Analysis of momentum distributions of projectile fragmentation products

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In the Goldhaber model* of the projectile fragmentation, the removal of independent nucleons from the projectile results in a Gaussian momentum distribution. The width of this distribution is given by the expression:

$$\sigma_{||} = \sigma_0 \sqrt{\frac{A_F (A_P - A_F)}{A_P - 1}}$$

where A_F is the fragment mass, A_P is the projectile mass, and σ_0 is the reduced width related to the Fermi momentum.

$$\sigma_0 = p_F / \sqrt{5} \approx 90\, MeV / c$$

The fragment velocity is supposed to be equal to the projectile velocity.

* A.S.Goldhaber, Phys.Lett. **B53** (1974) 306.

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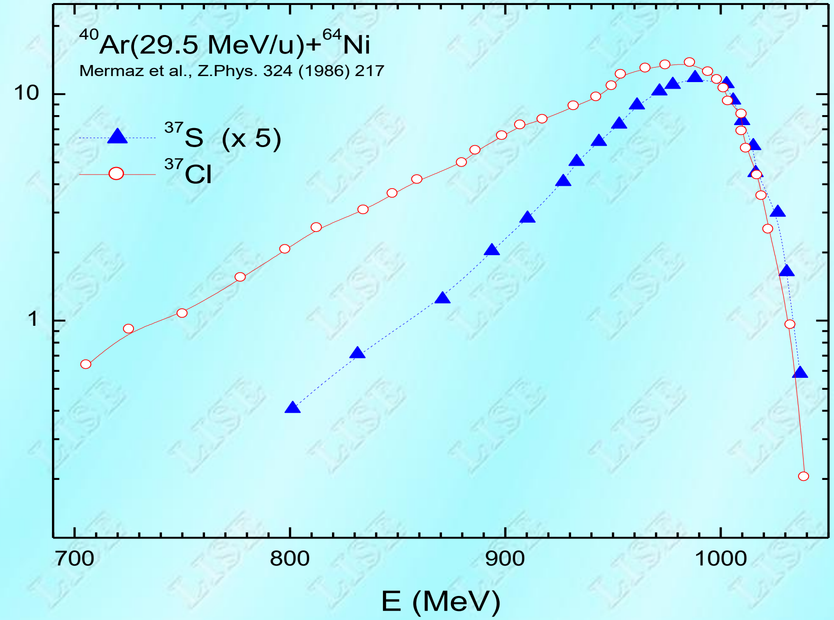
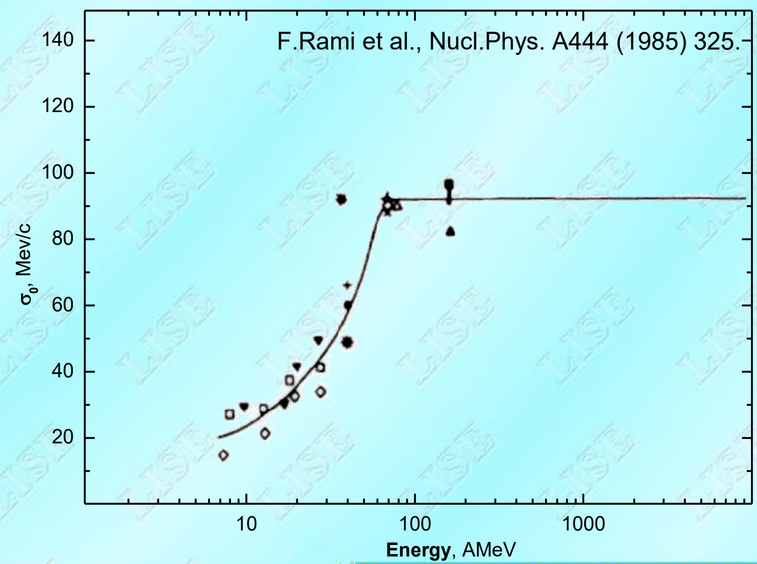
Discrepancy with experimental results

However, Goldhaber's model is unable to take into account the following things observed at low energies:

- the differences in widths associated with nuclides of the same mass
- the occurrence of an exponential tail in momentum distributions in reactions
- the reduction of the fragment to projectile velocity ratio (v/v_0)
- the anomalously small values of reduced width σ_0





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Different models : fragment velocity

Further different models were developed to explain these phenomena (both theoretical, and empirical parameterizations). Some models are entered in the LISE++ code* :

[1] V.Borrel et al., Z.Phys.A 314 (1983) 191. (solid curve)

removing 8 MeV per ablated nucleon:

$$\frac{v_F}{v_P} = \sqrt{1 - \frac{B_n (A_P - A_F)}{A_F\, E_P}}$$

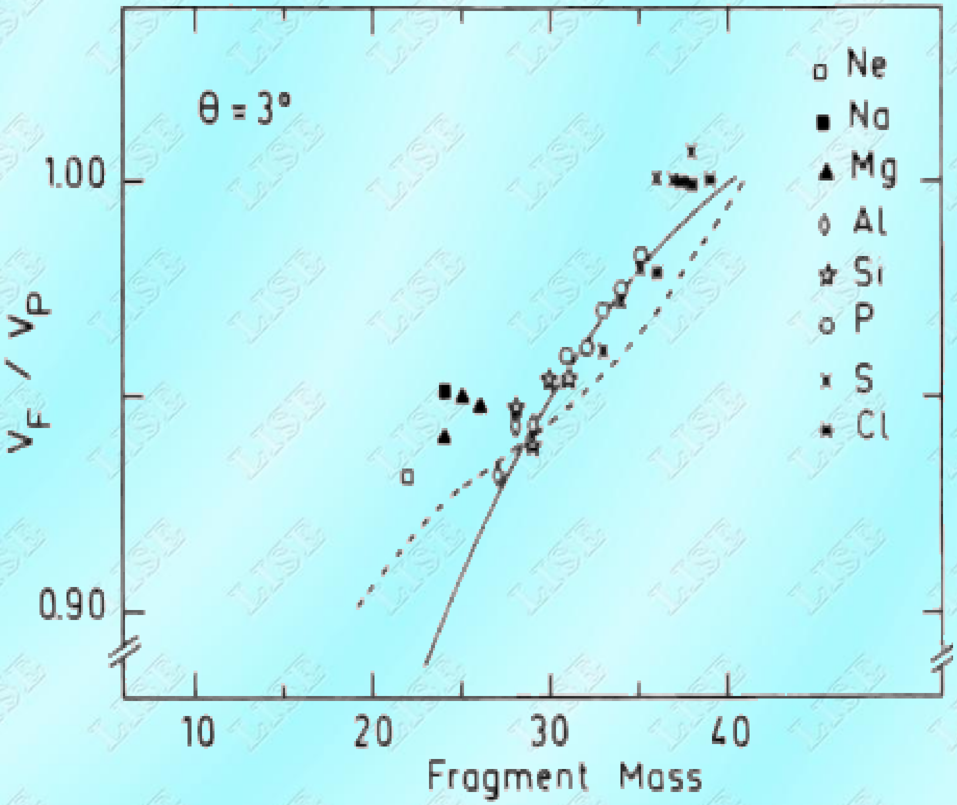
[2] F.Rami et al., Nucl.Phys. A444 (1985) 325.
(dotted curve)

Fragment velocity on the basis of surface energy excess:

$$\frac{v_F}{v_P} = \sqrt{1 - \frac{2S}{A_F\, E_P}},$$

where S is the surface energy of contact and equal to $2\gamma s$.
γ – the nuclear surface tension coefficient (0.95 MeV/fm^2),
s – the area of the interface between the abraded zone and the remaining fragment.

[3] D.J.Morrissey, Phys.Rev. C39 (1989) 460.



Ratio of the fragment to projectile velocities versus the mass of the fragment in the ^{40}Ar(26.5AMev)+ ^{68}Zn reaction [2].

*** See the poster "LISE++ : design your own spectrometer "**

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Different models : Longitudinal momentum distribution widths

1. A.S.Goldhaber, Phys.Lett. B53 (1974) 306

$$\sigma_{||} = \sigma_0 \sqrt{\frac{A_F (A_P - A_F)}{A_F - 1}} \,,$$

where σ_0 = 90 MeV/c.

2. D.J.Morrissey, Phys.Rev. C39 (1989) 460

$$\sigma_{||} = \frac{150}{\sqrt{3}} \sqrt{A_P - A_F}$$

"Coulomb correction"

This correction becomes significant only for energies below 20 MeV/u.

$$\sigma_0^* = \sigma_0 (1 - E_B / E_{CM})^{1/2}$$

3. W.A.Friedman, Phys.Rev. C27(1983) 569.

The model relates the widths of distributions to the separation energies and an absorptive cutoff radius. In this work a wave function $\psi_{F\text{-}r}(r)$ is entered which describes the relative separation between the observed fragment (F) and the removed portion of the projectile (R) to calculate only the region outside the absorption:

$$\psi_{F-r}(r) \cong e^{-\mu r} / r, \quad \mu = \sqrt{2 m_r E_s}$$

where m_r is the reduced mass and E_s is the separation energy. Including the lowest order of the Coulomb potential on the bound state wave function tail, the resulting distribution has gaussian form with width:

$$\sigma_{\mathrm{II}}^2 = \frac{\mu}{2x_0} \left[\frac{1 + 0.5y}{\sqrt{1+y}} + \frac{1}{\mu x_0} \right], \quad y = Z_1 Z_2 / x_0 E_s$$

