Average charges of heavy recoil ions in various gases and their mixtures

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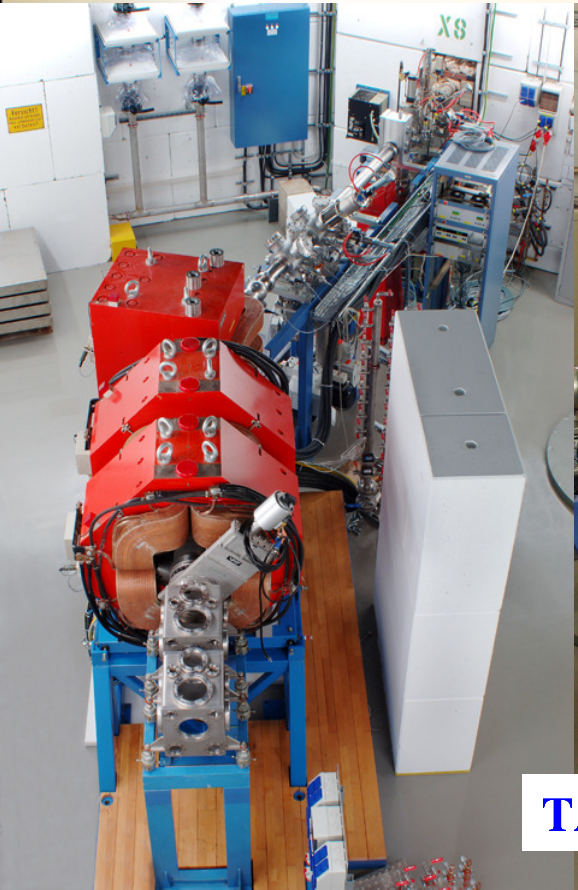


TASCA workshop at GSI, 18 November 2010

Introduction

- **Gas filled separator-Average charges of heavy ions**
- **Semi-empirical expressions from BGS (LBNL, Berkeley), DGFRS (JINR, Dubna), GARIS (RIKEN, Wako)…**

TASCA

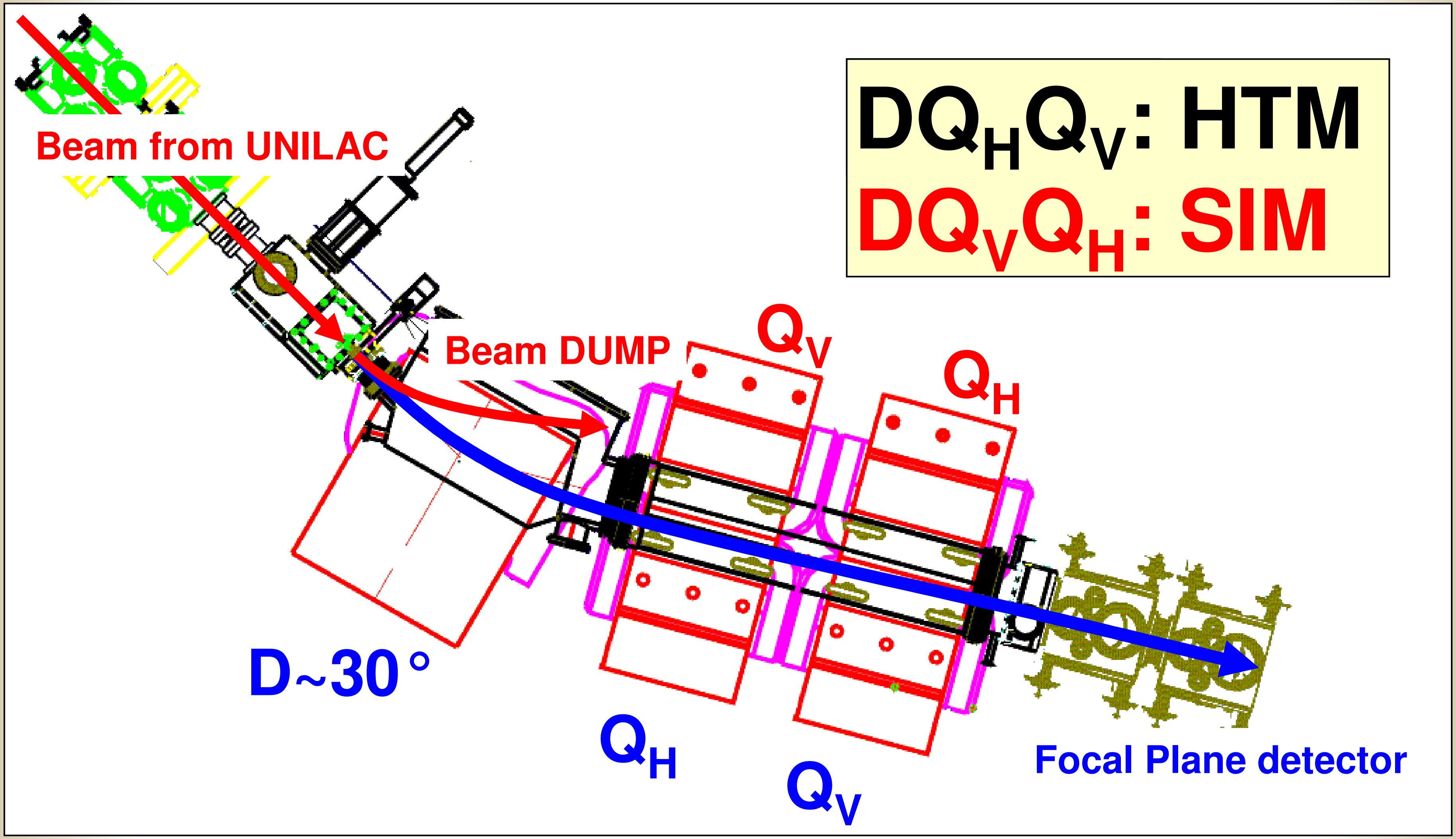
- **Determination of charges at different gas pressures of helium and hydrogen**
- **Use of gas mixtures (helium and hydrogen)**
- **Prediction of average charges in pure gases and mixtures**

Average charges of Nobelium ions produced in fusion-evaporation reactions $^{48}Ca+^{206\text{-}208}Pb$

- **^{48}Ca from ECR ions source, 5 ms pulse with 50 Hz frequency from UNILAC was used**
- **Three segments of lead sulfide (PbS) targets (ARTESIA type) with thicknesses of about 550 μg/cm^2 on 2.2μm Ti foils was used**

Experimental setup

TransActinide Separator and Chemistry Apparatus
TASCA



M. Schädel *et al.,* GSI Scientific Report 2005, GSI, Darmstadt, Germany, Report 2006-1, 2006, p. 262; see also http://www.gsi.de/TASCA

