Measurement of $\mathbf{\Lambda}^0$ polarization in $\nu_\mu N \to \mu^- \Lambda^0 X$ in NOMAD (CERN)

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for the NOMAD Collaboration

JINR (Dubna)

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ν_μ NOMAD ν_τ

Neutrino Oscillation MAgnetic Detector

Outline:

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Motivation

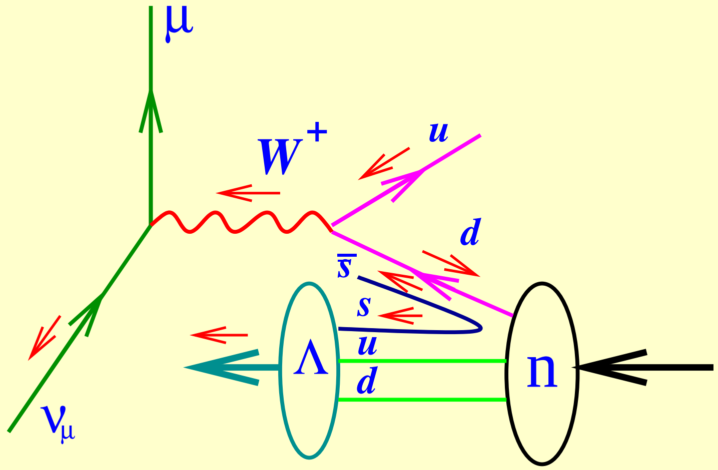
Spin Crysis $\Rightarrow$ assuming $SU(3)_F$ with info from β decays $\Delta u + \Delta d + \Delta s = 0.27 \pm 0.04$ $\Delta s = -0.11 \pm 0.03$ predicted 0.58 if $\Delta G = 0$

What can be learnt measuring Λ^0 polarization?

Are strange quarks in the nucleon sea polarized?

Target fragmentation region $x_F < 0$

M. Alberg, J. Ellis, M. Karliner, D.Kharzeev, A. Kotzinian, M. Sapozhnikov advocate negatively polarized $s\bar{s}$ pairs in nucleon



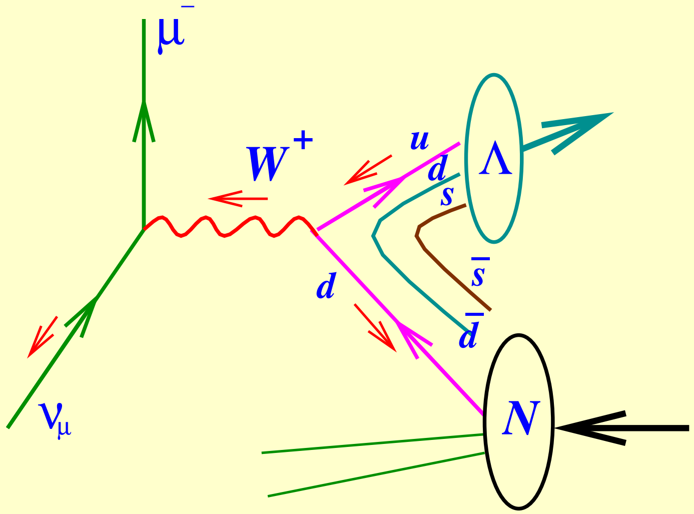
$\Rightarrow$ negative polarization of prompt Λ^0s

What is the spin content of Λ^0 hyperon?

