Strange Particles in Nuclear Matter

- Strangenes
- Expected effects on strange particles
- The experimental tool: FOPI spectrometer
- In-medium mass modification
- ϕ(1020) meson: not all strange particles originate from nuclear matter
- Absorption of strange particles

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Sir Ernest Rutherford 1871-1937

discovered atomic nucleus (1911)

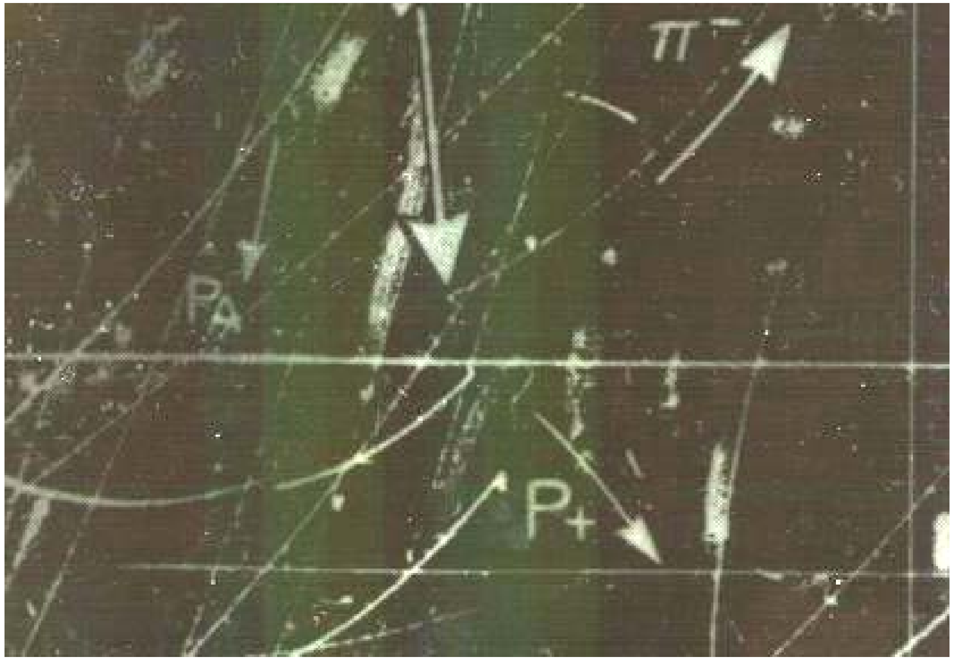
Nobel 1908

James Chadwick
1891-1974

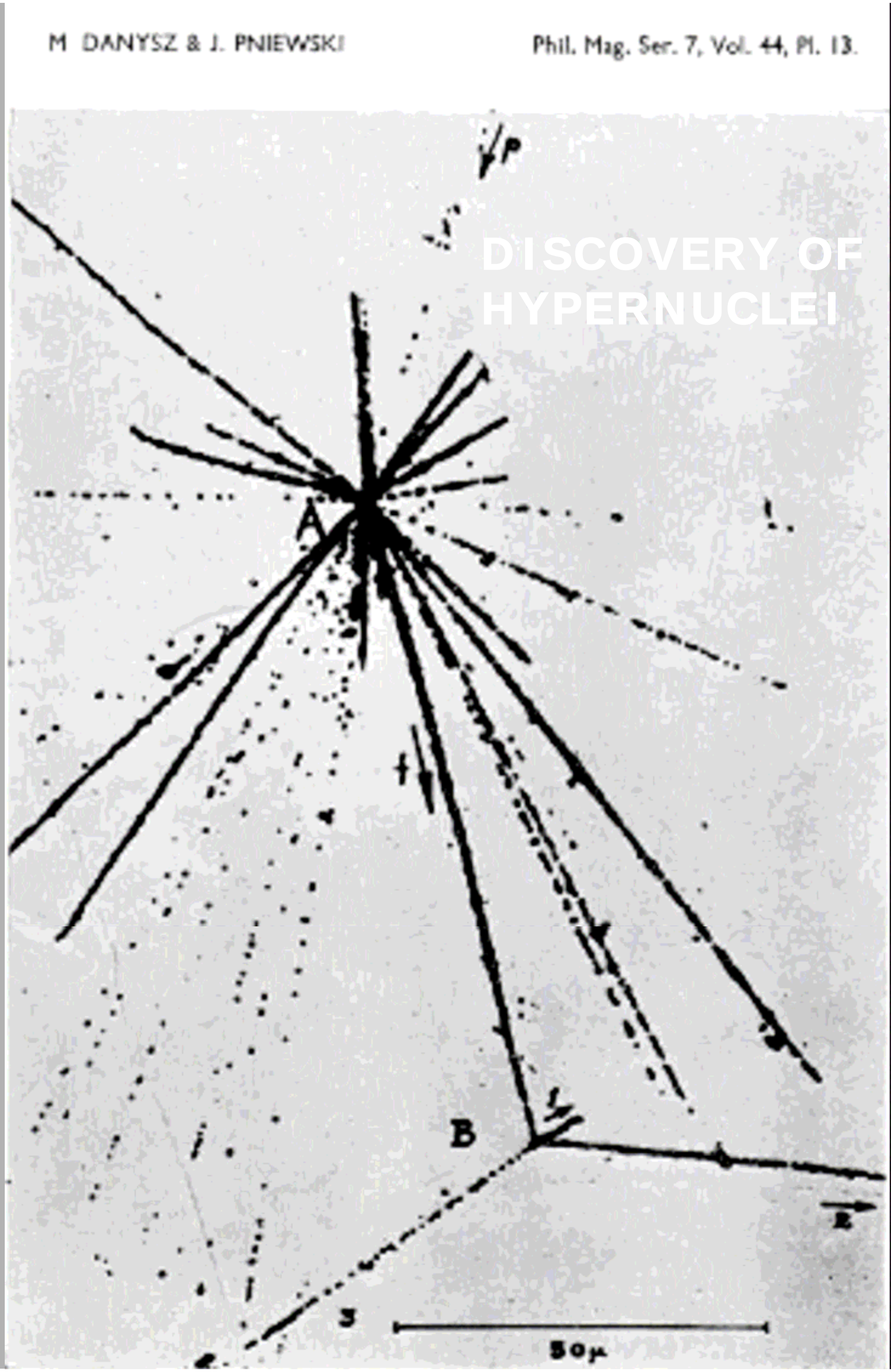
discovered neutron (1932)
Nobel 1935

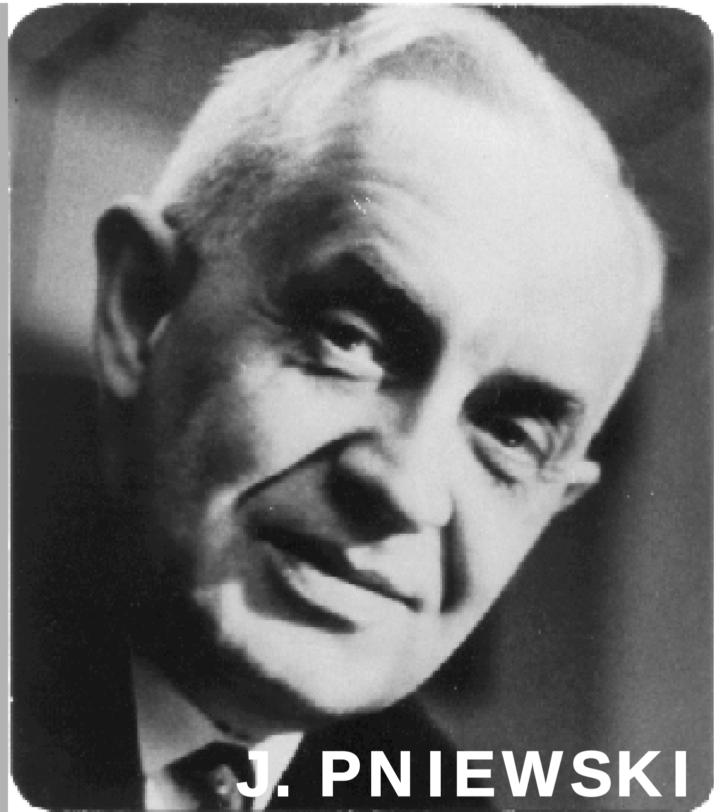
Discovery of „kaon meson” (K)

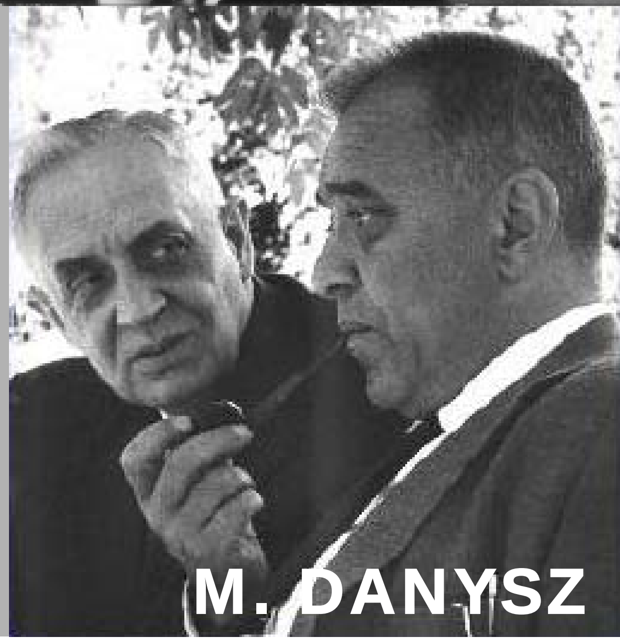
- **Rochester, Butler, 1947**
  - cosmic ray particles with masses in between pions and protons which were just like pions except for strangely long lifetime
  - **Always produced in pairs**



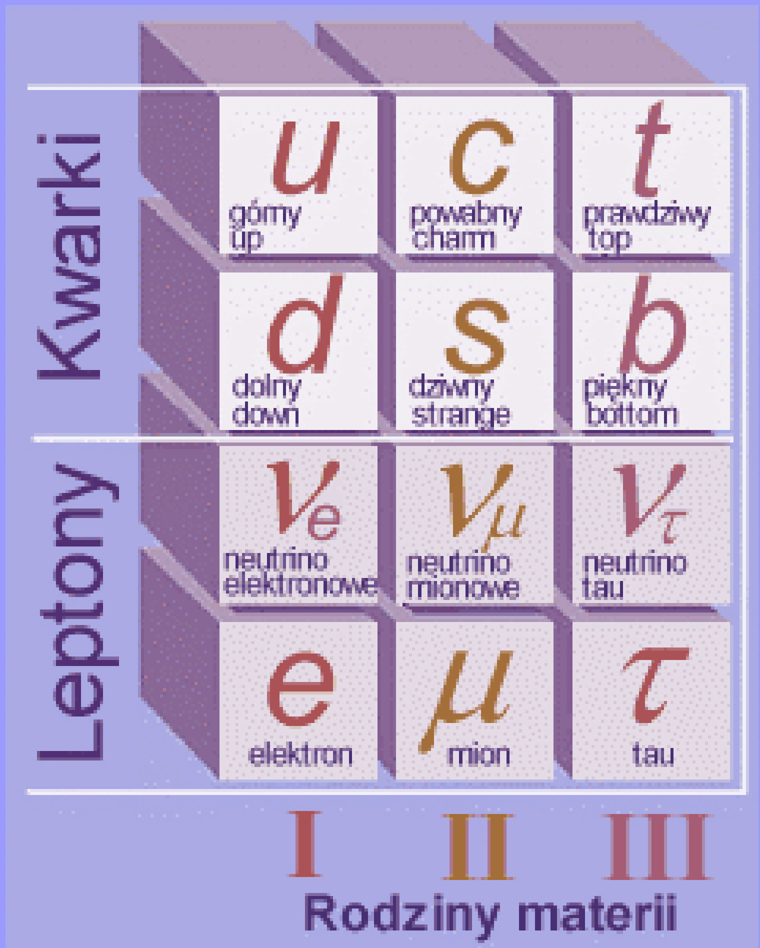
DISCOVERY OF HYPERNUCLEI







Hadrons: composed of quarks



- Barions: 3 quarks, or
- Mesons: quark-antiquark
- nucleons (proton or neutron) composed of u and d quarks
- Strange particles: presence of quark s

