Spin physics in the NOMAD experiment

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for the NOMAD collaboration

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SPIN 2003

ν_μ NOMAD ν_τ

Neutrino Oscillation MAgnetic Detector

Outline

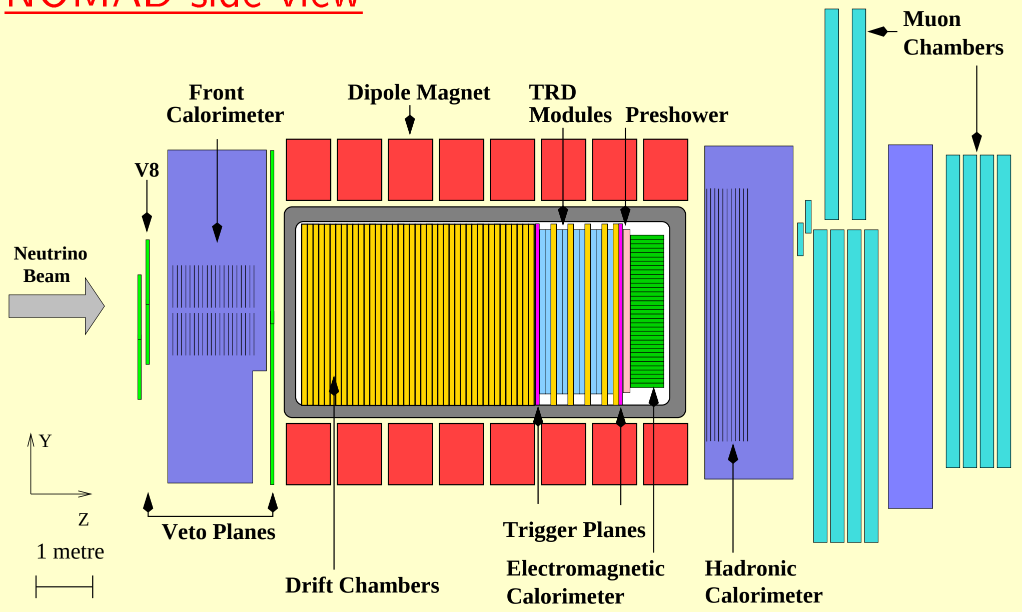
- Why spin physics in NOMAD?
- NOMAD experiment
- Identification of neutral strange particles
- Λ^0 and $\bar{\Lambda}^0$ polarization in ν_μ CC and NC DIS
- Spin alignment of $K^{\star\pm}$ mesons produced in ν_μ CC and NC DIS
- Conclusions

Why spin physics in NOMAD?

- naturally polarized ν beam
- weak parity violating interactions
- left handed quarks and right handed anti-quarks (in charged current interactions)
- big statistics with high reconstruction quality

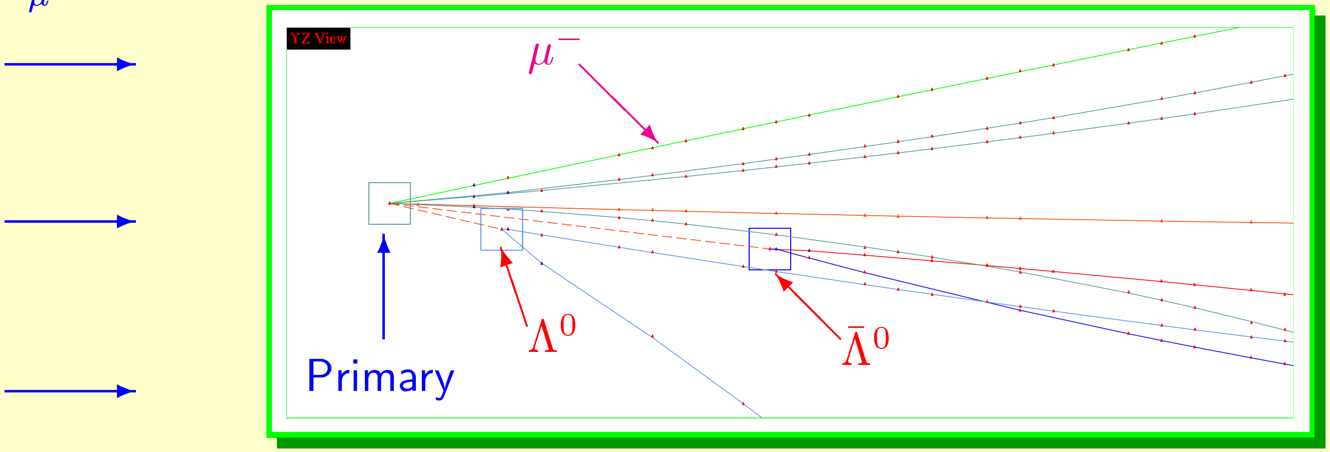
The NOMAD Experiment

NOMAD side view



- Drift chambers used as a target (2.7 tons) and for momentum measurement (3.5% resolution)
- Magnetic field: 0.4 T
- TRD and Preshower for electron identification
- ECAL and HCAL for energy measurement
- Muon chambers: detect and identify muon

