

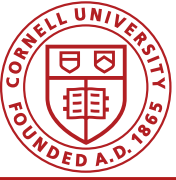
SAPIENZA
UNIVERSITÀ DI ROMA



Searching for dark photons with PADME

PADME

Andre Frankenthal on behalf of the
PADME Collaboration



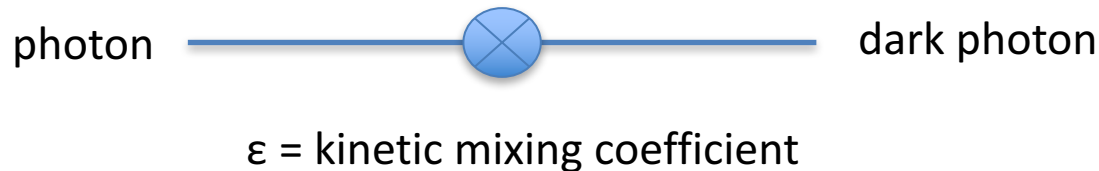
Outline



- Motivation: dark photons
- Fixed-target experiments
- PADME
- Status

- Renormalizable extension of the SM
- Additional U(1) gauge symmetry
- Kinetic mixing with SM U(1)_Y
- Leads to coupling between photon and dark photon:

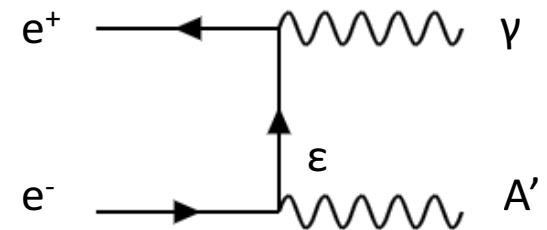
$$-\epsilon F'_{\mu\nu} B^{\mu\nu}$$



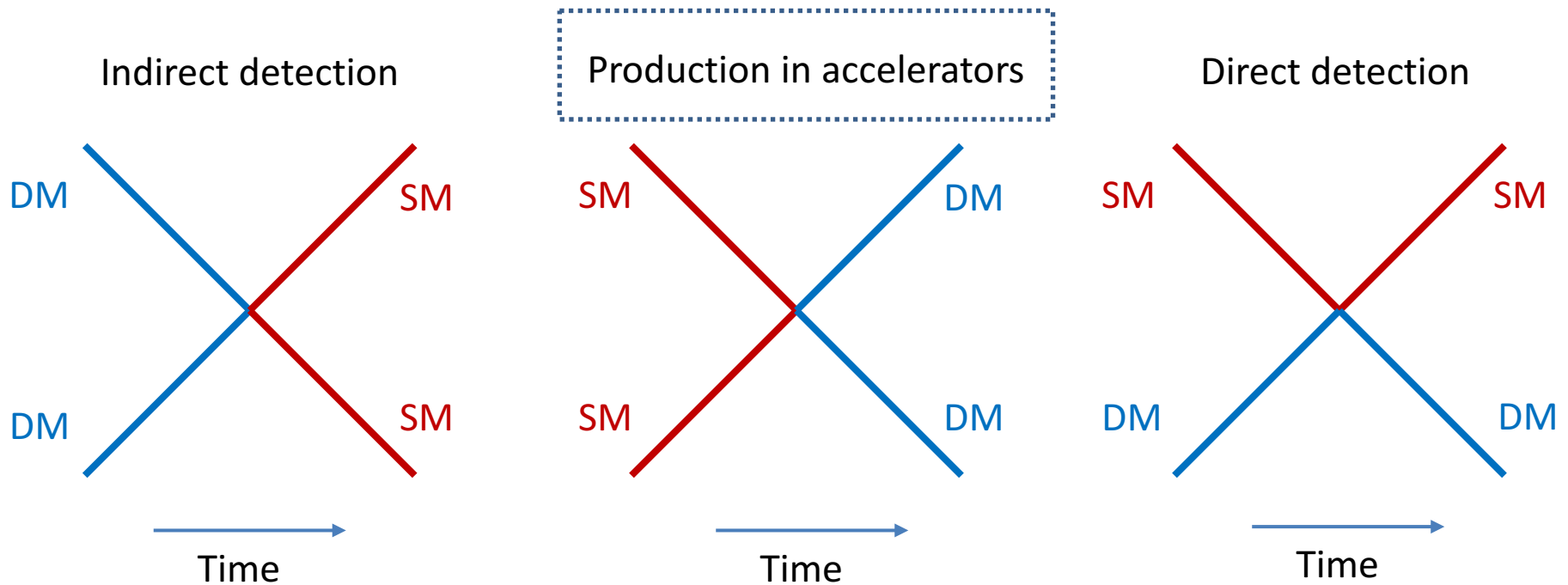
- Allows for processes such as:

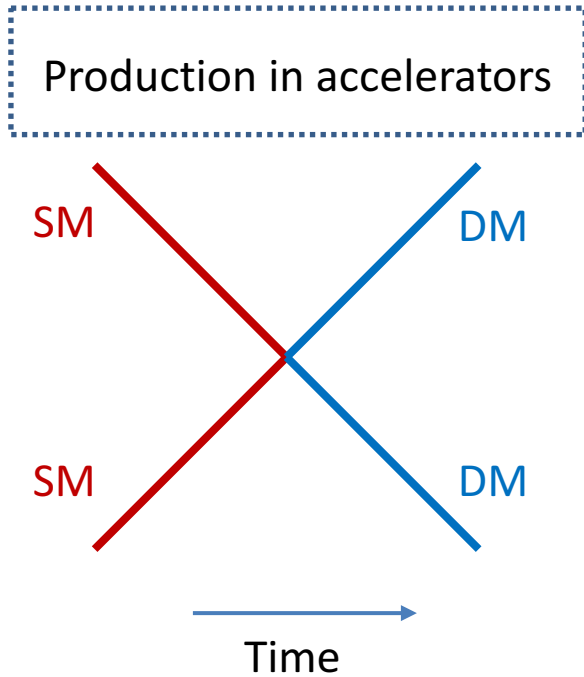
$$+\frac{1}{2}m_{A'}^2 A'^{\mu} A'_{\mu} \quad (\text{Mass term also allowed})$$

$$+\epsilon e A'^{\mu} J_{\mu}^{EM}$$

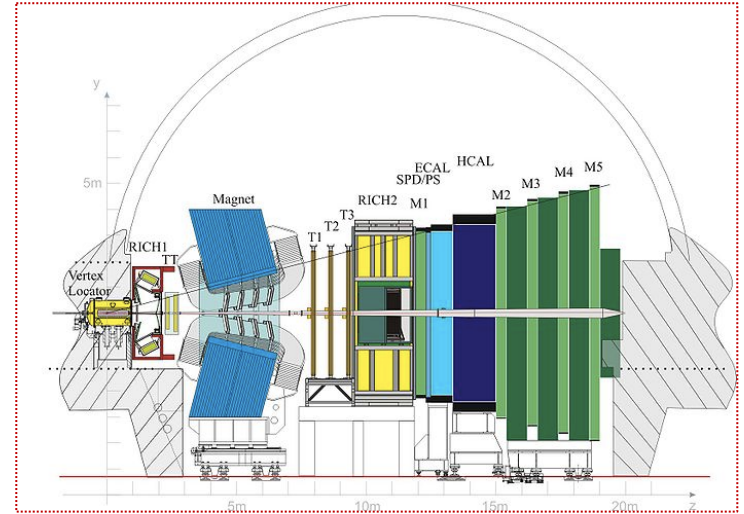


- Different DM search modes via interaction with SM particles:

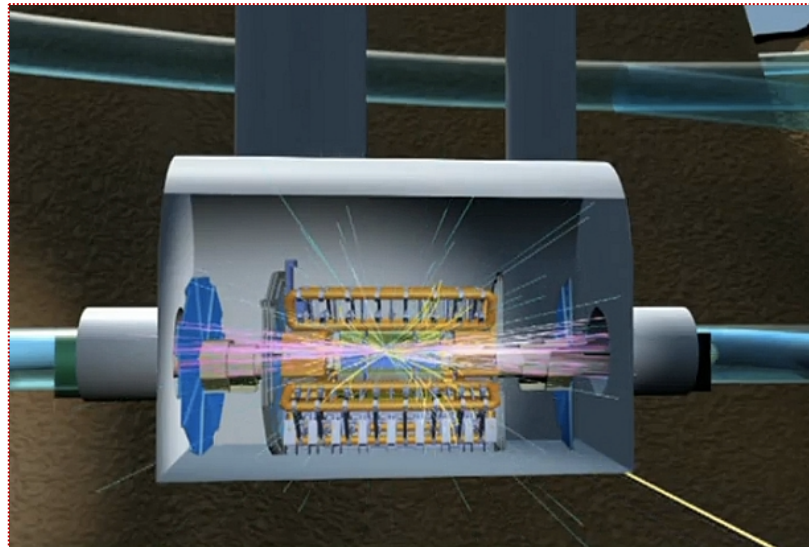




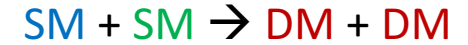
Fixed-target



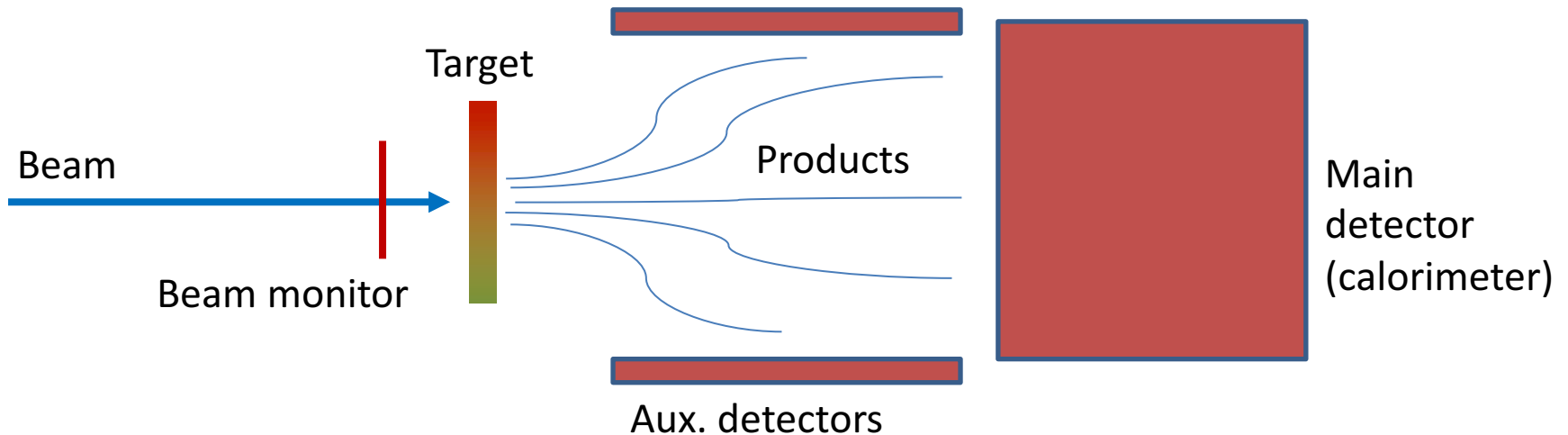
Colliders

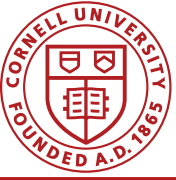


- General principles:

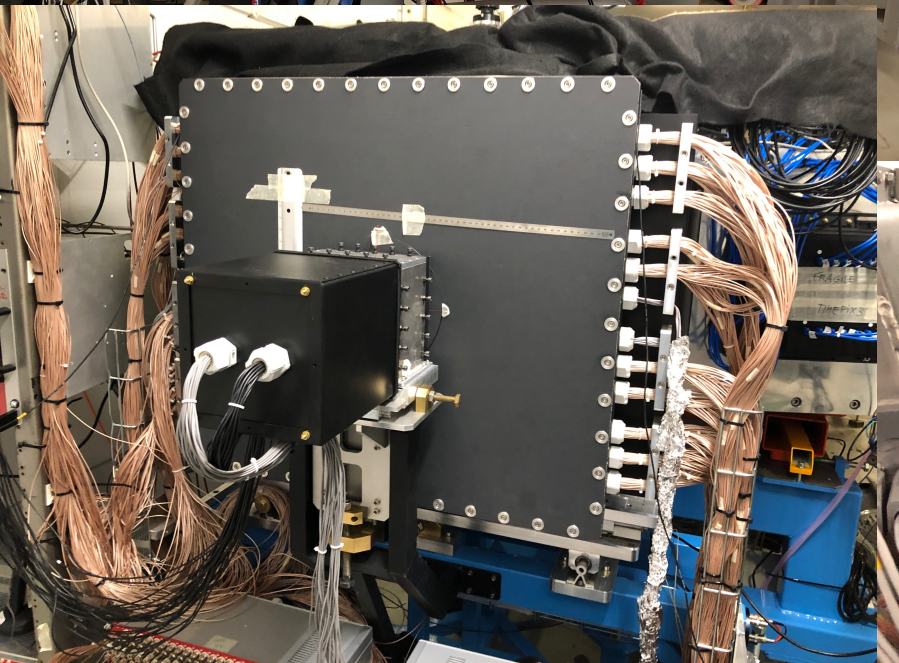
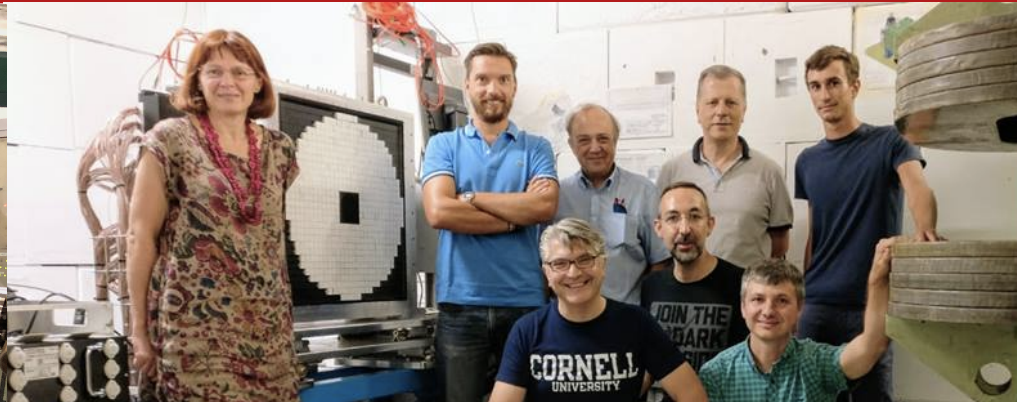
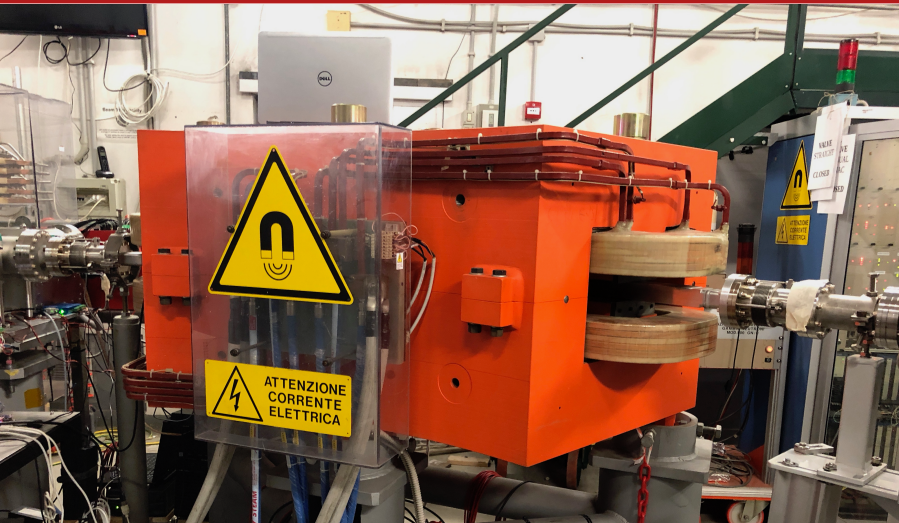


- One beam (e⁻, e⁺, protons, neutrinos, ...)
- One target (C, Be, W, ...)
- Detectors in front of target to measure beam
- Detectors behind the target to measure products

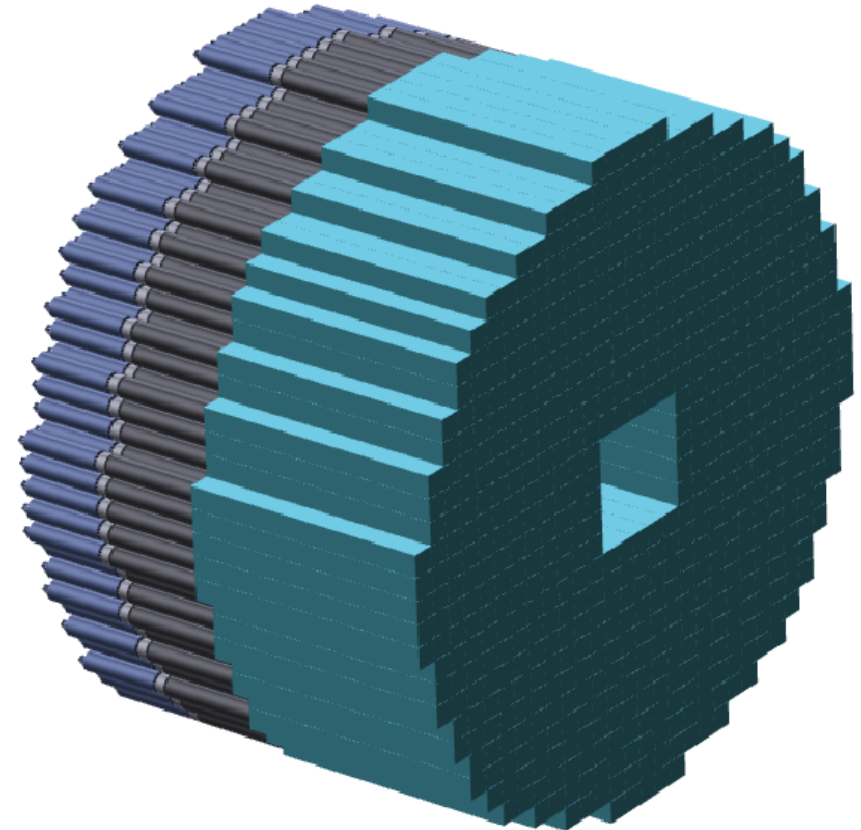


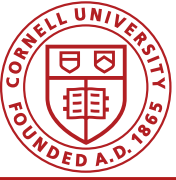


- *Positron Annihilation into Dark Matter Experiment*
- Goal: look for dark photons
- Fixed-target, missing-mass experiment
- **Beam:** 550 MeV e^+ , 20k e^+ /bunch @ 50 Hz
- **Target:** Diamond (C)
- **Detectors:** Electromagnetic calorimeter (ECAL), Small-Angle Calorimeter (SAC), vetos, active target
- 0.45 T B-field to bend beam after target



