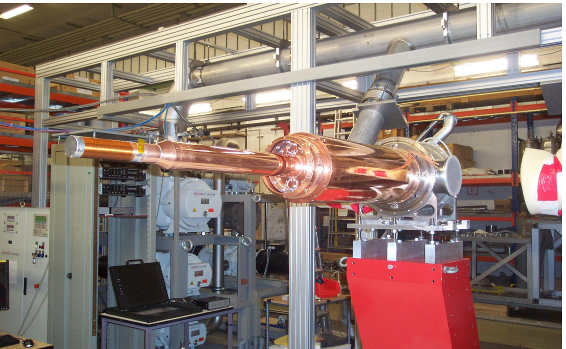
Review on the last developments on polarized targets at Mainz

1.- Exp. Boundary Conditions: What do we want to measure? How?

2.- Polarised Solid Target:
- a) Frozen Spin Target at MAMI
- b) Cryogenics
- c) New Magnet Technology
- d) New Active Target Material

3.- Conclusion and outlook



Annual Meeting of the GDR PH-QCD

27. November 2013

Saclay

Andreas Thomas

Standard Model

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	–1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	–1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	–1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

BOSONS

force carriers
spin = 0, 1, 2, ...

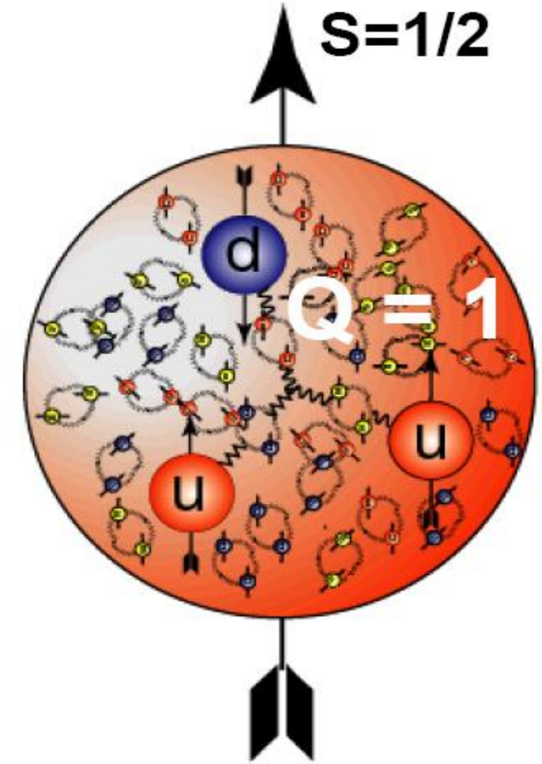
Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W$^-$	80.4	–1
W$^+$	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

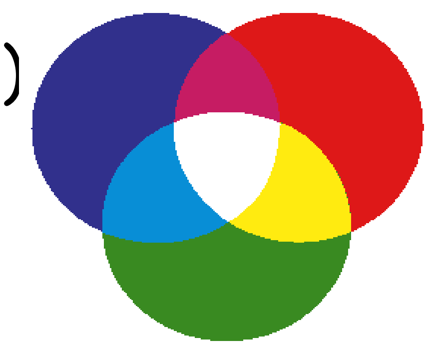
Picture of a Proton (Skale fm).



QCD Colourless objects:

Baryons (qqq)

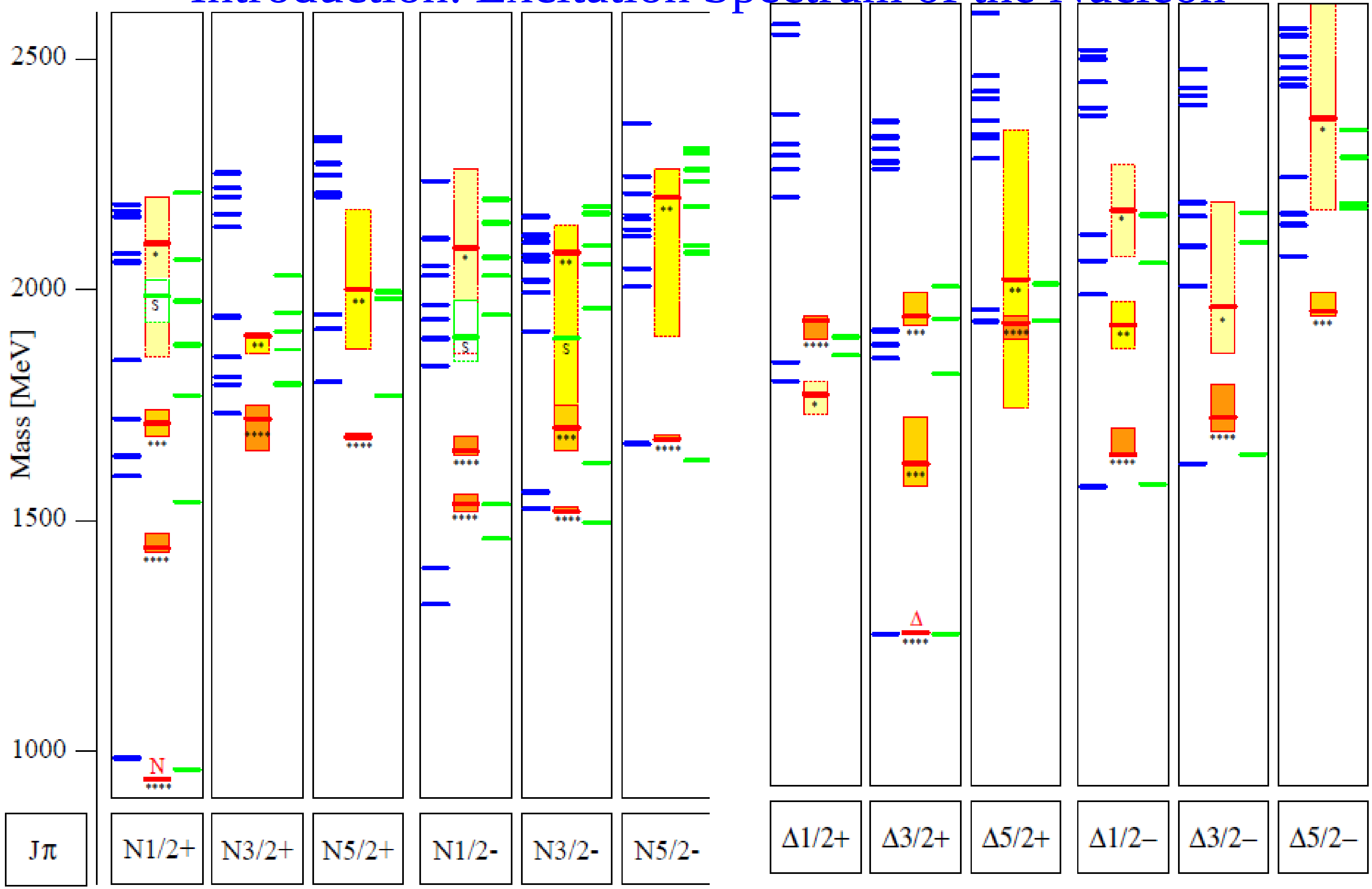
Mesons ($q\bar{q}$)



Introduction: Excitation Spectrum of the Nucleon

H He Hg

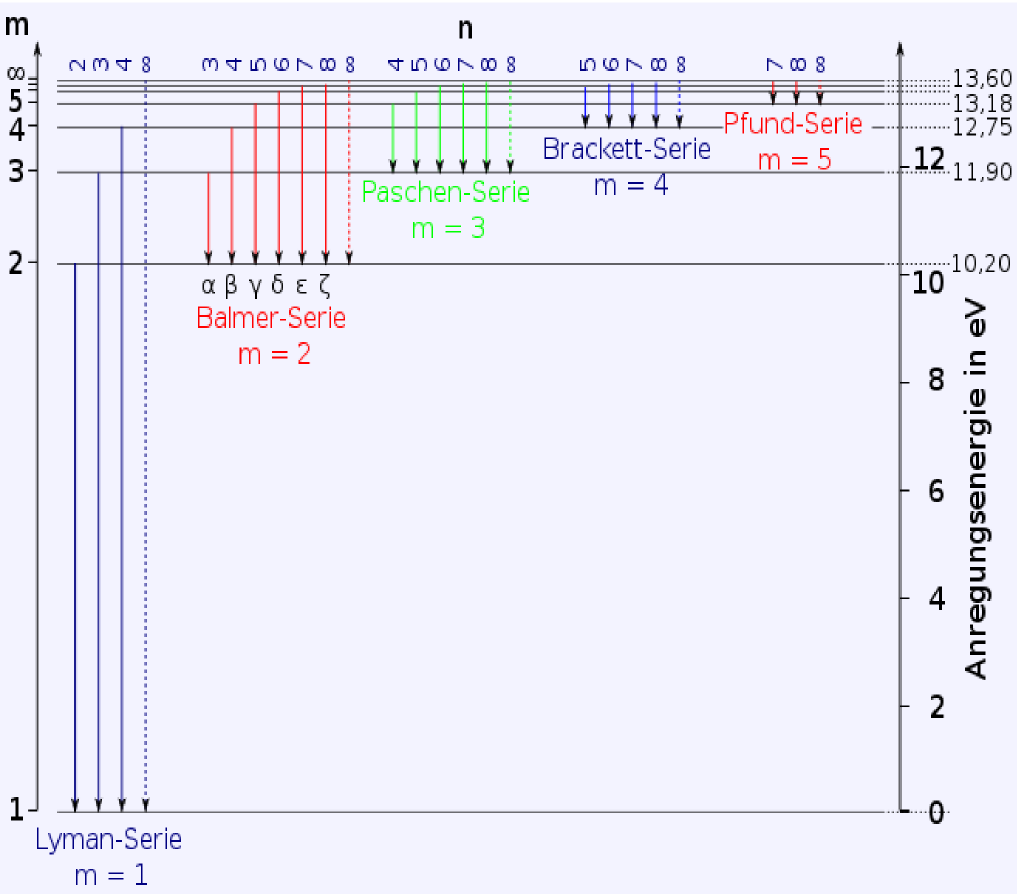
Atom

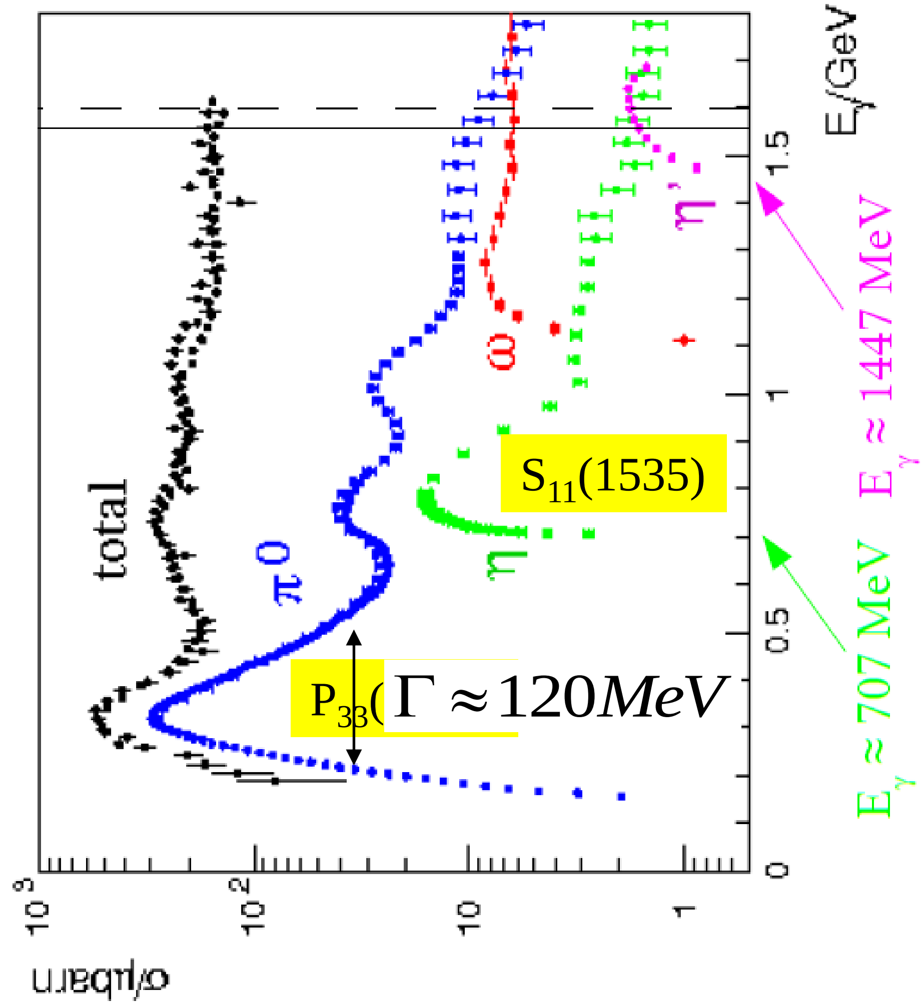


Nucleon

Löhrig, Metsch, Petry, Eur.Phys.J. A10 (2001) 395-446
The light baryon spectrum in a relativistic quark model

Hydrogen Atom E[eV] Nucleon E[GeV]





$\Gamma \sim 10^{-6}$ eV

$\tau \sim 10^{-8}$ s

$$\tau = \frac{\hbar}{\Gamma} \qquad \hbar = 6.582 \cdot 10^{-22} MeV \cdot s$$

Lifetime $\quad \tau \approx 10^{-24} s$

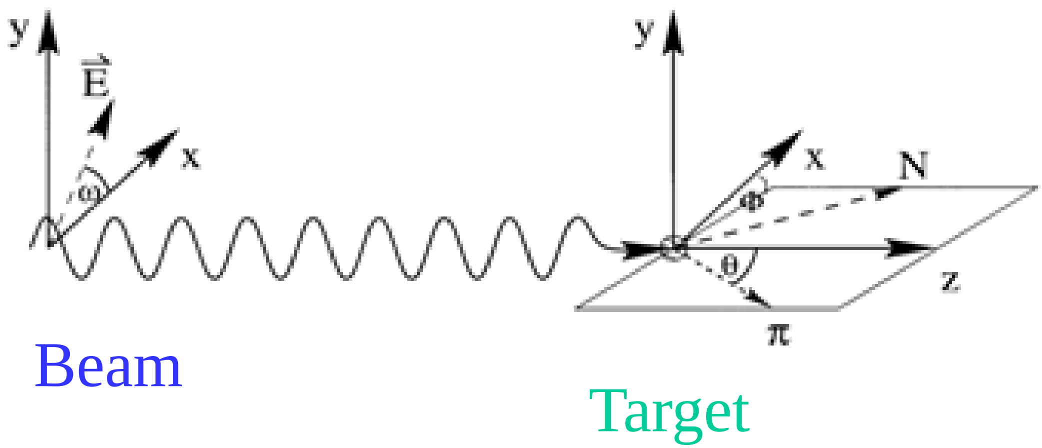
Polarisation Observables

→ Disentangle broad, overlapping resonances,
Measure meson threshold production, quark mass ratios,
Determine fundamental properties: Spin Polarisibiltities,
GDH sumrule.

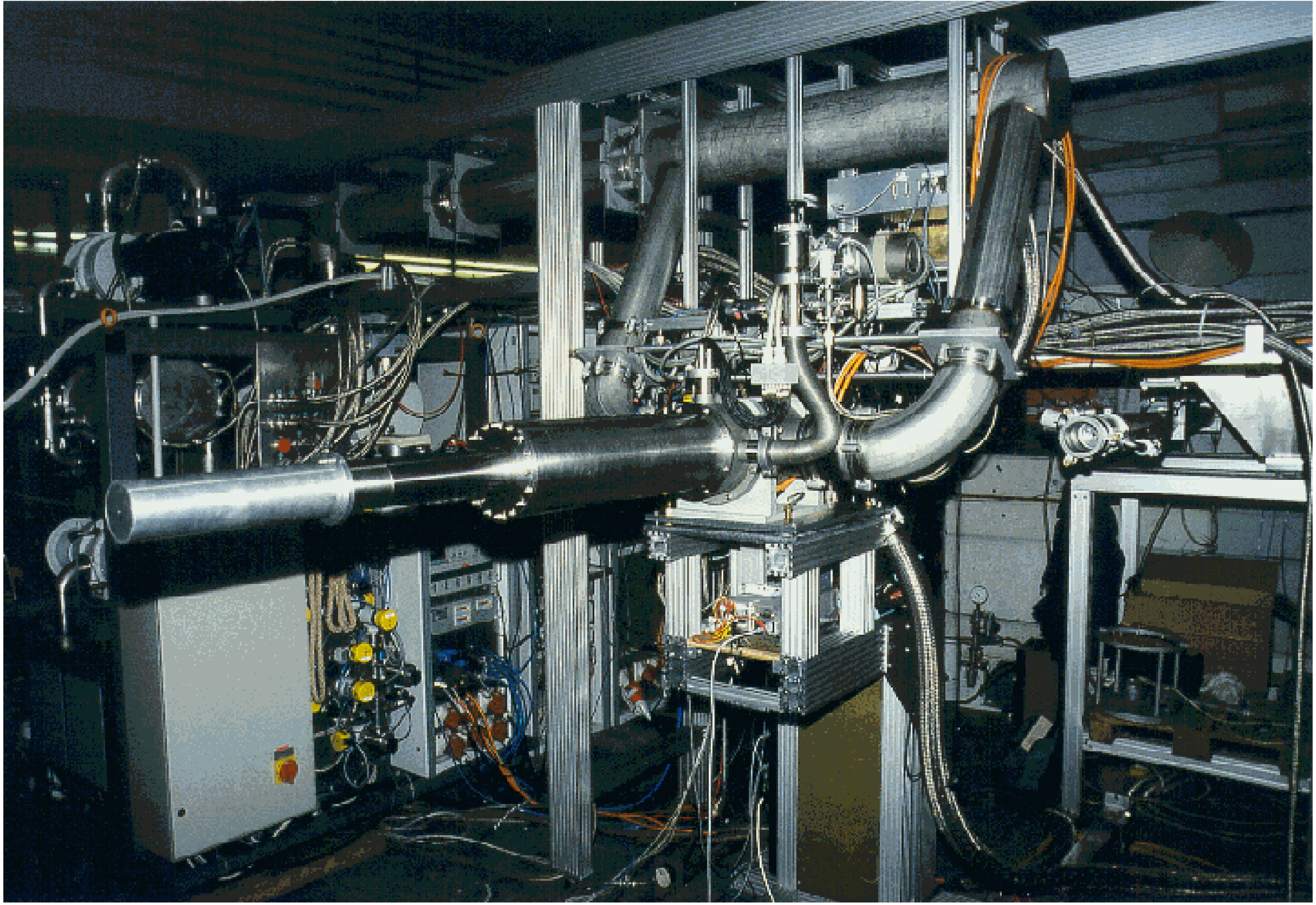
Observables in pseudoscalar meson prod.

