Polarised target for Drell–Yan experiment in COMPASS at CERN part I

Jan Matoušek
Charles University in Prague and Università degli studi di Trieste

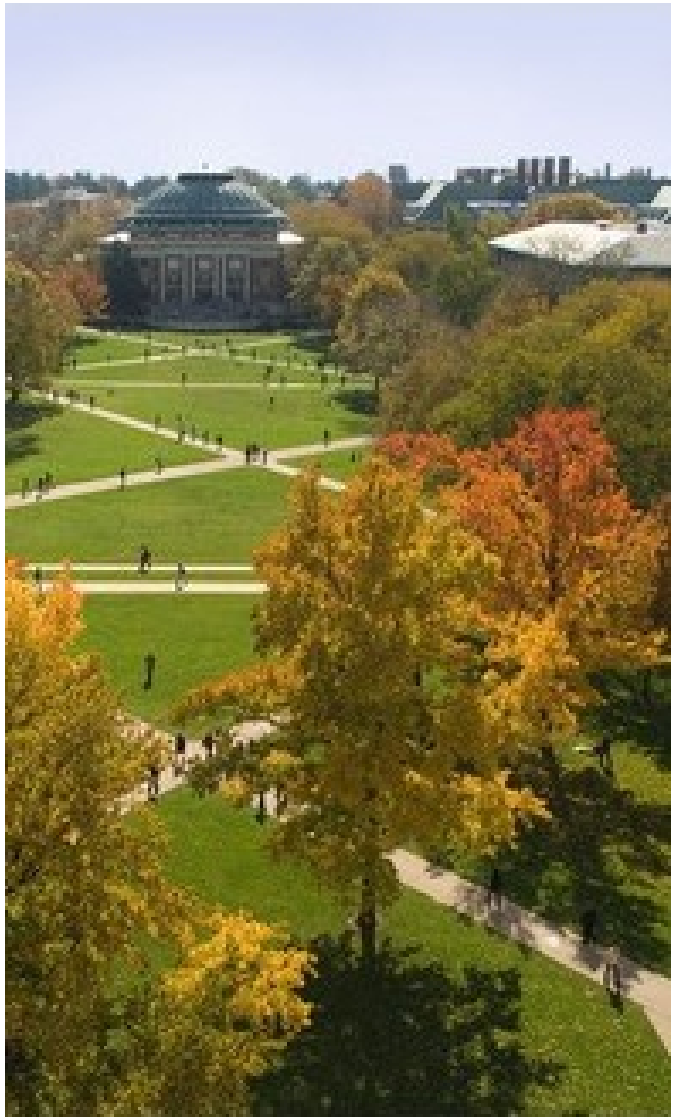
On behalf of the COMPASS Collaboration

http://www.forbes.com/pictures/eidm45elgl/university-of-illinois-urbana-champaign-2/#1d94a647a6f1

27. 9. 2016
The 22nd international spin symposium, Urbana, Illinois

Outline

1. The collaboration
2. Drell–Yan programme
3. Polarised target
4. Polarised target dilution cryostat
5. Polarised target magnet
6. Conclusion of the part I



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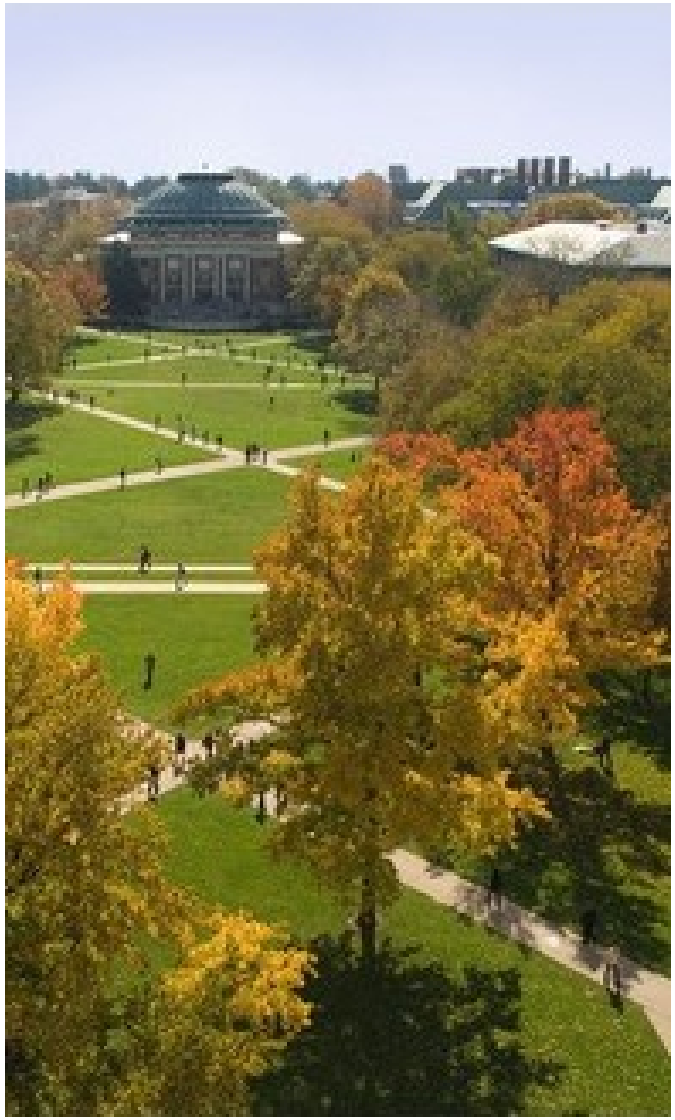


The collaboration: Institutes and location

- Collaboration: 24 institutions from 13 countries ($\approx$ 220 physicists).
- Experimental area: CERN Super Proton Synchrotron (SPS) North Area.
- Secondary beams of μ or hadrons at 160-200 GeV.
- Fixed targets.

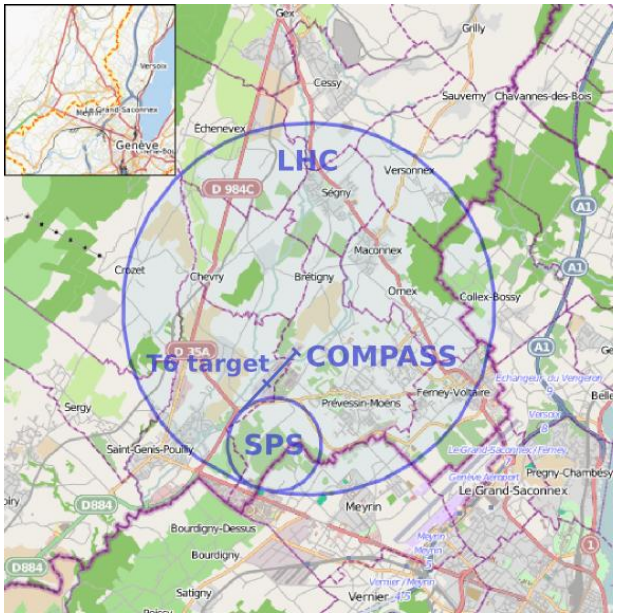


Image credit: Wikimedia Commons, https://en.wikipedia.org/wiki/File:Location_Large_Hadron_Collider.PNG

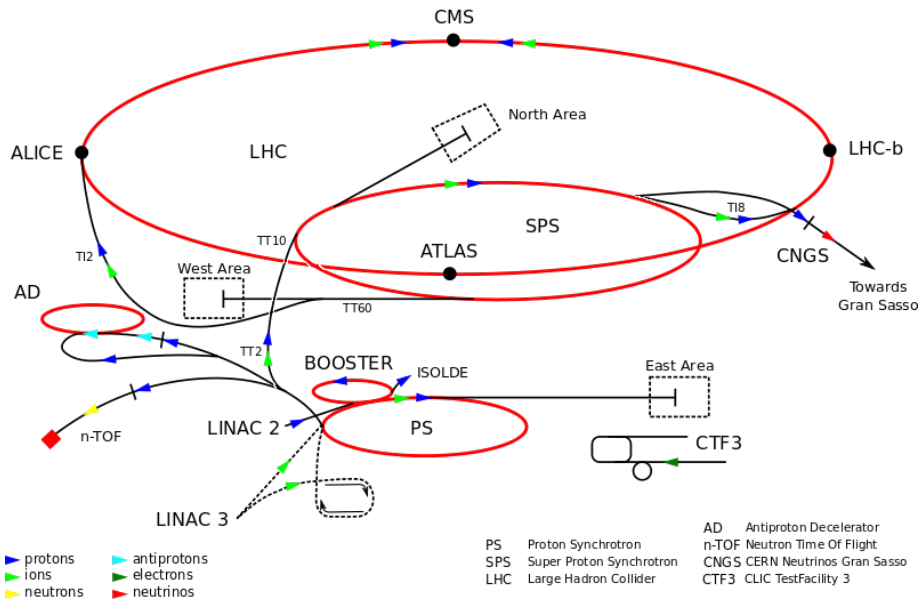
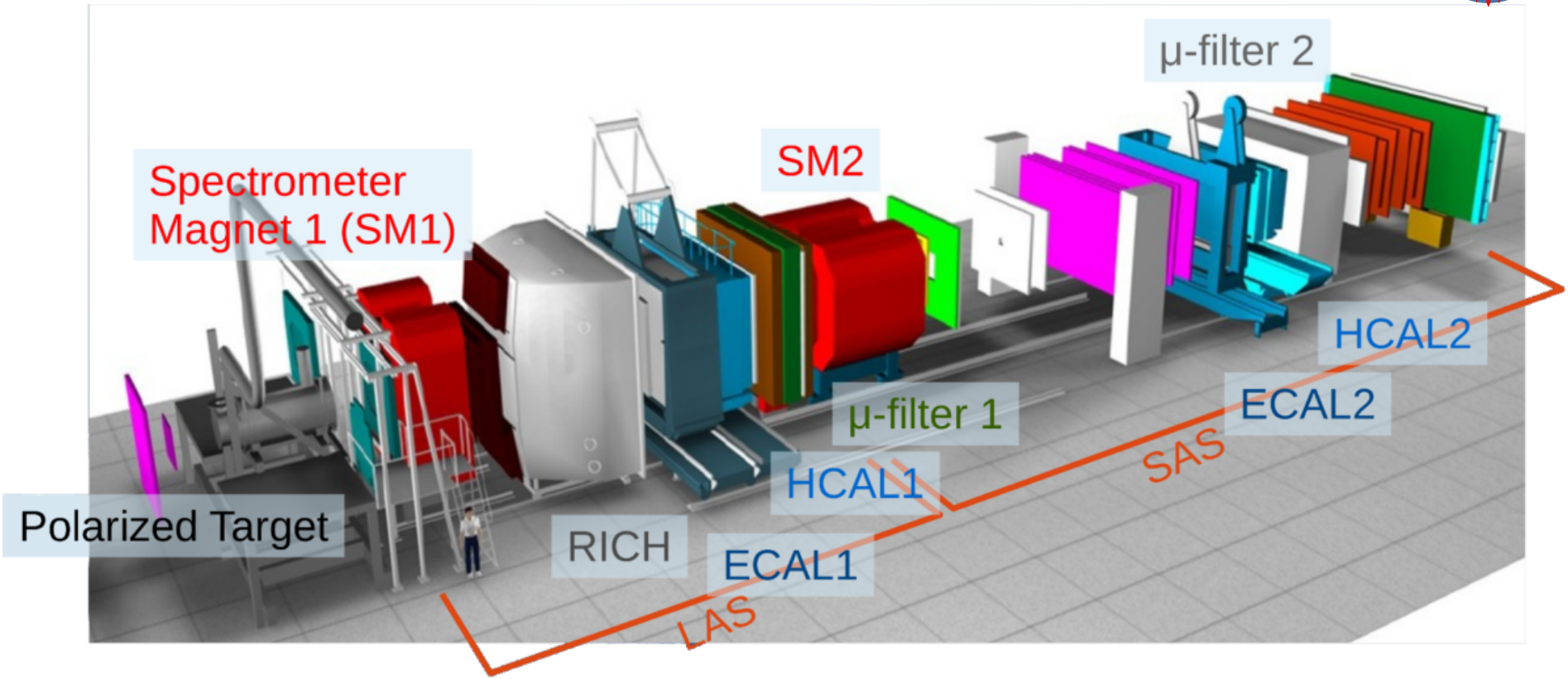


Image credit: Wikimedia Commons, https://en.wikipedia.org/wiki/File:Cern-accelerator-complex.svg

The collaboration: Apparatus

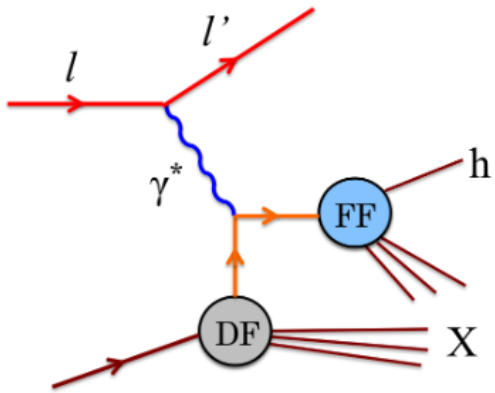


COMPASS set-up for polarised μ programme.

- Two-stage spectrometer.
- About 350 detector planes.
- Particle identification (RICH, calorimeters, μ filters).
- LH_2 and nuclear targets, large solid-state polarised targets (NH_3 and ^6LiD).

Nucleon Structure

- COMPASS I (2002–2011)
  - DIS and SIDIS on L-polarised targets
    $\vec{\mu}^+ + \vec{N} \to \mu^+ + \mathrm{X}$
    $\vec{\mu}^+ + \vec{N} \to \mu^+ + \mathrm{h} + \mathrm{X}$
    $\to$ helicity distributions of quarks and gluons.
  - SIDIS on T-polarised targets $\mu^+ + N^\uparrow \to \mu^+ + \mathrm{X} + \mathrm{h}$
    $\to$ Sivers and Collins effects and more.
- COMPASS II (2012–2017)
  - 2015: Drell–Yan with T-polarised p target
    $\pi^- + p^\uparrow \to \mu^+ + \mu^- + X$.
  - 2016–2017: DVCS and SIDIS with LH_2 target
    (DVCS: $\mu + \mathrm{p} \to \mu + \mathrm{p} + \gamma$ to get GPDs).



SIDIS reaction.

Hadron spectroscopy, chiral dynamics

- Study of light meson spectrum (using a partial-wave analysis of 3π final states).
- 2012: π and K polarisability by scattering π in nuclear Coulomb field.
- And more...

