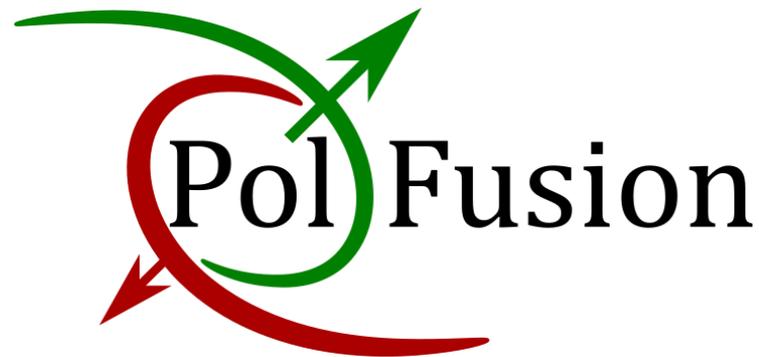
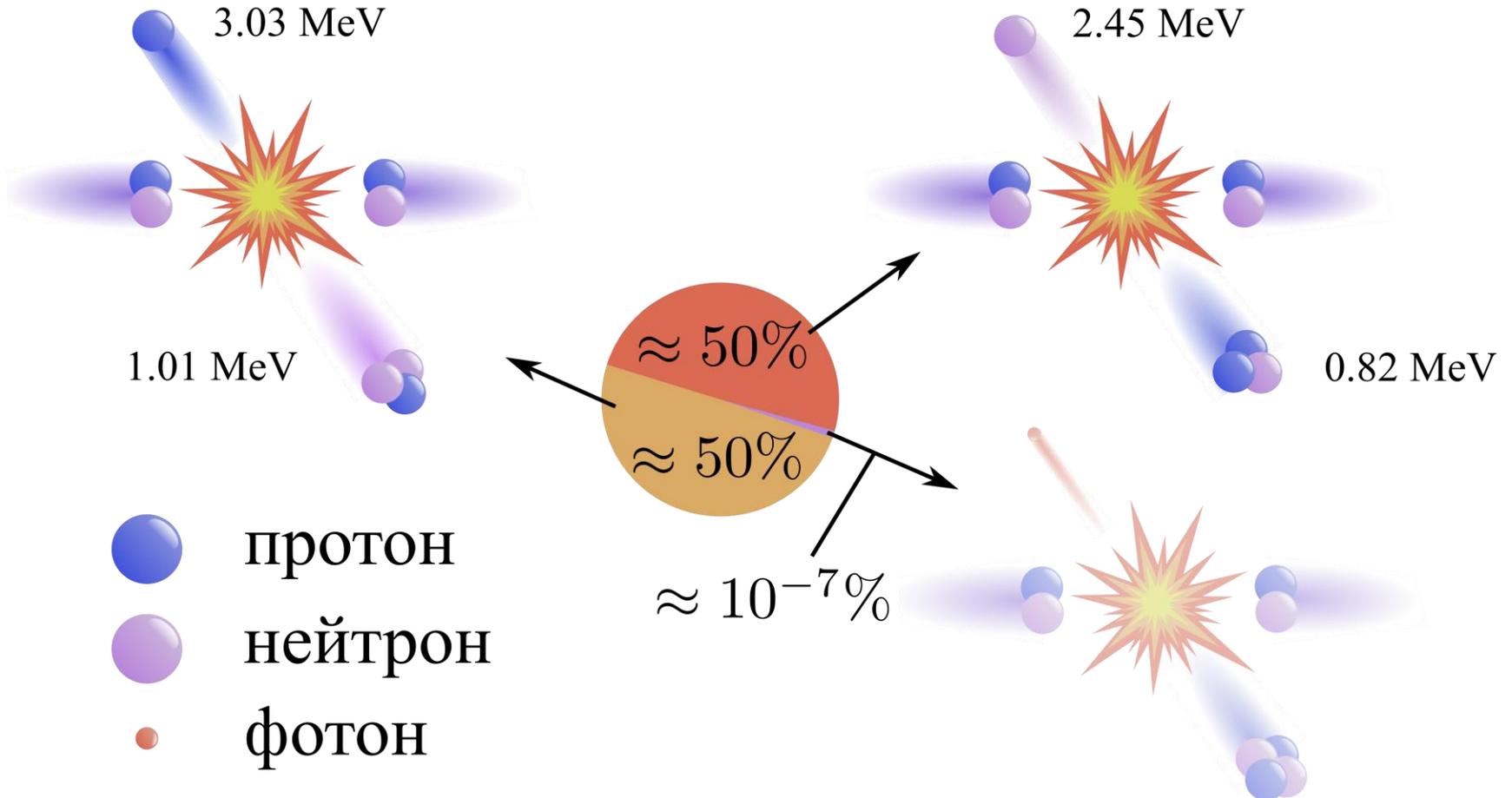
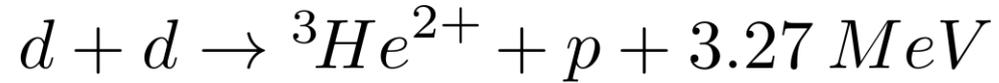
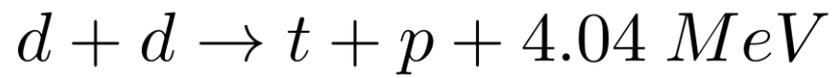


Источники поляризованных атомов и ионов дейтерия в эксперименте PolFusion.



Александр Николаевич Соловьев

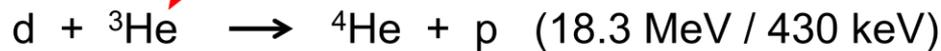
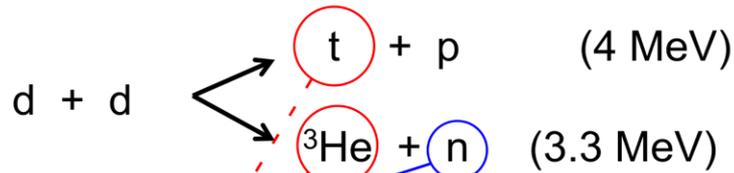
научный сотрудник ЛКСТ ОФВЭ



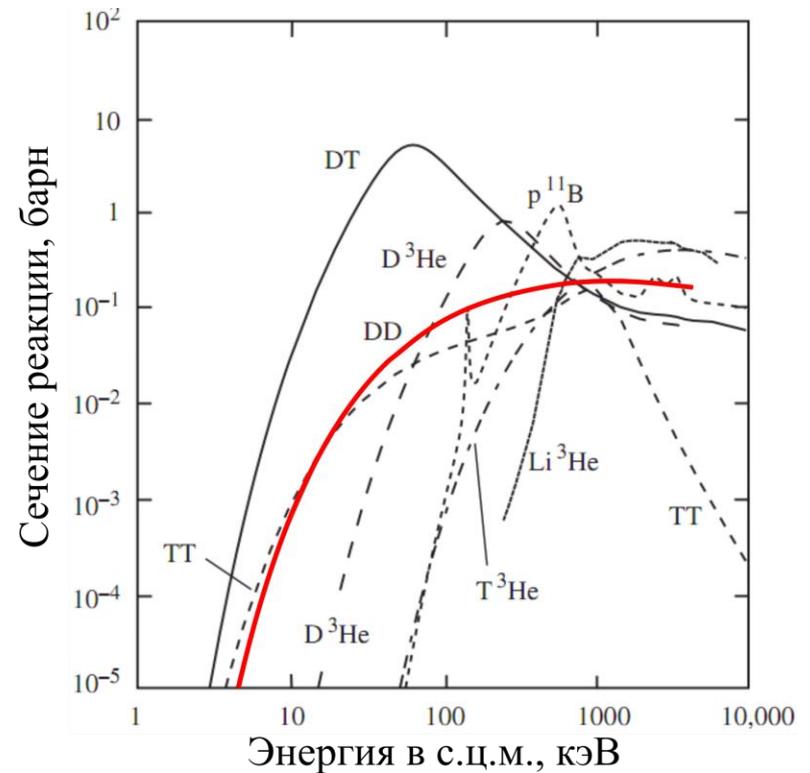
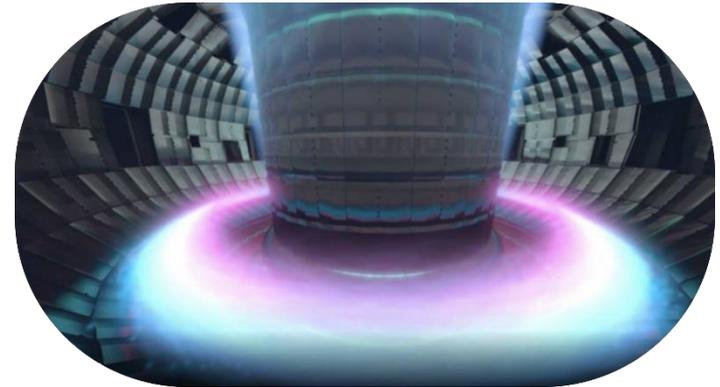
1 поколение:



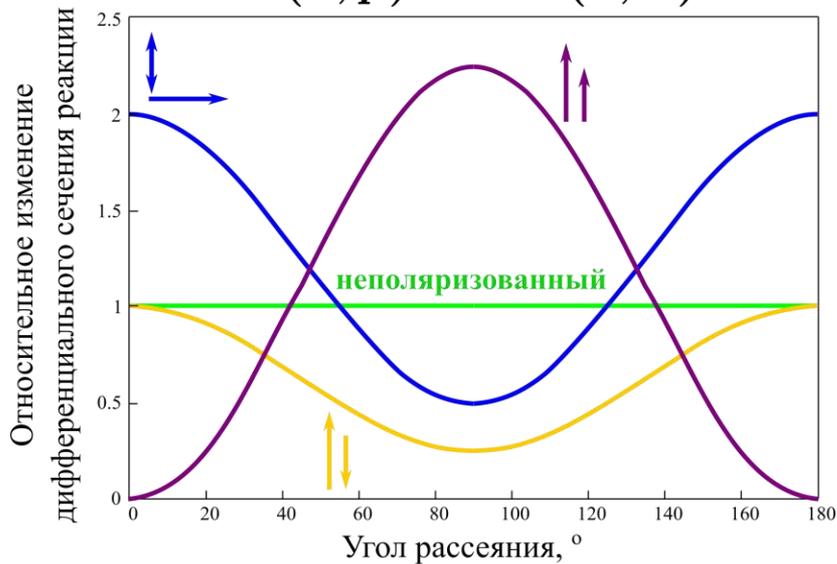
2 поколение:



3 поколение:



- Увеличение сечения реакции
- Контроль над направлением разлёта продуктов реакции
- Подавление нейтронного канала

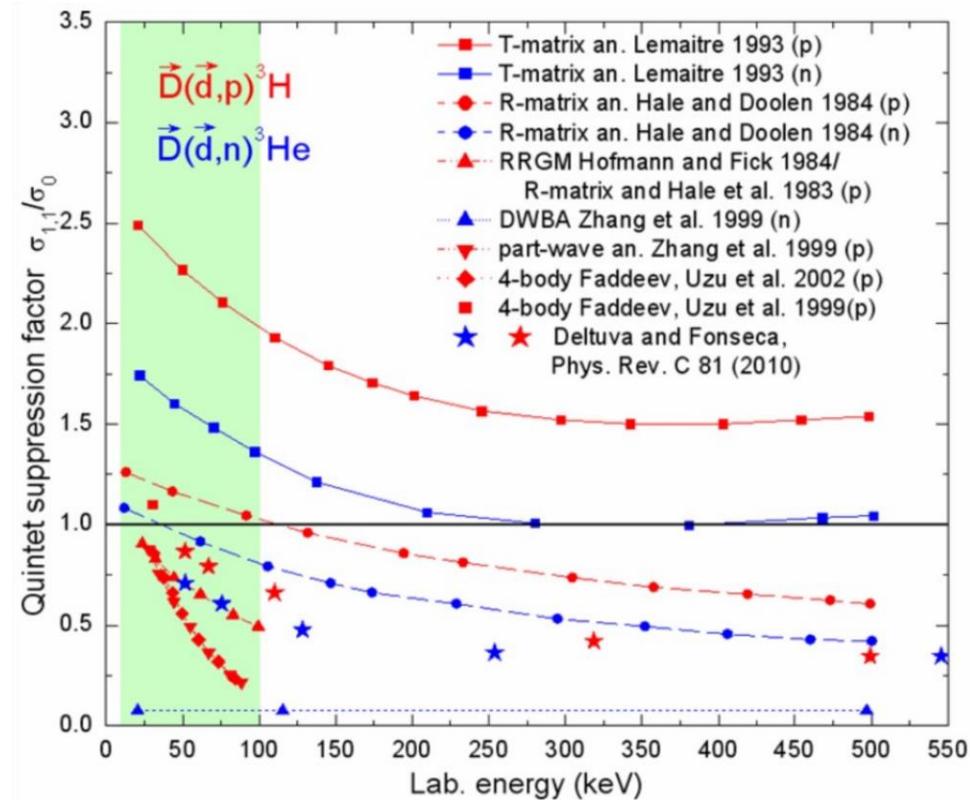


Ch. Leemann et al., *Helv. Phys. Acta* **44**, 141 (1971)

R. Engels et al., *PoS SPIN 2018*, 176 (2019)

H. Paetz gen. Schieck *Nuclear physics with polarized particles* (Springer Verlag, Berlin, 2012);
Eur. Phys. J. A **44**, (2010) 321; *Few-Body Syst.* **54** (2013) 2159

$$\text{QSF} = \frac{\sigma_{1,1}}{\sigma_0} \quad \sigma_0 = \frac{1}{9} \left(\underbrace{2\sigma_{1,1}}_{\text{Quintet}} + \underbrace{4\sigma_{1,0}}_{\text{Triplet}} + \underbrace{\sigma_{0,0} + 2\sigma_{1,-1}}_{\text{Singlet}} \right)$$



$$\sigma(\theta, \phi) = \sigma_0(\theta) \left(1 + \sum_1^9 p_j^b A_j^b(\theta) + \sum_1^9 p_j^t A_j^t(\theta) + \sum_1^9 \sum_1^9 p_j^b p_k^t C_{j,k}(\theta) \right)$$

$$p_{l'} \sigma(\theta, \phi) = \sigma_0(\theta) \left(P_{l'}(\theta) + \sum_1^9 p_j K_j^{l'}(\theta) \right)$$

Gerald G. Ohlsen, Rep. Prog. Phys. **35**, 717 (1972)

р-канал

п-канал

Тип эксперимента

Наблюдаемые

${}^2\vec{H}(\vec{d}, p){}^3H$
 ${}^2\vec{H}(\vec{d}, n){}^3He$

$C_{z,z}$ $C_{y,y}$
 $C_{zz,zz}$ $C_{y,zz}$
 $C_{y,xz}$ $C_{zz,xz}$



PolFusion

${}^2H(\vec{d}, \vec{p}){}^3H$
 ${}^2H(\vec{d}, \vec{n}){}^3He$

$K_x^{x'}$ $K_y^{y'}$
...

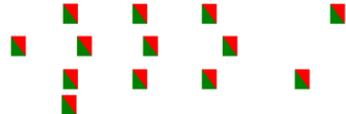


Imig A. et al., Phys. Rev. C **73**, 024001 (2006)

Katabuchi T. et al., Phys. Rev. C **64**, 047601 (2001)

${}^2H(\vec{d}, p){}^3H$
 ${}^2H(\vec{d}, n){}^3He$

A_y
 A_{xz} A_{zz}
 $A_{xx} - A_{yy}$



Tagishi Y. et al., Nucl. Instrum. Methods Phys. Res. A **402**, 436 (1998)

Fletcher K. A. et al., Phys. Rev. C **49**, 2305 (1994)

Tagishi Y. et al., Phys. Rev. C **46**, R1155 (1992)

Becker B. et al., Few-Body Syst. **13**, 19 (1992)

${}^2H(d, \vec{p}){}^3H$
 ${}^2H(d, \vec{n}){}^3He$

$P_{y'}$



Behof A. F., May T. H., McGarry W. I., Nucl. Phys. A **108**, 250 (1968)

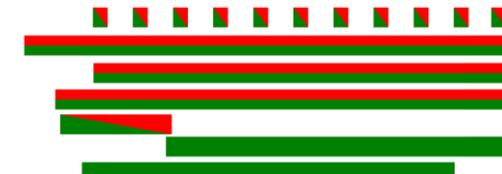
Haegnsgen H., et al., Nucl. Phys. **73**, 417 (1965)

Rogers J. T. and Bond C. D., Nuclear Physics **53** (1964) 297

Kane P. P., Nuclear Physics **10** (1959) 429

${}^2H(d, p){}^3H$
 ${}^2H(d, n){}^3He$

σ_0



Brown R. E. and N. Jarmie, Phys. Rev. C **41**, 1391 (1990)

Krauss A. et al., Nucl. Phys. A **465**, 150 (1987)

Theus R. B., W. I. McGarry, and L. A. Beach, Nucl. Phys. **80**, 273 (1966)

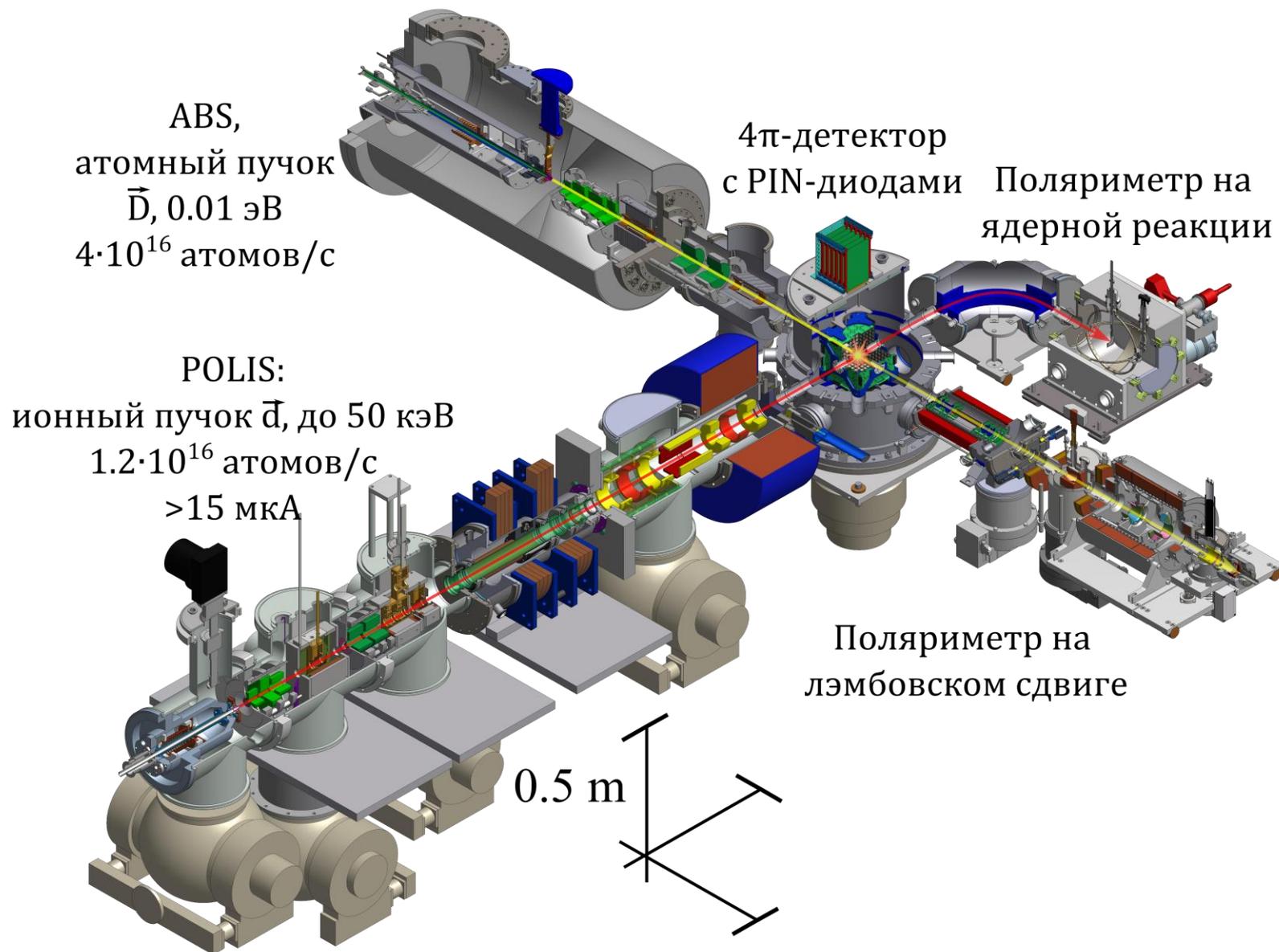
McNeill K. G., Phil. Mag. **46** (1955) 800; Arnold W. R. et al., Phys. Rev. **93** (1954) 483

