PNPI

Crystal-diffraction nEDM search experiment

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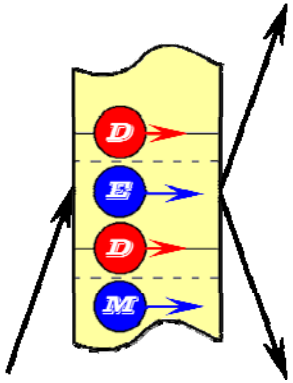
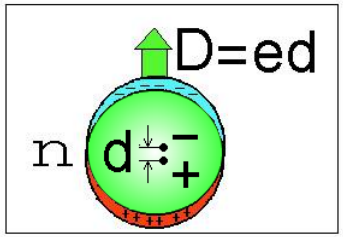
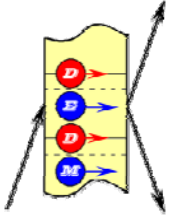


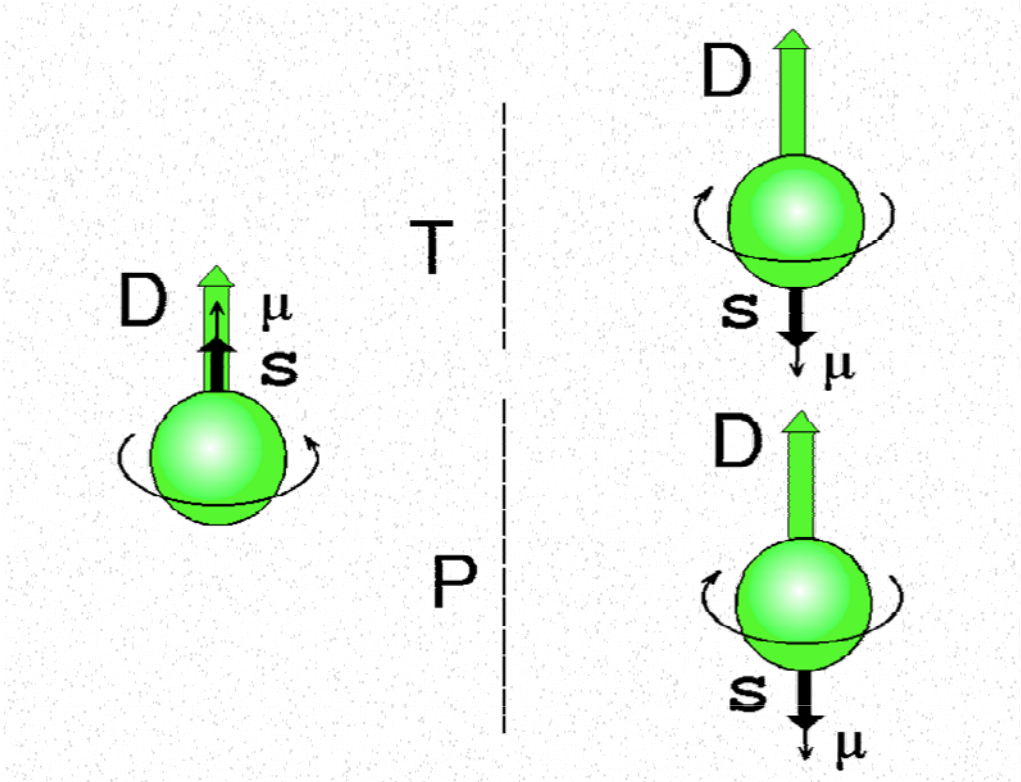
Neutron EDM





Non zero EDM means the P and T violation

P – spatial inversion
C – particle – antiparticle inversion
T – time inversion



CPT theorem
(Lüders (1954); Pauli(1955))

(Our world is CPT invariant)

