P10 – Applications of Nuclear Polarization techniques

(Conveners: G. Bison, A. Sandorfi and A. Vasilyev)

HEP, NP
⇔ constrains from
polarized reactions

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Applications:
- Polarization fusion
- Medical imaging
- Fundamental symmetries

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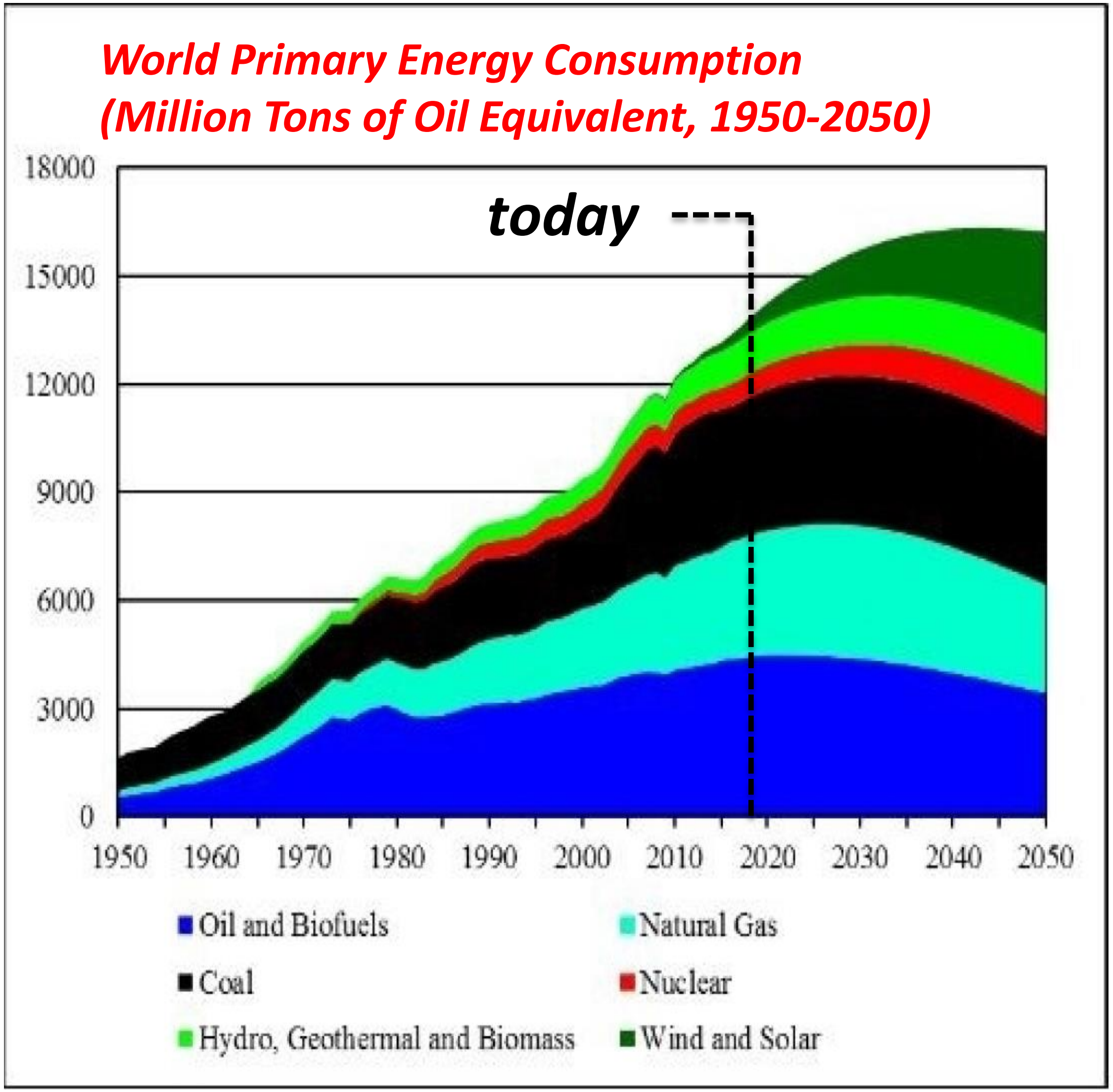
Applications:
- Polarization fusion **(7)**
- Medical imaging **(2)**
- Fundamental symmetries **(3)**

Polarized Fusion

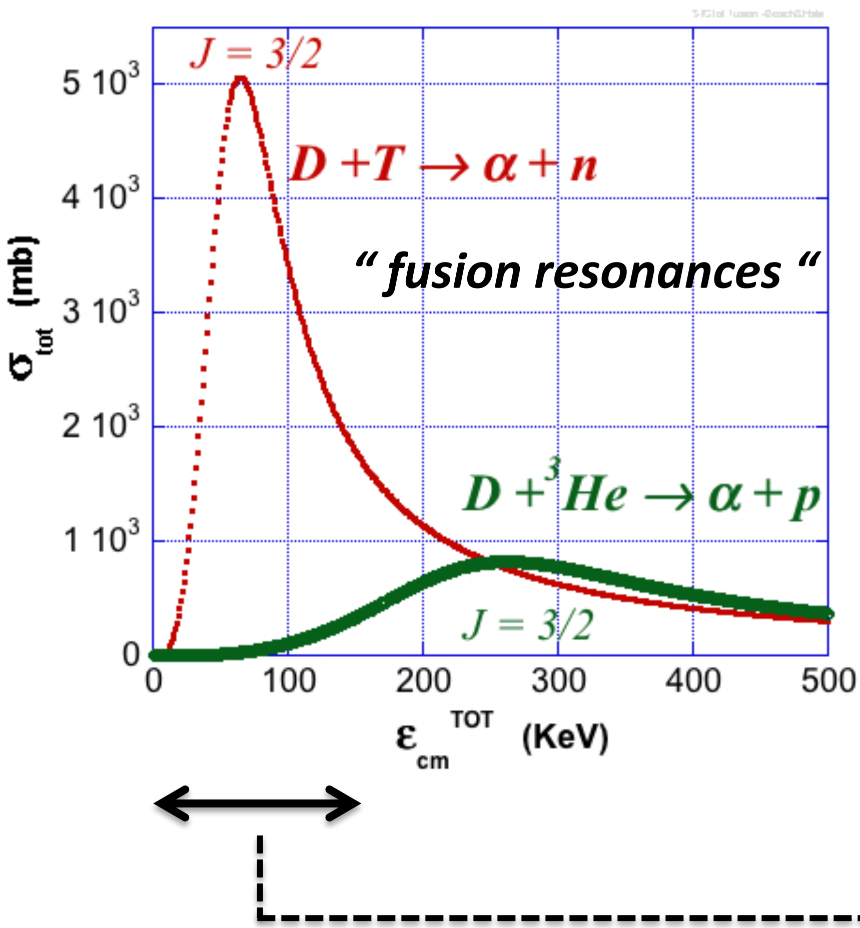


- Patterson, R. (2016) World Energy 2016-2050: Annual Report. http://peakoilbarrel.com/world-energy-2016-2050-annual-report/

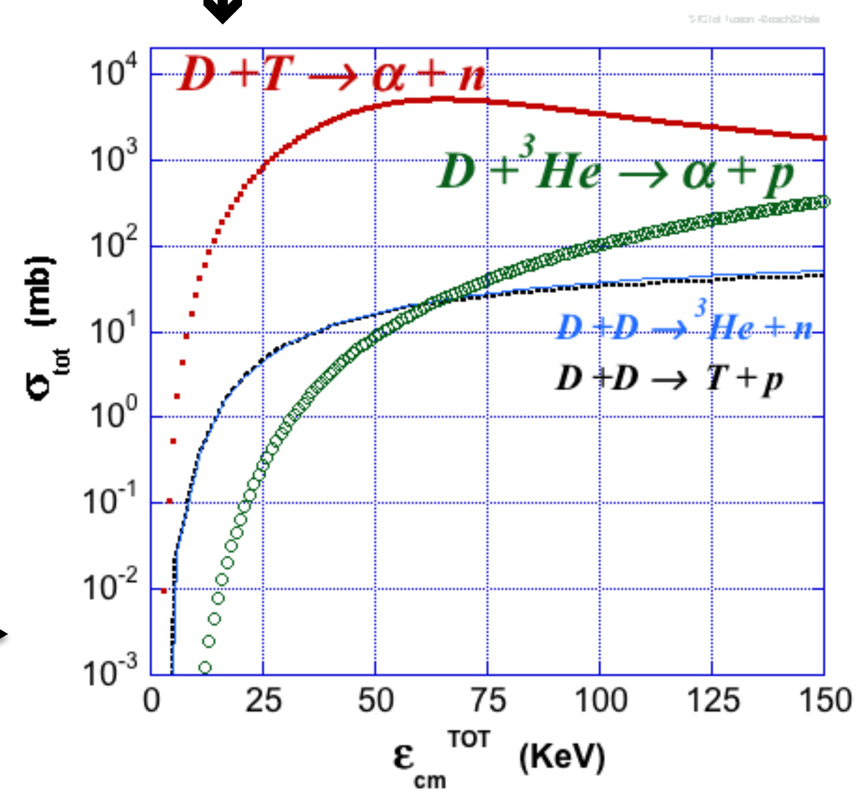
Demitriy Toporkov

Fusion ⇔ an as yet untapped source

Fusion Reactors *⇔ Reactions through the low energy tails of J=3/2 "fusion resonances" (in the Sun, or by Magnetic or Inertial confinement)*



