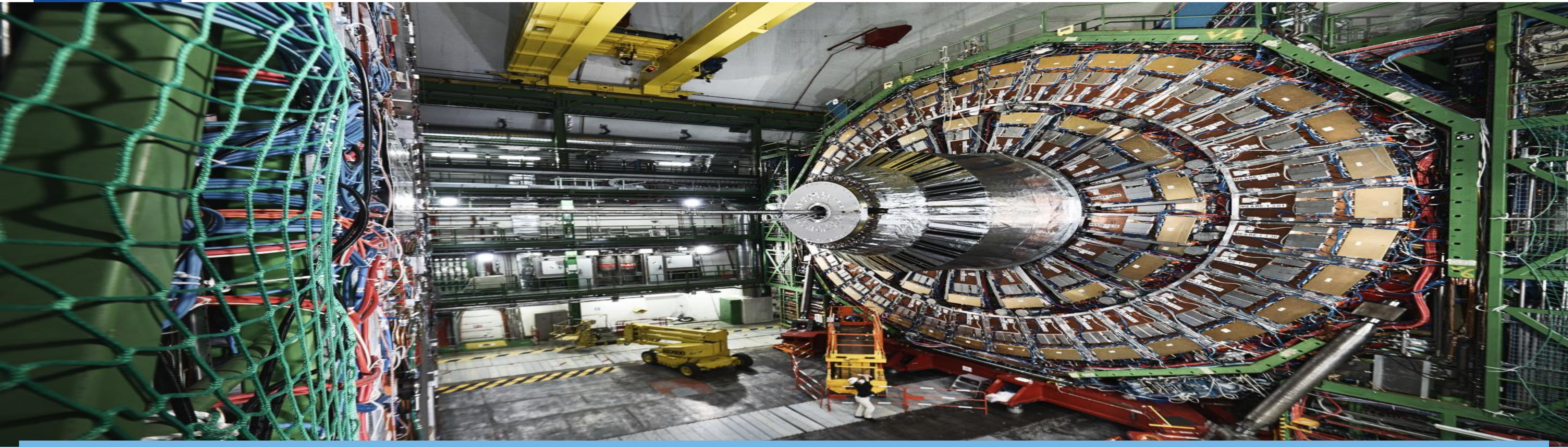


TA3: Transnational Access to LNF

Catalina Curceanu

INFN-LNF

STRONG-2020 Annual Meeting, November 8-9, 2021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

Plan of the presentation:

1. Progress made during the year towards the objectives

2. Minimum quantity of access to be provided at 31 October 2021

(Give the estimation of the access that had to be provided to the month 29 according to the GA)

3. Access actually provided at 31 October 2021

(If there are some deviations as regards the initial plans, explain the reasons, the consequences and the proposed corrective actions)

4. Other significant achievements

TA3 – Transnational Access to LNF

The DAΦNE Complex

TA3 – Transnational Access to LNF

DAΦNE

Experiments on the DAΦNE complex

- SIDDHARTA-2
- PADME

SIDDHARTA-2 Experiment

OBJECTIVES

Study of strong interaction effects in kaonic atoms

The study of the strong interaction effects was the major motivation for performing experiments with kaonic atoms. The electromagnetic interaction with the nucleus is very well known and the energy levels can be calculated at a precision of eV by solving the Klein-Gordon equation. Even a small deviation from the electromagnetic value allows to get information on the strong interaction between the kaon and the nucleus.

The binding energy of the ground state (K-, p)system is 8,61 KeV, to be compared with the tens of MeV in the low-energy scattering experiments.

Hence, kaonic atoms offer the unique opportunity to study the antikaon-nucleon/nucleus interaction, nearly "at threshold", namely at zero relative energy.

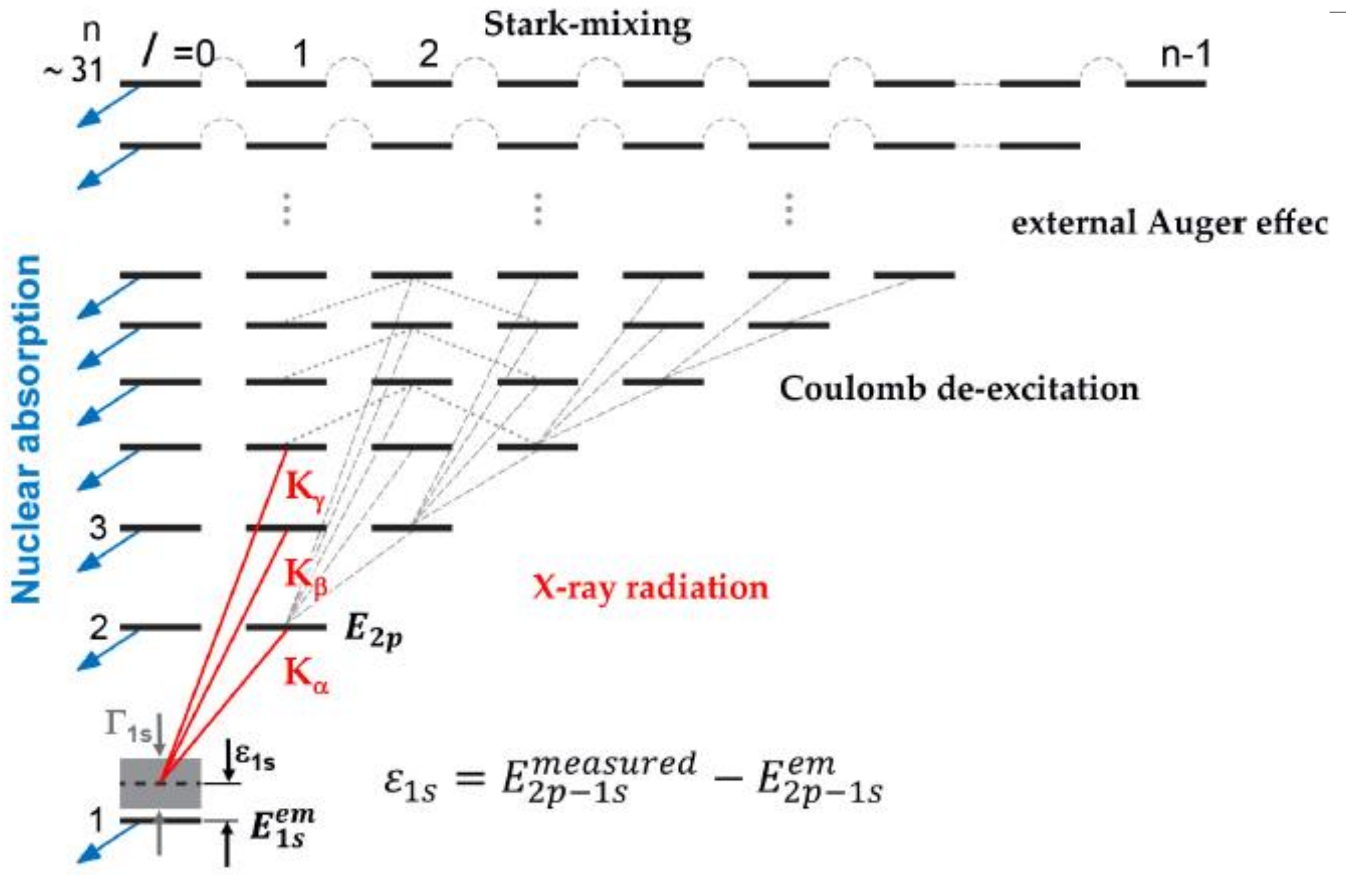
Formation of kaonic atoms

When a negatively charged particle other than an electron enters a target it is slowed down to a kinetic energy of a few tens of eV by ionizations and excitations of the molecules of the target. An exotic atom is formed when this particle is stopped inside the target and is captured by a target atom into an outer atomic orbit, replacing an electron.

When the particle is a kaon, the kaon cascades down via Coulomb deexcitation, external Auger emission, radiative transitions until interacts with the nucleus. The levels are shifted and broadened with respect to the e.m. value.

SIDDHARTA-2 Experiment

Kaonic hydrogen



SIDDHARTA-2 Experiment
Kaonic hydrogen

SCATTERING LENGTHS

Deser-type relation connects shift ε_{1s} and width Γ_{1s} to the real and imaginary part of $a_{K\text{-}p}$

$$\varepsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3 \mu_c^2 a_{K^-p}\left(1 - 2\alpha\mu_c(\ln\alpha - 1)a_{K^-p}\right)$$

(μ_c reduced mass of the K^-p system, α fine-structure constant)

U.-G. Meißner, U.Raha, A.Rusetsky, Eur. phys. J. C35 (2004) 349
next-to-leading order, including isospin breaking