The collaboration: Physics programme

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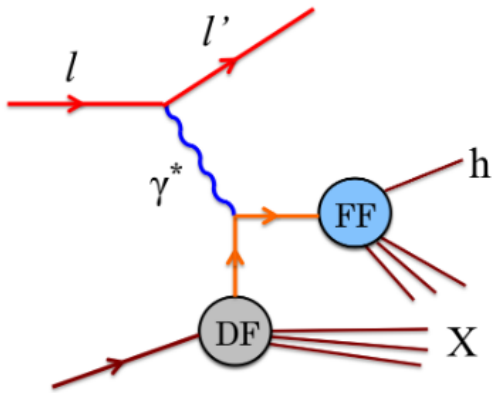

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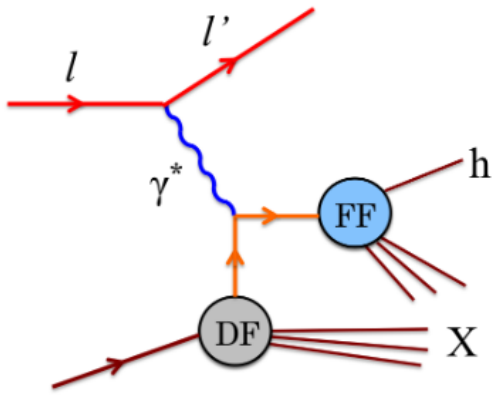

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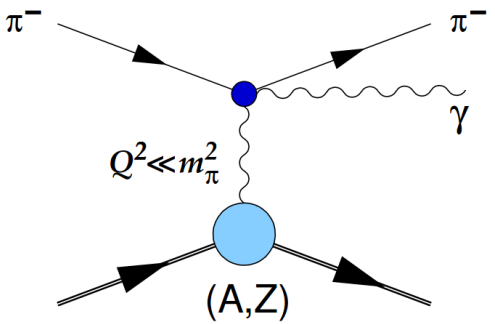

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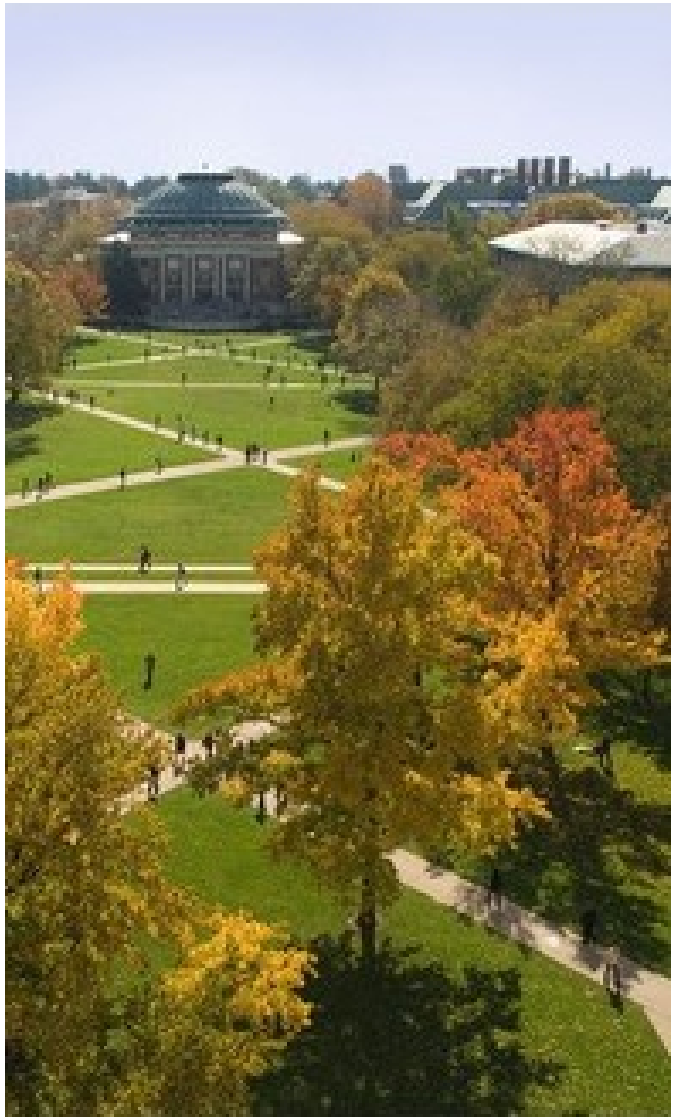

Drell–Yan programme: Motivation

T-polarised SIDIS

- COMPASS, $d^{\uparrow}$ 2002–2004, $p^{\uparrow}$ 2007 & 2010.
- $A = \mathrm{DF}_{q,h_{targ}} \otimes \mathrm{FF}_{q \to h}$.

T-polarised Drell–Yan

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- low x-section.
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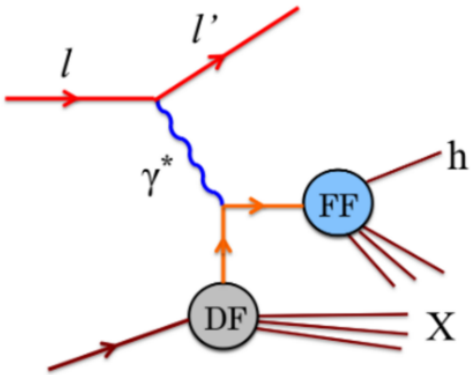

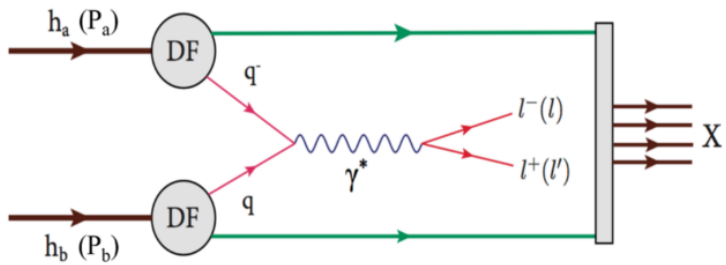

- Unique test of the universality of DF (Sivers function sign change).
- Partonic structure of hadrons (leading twist):
  - $\vec{k}_T$ integrated: number density , helicity , transversity PDFs.
  - k_T^2 dependent: 5 more distributions, including
    Sivers PDF (unpol. quarks in T-pol. hadron)
    Boer–Mulders PDF (T-pol. quarks in unpol. hadron)

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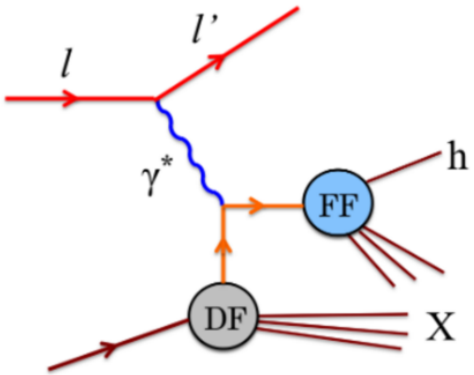

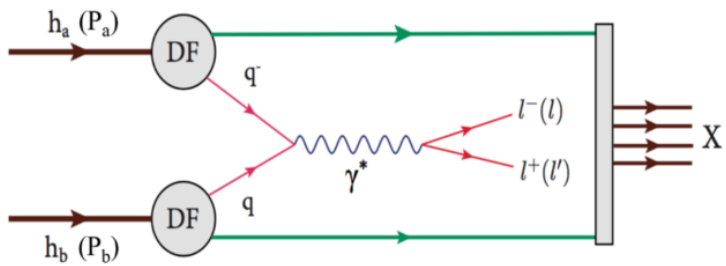

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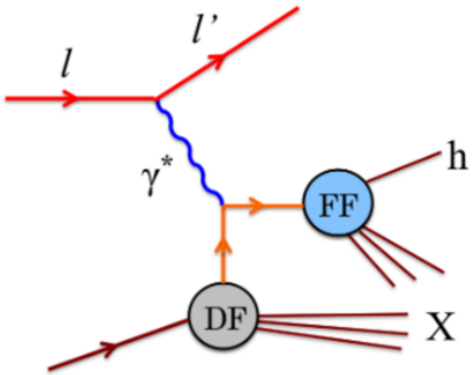

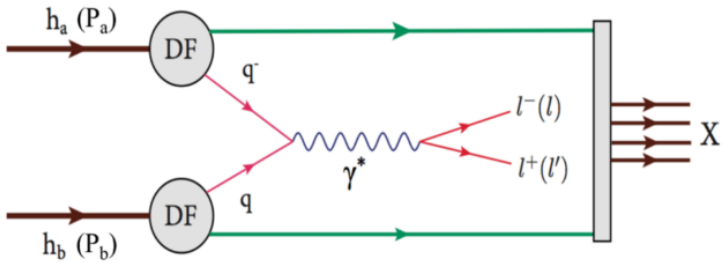

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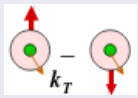
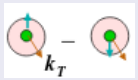
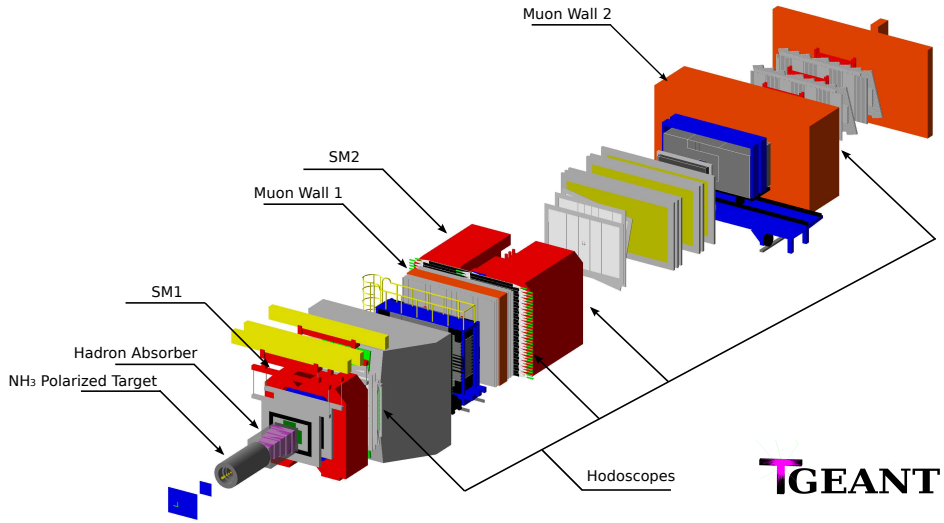
    Sivers PDF  (unpol. quarks in T-pol. hadron)

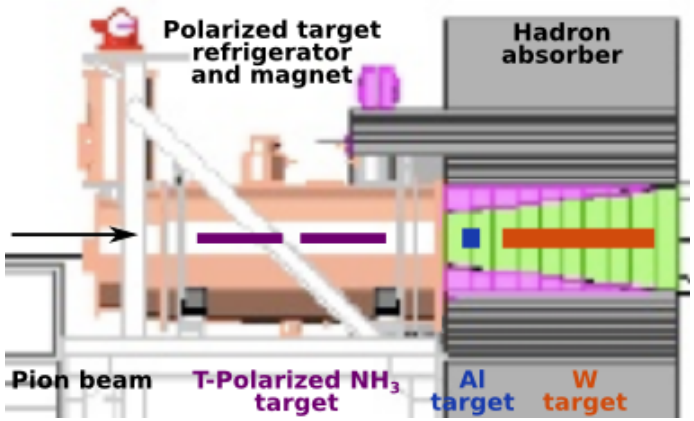
    Boer–Mulders PDF  (T-pol. quarks in unpol. hadron)

Drell–Yan programme: Characteristics and challenges



3D view of the DY set-up in COMPASS MC simulation.

- Transversely polarised p (NH_3) target plus Al and W targets.
- 190 GeV/c π^- beam (plus $\approx$ 2.5% K^-, 0.5% p^-)
- Low x-section $\rightarrow$ high beam flux needed ($\approx 10^9$ π^-/spill of 10 s).
- Hadron absorber – μ filter, ensures reasonable detector occupancies.



The target region.

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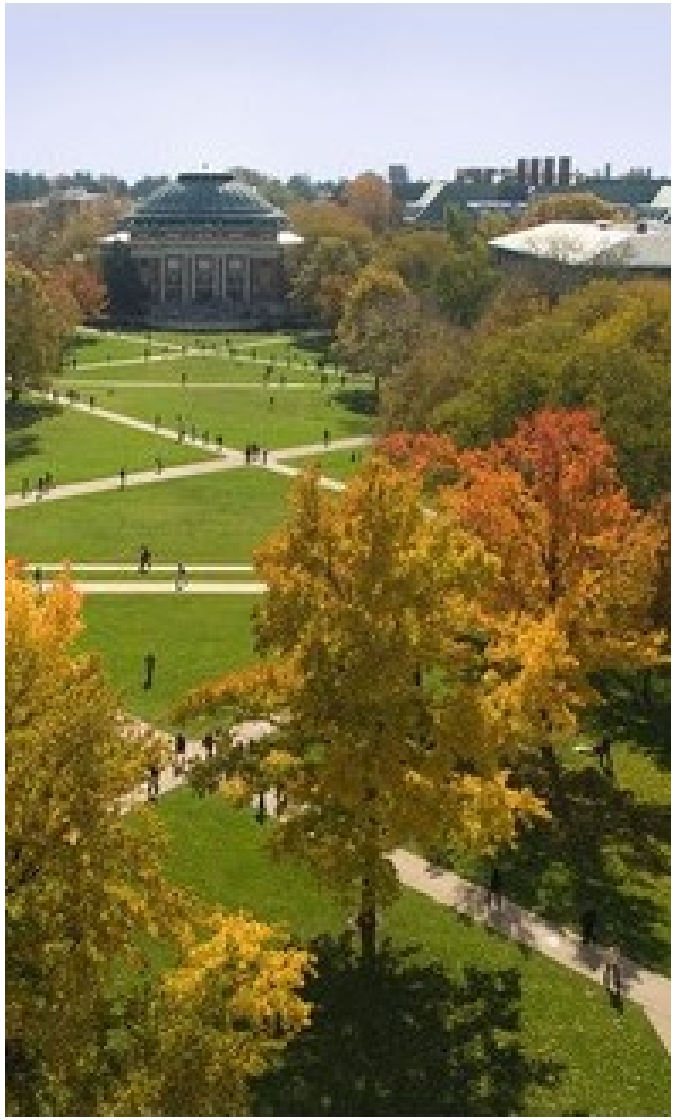

Polarised target: Requirements

- μ SIDIS (& Drell–Yan too): need maximize # interactions in the target.
- $\rightarrow$ Large solid-state target.
- Unlike e^-, nuclei reach polarisation only $P = \mathcal{O}(0.01)$, even at low T & high B.
- Relaxation times (to equilib. P) become very long.
- $\rightarrow$ Dynamic nuclear polarisation (DNP) is needed.
  - $\rightarrow$ High magnetic field ($\mathcal{O}(1)$ T).
  - $\rightarrow$ Microwave system.
  - $\rightarrow$ Very low temperature (≈ 0.3 K) & high cooling power ($\mathcal{O}(0.1)$ W).
- Fast 180° rotations of P, transverse P. $\rightarrow$ Frozen spin mode.
  - $\rightarrow$ Extremely low temperature (< 100 mK) & high cooling power ($\mathcal{O}(1)$ mW).
- $\rightarrow$ Dilution cryostat can meet the cooling needs in both regimes.
- polarisation measurement $\rightarrow$ continuous-wave NMR
  - $\rightarrow$ Precise thermometry for TE calibration at ≈ 1 K.