- Sun's core peaks at 1.3 keV
- ITER plasma will peak at ~ 18 keV



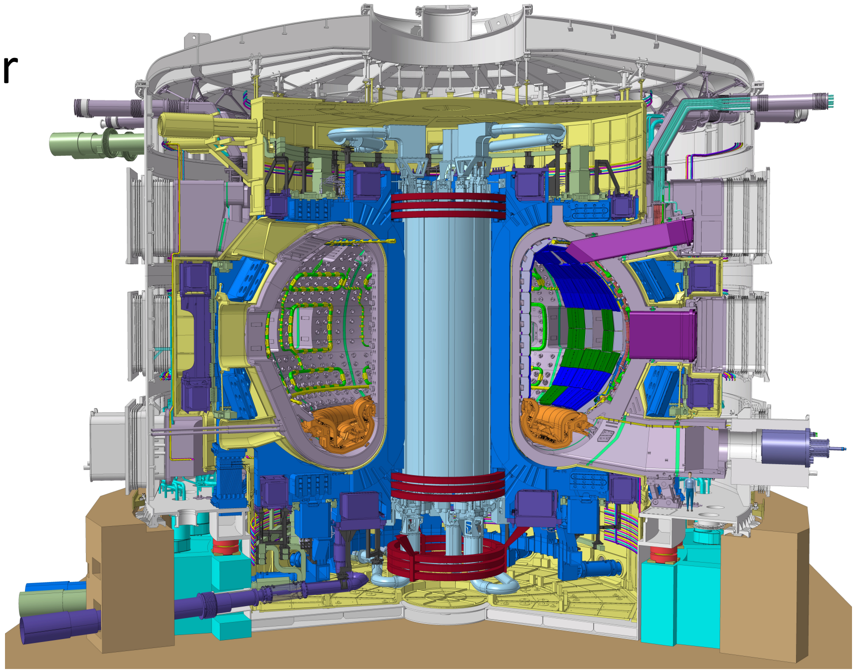
Fusion ⬄ an as yet untapped source

- intended fuel: ***D + t → α + n***
- about 180 research tokamaks have been built;
  there are currently about 30 in operation

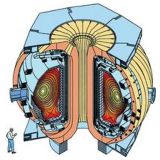
⬄ mostly studying ***D+D*** reactions

- quantum leap towards fusion power:
  Int. Thermonuclear Experimental Reactor

ITER
(Cadarache / France)



DIII-D
(San Diego / USA)



research tokamaks

½ GW reactor,
⬄ under construction @ ~ 40 B

1.) Can the total cross section of the fusion reactions be increased by using polarized particles?

$$t + d \longrightarrow {}^4He + n$$

J = 3/2 $^+$ / s-wave dominated (> 96%)

$$^3\vec{He} + \vec{d} \longrightarrow {}^4He + p$$

Factor: ~1.5 at 430 keV

[Ch. Leemann et al., Helv. Phys. Acta **44**, 141 (1971)]

(H. Paetz gen. Schieck, Eur. Phys. J. A **44**, 321-354 (2010))

1.) Can the total cross section of the fusion reactions be increased by using polarized particles ?

Yes

Energy Production:

Calculations for ITER:
(Magnetic confinement)

Factor ~ 2

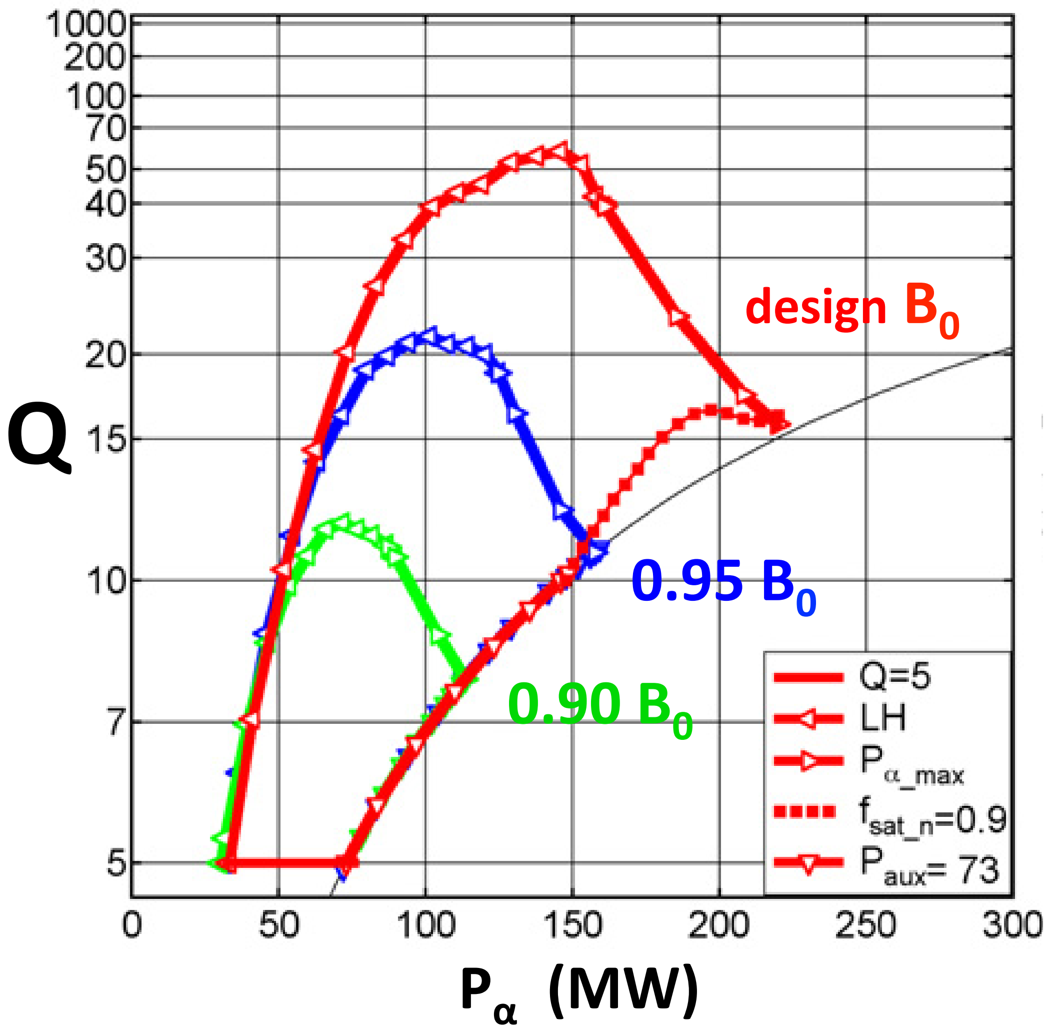
A.M. Sandorfi et al.; Proc. of the 22nd Int. Spin Symp., University of Illinois, Urbana IL, Sept 25-30, 2016.

Calculation for MEGAJOULE:
(Laser-induced intertial fusion)

Factor 1.5, and the necessary laser power can be reduced by ~25 %

M. Temporal et al.; Nucl. Fusion **52** (2012) 103011

Dependence on toroidal field



ITER simulations:

Pacher et al, NF**48** (08)105003

⇔ $Q \sim B^6$

- but, high neutron flux will lower critical current in SC coils

  M. Sawan, P. Walstrum, Fus Tech **10** (86)

⇔ could severely reduce parameter space for ITER operations

⇔ **gain from polarization is field independent and can recover the operating space**

History

- for polarization to be useful, it must survive long enough for complete fuel burn-up ⇔ a few sec in a tokamak

- Kulsrud *et al*, PRL **49** (1982) 1248
  … and many other papers of the 1980's calculated various depolarization mechanisms and found generally only small effects;

  - the exception was concern over depolarization at the walls (wall recycling)

- What's new ?

  ⇔ **in an ITER-scale reactor, there is negligible wall recycling**

  Pacher *et al.*, Nucl Fus **48** (2008) 105003;   Garzotti *et al., Nucl Fus* ***52*** *(2012) 013002*

Important Issues for Polarized Fusion

- fusion reactions increased by use of polarized particles:

  - T+D and ^{3}He+D fusion: σ gain factor = 1.5 ; Power gain ~ 2

  - fuel burn-up will include D+D reactions;

    what about D+D fusion: ????

- will polarization survive in a plasma?

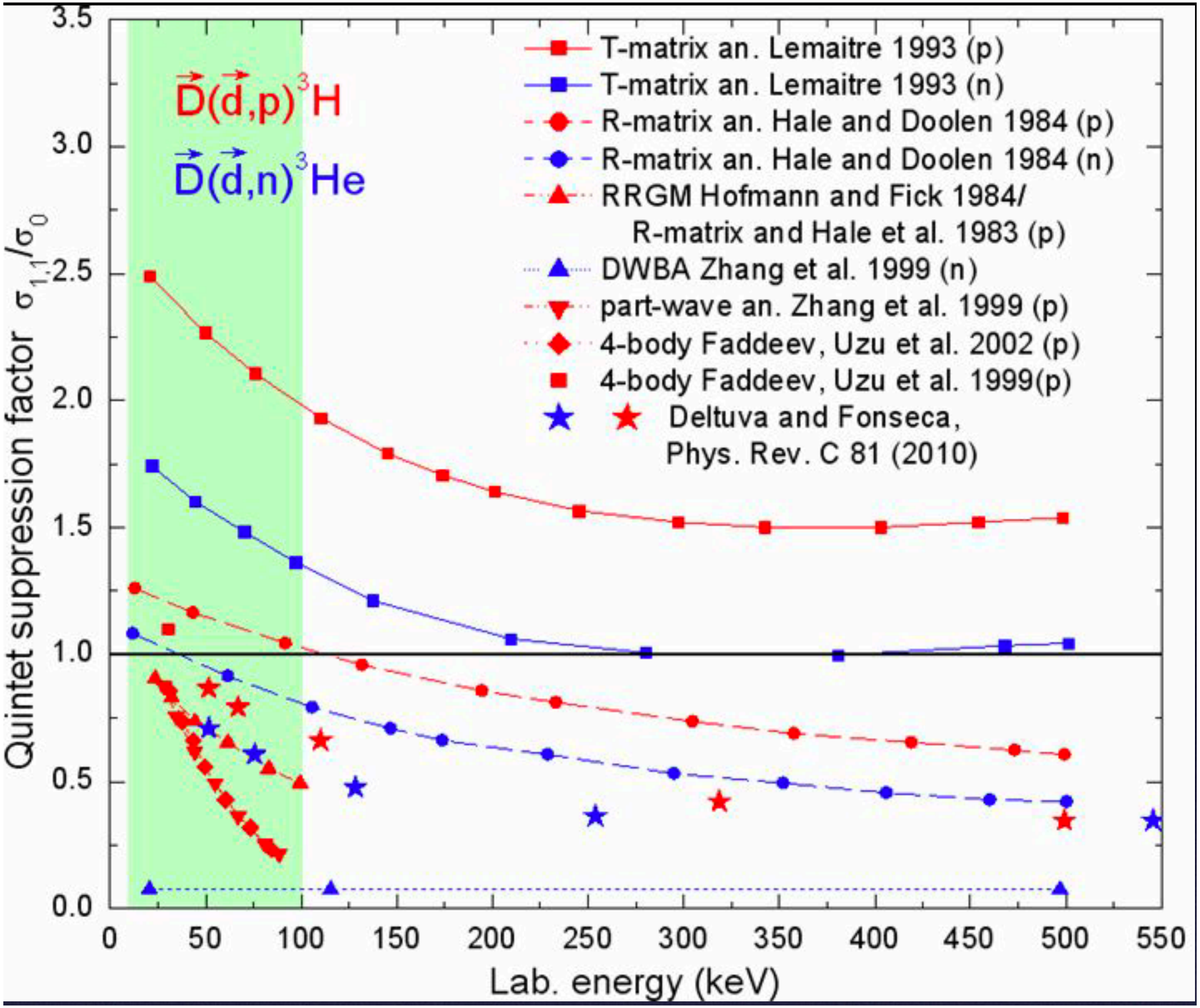
  (???? ↔ Must be tested for MCF and ICF separately!)

