Past and Future of the COMPASS Polarized Target

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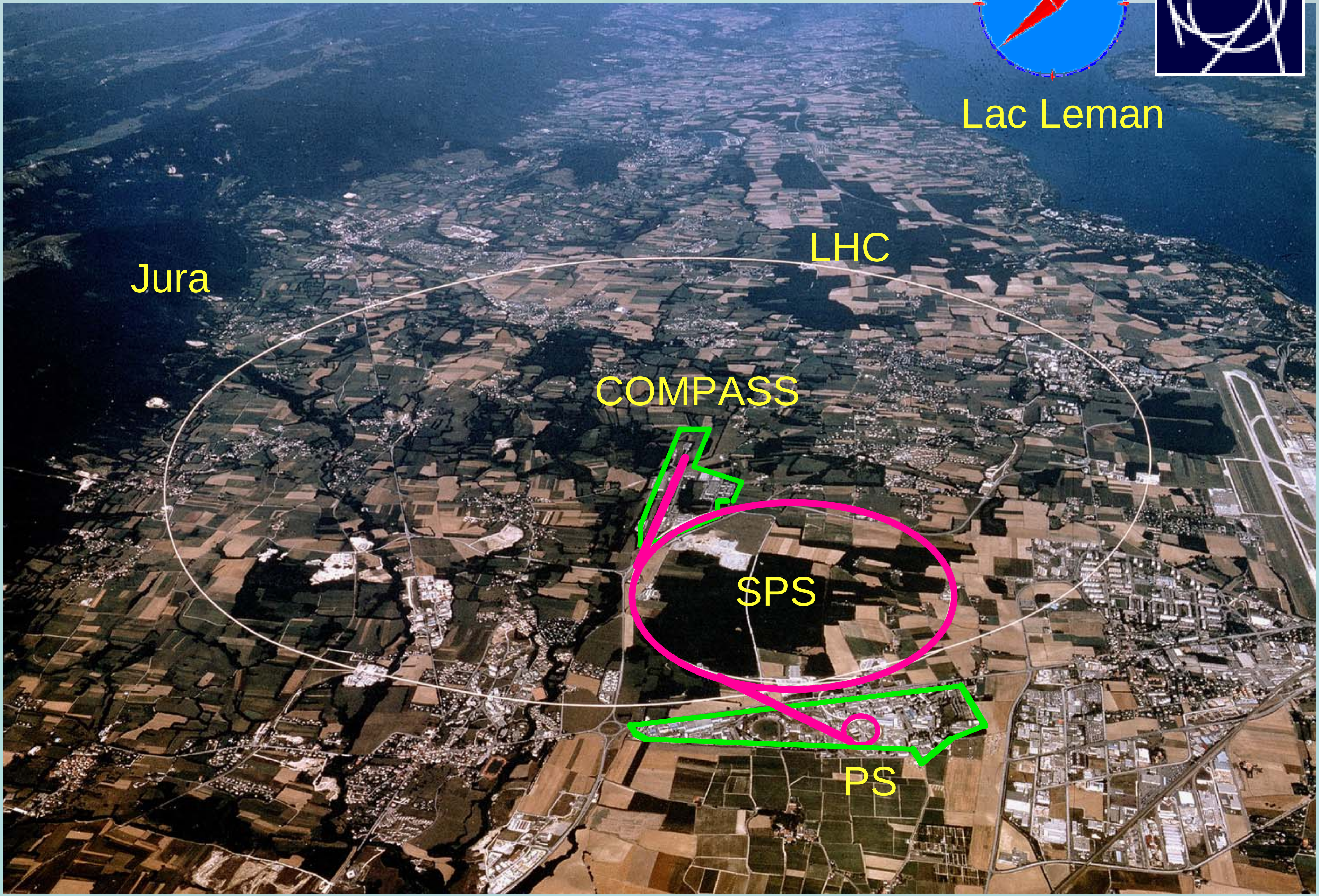
Outline

- 2007 run
  - Muon program
  - Polarized target system
  - NH_3 target material
  - Polarization and relaxation time
- Drell-Yan program
  - Introduction
  - Influence of heat input from the pion beam to the polarized target
  - New target material (^7LIH)

CERN and COMPASS



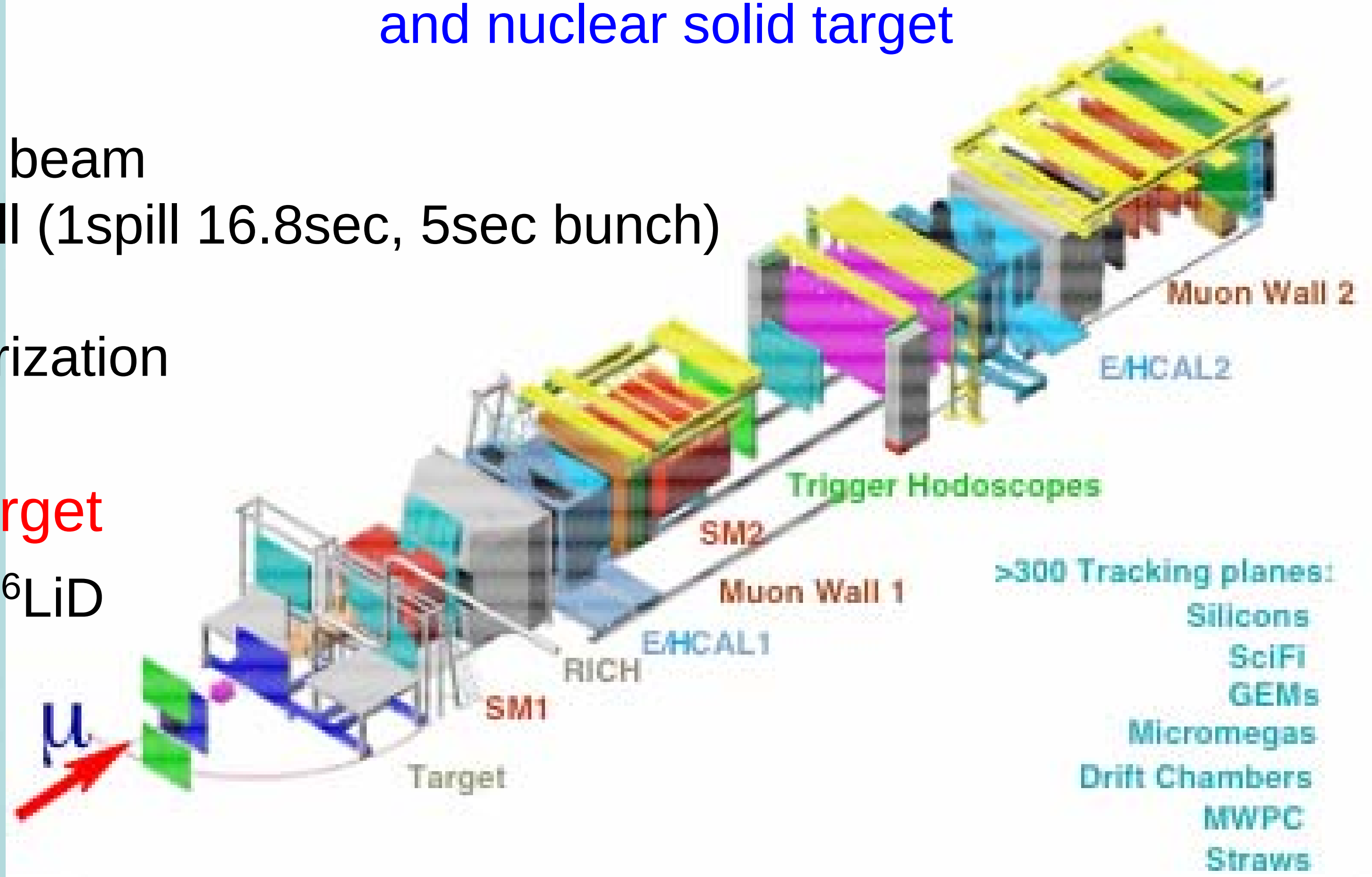
The COMPASS experiment - Muon program

Study of the nucleon spin structure

Double spin asymmetry of muon beam and nuclear solid target

Muon beam
- Secondary beam
- 2 x 10^8 /spill (1spill 16.8sec, 5sec bunch)
- 160 GeV/c
- ~80% polarization

Polarized target
- 2002-2006 ^{6}LiD
- 2007 NH_3



COMPASS polarized solid target system
(upgraded in 2006)

Dilution refrigerator

- 50mK
- 350mW cooling power at 300mK

Magnet

- Homogenized 2.5T solenoid (60ppm)
- 0.6T dipole (field rotation, trans. pol.)
- 180mrad acceptance

Target cell

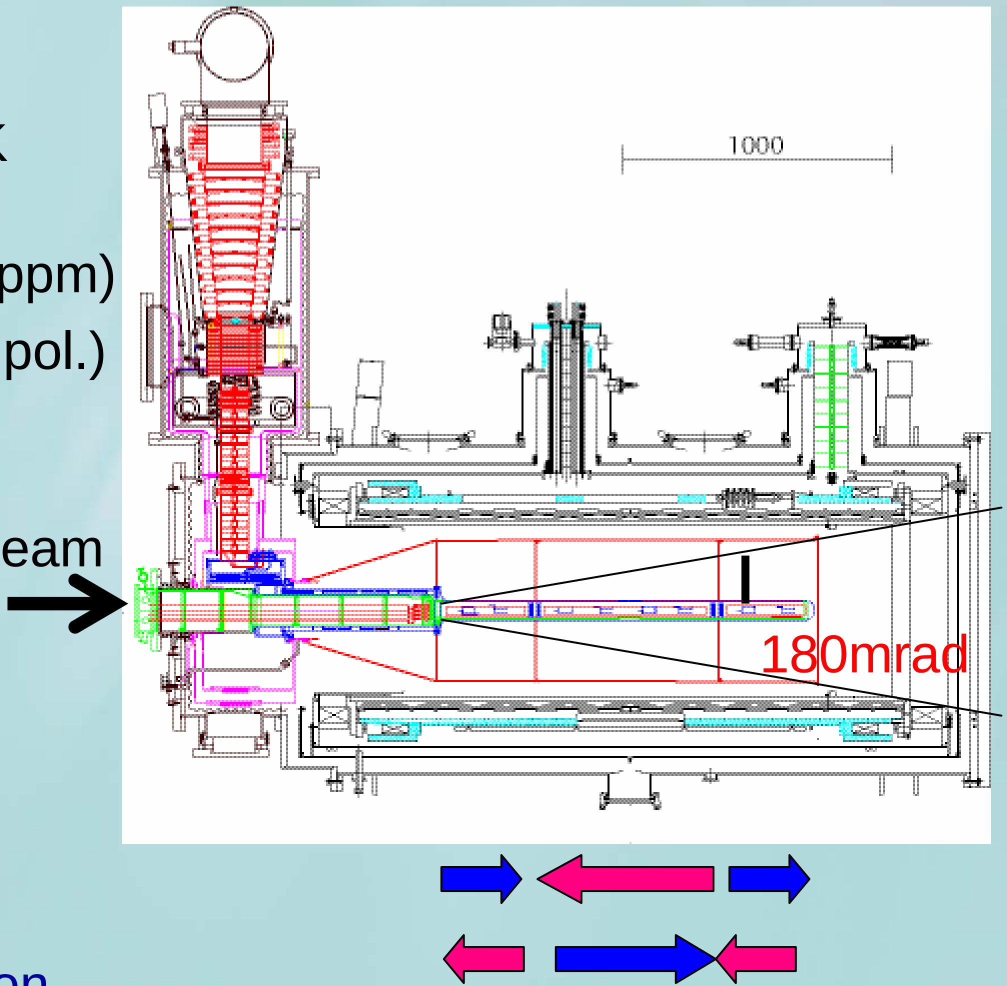
- 3 cells (30, 60, 30cm long)
- ϕ 3cm in 2006, 4cm in 2007

Microwave for DNP

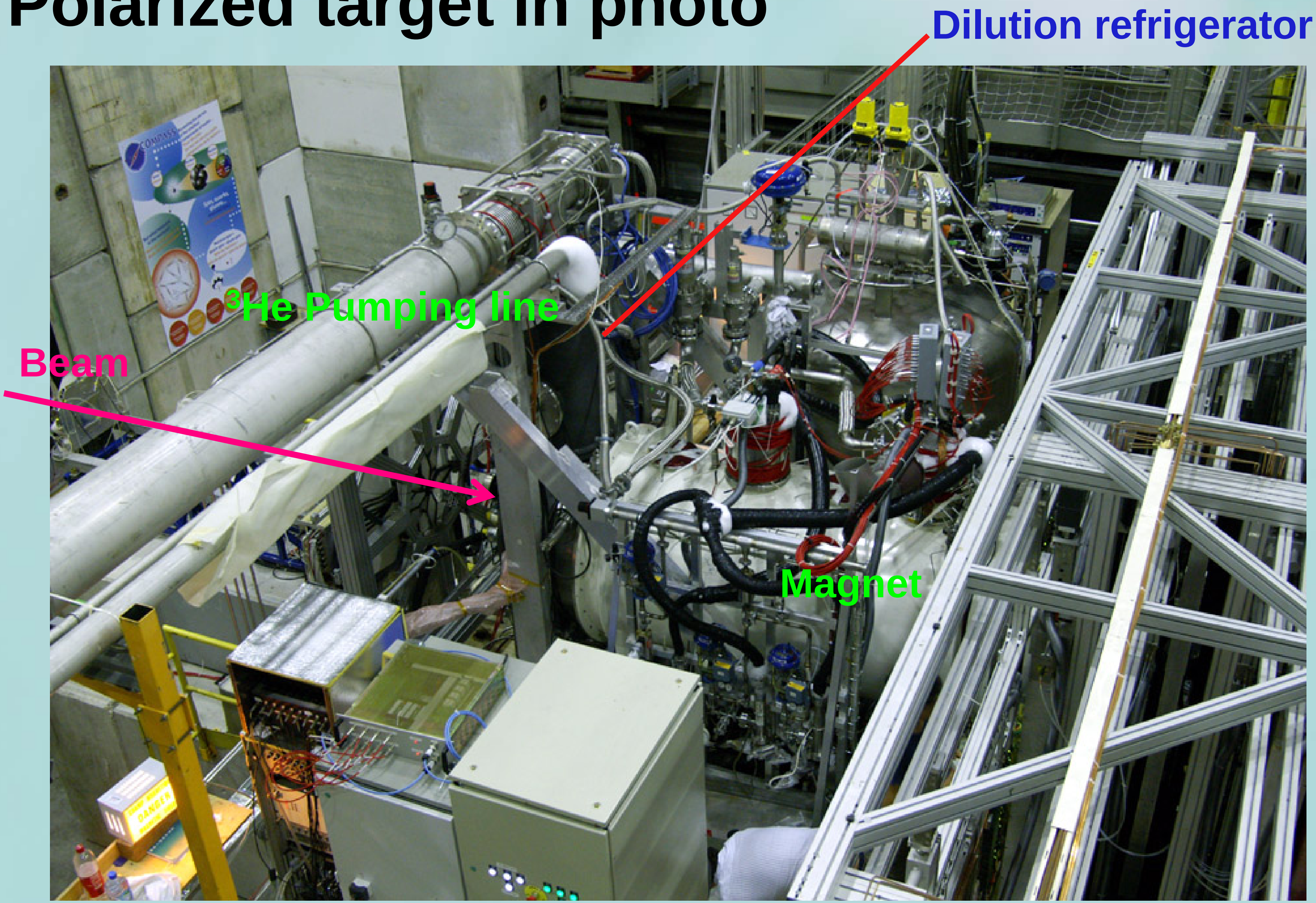
- 2 microwave systems (for 2.5 T)
- New large acceptance cavity

