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A Short Introduction to spallation reactions. Nuclear transport

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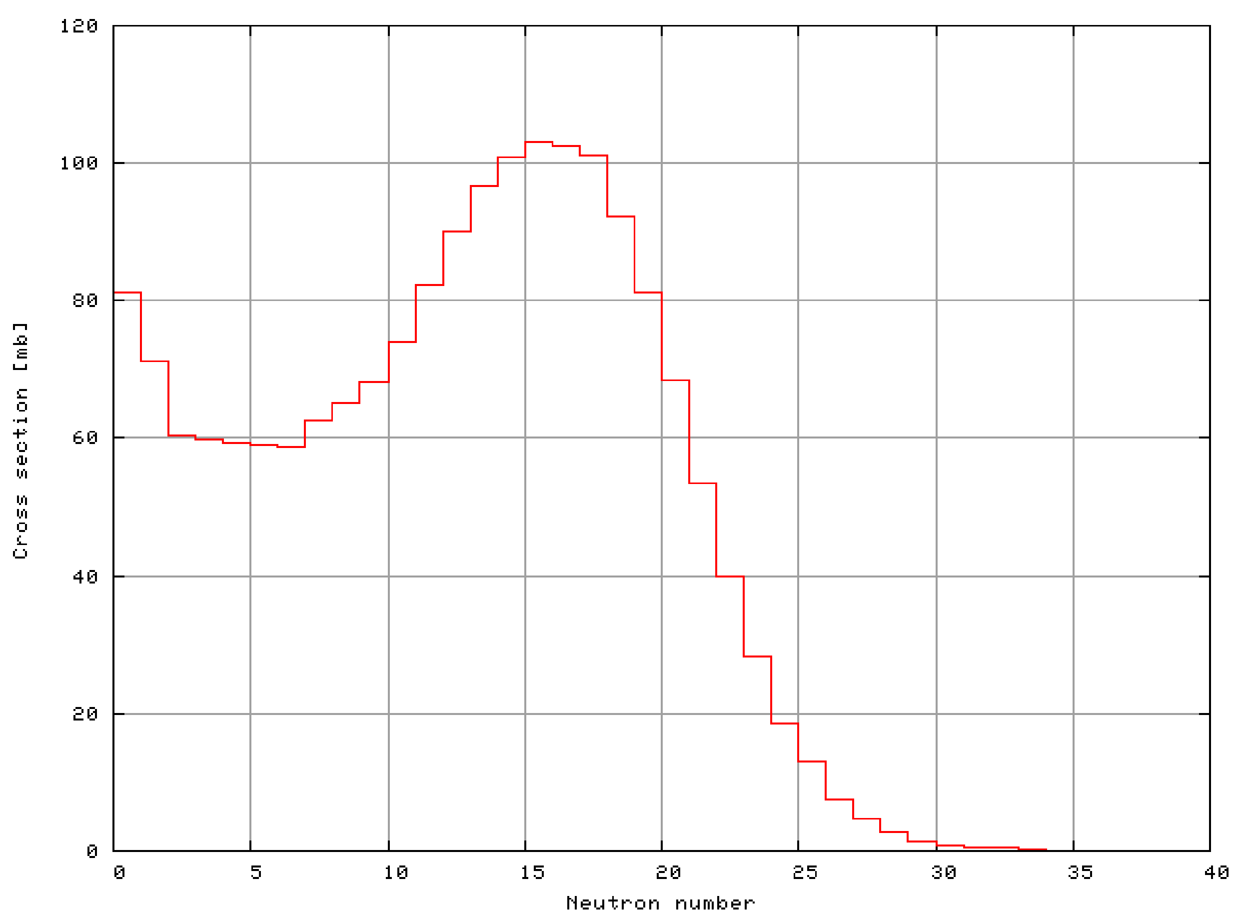
- *Spallation reactions*
- *Nuclear reactions as transport processes*
- *The collision regime. INC= a simple tool*
- *The validity of INC. Unification at intermediate energy*