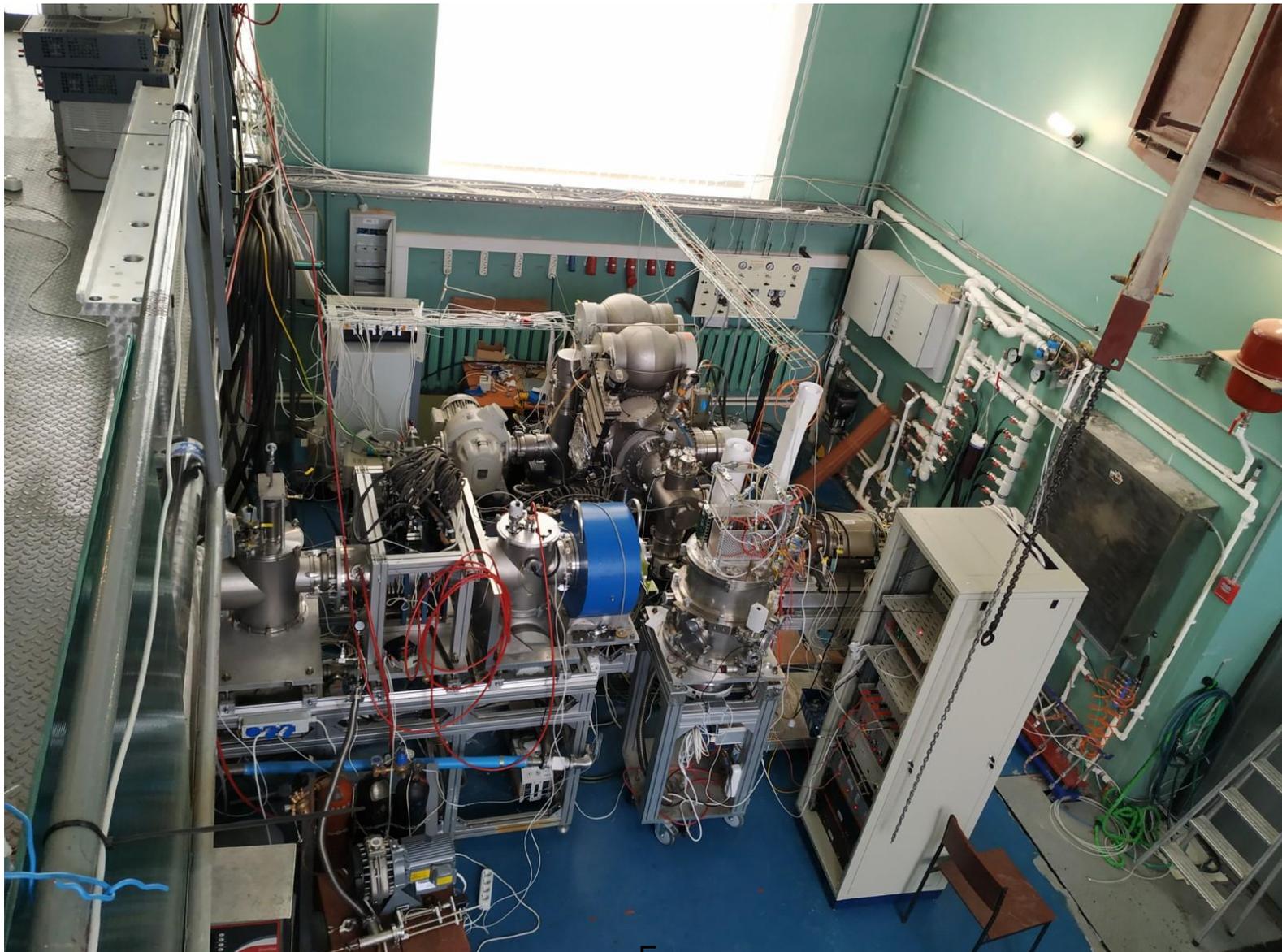
Moffat J., D. Roaf and J. H. Sanders, Proc. Roy. Soc. A **212** (1952) 220

Wenzel W. A. and W. Whaling, Phys. Rev. **88** (1952) 1149

Bretscher E., A. P. French and F. G. P. Seidl, Phys. Rev. **73** (1948) 815

0 50 100 150 E_{cm}, keV



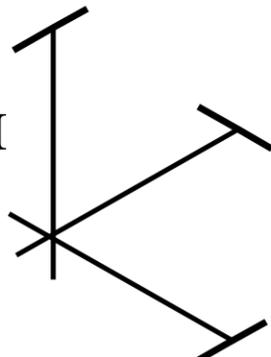
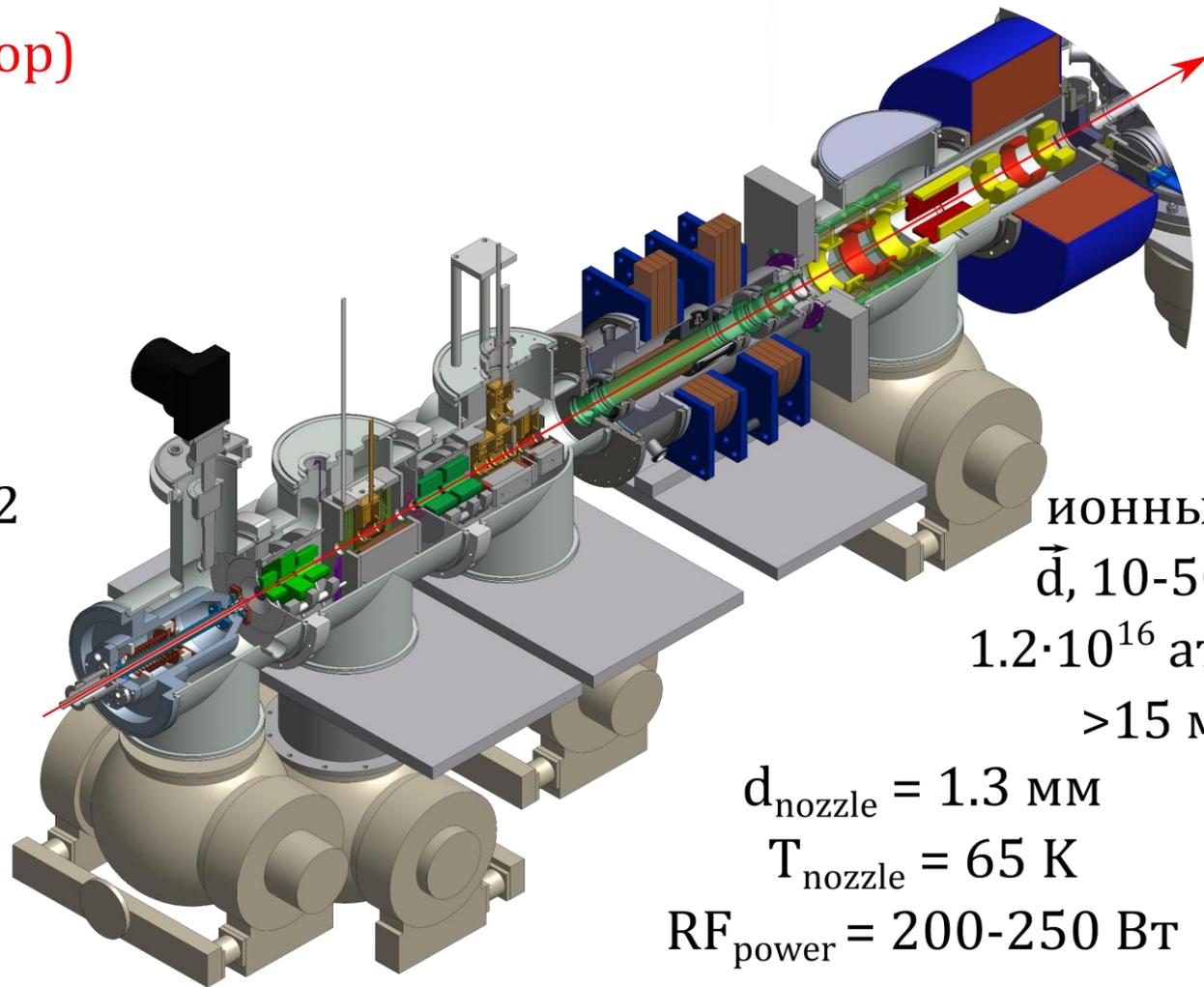


F

ρ_z (вектор) ρ_{zz} (тензор)

$\pm 2/3$	0
0	+1
0	-2
-1/3	± 1
+1/3	± 1
$\pm 1/3$	-1/2

0.5 м

ионный пучок
 \vec{d} , 10-50 кэВ
 $1.2 \cdot 10^{16}$ атомов/с
 > 15 мкА

$$d_{\text{nozzle}} = 1.3 \text{ мм}$$

$$T_{\text{nozzle}} = 65 \text{ К}$$

$$RF_{\text{power}} = 200-250 \text{ Вт}$$

Поляризатор:

Sextupoles + WFT + Sextupoles + WFT + SFT1 (460 MHz) + SFT2 (350 MHz)

ρ_z (вектор) ρ_{zz} (тензор)

-2/3

0

0

+1

-1/3

+1

-1

+1

$\pm 1/2$

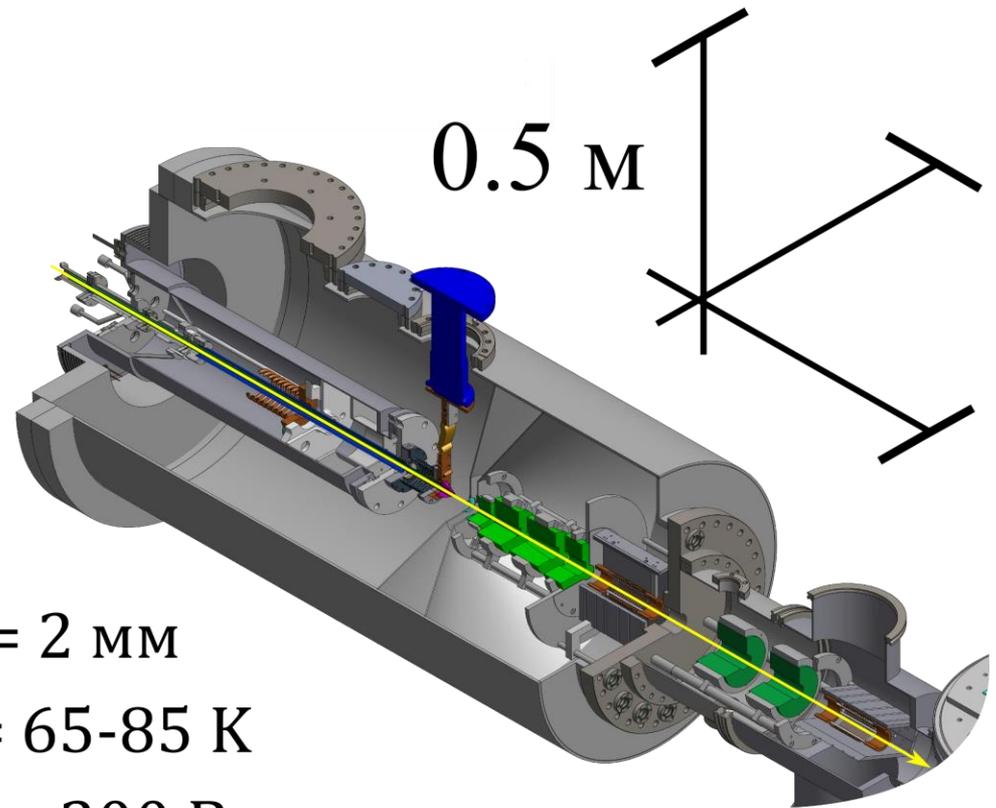
-1/2

атомный пучок $d_{\text{nozzle}} = 2 \text{ мм}$

\vec{D} , 0.01 эВ

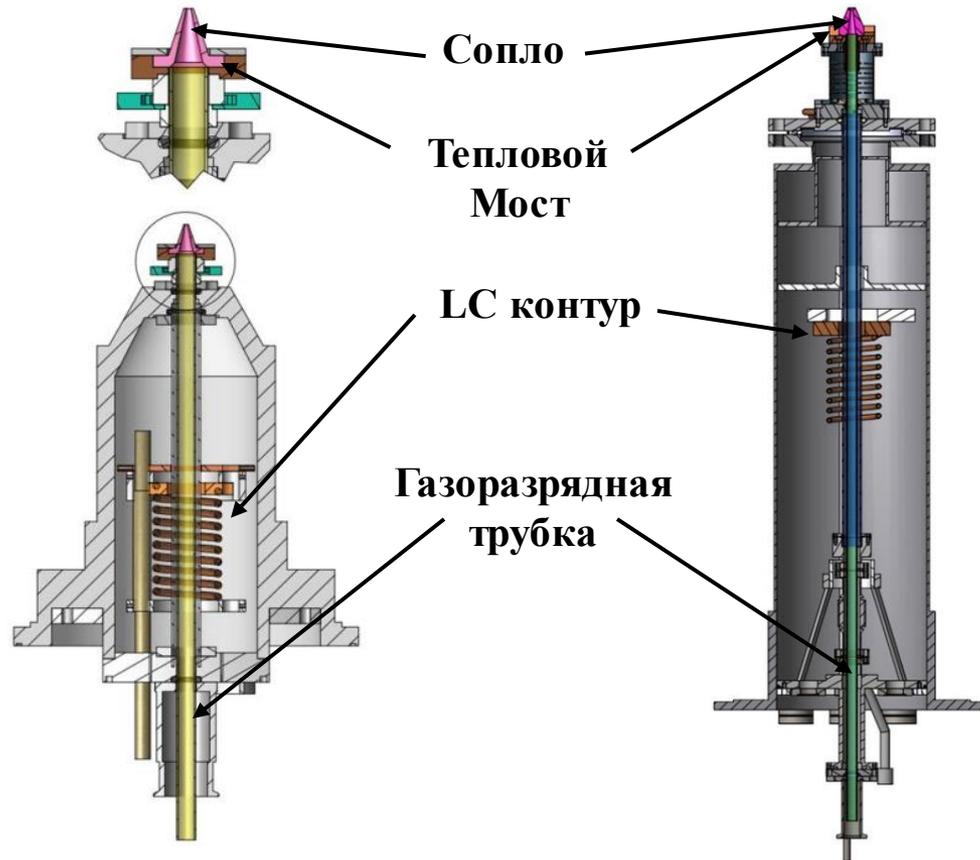
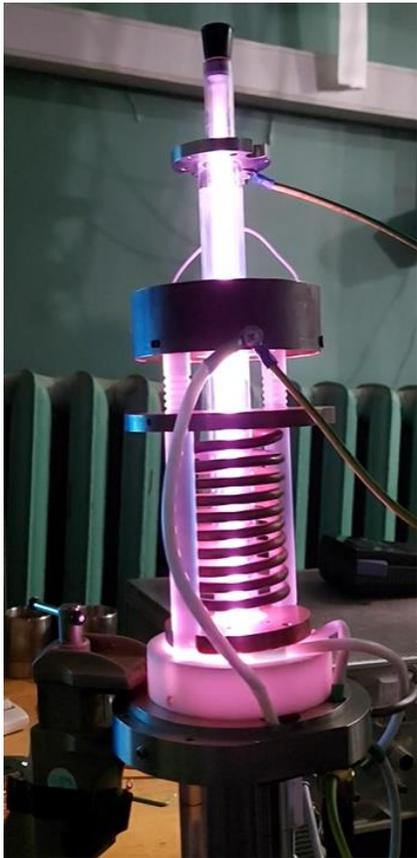
$T_{\text{nozzle}} = 65-85 \text{ К}$

$4 \cdot 10^{16}$ атомов/с $RF_{\text{power}} = 300 \text{ Вт}$

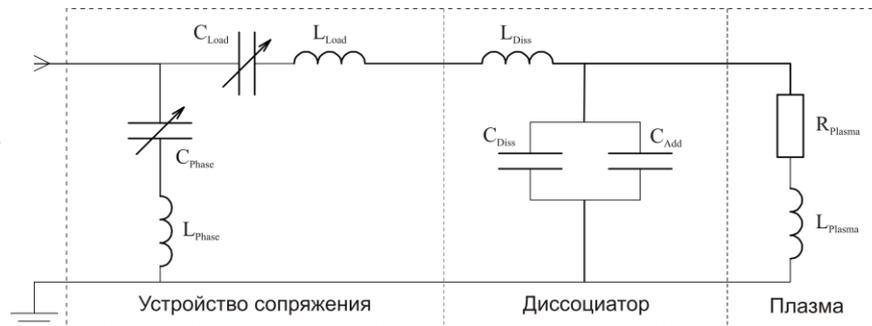


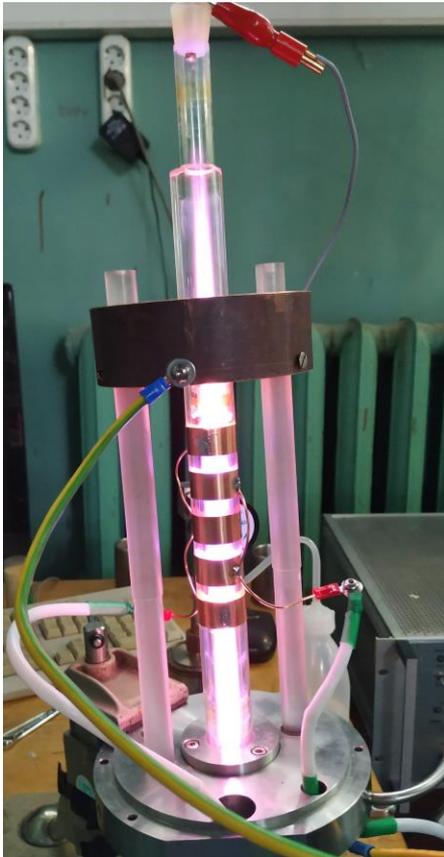
Поляризатор:

Sextupoles + MFT + Sextupoles + MFT



Энергия диссоциации молекулы дейтерия - 4,56 эВ
 Энергия ионизации дейтерия - 13,6 эВ



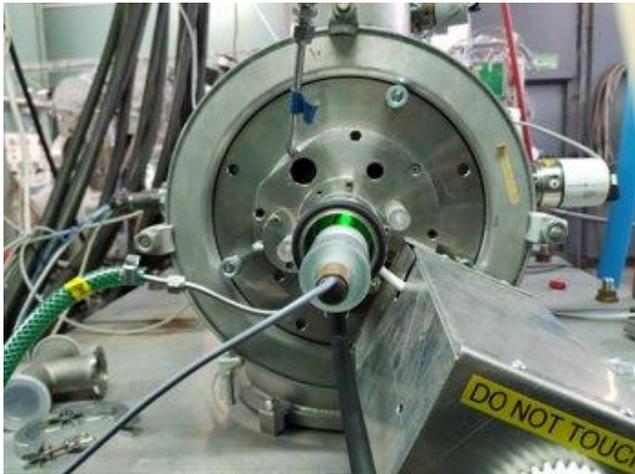


Емкостной диссоциатор: Для полного согласования не хватает индуктивности.



Параллельный LC контур: Узкая резонансная полоса, сложность в согласовании (обратная мощность на уровне 50%).