NMR for determination of polarization

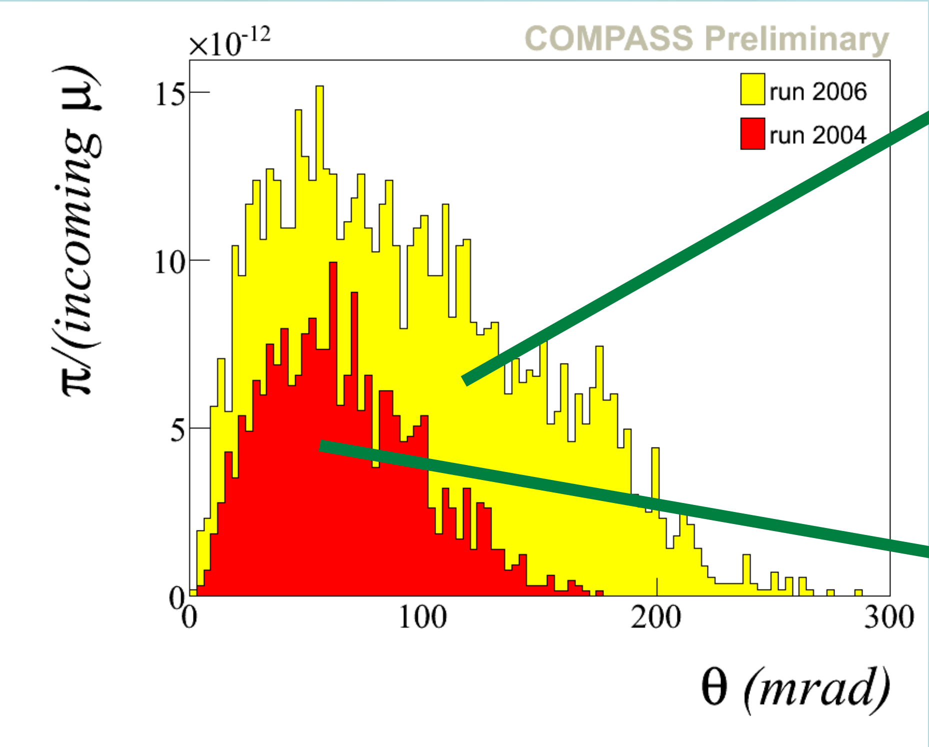
- 10 channels (3, 4, 3)



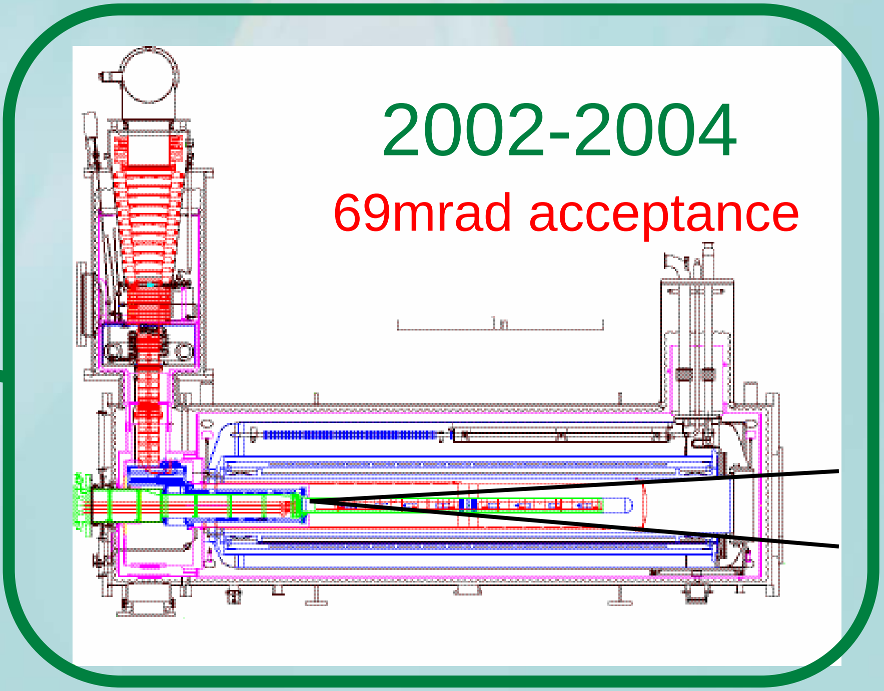
Polarized target in photo



Acceptance gains in 2006

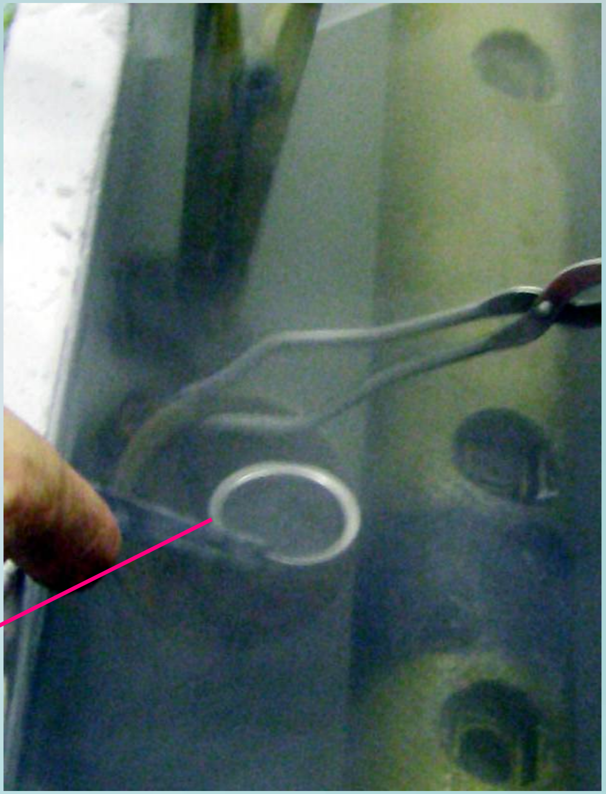


Larger magnet acceptance



Target material in 2007

- NH_3 as proton target
- Used in the SMC experiment (1996)
- Paramagnetic centers were produced by electron beam in the liquid argon.
- Critical temperature of 117K (W. Meyer, 1984 Bonn)
- Stored for more than 10 years in liquid nitrogen
- Material property changed



color : violet → pale

paramagnetic centers density : 6×10^{19} → 4.3×10^{19} /cm^3

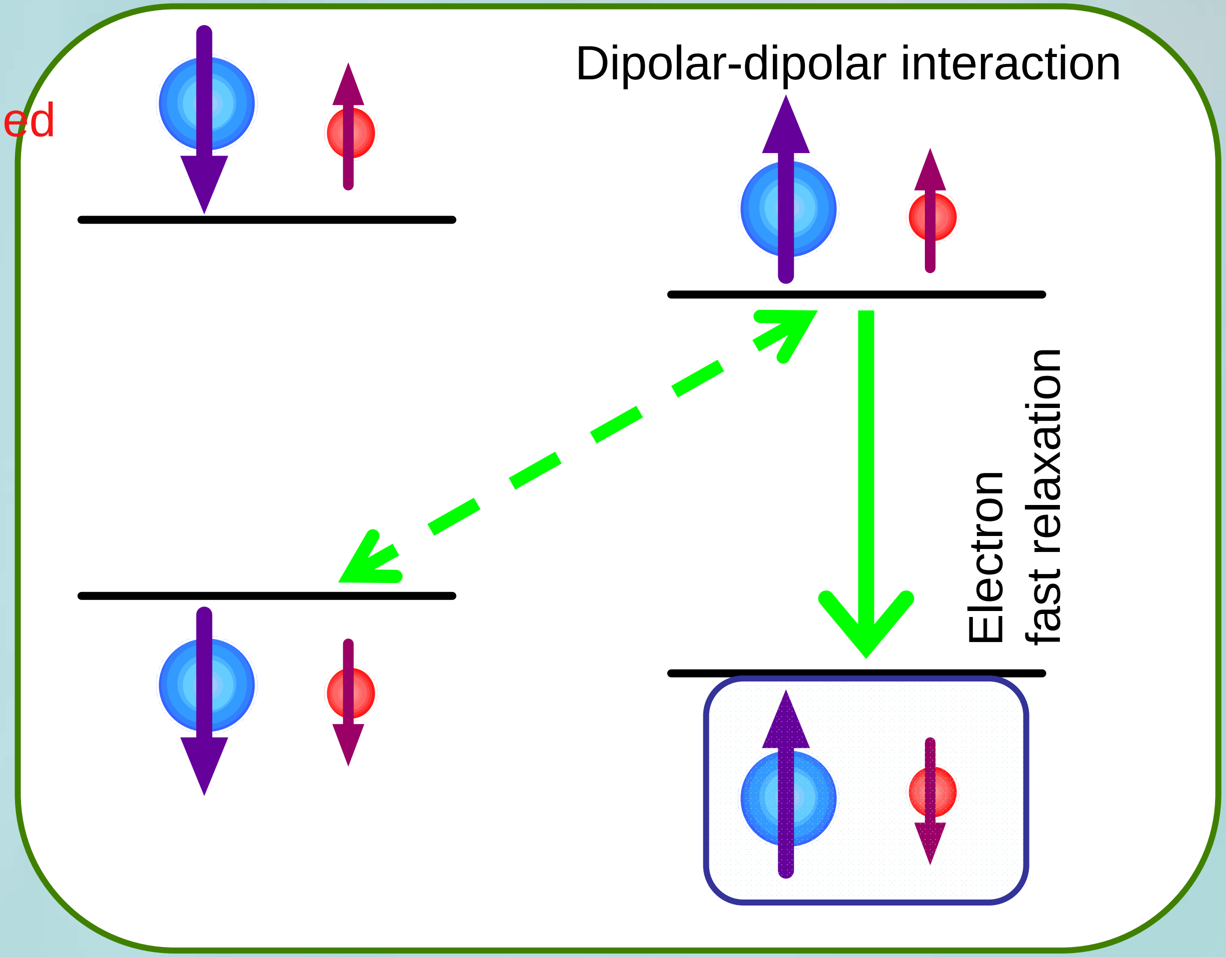
Dynamic Nuclear Polarization

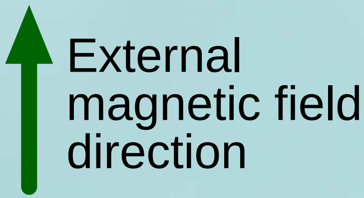
Paramagnetic centers
(Free electrons) are needed

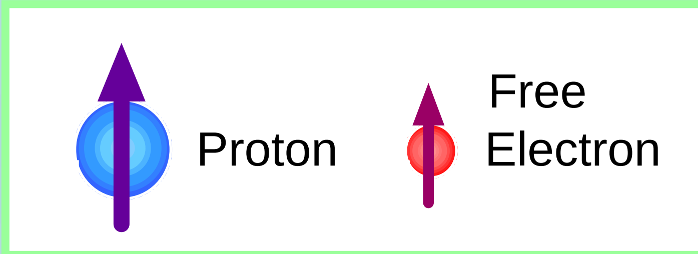
Polarization
@2.5T and 0.2K
Electron: 99.9%
Proton: 1.3%

↓

Transfer
the high electron
polarization to
proton
polarization







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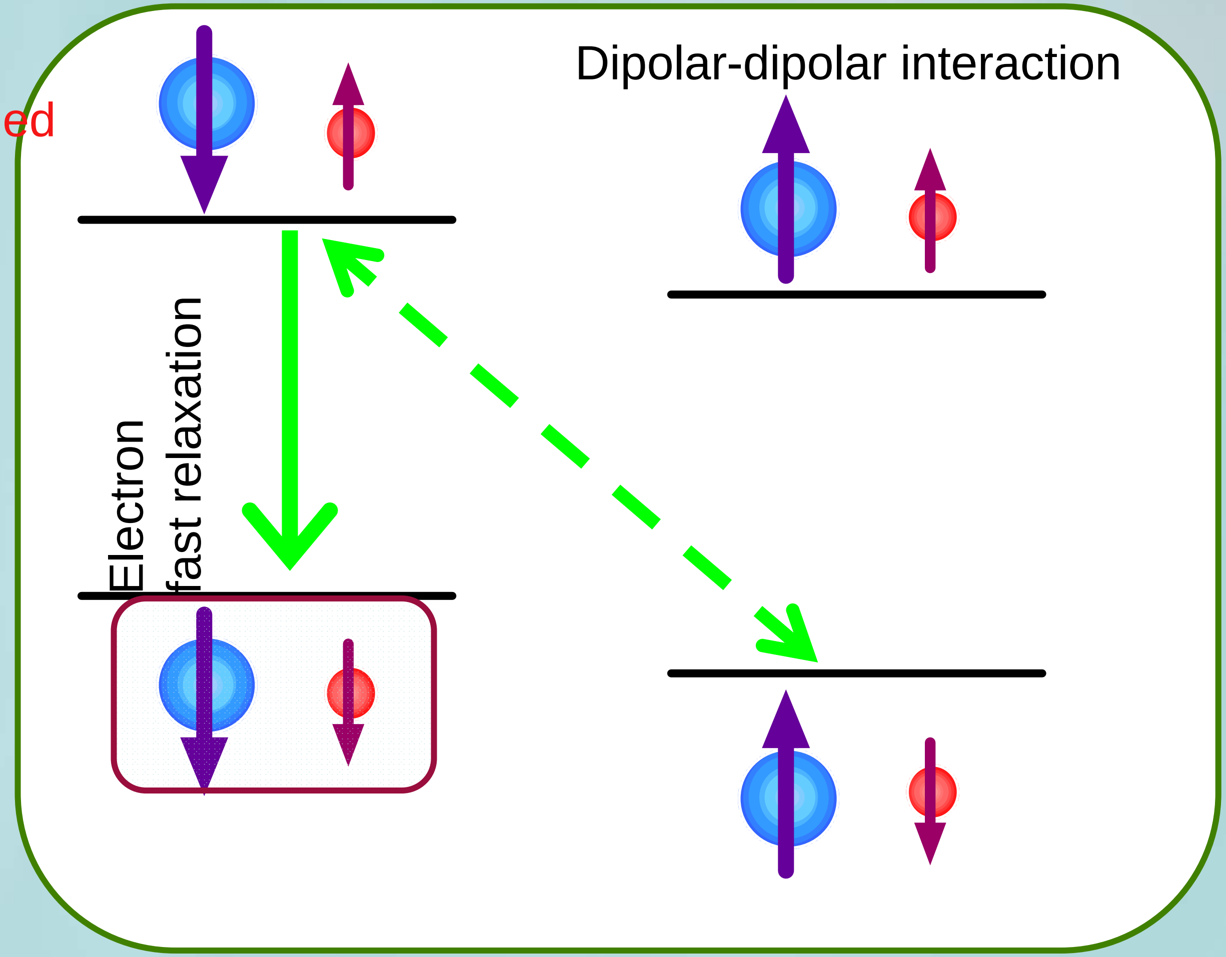
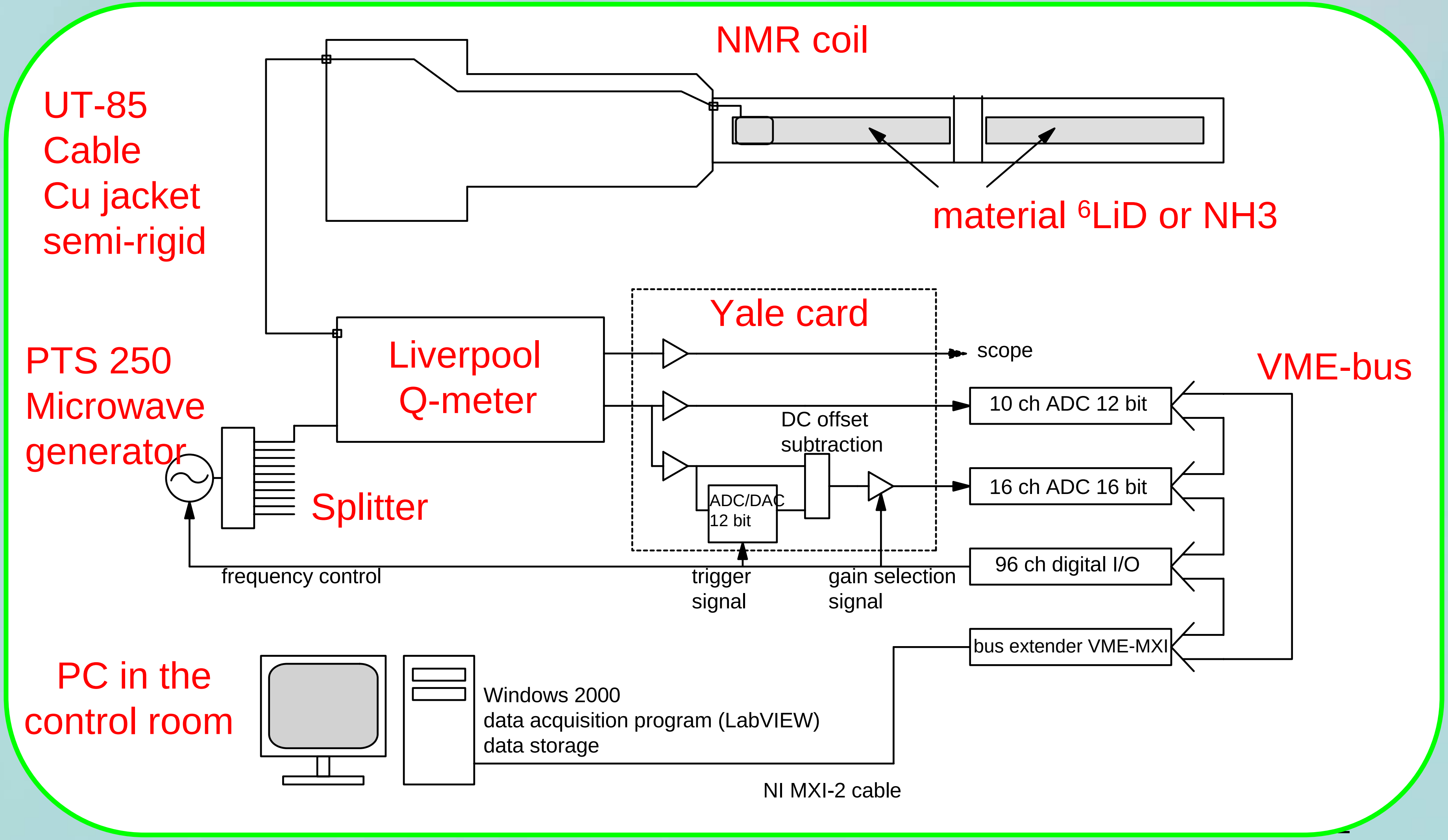


NMR system

to determine polarization

10 coils can be operated
at the same time.



