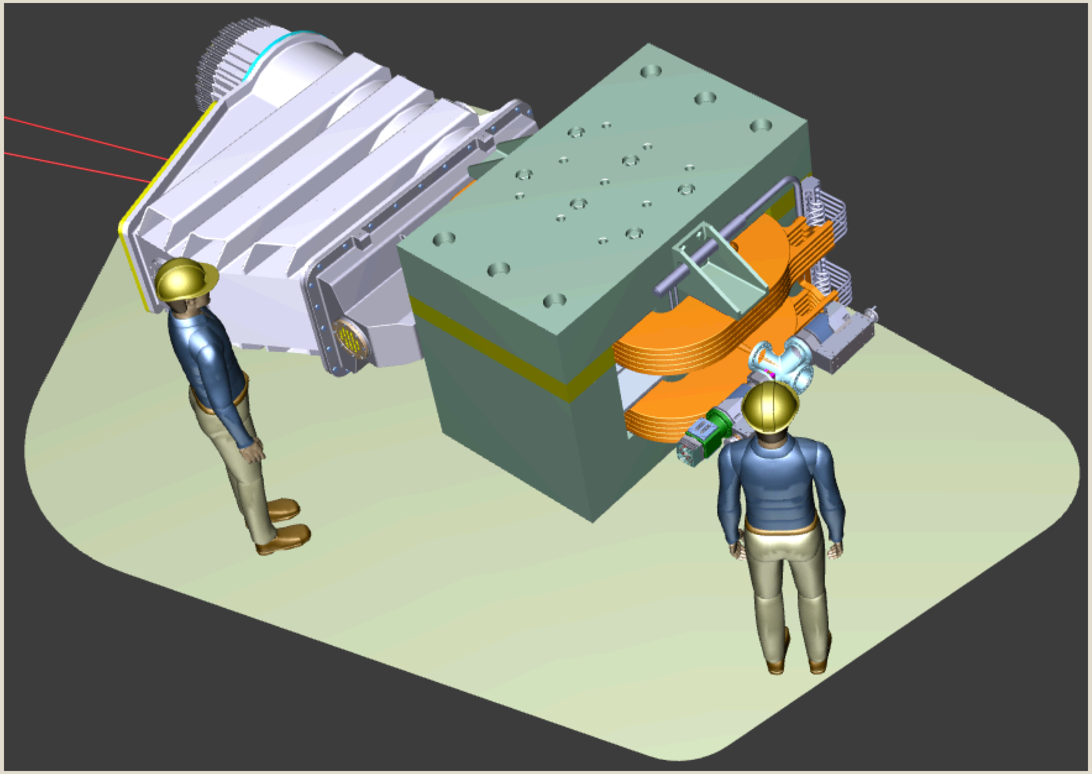
# Probing the dark sector with PADME

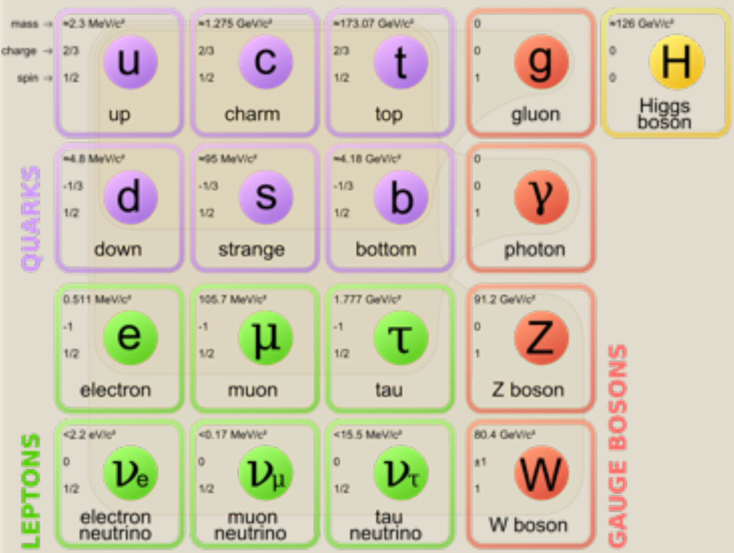


Dr. M. Raggi
Sapienza university of Rome & INFN Roma1
on behalf of the PADME collaboration

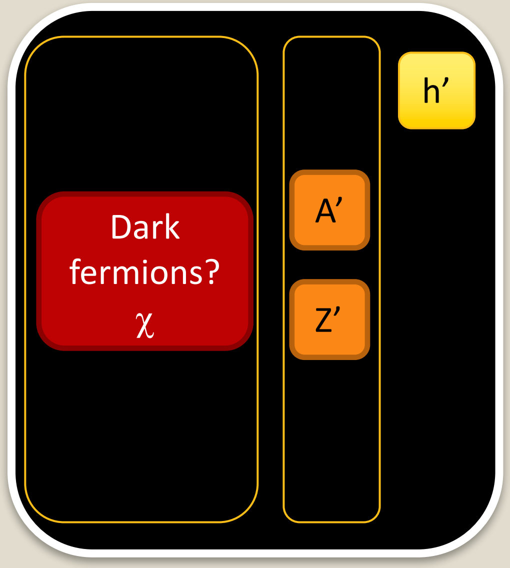
Les Rencontres de Physique de la Vallée d'Aoste 2018

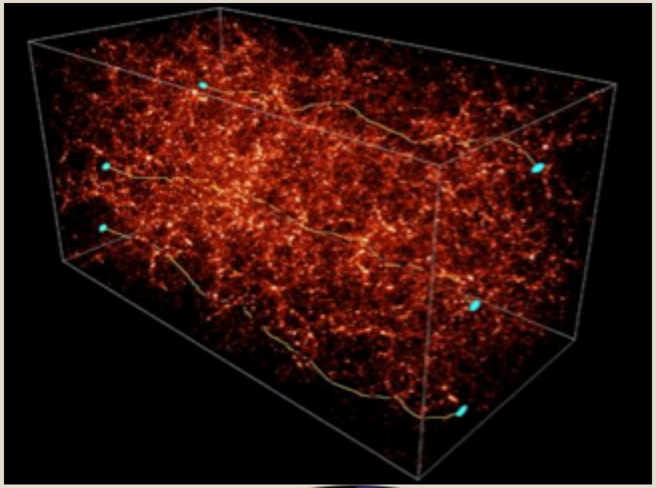
Results and Perspectives in Particle Physics

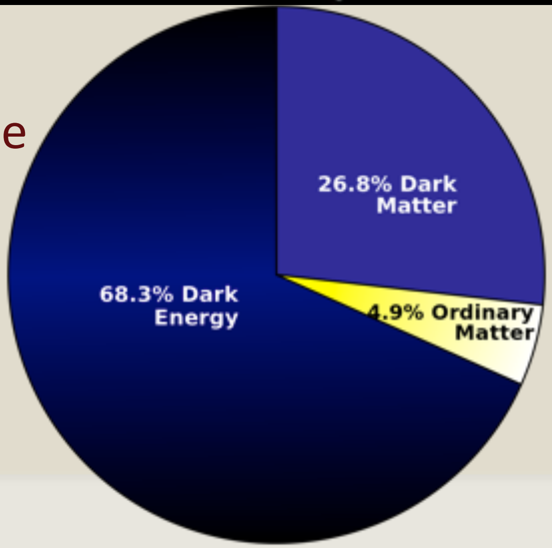
# What is the universe made of?




???Dark Sector???






- Standard model only includes <20% of the matter in the universe
  - We only know dark matter interact gravitationally
- Many open questions
  - What is dark Matter made of?
  - How dark matter interact, if it does, with SM particles?
  - Does one or more new dark force exist?
  - How complex is the dark sector particles spectrum?

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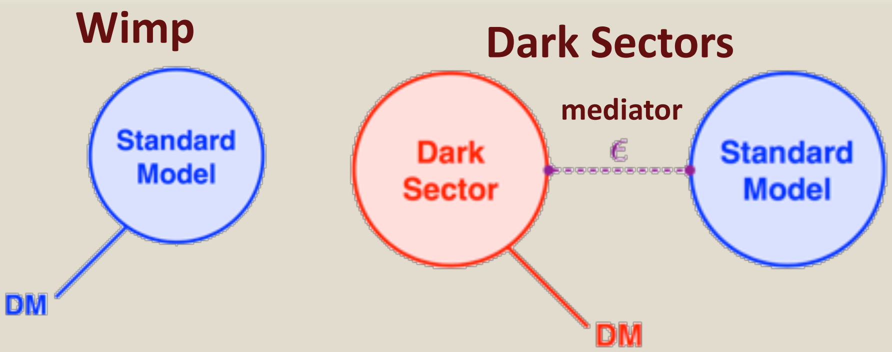
# DM, dark sector and portals




**Dark (or hidden) sector:**
DM particles **completely neutral** under SM forces, with **new interactions**
**Mediator:**
A **mediator particle** of the **new interaction**, interacting **very weekly** with SM particles
**Portal interaction:**
**New interaction connecting dark mediator and SM particles**

- The mediator can be scalar, fermion, **vector**, axion…
- The relic dark matter (DM) can be **either** the mediator particle **or** just coupled to SM via a hidden interaction
- Different portals can **co-exist:** e.g. dark photon and Higgs, or dark photon and axion
- Dark sectors invoked not only for the DM problem, but also for solving other puzzles:
  - **Muon *g*−2 anomaly**, proton radius, inflation, **$^{8}$Be anomaly**, …
- The **vector portal is the simplest** both from the theory [additional U(1) gauge symmetry] and experiment point of view [just replace an ordinary g with a dark one in any QED processes]
- **Wide mass and coupling ranges allowed**

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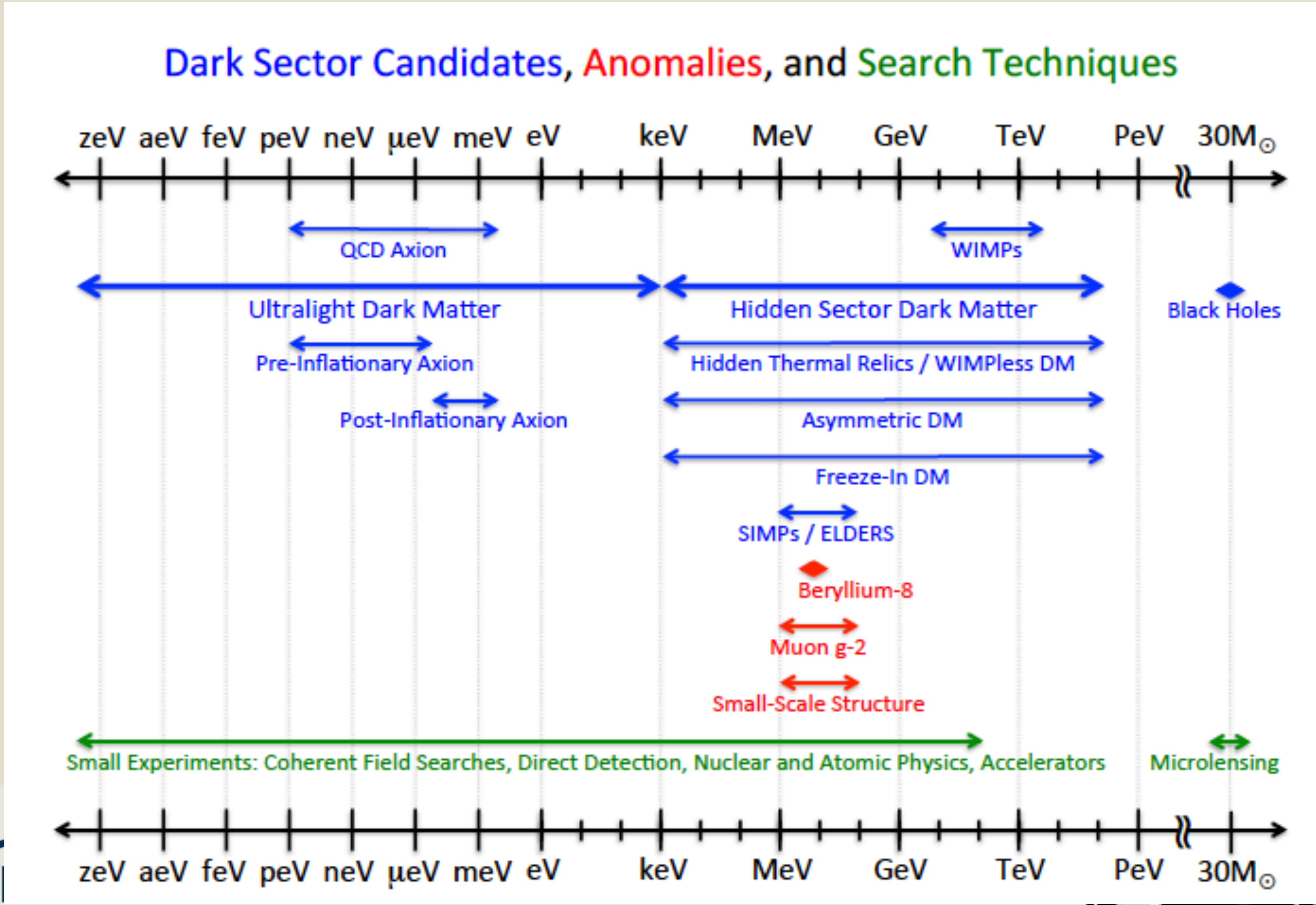
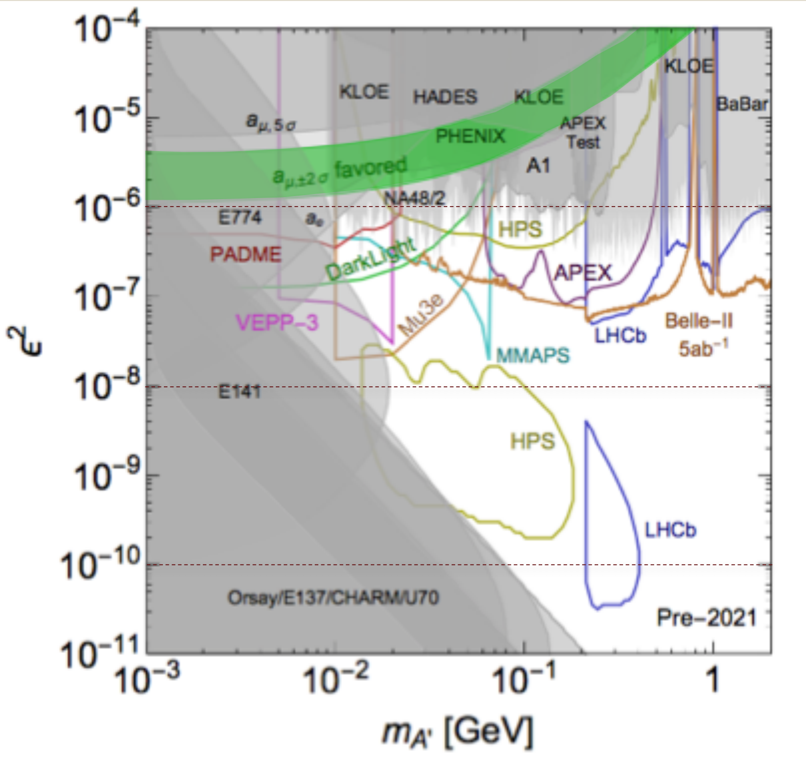
# Where to search for a new mediator?



