Stage 1 approval for SpinQuest upgrade

SpinQuest upgrade proponents

January 18, 2023

PAC meeting

Outline

- SpinQuest status and upgrade
- Scientific goals and impact
  - Spin physics
  - Dark Sector physics
  - Alignment with Fermilab mission, leveraging laboratory capabilities
- Technical requirements
  - Resource needs, schedule

SpinQuest upgrade presented at the June 2022 PAC meeting focusing on physics case
This presentation will focus on Stage 1 approval addressing the topics in the outline

Proponents

A joint dark sector and nuclear physics upgrade to SpinQuest at the 120 GeV Fermilab Main Injector

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Proponents from both the spin and dark sector physics, communities have been working together within SpinQuest colllaboration

Vibrant theory-experiment collaboration too!

SpinQuest status and upgrade

SeaQuest (e906) - dimuon spectrometer

SpinQuest (e1039) - dimuon spectrometer + polarized target

SpinQuest upgrade (e1XYZ) - EMCal, tracking, & target upgrade to dimuon spectrometer

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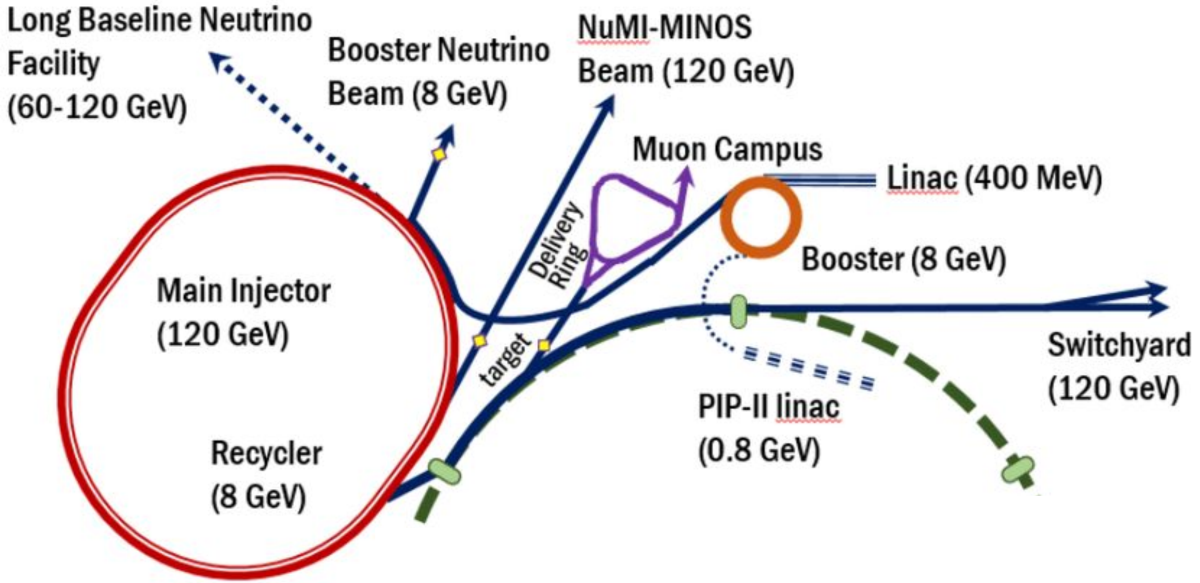
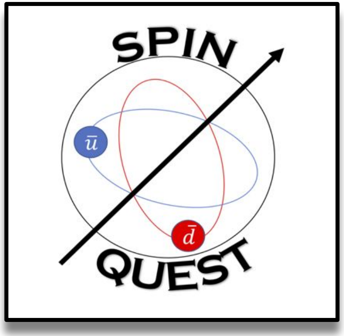
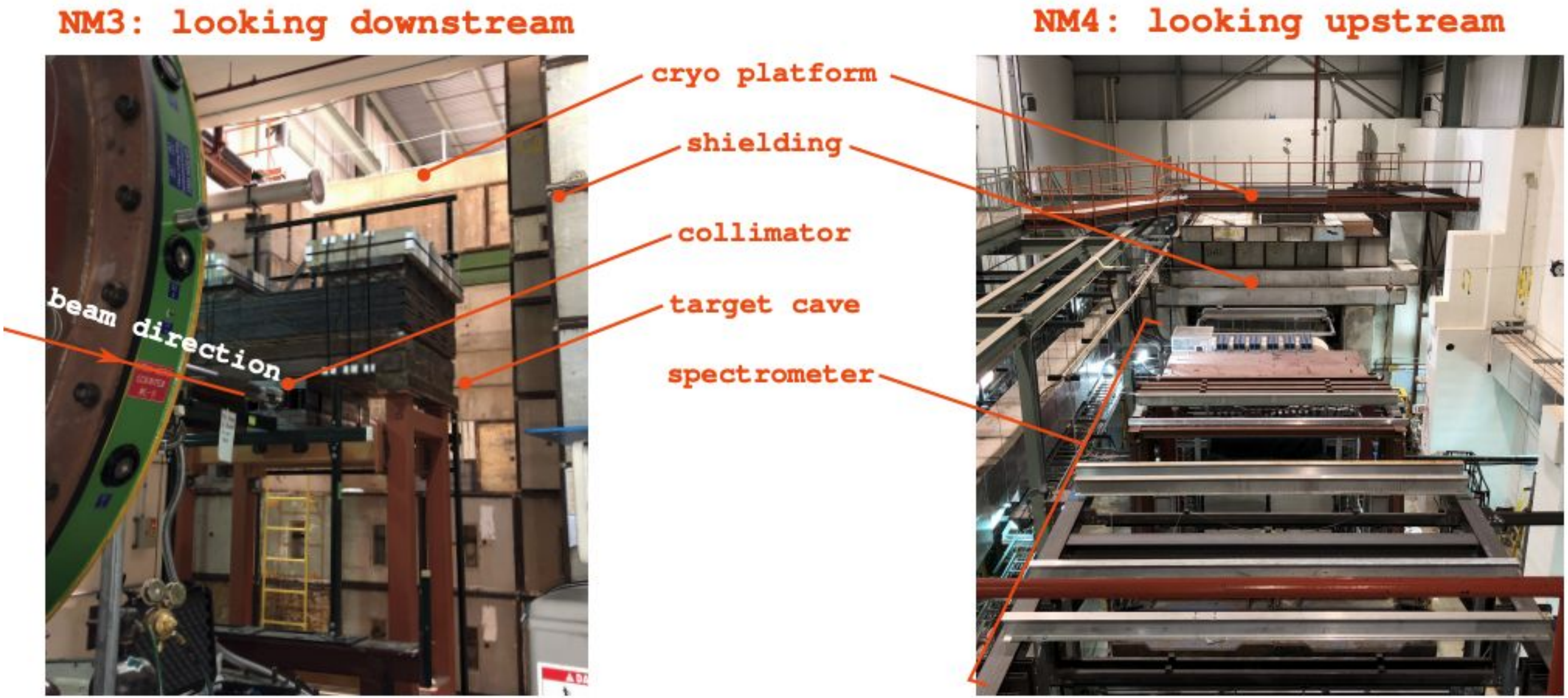
SpinQuest



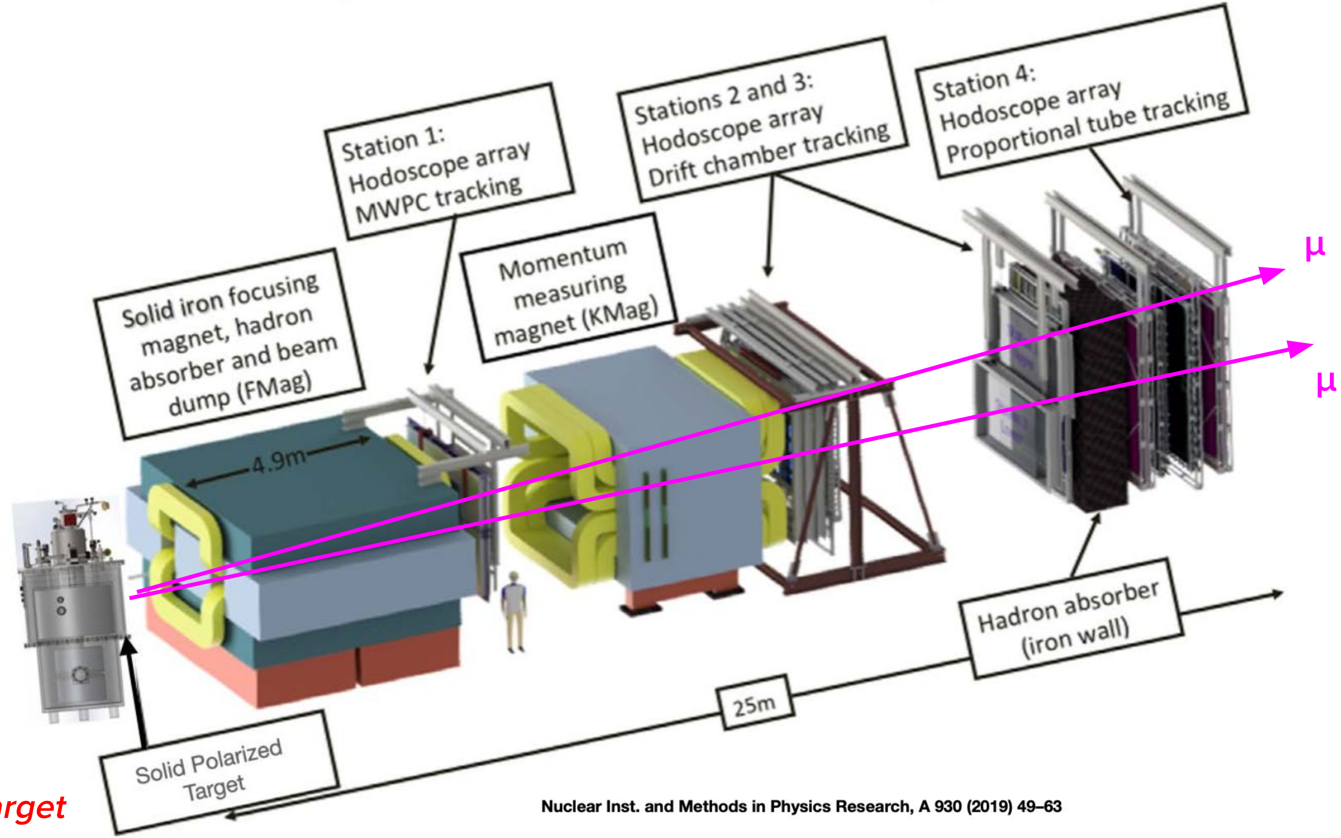
NM4 experimental hall



SpinQuest


NM3: looking downstream
NM4: looking upstream
cryo platform
shielding
collimator
target cave
spectrometer
beam direction