(Barker, Donnachie & Storrow Nucl Phys B95 (1975))

$$\rho_f \frac{d\sigma}{d\Omega} = \frac{1}{2}\left(\frac{d\sigma}{d\Omega}\right)_{unpol}\{1 - P_\gamma^{lin}\Sigma\cos 2\phi + P_x\left(P_\gamma^{circ}F + P_\gamma^{lin}H\sin 2\phi\right) + P_y\left(T - P_\gamma^{lin}P\cos 2\phi\right) + P_z\left(P_\gamma^{circ}E + P_\gamma^{lin}G\sin 2\phi\right)$$



Beam / Target	γ_{unpol}	P_γ^{lin} $\left(0, \frac{\pi}{2}\right)$	P_γ^{lin} $\left(+\frac{\pi}{4}, -\frac{\pi}{4}\right)$	P_γ^{circ}
P_{unpol}	$\left(\frac{d\sigma}{d\Omega}\right)$	$\Sigma(\theta)$	-	-
P_x	-	-	$H(\theta)$	$F(\theta)$
P_y	$T(\theta)$	$P(\theta)$	-	-
P_z	-	-	$G(\theta)$	$E(\theta)$

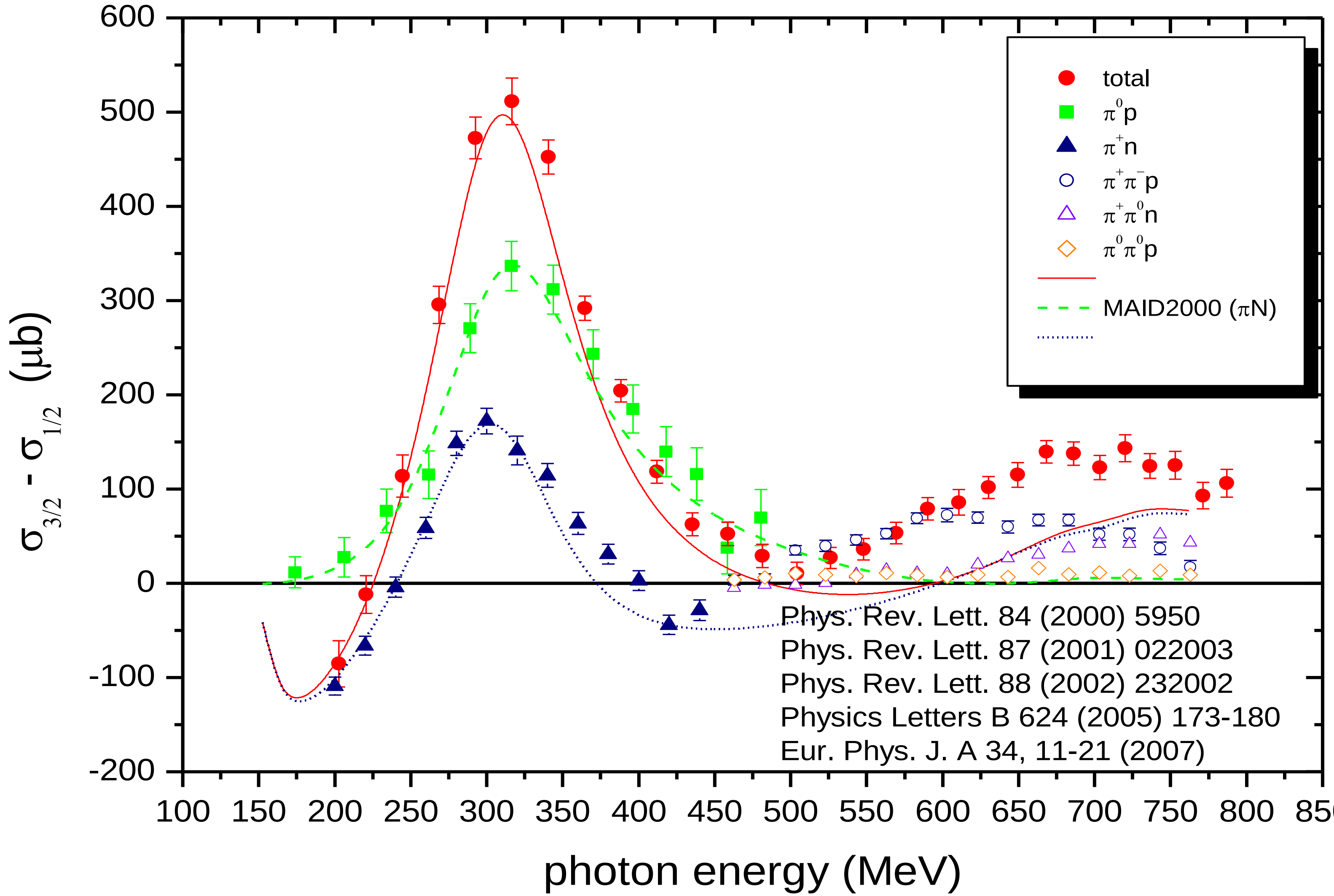


Bonn Frozen Spin Target at A2 / MAMI

[C.Bradtke et al., NIM **A436**, 430 (1999)]

First measurement of GDH sum rule.
Polarisation observable E with 4 π detector DAPHNE.
Prototype for CLAS/FROST and MPT.

Helicity Dependence E of Meson Photoproduction on the Proton and Neutron
GDH sum rule on Proton and Neutron



Published data: GDH-Experiment at ELSA and MAMI (DAPHNE).

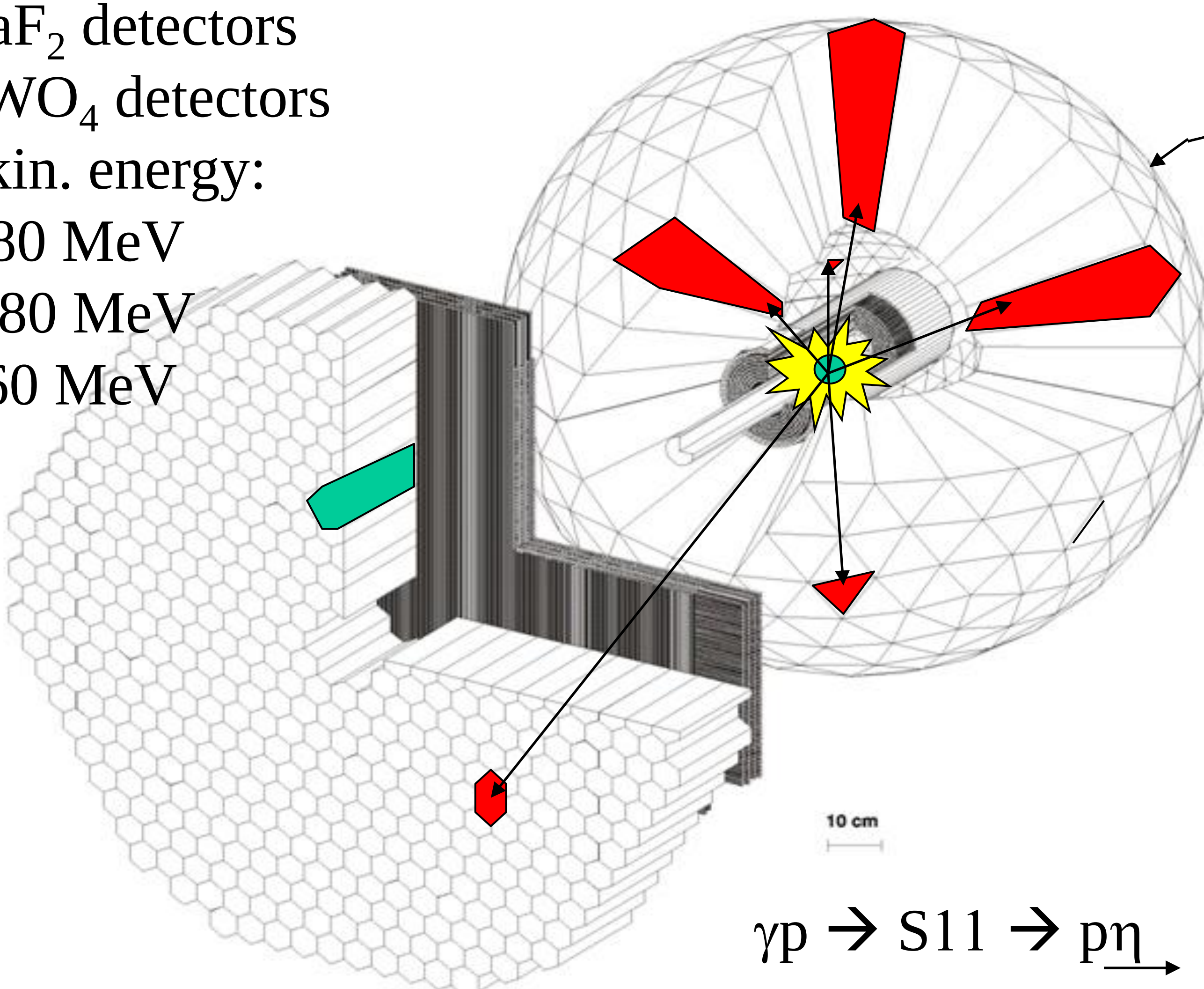
Preliminary results: 'Crystal Barrel ' and 'CLAS' for E > 500 MeV.

'LEGS experiment at BNL Brookhaven' in the $P_{33}(1232)$ region.

4π photon Spectrometer @ MAMI

TAPS:

366 BaF_2 detectors
72 $PbWO_4$ detectors
Max. kin. energy:
π^{+-} : 180 MeV
K^{+-} : 280 MeV
P : 360 MeV



Crystal Ball:

672 NaJ detectors
Max. kin. energy:
μ^{+-} : 233MeV
π^{+-} : 240 MeV
K^{+-} : 341 MeV
P : 425 MeV

Vertex detector:

2 Cylindr. MWPCs
480 wires, 320stripes

PID detector:

24 thin plastic detectors

$\gamma p \rightarrow S11 \rightarrow p\eta \rightarrow \pi^0\pi^0\pi^0 \rightarrow \gamma\gamma\gamma\gamma\gamma\gamma$

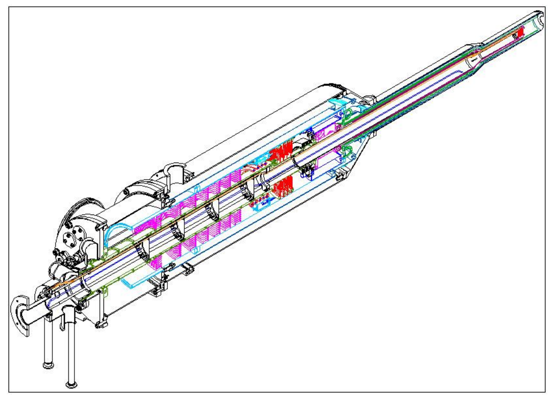
Components of the polarized target for the Crystal Ball detector

He^3/He^4 Roots
$4000 m^3/h$
Vacuum system

Targetmaterial

H-Butanol
D-Butanol

Mikrowaves
70GHz
Dynamic
Nuclear
Polarization



NMR-Apparatus

106MHz

Polarisation meas.

Horizontal He^3/He^4
Dilutionrefrigerator
(30mKelvin)
with internal
Holding coil

Superconducting
Polarization magnet
5Tesla

Polarized Target for Crystal Ball

Tagged CW photon beam $5\cdot10^{7}\ \frac{\gamma}{\sec}$ ➡ **4π- detector**

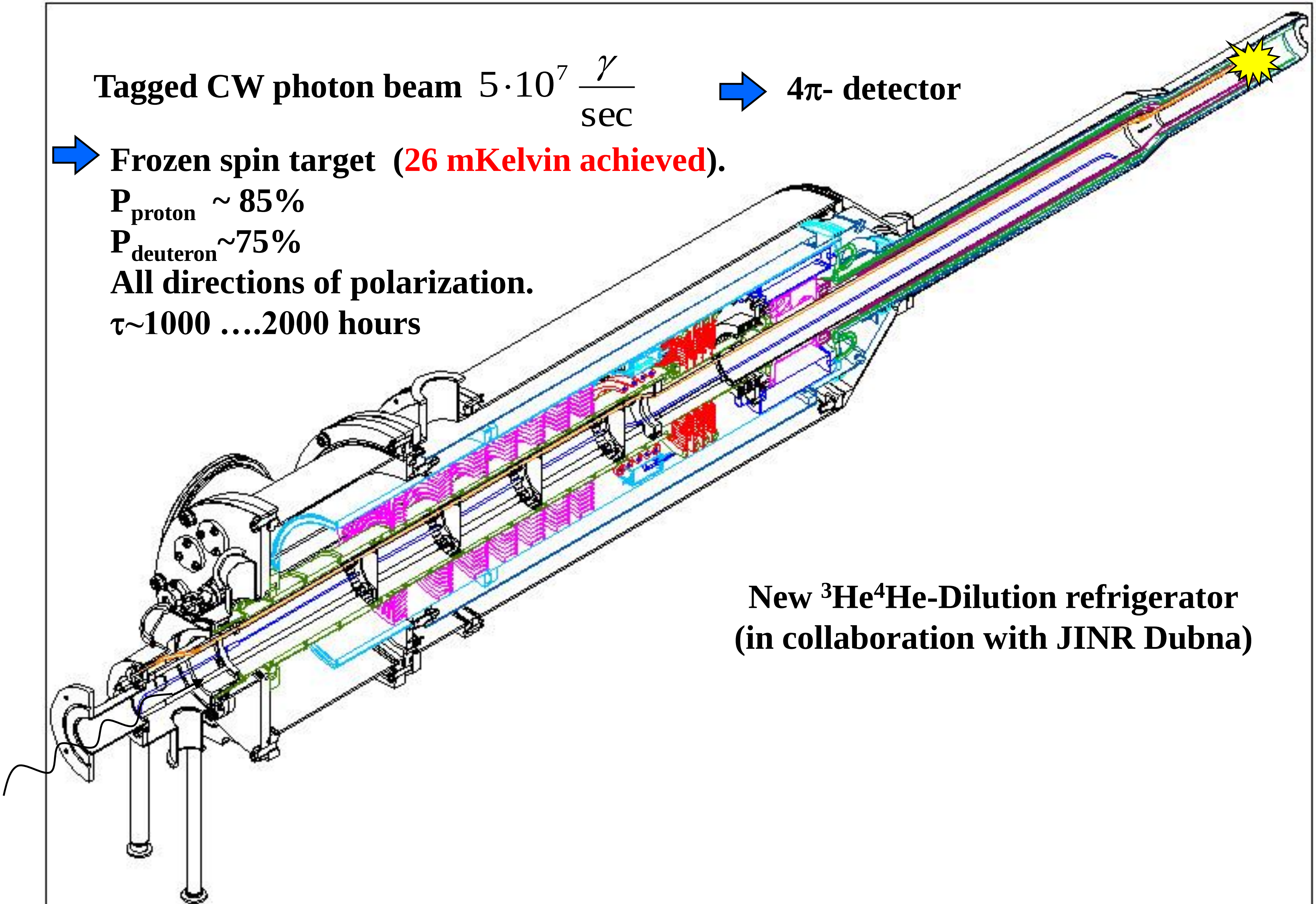
➡ **Frozen spin target (26 mKelvin achieved).**

P_{proton} ~ 85%

$P_{deuteron}$~75%

All directions of polarization.

