Towards the start of the data taking

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for the PADME experiment

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LNF scientific committee

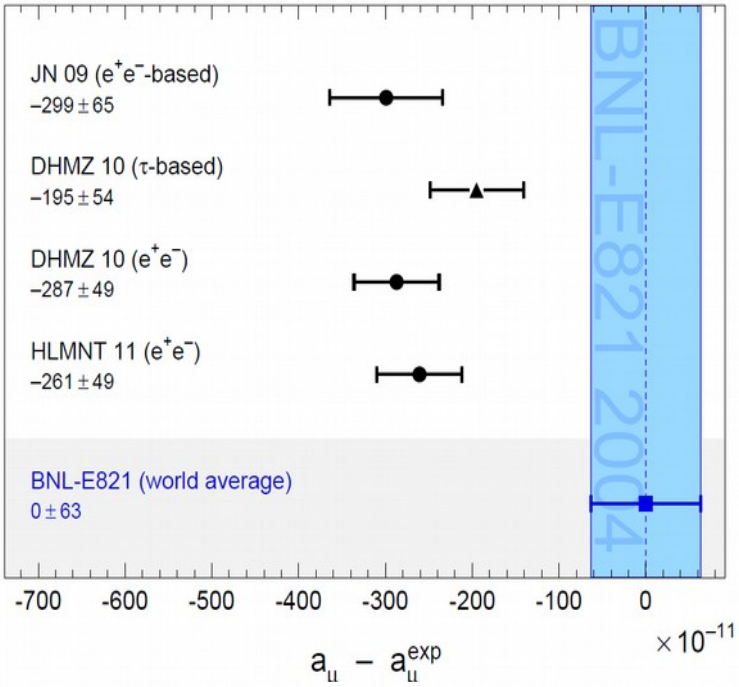
14.05.2018

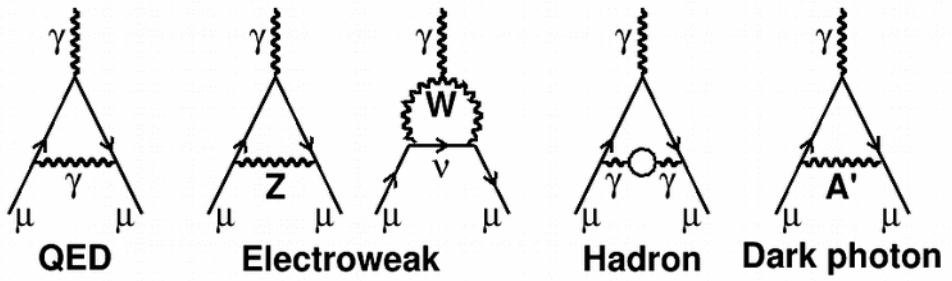
** partially supported by BG NSF, DN08-14/14.12.2016*
& LNF-SU 70-06-497/07-10-2014

Outline

- Motivation
- Technique
- Detector construction
- PADME physics case

Why Dark Photon?





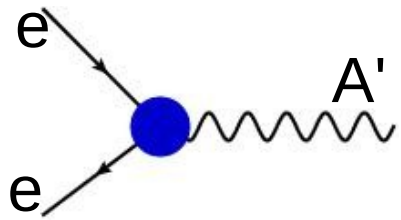
- About 3 σ discrepancy between theory and experiment (3.6 σ, if taking into account only $e^+e^- \rightarrow$ hadrons)

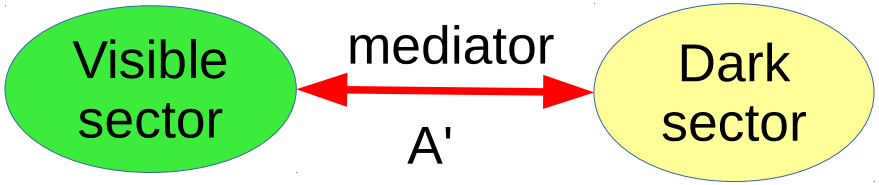
$$a_\mu^{\text{dark photon}} = \frac{\alpha}{2\pi}\varepsilon^2 F(m_V/m_\mu)\,, \qquad (17)$$

where $F(x) = \int_0^1 2z(1-z)^2/[(1-z)^2 + x^2 z]\,dz$. For values of $\varepsilon \sim 1\text{–}2 \cdot 10^{-3}$ and $m_V \sim 10\text{–}100\,\text{MeV}$, the dark photon, which was originally motivated by cosmology, can provide a viable solution to the muon $g-2$ discrepancy. Searches for the dark

Why Dark Photon?

- The effective interaction that can be studied is





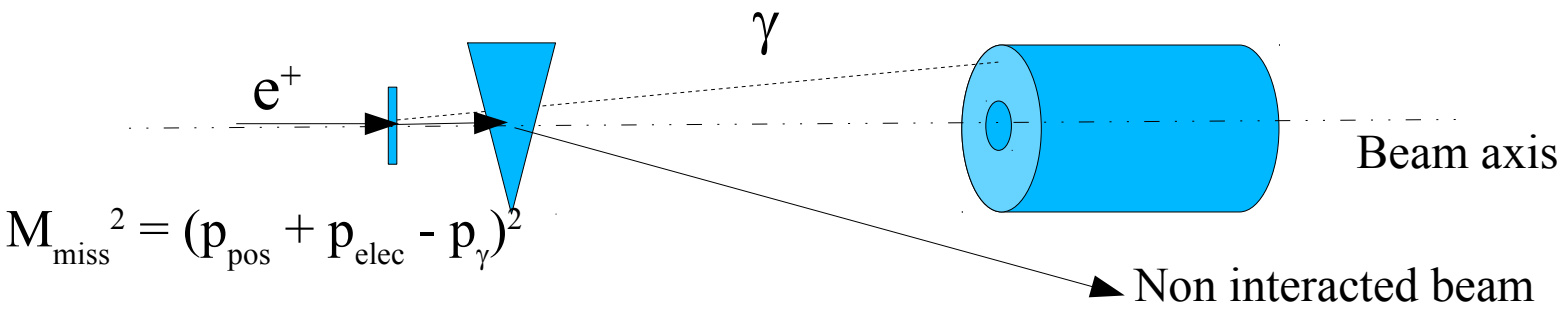
$$\mathcal{L} \sim g' q' \, \overline{\Psi} (\gamma_\mu + \alpha'_a \gamma_\mu \gamma^5) \Psi A'^\mu, \;\; usually \; \alpha'_a = 0$$

  - $q_f \rightarrow 0$ for some flavours
- Textbook scenario, could address the (g_μ-2) discrepancy, abundance of antimatter in cosmic rays, signals for DM scattering
  - **General U'(1) and kinetic mixing with B (A', Z')**
    - Universal coupling proportional to the q_{em}
    - Just single additional parameter – ε

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

  - **Leptophilic/leptophobic dark photon**
    - **„Gauging“ SM accidental symmetries: (e.g. Lμ - Lτ , B – L)**
- Related to Dark matter and its interactions

A' in annihilation

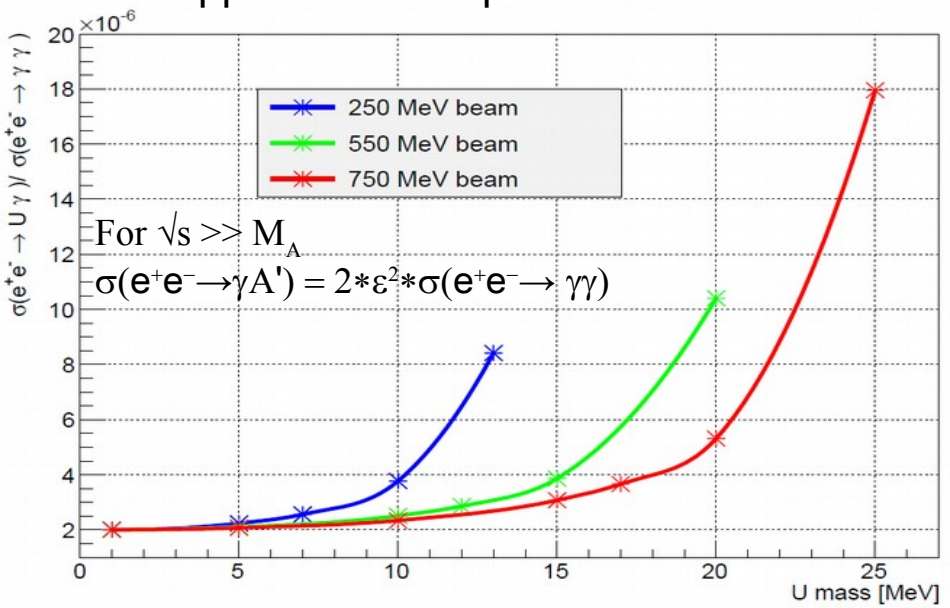


- Positron beam on a thin target
- Positron momentum is determined by the accelerator characteristics
- Missing mass resolution: annihilation point, E_γ, φ_γ

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

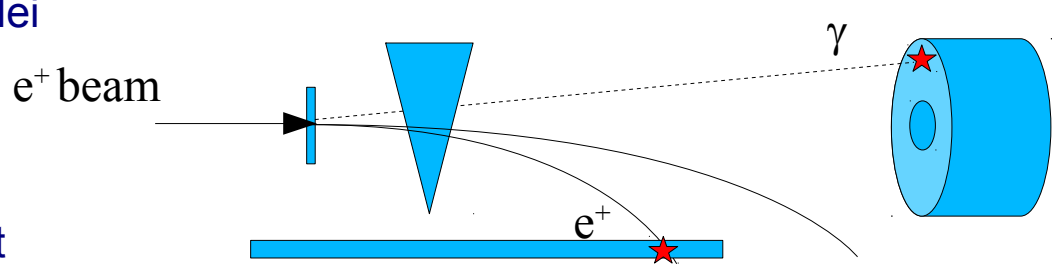
- Clear 2 body correlation
- Background minimization
  - Best possible resolution on energy/angle measurement
  - **Dominant process in e+/e- interactions with matter is bremsstrahlung**
  - Photons vetoing
  - Minimize the interaction remnants + vetoing

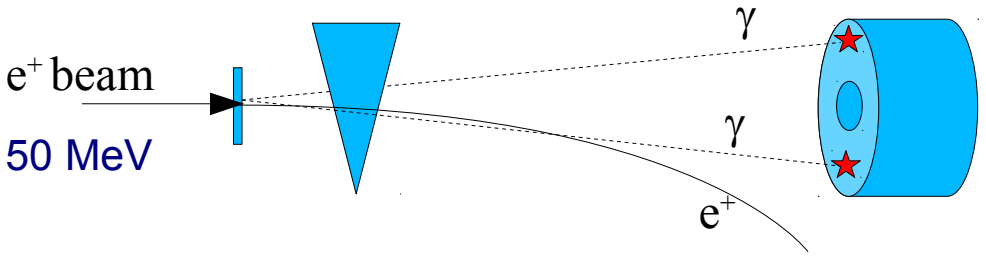
Cross section enhancement with the approach of the production threshold

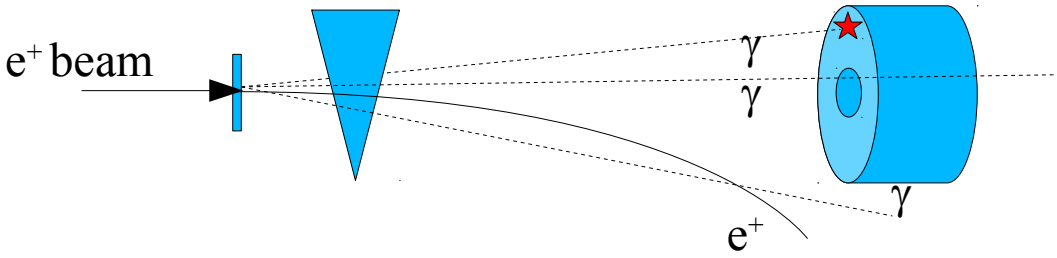


Backgrounds

- Bremsstrahlung in the field of the target nuclei
  - Photons mostly @ low energy, background dominates the high missing masses
  - An additional lower energy positron that could be detected due to stronger deflection
- 2 photon annihilation
  - Peaks at $M_{miss} = 0$
  - Quasi symmetric in gamma angles for $E\gamma > 50$ MeV
- 3 photon annihilation
  - Symmetry is lost – decrease in the vetoing capabilities
  - Does not peak
- Radiative bhabha scattering
  - Topology close to bremsstrahlung



