nEDM@SNS@STS

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Many slides provided by L. Broussard and J. Ramsey

nEDM@SNS

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SNS nEDM experiment key features

Golub and Lamoreaux, Phys. Rep. 237, 1 (1994)

- Experiment performed in superfluid LHe
- In situ production of UCN from 8.9 Å cold neutron beam via superthermal process
- Higher electric field expected to be achievable in LHe
- Longer UCN storage time expected at cryogenic temperatures
- ^{3}He as comagnetometer and spin analyzer for UCN
- Two complementary approaches to look for the nEDM signal ($\boldsymbol{d} \cdot \boldsymbol{E}$)
  - Free precession method
  - Dressed spin method

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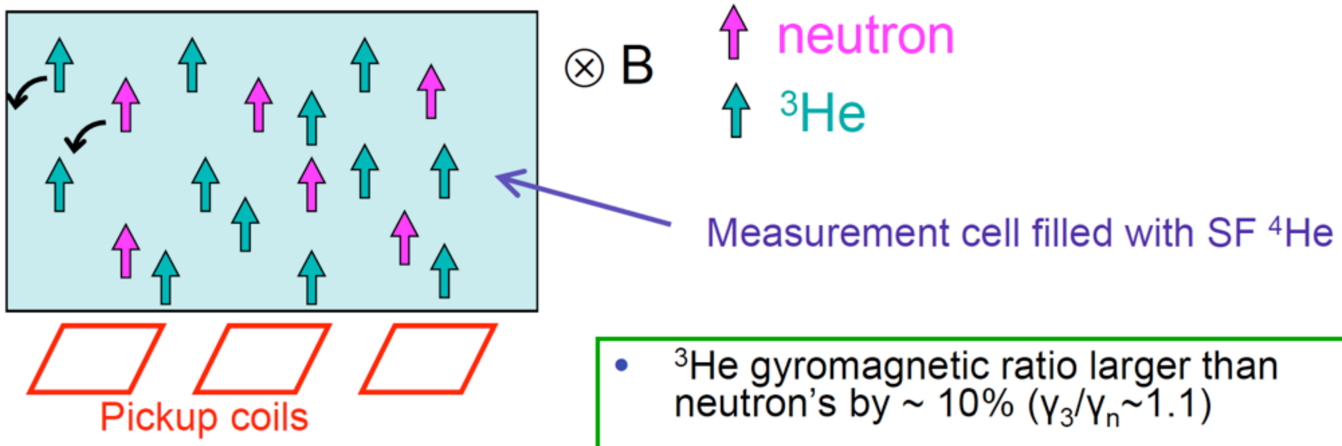
Free precession method

A dilute admixture of polarized ^3He atoms is introduced to the bath of SF ^4He ($x = N_3/N_4 \sim 10^{-10}$ or $\rho_{3He} \sim 10^{12}$/cc)



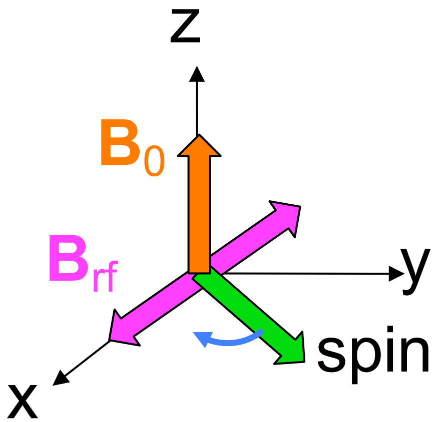
Change in magnetic field due to the rotating magnetization of ^3He detected by SQUID magnetometers

- ^3He gyromagnetic ratio larger than neutron's by ~ 10% ($\gamma_3/\gamma_n \sim 1.1$)
- Neutron absorption on ^3He highly spin dependent ($\sigma_{\uparrow\downarrow} >> \sigma_{\uparrow\uparrow}$)
- Reaction product of $n + {}^3He \rightarrow p + t$ generates UV (~80 nm) scintillation light in SF ^4He

Scintillation light from n-^3He capture reaction provides a measurement of $\omega_3 - \omega_n$

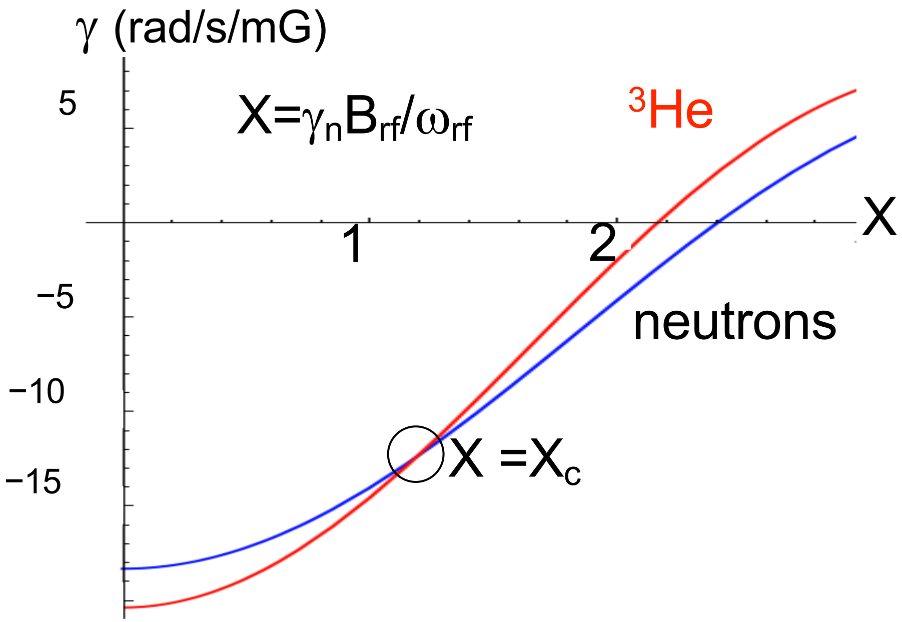
Signature of EDM appears as a shift in $\omega_3 - \omega_n$ corresponding to the reversal of ***E*** with respect to ***B*** with no change in ω_3

