The PADME experiment proposal

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49th LNF scientific committee
Frascati, 18-19 May 2015

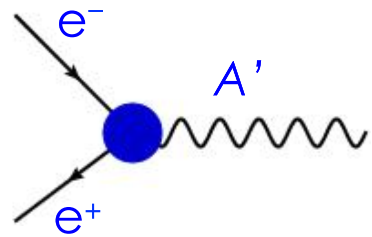
PADME website
http://www.lnf.infn.it/acceleratori/padme/
PADME Kick-off meeting
http://agenda.infn.it/event/padme-kickoff

The simplest dark sector model

- The simplest hidden sector model just introduces one extra U(1) gauge symmetry and a corresponding gauge boson: the “dark photon" or U boson.
  - Two type of interactions with SM particles should be considered

- As in QED, this will generate new interactions of the type:

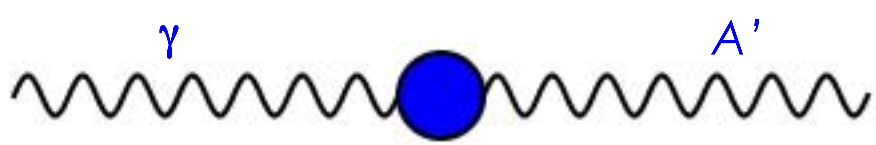
$$\mathcal{L} \sim g' q_f \bar{\psi}_f \gamma^\mu \psi_f U'_\mu$$



  - Not all the SM particles need to be charged under this new symmetry
  - In the most general case q_f is different in between leptons and quarks and can even be 0 for quarks. [P. Fayet, Phys. Lett. B 675, 267 (2009).]

- The coupling constant and the charges can be generated effectively through the kinetic mixing between the QED and the new U(1) gauge bosons

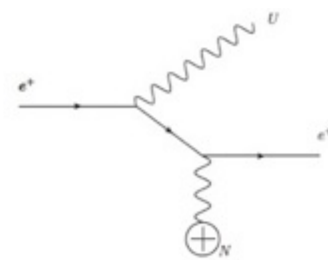
$$\mathcal{L}_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$$



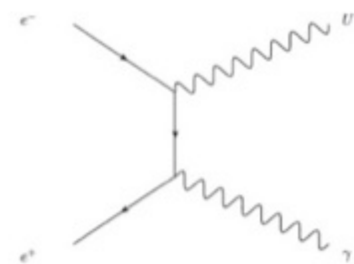
  - In this case q_f is just proportional to electric charge and it is equal for both quarks and leptons.

A' production and decays

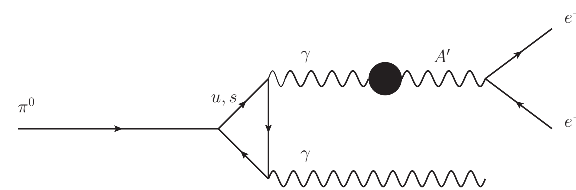
- A' boson can be produced in e^+ collision on target by:
  1. Bremsstrahlung: $e^+N \to e^+NA'$
  2. Annihilation: $e^+e^- \to \gamma A'$
  3. Meson decays



1. Bremsstrahlung



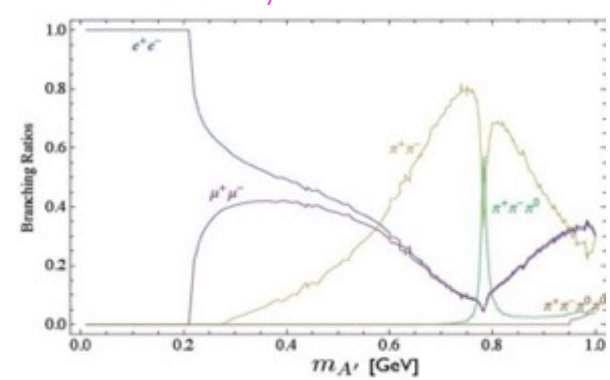
2. Annihilation



3. Meson decays

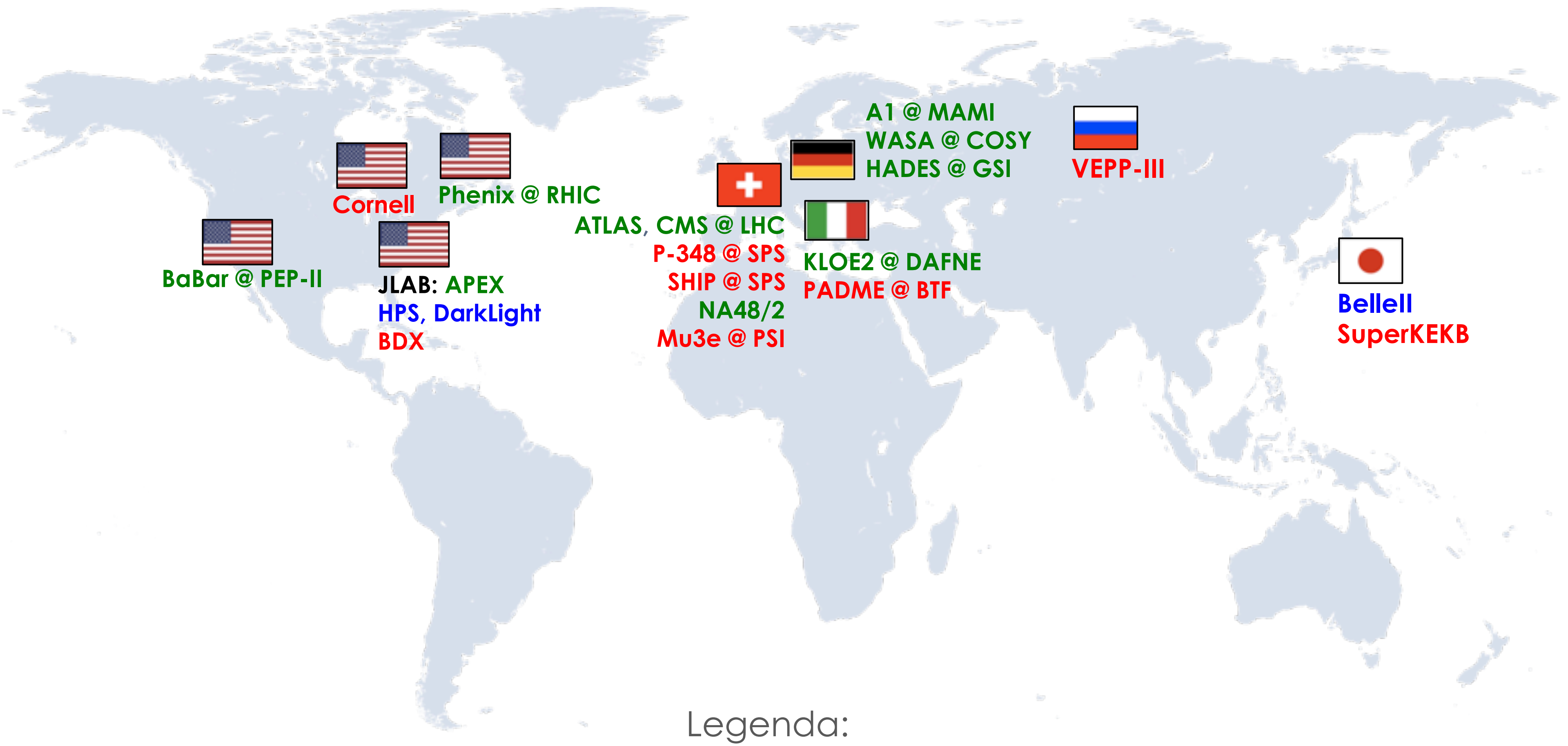
- If no dark matter candidate lighter than the A' boson exists:
  - $A' \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-$.
  - These are the so called "visible" decays
  - For $M_{A'}$<210 MeV A' only decays to e^+e^- with BR(e+e-)=1

Decays to "visibles"



- If any dark matter particle χ with $2M_\chi < M_{A'}$ exists
  - A' will dominantly decay into pure DM and BR(l+l-) becomes small ~ ε^2
  - $A' \to \chi\chi$ ~ 1. These are the so called decays to "invisible" particles

Dark photon searches in the world

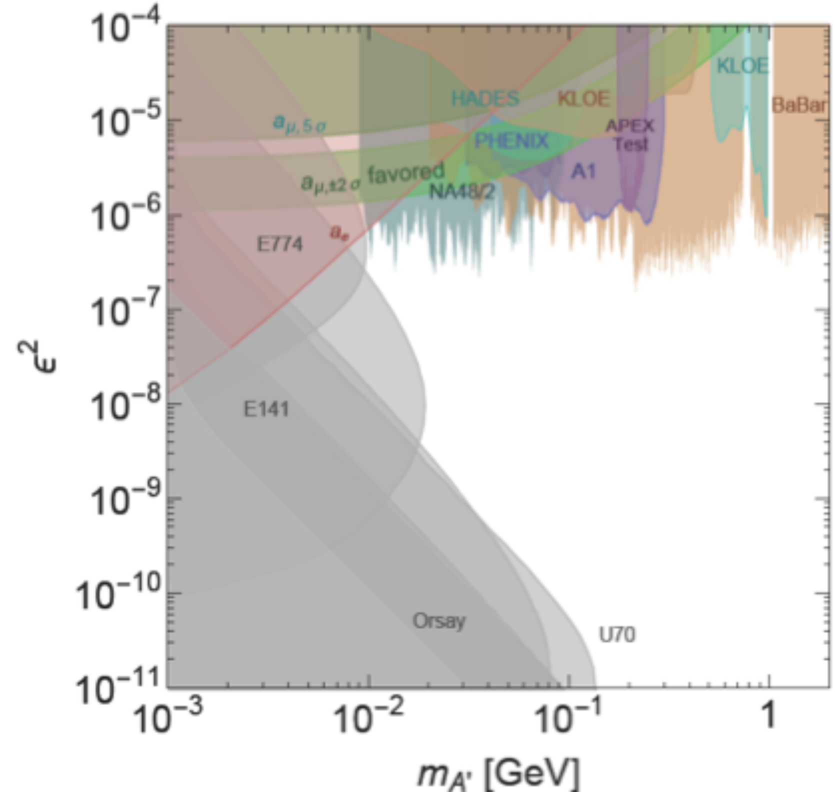


Legenda:

Publishing
Approved
Proposals

A' visible searches status

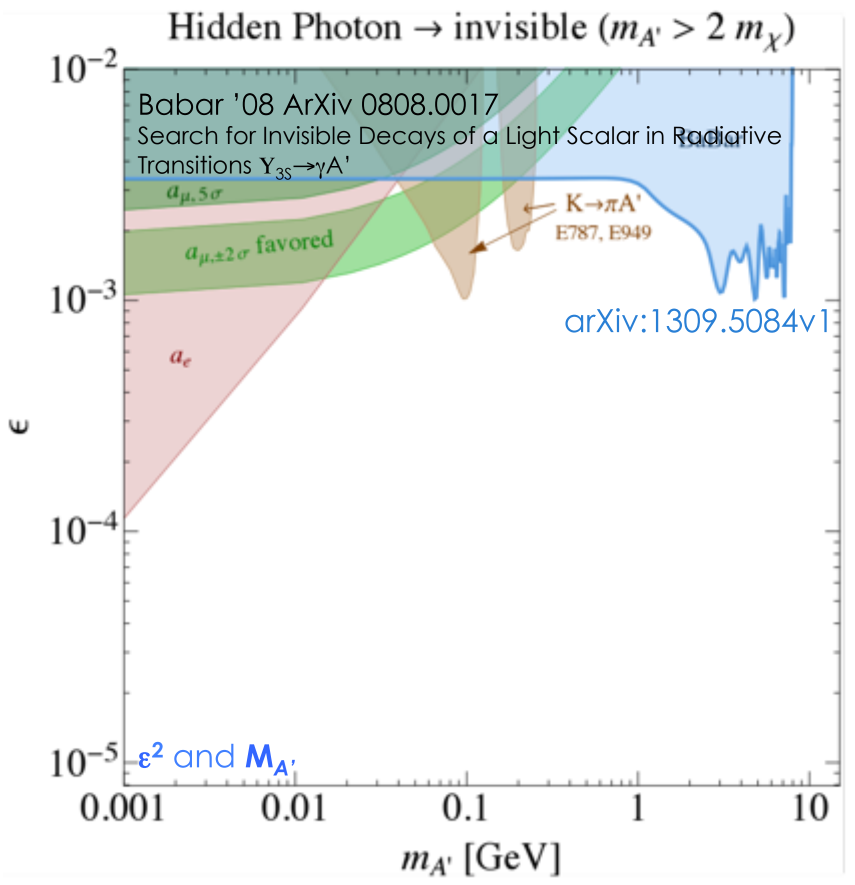
- Favored parameters values explaining $(g-2)_\mu$ (green band)
  - A'-boson light: 10-100 MeV
- Status of dark photon searches
  - Beam dump experiments (grey): e^+e^- appearance after a dump
  - Fixed target: Peak search over QED backgrounds
  - Mesons decays: Peaks in $M(e^+e^-)$ or $M(\mu+\mu-)$
- Indirect exclusion from g_e-2 and g_μ-2
  Recent tight limit in red filled area

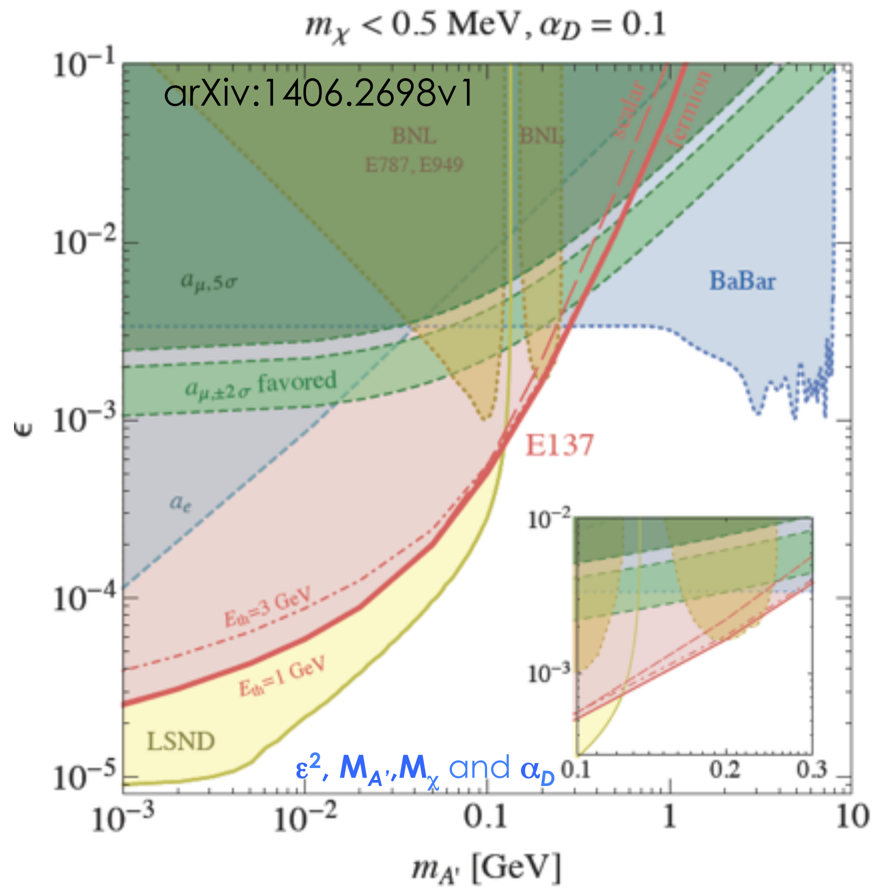


arXiv:1411.1770v2

- Many different techniques and assumptions on dark photon interaction models
  Kinetic mixing, decay to electrons, no dark sector particles
- $(g-2)_\mu$ band recently excluded by NA48/2 measurement in meson decays