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1992: SMC polarised target
[SMC Col., NIMA 437 (1999) 23].

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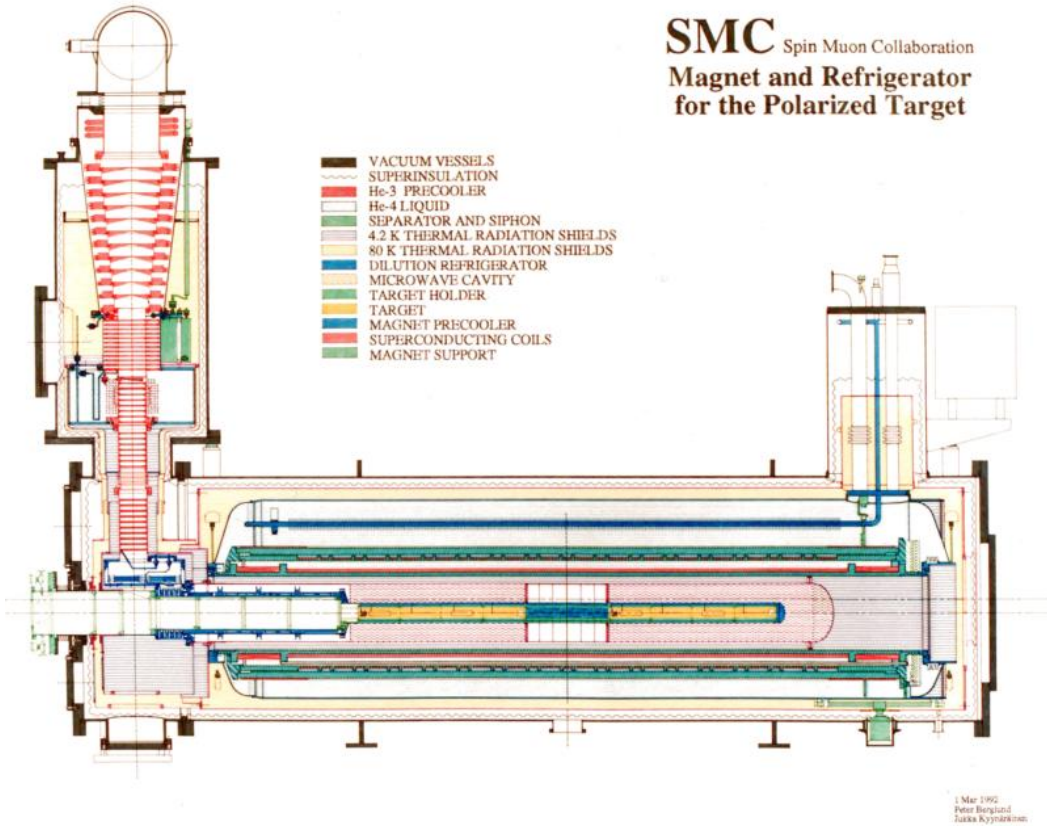

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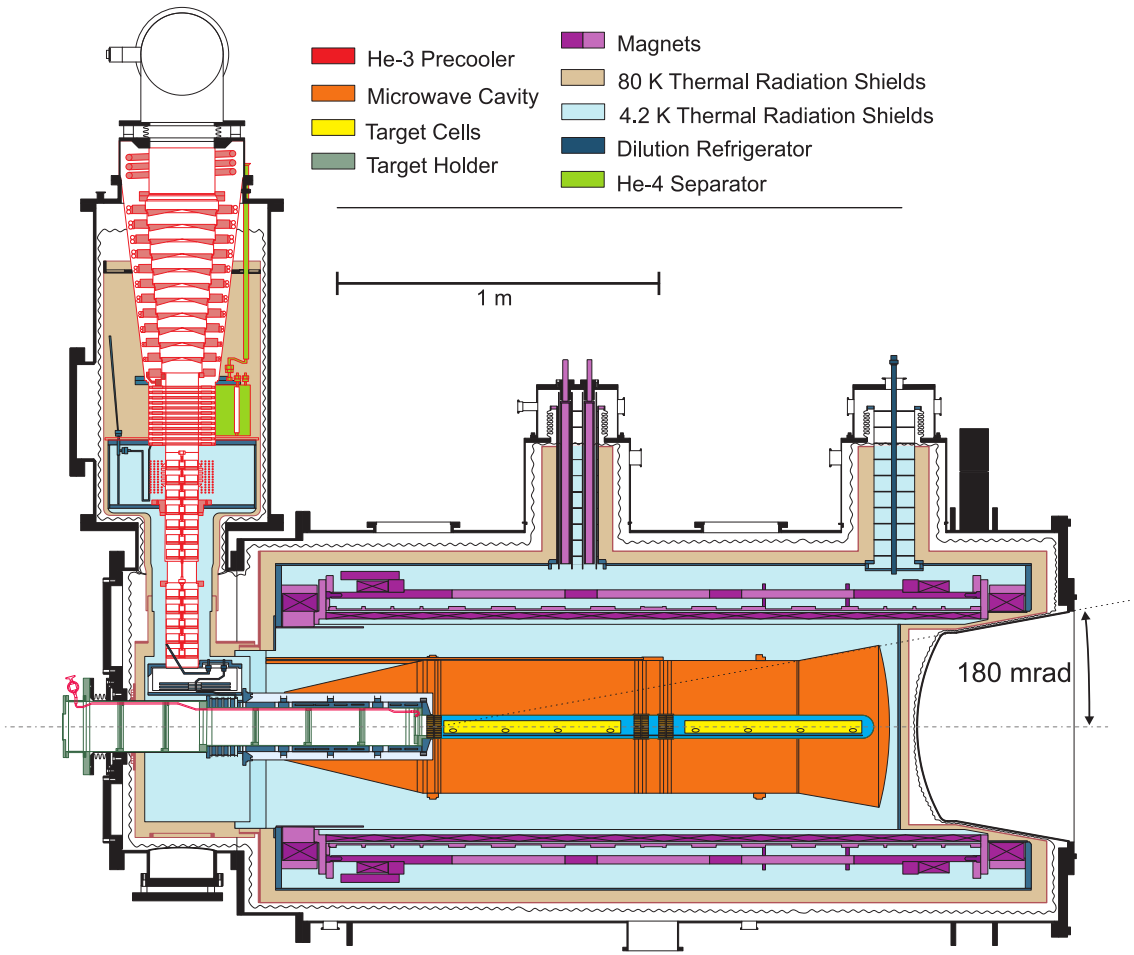

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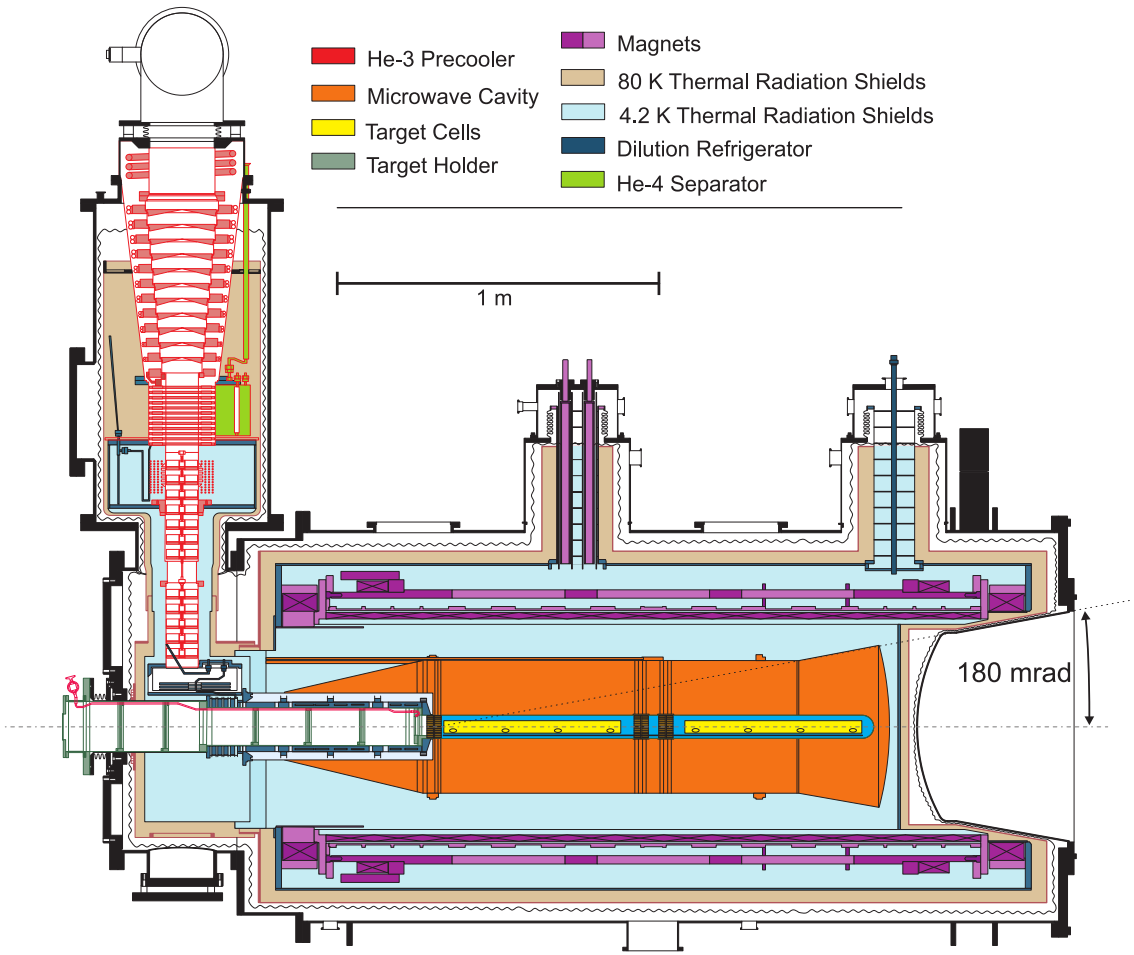
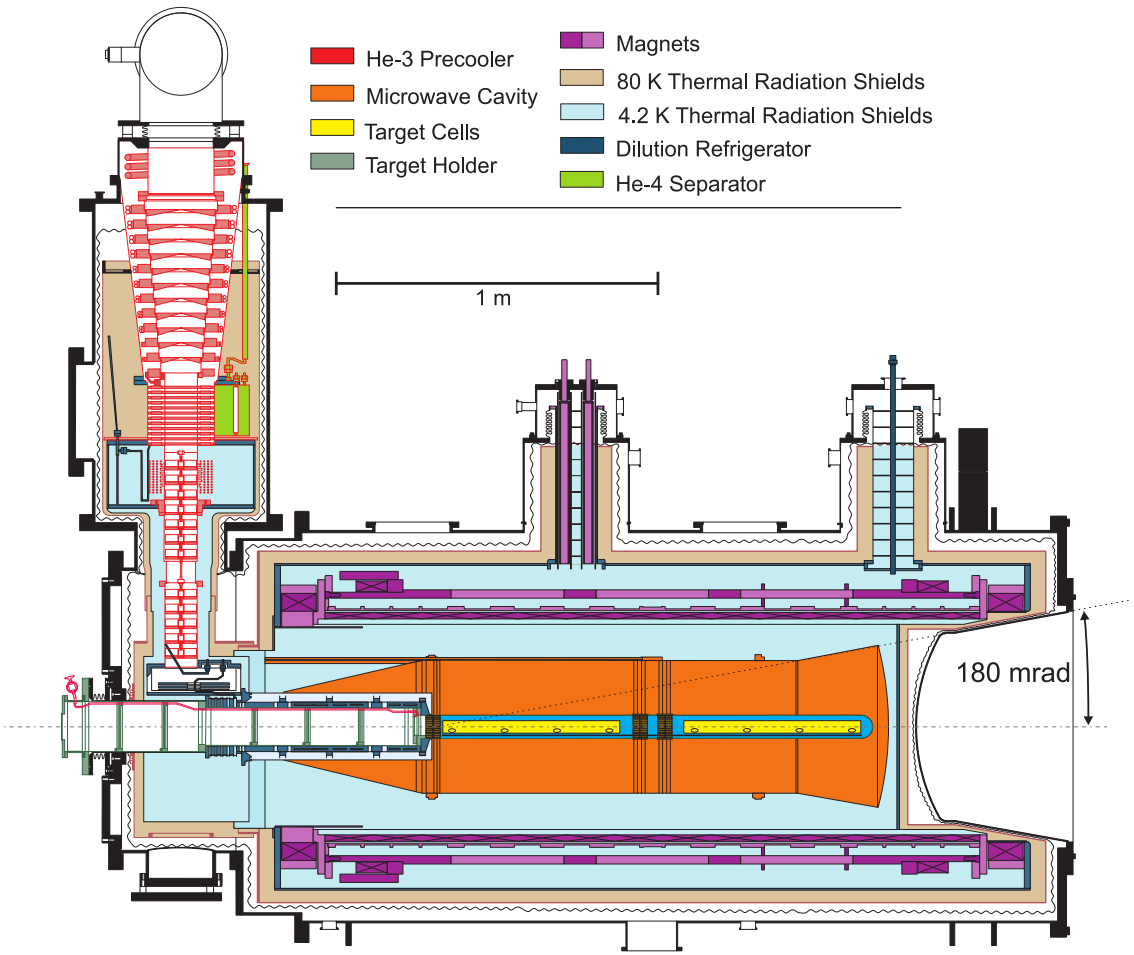


The polarised target

Polarised target: Key elements

- Target holder, beam window.
- Target cells.
- Microwave cavity.
- SC magnets.
- Dilution refrigerator
  - Mixing chamber,
  - ^{3}He evaporator (still),
  - ^{3}He pumping line,
  - ^{3}He precooler,
  - ^{4}He evaporator.



