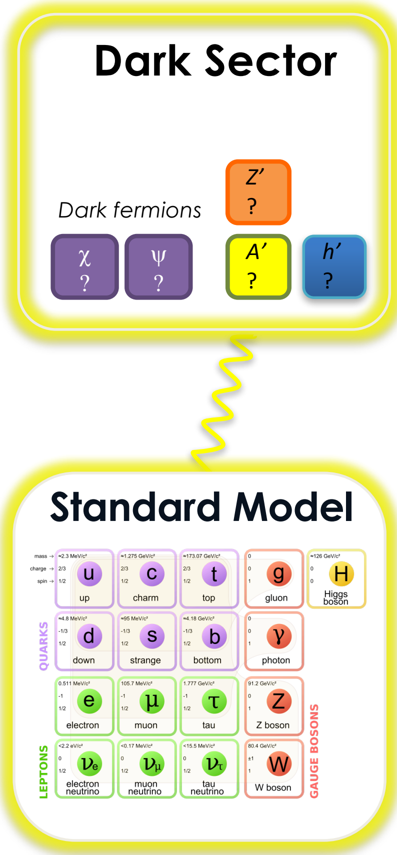
Status and prospects for the PADME experiment at LNF

P.Gianotti
INFN- LNF

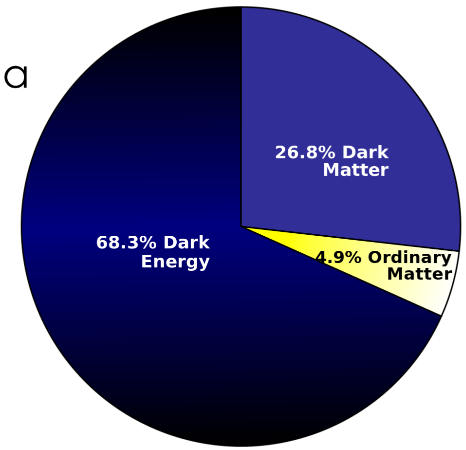
Outline

- Physics motivations
- PADME experiment
- PADME detector status
- Plans and prospects

Beyond the Standard Model



There are many attempts to look for new physics phenomena to explain Universe dark matter and energy.



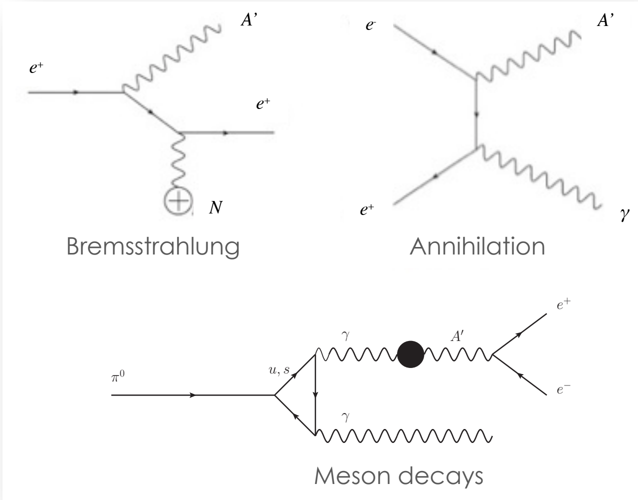
One of the simplest models just adds an additional U(1) symmetry to SM, with its corresponding vector boson (*A'*)

$$U(1)_Y+SU(2)_{Weak}+SU(3)_{Strong}[+U(1)_{A'}]$$

The *A'* could itself be the mediator between the visible and the dark sector mixing with the ordinary photon. The effective interaction between the fermions and the dark photon is parametrized in term of a factor ε representing the mixing strength.

The search for this new mediator *A'* is the goal of the PADME experiment at LNF.

A' production and decay



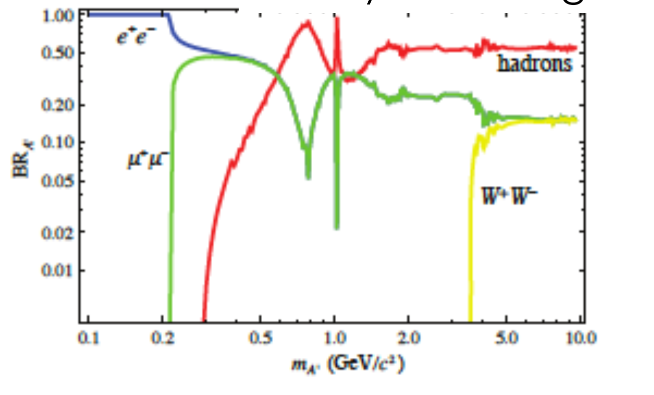
A' can be produced:

- in e⁺ collision on target via:
  - Bremsstrahlung: $e^+N \rightarrow e^+NA'$
  - Annihilation: $e^+e^- \rightarrow \gamma A'$
- Meson decays

For the *A'* decay modes two options are possible:

- No dark matter particles lighter than the *A'*:
  - $A' \rightarrow e^+e^-, \mu^+\mu^-$, hadrons, **"visible"** decays
  - For $M_{A'}$<210 MeV *A'* only decays to e^+e^- with $BR(e^+e^-)=1$
- Dark matter particles χ with $2M_\chi < M_{A'}$
  - *A'* will dominantly decay into pure DM
  - $BR(l^+l^-)$ suppressed by factor ε^2
  - $A' \rightarrow \chi\chi \sim 1$. These are the so called **"invisible"** decays

Decay Branching Fractions



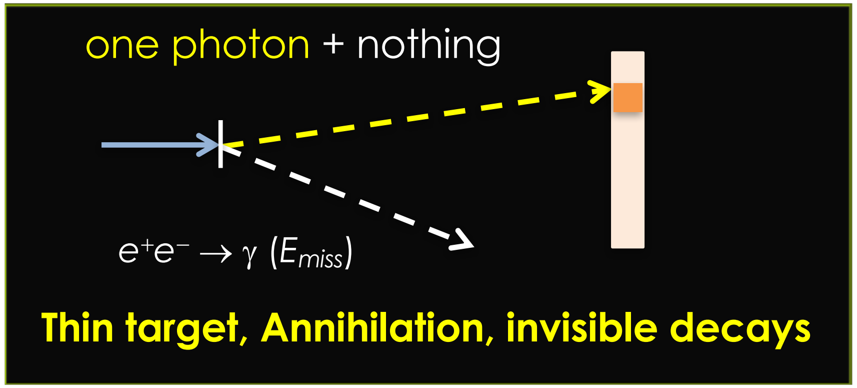
Dark photons searches

A' production at PADME

PADME aims to produce A' via de reaction: $e^+e^- \to A'\gamma$

Detecting the ordinary γ in a finely segmented e.m. calorimeter, and using a missing mass technique to identify the A'.

This technique allows to identify the A' even if it is stable or if predominantly decay via dark sector particles $\chi\bar{\chi}$.



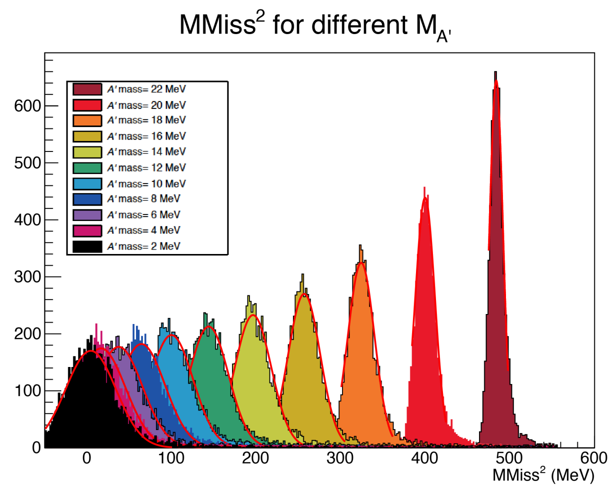
Know e⁺ beam **momentum and position**

- Tunable intensity (in order to optimize annihilation vs. pile-up)

Measure the recoil photon **position** and **energy**

Calculate $M^2_{miss} = (\underline{P}_{e+} + \underline{P}_{e-} - \underline{P}_{\gamma})^2$