- How to produce and how to handle polarized fuel?

  ITER-scale Tokomaks must be fed either with pellets or fast neutral beams (~ 1 MeV)

D+D fusion: $\sigma(\vec{D} + \vec{D}) / \sigma_0$

Polina Kravchenko



Experimental setup

Substantial part of the equipment from:

$^3He^{2+}\,(^3H^+)$

Forschungszentrum Jülich, Germany

Polarimetry

KVI, Gronningen, Netherlands

POLarized **I**on **S**ource

$\vec{d}^0\ (0.1keV)$

$$\sigma_0 = \frac{1}{9}(2\sigma_{1,1} + 4\sigma_{1,0} + \sigma_{0,0} + 2\sigma_{1,-1})$$

Quintet **Triplet** **Singlet**

$\vec{d}^+\ (30 - 100keV)$

Atom **B**eam **S**ource

Ferrara University, Italy

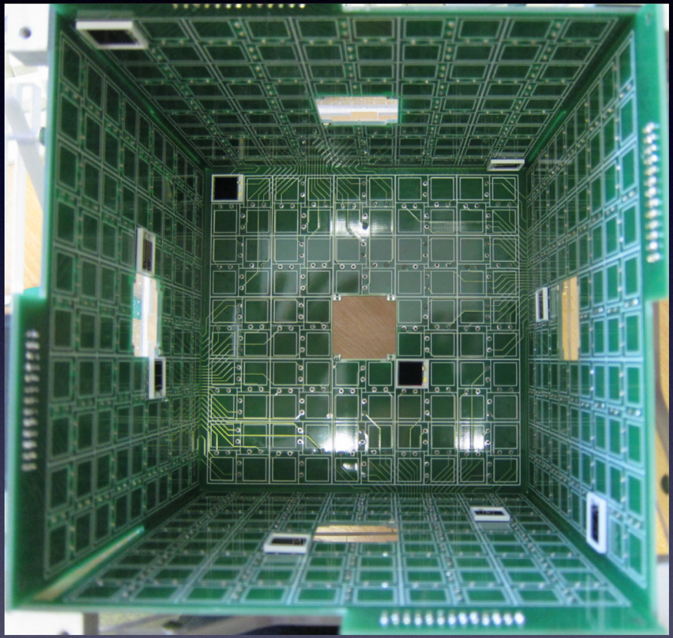
Central 4π detector

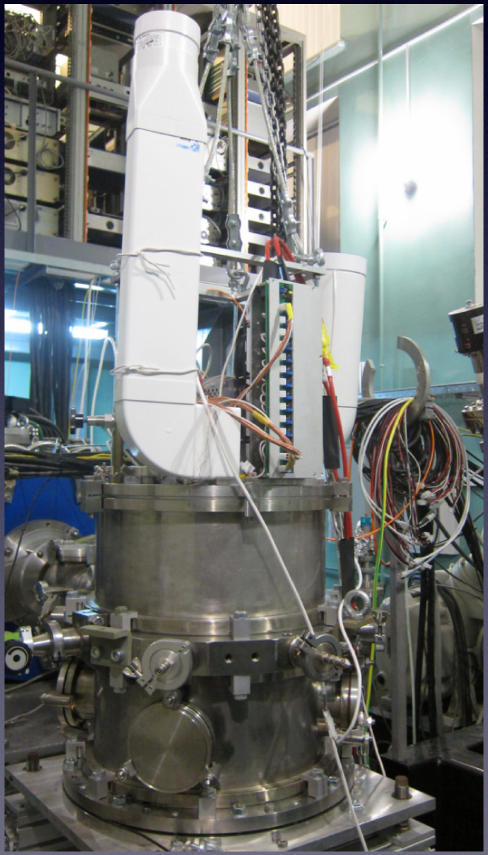
Petersburg Nuclear Physics Institute, Russia

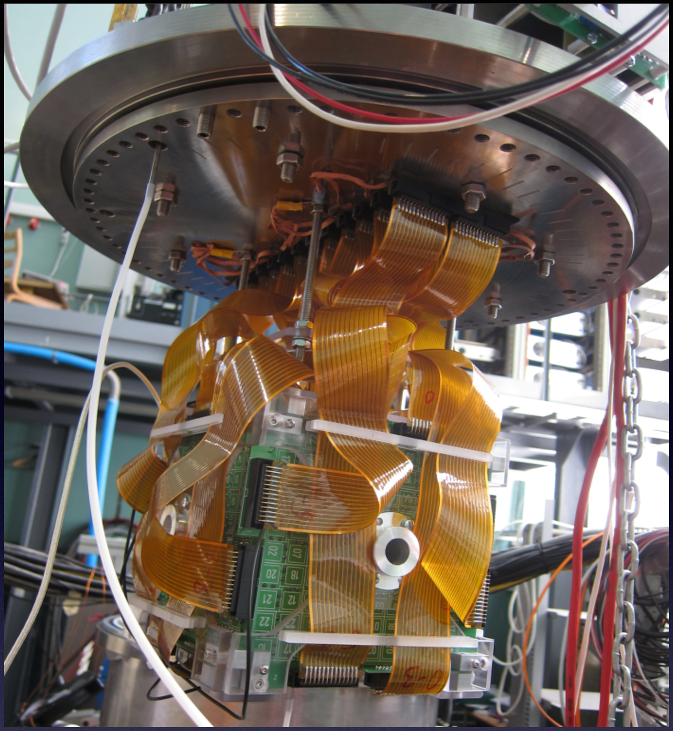
$n(p)$

Central detector

4-π detector with 51% filling
576 Hamamatsu PIN-diodes (S3590-09)
PIN-diode active area: 1 cm²
depleted layer: 300 um
energy resolution: <50keV
low reverse voltage (<=50V)







4-π detector with 51% filling
576 Hamamatsu PIN-diodes (S3590-09)
PIN-diode active area: 1 cm^2
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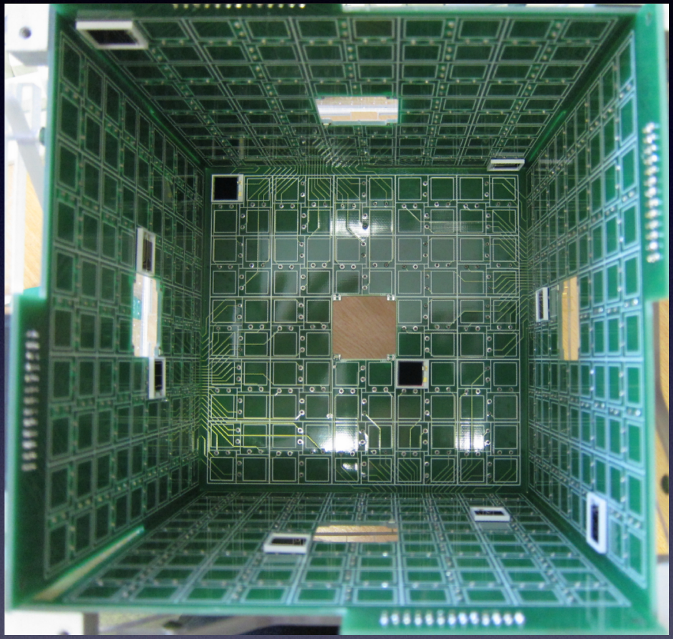
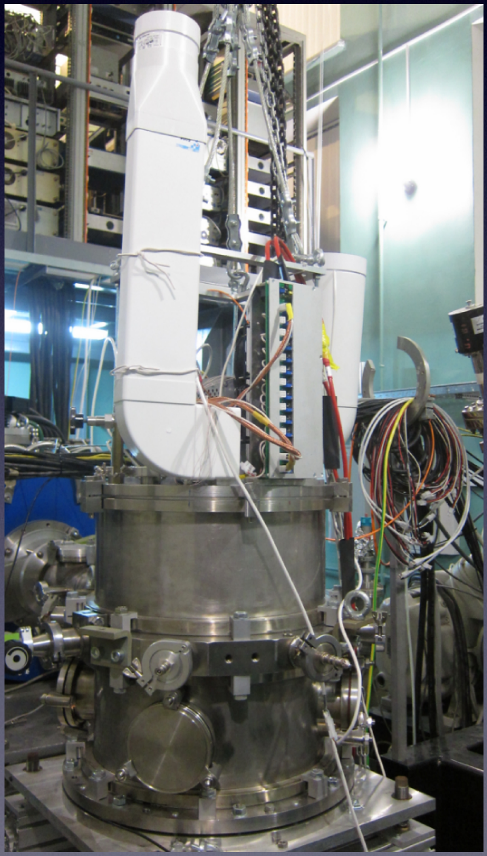
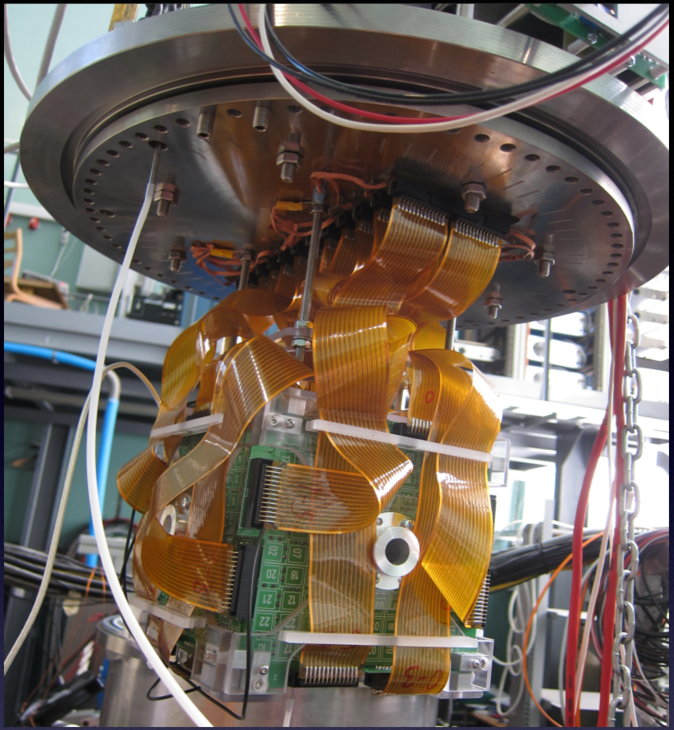
Central detector







