HL - POLARIZED ION AND LEPTON SOURCES AND TARGETS

-19 TALKS EVENLY DISTRIBUTED BETWEEN SOURCES AND TARGETS

Christopher Keith
Jefferson Lab
-Targets

Kurt Aulenbacher,
Johannes Gutenberg-Universität Mainz
-Sources

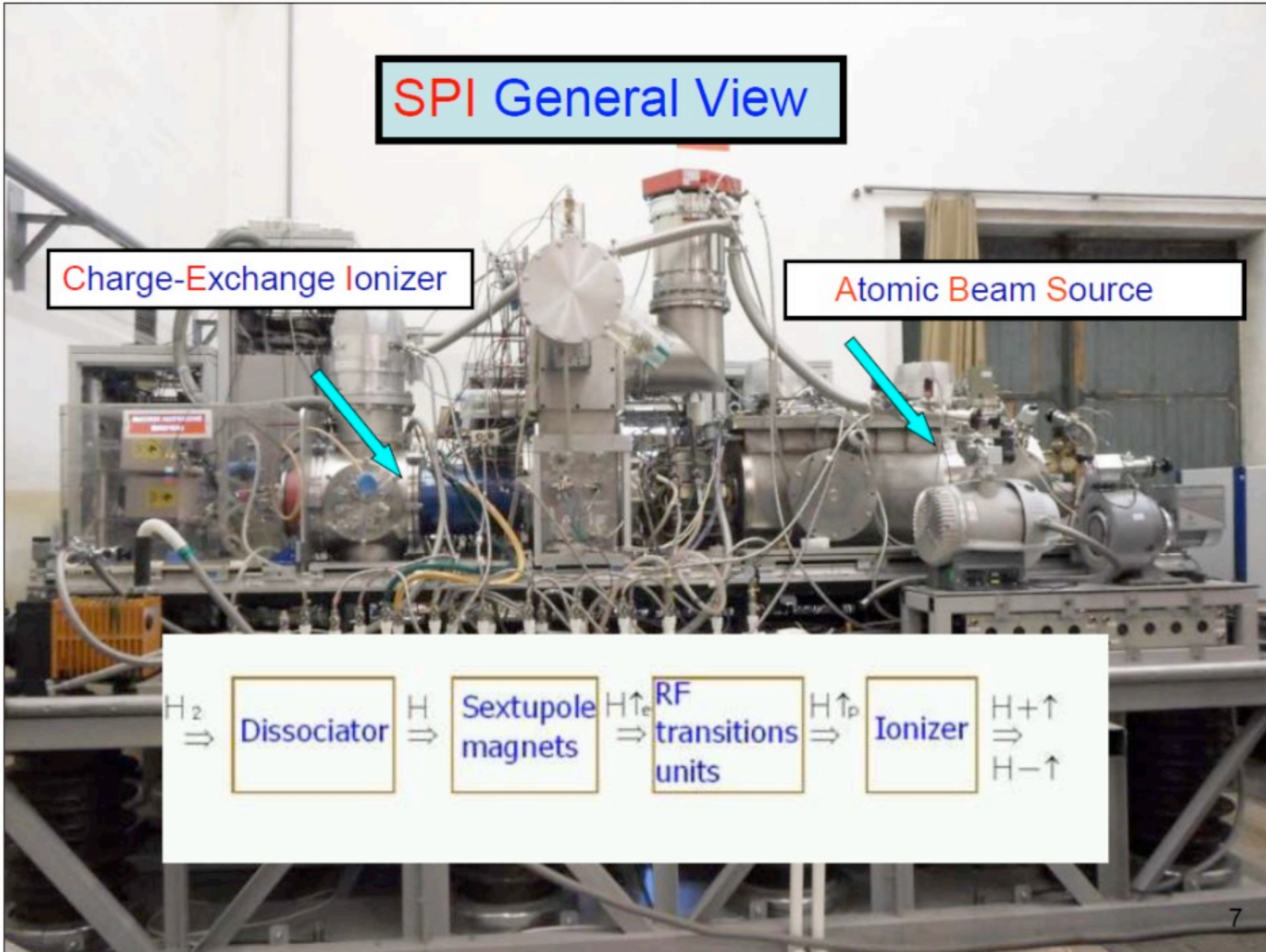
PART-1 HL - POLARIZED SOURCES

Apart from polarization degree, progress is measured by improving

- Peak current/brightness (storage ring based research), → RHIC, NICA, EIC,….
  -talks by Zelenski (BNL);Finushkin (JINR)
- Average current →
  c.w. LINACS/dc machines i.e. CEBAF/MAMI/MESA /LHeC
  -talks by Aulenbacher (Mainz), Tsentalovitch (MIT), Y.Plis, (JINR)
- Neutral Particle flux e.g. polarized Nuclei in Molecules
  talks by R. Engels, L Huxold (Jülich), D. Sofikitis (FORTH),

PROTON

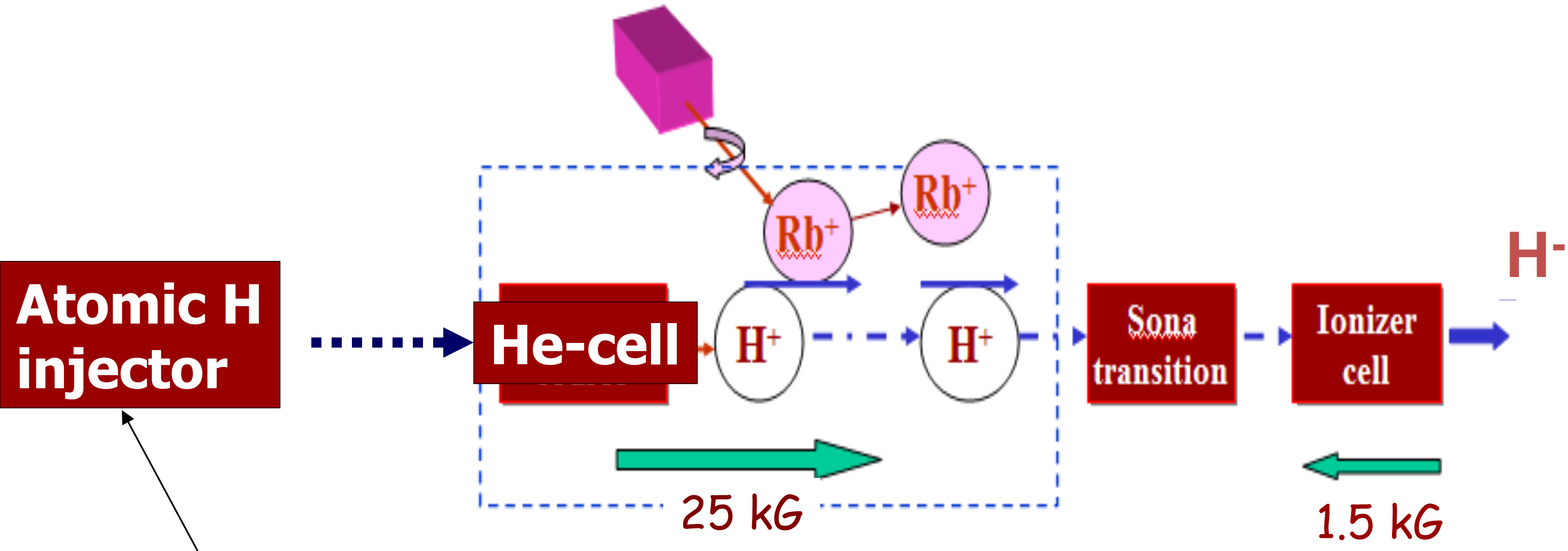

Spin 2018
23RD INTERNATIONAL SPIN SYMPOSIUM
FERRARA - ITALY
10 - 14
SEPTEMBER
2018



V. V. Fimuskin/JINR

OPPIS with atomic H^0 injector, 2013-17

High-brightness proton beam inside strong 2.5 T solenoid field produced by atomic H beam ionization in the He-gas ionizer cell



The primary proton beam and Equivalent atomic H intensity current is 2.5 A at 6.5 keV beam energy !

A. Zelenski
BNL

Beam intensity and polarization at 200 MeV

- Reliable long-term ·operation of the source was demonstrated.
- Very high suppression of un-polarized beam component was demonstrated.
- Small beam emittance (after collimation for energy separation) and high transmission to 200 MeV.

Rb-cell thickness-NL	4.5	5.5	7.5	10.4
Linac Current, μA	440	520	740	950
Booster Input $\times 10^{11}$	10.0	12.0	14.0	17.1
Pol. %, at 200 MeV	86	86	84.5	83

A. Zelenski
BNL

Rb-cell thickness ,NL $\times 10^{13}$ atoms/cm^2

RHIC Polarized beam in Run 2013-17

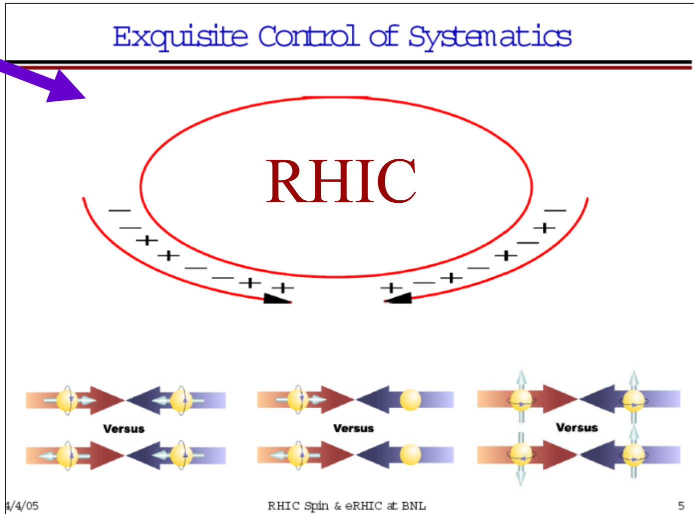
OPPIS → 1.0 mA x 300us→$18\cdot10^{11}$ polarized H^- /pulse.

LINAC → $9.0\cdot10^{11}$ polarized H^- /pulse at 200 MeV routinely in Run-17, Polarization-85%

