Pion production in low energy range

presented by

Jarosław W. Pasternak

IFT Wrocław
Poland

ISN Grenoble
France
(in close collaborations with Johann Collot
and Stephanie Schwenke)

◯ contents

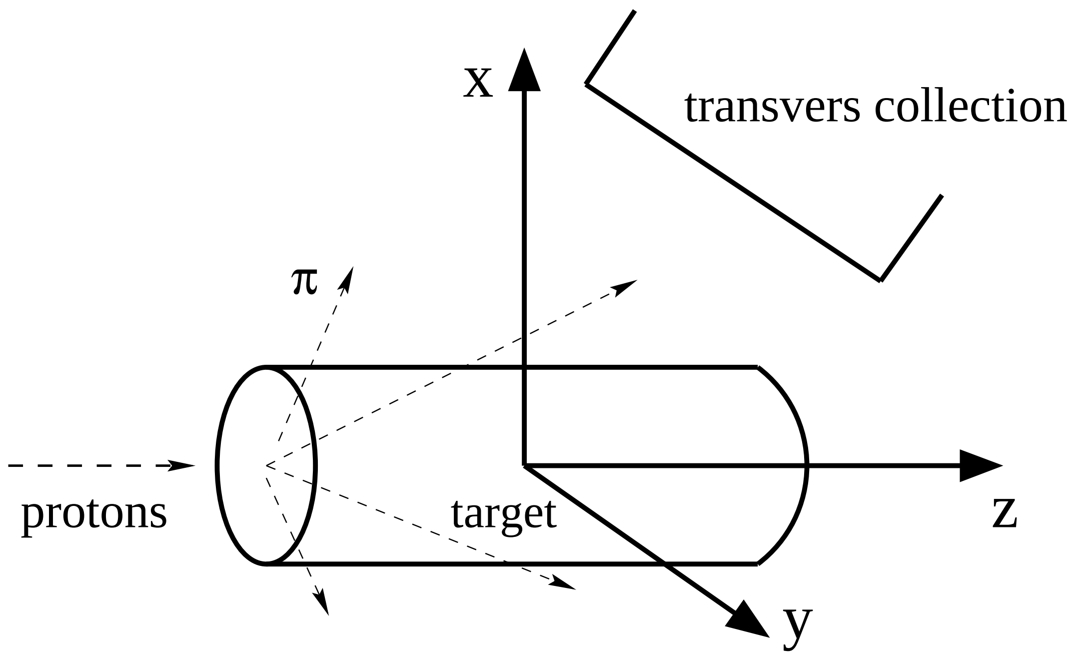
◯ Motivation for a study of the pion production

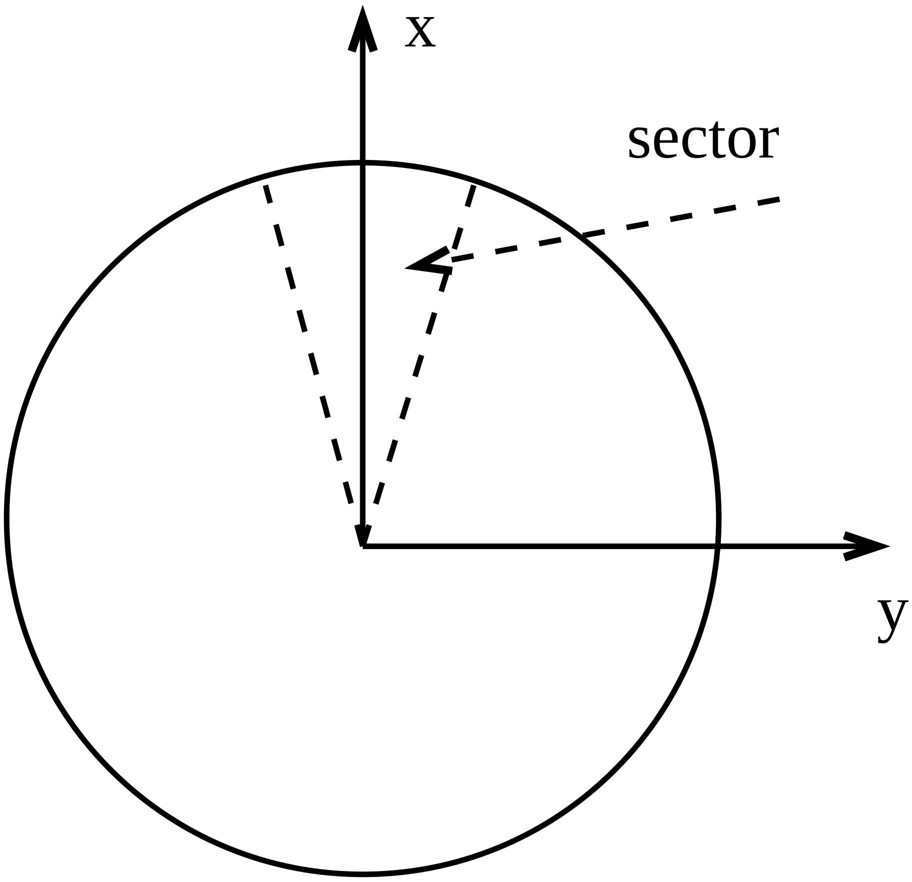
- pions as a source of neutrinos (*K2K*) and muons (*neutrino factory, muon collider*)
  $\pi^{\pm} \to \mu^{\pm}\bar{\nu}_{\mu}$
  $\mu^{\pm} \to \mathrm{e}^{\pm}\bar{\nu}_{e}\nu_{\mu}$
- better estimations of atmospheric neutrino flux
- precise knowledge of pion yields: mirror of intranuclear physics
- 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 (π^+ and π^-)
  - 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