- Goal: measure energy and transverse position of photon
- Central detector
- 616 BGO crystals ($21 \times 21 \times 230 \text{ mm}^3$)
- HZC PMTs for readout
- Square hole in middle to handle Bremsstrahlung background (via SAC)
- With energy and position, determine angle and hence momentum of photon

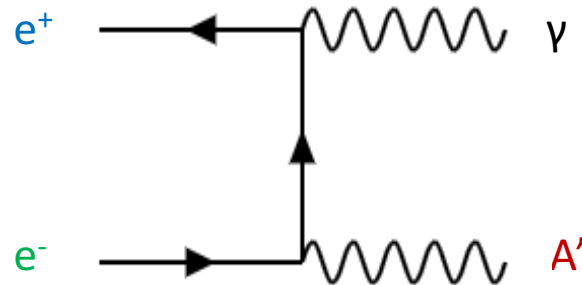


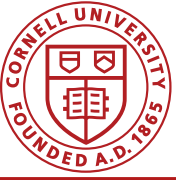


PADME: how it works



- e^+ and e^- scatter, produce a photon and a dark photon

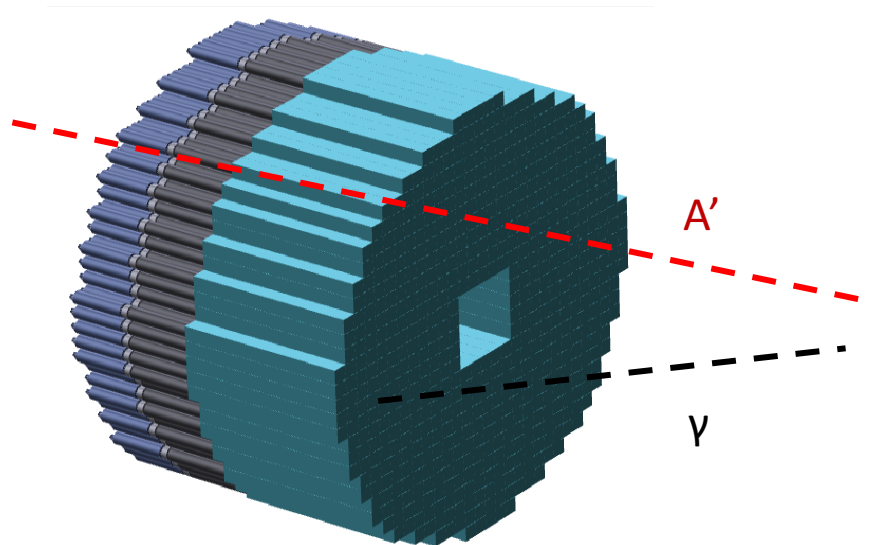
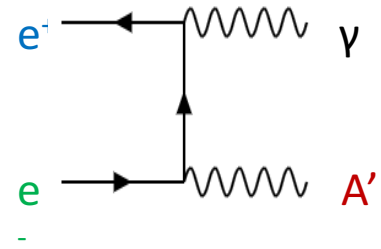




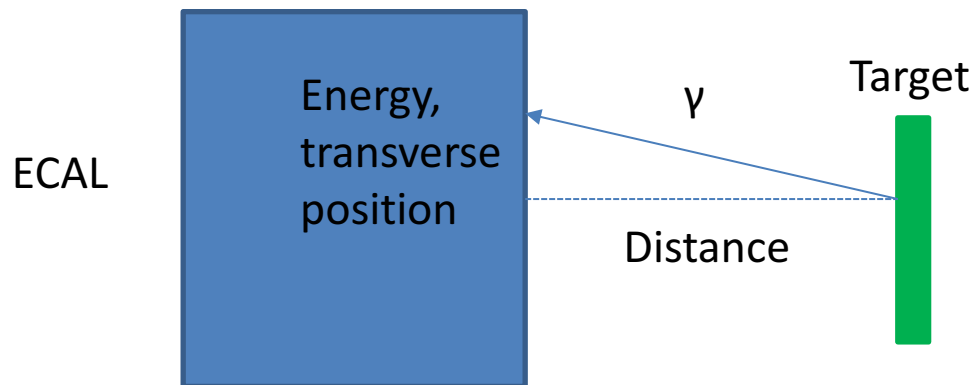
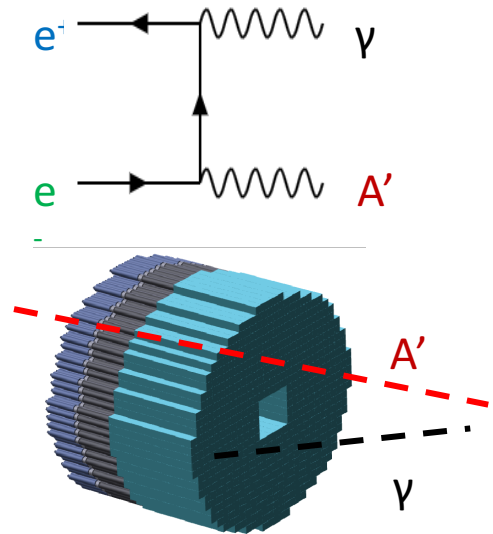
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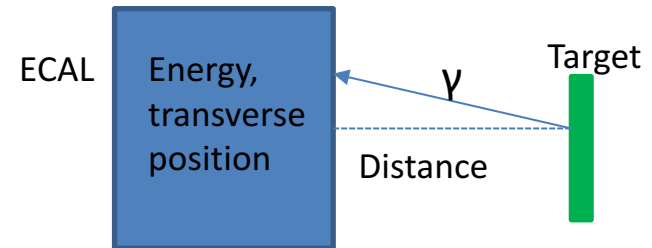
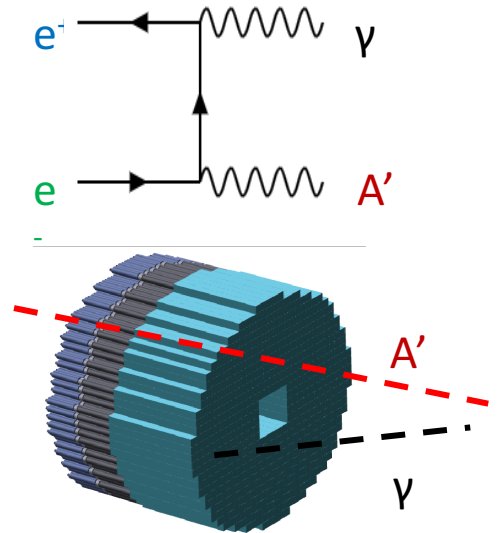
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- Photon momentum measured by ECAL

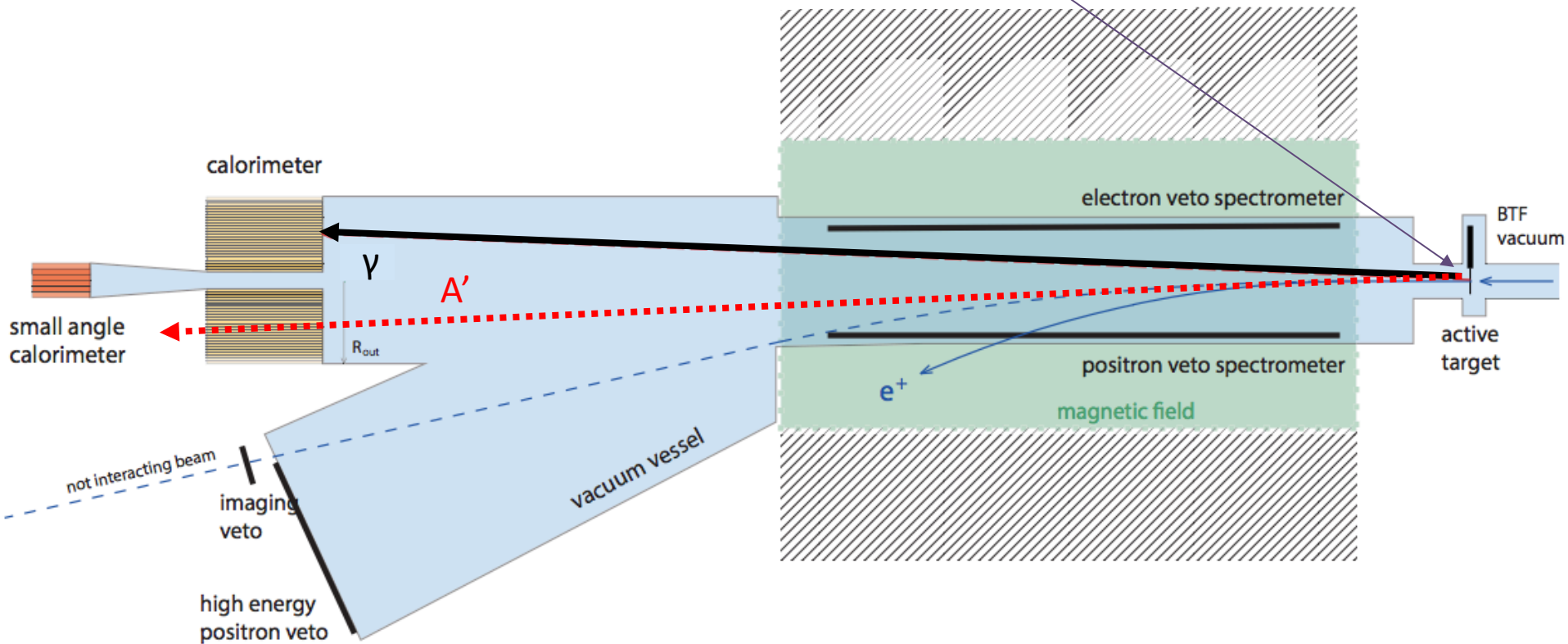
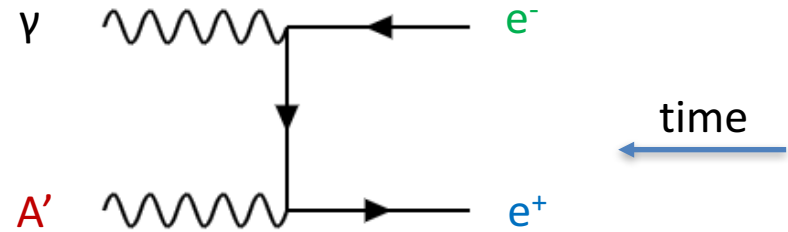


