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# Secondary fragment beams for studies of light nuclei structure using the emulsion technique at the LHEP facilities

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# Beryllium (Boron) Clustering Quest in Relativistic Multifragmentation (BECQUEREL Project)*

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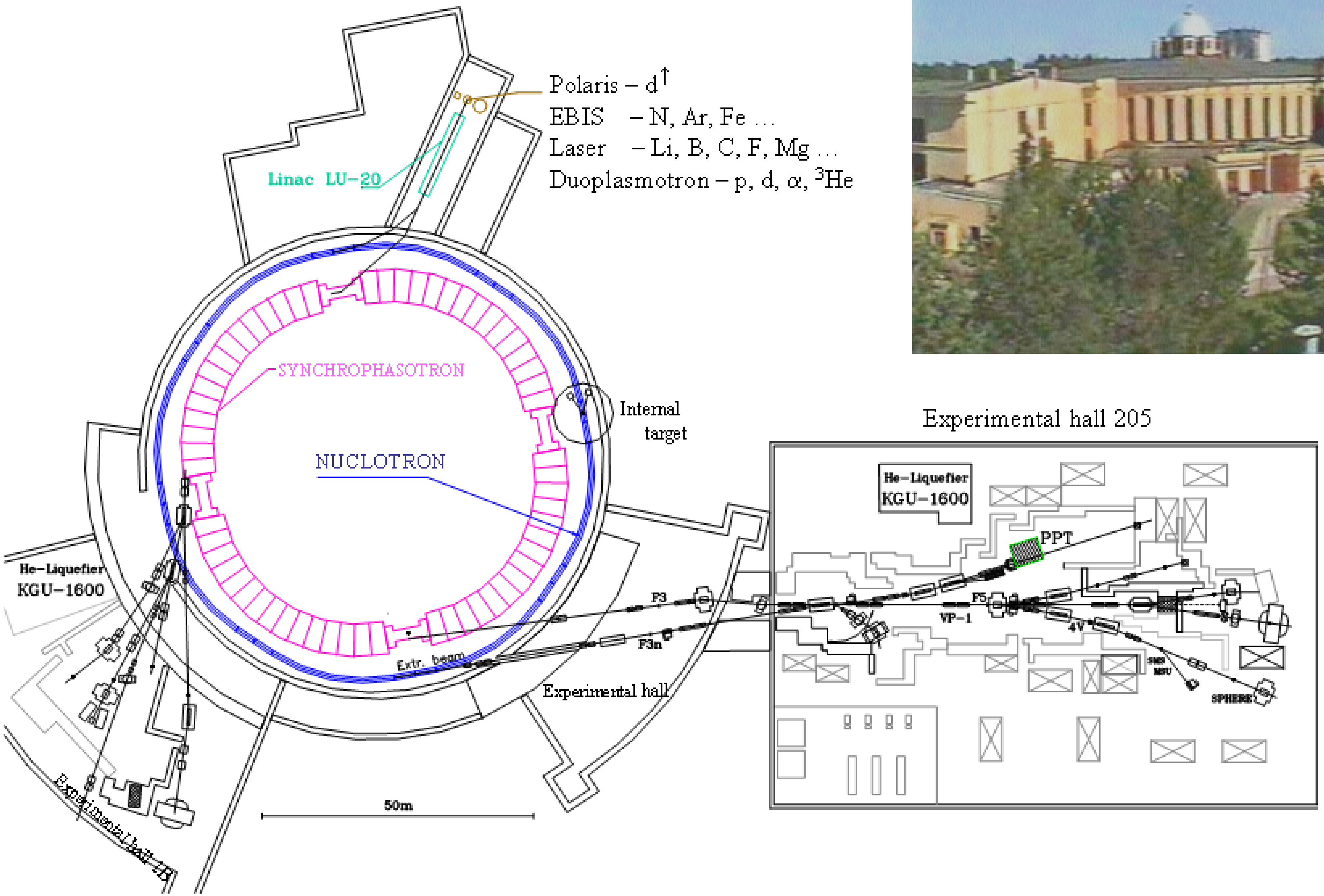
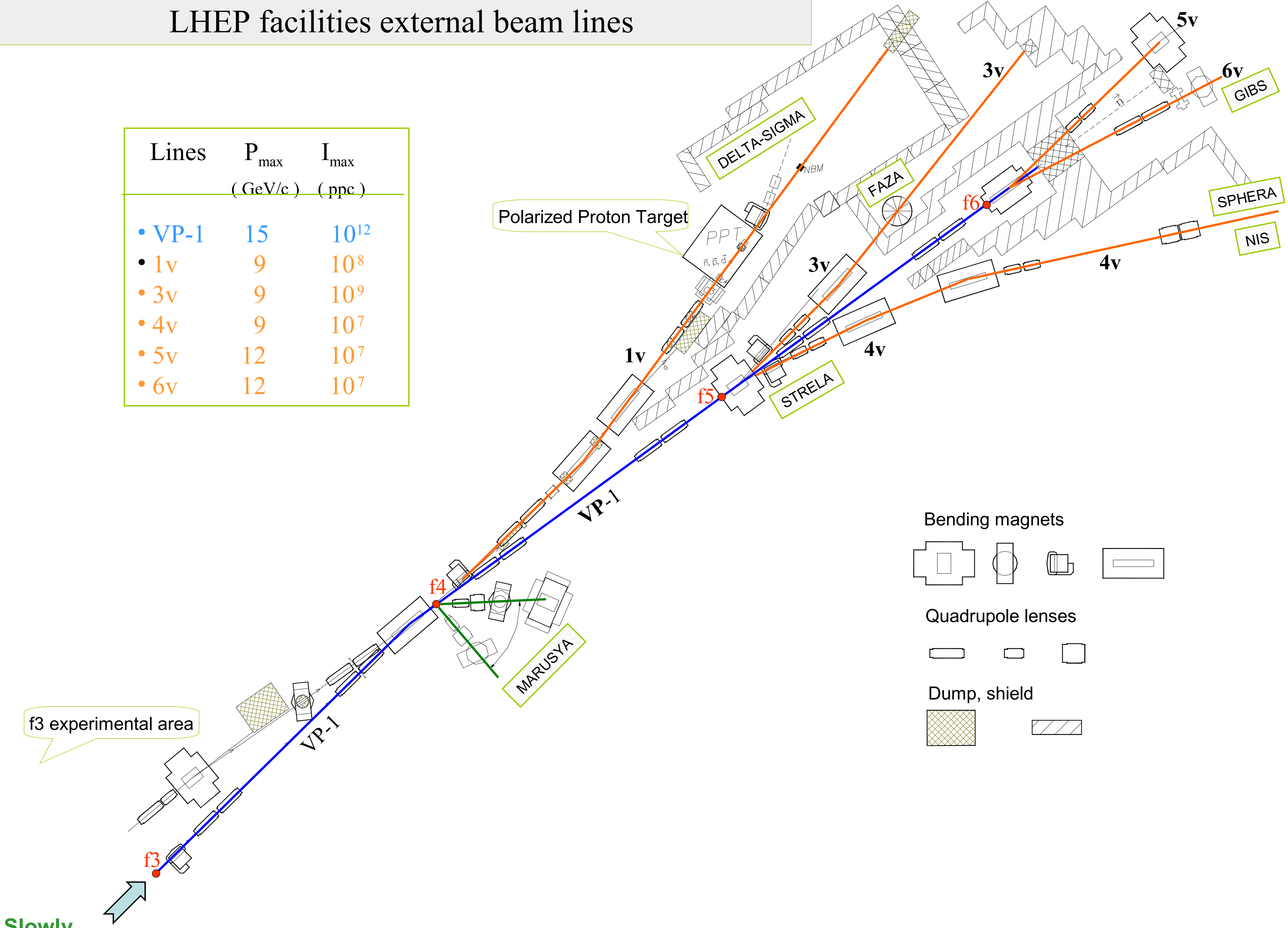
**Abstract**—A physical program of irradiation of emulsions in beams of relativistic nuclei named the BECQUEREL Project is reviewed. It is destined to study in detail the processes of relativistic fragmentation of light radioactive and stable nuclei. The expected results would make it possible to answer some topical questions concerning the cluster structure of light nuclei. Owing to the best spatial resolution, the nuclear emulsions would enable one to obtain unique and evident results. The most important irradiations will be performed in the secondary beams of He, Be, B, C, and N radioactive nuclei formed on the basis of JINR Nuclotron beams of stable nuclei. We present results on the charged state topology of relativistic fragmentation of the $^{10}B$ nucleus at low energy–momentum transfers as the first step of the research.