TransActinide Separator and Chemistry Apparatus TASCA

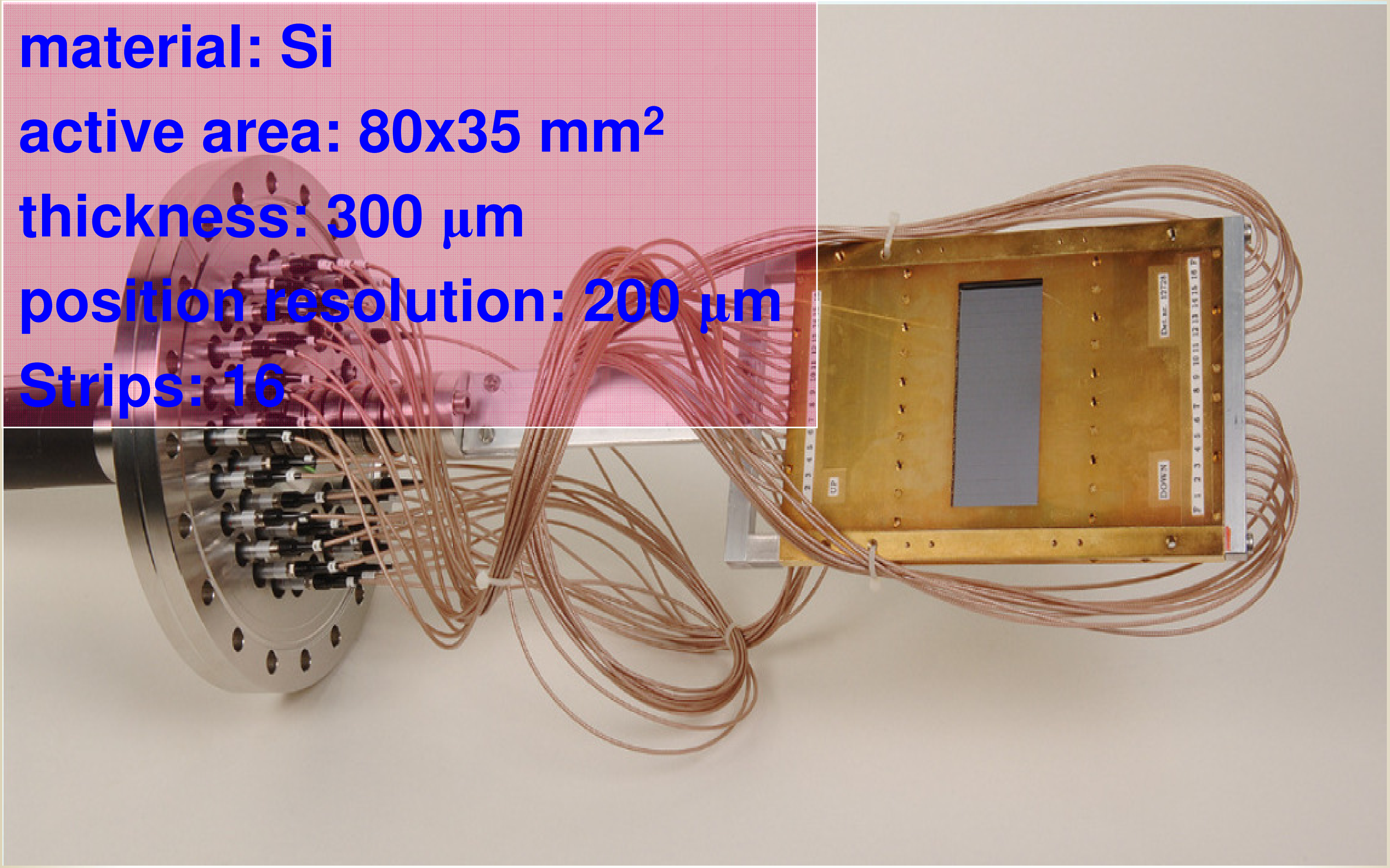
material: Si

active area: 80x35 mm^2

thickness: 300 μm

position resolution: 200 μm

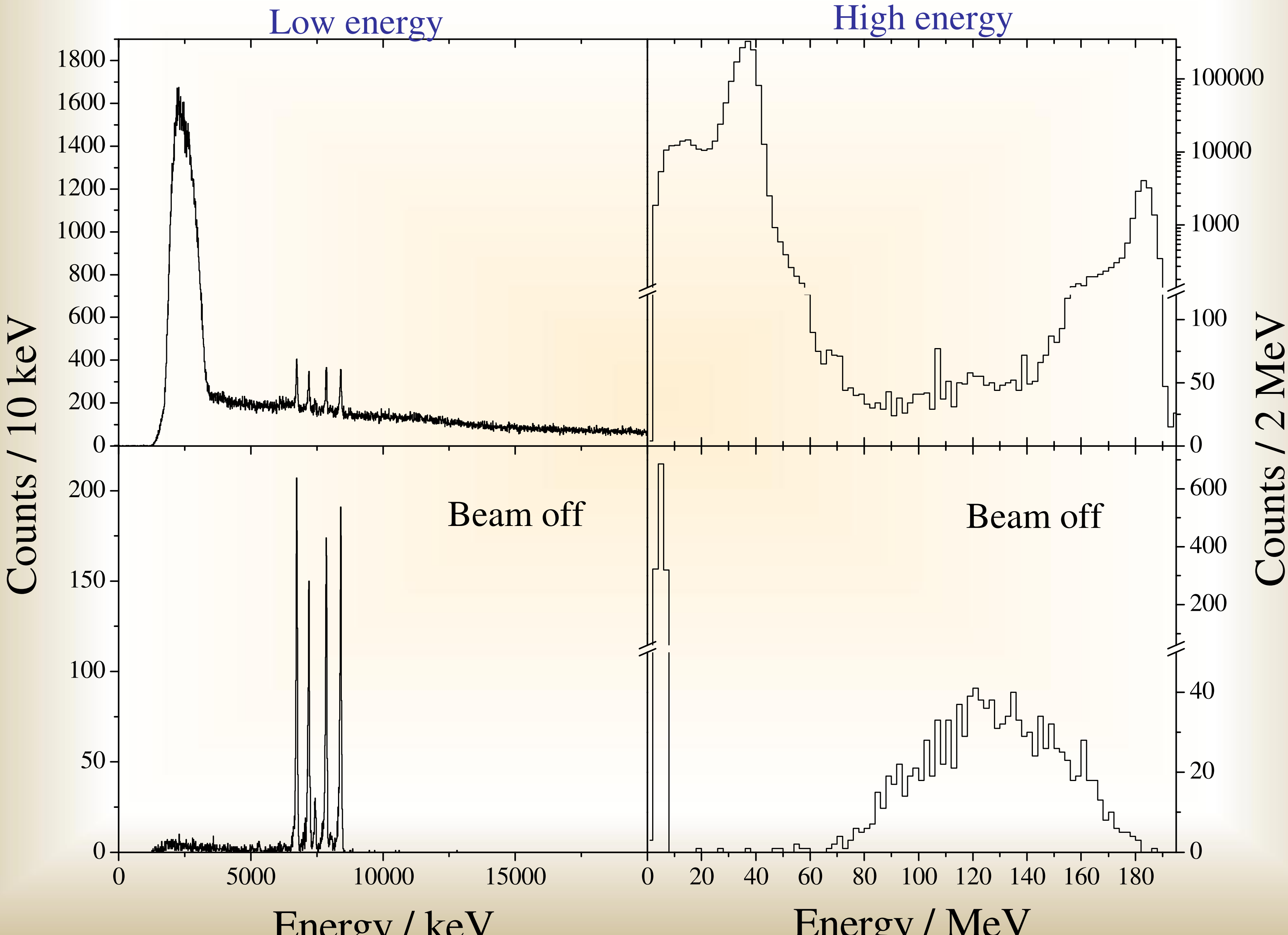
Strips: 16



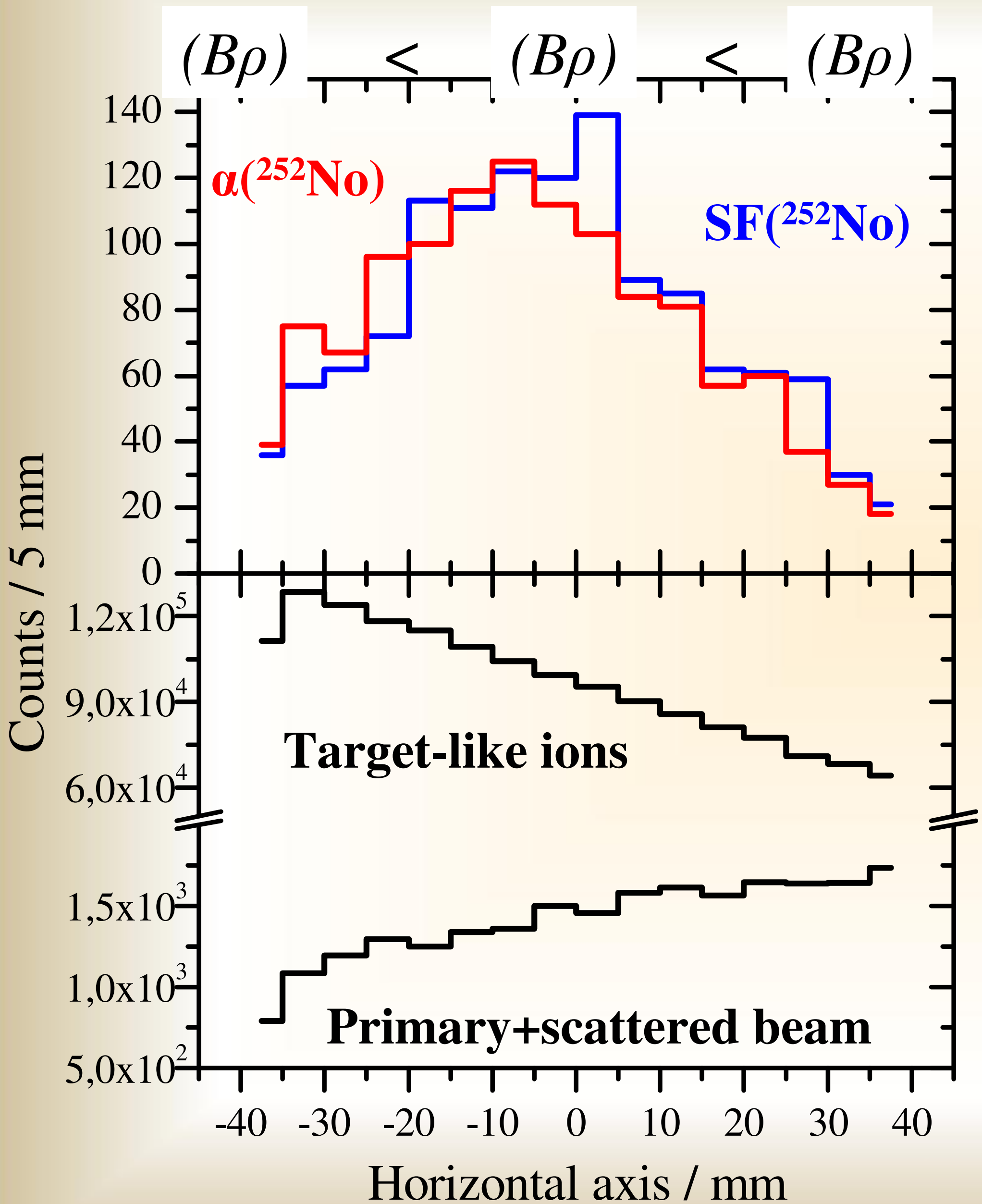
M. Schädel *et al.,* GSI Scientific Report 2005, GSI, Darmstadt, Germany, Report 2006-1, 2006, p. 262; see also http://www.gsi.de/TASCA

