{cases}$$

- η ist the parity of the $\mathbf{p}\pi^0$ resonance: $\eta = (-1)^{\mathbf{L}}$
- reflectivity ϵ is given as $\epsilon^2 = (-1)^{2\mathbf{J}} \Rightarrow \epsilon = \pm\mathbf{i}$
- M and λ are fixed by Clebsch-Gordan coefficients in this basis

Testing the fit

- Produce angular distributions in mass bins
  - include two Breit-Wigner peaks in mass spectrum
  - include phase shift between the peaks
- Run the fit over the produced distributions



Conclusion and Outlook

- COMPASS has large datasets for baryon spectroscopy in **pp** scattering
- different channels accessible
- PWA framework for (simple) 2-body decays currently being developed
- first tests yield promising results

Outlook

- acceptance correction still to be included
- Run fits on data

Thank you for your attention

Blatt-Weisskopf Faktoren

- Beschreiben die Drehimpulsbarriere beim Zerfall
- Abhängig von Impuls $\mathbf{p} = |\vec{\mathbf{p}}|$ und Drehimpuls $\mathbf{L}$
- Definiert über Hankelfunktionen:

$$F_L(p) = \frac{|h_L^{(1)}(1)|}{|x h_L^{(1)}(x)|} \qquad \text{mit } x = \frac{p}{p_R} \quad p_R = 0.1973\ \text{GeV}/c$$

$$F_0(p) = 1$$

$$F_1(p) = \sqrt{\frac{2z}{z+1}}$$

$$F_2(p) = \sqrt{\frac{13z^2}{(z-3)^2 + 9z}}$$

$$F_3(p) = \sqrt{\frac{277z^3}{z(z-15)^2 + 9(2z-5}}$$

$$F_4(p) = \sqrt{\frac{12746z^4}{(z^2-45z+105)^2 + 25z(2z-21)^2}}$$

$$z = \left(\frac{p}{p_R}\right)^2$$

Clebsch-Gordan-Koeffizienten

L	λ	J	M	CG
0	+1/2	1/2	+1/2	1
0	−1/2	1/2	+1/2	0
0	+1/2	1/2	−1/2	0
0	−1/2	1/2	−1/2	1
1	+1/2	1/2	+1/2	$-\frac{1}{\sqrt{3}}$
1	−1/2	1/2	+1/2	0
1	+1/2	1/2	−1/2	0
1	−1/2	1/2	−1/2	$\frac{1}{\sqrt{3}}$
1	+1/2	3/2	+1/2	$\sqrt{\frac{2}{3}}$
1	−1/2	3/2	+1/2	0
1	+1/2	3/2	−1/2	0
1	−1/2	3/2	−1/2	$\sqrt{\frac{2}{3}}$
2	+1/2	3/2	+1/2	$-\sqrt{\frac{2}{5}}$
2	−1/2	3/2	+1/2	0
2	+1/2	3/2	−1/2	0
2	−1/2	3/2	−1/2	$\sqrt{\frac{2}{5}}$
2	+1/2	5/2	+1/2	$\sqrt{\frac{3}{5}}$
2	−1/2	5/2	+1/2	0
2	+1/2	5/2	−1/2	0
2	−1/2	5/2	−1/2	$\sqrt{\frac{3}{5}}$

L	λ	J	M	CG
3	+1/2	5/2	+1/2	$-\sqrt{\frac{3}{7}}$
3	−1/2	5/2	+1/2	0
3	+1/2	5/2	−1/2	0
3	−1/2	5/2	−1/2	$\sqrt{\frac{3}{7}}$
3	+1/2	7/2	+1/2	$\sqrt{\frac{4}{7}}$
3	−1/2	7/2	+1/2	0
3	+1/2	7/2	−1/2	0
3	−1/2	7/2	−1/2	$\sqrt{\frac{4}{7}}$
4	+1/2	7/2	+1/2	$-\frac{2}{3}$
4	−1/2	7/2	+1/2	0
4	+1/2	7/2	−1/2	0
4	−1/2	7/2	−1/2	$\frac{2}{3}$
4	+1/2	9/2	+1/2	$\sqrt{\frac{5}{9}}$
4	−1/2	9/2	+1/2	0
4	+1/2	9/2	−1/2	0
4	−1/2	9/2	−1/2	$\sqrt{\frac{5}{9}}$