SPALLATION REACTIONS

Many particles are expelled



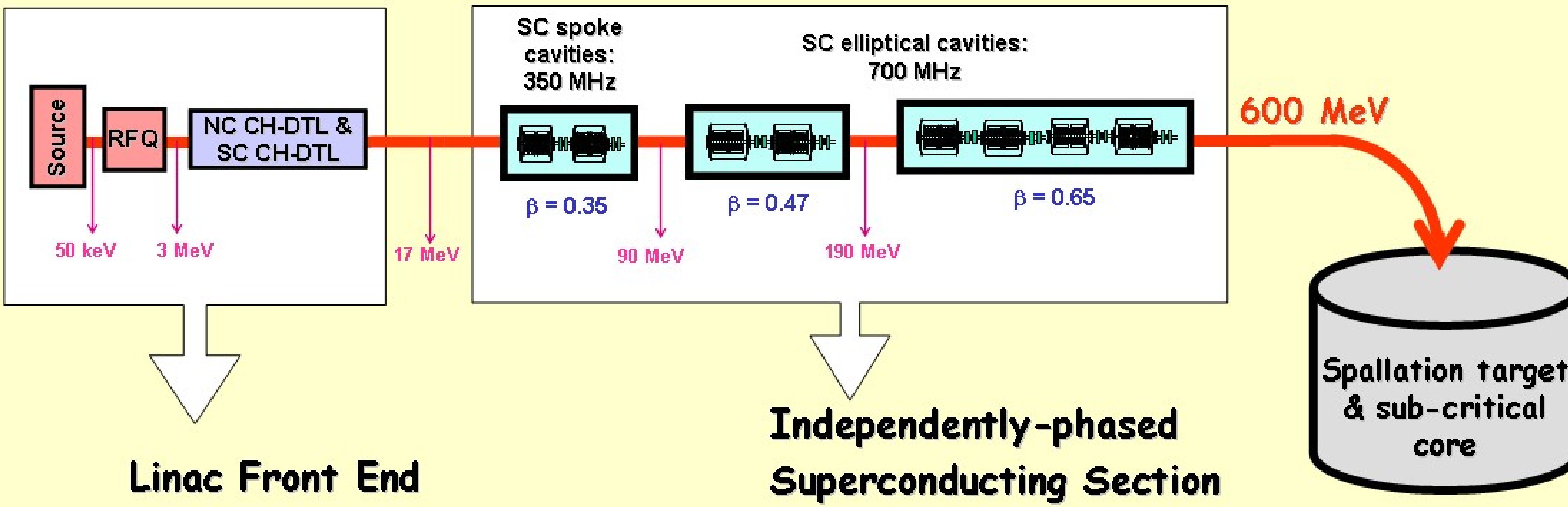
p (1.2 GeV) + Pb

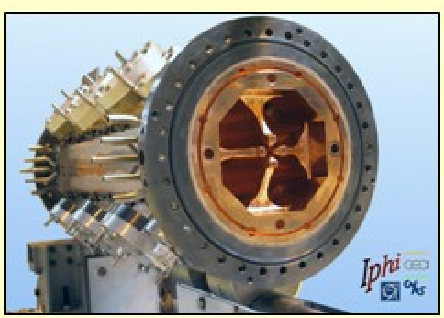
+ p, π, d, t,...

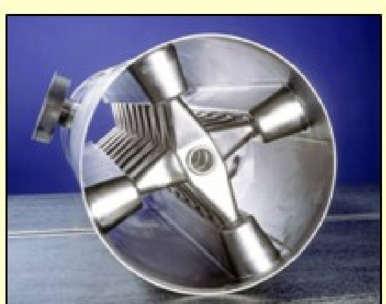
Spallation reaction=high-energy hadron-induced reactions

Macroscopic « spallation reactions » :