$$K^+|u\bar{s}\rangle \qquad \phi|s\bar{s}\rangle$$

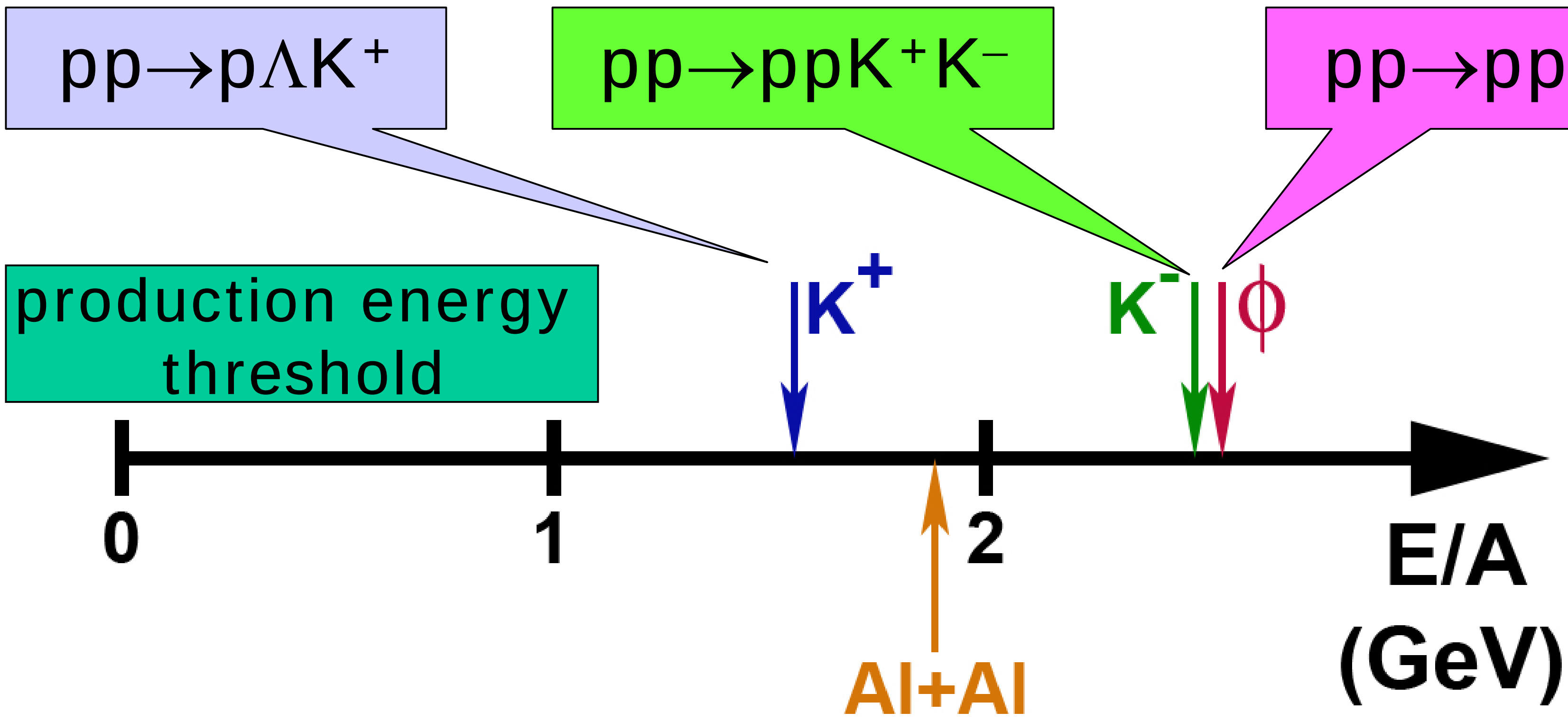
$$K^-|\bar{u}s\rangle \qquad \Lambda|uds\rangle$$

Strong interactions:
Conservation of quark numbers

Mesons K and ϕ

- Mesons K^+ i K^-
- Mass $\cong$ 494 MeV/c^2
- Decay $K^+ \rightarrow \mu^+ \nu_\mu$ (64%)
- $c\tau \approx 3,7$ m

- Meson ϕ
- Mass $\cong$ 1020 MeV/c^2
- Decay $\phi \rightarrow K^+K^-$ (49%)
- $c\tau \approx 47$ fm ($47 \cdot 10^{-15}$ m)



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Mesons K and ϕ

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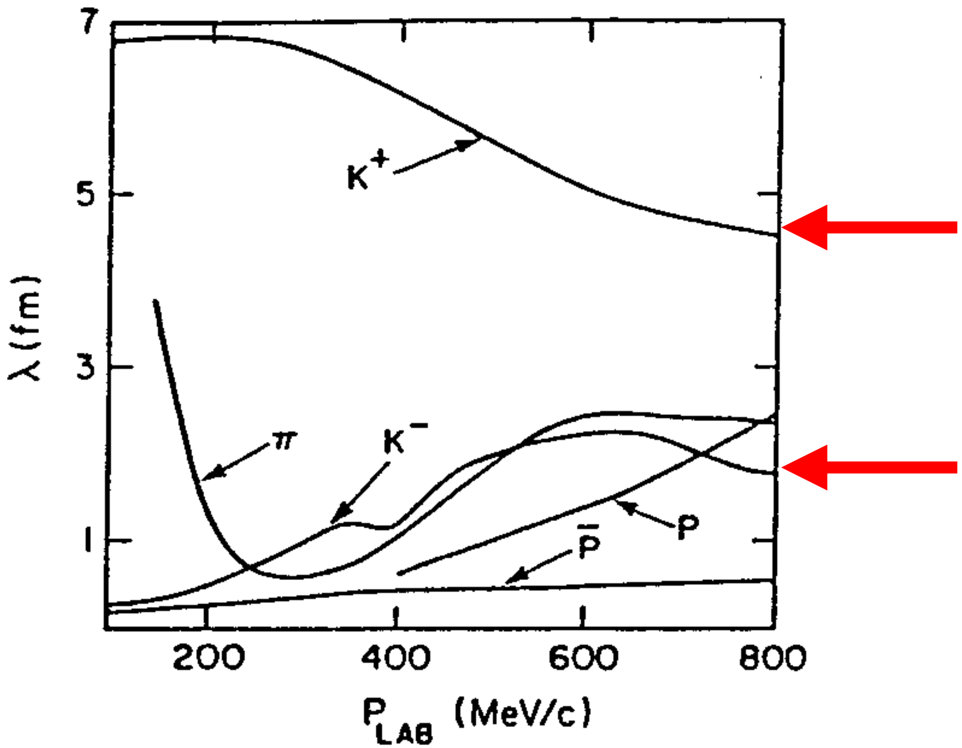
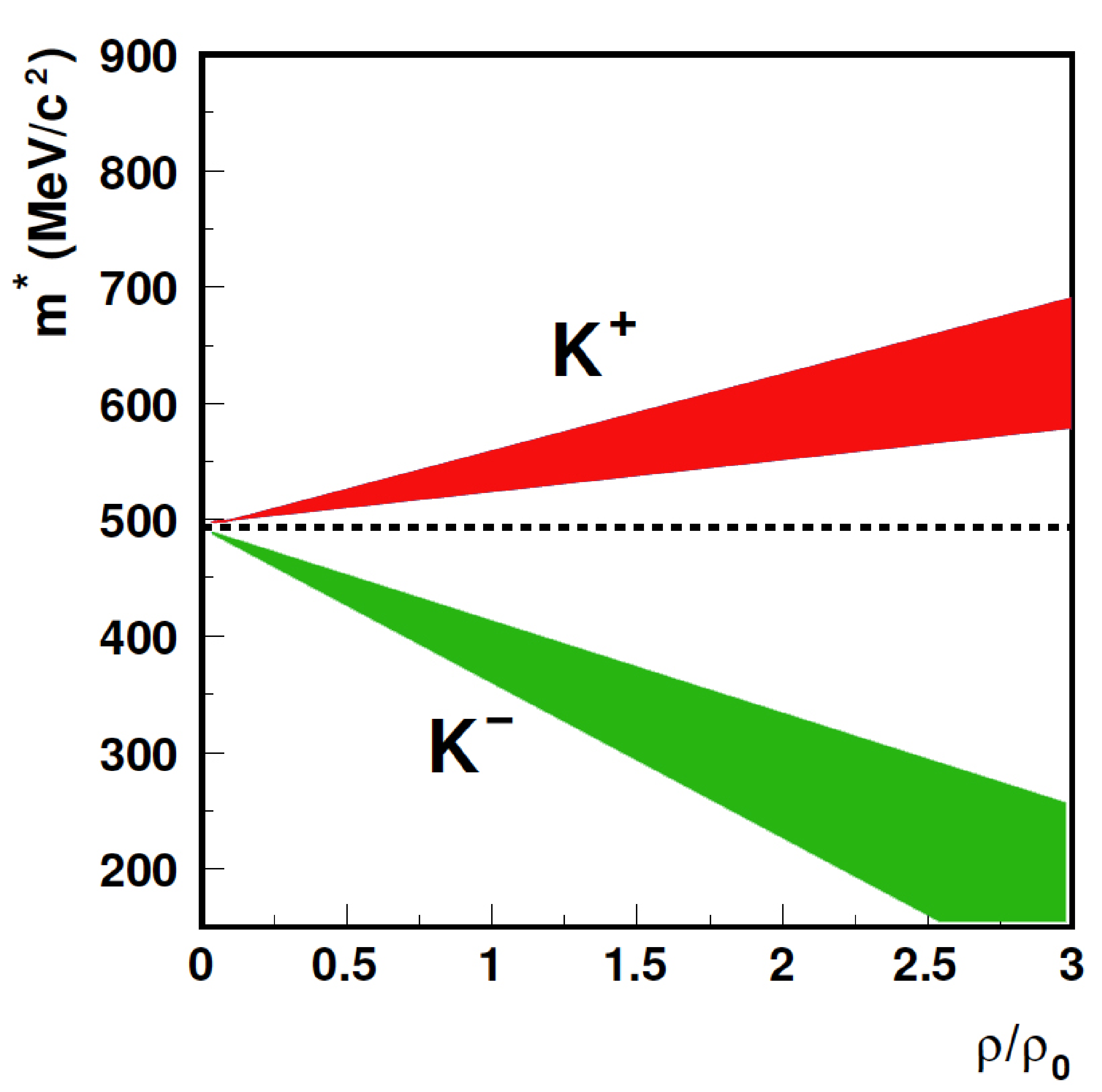
Mean free path in nuclear matter



$K^+ |u\bar{s}\rangle$

$K^- |\bar{u}s\rangle$



THEORY

KN potential:

repulsive for K^+

and

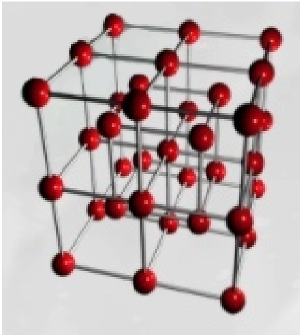
attractive for K^-

Stucture of matter

matter

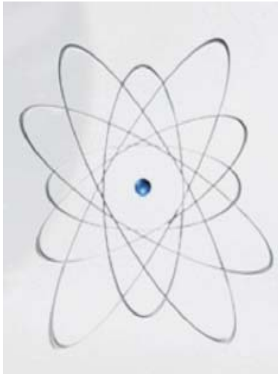
(macroscopic)

