From ADAMO

to ACROMASS

Atmospheric Cosmic Ray Observatory using a Magnetic Altazimuth Silicon Spectrometer

L. Bonechi

ACROMASS kick-off meeting
23 February 2024

International relevance of the ACROMASS proposal

Neutrino observatories (e.g. HyperK)

M. Honda et al., *Reduction of the Uncertainty in the Atmospheric Neutrino Flux Prediction Below 1 GeV Using Accurately Measured Atmospheric Muon Flux*, **Phys. Rev. D 100, 123022** – Published 30 December 2019

M. Honda et al., *Accuracy improvement of the atmospheric neutrino flux prediction using observed muon spectra at mountain altitude*, **Journal of Physics: Conference Series, 1468 (2020) 012190**

Previous invitation in Japan for the **Workshop for Atmospheric Neutrino Production in the MeV to PeV range**

- This workshop focus on the atmospheric neutrino measurement and its flux calculation which are getting more important for precise oscillation analysis in the low energy region and as background estimation of neutrino astronomy.
- https://indico.cern.ch/event/781361/ (2019)
- https://indico.cern.ch/event/873509/ (2020-2021) → presentation of ADAMO and data 2004
- https://www-kam2.icrr.u-tokyo.ac.jp/event/14/ (2022)

Muon radiography

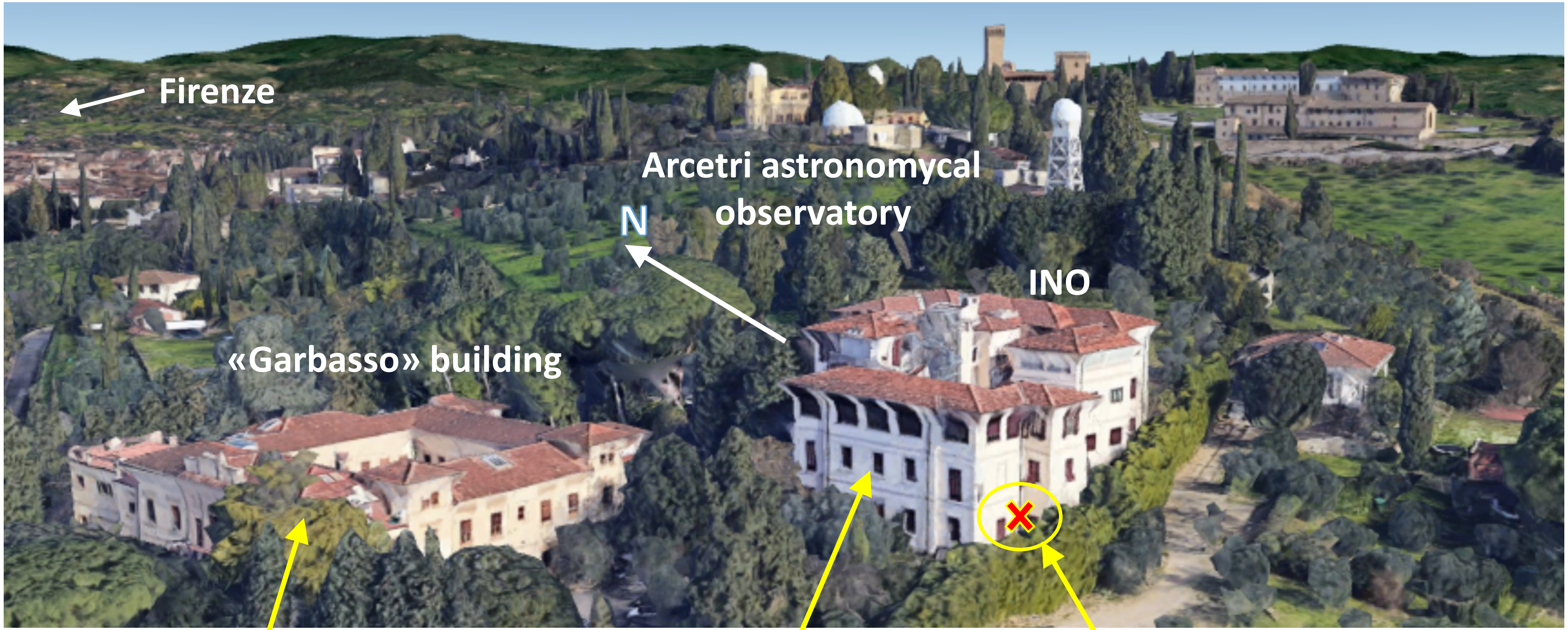
Worlwide need of precise measuremets in wide ranges of momentum and angles, in different places and different altitudes, for the implementation of reliable simulations to be compared with angular distributions measured downstream of target volumes

→ e.g. the **ECOMUG** muon generator (developed by the Brescia/Padova group and based on the 2004 ADAMO data)

→ e.g. the **ADAMO** Ground Muon Generator developed in Florence

Why ADAMO and why upgrading to ACROMASS

The ADAMO detector phase-1: 1998-2001



Old headquarters of the Department of Physics of the Florence University and INFN Unit

National Institute of Optics (INO-CNR)

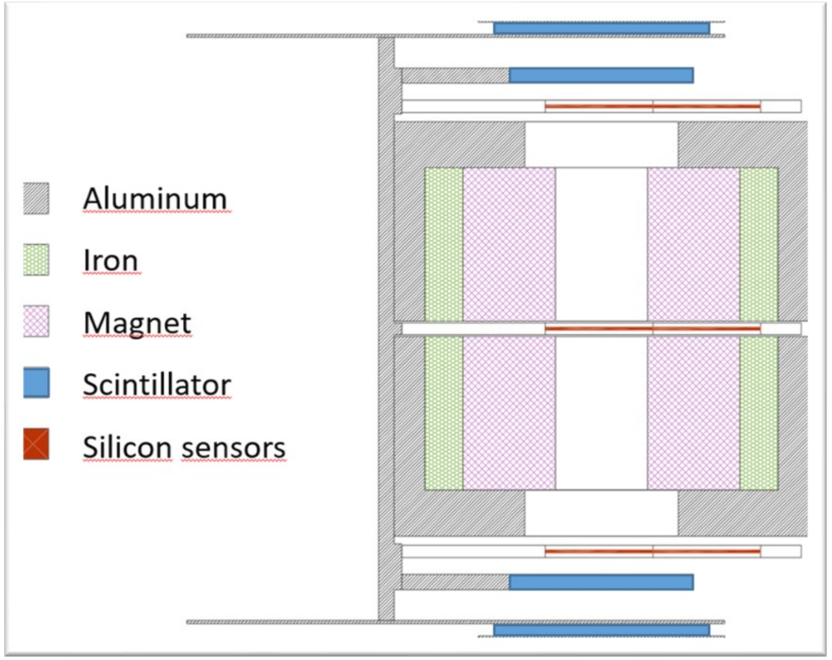
WiZard PAMELA/ADAMO lab
Lat: 43° 44′ 56.9″ N
Long: 11° 15′ 06.73″ E
Elev.: 148 m

The ADAMO detector phase-1: 1998-2001

Test system of the spectrometer degined for the **PAMELA satellite experiment**

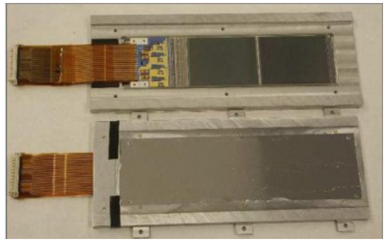
The apparatus

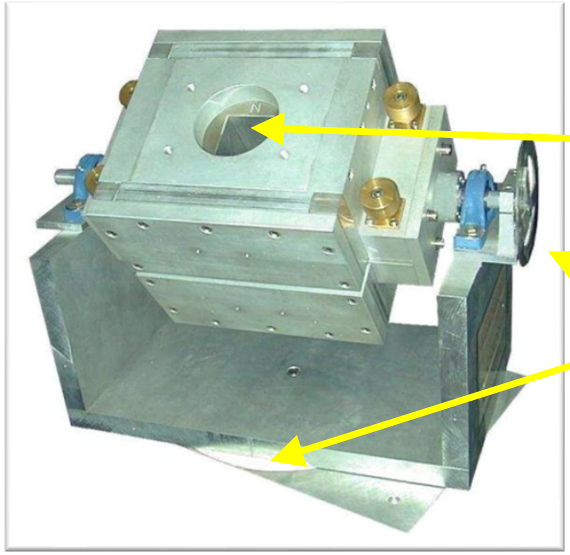
- **Tracker**: 3 double sided microstrip silicon planes
- **Trigger system**: 4 scintillator layers
- **Magnet**: NdFeB alloy, 1.3T residual magnetization
- Geometrical factor $G_F = 1$ cm^2 sr
- MDR ~ 650 GV/c



PAMELA μ–strip silicon tracking module

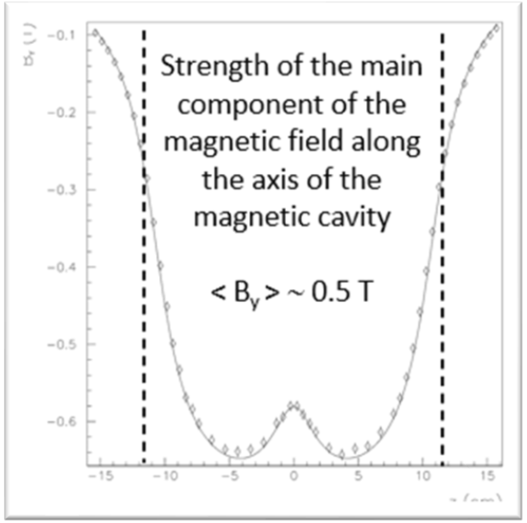
Double sided
300 μm thick
5.33 x 7 cm^2
$\sigma_x \sim 5$ μm





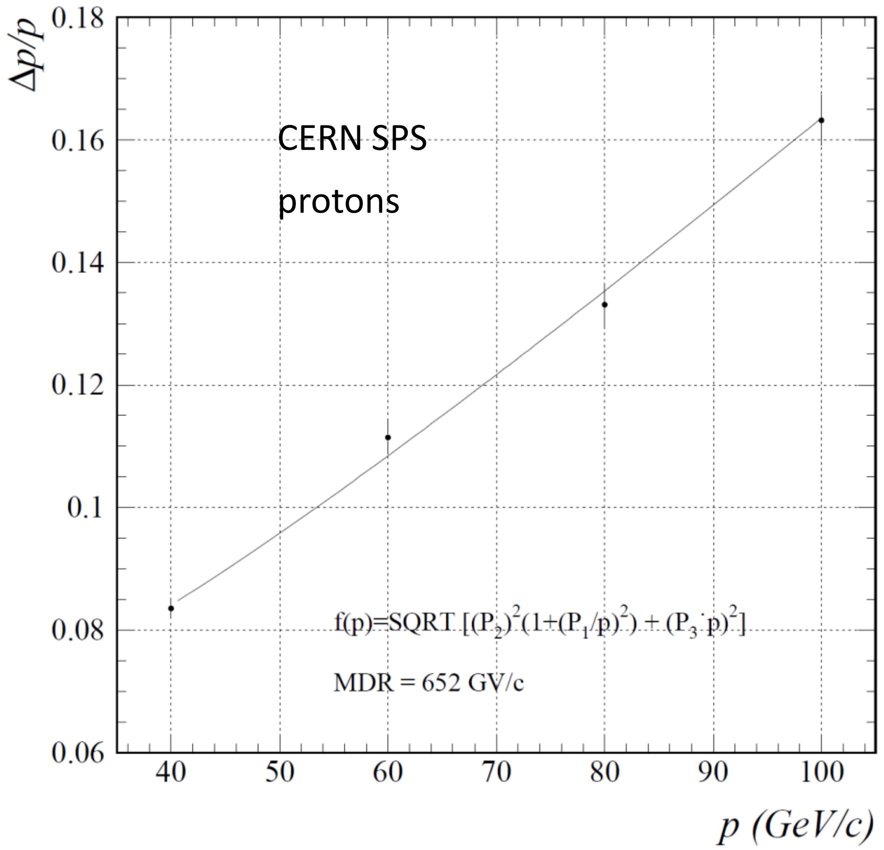
Magnetic cavity:
6 x 6 cm^2; h = 21 cm

Manual
altazimuth mount

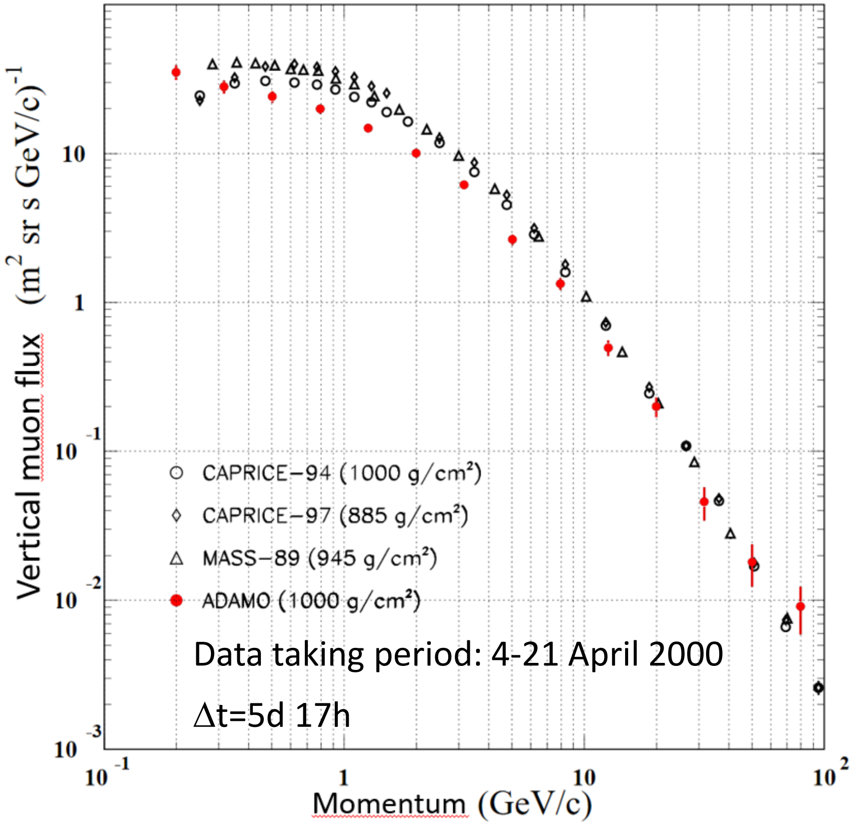


The ADAMO detector phase-1: 1998-2001

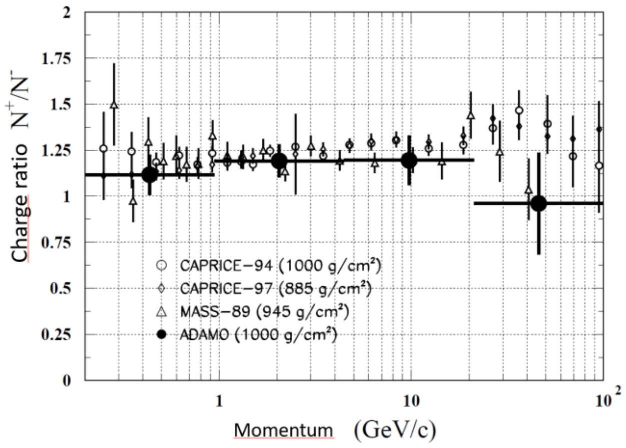
Beam test: momentum resolution



CR vertical momentum spectrum

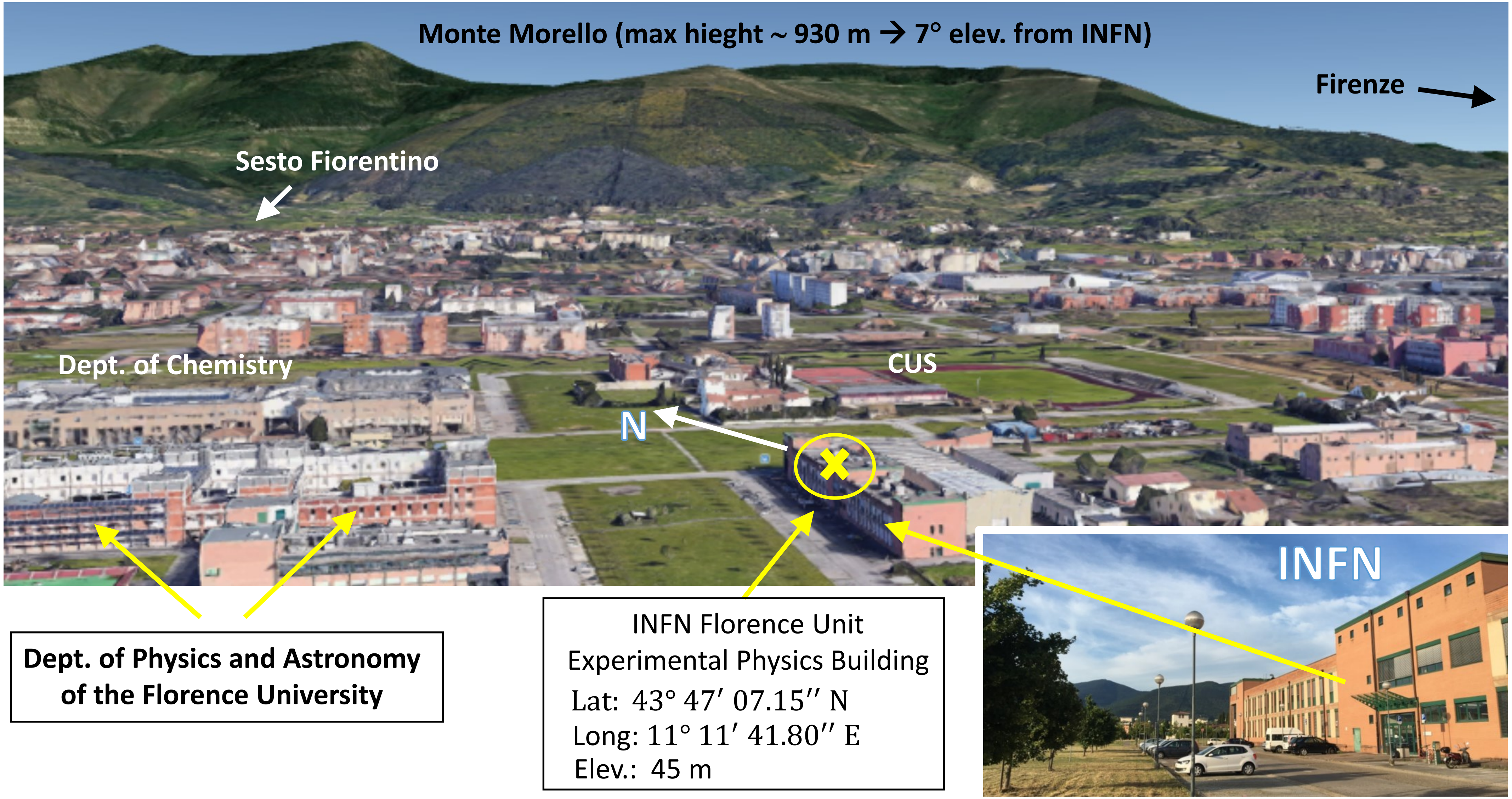


Muon charge ratio



The ADAMO detector phase-2: 2002-2004

Scientific Campus of Sesto Fiorentino (Firenze)



