A search for deviations from the inverse square law of gravity at nm range using a pulsed neutron beam

10th International Workshop on Fundamental Physics using Atoms

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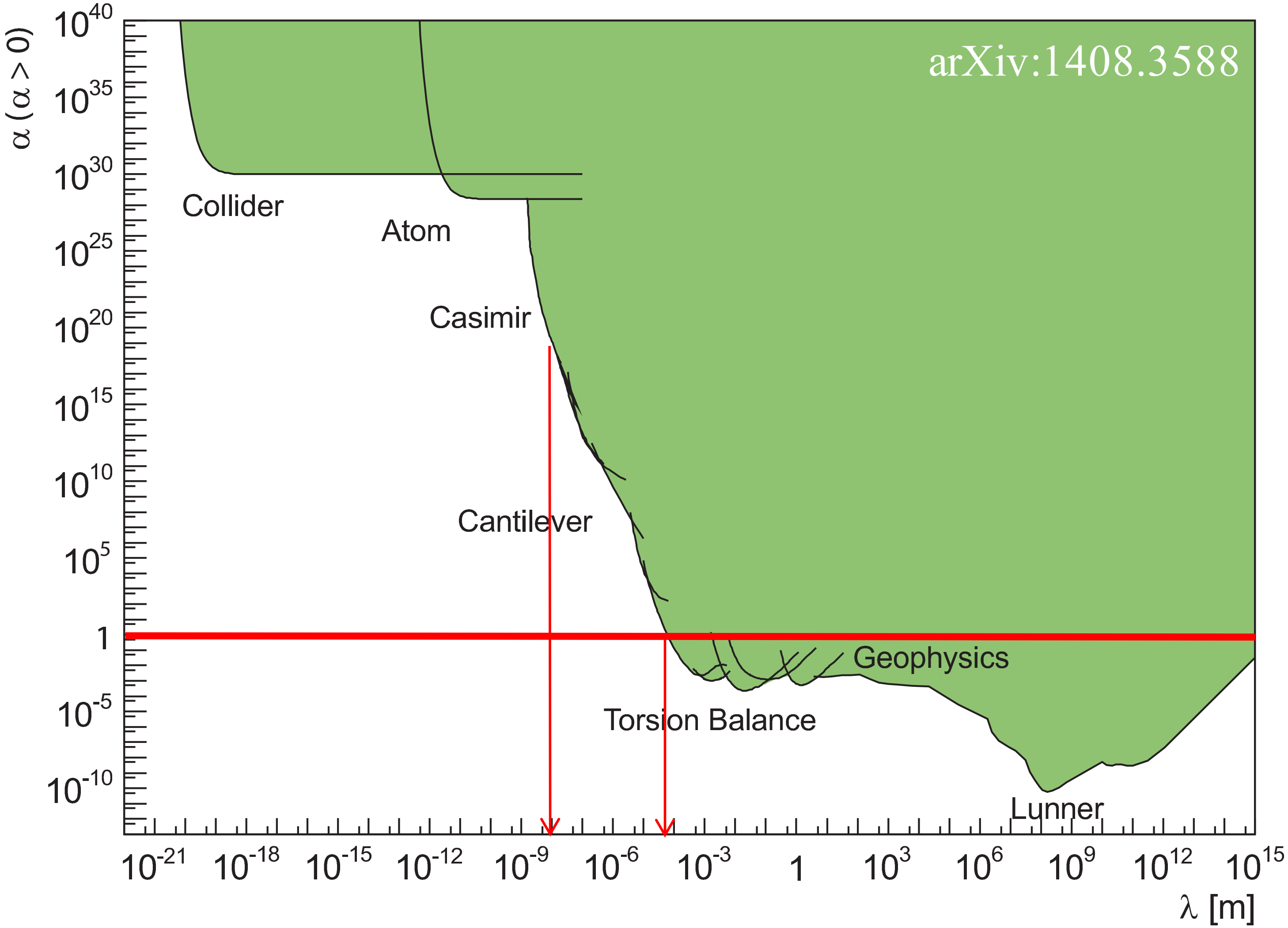
Kyushu University,

Research Center for Advanced Particle Physics

Tamaki Yoshioka

Test of Inverse Square Law of Gravity



ADD model

Physics Letters B 429 (1998) 263–272

The hierarchy problem and new dimensions at a millimeter

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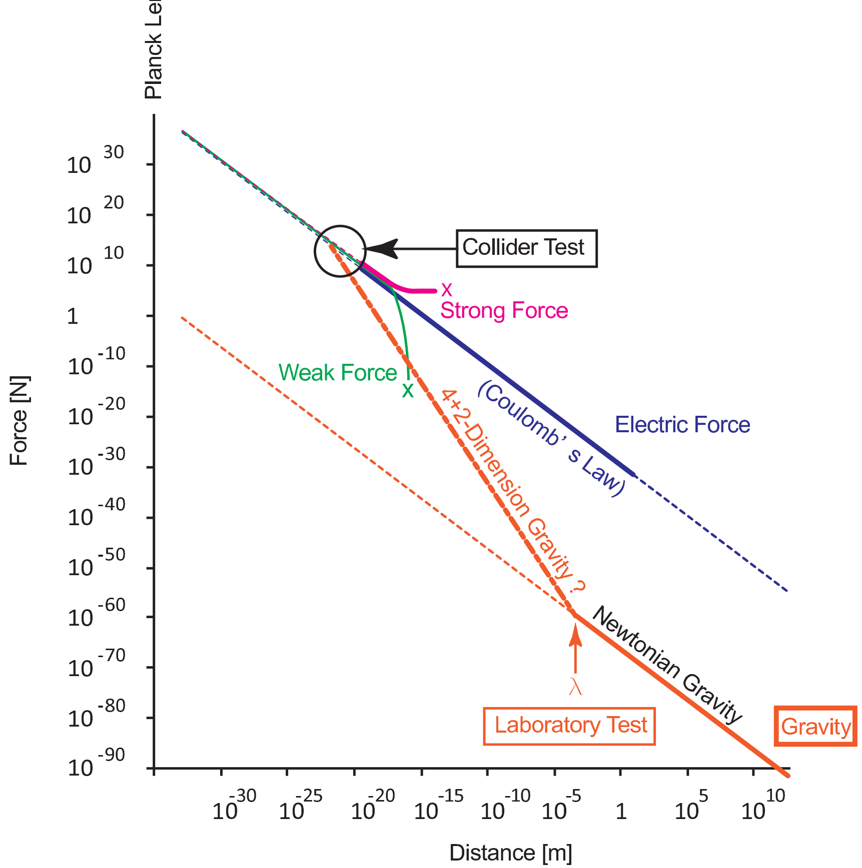
[c] *ICTP, Trieste 34100, Italy*

- Gravity has only been accurately measured in ~1cm range.
- Assuming the gravity become same order of other forces at TeV scale. Λ=0.1mm for n=2.
- Should be continuous at $r = \Lambda$.

$$F = \begin{cases} G\dfrac{Mm}{r^2} & (r > \Lambda) \\ G_{4+n}\dfrac{Mm}{r^{2+n}} & (r < \Lambda) \end{cases}$$

arXiv:1408.3588



Test of Inverse Square Law of Gravity

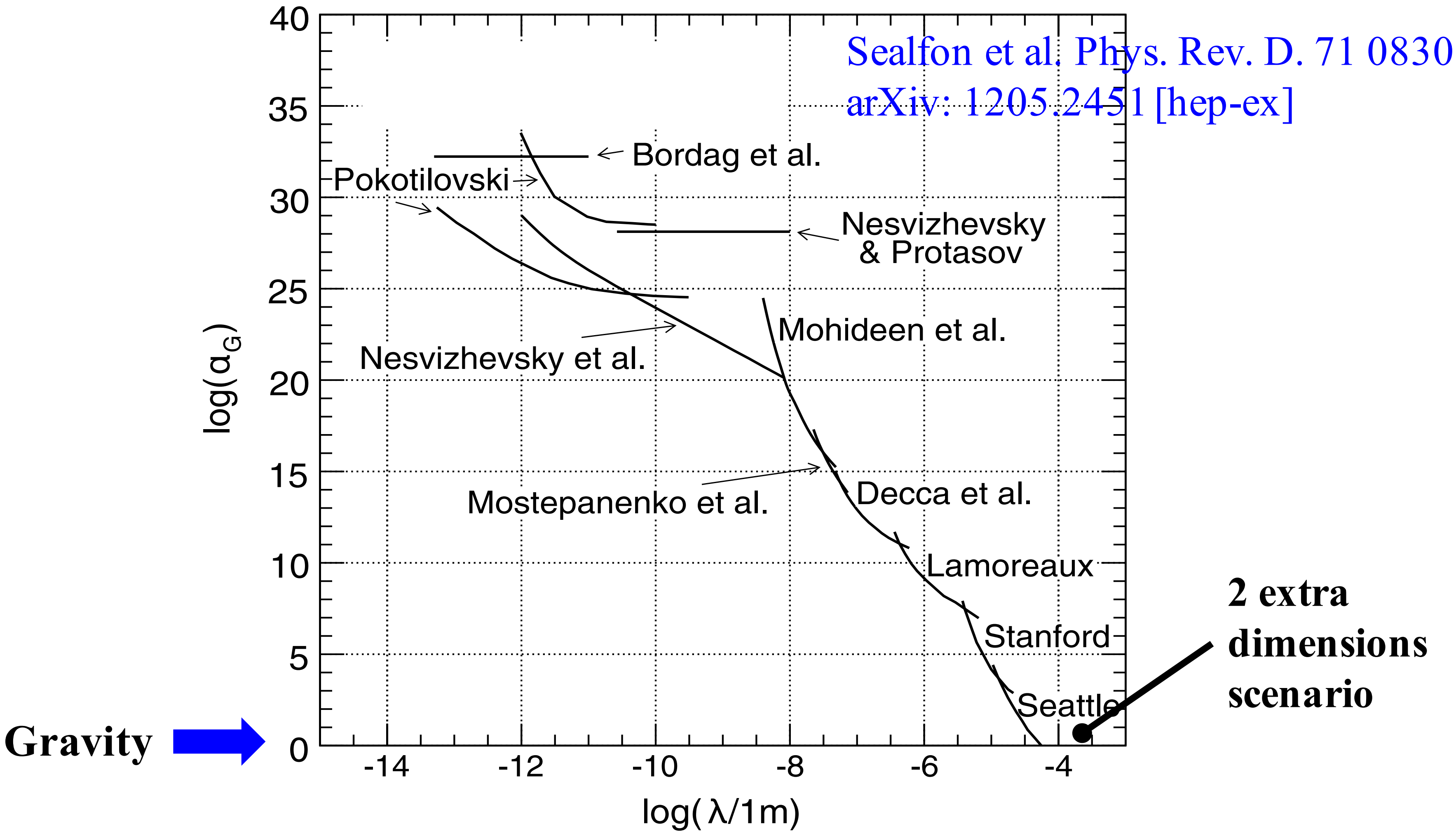
- Gravity is extremely weak compared to the other forces
  - Can be naturally explained by assuming extra dimensions.
  - Deviation from inverse square law is expected if extra dimensions exist.
  - Model-independent search is performed by assuming Yukawa-type force with coupling constant α and Compton wavelength λ.