Status A'→χχ invisible decays

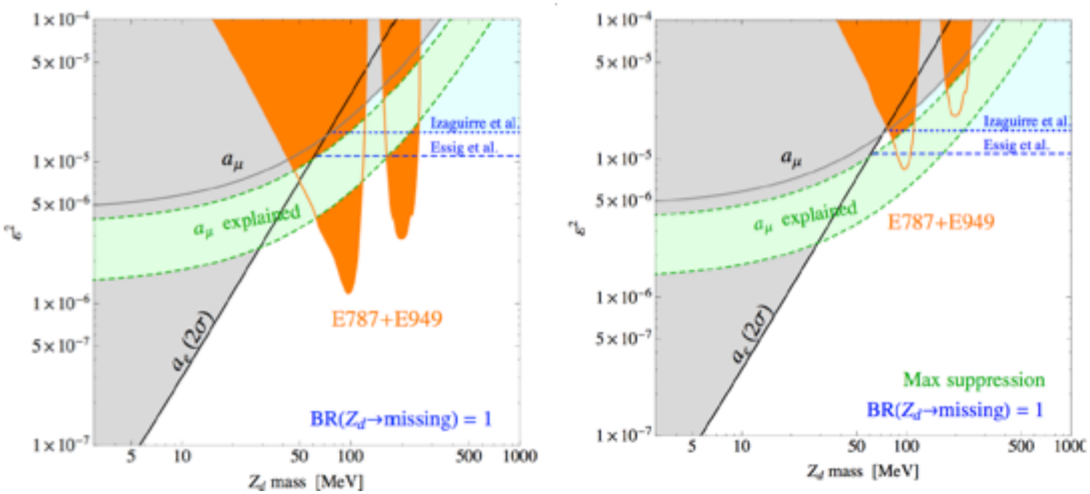




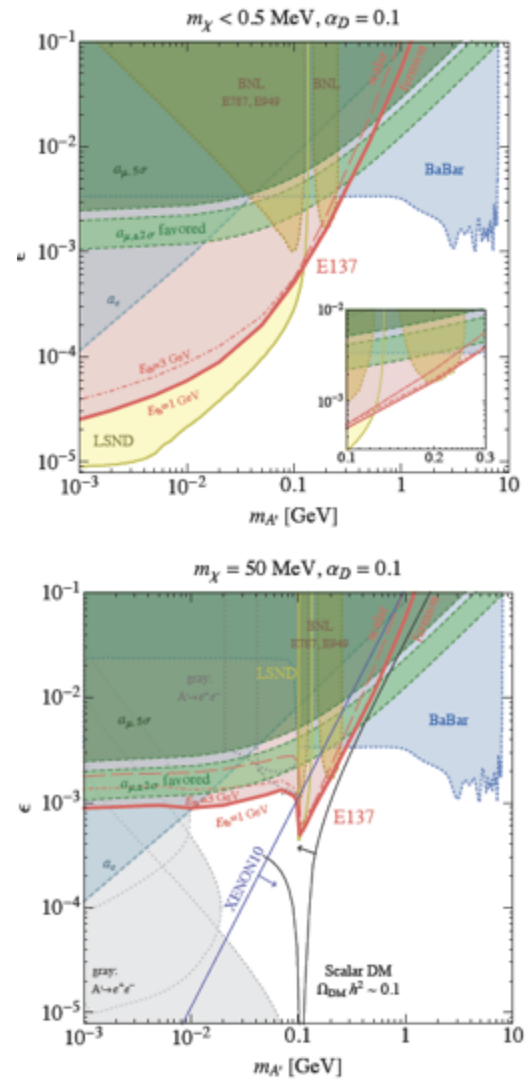
- Two different techniques are used: direct A' search, χ scattering searches
  - Direct searches for A' only depend on 2 parameters : ϵ^2 and $M_{A'}$
  - χ scattering searches depend on 4 parameters: ϵ^2, $M_{A'}$, M_χ and α_D
  - Kaon indirect constraints are on the other hand model dependent

Invisible A' model dependence

Exclusion with Kaons



Scattering exclusion



In models assuming that the dark photon couples to SM through kinetic mixing $\varepsilon_q \neq 0$ $K^\pm \to \pi^\pm \nu\nu$ can be used to constrain $K^\pm \to \pi^\pm A'$

$$\Gamma(K^\pm \to \pi^\pm Z_d)|_\varepsilon = \frac{\varepsilon^2 \alpha W^2 m_{Z_d}^2}{2^{10}\pi^4 \, m_K^7}\sqrt{\lambda(m_K^2, m_\pi^2, m_{Z_d}^2)} \times [(m_K^2 - m_\pi^2)^2 - m_{Z_d}^2(2m_K^2 + 2m_\pi^2 - m_{Z_d}^2)],$$

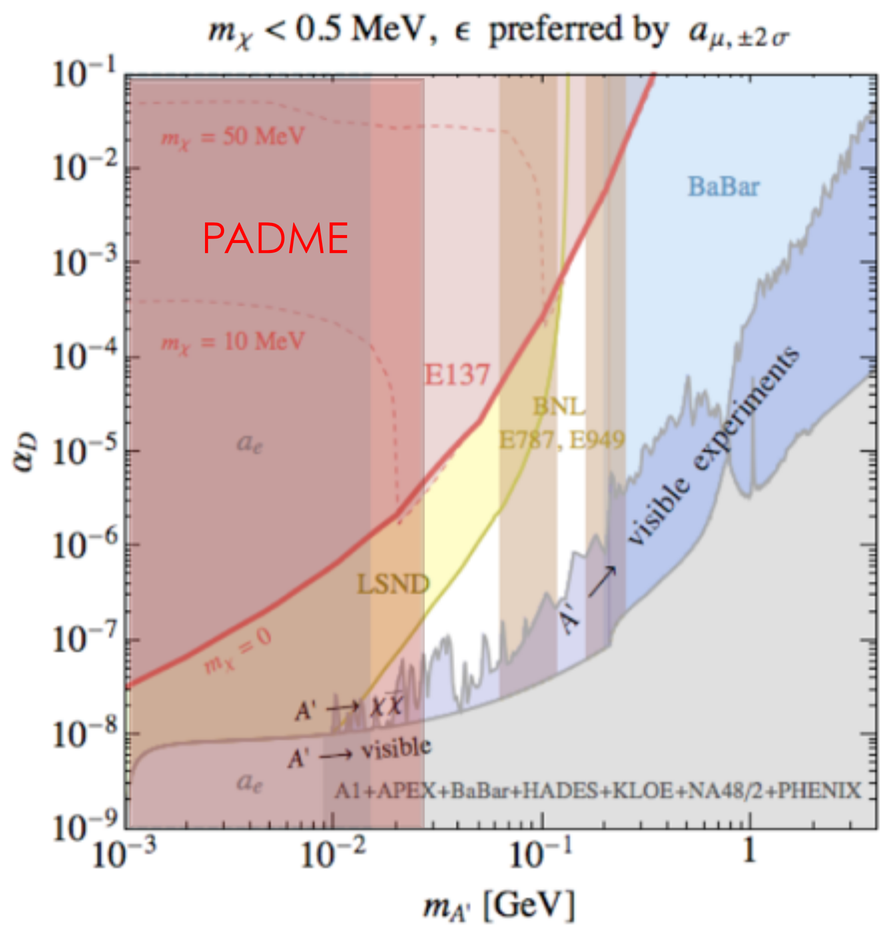
$Z_d = A'$

Depending on how the model is built the limit can change significantly for example allowing the mass mixing with SM Z.

PhysRevD.89.095006

Combining visible and invisible

N.B. This kind of exclusion plot fixes ε with $(g-2)_\mu$ and shows α_D vs $m_{A'}$



arXiv:1406.2698v1

PADME can access the plot independently of α_D up to 20-30MeV

The exclusion by PADME is independent from the value of m_χ as well

The PADME approach

- At present all experimental results rely on at least one of the following model-dependent assumptions:
  - *A'* decays to e^+e^- (visible decays assumption) and thus $BR(A' \rightarrow e^+e^-) = 1$
  - *A'* couples with the same strength to all fermions ($\varepsilon_q = \varepsilon_l$) (kinetic mixing)

- In the most general scenario (PADME)
  - *A'* can decay to dark sector particles with $m < M_{A'}/2$, and $BR(A' \rightarrow e^+e^- << 1)$

    Dump and meson decay experiment only limit $\varepsilon^2 BR(A' \rightarrow e^+e^- << 1)$
  - *A'* can couple to quark with a coupling constant smaller ε_l or even 0

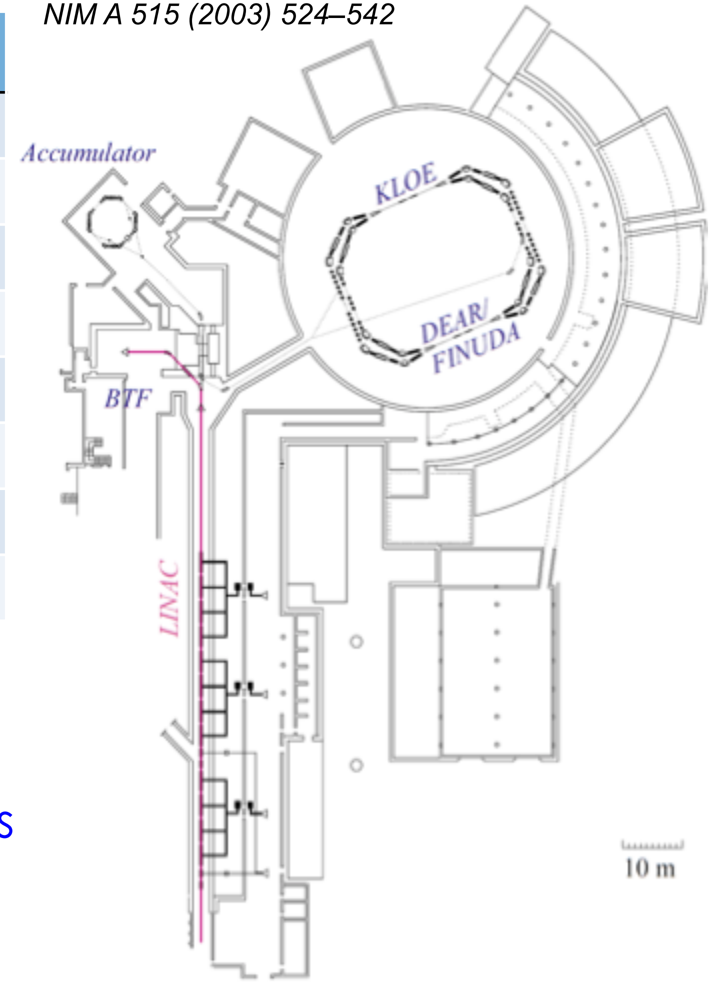
    Suppressed or no production at hadronic machines and in mesons decays

- PADME aims at detecting *A'* **produced in e^+e^- annihilation** and **decaying into any final state** by searching for missing mass in $e^+e^- \rightarrow \gamma A'$, $A' \rightarrow \chi\chi$
  - No assumption on the *A'* decays products and coupling to quarks
  - Only minimal assumption: *A'* bosons couples to leptons
  - PADME will limit the coupling of any new light particle produced in e^+e^- collisions: scalars (H_d), vectors (*A'* and Z_d)

DAΦNE Beam Test Facility (BTF)

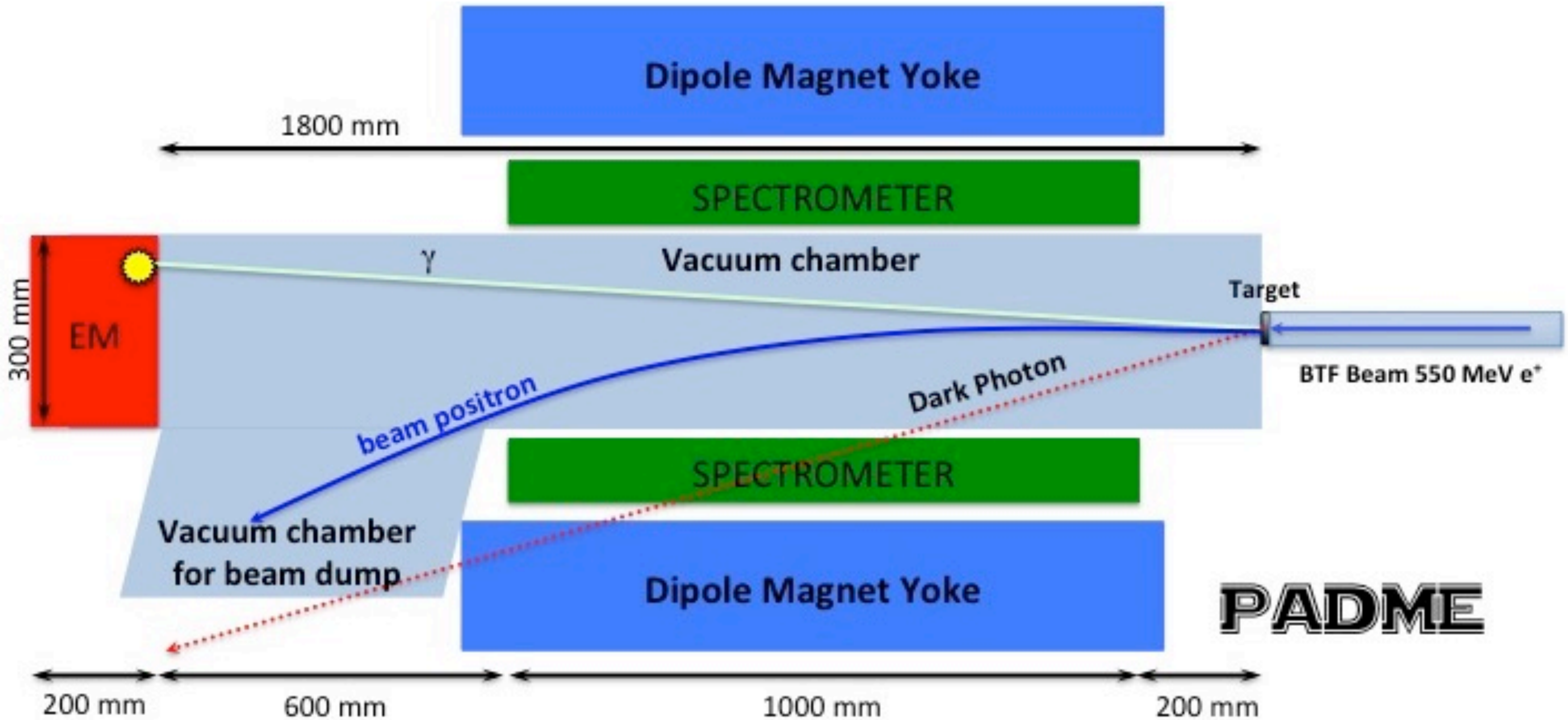
	electrons	positrons
Maximum energy [MeV]	750 (1050) MeV	550 (800) MeV
Linac energy spread [Δp/p]	0.5%	1%
Typical Charge [nC]	2 nC	0.85 nC
Bunch length [ns]	1.5 - 40	
Linac Repetition rate	1-50 Hz	1-50 Hz
Typical emittance [mm mrad]	1	~10
Beam spot σ [mm]	1 mm	
Beam divergence	1-1.5 mrad	