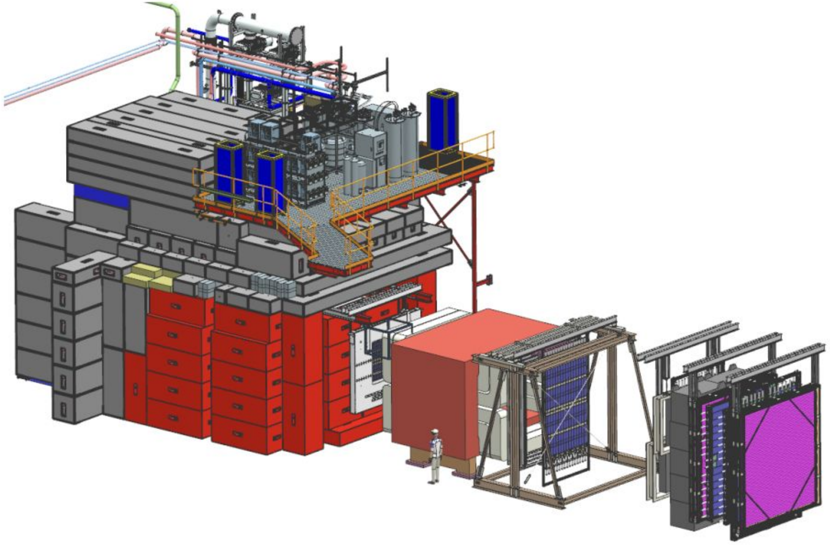
The SpinQuest Spectrometer

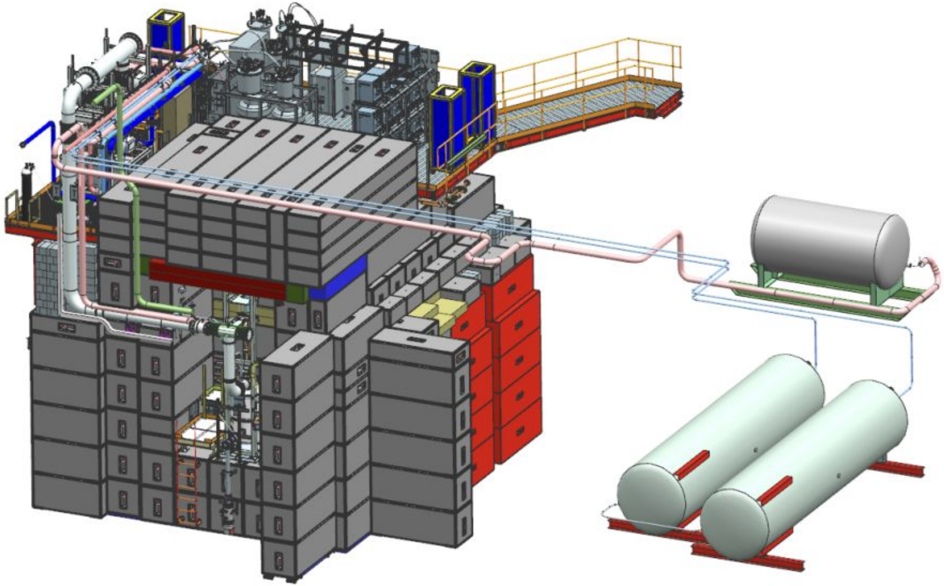


E1039 (2022+):
Polarized NH_3 target

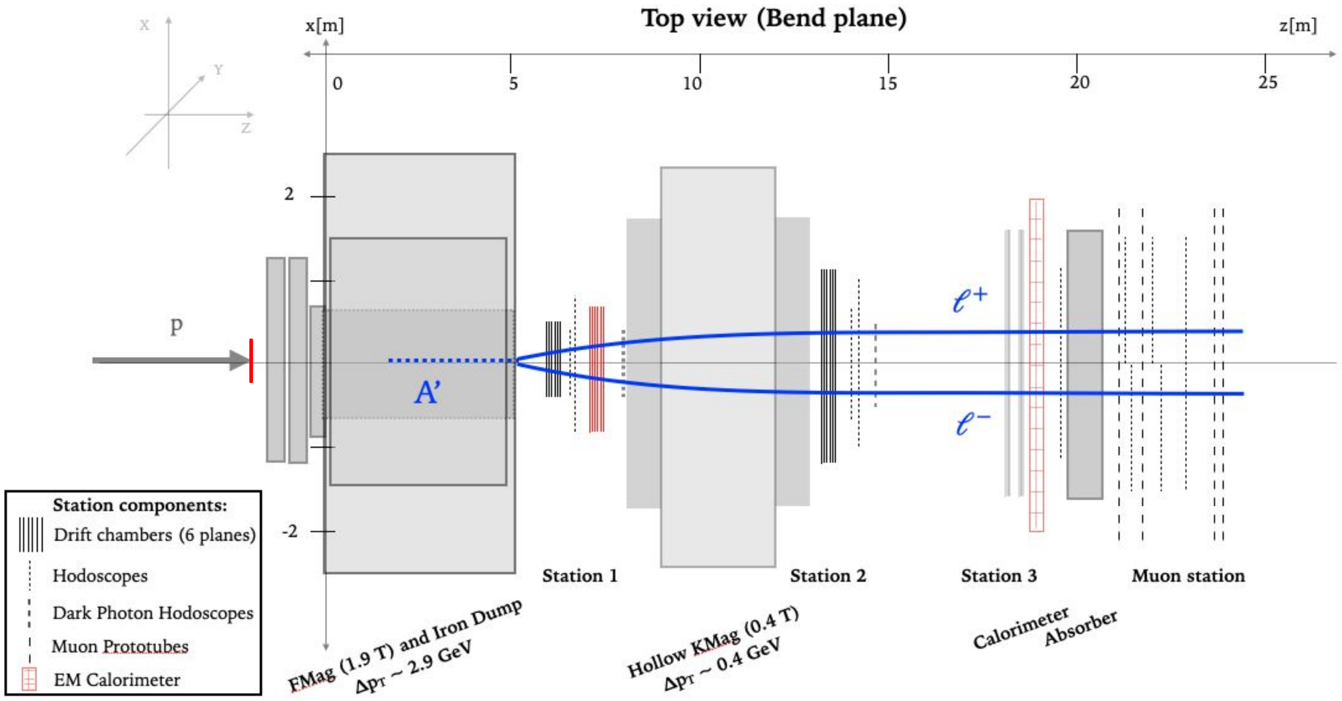
Nuclear Inst. and Methods in Physics Research, A 930 (2019) 49–63

The SpinQuest Target





SpinQuest upgrade



Dark sector signature

SpinQuest: muon final states

DarkQuest: e,γ,π,...

System upgrades

Existing EMCal from PHENIX

Tracking MWPC available

Tensor polarized deuteron target

SpinQuest status

Polarized Target System

- All polarized target subsystems are fully operational
- Bringing target material onsite to polarize

Spectrometry

- All detectors are fully operational
- Chambers on ArCO2

Shielding Construction

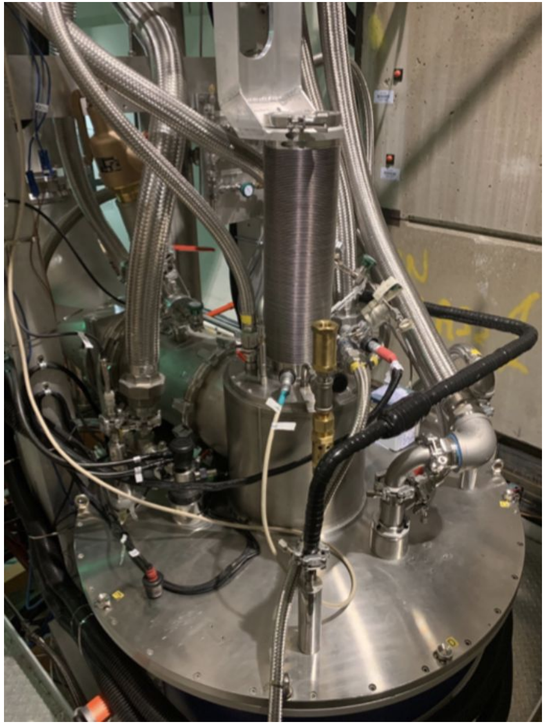
- Final shielding blocks are in place
- Construction project fully complete

Beamline

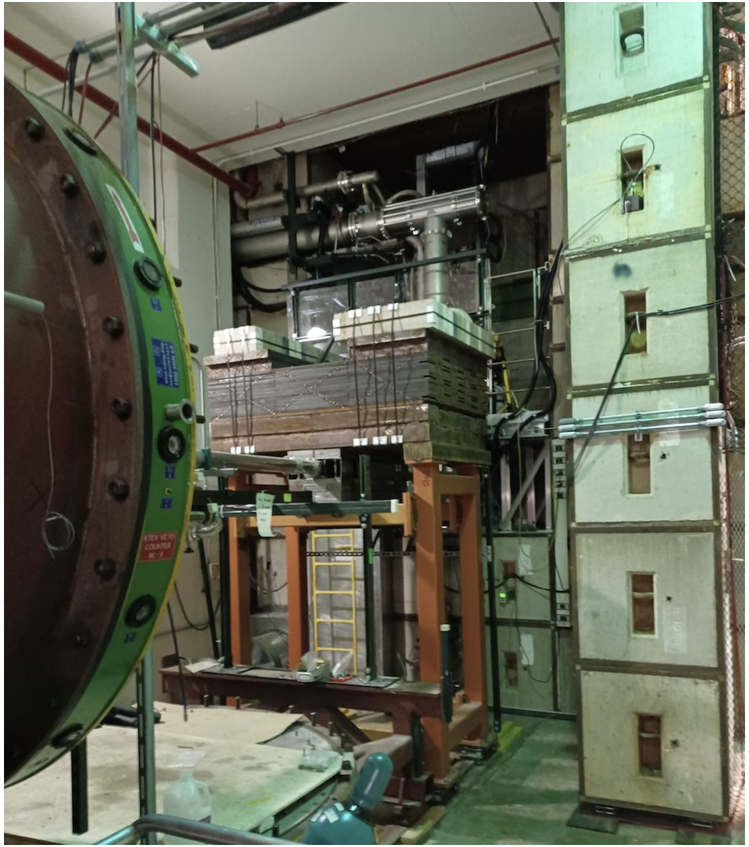
- Tests of upstream beamline (switchyard through NM1) complete
- NM2 power supply checks and repairs complete

Administrative Reviews

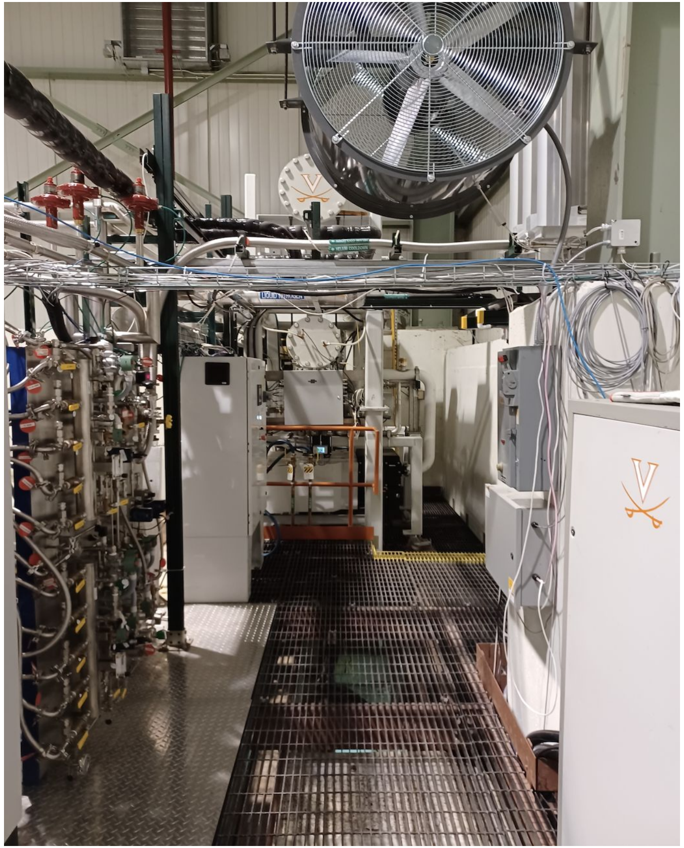
- Accelerator Safety Envelope (ASE)
- Accelerator Readiness Review (ARR)
- Target material review



SpinQuest status



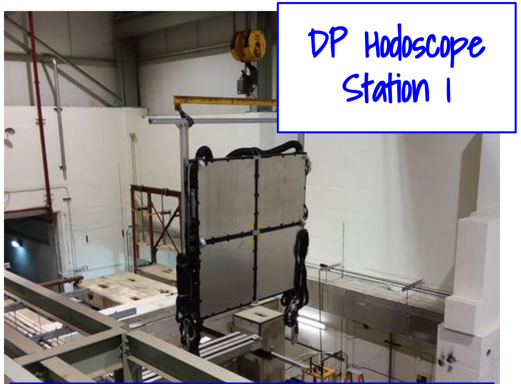
SpinQuest status



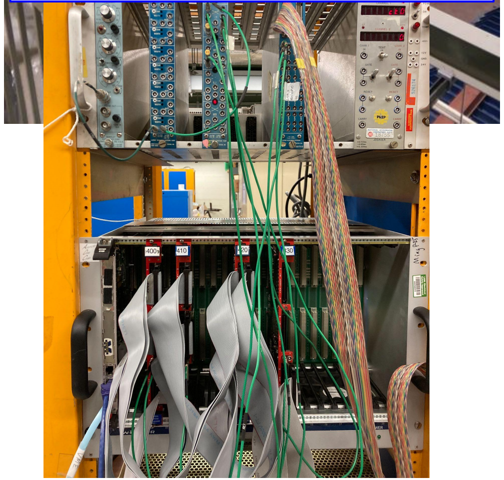
SpinQuest Dark Photon Trigger

- Utilizing the Fiber Hodoscope detectors installed in 2017
- Requiring two muons in the same quadrant which can reconstruct a decay vertex between 5-6m
- Dark Photon trigger roadset firmware fully validated using dedicated test bench
  - Efficiency of ~10-20% for decays in acceptance
- Currently being integrated into the SpinQuest trigger system for commissioning with first beam
  - Trigger rate predicted to be O(100) Hz

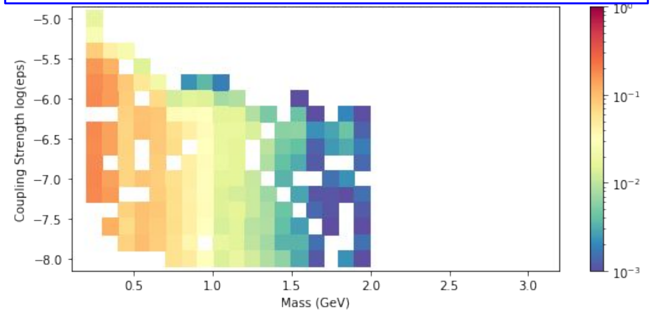
DP Hodoscope Station 1



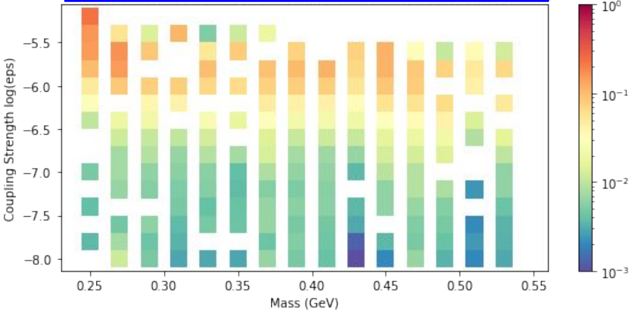
Dark Photon Trigger Test Stand

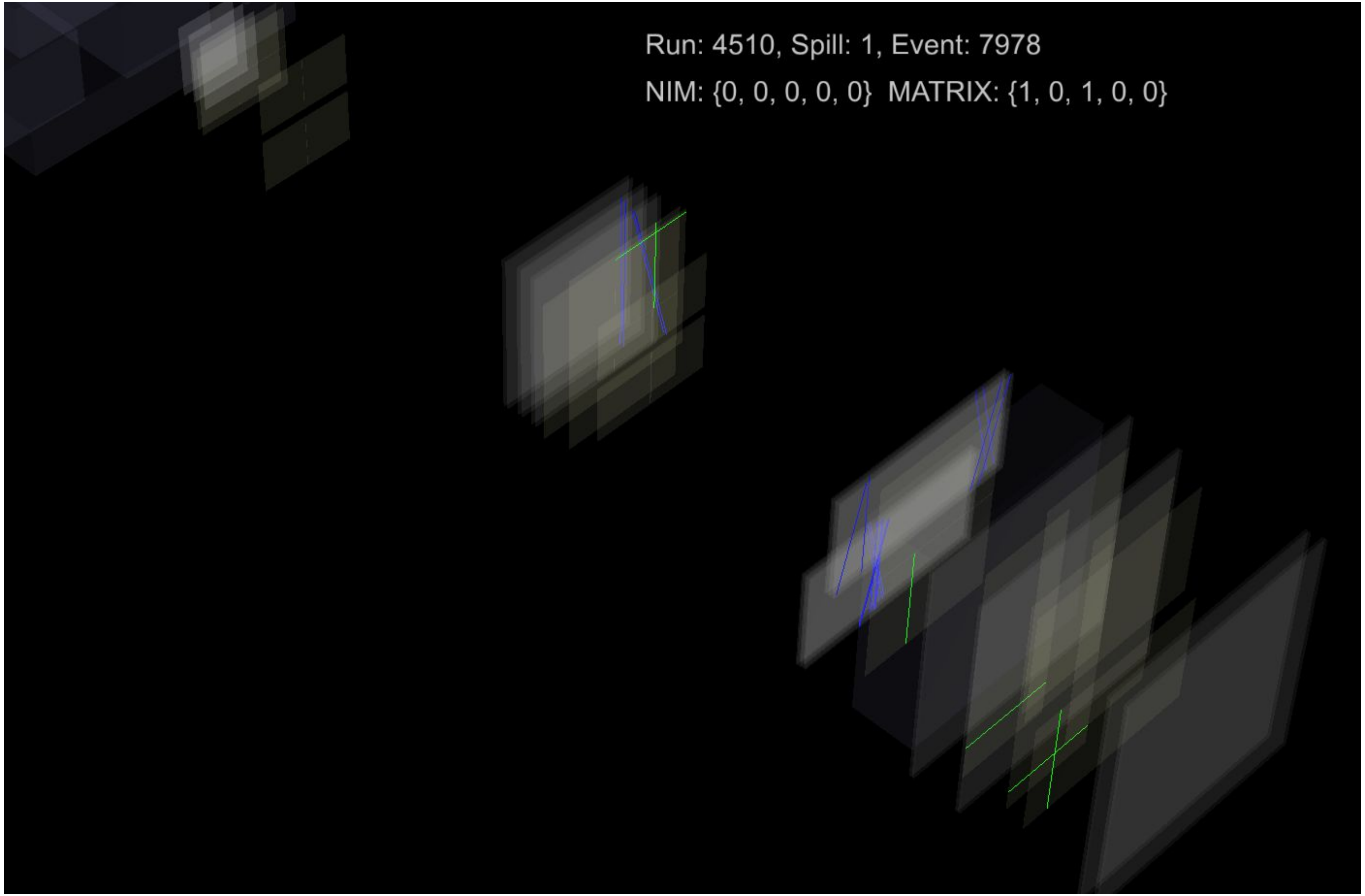


DP Trigger Efficiency (proton bremsstrahlung)



