Fragmentation studies in NOMAD experiment

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Outline

The NOMAD Experiment

MC tuning

Comparison of MC and Data

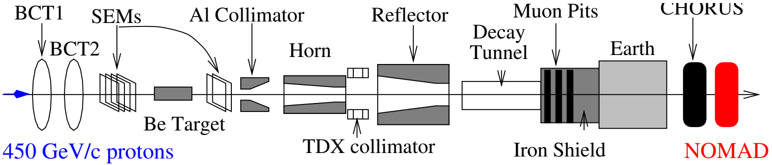
Comparison with GENIE generator

Summary

The NOMAD experiment

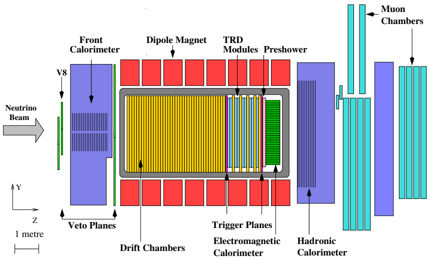
The NOMAD experiment

- was looking for the $\nu_\mu \to \nu_\tau$ oscillations
- protons energy from SPS (CERN) - 450 GeV
- distance between π, K decay channel and detector - 620 m
- mean neutrino energy $\langle E_{\nu_\mu} \rangle$ - 24.3 GeV
- high statistic: 1.3×10^6 ν_μ CC interactions
- more then 20 000 identified neutral strange particles



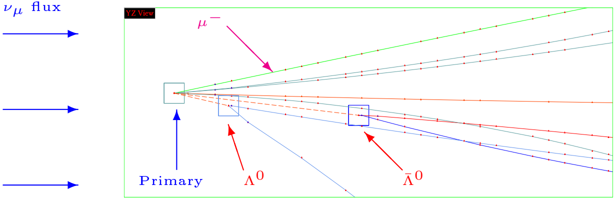
The NOMAD detector

NOMAD side view



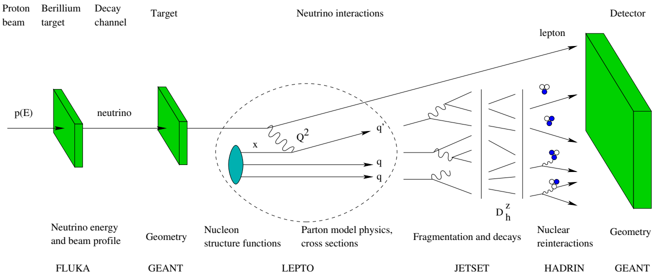
- Drift chambers used as a target (2.7 tons) and for momentum measurement (3.5% resolution)
- Magnetic field: 0.4 T
- TRD and Preshower for electron identification
- ECAL and HCAL for energy measurement
- Muon chambers: detect and identify muon

ν_μ flux



NOMAD neutrino event generation library

- LEPTO 6.1
- JETSET 7.4 (string fragmentation)
- GEANT 3 (tracing particles)
- DPMJET II (intranuclear reinteractions)



Default JETSET parameters - strange particles production yields. ν_μ CC interactions

Hadrons	MC (%)	Data (%)	MC/Data
K_S^0	11.4	8.99 ± 0.08	1.27 ± 0.01
Λ^0	9.0	6.21 ± 0.08	1.46 ± 0.02
$\bar{\Lambda}^0$	0.73	0.52 ± 0.02	1.41 ± 0.08
$\rho^0(770)$		19.50 ± 1.90	
$f_0(980)$		1.80 ± 0.40	
$f_2(1270)$		3.80 ± 0.90	
Fraction			
$\frac{N(K^{\star+}\to K_S^0\pi^+)}{N(K_S^0)}$	31.0	14.1 ± 0.9	2.20 ± 0.04
$\frac{N(K^{\star-}\to K_S^0\pi^-)}{N(K_S^0)}$	13.5	8.9 ± 0.08	1.5 ± 0.4
$\frac{N(\Sigma^{\star+}\to \Lambda\pi^+)}{N(\Lambda)}$	16.9	4.4 ± 1.0	3.8 ± 1.3

The agreement between MC and Data is poor

Tuning NOMAD event generator - ν_μ CC events

Reweighting for the cross-sections
Events selection: $Q^2 > 0.8\ GeV^2, E_{had} > 3GeV$