# Status of dark photon searches

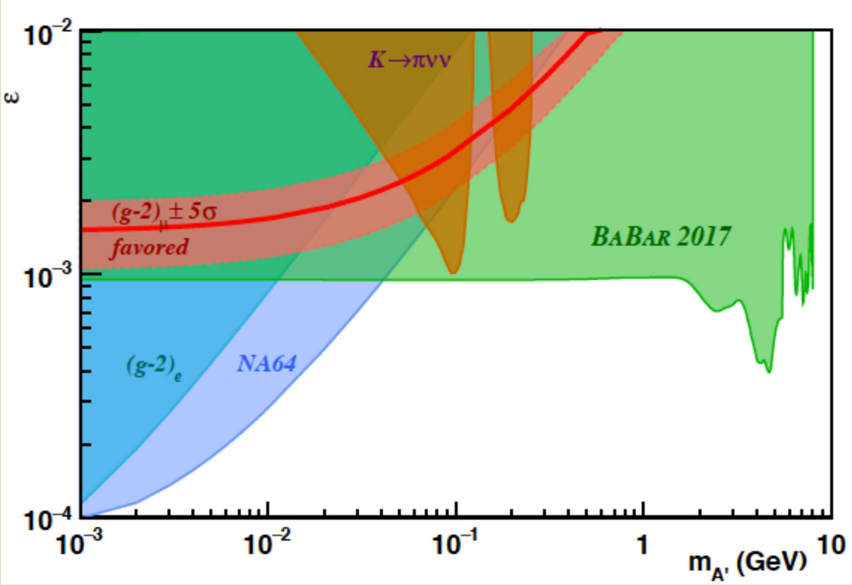
"Visible" final states ($A' \to l^+l^-$)

- $A'$-strahlung:
  - e- dumps
  - thin target: bump hunt, displaced vertices
- $e^+e^- \to A'\gamma$
- $\pi_0, \eta \to A'\gamma$




"Invisible" final states ($A' \to \chi\bar{\chi}$)

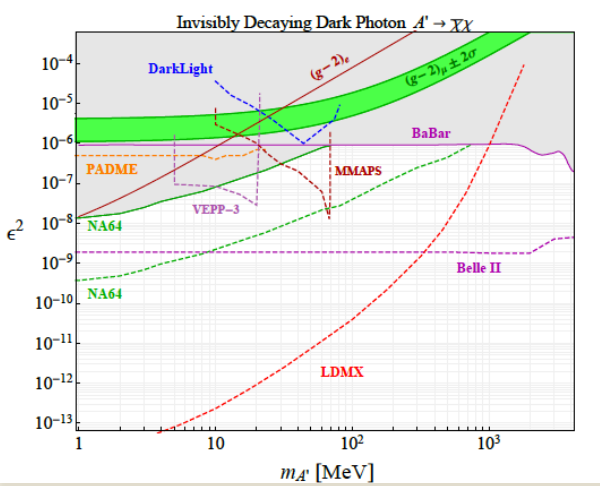
- A'-strahlung:
  - Missing energy NA64
- $e^+e^- \to A'\gamma$ , $A' \to \chi\chi$
  - Mono-photon events in $e^+e^-$ colliders
  - Fixed-target annihilations



# The PADME physics case(s)

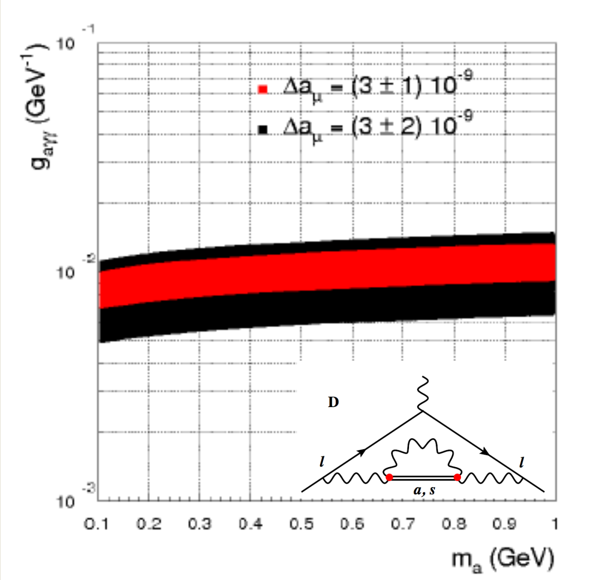
**PADME** is a multipurpose dark sector search experiment with positrons on fixed target able to detect photons and charged particles:
Main goal: **Invisible dark photon decays A'->χχ**
Aims to use annihilation production and missing mass searches. Several physics case under analysis

**Dark Photon** arXiv:1707.04591v1



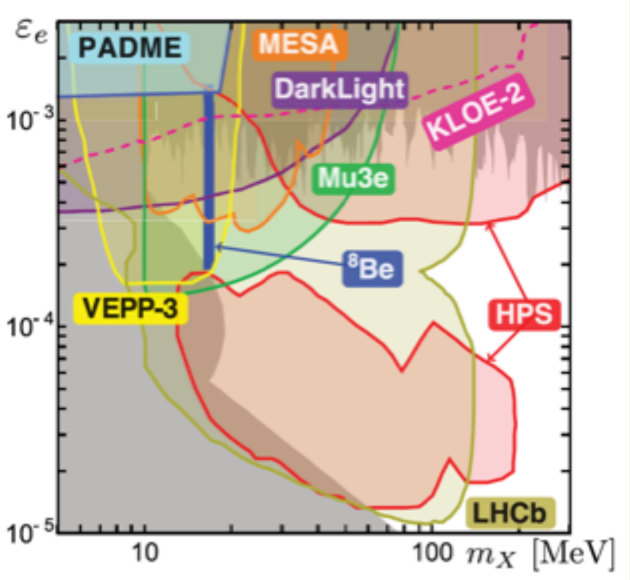

**Invisible final state $A' \to \chi\chi$ (γ+missing mass)**

**ALPs and g-2** PRD 94, 115033,2016




**ALPs final state $a \to \gamma\gamma$ (γγγ or eγγ)**

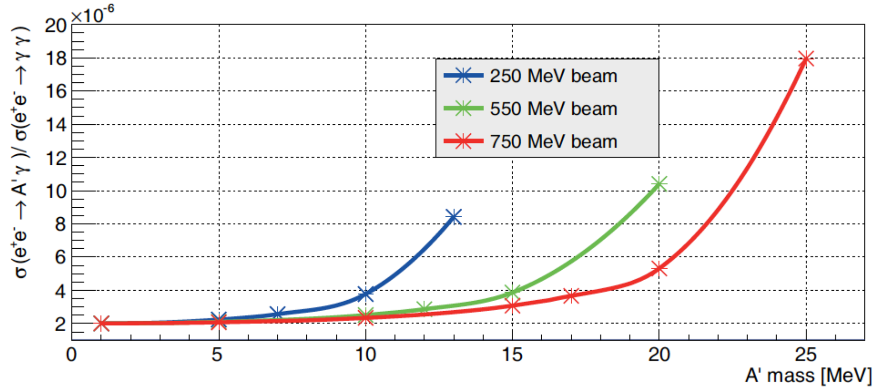
**Fifth force** PRL 117, 071803 (2016)




**Final state $X \to e^+e^-$**

# Why missing mass technique?

- The missing mass technique represents a unique opportunity:
  - Independent of the A' decays and dark sector structure ($\alpha_D$, $M\chi$) just $\varepsilon^2$ and $M_{A'}$ parameter explored!
  - Very clean signature for positive evidence (mass peak!)
  - Measure mass and coupling at the same time!
  - Theoretically clean (no dependence on missing energy and shower modelling)
  - Cross section enhanced for $m_{A'} \sim \sqrt{s}$
    (complementary to bremsstrahlung production decreasing with $m_{A'}$)
  - Searching for positive evidence is sensitive to a broader physics cases (ALPs, Dark Higgs)




$$\frac{d\sigma(e^+e^- \to \gamma A')}{d\cos\theta} = \frac{\alpha\epsilon^2}{2s^2(s-m_{A'}^2)}\left(\frac{s^2+m_{A'}^4}{\sin\theta^2} - \frac{(s-m_{A'}^2)^2}{2}\right)$$

$M_{A'} \to 0$

$$\sigma(e^+e^- \to \gamma A') = 2\epsilon^2\sigma(e^+e^- \to \gamma\gamma).$$

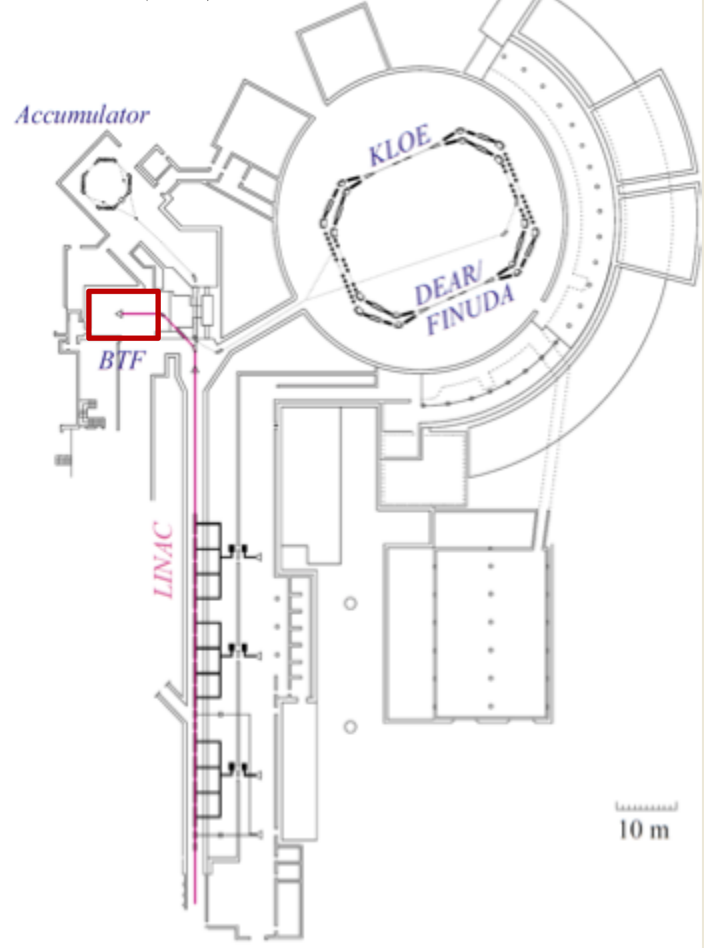
$$\frac{\sigma(e^+e^- \to U\gamma)}{\sigma(e^+e^- \to \gamma\gamma)} = \frac{N(U\gamma)}{N(\gamma\gamma)} * \frac{Acc(\gamma\gamma)}{Acc(U\gamma)} = \epsilon^2 * \delta,$$

# The DAΦNE Beam Test Facility (BTF)

| | Electrons | Positrons |
|---|---|---|
| Maximum beam energy ($E_{beam}$)[MeV] | 750 MeV | 550 MeV |
| Linac energy spread [Dp/p] | 0.5% | 1% |
| Typical Charge [nC] | 2 nC | 0.85 nC |
| Bunch length [ns] | 1.5 – 40 (can reach 200 in 2016) | |
| Linac Repetition rate | 1-50 Hz | 1-50 Hz |
| Typical emittance [mm mrad] | 1 | ~1.5 |
| Beam spot s [mm] | <1 mm | |
| Beam divergence | 1-1.5 mrad | |

- Able to deliver both electrons and positrons of tuneable E
  - Duty cycle 50 bunch x 40-200 ns = $2x10^{-6}$-$1x10^{-5}$ s
  - Precise energy tuning down to 100 MeV
  - Low emittance beam

NIM A 515 (2003) 524–542



# The PADME approach to A' searches

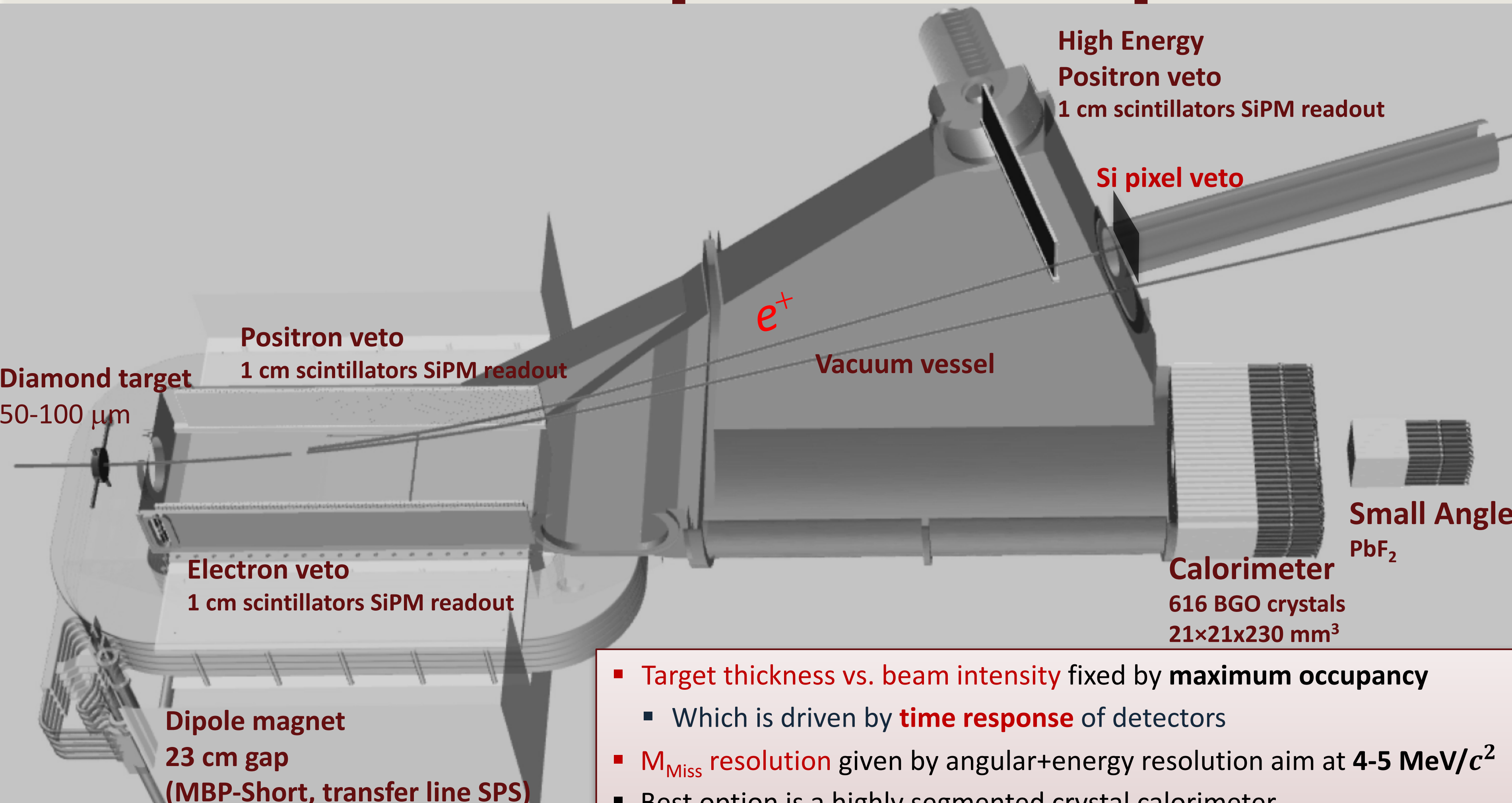
## The goal

- Develop a dark sector search which is as much as possible **model independent**
  - Explore several models at the same time (Vectors, pseudo-scalars)
- Minimize the number of interactions and parameters in the data interpretation
  - Need only to describe production mechanism
  - Needs only coupling to electrons
- Provide a **strong and unquestionable experimental evidence for A'**
  - Measure mass and coupling simultaneously can use data driven background estimate!