ν_μ flux

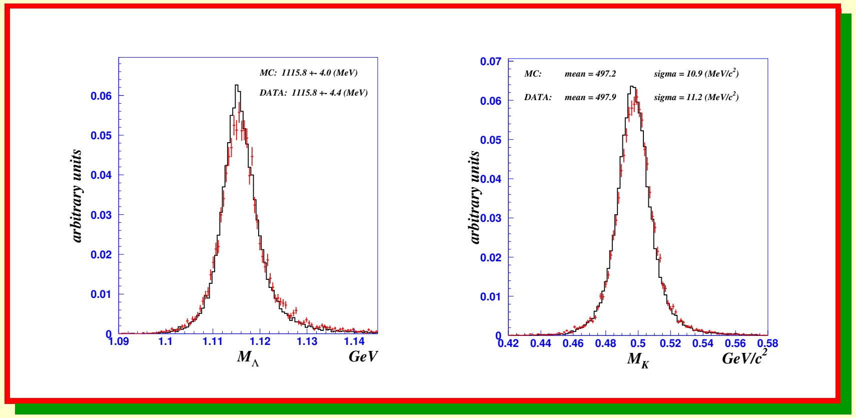


Λ^0, $\bar{\Lambda}^0$, K_S^0 identification

Identification Algorithm

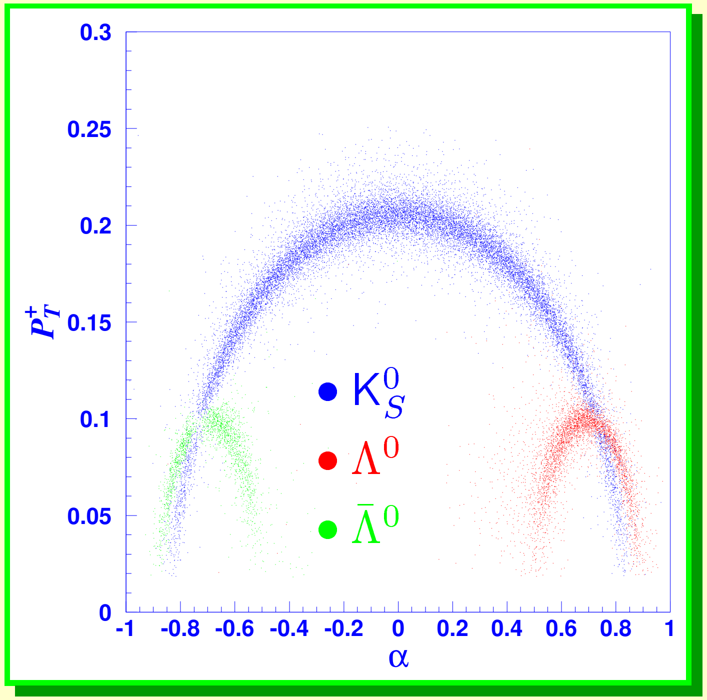
1. Reconstruction and selection of ν_μ CC and NC events
2. Preliminary selection of V^0
3. Kinematic fit with energy and momenta constraints

Mass resolution: Λ^0, K_S^0



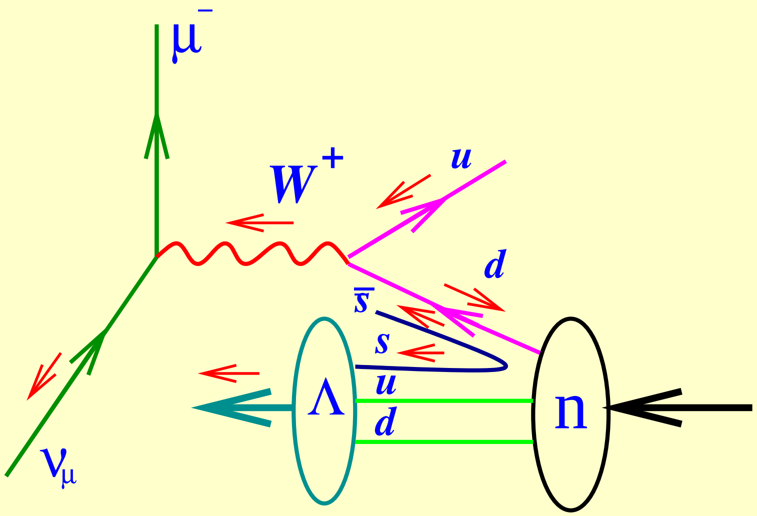
M_Λ: mean $=$ 1115.8, sigma $=$ 4.4 (MeV)
$M_{K_S^0}$: mean $=$ 497.9, sigma $=$ 11.2 (MeV)

Final samples: Armenteros plot



V^0	Data	Purity (%)	Efficiency (%)
Λ^0	7477	95.9 ± 0.1	17.7 ± 0.1
$\bar{\Lambda}^0$	590	89.7 ± 0.7	17.8 ± 0.4
K_S^0	13396	97.2 ± 0.1	22.3 ± 0.1

Λ^0 Polarization in ν_μ CC interactions



Reference system (*J system*)
($W \Rightarrow$ W-boson, $T \Rightarrow$ target nucleon)

$$\left.\begin{array}{l} \bullet\, \vec{n}_x = \vec{e}_W \\ \bullet\, \vec{n}_y = \vec{e}_W \times \vec{e}_T / |\vec{e}_W \times \vec{e}_T| \\ \bullet\, \vec{n}_z = \vec{n}_x \times \vec{n}_y \end{array}\right\}$$

$$P_x = -0.15 \pm 0.03\ (stat) \pm 0.02\ (syst)$$
$$P_y = -0.22 \pm 0.03\ (stat) \pm 0.01\ (syst)$$
$$P_z = -0.04 \pm 0.03\ (stat) \pm 0.02\ (syst)$$

- Observed negative longitudinal polarization
- For the first time in neutrino experiments observed transverse polarization
- P_z is consistent with zero (**Nuclear Physics B588**(2000))
- For the first time in neutrino experiments we measured polarization of $\bar{\Lambda}^0$ hyperons which is consistent with zero (**Nuclear Physics B605**(2001))

Strange particles production in ν NC interactions

Previous study has been performed by the **E632** Collaboration (**Phys. Rev. D45 (1992) 2232**) using Fermilab 15-foot bubble chamber exposed to the Tevatron neutrino beam with an average energy of $\langle E_{\nu(\bar{\nu})} \rangle = 150(110) GeV$.