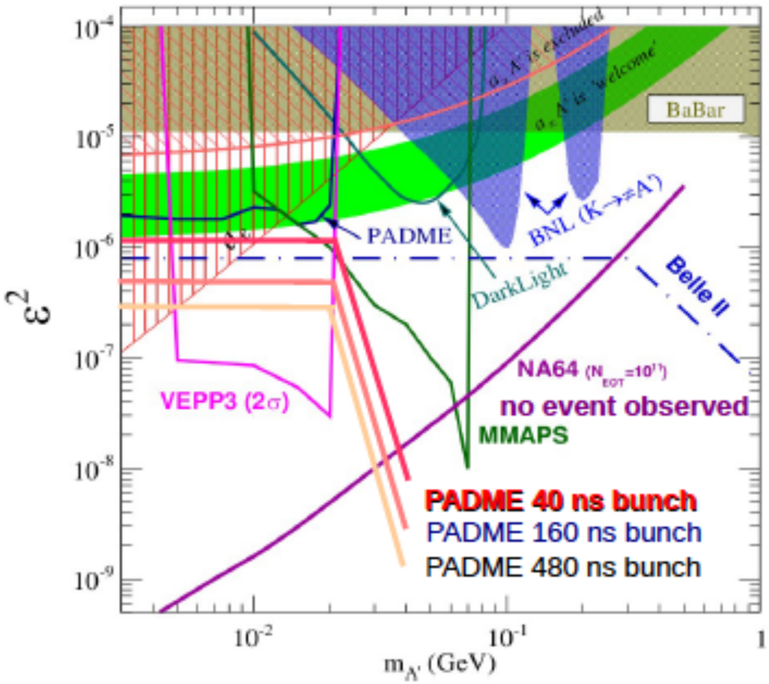
- Only minimal assumption: A' couples to leptons
  $\sigma(e^+e^- \to \gamma A') = 2\epsilon^2\sigma(e^+e^- \to \gamma\gamma).$



Expected results

Status and perspective of the "invisible" *A'* decay search

The possibilities of the PADME experiment are tightly linked with the characteristics of the positron beam.



Signal and Background

PADME signal events consist of single photons measured with high precision and efficiency by a forward **BGO calorimeter**.

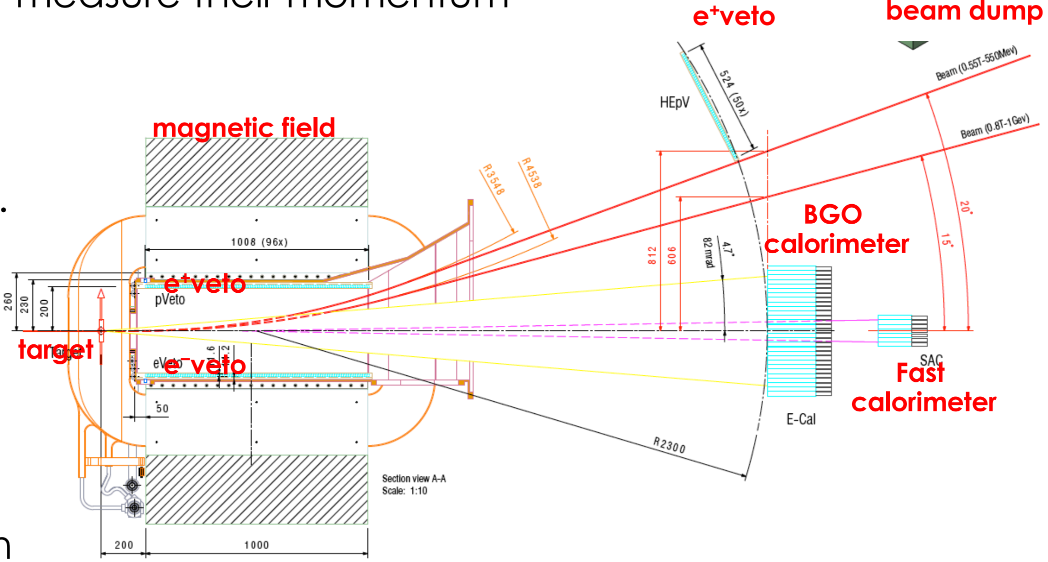
Since the **target** is extremely thin (~50 μm) the majority of the positron do not interact. A **magnetic field** is mandatory to precisely measure their momentum before deflecting them on a **beam dump**.

The main source of background for the *A'* search are Bremsstrahlung events. This is why the **BGO calorimeter** has been designed with a central hole.

A **fast calorimeter** will veto photons at small angle (θ<1°) to cut backgrounds:

$$e^+e^- \rightarrow \gamma\gamma;\ e^+e^- \rightarrow \gamma\gamma\gamma$$

In order to furtherly reduce background, the inner sides of the **magnetic field** will be instrumented with **veto** detectors for positrons/electrons that have lost energy.



For higher energy positron an other **veto** will be placed at the end of the vacuum chamber.

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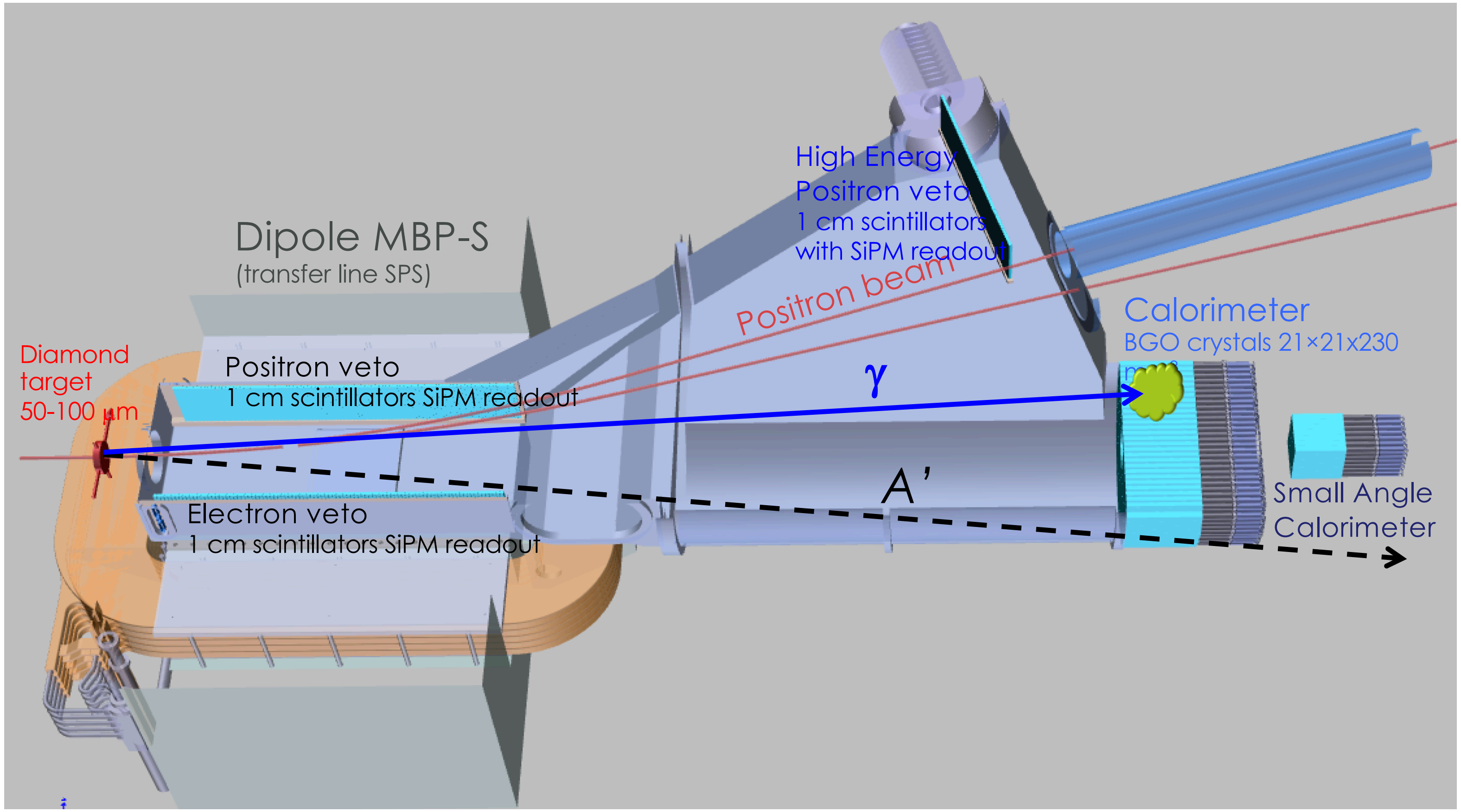
The PADME SETUP



