The OZI rule and spin alignment of vector mesons at COMPASS

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Outline

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- The COMPASS experiment
- Analysis
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- Results
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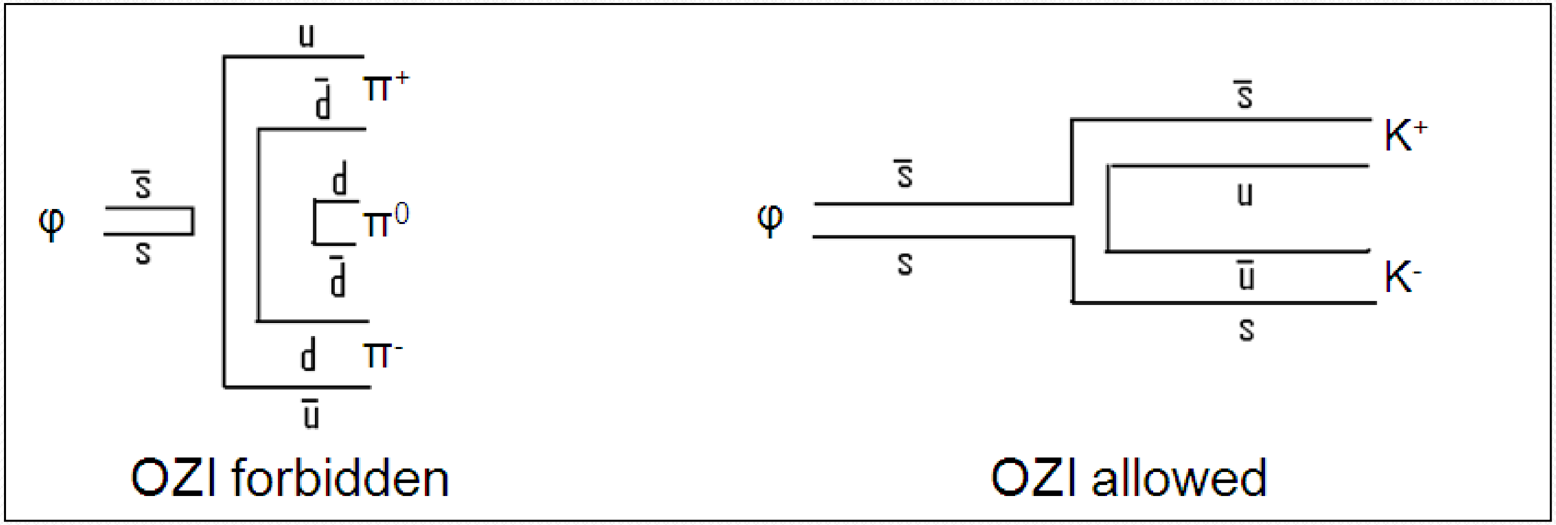
  - R(ϕ/ω) as a function of $x_F(p_{fast})$ and p_V
  - Spin alignment in the helicity frame
  - Spin alignment in the exchange particle frame
  - The relation between spin alignment and R(ϕ/ω)
- What do we learn from this?

Introduction: The OZI rule



- The Okubo-Zweig-Iizuka (OZI)* rule states that processes with disconnected quark lines are supressed.
- 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

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

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*
- Apparent 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

COMPASS

* 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

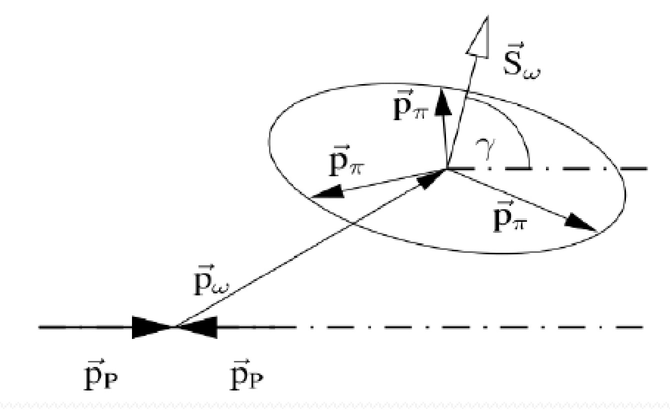
CERN

Introduction: spin alignment of vector mesons

- Sensitive to the production mechanism*
- Low energy *pd* experiments show that ω is produced arbitrarily aligned ** whereas ϕ is produced aligned with the incoming beam.***
- The differential cross section of the decay of a vector meson into 2 or 3 pseudoscalaras 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.