Analizing the following variables:

- Transverse size of the hadronic system
- Momentum and angle distributions of hadrons
- Primary tracks multiplicity
- Particles and resonances yields: Λ^0, $\bar{\Lambda}^0$, K^0_S, $K^{\star\pm}, \Sigma^{\star+}, D^0, D^{\star0}, \rho^0, f_0, f_2$, di-muon events
- Formation length

Tuning: JETSET, DPMJET

Find best JETSET parameters - strange particles production yields

Parameter	Description	Default	ALEPH	NOMAD
PARJ(1)	$\mathcal{P}(qq)/\mathcal{P}(q)$	0.10	0.106 ± 0.004	0.061
PARJ(2)	$\mathcal{P}(s)/\mathcal{P}(u)$	0.30	0.285 ± 0.015	0.198
PARJ(3)	$(\mathcal{P}(us)/\mathcal{P}(ud))/(\mathcal{P}(s)/\mathcal{P}(d))$	0.40	0.71 ± 0.08	0.130
PARJ(4)	$(1/3)\mathcal{P}(ud_1)/\mathcal{P}(ud_0)$	0.05	–	0.002
PARJ(5)	$\mathcal{P}(BM\bar{B})/(\mathcal{P}(B\bar{B})+\mathcal{P}(BM\bar{B}))$	0.50	–	0.600
PARJ(6)	$s\bar{s}$ suppression in $BM\bar{B}$	0.50	–	0.500
PARJ(7)	s-meson suppression in $BM\bar{B}$	0.50	–	0.220
PARJ(11)	$\mathcal{P}(s=1)_{u,d}$	0.50	0.55 ± 0.06	0.380
PARJ(12)	$\mathcal{P}(s=1)_{s}$	0.60	0.47 ± 0.06	0.680
PARJ(13)	$\mathcal{P}(s=1)_{c,b}$	0.75	0.65	0.660
PARJ(14)	$\mathcal{P}(S=0, L=1, J=1)$	0.0	0.12	0.150
PARJ(15)	$\mathcal{P}(S=1, L=1, J=0)$	0.0	0.04	0.105
PARJ(16)	$\mathcal{P}(S=1, L=1, J=1)$	0.0	0.12	0.150
PARJ(17)	$\mathcal{P}(S=1, L=1, J=2)$	0.0	0.20	0.295

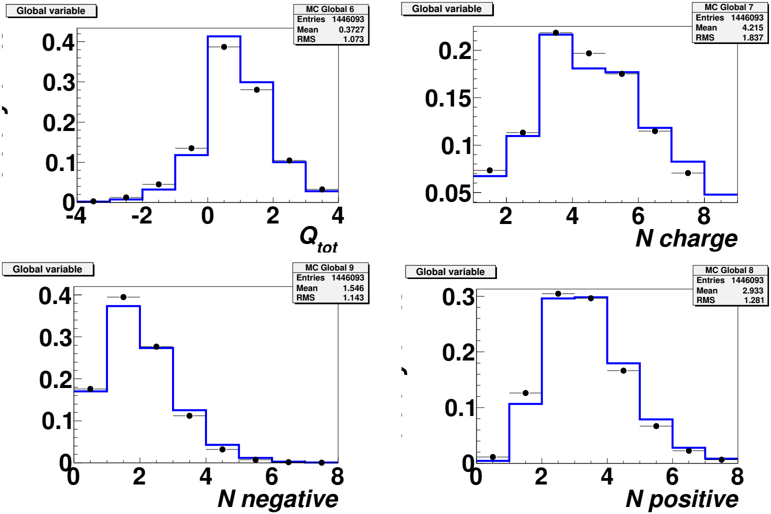
Find best JETSET parameters - global distributions behavior

Parameter	Description	Default	ALEPH	NOMAD
PARJ(19)	Leading baryon suppression	1.0	0.57 ± 0.10	0.500
PARJ(21)	σ_q (GeV)	0.36	0.370 ± 0.008	0.395
PARJ(23)	fraction of p_t tail	0.01	–	0.180
PARJ(32)	E_{min} (GeV)	1.0	–	0.200
PARJ(33)	E_{rem} (GeV)	0.80	–	0.200
PARJ(41)	a	0.30	0.40	1.350
PARJ(42)	b (GeV^{-2})	0.58	0.796 ± 0.035	0.800
PARJ(45)	a_{qq}	0.50	–	0.400
PARJ(54)	ε_c	-0.05	-0.04	-0.165
MSTJ(11)	fragmentation type	4	3	3
MSTJ(12)	baryon model	2	3	3