Booster: $(2.5\text{-}3.0)\cdot10^{11}$ protons /pulse at 2.3 GeV

AGS: $(2.0\text{-}2.5)\cdot10^{11}$ p/bunch, P-70%

~$1.8\cdot10^{11}$ p/bunch, P~65-75% at 100 GeV
P ~ 60-65% at 255 GeV

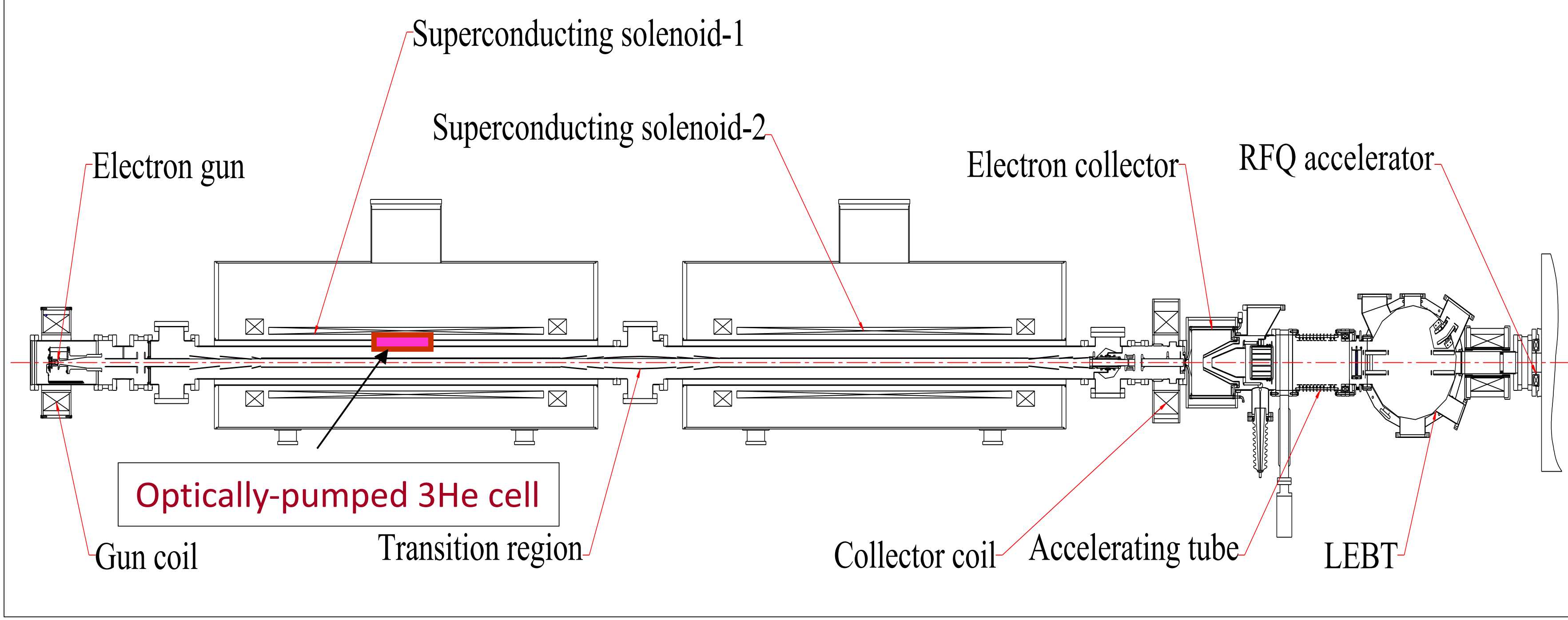


A. Zelenski
BNL

UNDER DEVELOPMENT: HIGH INTENSITY ^{3}HE SOURCE AT BNL

"Extended" EBIS upgrade with new "injector" solenoid for polarized 3He^{++} ion production.

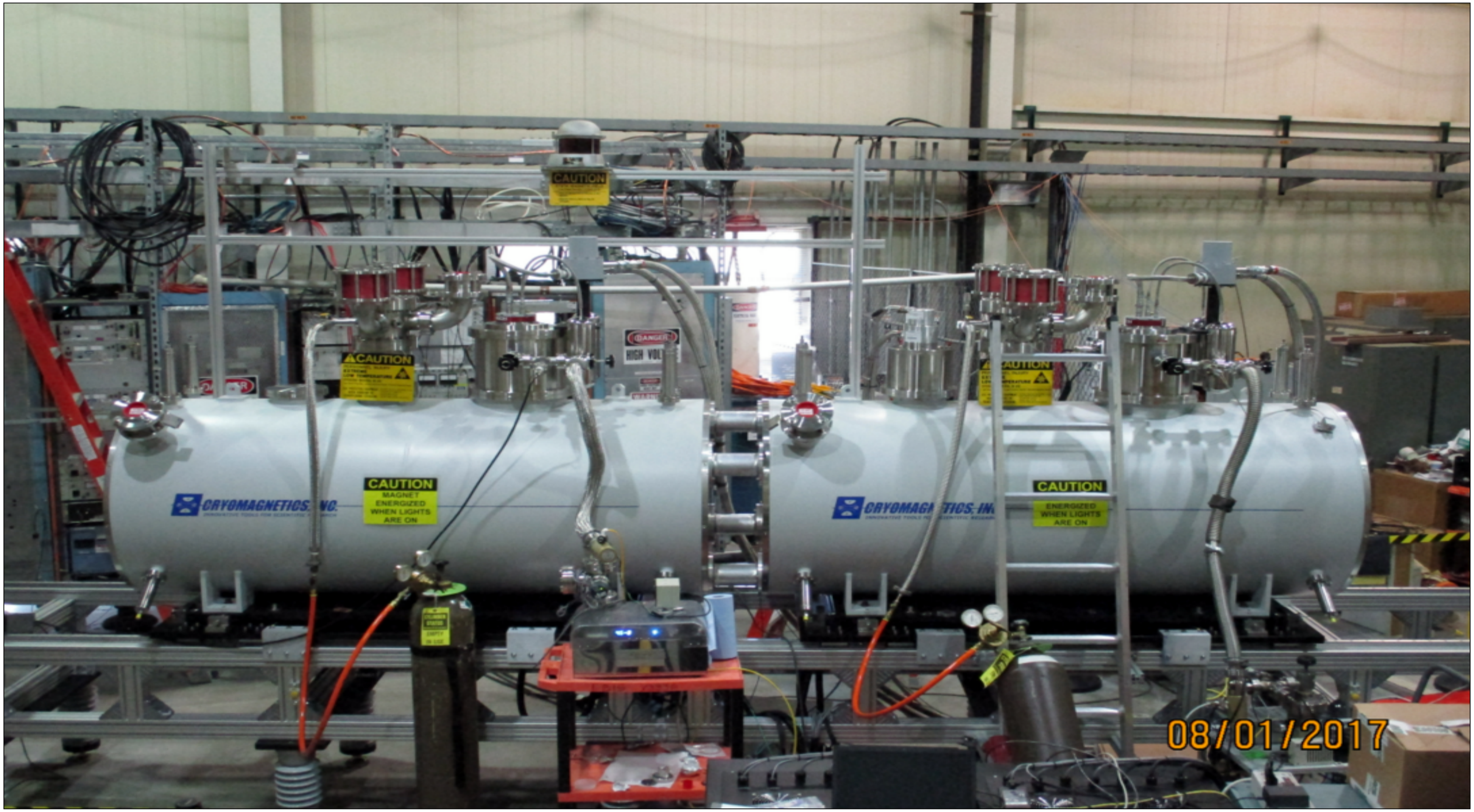
Polarization and ionization in high magnetic field will produce 3He^{++} ion beam with P ≥ 80%



3He^{+} → Ionization to 3He^{++} → Up to 2×10^{11} 3He^{++} ions/pulse

(A. Zelenski)

Extended EBIS superconducting solenoids, April 2018

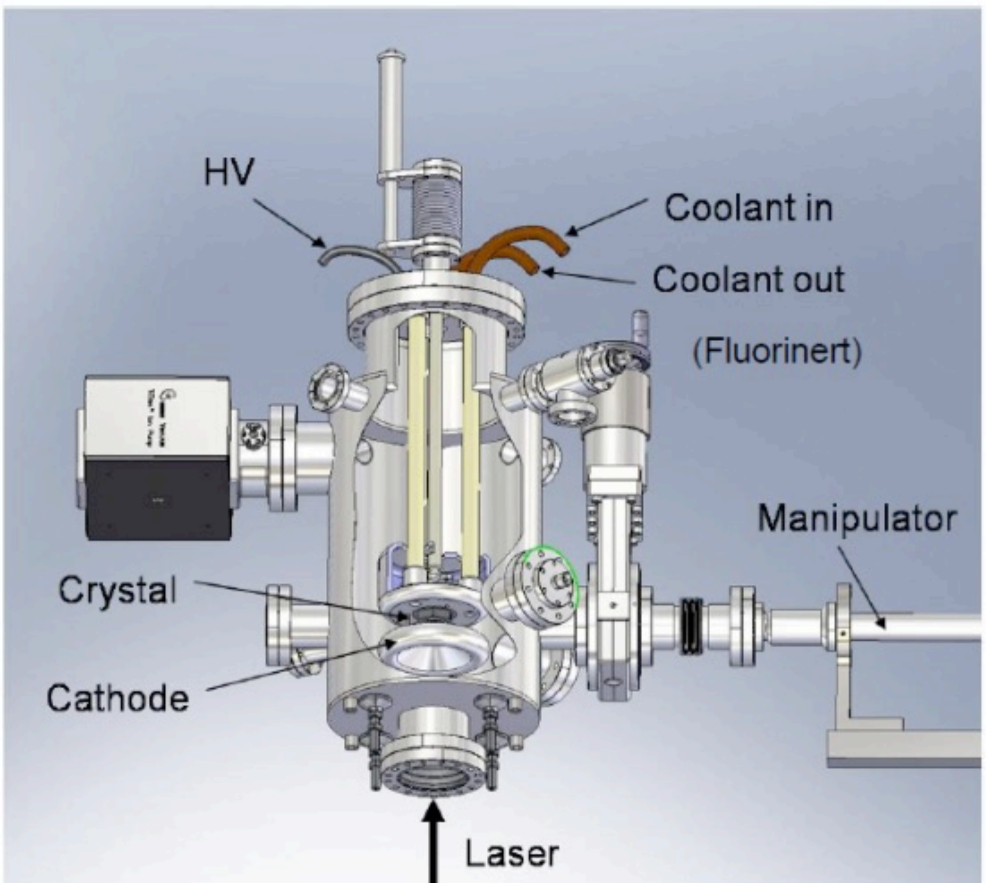


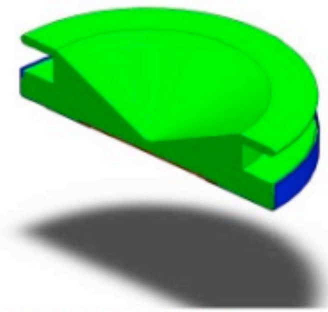
5.0 T field, about 1.0 T field at minimal solenoid separation-30 cm

ELECTRON SOURCE: HIGH AVERAGE CURRENT AT MIT (E. TSENTALOVICH, MIT)

- High brillance source at Mainz (increased Field strength 1MV/m→2.5MV/M)
- High current developments at MIT → ERL application

Cathode cooling



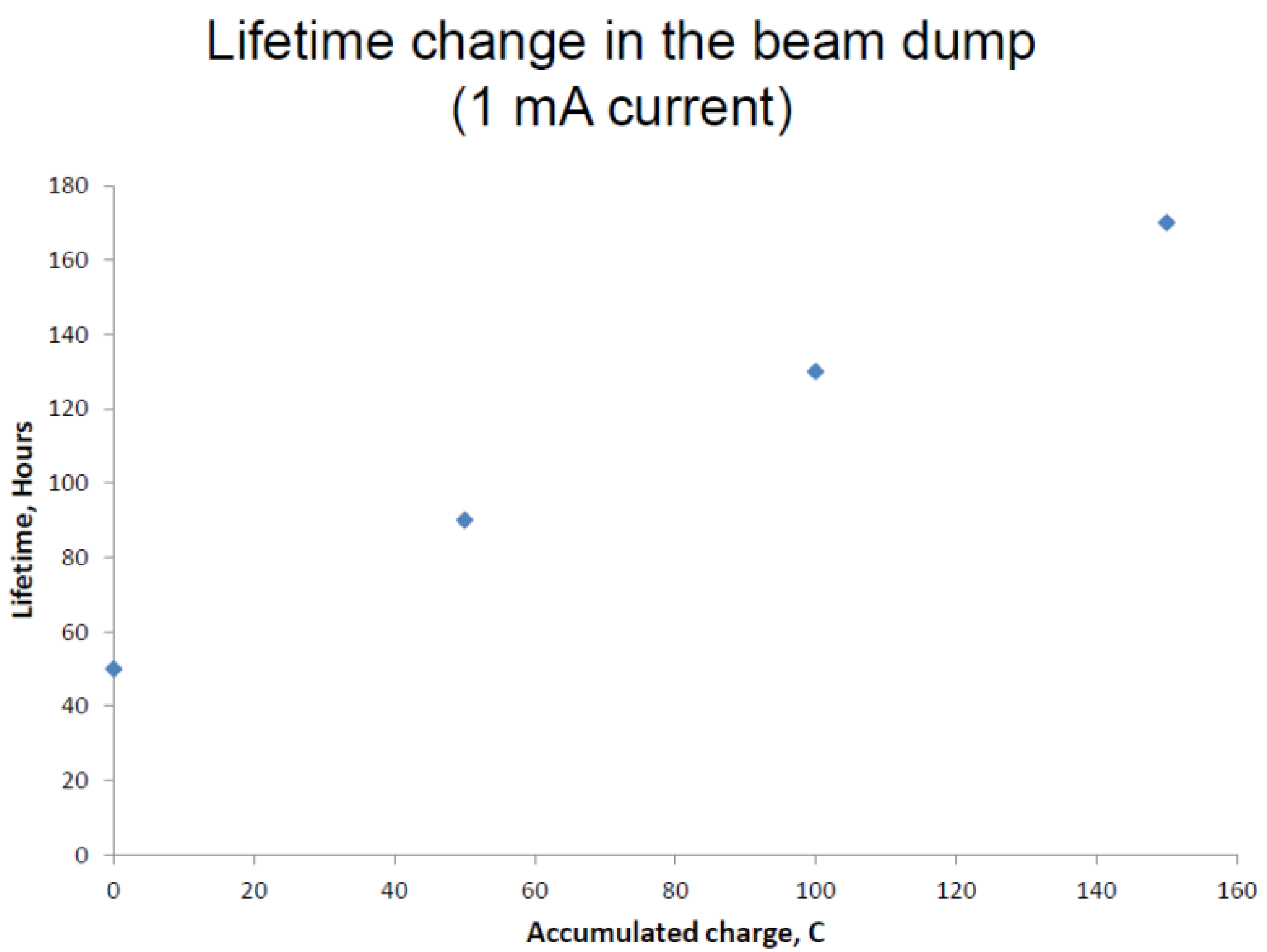


Cathode puck (Moly)

Heat exchanger

Up to 40 W of laser power

E. Tsentalovich, MIT



Hope to achieve very high charge lifetimes!
>>1000C? → Important for ERL based EIC like LHeC!!

