DOUBLE POLARIZED DD-FUSION

Status report

Participating Institutions

Petersburg Nuclear Physics Institute, Russia

Forschungszentrum Jülich, Germany

Cologne University, Germany

KVI, Gronningen, Netherlands

University ITMO, St.Petersburg, Russia

Financial support:
ISTC project #3881
Deutsche Forschungsgemeinschaft
Russian Academy of Science

Double polarized dd-fusion

$$\vec{d} + \vec{d} \rightarrow t + p$$

$$\vec{d} + \vec{d} \rightarrow {}^{3}He + n$$

- Systematic measurements of the spin-correlation coefficients
- Cross section increase

  [R.M. Kulsrud *et al*., Phys. Rev. Lett. **49**, 1248 (1982)]

  $^{3}He+d \rightarrow {}^{4}He+p$: Factor ~1.5 at 430 keV

  [Ch. Leemann et al., Annals of Phys. **66**, 810 (1971)]
- Neutrons suppression

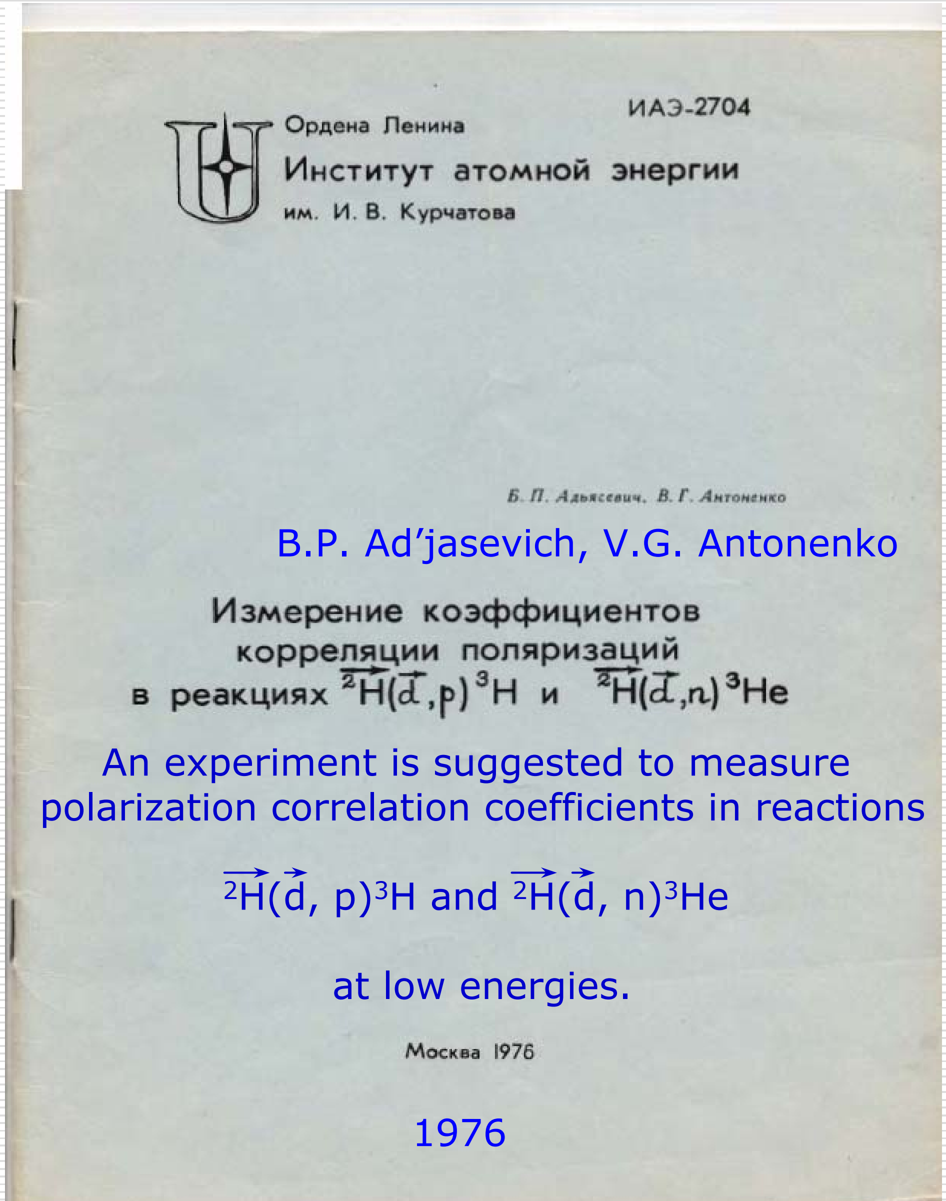
  Quintet suppression factor

  [H. Paetz gen. Schieck, Eur. Phys. J. A **44**, 321–354 (2010)]

  []
- Trajectories control of the fusion products
- United efforts on the practical use of the polarized fusion

  Persistence of the Polarization in a Fusion Process

  [J.-P. Didelez and C. Deutsch. Few-Body Conference, Bonn (2009)]



ИАЭ-2704

Ордена Ленина
Институт атомной энергии
им. И. В. Курчатова

Б. П. Адьясевич, В. Г. Антоненко

Измерение коэффициентов
корреляции поляризаций
в реакциях $^{2}\vec{H}(\vec{d},p)^{3}H$ и $^{2}\vec{H}(\vec{d},n)^{3}He$

Москва 1976

B.P. Ad’jasevich, V.G. Antonenko

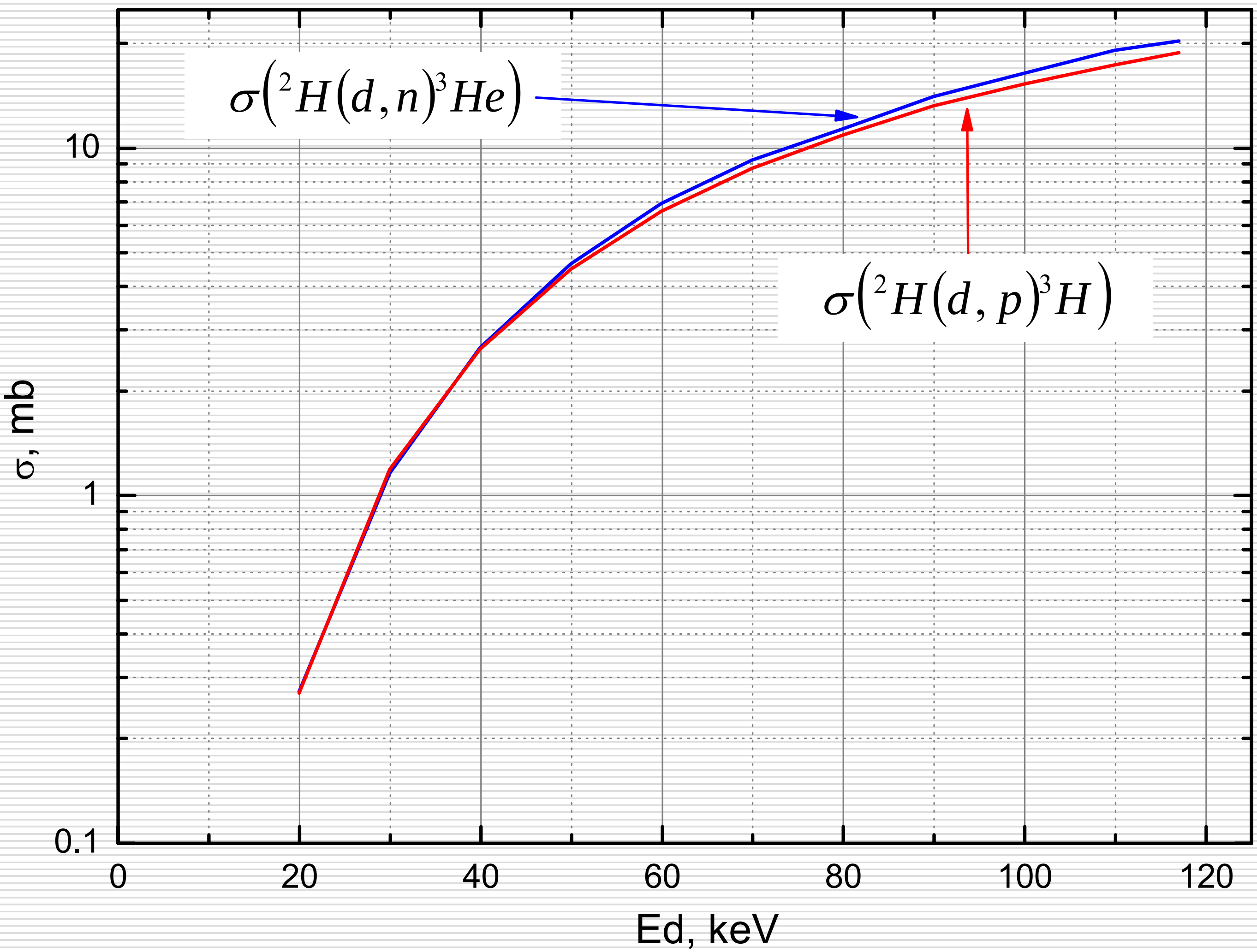
An experiment is suggested to measure polarization correlation coefficients in reactions

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

at low energies.