$$a_{K^-p} = \frac{1}{2}[a_0 + a_1]$$

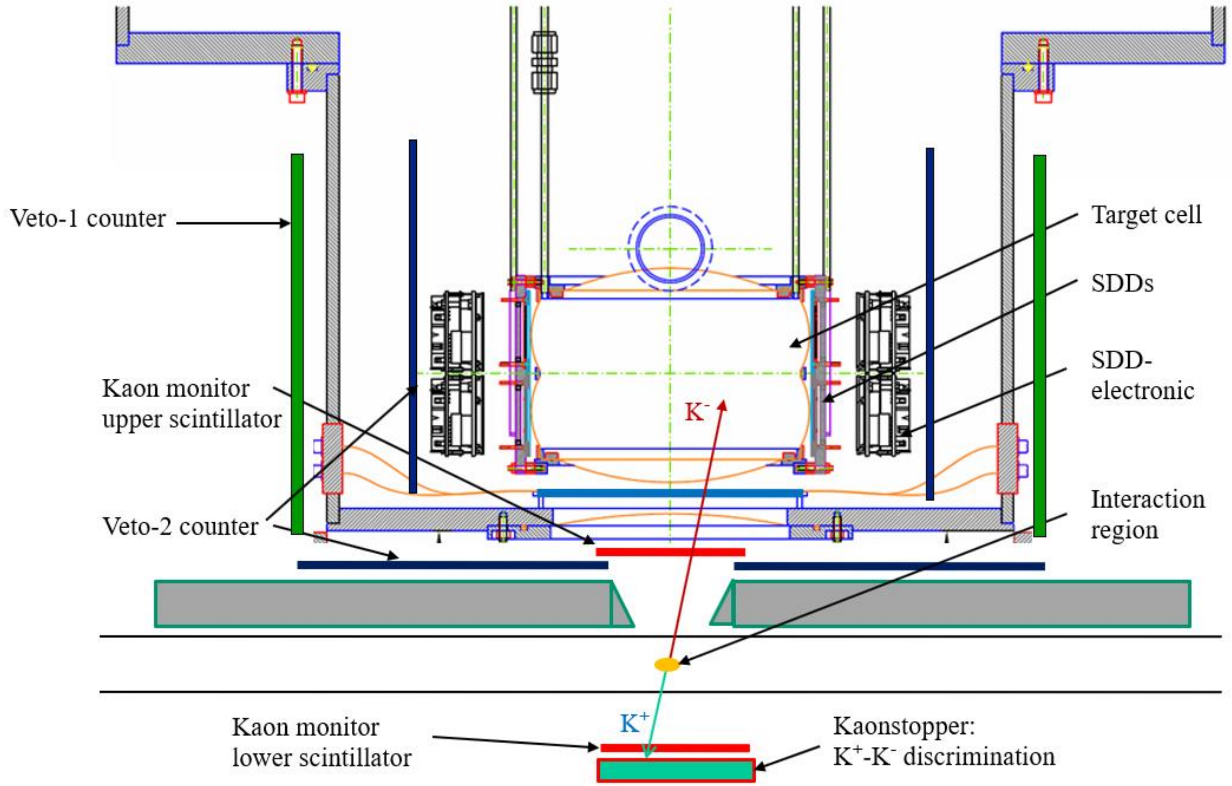
$$a_{K^-n} = a_1$$

$$a_{K^-d} = \frac{k}{2}\left[a_{K^-p} + a_{K^-n}\right] + C = \frac{k}{4}[a_0 + 3a_1] + C$$

$$k = \frac{4[m_n + m_K]}{[2m_n + m_K]}$$

SIDDHARTA-2 Experiment

TASKS



SIDDHARTA-2 Experiment

Strategy

Phase 1:

during the commissioning of DAΦNE

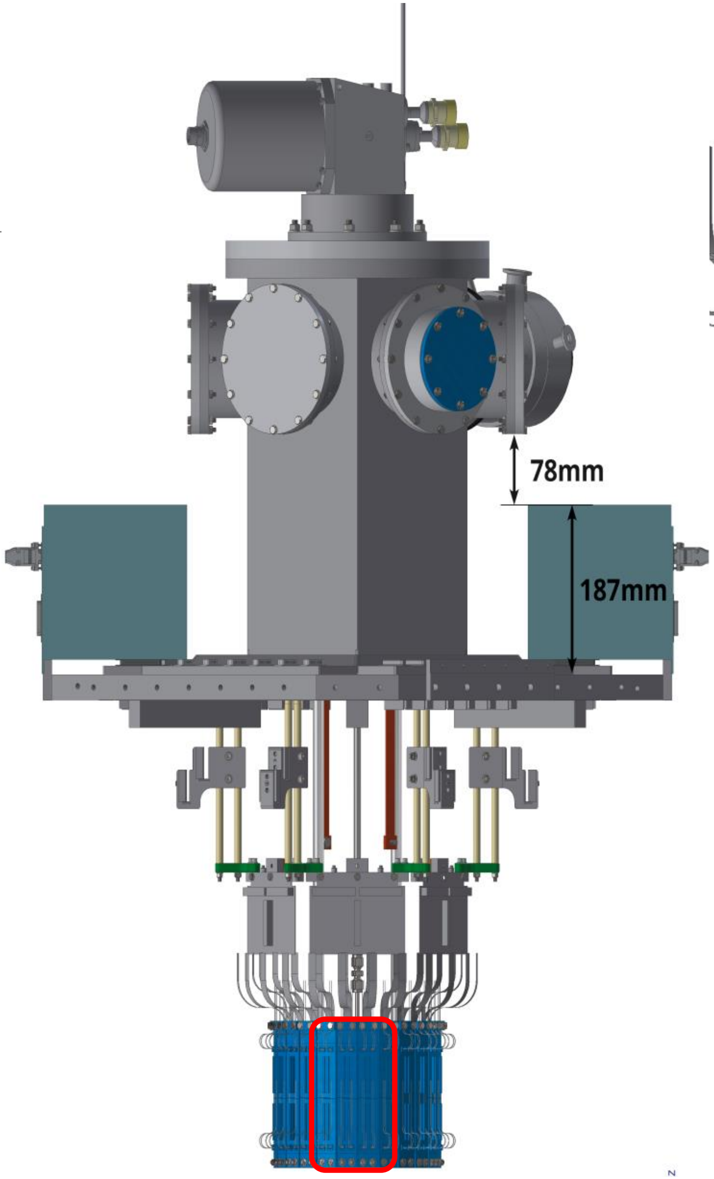
SIDDHARTINO: measurement of K-^{4}He (8 SDD arrays)

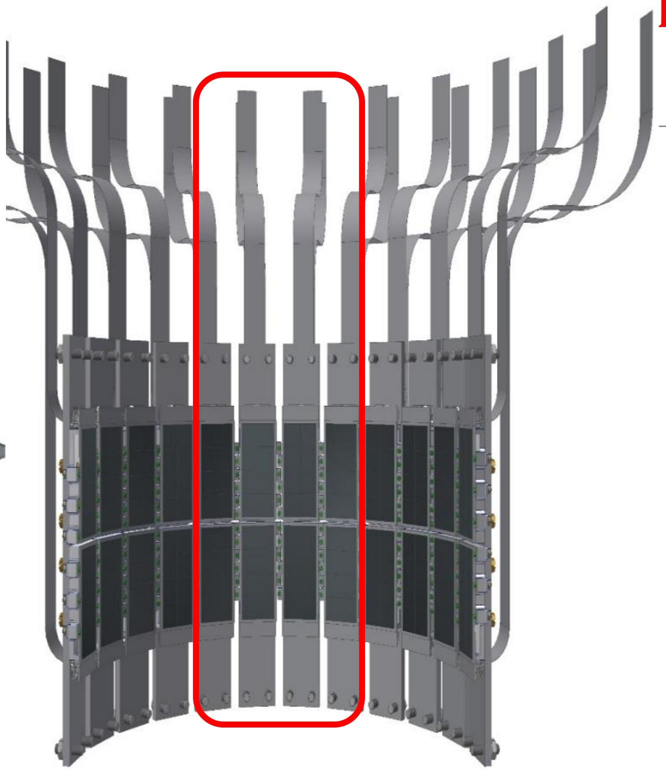
Phase 2:

when DAΦNE operating condition is comparable (S/B) with SIDDHARTA ones

***kaonic deuterium* (48 SDD arrays) run for 800 pb^{-1}**

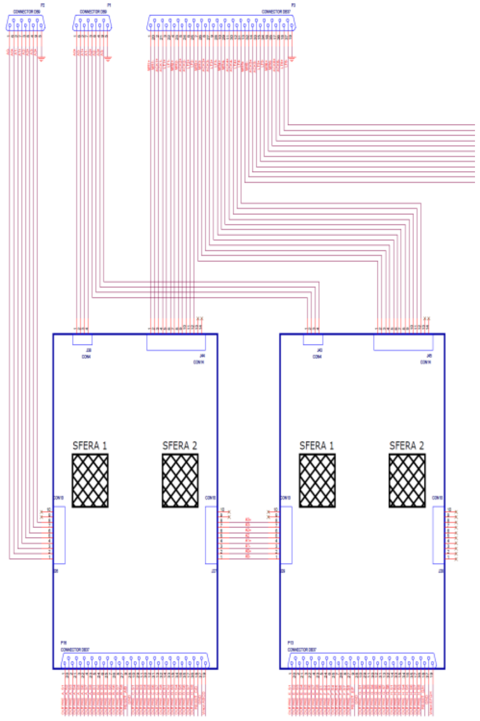
SIDDHARTINO = SIDDHARTA-2 with 8 SDD's





ONLY
8 SDD arrays
(out of 48)
1 BUS structure

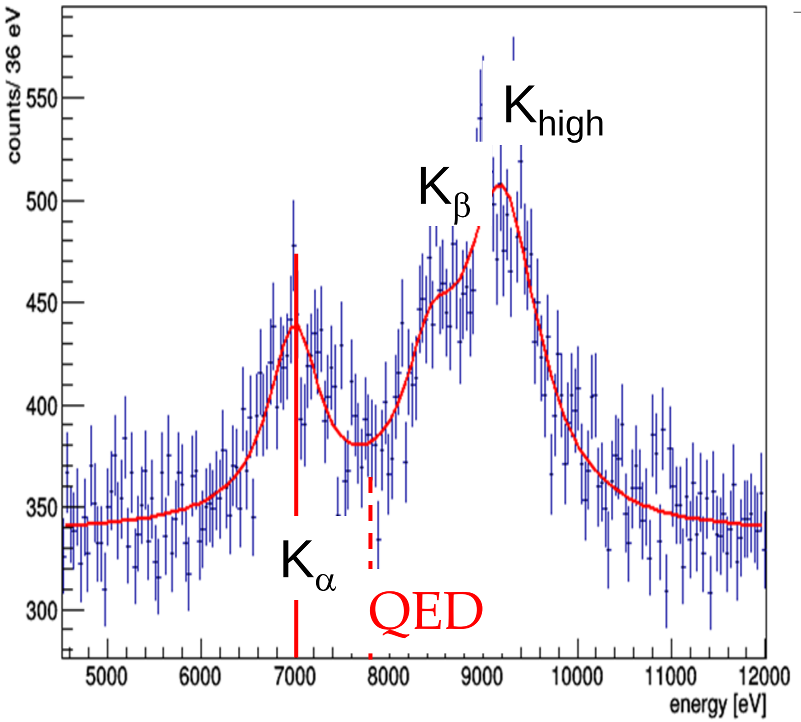
DAQ – BUS structure
- 4 SFERA ASICs
- 8 SDD arrays
- 4 ADC channels



SIDDHARTA-2 Experiment

SIDDHARTA-2 K-d measurement
Monte Carlo simulations

Kaonic deuterium run in
2021/2022 for 800 pb^{-1}
to perform the first measurement of the strong interaction induced
energy shift and width
(similar precision as K^-p)



achievable precision:
shift: 30 eV
width: 75 eV

PADME Experiment

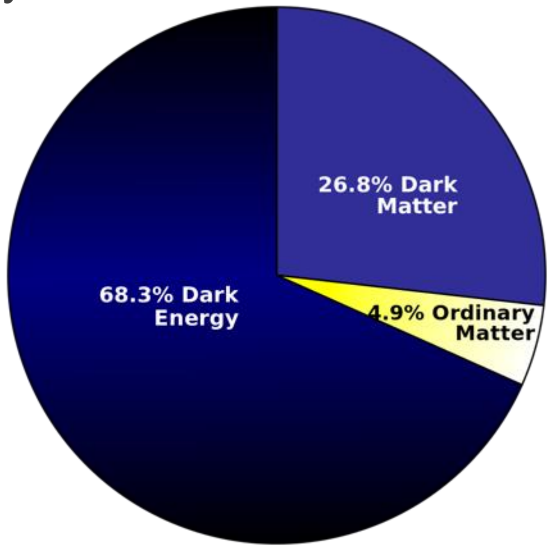
OBJECTIVES

The Dark Matter issue

From Cosmological and Astrophysical observations of gravitational effects, something else than ordinary Baryonic matter should exist.