Current fragmentation region $x_F > 0$

R.L. Jaffe advocates $\Delta u_\Lambda, \Delta d_\Lambda \approx -0.20$

Contributions from $\Sigma^*, \Sigma^0, \Xi^-$ are of great importance

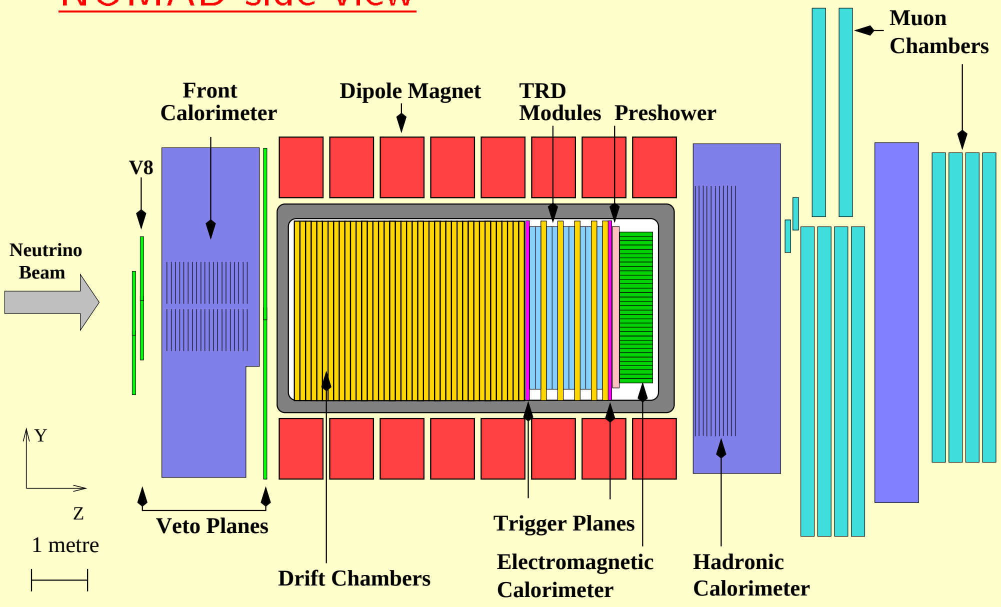


Study spin transfer coefficient C_Λ^u

NOMAD can study both $x_F < 0$ and $x_F > 0$

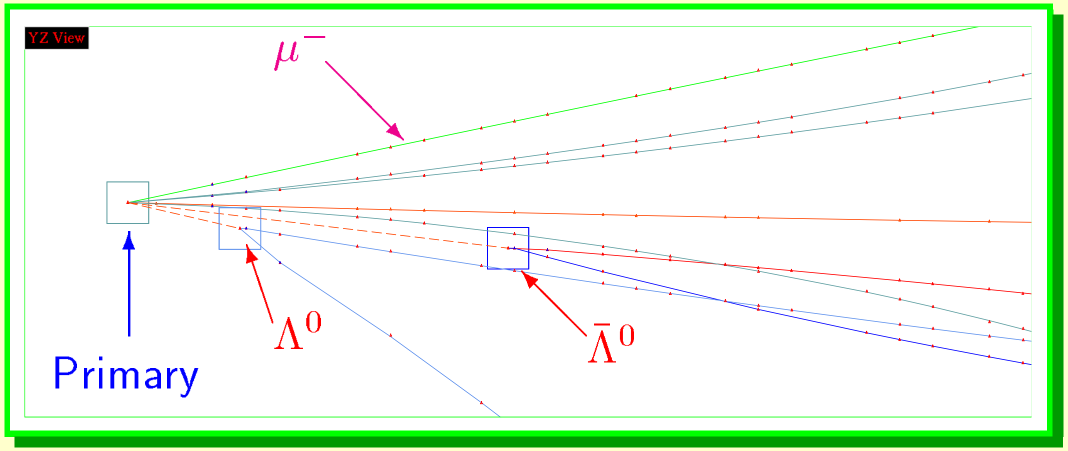
The NOMAD detector and V^0 reconstruction

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

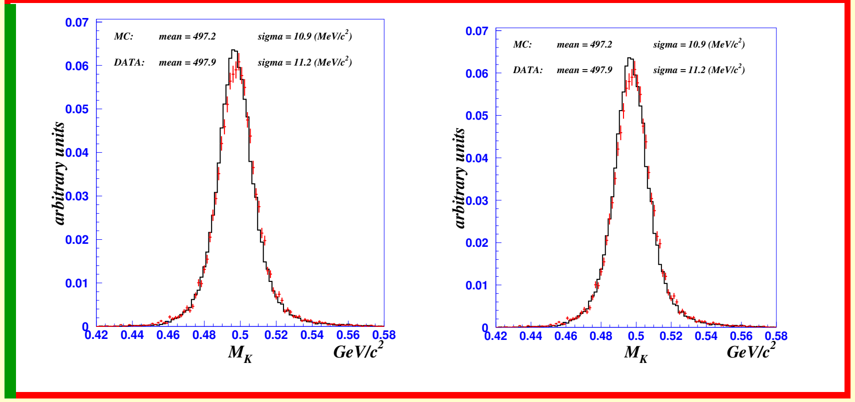


Λ^0,$\bar{\Lambda}^0$,K^0_S identification in ν_μ CC events

Identification Algorithm

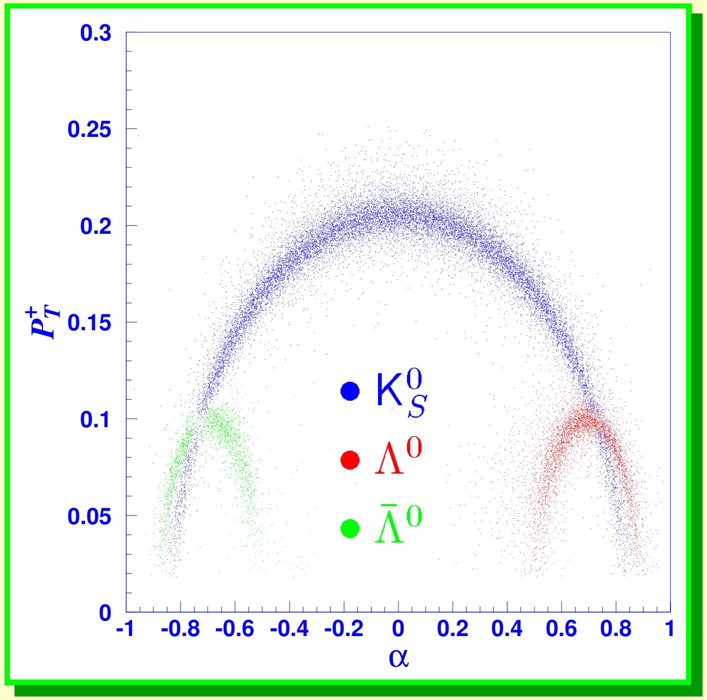
1. Reconstruction and selection of ν_μ CC events
2. Preliminary selection of V^0
3. Kinematic fit with energy and momenta constraints

