EF09 Highlights - Early Career Perspective

EF09: BSM (more general explorations)

Matthew Citron

https://snowmass21.org/energy/bsm_general

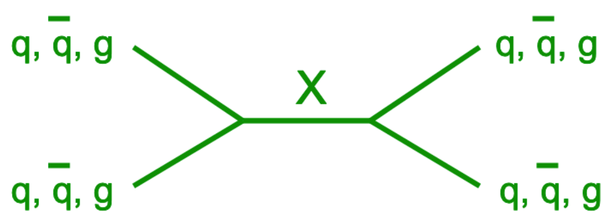
Focus questions for EF09

- Are there **new interactions** or **new particles** around or above the electroweak scale? To what extent can future experiments probe this?
- **Long-lived** and **feebly-interacting** particles represent an alternative paradigm with respect to traditional BSM searches. To what extent can future detectors and accelerators probe such particles?
- How do we conduct searches in a more **model-independent** way ?
- How do we **compare** the results of different experiments in a more model-independent way to **ensure complementarity** and **avoid gaps** in coverage?
- Is **lepton flavour universality** violated? What do we learn from high energy/p_T searches?

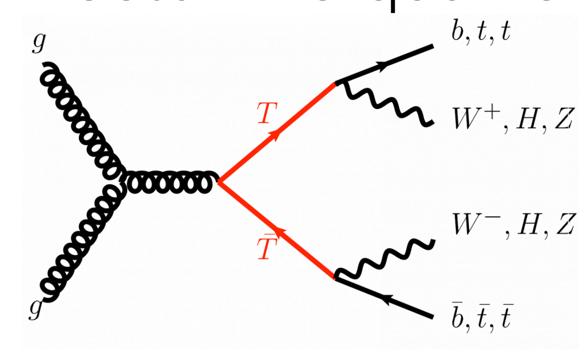
NB: **representative** not comprehensive!

EF09 organised into four areas

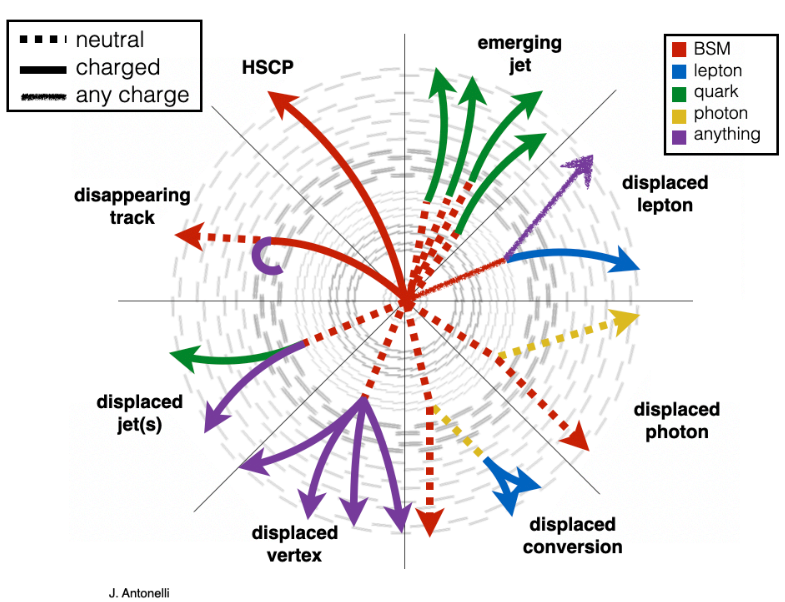
Heavy bosons:
Standard candles (Z’, W’, q*,…)
and new interactions



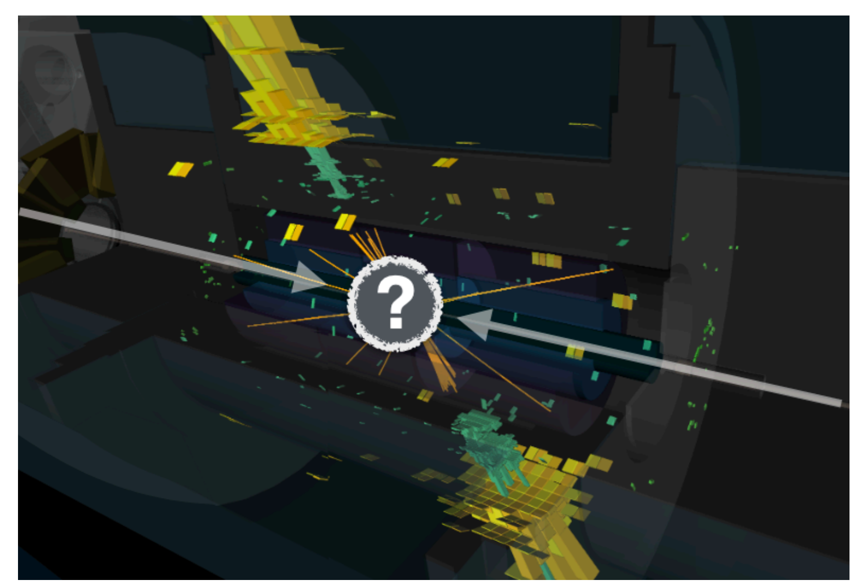
New fermions:
New matter content, HNLs,
vector-like quarks



Long-lived signatures:
New LLP (heavy and light),
interplay with detector design



Other exotica
AI-powered anomaly detection
techniques, inclusive BSM searches



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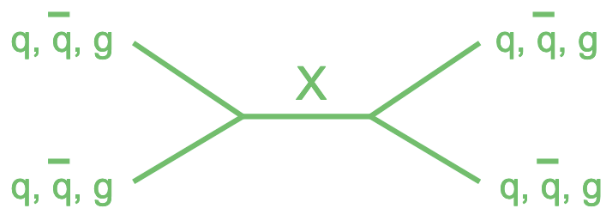

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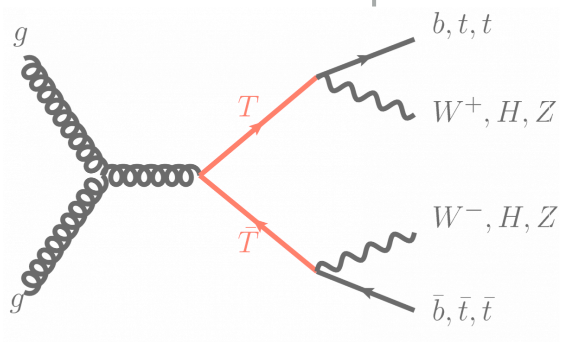

Long-lived signatures:
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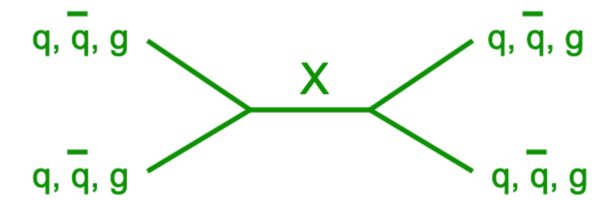
Other exotica
AI-powered anomaly detection
techniques, inclusive BSM searches

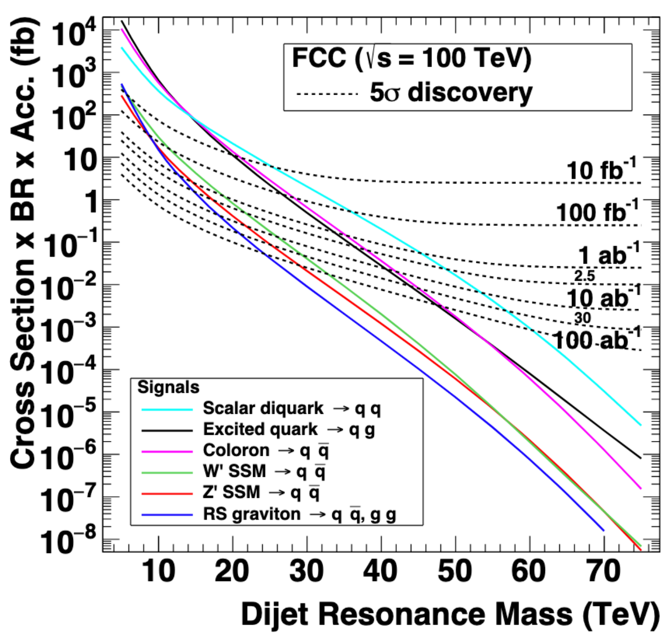
Wide range of activities in these areas (73 LoIs) to help ensure **future detectors and searches** have **comprehensive new physics coverage**

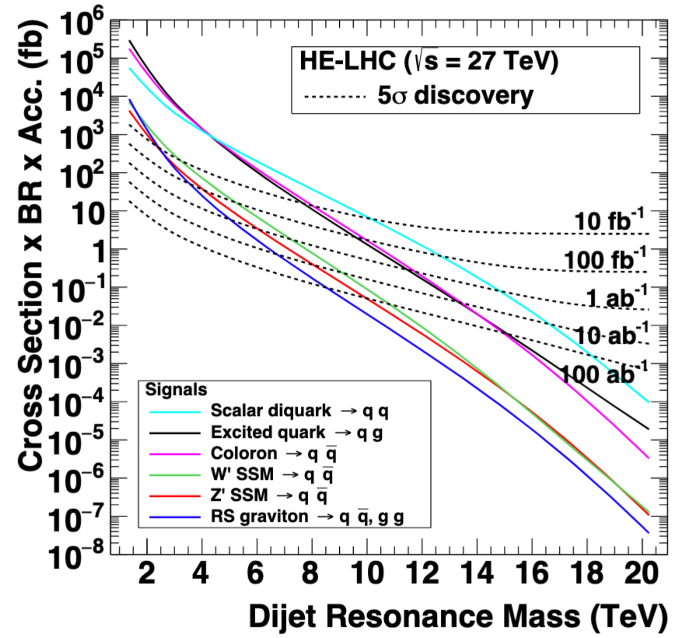
Highlight some recent interesting results across EF09