$$V = -G_N \frac{mM}{r}\left(1 + \alpha e^{-r/\lambda}\right)$$

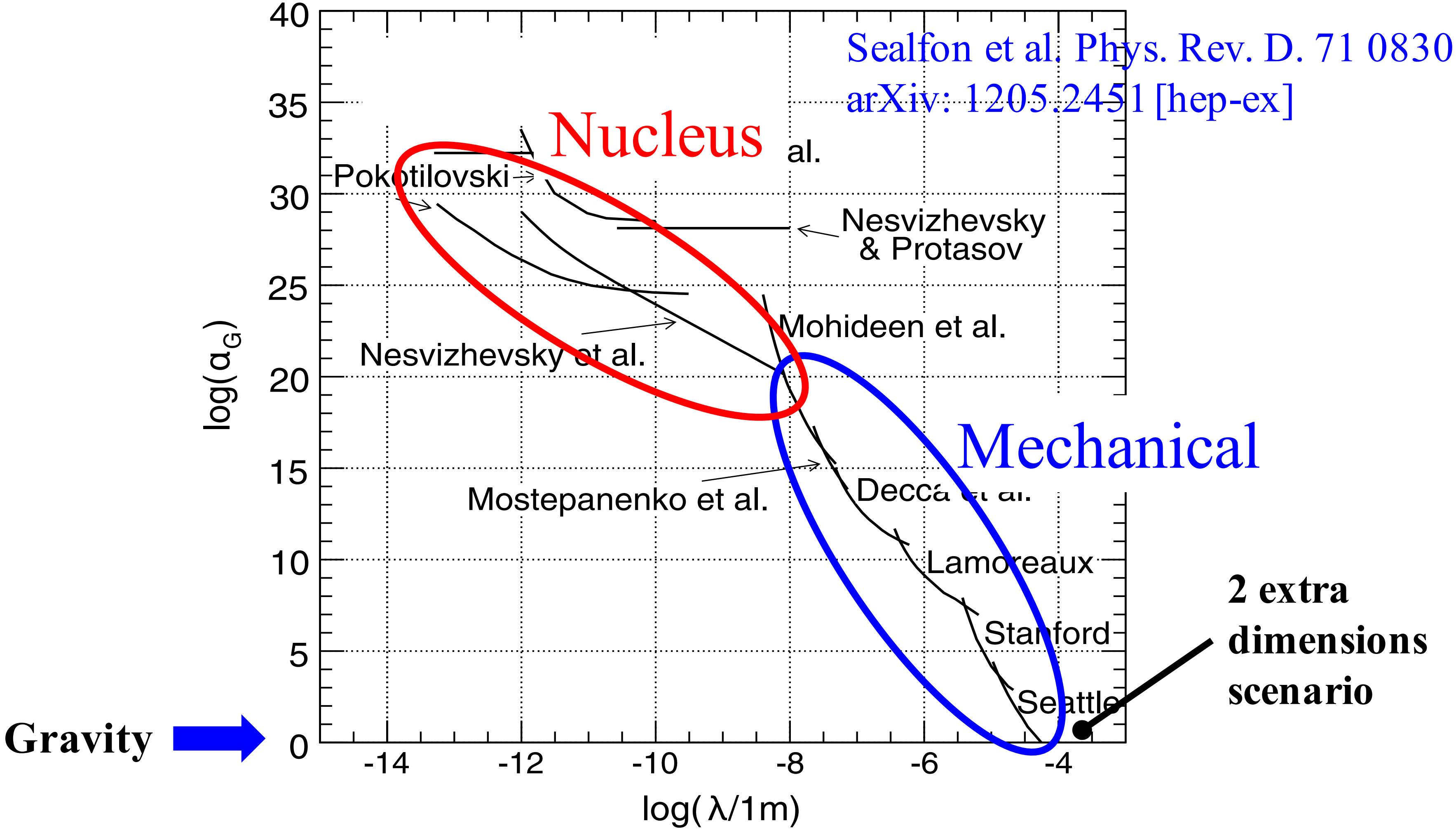
Newtonian potential

Yukawa potential

α-λ Exclusion plot



α-λ Exclusion plot



α-λ Exclusion plot

Main background is Van der Waals force

$$U = -\frac{3\hbar c}{8\pi}\frac{\alpha_0}{r^4}$$

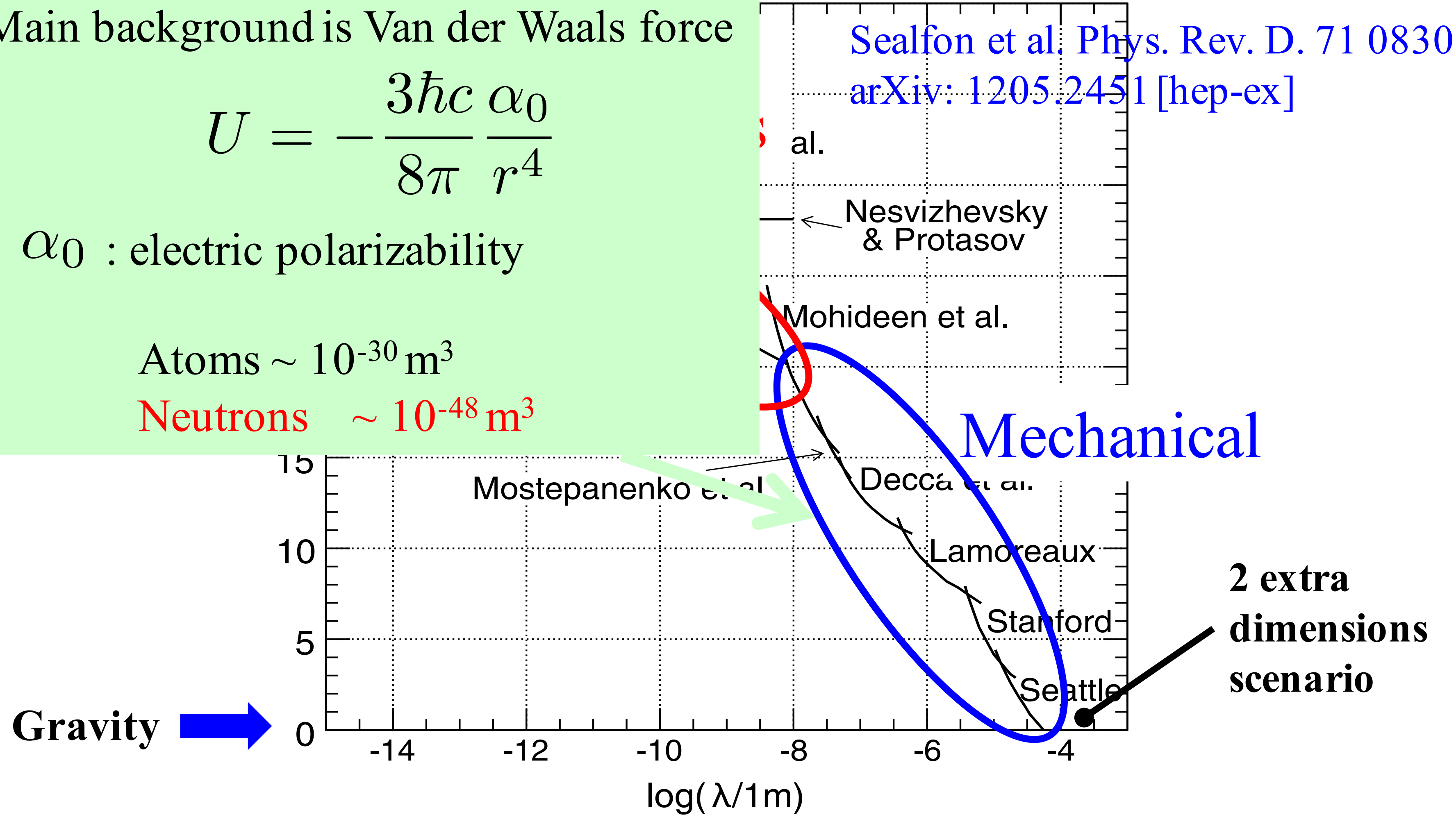
α_0 : electric polarizability

Atoms ~ 10^{-30} m^3

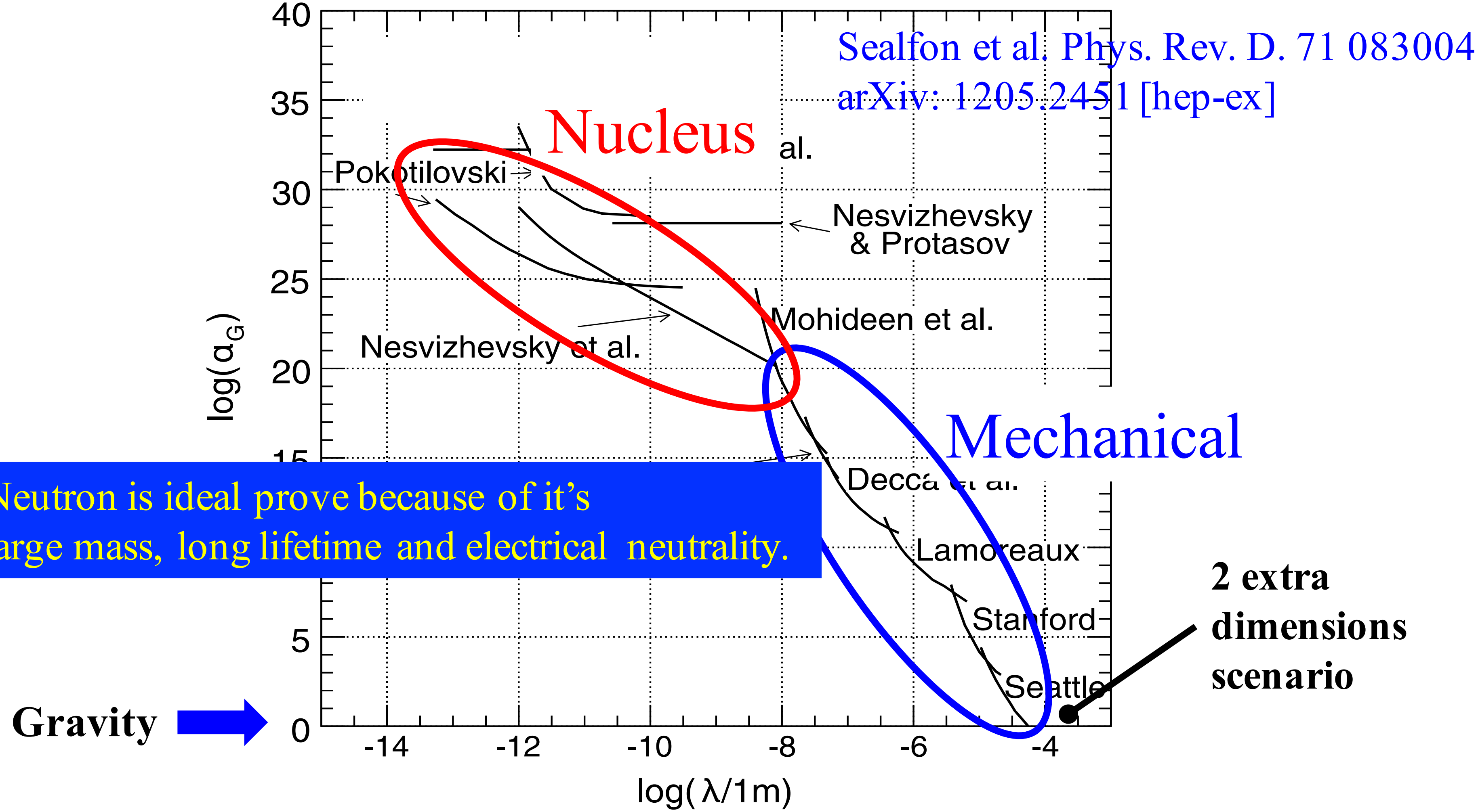
Neutrons ~ 10^{-48} m^3

Sealfon et al. Phys. Rev. D. 71 083004

arXiv: 1205.2451 [hep-ex]

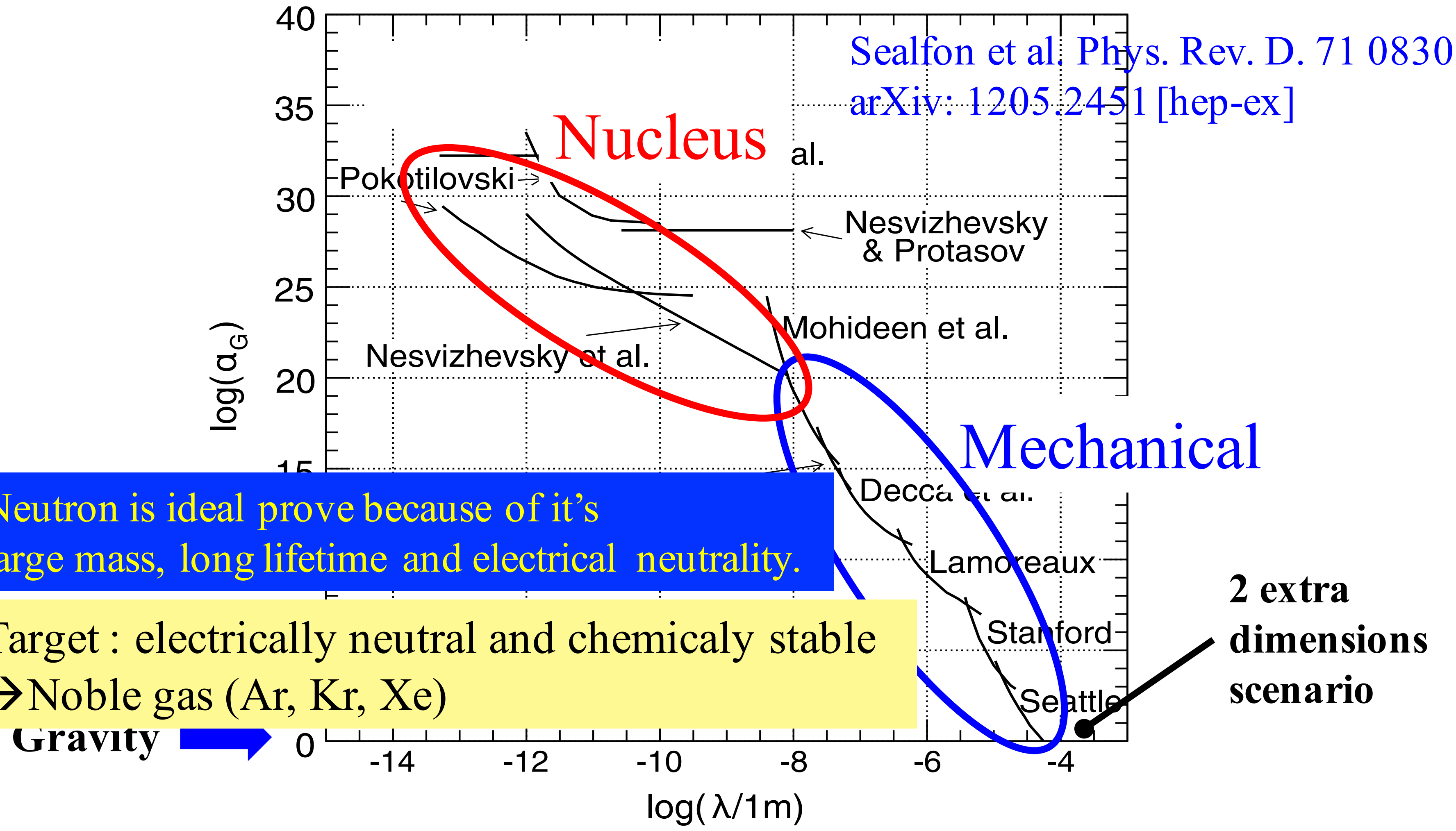


α-λ Exclusion plot



Neutron is ideal prove because of it's large mass, long lifetime and electrical neutrality.