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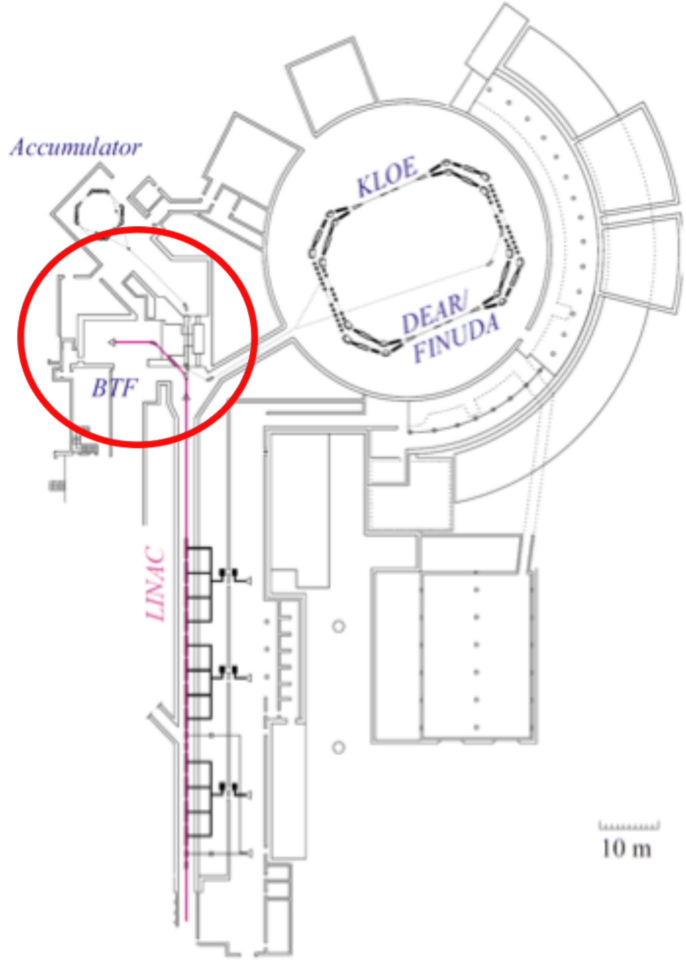
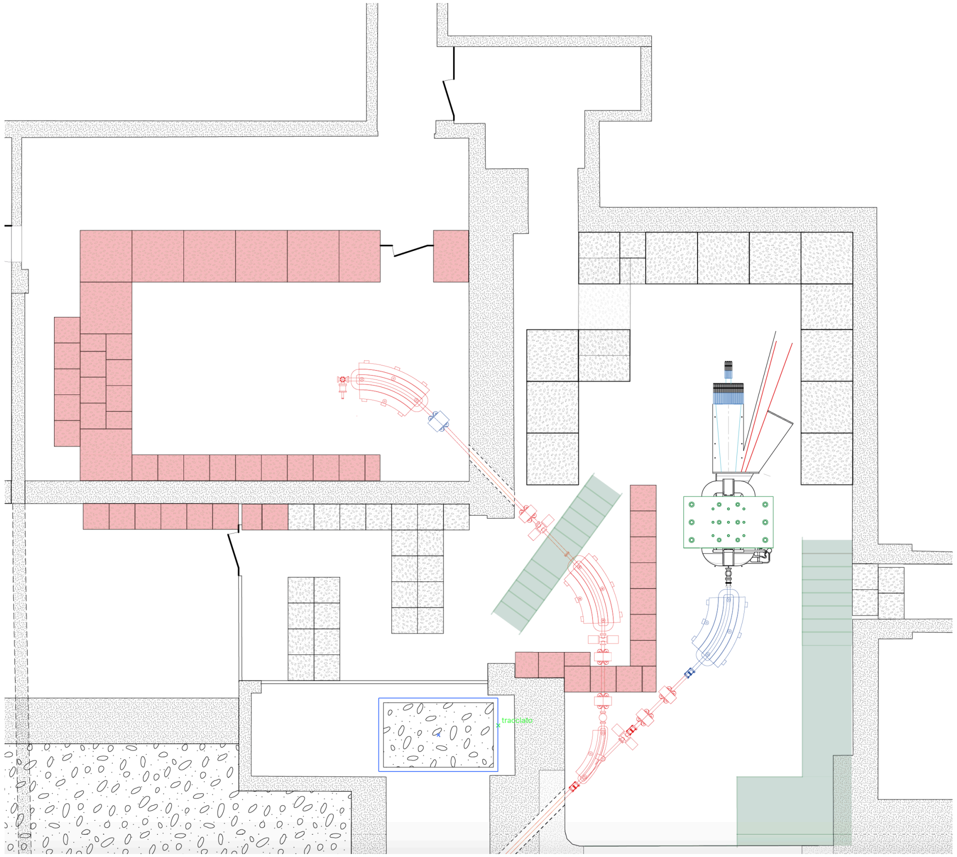
LNF LINAC beam line

	electrons	positrons
Maximum beam energy (E_{beam}) [MeV]	750 MeV	550 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	~1.5
Beam spot σ [mm]	<1 mm	
Beam divergence	1-1.5 mrad	

- Able to provide electrons and positrons
  - Duty cycle 50*40 ns= 2×10^{-7} s
    work done to reach 160 ns ideas for 480 ns
  - Request submitted for energy upgrade to reach ~1GeV.
- The accessible $M_{A'}$ region is limited by E_{beam}
  - 0-22 MeV can be explored with 550 MeV e^+ beam
  - Up to ~30 MeV with 1 GeV positrons



PADME experimental area

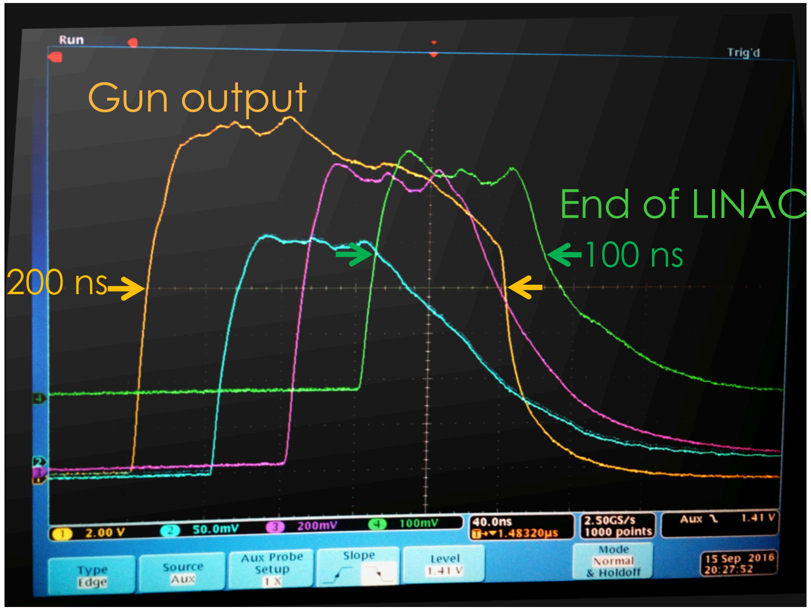


- The split of the present BTF beam line is needed
  - Foreseen in early 2017
  - Dedicated line for PADME in the present experimental hall
- Limits to the experiment dimension
  - No more than 4m in between target and Ecal
  - If distance shorter than 3m additional optics could be installed to improve beam quality

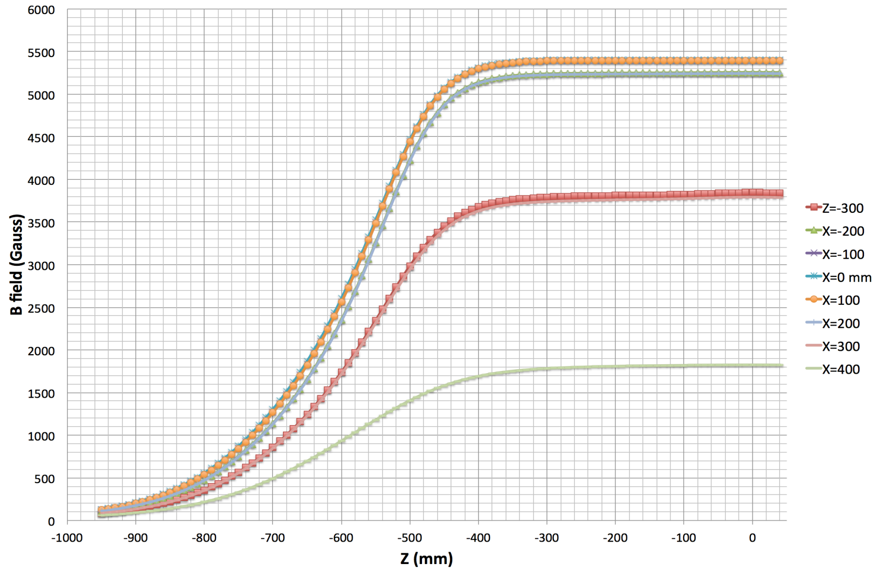
Summer shutdown activity

- New LINAC pulsing system (KENTECH) delivered and installed for generating pulse lengths >40 ns
- Capable of delivering up to 5 μs square waveforms, up to 1 KV
- 10 ns steps above 50 ns, 0.5 ns below (as existing one)
- Modulator maintenance (cooling oil)
- Power supplies tests
- Commissioning of new pulser under way:
  - New pulse voltage/grid counter-voltage settings
  - Tests of acceleration for >50ns pulses
    - Beam energy spread
    - Charge
    - Time structure

