Light Dark Matter searches at accelerators

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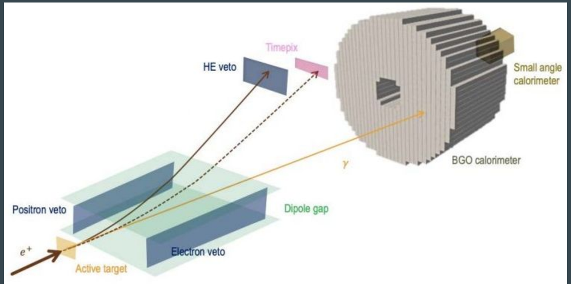
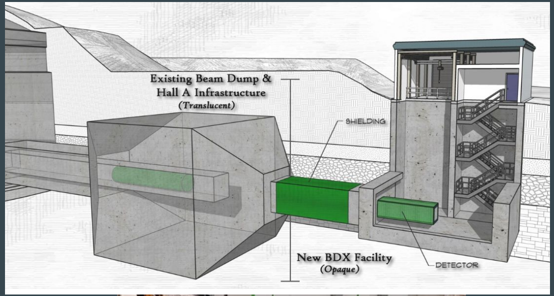
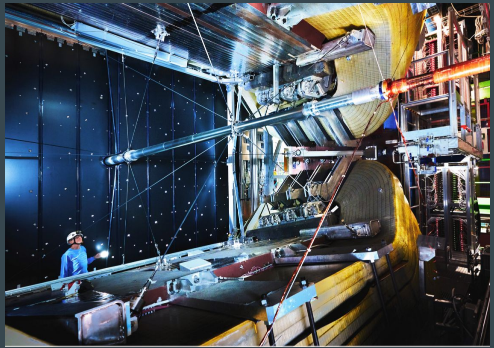
Luca Marsicano - INFN Genova
Second School on Dark Matter and Neutrino Detection
ICTP SAIFR

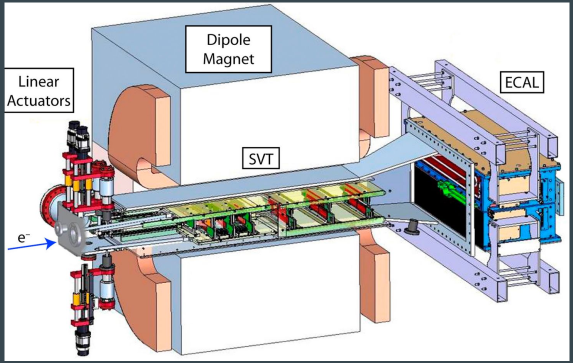
Istituto Nazionale di Fisica Nucleare

Light DM searches at accelerators - missing energy/momentum

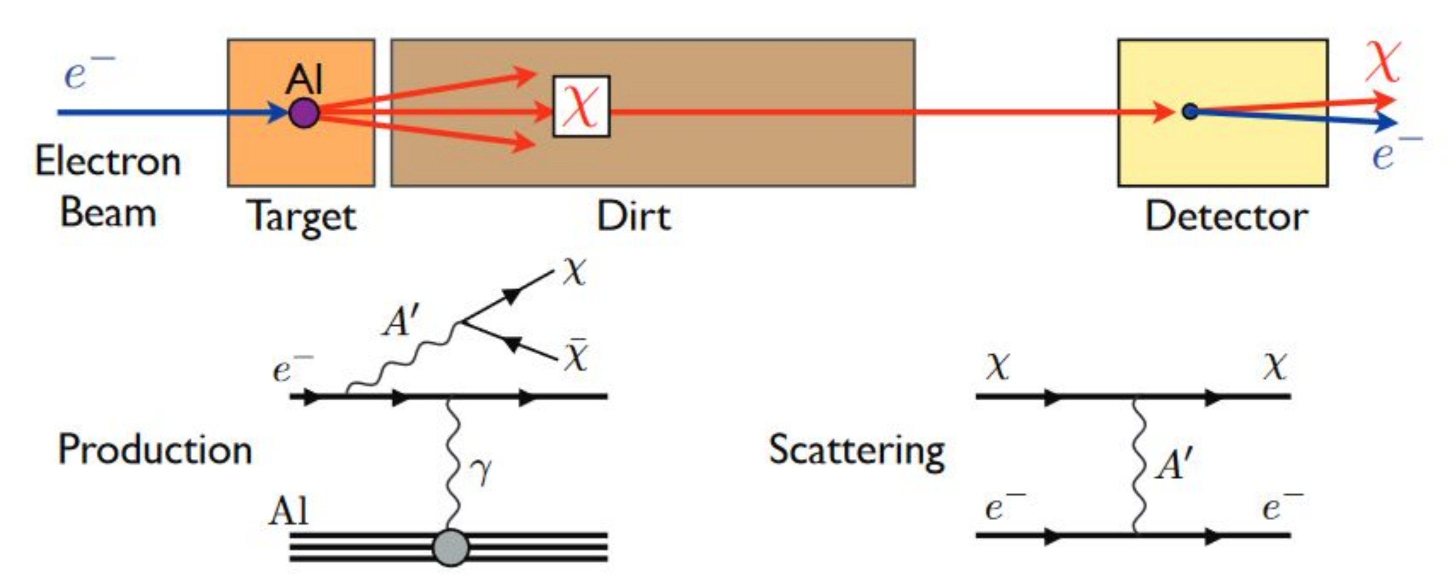








Beam-dump drawback



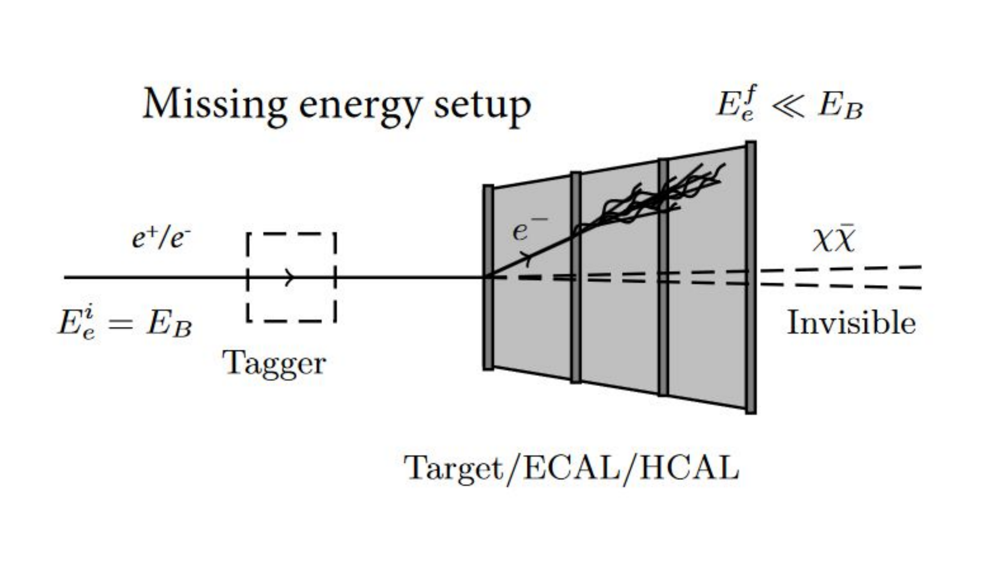
Price for both producing DM (rare process) and detecting its scattering (rare process):

$N_{signal} \propto \varepsilon^4$

Can we “skip” the detection part?

Missing energy strategy

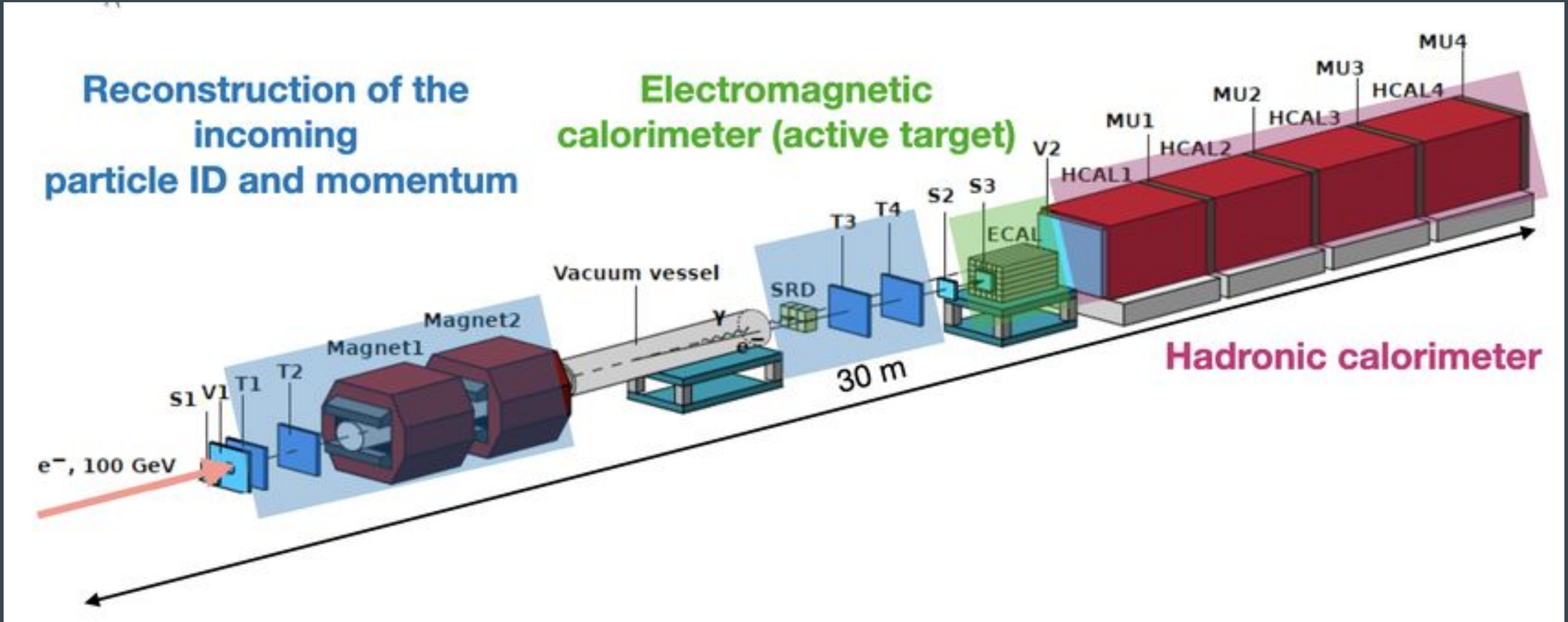
- Specific beam structure: particles impinging "one at a time" on the active target
- Deposited energy E_{dep} measured event-by-event
- **Signal:** events with large $E_{miss} = E_B - E_{dep}$
- **Backgrounds:** events with ν /long-lived (K_L) / highly penetrating(μ) escaping the detector, beam contaminants



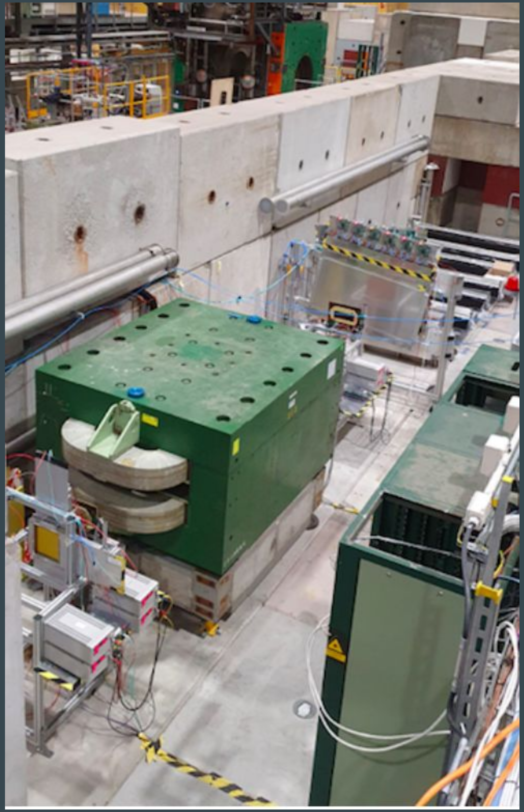
Signal scaling: $\propto \varepsilon^2$

The NA64-e experiment

Missing energy experiment at CERN SPS, H4 line (CERN North Area)

