Suggested Investigations to Understand Unresolved Experimental Observables

W. Westmeier[1,3], R. Brandt[1], S. Tyutyunnikov[2]

[1]Kernchemie, FB Chemie, Philipps Universität, D-35037 Marburg, Germany
[2]JINR, 141980 Dubna near Moscow, Russian Federation
[3]Gesellschaft für Kernspektrometrie, D-35085 Ebsdorfergrund, Germany

Experiments that are normally avoided:

Extremely high projectile energies (GeV) on very thick targets

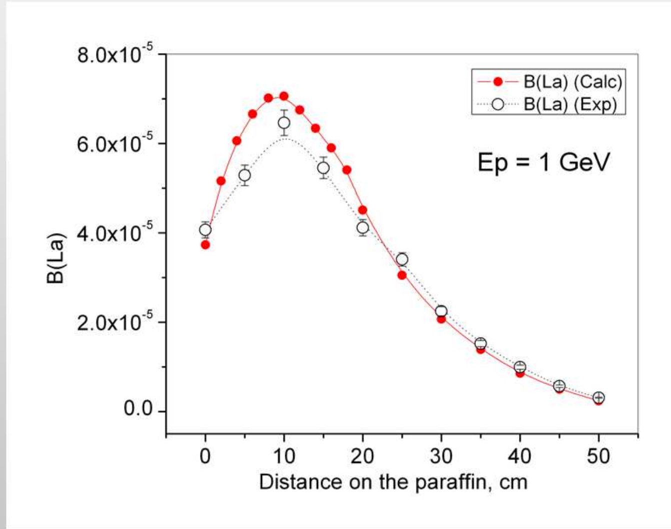
where secondary particles also interact

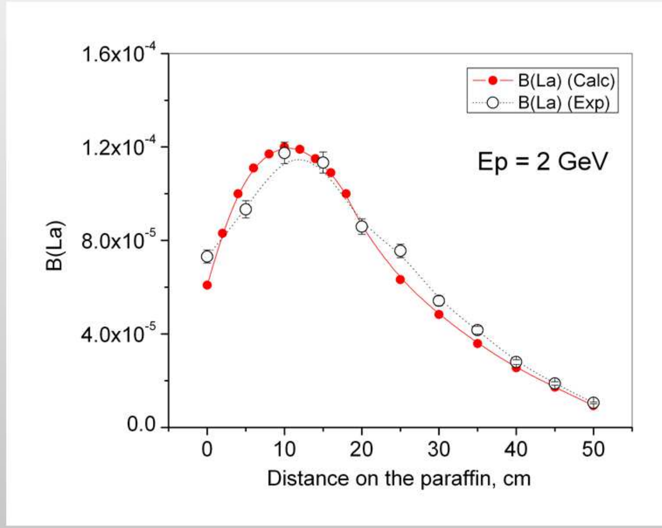
➡ **yield integral data from a range of projectiles having a range of energies**

Basically simple:

- range of projectile energies → integrate or do MC
- range of projectiles → integrate or do MC

Experiment: Protons on 50 cm Pb-target,
(n,γ)-reactions on top of 6 cm thick paraffin moderator





Calculation with MCNPX: Beam scattering – fast cascade – evaporation - neutron transport – n-secondary reactions – (n,γ)-reaction with a neutron spectrum

<Agreement>: @ 1 GeV ± 7%, @ 2 GeV ± 2%

Make many MC comparisons : there is agreement between MC and experiment

- Secondary hadron spectra o.k. (intensities and energies)
- Angular distributions o.k.
- Product yields o.k.

provided that target and environment are well-defined

- detailed geometry and surroundings up to several meters
- materials (incl. air)
- beamshape and beam impact

BUT !! There are experiments where model calculation cannot match experimental results

