Pion production in low energy range

presented by

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(in close collaborations with Johann Collot and Stephanie Schwenke)
• motivation for a study of pion production
• definition of a problem
• thin target results
• physical considerations of the used methods
• thick target results
• conclusions
Motivation for a study of the pion production

- pions as a source of neutrinos (K2K) and muons (neutrino factory, muon collider)
  \[ \pi^\pm \rightarrow \mu^\pm \bar{\nu}_\mu \]
  \[ \mu^\pm \rightarrow e^\pm \bar{\nu}_e \nu_\mu \]
- better estimations of atmospheric neutrino flux
- precise knowledge of pion yields: mirror of intranuclear physics
- pions used to test models of nuclear interactions based on considerations from nuclear and particle physics
• definition of a problem

  • lack of experimental results, especially for different (heavy) targets:
    - different energy ranges
    - both charges ($\pi^+$ and $\pi^-$)
    - angular distributions
  (data from HARP)

• simulation show:
  - $\approx$ linear dependence of a total yield as a function of energy between (1-8)GeV and decreasing nature for higher energy

• possible collection in transverse direction
protons

π

target

x

y

z

transvers collection
○ thin target results

- test the physics of particle generation
- comparison FLUKA - UrQMD:

Fluka (CERN, Milano):
- enables full target geometry and includes transport and tracking of particles through the matter

UrQMD (Unified ultra-relativistic quantum molecular dynamics, Frankfurt):
- only nuclear interaction allowed
- in Geant4
- enables to use isoscalar projectiles (d, Hg,...)
...thin target results

proton

nucleus
...thin Hg-target results

- $\pi^+$ rapidity
- normalized yield versus lab rapidity
- normalized yield: $NY = \frac{\text{yield per bin}}{\text{total yield}} \cdot \text{(per charge)}$
- rapidity: $\text{rap}_c = \frac{1}{2} \cdot \log\left(\frac{p_c+E}{p_c-E}\right)$
  $1 < \text{rap}_c < 2$; $c$: direction of collection

![Graph showing normalized yield versus lab rapidity for $\pi^+$ in thin Hg at 2 GeV, comparing Fluka, UrQMD, and UrQMD with potential.]
...thin Hg-target results

- \( \pi^- \) rapidity

- normalized yield versus lab rapidity

- normalized yield: \( NY = \frac{\text{yield per bin}}{\text{total yield}} \cdot \text{(per charge)} \)

- rapidity: \( \text{rap}_c = \frac{1}{2} \cdot \log \left( \frac{p_c + E}{p_c - E} \right) \)
  \[ 1 < \text{rap}_c < 2; \ c: \text{ direction of collection} \]
...thin H-target results

- hydrogen target: angular momentum distribution: $p + p \rightarrow \pi^+ pn$, $p + p \rightarrow \pi^+ \pi^- pp$
- normalized yield versus angle

![Graph showing normalized yield versus angle](image)
...thin H-target results

- hydrogen target: spectrum
- normalized yield versus lab momentum
...thin Hg-target results

- $\pi^+$ - angular distribution
- normalized yield versus angle

![Angular distr. of Pi+ 2 GeV thin Hg](image)

Figure 1:
...thin Hg-target results

- $\pi^-$ - angular distribution
- normalized yield versus angle
...thin Hg-target results

- $\pi^+$ - spectrum
- normalized yield versus lab momentum

![Graph showing normalized yield versus lab momentum for $\pi^+$ spectrum in Hg-target. The graph compares Fluka and UrQMD, with and without potential corrections.]
...thin Hg-target results

- $\pi^-$ spectrum
- normalized yield versus lab momentum
...thin Hg-target results

- good pions (with $1 < rap_z < 2$)
- normalized yield versus angle
Circle physical considerations of the used methods

question: where could the differences of FLUKA and UrQMD come from?

• physical considerations treated similar for both:
  – initial nucleons in nuclei are sampled according to the nuclear density and Fermi-momentum
  – Pauli principle reduces an accessible phase-space

• differences:
  – FLUKA uses free cross sections
  – UrQMD uses cross sections in medium, according to the introduced effective masses and momenta
  – UrQDM contains much more hadronic species
  – used potential
thick target results

- we used FLUKA
- collection-sectors: collector is near the target → estimation of the number of pions collected per second in a kinematic window using a 4MW proton beam:
  \[ 1 < \text{rap}_x < 2 \] as a function of the collecting angle
- 2GeV: longitudinal collection on 20cm Hg-target, \( \varepsilon = 24 \cdot 10^{-3} \text{m.rad} \):
  \[ 8.3 \cdot 10^{13} \pi^+ / \text{seconds} ; 5.1 \cdot 10^{13} \pi^- / \text{seconds} \]
- 2GeV: transverse collection in \( \pi / \text{second} \):
  emittance \( \varepsilon = x \cdot px / m_0 = 6 \cdot 10^{-3} \text{m.rad} \)
  64 sectors

<table>
<thead>
<tr>
<th>angle</th>
<th>( \pi^+ )</th>
<th>( \pi^- )</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>( 9.2 \cdot 10^{13} )</td>
<td>( 7.2 \cdot 10^{13} )</td>
</tr>
<tr>
<td>90</td>
<td>( 3.5 \cdot 10^{13} )</td>
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<td>( 0.8 \cdot 10^{14} )</td>
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...thick target results

- $1 < r a p_x < 2$ without special cut
- $x$ versus $p_x/m_0$
...thick target results

- $1 < rap_x < 2$ with special cut
- $x$ versus $p_x/m_0$
• experiment is really needed to check models
• collection according to the angle $40^\circ - 60^\circ$ gives the possibility to collect 3 times more pions than in the longitudinal collection
• further simulations including full geometry of quadrupols section is needed