DP Trigger Efficiency (η decay)

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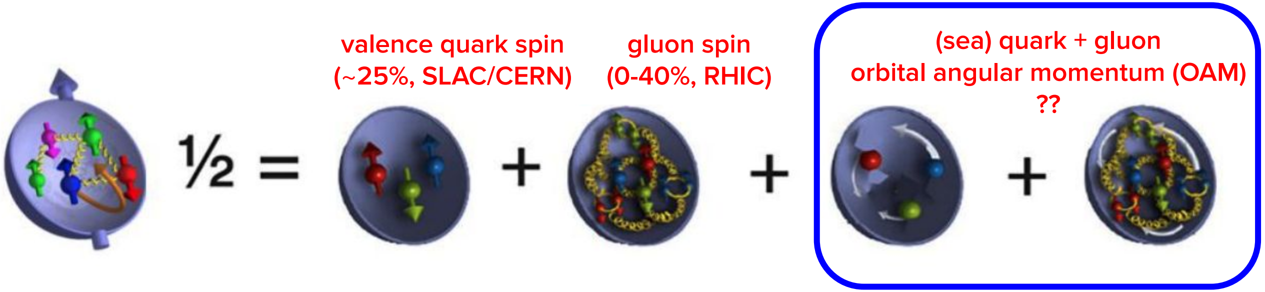
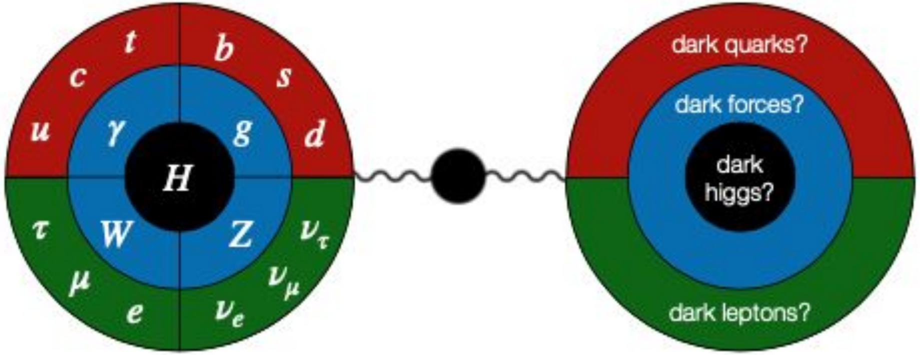
SpinQuest upgrade: Scientific goals and impact

Scientific program

World-leading **spin and dark sector physics** with unique experimental capabilities



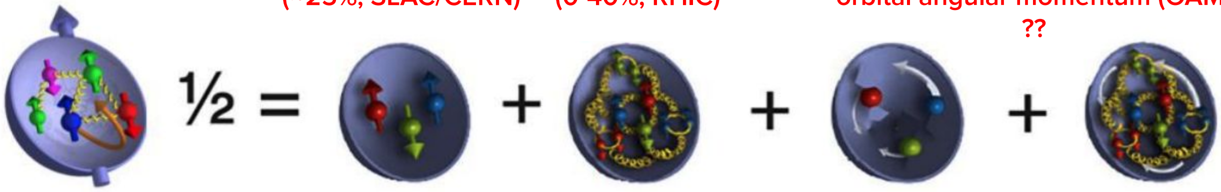


Spin Physics - proton spin puzzle

valence quark spin (~25%, SLAC/CERN)

gluon spin (0-40%, RHIC)

(sea) quark + gluon orbital angular momentum (OAM) ??



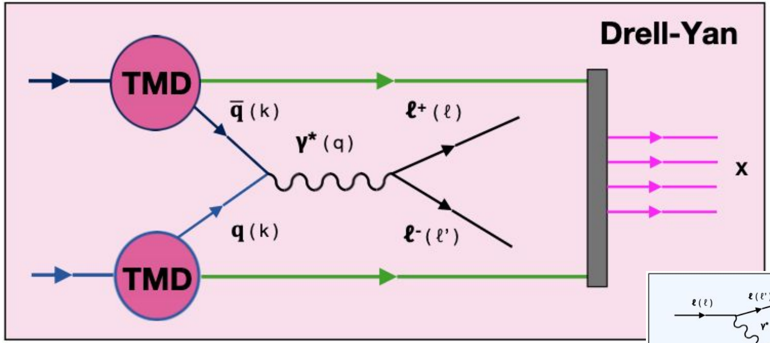
<u>Puzzle</u>: EMC experiment (1987) measured only ~25% of proton spin comes from valence quarks (unexpected!)

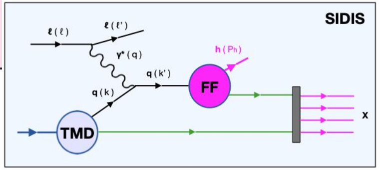
Other potential contributions:
Orbital angular momentum (OAM) of the quarks and gluons

[Lattice QCD predicts non-zero quark OAM]

Drell-Yan is a critical complement to **SIDIS** (semi-inclusive deep inelastic scattering) for measuring the proton spin and testing QCD, *both are required*

Cleanest method with no fragmentation function, two parton TMDs, direct access to sea-quark distributions





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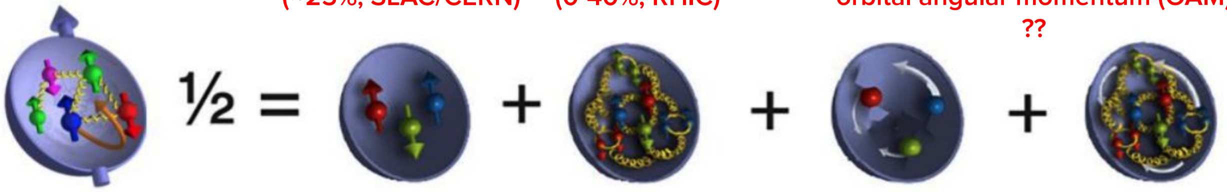
Spin Physics - proton spin puzzle

$$A_N(p_{\rm beam}+p^{\uparrow}_{\rm trg}\to {\rm DY}) \propto \frac{N_L^{DY}-N_R^{DY}}{N_L^{DY}+N_R^{DY}} \propto \frac{f_{1T}^{\perp,\bar{u}}(x_t)}{f_1^{\bar{u}}(x_t)}$$

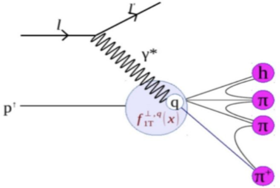
valence quark spin (~25%, SLAC/CERN)

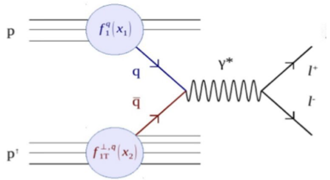
gluon spin (0-40%, RHIC)

(sea) quark + gluon orbital angular momentum (OAM) ??



Measuring non-zero Sivers asymmetry at SpinQuest requires sea-quark OAM - **This observation would be a major discovery!**





$A_{UU}^{\cos 2\phi_h} \propto h_1^{\perp q} \otimes H_{1q}^{\perp h}$

$A_{UT}^{\sin(\phi_h-\phi_s)} \propto f_{1T}^{\perp q} \otimes D_{1q}^{h}$

$A_{UT}^{\sin(\phi_h+\phi_s)} \propto h_1^{q} \otimes H_{1q}^{\perp h}$

$A_{UT}^{\sin(3\phi_h-\phi_s)} \propto h_{1T}^{\perp q} \otimes H_{1q}^{\perp h}$

$h_1^q\big|_{SIDIS} = h_1^q\big|_{DY}$

$h_{1T}^{\perp q}\big|_{SIDIS} = h_{1T}^{\perp q}\big|_{DY}$

$h_1^{\perp q}\big|_{SIDIS} = -h_1^{\perp q}\big|_{DY}$

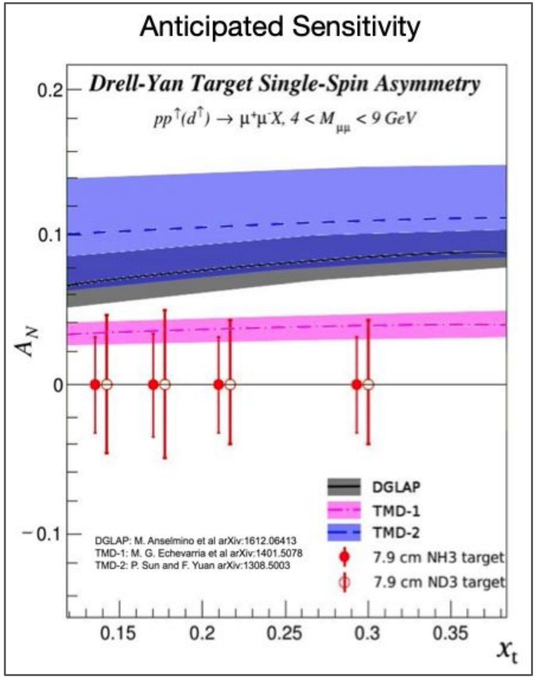
$f_{1T}^{\perp q}\big|_{SIDIS} = -f_{1T}^{\perp q}\big|_{DY}$

$A_T^{\cos 2\varphi_{cs}} \propto h_1^{\perp q} \otimes h_1^{\perp q}$

$A_T^{\sin\varphi_s} \propto f_1^{q} \otimes f_{1T}^{\perp q}$

$A_T^{\sin(2\varphi_{cs}-\varphi_s)} \propto h_1^{\perp q} \otimes h_{1T}^{\perp q}$

$A_T^{\sin(2\varphi_{cs}+\varphi_s)} \propto h_1^{\perp q} \otimes h_1^{q}$

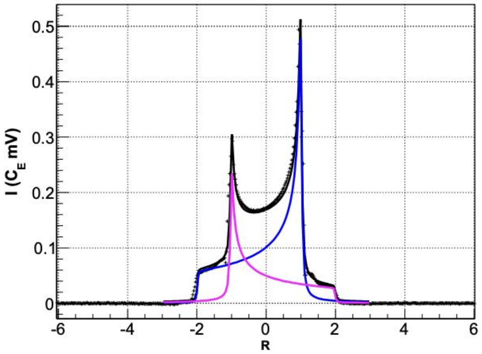


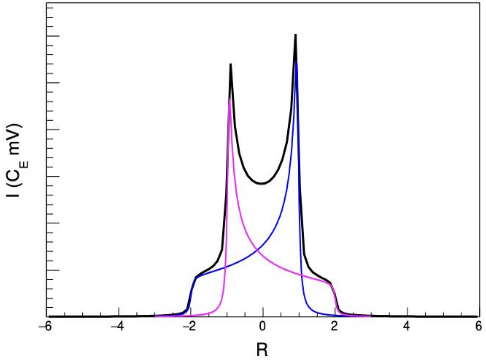
SpinQuest upgrade - future transversity program

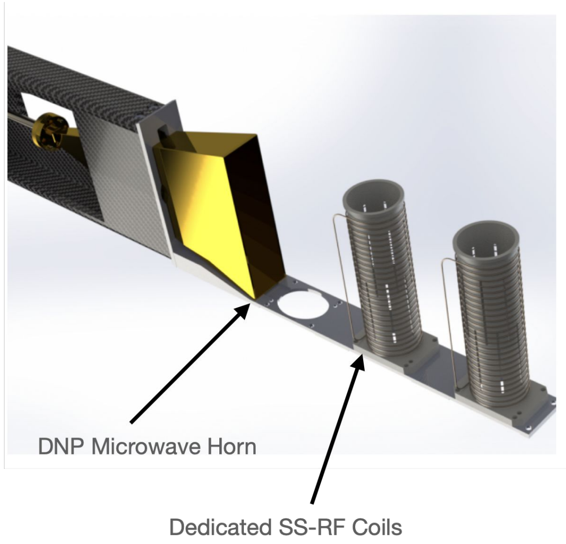
Modest upgrade brings expanded nucleon transversity physics program

Beyond non-zero Sivers/OAM, see more at [Tranversity 2022 conference]

A focus on Sea and Gluon Transversity – this would be the first experiment of its kind on a very hot topic in Spin Physics



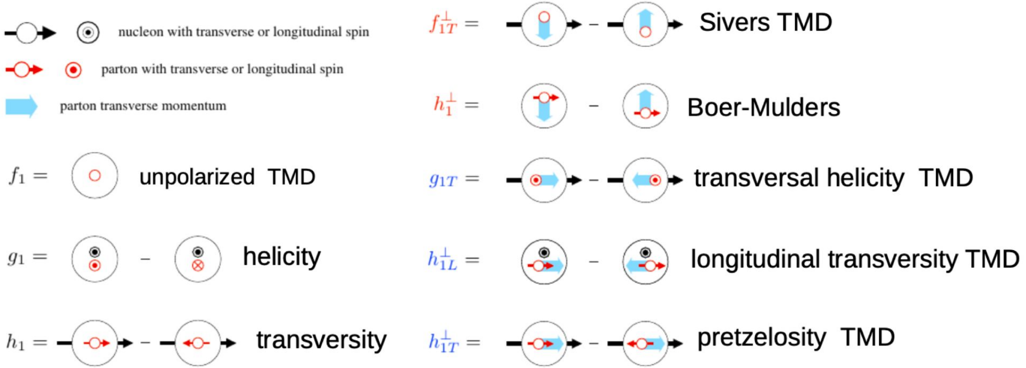




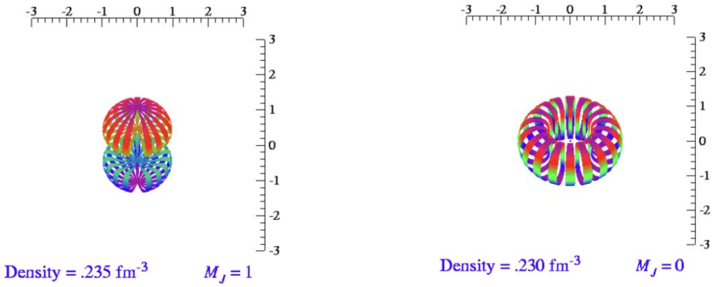
NIM 981, 21 (2020) 164504 (arxiv.org/abs/2008.09515)