α-λ Exclusion plot



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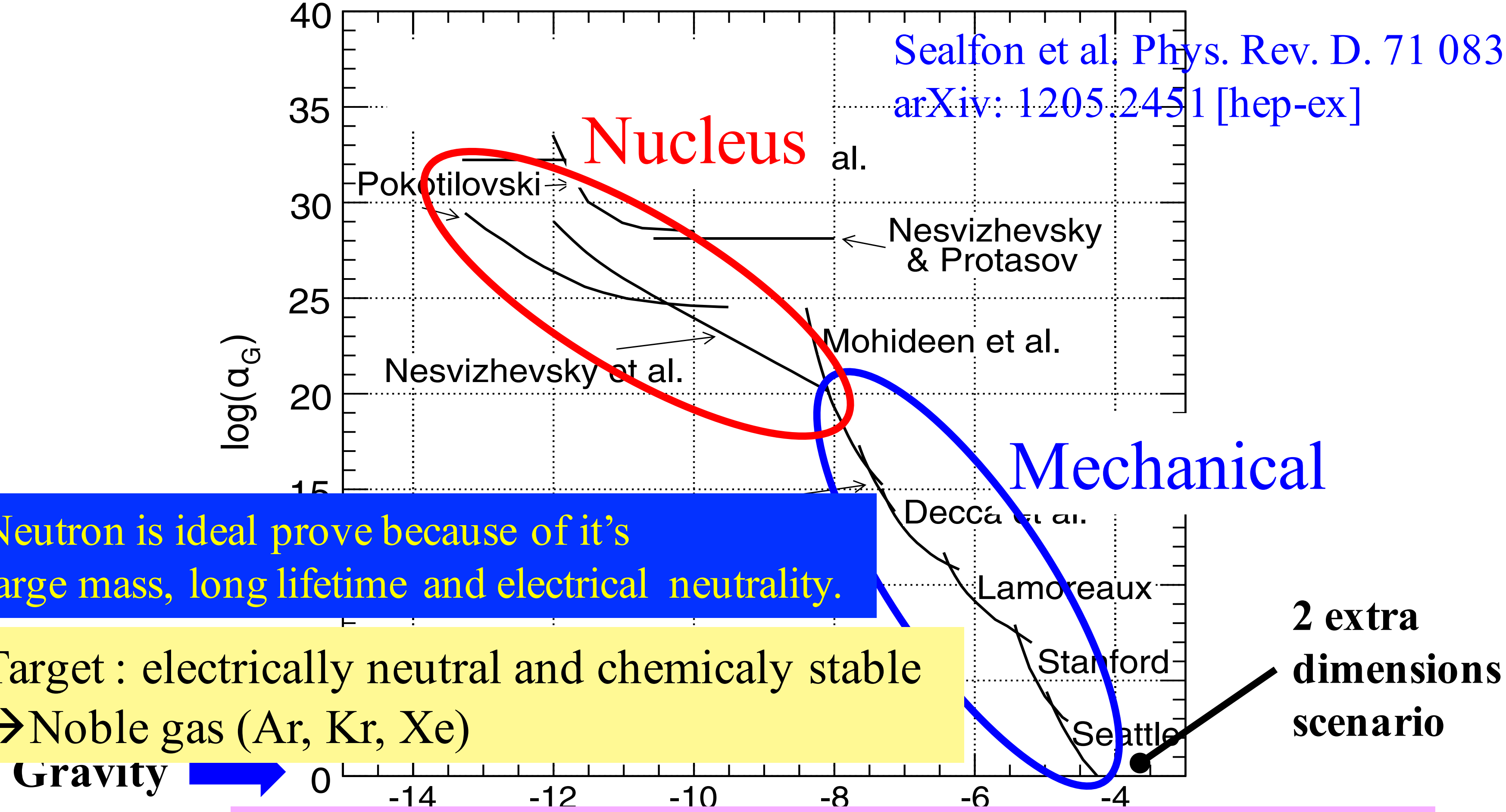
Target : electrically neutral and chemicaly stable
→Noble gas (Ar, Kr, Xe)

α-λ Exclusion plot



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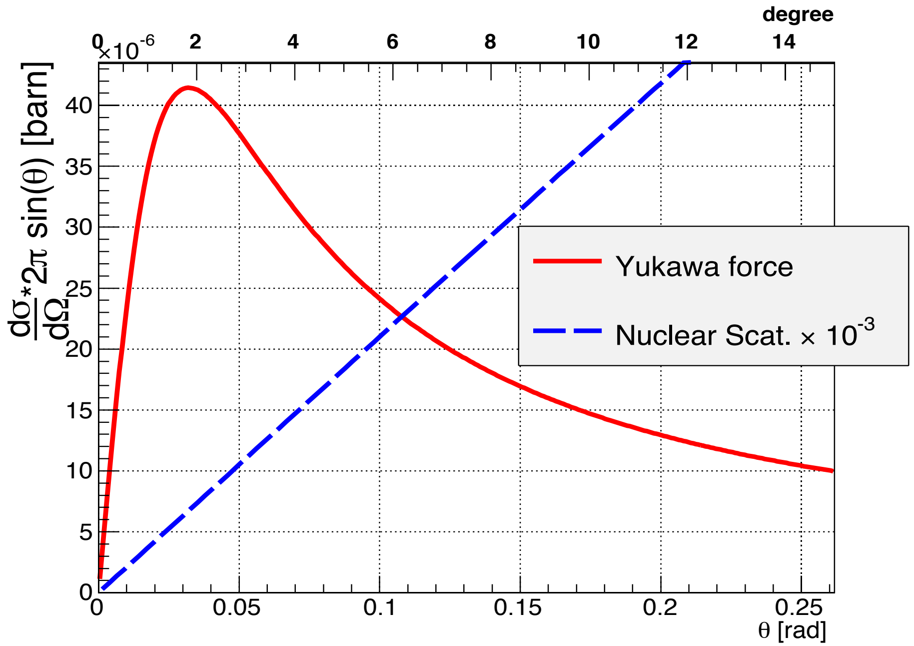
Searching for deviations from inverse square law of gravity at nm range via neutron-noble gas scattering

Experimental Principle

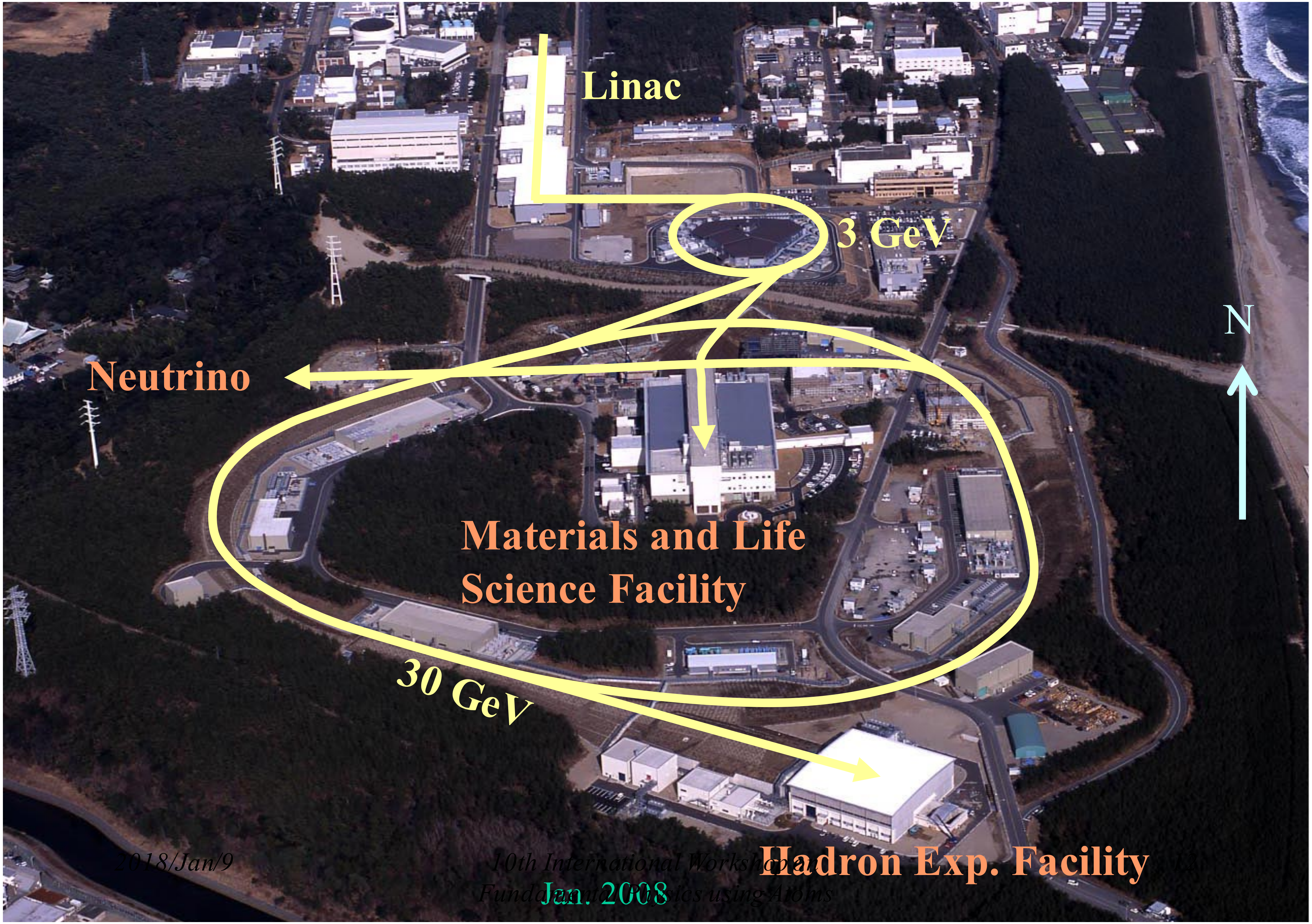
- Differential cross section of Yukawa force is evaluated with Born approximation.

$$\left.\frac{d\sigma(\theta)}{d\Omega}\right|_Y \propto \sqrt{\sigma_{\mathrm{Nuclear}}}\,\alpha m_{\mathrm{T}}\lambda^2 \left(\frac{1}{1+C\sin^2\left(\frac{\theta}{2}\right)}\right)$$

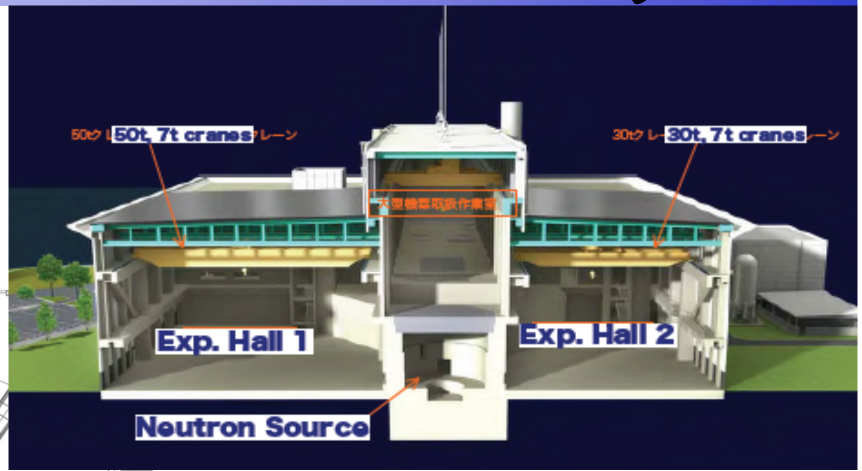
m_{T} : Target mass
$\sigma_{\mathrm{Nuclear}}$: nuclear scattering cross section