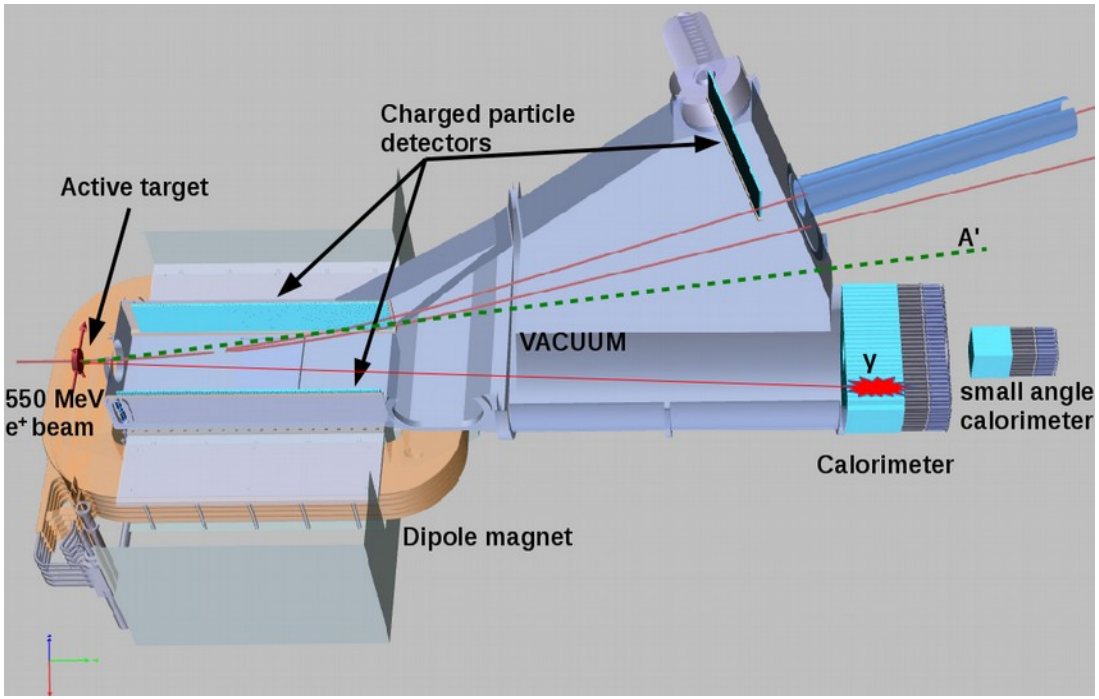




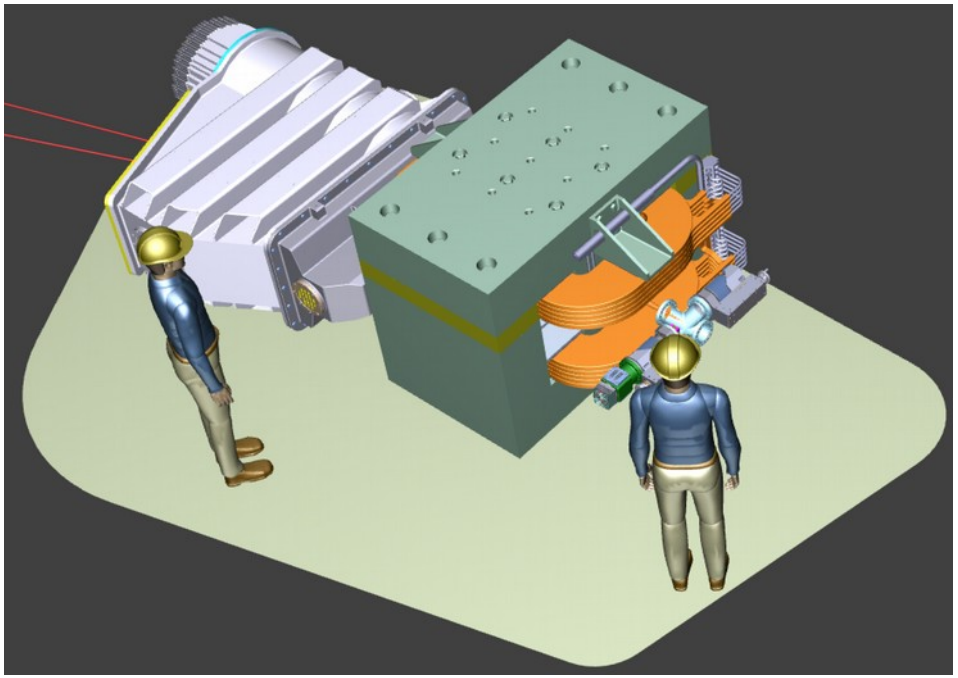
PADME

Positron Annihilation into Dark Matter Experiment

Adv. HEP 2014 (2014) 959802



- Small scale fixed target experiment
  - e^+ @ Frascati Beam test facility
  - Solid state target
  - Charged particles detectors
  - Calorimeter



Sensitivity

2.5×10^{10} fully GEANT4 simulated 550MeV e+ on target events

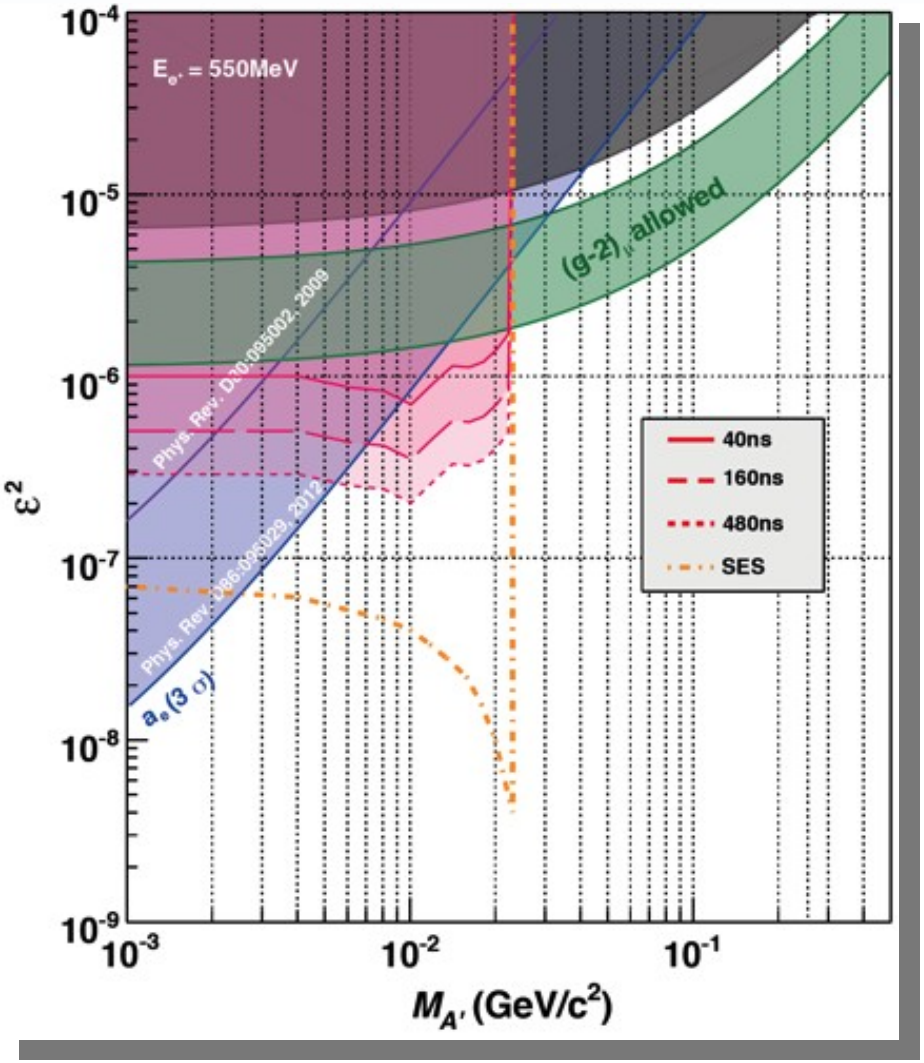
Number of BG events is extrapolated to 1×10^{13} electrons on target

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

PADME:

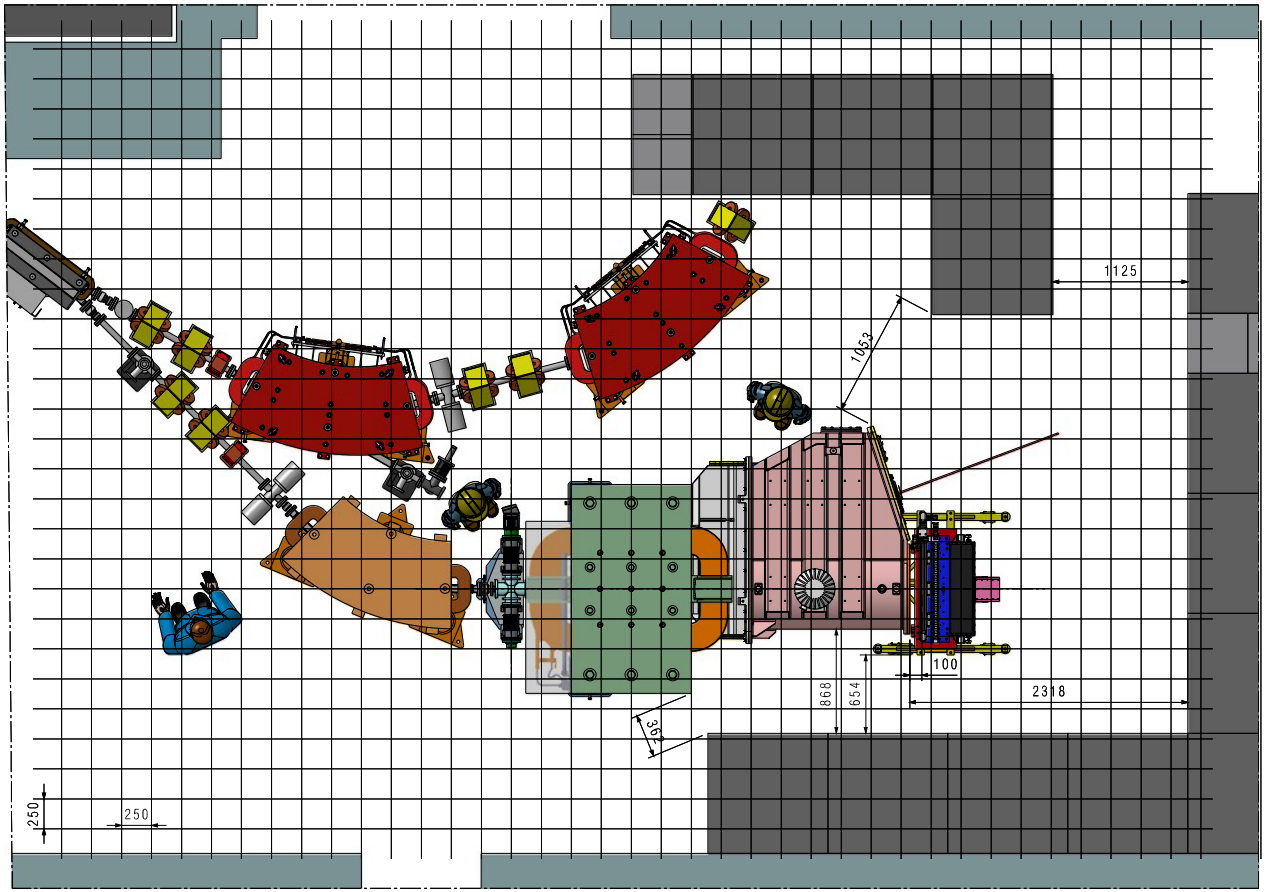
2 years of data taking at 60% efficiency with bunch length of 200 ns

4×10^{13} EOT = **20000 e^+**/bunch × 2 × **$3.1 \cdot 10^7$**s x 0.6 · **49 Hz**