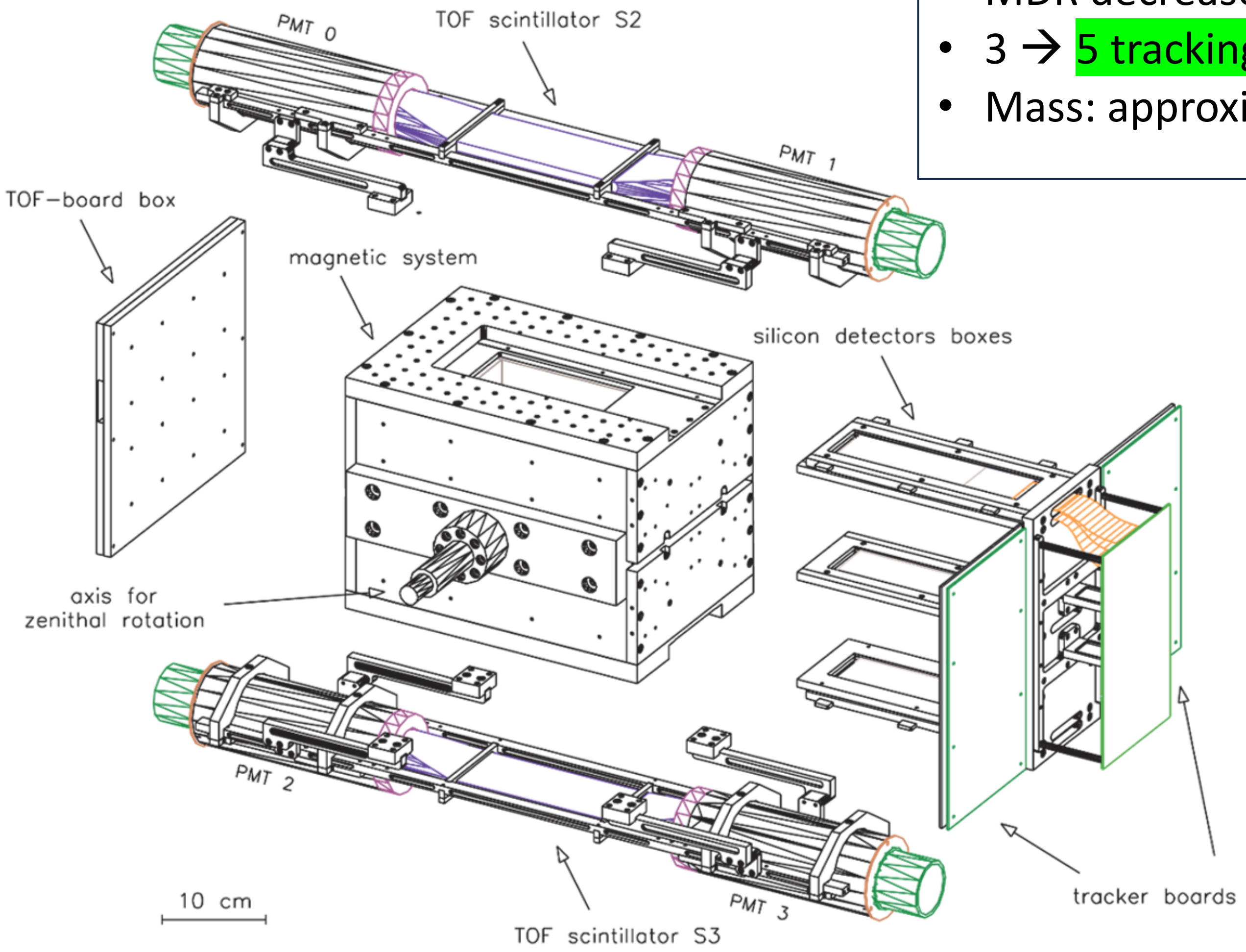
Dept. of Physics and Astronomy of the Florence University

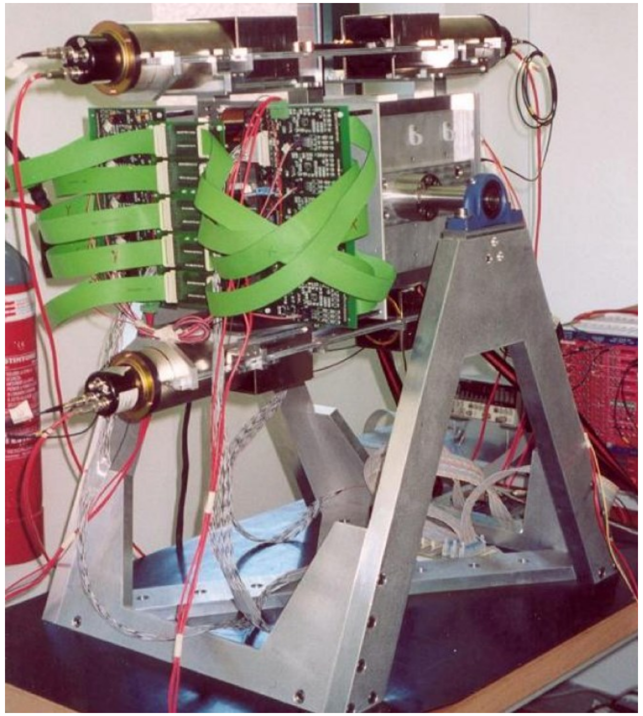
INFN Florence Unit
Experimental Physics Building
Lat: $43° \, 47' \, 07.15'' \, \mathrm{N}$
Long: $11° \, 11' \, 41.80'' \, \mathrm{E}$
Elev.: 45 m

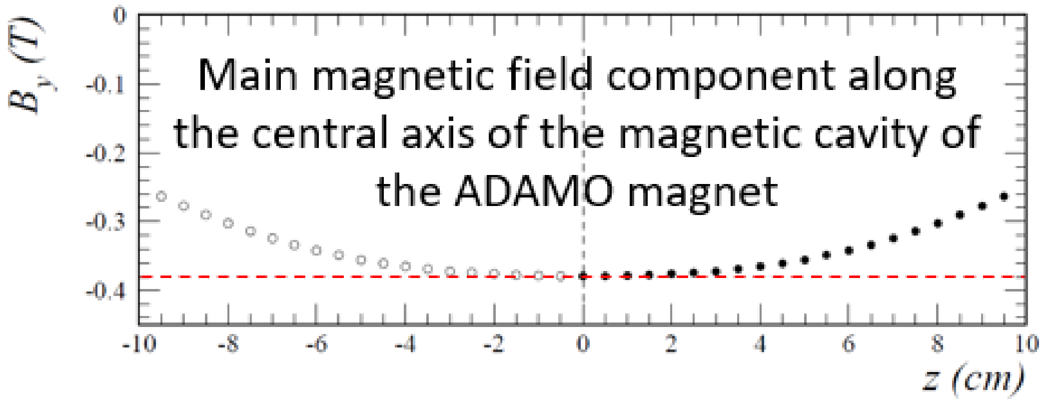
The ADAMO detector phase-2: 2002-2004

First upgrade: increase of the acceptance for **cosmic-ray measurements**

- Re-assebling of the magnet
  - → G_F = 6.7 cm^2sr (old was 1 cm^2sr)
- MDR decrease: 650 → 250 GV/*c*
- 3 → 5 tracking planes
- Mass: approximately 100 kg

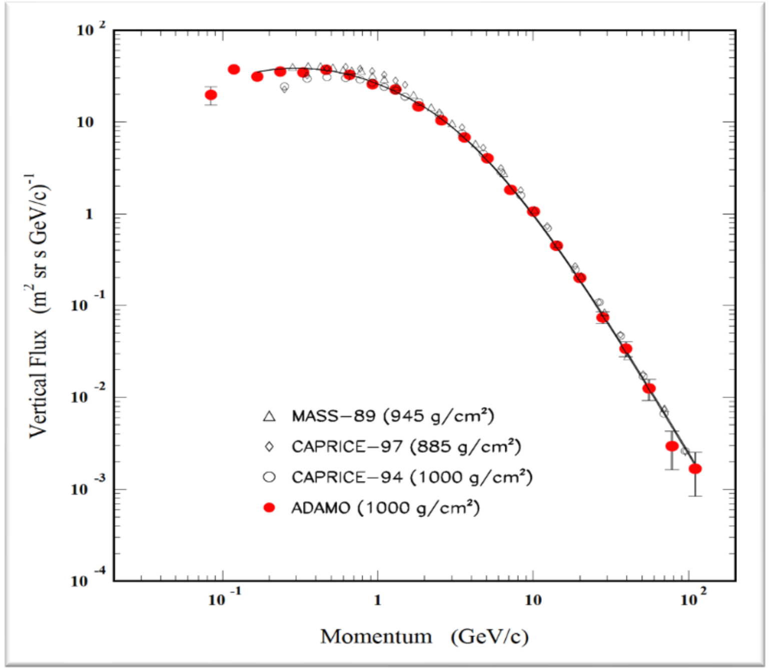






Measurements with ADAMO in phase-2

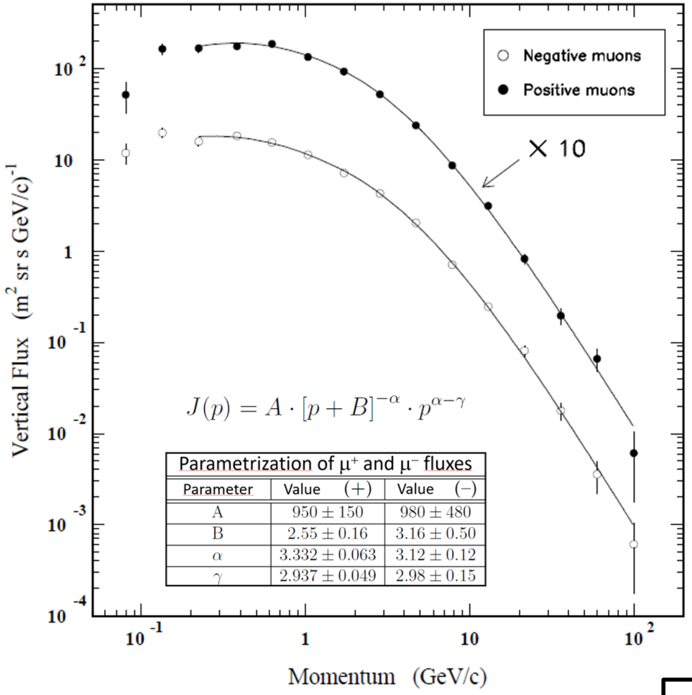
Cosmic ray vertical spectrum



$$J(p) = A \cdot [p + B]^{-\alpha} \cdot p^{\alpha-\gamma}$$

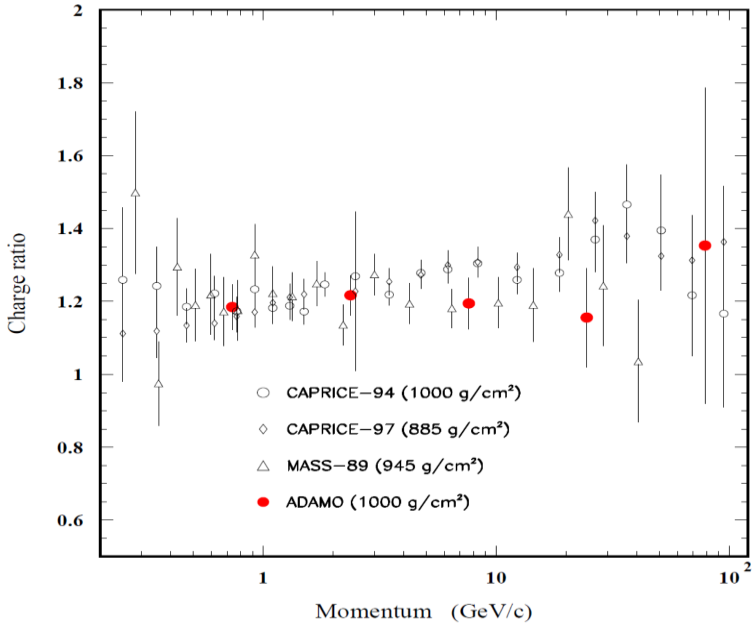
A	1600 ± 170
B	2.68 ± 0.13
α	3.175 ± 0.046
γ	2.896 ± 0.032

Spectra of **negative** and **positive** cosmic rays



$$\Delta t_{acq} = 2d\ 13h\ 47m\ 25s$$

Vertical charge ratio



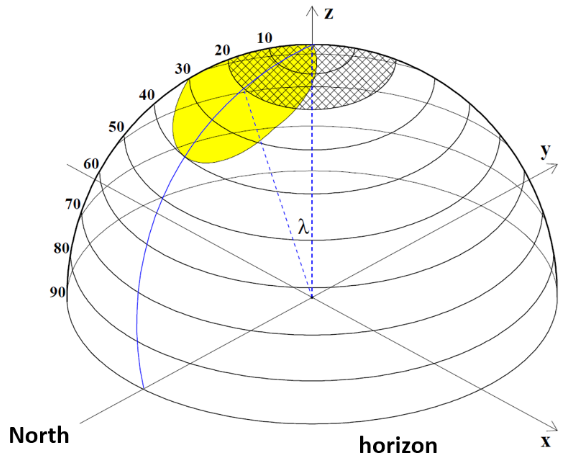
Measurement of charge ration in the vertical direction

$c\,p_{min}$ (GeV/c)	$c\,p_{max}$ (GeV/c)	$c\,\tilde{p}$ (GeV/c)	counts +	counts −	Charge ratio	Stat. error
0.350	1.125	0.737	790	667	1.184	0.062
1.125	3.615	2.370	1105	908	1.217	0.055
3.615	11.618	7.617	632	529	1.195	0.070
11.618	37.339	24.478	156	135	1.16	0.14
37.339	120	78.669	23	17	1.35	0.43

Measurements with ADAMO in phase-2

Data taking at <u>4 different detector's orientations</u>

- Detector's acceptance > 20°
- Combining data from consecutive configurations
- Muon zenith angle range: $0° < \theta < 80°$