250 ns pulses could be obtained with further optimizations



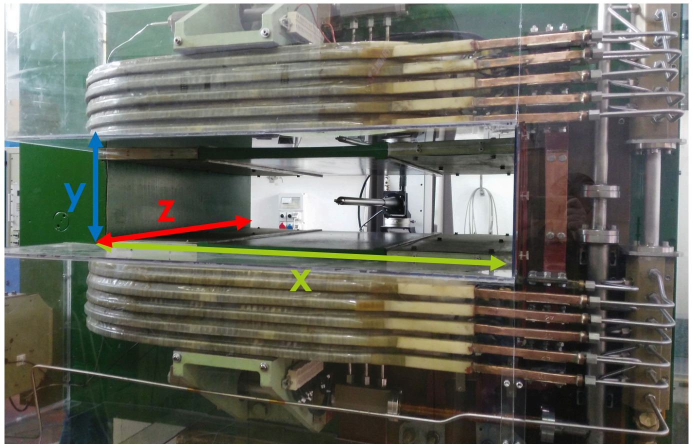
PADME Magnet



PADME magnet is a spare dipole from CERN SPS transport line:

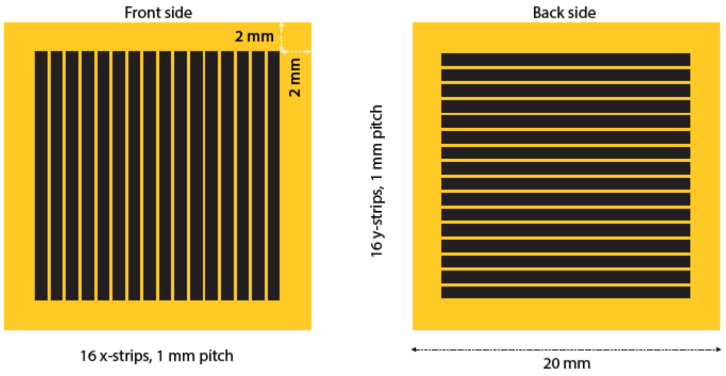
- 16/12/2015 arrived at Frascati
- Vertical gap enhanced to 230mm
- ≈95 KW at maximum current of 675 A

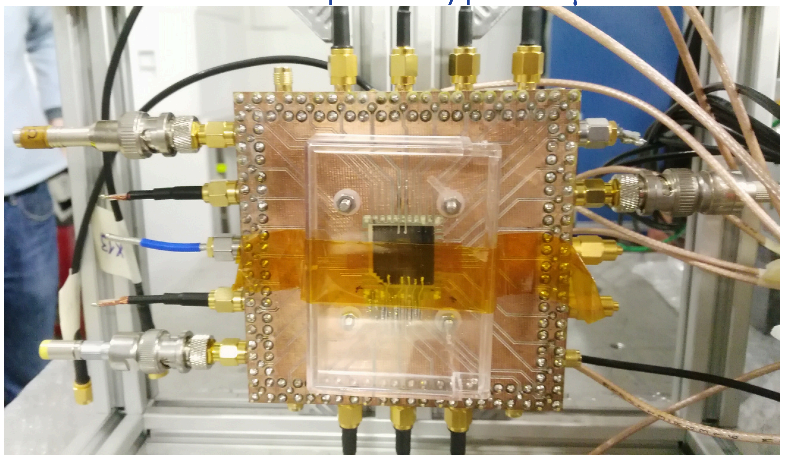
- Already performed steps :
  - Mechanical survey (OK)
  - Magnetic filed mapping at 400A 230mm gap
- Next steps :
  - Mechanical support and BTF integration

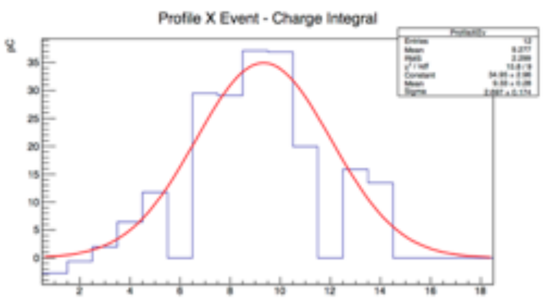


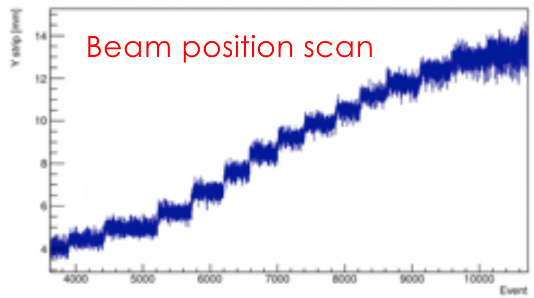
Diamond target

- Diamond is the rigid material with the best ee($\gamma\gamma$)/Brem. ratio (Z=6)
- Measure number and position of 5000-10000 positron/bunch
  - Below millimeter precision in X-Y coordinates
  - Better than 10% intensity measurement
- Polycrystalline diamonds 50-100 μm thickness:
  - 16x1mm^2 strip and X-Y readout in a single detector
  - **Readout strips are graphitized by using a laser to avoid metallization**
  - PADME prototype 50μm × 20 × 20mm^2 produced and tested in October 2015







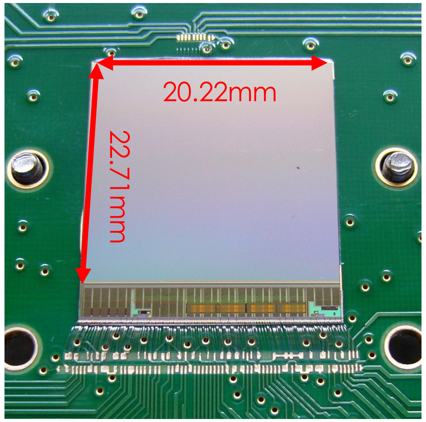


Beam monitor

To monitor beam characteristics, 2 planes of Silicon pixels will be placed up and down stream the Diamond target. Each plane will consist of 2 MIMOSA 28 Ultimate chips.

- MIMOSA 28 Ultimate chip
  - It is the final sensor developed for the upgraded STAR inner layer of the vertex detector
  - Its architecture integrates a Monolithic Active Pixel Sensor (MAPS) with fast binary readout
  - The sensor consists of a matrix composed by 928 (rows) x 960 (columns) pixels of 20.7 μm pitch for a size of the chip of 20.22 mm x 22.71 mm and a thickness of 50 μm.

- The chip dissipates ~ 150 mW/cm^2 and at STAR the sensor is operated at room temperature (30-35^o C) with simply air cooling
- For PADME it will be placed in a 10^{-4}÷10^{-5} mbar vacuum and cooling will be necessary
- A new PCB or a modified version of the existing is underway