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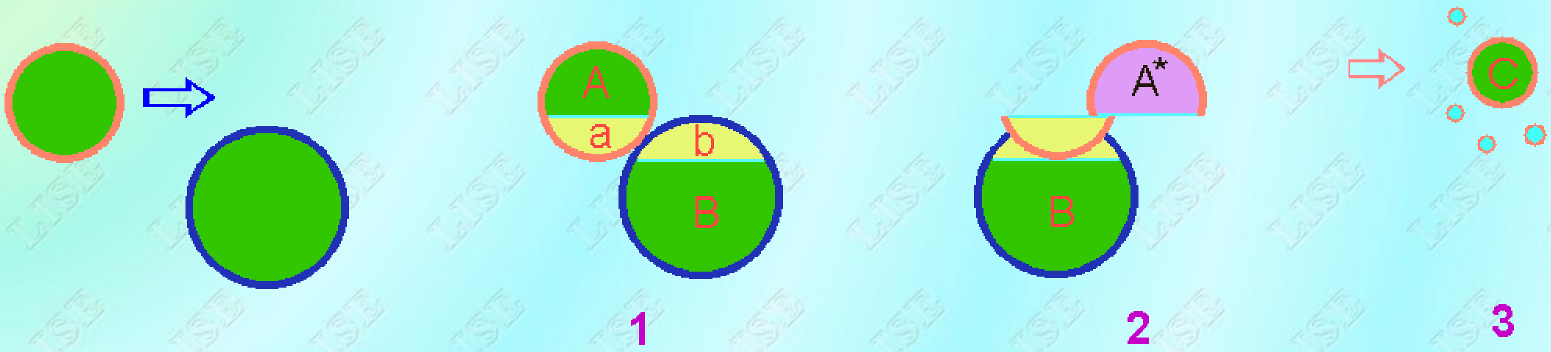
3-step projectile fragmentation model



Process		Momentum distribution
1 Abrasion Removal of the part "a" (statistics)	Gaussian	$\psi(p_{pf}) = \frac{1}{\sqrt{2\pi}\,\sigma_{pf}} \exp\left(\frac{-(p_{pf}-p_{0pf})^2}{2\sigma^2_{pf}}\right)$
2 Friction - loss of kinetic energy Transformation into the internal degrees of freedom. Exchange of nucleons	Exponential attenuation	$\phi(p_1, p_2) = \frac{1}{\tau}\exp\left(-\frac{p_2 - p_1}{\tau}\right)$
3 Ablation light nuclei emission, gamma-emission	Broadening	velocity peak maximum does not shift

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Convolution model: "Universal parameterization"

$$f(p) = \phi \otimes \psi \cong \exp\left(\frac{p}{\tau}\right) \cdot \left[1 - ferr\left(\frac{p - p_0 + \frac{\sigma_{pf}^2}{\tau} - s \cdot \tau}{\sqrt{2}\,\sigma_{pf}} \right) \right]$$

where

$$\tau = coef \cdot \sqrt{A_{PF} \cdot E_S} \,/\, \beta\,,$$

$$\sigma_{pf}^2 = \beta\,\sigma_0^2 \; \frac{A_{PF}\,(A_P - A_{PF})}{A_P - 1}$$

E_S is the energy spent to split the projectile (mass difference, surface energy excess)

A_{PF} is the mass number of the prefragment.

Three parameters to fit: σ_0, **s, coef.**

Why is Universal?

- **Distribution Width**
- **Velocity (v_{frag}/v_{beam})**
- **Low-energy tail**

Calculation steps

1. **Search the more probable prefragment for a given fragment.**
2. **Calculation of energy surface excess for the prefragment**
   [J.Gosset et al., Prys.Rev.C 16 (1977) 629]
3. **Calculation of Q-value using the database of mass.**

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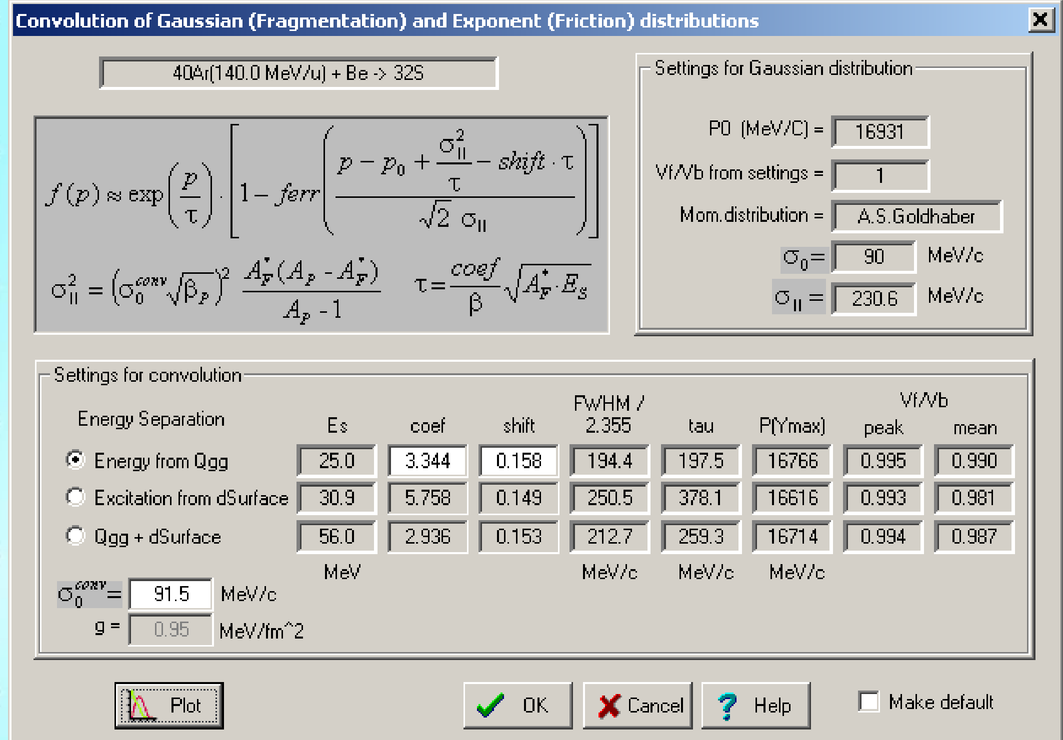
LISE++ and Universal parameterization