Energy spectra from the reaction $^{48}Ca+^{206}Pb$

(HTM, $(B\rho)_0$=2.08 TM, P_{He}=0.8 mbar)



Distribution of detected events which have different origins



Transmission:
$\alpha(^{252}No)$ and $SF(^{252}No) \rightarrow EVR(^{252}No)$

Target-like ions:
Events with E=(20-100) MeV

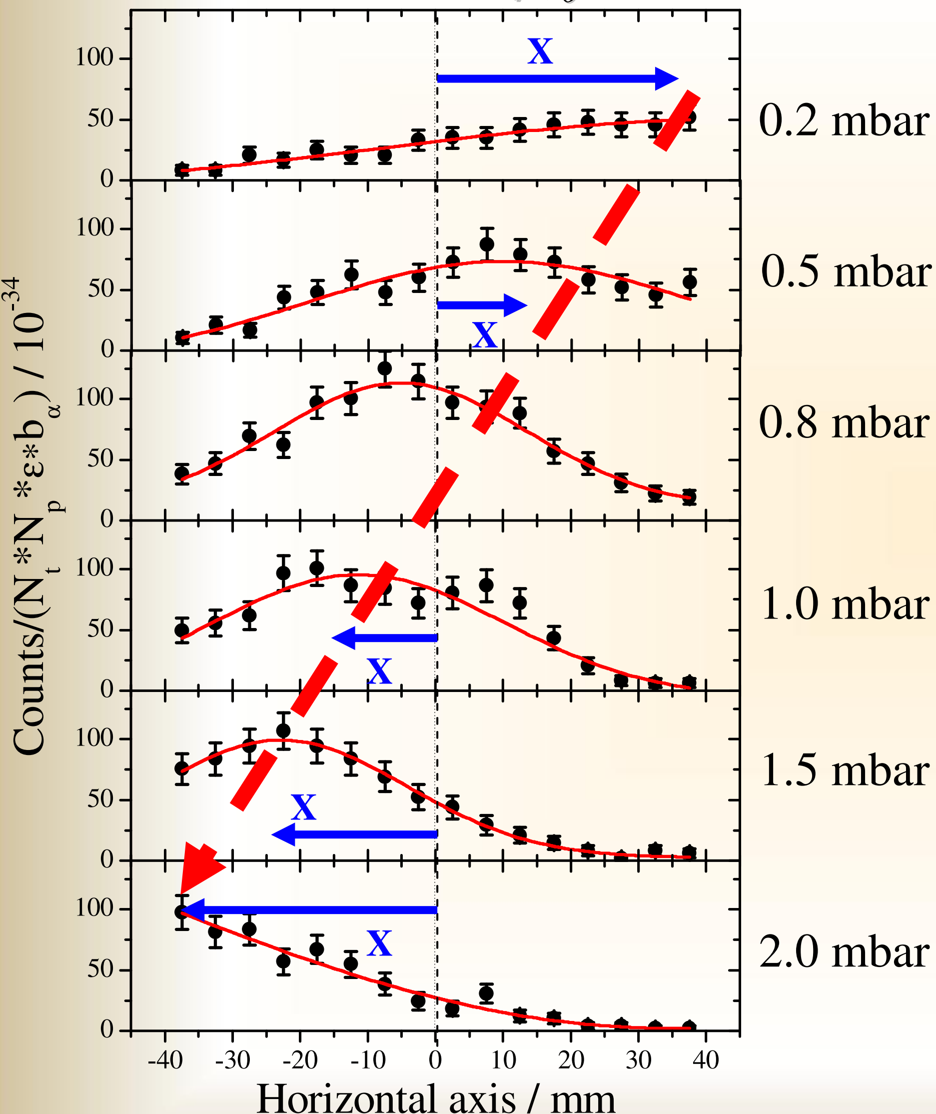
Beam-like ions:
Events with E>100 MeV

Main counting rate on the detector produced by target-like and beam-like ions.