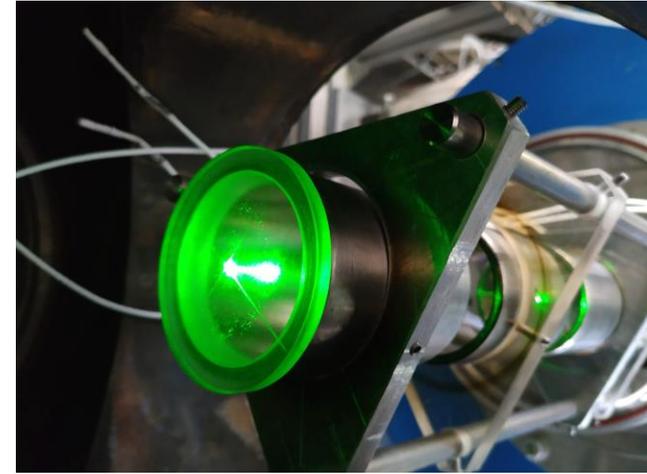
Подача дейтерия



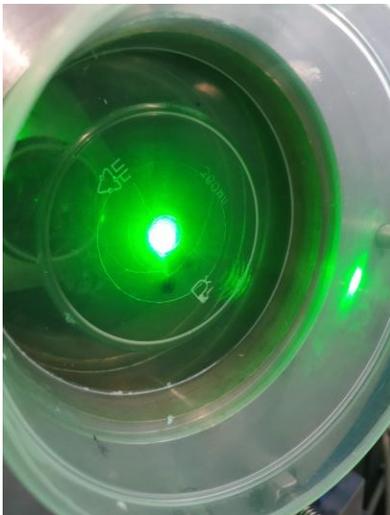
Выход ABS POLIS



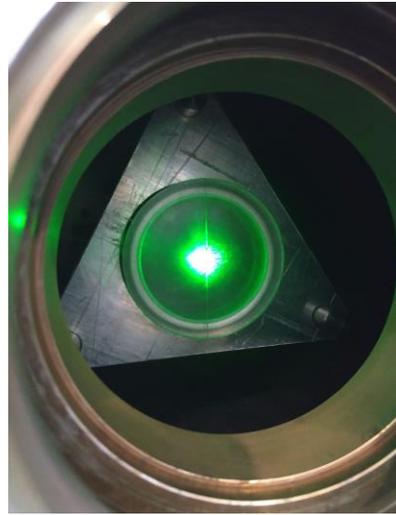
Первая линза



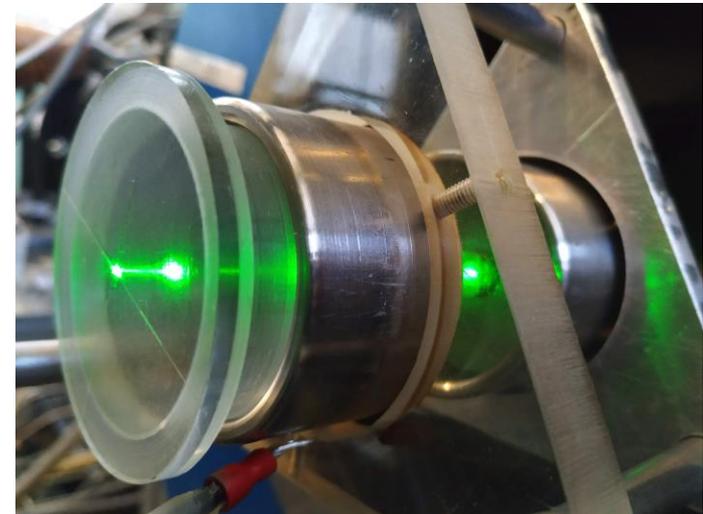
Выход POLIS'a



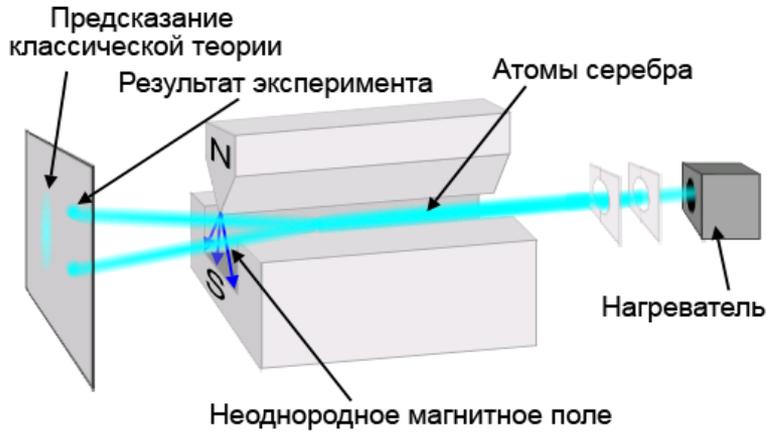
Выход второй линзы



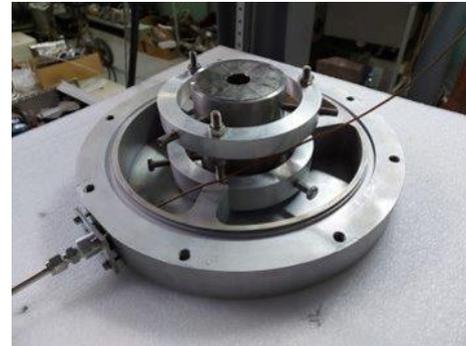
Вторая линза



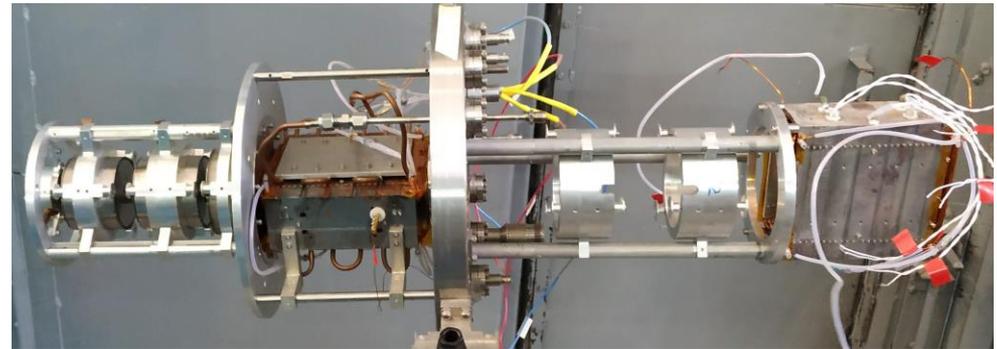
Эксперимент Штерн-Герлаха



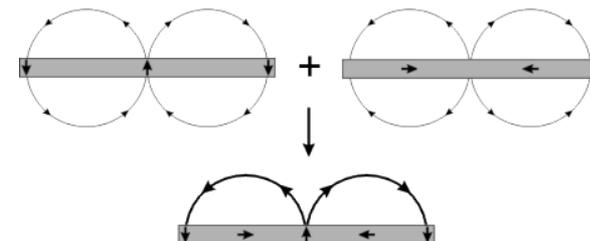
Магнитная система POLIS



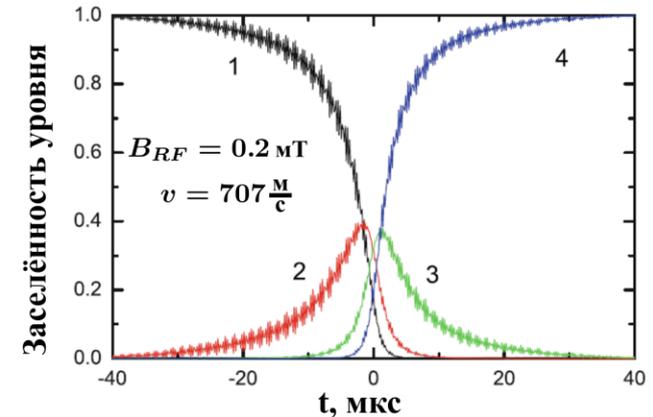
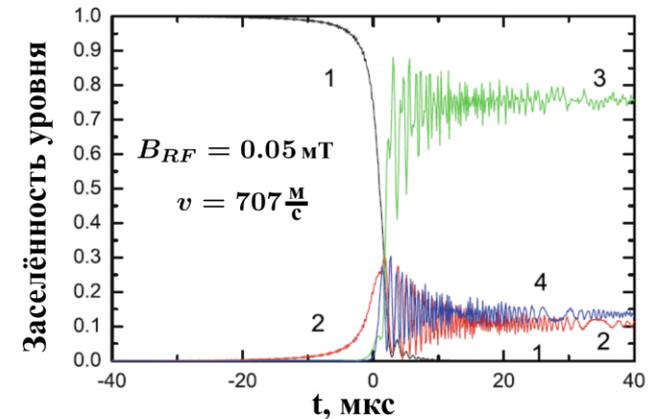
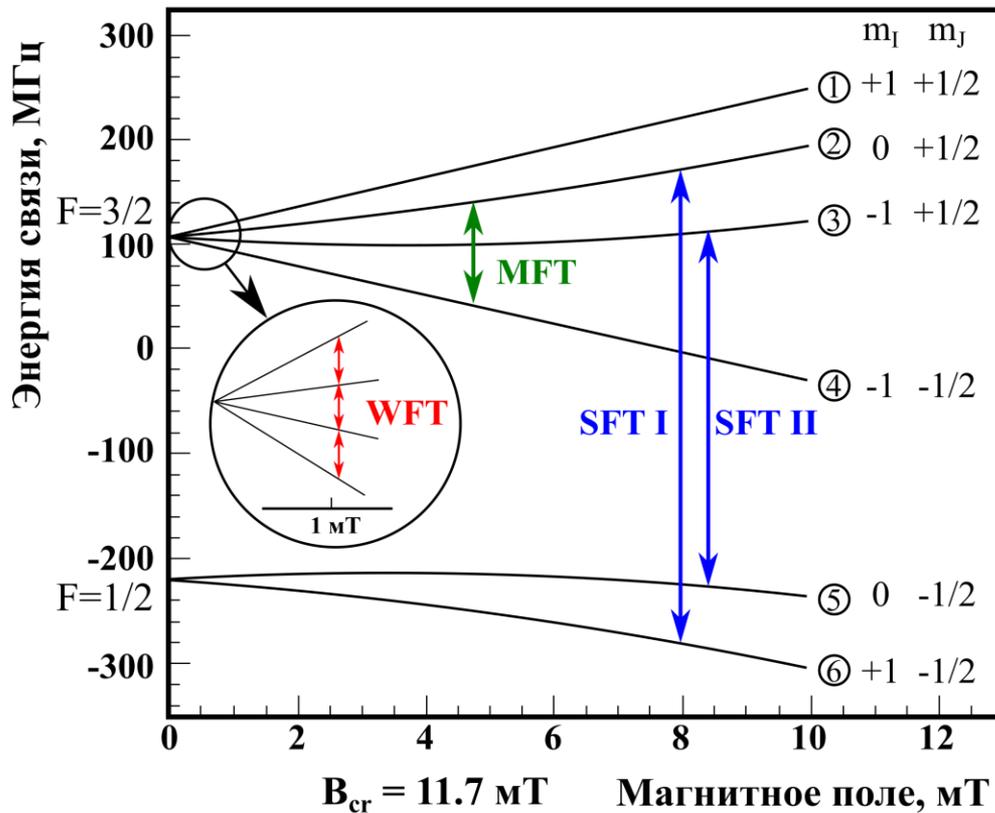
Магнитная система ABS Ferrara

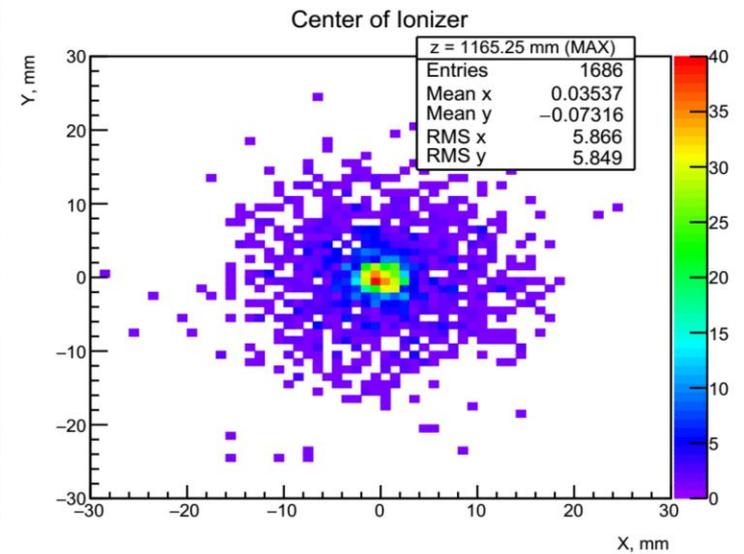
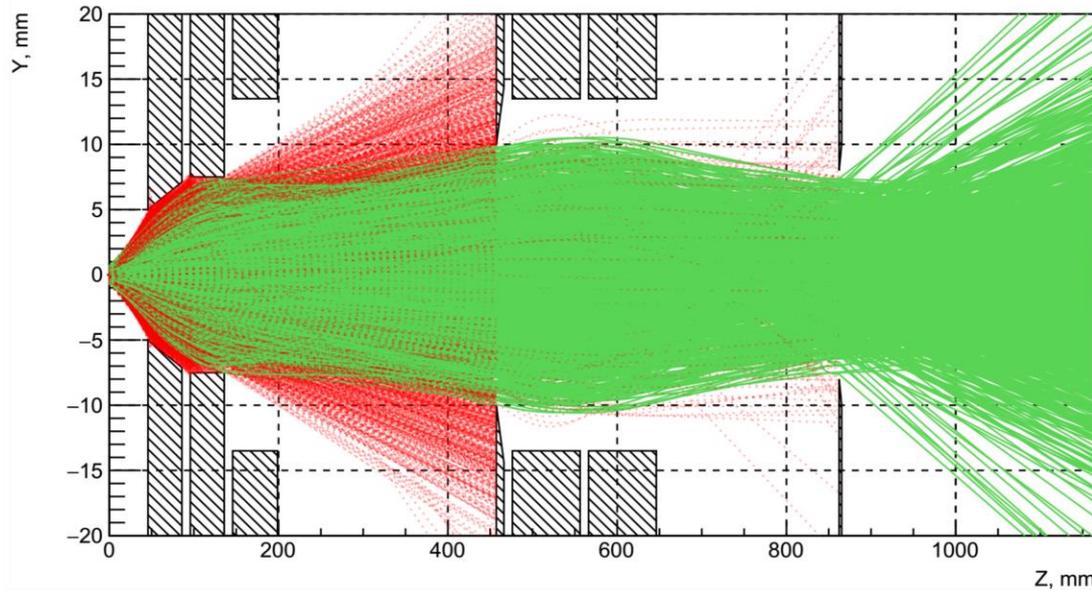
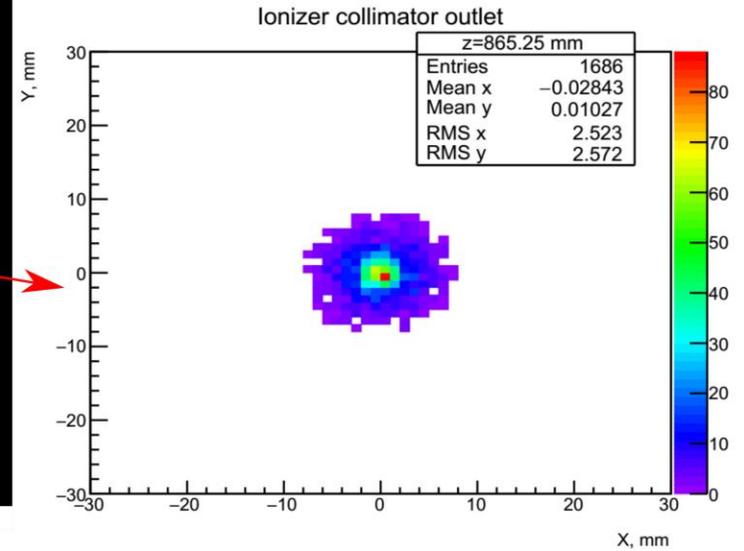
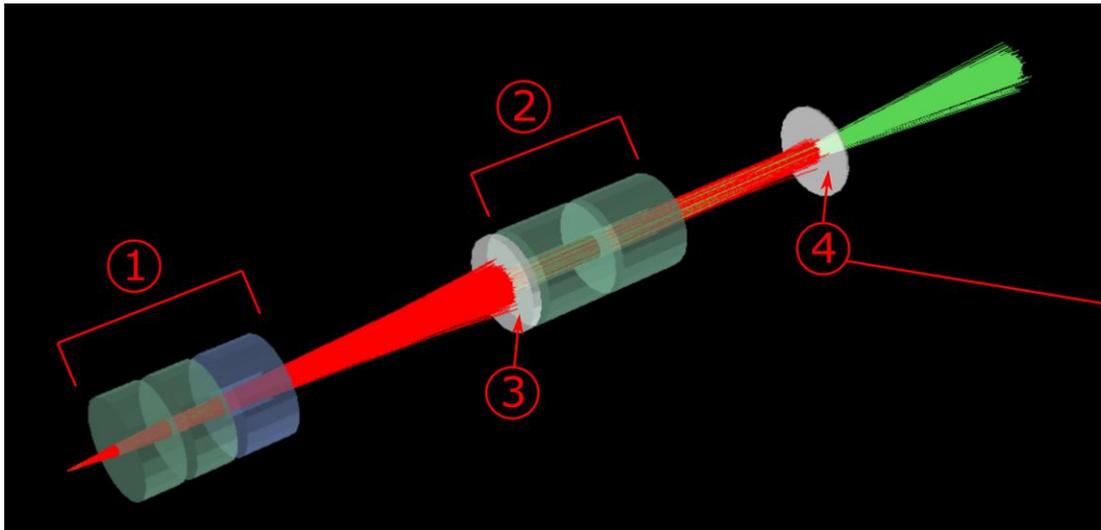


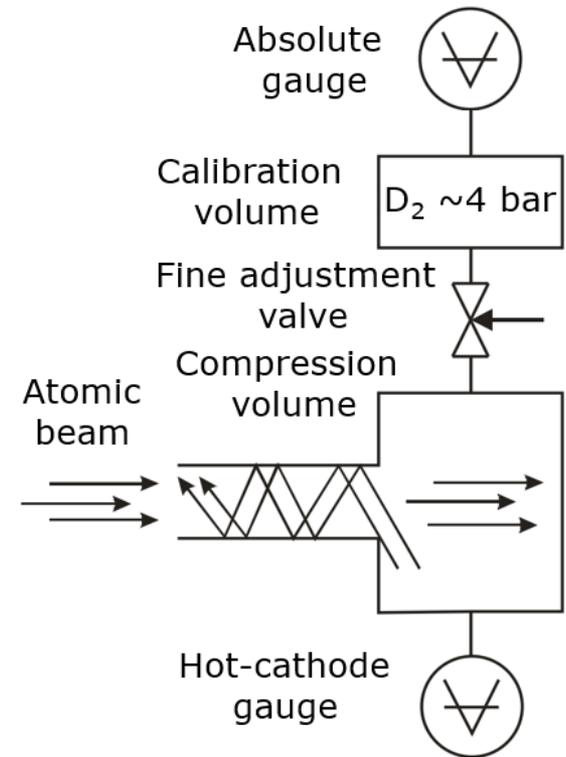
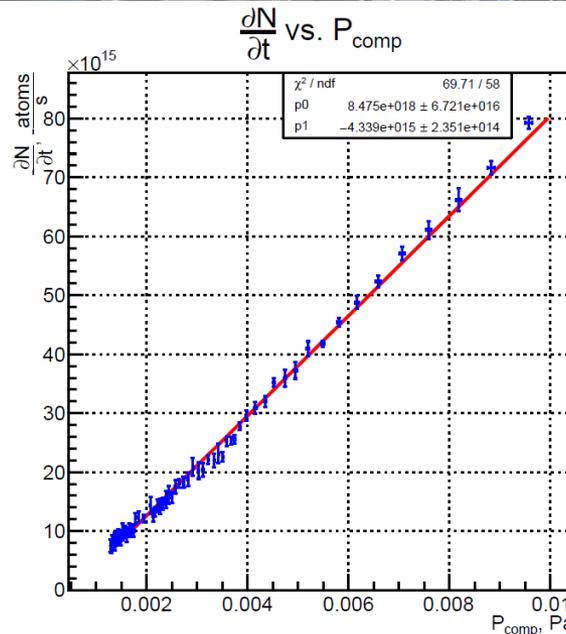
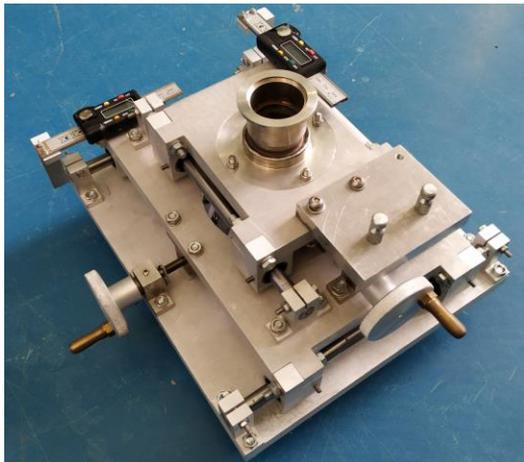
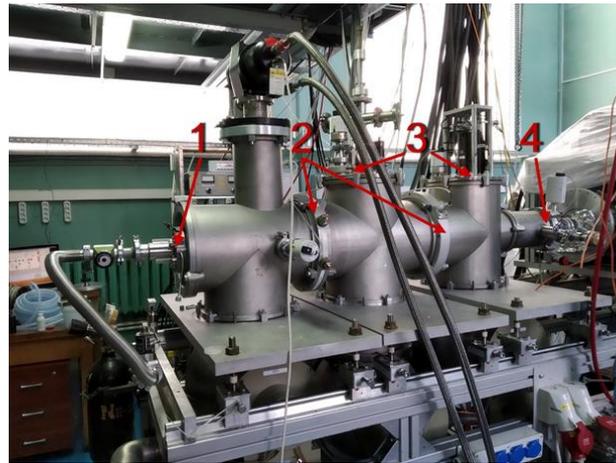
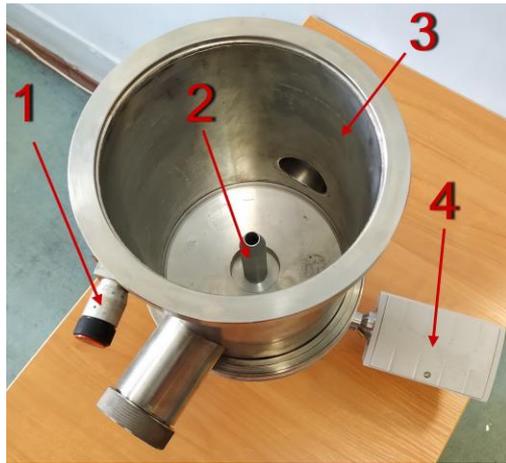
Магнитная сборка Халбаха



	WFT	MFT	SFT1	SFT2
f , MHz	8	25.4	460	350
B_{RF} , mT	0.2	0.1	0.2	0.2
B_0/B_{cr}	0.07	0.2 0.24 0.28	0.68	0.85
ΔB_0 , mT	0.2	0.2	0.7	0.7
l_{RF} , mm	40	69	40	40





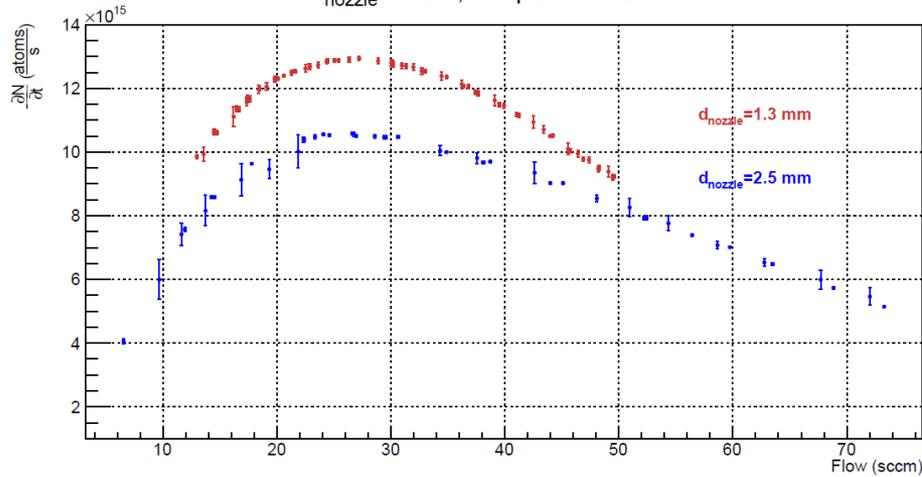


$$\frac{\partial N_{D_2}}{\partial t} = \frac{V_{cal} \cdot \mu_{D_2}}{m_{D_2} \cdot R \cdot T_{cal}} \cdot \frac{\partial P_{cal}}{\partial t}$$

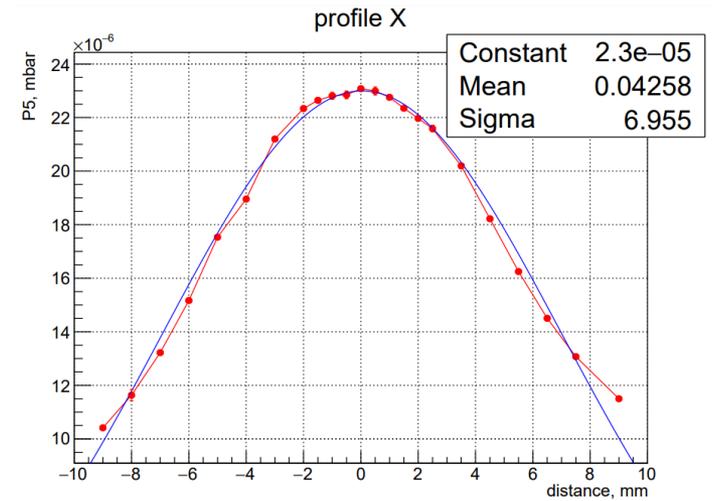
Зависимость интенсивности пучка от потока