35 spectra in the energy region **26-2200 MeV/u** were used for fit from the following works:

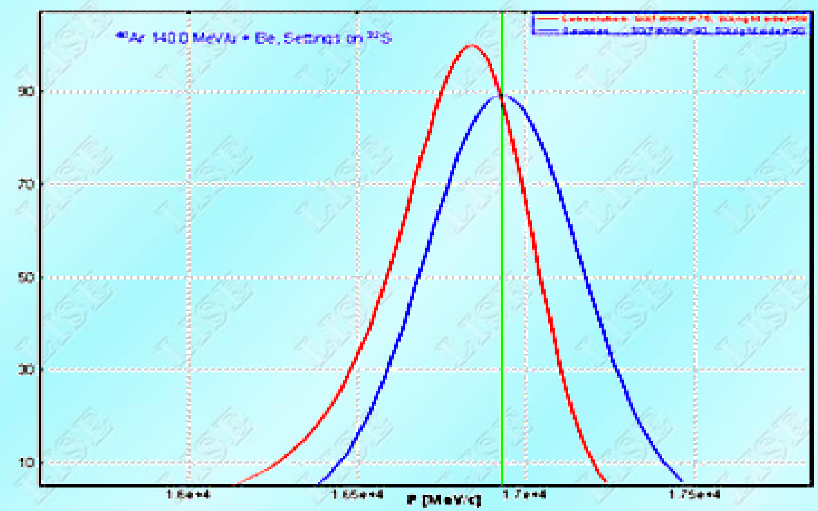
V.Borrel et al., Z.Phys.**A 324** (1986) 205.
Y.Blumenfeld et al., Nucl.Phys **A455** (1986) 357.
R.Dayras et al., Nucl.Phys. **A460** (1986) 299.
D.E.Greiner et al., Prys.Rev.lett. **35** (1975) 152.
J.Mougey et al., Phys.Lett. **B105** (1981) 25.
M.C.Mermaz et al., Z.Phys. **A324** (1986) 217.
F.Rami et al., Nucl.Phys. **A444** (1985) 325.
Y.P.Viyogi et al., Phys.Rev.Lett. **C42** (1979) 33.



Results:

$$\sigma_0^{conv} = 91.5 \text{ MeV/c}$$

Energy separaton	coef	shift
Energy from Qgg	3.344	0.1581
Surface excess	5.758	0.1487
Their sum	2.936	0.1526



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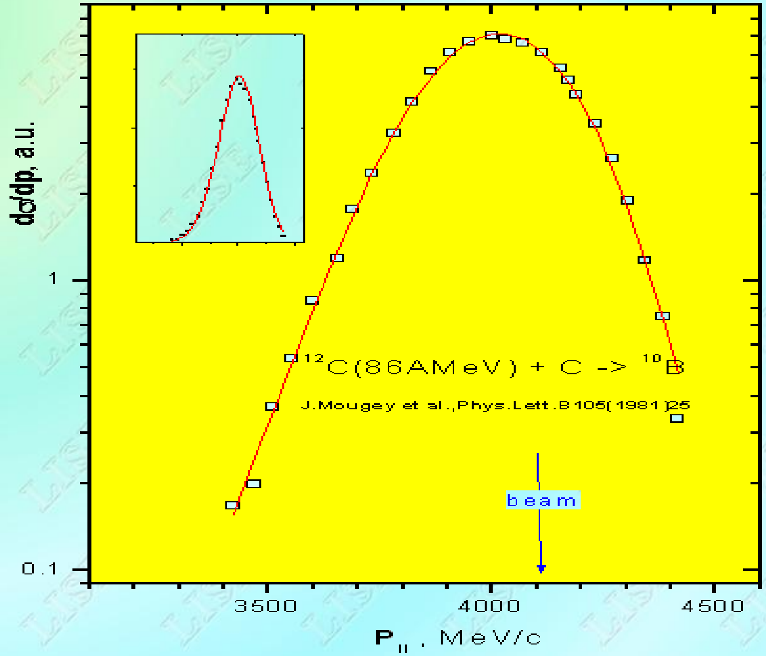