Sensitivity to dijet resonances at proton-proton colliders

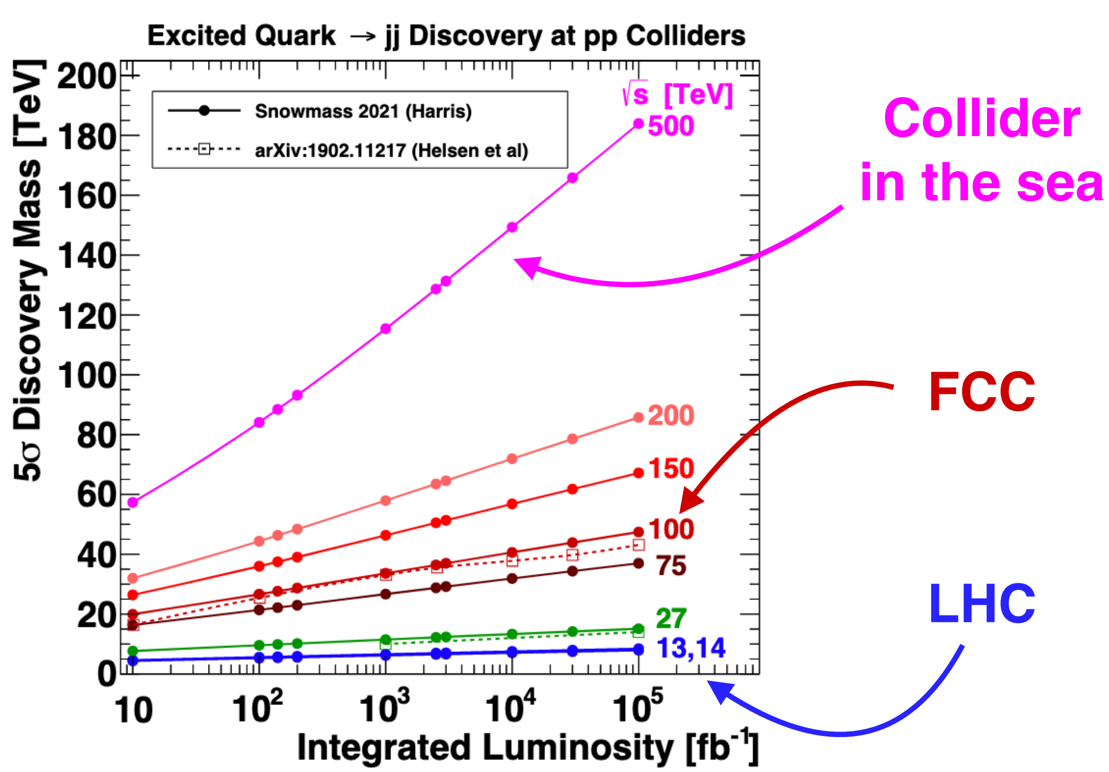


R. Harris with E. Gurpinar Guler, Y. Guler





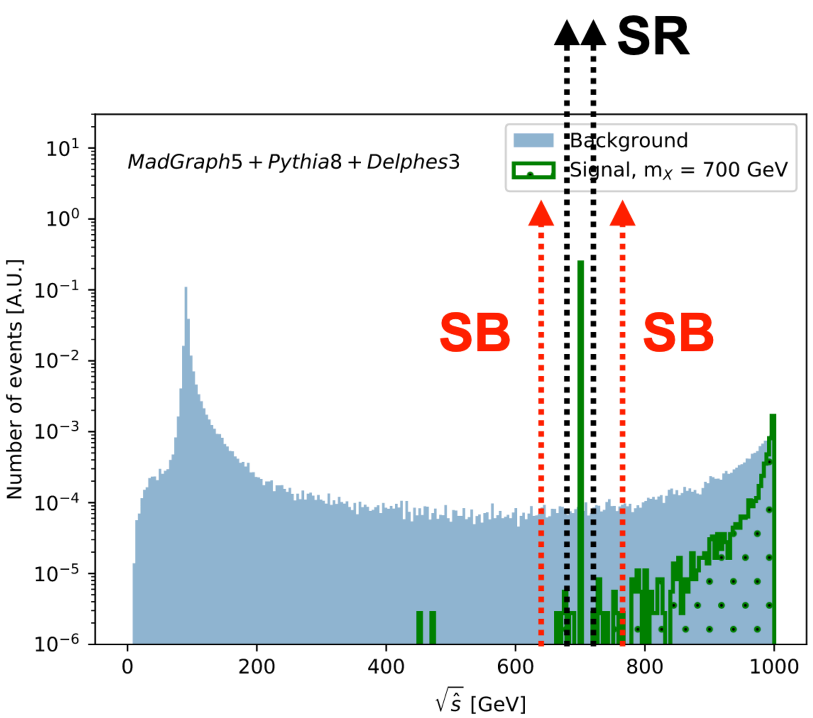
e.g. q* discovery mass (10 ab-1): **44 TeV** **13 TeV**



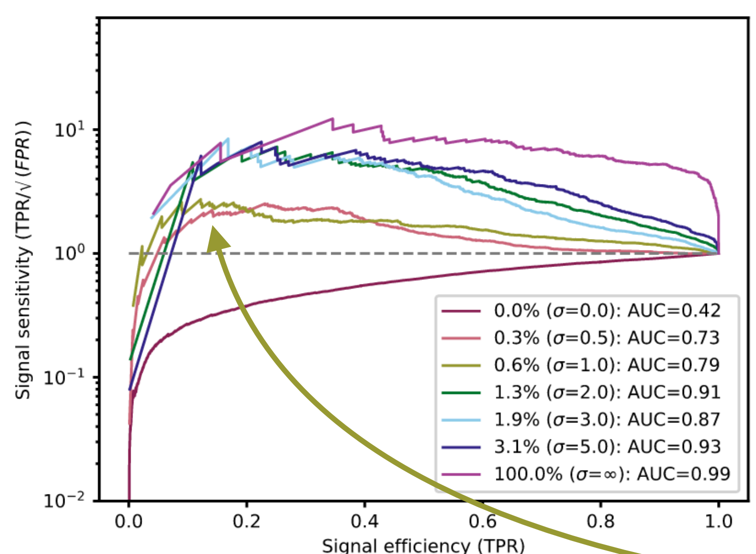
- Standard candle to benchmark hadronic colliders
- Long history: Snowmass 96' first iteration of this effort!
- Granular "scan" of $\sqrt{s}$ indicates **scale of new physics** that can be comprehensively studied
- More benchmark models to be added!

High-dimensional anomaly detection with radiative return in e^+e^- collisions

J. Gonski, J. Lai, B. Nachman, I. Ochoa



SIC: X=700 GeV vs. bkg



Focus on hadronically decaying resonance in generic e^+e^- collider

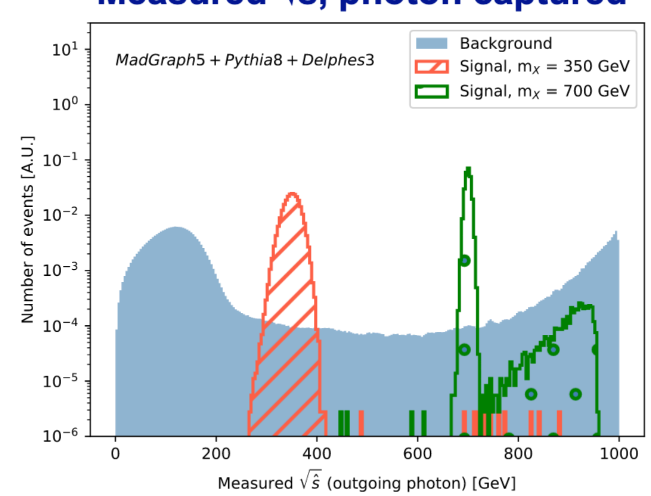
Scan collision $\sqrt{s}$ using **ISR photon energy**

Train PFN using **weakly supervised** data-driven signal vs sideband region configuration

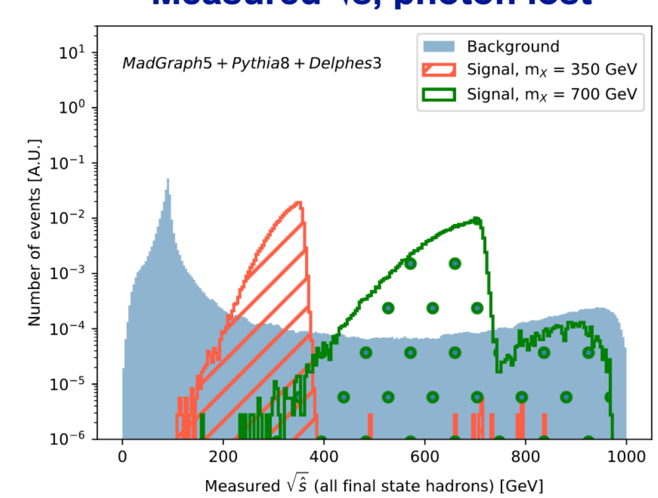
1σ excess enhanced to ~3σ

Important insights into detector design: investigating performance impact of ISR photon direct reconstruction

Measured √s, photon captured



Measured √s, photon lost



https://arxiv.org/abs/2108.13451

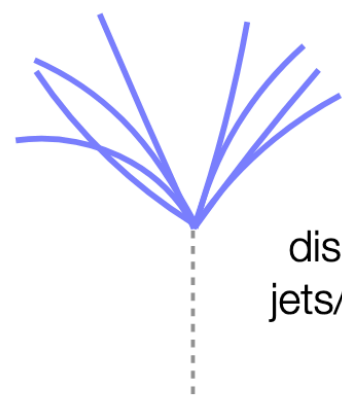
Track based triggers for exotic signatures

K. Di Petrillo, J. Farr, C. Guo, T. Holmes, J. Nelson, K. Pachal

Hardware trigger often **major limitation** for soft exotic signatures

Signatures considered:

long-lived particles

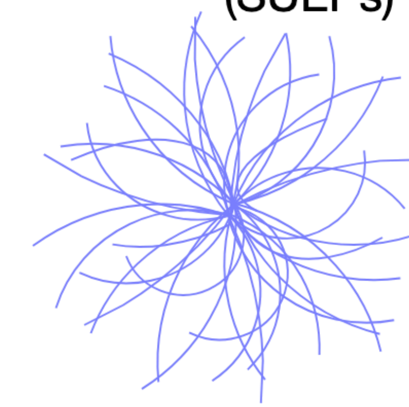


displaced jets/leptons

heavy meta-stable charged particles (HSCPs)

slow moving/ highly ionizing

soft-unclustered energy patterns (SUEPs)

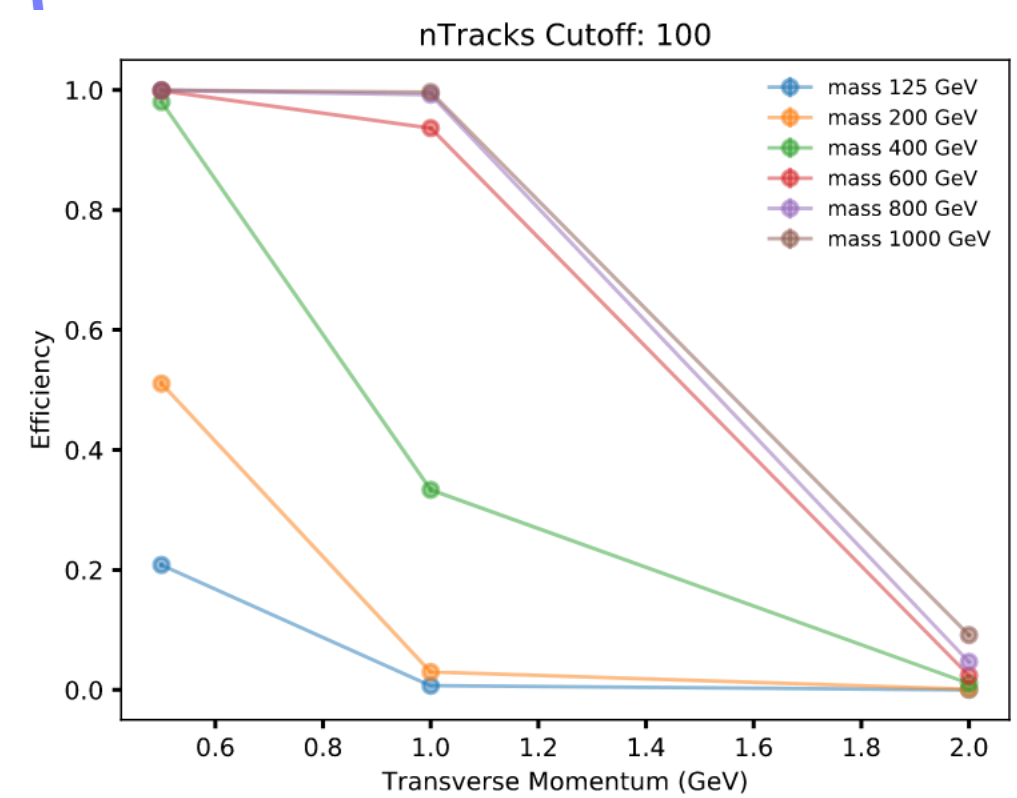


large multiplicity of soft tracks

Determine event level efficiencies for different tracker quantities: p_T, η, d_0 ranges, number of tracks, timing,…

