FLAME: The Hunt for Millicharged Particles

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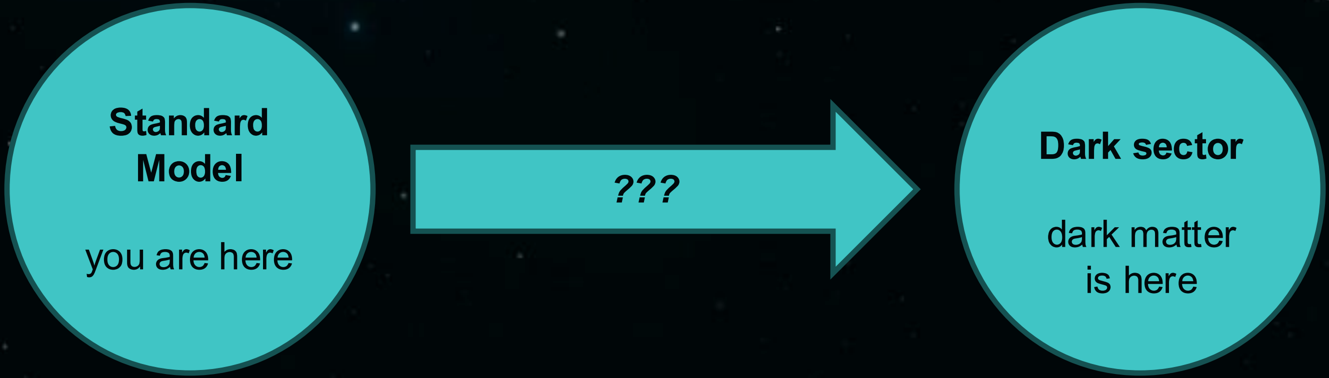
There's a problem in physics research

No signs of new physics at the LHC

Motivated to look for dark matter by gravitational effects, but how?

Dark matter and the Standard Model

- Many Standard Model extensions include a dark sector
- Currently unknown how to bridge the gap SM → DM



- No significant interaction between dark matter and Standard Model observed to date
- What if dark matter doesn’t interact with Standard Model at all?

Dark matter and the Standard Model

- What if dark matter is part of “hidden” universe?
  - No SM gauge interactions could explain lack of observations
  - Still needs to be some communication between the sectors

  - Communication: kinetic mixing with a massless dark photon

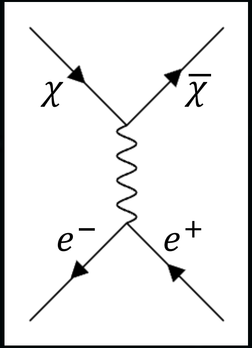
Dark massless photons

- Dark massless photon kinetically mixes with SM hypercharge gauge field
- Need to remove off-diagonal mixing, put kinetic terms into canonical form

$$A'_\mu \to A'_\mu + \frac{\epsilon}{\cos\theta_W} B_\mu$$

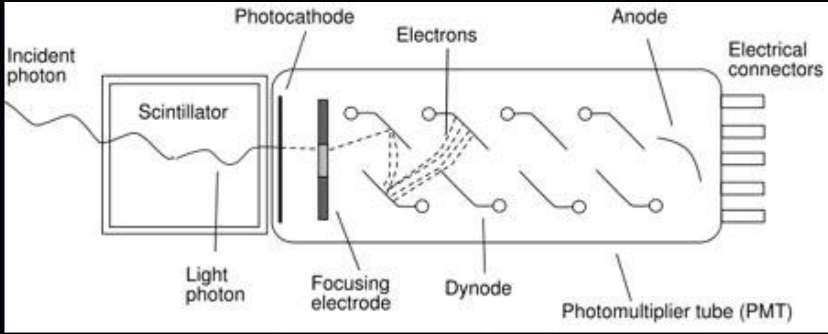
Type equation here.