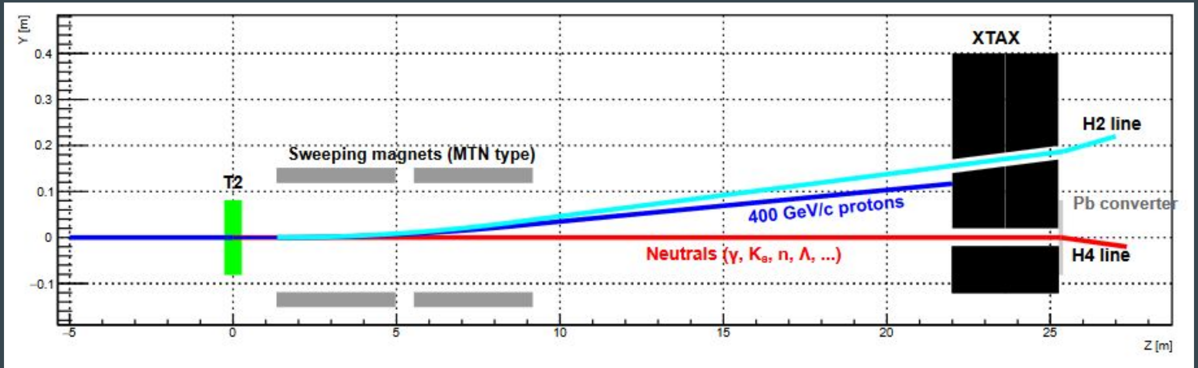


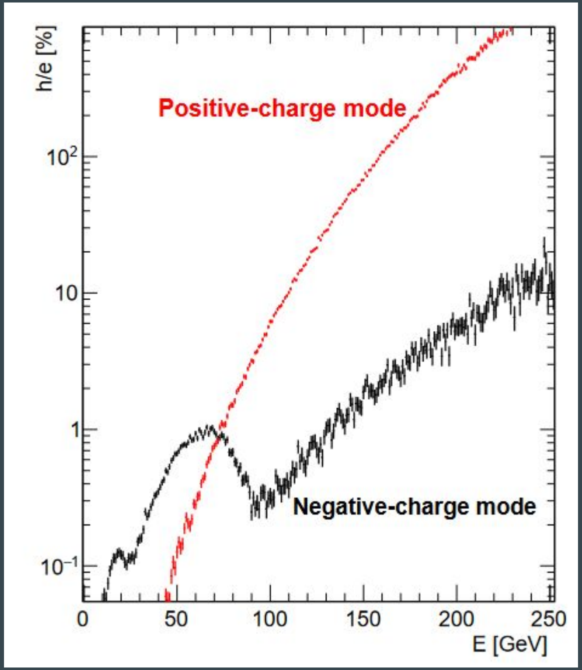
NA64-e at SPS - H4 line



The H4 beam-line at Cern SPS

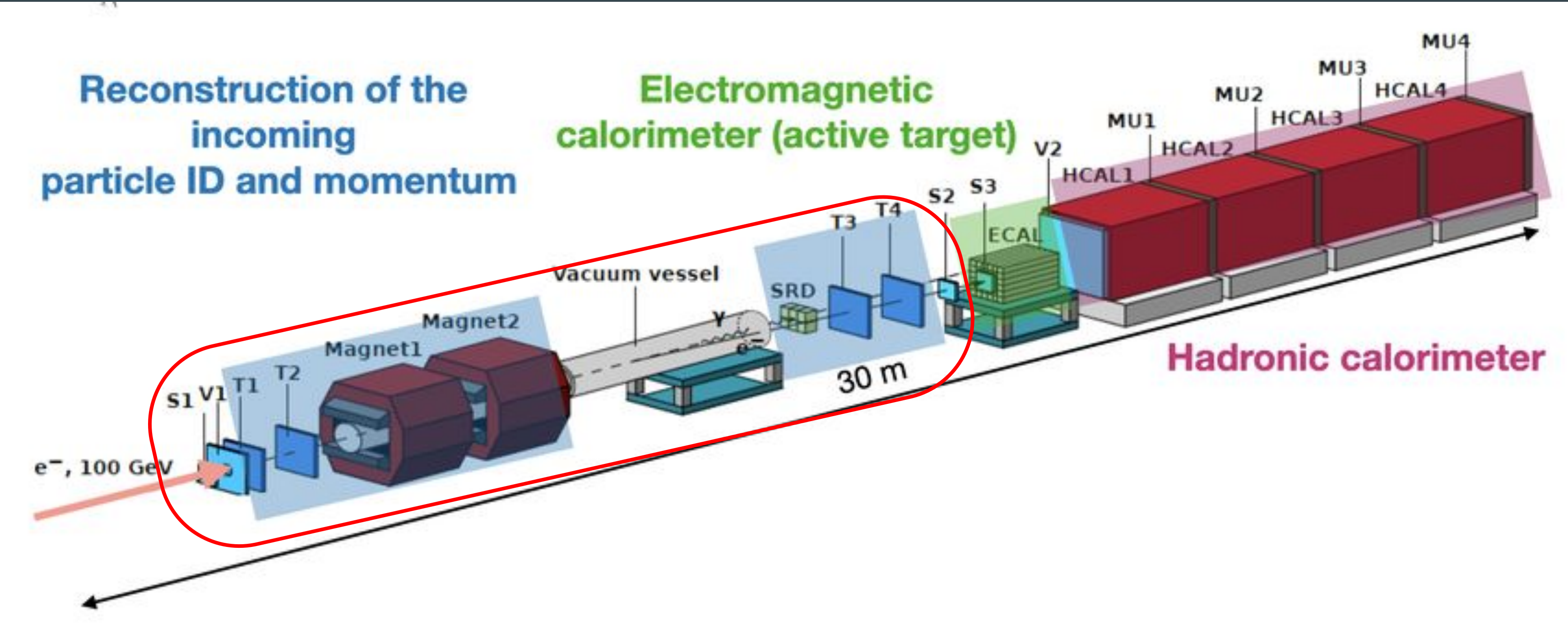
- e^- produced starting from the 400 GeV SPS proton beam, impinging on the beryllium T2 target
- Intensity on T2 target: 2–3 × 10^{12} protons per 4.8 s spill
- photons from T2 selected via XTAX absorber
- e^- obtained from photons converting on a downstream Pb target
- hadron contaminants arise from neutrals produced in the T2, and decaying after the sweeping magnets





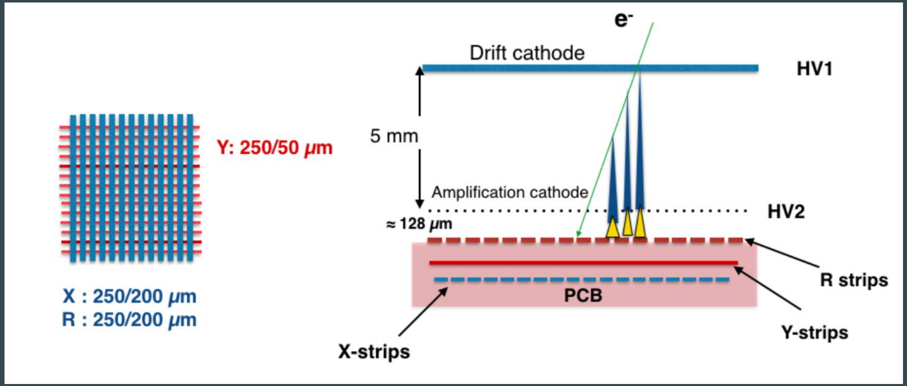
Hadron contamination at 100 GeV e^- mode: ~ 0.3%

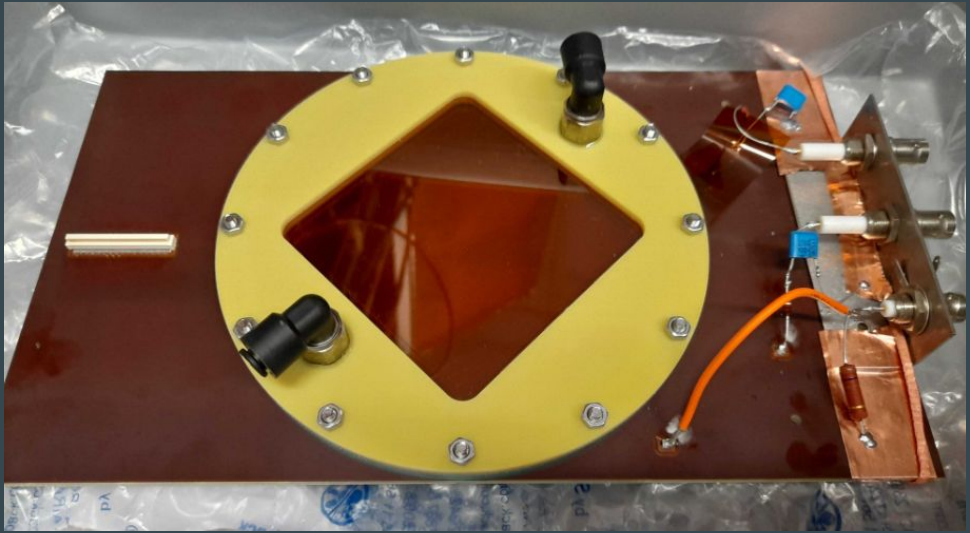
The NA64-e Detector- Upstream Trackers

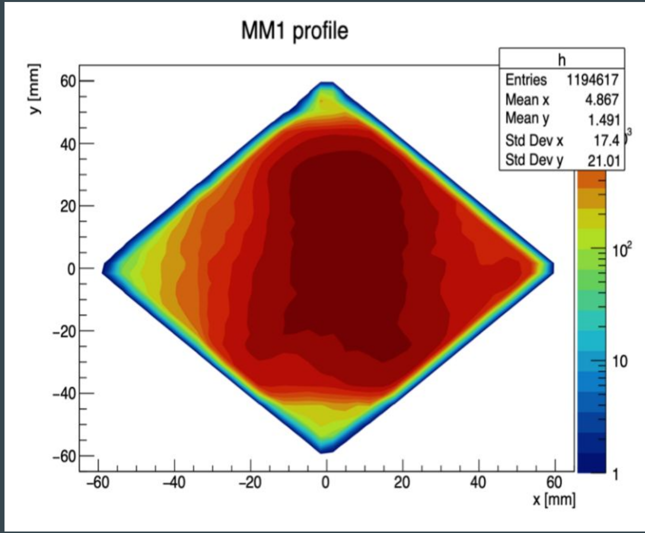


MicroMegas Detector

- 6× main MM stations along the line
- 5 mm drift gap, 128 μm amplification gap; Ar-CO2 gas admixture
- Drift: 720 V/cm; amplification 43 kV/cm





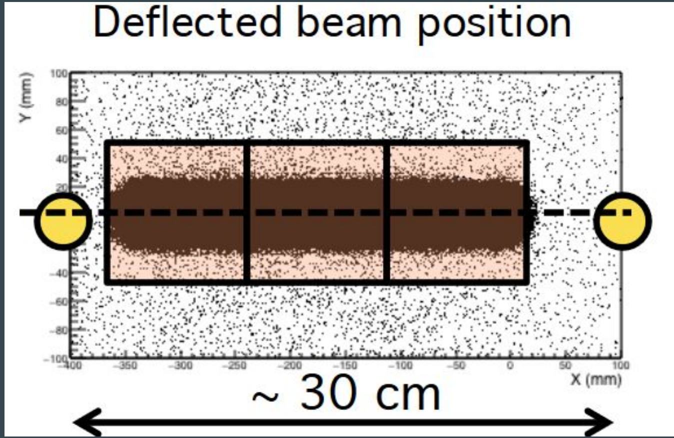


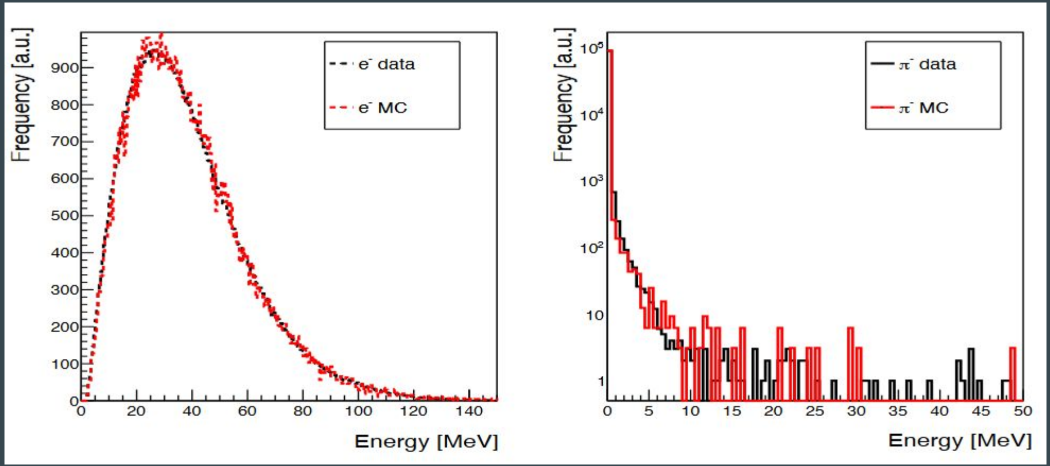
Tagging e^- with SRD detector

- Reject hadron with synchrotron radiation detector (SRD)
- Three modules: plastic scintillator + Pb layers, PMT readout
- Pion rejection inefficiency at 100 GeV: 10^{-4} - 10^{-5}

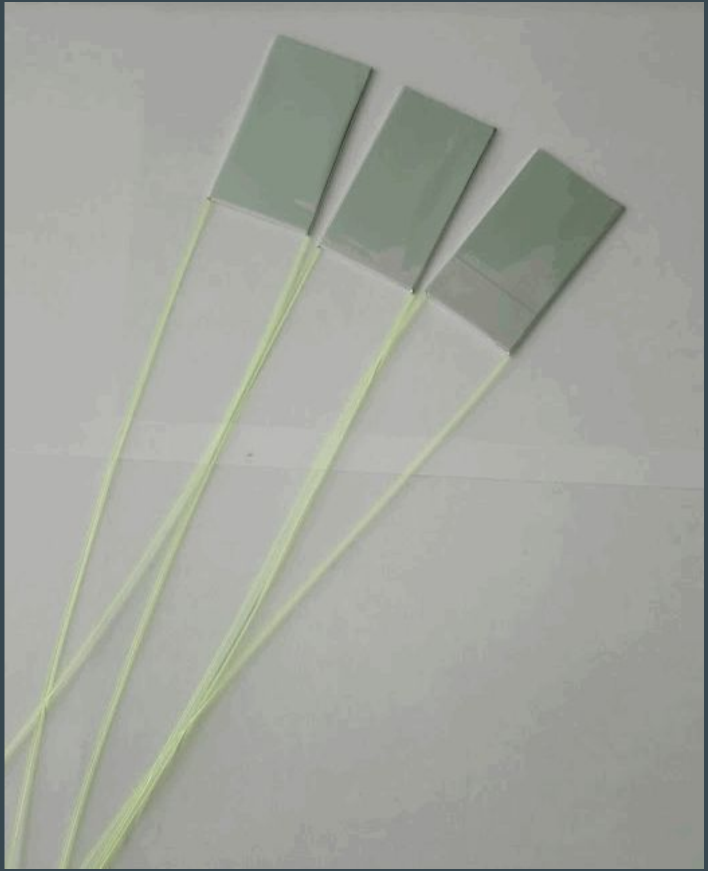
Larmor's formula:

$$P_\gamma = \frac{q^2}{6\pi\varepsilon_0 c^3} a^2 \gamma^4 = \frac{q^2 c}{6\pi\varepsilon_0} \frac{\beta^4 \gamma^4}{\rho^2}$$