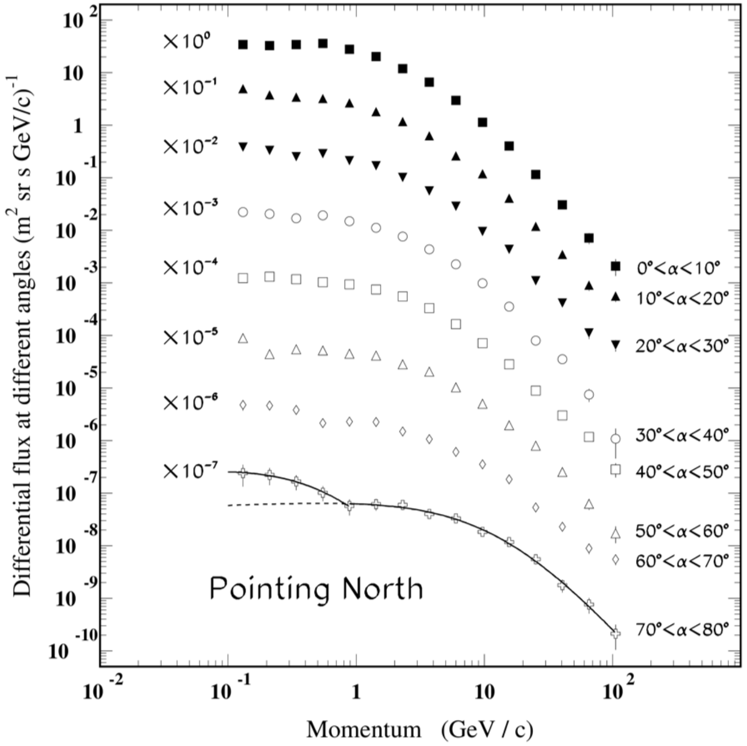


Duration of the data taking

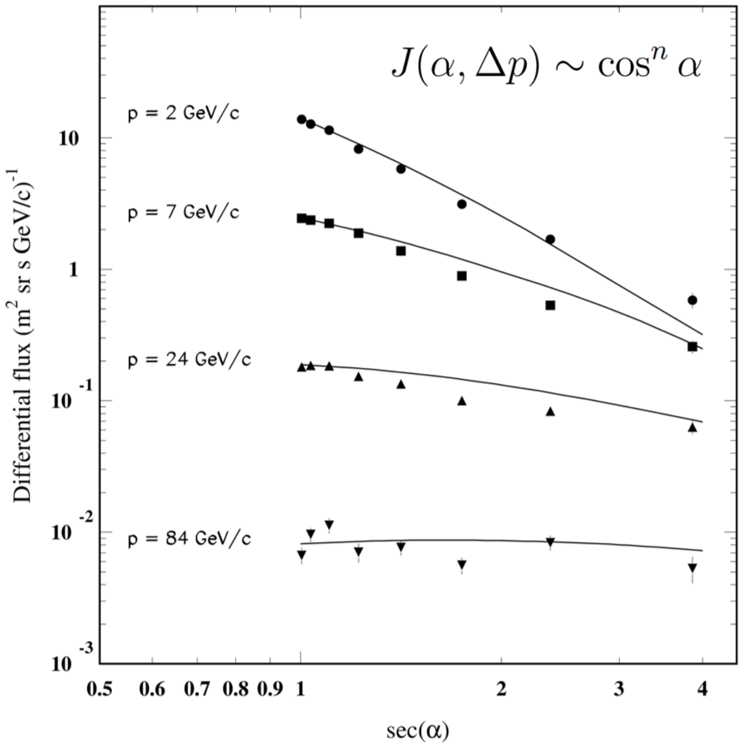
λ	Δt_{acq}
0°	222445 s (2d 13h 47m 25s)
20°	195848 s (2d 06h 24m 08s)
40°	255009 s (2d 22h 50m 09s)
60°	466121 s (5d 09h 28m 41s)

Study of the muon spectrum <u>dependence on the zenith angle</u>

CR momentum spectrum in different intervals of the zenith angle



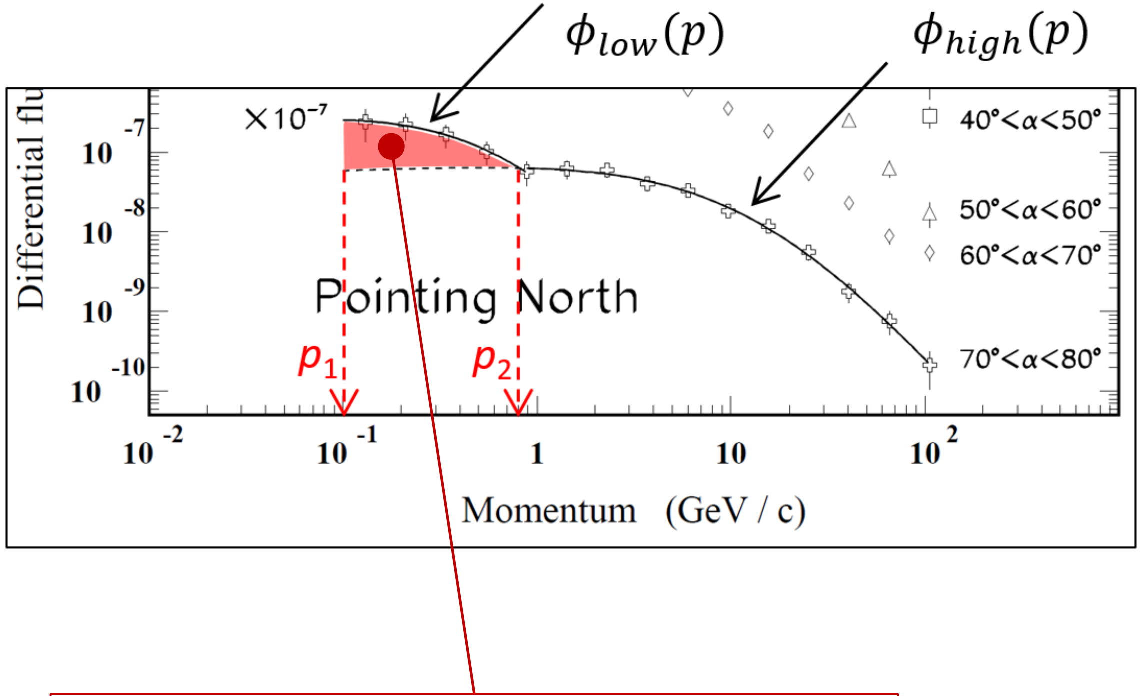
Zenith angle dependence of the CR flux at different momenta



Measurements with ADAMO in phase-2

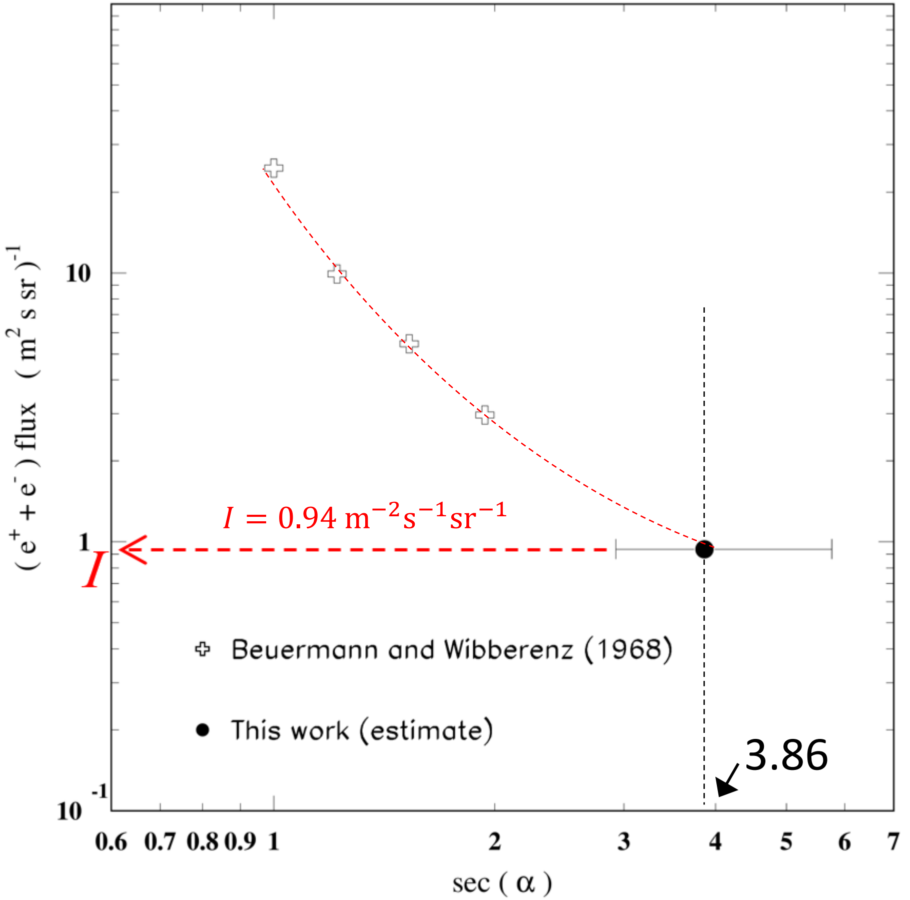
Study of the low energy region: probable contamination by e^+/e^-

Integration of the low energy «bump» appearing in the CR spectrum:



$$I = \int_{p_1}^{p_2} \left(\phi_{low}(p) - \phi_{high}(p)\right) dp$$

Interpretation of the low energy bump of the CR spectrum as due to electron contamination



Measurements with ADAMO in phase-2

Current use of the ADAMO measurement

- Muon generator developed in Florence
  - Article in preparation…
- EcoMug: muon generatorintegrated in a GEANT4 simulation developed by INFN and UNIV groups from Brescia, Padova and Pavia
  - Implement generation on flat, cylindrical (with or without cover) and spheric surfaces

ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 1014, 21 October 2021, 165732

EcoMug: An Efficient COsmic MUon Generator for cosmic-ray muon applications

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Received 22 June 2021, Revised 4 August 2021, Accepted 9 August 2021, Available online 19 August 2021, Version of Record 1 September 2021.

The ACROMASS project

Preliminary estimation based on the ADAMO phase-2

Feasibility of the measurement with ACROMASS at low energy

Misura del flusso nell'intervallo di angolo zenitale ($0° < \alpha < 10°$) $\Delta t_{acq} \sim 2.5d$

p_{min}	p_{max}	$\tilde{p}$	Ev. tot.	Ev. +	Ev. -	Flusso tot.	Errore stat.tot.	Errore sist.tot.	Flusso +	Errore stat.+	Errore sist.+	Flusso -	Errore stat.-	Errore sist.-
0.1000	0.1613	0.1306	124	55	69	33.8	3.0	0.39	15.0	2.0	0.17	18.8	2.3	0.22
0.1613	0.2601	0.2107	223	109	114	32.1	2.1	0.37	15.7	1.5	0.18	16.4	1.5	0.19
0.2601	0.4196	0.3398	404	200	204	33.9	1.7	0.39	16.8	1.2	0.19	17.1	1.2	0.20
0.4196	0.6767	0.5481	695	372	323	35.2	1.3	0.40	18.85	0.98	0.21	16.37	0.91	0.19
0.6767	1.091	0.8840	880	492	388	27.36	0.92	0.31	15.30	0.69	0.17	12.06	0.61	0.14

Misura del flusso nell'intervallo di angolo zenitale ($40° < \alpha < 50°$) $\Delta t_{acq} \sim 3d$

p_{min}	p_{max}	$\tilde{p}$	Ev. tot.	Ev. +	Ev. -	Flusso tot.	Errore stat.tot.	Errore sist.tot.	Flusso +	Errore stat.+	Errore sist.+	Flusso -	Errore stat.-	Errore sist.-
0.1000	0.1613	0.1306	52	20	32	12.1	1.7	0.15	4.7	1.0	0.058	7.5	1.3	0.093
0.1613	0.2601	0.2107	97	52	45	13.0	1.3	0.16	6.97	0.97	0.086	6.03	0.90	0.074
0.2601	0.4196	0.3398	144	67	77	11.61	0.97	0.14	5.40	0.66	0.066	6.21	0.71	0.076
0.4196	0.6767	0.5481	207	110	97	10.23	0.71	0.12	5.44	0.52	0.066	4.79	0.49	0.058
0.6767	1.091	0.8840	301	185	116	9.17	0.53	0.11	5.64	0.41	0.069	3.53	0.33	0.043

Misura del flusso nell'intervallo di angolo zenitale ($70° < \alpha < 80°$) $\Delta t_{acq} \sim 5.5d$

p_{min}	p_{max}	$\tilde{p}$	Ev. tot.	Ev. +	Ev. -	Flusso tot.	Errore stat.tot.	Errore sist.tot.	Flusso +	Errore stat.+	Errore sist.+	Flusso -	Errore stat.-	Errore sist.-
0.1000	0.1613	0.1306	5	2	3	2.4	1.1	0.037	0.94	0.67	0.015	1.41	0.82	0.022
0.1613	0.2601	0.2107	8	4	4	2.17	0.77	0.033	1.09	0.54	0.016	1.09	0.54	0.016
0.2601	0.4196	0.3398	10	5	5	1.64	0.52	0.024	0.82	0.37	0.012	0.82	0.37	0.012
0.4196	0.6767	0.5481	10	8	2	1.00	0.32	0.015	0.80	0.28	0.012	0.20	0.14	0.0030
0.6767	1.091	0.8840	9	4	5	0.56	0.19	0.0082	0.25	0.12	0.0036	0.31	0.14	0.0045

Statistics (VERTICAL):

To have 5% fluctuation in the bin 100-161 MeV/c:

- Factor 3.2 (stat)
- Factor 1/3 (altitude)

$\Delta t_{acq} \sim 3d$

Statistics (INTERMEDIATE ANGLES):

To have 5% fluctuation in the bin 100-161 MeV/c:

- Factor 7.7 (stat)
- Factor 1/3 (altitude)

$\Delta t_{acq} \sim 8d$

Statistics (HIGH ANGLE):

To have 5% fluctuation in the bin 100-400 MeV/c:

- Factor 35 (stat)
- Factor 1/3 (altitude)