# Accelerator facilities of LHEP

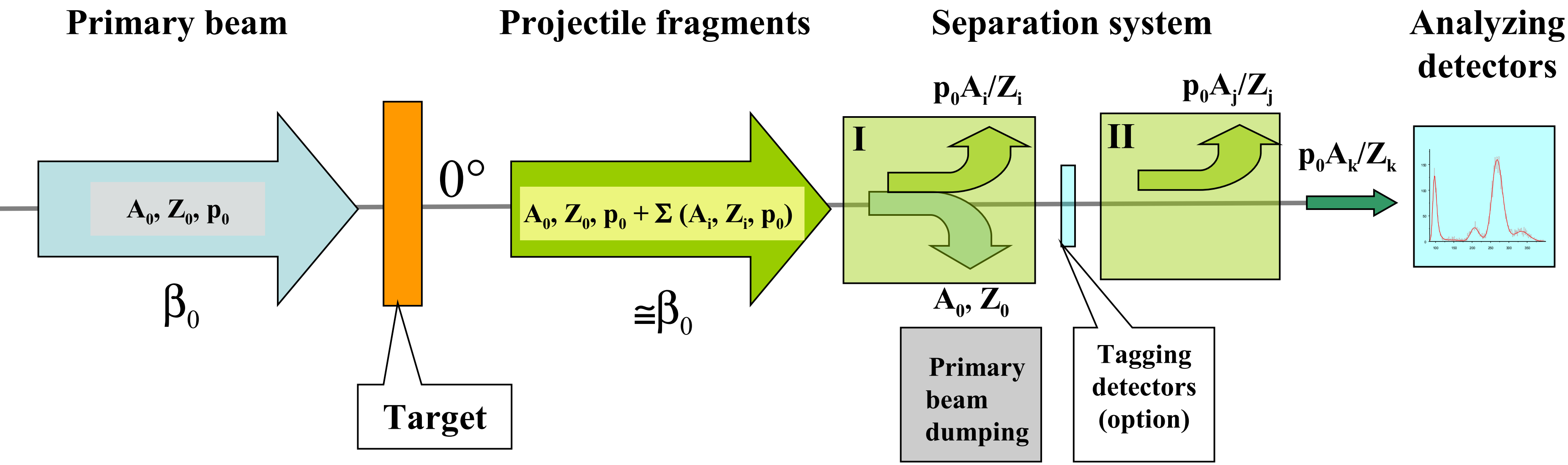



# LHEP facilities external beam lines

| Lines | $P_{max}$ (GeV/c) | $I_{max}$ (ppc) |
|---|---|---|
| • VP-1 | 15 | $10^{12}$ |
| • 1v | 9 | $10^{8}$ |
| • 3v | 9 | $10^{9}$ |
| • 4v | 9 | $10^{7}$ |
| • 5v | 12 | $10^{7}$ |
| • 6v | 12 | $10^{7}$ |



# Secondary relativistic fragments beams: a general scheme




$p_0$ -- projectile momentum per nucleon

# Secondary relativistic fragment beams: relations

## Fragment momentum spread in the projectile rest frame

$$\sigma = \sigma_0 \sqrt{\frac{B(A-B)}{(A-1)}}$$

$\sigma_0 \cong 90$ MeV/c
A – projectile mass number
B – fragment mass number

*A.S. Goldhaber, Phys. Lett. 53B, p.306*

## Fragment angular and relative momentum spread in the laboratory frame

$$\sigma_{\theta_x} \simeq \frac{\sigma}{B p_0}$$

$$\sigma_{\delta_p} \simeq \frac{\sigma}{\beta_0 B m}$$

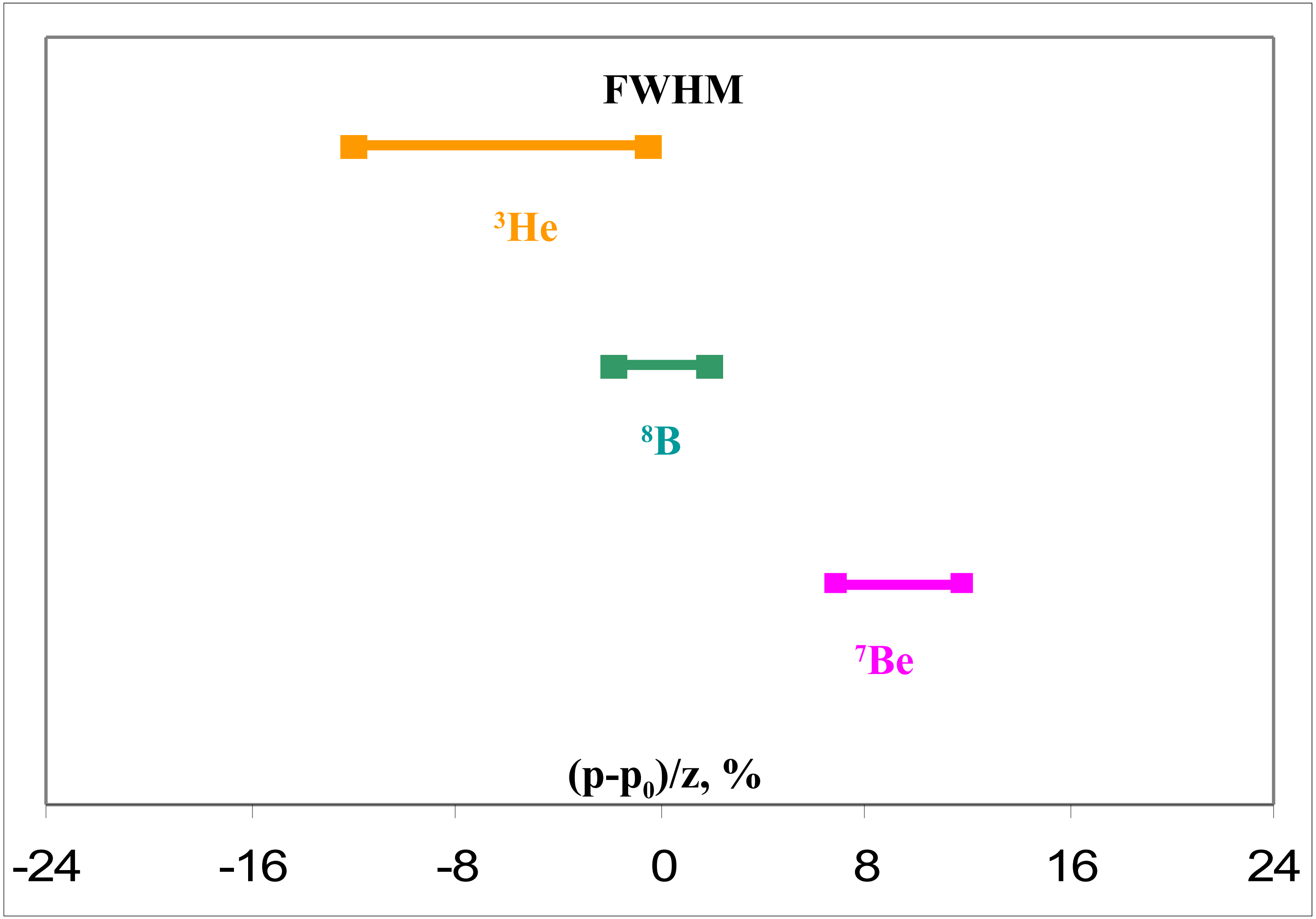
$p_0$ – projectile momentum per nucl.
$\beta_0$ – projectile velocity
m – nucleon mass

## A numerical illustration

$^{10}B \rightarrow {}^{8}B$ ( A=10, B=8 ) at $p_0 = 2$ GeV/c/nucl. ($t_0 \cong 1.3$ GeV/nucl.) :

**$\sigma_\theta \cong 7.5$ mr, $\sigma_\delta \cong 1.8$ %**

## $^{10}B \rightarrow {}^{8}B$ fragmentation: momentum distribution width comparing



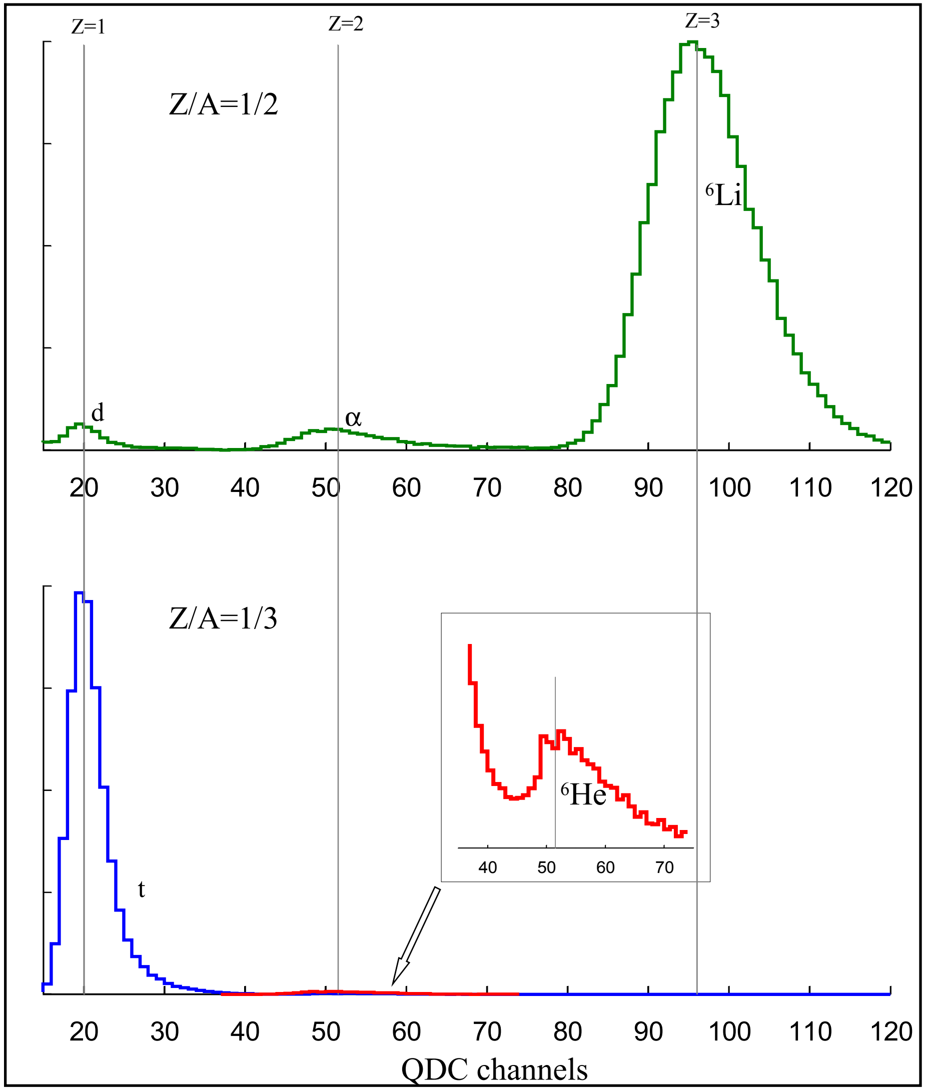
# Beam by reactions $^6$Li + A → Nucleus + …