τ~1000 ….2000 hours



New $^{3}He^{4}He$-Dilution refrigerator
(in collaboration with JINR Dubna)

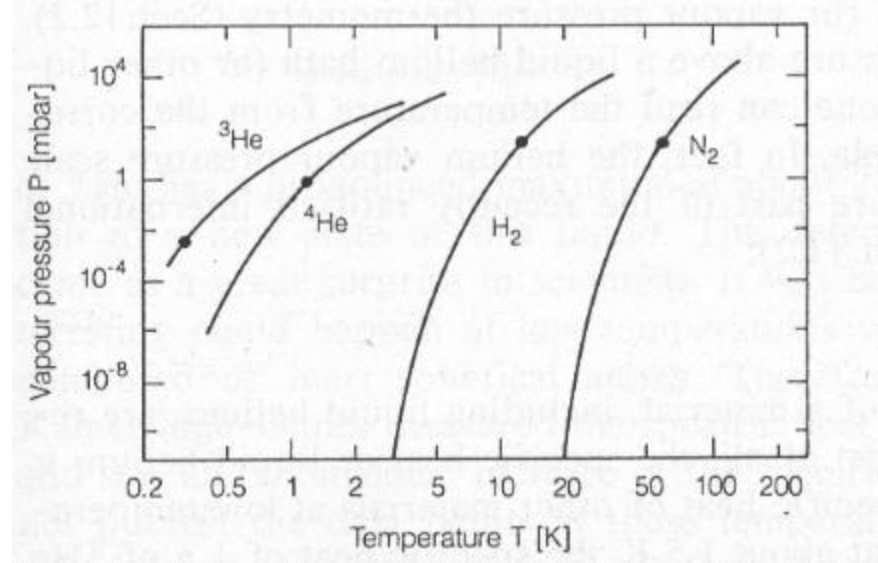
Cryogenics

2 Precooling stages:

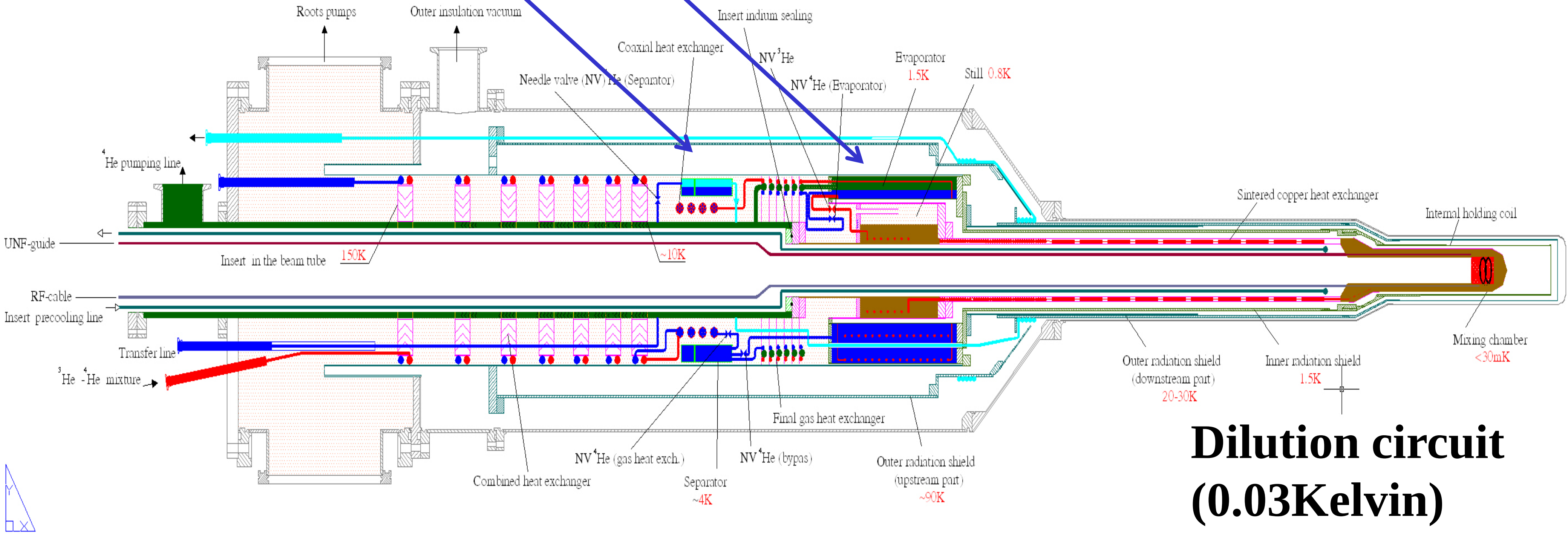
Evaporator (1.5Kelvin)

Separator (4.2Kelvin pot)

Evaporation cooling



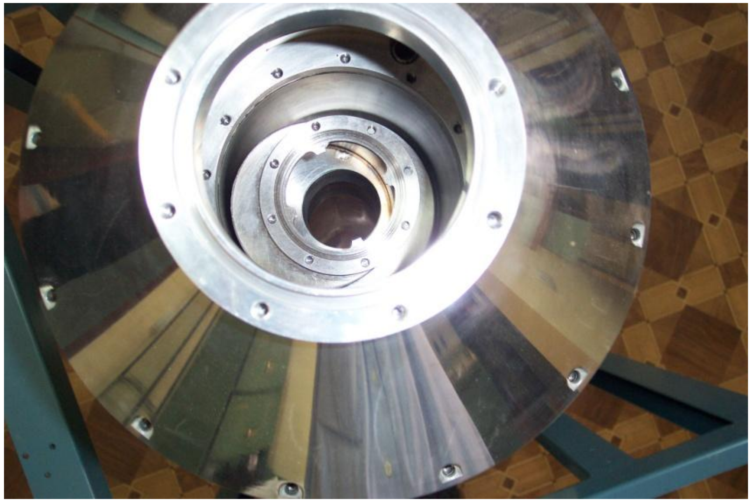
^{3}He^{4}He-Dilution refrigerator



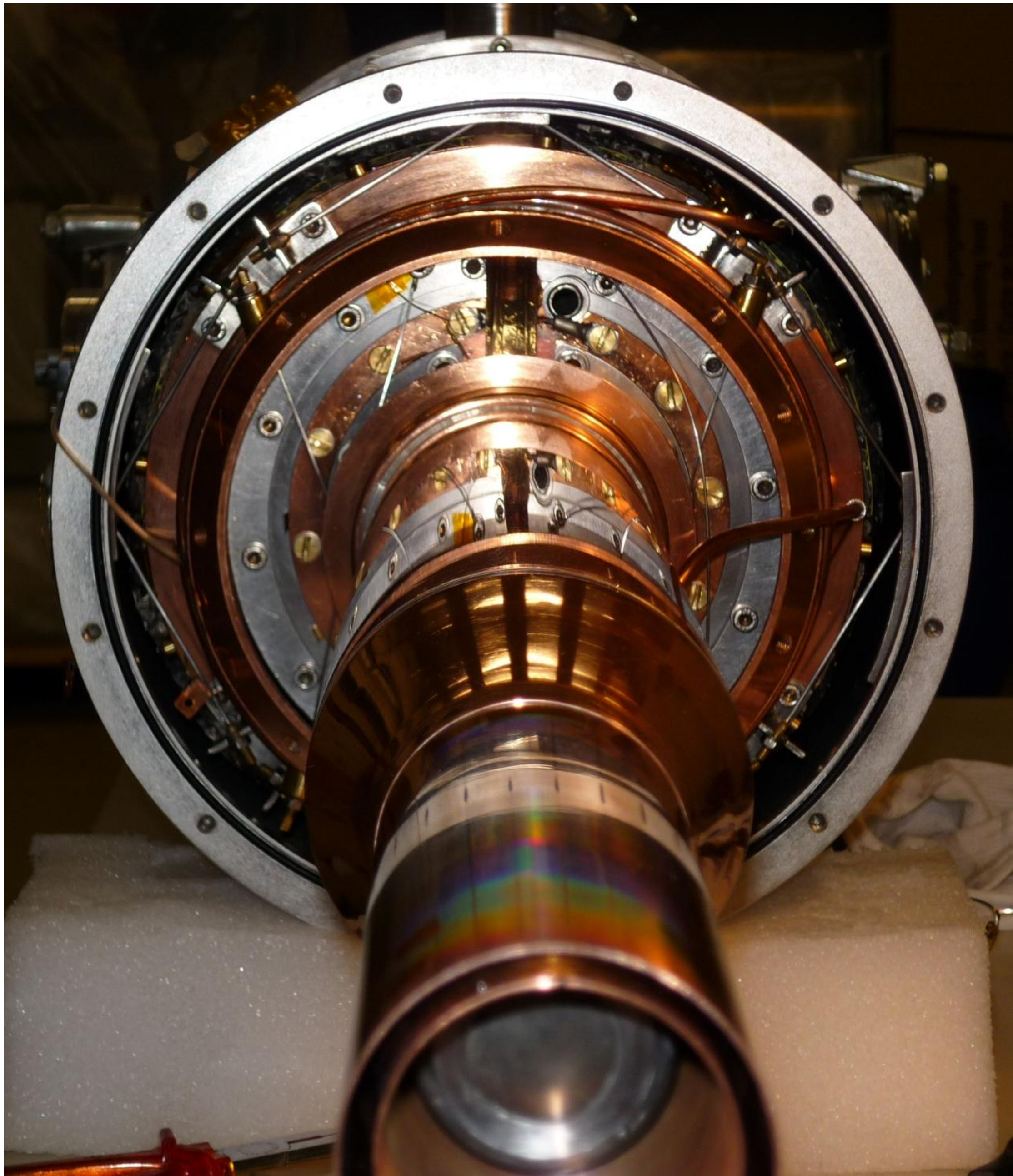
Dilution circuit (0.03Kelvin)

Impressions from the technical realisation

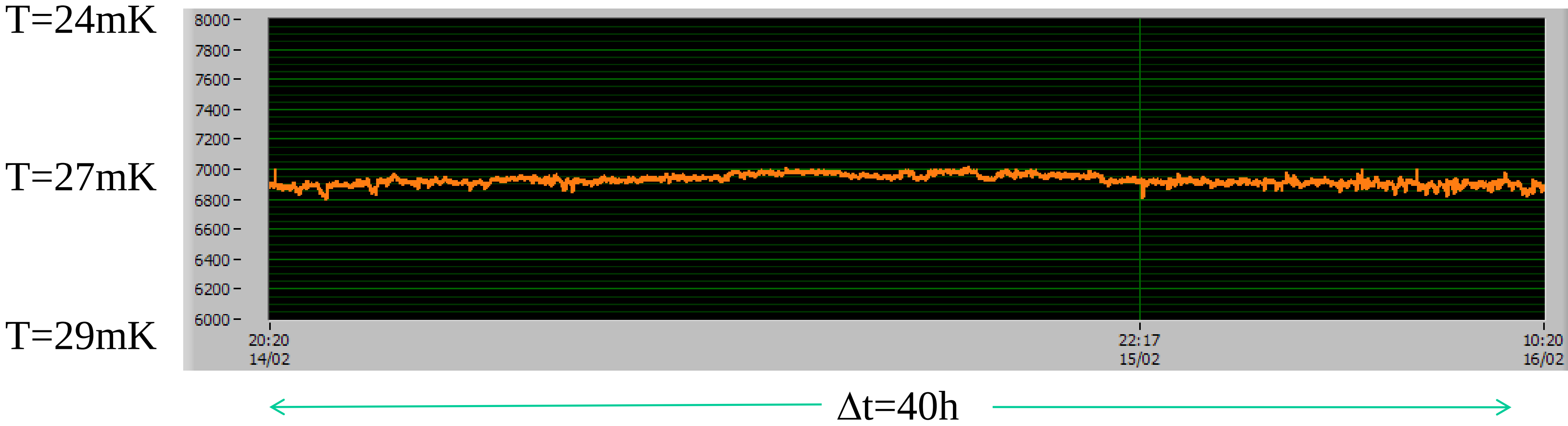
Alignment still and evaporator



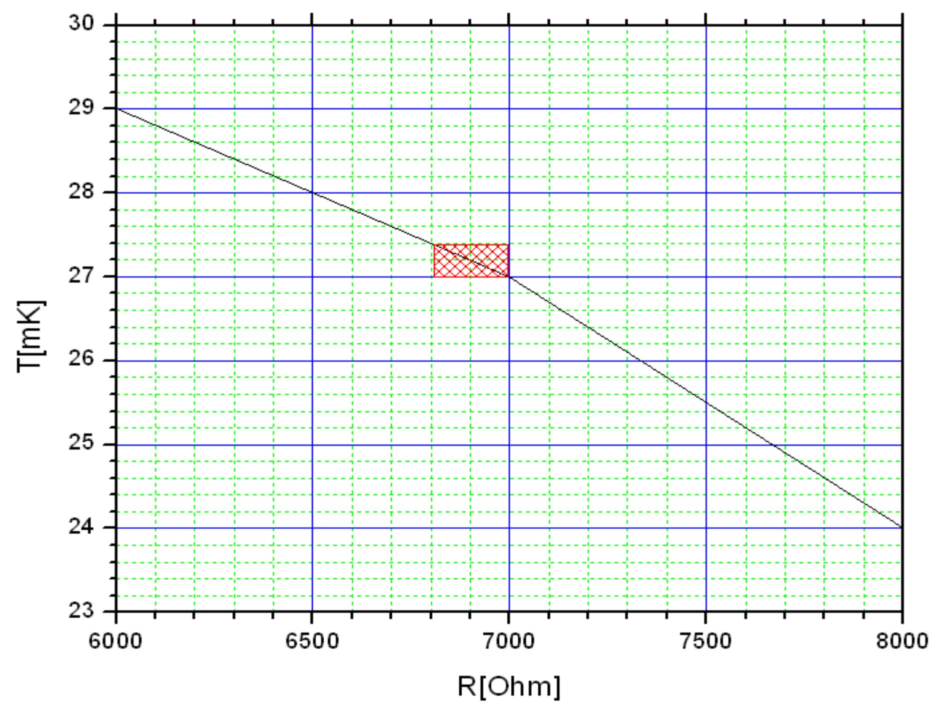
Alignment thermal radiation shields



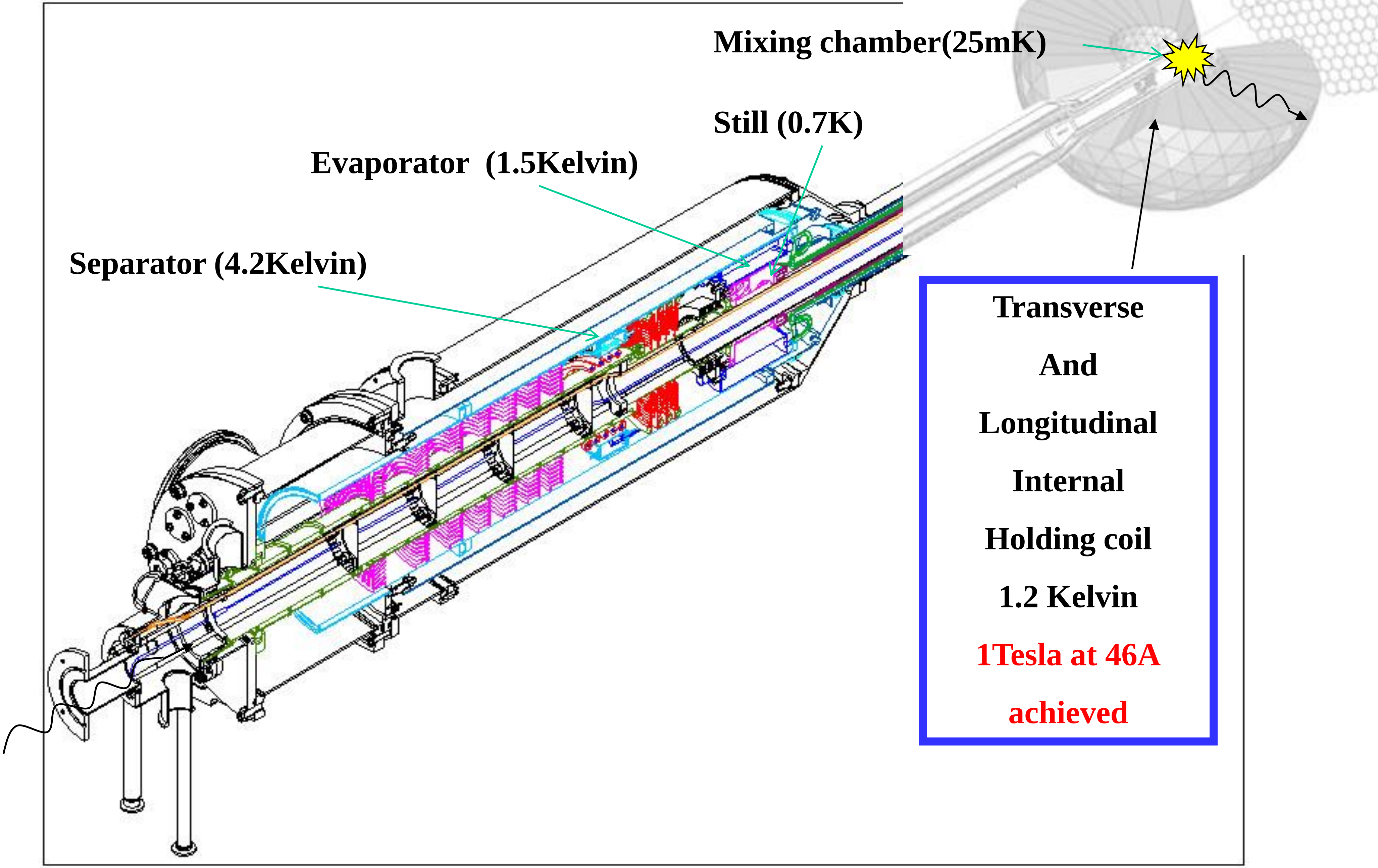
Cryostat Performance



Temperature stability:
ΔT ~ +- 0.2mKelvin (one day)
(typical one week measurement period).



Magnet Technology



Holding Coil

Coil has to be as thin as possible to allow low energetic particles to punch through.

