THE DOUBLE-POLARIZED DD-FUSION EXPERIMENT + DETECTOR SYSTEM

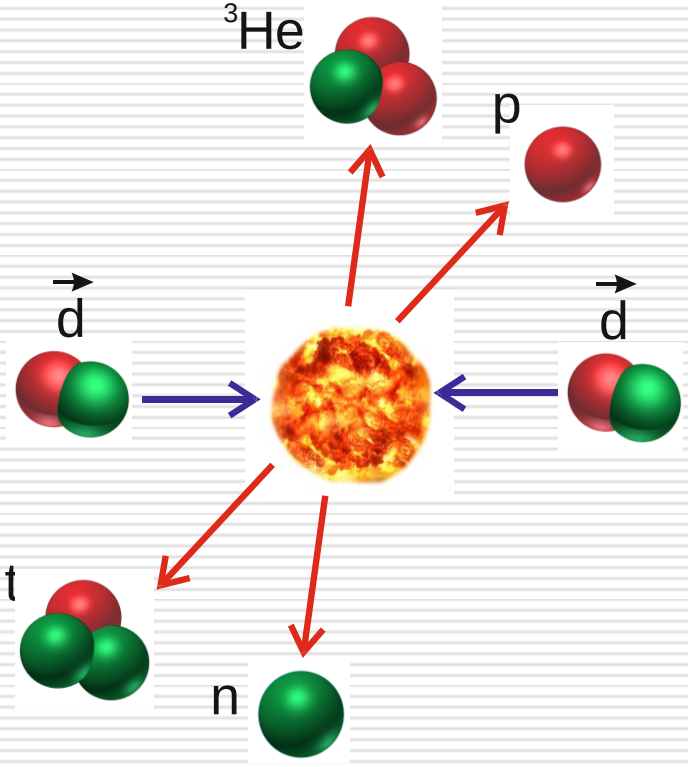
P. Kravtsov

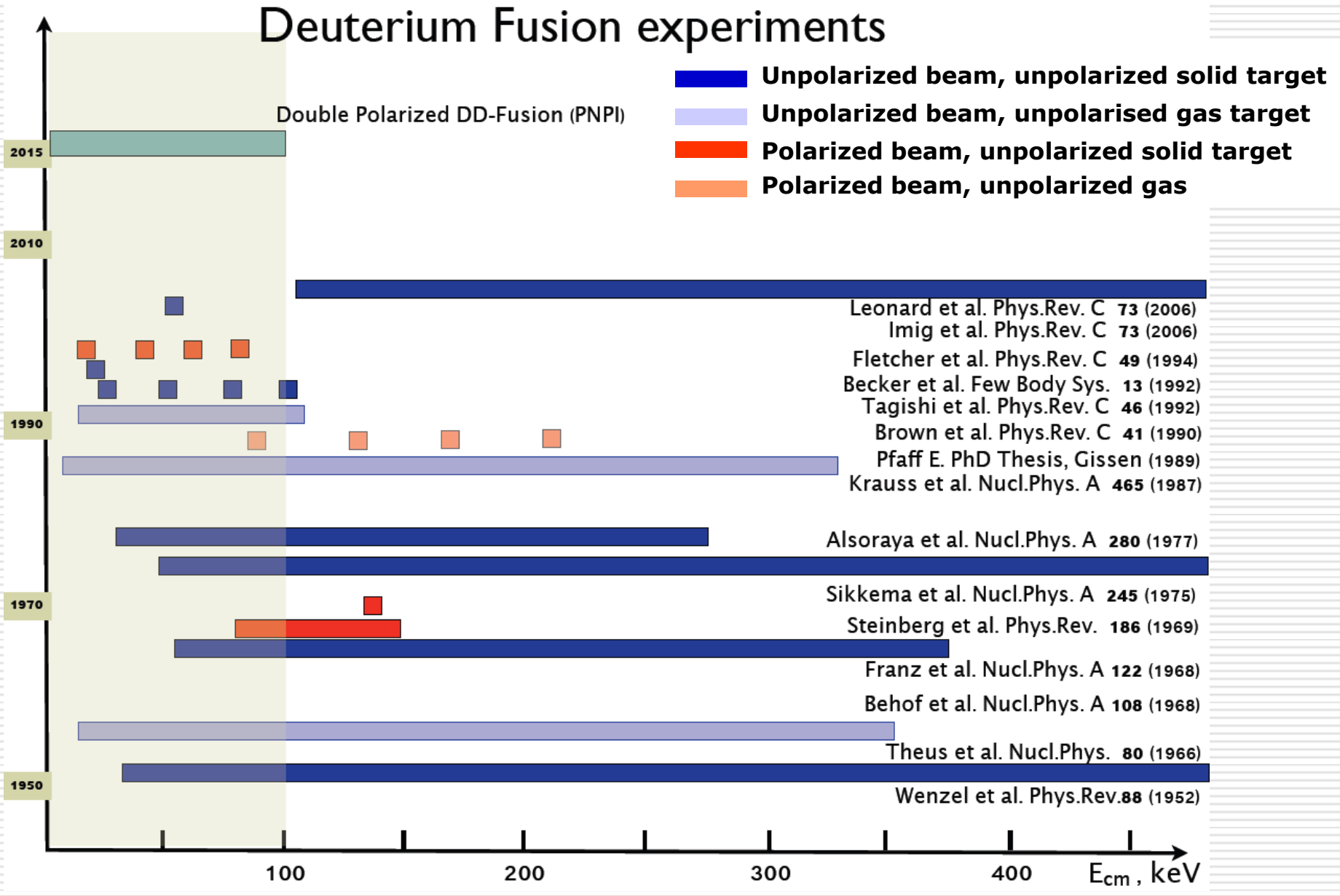
for the PolFusion collaboration

The experiment goal

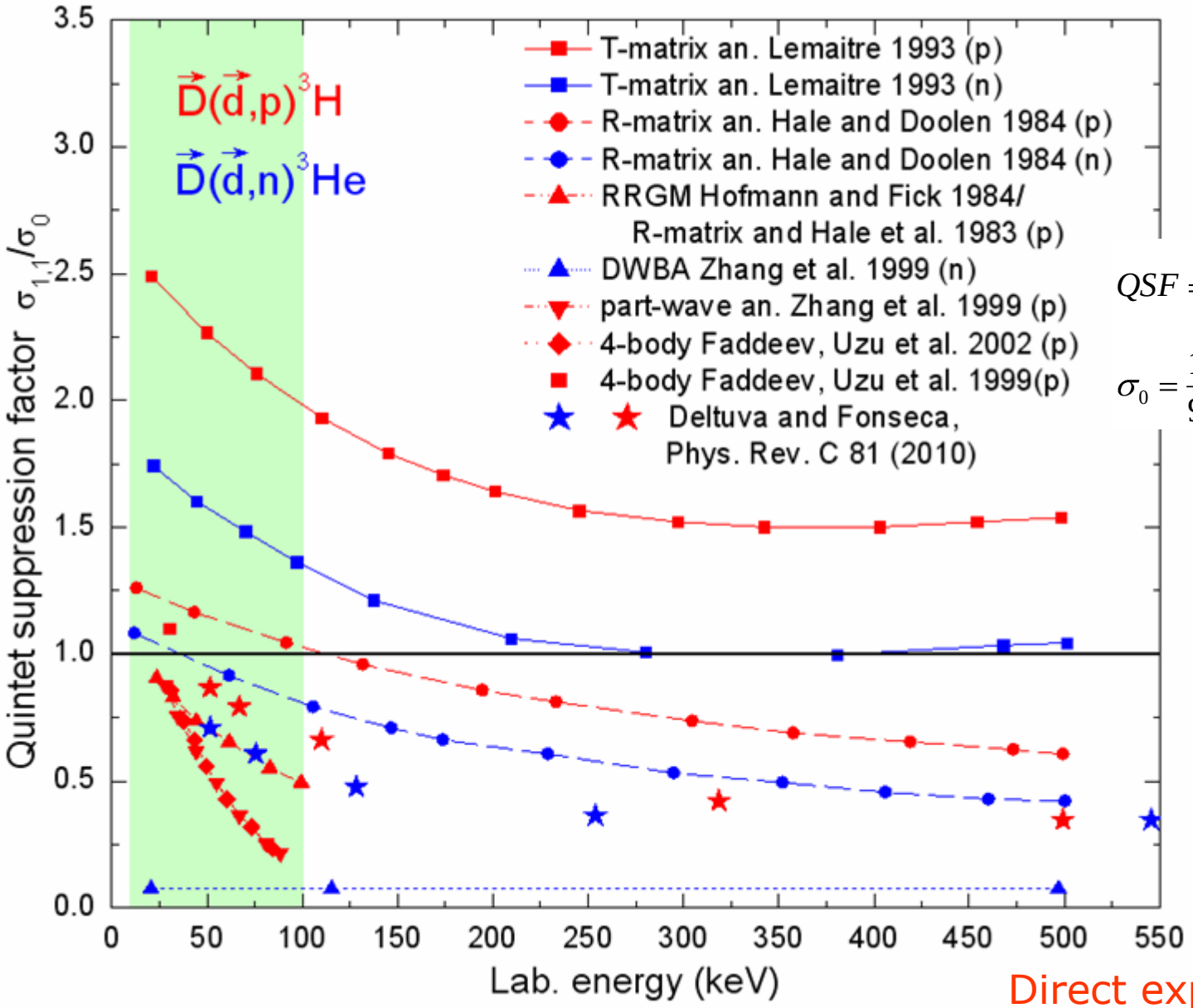
Investigation of 4-nucleons reaction
with polarization of the both initial particles
at 10-100 keV energy (center of mass) .

$$\vec{d} + \vec{d} \rightarrow \begin{cases} t + p \\ {}^3He + n \end{cases}$$



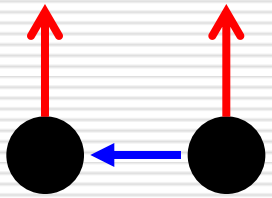

Deuterium Fusion experiments
Unpolarized beam, unpolarized solid target
Unpolarized beam, unpolarised gas target
Polarized beam, unpolarized solid target
Polarized beam, unpolarized gas
Double Polarized DD-Fusion (PNPI)
2015
2010
1990
1970
1950
Leonard et al. Phys.Rev. C 73 (2006)
Imig et al. Phys.Rev. C 73 (2006)
Fletcher et al. Phys.Rev. C 49 (1994)
Becker et al. Few Body Sys. 13 (1992)
Tagishi et al. Phys.Rev. C 46 (1992)
Brown et al. Phys.Rev. C 41 (1990)
Pfaff E. PhD Thesis, Gissen (1989)
Krauss et al. Nucl.Phys. A 465 (1987)
Alsoraya et al. Nucl.Phys. A 280 (1977)
Sikkema et al. Nucl.Phys. A 245 (1975)
Steinberg et al. Phys.Rev. 186 (1969)
Franz et al. Nucl.Phys. A 122 (1968)
Behof et al. Nucl.Phys. A 108 (1968)
Theus et al. Nucl.Phys. 80 (1966)
Wenzel et al. Phys.Rev.88 (1952)
100
200
300
400
Ecm , keV

The Quintet suppression factor



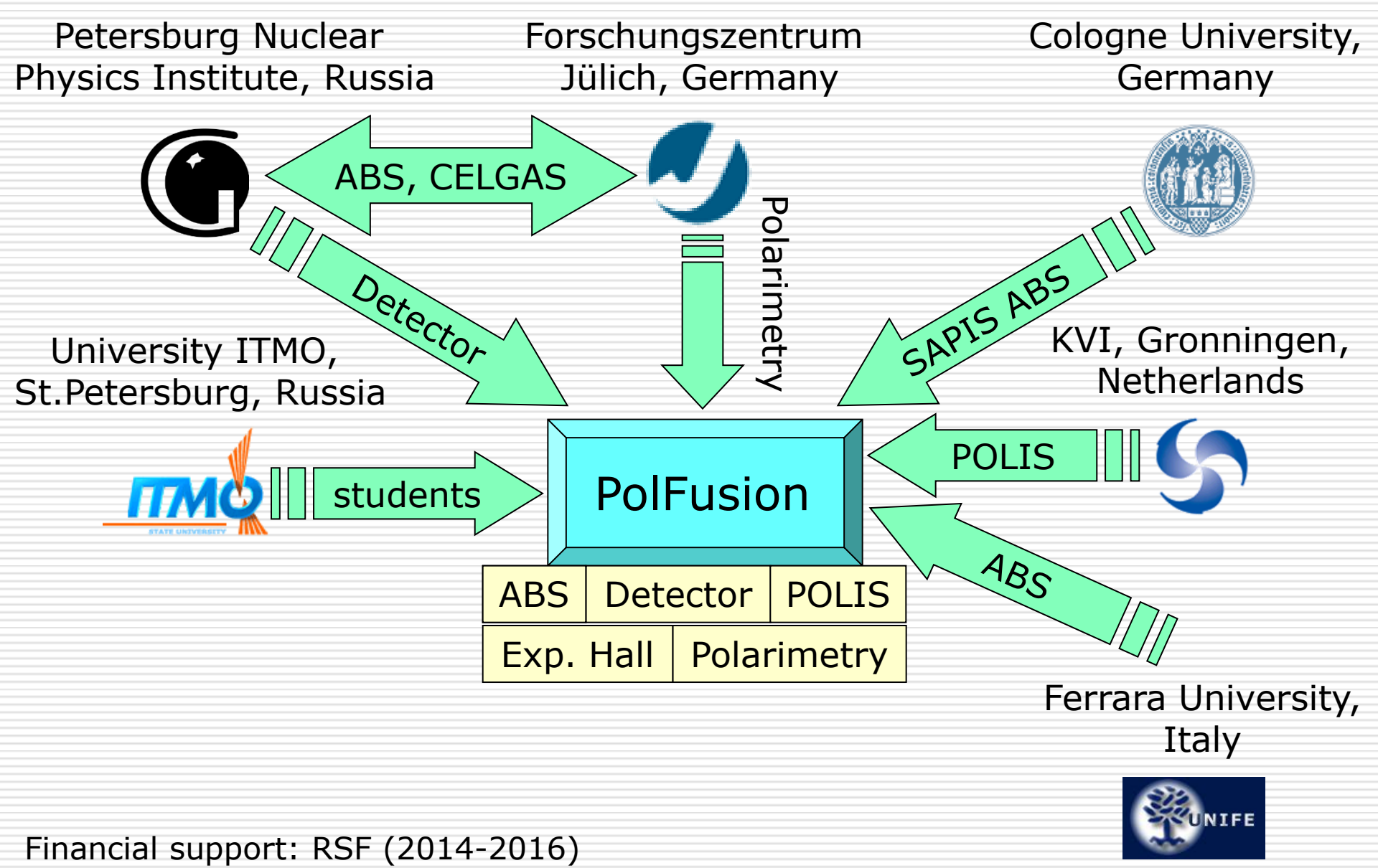
$$QSF = \frac{\sigma_{1,1}}{\sigma_0}$$

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



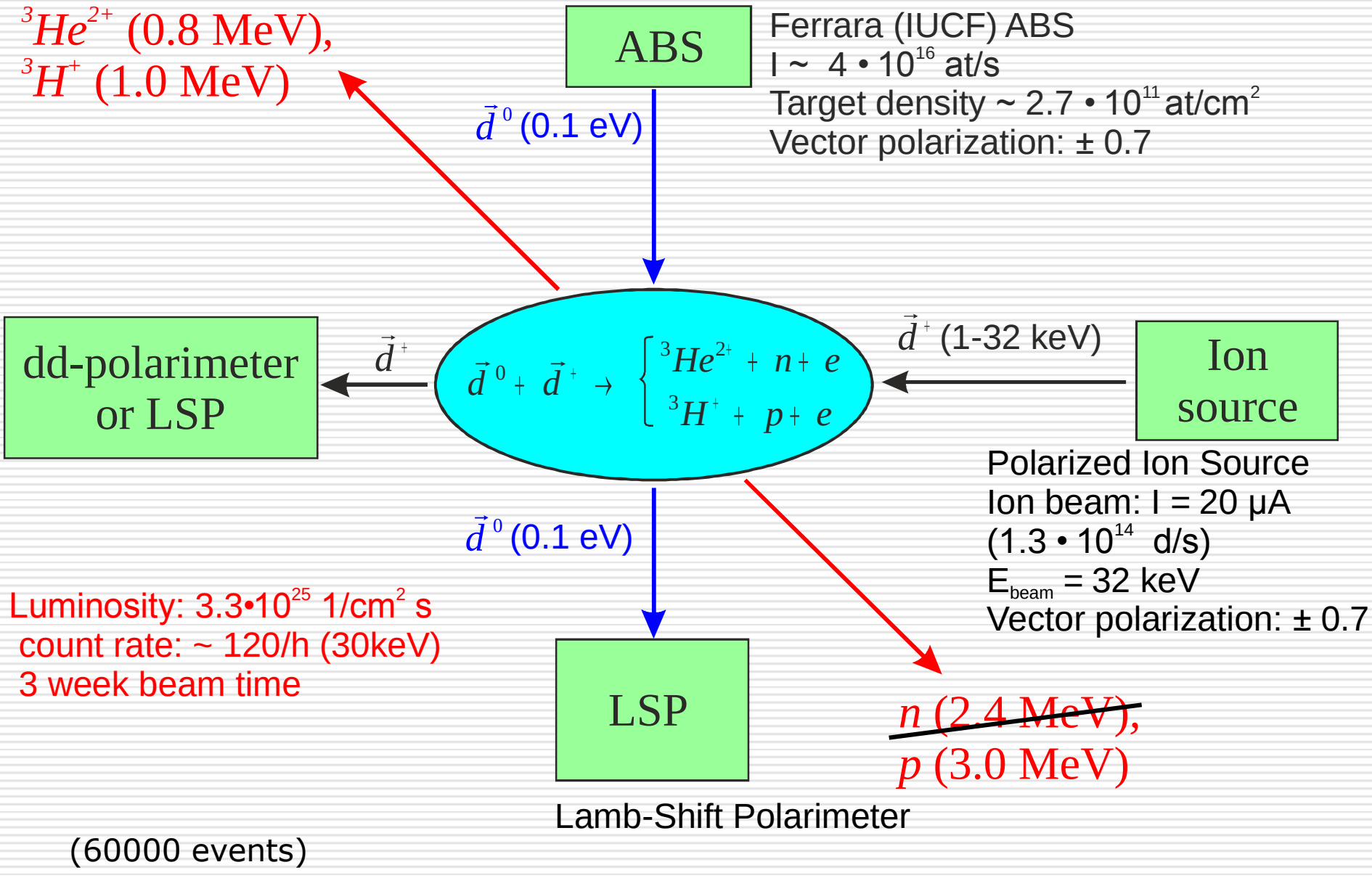
Direct experiment required!

