The OZI rule and spin alignment of vector mesons at COMPASS

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Outline

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- Results
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  - F_{OZI} as a function of $x_F(p_{fast})$ and p_V
  - Spin alignment
- What do we learn from this?

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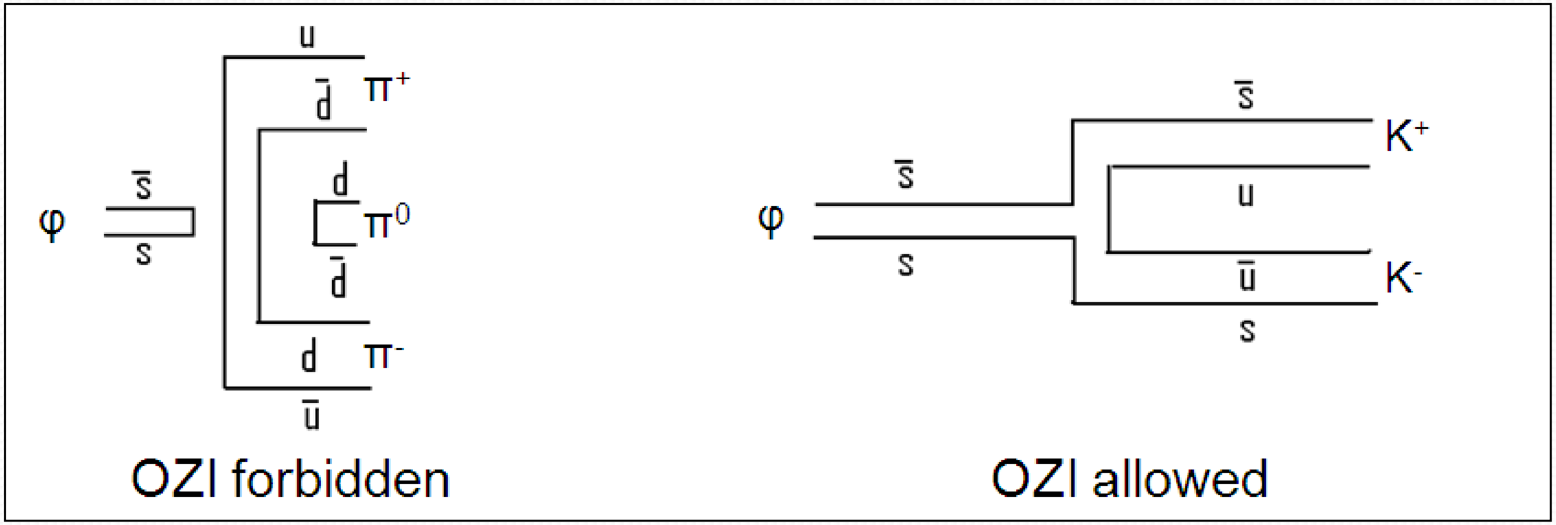
The results have been published in NPB 886 (2014) 1078-1101

Introduction: The OZI rule



- The Okubo-Zweig-Iizuka (OZI)* rule states that processes with disconnected quark lines are suppressed.
- Production of ϕ should then be allowed only thanks to deviation from ideal mixing, $\delta_V = 3.7^o$, and be suppressed w.r.t. ω production according to

$$(AB \rightarrow X\,\phi)/(AB \rightarrow \omega X) = \tan^2 \delta_V = 4.2 \cdot 10^{-3}{}^{**}$$

where A, B and X are non-strange hadrons.

* S. Okubo, Phys. Lett. 5 (1963) 165, G. Zweig, CERN report TH-401 (1964), J. Iizuka, Prog. Theor. Suppl. 38 (1966) 21
** H.J. Lipkin, Phys. Lett. B 60 (1976) 371

Introduction: the OZI rule

- The OZI rule is generally well fulfilled*.
- Large violations have been observed in

  -proton-antiproton annihilations at rest.
  -*NN* collisions.
  -reactions near the kinematic threshold.

- Apparent violation are usually interpreted as

  - Intermediate gluonic states**.
  - A polarised strangeness component in the nucleon***.
  - Features of the meson-nucleon interaction.

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* V.P. Nomokonov, M.G. Sapozhnikov, Particles and Nuclei 24 (2003) 184
** S. J. Lindenbaum, Nouvo Cim. 65 A (1981) 222
*** J. Ellis et al. Phys. Lett. B 353 (1995) 319, J. Ellis et al. Nucl. Phys. A 673 (2000) 256

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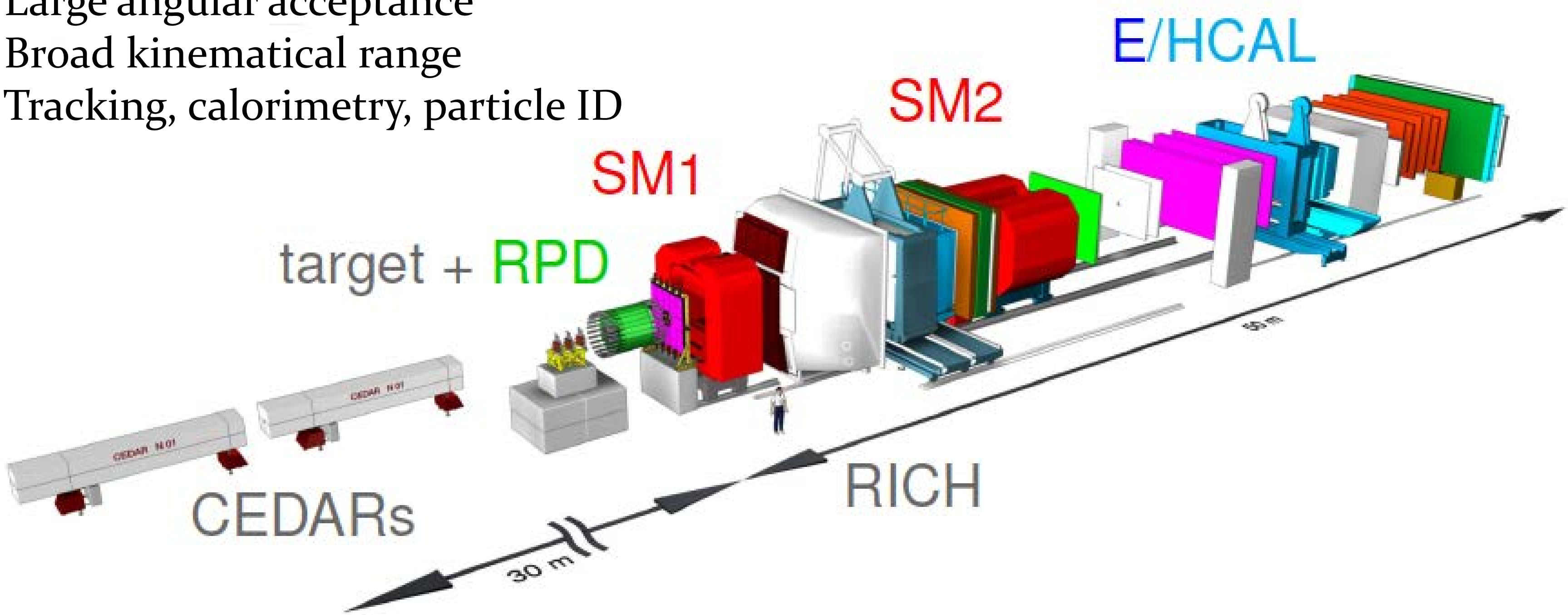
The COMPASS experiment