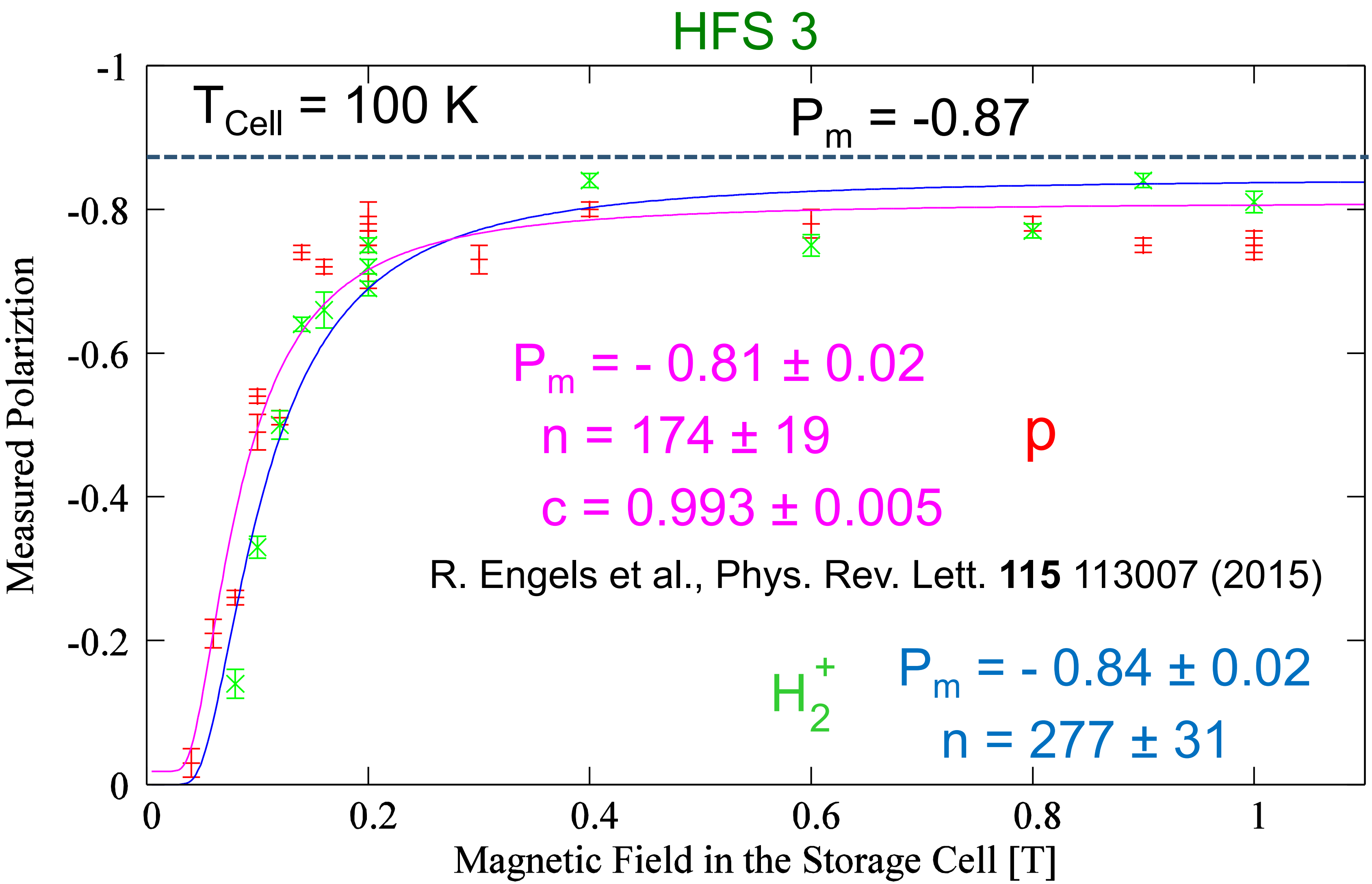
E. Tsentalovich, MIT

NUCLEAR SPIN MOLECULES TO PRODUCE, (E.G.), HD ICE (R. ENGELS (JÜLICH), L. HUXOLD , D. SOFIKITIS (FORTH)

- Generate pol. Nuclei in Molecules by chemical or optical orientation

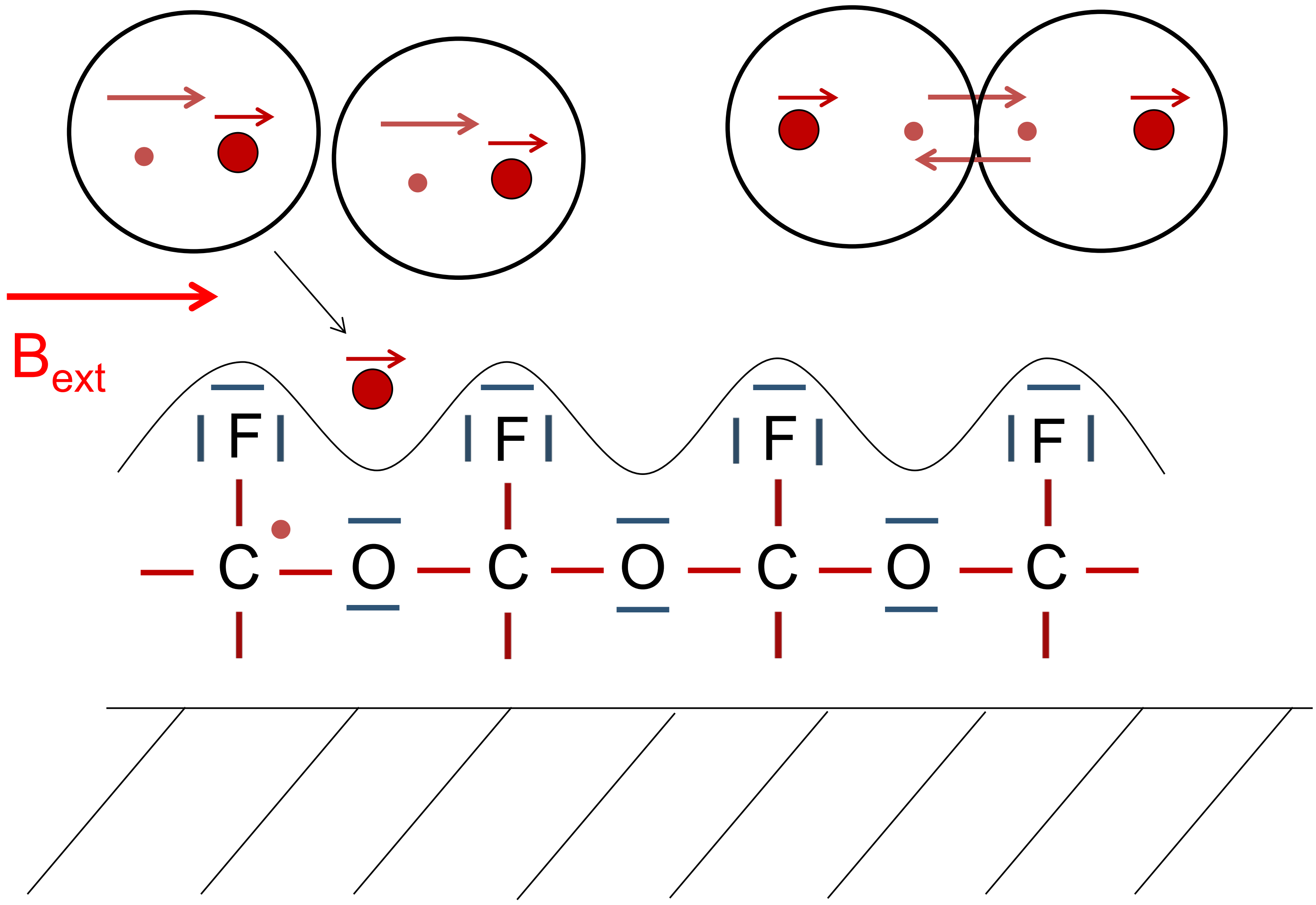
Experimental results

Measurements on Fomblin Oil (Perfluoropolyether PFPE)



R. Engels (Jülich),

Recombination on Fomblin (?)



Fused Quarz

R. Engels (Jülich),

We can produce polarized H_2, D_2 and HD molecules with large vector- and tensor-polarization (~ 0.8) in many spin combinations.

For what it is usefull?

1.) **More dense polarized targets.**

2.) Spectroscopy of the molecules or molecular ions (Contact with the University of Düsseldorf).

3.) New insights in chemical reactions / surface physics.

4.) Polarized fuel to increase the energy output of Fusion reactors. **-> see talk on Wednesday, 2:30 pm**

5.) Polarized targets for laser acceleration. **-> see talk by M. Büscher on Wednesday, 5:05 pm**

6.) EDM measurements ?

7.) An option to produce polarized molecules for medical application ?

PART 2: Polarized Targets at SPIN 2018

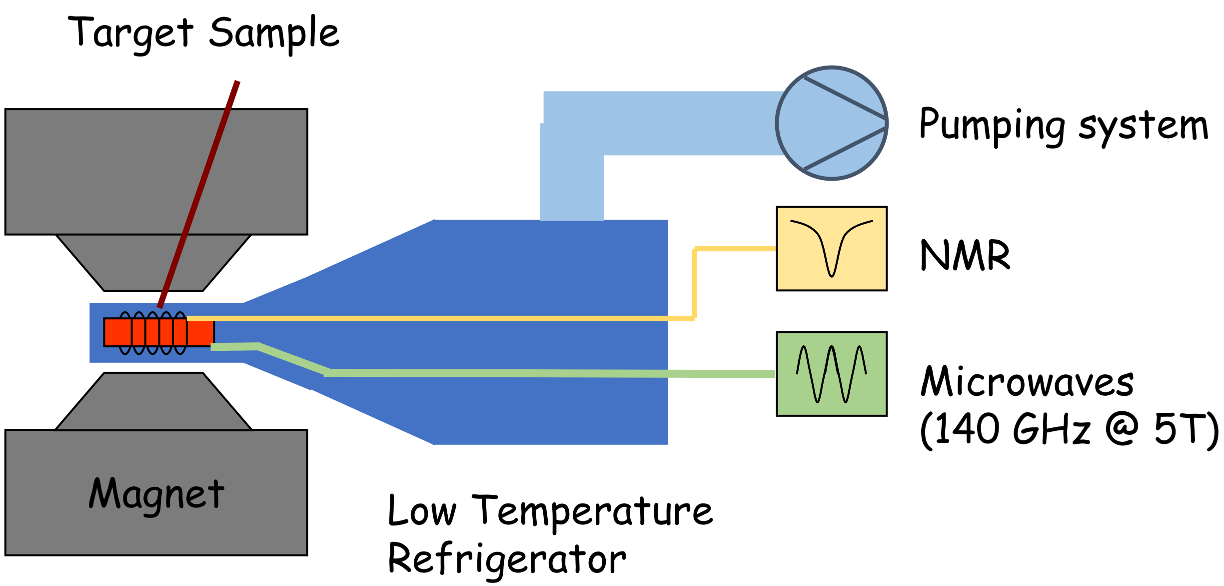
Thanks to all my polarized target colleagues for making this an interesting and stimulating SPIN symposium!