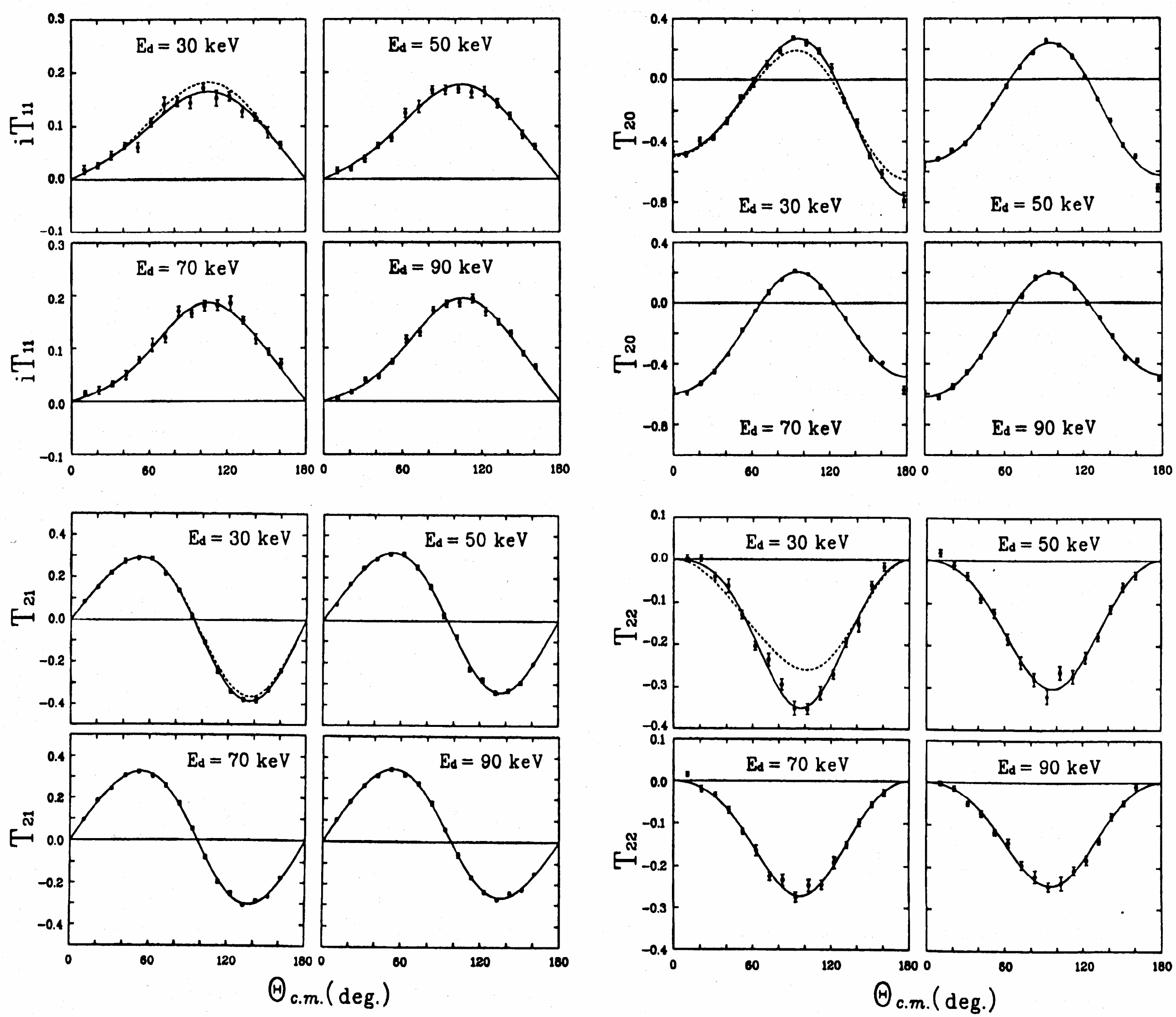
1976

Unpolarized cross sections



R. E. Brown, N. Jarmie, Phys. Rev. C **41** N4 (1990)

Data situation

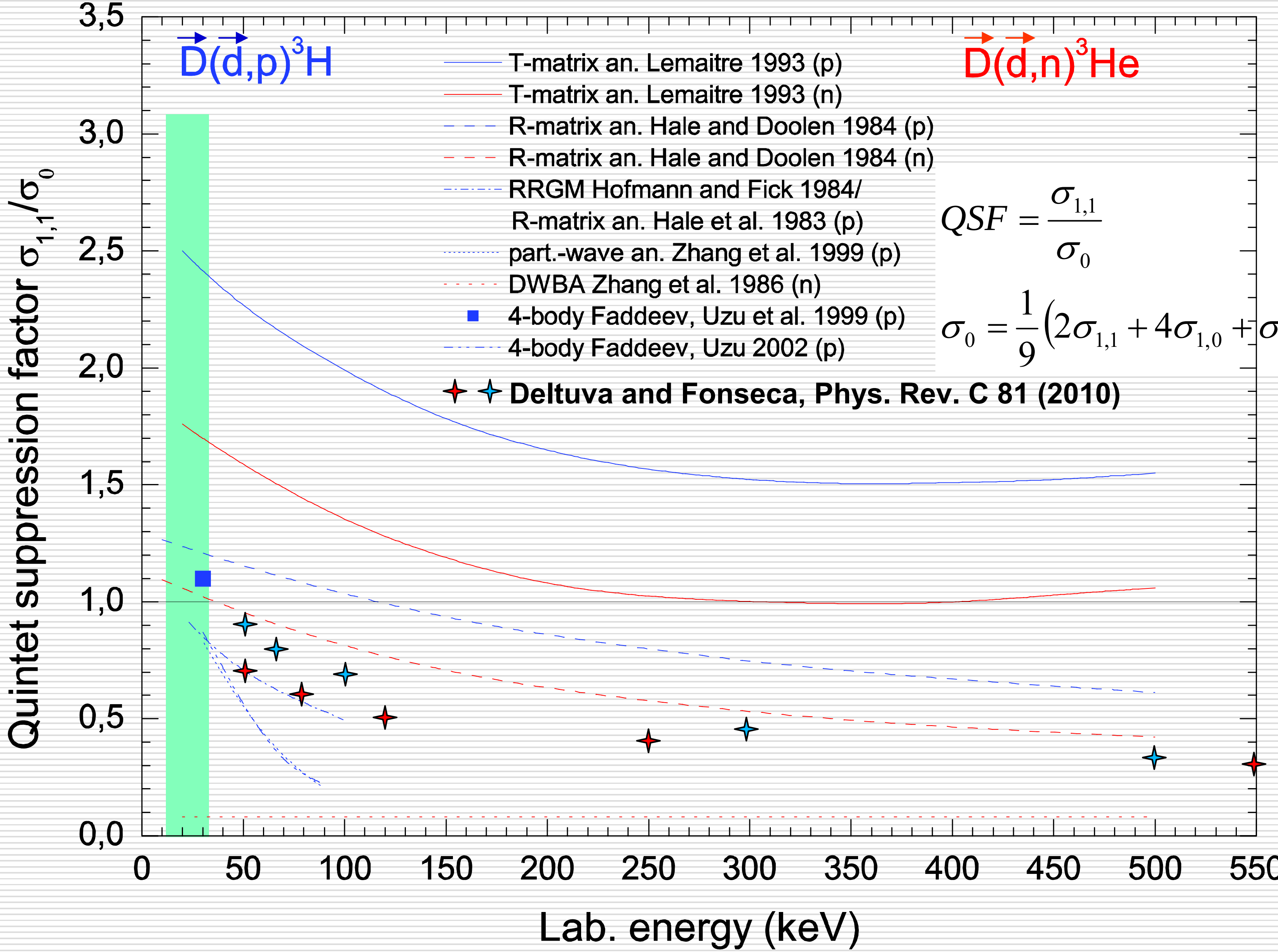


Tagishi et al.; Phy. Rev. C **46** (1992) 1155-1158
[Analysing Powers: ^{2}H(d,p)^{3}H, solid target]

Becker et al.
Few Body Sys. **13** (1992)
[Analysing Powers]

Imig et al.
Phys.Rev. C **73** (2006)
[Spin-Transfer Koeff.]