Two-stage magnetic spectrometer:

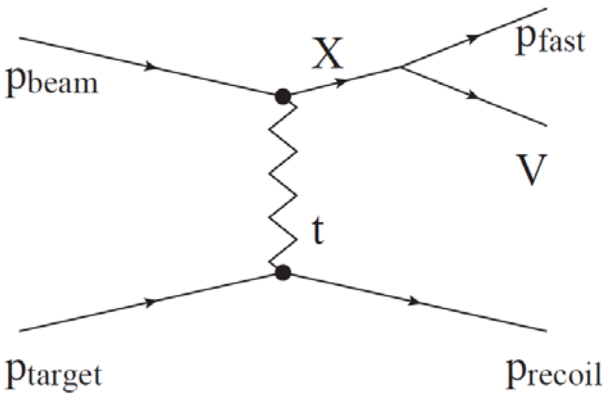
- Large angular acceptance
- Broad kinematical range
- Tracking, calorimetry, particle ID



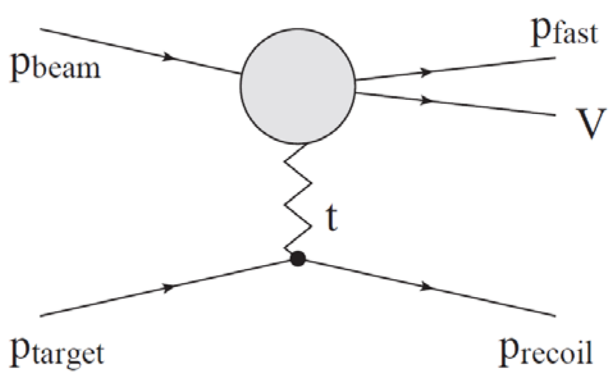
This work:
Beam: 190 GeV positive hadrons (p, π^+, K^+) .
Target: Liquid H_2.
$\sqrt{s} = 18.97$ GeV
More details in other COMPASS talks, *e.g.* by S. Uhl.

The COMPASS experiment

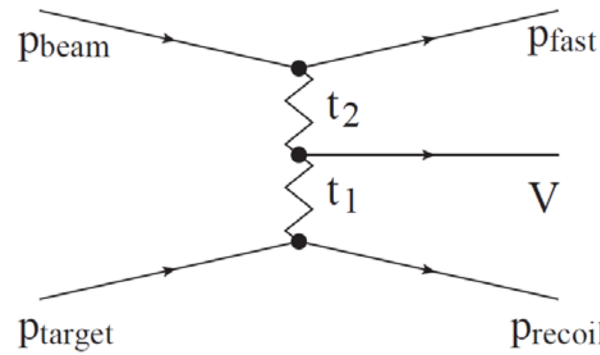
For the $pp \to p_{fast}\, p_{recoil}\, V$ reaction at beam momentum 190 GeV/c,
the Recoil Proton Detector Trigger
selects events produced by mainly three types of mechanisms:



Resonant diffractive



Non-resonant diffractive



Central Production

Concerning the vector meson dynamics, we consider two cases :

1) The vector meson dynamics depends on the intermediate *X*.
2) The vector meson dynamics depends on the exchange Pomeron/Reggeon (central production and knock-out of a preformed $q\bar{q}$ state).

Analysis: Event selection

Common cuts, $pp \rightarrow p_{fast}\, p_{recoil}\, V$

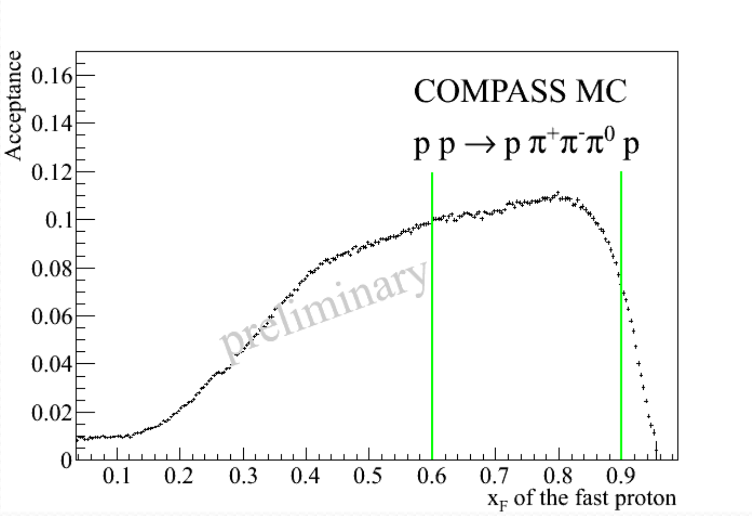
- beam proton ID
- p_{recoil} in RPD
- exclusivity & coplanarity
- $0.6 < x_F < 0.9$
- $0.1 < t' < 1.0\ (GeV/c)^2$

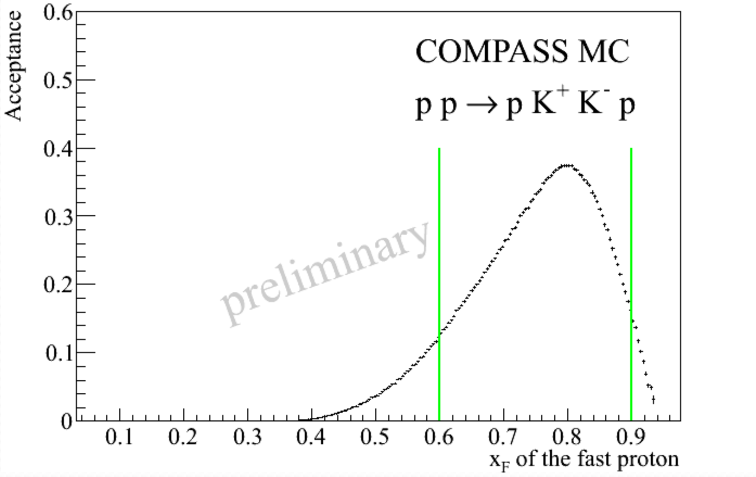
$pp \rightarrow p_{fast}\, p_{recoil}\, \omega$, $\omega \rightarrow \pi^+\pi^-\pi^0$

- p_{fast}, π^+ and π^- in spectrometer
- ≥2 photons in ECALs forming a π^0
- π^+ ID in RICH
- $1.8 < M(p\omega) < 4.0\ GeV/c^2$