MIMOSA 28 Ultimate mounted on PCB

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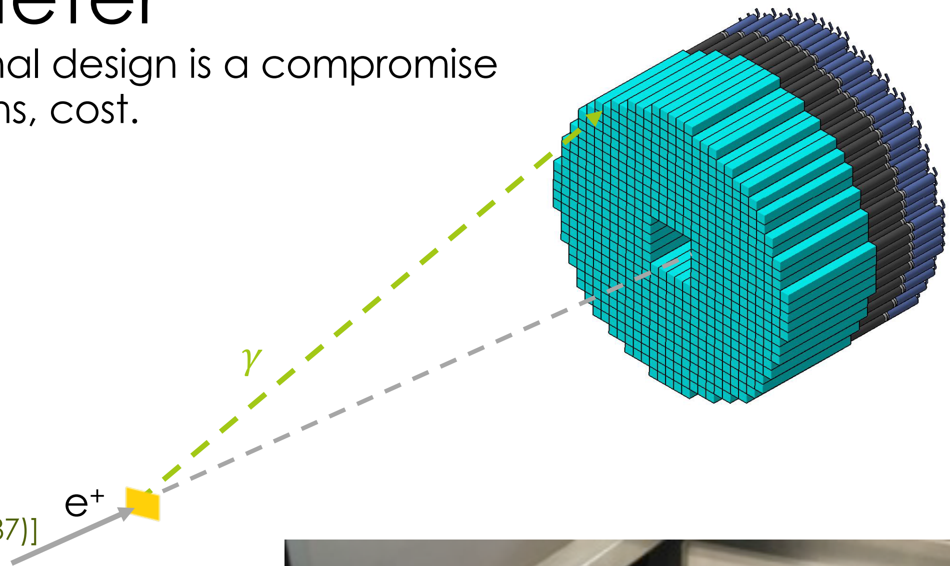
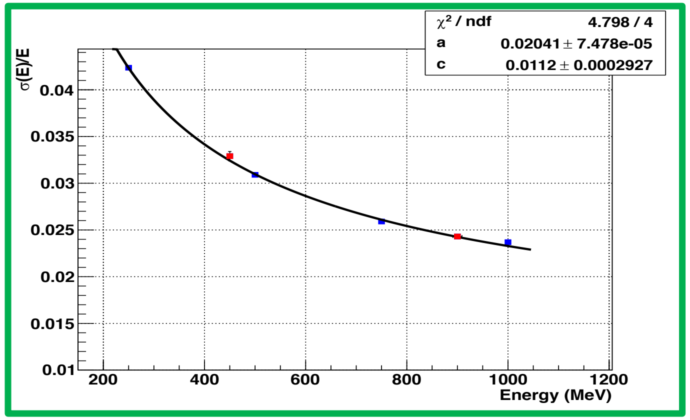
E.M. Calorimeter

This is PADME main detector. Its final design is a compromise between performance, dimensions, cost.

- Cylindrical shape: radius 300 mm, depth of 230 mm
  - Inner hole 60-80 mm radius
  - 616 crystals **$21 \times 21 \times 230$ mm^3**
- Material BGO: high LY, high ρ, small X_0 and MR, long τ_{decay} (L3 calorimeter obtained for free)
- Expected performance:
  - $\sigma(E)/E = 1.57\%/\sqrt{E} \oplus 0.35\%/E$
    L3 calorimeter [LAPP-EXP-95-002(95/02,rec.Apr.) 9 p. (510187)]
  - $\sigma(\theta) \sim$ 1-2 mrad
  - Angular acceptance (20 – 75) mrad

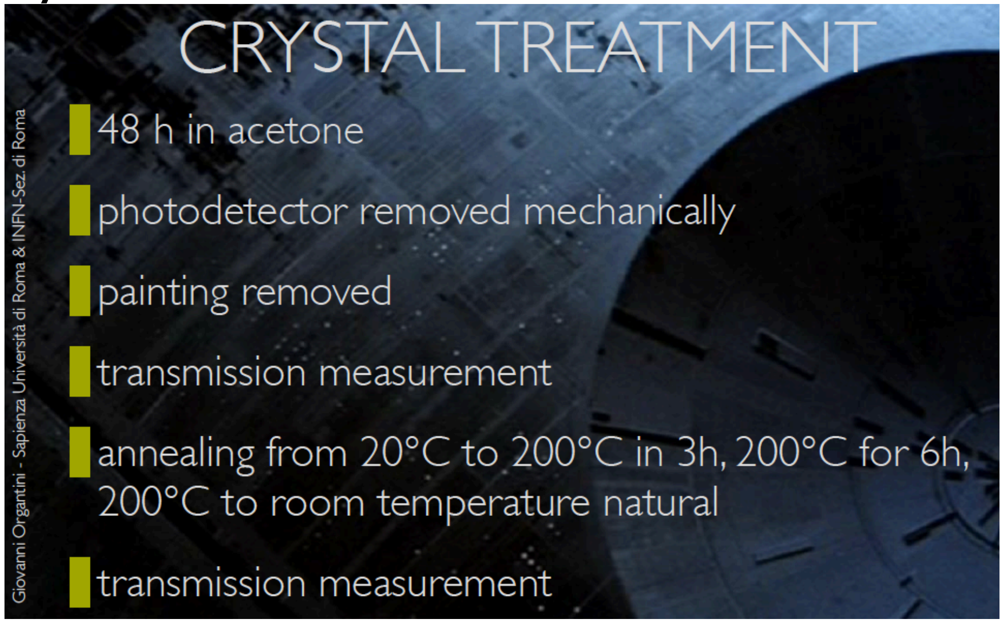


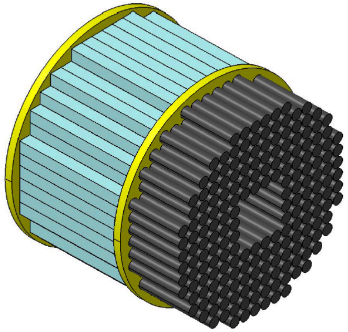


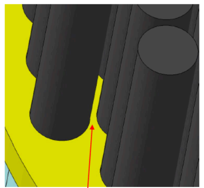
Measured energy resolution on eCal prototype with XP1912 HZC Photonics PMTs

Present activity

- L3 crystals collection and refurbishment (~ 50%)
- PMTs procurement under way. Tender ongoing
- Crystal preparation (cut and painting) defined
- Assembly procedure and global mechanical structure under study

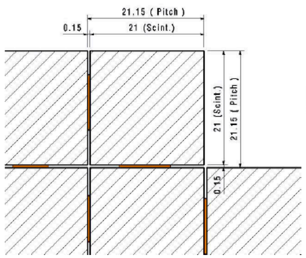


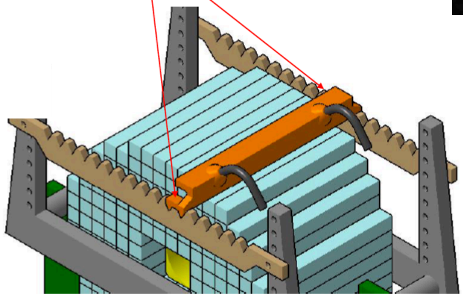


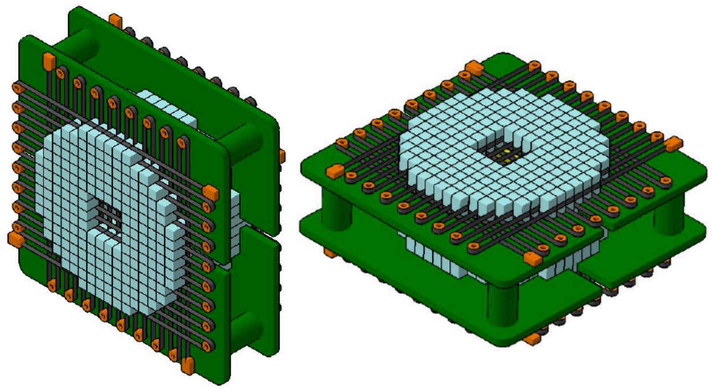


Not enough space!
Considering tollerances,
we have less than one
millimeter available.

The new crystal is added by
fixing its location (X-Y) by
the references of Jigging

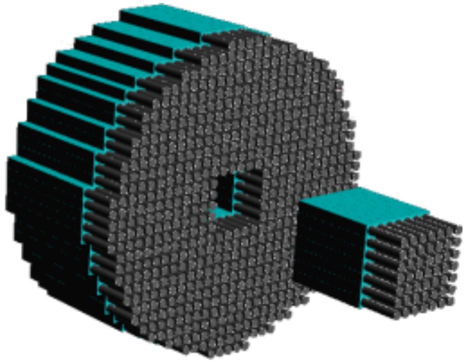






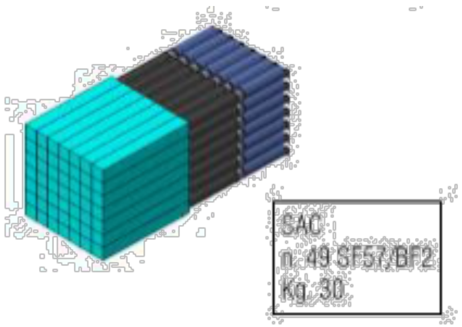
Small Angle Calorimeter

The central hole of the BGO calorimeter is necessary to cut out Bremsstrahlung photons



- A Small Angle Calorimeter (SAC) able to tolerate a rate ~ 10 clusters per 40 ns will be placed behind
- It will consist of an array of 32 crystals placed 50 cm downstream.
- It will cover $\theta < 1^0$
- Fast enough material are BaF_2 or $PbWO_4$ with a fast PMT readout
- A Cherenkov detector option is under discussion

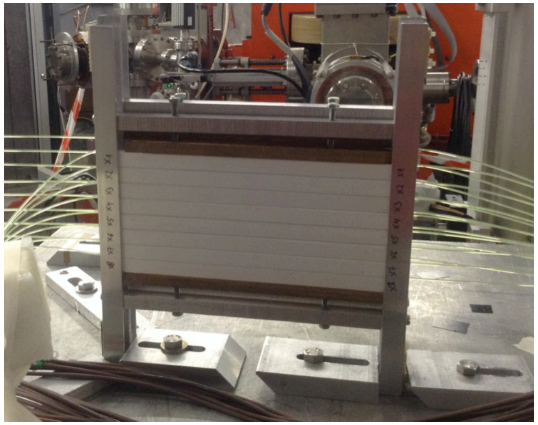
Half of the crystals and 5 PMs are available. Tests of the maximum tolerable rate and of double pulse resolution (with CAEN V1742) are foreseen for next July



Charged particle veto

To detect and veto irradiating positrons, inside the magnet (low energy e^+) and close to beam path (high energy e^+) detectors are necessary.