- e^+ and e^- scatter, produce a photon and a dark photon
- Dark photon invisible, escapes detector
- Photon momentum measured by ECAL
- Subtracting from beam and target momentum, missing mass is inferred:



$$m_{\text{miss}}^2 = (p_{e^-} + p_{e^+} - p_{\gamma})^2$$

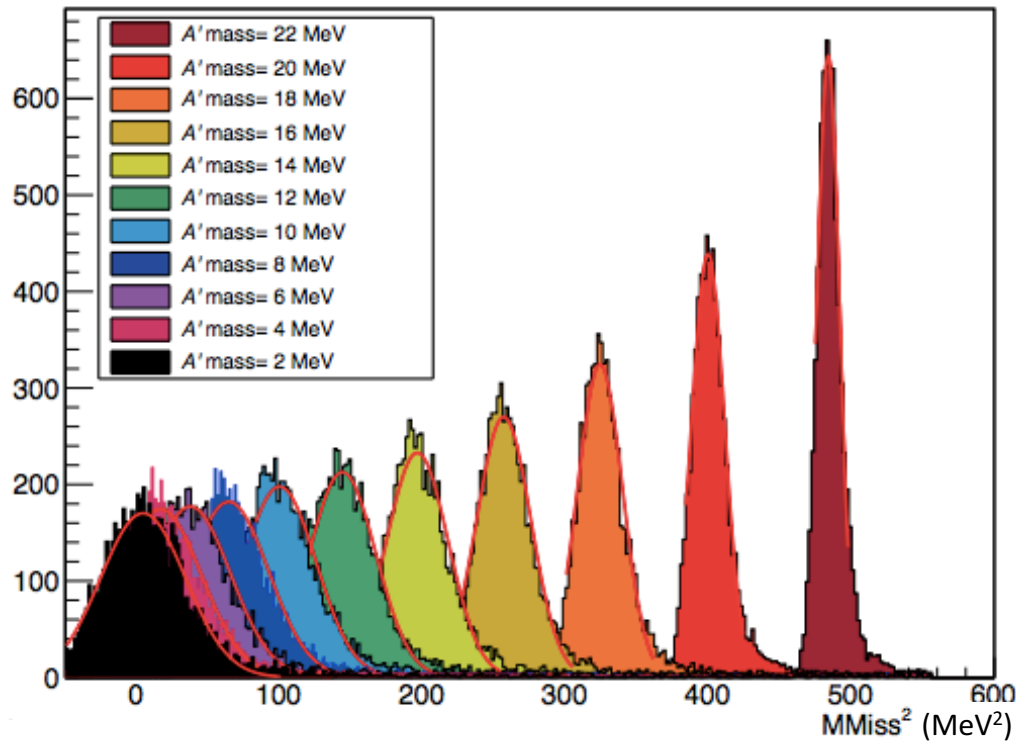
$$e^+ + e^- \rightarrow \gamma + A'$$



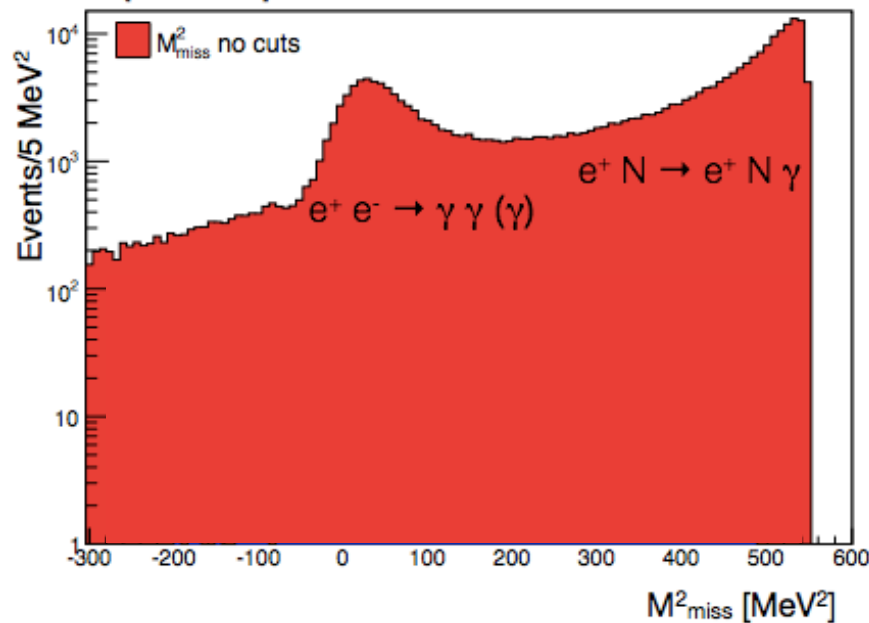
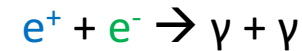
- Geant4-based PADME MC simulation, for different dark photon masses:

M_{Miss}² for different M_{A'}

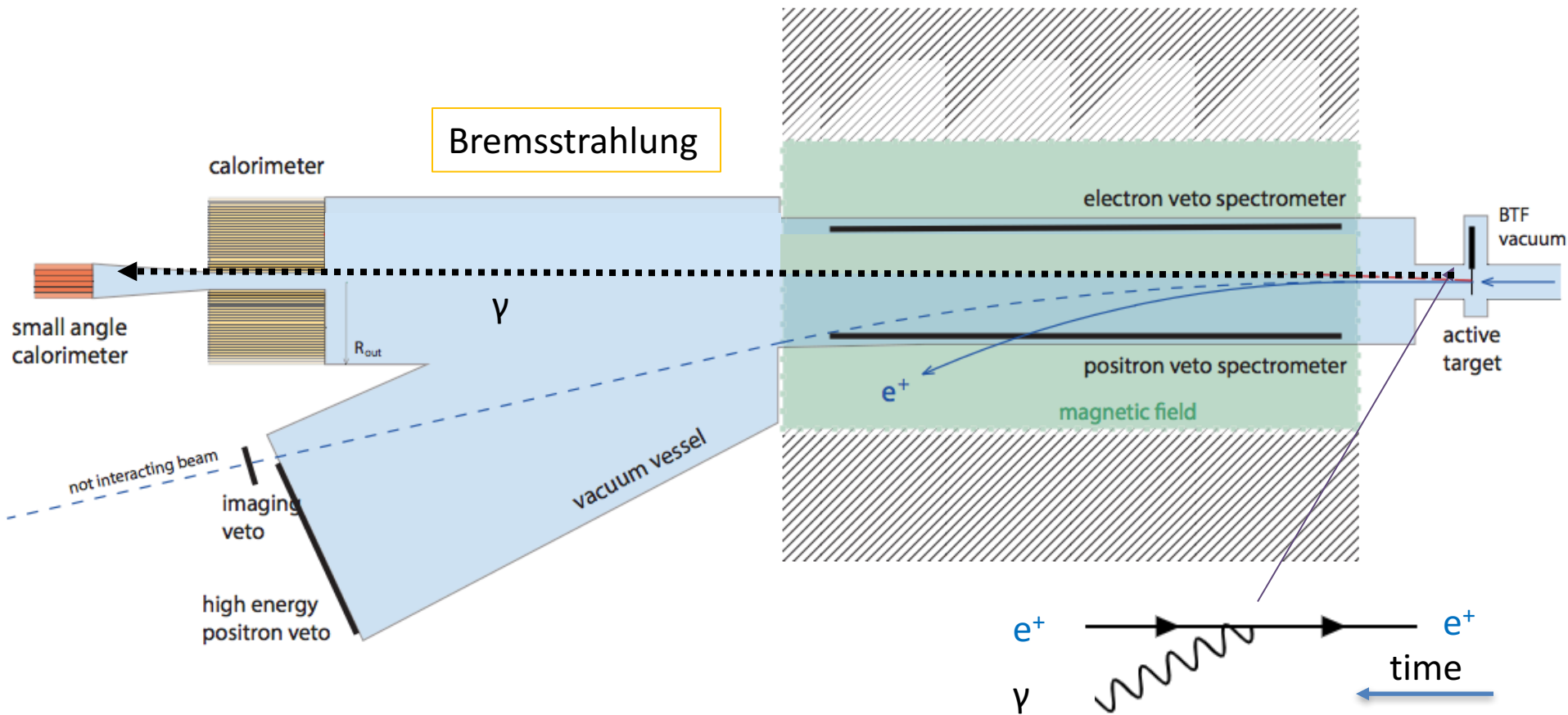
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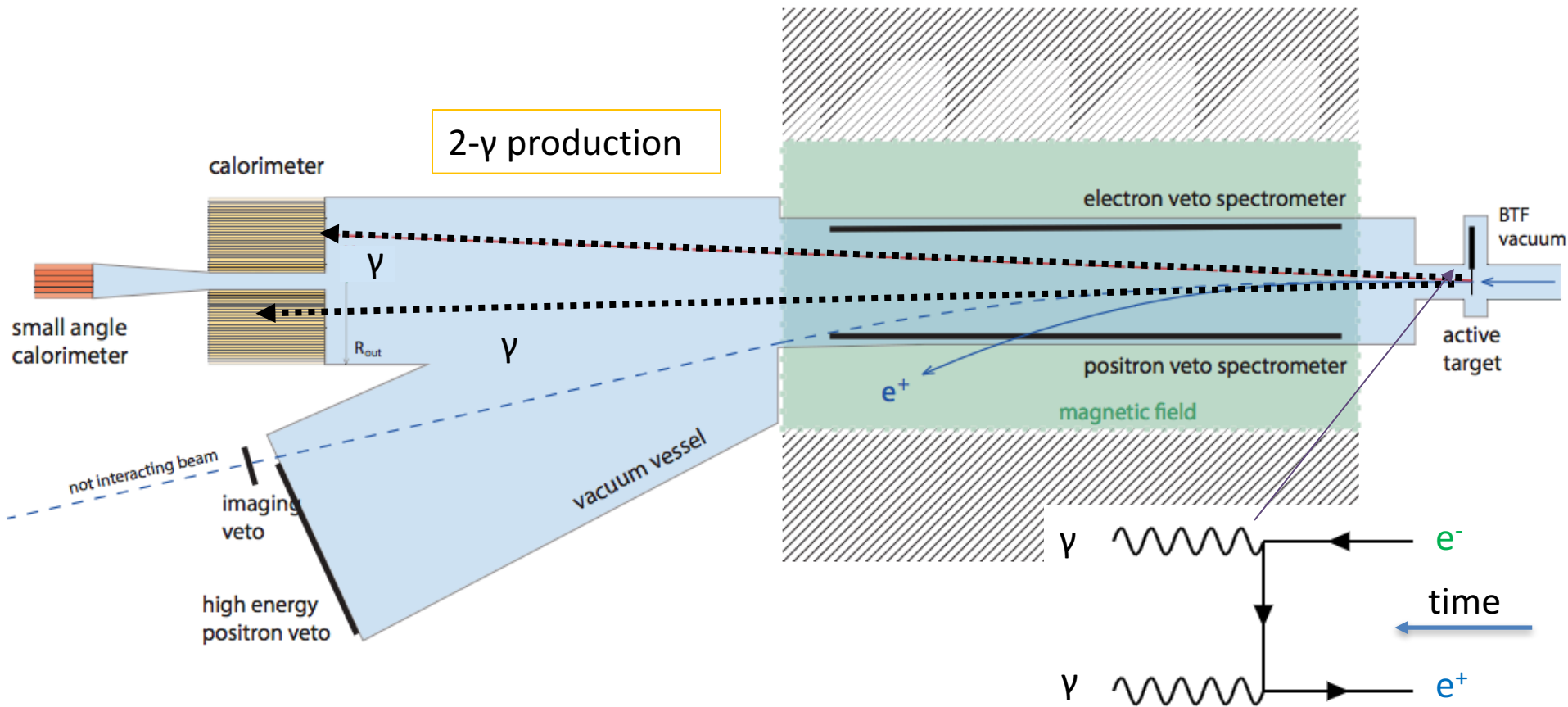
- Major backgrounds:
 - Bremsstrahlung
 - 2- and 3-gamma production
 - **Beam-induced backgrounds**