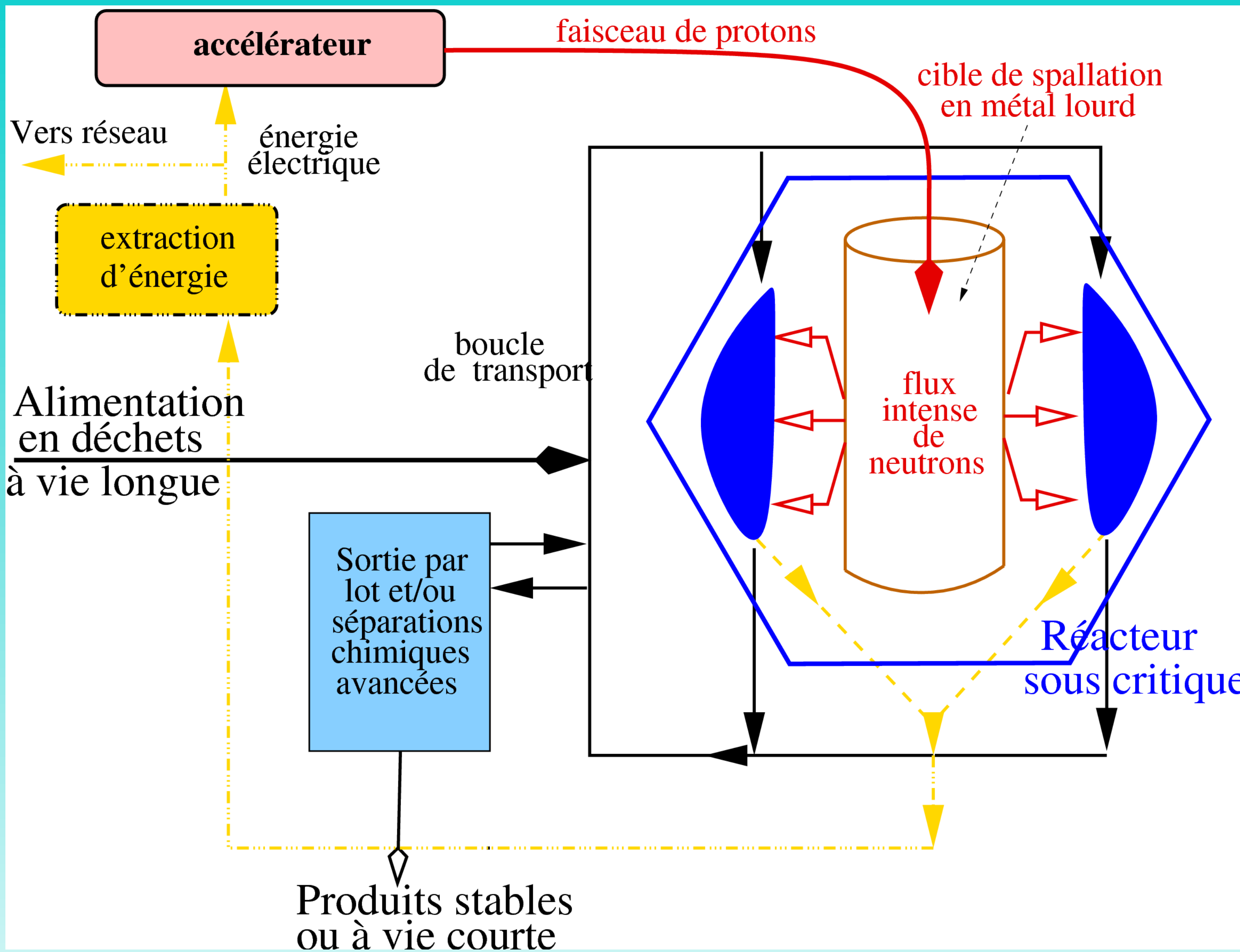
The MYRRHA accelerator reference scheme (2010)