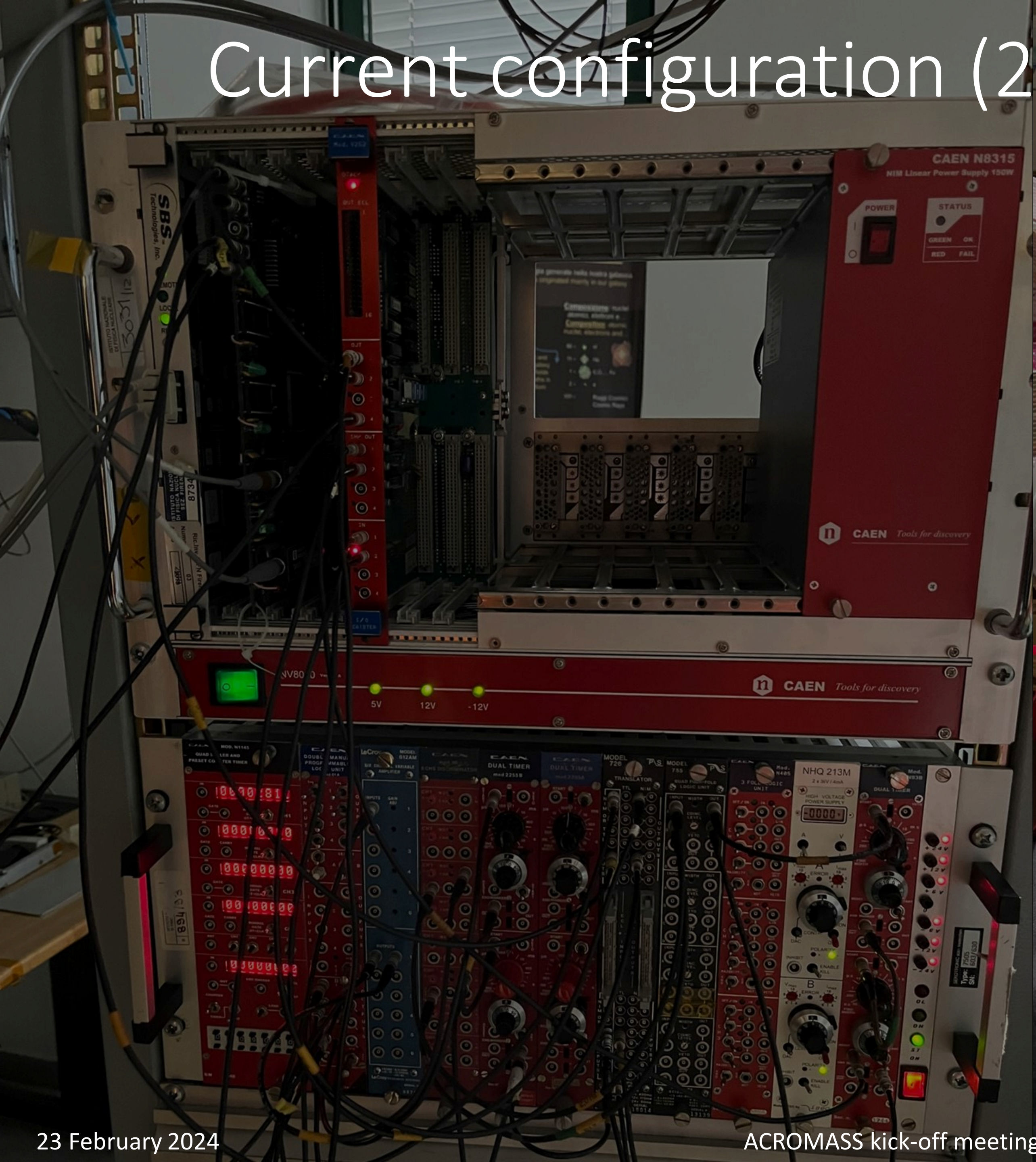
$\Delta t_{acq} \sim 2M$

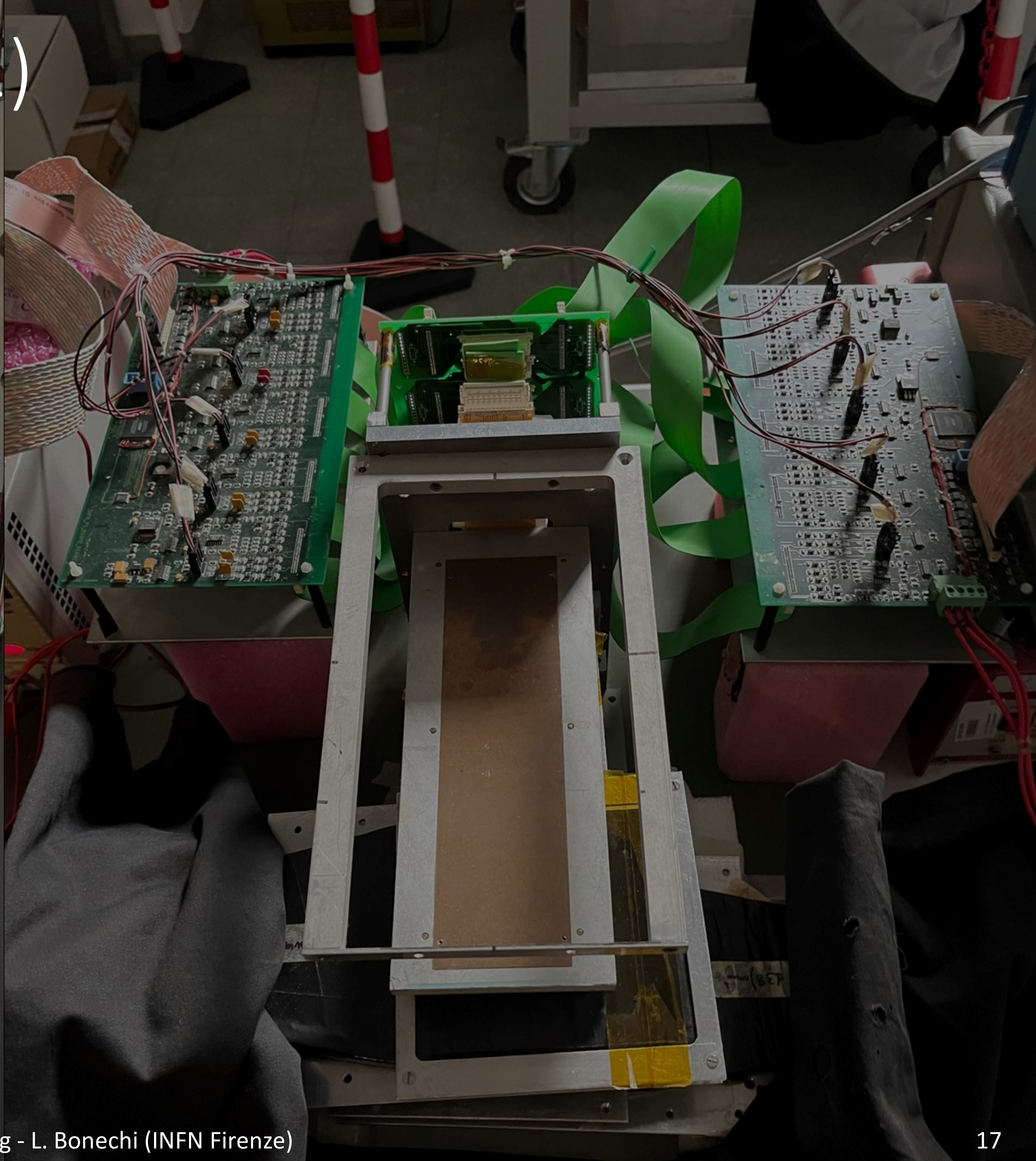
Current ADAMO configuration: main issues

- **Extremely old DAQ system**
  - Difficult to repair/refurbish (too old electronic components)
  - More than 50% based on cumbersome NIM and VME systems
- **Cumbersome and difficult to transport powering/trigger system**
  - NIM crate/modules + desktop power supplies)
- **Need sub-detectors for PID**
  - To remove the contamination from e^+, e^- and p in the muon spectra…
  - … but also to study the spectra of these more rare components
- **Old microstrip silicon sensors with several defects and some «bad» VA1 chips**
  - First production of the PAMELA experiment with implantation defects
    - Solved for the successive production
  - System worn over time
    - Used since 1998 for ADAMO
    - Used for several beam tests at CERN
    - Used for many years for didactics (Laboratorio Subnucleare)

Current configuration

Current configuration (2)





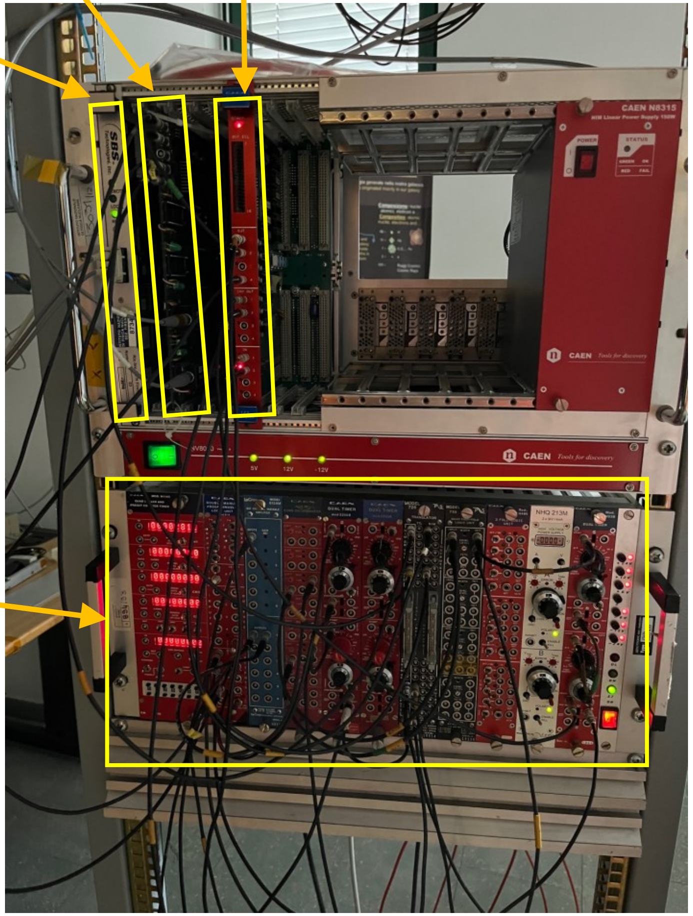
Current configuration (3)

Custom DAQ board

I/O register CAEN V262

SBS interface (VME→fiber→PCI)

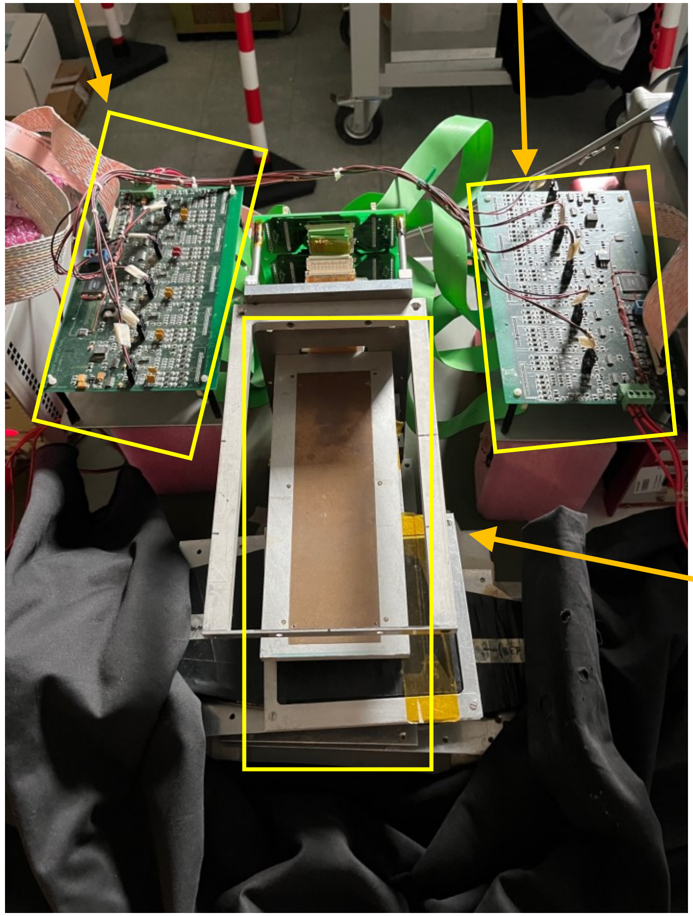
Trigger/Veto + HV P.S.



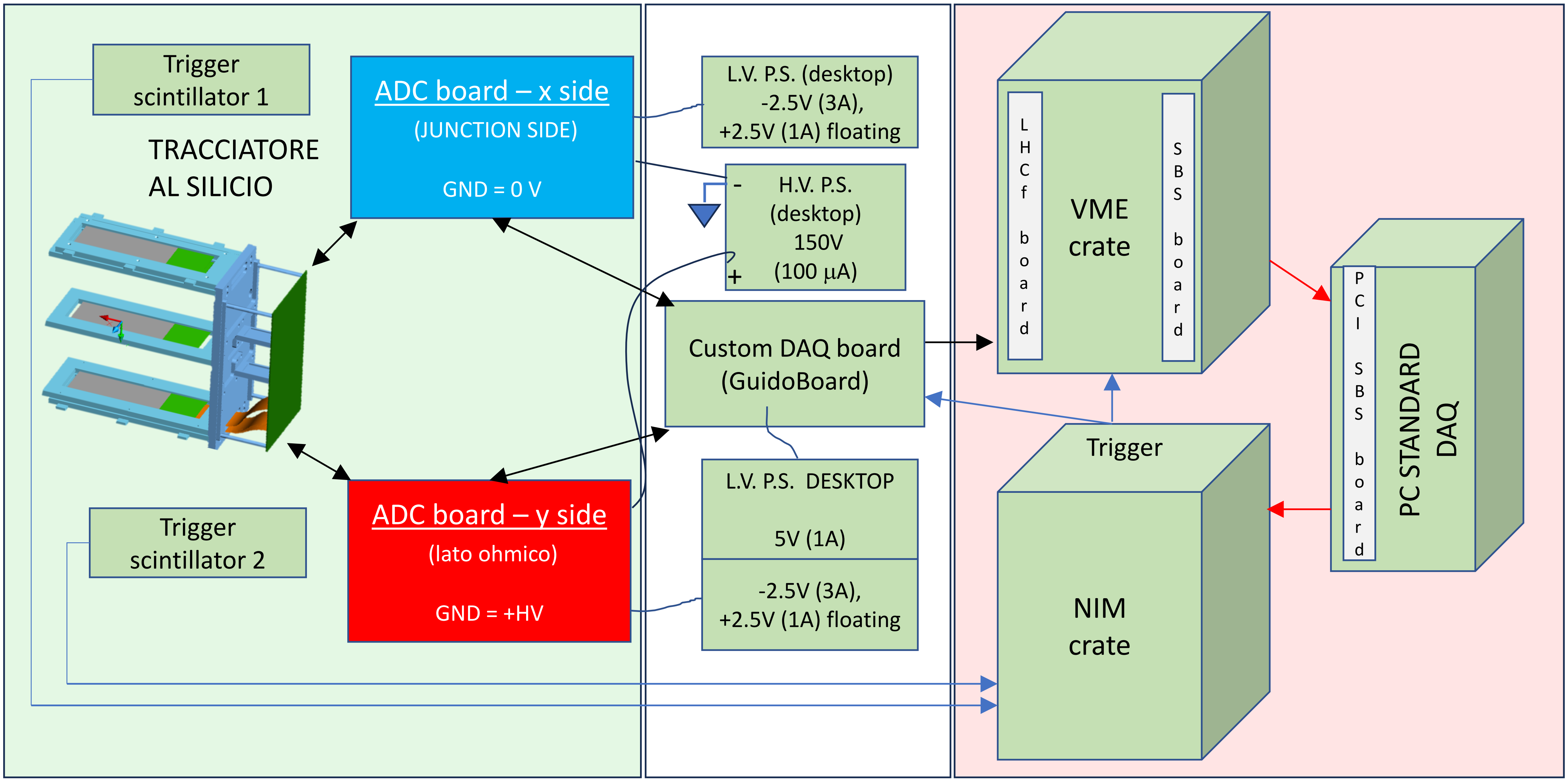
ADC board Y-side (ohmic side, GND=+80V)

ADC board X-side (junction side, GND=0V)

Tracker (Si μ-strip)



BLOCK SCHEME OF THE CURRENT CONFIGURATION: ADAMO



Goal of the ACROMASS project

1

Replace some of the silicon tracking modules

- Using spare sensors and hybrid circuits inherited from the PAMELA experiment

2

Subdetectors for PID (e,p,μ)

- TOF system
- E.M. calorimeter
- … (Cherenkov?)

3

Semplification of the detector's structure

- New DAQ system
- Small electronics' box
- Easy transportation
- Easy installation

4

Measure at high altitude

(3000-4500 m a.s.l.)

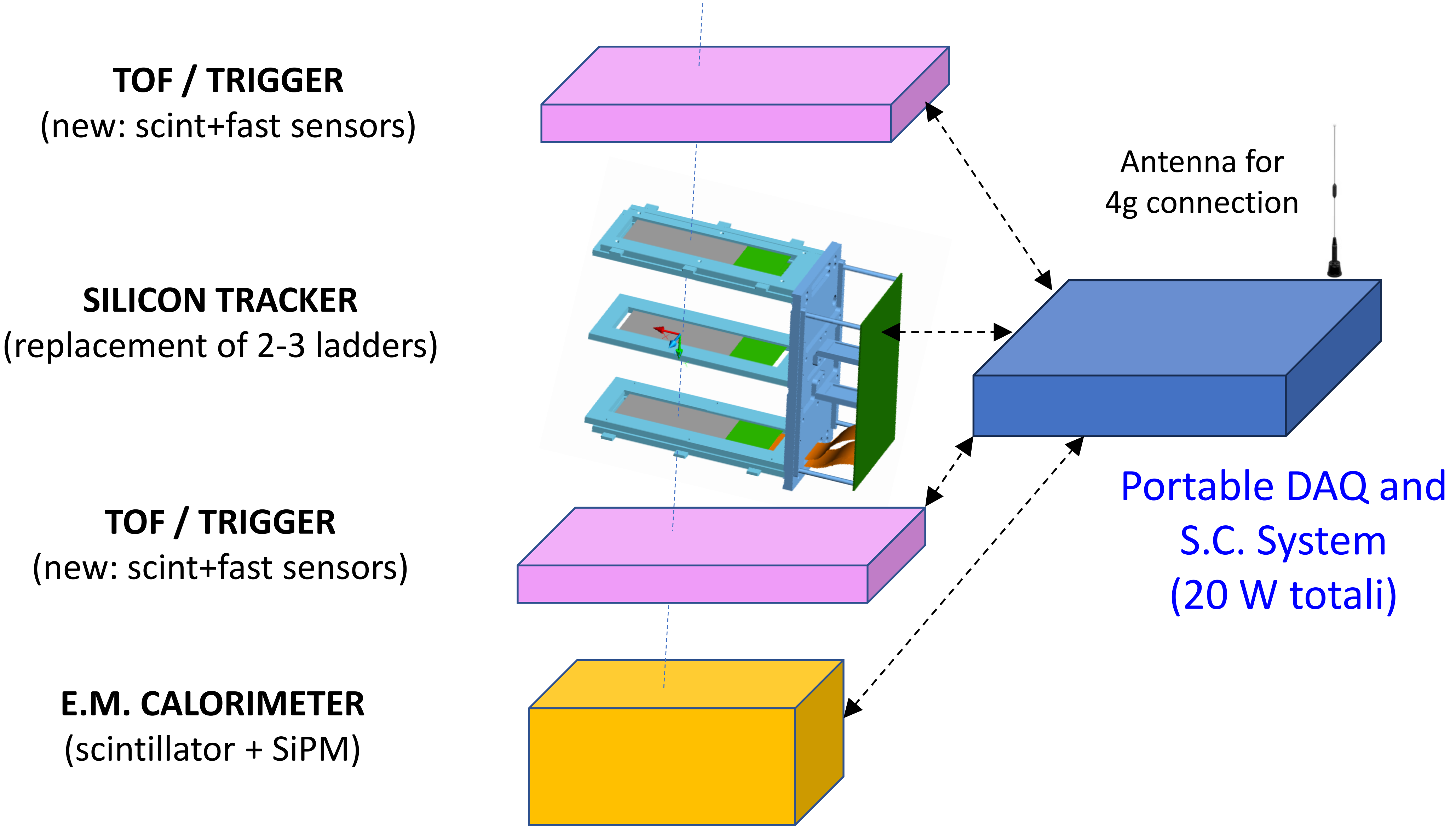
We plan to:

- Test the apparatus intensively in lab.
- Implement a measurement in a site at an altitude of about 3000 m a.s.l.
- Start contacts to schedule a measurement in a site at an altitude of about 4500 m a.s.l. (to be done later, as a new project)