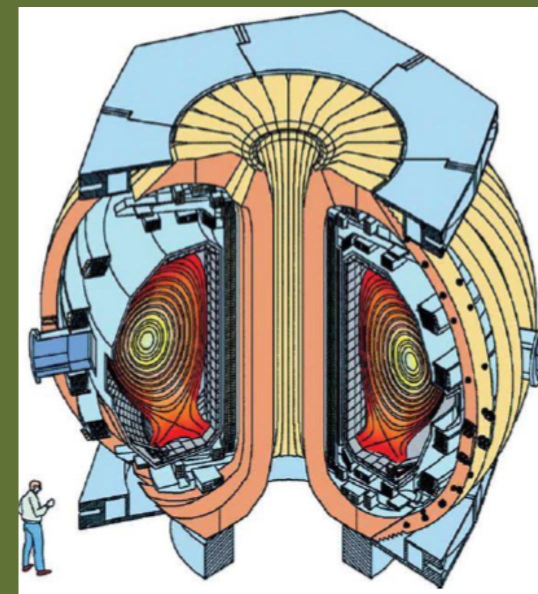
- expected startup ⇔ 2020

Direct *in situ* test of polarization survival in a tokamak plasma

(**Sina Tafti** for the Jefferson Lab – Univ Virginia – General Atomics collaboration)

- test reaction: $\vec{D} + {}^3\vec{He} \rightarrow \alpha + p$

Polarized fuel can be delivered to the plasma using hollow polymer shells (~2 mm diameter ICF pellets)



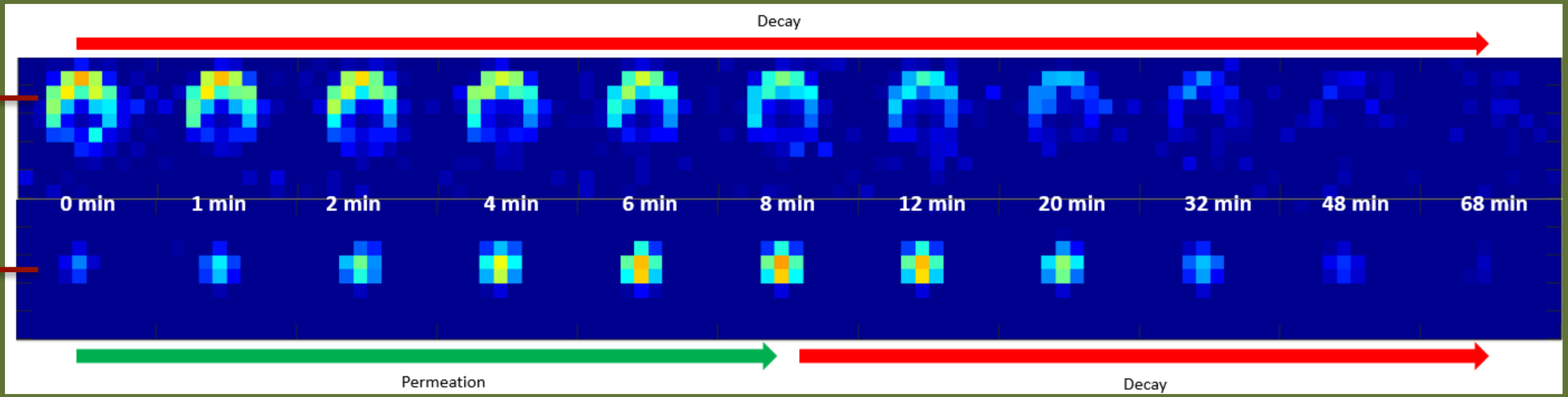
D-III D Tokamak
(San Diego)

- D can be permeated into pellets and then polarized ⇔ a small NP target

- ^{3}He, must be polarized first (SEOP) and then permeated

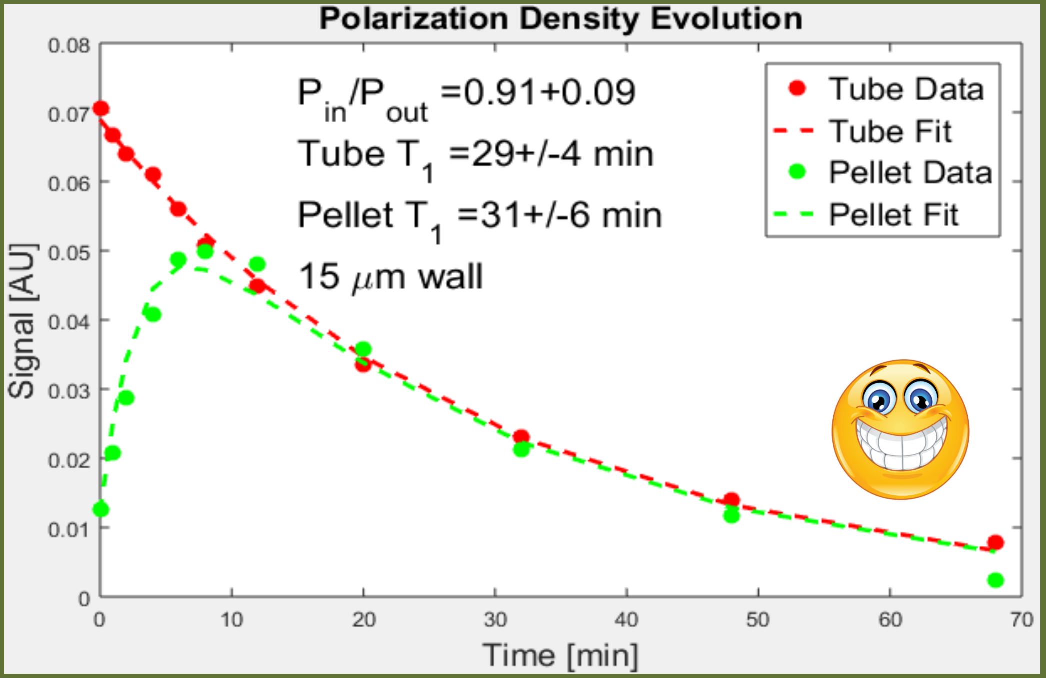
⇔ does the polarization survive ?

- polarized ^{3}He permeation tracked with medical-imaging MRI



- 90% of the polarization gets into the pellet

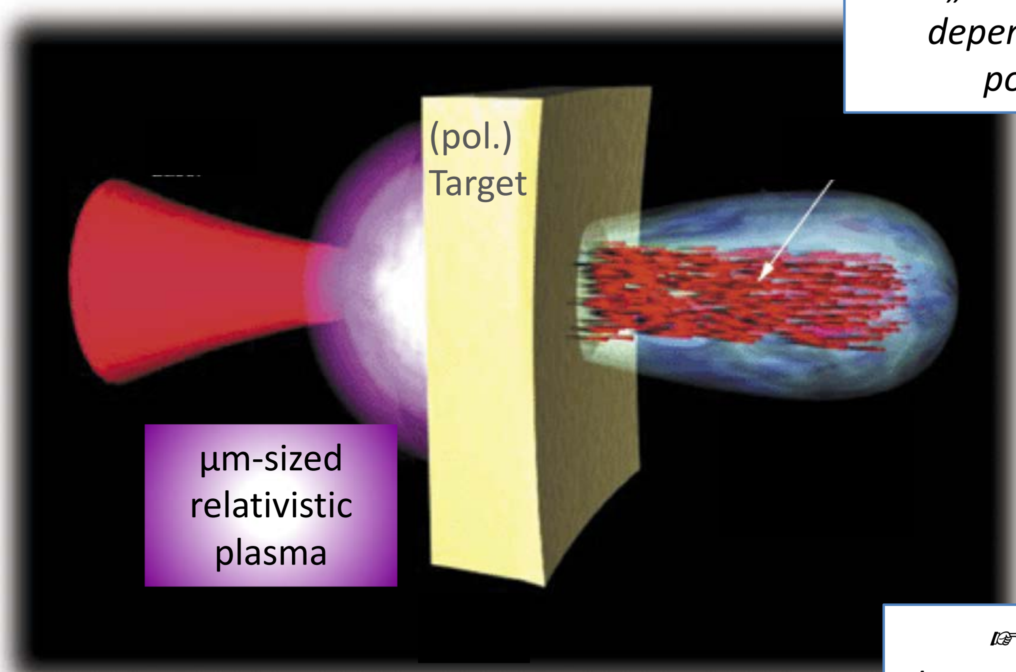
- T_1 (77K) ~ 5 hours



- Test of polarization survival
  during laser-induced plasma acceleration (to ~ few MeV)
- plans for experiments with $\vec{\mathrm{D}}$ and $^{3}\vec{\mathrm{He}}$