Gerhard Reicherz (Bochum)	*COMPASS Polarized Target in 2018 and 2021*
Erhard Steffans (Erlangen)	*Design of a Polarized Gas Target for the LHC*
James Brock (JLab)	*Design & Construction Techniques for the CLAS12 Polarized Target*
James Maxwell (JLab)	*NMR Measurements for Jefferson Lab's Solid Polarized Targets*
Josh Pierce (ORNL)	*Dynamic Polarization for Neutron Macromolecular Crystallography*
Harmut Dutz (Bonn)	*Recent Activities of the Bonn Polarized Target Group*
Marcel Bronstein (Bonn)	*Design and calculation of 4Pi-Continuous-Mode-Target current leads*
Stefan Runkel (Bonn)	*Polarized Target at the CBELSA/TAPS Experiment*
Andy Sandorfi (JLab)	*Potential use of Solid Frozen-Spin HD Targets with Electron Beams*
Marco Statera (INFN Ferrara)	*Measurements of transverse magnetization of a bulk MgB2 cylinder*

Thanks also to two plenary speakers:

Don Crabb (Virginia)	*More Than Fifty Years of Polarized Targets*
Arnaud Comment (Cambridge)	*Hyperpolarizing 13C spins by DNP for MRI applications*

Instrumentation for a typical polarized (solid) target



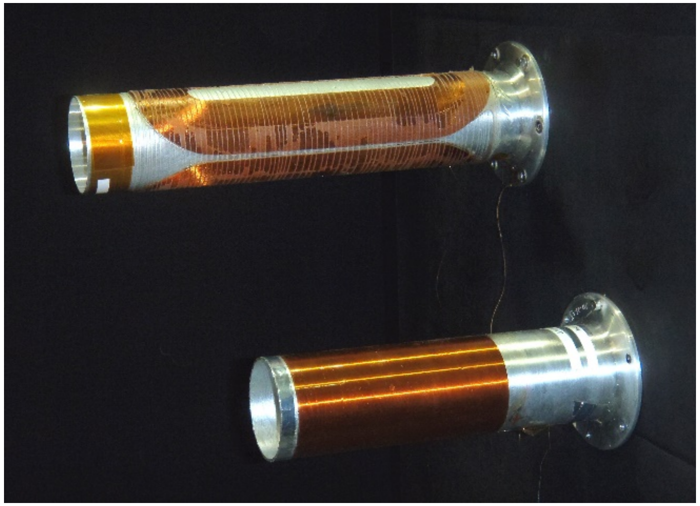
Interesting developments in nearly all aspects of target instrumentation:

Magnets for polarized (solid) targets

Most targets have one or two superconducting magnets

- High field, high homogeneity (2.5 – 5 T, 100 ppm) for polarizing
- Lower field, higher acceptance for holding polarization (Frozen spin only)

5 Tesla Split-coil Magnet

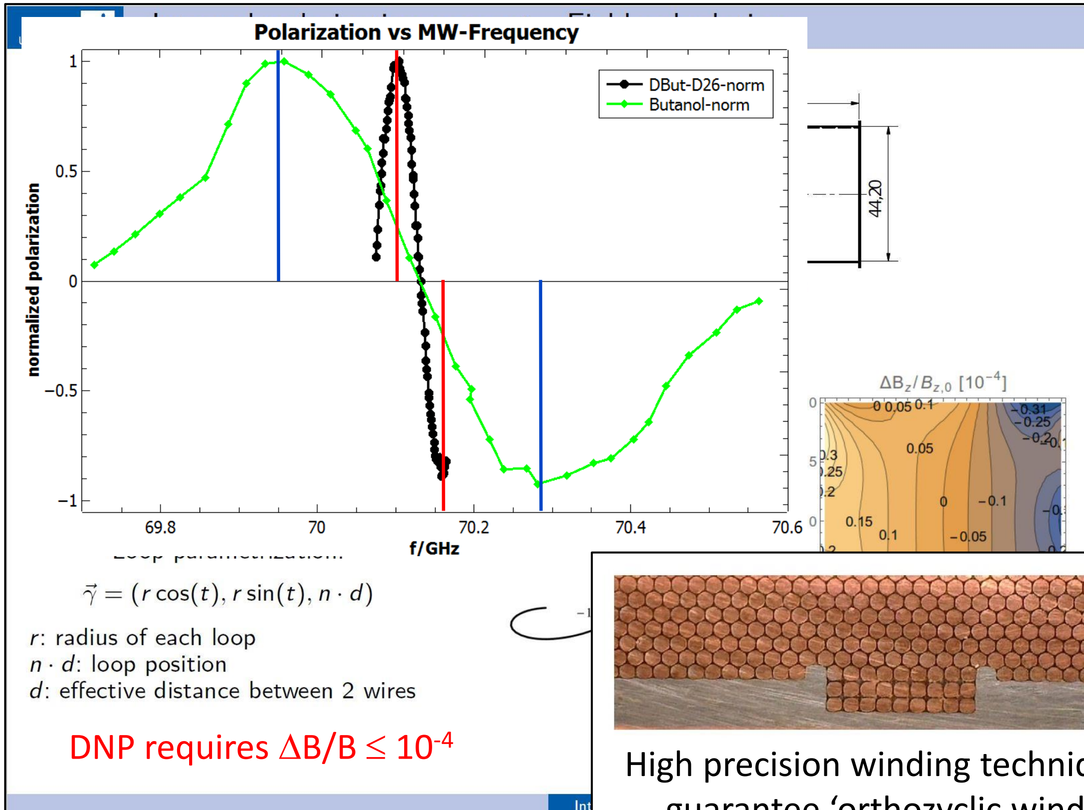


1/2 Tesla, internal holding coils

Magnets for polarized (solid) targets

Recent activities of the Bonn Polarized Target Group

Research Objectives: high field thin s.c. magnets



DNP requires $\Delta B/B \leq 10^{-4}$

High precision winding technique to guarantee 'orthozyclic winding'

Harmut Dutz (Bonn): Design, construction, and testing of a high-field, thin, *internal* polarizing magnet (and many other topics!)

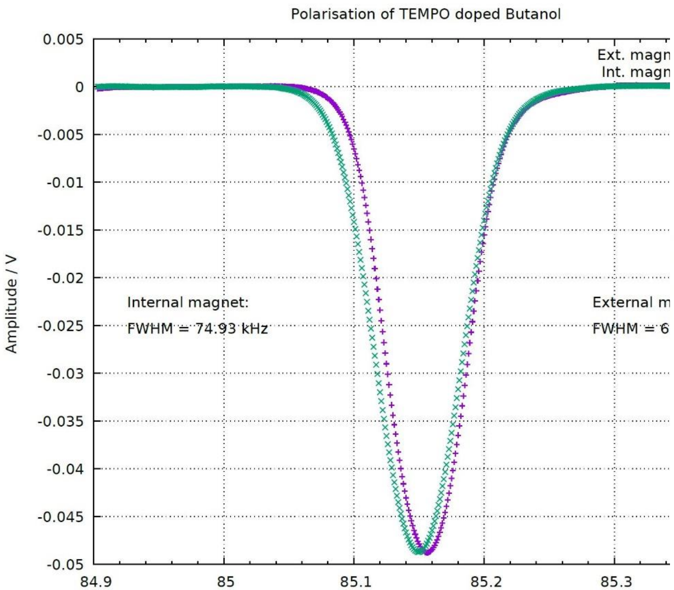
Magnets for polarized (solid) targets

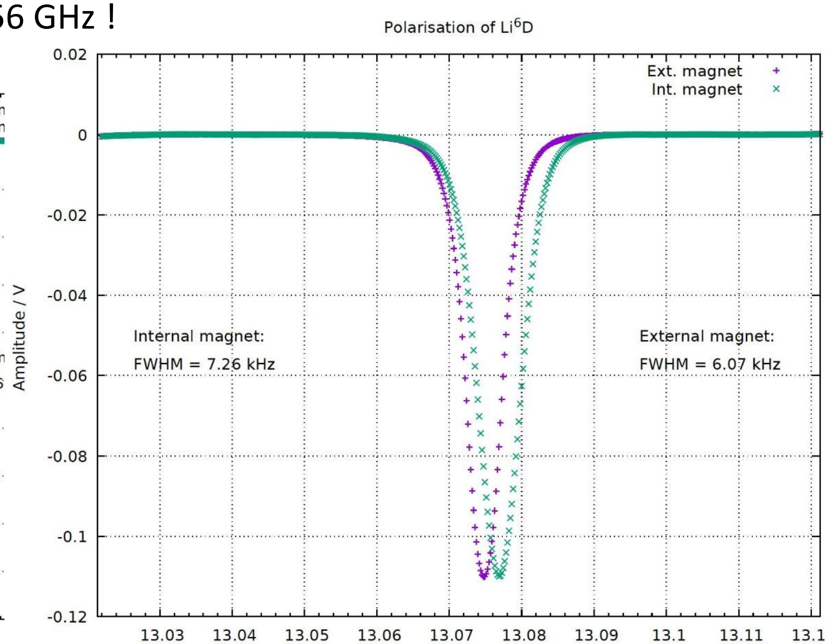
Recent activities of the Bonn Polarized Target Group

Research Objectives: high field thin s.c. magnets

First DNP-signals in the **new internal thin s.c. polarizing magnet**

T_P = 1K!, B_P = 2 Tesla, $F_{\mu w}$ = 56 GHz !





4π-continiuous mode scheme has been proven

Next: 8-layers coil for the new refrigerator

more information next talk: Marcel Bornstein “Design and calculation of the 4π-Continuous-Mode-Target current leads”

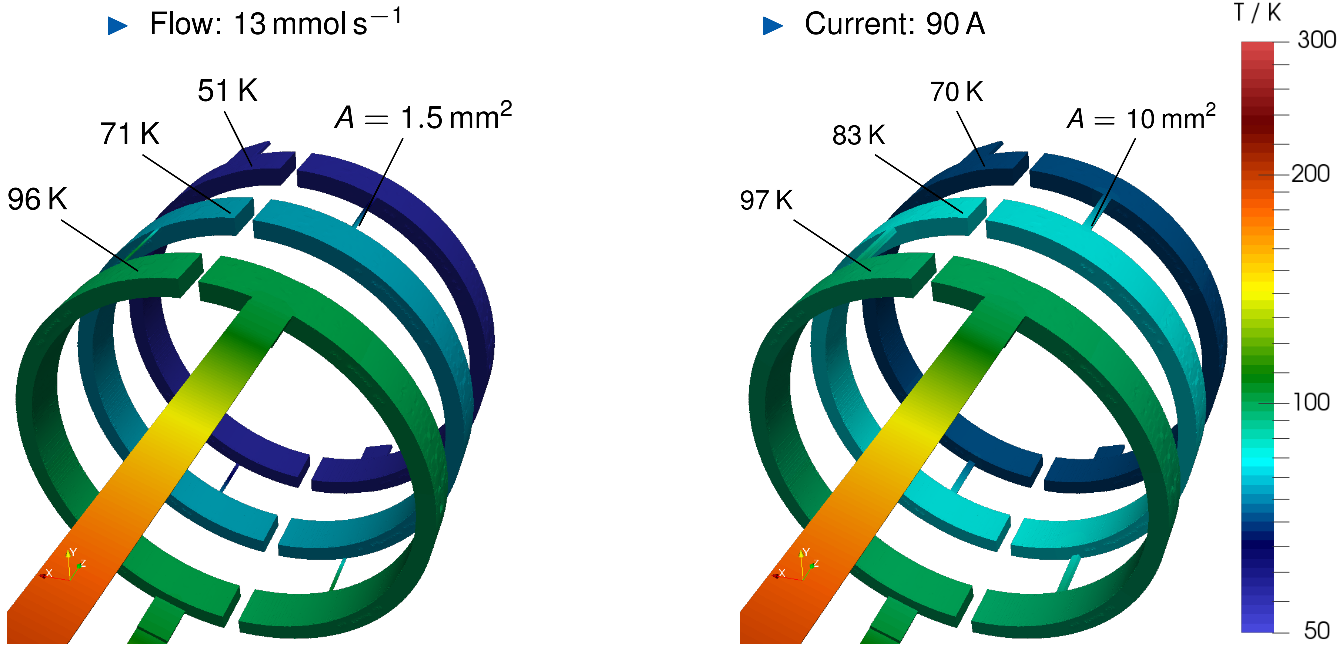
Harmut Dutz (Bonn): Design, construction, and testing of a high-field, thin, *internal* polarizing magnet (and many other topics!)