Calibration of proton polarization for NH_3

- Polarization (P) is proportional to area of NMR signal (S).
- Thermal equilibrium NMR signal S_0 :
  target material + background
  ↓
- Target cell material: Polyamide

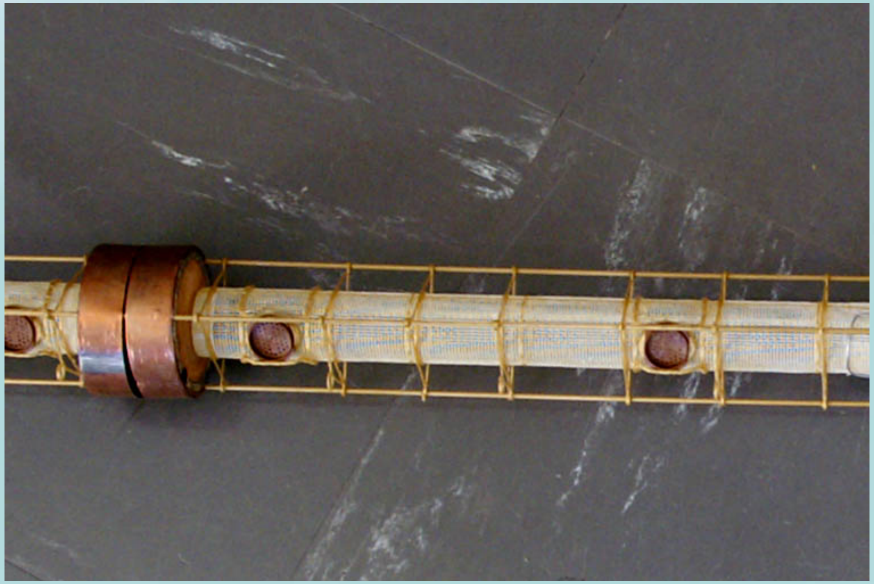
→ **high proton contamination**

- BG measurement is needed:
  with empty target

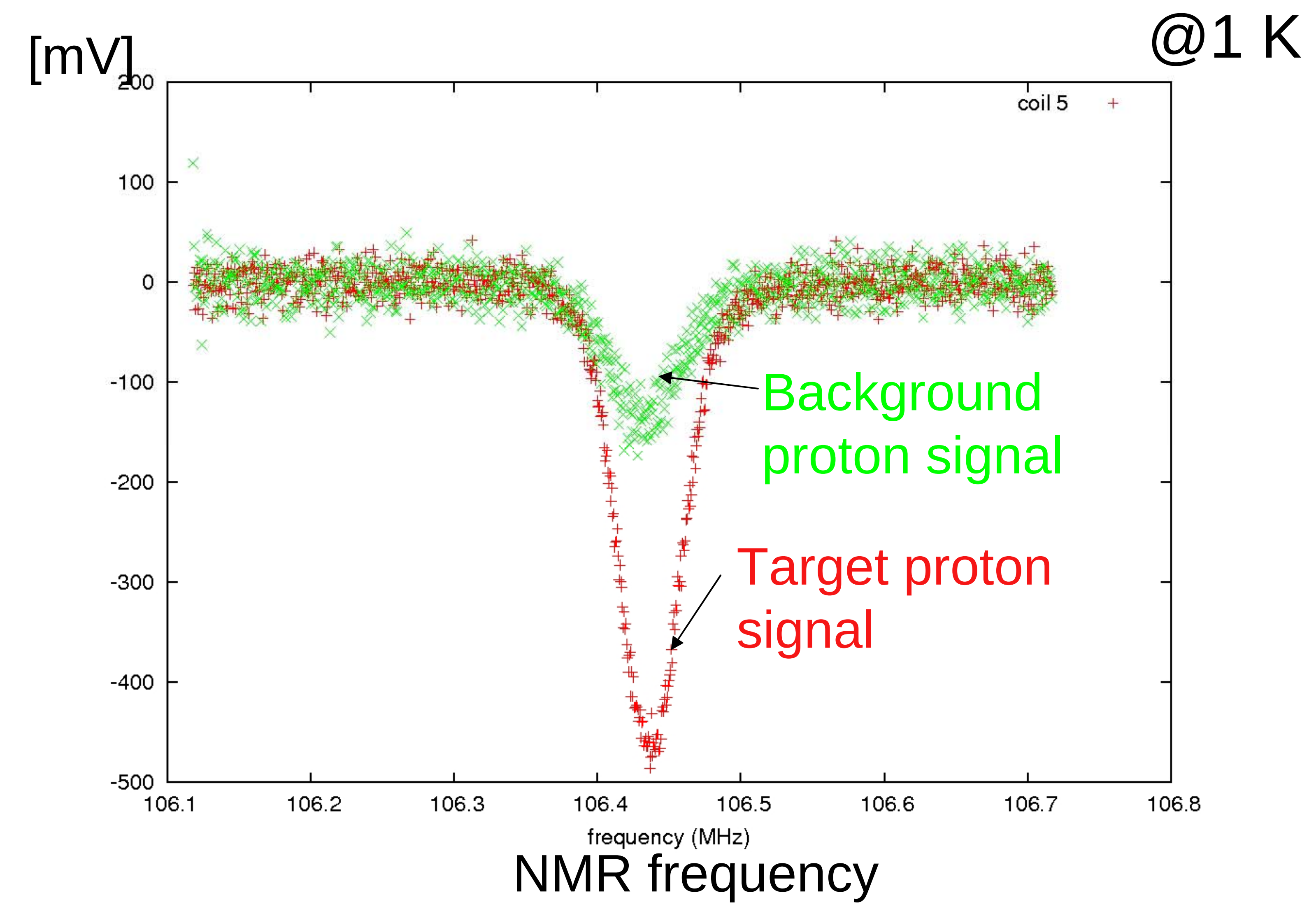
calibration coefficient

$$P = \frac{P_0}{S_0} S$$

P_0 is determined by temperature.

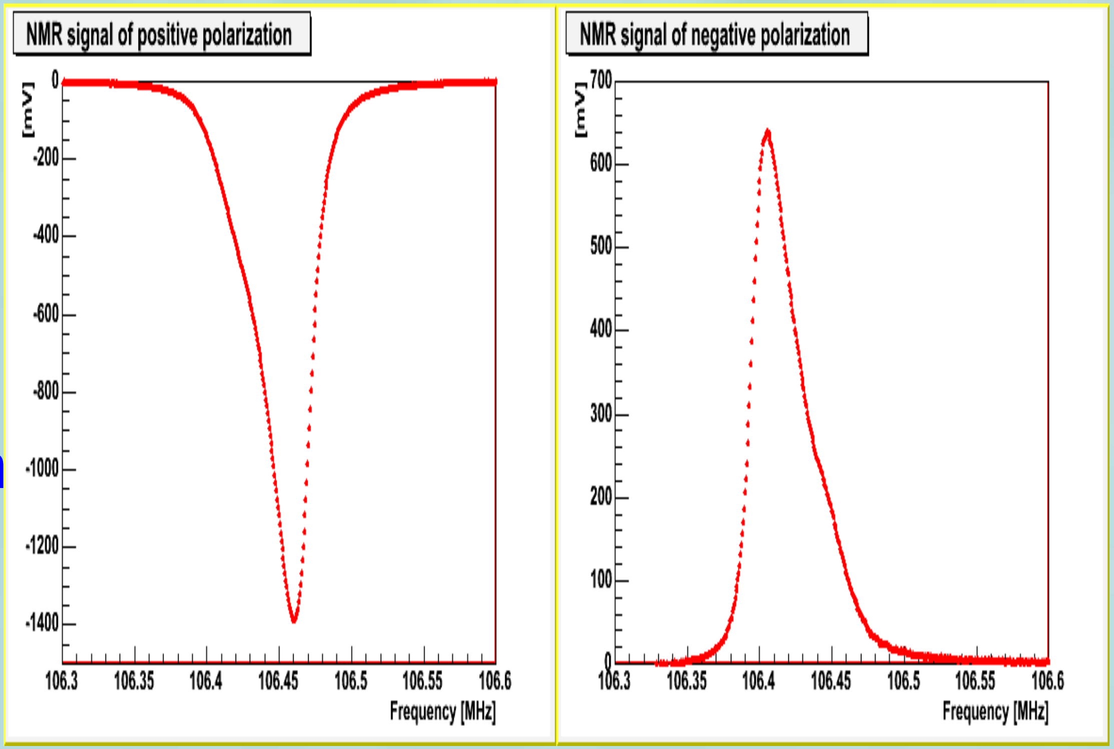


TE signal from background proton



NMR proton enhanced signal

positive polarization

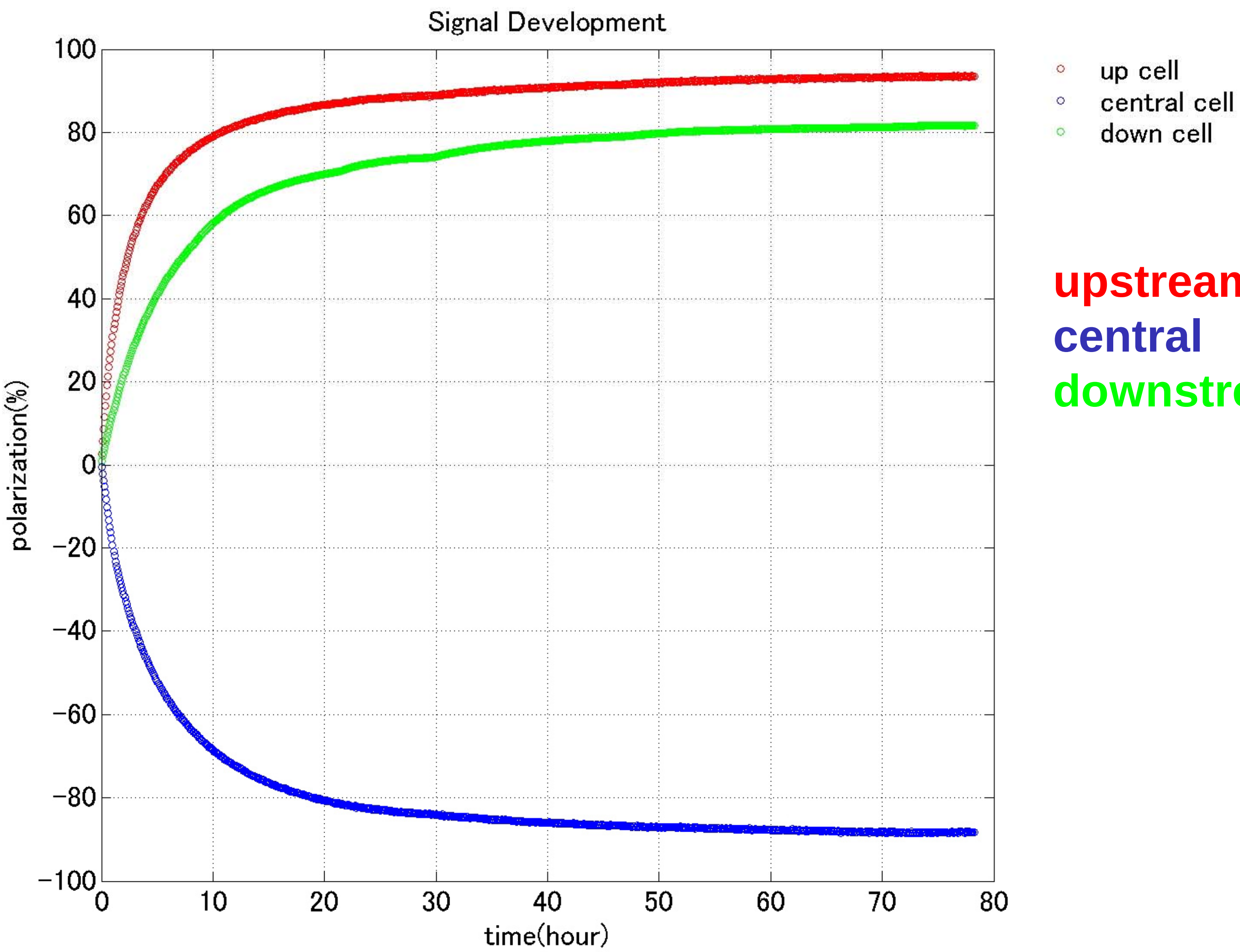


negative polarization

Asymmetry signal: line shape ⟺ polarization

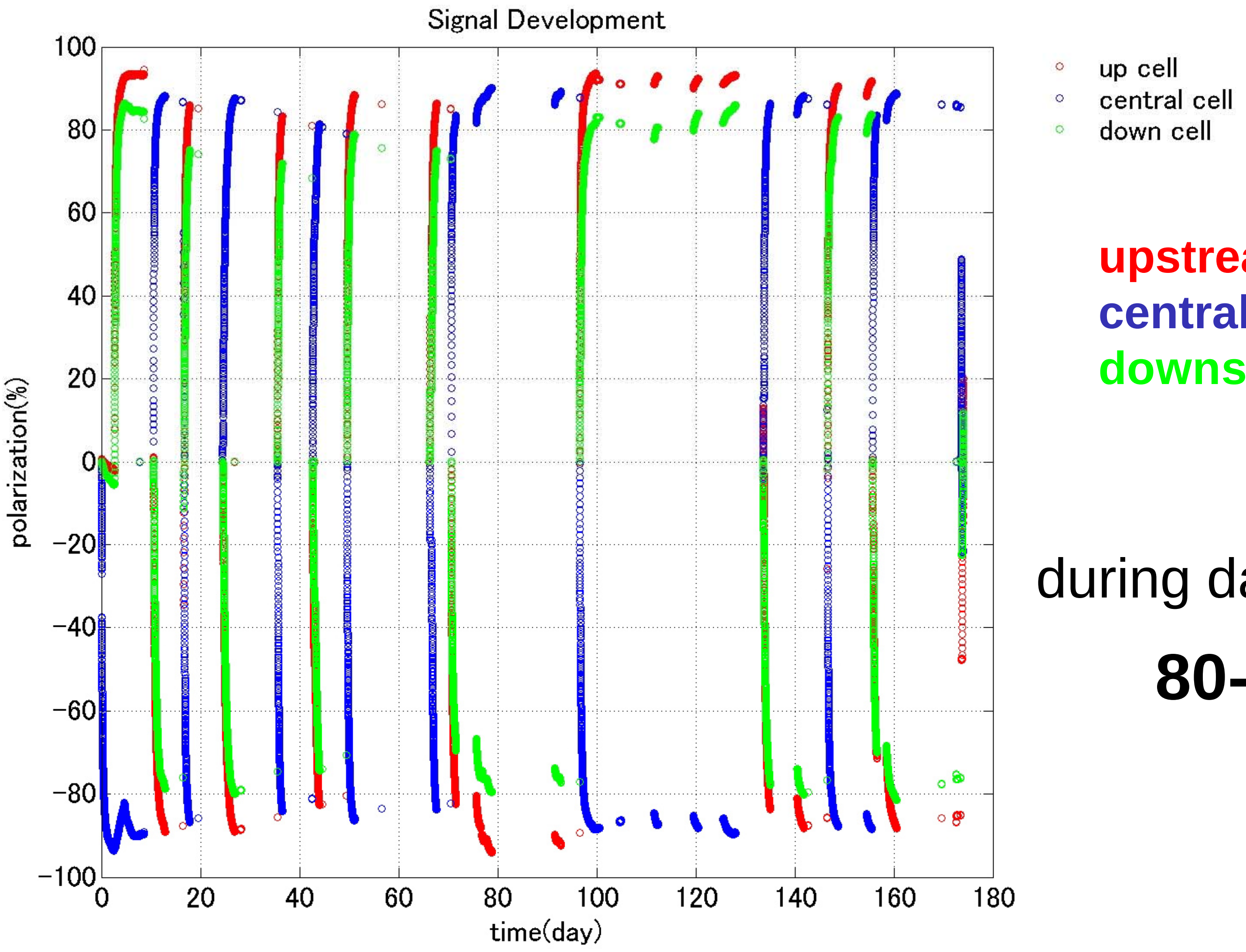
➡ This will be presented by Y. Kisselev

Proton polarization build up (at 2.5T)