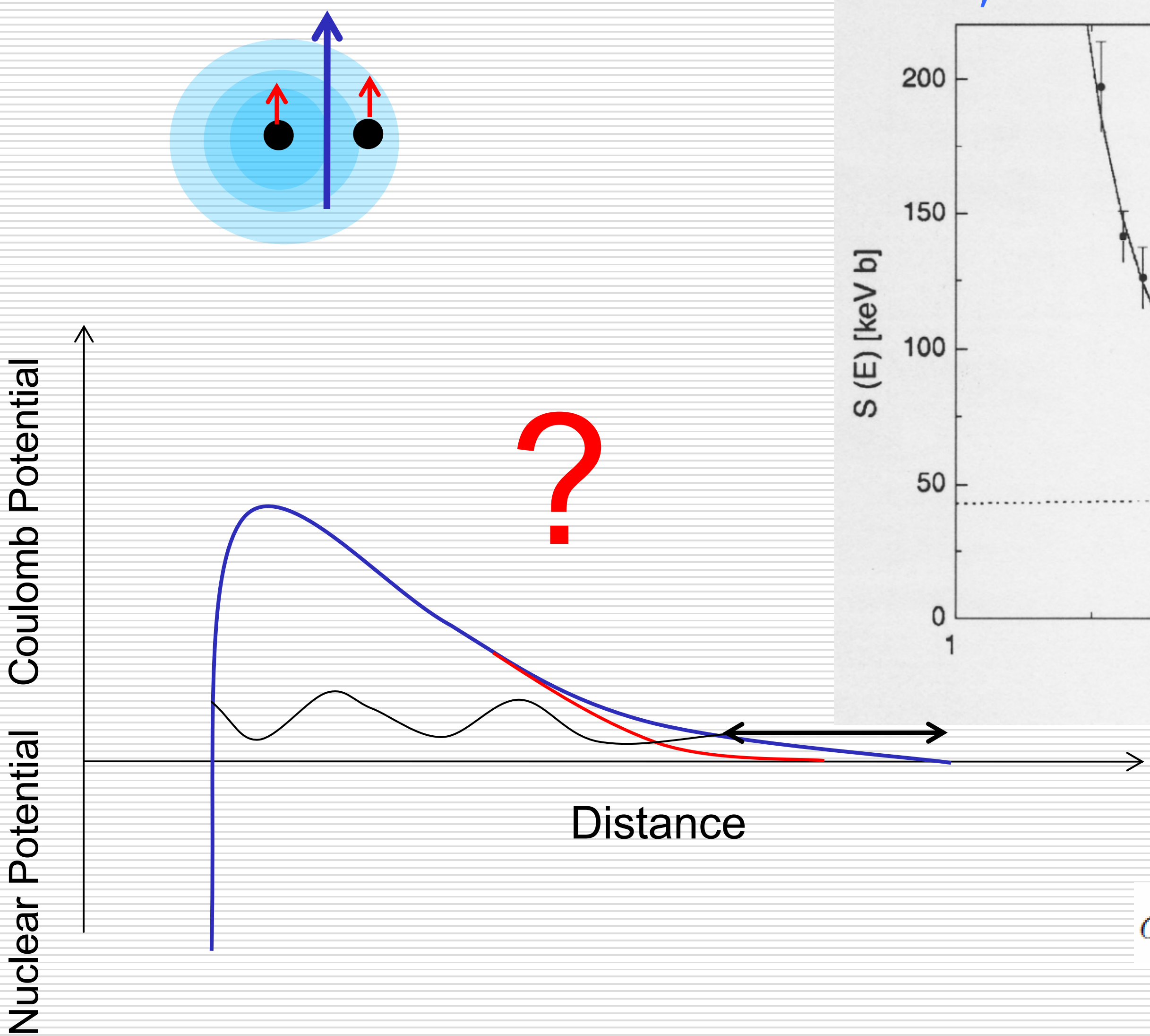
The Quintet suppression factor

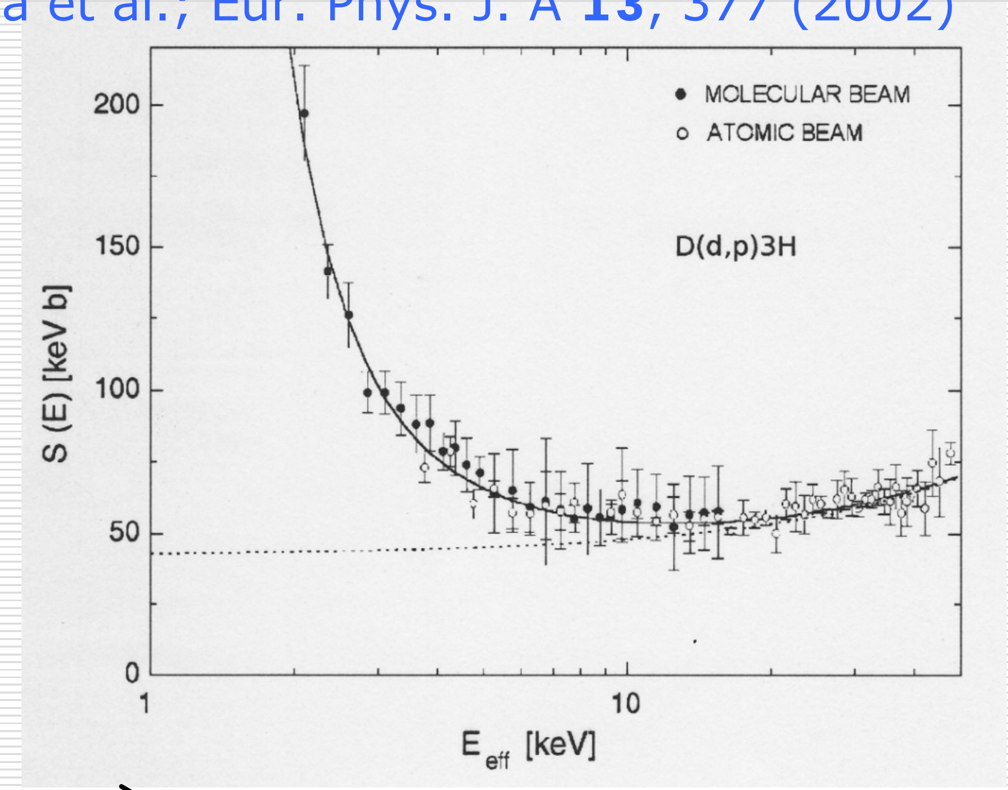


$$QSF = \frac{\sigma_{1,1}}{\sigma_0}$$

$$\sigma_0 = \frac{1}{9}\left(2\sigma_{1,1} + 4\sigma_{1,0} + \sigma_{0,0} + 2\sigma_{1,-1}\right)$$

Astrophysical S-Factor:
F. Raiola et al.; Eur. Phys. J. A **13**, 377 (2002)

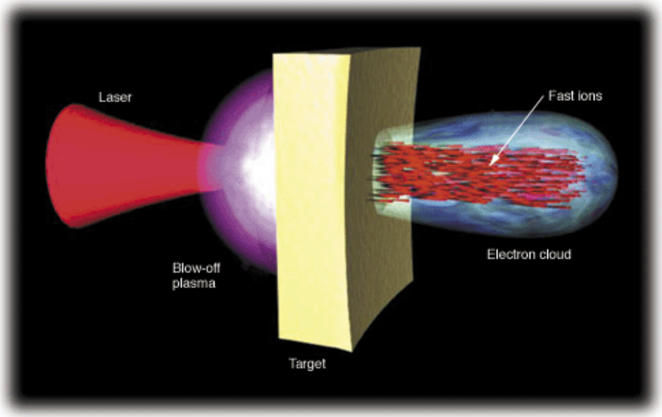




$$\sigma(E) = S(E)E^{-1}\exp(-2\pi\eta)$$

$$\eta = 2\pi Z_1 Z_2 e^2/hv$$

Persistence of the Polarization in a Fusion Process.
J.-P. Didelez and C. Deutsch. Few-Body Conference, Bonn (2009).



In laboratory experiments, the Petawatt laser's tremendous power produced intense beams of protons, proving the laser to be a powerful ion accelerator.

Basic study on polarized D-D fusion.
N. Horikawa. International Symposium on Polarized Target and its Application (2008).

Proposal for Basic Study on Spin Polarized D-D Collision

1. **Condition for the Pol. Beam**
   Beam Intensity : I > 10^{16} particles/s
   Beam Polarization : P > 50%

2. **Event Rate**
   E = 10 ~ 100keV Region
   About n> 10^{-2} (events/s)

3. **Data acquisition**
   Statistical Error < 5% → Confirmation of Effect of Spin Pol. Collision

Estimation of Cost and Time

1. Cost :

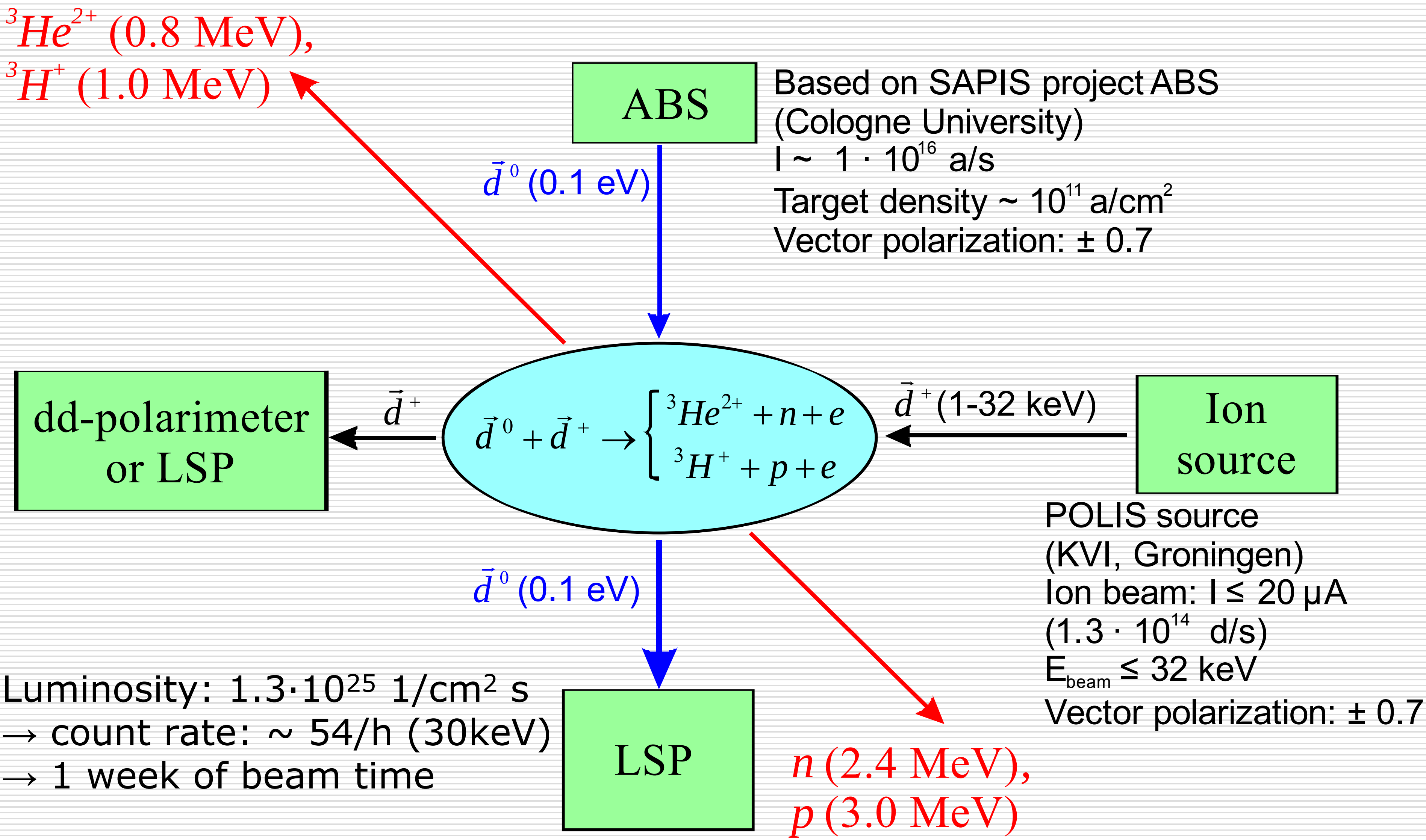
- Pol. Ion Source : ¥ 328,000,000 (for 2 stations)
- Beam Channel : 28,000,000
- Scattering Ch.+ Detectors : 40,000,000
- Comsumable matterials : 51,000,000
- Employment : 54,000,000
- Travel Expenses : 11,000,000