Mass resolution: Λ^0, K^0_S



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

Final samples: Armenteros's plot

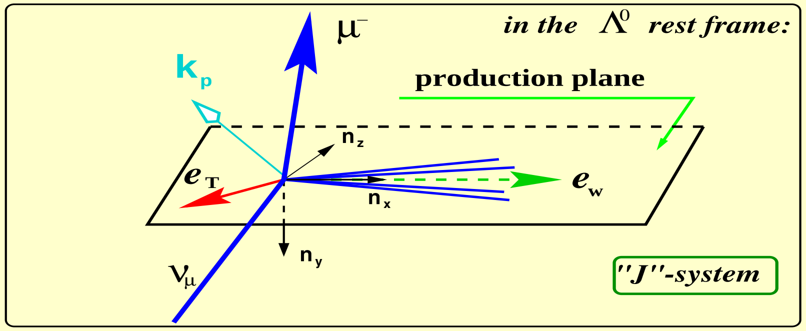


V^0	Data	Purity (%)	Efficiency (%)
Λ^0	8087	95.9 ± 0.1	16.4 ± 0.1
$\bar{\Lambda}^0$	649	89.7 ± 0.7	18.6 ± 0.5
K^0_S	15074	97.2 ± 0.1	22.1 ± 0.1

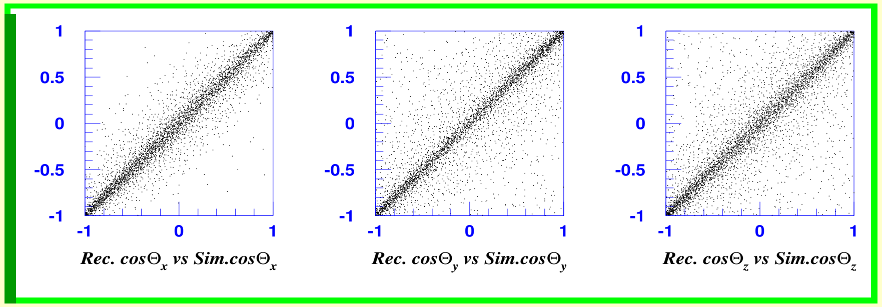
Polarization measurement

Reference system (in Λ^0 rest frame)
Correlated with expected polarization
($W \Rightarrow$ W-boson, $T \Rightarrow$ target nucleon)

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

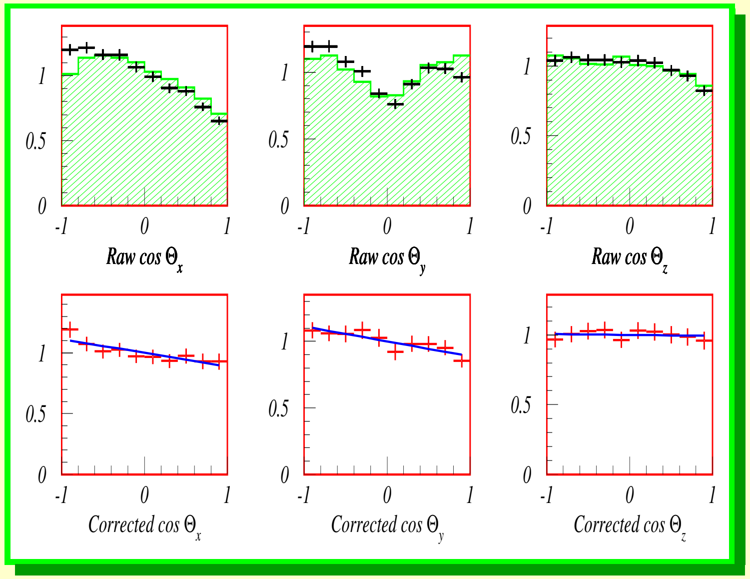


Simulated *versus* reconstructed $\vec{k}_p \cdot \vec{n}_i$:



2 methods for polarization extraction:

- correct real data angular distributions for detector acceptance and fit with a straight line: $A_i(1 + \alpha P_i \cos\theta_i)$



- developed advanced 3D fit taking into account smearing of the angluar variables and the detector acceptance