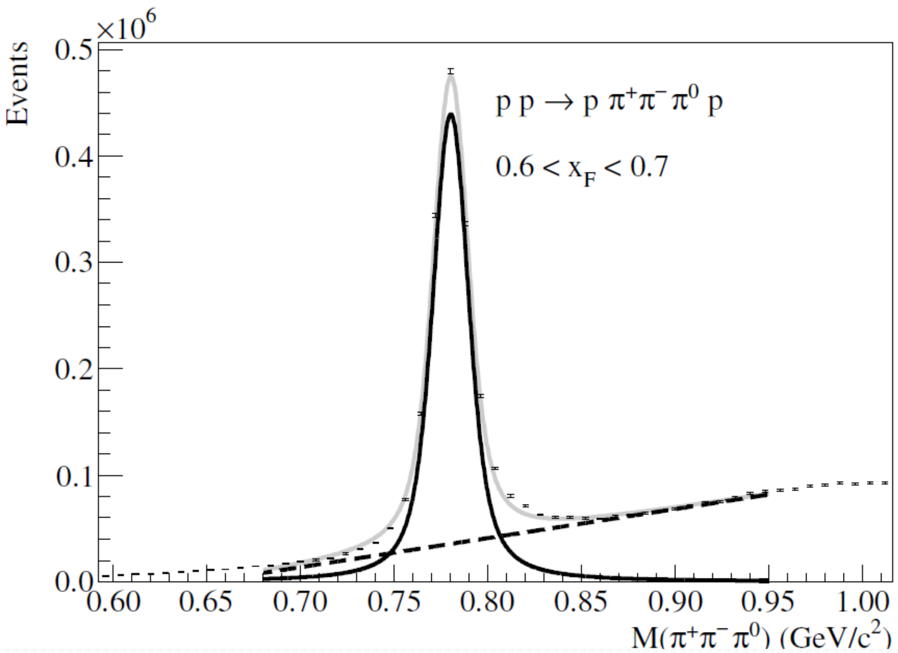
$pp \rightarrow p_{fast}\, p_{recoil}\, \phi$, $\phi \rightarrow K^+K^-$

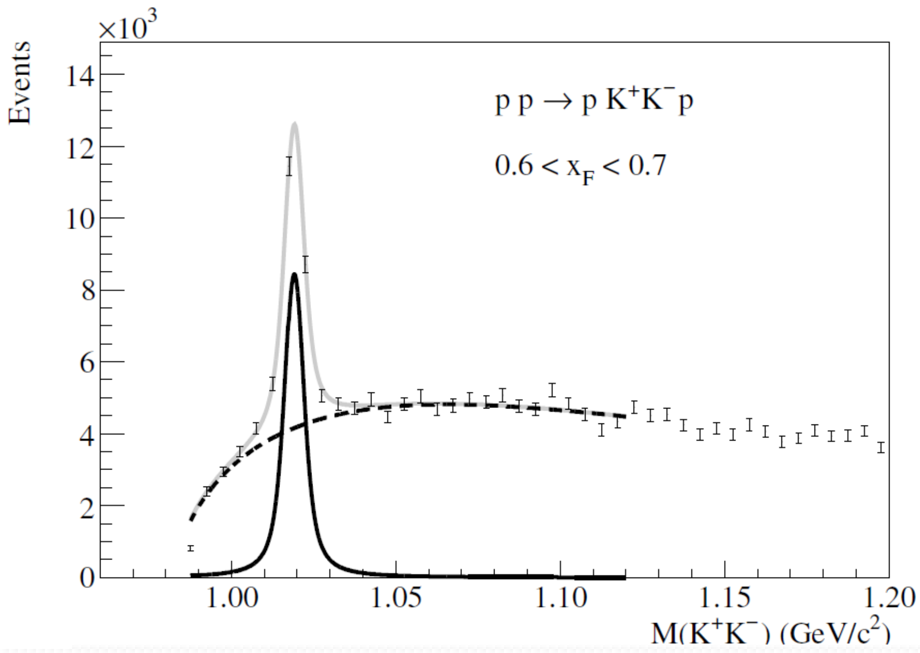
- p_{fast}, K^+ and K^- in spectrometer
- K^+ ID in RICH
- $2.1 < M(p\,\phi) < 4.3\ GeV/c^2$





Analysis





Background subtraction:

Fit: Breit-Wigner function folded with single (ϕ) or double (ω) gaussian + polynomial bg.

Acceptance corrections:

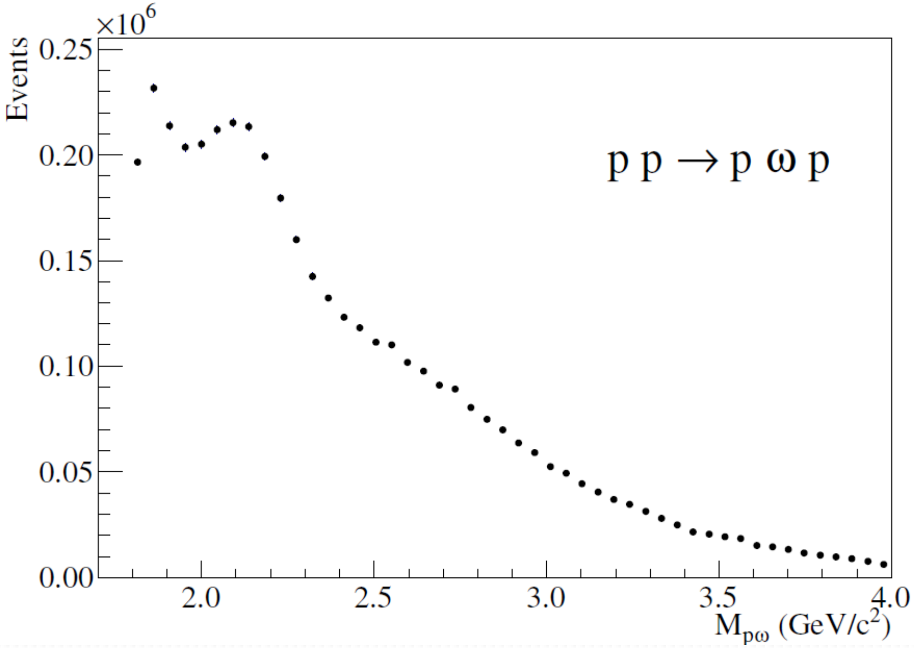
Event-by-event weighting using a 3D-acceptance matrix