Non zero nEDM means CP violation

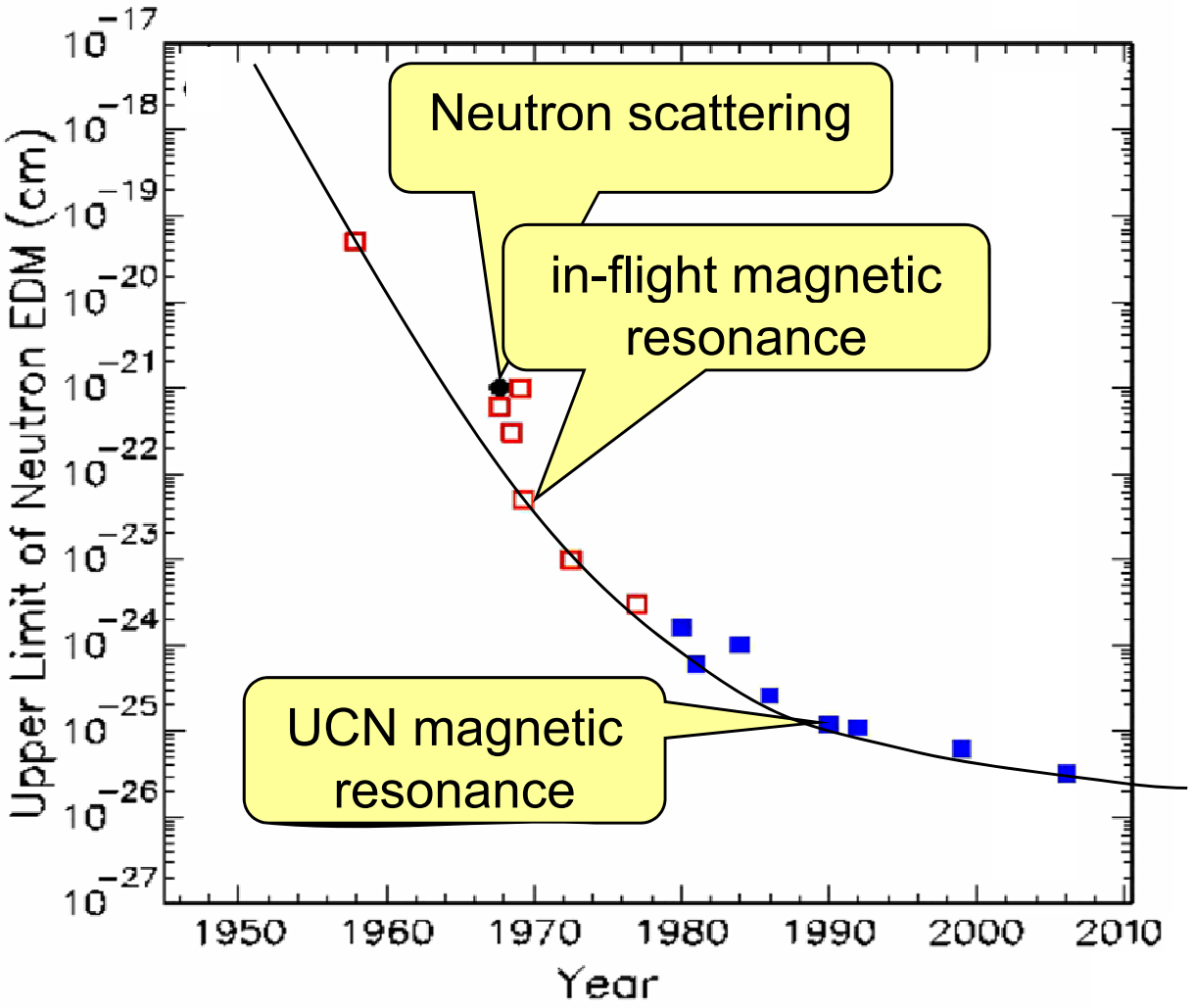
History of nEDM experiment

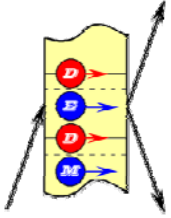
Standard model

$d_n \sim (10^{-31}-10^{-33})$ e cm

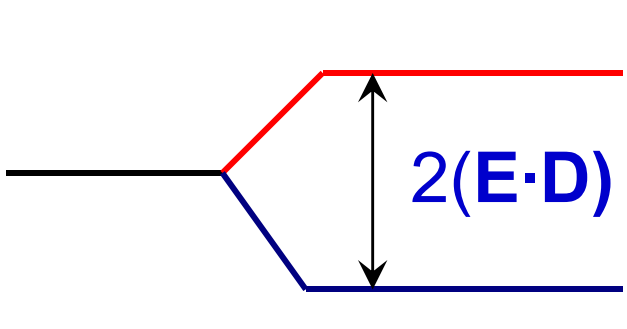
New physics to explain the baryon asymmetry
(experiment - $n_b/n_\gamma \sim 10^{-11}$
SM - $n_b/n_\gamma \sim 10^{-21}$)

$d_n \sim (10^{-25}-10^{-30})$ e cm





Idea nEDM experiment



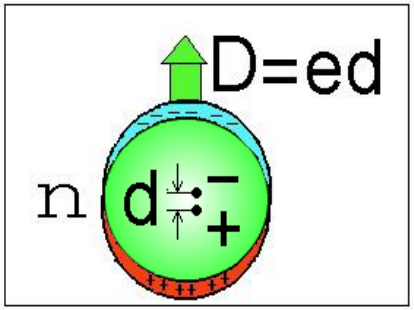
Interaction time with E

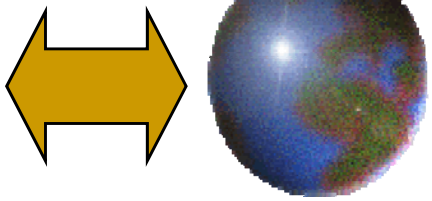
$$\varphi_D = 2(\mathbf{E}\cdot\mathbf{D})\tau/\hbar$$

Sensitivity to nEDM

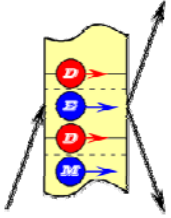
$$\sigma^{-1} \sim E\tau\sqrt{N}$$

Current accuracy to d_n





Neutron size $R_n \sim 10^{-13}$ cm,
$d_n/R_n \sim 3\cdot 10^{-13}$.
Corresponding size from Earth is
~ 2 μm



Sensitivity to neutron EDM

$$\sigma^{-1} \sim E\tau\sqrt{N}$$

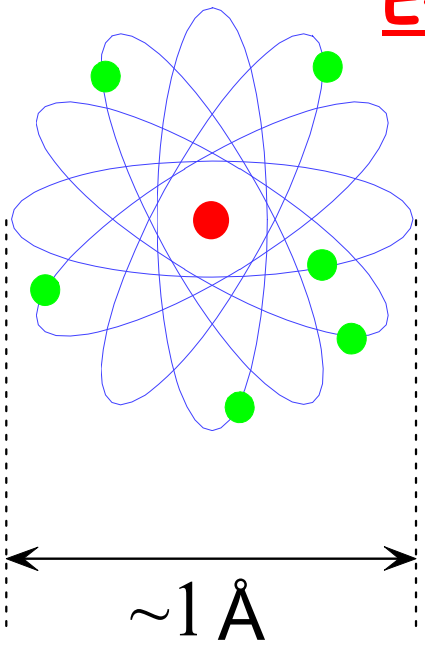
UCN method

E ~ 10 kV/cm
τ ~ 1000s (time of life)
Eτ ~ 10^7(V·s)/cm
Now
Eτ ≈ 10^6 (V·s)/cm

Crystal-diffraction method

Electron bonding energy ~ a few eV

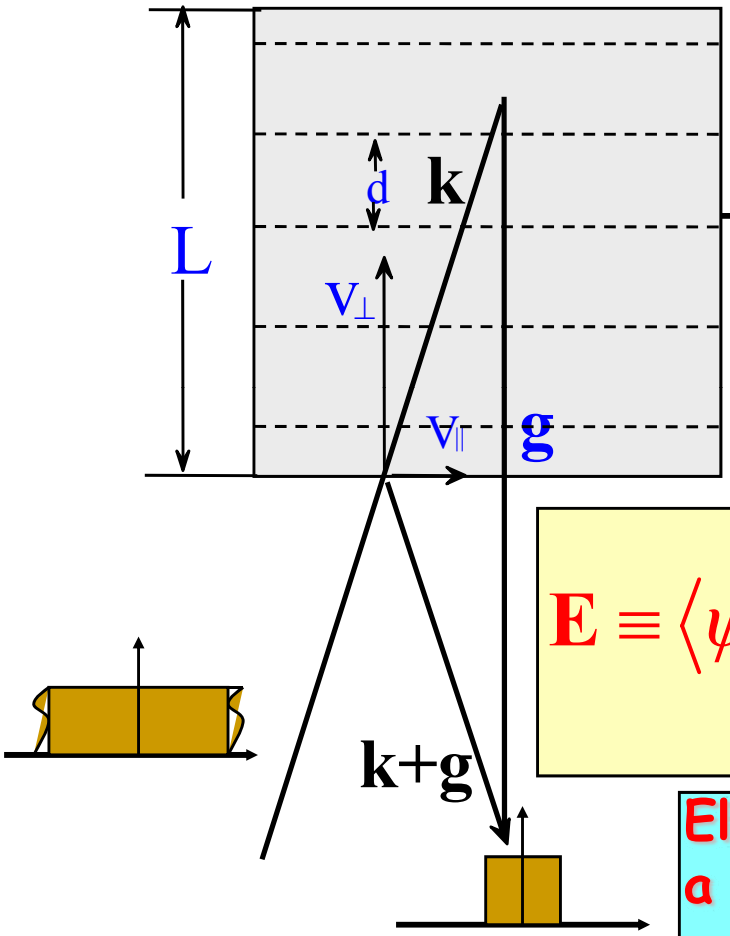
E~ grad V_e ~(0.1-1)GV/cm

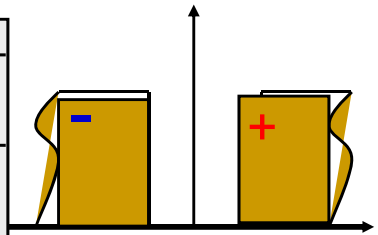


τ_a ~ 0.01 c
(absorption)