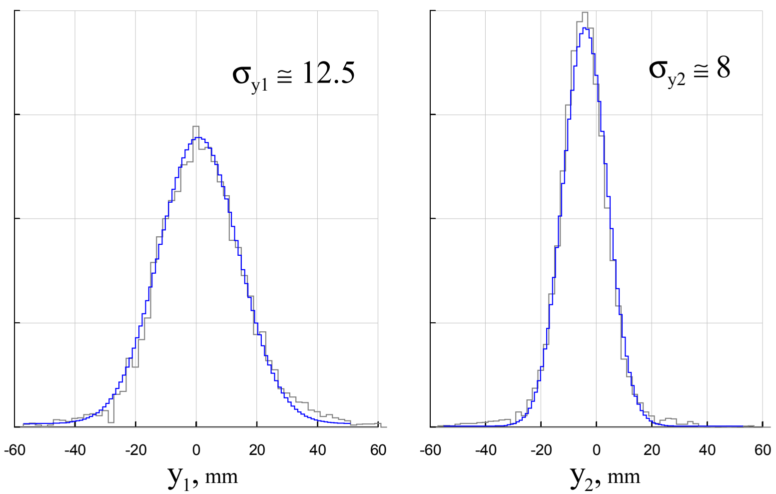
Primary beam:

- $^6$**Li**, t = 1.9 GeV/amu, (p = 2.67 GeV/c/amu )
- Intensity ≅ $5{\cdot}10^7$ nuclei/cycle (Synchr.)
- Beam sizes on a target: $\sigma_x \le 4$ mm, $\sigma_y \le 8$ mm
- Target: organic glass, 4.7 g/cm$^2$, at $F_5$

Secondary beam (4v line):

- p/Z = 8.0 GeV/c (Z/A=1/3), 5.35 GeV/c (Z/A=1/2);
- **ΔΩ ≅ 60** μsr;
- **Δp ≅ 2%**;
- Intensity ≅ $10^4$ nuclei/cycle (Z/A=1/3);




Vertical beam profiles at two positions before emulsion.

Beam divergence relatively to the emulsion layers - $\boldsymbol{\sigma_{\theta y} \le 2.5}$ **mr**

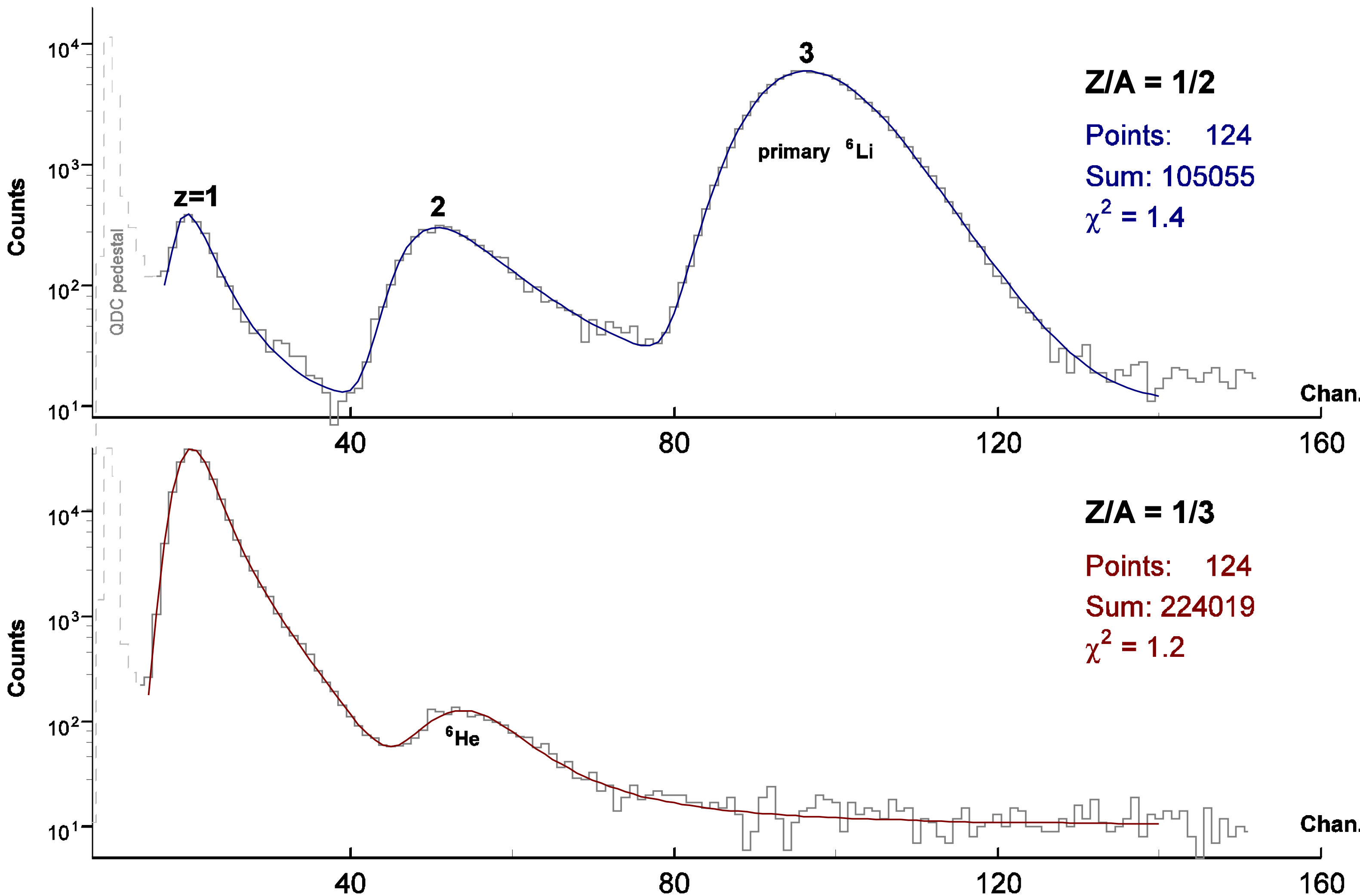
$$f(x,\mathbf{p}) = \frac{1}{\sqrt{2\pi}\sigma} \int \sum_{i=1}^{m} S_i\, v_i(x-t)\, e^{-t^2/2\sigma^2}\, dt + y_0$$