## The way

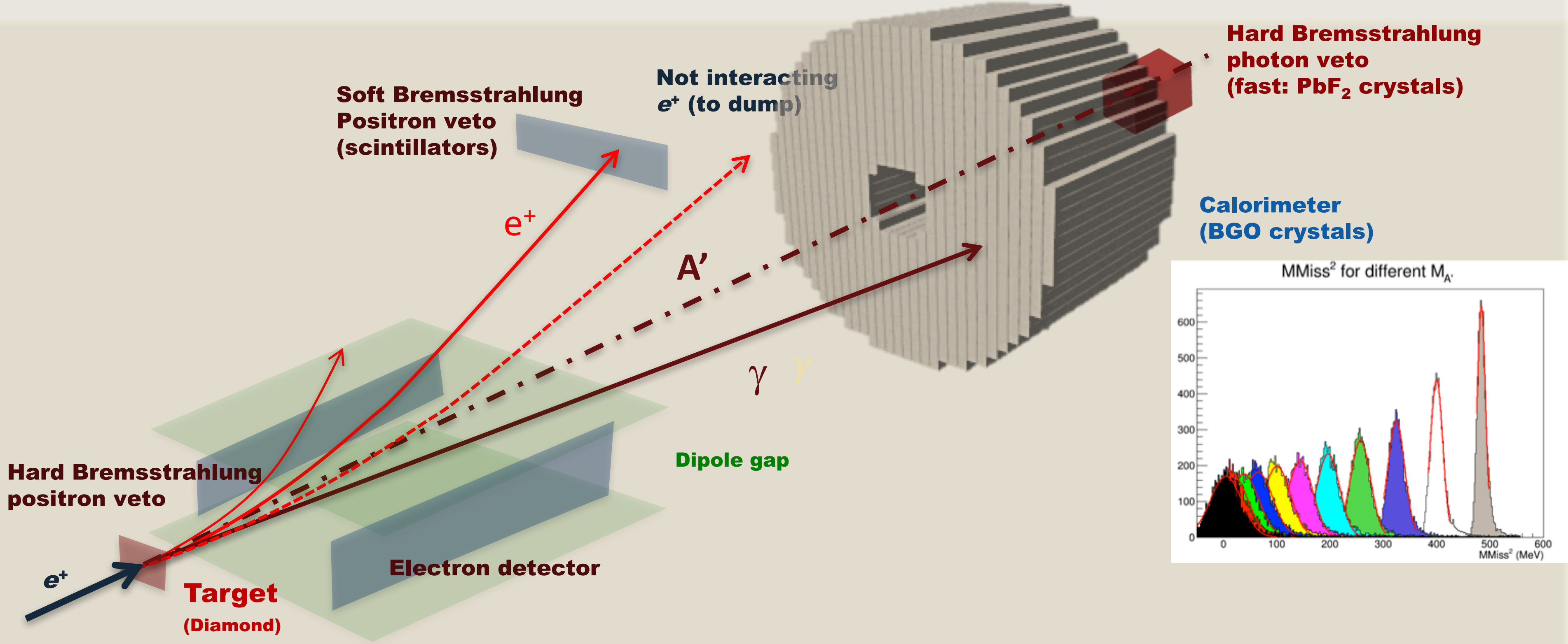
- Search for the process **$e^+e^-$ ->$\gamma$A'** A'->Inv. by **measuring the final state missing mass**
  - Independent from the A' decay mechanism, A' lifetime, nature and mass of the dark matter $\chi$
- **Measure $\varepsilon^2$** from rate **and $M_{A'}$** from the missing mass
  - Completely constrain the minimal A' model
- Measure $\varepsilon^2$ with minimal theoretical uncertainties
  - Just the delta cross section enhancement factor.

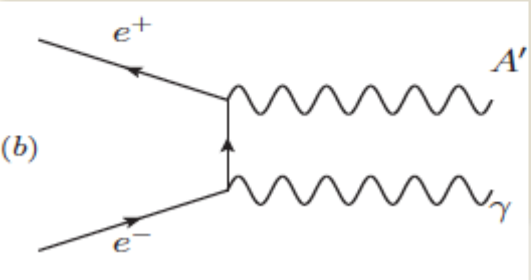
# PADME experiment setup



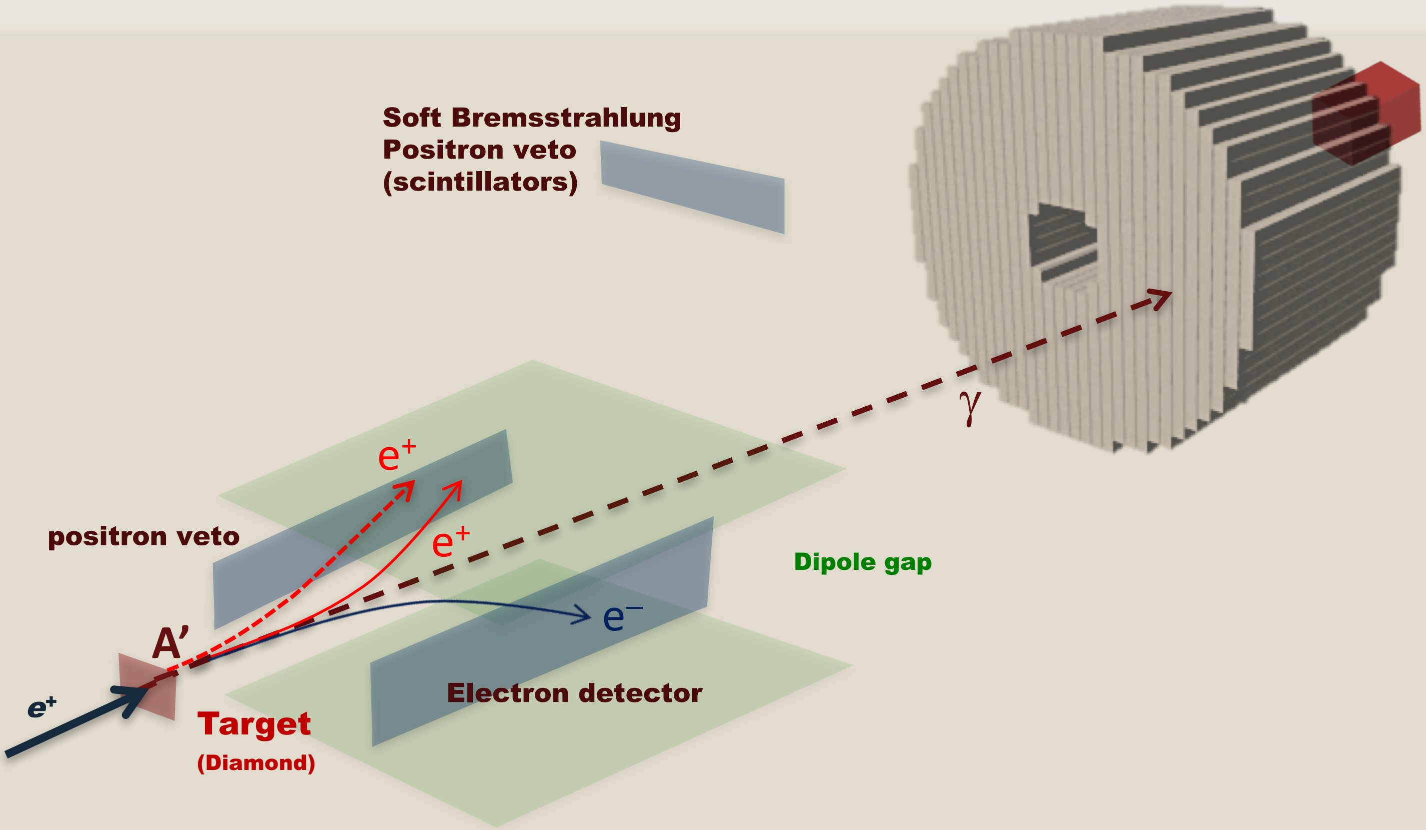

- Target thickness vs. beam intensity fixed by **maximum occupancy**
  - Which is driven by **time response** of detectors
- $M_{Miss}$ resolution given by angular+energy resolution aim at **4-5 MeV/$c^2$**
- Best option is a highly segmented crystal calorimeter
  - Crystal size 20x20x230mm³ fixed by Moliére radius
  - Calorimeter size fixes the number of crystals
  - Distance + dipole gap fixes the **acceptance**
  - Hole in BGO calorimeter + small angle fast detector to cope with rate
- Everything in **vacuum to avoid e+ interaction outside the target**

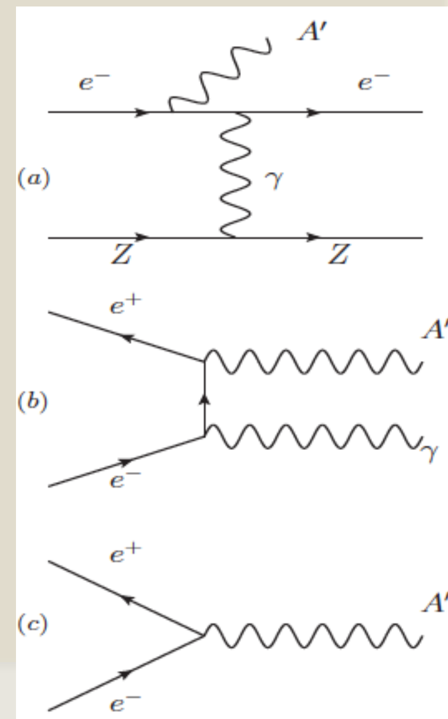
# PADME invisible technique: A→χχ



# PADME visible technique: $A \rightarrow e^+e^-$




- Three different final states can be explored using 3 different production
  a) Final state A'-strahlung: $e^+e^-e^+$
  b) Annihilation in 2g final state: $e^+e^-\gamma$
  c) Final state: $e^+e^-$ (only for defined A' mass sqrt($2m_eE_B$) )

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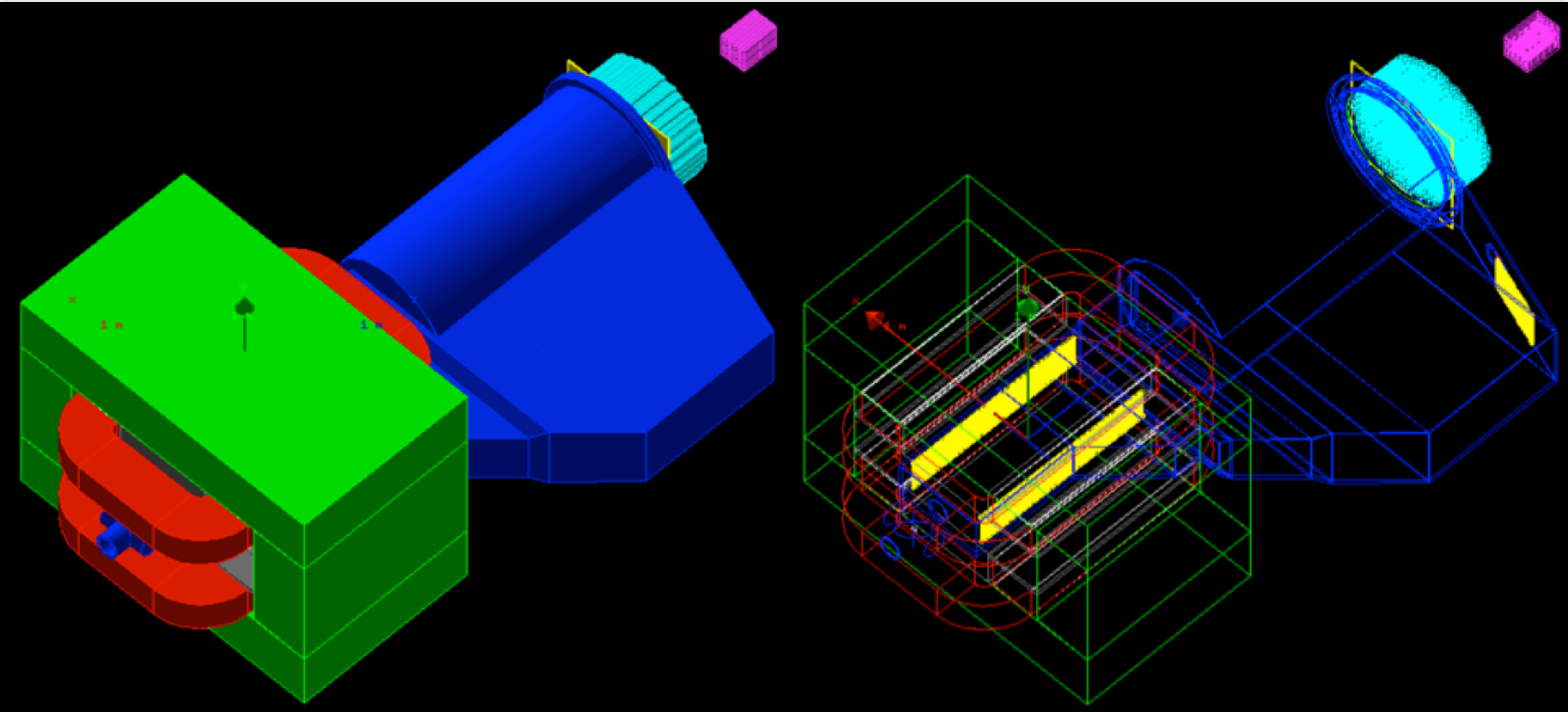
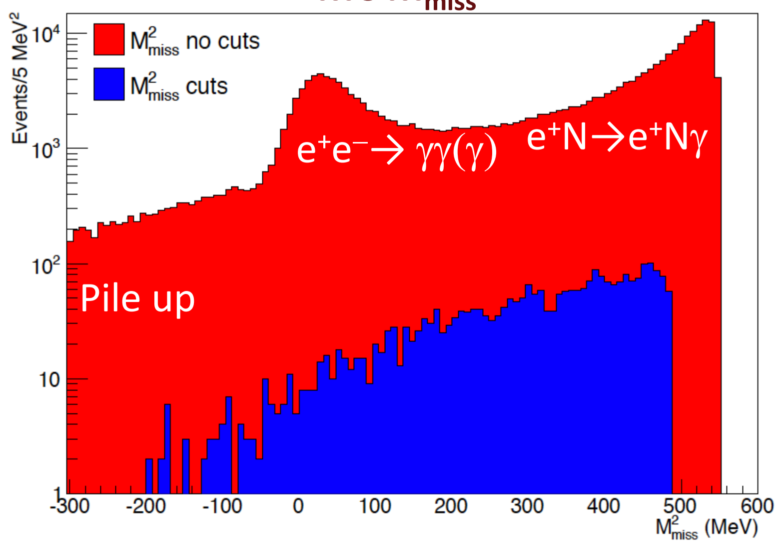
# PADME GEANT4 Monte Carlo