NIM A 515 (2003) 524–542



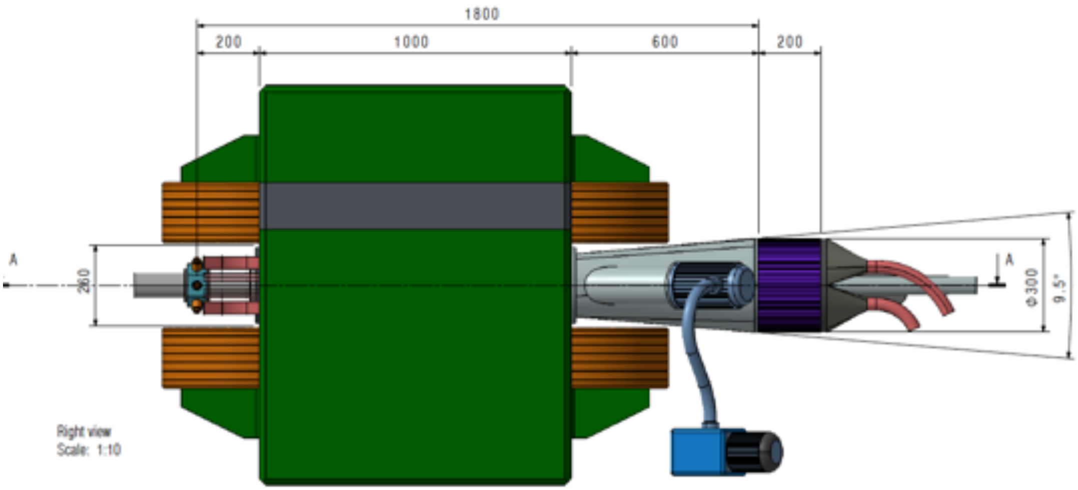
- Longer Duty Cycle
  - Standard BTF duty cycle = 50*10 ns = 5×10^{-7} s
  - Already obtained upgrade 50*40 ns= 20×10^{-7} s work in progress to exceed 100 ns
  - Energy upgrade possible in 2017.
- The accessible $M_{A'}$ region is limited by beam energy
  - Region from 0-22 MeV can be explored with 550 MeV e^+ beam

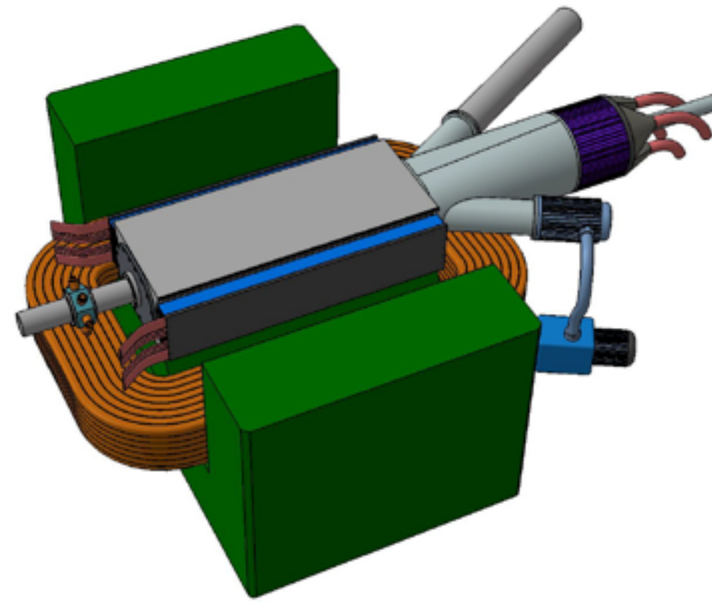
The PADME experiment

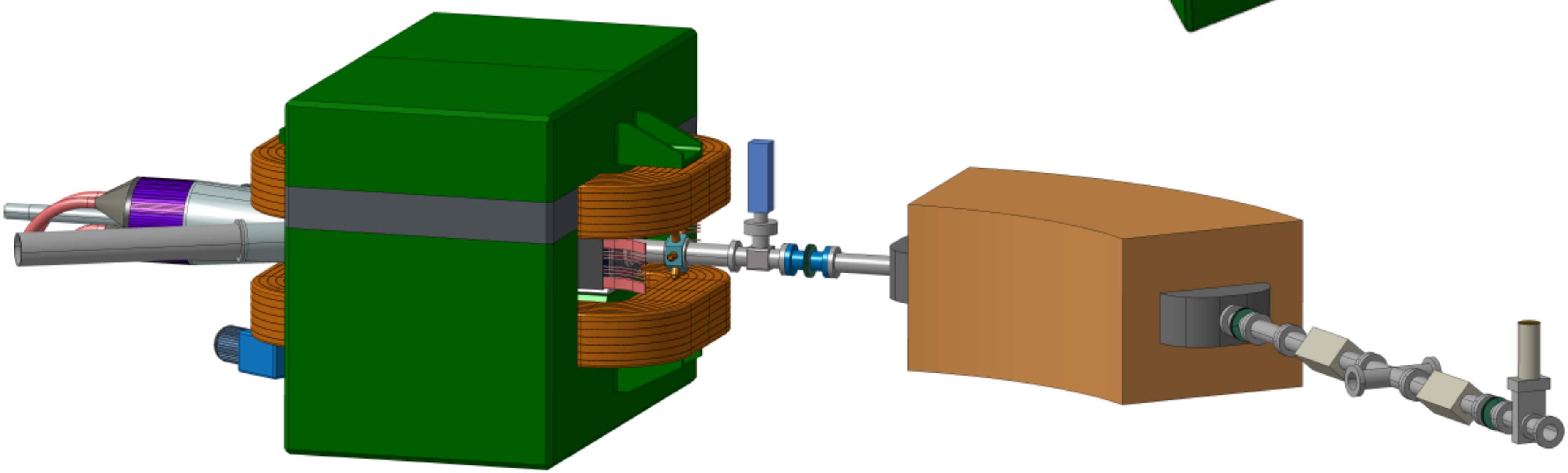


- 10^3-10^4 e^+ on target per bunch, at 50 bunch/s (10^{13}-10^{14} e^+/year)
- Basic detector components:
  - Active target, thin: 50-100μm diamond
  - Magnetic spectrometer/veto ~1m length
  - Conventional magnet, B≈0.6T but large gap for gaining acceptance
    - Available from CERN, former PS to SPS transfer line H-dipole
  - R=15 cm cylindrical crystal calorimeter with $1 \times 1 \times 20$ cm^3 crystals

The PADME experiment

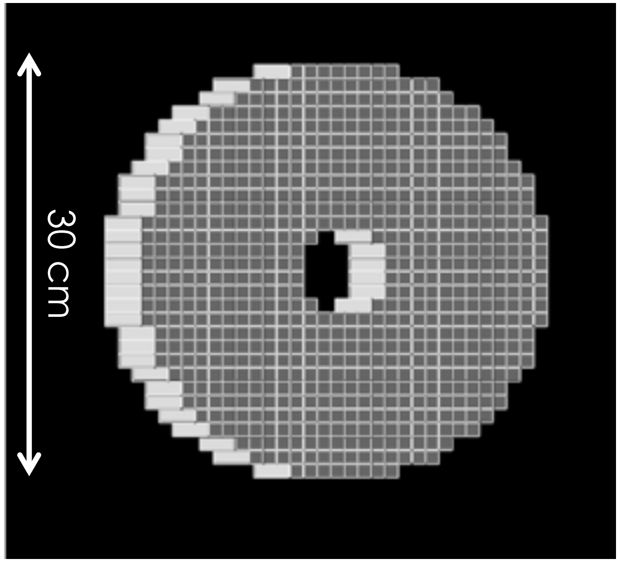






By C. Capoccia LNF SPAS

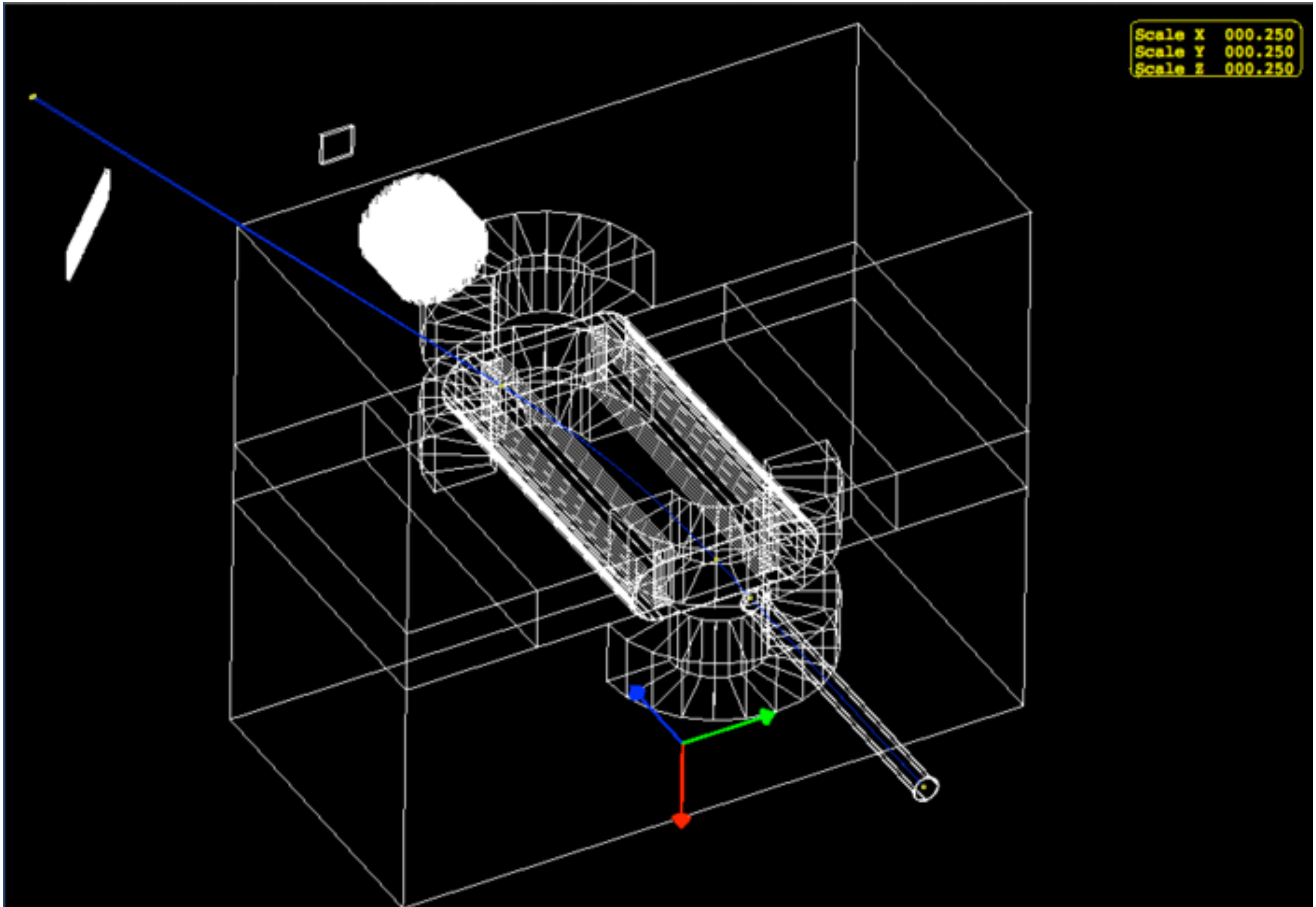
The electromagnetic calorimeter



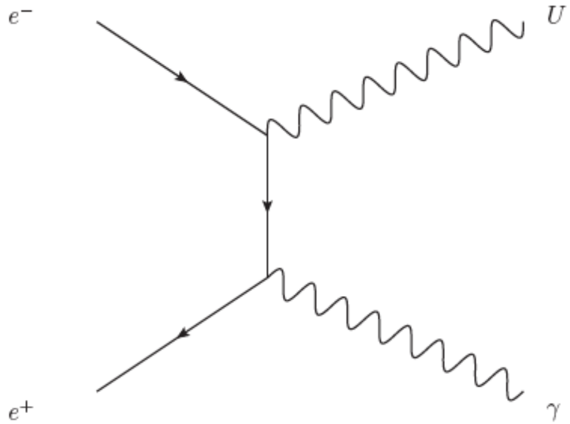
Parameter:	ρ	MP	X_0^*	R_M^*	dE^*/dx	λ_I^*	τ_{decay}	λ_{max}	$n^\natural$	Relative output†	Hygro-scopic?	$d(LY)/dT$
Units:	g/cm^3	°C	cm	cm	MeV/cm	cm	ns	nm				%/°C‡
NaI(Tl)	3.67	651	2.59	4.13	4.8	42.9	245	410	1.85	100	yes	−0.2
BGO	7.13	1050	1.12	2.23	9.0	22.8	300	480	2.15	21	no	−0.9
BaF_2	4.89	1280	2.03	3.10	6.5	30.7	650^s	300^s	1.50	36^s	no	-1.9^s
							0.9^f	220^f		4.1^f		0.1^f
CsI(Tl)	4.51	621	1.86	3.57	5.6	39.3	1220	550	1.79	165	slight	0.4
CsI(pure)	4.51	621	1.86	3.57	5.6	39.3	30^s	420^s	1.95	3.6^s	slight	−1.4
							6^f	310^f		1.1^f		
$PbWO_4$	8.3	1123	0.89	2.00	10.1	20.7	30^s	425^s	2.20	0.3^s	no	−2.5
							10^f	420^f		0.077^f		
LSO(Ce)	7.40	2050	1.14	2.07	9.6	20.9	40	402	1.82	85	no	−0.2
$LaBr_3$(Ce)	5.29	788	1.88	2.85	6.9	30.4	20	356	1.9	130	yes	0.2

- Cylindrical shape: radius 150 mm, depth of 200 mm
  - Inner hole 4 cm radius
  - Active volume 13120 cm^3, total of 656 crystals,10x10x200 mm^3
- Material LSO(Ce): high LY, high ρ, small X_0 and R_M, short τ_{decay}
- Material BGO: high LY, high ρ, small X_0 and R_M, long τ_{decay}, (free from L3?)
- Expected performance:
  - $\sigma(E)/E = 1.1\%/\sqrt{E} \oplus 0.4\%/E \oplus 1.2\%$ SuperB calorimeter test at BTF [NIM A 718 (2013) 107–109]
  - $\sigma(\theta)$ = 3 mm/1.75 m < 2 mrad
  - Angular acceptance 1.5-5 degrees