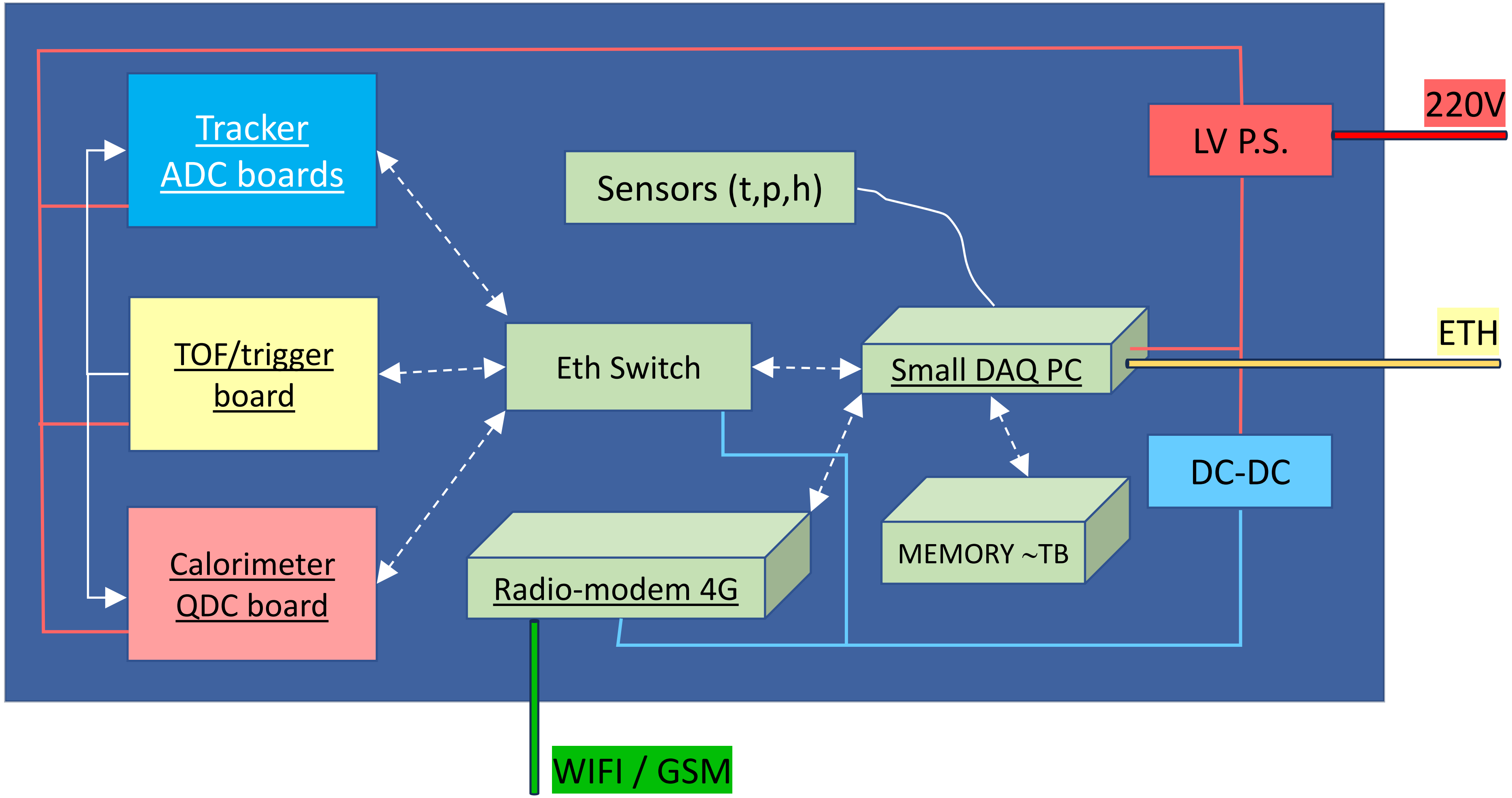
Keypoints of the ACROMASS proposal

- Upgrade of the ADAMO existing magnetic spectrometer
  - Re-use the very expensive magnetic system
  - Renew the silicon microstrip tracker
    - Production of some new modules using PAMELA's spare devices
- Production of new subdetectors for PID
  - Finalization of the new e.m. calorimeter developed for the thesis' work of dr. S. Scordamaglia, and designed for PID over the full measurable momentum range
  - Design and construction of a new trigger/TOF system for a better performance at momentum $p < 1$ GeV/c (thesis of G. Balloni)
- New custom DAQ system
  - Design and production of new DAQ and Slow Control boards
    - Based on the Ethernet communication protocol
- Beam tests at the PS/SPS facilities (CERN, Frascati,…?)
  - Characterization and calibration at low and high energy
- Measurement in the high mountains
  - ~3000-4500 m, as required for atmospheric muon neutrino studies

ACROMASS PROJECT: NEW CONFIGURATION

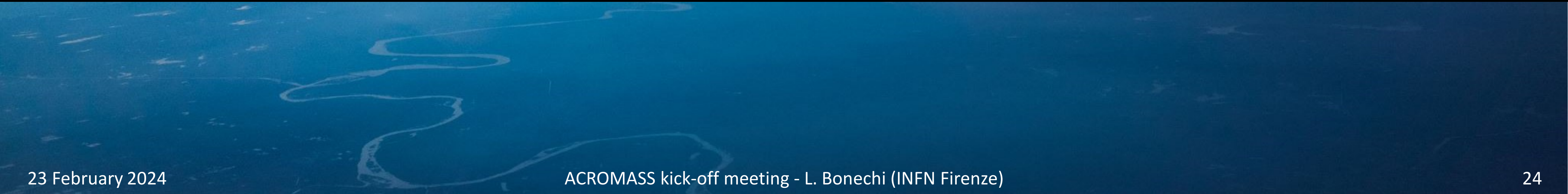


Portable DAQ + S.C. System



- The complete (low power) system will work with power mains (220V) or with photovoltaic panels
- External ethernet or WIFI or 4G connection for remote control and data transfer (not mandatory)

On-going and To-Do: Time Of Flight

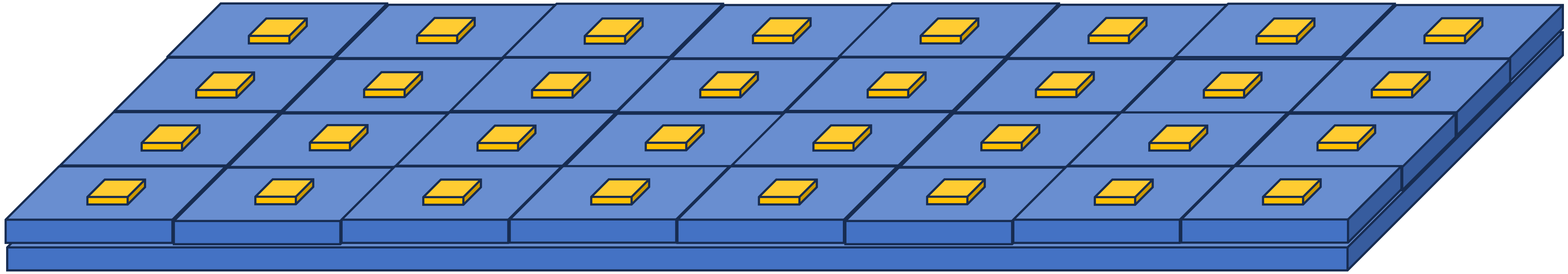


Tesi magistrale G. Balloni

SCOPO: sistema di discriminazione muoni/protoni fino a p = 1 GeV/c

PRESTAZIONI RICHIESTE: risoluzione temporale dt < 100 ps

Tesi magistrale G. Balloni



DESCRIZIONE:

Scintillatore plastico veloce + SiPM veloci
Tessere: (3 x 3 x 0.5) cm^3
Superficie tot: (24 x 12) cm^2
Canali di lettura: 4x8=32, SiPM veloci da (1-3) mm^2
Piano aggiuntivo di scintillatore plastico per trigger

Test in corso:

- SiPM Hamamatsu BLEMAB + scintillatore plastico standard
  - Risoluzione finale TOF: 700 ps (obiettivo → 100 ps…)

Test successivo

- SiPM con uscita fast + stesso scintillatore

DA FARE:

SiPM: già acquistati 70 pezzi

Acquisto degli scintillatori (?)

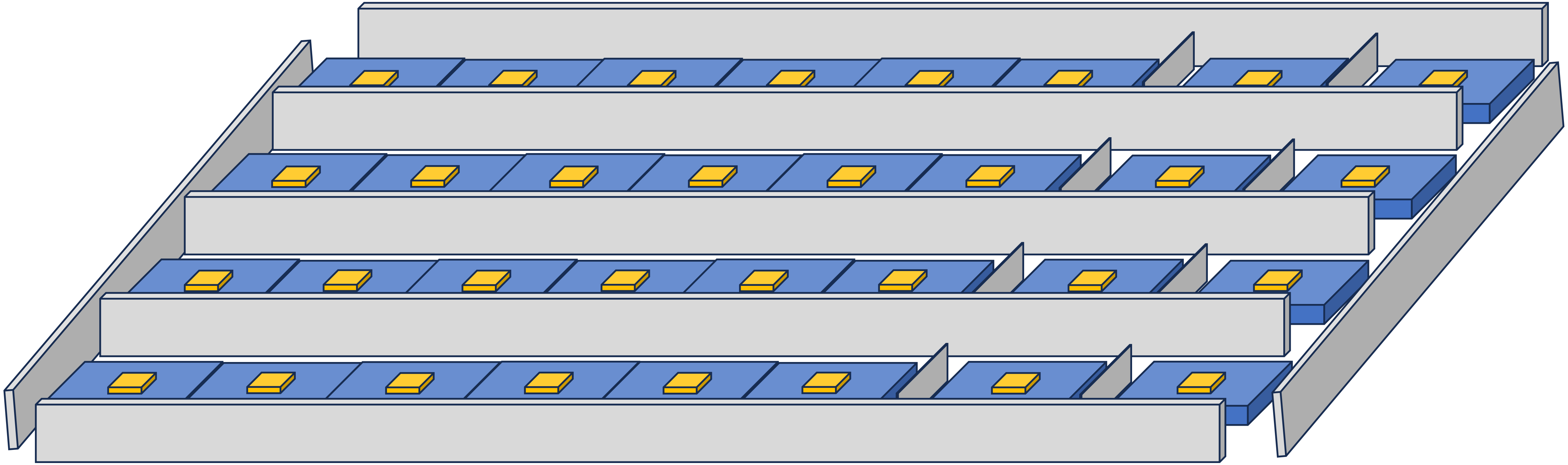
Preparazione di tutte le tessere

Progettazione/produzione della meccanica

- Contenitore
- Sistema di fissaggio al magnete
- Alloggiamento della scheda di TOF sul magnete (?)

Tesi magistrale G. Balloni

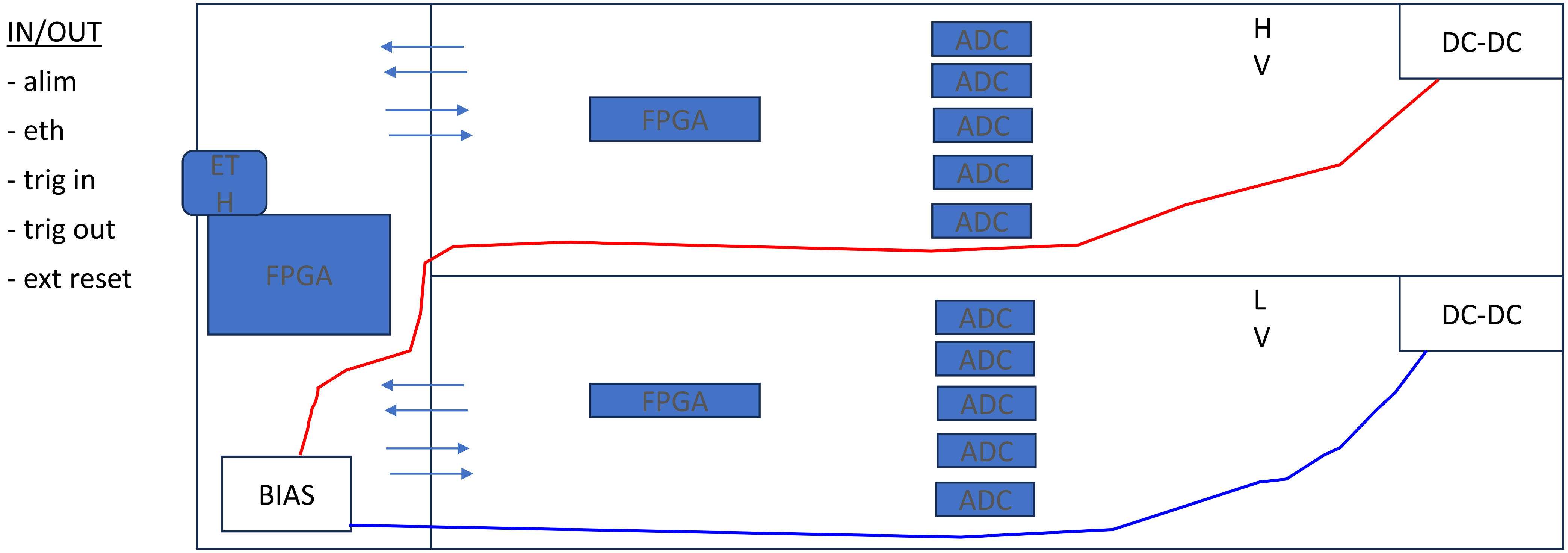
Isolamento ottico tra le tessere di scintillatore



To-Do: tracciatore

Scheda DAQ silicio – versione 1 (Monica)

Sketch molto preliminare



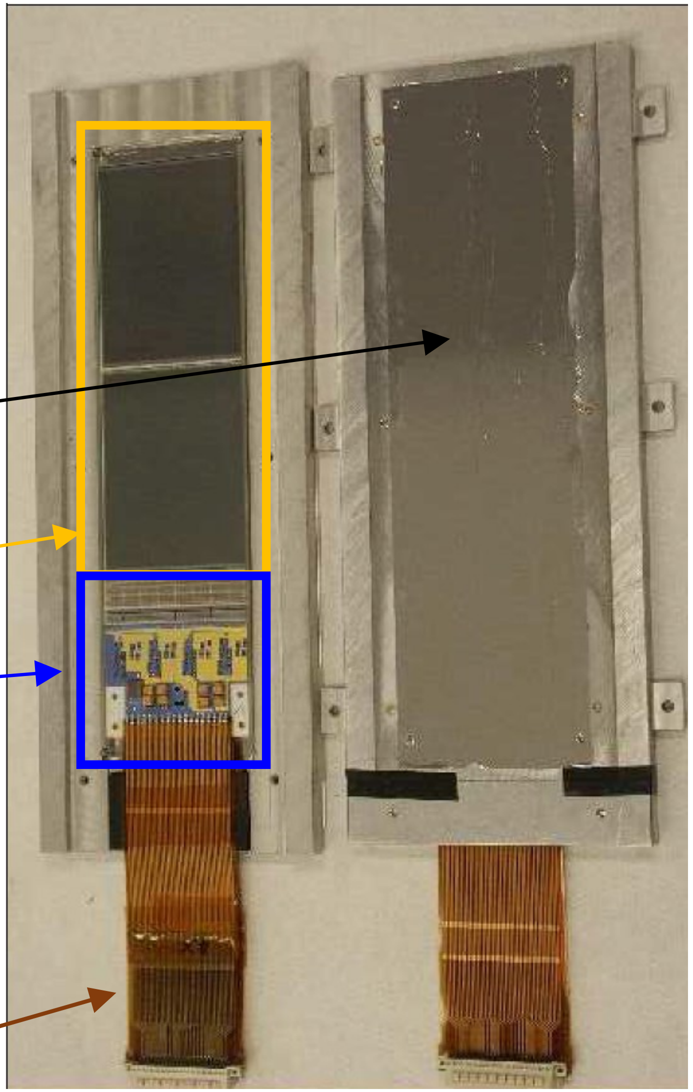
Piani di silicio

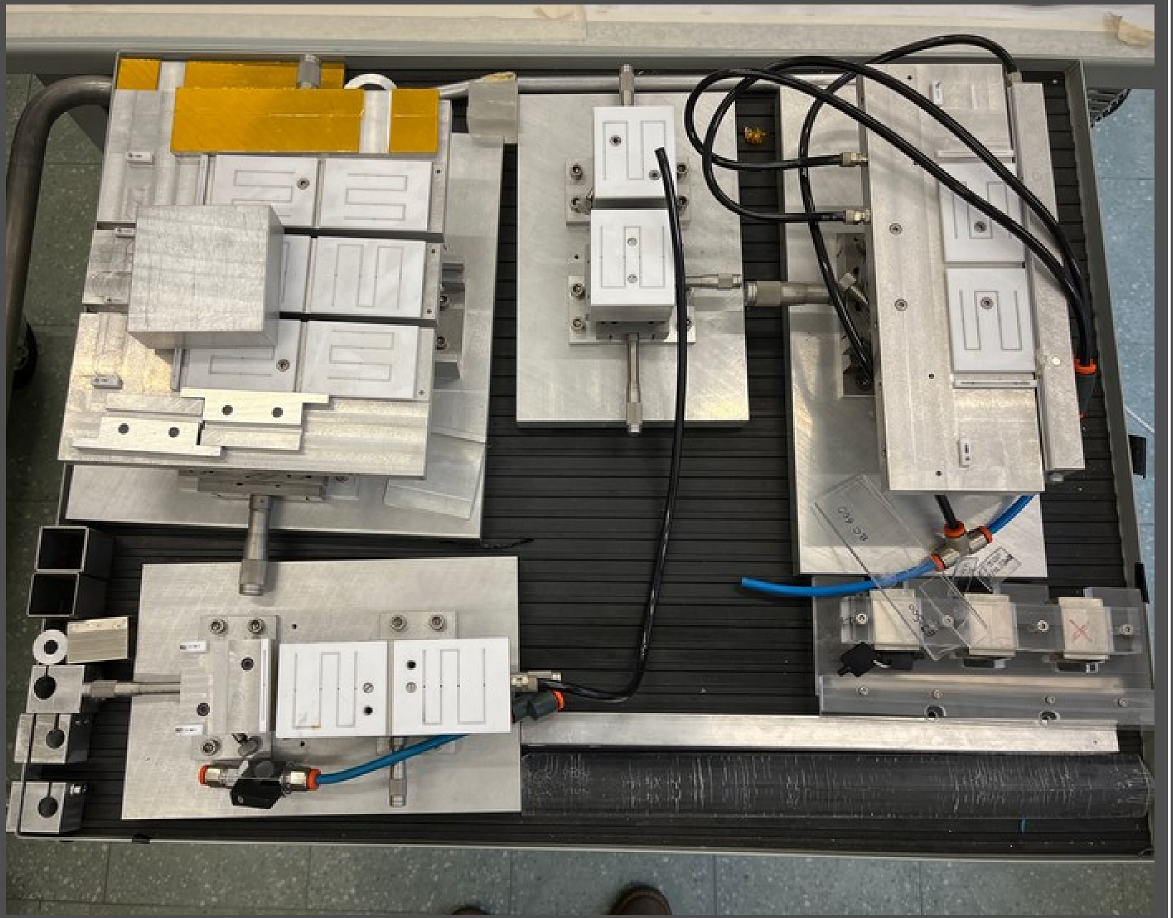
ORIGINALI DI ADAMO: 5

- Da provare a riparare (Mirko)