crystal



10^{-9} m

atom



10^{-10} m

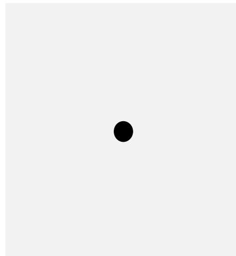
nucleus

10^{-14} m

nucleon

10^{-15} m

quark

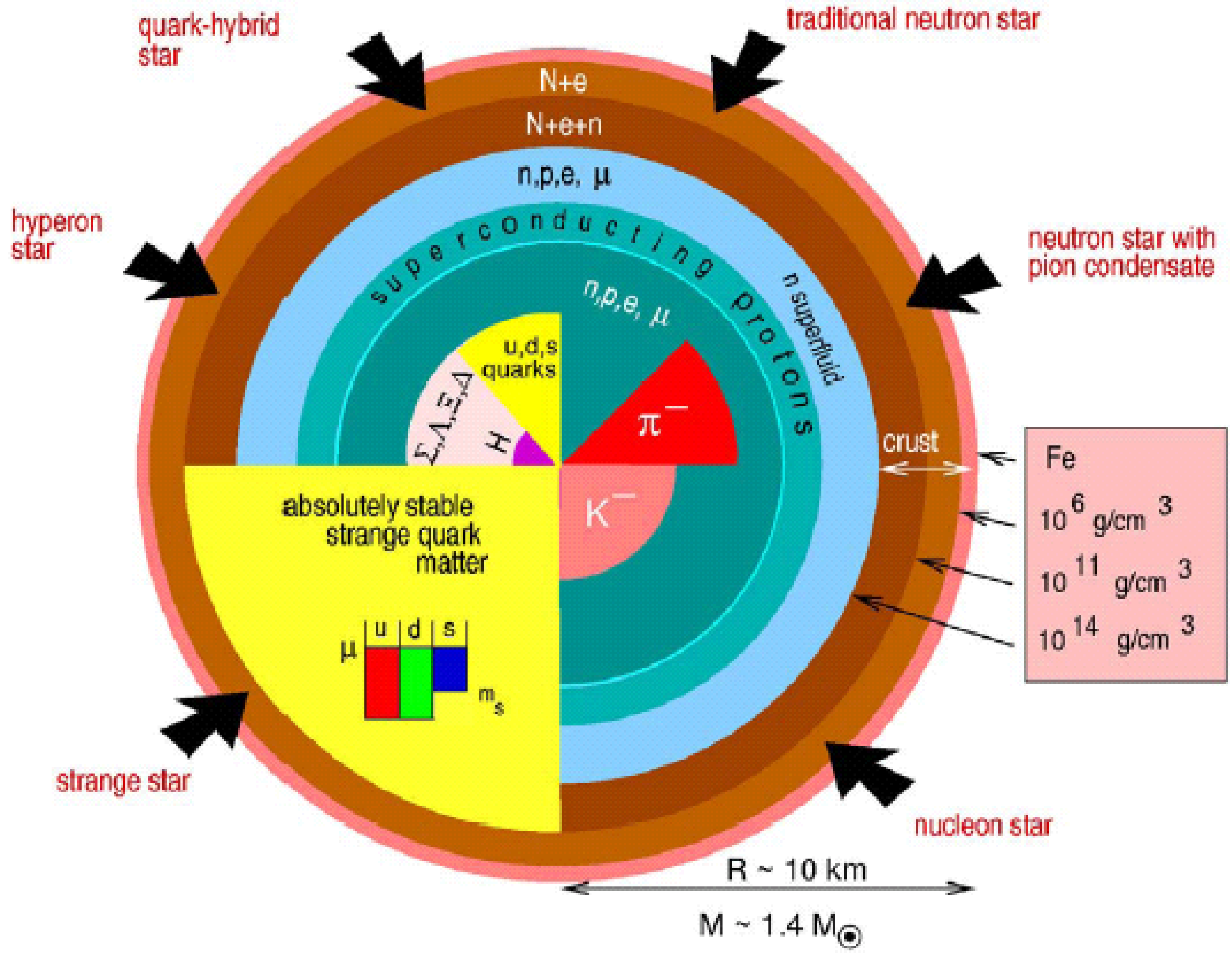


$< 10^{-18}$ m

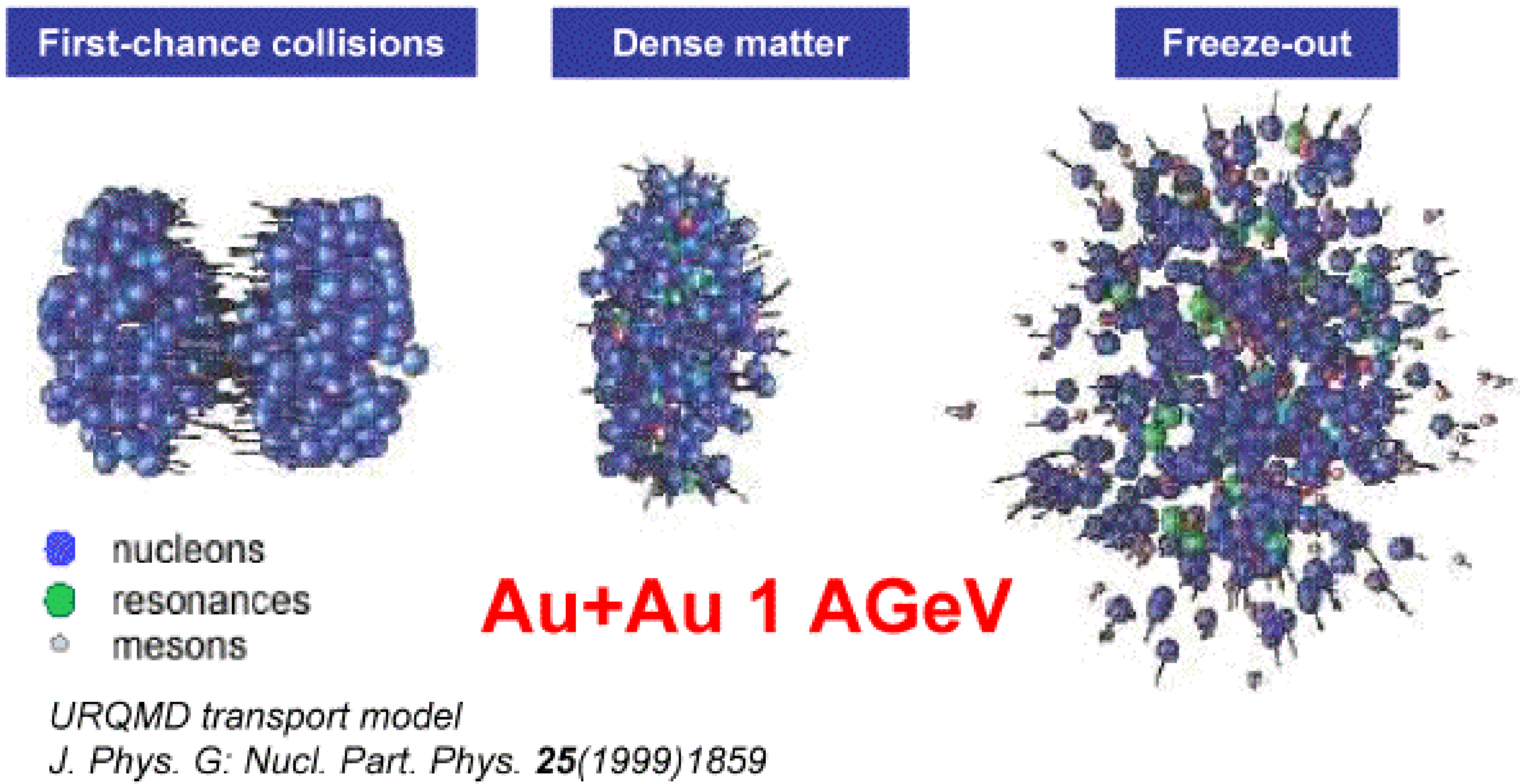
$m_u \sim m_d \sim 2\text{-}6\ \mathrm{MeV}/c^2$

$m_N \sim 940\ \mathrm{MeV}/c^2$

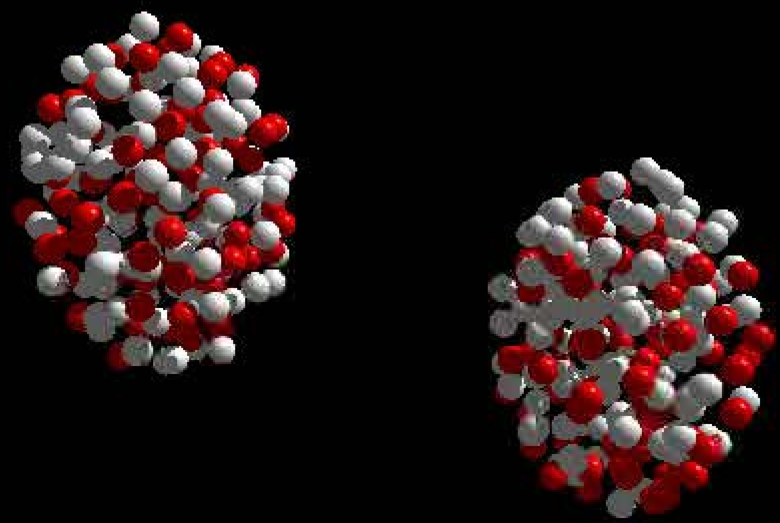
What's inside the neutron star?