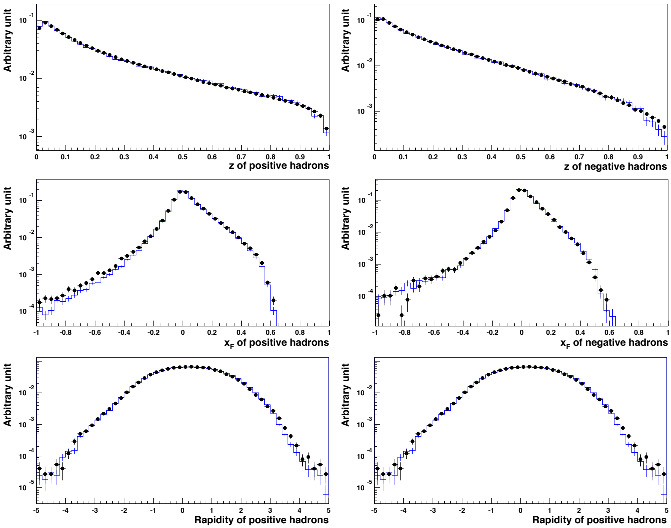
DPMJET: formation length - 2.5 fm

Comparison of MC and Data for the NOMAD experiment

New JETSET parameters - global variables



New JETSET parameters - global variables



New JETSET parameters - particles and resonances production yields. ν_μ CC interactions

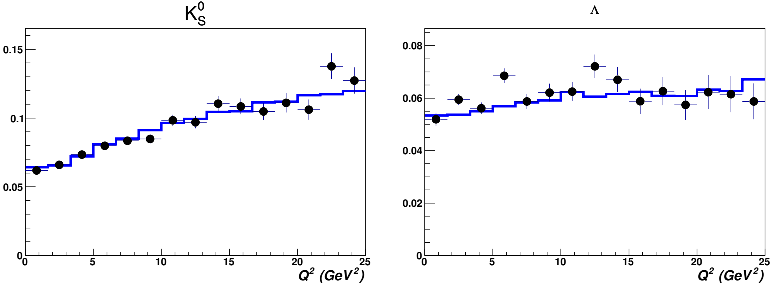
Hadrons	MC (%)	Data (%)	MC/Data
K_S^0	8.80 ± 0.06	8.69 ± 0.08	1.01 ± 0.01
Λ^0	5.64 ± 0.05	5.86 ± 0.08	0.96 ± 0.02
$\bar{\Lambda}^0$	0.44 ± 0.01	0.43 ± 0.02	1.03 ± 0.06
$\rho^0(770)$	17.21 ± 0.04	19.50 ± 1.90	0.88 ± 0.09
$f_0(980)$	1.59 ± 0.01	1.80 ± 0.40	0.88 ± 0.20
$f_2(1270)$	3.52 ± 0.02	3.80 ± 0.90	0.88 ± 0.21
D^{*+}	0.98 ± 0.01	0.97 ± 0.14	1.01 ± 0.15
D^0	2.52 ± 0.02	2.69 ± 0.22	0.94 ± 0.08
Fraction			
$\frac{N(K^{\star+} \to K_S^0 \pi^+)}{N(K_S^0)}$	17.1 ± 0.7	16.3 ± 1.1	1.0 ± 0.1
$\frac{N(K^{\star-} \to K_S^0 \pi^-)}{N(K_S^0)}$	9.9 ± 0.5	8.9 ± 0.8	1.1 ± 0.1
$\frac{N(\Sigma^{\star+} \to \Lambda \pi^+)}{N(\Lambda)}$	6.1 ± 0.7	6.2 ± 1.4	1.0 ± 0.3

New JETSET parameters - particles and resonances production yields. ν NC interactions