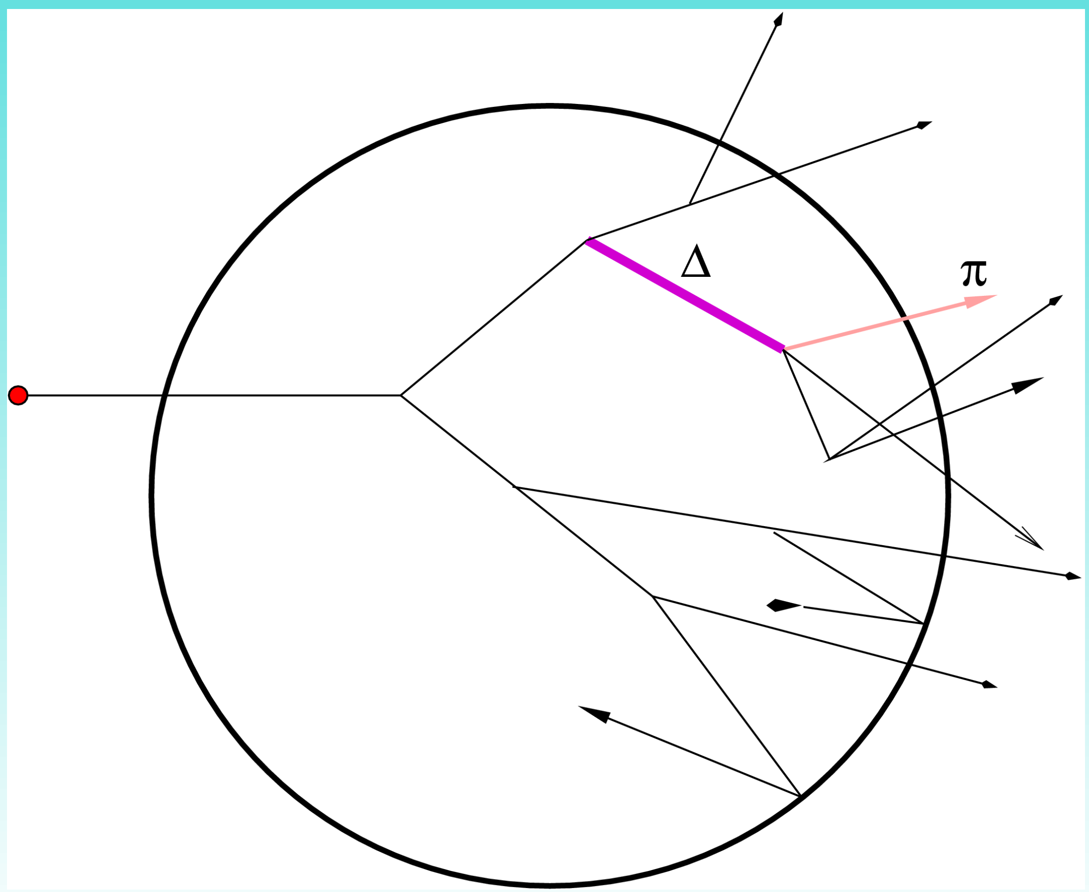
MYRRHA project is operated by SCK-CEN Mol



accélérateur
faisceau de protons
cible de spallation
en métal lourd
Vers réseau
énergie
électrique
extraction
d'énergie
boucle
de transport
Alimentation
en déchets
à vie longue
flux
intense
de
neutrons
Sortie par
lot et/ou
séparations
chimiques
avancées
Réacteur
sous critique
Produits stables
ou à vie courte

2. NUCLEAR REACTIONS AS TRANSPORT PROCESSES

At high energy, nuclear reactions are expected to proceed by binary collisions (R.Serber, 1947)



Reaction= diffusion of particles in the nuclear medium (under collisions, creation, destruction, modification ,...)

Heavy ion collisions= diffusion of projectile part. in the target + diffusion of target part. in the projectile

Diffusion processes:

- deterministic equations for average quantities
- simulations

The production of high-energy protons in central relativistic nuclear collisions*1

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Abstract

We extend our model of transport theory to be applicable to the inclusive production of protons with very high energy. We then consider the angular distribution of such protons, produced in a central collision of Ar on KC1 at 800 MeV per nucleon. The slight anisotropy observed in the data can be explained by a finite value of the friction constant which in turn determines the number of collisions needed for equilibrium to be reached. We also show that these data are quite sensitive to the reaction geometry and cannot be explained by the firestreak model.