- Plastic scintillator bars 10×10×200 mm^3
- 3 sections for a total of 250 channels:
  - electrons (100), positrons (100), and high energy positrons (50)
- Inside vacuum and magnetic field region
- Main requirement:
  - Time resolution ≃ 300ps
  - Efficiency better than 99.5% for MIPs

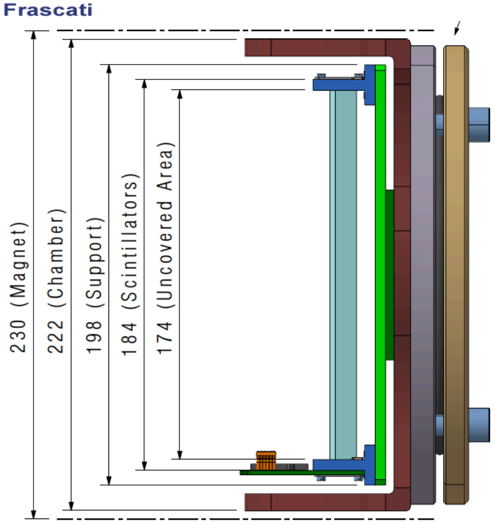


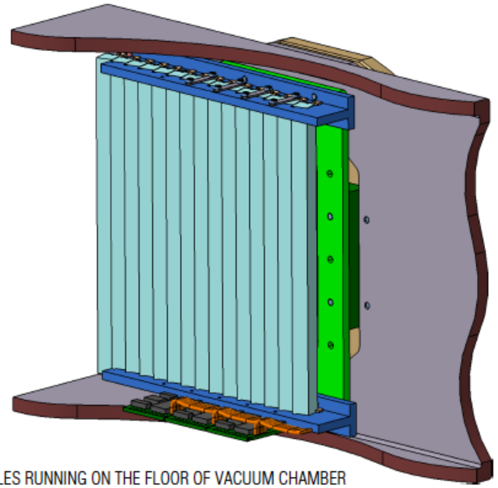
Prototype tested at BTF with multi-anode PMT and fibers

The position of the hit gives a rough estimate(~%) of the particle momentum

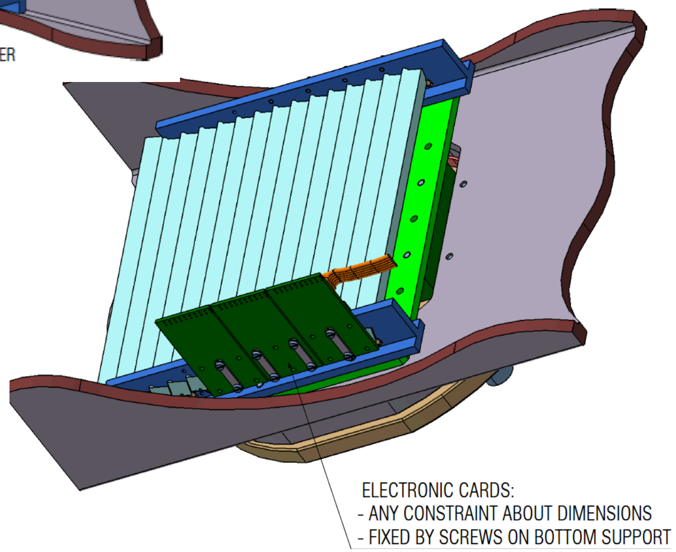
SiPM could be a good alternative for the veto read-out …

Internal veto layout



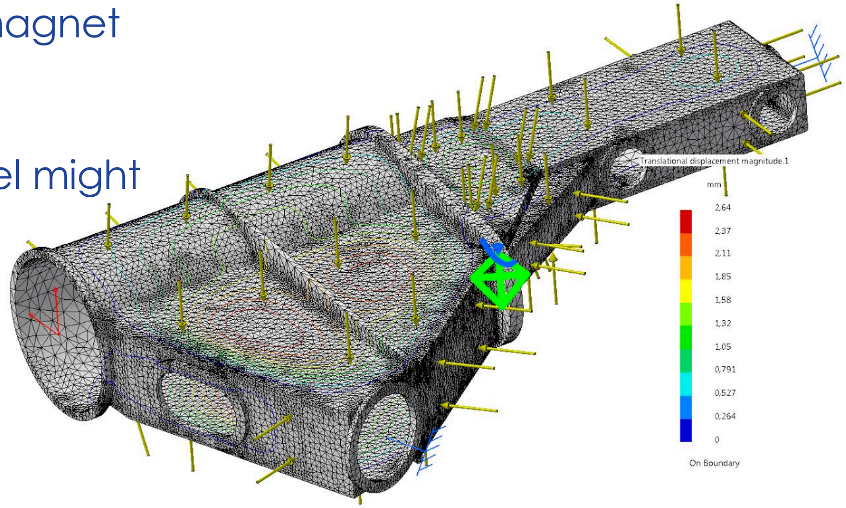


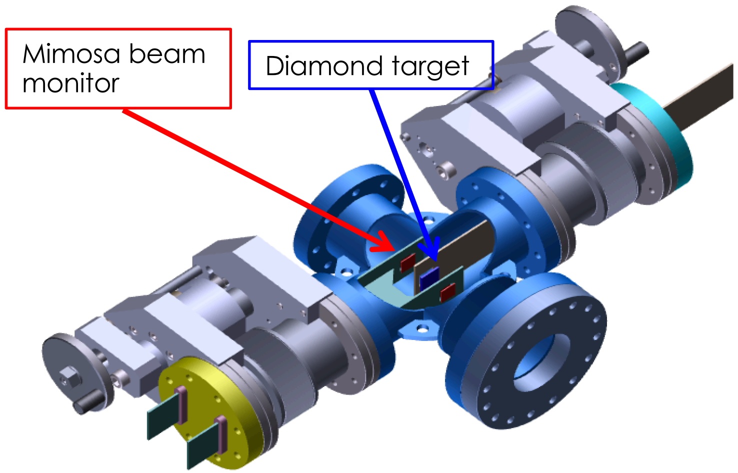
- SiPM are small and eventually can be glued directly on the scintillator bars
- Improved scintillator dimension from 16 to 18.4cm
- New clean area 17.4 vs 16 cm
- Better veto efficiency



Vacuum chamber

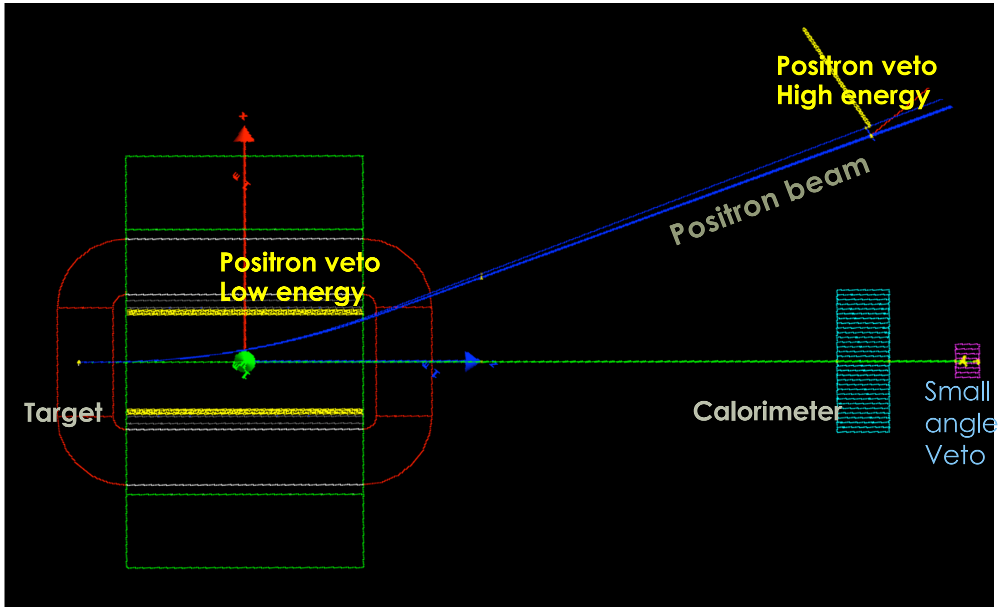
- Complex shape to follow the beam bending inside the magnet
- Vacuum requirement fixed to 10^{-4}-10^{-5} mbar
- Will include all the charged veto
- Preliminary studies indicates that 1mm stainless steel vessel might be able to sustain the pressure