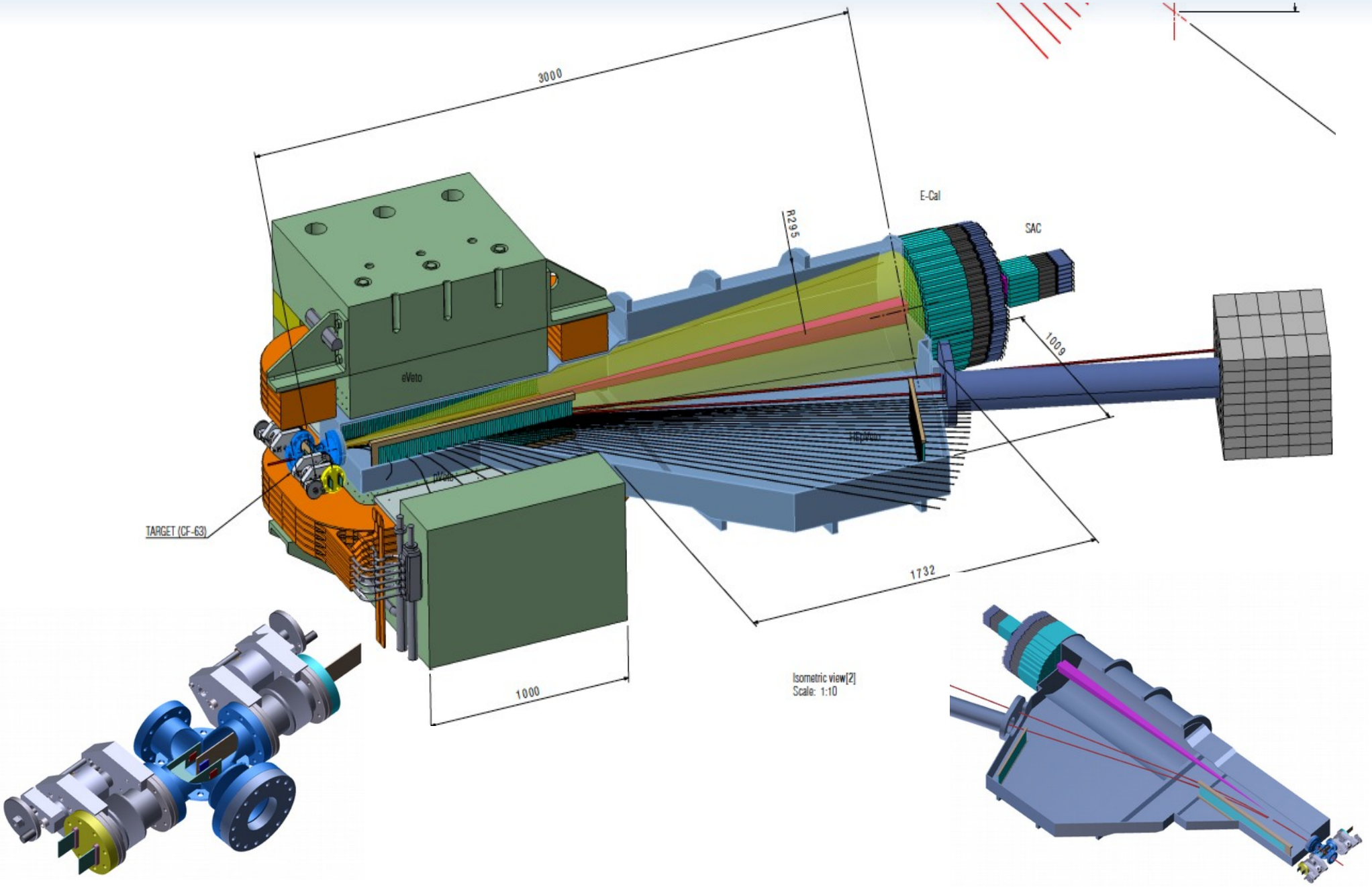


PADME @ BTF

	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	

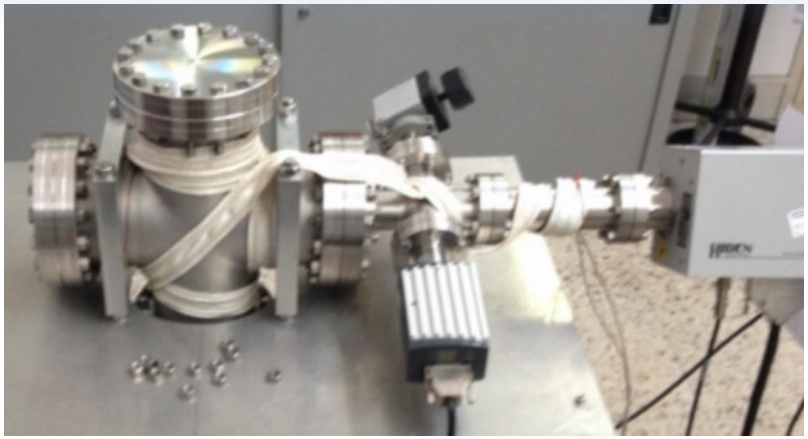


Construction

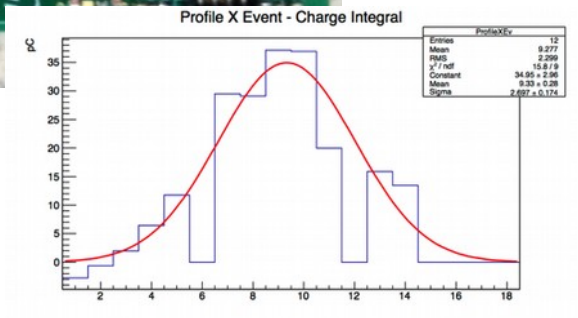


Diamond target

G. Chiodini et al., Lecce



Motorized support structure ready vacuum tests performed



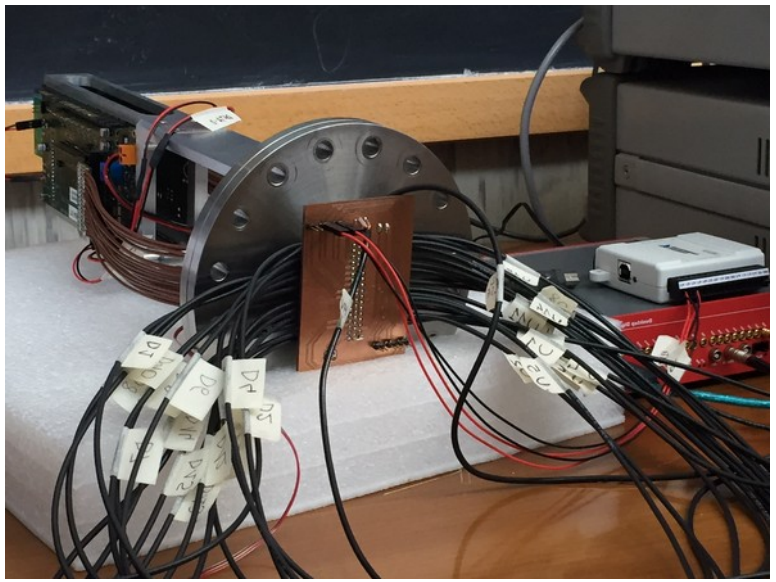
Polycrystalline diamonds

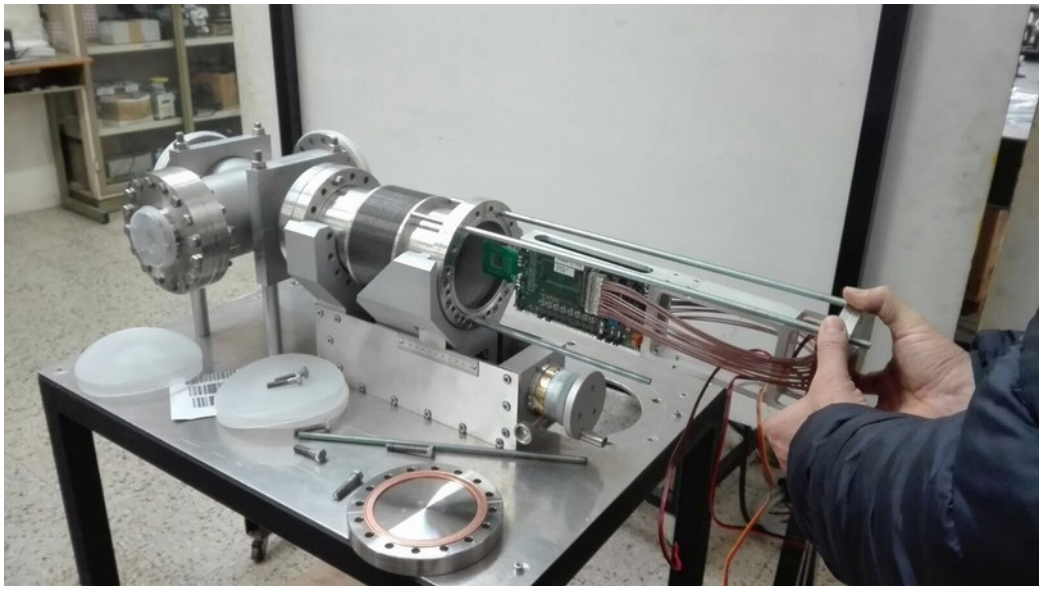
- 100 μm thickness:
- 16 × 1 mm strip and X-Y readout in a single detector
- Samples with graphitized and metallized strips available
- PADME prototype 20 × 20 mm^2 produced and tested 2015
- Low noise CSA integrated in the 16 channel chip AMADEUS from IDEAS

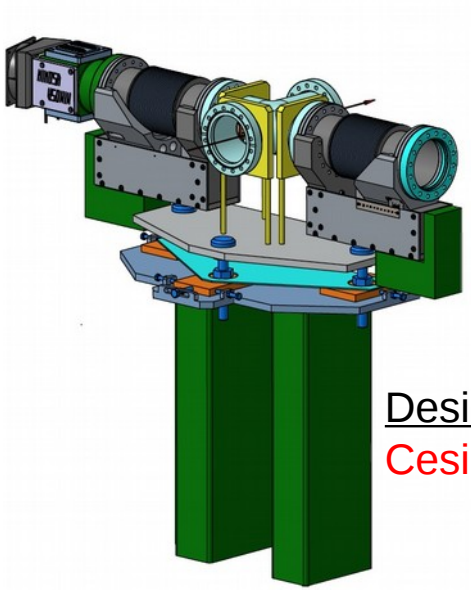
- Test beam results (~5000 e):
  - **good efficiency**
  - resolution on the position of the beam center **< 0.2 mm**
- FE electronics defined

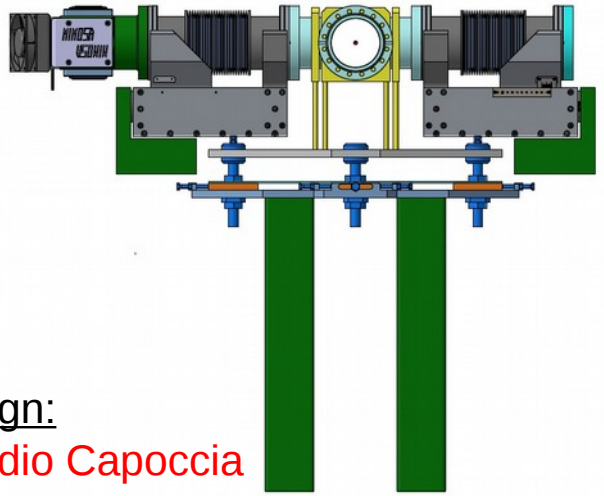
Diamond target

G. Chiodini et al., Lecce









Design:
Cesidio Capoccia

TARGET & MIMOSA SUPPORT
PLATFORM - UPPER PART

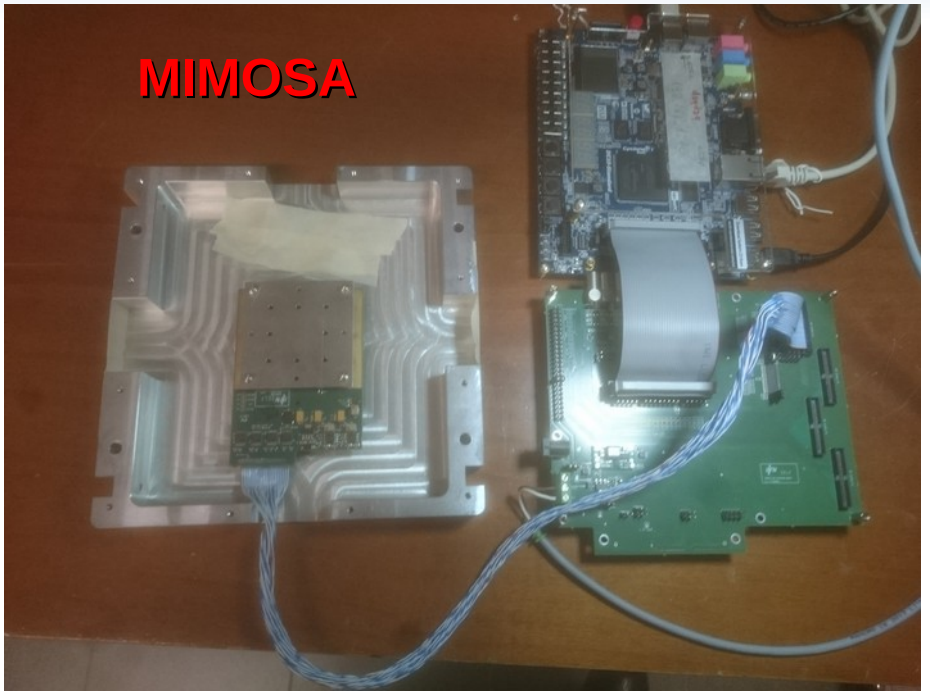
- Ready to move to BTF
- Final commissioning and calibration are being planned
- Noise studies with HV connections
- DCS and DAQ system are ready

Thanks to: Maria Ionica and G. Ambrosi (INFN Perugia) for the sensor wirebonding

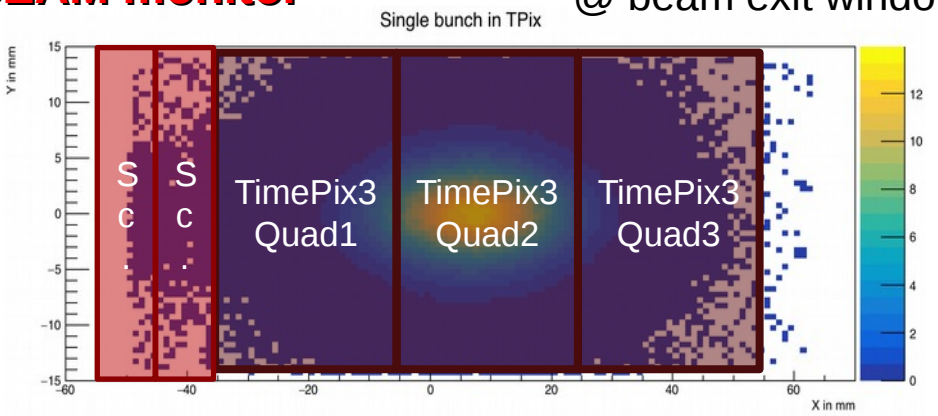
Beam measurement

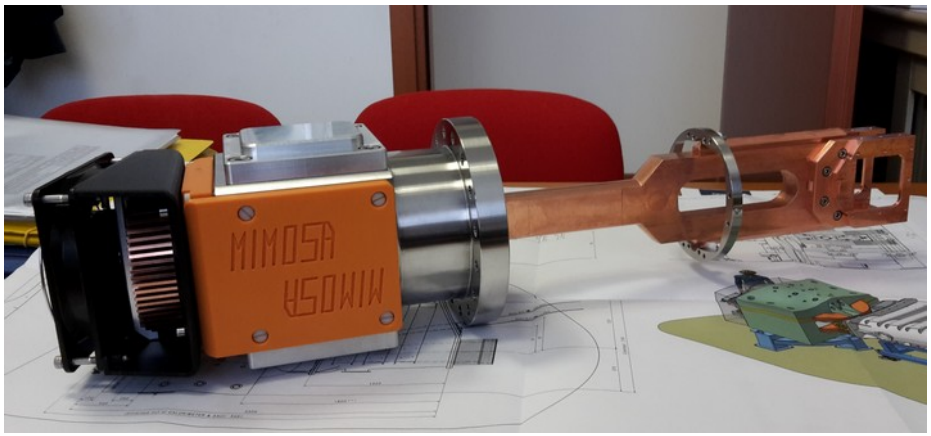
E. Spiriti

- 3 sensors out of 4 set up and tested
  - All 4 available in the lab
  - 1 tested with beam
- DAQ system is ready
  - Data extraction is correct
- Mechanics is ready
- Items towards finalization
  - Thermal dissipation test and certification
    - Power consumption is 0.7 W / sensor → 1 W per board
    - 4 boards in total
  - Firmware for temperature reading to be debugged