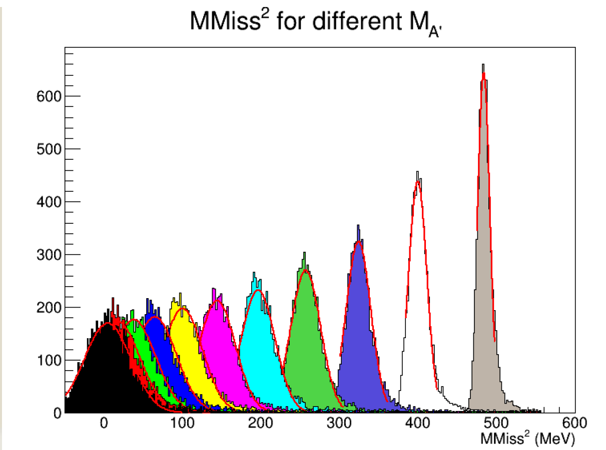


- Full description of the detector achieved including passive materials
- **New sensitivity estimate ongoing**
- **Need theoretical guidance to study sensitivity non dark photon scenario:**
  - **ALPs generators**
  - **X-Bosons optimization needed**

# A' to invisible sensitivity analysis

MC $M_{miss}^2$



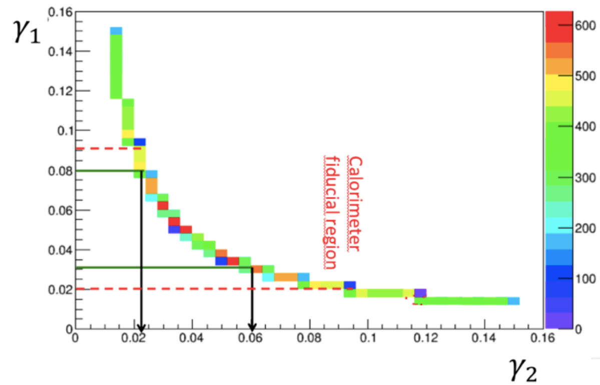

## Candidate Signal selection

- Just one photon cluster in the ECal
- 30 mrad < $\theta_{Cl}$ < 65 mrad
- No tracks in the charged veto in within ±2 ns
- No photons with $E_\gamma$>50 MeV in within ±2ns in the SAC
- Cluster Energy: $E_{min}(M_{A'}) < E_{Cl} < E_{max}(M_{A'})$ MeV
- Missing mass in the region: $M_{A'}^2 \pm \sigma(M_{miss2})$

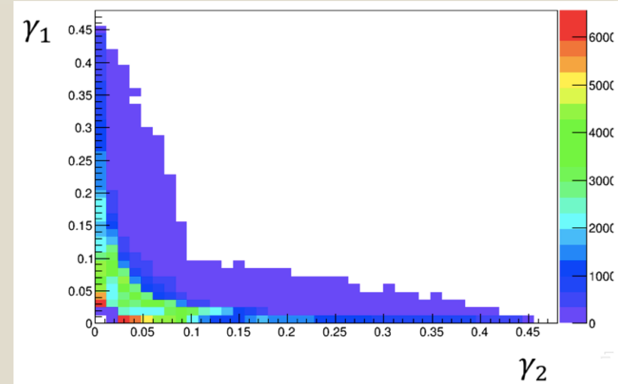
## Search technique

- Count the number of BG events in each mass region from the blue distribution
- Consider them as A' candidate

# A’ to invisible backgrounds

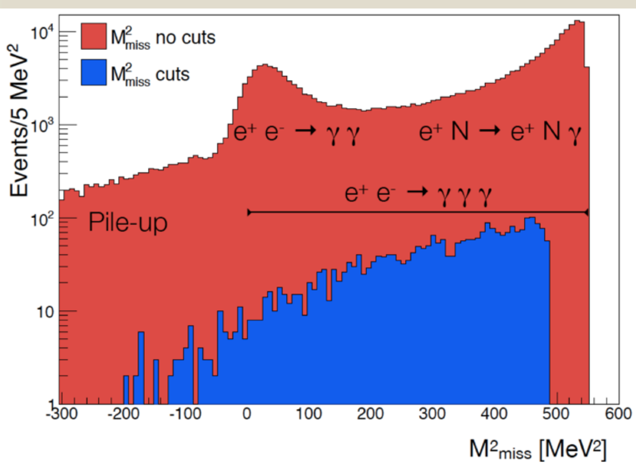


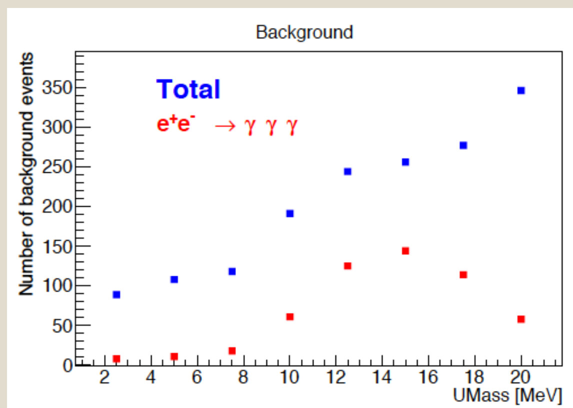

For **$\gamma\gamma$ events**, given one photon in fiducial region, also the second is in the **calorimeter easy to control**

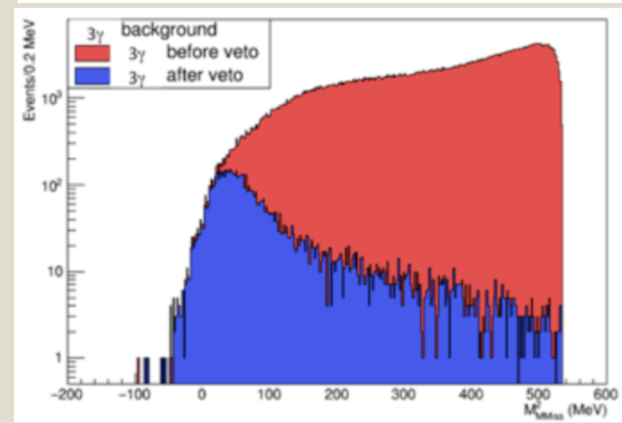



For **$\gamma\gamma(\gamma)$ events**, given one photon in fiducial region, the **small angle calorimeter** is crucial to recover full efficiency on second photon

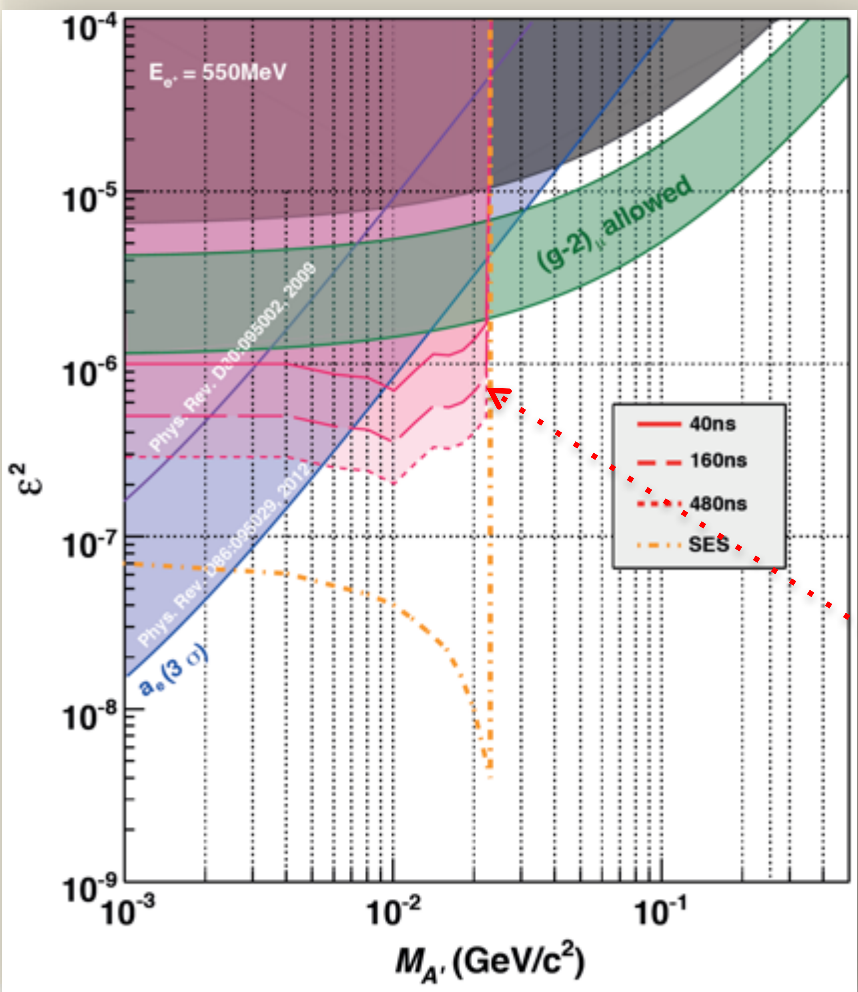
**Residual background** dominated by Bremsstrahlung with $e^+$ missed by the scintillating bars veto



# PADME-invisible decay sensitivity




- Based on $2.5\times10^{10}$ fully GEANT4 simulated 550MeV e+ on target events
  - Number of BG events is extrapolated to $1\times10^{13}$ electrons on target
- Using $N(A'\gamma)=\sigma(N_{BG})$
- δ enhancement factor $\delta(M_{A'}) = \sigma(A'\gamma)/\sigma(\gamma\gamma)$ with ε=1 due to A' mass

$$\frac{\Gamma(e^+e^- \to A'\gamma)}{\Gamma(e^+e^- \to \gamma\gamma)} = \frac{N(A'\gamma)}{N(\gamma)} \frac{Acc(\gamma\gamma)}{Acc(A'\gamma)} = \varepsilon \cdot \delta$$

PADME 2 years of data taking at 60% efficiency with bunch length of 200 ns
$4\times10^{13}$ EOT = **20000 e⁺**/bunch × 2 × **$3.1\cdot10^7$**s x 0.6 · **49 Hz**

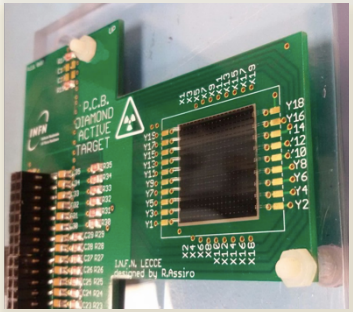
PADME single event sensitivity far to be reached improvement on the limits still possible.

$E_{e+}$=550 MeV: $M_{A'} < 23.7$ MeV/$c^2$

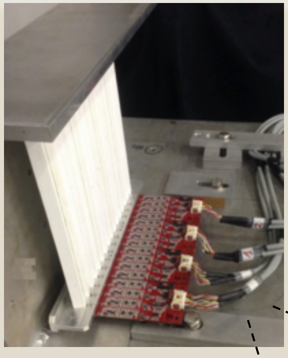
$E_{e+}$=750 MeV: $M_{A'} < 27.7$ MeV/$c^2$

$E_{e+}$=1 GeV: $M_{A'} < 32$ MeV/$c^2$

# PADME detector status

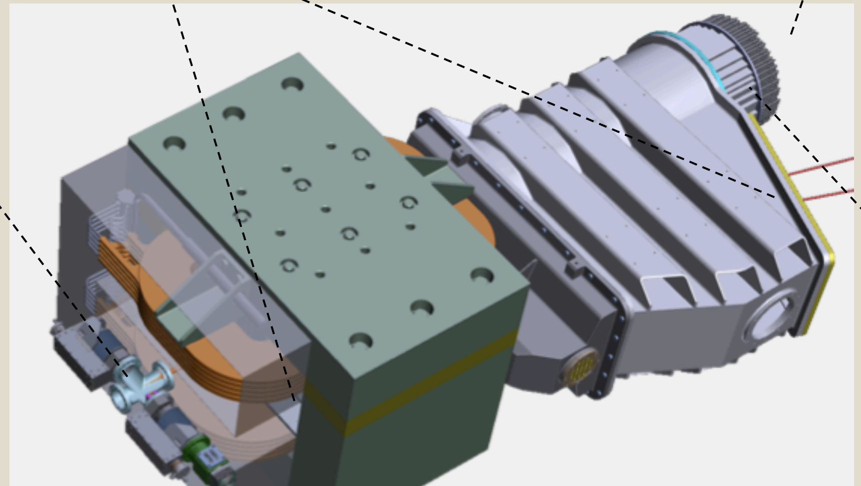



Diamond with grafite strips: All-Carbon active **target**, beam position & size and luminosity monitor. Custom electronics readout



Scintillating bars with SiPM readout for rejecting Bremsstrahlung background events (tagging positrons)
Inside vacuum vessel

Very fast $PbF_2$ Cherenkov calorimeter for rejecting 2 and 3 photon background events and withstand Bremsstrahlung rate
Fast PMT readout



Spare dipole from CERN SPS
(23 cm gap, 1 m long)


BGO calorimeter

# The PADME collaboration

**Istituto Nazionale di Fisica Nucleare ITALY**

- Hosting the experiment at Laboratory Nazionali di Frascati
- Participating institutions: LNF, Roma1, Roma3, and Lecce
- 32 researchers working on the project part of their time

**University of Sofia**, prof. Venelin Kozhuharov and collaborators

- Responsibility of scintillator veto detectors
- Grant obtained to participate into PADME in the next 3 years!

**MTA Atomki**, Debrecen (Hungary), prof. Attila Krasznahorkay and collaborators

**Cornell University**, CLASSE laboratory, prof. J. Alexander and collaborators

- MRI submitted for positron extraction line at Cornell to run PADME.

**College William and Mary,** Prof. B. Wojtsekhowski

**The University of Iowa,** Adj. Prof. Burak Bilki

# commissioning and running plans

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Commissioning | | | PADME Physics Run 1 | | | | DAΦNE collisions | | | Run 1 | | 2018 |

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beam time for PADME to be negotiated with INFN and LNF management | | | | | | | | | | | | 2019 |

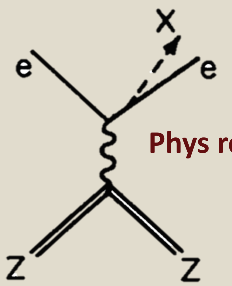
## 2018: commissioning and running

- PADME aims at collecting **$1x10^{13}$** positrons on target **by the end of 2018**
- **Start of data taking for physics during May 2018**
- **Approved running time**
  - **1 April – 31 July** + **1 November to end of 2017**.
  - Assuming a 65% eff. with 200 ns pulse length: 1.5E7s*49pulses/s*2E4e+/pulse*0.65 = **$10^{13}$ $e^{+}$ on target**

# ALPs physics at PADME

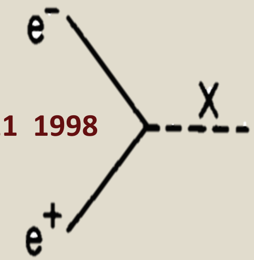
PADME can search for ALP having electron or photon couplings exploring different production mechanisms.