512,000,000

2. Time schedule :

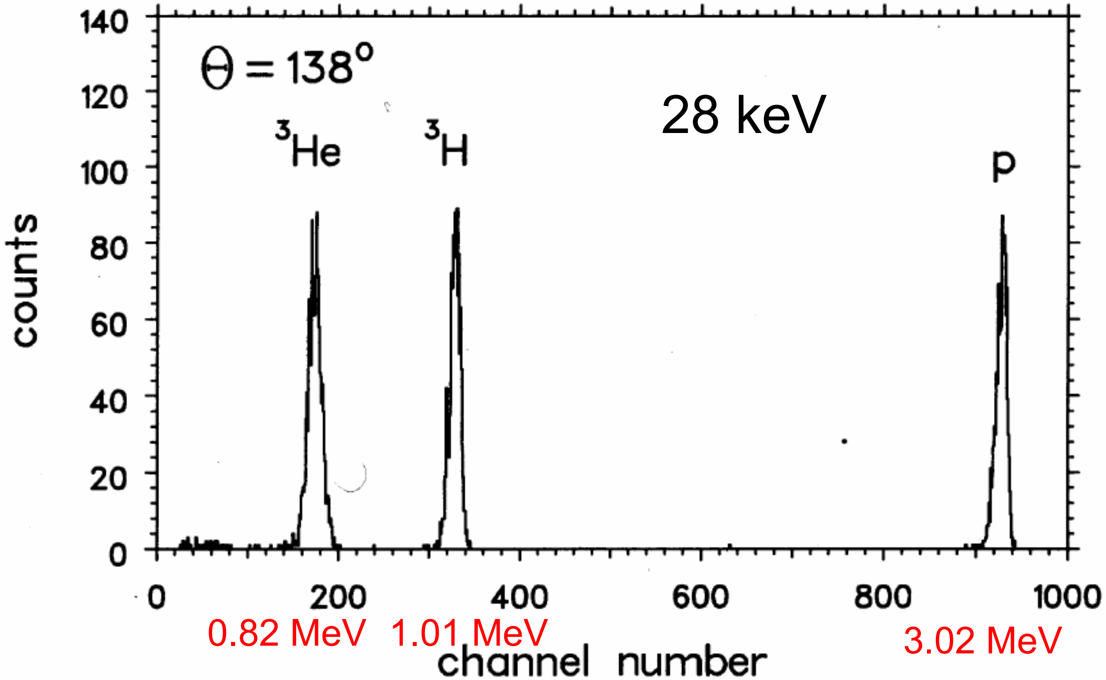
3 years : for Construction
1 year : for tuning
1 year : measurement

Experimental setup



Count rate

Typical charged-particle spectra [Becker et al. Few Body Sys. **13** (1992)]



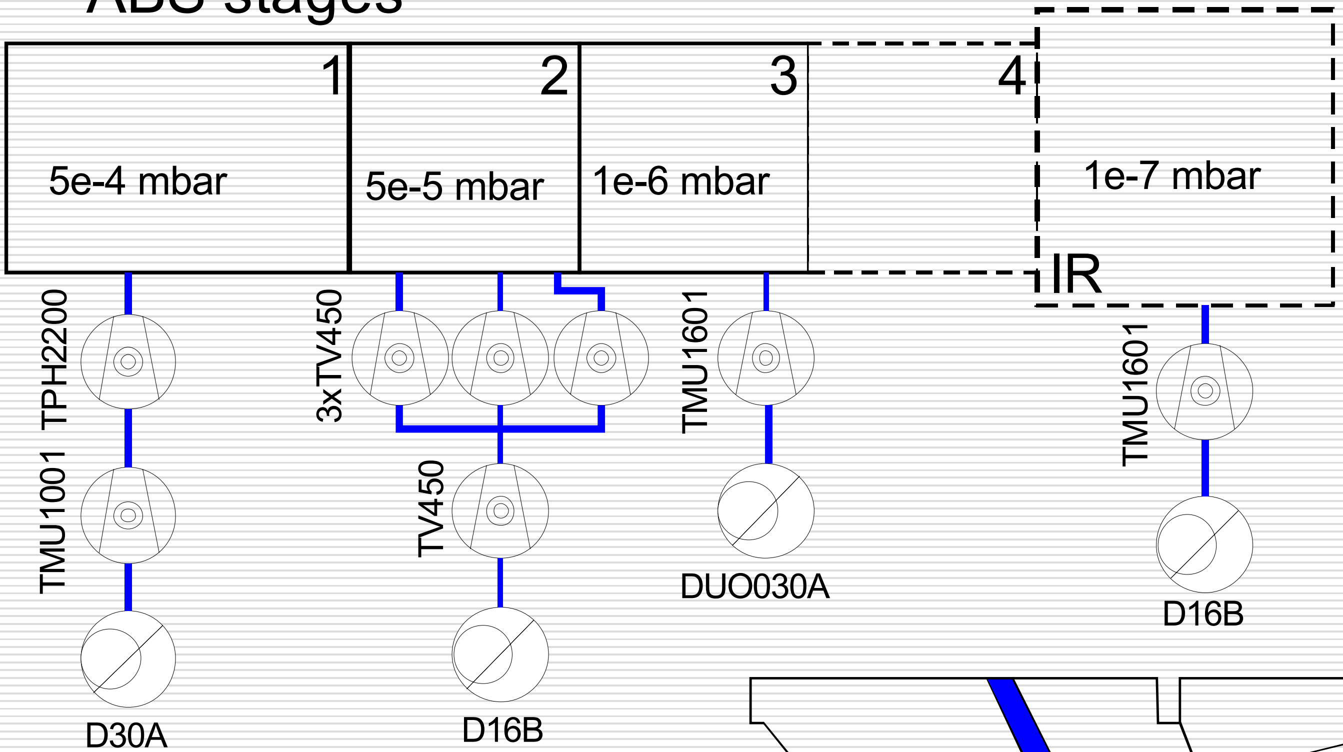
Energy, keV	Cross-section, mb	Count rate 1/hr	Beam time (10000), h	Beam time (10000), days
10	0.09	4	2374	98.9
20	0.273	13	783	32.6
30	1.161	54	184	7.7
40	2.667	125	80	3.3
50	4.651	218	46	1.9
60	6.927	324	31	1.3
70	9.237	432	23	1.0
80	11.38	533	19	0.8
90	14.08	659	15	0.6
100	16.44	769	13	0.5

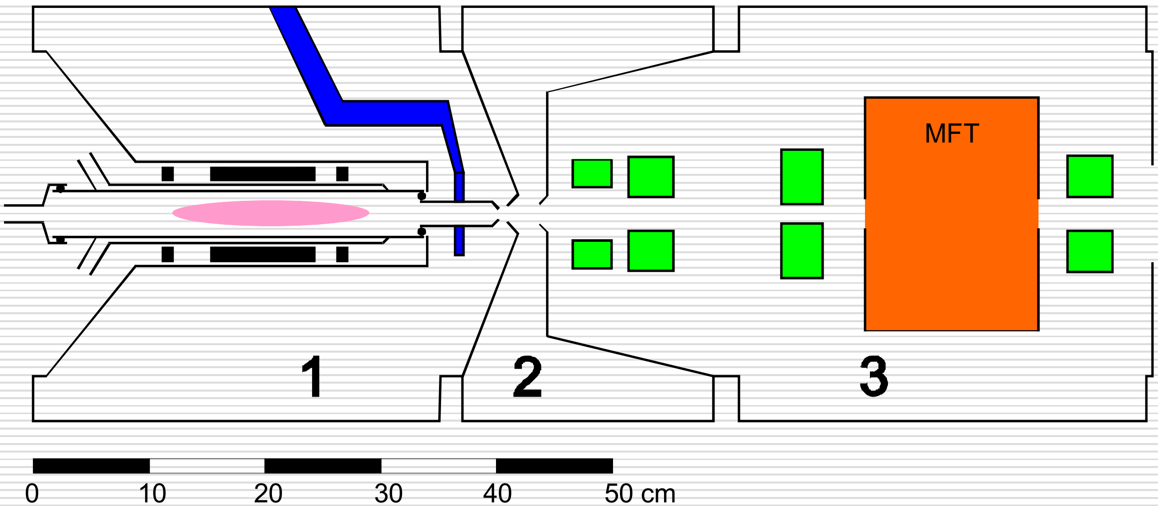
Experiment Status

- ☑ Experimental hall preparation
  - ☑ Renovation
  - ☑ Electrical supply
  - ⧗ Water cooling
- ⧗ Upgrade of the SAPIS ABS
  - ⧗ Vacuum system
  - ⧗ Magnet system
  - ⧗ Dissociator
  - ❑ Transition units
- ⧗ Transportation of the POLIS source (should arrive this week)
- ⧗ Detector system
  - ⧗ Mechanical support
  - ⧗ Readout electronics
- ⧗ Data analysis software

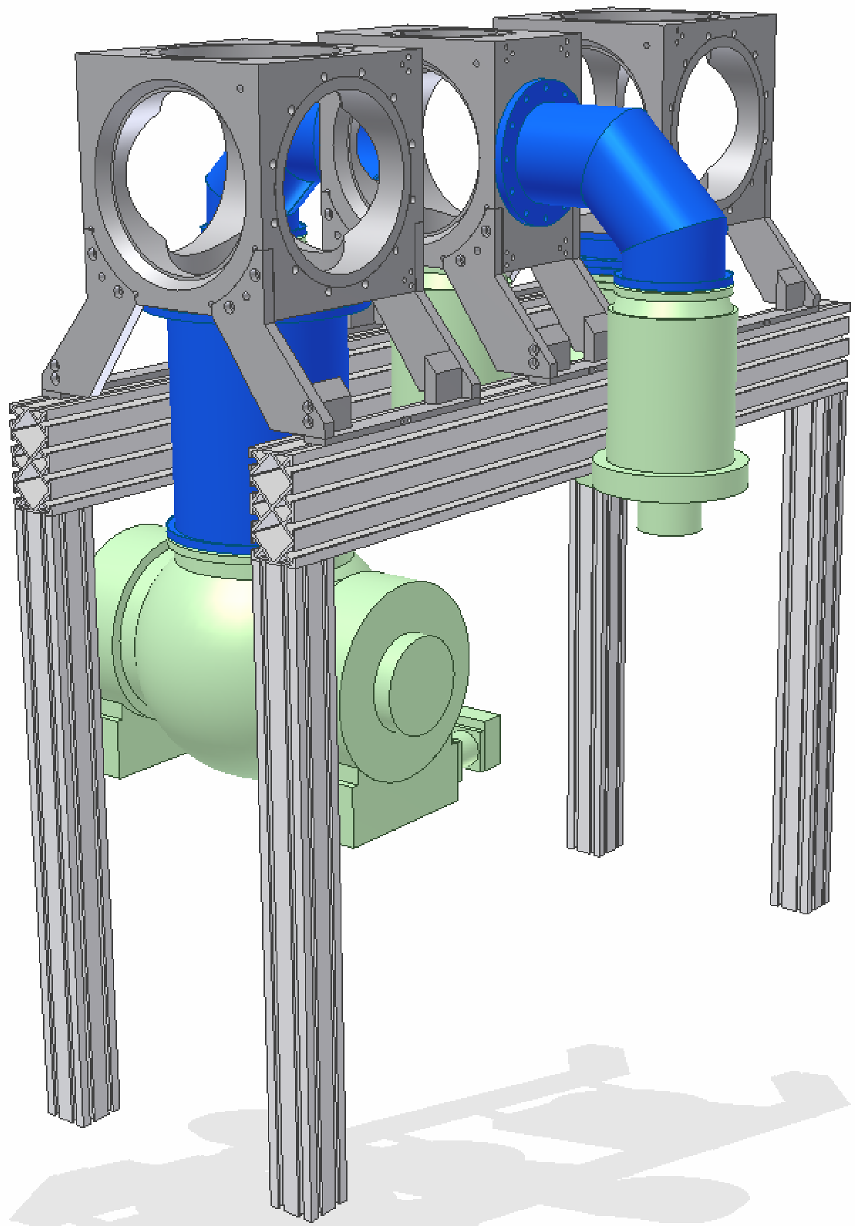
Experimental hall

ABS stages


1
2
3
4
5e-4 mbar
5e-5 mbar
1e-6 mbar
1e-7 mbar
IR
TPH2200
TMU1001
D30A
3xTV450
TV450
D16B
TMU1601
DUO030A
TMU1601
D16B