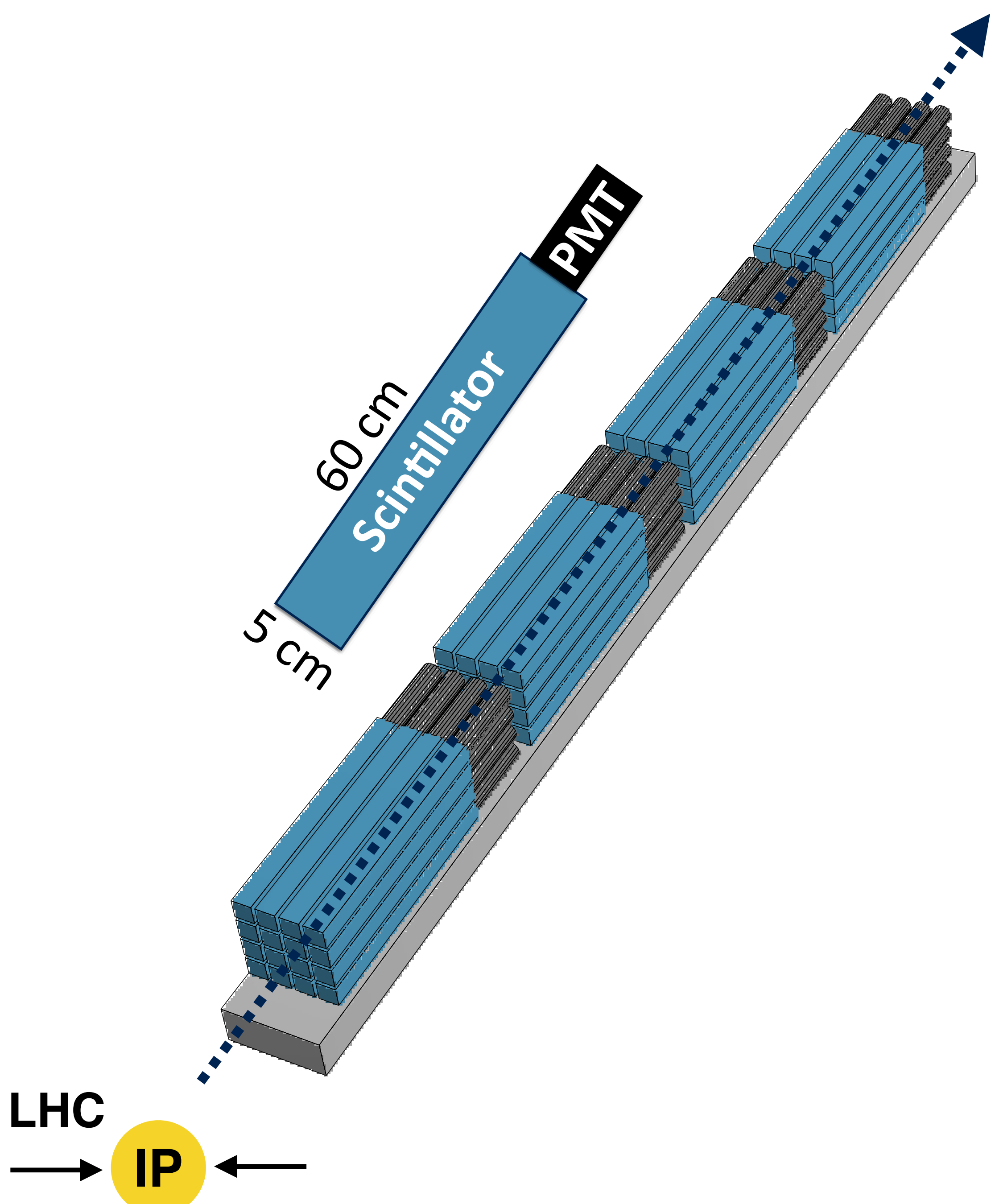
Identify how to achieve **optimal coverage** by **balancing thresholds**

Provide recommendations for design of future track triggers (LHC and beyond)



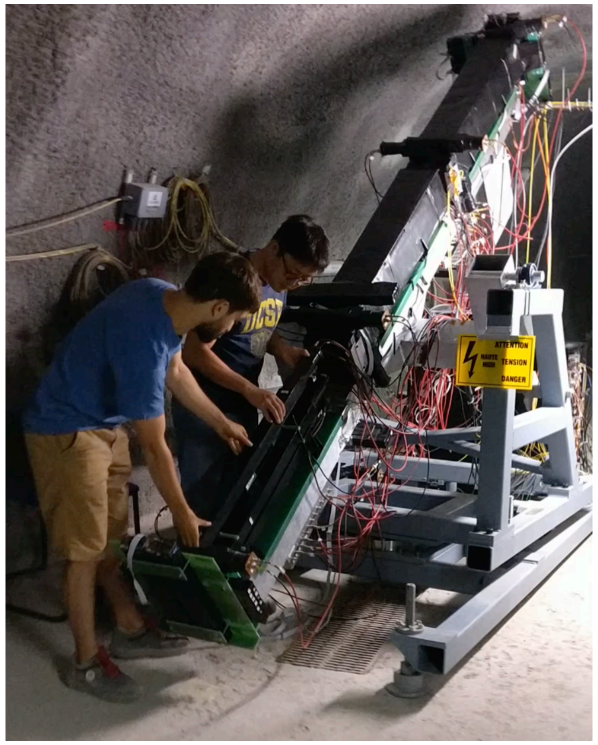
e.g. SUEP result: strong dependence on track p_T threshold

Scintillator searches for millicharged particles

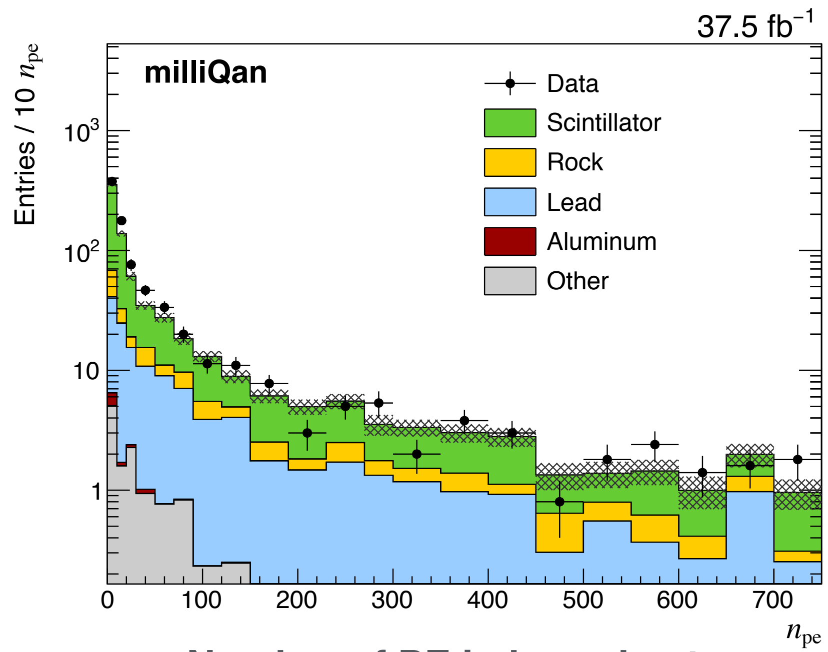


- **Key idea**: use scintillator bar array to detect (very) small ionisation from low charged particles
- Proposals for such detectors at range of facilities: LHC (milliQan/ FORMOSA/MoEDAL-MAPP), J-PARC (SUBMET), FNAL (FerMINI)
- Studies form significant part of (at least) four snowmass efforts: EF/72, RF/114, EF/193, EF/88
- How do we know they'll work?
  → milliQan demonstrator installed at the LHC!

The milliQan demonstrator

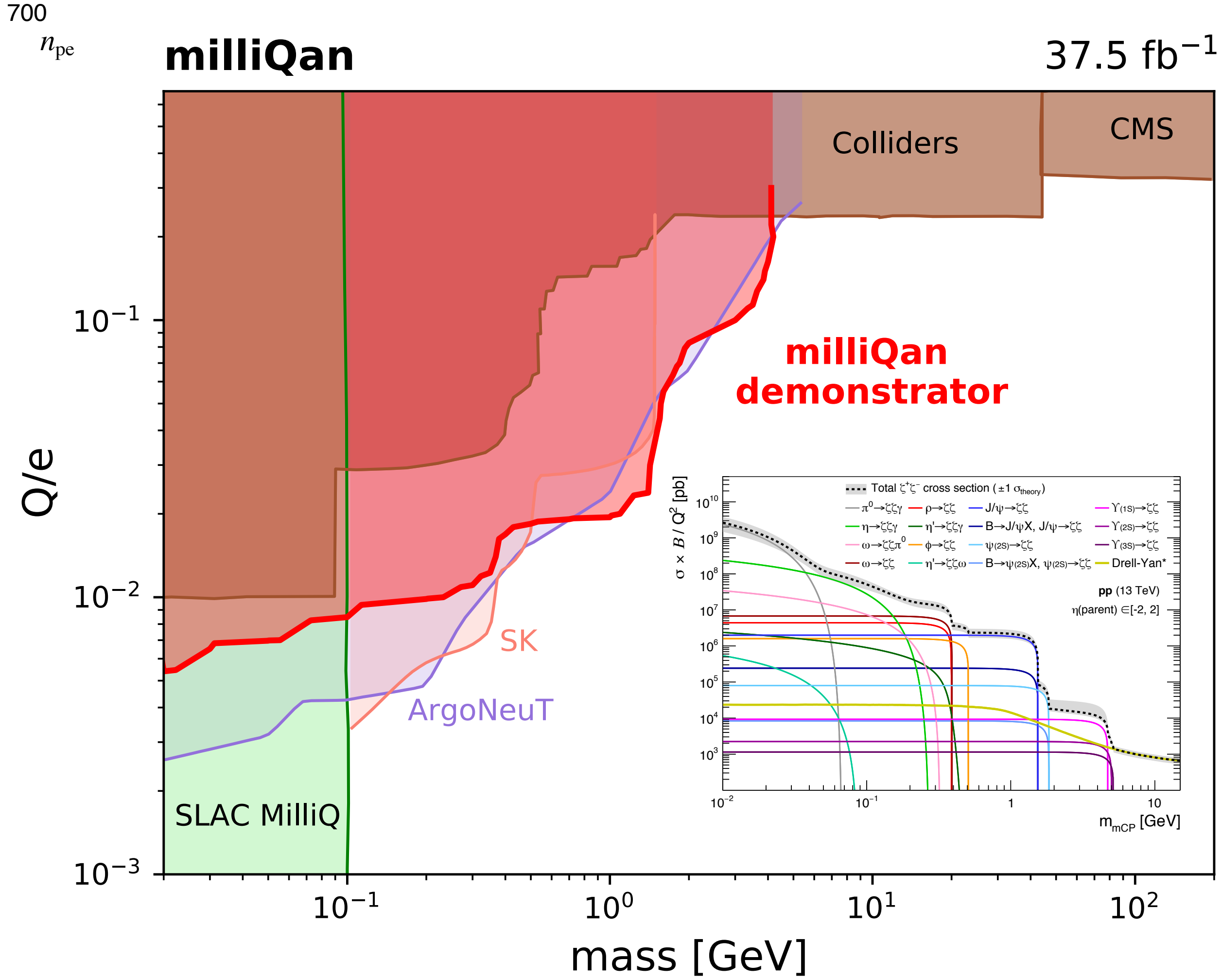


Installed on mount designed to hold full detector in CMS cavern: 33m from IP (17m of rock shielding)



Number of PE in bars due to muon shower products

- Demonstrator ran very successfully, collecting **~35/fb, 2000h** of data in 2018
- Used for range of studies to prove feasibility of full detector: **alignment, calibrations, background measurements**



- **First search** for millicharged particles at a hadron collider with new sensitivity
- **Quantitative understanding** of backgrounds and detector performance

→ **Use this to guide future detectors!**

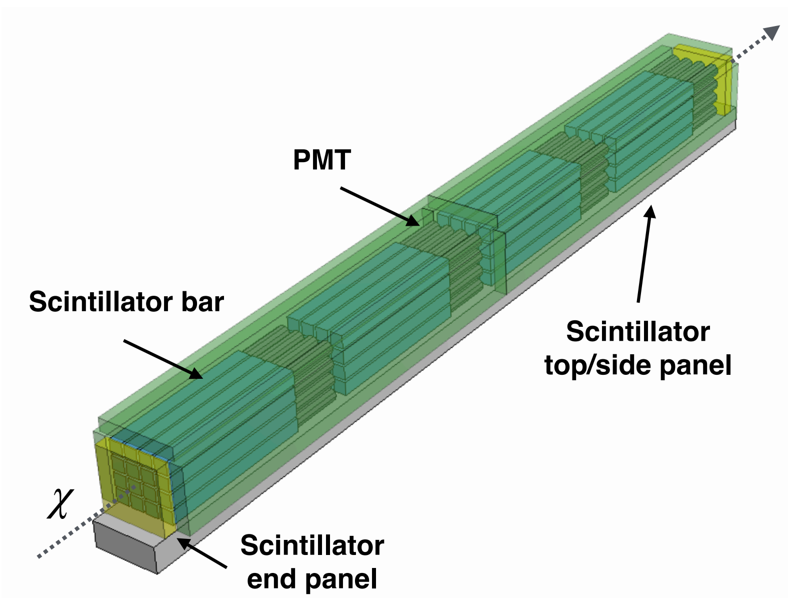
Published in PRD: PhysRevD.102.032002

Run 3 milliQan experiment

Fully funded and under construction!