PolFusion collaboration



Financial support: RSF (2014-2016)

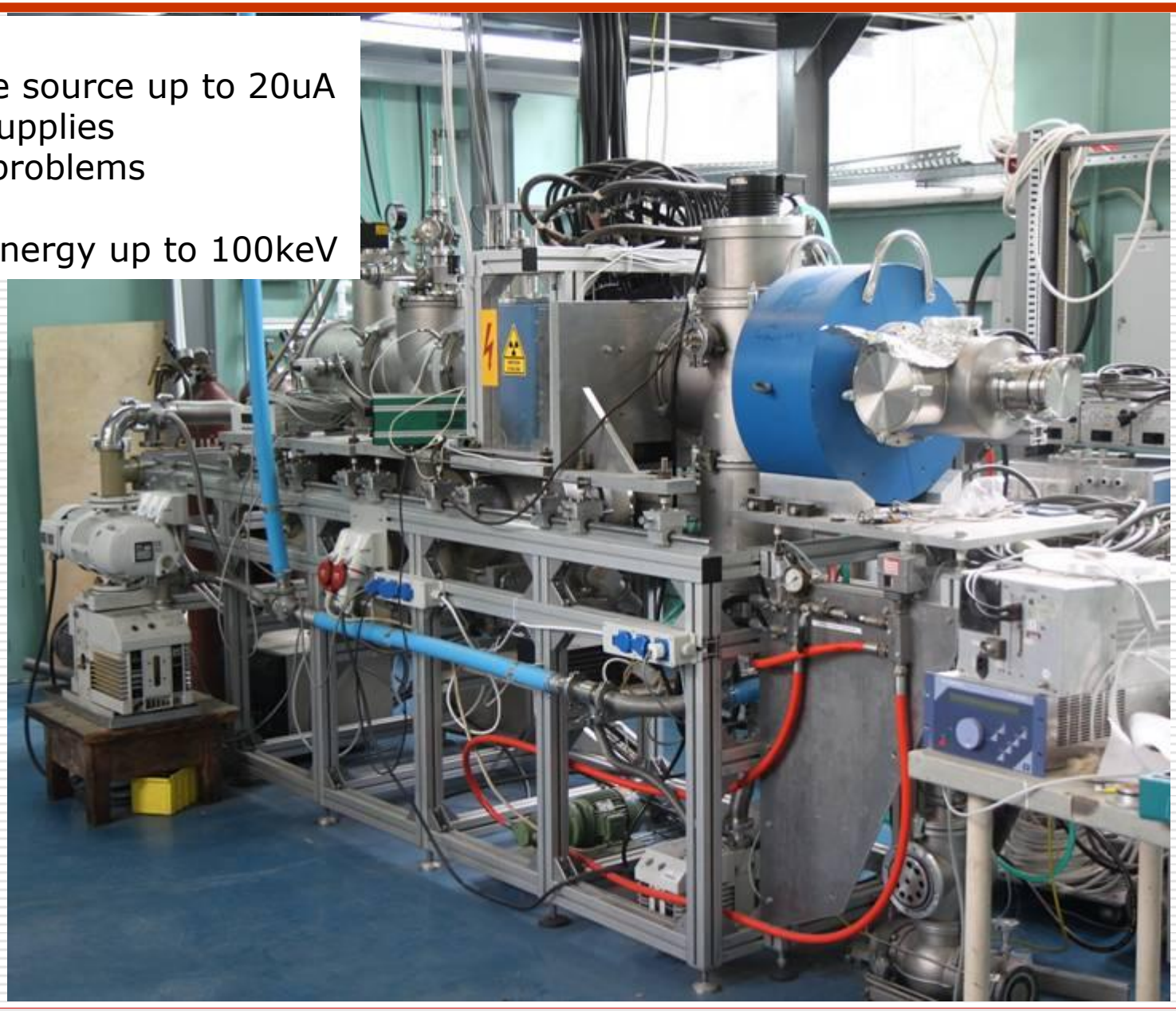
The layout of the experiment



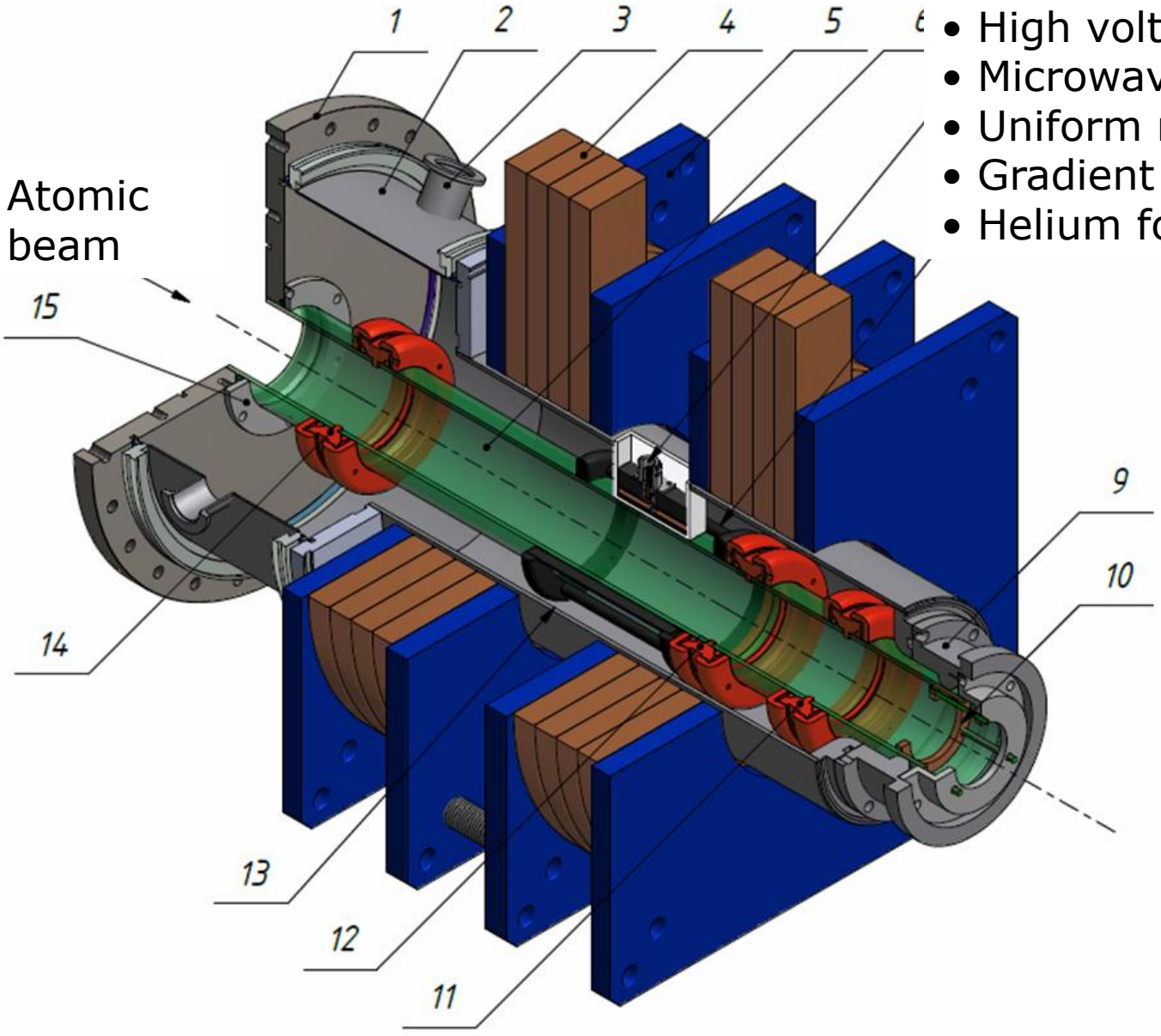
Polarized ion source (POLIS)

POLIS

- ✓ Ion current at the source up to 20uA
- ✓ Magnets power supplies
- ✓ Vacuum system problems
- ❑ Unstable beam
- ❑ New ionizer for energy up to 100keV



POLIS. New ECR Ionizer

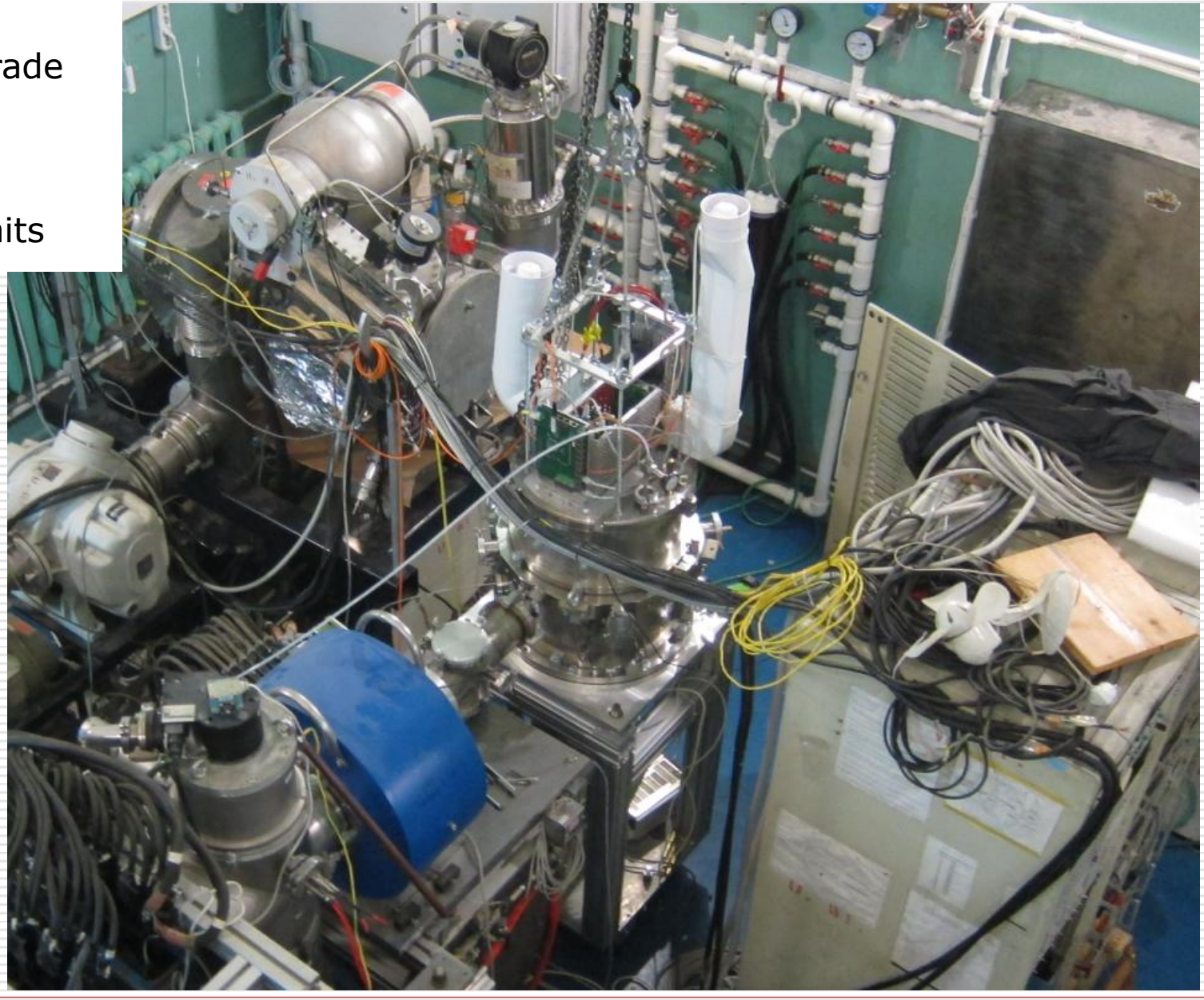


- High voltage (100kV)
- Microwave 2.45GHz ~200W
- Uniform magnetic field (875G)
- Gradient magnetic field
- Helium for plasma ignition

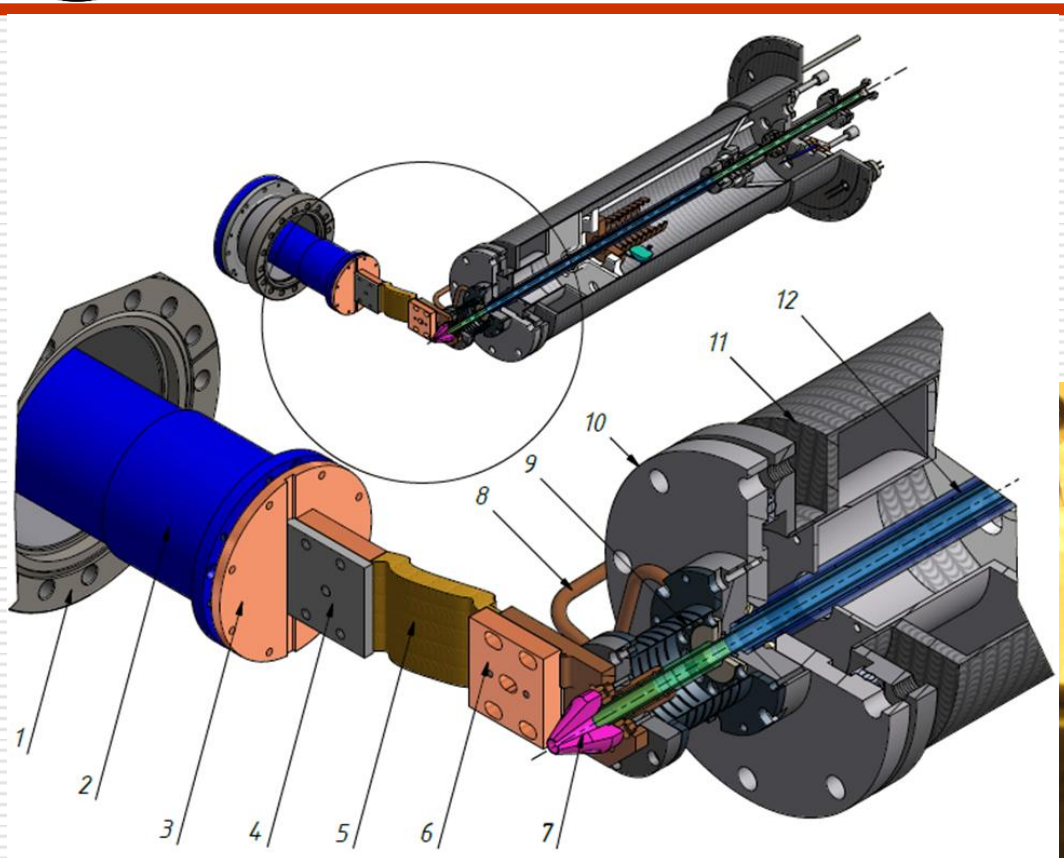
Polarized atomic beam source (ABS)

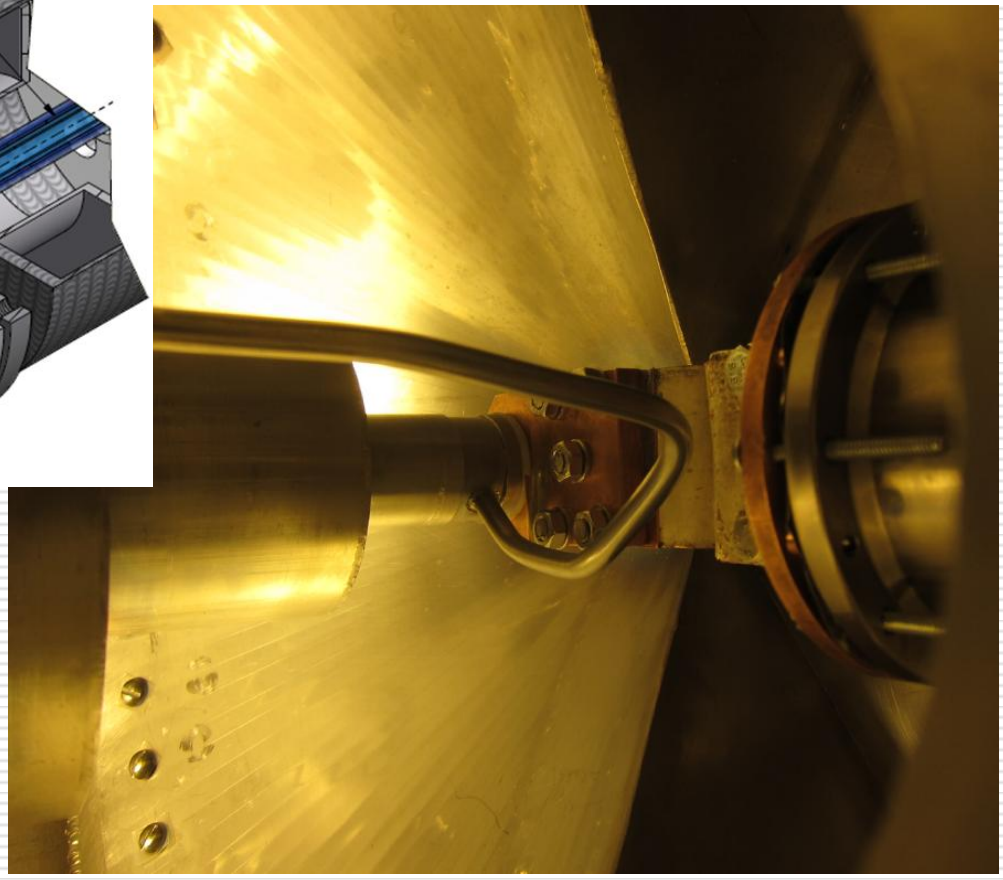
Ferrara ABS

- ✓ Dissociator upgrade
- ✓ Nozzle cooling
- ✓ Control system
- ✓ Vacuum system
- ❑ RF transition units



