HARP and NA61 (SHINE) hadron production experiments and their implications for neutrino physics

VIth International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region
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Boris A. Popov (LPNHE, Paris & JINR, Dubna) for the HARP and NA61 Collaborations

- HARP experiment
- Physics goals
- Results and Impacts
- NA61 experiment
- Status and plans
- Summary
HARP is a large acceptance spectrometer to measure hadron production from various nuclear targets and a range of incident beam momenta.

- Nuclear target materials: $A = 1 – 200$
- Nuclear target thickness: $\lambda = 2 – 100 \%$
- Beam particles: $h = p, \pi^+, e^+$
- Beam momenta: $p_{\text{beam}} = 1.5 – 15 \text{ GeV/c}$
- Secondaries measured: $h = p, \pi^+, K^+$
- Kinematic acceptance
  
  $p = 0.5 – 8.0 \text{ GeV/c} \quad \theta = 25 – 250 \text{ mrad} \quad \text{(forward)}$
  
  $p = 0.1 – 0.8 \text{ GeV/c} \quad \theta = 350 – 2150 \text{ mrad} \quad \text{(large angle)}$

Data taking in 2001-2002

Detailed description of the experimental apparatus

NIM A571 (2007) 524
HARP physics goals

Input for prediction of neutrino fluxes for the K2K and MiniBooNE / SciBooNE accelerator experiments

Pion/Kaon yield for the design of the proton driver and target system of Neutrino Factories and Super-Beams

Input for precise calculation of the atmospheric neutrino flux (from yields of secondary $\pi, K$)

Input for Monte Carlo generators (GEANT4 and others)
HARP: Data taking summary

HARP took data at the CERN PS T9 beamline in 2001-2002
Total: 420 M events, ~300 settings

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HARP: Analyses with the forward spectrometer

Large angle spectrometer

Forward spectrometer

$0.03 < \theta < 0.24$ rad
Neutrino Oscillation Experiments at Accelerators

Neutrino fluxes of conventional accelerator neutrino beams are not known accurately.

measure pion and kaon production and use relevant targets and momenta:
- \textbf{K2K}: Al target, 12.9 GeV/c
- \textbf{MiniBooNE}: Be target, 8.9 GeV/c
- \textbf{SciBooNE}:

Removes \textit{major} source of uncertainties for these experiments (in collaboration with \textit{K2K} and \textit{MiniBooNE})

\textbf{HARP p-Al data 12.9 GeV/c:}

\textbf{K2K results, with detailed discussion of relevance of hadron production measurement:}

\textbf{HARP p-Be data 8.9 GeV/c:}

\textbf{MiniBooNE results with HARP input:}
K2K Far/Near flux ratio prediction

HARP Al cross-section results have provided an important cross-check on previous K2K flux predictions. Results completely consistent in shape

Far-to-near (F/N) ratio

- HARP measurements allowed to reduce the main systematic error by a factor of 2
- F/N ratio is no longer a dominant systematic error

$\pi^+$

$p(12.9 \text{ GeV/c}) + \text{Al} \rightarrow \pi^+ + X$


HARP: p+Be at 8.9 GeV/c

5% λ Be target

\[ \theta_{\pi} = [30, 60, 90, 120, 150, 180, 210] \text{ mrad} \]

\[ p_\pi = [0.75 - 6.5] \text{ GeV/c} \]

typical error on point = 9.8%

error on integral = 4.9%

analysis includes significant improvements relative to Al measurement in PID and momentum resolution description

\[ p(8.9 \text{ GeV/c}) + \text{Be} \rightarrow \pi^+ + X \]
An aside on the SW parameterization

\[
\frac{d^2\sigma(p+A \rightarrow \pi^+ + X)}{dpd\Omega}(p, \theta) = c_1 p^{c_2}(1 - \frac{p}{p_{\text{beam}}}) \exp[-c_3 \frac{p^{c_4}}{p_{\text{beam}}^{c_5}} - c_6 \theta(p - c_7 p_{\text{beam}} \cos^{c_8} \theta)]
\]

- \(X\) : any other final state particle
- \(p_{\text{beam}}\) : proton beam momentum (GeV/c)
- \(p, \theta\) : pion lab-frame momentum (GeV/c) and angle (rad)
- \(c_1, ..., c_8\) : empirical fit parameters

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HARP measurements for p+Be at 8.9 GeV/c

MiniBooNE $\nu_\mu$ flux prediction

- Combining HARP and E910 data gives maximal coverage of the relevant pion phase space for MiniBooNE.