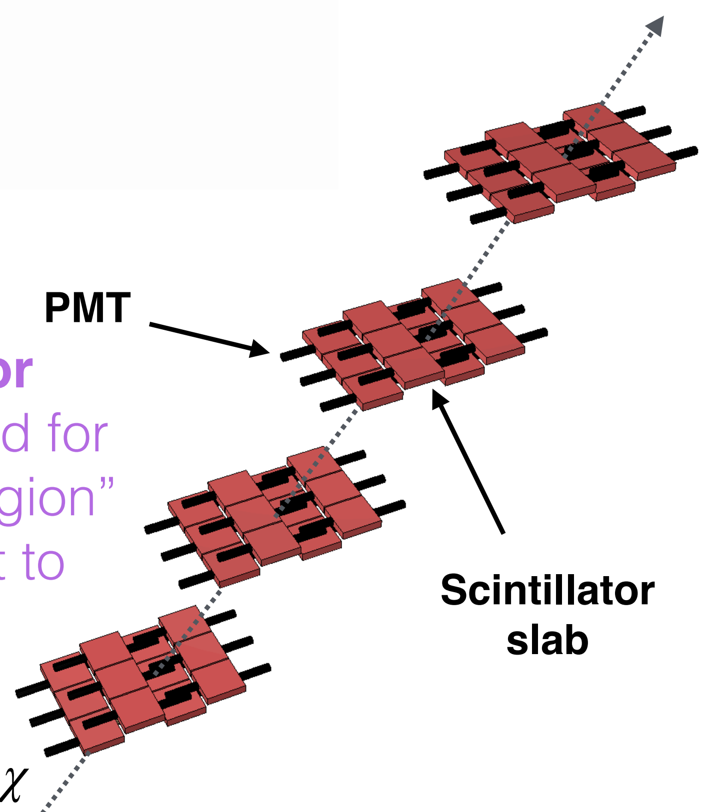
Run 3 bar detector

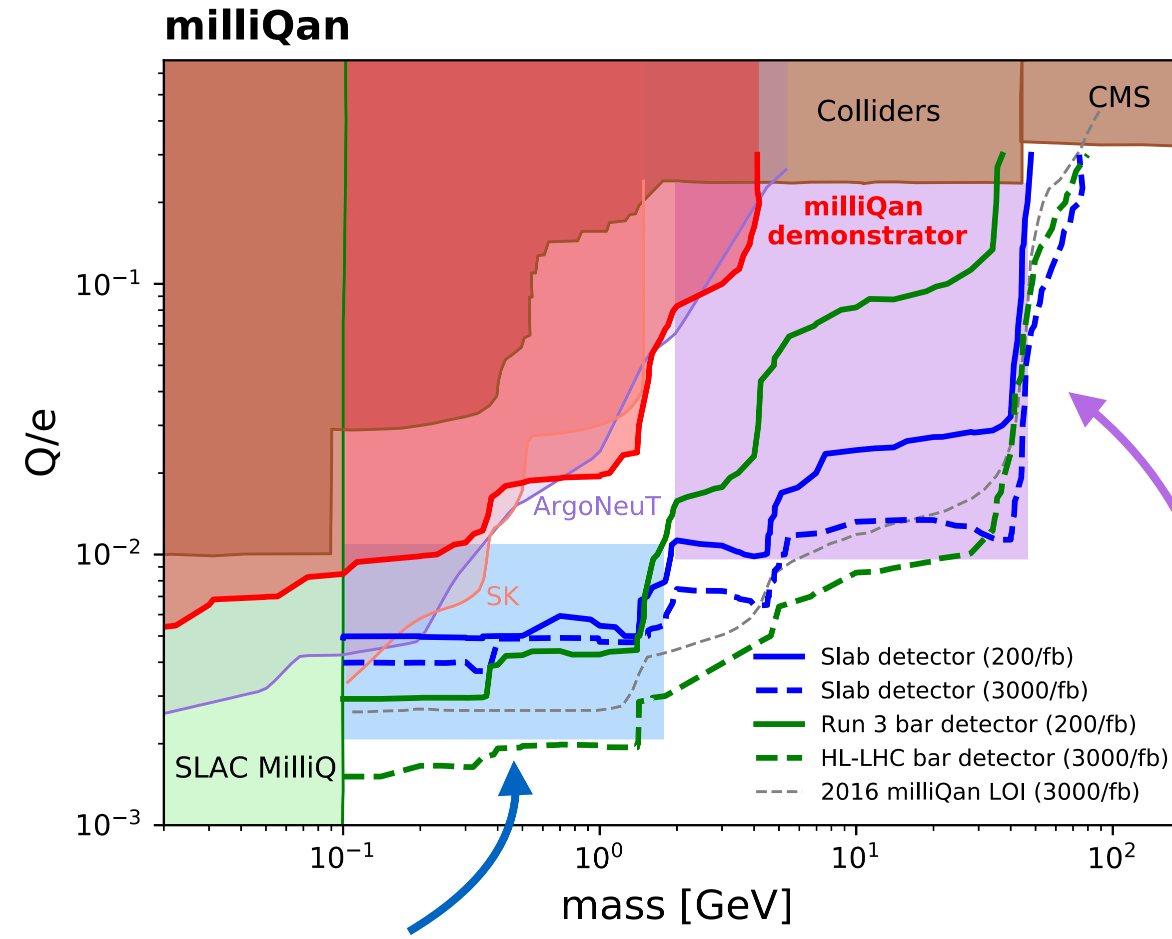
design based on lessons from demonstrator: expanded size (4x4 bars), four layers, thicker veto panels, signal amplification



Run 3 slab detector

thinner slabs optimised for "acceptance limited region" (total area equivalent to >1000 bars!)





Charge limited region: very high mcp flux but low efficiency

Acceptance limited region: high efficiency but low mcp flux

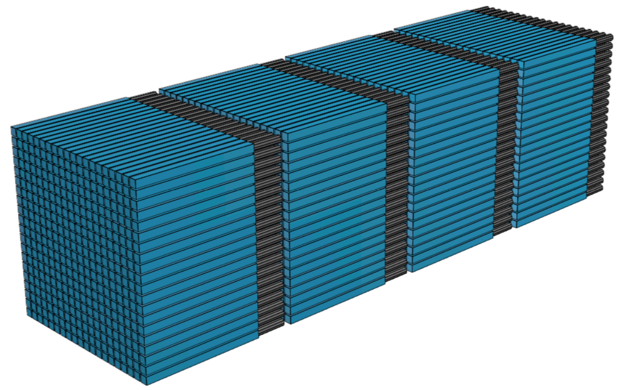
Backgrounds/signal efficiencies estimated using **data collected by demonstrator**

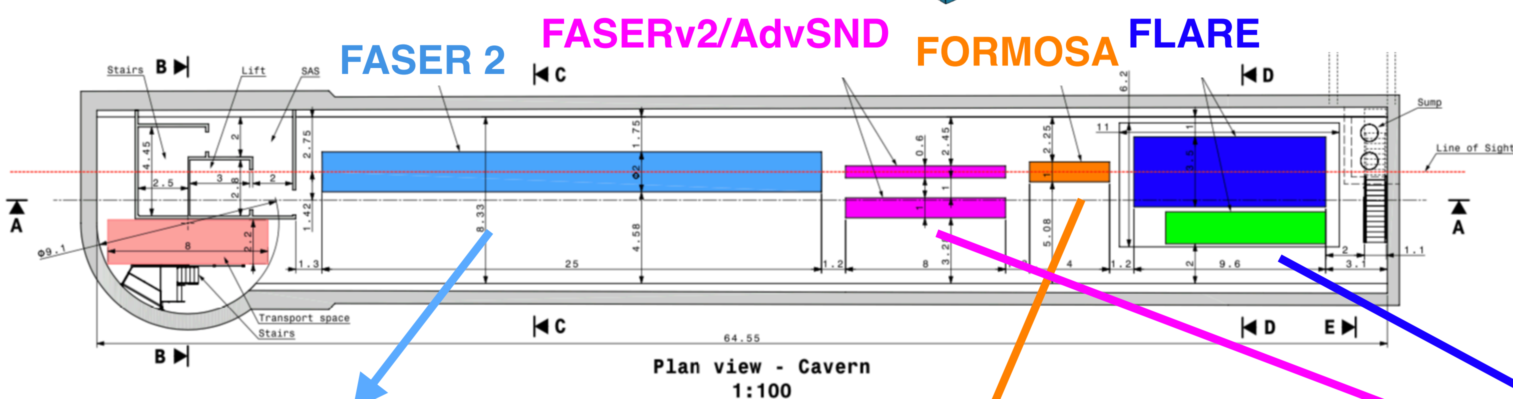
Expect world leading sensitivity for **0.1 < m < 45 GeV** using **combination** of **slab and bar** detector

Just published in PRD: PhysRevD.104.032002

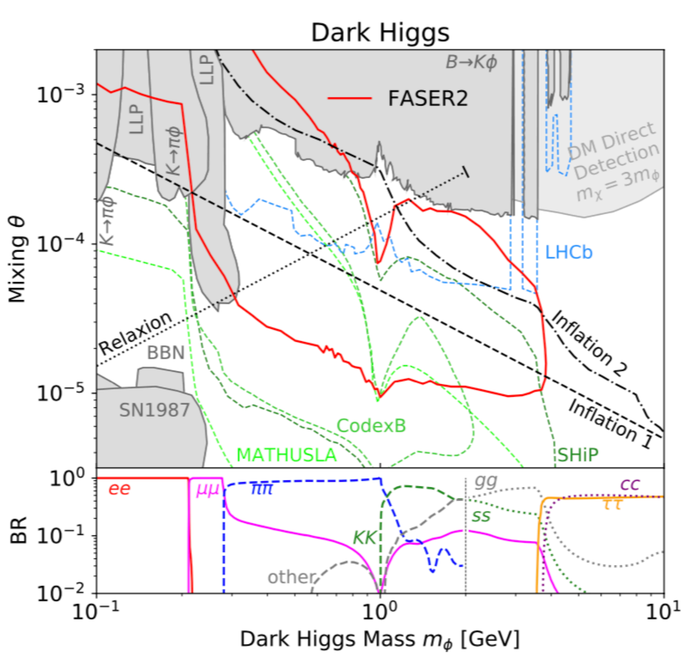
Forward physics facility at the HL-LHC

<u>FORMOSA</u> design based on **lessons from demonstrator**

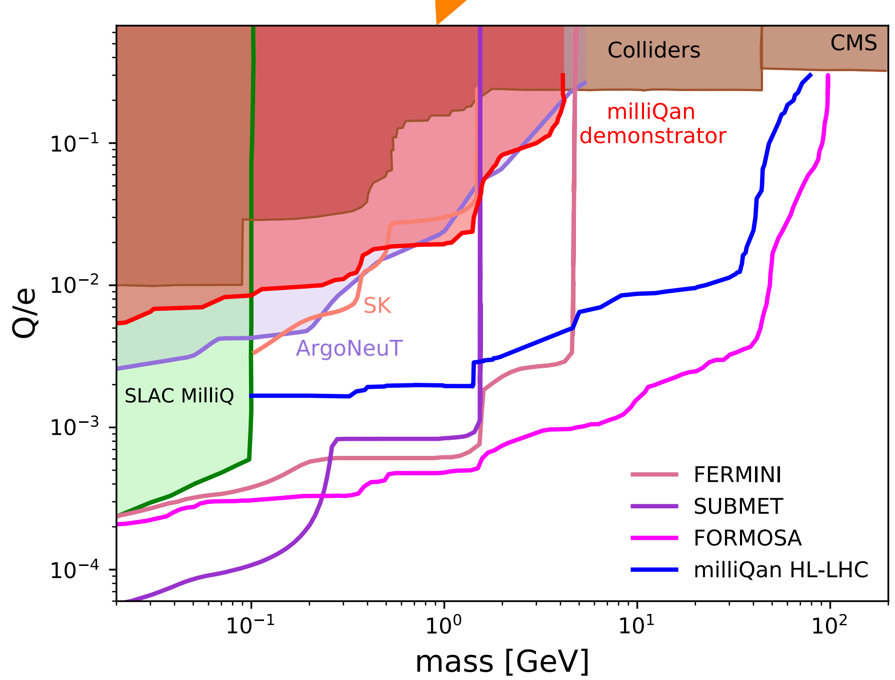




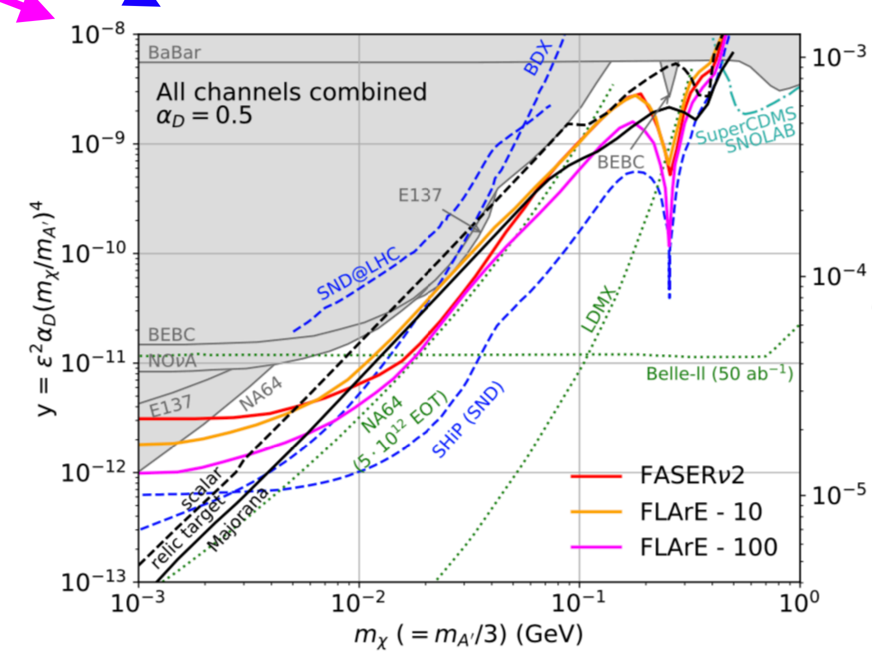
- FPF provides extensive probe of wide range of forward BSM (and SM) signatures to fully exploit physics potential of the LHC!
- e.g. FORMOSA proposal: forward mcp detector would see up to **factor ~ 250 higher mcp** rate compared to central location