***m – number of peaks***

***$v_i = v((x-x_i)/w_i, k_i, \beta^2)$ – Vavilov functions***

**p = ($S_1$, $x_1$, $w_1$, …, $S_m$, $x_m$, $w_m$, σ, $y_0$) – *4m + 2 fit parameters***

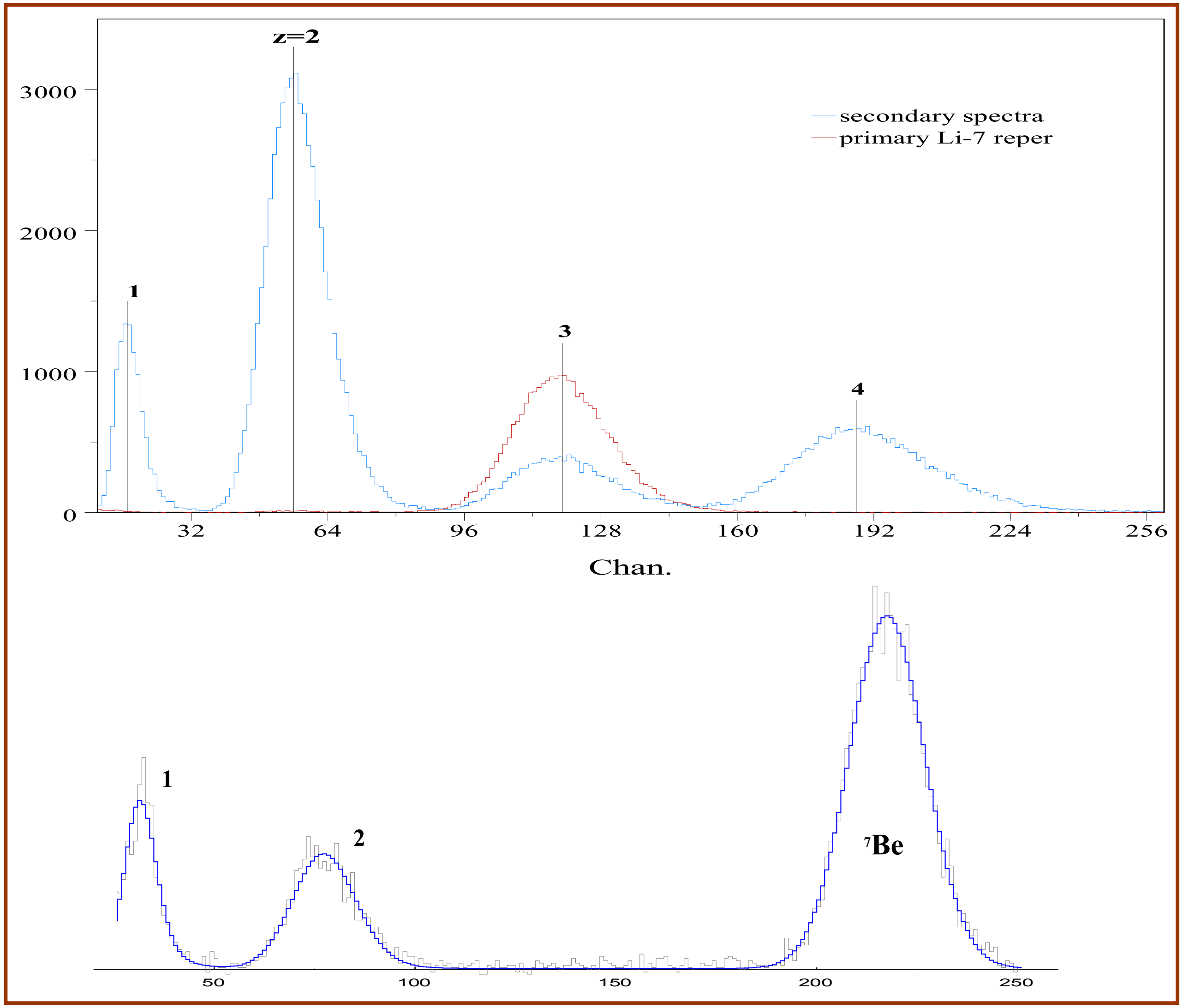
# Beam by reactions $^6$Li + A → Nucleus + …




**Yields ratios, %:**

**d : α = 51 ± 3;   $^6$He : t = 0.85 ± 0.05**

# Secondary nuclei beam: $^{7}$Li + A → $^{7}$Be + …




$^{7}$Be atom – $T_{1/2} \cong$ 53.4 d (e-cap.)