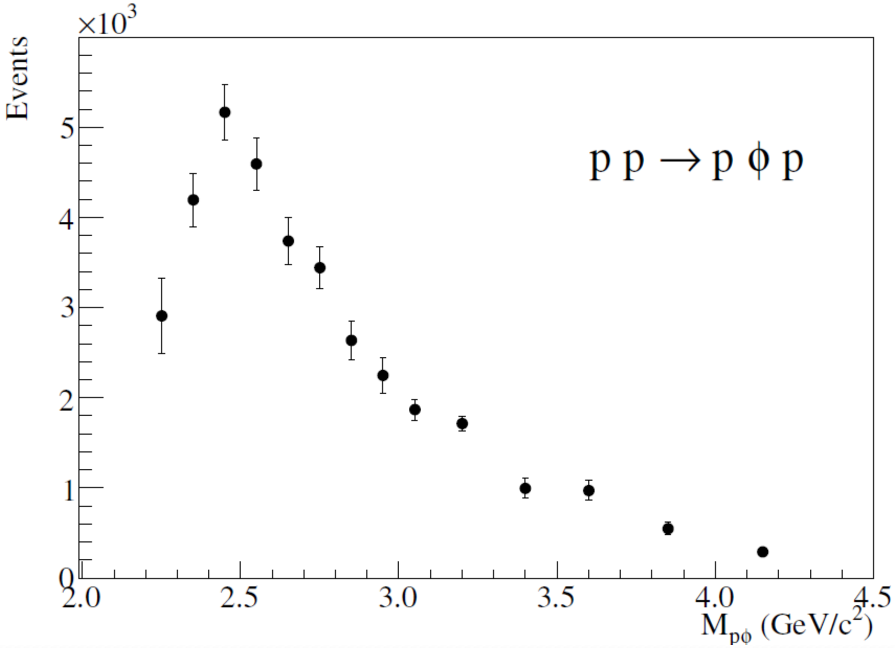
in $x_F(p_{fast})$, t', $M(p_{fast}\,\phi)$

Overall systematic uncertainty: 12.5%

ECAL and RICH efficiencies

The M(p_{fast} *V*) invariant mass





- Clear structures in the $M(p_{fast}\omega)$ spectrum
- No visible structures in the $M(p_{fast}\ \phi)$ spectrum
- Poor acceptance at low $M(p_{fast}\phi)$

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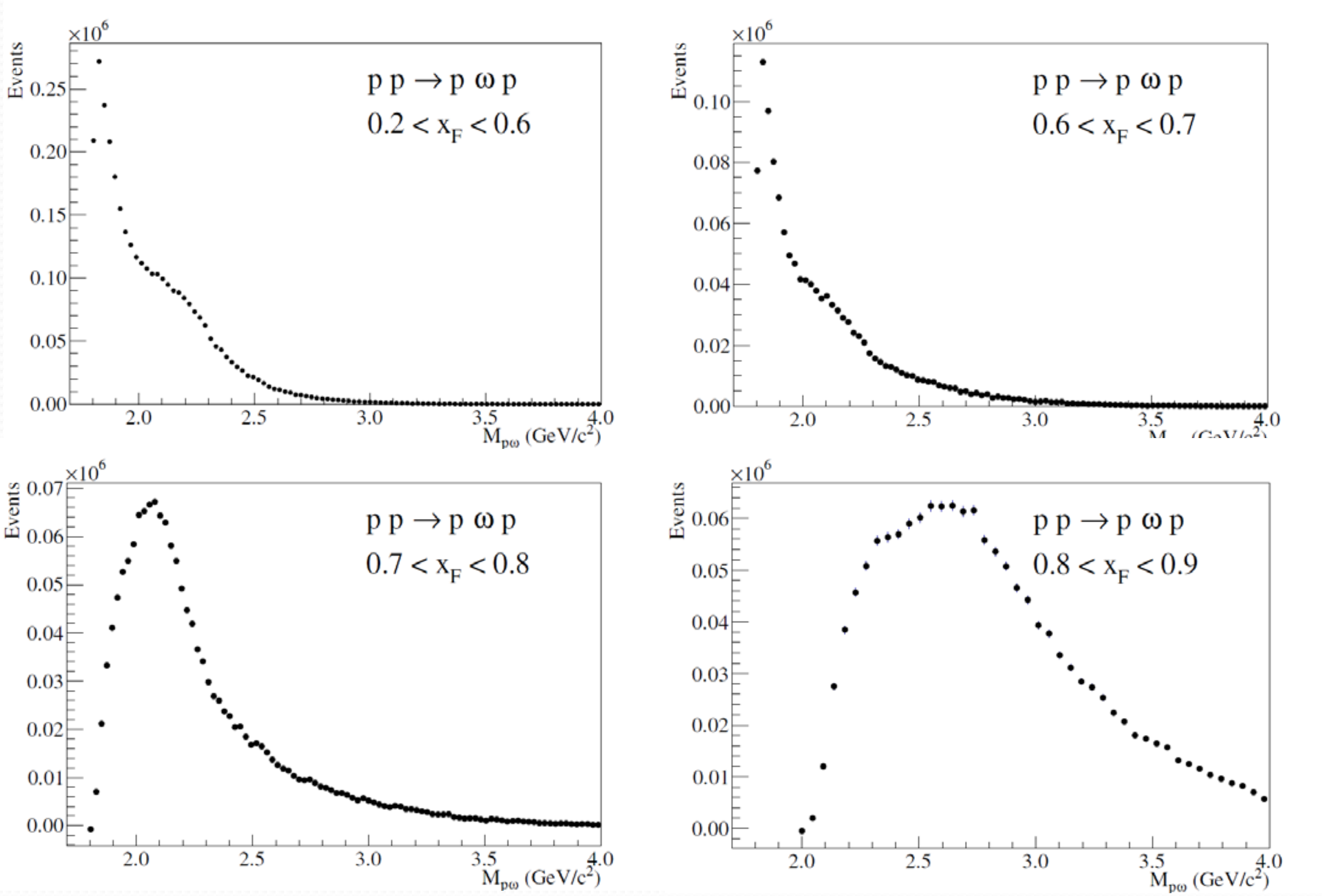
The M(p_{fast} V) invariant mass



• The $M(p_{fast}\omega)$ spectrum varies with x_F

• Structures near 1800 MeV/c², 2100 MeV/c² and 2600 MeV/c² , consistent with N^* resonances listed by PDG.

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F_{OZI} as a function of x_F