MFT
1
2
3
0
10
20
30
40
50 cm

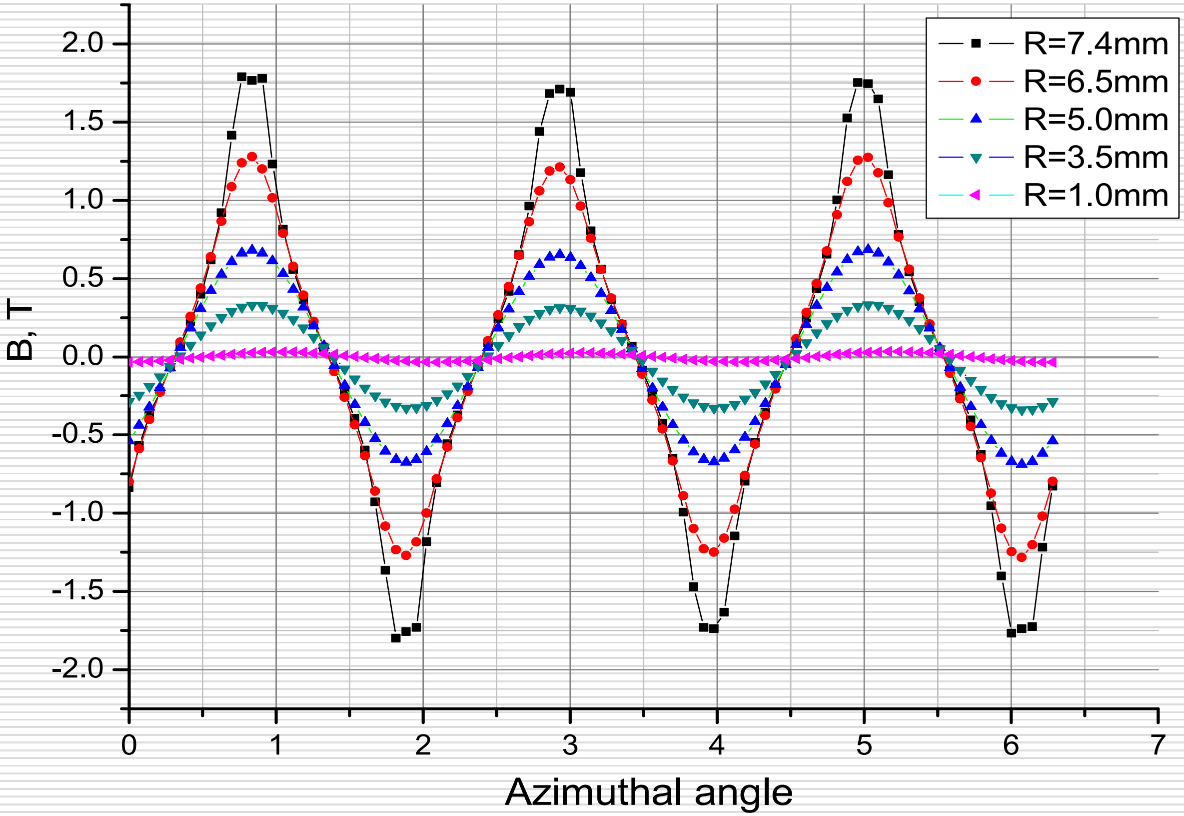
ABS: vacuum system



ABS: Magnet system

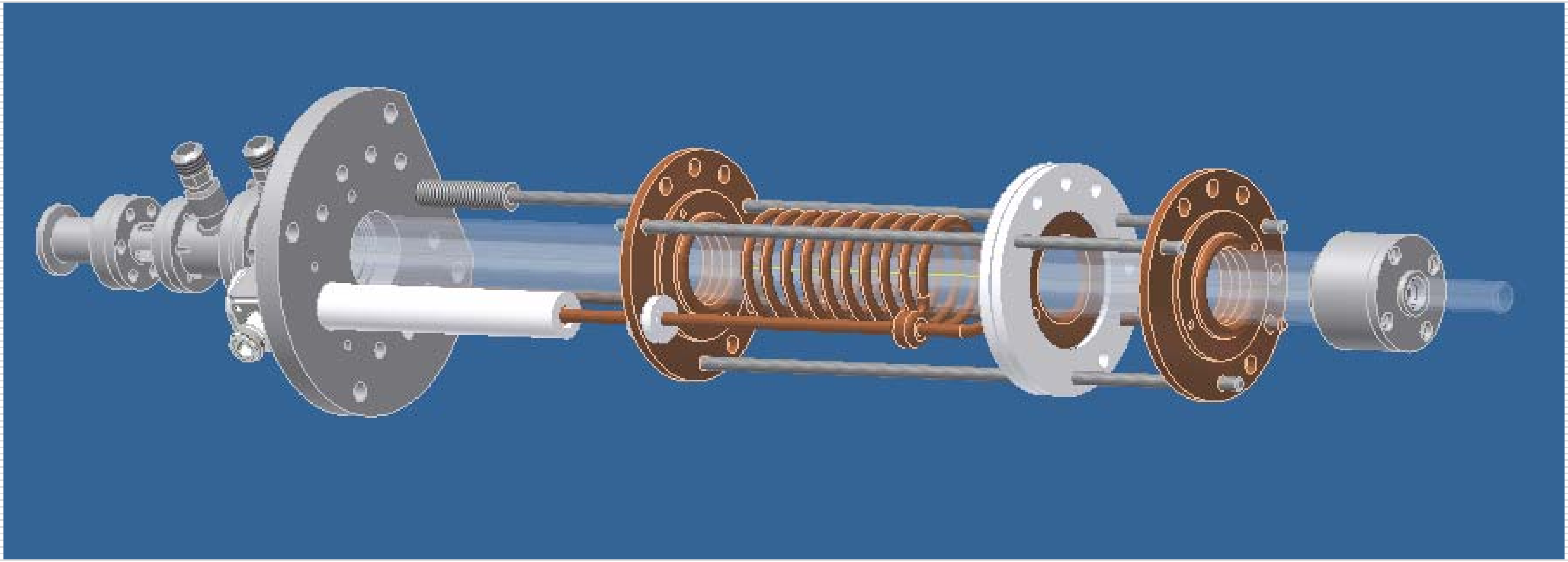
N	N_Poles	Length, mm	Diameter 1, mm	Diameter 2, mm	B, T
M1	6	40.1	15	-	1.8
M2	6	42	9.3	13.1	0.85
M3	6	41.6	9.1	13.5	1
M4	6	41.6	9.8	13.5	1.05
072	4	50.5	27	-	0.8
114	4	76.05	31.8	-	0.6
092	4	76.05	31.8	-	0.6

Magnet N1



ABS: Dissociator

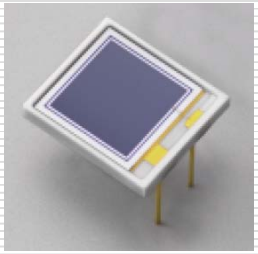
HERMES ABS → ANKE ABS → POLFUSION ABS



Nozzle cooling (~70-80K):