upstream
central
downstream

Polarization in full period in 2007



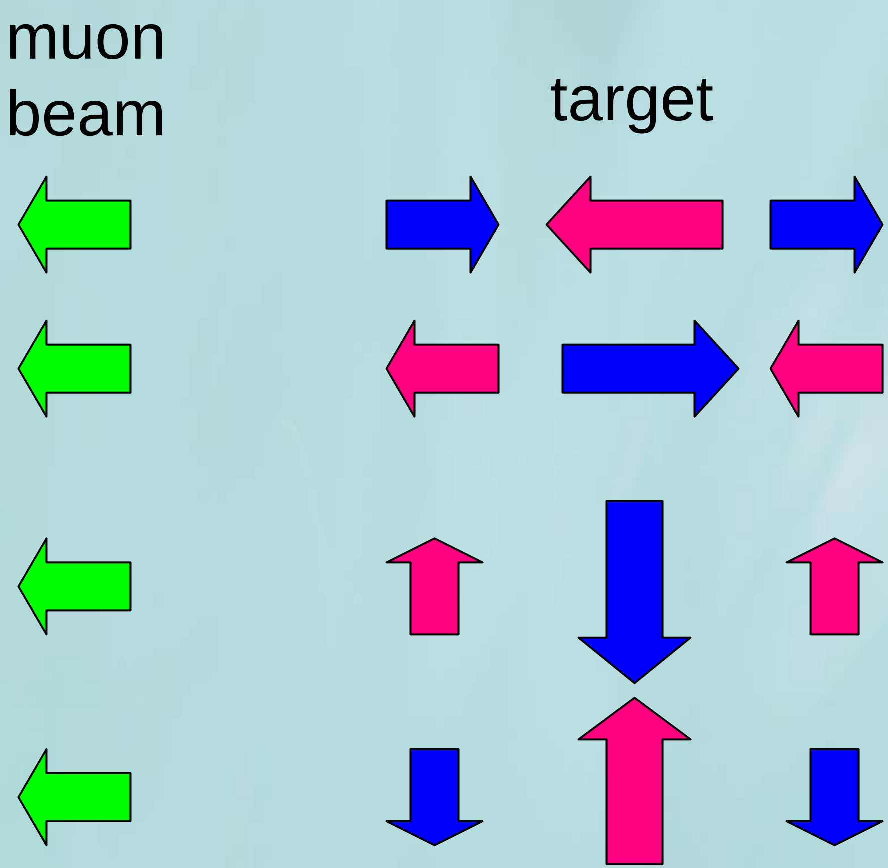
upstream
central
downstream

during data taking

80-90 %

Spin frozen target (for data taking)

The fringe field of solenoid is strong.

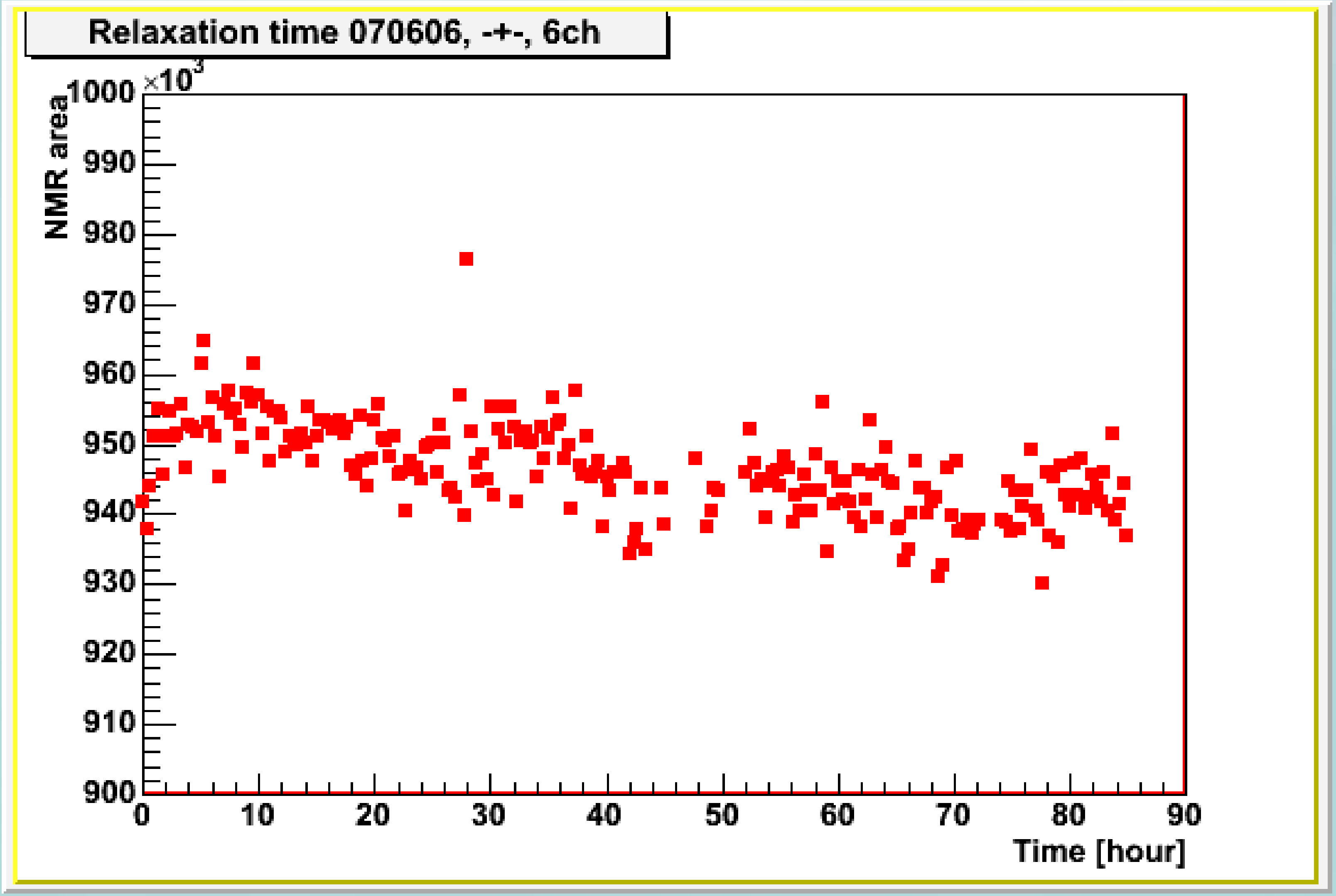


Longitudinal polarization
Solenoid 1.0T

Transversal polarization
Dipole 0.6T

- Polarization decreases with a relaxation time.
- The target has to be re-polarized at somewhere.

Proton spin relaxation at 0.6T



Relaxation time

Temperature ~60mK

	Material	Magnetic field	Relaxation time
COMPASS	^{6}LiD	2.5 T	>15000 h
COMPASS	^{6}LiD	1.0 T	~ 10000 h
COMPASS	NH_3	1.0 T	~ 9000 h
COMPASS	NH_3	0.6 T	~ 4000 h
SMC	NH_3	0.5 T	500 h
COMPASS	^{6}LiD	0.0 T	2.5 min. for positive
COMPASS	NH_3	0.0 T	~ 70 min. for positive ~ 10 min. for negative

Summary for the 2007 run

- The 2007 run successfully finished.

  (new magnet, 3 target cells, large microwave cavity)
- NH_3 is used in the 2007 run.

NH_3 material	SMC	COMPASS
	1996	2007
color	violet	pale
spin density [/cm^3]	6 x 10^{19}	4.3 x 10^{19}
relaxation time (60mK)	500h at 0.5T	4000h at 0.6T
Polarization [%]	~ 90	~ 90

- Y. Kisselev will show detail proton polarization analysis.

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  - Introduction
  - Influence of heat input from the pion beam to the polarized target
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The COMPASS experiment

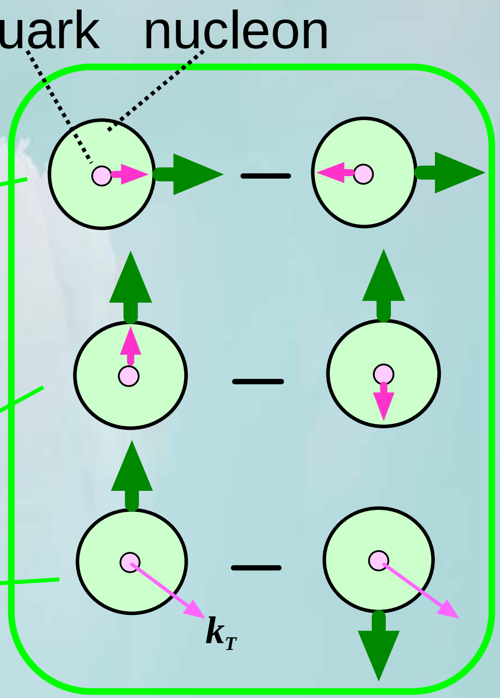
muon program (2002 ~ 2007) with polarized muon beam

Longitudinal polarized target
- gluon spin distribution: ΔG
- quark helicity distribution : $\Delta q(x)$

Since SMC experiment

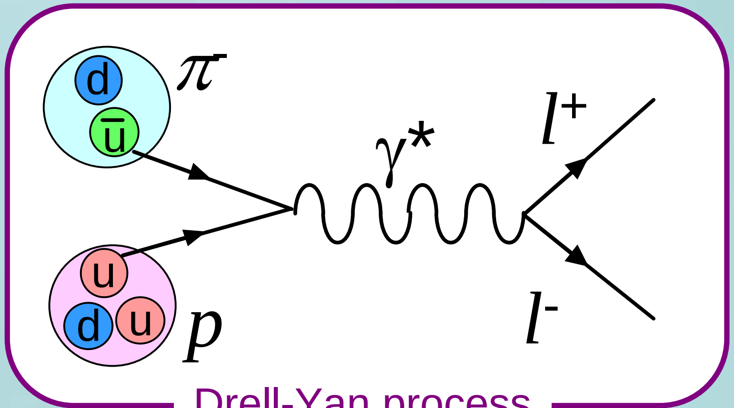
Transversal polarized target
- quark transversity distribution : $\Delta_T q(x)$
- Sivers function : $f_{1T}^{\perp}$

Quark orbital angular momentum



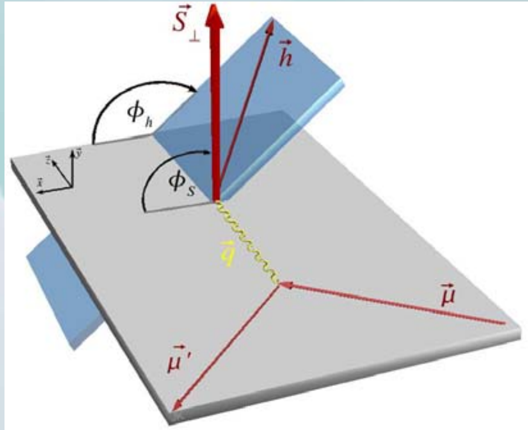
Drell-Yan program (2011? ~)

with pion beam and
transversally polarized target



Drell-Yan process

Motivation - Transversity and Sivers function



SIDIS many components of transverse target spin dependent azimuthal modulations

$$A_{Collins}^{\sin(\phi_h+\phi_S)} \propto \Delta_T q(x)\, H_1(z)$$

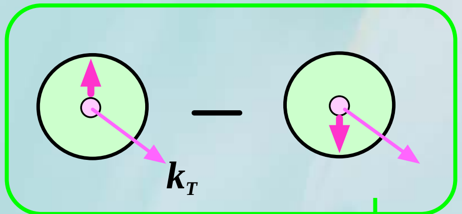
$$A_{Sivers}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp}(x)\, D_1(z)$$

Uncertainty of Fragmentation Function

Drell-Yan

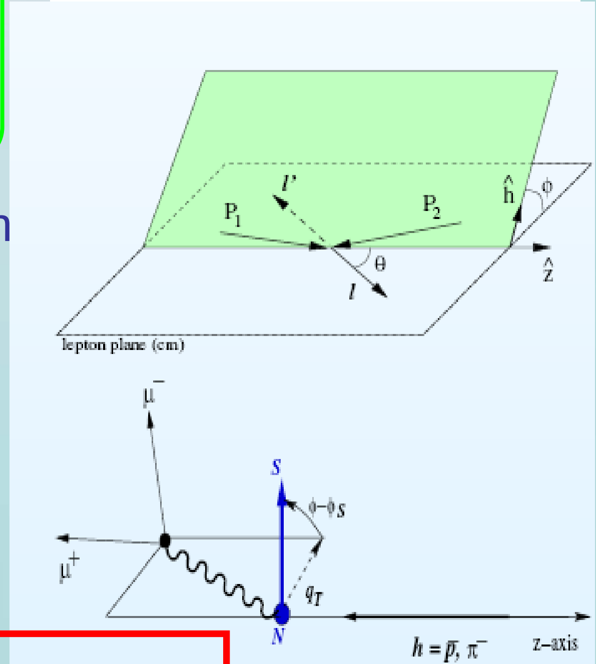
unpol. DY

$$\hat{k} \propto h_1^{\perp(1)}(x_1)\, h_1^{\perp(1)}(x_2)$$



Coefficient at cos2ϕ dependent part of the properly integrated over q_T ratio of the cross-section

$h_1^{\perp(1)}(x)$ 1st moment of Boer-Mulders function $h_1^{\perp}(x)$



single spin DY asymmetries

FF free

$$A^{\sin(\phi+\phi_{S2})} \propto h_1^{\perp(1)}(x_1)\, \Delta_T q(x_2)$$

$$A^{\sin(\phi-\phi_{S2})} \propto f_1(x_1)\, f_{1T}^{\perp(1)}(x_2)$$

Unpol. PDF

prediction

$$f_{1T}^{\perp}\Big|_{DY} = - f_{1T}^{\perp}\Big|_{SIDIS}$$

Experimental condition in terms of DY target

Transverse mode with hadron beam

- The present system can be used

- Proton target

  High polarization, high dilution factor and long relaxation time ➡ NH3

- Frozen spin mode with 0.62 T for transverse polarization

  Cannot be polarized (only at 2.5T can be)