PADME Geant4 simulation

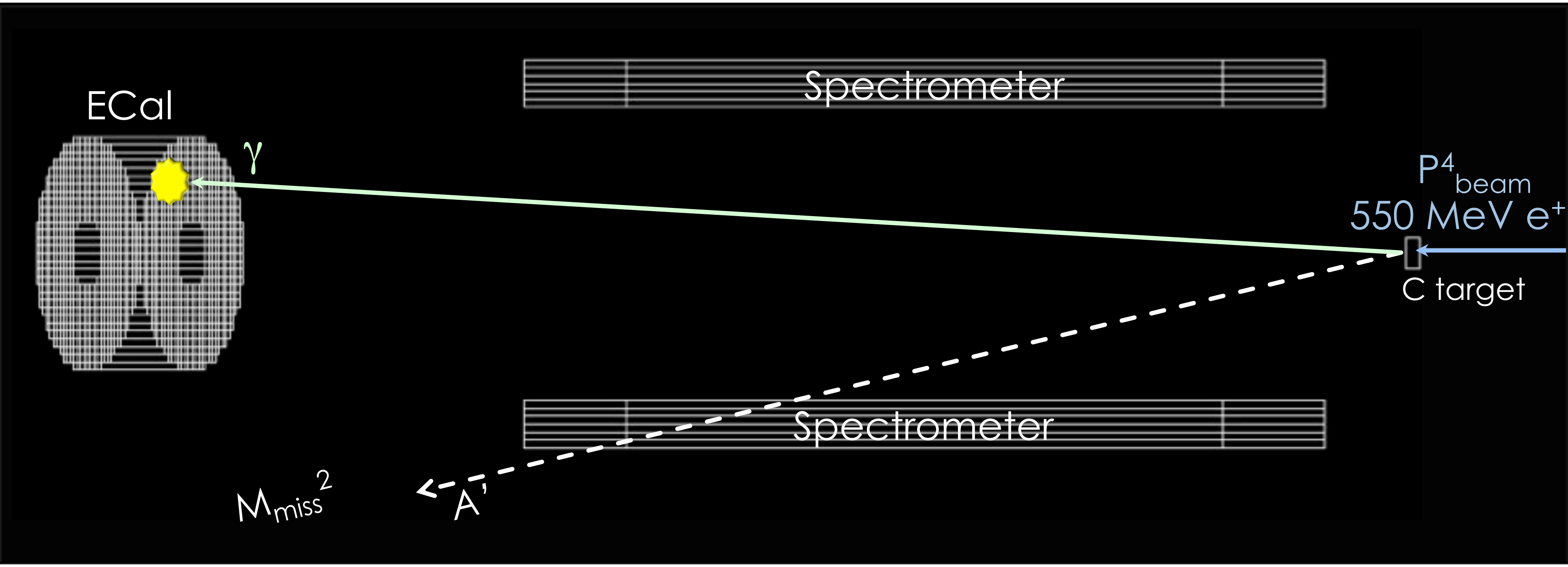


Search in annihilation production



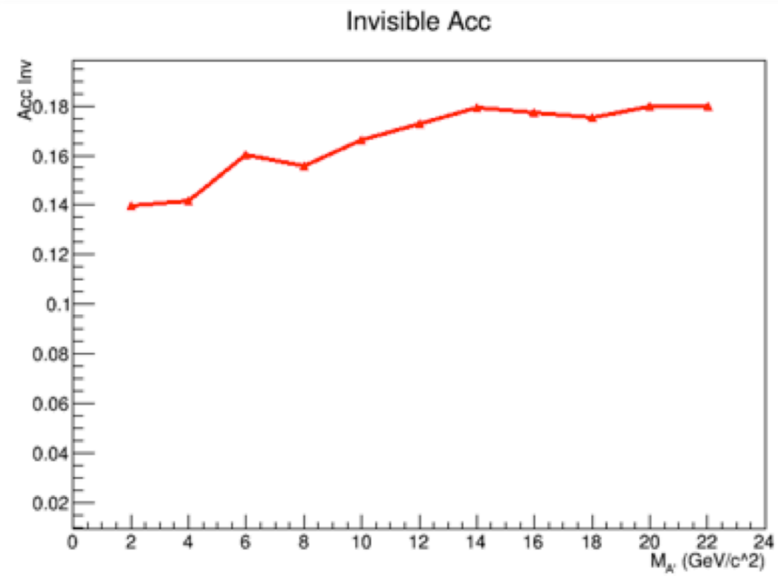
Annihilation

Experimental technique



- Search for the process: $e^+e^- \rightarrow \gamma A'$ on target e^- at rest
- (10^4 e^+)/bunch beam on a 100 μm diamond target, 550 MeV energy
  - 40 ns long bunches, 49 bunches/s
  - Collect 10^{13} e^+ on target in 2×10^7 s of data taking
- Measure in the calorimeter the E_γ and θ_γ angle wrt to beam direction
- Compute the $M_{miss}^2 = (P^4_{e-} + P^4_{beam} - P^4_{\gamma})^2$
  - $P^4_{e-} = (0,0,0,m_e)$ and $P^4_{beam} = (0,0,550,\mathrm{sqrt}(550^2 + m_e^2))$

Decay to invisible signal selection

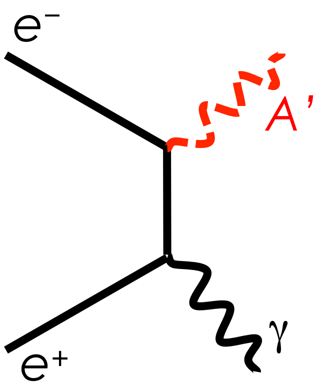


Selection cuts

- Only one cluster in calorimeter
  - Rejects $e^+e^- \rightarrow \gamma\gamma$, $e^+e^- \rightarrow \gamma\gamma(\gamma)$ final states
- 5 cm < R_{Cl} < 13 cm
  - Improve shower containment $\sigma(E)/E$
- Positron veto: no tracks in the spectrometer in ±2 ns
  - Reject BG from Bremsstrahlung identifying primary positrons
- Photon veto: no γ with E_γ>50 MeV in time in ±1ns in the additional small angle veto (SAV), covering the hole acceptance
- Cluster energy within: $E_{min}(M_{A'}) < E_{Cl} < E_{max}(M_{A'})$ MeV
  - Removes low energy bremsstrahlung photons and piled up clusters
- Missing mass in the region: $M_{miss}^2 \pm \sigma(M_{miss}^2)$

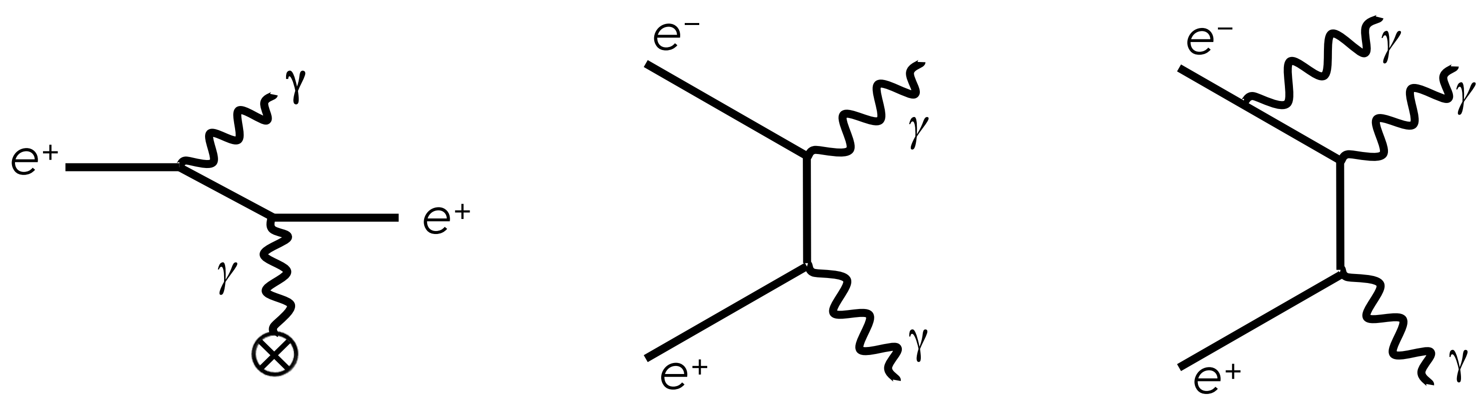
Main background sources

- Geant4 simulation accounts for:
  - Bremsstrahlung, 2 photon annihilation, Ionization processes, Bhabha and Moller scattering, and production of δ -rays.
  - Custom treatment of $e^+e^- \to \gamma\gamma(\gamma)$ using CalcHep generator.



Signal: $e^+e^- \to \gamma$ +missing mass (A')

Backgrounds

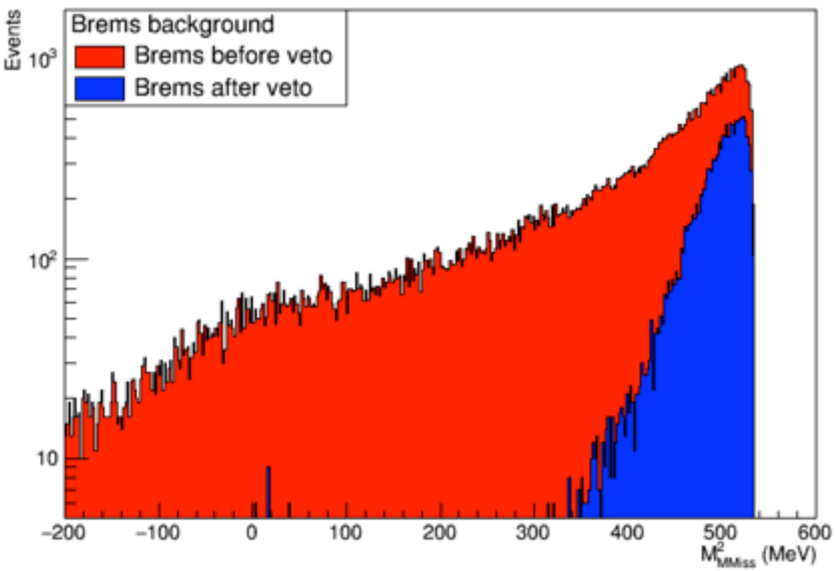


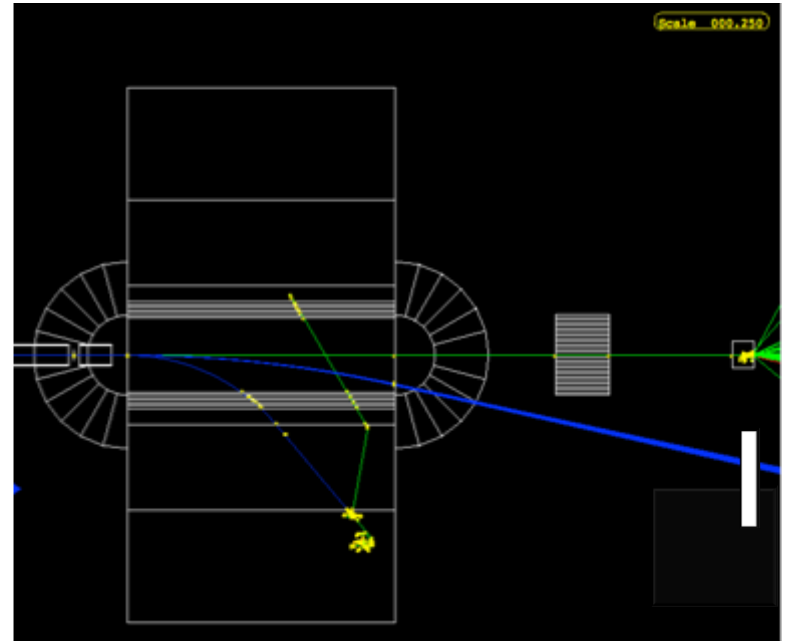
+1 electron

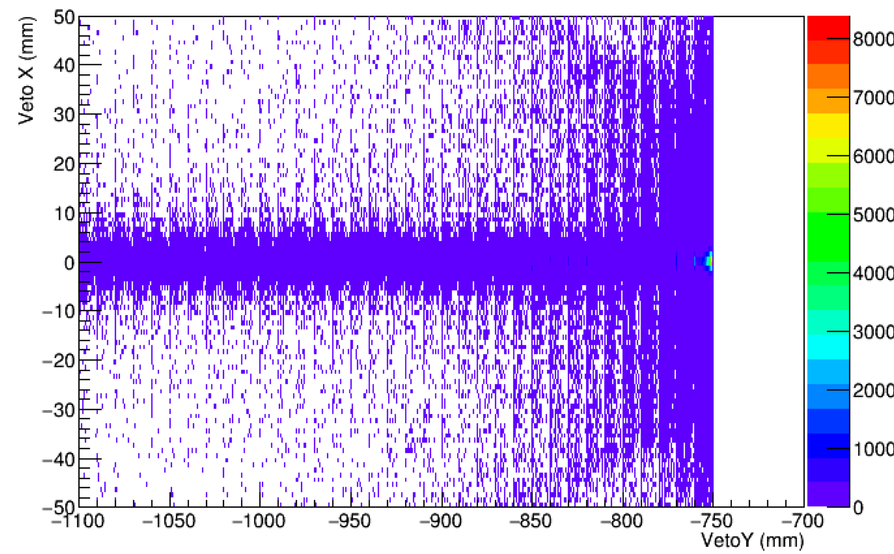
+1 γ

+2 γ

Bremsstrahlung background



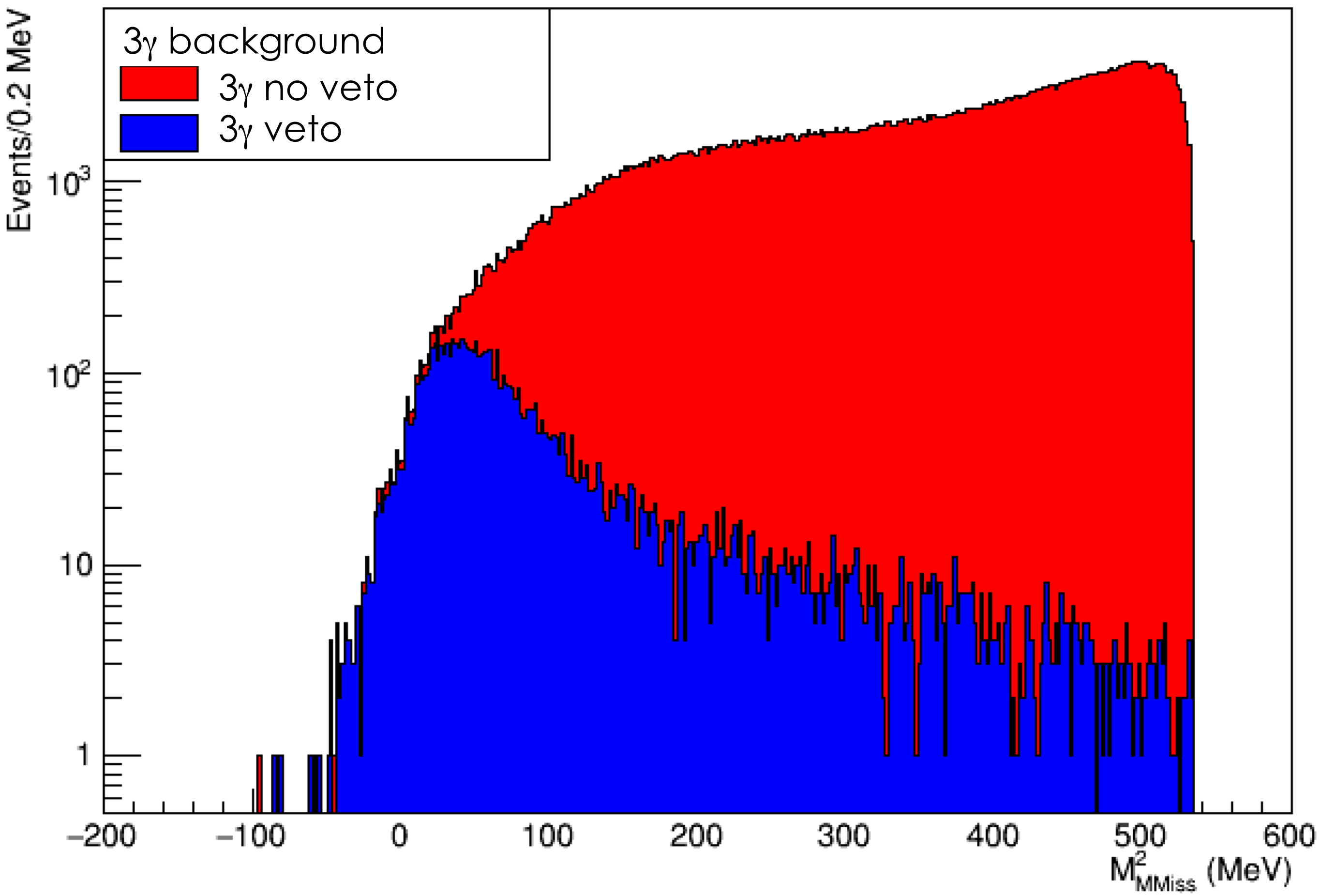




Present inefficiency is due to particles remaining very close to the beam spot due to the emission of low energy photons.

Improving with an imaging veto?

Rejecting 3γ with SAV veto



Low mass region is less suppressed due to the request of E_{SAV}>50MeV

Are the missing photon at large angle?