ABS nozzle cooling

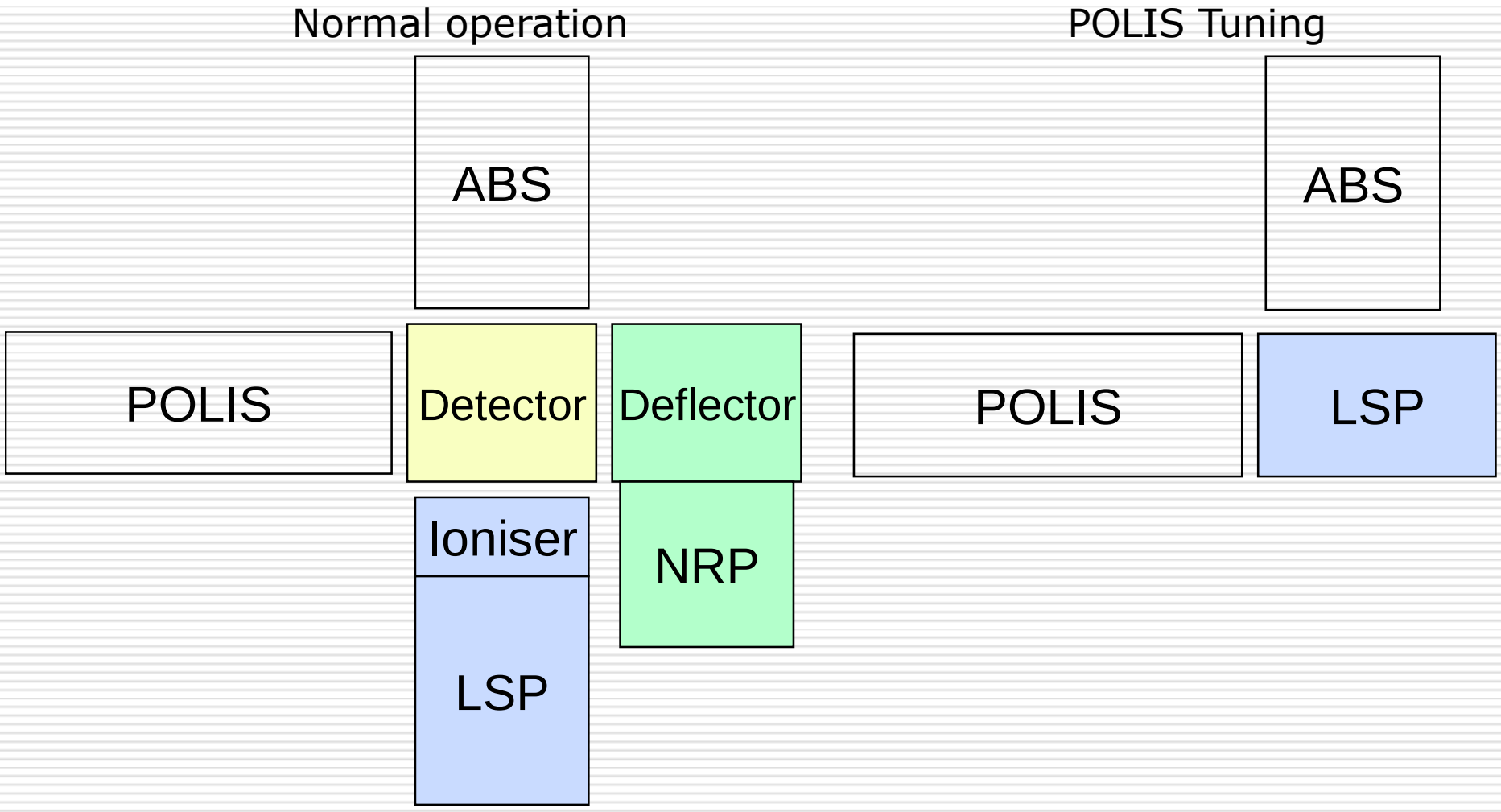




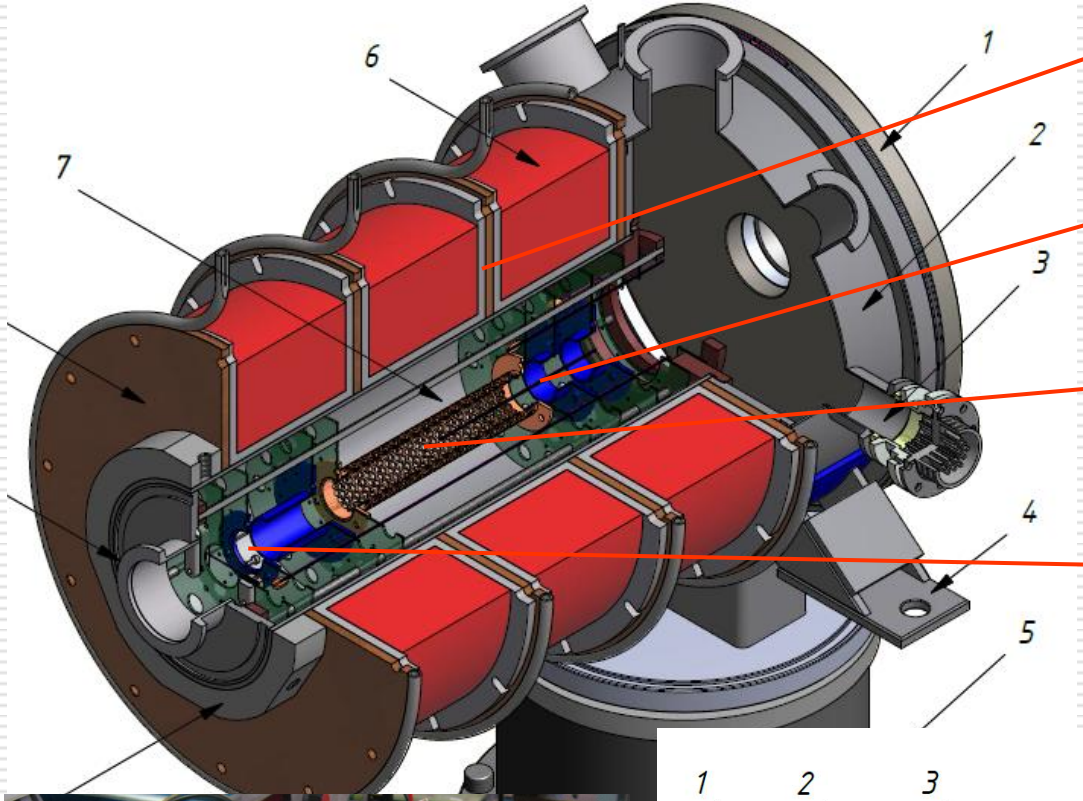
Stable temperature down to 55K

ABS. Dissociator upgrade

- New schematic for better matching with generator
- Geometry optimization of RF circuit
- Reflected power decreased from 150W to 3W (@250W)
- Two-channel RF matchbox with splitter to feed both dissociators from single generator


Normal operation
ABS
POLIS
Detector
Deflector
Ioniser
NRP
LSP
POLIS Tuning
ABS
POLIS
LSP

Polarimetry. LSP ionizer

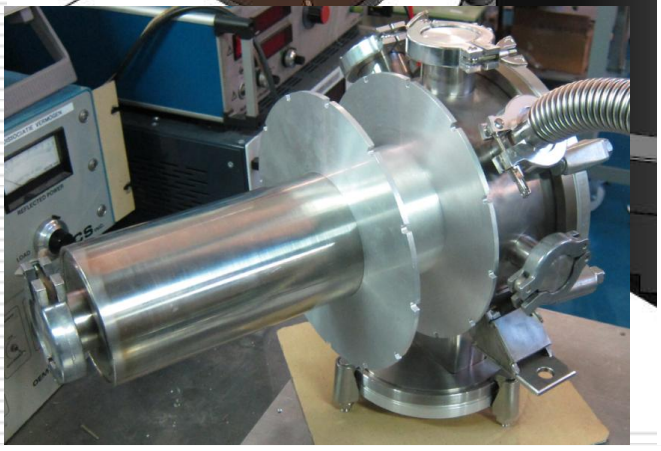


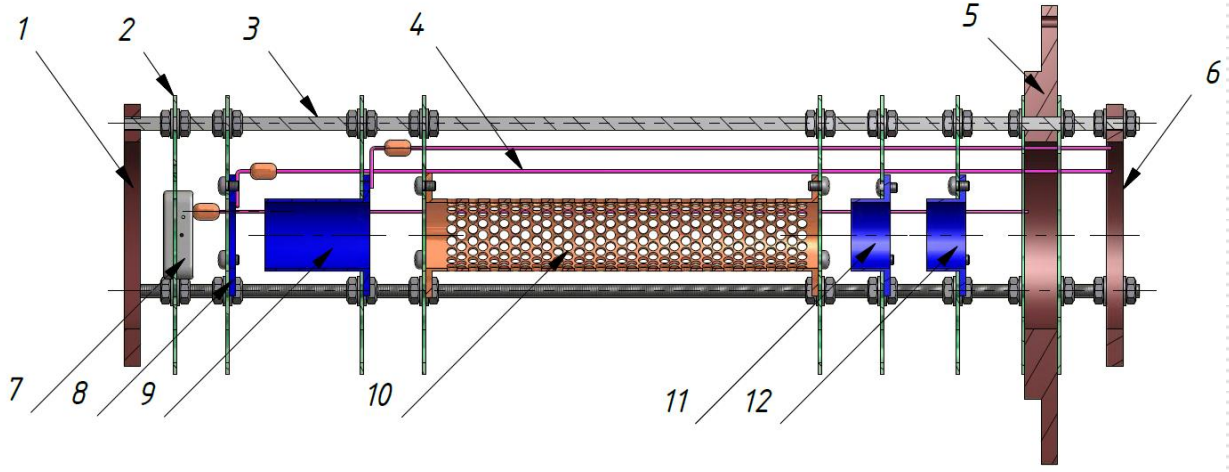
Magnets (1000G)