- High intensity hadron beam (~2 x 10^7 hadrons/s) ➡ heat input

  Nuclear interaction produces secondly hadrons

  ⬇ Material temp. warms up

  ⬇ Fast spin relaxation time

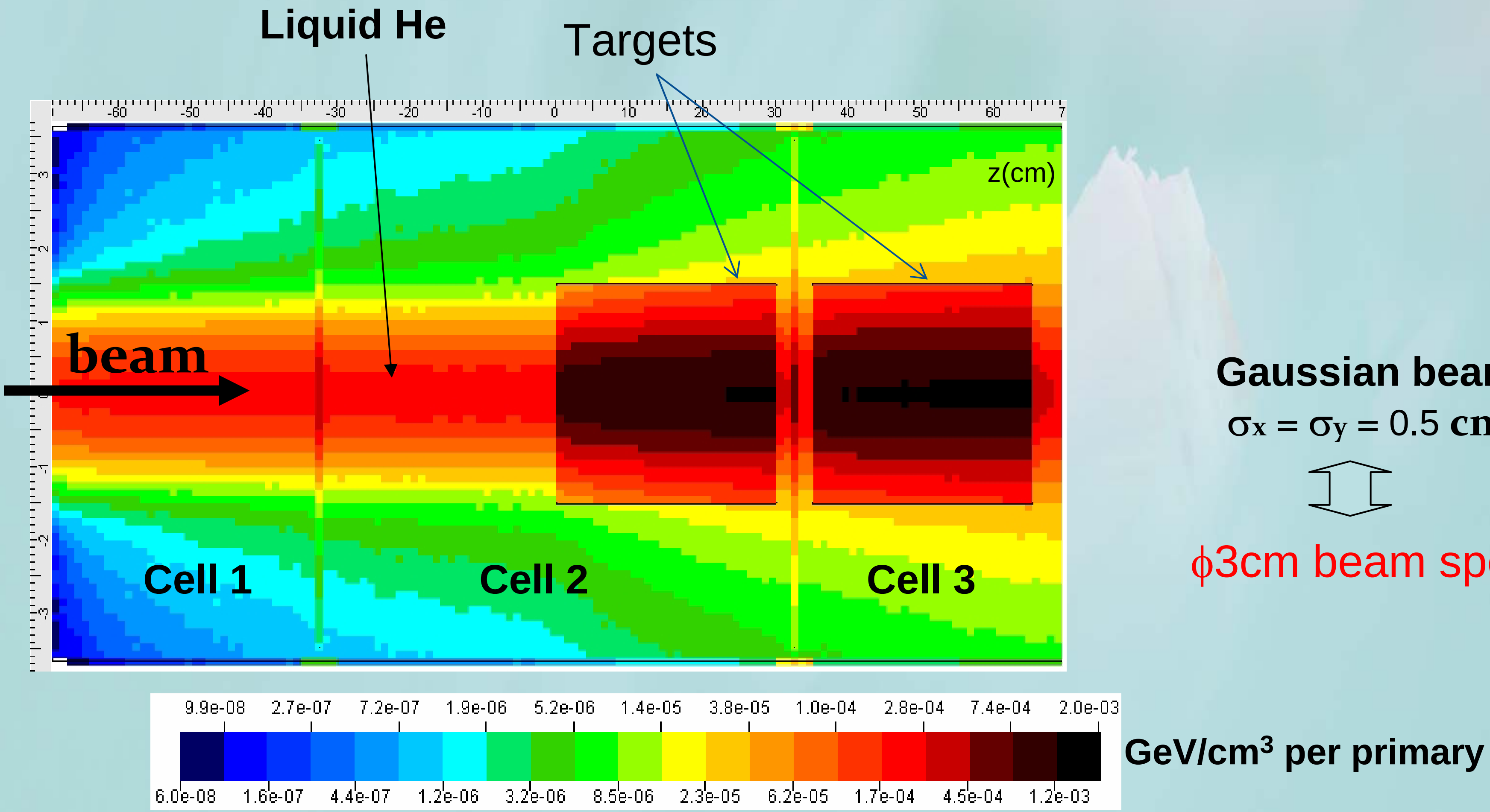
multiplicity = Total probability factor of secondly particle productions

- Smaller beam focus size ➡ The beam intensity gets higher on a material bead

  Smaller diameter target is preferred

- Target length of 15-30 cm x 2 cells

Energy deposition in 30-30cm target



Gaussian beam

$\sigma_x = \sigma_y = 0.5$ cm

ϕ3cm beam spot

done by H. Vincke and E. Feldbaumer

Average multiplicity per a incoming hadron

$$\text{Multiplicity} = \frac{\text{Energy deposition [GeV]}}{2\ [\text{MeV/g/cm2}] \times 0.85\ [\text{g/cm3}] \times L\ [\text{cm}] \times 0.5}$$

packing factor

Heinz and Eduard's result

Energy deposition[GeV]
(Multiplicity)

	cell 1	cell 2	cell 3
30-30	7.03×10^{-2} (2.8)	9.04×10^{-2} (3.5)	
20-20	3.99×10^{-2} (2.3)	4.89×10^{-2} (2.9)	
30-60-30	5.94×10^{-2} (2.3)	1.97×10^{-1} (3.9)	1.20×10^{-1} **(4.7)**

DY beam test, 11-12 November 2007

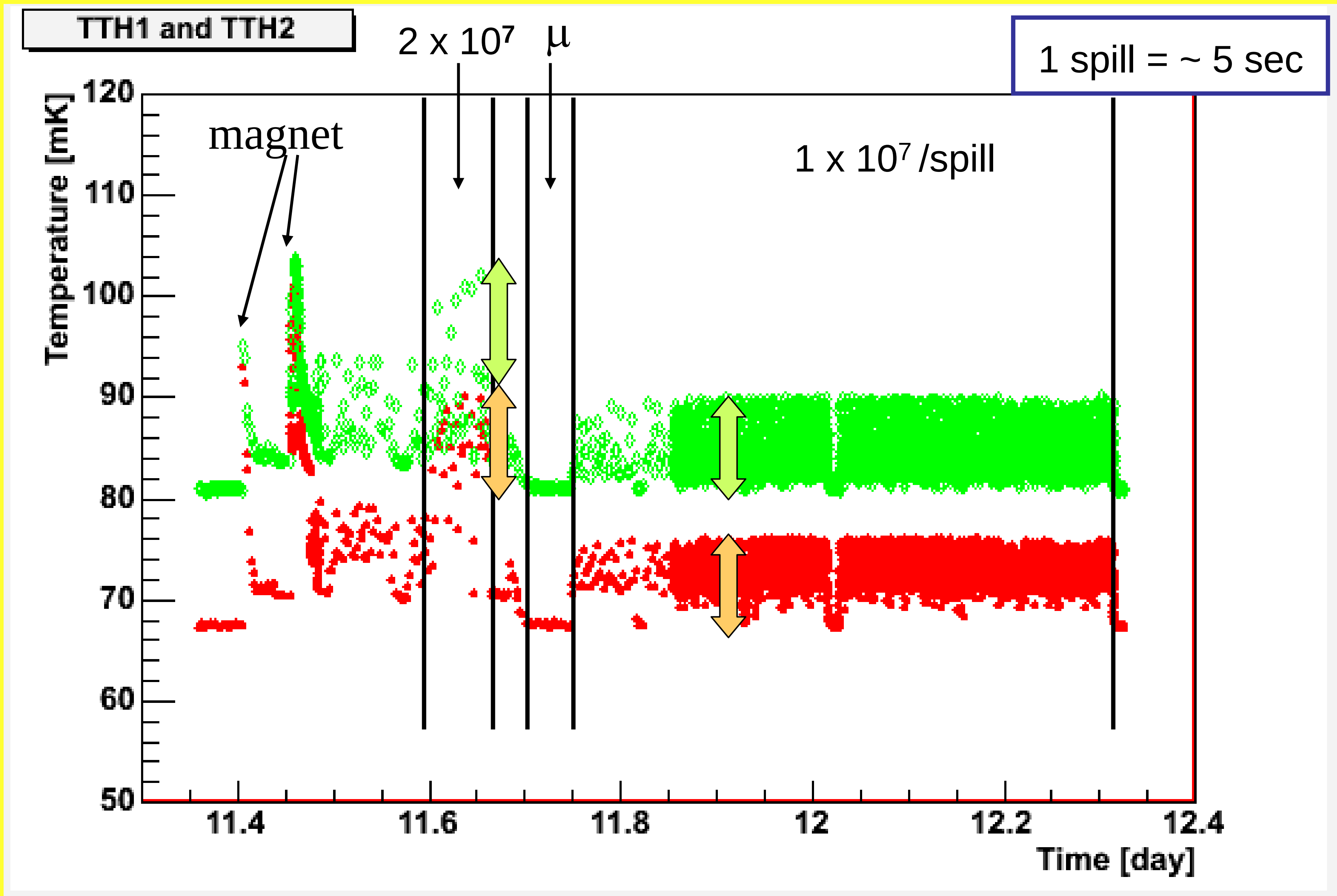
Feasibility study of the Drell-Yan program with COMPASS spectrometer

- 160 GeV negative pion beam
- COMPASS PT performance during the operation with the high intensity hadron beam
- Radiation conditions in the experimental hall with COMPASS PT (full length ~ 100% int.leng.);

  operation with high intensity hadron beam: 2×10^7 hadrons/spill

  L ~10^{31} cm^{-2} s^{-1} (~ equivalent to 10^8 hadrons/spill on 25% int.leng. PT)
- J/Ψ event rates (good normalization for DY and background)
- **COMPASS spectrometer performance during the operation with high intensity hadron beam**
- Background/Signal level and trigger rates

Temperature sensors behavior during the beam test



Average multiplicity per a incoming hadron

Comparing with data with muon beam,

5 x 10^7 muons/spill ⟺ 1 x 10^7 pions/spill

Multiplicity ~ 5 with 30-60-30cm long

Energy deposition[GeV]
(Multiplicity)

	cell 1	cell 2	cell 3
30-30	7.03 x 10^{-2} (2.8)	9.04 x 10^{-2} (3.5)	
20-20	3.99 x 10^{-2} (2.3)	4.89 x 10^{-2} **(2.9)**	
30-60-30	5.94 x 10^{-2} (2.3)	1.97 x 10^{-1} (3.9)	1.20 x 10^{-1} **(4.7)**

Beam test
4.7 x 1·10^7 [/s] = 4.7 x 10^7 [/s]

Physics run
2.9 x 2·10^7 [/s] = 5.8 x 10^7 [/s] ~ muon intensity for muon program

Limitation of target cell size

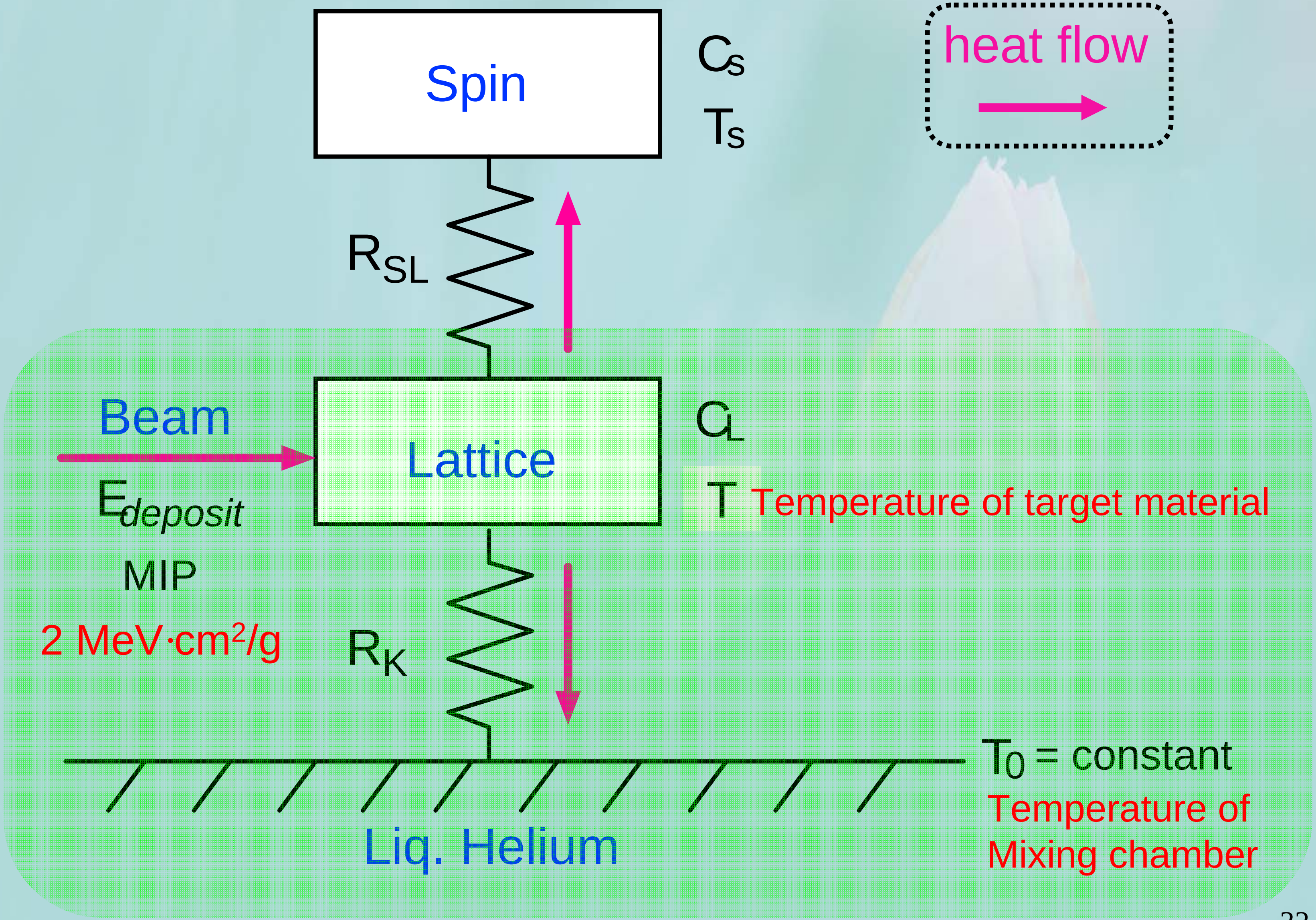
heat input by high intensity of hadron beam

- **Diameter** ⇒ beam intensity in terms of a bead ⇒ **Temperature of material bead**
- **Length** (20 cm x 2) ⇒ total heat input into cells ⇒ **Temperature of Mixing chamber** ⟺ Cooling power of DR

↳

Investigate the possibility of
-smaller beam focus size and target cell
-higher beam intensity
via
-temperature variation of the material
-total heat input into Mixing chamber
with
-NH_3

Heat flow diagram



Specific Heat

$C_L = C_{phonon} + C_{cryocrystal} + C_{non\text{-}crystal}$

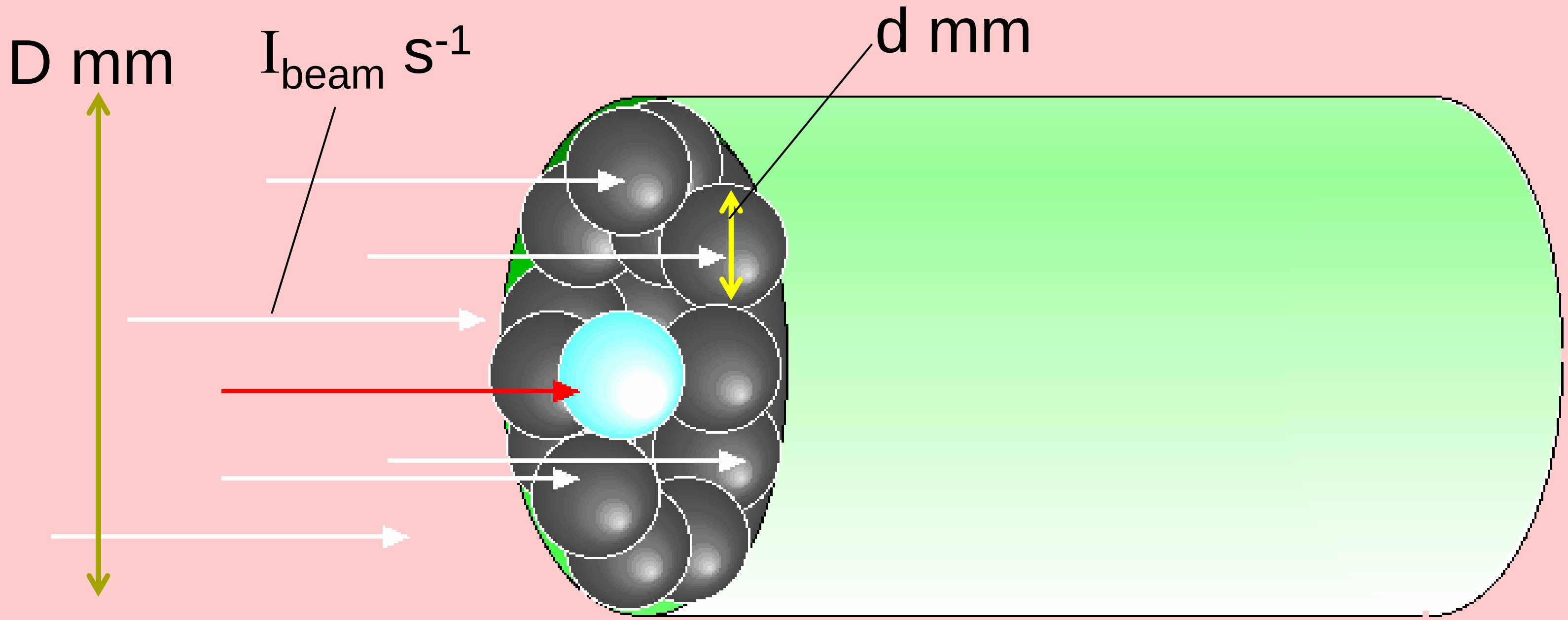
$$C_{phonon}(T) = \frac{12}{5}\pi^4 N_A k_B \left(\frac{T}{\theta_D}\right)^3$$