Verbleibende Amplituden

$$\frac{1}{2}^{+}: \quad T^{\epsilon}_{\frac{1}{2}+} \cdot \frac{1}{\sqrt{2}} \cdot \left(D^{\frac{1}{2}}_{\frac{1}{2}\frac{1}{2}}(\phi,\theta,0) - \epsilon D^{\frac{1}{2}}_{-\frac{1}{2}\frac{1}{2}}(\phi,\theta,0)\right) \cdot F_0(q)$$

$$\frac{1}{2}^{-}: \quad -T^{\epsilon}_{\frac{1}{2}-} \cdot \frac{1}{\sqrt{2}} \cdot \left(D^{\frac{1}{2}}_{\frac{1}{2}\frac{1}{2}}(\phi,\theta,0) + \epsilon D^{\frac{1}{2}}_{-\frac{1}{2}\frac{1}{2}}(\phi,\theta,0)\right) \cdot F_1(q)$$

$$\frac{3}{2}^{+}: \quad -T^{\epsilon}_{\frac{3}{2}+} \cdot 1 \cdot \left(D^{\frac{3}{2}}_{\frac{1}{2}\frac{1}{2}}(\phi,\theta,0) + \epsilon D^{\frac{3}{2}}_{-\frac{1}{2}\frac{1}{2}}(\phi,\theta,0)\right) \cdot F_2(q)$$

$$\frac{3}{2}^{-}: \quad T^{\epsilon}_{\frac{3}{2}-} \cdot 1 \cdot \left(D^{\frac{3}{2}}_{\frac{1}{2}\frac{1}{2}}(\phi,\theta,0) - \epsilon D^{\frac{3}{2}}_{-\frac{1}{2}\frac{1}{2}}(\phi,\theta,0)\right) \cdot F_1(q)$$

$$\frac{5}{2}^{+}: \quad T^{\epsilon}_{\frac{5}{2}+} \cdot \sqrt{\frac{3}{2}} \cdot \left(D^{\frac{5}{2}}_{\frac{1}{2}\frac{1}{2}}(\phi,\theta,0) - \epsilon D^{\frac{5}{2}}_{-\frac{1}{2}\frac{1}{2}}(\phi,\theta,0)\right) \cdot F_2(q)$$

$$\frac{5}{2}^{-}: \quad -T^{\epsilon}_{\frac{5}{2}-} \cdot \sqrt{\frac{3}{2}} \cdot \left(D^{\frac{5}{2}}_{\frac{1}{2}\frac{1}{2}}(\phi,\theta,0) + \epsilon D^{\frac{5}{2}}_{-\frac{1}{2}\frac{1}{2}}(\phi,\theta,0)\right) \cdot F_3(q)$$

$$\frac{7}{2}^{+}: \quad -T^{\epsilon}_{\frac{7}{2}+} \cdot \sqrt{2} \cdot \left(D^{\frac{7}{2}}_{\frac{1}{2}\frac{1}{2}}(\phi,\theta,0) + \epsilon D^{\frac{7}{2}}_{-\frac{1}{2}\frac{1}{2}}(\phi,\theta,0)\right) \cdot F_4(q)$$

$$\frac{7}{2}^{-}: \quad T^{\epsilon}_{\frac{7}{2}-} \cdot \sqrt{2} \cdot \left(D^{\frac{7}{2}}_{\frac{1}{2}\frac{1}{2}}(\phi,\theta,0) - \epsilon D^{\frac{7}{2}}_{-\frac{1}{2}\frac{1}{2}}(\phi,\theta,0)\right) \cdot F_3(q)$$

$$\frac{9}{2}^{+}: \quad T^{\epsilon}_{\frac{9}{2}+} \cdot \sqrt{\frac{5}{2}} \cdot \left(D^{\frac{9}{2}}_{\frac{1}{2}\frac{1}{2}}(\phi,\theta,0) - \epsilon D^{\frac{9}{2}}_{-\frac{1}{2}\frac{1}{2}}(\phi,\theta,0)\right) \cdot F_4(q)$$