Eτ
10^7 (V·s)/cm

Neutron optic of NCS crystal





Wave function

$$\psi(\mathbf{r}) = e^{i(\mathbf{kr})}\left(1 + \frac{V_g}{E_K - E_{K_g}} e^{i(\mathbf{gr})}\right)$$

Electric field

Deviation from Bragg condition

$$\mathbf{E} \equiv \langle \psi(\mathbf{r}) | E(\mathbf{r}) | \psi(\mathbf{r}) \rangle = \frac{2|V_g|}{E_K - E_{K_g}} \cdot \mathbf{E_g}$$

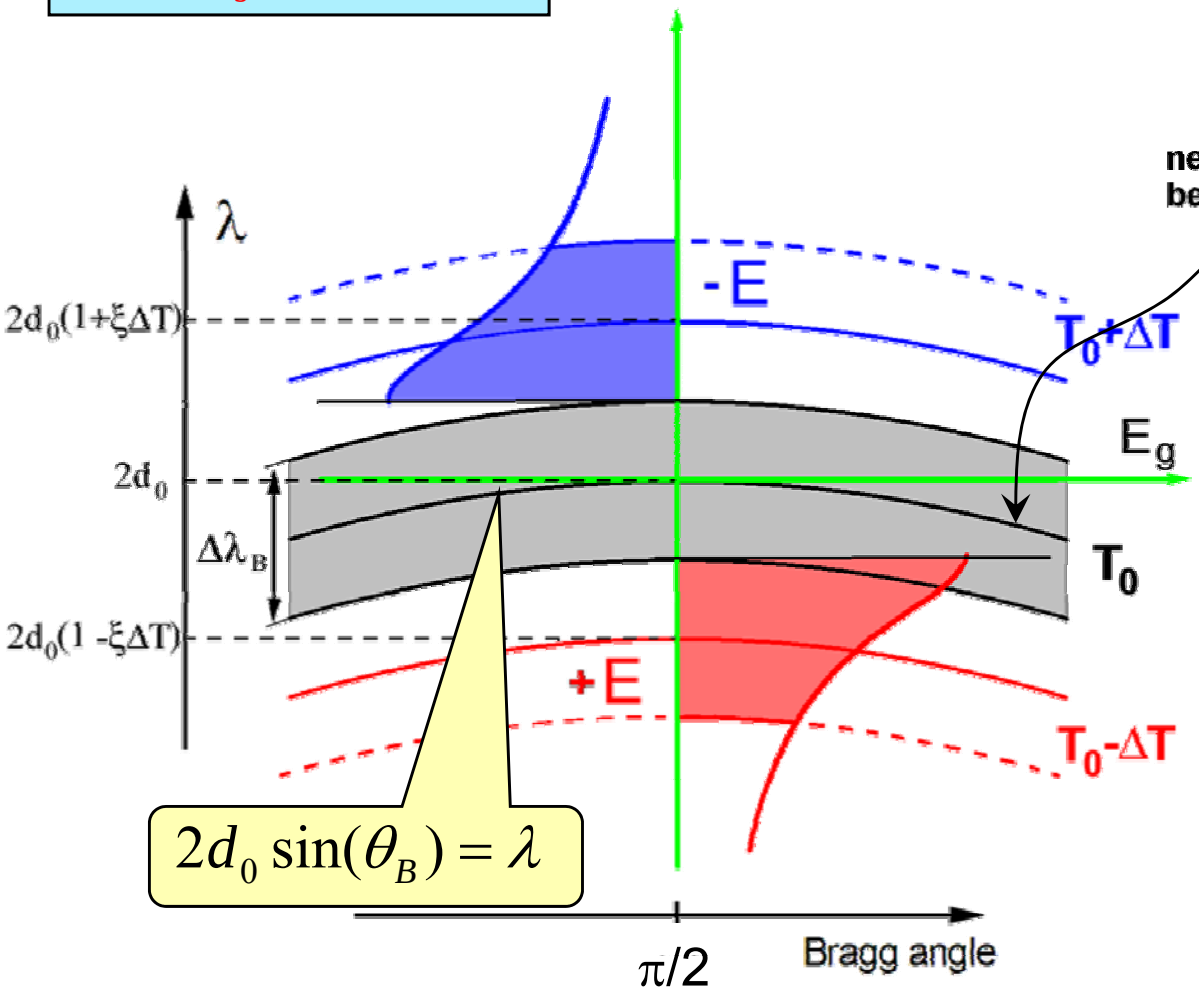
Electric field depends on a deviation from Bragg condition

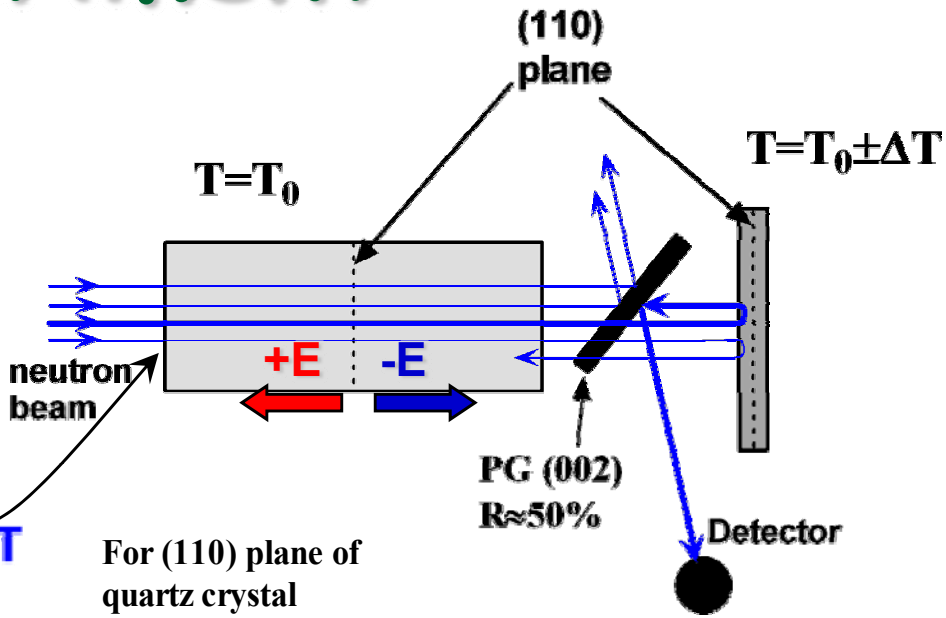
E(Neutron energy)

- M. Forte, J. Phys. G: Nucl. Phys. (1983) 745-754.
- V. G. Baryshevskii and S. V. Cherepitsa, Phys. Stat. Sol. B128 (1985) 379-387.
- V. V. Fedorov, Proc. of XXVI Winter LNPI School, vol. 1, Leningrad (1991) 65.