Average charges in pure He and H_2

Dependence of the EVR's distributions on the gas pressure

HTM, $^{48}Ca+^{206}Pb$, $(B\rho)_0$=2.07 Tm



Real magnetic rigidity of EVR's

$$(B\rho)_{ion} = (B\rho)_0 \times \left\{1 + \frac{x}{100 \cdot D}\right\}$$

Yu.Ts. Oganessian *et al.*, PRC. 64 (2001)064309.

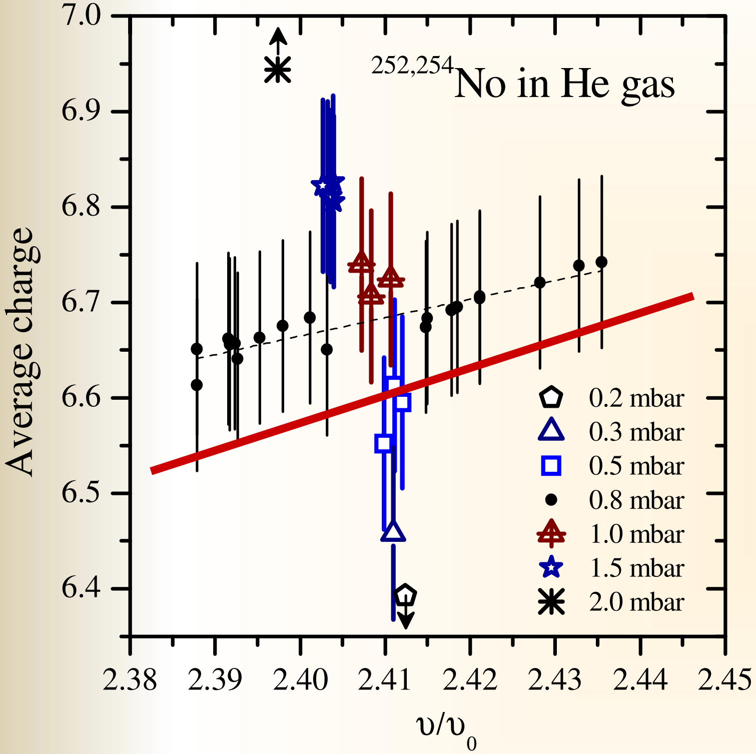
$(B\rho)_0$-magnetic rigidity of separator

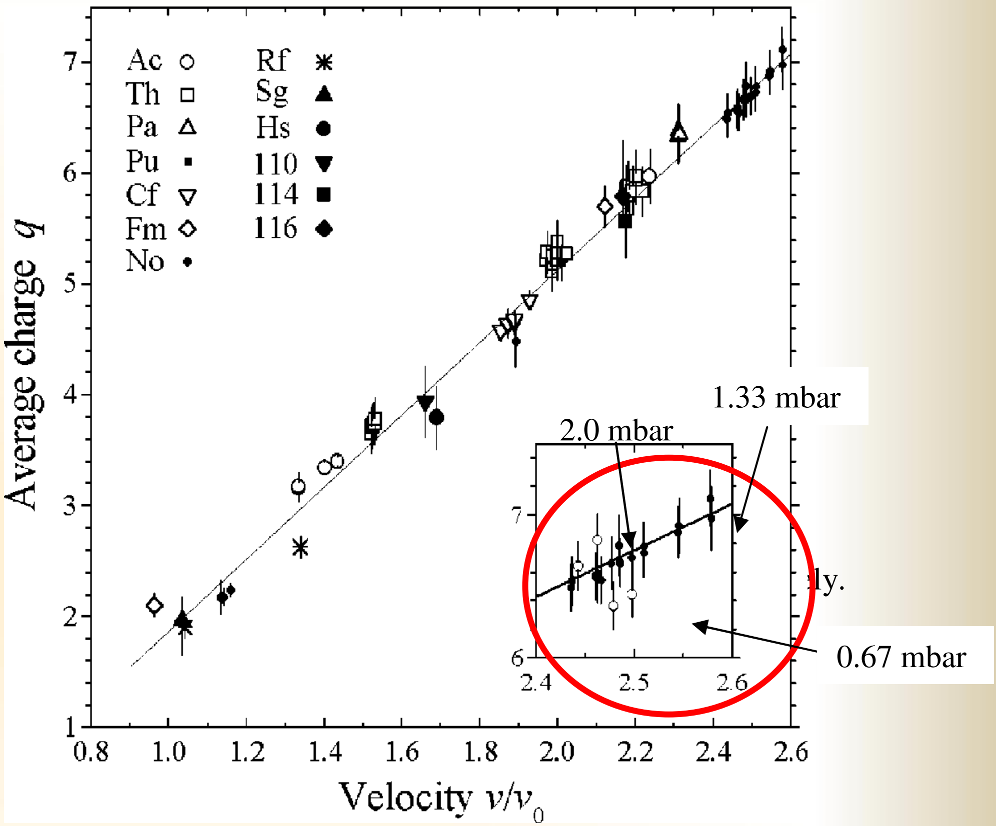
$$(B\rho)_{ion} = 0.0227A\frac{(\upsilon/\upsilon_0)}{\bar{q}}$$

υ-was estimated in the middle of dipole magnet using the PACE2, TRIM and table of L. C. Nortiicliffe for reaction kinematics, energy loss of ER's in target and gas, respectively.

Dependence of the EVR's distributions on the gas pressure

HTM, $^{48}Ca+^{206}Pb$, $(B\rho)_0$=2.07 Tm





Average charges in the hydrogen gas depend on velocities
Figure from Yu.Ts. Oganessian *et al*., PRC. 64 (2001)064309.

Our measured average charges were in agreements with calculated ones within error bars. Semi-empirical formulas were taken from K.E. Gregorich *et al*., PRC. 72 (2005) 014605. and Yu.Ts. Oganessian *et al*., PRC. 64 (2001) 064309.

“Density effect”

$$q_{ion} = \overline{q} + \Delta q$$
$$\Delta q = \overline{q} / 5$$

The maximum density effect was estimated by Bohr and Lindhard as 20%.

H.-D. Betz, Rev. Mod. Phys. 44 (1972) 465.