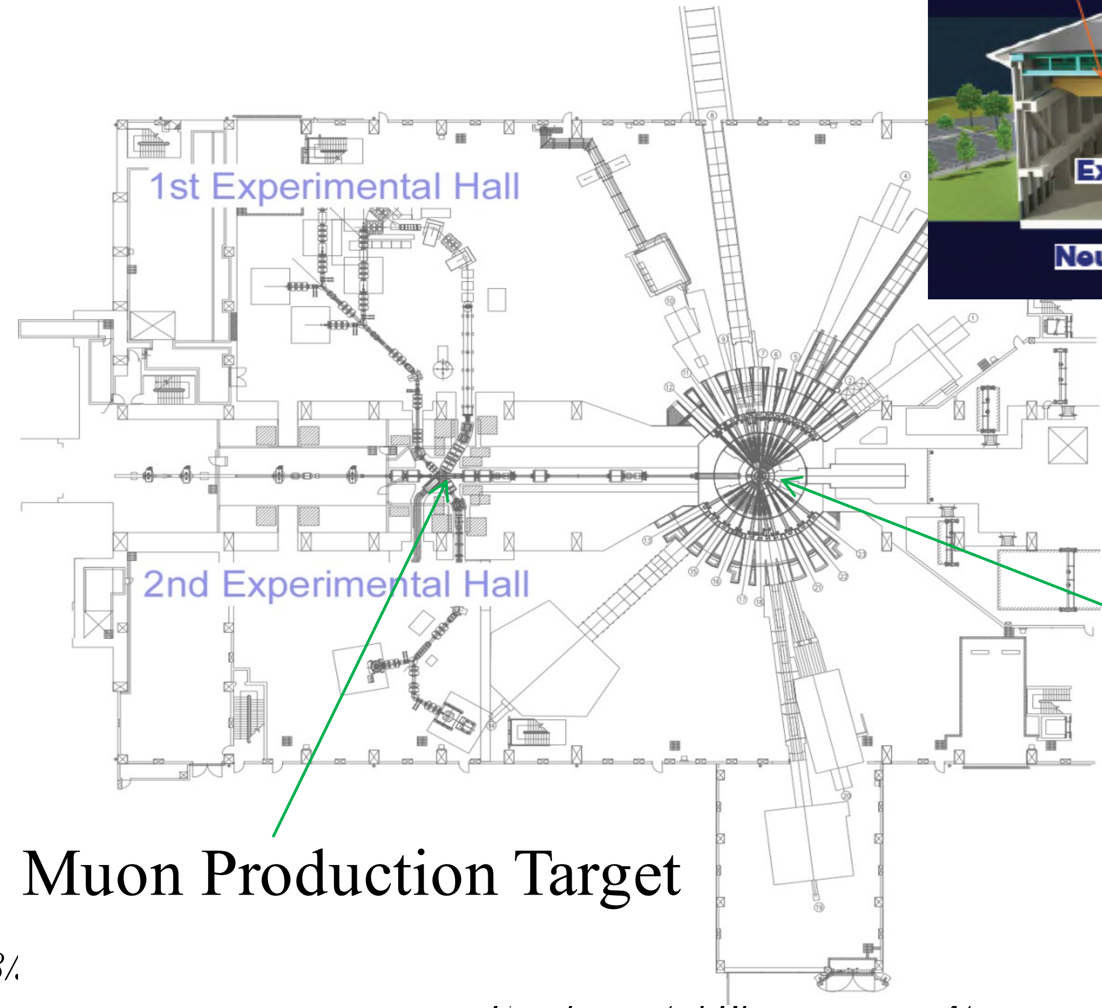


- Nuclear scattering → Isotropic
- Yukawa force → strong angular dependence in the forward region


Linac
3 GeV
N
Neutrino
Materials and Life
Science Facility
30 GeV
Hadron Exp. Facility
Jan. 2008