Extractor and focusing

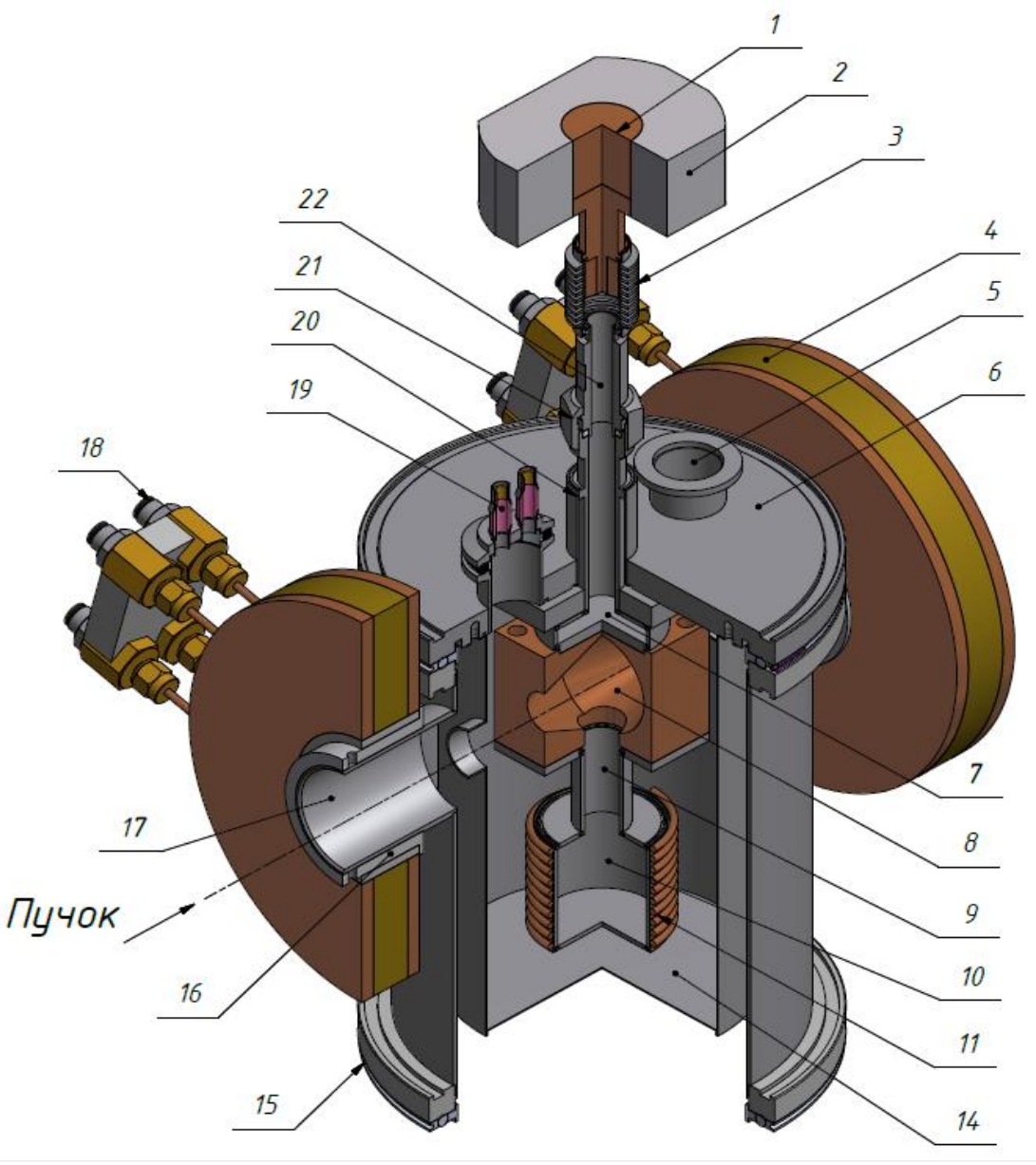
Ionizer cell

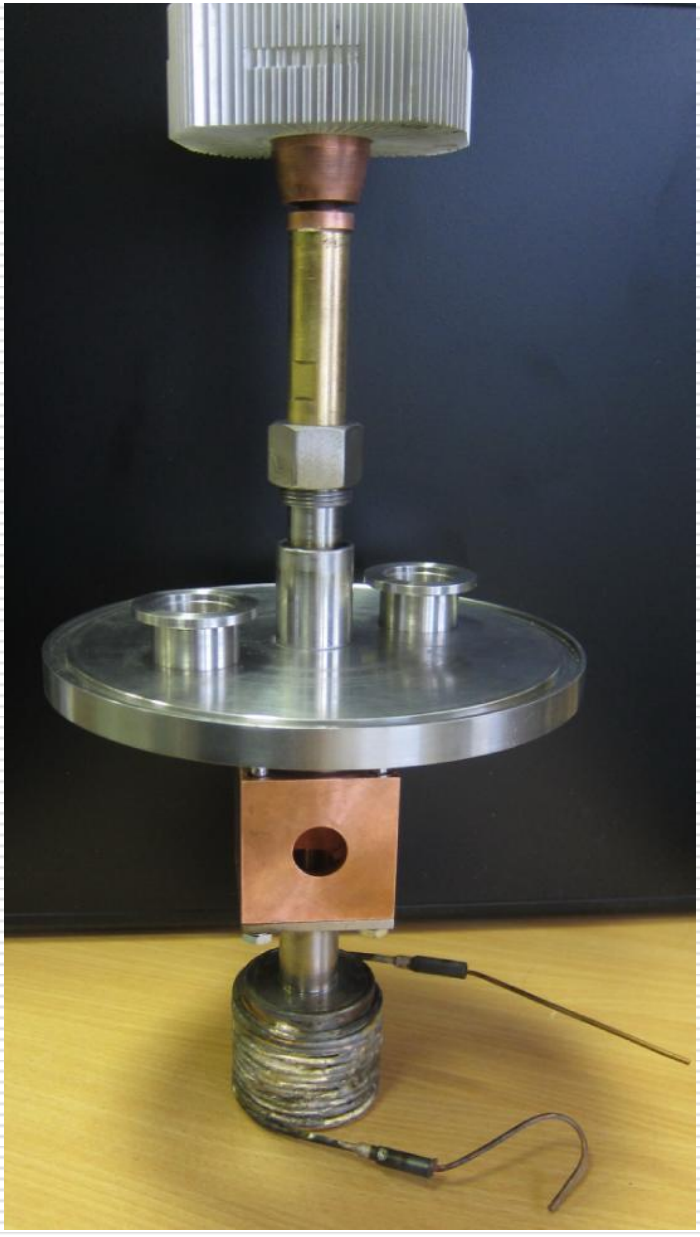
Cathode



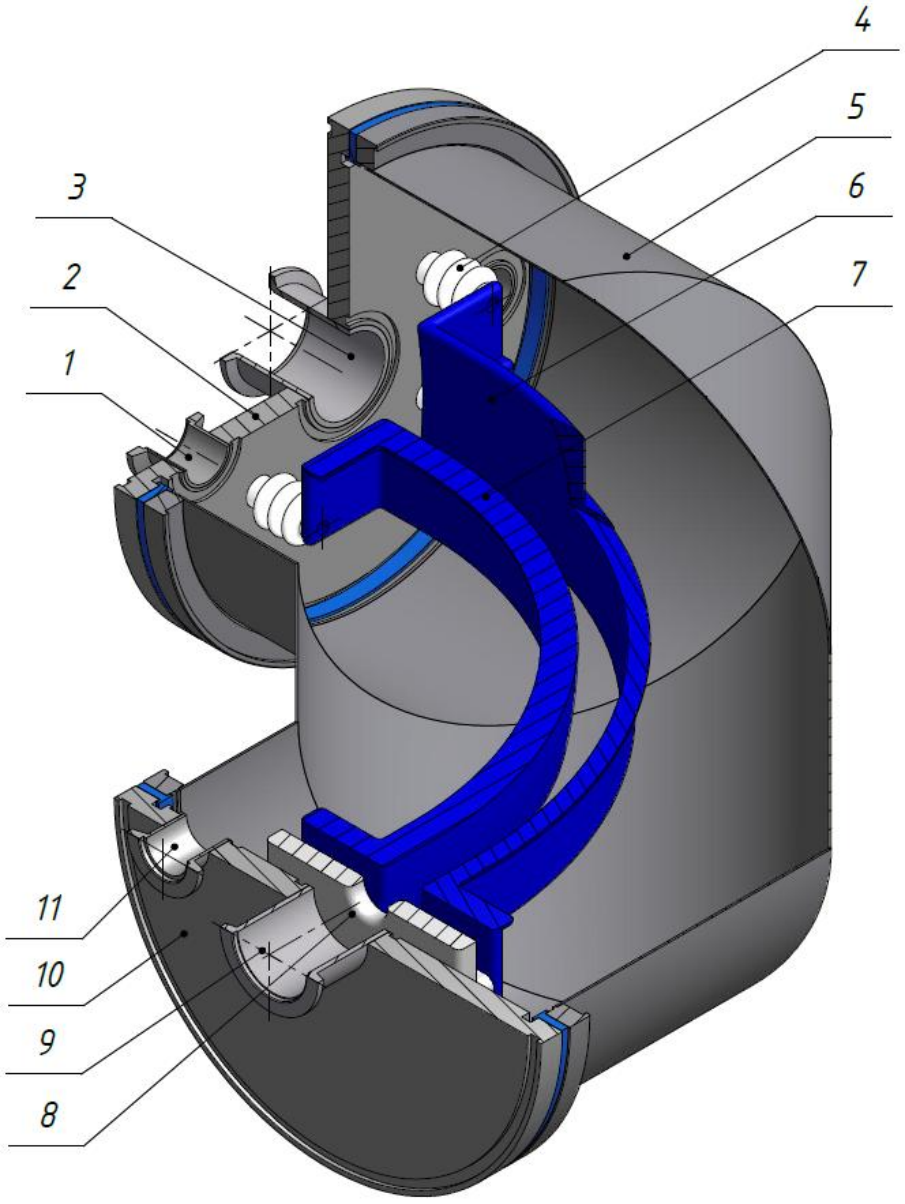


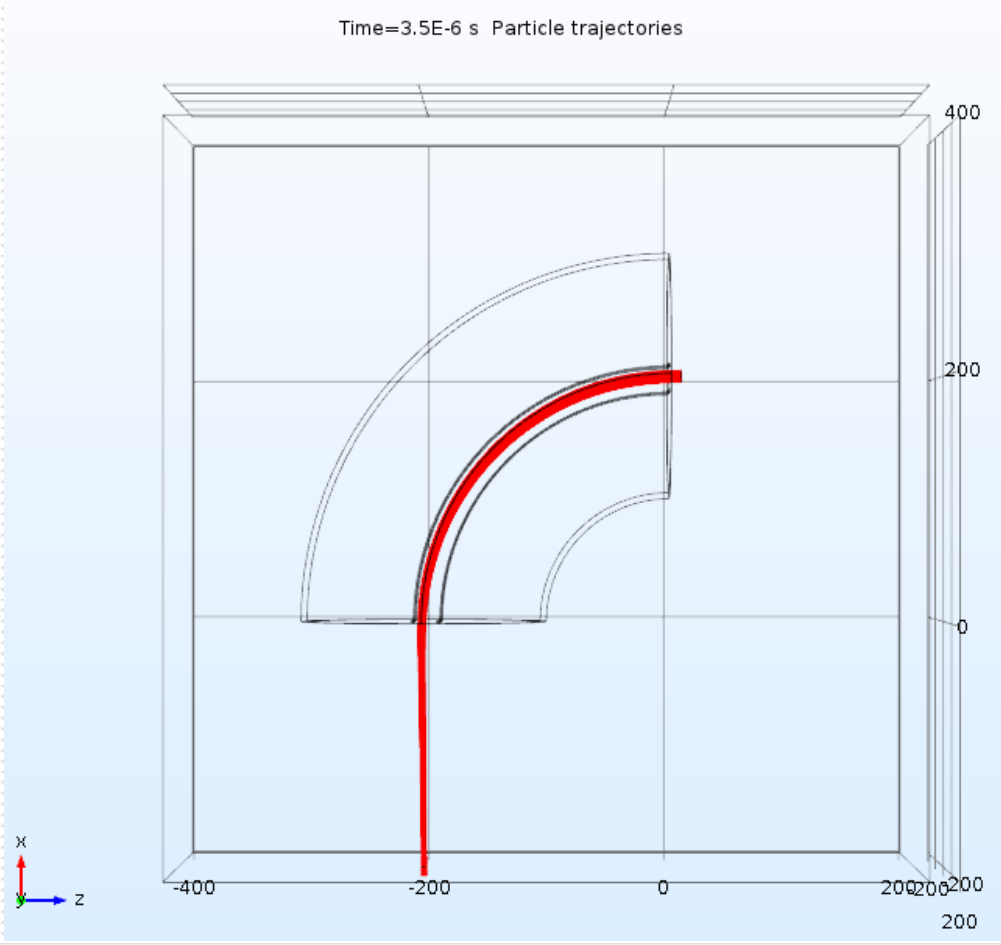
Polarimetry. LSP Na cell

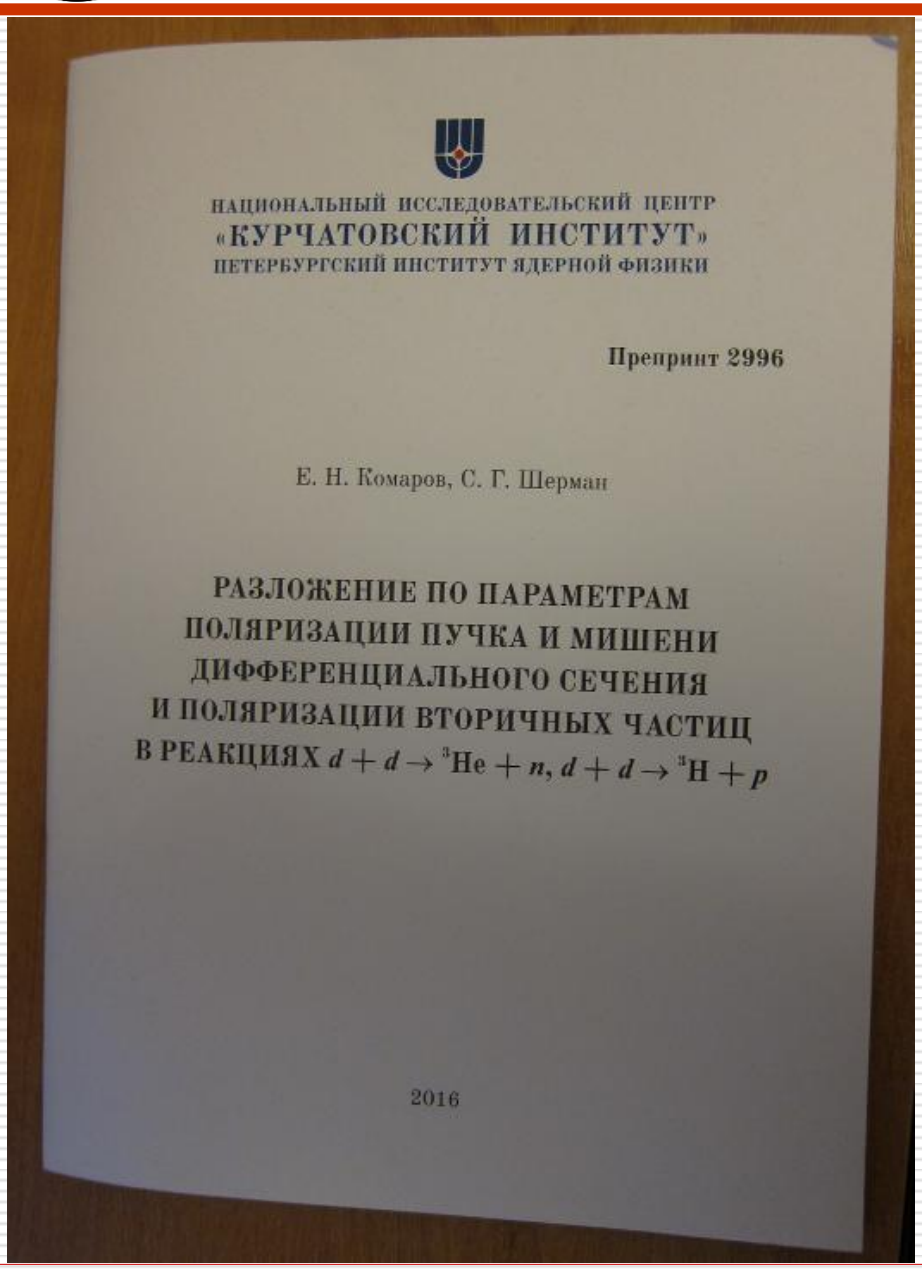




Polarimetry. Deflector for NRP







НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ЦЕНТР
«КУРЧАТОВСКИЙ ИНСТИТУТ»
ПЕТЕРБУРГСКИЙ ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ

Препринт 2996

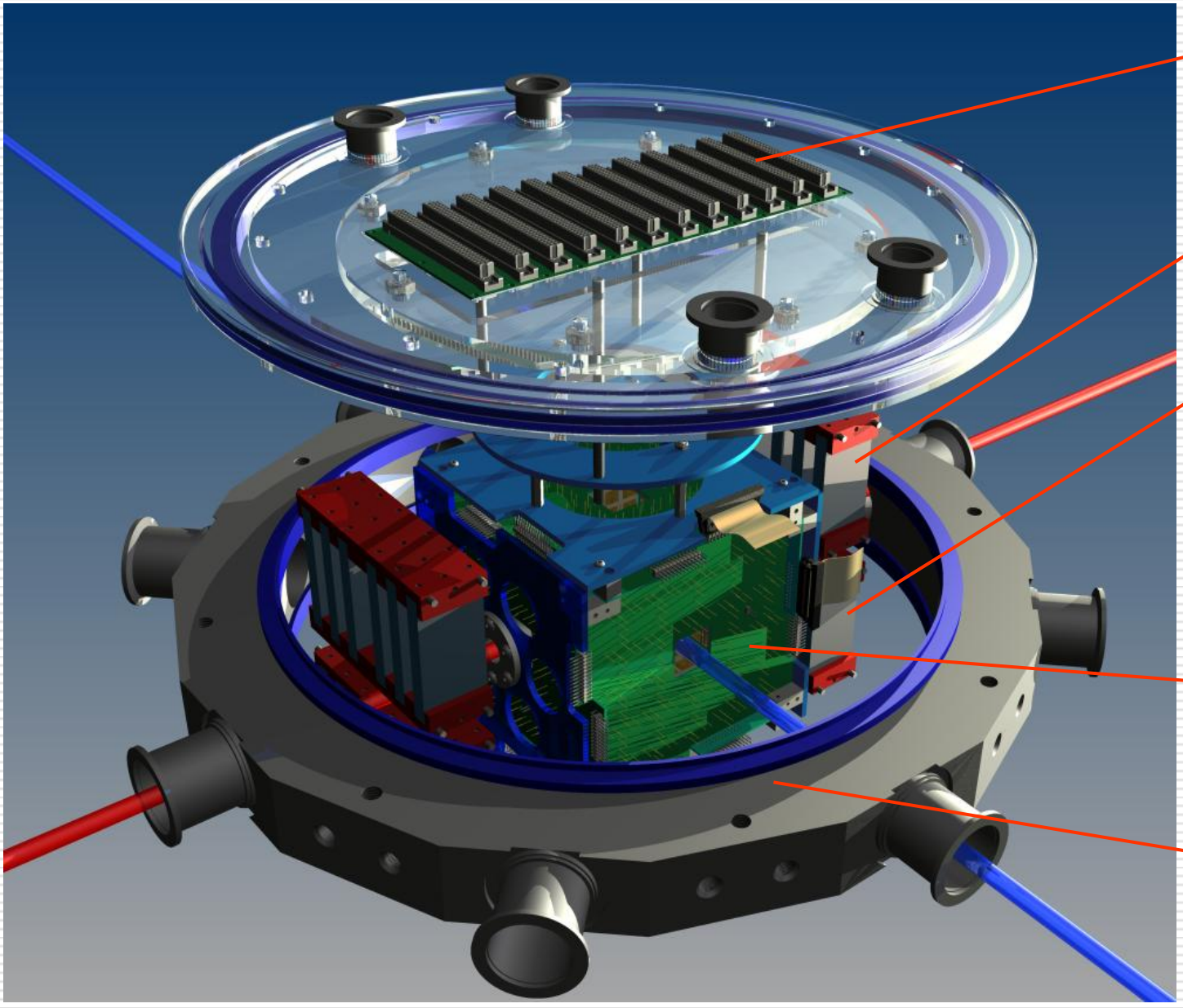
Е. Н. Комаров, С. Г. Шерман

РАЗЛОЖЕНИЕ ПО ПАРАМЕТРАМ
ПОЛЯРИЗАЦИИ ПУЧКА И МИШЕНИ
ДИФФЕРЕНЦИАЛЬНОГО СЕЧЕНИЯ
И ПОЛЯРИЗАЦИИ ВТОРИЧНЫХ ЧАСТИЦ
В РЕАКЦИЯХ $d + d \to {}^3\mathrm{He} + n$, $d + d \to {}^3\mathrm{H} + p$

2016

The observables in the d+d ->^{3}He+n and d+d->^{3}H+p reactions with polarized deuterons

Detector system design



Readout electronics connectors

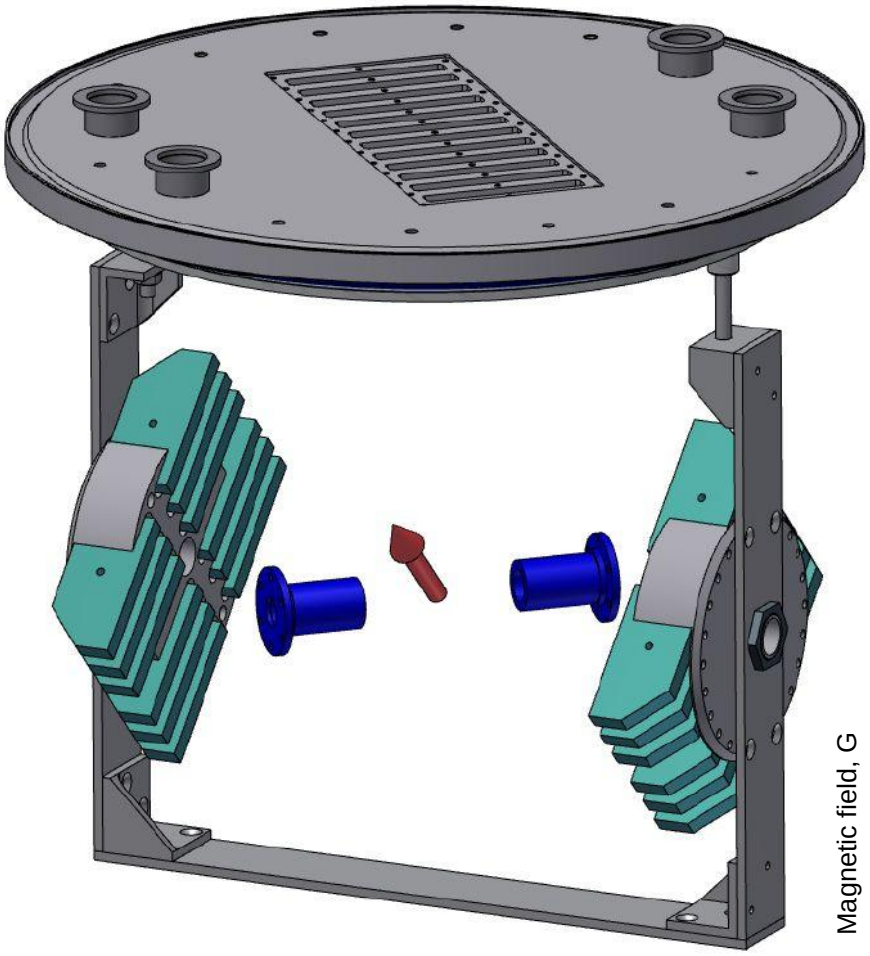
Helmholtz coils

NdFeB permanent magnets

Detector system

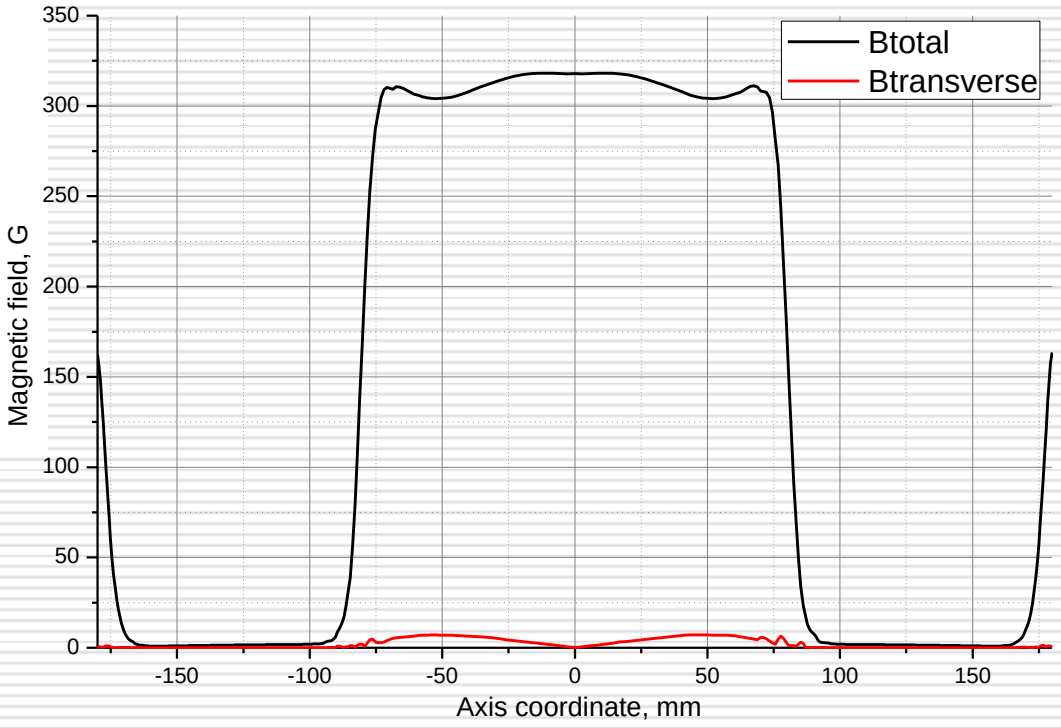
Detector chamber

Magnet system

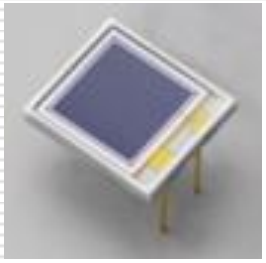


B =300 G = 2.5 Bc

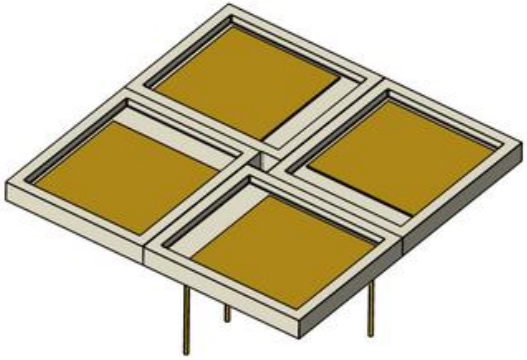
Magnet field is generated by 24 permanent magnets with dimensions 80x40x10 mm^3 with pole tip field of 1.25 T at the surface (NdFeB N40)