In order to explain the experimental results on the density effect obtained by Lassen (1951a, b), Bohr and Lindhard (1954) describe a simplifying model for the excitation and de-excitation of fission fragments. They derive an expression for the increase of the average equilibrium charge as a function of the target gas density

$$\Delta\bar{q} = (\beta_t + \beta_c)\tau v \sigma_t \rho / [(\alpha_t + \alpha_c)(2\tau v \sigma_t \rho + 1)], \qquad (6.9)$$

where τ is the lifetime under investigation, v the ion velocity, ρ the density of the target gas, and σ_t the total charge-changing cross section which, in fact, stands for the effective excitation cross section. For

Fit functions

$$q_{ion} = \overline{q} + \frac{a}{b + y}$$

Where y is a variable determined as

$y = [(\upsilon/\upsilon_0) \cdot P]^{-1}$

P is the gas pressure

$$(B\rho)_{ion} = \frac{a + b \cdot y}{c + y}$$

Magnetic rigidities and average charges of No ions at different gas pressures

Mean charges have linear dependences on velocities

$$\bar{q} = Z^{1/3} \cdot (\upsilon / \upsilon_0) \quad \text{for} \quad 1 < (\upsilon/\upsilon_0) < Z^{2/3} \Rightarrow (B\rho) = 0.0227 \times \frac{A}{Z^{1/3}} \quad [Tm]$$

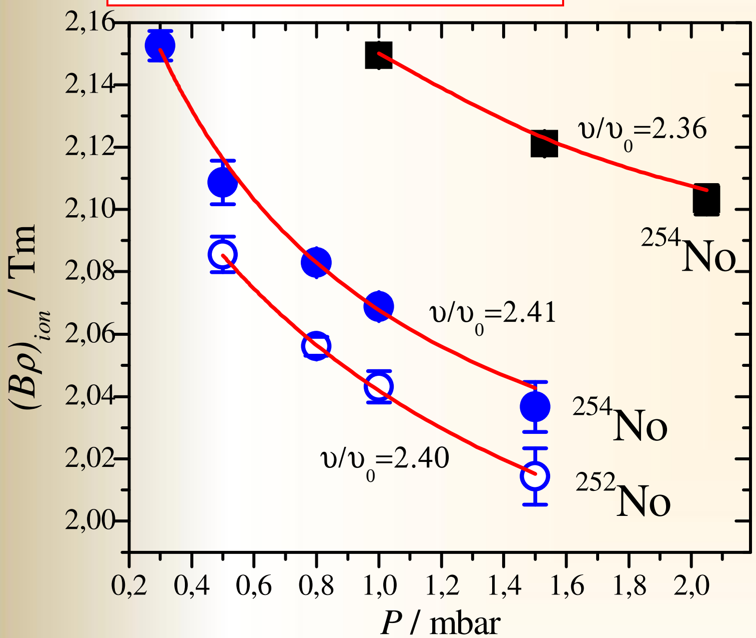
N. Bohr, Phys. Rev. 58 (1940) 654.

Magnetic rigidity does not depend on initial velocity and charge state

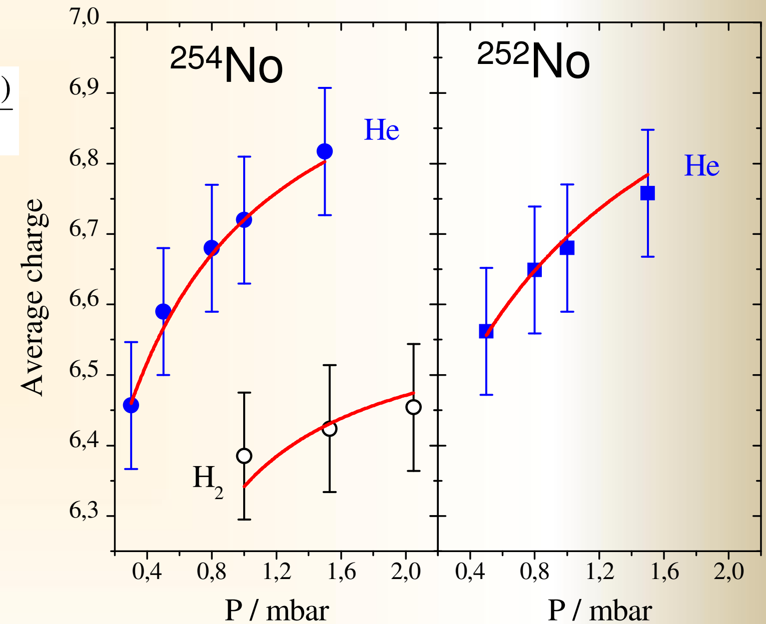
$$(B\rho)_{ion} = (B\rho)_0 \times \left\{ 1 + \frac{x}{100 \cdot D} \right\}$$

$(B\rho)_0$ is same for each measurements

Use of the magnetic rigidity for the determination of "density effect".



$$(B\rho)_{ion} = 0.0227 \cdot \frac{A \cdot (\upsilon / \upsilon_0)}{\bar{q}}$$



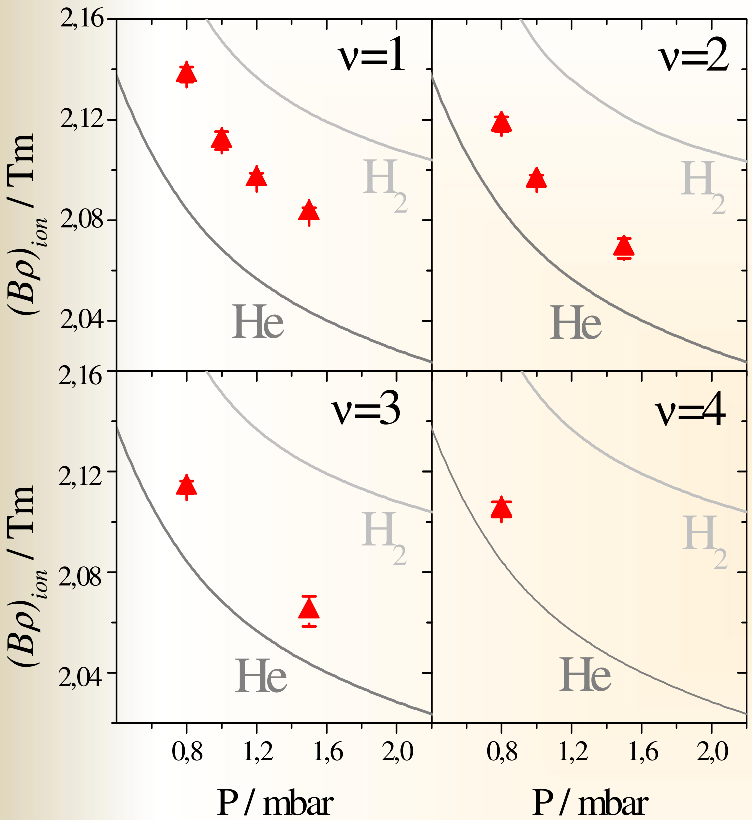
He: $(B\rho)_{ion} = \dfrac{a + b \cdot y}{c + y}$