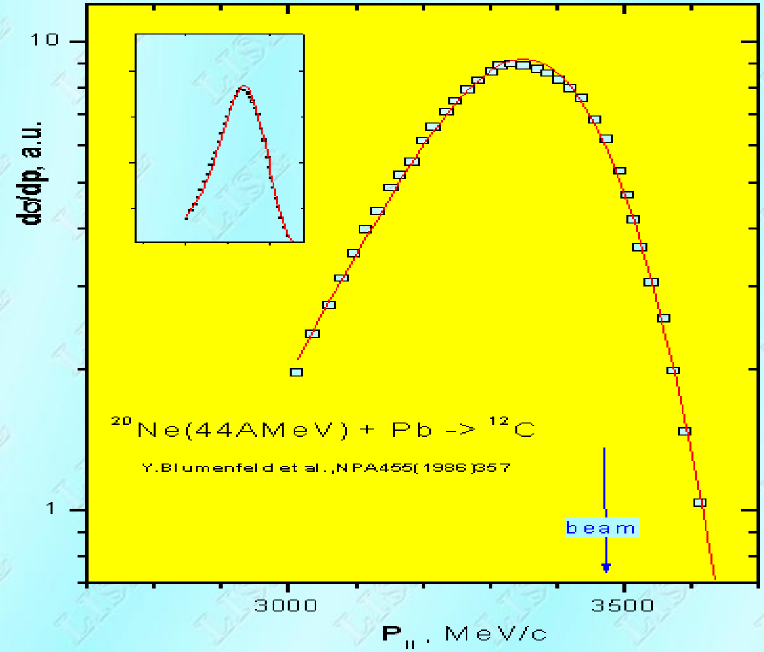

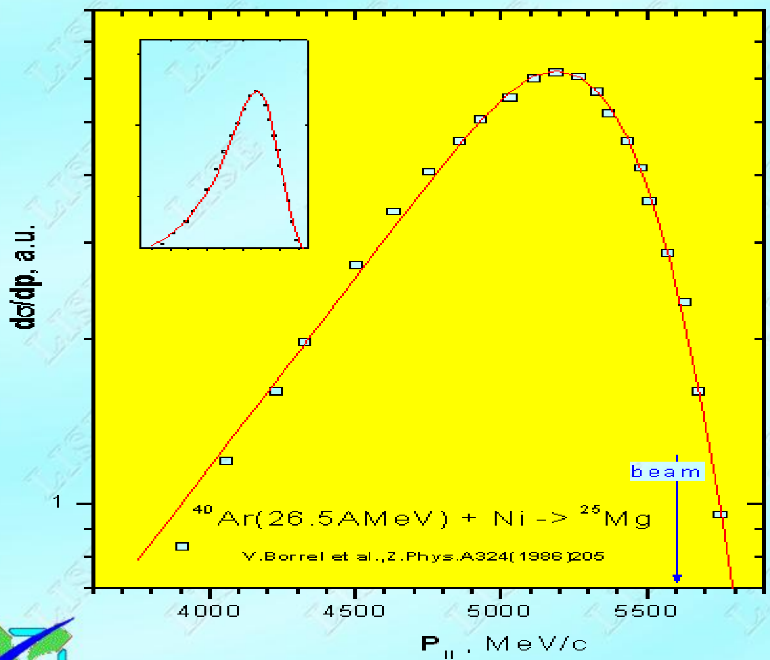

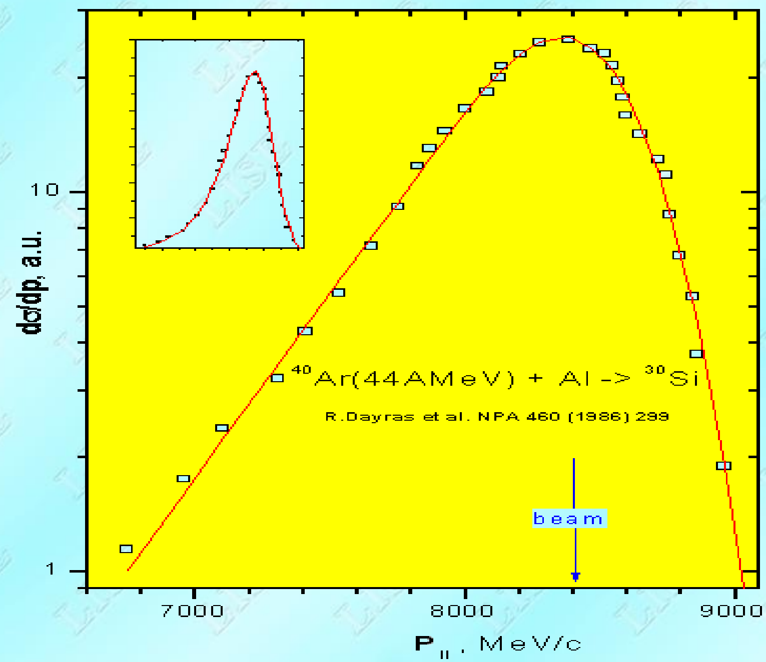

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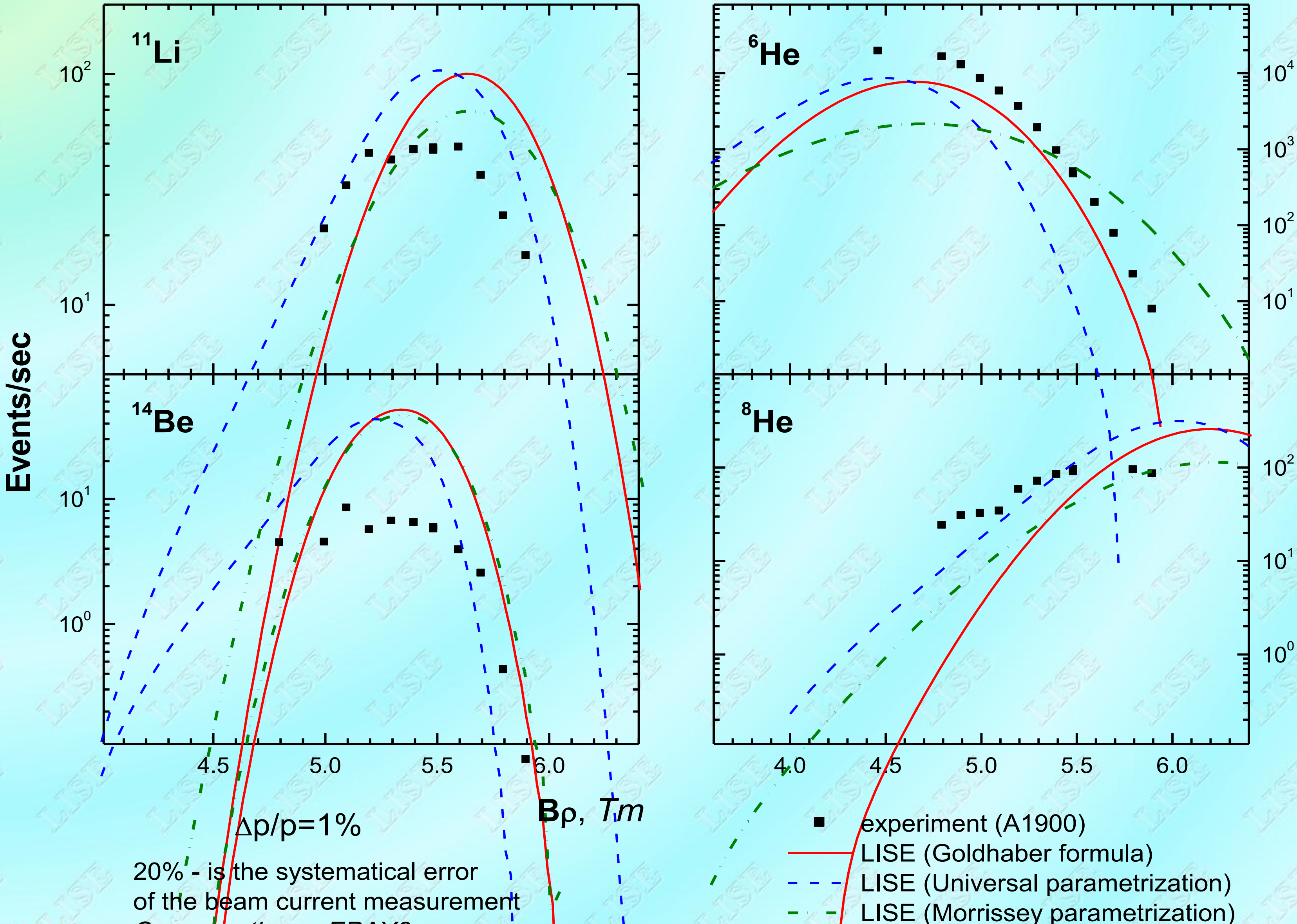
A1900 / NSCL : ^{18}O (120MeV/u, 1pna) + Be (1166 mg/cm^2)