дейтерия

$T_{\text{nozzle}} = 50\text{K}$, RF power = 200 W



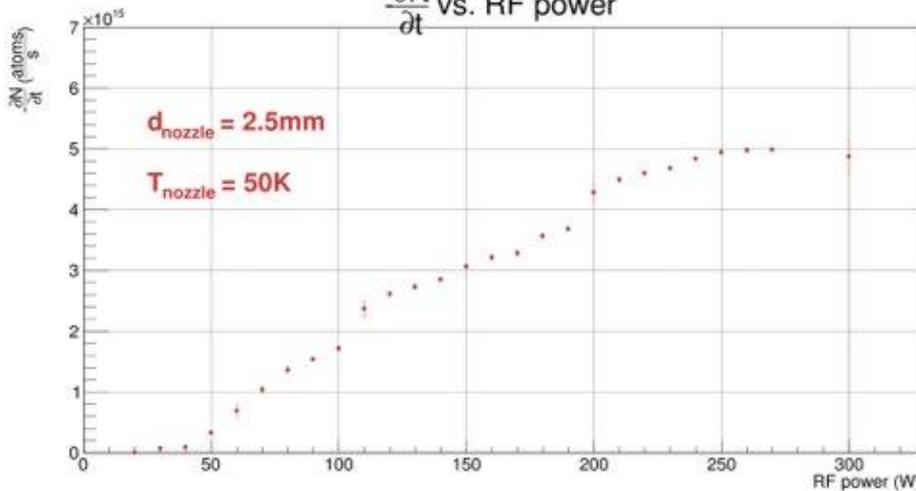
Профиль атомарного пучка



Зависимость интенсивности пучка от

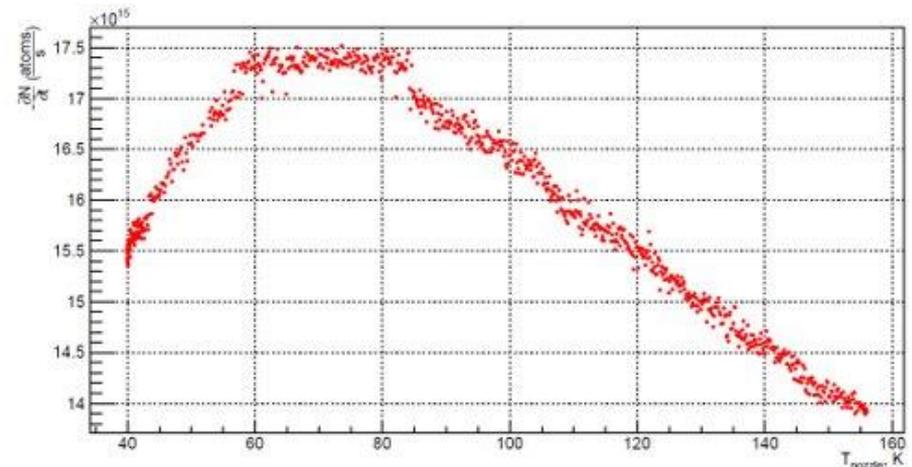
ВЧ мощности

$\frac{\partial N}{\partial t}$ vs. RF power



Зависимость интенсивности пучка от

температуры сопла



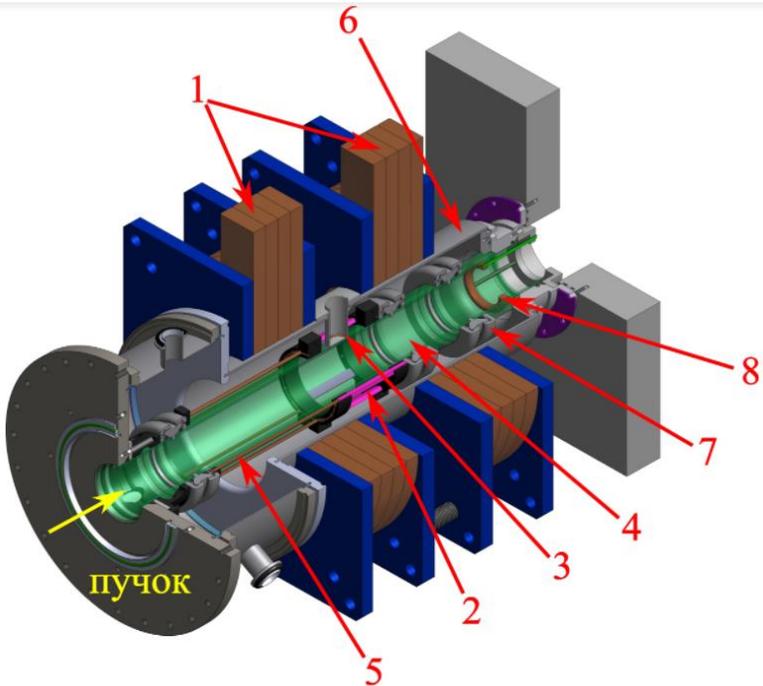
Условие ЭЦР: циклотронная частота ω_c электрона близка к частоте внешнего СВЧ поля ω

$$\omega_c = eB/m_e, \quad (1)$$

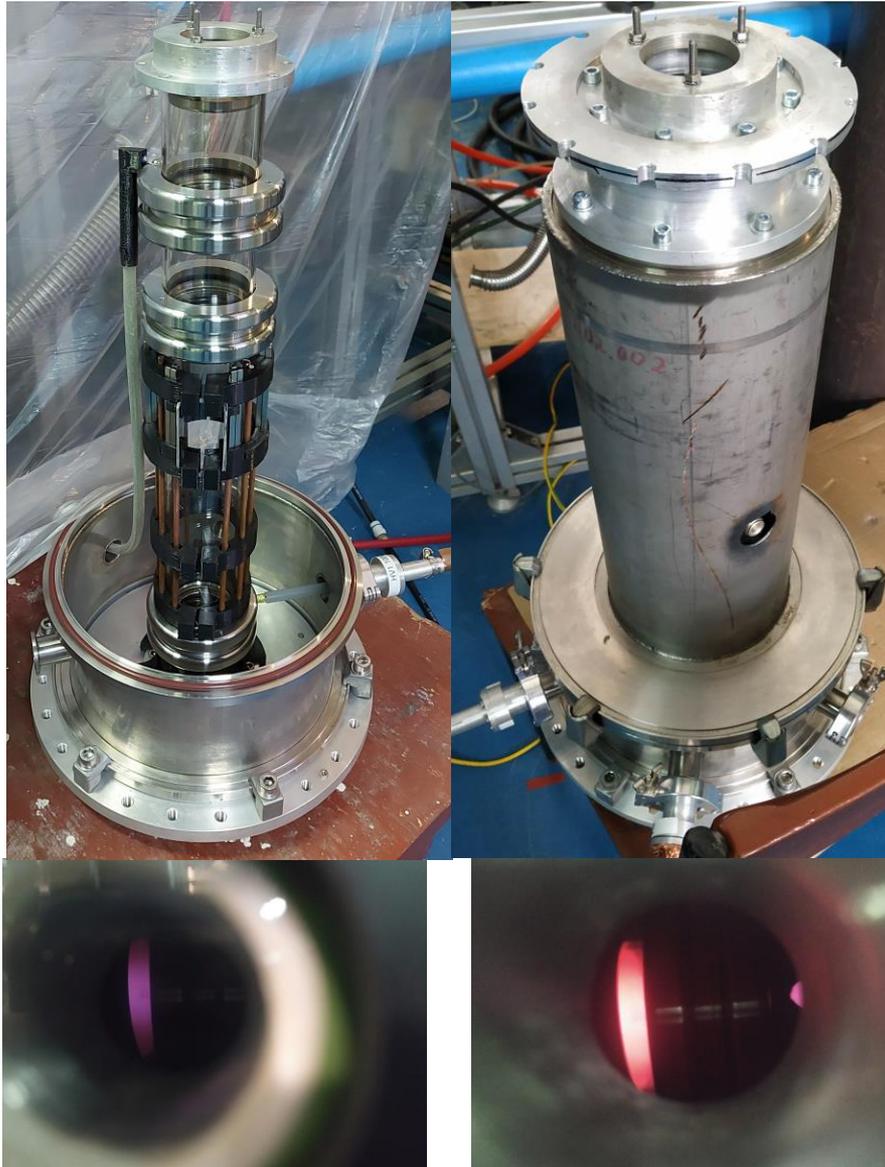
где e - заряд электрона, а m_e - масса электрона, B - индукция магнитного поля.

$$f_{ce} = \omega_c/2\pi = 28 \cdot B \quad (2)$$

где частота внешнего СВЧ поля f_{ce} выражена в ГГц, а B в Теслах.



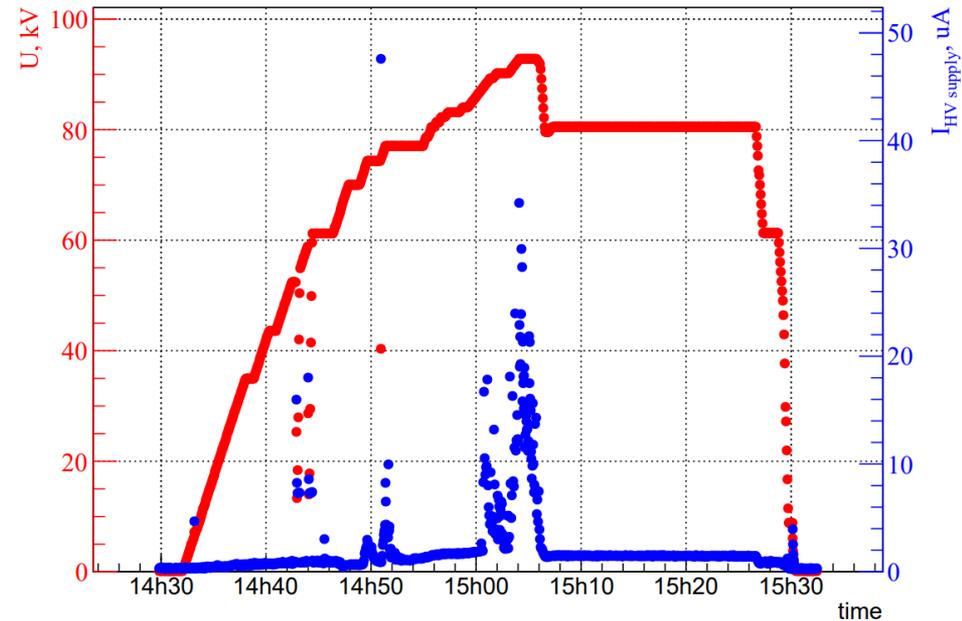
- 1 – катушки индуктивности пробкотрона
- 2 - секступольный магнит
- 3 - полуволновая рамочная антенна
- 4 - газоразрядная камера
- 5, 7, 8 - ионно-оптическая система
- 6 - элегазовый корпус

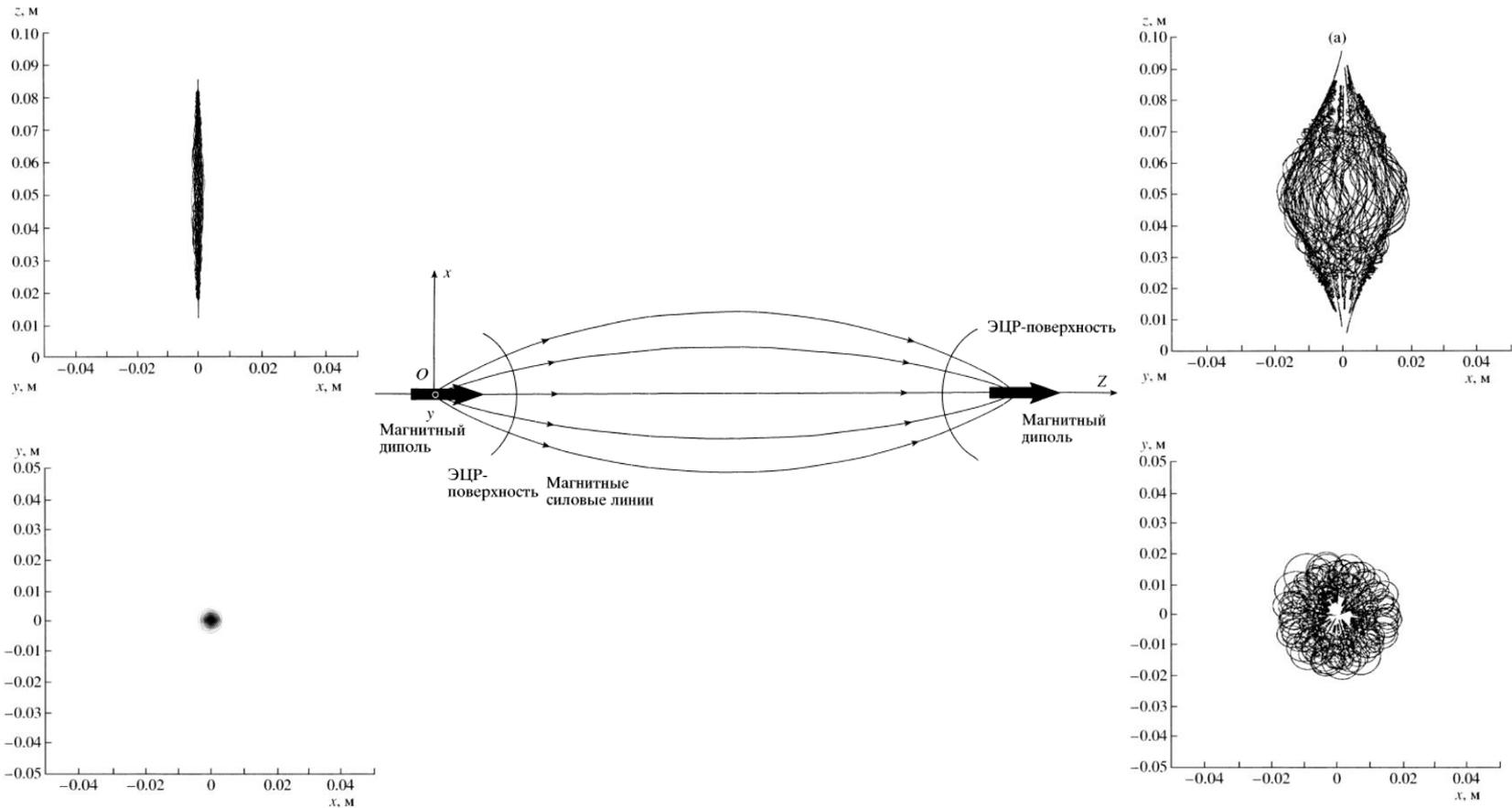


ЭЦР ионизатор состоит из:

1. Газоразрядной камеры
2. Магнитной ловушки типа пробкотрон
3. LOOP - антенны
4. Ионно-оптической системы
5. Элегазового кожуха

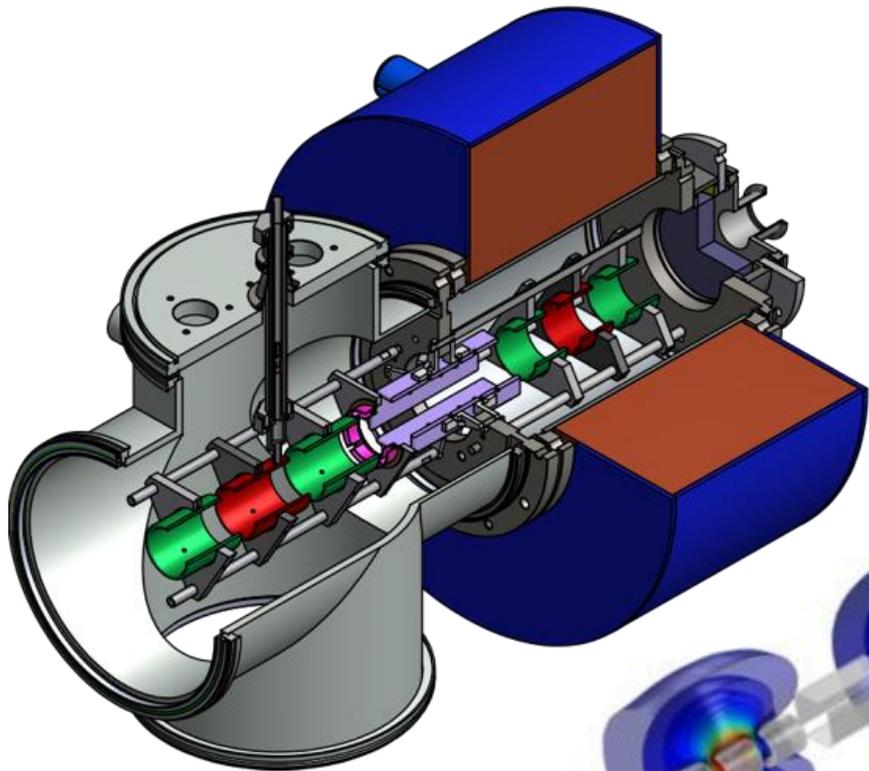
Checking the ionizer for high voltage



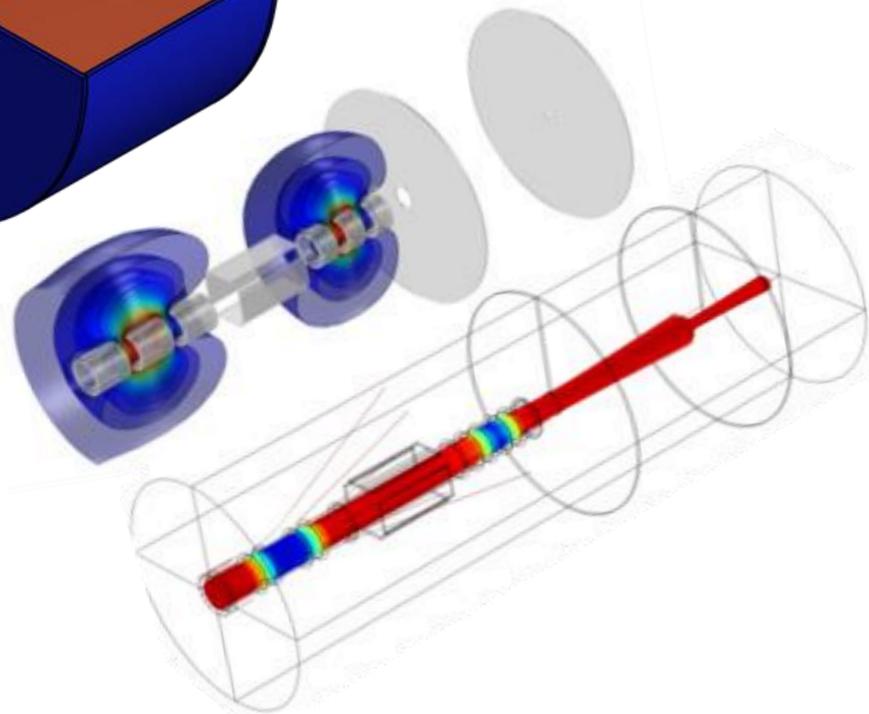


Траектория движения в магнитной ловушке электрона, находящегося в начальный момент на оси Z системы в проекции на плоскости (а) XZ; (б) XY.

Траектория движения в магнитной ловушке электрона, находящегося в начальный момент не на оси Z системы в проекции на плоскости (а) XZ; (б) XY.



- Фокусирующая система состоит из:**
- 1. Симметричных электростатических линз.**
 - 2. Ввода высокого напряжения до 40 кВ.**
 - 3. Четырех сегментного фарадей капа**
 - 4. Отклоняющих пластин**
 - 5. Система юстировки линз**



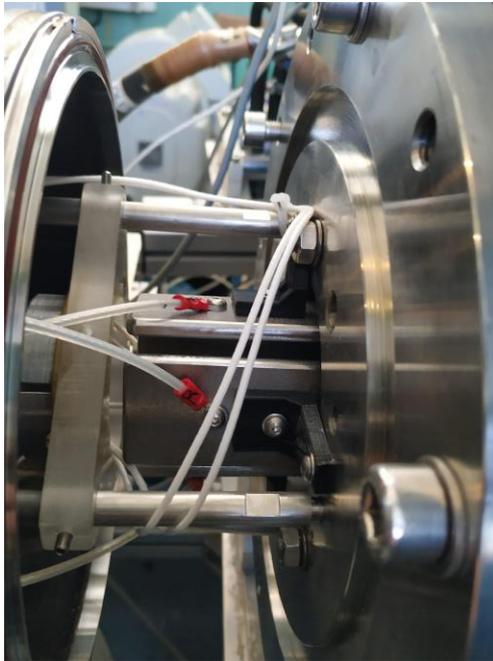
Линзы в сборе



Ввод высокого напряжения



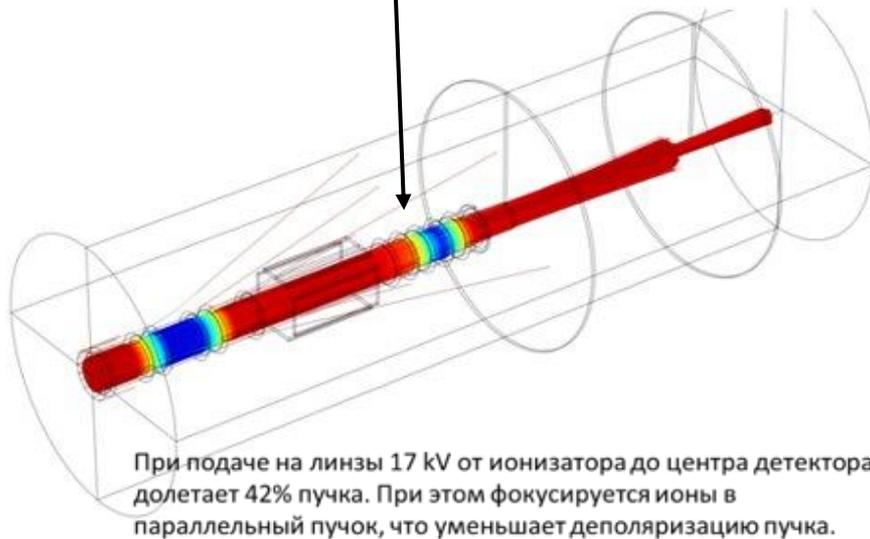
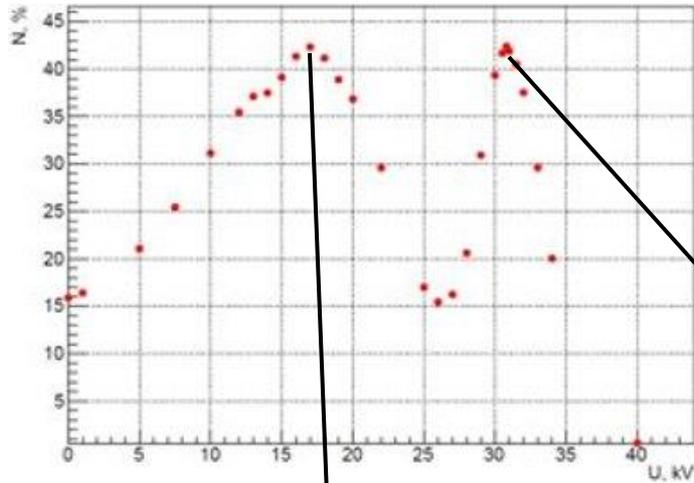
Отклоняющие пластины