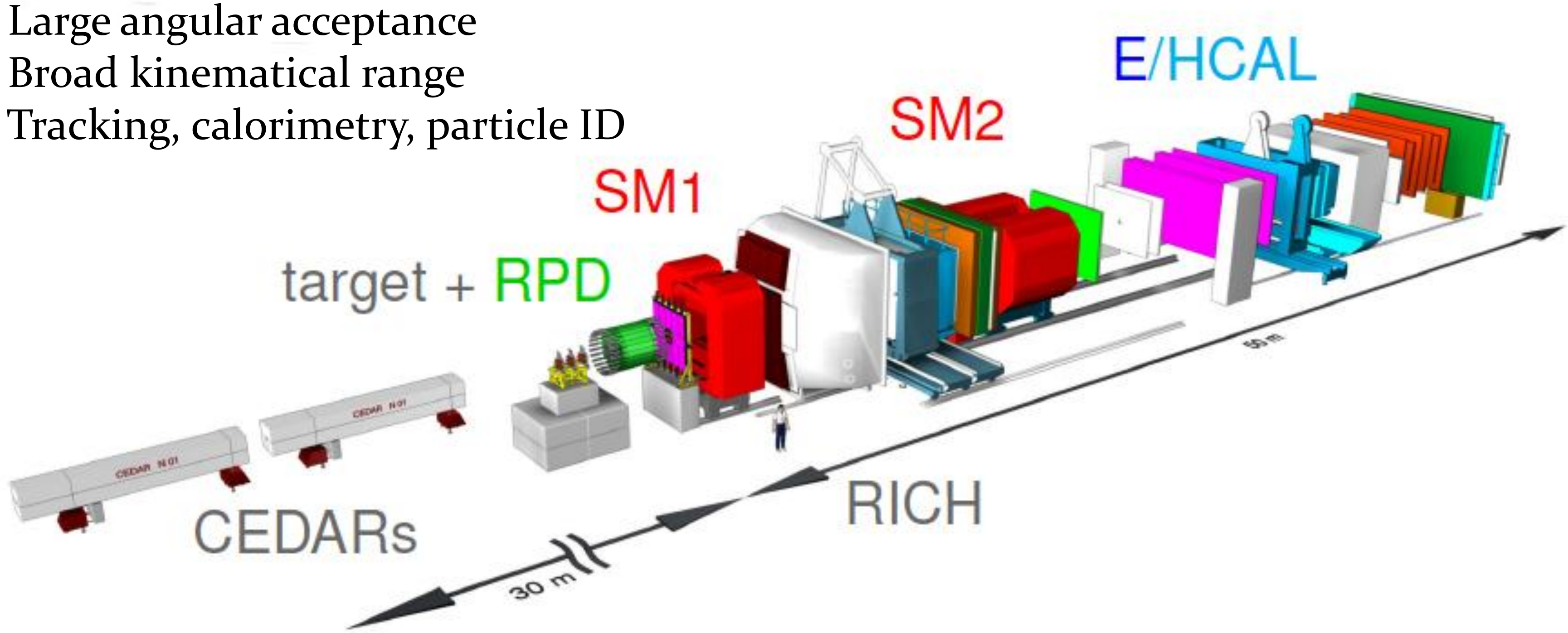
Analyser:
- the normal of the decay plane in the 3-body case (ω→πππ)
- the direction of one of the decay kaons in the 2-body case (ϕ→KK)

* K. Gottfried & J.D. Jackson, Nuovo Cim. 33 (1964) 302.
** K. Schönning *et al.*, Phys. Lett. B 668 (2008) 258.
***F. Belleman *et al.*, Phys. Rev. C 75 (2007) 015204

The COMPASS experiment

Two-stage magnetic spectrometer:

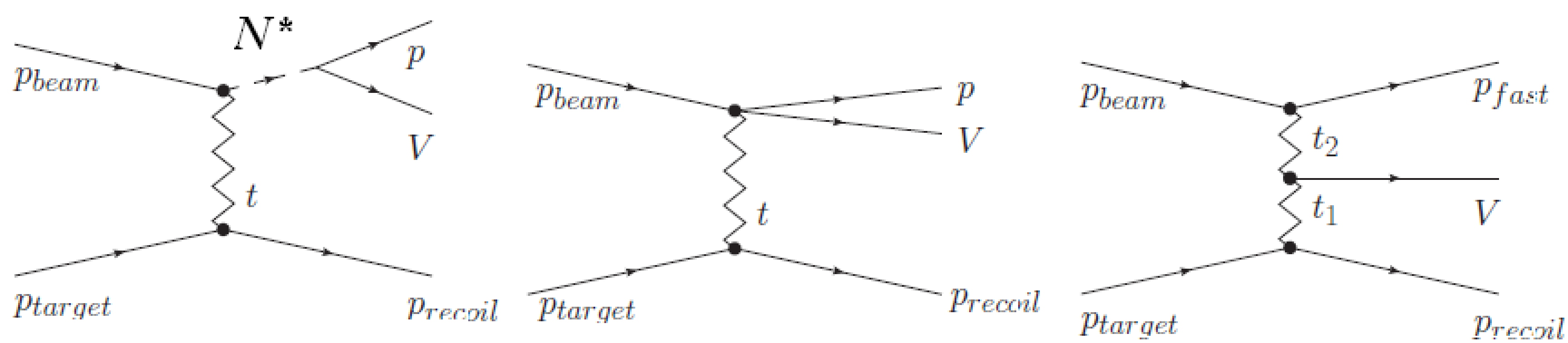
- Large angular acceptance
- Broad kinematical range
- Tracking, calorimetry, particle ID



Beam: 190 GeV positive (p, π^+, K^+) or negative (π^-, K^-) hadron beam.
Targets: Liquid H_2, Nuclear targets (Pb, Ni, W).
Final states: charged ($\pi^\pm$, p, ...), neutral (π^0, η, η', ...), kaonic ($K^\pm$, K_S, ...)
See also: talks by *e.g.* B. Grube, Y. Bedfer...