Material and Life Science Facility

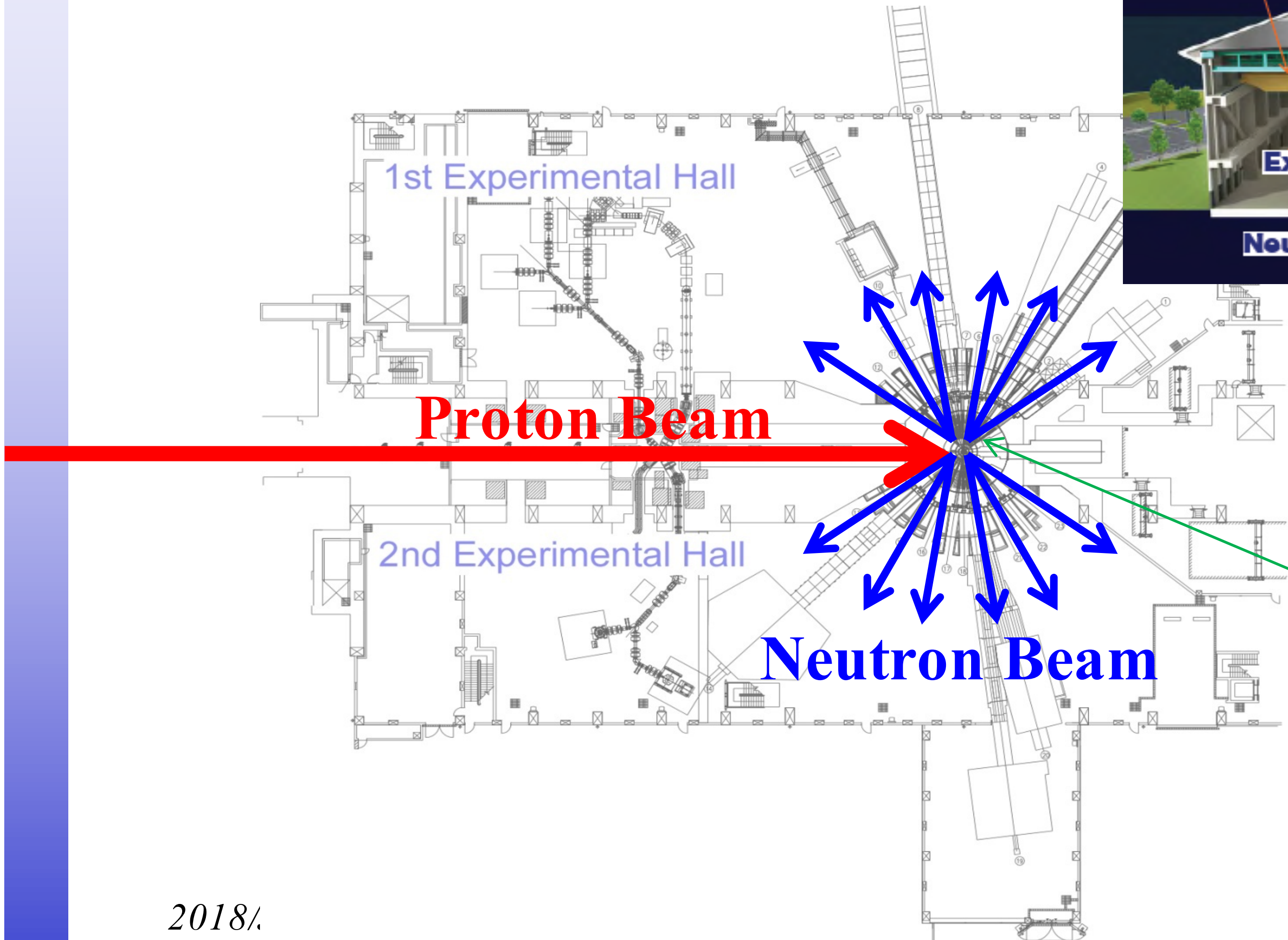


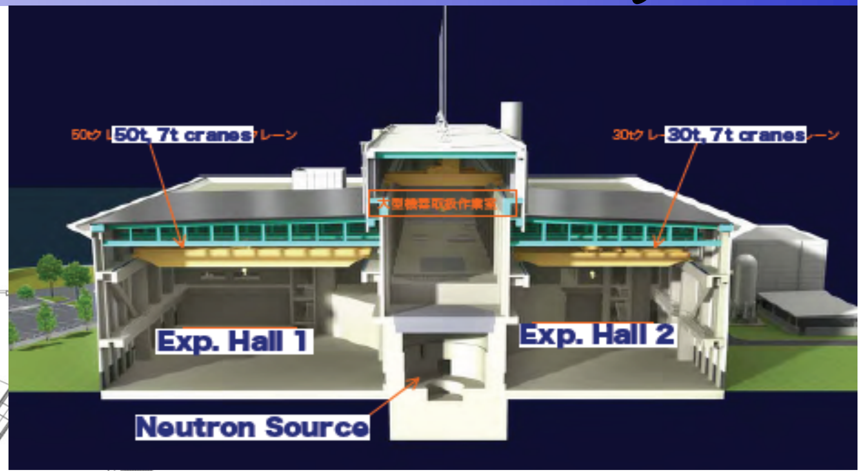


Mercury Target
for neutron production

Muon Production Target

Material and Life Science Facility