➡

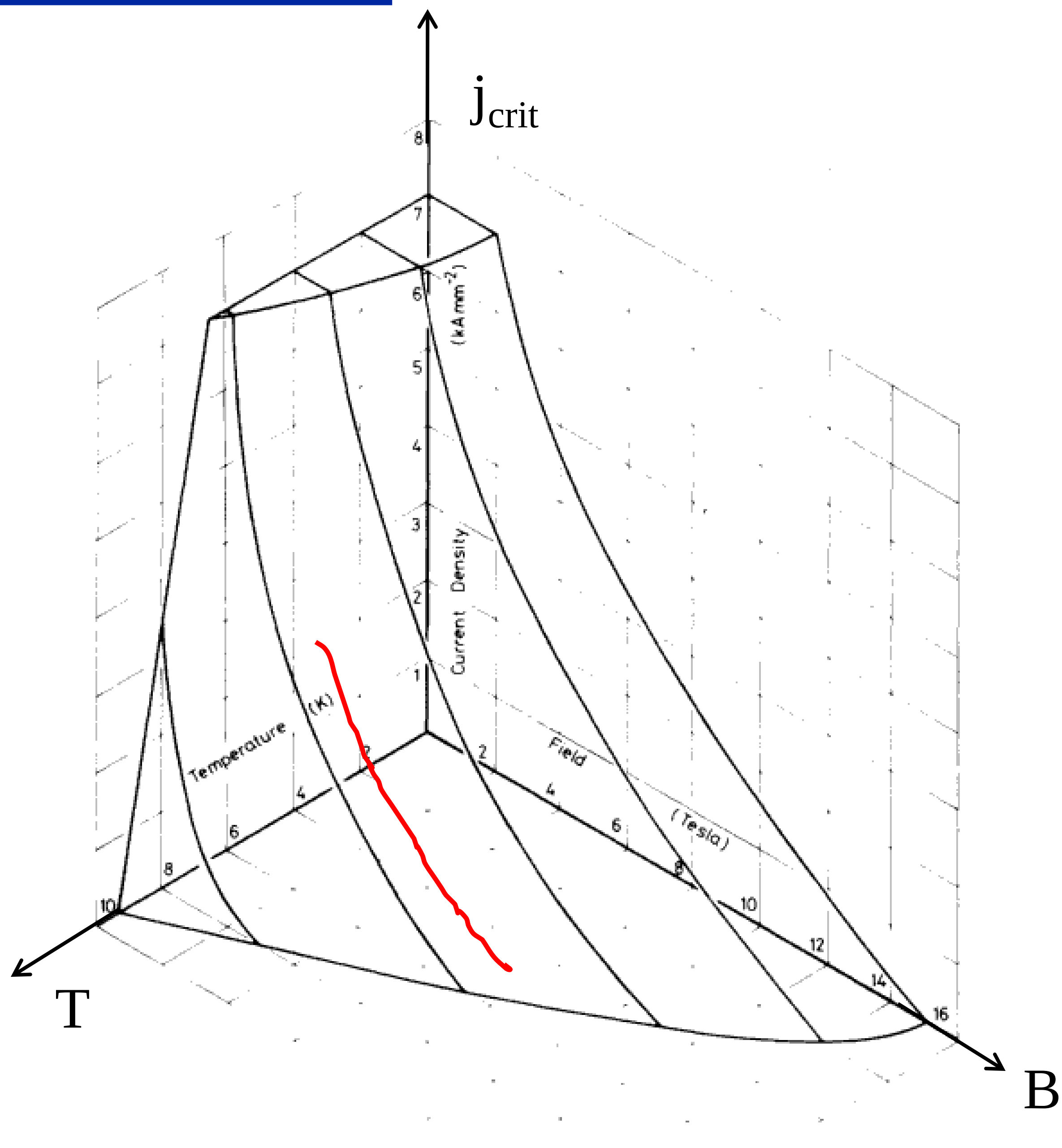
Subcooled Superconductor

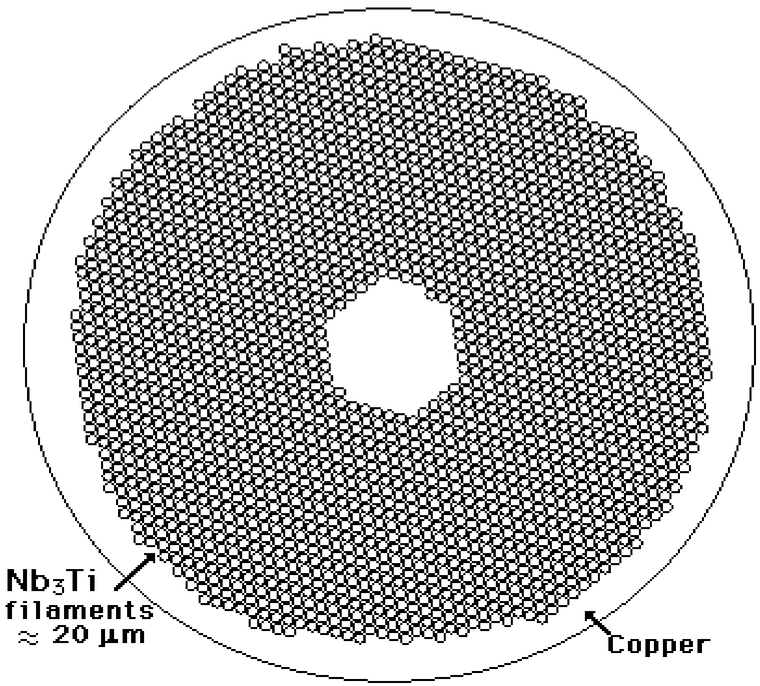
F54-1.35(0.20)TV

	1 T	2 T	3 T	4 T
I_c (A)	51.8	39.1	33.5	29.5

@4.2Kelvin

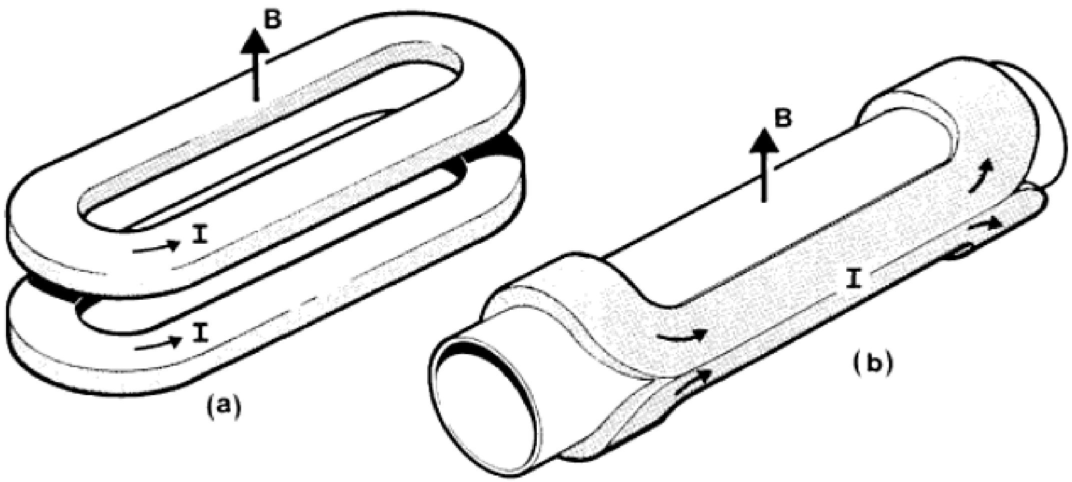
➡ @1.3Kelvin

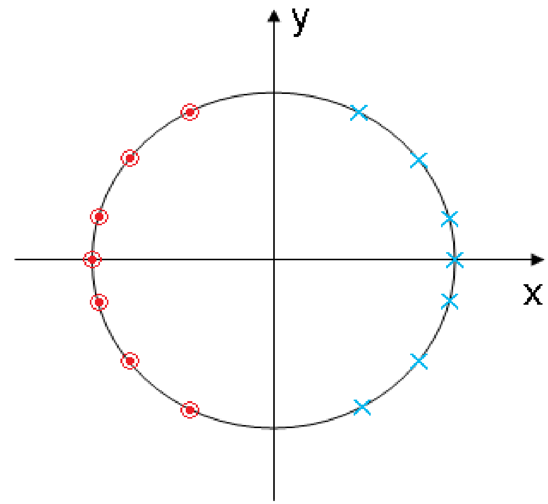




- Copper/scandium wire with 54 Nb-Ti filaments embedded in it.
- Cu:Sc=1.35:1
- Alloy composition: Nb47wt.%Ti
- Diameter=0.222mm
- It achieves currents up to 50A at 4.2K and 1T.

Simulation and Optimisation Transverse Field





Ideal case for dipole magnet:

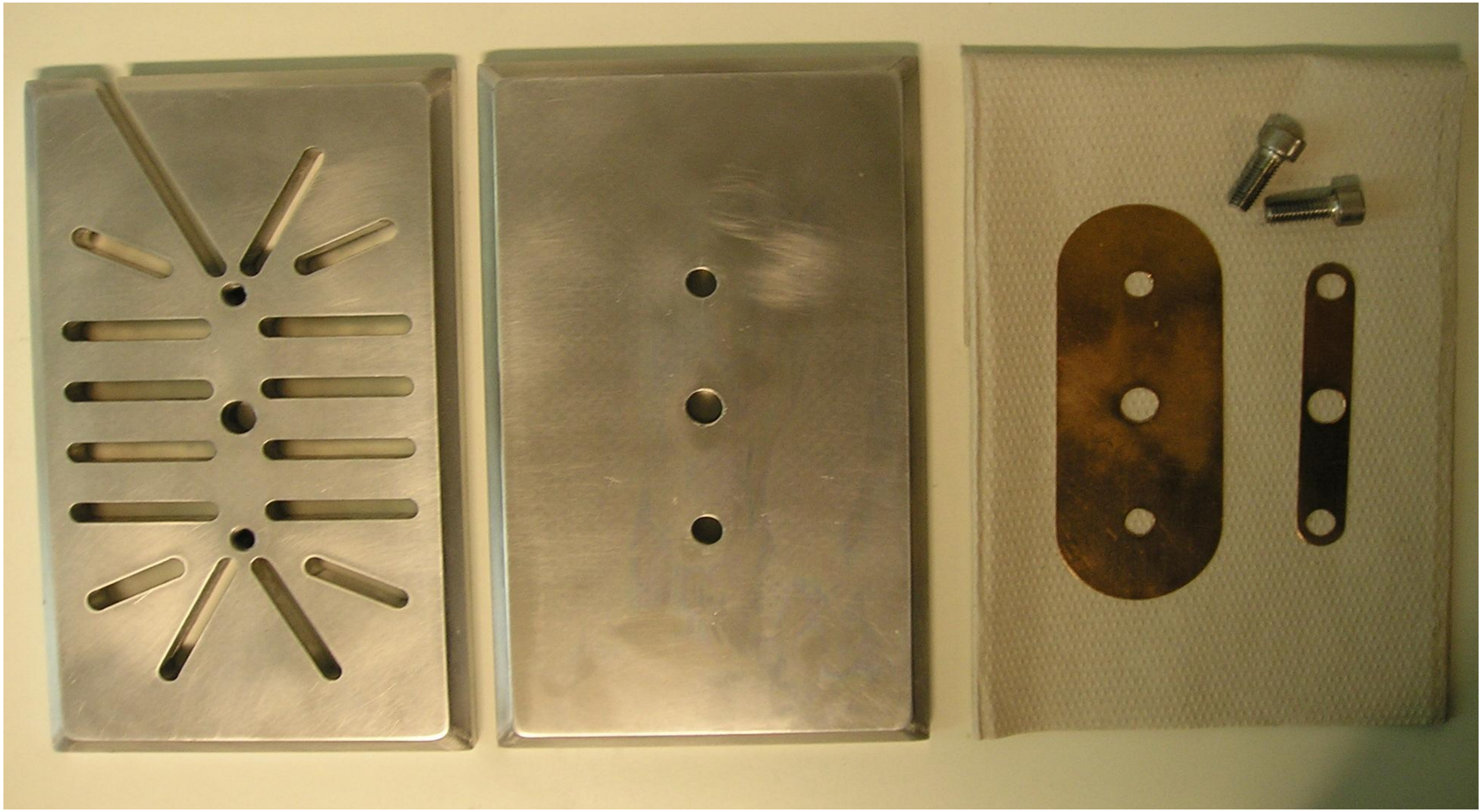
$$J(\Phi) \propto \cos\Phi$$

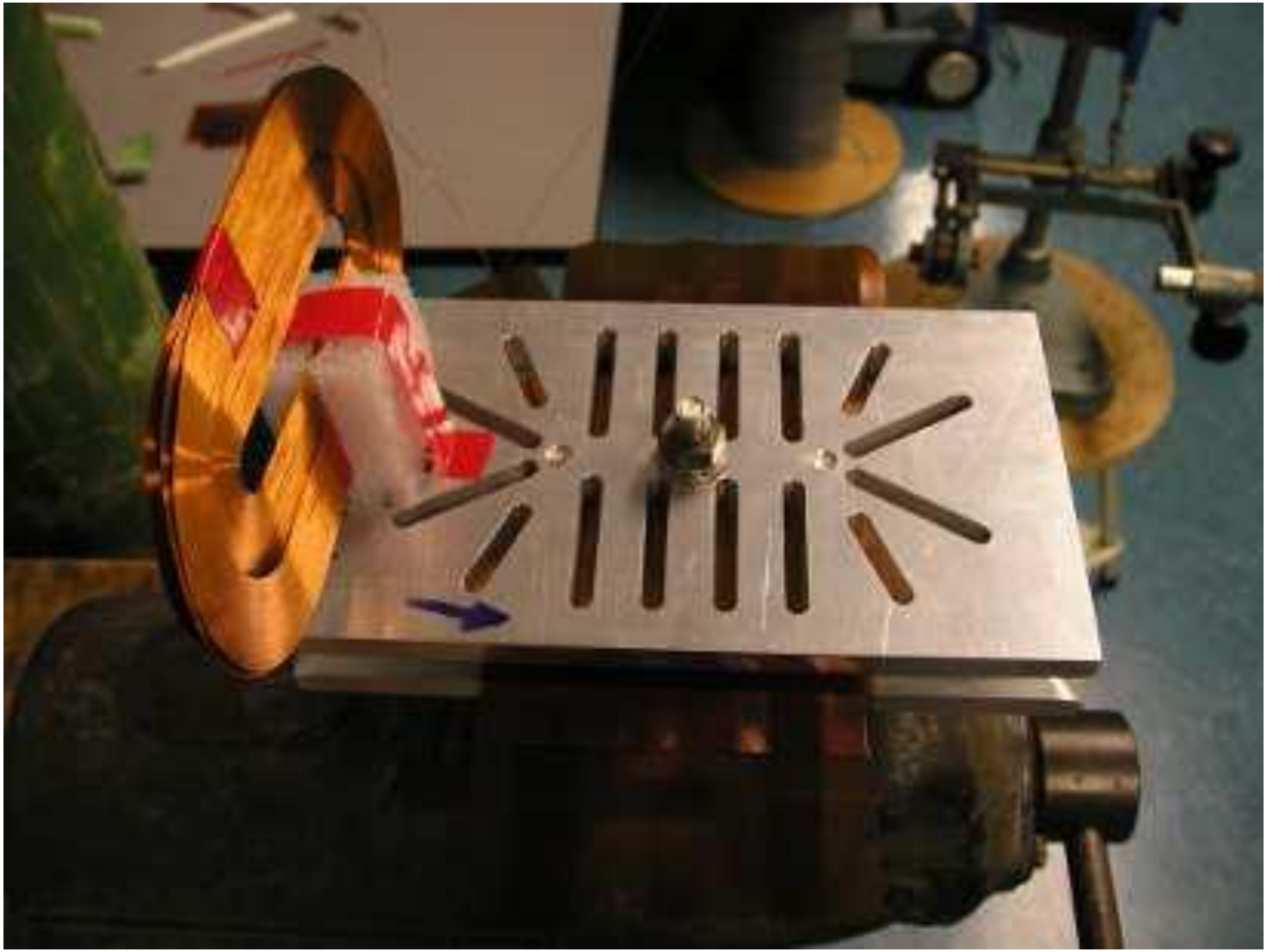
4-layer dipole:

$N_1 = N_2 = 138$

$N_3 = N_4 = 78$

Production





4-layer dipole:

$N_1=N_2=138$

$N_3=N_4=78$

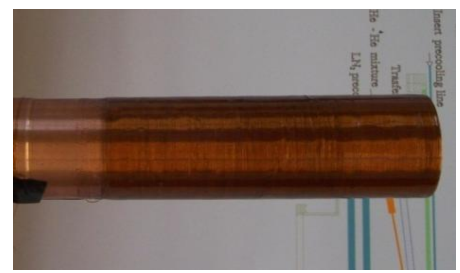
150mm

DNP at 200mK and 2.5T with 70GHz microwaves.
Frozen spin target (25mKelvin, 0.6T).
Secondary particles punch through holding coil.
All directions of polarization.

Transverse (Saddle coil)

and

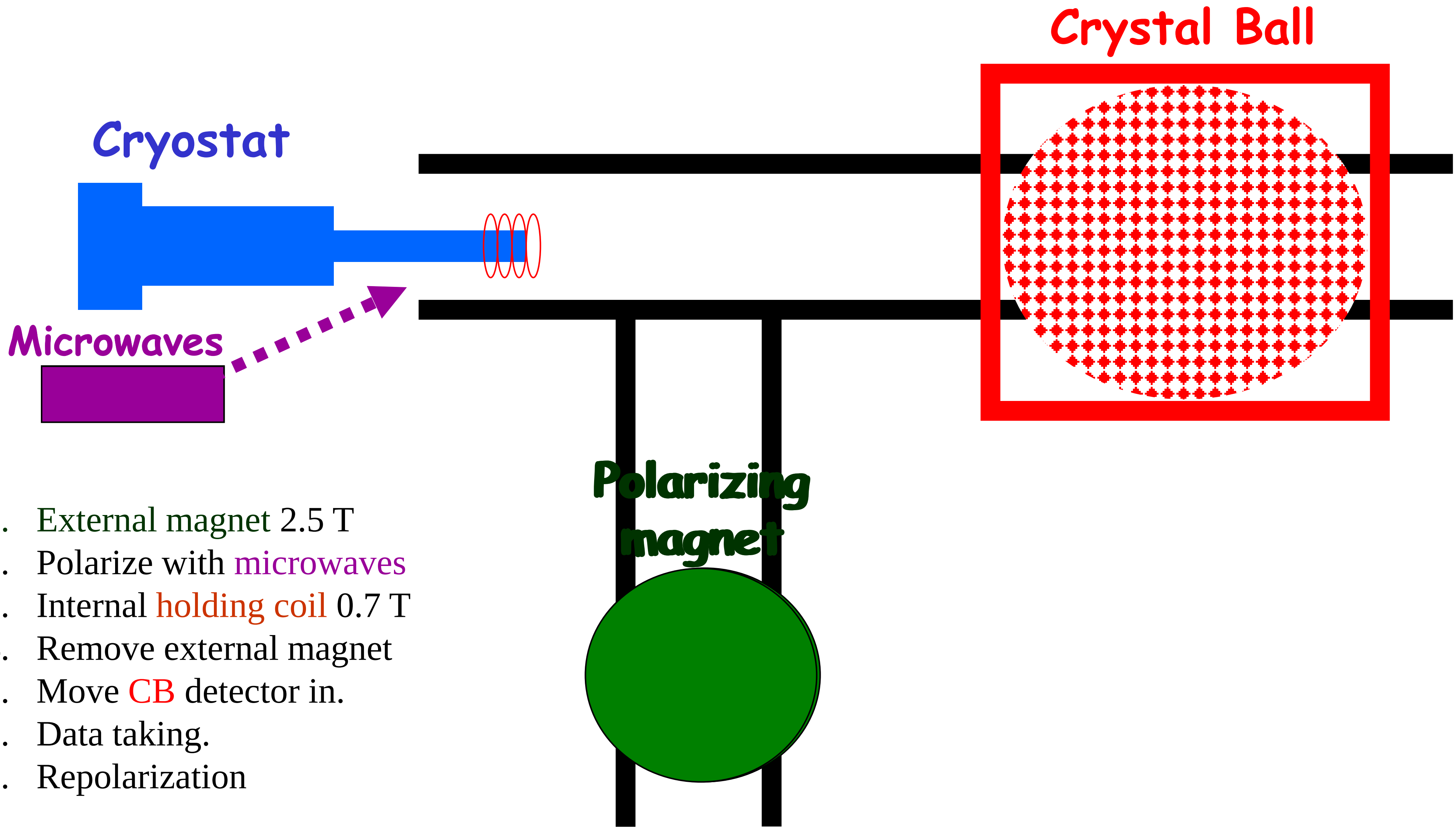
Longitudinal (Solenoid)