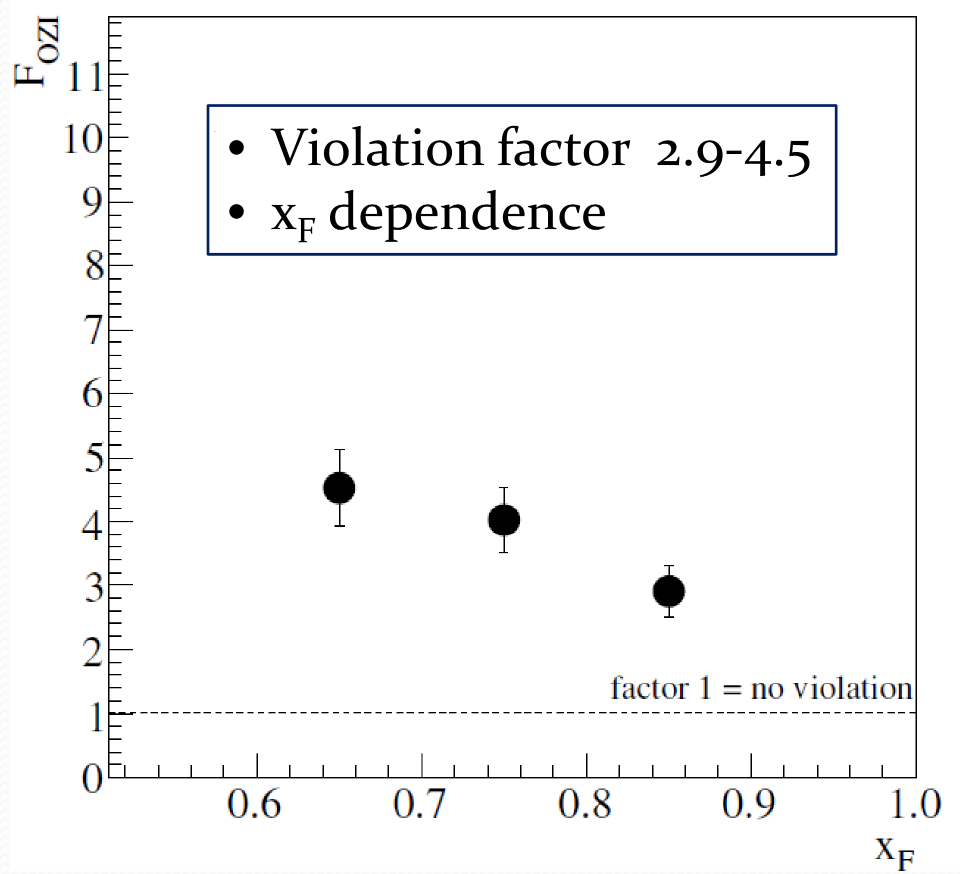
The OZI violation factor

$$F_{OZI} = \frac{R(\phi/\omega)}{\tan^2 \delta_V} \qquad \text{where} \qquad \tan^2 \delta_V = 0.0042$$

and

$$R(\phi/\omega) = \frac{\dfrac{d\sigma}{dx_F}(pp \to p\phi p)}{\dfrac{d\sigma}{dx_F}(pp \to p\omega p)}$$

has been calculated in 3 bins of x_F.



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F_{OZI} as a function of x_F

- The observed baryon resonances X decaying into *pω* may enhance the ω cross section. The measured F_{OZI} then reflects the structure of X.

- Define vector meson momentum in rest system of the *pV* system:

$$p_V = \frac{\sqrt{(M_{pV}^2 - (m_V + m_p)^2)(M_{pV}^2 - (m_V - m_p)^2)}}{2M_{pV}}$$

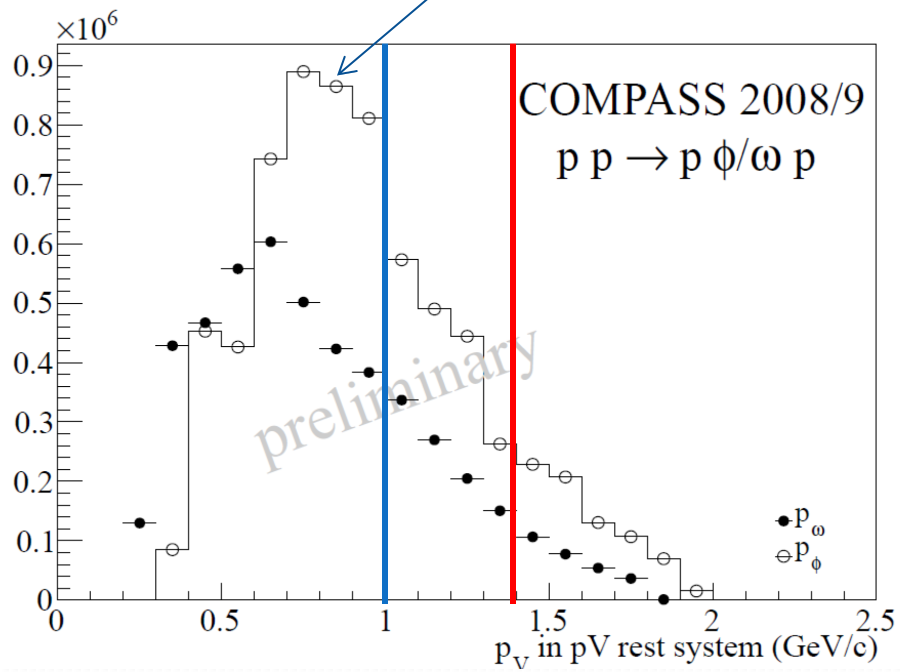
- Remove resonant region by a cut:

$$p_V > 1.4 \text{ GeV}$$

- SPHINX made a similar cut*:

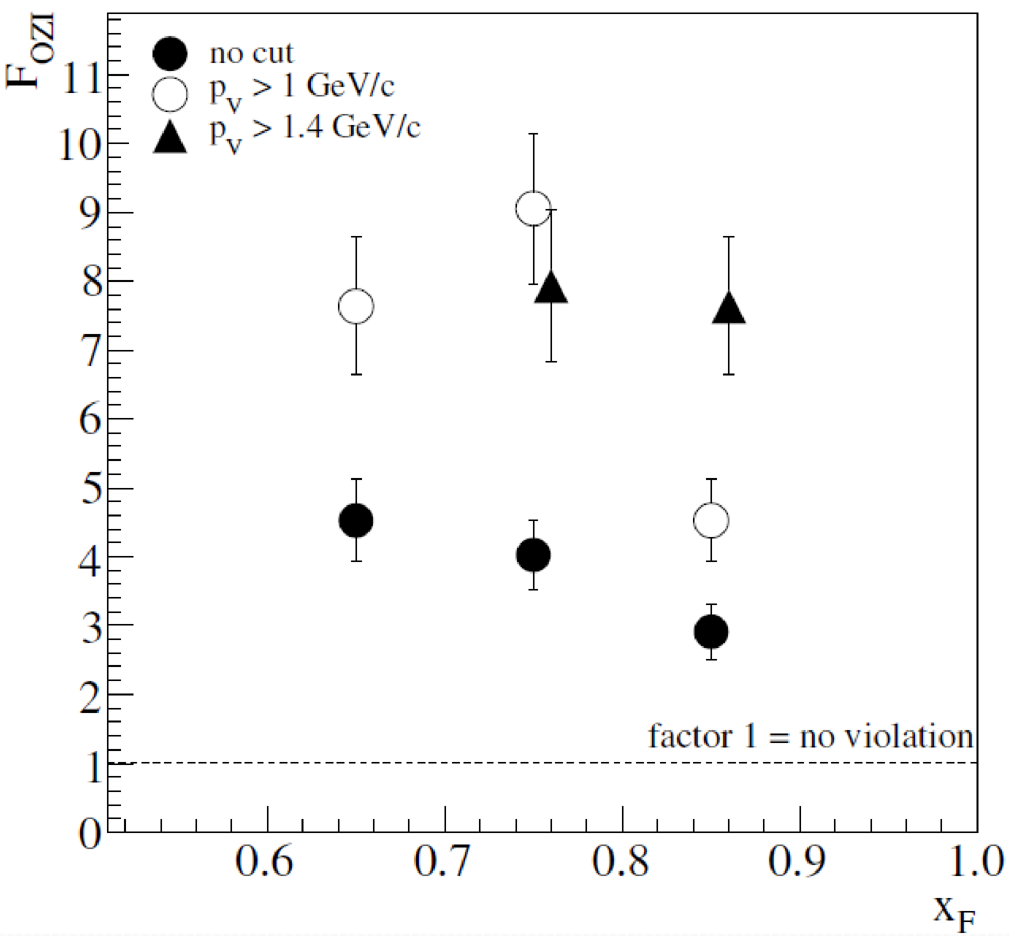
$$p_V > 1.0 \text{ GeV/c}$$

Φ data scaled by 100



*ZPA 359 (1997) 435.