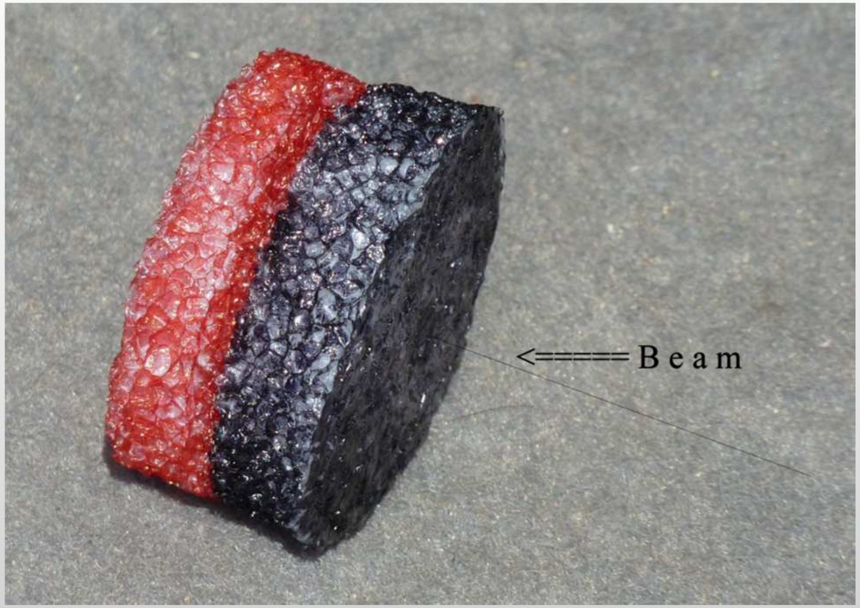
Reproduced by various scientists at various accelerators

This is not „polywater“ or
„cold fusion“ or
„superluminal particle“ or …

The experimental findings are real

Which findings ?

What happens in thick targets (theory)?



- Second target is exposed to less full-energy beam = less products
- Additional secondaries with lower energy hit second target = more products just below the target mass

- **R_0=N(2)/N(1) is ≤1 far away from the target mass**
  is ≥1 near to the target mass
- **As most secondaries have low energies the maximum of R_0 is just below target mass**

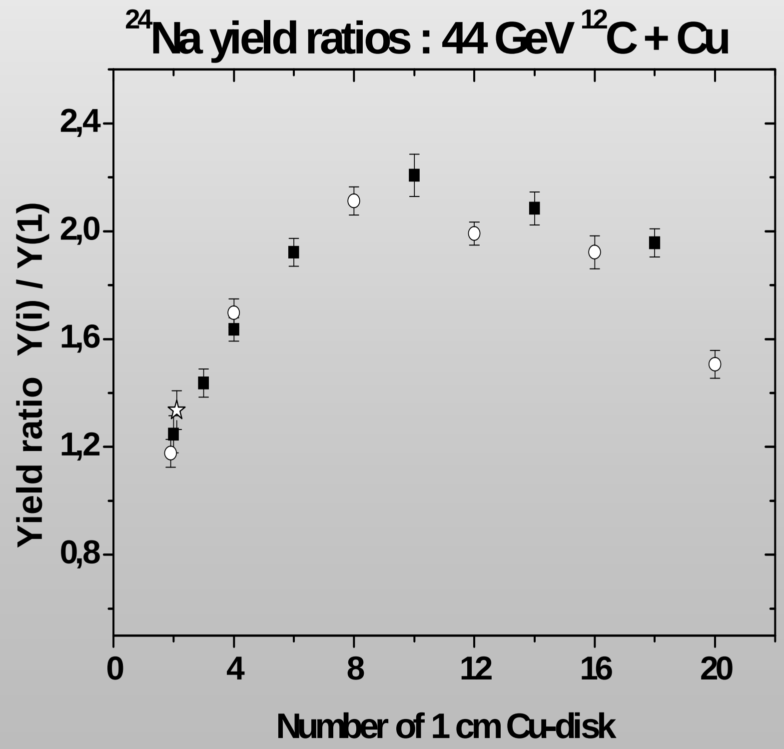
Finding: Excessive product yield at large ΔA

20 cm of Cu target (A=63,65)
Measure production of ^{24}Na
in various slices (ΔA ≈ 40)