x
transvers collection
π
protons
target
z
y


x
sector
y

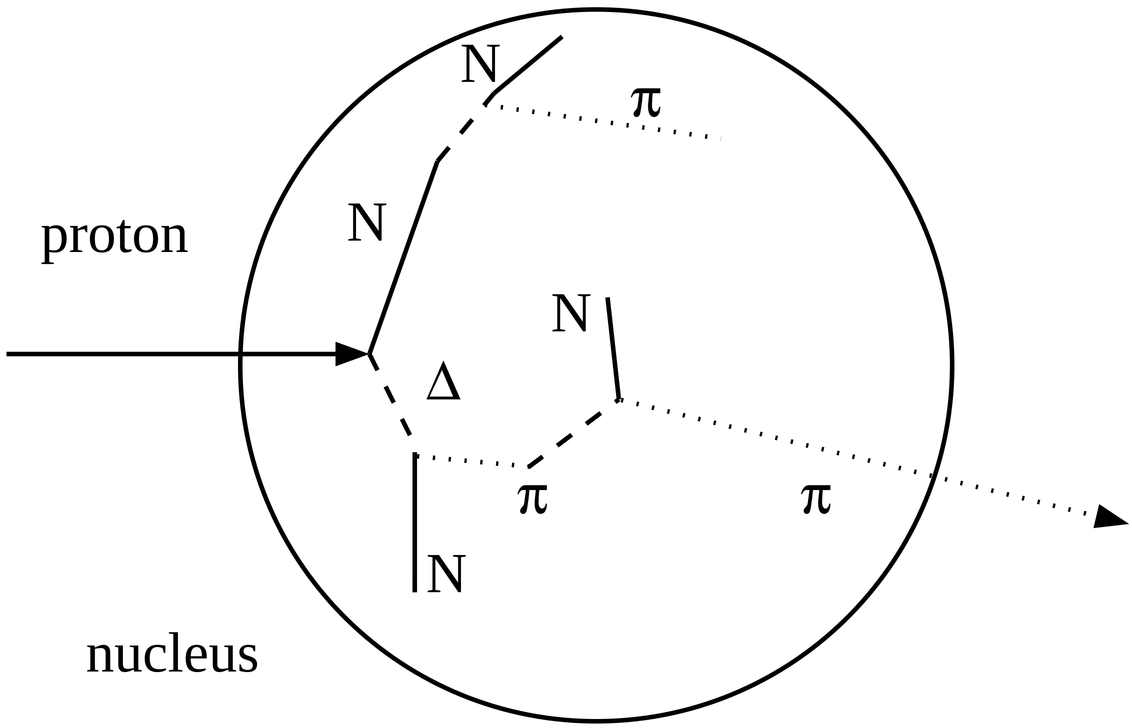
◯ thin target results

- 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

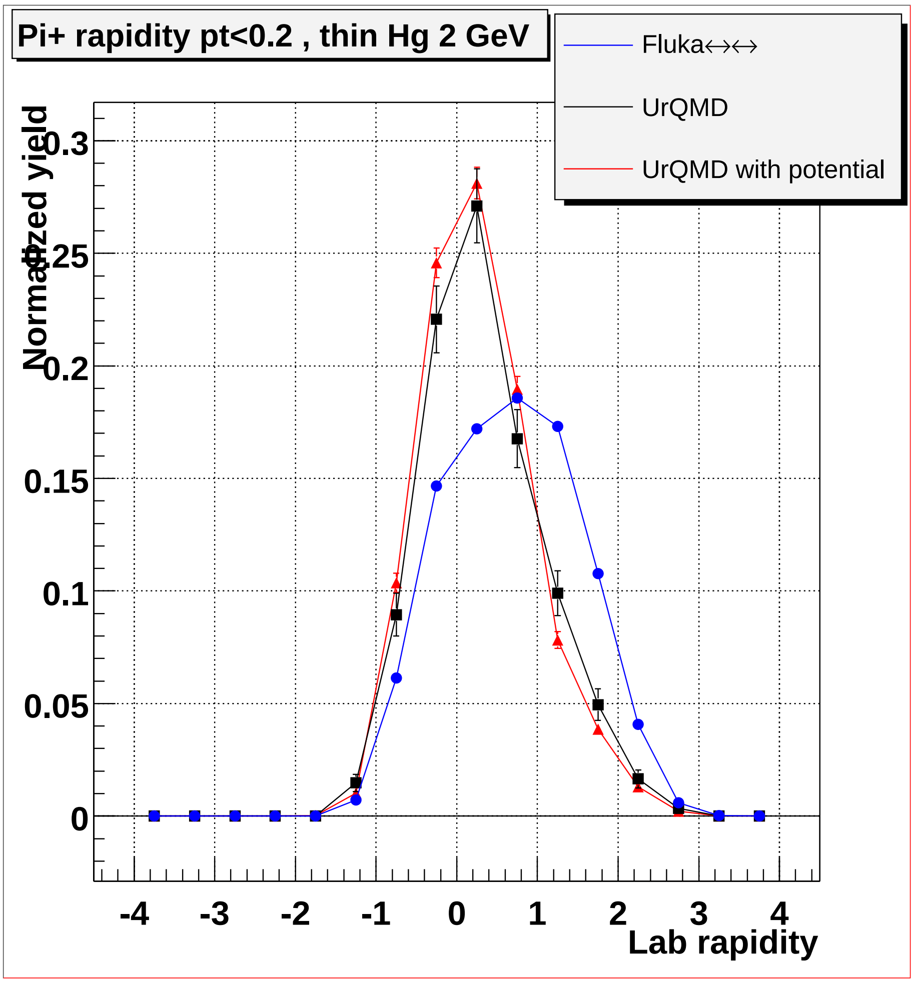
UrQMD (**U**nified **u**ltra-**r**elativistic **q**uantum **m**olecular **d**ynamics, Frankfurt):
- only nuclear interaction allowed
- in Geant4
- enables to use isoscalar projectiles (d, Hg,...)