Systematics

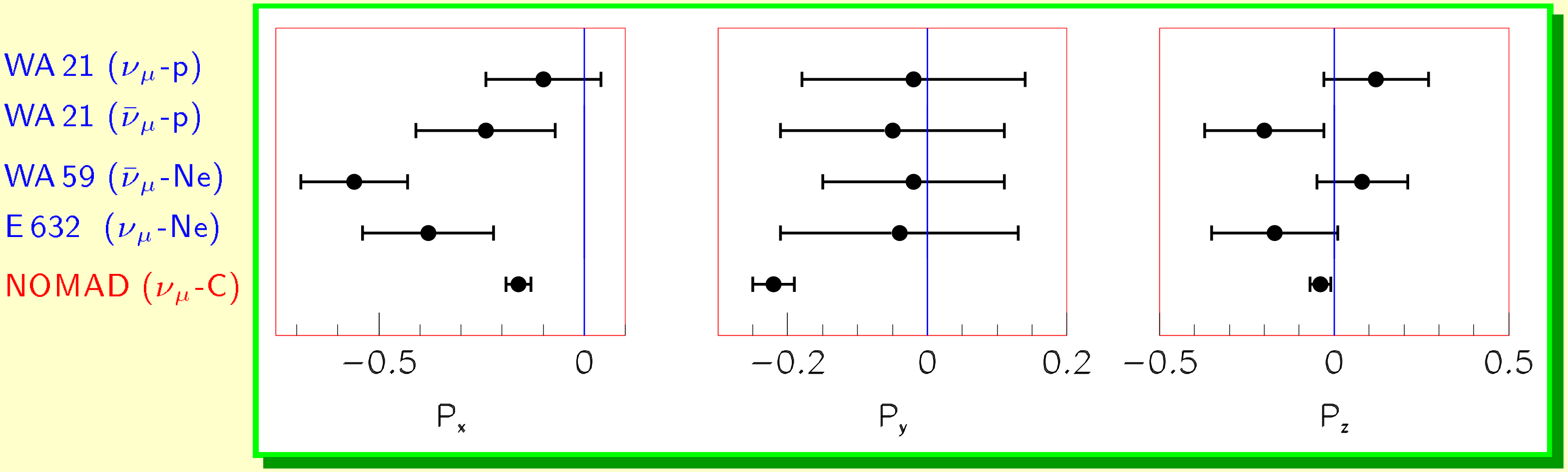
- Uncertainty in the frame axes:
  - uncertainty in the incoming neutrino energy determination
  - spin precession for a particle traveling through a magnetic field
  - Fermi motion effects
  - in addition the analysis was repeated in two more reference systems: T and ν
- Background effects:
  - uncertainty in the background predictions
  - potential dependence of final results on the selection criteria
  - contamination from ν neutral current interactions
- smearing of the x_F distribution
- Detector alignment:
  - gives consistent results in different periods of data taking
- Identification effects:
  - repeated with two different methods of Identification: invariant mass and α asymmetry
- Independent verification:
  - K_S^0 polarization consistent with zero

P_i	ν energy reconstruction	V^0 induced background	Variation of cuts	Spin precession	Total
P_x	$3.4 \cdot 10^{-3}$	$3.5 \cdot 10^{-3}$	$1.7 \cdot 10^{-2}$	$1.4 \cdot 10^{-3}$	$1.8 \cdot 10^{-2}$
P_y	$8.5 \cdot 10^{-3}$	$4.9 \cdot 10^{-3}$	$3.8 \cdot 10^{-3}$	$7.2 \cdot 10^{-5}$	$1.1 \cdot 10^{-2}$
P_z	$1.2 \cdot 10^{-2}$	$7.8 \cdot 10^{-3}$	$1.2 \cdot 10^{-2}$	$8.6 \cdot 10^{-4}$	$1.9 \cdot 10^{-2}$

General results

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

NOMAD results with respect to previous bubble chamber measurements



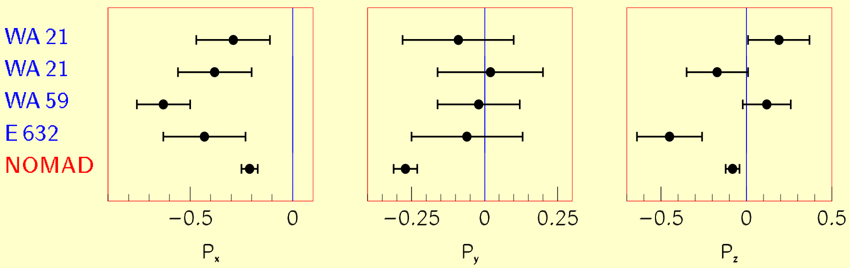
- Observed negative longitudinal polarization
- For the first time in neutrino experiments observed transverse polarization
- P_z is consistent with zero

Results: Target and Current Fragmentation

Target fragmentation region: $x_F < 0$

$N_{\Lambda^0} = 5608 \qquad < x_F >= -0.36$

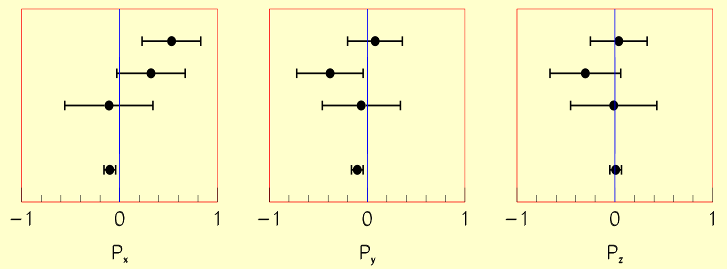
P_x	P_y	P_z
-0.21 ± 0.04	-0.26 ± 0.04	-0.08 ± 0.04