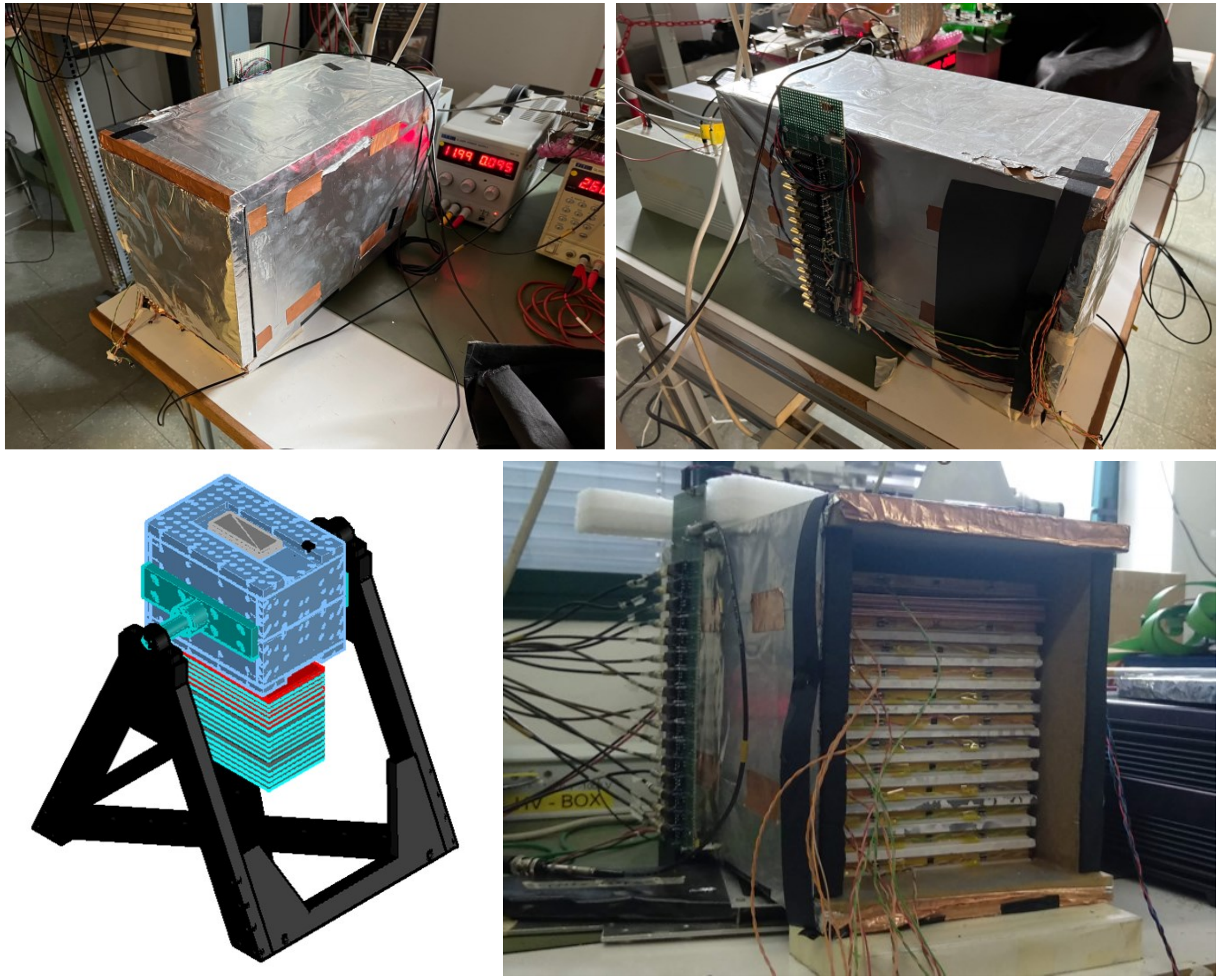
NUOVI DA PRODURRE:

- Nuovi frame in alluminio già prodotti: 4
    - Da predisporre Mylar Al.
- Moduli PAMELA già pronti (da testare): 1
- Coppie di sensori pronte: 1
- Ibridi a disposizione: 7
- Sensori silicio ancora disponibili: 10-20
- Jig e linee di vuoto per assemblaggio
    - Attualmente conservati nel lab 31 (muografia)
    - da preparare nella clean room → accordarsi con Mirko
- Cavetti in kapton: modelli PAMELA o ADAMO
    - Ci sono (in qualche lab…)



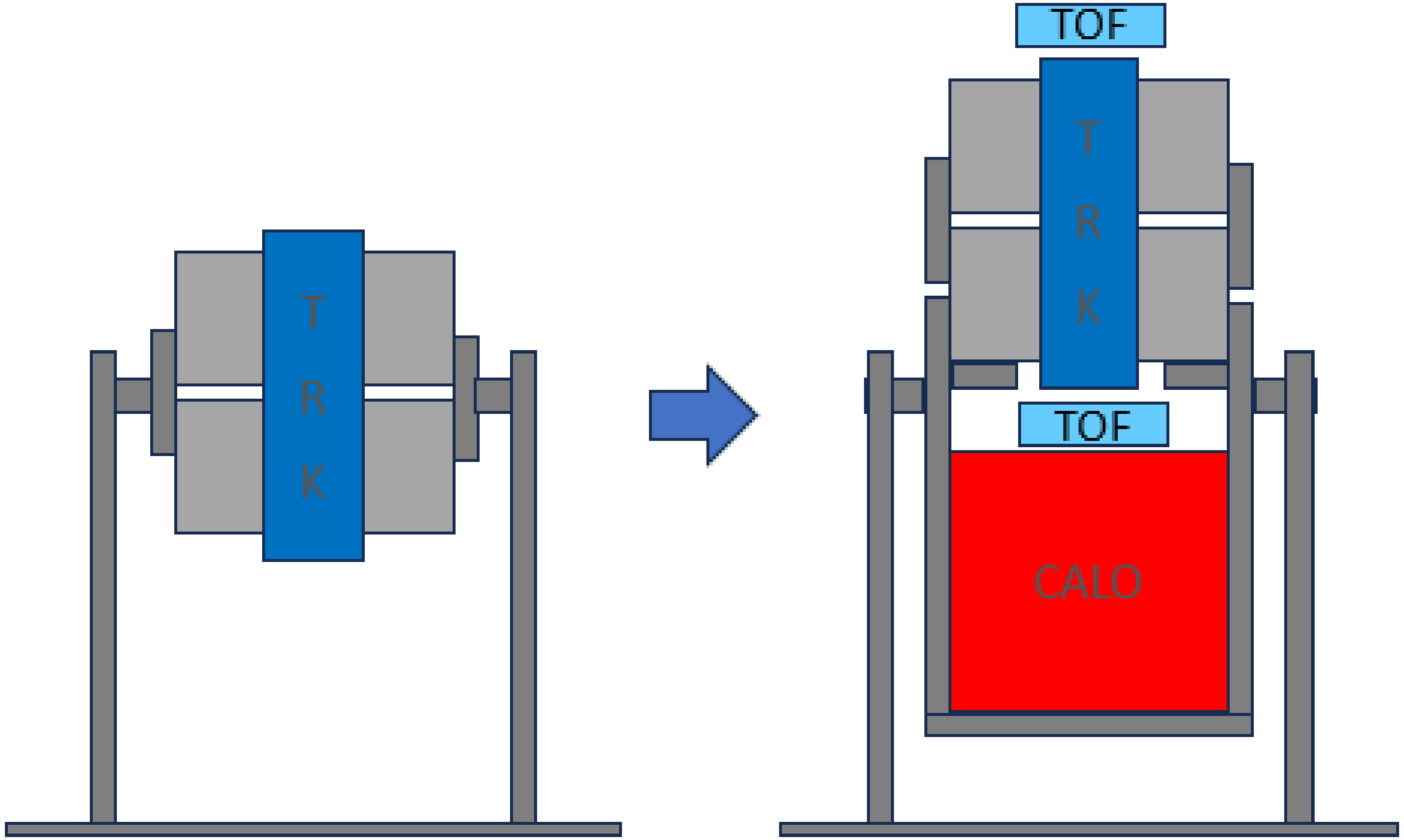


To-Do: calorimetro e.m.



E.M. CALORIMETER

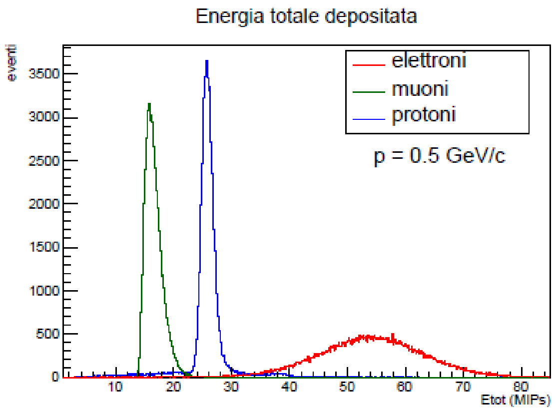
E.M. CALORIMETER



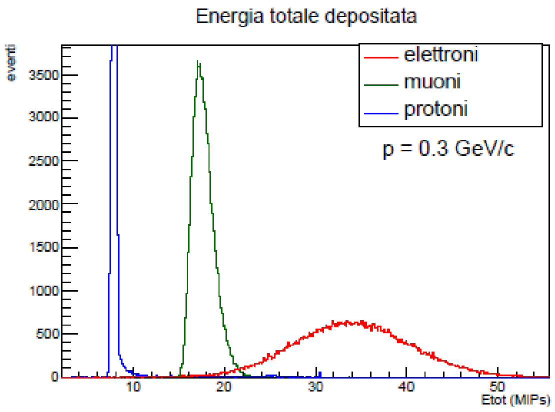
E.M. CALORIMETER – simulation and first tests

S. Scordamaglia, *Sviluppo e costruzione di un calorimetro a campionamento per misure di raggi cosmici con l'esperimento ADAMO, tesi di Laurea in Fisica, Università di Firenze, A.A. 2020/2021*

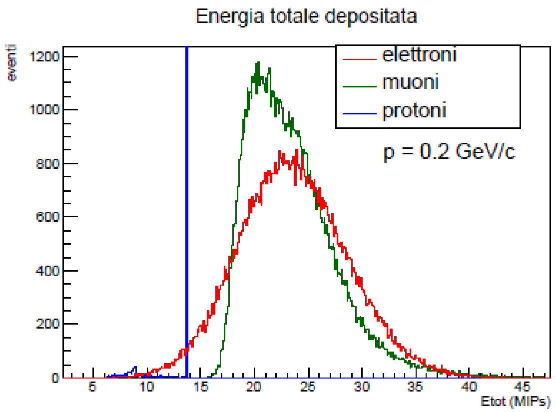
GEANT4 SIMULATION

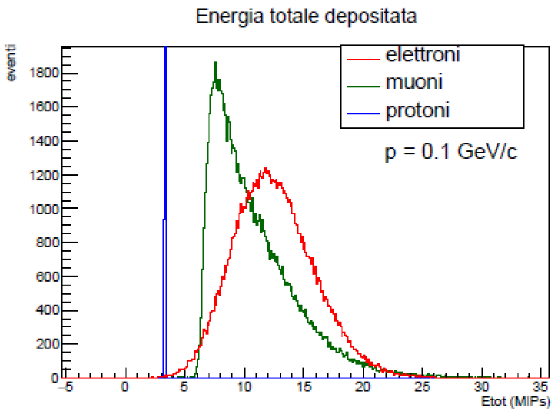


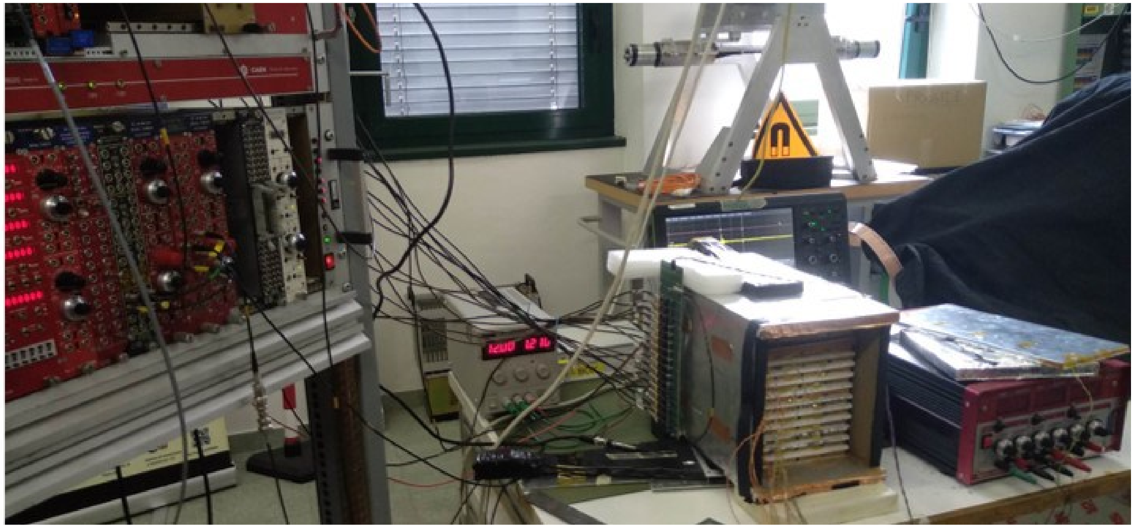
(a)

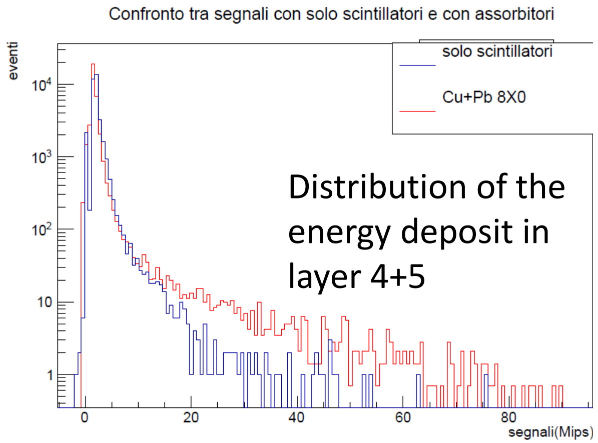


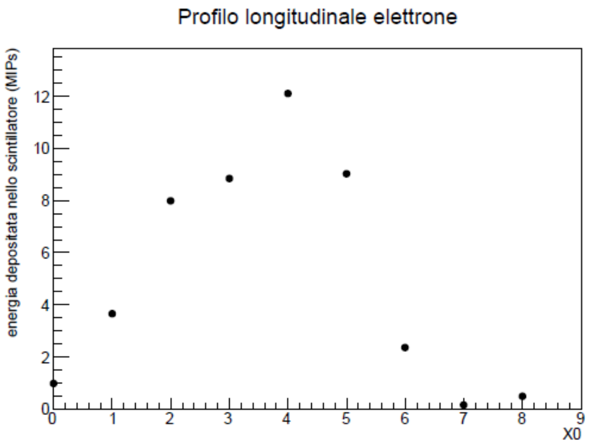
(b)











CALO: meccanica e DAQ

SIMULAZIONI

- Determinazione della configurazione per ottimizzare la discriminazione a bassa energia

MECCANICA:

- Progettazione box contenimento
  - Deve poter alloggiare i 15-20 piani di scintillatore esistenti e gli spessori in Pb, Cu e W preparati nel corso della tesi magistrale di S. Scordamaglia
- Modifica asse rotazione dell'intero rivelatore
  - Per posizionare meglio il baricentro complessivo TRK+CALO

DAQ

- Progettazione: scheda QDC 32ch (?)
  - Front-end?
  - Back-end: protocollo comunicazione ethernet → erditato da DAQ tracciatore