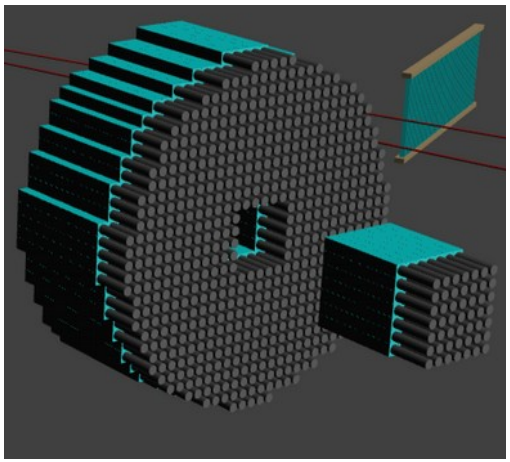
BEAM monitor @ beam exit window

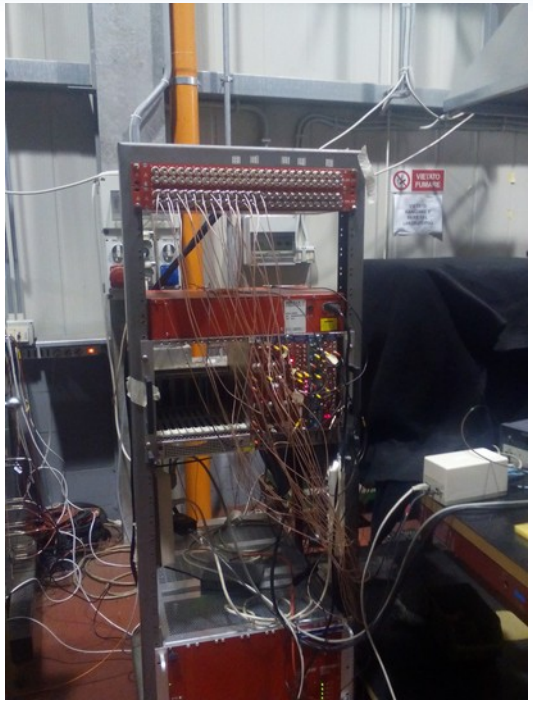


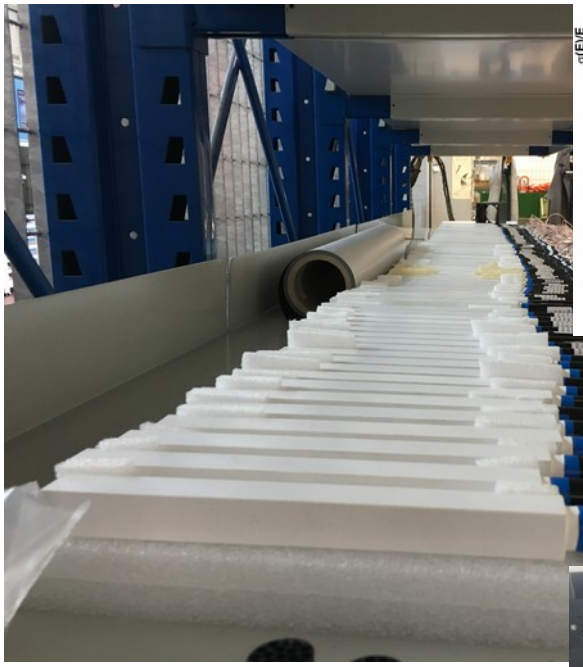


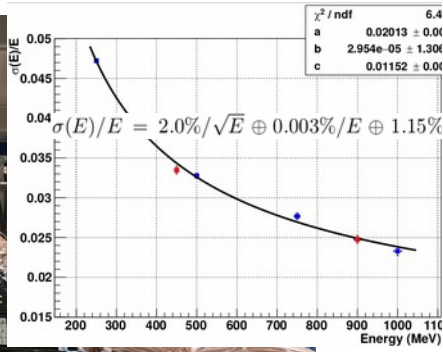
Calorimeter

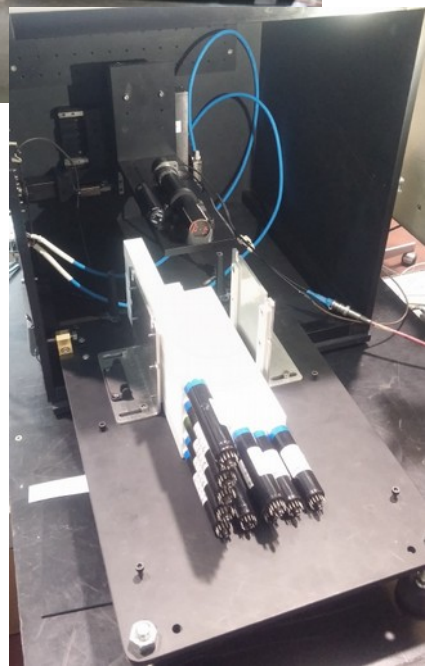
616 BGO crystals,
2.1 x 2.1 x 23 cm^3







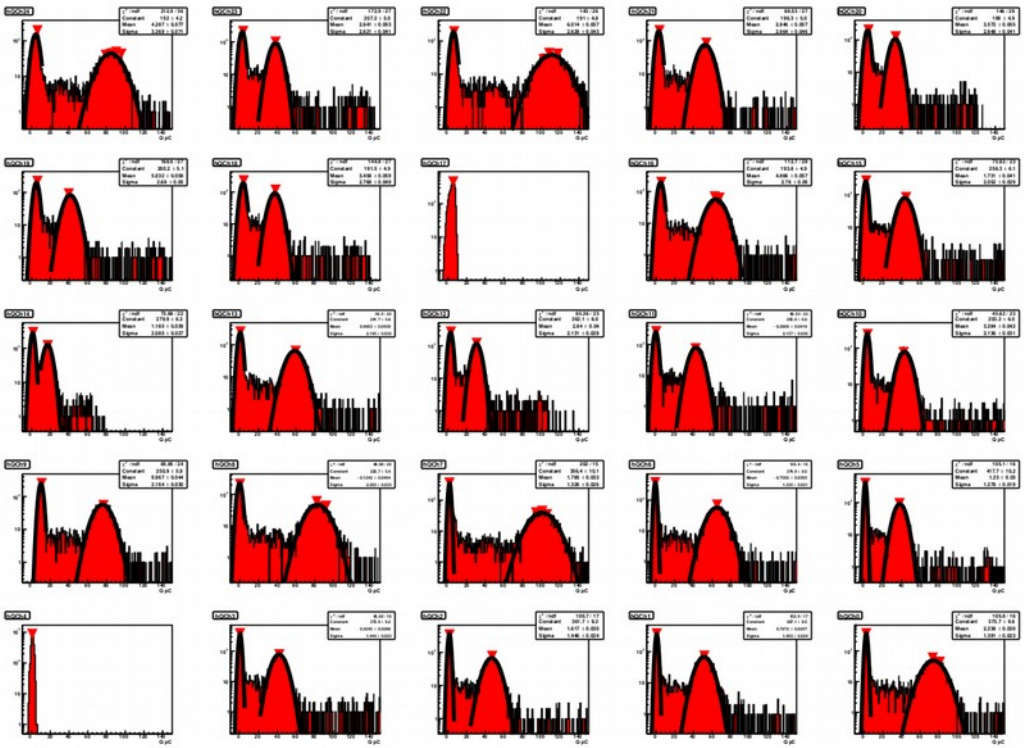


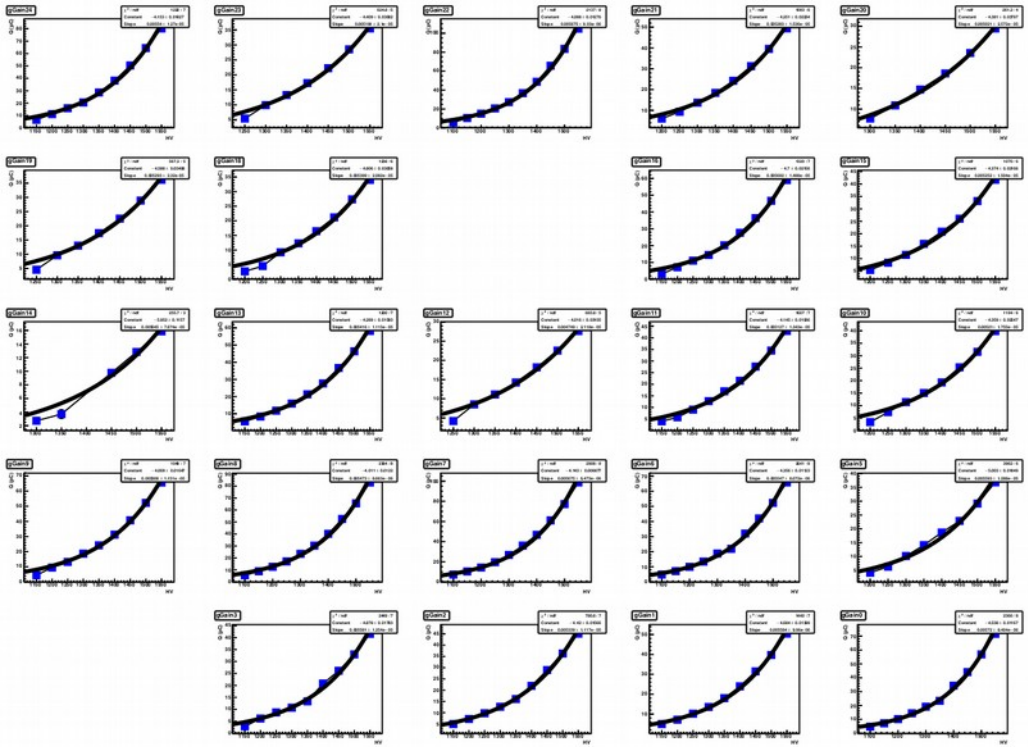


- The necessary crystal-PMT assemblies were delivered and are being tested
- Quasi-automatic testing and calibration system designed and in exploitation
  - Using ^{22}Na source with a tagged 511 keV photon
  - Testing proceeds in bunches of 25 crystals
    - Step motor position of the source
  - Reconstructing the gain curve and calibration to 15 pC/MeV