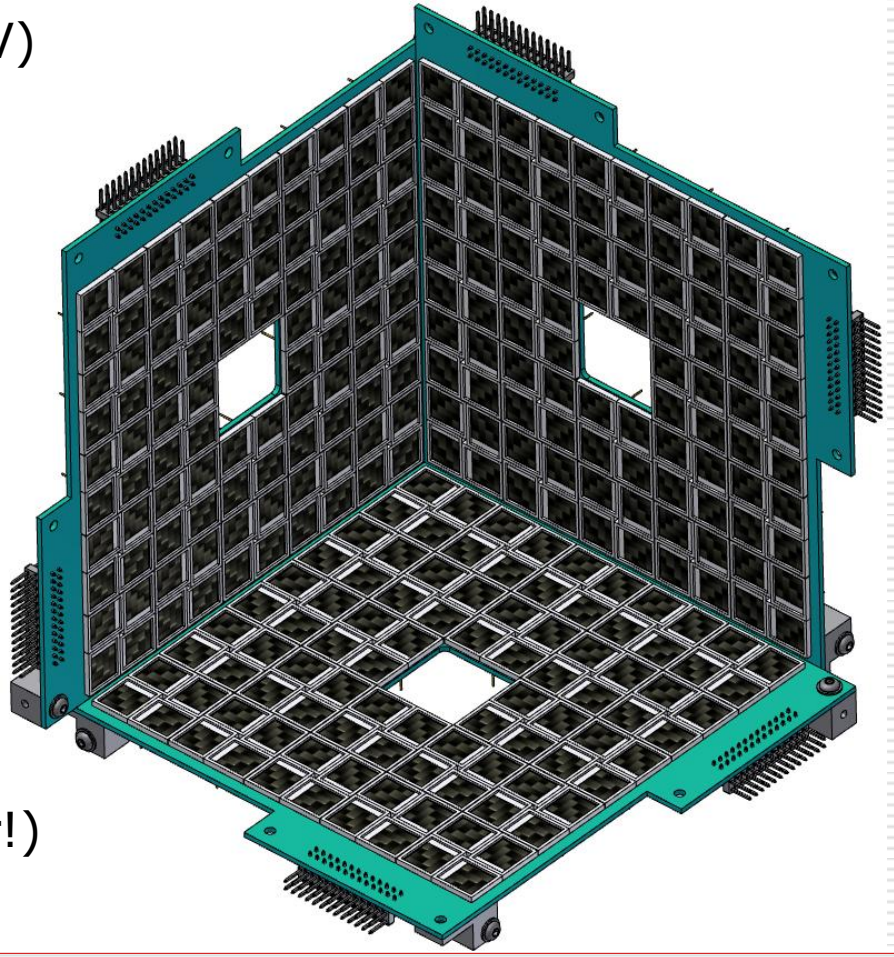


Detector system. PIN diodes version.



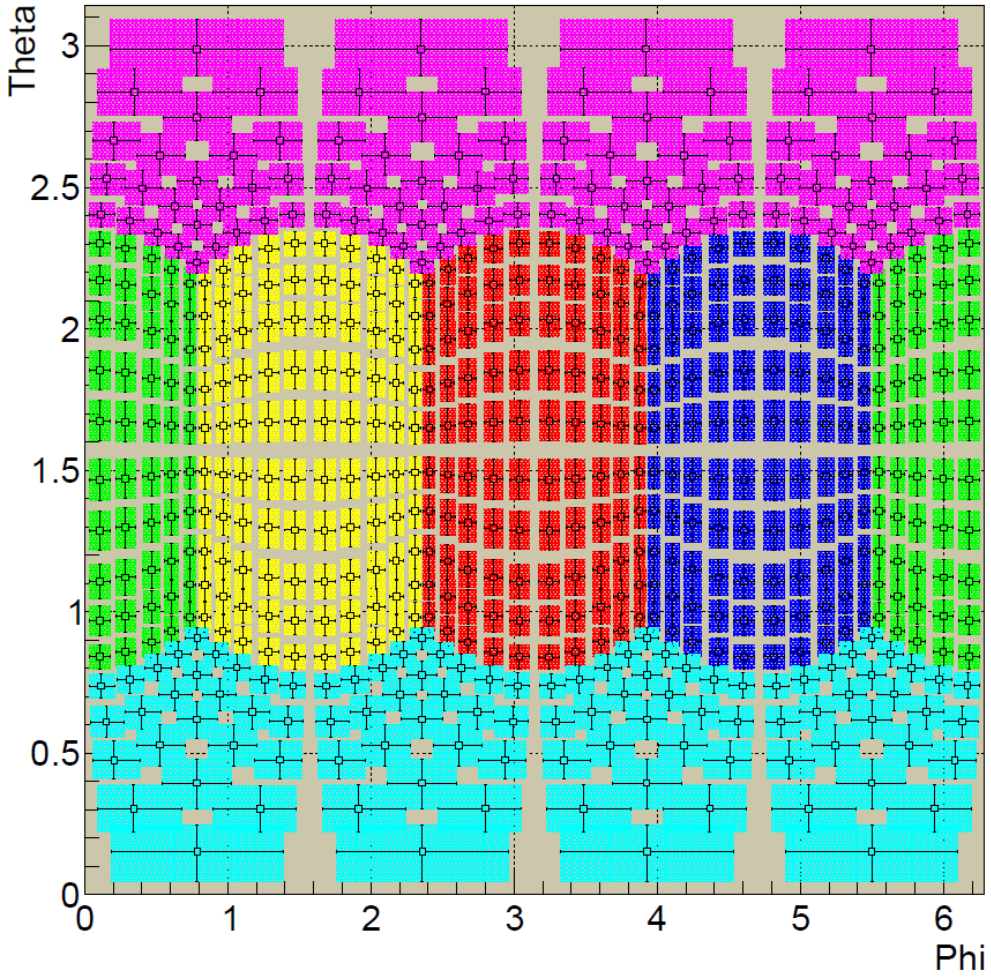
- 4-π detector with 51% filling
- 576 Hamamatsu PIN-diodes (S3590-09)
- PIN-diode active area: 1 cm^2
- depleted layer: 300 um
- energy resolution: <50keV
- low reverse voltage (<=50V)

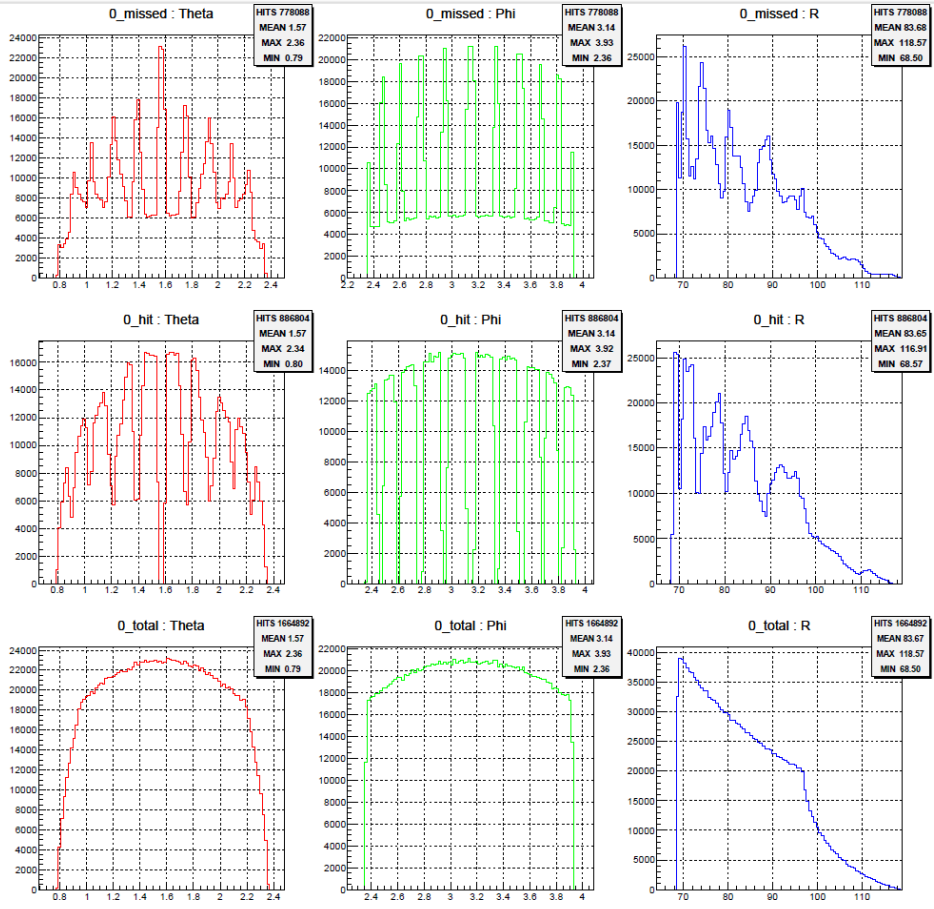




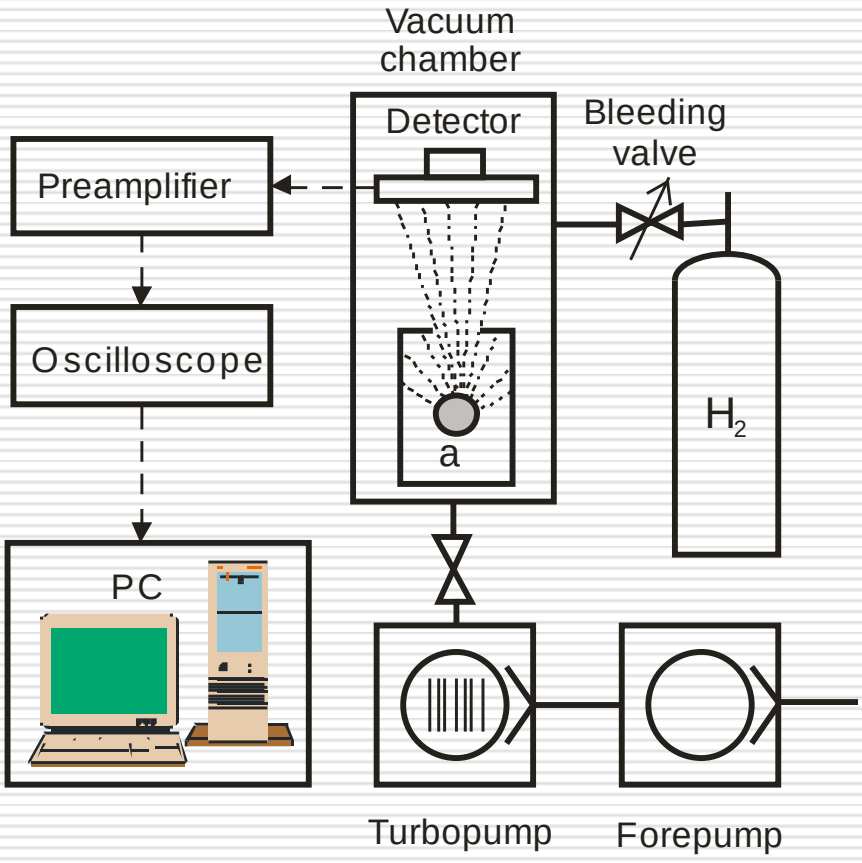
Square detector elements (4x4 diodes)
Standard PCB assembly with
spring through-hole mounting (no solder!)

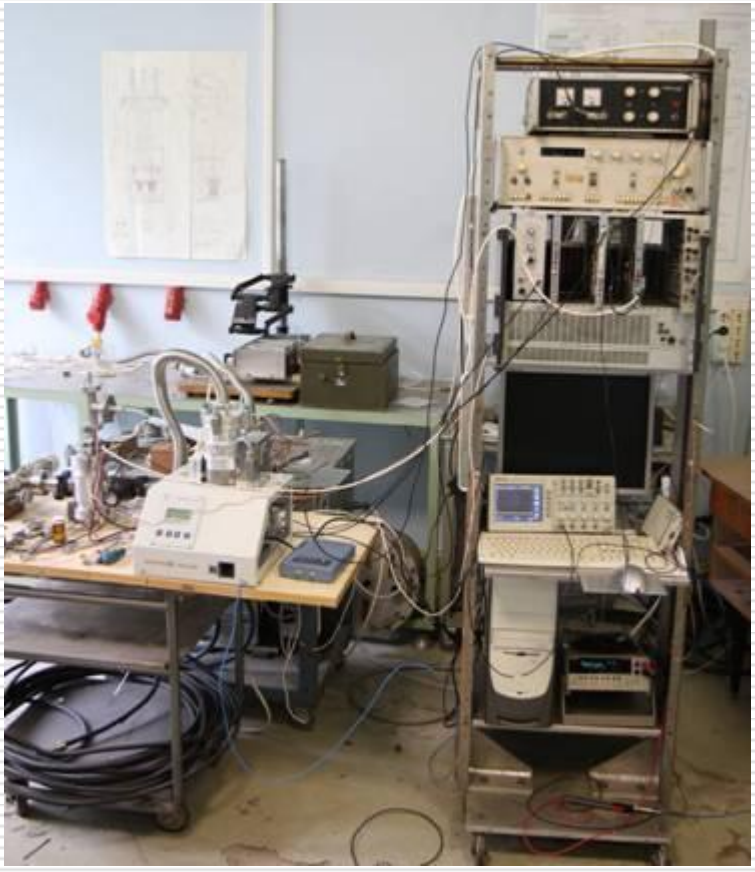
Simulation of the detector system

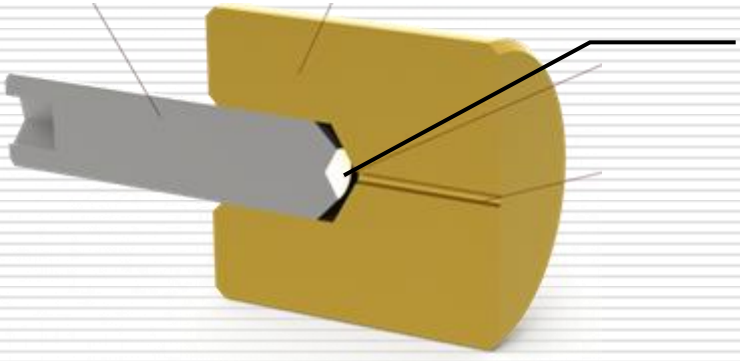




PIN-diodes test bench







Alpha-source:
$^{239}Pu + {}^{240}Pu = 80.4\%$ $^{238}Pu + {}^{241}Am = 19.6\%$
$^{234}U + {}^{235}U + {}^{238}U$
^{241}Am

PIN diode test measurements

- ✓ Dead layer thickness measurement (D≤1μm)

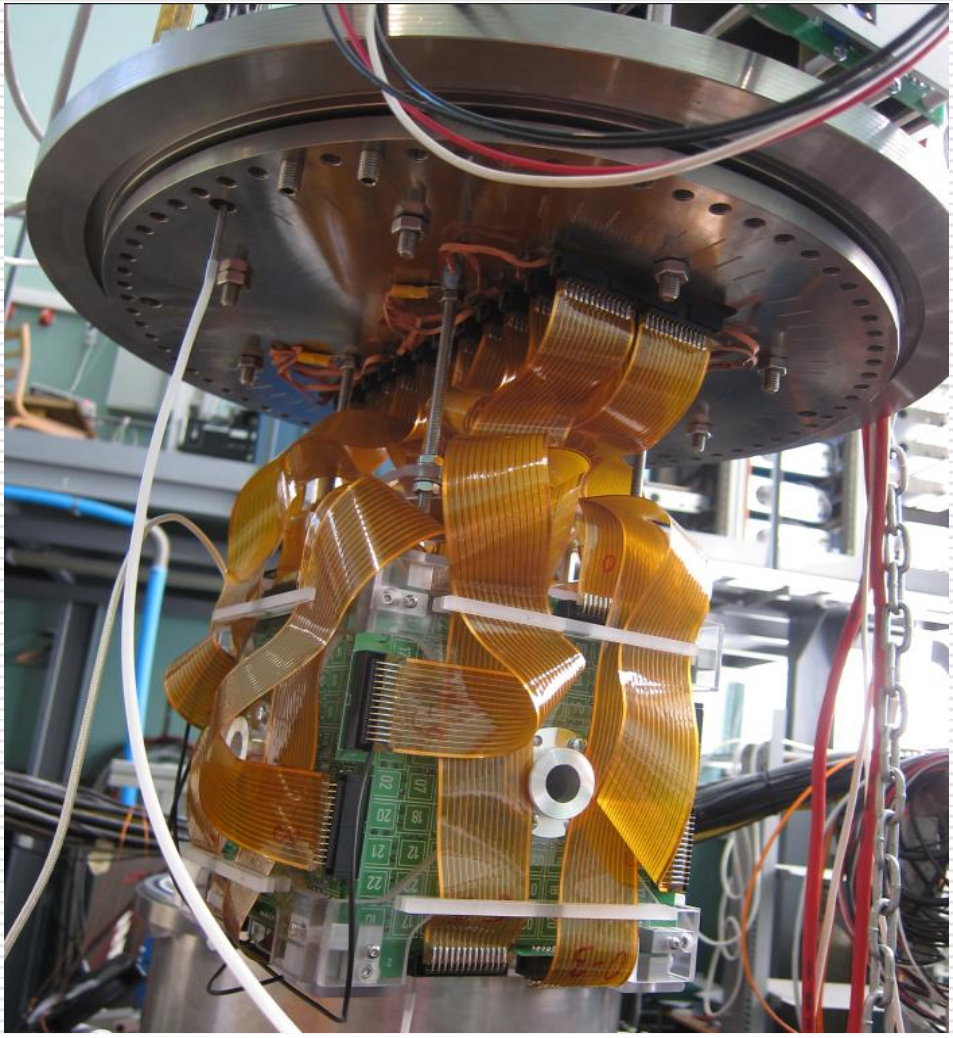
  P. Monich. Bachelor thesis (ITMO university).
- ✓ Active area uniformity tests