Published results correspond to 10% of the film taken in 1985.

Selected V^0 in NC events

	$p_{had}^{vis} > 10\ GeV$	$p_{had}^{vis} > 25\ GeV$
NC events	670	437
Observed $\mathrm{K_S^0}$	48	28
Observed Λ^0	29	19
Observed $\bar{\Lambda}^0$	4	2
Corrected K^0 rate	0.344 ± 0.065	0.322 ± 0.073
Corrected Λ^0 rate	0.153 ± 0.049	0.113 ± 0.030

Strange particle production in ν NC is different from ν CC at the quark level: NC interactions can produce a leading down quark, a leading up quark and even a leading strange quark.

CC vs NC

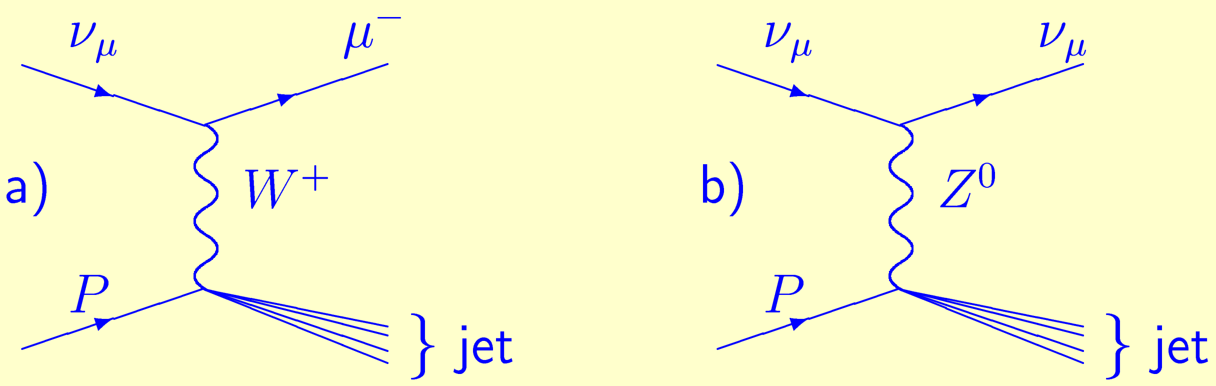
CC identification:

A track that was positively identified by the NOMAD reconstruction algorithm as a muon (purity > 99 %)

Candidate to NC:

An absence of identified a muon or an electron track (purity ≈ 70 %)

Kinematical properties



Likelihood function relying on kinematic variables

Strange Particles in ν NC interactions

For this analysis we used a MC tuned to reproduce the measured yields of V^0's in CC interactions

In the NOMAD data we selected 260k ν NC events with purity $\approx$ 85%

The statistics of V^0 decays.

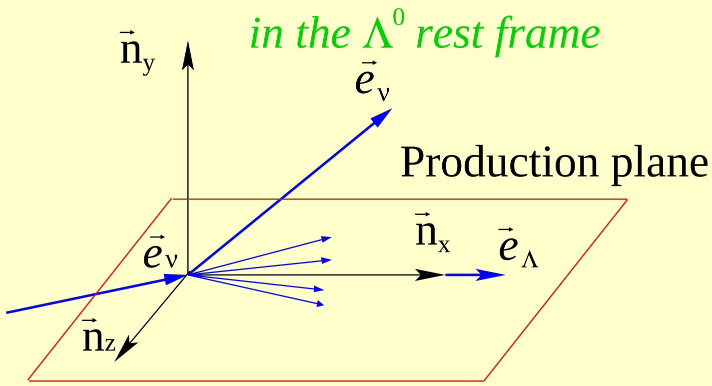
The same V^0 selection algorithm as the one used for the ν CC sample.

#	DATA	Purity
$N(\mathrm{K}^0_\mathrm{S})$	4103	97%
$N(\Lambda^0)$	1773	93%
$N(\bar{\Lambda}^0)$	170	83%

Λ and $\bar{\Lambda}$ polarization in ν_μ NC DIS

The coordinate system used:

$$\left.\begin{array}{l} \bullet\ \vec{n}_x = \vec{e}_\Lambda \\ \bullet\ \vec{n}_y = \vec{e}_\Lambda \times \vec{e}_\nu / |\vec{e}_\Lambda \times \vec{e}_\nu| \\ \bullet\ \vec{n}_z = \vec{n}_x \times \vec{n}_y \end{array}\right\}$$