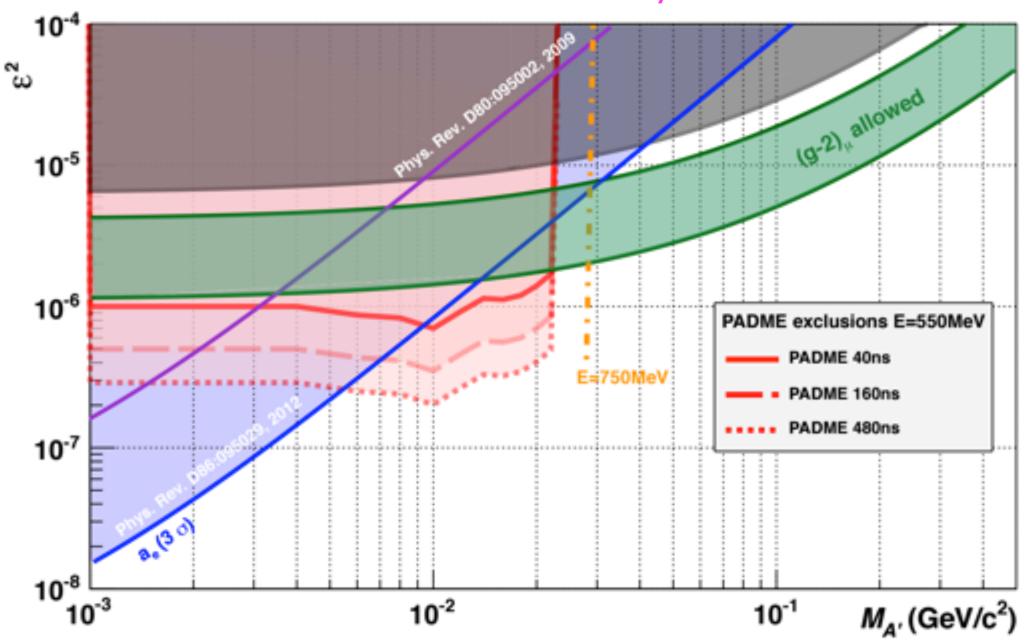
Can we have veto detectors also at large angles?

PADME invisible sensitivity estimate

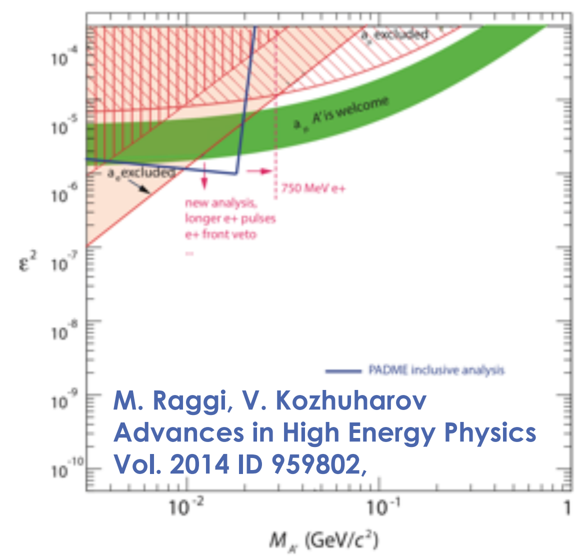
- Based on 2.5x10[10] fully GEANT4 simulated 550MeV e^+ on target events
- Number of BG events is extrapolated to 1x10[13] electrons on target
  - Using $N(A'\gamma)=\sigma(N_{BG})$
  - δ enhancement factor $\delta(M_{A'}) = \sigma(A'\gamma)/\sigma(\gamma\gamma)$ with $\varepsilon=1$

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

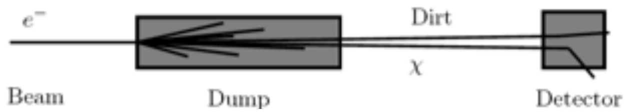
PADME invisible decays exclusion

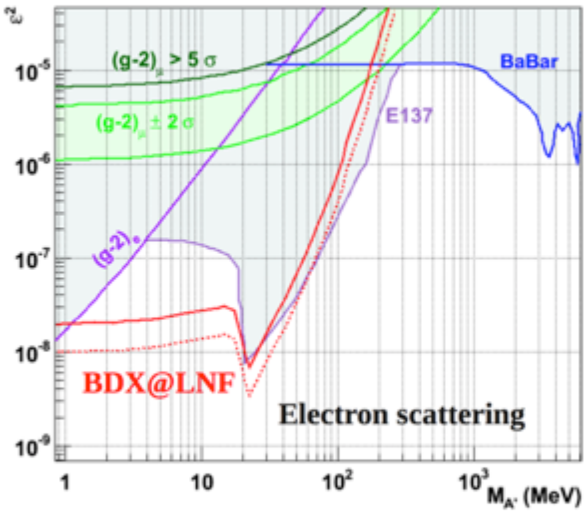


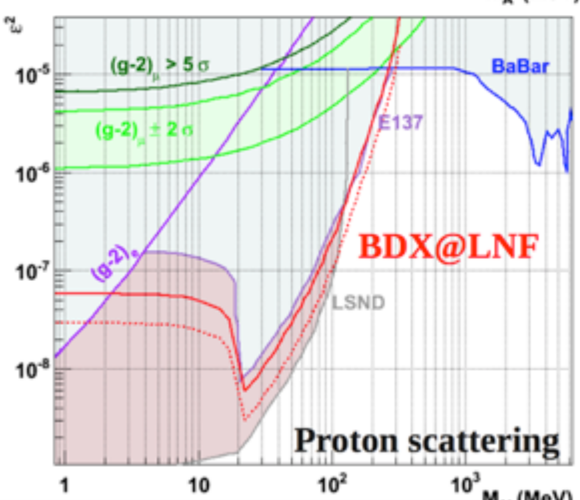
First inclusive analysis



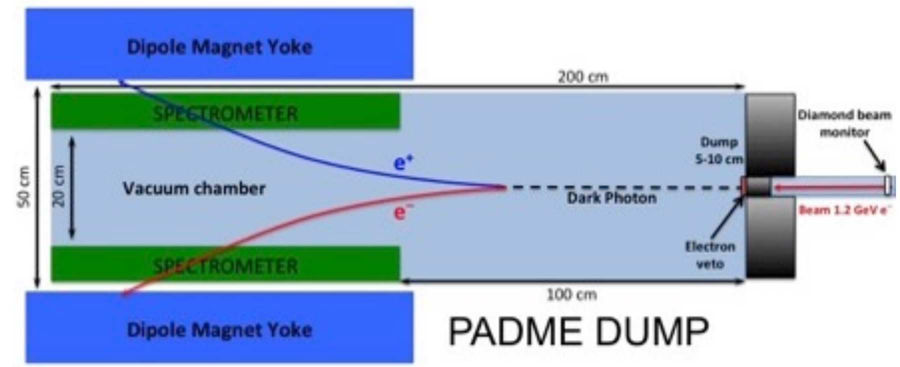
And much more…



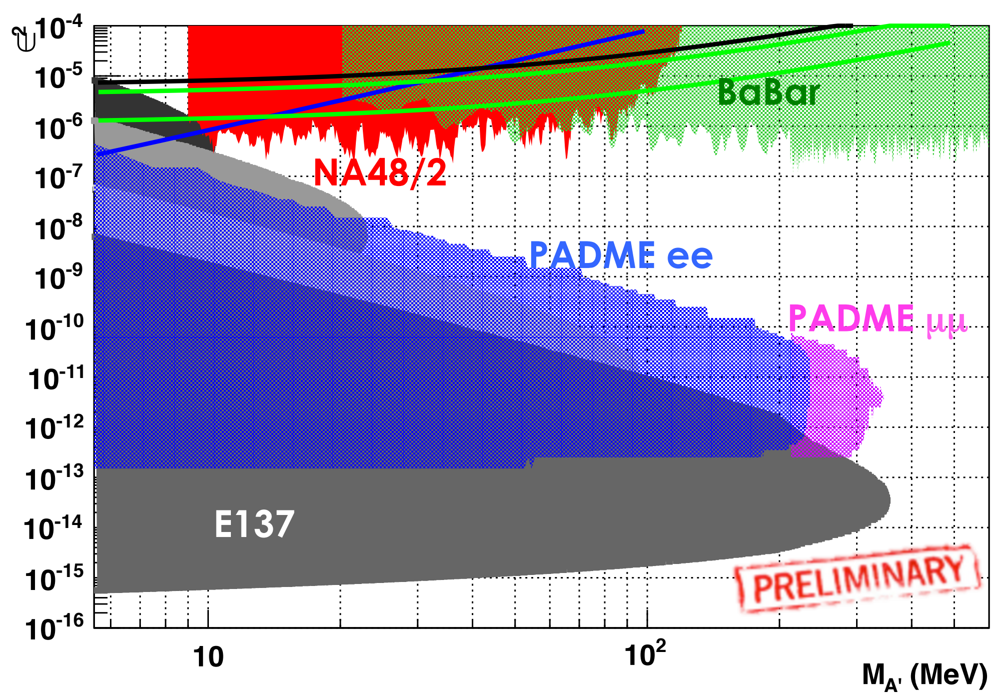




1.2 GeV electrons
CsI detector 60×60×225 cm³ built with crystals from dismounted BaBar ECal?



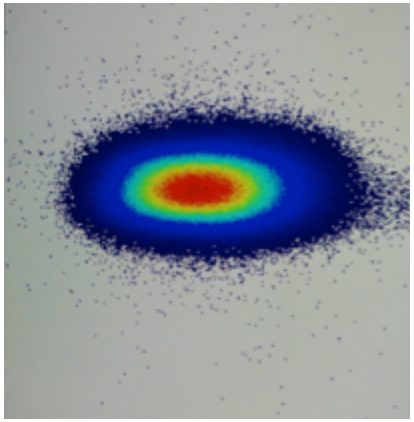
1 · 10^{20}, 1.2 GeV electrons;
20 cm aperture at 50 cm from 10 cm W dump



PADME project plans

- Project has been presented as a "What Next" Project in INFN CSN1
  - The project has received positive feedback form CSN1 referees
  - Proposal for R&D financing will be presented in the June 2015 CSN1 meeting
  - First test beams with calorimeter are ongoing
- Proto collaboration formed including
  - LNF, Rome1, Lecce and Sofia university
  - Formal commitment of INFN groups by July 2015 CSN1 meeting
- **6 weeks** test beam time asked at **DAΦNE BTF in 2015**
  - Study the prototype of BGO calorimeter solution (L3 crystals)
    - Photo-detector studies (SiPM vs. APD)
    - Readout electronics: pre-amp, readout boards, digitization, etc.
  - Test diamond target prototypes (October 2015)
  - Study the maximum beam current per bunch for PADME dump
  - Study and optimize positron beam for PADME invisible:
    - Spot size and stability
    - Maximum positron energy
    - Divergence and momentum spread
    - Intensity
    - Bunch length
    - Charged and neutral background

Very preliminary results from BTF tests



- Primary beam (DAFNE running):
  - Electrons, E_0=510 MeV, 1 nC
  - BTF target at 1.7 X_0
- TB3 UP, DOWN = 0.1,0.1 mm
- TB4 LEFT, RIGHT = OPEN
- TB1 and TB2 = OPEN

447 MeV positrons = 88% E_0
≈2000 particles/bunch
10 ns bunch width

σ_y≈0.8 mm
- Dominated by multiple scattering on 0.5 mm Be window + 20 cm of air
- Further improved operating in vacuum

σ_x≈2 mm
- Dominated by momentum spread, due to TB2 slits completely OPEN
- Can be improved by using an optimized (thinner) target and by closing the TB2 slits
  - A thinner target also allows to run closer to the primary energy

Running in parallel to DAFNE injections implies some limitations:
- Bunch width fixed at 10 ns (<<40 ns already achieved with present gun hardware)
- $E_0 < E_{max}$(550 MeV)

Further limitation if BTF target is used for positron production (DAFNE needs both e^+ and e^-)
- $E < E_0$ in order to have 10^3-10^4 particles/pulse
- Overall limit: $E \leq 450$ MeV

A possible schedule for PADME-invisible

- Vacuum: design and build vessel and interface to BTF
  - Preliminary design done
  - Construction and installation
- Magnet and positron veto:
  - Magnet transportation to Frascati, tests, field-mapping, cabling from main DAFNE power supply hall to BTF (Former splitter magnet power supplies available, 400 A/80 V)
  - Scintillating bars with wavelength shifting fibers + SiPM readout (<200 channels)
- EM Calorimeters
  - Cutting and polishing of available (≈70 crystals)
  - Procurement of missing ≈150 L3 BGO crystals and cutting and polishing
    - Or: purchase of new LYSO crystals
    - Choice of photo-sensor, design of front-end electronics
    - DAQ and trigger already being developed
  - Build SAV and – in case – large angle calorimeters
- Diamond Target
  - Thin diamond R&D
  - Grafitization vs. metallization
  - Readout
- Beam
  - Positron beam at 550 MeV/40 ns already available
  - Assess longer pulse with acceptable energy spread
    - New pulser (up to 1 μs)
    - Try additional double phase inversions
  - Proposed upgrade to 750 MeV positrons or more under evaluation

Order of 1.5 years starting from cash flow start

Legenda:

2015
2016
2017+

Conclusions

- An experiment running at the DAΦNE BTF sensitive to both A'→invisible and A'→e^+e^- decays has been proposed to INFN.

- A model-independent exclusion limit in ε^2 down to $1 \cdot 10^{-6}$ can be achieved in invisible decays with the present Linac/BTF beam parameters in the region $M_{A'}$ 2-22 MeV with 10^{13} eot (2×10^7 s at 49 Hz)

- Any increase of the bunch width will reflect in higher statistics and thus improved sensitivity: aiming at 150-200 ns, but 500 ns seems to be possible

- Increasing the **positron energy** would extend the exclusion to higher A' masses
  - The proposed upgrade to 750 MeV/1 GeV for primary positrons/ electrons would extend the sensitivity to **≈30 MeV**

SPARE SLIDES

Limiting factors to invisible sensitivity

- The limiting factor to the present sensitivity are:
  - The 50Hz repetition rate of the linac (coupling)
  - The energy of the linac (mass)
  - The efficiency of the positron veto due to beam spot and energy spread
  - Gamma veto for low energy.