θ_D : Debye temperature
^{7}LiD ~1030K
$^{14}NH_3$ ~235K

$C_{cryocrystal}(T) = ??$ For NH_3, ND_3

$C_{non\text{-}crystal}(T) = ??$ For butanol?, CH_2, CD_2

Model for calculation of temp. variation



- Target material : spherical shape, LiD: d=4 mm, NH_3: d=3 mm

- Beam focus = target size: circular cross section (D=30mm for muon program)

- Beam intensity in terms of one bead : $I_{bead} = \frac{d^2}{D^2} \cdot I_{beam} \cdot N_m$ (multiplicity)

Algorithm for the calculation

Beam interval: $t_i - t_{i-1} = \nu$ sec $= 1/I_{bead}$

$$E_{deposit} = n\, C_L(T(t_{i-1}))\, (T(t_i) - T'(t_{i-1})) \Rightarrow T(t_i)$$

$$\int_0^{\nu} \dot{Q}\, dt = \int_0^{\nu} \frac{A}{R_K} (T(t_{i-1})^4 - T_0^4)\, dt$$

T_0 = 65 mK

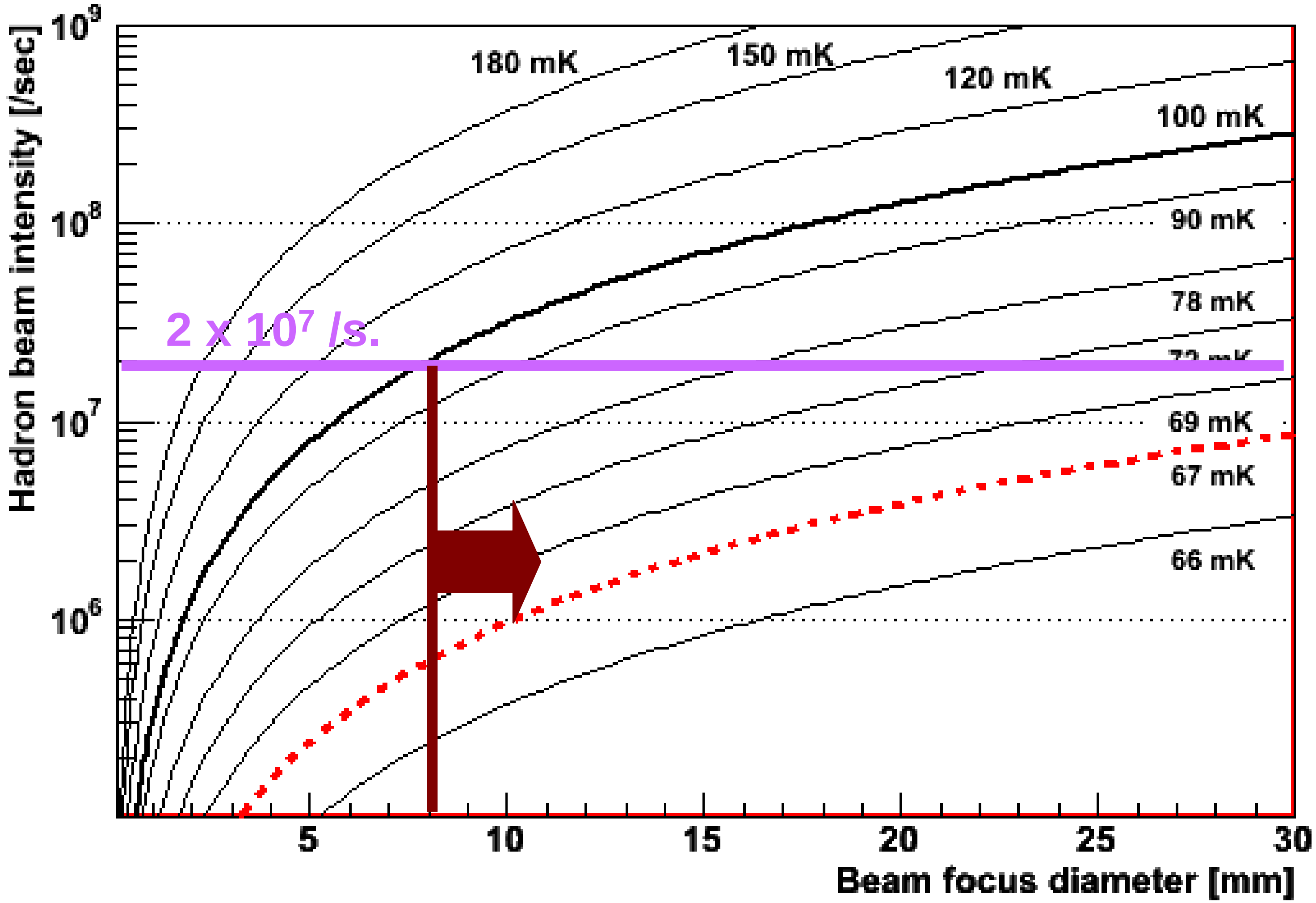
R_K = 50 cm^2K^4/W

(CrK crystal - ^4He)

$$T'(t_i) = \frac{E_{deposit} - Q}{n\, C_L(T(t_{i-1}))} + T(t_{i-1})$$

NH_3 material temperature

It should be kept below 100 mK.



Total heat input in the target cells

$$\dot{Q}_{total} = N_m \cdot (\rho_m \cdot \kappa + \rho_{He} \cdot (1 - \kappa)) \cdot 2L \cdot E_{MIP} \cdot I_{beam}$$

This heat should be removed by Dilution refrigerator

N_m : Multiplicity

ρ : Material or helium density

κ : Packing factor

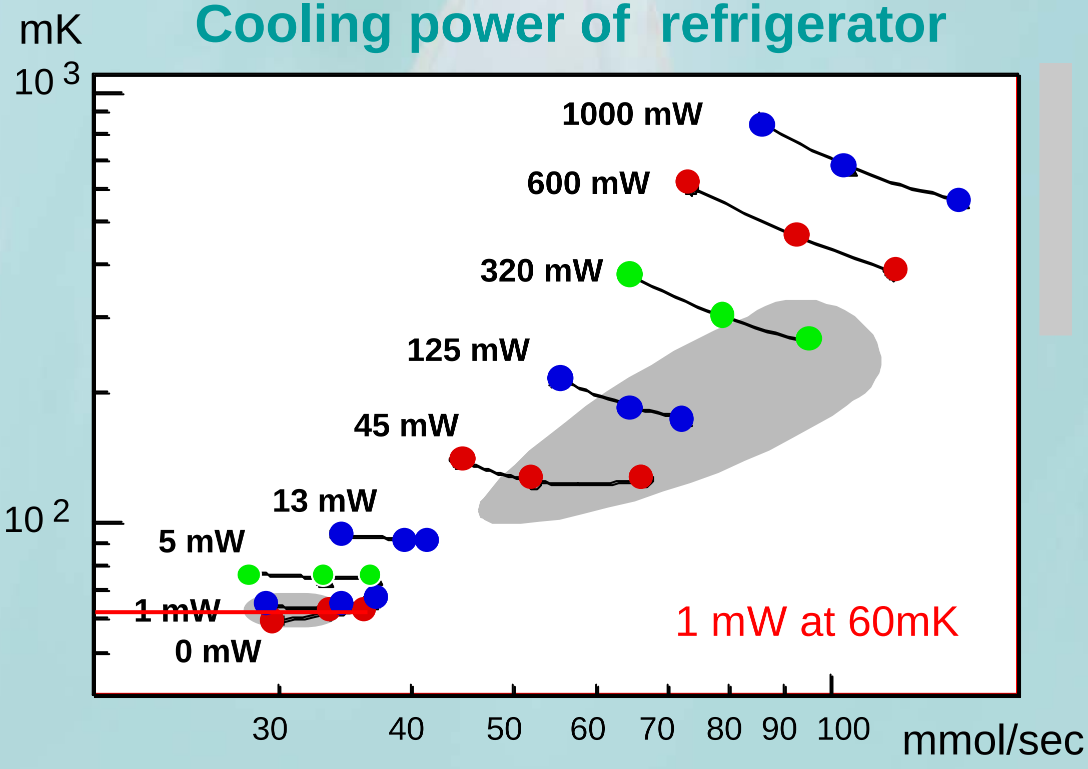
L : Target cell length =20cm

E_{MIP} : 2 MeV· cm²/g

I_{beam} : Beam intensity

Q_{total} = 0.6 mW

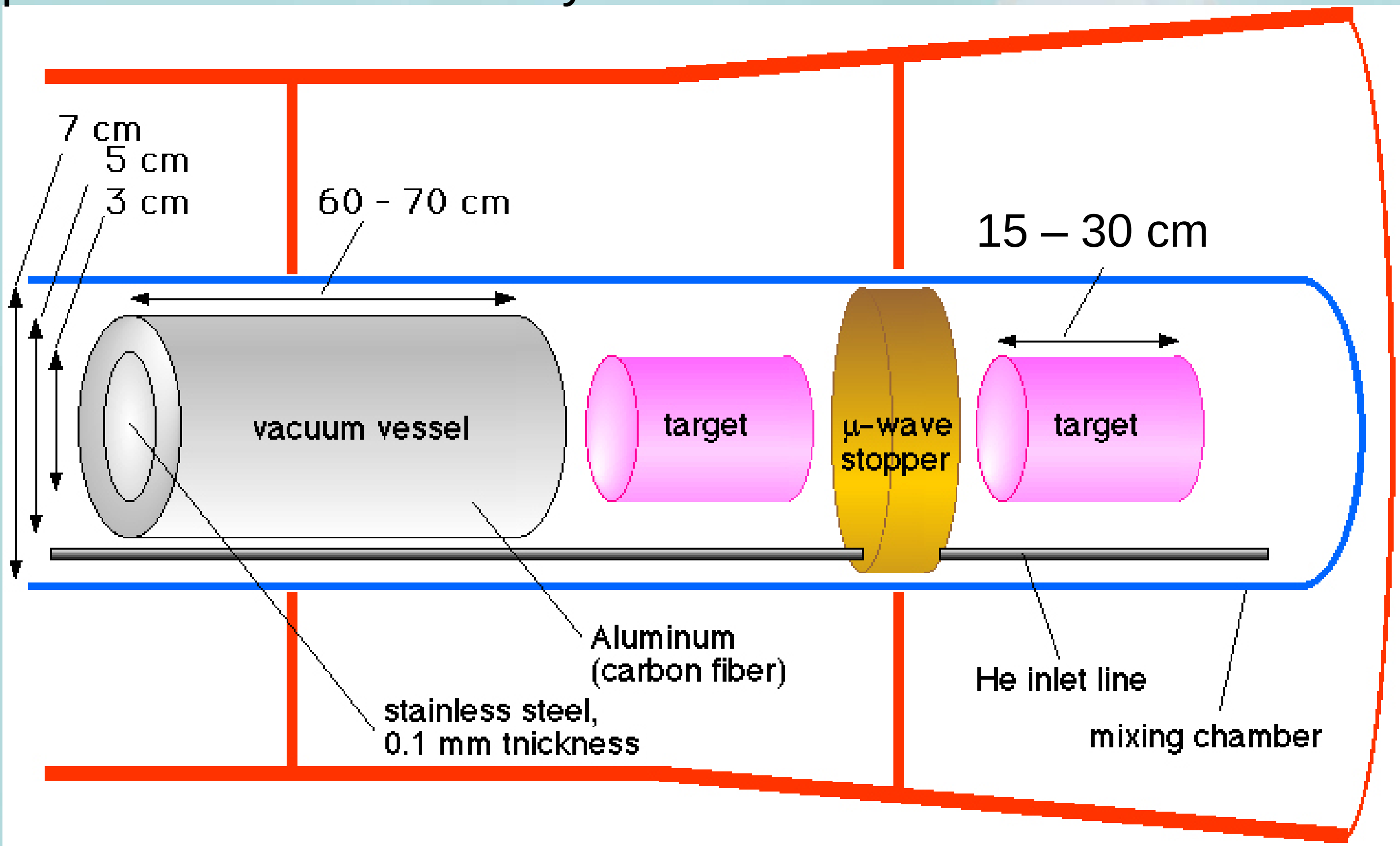
Cooling power of refrigerator



New target cells idea

Liq. He 50cm = 10% int. length
NH3 target cell 20cm x 2 = 30% int. length

- The cells will be put in the downstream to get higher acceptance.
- The present microwave cavity can be used.



New target material - ^{7}LiH

1960s : Abragam used ^{6}LiF to check experimentally DNP.

1980s : Saclay group investigated ^{7}LiH and ^{6}LiD.

(J. Ball, NIM A 526 (2004) 7-11)

High dilution factor

^{7}Li can be recognized as $\alpha + 2n + p$.

Dilution factor : 2/8

spin 3/2

(J. Phys. G: Nucl. Part. Phys. 30 (2004) 1479-1485)

It doesn't have exact same proton polarization with spin 1/2 .

How can be extracted proton polarization in ^{7}Li ?

Definition of vector polarization

$$P = \frac{\langle I_z \rangle}{I}$$

expectation

Proton polarization

$$P_p = \frac{\frac{1}{2}N_{+1/2} - \frac{1}{2}N_{-1/2}}{\frac{1}{2}(N_{+1/2} + N_{-1/2})}$$

$$N_{I_z} = \exp(I_Z \upsilon h B / k_B T_S)$$

k_B: Boltzmann constant

T_S: Spin temperature

B=2.5T at COMPASS

$\upsilon_p h = 2\,\mu_p \quad \mu_p = 1.41 \times 10^{-26}$ [J/T]

$\upsilon_{7Li} h = \frac{2}{3}\,\mu_{7Li} \quad \mu_{7Li} = 1.64 \times 10^{-26}$ [J/T]

μ: Magnetic moment

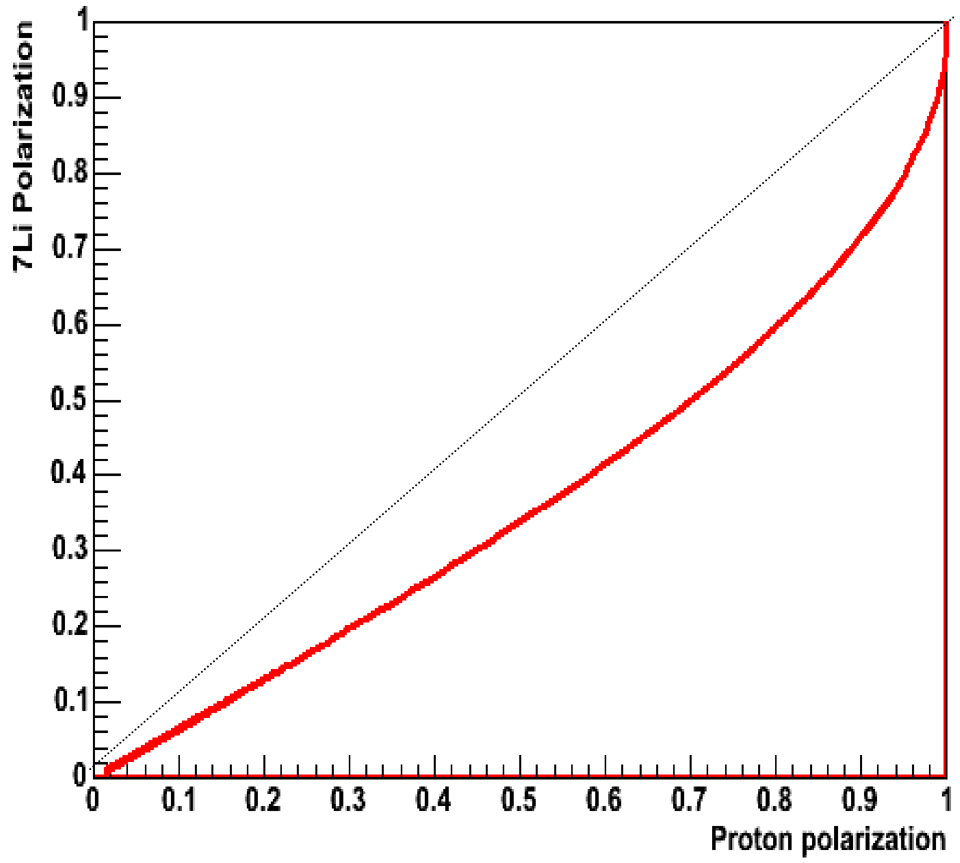
^{7}Li polarization

^{7}LiH   7Li and H have same spin temperature.