Magnets for polarized (solid) targets

Results - Temperature distribution

Boundary conditions

- Inlet: Gas-Temperature 40 K
- Flow: 13 mmol s^{-1}
- Outlet-Pressure 50 mbar
- Current: 90 A



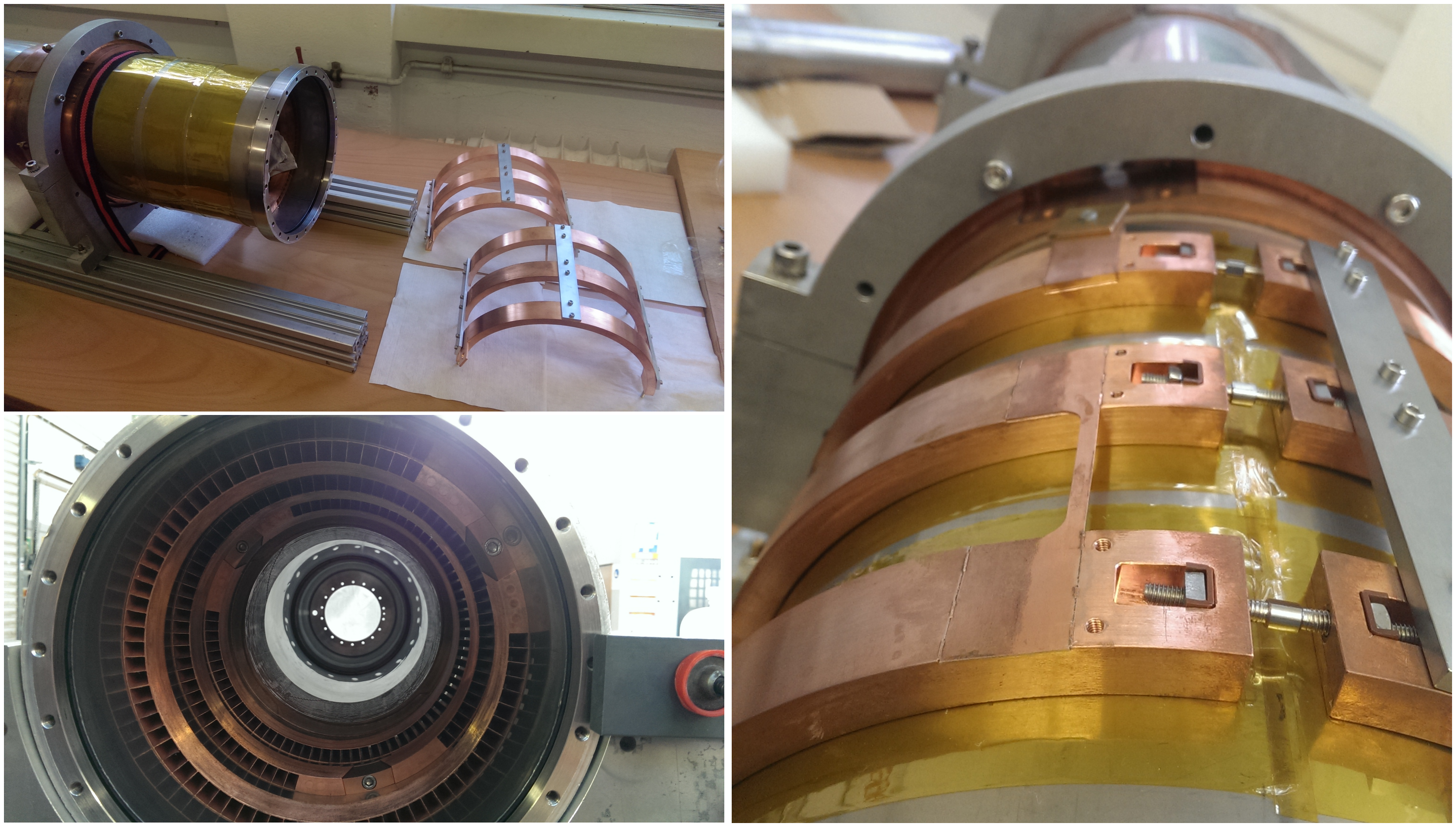
- Joule heating: 2 x 4.15 W
  (consistent with McFee)
- Joule heating: 2 x 3 W

Result: Lower end temperatures by thermal decoupling of each sink with optimised bridges

Marcel Borstein (Bonn): FEA modelling and construction of current leads for internal polarizing magnet

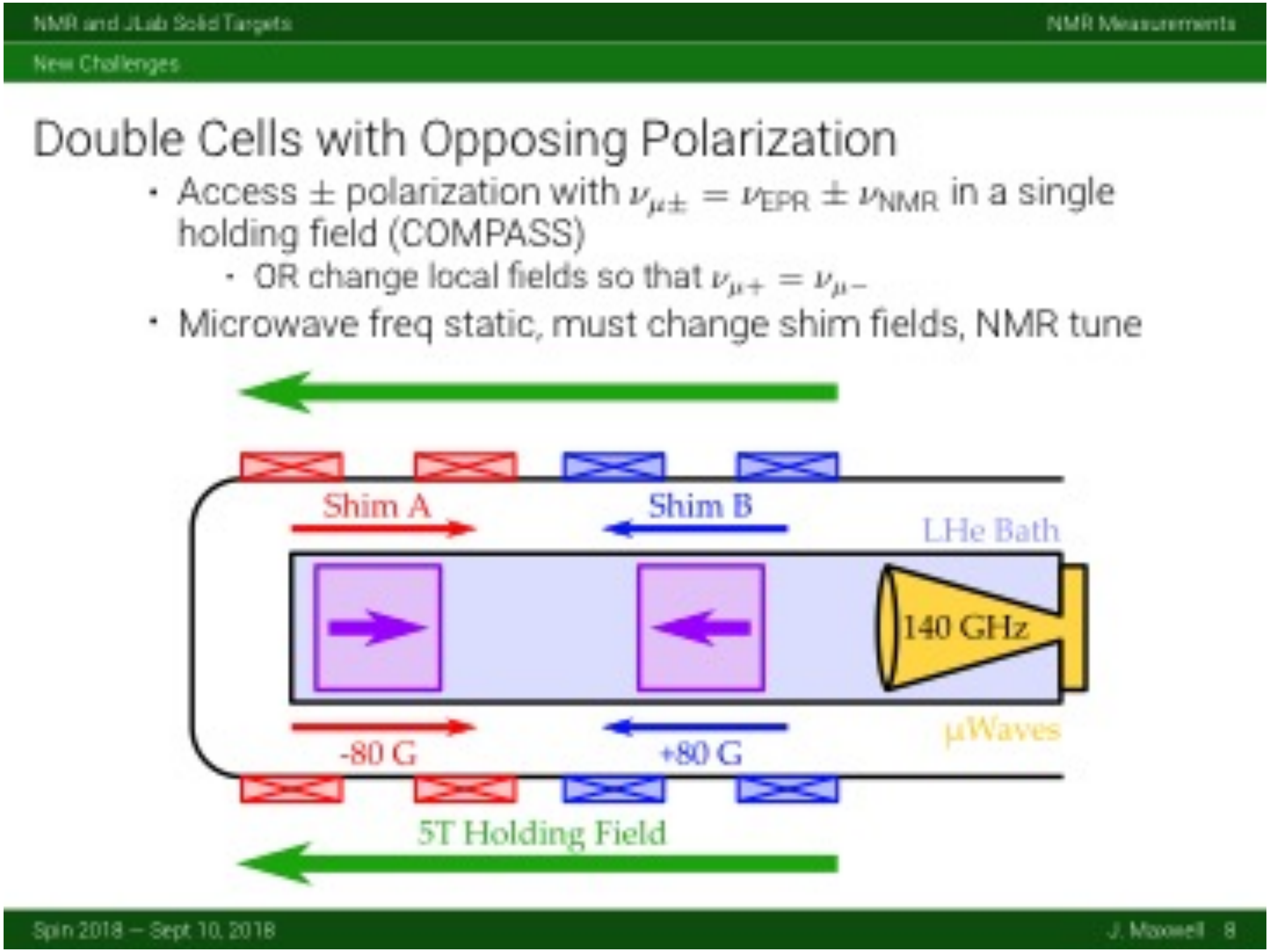
Magnets for polarized (solid) targets

Current leads concept- Impressions



Marcel Borstein (Bonn): FEA modelling and construction of current leads for internal polarizing magnet

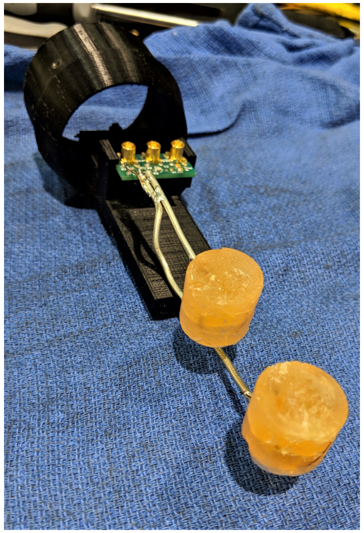
Magnets for polarized (solid) targets

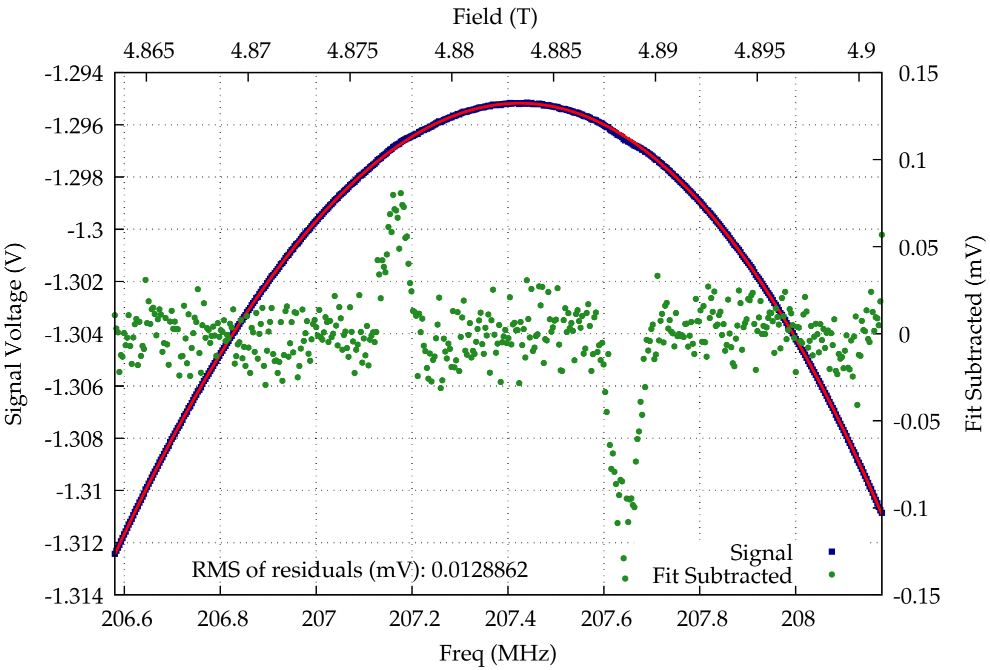


James Maxwell (JLab): Demonstration of double-sample polarization with internal shim coils