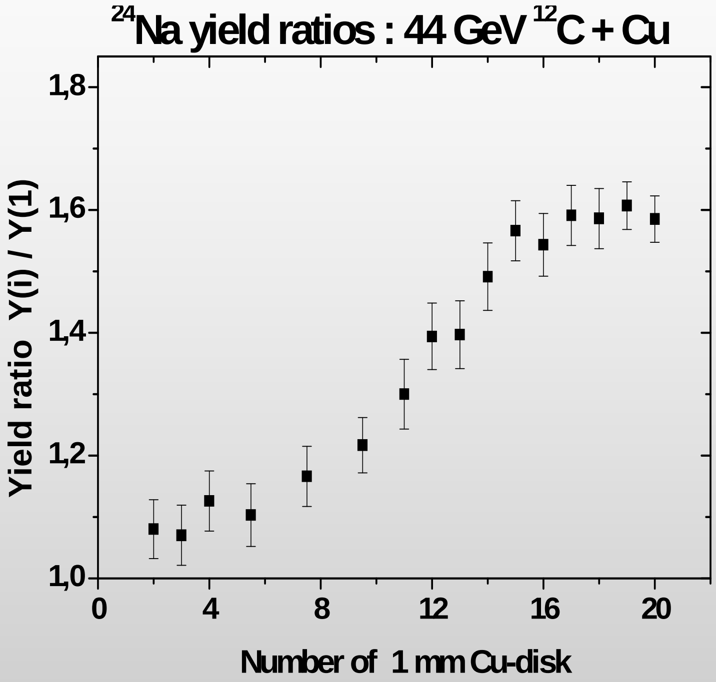
ΔA ≈ 40 needs plenty energy

Deeper down in target:
- less E of primary beam
- less I of primary beam
- expect less ^{24}Na production

There is excessive energy deposition deep down in target from (projectile and) secondaries