Studies of the target region are started in order to include also silicon beam monitor

Monte Carlo simulations



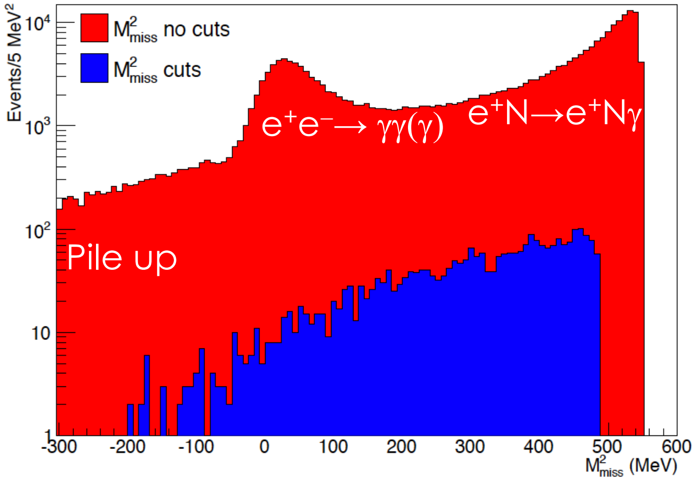
MC simulations main components

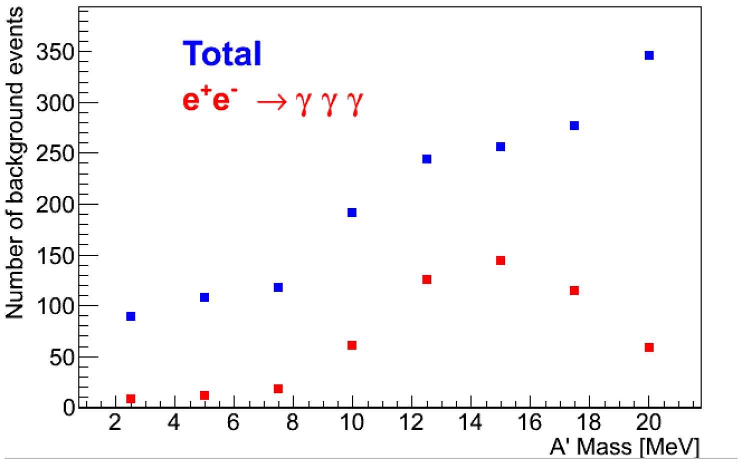
- e^+ on target simulated in GEANT4
  Dedicated MC $e^+e^- \rightarrow \gamma\gamma(\gamma)$ CalcHEP
- Dedicated *A'* annihilation generator
- Need fast simulation need 10^{11} evt
  Showers in the SAC not simulated
  Beam dumping not simulated

- Realistic treatment of the beam
  Energy spread, emittance, micro-bunching, and beam spot
- Final geometry for the detectors implemented
  Measured magnetic field map
- Still to be implemented:
  Passive material, vacuum chamber
  Detector digitization except the calorimeter clustering

Background studies

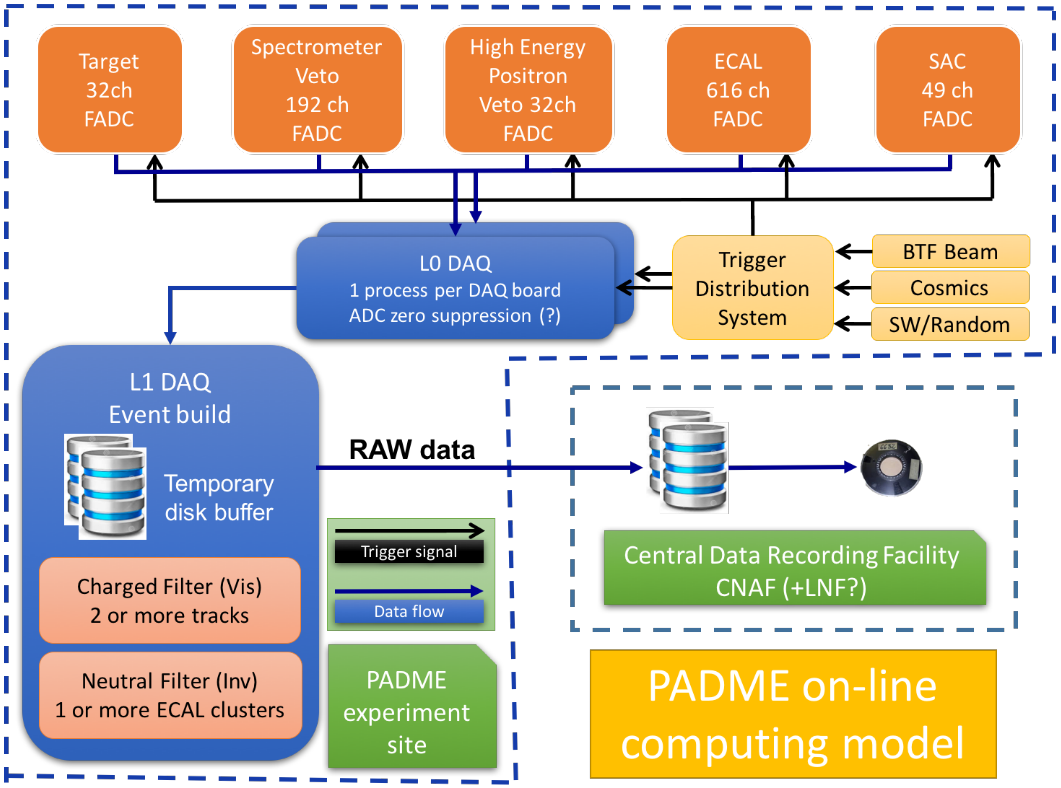
Data M_{miss}^2





- BG sources are: $e^+e^- \to \gamma\gamma$, $e^+e^- \to \gamma\gamma(\gamma)$, $e^+N \to e^+N\gamma$, Pile up
- Pile up contribution is important but rejected by the maximum cluster energy cut and M_{Miss2}.
- **Veto inefficiency at high missing mass ($E(e^+) \simeq E(e^+)$beam)**
  - New Veto detector introduced to reject residual BG
  - New sensitivity estimate ongoing

Computing



Storage

- Agreement with CNAF to use the tape library of T1
- 100TB of tapes and 10TB of disk space(buffer) for 2017
- Setup of the system to transfer data LNF → CNAF within 2016

GRID

- The VO of PADME is in operation since July 2016:

  vo.padme.org
- An area CVMFS available since September 2016
- First GRID accesses for tests in “parasitic” mode
- Possible hosting sites: CNAF, LNF, Roma1
- To be defined GRID for the production
- Sites, quantity, time-line

Reconstruction

- First full version end 2016/start 2017

The Collaboration

INFN Lecce, Università del Salento, INFN LNF, University and INFN Roma, University of Sofia ≈ 30 people

In September 2016 signed mutual agreement of collaboration with MTA Atomki from Hungary

- Exchange of researchers students
- Last 3 years
- Defining the Atomiki collaboration to PADME and the contribution they would give

Contacts are ongoing with Cornell in the framework of MAECI project PGR-226.