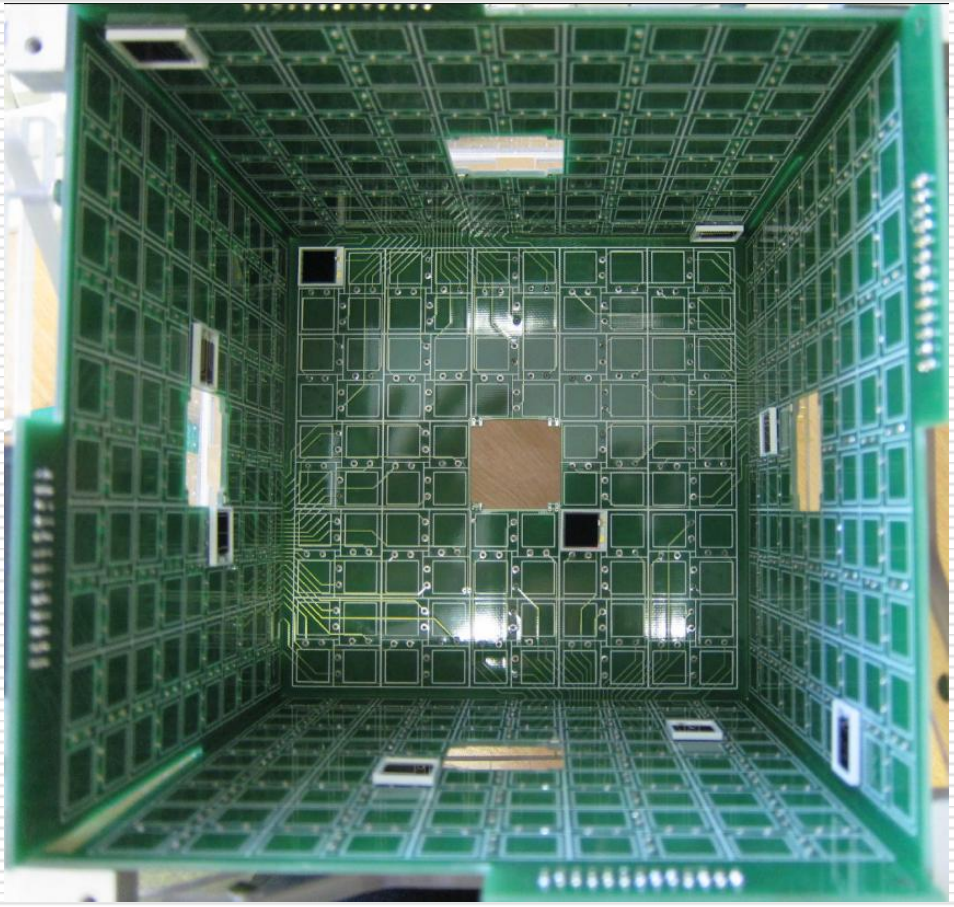
  Inhomogeneity <0.5% for the whole active area
- ✓ Hydrogen vacuum performance

  Better 0.16% stability at hydrogen pressure of 10^{-4} mbar.

  Expected vacuum in the experiment $10^{-5} \div 10^{-6}$ mbar.

Detector system assembly





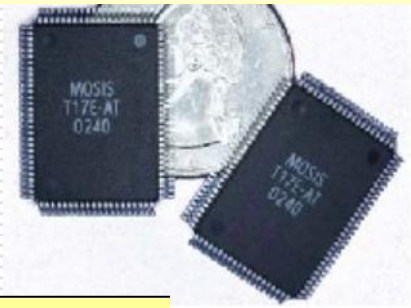
Readout electronics

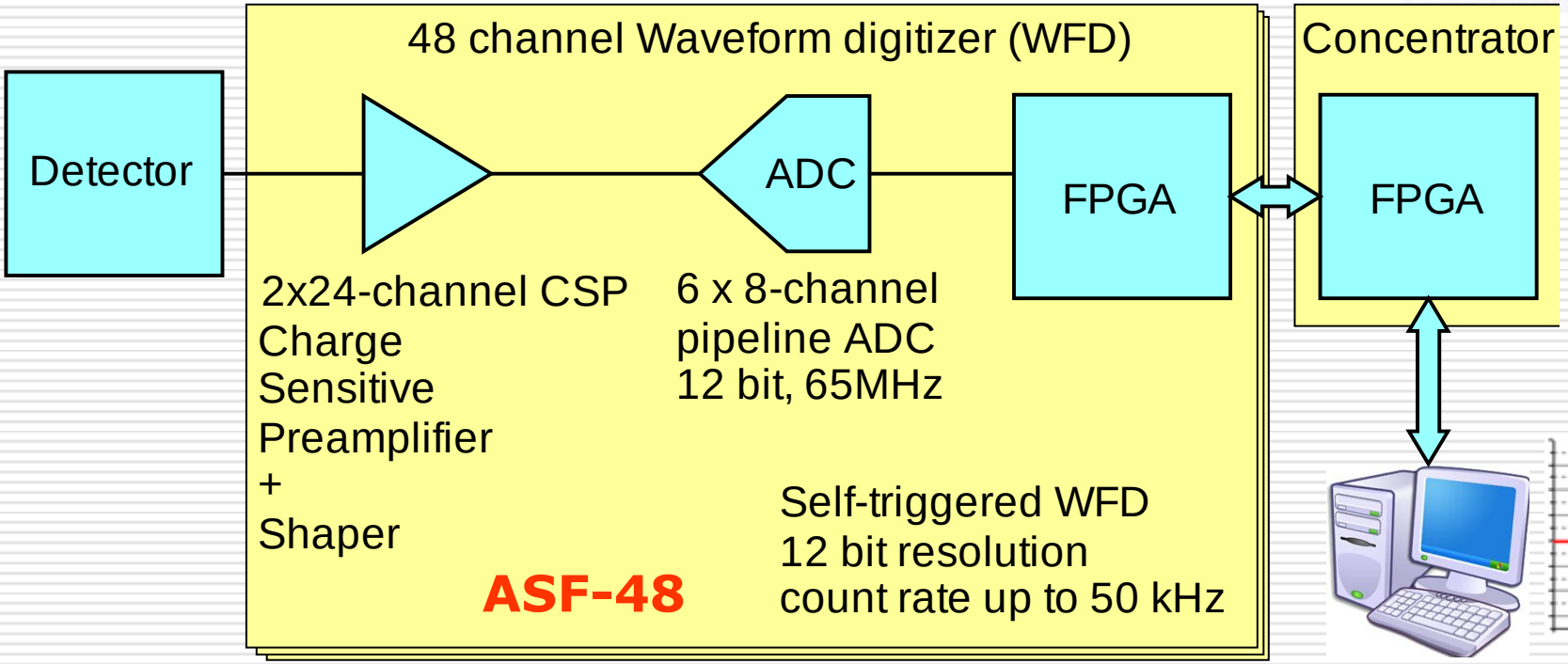
Readout requirements:

- 600 channels
- Total count rate ≤ 1kHz
- Standard interface (Ethernet?)
- Event synchronization for coincidence trigger

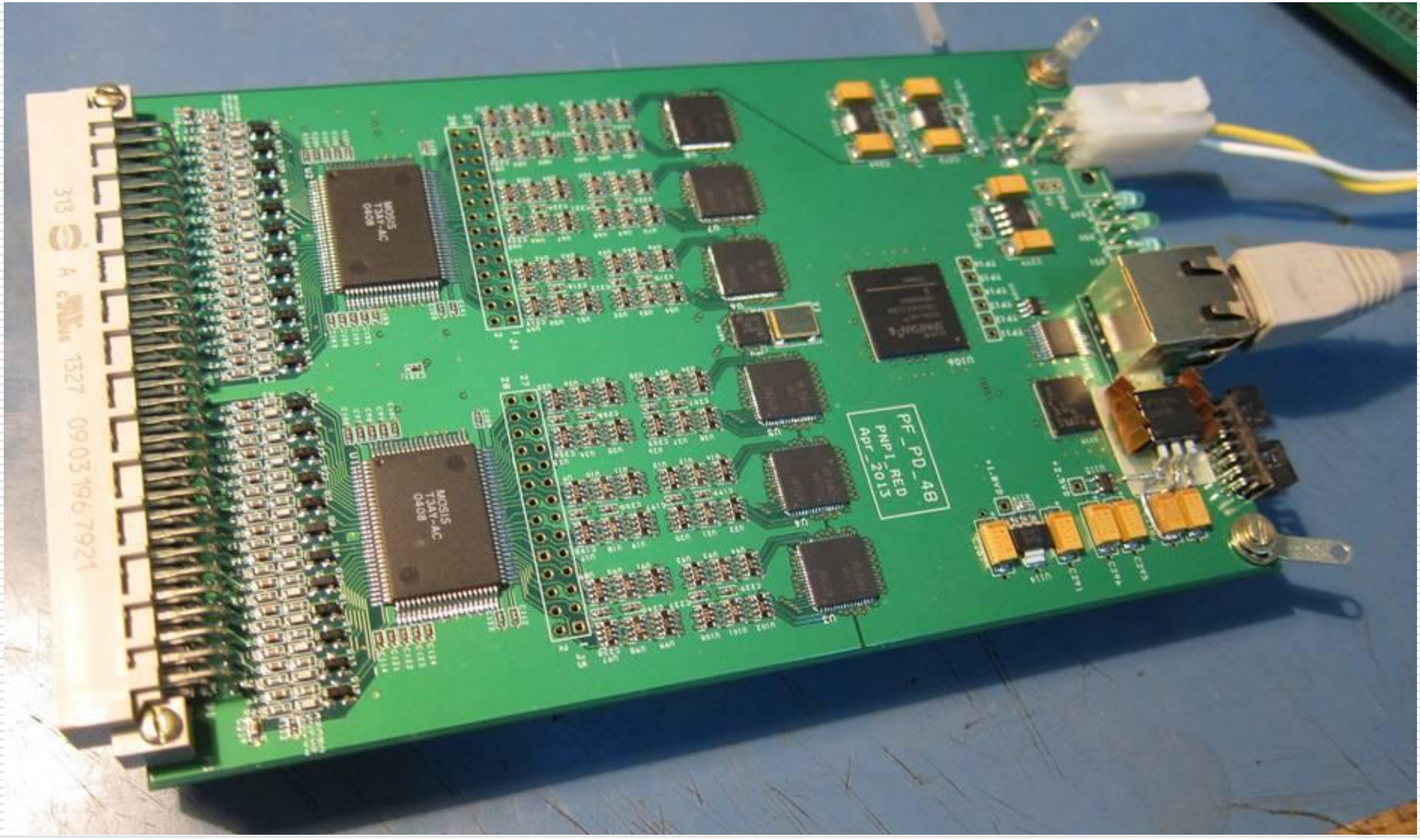
CSP from ATLAS CSC [BNL]

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

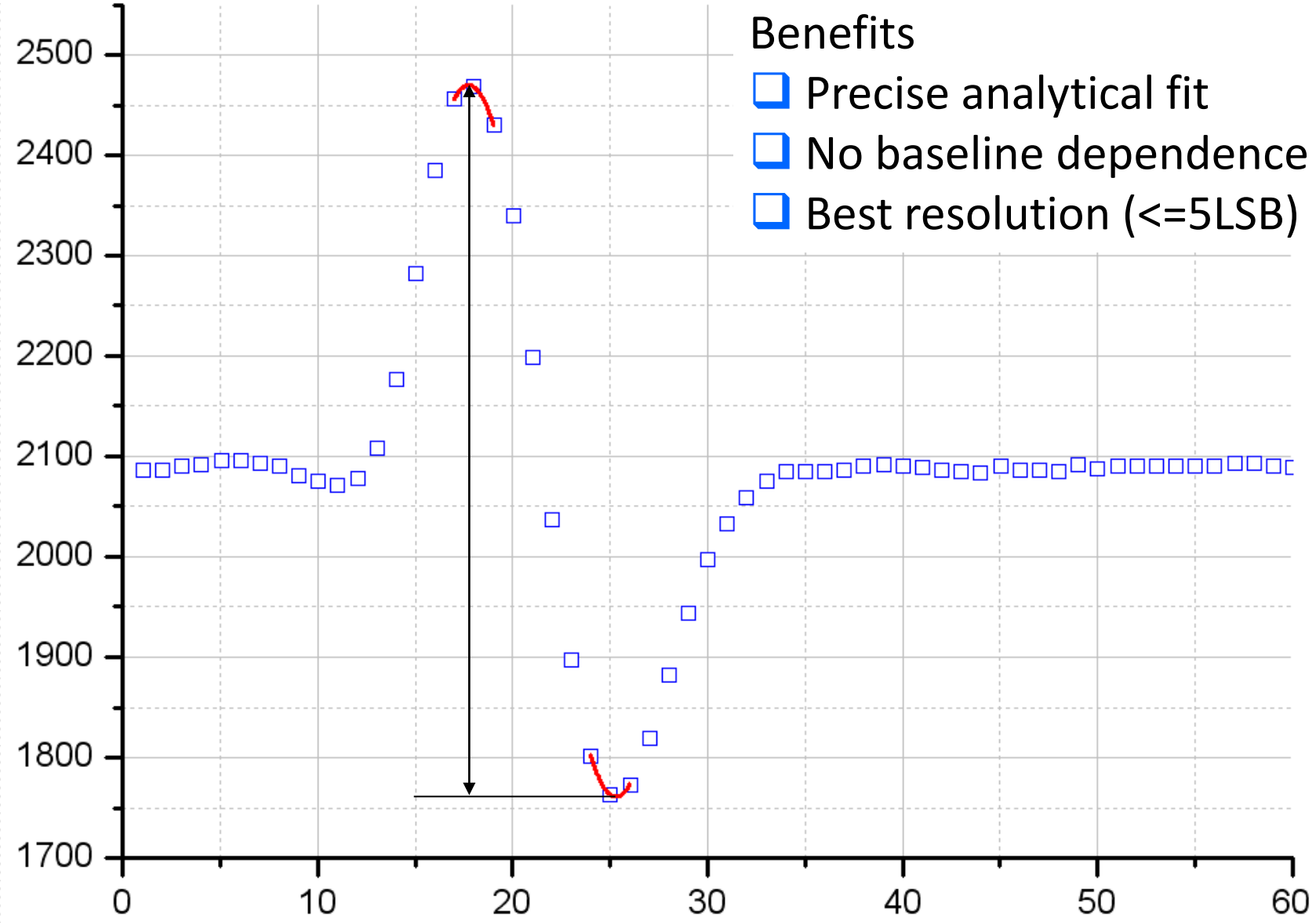




ASF48 readout board



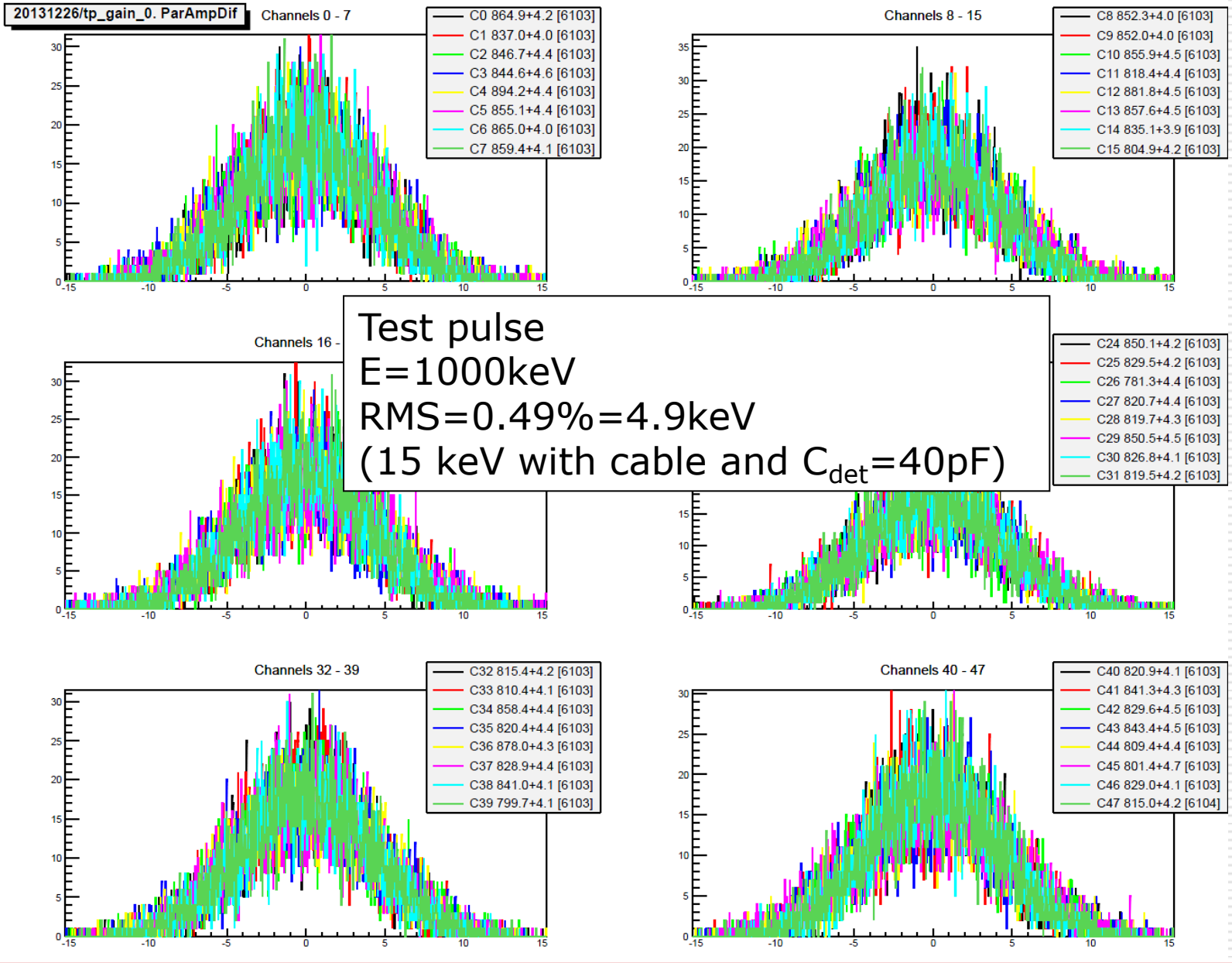
Readout signal processing



Benefits

- Precise analytical fit
- No baseline dependence
- Best resolution (<=5LSB)