$^{7}$Be nucleus – stable

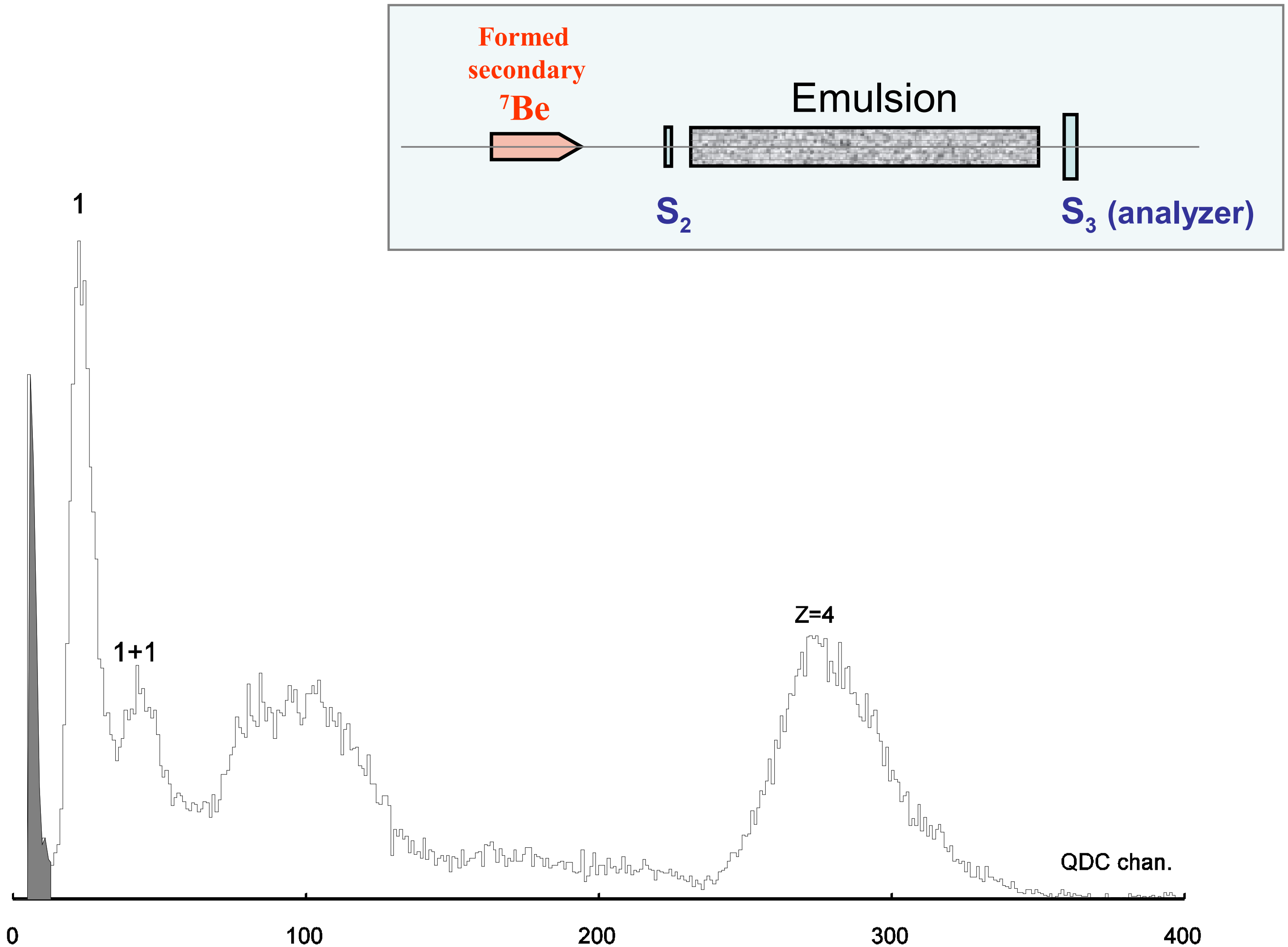
**Beam rejection variant 1**

$Y_4 : Y_{1+2+3} \cong 1 : 3.3$

**Beam rejection variant 2**

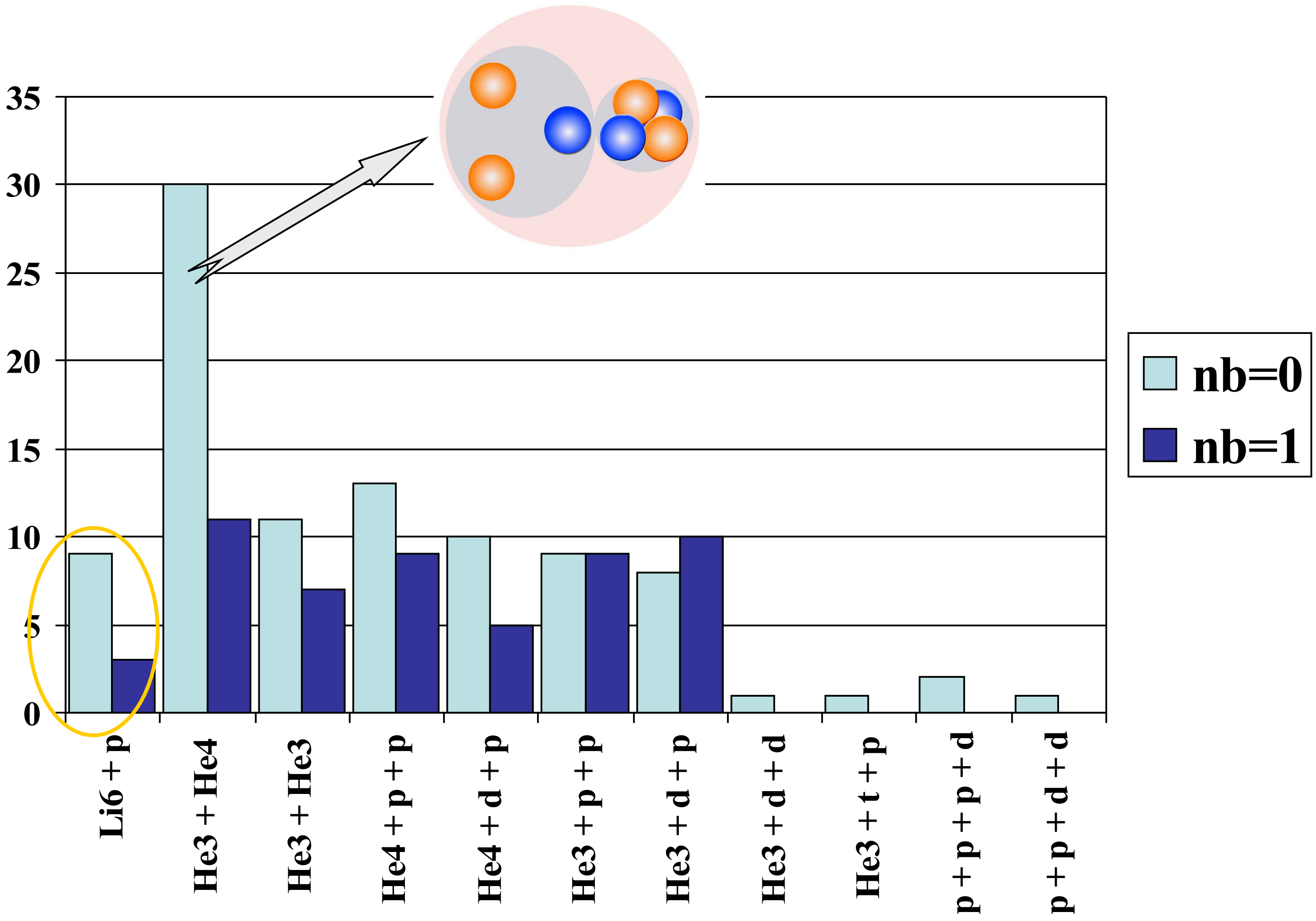
$Y_4 : Y_{1+2+\dots} \cong 1.9 : 1$

# Secondary nuclei beam: $^{7}Li + A \rightarrow {}^{7}Be + \ldots$

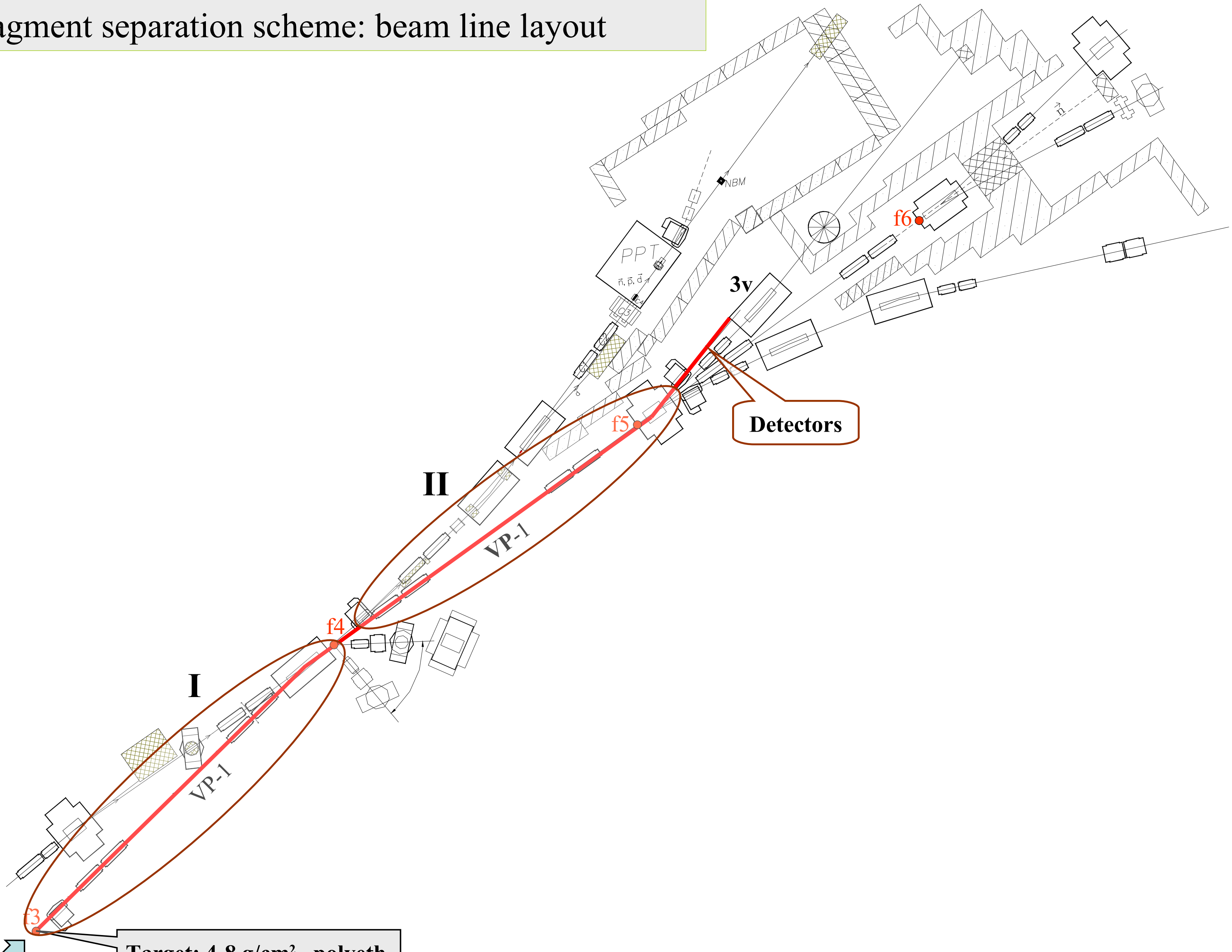


N.G. Peresadko et al., Physics of Atomic Nuclei, 2007, Vol. 70, No. 7, pp. 1226–1229.