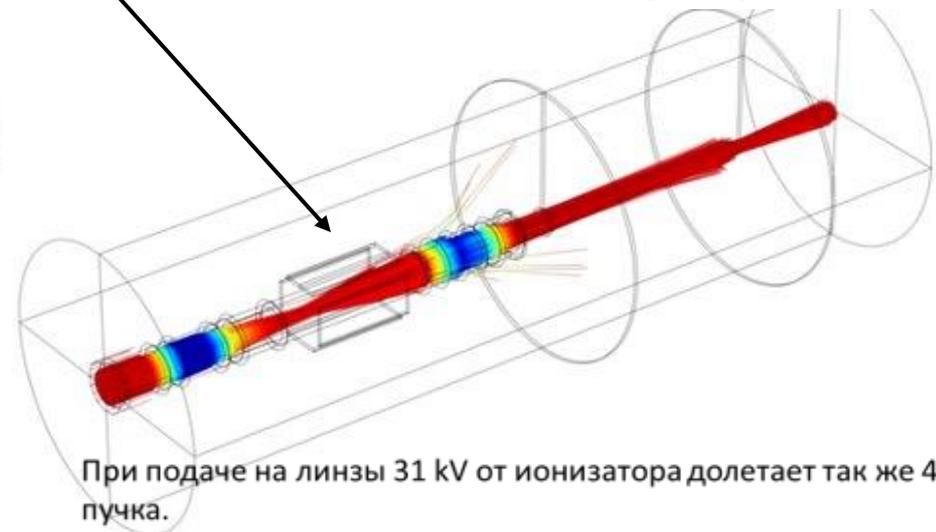
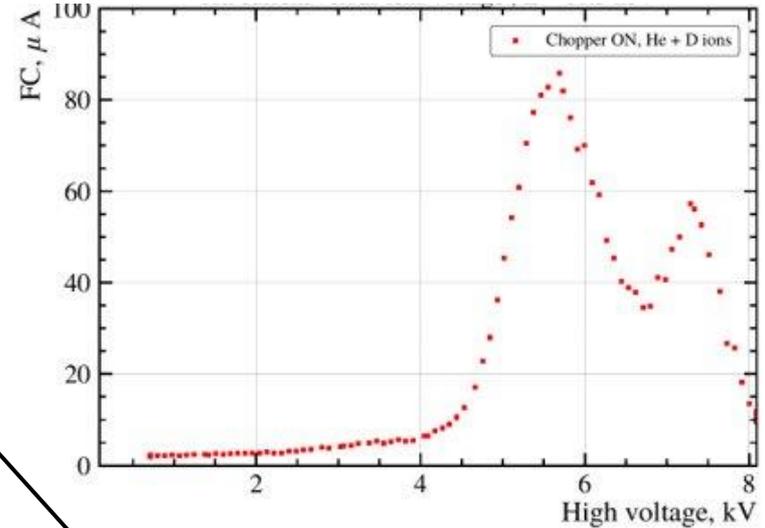
Линзы в сборе, на пучке

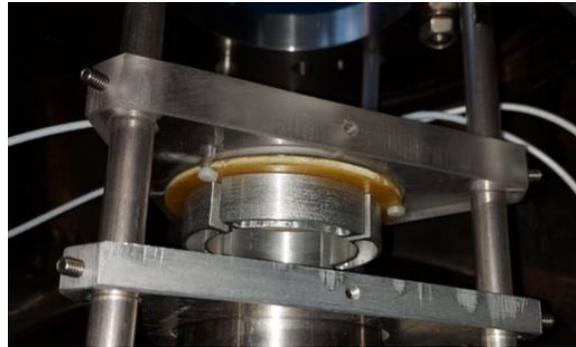
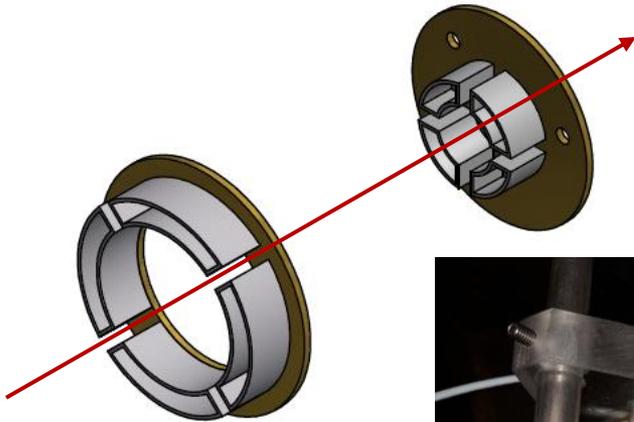


Моделирование фокусировки ионного пучка



Фокусировки ионного пучка при энергии дейтронов 10.3 кеВ

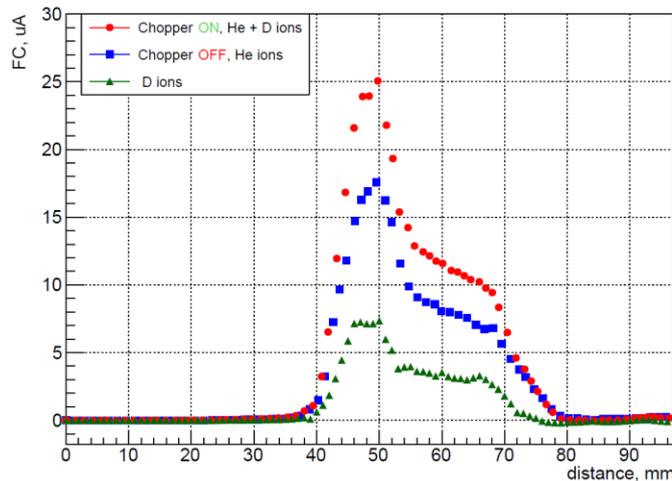




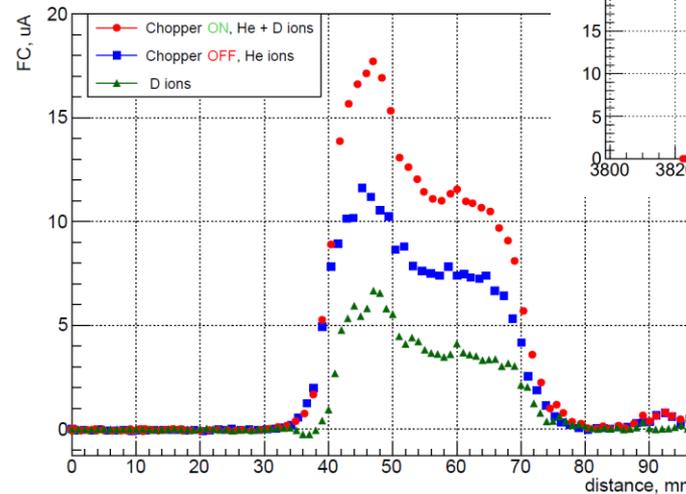
Система детектирования ионного пучка состоит из:

1. Двух четырех сегментных чашки фарадея
2. Выдвижной чашки фарадея

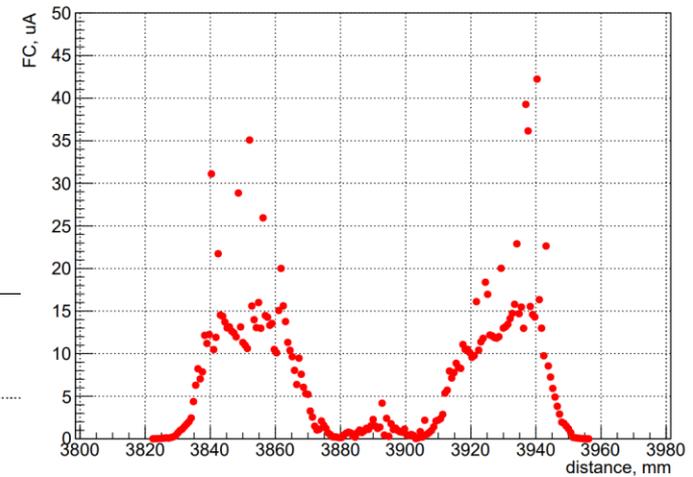
Profile, E = 10,3 keV



Profile, E = 20,8 keV



Profile, E = 41,9 keV



$$\frac{L-R}{L+R} = \frac{\frac{3}{2} P_Z \sin \beta A_y}{1 + \frac{1}{2} P_{ZZ} [\sin^2 \beta A_{yy} + \cos^2 \beta A_{zz}]}$$

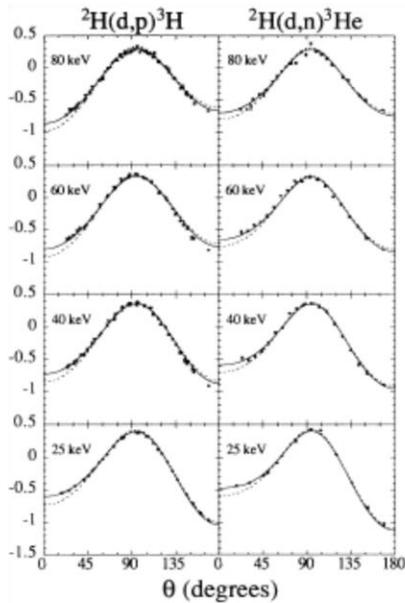
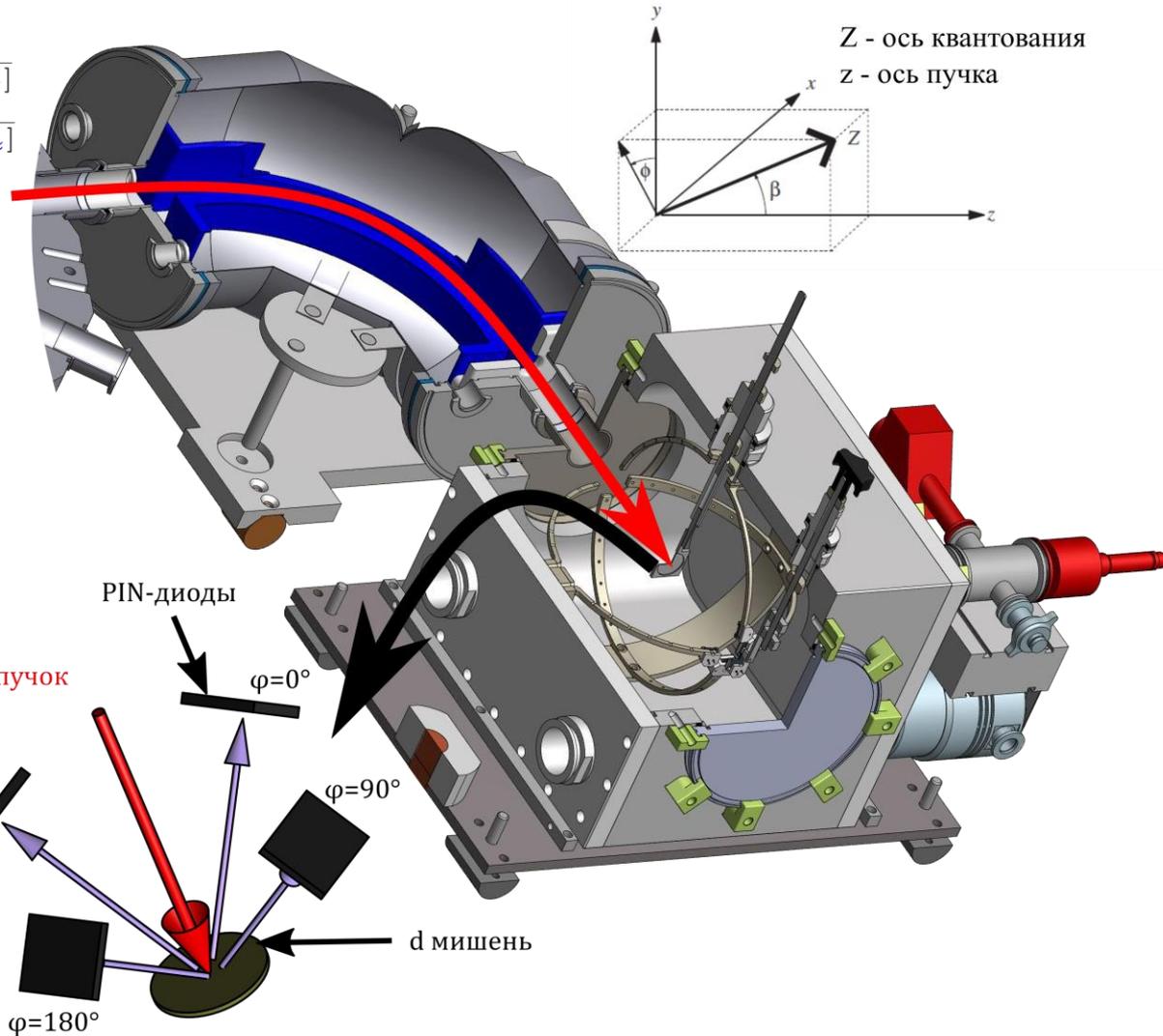
$$\frac{U-D}{U+D} = \frac{P_{ZZ} \sin \beta \cos \beta A_{xz}}{1 + \frac{1}{2} P_{ZZ} [\sin^2 \beta A_{xx} + \cos^2 \beta A_{zz}]}$$

$$\frac{2(L-R)}{L+R+U+D} = \frac{\frac{3}{2} P_Z \sin \beta A_y}{1 + \frac{1}{4} P_{ZZ} [3(\cos^2 \beta - 1) A_{zz}]}$$

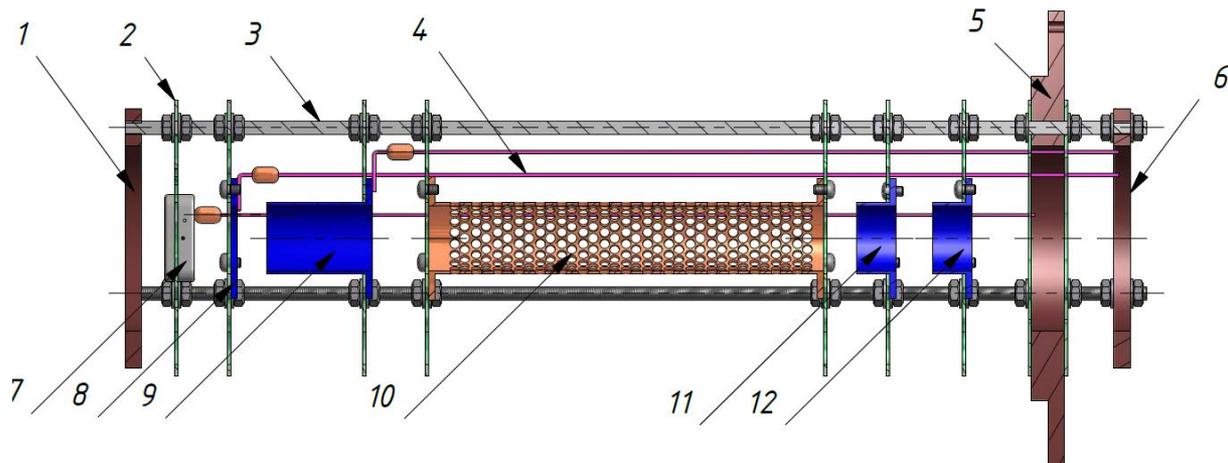
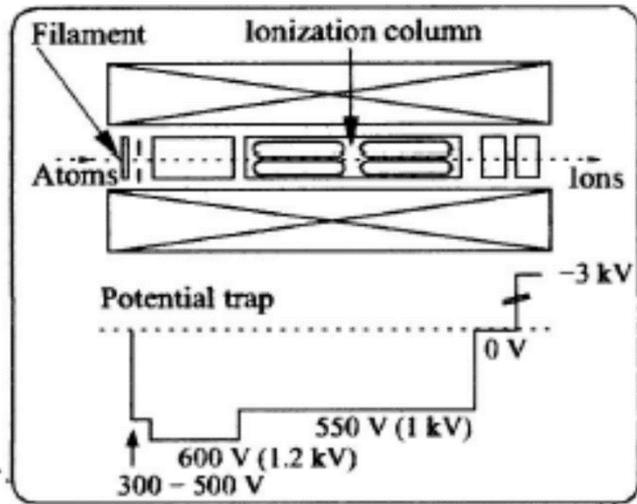
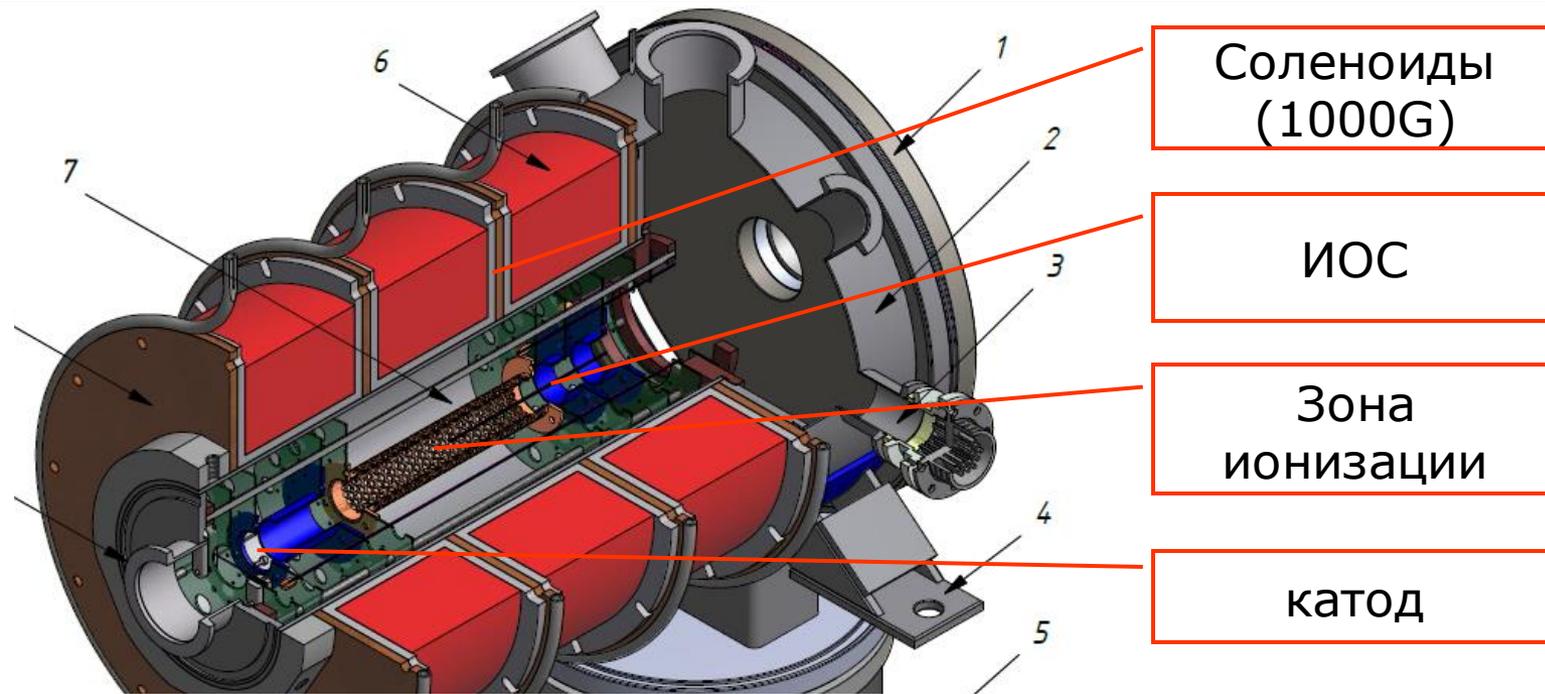
$$\frac{2(U-D)}{L+R+U+D} = \frac{P_{ZZ} \sin \beta \cos \beta A_{xz}}{1 + \frac{1}{4} P_{ZZ} [3(\cos^2 \beta - 1) A_{zz}]}$$

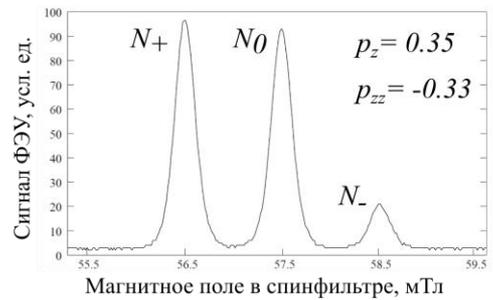
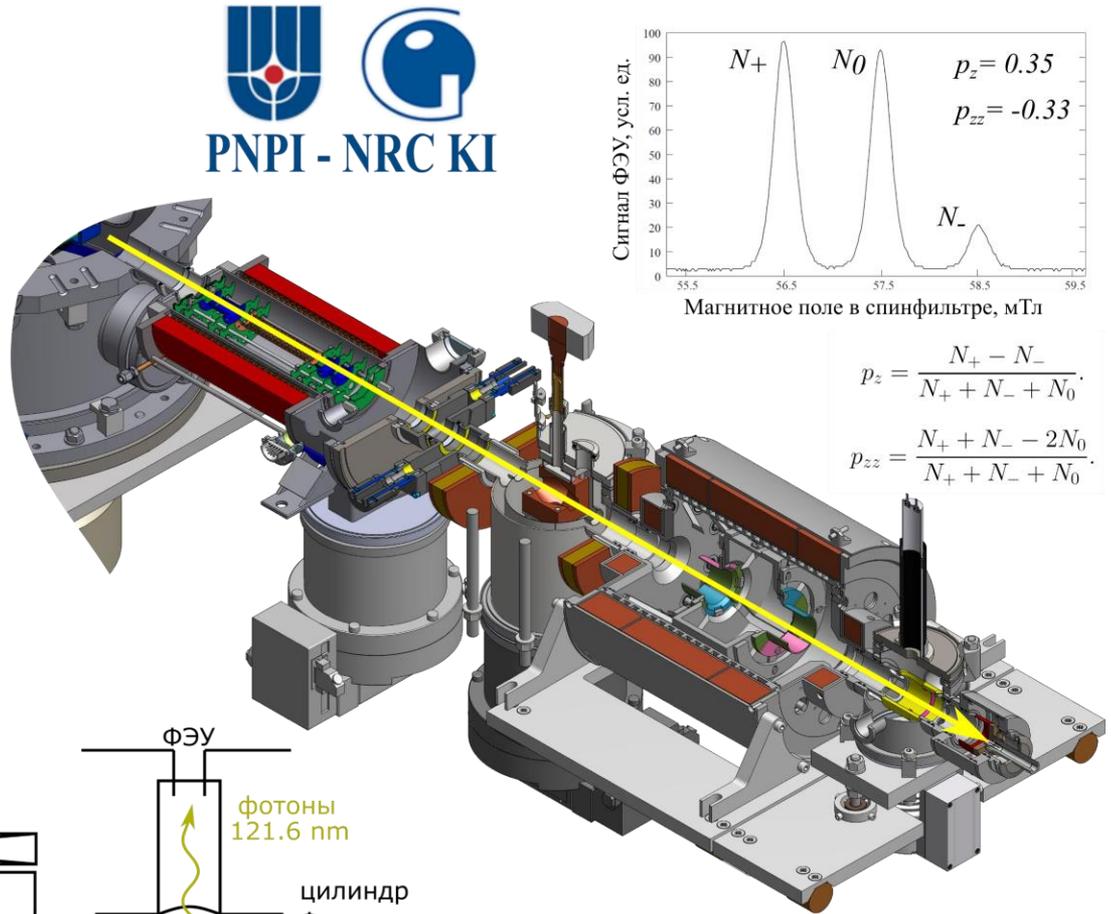
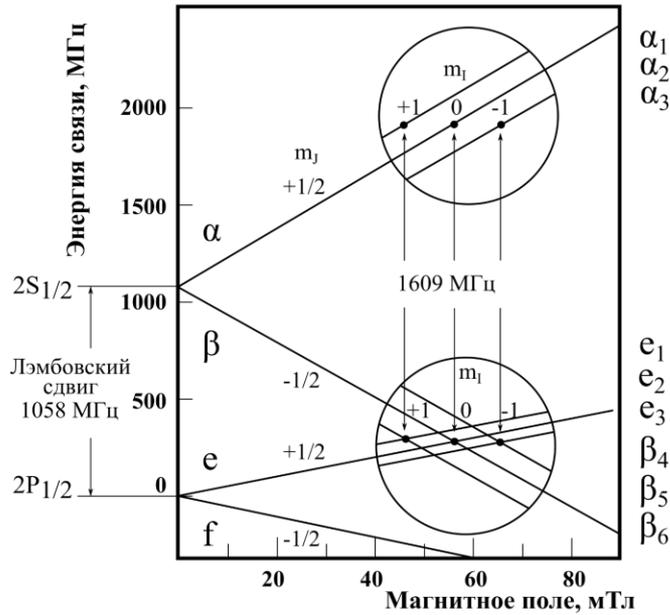
$$\frac{(L+R)-(U+D)}{L+R+U+D} = \frac{-\frac{1}{4} P_{ZZ} \sin^2 \beta (A_{xx} - A_{yy})}{1 + \frac{1}{4} P_{ZZ} [3(\cos^2 \beta - 1) A_{zz}]}$$

G.G. Ohlsen, P.W. Keaton, Jr., Nucl. Instr. and Meth. **109**, 41 (1973).