- Perform a shift → dark photon field now includes small piece of hypercharge field
- As a result, DM feels tiny influence of hypercharge field, depositing weak SM charge
    - *Millicharged particles*



The hunt for mCPs

- mCPs
  - Small charge $\epsilon = \frac{Q_\chi}{e} \ll 1$
  - Ionize matter weakly
- When passing through scintillator bar, electric charge ϵe ionizes atoms
  - Produces tiny amount of energy deposition $\frac{dE}{dx} \propto \epsilon^2$
- Energy excites molecules in scintillator
  - UV/visible light emitted
- Light collected by PMT



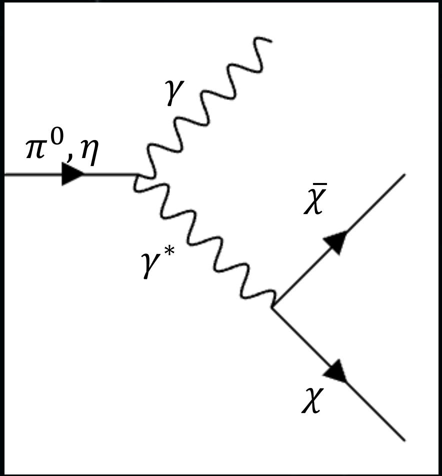
FLAME: Design

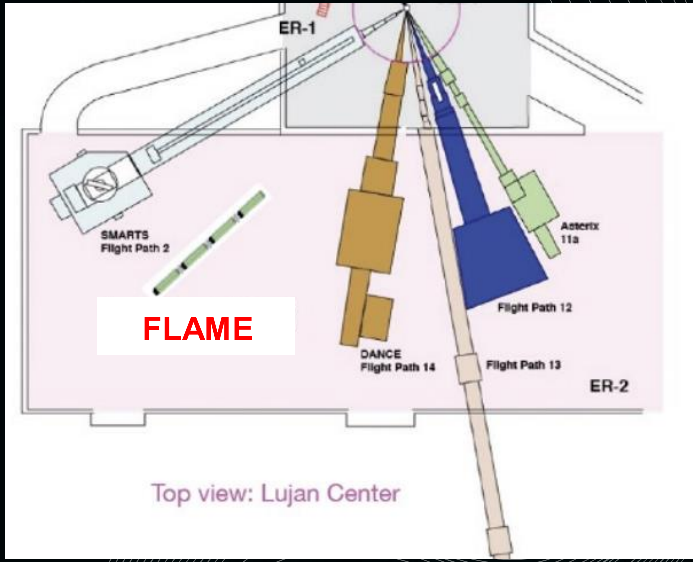
- Goal: search for mcPs produced in meson decays
  - Must separate from neutron background

Component	Design	Motivation
Beam	Proton beam, 800 MeV	Produce mesons from tungsten target
mCP	$\pi^0, \eta \rightarrow \gamma + \chi\bar{\chi}$	Neutral mesons decay to mCPs
Location	ER2 (35 m from Lujan neutron spallation target)	Balancing high flux vs. lower background
Core	Multi-layer scintillator array	Detect tiny ionization signals
Readout	PMTs with ns timing	Catch brief, low-light pulses
Shielding	30 cm lead + polyethylene	Block beam-induced neutrons, gammas
Triggering	Coincidence in multiple layers + beam timing	Suppress PMT dark current and cosmics

FLAME: Beam, mCP, Location

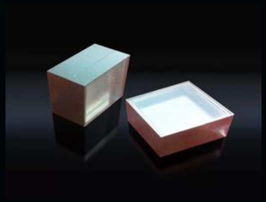
- 800 MeV proton beam hits tungsten target
- Tungsten: High-Z (74) → more π^0, η production
- Meson decay: $\pi^0, \eta \rightarrow \gamma + \chi\bar{\chi}$
- ER2 (35 m) → lower neutron + gamma bg, better signal/noise