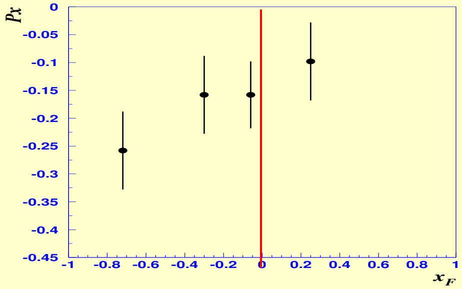
Current fragmentation region: $x_F > 0$

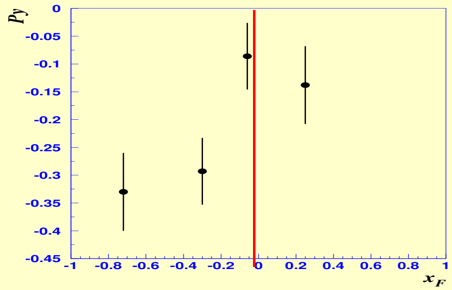
$N_{\Lambda^0} = 2479 \qquad < x_F >= 0.21$

P_x	P_y	P_z
-0.09 ± 0.06	-0.10 ± 0.06	0.02 ± 0.06



- $-P_x$ is enhanced
  $\Rightarrow$ consistent with negatively polarized $s\bar{s}$ pairs in the nucleon
- Contributions from Σ^0, $\Sigma^\star$ and Ξ are expected to be important
- $-P_y$ is enhanced
- Look for different targets!





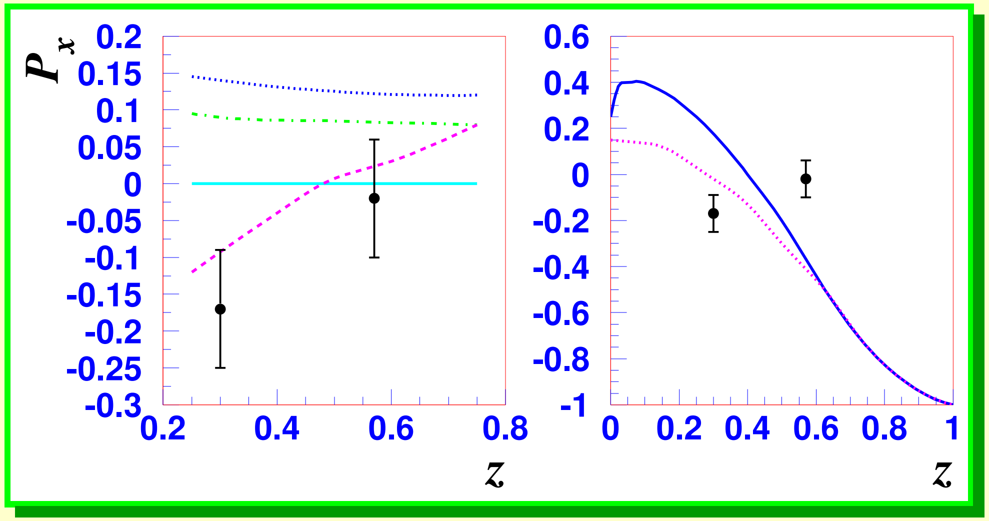
- measured spin transfer coefficient:

$$P_x^\Lambda \approx -\frac{\Delta D_u^\Lambda}{D_u^\Lambda} = -C_u^\Lambda$$

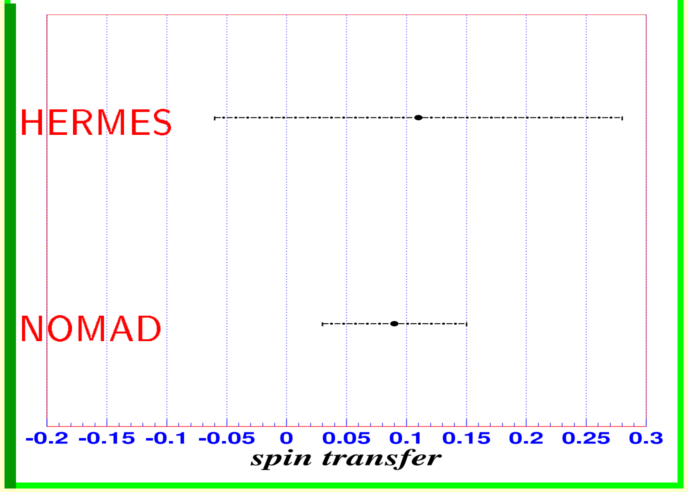
- interpretation depends strongly on the yields of Σ^0, $\Sigma^\star$ and Ξ