The COMPASS experiment

At the COMPASS beam momentum (190 GeV/c) and with the Recoil Proton Detector Trigger, events produced by mainly three types of mechanisms are selected:



Resonant diffractive | Non-resonant diffractive | Central Production

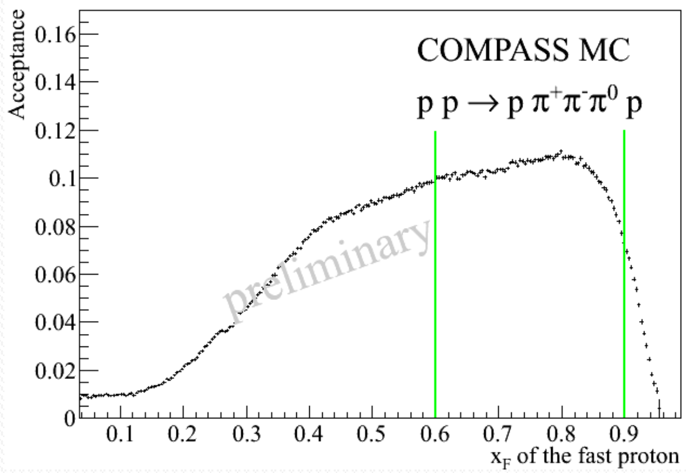
Concerning the vector meson dynamics, we consider two cases :

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

Analysis: Event selection

Common cuts for ϕ / ω:

- primary vertex in target volume
- three charged tracks, charge conservation
- beam proton (tagged with CEDARs)
- recoil proton (tagged by RPD)
- exclusivity and coplanarity
- $0.6 < x_F(p_{fast}) < 0.9$
- $0.1 < t' < 1.0\ (GeV/c)^2$

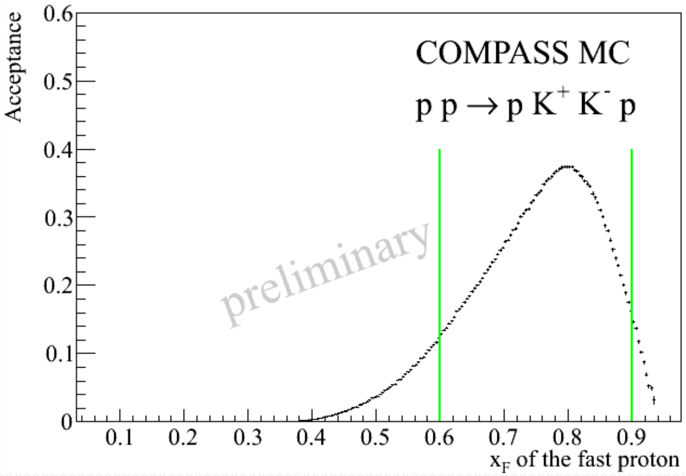


Specific cuts for ω:

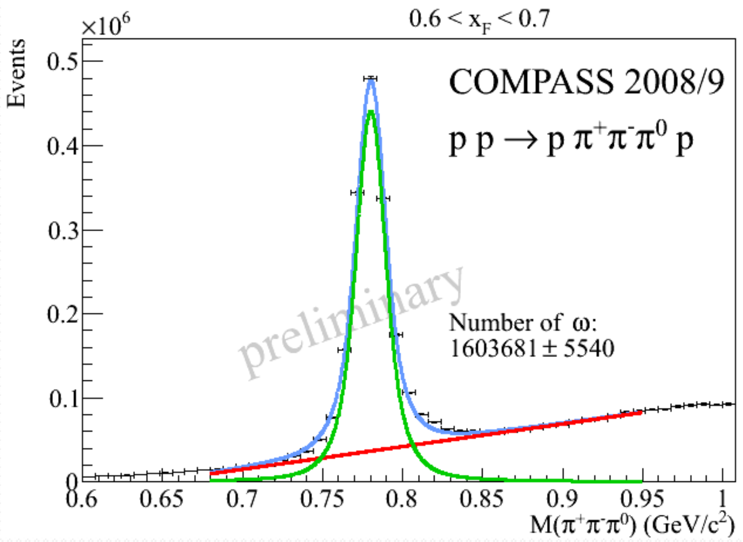
- >1 photon in any of the ECALs
- exactly one π^0
- one π^+ in RICH
- $1.8 < M(p\omega) < 4.0\ GeV/c^2$

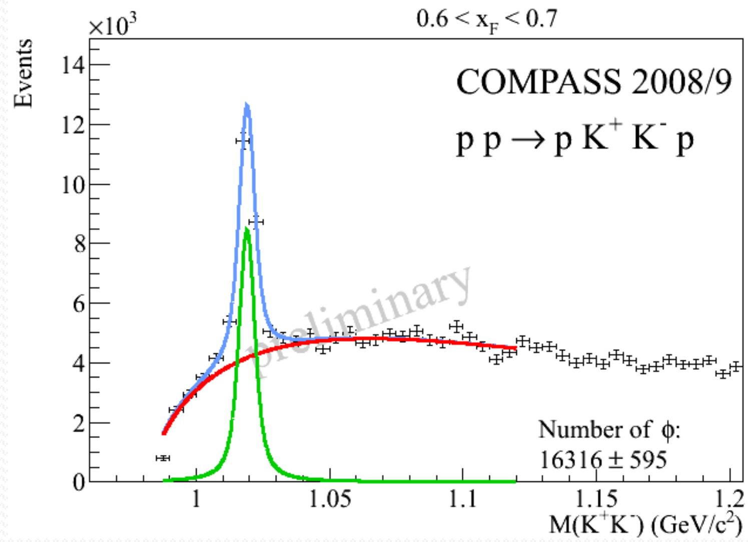
Specific cuts for ϕ :

- one K^+ in RICH
- $2.1 < M(p\phi) < 4.3\ GeV/c^2$



Analysis





Background subtraction:

A Breit-Wigner function, convoluted with a single (ϕ) or a double (ω) gaussian and a polynomial background was fitted to the data in order to extract the ϕ and ω yields.