Fusion reactions

Multi-TW laser beam



☞ „Does the fusion rate depend on the target polarization?“

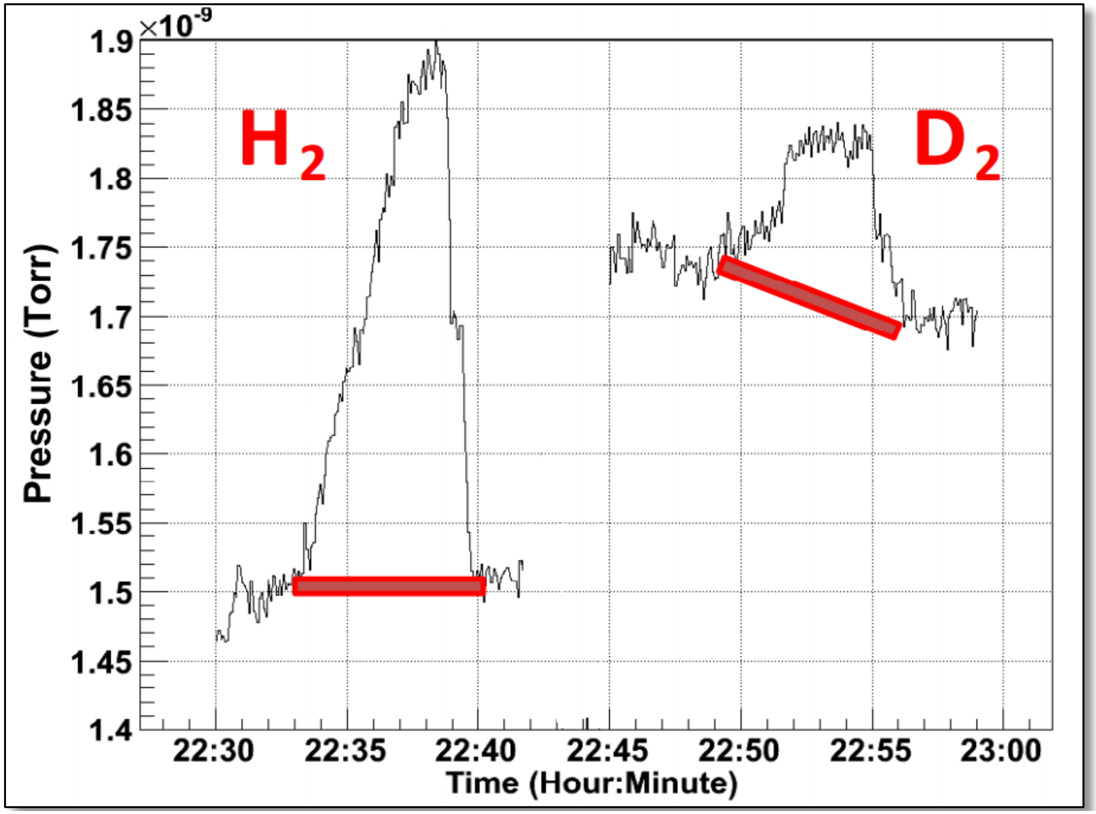
Accelerated Ions

☞ „Are the accelerated ions polarized?“

☞ „Angular dependence of fusion products?“

Exploring methods to polarize enough fuel for a reactor

- ITER-scale reactor would require ~ 10^{22} /s
- **Dimitriy Toporkov**
  - atomic beam source limits ~ 10^{17} atoms/s
  - joint effort to develop polarized molecular beams (Budker Inst – U Düsseldorf – Jülich)

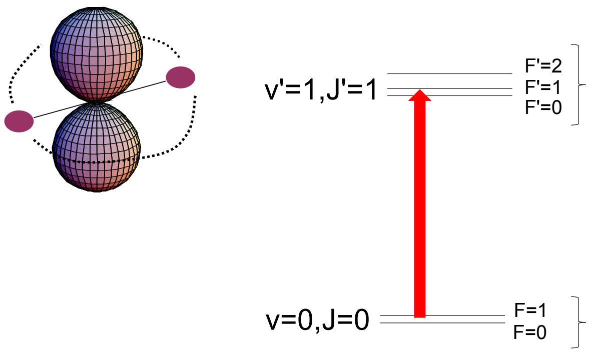


D_2 / H_2 fluxes in the ratio of their magnetic moments

Exploring methods to polarize enough fuel for a reactor

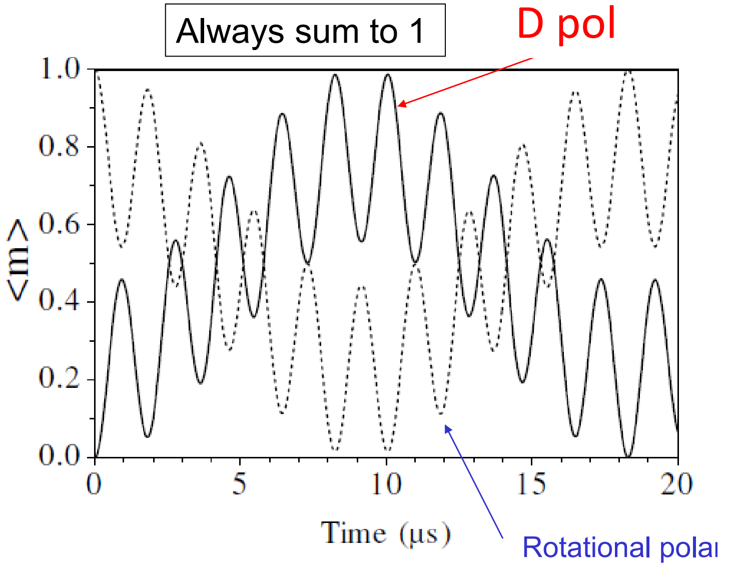
Peter Rakitzis - optical methods for producing polarizing beams

eg. - IR laser excites a deuterated molecule into a rotational-vibrational state



- hyperfine beating between the D spin and the J of the molecule

- stop beating when all the spin is on the D, by turning on a magnetic field



- UV laser dissociates the molecule

Optical methods of producing light flux polarized beams - P. Rakitzis

- **potential exists for producing up to 10^{22} s^{-1} polarized fluxes using commercially available lasers !**