20% - is the systematical error of the beam current measurement

Cross sections - EPAX2

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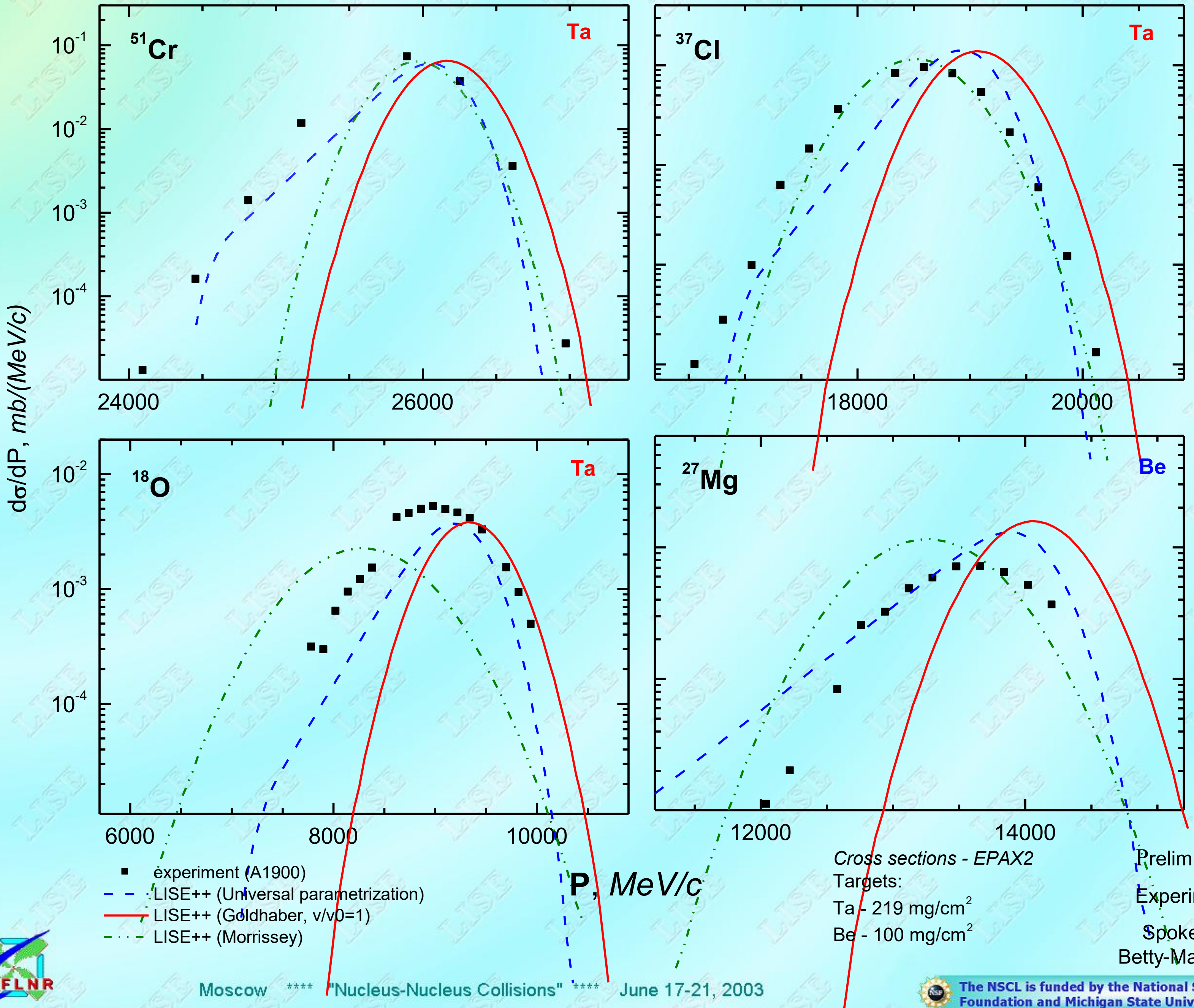
A1900 / NSCL : ^{58}Ni (140 MeV/u) + Be,Ta