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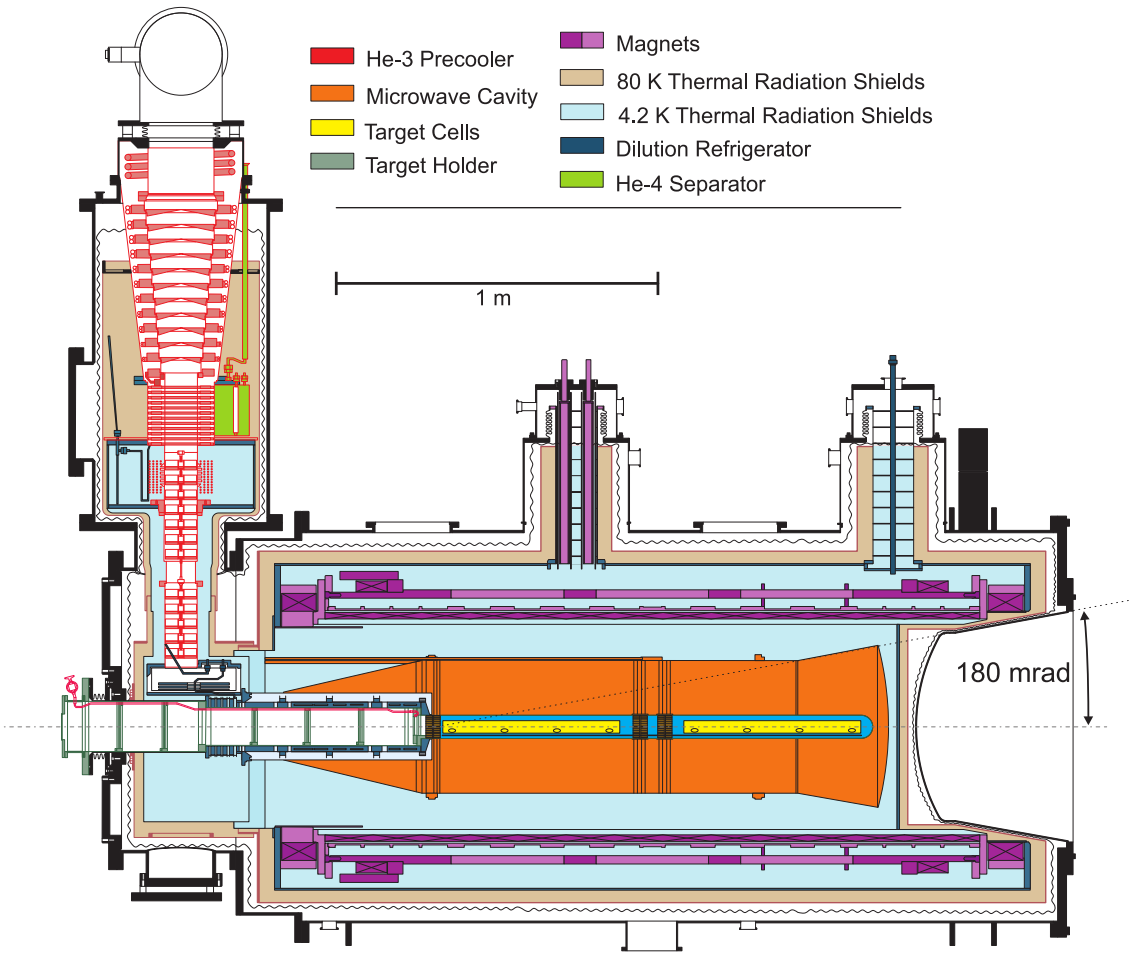

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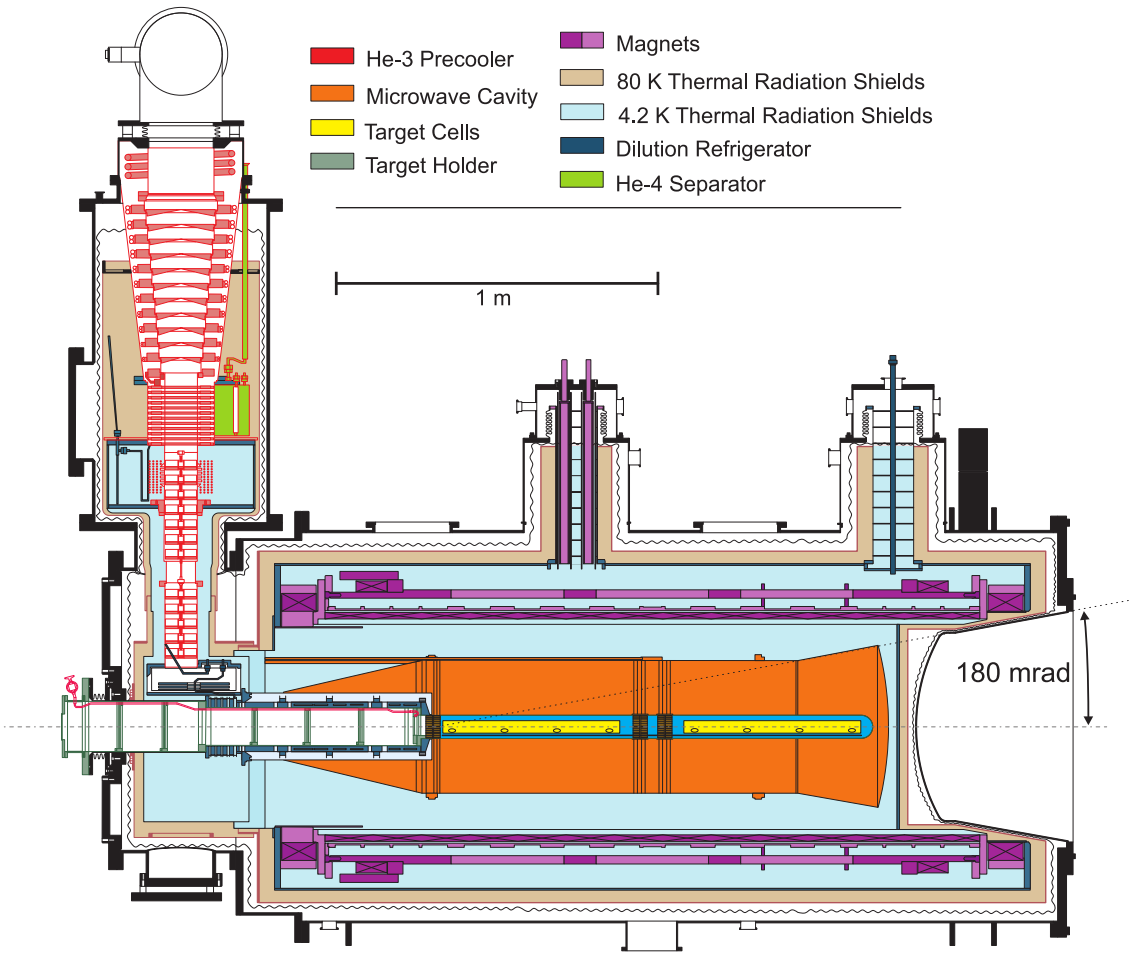

The polarised target

Polarised target: Key elements

- Target holder, beam window.
- Target cells.
- Microwave cavity.
- SC magnets.
- Dilution refrigerator
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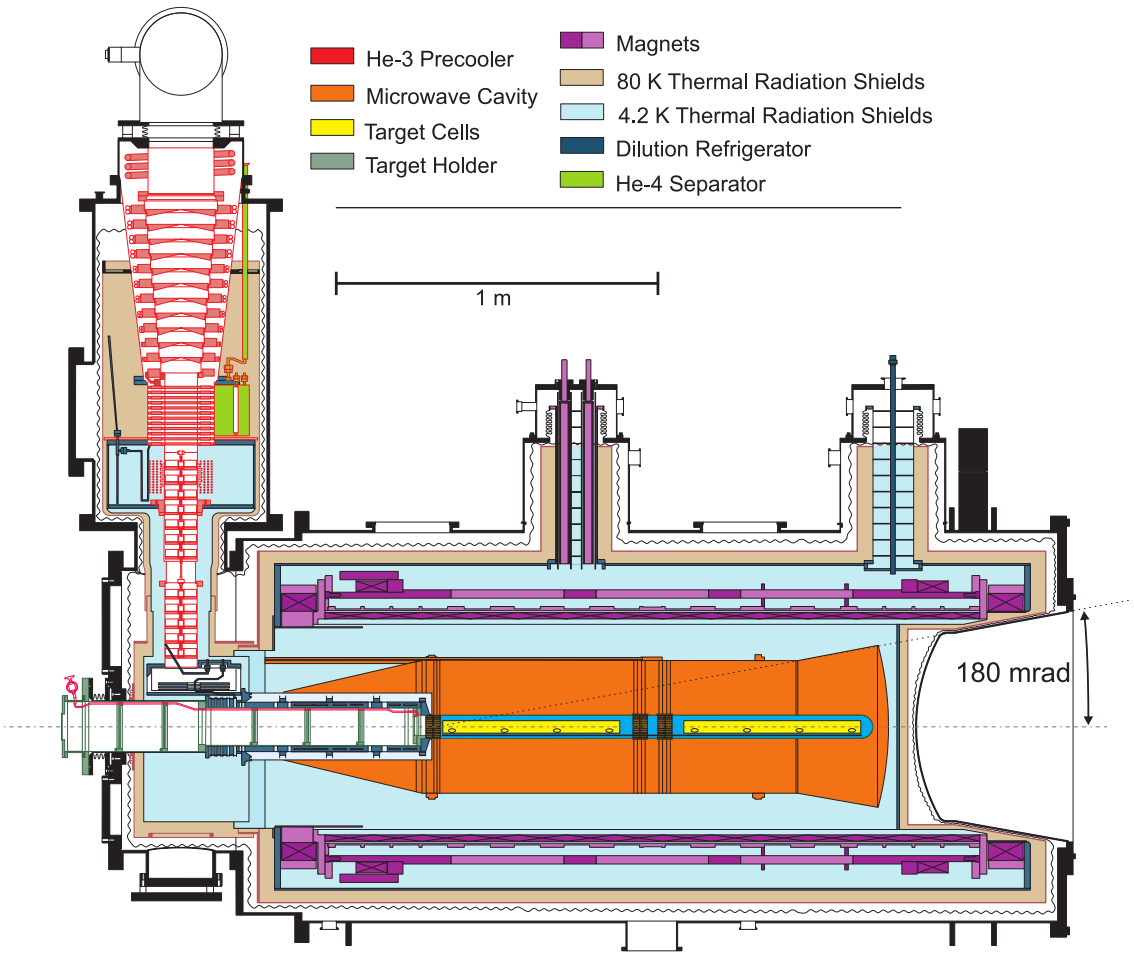

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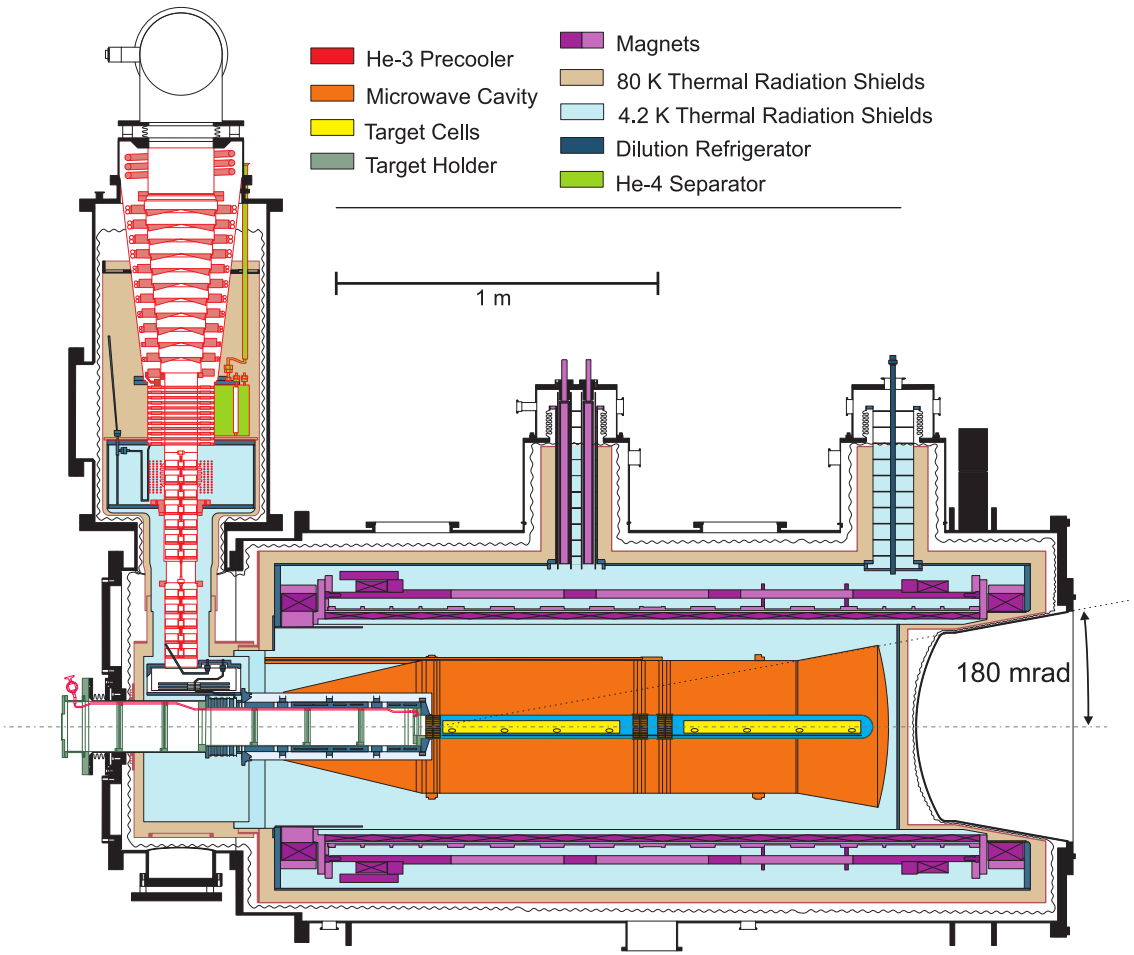