F_{OZI} as a function of x_F



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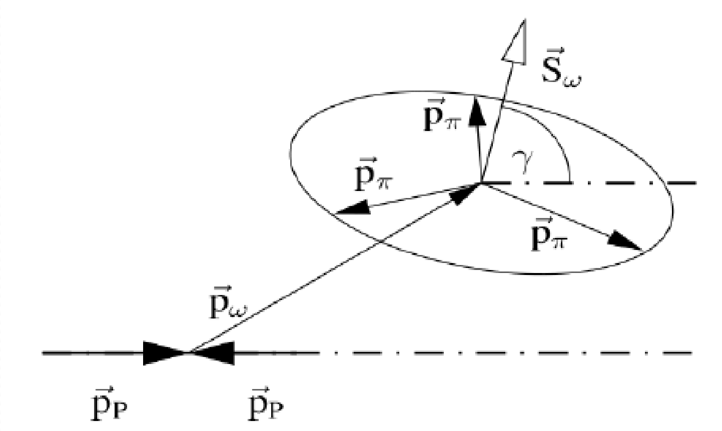
Spin alignment of vector mesons

- Sensitive to the production mechanism*

- The differential cross section of the decay of a vector meson into 2 or 3 pseudoscalars can be parametrised in terms of spin density matrix element and angles, a lengthy expression which in the case of unpolarised beam and unpolarised target reduces to

$$W(cos\theta) = \frac{3}{4}(1 - \rho_{00} + (3\rho_{00} - 1)cos^2\theta)$$

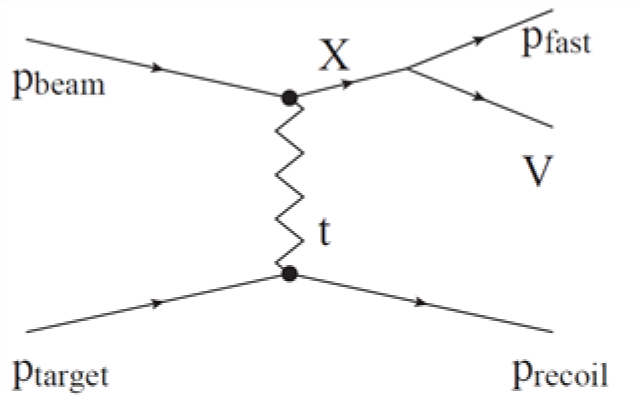
where ρ_{00} is the zeroth element of the spin-density matrix and θ is the angle between the analyser and some reference axis.



Analyser:
- the normal of the decay plane in the 3-body case ($\omega \to \pi\pi\pi$)
- the direction of one of the decay kaons in the 2-body case ($\phi \to KK$)

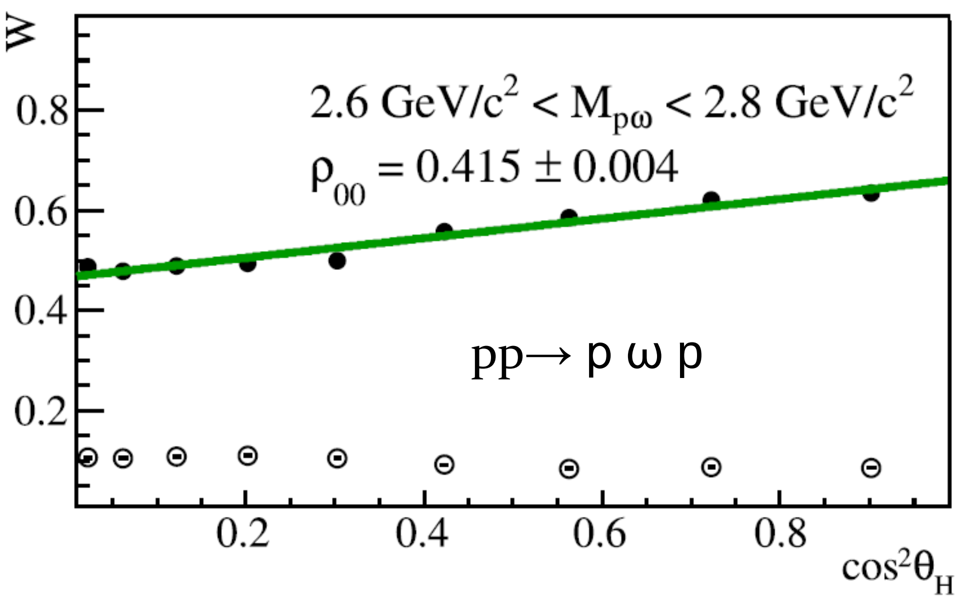
* K. Gottfried & J.D. Jackson, Nuovo Cim. 33 (1964) 302.

The ρ_{00} in the helicity frame

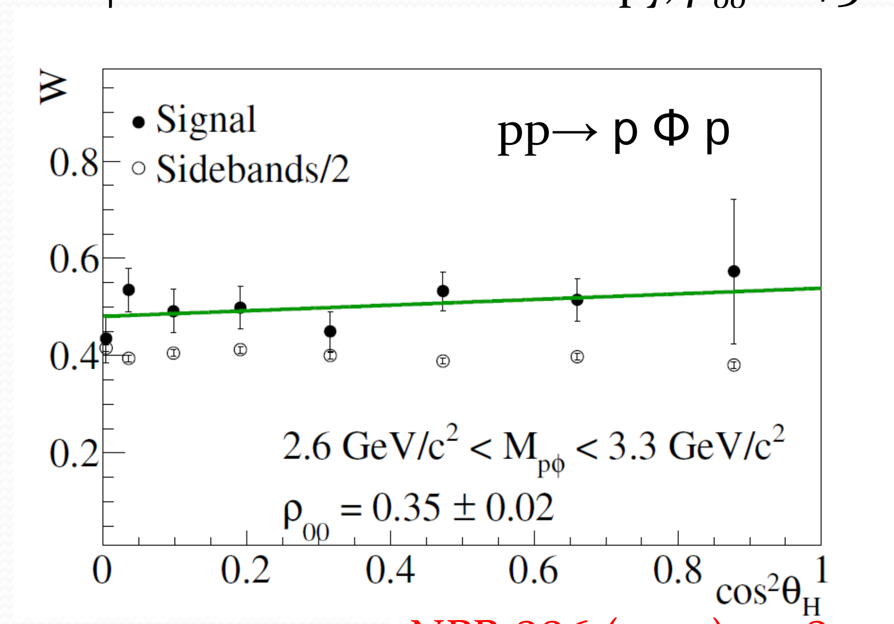


Reference axis: the direction of flight of the *X* resonance in the rest system of the vector meson