...thin target results



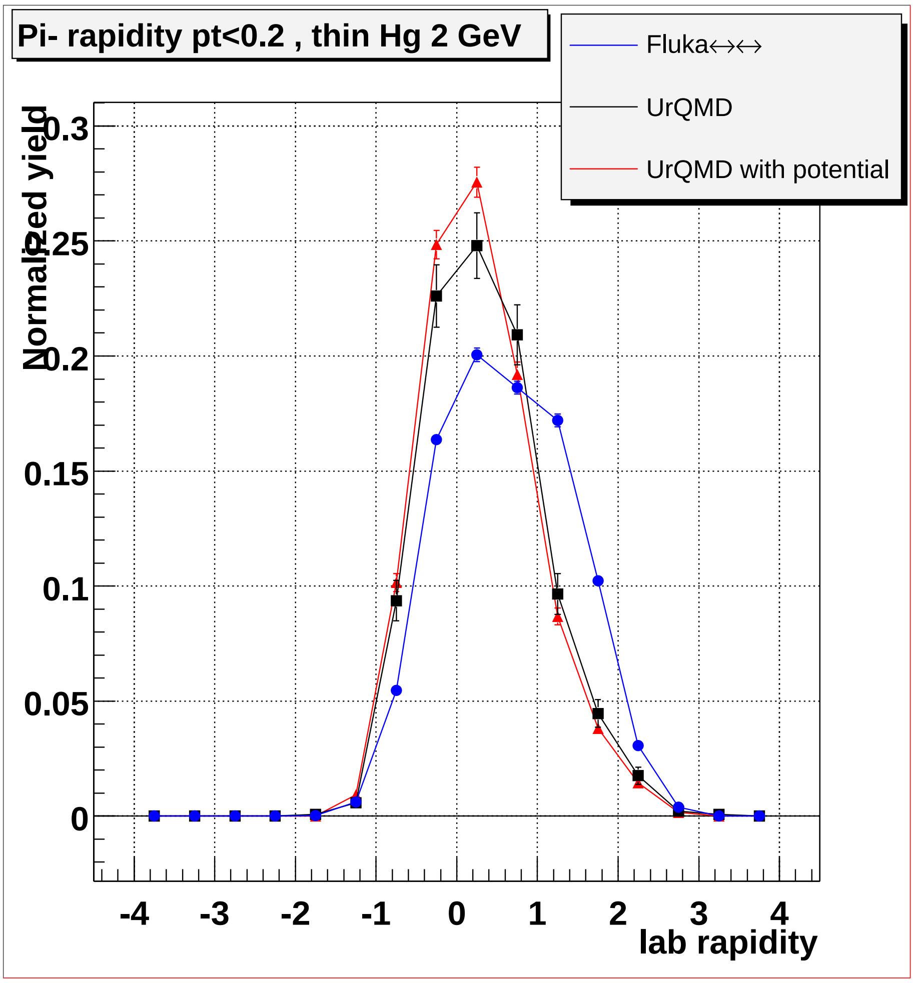
...thin Hg-target results

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



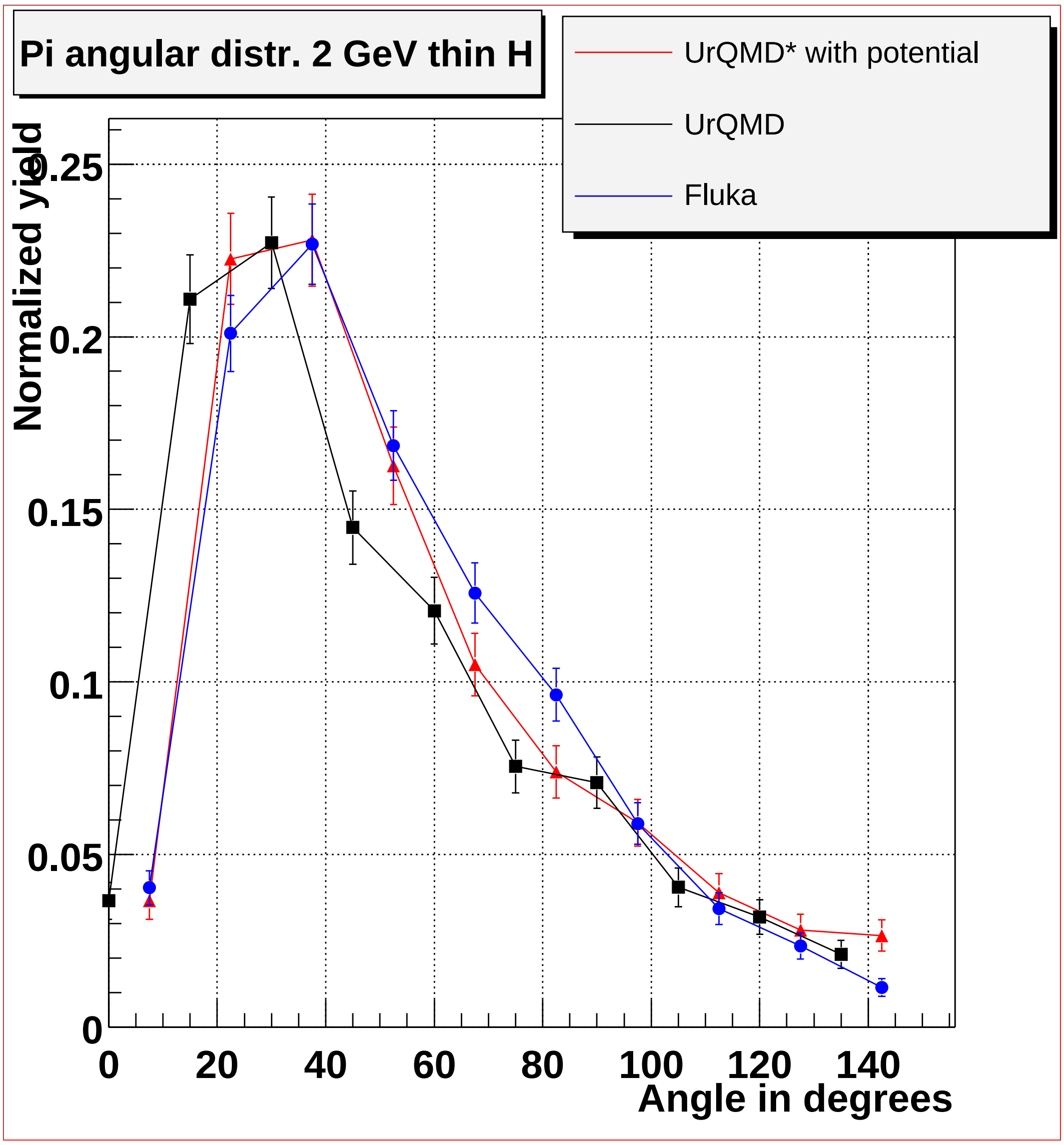
...thin Hg-target results