Separation of sea-quark and gluon TMDs

Extraction of information on partonic dynamics and spin structure of nuclei



leading twist	quark operator		
	unpolarized [U]	longitudinal [L]	transverse [T]
target polarization U	$f_1 =$ unpolarized		$h_1^{\perp} =$ − Boer-Mulders
target polarization L		$g_1 =$ − helicity	$h_{1L}^{\perp} =$ − worm gear 1
target polarization T	$f_{1T}^{\perp} =$ − Sivers	$g_{1T} =$ − worm gear 2	$h_1 =$ − transversity $h_{1T}^{\perp} =$ − pretzelosity
TENSOR	$f_{1LL}(x, \boldsymbol{k}_T^2)$ $f_{1LT}(x, \boldsymbol{k}_T^2)$ $f_{1TT}(x, \boldsymbol{k}_T^2)$	$g_{1TT}(x, \boldsymbol{k}_T^2)$ $g_{1LT}(x, \boldsymbol{k}_T^2)$	$h_{1LL}^{\perp}(x, \boldsymbol{k}_T^2)$ h_{1TT}, $h_{1TT}^{\perp}$ h_{1LT}, $h_{1LT}^{\perp}$



Leading Twist		Unpolarized	Circular	Linear
Vector Polarized	U	f_1		$h_1^{\perp}$
	L		g_1	$h_{1L}^{\perp}$
	T	$f_{1T}^{\perp}$	g_{1T}	$h_1, h_{1T}^{\perp}$
Tensor Polarized	LL	f_{1LL}		$h_{1LL}^{\perp}$
	LT	f_{1LT}	g_{1LT}	$h_{1LT}, h_{1LT}^{\perp}$
	TT	f_{1TT}	g_{1TT}	h_{1TT}, $h_{1TT}^{\perp}$ $h_{1TT}^{\perp\perp}$

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SpinQuest upgrade - future transversity program

Modest upgrade brings expanded nucleon transversity physics program

- **Separation of Quark and Gluon TMDs**
  - Quark transversity distributions decouple from the gluon transversity in evolution
  - Gluon transversity only exists for target ≥1vdue to chiral odd property
  - Use separate tensor polarized asymmetry to isolate linearly polarized gluon observable
- **Using Drell-Yan process to understand geometry in terms of partonic dynamics**
  - Tensor force is largely responsible for the change in shape between the magnet sublevels
  - Observables vanish for nucleus made strictly of non-interacting p-n
  - Gluon transversity do not mix at leading twist with sea quark transversity
  - Novel target system modulates between tensor and vector polarized observables

Linearly polarized gluons in the target can be used to study fundamental relations in QCD

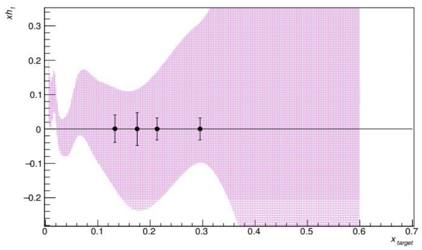
$$h^g_{1TT}|_{SIDIS} = h^g_{1TT}|_{DY}$$

SpinQuest upgrade - future transversity program

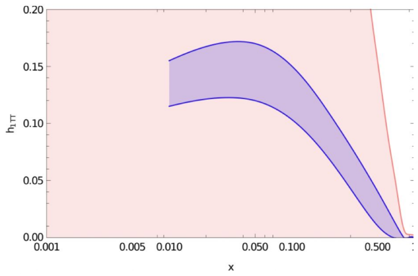
Modest upgrade brings expanded transversity physics program

Beyond non-zero Sivers/OAM, see more at [Tranversity 2022 conference]

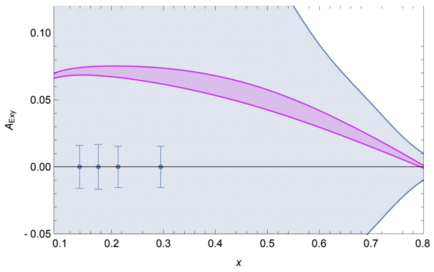
SeaQuark Transversity



Gluon Transversity



Gluon Tensor Transverse Asymmetry



The Transverse Structure of the Deuteron with Drell-Yan

The SpinQuest Collaboration[a]

We propose to measure neutron and deuteron transversity TMDs. The quark transversity distributions of the nucleon are decoupled from the deuteron gluon transversity in the Q^2 evolution due to the chiral-odd property in the transversely-polarized target. The gluon transversity TMD only exists for targets of spin greater or equal to 1 and does not mix with quark distributions at leading twist, thereby providing a particularly clean probe of gluonic degrees of freedom. This experiment would be the first of its kind and would probe the gluonic structure of the deuteron, investigating exotic glue contributions in the nucleus not associated with individual nucleons. This experiment can be performed with the SpinQuest polarized target recently assembled for experiment E1039 and the spectrometer already in place in NM4. This new experimental setup would require very minimal modification to the target system and no modification to the detector package. An additional RF-circuit and target coil are necessary to RF-modulate across the domain of the Larmor frequency to manipulate the solid-state target spin population densities. Dedicated beam-time with this novel target system is required to achieve our physics goals.

Spin/NP upgrade program

arXiv:2205.01249

- Very high proton luminosity from Main Injector
- Large kinematic coverage overlaps with JLab and future EIC
- Beam cycle allows target RF manipulations between spills (55 sec)
- No other facility can offer these two combinations allowing access to these sought after observables

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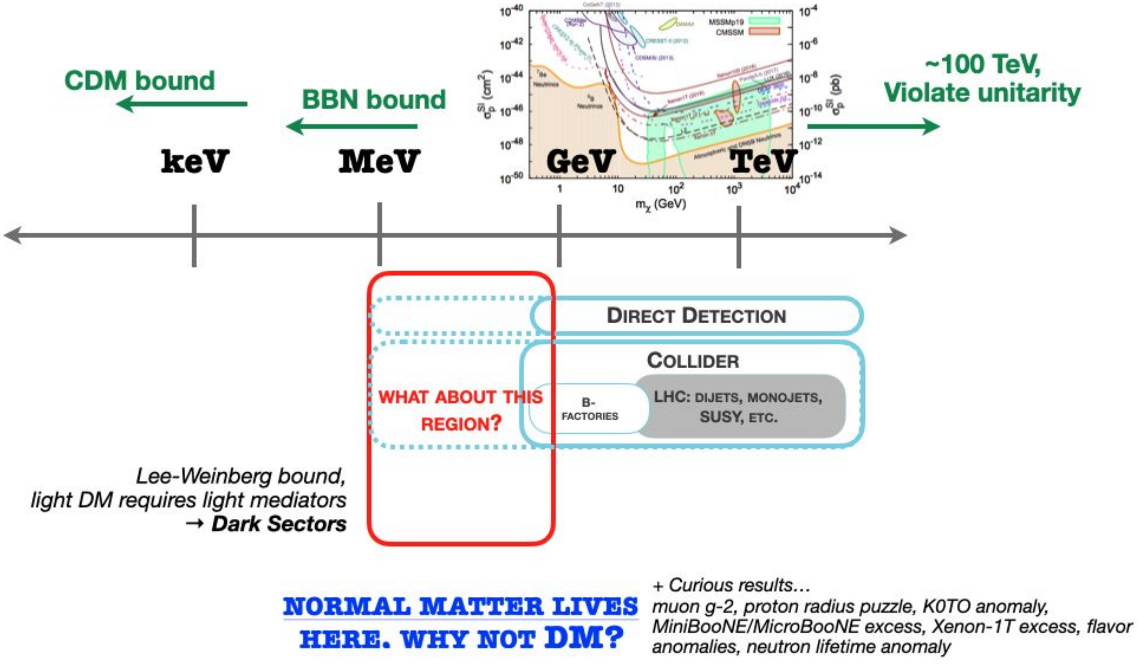
Dark Sectors – thermal but not WIMP

- **Dark matter** exists
  - Thermal freeze-out DM narrows the mass range to ~MeV-TeV, clear milestones
  - No discovery in WIMP searches thus far
- **Dark sectors** can solve many exp/theory puzzles
  - Strong CP, hierarchy problem, ...
  - Dark sectors mean SM-neutral forces (typically < ~GeV)
  - Visible (SM) final states important to explore for discovery



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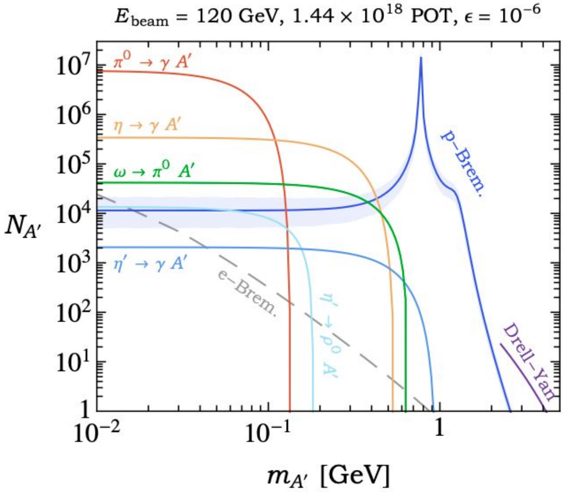
Unique features of SpinQuest for dark sectors

Berlin, Gori, Schuster, Toro
https://arxiv.org/abs/1804.00661

- Large putative dark sector production cross section with **120 GeV proton beam**
- 5m beam dump - geometry sensitive to **unique lifetime baseline**
- Spectrometer with KMAG provides good momentum measurement for forward decays
- EMCal opens up new final states distinct from large muon backgrounds



Existing experiment and infrastructure means we require modest investment - short time to high impact physics!

Snowmass RF6 (dark sectors at accelerators)

https://arxiv.org/abs/2209.04671

Strong connection with NF03, EF10, AF5, CF6

Dark matter production at intensity frontier experiments

Benchmarks:
***dark photon*,**
scalar, neutrino portal,
millicharged

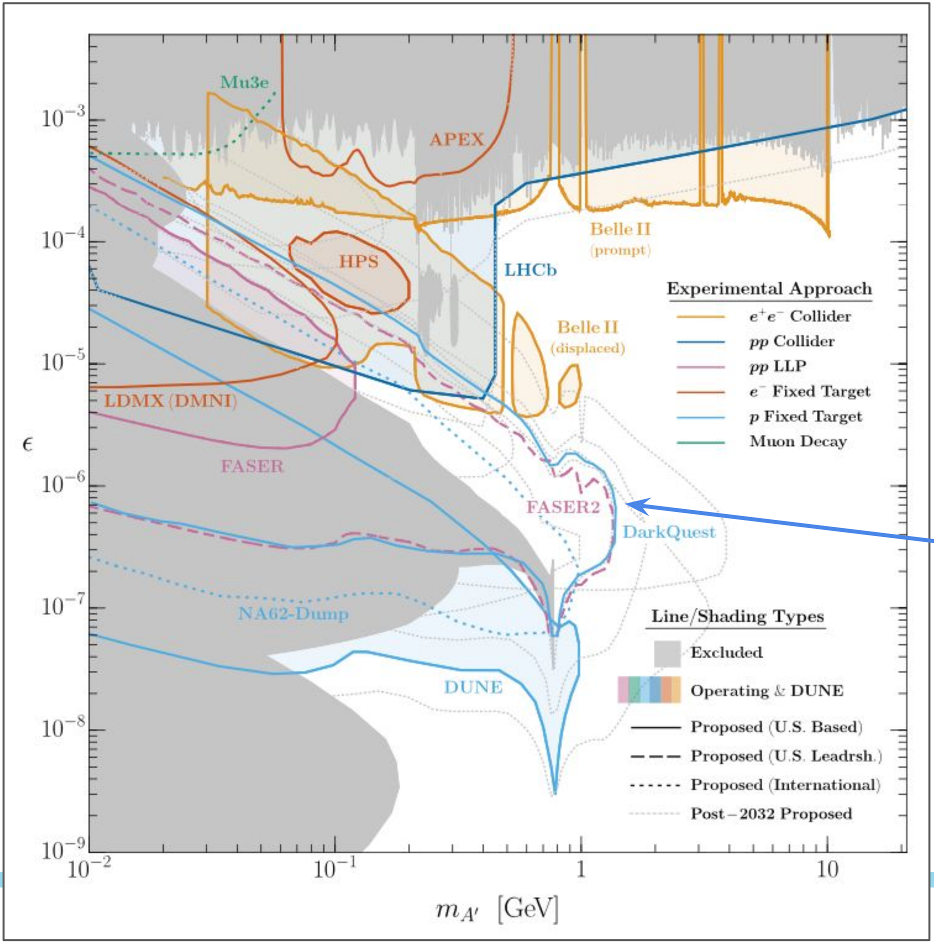
Exploring dark sector portals with high intensity experiments

Benchmarks:
***dark photon*,**
scalar, neutrino portal,
axion-like particle (ALPs)