The abundance of this new entity is 5 times larger than SM particles.

Dark Matter is the best indication of physics Beyond SM (BSM)



A new mediator

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

One class of simple 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.

PADME Experiment

A' production at PADME

PADME aims to produce *A'* via the reaction:

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

This technique allows to identify the *A'* even if it is stable or if predominantly decay into dark sector particles.

Know e^+ beam **momentum and position**

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

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

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

PADME Experiment

TASKS

Goal: collect 5×10^{13} Positron On Tar… , to reach sensitivity $\epsilon^2 \sim 10^{-4}$

Run1 (Oct. 2018 – Feb. 2… …ed to beam and background studies to have the … possible data sample.

Run2 (… …meant to study primary beam.

Run3 foreseen in Autumn 2019.

Plans changed due to pandemic

PADME Experiment

Signal and Background

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

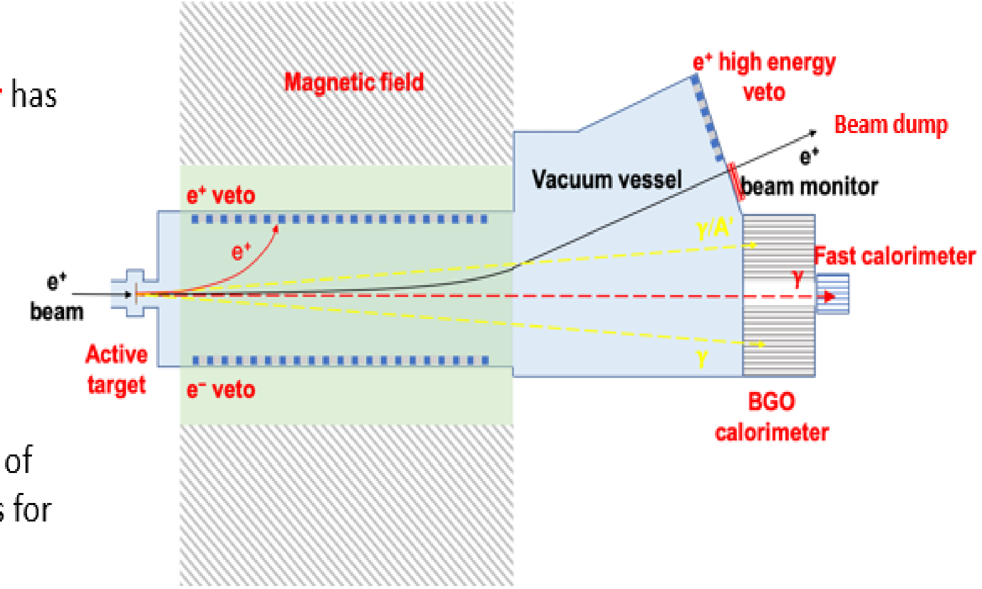
Since the **active target** is extremely thin (~100 μm), the majority of the positrons do not interact.
A **magnetic field** is mandatory to precisely measure their momentum before deflecting them on a **beam dump**.

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** vetos photons at small angle (θ<1°) to cut backgrounds:

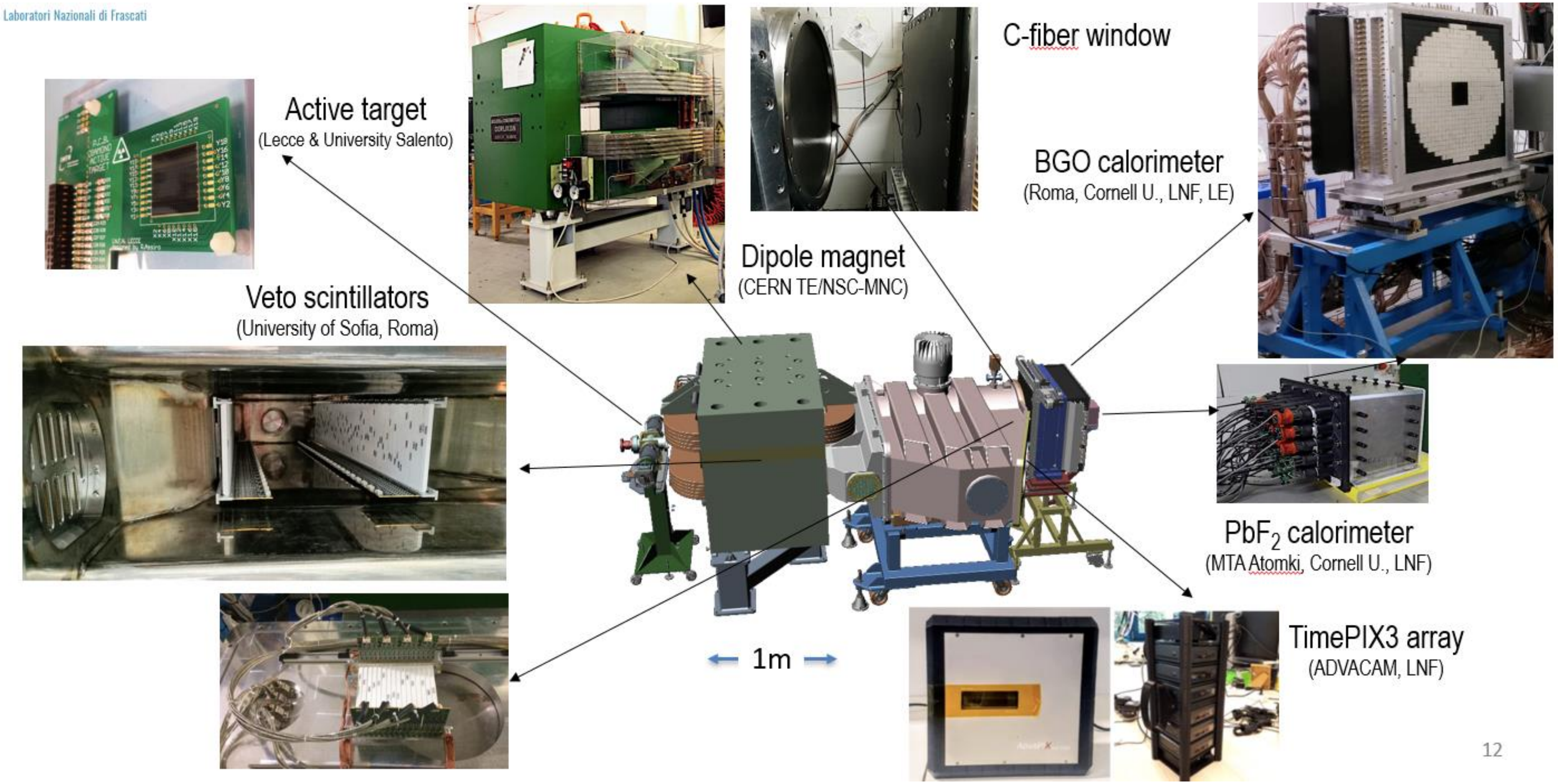
$$e^+N \to e^+N\gamma; e^+e^- \to \gamma\gamma; e^+e^- \to \gamma\gamma\gamma$$

In order to furtherly reduce background, the inner sides of the **magnetic field** are instrumented with **veto** detectors for positrons/electrons.



For higher energy positron another **veto** is placed at the end of the vacuum chamber.