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



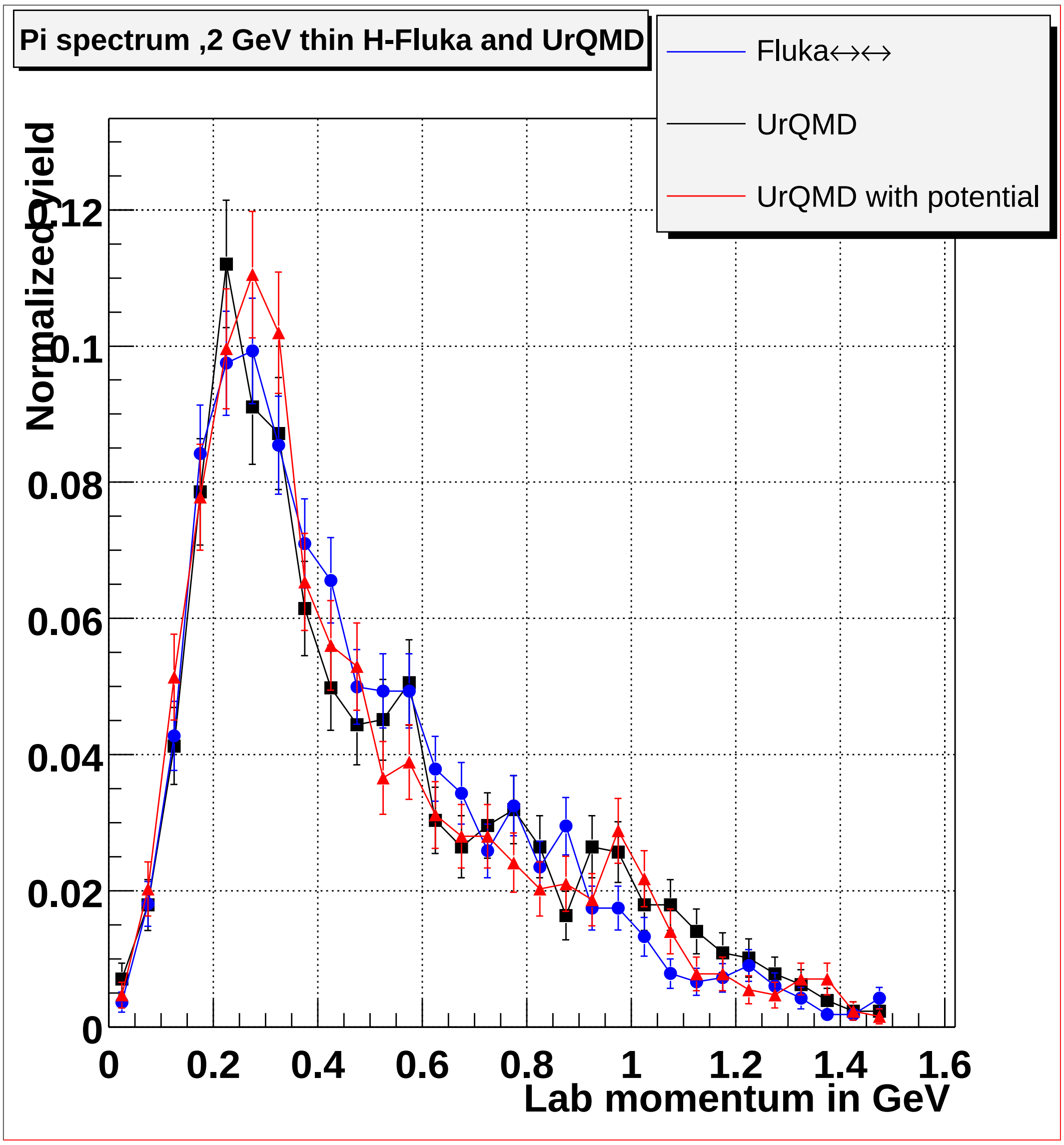
...thin H-target results

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



...thin H-target results

- hydrogen target: spectrum