Cross sections - EPAX2
Targets:
Ta - 219 mg/cm^2
Be - 100 mg/cm^2

Preliminary data.
Experiment 1036
Spokeswoman:
Betty-Manyee Tsang

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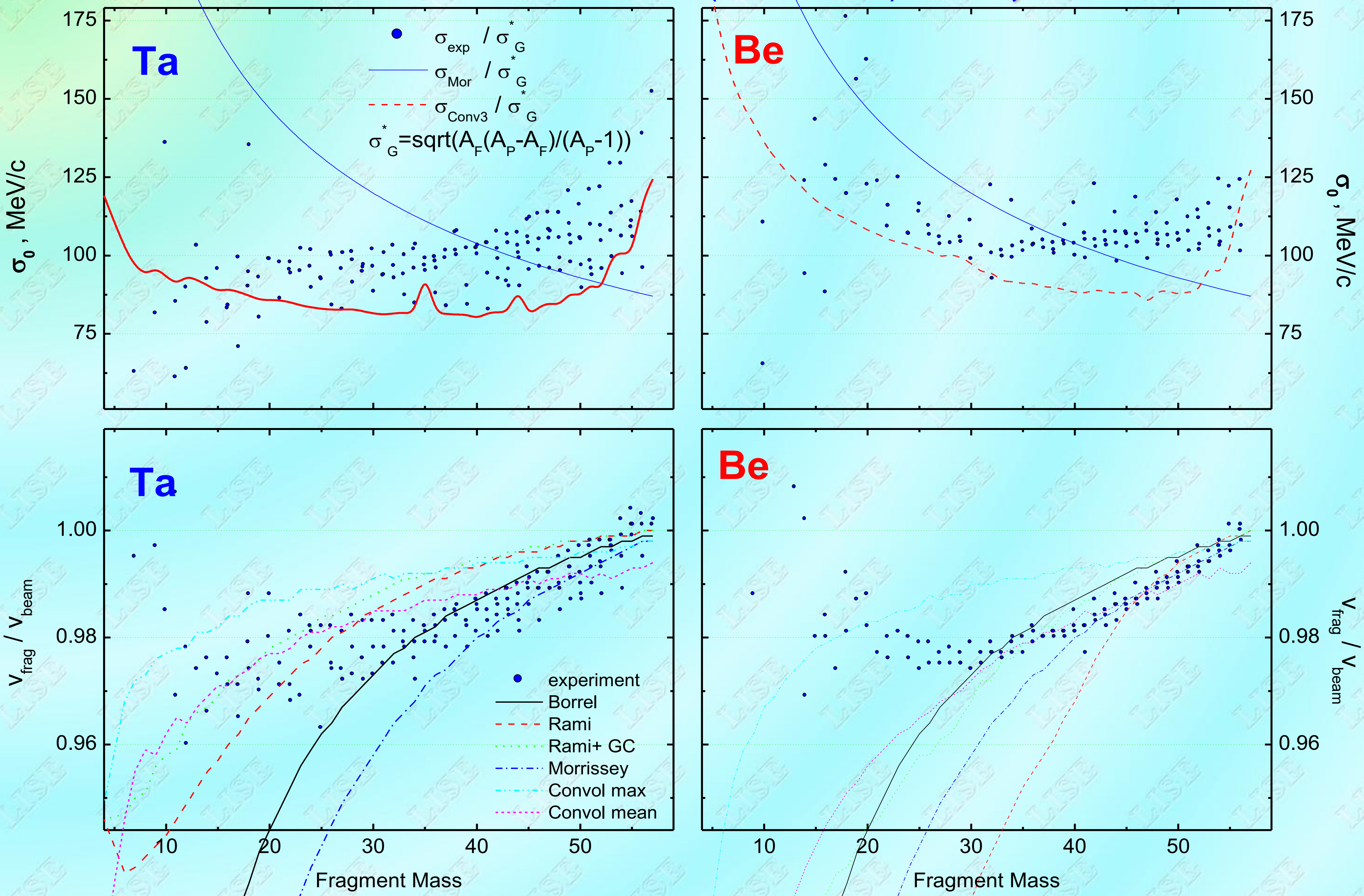
A1900 / NSCL : ^{58}Ni (140 MeV/u) + Be,Ta