Dark Higgs LLP



millicharged particle



Dark photon mediated DM

Just on arXiv: <u>2109.10905</u>

Summary

- My perspective: worst case scenario is **not** that new physics too heavy/weakly coupled to produce at a future collider but that we fail to look widely enough

- Activities in EF09 geared towards ensuring this does not happen:

  - Providing insights into **general purpose/dedicated detector design** for **optimal coverage** of phenomena at any future pp/ee/μμ machine

  - **Inclusive** searches/triggers proposed (often using AI) to cover the **"unknown unknowns"**

  - Wide range of signal benchmarks (including "exotic" new physics) being identified to allow easy sensitivity comparison and **avoid gaps in coverage**

- Many places to **get involved** in <u>ongoing and new activities in EF09</u>

Backup

milliQan collaboration

C. Hill, B. Francis,
M. Carrigan, L. Lavezzo,
B. Manley

A. Haas,
M. Ghimire

D. Stuart, C. Campagnari,
M. Citron, B. Marsh, B. Odegard,
R. Schmitz, F. Setti, R. Heller

D. Miller,
M. Swiatlowski

S. Lowette

Y-D. Tsai

M. Ezzeldine,
J. Sahili, H. Zaraket,

F. Golf

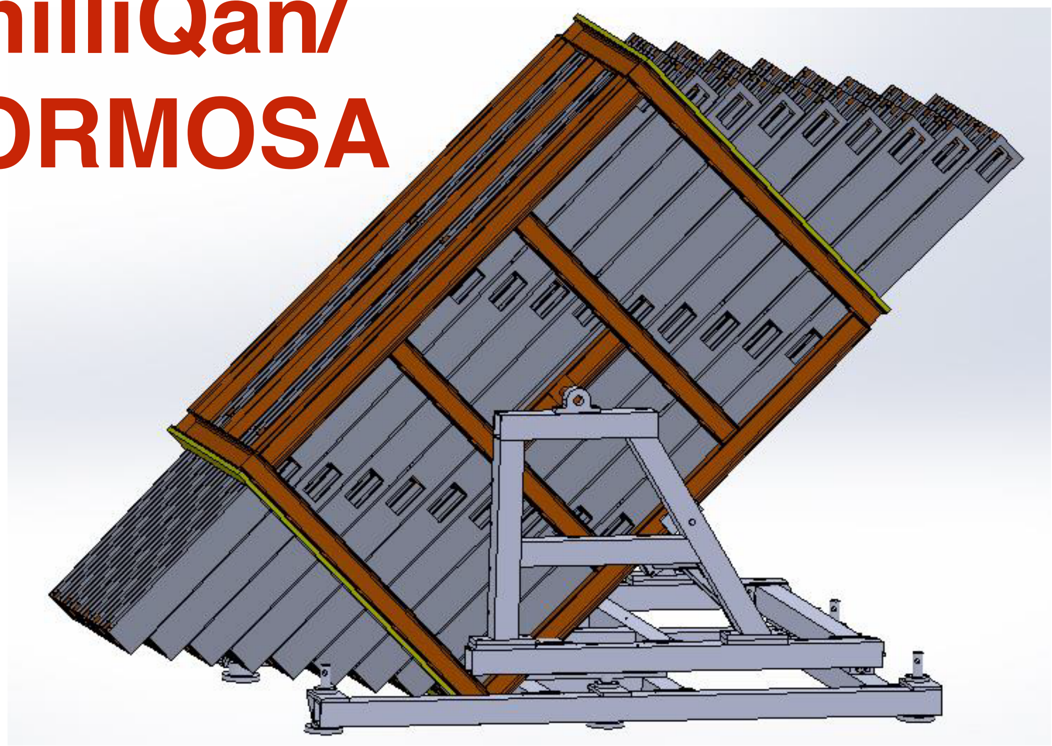
A. Ball, A. De Roeck,
M. Gastal, R. Loos,
H. Shakeshaft

J. Brooke,
J. Goldstein

This speaker supported by
funding from DOE Office of Science

Scintillator-based searches for mcps

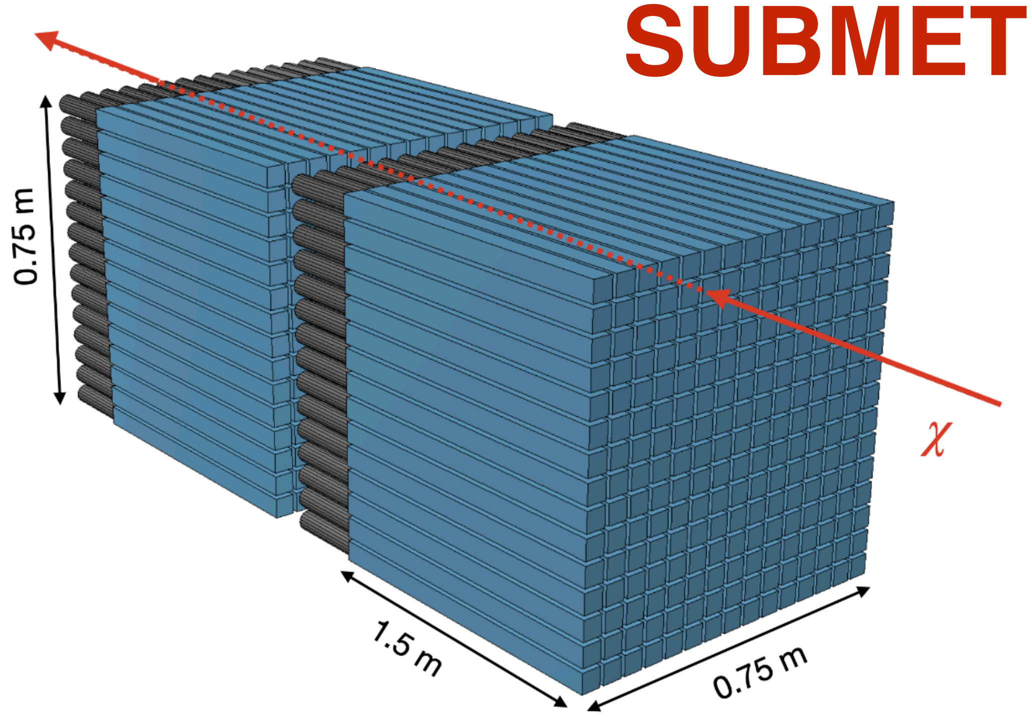
milliQan/ FORMOSA



LHC with sensitivity for m < ~45 GeV

1607.04669

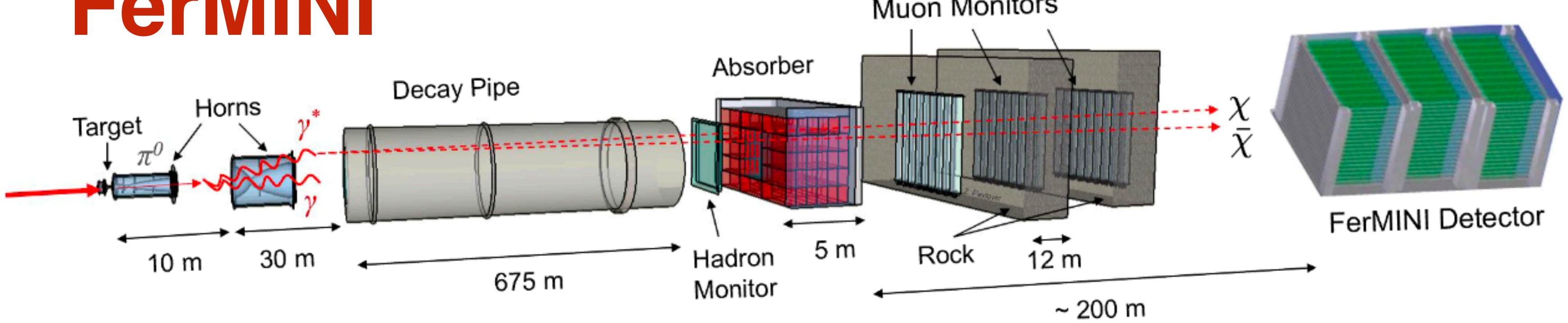
SUBMET



J-PARC with sensitivity for m < ~1.5 GeV

2007.06329

FerMINI



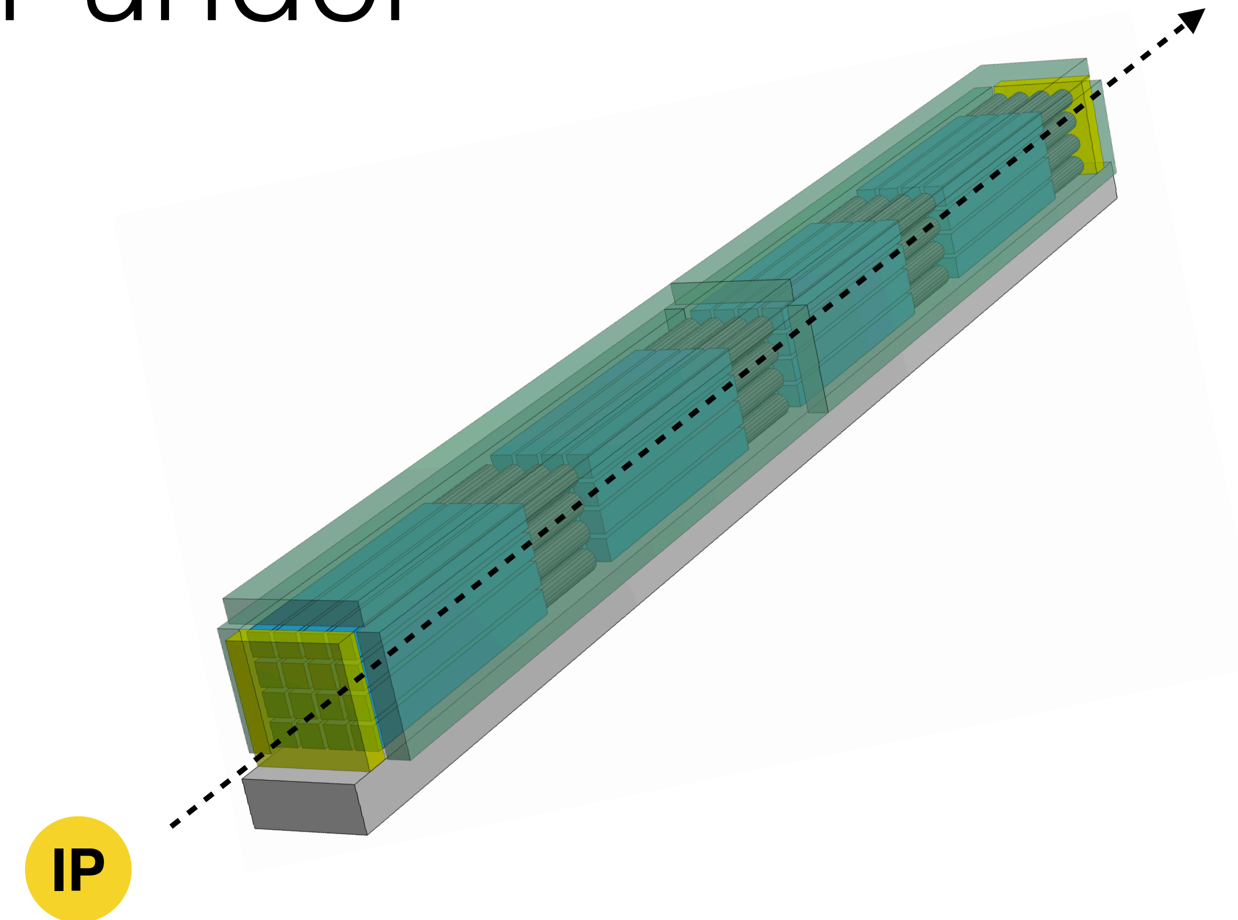
Fermilab with sensitivity for m < ~5 GeV