- studies planned at (a) Jülich
  and at (b) JLab

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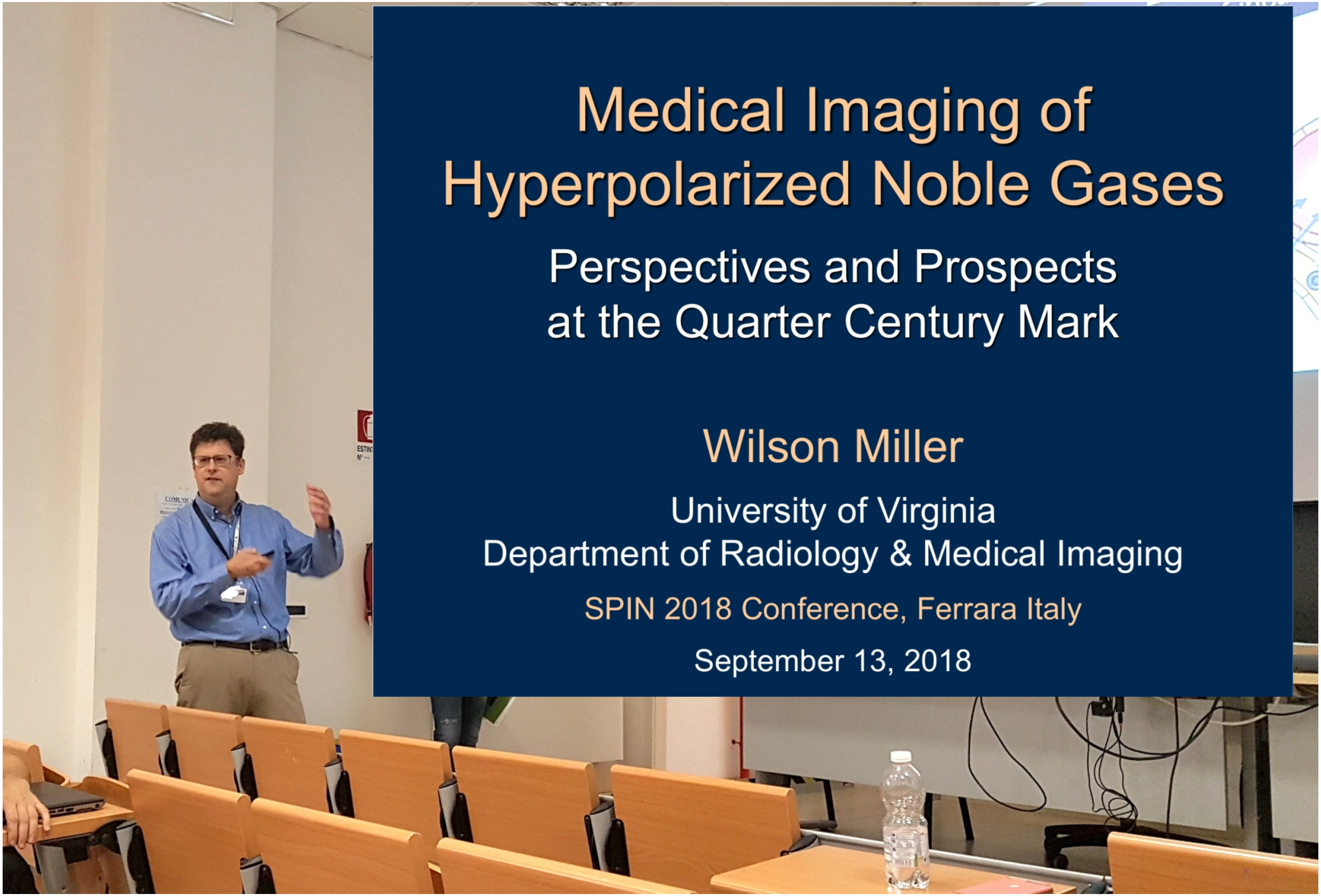
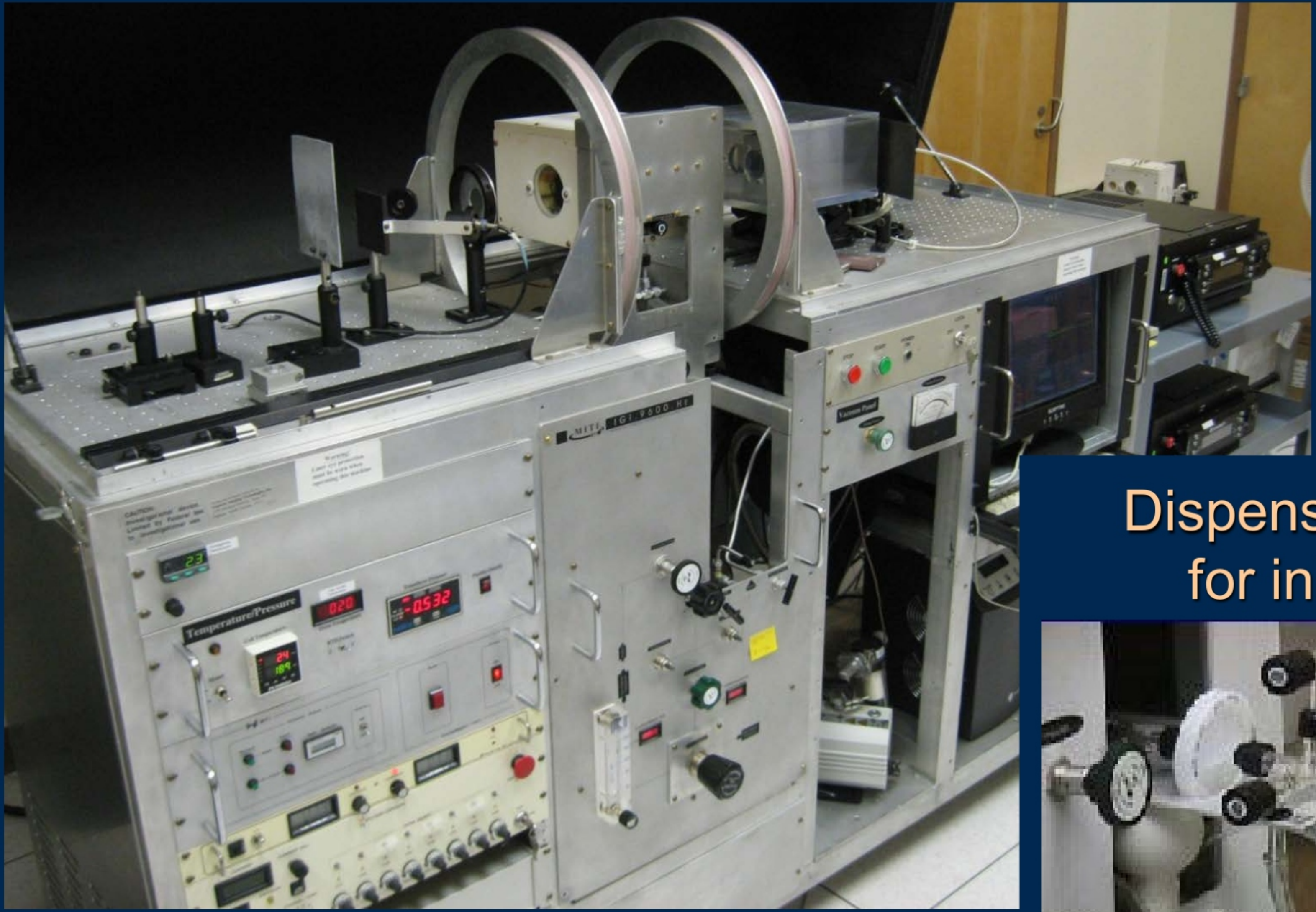

Medical Imaging of
Hyperpolarized Noble Gases
Perspectives and Prospects
at the Quarter Century Mark
Wilson Miller
University of Virginia
Department of Radiology & Medical Imaging
SPIN 2018 Conference, Ferrara Italy
September 13, 2018

First Commercial Polarizer (ca. 1997)



Dispense into bag for inhalation

Can do ^{129}Xe: 500 mL @ 5~10%

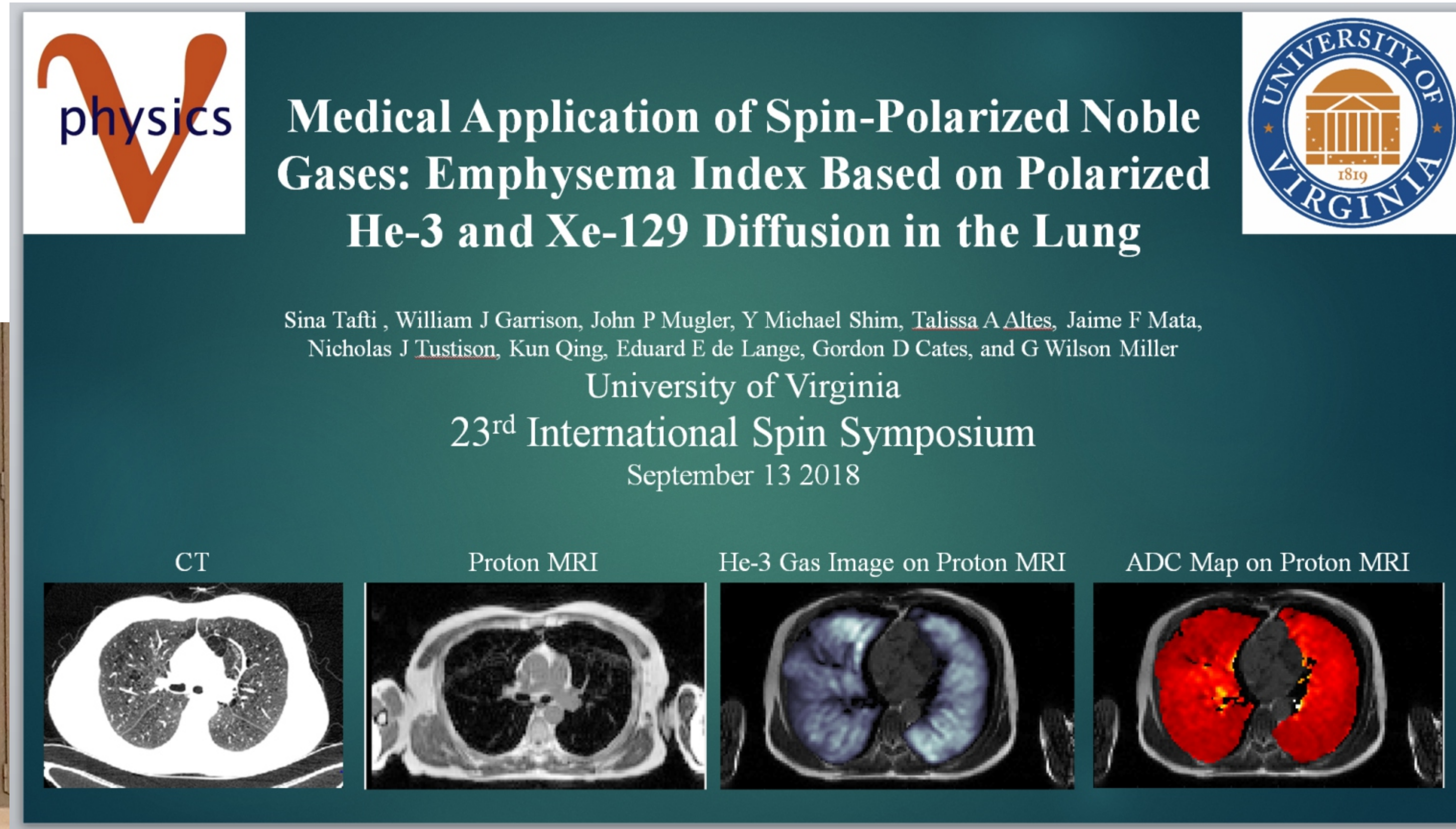
or ^{3}He: 1 L @ 30~40%

1.5 Tesla Clinical MRI Scanner

Vest-type RF coil
(48.5 MHz for ^3He)