Finding: Excessive product yield at large ΔA

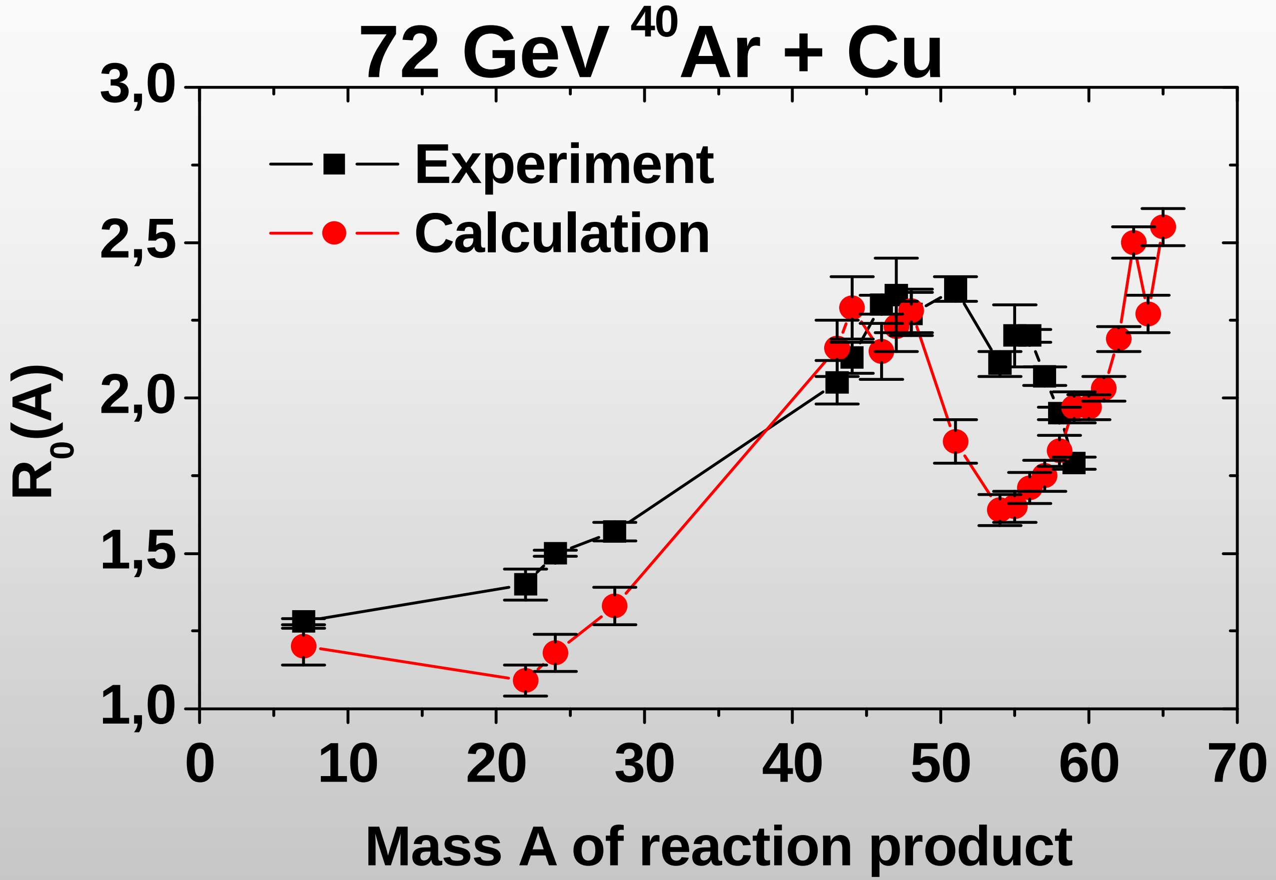


There is an onset of excessive yield

There is a saturation of excessive yield after approx. 10 cm (<300 ps)

Does something happen on the first 10 cm only?

Finding: Excessive product yield at medium ΔA



Experiment on two Cu-disks

Calculation with MCNPX cannot fit the experiment

Cross-sections are „pushed“ to smaller masses and forward into the second target!

Finding: Excessive neutron production

Found in : 72 GeV ^{40}Ar+Cu 44 GeV ^{12}C+Cu
44 GeV ^{12}C+Pb 44 GeV ^{12}C+U

How much is neutron density enhanced?

a) Experimental B-value of ^{140}La is a measure of neutron density

b) Calculate the number of neutrons N per projectile atom

Thus, V = B/N characterizes the neutron density in units of the expected (calculated) density

In „normal" reactions: V = 0.319±0.017 [10^{-5} g^{-1} $neutron^{-1}$]

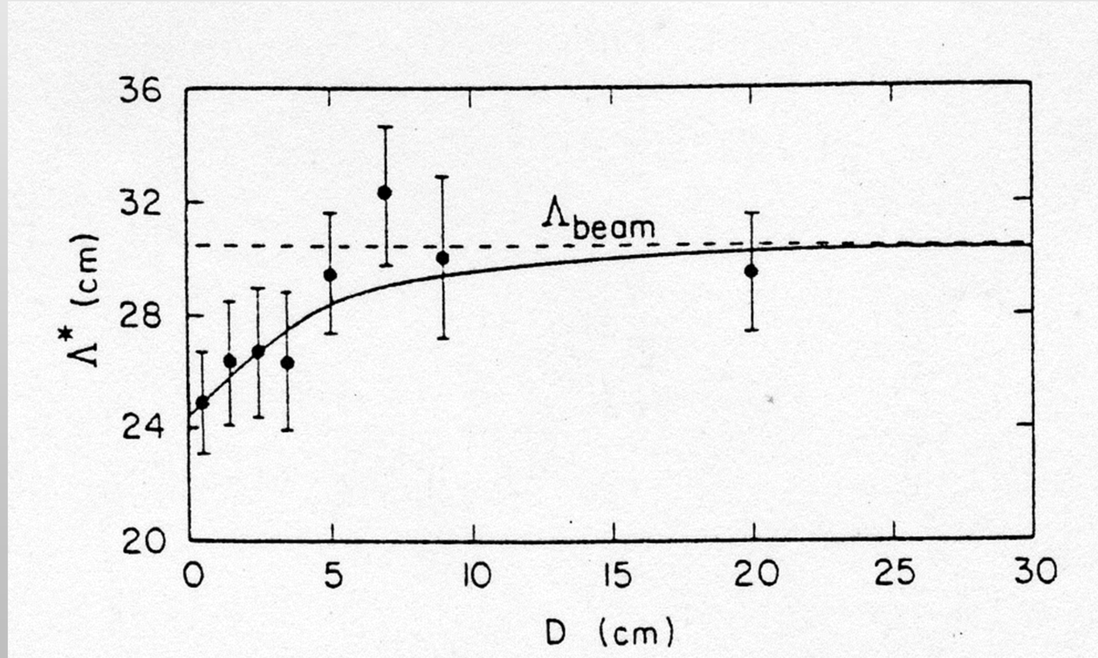
In "unresolved" reactions: V = 0.963±0.043 [10^{-5} g^{-1} $neutron^{-1}$]
(all 44 GeV ^{12}C)

