Nuclear Data Needs and Capabilities for Applications (NDNCA)

Triangle Universities Nuclear Laboratory Facilities Review

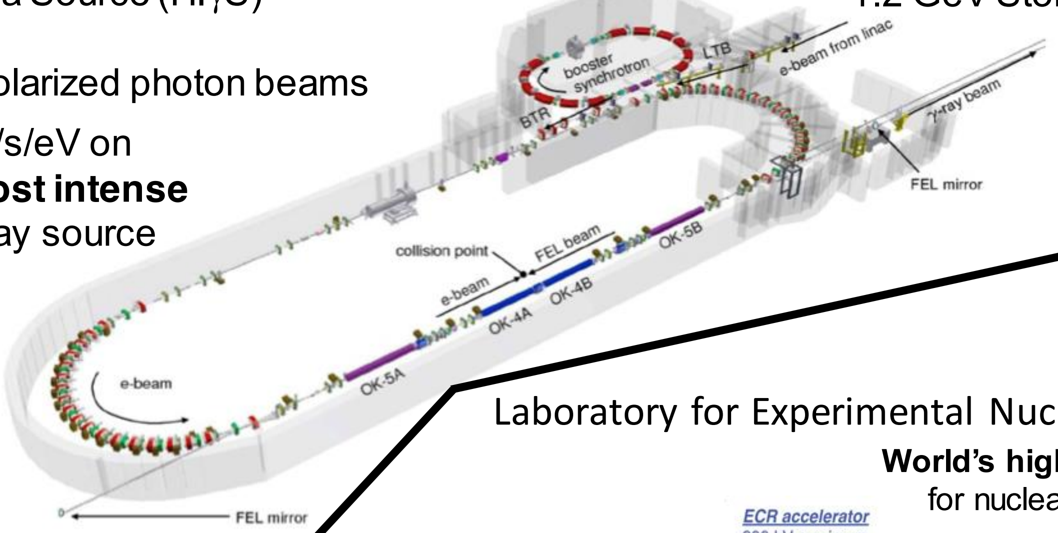
Werner Tornow
Duke University & TUNL

TUNL: Accelerator Facilities

High Intensity Gamma Source (HIγS)
E_γ = 1 – 100 MeV
Linear and circular polarized photon beams

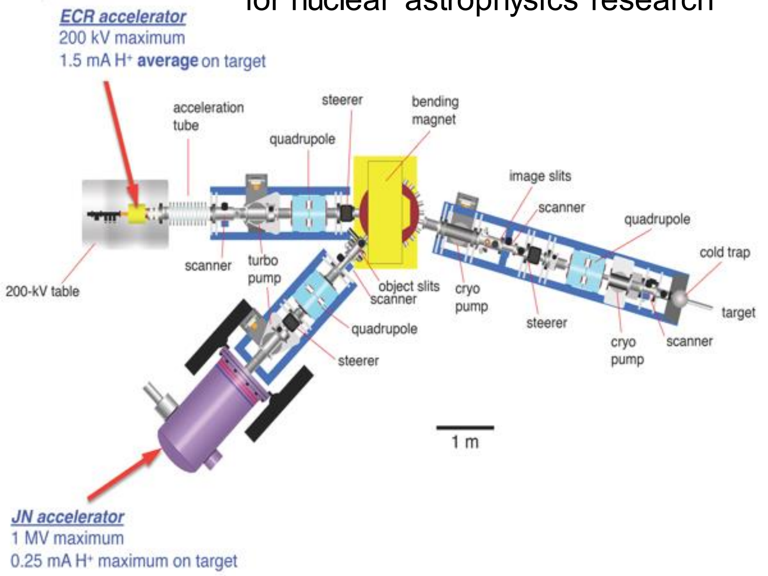
Delivering up to 10^3 γ/s/eV on target, **HIγS is the most intense** accelerator-driven γ-ray source in the world

1.2 GeV Storage Ring FEL

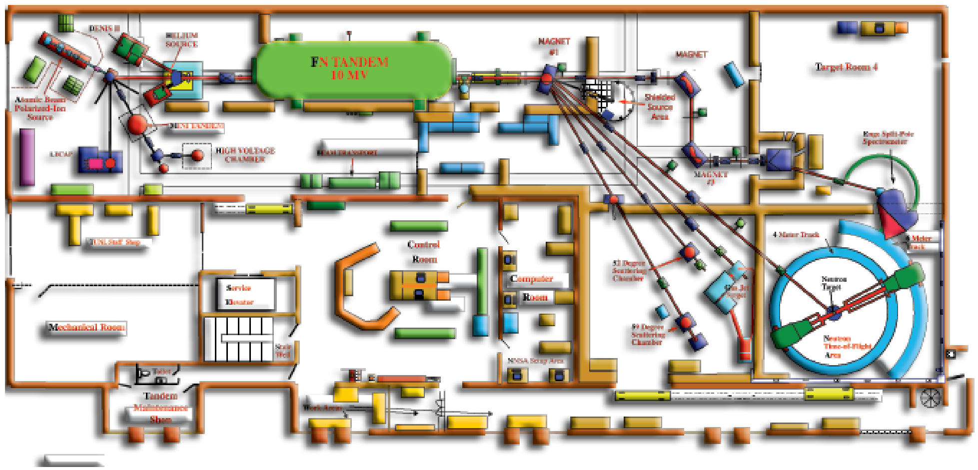


Laboratory for Experimental Nuclear Astrophysics (LENA)

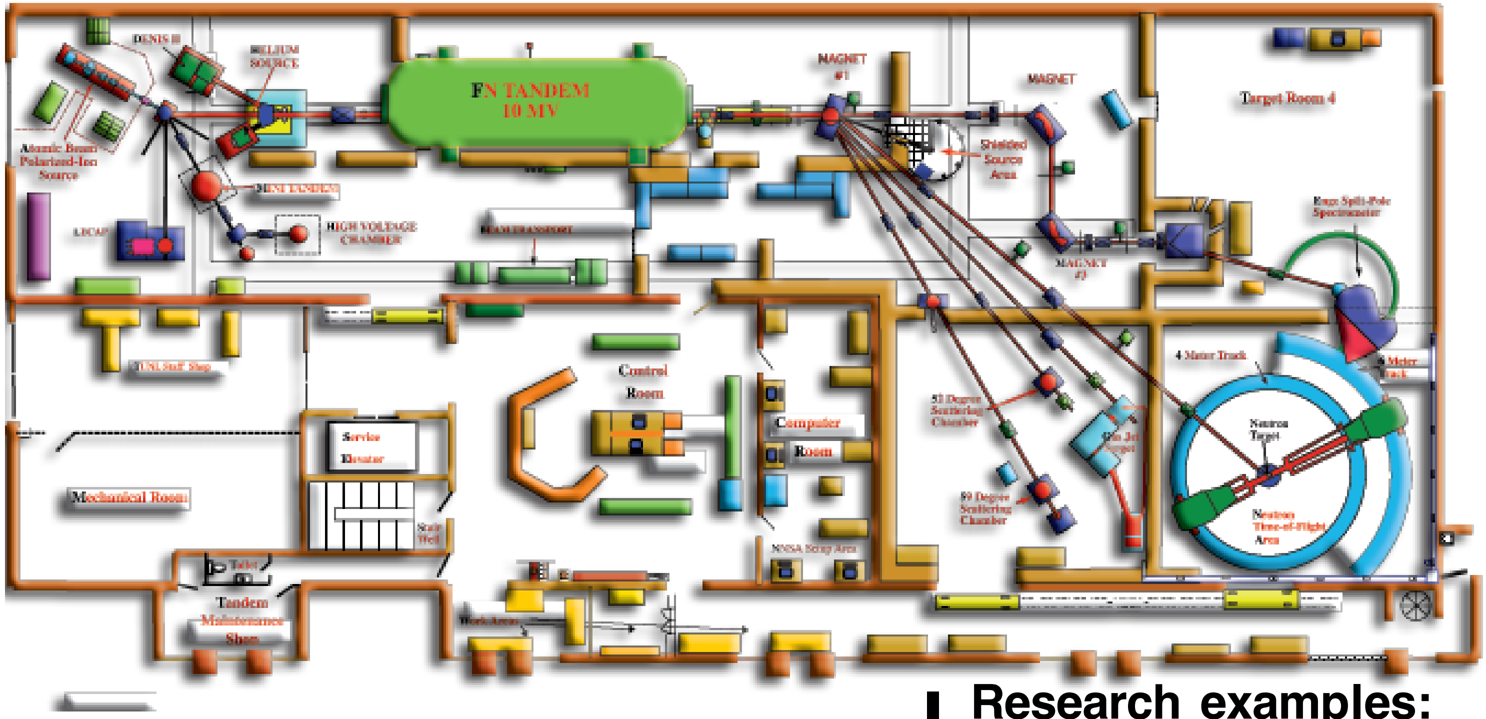
World's highest current proton beam
for nuclear astrophysics research



Tandem Laboratory: light-ion and pulsed neutron beams



Tandem Lab



Accelerator and Source Features:

TV_{max} = 10 MV

Particles: light ions (p, d, ^{3}He, ^{4}He)

Secondary beams: pulsed neutron beams

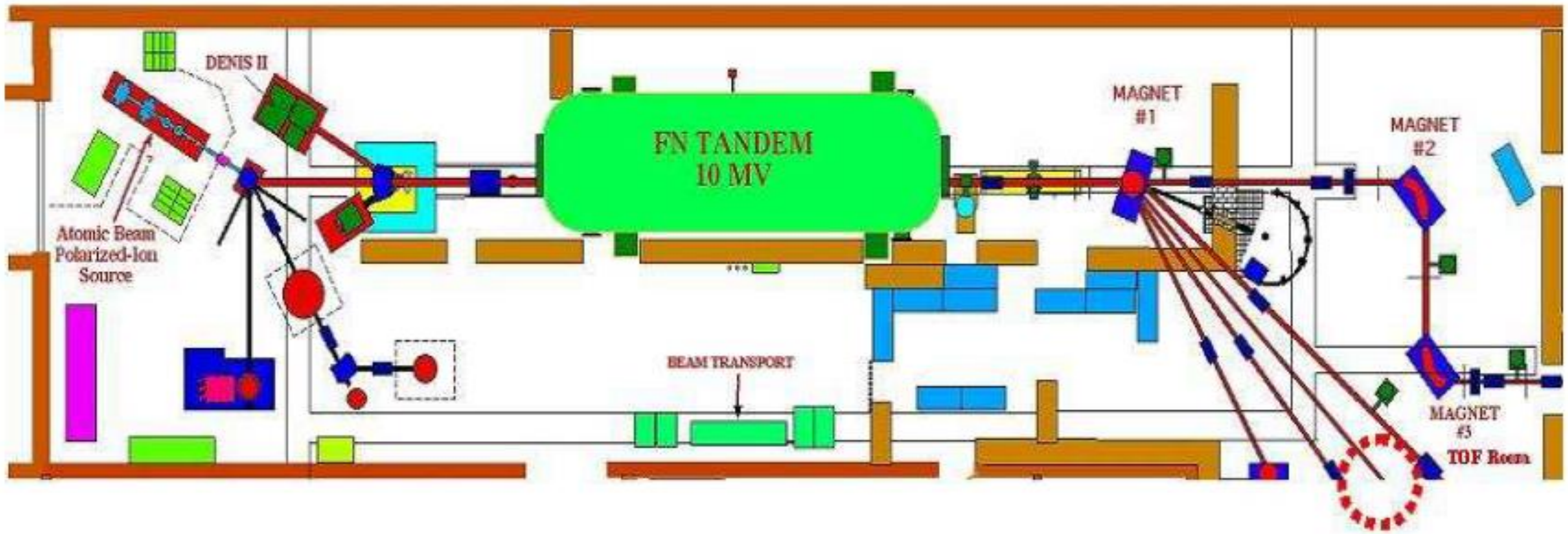
Polarized beams: p and d

Research examples:

1. Few-nucleon dynamics: ^{2}H(n,nnp)
2. 2-nucleon transfer reactions relevant to $0\nu\beta\beta$, e.g., A(^{3}He,n)
3. Neutron multiplication: A(n,2nγ)
4. Detector Characterization (ν scattering)
5. Nuclear astrophysics
6. Applications

Concentrate on neutron physics capabilities

Floor Plan of TUNL (Triangle Universities Nuclear Laboratory)