Article Outline

*1 Supported in part by the Bundesministerium für Forschung und Technologie.** Present address.

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3. THE COLLISION REGIME. INTRANUCLEAR CASCADE (INC) AS A TOOL

The nuclear transport equation :

Schrödinger many-body equation

$$\left(\frac{\partial}{\partial t}+\frac{\vec{p}}{m}.\vec{\nabla}-\frac{1}{m}\vec{\nabla}U.\vec{\nabla}_{\vec{p}}\right)f(\vec{r},\vec{p},t)=$$

$$\int\frac{d^3p_2}{(2\pi)^3}\int\frac{d^3p_3}{(2\pi)^3}\int\frac{d^3p_4}{(2\pi)^3}|W(12\rightarrow 34)|^2\{f_3f_4(1-f_1)(1-f_2)-f_1f_2(1-f_3)(1-f_4)\}\delta(\vec{p})\delta(e(p))$$

$$f_i=f(\vec{r}_i,\vec{p}_i,t),f_1=f$$

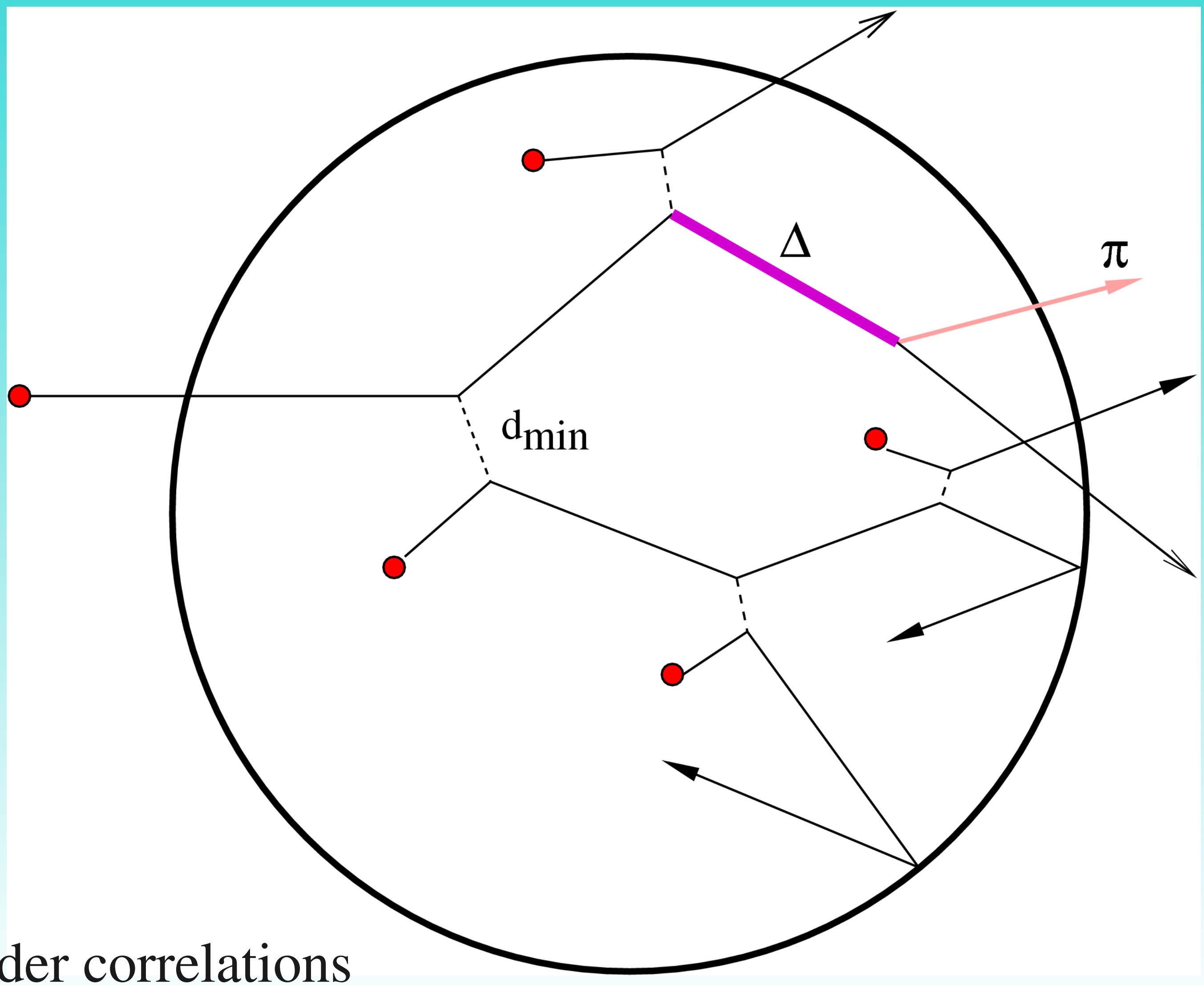
Approximations :