Simulation of Au+Au collision

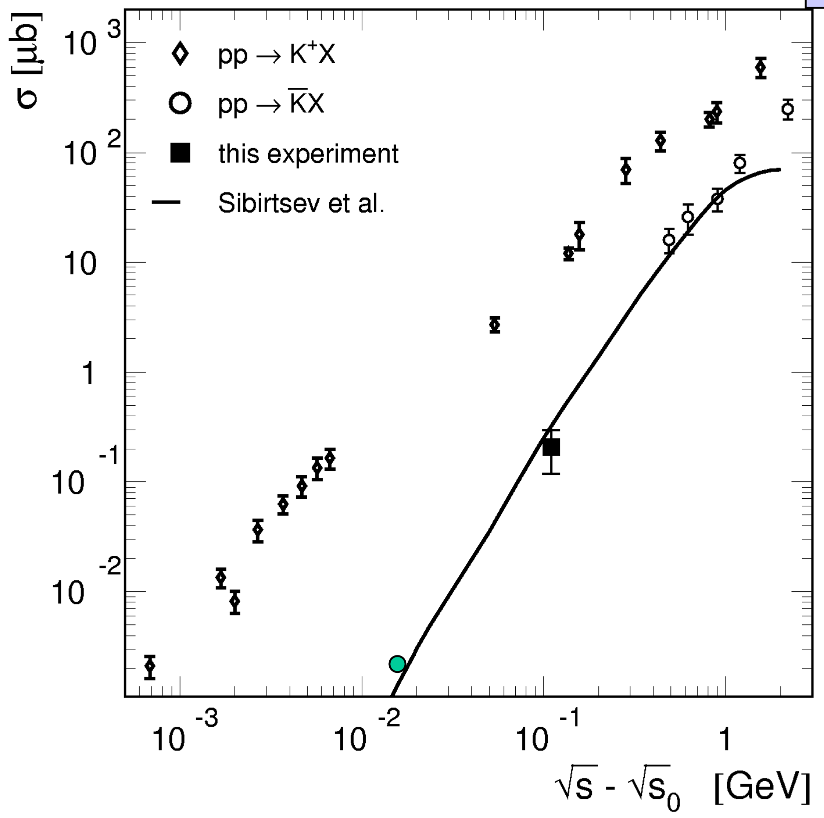


Au+Au 1.5A GeV



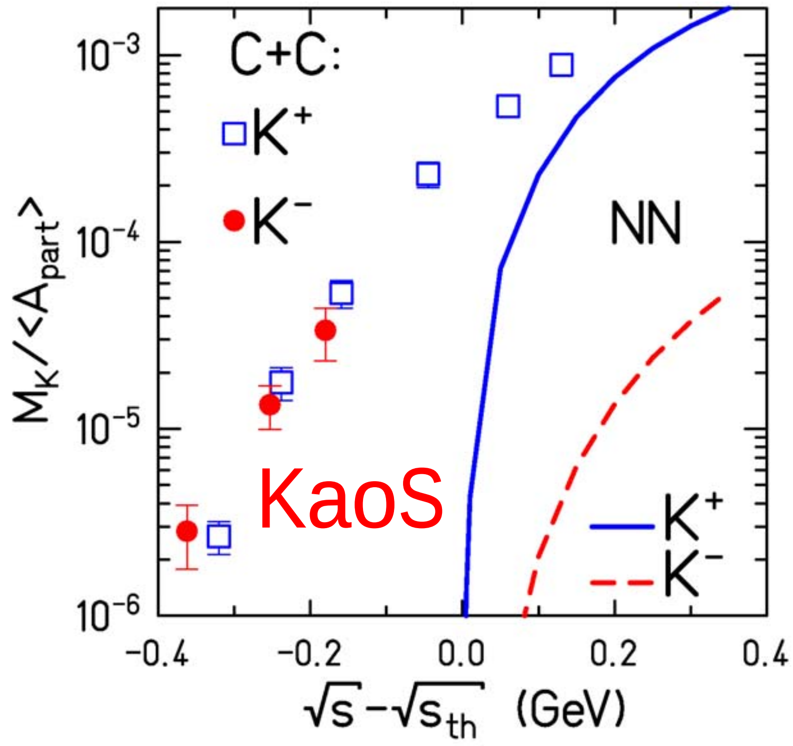
cross section for K-meson production

Comparison of proton-proton and nucleus-nucleus



"Subthreshold" production: qualitative explanantion through the Fermi motion

Strong rise of the production of K⁻ mesons



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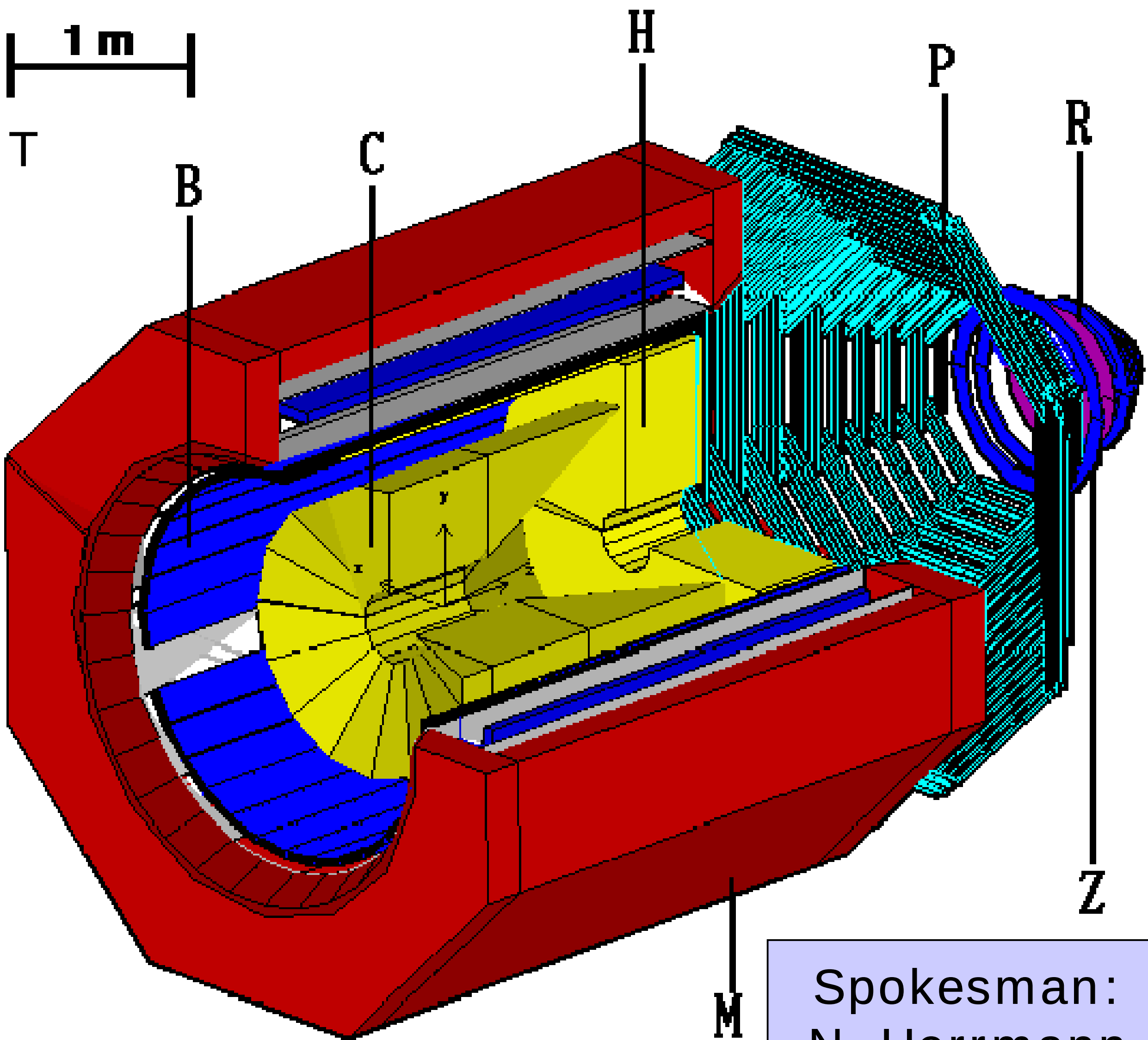
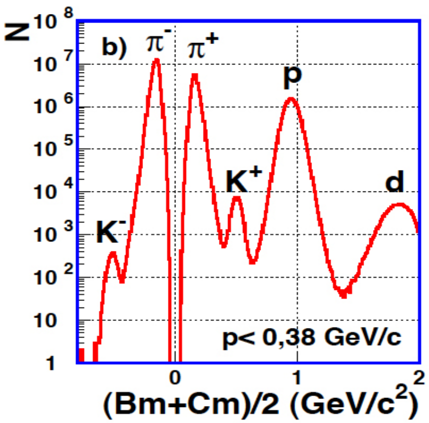
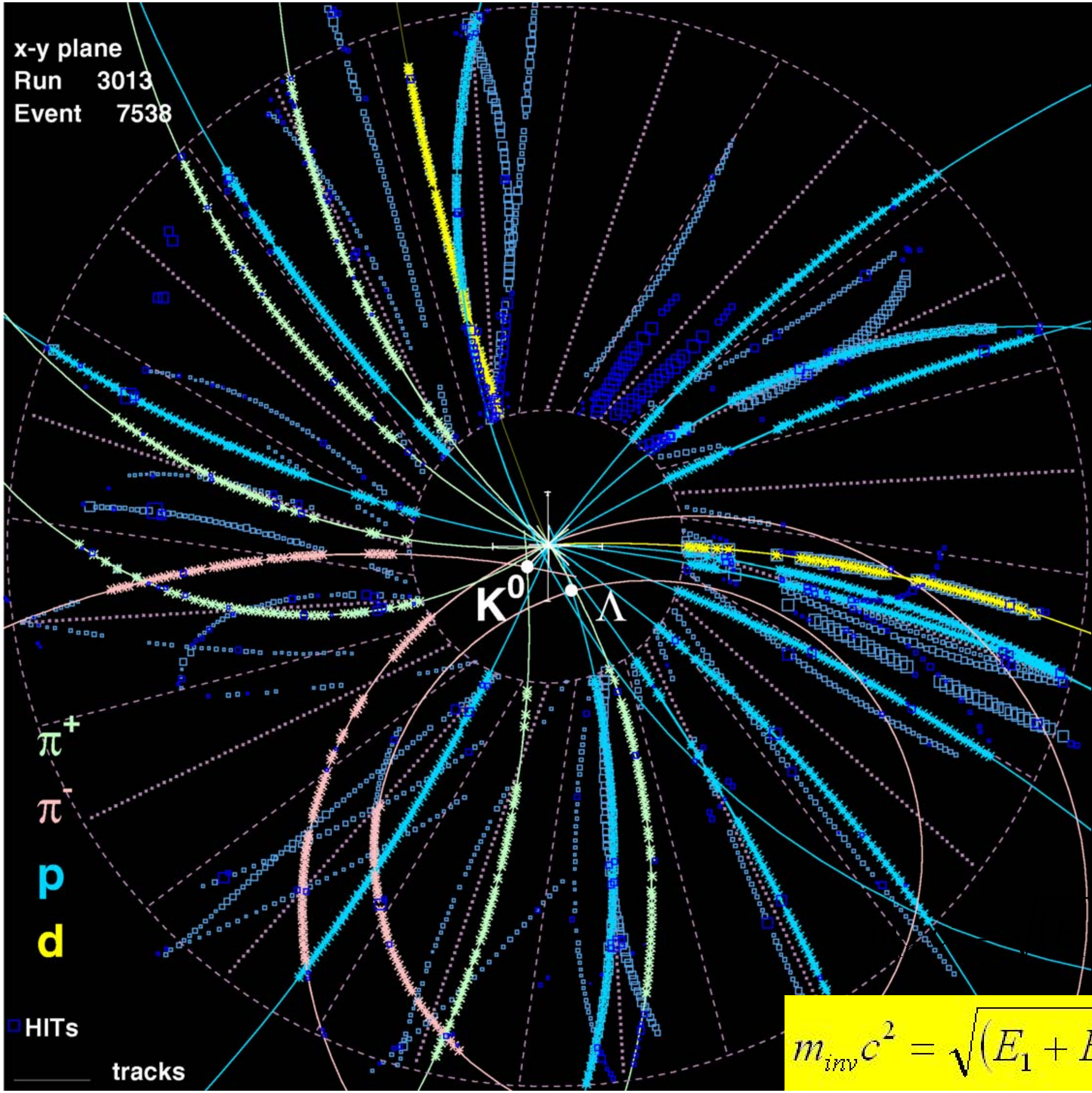
FOPI spectrometer at GSI Darmstadt

- Covers almost full solid angle (FOur PI)
- Magnetic field B=0,6 T
- 2 types of detectors: drift chambers (dE/dx, p_t) and scintillation (ToF)
- Directly measured: p, d, t, ^{3}He, $\pi^\pm$, $K^\pm$

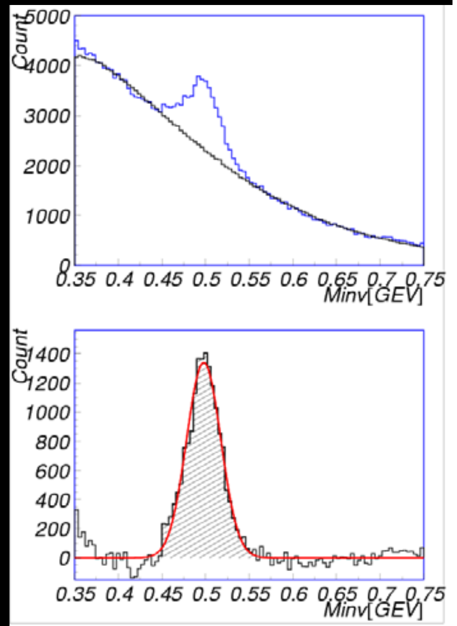




Spokesman:
N. Herrmann
U. Heidelberg



Invariant mass analysis of pairs of particles allows to identify short-lived neutral particles:
Λ, K^0, ϕ



$$m_{inv}c^2 = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2 c^2}$$

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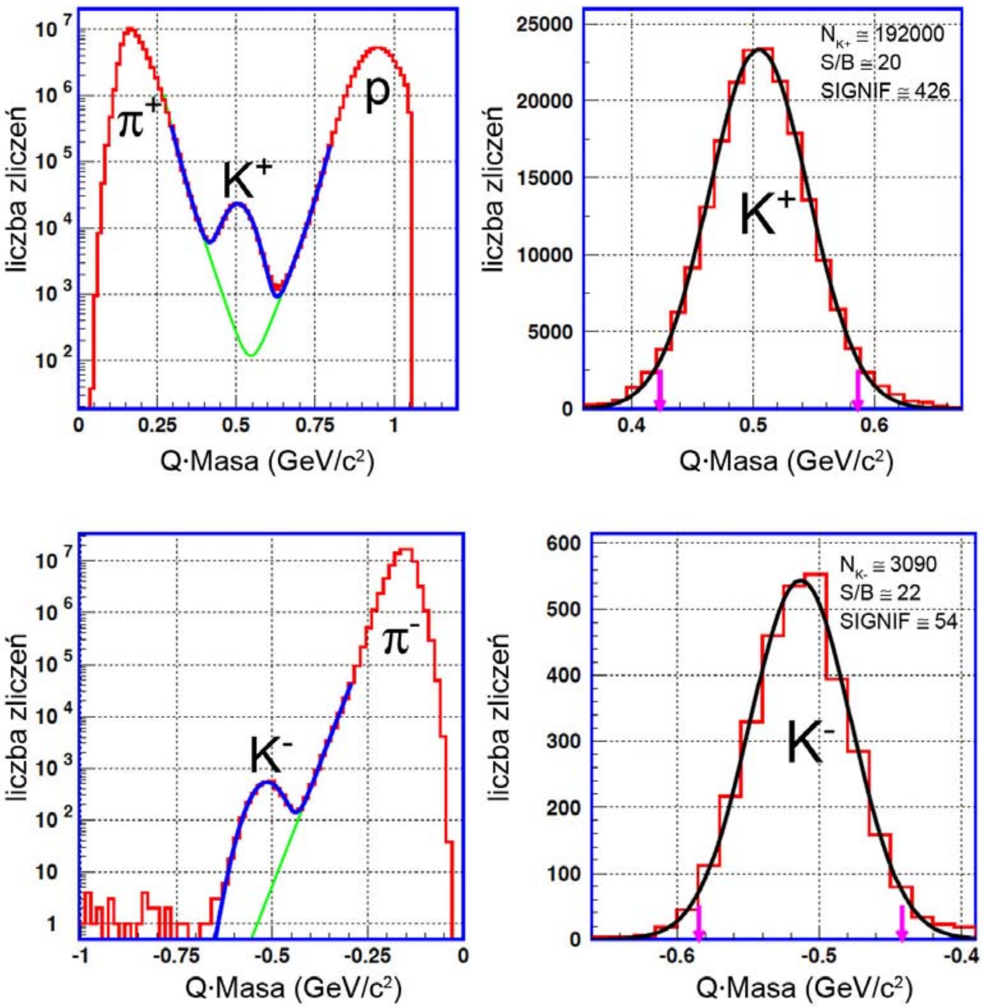
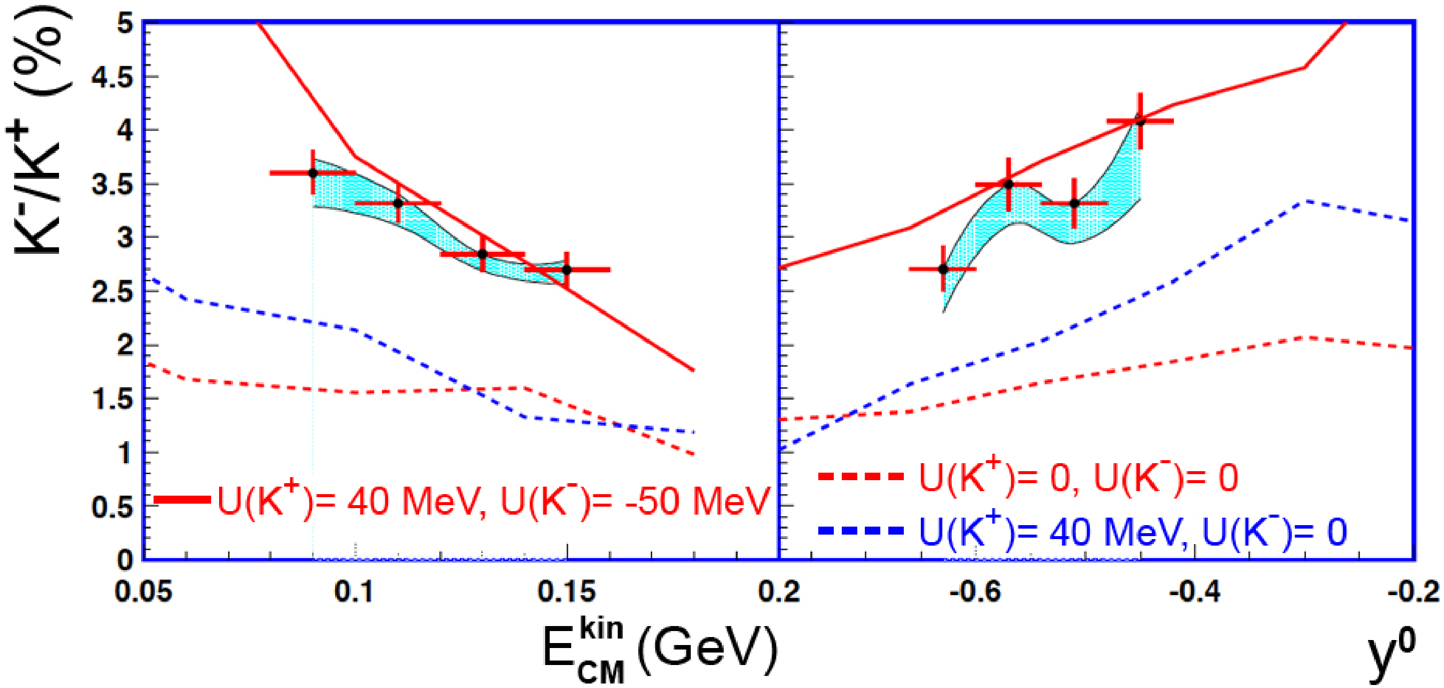
Identification of K mesons



- Al+Al, E=1,9A GeV
- 192500 K^+ mesons
- 3090 K^- mesons
- The simulation of the response function of the spectrometer allows to correct for thhe efficiency and get the emission probability per collision:
  K^+: 3,73%
  K^- : 0,11%
- Relative errors:
  K^+: ±15% (syst!)
  K^- : ±30% (stat!)