For neutron energies below E_n=0.6 MeV: $^7Li(p,n)^7Be$

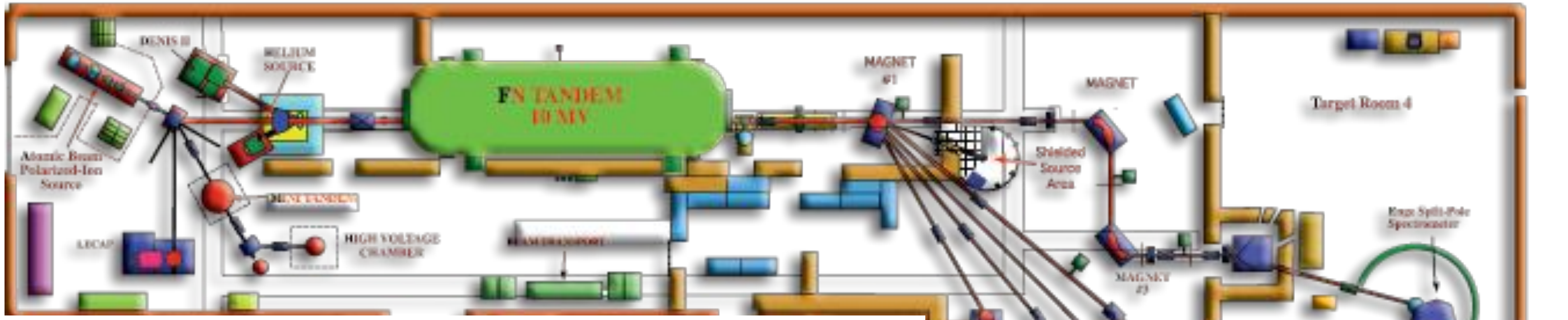
For neutron energies below E_n=4 MeV: $^3H(p,n)^3He$

For neutron energies above E_n=4 MeV: $^2H(d,n)^3He$

For neutron energies above E_n=14.5 MeV and below 35 MeV: $^3H(d,n)^4He$

DC or pulsed beam operation at 2.5 MHz (i.e., 400 ns between pulses) or factors of 2 in rep rate reduction

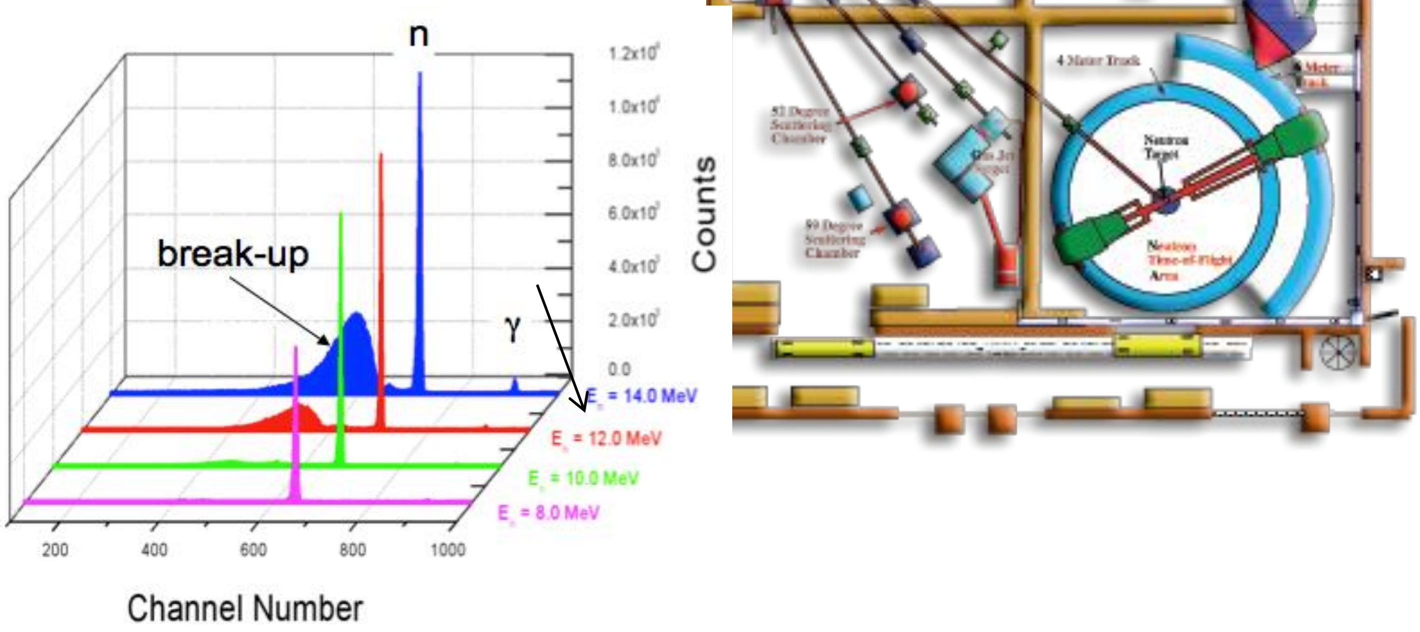
Ion Sources FN-Tandem 10 MV Shielded Neutron Source



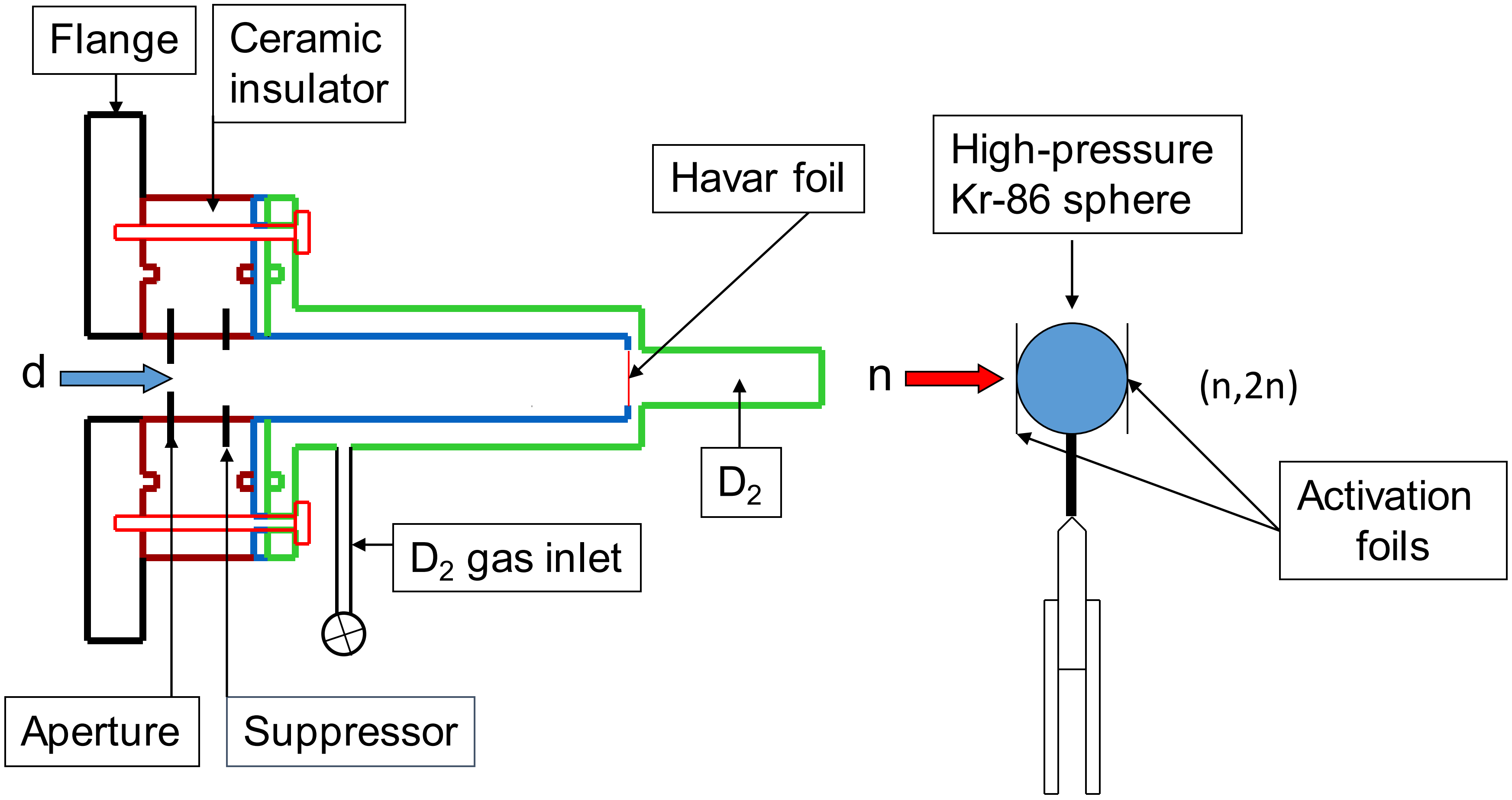
ENGE Spectrometer

NTOF Target Room

- **$^{2}H(d,n)^{3}He$ neutron source**
- I_d = (1-4) μA, pulsed up to 1 μA
- Deuterium gas pressure 1 - 8 atm
- Tunable energy from 4 to 20 MeV
- Flux on target $(10^7 - 10^8)$ cm^{-2} s^{-1}
- Energy spread dE/E = 0.02 to 0.15