Dressed spin method



A strong non-resonant RF field

$$\mathbf{B}_{rf} \perp \mathbf{B}_0,\ B_{rf} >> B_0,\ \omega_{rf} >> \omega_0$$

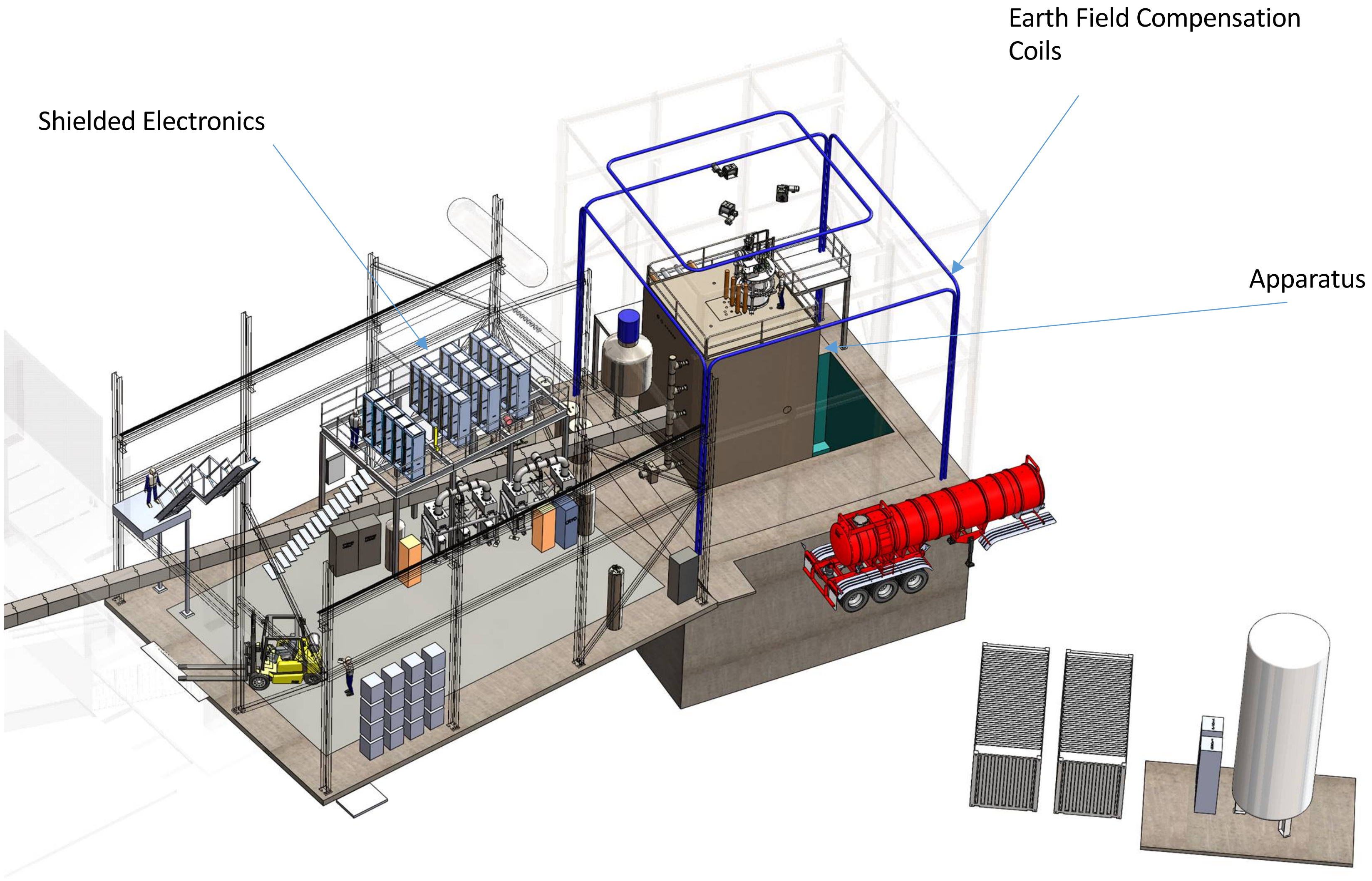


- By applying a strong non-resonant RF field, the gyromagnetic ratio can be modified or "dressed"