V^0 type	Entries	Polarization		
		P_x	P_y	P_z
Λ^0	1773	$-0.36 \pm 0.08 \pm 0.05$	$-0.23 \pm 0.07 \pm 0.03$	$0.00 \pm 0.07 \pm 0.04$
$\bar{\Lambda}^0$	170	$0.04 \pm 0.26 \pm 0.15$	$0.48 \pm 0.23 \pm 0.14$	$-0.11 \pm 0.28 \pm 0.20$
K^0_S	4103	$-0.08 \pm 0.03 \pm 0.01$	$-0.05 \pm 0.03 \pm 0.02$	$-0.02 \pm 0.03 \pm 0.02$

- Observed negative longitudinal and transverse polarizations for Λ^0
- Polarization of K^0_S mesons is consistent with zero

Yields of neutral strange particles in ν NC

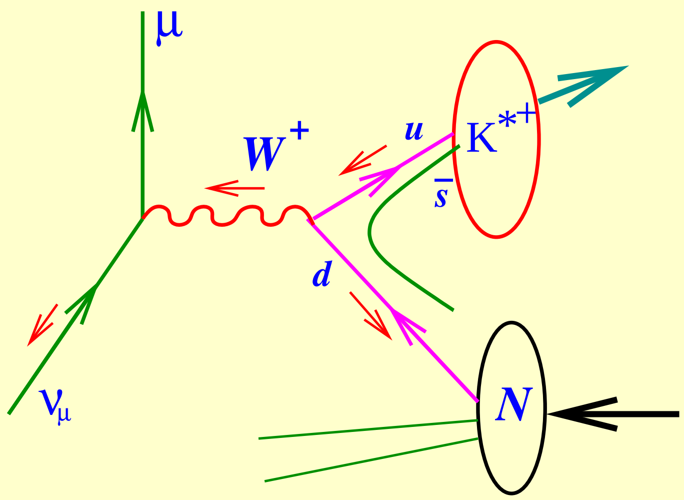
V^0Type	$\mathcal{T}_{\mathrm{V}^0}$ DATA	$\mathcal{T}_{\mathrm{V}^0}$ MC	$\mathcal{T}_{\mathrm{V}^0}^{\mathrm{MC}}/\mathcal{T}_{\mathrm{V}^0}^{\mathrm{DATA}}$
Λ^0	$(5.2 \pm 0.1)\%$	$(5.9 \pm 0.03)\%$	1.13 ± 0.04
$\mathrm{K}_{\mathrm{S}}^0$	$(8.4 \pm 0.2)\%$	$(8.3 \pm 0.04)\%$	1.00 ± 0.02
$\bar{\Lambda}^0$	$(0.45 \pm 0.04)\%$	$(0.56 \pm 0.01)\%$	1.2 ± 0.14

Spin Alignment of $K^{\star\pm}$ mesons

- motivation
- theoretical predictions
- experimental procedure
- systematic uncertainties
- results
- conclusion

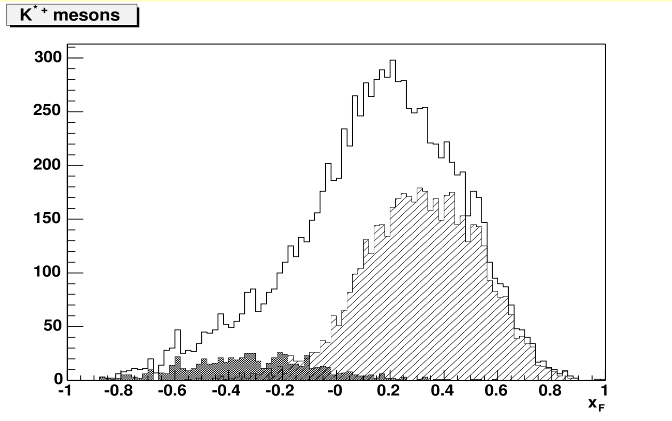
Spin alignment of $K^{\star}(892)^{\pm}$ mesons

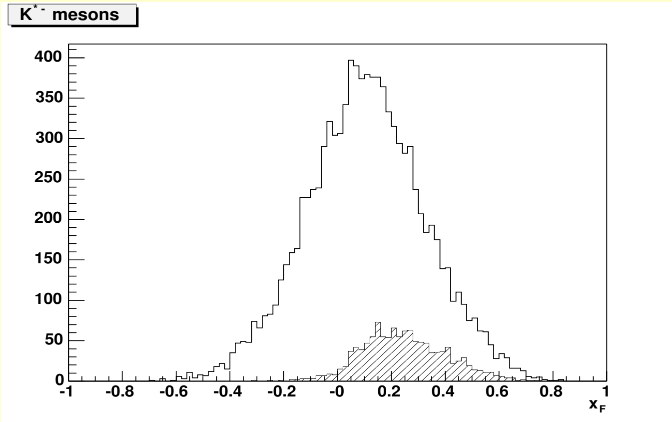
In ν_μ CC interactions with nucleon



$\nu_\mu d \to \mu^- u$ we have 100 % left polarized u-quark, it can fragment into $K^{\star +}(u\bar{s})$ vector meson (1^-).

The yield of the reaction $\nu_\mu d \to \mu^- c(\to s \to K^{\star -})$ compared to the first one is very low





Measurement of Spin Alignment

Spin density matrix $\rho = \rho^u \otimes \rho^{\bar{s}}$ defines the spin state of vector meson, and it's diagonal elements are measured experimentally: $\rho_{00}, \rho_{11}, \rho_{-1-1}$.