Idea of the experiment

$$\frac{2v_g^N}{E_K - E_{K_g}} \sim (0.5 \div 0.3)$$





For (110) plane of quartz crystal

$\Delta T = 1^0 K$

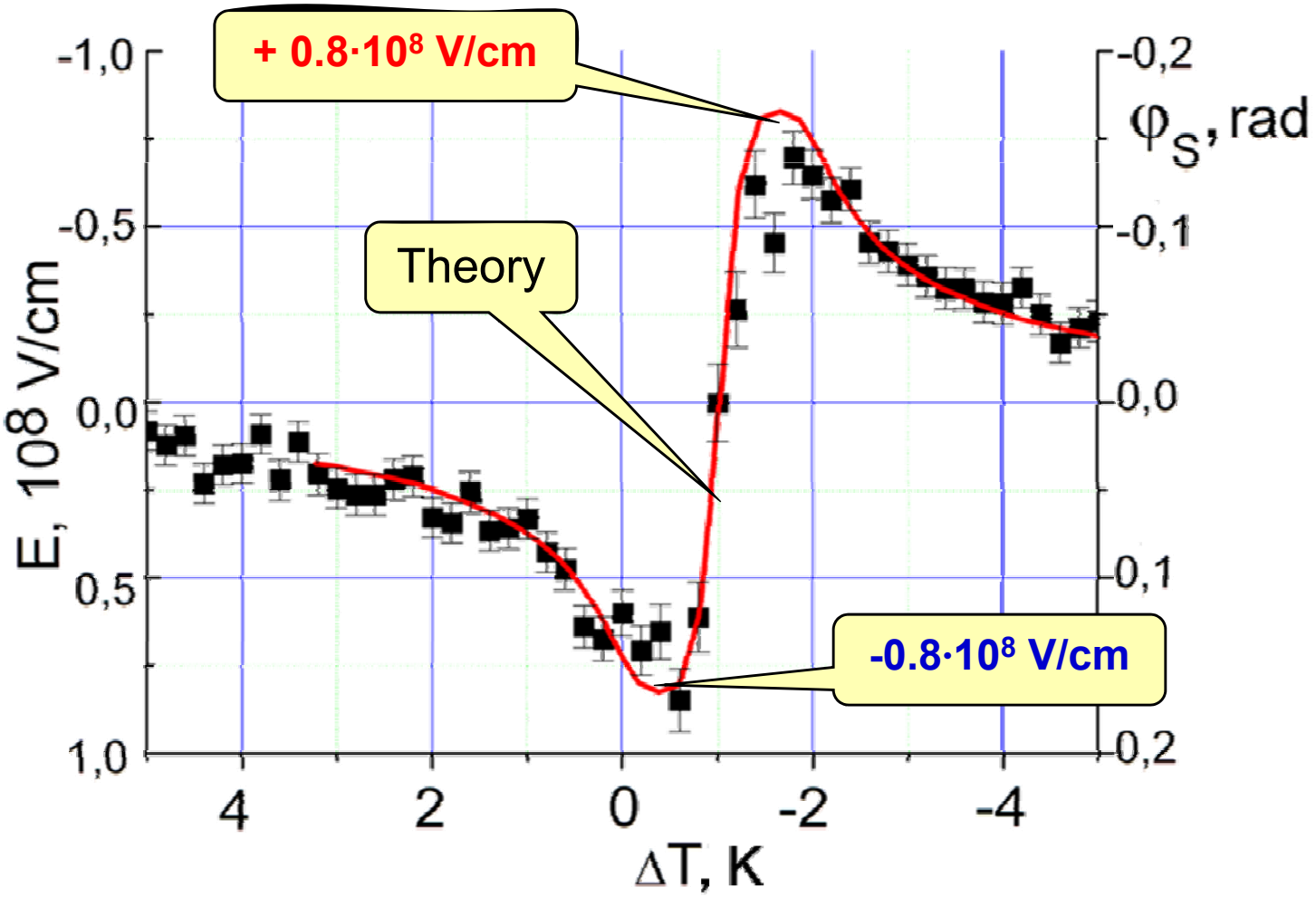
$\Delta\lambda/\lambda \approx 10^{-5} = \Delta\lambda_B/\lambda$

For $\pi/2$ reflection

$\mathbf{E} \parallel \mathbf{v_n}$ and

$\mathbf{H_s} \sim [\mathbf{E} \times \mathbf{v_n}] \approx 0$

Electric field

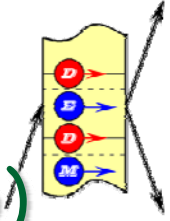


quartz (110) plane
L_c=14 cm
Bragg angle ≈ 86⁰

Variation of the ΔT on ±1K

E ≈ ± 10⁸ V/cm

Test experiment (ILL-3-07-196) (2006)