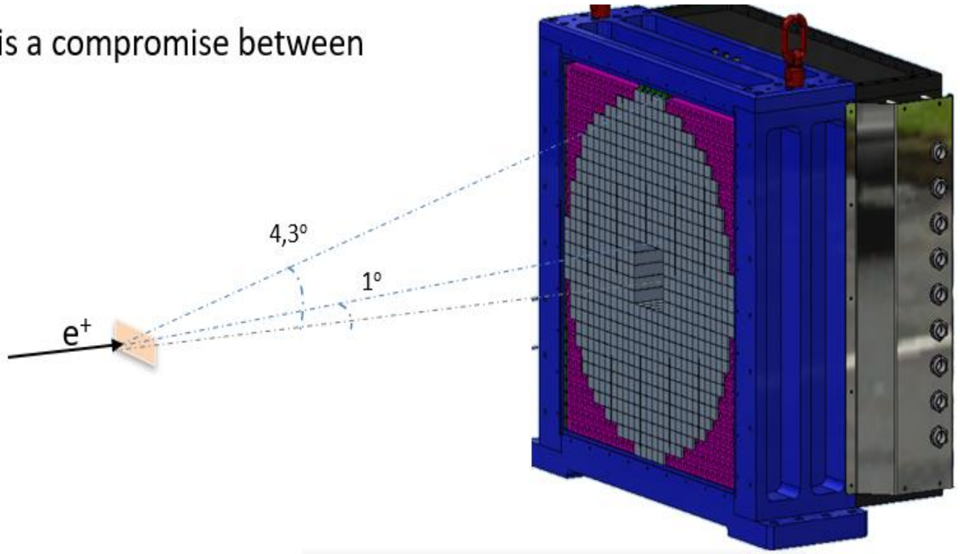
The PADME detector in a nutshell

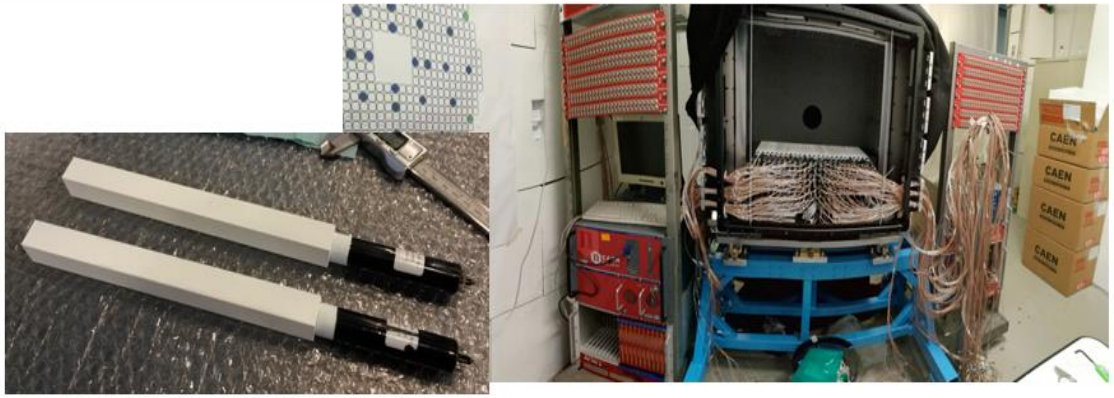


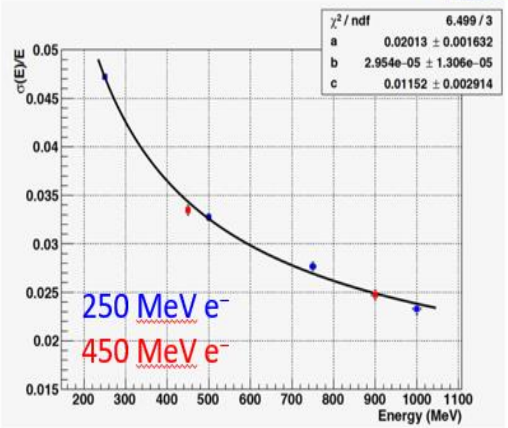
BGO Calorimeter

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

- Cylindrical shape: radius 300 mm, depth of 230 mm
  - 616 crystals **21×21×230 mm³**
  - Inner hole 5 crystals
- Material BGO: high LY, high ρ, small X_0 and MR, long τ_{decay} (L3 calorimeter obtained for free)
- Detector performance:
  - σ(E)/E ≈2%/√E
  - σ(θ) ~ 1-2 mrad
  - Angular acceptance (20 – 75) mrad







Update on progress

- Management
- Experiments

Update on progress

➢ Management

- Launch of the second Call 15/07/2020 dead line 10/09/ 2020
  Remind: 12/03/2021 and 04/06/2021
- Re-launch second Call 27/10/2021 dead line 14/11/ 2021

Update on progress

EXPERIMENTS

- SIDDHARTA-2
- PADME

Update on progress

SIDDHARTA-2 EXPERIMENT

TA3 – Transnational Access to LNF

SIDDHARTINO installed on DAΦNE
(17 April 2019)

Project time line SIDDHARTINO

SIDDHARTINO and Laboratory activities: working on SDD calibration and optimization

Up to end of 2020

During pandemic

Collisions started: luminosity measurement tuning of detector

Dafne restart, collider mode

2021, January

Mechanics and hardware optimization:

Kaon trigger

Electronics

Dafne shutdown for Easter holiday and maintenance

2021, April 02 - 15

New cooling system installed and tested restart collisions and measurements

DAFNE collisions optimization

2021, April 16 – 31 May

June – 18 July 2021

Back. Reduction

KHe

SIDDHARTA-2: phase 1 (SIDDHARTINO)
Shielding optimization – background rediction

JINST
PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB
RECEIVED: *August 12, 2020*
ACCEPTED: *September 22, 2020*
PUBLISHED: *October 14, 2020*

Characterization of the SIDDHARTA-2 luminosity monitor

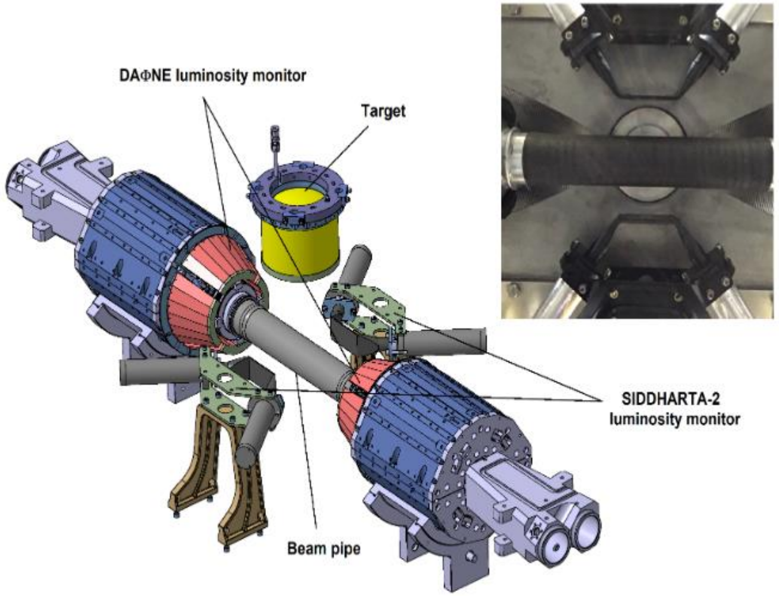


Figure 2. Schematic representation of the SIDDHARTA-2 setup with implemented luminosity monitor and the top view picture of the two installed modules (right upper corner).

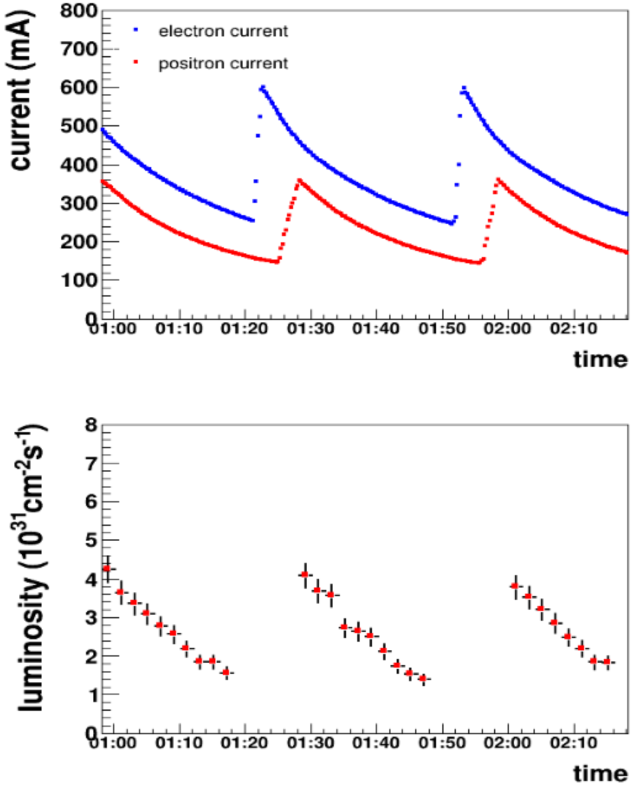
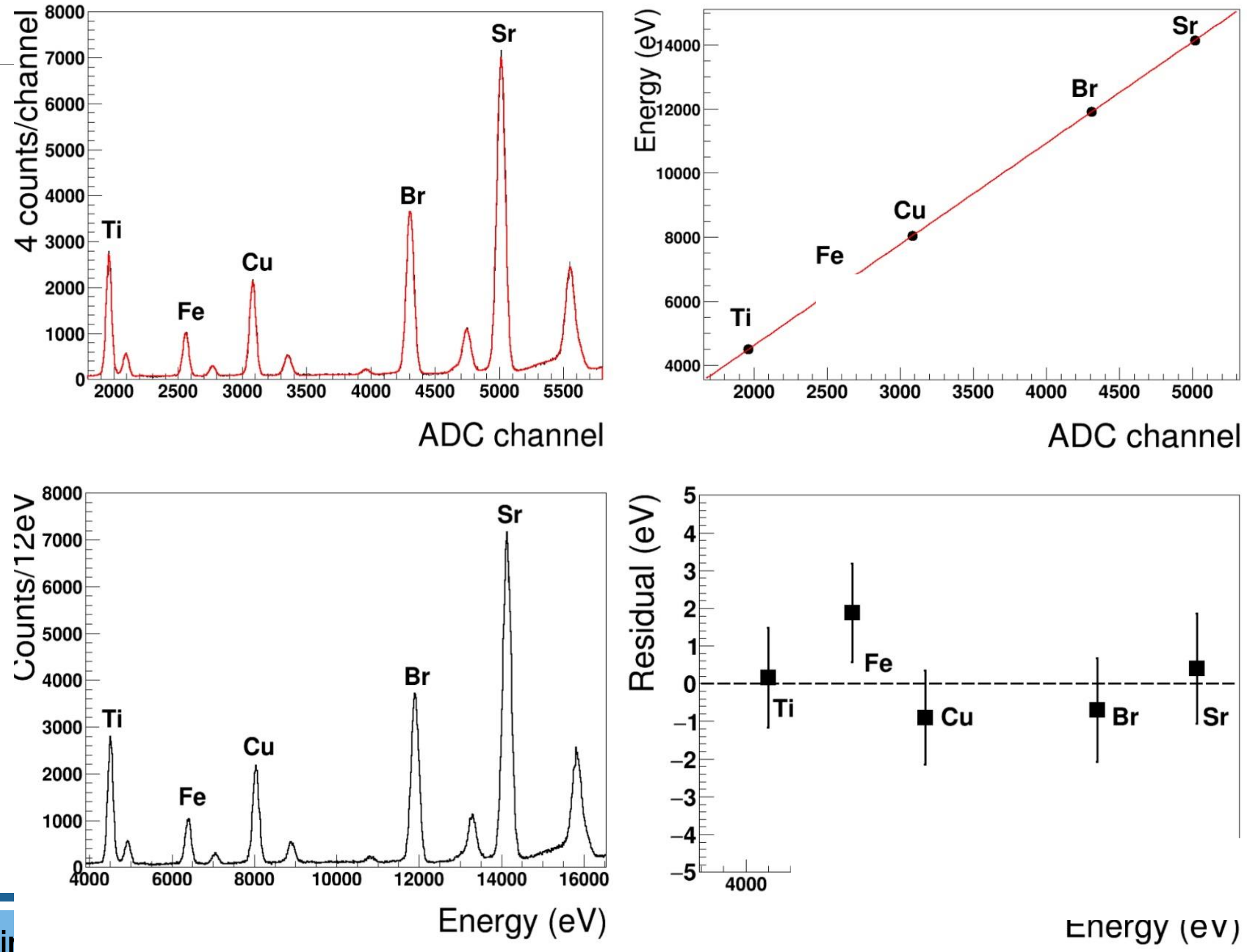


Figure 10. (upper) DAΦNE currents: electron (blue) and positron (red); (lower) measured luminosity — each point corresponds to 2 min of data taking.