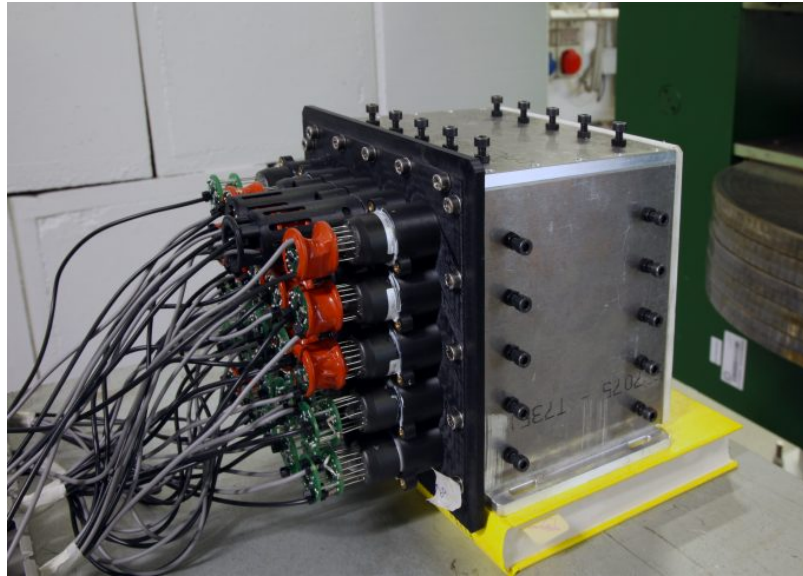
- Auxiliary detectors tag background events
- Tagged events are rejected



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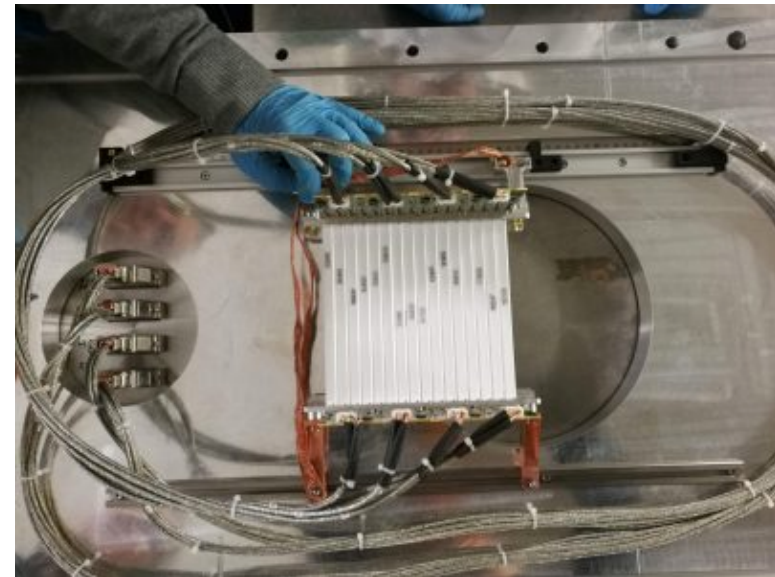


Small-Angle Calorimeter (SAC)



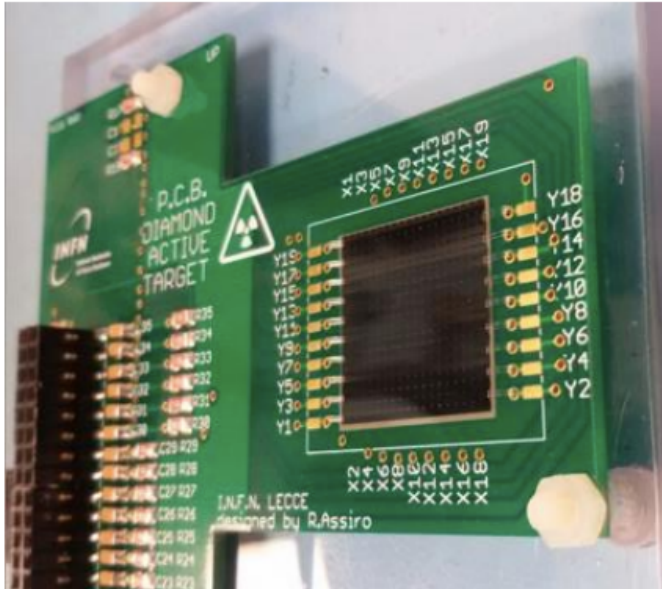
- Sits behind main ECAL
- Fast (~ 80 ps res., < 1 ns peak separation)
- 5×5 PbF_2 Cherenkov detector
- $30 \times 30 \times 140$ mm³ crystals
- Identifies Bremsstrahlung photons

Electron/Positron/HEP vetoes



- Inside walls of magnet and by beam dump
- Plastic scintillator bars w/ SiPM readout
- Detect e^+ and e^- that radiated photons and lost momentum, bending under B field

Active diamond target



- 100 um thick polycrystalline diamond
- 19 x 19 (x and y) graphite stripes on surface
- Active target: charge measured proportional to beam intensity, plus profile information

- In a single sensor: matrix of 256 x 256 pixels, 55 um in size
- Whole detector: 12 such sensors (786,432 pixels), 8.4 x 2.8 mm²
- Monitors non-interacting beam