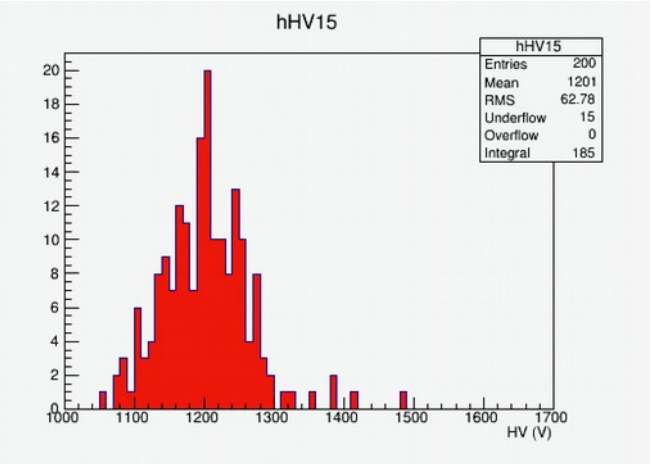
Crystals test

G. Piperno and C. Taruggi LNF

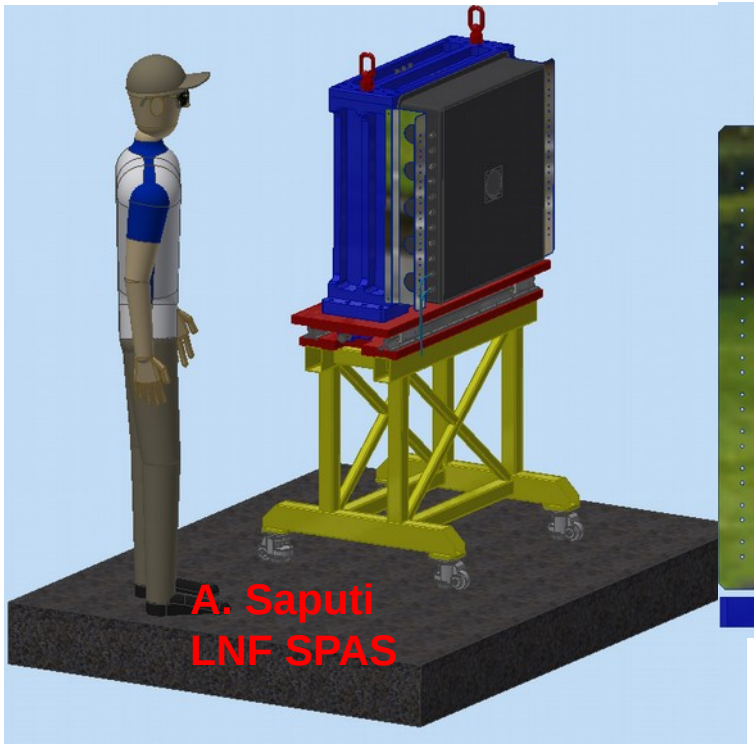


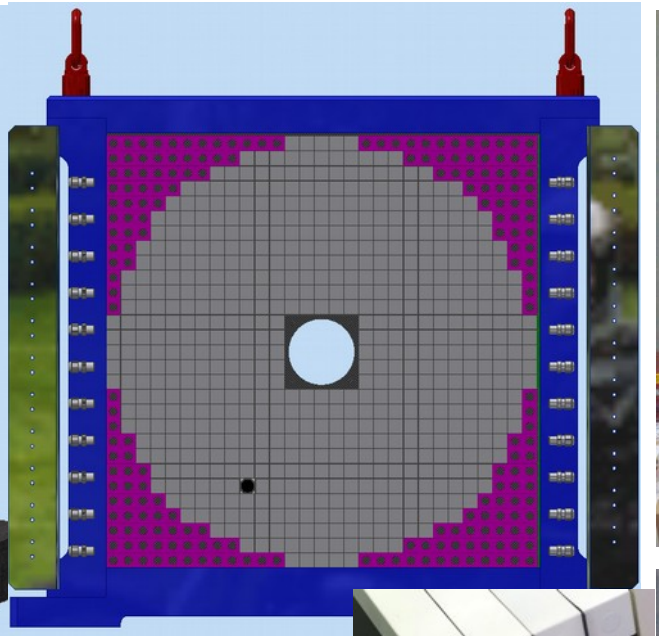


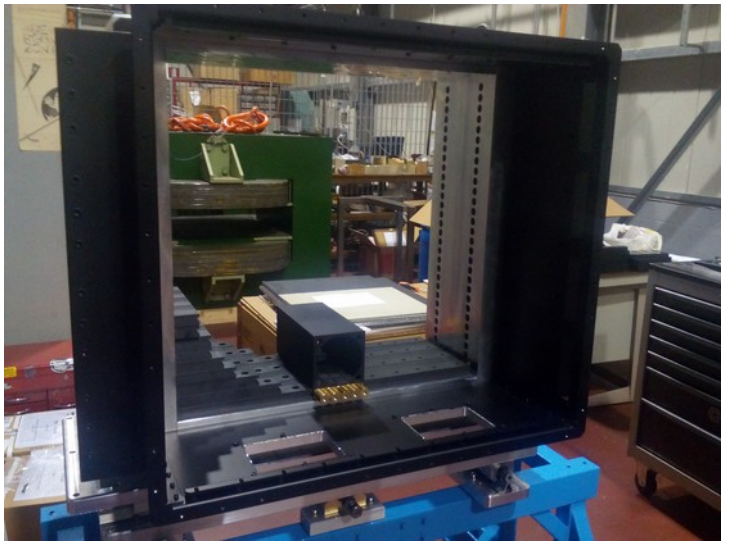
- 250 crystal+PMT already tested
  - 40% of the total number of crystals to be checked
- Failure rate: < 5 %
  - mostly due to HV divider problems
  - repairable

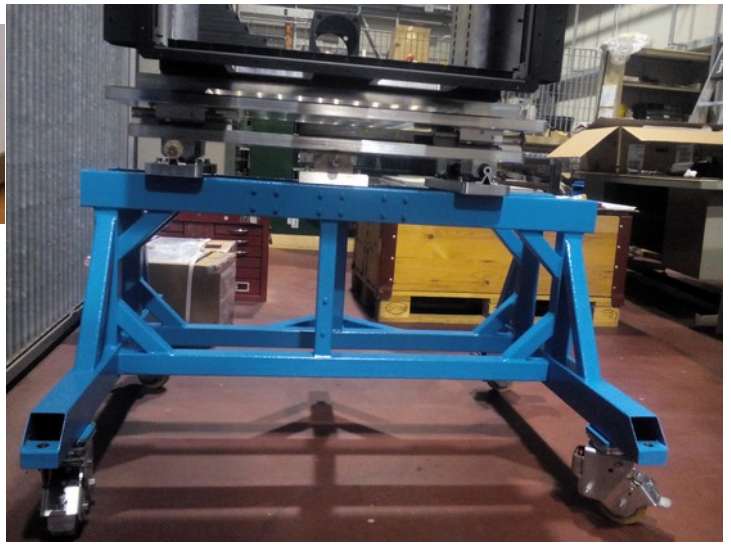


Calorimeter construction





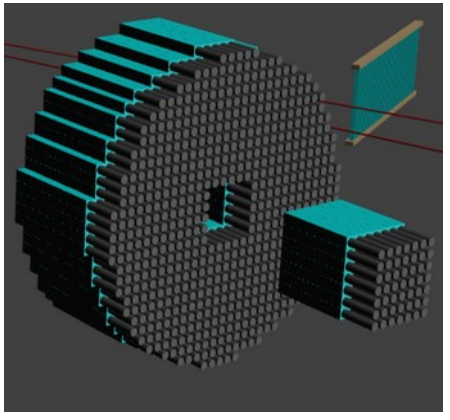


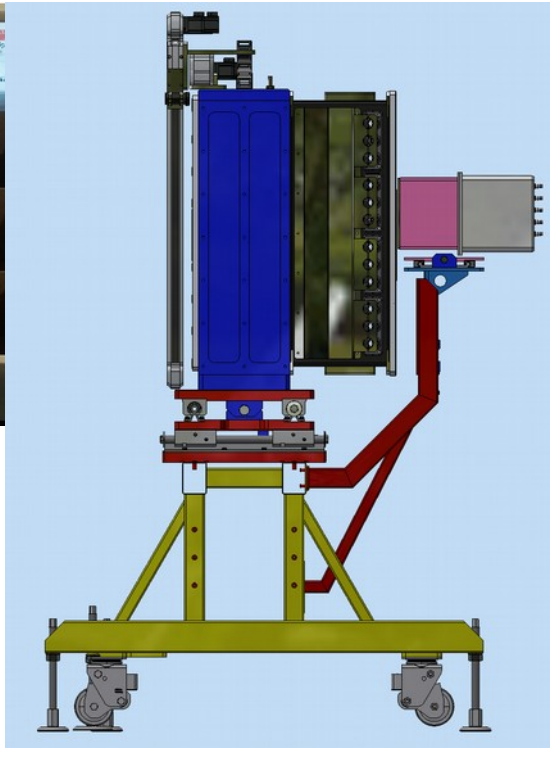


- The major mechanical components for the calorimeter are ready (RM3 & LNF workshops)
- Finalization of the assembly procedure and crystals wrapping
- Initial assembly test to start soon, final assembly at BTF hall to avoid damages during transportation

Forward photon detector: SAC

- 5 x 5 matrix of PbF_2 crystals
  - 30 x 30 mm^2 front face
  - All crystals delivered to LNF
- Support mechanics attached to the ECAL one
  - Design at the final stage
  - To be produced soon
  - Most of the components are 3D printed
- Hamamatsu R13478UV-11 with custom dividers
  - Available at LNF
  - HV and RO system identical to the ECAL one
- Analysis of test beam data performed by the Cornell group

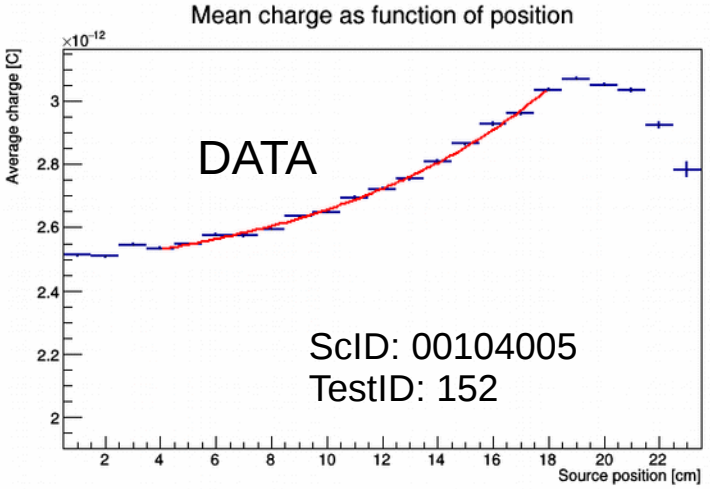


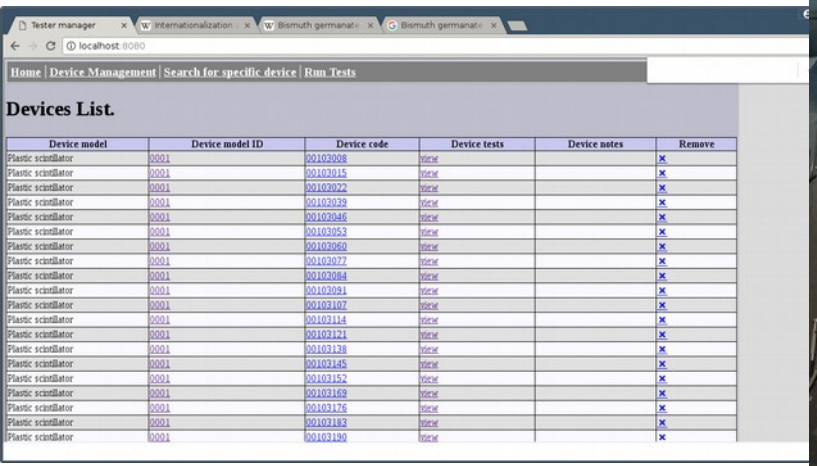


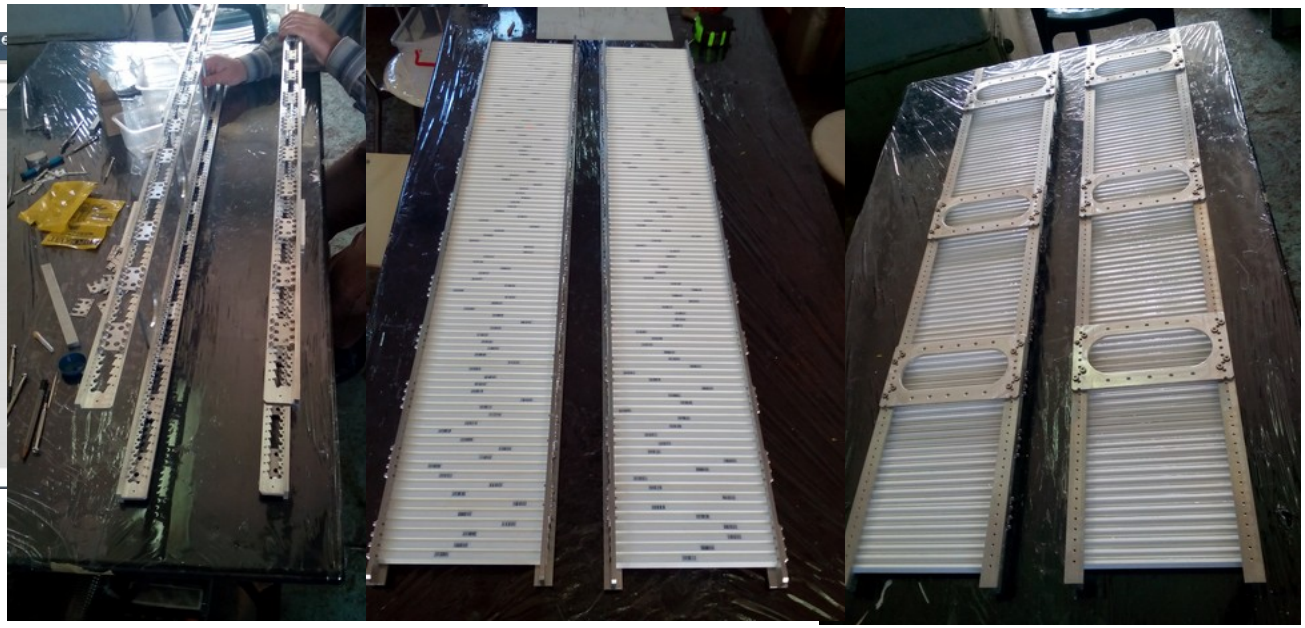
Magnet

- Magnet support already produced
- Magnet power supplies available and being tested
- Ready for transportation to BTF