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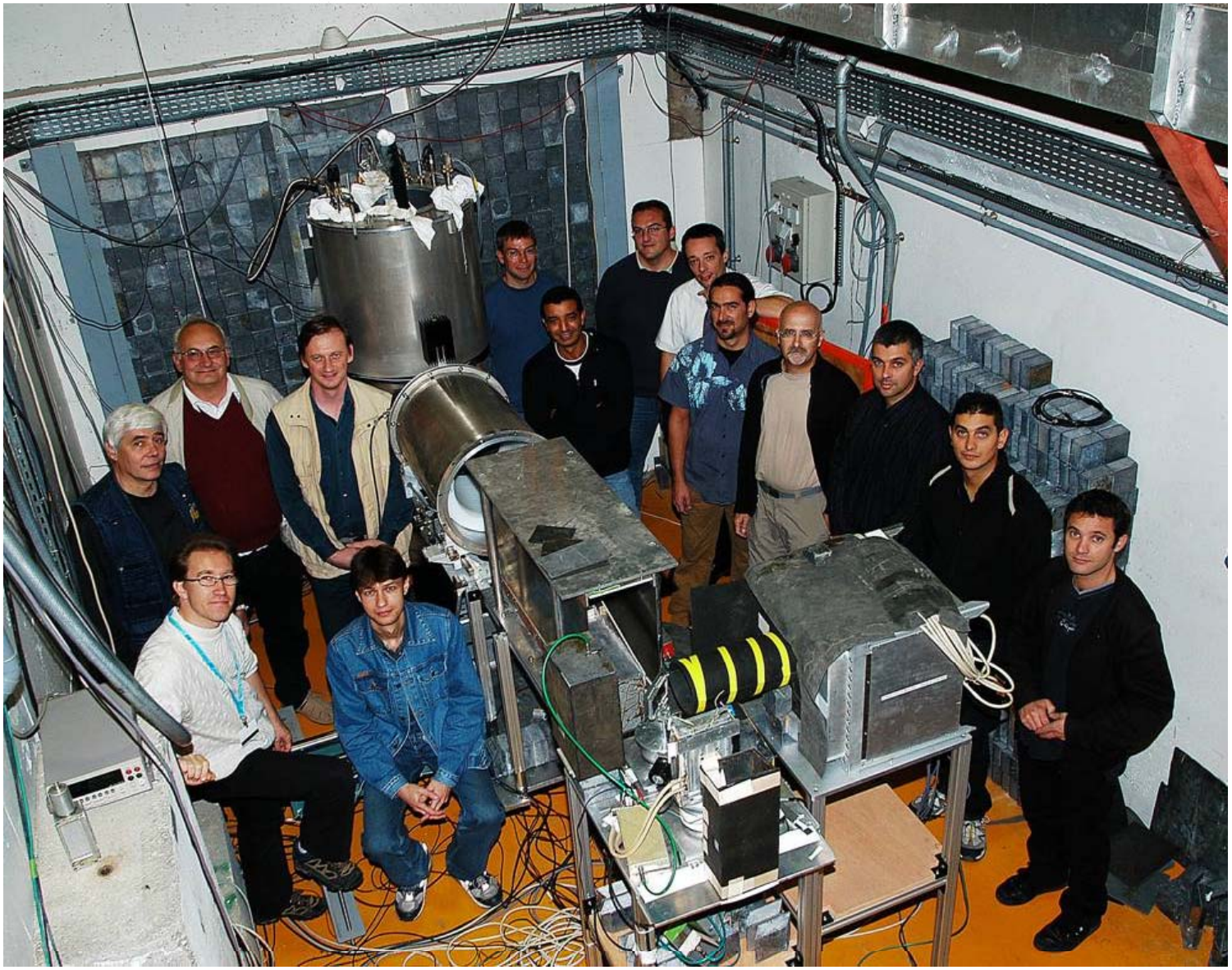