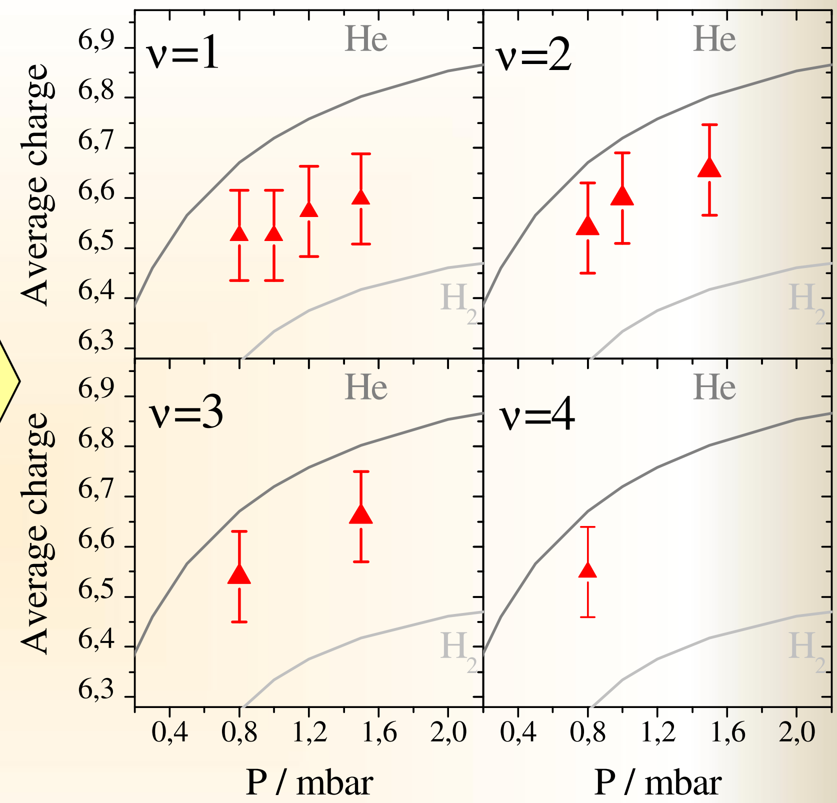
H$_2$: $(B\rho)_{ion} = a + b \cdot y$

Curve is determine the influence of "density effect". Similar behavior of curves for ^{254}No and ^{252}No ions in the helium gas means that influence of "density effects" to these ions are same. This could be due to the same charge-exchange cross-sections (these ions have same atomic shells).

Average charges in the mixture of He and H_2

Magnetic rigidities and average charges of ^{254}No ions in the gas mixture





In the present experiments the velocities of EVR's (^{254}No) were within the regions:

Helium: $(\upsilon/\upsilon_0)=2.41\pm0.03$

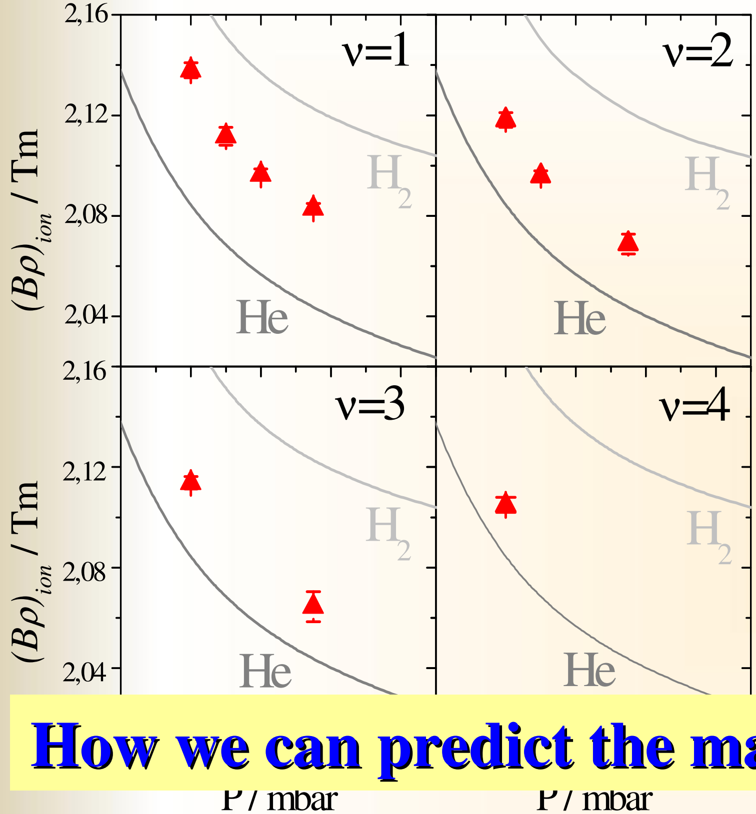
Hydrogen: $(\upsilon/\upsilon_0)=2.36\pm0.03$

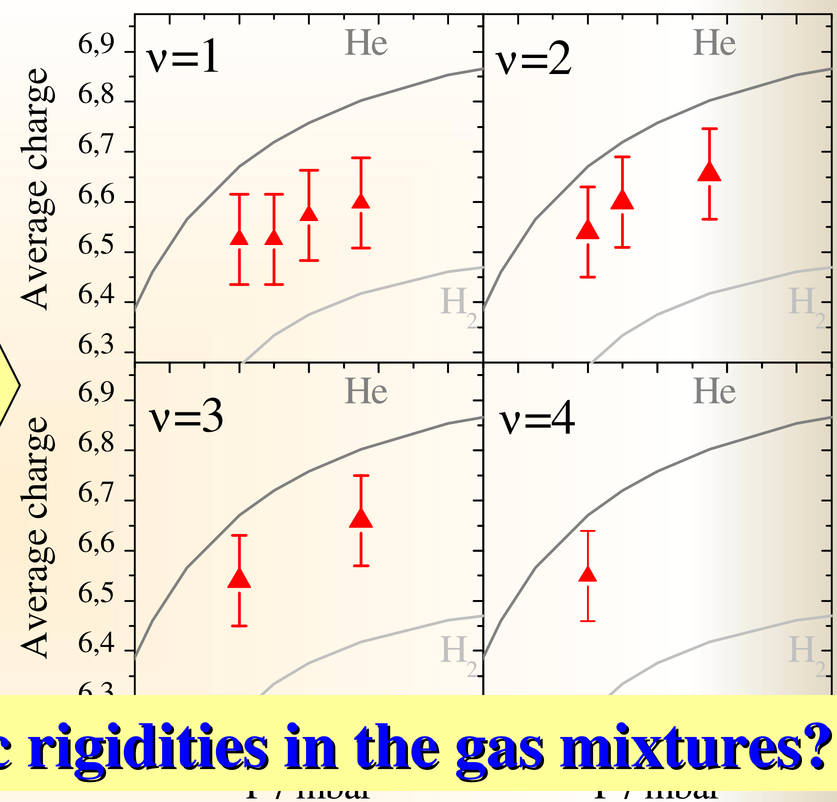
Mixture: $(\upsilon/\upsilon_0)=2.39\pm0.03$

*We know: **$(B\rho)_{ion}$** for pure **helium** and **hydrogen** depends on gas pressure!*

*Ratio of gases **$\nu=n_{He}/n_{H2}$***

Magnetic rigidities and average charges of ^{254}No ions in the gas mixture





How we can predict the magnetic rigidities in the gas mixtures?