Magnets for polarized (solid) targets

Double Cell, Opposing Polarization





James Maxwell (JLab): Demonstration of double-sample polarization with internal shim coils

Magnets for polarized (solid) targets

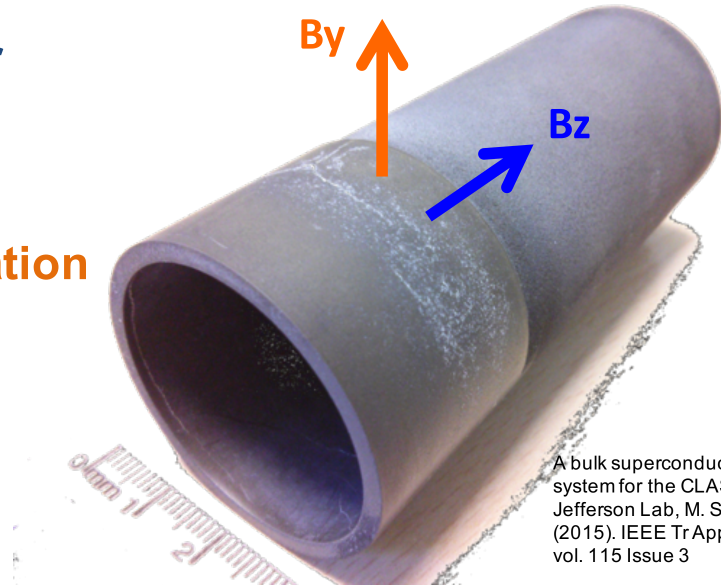
A BULK TRANSVERSE MAGNET?

bulk cylinder

- **MgB_2**
- **longitudinal shield**
- **transverse magnetization**

features

- no current leads
- Cu free
- self tuning
- simple
- low making cost
- few mm thickness
- external magnet (magnetization)

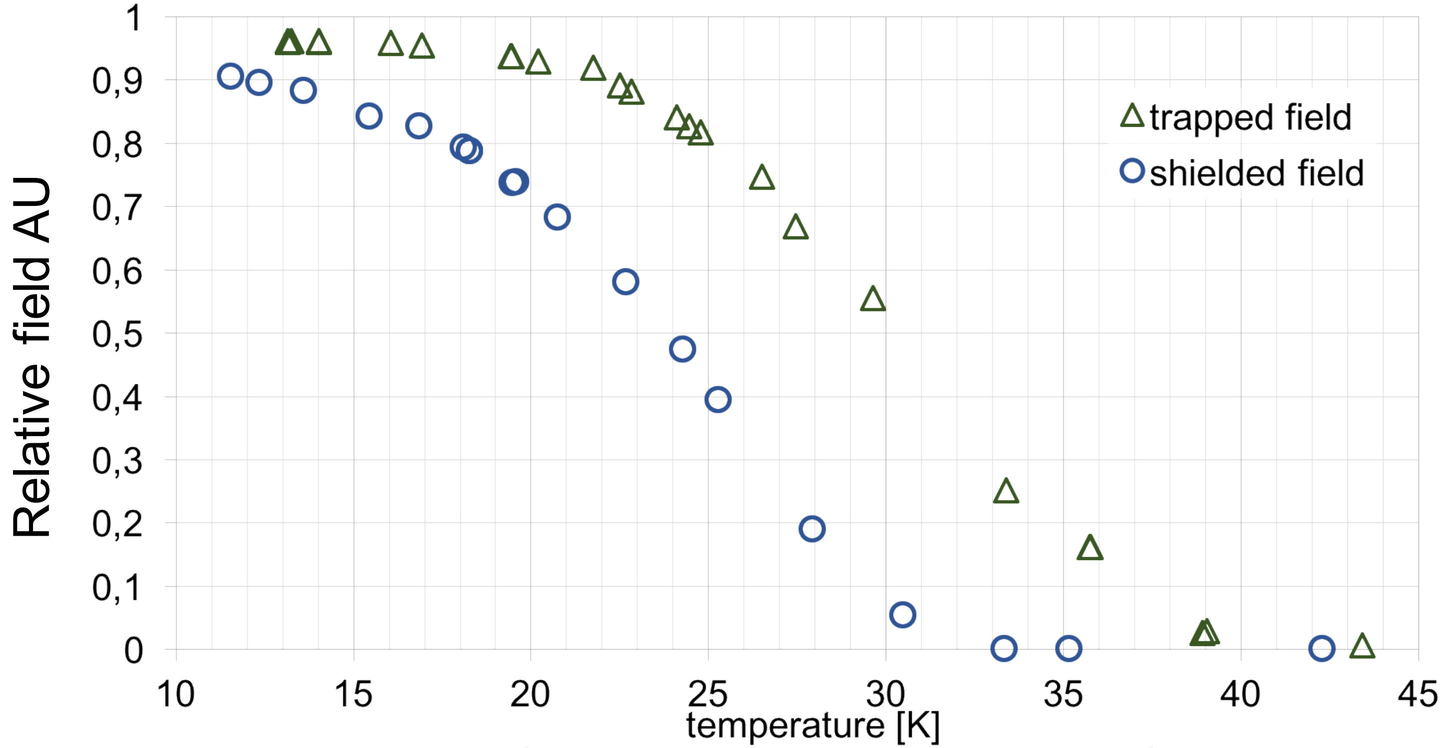


existing sample (courtesy of G. Giunchi)
diameter 39 mm - length 90 mm
thickness ~1 mm

Marco Statera (INFN Ferrara): Bulk superconducting magnet (and shield!) for transverse polarized target

Magnets for polarized (solid) targets

SHIELDING VS TRAPPED FIELD



- field trapping: residual field
- shielding: shielded field

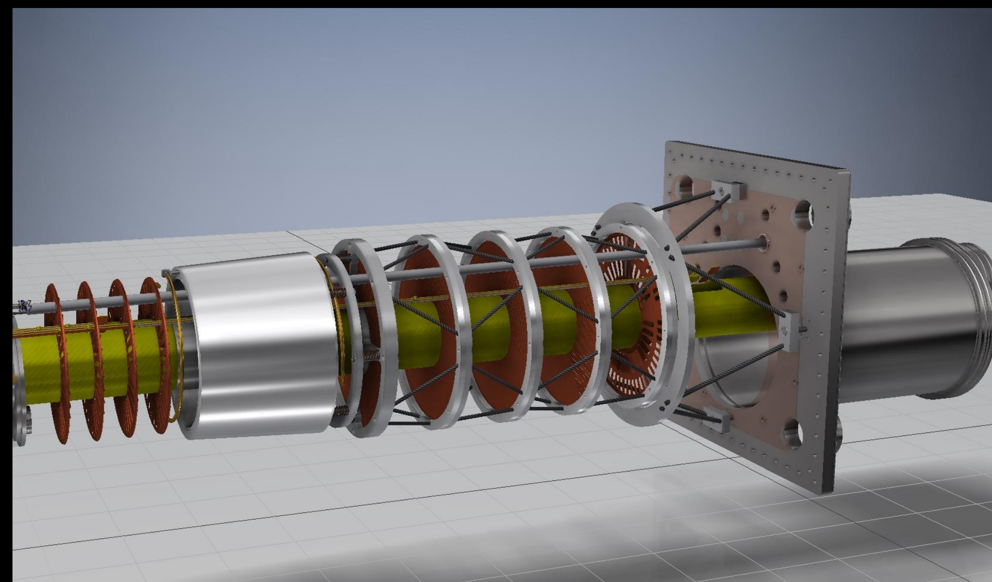
Marco Statera (INFN Ferrara): Bulk superconducting magnet (and shield!) for transverse polarized target

Refrigerators for polarized (solid) targets

12 GeV POLTAR Target Design

Modular Geometric Truss structure

- Conical HX Spring loaded into Pump Tube to ensure good thermal contact with Pump Tube Heat Sink
- All Refrigerator Components are modular and can be uncoupled without cutting or grinding of parts



Jefferson Lab

TARGET GROUP

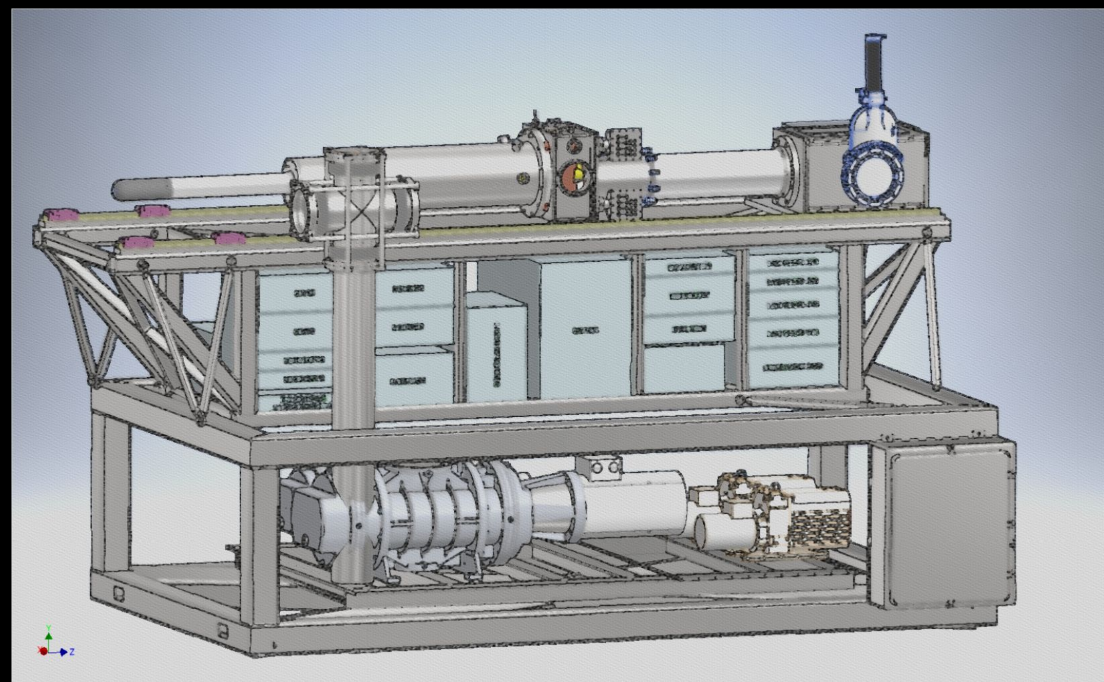
James Brock (JLab): Innovative design and construction techniques for the CLAS12 polarized target

Refrigerators for polarized (solid) targets

12 GeV POLTAR Plug and Play Target

Transportation Configuration

- Refrigerator Retracted Over Cart
- Isolation Valve for Refrigerator
- Modeling Complete Target System Allows Strategically Place Lifting Points Based on COG