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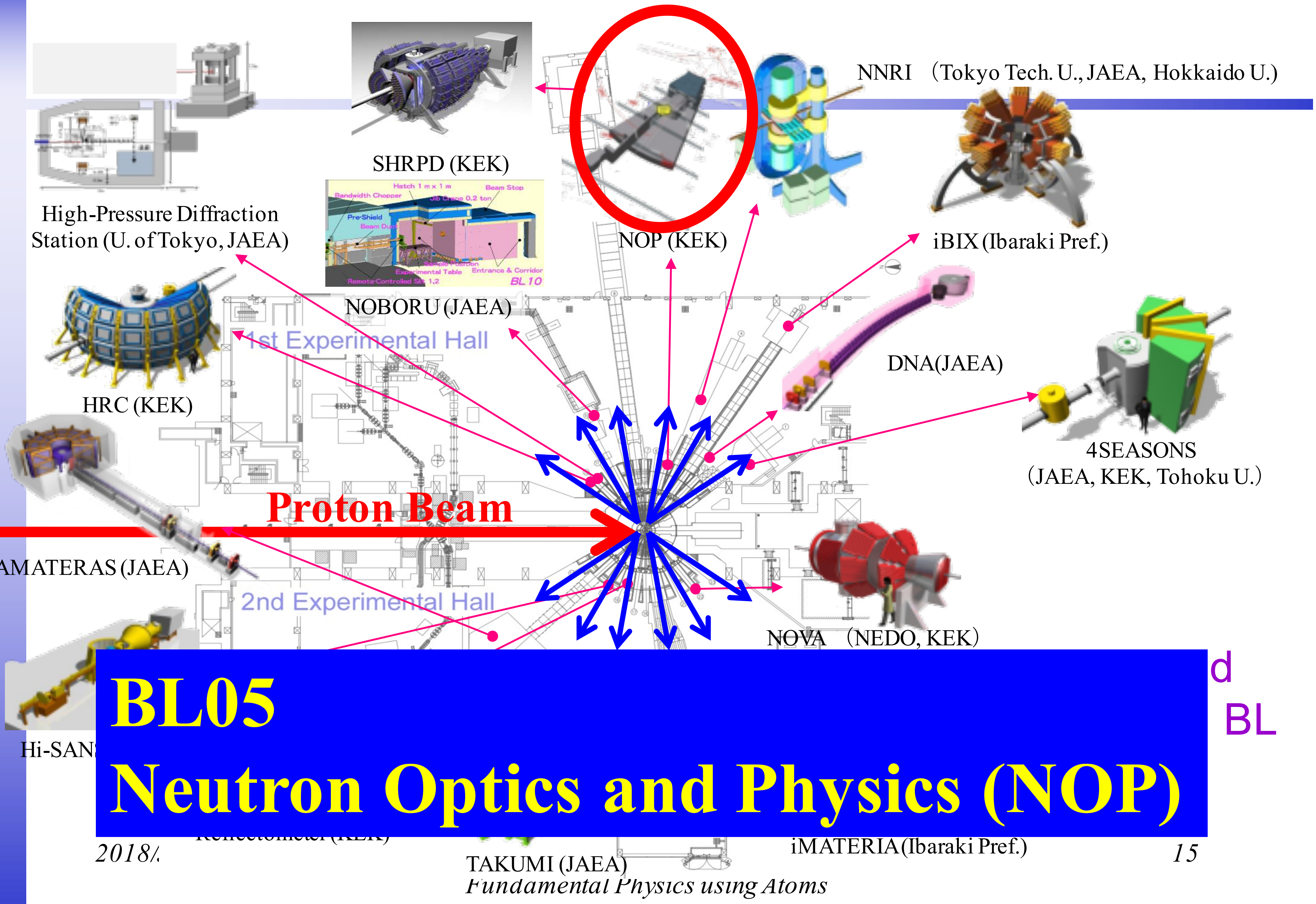
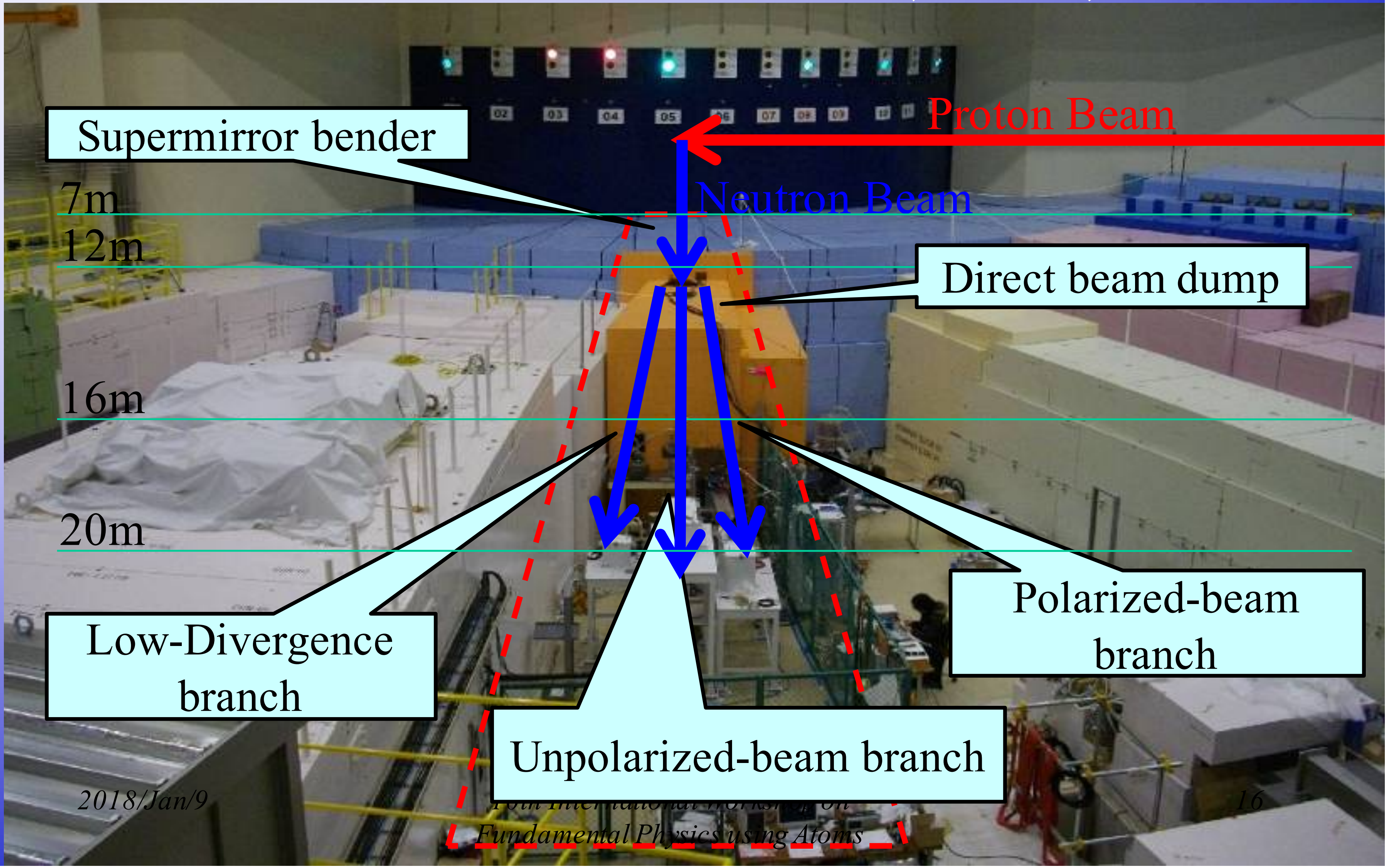


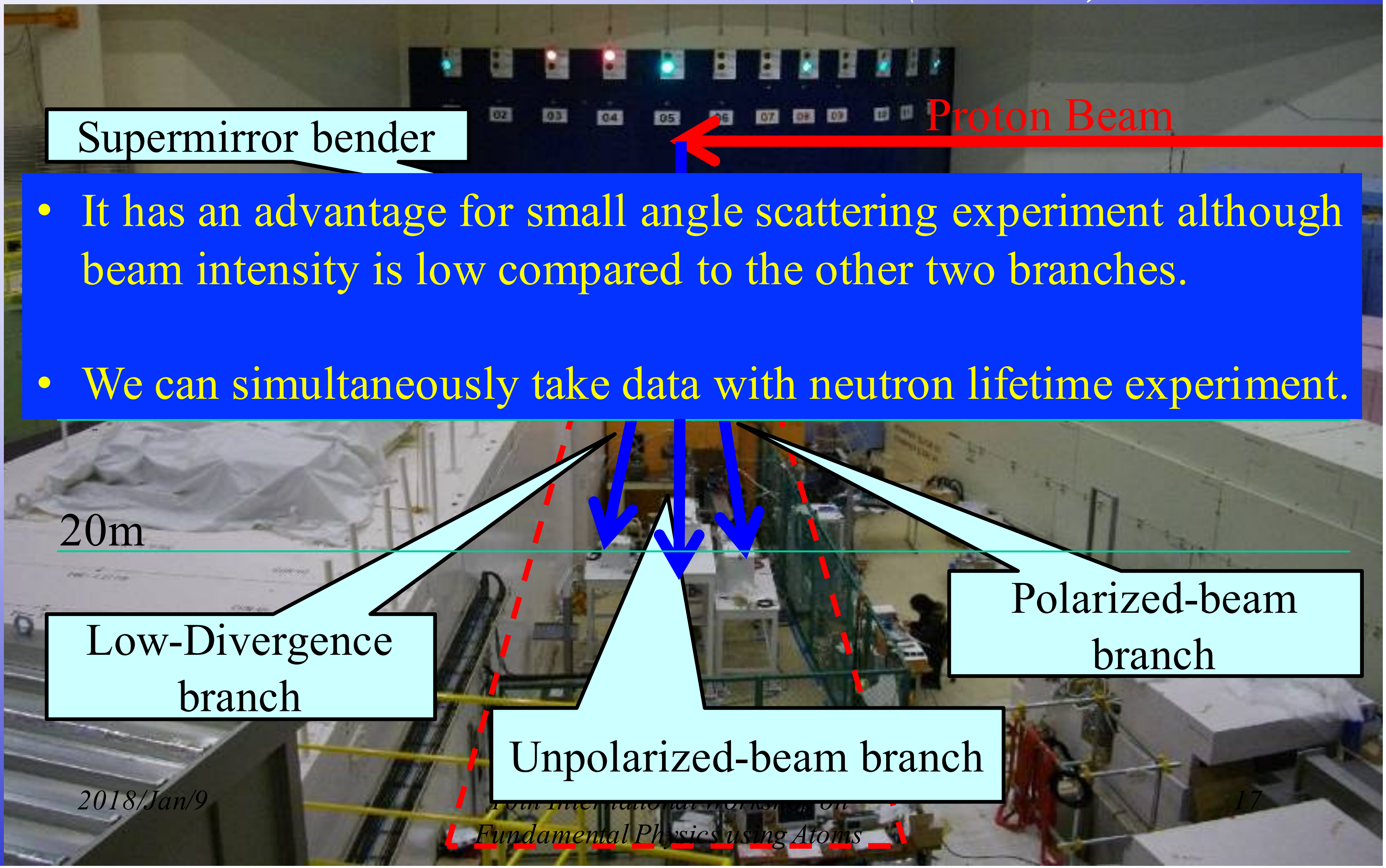
BL05
Neutron Optics and Physics (NOP)