- normalized yield versus lab momentum



...thin Hg-target results

- π^+ - angular distribution
- normalized yield versus angle

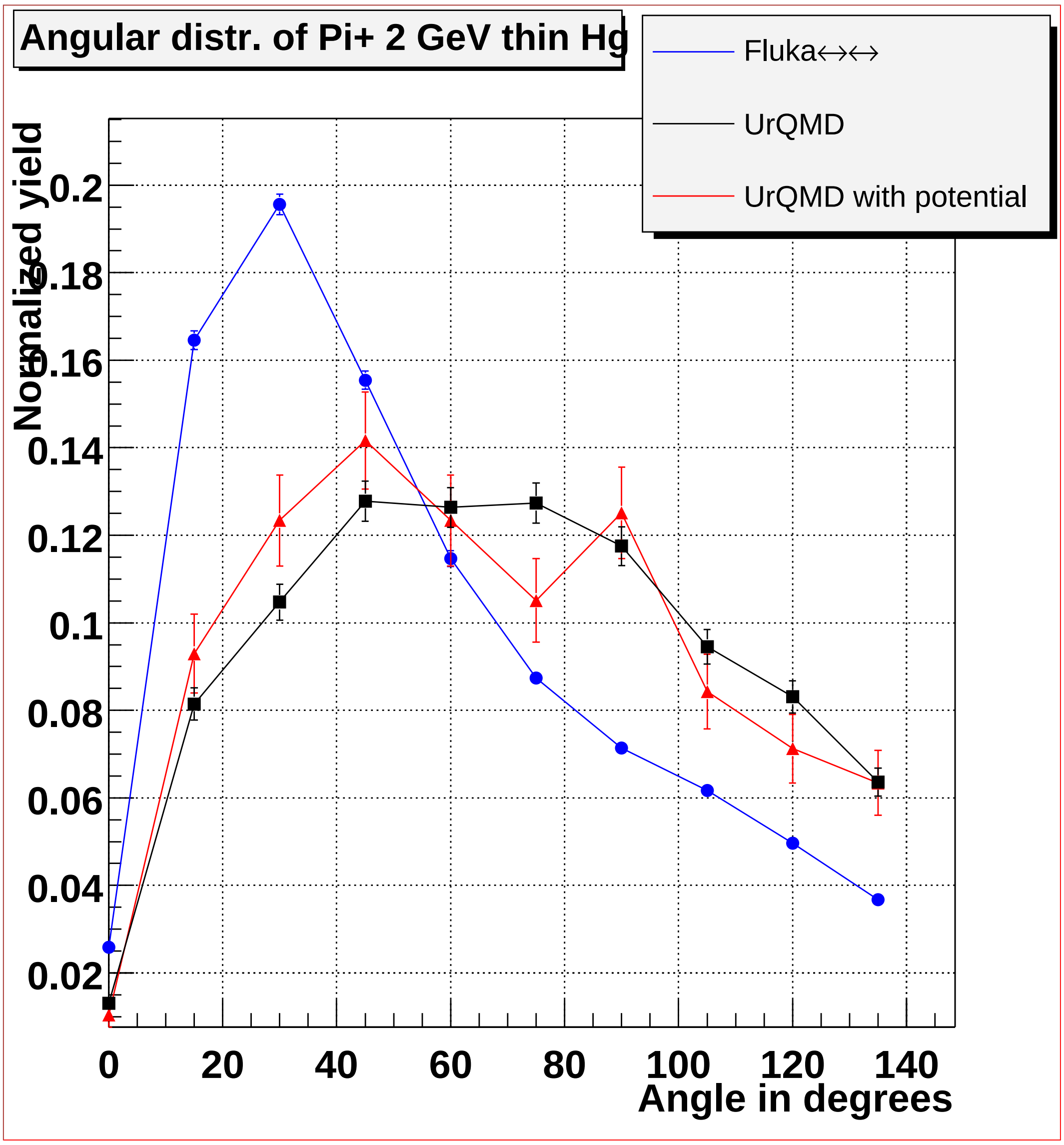
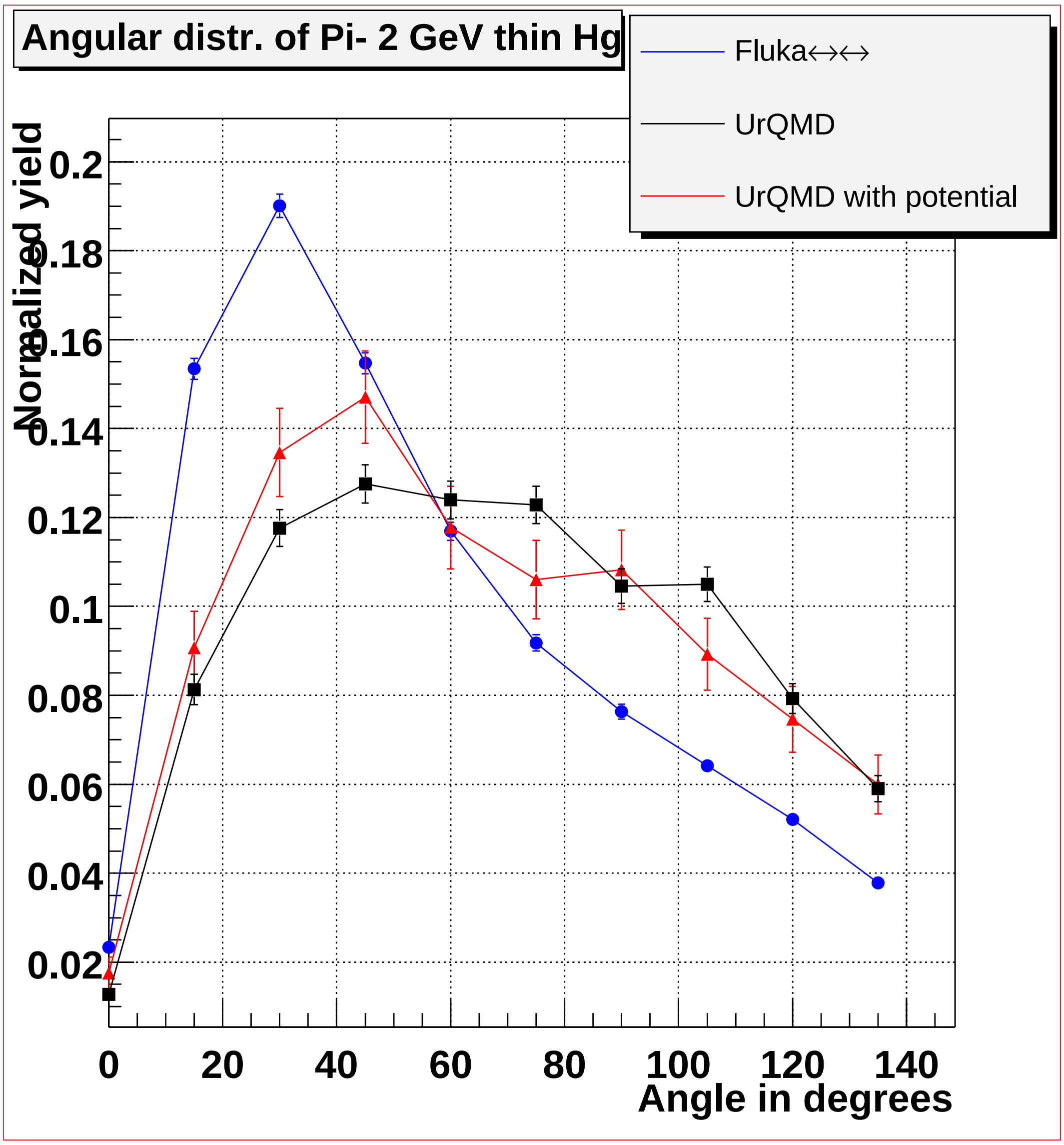


Figure 1:

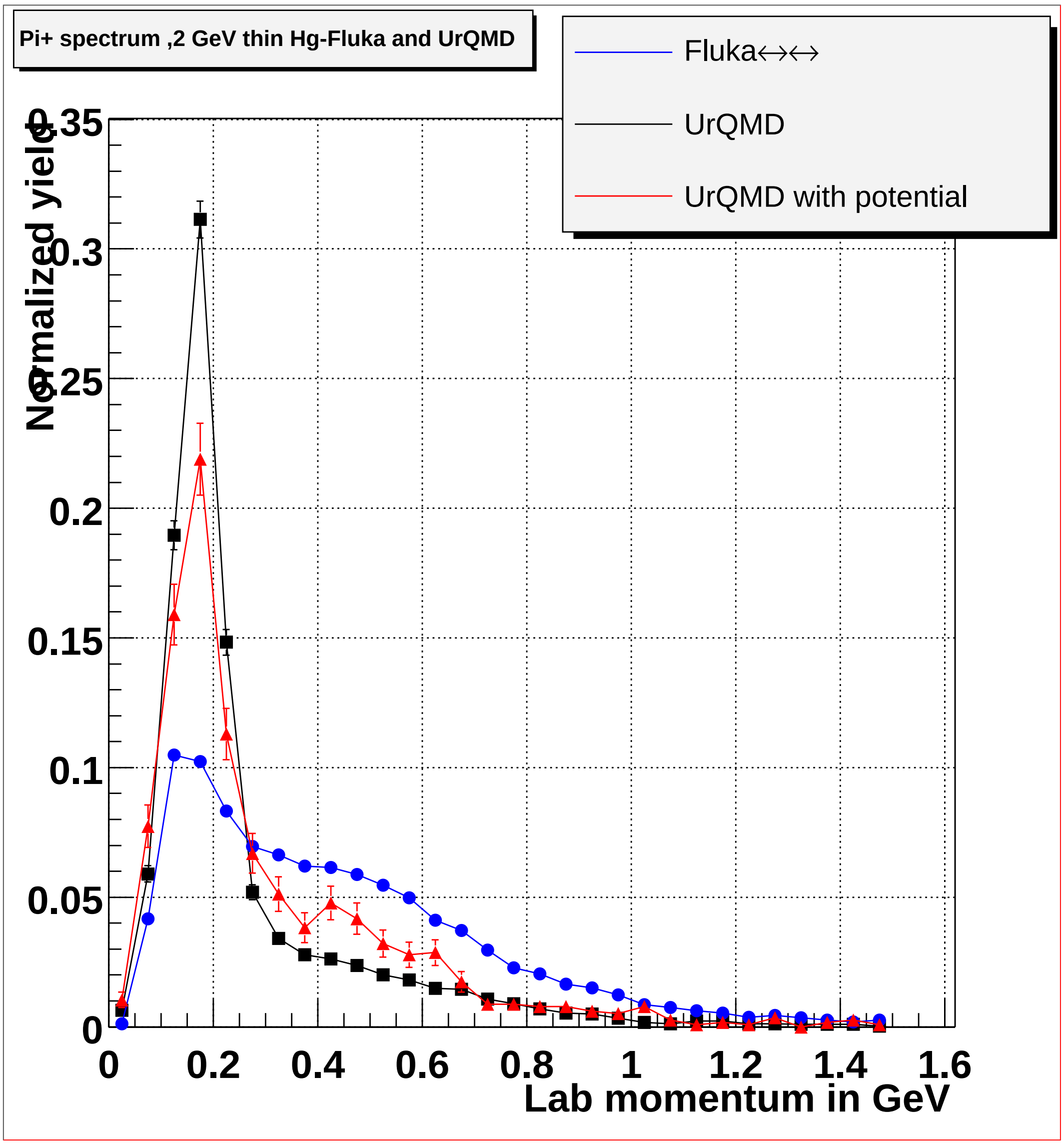
...thin Hg-target results

- π^- - angular distribution
- normalized yield versus angle



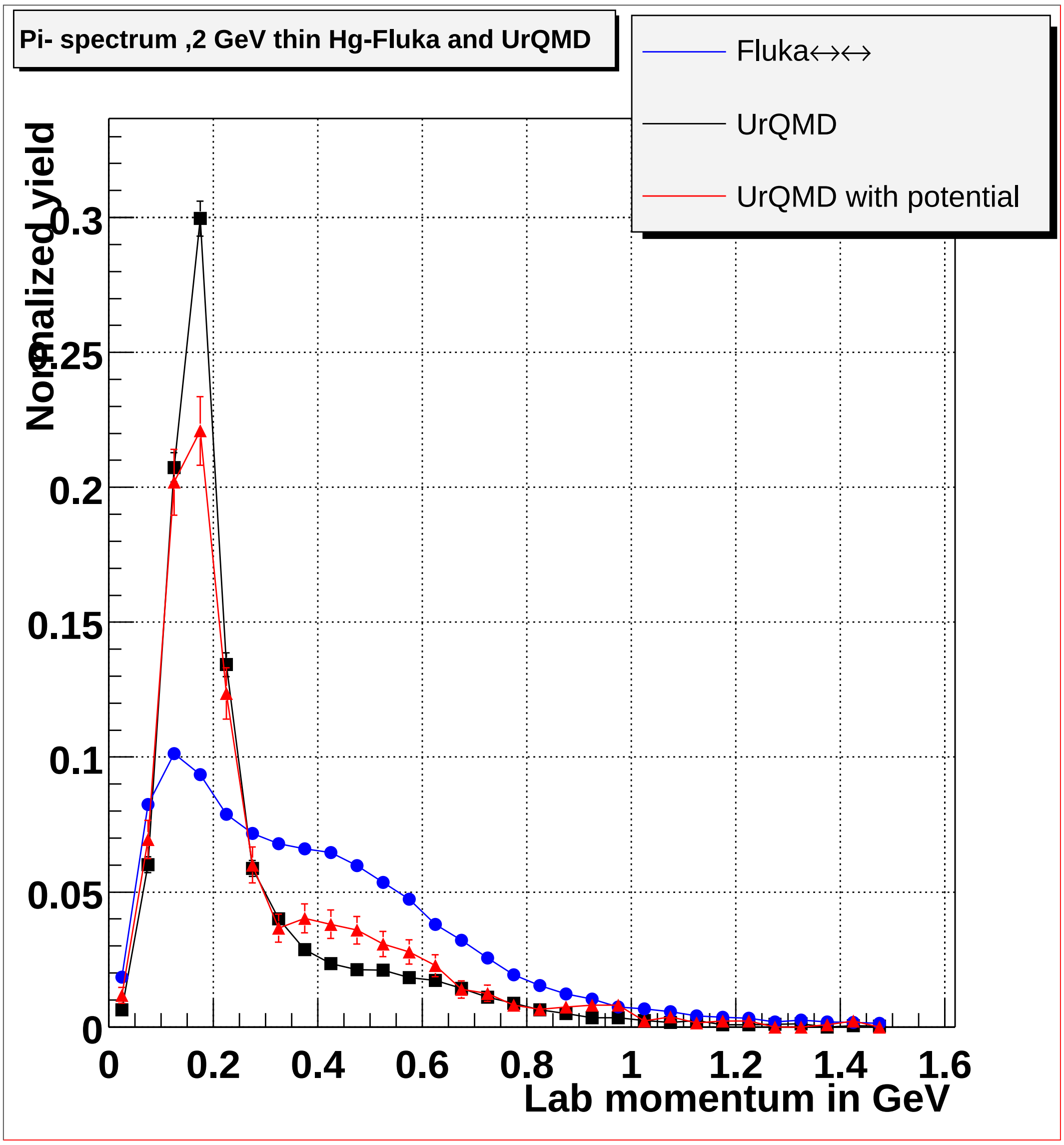
...thin Hg-target results

- π^+ - spectrum
- normalized yield versus lab momentum



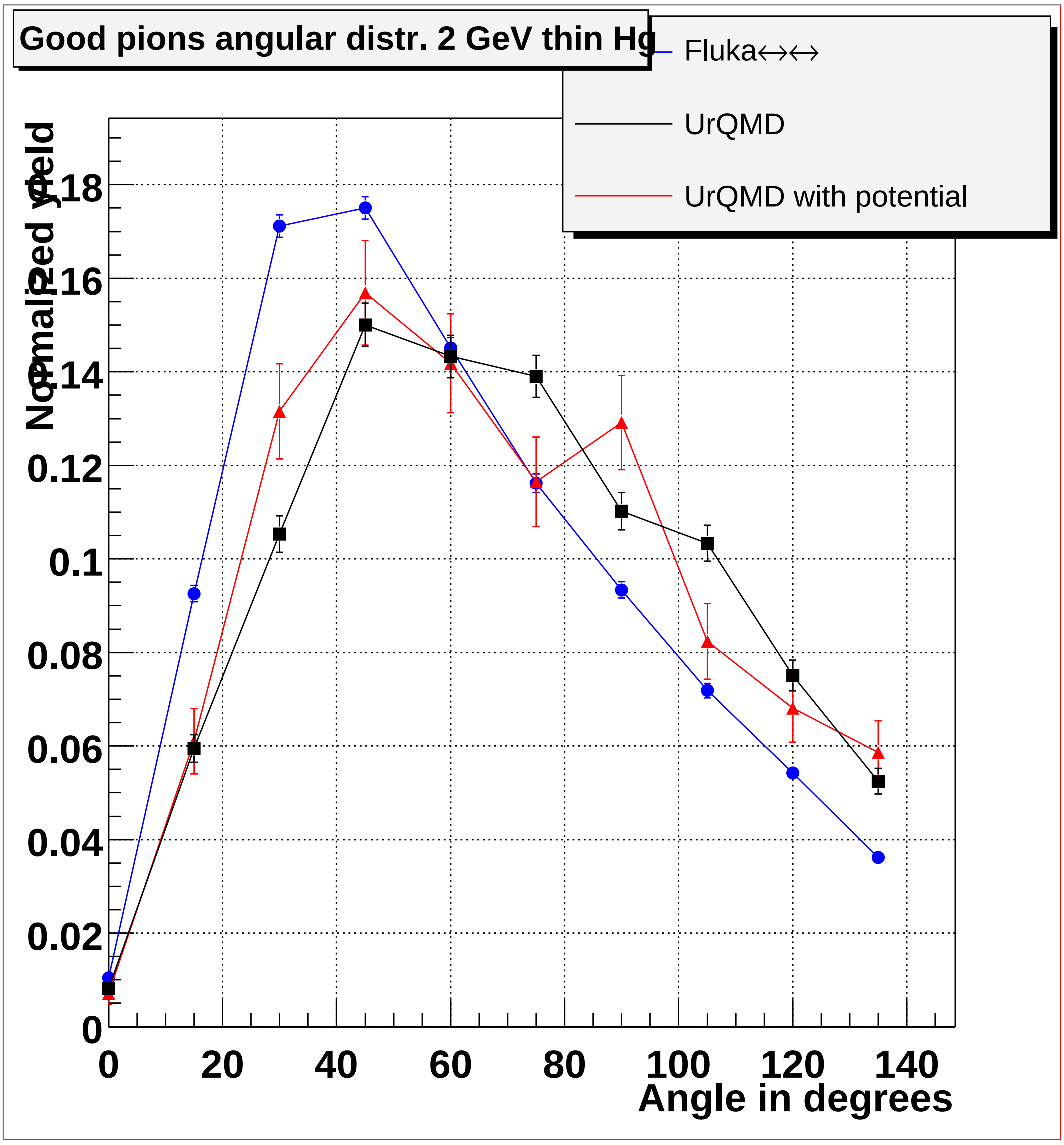
...thin Hg-target results

- π^- - spectrum
- normalized yield versus lab momentum



...thin Hg-target results

- good pions (with 1< rap_z <2)
- normalized yield versus angle



◯ 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 $\rightarrow$ estimation of the number of pions collected per second in a kinematic window using a 4MW proton beam:
  $1 < \mathrm{rap}_x < 2$ as a function of the collecting angle

• 2GeV: *longitudenal* collection on 20cm Hg-target, $\varepsilon = 24 \cdot 10^{-3}$m.rad:
$\mathbf{8.3 \cdot 10^{13}}\pi^+$/seconds ; $\mathbf{5.1 \cdot 10^{13}}\pi^-$/seconds
• 2GeV: *transverse* collection in π/second:

emittance $\varepsilon = x \cdot px/m_0 = 6 \cdot 10^{-3}$m.rad
64 sectors

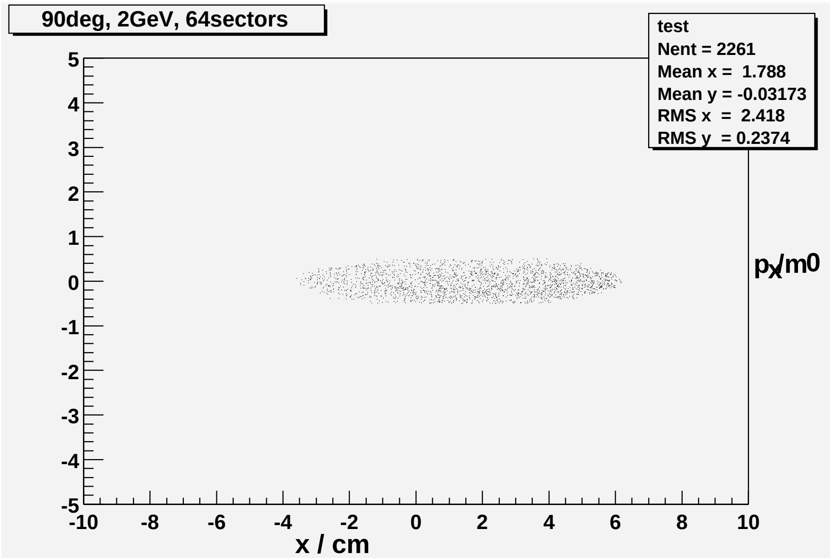
angle	π^+	π^-
45	$9.2 \cdot 10^{13}$	$7.2 \cdot 10^{13}$
90	$3.5 \cdot 10^{13}$	$2.6 \cdot 10^{13}$

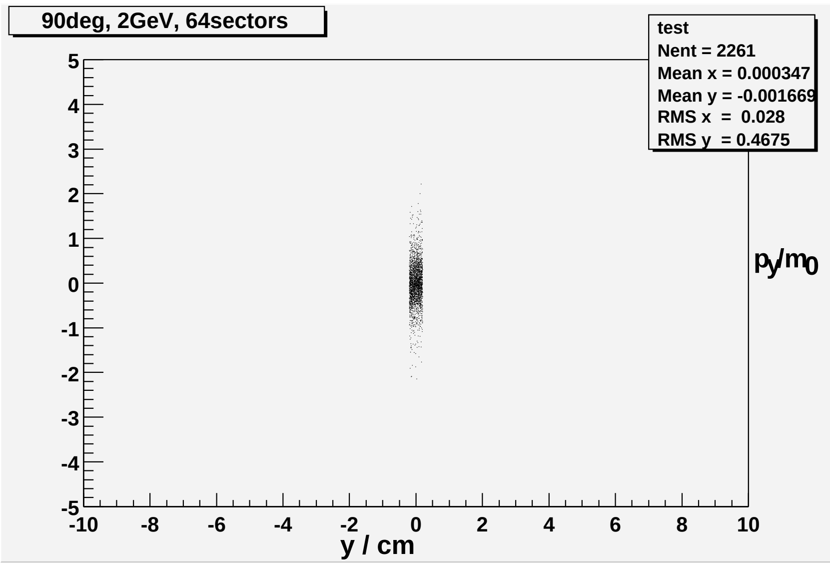
emittance $\varepsilon = x \cdot px/m_0 = 24 \cdot 10^{-3}$m.rad
64 sectors

angle	π^+	π^-
45	$3.1 \cdot 10^{14}$	$2.5 \cdot 10^{14}$
90	$1.0 \cdot 10^{14}$	$0.8 \cdot 10^{14}$

...thick target results

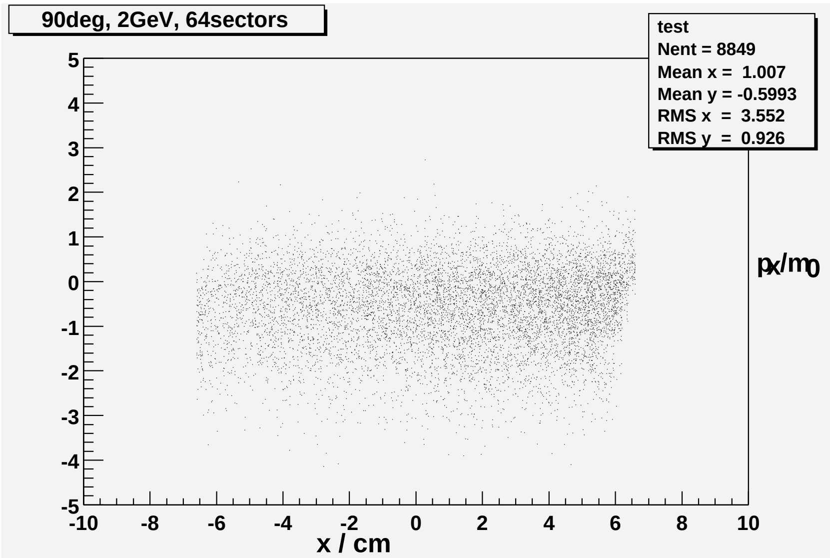
- $1 < rap_x < 2$ without special cut
- x versus p_x/m_0

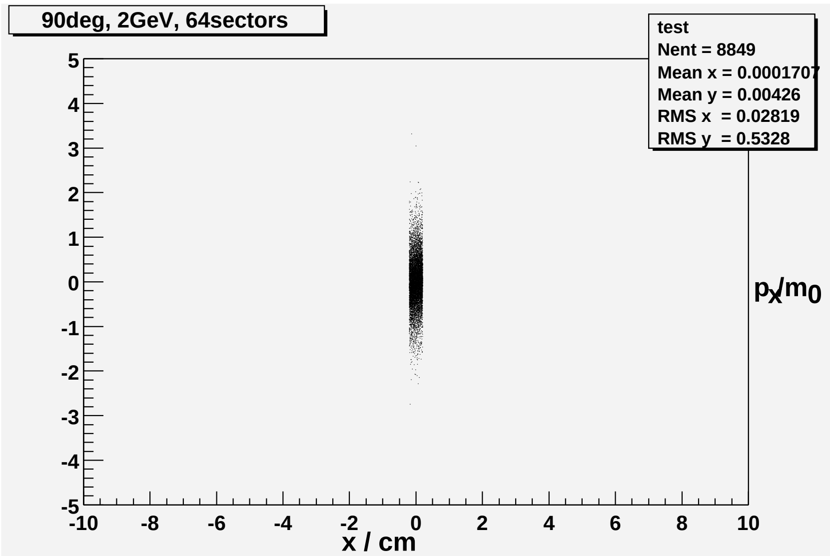




...thick target results

- $1 < rap_x < 2$ with special cut
- x versus p_x/m_0





○ conclusion

- experiment is really needed to check models
- colllection 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