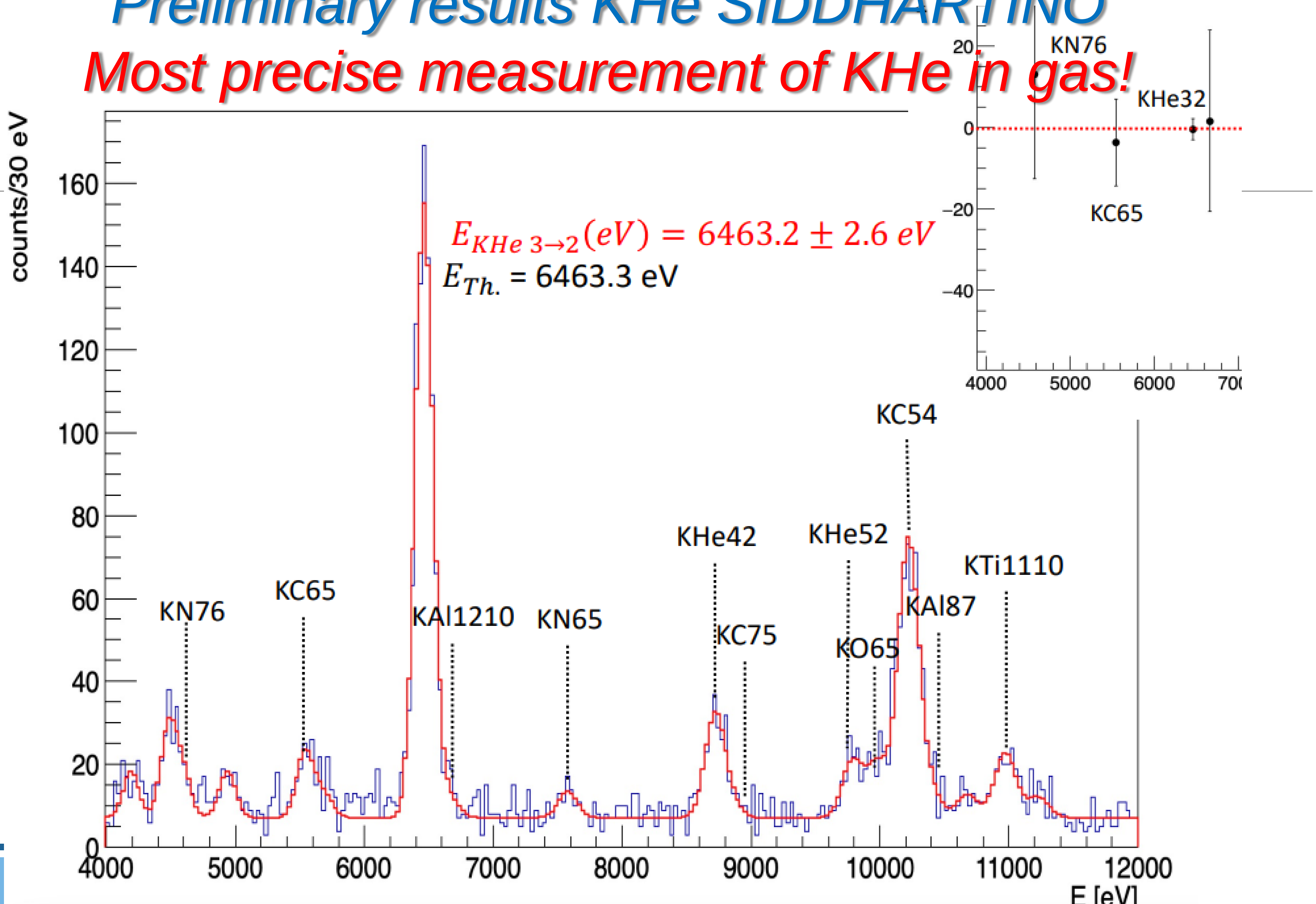
Silicon drift detectors system for high-precision light kaonic atoms spectroscopy

Measur.Sci.Tech. 32 (2021) 9, 095501



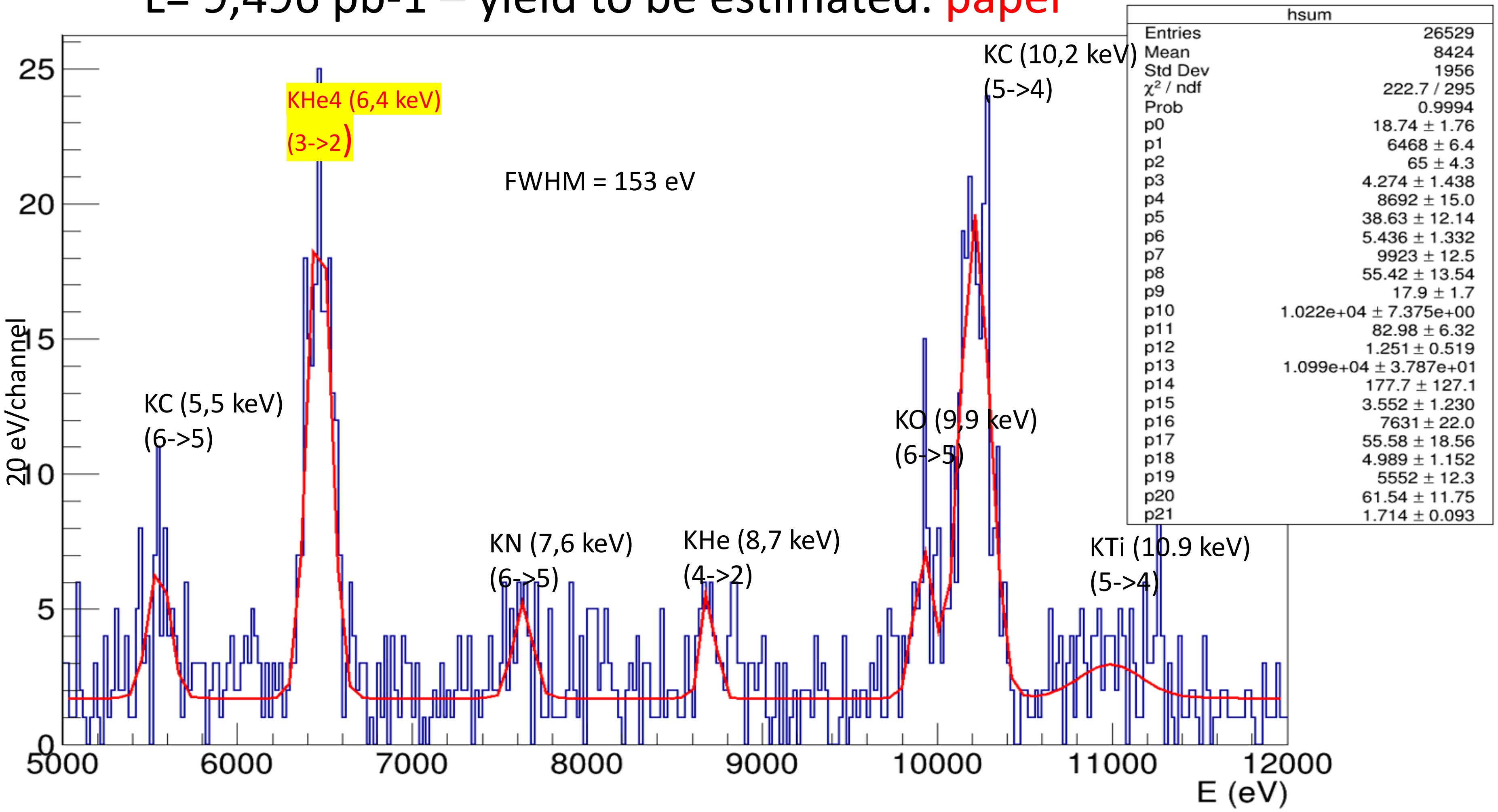
Preliminary results KHe SIDDHARTINO

Most precise measurement of KHe in gas!