Factor 3.0 ± 0.2

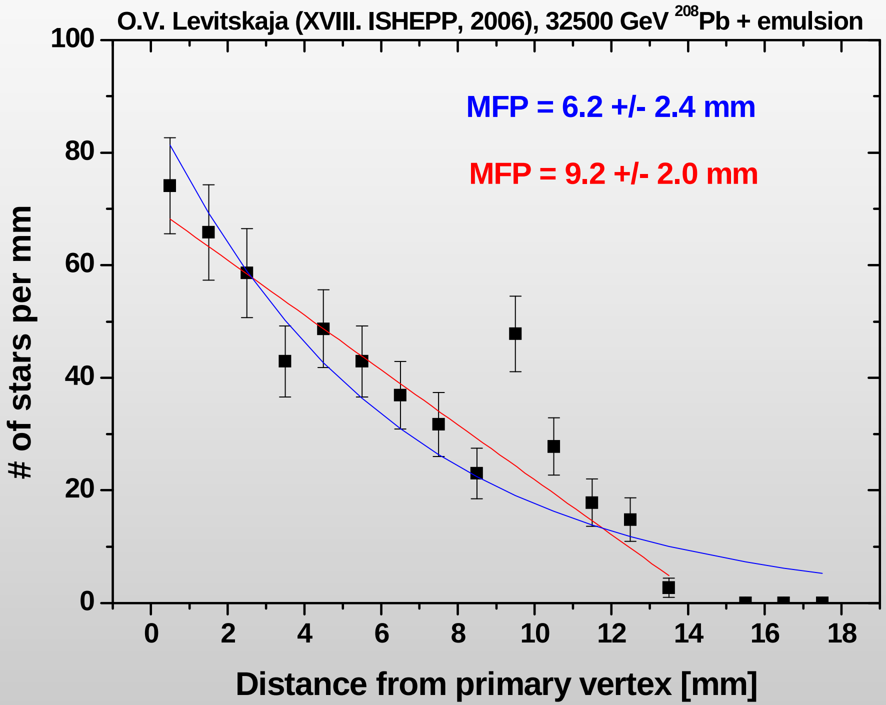
Finding: Reduced mean free path

First systematic hints about something strange came from emulsion work: the mean free path of charged secondary hadrons is shorter than expected

Friedlander et al. (1983) :
2 AGeV ^{16}O and ^{56}Fe Bevalac beams



Finding: Reduced mean free path



Interaction of secondaries (minimum ionising particles) from 158 AGeV ^{208}Pb on emulsion gives m.f.p of 6 to 9 mm

➔ Expect ≈ 300 mm

Classification

One can classify – not explain – unresolved experimental observations with the parameter

$$E_{CM}/u = E_{CM} / (A_P+A_T)$$

All reactions where E_{CM}/u is <107 MeV → no problem
All reactions where E_{CM}/u is >168 MeV → unresolved

With no exception !

This is a scaling parameter, it has no physical meaning yet.

To summarize:

- At high E_{CM}/u experimental results cannot be reproduced by model calculations – no exception
- At low E_{CM}/u experimental results are correctly reproduced by model calculations – no exception
- The effects are real and reproducible

Transition energy where consistent results switch to inconsistent is not well defined

Need experimental verification !

Proposed experiment 1: scan onset of „unresolved“

Irradiate a stack of 20 Cu disks with ^{12}C ions of
0.8 GeV/u ≤ E ≤ 1.6 GeV/u (105 MeV ≤ E_{CM}/u ≤ 210 MeV)
Seven energies with $5*10^{12}$ particles on target each

Measure during irradiation: neutron production by activation (passive) and with ^{3}He detector (active)

Measure after irradiation: γ-ray spectrometry of several disks for product cross sections

Proposed experiment 2: Quantify neutrons

Repeat LBL Bevalac experiment from 1987

Irradiate a stack of 20 Cu disks with ^{40}Ar ions of 1.8 GeV/u

Measure during irradiation: neutron production by activation (passive) and with ^{3}He detector (active)

Measure after irradiation: γ-ray spectrometry of several disks for product cross section

Reason:
Neutron production was high but value is unknown !