- Use the parameterization of Sanford and Wang and fit to both data sets combined.

\[ p(8.9 \text{ GeV/c}) + \text{Be} \rightarrow \pi^+ \rightarrow \nu_\mu \text{MB} \]

HARP Be measurements were used for the neutrino flux prediction in MiniBooNE.


0806.1449 [hep-ex]
Atmospheric neutrino flux predictions

- HARP p+C @ 12 GeV/c data are relevant to the prediction of atmospheric neutrino fluxes and EAS simulations.

Simulations predict that collisions of protons with a carbon target are very similar to proton interactions with air. This hypothesis can be tested with HARP data.
HARP: p, π± + C at 12 GeV/c and SW parameterizations

Incoming charged pion HARP data are the first precision measurements in this kinematic region.

First precision measurements for N$_2$ and O$_2$ in this energy range, SW parameterizations for p-C data

HARP results confirm that p-C data can be used to predict p-N$_2$ and p-O$_2$ pion production.
HARP: more FW data with incident $\pi^\pm$

All thin target FW data taken in pion beams are now published

Interesting to tune models for re-interactions, etc.

An example of more HARP data on the FW production with incident pions

Model comparisons

$\cdot$ All thin target FW data taken in pion beams are now published
$\cdot$ Interesting to tune models for re-interactions, etc.

Dependence on the atomic number $A$ of the pion yields in $\pi$-$A$ interactions averaged over two FW angular regions ([50,150], [150,250] rad) and four momentum regions ([0.5-1.5], [1.5,2.5], [2.5,3.5], [3.5,4.5] GeV/c) for incoming beam momenta 3,5,8,12 GeV/c.

Dependence on the atomic number \( A \) of the pion yields in \( p-A \) interactions averaged over two FW angular regions ([50,150], [150,250] rad) and four momentum regions ([0.5-1.5], [1.5,2.5], [2.5,3.5], [3.5,4.5] GeV/c) for incoming beam momenta 3,5,8,12 GeV/c

Paper in preparation
HARP: Analyses with the large angle spectrometer

Large Angle (LA) spectrometer: TPC

0.35 < \theta < 2.15 \text{ rad}
Beam momenta:
3, 5, 8, 12 GeV/c
beam particle selection and normalization same as previous analysis
Data:
5% λ targets Be, C, Al, Cu, Sn, Ta, Pb
Events:
require trigger in ITC (cylinder around target)
TPC tracks:
>11 points and momentum measured and track originating in target
PID selection
additional selection to avoid track distortions due to ion charges in TPC:
first part of spill (30-40% typically of data kept, correction available for future)
all data in spill are analysed now (the results are compatible within errors)
Corrections:
Efficiency, absorption, PID, momentum and angle smearing by unfolding method
(same as p-C data analysis in forward spectrometer)
Backgrounds:
secondary interactions (simulated)
low energy electrons and positrons (all from π^0)
predicted from π^+ and π^- spectra (iterative) and normalized to identified e^+. 

Full statistics now analysed (“full spill data” with dynamic distortion corrections).
No significant difference is observed with respect to first analyses of the partial
data (first 100-150 events in spill)
HARP TPC calibration: elastic scattering benchmark

Comparison of predicted vs measured track allows LA tracking benchmark

missing mass peak from large angle proton track (position of peak verifies momentum scale: +15% shift is completely excluded)

