BSM and Rare Processes - Moving Forwards

Muon Collider Synergies Workshop

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Orsay - 2023

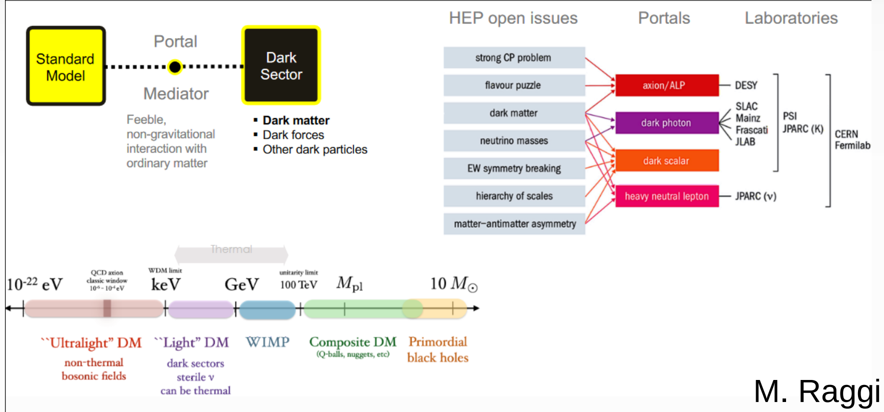
Probing Low Scales With Muon Facilities

Main Idea

- Light new physics is well motivated. Portals are constrained by gauge group of SM.
- On-shell decays have much better reach than off-shell mediated processes
- This is the opposite of high-scale scenarios.

R. Plestid

The dark sector paradigm



M. Raggi

Different models and different portals

- **A'**: new **vector** state mixing to SM photon
  - Produced by dark proton strahlung
  - or decays of secondary mesons π^0,η,ρ
  - free parameters are $m_{A'}$ and ε

Portal	FIPs
Vector	Dark photon, A'
Scalar	Dark Higgs/scalar, S
Fermion	Heavy neutral lepton (HNL), N
Pseudoscalar	Axion/axion-like particle (ALP), a

- **S**: new **scalar** state S mixing with SM Higgs
  - produced in FCNC B mesons decays ($B \to K^{(*)}S$)
  - free parameters of are m_S and θ
- **HNL**: new **heavy fermions** interacting with the SM lepton doublets
  - Produced in semi-leptonic decays of charmed mesons or τ leptons
  - Decay to meson-lepton or meson-neutrino two-body final states
  - free parameters of the models are m_N $U_{e,\mu,\tau}$
- **ALP**: a new pseudoscalar **Axion Like Particle** interacting with the SM field
  - Produced by primakoff interaction by photons from meson decays π^0,η,ρ
  - free parameters m_a coupling to photons($g_{a\gamma}$) electrons (g_{ae}) gluons ($g_{a\gamma}$)

SAPIENZA Università di Roma — Mauro Raggi, Sapienza

New light, weakly coupled particles are predicted by well-motivated new physics scenarios

Intensity, not energy, is the currency of this realm!

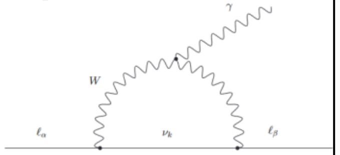
CLFV and ALPs

L. Callibi

Why are we interested in CLFV?

- Neutrinos oscillate → Lepton family numbers are not conserved! (while they would be exact global symmetries, if neutrinos were massless)
- Neutrino mass eigenstates couple to charged leptons of different flavours through the PMNS
- In the SM + massive neutrinos:

$$\frac{\Gamma(\ell_\alpha \to \ell_\beta \gamma)}{\Gamma(\ell_\alpha \to \ell_\beta \nu \bar{\nu})} = \frac{3\alpha}{32\pi} \left| \sum_{k=1,3} U_{\alpha k} U^*_{\beta k} \frac{m^2_{\nu_k}}{M^2_W} \right|^2$$



Cheng Li '77, '80; Petcov '77

⇨ $\mathrm{BR}(\mu \to e\gamma) \approx \mathrm{BR}(\tau \to e\gamma) \approx \mathrm{BR}(\tau \to \mu\gamma) = 10^{-55} \div 10^{-54}$
Large mixing, but huge suppression due to small neutrino masses

⇨ In presence of NP at the TeV we can expect large effects

Lepton-flavour-violating ALPs

Why should a be light and feebly-coupled?