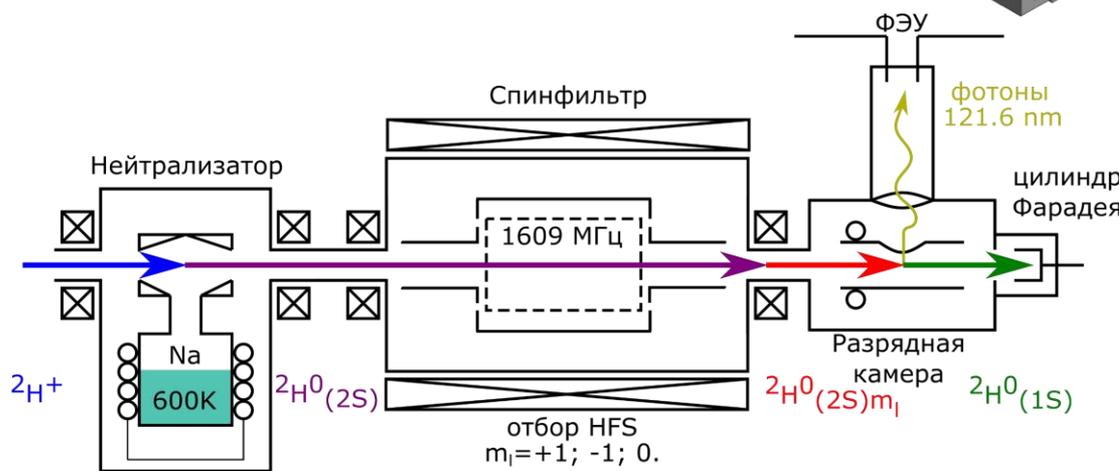
K. Fletcher, et al., Phys. Rev. C **49**, 2305 (1994).





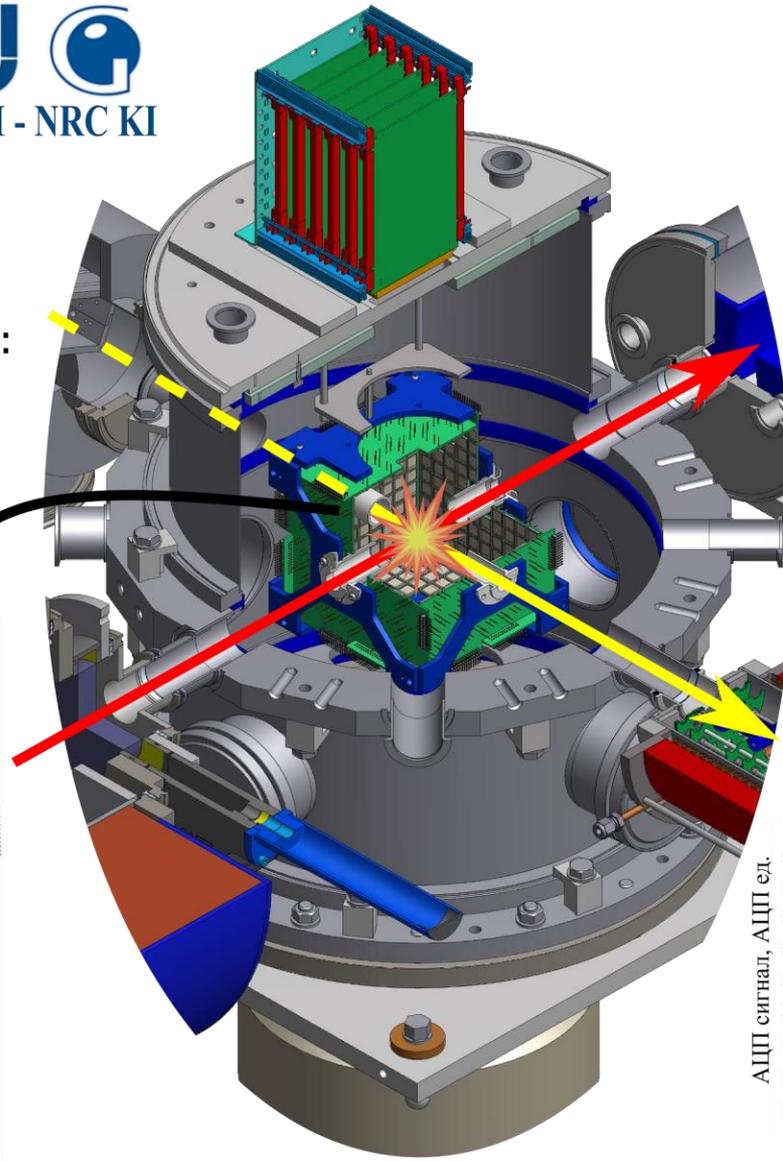
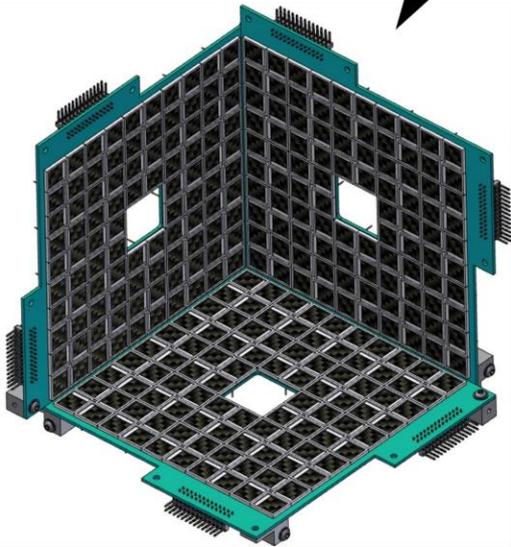
$$p_z = \frac{N_+ - N_-}{N_+ + N_- + N_0}$$

$$p_{zz} = \frac{N_+ + N_- - 2N_0}{N_+ + N_- + N_0}$$

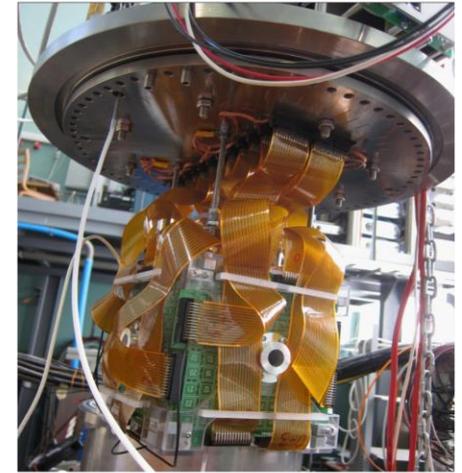




576 PIN диоды
 Hamamatsu S3590-09
 заряженные частицы:
 0.2 - 4 MeV
 с энергетическим
 разрешением
 < 50 keV

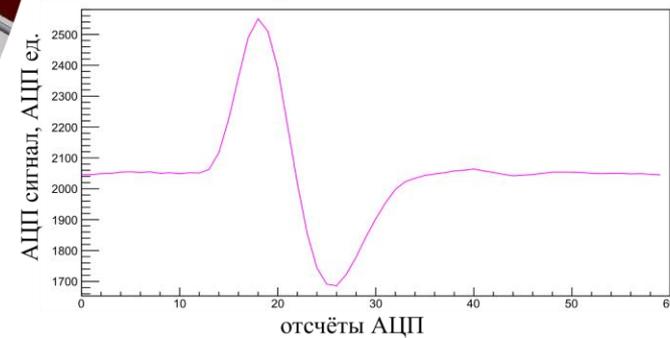


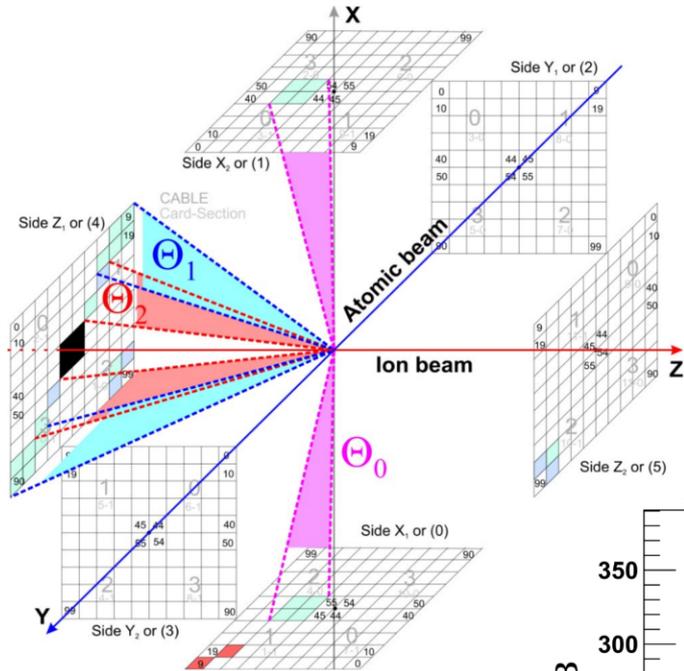
50% покрытие



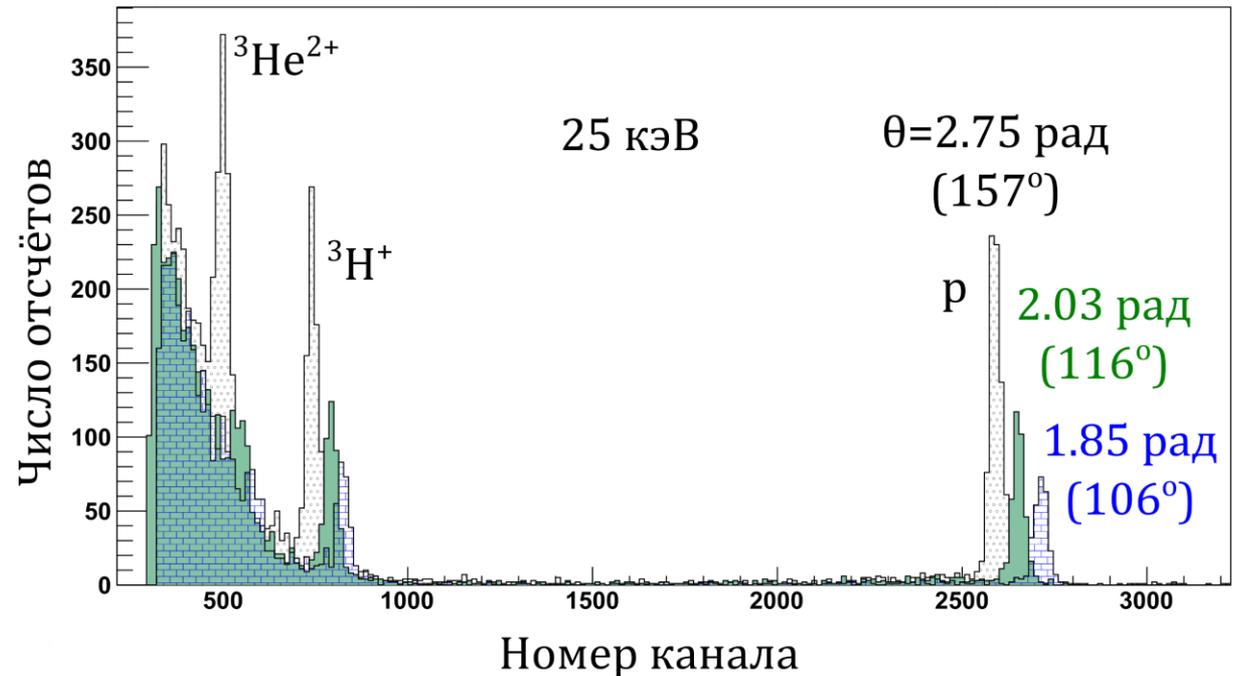
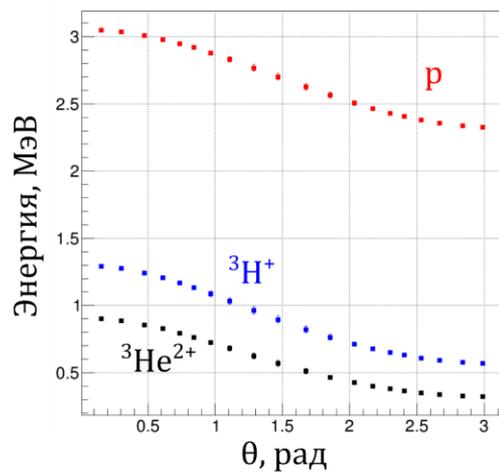
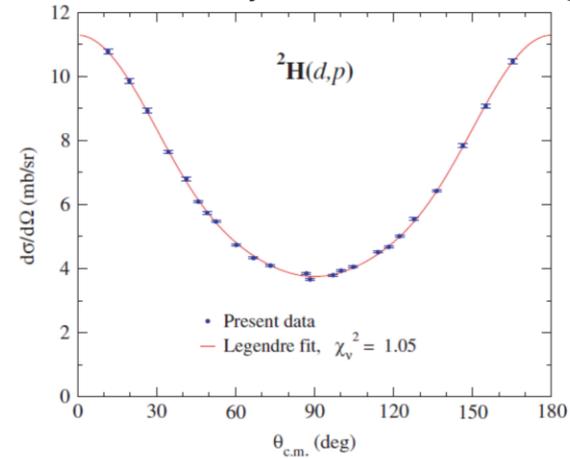
10 нс точность записи
 времени сигнала

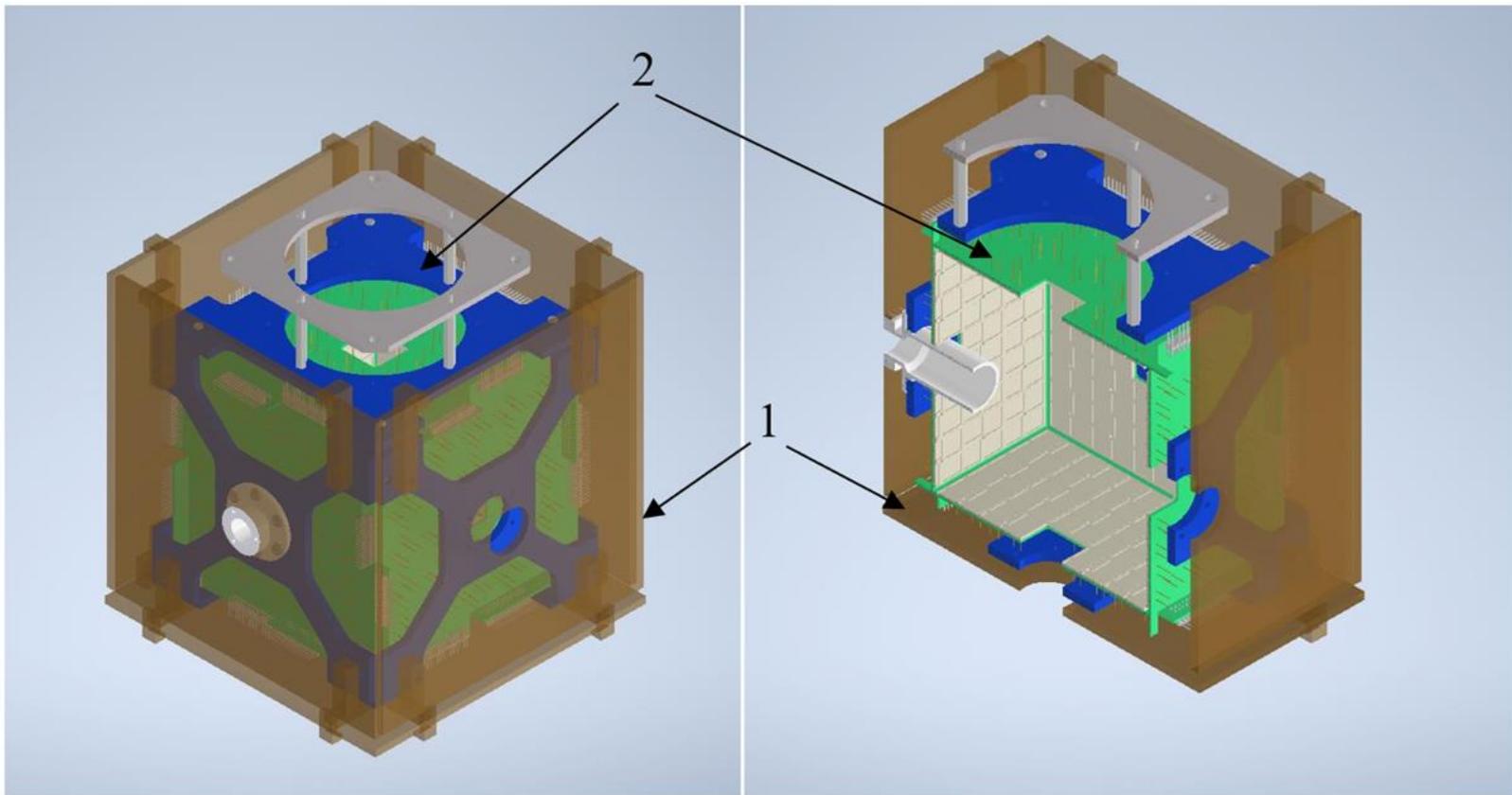
Форма сигнала:





D.S. Leonard et al, Phys. Rev. C **73**, 045801 (2006).

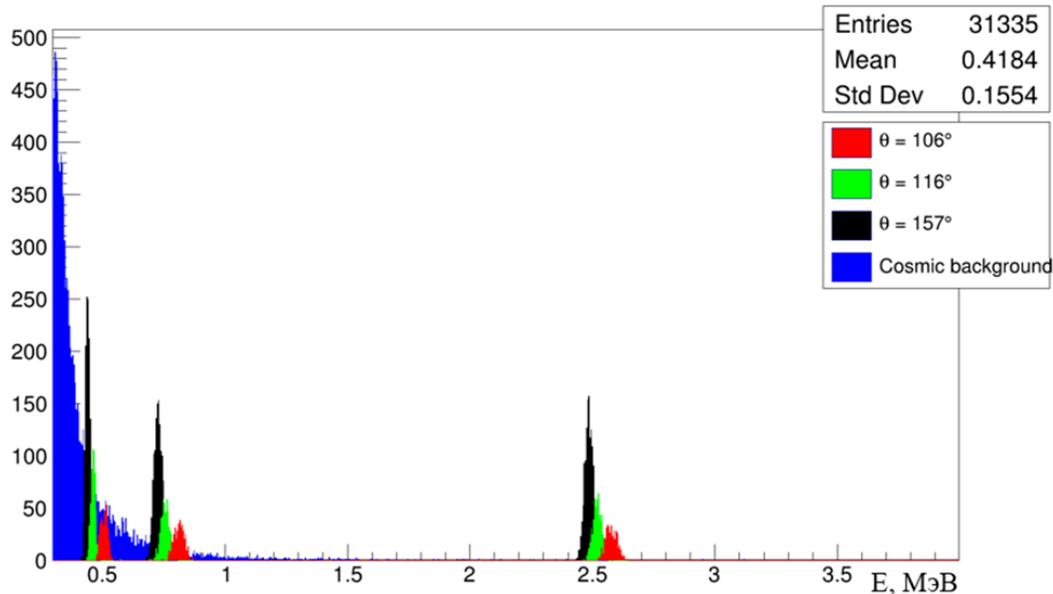




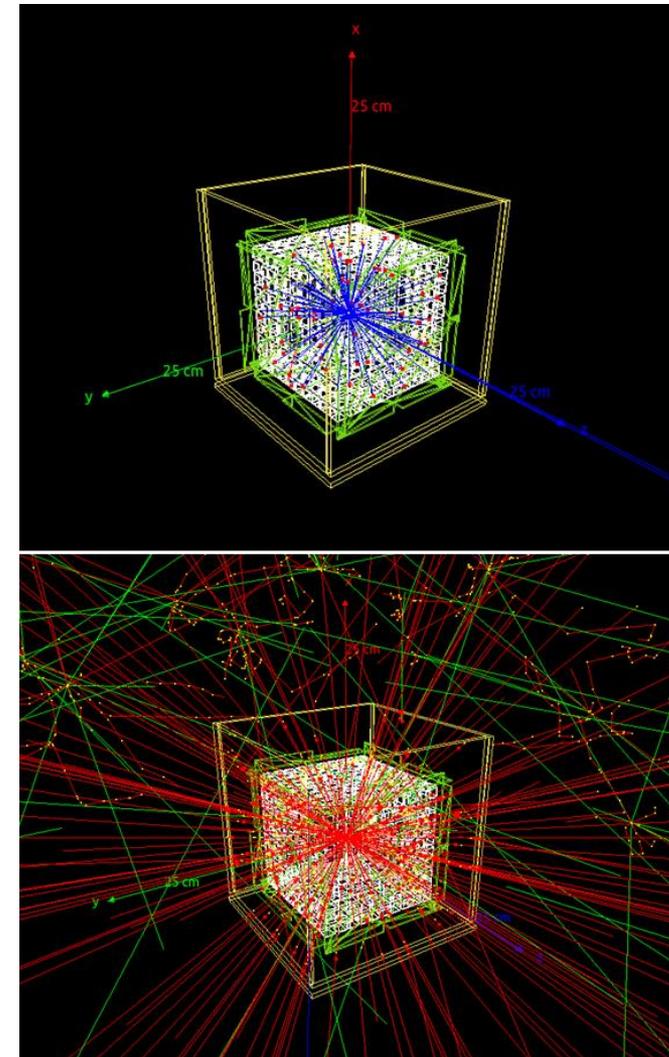
Модель детекторной системы, смоделированная в программном пакете Autodesk Inventor в полной сборке (слева) и разрезе (справа):

1 – сцинтиляционные панели; 2 – главный детектор.