# $^{7}$Be fragmentation channels

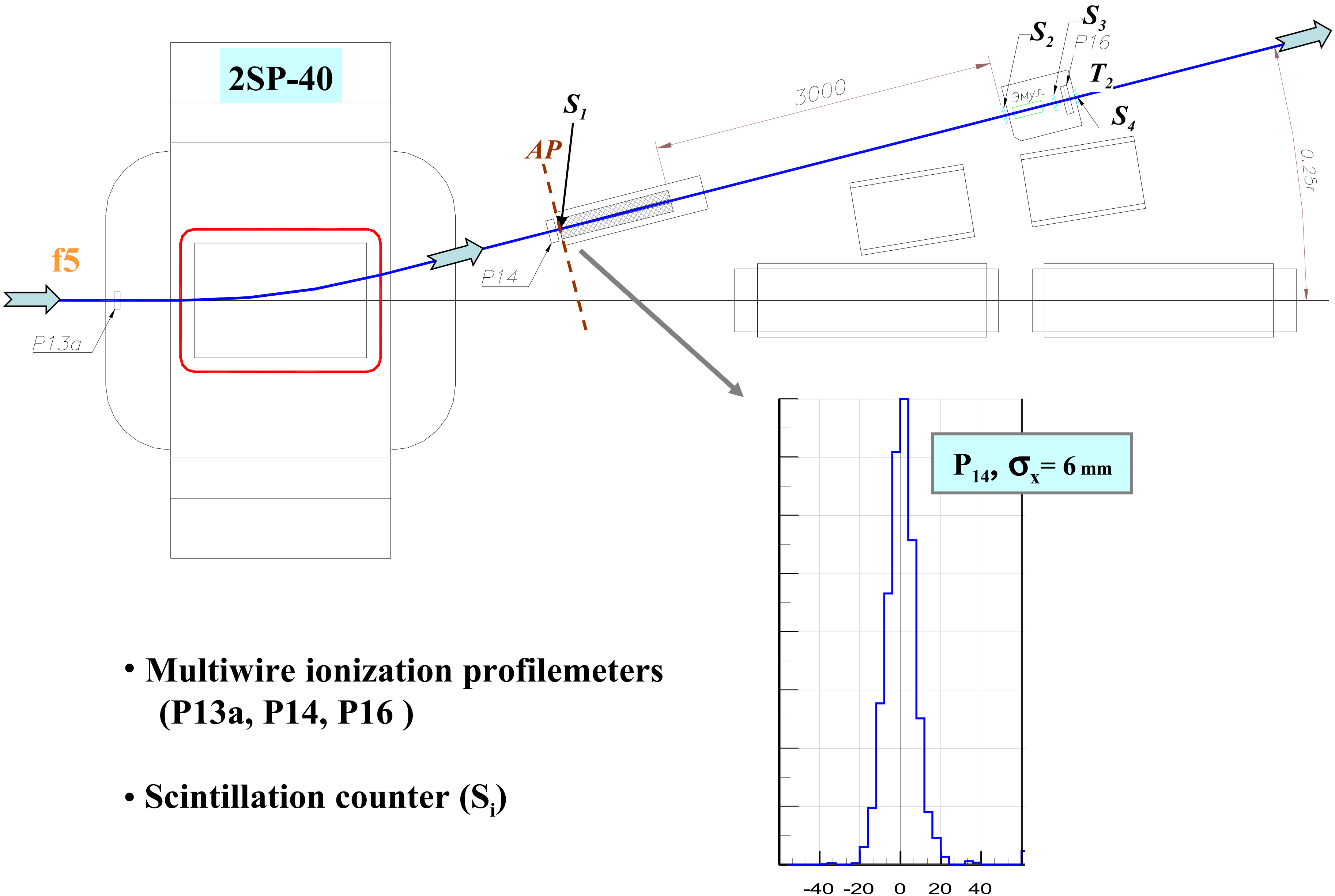


# Fragment separation scheme: beam line layout



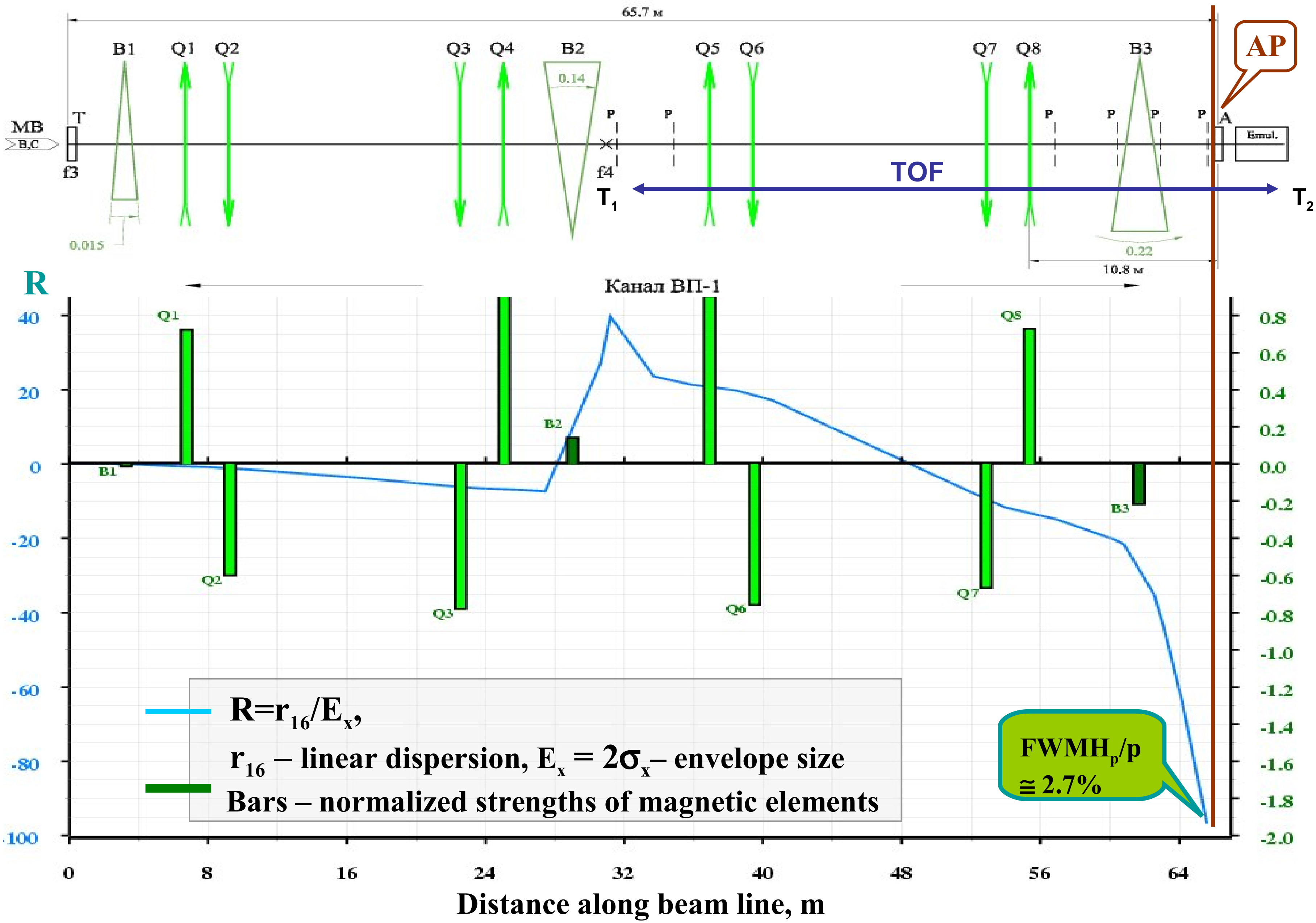

Extracted beams: $^{12}C$, $^{10}B$, $^{7}Li$

# Fragment separation scheme:  detector layout

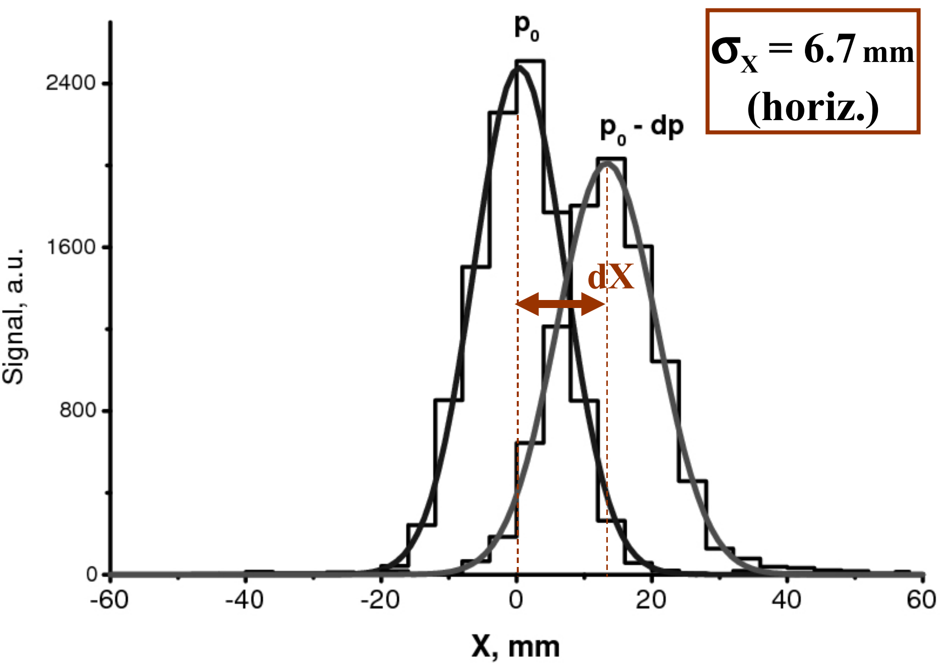


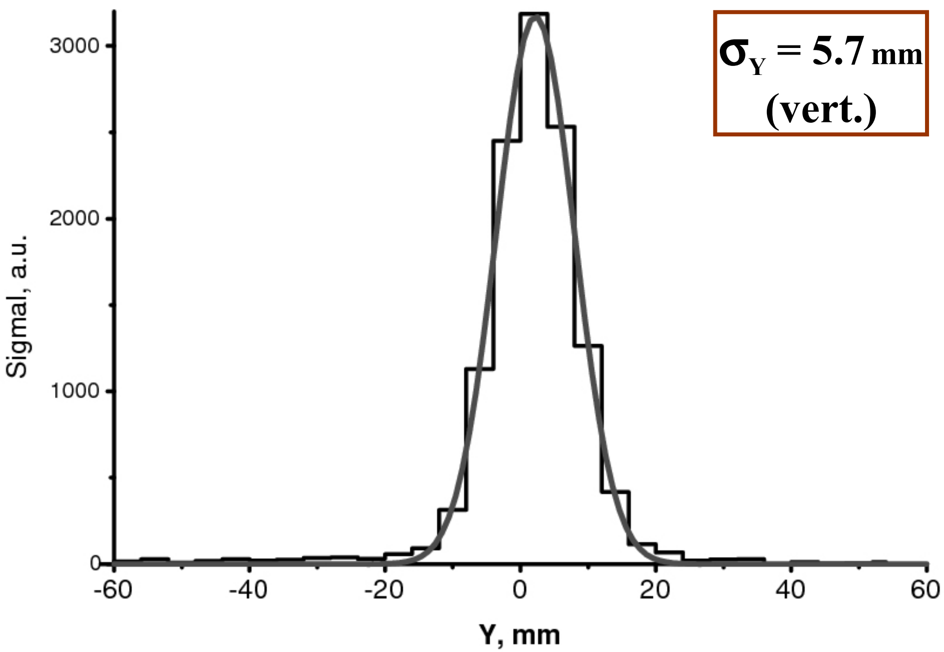

- **Multiwire ionization profilemeters (P13a, P14, P16 )**
- **Scintillation counter ($S_i$)**