$$P_{^7Li} = \frac{\frac{3}{2}N_{+3/2} + \frac{1}{2}N_{+1/2} - \frac{1}{2}N_{-1/2} - \frac{3}{2}N_{-3/2}}{\frac{3}{2}(N_{+3/2} + N_{+1/2} + N_{-1/2} + N_{-3/2})}$$

$$= \frac{N_{+3/2} + \frac{1}{3}N_{+1/2} - \frac{1}{3}N_{-1/2} - N_{-3/2}}{N_{+3/2} + N_{+1/2} + N_{-1/2} + N_{-3/2}}$$

Proton polarization vs 7Li polarization



Proton polarization in ^{7}Li

^{7}Li : 1p state in energy level

$\alpha + 2n + p \Rightarrow$ proton : J = 3/2

J = S + L

S : spin

L : orbital angular momentum

Clebsch-Gordan coefficients of 1 x 1/2 system

Jz = +3/2 : Sz = +1/2, Lz=+1:: 1/1

Jz = +1/2 : Sz = +1/2, Lz= 0:: 2/3

Sz = -1/2, Lz=+1:: 1/3

Jz = -1/2 : Sz = -1/2, Lz= 0:: 2/3

Sz = +1/2, Lz=-1:: 1/3

Jz = -3/2 : Sz = -1/2, Lz=-1:: 1/1

$$P_{P\,in\,^7Li} = \frac{\frac{1}{2}N_{+3/2}+\frac{1}{2}\left(\frac{2}{3}N_{+1/2}-\frac{1}{3}N_{+1/2}\right)-\frac{1}{2}\left(\frac{2}{3}N_{-1/2}-\frac{1}{3}N_{-1/2}\right)-\frac{1}{2}N_{-3/2}}{\frac{1}{2}\left(N_{+3/2}+N_{+1/2}+N_{-1/2}+N_{-3/2}\right)}$$

$$= \frac{N_{+3/2}+\frac{1}{3}N_{+1/2}-\frac{1}{3}N_{-1/2}-N_{-3/2}}{N_{+3/2}+N_{+1/2}+N_{-1/2}+N_{-3/2}}$$

same as 7Li by chance!

Proton polarization in ^{7}Li

Polarization of proton in ^{7}Li vs proton polarization

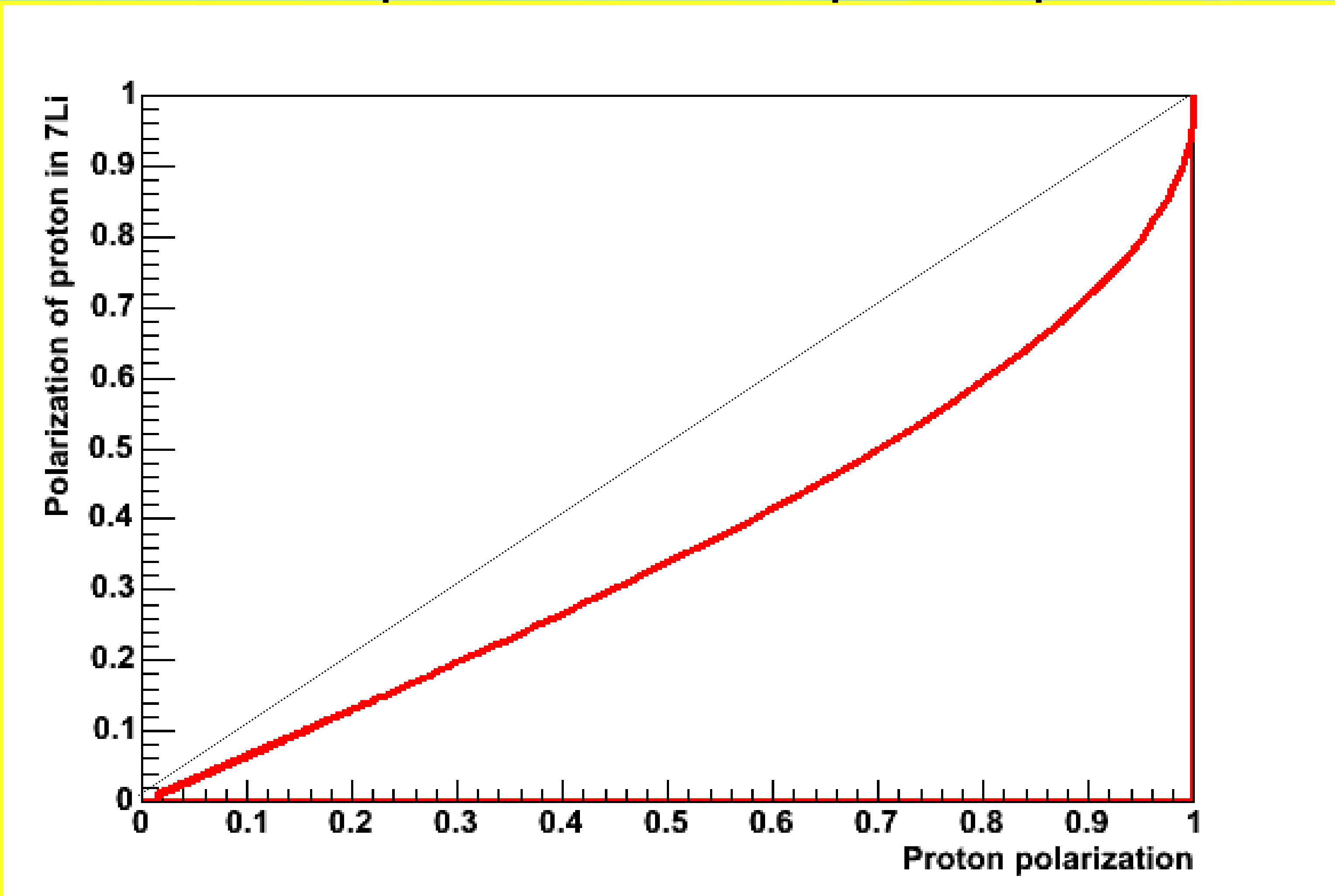


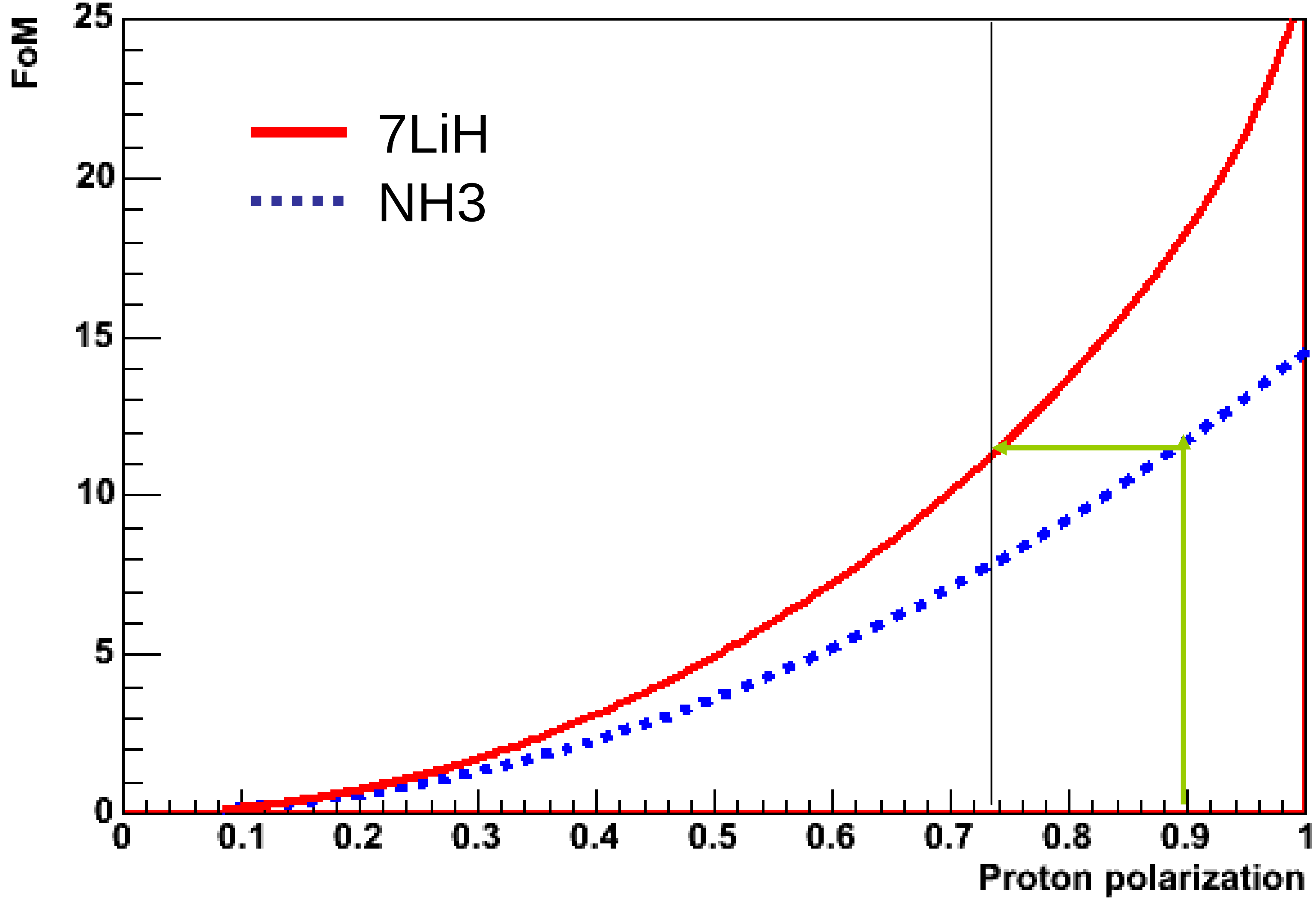
Figure of Merit for the target materials

	NH_3	^7LiH
polarization	0.90 at 2.5T	0.56 at 2.5T in 1988 at Saclay
density [kg/m3] : ρ	850	820
dilution factor : f	0.176	0.125 for proton 0.125 for proton in 7Li
packing factor: κ	0.55	0.55
FoM	11.7	6.3
FoM II	9.0	4.8

$FoM = \rho \kappa f^2 P^2$

Liq He as non-polarized material is included in FoM II.

Figure of Merit for NH_3 and ^{7}LiH



Investigations in 1990s

Bochum group's results in 1995

	1K, 2.5T	200mK, 2.5T	60mK, 2.5T (COMPASS)
^6LiD deuteron	12.5 %	> 30%	55%
^7LiH proton	14.5 %	??	??

Irradiation : temperature 180K and 1 x 10^{17} e-/cm^2 .
(additional irradiation of 10^{15} e-/cm^2 at 1K)

Temperature and dose of irradiation have to be optimized.

Summary of the DY program

- Compass plans for the Drell-Yan program.
- Multiplicity of 3 in the 20-20cm long target is estimated.
- Any problems of the material temperature cannot be expected at the beam spot size more than 10 mm diameter.
- The modification of the target place is needed.
- ^{7}LiH has a higher dilution factor.
- Investigation of ^{7}LiH is needed.

Another future program (GPD)

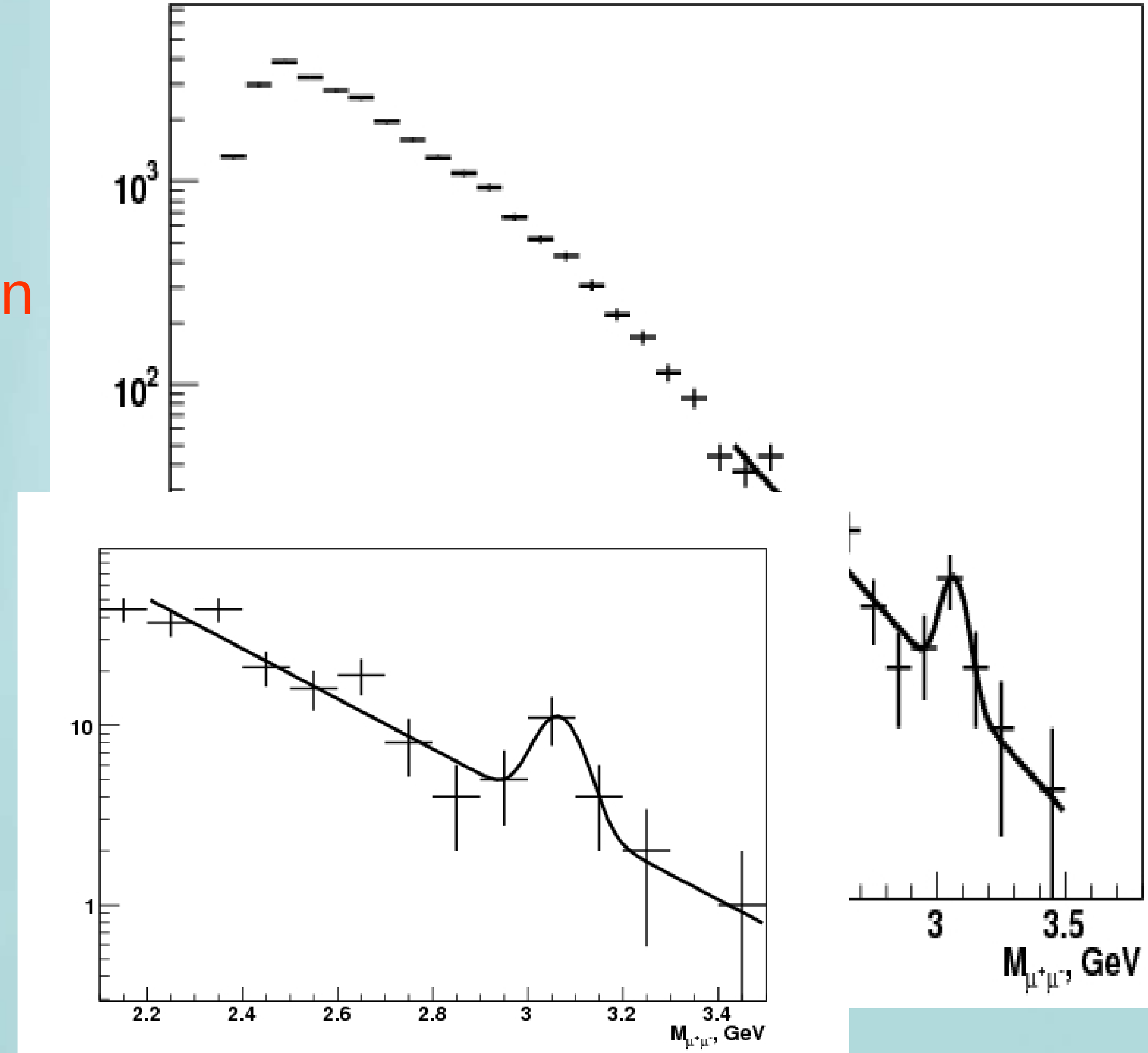
- A 2.5m long liquid hydrogen target for GPD program
- A long transverse PT surrounded by recoil detector

⇨ Discussion has already started.