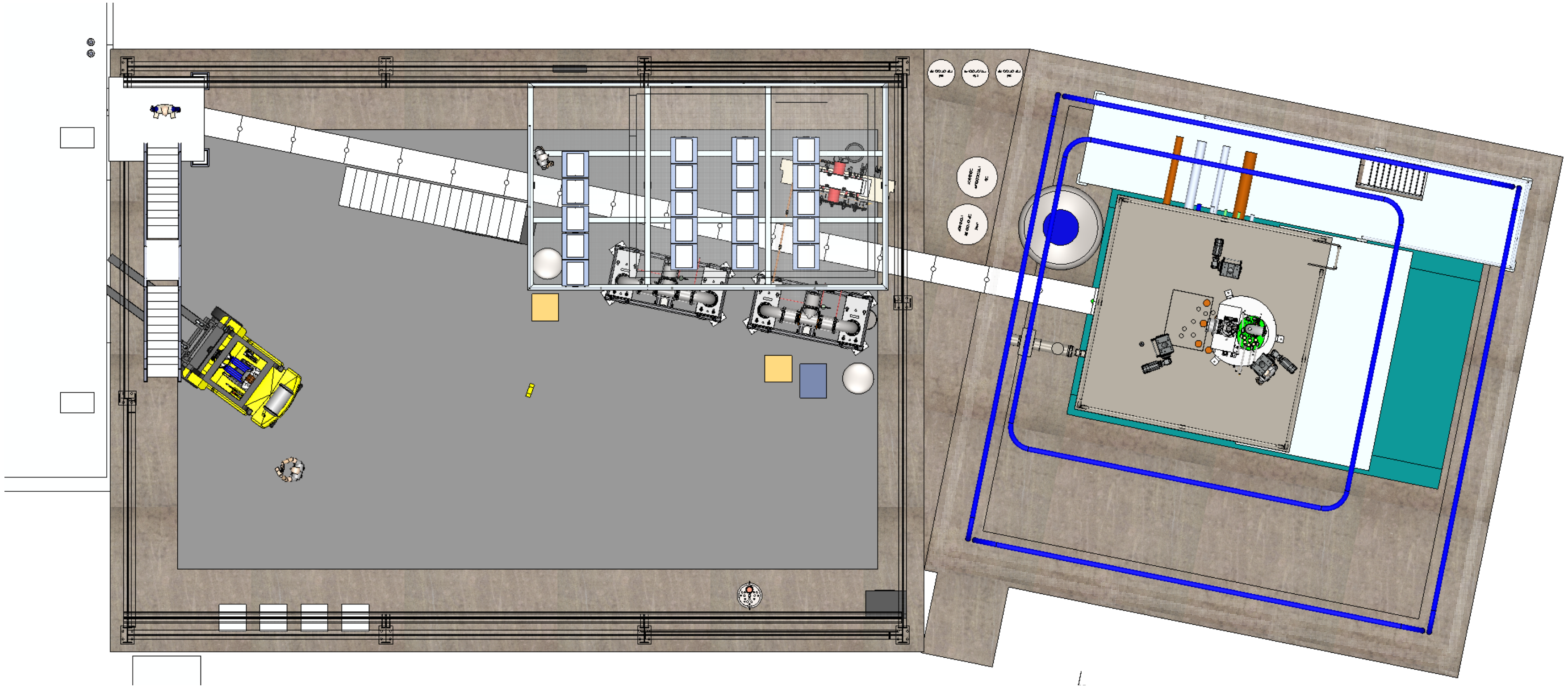
$$\gamma' = \gamma J_0\left(\gamma B_{rf}/\omega_{rf}\right) = \gamma J_0(X)$$

- Can tune the dressing parameter ($X = \gamma_n B_{rf}/\omega_{rf}$) until the relative precession between 3He and neutrons is zero ($X = X_c$).
- Look for X_c dependence on E field
- Provides access to EDM that is independent of variations of the ambient B-field

SNS nEDM at FTS



nEDM facility plan view



Sensitivity reach at FTS

- Free Precession Measurement (SQUIDs)
  - Sensitivity: 3.1 x 10^{-28} e-cm
  - 90% CL : 5.1 x 10^{-28} e-cm

  300 live-days ~ 3 yrs

- Dressed Spin Measurement (AC Field)
  - Sensitivity: 2.1 x 10^{-28} e-cm
  - 90% CL : 3.4 x 10^{-28} e-cm