Ratio of K^-/K^+ emission



- Without additional potentials (change of the effective mass of K mesons) the data are not described: $U(K^-)=-50$ MeV, $U(K^+)=40$MeV
- K^- are attracted, while K^+ repulsed: the rise of K^-/K^+ ratio for low kinetic energies

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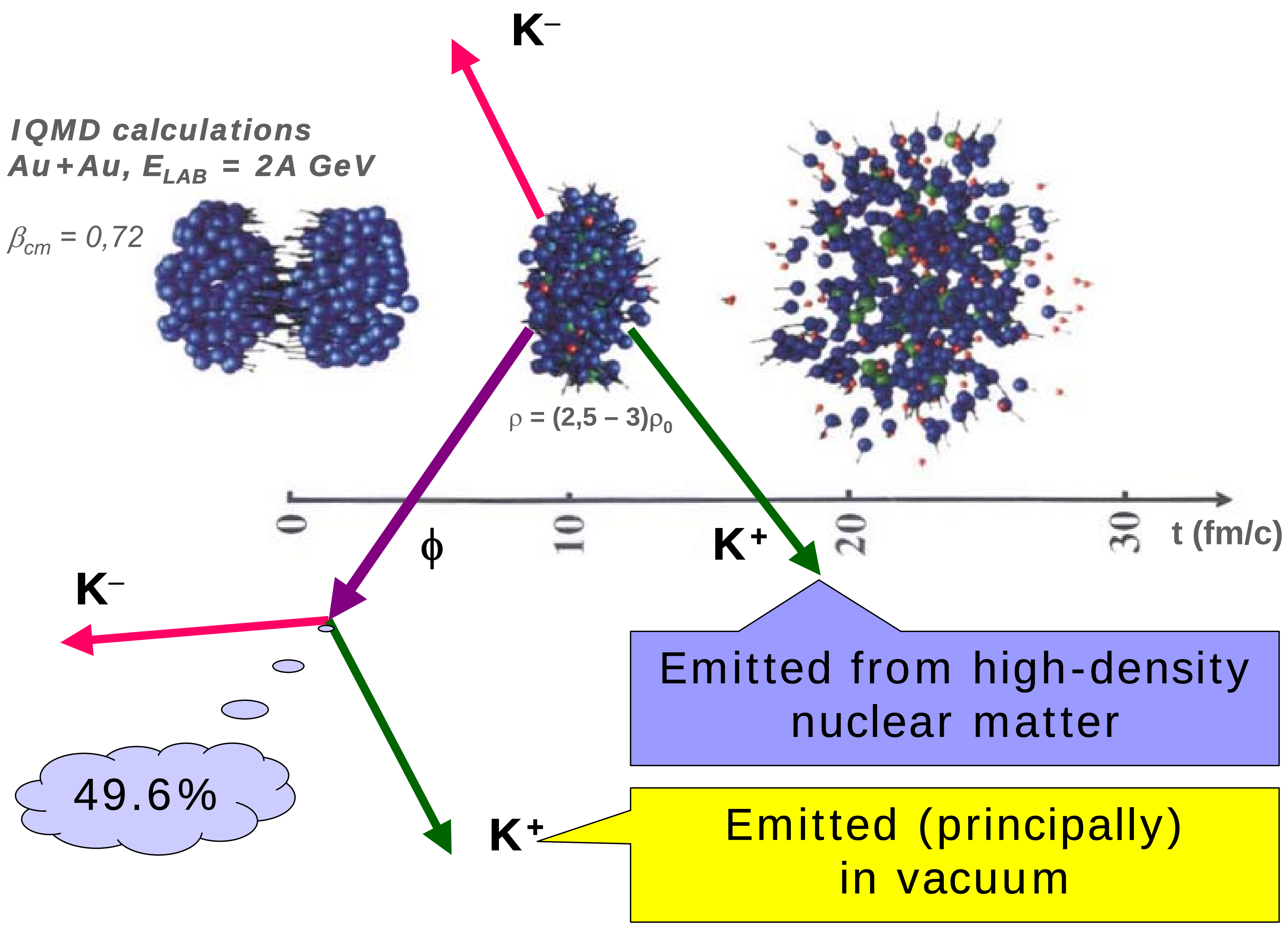
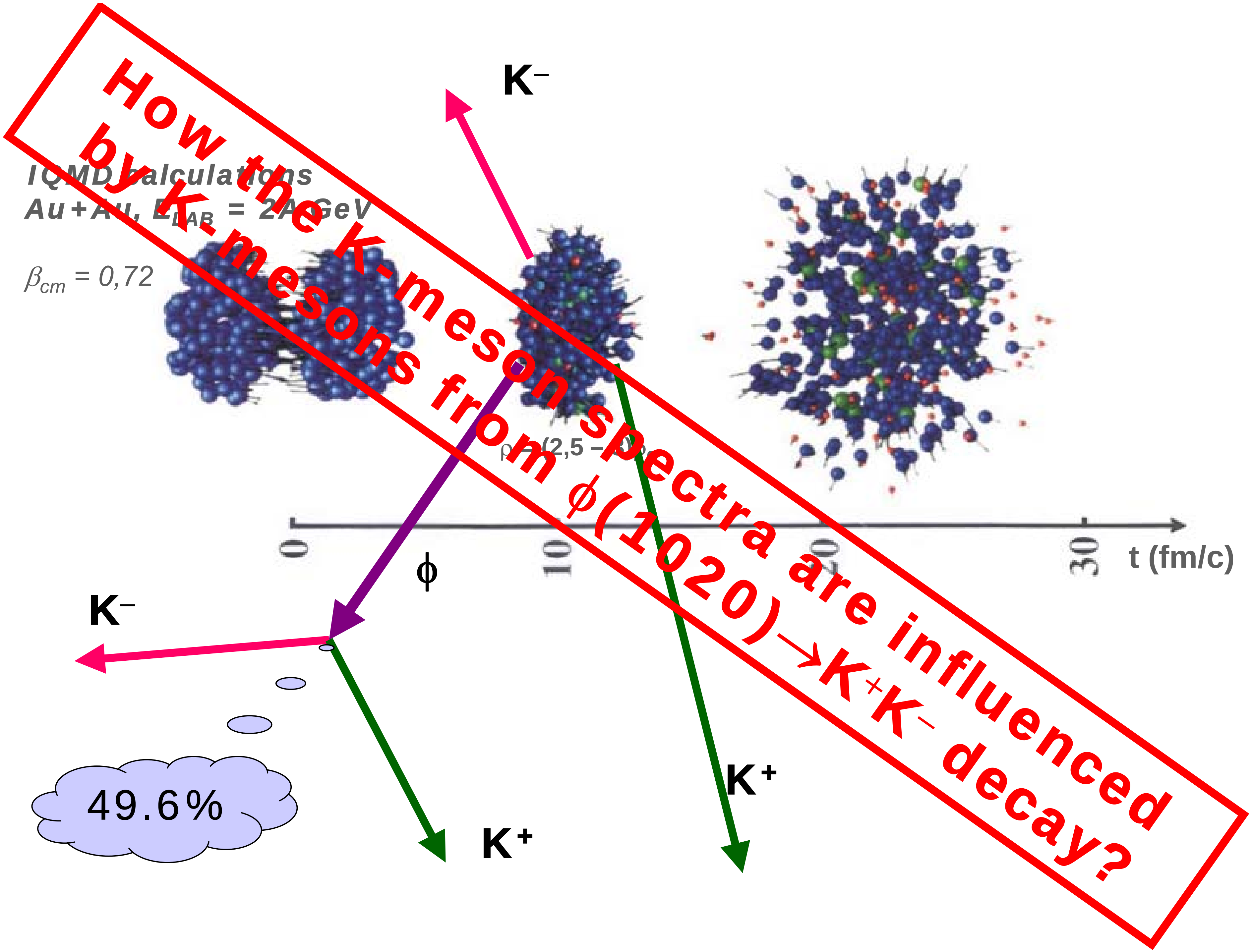
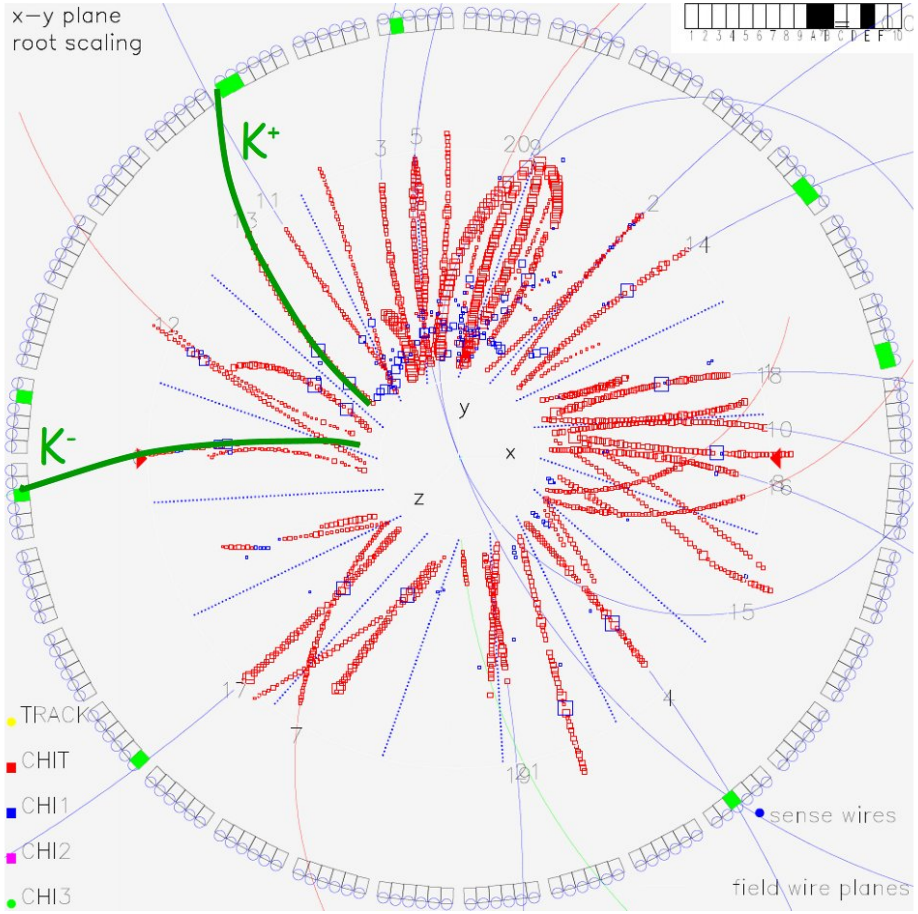