Internal

Holding Field (1.2K, 0.6T)

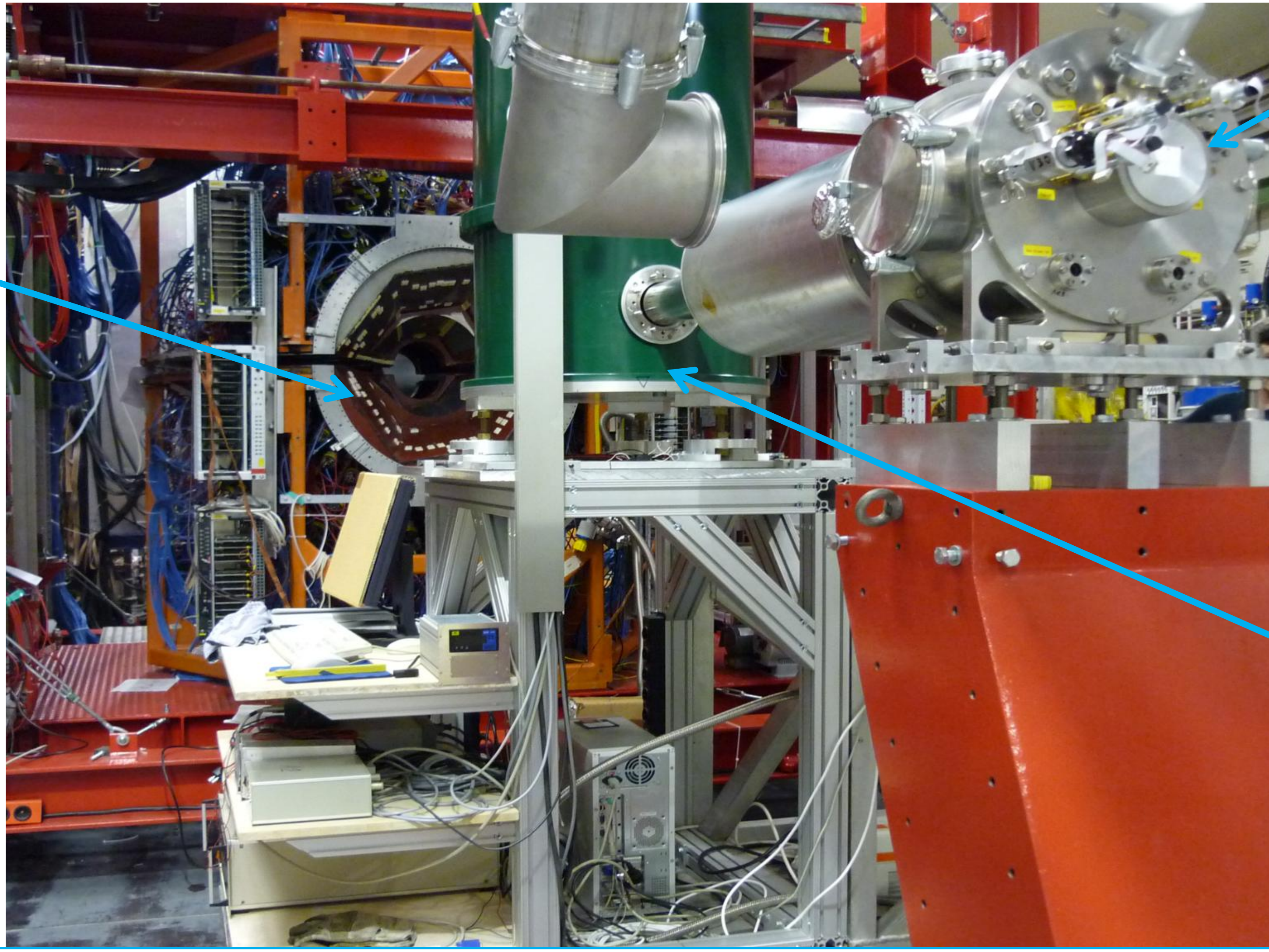
Frozen Spin Target Waltz



1. External magnet 2.5 T
2. Polarize with microwaves
3. Internal holding coil 0.7 T
4. Remove external magnet
5. Move CB detector in.
6. Data taking.
7. Repolarization

Setup in the A2 - Taggerhall

Movable Crystal Ball 4π-Photon Detector



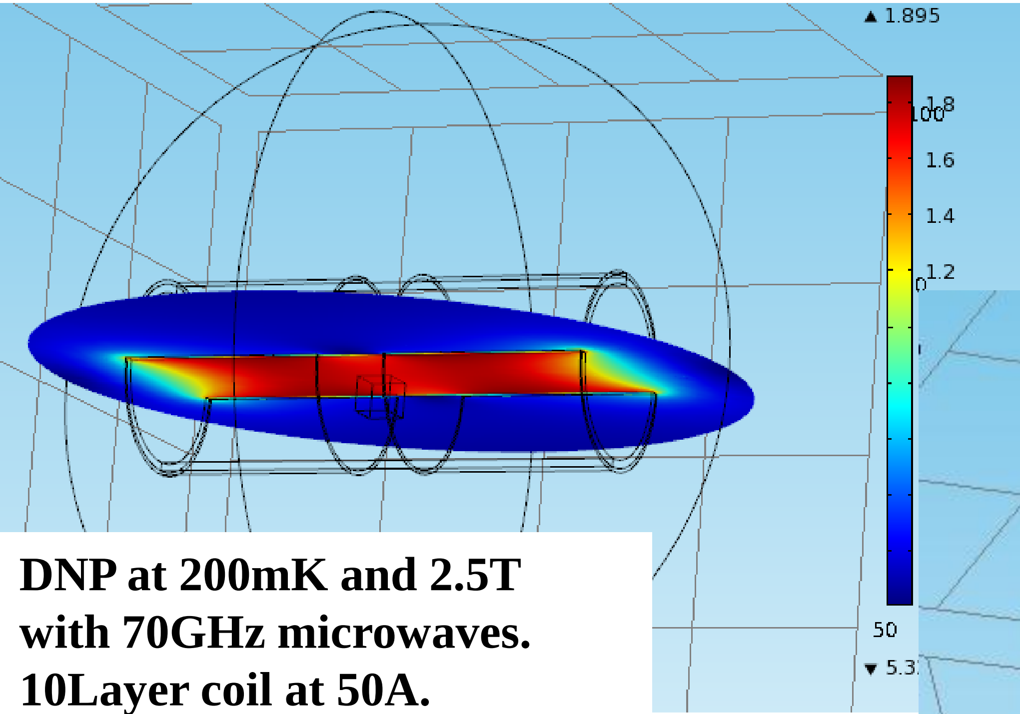
Cryostat

Movable 5Tesla Polarising Magnet

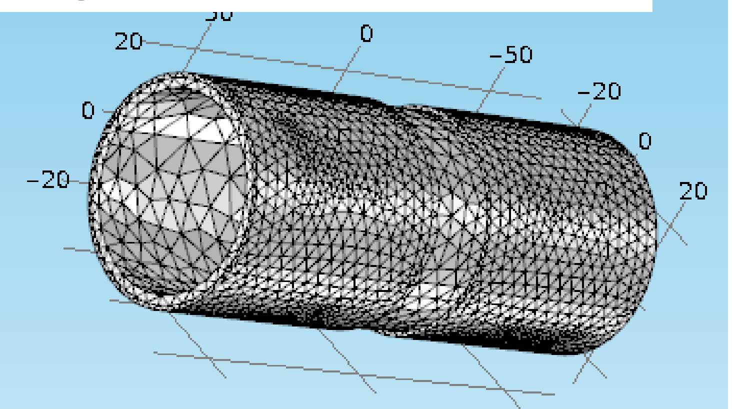
First Beam with Transverse Polarisation started 15th December 2009.
In 2010/11 we had more than 5000 hours beam on this target. Longitudinal Target since July 2013.

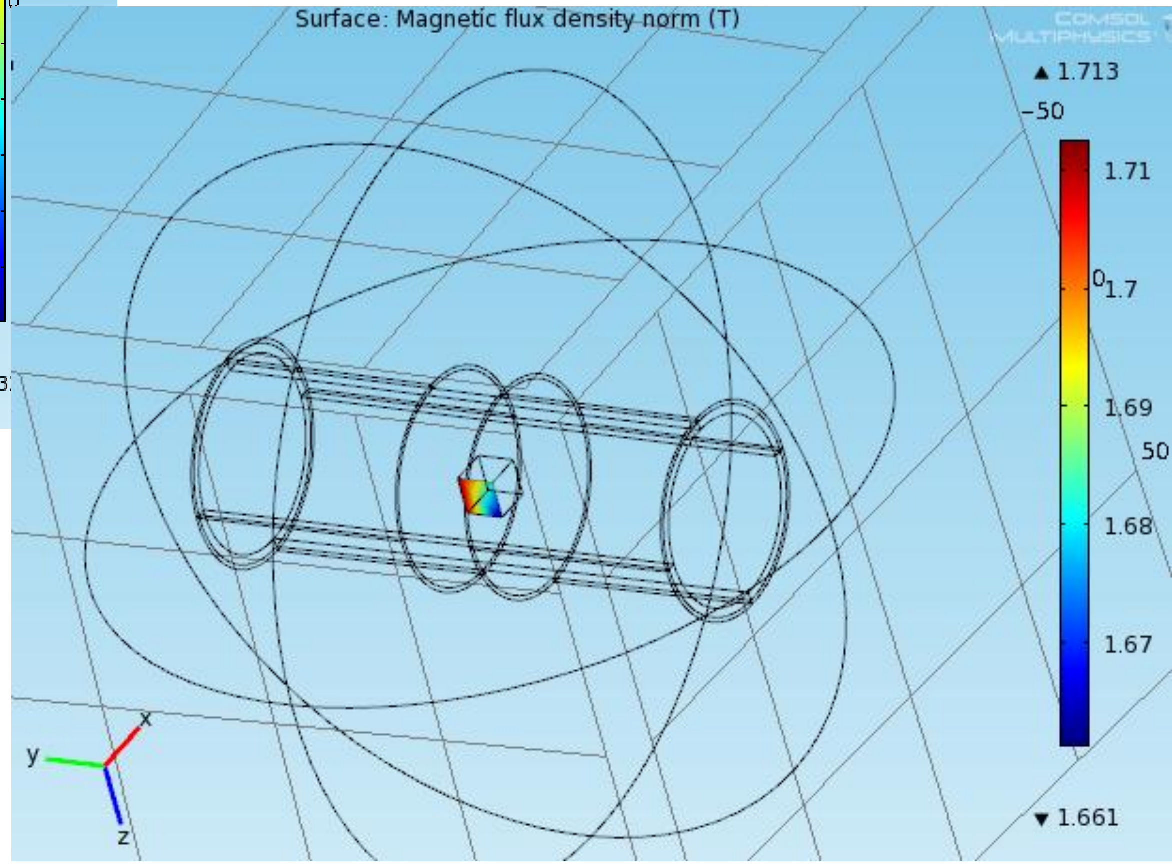
Perspectives: Internal Polarising Coil

Problem is the required field homogeniety of 10-E4. Notched solenoid.
3d finite element calculation, optimisation and precise production needed.

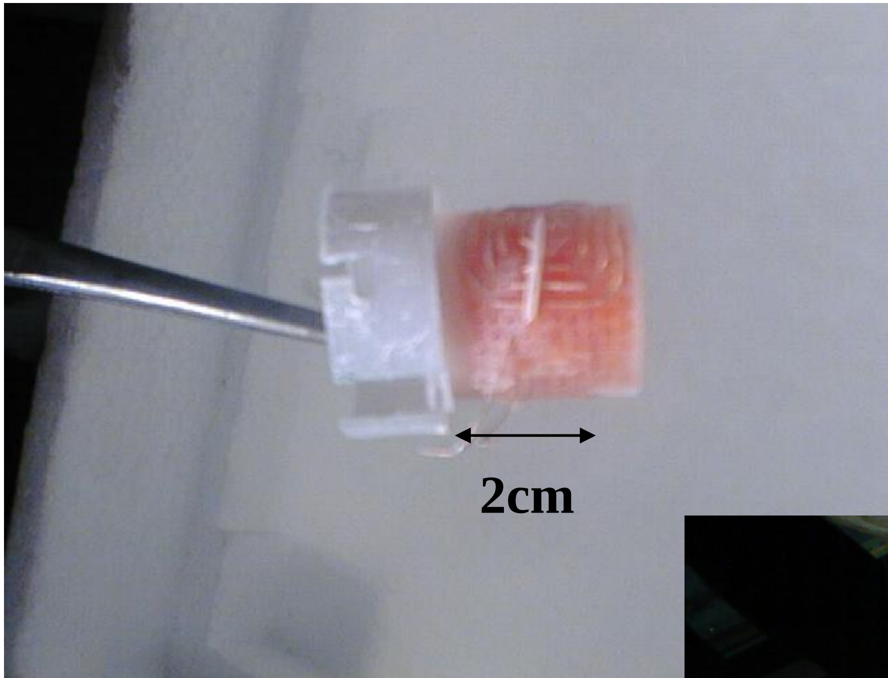


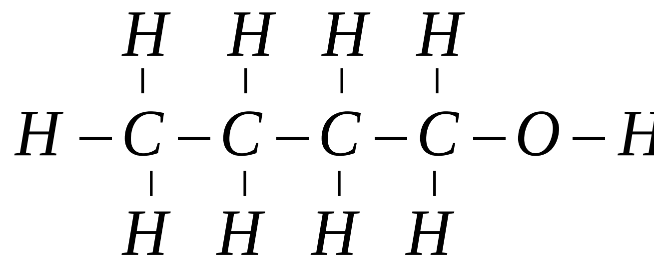
DNP at 200mK and 2.5T with 70GHz microwaves.
10Layer coil at 50A.
Secondary particles punch through holding coil.
Higher momentum threshold.





Target Material Technology

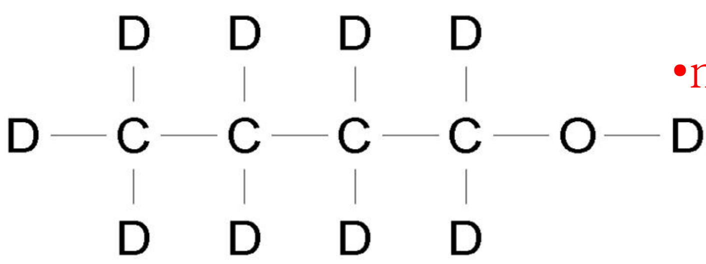




Butanol

X-ray picture with
Beamspot and
NMR coil

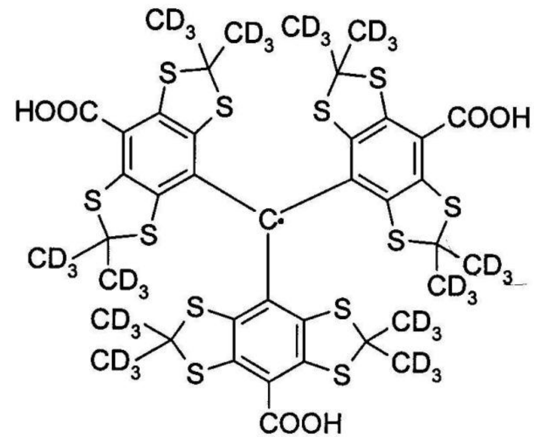
Target material D-Butanol

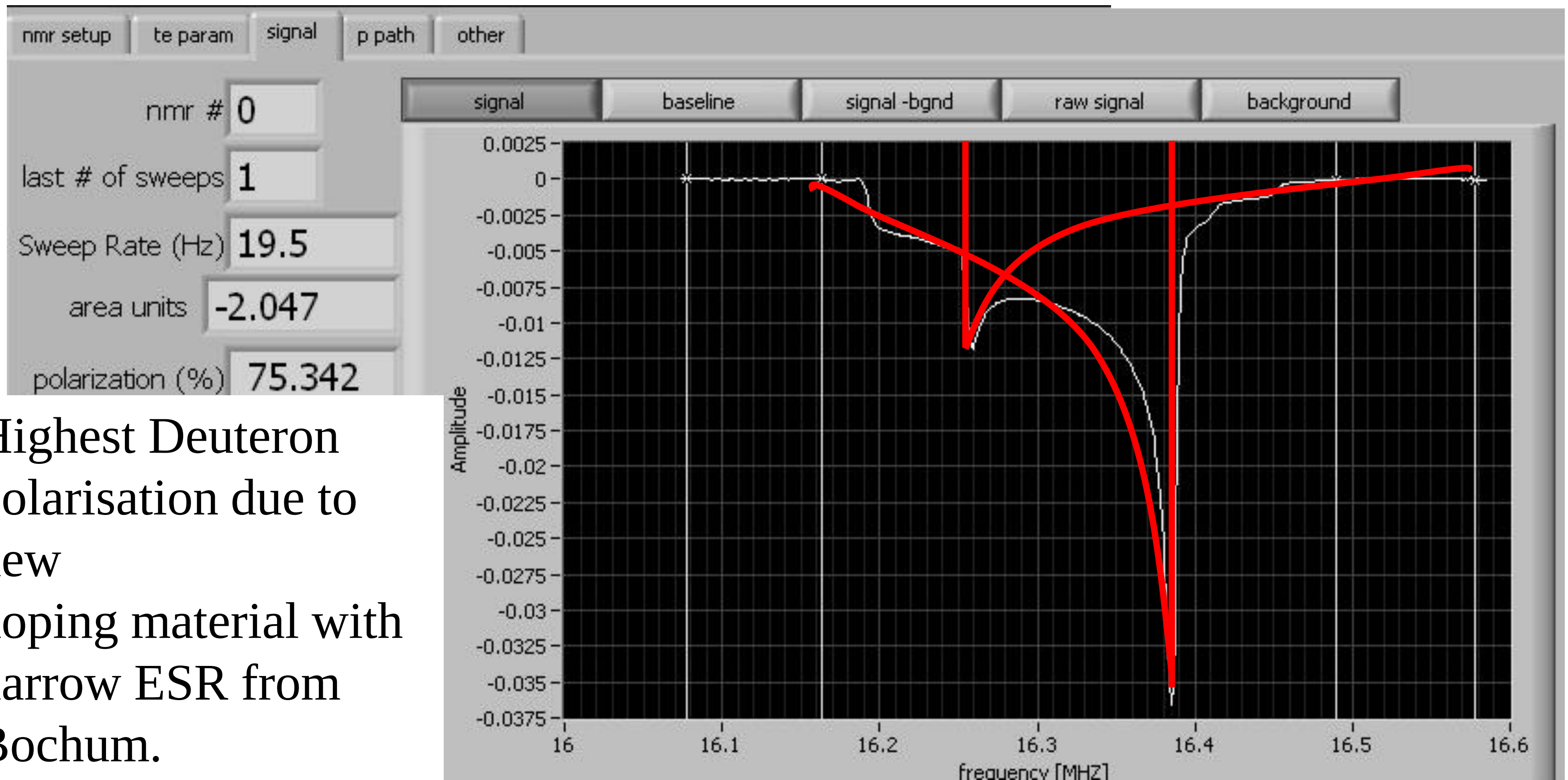


Density and species of the radical are very important for:

- maximum degree of polarization
- polarization build up times
- relaxation times

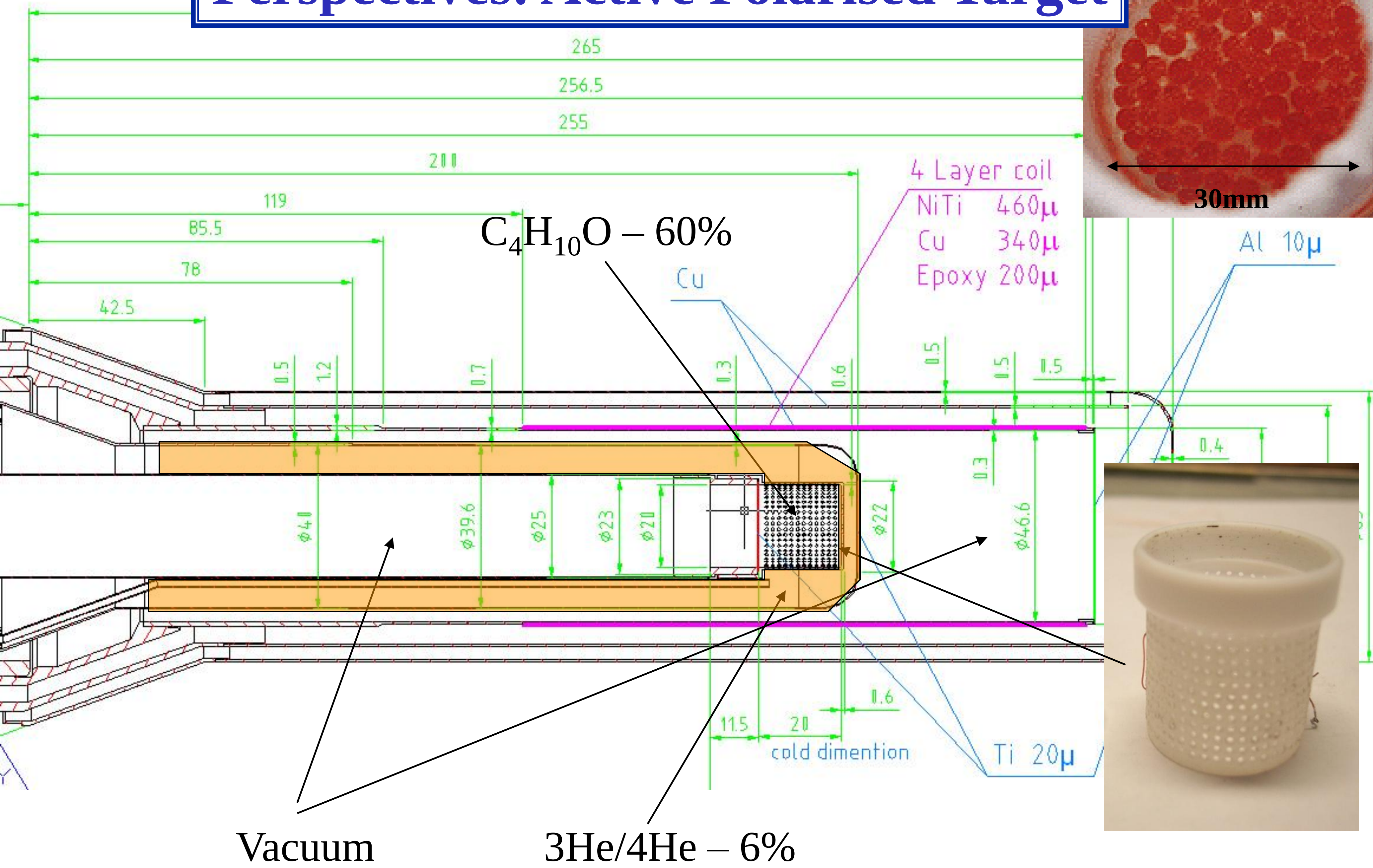
Trityl-Radikal





Highest Deuteron polarisation due to new doping material with narrow ESR from Bochum.

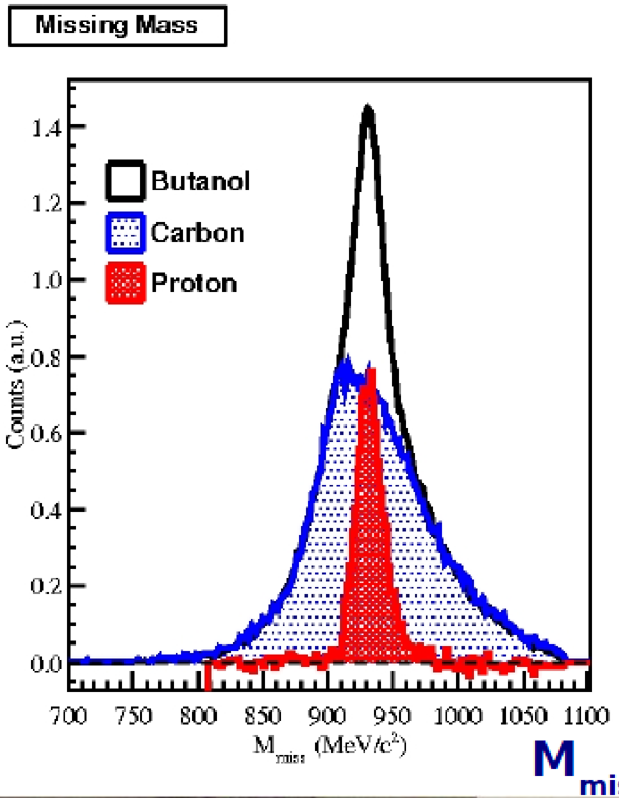
Perspectives: Active Polarised Target

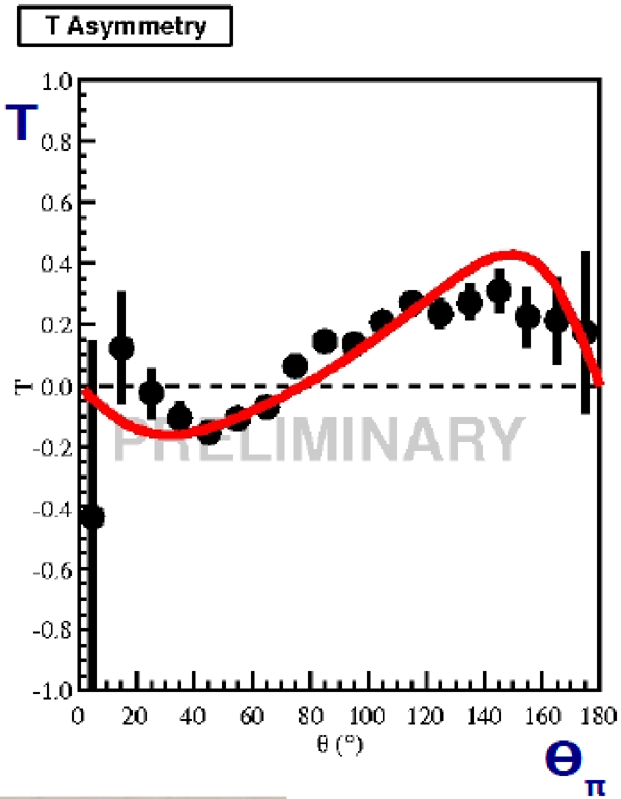


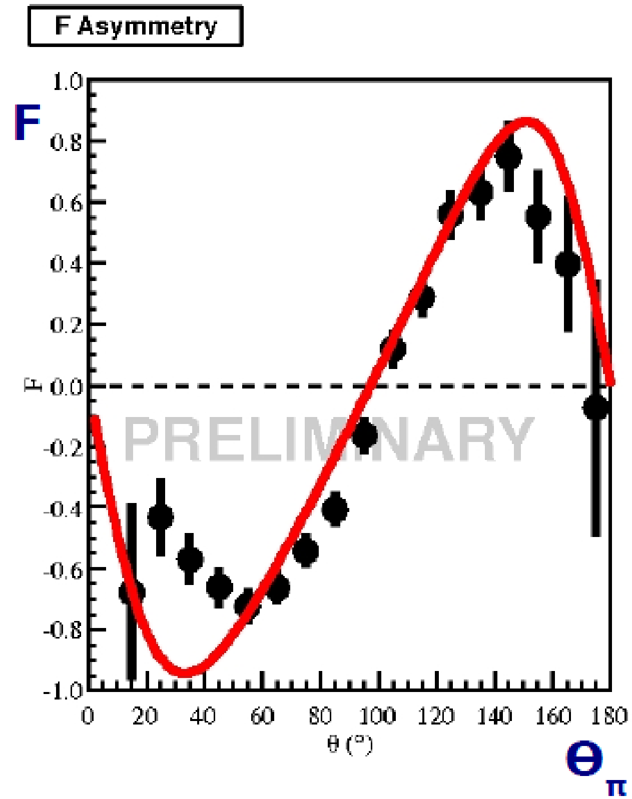
Data taken in September 2010 & February 2011

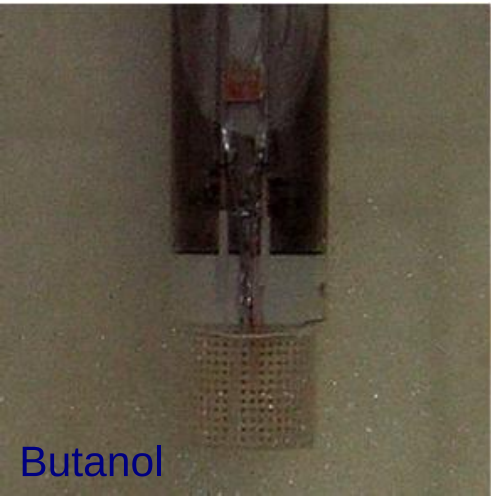
E_γ=320MeV

Analysis: S. Schumann (MIT)



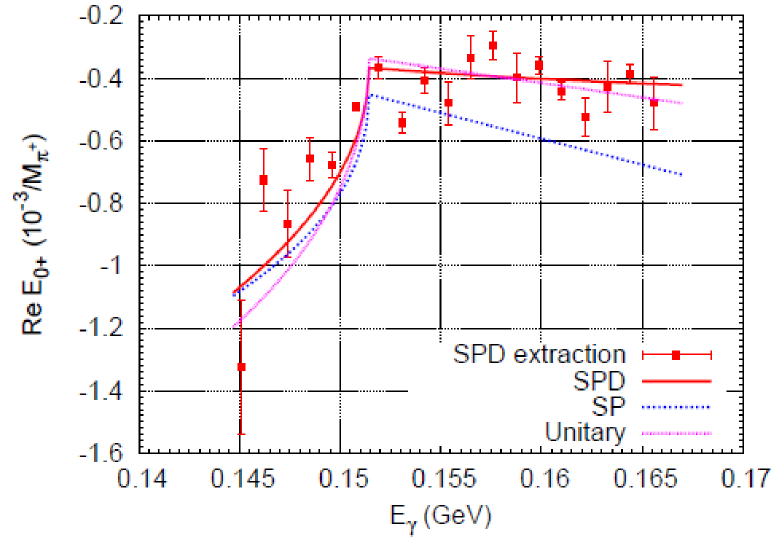






Hydrogen

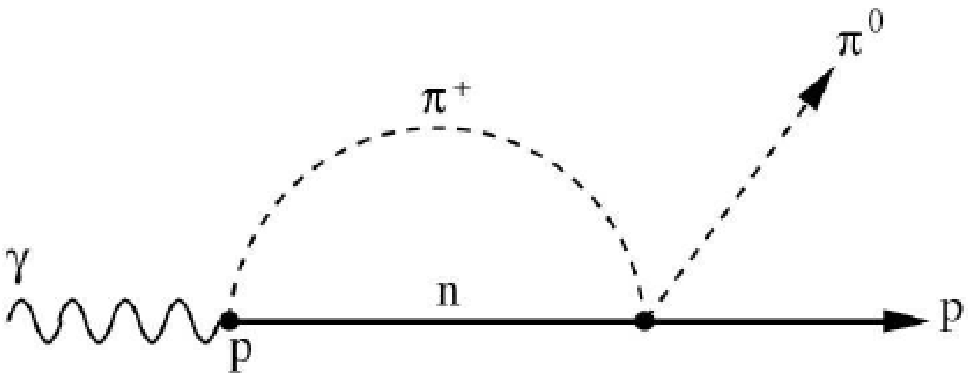
Asymmetries T and F in $\gamma p \rightarrow p\pi^0$ at threshold



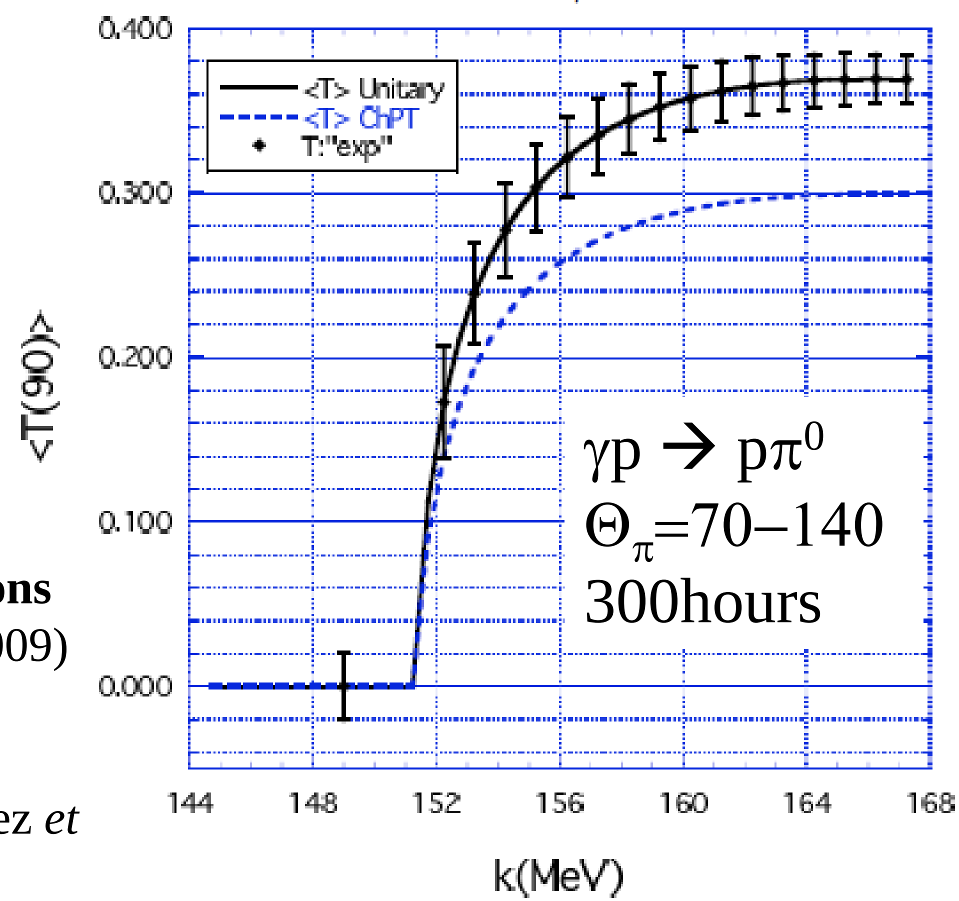
- Study of the dynamic consequences of $m_d - m_u > 0$.

m_{π^0} =135 MeV $\quad \frac{1}{\sqrt{2}} \cdot (|u\bar{u}> - |d\bar{d}>)$

m_{π^+}=139.6 MeV $\quad |u\bar{d}>$



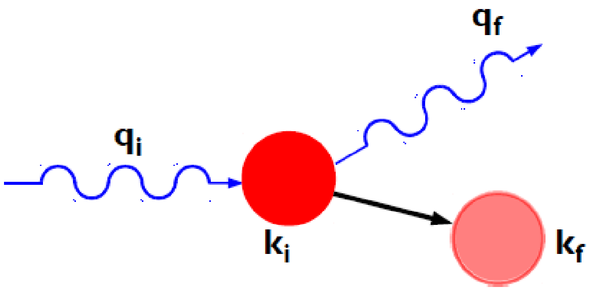
Rescattering diagram responsible for the unitary cusp observed in E_{0+} ($\gamma p \rightarrow p\pi^0$)



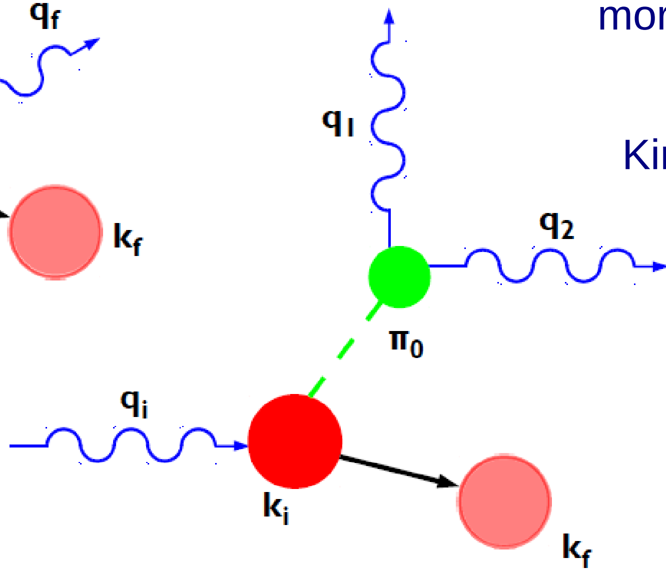
- Precission experiment to test the **unitary calculations** [Bernstein et al. arXiv:0902.3412 [nucl-th] (Feb. 2009) and **ChPT calculations** [V.Bernard, N.Kaiser, and U.G.Meissner, Eur. Phys. J. A11, 209 (2001), C. Fernandez-Ramirez *et al., PLB 679 (2009)*] of ImE_{0+} .