1812.03998

Range of detectors with complementary sensitivity

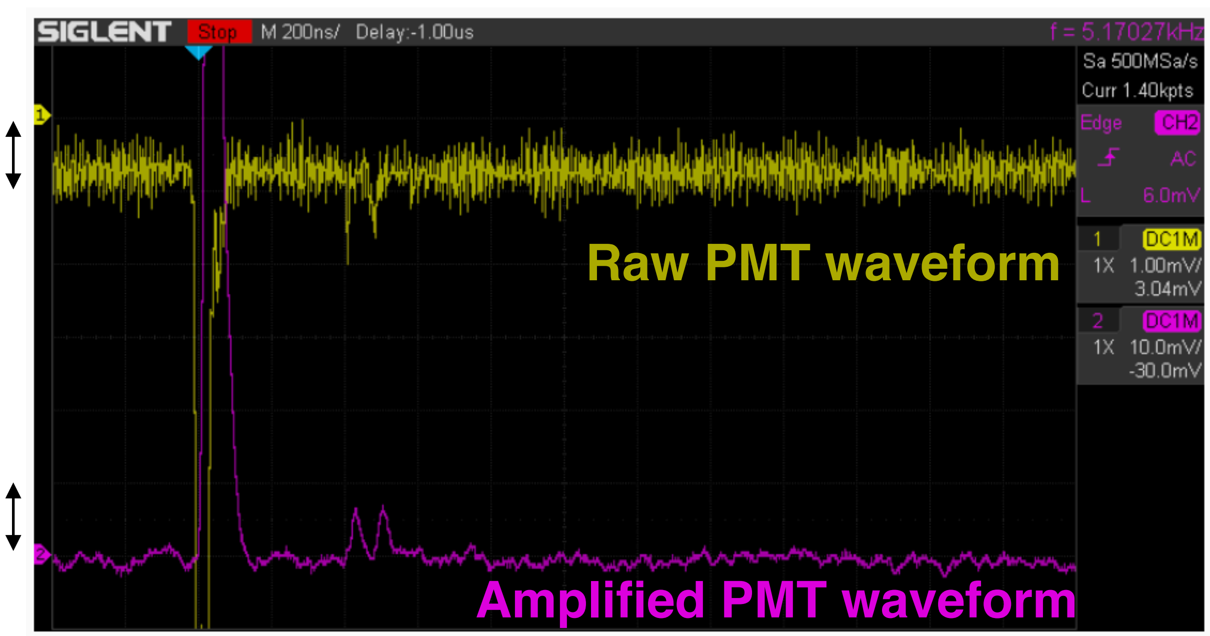
Run 3 milliQan detector under construction!

- Funding received for **Run 3** detector with updated design based on lessons from demonstrator
- **Four** layers of scintillator bars to control background from cosmic ray showers
- **Expanded size** of each layer (4x4 scintillator bars) to improve background rejection and increase signal acceptance
- Increased thickness of scintillator **veto** "panels/slab" to 5cm for improved shower tagging
- **Dedicated signal amplification** will allow reconstruction of very low energy deposits
- HL-LHC detector design in backup (four layers of 216 bars)



1 mV

10 mV



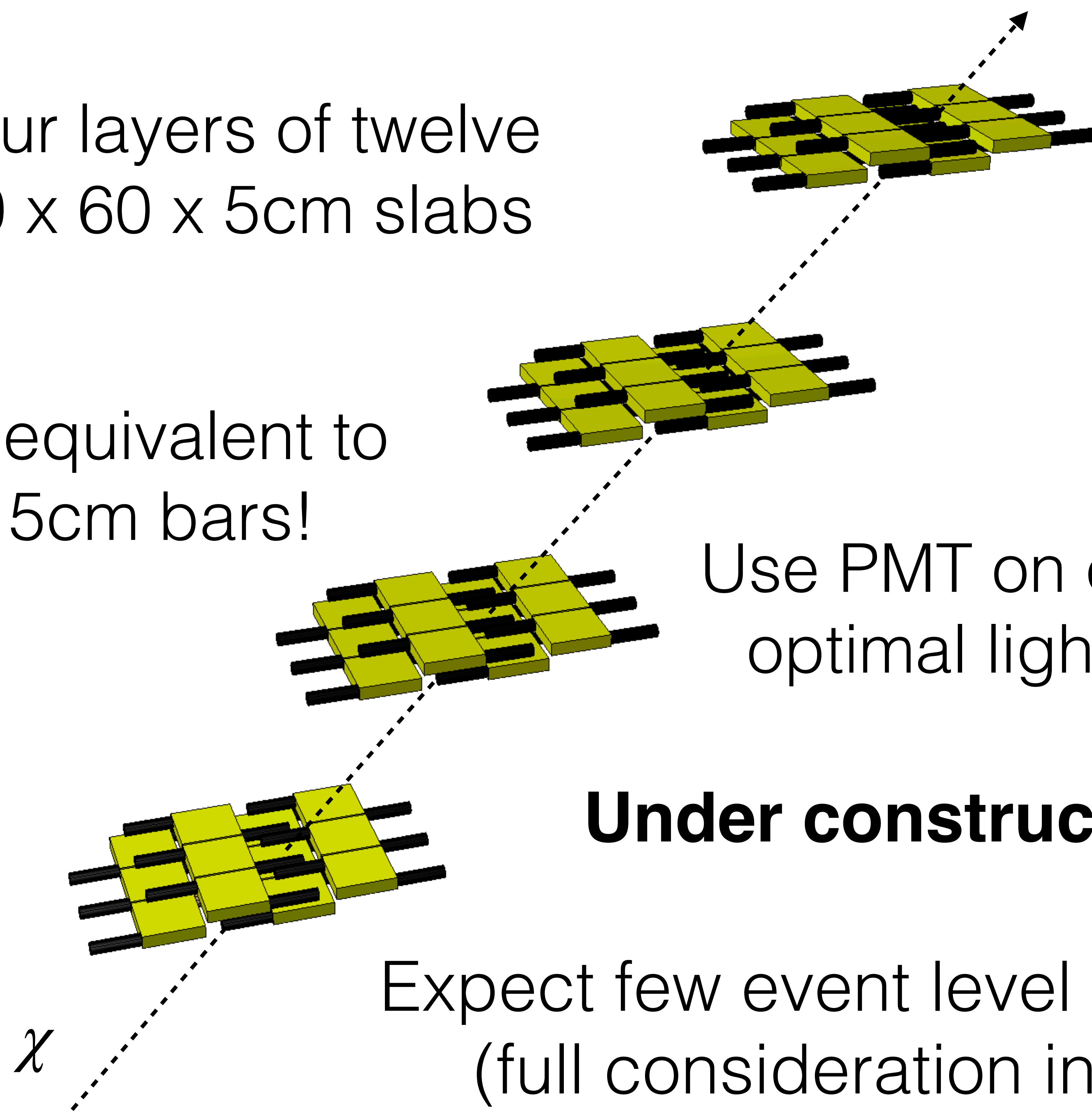
Signal amplification

M. Citron mcitron@ucsb.edu

The Run 3 milliQan slab detector

Four layers of twelve
40 x 60 x 5cm slabs

Surface area equivalent to
~**1100** 5 x 5cm bars!



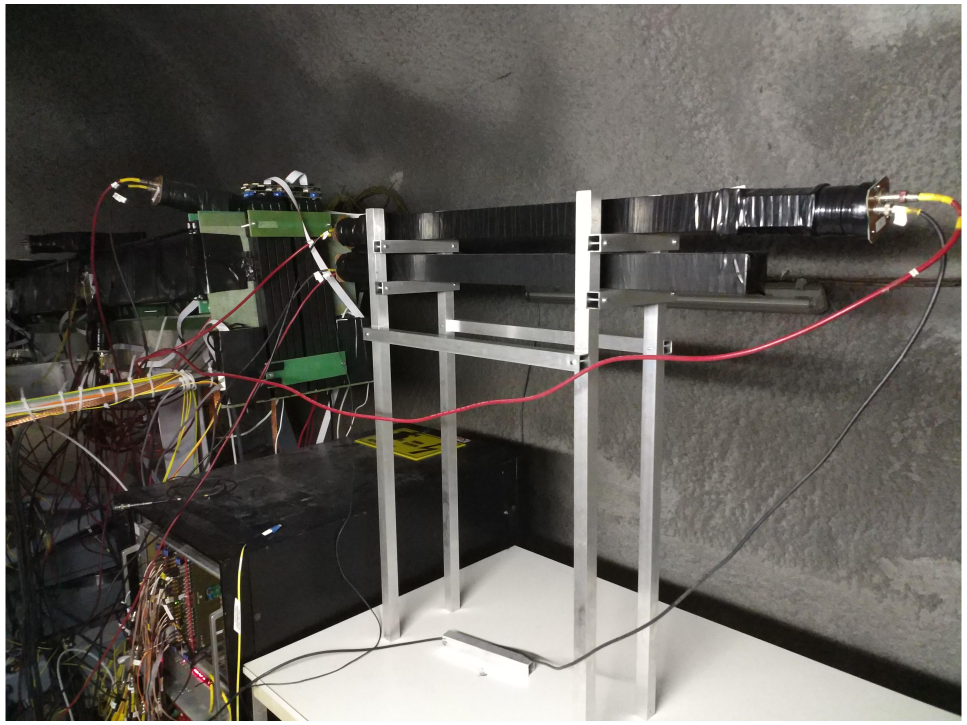
Use PMT on each end for
optimal light collection

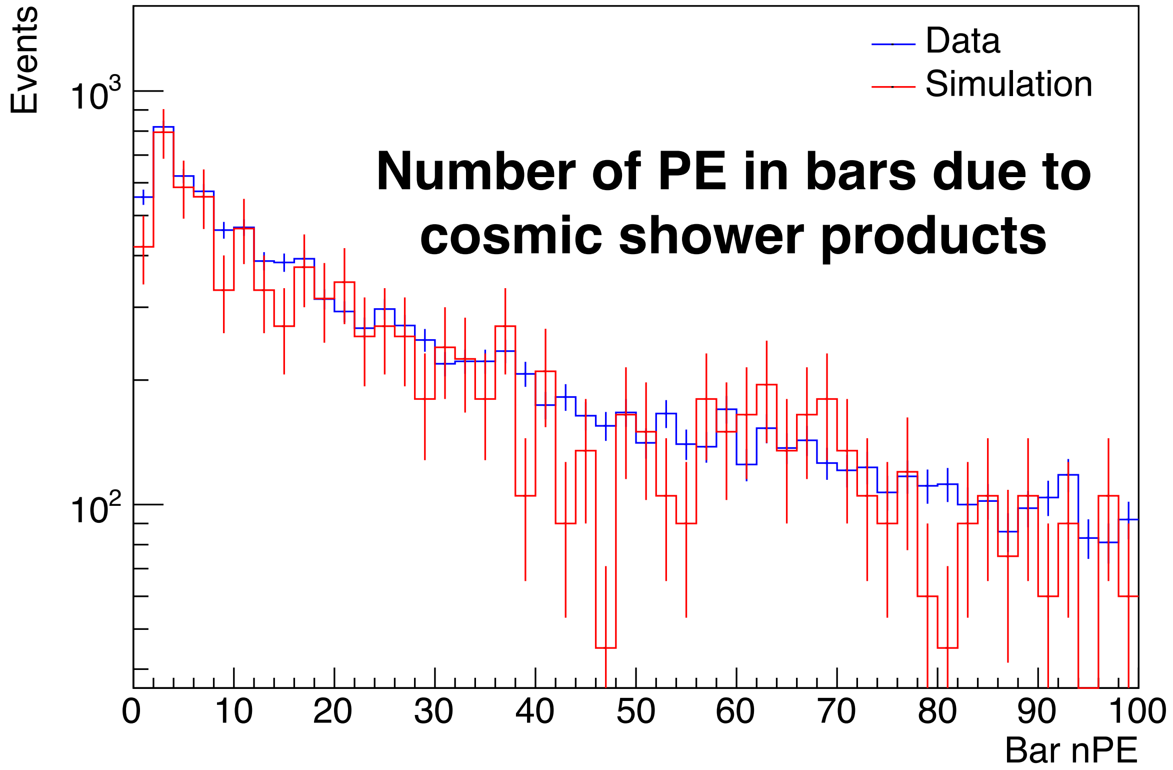
Under construction now!