  300 live-days ~ 3 yrs

SNS nEDM@FTS schedule

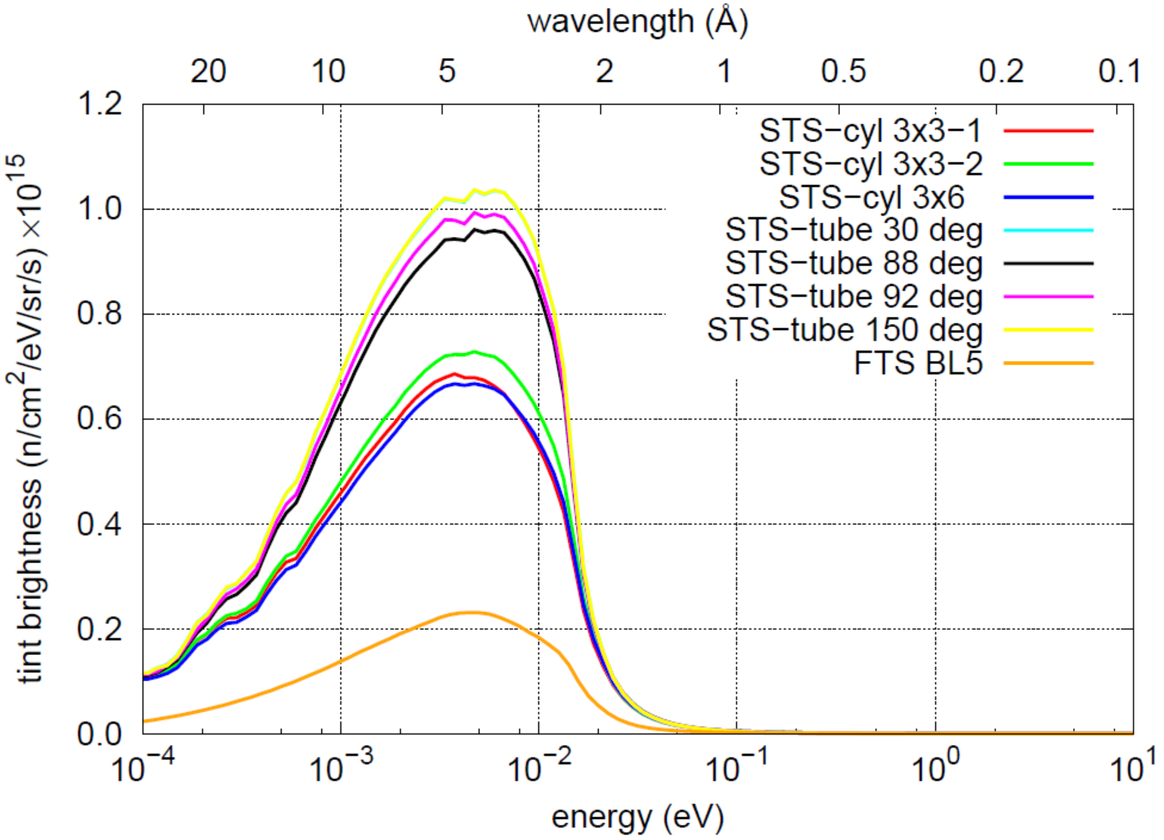
- Beginning Large Scale Integration (LSI) phase where the major components are completed and tested
- 2020 – Magnet System moved to ORNL for neutron polarization and transport testing
- 2022 – Central Detector System to ORNL for testing and commissioning
- 2023 – 3He System to ORNL for testing and commissioning
- 2023 – Initial data taking begins

Opportunities at the STS

- STS has factor 3 lower pulse rate than FTS.
  - FTS = (60-15) Hz
  - STS = 15 Hz
- We can gain elsewhere:
  - Optimize moderator and guides: cross section of experiment is larger so larger moderator and guide entrance desirable
  - Avoid losses of useful neutrons through shielding seen at FTS
  - More gains possible from efficient transport after exit to experiment
  - We expect x10 more 8.9 Å neutrons at the experiment

Moderator Brightness

- Two moderators at STS
  - Upper cylindrical: 2 sizes considered
  - Lower triangular
- STS has higher **brightness** but not intensity
  - Achieved with smaller moderator and guide entrance
- We will ask for bigger moderator & guide entrance, and use ballistic guide for high brightness of colder neutrons in larger area



Comparison of moderators: FTS vs STS

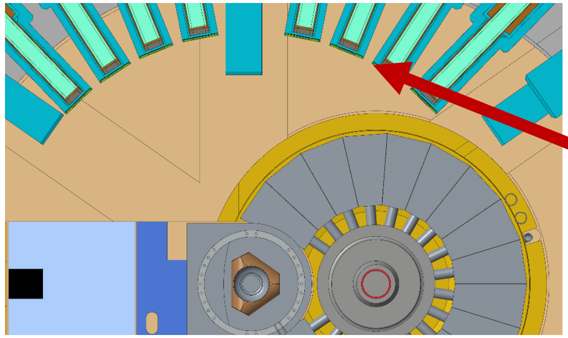
	FTS	STS ▲	STS 3x3	STS 3x6
Pulse rate	60 Hz – 15 Hz	15 Hz		
Guide entrance viewing moderator	10 x 12 cm^2	5 x 5 cm^2		
n/s/Å at 8.9Å at guide entrance	**44e9**	3.0e9 @ 100 cm 6.6e9 @ 70 cm	2.4e9 @ 100 cm 5.3e9 @ 70 cm	4.4e9 @ 100 cm 9.5e9 @ 70 cm
Guide entrance viewing moderator	-	5 x 10 cm^2 (as in QIKR instrument)		
n/s/Å at 8.9Å at guide entrance	-	5.6e9 @ 100 cm 13e9 @ 70 cm	5.3e9 @ 100 cm 10e9 @ 70 cm	9.7e9 @ 100 cm **19e9 @ 70 cm**