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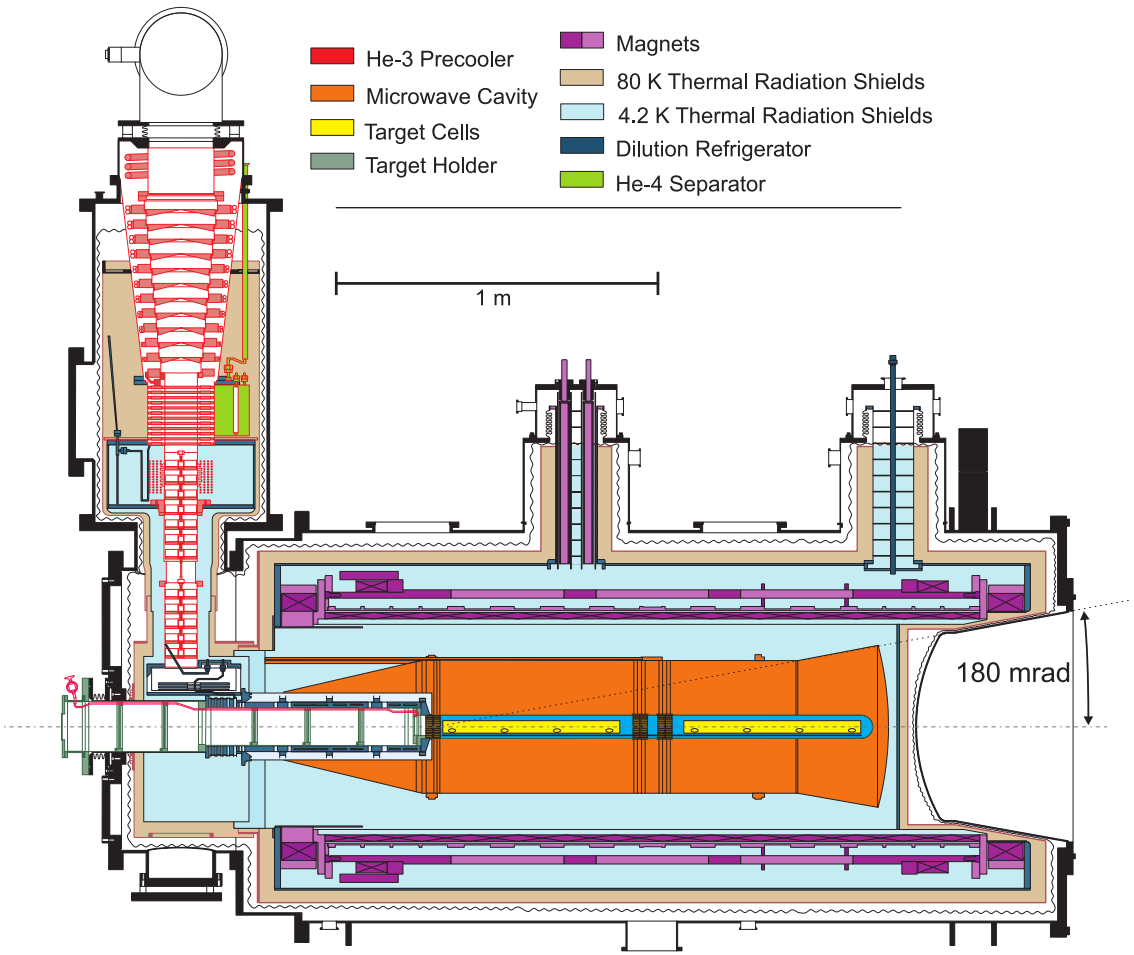

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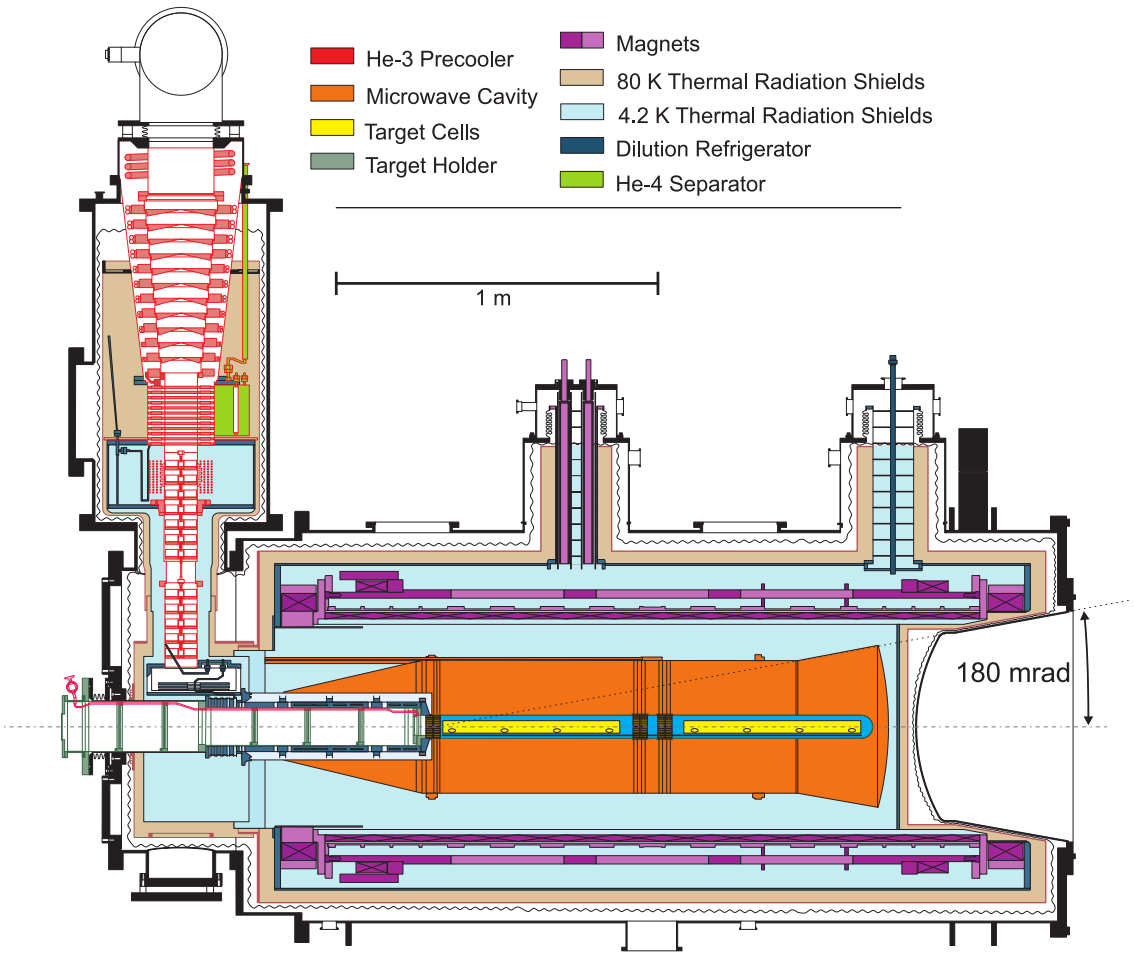

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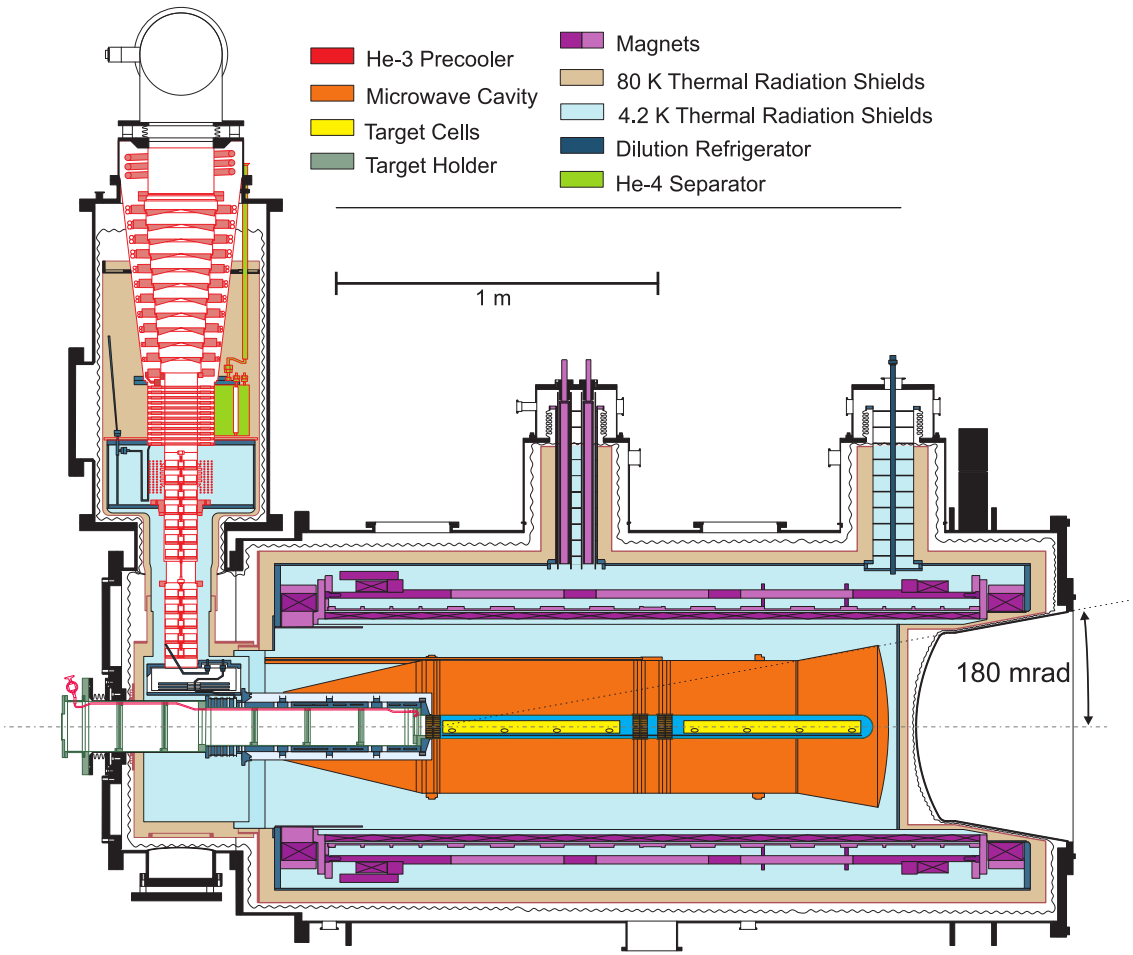

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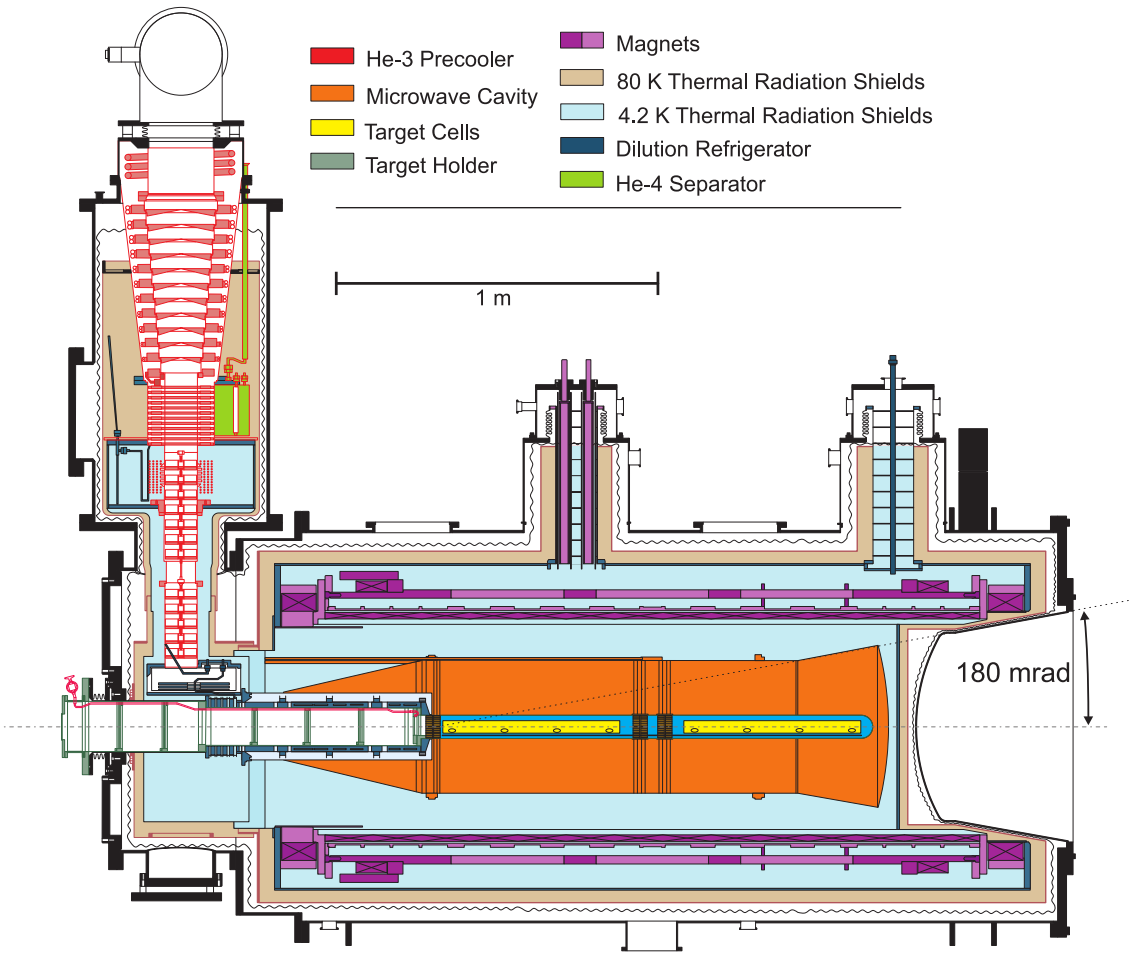