- Possible improvements
  - Smaller beam energy spread (0.25% is not out of reach)
  - Smaller spot size (0.5 mm is in within reach)
  - Positron energy up to 1GeV is technically possible

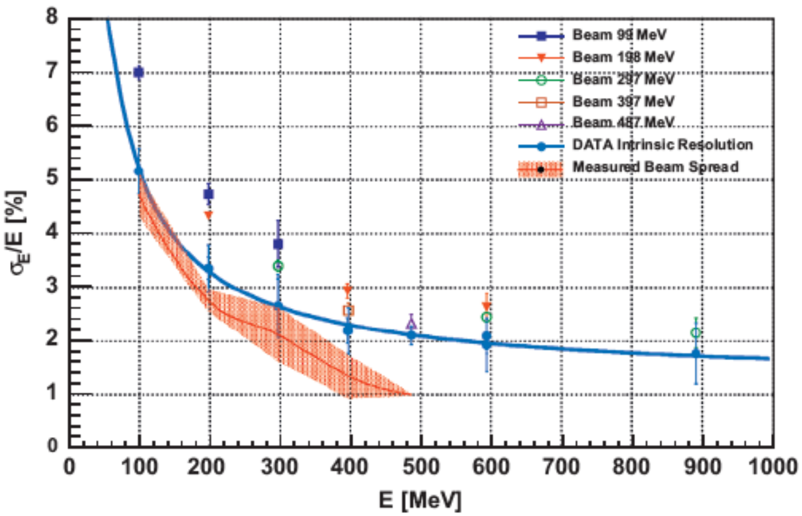
BTF beam summary

- Energy spread **Δp/p ~1%**
- Beam spot: **0.7 – 2 mm RMS** (depending on intensity)
- Divergence: **1 – 1.5 mrad**

  Effect of **multiple scattering and Bremsstrahlung** on the Beryllium exit window and in air has to be considered

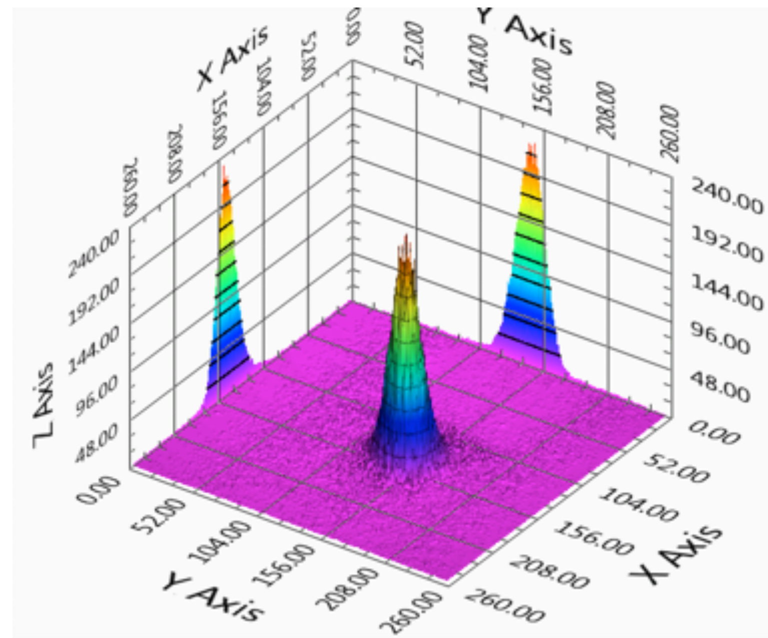
  Both size and divergence depend on the **optics**
- Beam position: **0.25 mm RMS**
- Pulse duration: **1.5 – 40 ns**
  - 10 ns during collider operations

Measurement of the beam *E* spread

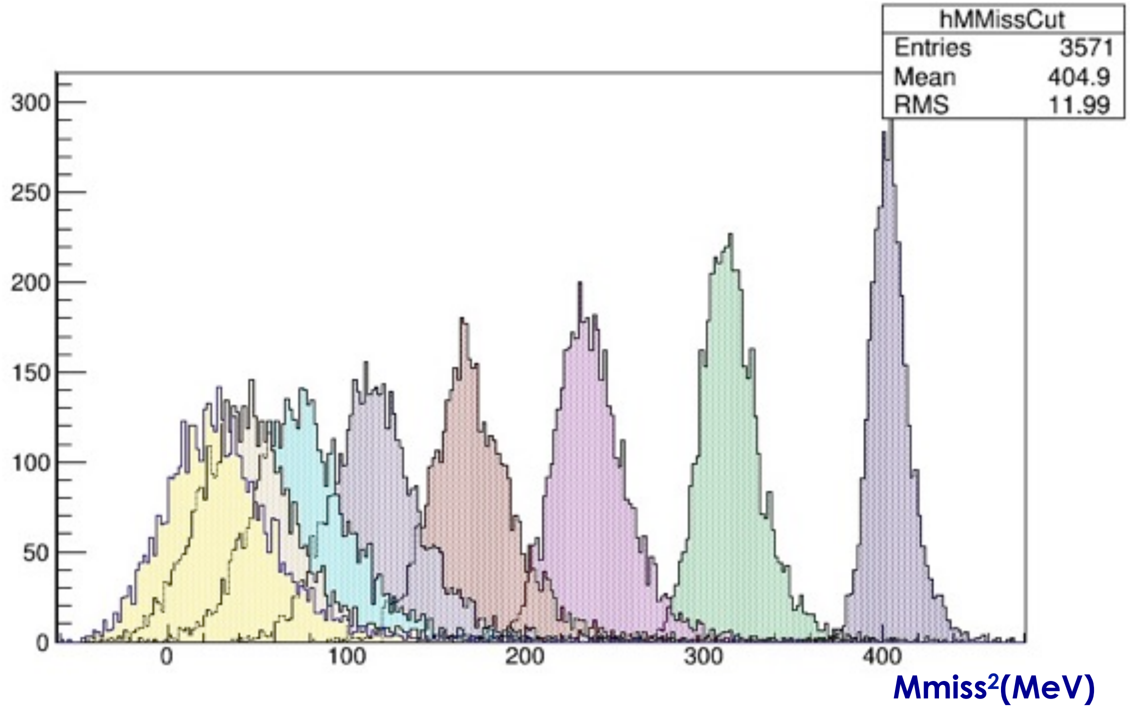


Nucl. Instrum. Meth. **A718** (2013) 107–109

Beam spot size



MC calorimeter performance



- Missing mass resolution in agreement with toy MC using
  - $\sigma(E)/E = 1.1\%/\sqrt{E} \oplus 0.4\%/E \oplus 1.2\%$ [NIM A 718 (2013) 107–109]
  - Differences are ~ 10%
- Resolution is the result of combination of angular resolution energy resolution and angle energy correlation due to production

Possible BTF upgrades

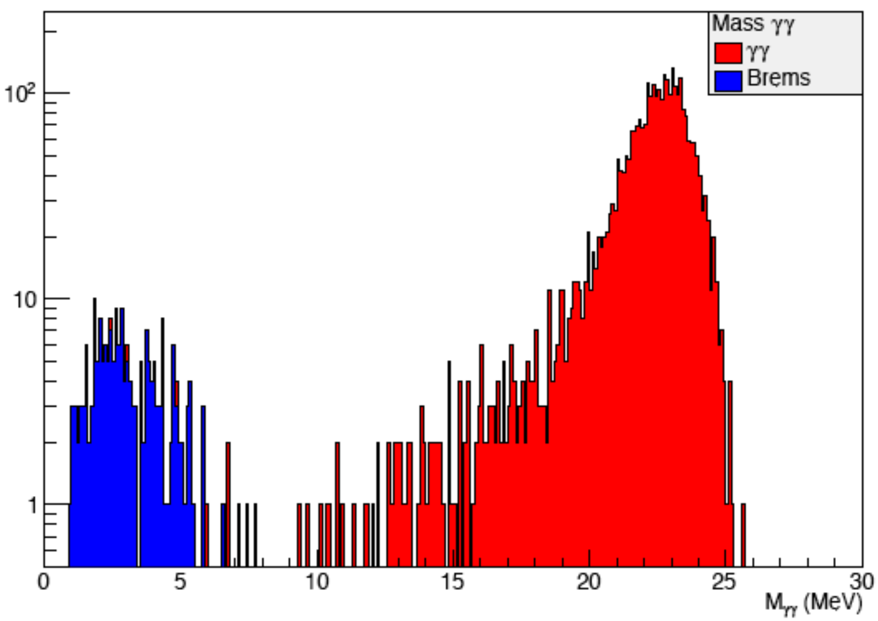
- Energy upgrades up to 1.2 GeV electrons
  - Proposal to reach >800 MeV energy for positrons (see B. Buonomo, BTF user workshop)
- Longer Duty Cycle
  - Standard BTF duty cycle = 50*10 ns = 5×10^{-7} s
  - Already obtained upgrade 50*40ns= 20×10^{-7} s (Thanks to BTF team)
  - Any increase of duty cycle increase linearly experiment statistics
- Collimation system
  - Assure better beam definition for positrons beam
- Maximum current in BTF hall
  - Limited by radio protection to 6.2×10^{8} per bunch for long term operation
  - Can reach $>3 \times 10^{10}$ particle per bunch after proper screening

See recent BTF user workshop for details at:
https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=7359

The γγ normalization selection

Used to measure the beam flux, in alternative to the diamond

$$N_{\gamma\gamma}^{tot} = \frac{N_{\gamma\gamma}}{Acc_{\gamma\gamma}} = Flux(e^+) \cdot \sigma_{\gamma\gamma}$$

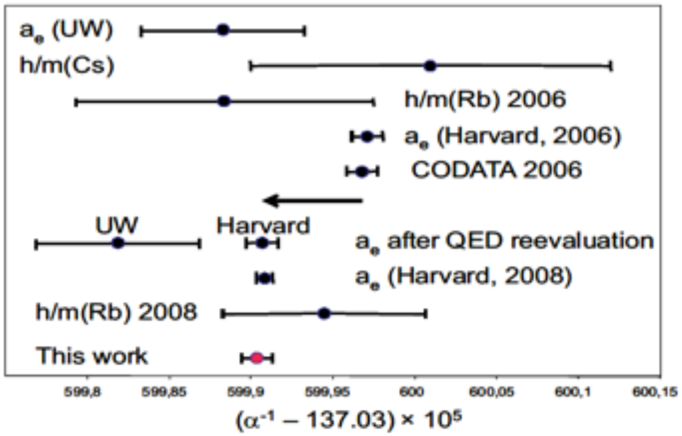


- Number of calorimeter clusters = 2
- Cluster energy: 100MeV<E_{Cl}<400 MeV
- Cluster radial position 5 cm <R_{Cl}< 13 cm
- γγ invariant mass 20 MeV < $M_{\gamma\gamma}$ < 26 MeV

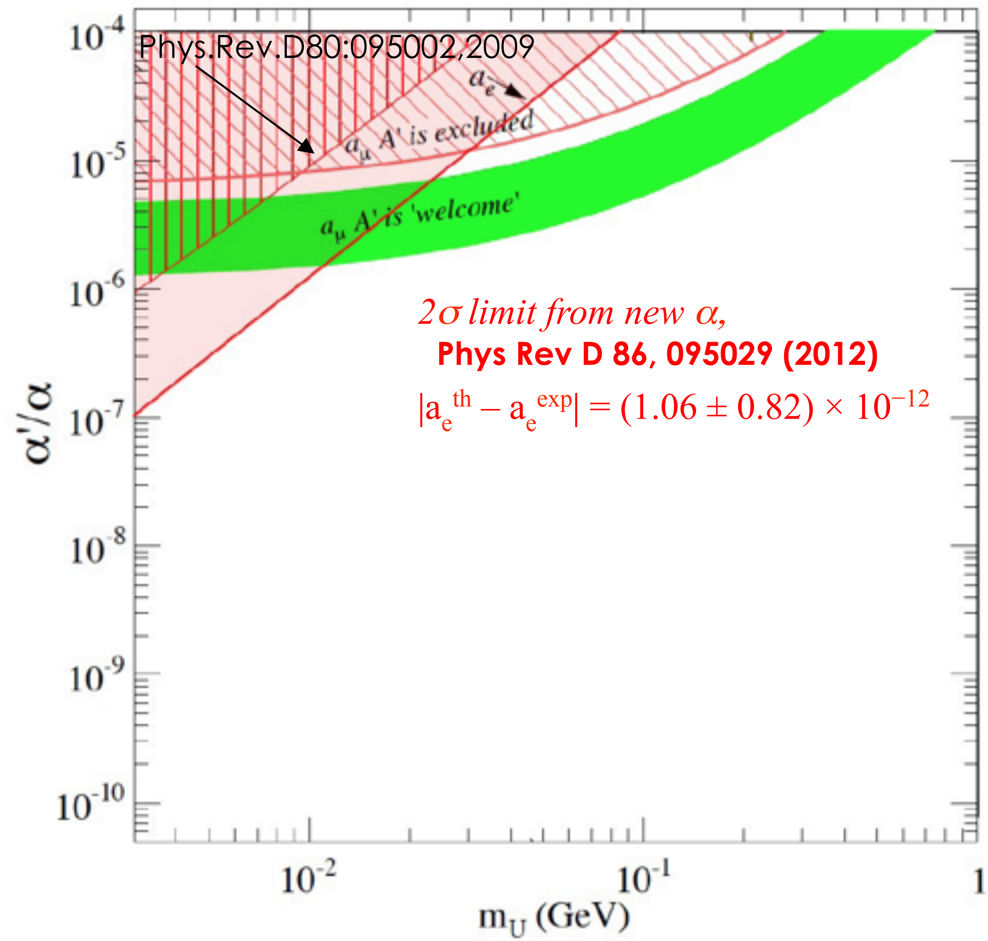
$$M_{\gamma\gamma} = \frac{\sqrt{[(X_{\gamma 1} - X_{\gamma 2}) + (Y_{\gamma 1} - Y_{\gamma 2})]E_{\gamma 2}E_{\gamma 2}}}{Z_{EMcal} - Z_{Target}}$$

Indirect limits

Phys.Rev.Lett.106:080801,2011

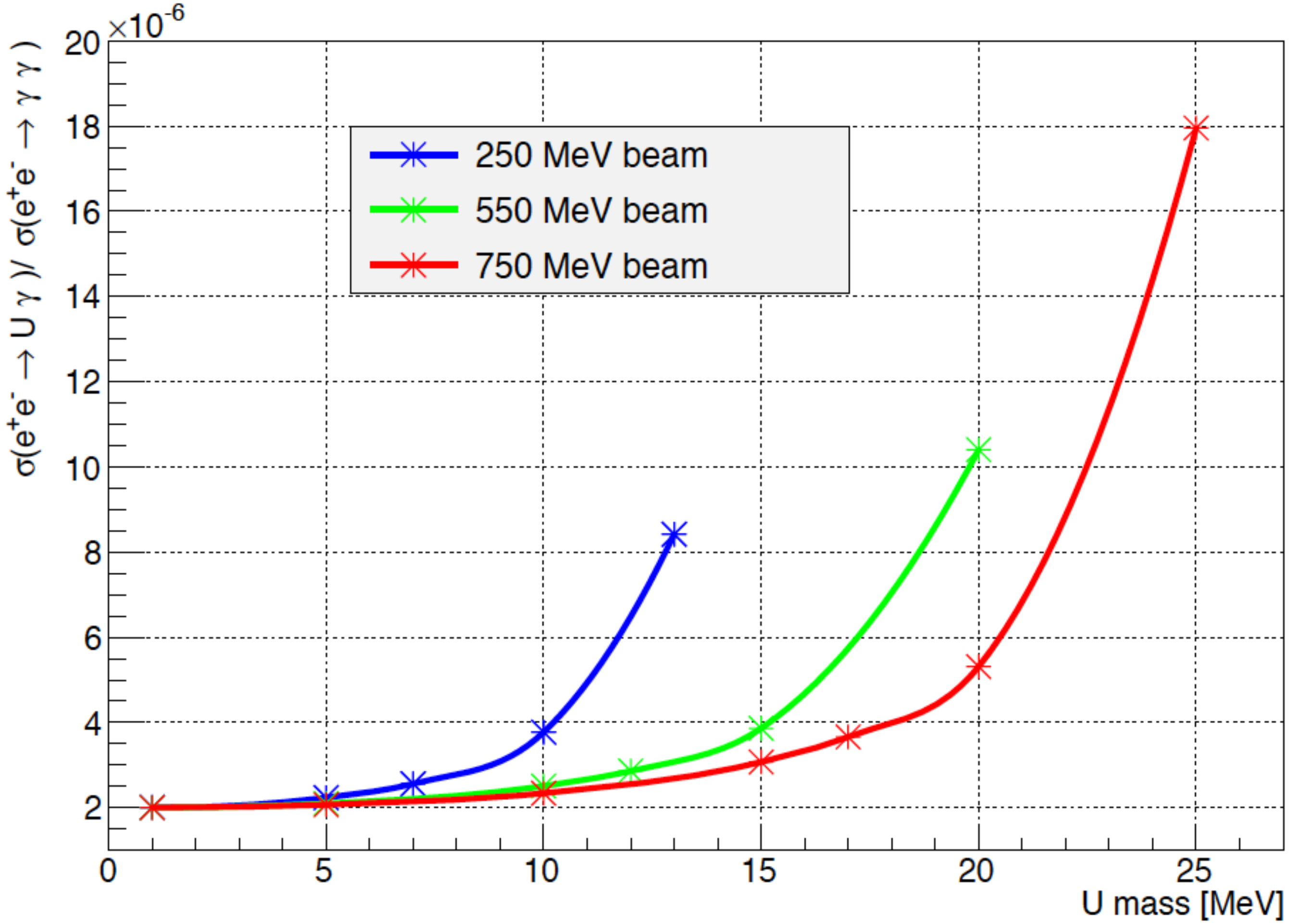


$\alpha^{-1} = 137.035\,999\,037\,(91)$



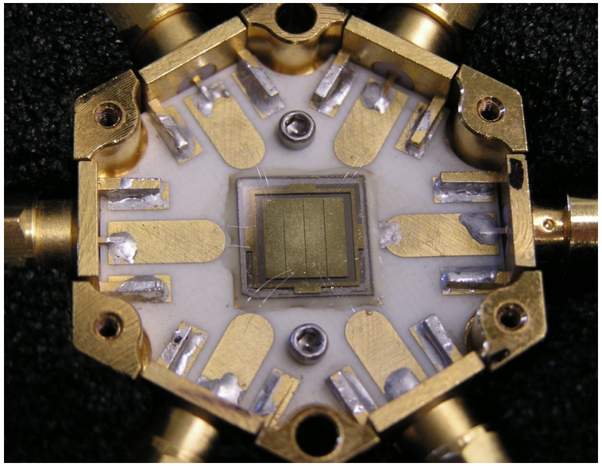
However this is based on a single measurement with drastically improved precision