- Figure of merit: intensity of useful neutrons (8.9 Å) to nEDM
- For more gains need larger viewing area and more efficient transport

Comparison of guide entrance: STS

Time averaged intensity of 8.9 Å neutrons at guide entrance relative to FTS

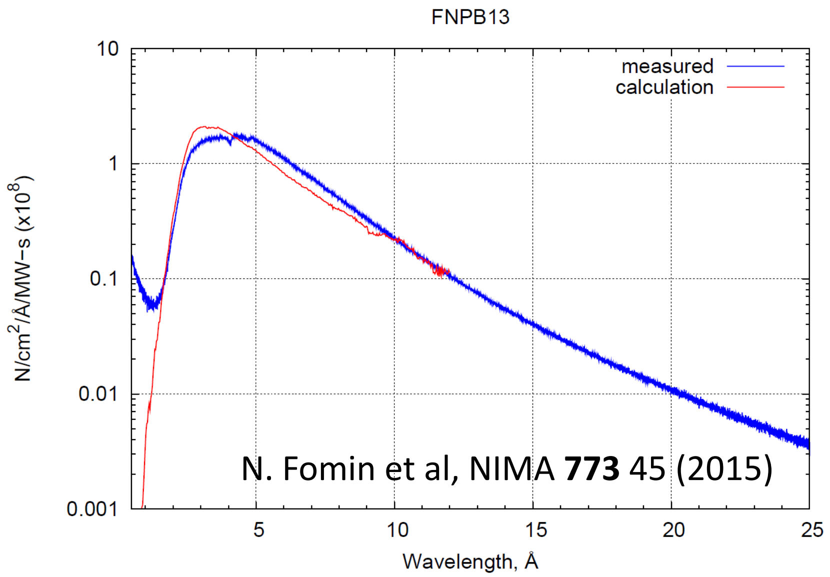
- Vertical limitation of <10 cm by shutter design [Van's talk next], but high gains possible if we can avoid
- Horizontal limitation from beamline density
  - 2 beamlines = 20 cm wide guide

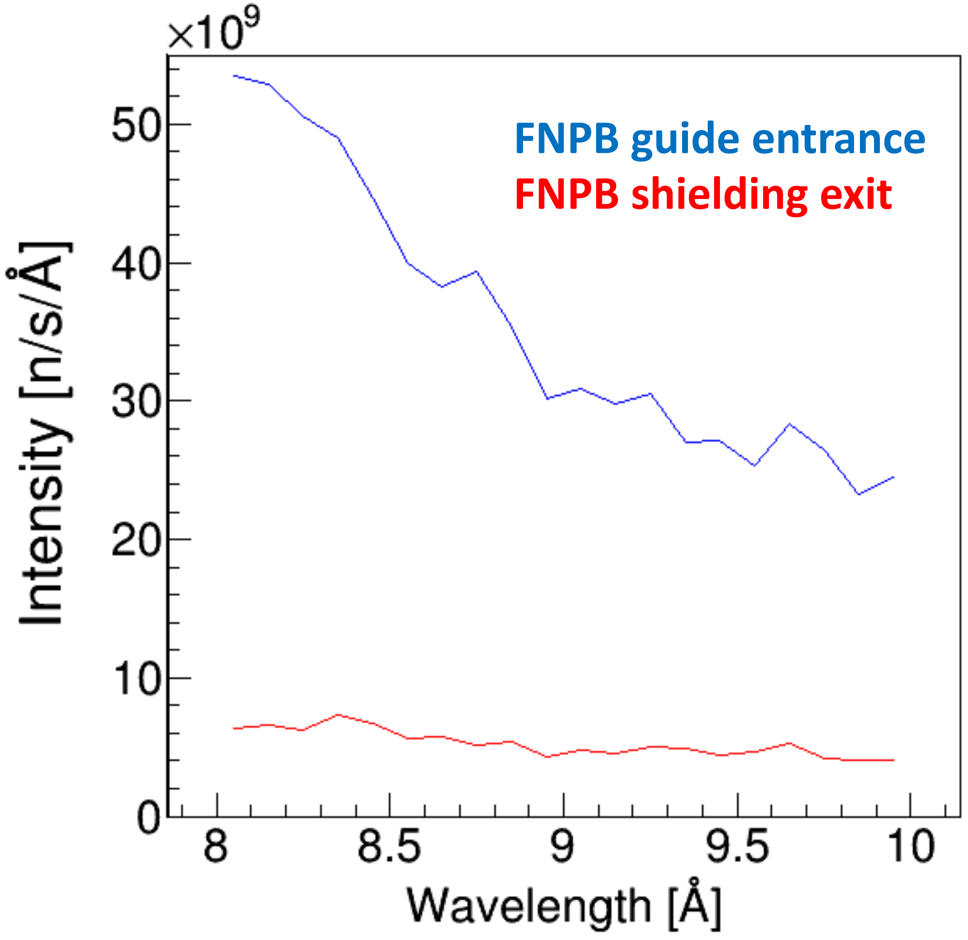


50 mm wide neutron beam requires 140 mm wide Monolith Insert & ultimately limits moderator approach distance