J-PARC/MLF/BL05(NOP)

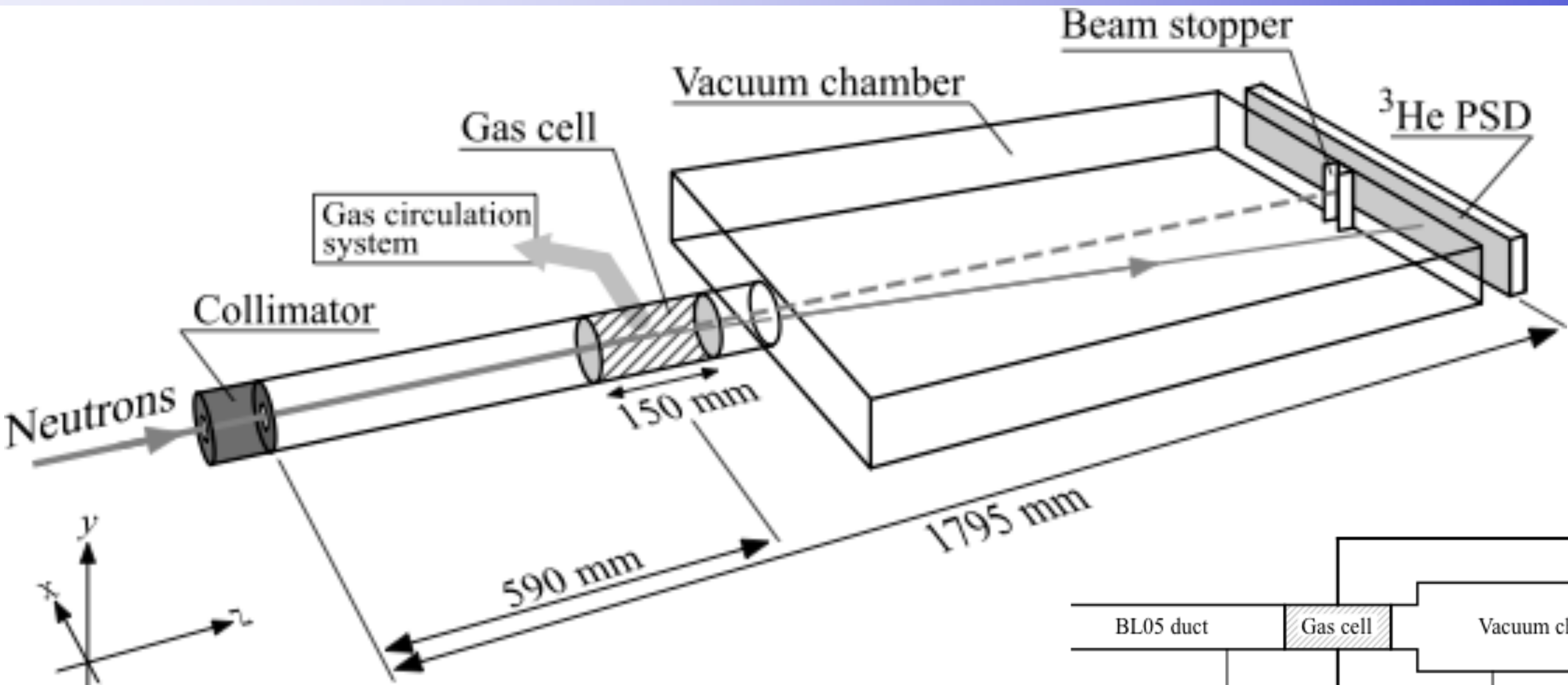


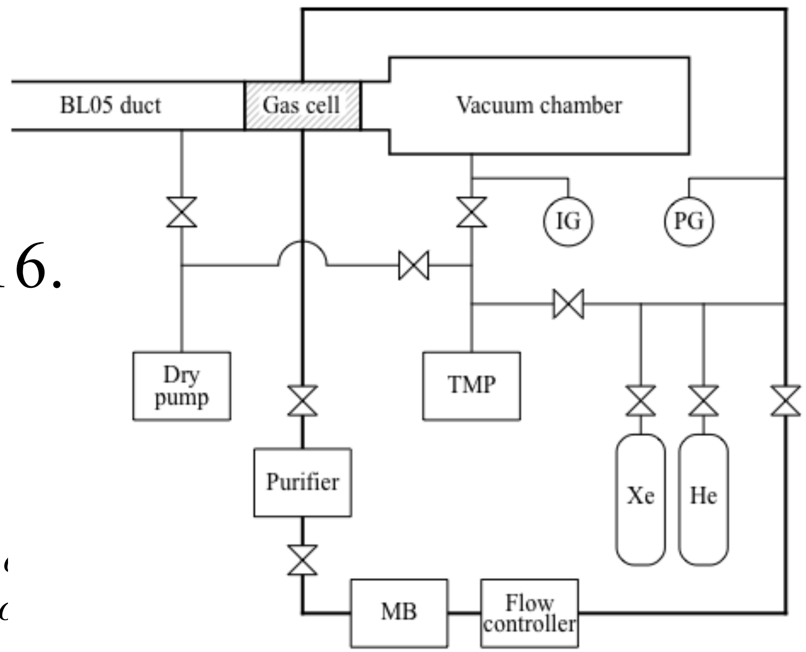
J-PARC/MLF/BL05(NOP)

- It has an advantage for small angle scattering experiment although beam intensity is low compared to the other two branches.
- We can simultaneously take data with neutron lifetime experiment.