- closure (2 body correlations are unimportant)
- low-gradient expansion
- independence of collisions

$$\lambda_B \ll t_{coll} v \ll d$$

For U fixed, and $W^2 = v_{12}\,\sigma$

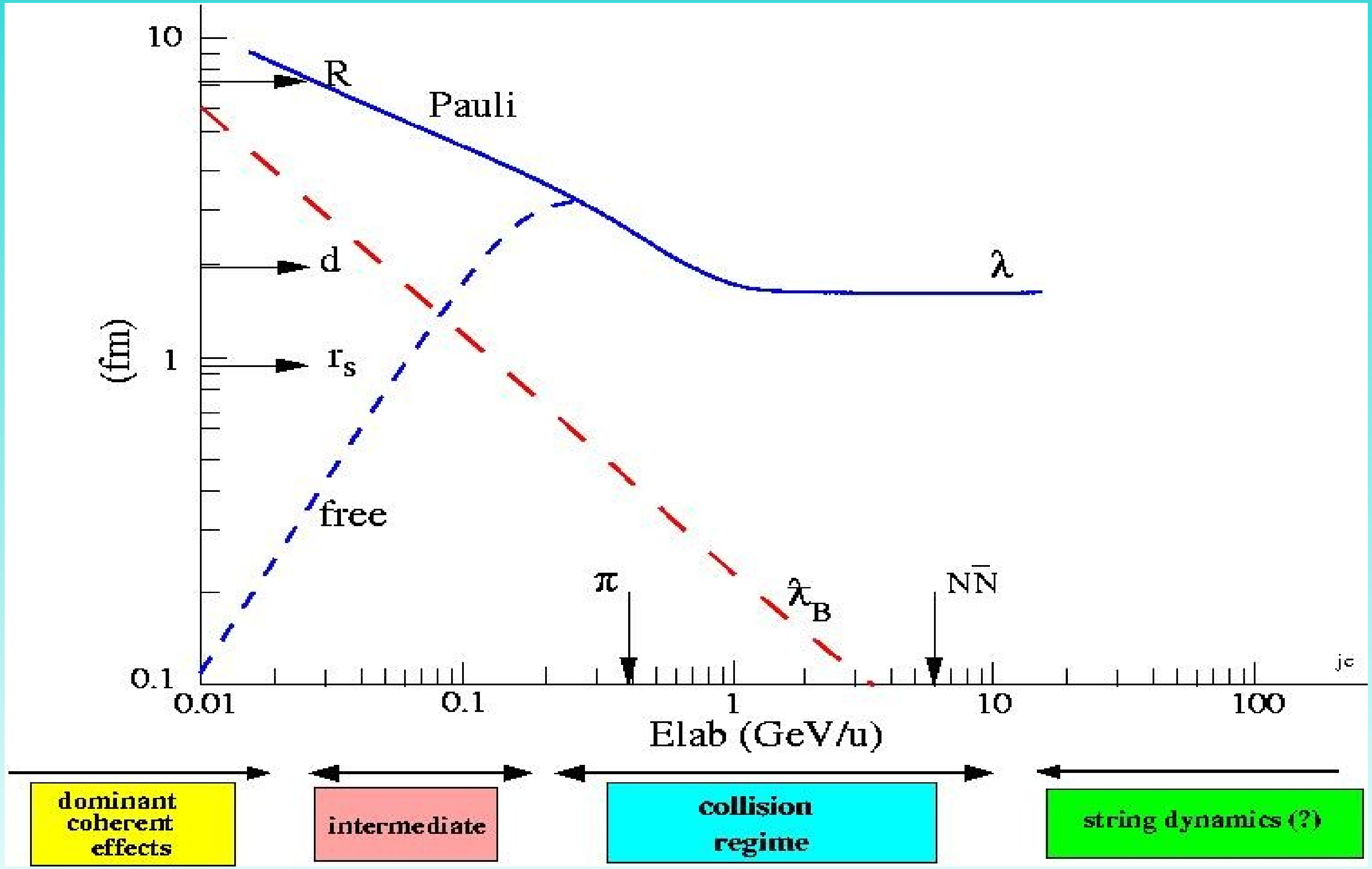
Simulations are easy and correspond to INC