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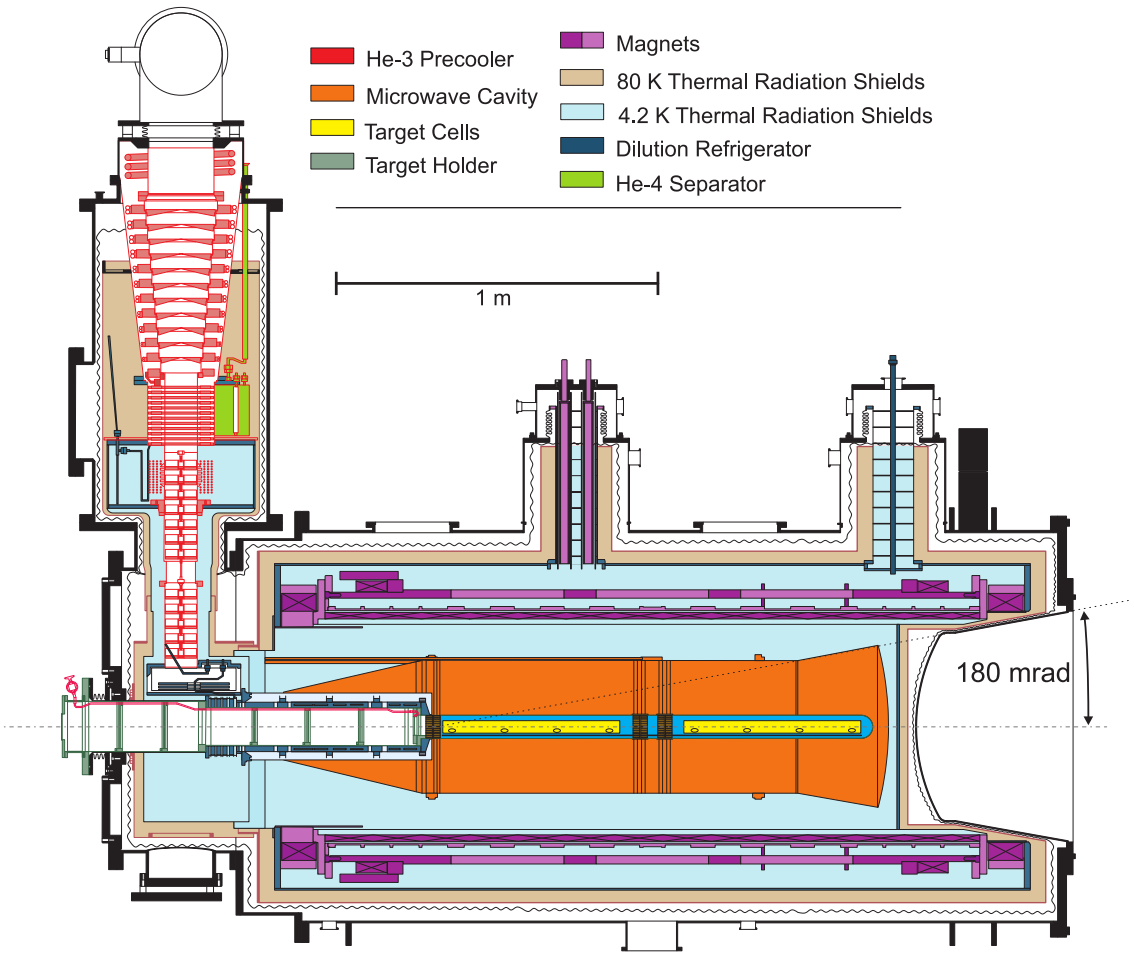

The polarised target

Outline

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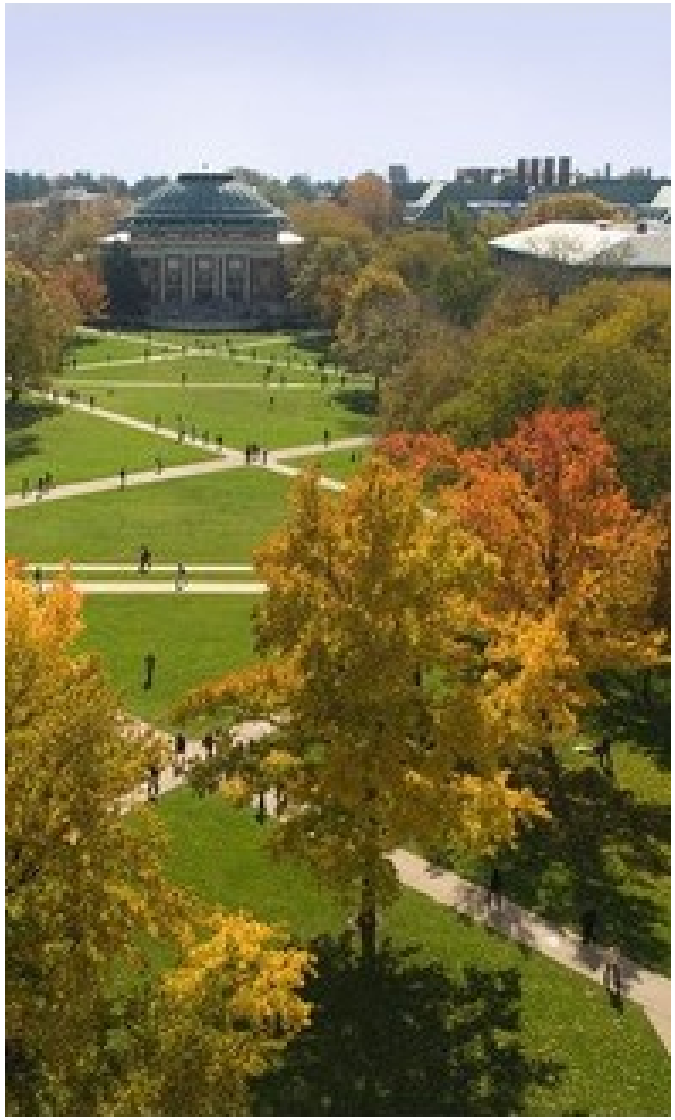
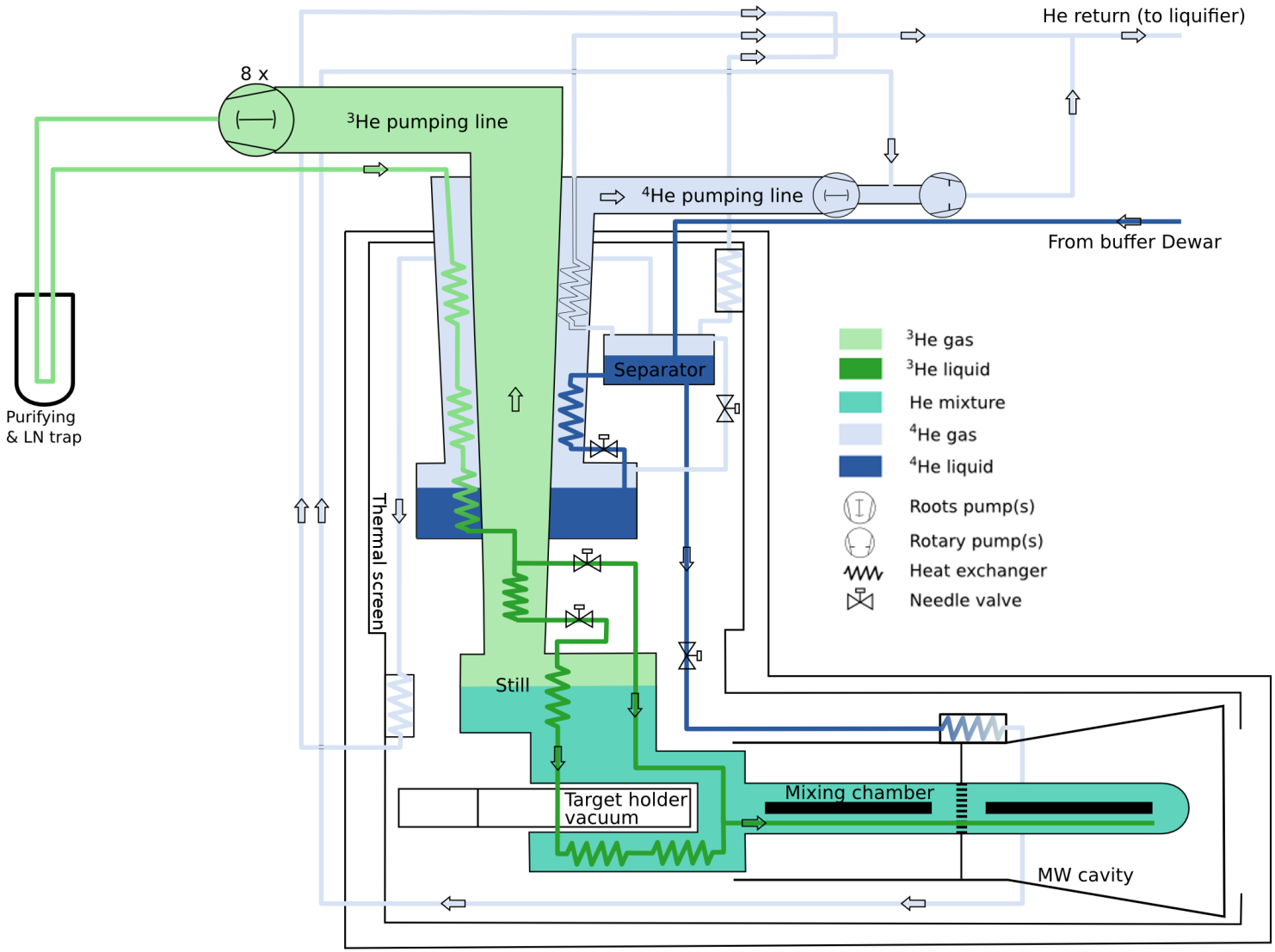
2. Drell–Yan programme
3. Polarised target
4. Polarised target dilution cryostat
5. Polarised target magnet
6. Conclusion of the part I



Polarised target dilution cryostat: Scheme



Simplified dilution cryostat scheme.

Polarised target dilution cryostat: Parameters

- Large mixing chamber ($l = 1.6$ m, $d = 7$ cm).
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- DNP mode: cooling power up to 350 mW at ≈ 300 mK (^{3}He flow 100 mmol/s).
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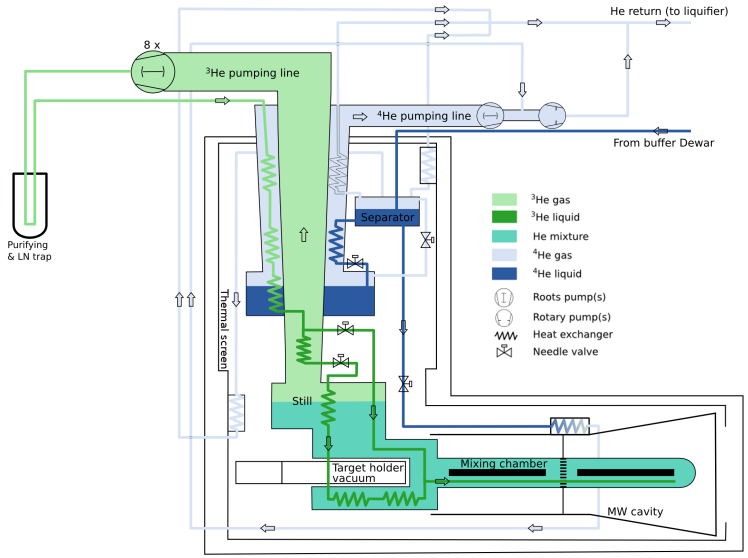

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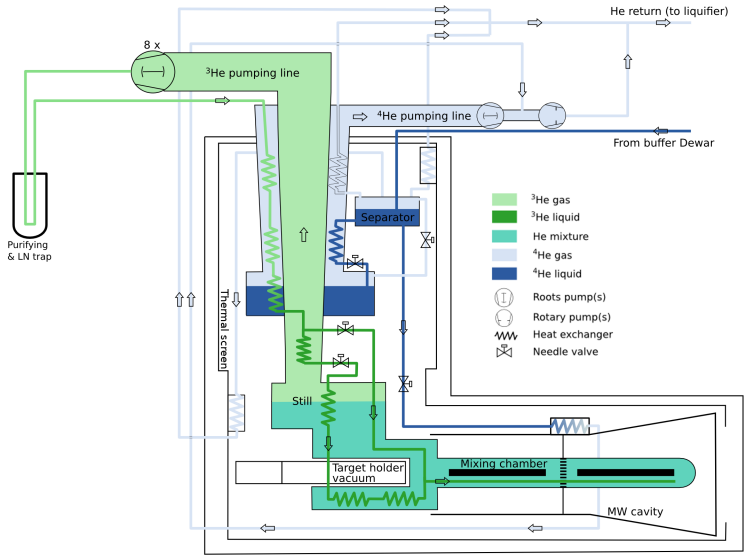

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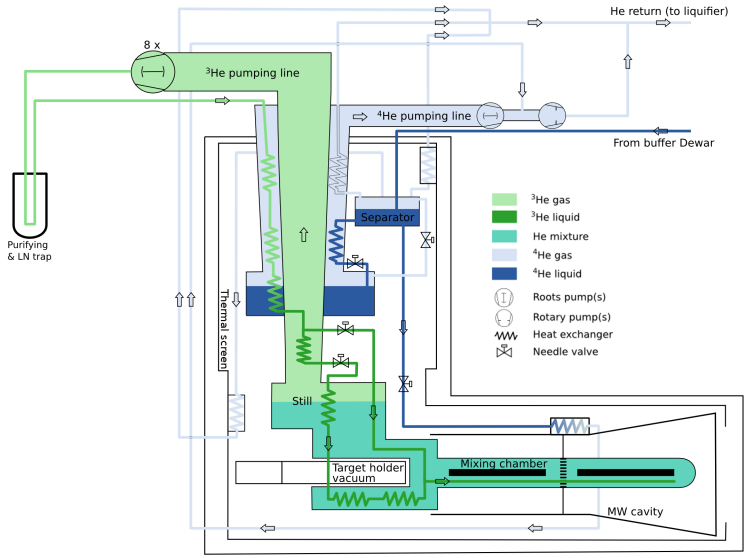

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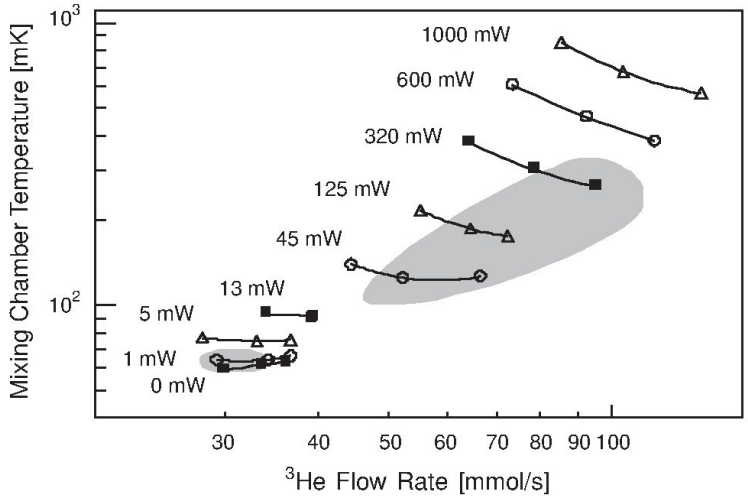