$^{2}H(d,n)^{3}He$; Q-value = + 3.27 MeV



$^{238}U(n,2n)^{237}U$

Activation and TOF Measurements at TUNL with PT Source

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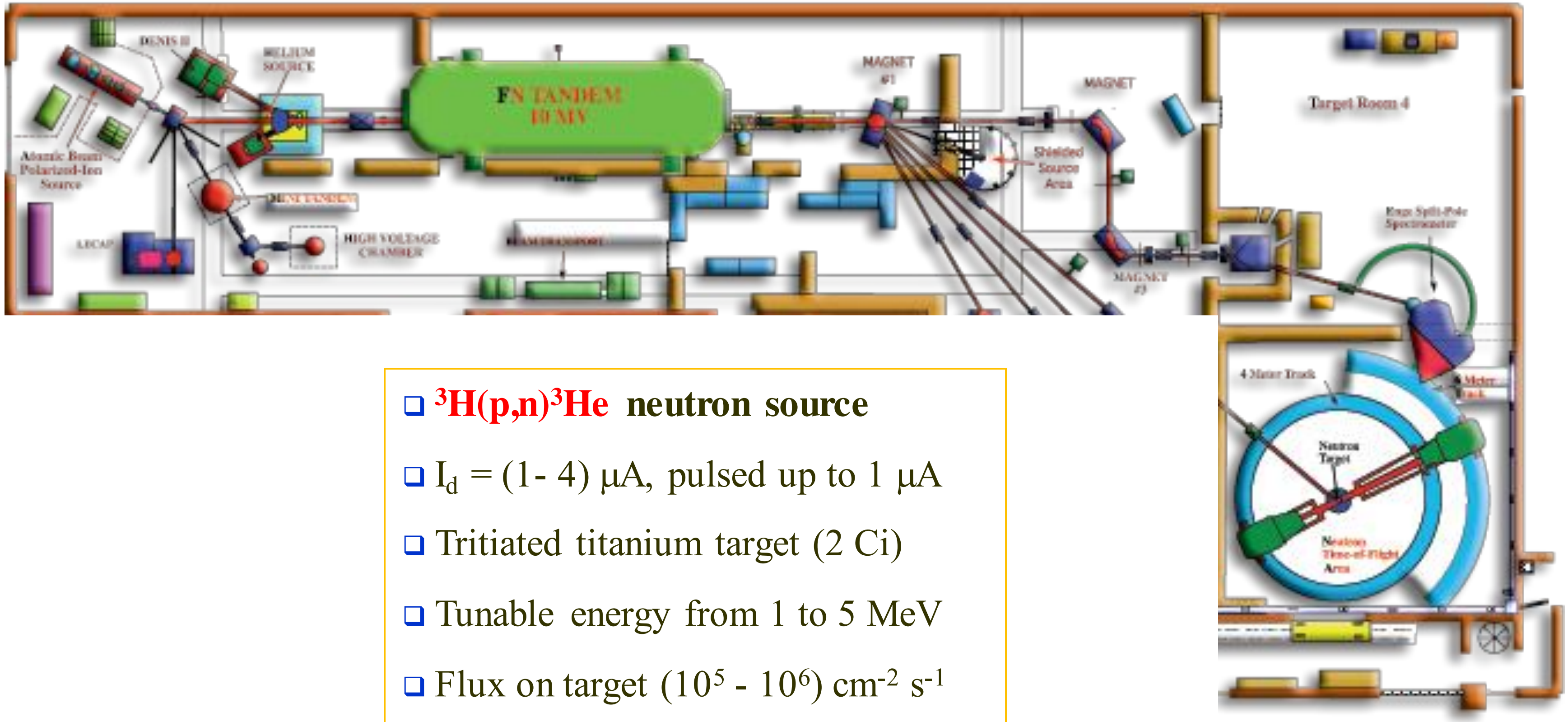
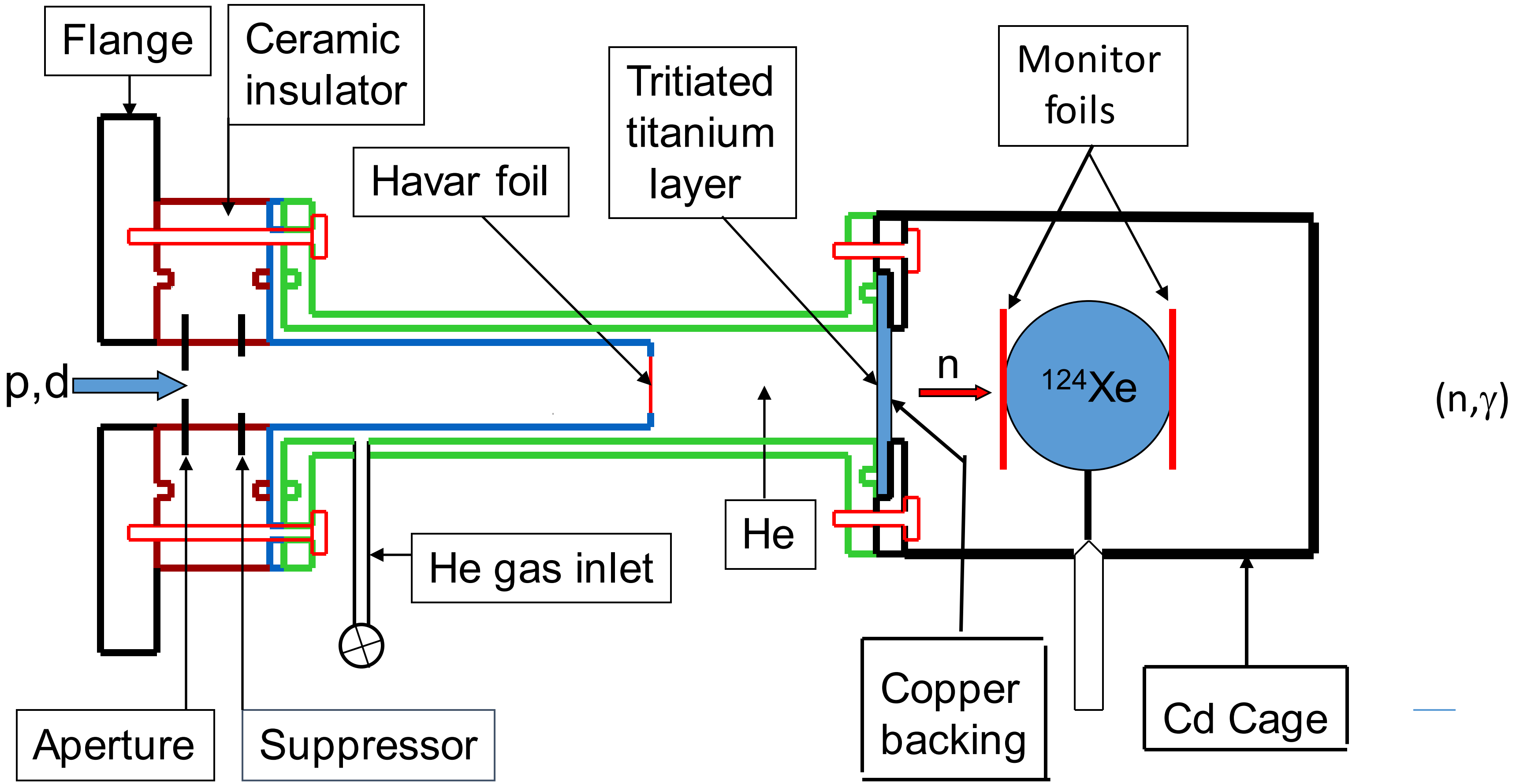


Enge Spectrometer

NTOF Target Room

- $^3H(p,n)^3He$ **neutron source**
- I_d = (1- 4) μA, pulsed up to 1 μA
- Tritiated titanium target (2 Ci)
- Tunable energy from 1 to 5 MeV
- Flux on target $(10^5 - 10^6)\ cm^{-2}\ s^{-1}$
- Energy spread dE/E = 0.02 to 0.10

$^3H(p,n)^3He$; Q-value = - 0.763 MeV



Flange
Ceramic insulator
Havar foil
Tritiated titanium layer
Monitor foils
p,d
n
^{124}Xe
(n,γ)
He
He gas inlet
Aperture
Suppressor
Copper backing
Cd Cage

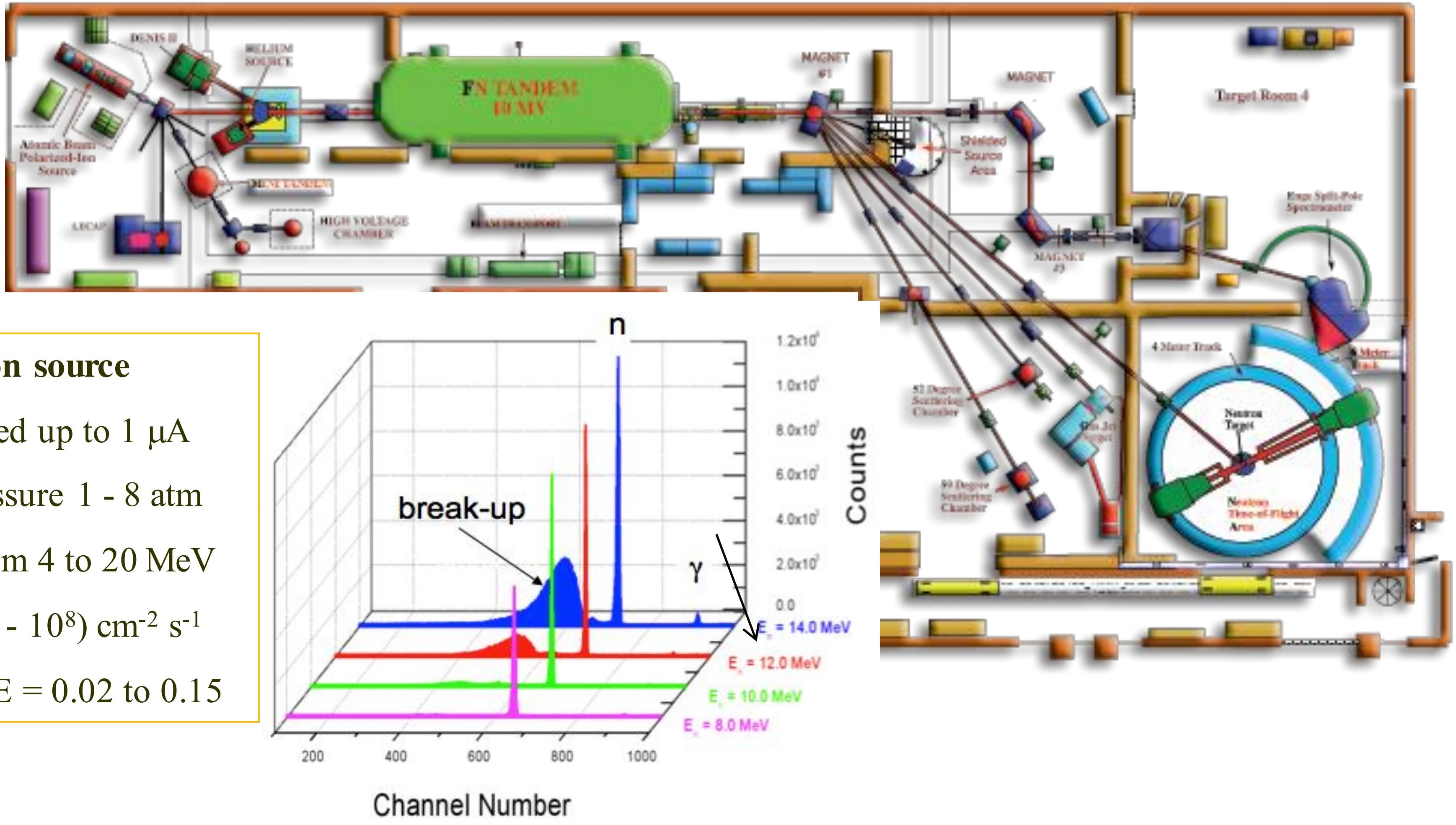
$^3H(d,n)^4He$

Q=17.589 MeV

10^8 n/(cm^{2}s) at 14.1 to 14.8 MeV

10^5 n/(cm^{2}s) at 30 MeV

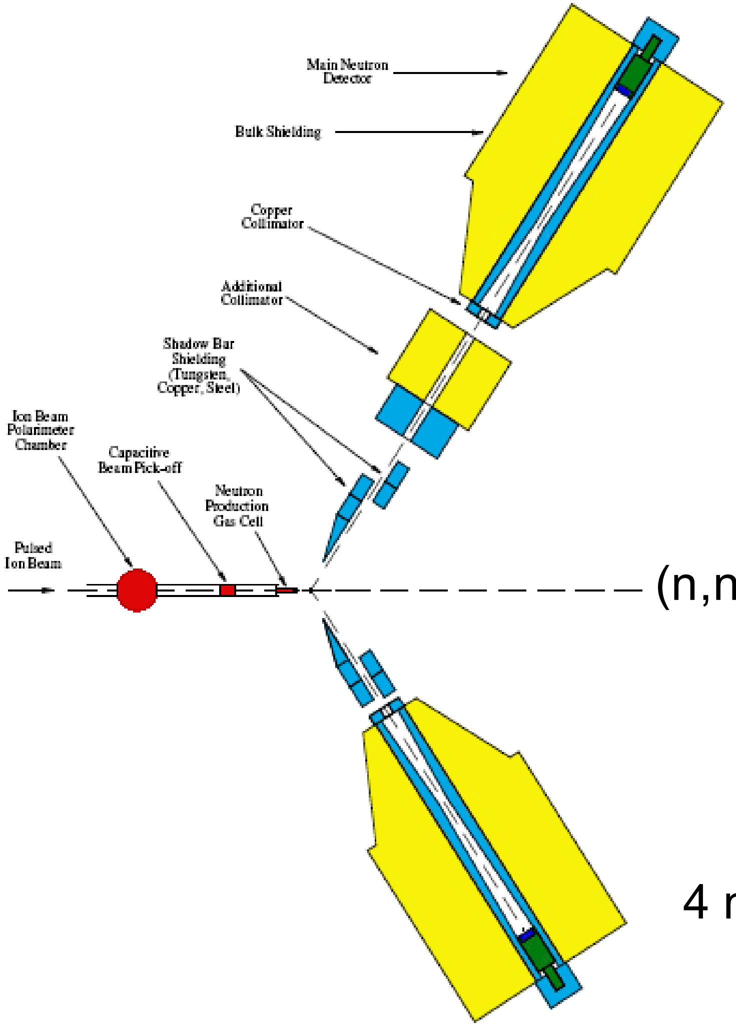
DC or pulsed beam operation at 2.5 MHz (i.e., 400 ns between pulses) or factors of 2 in rep rate reduction



- $^{2}H(d,n)^{3}He$ **neutron source**
- I_d = (1-4) μA, pulsed up to 1 μA
- Deuteriumgas pressure 1 - 8 atm
- Tunable energy from 4 to 20 MeV
- Flux on target (10^7 - 10^8) cm^{-2} s^{-1}
- Energy spread dE/E = 0.02 to 0.15