calculations have been done for more probable Z(A)

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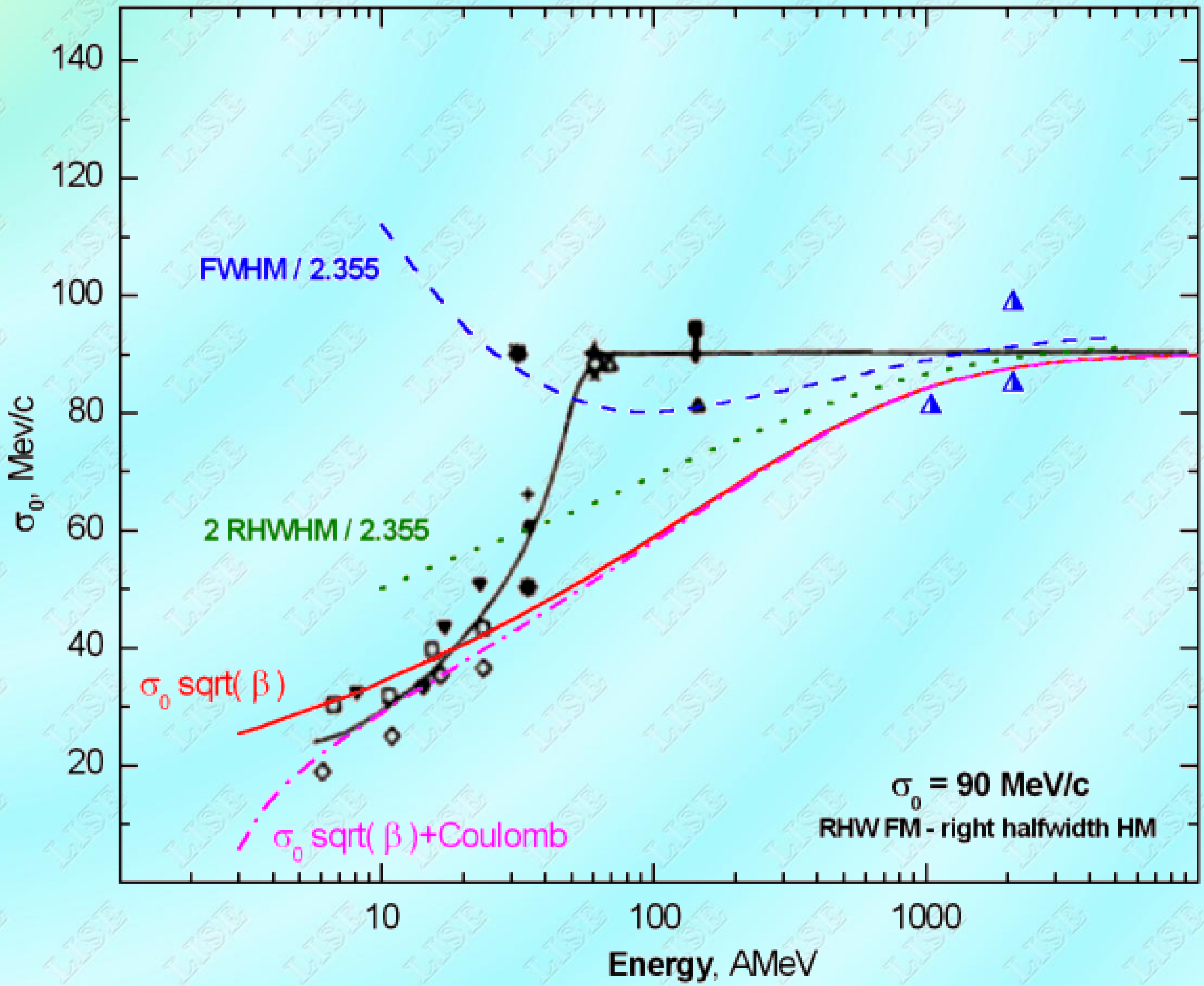
Momentum distribution width systematization



Summary

- A model for fragment momentum distributions was developed as a function of a projectile energy.
- Analysis of several experimental studies has been performed to obtain coefficients of the Universal Parameterization, which allows to overcome drawbacks inherent to Goldhaber's and Morrissey's models.
- The Universal parameterization is incorporated in the LISE++ code for fragment transmission calculation.
- Comparisons with recent experimental data in the energy region of 120-140 MeV/u for various combinations of primary beams and targets are presented.

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