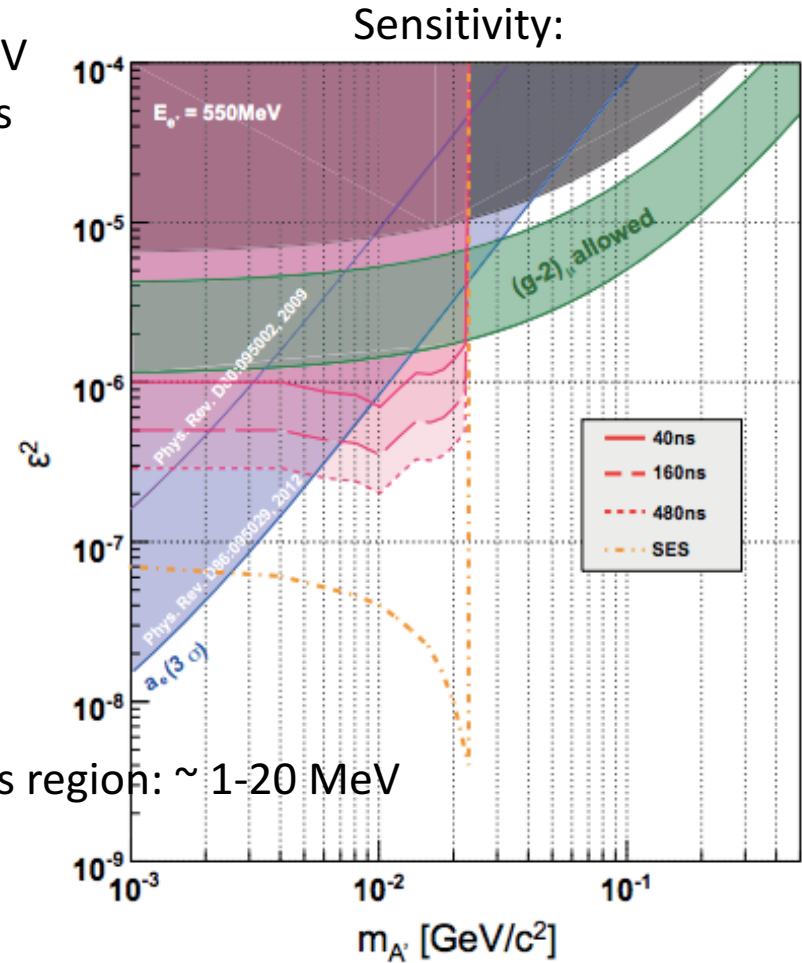
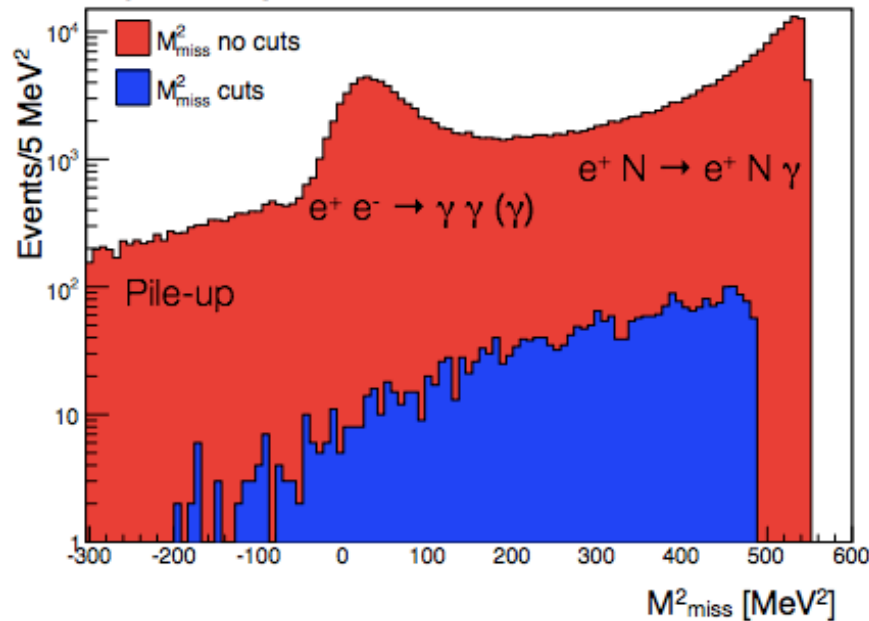
TimePix3 beam monitor

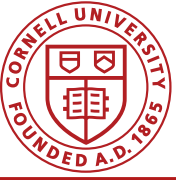


• Backgrounds limited after mitigation:

- 1 cluster in ECAL
- No hits in vetos
- No γ in SAC w/ energy > 50 MeV
- 20-150 MeV < ECAL energy < 120-350 MeV depending on A' mass

Simulation (log scale)



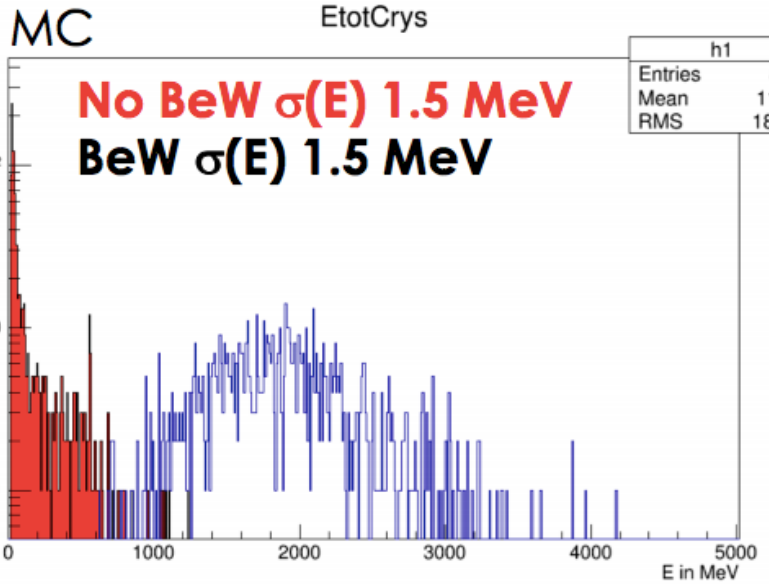
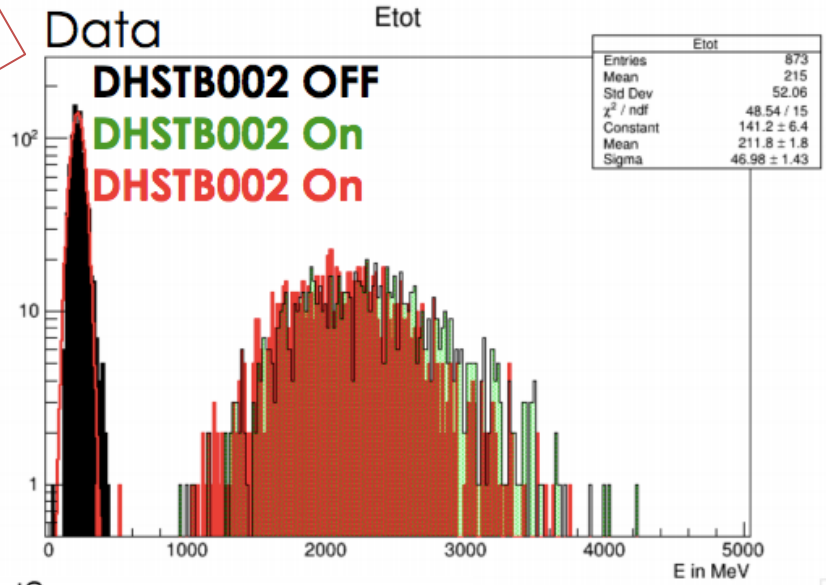


Beam-induced backgrounds **IPADME**

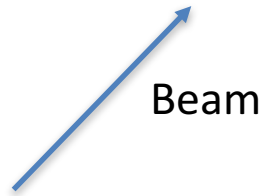
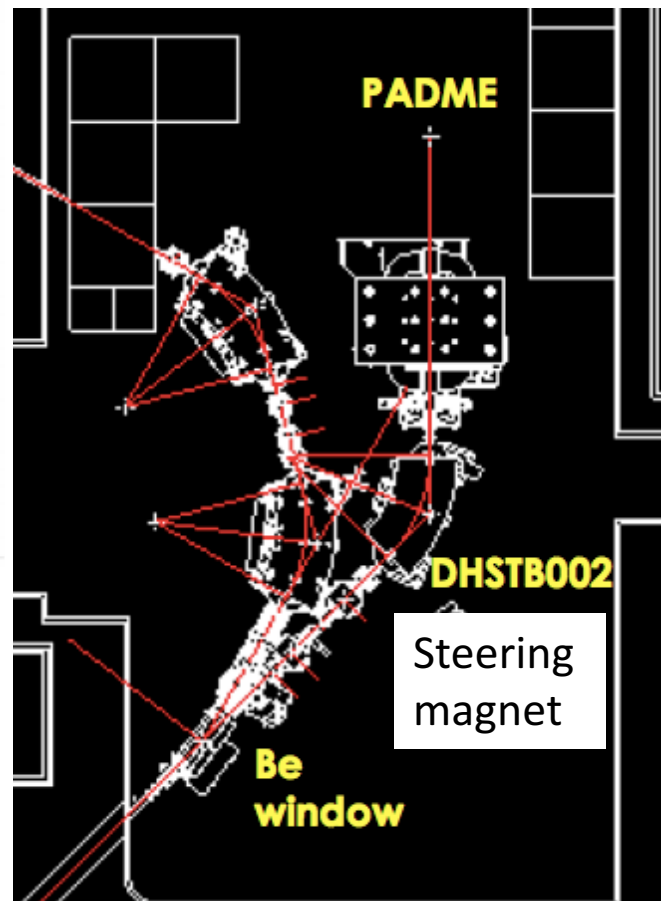
- Over the course of first data-taking run, observed additional background due to beam
- Extended MC simulation to understand causes
- Found three main culprits:
 - Beryllium window separating detector vacuum from accelerator vacuum
 - Steering beam magnet from accelerator structure
 - Early showers when using a secondary beam
- Mitigation now being applied, 3x lower already