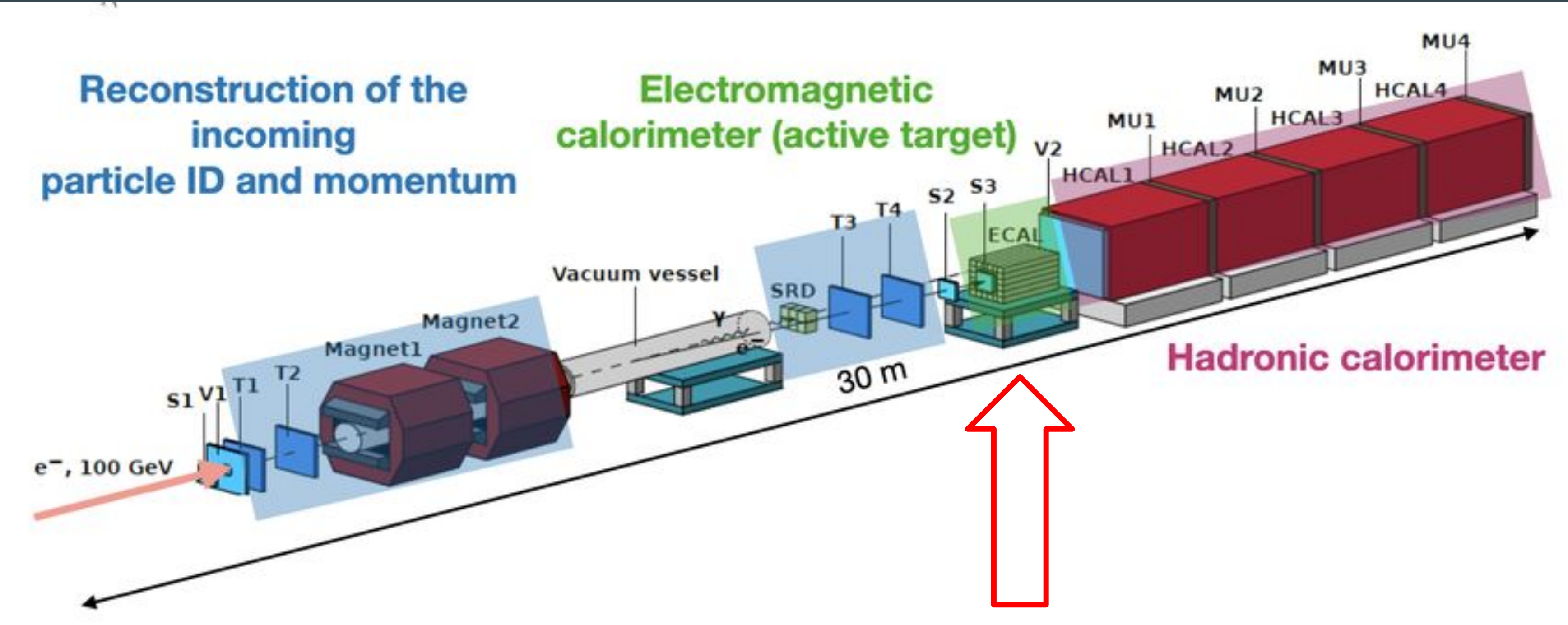




The SRD detector

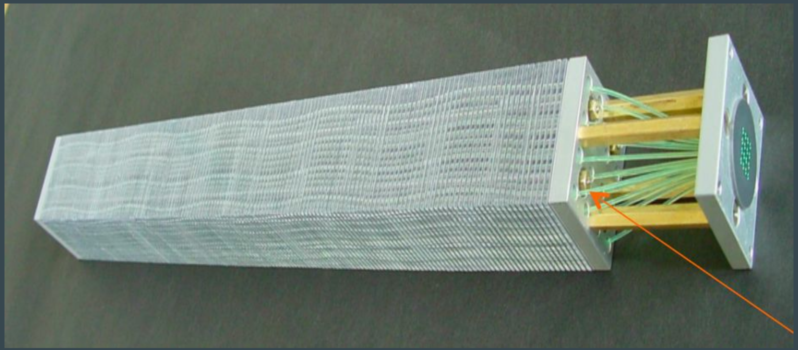


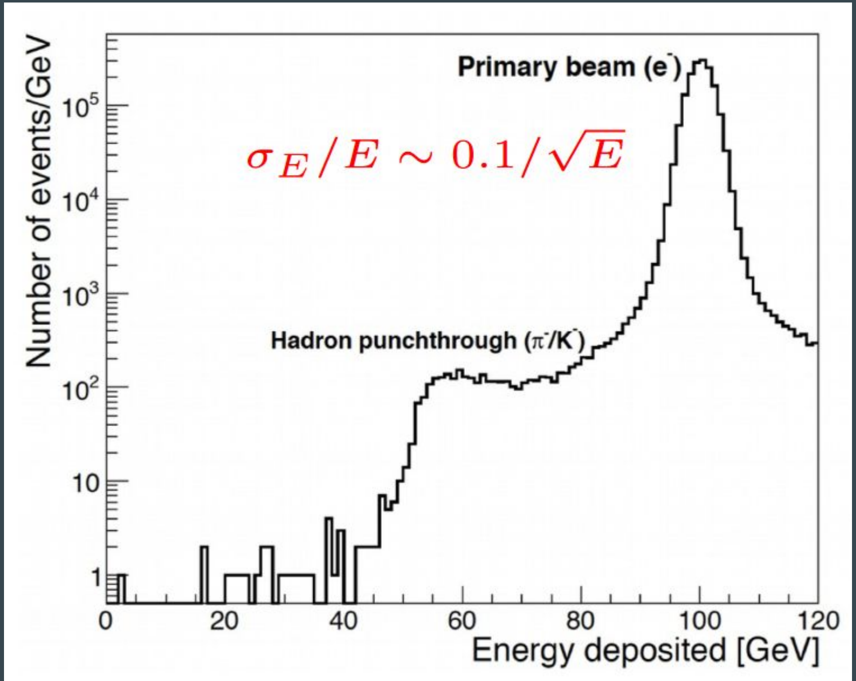
The NA64-e Detector- The Active Target



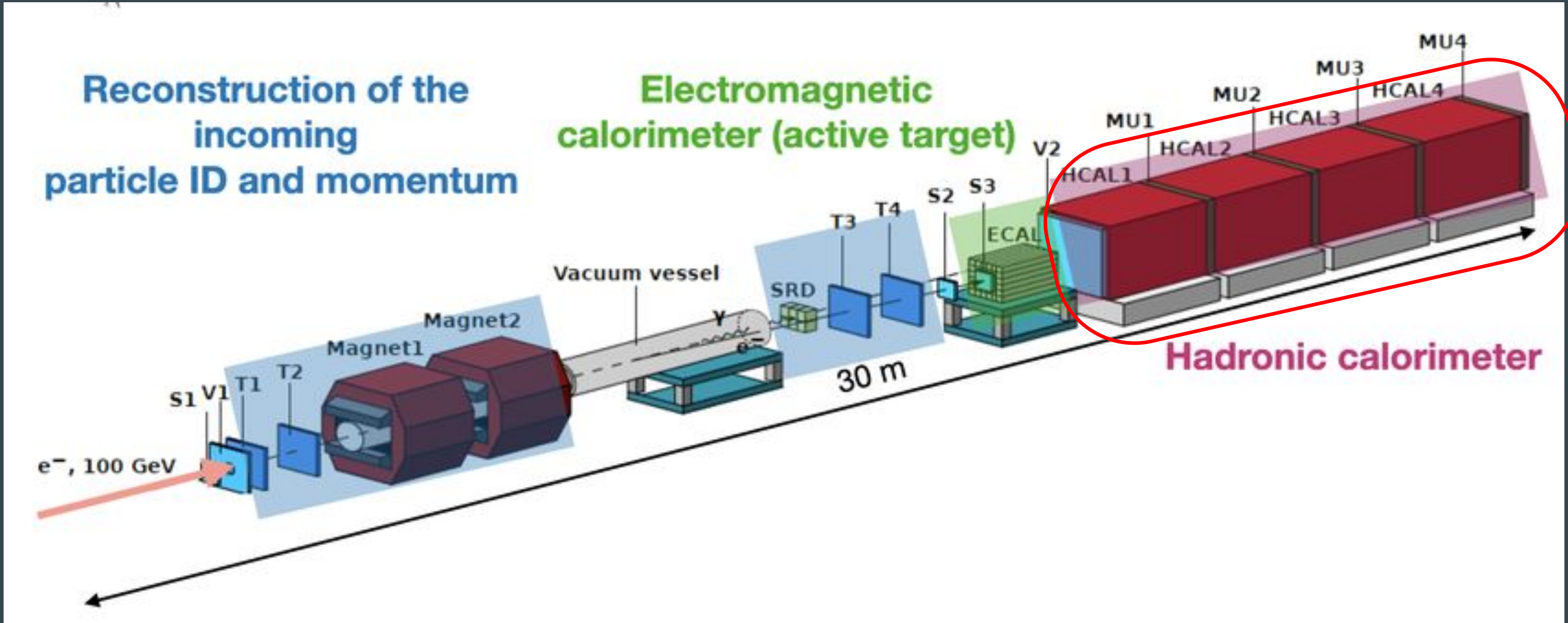
The Electromagnetic Calorimeter (ECal)

- EM-Calorimeter: 40 X_0, Pb/Sc Shashlik, PMT readout
- Readout WLS fibers go in a spiral to avoid E-leak and dead zones
- Hermeticity scan: no potential source of background is found



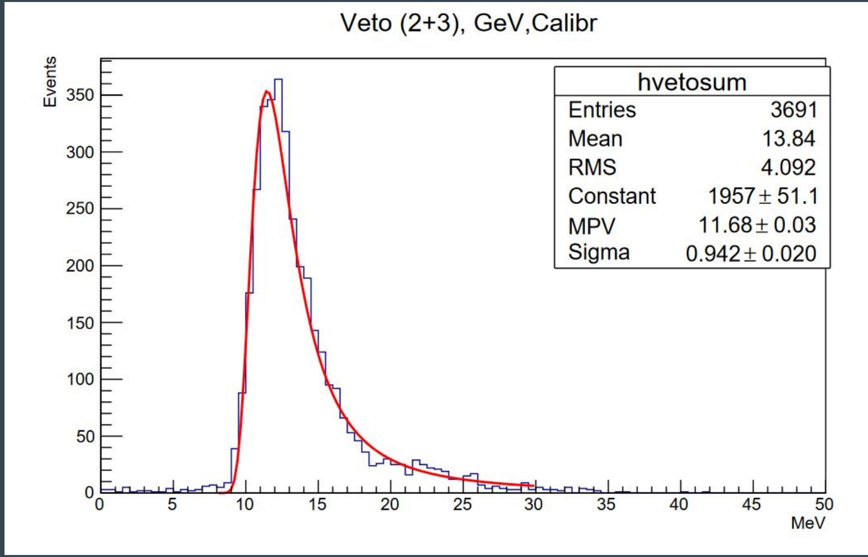


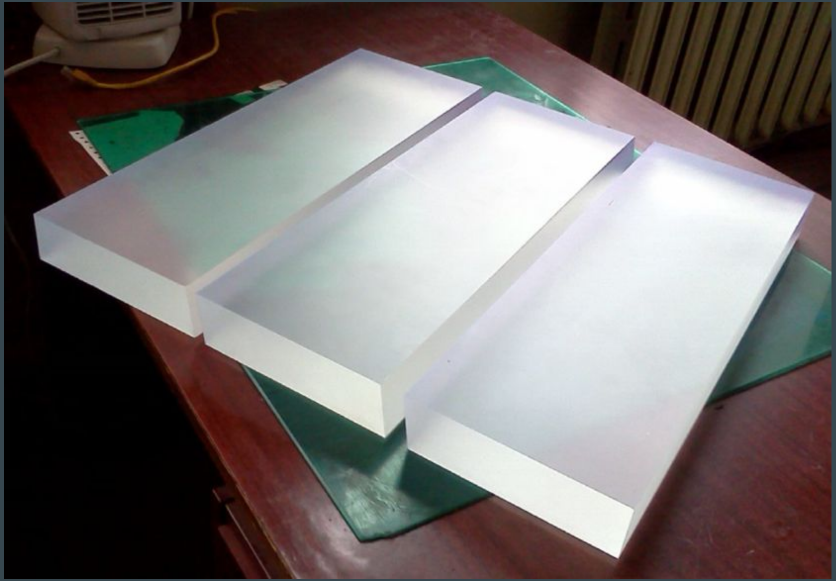
The NA64-e Detector - Downstream



The muon VETO

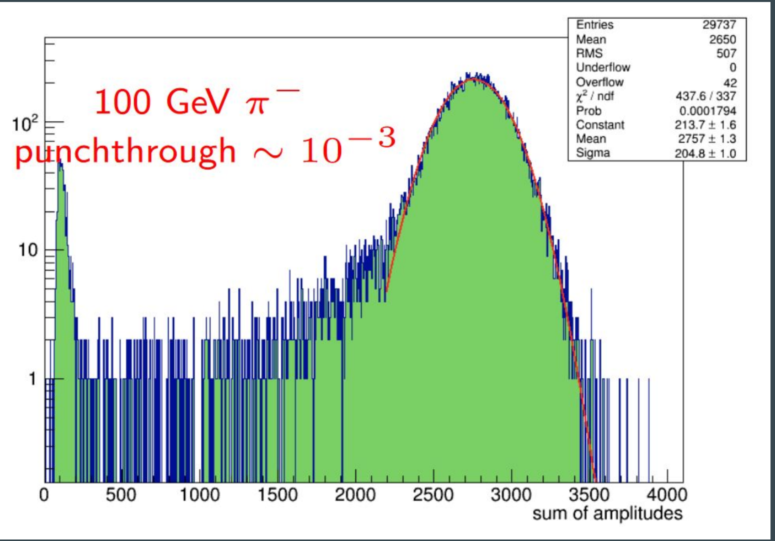
- Active veto for muon and other penetrating particles produced in the ECcal
- 3× 51×17×45 mm^3 scintillator plates
- PMT readout