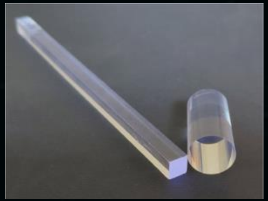




FLAME: Core, Readout

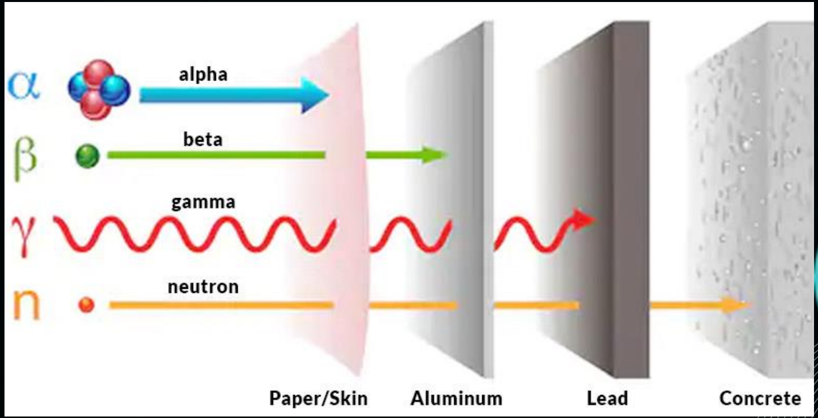
- Option 1: Plastic scintillators
  - 2-3 layers of 5 x 5 x 80 cm bars
  - PMTs on each end for readout
  - Low light yield, large volume needed
  - More neutron capture, dark current ☹
  - Incredibly cost-effective ☺
- Option 2: CeBr3
  - Smaller blocks
  - PMTs for readout
  - High light yield, low volume needed
    - Generates ~30x light per unit length vs. plastic
  - Less volume → less background ☺
  - Incredibly expensive ☹





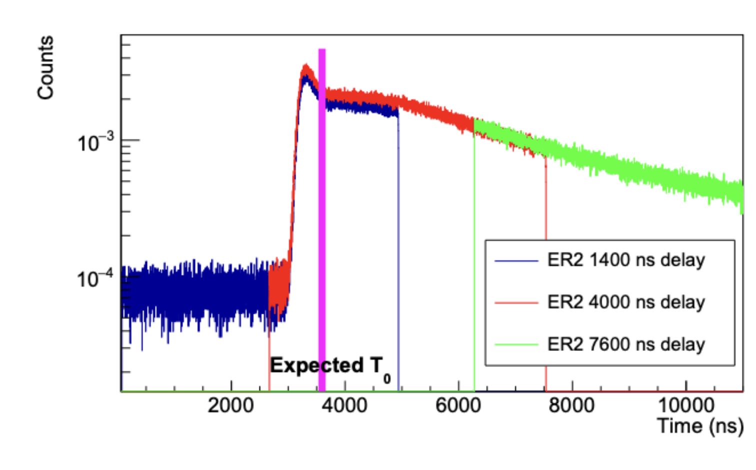
FLAME: Shielding

- LANSCE beam dumps generate many neutrons, gammas
- ~30 cm of layered shielding
  - Polyethylene: blocks fast neutrons via elastic scattering
  - Borated polyethylene: captures thermal neutrons
  - Lead: blocks gamma rays
- Shielding dramatically reduces false signals from radiation