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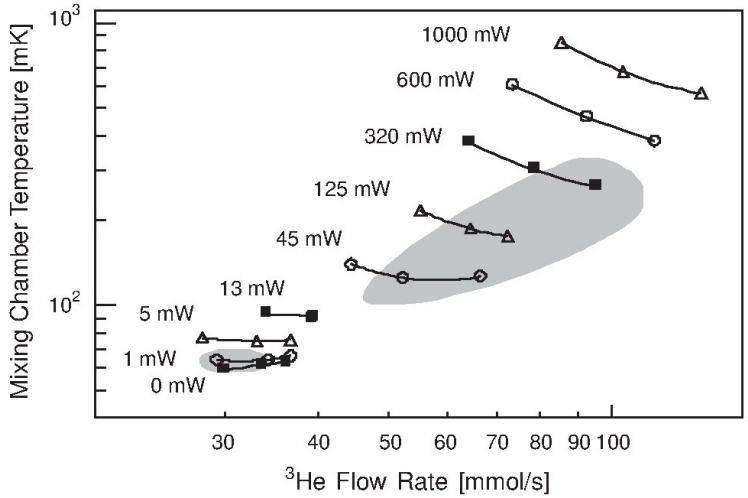

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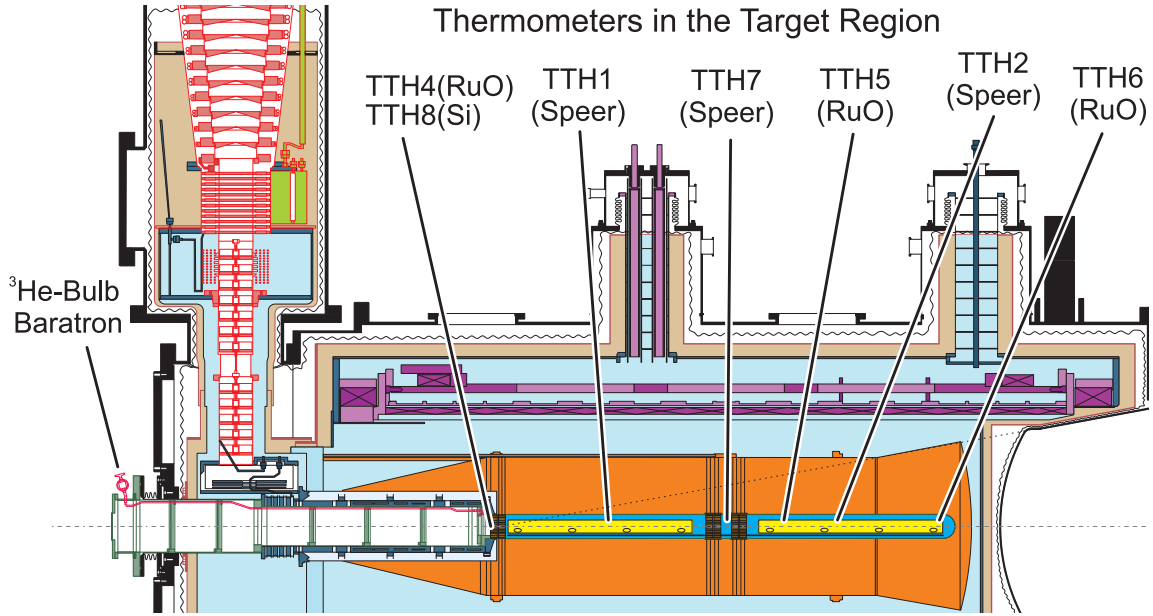

TE calibration: Precise measurement at ≈ 1 K – ^{3}He vapour pressure.

Dilution chamber: Resistive thermometers read by Picowatt AVS-46/47 res. bridges.

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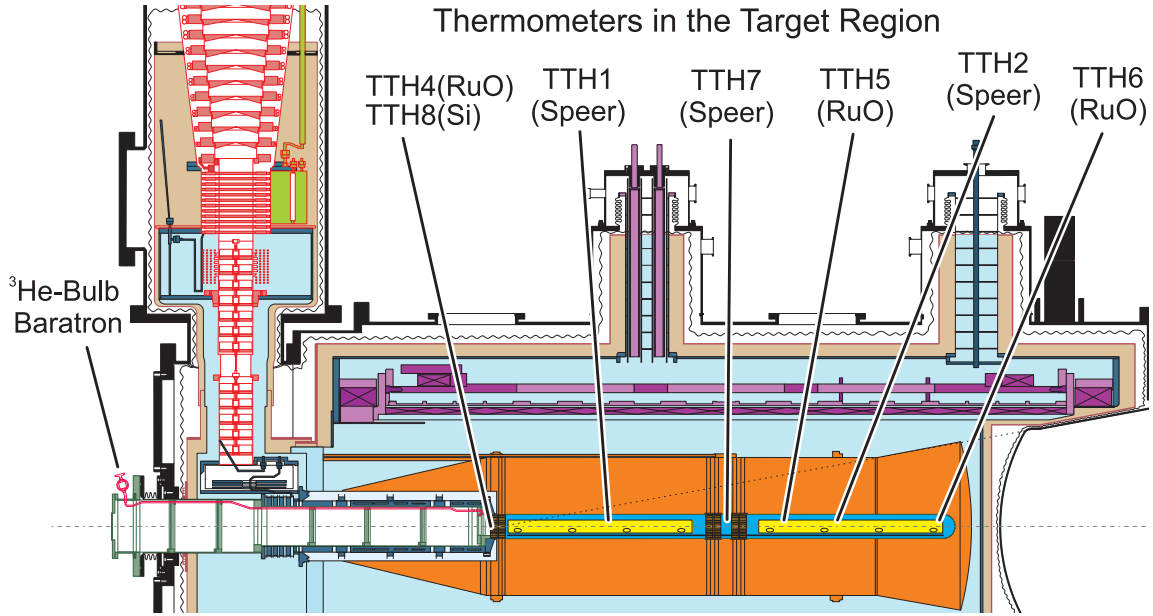

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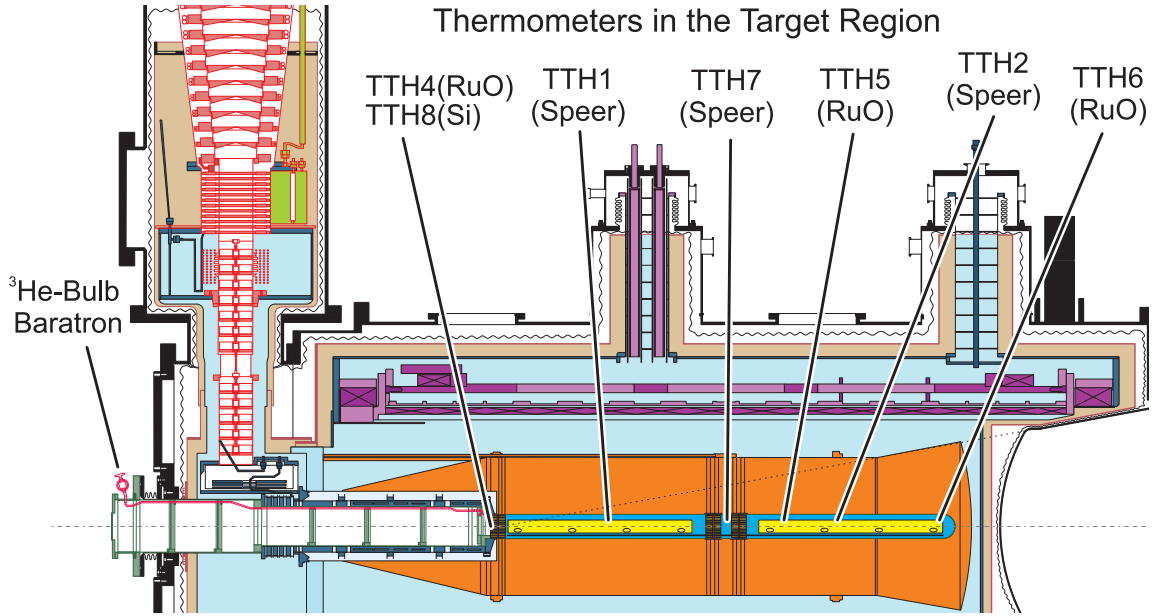

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Polarised target dilution cryostat: Modifications for DY

- New pumping lines welded.
- New water-cooled heat exchangers for ^{3}He pumping line.
- New remote monitoring system – ptread:
  - Linux-based, modular.
  - Instruments (AVS, Lakeshore etc.) connected by GPIB or RS232 interfaces.
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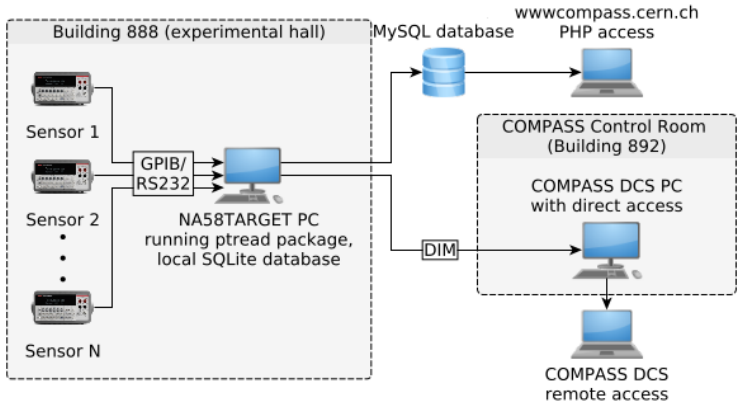

ptread package scheme.

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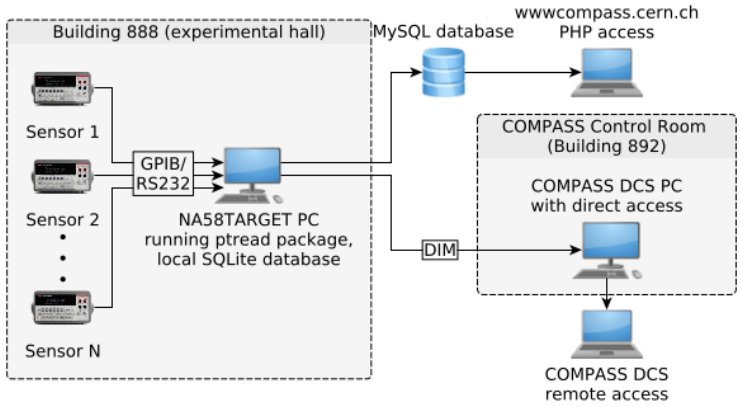

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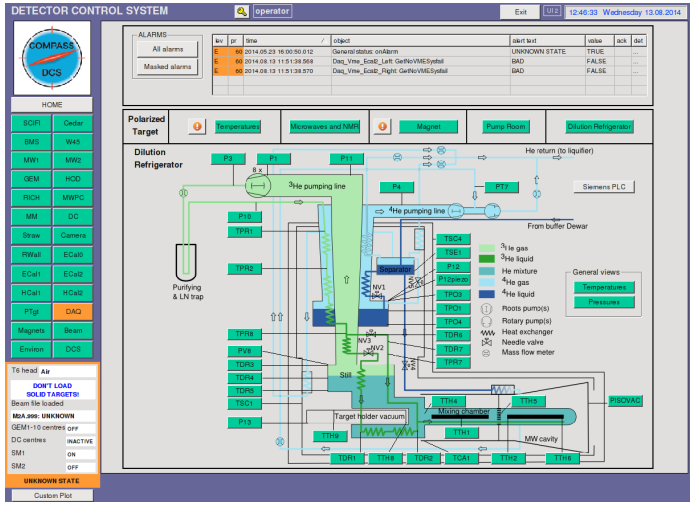

COMPASS DCS.

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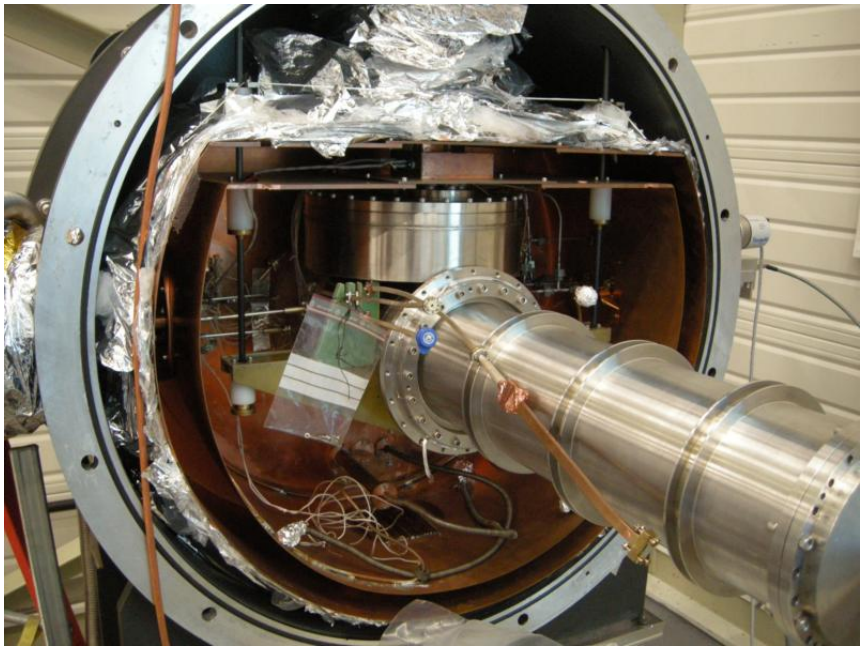

2013 – cryostat inspection.