Monitors registered excessive neutron density in a shielded location at a distance of about 240 m

Proposed experiment 3: details of time structure?

Irradiate 20 Cu disks of 2 mm thickness with 1.8 GeV/u ^{12}C, $5*10^{12}$ particles on target

Measure after irradiation: γ-ray spectrometry of all disks for product cross sections

Conclusions

- Unresolved experimental observations are real
- Only found in thick targets at very high energies
- Parameter E_{CM}/u is good for classification
- Limit value of E_{CM}/u separating resolved (=consistent with model calculations) from unresolved results is not well defined
- Experiments to find E_{CM}/u limit are proposed

- Investigations can be made at Nuclotron in Dubna?

Thank you

R. Brandt et al., „Interactions of Relativistic Heavy ions in Thick Heavy Element Targets and some Unresolved Problems", Physics of Particles and Nuclei, 2008, Vol. 39/2, pp. 259-285

W. Westmeier et al., „ Correlations in nuclear interactions between E_{CM}/u and unexplained experimental observables", Proceedings of ISHEPP XX, Dubna, October 4-9, 2010, Vol. 2, pp. 74-84

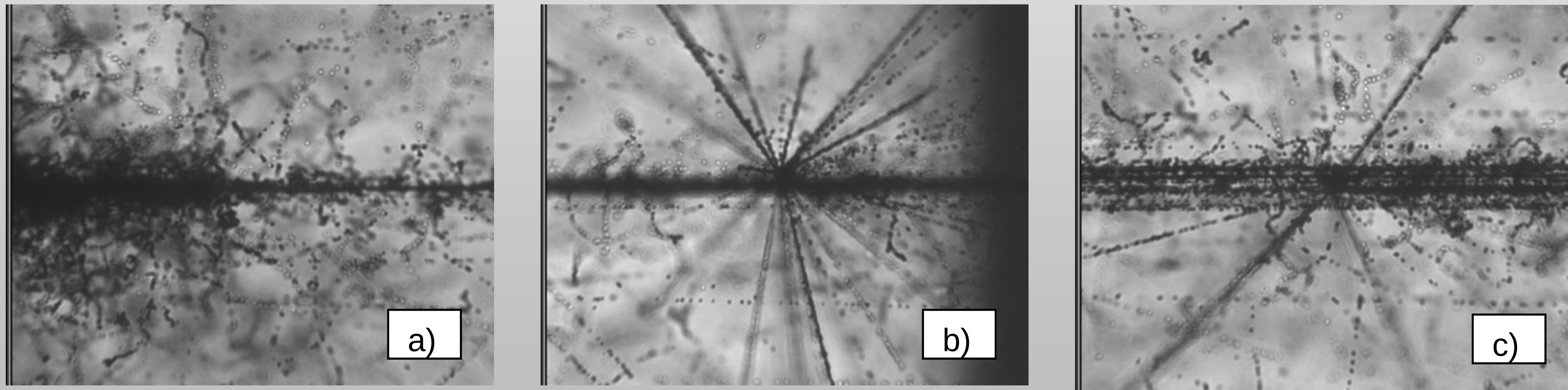
S.R. Hashemi-Nezhad et al., „Neutron Production in Thick Targets Irradiated with High-Energy Ions", Physics Research International, Vol. 2011, Article ID 128429, doi: 10.1155/2011/128429

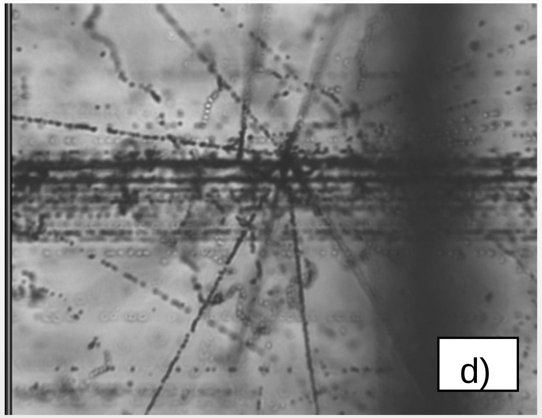
W. Westmeier et al., „Correlations in nuclear interactions between E_{CM}/u and unexplained experimental observables",
World Journal of Nuclear Science and Technology, 2012, in print