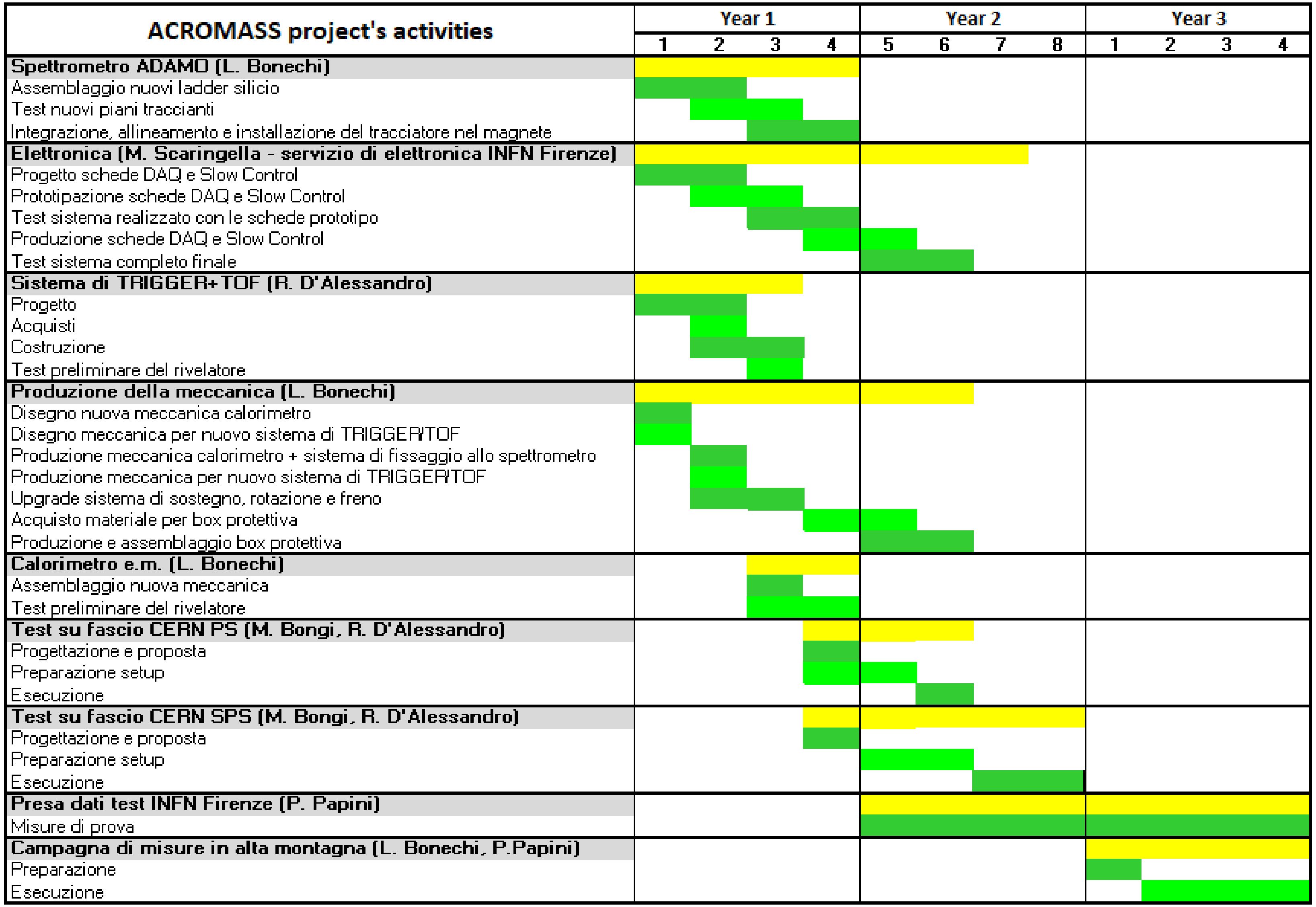
To-Do: software

Sviluppi software

- **SIMULAZIONI**
  - Spettrometro con campo magnetico
  - Calorimetro
- **DAQ**
  - Tracciatore
  - ToF
  - Calorimetro
- **SLOW CONTROL**
  - Gestione e monitoraggio
  - Analisi online dati raw
- **ANALISI**
  - Allineamento tracciatore
  - Ricostruzione dell'impulso
  - Discriminazione del tipo di particella
    - Calorimetro
    - TOF

Organizzazione del progetto

ACROMASS: activities and participants



Surname	Name	Contr.	Profile	Aff.	%
Bonechi	Lorenzo	Dip.	PR	CSN1	30
Bongi	Massimo	Assoc. U	PA	CSN2	50
Cialdai	Carlo	Dip.	PT		10
D'Alessandro	Raffaello	Assoc. U	PO	CSN1	20
Frosin	Catalin	Assoc. U	R	CSN5	20
Papini	Paolo	Dip.	R	CSN2	10
Ricciarini	Sergio	Assoc. CNR	R	CSN1	10
Scaringella	Monica	Dip.	T		10

Program of activities - ACROMASS

- **YEAR 1 (2024)**
  - Assembling and test of new silicon tracking modules
    - *spare* material from the PAMELA experiment
  - Design, prototyping and test of the DAQ and SC boards
    - Based on the development of the new DAQ system of LHCf
  - Design and development of the *trigger*/TOF system
  - Production of the e.m. calorimeter's mechanics
  - Modification of the global mechanics
  - Preparation of beam tests

- **YEAR 2 (2025)**
  - Production of the final version of the DAQ and SC boards
  - Production of the protective box of the detector
  - Test/monitoring measurements in lab
    - test of the complete ACROMASS detector
  - Beam tests
    - Low energy (PS@CERN or BTF@LNF)
    - High energy (SPS@CERN)
    - Electrons
    - Muons
    - Protons

- **YEAR 3 (2026)**
  - Test/monitoring measurements in lab
  - First measurement in the high mountains

Fase successiva ai 3 anni di progetto CSN5

Capanna Margherita

La Capanna Regina Margherita: il rifugio più alto d'Europa

Metri 4554 slm

Punta Gnifetti (Signalkuppe)

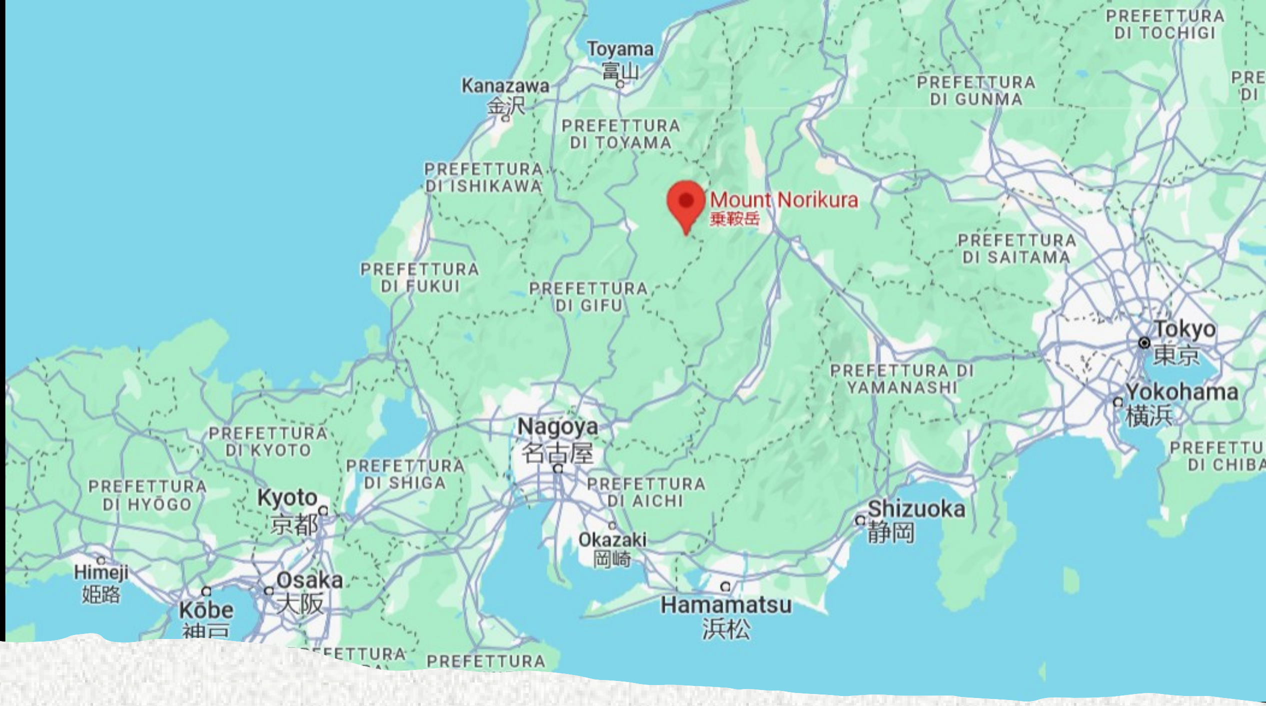
GPS: 45° 55' 38

CIR Regione Piemonte: 002002-RIF-00003

Posti **70** - Locale invernale con 10 posti letto, coperte, gas per uso cucina. Non ci sono pentole, piatti, forchette, cucchiai e tazze. Si consiglia di portare il sacco a pelo.

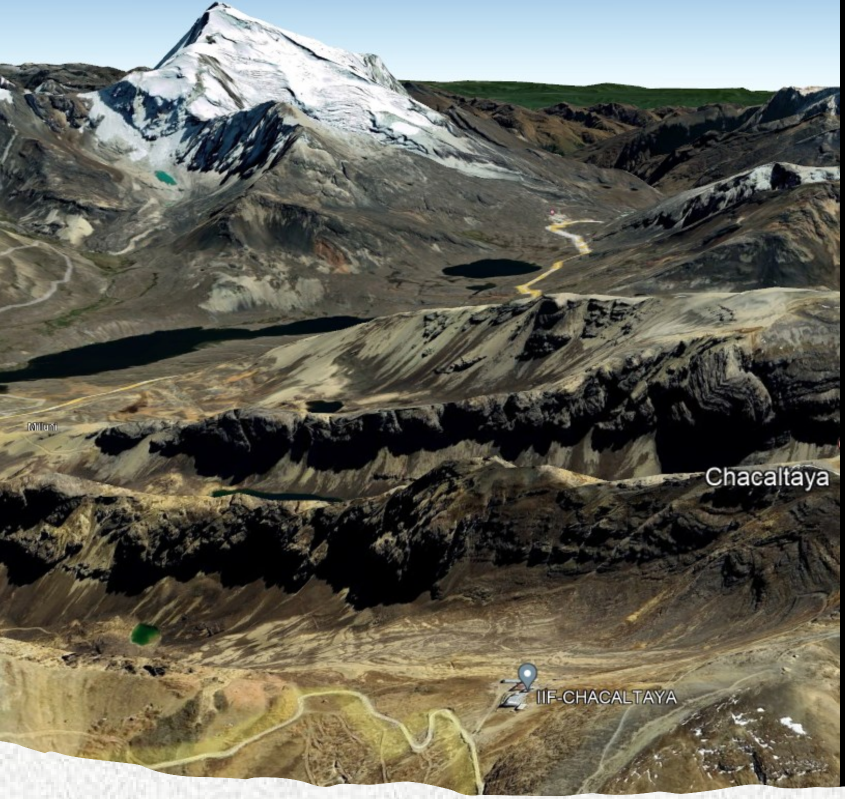
Obiettivo principale

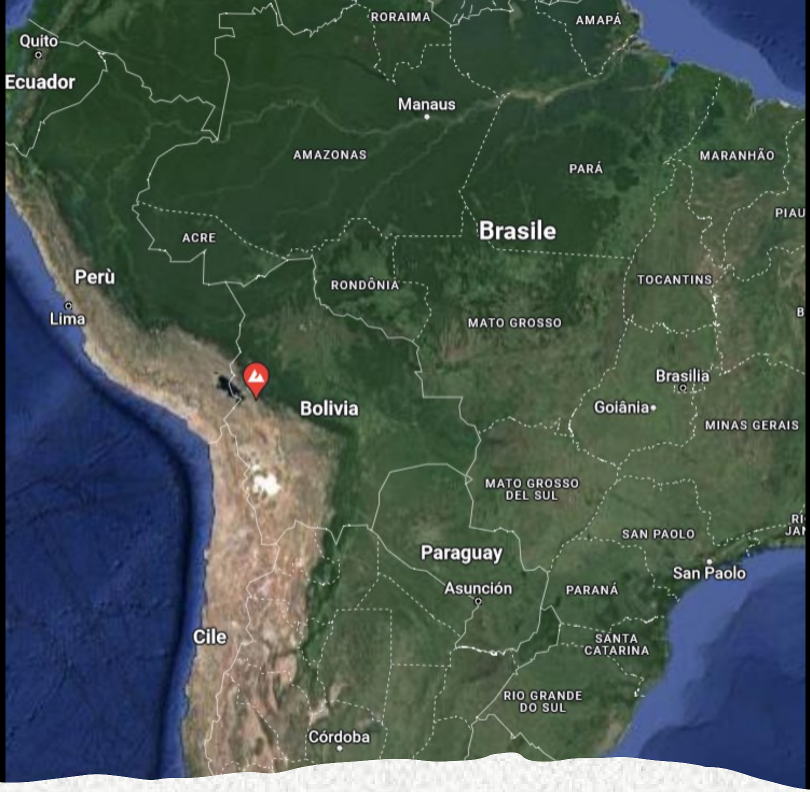
- Misure in alta quota: Capanna Margherita
  - http://www.rifugimonterosa.it/it/web/capanna-margherita-7



Manifestazioni d'interesse

- Giappone: Norikura Solar Observatory
- 2770 m a.s.l.





Manifestazioni d’interesse

- Bolivia: Chakaltaya Observatory
- 5240 m a.s.l.

Conclusioni – summary (?)

BACKUP

Interest for a precise study of μ spectra and angular distributions for neutrino physics research

Main points from the paper by Honda et al. (2019)

- Knowledge of the ν_μ flux, ϕ_{ν_μ}, for $E_{\nu_\mu} < 1\,\mathrm{GeV}$ is important for a precision study of the neutrino oscillation parameters
- The Honda SK and HK group uses a custom simulation based on Monte Carlo techniques to evaluate the ν_μ flux at the altitude of interest
- The hadronic interaction model(s) used in the simulation is(are) calibrated using existing data of the atmospheric muon spectra
  - the best performance is obtained with measurements down to low momentum in the high mountains
- Not many measurements are reported in the literature of the absolute atmospheric muon spectra, many of which date back to the 1960s and 1970s; in particular no systematic study of atmospheric muon spectra can be found, but usually the measurements are single measurements done at different locations/altitudes, in different momentum and angular ranges, with different detectors and in different phases of the solar modulation

Interest for a precise study of μ spectra and angular distributions for neutrino physics research

Main goals of ACROMASS (based on the paper by Honda et al., 2019)

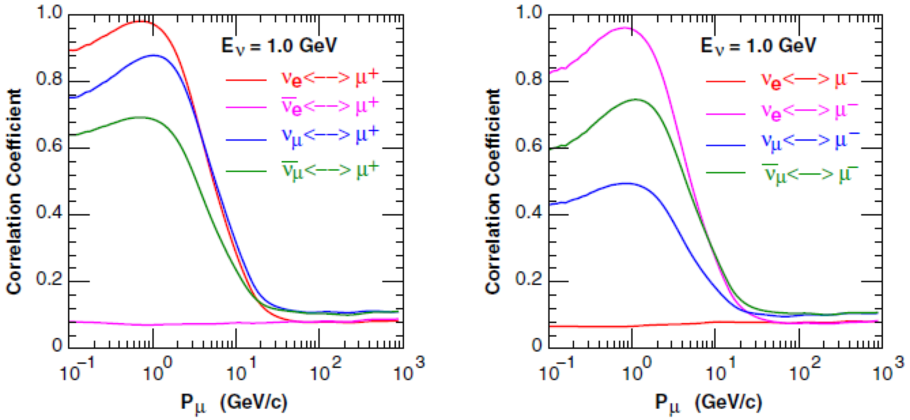
- GOAL 1: measurement of the muon spectra with a precision $\left|\frac{\Delta\phi_\mu}{\phi_\mu}\right| \leq \mathbf{0.05}$
- GOAL 2: measurement of the muon spectra down to $p_{min} \approx \mathbf{0.1}$ GeV/c
- GOAL 3: measurements to be carried out in the high mountains (3 - 4.5 km a.s.l.)
- GOAL 4: study of the dependence $\phi_\mu(\theta)$ in the high mountains (3 - 4.5 km a.s.l.)

Results reported on the Honda et al. (2019) paper

i. The lepton fluxes ϕ_L in atmosphere are evaluated using an integral expression including the **hadronic interaction model H**, which describes the probability that a projectile particle interacts with an atmospheric nucleus producing a lepton L; the simulation is calibrate using the muon flux measured by BESS for $p_\mu \gtrsim 0.1$ GeV/c

ii. Assuming the validity of H, random variations of H around the unmodified version are introduced to evaluate the effects on the estimation of the lepton fluxes

- A **correlation between the variations of ϕ_ν and ϕ_μ** is found
- If the energy $E_\nu = 1$ GeV is selected the correlation is large for $p_\mu \lesssim 1$ GeV/c and not negligible for $p_\mu \lesssim 10$ GeV/c



$$\gamma(p_\nu^{obs}, x_\nu^{obs}; p_\mu^{obs}, x_\mu^{obs}) = \frac{\sum (\Delta\Phi_\nu(p_\nu^{obs}, x_\nu^{obs}) \Delta\Phi_\mu(p_\mu^{obs}, x_\mu^{obs}))}{\sqrt{\sum (\Delta\Phi_\nu^k(p_\nu^{obs}, x_\nu^{obs}))^2 \sum (\Delta\Phi_\mu^k(p_\mu^{obs}, x_\mu^{obs}))^2}}$$

FIG. 3. Correlation coefficient for each combination of neutrinos $(\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e)$ and muons (μ^+, μ^-) tat neutrino energy of 1 GeV. We used the integral kernels of atmospheric neutrinos and muons both for vertically downward moving ones at Kamioka.