JINST 3: P04007 (2008)
Stability from LH2 target to other targets

consider average momentum of protons with $dE/dx \in [7-8] \text{ MIPs}$

Stability

H2 setting

$\pm 2\%$

JINST 3: P04007 (2008)
9 angular bins: p-Ta $\pi^+$

HARP p–Ta $\pi^+$

- Forward: $350 < \theta$ (mrad) < 1550
- Backward: $1550 < \theta$ (mrad) < 2150

momentum range $0.1 < p < 0.8$ GeV/c

stat. and syst. errors combined

EPJ C 51 (2007) 787
p-Ta \( \pi^- \)

Pion production yields

\[
350 < \theta \text{(mrad)} < 1550
\]

\[
1550 < \theta \text{(mrad)} < 2150
\]

momentum range 0.1 < p < 0.8 GeV/c
Neutrino factory study

Cross-sections to be fed into neutrino factory studies to find optimum design
Pion yields

HARP – PS214 at CERN

p-C data as an example of many other available spectra
Comparison with...

BNL E910 at 12.3 GeV/c: data points; HARP: shaded region

squares: Shibata et al. (KEK), 12 GeV/c at 90°; circles: HARP data
HARP TPC: corrections for dynamic distortions

Analyses of full data sample
comparison of $\pi^+$ and $\pi^-$ yields in p-A for Be, C, Al, Cu, Sn, Ta and Pb as a function of beam momentum (full spill data)

forward production only $0.35 < \theta < 1.55$ rad

Pion yields

A-dependence of $\pi^+$ and $\pi^-$ yields in p-A for Be, C, Al, Cu, Sn, Ta and Pb (3, 5, 8, 12 GeV/c)
Full spill data

forward production only $0.35 < \theta < 1.55$ rad

Measured with the same detector!

Similar measurements of the $\pi^\pm$ production for all available target have been performed using beams of incident pions of both polarities.

Dependence of the $\pi^+$ and $\pi^-$ yields in $\pi^\pm$-A interactions for Be, C, Al, Cu, Sn, Ta, Pb as a function of beam momentum (full spill data)
Ratio of pion yields in 100% $\lambda$ over 5% $\lambda$ Carbon target; solid line – MARS predictions; grey line – ratio of pions produced by “first generation” beam proton to all pions in MARS

Paper in preparation
Many comparisons with models from GEANT4 and MARS are being done. Only some examples are shown here.

Binary cascade
Bertini cascade
Quark-Gluon string (QGS)
Fritiof (FTFP)
LHEP

HARP vs GiBUU

HARP: comparison with MC

MARS

GiBUU (arXiv:0901.1770 [hep-ex])

Some models do a good job in some regions, but there is no model that describes all aspects of the data.
HARP: $\pi^+$ LA 3 GeV/c data vs GiBUU

... just as an example of many other comparisons made...

arXiv:0901.1770 [hep-ex]
HARP: 5 GeV/c p-Ta π⁺

... just as an example of many other comparisons made...

HARP hadron production experiment has already made important contributions to hadronic cross-section measurements relevant to neutrino experiments.

HARP results with Al target for K2K have been used for the final K2K publication.

HARP results with Be target for MiniBooNE/SciBooNE have been used for the neutrino flux predictions and for the first MiniBooNE oscillation paper.

HARP results for the Neutrino Factory studies for the full data set with all targets (Carbon, Copper, Tin, Beryllium, Aluminium, Tantalum and Lead) are also published.

HARP results for Carbon, N₂ and O₂ targets for atmospheric neutrino fluxes are published.

Production cross-section measurements for forward production of charged pions with incident pions on targets from Be to Pb have been recently published.

HARP measurements are being used to validate/tune MC hadron production models.

More production cross-section measurements are now finalized and are being prepared for publication (forward production with incident protons on targets from Be to Pb, LA production with pion beams, production with long targets, etc.).

The HARP detector is well understood and the analysis techniques established.