ω – significant alignment



ϕ – consistent with isotropy, $\rho_{oo} \sim 1/3$



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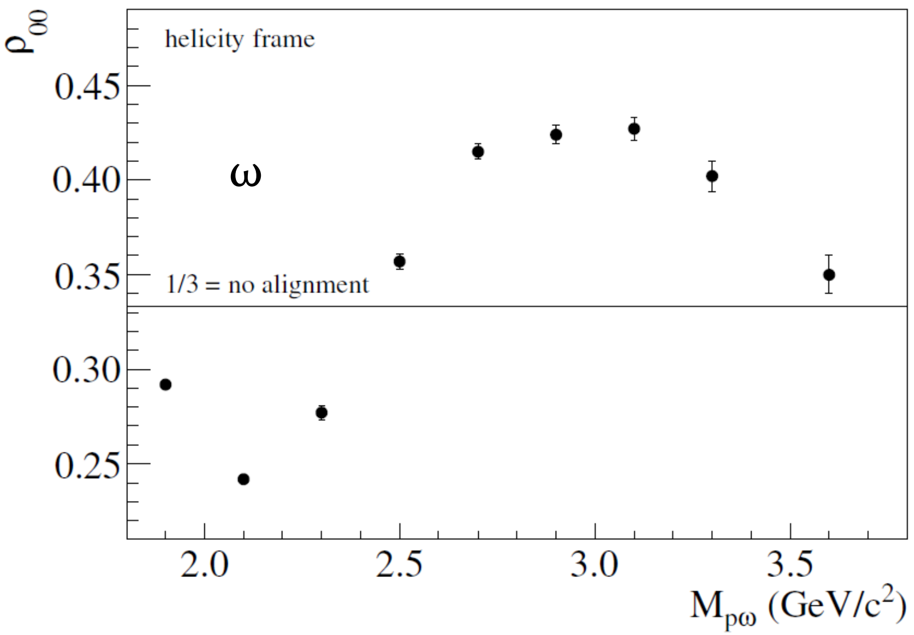
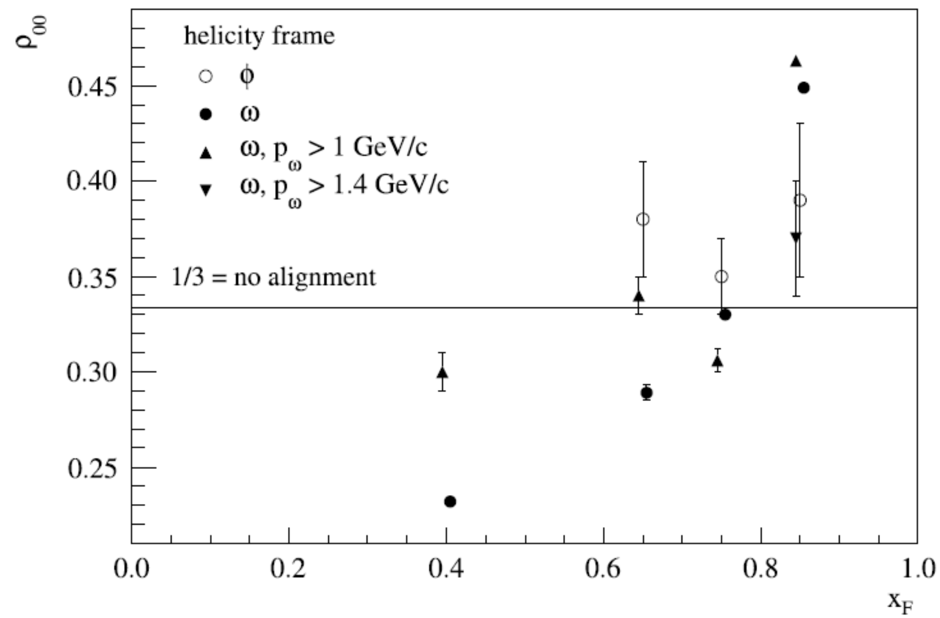
The ρ_{00} w.r.t $M(p_{fast}V)$ and x_F





- ω: Significant deviation from isotropy in resonant region .
- ω: Clear dependence of ρ_{oo} on $M(p\omega)$.
- ω : consistent with isotropy outside resonant region.
- ϕ : consistent with isotropy for all x_F and $M(p\phi)$

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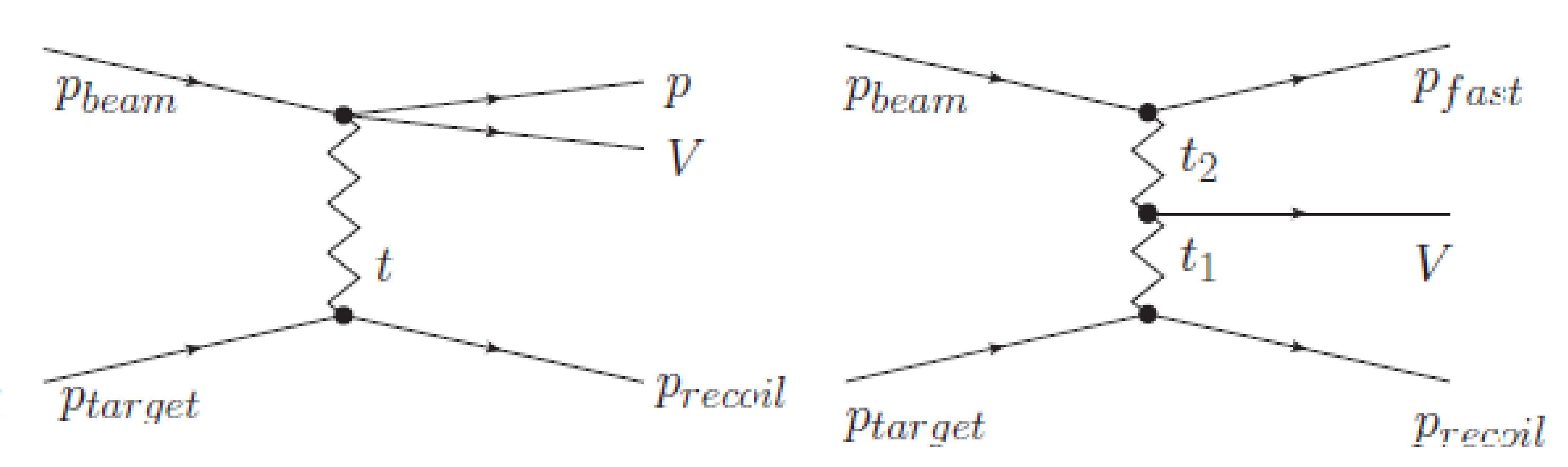
ρ_{00} w.r.t. the transferred momentum



Reference axis: direction of the transferred momentum from the beam proton in the initial state to the fast proton in the final state.