$^{2}H(d,n)^{3}He$; Q-value = + 3.27 MeV

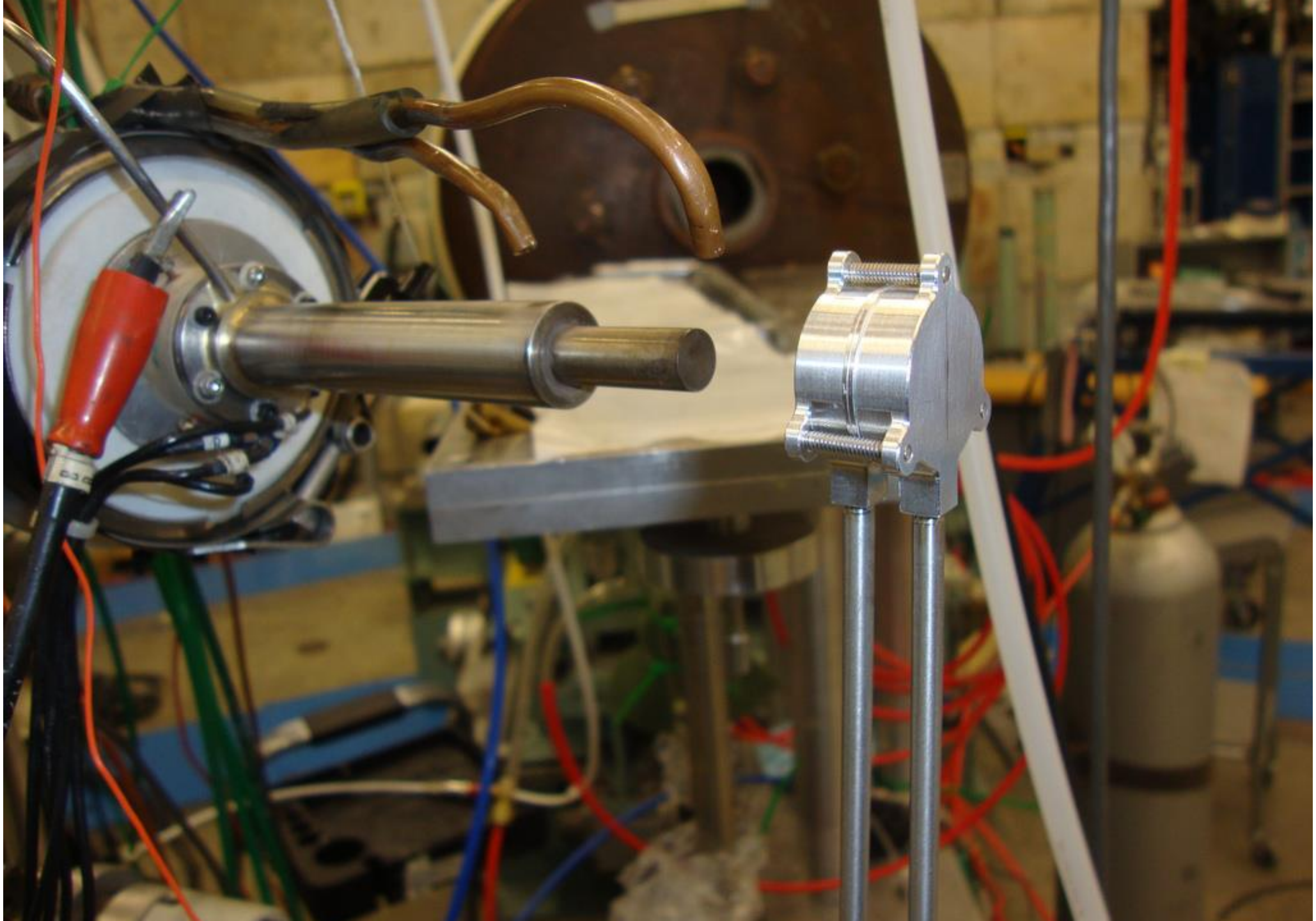
TUNL: 1 - 20 MeV mono-energetic neutrons



6 m detector

(n,n_0) and (n,n') $d\sigma/d\Omega(\theta)$

4 m detector



FPY
^{235}U
^{238}U
^{239}Pu

DC or pulsed beam operation at 2.5 MHz (i.e., 400 ns between pulses) or factors of 2 in rep rate reduction

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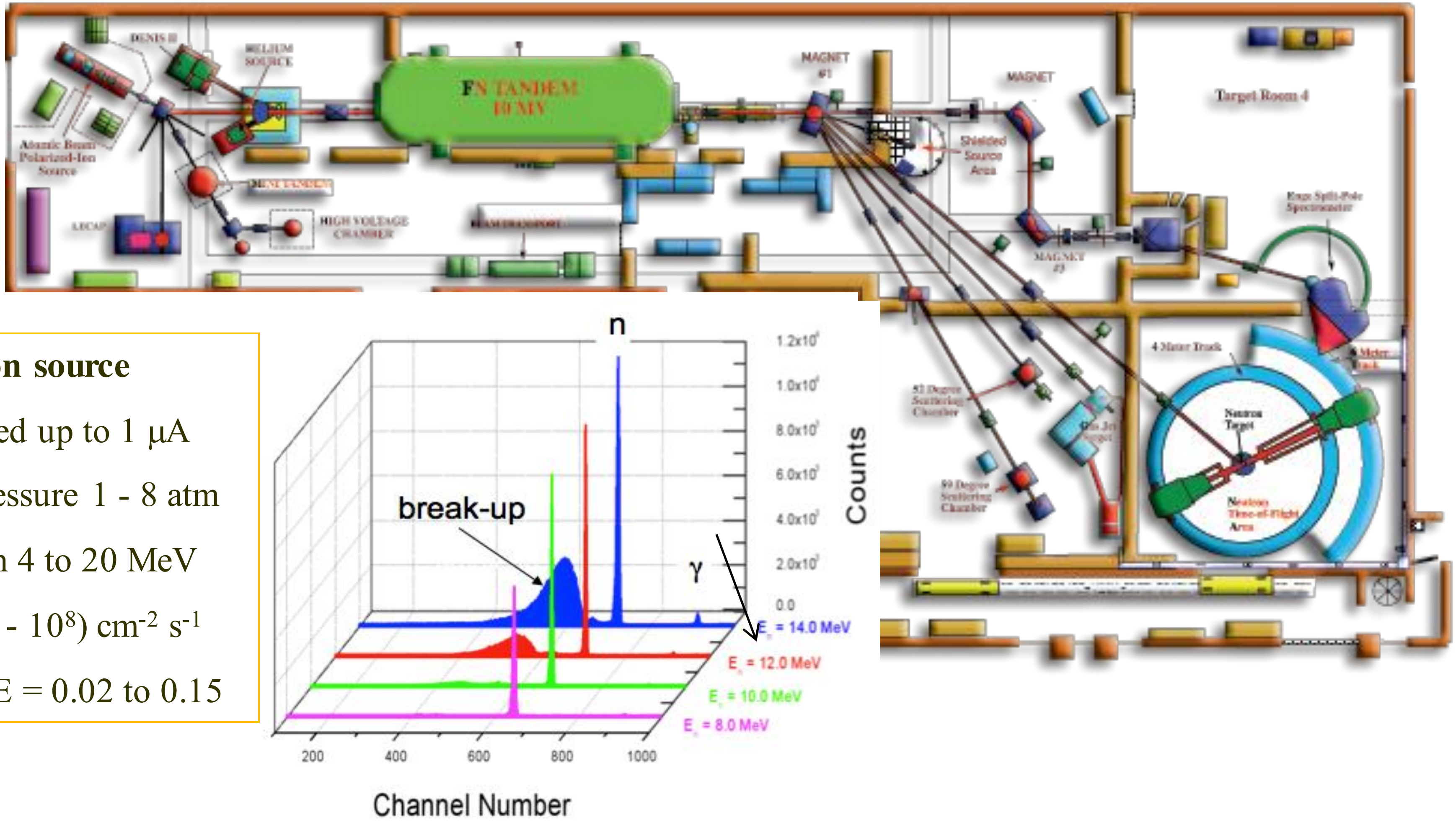

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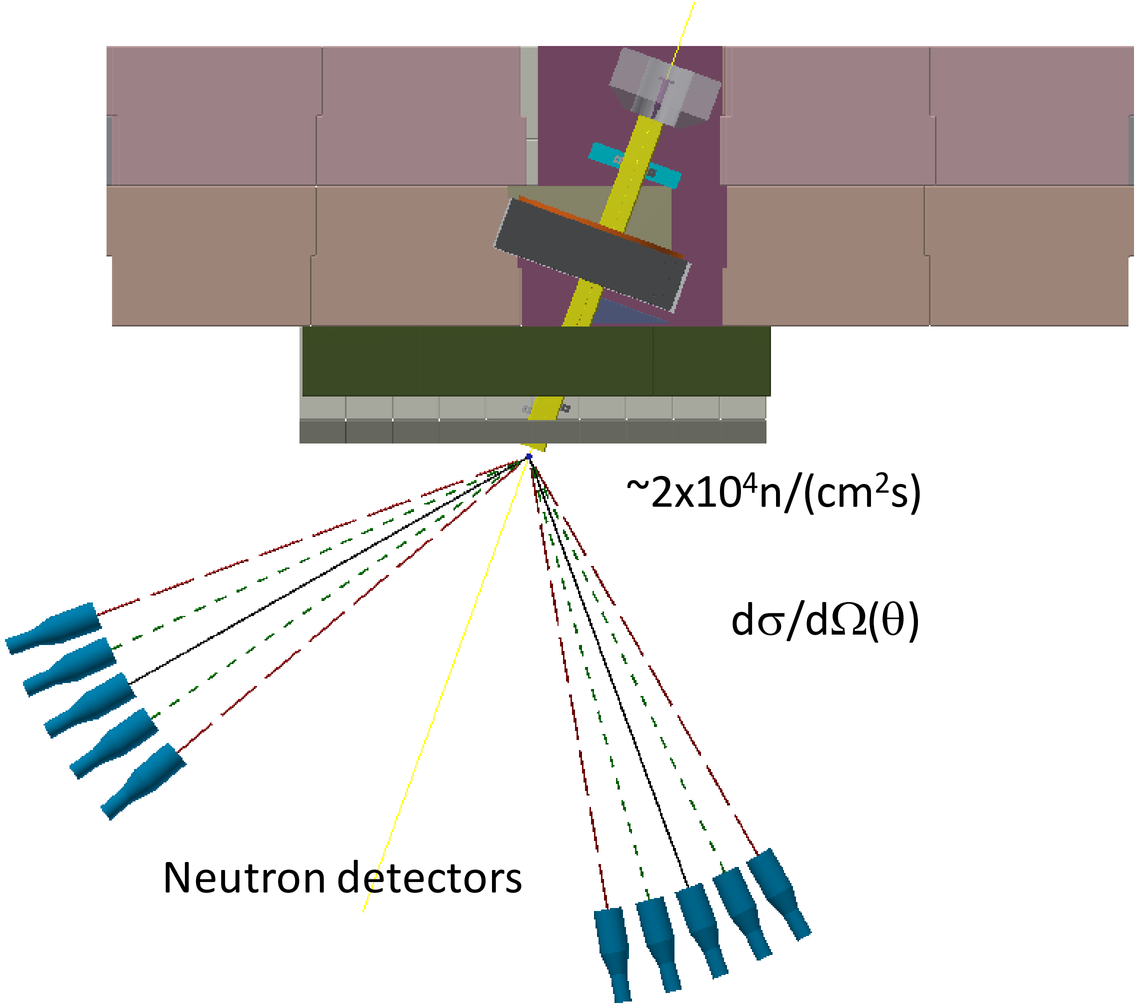
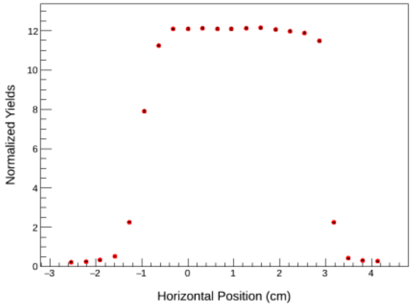
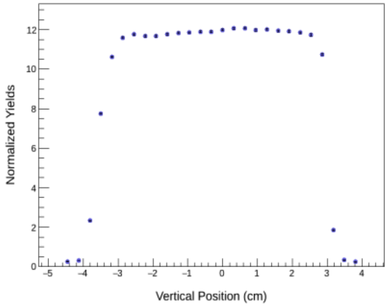
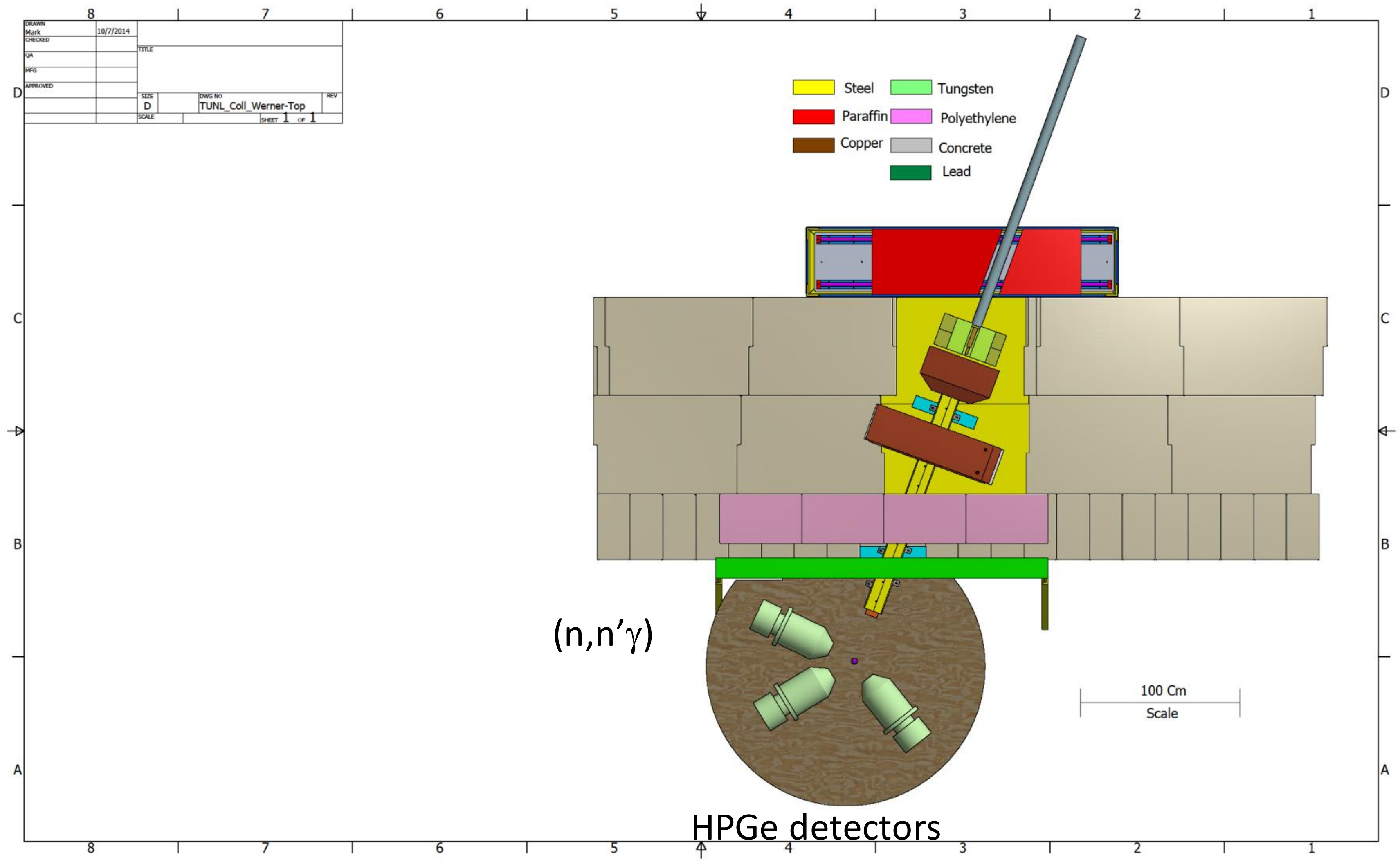
$^{2}H(d,n)^{3}He$; Q-value = + 3.27 MeV