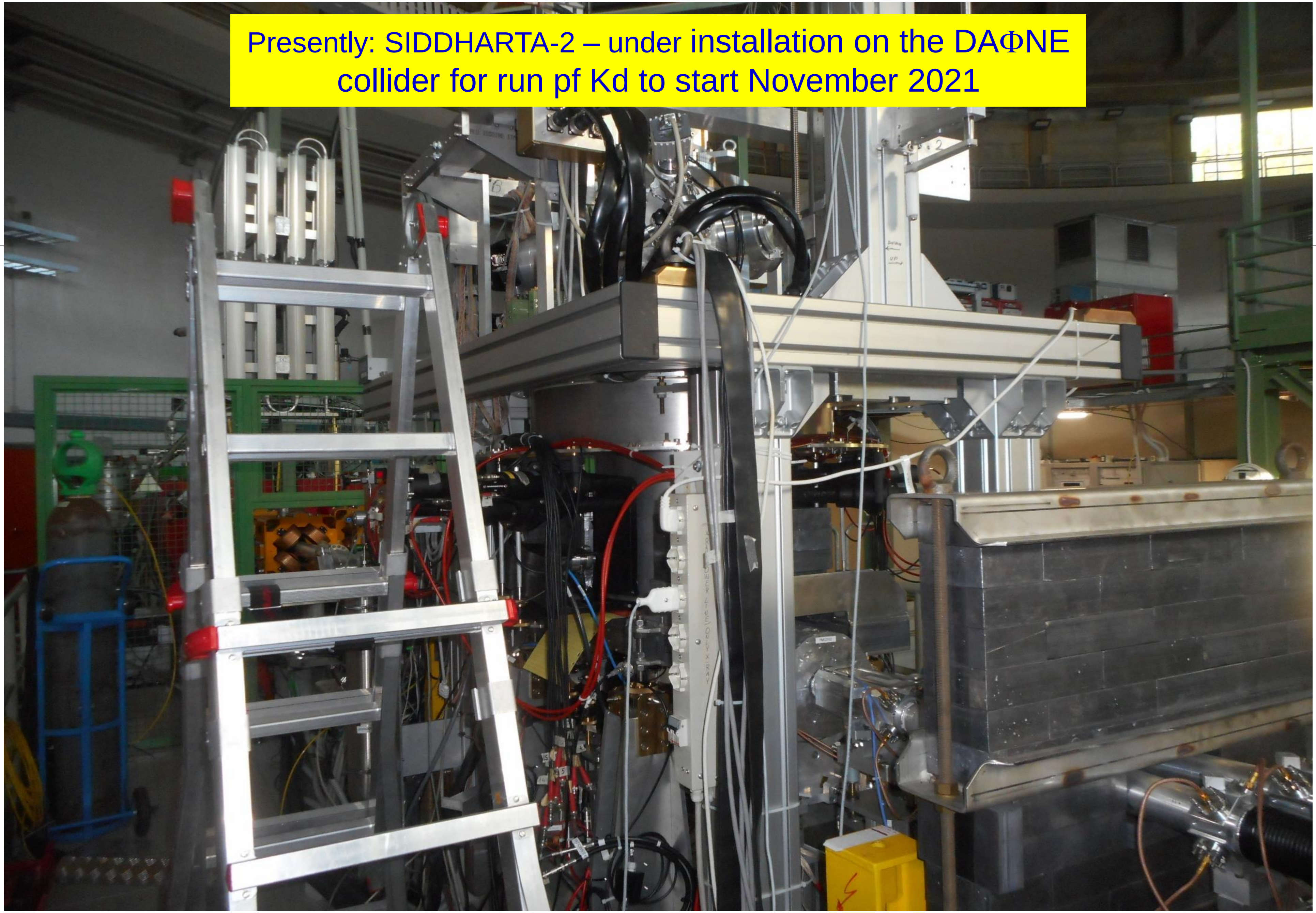


First Kaonic Helium measurement at LOW DENSITY: (0.73+-0.04)% liquid density

L= 9,496 pb-1 – yield to be estimated: paper

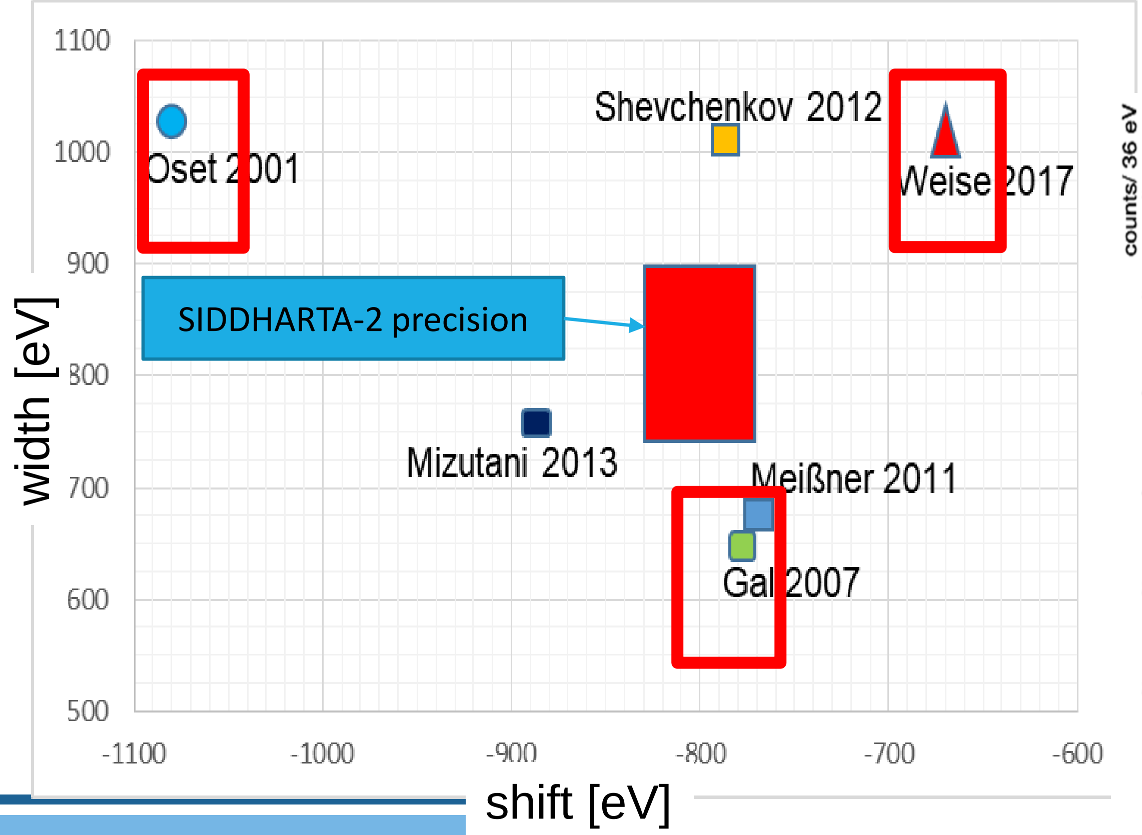


Presently: SIDDHARTA-2 – under installation on the DAΦNE collider for run pf Kd to start November 2021

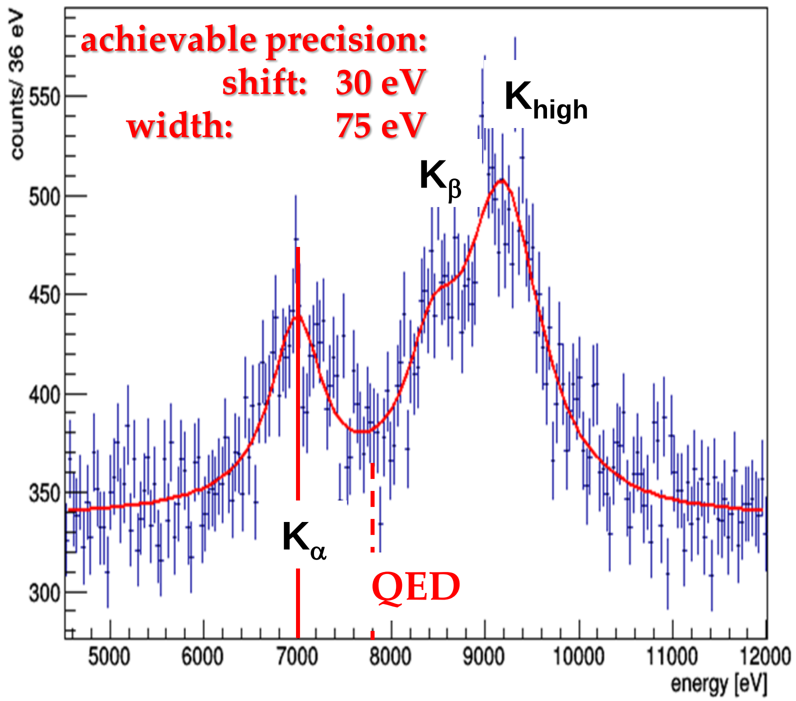


SIDDHARTA-2: the scientific aim

- To perform precision measurement of kaonic atoms X-ray transitions
  -> unique info about the QCD in non-perturbative regime in the strangeness sector not obtainable otherwise; impact in astrophysics (EOS neutron stars)
- Precision *measurement of the shift* and *of the width* of the 1s level of kaonic deuterium and the of and of other types of kaonic atoms
- Comparison with various theoretical models



MCarlo Kd spectrum for 800 pb^{-1}



TA3 – Transnational Access to LNF

Update on progress

PADME EXPERIMENT

TA3 – Transnational Access to LNF

Update on progress

PADME EXPERIMENT

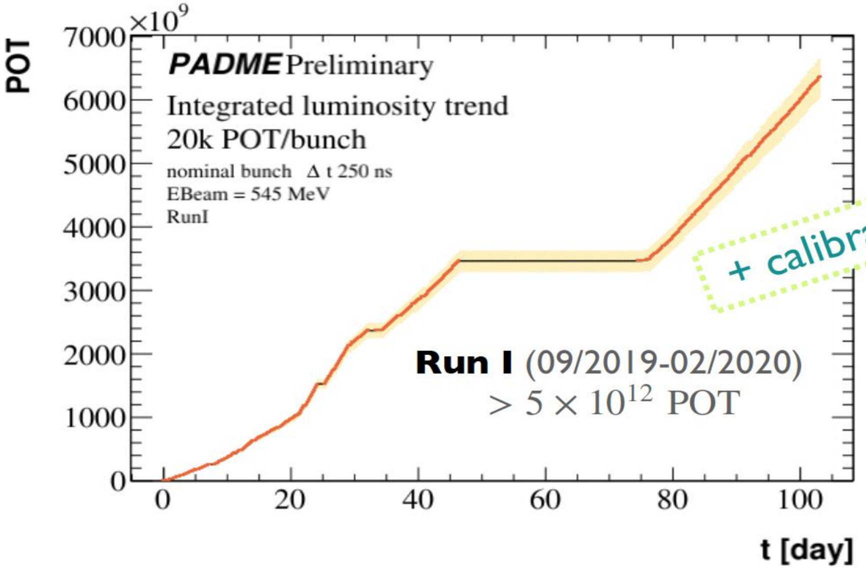
Run1 (Oct. 2018 – Feb. 2019) commissioning and background studies.