New flavors and rich structures in dark sectors

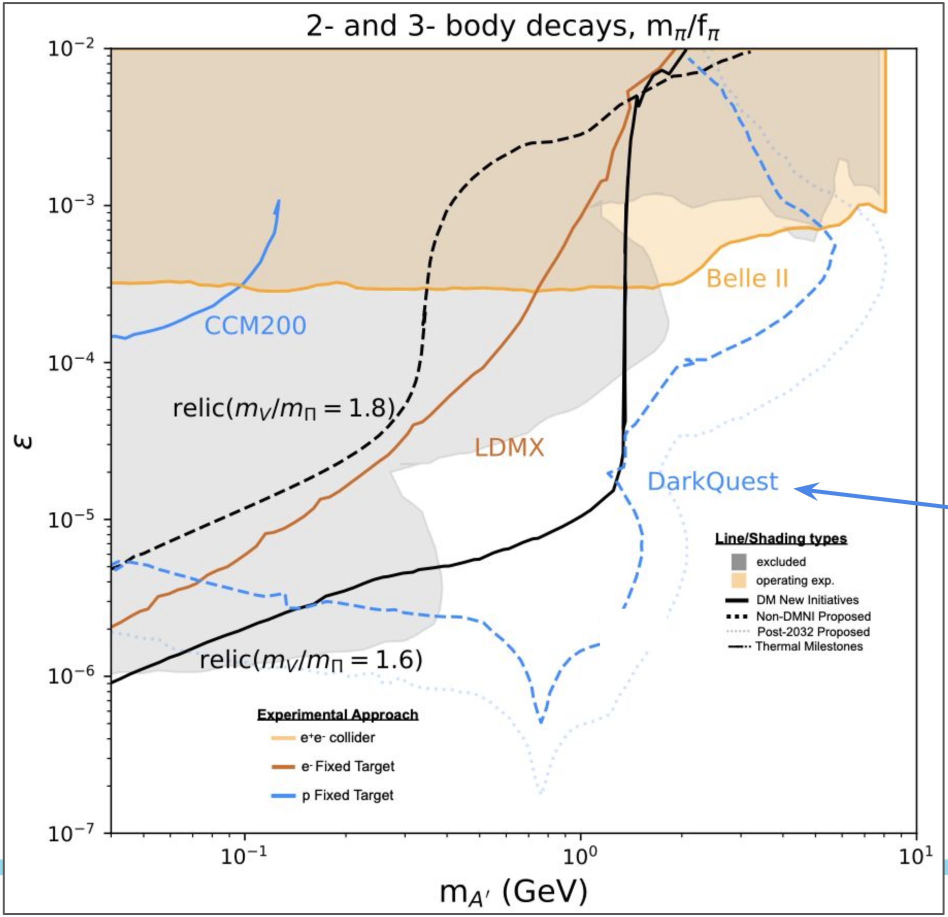
Benchmarks:
***g-2*, SIMPs,**
inelastic DM,
non-minimal ALPs

Snowmass: dark sectors at accelerators summary



Visible Dark Photon portal benchmark

Snowmass: dark sectors at accelerators summary



SIMP benchmark

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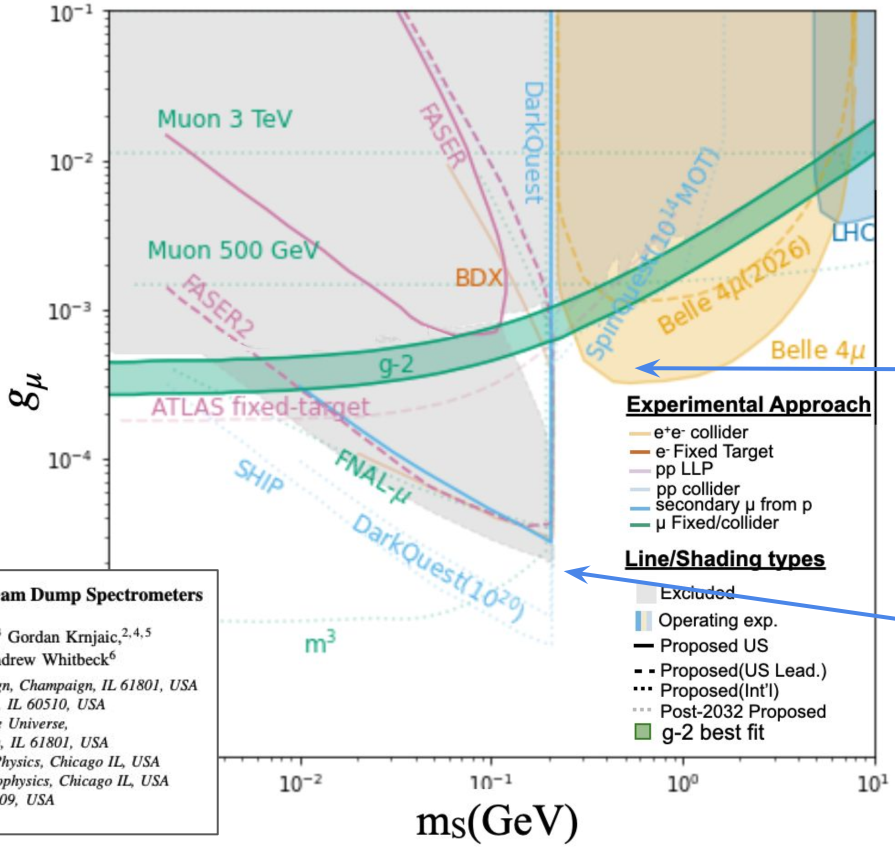
Snowmass: dark sectors at accelerators summary

Muon-philic scalar
g-2 benchmark



Secondary Muons from SpinQuest with 10^{14} Muons

Photons from DarkQuest

https://arxiv.org/abs/2212.00033

New Searches for Muonphilic Particles at Proton Beam Dump Spectrometers

Diana Forbes,[1] Christian Herwig,[2] Yonatan Kahn,[1,3] Gordan Krnjaic,[2,4,5]
Cristina Mantilla Suarez,[2] Nhan Tran,[2] and Andrew Whitbeck[6]

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[6]*Texas Tech University, Lubbock, TX 79409, USA*

(Dated: December 2, 2022)

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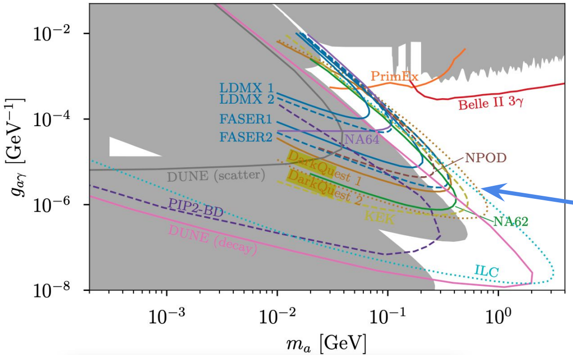
Rich phenomenology beyond Snowmass benchmarks

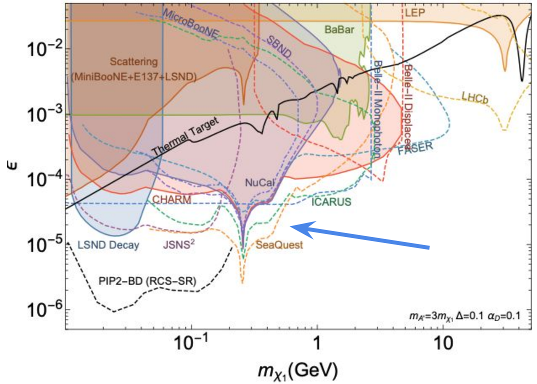
Many different dark sector signatures and many different models can be looked for by SpinQuest.

A couple of examples:

Axions



Inelastic Dark Matter



Signature	Model
e^+e^-	dark photon dark Higgs leptophilic scalar*
$e^+e^-e^+e^-$	Higgsed dark photon
$e^\pm\pi^\mp, e^\pm K^\mp, \cdots$	sterile neutrino
$e^+e^- +$MET	inelastic dark matter strongly interacting dark matter hidden valleys
$\pi^+\pi^-, K^+K^-, \cdots$	dark Higgs*
$\gamma\gamma$	axion-like particle*

Dark Sectors at SpinQuest and upgrade

SpinQuest (now!)

- Initial long-lived dark photon (μμ) searches, commission displaced tracking
- Explore open g-2 phase space, prompt S/V → μμ

SpinQuest upgrade (soon!)

- Large increase in sensitivity to dark photon phase space
- Cover open g-2 phase space, displaced S/V → ee,γγ
- Enable searches for inelastic DM, SIMPs, ALPs, etc.

Scientific program

Deliver world-leading **spin and dark sector physics** with unique experimental capabilities **in the next 2-4 years** before the PIP-II shutdown

Alignment of the experiment with the laboratory's scientific mission

- Spin physics important for fundamental understanding of proton structure, underpinning many aspects of nuclear theory and exploration of the proton spin puzzle
- Searches for dark matter and sectors among the most critical HEP questions of this generation
    - Thermal freeze out relic DM (MeV-TeV) at accelerators is highly motivated DM scenario
    - Highly aligned with searches at other Fermilab experiments
        - MiniBooNE DM, ArgoNeuT millicharged, Short-baseline program, Nova, DUNE, and more!

Potential to leverage and augment the laboratory's capability

- **Highly leverages existing Fermilab infrastructure, accelerator, detector capabilities**
    - 120 GeV high intensity proton beam, NM4 hall, SeaQuest/SpinQuest detector
- Unique accelerator-based proton fixed target experiment gives new window into dark sector searches
- Drell-Yan for spin physics is a powerful complement to future nuclear facilities (e.g. EIC (SIDIS))

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Technical requirements: resources & schedule

Technical requirements

1. **Dark sector searches beyond muon final states**
   - Identify and reconstruct displaced electromagnetic/hadronic signatures
   - EMCal with good energy resolution, granularity at high beam repetition rate

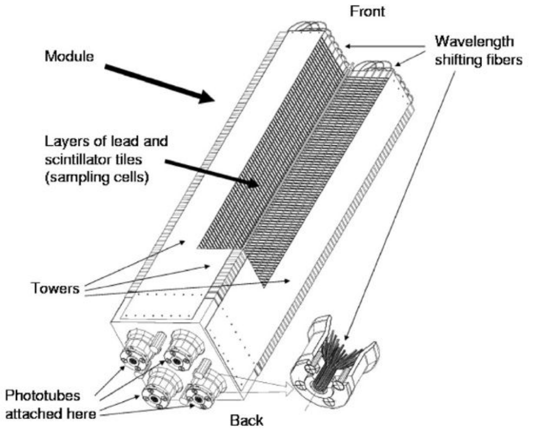
2. **Gluon transversity measurements in Drell-Yan**
   - Installation of a new coil around target cell
   - Building and installing a new ss-RF modulating NMR system

3. **Increased (displaced) tracking acceptance and performance**
   - Additional tracking layer before the KMAG
   - Large area detector with good position granularity

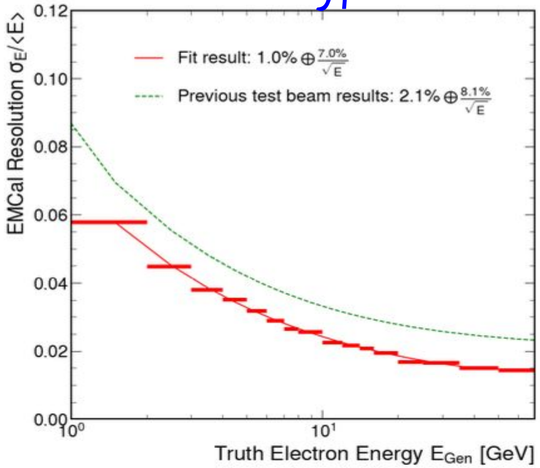
EMCal technology and performance

Sampling calorimeter (Pb-Scintillator) from PHENIX

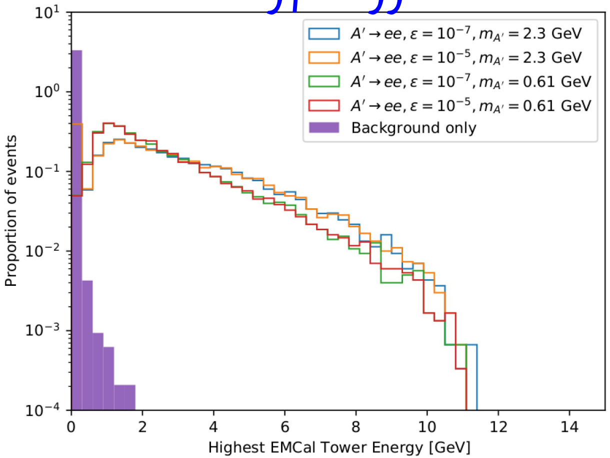
- Excellent light yield and energy resolution
- Low background signature for simple triggering
- Particle identification from E/p ratio

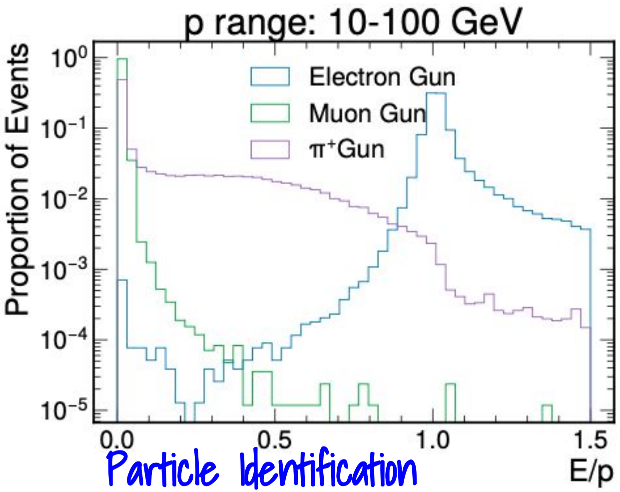


Electron energy resolution



EMCal Energy Trigger



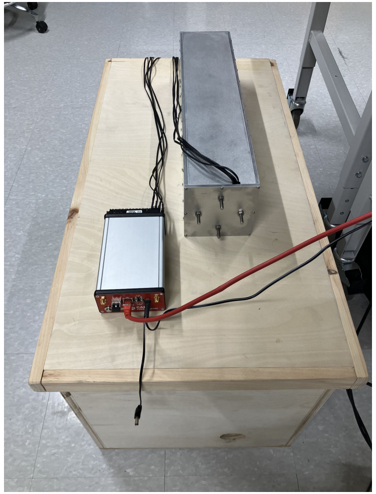


Particle Identification

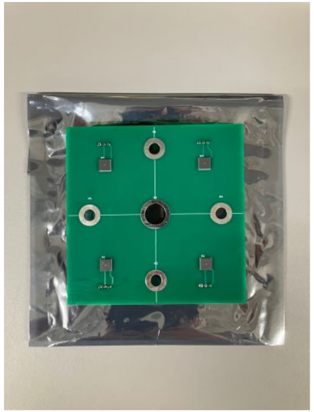
EMCal Readout Electronics

- Test stand has been developed to study new EMCal readout electronics
- Working prototype based on CAEN FERS-5200 system (Citiroc ASIC) with custom front-end 4-channel SiPM board
- Available for Test Beam and background rate measurements in NM4 in 2023