Longitudinal polarization: $x_F > 0$

- A.Kotzinian, A.Bravar, D.von Harrach, Eur. Phys. J. **C2** (1998) 329 (left)
- B.Ma, I.Schmidt, J.Soffer and J.Yang, hep-ph/0001259 (right)



Spin transfer C^u_Λ:



Target nucleon effects:

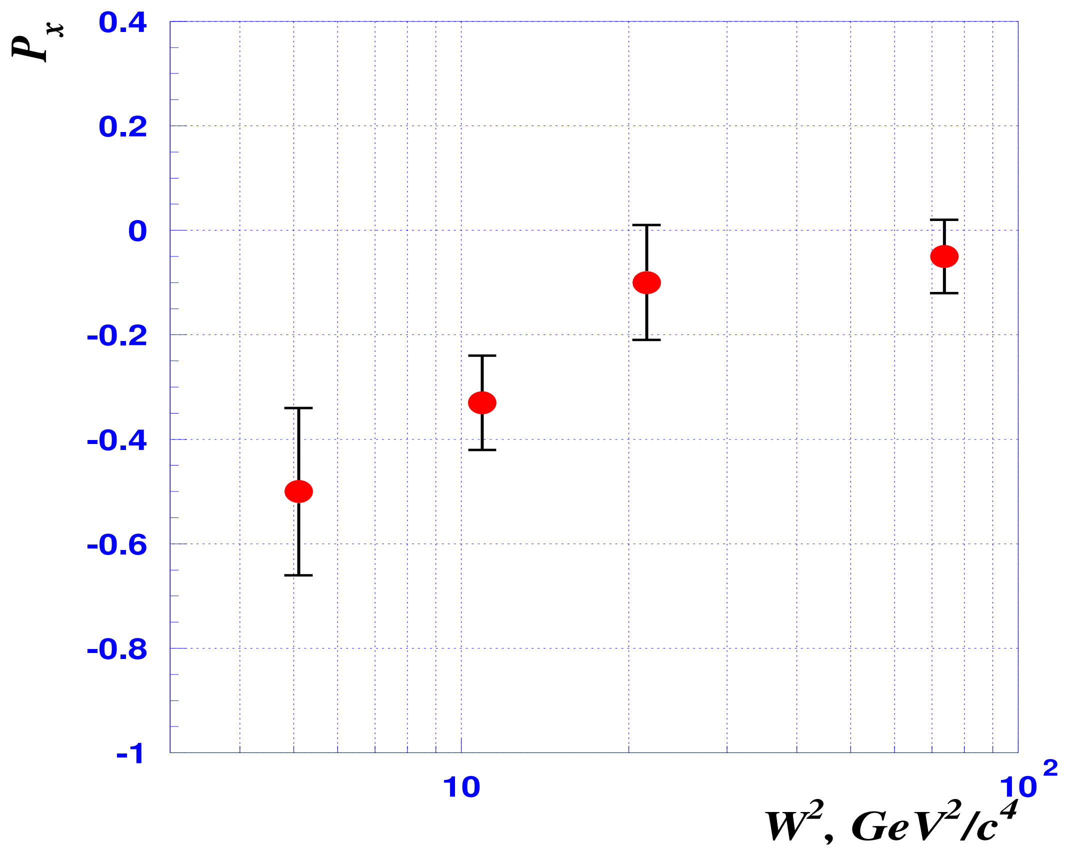
(p-like $\Rightarrow$ purity 76%), (n-like $\Rightarrow$ purity 85%)

target	N_Λ	P_x
p-like	1064	-0.23 ± 0.09
n-like	1414	0.01 ± 0.08

- In p-like events the chain $\overleftarrow{u} \Rightarrow \overleftarrow{\Sigma^{\star +}} \Rightarrow \overleftarrow{\Lambda}$ is important
- In n-like events the chain $\overleftarrow{u} \Rightarrow \Lambda$ is dominant

Naive QPM is favoured...

Longitudinal polarization: $x_F < 0$



W^2 dependence:

- smaller W^2 $\Rightarrow$ better chance for Λ to get the s-quark from the *nucleon sea*
- similar dependence on Q^2
- *polarized* strangeness inside the nucleon is favoured

Longitudinal polarization: $x_F < 0$

2 possible interpretations of polarized strangeness model:

1. if $s^{\uparrow}$ anticorrelates with $N^{\uparrow}$ $\Rightarrow$ Λ polarization should be different for different nucleon targets:

$$P_{\Lambda}(\nu p) > 0 \text{ and } P_{\Lambda}(\nu n) < 0$$

2. if $s^{\uparrow}$ anticorrelates with $q^{\uparrow}_{struck}$ $\Rightarrow$ Λ polarization should be the same for both targets:

$$P_{\Lambda}(\nu N) < 0$$

Results: Target nucleon effects

(p-like $\Rightarrow$ purity 76%), (n-like $\Rightarrow$ purity 85%)