Beam Test (Apr. – Jul. 2020) beam line optimization

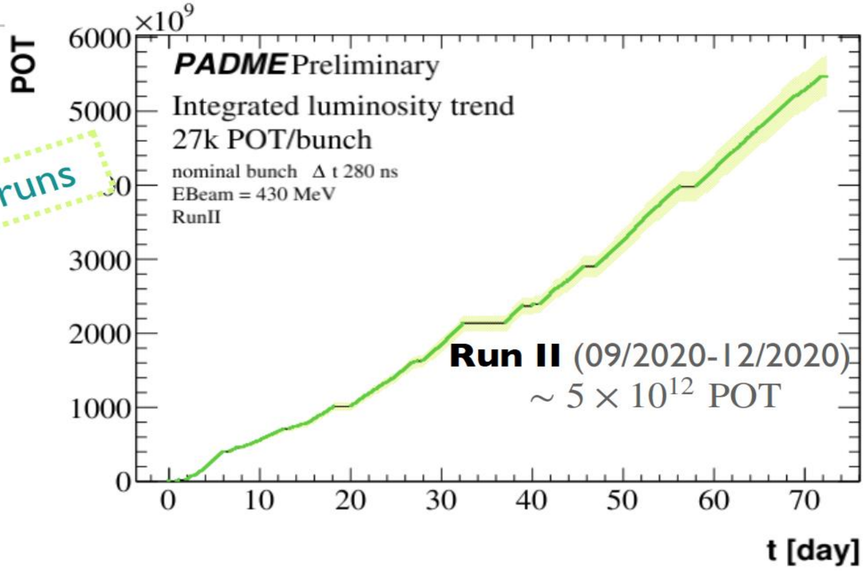
Run2 (Sep. – Dec. 2020) Collected 5×10^{12} POT

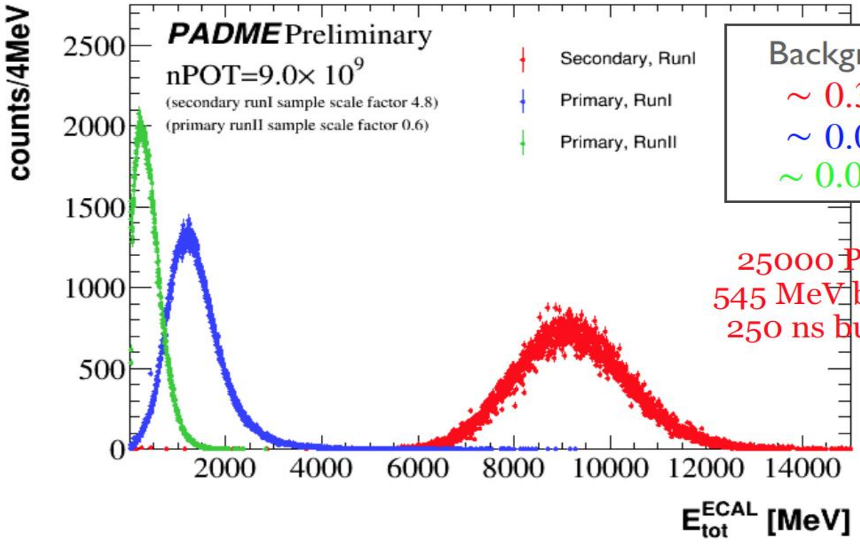
Run3 foreseen 2021 to study X17 boson.

Data Quality in different RUN periods



+ calibration runs





Background index:
~ 0.36 MeV/e^+
~ 0.03 MeV/e^+
~ 0.013 MeV/e^+

25000 POT/bunch
545 MeV beam energy
250 ns bunch length

- Beam related background is observed
- Detailed beam line description in the MC used to investigate it
- Improving of the beam line → beam transportation

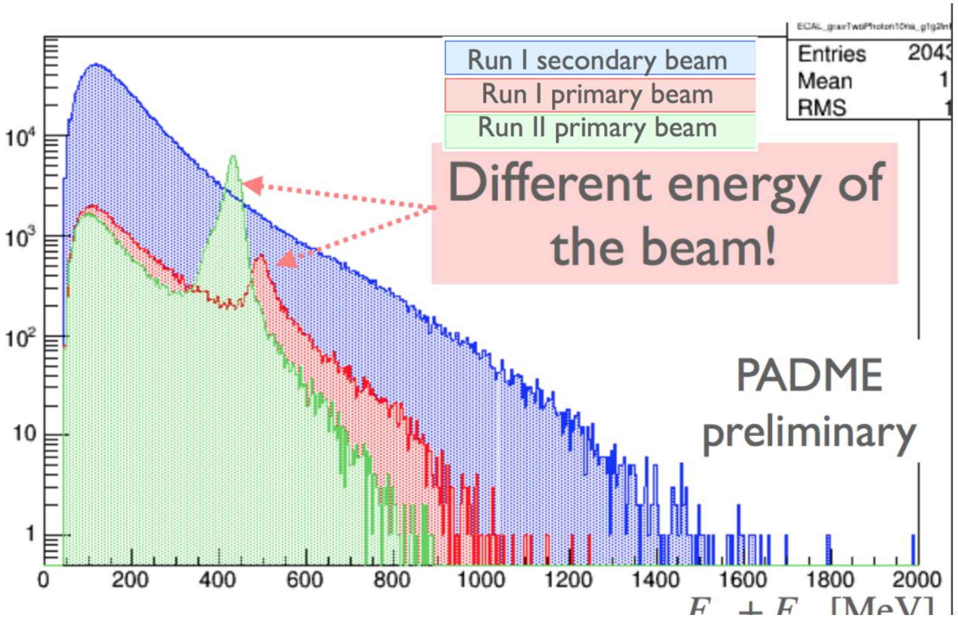
25000 POT/bunch
490 MeV beam energy
250 ns bunch length

28000 POT/bunch
430 MeV beam energy
280 ns bunch length

10

di, I.Oceano Sept. 14th, 2021

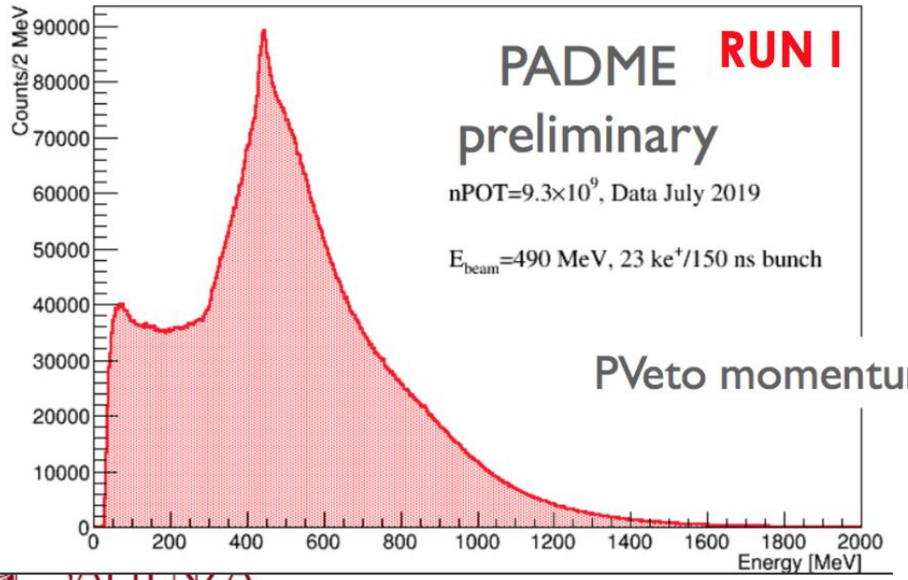
Physical channels comparison Run1 Run2

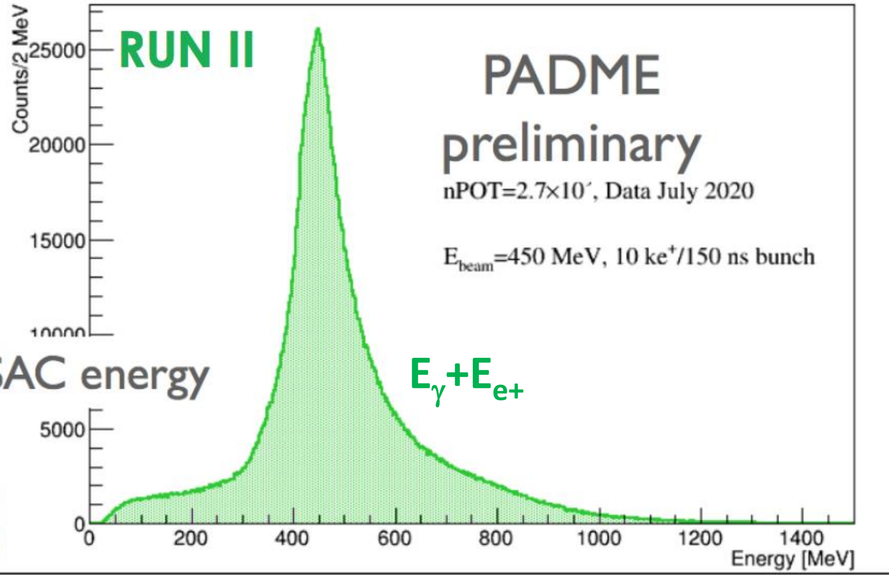


e^+e^- –> $\gamma\gamma$ **RUN2** better signal/noise ratio.