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

- θ is the angle between direction of outgoing π and $K^\star$ in the $K^\star$ rest frame ($K^{\star\pm} \to K^0\pi^\pm$ decay);
- ρ_{00} - represents relative intensity of vector mesons with zero *z* - component of the spin (*z*-axis is chosen as the flight direction of the meson).

Interpretation of some cases:

$\rho_{00} = \frac{1}{3}$ – no **spin alignment**, when the probability of meson's spin $+, -$ and 0 projections on the *z* axis are equal;
$\rho_{00} = 0$ – **spin alignment**, when only $+, -$ projections are possible;
$\rho_{00} = 1$ – **spin alignment**, when only 0 projection is possible.

Experimental Review

Meson	ρ_{00}	data	Comments
$\rho^{\pm}$	0.398	0.373 ± 0.052 (OPAL)	$0.3 < x_E < 0.6$
ρ^0	0.498	0.43 ± 0.05 (DELPHI)	$x_E > 0.4$
ω	0.405	0.142 ± 0.114 (OPAL)	$0.3 < x_E < 0.6$
$K^{\star 0}$	0.504	0.46 ± 0.08 (DELPHI)	$x_E > 0.4$
ϕ	0.557	$0.54 \pm 0.06 \pm 0.05$ (OPAL) 0.55 ± 0.10 (DELPHI)	$x_E > 0.7$
$D^{*\pm}$	0.415	$0.40 \pm 0.02 \pm 0.01$ (OPAL)	$x_E > 0.5$
B^*	0.567	$0.32 \pm 0.04 \pm 0.03$ (DELPHI) $0.33 \pm 0.06 \pm 0.05$ (ALEPH) $0.36 \pm 0.06 \pm 0.07$ (OPAL)	$0 < x_E < 1$
$K^{\star +}$ $K^{\star -}$		0.424 ± 0.011 (EXCHARM) 0.393 ± 0.025 (EXCHARM)	in the transversity frame of $K^\star$

Theoretical Predictions

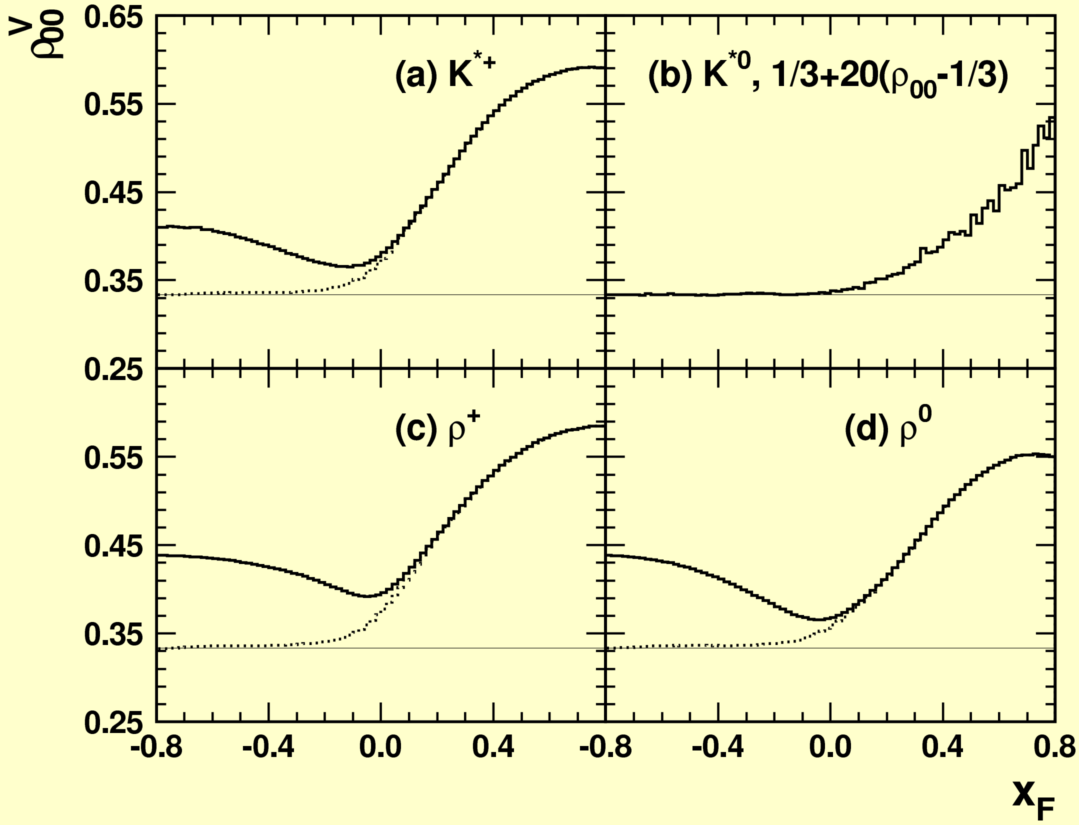
Spin alignment of vector mesons produced in ν_μ CC interactions with $E_\nu = 43.8$ GeV predicted by