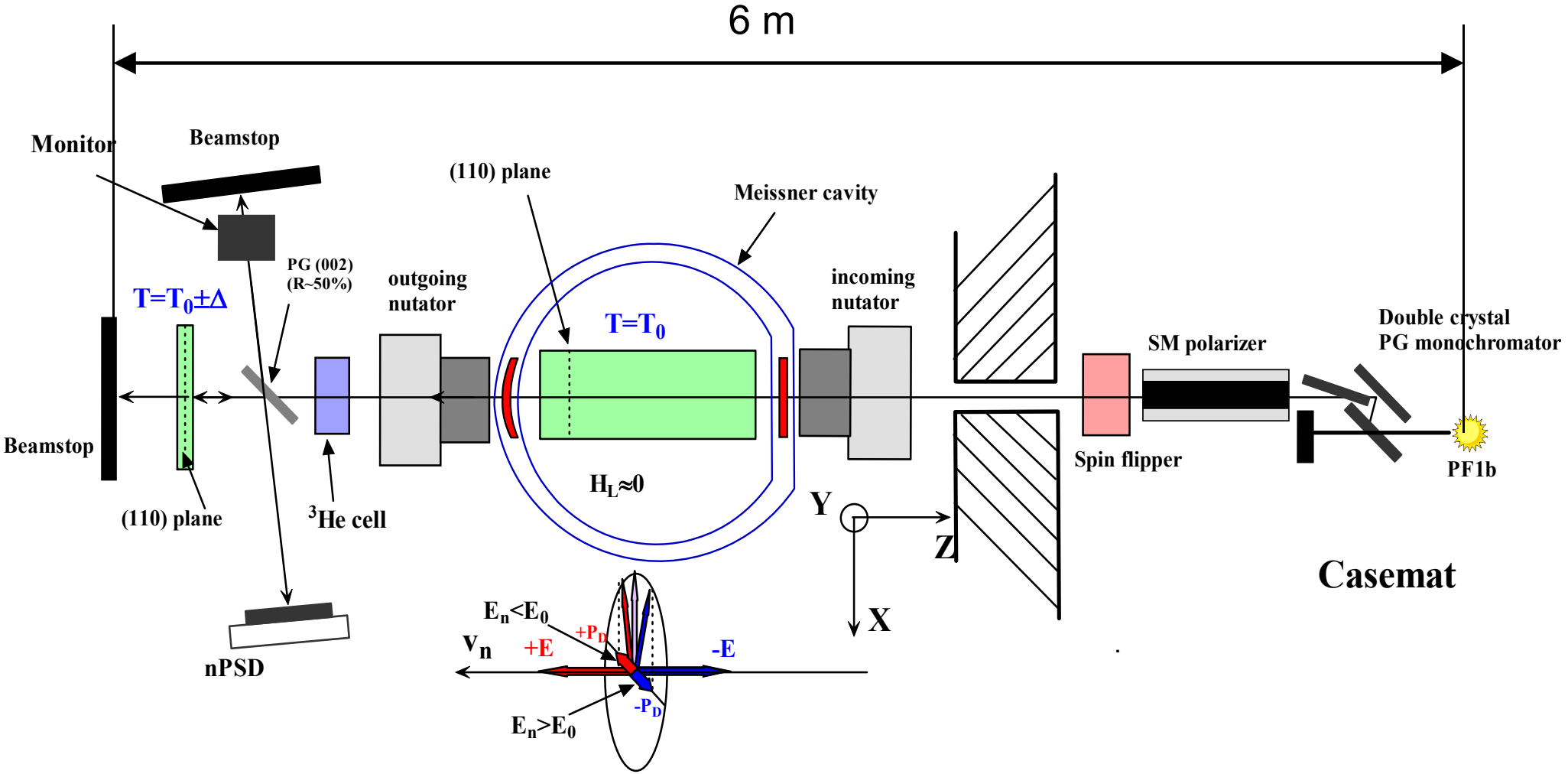
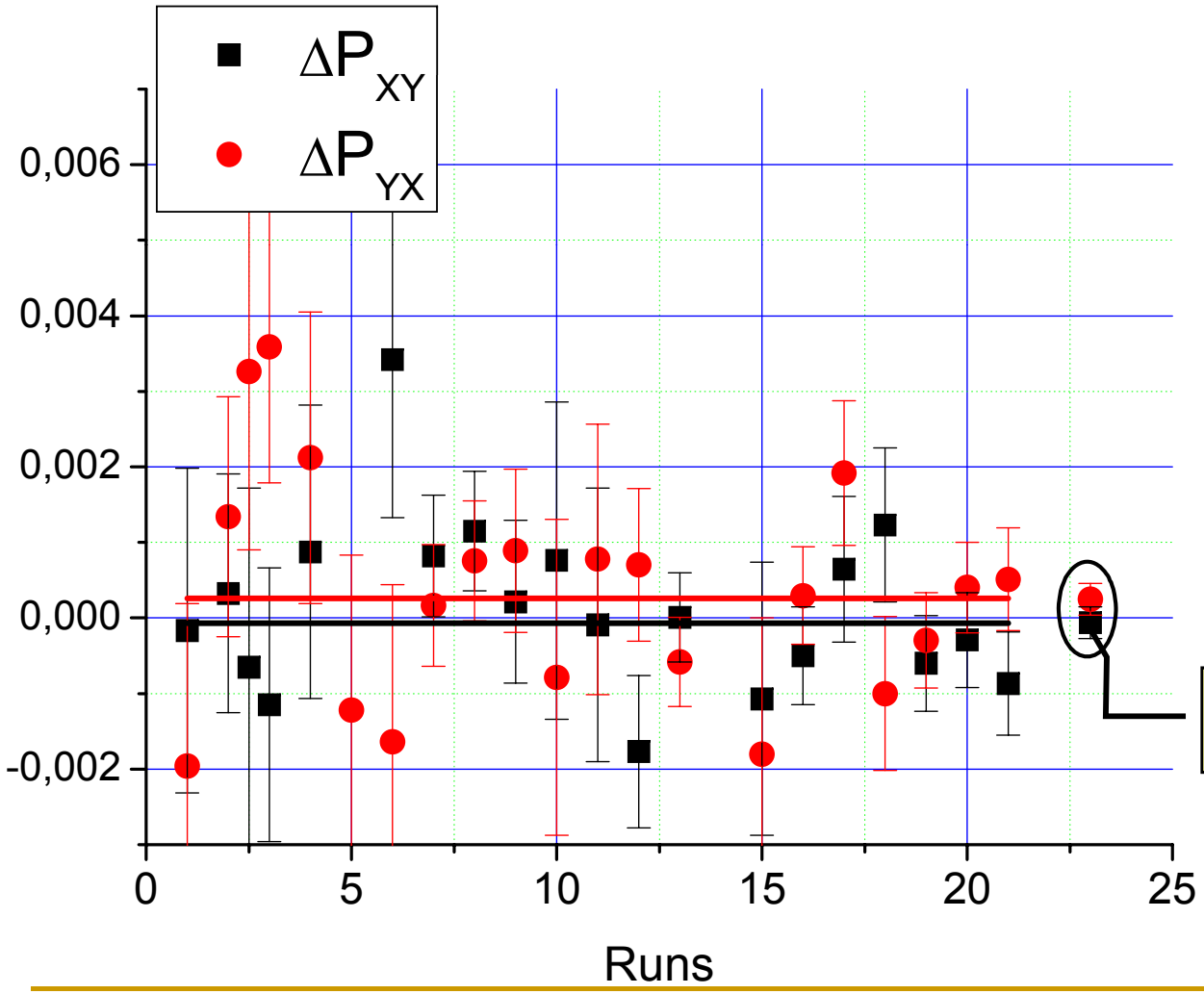