That's natural, if it is the (pseudo) Nambu-Goldstone boson (PNGB) of a broken global U(1), *aka* an axion-like particle (ALP)

Examples:

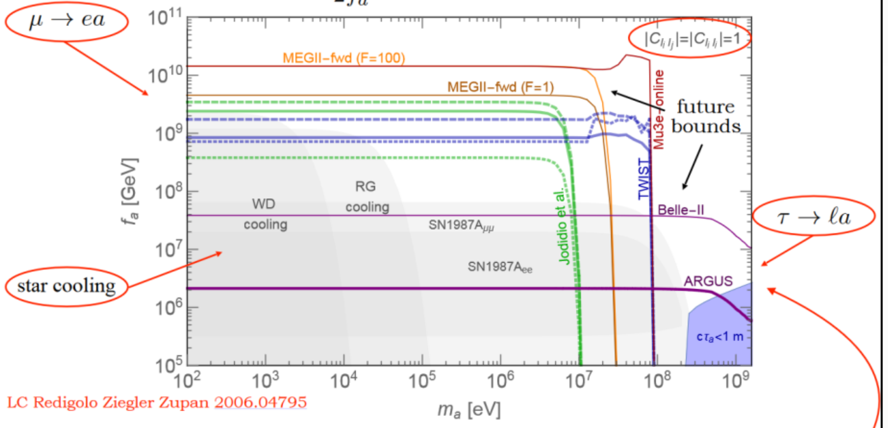
Global symmetry:	PNGB:	
• Lepton Number	Majoron	Wilczek '82, Pilaftsis '93
• Peccei-Quinn	Axion	Feng et al. '97
• Flavour symmetry	Familon	LC Goertz Redigolo Ziegler Zupan '16; Di Luzio et al. '17, '19
...		...

Equivalent possibility: light Z' of a local U(1), e.g. L_i-L_j (with $g \ll 1$)
Heeck '16

CLFV and Axions — Lorenzo Calibbi (Nankai)

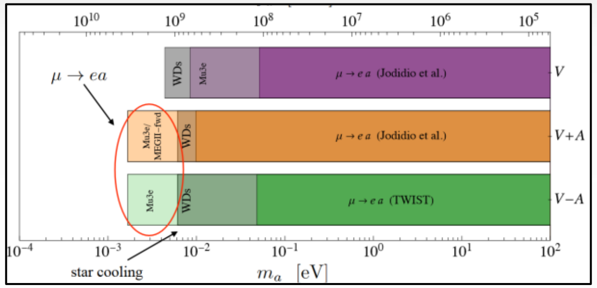
Lepton-flavour-violating invisible ALPs

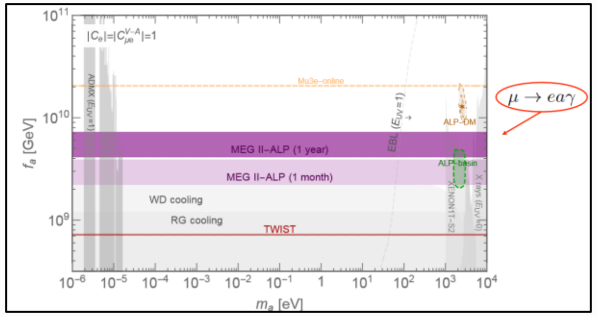
$$\mathcal{L}_{aff} = \frac{\partial_\mu a}{2 f_a} \bar{f}_i \gamma^\mu (C^V_{f_i f_j} + C^A_{f_i f_j} \gamma_5) f_j$$