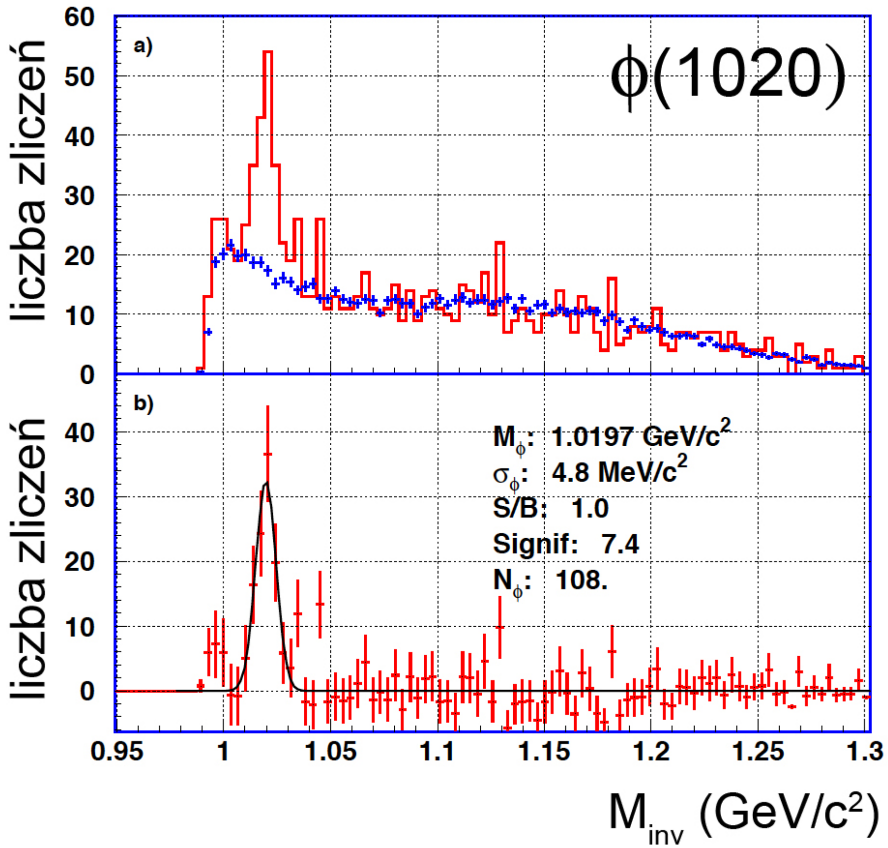
IQMD calculations
Au+Au, E_LAB = 2A GeV
β_cm = 0,72
K⁻
ρ = (2,5 – 3)ρ0
0
10
20
30
t (fm/c)
φ
K⁺
K⁻
Emitted from high-density nuclear matter
49.6%
K⁺
Emitted (principally) in vacuum



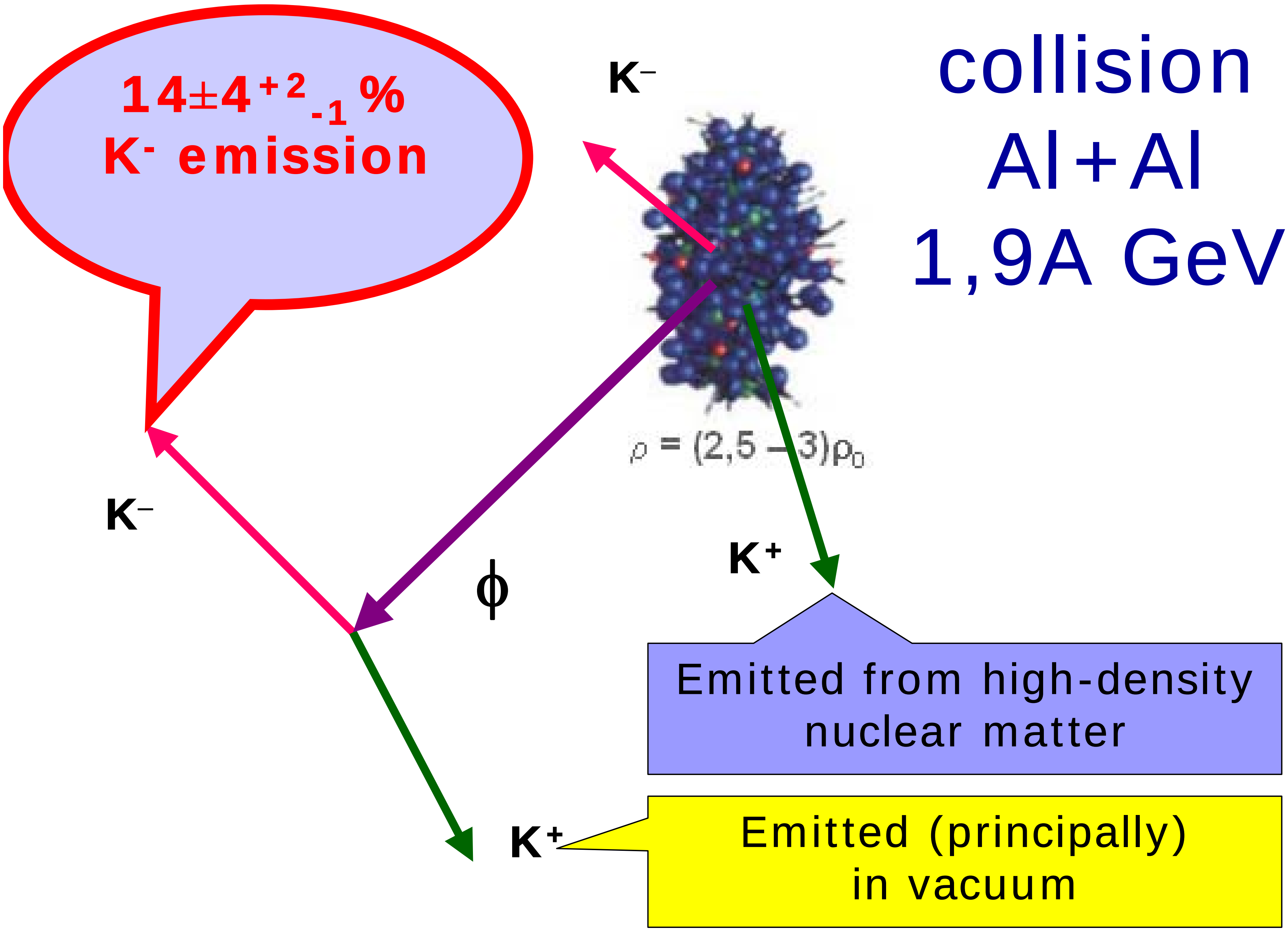
How the K-meson spectra are influenced
by K-mesons from φ(1020)→K⁺K⁻ decay?
IQMD calculations
Au+Au, E_LAB = 2A GeV
β_cm = 0,72
K⁻
K⁻
φ
K⁺
K⁺
0
10
20
30
t (fm/c)
49.6%

Identification of ϕ-meson through decay $\phi \to K^+K^-$

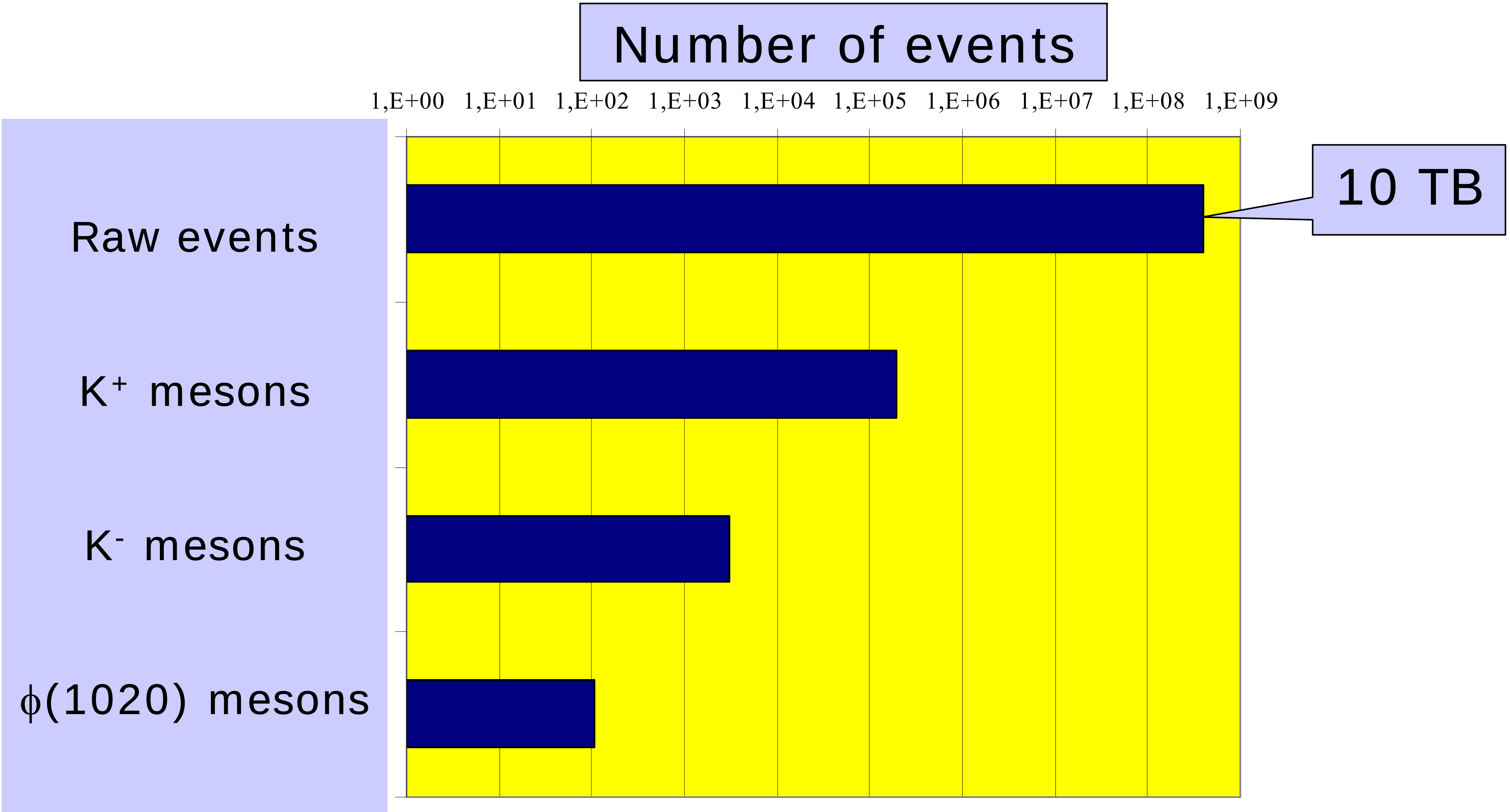




- Analysis of the invariant mass spectrum of K^+K^- pairs allowed to determine the number of ϕ: 108


14±4$^{+2}_{-1}$ %
K$^-$ emission
collision
Al+Al
1,9A GeV
K$^-$
$\rho = (2,5 - 3)\rho_0$
K$^-$
ϕ
K$^+$
Emitted from high-density nuclear matter
K$^+$
Emitted (principally) in vacuum

From raw data to the result



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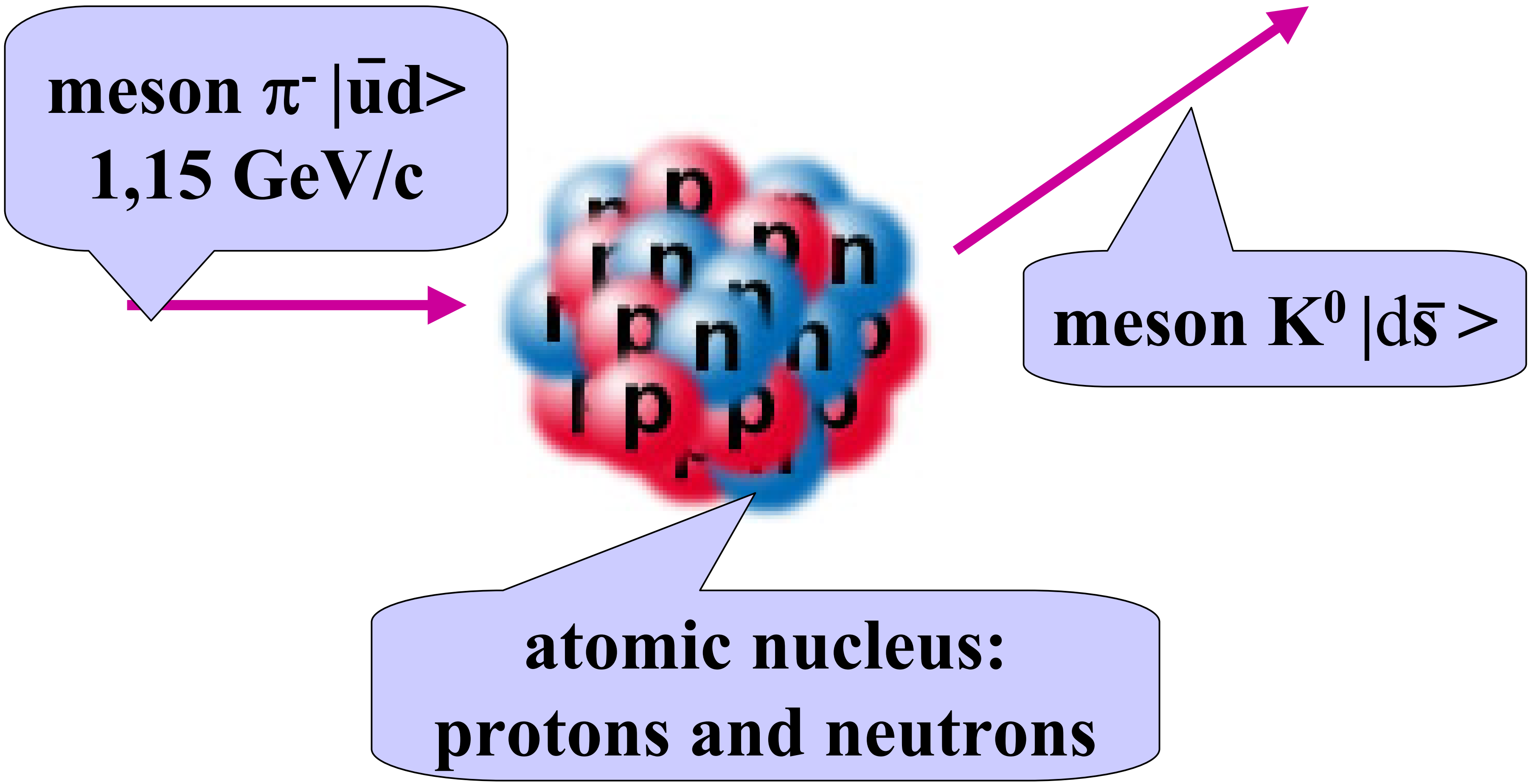
Investigation of the $\pi^- p \to \Lambda K^0$ process in nuclear matter