Event Selection

- Compton Scattering



- Pion Photoproduction

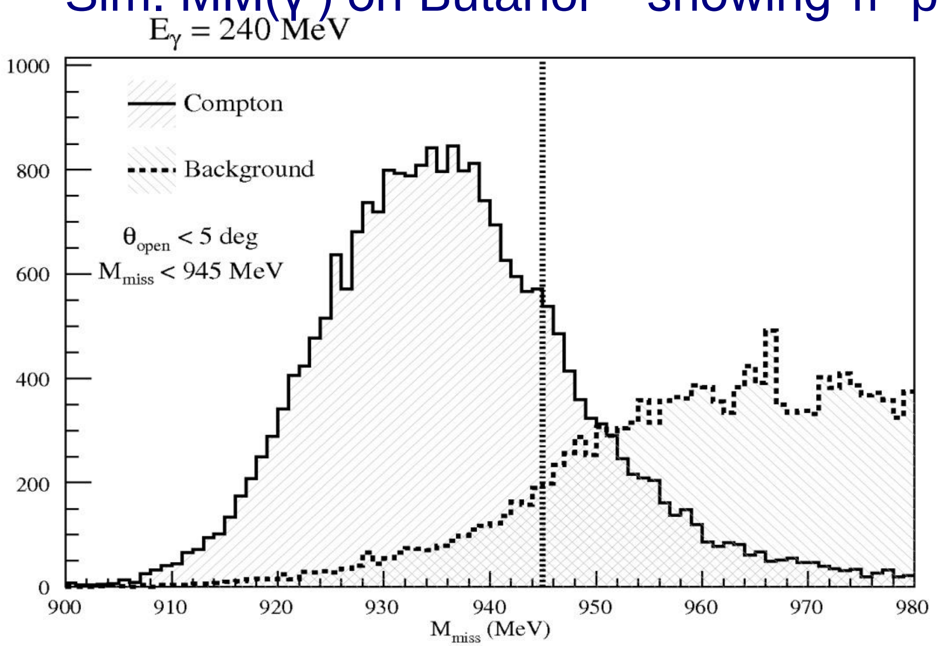


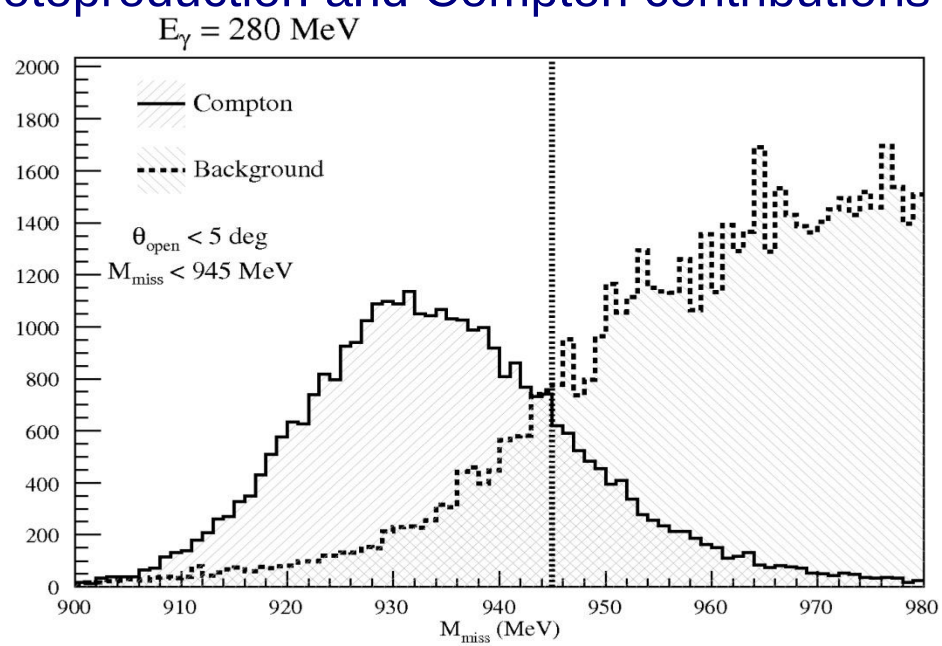
Pion photoproduction off of a proton is 75-100 times more likely than Compton (in the 240-280 MeV range)
→

Kinematic overdetermination used for cuts (missing mass, proton angle, …).

Test with 'substraction target'.

Sim. MM(γ') on Butanol – showing π^0 photoproduction and Compton contributions





ELSEVIER Nuclear Instruments and Methods in Physics Research A 446 (2000) 592–599

Section A

www.elsevier.nl/locate/nima

Polarized scintillator targets

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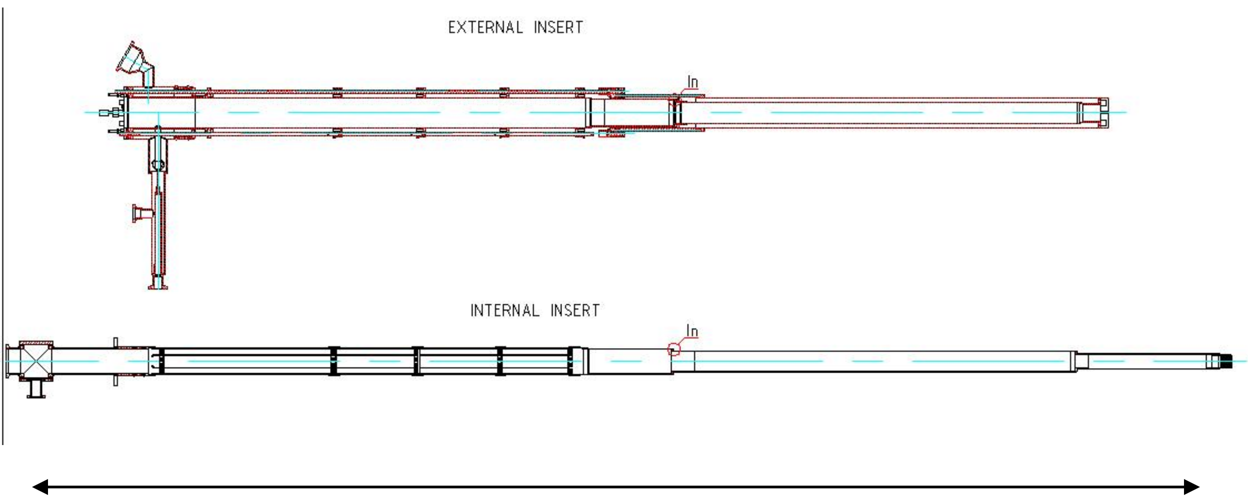
Abstract

The hydrogen nuclei in an organic scintillator have been polarized to more than 80% and the deuterons in its full deuterated version to 24%. The scintillator, doped with TEMPO, has been polarized dynamically in a field of 2.5 T i a vertical dilution refrigerator in which a plastic lightguide transports the scintillation light from the sample in the mixir chamber to a photomultiplier outside the cryostat. Sizeable solid samples with acceptable optical properties and ligl output have been prepared and successfully operated as "live" polarized targets in nuclear physics experiments. © 20(Elsevier Science B.V. All rights reserved.



2 Meter

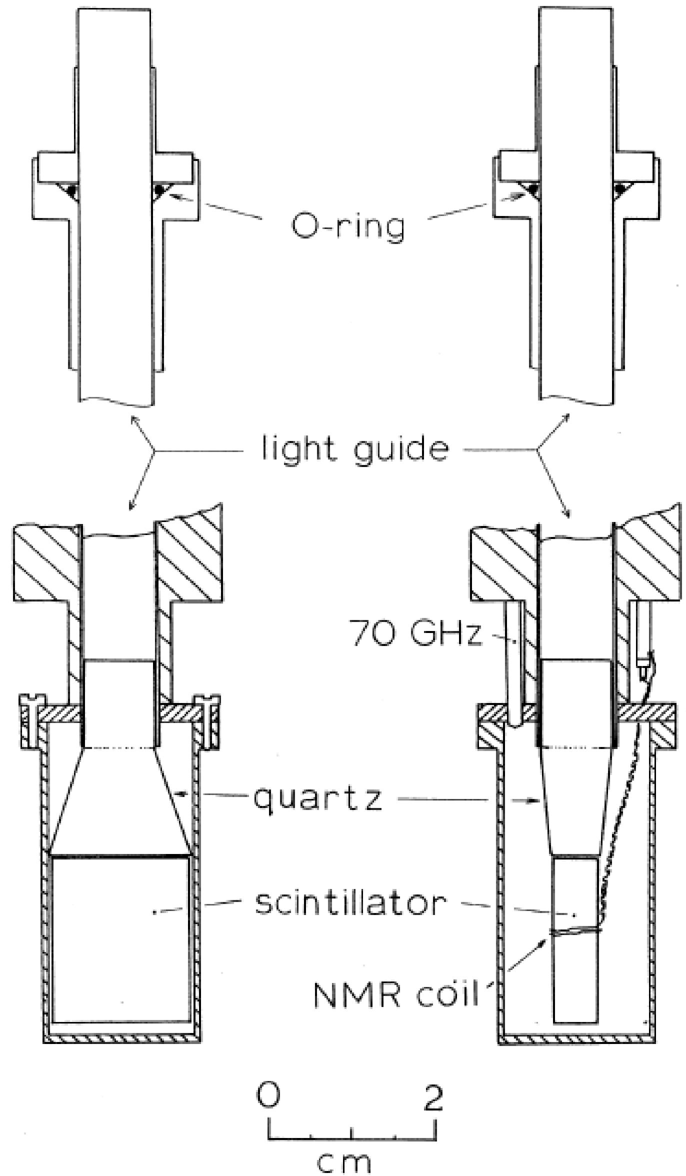
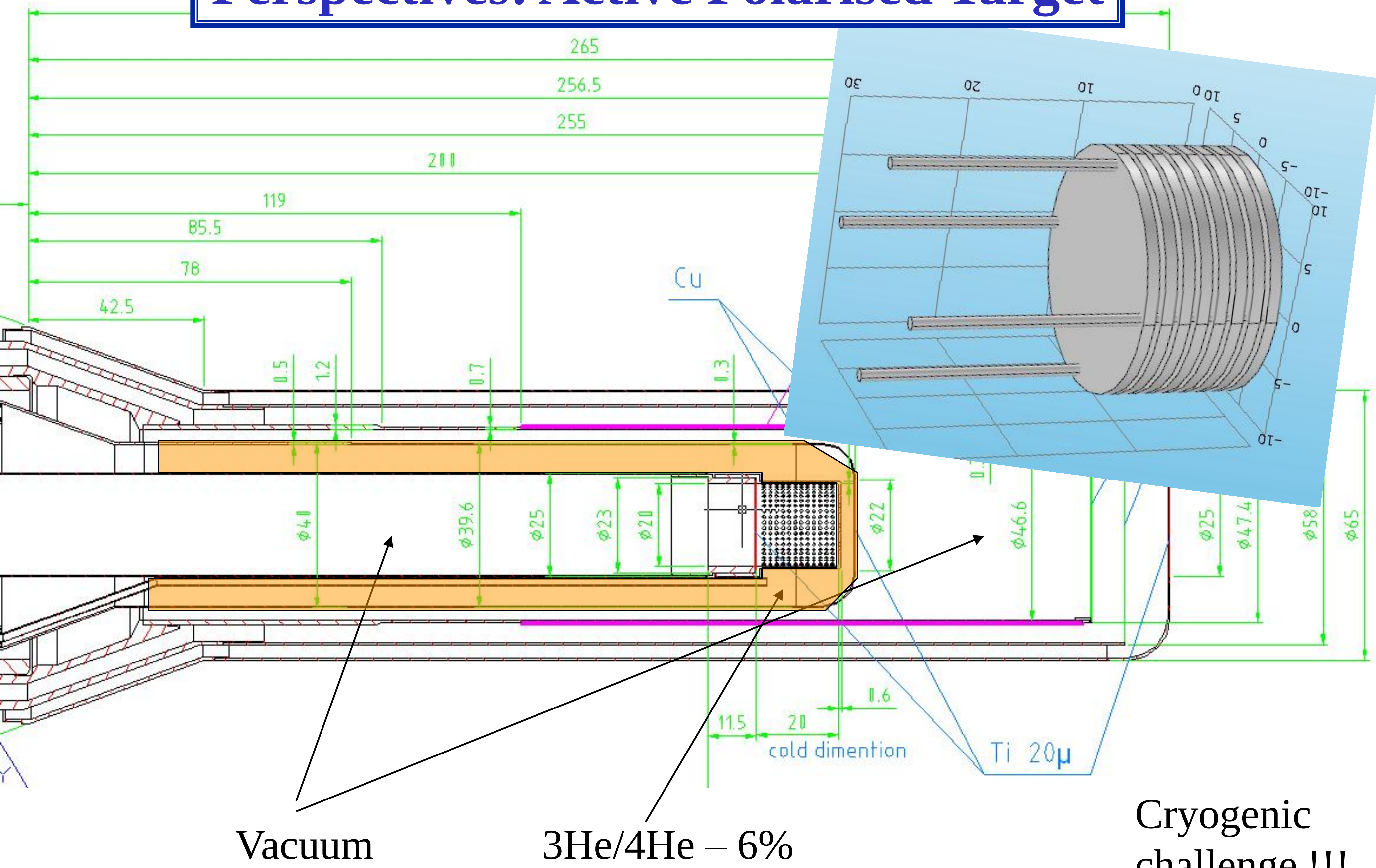


Fig. 3. Dilution refrigerator: details of the sampleholder with lightguide and of the scintillating target itself.

Perspectives: Active Polarised Target



Cryogenic challenge !!!

Active Polarised Target Material

First tests without light readout:

10 discs with 20mm diameter stacked in teflon container with teflon spacers.

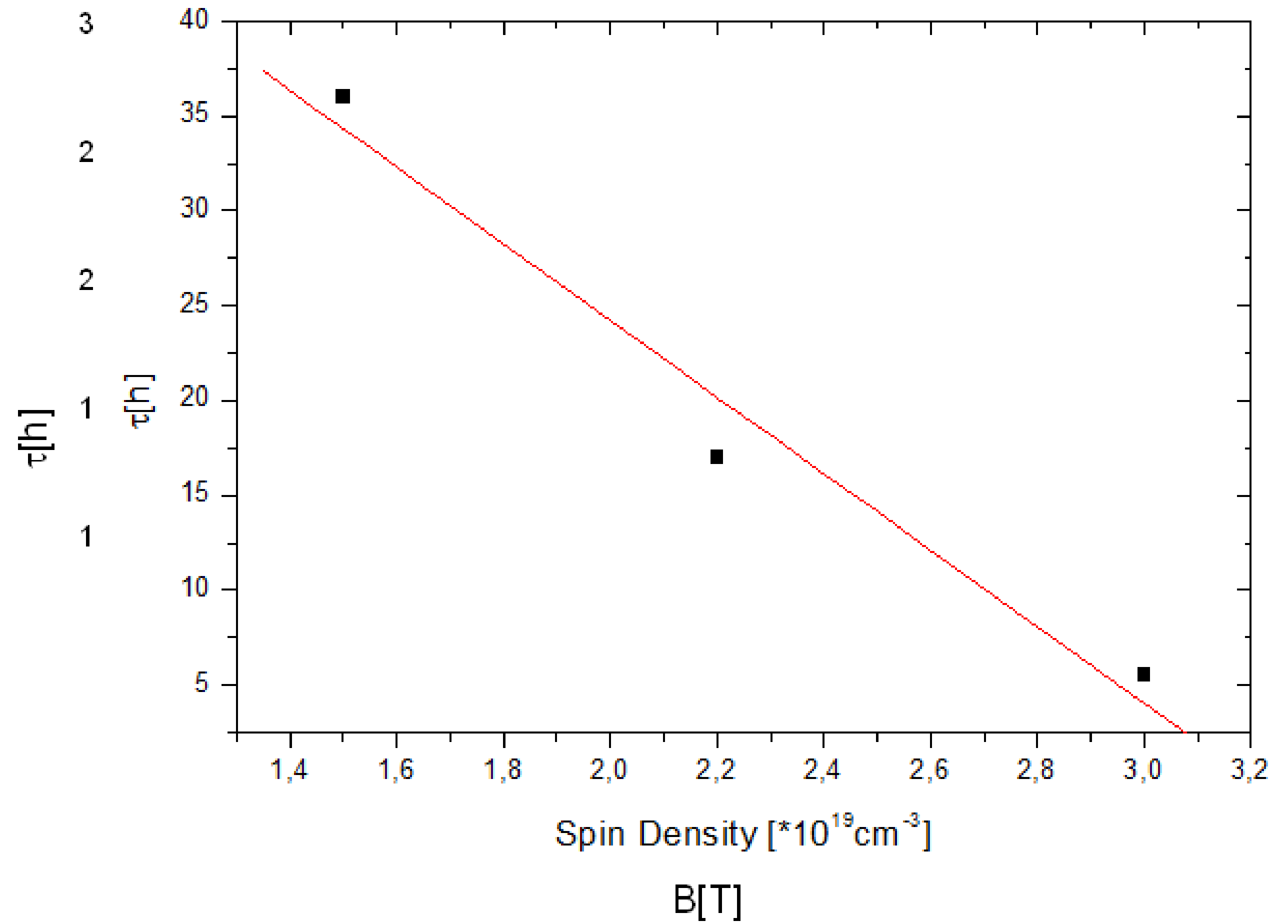
Polystyrene
+ ~5%Butanol
Spin density 2.2 *10^{19} c
T=25 mK
P_{max} ~ 50%