Cross section enhancement

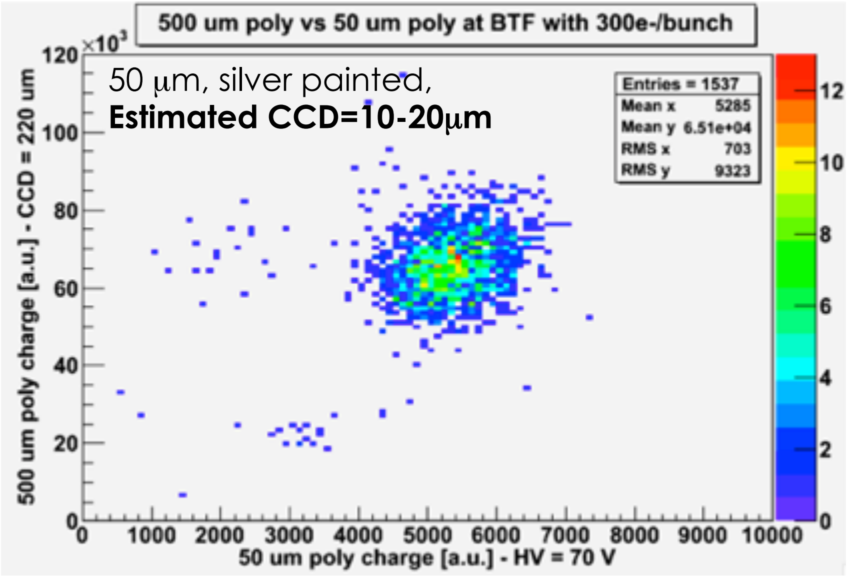


The PADME diamond target

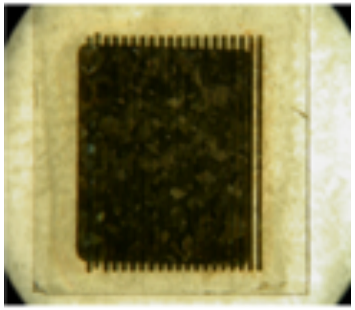
- First BTF test-beam with polycrystalline diamonds:
  1. Two 500 μm thick and 4 **metal** strips: 6.5 mm long and 1.5 mm pitch
  2. 300 μm thick 40 **graphitized** strips 3 mm long, 100 μm width, and 170 μm pitch
  3. 50 μm thick, 2×2cm^2 sample for first PADME prototype
  4. 50 μm thick 5×5mm^2 sample for BTF beam diagnostics with Silver Paint

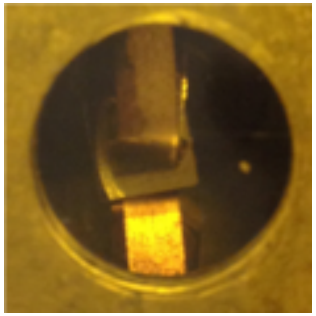


1.



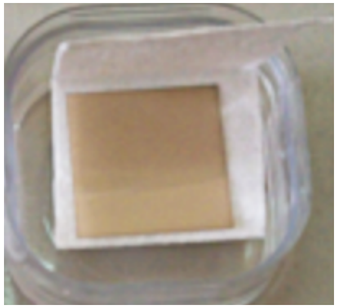
2.





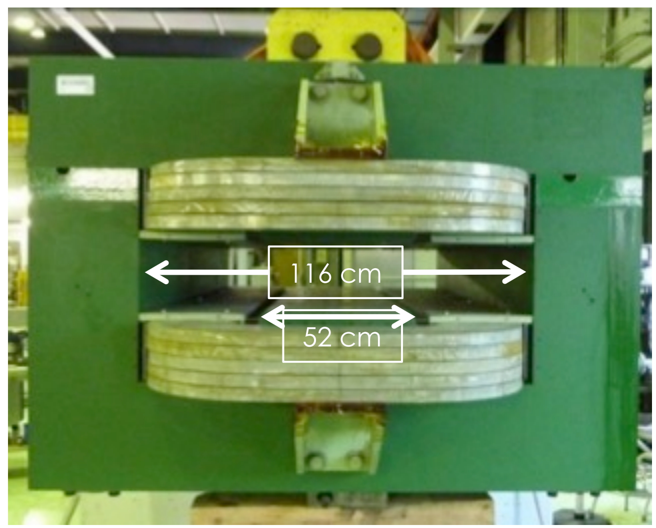
Main result of feasibility of 50 μm sensors already established

3.



4.

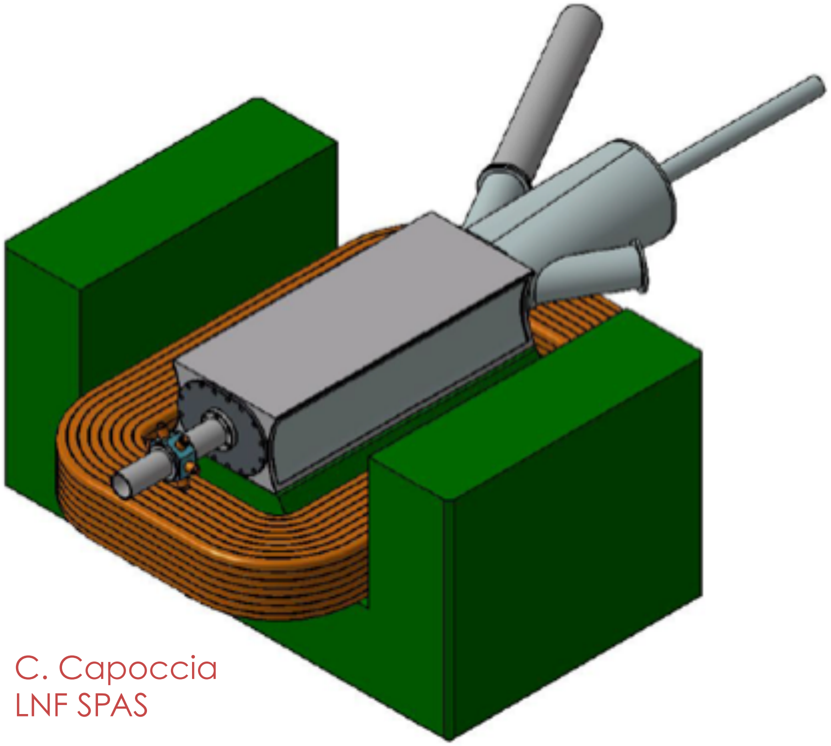
A possible analyzing magnet for PADME



11 to 20 cm gap

Available at CERN magnet division

PADME vacuum vessel study

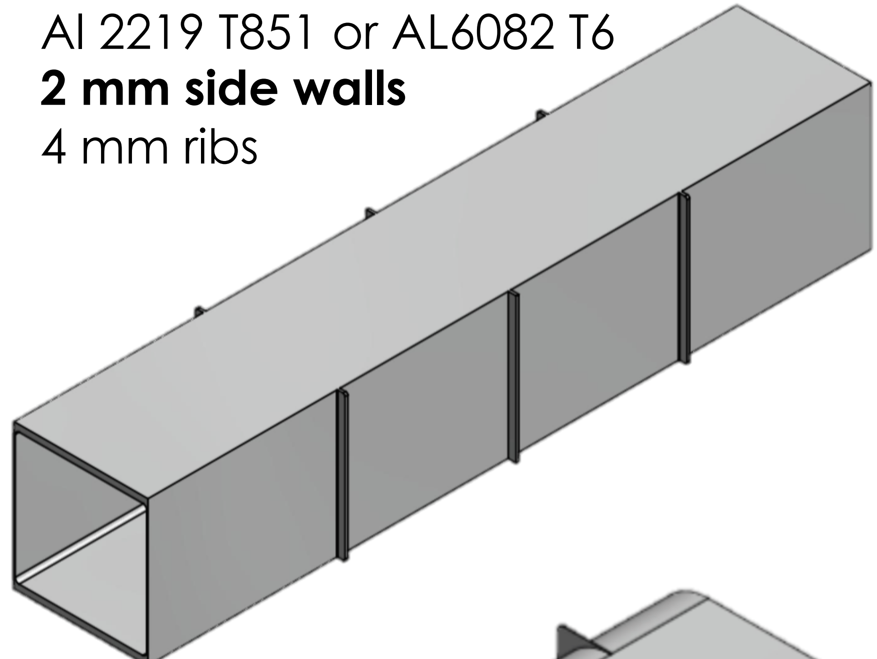


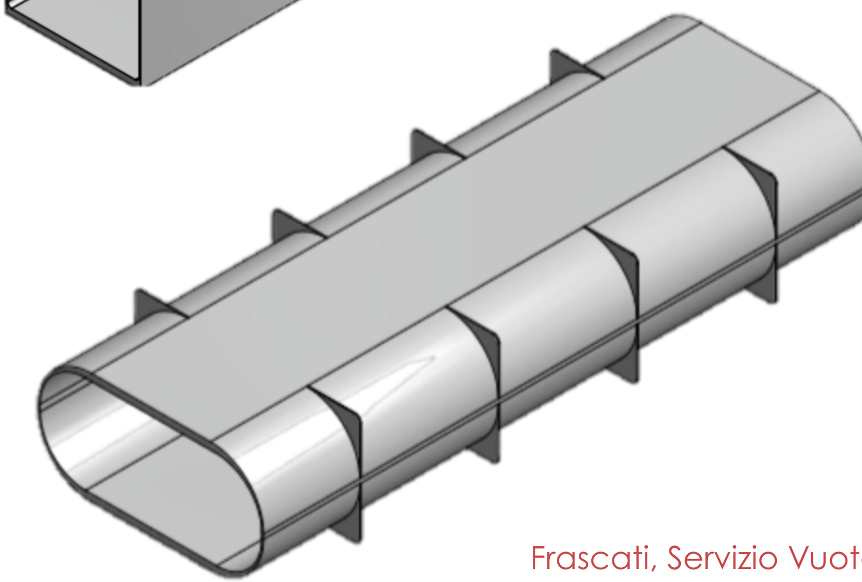
C. Capoccia
LNF SPAS

Different possibilities under study to minimize the material thickness

Different possibilities under study to minimize the material thickness

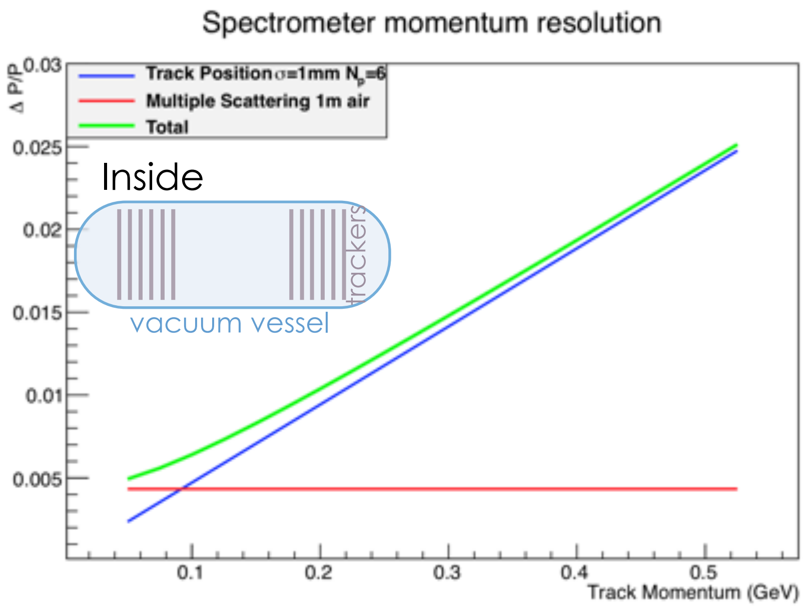
Al 2219 T851 or AL6082 T6
2 mm side walls
4 mm ribs