Jefferson Lab

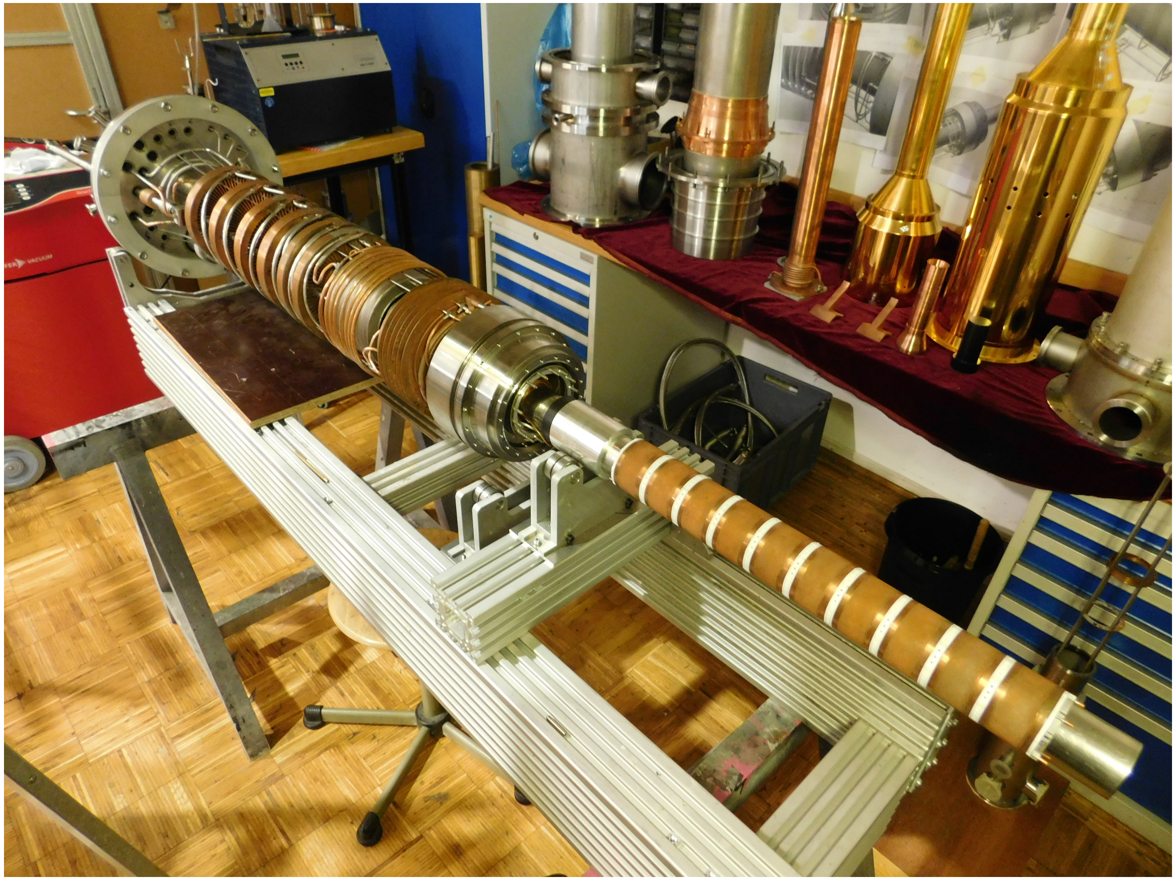
TARGET GROUP

James Brock (JLab): Innovative design and construction techniques for the CLAS12 polarized target

Refrigerators for polarized (solid) targets

4π-Continuous Target

UNIVERSITÄT BONN

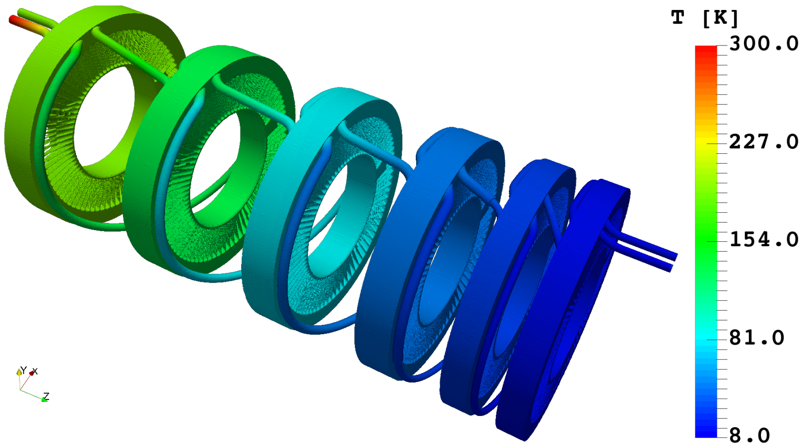


Stefan Runkel (Bonn): CFD modelling of polarized target heat exchangers

Refrigerators for polarized (solid) targets

Heat Exchanger 1

UNIVERSITÄT BONN



- Data for $\dot{n}_{^3\mathrm{He}} = 1\,\mathrm{mmol\,s^{-1}}$.
- Well defined temperature gradient along the heat exchanger.
- Temperature after the last stage of 8 K is reached.
- Simulation performed for all heat exchangers and a circulation rate of 1 to 20 $\mathrm{mmol\,s^{-1}}$

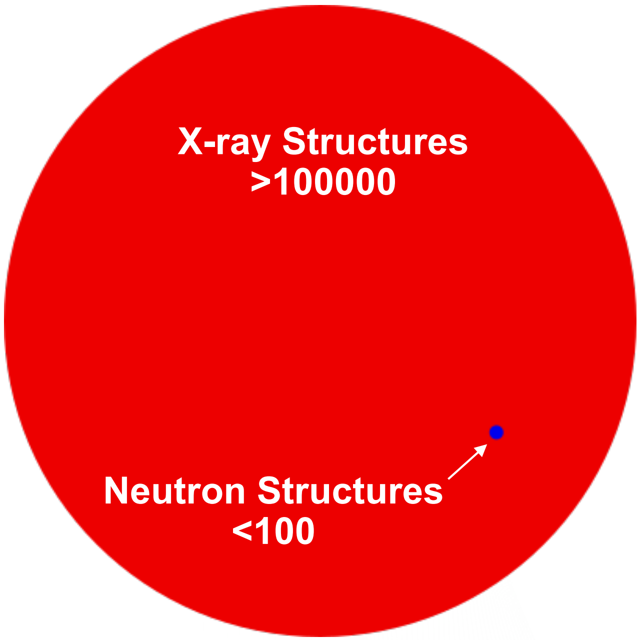
	Simulation	Measurement
$\mathrm{HE1_{in}}$	170 K	170(5) K
$\mathrm{HE1_{middle}}$	43 K	43(3) K
$\mathrm{HE1_{out}}$	8 K	8(1) K
$p_{^3\mathrm{He_{in}}}$	100 mbar	105(10) mbar
$p_{^3\mathrm{He_{out}}}$	2.1×10^{-2} mbar	$2.2(2) \times 10^{-2}$ mbar
$p_{^4\mathrm{He_{out}}}$	15 mbar	15(3) mbar

Stefan Runkel (Bonn): CFD modelling of polarized target heat exchangers

Materials for polarized (solid) targets

Neutron protein crystallography

- Usually, macromolecular crystallography uses X-ray facilities to measure molecular structure
  - Modern light sources have incredibly high flux
- Using neutrons for crystallography has pros/cons:
  - Comparatively low flux
  - Sensitivity of the neutron cross section to lighter elements (especially hydrogen)
  - Sensitivity to isotopes
- NPX is a unique experimental tool for the experimental location of key hydrogen atoms and water molecules in biological macromolecules, but use is limited by requirement for huge crystals.



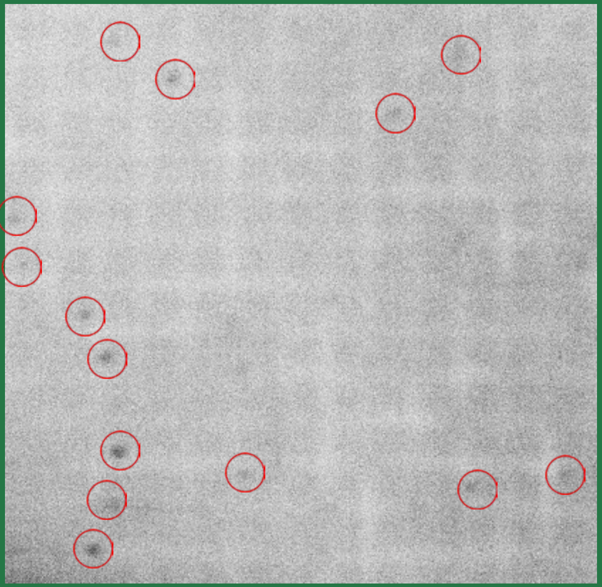
X-ray Crystals $<0.001mm^3$
Neutron Crystals $>0.1mm^3$

Josh Pierce (ORNL): Neutron crystallography of dynamically polarized protein samples

Materials for polarized (solid) targets

T4 Lysozyme Results

- Doped with TEMPO
- "Large" crystals
  - ~0.5mm-1.0mm on edge
- Detector was uncalibrated, and shifted between frames
- Short hold times in "frozen spin" mode
  - ~60-180 min T_1
  - Very high temperatures
    - ~230 mK
- Measured diffraction pattern change
- Enhancements of 2-3 in integrated diffraction pattern for anti-aligned spins
  - The enhancement of individual reflections depends varies depending on the relative contribution of hydrogen
- Consistent with maximum polarizations of around 50%



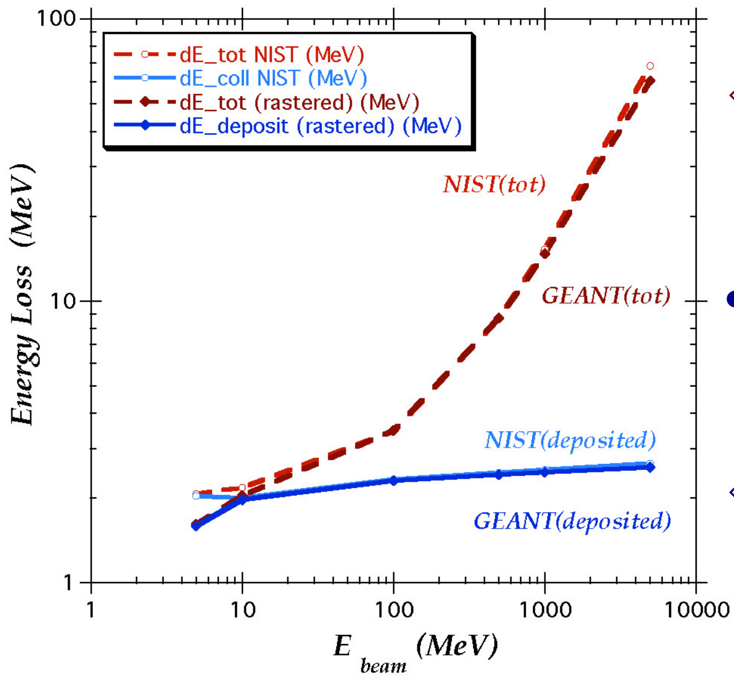
Polarized

Josh Pierce (ORNL): Neutron crystallography of dynamically polarized protein samples

Materials for polarized (solid) targets

energy deposited in HD

Electron energy loss in 5 cm of HD:



⇦ loss dominated by bremsstrahlung

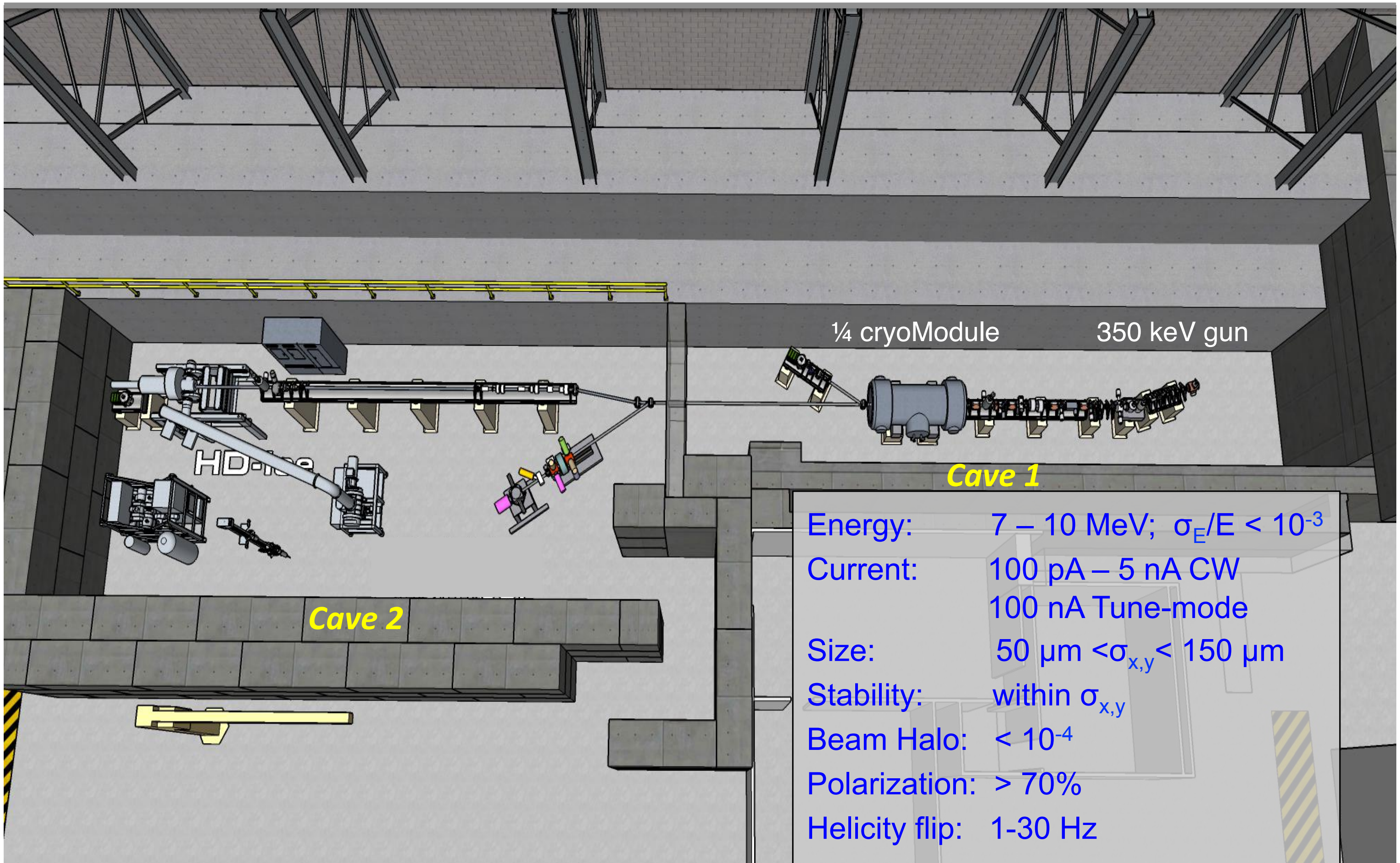
- deposition dominated by Møllers
  $\sigma_{Møller} \sim (1 + 1/\gamma)^2$
  ~ independent of beam energy

⇦ deposition: 2 Mev/e⁻ = 1 mW/ ½ nA
  ~ independent of beam energy

Andy Sandorfi (JLab): testing solid HD target (HDice) with electron beams

Materials for polarized (solid) targets

Testing eHD at Jlab's ***Upgraded Injector Test Facility*** *(UITF)*



SPIN'2018 – Sept 11, 2018

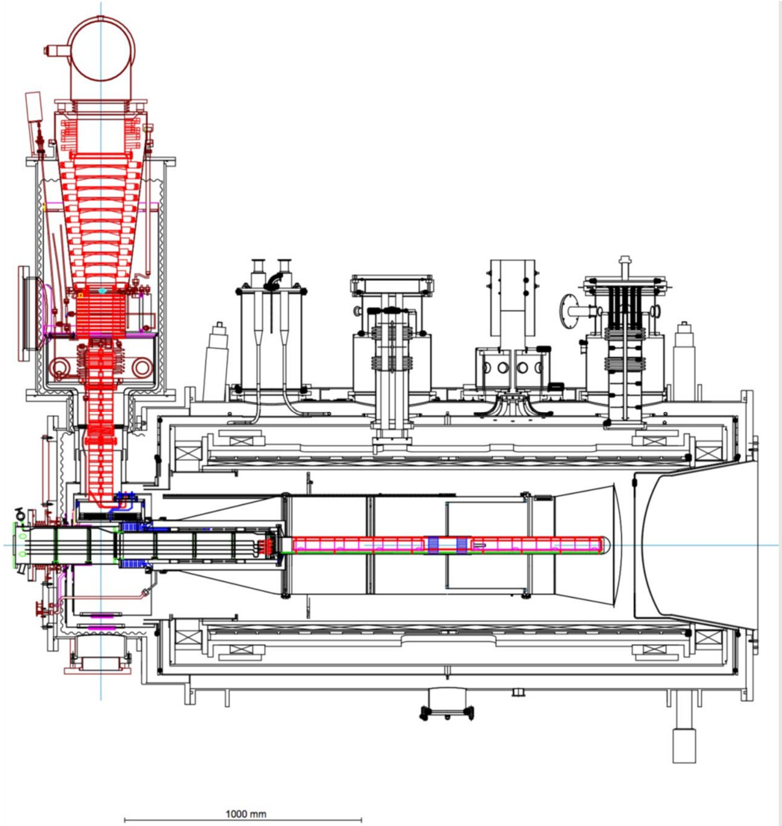
Andy Sandorfi (JLab): testing solid HD target (HDice) with electron beams

Polarized (solid) targets

RUHR-UNIVERSITÄT BOCHUM

RUB

COMPASS Polarized Target



First time hadron beam was used with the COMPASS PT system

- 2.5 T solenoid + 0.6 T dipole
- 50 mK dilution refrigerator
- 2 x 55 cm long target cells
- NH_3 as proton target (17% df)
- DNP by microwave of 70 GHz
- 10 NMR coils
- Frozen spin mode at 50mK

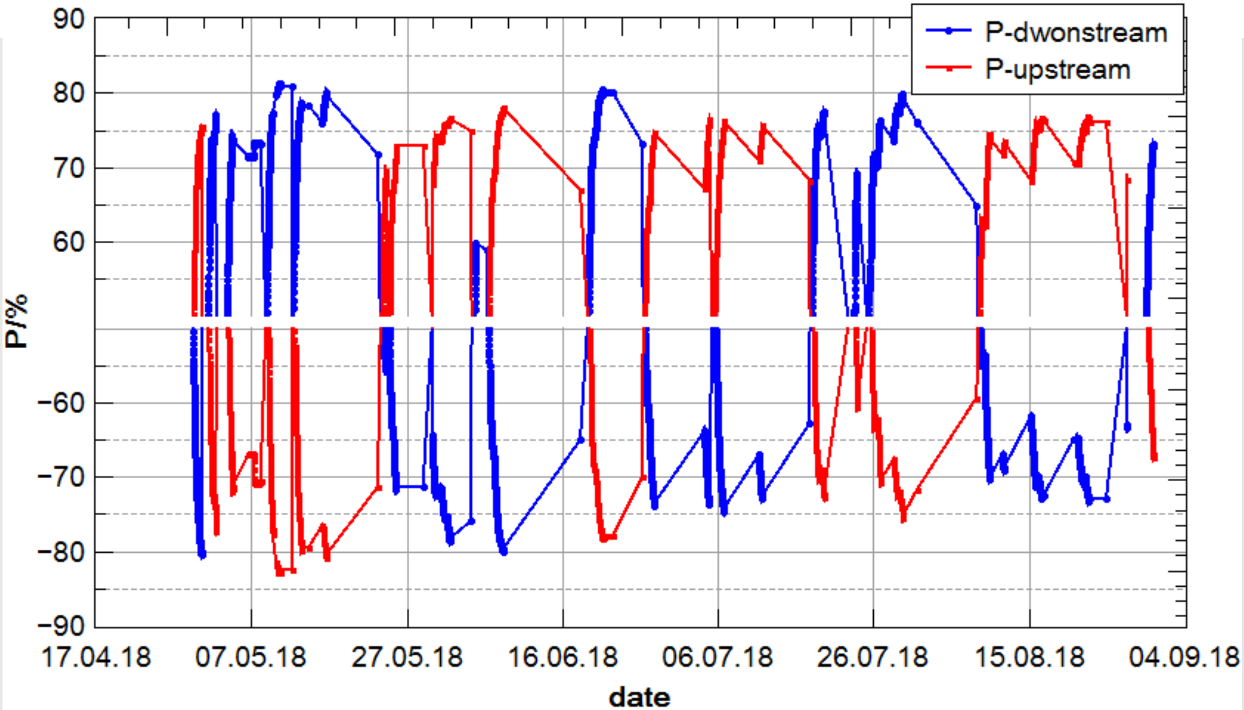
Gerhard Reichertz (Bochum): Performance of COMPASS target in 2018, prospects for use in 2021

Polarized (solid) targets

RUHR-UNIVERSITÄT BOCHUM

Polarization in 2018

RUB



Maximum Polarization

upstream : 78.1% , -82.8%

downstream : 81.3% , -80.5%

preliminary

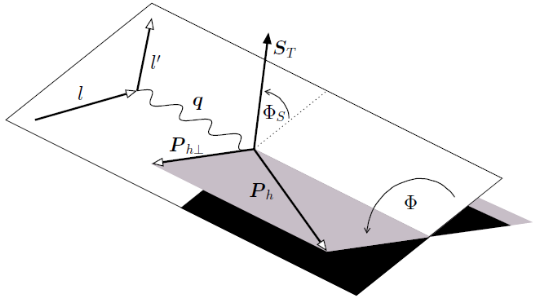
Gerhard Reichertz (Bochum): Performance of COMPASS target in 2018, prospects for use in 2021

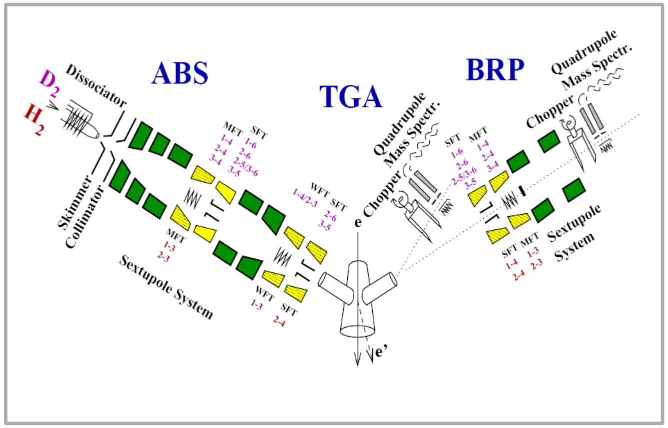
Polarized (gas) targets

Overview: Polarized Gas Target for the LHC

Design considerations for a PGT

- Physics accessible at LHC (no polarized beam): Single Spin Azimuthal Asymmetries (SSAA), measured with **transverse polarization of the target S_T** and Φ-dependence of the final-state hadrons.
- Polarized gas target similar to HERMES (see sketch), incl. Atomic Beam Source (ABS), Storage Cell (SC) target with strong transverse guide field, target gas analyzer (TGA) and polarimeter (BRP), powerful differential pumping, etc.
- All narrow openings in the LHC, like the VELO detector, have to be openable during injection and tuning ($r_{min} \approx 27$ mm at IP8). This holds for the PGT set-up as well, with cell, wake field suppressors, detectors, diaphragms etc.





Erhard Steffens (Erlangen): Design considerations for a polarized gas target at the LHC

Polarized (gas) targets

Estimate of the areal density of the PGT

Assumed:

- I_H (100 % HERMES ABS flow) = $6.5 \cdot 10^{16}$/s, may be limited by LHC vacuum constraints or space limitations for the PGT;
- Cell 30 cm long, 1.0 cm i.d., at 100K, with standard feed tube 10 cm long, 1.0 cm i.d.

The **resulting** 100% **density of the polarized gas target is**
$\theta = 1.2 \cdot 10^{14}/\text{cm}^2$, comparable with HERMES.

For the future HL-LHC-25ns, the Luminosity achievable with the PGT would be up to $8.3 \cdot 10^{32}$ /cm^2 s. To which extent such densities can be realized and exploited in a real experiment, depends on many factors and has to be investigated in more detail.

Erhard Steffens (Erlangen): Design considerations for a polarized gas target at the LHC