Only a small fraction of available HARP results could be presented during this talk…
NA61 (SHINE): PHYSICS GOALS

SHINE = SPS Heavy Ion and Neutrino Experiment

**Physics of strongly interacting matter**

*Discovery potential:*

**Search for the critical point of strongly interacting matter**

*Precision measurements:*

**Study the properties of the onset of deconfinement in nucleus-nucleus collisions**

**Measure hadron production at high transverse momenta in p+p and p+Pb collisions as reference for Pb+Pb results**

**Data for neutrino and cosmic ray experiments**

*Precision measurements:*

**Measure hadron production in the T2K target needed for the T2K (neutrino) physics**

**Measure hadron production in p+C interactions needed for T2K and cosmic-ray, Pierre Auger Observatory and KASCADE, experiments**
One of the main physics goals of NA61/SHINE:

Precision measurements of hadron production for prediction of $\nu$-fluxes in the T2K experiment

T2K @ JPARC (Japan):
- Long baseline (295km) neutrino oscillation experiment
- Protons (30-50GeV) + carbon target (90cm) $\rightarrow$ intense off-axis $\nu_\mu$-beam
- Neutrino spectra measured at the near and far detectors: ND280 and SK
The goal is to reduce the error on the F/N ratio to a negligible level compared to other contributions to the systematics (ND280 spectrum measurements, cross-section, efficiencies, etc.), therefore we aim at: \( \delta (R_{\mu,e}) < 3\% \)

In order to reach this precision we need \(~200k\) reconstructed \(\pi^+\) tracks (at the same time we will collect a similar number of \(\pi^-\) since the NA61 acceptance is symmetric)

We also need to measure the \(K/\pi\) ratio with an uncertainty of: \(\delta (K/\pi) < 10\%\)
NA61/SHINE – Fixed Target Experiment at CERN SPS

NA49 Setup + Upgrades:

- Large Acceptance Spectrometer for charged particles
- TPCs as main tracking devices
- 2 dipole magnets with bending power of max 9 Tm over 7 m length (2007-Run: 1.14 Tm)
- New ToF-F to entirely cover T2K acceptance
- High momentum resolution
- Good particle identification: \( \sigma(\text{ToF-L/R}) \approx 60 \text{ ps}, \sigma(\text{ToF-F}) \leq 120 \text{ ps} \), \( \sigma(dE/dx)/\langle dE/dx \rangle \approx 0.04 \), \( \sigma(m_{\text{inv}}) \approx 5 \text{ MeV} \)

CERN-SPS-2006-034
NA61: Targets during 2007 pilot run

- 2 different carbon targets (isotropic graphite)

**Thin Carbon Target**
- length = 2 cm, cross section 2.5x2.5 cm²
- $\rho = 1.84$ g/cm³
- $\sim 0.04 \lambda_{\text{int}}$

**T2K replica Target**
- length = 90 cm, $\varnothing = 2.6$ cm
- $\rho = 1.83$ g/cm³
- $\sim 1.9 \lambda_{\text{int}}$

- **During October 2007 Run (~30 days):**
- taken pilot physics data for T2K with 30.9 GeV/c protons (~2 weeks)

Thin target: ~670k triggers
Empty target: ~80k triggers
Replica target: ~230k triggers
NA61 : BEAM PROPERTIES

momentum from TPC

30.8 GeV/c

all beam particles

$
\begin{array}{c}
\text{Entries: } 2514 \\
\text{Mean: } 30.77 \\
\text{RMS: } 0.1504 \\
\chi^2 / \text{ndf: } 113.67 / 77 \\
\text{Constant: } 155.86 \pm 4.32 \\
\text{Mean: } 30.773 \pm 0.002 \\
\text{Sigma: } 0.11669 \pm 0.00211
\end{array}
$

dE/dx from TPC

beam spot from BPD-3

triggered protons
NA61 : TRACKING PERFORMANCE

TPC cluster parameters

Momentum fit

<χ^2/NDF> = 1.1

Vertex fit

<z> = -500.6 cm

T2K replica target: fitted vertex

V0 analysis

Λ

K^0_s
- Measurement of the $\sigma_{\text{inel}}$ for p+C @ 31 GeV/c

- Normalization of the hadron spectra to inclusive cross sections

• From the thin C target (4% $\lambda_t$) data, we measure a double differential inclusive inelastic cross-section:

$$\frac{d^2\sigma_{\text{inel(\alpha)}}}{dpd\theta} = \frac{1}{\rho L_{\text{eff}}} \frac{1}{N_A} \frac{1}{N_{\text{beam}}} \frac{d^2n_{\alpha}}{dpd\theta} = \frac{1}{\rho L_{\text{eff}}} \frac{N_{\text{trig}}}{N_A} \frac{1}{N_{\text{beam}}} \frac{d^2n_{\alpha}}{N_{\text{trig}} dpd\theta} = \frac{\sigma_{\text{trig}}}{N_{\text{trig}}} \frac{d^2n_{\alpha}}{dpd\theta}$$