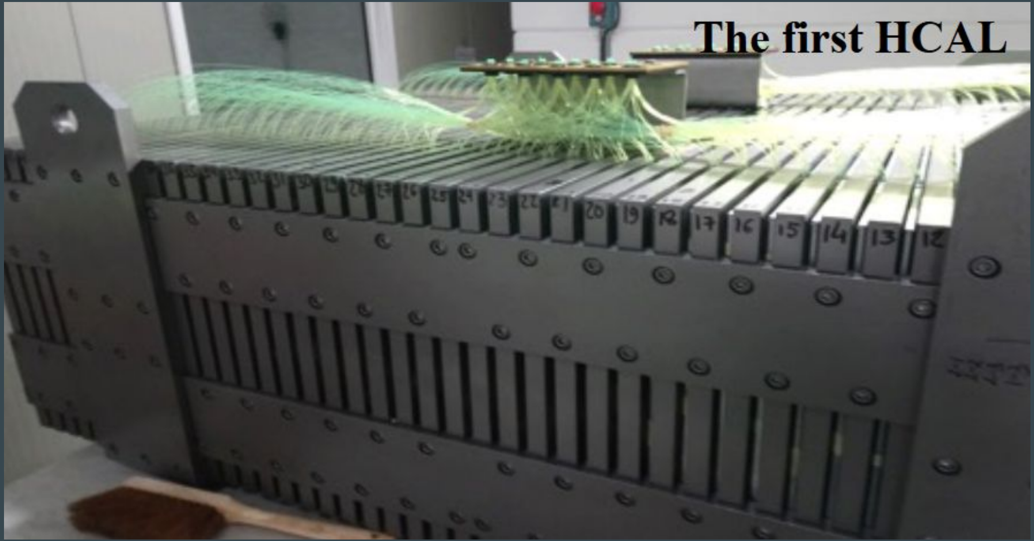




Hadronic Calorimeter (HCal)

- 4× 1-m long sandwich modules ~ 30 nuclear interaction length
- Optical fibers + PMT readout
- Pion punchthrough probability: 10^{-3} per module

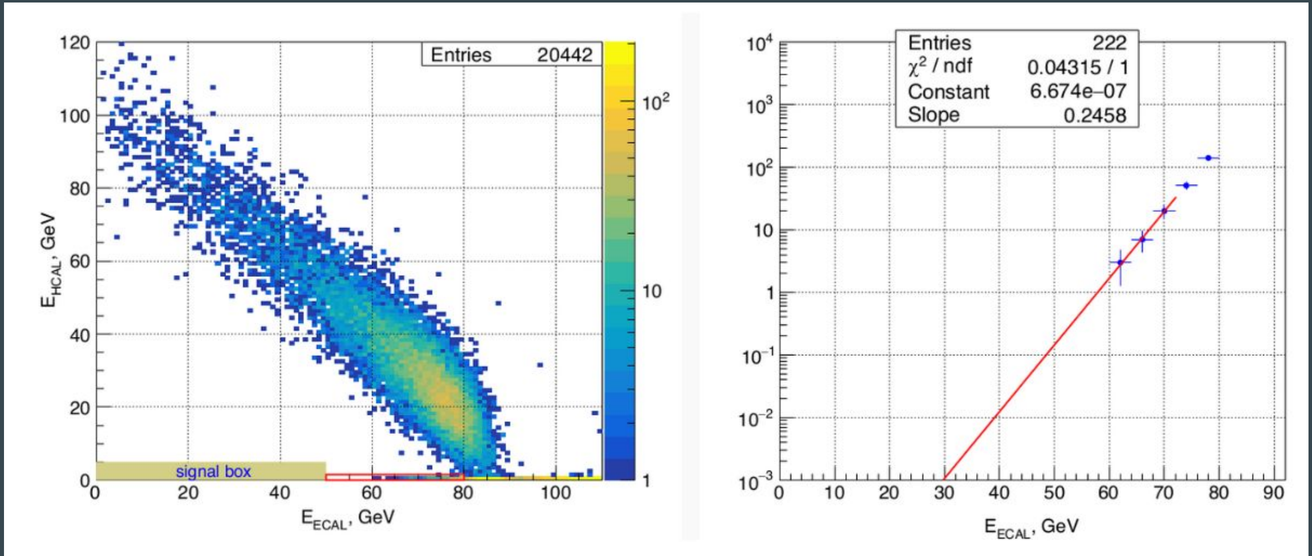




NA64 analysis flow

- Selection cuts:
  - Clean impinging 100 GeV/c e-
  - no activity in VETO/HCAL, including HCAL4
  - EM shower-shape compatible with e- induced one (data-driven shower shape χ2 distribution)
- Signal window: E < 47-50 GeV, EHCAL < 1 GeV
- Expected background yield: ~ 0.5 events

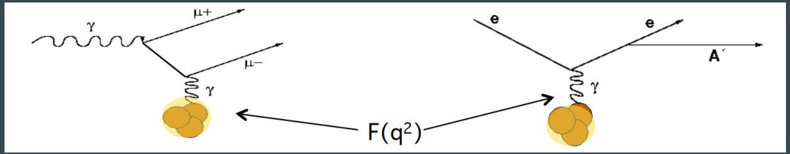
Background source	Background, n_b
1. Di-muons losses or decays in the target	0.04 ± 0.01
2. μ, π, K $\rightarrow$ e +... decays in the beam line	0.3 ± 0.05
3. lost neutrals (γ, n, K^0) from upstream interactions	0.16 ± 0.12
4. Punch-through leading n, K_L^0	< 0.01
Total (conservatively) n_b	0.51 ± 0.13

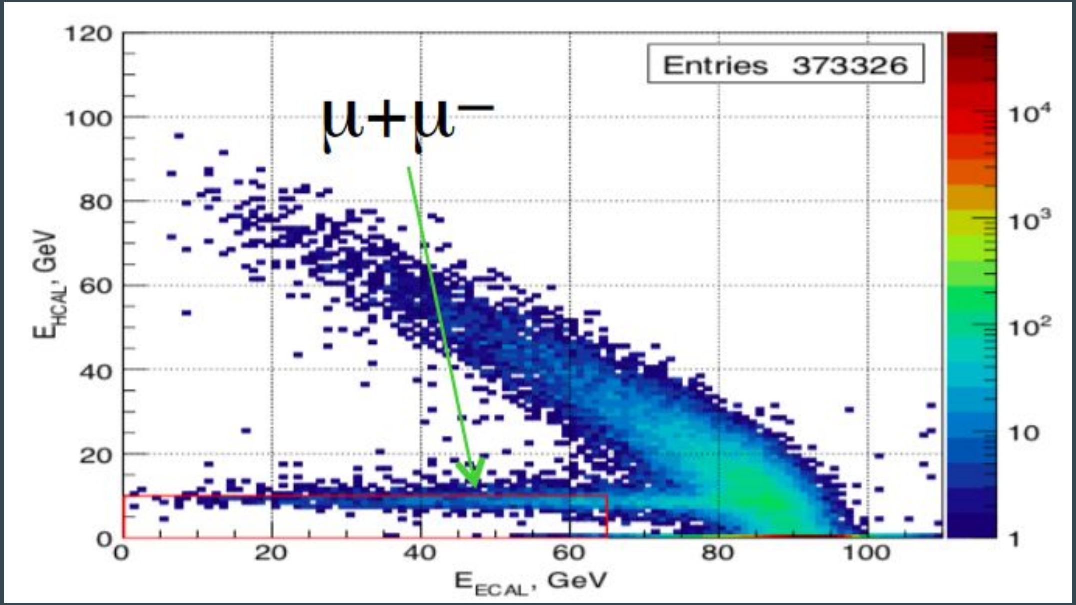


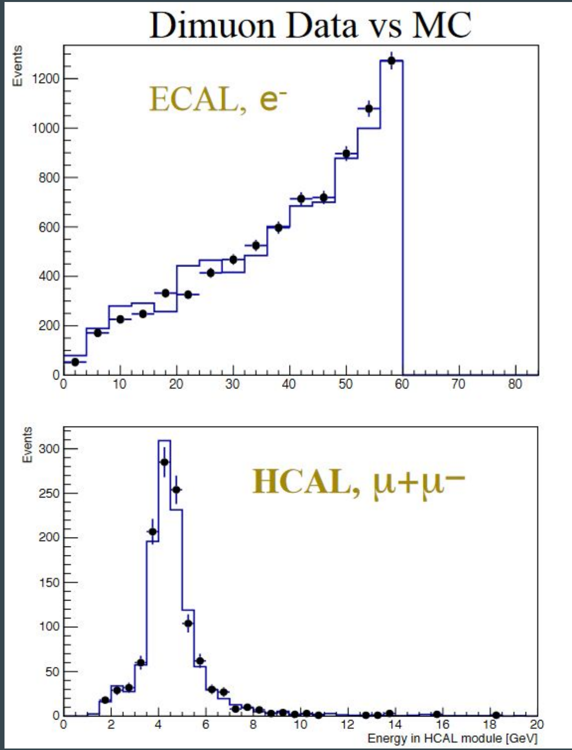
Di-muon events analysis

Rare QED process ~10-5/EOT:

- similar to the A′ production
- cross check of A′ yield, systematic errors
- background prediction from data
- cross check of overall efficiency