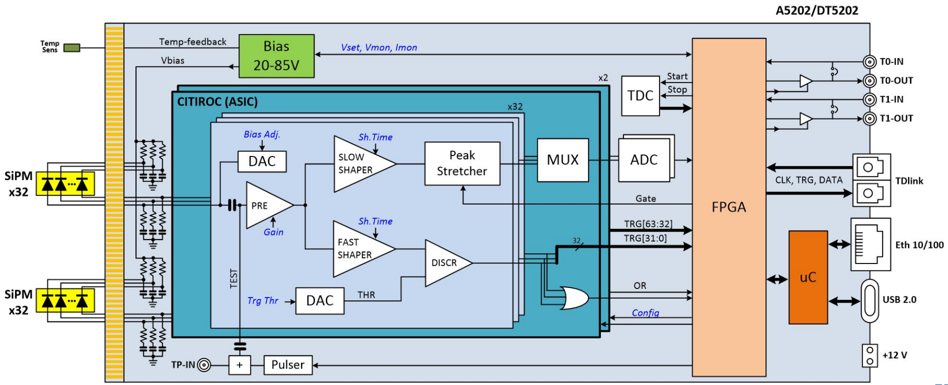
EMCal Test Stand at BU



Custom 4-ch SiPM Board



CAEN 64-ch A5202 ASIC Board



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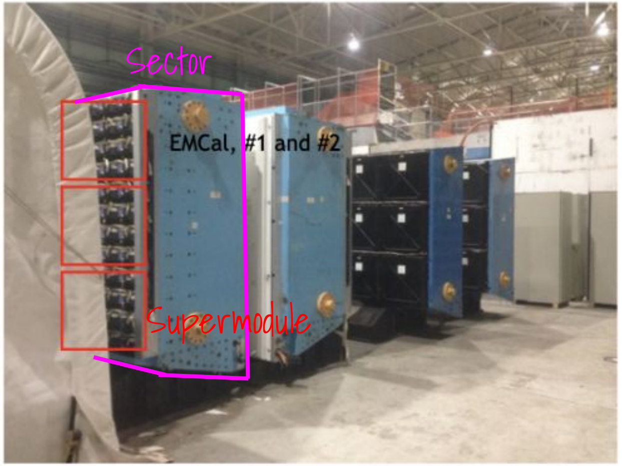
EMCal upgrade resources

- Readout Electronics upgrade budgeted to be ~$500k
  - ~$150k for 648 SiPM boards (2592 readout channels)
  - ~$350k for 41 64ch ASIC boards, DAQ system, cables, power supplies, etc.
  - Only modest electrical engineering support needed (available at Universities)
- Shipping from Brookhaven to Fermilab and temporary storage
- Detector installation
  - Move forward third tracking station
  - Mechanical structure for the EMCal sector
  - Sector and Module installation
  - Safety review and documentation
  - Requirements
    - ~1-2 technician support for 1 month
    - ~2 months for mech. engineering
    - ~1 week of geodesist
    - ~1 week of 2 metrologist team



Polarized target for transversity measurements

Semi-saturating RF NMR System

- Manipulates spin of the deuterons in frequency domain
  - Driving transitions from m=-1 to m=0
  - Quickly switch between vector+tensor to vector only
- Nuclear Magnetic Resonance Measurements
- Capabilities to:
  - Measure the polarization
  - Determine How to Optimize
  - Manipulate in Real Time

Prototype already built and operational at UVA
Synergistic with planned/approved experiments at JLab using this system

Optimal system estimated to cost $65K to construct

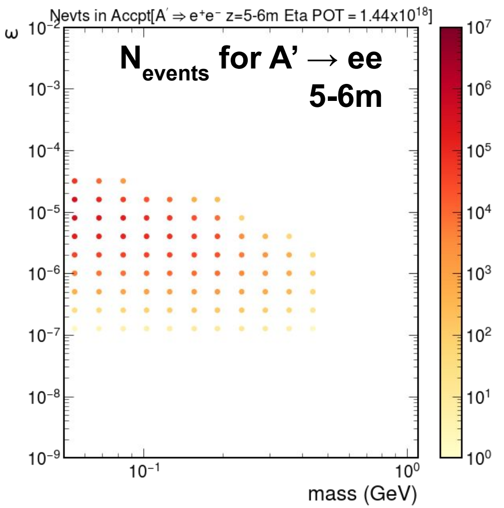
Additional tracking layer

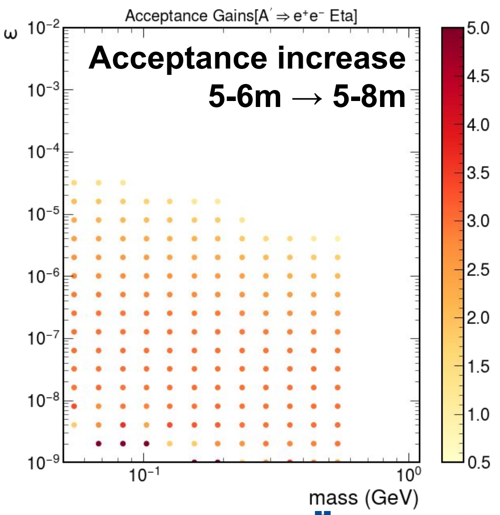
An additional tracking layer between FMAG and KMAG would increase acceptance for displaced particles and help with pattern recognition

- increased signal yield, particularly for lower coupling values
- simulation studies in the next few months to quantify the latter improvements

This upgrade is not critical path but we would like to consider the performance and physics gains for both spin and dark sectors

Proportional chambers from HyperCP exist and there are sufficient readout electronics if we would like to pursue this with modest resources.





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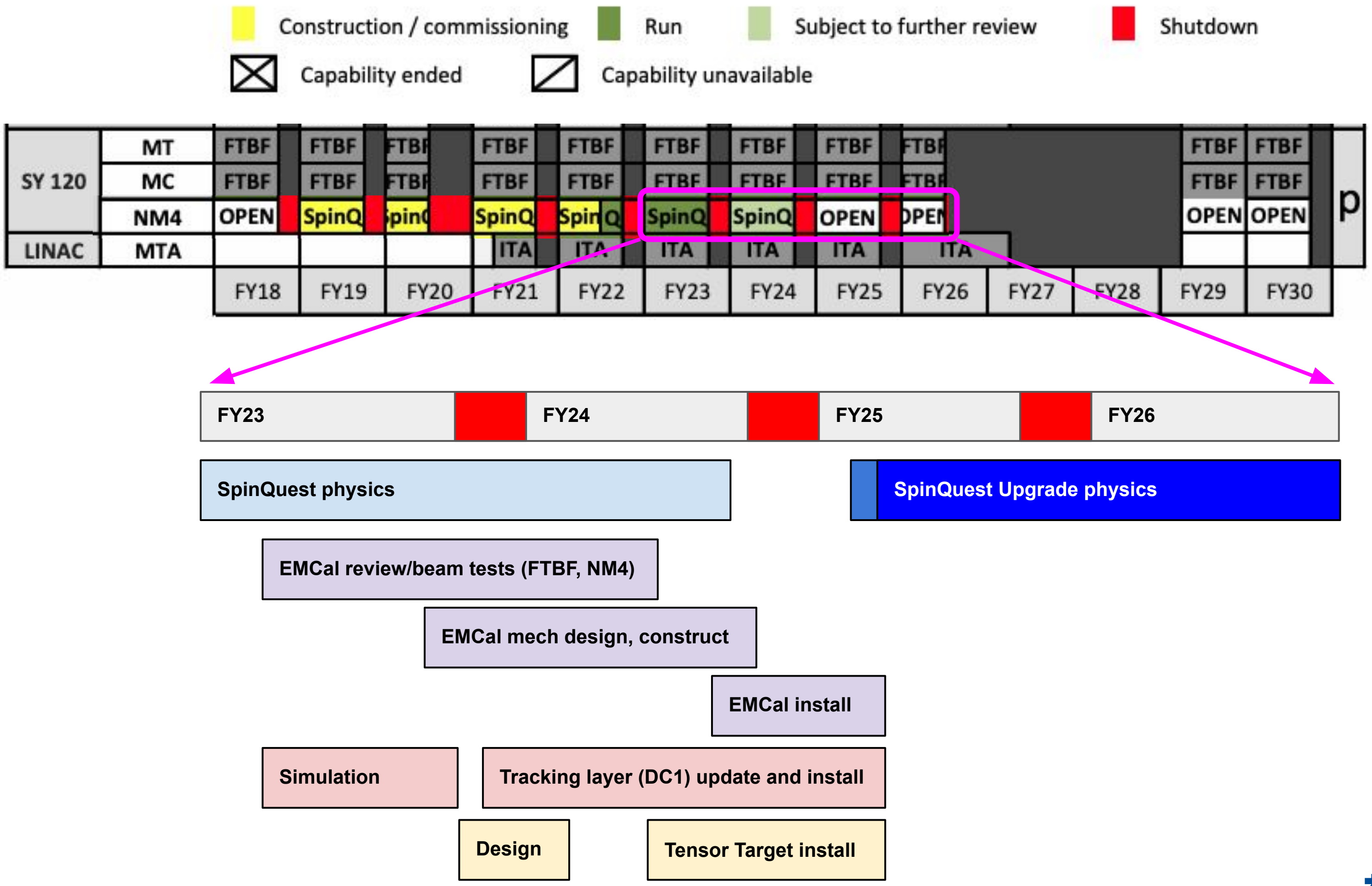
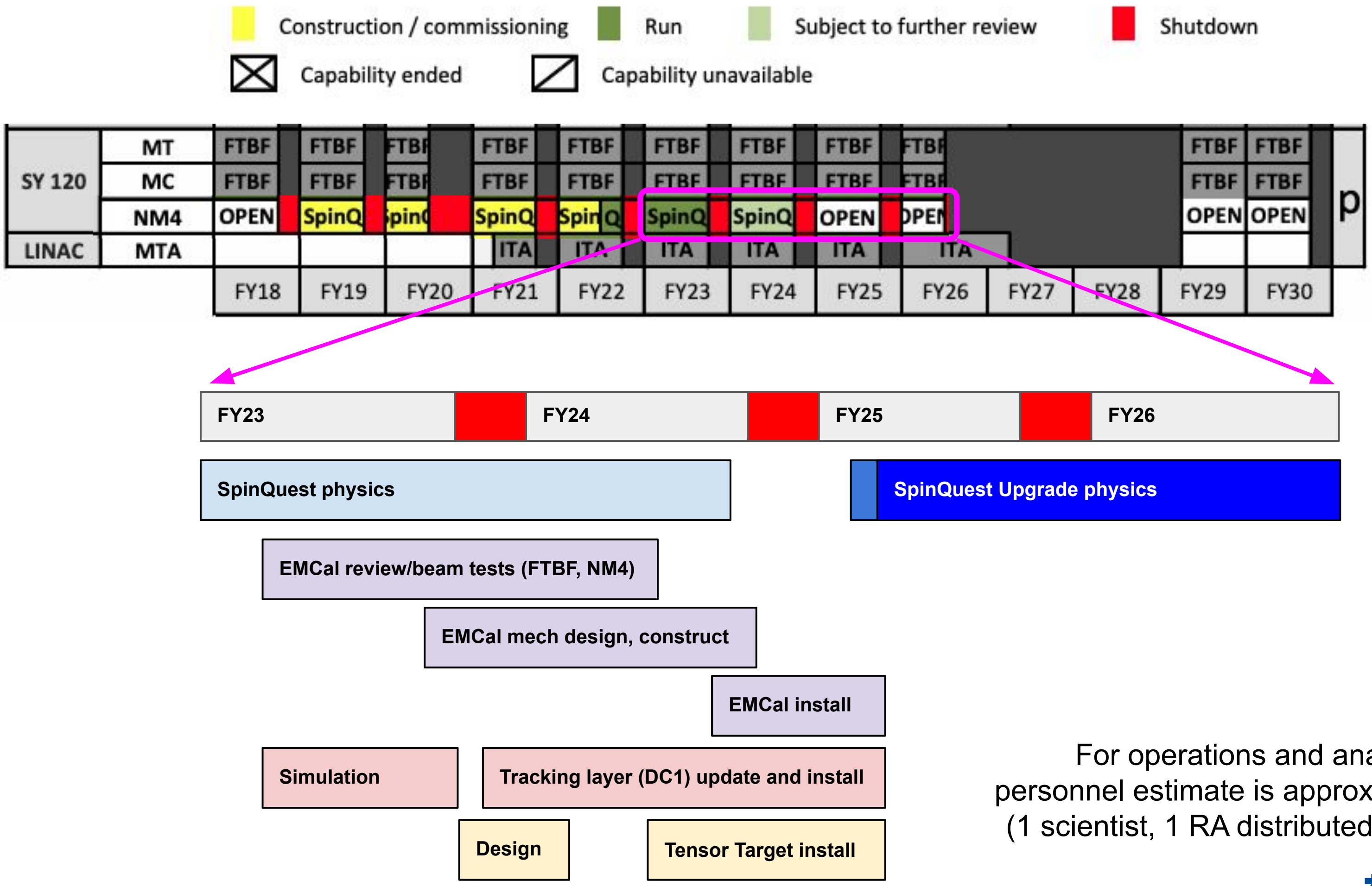


Construction / commissioning
Run
Subject to further review
Shutdown
Capability ended
Capability unavailable
SY 120
MT
MC
NM4
LINAC
MTA
FTBF
OPEN
SpinQ
ITA
p
FY18
FY19
FY20
FY21
FY22
FY23
FY24
FY25
FY26
FY27
FY28
FY29
FY30
FY23
FY24
FY25
FY26
SpinQuest physics
SpinQuest Upgrade physics
EMCal review/beam tests (FTBF, NM4)
EMCal mech design, construct
EMCal install
Simulation
Tracking layer (DC1) update and install
Design
Tensor Target install



For operations and analysis, Fermilab personnel estimate is approximately 2 FTEs (1 scientist, 1 RA distributed over 5 people)