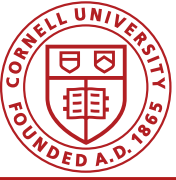
preliminary

Total energy deposition in ECAL



MC comparison with and without Be window



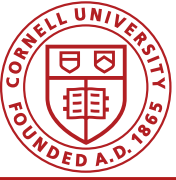


Summary



- PADME is a **fixed-target, missing-mass** experiment to look for low-mass dark photons
- Model-independent (kinetic mixing)
- Run 1 just finished in early March
- ~ 4 months of data
- Data reconstruction and analysis ongoing
- Calibration run ongoing and starting physics run 2 in early November
- Plan to have first physics results next year

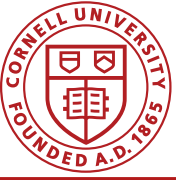
BACKUP



Future ideas



- PADME could also potentially be used for ALP searches, studies underway to assess sensitivity and reach
- Could be sensitive to both g_{aee} and $g_{a\gamma\gamma}$ couplings
- Signal: three gammas or a gamma and e^+ / e^- pair in the calorimeter



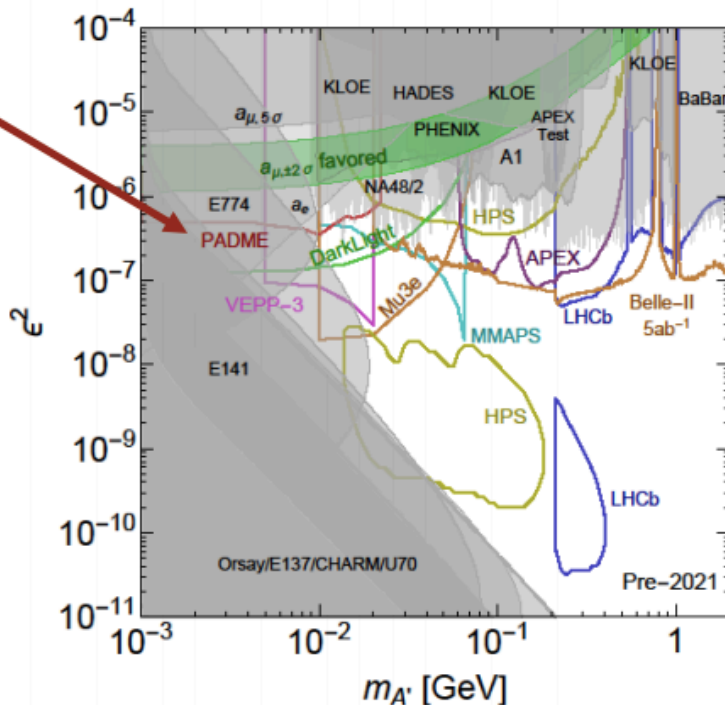
Future ideas



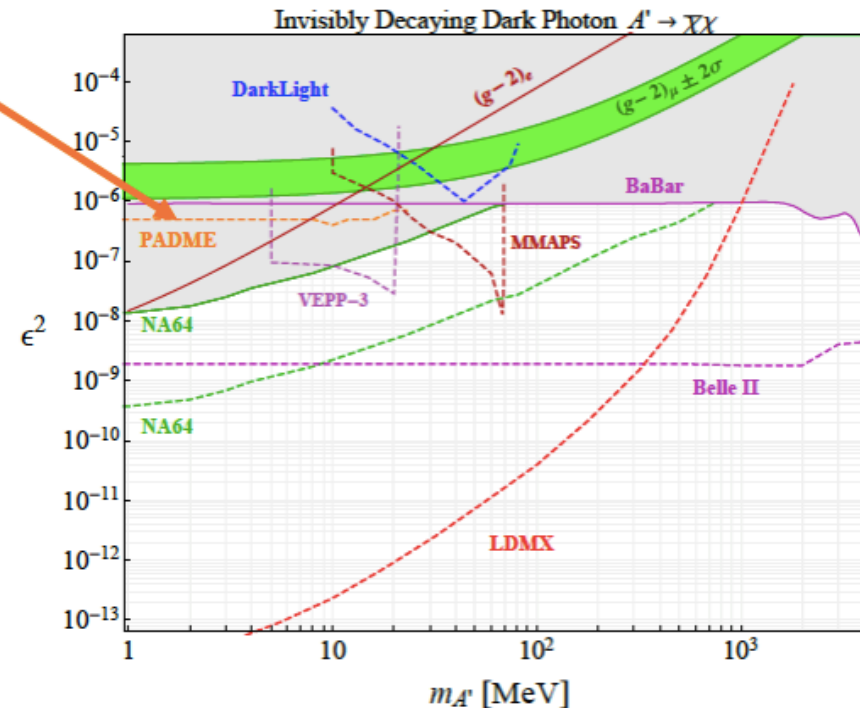
- Tentative plans to bring the PADME detector to higher energy and intensity beams
- For example, Cornell has a 6 GeV e^+ beam (10x more energy)
- With resonant extraction, could distribute beam intensity over longer periods, decreasing pile-up and maximizing efficiency of event collection

- With Cornell beam, sensitivity would increase significantly ('MMAPS' label):

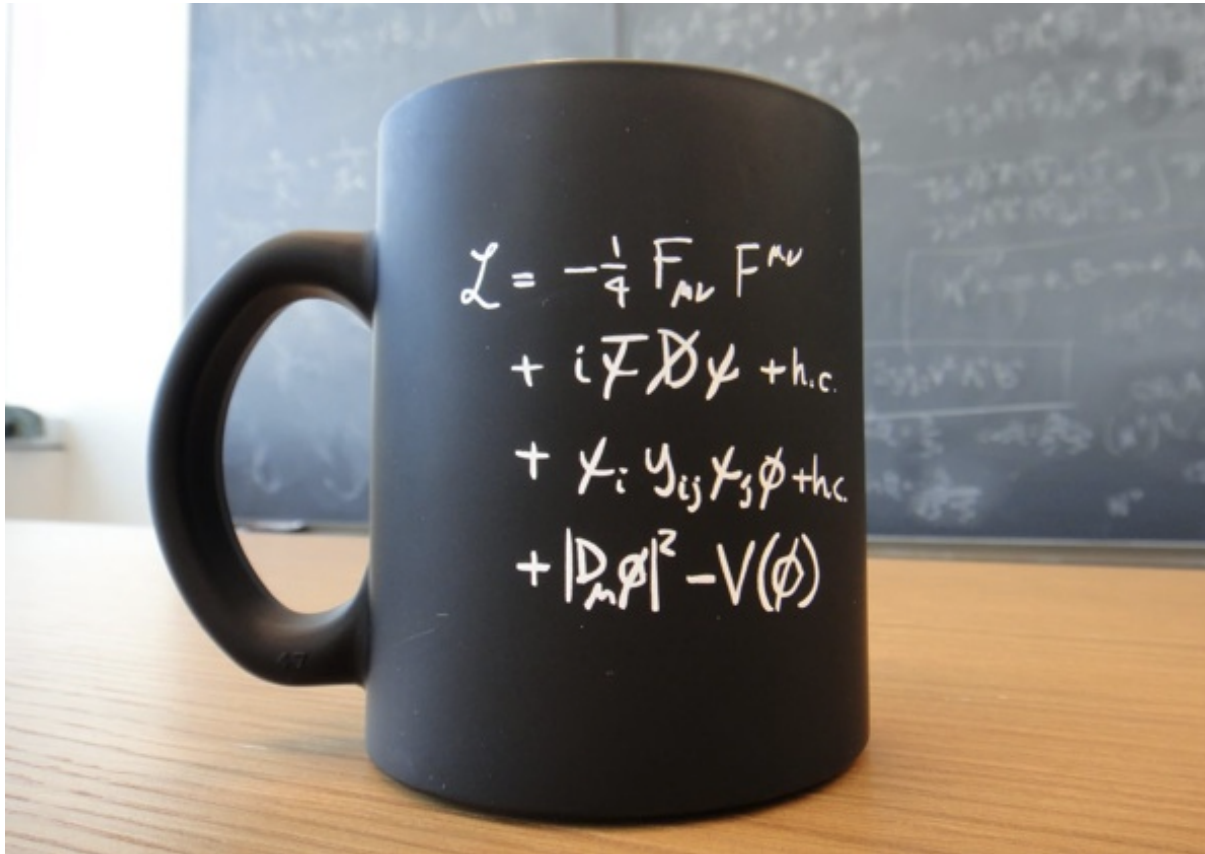
- Visible, in SM particles if $m_{DM} \geq m_{A'}/2$