**Bremsstrahlung**

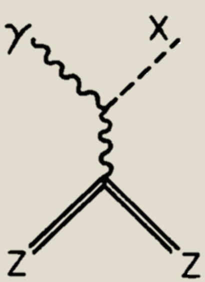



Phys rev D 38 11 1998

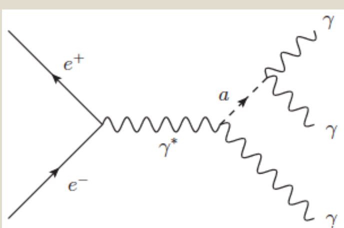
**Annihilation**




**Primakoff**

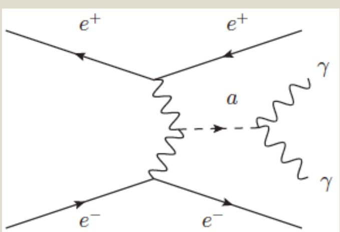



**aγ Ann.**



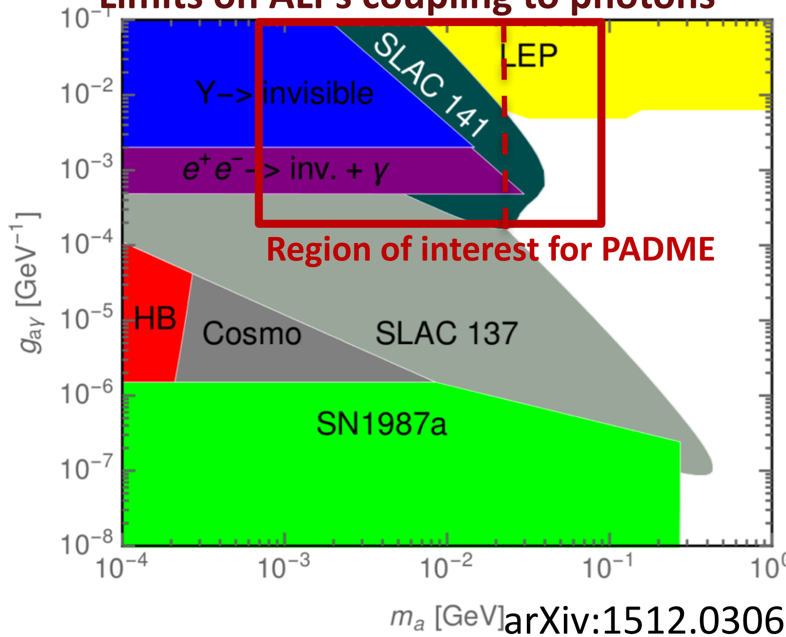

$(e^+e^- \to \gamma^* \to \gamma + a)$

**Photon fusion**

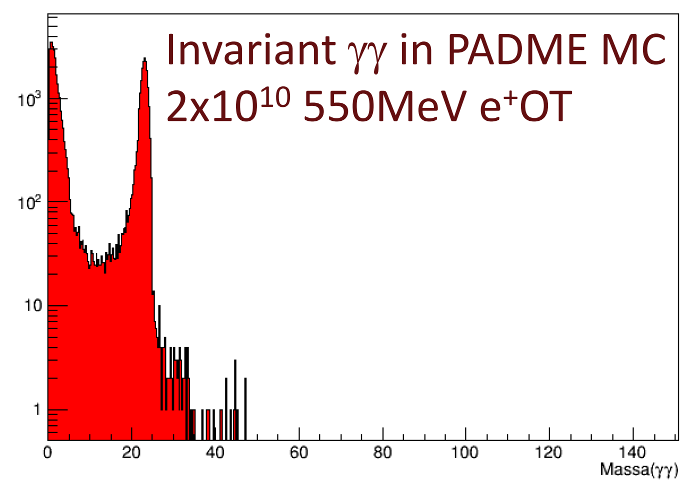



$(e^+e^- \to e^+e^- + a)$

**Limits on ALPs coupling to photons**




arXiv:1512.03069

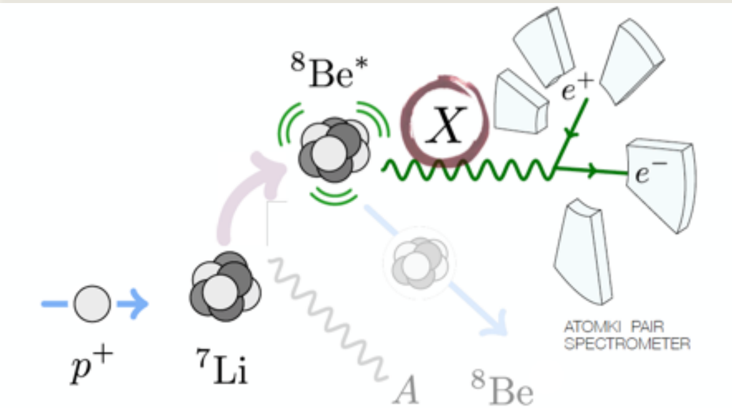


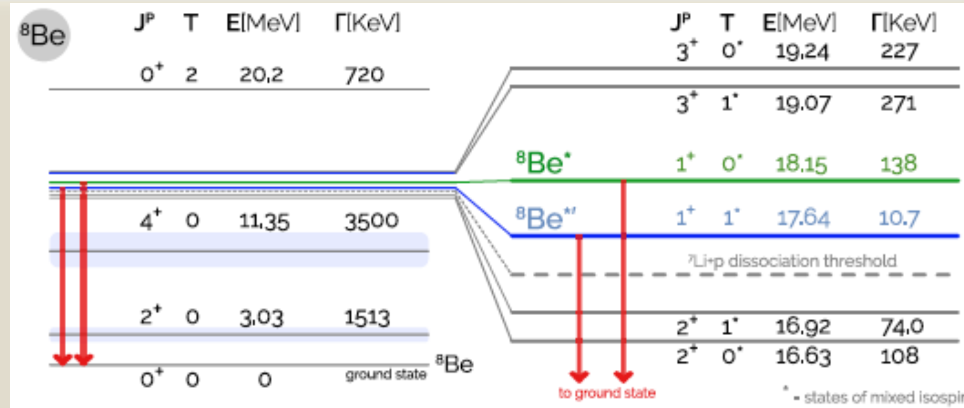

The observables at PADME might be:

Visible ALPs: $e^+\gamma\gamma$, $\gamma\gamma\gamma$, $e^+\gamma\gamma$

Invisible ALPs: $\gamma + M_{miss}$

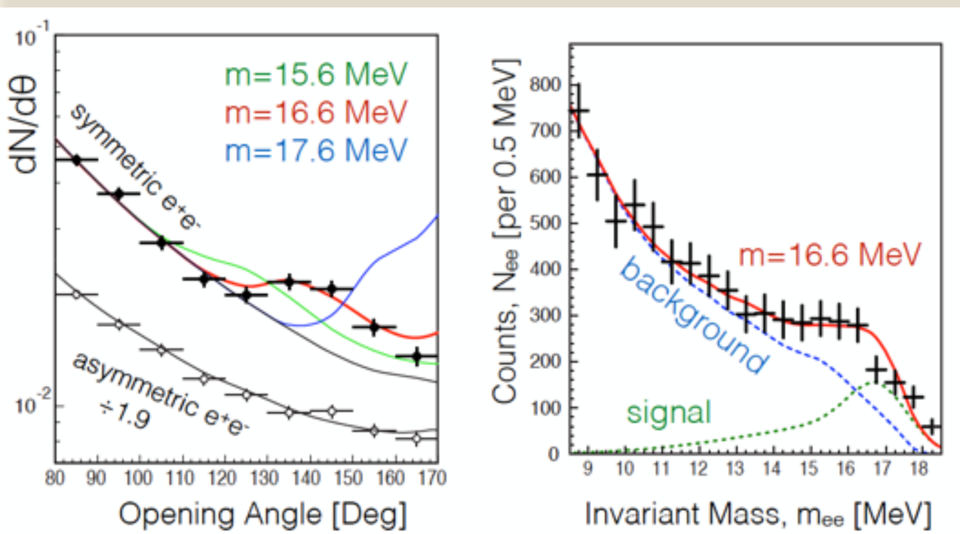
# The $^8$Be anomaly




Is this an evidence of a new light dark photon?

- Sanity checks performed
  - Excess disappears as one scans through the proton beam resonance kinetic energy of 1.03 MeV
  - excess becomes more pronounced when restricting to the subset of events with E > 18 MeV and is absent for lower energy events
  - Excess only appears for events with symmetric $E_{e+}$ and $E_{e-}$




$$m_X = 16.7 \pm 0.35(\text{stat}) \pm 0.5(\text{sys})\ \text{MeV}$$

Can nuclear physics explain the anomaly observed in the internal pair production in the Beryllium-8 nucleus?


Xilin Zhang[1,*] and Gerald A. Miller[1,†]

[1]Department of Physics, University of Washington, Seattle, WA 98195, USA


(Dated: March 16, 2017)

Can only mitigate the anomaly by 1σ by improving nuclear treatment. j.physletb.2017.08.013

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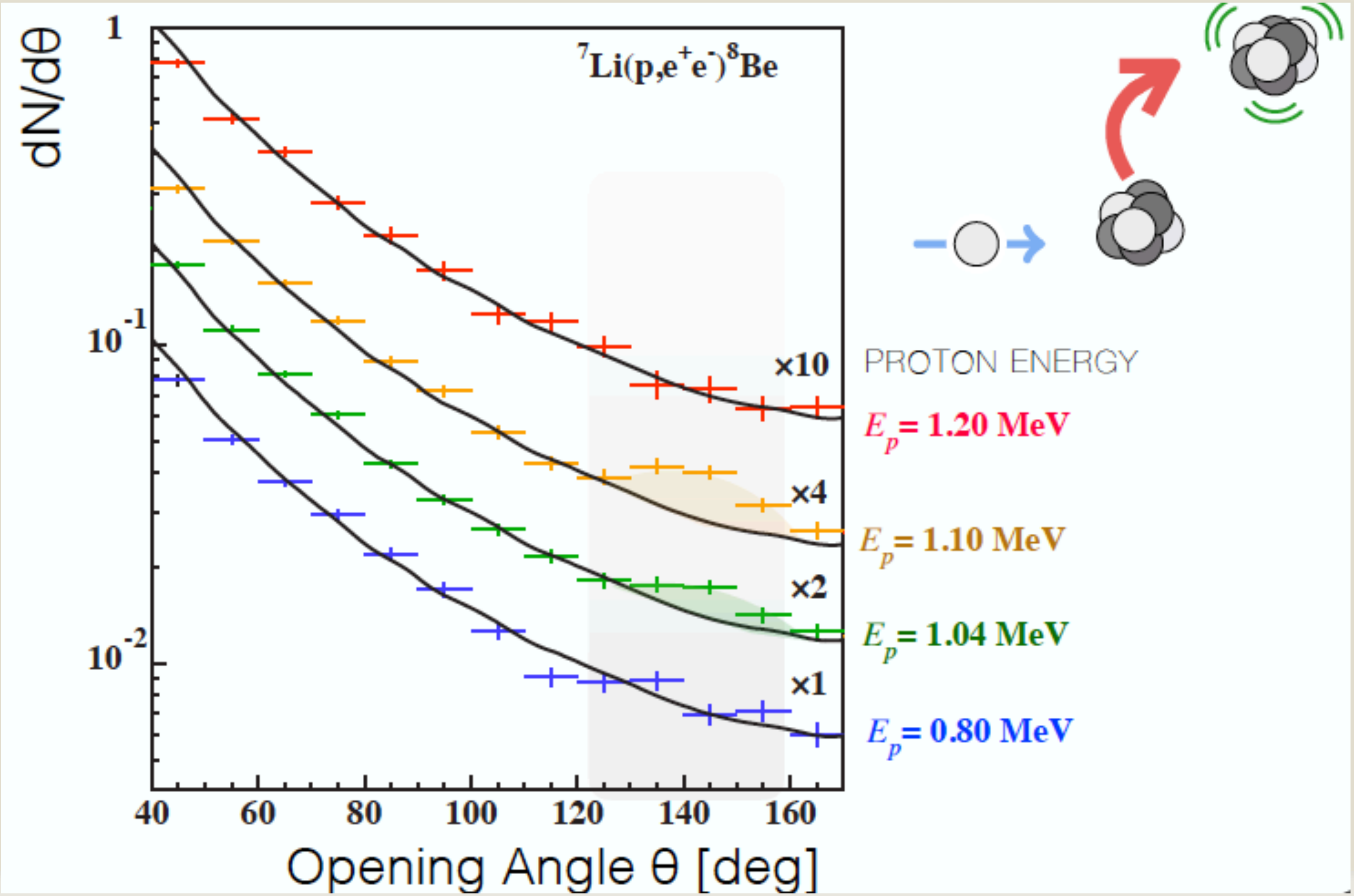
# Excitation energy checks

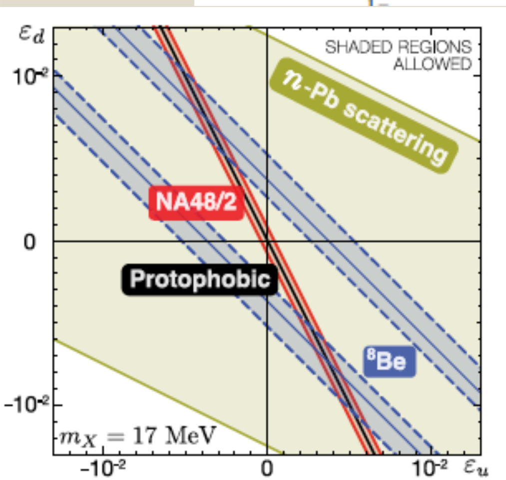


# The $^{8}$Be anomaly interpretation

PRL 117, 071803 (2016) PHYSICAL REVIEW LETTERS week ending 12 AUGUST 2016

**Protophobic Fifth-Force Interpretation of the Observed Anomaly in $^{8}$Be Nuclear Transitions**

Jonathan L. Feng,[1] Bartosz Fornal,[1] Iftah Galon,[1] Susan Gardner,[1,2] Jordan Smolinsky,[1] Tim M. P. Tait,[1] and Philip Tanedo[1]

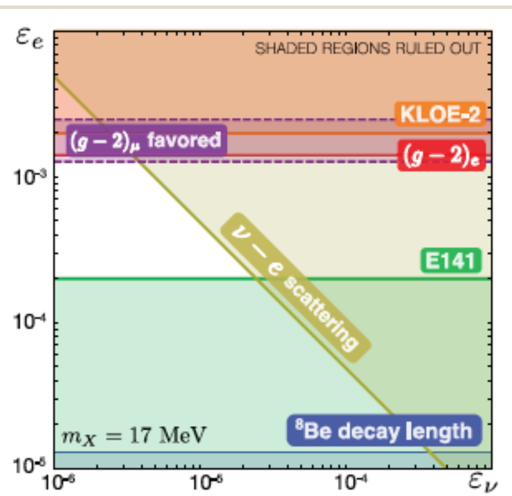



## Protophobia

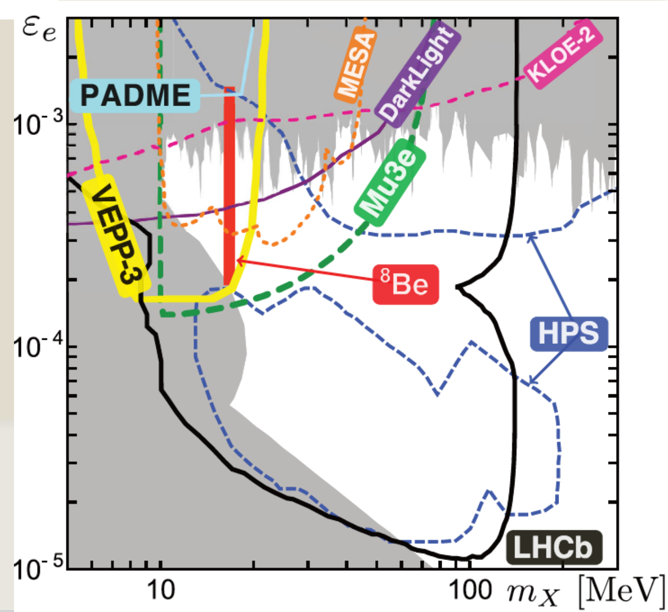
Equations (5) and (8) may be satisfied with a mild ∼10% cancellation, provided the charges satisfy

$$-2.3 < \frac{\varepsilon_d}{\varepsilon_u} < -1.8, \qquad -0.067 < \frac{\varepsilon_p}{\varepsilon_n} < 0.078. \quad (9)$$

Given the latter condition, we call the general class of vector models that can both explain the $^{8}$Be anomaly and satisfy pion decay constraints "protophobic."