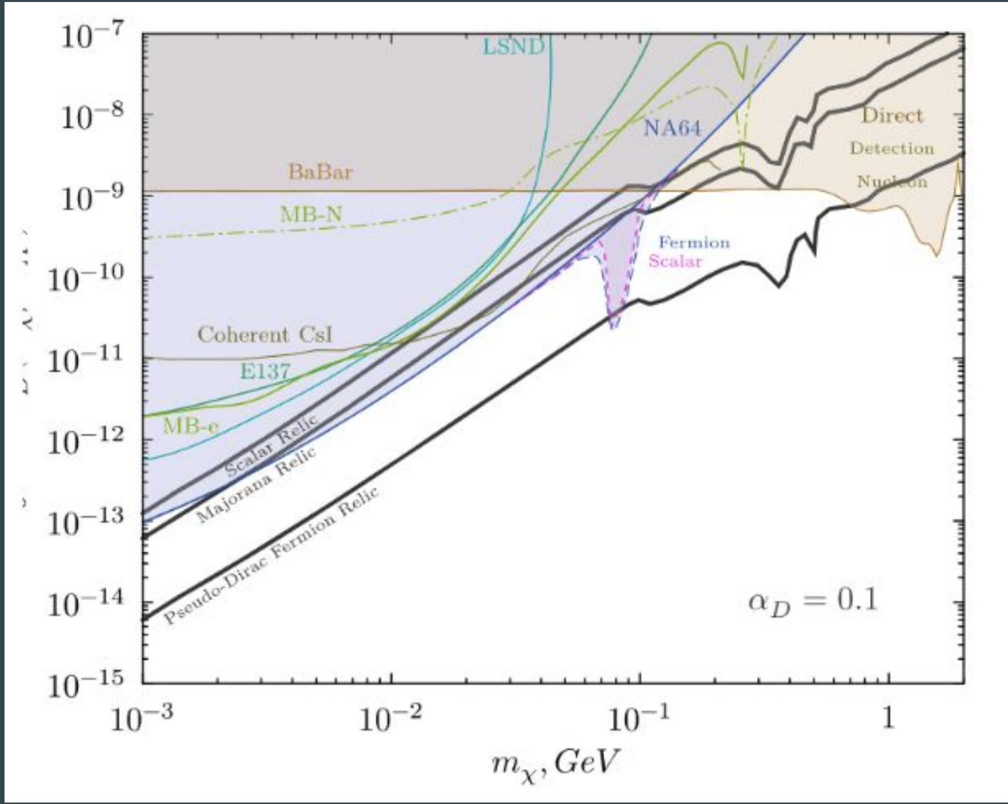






NA64-e reach

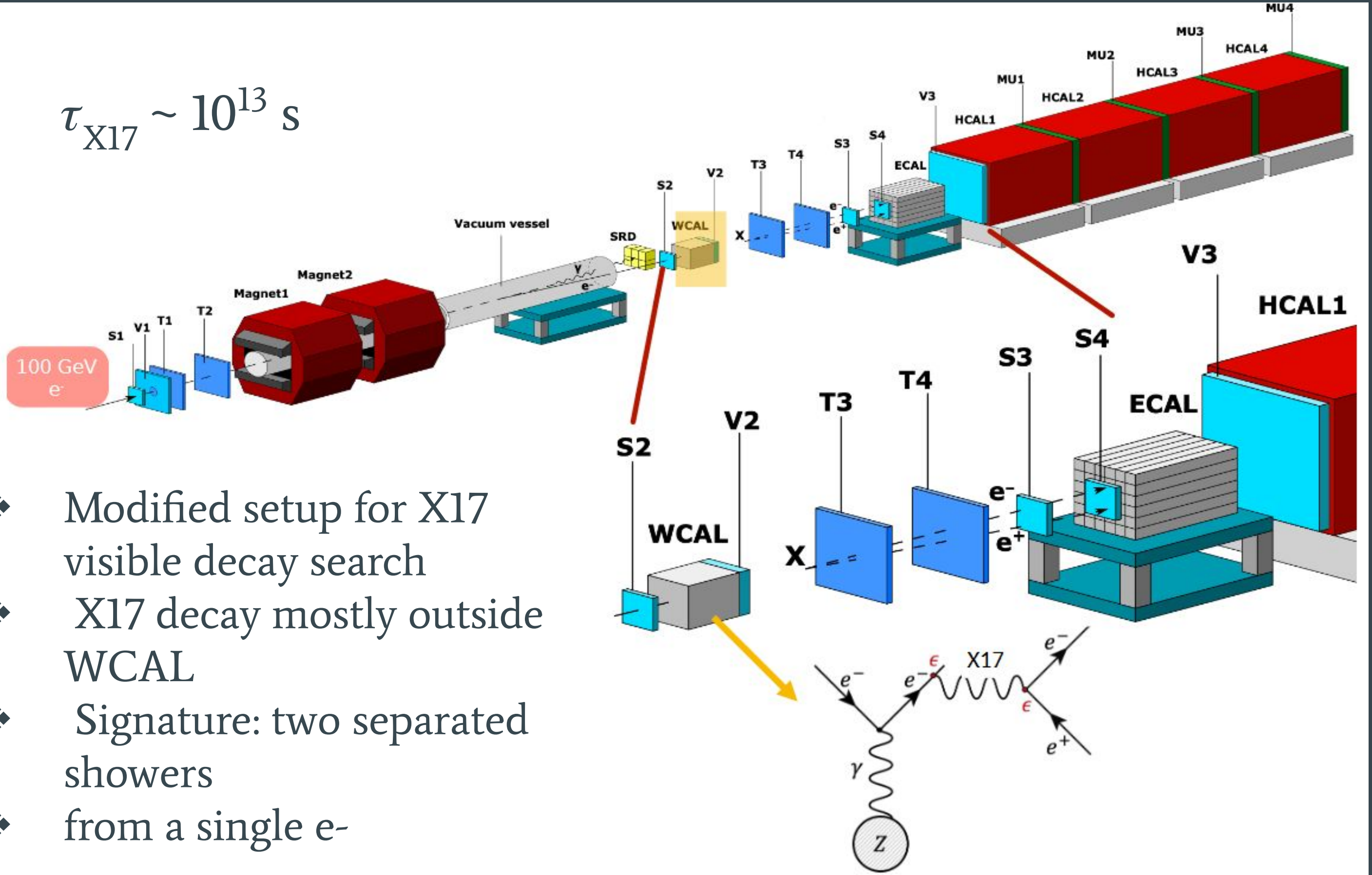
- Current results based on~ 10^{12} EOT
- For αD = 0.1, NA64-e excludes the Scalar and Majorana scenarios in a large mχ interval.



arXiv:1906.00176

NA64-e search for X17

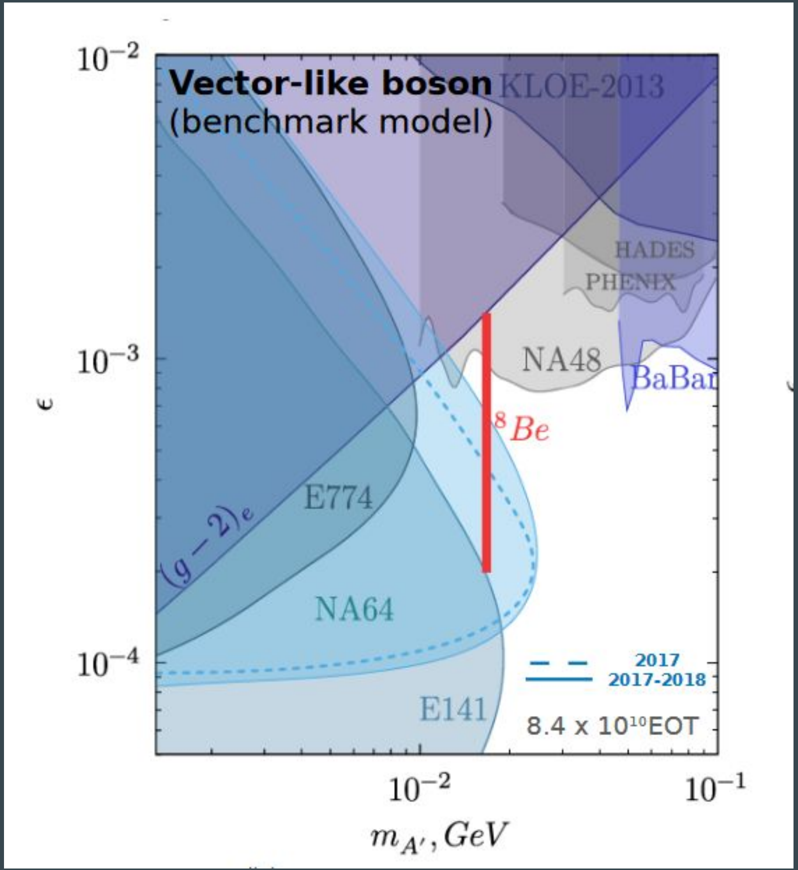
$\tau_{X17} \sim 10^{13}$ s



- Modified setup for X17 visible decay search
- X17 decay mostly outside WCAL
- Signature: two separated showers
- from a single e-

NA64-e search for X17

8.4×10^{10} EOT collected in visible mode: ruled out part of the available X17 parameter space



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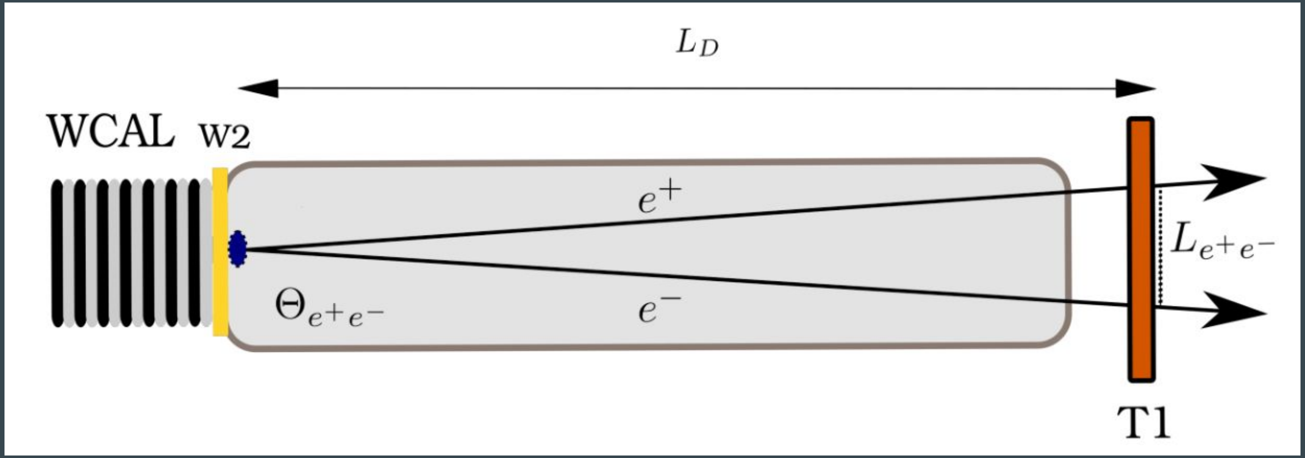
NA64-e upgrades for the X17 search

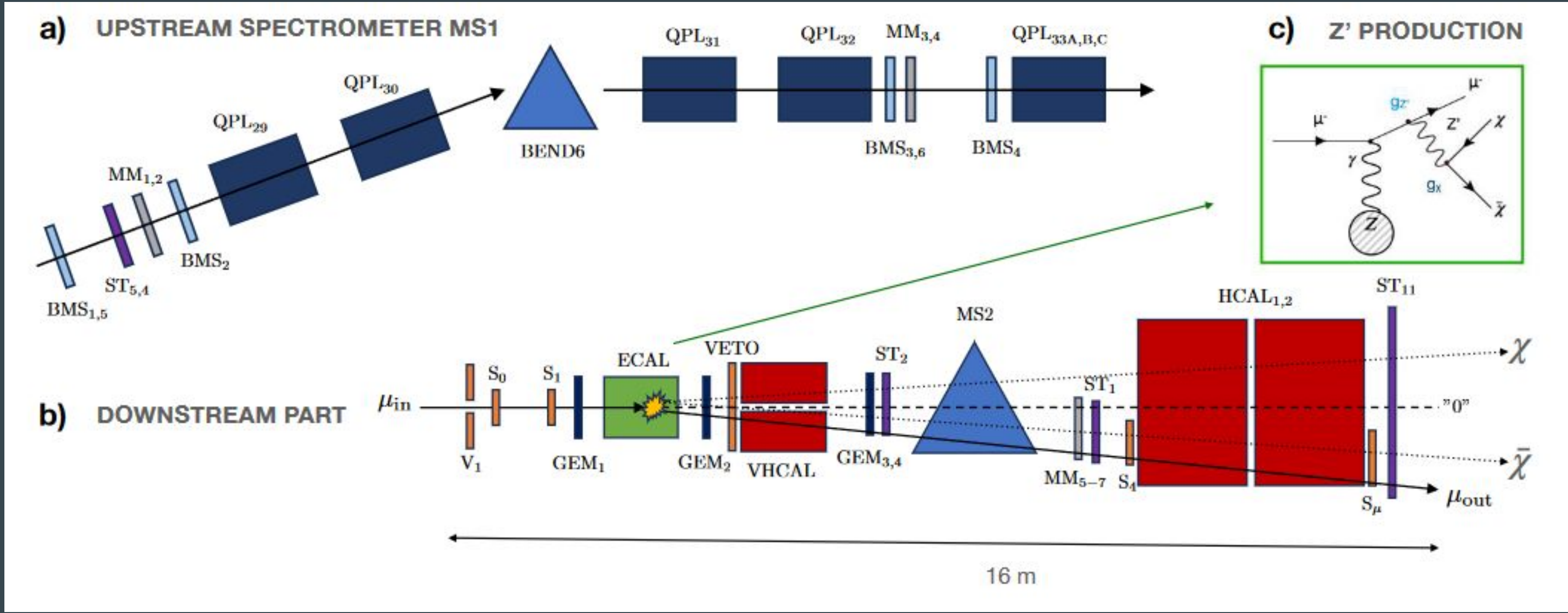
- The sensitivity to the X17 in the NA64 visible mode is limited by the WCAL length ($\gamma c \tau_{X17}$ ~ 30 mm) and the capability to separate the very close tracks of the X17 → e+e− decay → new setup under consideration
- New WCAL geometry for improved signal efficiency
- Dipole magnet + ~ 18 m vacuum pipe for tracks separation
- GEM trackers + ECAL for invariant mass measurement (10% invariant mass resolution)
- Possible to probe significant part of the X17 parameter space in a ~ 20 days run



NA64-μ exploring the L_μ -L_τ scenario

- LDM Model variation: *Z'* as a portal to DM sector
- Z': light boson coupled to the second generation leptons (μ,τ) in the L_μ -L_τ scenario
- Possible low mass explanation of the (g-2)μ (the muon anomaly)

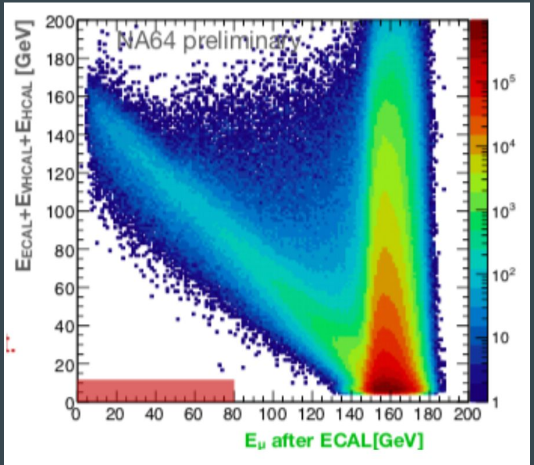
- NA64-μ: Missing momentum search for Z' using the 160-GeV muon beam by the M2 line at Cern