ν_μ NC interactions were not used for tuning

Hadrons	MC (%)	Data (%)	MC/Data
K_S^0	8.82 ± 0.10	8.78 ± 0.15	1.00 ± 0.02
Λ^0	6.31 ± 0.11	5.46 ± 0.14	1.16 ± 0.04
$\bar{\Lambda}^0$	0.42 ± 0.03	0.40 ± 0.04	1.05 ± 0.11
Fraction			
$\frac{N(K^{\star +} \to K_S^0 \pi^+)}{N(K_S^0)}$	14.3 ± 1.3	17.3 ± 2.2	0.8 ± 0.1
$\frac{N(K^{\star -} \to K_S^0 \pi^-)}{N(K_S^0)}$	8.7 ± 0.9	6.8 ± 1.6	1.3 ± 0.3
$\frac{N(\Sigma^{\star +} \to \Lambda \pi^+)}{N(\Lambda)}$	4.9 ± 0.9	3.0 ± 1.8	1.6 ± 1.0

New JETSET parameters - Q^2 distributions



We can tune/study different kinematic regions (e.g. SIS). Thanks to the large statistics and the excellent reconstruction of the complete event kinematics.

Multiple V^0 particles production in ν_μ CC interactions

Channels	Reconstructed events		MC/Data
	MC	Data	
$\Lambda^0 X$	6739	7123	0.95 ± 0.02
$K^0_S X$	13379	13498	0.99 ± 0.01
$\bar{\Lambda}^0 X$	559	559	1.00 ± 0.06
$K^0_S K^0_S X$	397	306	1.30 ± 0.10
$\Lambda^0 K^0_S X$	367	266	1.38 ± 0.11
$\Lambda^0 \bar{\Lambda}^0$	50	39	1.28 ± 0.27
$K^0_S \bar{\Lambda}^0 X$	21	14	1.47 ± 0.51
$\Lambda^0 \Lambda^0 X$	8	10	0.84 ± 0.39
$K^0_S K^0_S K^0_S X$	6	2	3.06 ± 2.49

Comparison with GENIE-2.8.4 event generator

Comparison of tuned NOMAD event generator with GENIE at event generator level for CNGS beam. ν_μ CC interactions

Hadrons	NOMAD (%)	GENIE (%)	GENIE/NOMAD
K_S^0	5.31	6.46	1.21
Λ^0	4.88	7.63	1.56
$\bar{\Lambda}^0$	0.28	0.25	0.89
$\rho^0(770)$	14.27	19.30	1.35
$f_0(980)$	1.39	0	-
$f_2(1270)$	2.75	0	-
D^0	1.99	4.11	2.07
K^+	8.17	11.91	1.46
K^-	3.63	4.88	1.34
Fraction			
$\frac{N(K^{\star +} \to K_S^0 \pi^+)}{N(K_S^0)}$	18.19	25.97	1.42
$\frac{N(K^{\star -} \to K_S^0 \pi^-)}{N(K_S^0)}$	7.13	9.09	1.27
$\frac{N(\Sigma^{\star +} \to \Lambda \pi^+)}{N(\Lambda)}$	3.47	13.4	3.86

Setting tuned JETSET parameters to the GENIE event generator

Comparison of tuned NOMAD event generator with GENIE at event generator level for CNGS beam. ν_μ CC interactions

Hadrons	NOMAD (%)	GENIE (%)	GENIE/NOMAD
K_S^0	5.31	4.38	0.82
Λ^0	4.88	4.67	0.96
$\bar{\Lambda}^0$	0.28	0.14	0.5
$\rho^0(770)$	14.27	14.76	1.03
$f_0(980)$	1.39	1.56	1.12
$f_2(1270)$	2.75	3.57	1.30
D^0	1.99	4.15	2.09
K^+	8.17	7.54	0.92
K^-	3.63	3.42	0.94
Fraction			
$\frac{N(K^{\star +}\to K_S^0\pi^+)}{N(K_S^0)}$	18.19	17.32	0.95
$\frac{N(K^{\star -}\to K_S^0\pi^-)}{N(K_S^0)}$	7.13	7.13	1.00
$\frac{N(\Sigma^{\star +}\to \Lambda\pi^+)}{N(\Lambda)}$	3.47	5.49	1.58

Agreement is much better. Other hidden switches in GENIE

Summary

- a tuning of JETSET parameters has been perform with NOMAD data
- the default GENIE-2.8.4 fragmentation parameters disagree with NOMAD results
- the use of the tuned JETSET parameters in GENIE improves the agreement with NOMAD
- additional studies with GENIE event generator are required

NOMAD data offer an excellent tool for the optimization and development of existing event generators!