Strongest experimental limit on the electron coupling comes from KLOE data: $\varepsilon_e$<2E-3




M. Raggi La Thuile 2018 Conference

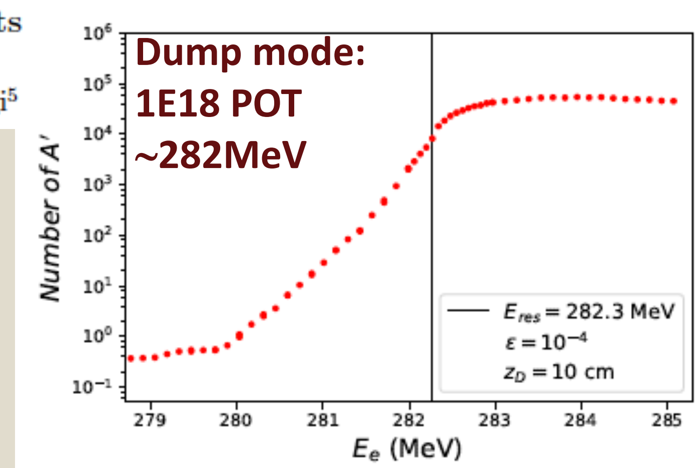
# $^8$Be anomaly at PADME

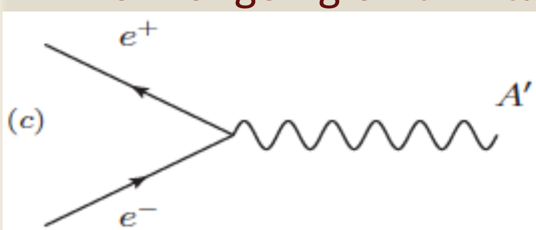
**Resonant production of dark photons in positron beam dump experiments**

ArXiv1802.04756v1

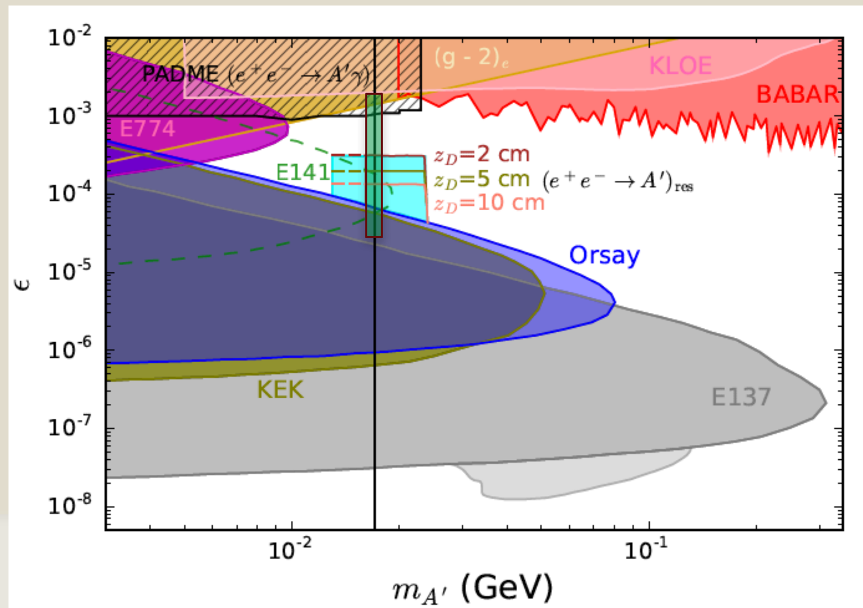
Enrico Nardi,[1,*] Cristian D. R. Carvajal,[2] Anish Ghoshal,[1,3] Davide Meloni,[3,4] and Mauro Raggi[5]

- Exploit the fact that you "know" where to search 17 MeV
- Exploit the possibility to have $e^+$ at 282.7 MeV @LNF
- Tune $E_{e+}$ such that $E_{CM}$=sqrt(2*$m_e$*$E_B$)=17MeV
  - Produce A' of 17MeV on shell through direct annihilation ee->A'
  - Parametrically enhanced wrt ee->A'γ
- Use threshold effect to have solid evidence is any
- Absorb any SM BG in W dump
- Work ongoing on thin target reaches

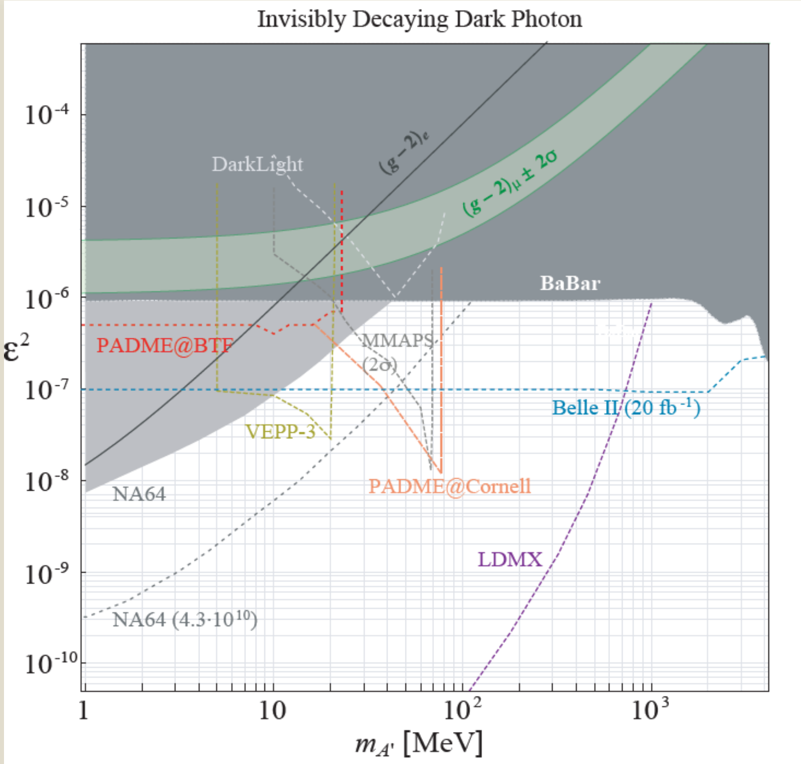



| $\epsilon / N_{A'}^{\rm prod}$ | $E_{\rm res}$ $(v_e = 0)$ | $E_{\rm res}$ | $E_{\rm res} + 2\sigma_b$ |
|---|---|---|---|
| $1.0 \times 10^{-3}$ | $7.69 \times 10^{11}$ | $1.51 \times 10^{11}$ | $4.72 \times 10^{11}$ |
| $5.0 \times 10^{-4}$ | $1.81 \times 10^{11}$ | $3.79 \times 10^{10}$ | $1.17 \times 10^{11}$ |
| $1.0 \times 10^{-4}$ | $7.25 \times 10^{9}$ | $1.49 \times 10^{9}$ | $4.73 \times 10^{9}$ |



# Possible future for PADME in the USA?




- Main limitation on PADME sensitivity comes from very small duty cycle of DAFNE Linac (2E-6 – 1E-5)
  - **50Hz x 40-250ns bunches**
- Beam energy limits PADME mass reach
  - 550MeV limits $M_{A'} < 23.7$MeV
- **PADME moved to CESR @ Cornell can profit of:**
  - x10000 higher luminosity
  - x12 Higher energy (6 GeV) $M_{A'} < 78$ MeV
- **PADME can offer to Cornell:**
  - High resolution BGO crystal Ecal
  - Spectrometer magnet and veto detectors

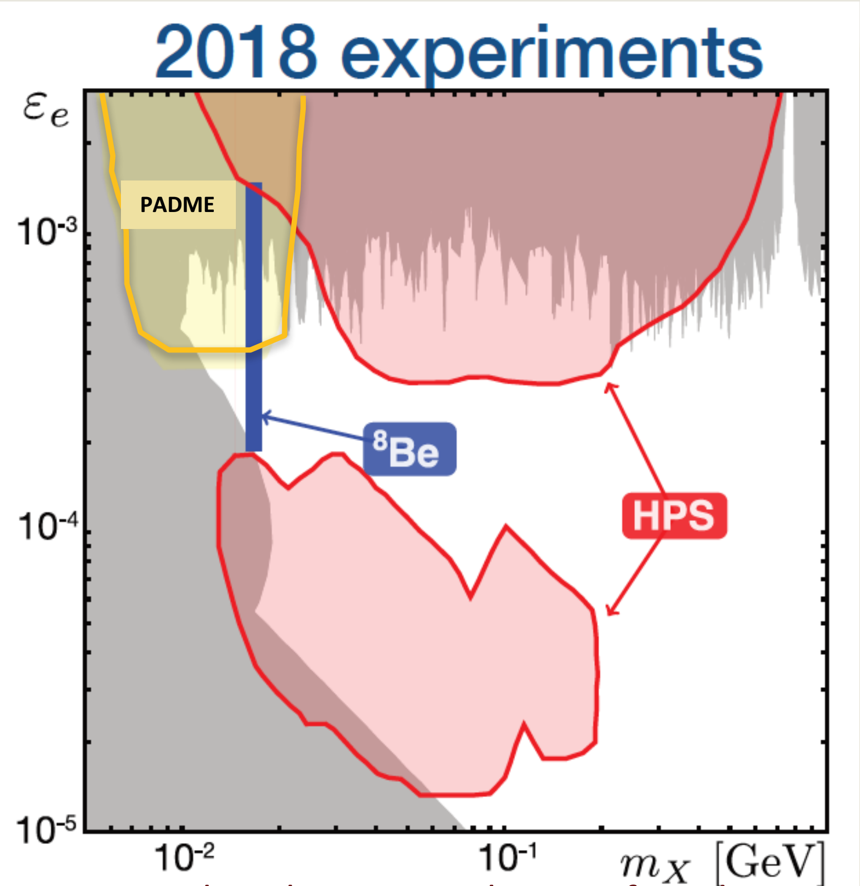
PADME to Cornell will be a 1-2M$ scale project (detector ready by the end of 2018!)
MRI for the extraction of a positron beam from CESR submitted (Feb 2018)
PADME might be able to run @CESR in just few years 2021?
A very interesting physics potential could be including visible and invisible A', ALPs

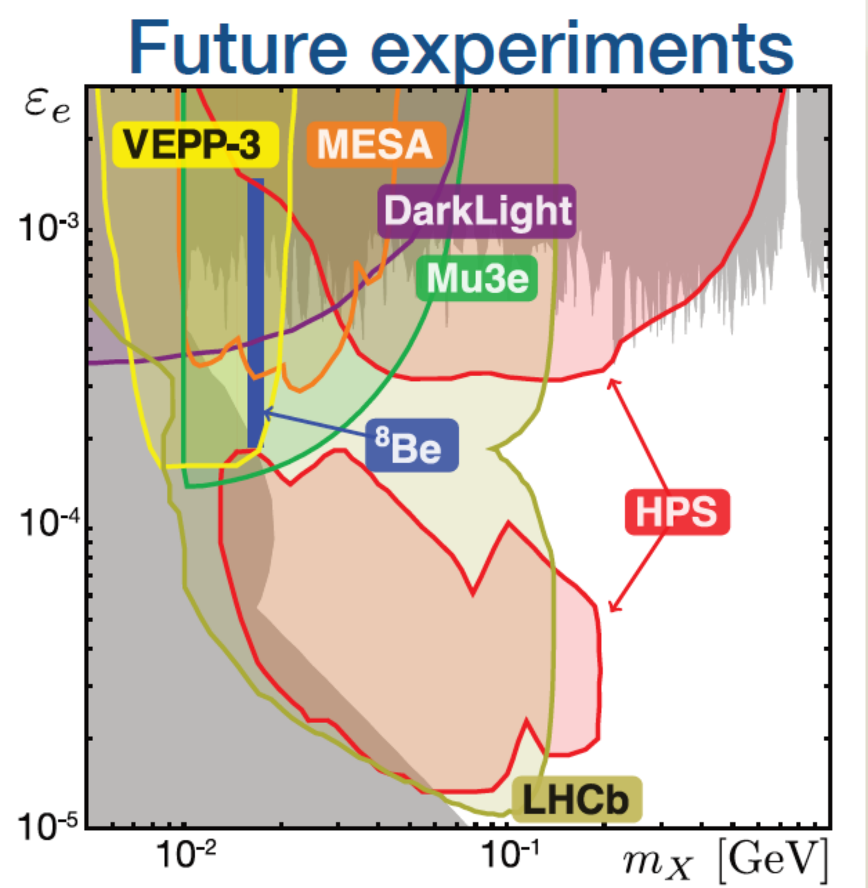
# Conclusions

- The PADME experiment construction is expected to be completed by the end of April
- PADME can be the first experiment to explore the process $e^+e^- \rightarrow \gamma A'$, $A \rightarrow \chi\chi$ in a low energy fixed target environment.
- With 1-2 year of running PADME can still extend the BaBar sensitivity to invisible A' decays to lower couplings.
- PADME experiment is **extending its physics case to other dark sector models**
  - Visible Dark Photons, ALPs searches, Fifth force, dark Higgs
- **PADME is aiming at extending its international collaboration**
  - Your are welcome to join us!
- **In line for starting physics data-taking at the beginning May 2018**