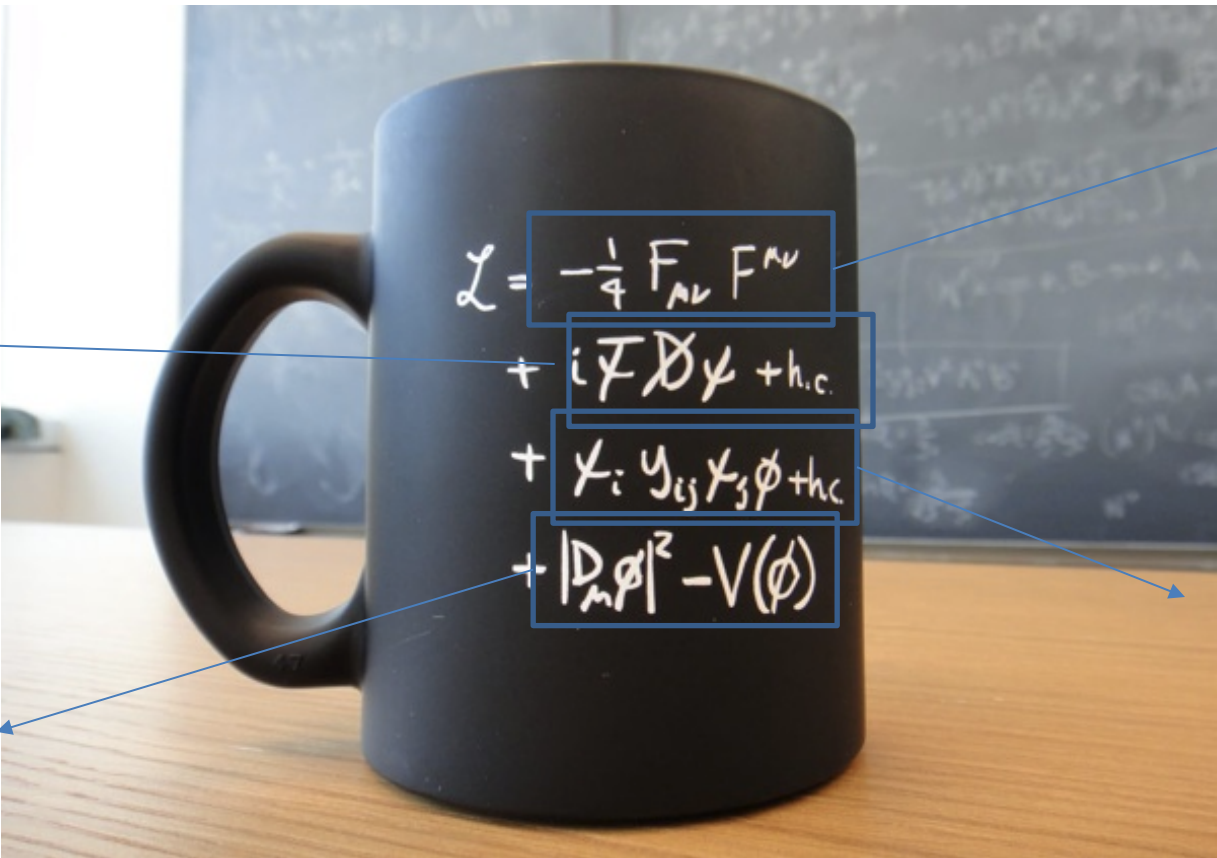
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- The SM in a nutshell:



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Kinetic terms for fermions

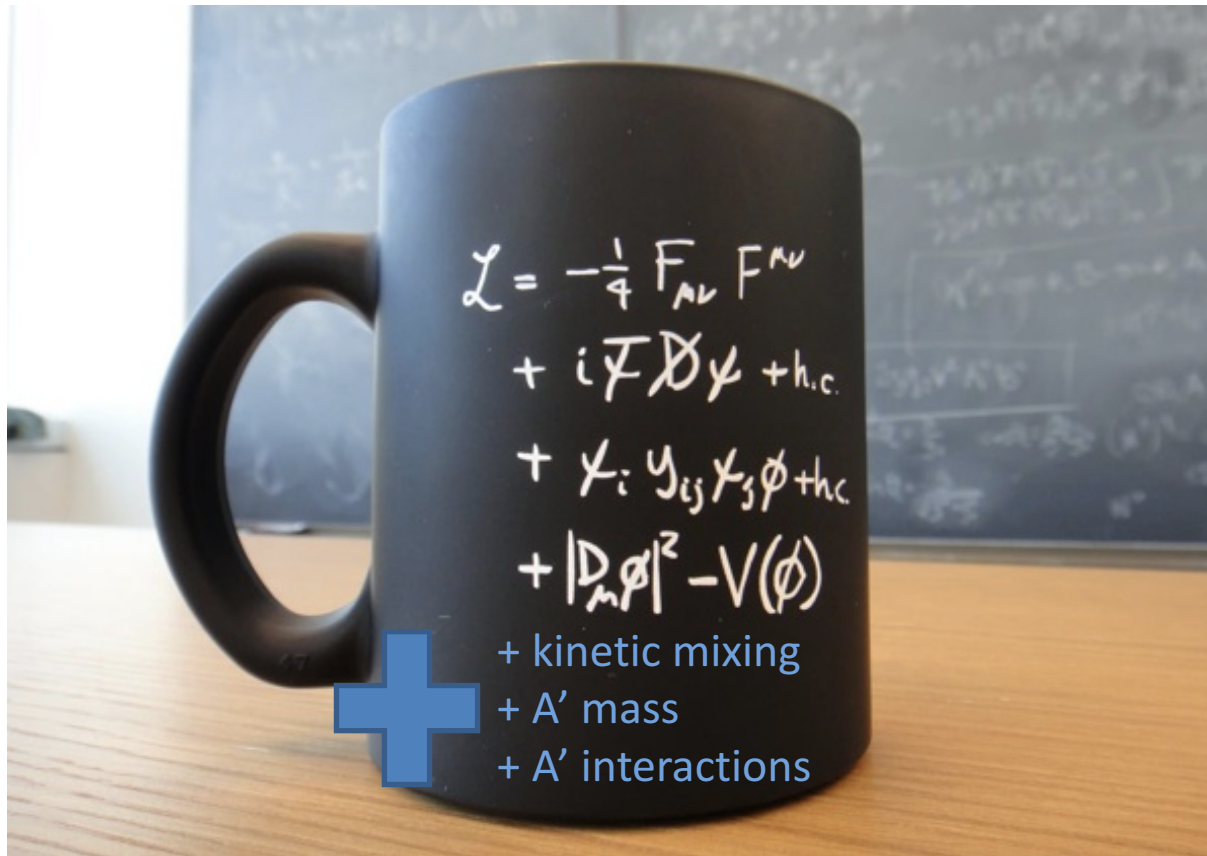
Kinetic terms for bosons (makes fields 'dynamic')

Higgs potential

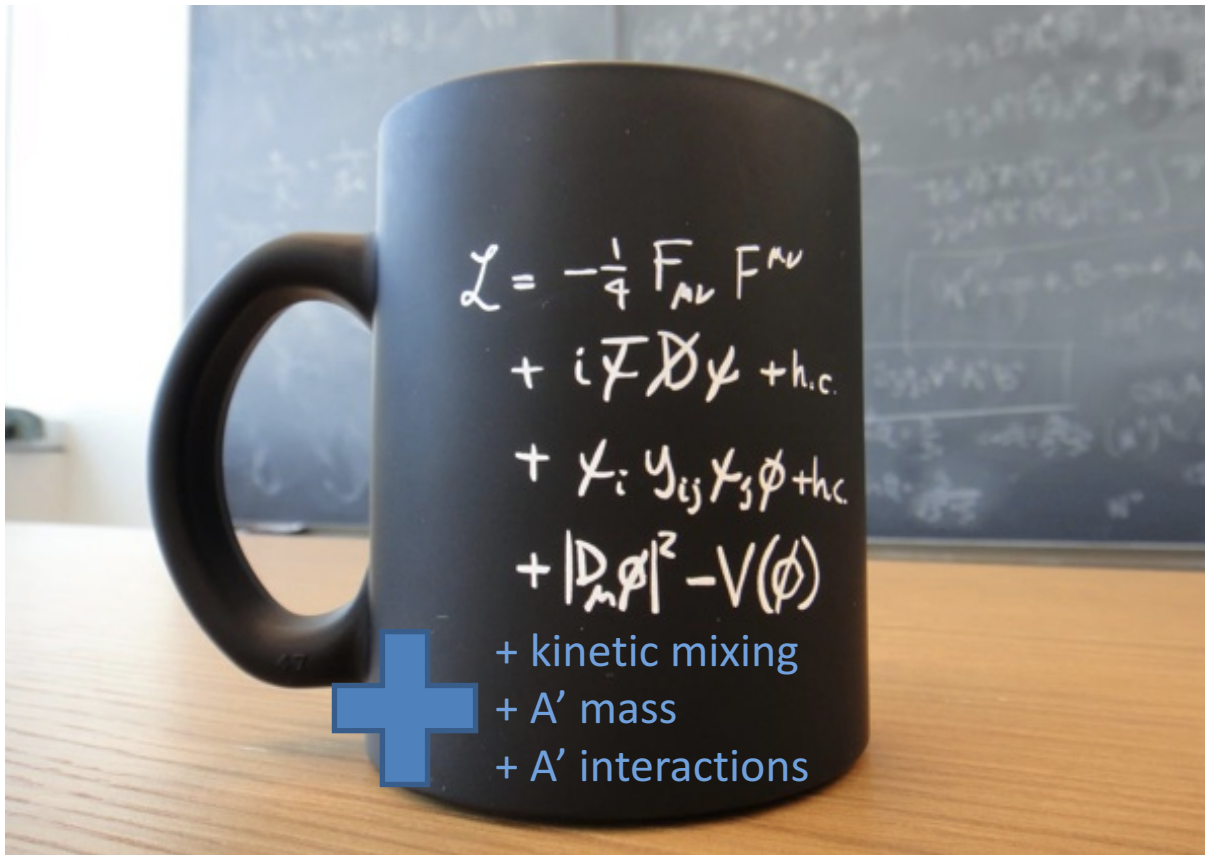
Interaction terms (connects fields together)

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi} \not{D} \psi + \text{h.c.} + \chi_i y_{ij} \chi_j \phi + \text{h.c.} + |D_\mu \phi|^2 - V(\phi)$$

- Add dark photon terms to the Lagrangian:



- All additional A' terms are allowed



Kinetic mixing

$$-\frac{1}{4} F'_{\mu\nu} B^{\mu\nu}$$

A' interactions

$$+\epsilon e A'^{\mu} J_{\mu}^{EM}$$

A' mass

$$+\frac{1}{2} m_{A'}^2 A'^{\mu} A'_{\mu}$$