ρ_{00} w.r.t. the transferred momentum

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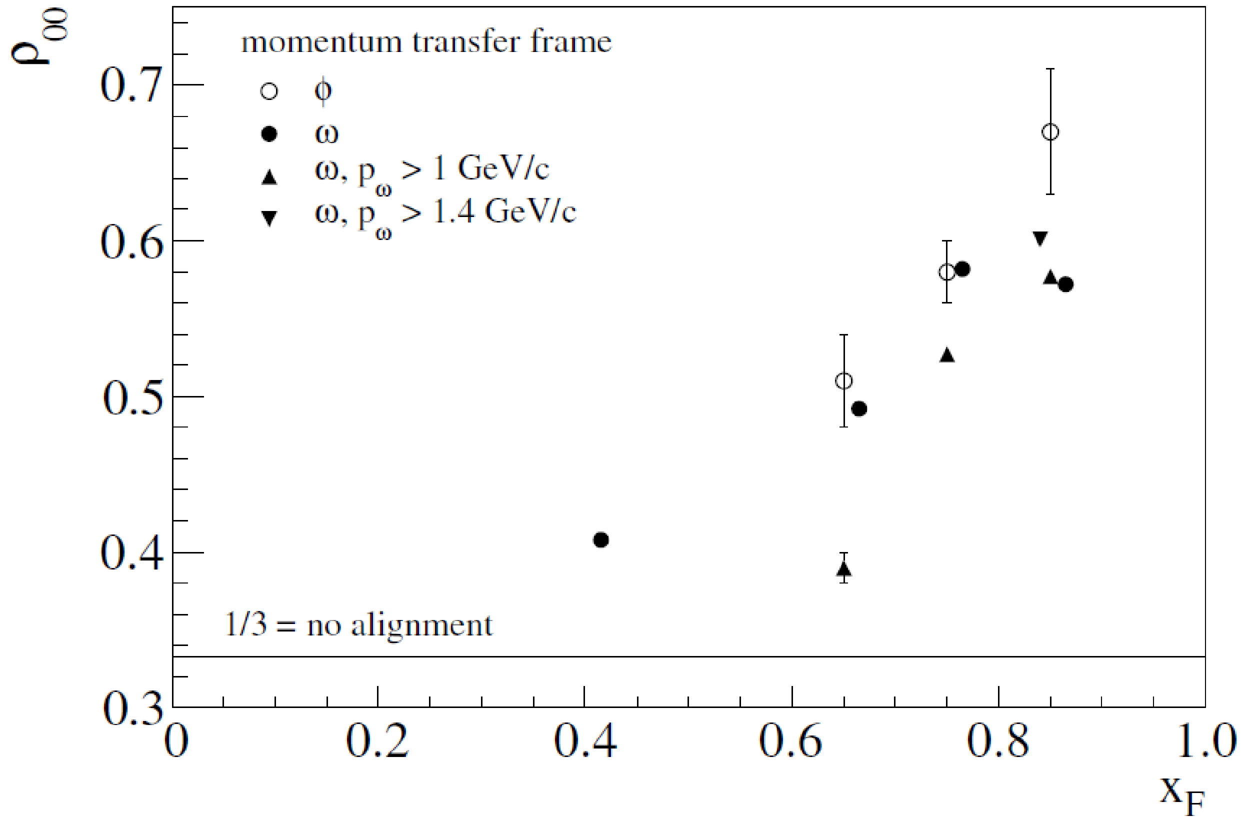

- ϕ: Strong alignment with respect to the transferred momentum.
- ϕ: Alignment increases with x_F.
- ω: Strong alignment, though weaker than for ϕ.
- ω: Cutting in p_V gives similar results as for ϕ .

What do we learn from this?

- Importance of baryon resonances in ω production confirmed by
  - Structures in *M(pω)* distributions .
  - Spin alignment of ω in the helicity frame.

- OZI suppression of baryon resonance decays $N^* \rightarrow p\,\phi$
  - No observed structures in *M(p ϕ).*
  - No observed alignment of ϕ spin in helicity frame.

- F_{OZI} in the non-resonant region, ~8 is consistent with SPHINX* and near-threshold experiments at ANKE, DISTO and COSY-TOF **

- Non-resonant region: strong alignment of the vector meson spin with the transferred momentum.

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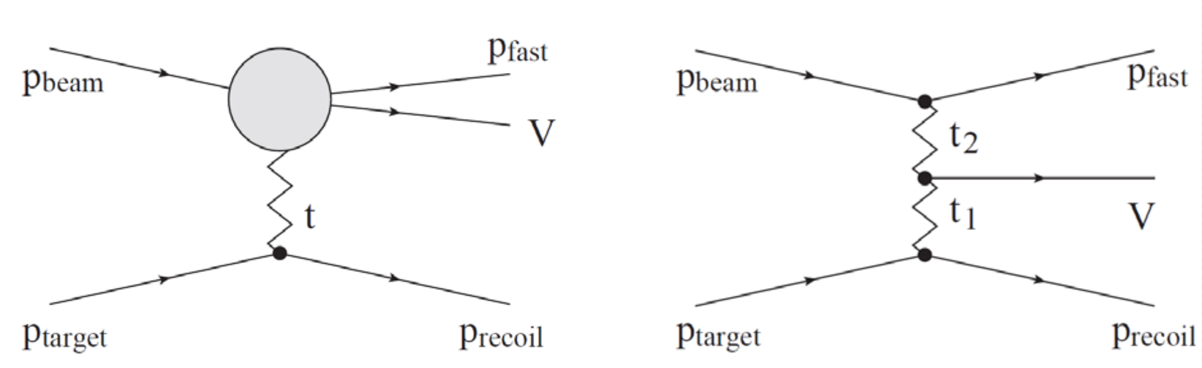
*ZPA 359 (1997) 435.
**PRL96 (2006) 242301, PRC 63 (2001) 024004, PLB 522 (2001) 16, PLB 647 (2007) 351

Possible non-resonant mechanisms

- ~~Central Pomeron-Pomeron fusion~~ Forbidden due to G-parity conservation!
- Central Pomeron-Odderon fusion: completely OZI violating, would give a much larger OZI violation than the observed one.
- Central Reggeon-Pomeron fusion. ←
- Knock-out of a preformed $q\bar{q}$ state in the beam proton by a Pomeron from the target. ←



Thanks for your attention!

Further details can be found in

- C. Adolph *et al.* (The COMPASS collaboration) Nucl. Phys. B 886 (2014) 1078-1101.
- J. Bernhard, Ph.D. Thesis, Mainz University (2014)

Backup:Analysis