**Join the dark side!**

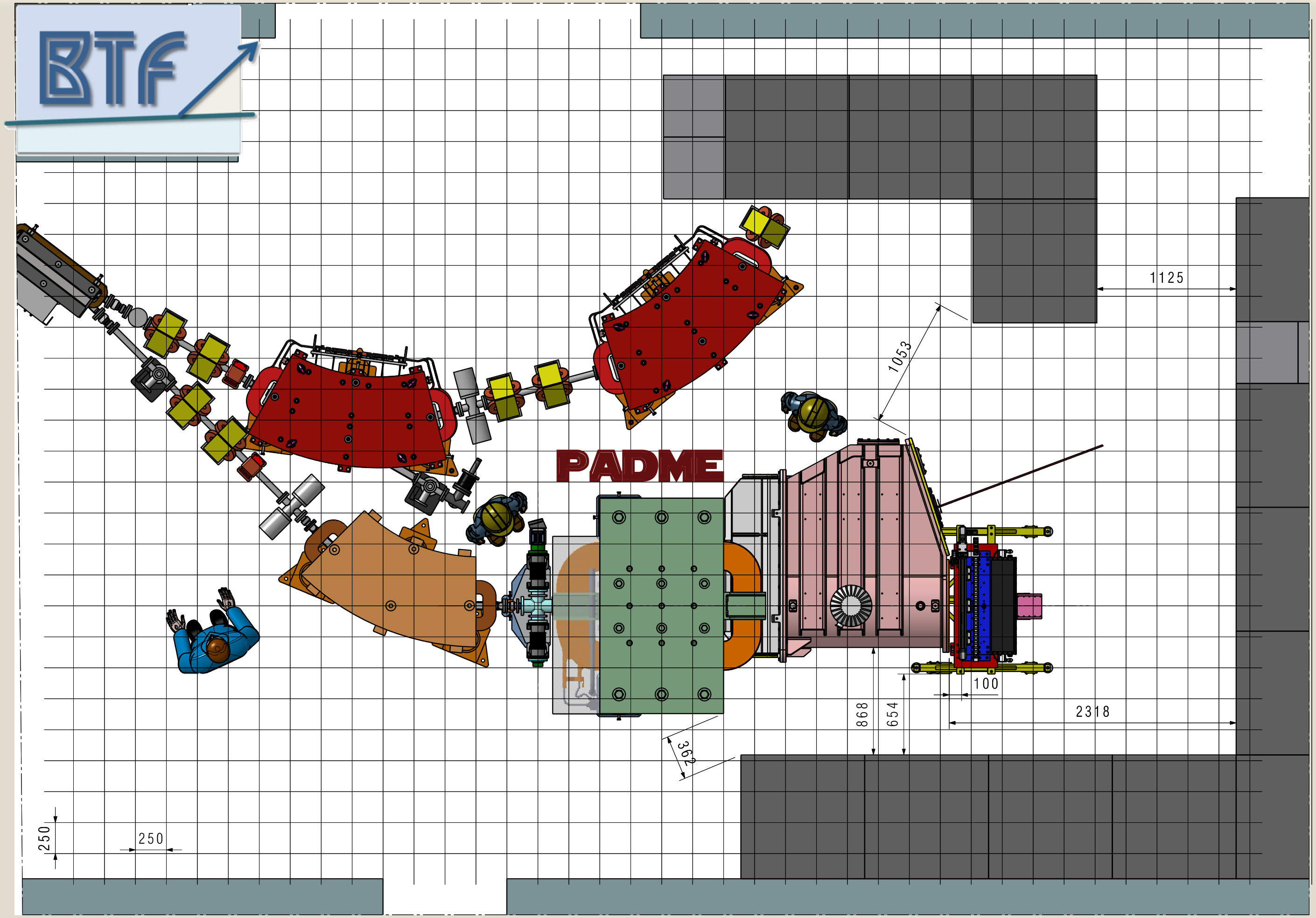
# $^8$Be anomaly at PADME?



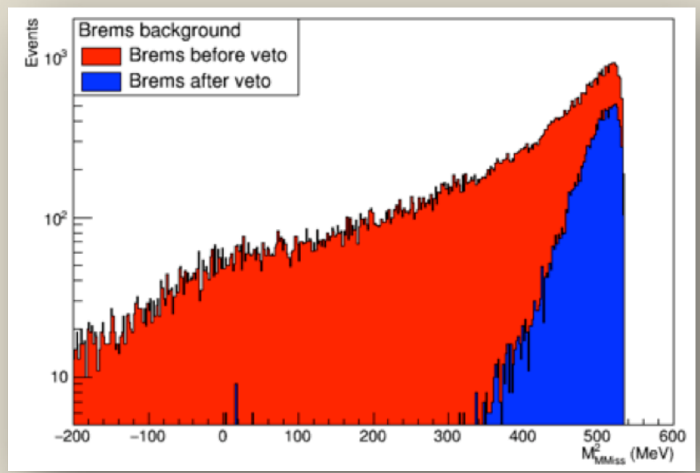

- PADME has the unique chance of producing X in resonant mode BTF a 282 MeV
- Measurement limited from the radiative babbah scattering ee-> ee$\gamma$
  - Thin or thick target? Get rid of radiative babbah!
- Need a computation of X production cross section at 550 MeV to assess PADME sensitivity

# The PADME experiment at the BTF

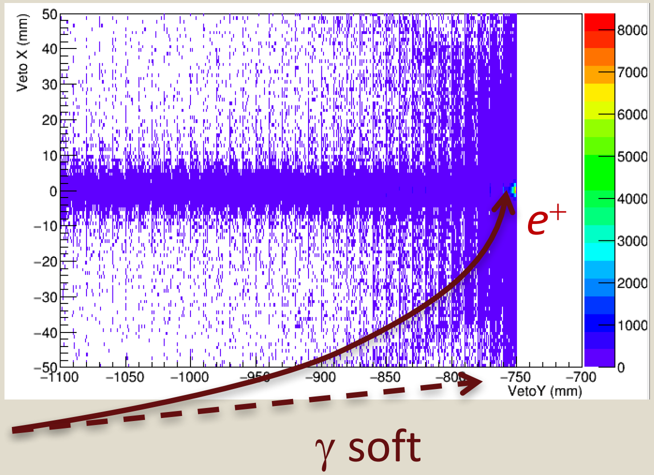


# Residual background

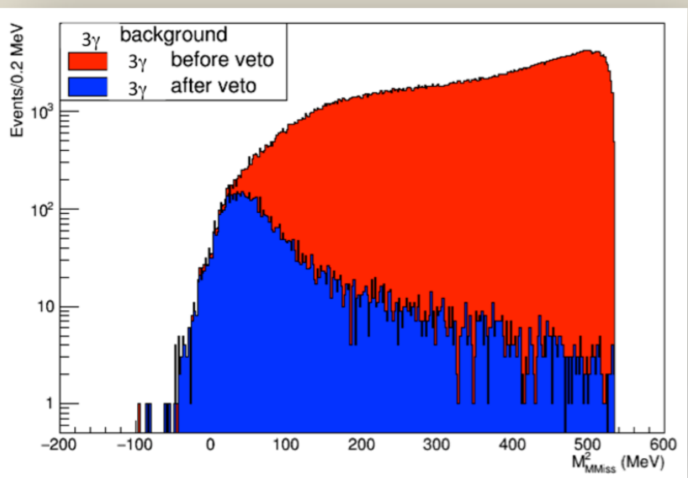
## Bremsstrahlung




Difficult to veto positron with Ee+≈Ebeam events




## 3 photons decay




Difficult to veto low energy photons due to high bremsstrahlung rate in the SAC

Design optimization ongoing to reduce residual background new sensitivity expected by summer

# Cross sections at PADME

☆ **Vladimir Ivantchenko** PADME 24 febbraio 2017 18:38 VI

RE: cross section measurement at PADME Dettagli

A: Mauro Raggi, Cc: Paolo Valente e altri 1

Dear Mauro,

For these energies, in Geant4 EM usually theoretical formulas are used for majority of models. Comparison with the data allow to clarify validity of chosen models and their configurations. For EM physics, there are not much data which can be used for validation purposes. For example, known data for bremsstrahlung thin target are available for 1-2 MeV, 15-30 MeV, and 8, 25, 170, 250, 300 GeV. Of course, there are checks in each experiment for calorimeters as a whole, where EM shower is measured and all processes contribute together.

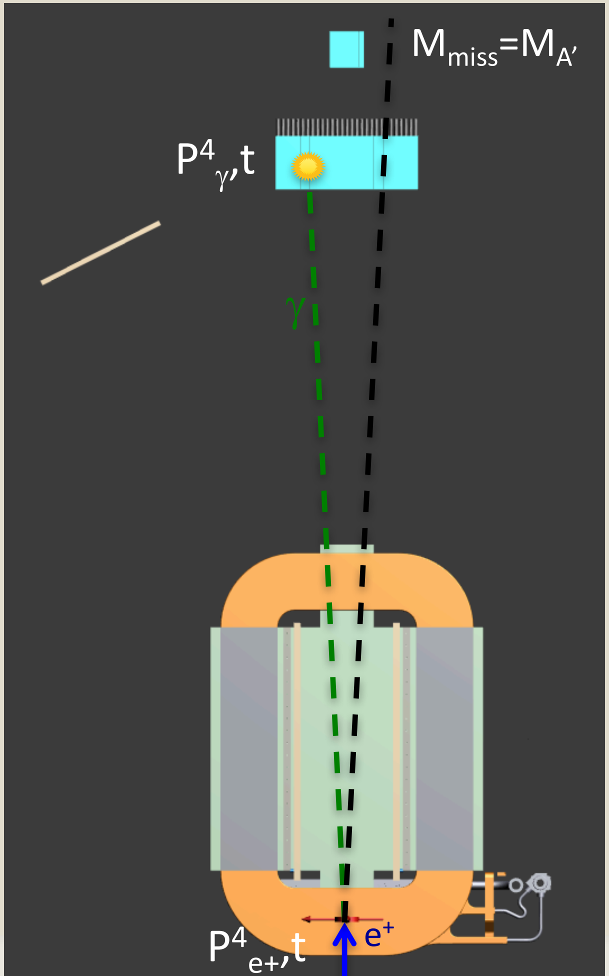
I do not know good thin target data suitable for comparisons for 100-1000 MeV energy range for bremsstrahlung. From my point of view, your measurements may be very useful.

Cheers,
Vladimir

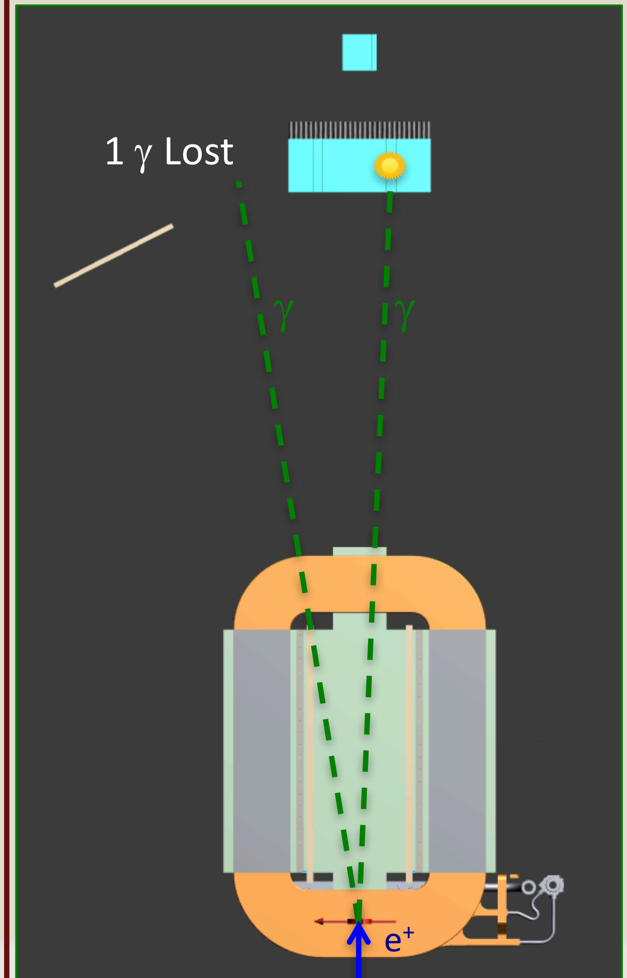
**GEANT4** low energy EM libraries

# PADME A' main backgrounds

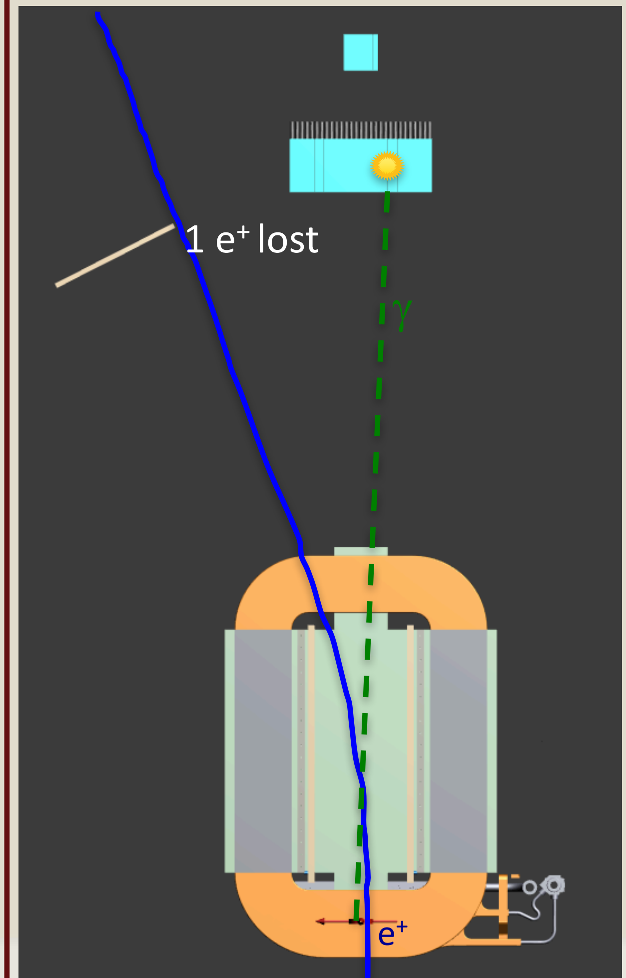
Signal $e^+e^- \to \gamma A'$




BG annihilation $e^+e^- \to \gamma\gamma(\gamma)$




BG SM Brems.: $e^+N \to e^+N\gamma$

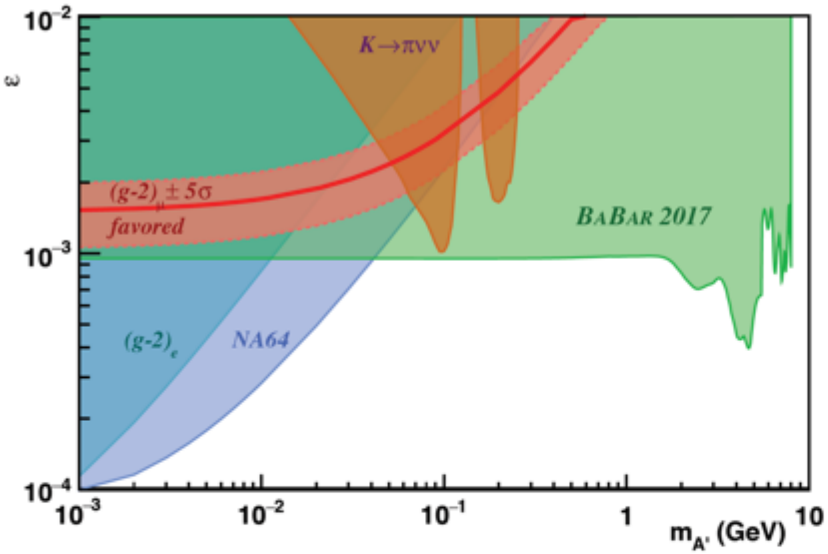


# Why at low energy fixed target?

- Can play with the target material to get cross section enhancement (ie high Z)
- Can play with beam energy to get resonant production (if mass is known X Boson)
- Just few background sources
  - (below pion production thresholds only QED is involved)
- Can use electron and positron to isolate exotic annihilation productions.
- Small scale and relatively cheap detectors
- Moreover NO ONE ever performed an A' annihilation search experiment at fixed target!