LC Redigolo Ziegler Zupan 2006.04795

Decays mediated by dim-5 operators: much larger NP scales can be reached
Essential interplay among μ decays, τ decays, and astrophysical bounds





CLFV exists and an observation is a smoking gun of BSM physics

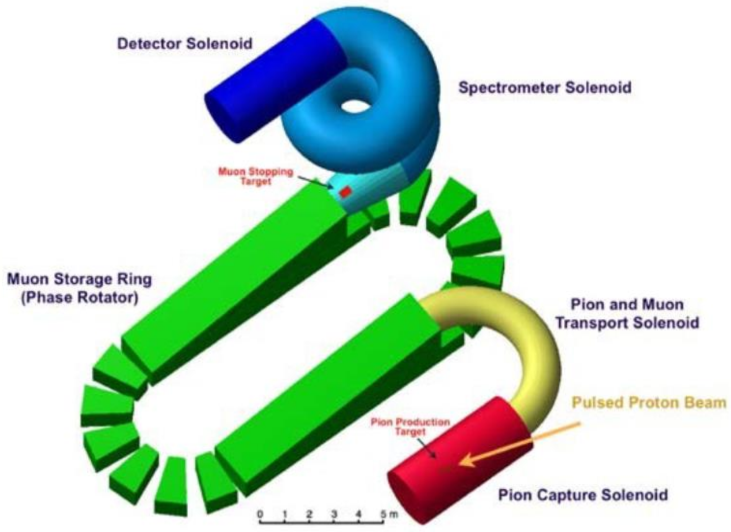
Current and planned experiments produce the most stringent bounds for many NP scenarios

Is there a way to exploit the muon beam to improve CLFV searches (formidable competition)?

K. Lynch

AMF enabling technologies

- PIP-II
  - Proton source
- Proton compressor ring
  - Convert CW beam to intense proton pulses
- Production solenoid and target systems
  - House production target
- Muon transport
  - Eliminate LOS from target to experiments
  - Match beam dynamics solenoid ↔ FFA
- FFA ring
  - Phase rotation → monochromator
- Induction linac
  - Reduce bunch energy to minimize target thickness



Fermilab

16 Lynch | MCSW 2023

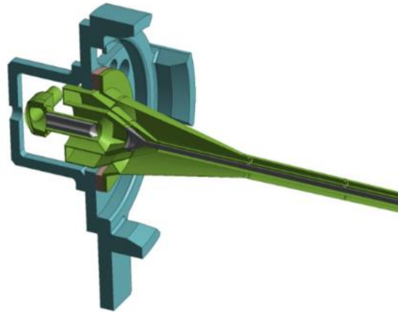
Chief AMF technical challenges – with Muon Collider synergies!

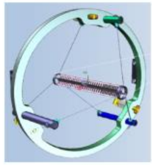
- Compressor ring
  - Kicker rates and rise/fall times limit beam power
  - 100Hz → 1kHz?
- Target and PS
  - Concepts for 100kW targets exist
    - Mu2e-II
  - Compact MW scale targets are a true R&D effort!