Энергетический спектр с фоном космического излучения



Первые оценки Монте-Карло говорят о том, что эффективность подавления космического излучения при использовании системы сцинтилляционных детекторов находится на уровне не менее 80 %, что подтверждает эффективность разработанной системы.



План на 2022 (первая половина)

- Подготовка поляриметра на лэмбовском сдвиге для работы с ABS
- Отладка RF ячеек POLIS
- Сеанс с неполяризованным ионным и неполяризованным атомарным пучками

План на 2022 (вторая половина)

- Разработка системы детектирования космического фона
- Настройка RF ячеек ABS
- Сеанс с поляризованным ионным и неполяризованным атомарным пучками



Спасибо
за
внимание!

$$\sigma(\theta, \phi) = \sigma_0(\theta) \left(1 + \sum_{j=1}^9 \bar{p}_j^b A_j^b(\theta) + \sum_{j=1}^9 \bar{p}_j^t A_j^t(\theta) + \sum_{j=1}^9 \sum_{k=1}^9 \bar{p}_j^b \bar{p}_k^t C_{j,k}(\theta) \right)$$

$$p_{l'} \sigma(\theta, \phi) = \sigma_0(\theta) \left(P_{l'}(\theta) + \sum_{j=1}^9 \bar{p}_j K_j^{l'}(\theta) \right)$$

$$\bar{p}_1 = \frac{3}{2} p_x$$

$$\bar{p}_2 = \frac{3}{2} p_y$$

$$\bar{p}_3 = \frac{3}{2} p_z$$

$$\bar{p}_4 = \frac{2}{3} p_{xy}$$

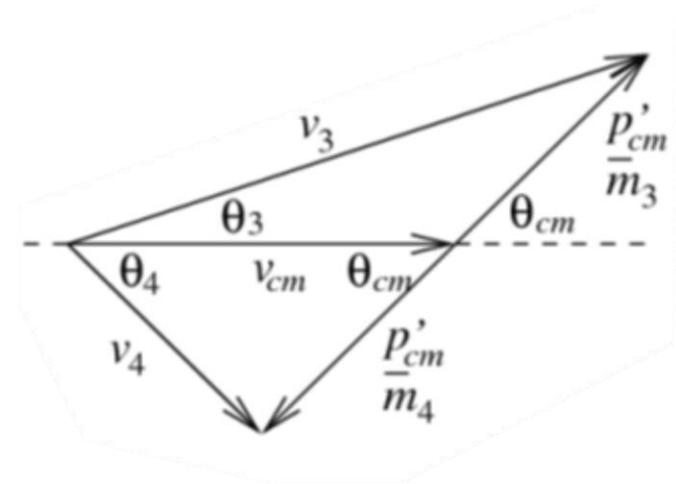
$$\bar{p}_5 = \frac{2}{3} p_{xz}$$

$$\bar{p}_6 = \frac{2}{3} p_{yz}$$

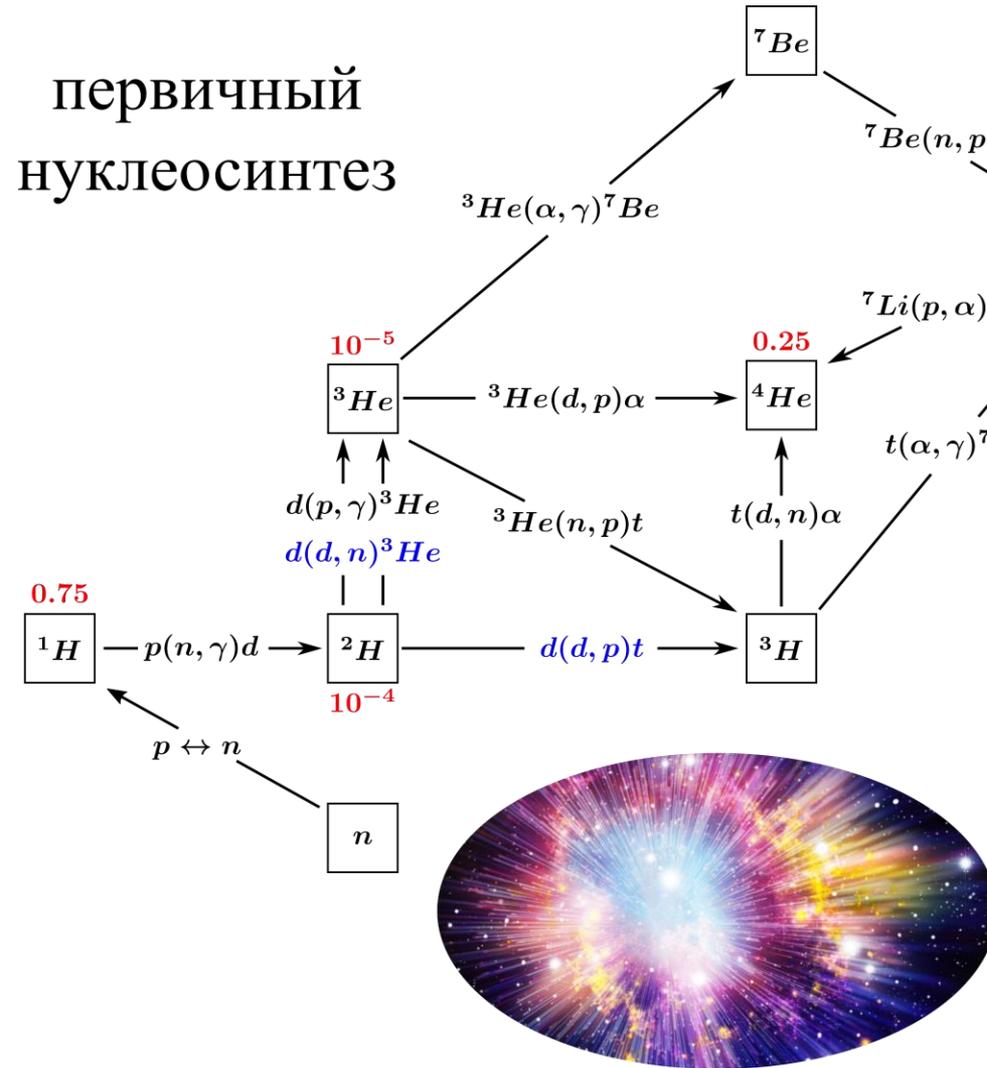
$$\bar{p}_7 = \frac{1}{3} p_{xx}$$

$$\bar{p}_8 = \frac{1}{3} p_{yy}$$

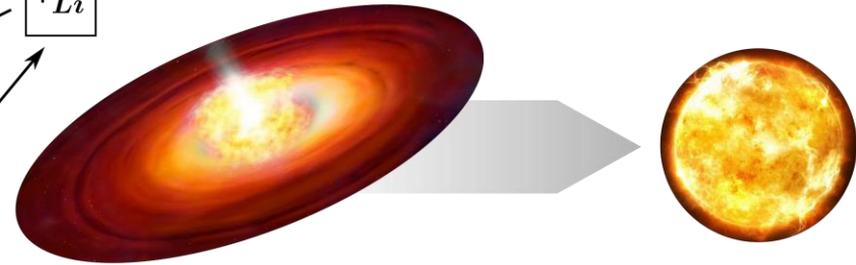
$$\bar{p}_9 = \frac{1}{3} p_{zz}$$



первичный нуклеосинтез



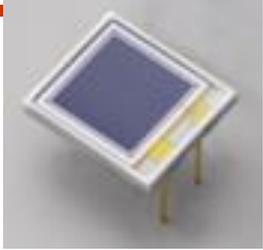
Эволюция звёзд



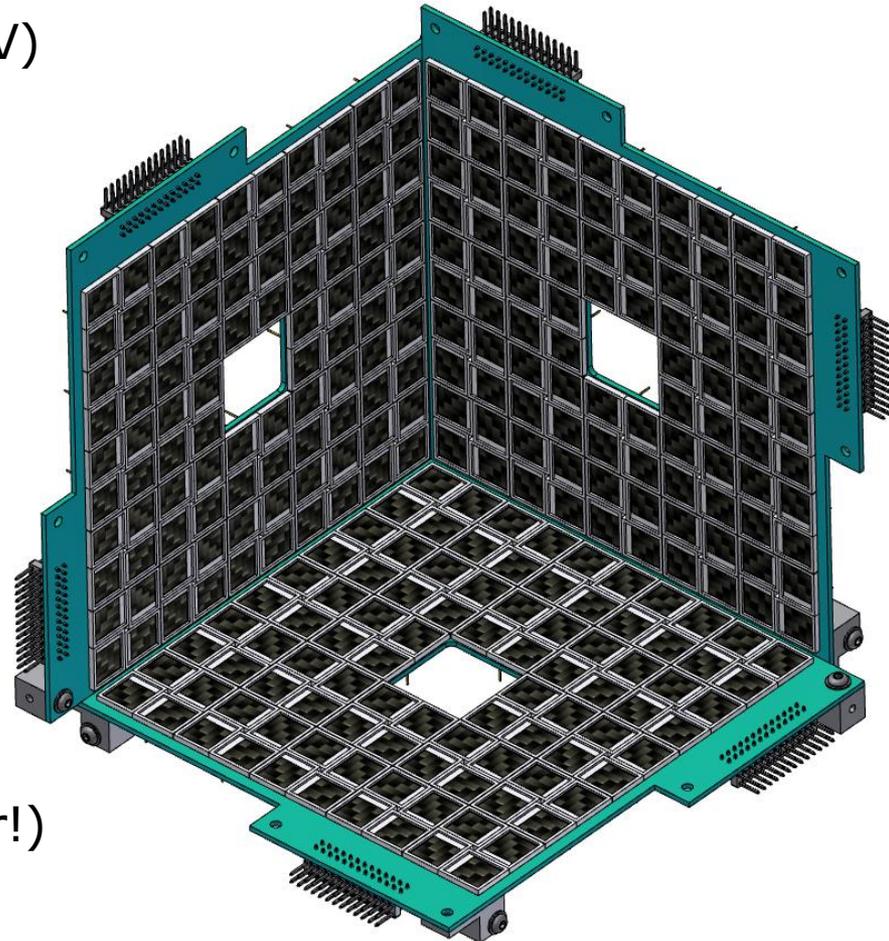
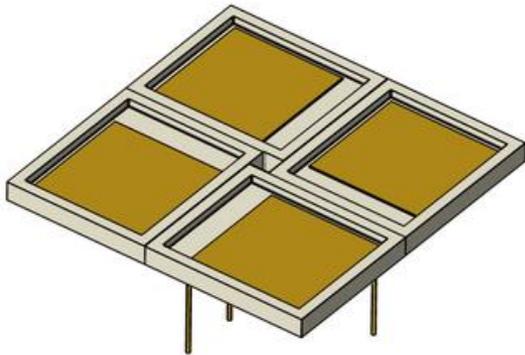
	$S(0), eV \times b$	T, K
$p(p, \nu e^+)d$	4×10^{-19}	10^7
$^3\text{He}(p, \nu e^+)\alpha$	8.6×10^{-17}	
$d(p, \gamma)^3\text{He}$	0.2	
$^3\text{He}(\alpha, \gamma)^7\text{Be}$	560	
$d(\alpha, \gamma)^6\text{Li}$	2×10^{-3}	
$d(d, \gamma)\alpha$	5.4×10^{-3}	
$d(d, n)^3\text{He}$	50000	10^6
$d(d, p)t$	56000	10^6

E. G. Adelberger et al., Rev. Mod. Phys. **83**, 195 (2011)

C. Angulo et al., Nuclear Physics A **656**, 3-183 (1999)



- 4- π detector with 51% filling
- 576 Hamamatsu PIN-diodes (S3590-09)
- PIN-diode active area: 1 cm²
- depleted layer: 300 μ m
- energy resolution: <50keV
- low reverse voltage (\leq 50V)



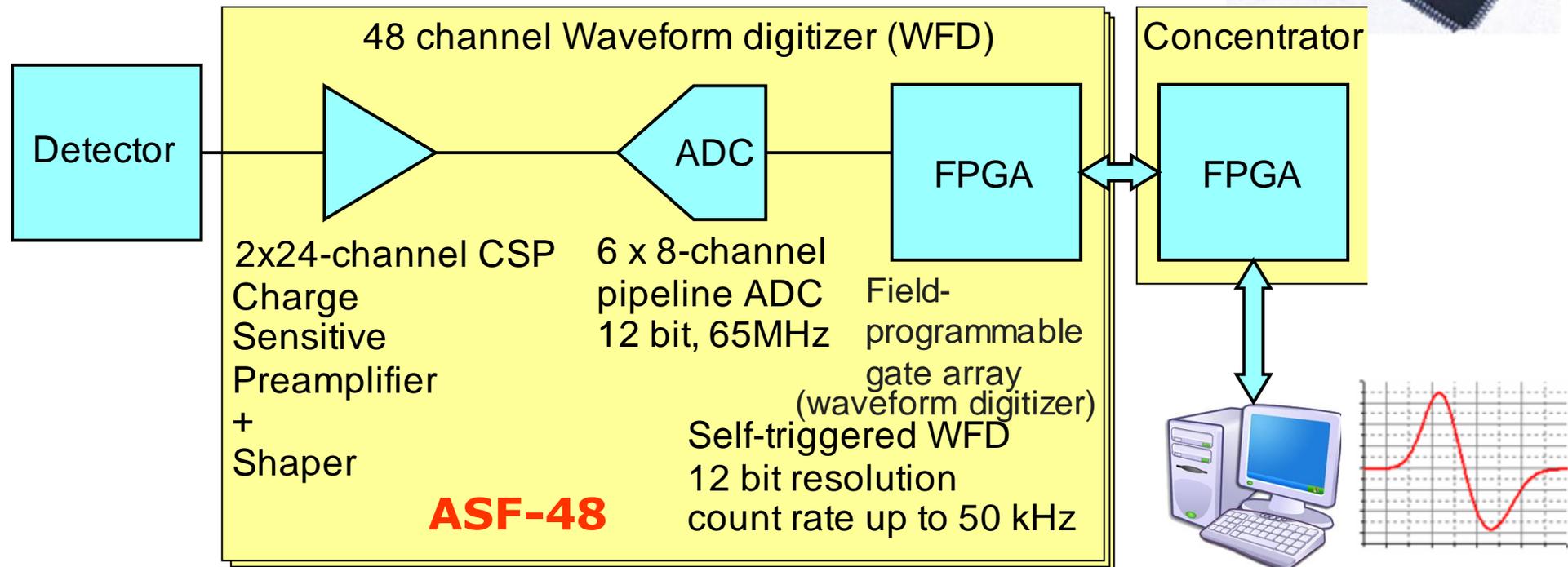
Square detector elements (4x4 diodes)
 Standard PCB assembly with
 spring through-hole mounting (no solder!)

Readout requirements:

- 600 channels
- Total count rate $\leq 1\text{kHz}$
- Standard interface (Ethernet?)
- Event synchronization for coincidence trigger

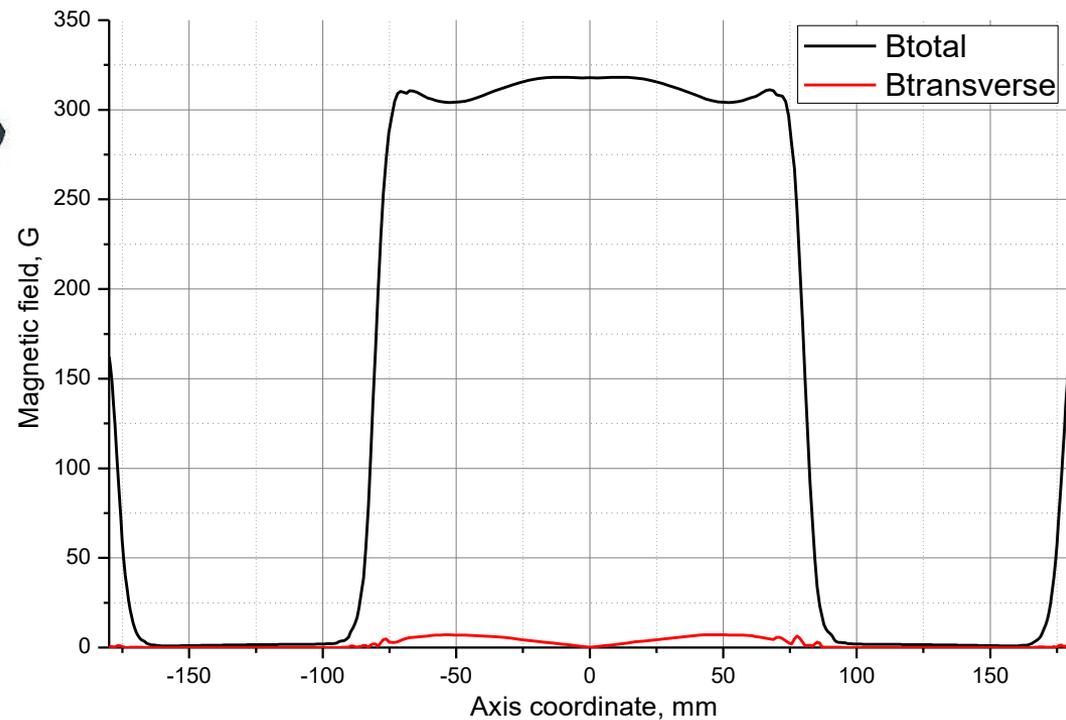
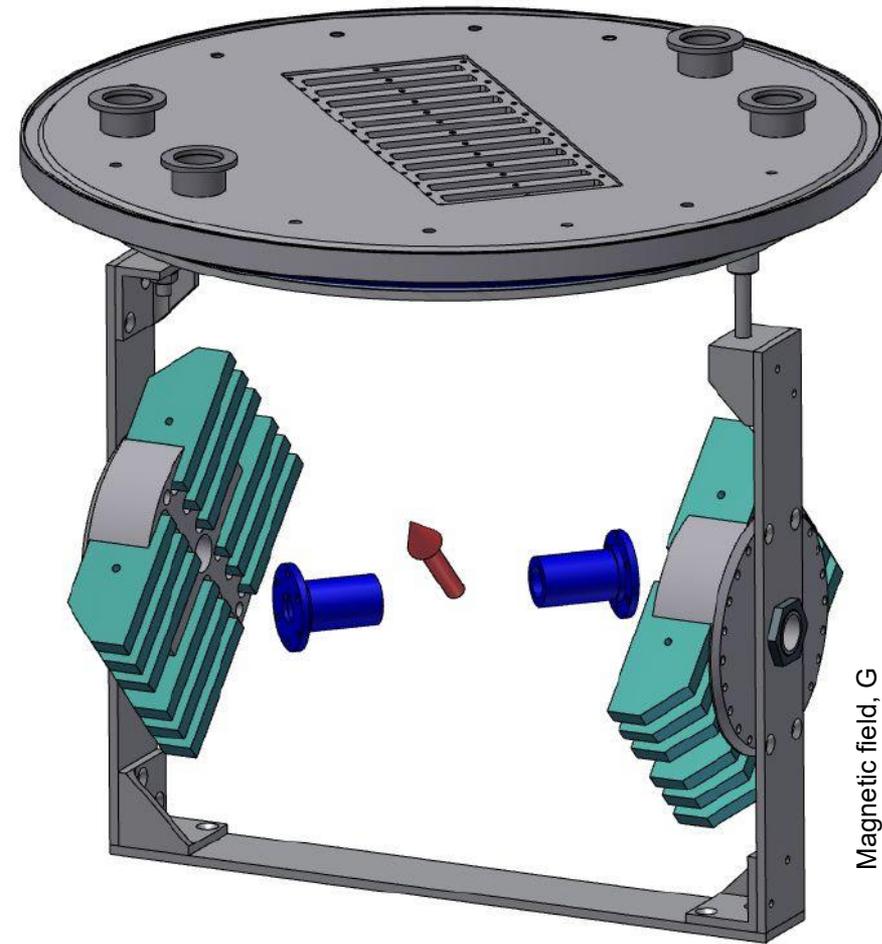
CSP from ATLAS CSC [BNL]