# Fragment separation: an optics scheme and realized resolution



## Primary beam profiles at the analyzer plane, $^{12}C$, p= 2A Gev/c



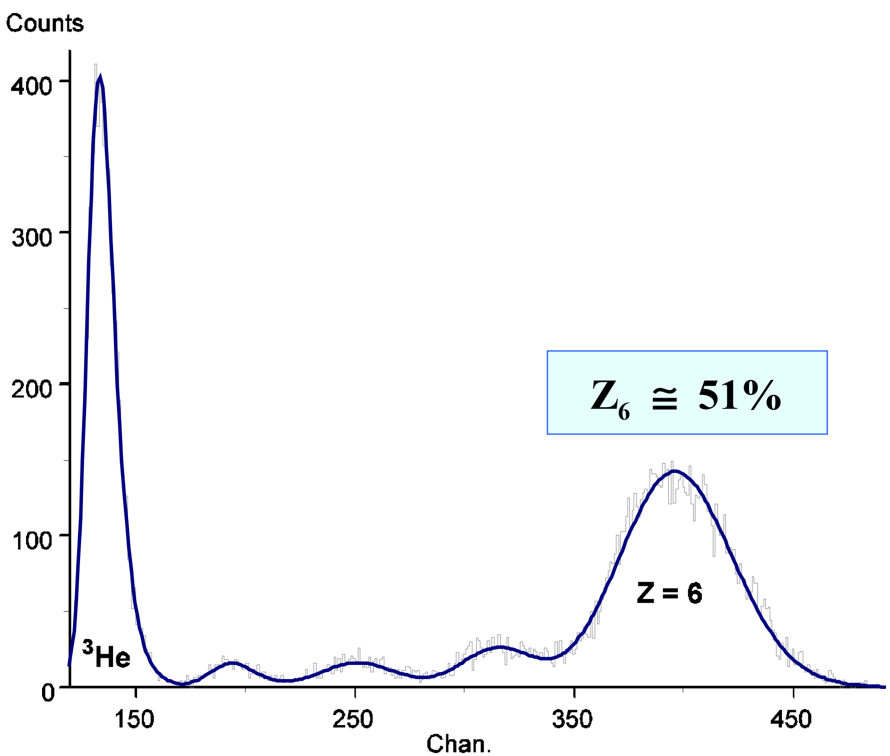



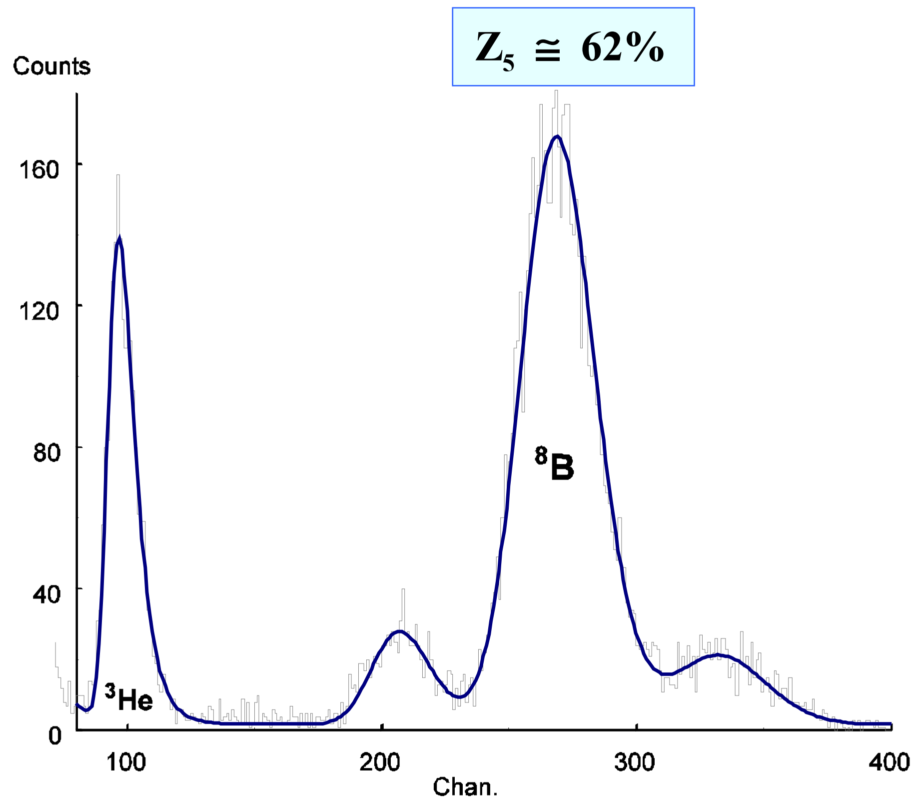

$$R_{exp} = dX/(2\sigma_X\, dP_{deg}) \cong 80,$$

($dP_{deg} \cong 1.3\%$ itrodused by a degrader)

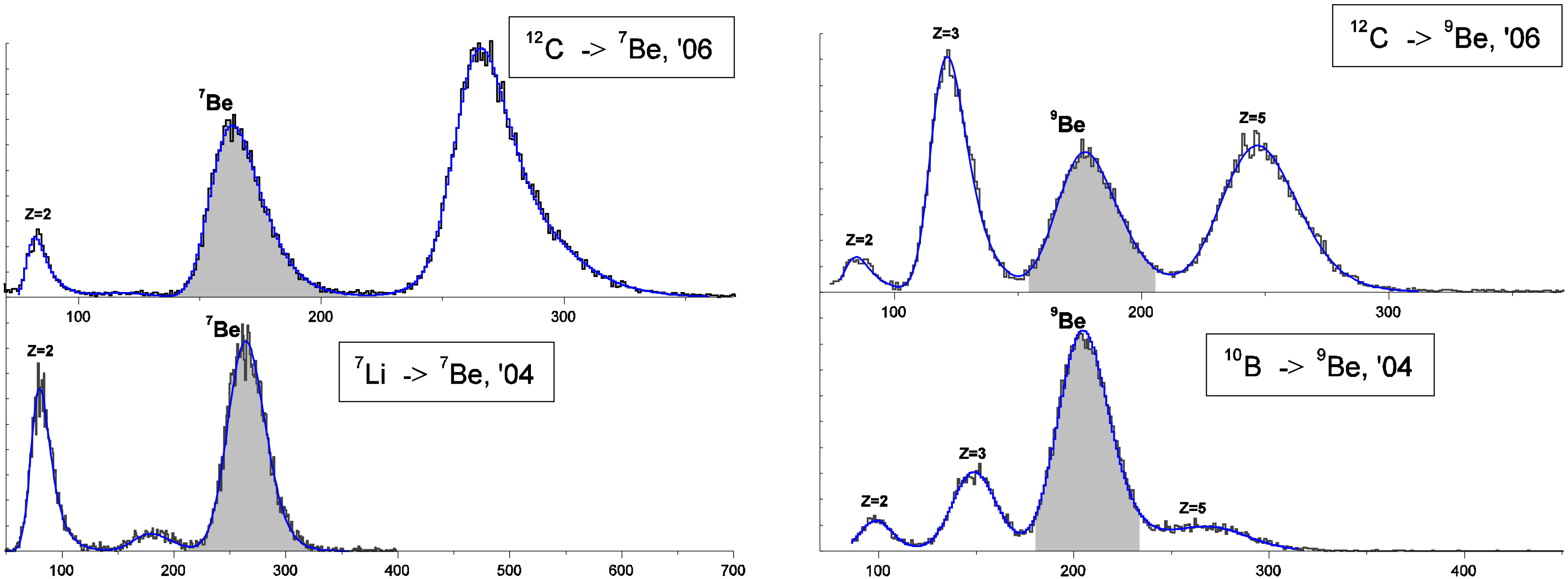
# Secondary fragments beams: $^{12}C + A \rightarrow {}^{9}C + \ldots$, $^{10}B + A \rightarrow {}^{8}B + \ldots$

| Primary beam momentum: | Target: | Separation scheme: | Analyzer: |
|---|---|---|---|
| $p_0 = \mathbf{2.0}$ GeV/c/nucl. | • Polyethylene, **8 g/cm²**<br>• Placing – F3 focus | • VP-1, f3 – f5 + 2SP-40,<br>• $\varphi_{2SP-40} = 0.22$ r | • Plastic scintillator, d=5 mm |



# Secondary beams of the beryllium isotopes - comarission

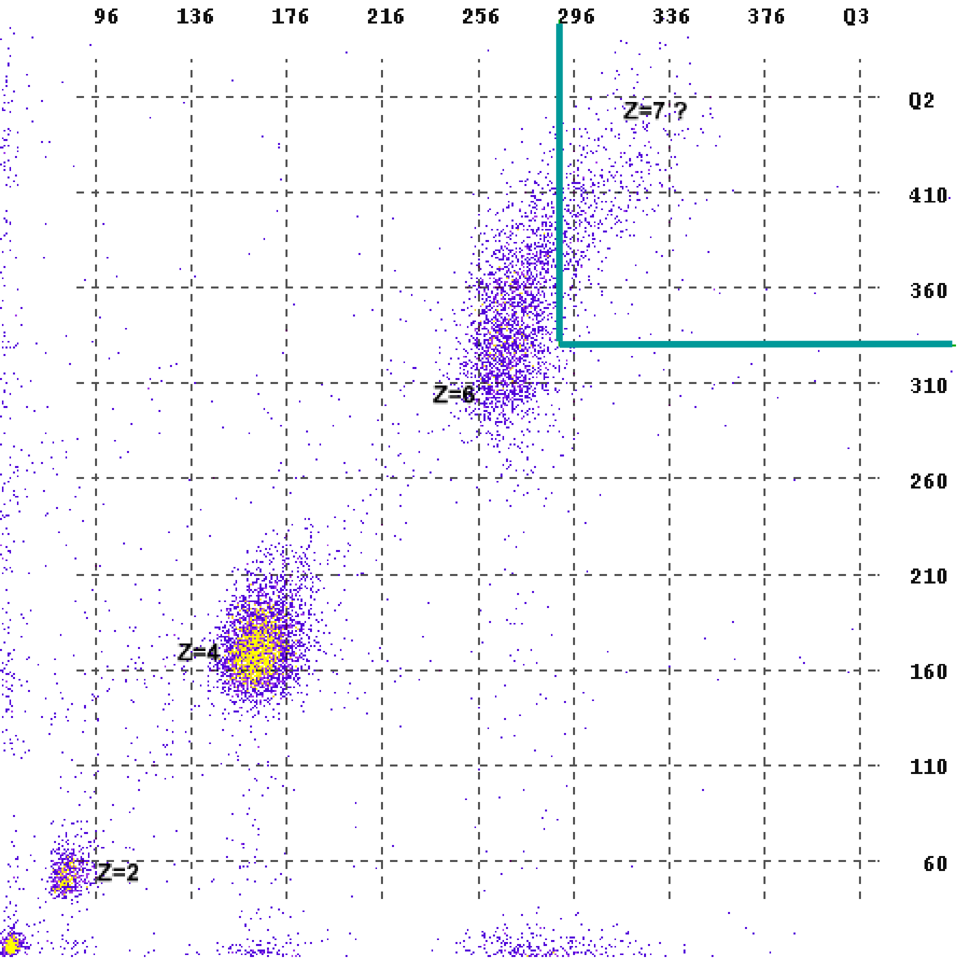


Secondary beam: $^{12}C + A \rightarrow {}^{12}N + \ldots$ ( $p_0$ = 2.0 GeV/c/nucl )