1. Liquid Nitrogen
2. Cold Head

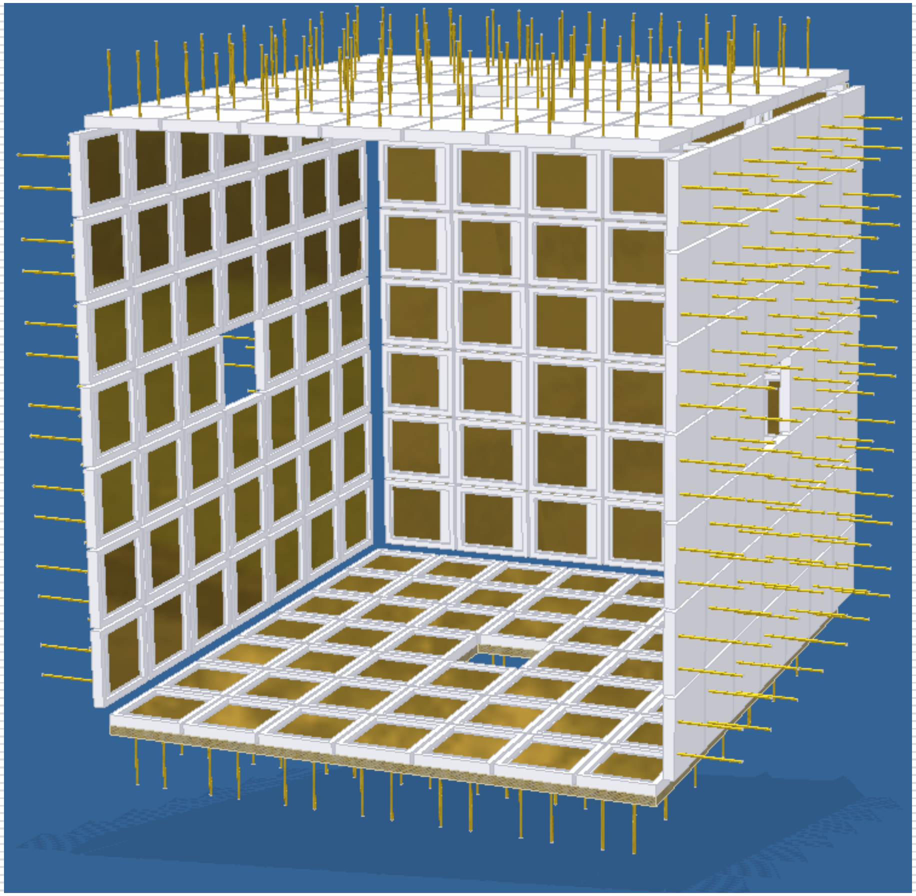
Detector system

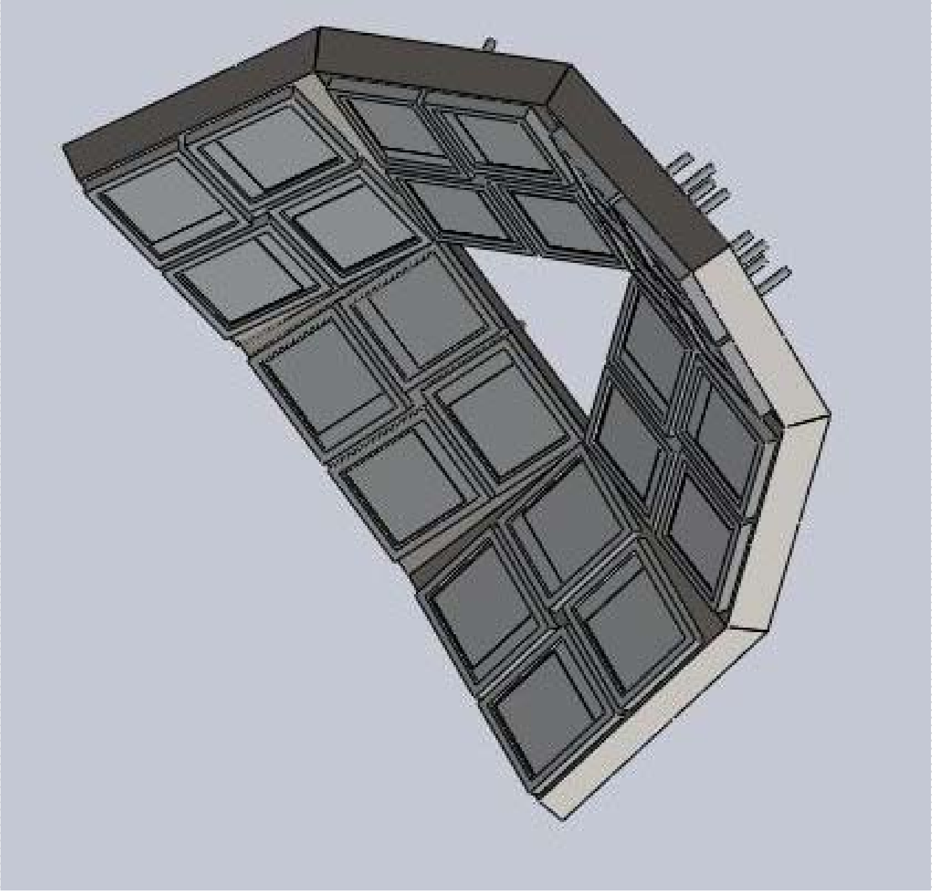


4-π detector setup with 60% filling

~300 Hamamatsu Si PIN photodiodes (S3590)

- $1cm^2$ active area
- 300um depletion layer
- good energy resolution (20keV for 1MeV Carbon ions at RHIC)

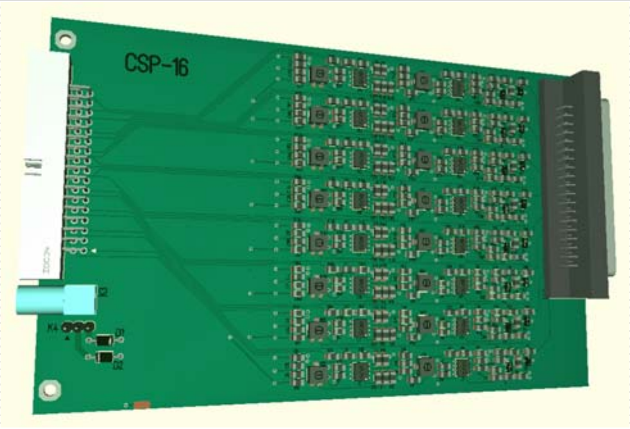




Detector system: Readout electronics

Readout electronics requirements:

- 320 PIN diodes
- ≤ 1kHz total count rate
- Amplitude analyzer (no signal shape digitizing!)
- Fast standard interface for data acquisition
- Common clock for off-line coincidence analysis
- Use of Charge Sensitive Preamplifiers from MuSun experiment

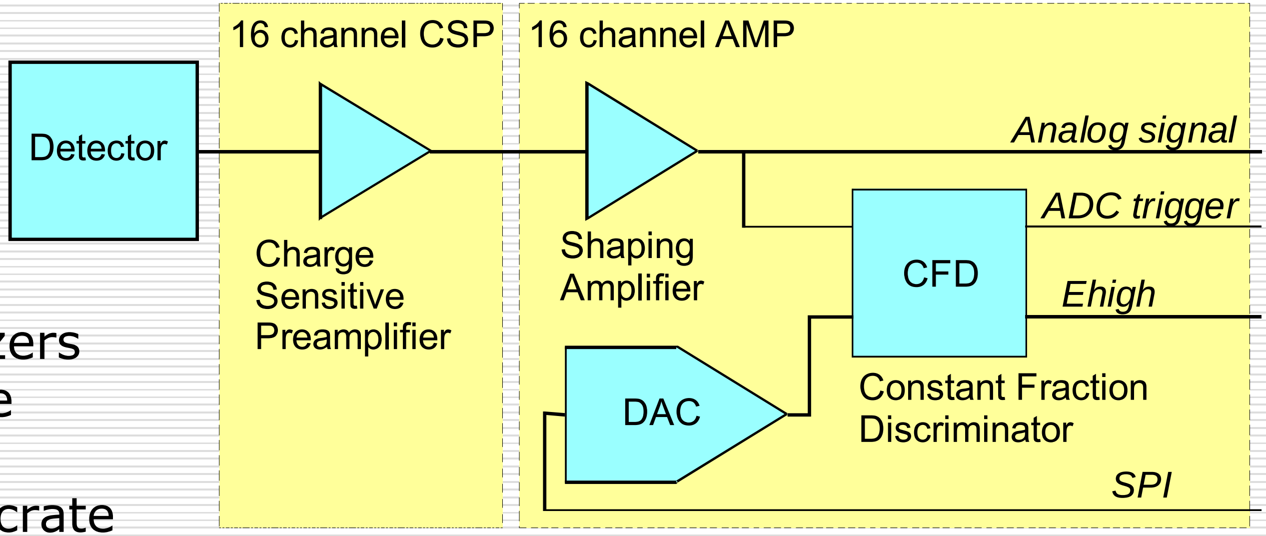


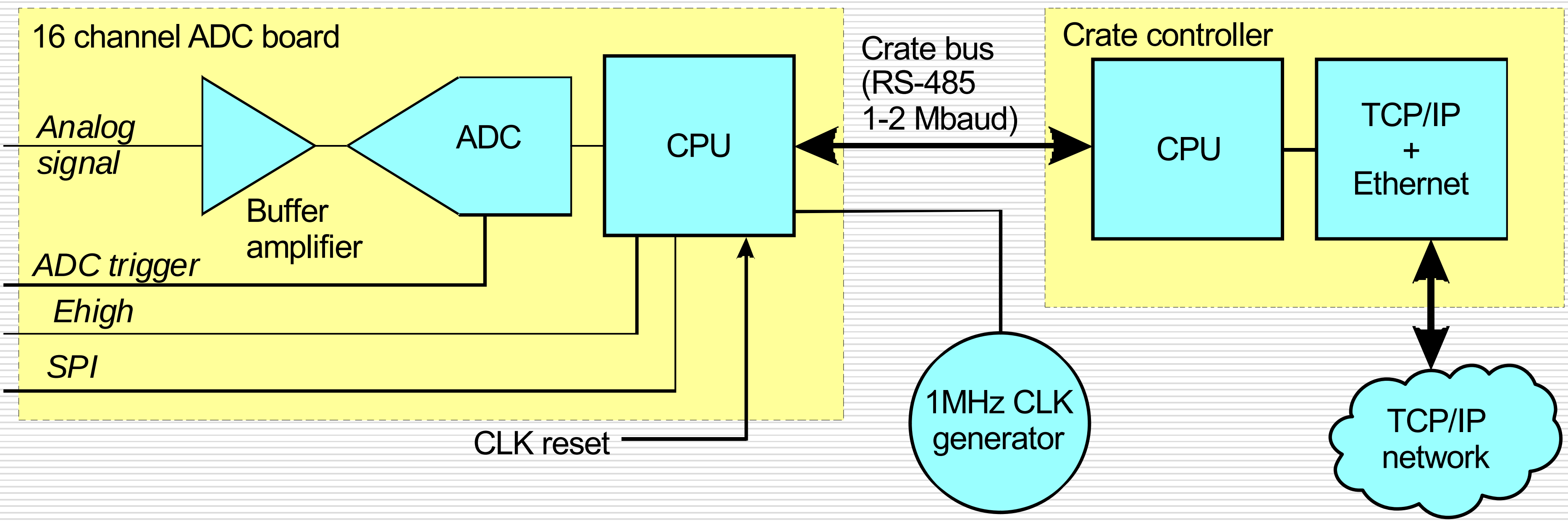
CSP-16 vs. Hamamatsu H4083:

Parameter	**CSP-16**	**H4083**
Noise, electrons	270 at τ = 0.4 μs	234 at τ = 2.5 μs
(without detector)	~170 at τ = 1.0 μs	
Power consumption	180 mW	150 mW
Power supply	± 6 V	± 12 V
Dimensions	80 x 11 mm	24 x 19 mm
Configuration	16-channel module	Single module
Price per channel	~ $ 25	~ 100 €

Detector system: Readout electronics

- Microcontroller based
- 320 channels
- ≤ 1kHz total count rate
- 14-bit amplitude analyzers
- 16 channels per module
- 8 modules per crate
- TCP/IP server in every crate
- Common 1MHz clock