Liang Zuo-tang, **arXiv:hep-ph/0205291**

$$P_z = -\alpha P_f$$

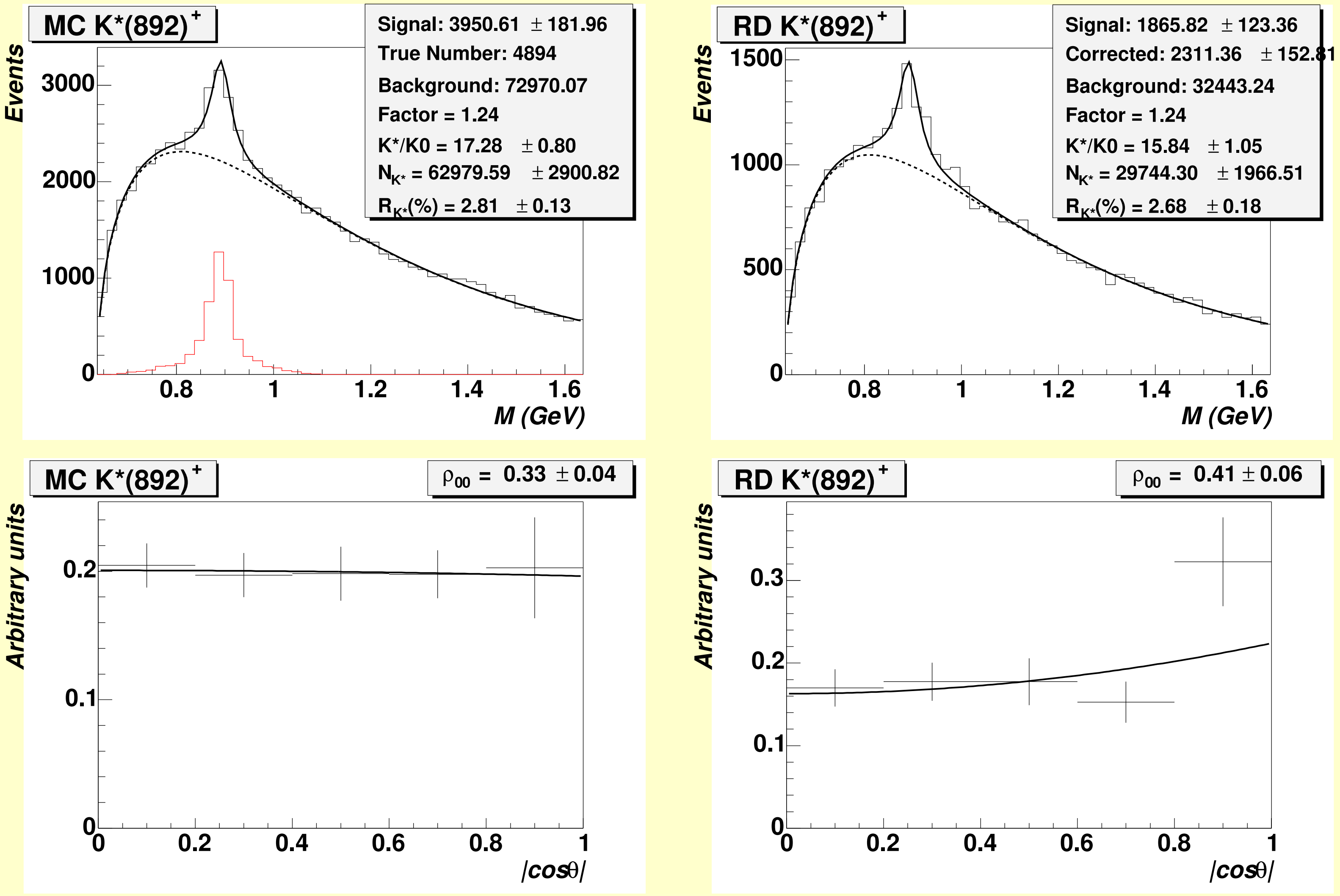
$$\rho_{00}(x_F) = \sum_f \frac{1+\alpha P_f^2}{3-\alpha P_f^2} \frac{\langle n(x_F|a,f)\rangle}{\langle n(x_F)\rangle} + \frac{1}{3}\frac{\langle n(x_F|b)\rangle}{\langle n(x_F)\rangle}.$$

From **LEP** experiments $\alpha \approx 0.5$.