Shielded Neutron Source: $^{2}H(d,n)^{3}He$









DRAWN
Mark
10/7/2014
CHECKED
QA
MFG
APPROVED
TITLE
SIZE
D
DWG NO
TUNL_Coll_Werner-Top
REV
SCALE
SHEET 1 OF 1
Steel
Tungsten
Paraffin
Polyethylene
Copper
Concrete
Lead
(n,n'γ)
100 Cm
Scale
HPGe detectors

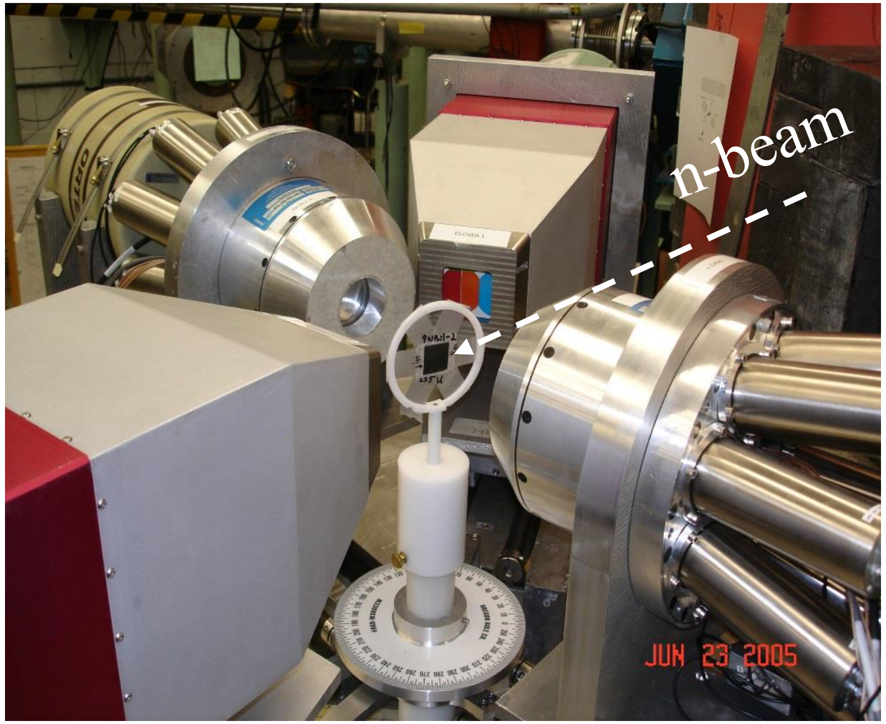
NNSA Setup at TUNL

- 4 Clovers + BGO
- 2 Planars + BGO
- 10 keV < E_γ < 10 MeV
- $20^0 < \theta_{lab} < 160^0$
- $\varepsilon_{array} = 1.4\%@E_\gamma = 1.33$ MeV

Total cost of $1M

Capabilities

- γ-γ coincidence measurements
- Angular distribution measurements
- Lifetimes (by Doppler method)



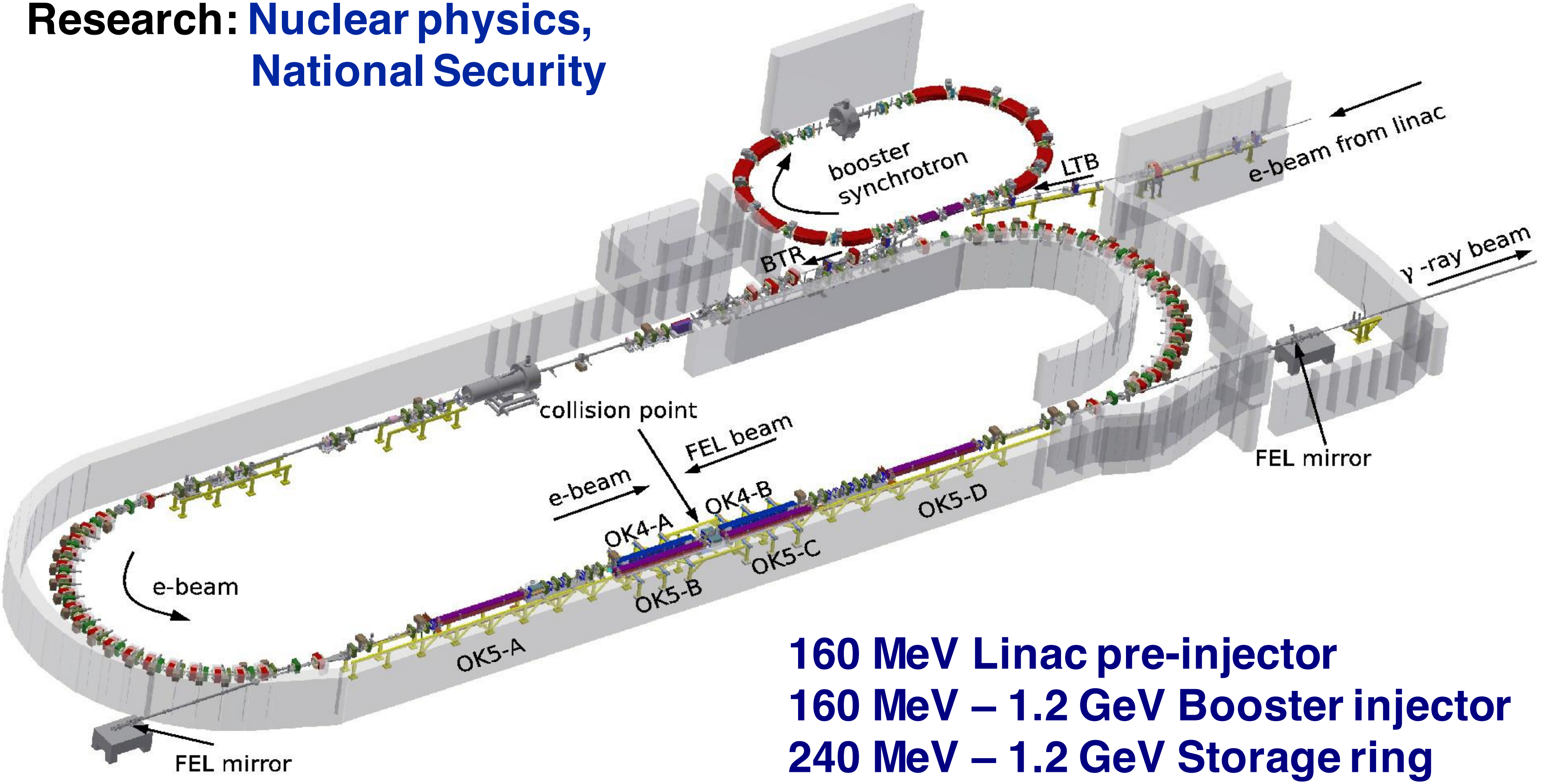
⇒ Excellent tool for precision neutron induced cross section measurements in the fast neutron energy region ($4 \le E_n \le 18$ MeV)