The sum $E_\gamma+E_{e+}$ **RUN2** brems. channel

e^+N –> $e^+N\gamma$
shows a cleaner peak





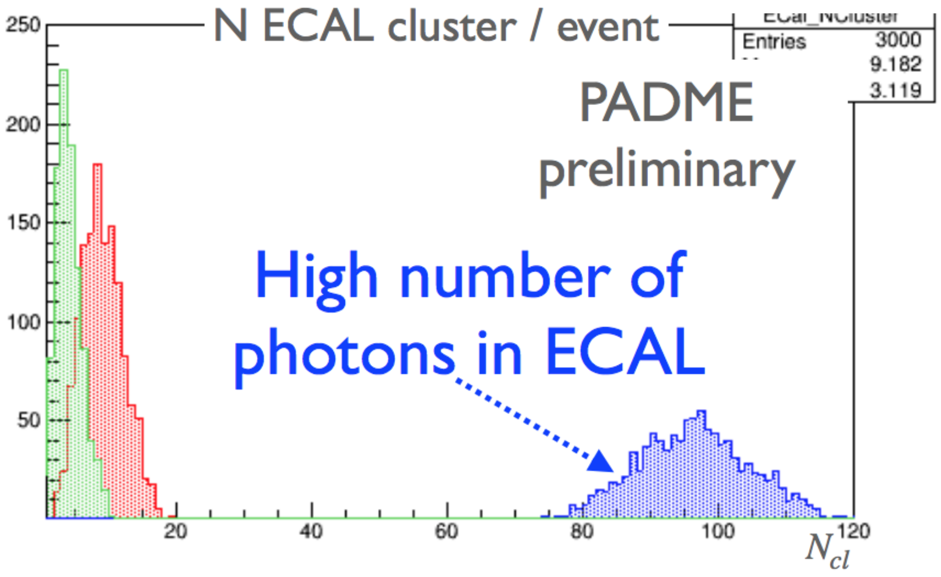
Backgrounds in different Run periods

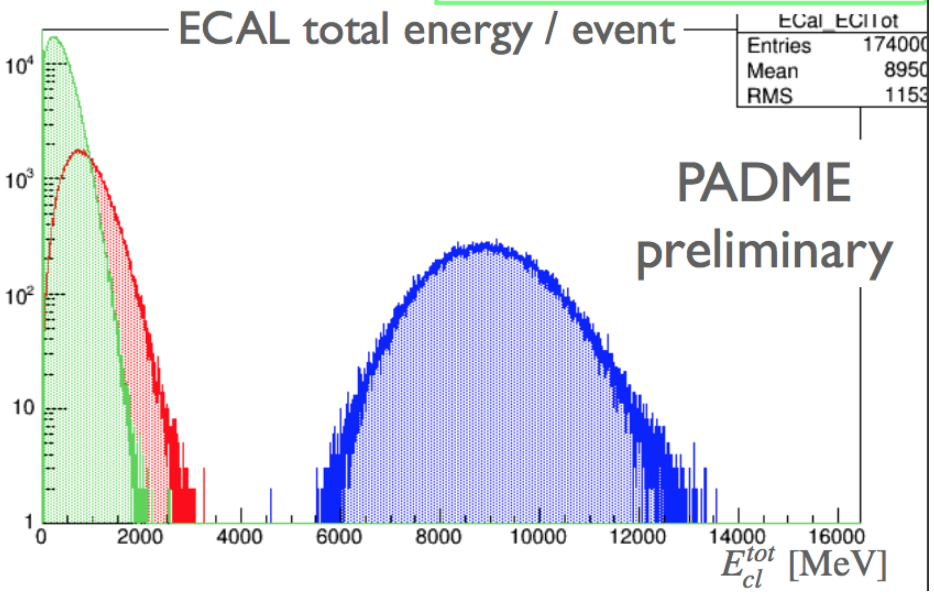
- Due to the several condition of data taking, the quality of data is very different
  - Run I secondary beam:
    - Huge background coming from the beam
  - Run I primary beam:
    - Beam related background is observed.
    - Detailed beam line description in the MC used to investigate it.
    - With primary e+ beam the beryllium window, used to separate the detector vacuum from the accelerator vacuum, produces a high beam momentum spread. As a consequence some particles can shower on the beam line;
  - Run II primary beam:
    - Very clean beam. SM processes, like annihilation and bremsstrahlung, easy to identify

25000 kPOT/bunch
545 MeV beam energy
250 ns bunch length

25000 kPOT/bunch
490 MeV beam energy
250 ns bunch length

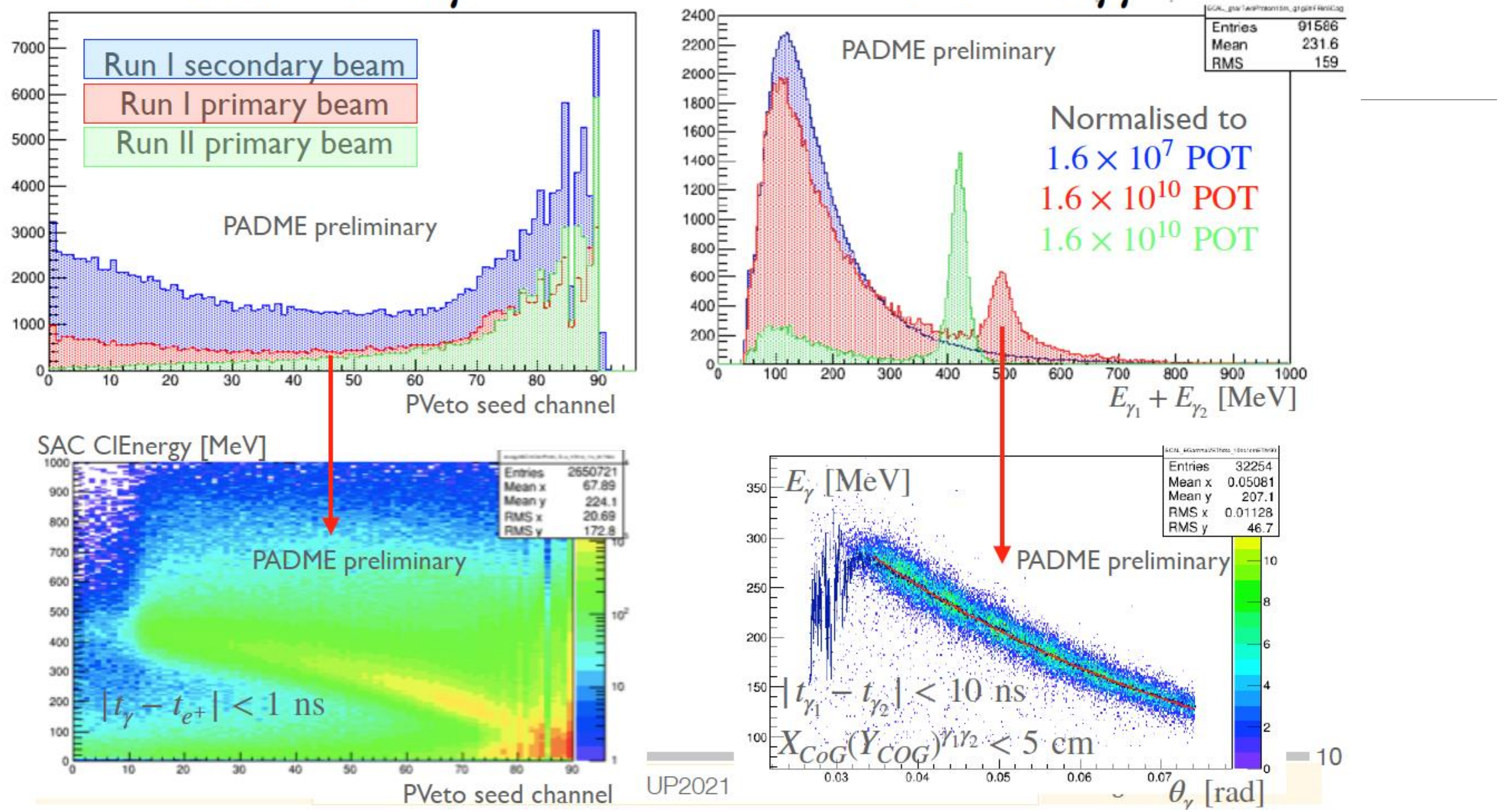
28000 kPOT/bunch
430 MeV beam energy
280 ns bunch length





SM physics @ PADME

$e^+N \to e^+N\gamma$ $\qquad$ $e^+e^- \to \gamma\gamma$



UP2021 10

TA3 – Transnational Access to LNF

Transnational Access to LNF in the period: 01/06/2019-31/10/2021

Project	Days spent at LNF	Days indicated in GA	Access provided (beam x hours)	Access in GA (beam x hours)
PADME	62			
SIDDHARTA-2	63			
TOTAL	**125**	**1208**	**1500**	**1510**

Work in remote : equivalent of more than 150 days
Only from summer 2021 situation somehow normalized
Other 50 days planned within 2021
Planned to intensify days in 2022 SIDDHARTA-2 full run and PADME periods of runs

Publications 2020-2021

1. M. Miliucci et al, Low-energy Kaon Nucleon/Nuclei Studies at DAΦNE: the SIDDHARTA-2 Experiment, Acta Phys. Polon. Supp. 4 (2021) 49.

2. M. Skurzok et al, Characterization of the SIDDHARTA-2 luminosity monitor, JINST 15 (2020) 10, P10010.

3. D. Sirghi et al, Studies of kaonic atoms at the DAΦNE collider: from SIDDHARTA to SIDDHARTA-2, J. Phys. Conf. Ser. 1526 (2020) 012023.

4. C. Curceanu et al, Kaonic Atoms to Investigate Global Symmetry Breaking, Symmetry 12 (2020) 4, 547.

5. M. Skurzok et al, Kaonic atoms experiment at the DAΦNE collider by SIDDHARTA/SIDDHARTA-2, SciPost Phys.Proc. 3 (2020) 039.

6. C. Curceanu et al, Kaonic Deuterium Measurement with SIDDHARTA-2 on DAΦNE, Acta Phys. Polon. B 51 (2020) 257.

7. M. Miliucci et al, Kaonic Deuterium Precision Measurement at DAΦNE: The SIDDHARTA-2 Experiment, Springer Proc. Phys. 238 (2020) 969.

8. M. Miliucci et al., Silicon Drift Detectors system for high precision light kaonic atoms spectroscopy, in print on Measurement Science and Technology 32 (2021) 3 095501

Publications 2021

9. M. Miliucci et al., Low energy kaon-nuclei interaction at DAΦNE:The SIDDHARTA-2 experiment, Il Nuovo Cimento 44 C (2021).
Selected communication at 106° SIF Congress (best presentation: Marco Miliucci) for with publication on Rivista de il Nuovo Cimento.

10. C. Curceanu et al, Kaonic Atoms Measurements at DAΦNE: SIDDHARTA-2 and Future Perspectives, Few Body Syst. 62, 4 (2021).

11. M. Miliucci et al., Silicon Drift Detectors spectroscopic response during the SIDDHARTA-2 Kaonic Helium run at the DAΦNE collider, submitted to Condensed Matter, arXiv:2111.01572.

12. M. Miliucci et al., HIGH PRECISION KAONIC ATOMS X-RAY SPECTROSCOPY AT THE DAΦNE COLLIDER: THE SIDDHARTA-2 EXPERIMENT (submitted to RAP Conference Proceedings)

13. M. Miliucci et al., Silicon Drift Detectors Technology for High Precision Light Kaonic Atoms Spectroscopic Measurements at the DAΦNE Collider, in print on AIP-CP.

THANK YOU
FOR THE ATTENTION!