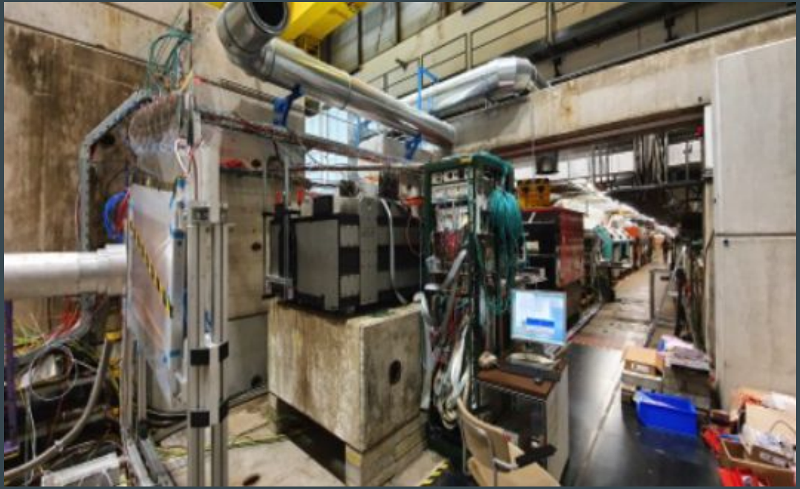


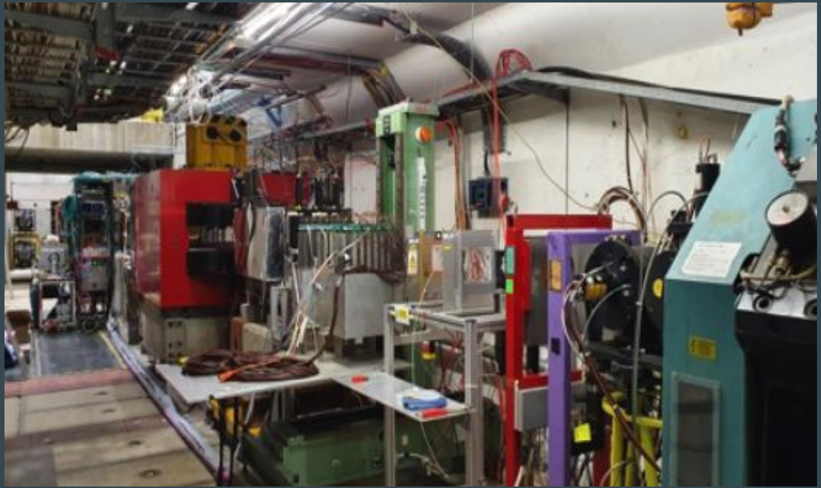
NA64-μ

Signal Signature:

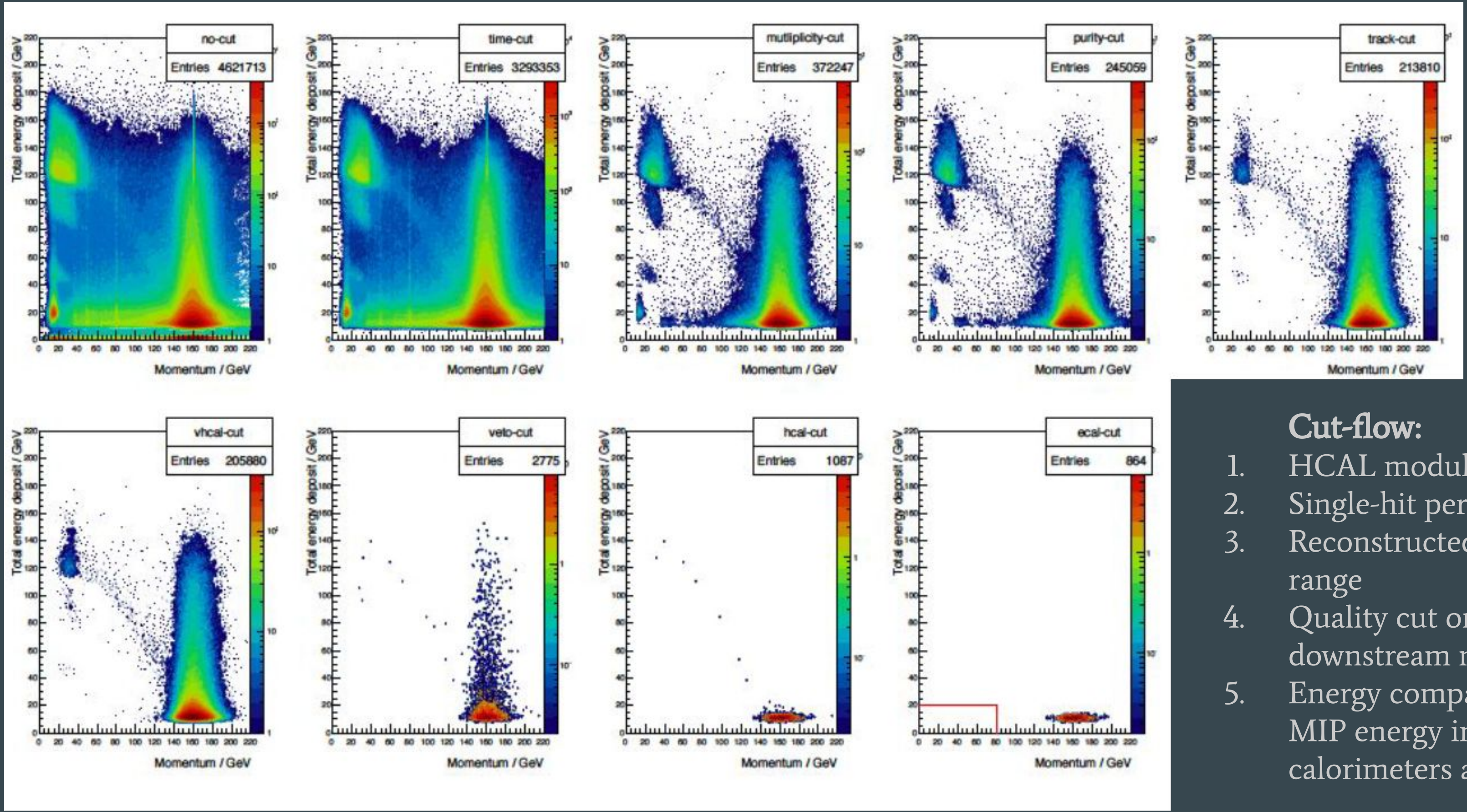
- in: clean 160 GeV μ- track
- out: < ~80 GeV μ- track
- no energy in the ECAL, Veto, HCAL







NA64-μ analysis cut-flow



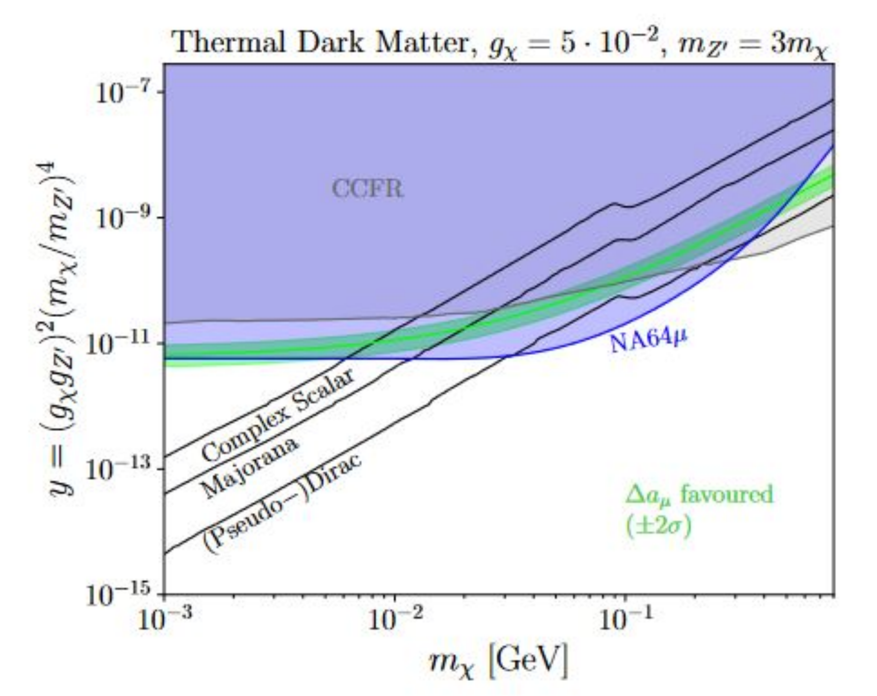
Cut-flow:

1. HCAL modules in-time
2. Single-hit per tracker
3. Reconstructed momenta range
4. Quality cut on downstream momenta
5. Energy compatible with MIP energy in calorimeters and veto

NA64-μ limits

- Total statistic of $(1.98 \pm 0.02) \times 10^{10}$ muons on target
- No events observed
- Almost completely excluded the explanation of the (g-2)μ in this particular model

Background source	Background, n_b
(I) Momentum mis-reconstruction	0.05 ± 0.03
(II) $K \to \mu + \nu$, ... in-flight decays	0.010 ± 0.001
(III) Calorimeter non-hermeticity	< 0.01
Total n_b (conservatively)	0.07 ± 0.03



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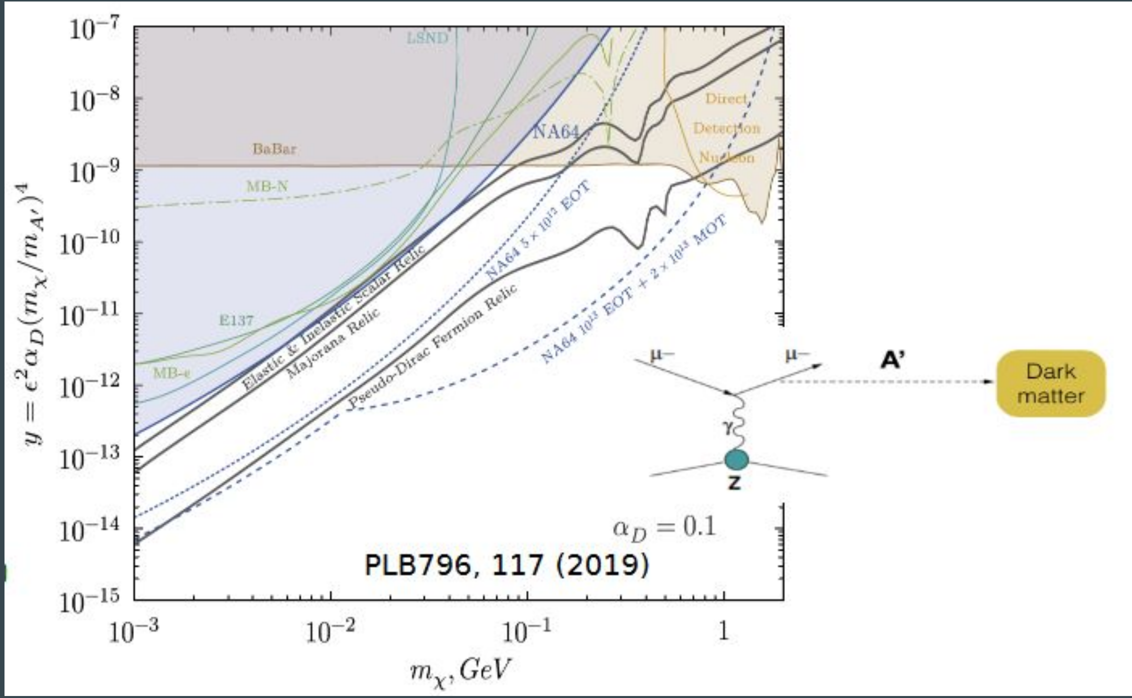
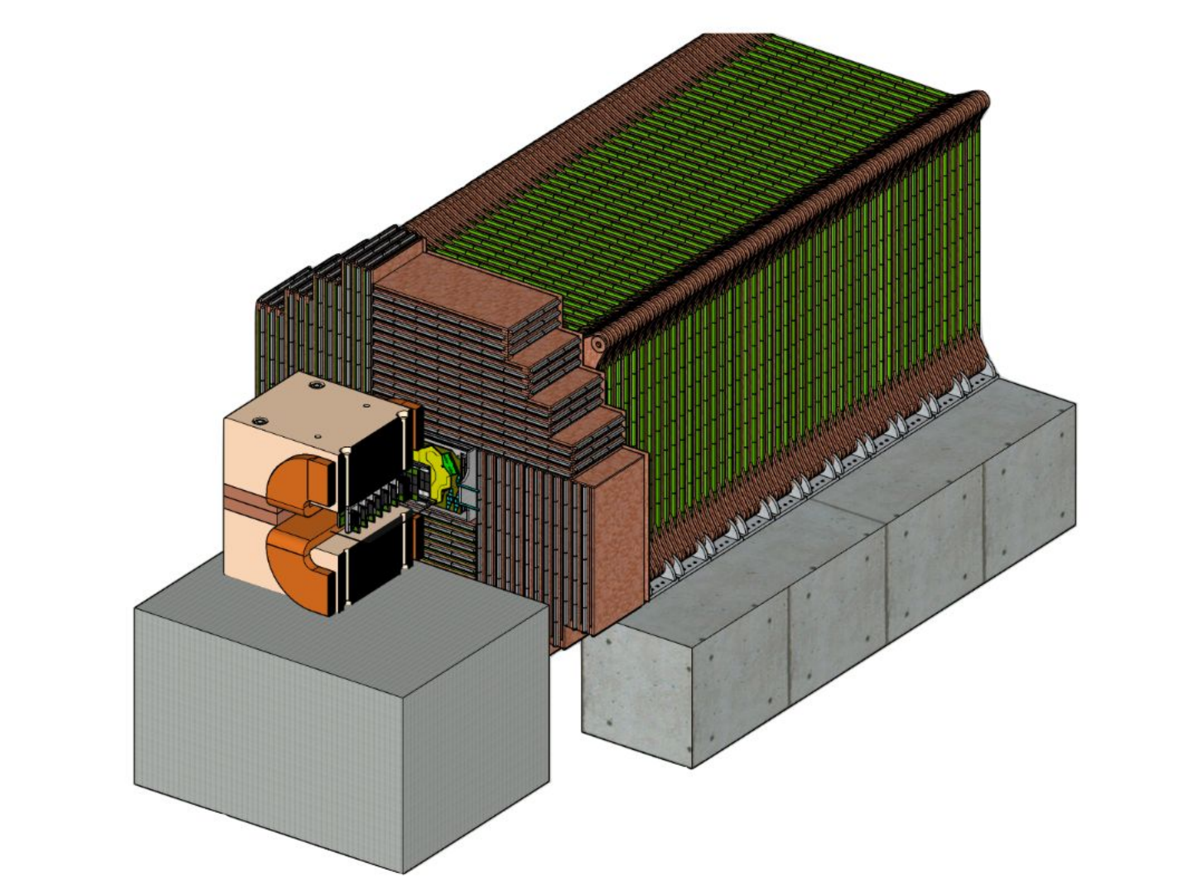
NA64-μ projected reach in the A' scenario