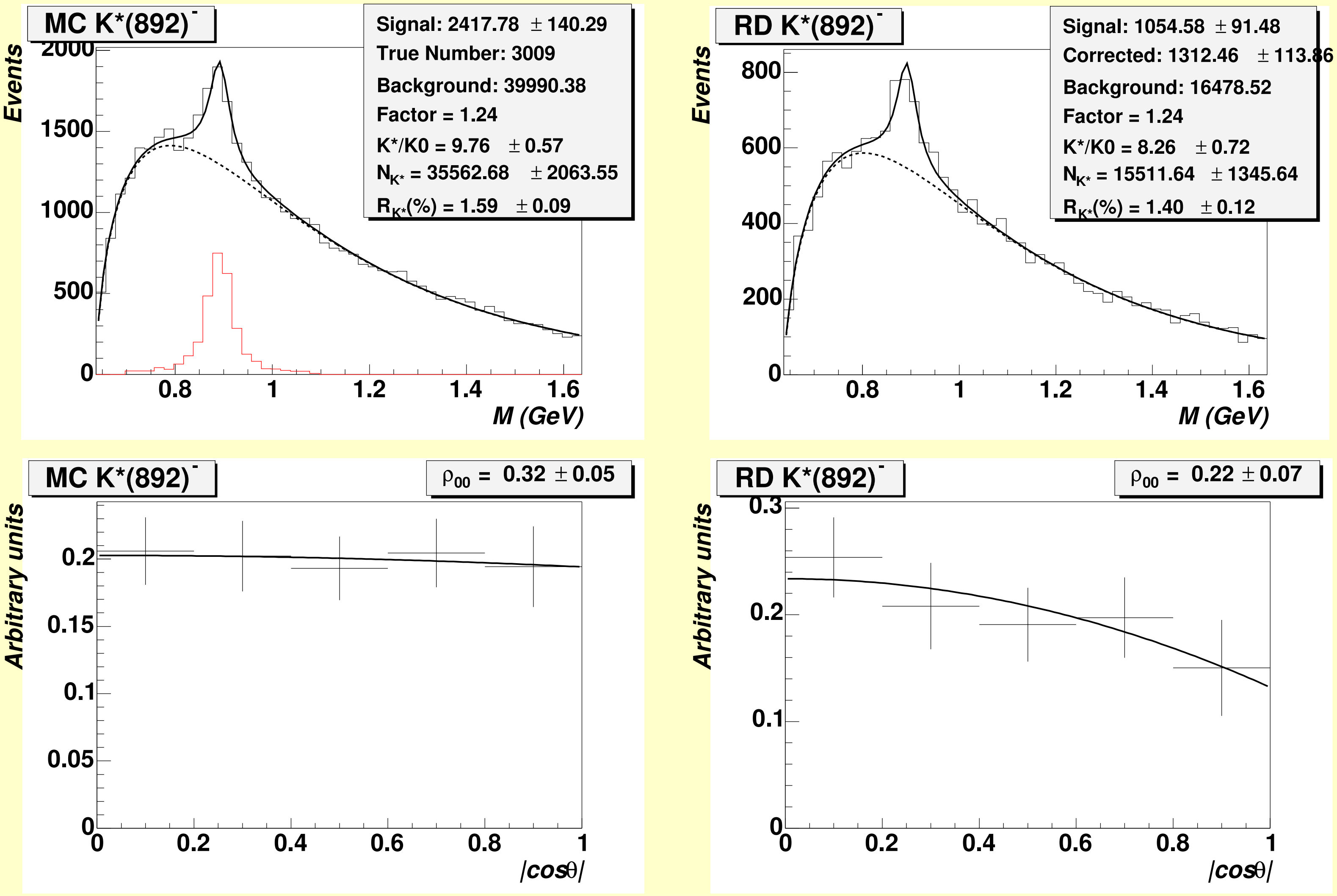
Experimental Procedure - $K^{\star+}$

MC DATA



Experimental Procedure - $K^{\star -}$

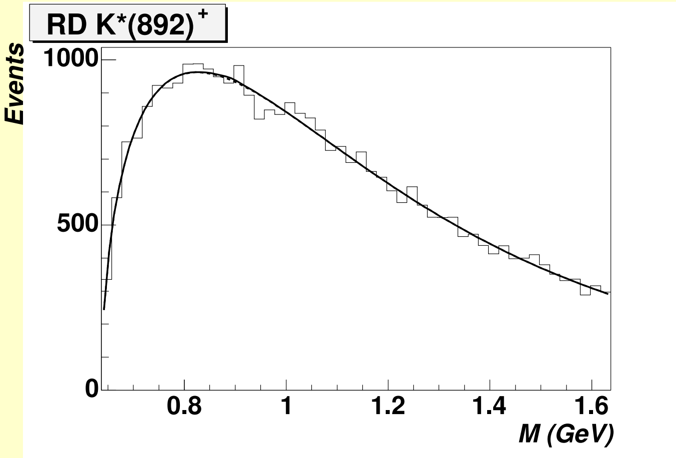
MC　　　　　　　　DATA



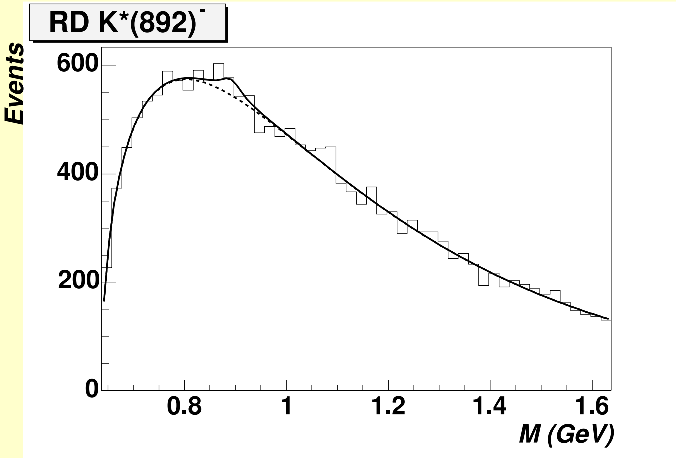
Systematic Uncertainties

To check the stability of the final results we did the following:

- Change the K_S^0's mesons selection criteria
- For the NC sample we varied likelihood selection criteria
- Change the number of bins while fitting invariant mass
- Investigate possible combinatorial nature of the signal while fitting invariant mass.