# BaBar 2017

arXiv:1702.03327v1 [hep-ex]




$$\sigma(M_X^2) = 1.5 \text{ GeV}^2 \text{ for } m_{A'} \approx 0$$

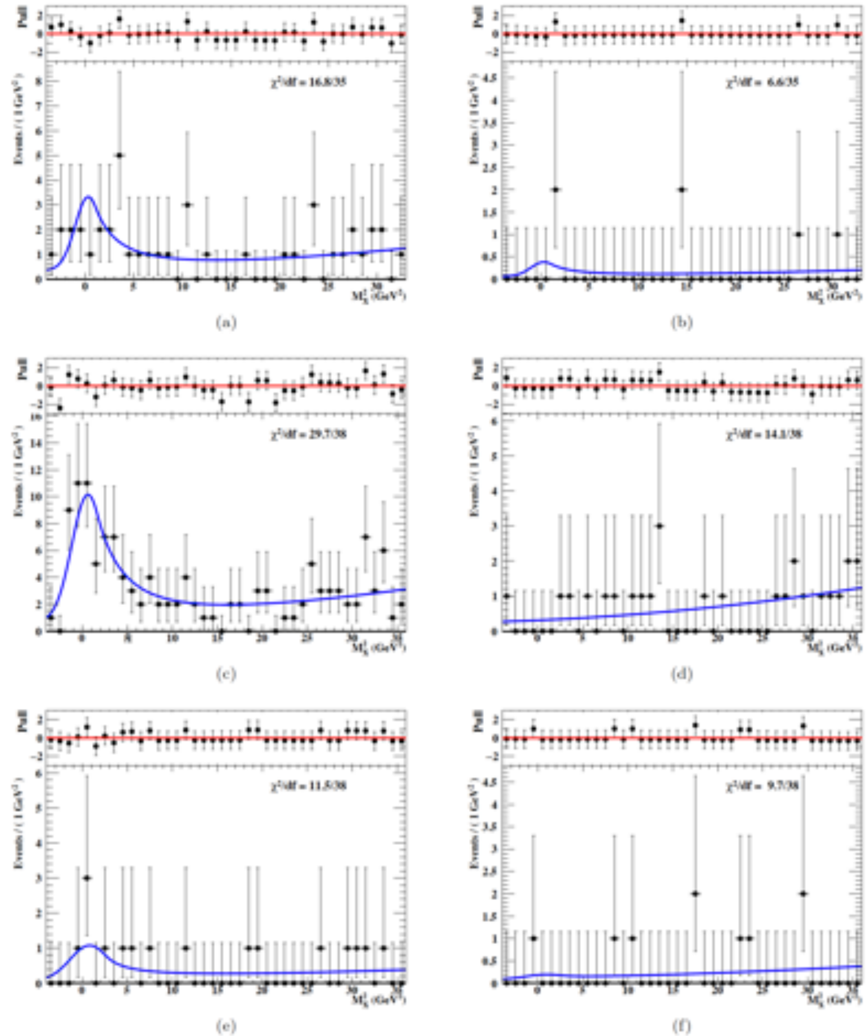
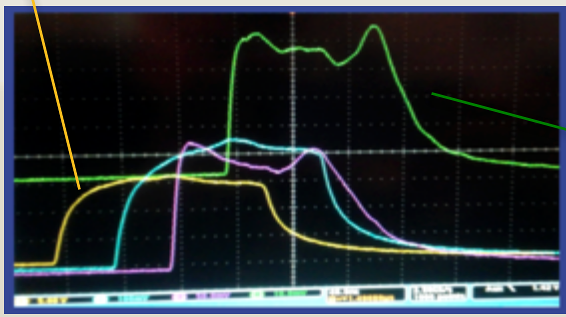



FIG. 6: Distributions of the missing mass squared $M_X^2$ in the "lowM" data samples collected near (a,b) $\Upsilon(2S)$, (c,d) $\Upsilon(3S)$, and (e,f) $\Upsilon(4S)$ resonances. Data are selected with (a,c,e) $\mathcal{R}'_L$ and (b,d,f) $\mathcal{R}_T$ selections. The solid blue line represents the background-only fit with $\varepsilon^2 \equiv 0$. Normalized fit residuals are shown above each plot.

# BTF long pulses

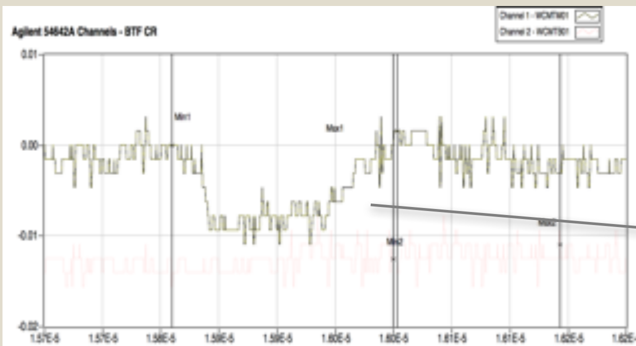
Electron gun



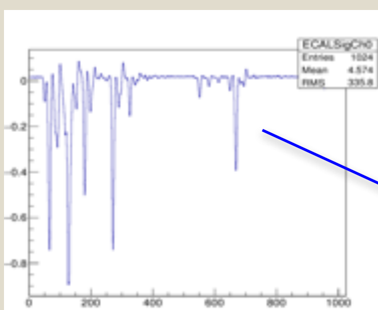
Nov. 8th: Gun at 150 ns, flat pulse,
>510 MeV, 1% spread

End of LINAC

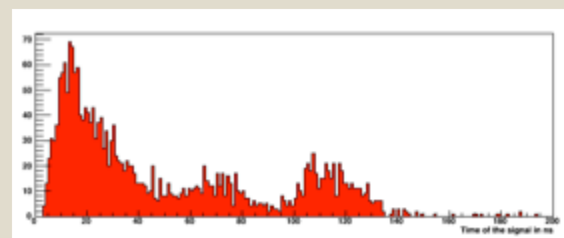
- Ancora è necessario del lavoro di ottimizzazione del LINAC allo scopo di ottenere il miglior possibile **spread** in energia e – di conseguenza – un impulso più piatto su un intervallo temporale più lungo possibile




WCM at BTF target




SF57 crystal signal



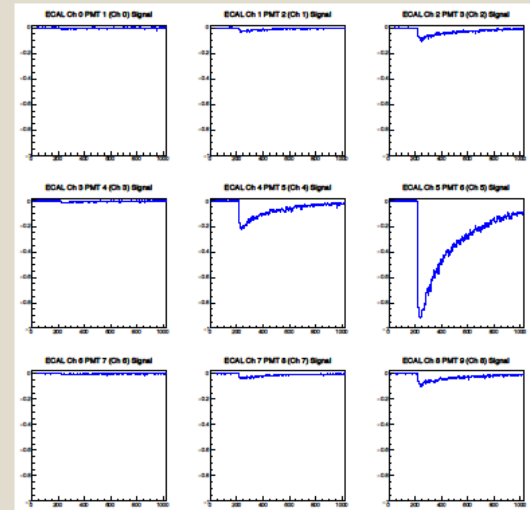
SF57 crystal signals time distribution

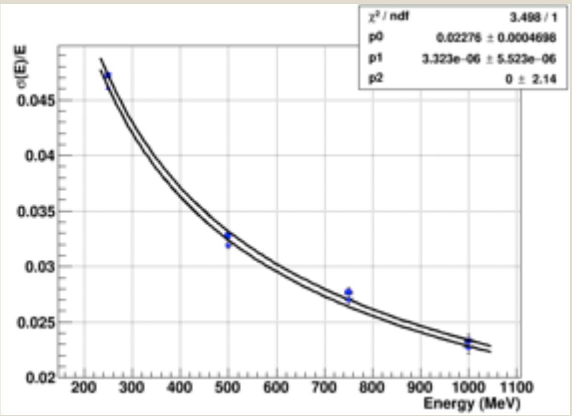
# Calorimeter/1

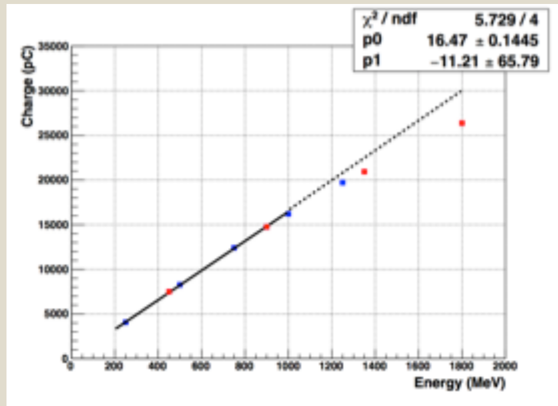
Test with electrons at BTF with 5×5 prototype:
**20×20×220 mm3 BGO** crystals + **HZC XP1912** PMT's

- Energy resolution **2.3% at 1 GeV**
- Contribution of BTF **energy spread** almost negligible
  - Submitted to Nucl. Instrum. Meth. A, arXiv:1611.05649

**CAEN V1742** at 1 GS/s digitizers



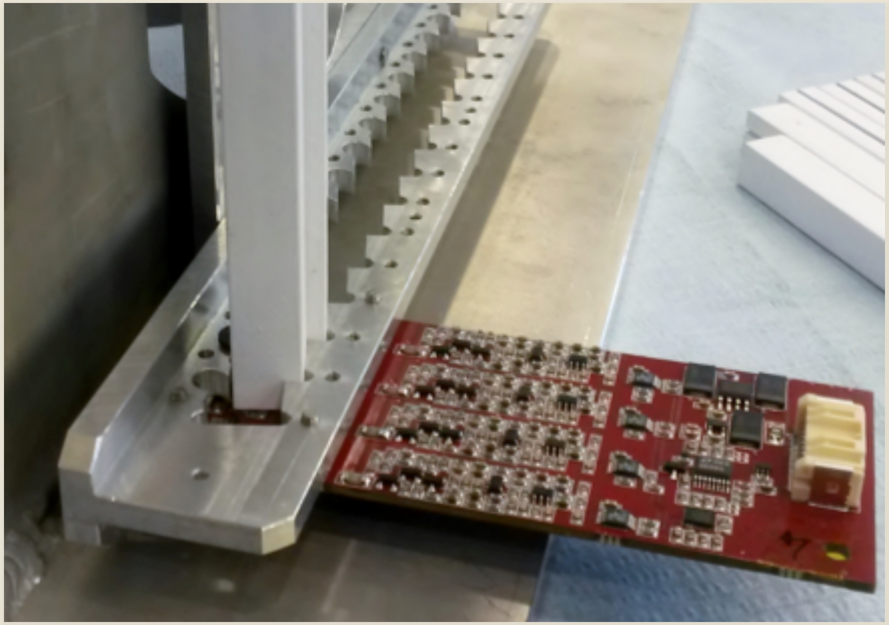


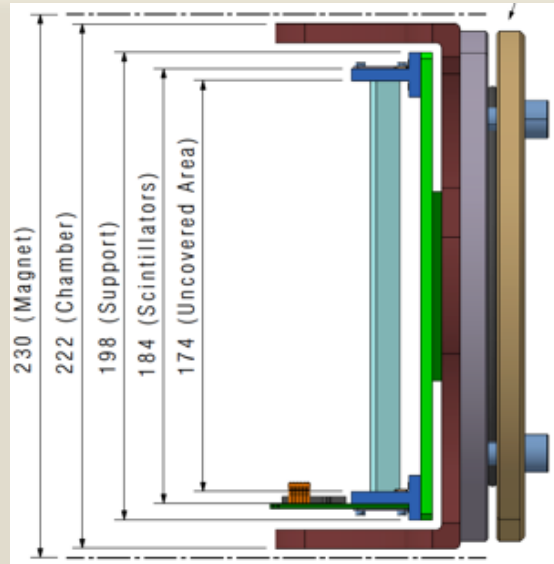



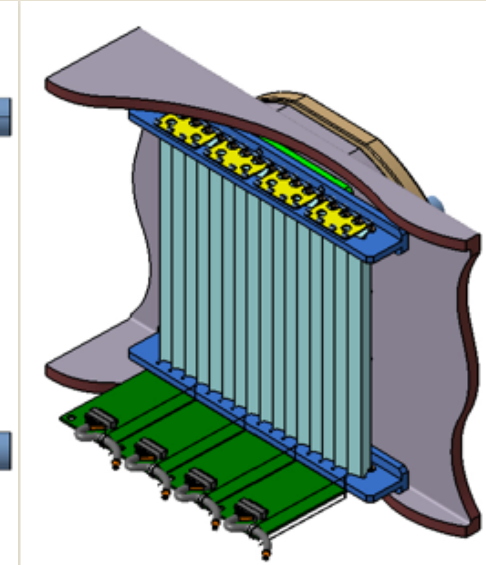

Results are very reassuring, however we feel that one more **final beam-test** is needed:

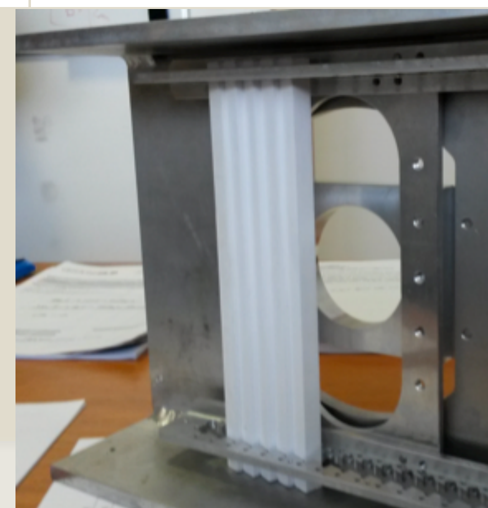
- **HZC XP1911** selected (better dark current wrt XP1912)
- Improvement of the standard **voltage divider** (type B) requested to HZC
- PMT's were **glued**, but only in the central 3×3 part of the matrix (and with two different types of glue: UV cured and EJ optical glue)
- Crystals were wrapped, while we plan to **paint** them
- No energy point below 250 MeV (we went down to <100 MeV with the previous test with 3×3 prototype and no glue)

# Charged particle veto detectors







10×10x184 $mm^3$ scintillator read out by silicon Photomultipliers

- All scintillator bars **delivered**
- Design of the mechanics **ready**
  - Prototype of the mechanical assembly **ready**
- Prototype electronics prototype **ready**
  - Test-beam in April to measure efficiency and time resolution
- Read-out by same digitizing system as calorimeter (**ready**)

# Dark sector search priorhedron©

**Dark sector coupling prior**

| $m\chi$ prior | **Weak** | **Strong** |
|---|---|---|
| **Light** | A’ invisible decays<br>ALPs | Axions |
| **Heavy** | B-L couplings<br>Proto-phobic (X->ee) | WIMPs<br>Visible universal A’ decays<br>(ee, $\mu\mu$, $\pi\pi$ …) |

- Early A’ searches inspired by strong priors:
  - Heavy dark matter  A’ the lightest dark sector state
  - A’ coupling to fermions universal!
- It’s now time to take a step back in the priors and explore a wider panorama
  - Any dark matter mass no prejudice on the coupling to fermions

©Neal Weiner thanks for the inspiring talk