• $p$ and $\theta$ are laboratory momentum and polar angle of the produced particle $\alpha$ ($\pi$, K, or p) and $dn_{\alpha}$ is the number of identified particles from the target measured in the bin $dpd\theta$

• $\sigma_{\text{inel}}$ denotes the inelastic cross-section for p+C interactions, including all processes due to strong interactions with exception of elastic p+C interactions (p+C in the final state)

• Inelastic interactions are selected by an interaction trigger. $N_{\text{trig}}$ and $N_{\text{beam}}$ are the number of collected triggers and measured beam particles on the target, respectively
**NA61: Determination of the Inelastic Cross Section**

- \( \sigma_{\text{inel}} \) can be obtained from the \( \sigma_{\text{trig}} \) by applying the following corrections:

1) Subtract the contribution of elastic interactions due to large angle coherent scattering

2) Add the contribution of lost events where a secondary particle hits S4 trigger counter. Here, the major contribution comes from quasi-elastic scattering of the incident protons (\( \sigma_{\text{loss-p}} \)). Also secondary pions or kaons hitting S4 have to be taken into account (\( \sigma_{\text{loss-}\pi/\text{K}} \)).

→ Corrections have been estimated with Geant4 simulation

| \( \sigma \) [mb] | \( \sigma_{\text{trig}} \) | 297.5±0.7±3.0\(^1\) | \( \sigma_{\text{loss-p}} \) | 5.8±0.2±? | \( \sigma_{\text{loss-}\pi/\text{K}} \) | 0.6±0.1±? | \( \sigma_{\text{elastic}} \) | -49.2±0.6±5.9\(^2\) | \( \sigma_{\text{inel}} \) | 254.7±1.0±6.6 |

1) Syst. error on \( \sigma_{\text{trig}} \) currently estimated with various cross-checks

2) Syst. error on \( \sigma_{\text{elastic}} \) currently estimated by comparing Geant4 simulations with known exp. values

→ Preliminary value for the \( \sigma_{\text{inel}} \) is in good agreement with previous measurements

The analysis of negatively charged hadrons from the primary vertex is motivated by estimates that more than 90% of produced negatively charged particles at 31GeV/c proton carbon interactions are $\pi^-$ mesons.

The remaining small fraction includes $K^-$ mesons and electrons and negligible number of anti-protons. Venus-GHEISHA and Geant Monte-Carlo simulation chain is used to calculate corrections for geometrical acceptance, reconstruction efficiency, weak decays and leptons.

Finally corrected spectra of all negatively charged particles and only $\pi^-$ mesons from the primary interaction are obtained. Results presented here are based on thin target 2007 data.
NA61: Negative hadron analysis

- The negatively charged hadrons analysis, further referred to as h- analysis, **starts from the selection of negatively charged particles from the primary vertex.**
- The analyzed runs contained 671325 events (100%). After quality cuts on beam tracks we have 537257 events (~80%)
- Track statistics after successive track quality cuts is summarized here:

<table>
<thead>
<tr>
<th>All negative tracks:</th>
<th>427627 (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Momentum determination: Minimum number of points in VTPC1+2 is 5</td>
<td>414890 (97%)</td>
</tr>
<tr>
<td>Cut on the impact parameter</td>
<td>354898 (83%)</td>
</tr>
<tr>
<td>Cut on the number of potential points (larger than 30)</td>
<td>258173 (60%)</td>
</tr>
<tr>
<td>Cut on the ratio of measured and potential points: Ratio larger than 0.5</td>
<td>258160 (60%)</td>
</tr>
</tbody>
</table>

The uncorrected spectrum of negatively charged particles in p+C interactions at 31GeV/c registered by NA61 – (polar angle –momentum) plane

T2K phase-space fully covered
**NA61: Negative hadron analysis**

Venus 4.12 -GHEISHA and Geant 3.21 Monte-Carlo simulation chain was used to calculate corrections for:
- geometrical acceptance,
- reconstruction efficiency,
- momentum resolution
- weak decays,
- and leptons contamination.
- in $\pi$ - correction case also non pion contamination.