In the present experiments the velocities of EVR's (^{254}No) were within the regions:

Helium: $(\upsilon/\upsilon_0)=2.41\pm0.03$

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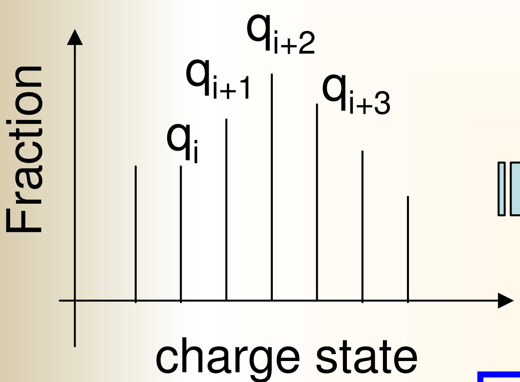
*We know: $(B\rho)_{ion}$ for pure **helium** and **hydrogen** depends on gas pressure!*

Ratio of gases $\nu=n_{He}/n_{H2}$

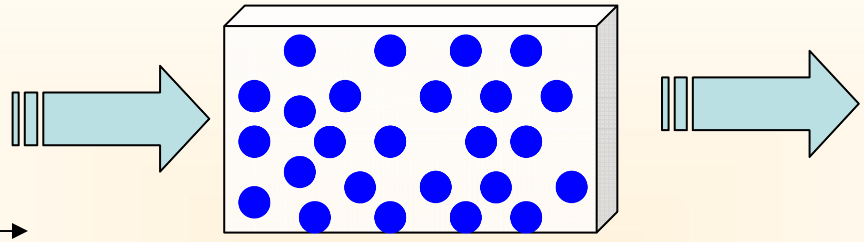
Mathematical description of the charge-exchange process

EVR

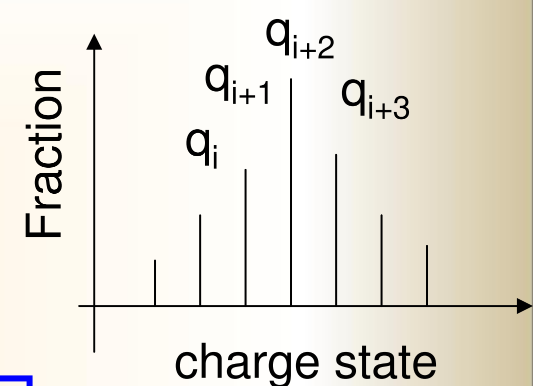


Gas filled region

Pure gas (He or H_2)



EVR



Charge state - i,

Fraction – F_i

$\Sigma F_i = 1$

$$\frac{dF_i(n)}{dx} = \sum_{j,\, j \neq i} \left[\sigma_{ij} \cdot F_j(n) - \sigma_{ji} \cdot F_i(n) \right]$$

x-density of gas [1/cm^2]

σ_{ij}-electron capture cross-section

σ_{ji}-electron loss cross-section

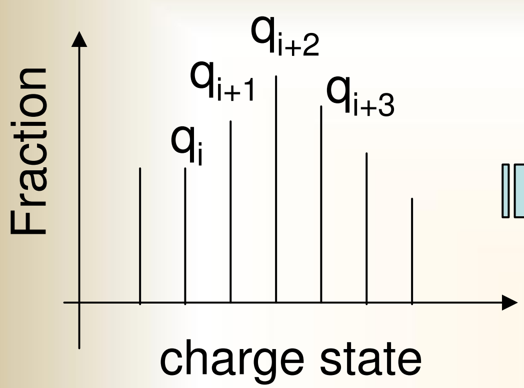
n -number of particles per square centimeter traversed by the heavy ion

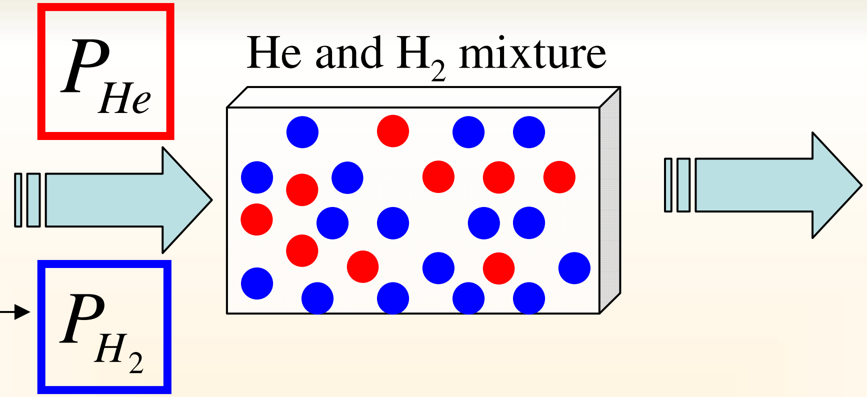
$$\overline{q} = \sum_i q_i \cdot F_i$$

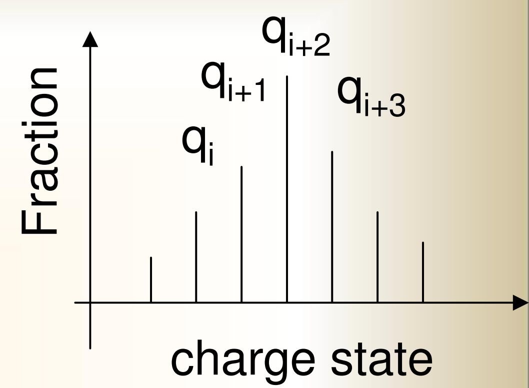
If ***$dF_i(n)/dx \rightarrow 0$*** *than charge states of heavy ions will be equilibrated!*

H.-D. Betz, Rev. Mod. Phys. 44 (1972) 465.

EVR | **Gas filled region** | **EVR**







Charge state - i,

Fraction – F_i

$\Sigma F_i = 1$

$$F_i^{mix} = F_i \cdot P_{He} + F_i \cdot P_{H_2}$$

$$\sum_i F_i^{mix} = \sum_i \left[F_i \cdot P_{He} + F_i \cdot P_{H_2} \right] = 1$$

$$\overline{q}_{mix} = \sum_i q_i \cdot F_i^{mix}$$

$$\overline{q}_{mix} = \sum_i q_i \cdot \left[F_i \cdot P_{He} + F_i \cdot P_{H_2} \right]$$

$$\overline{q}_{mix}(n_{tot}) = P_{He} \cdot \sum_i q_i \cdot F_i + P_{H_2} \cdot \sum_i q_i \cdot F_i$$