Future Plan

❑ Assemble and run the POLIS source	January 2011
❑ Mechanical assembling	October 2010
❑ Vacuum system	November 2010
❑ Water cooling for magnets	December 2010
❑ Control system	January 2011
❑ Solid target experiment	Spring 2011
❑ Upgrade of the SAPIS ABS	June 2011
❑ Vacuum system	Fall 2010
❑ Magnet system design	December 2010
❑ Dissociator design	October 2010
❑ Transition units design	February 2011
❑ ABS tests and tuning	Spring 2011
❑ Detector system	June 2011
❑ Interaction chamber	September 2010
❑ Mechanical support design	September 2010
❑ Readout electronics design	November 2010
❑ Electronics production	January 2011
❑ Assembling and tuning	Spring 2011

The Formula

$$\sigma(\Theta,\Phi) = \sigma_0(\Theta)\,\{1 + \frac{3}{2}\left[A_y^{(b)}(\Theta)p_y + A_y^{(t)}q_y\right] + \frac{1}{2}\left[A_{zz}^{(b)}(\Theta)p_{zz} + A_{zz}^{(t)}(\Theta)q_{zz}\right]$$
$$+ \frac{1}{6}\left[A_{xx-yy}^{(b)}(\Theta)p_{xx-yy} + A_{xx-yy}^{(t)}(\Theta)q_{xx-yy}\right]$$
$$+ \frac{2}{3}\left[A_{xz}^{(b)}(\Theta)p_{xz} + A_{xz}^{(t)}(\Theta)q_{xz}\right]$$
$$+ \frac{9}{4}\left[C_{y,y}(\Theta)p_yq_y + C_{x,x}(\Theta)p_xq_x + C_{x,z}(\Theta)p_xq_z + C_{z,x}(\Theta)p_zq_x + C_{z,z}(\Theta)p_zq_z\right]$$
$$+ \frac{3}{4}\left[C_{y,zz}(\Theta)p_yq_{zz} + C_{zz,y}(\Theta)p_{zz}q_y\right]$$
$$+ C_{y,xz}(\Theta)p_yq_{xz} + C_{xz,y}(\Theta)p_{xz}q_y + C_{x,yz}(\Theta)p_xq_{yz}$$
$$+ C_{yz,x}(\Theta)p_{yz}q_x + C_{z,yz}(\Theta)p_zq_{yz} + C_{yz,z}(\Theta)p_{yz}q_z$$
$$+ \frac{1}{4}\left[C_{y,xx-yy}(\Theta)p_yq_{xx-yy} + C_{xx-yy,y}(\Theta)p_{xx-yy}q_y + C_{zz,zz}(\Theta)p_{zz}q_{zz}\right]$$
$$+ \frac{1}{3}\left[C_{zz,xz}(\Theta)p_{zz}q_{xz} + C_{xz,zz}(\Theta)p_{xz}q_{zz}\right]$$
$$+ \frac{1}{12}\left[C_{zz,xx-yy}(\Theta)p_{zz}q_{xx-yy} + C_{xx-yy,zz}(\Theta)p_{xx-yy}q_{zz}\right]$$
$$+ \frac{4}{9}\left[C_{xz,xz}(\Theta)p_{xz}q_{xz} + C_{yz,yz}(\Theta)p_{yz}q_{yz}\right]$$
$$+ \frac{8}{9}\left[C_{xy,yz}(\Theta)p_{xy}q_{yz} + C_{yz,xy}(\Theta)p_{yz}q_{xy}\right]$$
$$+ \frac{16}{9}C_{xy,xy}(\Theta)p_{xy}q_{xy}$$
$$+ \frac{1}{9}\left[C_{xz,xx-yy}(\Theta)p_{xz}q_{xx-yy} + C_{xx-yy,xz}(\Theta)p_{xx-yy}q_{xz}\right]$$
$$+ \frac{1}{36}C_{xx-yy,xx-yy}(\Theta)p_{xx-yy}q_{xx-yy}$$
$$+ \frac{1}{2}\left[C_{x,xy}(\Theta)p_xq_{xy} + C_{xy,x}(\Theta)p_{xy}q_x + C_{z,xy}(\Theta)p_zq_{xy} + C_{xy,z}(\Theta)p_{xy}q_z\right]\}$$

Spins of both deuterons are aligned:

Only $p_z(q_z)$ and $p_{zz}(q_{zz}) \neq 0$

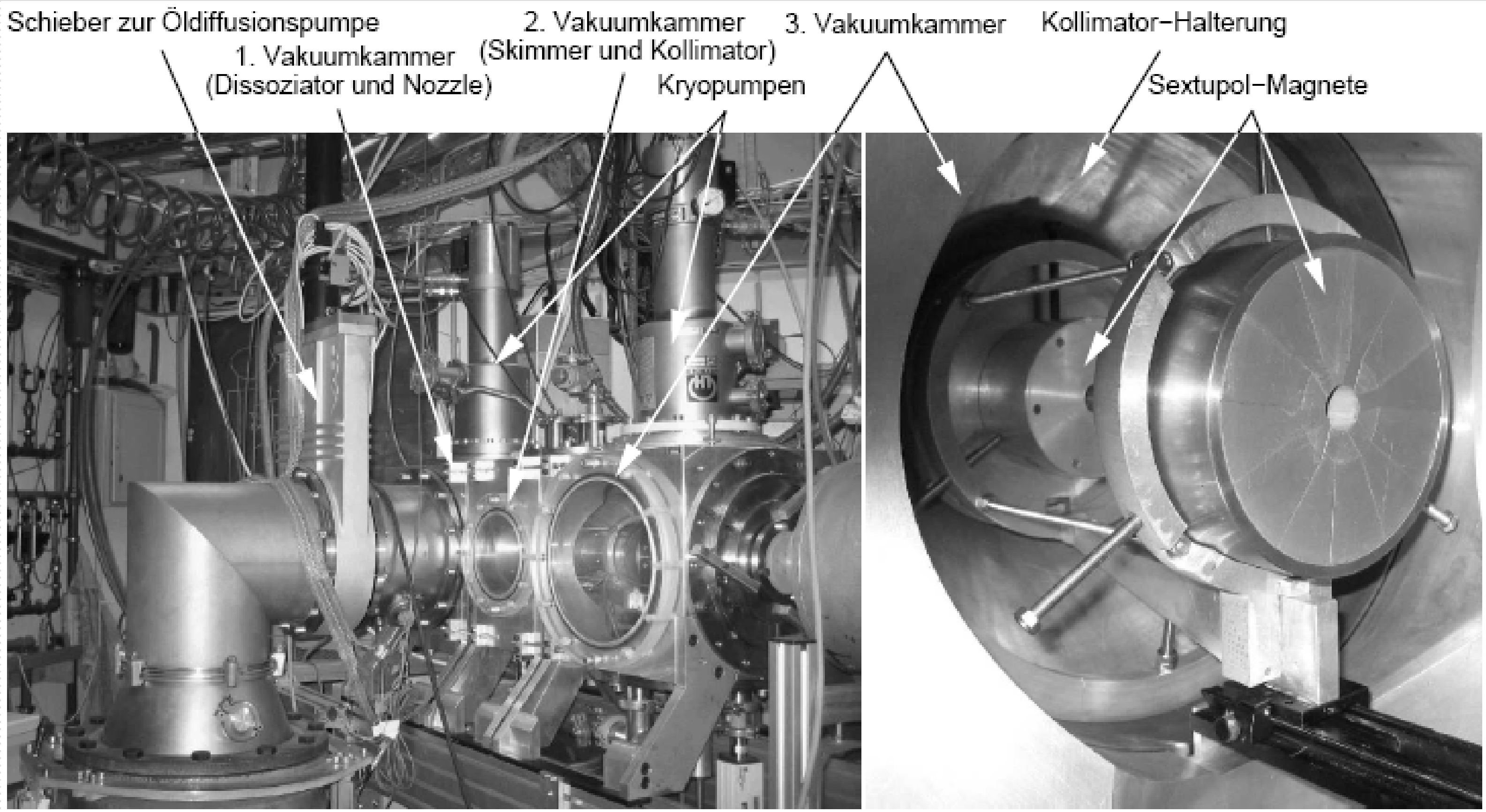
$$\sigma(\Theta,\Phi) = \sigma_0(\Theta)\,\{1 + \frac{3}{2}\left[A_{zz}^{(b)}(\Theta)p_{zz} + A_{zz}^{(t)}(\Theta)q_{zz}\right] + \frac{9}{4}C_{z,z}(\Theta)p_zq_z + \frac{1}{4}C_{zz,zz}(\Theta)p_{zz}q_{zz}\}$$

Only beam is polarized:

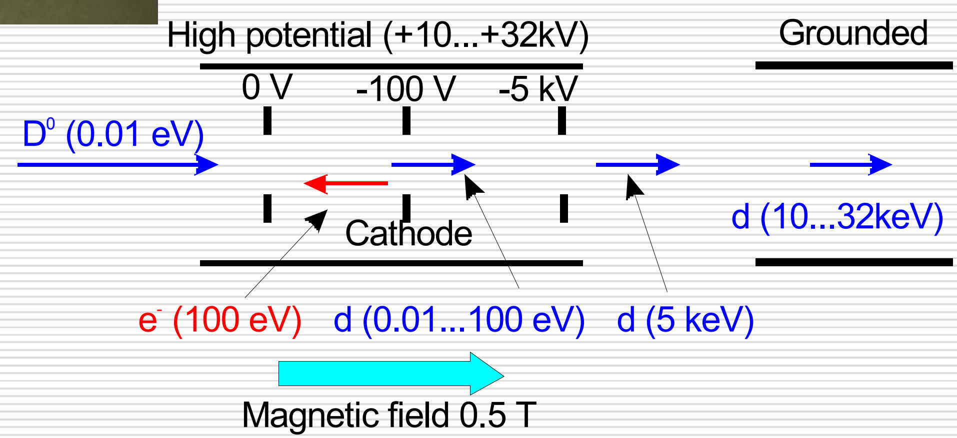
$(p_{i,j} \neq 0,\ q_{i,j} = 0)$

$$\sigma(\Theta,\Phi) = \sigma_0(\Theta)\cdot\{1 + 3/2\,A_y(\Theta)\,p_y + 1/2\,A_{xz}(\Theta)\,p_{xz} + 1/6\,A_{xx\text{-}yy}(\Theta)\,p_{xx\text{-}zz} + 2/3\,A_{zz}(\Theta)\,p_{zz}\}$$