Charged particle detectors

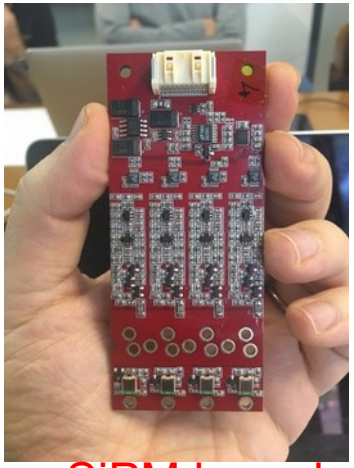


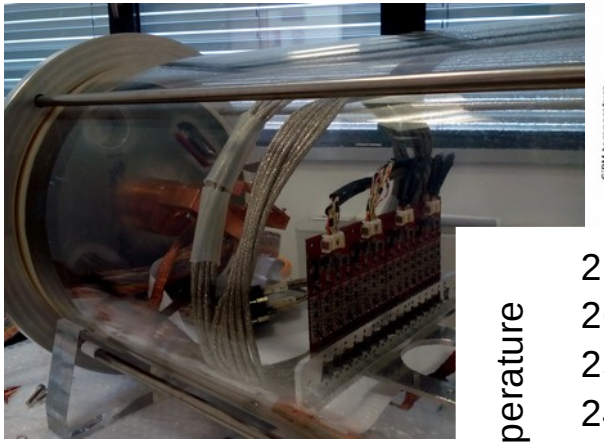


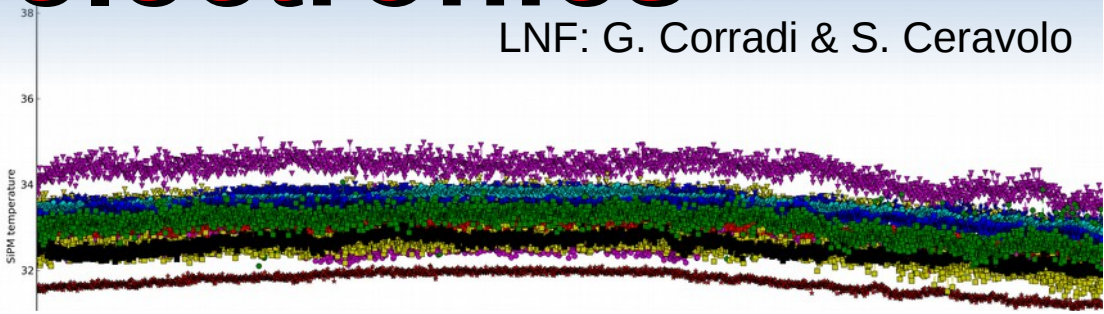


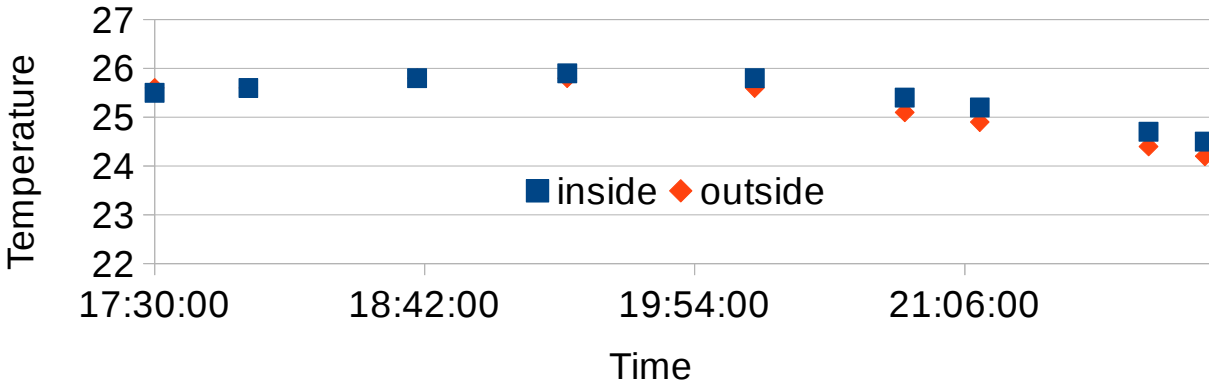
Veto FEE electronics

LNF: G. Corradi & S. Ceravolo

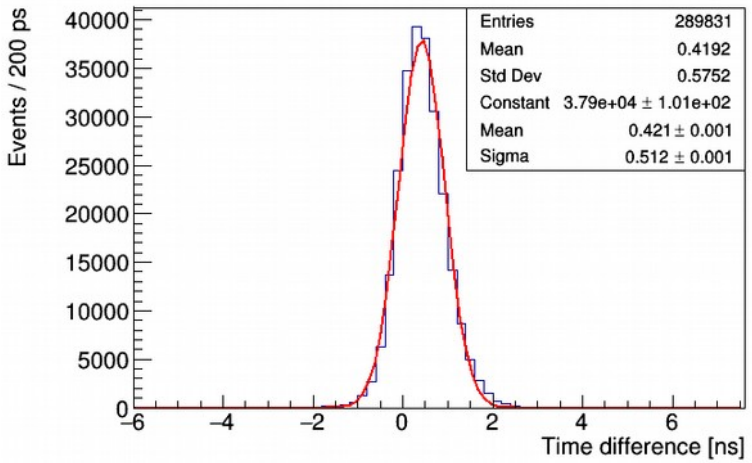








SiPM based readout

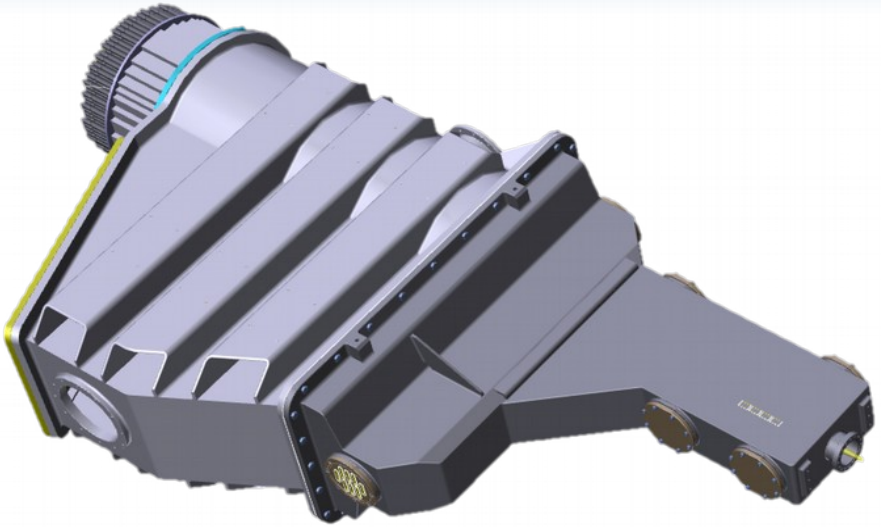


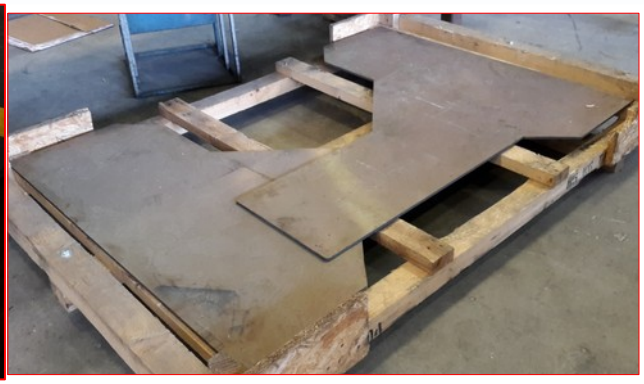
- The LV current @ 9V: **< 10 mA/channel**
- Current on the HV line (when HV is ON) is fixed to ~312 mA/channel (300 mA by specification)
- Total power consumption: ~10 W per Veto station

- 72 FEE cards and 18 controllers produced
  - Sufficient for the operation of the Vetoes
  - Internal time resolution → better than 300 – 400 ps

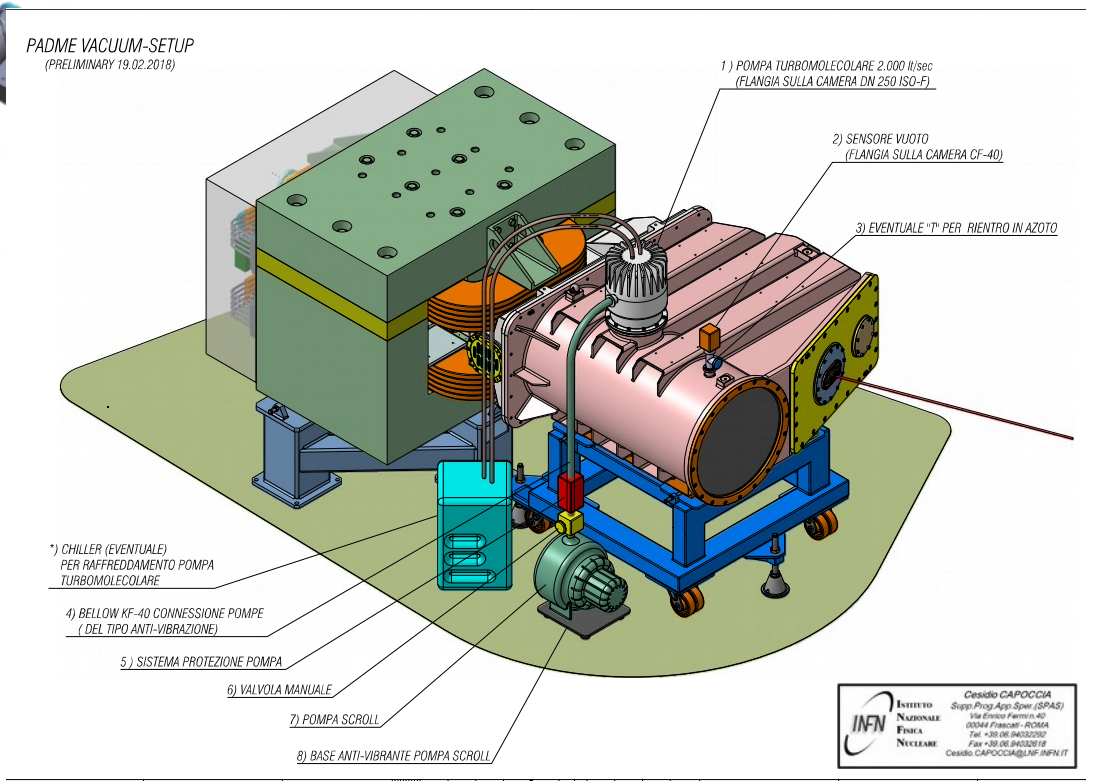
Vacuum chamber

Cesidio Capoccia



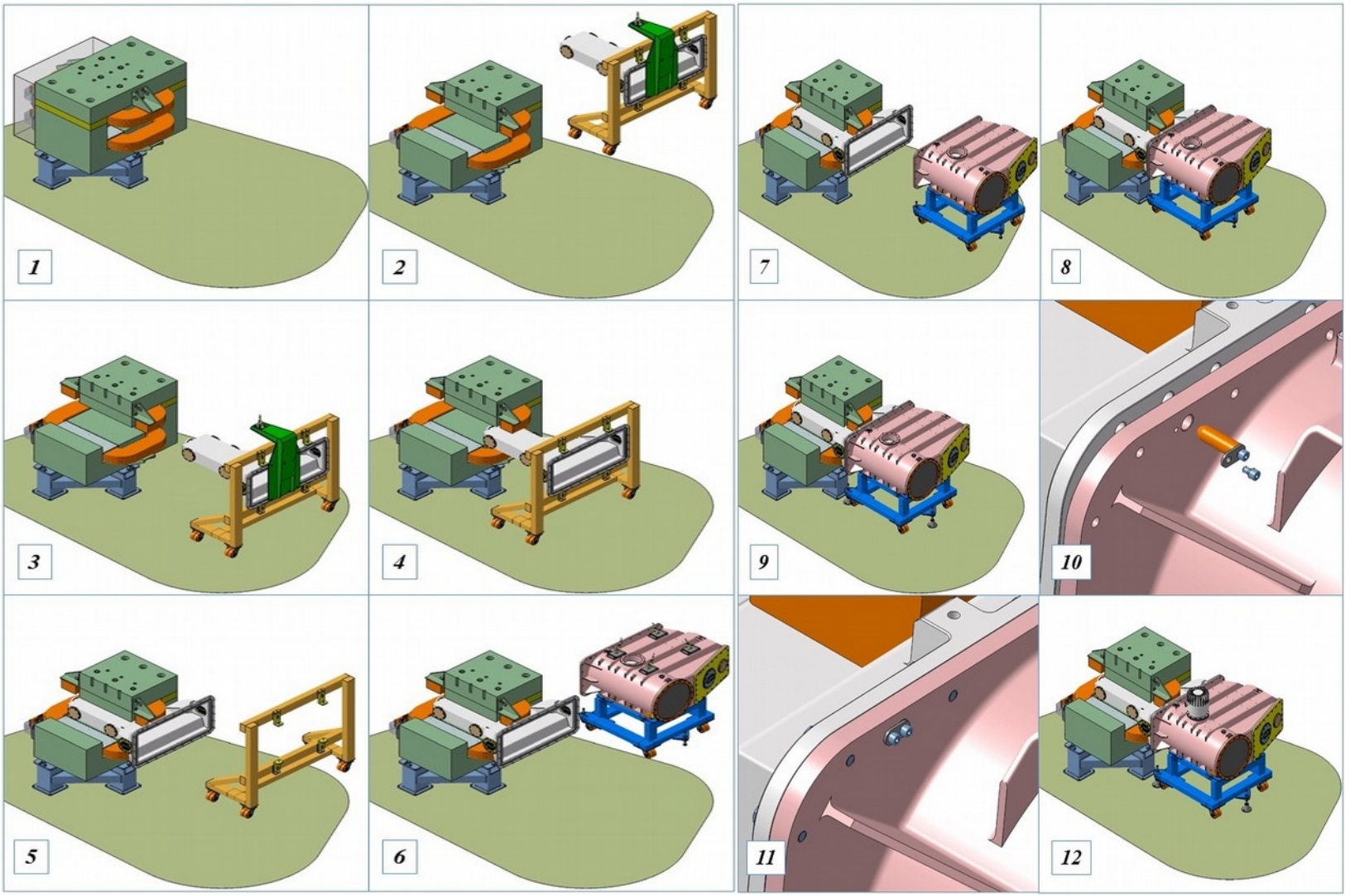


- Vacuum chamber in production
- Flanges and feed-throughs ordered
- The necessary pumping equipment already delivered at LNF
- A critical component for the success of the experiment