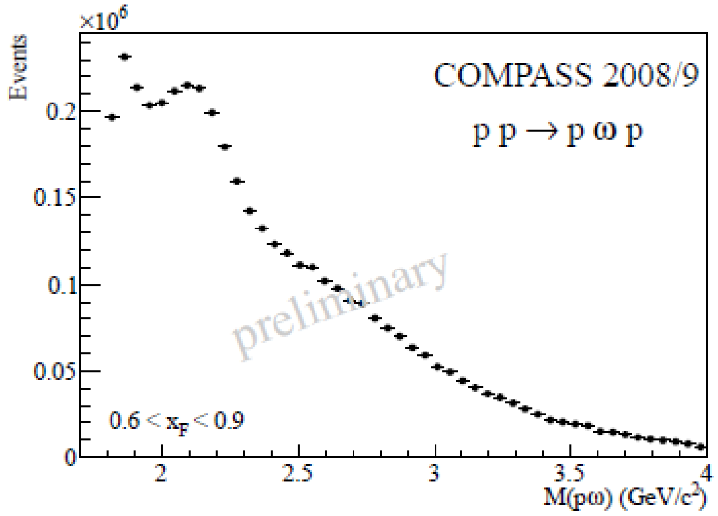
Acceptance corrections:

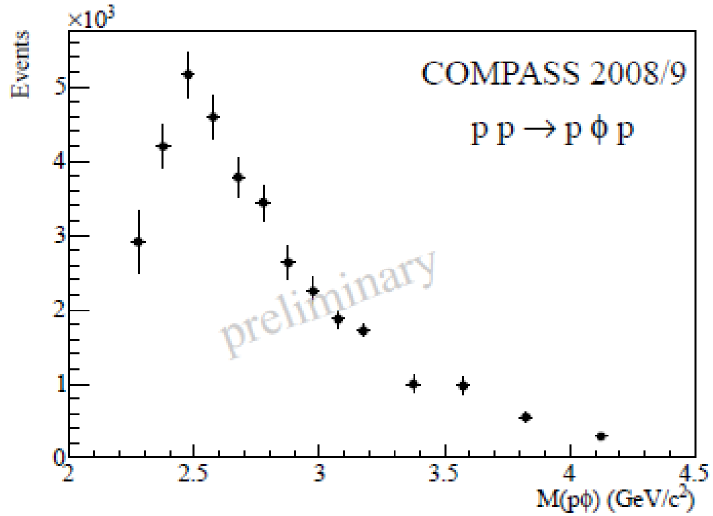
Event-by-event weighting using a 3D-acceptance matrix in $x_F(p_{fast})$, t', $M(p_{fast}\,\phi)$