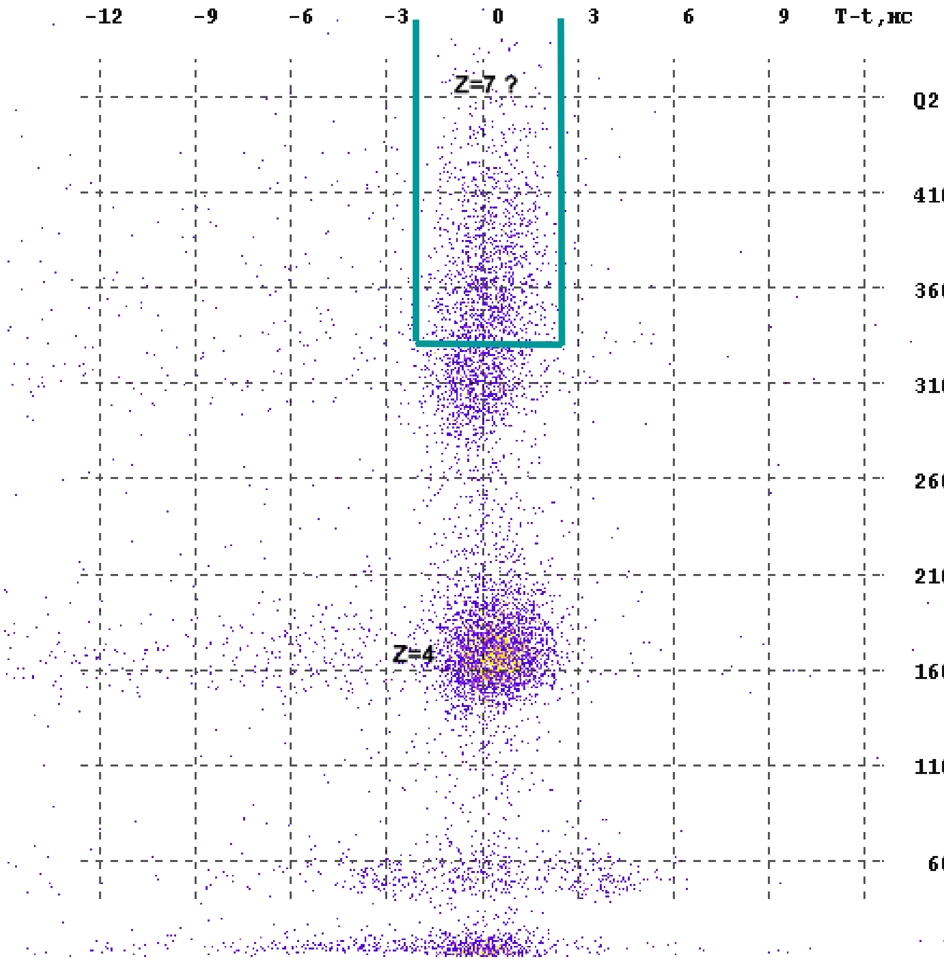
$^{12}N$: $T_{1/2} = 11$ ms

## Correlation plots

### $Q_3 - Q_2$

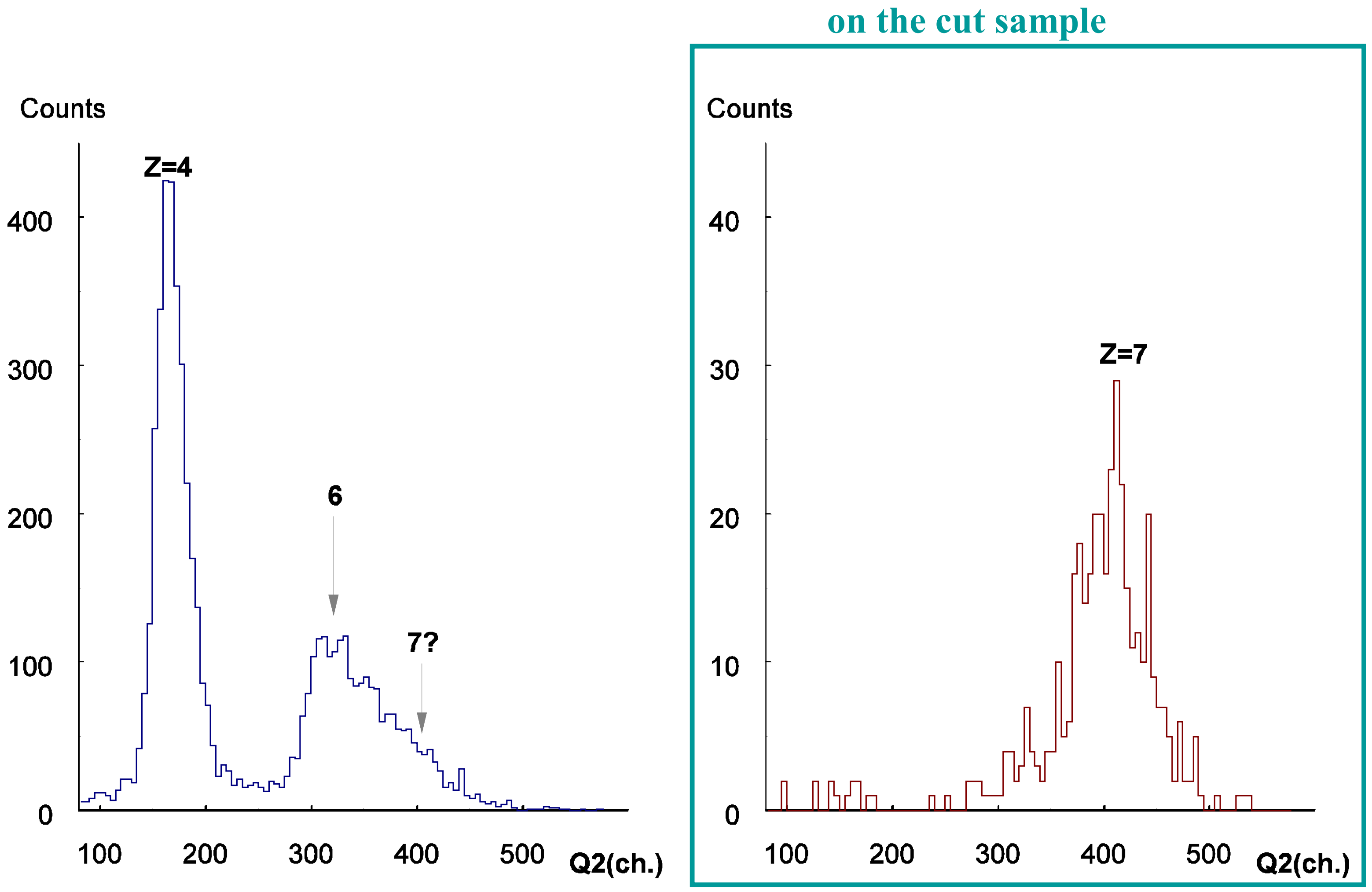



### TOF – $Q_2$



## Secondary beam: $^{12}C + A \rightarrow {}^{12}N + \ldots$ ( $p_0$ = 2.0 GeV/c/nucl )

**Energy losses spectrum in the $S_2$ analyzer (5 mm)**



## Summary

| | $p_0$, $A$ $GeV/c$ | $Proj.$ | $Sec.$[a] | $Registered\ components\ fractions,\ \%$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Z=1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 2.7 | $^6Li$ | $^6He$ | $> 99$ | **0.85** | | | | | |
| 2 | 1.7 | $^7Li$ | $^7Be$ | $2 <$ | 28.3 | $\simeq 5$ | **64.7** | | | |
| 3 | 2.0 | $^{10}B$ | $^9Be$ | | 5.6 | 19.2 | **66.8** | 8.4 | | |
| 4 | 2.0 | $^{10}B$ | $^8B$ | | 19.8 | | 9.1 | **61.6** | 9.5 | |
| 5 | 2.0 | $^{12}C$ | $^9C$ | | 37.3 | 2.2 | 4.0 | 5.6 | **50.9** | |
| 6[b] | 2.0 | $^{12}C$ | $^{12}N$ | | $\simeq 10$ | | 53 | | 34 | $\simeq$ **3** |
| 7[b] | 2.0 | $^{12}C$ | $^7Be$ | | $\simeq 5$ | | **32** | | 63 | |
| 8[b] | 2.0 | $^{12}C$ | $^9Be$ | | $\simeq 3$ | 31 | **29** | 37 | | |

[a]Nominal beam line momentum corresponds to the fragment
[b]Preliminary

## Acknowledgments

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# Thank for your attention