For current Monte Carlo studies we have used 281078 events.

The same track cuts were applied as for real data, effects of these cuts on the number of negatively charged tracks are summarized here:

<table>
<thead>
<tr>
<th>All reconstructed negative tracks:</th>
<th>288134 (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Momentum determination: Minimum number of points in VTPC1+2 is 5</td>
<td>278120 (96 %)</td>
</tr>
<tr>
<td>Cut on the impact parameter</td>
<td>243152 (84 %)</td>
</tr>
<tr>
<td>Cut on the number of potential points (larger than 30)</td>
<td>172440 (60 %)</td>
</tr>
<tr>
<td>Cut on the ratio of measured and potential points: Ratio larger than 0.5</td>
<td>172438 (60 %)</td>
</tr>
</tbody>
</table>

The correction factors: at the left side for the $h$ minus case, at the right side for the $\pi$ - case

Correction factors errors were calculated using binominal distribution.
NA61: PID by dE/dx and TOF measurements

Positive particles

Negative particles

ToF-F raw spectrum

$1 < p < 3 \text{ GeV}/c$

ToF-L/R raw spectrum

log scale
NA61: PID by combined dE/dx and TOF measurements

ToF-F and TPCs

2 < p < 3 GeV/c

4 < p < 5 GeV/c

π⁺

K⁺

T2K phase-space is well covered
NA61 : Original plans for 2008 run

- ~50 days of beam time were foreseen for September – October 2008
  → T2K and cosmic ray measurements

- NA61 Coll. decided for a TPC read-out and DAQ upgrade before the physics run
  - an increase of the event rate by a factor of 10 (crucial for NA61 physics program)
  - new TPC read-out electronics and DAQ designed and tested in 2008
  - total cost 400 k CHF
  - the production and installation of the new electronics was completed by mid September
  - during the commissioning phase the designed event rate of ~70Hz was reached

- In addition to the TPC read-out and DAQ upgrade
  - upgrade of Data Control System for gas, LV, HV and trigger systems to new PCs running Scientific Linux (in place of old Macintoshes)
  - commissioning of new beam position detectors of 5x5 cm² area (instead of 3x3 cm²) to fully cover cross section of the T2K replica target

LHC incident…
NA61 : SUMMARY

- Significant progress in data calibration and analysis
  - Status report to SPSC: http://cdsweb.cern.ch/record/1113279

- Good quality of 2007 data, though limited in statistics
  - High quality of track reconstruction and particle identification has been achieved
  - First preliminary results for the thin target data to be released soon.
  - Work on T2K replica target is in progress

- Important detector upgrades, TPC read-out and DAQ upgrade

- We will hopefully be able to recover the lost beam time during 2009 run
  - NA61 has 3 months of beam time in 2009

- First preliminary fully corrected hadron spectra for T2K have been obtained and the work continues to make full use of the PID detector capabilities, to minimize systematic biases and to estimate systematic errors

- Plan to release first results during this summer

Thank you for your attention
Backup slides
Detailed description of the experimental apparatus

NIM A571 (2007) 524
FW: PID principle

Harp Particle Identification

Pions
protons

Cerenkov Light (p.e.)

velocity (c)
momentum (GeV/c)

TOF
FW: Momentum Resolution

ELASTICS

theta-p plane:

open: data
filled: MC
HARP: two spectrometers match each other

$\pi^+ / \pi^-$ ratio in pBe at 12 GeV/c

$0.5 \text{ GeV/c} \leq p < 0.75 \text{ GeV/c}$

CERN-SPSC-2008-030 / SPSC-SR-038
Relevance of HARP for K2K neutrino beam

One of the largest K2K systematic errors comes from the uncertainty of the far/near ratio.