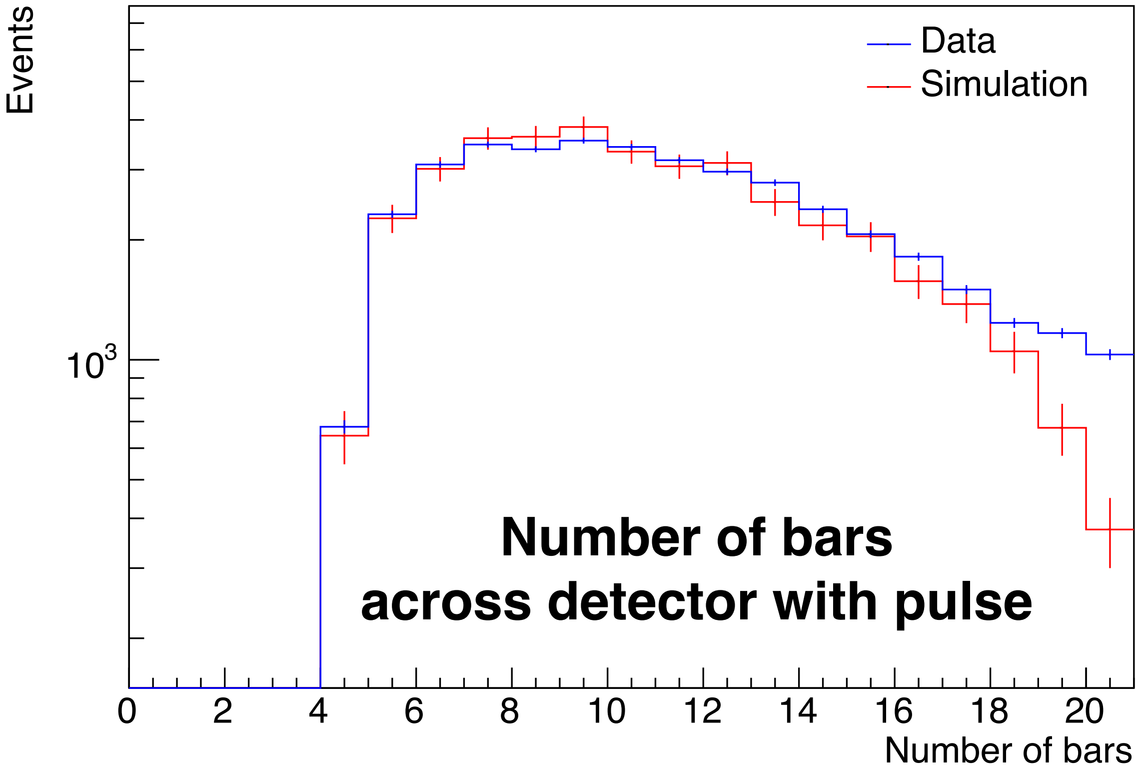
Expect few event level background
(full consideration in backup)

Cosmic background characterisation

- Cosmic muons propagated from surface (as for beam muons) and simulated with GEANT4
- Calibrate rate with “four layer” demonstrator data and compare modelling of crucial variables
- Cosmic shower background well described by simulation → **use calibrated simulation to estimate background rates** for full detectors





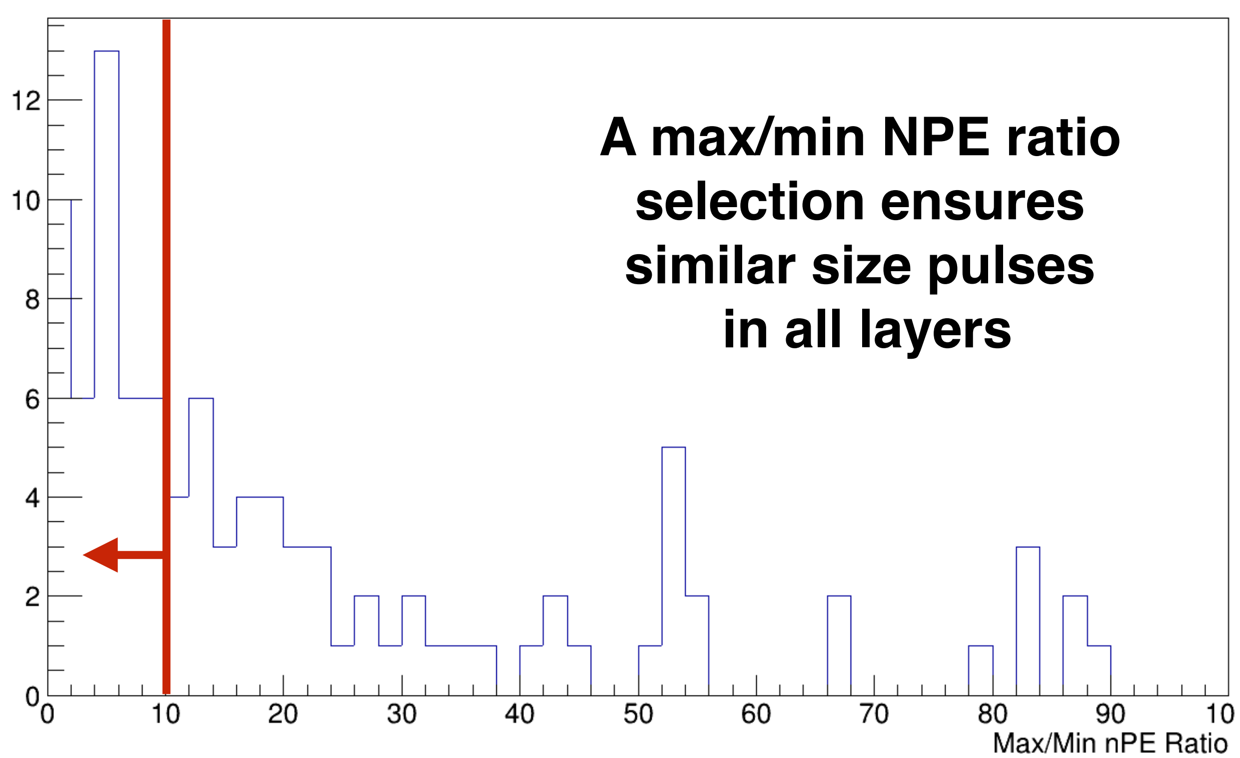


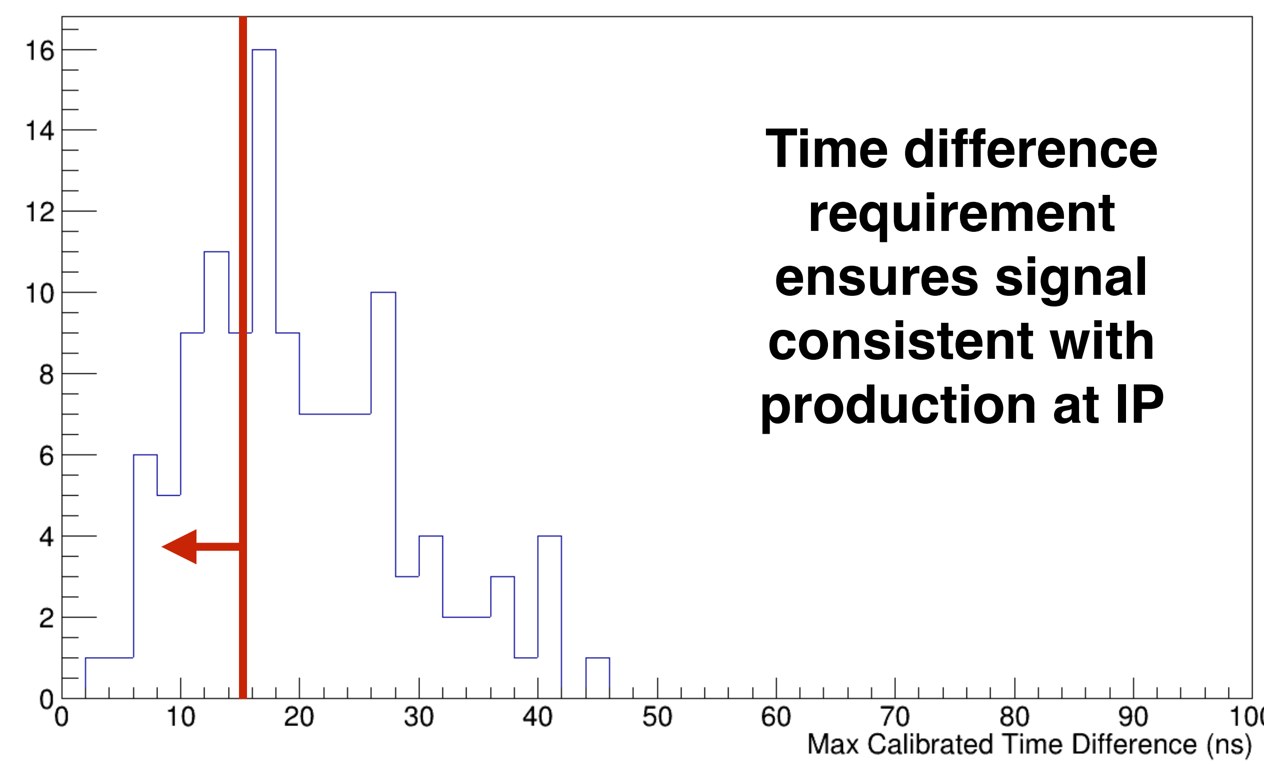
Bar detector background measurement

Selection	Run 3	HL-LHC
≥ 1 per layer	8.1×10^5	8.2×10^7
$= 1$ Per Layer	6.0×10^3	1.1×10^4
Panel Veto	1.1×10^3	3.1×10^3
Slab Veto	780	3.0×10^3
Four In Line	0.19	2.9×10^{-4}
Max n_{pe}/Min $n_{\mathrm{pe}} < 10$	0.061	9.1×10^{-5}
-15 ns $< \Delta t_{\max} <$ 15 ns	0.012	2.0×10^{-5}

+ background from dark-rate: expect 0.05/1.4 events in full Run 3/HL-LHC dataset

- Evaluate background using cosmic shower simulation that has been **calibrated and validated** with four layer demonstrator
- Selections motivated by Run 2 demonstrator search to reject backgrounds with high signal efficiency
- Once detector is installed will measure backgrounds directly in beam-off running and in beam-on control regions