Layout of the experiment



nEDM measurement

E= (0.7±0.1) 10⁸ V/cm



$$\Delta P_{XY} = (0.6 \pm 2.3)10^{-4}$$

$$\Delta P_{YX} = (1.9 \pm 2.2)10^{-4}$$

$$\Delta P_d = (0.6 \pm 1.6)10^{-4}$$

P_0=0.82
K_{BG}= 0.85
K_r=0.7

$$\Delta \varphi_d = (0.9 \pm 2.3)10^{-4}$$

d_n=(2.4±6.5)10^{-24} e cm

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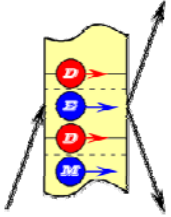


Improvement the sensitivity for current geometry of experiment

	Test setup	Full scale setup	K_{imp}
Crystal length, cm	**14**	**50**	3.6
Beam size, cm	∅27 S=**5.7**	6x12 S=**72**	3.6
Beam collimation, sr	$(4/700)^2$= **$3.2 \cdot 10^{-5}$**	$(12/450)^2$ **$=7.1 \cdot 10^{-4}$**	4.7
Reducing the background	**0.85**	**1**	1.17
Absorption in quartz	**0.84**	**0.54**	0.8

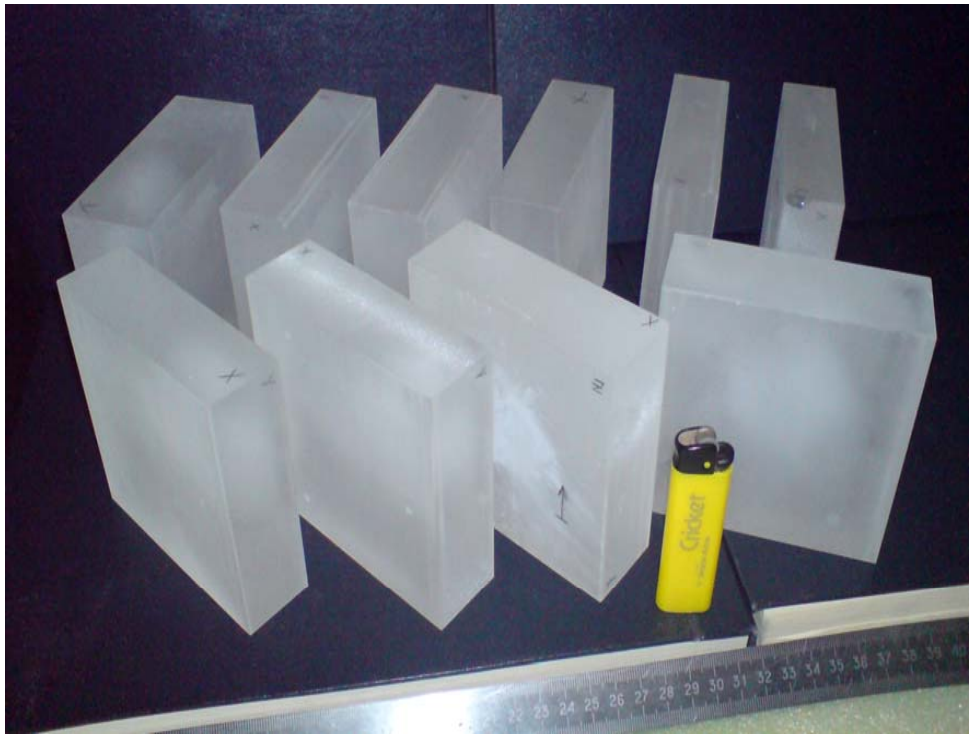
K_s=57

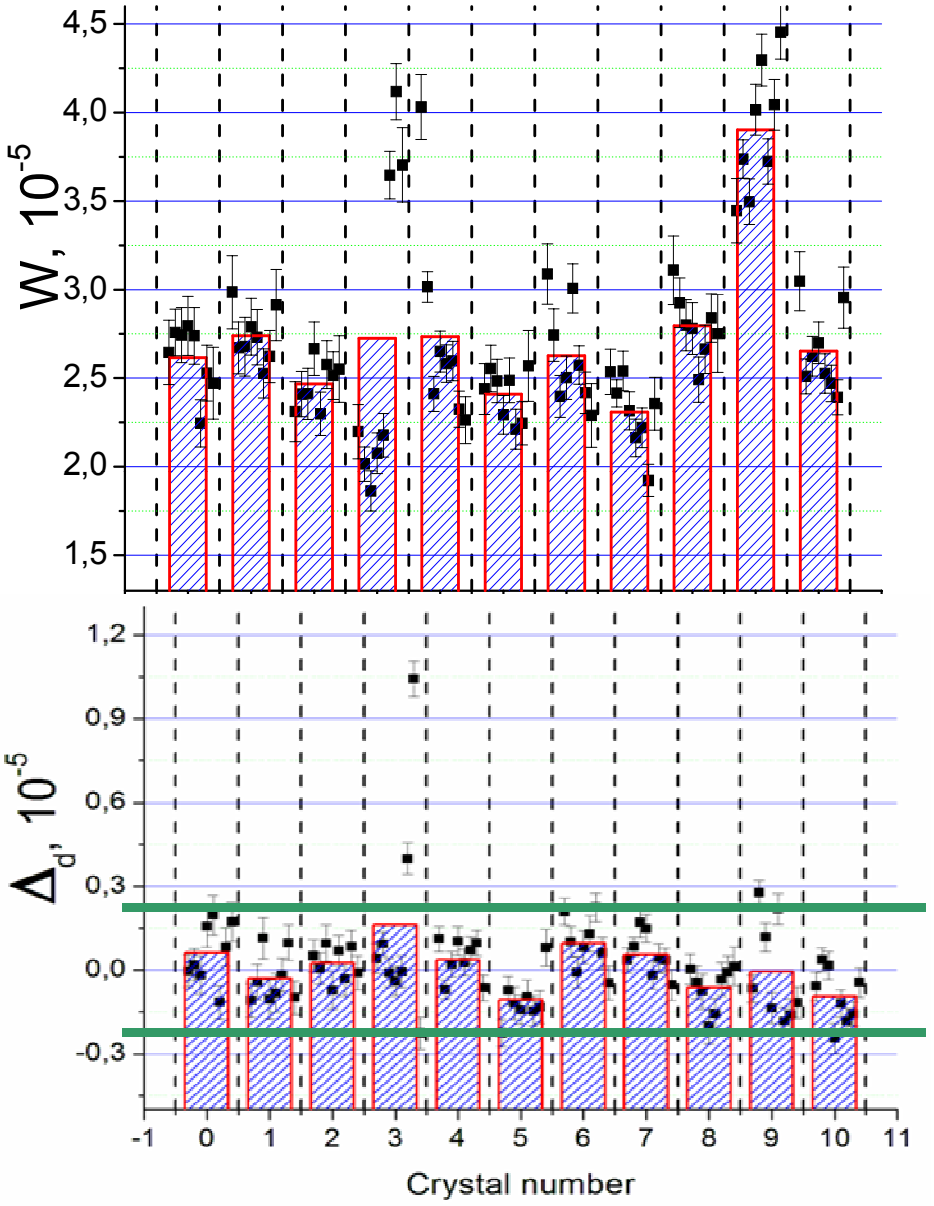
d_n, e cm per day

$1.6\ 10^{-23}$

$2.8\ 10^{-25}$

Crystal quartz test

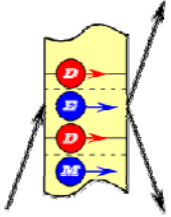




Now we have quartz crystal with summary size

100x100x500 mm^3 with **$\Delta d/d \sim 4\ 10^{-6}$**

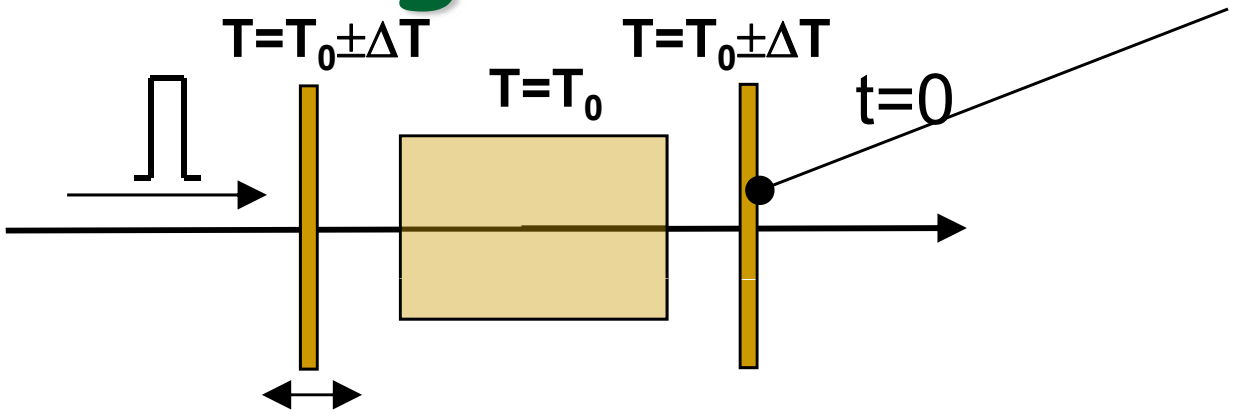
Parameters of some NCS crystals

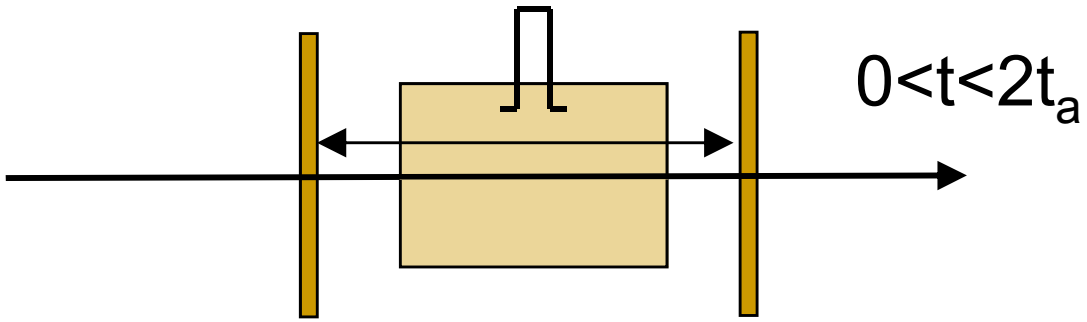


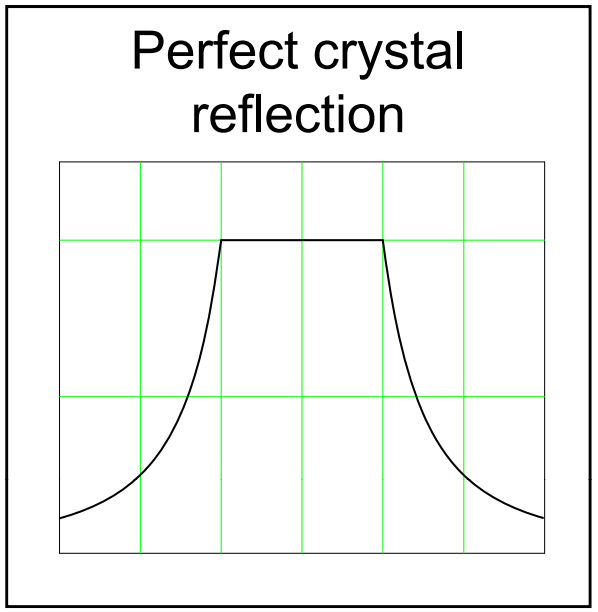
Crystal	Symmetry group	hkl	d, (Å)	E_g, 10^8V/cm	τ_a, ms	$E_g\ \tau_a$, (kV·s/cm)
α-quartz (SiO_2)	32(D^6_3)	111	2.236	**2.3**	**1**	**230**
		110	2.457	**2.0**		**200**
$Bi_{12}SiO_{20}$	I23	433	1.75	4.3	**4**	1720
		444	1.46	4.65		1860
$Bi_{12}GeO_{20}$	I23	433	1.74	4.65	1	465