Chief AMF technical challenges

LBNF Target core
16mm x 1.5m x 25kW

Mu2e Target Core
6.3mm x 220mm x 250kW

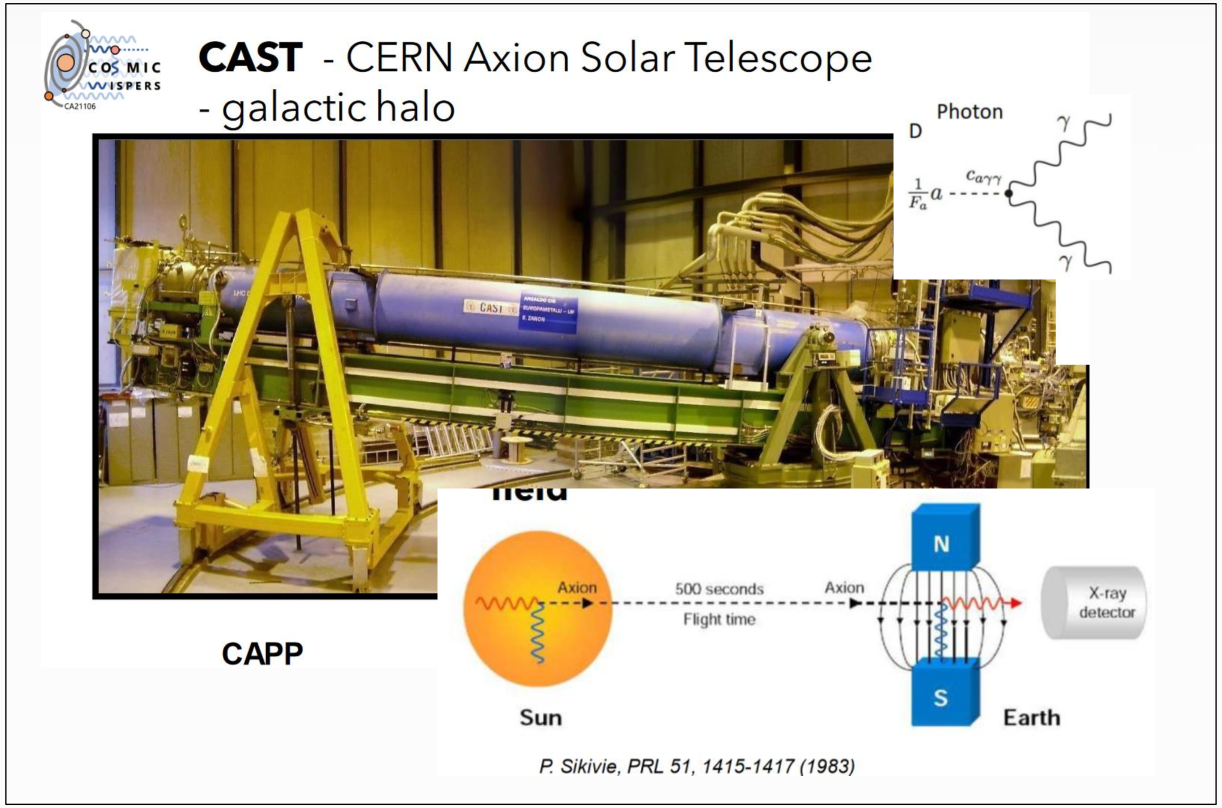


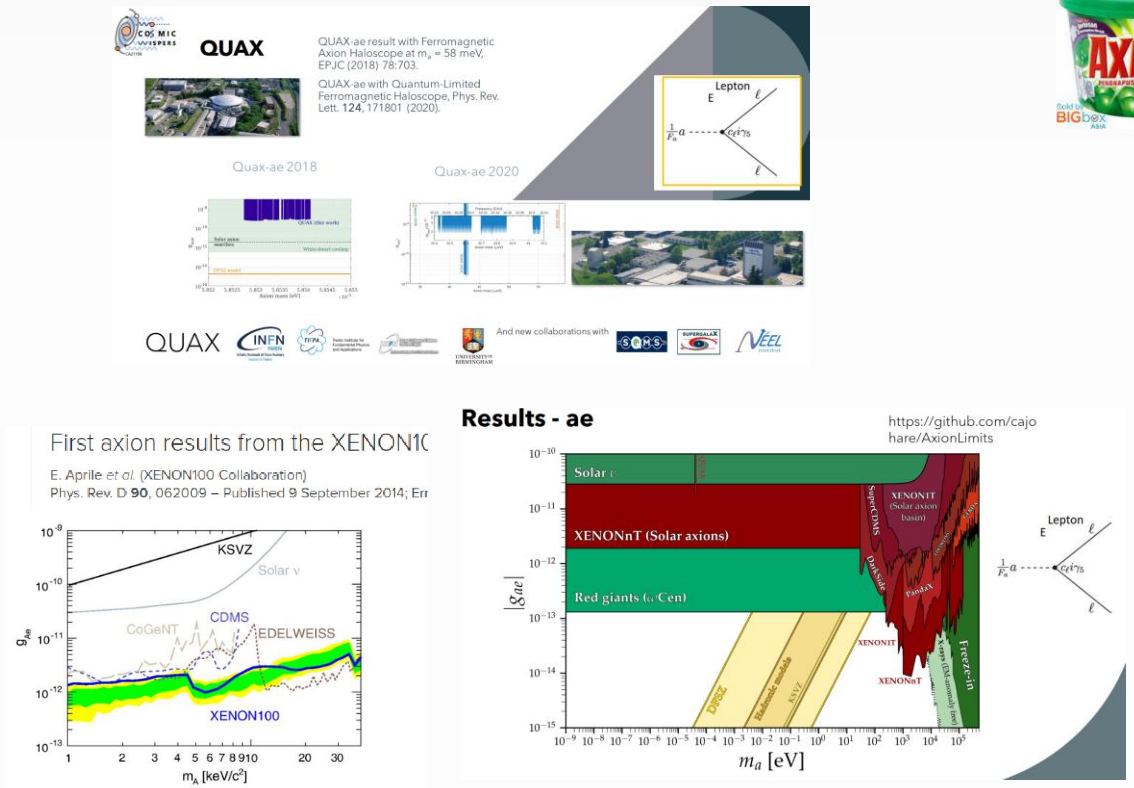


Many R&D synergies between MuC and AMF (e.g. targetry) – how to best exploit these opportunities?

Can a MuC demonstrator be reused or adapted to a muon facility like AMF?