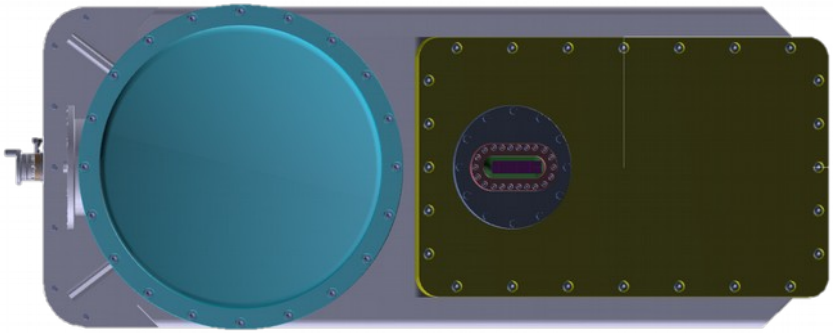
Installation procedure

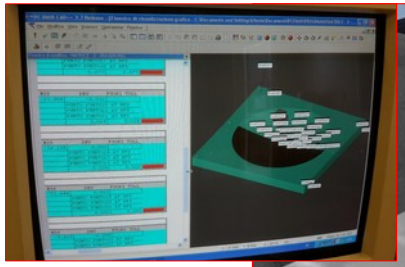
Cesidio Capoccia

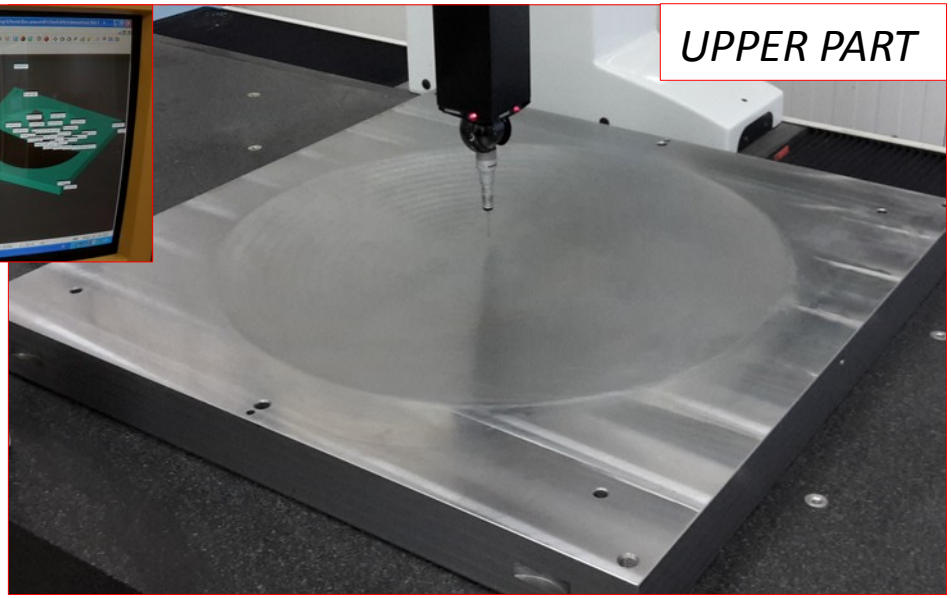


ECAL Vacuum chamber window

Cesidio Capoccia







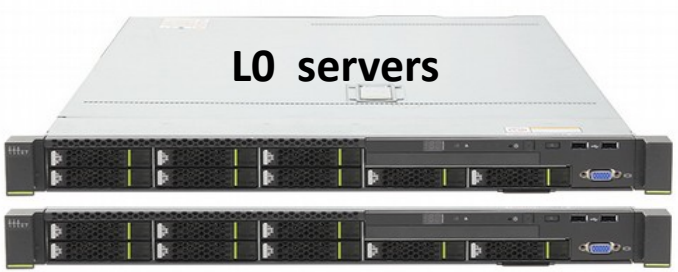
- 630 mm diameter carbon fiber window
  - Minimize the bremsstralung photons interactions
- In advanced production stage
- Molds ready and checked
- The produced window will be tested with 3 bar over pressure
- Outgassing tests also foreseen

DAQ: online

E. Leonardi, F. Safai-Tehrani (RM1)

- Front-end DAQ boards: 32 CAEN V1742 ADC boards
- L0 servers: 2 Huawei RH1288 with 1 A3818 board each
- L1 servers: 2 Dell R730xd with 22TB of RAID storage each
- Service nodes: 3 Dell R630 servers
  - Run Control + DB server + DCS server
  - On-line monitor
  - Data mover (installed at LNF Tier2, 10Gbps connection)
- Trigger Service: custom board developed @ INFN Roma3
- Central switch: stack of 3 Cisco Catalyst 2960-X (thanks to LNF IT group support)
  - Ports: 144 x 1Gbps copper + 6 x 10Gbps optical fiber

Service nodes

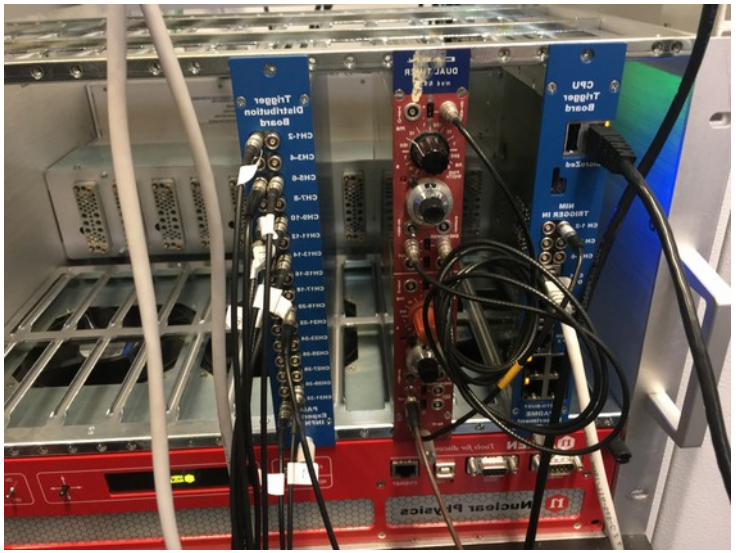


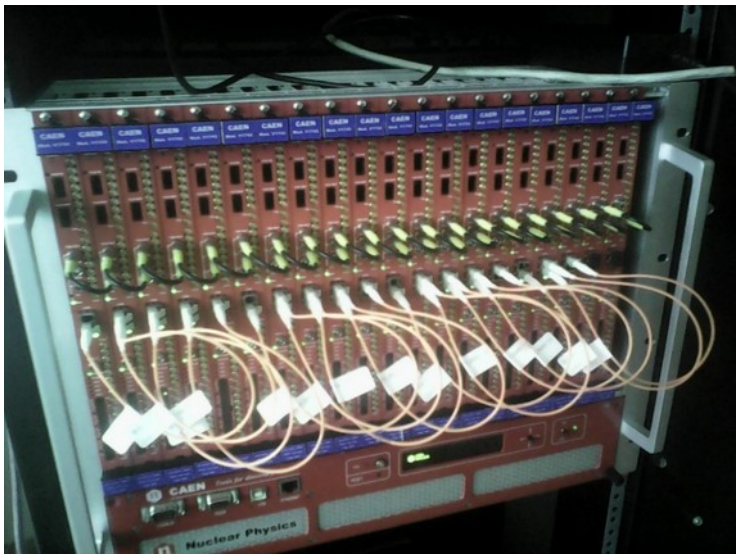
L1 servers

L0 trigger and DAQ setup

P. Branchini, D. Tagnani (RM3), P. Albicocco (LNF), E. Leonardi (RM1)

- A DAQ test setup created @ new BTF Control Room
  - Will be moved to BTF experimental area when ready
- Realistic DAQ with all ADC boards
  - Data throughput identical to final experiment
- First tests with new Roma3 Trigger board were successful
  - Final version of board firmware under development
- Final Run Control software being tested
  - Based on working prototype in use since 2015
  - Includes new zero-suppression algorithm
  - Optimized for multi-core machines (Huawei servers have 24 cores each)
  - Modular I/O schema for flexible distribution of data (e.g. to L1 and on-line monitor)





DCS

G. Georgiev (Sofia), F. Ferrarotto (RM1)

- A Detector Control System is being implemented to:
  - Control and monitor all HV systems
  - Control target area stepping motors
  - Collect information from environmental probes
- Central DCS service running on Run Control node
  - Standard interface to all DCS modules
- Independent DCS modules to control single devices
  - Modules will run on separated machines (PCs, Raspberry Pi, etc.) and will talk to central DCS server via standard network connections

Offline computing

E. Leonardi (RM1), E. Vilucchi (LNF)

HARDWARE

- CPU: 2.5 kHEPSpec @ LNF Tier2 Batch System
  - 1kHS in 2017, 1.5 kHS in 2018
- CPU: 1.5 kHS @ CNAF (in 2018).
- Disk: 80 TB full RAID box @LNF Tier2 Storage System.
- Disk: 10 TB @ CNAF Storage System.
- Tape: 500 TB @ CNAF Tape Library
  - 100 TB in 2017, 400 TB in 2018
- Tape: 300 TB @ LNF KLOE2 Tape Library (in 2018)
  - Will host full emergency copy of experimental data

SERVICES

- All GRID services for PADME are active
  - VO: vo.padme.org. VOMS based at CNAF.
  - CVMFS area: /cvmfs/padme.infn.it
  - Fully recovered after October 2017 flood
- Central Data Recording facility
  - Service running on dedicated node
  - 10 Gbps connection to BTF experiment and Tier2 Disk Storage System
  - Data are «pulled» from the PADME DAQ system and copied to the LNF Disk Storage System, to the CNAF Tape Library, and to the KLOE2 Tape Library.
- GRID-based MC Production Manager
  - Automatic jobs generation and submission
  - Automatic data copy to CNAF tape library

Installation

- PADME installation inside the BTF hall to begin as soon as possible
  - Expected to enter on May, 21st
- All ordered electronic components already delivered at 100 %
- Few additional accessories necessary and will be ordered asap
- Components installation
  - Magnet + services (power & cooling)
  - Vacuum chamber
  - Calorimeter
  - Racks and crates
  - RO electronics
- Aim to perform this activities in the next few weeks!

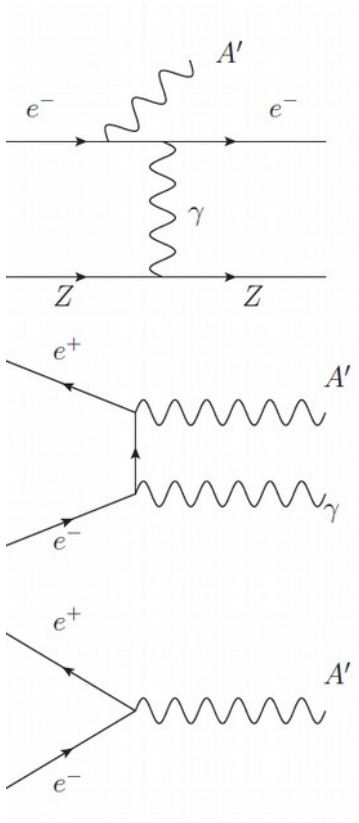
Schedule


Title
Feb 2018
Mar 2018
Apr 2018
May 2018
Jun 2018
Jul 2018
1) ECAL
1.1) SILO crystals delivery
1.2) Mechanics construction
1.3) Crystal Test NA22
1.4) Assembly
1.5) Installation @ BTF
1.6) Comm. & calibration
2) Vacuum Chamber
3) Veto
3.1) Scintillators bar tests
3.2) Test of FEE electronics
3.3) FEE to Sofia
3.4) Mechanical construction
3.5) Delivery to LNF
3.6) Full detector test
4) Target
4.1) Diamond Target
4.2) Mechanical support
5) Beam Line
5.1) Linac Warm Up
5.2) PADME Run Start
6) Trigger System
7) Installation
7.1) Magnet
7.2) DAQ racks
7.3) Ecal Installation

PADME early physics

- The PADME physics program is inevitably related to **precise calibration** and **monitoring of the calibration** of the detectors
- Background understanding
  - The background in the New Physics searches is the calibration tool
  - Understanding the Standard Model processes is the ticket to the “big event”
- Major background sources (or major SM processes)
  - Multiphoton annihilation
    $e^+e^- \rightarrow \gamma\gamma$, $e^+e^- \rightarrow \gamma\gamma\gamma$, $e^+e^- \rightarrow \gamma\gamma\gamma\gamma$, ….
  - Bremsstrahlung in the field of the nuclei – lack of experimental data in the range of O(100 MeV), precision of GEANT4 - ~ (3-4) %
  - Photon emission in the field of orbital electrons
- Bremsstrahlung differential cross-section measurements at different energy in the O(100 MeV) interval and (if possible) materials highly desirable
- Multiphoton annihilation to be studied and compared with MC generators

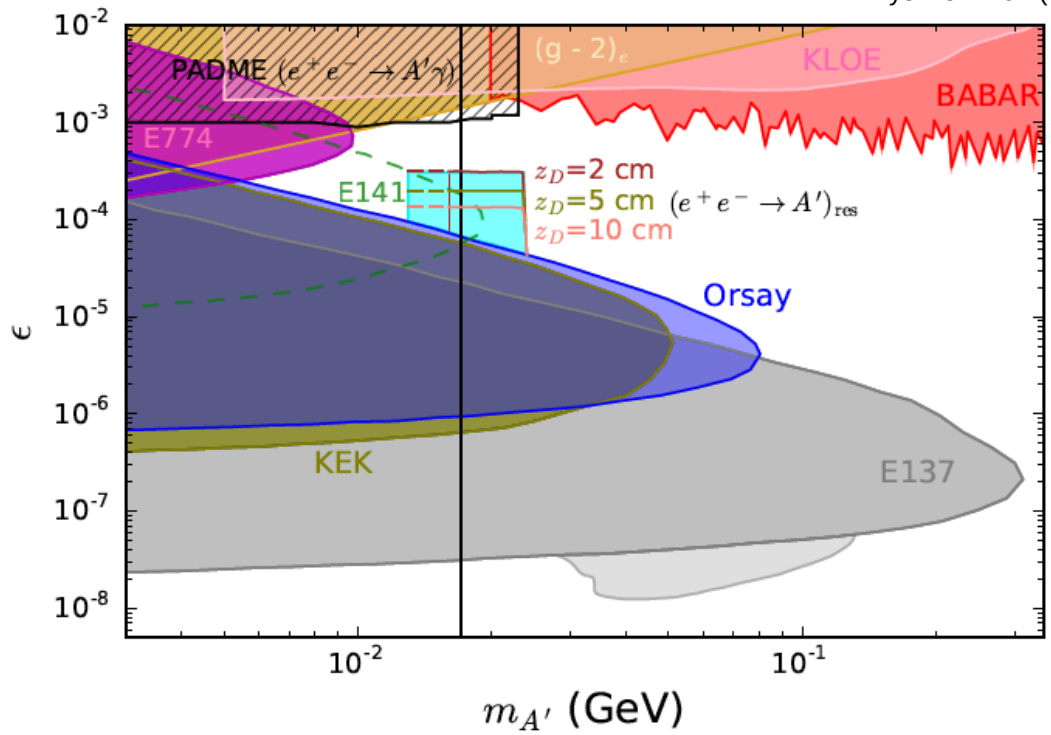
Exploiting further the annihilation



Thanks to LNF theoretical division, E. Nardi et. al.