Guide entrance [cm^2]	STS 3x6 / FTS
5x10 (QIKR insert)	0.22 @ 100 cm 0.43 @ 70 cm
5x20	0.43 @ 100 cm 0.89 @ 70 cm
10x10	0.43 @ 100 cm
10x30	1.3 @ 100 cm
20x20	1.7 @ 100 cm
20x30	2.6 @ 100 cm

8.9 Å at FNPB





- Using McStas model of FNPB BL-13
- **Factor 6.5** lost intensity of 8.9Å at shielding exit
- Need more efficient transport

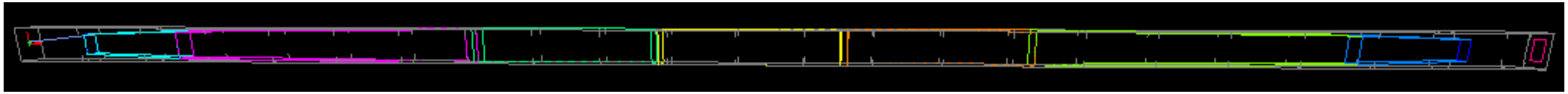
Possible transport schemes

- How to efficiently transport through a 10 cm high shutter at 6 m?

m=3.6 m=5 m=3.6

20 x **15** 27.5 x 22 35 x 10 35 x 30 → 20 x 30

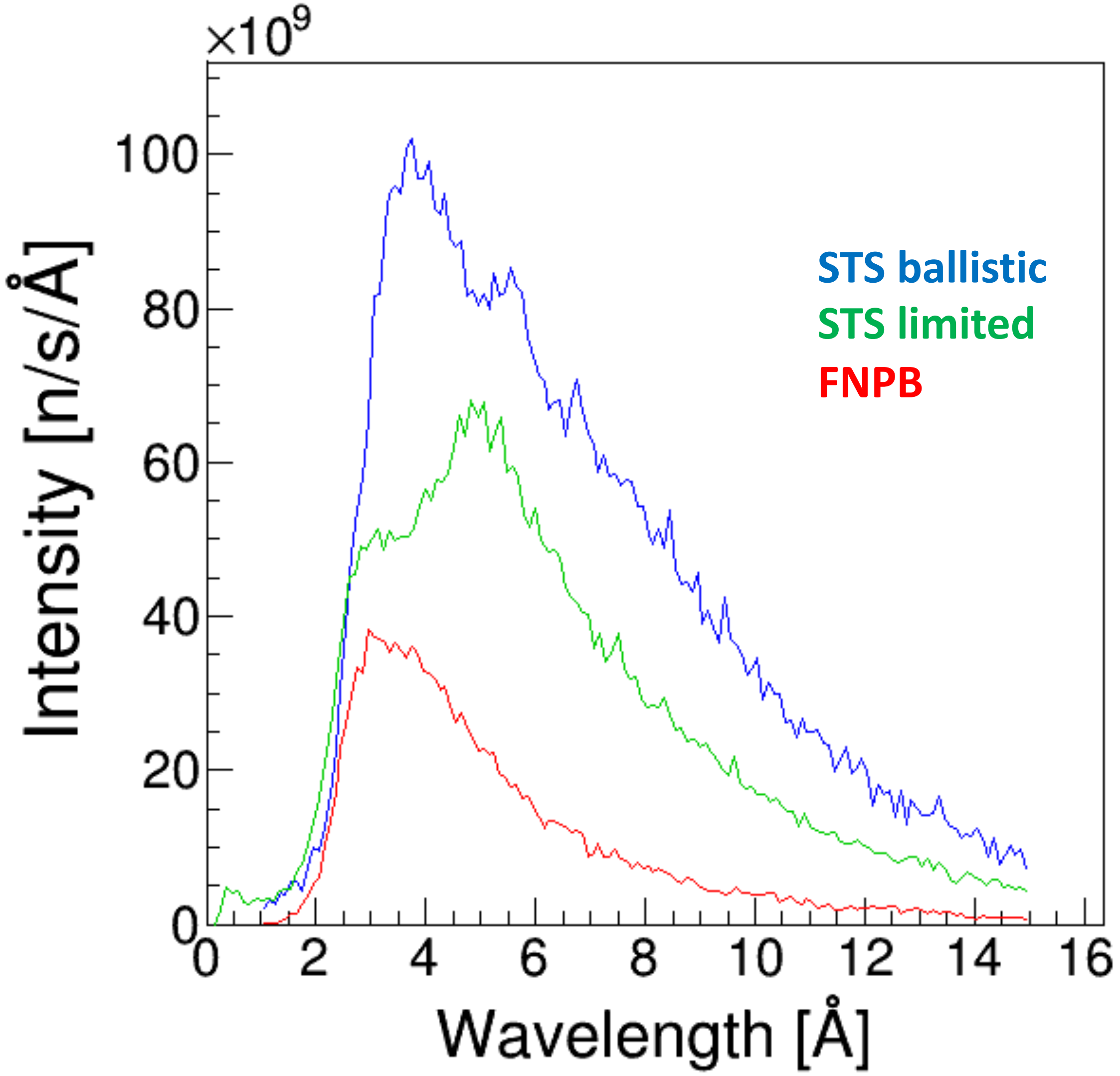
- If we can avoid: ballistic guide with large view area (m = 3.6)