Overall systematic uncertainty: 12.5%

ECAL and RICH efficiencies

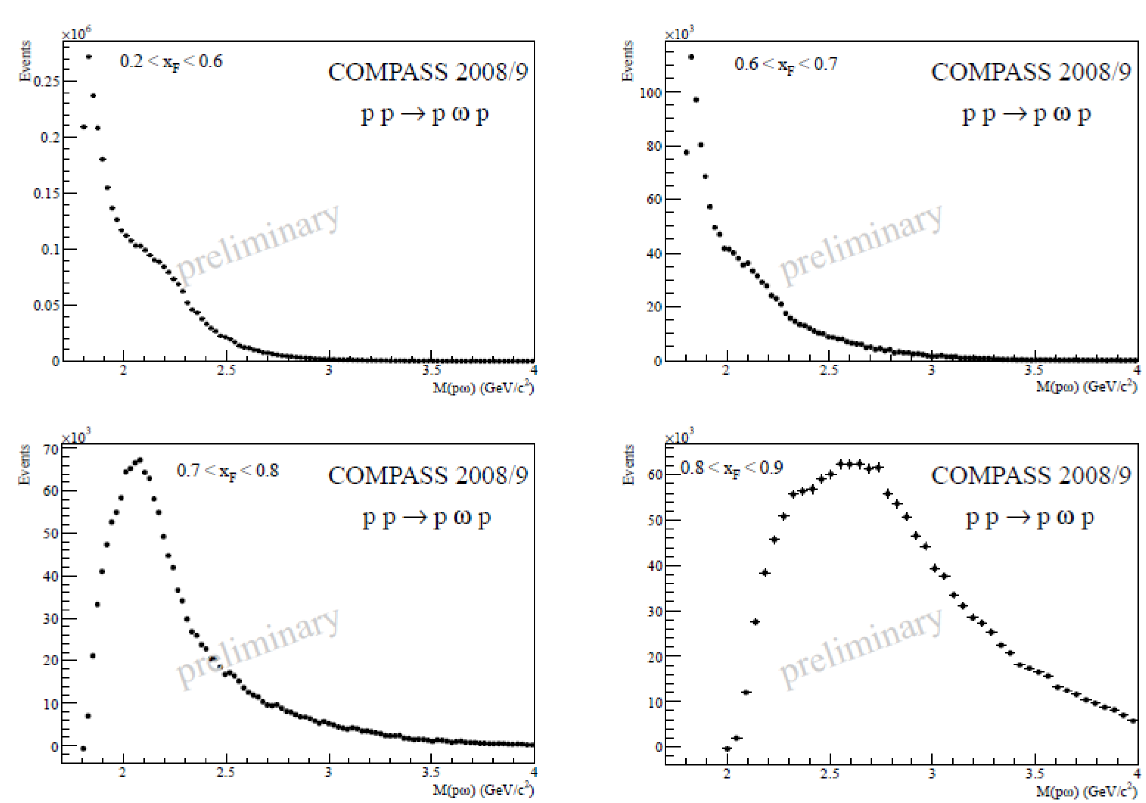
The M(p_{fast} V) invariant mass





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

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

R(ϕ /ω) as a function of x_F

The cross section ratio

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

has been calculated in 3 bins in x_F .

The OZI violation factor is defined by $R(\varphi/\omega)/4.2 \cdot 10^{-3}$ and varies between 2.9 and 4.5, depending on x_F.

This is consistent with results from SPHINX*

We learned that ω mesons in this kinematic region is produced to a large extent *via* intermediate baryon resonances.

What if we remove the resonant region?

* S.V. Golovkin et al., Z. Phys. A 359 (1997) 435.

R(ϕ /ω) as a function of x_F

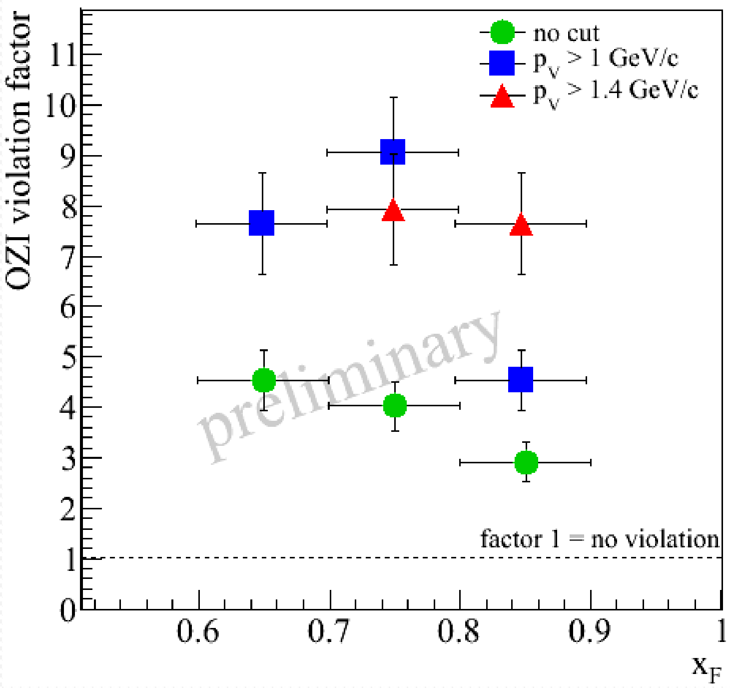
The visible resonances are below $M(p\omega)$ = 3.3 GeV/c².
This corresponds to a vector meson momentum in the rest system of the resonance

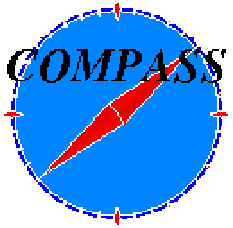
$$p_V = \frac{\sqrt{(M_{pV}^2 - (m_V + m_p)^2)(M_{pV}^2 - (m_V - m_p)^2)}}{2M_{pV}}$$

of p_V = 1.41 GeV/c.

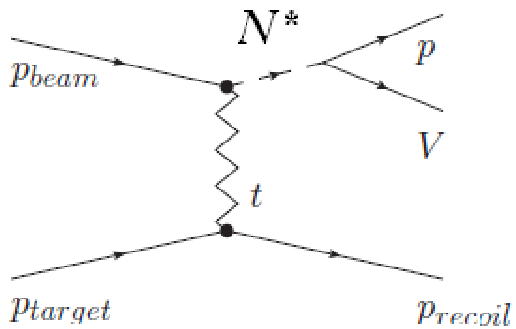
Requiring p_V > 1.41 GeV/c gives an OZI violation factor of ~8.

This is consistent with SPHINX but also with near threshold *pp* measurements from ANKE, DISTO and COSY-TOF.