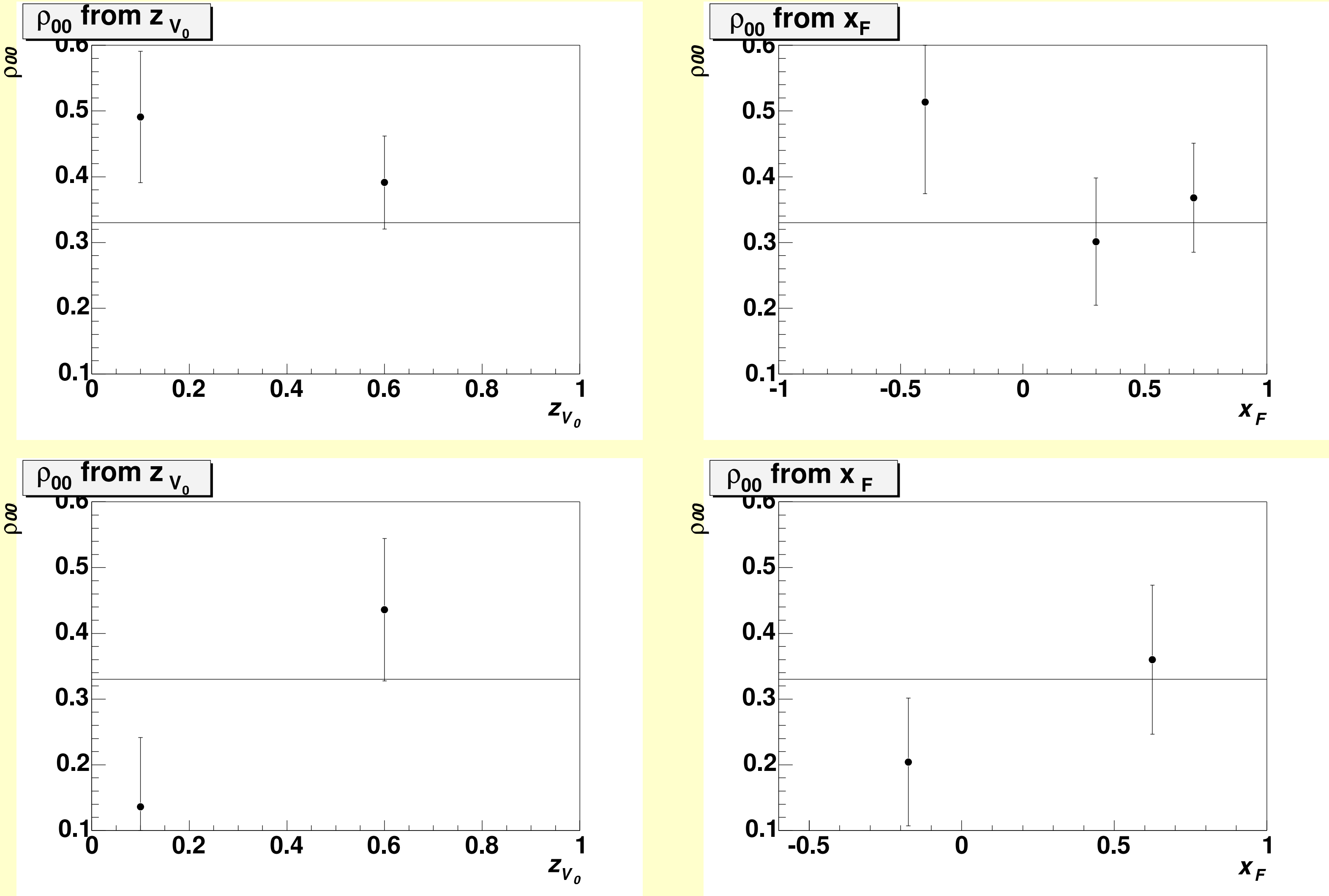
K_S^0 + *positively charged track*



K_S^0 + *negatively charged track*

Dependence of Spin Alignment on z and x_F

z $\qquad\qquad$ x_F



Results

	Number of $K^\star$	Yields of $K^\star$ (%)	$K^\star/K^0$ (%)
$K^{\star+}$ CC	$29744 \pm 1967 \pm 1558$	$2.68 \pm 0.18 \pm 0.14$	$15.84 \pm 1.05 \pm 0.75$
$K^{\star-}$ CC	$15512 \pm 1346 \pm 438$	$1.40 \pm 0.12 \pm 0.04$	$8.26 \pm 0.72 \pm 0.27$
$K^{\star+}$ NC	$12355 \pm 1479 \pm 3417$	$2.49 \pm 0.30 \pm 0.63$	$15.46 \pm 1.85 \pm 3.13$
$K^{\star-}$ NC	$6265 \pm 1176 \pm 1821$	$1.26 \pm 0.24 \pm 0.31$	$7.84 \pm 1.47 \pm 1.76$

ρ_{00} parameter

$K^{\star+}$ CC	$0.41 \pm 0.06 \pm 0.05$
$K^{\star-}$ CC	$0.22 \pm 0.07 \pm 0.02$
$K^{\star+}$ NC	$0.18 \pm 0.09 \pm 0.12$

We observe a little deviation from the $\frac{1}{3}$ value – possible spin alignment

Conclusions

- We identified 260k of NC events with 85% purity
- for the first time in ν NC interactions we measured polarization of Λ^0 and $\bar{\Lambda}^0$
- Yields of Λ^0, $\bar{\Lambda}^0$, $\mathrm{K^0_S}$ hadrons are obtained
- yields of $K^\star(892)^\pm$ that decay into $K^0\pi^\pm$ in ν_μ CC and NC interactions were measured with a good precision
- for the first time in neutrino experiments we measured ρ_{00} parameters for the $K^\star(892)^\pm$ vector mesons
- ρ_{00} parameters slightly differ from $1/3$ value
- x_F dependence of ρ_{00} is compared to *Liang* predictions

3 papers apear soon