- Annihilation in thin targets

Phys.Rev. D97 (2018) 095004



- Associate production of dark photon vs resonant annihilation
- Increasing interest within LNF laboratory
- A promising technique to cover the gap between dump and fixed (or no) target experiments
  - However, needs to control the leakage from the beam shower…

PADME visibility

Scarica come file tabbed per excel

	Speaker	Conference	Contr. Title	Type	Place	
1	**Kozhuharov Venelin** (M)	*Les Rencontres de Physique de la Va...*	The PADME experiment for dark mediator searches at the Frascati BTF	ple	La Thuile	✔
2	**Raggi Mauro** (M)	*U.S. Cosmic Visions: New Ideas in D...*	The PADME experiment	inv	Washington	✔
3	**Kozhuharov Venelin** (M)	*Restricted ECFA meeting Bulgaria 2017*	NA62 and PADME: looking for rare processes	ple	Sofia	✔
4	**Taruggi Clara** (F)	*IFAE 2017*	Prestazioni del prototipo di calorimetro elettromagnetico dell'esperimento ...	pos	Trieste	✔
5	**Piperno Gabriele** (M)	*16th Incontri di Fisica delle Alte ...*	Dark Photon search with the PADME experiment	ple	Trieste	✔
6	**Scherini Viviana** (F)	*13th AxionWIMP conference*	Search for the Dark Photon with the PADME experiment at LNF	ple	Patras	✔
7	**Leonardi Emanuele** (M)	*Workshop della Commissione Calcolo ...*	Il modello di calcolo dell'esperimento PADME alla BTF di Frascati	inv	Gran Sasso	✔
8	**Kozhuharov Venelin** (M)	*International Workshop on Light Dar...*	The PADME experiment at LNF	inv	La Biodola	✔
9	**Valente Paolo** (M)	*XIV Seminar on Software for Nuclear...*	Dark Matter searches at low energy accelerators	ple	Alghero	✔
10	**Gianotti Paola** (F)	*The European Physical Society Confe...*	Search for the gauge boson of a secluded sector with the PADME experiment a...	ple	Venezia	✔
11	**Gianotti Paola** (F)	*ANIMMA 2017*	The PADME Detector	ple	Potoroz	✔
12	**Piperno Gabriele** (M)	*Particles and Nuclei International ...*	Dark Photon search with PADME at LNF	par	Pechino	✔
13	**Raggi Mauro** (M)	*FCCP2017 Workshop Anacapri*	Status of PADME experiment and review on dark photon searches	inv	Anacapri	✔
14	**Taruggi Clara** (F)	*103° Congresso Nazionale della Soci...*	Ricerca di materia oscura: l'esperimento PADME	par	Trento	✔
15	**Valente Paolo** (M)	*International Workshop on Physics w...*	Dark forces searches with positrons: experiments and facilities	inv	Newport News Virginia	✔
16	**Kozhuharov Venelin** (M)	*XXVI International Scientific Confe...*	A Test System for the Front-End Electronics of the PADME charged particle d...	ple	Sozopol	✔
17	**Georgiev Georgi Stefanov** (M)	*SCINT 2017*	A scintillator based charged particle veto system for the PADME experiment	pos	Chamonix	✔
18	**Ferrarotto Fabio** (M)	*Calorimetry for the High Energy Fro...*	The PADME experiment calorimeters for missing mass dark photon searches	ple	Lione	✔
19	**Taruggi Clara** (F)	*13th Central European Seminar on Pa...*	Searching for dark photon: the PADME experiment	pos	Vienna	✔

- G. Georgiev et al, “Performance of the prototype of the charged particle veto system of the PADME experiment”, IEEE TNS, 10.1109/TNS.2018.2822724

Acknowledgement

These achievements would have been impossible without:

- **SPCM LNF service**
  - T. Napolitano, A. De Paolis, M. Arpaia, A. Zossi, F. Angeloni, A. Cassarà
- **SPAS LNF service**
  - C. Capoccia, D. Orecchini
- **SEA LNF service**
  - G. Corradi, S. Ceravolo, P. Albicocco, R. Lenci
- **DR staff**
  - A. Saputi, E. Capitolo
- **RM1 LABE**
  - L. Recchia
- **RM3 mech. Workshop**
  - S. Mari, G. Paruzza
- **RM3 trigger**
  - P. Branchini, D. Tagnani
- **Lecce**
  - C. Pinto, R. Assiro, G. Fiore, M. Corrado

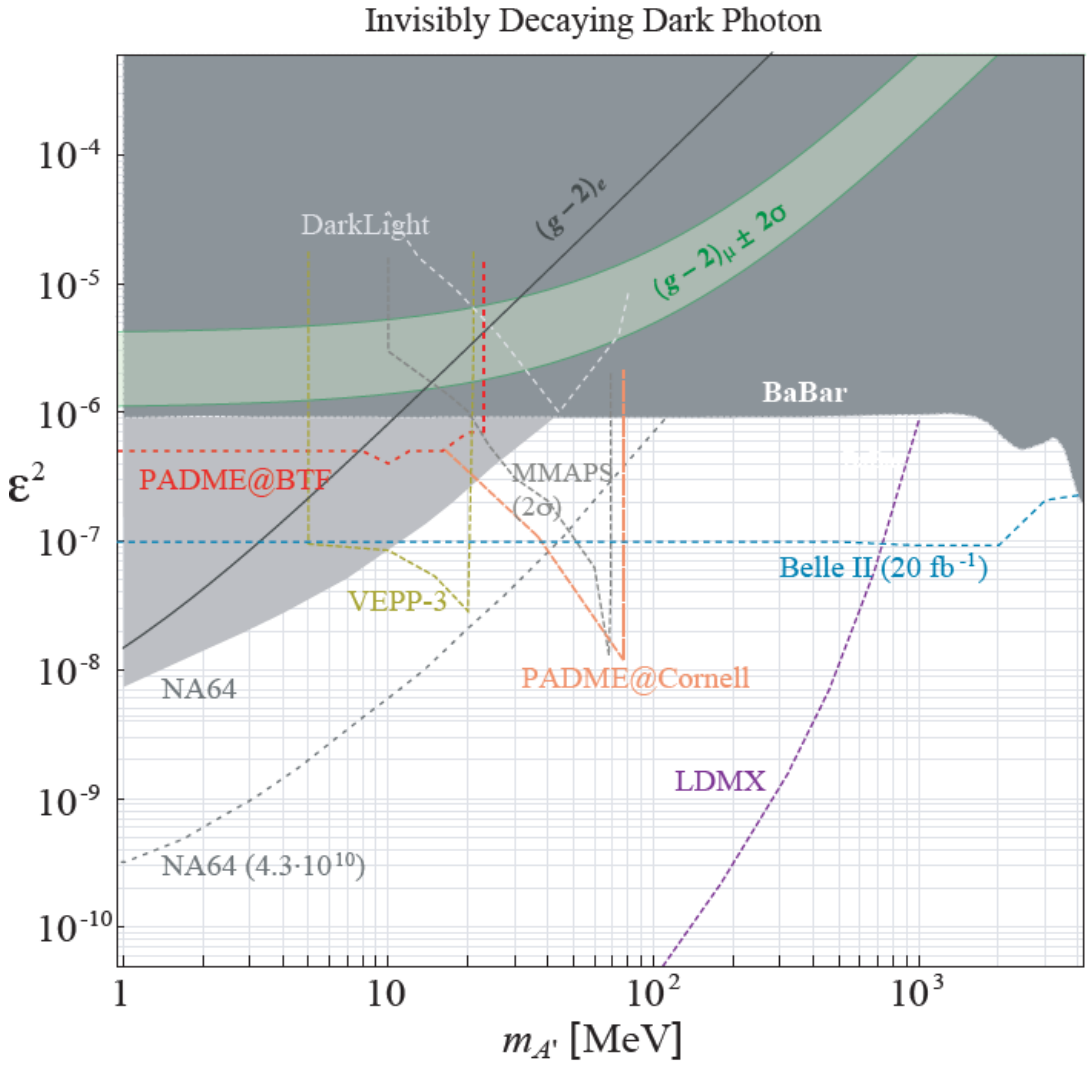
Many thanks from PADME collaboration!

Conclusion

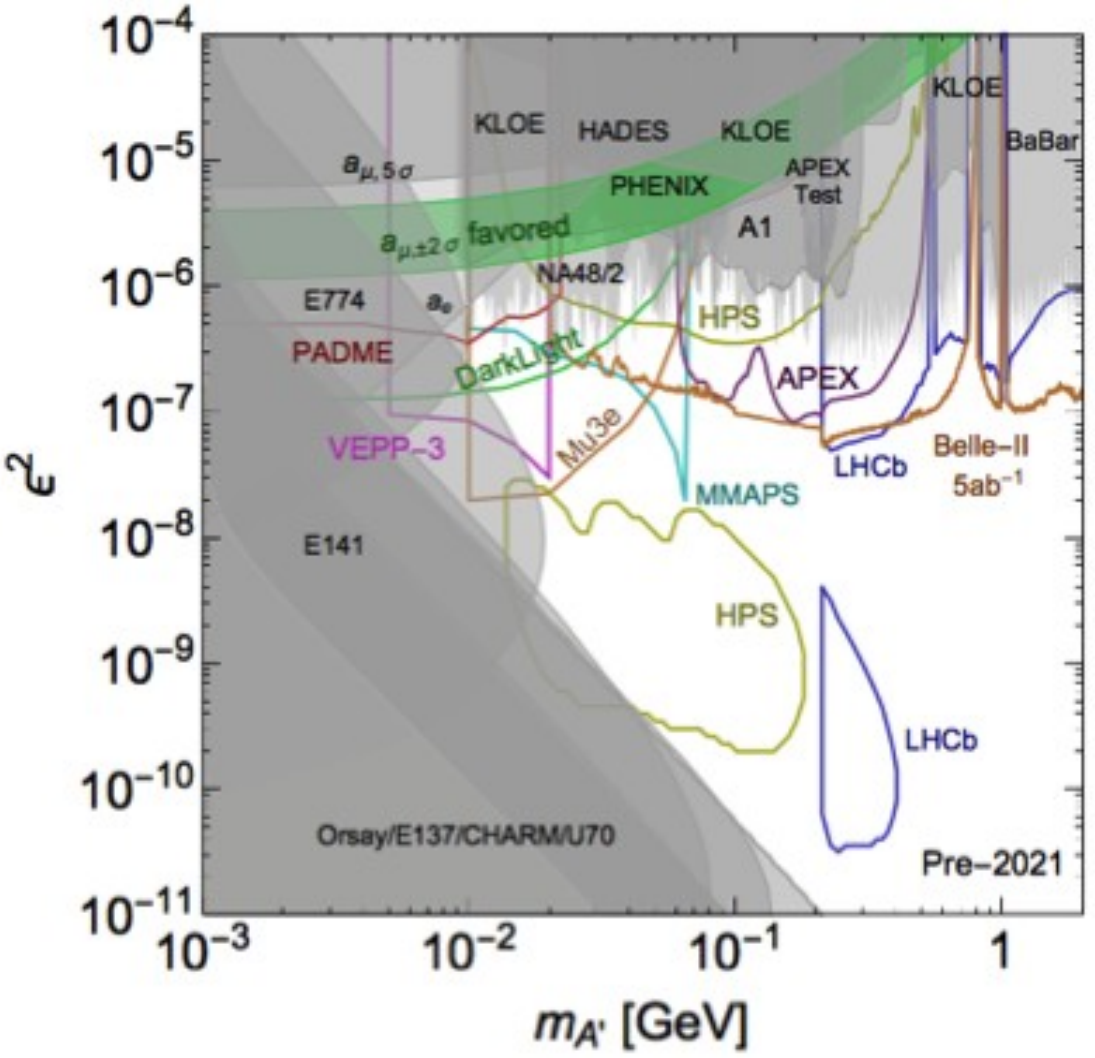
- PADME is on the final track before starting operation
- All systems are arriving to finalization
- With the approaching start of the experiment the interest increases
  - And also the pressure
- Dark photons might be just knocking at the door

SPARE

Invisible searches



Searches prospects



Missing mass searches

	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	$2x10^{22}$ e^-/cm^2	$O(2x10^{23})$ e^-/cm^2	$5x10^{15}$ e^-/cm^2
Beam intensity	8 x 10^{-11} mA	2.3 x 10^{-6} mA	30 mA
$e^+e^- \rightarrow \gamma\gamma$ rate [s^{-1}]	15	2.2 x 10^6	1.5 x 10^6
ε^2 limit (plateau)	**10^{-6} (*10^{-7} SES*)**	**10^{-6} – 10^{-7}**	**10^{-7}**
Time scale	2018	?	2020 (ByPass)
Status	**Preparation for run**	**Not funded by NSF**	**Proposal in construction**