- Optimal sensitivity for A' with mass>10 MeV
- Complementary to NA64-e

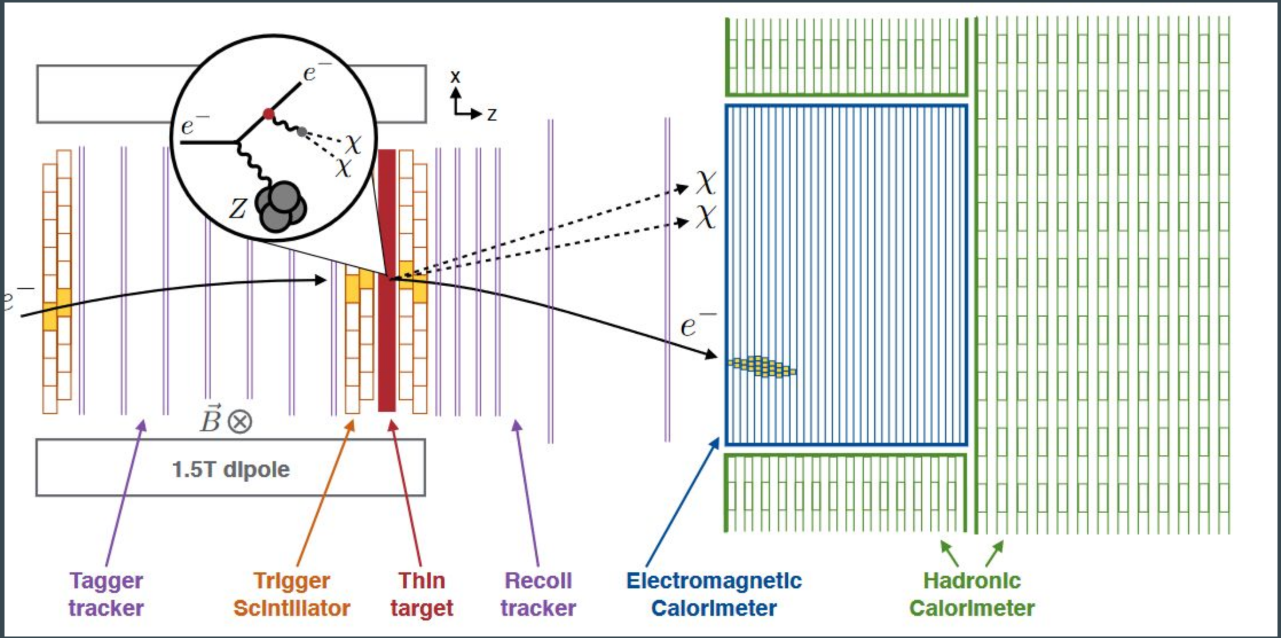


The Light Dark Matter eXperiment (LDMX)



LDMX - Experimental approach

- 4 - 8 GeV electron beam on thin target
- measure momentum before and after the interaction in the target
- **signal signature:**   low energy e^- with detectable transverse missing momentum - NO other activity in the ECAL/HCAL

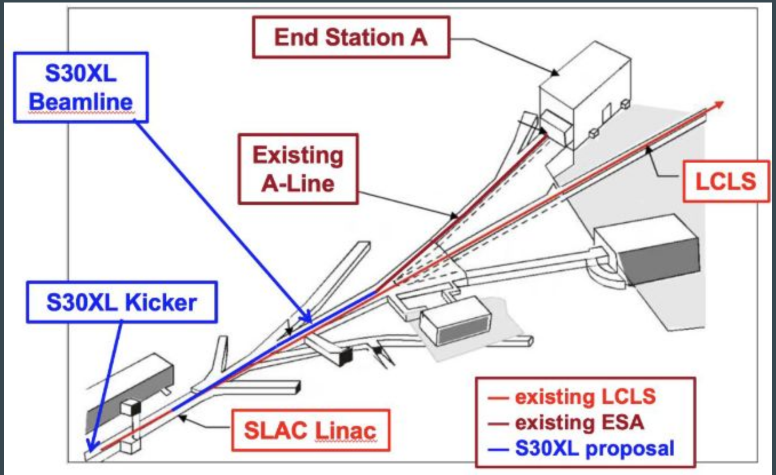


- Beam temporal structure allowing for one-by-one tagging of electrons

Beam Facility

Beam provided by SLAC:

- Planning on 4 GeV and 8 GeV runs
- low current, high repetition rate of 37 MHz

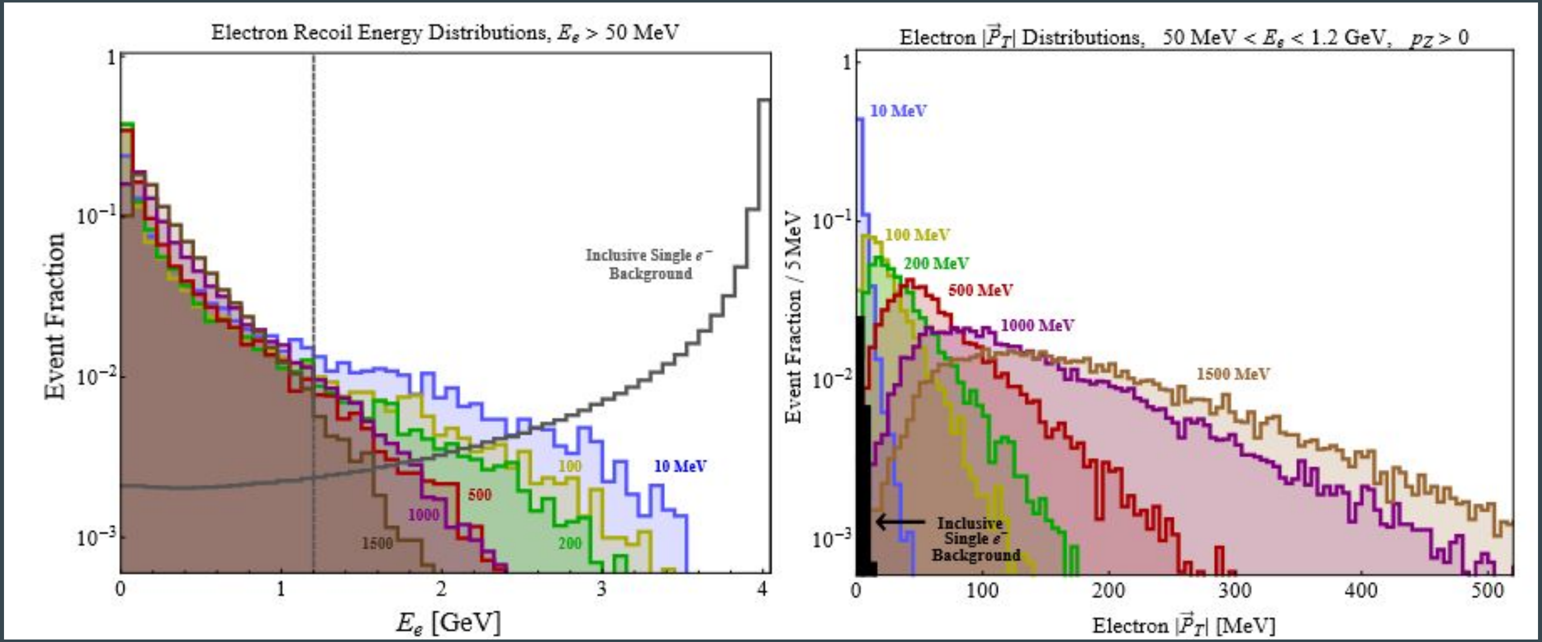


SLAC aerial

Kogut, John. (2022). Discovery of Heavy Quark Bound States, Evidence for Confinement and the Path Forward. European Physical Journal C.

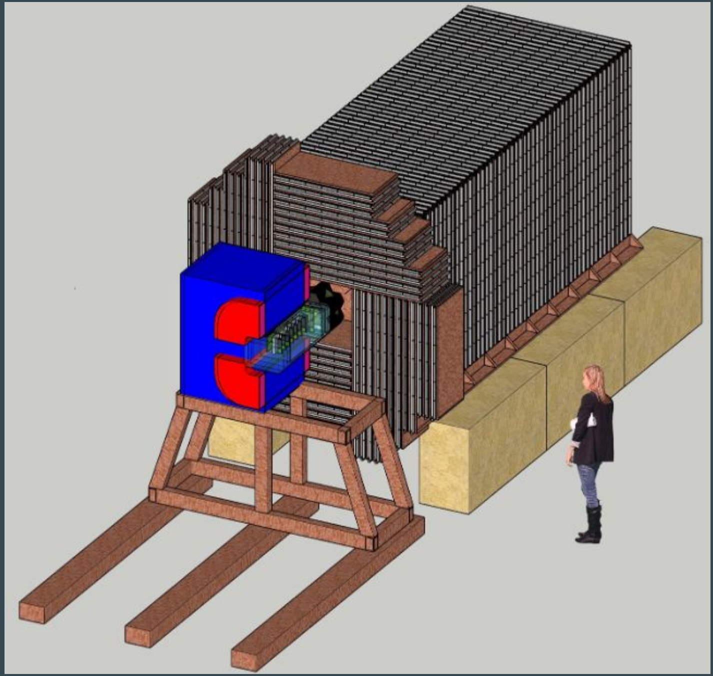
Signal Identification

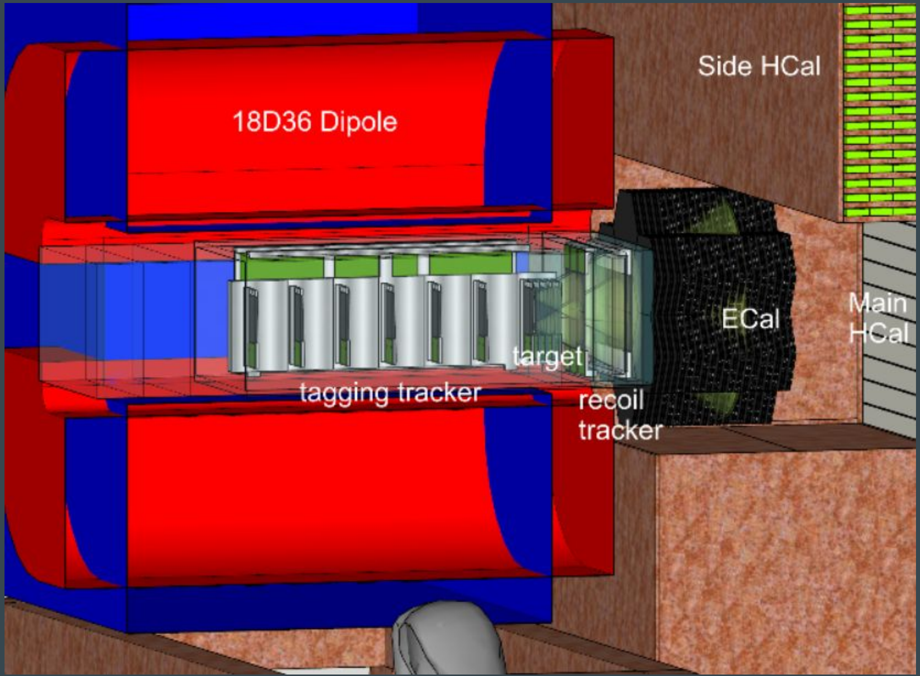
- DM bremsstrahlung VS SM bremsstrahlung: different kinematics



arXiv:1808.05219

LDMX Detector Concept





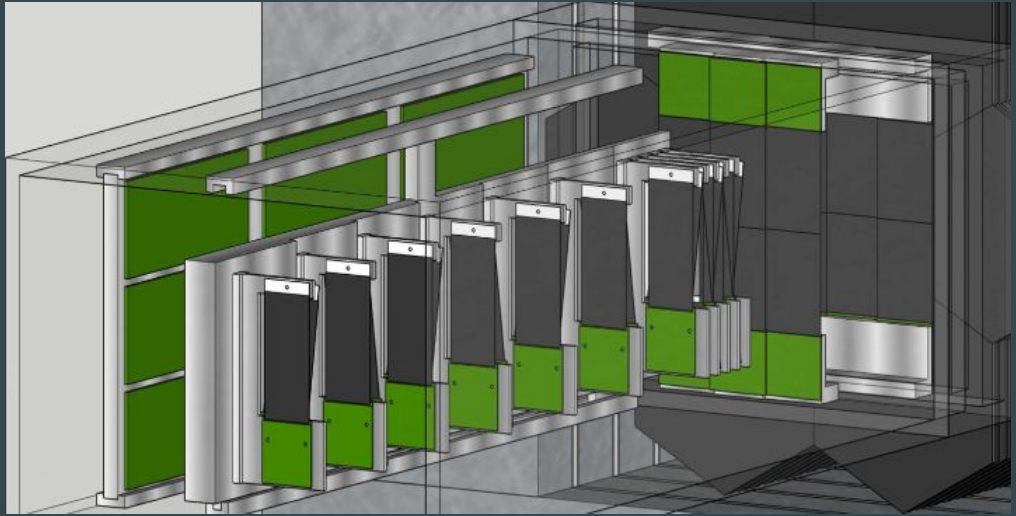
- Fast, low mass tagging and recoil trackers
- Fast, granular and radiation hard electromagnetic calorimeter enclosed by hermetic hadronic calorimeter.
- Trigger scintillator for counting incoming e-