		444	1.46	4.8		480
PbO	P c a 21	002	2.94	10.4	**1**	**1040**
		004	1.47	10		**1000**
BeO	6mm	011	2.06	5.4	7	3700
		201	1.13	6.5		4500

!!! We should looking for new NCS crystal !!!

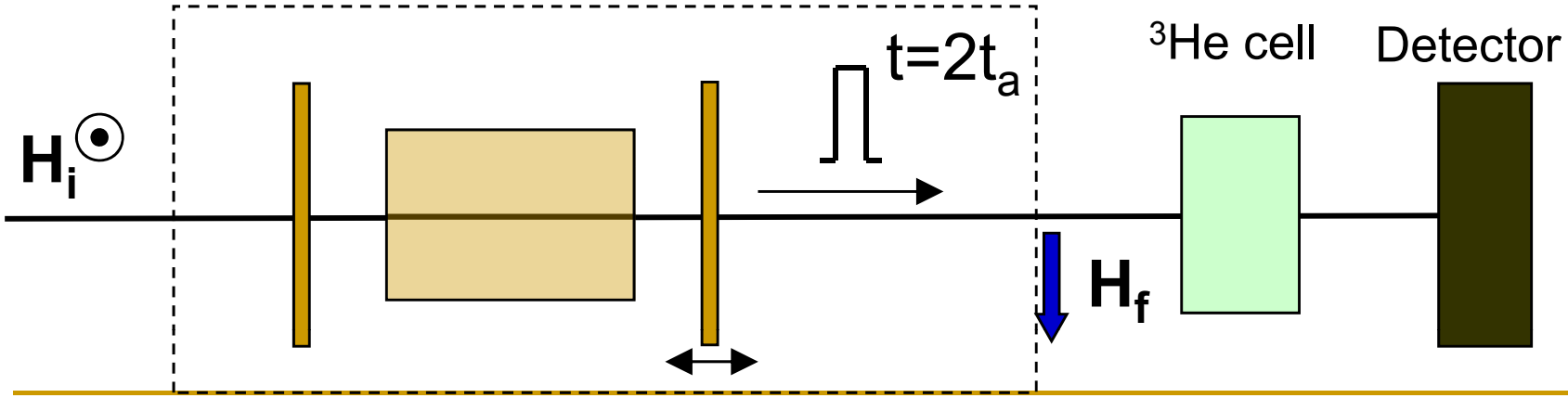
Storage variant







Up to 1000 reflections (τ_s~1 s)
M.R. Jaekel, C.J. Carlile, E.Jericha, D.E. Schwab and H. Rauch, SPIE Vol. 3767 EUV, X-Ray, and Neutron Opticas and Sources, 353 (2000)



Some numerical estimation

- Bragg width –

$$\Delta v_B = \frac{4\hbar F_g d}{m V_c} \xrightarrow{(444)BSO} 0.6\ cm/s$$

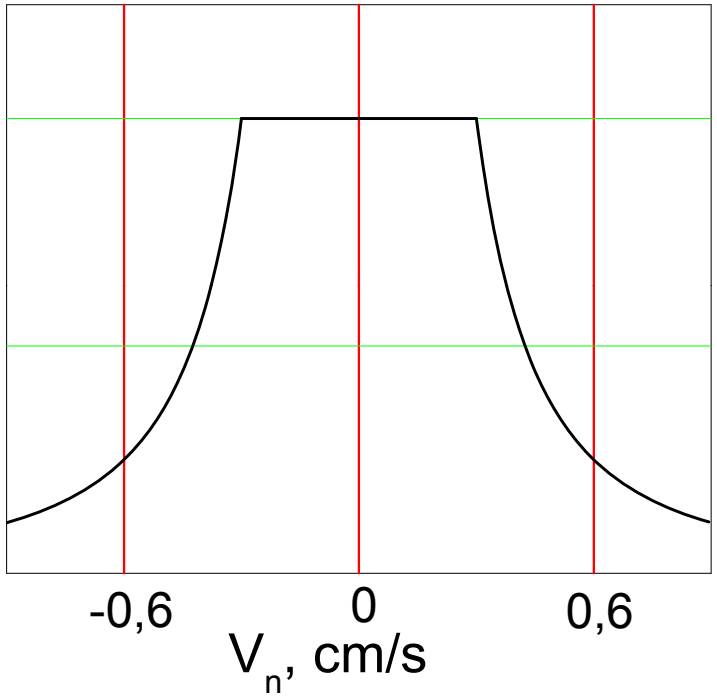
- Responsible time –

$$\tau_r \sim 2L/v_n \xrightarrow{L=15cm} \sim 0.2ms$$

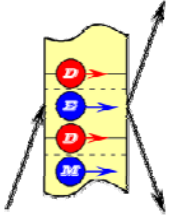
- Crystal acceleration –

$$a_c = \Delta v_B / \tau_r \sim 30\ m/s = 3g$$

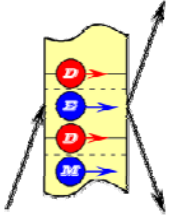
(fast piezoelectric element?)



Sensitivity estimation



	E_g, 10^8V/cm	τ, ms	Count rate	K_g	σ_d, e·cm per day
α-quartz (110) in-flight	**2.0**	**0.6** (L=50cm)	**10^4 n/s** (ILL PF1)		**$(2\text{-}3)10^{-25}$**
$Bi_{12}SiO_{20}$ (444) storage	**4.65**	**8** (L=15 cm)	**10^3 n/s** (ESSS - SP)	**10**	**$(2\text{-}3)10^{-26}$**



Conclusion

- Full-scale setup with quartz crystal could have a sensitivity $\sigma_d \sim (2\text{-}3)\cdot 10^{-26}$ **e·cm** per 100 day of measurement
- Storage modification of crystal-diffraction nEDM experiment could reach a sensitivity $\sigma_d \sim (2\text{-}3)\cdot 10^{-27}$ **e·cm** for the short pulse ESSS and BSO crystal