M. Karuza

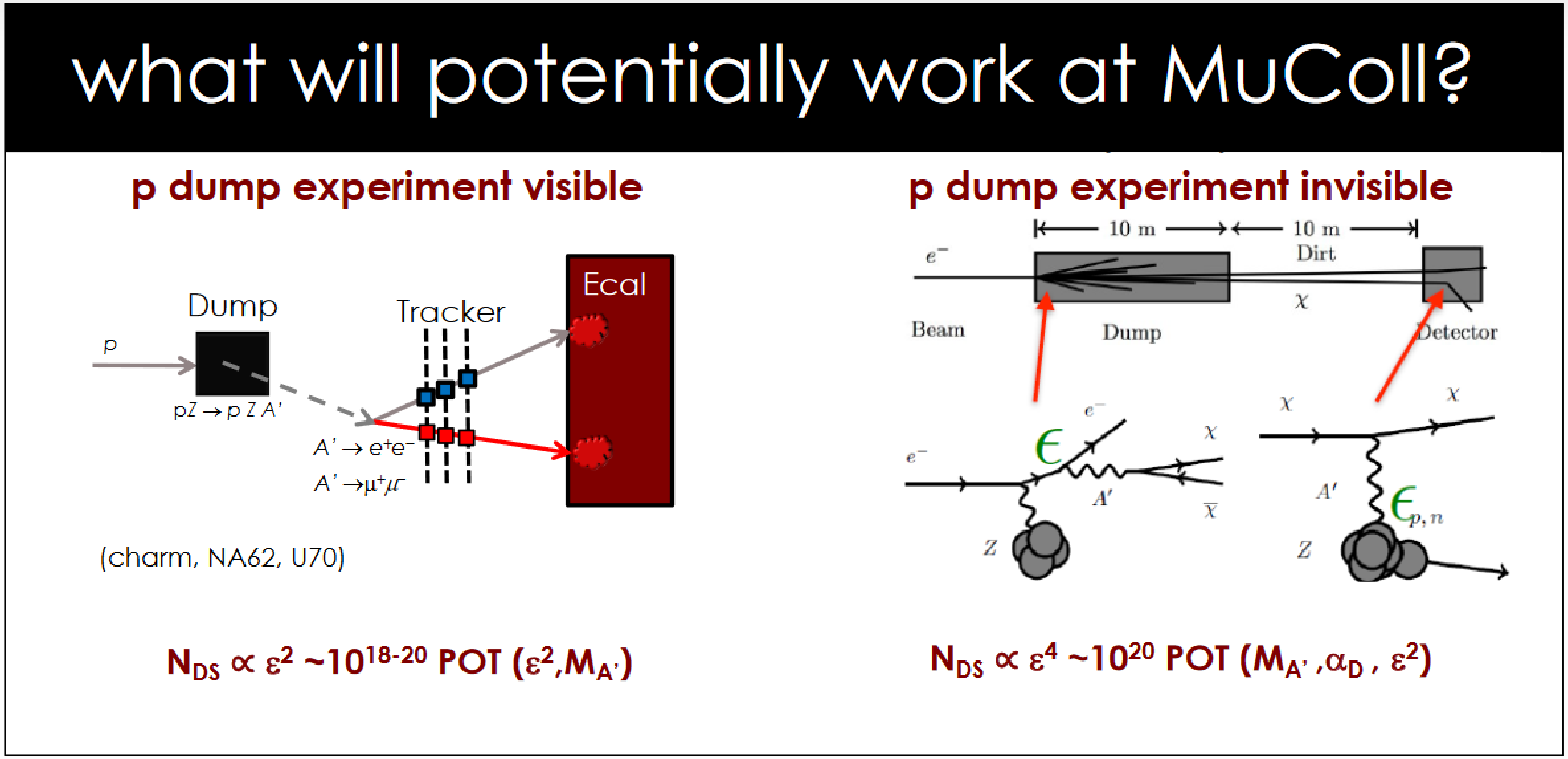


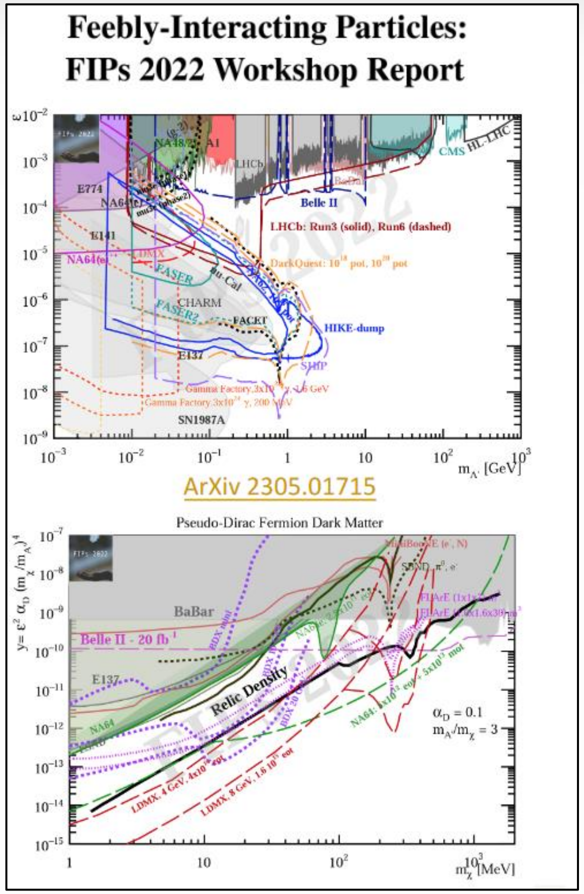


Developing stronger magnets could have useful applications for axion searches as well

Can we use a muon beam to probe ALP-lepton coupling (e.g. shining through wall expt near beam)?

M. Raggi





Beam dump experiments could be a possibility (great way to maximize proton economics)

Need to understand what level of sensitivity could be achieved (competition, but large number of POT)

There is a strong physics case for light new physics

Intensity, not energy, is key to explore these possibilities

There are also R&D synergies between muon collider and future CLFV experiments $\rightarrow$ need to exploit every opportunity

This workshop outlined the possibilities of BSM physics at low-energy, now we need to understand the physics potential of a demonstrator facility