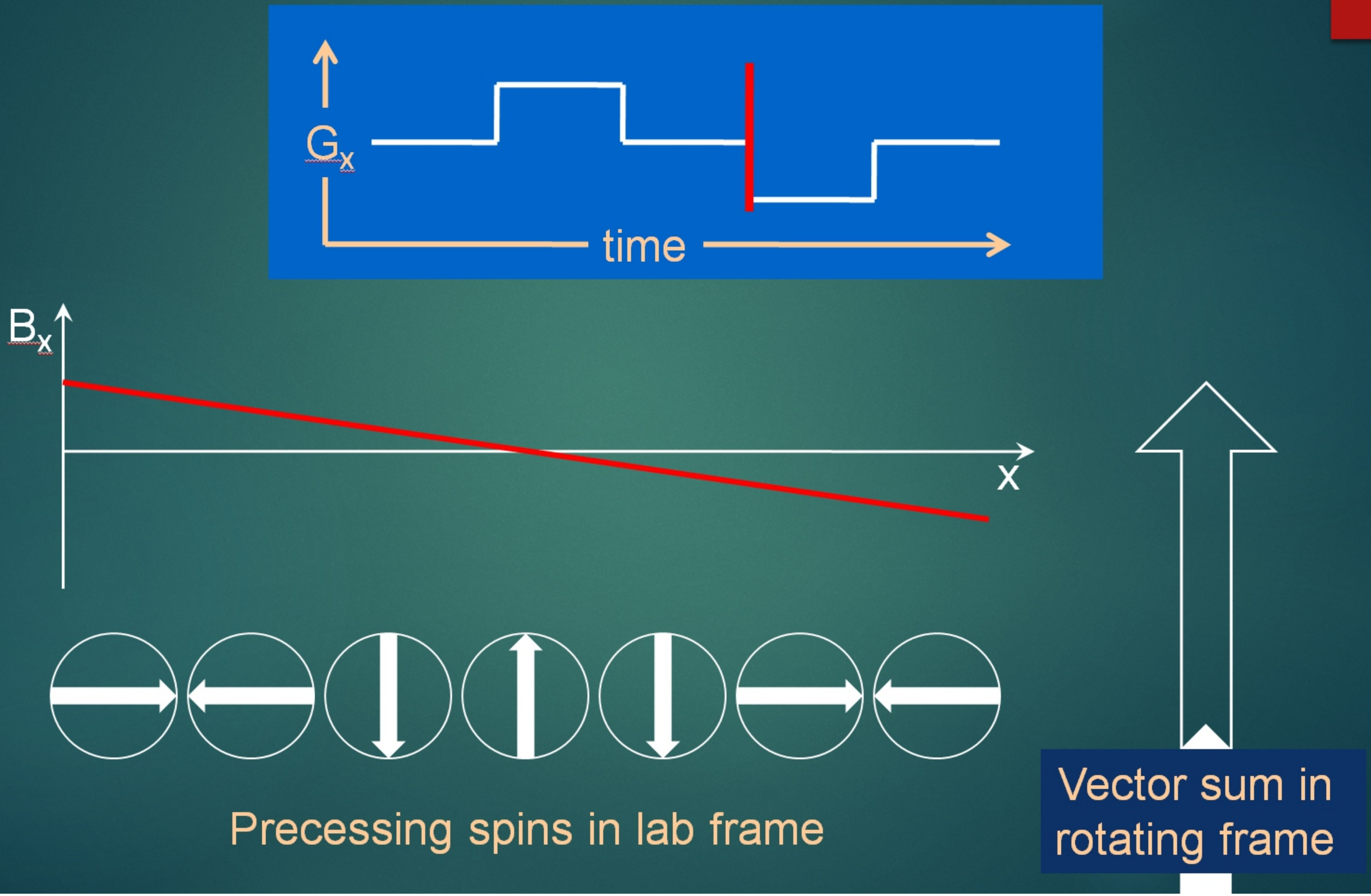
Inhale gas from bag

ESTINTORE
COMUNICATO



physics
UNIVERSITY OF VIRGINIA
1819
Medical Application of Spin-Polarized Noble Gases: Emphysema Index Based on Polarized He-3 and Xe-129 Diffusion in the Lung
Sina Tafti , William J Garrison, John P Mugler, Y Michael Shim, Talissa A Altes, Jaime F Mata, Nicholas J Tustison, Kun Qing, Eduard E de Lange, Gordon D Cates, and G Wilson Miller
University of Virginia
23rd International Spin Symposium
September 13 2018
CT
Proton MRI
He-3 Gas Image on Proton MRI
ADC Map on Proton MRI

Diffusion-Weighted MRI



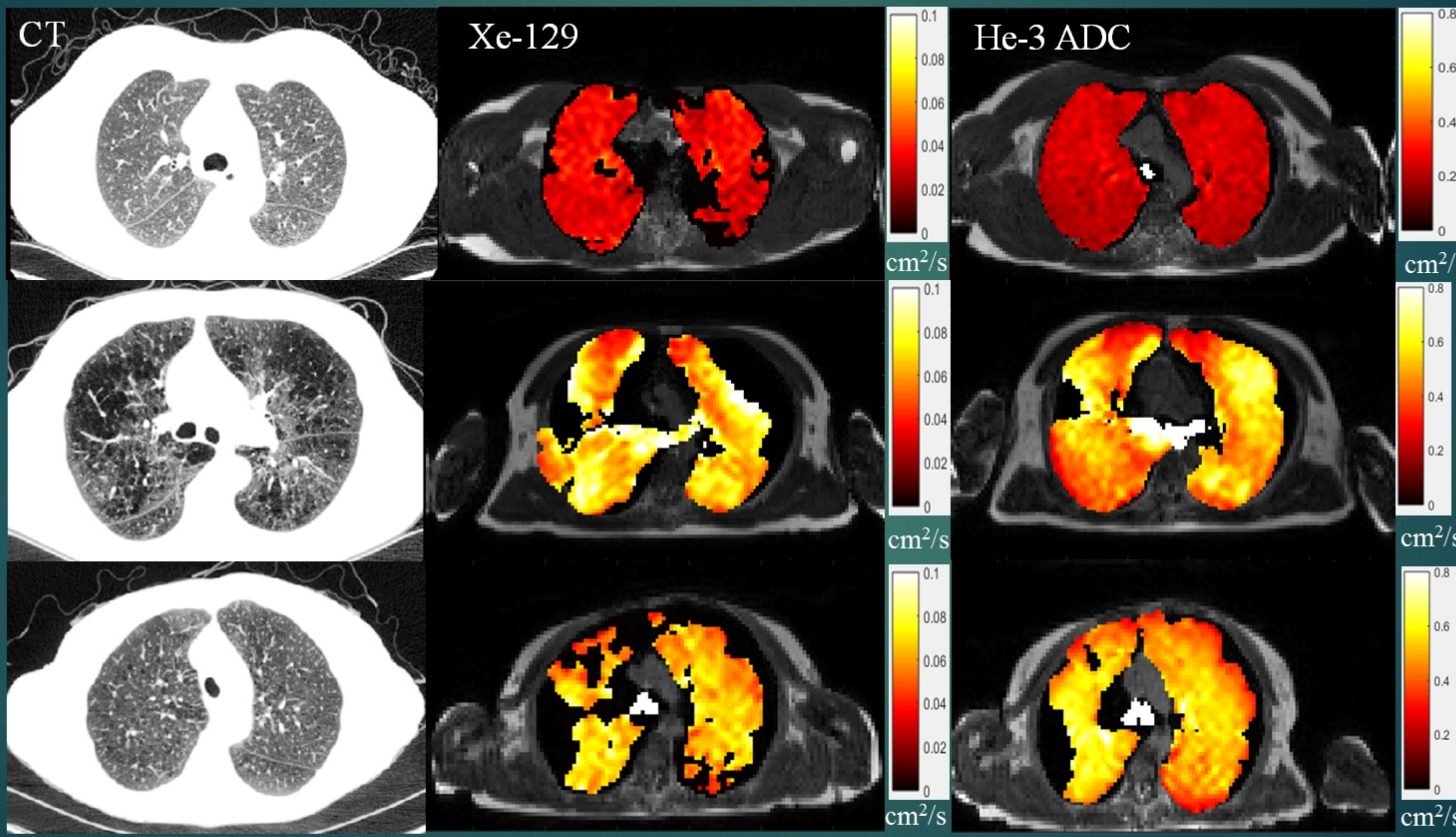
Results

CT EI

0.01

0.23

0.01



ADC EI

^{3}He: 0.03
^{129}Xe: 0.05

^{3}He: 0.93
^{129}Xe: 0.84

^{3}He: 0.60
^{129}Xe: 0.65

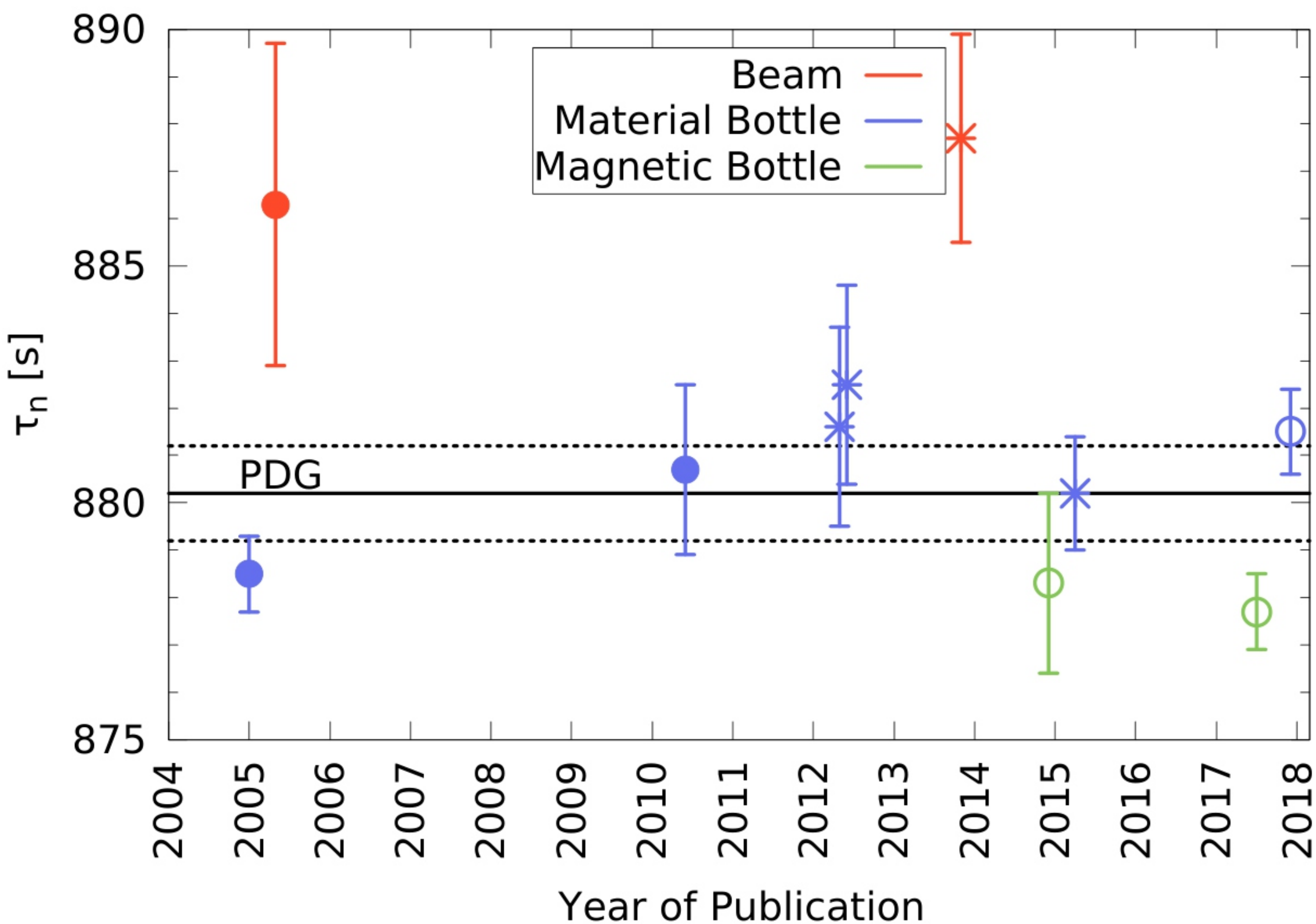
Measuring the free neutron lifetime with spin-polarized ultracold neutrons at TRIGA Mainz