Energy resolution

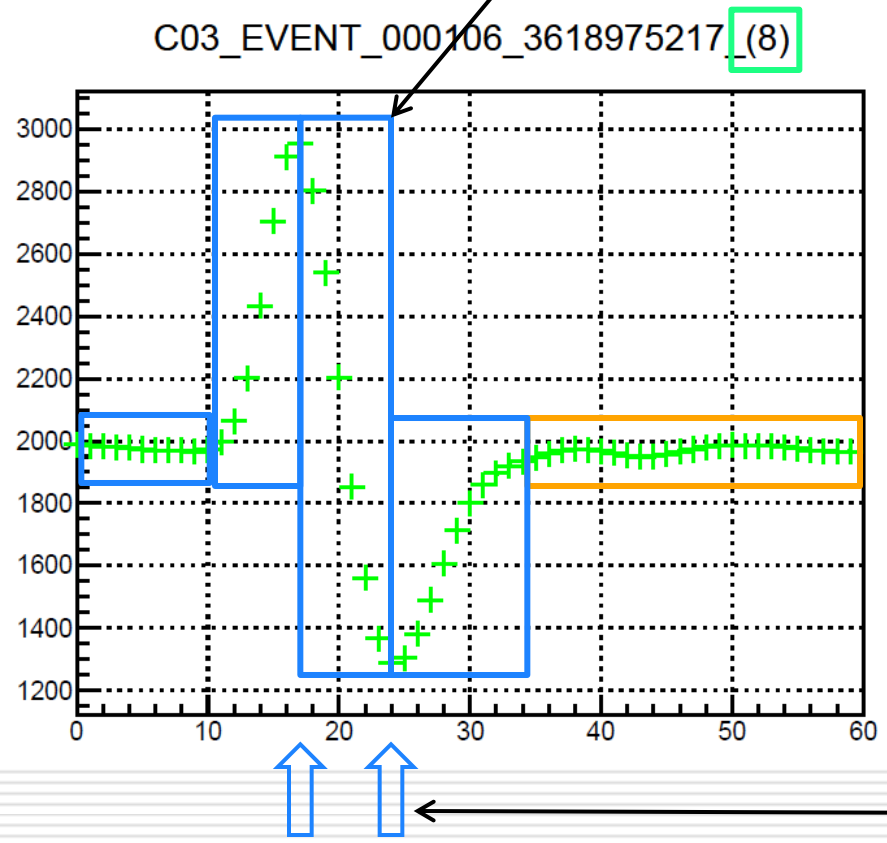


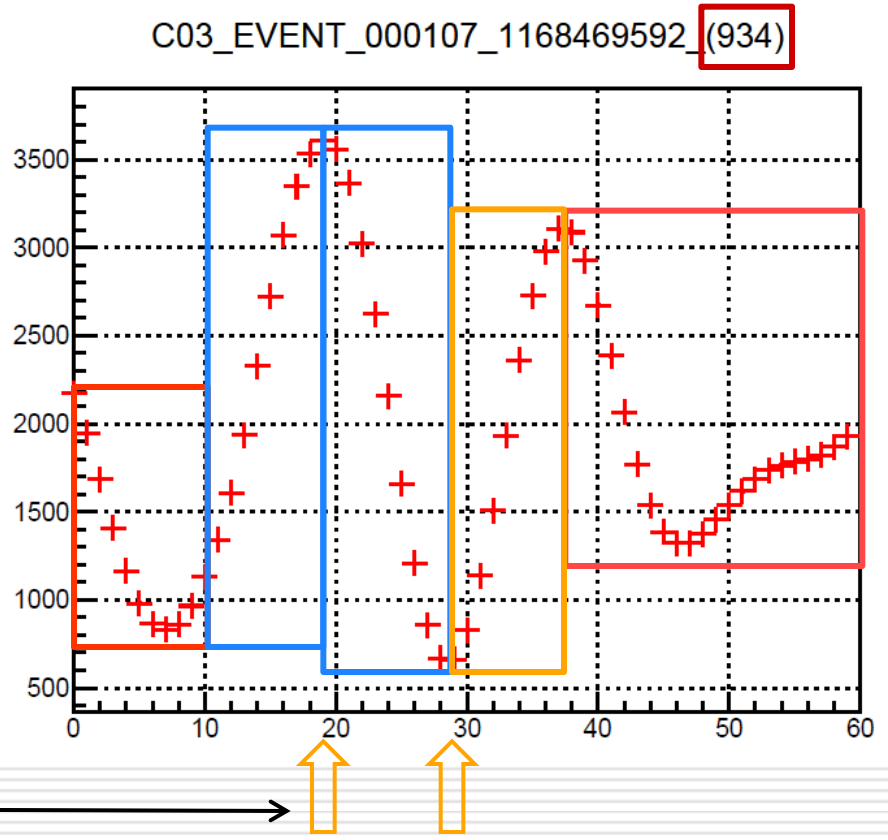
Test pulse
E=1000keV
RMS=0.49%=4.9keV
(15 keV with cable and C_{det}=40pF)

Signal quality

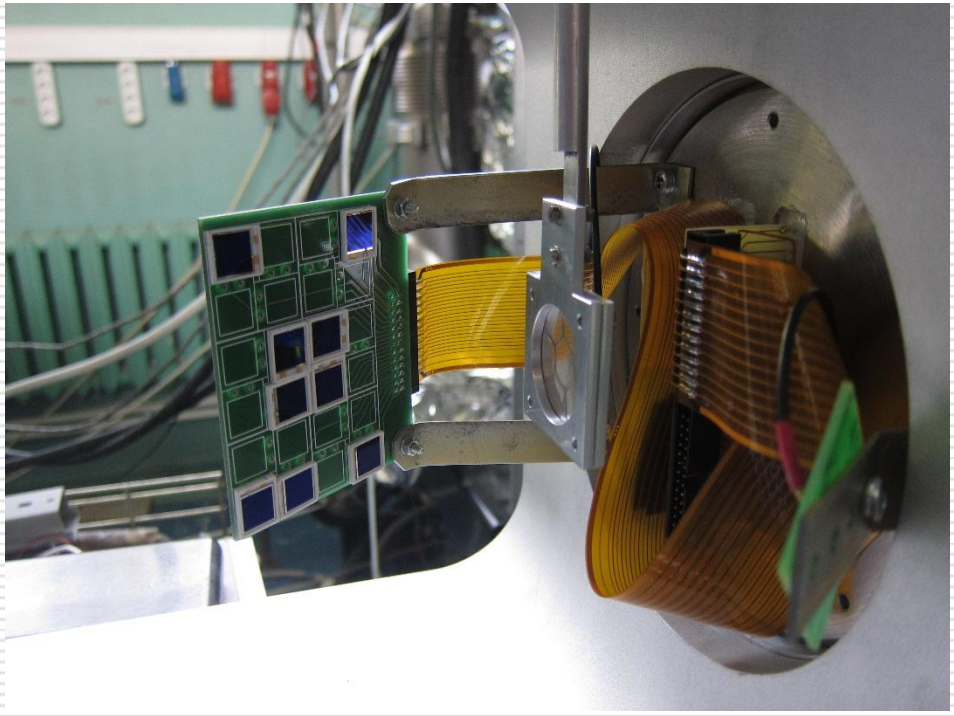
Signal quality checks:

- ADC range clipping
- Signal shape (derivatives)
- Peaks position

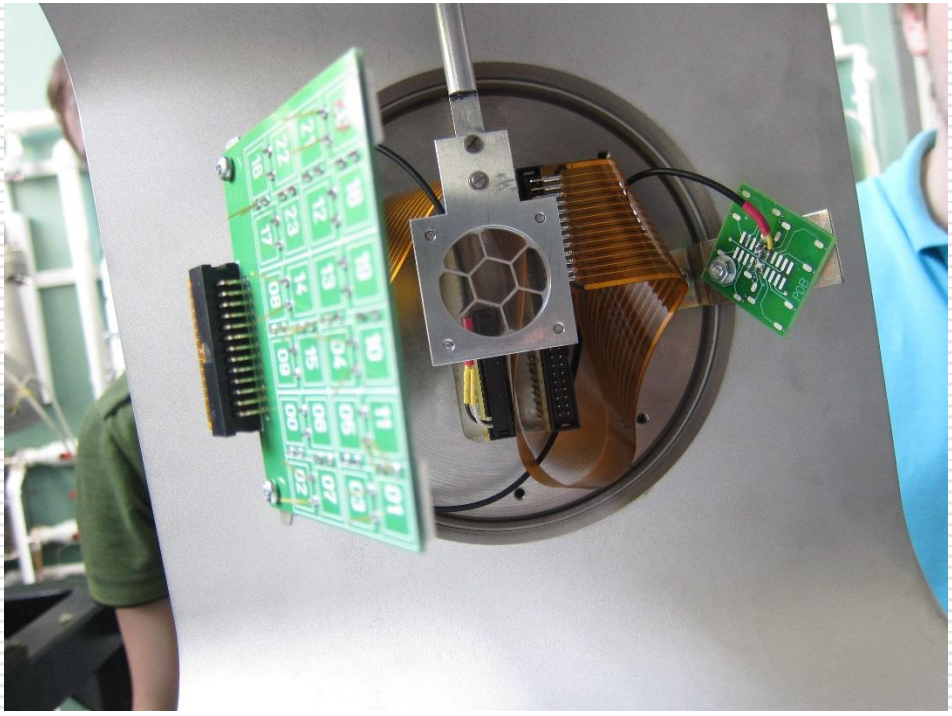




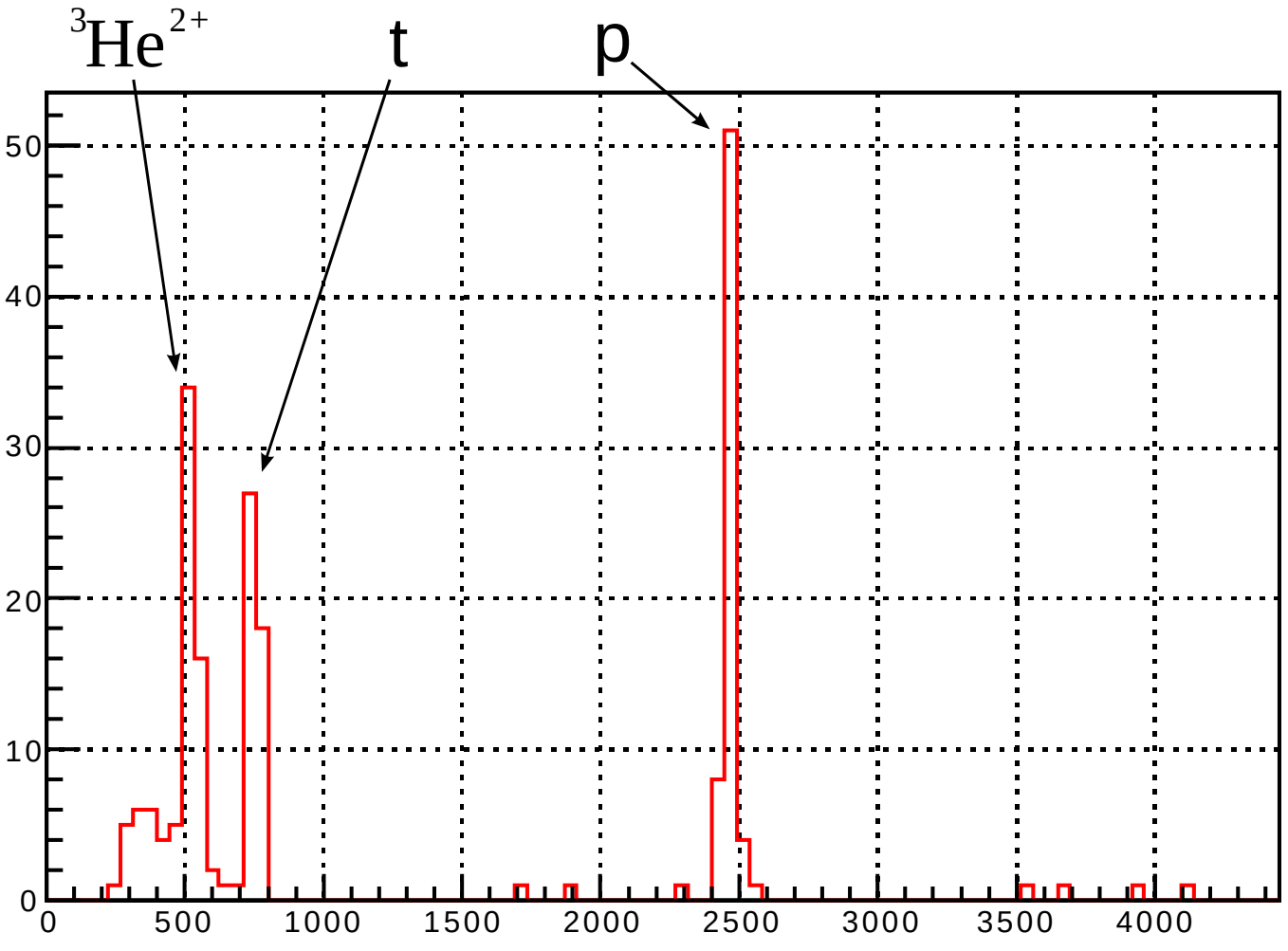
Solid target experiment



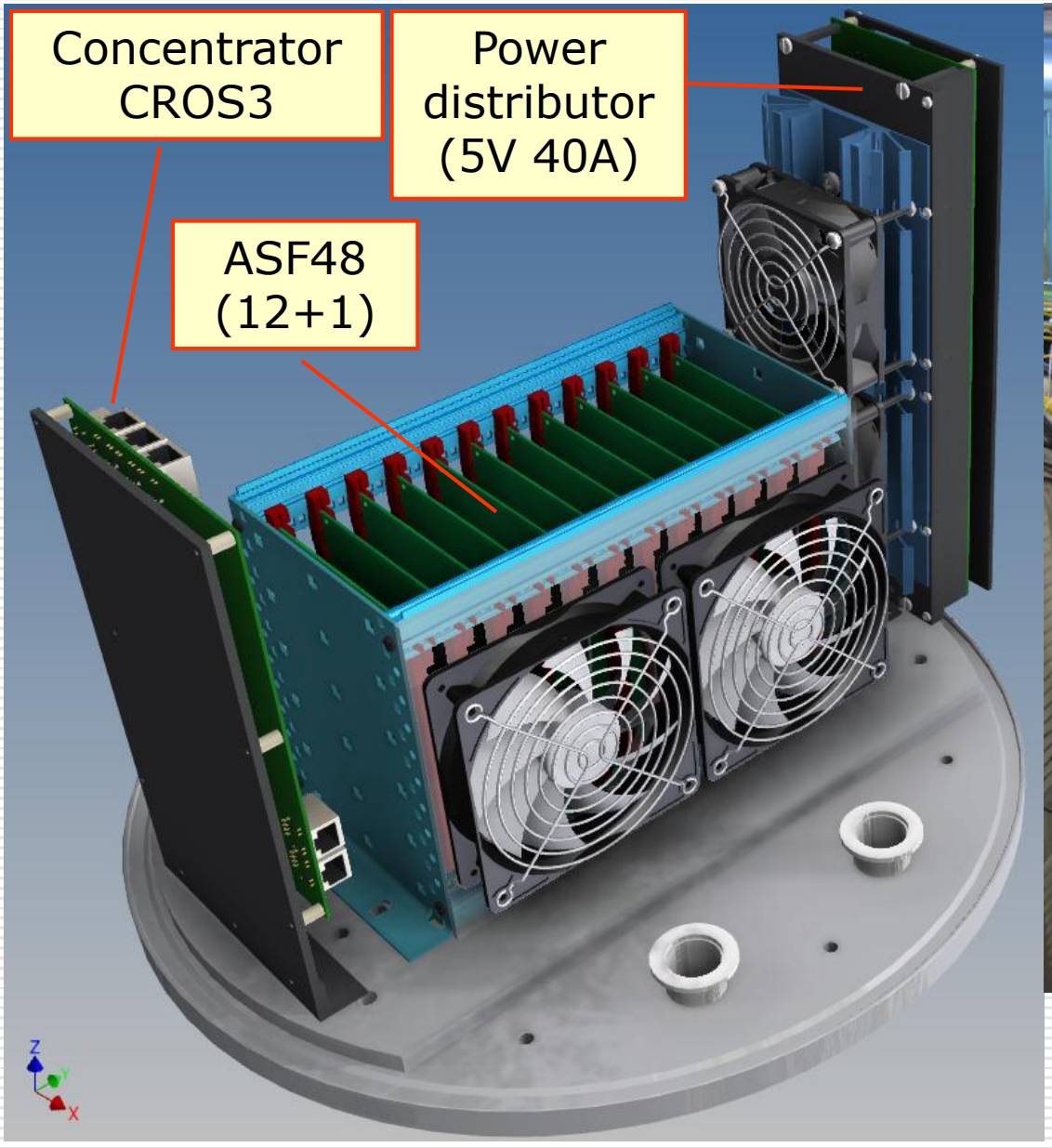
Target: deuterated
polymethylmethacrylate
Deuteron beam 15keV ~5uA