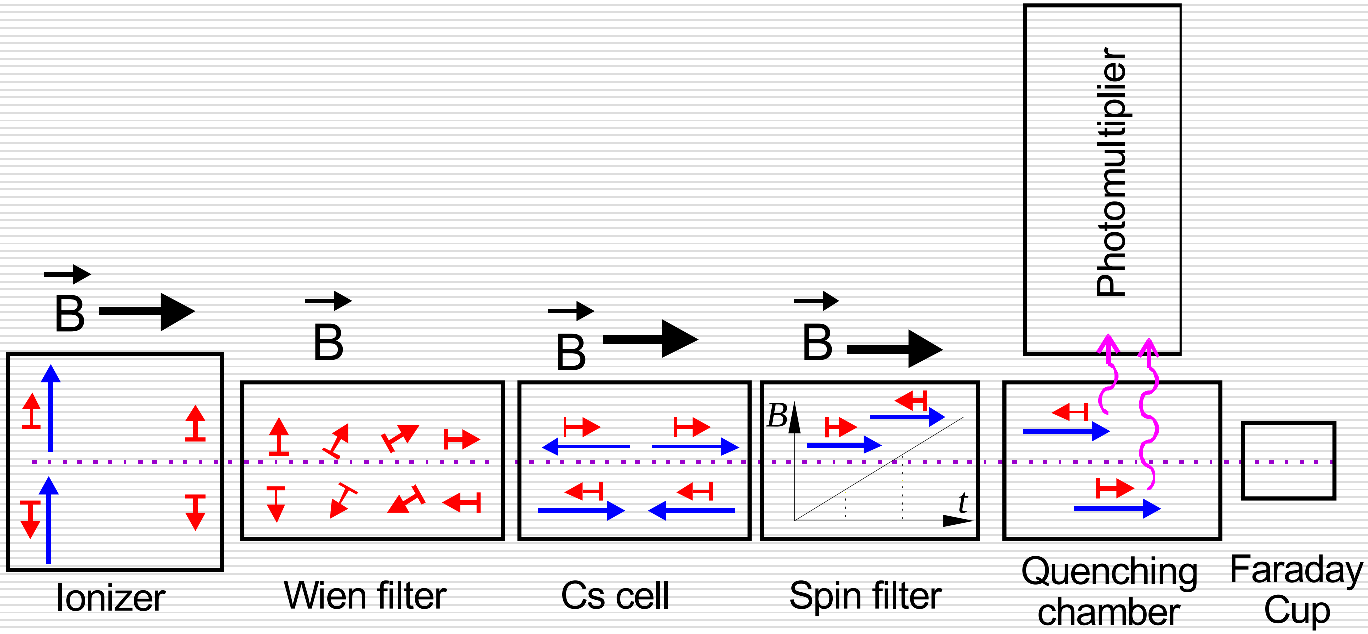
SAPIS ABS


Schieber zur Öldiffusionspumpe
1. Vakuumkammer
(Dissoziator und Nozzle)
2. Vakuumkammer
(Skimmer und Kollimator)
3. Vakuumkammer
Kryopumpen
Kollimator−Halterung
Sextupol−Magnete

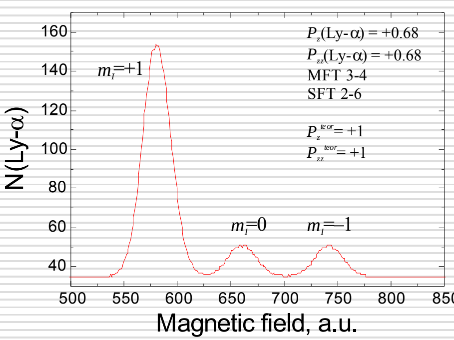
Ion source


High potential (+10...+32kV)
Grounded
0 V
-100 V
-5 kV
D0 (0.01 eV)
Cathode
d (10...32keV)
e- (100 eV)
d (0.01...100 eV)
d (5 keV)
Magnetic field 0.5 T

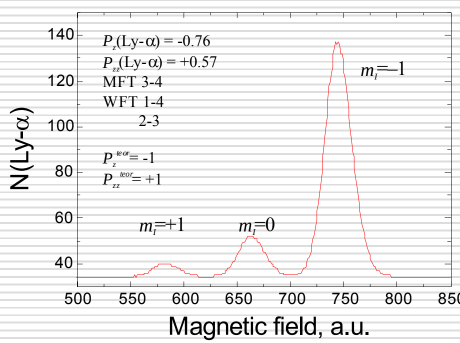
Polarization measurement



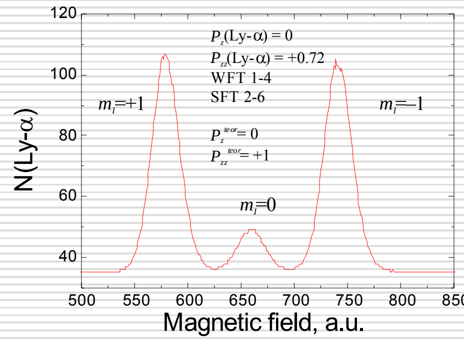
Atomic beam from the ABS → **Ionization of atoms** → **Spin axis rotation** → **Ions to metastable atoms** → **Spin separation** → **Emission of photons** → **Ly-α spectrum**



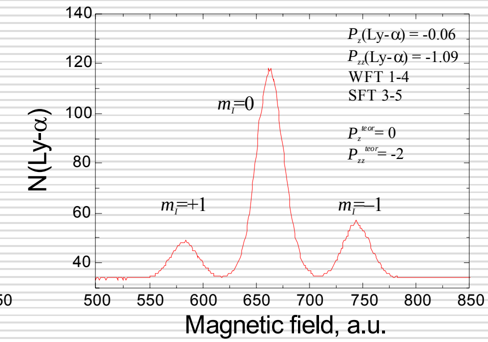
$P_z = 0.73 \pm 0.05$



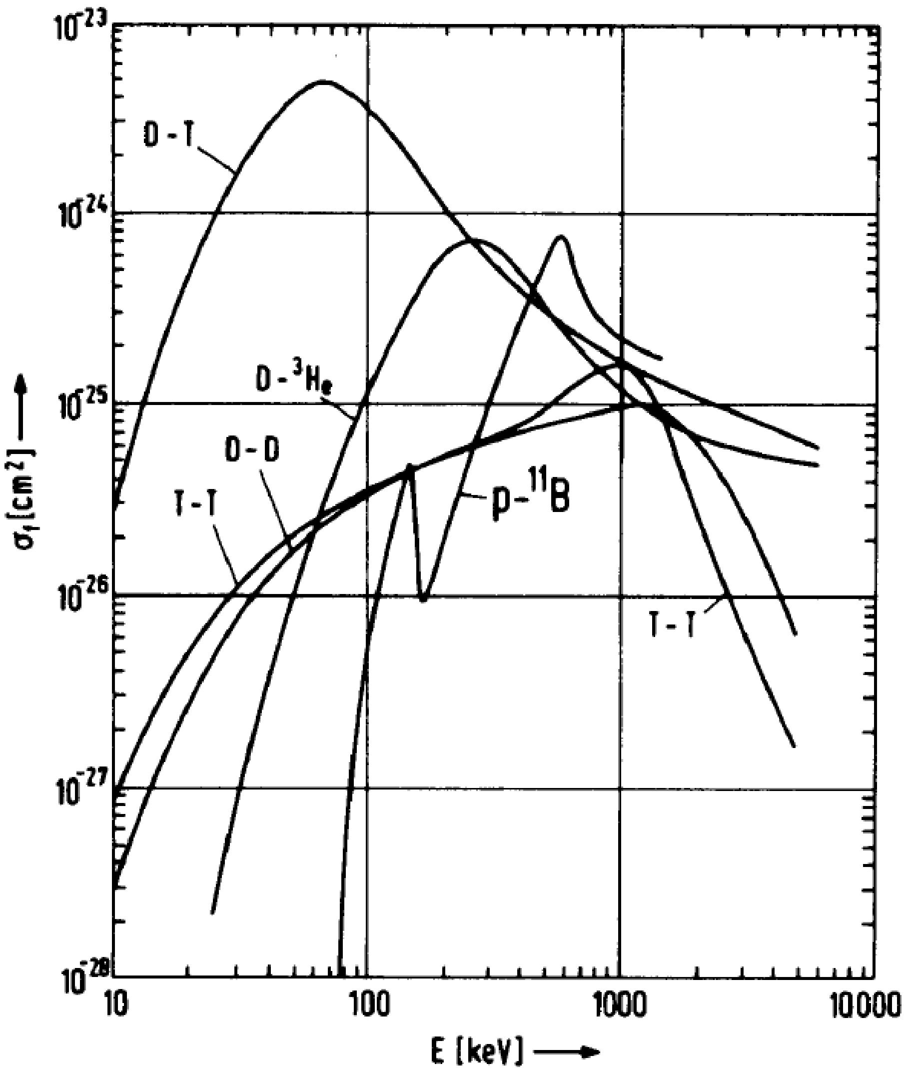
$P_z = -0.82 \pm 0.06$



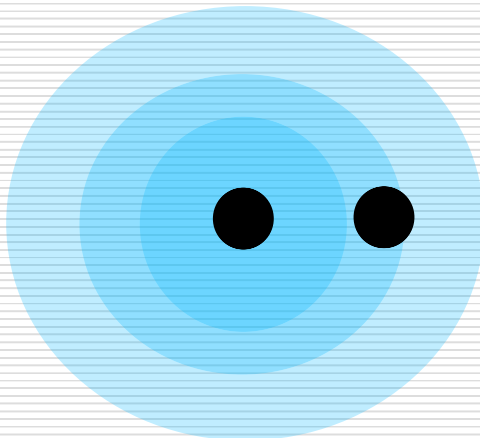
$P_{zz} = 0.77 \pm 0.06$



$P_{zz} = -1.17 \pm 0.08$



J. Raeder *et al.*, Kontrollierte Kernfusion, Teubner, Stutgart (1987)



Projectile: Deuteron

Target: Deuterium Atom

(Deuteron + Electron)