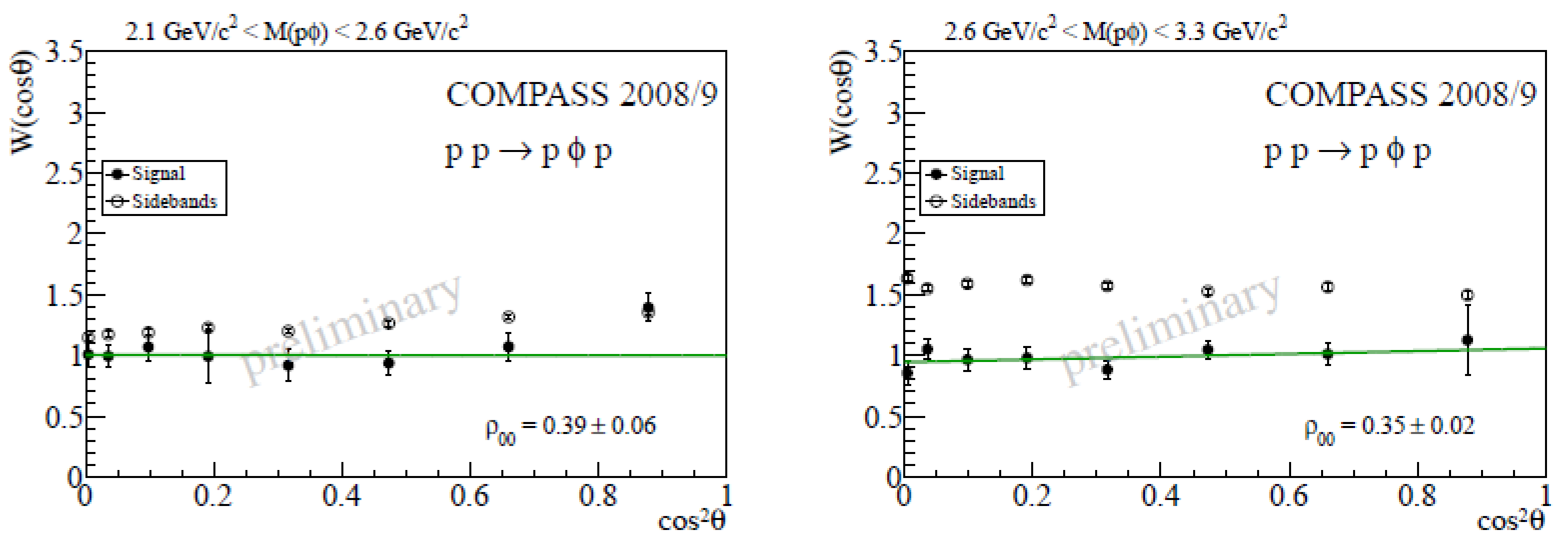


The ρ_{00} in the helicity frame



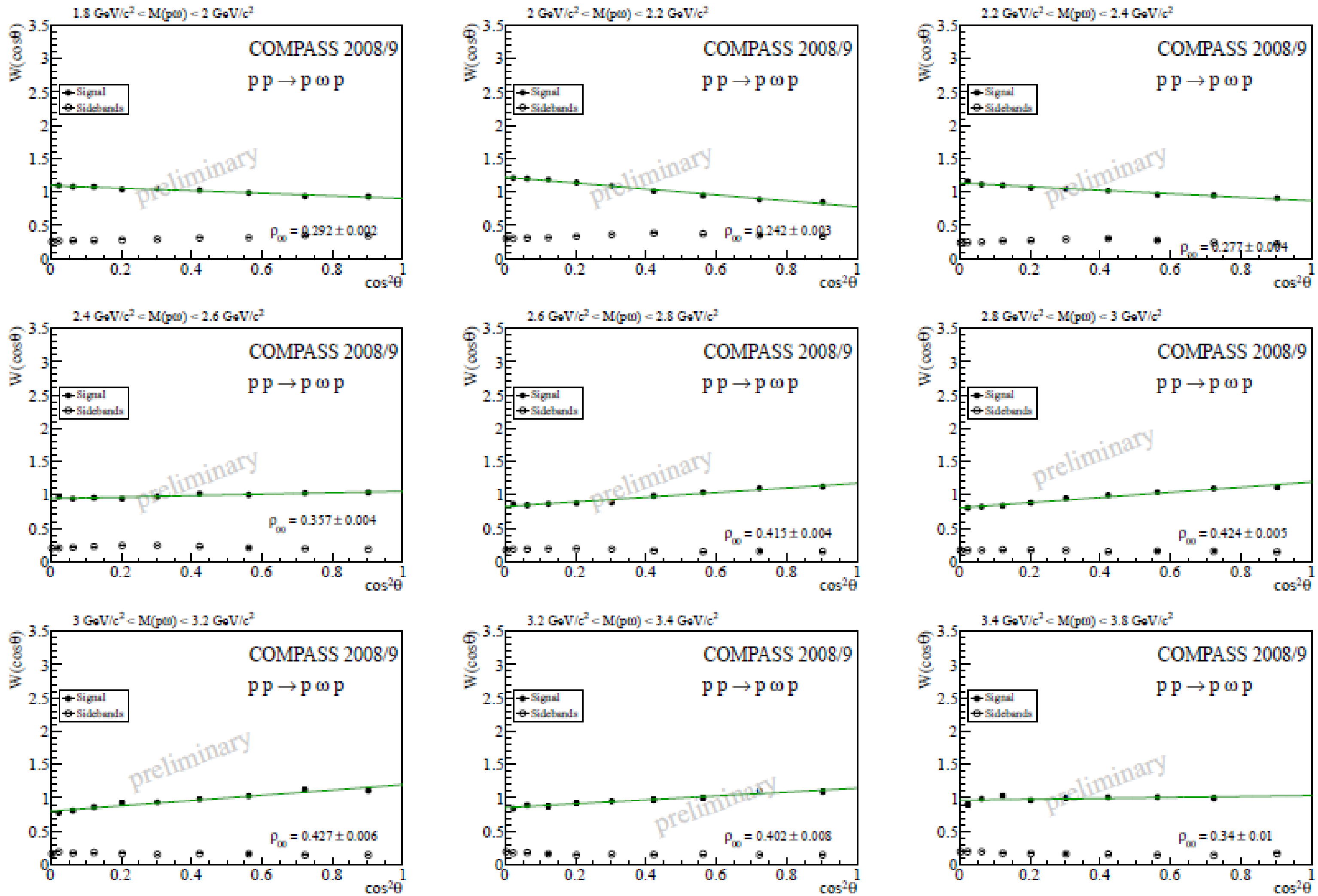
Reference axis: the direction of flight of the N^* resonance in the rest system of the vector meson