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5. Polarised target magnet
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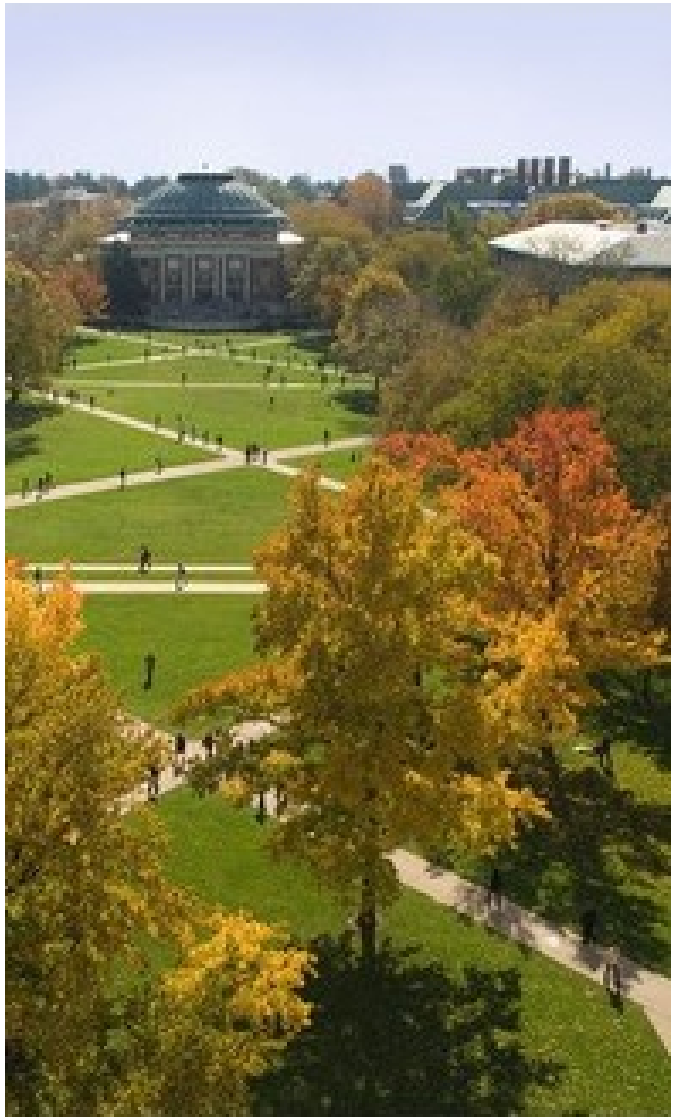

Polarised target magnet: Parameters

Dimensions:
- $l = 2\,350$ mm,
- internal $d = 638$ mm.

SC solenoid:
- 2.5 T field,
- 16 shim coils,
- 10^{-5} homogeneity in target cells.

SC dipole:
- 0.63 T field,

Operation:
- Coils can be ramped up/down in given sequences (pre-programmed scripts)
- $\rightarrow$ field on/off/rotation.

Cooling:
- Liquid He.
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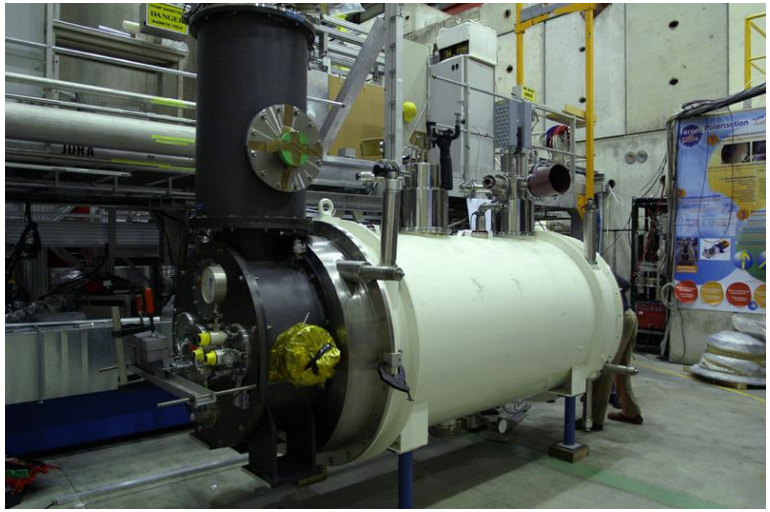
- LHe consumption (2015): 15 l/day.



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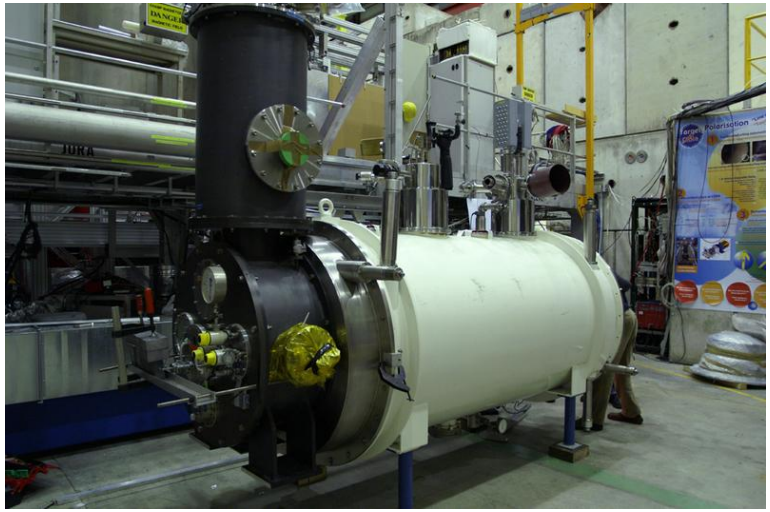

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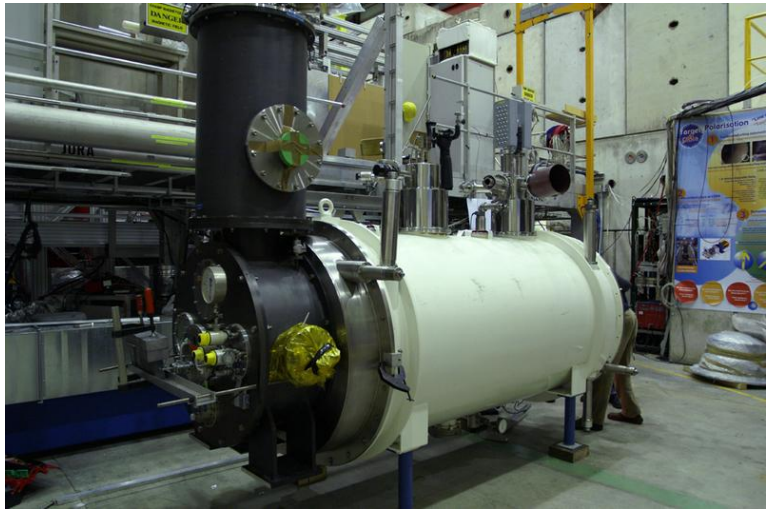

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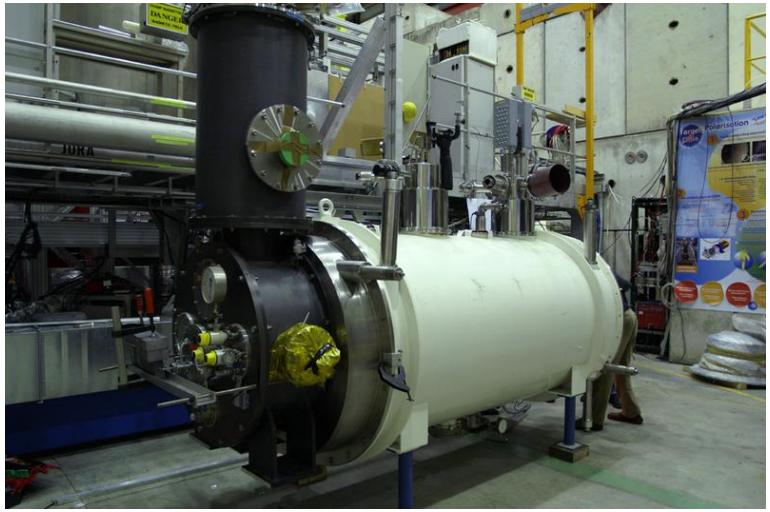

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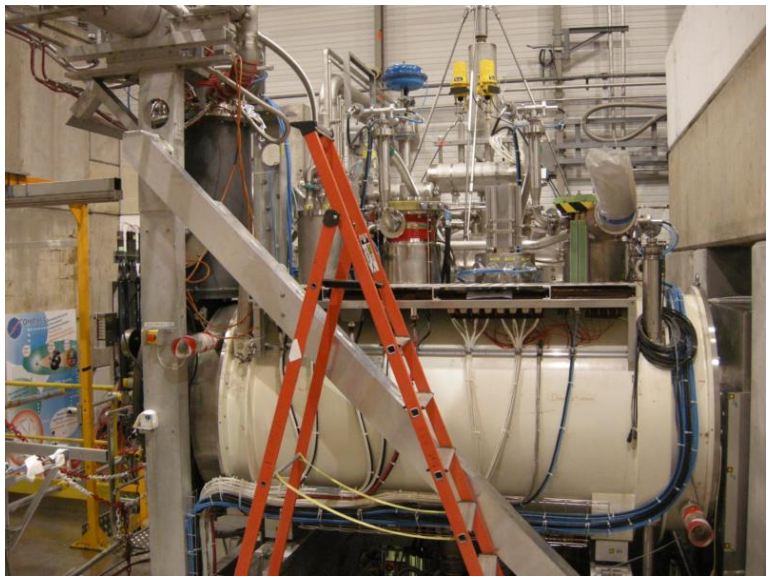

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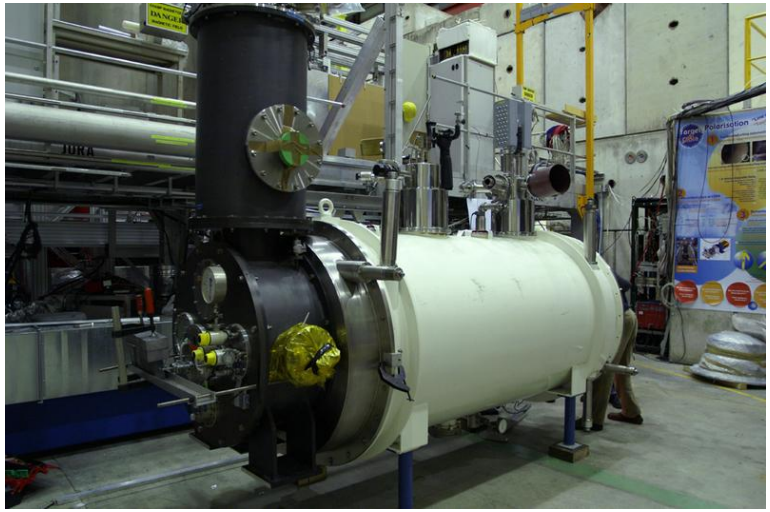

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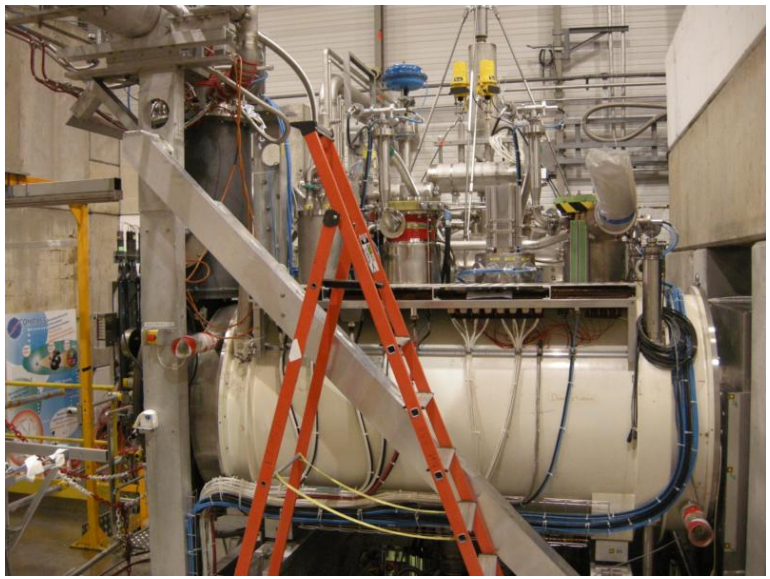

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Polarised target magnet: 2012–14 Refurbishment

- Done by CERN magnet group.
- Cryogenics rebuilt,
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- New temp. monitoring,
  - 9 Pt1000 sensors,
  - 9 CERN bridges for He temps.
- New power converters.
- Shorts on trim coils repaired.
- Quench protection improved.
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Magnet control racks.

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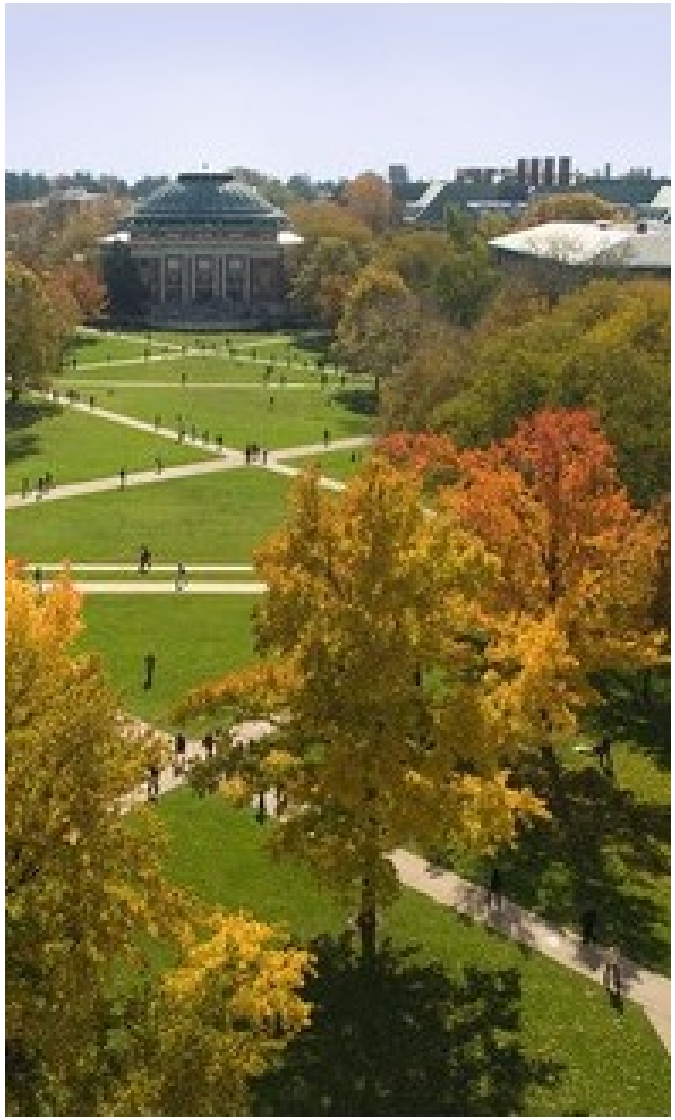

Conclusion of the part I

- COMPASS has a wide physics programme,
- including nucleon spin structure studies in SIDIS and (recently) Drell–Yan reactions.
- It utilizes a large solid-state polarized target system.
  - SC magnet (2.5 T solenoid and 0.6 T dipole),
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