HIγS

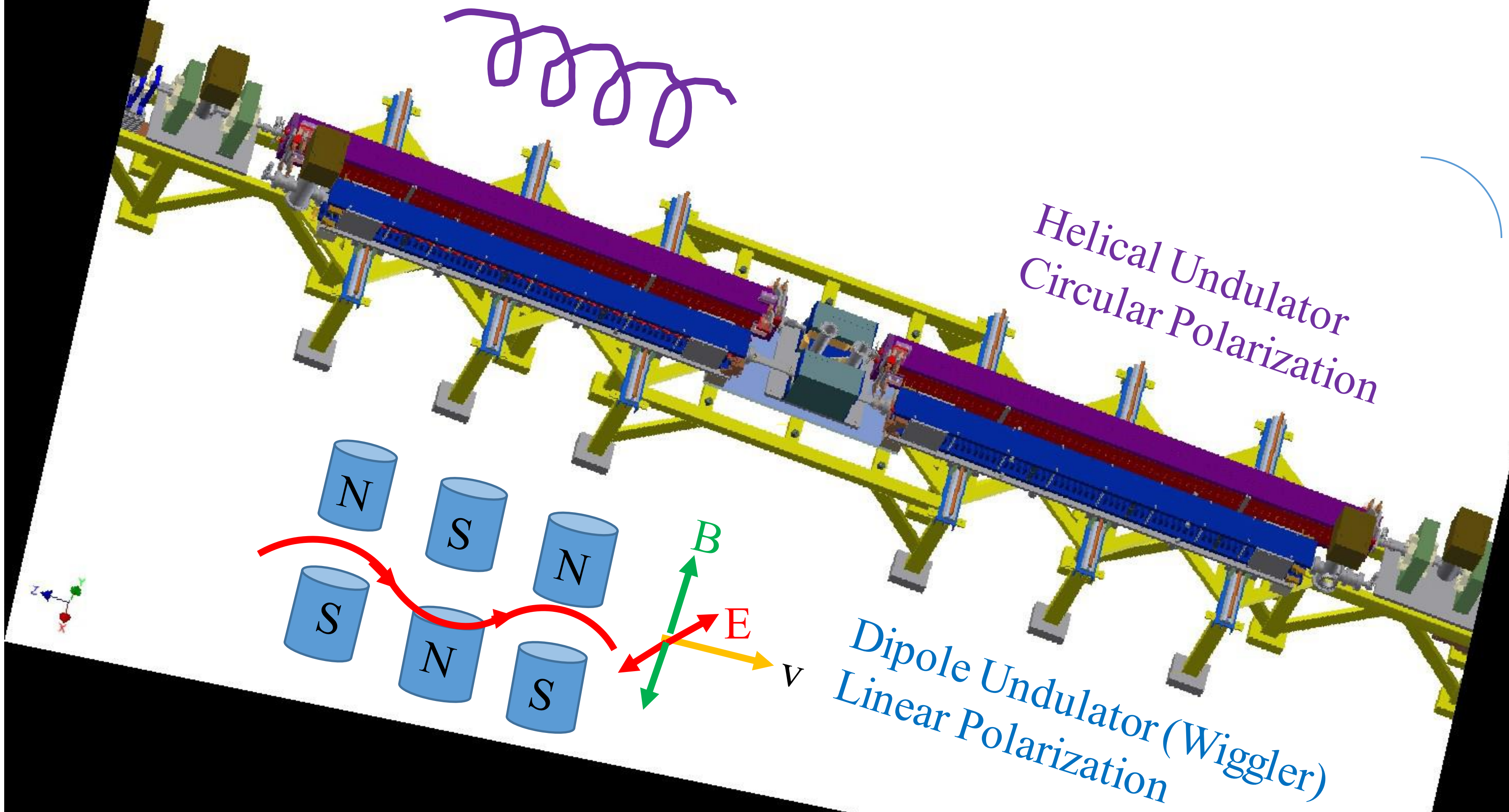
High-Intensity γ-ray Source

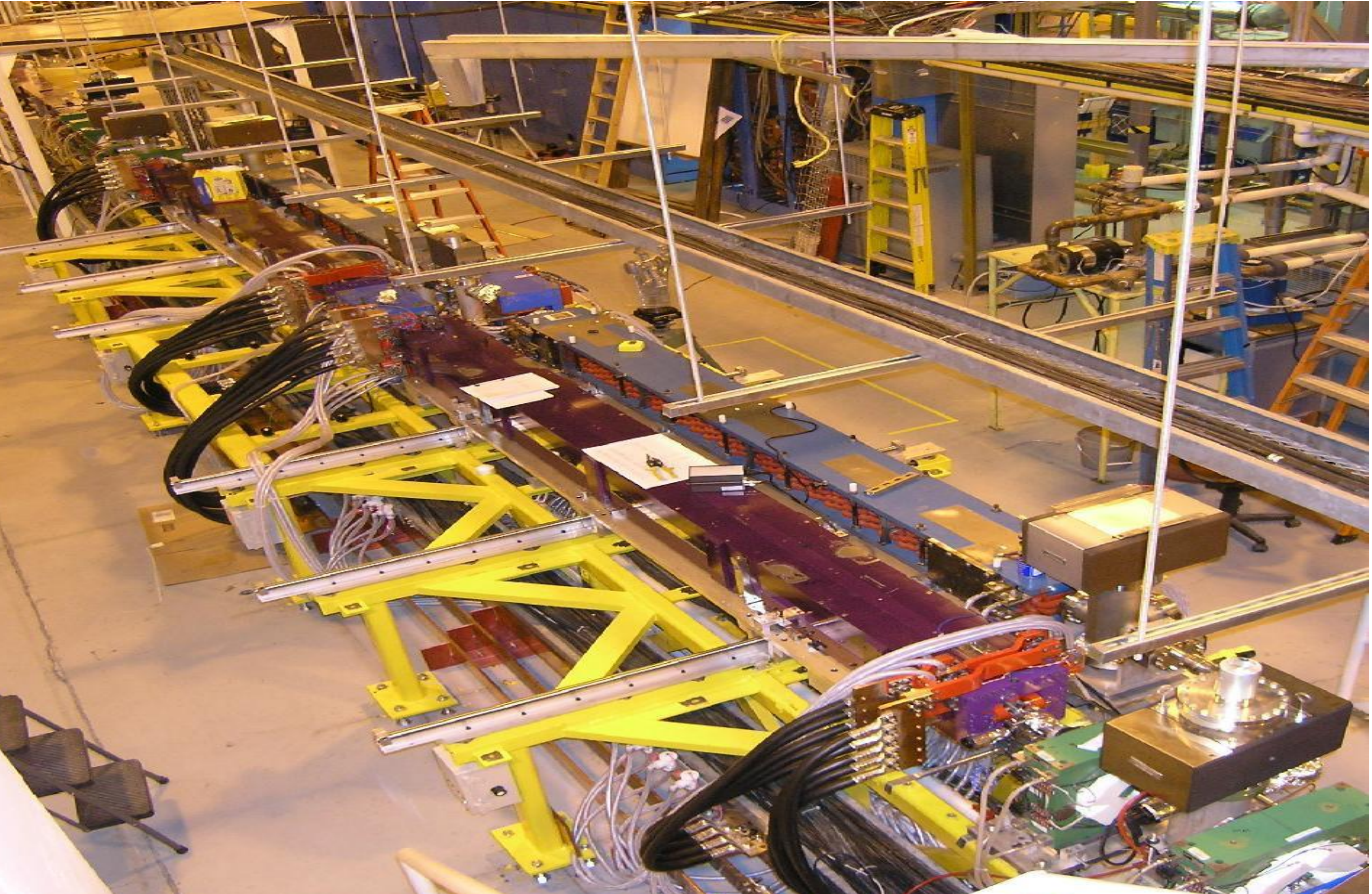
HIγS (High-Intensity Gamma-ray Source): An electron-photon collider

Energy (MeV): 1 – 100 MeV
Laser: FEL, 1060 – 190 nm (1.17 – 6.53 eV)
Total flux: 10^7 – $3x10^{10}$g/s (max ~10 MeV)
Spectral flux: 10^3g/s/eV (max ~10 MeV)
Research: Nuclear physics,
National Security



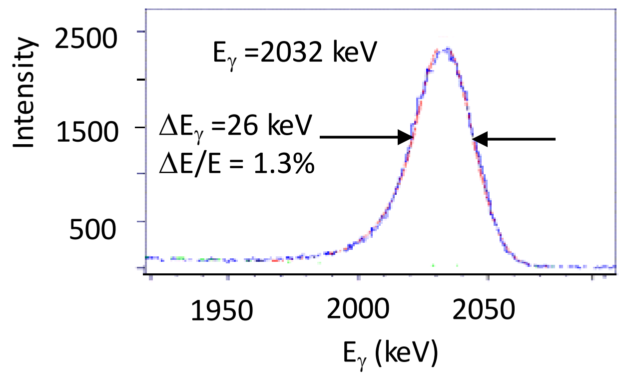
160 MeV Linac pre-injector
160 MeV – 1.2 GeV Booster injector
240 MeV – 1.2 GeV Storage ring
FELs: OK-4 (lin), OK-5 (circ)
HIγS: two-bunch, 40 – 120 mA (typ)

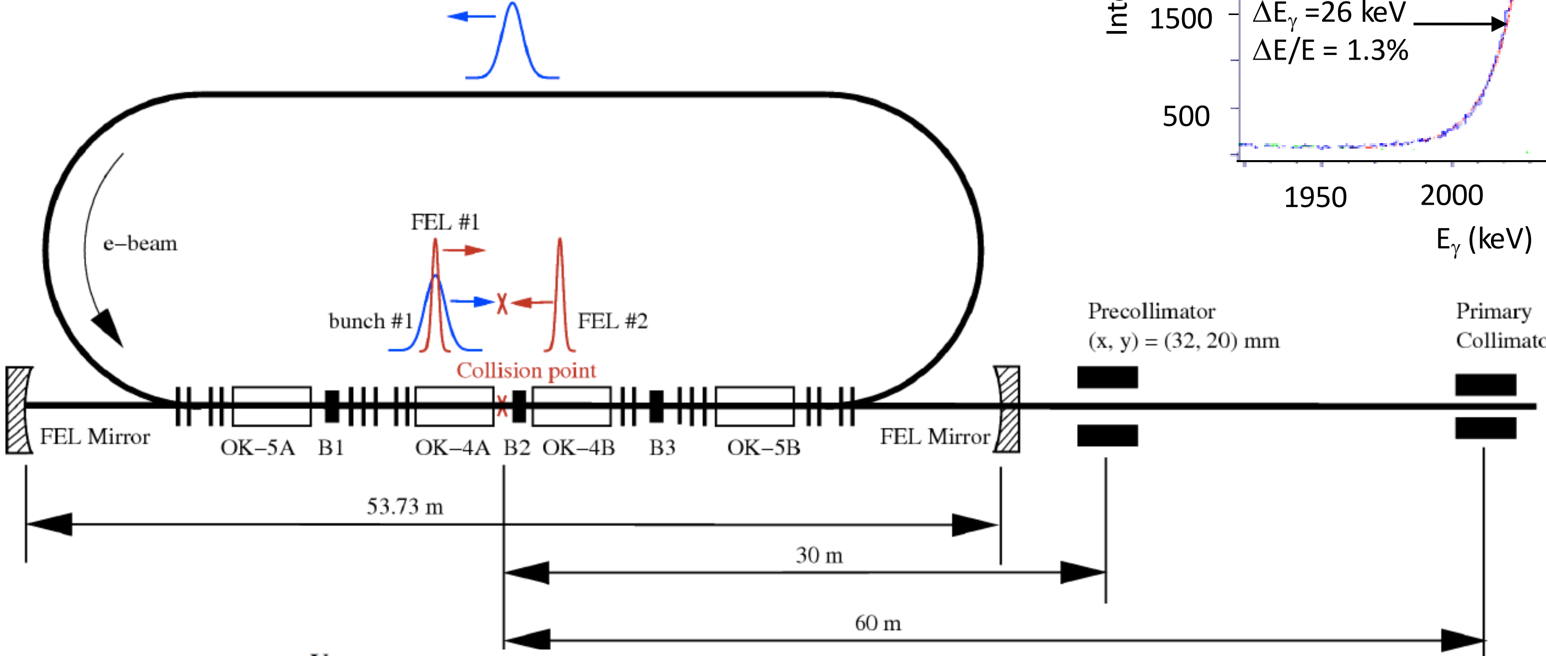

Helical Undulator
Circular Polarization
N
S
N
S
N
S
B
E
v
Dipole Undulator (Wiggler)
Linear Polarization



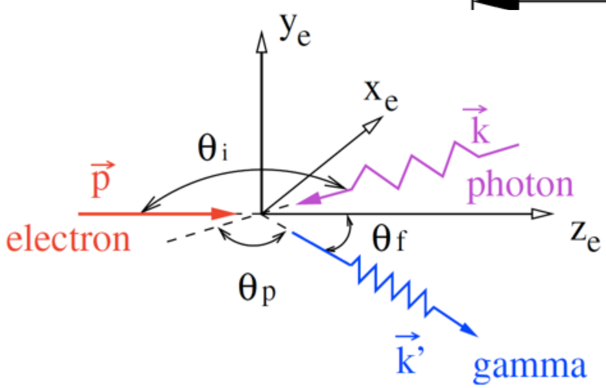
How to produce γ rays?

HIγS: Intracavity Compton-Back Scattering





¾” dia.
ΔE/E~3%



$$E_\gamma \equiv \hbar\omega' = \frac{\hbar\omega(1-\beta\cos\theta_i)}{1-\beta\cos\theta_f+\frac{\hbar\omega}{\varepsilon_e}(1-\cos\theta_{ph})}$$

Head-on collision: $E_\gamma \approx 4\gamma^2\hbar\omega$

Example: E_e = 500 MeV ➔ $\gamma = 978$

λ_{FEL} = 400 nm

$\hbar\omega$ = 3.11 eV

E_γ = 11.9 MeV

Vladimir Litvinenko

Why do we have a booster synchrotron?