The ρ_{00} w.r.t $M(p_{fast}V)$ for ϕ



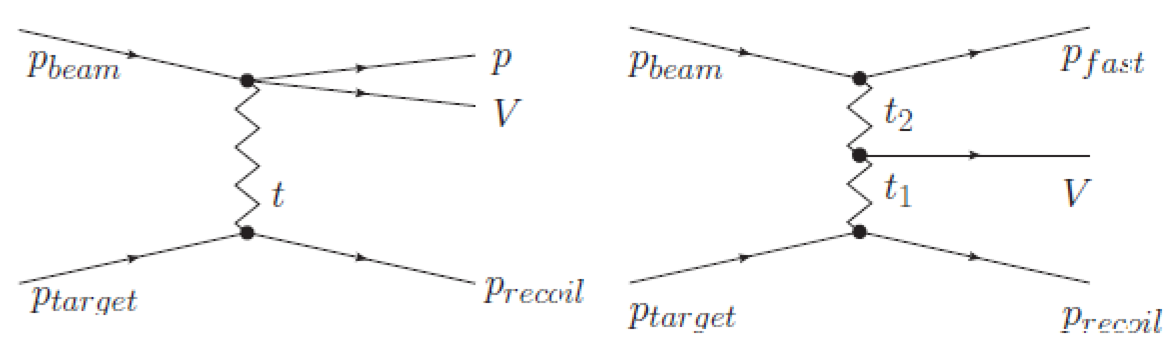
No significant deviation from isotropy.

The ρ_{00} w.r.t $M(p_{fast}V)$ for ω

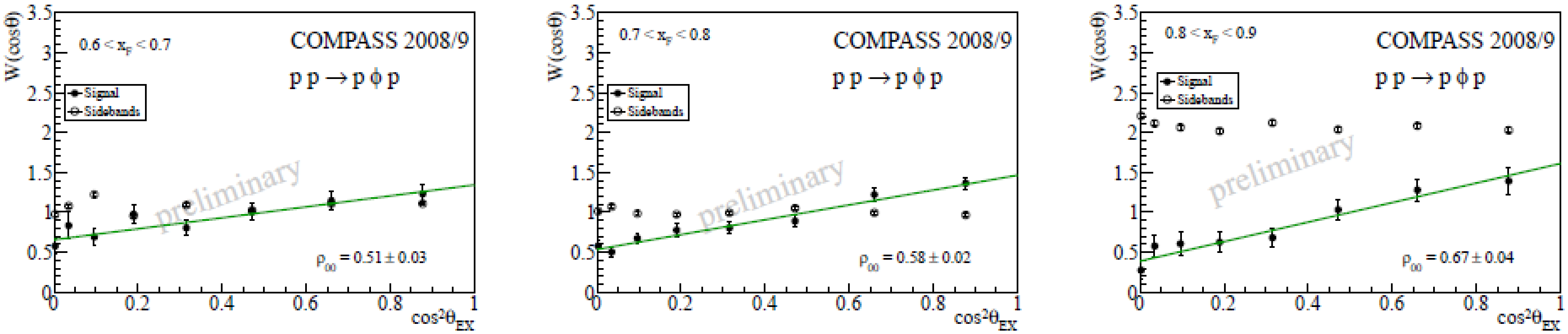


- Significant deviation from isotropy.
- Clear dependence of ρ_{oo} on $M(p\omega)$