+higher-order correlations

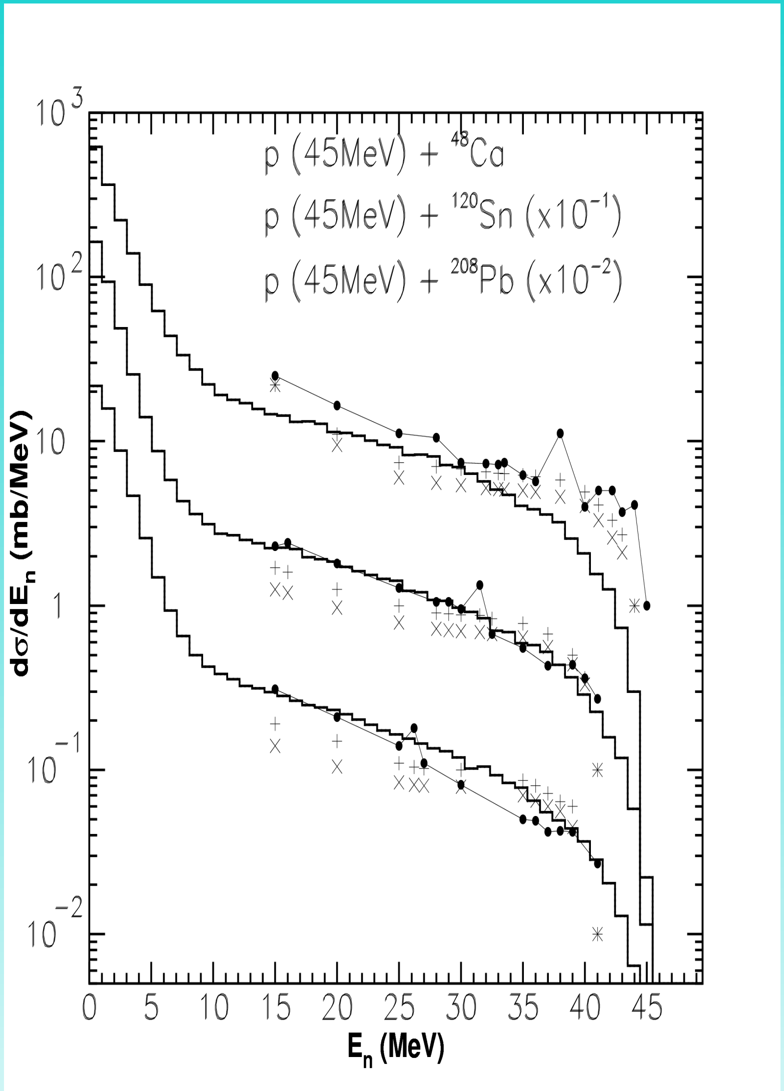
4. VALIDITY OF INC. UNIFICATION AT INTERMEDIATE ENERGY

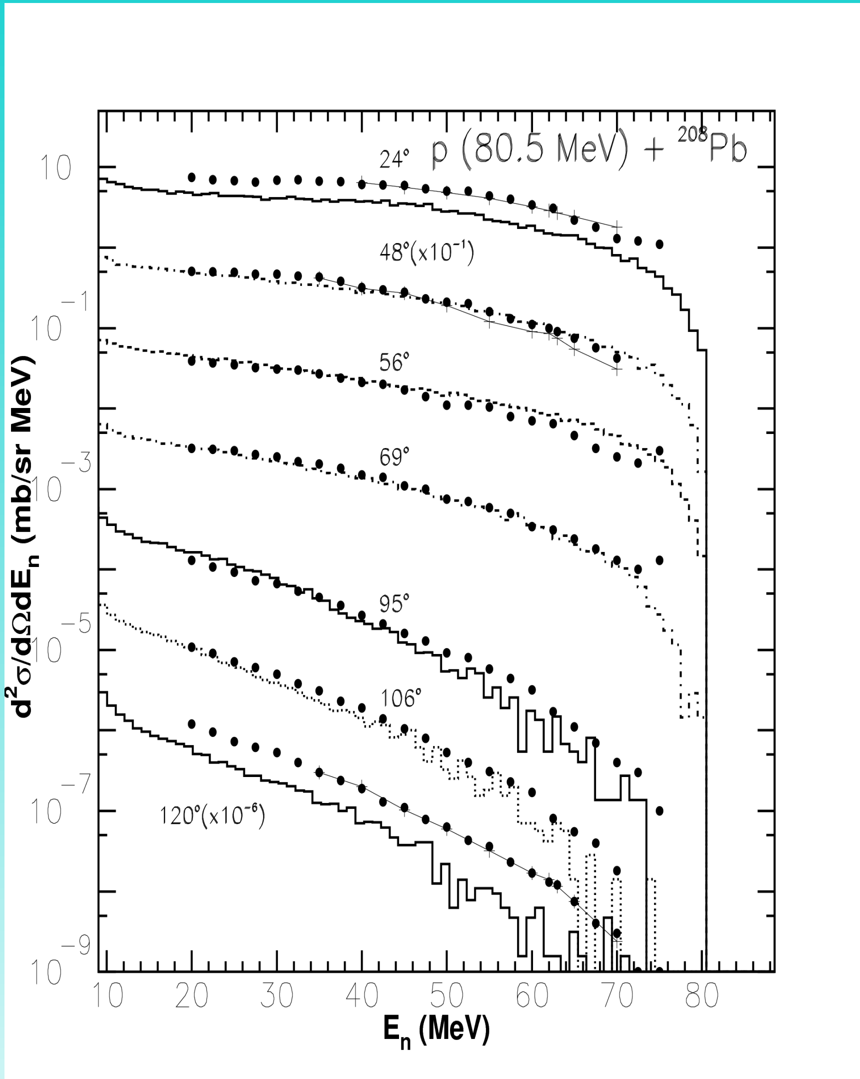
Low energy $\lambda_B \ll t_{coll} v \ll d$ → T_{lab} >200 MeV



High energy → T_{lab} < 20 GeV

For T_{lab} below 200 MeV, INC is working well





Explanation : Pauli blocking makes distance between collisions large eneough

Typical alternative models= pre-equilibrium models

Collision process=particle-hole excitations, with various transition probabilities

Equivalent physics :

- probabilities are dictated by cross sections
- continuous phase space in INC = discrete p-h space with finite width

Interaction of an incident particle with a Fermi gas system dominated by « Pauli-blocked » binary collisions

CONCLUSIONS

Let us listen to the following lecturers