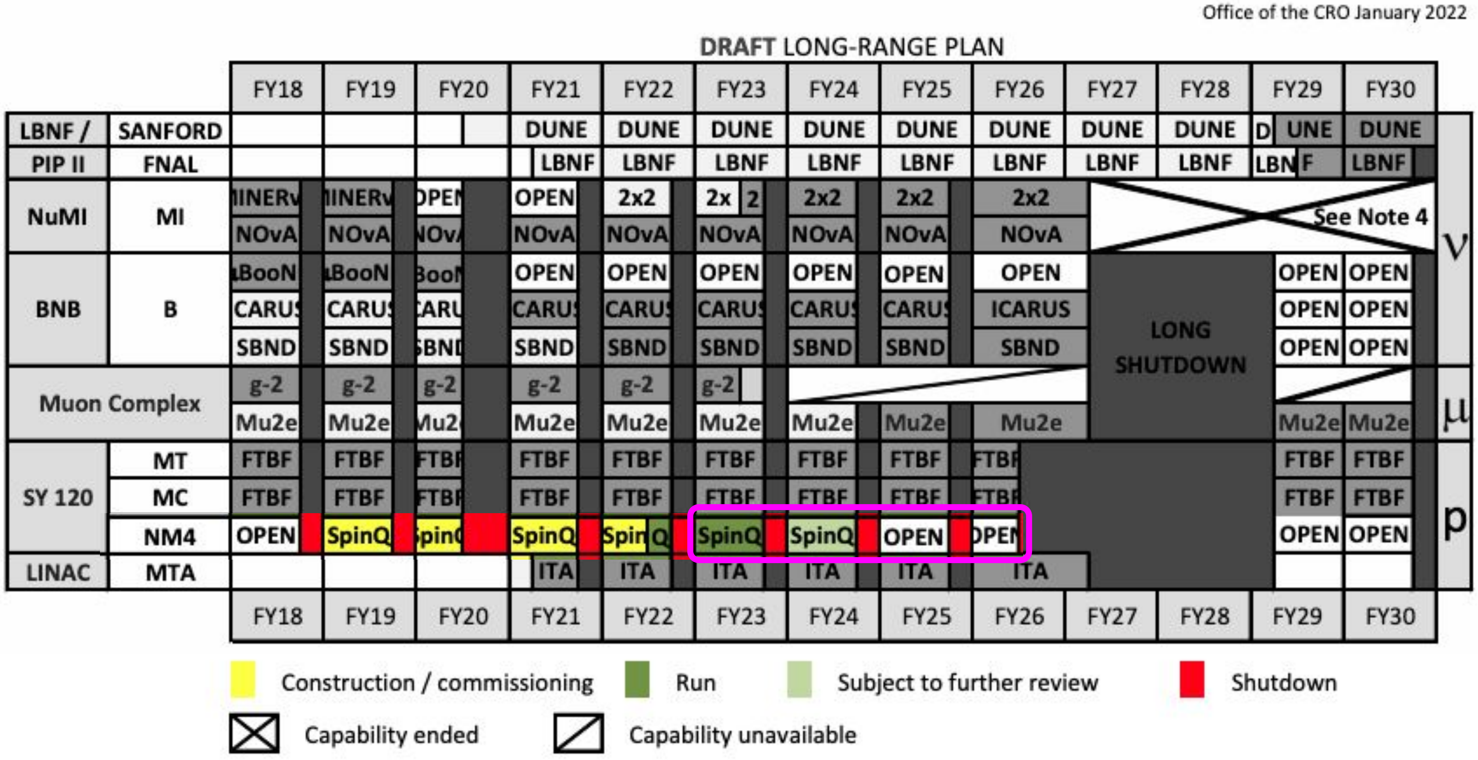
Outlook

- Scientific goals and impact
  - **Spin physics** - world-leading and unique transversity program
  - **Dark Sector physics** - high-impact search program for visible portals, scenarios related to g-2, and non-minimal models
- Alignment with Fermilab mission and dark sector searches at neutrino experiments, leveraging laboratory capabilities
- Technical requirements
  - Needs presented for EMCal, target upgrade, and potential additional tracking layer

Vision: cutting-edge spin and dark sector program running together

Additional material

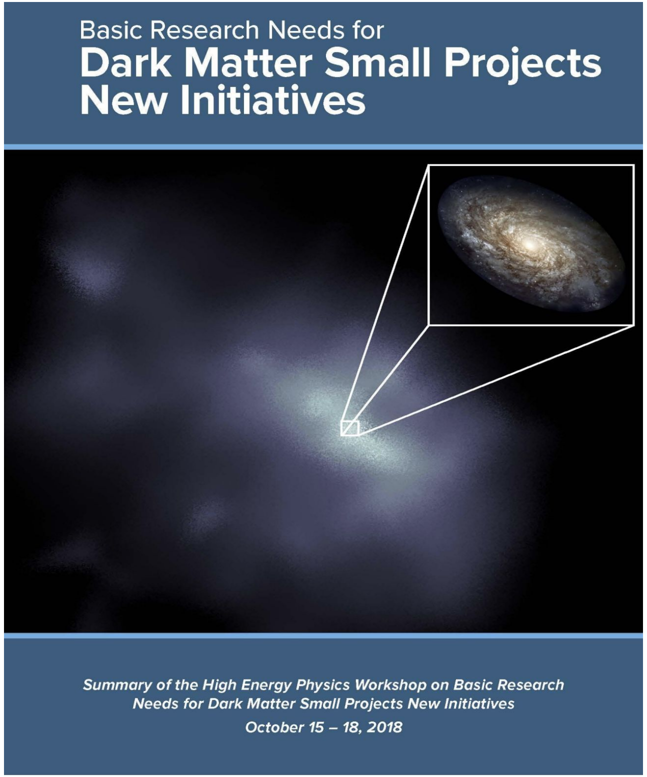
Timelines

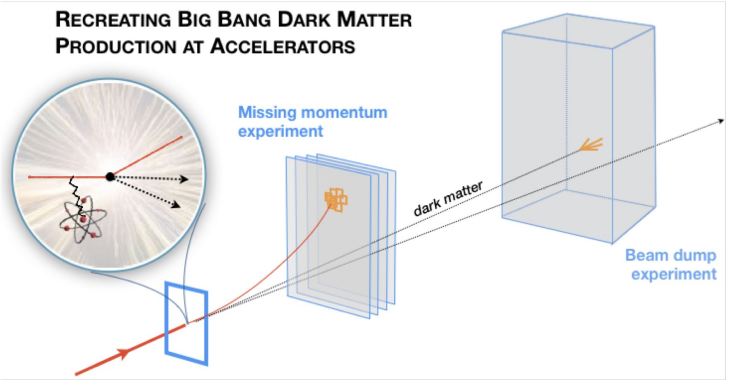


Near-term window of opportunity, including FY25-26

Setting the stage: dark sectors at accelerators

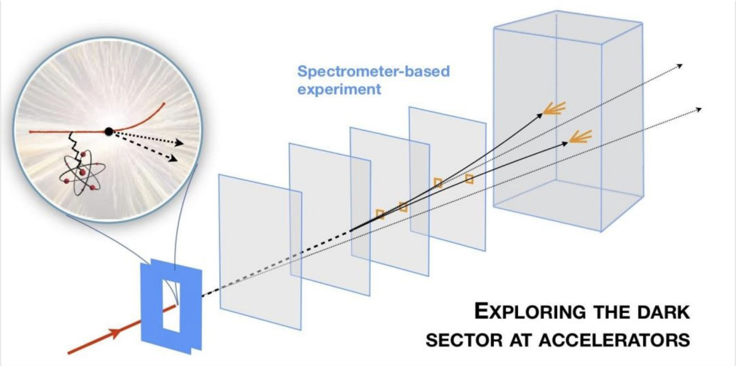
Dark Matter New Initiatives report





Thrust 1: target thermal dark matter milestones

Thrust 2: Exploration structure of dark sectors



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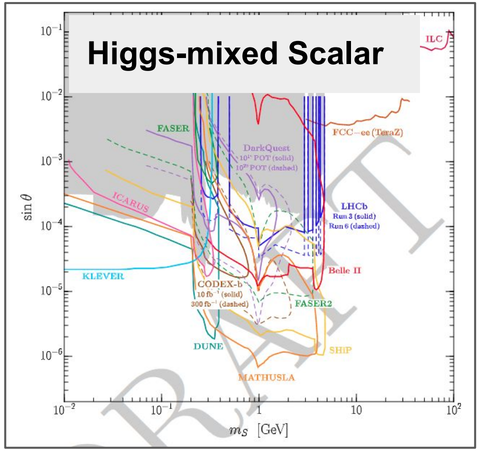
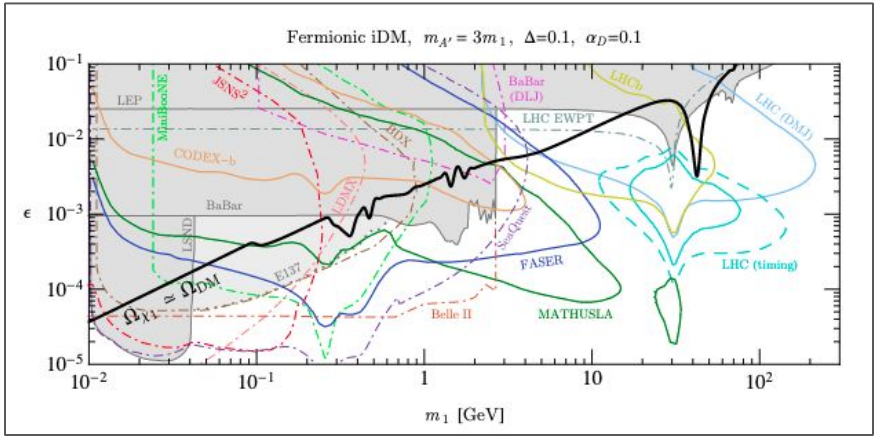
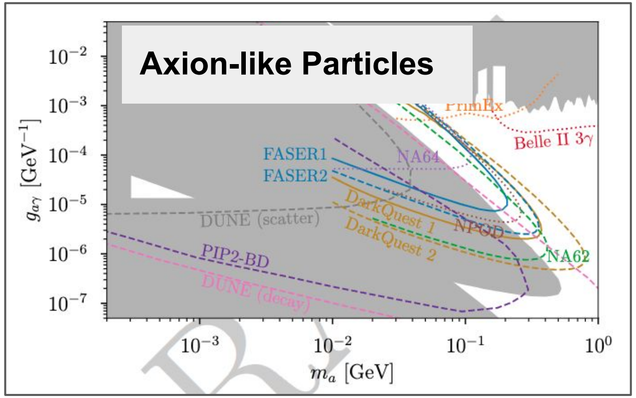
Sensitivity to other Snowmass benchmark scenarios

RF6 reports (to appear)
Berlin, Gori, Schuster, Toro: 1804.00661
Batell, Evans, Gori, Rai: 2008.08108
Blinov, Kowalczyk, Wynne: 2112.09814

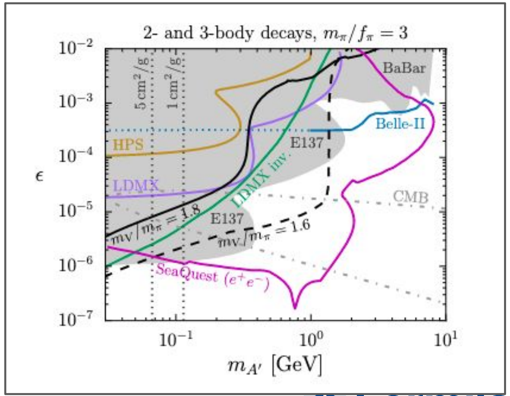


Inelastic Dark Matter
(DM candidate with *testable* targets)





Strongly-Interacting Massive Particles
(DM candidate with *testable* targets)



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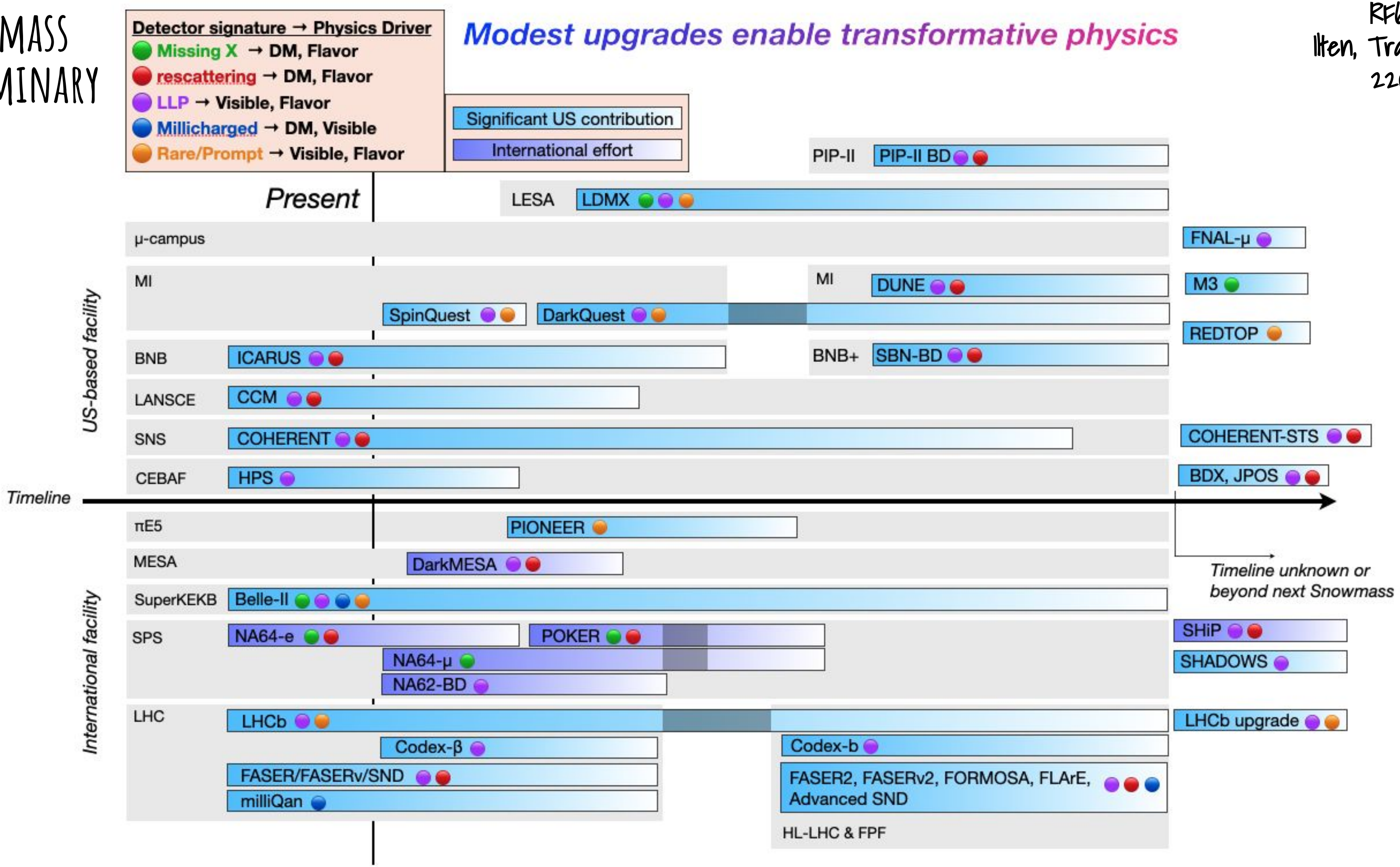
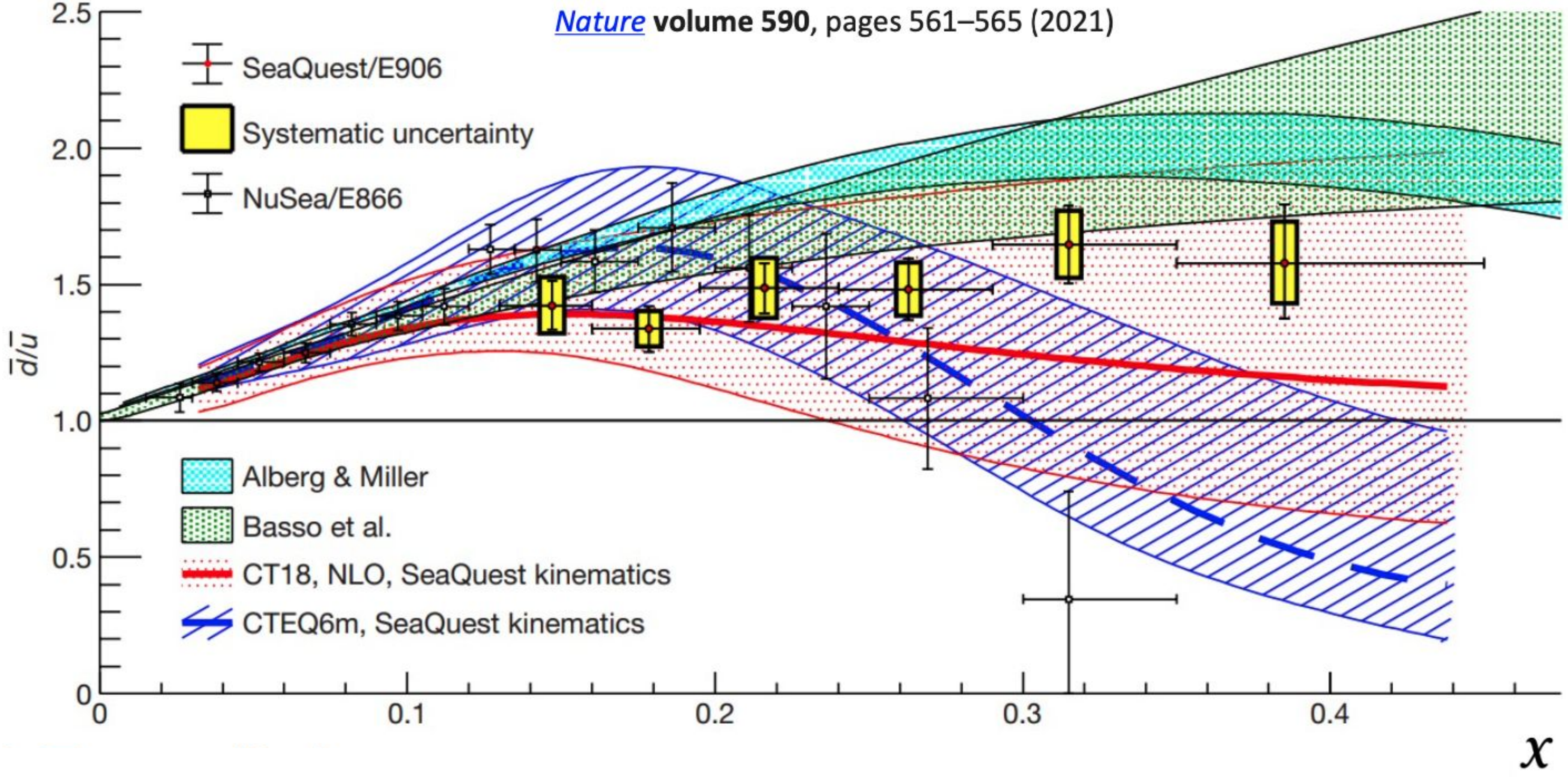
Snowmass Preliminary