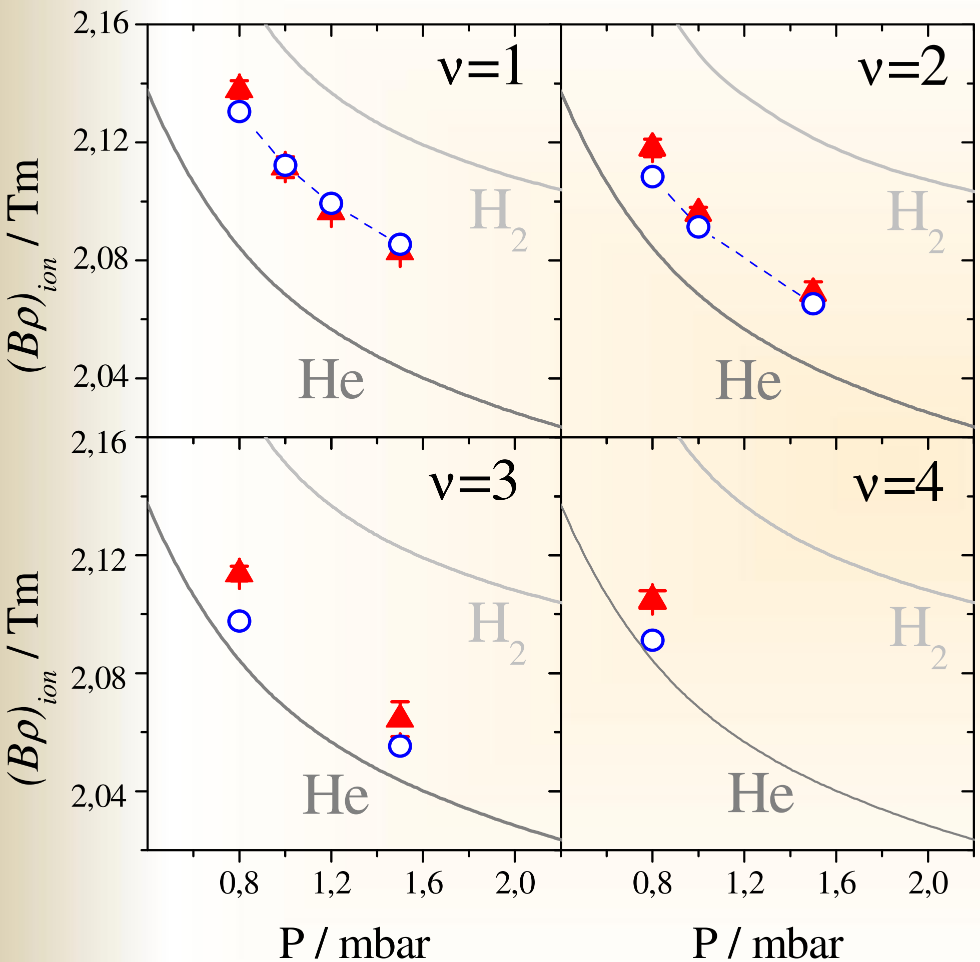
$$\overline{q}_{mix}(n_{tot}) = q_{He}(n_{tot}) \cdot P_{He} + q_{H_2}(n_{tot}) \cdot P_{H_2}$$

Weighted mean value!!

***n_{tot}*- total number of atoms**

$$(B\rho)_{ion}^{mix}(n_{tot}) = \frac{(B\rho)_{ion}^{He}(n_{tot}) \cdot (B\rho)_{ion}^{H_2}(n_{tot}) \cdot (1+\nu)}{(B\rho)_{ion}^{He}(n_{tot}) \cdot (\upsilon/\upsilon_0)_{H_2} + (B\rho)_{ion}^{H_2}(n_{tot}) \cdot (\upsilon/\upsilon_0)_{He} \cdot \nu} \cdot (\upsilon/\upsilon_0)^{mix}$$

Magnetic rigidities of ^{254}No ions in the gas mixture



With increasing of the gas ratios the magnetic rigidities are changing.

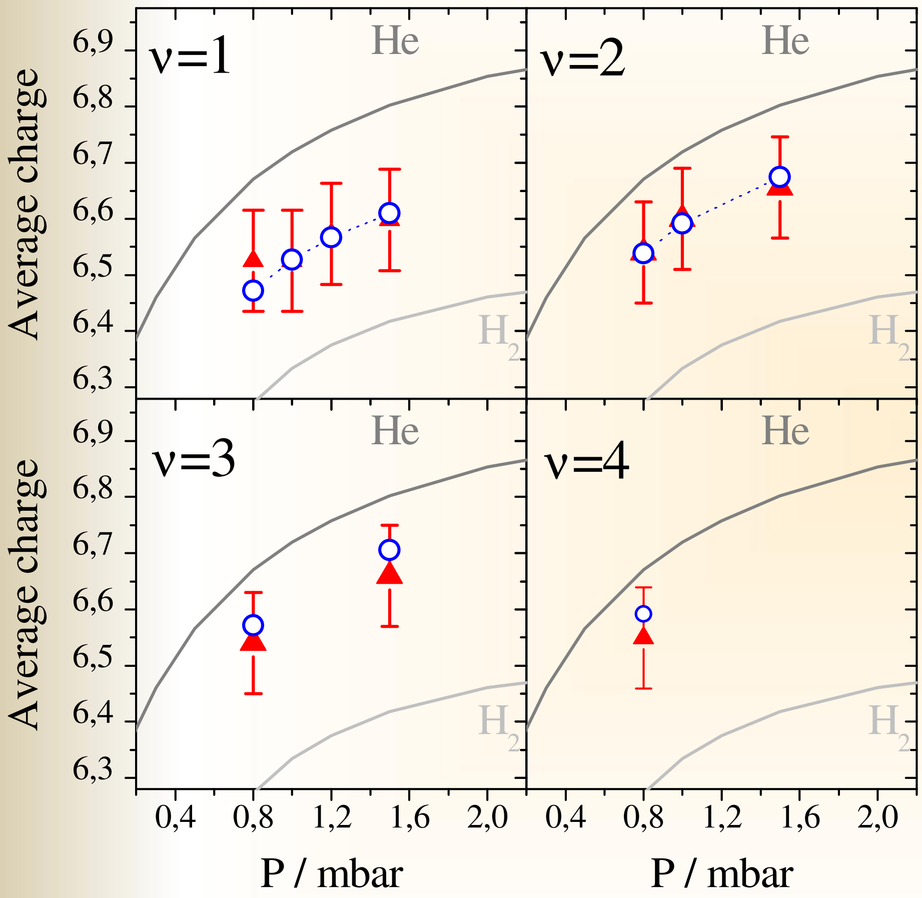
If $\nu = n_{He}/n_{H2} > 1$ increase then

$(B\rho)^{mix} \rightarrow (B\rho)^{He}$

If $\nu = n_{He}/n_{H2} < 1$ decrease then

$(B\rho)^{mix} \rightarrow (B\rho)^{H2}$

Average charges of ^{254}No ions in the gas mixture



With increasing of the gas ratios the average charges are changing.

If $\nu = n_{He}/n_{H2} > 1$ increase then

$(q)^{mix} \rightarrow (q)^{He}$

If $\nu = n_{He}/n_{H2} < 1$ decrease then

$(q)^{mix} \rightarrow (q)^{H2}$

Summary and conclusions

- Magnetic rigidities and average charges of No's were determined in the He, H_2 and mixtures of them.

- Average charges of heavy ions (EVR's) are changing depend on the gas pressure of pure He and H_2.
- This effect can be attributed to the so called "density effect".
- Average charges of heavy ions can be determined by the semi-empirical expression (i).

- The expression for the determination of average charges of heavy ions in the gas mixture is given (ii)

- Experimentally determined magnetic rigidities and average charges well predicting by using the (i) and (ii) at different gas pressures and mixtures

"Density effect" and gas mixtures should be studied in "more" heavy ion reactions and also it could be tested for the improvement of transmissions and suppression factors for various kind of reactions. It also should be included to the ion optical simulation programs.