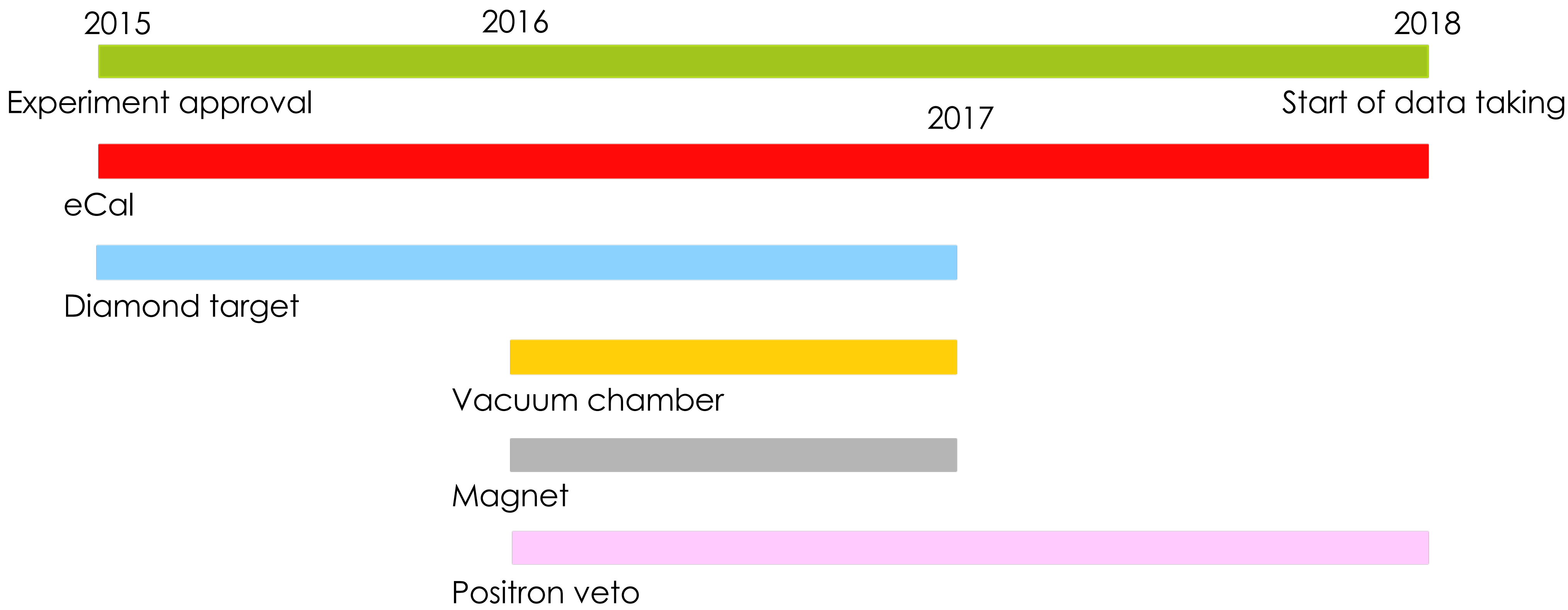
- Joint workshop in Messina this week
- Joint test-beam in November at BTF (MMAPS CsI calorimeter)

Mutual agreement can be signed (on the model of Sofia or Atomki) with CLASSE

- Exchange of researchers students
- Defining:
  - Cornell collaboration to PADME
  - Possibility of a PADME' moving the detector to the 5.3 GeV positron beam in Cornell …
  - … or possible contribution to MMAPS experiment
- In any case the extraction line from CESR ring is needed

PADME schedule

Technical run in late 2017 and first physics run in 2018



LNF Scientific Committee recommendation

This is an extract from the report of the 51st LNF Scientific Committee (23-24 May 2016)

PADME has full support from LNF management

4. PADME

The experiment has been approved and funded. They aim at a technical run in late 2017 and a physics run in 2018. The various detector elements are in preparation. A prototype of the target has been tested. The SPS transport magnet has been delivered at LNF and tested. The scintillators for the charged particle veto have been produced. The design for the vacuum vessel has been completed. The authorization to re-use the crystals of the L3 calorimeter for the PADME calorimeter has been obtained and a plan for their recovery has been established.

4.1 Recommendations

The SC takes note with satisfaction of the approval and funding of the experiment. The schedule for the detector construction is quite aggressive and will require support form the Laboratory. It is important that PADME be ready to take data when KLOE will stop the data taking in order to efficiently use the gap between the end of KLOE and the start of SIDDHARTA.

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Conclusions

The PADME construction phase is started

- Magnet delivered, modified and measured at LNF
- Diamond target prototype tested (20x20mm^{2}x50μm thickness)
- Ecal test beams showed that the needed energy resolution is achieved
- Full detector design is ongoing
- Material and electronics procurement started
- The collaboration is growing…

PADME is ready to test the DARK SECTOR…

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Backup

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Table 34.4: Properties of several inorganic crystals. Most of the notation is defined in Sec. 6 of this *Review*.

Parameter:	ρ	MP	X_0^*	R_M^*	dE^*/dx	λ_I^*	τ_{decay}	λ_{max}	$n^\natural$	Relative output†	Hygro-scopic?	$d(\mathrm{LY})/dT$
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(Na)	4.51	621	1.86	3.57	5.6	39.3	690	420	1.84	88	yes	0.4
CsI(pure)	4.51	621	1.86	3.57	5.6	39.3	30^s	310	1.95	3.6^s	slight	−1.4
							6^f			1.1^f		
$PbWO_4$	8.30	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
PbF_2	7.77	824	0.93	2.21	9.4	21.0	-	-	-	Cherenkov	no	-
CeF_3	6.16	1460	1.70	2.41	8.42	23.2	30	340	1.62	7.3	no	0
$LaBr_3$(Ce)	5.29	783	1.88	2.85	6.90	30.4	20	356	1.9	180	yes	0.2
$CeBr_3$	5.23	722	1.96	2.97	6.65	31.5	17	371	1.9	165	yes	−0.1

Background cross-sections

Table 1: *Dominant background contributions to the missing mass technique*

Background process	σ ($E_{beam} = 550$ MeV)	Comment
$e^+e^- \to \gamma\gamma$	1.55 mb	
$e^+N \to e^+N\gamma$	4000 mb	$E_\gamma > 1MeV$, on carbon
$e^+e^- \to \gamma\gamma\gamma$	0.16 mb	$E_\gamma > 1MeV$, CalcHEP [16]
$e^+e^- \to e^+e^-\gamma$	188 mb	$E_\gamma > 1MeV$, CalcHEP

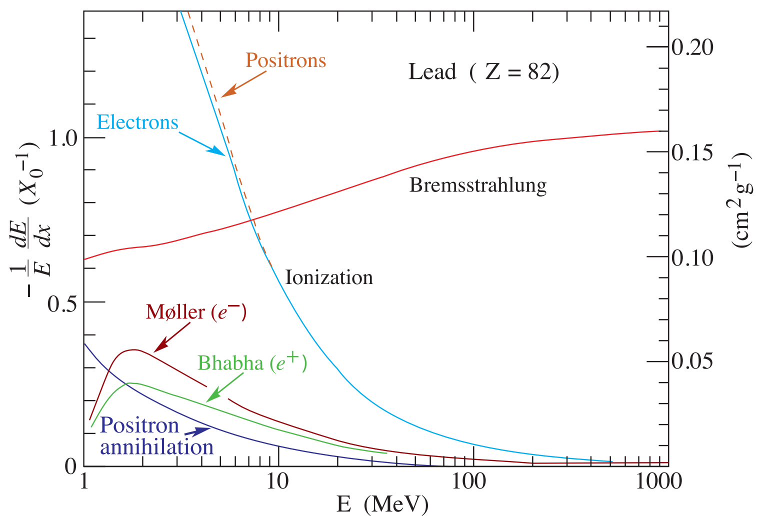
Different experiments exploiting missing mass technique

	PADME	MMAPS	VEPP3
Place	LNF	Cornell	Novosibirsk
Beam energy	550 MeV	Up to 5.3 GeV	500 MeV
$M_{A'}$ limit	23 MeV	74 MeV	22 MeV
Target thickness [e^-/cm^2]	2×10^{22}	$O(2 \times 10^{23})$	5×10^{15}
Beam intensity	8×10^{-11} mA	2.3×10^{-6} mA	30 mA
$e^+e^- \to \gamma\gamma$ rate [s^{-1}]	15	2.2×10^6	1.5×10^6
ϵ^2 limit (plateau)	10^{-6}	10^{-6} - 10^{-7}	10^{-7}
Time scale	2017-2018	?	2020 (ByPass)
Status	Approved	Not funded	Proposal

Both MMAPS and VEPP3 will use CsI crystals from CLEO. $\sigma(E)/E = 3\%/\sqrt{E}$ @ 180 MeV

INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Bremsstrahlung



$$-\langle \frac{dE}{dx} \rangle \approx \frac{4N_a Z^2 \alpha^3 (\hbar c)^2}{m_e^2 c^4} E \ \ln \frac{183}{Z^{1/3}}$$

N_a number of atoms per unit of volume,
Z atomic number