Spin density 3.0 *10^{19} cm^{-3}
T=32 mK and B= 0.2 T
P_{max} ~ 70%, tau ~ 5.5 h

Spin density 1.5 *10^{19} cm^{-3}
T=26 mK and B= 0.2 T
P_{max} ~ 44%, tau ~ 36 h

Optimisation of P_{max} and τ

B[T]	τ[h]
0.2	17
0.1	2.6
0.08	0.92
0.05	0.33

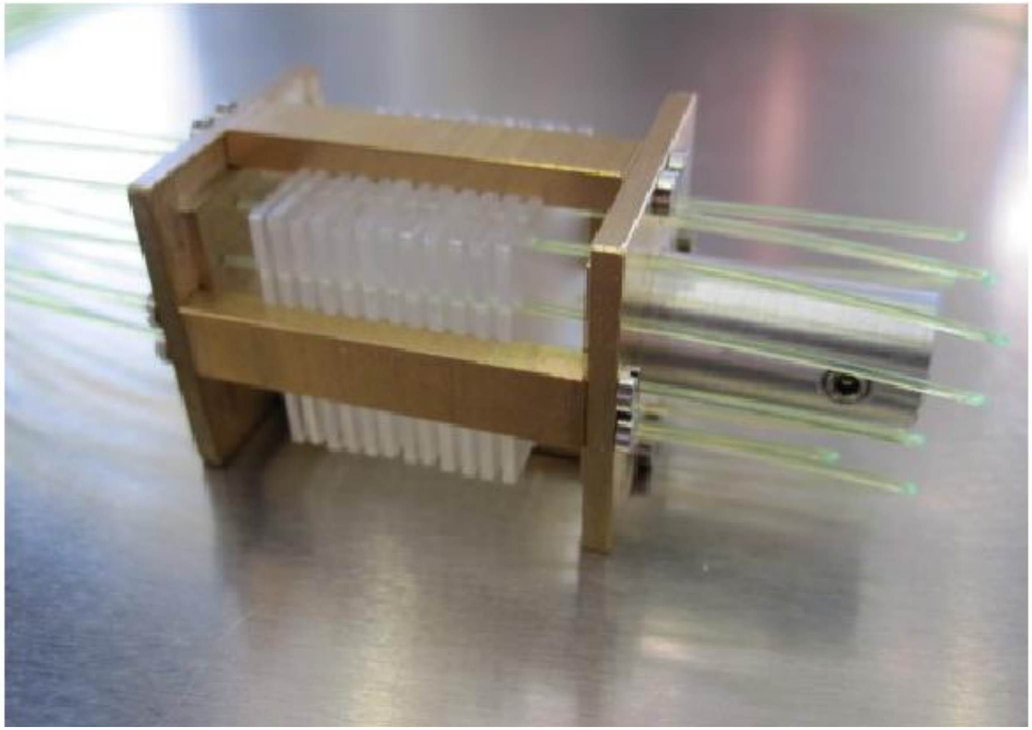


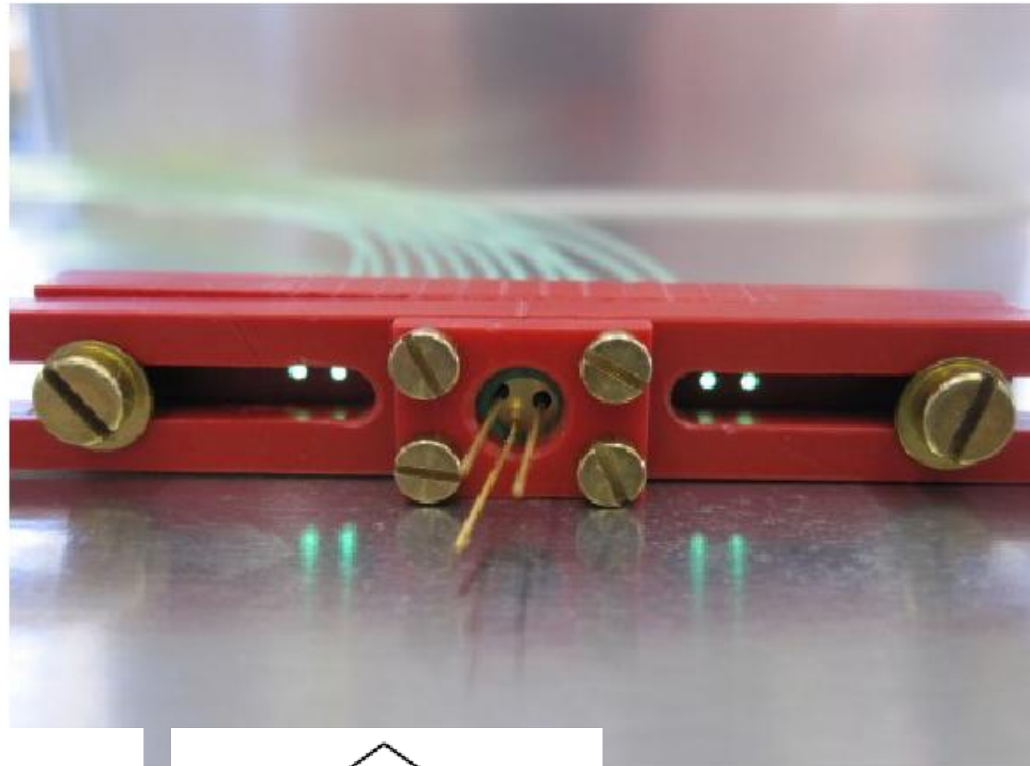
[W. de Boer, CERN 1974]

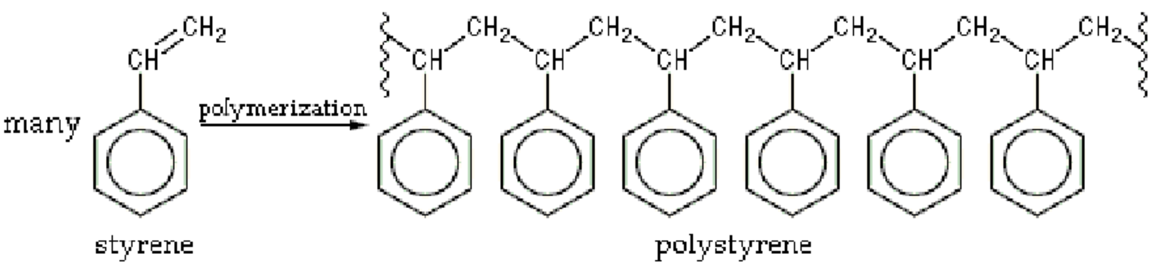
$$T_{1n} = \left(\frac{H}{\hbar \gamma_n} \right)^2 \left(d^3 R^3 \right) \frac{T_{1e}}{1 - P_e P_0}$$

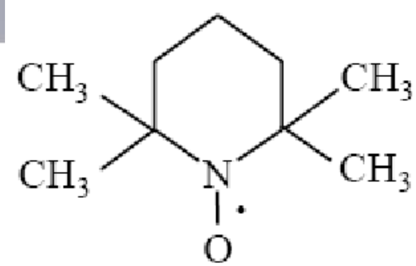
$\#e^-$ ($*10^{19}cm^{-3}$)	1.5	2.2 (But)	3.0
t[h] @0.2T	36	17	5.5

Light Readout: Active Polarised Target









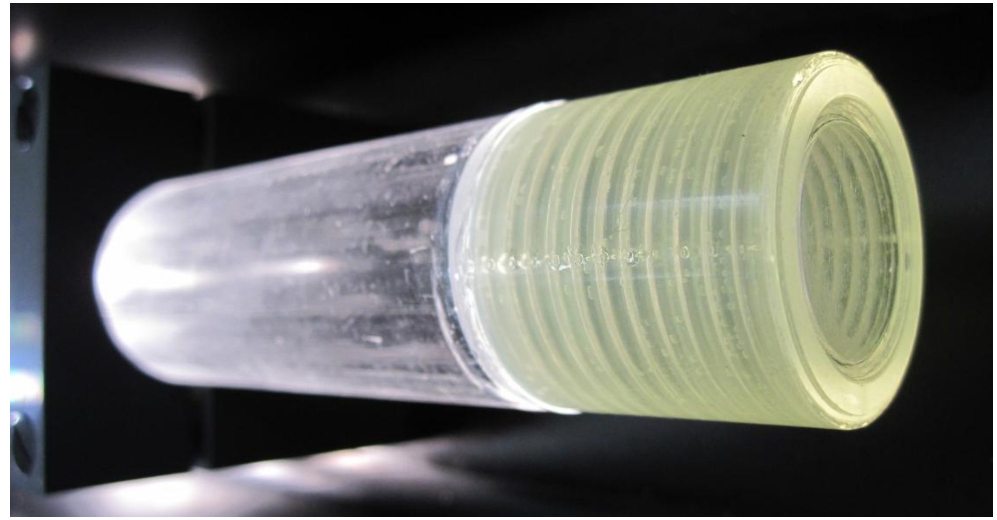
Material

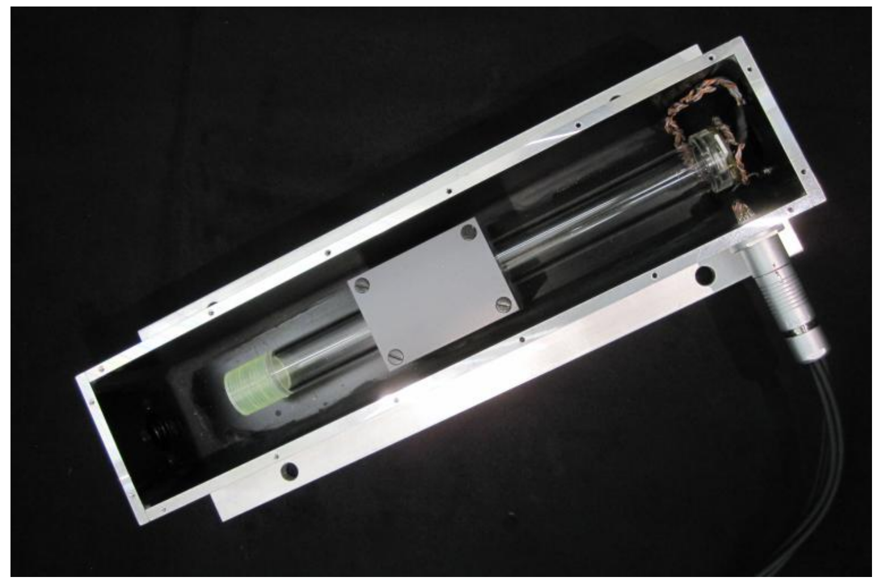
&

Detector challenge !!!

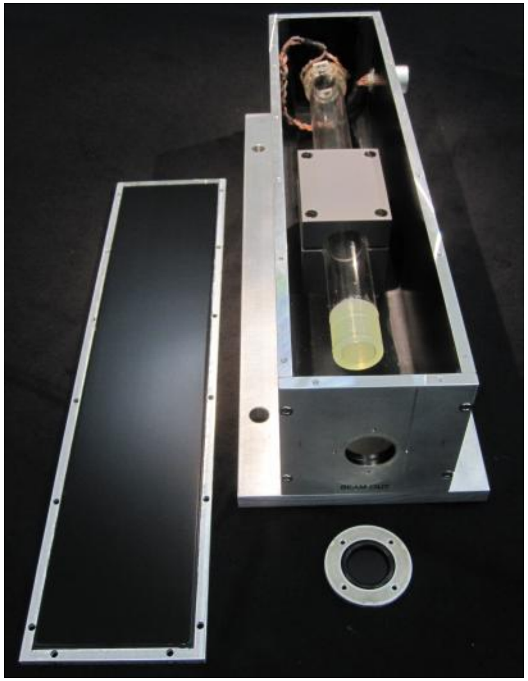
Miskimen (UMass Amherst), Downie (GWU),
Biroth, Thomas (Mainz),
Borisov , Usov (JINR).

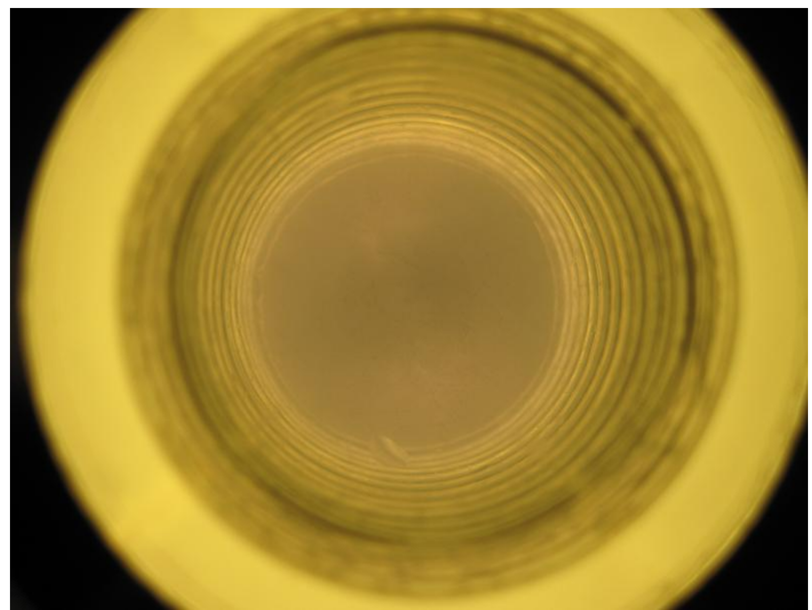
Cryogenic – Insert
Arrived in Mainz last Fri.,
To be mounted.



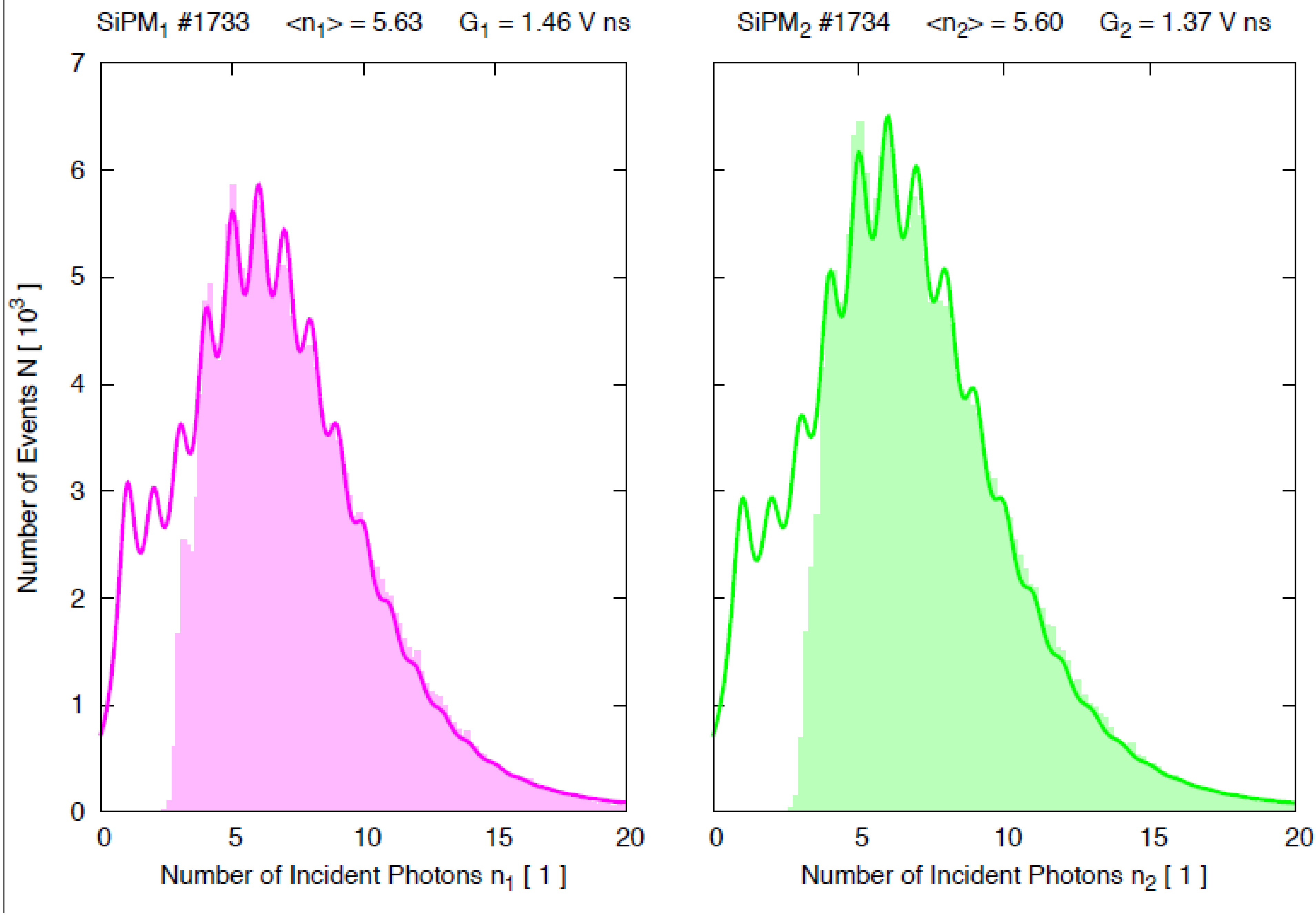


First warm in beam test
done Yesterday.





Different methods to stack and glue the active polarized target plates.
(ligth collection efficiency?)



SiPM in A2 beam. Other candidates are APD‘s. Operation at 2-4Kelvin.

Conclusions

- **Frozen Spin Target** offers all directions of polarization. $\tau \sim 1000 \ldots 4000$h.

- Data taking for 5000h with **CBall TAPS detector system** 2010/2011.

  Spin observables with focus to $P_{11}(1440)$, $S_{11}(1535)$, and $D_{33}(1700)$ resonance regions. Meson Production. Complete Experiments.

  First Measurement of 4 Vector Spin Polarisabilities in Compton Scattering, F and T in π-threshold region. Light quark mass difference. Isospin breaking.

Outlook Technology

- **Production** of an **internal polarising coil avoids FST waltz → DNP Target**
  (+better systematics (position, noise,...), +better statistics (efficiency), +higher polarisation, +less manpower, -more material, momentum threshold)

- **R&D for polarised active szintillator target for threshold production.**
  (+new kinematic range in combination with 4π detectors)