target	N_{Λ}	P_x
p-like	2335	-0.27 ± 0.06
n-like	3096	-0.13 ± 0.06

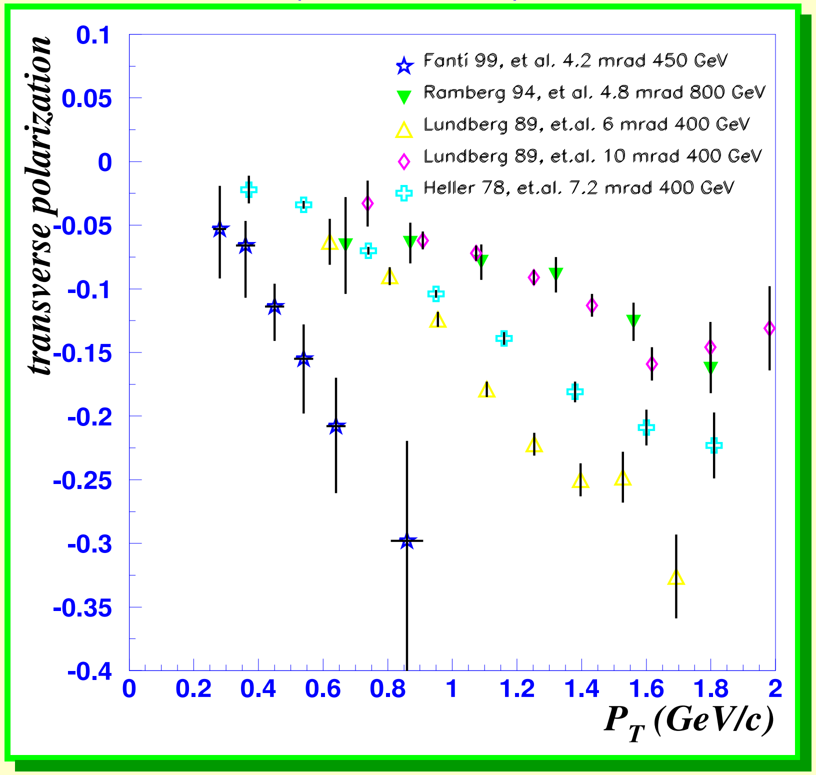
Conclusions:

- P_x is negative for both p-like and n-like events $\Rightarrow$ *spin correlation with the struck quark*
- In p-like events the chain $\overleftarrow{uu} \Rightarrow \overleftarrow{\Sigma^{\star +}} \Rightarrow \overleftarrow{\Lambda}$ is important
- In n-like events prompt Λs are dominant $\Rightarrow$ *sensitive to intrinstic nucleon strangeness polarization*

Transverse polarization versus P_T

unpolarized hadron-hadron experiments:

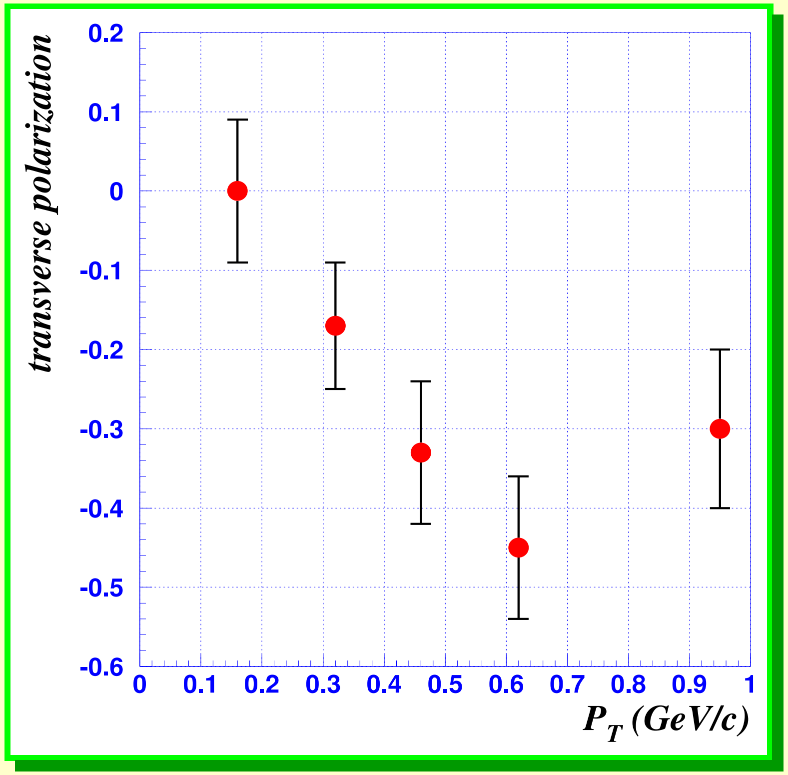
(plot NA 48)



- where p_T is the transverse momentum of the Λ with respect to the beam direction
- absolute value grows linearly with P_T

NOMAD $\nu_\mu N \to \mu^- \Lambda X$:

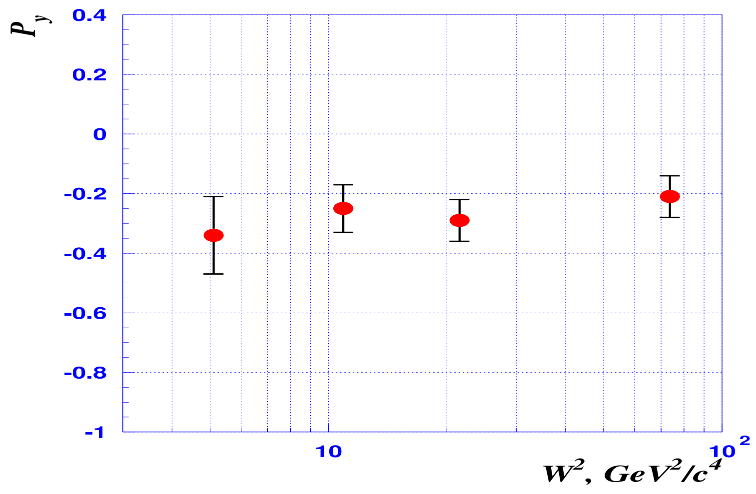
$(x_F < 0)$



- similar dependence on p_T
- where p_T is the transverse momentum of the Λ with respect to the hadronic jet

Transverse polarization

W^2 dependence ($x_F < 0$):



- no statistically significant effect found in both $x_F < 0$ and $x_F > 0$
- transverse polarization likely *originates in the fragmentation process*

Target nucleon effects:

(p-like $\Rightarrow$ purity 76%), (n-like $\Rightarrow$ purity 85%)

$x_F < 0$

target	N_Λ	P_y
p-like	2335	-0.10 ± 0.06
n-like	3096	-0.34 ± 0.05

- In p-like events the s-quark polarization is washed out due to the considerable contribution from $\Sigma^\star$, etc
- In n-like events the s-quark polarization is preserved due to the dominant production channel of prompt Λs

$x_F > 0$

target	N_Λ	P_y
p-like	1064	-0.06 ± 0.09
n-like	1414	-0.11 ± 0.08

- no statistically significant effect found

What we learnt measured Λ^0 polarization?

Longitudinal polarization

- **nucleon strangeness**
  - message from $x_F < 0$ is that *the nucleon strangeness is likely to be negatively polarized*
  - $W^2(Q^2)$ dependence indicates that the Λ^0 polarization originates from the *nucleon sea* and not from the fragmentation process
  - Target nucleon effects show that $s^\uparrow$ is correlated with $d^\uparrow$ and not with $N^\uparrow$
  - solid quantitative theoretical predictions are currently not available

- **spin transfer**
  - y_B independence confirms a suppression of $\bar{d} \to \Lambda$ production channel
  - measured C_u^Λ absorbs contributions from $\Sigma^\star$, Σ^0, Ξ decays
  - Target nucleon effects show a considerable contribution from $\Sigma^\star$ etc
  - message from $x_F > 0$ is that *Naive Quark Parton Model is favoured*

What we learnt measured Λ^0 polarization?

Transverse polarization

- **Target fragmentation**
  - Negative Sign as in unpolarized hadron-hadron experiments likely indicates that the transverse polarization is independent of the type of the beam particle
  - $W^2(Q^2)$ independence can be interpreted as a manifestation of the transverse polarization origin in the fragmentation process
  - P_T dependence is in perfect agreement with that in unpolarized hadron-hadron experiments
  - The P_T slope is x_F dependent as in unpolarized hadron-hadron experiments
  - Target nucleon effects show that the polarization mainly originates from interactions on neutrons, where ud pair is left

- **Current fragmentation**
  - The effect is comparable with statistical errors, while being similar to that in the target fragmentation

Open Questions

- Can negatively polarized nucleon strangeness rub along with NQM for Λ^0 both likely to be favoured in NOMAD? OR does $SU(3)_F$ works?
- We need a good theory in the target fragmentation region: is it possible to relate Δs_N with the measured *longitudinal polarization of Λ^0s*?
- The measured yields of $\Sigma^{\star\pm}$, Σ^0, Ξ^- should be taken into account in the corresponding theoretical calculations.
- The origin of the *transverse polarization* seems to be similar to that in unpolarized hadron-hadron collisions. Do we have a good theory for this?
- What is the next update? (ν factory?)

Conclusions

- NOMAD has collected 8087 Λs in $\nu_\mu CC$ events, which is 30 times more than previous record
- NOMAD observes longitudinal and (*for the first time*) transverse polarization of Λ hyperons produced in νN DIS
- The longitudinal polarization at $x_F < 0$ favours negatively polarized nucleon strangeness model
- NOMAD provides a measurement of the spin transfer coefficent C_u^Λ at $x_F > 0$ favouring Naive Quark Parton Model
- The transverse polarization obeys similar laws as that in unpolarized hadron-hadron collisions.
- Strong target nucleon effects are found
- A study of the polarization dependence on different kinematic variables is performed

These results are published in **Nuclear Physics B588**(2000) and also as CERN-EP/2000-111

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