the nuclear matter influences the cross section

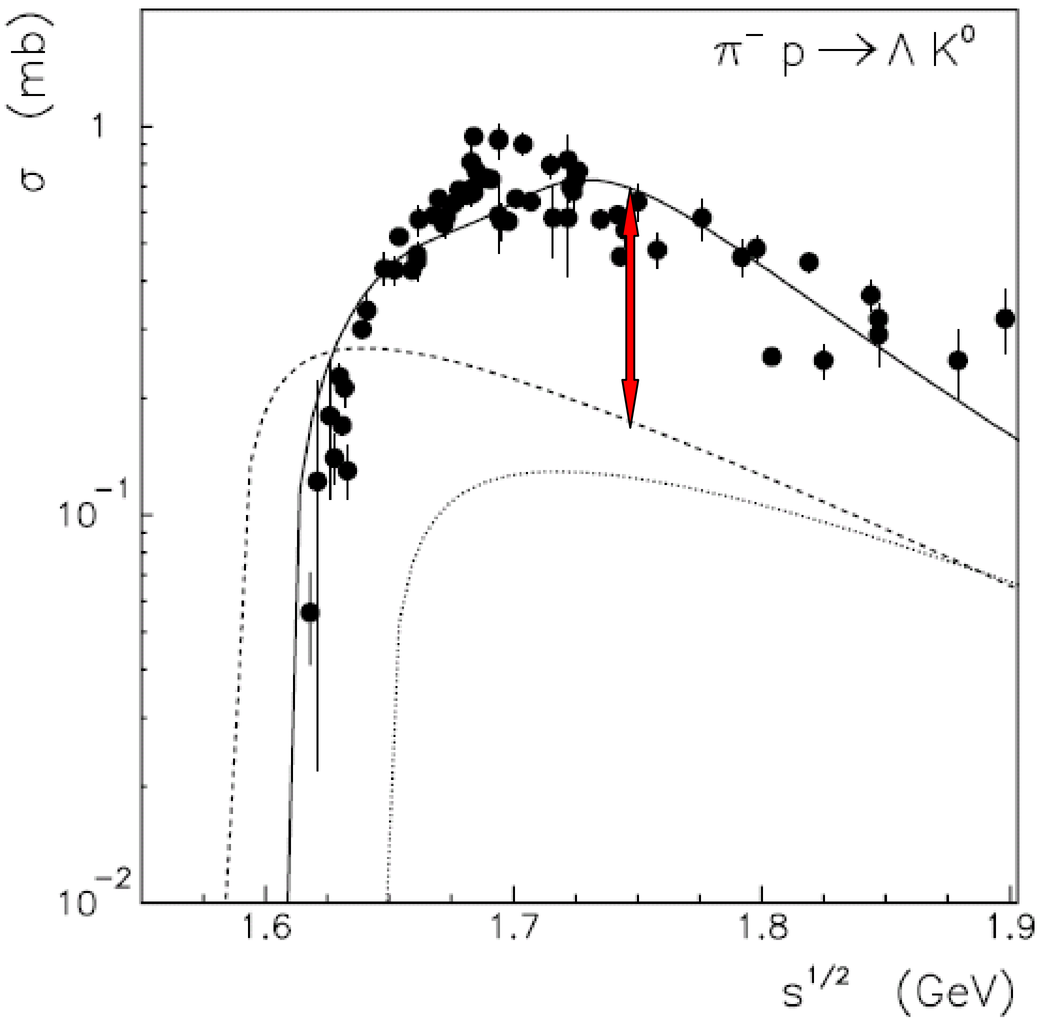


Figure 1: *Momentum dependence of the cross section of the $\pi^- p \to \Lambda K^0$ reaction; points – data, lines – calculation in free space (solid), at the normal baryon density (dashed), and at twice the normal baryon density (dotted).*

THEORY:

The cross section for the $\pi^- p \to \Lambda K^0$ reaction depends on the density of nuclear matter

the nuclear matter influences the cross section

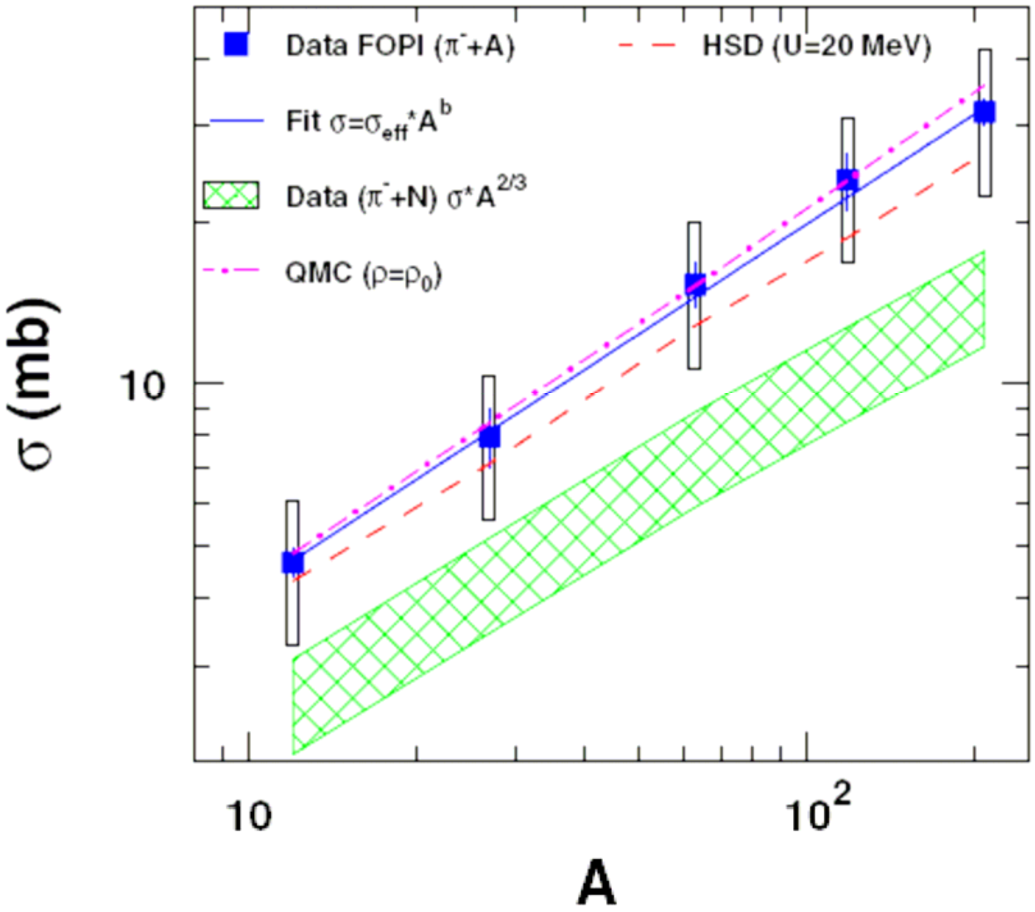
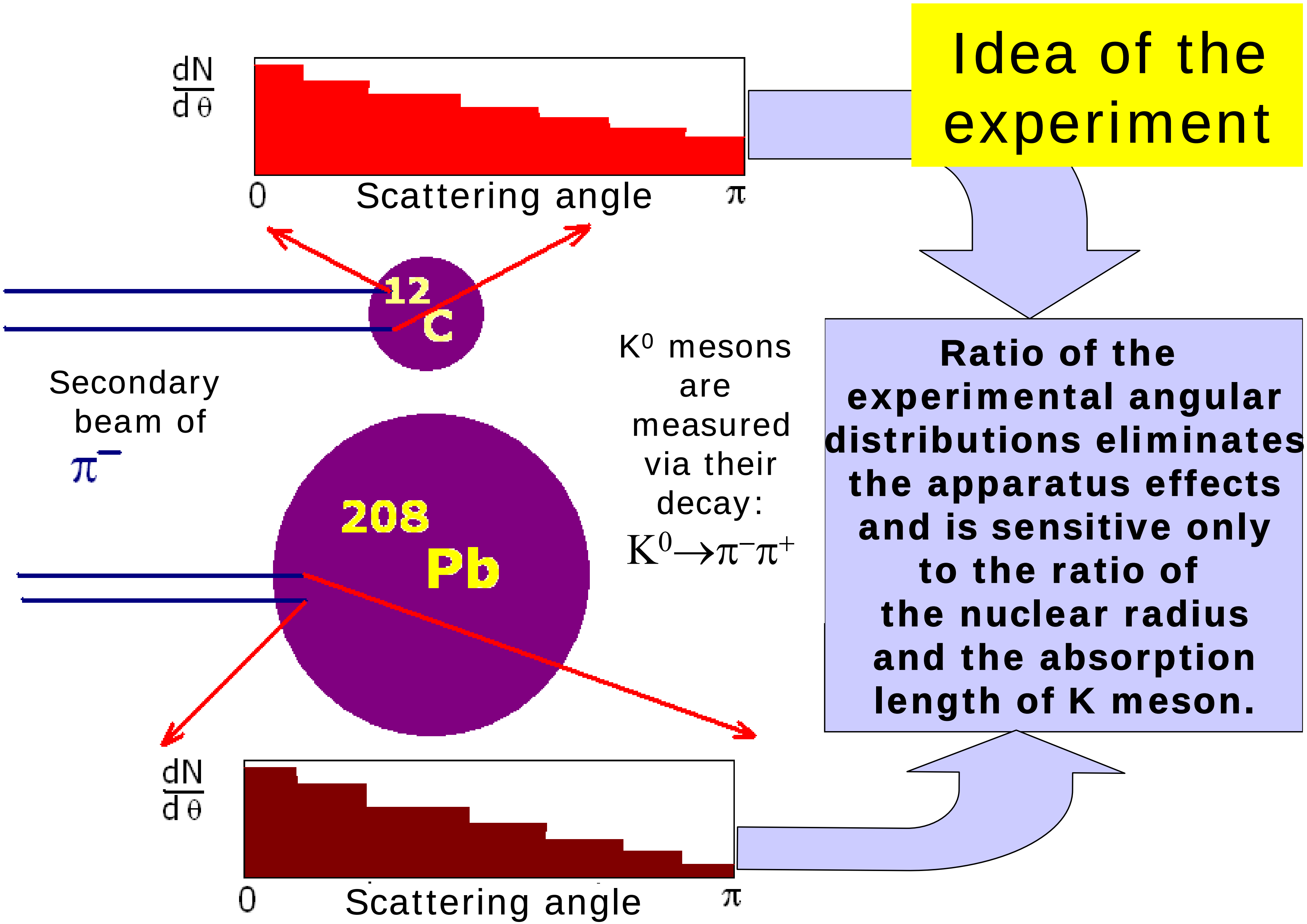


FIG. 2 (color online). The K^0 inclusive production cross section (squares) as a function of the mass number of the target nucleus. The solid line represents the fit with a power law function. The hatched area corresponds to the sum of the cross sections of the elementary processes scaled according to the transverse size of the target nuclei. QMC model predictions at $\rho = \rho_0$ [6] (dashed-dotted line) are scaled with the same prescription, whereas HSD transport-model calculations (dashed line) yield absolute predictions.