Modest upgrades enable transformative physics

RF6 report
Ilten, Tran, et al
2206.04220



SeaQuest

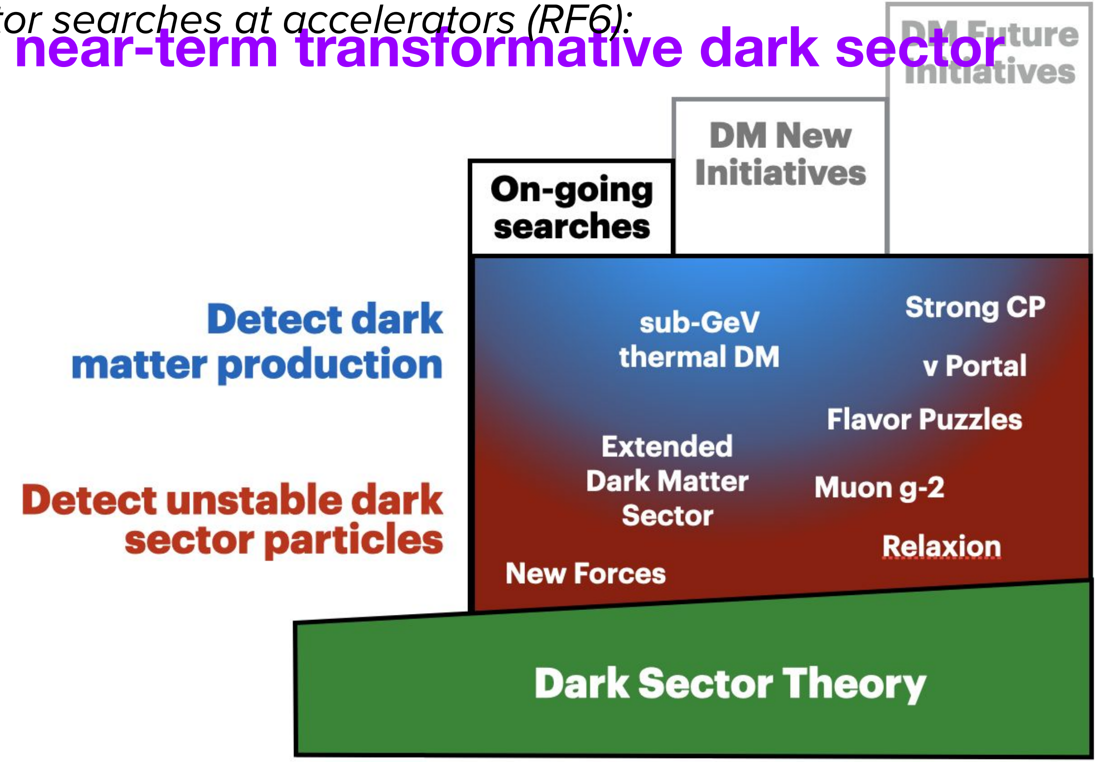

Nature volume 590, pages 561–565 (2021)
SeaQuest/E906
Systematic uncertainty
NuSea/E866
Alberg & Miller
Basso et al.
CT18, NLO, SeaQuest kinematics
CTEQ6m, SeaQuest kinematics
$\bar{d}/\bar{u}$
2.5
2.0
1.5
1.0
0.5
0
0
0.1
0.2
0.3
0.4
x

Setting the stage: dark sectors at accelerators

RF6 report (to appear)

Snowmass message from dark sector searches at accelerators (RF6):

Modest upgrades enable near-term transformative dark sector physics



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Physics Beyond Colliders

PBC Experiments/projects able to produce results within 10 years

Experiment	Dataset assumed for sensitivities, beams	Tentative Timescale	References	Benchmarks	Comments
NA64-e	$3x10^{12}$ eot, electrons, 100 GeV	< LS3 (2025) (approved)	CERN-SPSC-2018-004 ; SPSC-P-348-ADD-2.	BC1, BC2, BC9	Extrapolation from data
FASER	150 fb^{-1}, pp@13 TeV	< LS3 (2025) (approved)	arXiv:1812.09139 ; CERN-LHCC-2018-036	BC1, BC9, BC9, BC11	Full simulation ? Bkg included?
NA62-dump	10^{18} pot, protons 400 GeV	< LS3 (2025) (approved)	CERN-SPSC-2019-039 ; SPSC-P-326-ADD-1	BC1, BC4, BC5, BC6, BC7, BC8, BC9, BC10, BC11	Full simulation, bkg from data
milliQan	3 ab^{-1}	First run: 2022		BC3	
nTOF	$6x10^{17}$ pot, protons, 20 GeV	2022-2023	INTC-I_233	BC1	New experiment
NA64-mu	Up to $2x10^{13}$ mot, muons, 160 GeV ~10^7 μ/spill	LS3 (2026) < run < LS4 (2031) Pilot run 11/2021	CERN-SPSC-2019-002 ; SPSC-P-359, CERN-SPSC-2018-024 ; SPSC-P-348-ADD-3 1903.07899, 2110.15111	BC2	Full simulation, Bkg included.
SHADOWS	Phase1: 10^{19} pot, protons , 400 GeV Phase2: 5 10^{19}, protons, 400 GeV	LS3 < run < LS4 (2031) LS4 < run < LS5 (2035)	EoI: 2110.08025	BC4, BC5, BC6, BC7, BC8, BC10, BC11	Fast simulation, bkg being estimated using dump data in ECN3

UNDER CONSTRUCTION

In green: already approved
In black: under consideration

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Physics Beyond Colliders

PBC experiments/projects able to produce results between 10 and 20 years

Experiment	Dataset assumed for sensitivities, beams	Tentative Timescale	References	Benchmarks	Comments
SHiP	$2x10^{20}$ pot, 400 GeV protons	2037+ ?	CDS: CERN-SPSC-2019-049 ; SPSC-SR-263 Progress Report: CERN-SPSC-2019-010	BC1, BC2, BC4, BC5, BC6, BC7, BC8, BC9, BC10, BC11	Full simulation, bkg included Based on MC sample: $1.8x10^9$ pot, with p>1 GeV from Progress Report, p. 24, CERN-SPSC-2019-010 ; SPSC-SR-248)
KLEVER/NA62 high intensity	A few 10^{19} pot/year	After LS4 ?	1901.03199	BC4, BC9, ….	Full simulation, bkg evaluated but not included in results?
CODEX-b	300 fb^{-1}, pp@14 TeV	2038 (end of HiLumi) CODEX-beta could start after LS3	EOI: 1911.00481 Background: 1912.03846	BC4, BC5, BC6, BC7, BC8, BC10, BC11	Fast simulation, background evaluated but not included in results?
MATHUSLA	3 ab^{-1}	2038 (end of HiLumi)	Physics case: 1806.07396 LoI: 1811.00927	BC4, BC5, BC6, BC7, BC8, BC10, BC11	Fast simulation, no bkg (bkg being evaluated with data)
FLArE@FPF	3 ab^{-1}	2038 (end of HiLumi)	2109.10905	DM via scattering (BC2)	Fast simulation, no bkg
FASER-2@FPF	3 ab^{-1}	2038 (end of HiLumi)	2109.10905	BC1, BC4, BC5, BC6, BC7, BC8, BC9, BC10, BC11	Fast simulation, no bkg
FORMOSA@FPF	3 ab^{-1}	2038 (end of HiLumi)	2109.10905, 2010.07941	BC3	Fast simulation, no bkg
Gamma Factory	Laser on stripped ions (LHC)	Still undefined.. PoP crucial to understand.	2105.10289 (DP)	BC1, BC6	Fast simulation, no bkg

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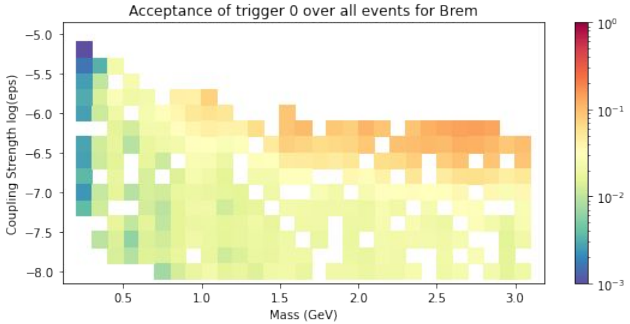
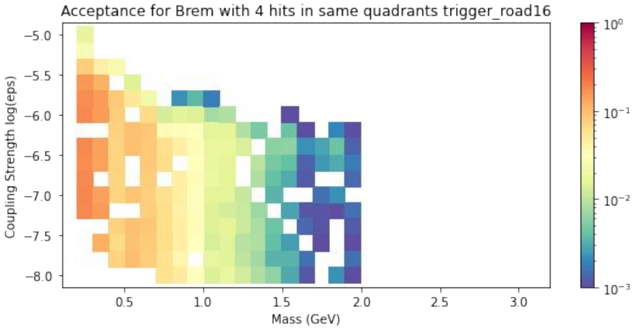
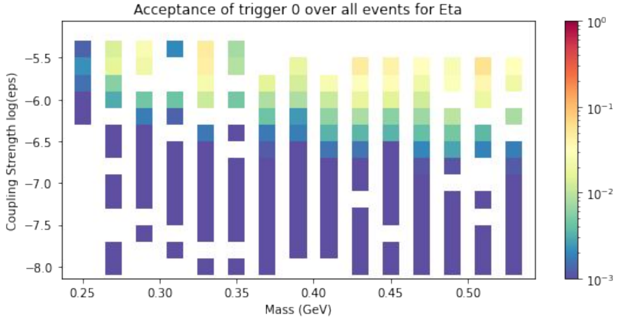
Dark Photon Trigger Efficiency Improvement

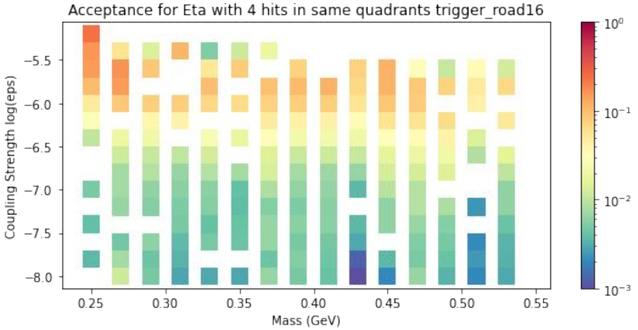
Current FPGA Trigger Efficiency for dark photons

DP Hodo Trigger Efficiency for dark photons









Proton vs. Electron Beams

Proton		Electron
• nuclear collision length ~ 10 cm	$L \sim n_{\text{atom}}\, \ell$	• radiation length ~ 1 cm
• QCD reactions	$\alpha_s \gg \alpha_{\text{em}}$	• EM reactions
• $\gamma + \pi + \mu + \cdots$	dark Higgs, axion, leptophilic scalar	• $\gamma + \cdots$
• Main Injector (FNAL), SPS and LHC (CERN)	100 GeV $\gg$ 1 GeV	• LCLS (SLAC), CEBAF (JLab)