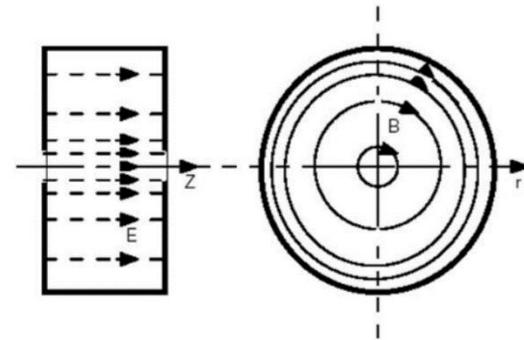
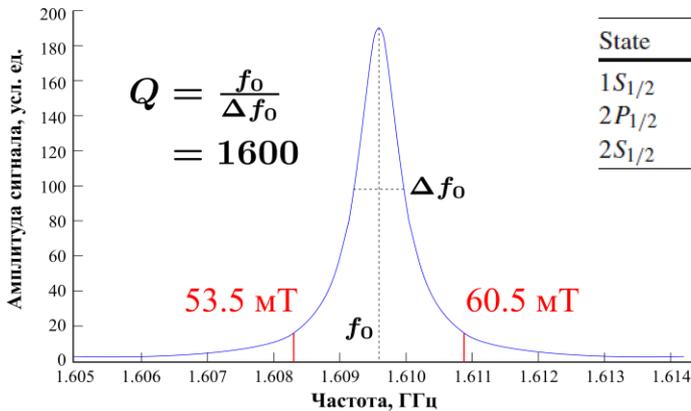
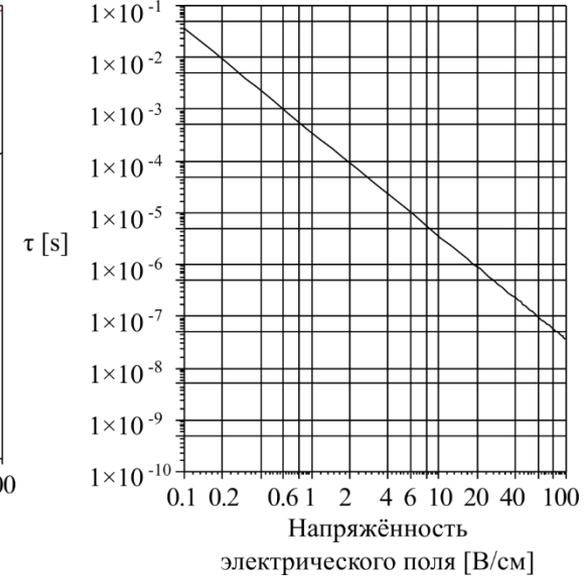
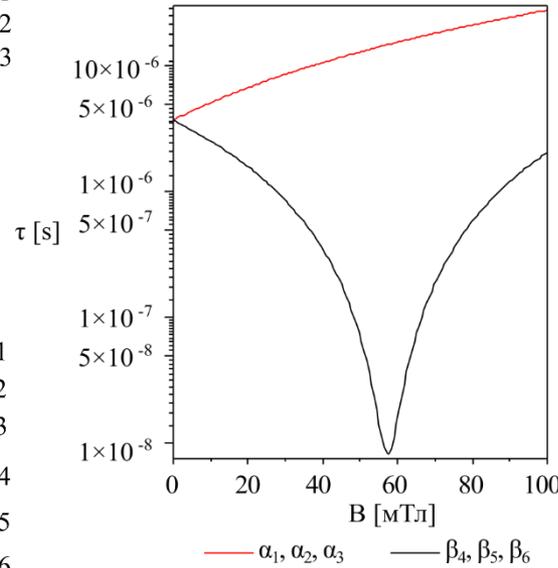
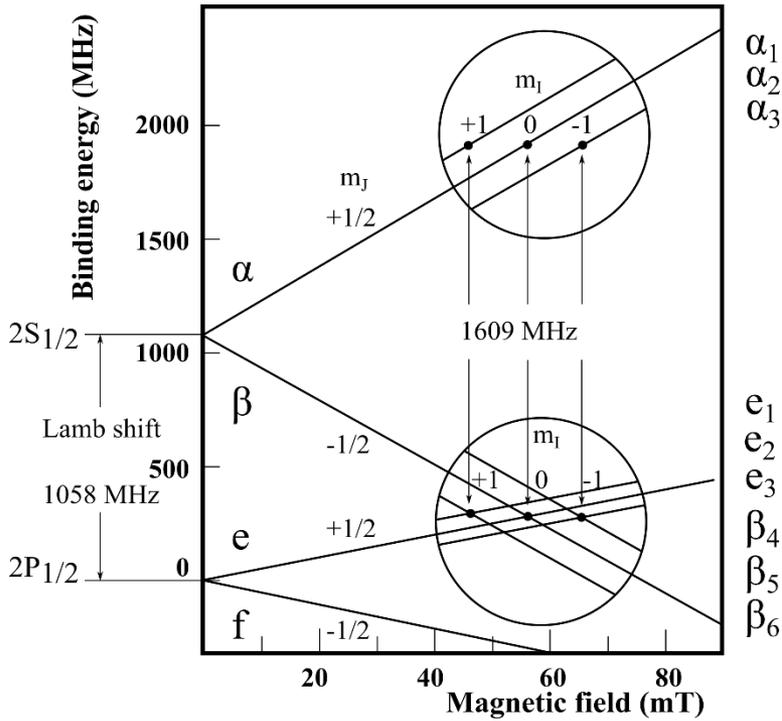
Junnarkar et al. IEEE Nuclear Science Symposium Conference Record (2005)



$$B = 300 \text{ G} = 2.5 B_c$$

Magnet field is generated by 24 permanent magnets with dimensions $80 \times 40 \times 10 \text{ mm}^3$ with pole tip field of 1.25 T at the surface (NdFeB N40)





$$\sigma(\theta, \phi) = \sigma_0 \left(1 + \frac{3}{2} P_Z A_y(\theta) \cos \phi \sin \beta - P_{ZZ} A_{xz}(\theta) \sin \beta \cos \beta \sin \phi - \frac{1}{4} P_{ZZ} (A_{xx}(\theta) - A_{yy}(\theta)) \sin^2 \beta \cos 2\phi + \frac{1}{4} P_{ZZ} A_{zz}(\theta) (3 \cos^2 \beta - 1) \right).$$

G.G. Ohlsen, P.W. Keaton, Jr., Nucl. Instr. and Meth. **109**, 41 (1973).

$$\sigma_L = \sigma_0 \left(1 + \frac{3}{2} P_Z A_y(\theta) \sin \beta + \frac{1}{2} P_{ZZ} (A_{yy}(\theta) \sin^2 \beta + A_{zz} \cos^2 \beta) \right),$$

$$\sigma_R = \sigma_0 \left(1 - \frac{3}{2} P_Z A_y(\theta) \sin \beta + \frac{1}{2} P_{ZZ} (A_{yy}(\theta) \sin^2 \beta + A_{zz} \cos^2 \beta) \right),$$

$$\sigma_U = \sigma_0 \left(1 + P_{ZZ} A_{xz}(\theta) \sin \beta \cos \beta + \frac{1}{2} P_{ZZ} (A_{xx}(\theta) \sin^2 \beta + A_{zz} \cos^2 \beta) \right),$$

$$\sigma_D = \sigma_0 \left(1 + P_{ZZ} A_{xz}(\theta) \sin \beta + \frac{1}{2} P_{ZZ} (A_{yy}(\theta) \sin^2 \beta \cos \beta + A_{zz} \cos^2 \beta) \right).$$

$$L \propto \sigma_L$$

$$R \propto \sigma_R$$

$$U \propto \sigma_U$$

$$D \propto \sigma_D.$$

$$R = \frac{R_{polarized}}{R_{unpolarized}}.$$



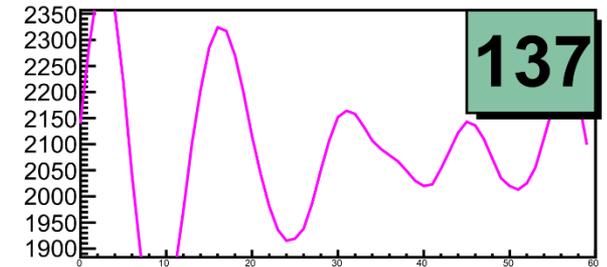
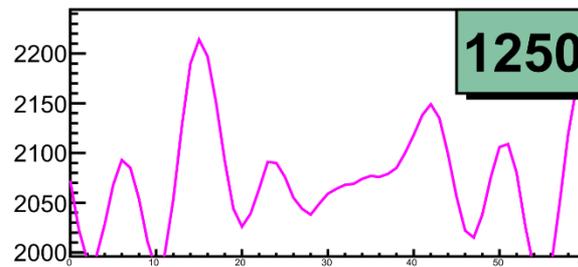
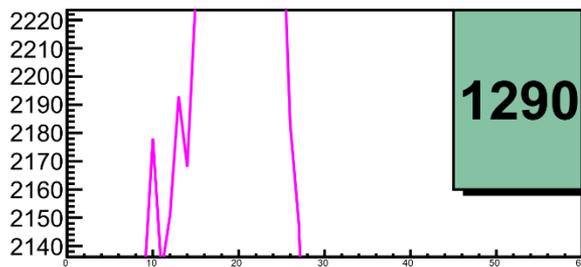
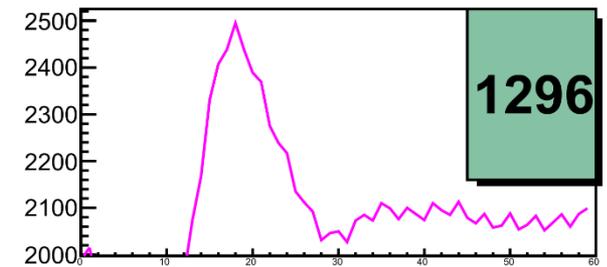
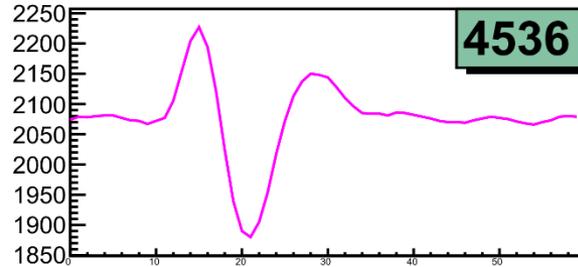
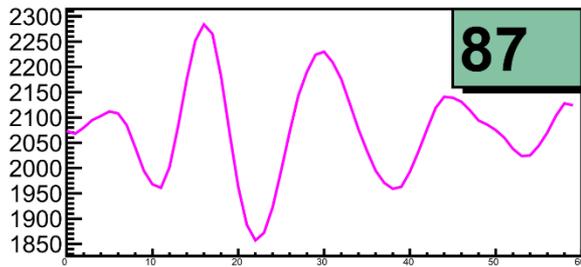
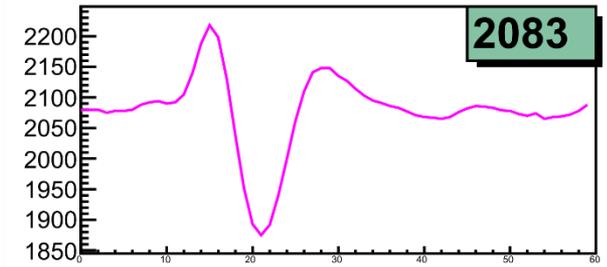
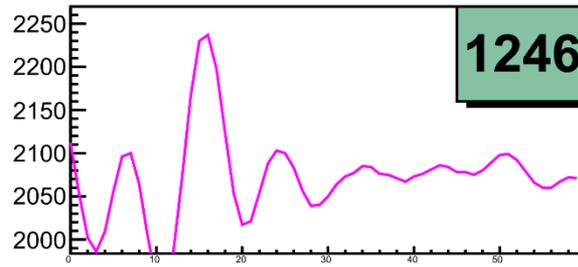
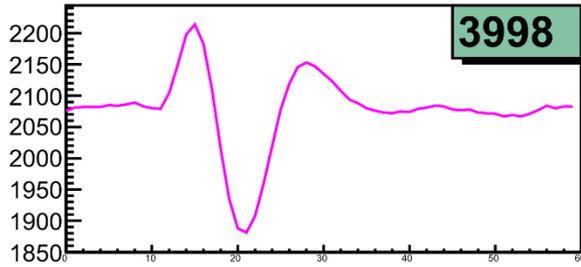
$$\epsilon_1 \equiv \frac{L - R}{L + R} = \frac{\frac{3}{2} P_Z \sin \beta A_y}{1 + \frac{1}{2} P_{ZZ} [\sin^2 \beta A_{yy} + \cos^2 \beta A_{zz}]}$$

$$\epsilon_2 \equiv \frac{U - D}{U + D} = \frac{P_{ZZ} \sin \beta \cos \beta A_{xz}}{1 + \frac{1}{2} P_{ZZ} [\sin^2 \beta A_{xx} + \cos^2 \beta A_{zz}]}$$

$$\epsilon_3 \equiv \frac{2(L - R)}{L + R + U + D} = \frac{\frac{3}{2} P_Z \sin \beta A_y}{1 + \frac{1}{4} P_{ZZ} [3(\cos^2 \beta - 1) A_{zz}]}$$

$$\epsilon_4 \equiv \frac{2(U - D)}{L + R + U + D} = \frac{P_{ZZ} \sin \beta \cos \beta A_{xz}}{1 + \frac{1}{4} P_{ZZ} [3(\cos^2 \beta - 1) A_{zz}]}$$

$$\epsilon_5 \equiv \frac{(L + R) - (U + D)}{L + R + U + D} = \frac{-\frac{1}{4} P_{ZZ} \sin^2 \beta (A_{xx} - A_{yy})}{1 + \frac{1}{4} P_{ZZ} [3(\cos^2 \beta - 1) A_{zz}]},$$



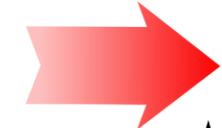
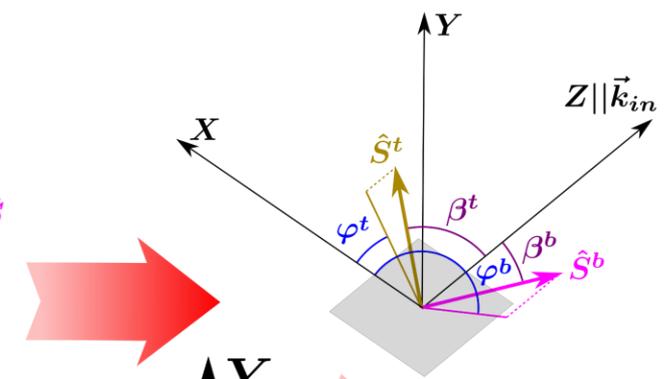
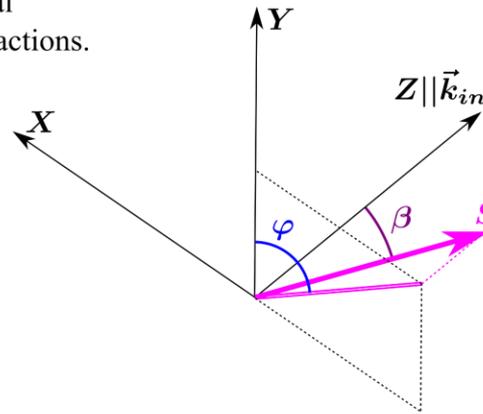


Basel convention (1961): Huber, P., Meyer, K.P. (eds.): Proceedings of the International Symposium on Polarization Phenomena of Nucleons. Helv. Phys. Acta Suppl. VI. Birkhäuser

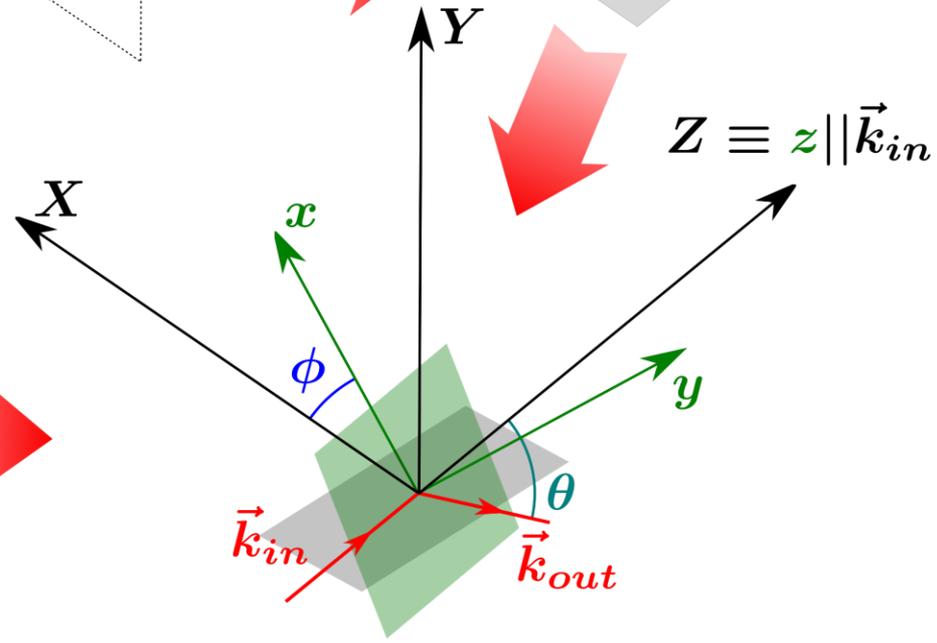
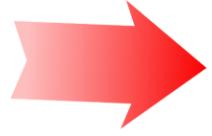
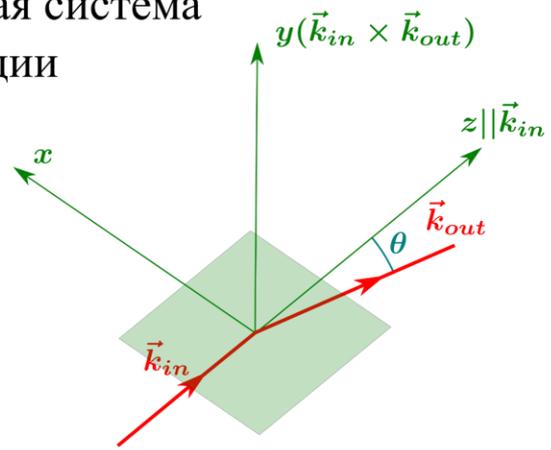
Madison convention (1971): Barschall, H.H., Haeberli, W. (eds.): Proceedings of the 3rd International Symposium on Polarization Phenomena in Nuclear Reactions. University of Wisconsin Press

Описание поляризации
(фиксированная в пространстве
координатная система)

- | | |
|------------------------|---|
| \vec{k}_{in} | - МОМЕНТ ИМПУЛЬСА
налетающей частицы |
| \vec{k}_{out} | - МОМЕНТ ИМПУЛЬСА
вылетающей частицы |
| \hat{S}^b, \hat{S}^t | - ОСИ КВАНТОВАНИЯ
пучка и мишени |



Координатная система
реакции



$$Y(\theta, \phi) = L \cdot \sigma(\theta, \phi)$$

$$\sigma(\theta, \phi) = \sigma_0(\theta) \left(1 + \sum_1^9 p_j^b A_j^b(\theta) + \sum_1^9 p_j^t A_j^t(\theta) + \sum_1^9 \sum_1^9 p_j^b p_k^t C_{j,k}(\theta) \right)$$

Gerald G. Ohlsen, Rep. Prog. Phys. **35**, 717 (1972)

Знак поляризации: (L_{POLIS}, ABS)

$$L_{++} = L_{-+} = L_{+-} = L_{--}$$

$$\mathcal{A}^b(\theta, \phi) = \frac{(Y_{++} + Y_{+-}) - (Y_{-+} + Y_{--})}{Y_{++} + Y_{+-} + Y_{-+} + Y_{--}}$$

$$\mathcal{A}^t(\theta, \phi) = \frac{(Y_{++} + Y_{-+}) - (Y_{+-} + Y_{--})}{Y_{++} + Y_{+-} + Y_{-+} + Y_{--}}$$

$$\mathcal{A}^{b,t}(\theta, \phi) = \frac{(Y_{++} + Y_{--}) - (Y_{-+} + Y_{+-})}{Y_{++} + Y_{+-} + Y_{-+} + Y_{--}}$$

$$\beta^b = \beta^t = 0^\circ :$$

$$\sigma(\theta, \phi) = \sigma_0(\theta) \left[1 + \frac{1}{2} p_{ZZ}^b A_{zz}^b(\theta) + \frac{1}{2} p_{ZZ}^t A_{zz}^t(\theta) + \frac{9}{4} p_Z^b p_Z^t C_{z,z}(\theta) + \frac{1}{4} p_{ZZ}^b p_{ZZ}^t C_{zz,zz}(\theta) \right]$$

$$\mathcal{A}^b(\theta, \phi) = \frac{2|p_{ZZ}^b| A_{zz}^b(\theta)}{4+9C_{z,z}}$$

$$\mathcal{A}^t(\theta, \phi) = \frac{2|p_{ZZ}^t| A_{zz}^t(\theta)}{4+9C_{z,z}}$$

$$\mathcal{A}_Z^{b,t}(\theta, \phi) = \frac{9|p_Z^b| |p_Z^t| C_{z,z}(\theta)}{4+2p_{ZZ}^b A_{zz}^b(\theta) + 2p_{ZZ}^t A_{zz}^t(\theta) + p_{ZZ}^b p_{ZZ}^t C_{zz,zz}(\theta)}$$

$$\mathcal{A}_{ZZ}^{b,t}(\theta, \phi) = \frac{|p_{ZZ}^b| |p_{ZZ}^t| C_{zz,zz}}{4+9|p_Z^b| |p_Z^t| C_{z,z}}$$

$$p_Z^b = p_Z^t = \pm \frac{2}{3}$$

$$p_{ZZ}^b = p_{ZZ}^t = 0$$

$$\mathcal{A}_Z^{b,t}(\theta, \phi) = C_{z,z}$$

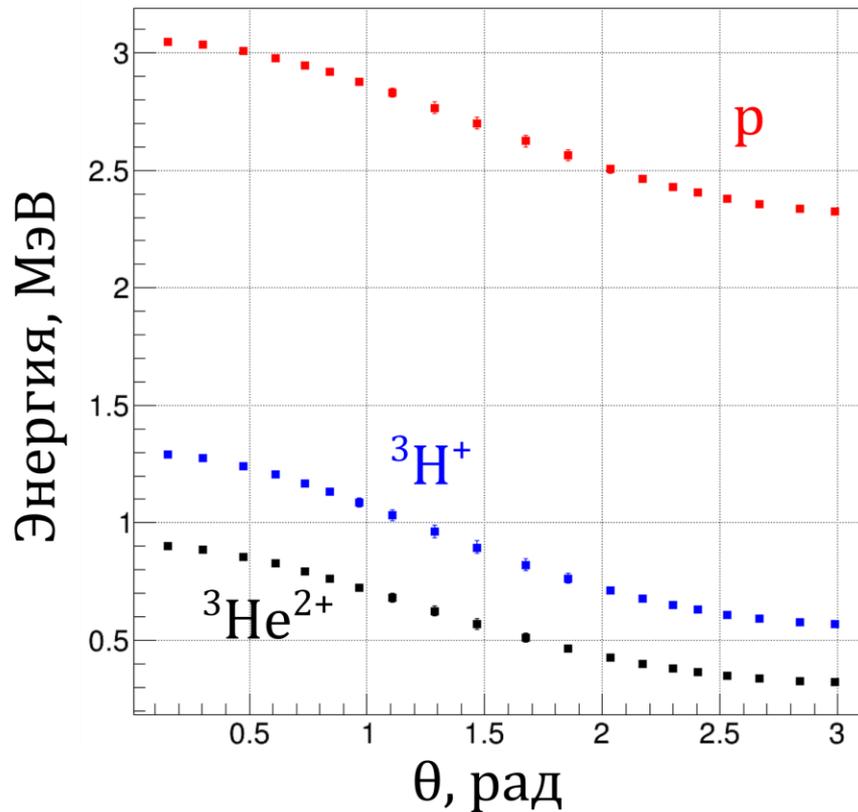
$$p_Z^b = p_Z^t = +\frac{1}{3}$$

$$p_{ZZ}^b = p_{ZZ}^t = \pm 1$$

$$\mathcal{A}_{ZZ}^{b,t}(\theta, \phi) = \frac{C_{zz,zz}}{4+C_{z,z}}$$

$$\mathcal{A}_{ZZ}^b(\theta, \phi) = \frac{2A_{zz}^b(\theta)}{4+9C_{z,z}}$$

$$\mathcal{A}_{ZZ}^t(\theta, \phi) = \frac{2A_{zz}^t(\theta)}{4+9C_{z,z}}$$



На основе формул из [Г.А.Борисов, Р.Д.Васильев, В.Ф.Шевченко
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