The result of the measurement confirms the strong modification of cross section

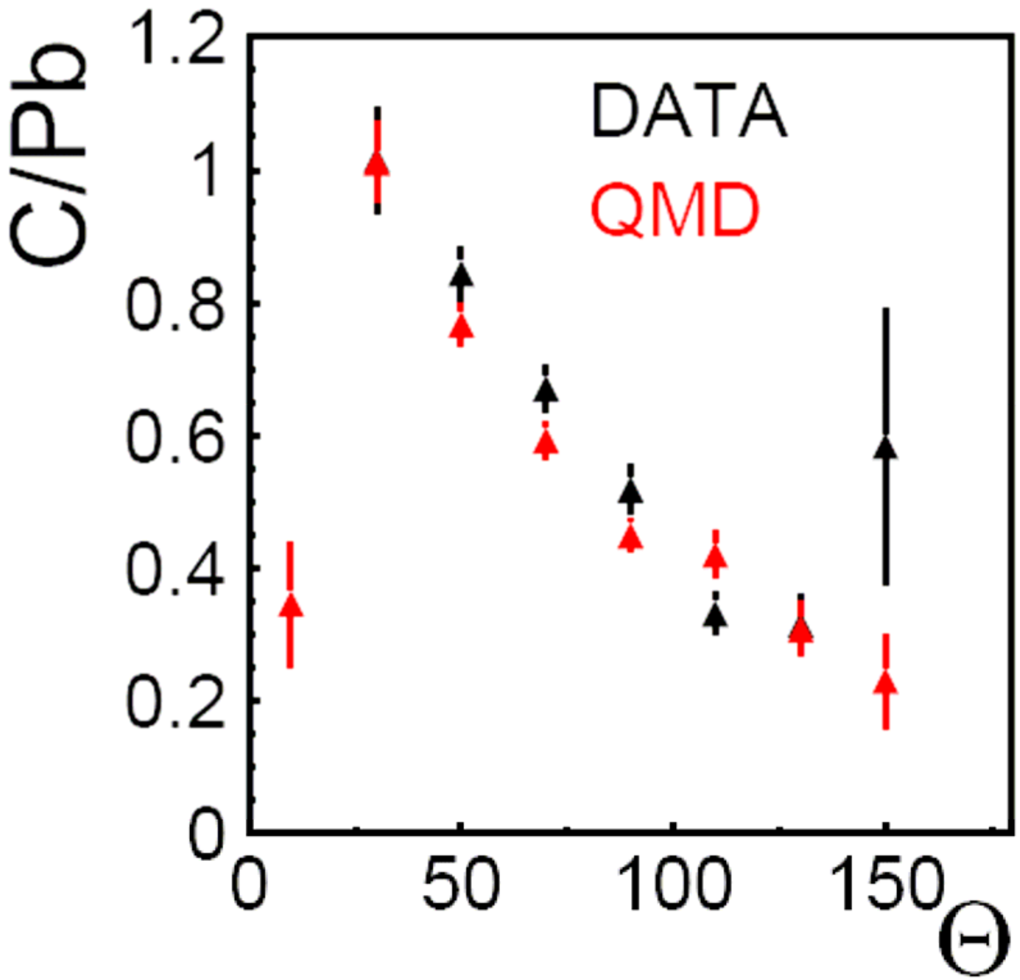
PRL **102**, 182501 (2009)

PHYSICAL REVIEW LETTERS



Idea of the experiment
dN/dθ
0
Scattering angle
π
12 C
Secondary beam of π^-
208 Pb
K⁰ mesons are measured via their decay:
$K^0 \to \pi^-\pi^+$
Ratio of the experimental angular distributions eliminates the apparatus effects and is sensitive only to the ratio of the nuclear radius and the absorption length of K meson.
dN/dθ
0
Scattering angle
π

Ratio of angular distributions



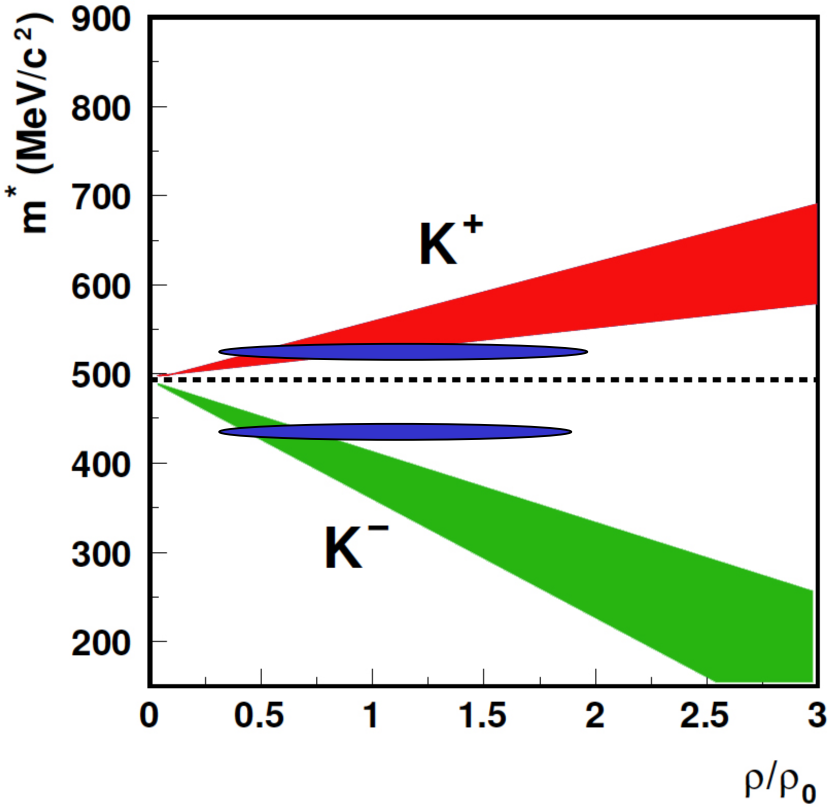
Ratio of angular distributions for C and Pb targets, normalized at $\theta=30°$.

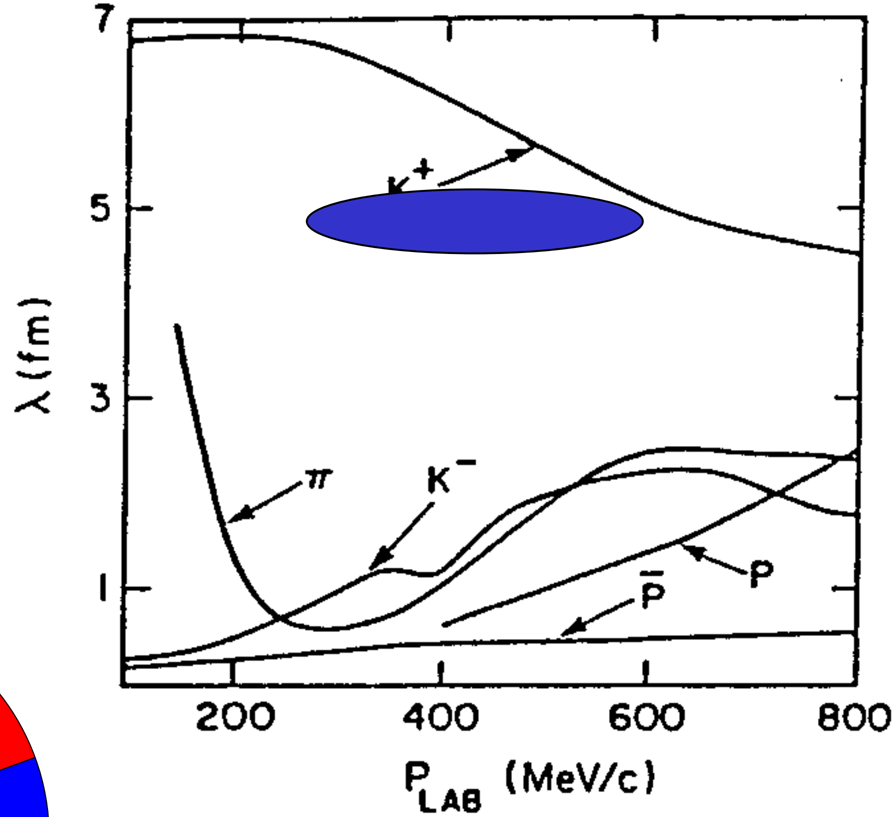
Intense emission of K^0 mesons at low angles for light target (C) compared to heavy target (Pb): reabsorption of mesons in nuclear matter.

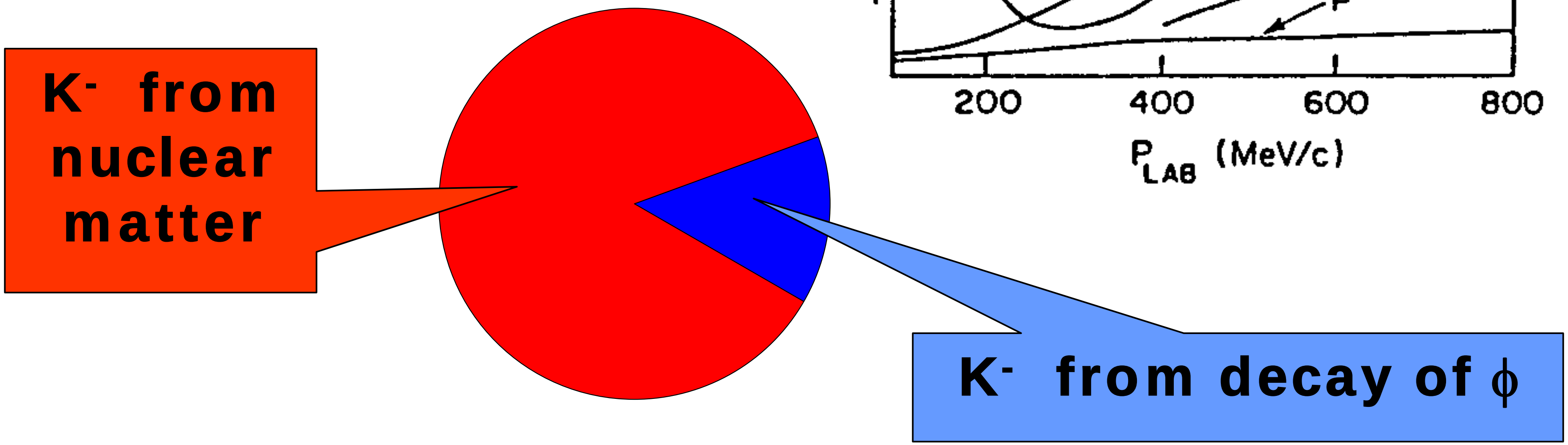
λ_K = 4…5 fm

Red points: results of the quantum dynamical model IQMD filtered with the detector acceptance

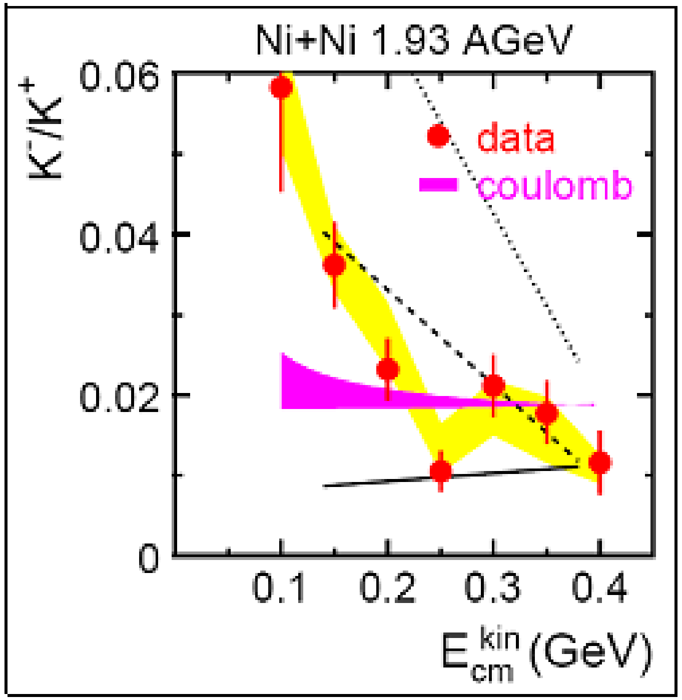
conclusions





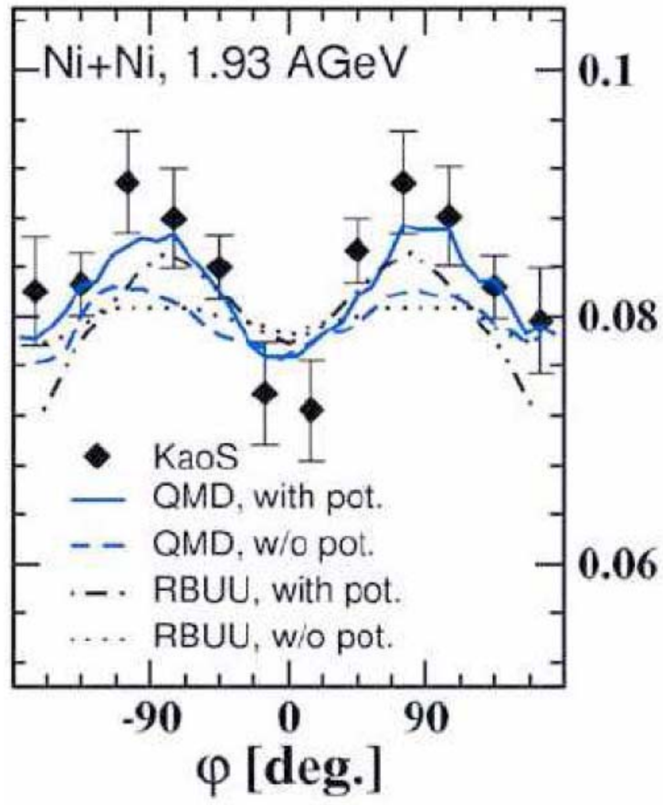


experimental facts ...



	U(K+)	U(K-) (MeV)
·······	30	-120
----	30	-70
——	0	0

K. Wiśniewski et al., Eur. Phys. J. ***A 9*** *(2000) 515*



C. Fuchs, Prog. Part. Nucl. Phys. ***56*** *(2006) 1*

Ratio of K^-/K^+ emission