The ρ_{00} in the exchange particle frame

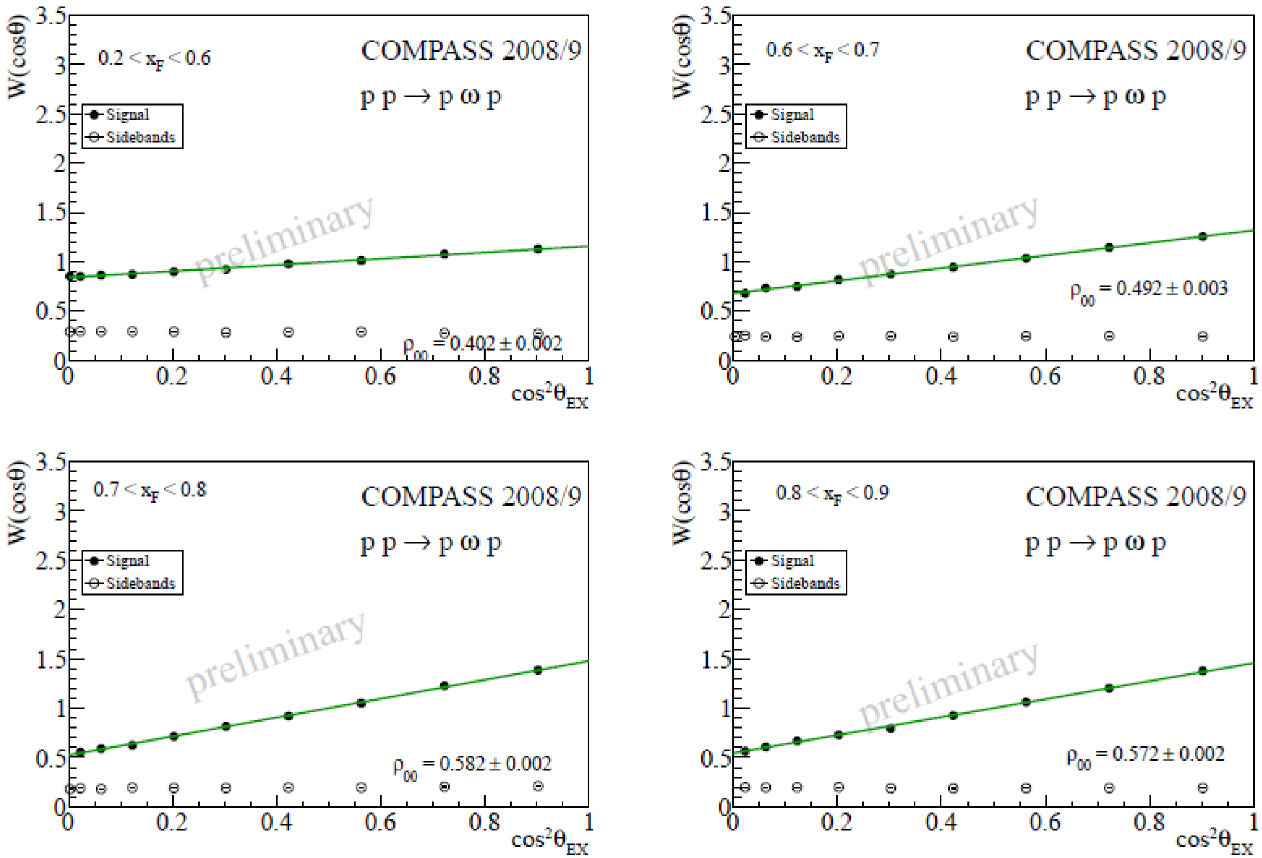


The ρ_{00} w.r.t x_F for ϕ



- Strong alignment with respect to the exchange Pomeron/Reggeon
- Alignment increases with x_F

The ρ_{00} in the exchange particle frame



The ρ_{00} w.r.t x_F for ω

- Strong alignment, though weaker than for ϕ
  - Cutting in p_V gives similar results as for ϕ

Relation between R(ϕ /ω) and the spin alignment

x_F	p_V (MeV/c)	ρ^{hel}_{00}, ϕ	ρ^{hel}_{00}, ω	ρ^{EX}_{00}, ϕ	ρ^{EX}_{00}, ω	OZI viol.
0.6-0.7	> 0	0.38±0.03	0.289±0.004	0.51±0.03	0.492±0.003	4.5±0.6
0.7-0.8	> 0	0.35±0.02	0.330±0.003	0.58±0.02	0.582±0.002	4.0±0.5
0.8-0.9	> 0	0.39±0.04	0.449±0.003	0.67±0.04	0.572±0.002	2.9±0.4
0.6-0.7	> 1.0	-	0.34±0.01	-	0.39±0.01	7.6±1.0
0.7-0.8	> 1.0	-	0.306±0.006	-	0.527±0.005	9.0±1.1
0.8-0.9	> 1.0	-	0.463±0.003	-	0.577±0.002	4.5±0.6
0.7-0.8	> 1.4	-	-	-	-	7.9±1.1
0.8-0.9	>1.4	-	0.37±0.03	-	0.601±0.005	7.6±1.0

What do we learn from this?

- The role of baryon resonances is ω production is confirmed by the *M(pω)* distributions and the spin alignment in the helicity frame.
- No evidence for baryon resonances decaying into *p*ϕ was observed: a consequence of the OZI rule which supresses $N^{*} \rightarrow p\,\phi$.
- The OZI violation (by a factor 2.9-4.5) in the resonant region would then be caused by other contributing processes.
- In the non-resonant region, *i.e.* $p_V > 1.41$ GeV/c, the OZI violation factor is ~8.
- The spin alignment for ω and ϕ have the same behaviour in the helicity frame (isotropic) and in the exchange particle frame (strong alignment that increases with x_F).

What do we learn from this?

Possible non-resonant mechanisms:

- Bremsstrahlung with subsequent fluctuation into a vector meson : low cross section and weak sensitivity to the exchange particle
- ~~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