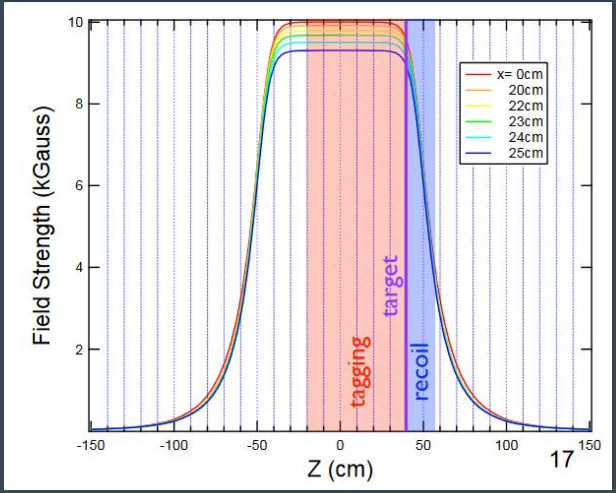
arXiv:1808.05219

Tracker

- Tagger tracker
  - 7 double-sided low mass silicon strip (~0.7 X_0)
- Recoil tracker
  - 6 low-mass layers
  - Efficient reconstruction of 50MeV - 1.2 GeV recoil e–

- Tungsten Target
  - ~0.1 X_0 good compromise between rate and momentum resolution
  - Scintillator pads in the front/back

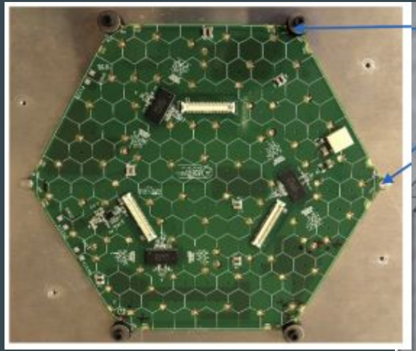


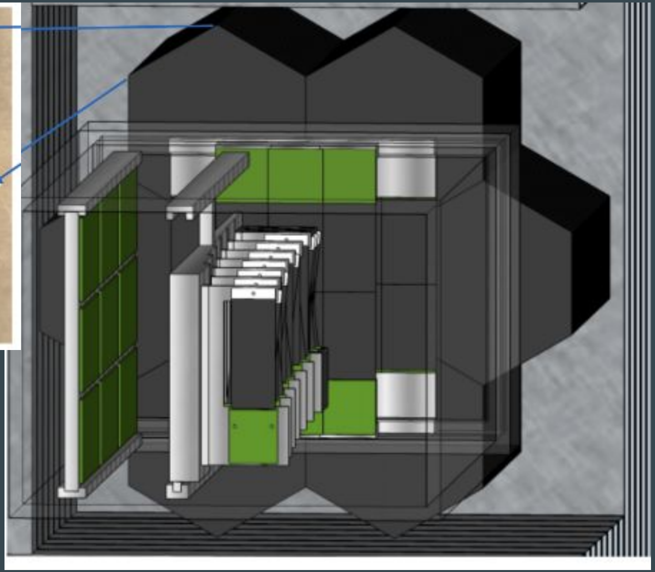


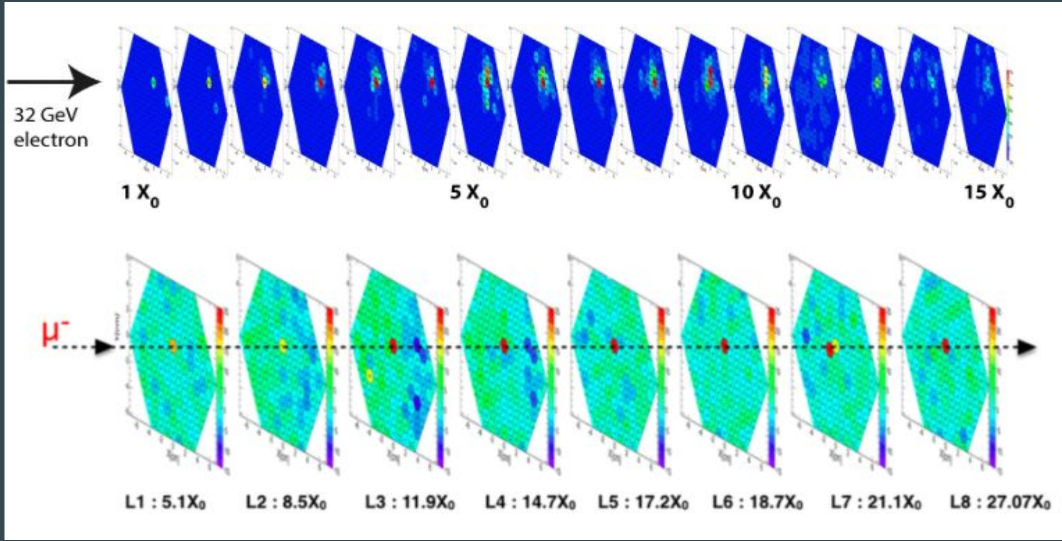
arXiv:1808.05219

Electromagnetic Calorimeter

- Si-W sampling calorimeter, with high granularity and shower containment (~40 X_0)
- ECal signal used in the trigger







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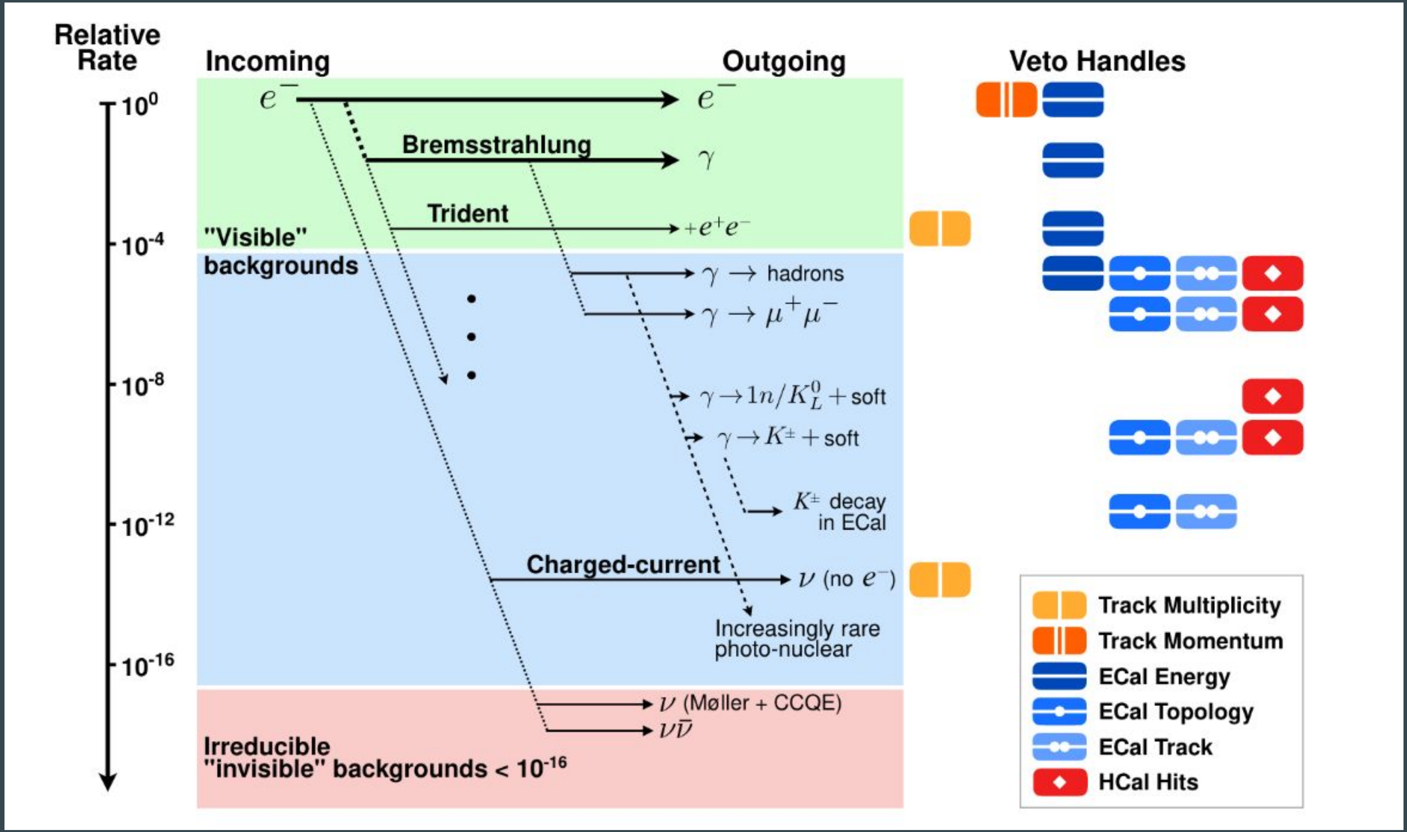
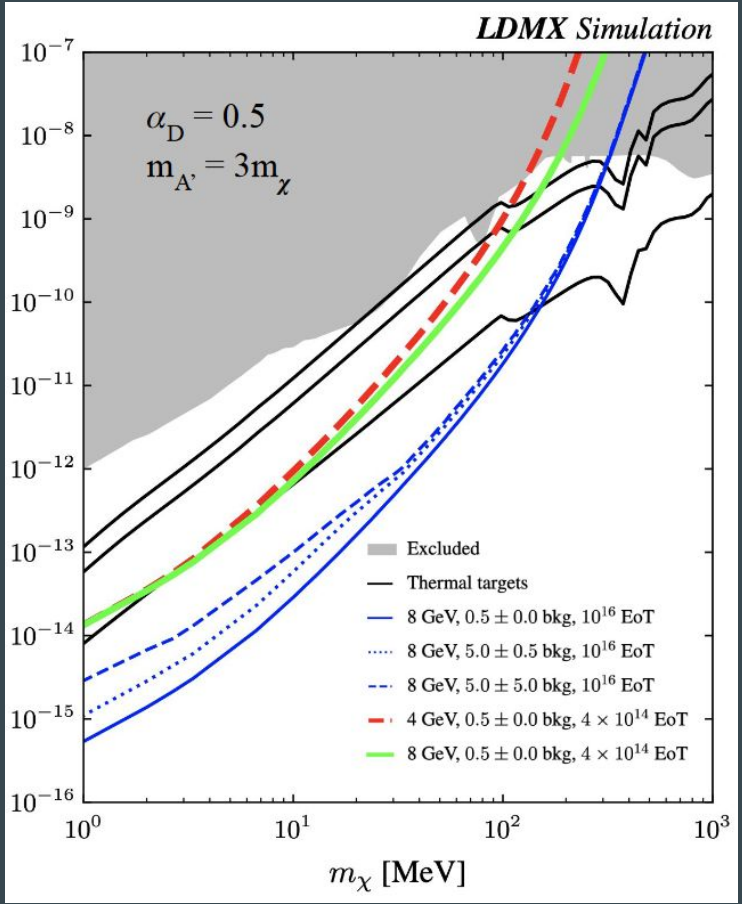
Backgrounds



LDMX - Reach

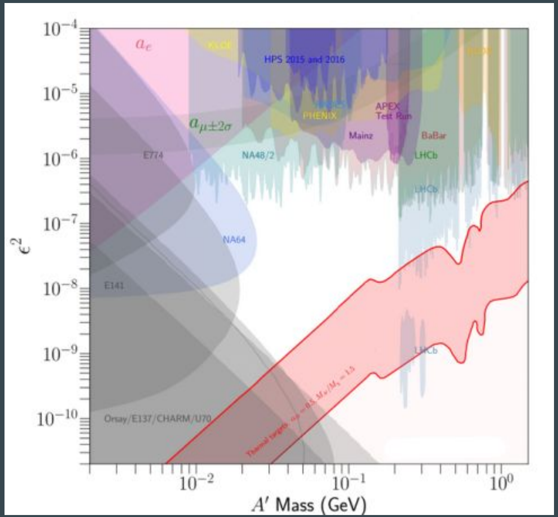
- Final goal 10^{16} EOT
- Capable to explore all the thermal targets
- Sensitivity to all targets even accounting for up to ~10 background events

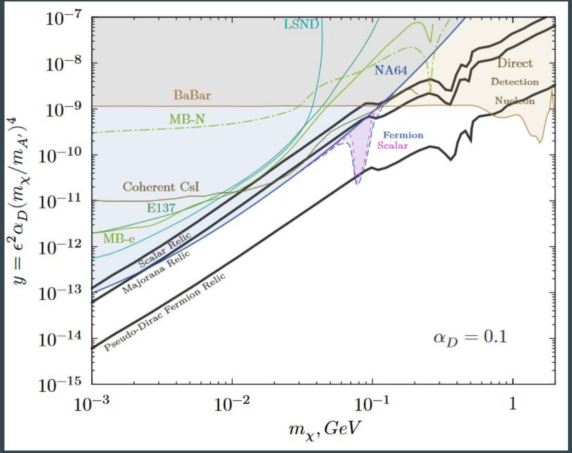


JHEP 12 (2023) 092

Summary

- ❖ Vector mediated LDM is a well motivated model giving rise to a rich phenomenology at accelerator experiments
- ❖ Many radically different ideas proposed in the years
  - ➢ Searches at colliders (prompt/detached vertices, electron/proton colliders)
  - ➢ Fixed target experiments
    - ■ Thin target: HPS, PADME...
    - ■ Beam-dump: E137, BDX, SHiP...
  - ➢ Missing energy/momentum: NA64,LDMX...
- ❖ The parameter space will be intensely explored in the next years.....stay tuned!





Thanks of the attention!!