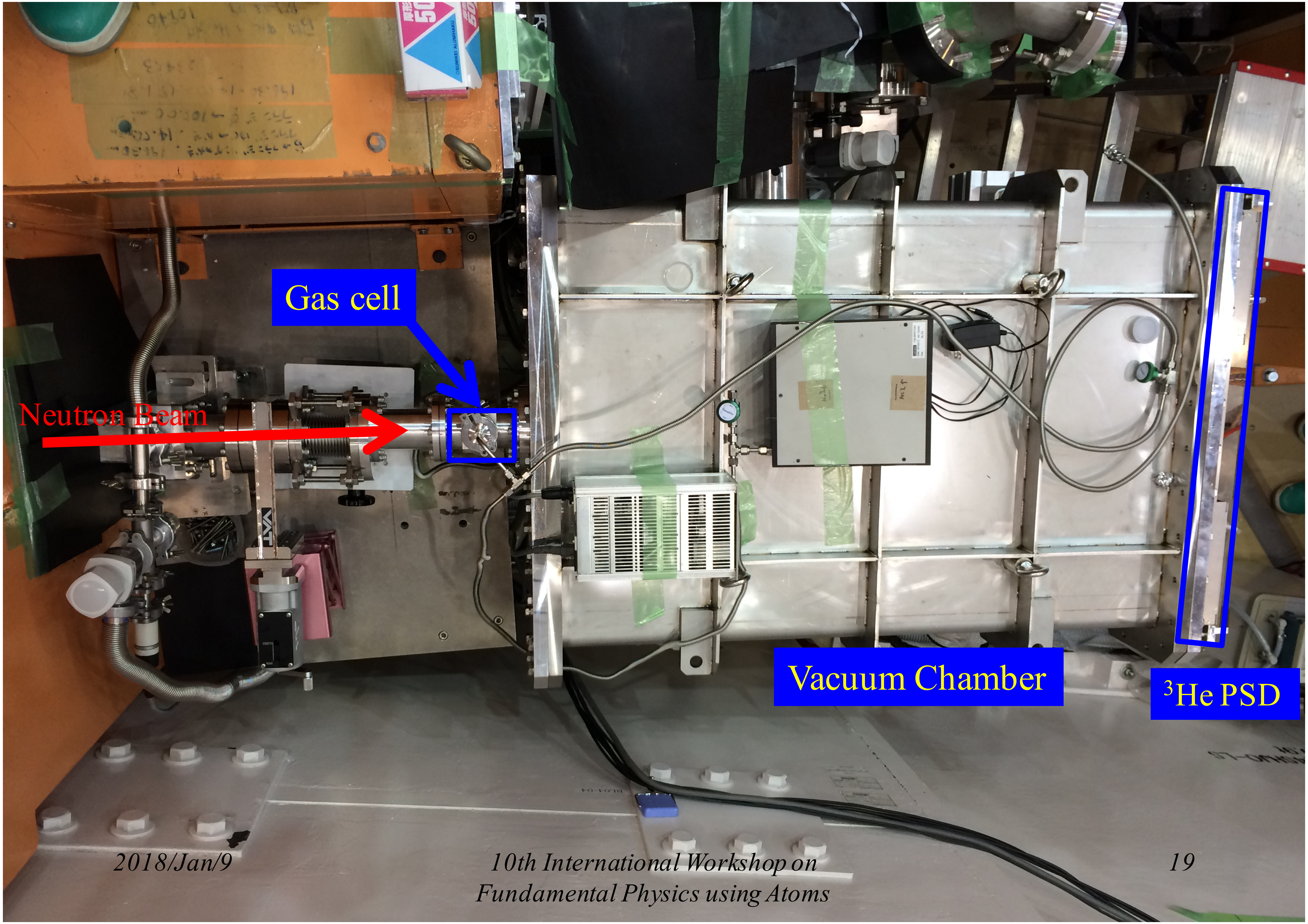


Experimental Setup

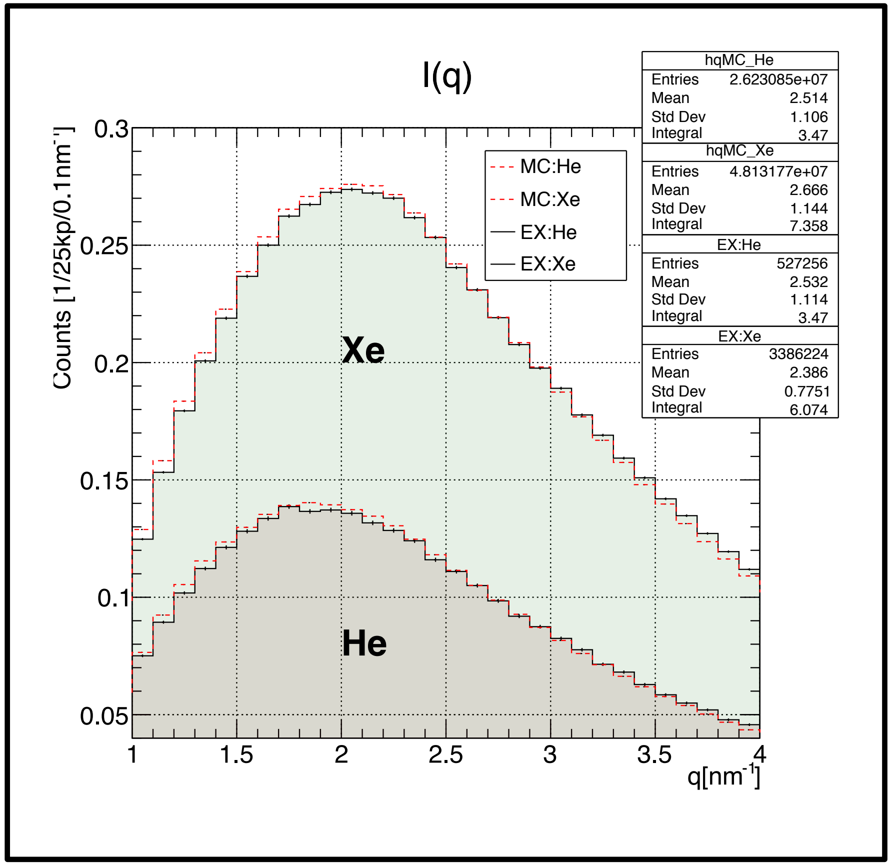


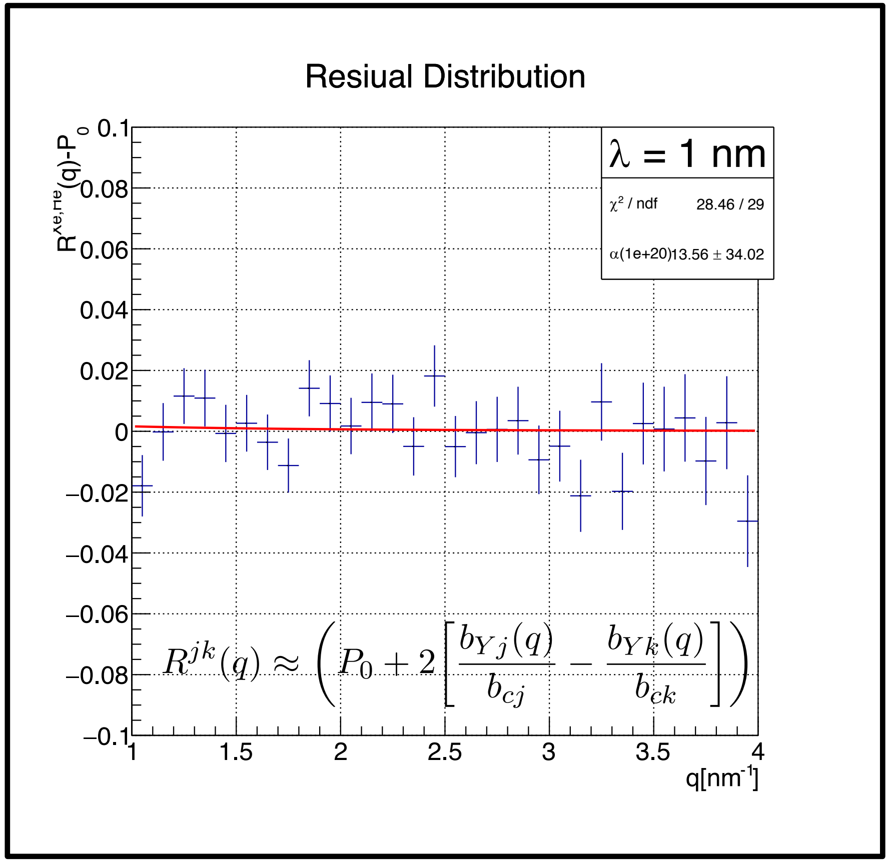


- Physics run has been started in late 2016.
- J-PARC beam power : 150 kW
- 2 atm Xe and He with gas circulation


Gas cell
Neutron Beam
Vacuum Chamber
³He PSD

Results

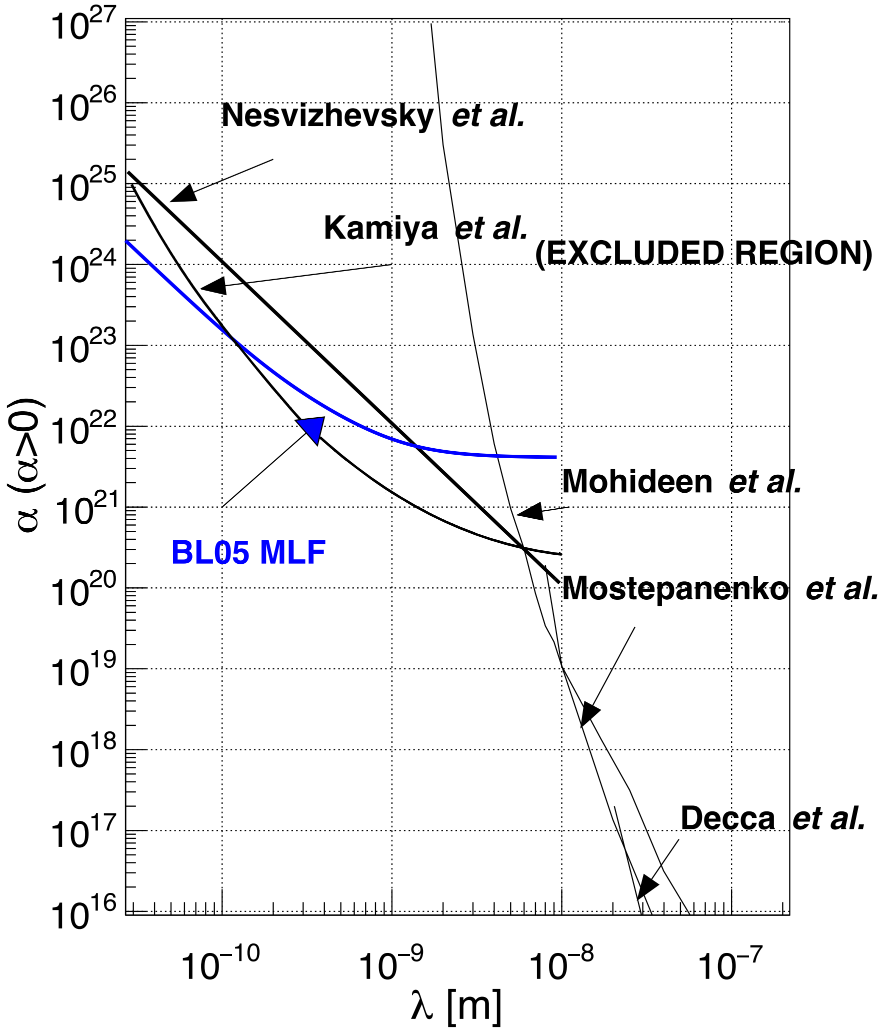




- First, experimental data is normalized by the corresponding simulation data for each gas species to remove any q-dependence, then the ratio of two gases was taken.

Results

- Set new limit below 0.1 nm.
- Degradation > 0.1 nm is due to background caused by scattered neutron from beam stopper.
- < 0.01 nm is dominated by "Schwinger effect".
- C. C. Haddock et al., https://arxiv.org/abs/1712.02984



Summary & Prospects

- A search for deviations from inverse square law of gravity at nm range via neutron-noble gas scattering has been performed at J-PARC/MLF/BL05.
- We set new limit below $\lambda < 0.1$ nm using first data taken in 2016/2017.

- We have already collected more data with improved apparatus and higher beam power (300kW) in Dec. 2017.
  – Background was greatly reduced. Can be access larger λ region.
- Continue data taking until this summer.
  – J-PARC beam power will be 400kW from Jan., 500kW from Apr. and more after summer shutdown.
- Ne and Kr will be tried for the systematics studies.