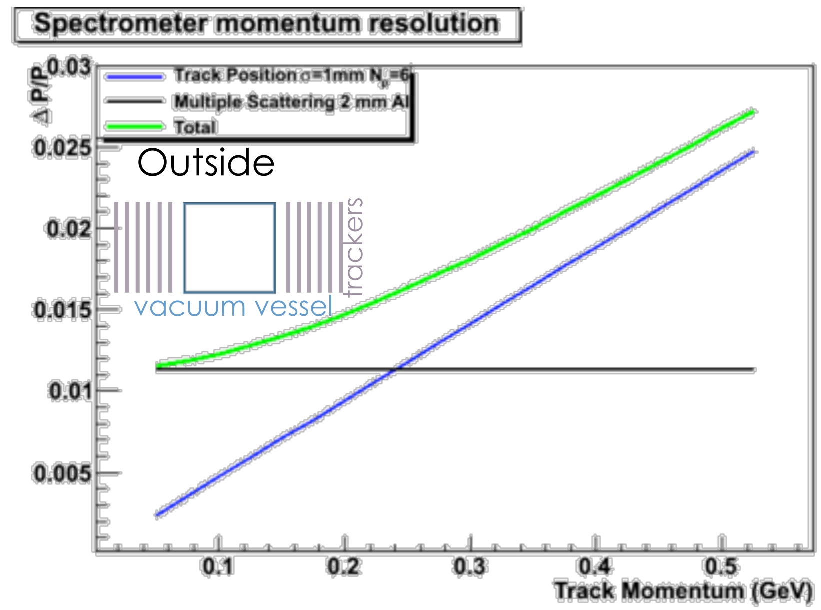




Frascati, Servizio Vuoto
V. Lollo, S. Bini

PADME spectrometer





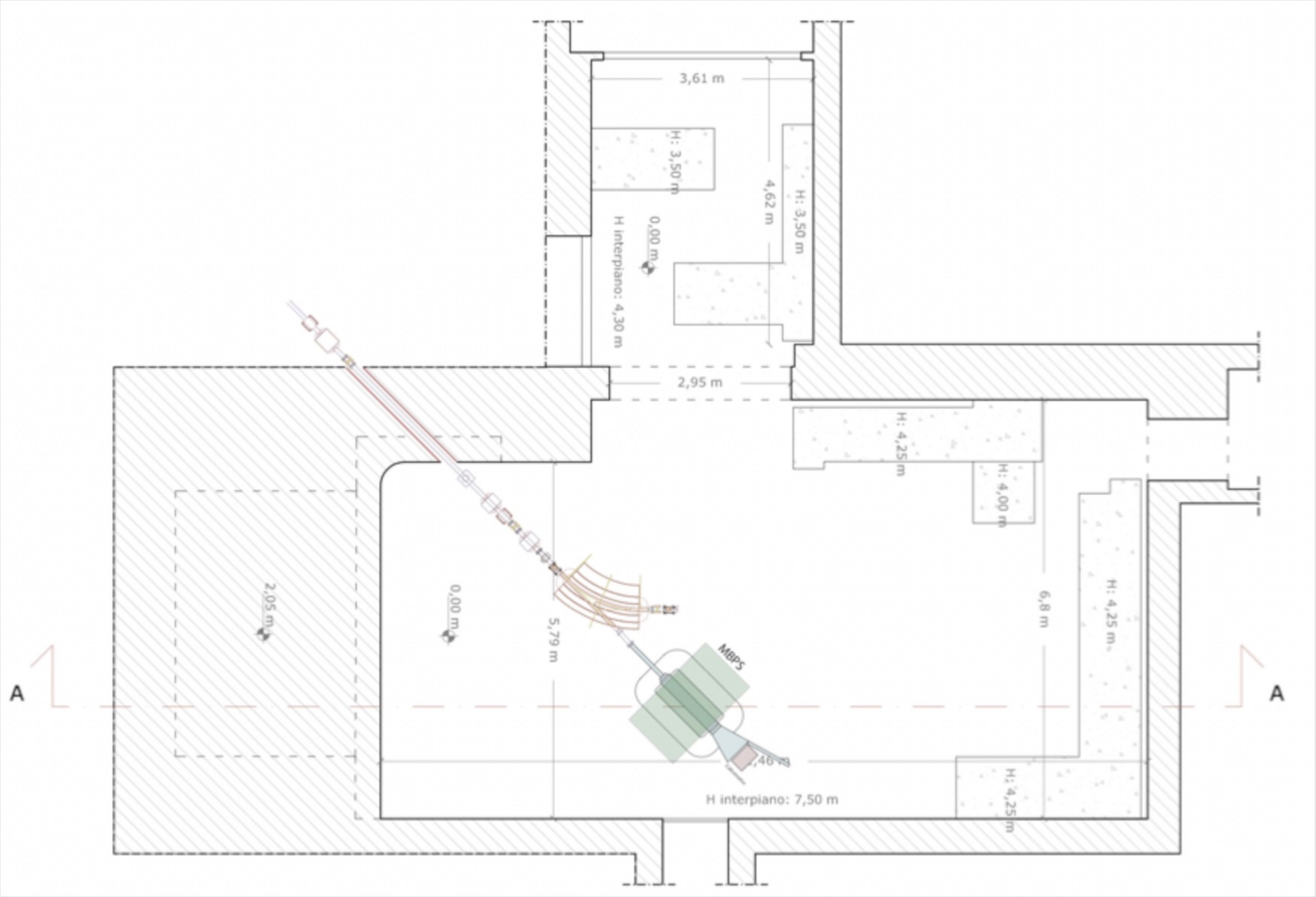
$$\left.\frac{\sigma(p)}{p}\right|^{\text{track error}} = \frac{\sigma(x)\ [\text{m}]}{0.3\ B\ [\text{T}]\ (L\ [\text{m}])^2}\sqrt{720/(N+4)}\cdot p\ [\text{GeV}/c]$$

$$\left.\frac{\sigma(p)}{p}\right|^{\text{MS}} = \frac{\Delta p_x^{\text{MS}}}{\Delta p_x^{\text{magn}}} = \frac{13.6\sqrt{L/X_0}\ \text{MeV}/c}{e\int_0^L B_y(l)\,\text{d}l}$$

There is the possibility of having a spectrometer outside the vacuum: Impact on the PADME-visible experiment to be understood

In what follow we will use a simplified version of the spectrometer just made of scintillators that is not used for measuring the momentum

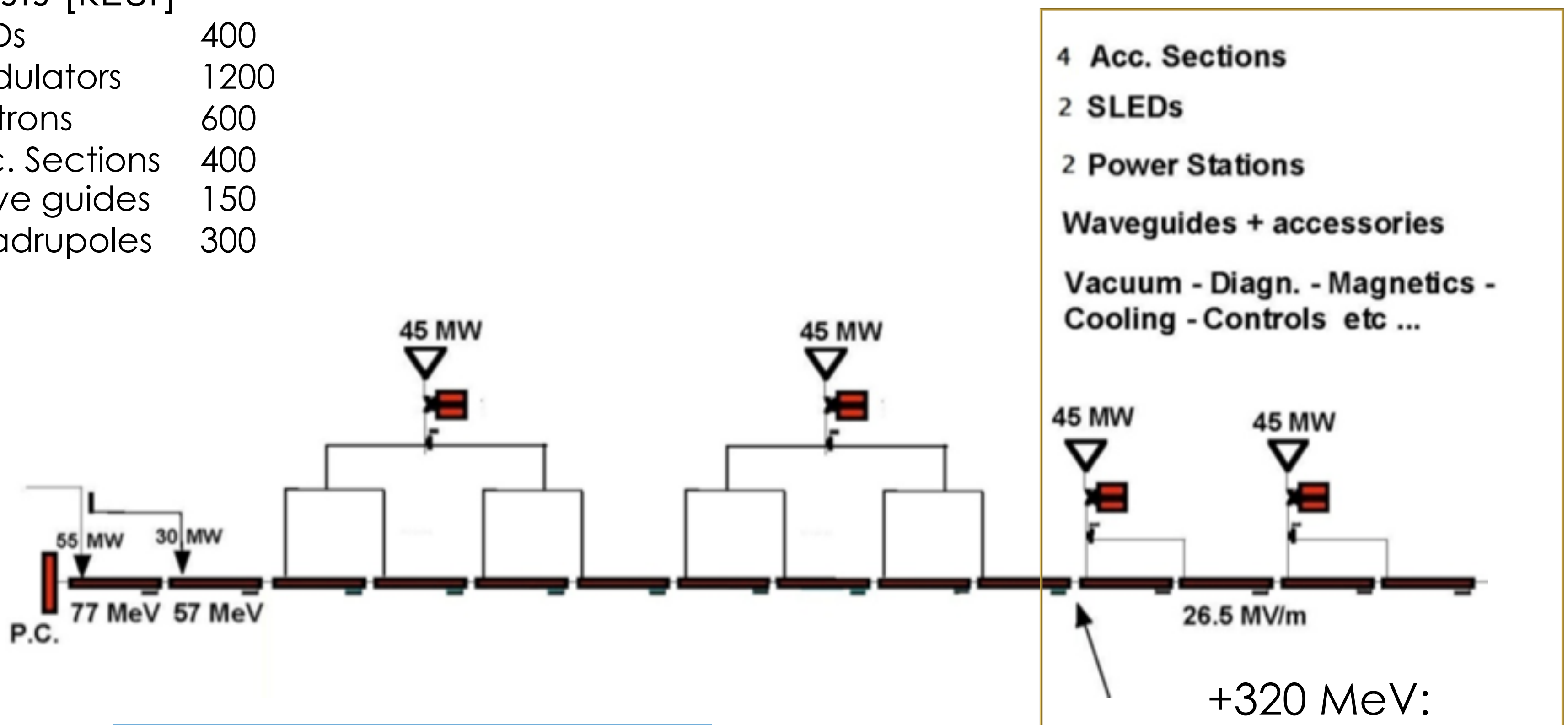
Possible PADME installation



Add 4 sections + 2 SLED-ed klystrons

Costs [kEur]

SLEDs	400
Modulators	1200
Klystrons	600
Acc. Sections	400
Wave guides	150
Quadrupoles	300



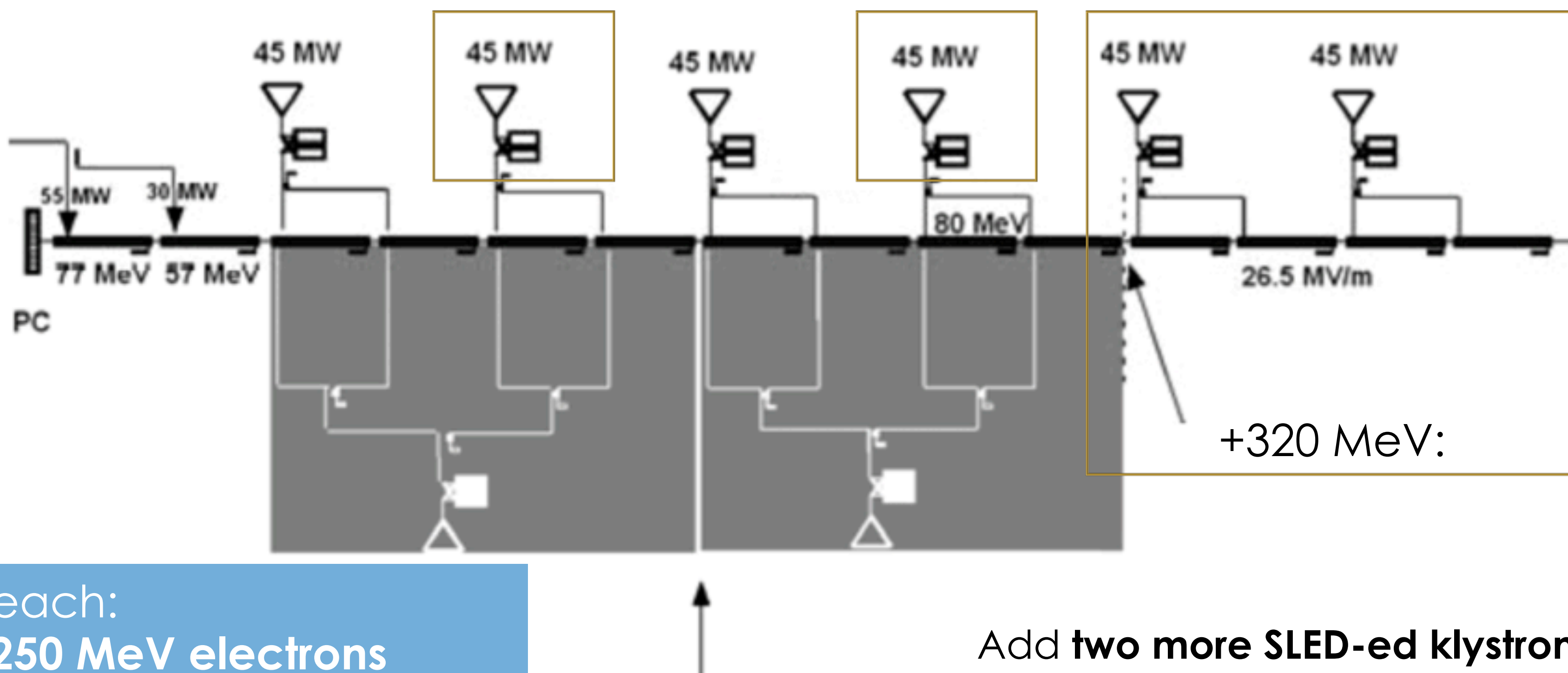
Reach:
1070 MeV electrons
950 MeV positrons

Add 4 sections + 4 SLED-ed klystrons

Additional Cost [kEur]

SLEDs	400
Modulators	1200
Klystrons	600

+180 MeV:

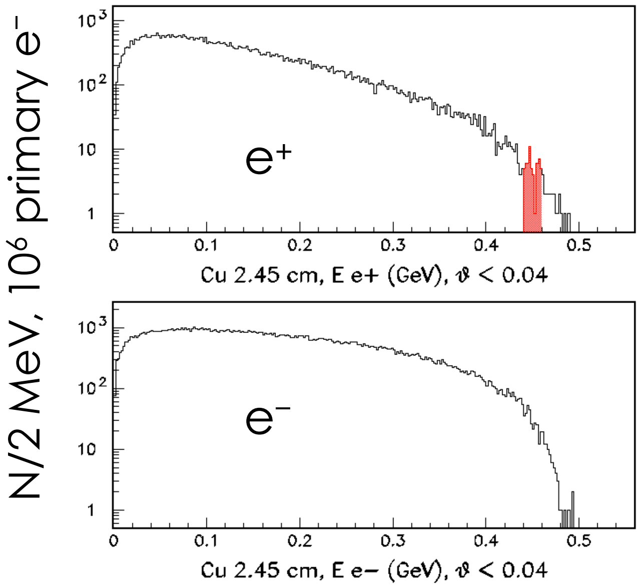


ORIGINAL RF LAYOUT

Reach:
1250 MeV electrons
1100 MeV positrons

Add **two more SLED-ed klystrons** and split power only in two sections instead of four

Positron yield with BTF target



Out of target, $\theta < 40$ mrad

2% energy slice at 88% of primary E_-

E_-=510 MeV, E_+=447 MeV

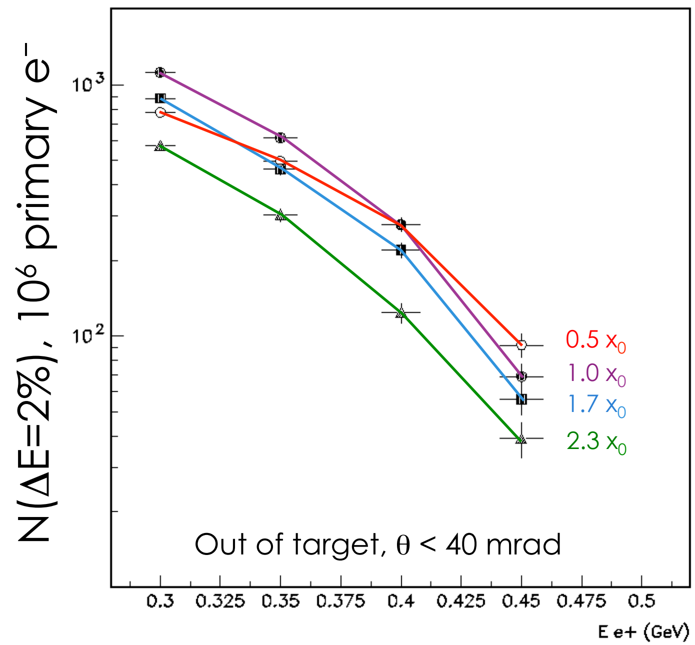
Q=1 nC=0.625 10^{10} e^-

Few 10^3 e^+

≈1% collimation, selection and transport efficiency

We can optimize the positron yield close to the end-point with a thinner target

Probably higher Z would also slightly increase the yield



Possible beam requests in 2016-2017

- "Machine developments" periods with full availability of the LINAC (no DAFNE collider operation) for:
  - Installation of the new gun pulser and commissioning
    - Installation can be performed during a DAFNE shutdown (e.g. end of 2015) but commissioning and tests will require at least 1 period of ≈2-4 weeks of dedicated running
  - Test of long pulses vs energy spread, beam loading, transport efficiency, etc.
    - ≈2-4 periods of 1 week of dedicated running during the first part of 2016

- PADME "engineering runs" with staged setup and full availability of the LINAC (no DAFNE collider operation) for:
  - Start with diamond target, magnet, scintillating bars positron veto detector
    - 1-2 weeks of commissioning run with beam (possibly with DAFNE operation, but no BTF running)
  - Add calorimeter when available
    - 2-4 weeks of commissioning run with beam (possibly with DAFNE operation, but no BTF running)
  - Add small angle veto and front positron veto tracker when available
    - Assess background conditions in **PADME beam conditions**:
    - Longest achievable pulse (40 – 160ns?), highest E(e^- primary)≈730-750 MeV, N=5000 e^+/10ns*Δt
    - 4-8 weeks of data taking with ≈final setup, no DAFNE collider operation