Pions producing neutrinos in the oscillation peak

\[ 0.5 < E_\nu < 0.75 \text{ GeV} \]

K2K far/near ratio measured by HARP

Oscillation peak

\[ P_\pi > 1 \text{ GeV} \]
\[ \theta_\pi < 250 \text{ mrad} \]

Beam MC confirmed by Pion Monitor

Integrated above 2.5 GeV

Beam MC

K2K interest
HARP gives ~ factor of 2 error reduction across all energies

hep-ex/0510039
HARP: p-Be

Corrections for dynamic distortions: ratio of the cross-sections without and with corrections

HARP: pion yields

comparison of $\pi^-/\pi^+$ ratio for light and heavy nuclei

forward production only $350 < \theta (\text{mrad}) < 1550$

8 GeV/c \( p \)-Ta \( \pi^{+/−} \) [HARP – PS214 at CERN]

5% \( \lambda \) target

MODELS
8 GeV/c p-C π⁺⁻

5% λ target

HARP – P214 at CERN

MODELS
1. Data available on many thin (5%) targets from light nuclei (Be) to heavy ones (Ta,Pb)

2. Comparisons with GEANT4 and MARS15 MonteCarlo show large discrepancies both in normalization and shape
   - Backward or central region production seems described better than more forward production
   - At higher energies FTP models (from GEANT4) and MARS look better, at lower energies this is true for Bertini and binary cascade models (from GEANT4)
   - In general $\pi^+$ production is better described than $\pi^-$ production
   - Parametrized models (such as LHEP) have big discrepancies

CONCLUSIONS: MCs need tuning with HARP data for $p_{inc} < 15$ GeV/c
NA61 : COLLABORATION

121 physicists from 24 institutes and 14 countries:

University of Athens, Athens, Greece
University of Bergen, Bergen, Norway
University of Bern, Bern, Switzerland
KEK, IPNP, Budapest, Hungary
Cape Town University, Cape Town, South Africa
Jagiellonian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Fachhochschule Frankfurt, Frankfurt, Germany
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
Forschungszentrum Karlsruhe, Karlsruhe, Germany
Swietokrzyska Academy, Kielce, Poland
Institute for Nuclear Research, Moscow, Russia
LPNHE, Universites de Paris VI et VII, Paris, France
Pusan National University, Pusan, Republic of Korea
Faculty of Physics, University of Sofia, Sofia, Bulgaria
St. Petersburg State University, St. Petersburg, Russia
State University of New York, Stony Brook, USA
KEK, Tsukuba, Japan
Soltan Institute for Nuclear Studies, Warsaw, Poland
Warsaw University of Technology, Warsaw, Poland
University of Warsaw, Warsaw, Poland
Rudjer Boskovic Institute, Zagreb, Croatia
ETH Zurich, Zurich, Switzerland
NA61 : DOCUMENTS AND REFERENCES


LoI: CERN-SPSC-2006-001, SPSC-I-235 (January 6, 2006)

Report from the NA61/SHINE experiment at the CERN SPS, CERN-OPEN-2008-012
Both analyses rely on the comparison of \(\nu\) spectra measured at SK and the extrapolated spectra at SK from the ND measurement:

\[
\Phi_{\mu,e}^{SK}(E_\nu) = R_{\mu,e}(E_\nu) \times \Phi_{\mu,e}^{ND}(E_\nu)
\]

• Far to Near (F/N) ratio \(R\): is not constant with respect to the \(\nu\) energy and therefore depends on the particle production properties

→ To fulfill the T2K goals detailed information on the pion and kaon production off the T2K target is needed!
NA61 : 2007 PILOT RUN

Upgrades

Additional ToF

Data

p+C at 31 GeV/c

R&D

PSD prototype

on thin target and

T2K replica target
-event visualization of data after different stages of reconstruction and in different formats