20 x **30** 40 x 50 20 x 30

Neutron spectra

- Colder, more intense than FNPB
- FNPB (shielding exit): **6.4e9** n/s/Å
- 20m shutter-limited beamline: **21e9** n/s/Å
- 20m ballistic beamline: **44e9** n/s/Å

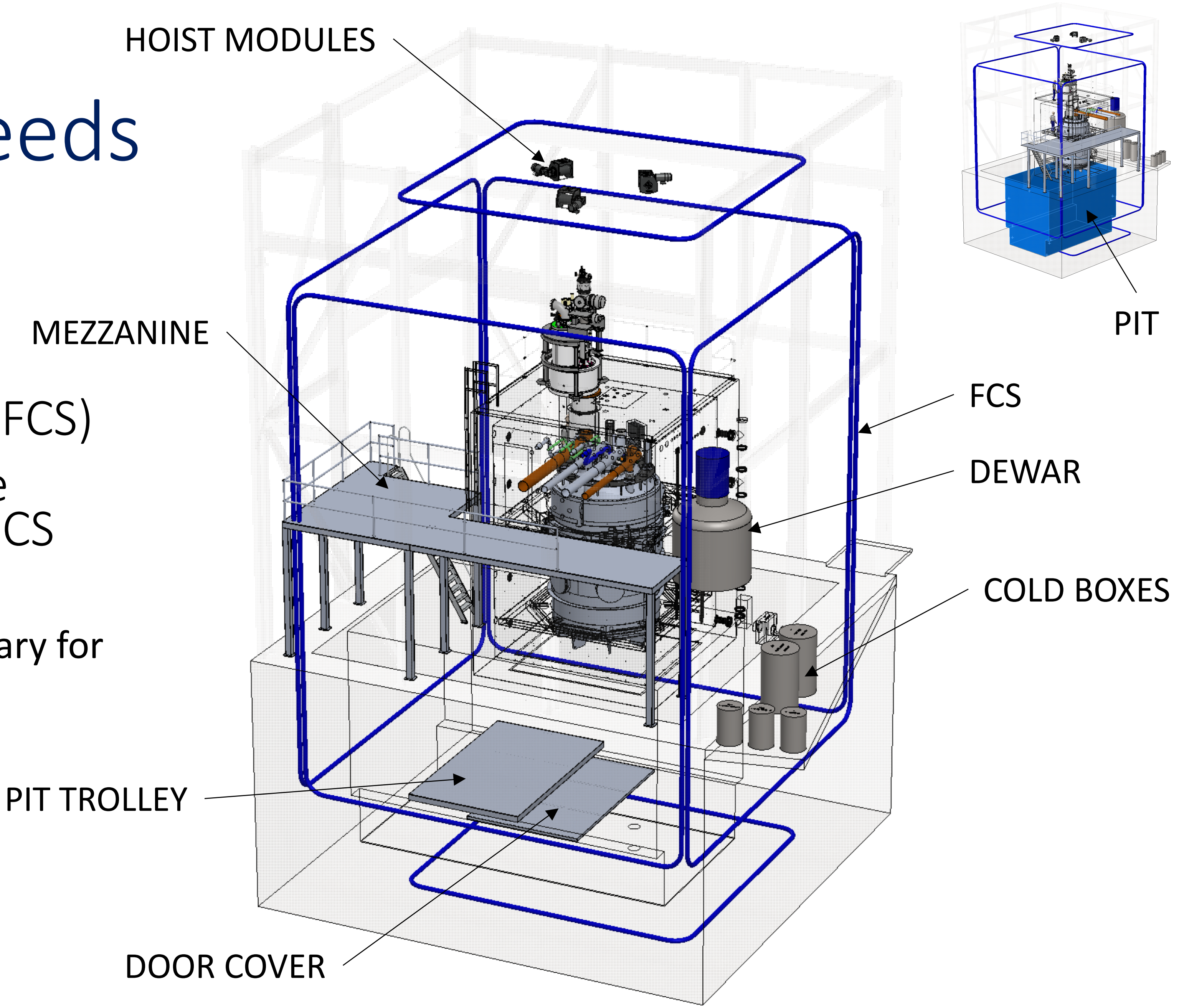


Gains factors for 8.9 Å at STS over FTS

Factors	Gain
Pulse rate	1/3
5x5 cm^2 view of 3x6 moderator (per pulse)	1/3
20x30 cm^2 view of 3x6 moderator (per pulse)	10
Ballistic 20x30 cm^2 guide through shielding	2.8
Efficient transport from shielding to experiment	~2
Total	**6 - 18**