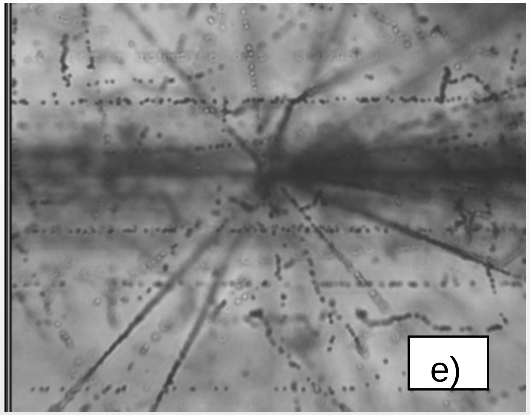
Experiments at very very high energies

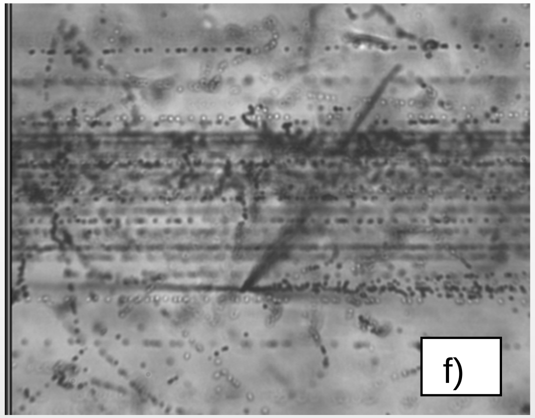
Brandt et al. (1992): R(^{24}Na) at 7000 GeV ^{32}S + Cu is 1.8 ± 0.1

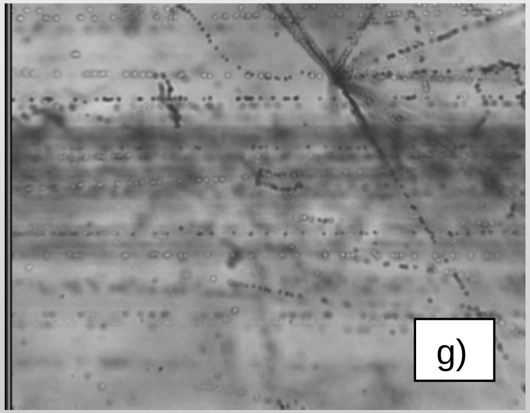
Levitskaja: very short mean free path at 32500 GeV ^{208}Pb in emulsion (H, C, N, O, Br, Ag)





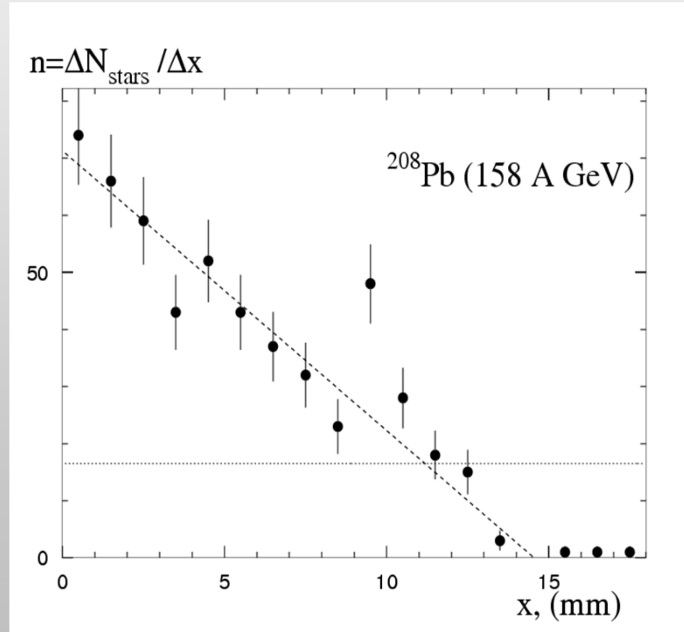






7 „stars“ in 19 mm

Analysis of 350 Pb-tracks yields this density distribution of „stars“



Mean free path = 0.62±0.24 cm

(Expected: ~ 30 cm)

(Alexander et al. (1957): MFP(π^+) 11 ± 2.4 cm; expected 31 ± 2 cm)