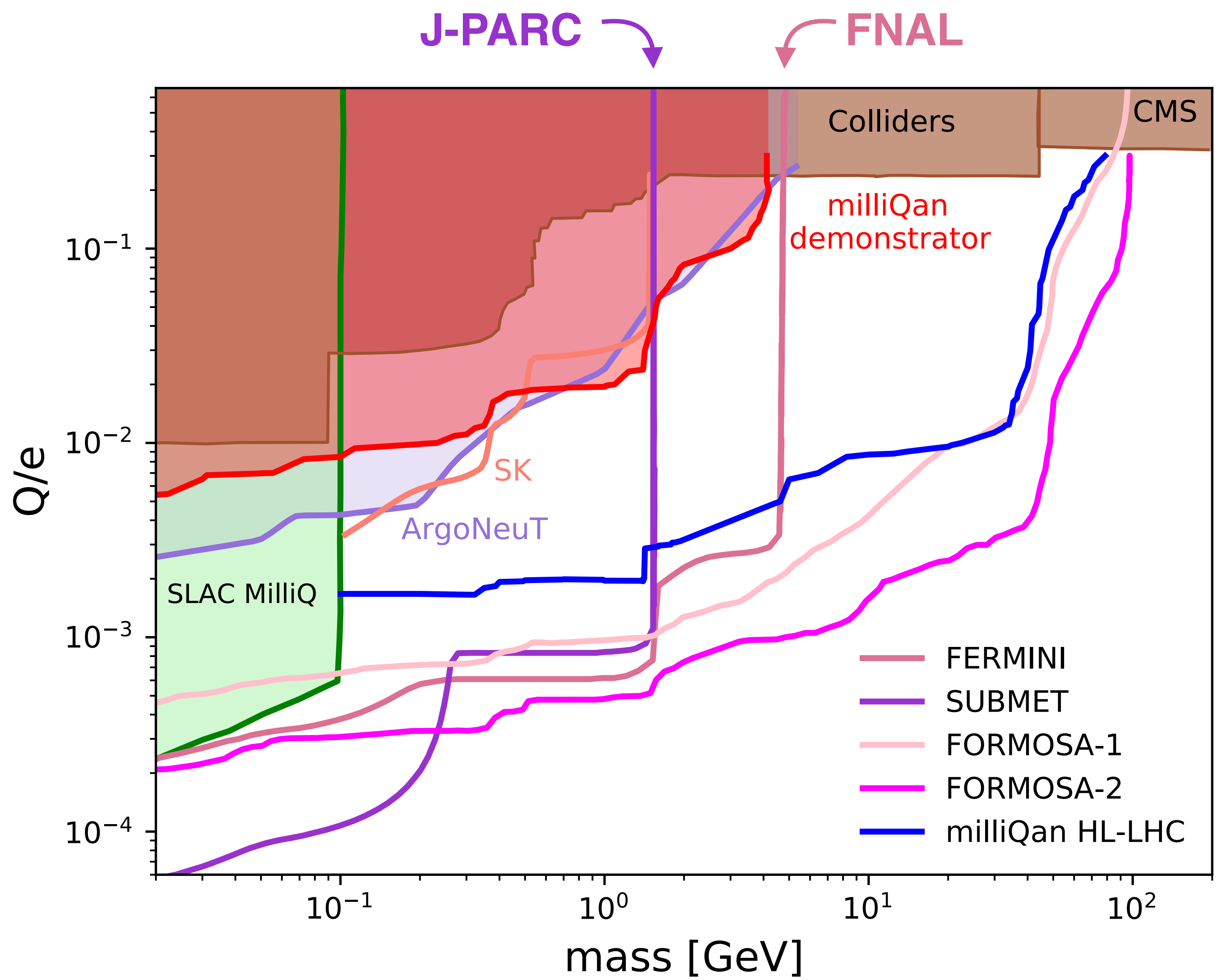
Slab detector background measurement

- Evaluate background with fully validated cosmic simulation (as for bar detector)
- Use additional "high time" signal region to improve performance near resonance mass thresholds (where mcp β < 1)
- Using 4 layers, achieve low background in both regions
- Confirm with in-situ measurements - modular design easy to alter if required!

Selection	Slab Detector
≥ 1 per layer	2.0×10^7
$= 1$ Per Layer	4.8×10^6
Muon Veto	2.6×10^5
Four In Line	76
Max n_{pe}/Min $n_{\mathrm{pe}} < 10$	23
-15 ns $< \Delta t_{max} <$ 15 ns	7.1
15 ns $< \Delta t_{max} <$ 45 ns	1.4

+ background from dark-rate: expect 0.03 (|Δt| < 15)/ 0.7 (15 < Δt < 45) events in full Run 3 dataset

Future detector sensitivities



- Complementary sensitivity from detectors at range of facilities
- Forward regime at the LHC provides very exciting sensitivity prospects **if** backgrounds can be controlled!
- Demonstrator results **key** in proving feasibility of all proposals!
- Exploring further for snowmass - see LOIs 72 and 114
- Considering connections with dark matter (next slides)

Sources

FORMOSA: 2102.11493

SUBMET: 2007.06329

FERMINI: 1812.03998

milliQan: 2104.07151

Major caveat: FORMOSA lines assume efficient triggering and rejection of beam muon induced backgrounds

Sensitivity reach of scintillation-based detectors for millicharged particles

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[2]*The Ohio State University, Columbus, Ohio 43218, USA*
[3]*University of Chicago, Chicago, Illinois 60637, USA*
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[6]*Korea University, Seoul 02841, Republic of Korea*

(Dated: September 30, 2020)

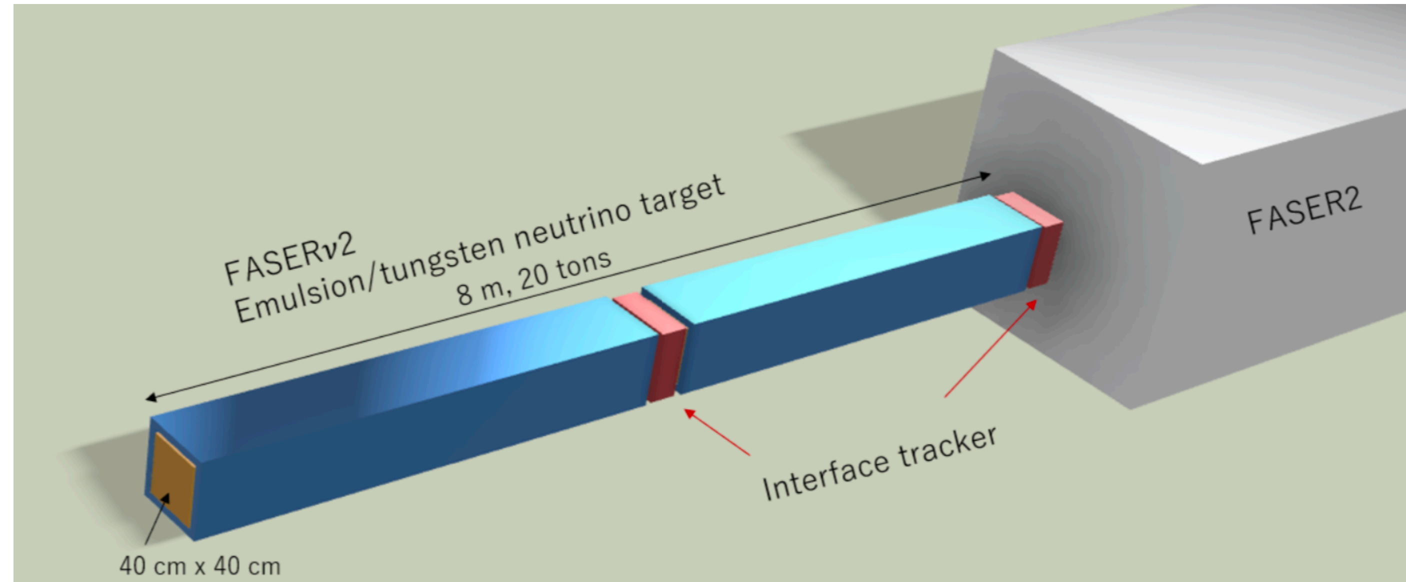
In this project we will evaluate the sensitivity for particles with charge much smaller than the electron charge with dedicated scintillator-based detectors at a range of facilities, including the CERN LHC, Fermilab and J-PARC. The data from the milliQan demonstrator will be used to comprehensively evaluate backgrounds for each detector, as well as provide a robust simulation of the response of the detector to low-charge particles.

FPF detectors

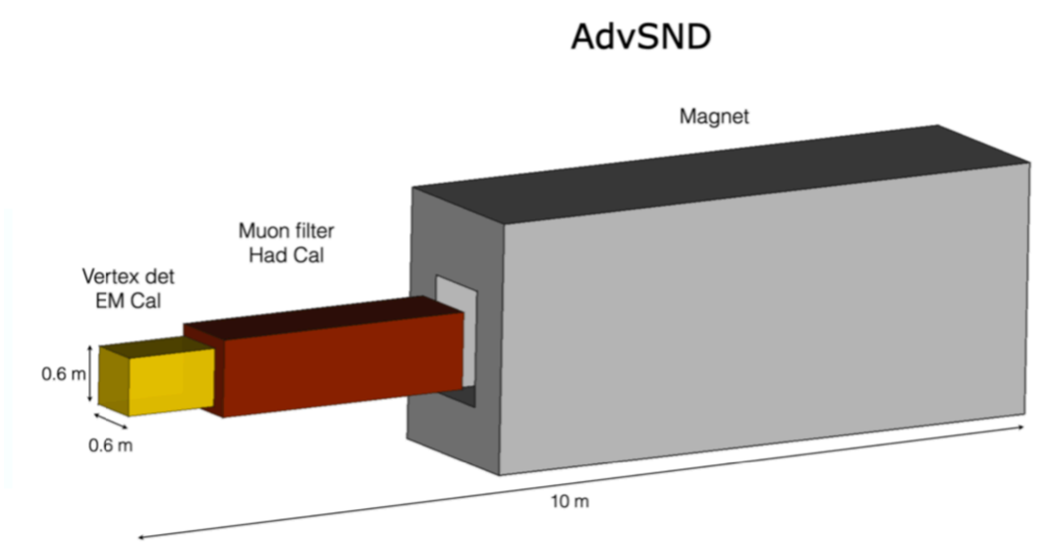
FLARE (LArTPC)

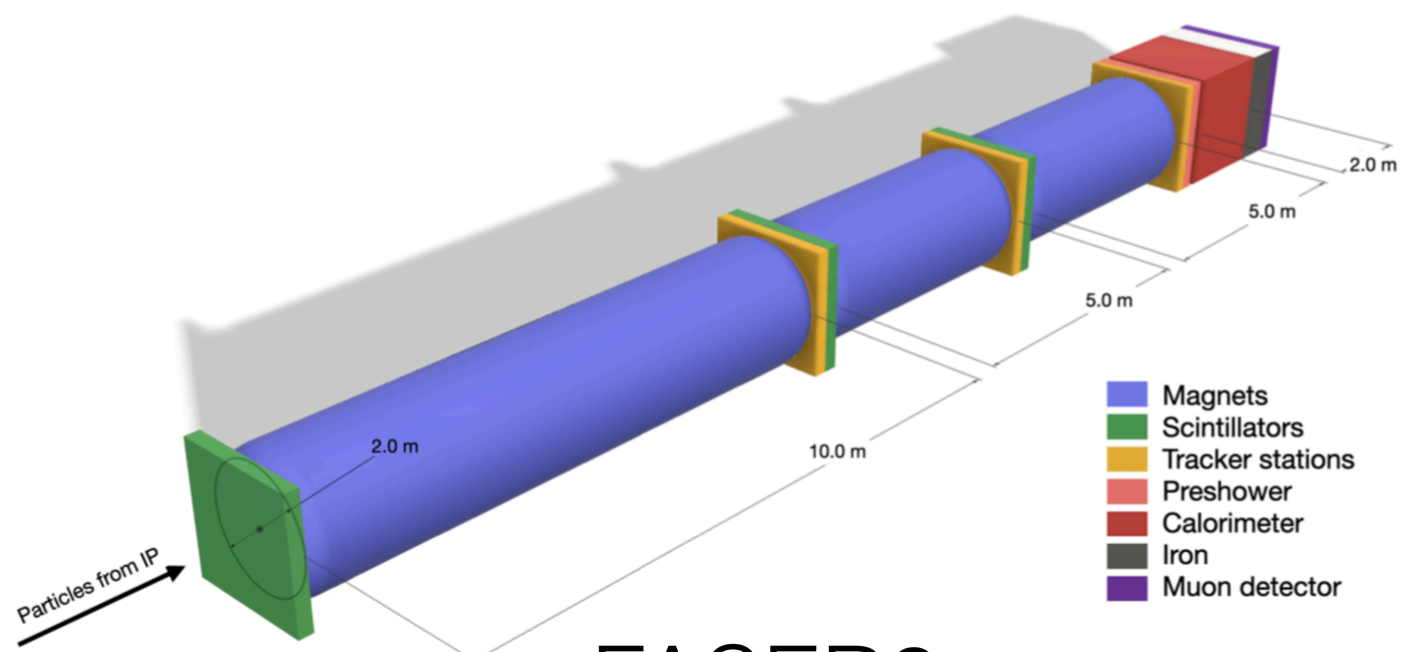
	Value	Remarks
Detector length	7 m	Not including cryostat
TPC drift length	0.75 to 1.00 m	2 TPC volumes with HV cathode in center
TPC height	1.5 m	
Total LAr mass	$\sim$ 50 ton	Volume in the cryostat
Fiducial mass	10–20 ton	
Background muon rate	$\sim 1/\text{cm}^2/\text{s}$	Maximum luminosity of $5 \times 10^{34}/\text{cm}^2/\text{s}$
Neutrino event rate	$\sim 50/\text{ton}/\text{fb}^{-1}$	For all flavors of neutrinos
stopping power (MIP)	2.1 MeV/cm	
radiation length	14 cm	
interaction length	85 cm	
Molière radius	9 cm	
light yield	50 ph/keV	at 0 V/cm
scintillation time	singlet 7 ns, triplet 1.6 μs	peaked at 128 nm
Rayleigh scattering length	90 cm	at 128 nm
ionisation charge yield	10 fC/cm	for MIP at 500 V/cm
electron drift velocity	1.6 mm/us	at 500 V/cm
electron diffusion coefficient	7.2 cm^2/s	at 500 V/cm
achievable drifting electron lifetime	> 10 ms	< 30 ppt O_2^{eq} contamination
demonstrated drift length	3.6 m	$\approx$ 2.3 ms drift time

FASERν2



AdvSND





FASER2