Infrastructure needs

- Crane hook @ ~35’
- Hoist module array
- Field cancellation system (FCS)
- Non-magnetic rebar in the vicinity of apparatus and FCS
- Pit
  - ~17’x28’x20’ deep pit necessary for assembly of components
  - Includes:
  - Pit trolley
  - Trap door storage space
  - Trap door cover
  - Sump pump



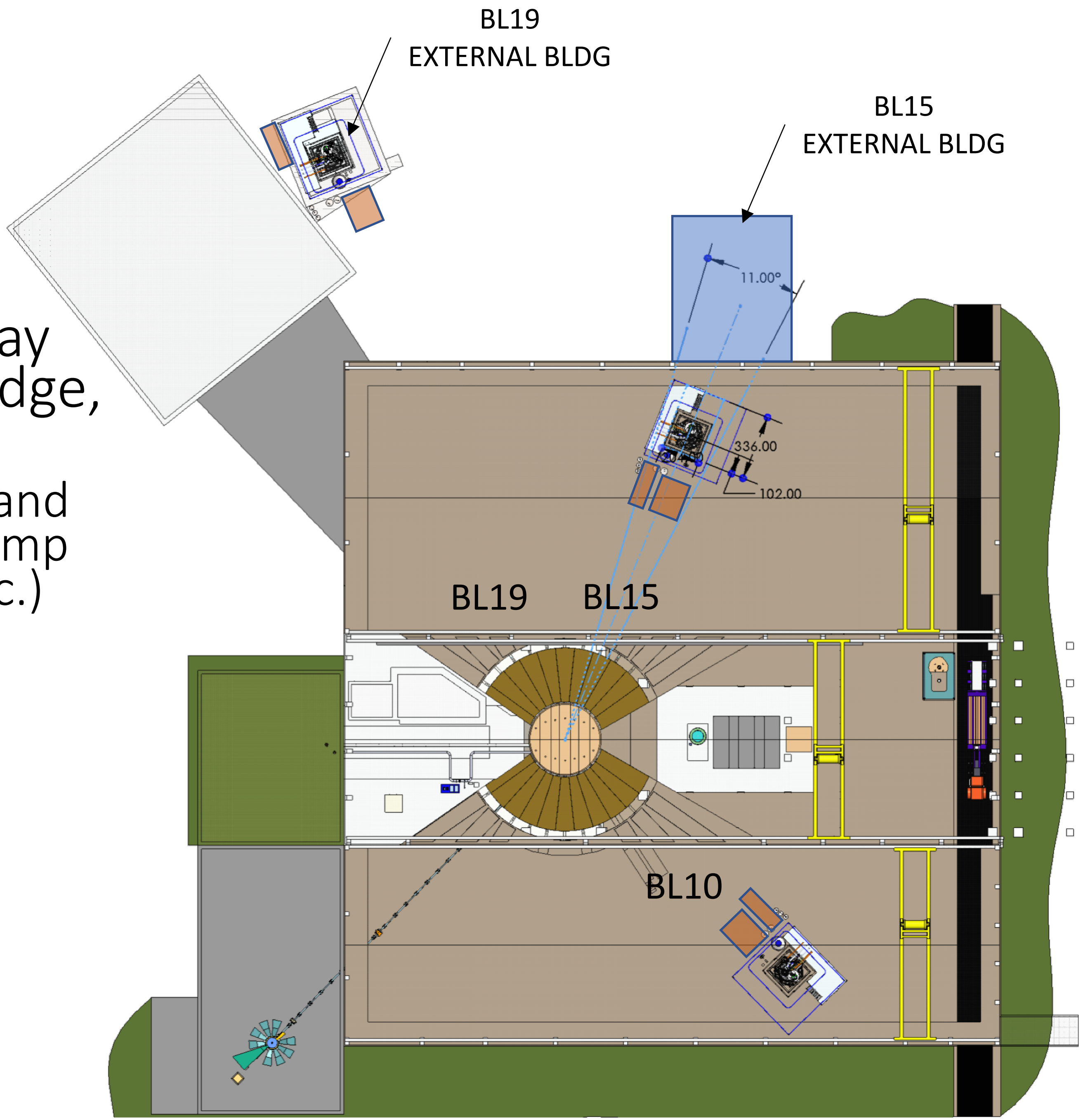
More infrastructure requirements

- Approximate power needs
  - 480V: ~313 kVA
  - 208/120V: ~71 kVA
  - Clean 120V: ~26 kVA
- Cooling water - ~70-80 gallons/minute
- Liquid nitrogen – 3000-5000 liter storage
  - Liquid nitrogen service will be necessary to support helium liquefaction and transfer
  - LN2 storage dewar outside accessible for filling
- Assembly and storage space
  - We generally need space comparable to the combined EB-1 and EB-2

Where at STS?

- Experiment equipment may be able to fit in an 11° wedge, but cramped
  - Need space for assembly, and supporting equipment (pump stacks, RF screen room, etc.) and storage
  - 2 beamline widths is more comfortable
- Some potential locations
  - BL19
  - BL15
  - BL10

EXTERNAL BUILDING? (BL19, BL15)



Conclusion

- STS provides an exciting opportunity to increase the sensitivity of the SNS nEDM experiment by a factor 3 or more.