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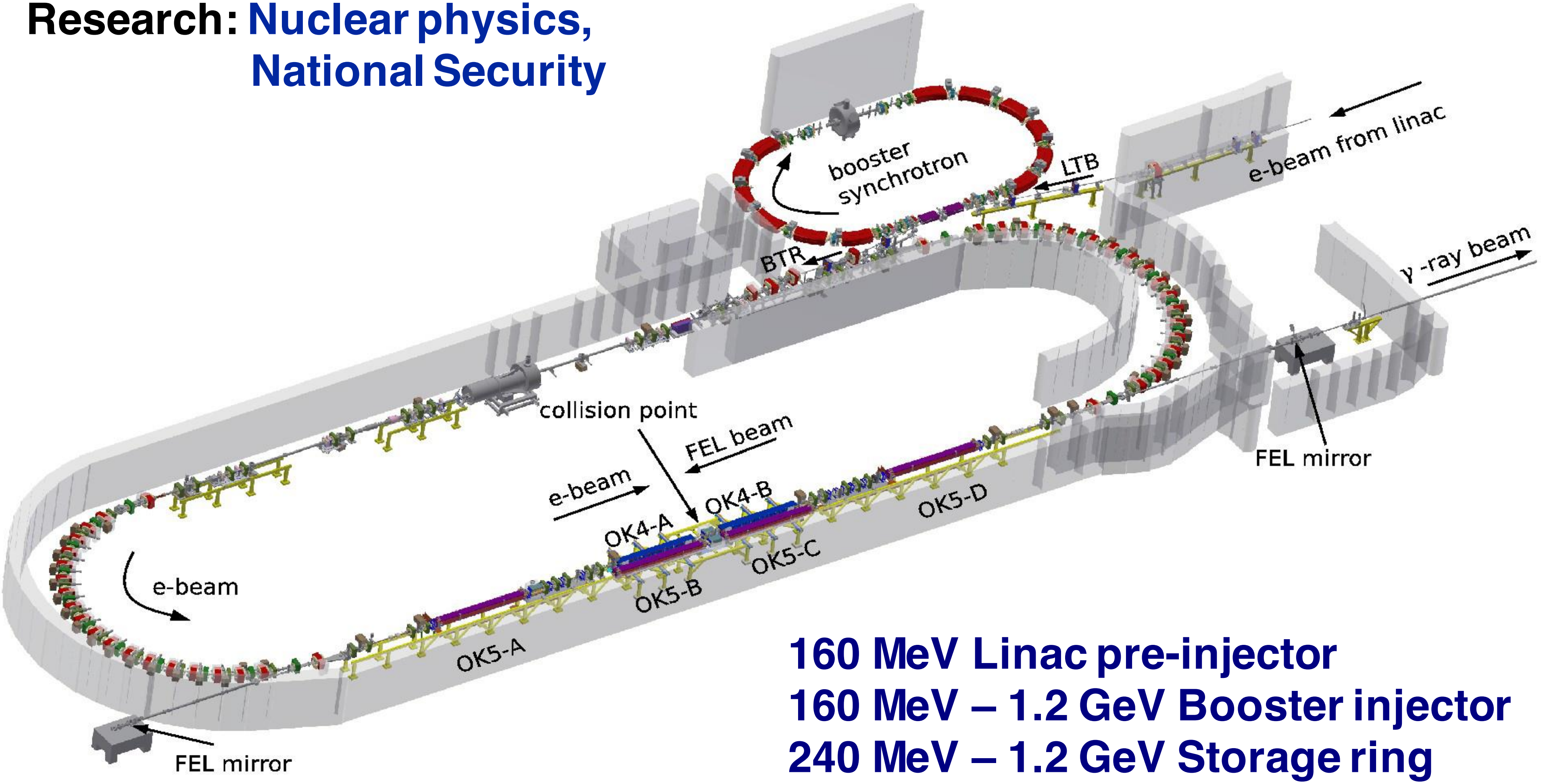

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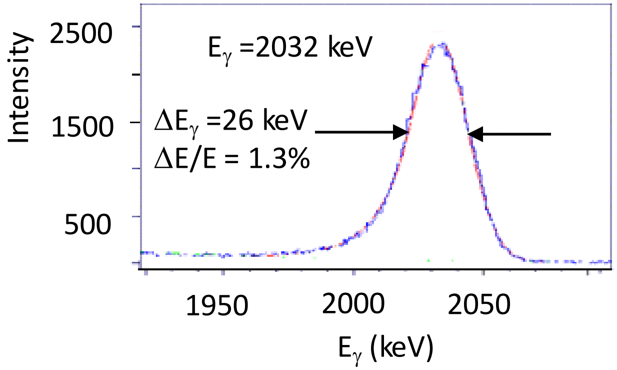
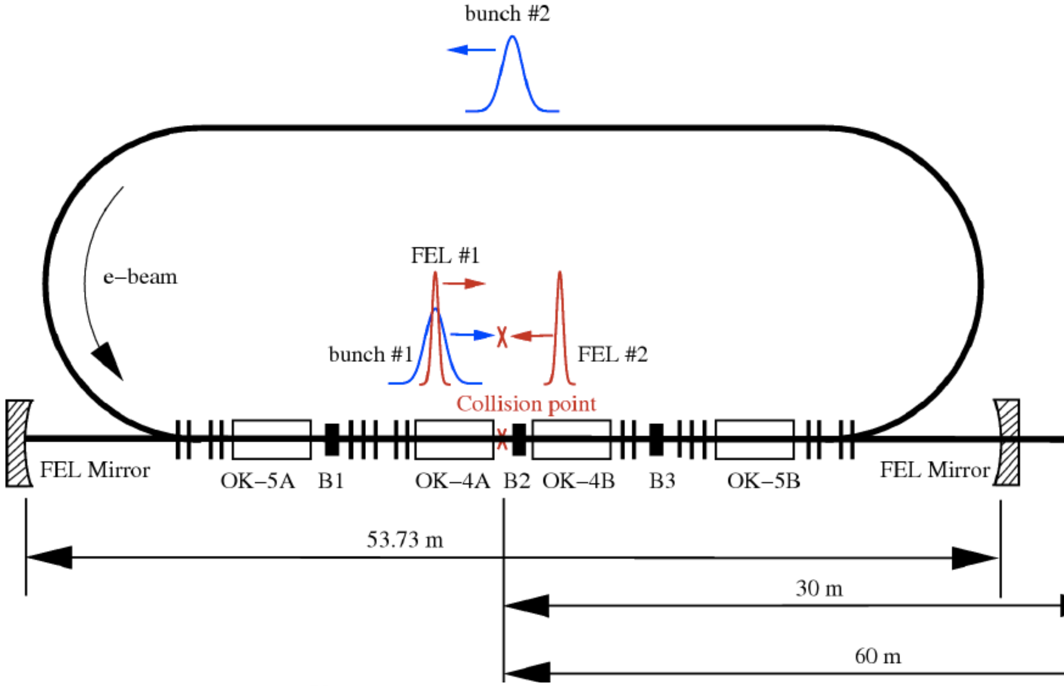
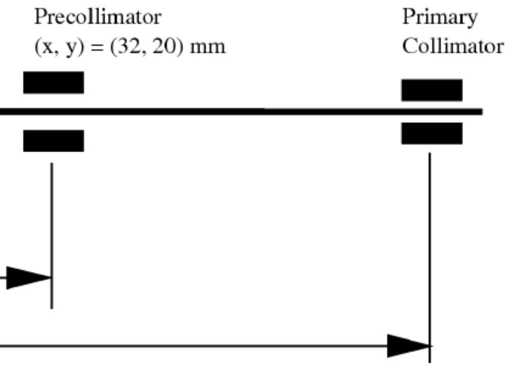
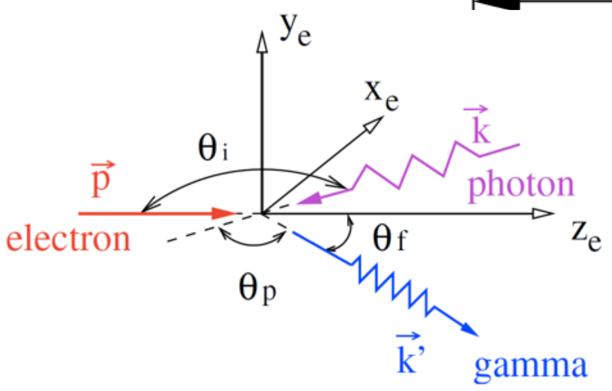
HIγS: two-bunch, 40 – 120 mA (typ)

How do we select our γ-ray energy spread?

HIγS: Intracavity Compton-Back Scattering





Vladimir Litvinenko

$$E_\gamma \equiv \hbar\omega' = \frac{\hbar\omega(1-\beta\cos\theta_i)}{1-\beta\cos\theta_f + \frac{\hbar\omega}{g_e}(1-\cos\theta_{ph})}$$

Head-on collision: $E_\gamma \approx 4\gamma^2\hbar\omega$

Example: E_e = 500 MeV ➔ γ = 978

λ_{FEL} = 400 nm

ħω = 3.11 eV

E_γ = 11.9 MeV

Rep. rate 5.58 Mz: pulse every ~180 ns

How do we change the γ-ray energy?

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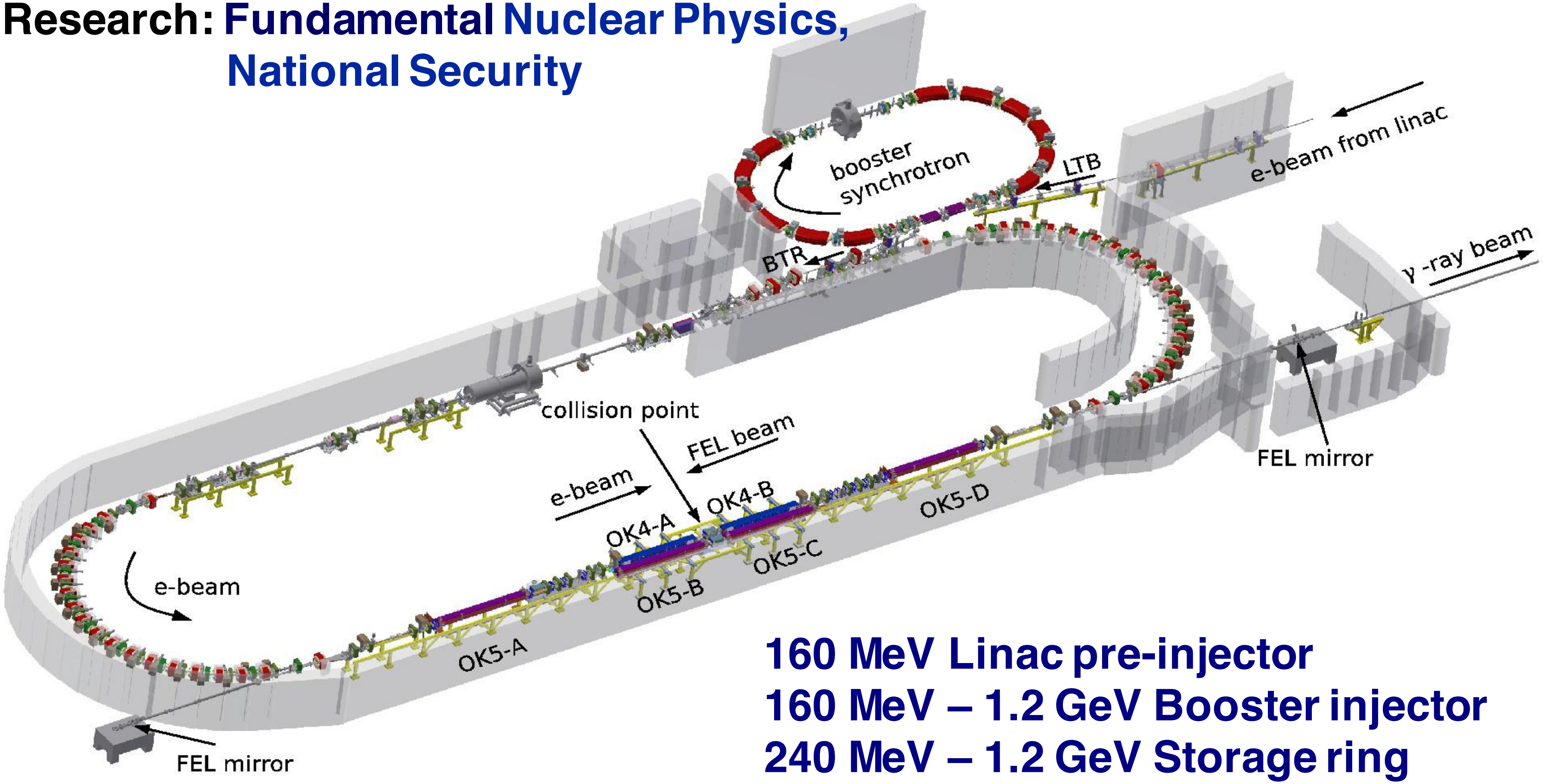
Total flux: $10^7 - 3\times10^{10}\,\gamma$/s (max ~10 MeV)
Spectral flux: $10^3\,\gamma$/s/eV (max ~10 MeV)
Research: Fundamental Nuclear Physics, National Security