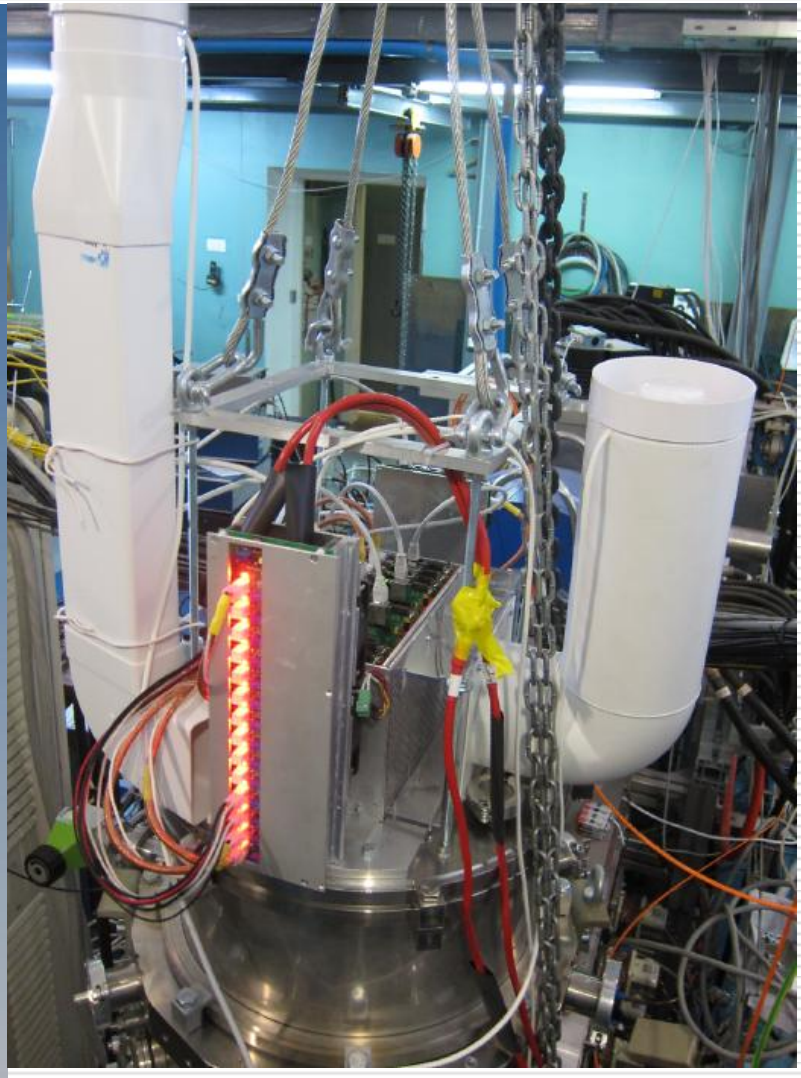


Solid target results

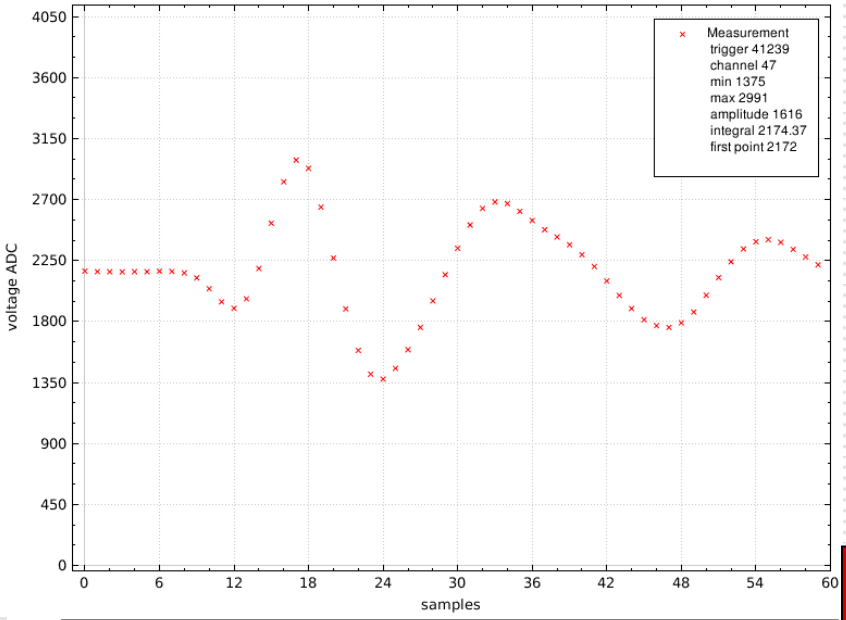


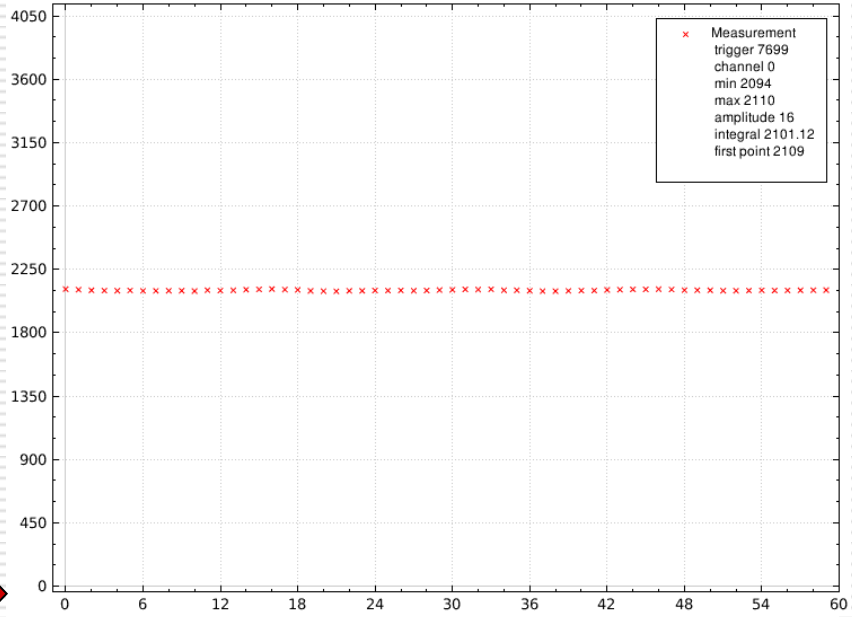
Full scale readout electronics (ASF-48)

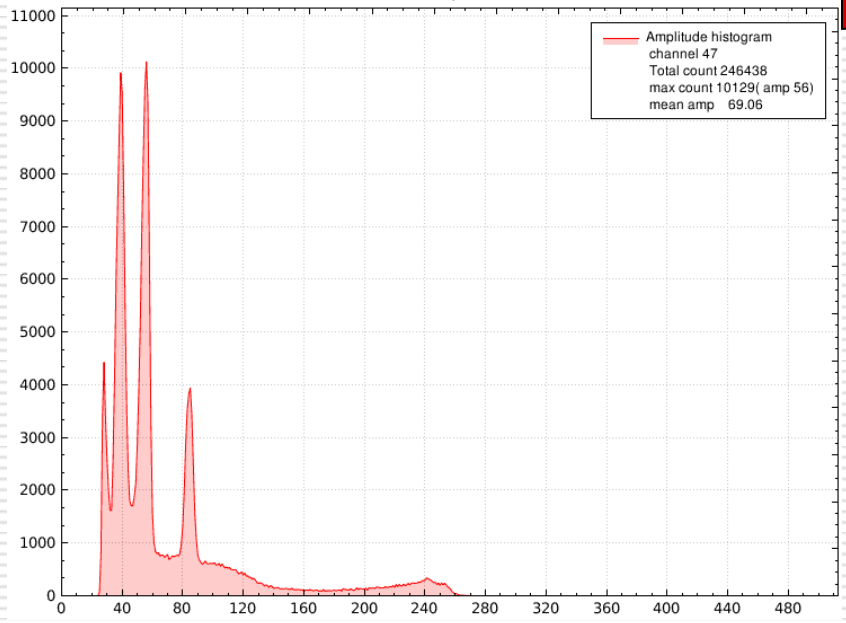


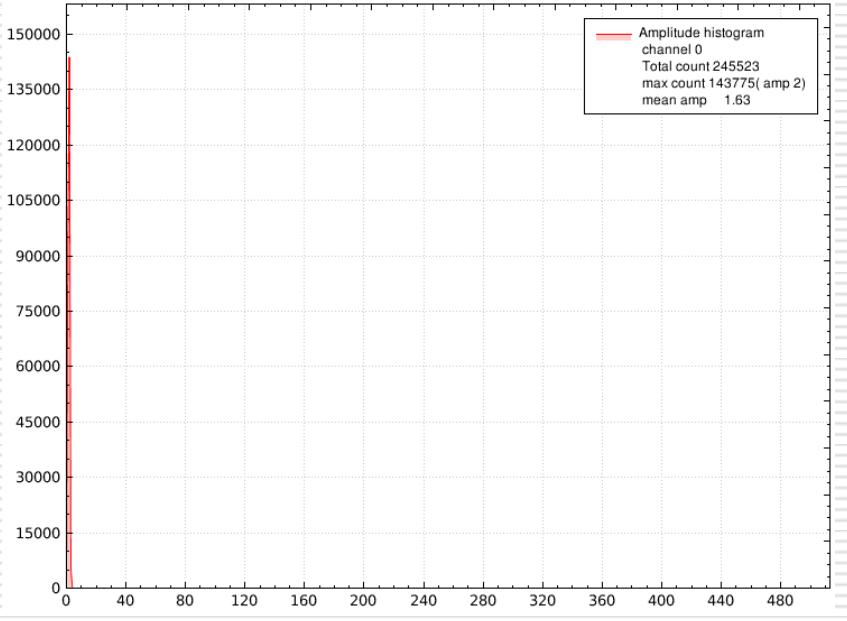


Optimizations (grounding, pickups…)





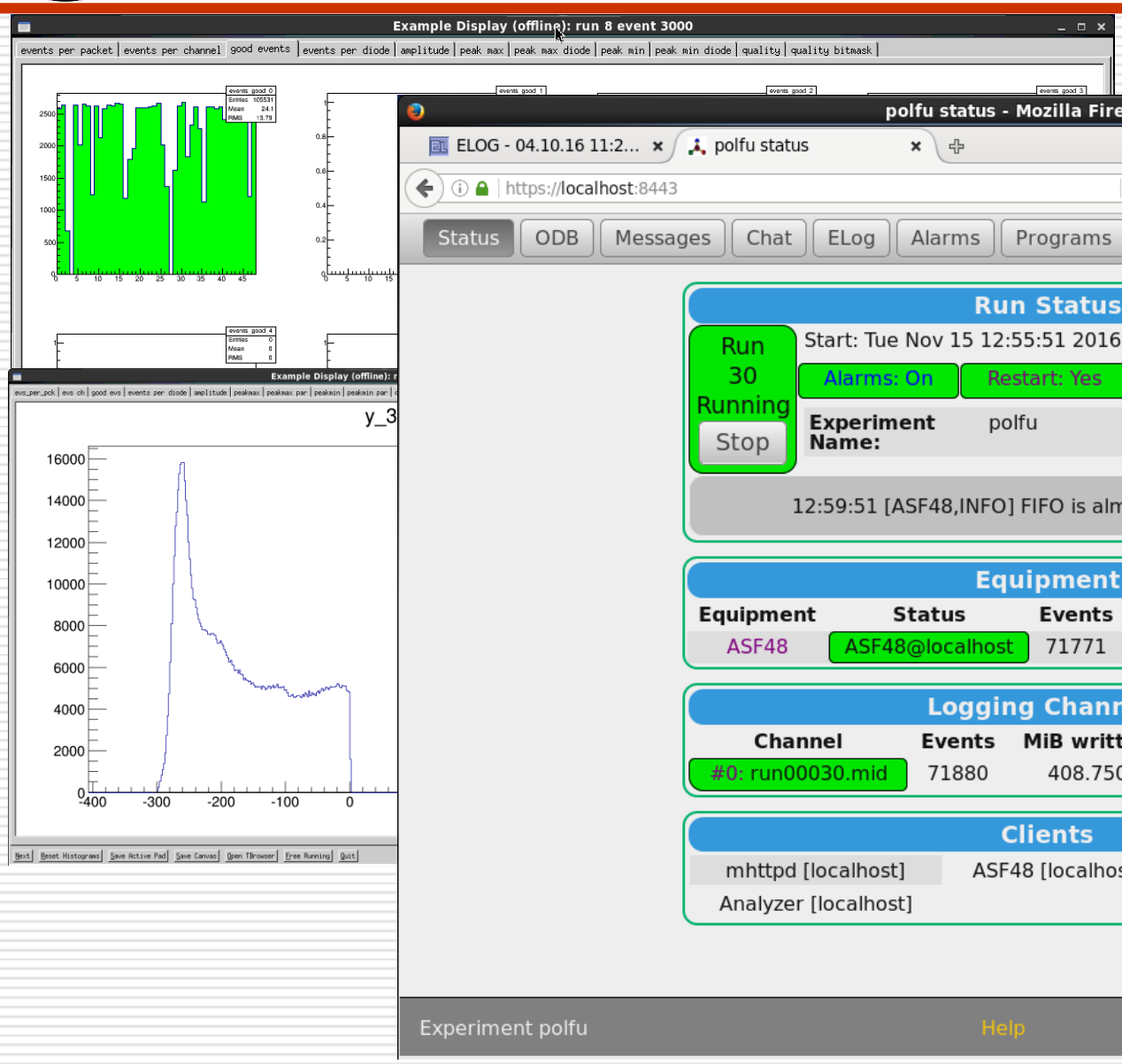




Data acquisition software

- ASF48 test software
- Full scale DAQ software based on MIDAS (Maximum Integrated Data Acquisition System) http://midas.psi.ch
  - Flexible distributed DAQ system
  - Web interface for run control and monitoring
  - Data transfer / logging capability
  - Online data monitoring
  - Online database
  - Message logging
  - Alarms

Data acquisition software



Thank you!

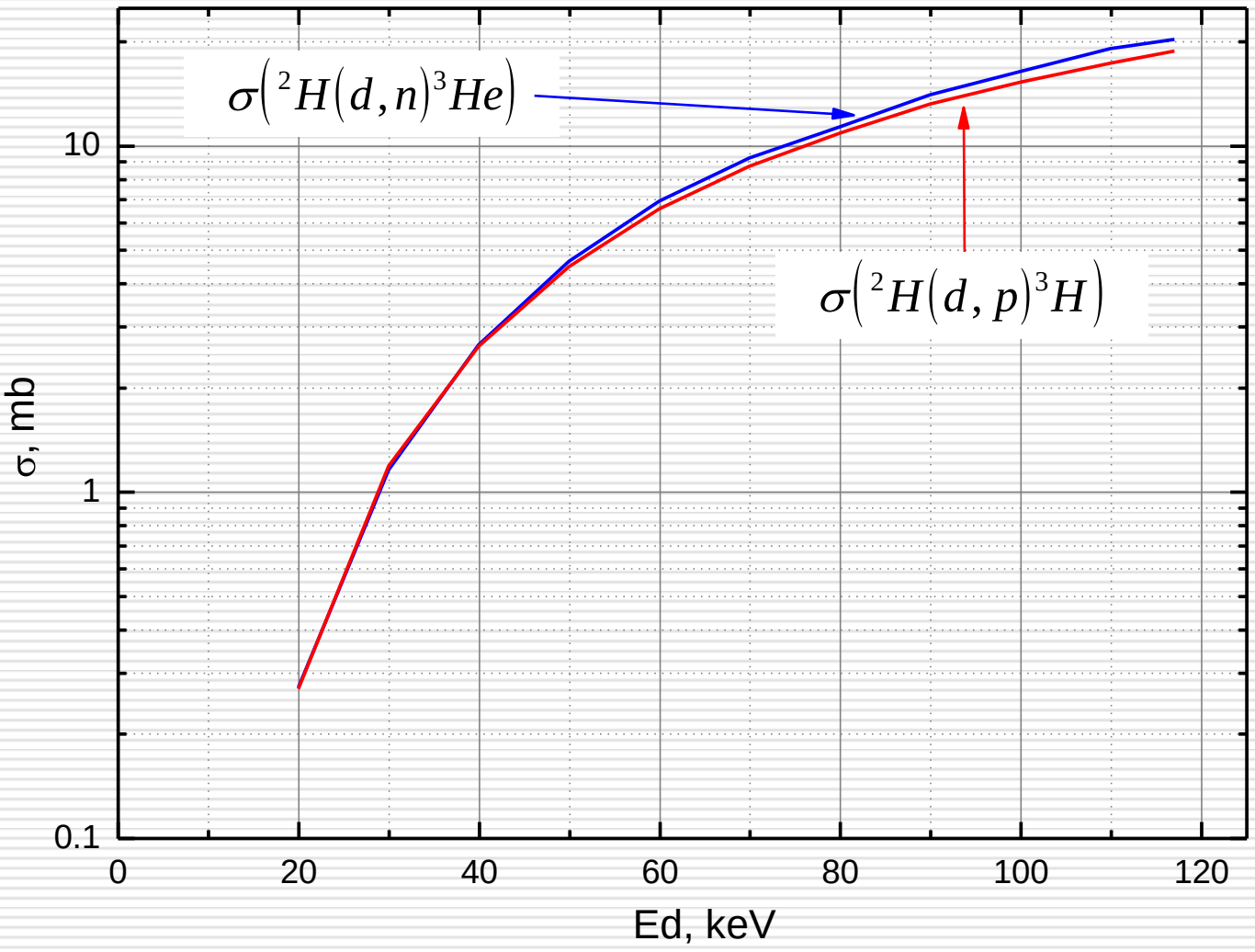
BACKUP

Hyperfine states

ABS								85% value		
HFS after Sextupole 1	MFT	HFS after Sextupole 2	SFT	WFT	HFS after ABS	Pz	Pzz	Pz	Pzz	Beam
1, 2, 3	---	1, 2, 3	---	---	1, 2, 3	+1/3	-1/3	0.272	-0.332	0
1, 2, 3	1-4	2, 3	---	---	2, 3	0	-1	-0.02	-0.85	1
1, 2, 3	3-4	1, 2	---	---	1, 2	+2/3	0	+0.561	-0.02	2
1, 2, 3	3-4	1, 2	---	on	3, 4	-2/3	0	-0.561	+0.02	3
1, 2, 3	3-4	1, 2	2-6	---	1, 6	+5/6	+0.5	+0.714	+0.434	4
1, 2, 3	1-4	2, 3	2-6	---	3, 6	+1/6	-0.5	+0.145	-0.391	5
1, 2, 3	1-4	2, 3	3-5	---	2, 5	-1/6	-0.5	-0.145	-0.459	6

POLIS								75% value		
HFS after Sextupole 1	MFT	HFS after Sextupole 2	SFT	WFT	HFS after ABS	Pz	Pzz	Pz	Pzz	Beam
1, 2, 3	---	1, 2, 3	---	---	1, 2, 3	0	0	0	0	0
1, 2, 3	1-4	2, 3	---	---	2, 3	-0.5	-0.5	-0.375	-0.375	1
1, 2, 3	3-4	1, 2	---	---	1, 2	+0.5	-0.5	+0.375	-0.375	2
1, 2, 3	3-4	1, 2	---	on	3, 4	-1	+1	-0.75	+0.75	3
1, 2, 3	3-4	1, 2	2-6	---	1, 6	+1	+1	+0.75	+0.75	4
1, 2, 3	1-4	2, 3	2-6	---	3, 6	0	+1	+0.02	+0.75	5
1, 2, 3	1-4	2, 3	3-5	---	2, 5	0	-2	-0.02	-1.5	6

Unpolarized cross sections



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