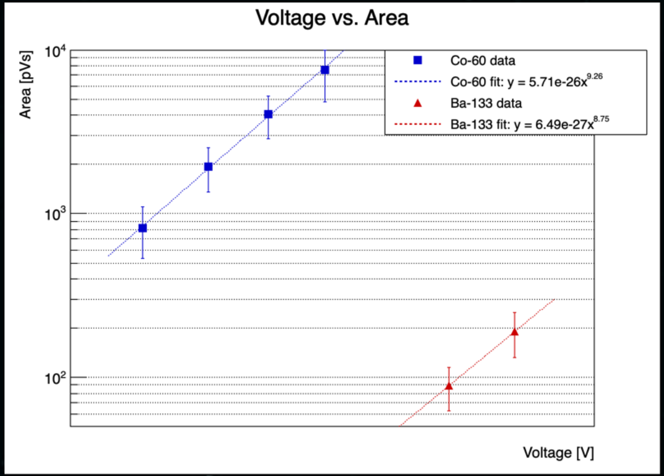
FLAME: Triggering

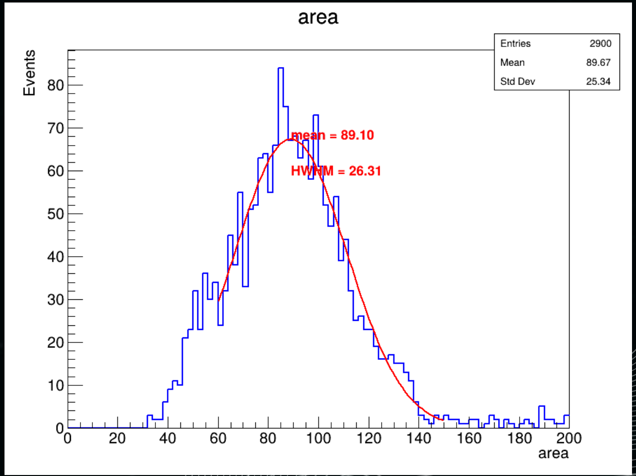
- mCP deposits tiny energy in one bar, may produce one PE
- Require coincident hits in 2+ layers within a few nanoseconds
- LANSCE's beam structure: ~20 pulses/sec
    - PMT dark current random → rarely overlaps in time
    - Beam-induced neutrons often delayed/one layer hits
    - Filters out accidental signals



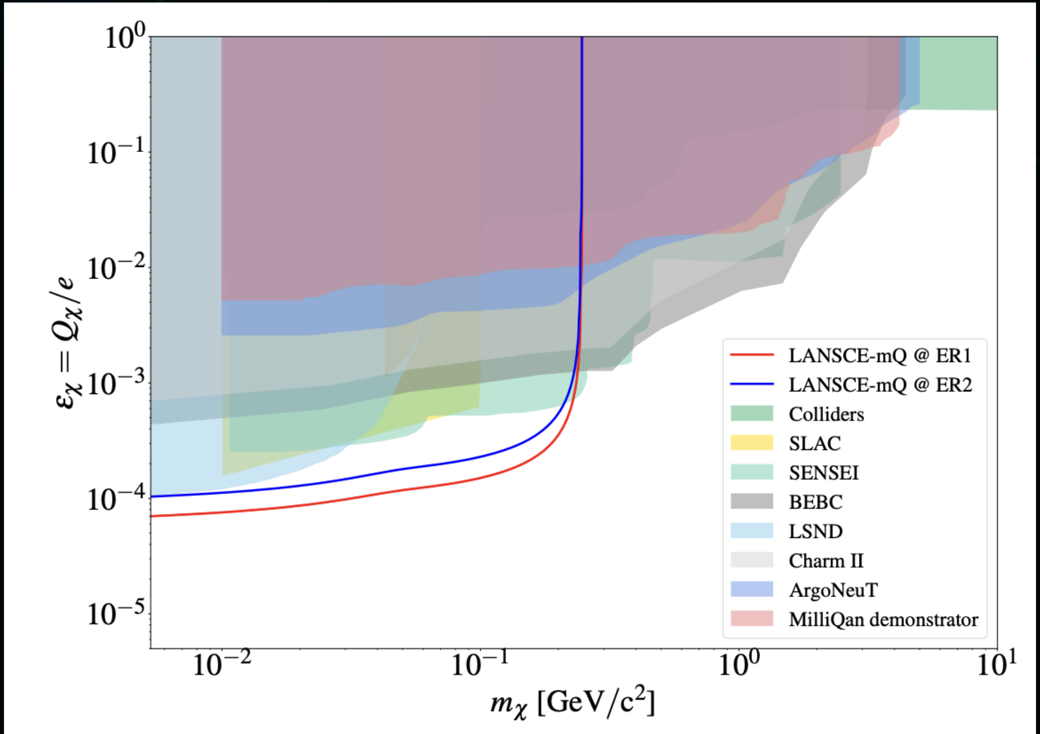
FLAME: Calibration

- To separate mCP signal from background, detector needs to be calibrated
  - Can calibrate to source peaks with known energies
- Pulse area proportional to number of PE produced by scintillation event
  - Subsequently proportional to energy deposition





mCPs on the horizon



Citations

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