Dieter Ries
for the τSPECT collaboration
d.ries@uni-mainz.de

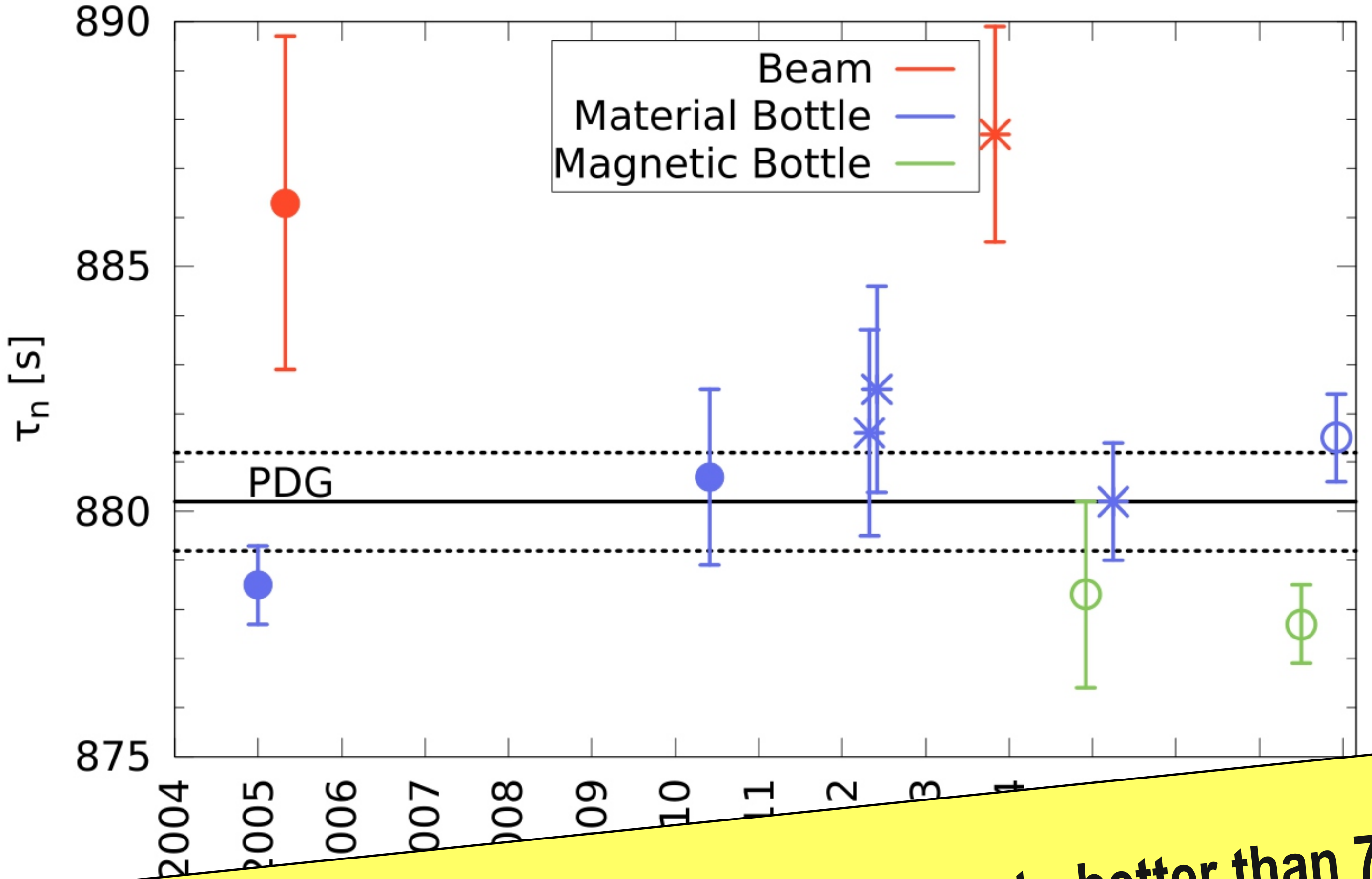
SPIN 2018

September 13, 2018

The Lifetime Puzzle

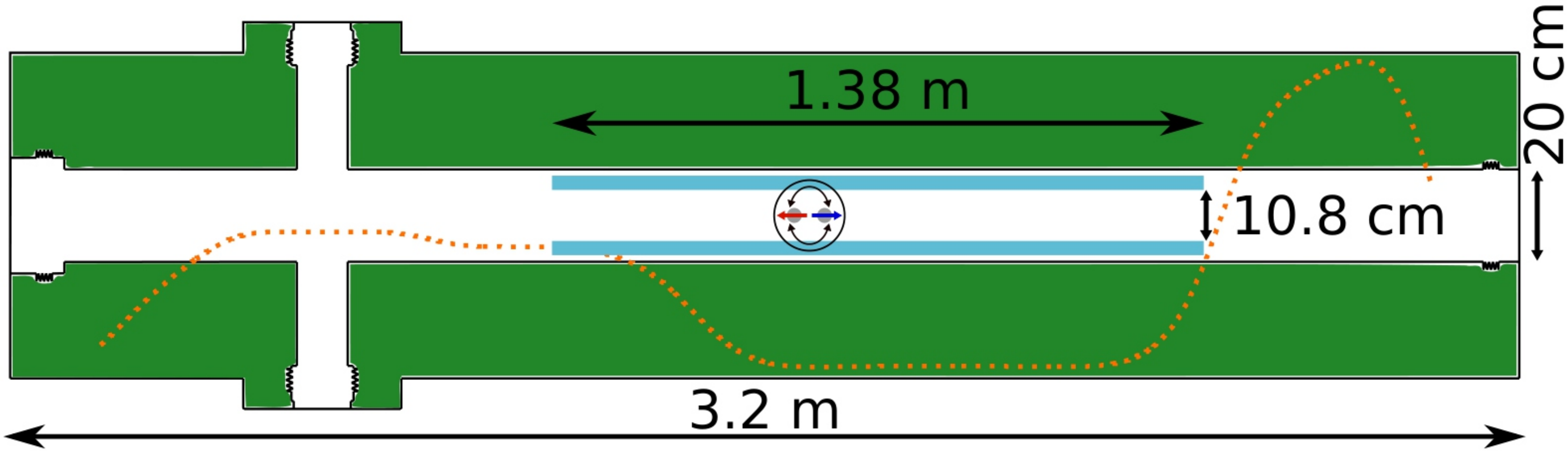


The Lifetime Puzzle



"It's 2018 and we cannot agree on τ_n to better than 7s?!"

Measurement Procedure



1. UCN production (30 ms reactor pulse)
2. Fill UCN into τSPECT Magnet from the left
    - Polarization due to high Magnetic Field
    - Simultaneously: Intensity Monitoring (not spin-flipped Neutrons)
    - Short Axial Field Lowering (spectral cleaning)
3. Wait ...
4. Count remaining UCN

Storage of polarized ultracold neutrons

Guillaume Pignol, Sep 13 2018
SPIN 2018, Ferrara, Italy

UNIVERSITÉ Grenoble Alpes
erc European Research Council

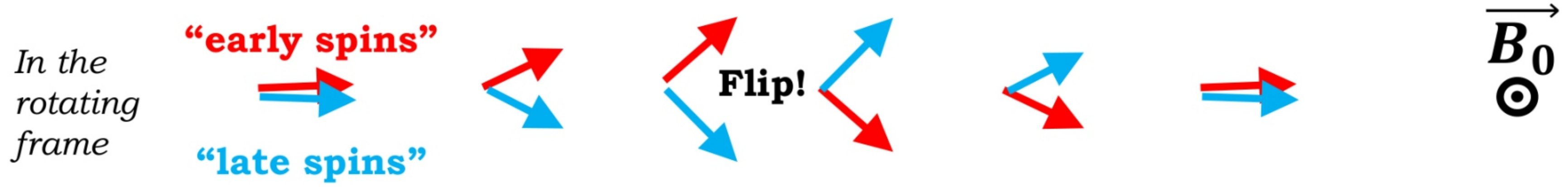
Principle of the spin-echo method

Ramsey cycles

Filling	$\pi/2$ pulse		$\pi/2$ pulse	Emptying neutrons, counting N_+ and N_-

Spin-echo cycles

Filling	$\pi/2$ pulse		π pulse		$\pi/2$ pulse	Emptying neutrons, counting N_+ and N_-



time

We scan the vertical field gradient

Spin echo cancels the gravitational depolarization.