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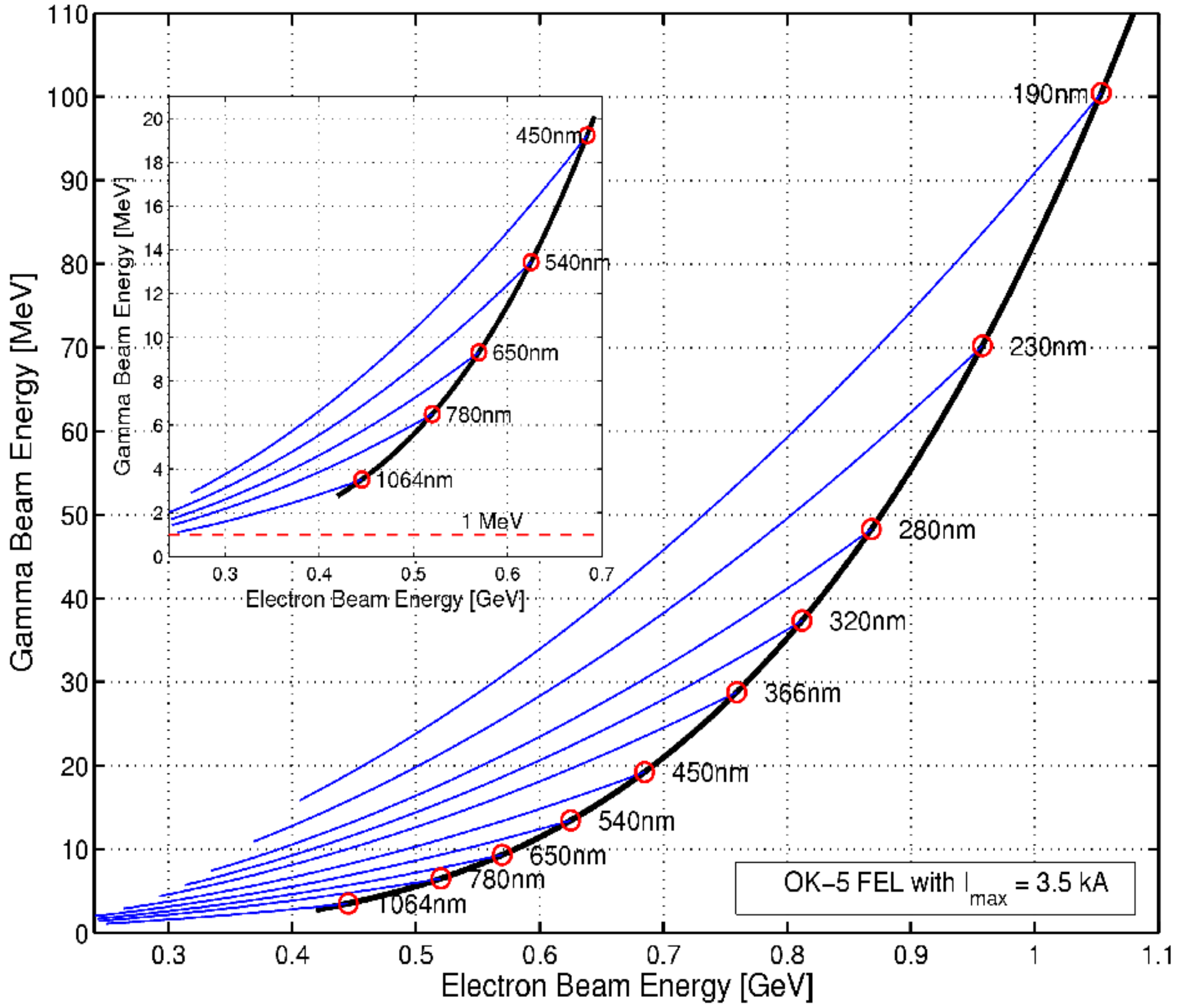
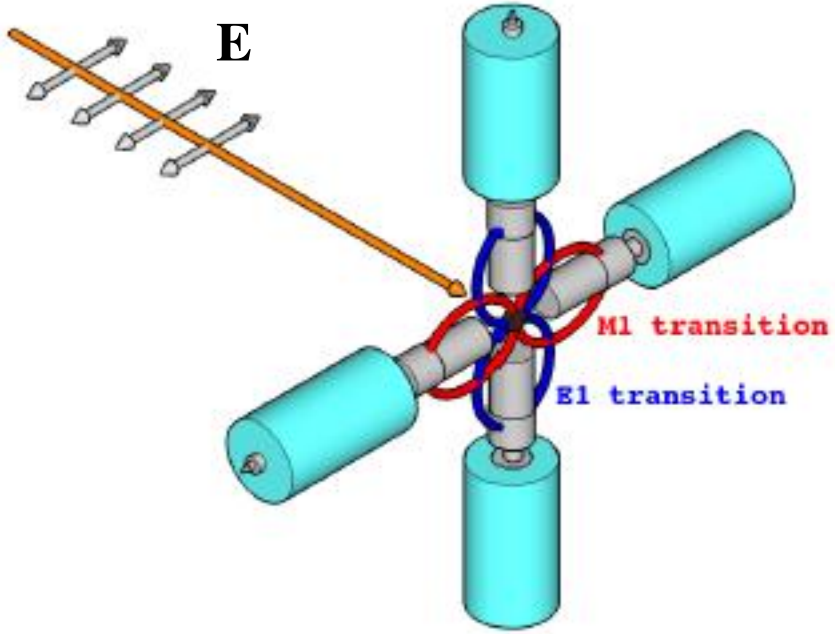
Gamma-ray Energy Tuning Range at HIγS

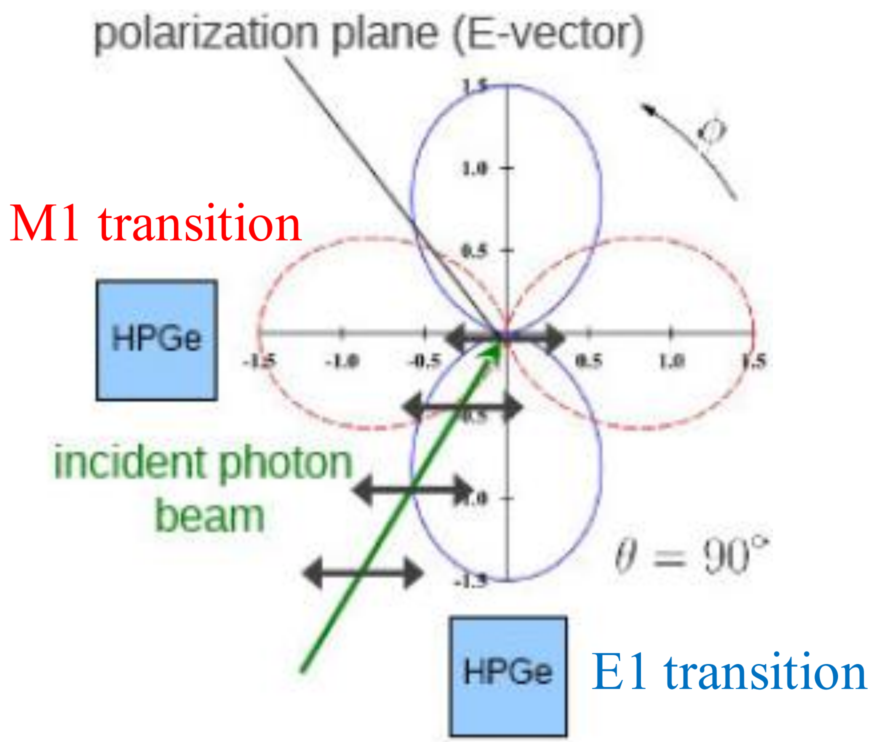


Nuclear Resonance Fluorescence (NRF)

(γ,γ) & (γ,γ')

mono-energetic,
polarized and
pencil-like beam



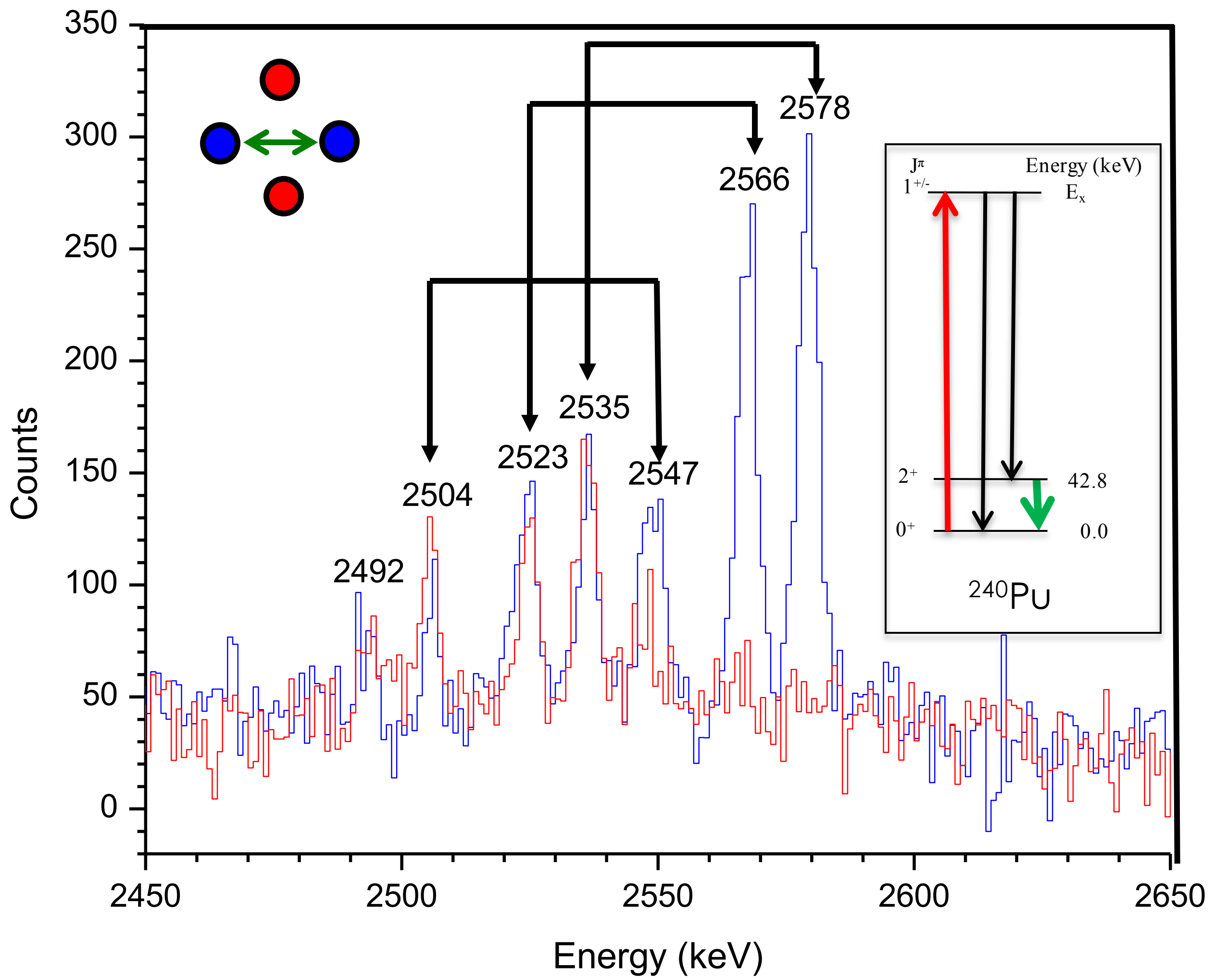


Asymmetry: $$\varepsilon = \frac{N_{\parallel} - N_{\perp}}{N_{\parallel} + N_{\perp}}$$

ε=–1 E1 transition

ε=+1 M1 transition

^{240}Pu: Determination of spin and parity



Nuclear Forensics

(γ,γ')

(γ,n)

(γ,f)

NNSA

DNDO

COSTS

Tandem: $ 200-250 per hour

HIγS: $ 950 per hour

PAC

Backup


CANBERRA

Tandem: Enge split-pole spectrometer

Hale, S. et al., PRC65 (2002) 015801
Bertone, P. et al., PRC66 (2002) 055804

Hansper, V. Y., et al., PRC61 (2000) 028801

- Only spectrometer for nuclear astrophysics experiments in North America
- Perform particle transfer and charge-exchange reactions
- Requires recommissioning
  - New DAQ
  - Upgrade control system
  - Repair vacuum system