Back up

Very first J/Ψ signal

Just a fraction of
statistics (~1/3)
No cut tuning
No Coral and option
files modification
– just everything
standard J/Ψ yield
close to expected



$\mu^+\mu^-$ Invariant mass 450 GeV

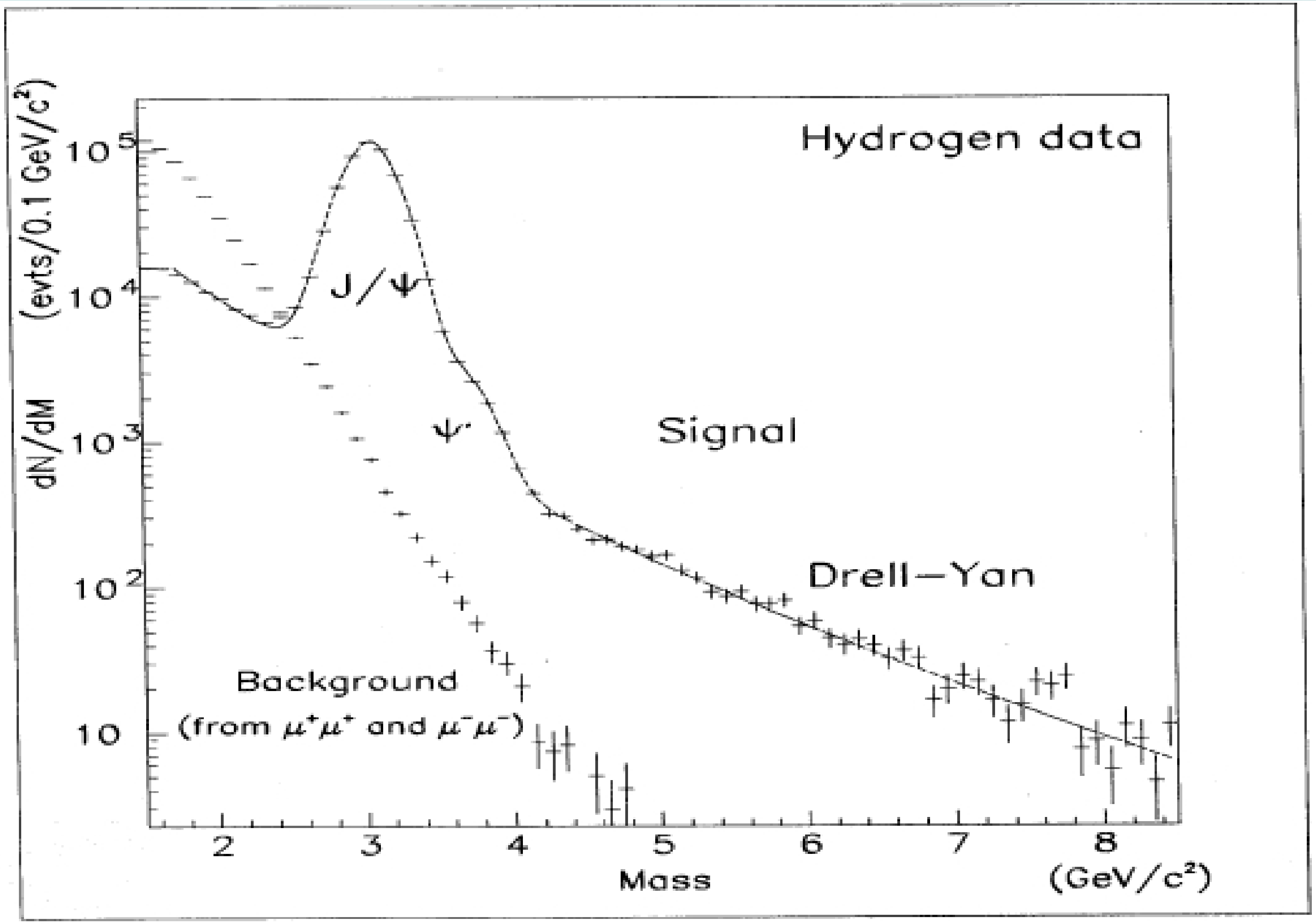


Figure 1: Mass spectra of background and signal for p-p events.

Very preliminary DY event rates estimate

- Target: NH3 and L_{NH3}=15 cm x 2, (ρ_{NH3} : 0.85 g/cm^3)
- PT material filling factor F_f = 0.6
- Number of nucleon in NH_3 molecule: A_{NH3} =17
- π- beam intensity: $I_{beam} = 2\times10^7$ p/s
- $N_A = 6.0 \times 10^{23}$ mol^{-1}

Luminosity: $L = L_{NH3} \times N_{cell} \times \rho_{NH3} \times F_f \times N_A \times 1/A_{NH3} \times I_{beam} \approx$

1.1×10^{31} cm^{-2} s^{-1}

- Compass DY pairs reconstruction efficiency (acceptance included) : $A \approx 0.4$
- DY cross section on NH_3: $\sigma_{NH3} = N_{nucl} \times \sigma_{\pi p}$, where N_{nucl}=17
- D_{spill} = 5 s (duration of spill), N_{spill} =4000 (number of spills per day), E_{sps}= 80% (efficiency of the machine)
- Duration of the Run 150 days: D_{RUN}=150

$$R = L \times N_{nucl} \times \sigma_{\pi p} \times A \times D_{spill} \times N_{spill} \times E_{SPS} \times D_{RUN}$$

DY cross sections and statistics estimate (150 days of running)

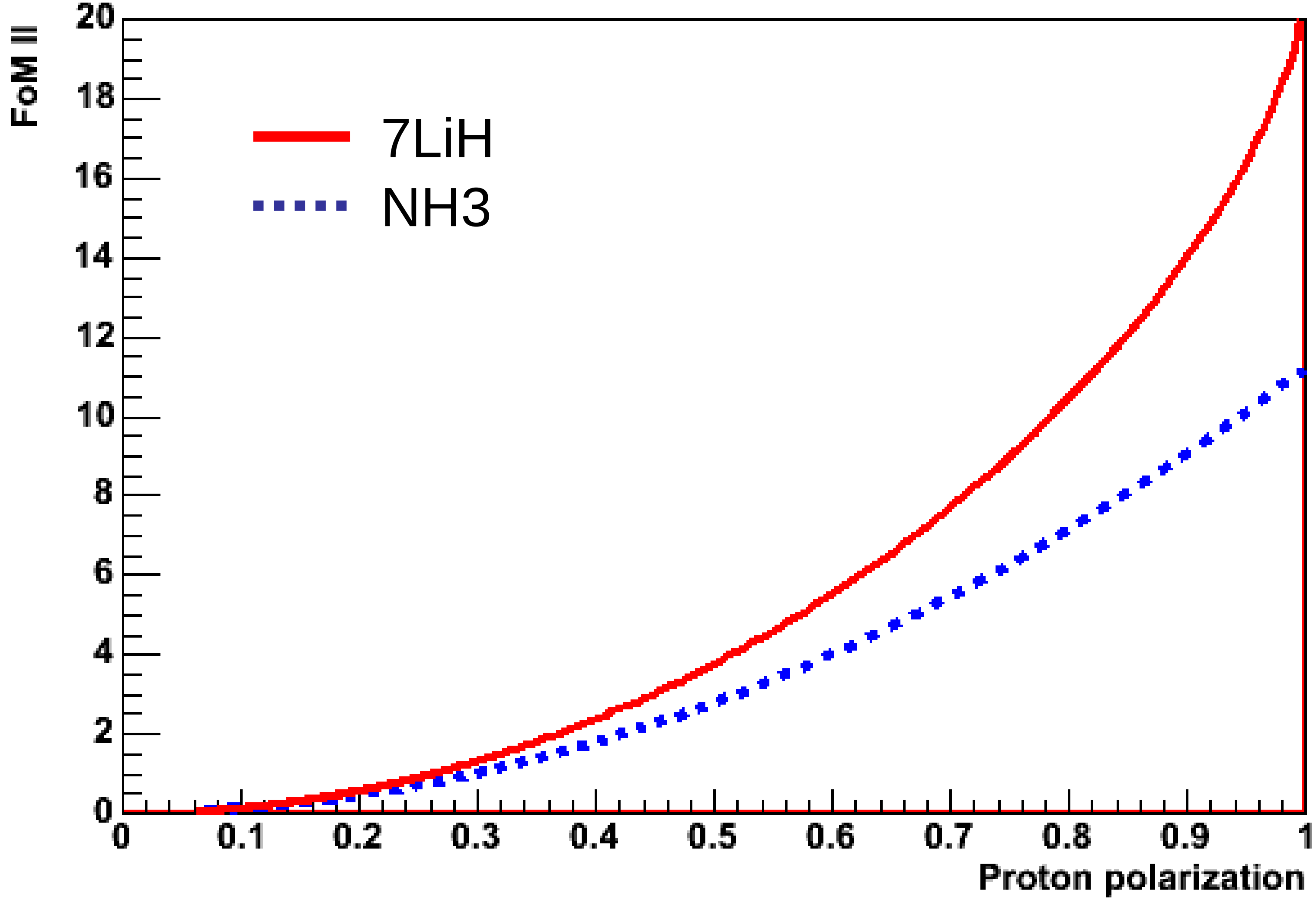
Statistical error ~ 4% for 2 years

M ($\mu^+\mu^-$), GeV S, GeV^2		2.5-4.	4.-9.
100		0.35 nb	0.03 nb
200		0.65 nb	0.10 nb
300		0.78 nb	0.15 nb

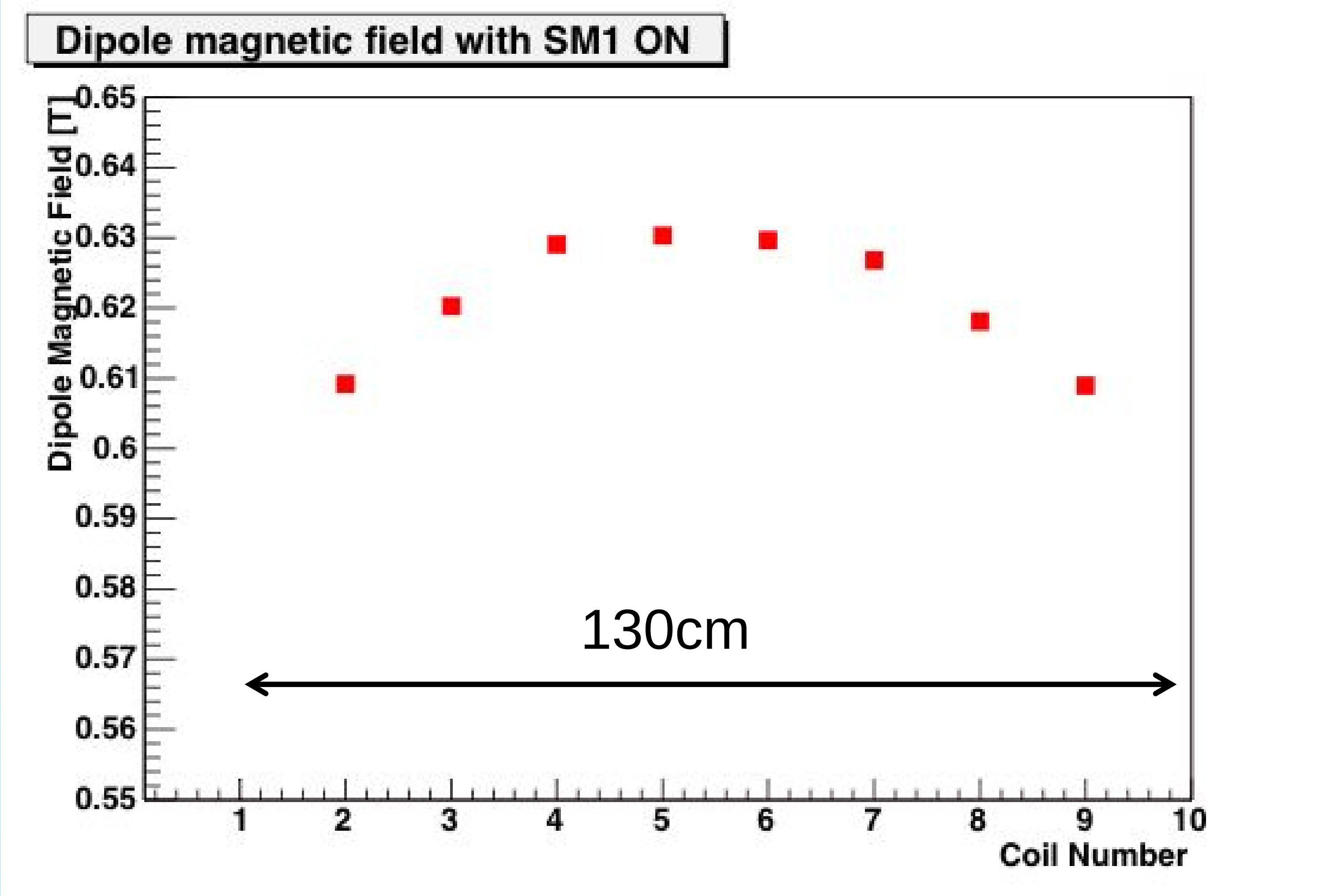
M ($\mu^+\mu^-$), GeV
S, GeV^2
2.5-4.
4.-9.

Cross section values were taken from AB_5 A.Bianconi generator cross-checked with PYTHIA data (A.Nagaytsev, Dubna), without J/Ψ contribution

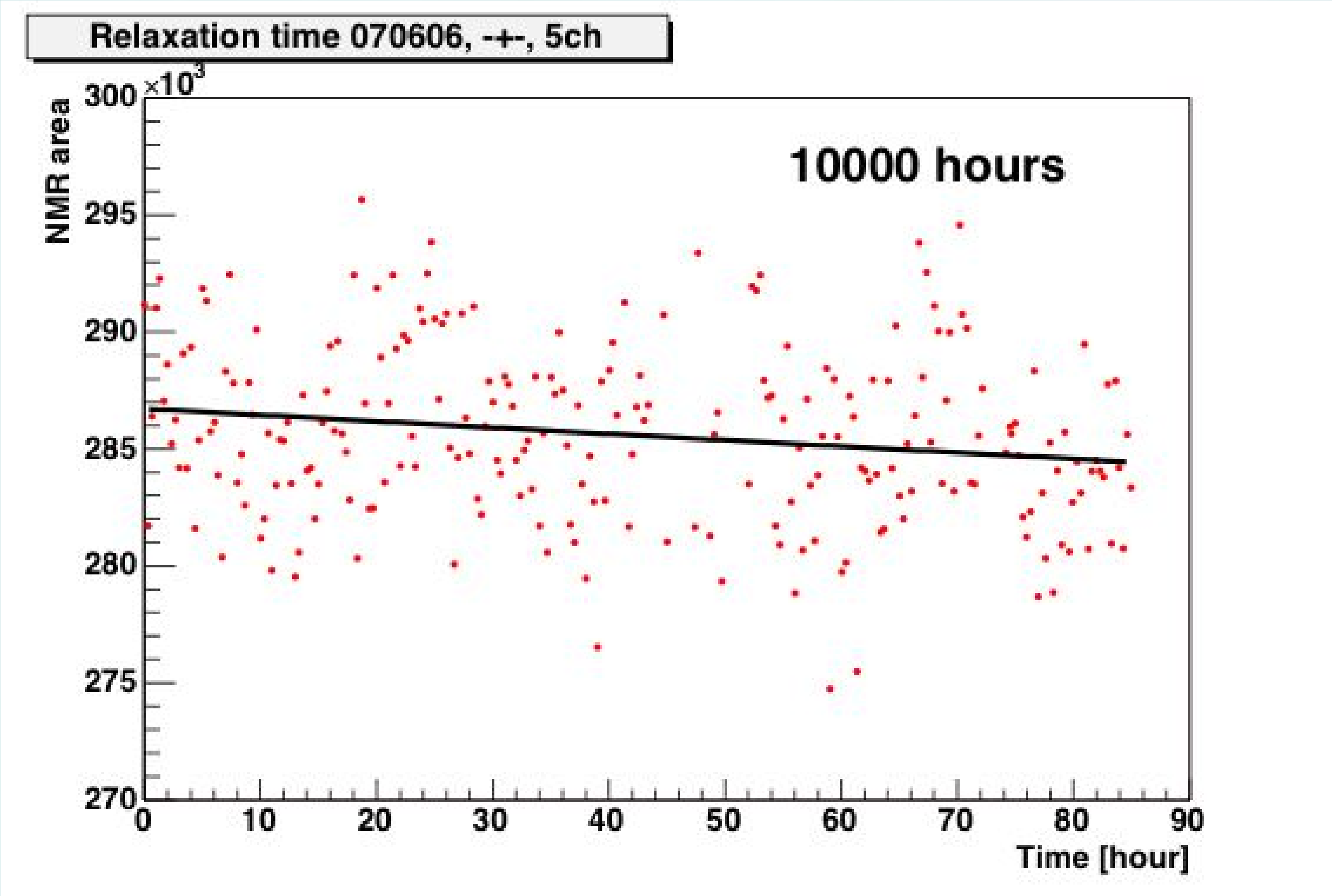
Figure of Merit II for NH_3 and ^7LiH



Dipole magnetic field



Proton spin relaxation at 1.0T



Total heat input in the cells