Results reported on the Honda et al. (2019) paper

iii. $\left|\frac{\Delta\phi_\mu}{\phi_\mu}\right|$ and $\left|\frac{\Delta\phi_\nu}{\phi_\nu}\right|$ follow a Gaussian distribution with some width

iv. If we set a limit to the variation of the muon flux, $\left|\frac{\Delta\phi_\mu}{\phi_\mu}\right| < \varepsilon$, the width of the distribution of $\frac{\Delta\phi_\nu}{\phi_\nu}(\varepsilon)$ becomes smaller

v. If we normalize the distribution of $\frac{\Delta\phi_\nu}{\phi_\nu}(\varepsilon)$ to te case with unmodified interaction model, $\frac{\Delta\phi_\nu}{\phi_\nu}(\varepsilon \to \infty)$ we find a Gaussian with width σ_{shrink}

vi. The dependence of σ_{shrink} on ε can be fitted well with a function $\boldsymbol{\sigma_{shrink} = \sqrt{\zeta_0^2 + (\zeta_1 \cdot \varepsilon)^2}}$ and we see that σ_{shrink} decreases for small values of ε

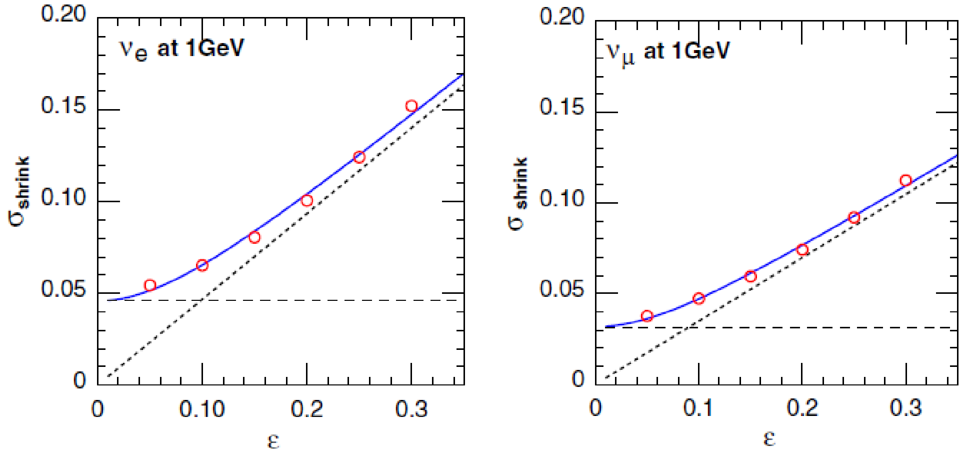
→ If the model describes the muon flux with precision, then the model describes also the neutrino flux with precision

vii. This means that **if the simulation is calibrated in such a way to reproduce accurately the muon flux measured by a precision experiment, then the same simulation can describe accurately the neutrino flux as well**

Results reported on the Honda et al. (2019) paper

viii. Let's consider the term ζ_0 in the expression of σ_{shrink}, which is a term that does not depend on how precisely the muon flux is known

ix. If $\varepsilon \lesssim 0.05$ (the muon flux used for calibrating the simulation is know with 5% precision or less) then $\sigma_{\text{shrink}} \approx \zeta_0$



Fit function:

$$\sigma_{shrink} = \sqrt{\zeta_0^2 + (\zeta_1 \cdot \varepsilon)^2}$$

FIG. 6. The σ_{shrink} obtained by the variation study of atmospheric neutrino flux for vertically downward moving atmospheric electron neutrino and downward moving atmospheric muon fluxes at Kamioka for $\varepsilon = 0.5, 1.0, 1.5, 2.0, 2.5$ and 3.0. The solid curve shows the best fit curve with Eq. (20), and the dash and dotted lines show two asymptotic lines of Eq. (20); $\sigma_{\text{shrink}} = \varsigma_0$, and $\sigma_{\text{shrink}} = \varsigma_1 \cdot \varepsilon$. We show those for ν_e in the left panel, and for ν_μ in the right panel.

x. **GOAL 1**: measurement of the muon spectra with a precision $\left|\frac{\Delta\phi_\mu}{\phi_\mu}\right| \leq \mathbf{0.05}$

Results reported on the Honda et al. (2019) paper

xi. If we set the constrain on the muon flux variation only for $p_\mu \gtrsim 1$ GeV/c instead of 0.1 GeV/c, then ζ_0 increases and we have a worsening in the energy range of interest $E_{\nu_\mu} < 1$ GeV

xii. GOAL 2: measurement of the muon spectra down to $\boldsymbol{p_{min} \approx 0.1}$ **GeV**$/\boldsymbol{c}$

xiii. All previous considerations were obtained using the measurement by BESS at sea level in Tsukuba. Replacing this measurement with other measurements at different altitudes we have the following results:

- BESS, mount Norikura, 2770 m a.s.l. → reduction of the ζ_0 value (→ better performance)
- Hanle, India, 4500 m a.s.l. → further reduction of the ζ_0 value (→ best performance)
- BESS (balloon), near South Pole, ~32 km a.s.l → increase of uncertainty (also poor statistics)

xiv. GOAL 3: the measurements must be carried out in the high mountains (3 - 4.5 km a.s.l.)

Results reported on the Honda et al. (2019) paper

xv. Lepton production in atmosphere results mainly from collisions of secondary protons and neutrons with air nuclei and to a much lesser extent to the collision of mesons; introducing ±10% variations of the ratio between the numbers of the protons and neutrons responsible of the production of a) the sole muon component or b) the sole neutrino component, a variation < 3% is found for the fluxes → the effect on the lepton fluxes due to the uncertainty on the flux of projectiles producing leptons is small

xvi. An important contribution to the lepton fluxes uncertainties is due to the uncertainty of the hadronic interaction model on the scattering angle distribution of secondary particles

- An error of ±20% on the angle distribution determines a ±10% contribution on the neutrino fluxes
- To limit the uncertainty to 5%, $\left|\frac{\Delta\phi_\nu}{\phi_\nu}\right| < 0.05$, it is necessary to know the scattering angle with a precision of 10%

xvii. A variation of the scattering angle distribution determines also a variation of the dependence of ϕ_μ on the zenith angle θ. This happens at high altitude (4500 m), while this effect is negligible at sea level. A precise measurement of $\phi_\mu(\theta)$ at 4500 m would allow to reduce the uncertainty on the angular distributions of secondary particles and therefore also on ϕ_ν.

xviii. GOAL 4: **measurement of the dependence $\phi_\mu(\theta)$ in the high mountains (3 - 4.5 km a.s.l.)**

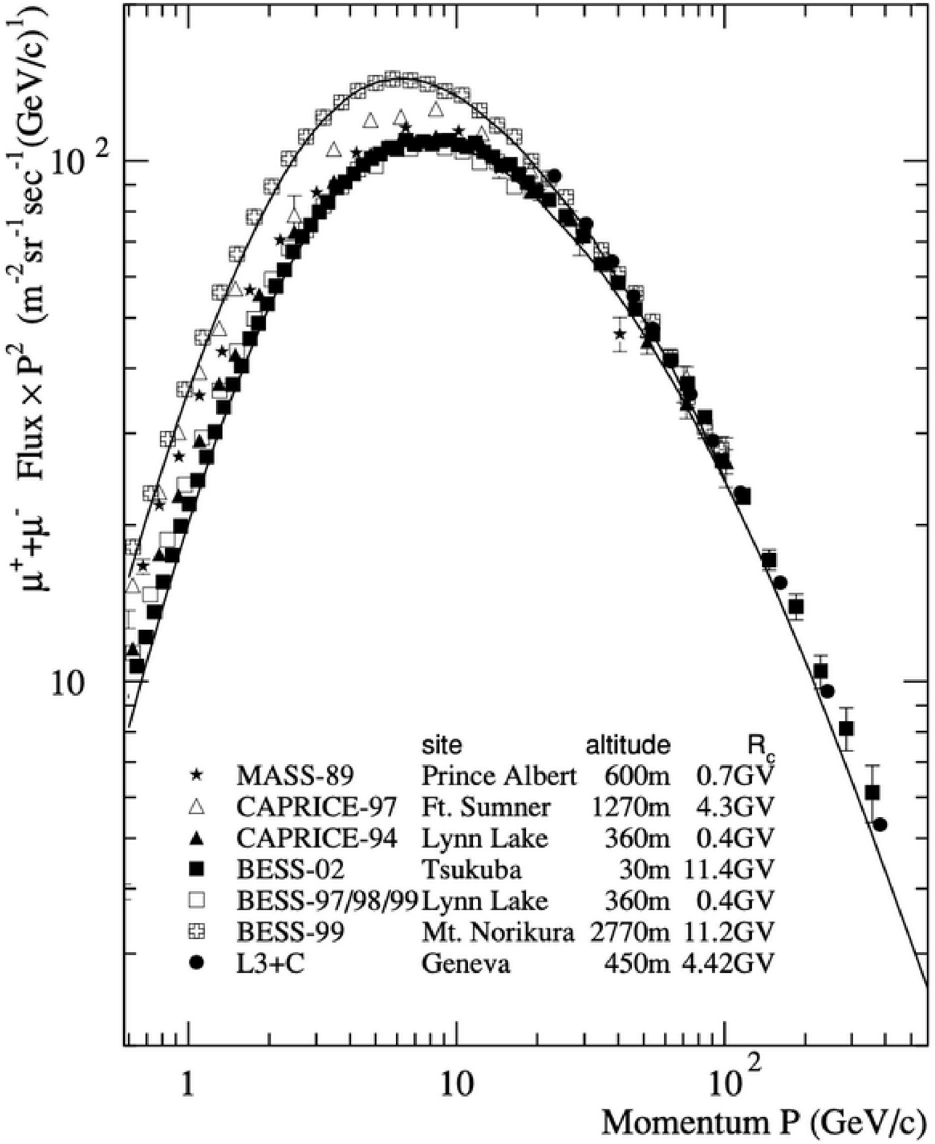
Principali problemi attuali e upgrade/attività previsti

Estratto email proposta inviata al Presidente di CSN5

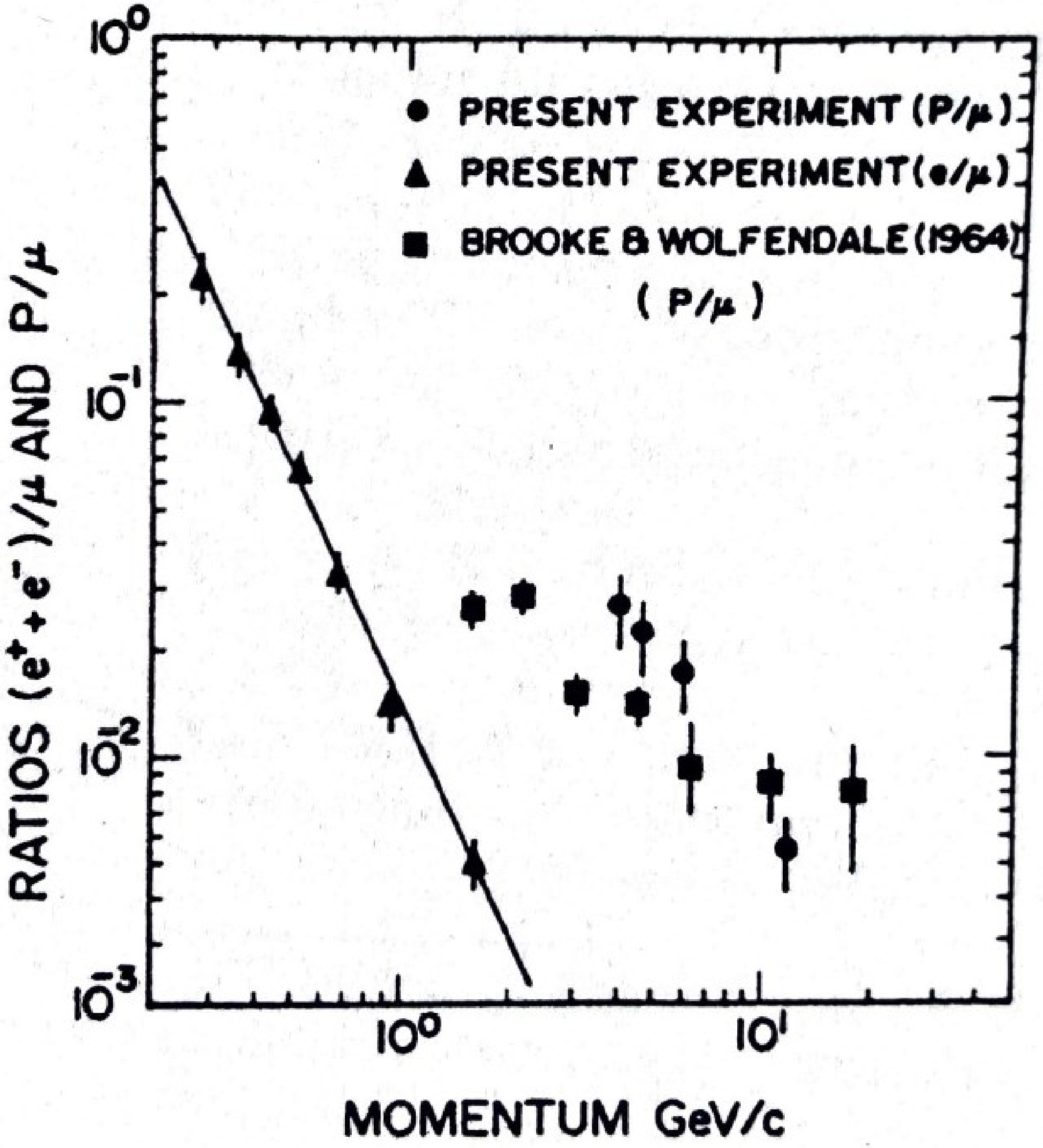
1) elettronica di DAQ estremamente datata (difficile da riparare) e per il 50% basata su ingombranti sistemi NIM e VME
2) sistema di alimentazione ingombrante, in parte da banco e in parte NIM
3) mancanza di un sistema di identificazione del tipo di particelle
4) silici a microstrisce con molti difetti
   in parte danneggiati dal lungo utilizzo come sistema ausiliario di tracciamento per test su fascio

- realizzazione di un **nuovo sistema di DAQ**, basato sul protocollo GbE e su dispositivi commerciali facilmente reperibili
- realizzazione di un **nuovo sistema di alimentazione** che permetta di operare ADAMO in un qualsiasi sito con la sola linea di alimentazione (220V/110V)
- (entrambi i sistemi precedenti verrebbero gestiti da remoto mediante la connessione ad una rete wifi o ethernet e permetterebbero di ridurre notevolmente l'ingombro meccanico e il peso dell'apparato, operazione necessaria per poter operare lo strumento in maniera relativamente semplice e sicura in luoghi di alta montagna difficilmente accessibili)
- realizzazione di alcuni **nuovi piani traccianti**, costituiti da parti spare di PAMELA, per migliorare le prestazioni dello spettrometro
- **completamento del calorimetro e.m.** e finalizzazione dell'elettronica di readout
- **realizzazione di un sistema di TOF a scintillatore plastico** per l'identificazione del tipo di particelle a bassi impulsi
- **realizzazione di una box protettiva** per l'instlalazione all'aperto
- **test presso il PS del CERN** per la caratterizzazione e la calibrazione dello strumento a basse energie
- **test presso SPS del CERN** per la caratterizzazione e la calibrazione dello strumento ad alte energie
- **implementazione di misure in alta montagna** (da definire sulla base di valutazioni in collaborazione con gli esperimenti interessati alla fisica dei neutrini atmosferici)
- **implementazione di misure a diverse latitudini/altitudini**

Compilation of vertical measurements of muons



$e^+ + e^-$ and proton contribution at ground level



Richieste finanziarie ACROMASS

Anno 1		k€
Meccanica-viti-colle per assemblaggio ladder silicio		1.0
Prototipi ADC tracker (x + y)	SJ	4.0
Prototipo TOF/trigger	SJ	3.0
Prototipo QDC calorimetro	SJ	3.0
Acquisto scintillatore e SiPM per TOF		2.0
Materiale per assemblaggio e costruzione meccanica TOF		1.0
Upgrade meccanica altazimutale		2.0
Materiale per assemblaggio e costruzione meccanica calorimetro		2.0
Materiale per assemblaggio e costruzione meccanica box protettiva		2.0
Raspberry DAQ + cavetti/connettori + HD		1.0
Raspberry S.C. + sensori t,p,h		1.0
Radiomodem + switch ethernet + scheda SIM		1.5
Produzione ADC tracker (x + y + spare)	SJ	3.0
Produzione TOF/trigger (1+1 spare)	SJ	2.0
Produzione QDC calorimetro (1+1 spare)	SJ	2.0
Metabolismo di laboratorio		1.5
Sopralluoghi locazioni in alta quota (2 persone x 1 settimana)		2.0
TOT		**34.0**

Stima di richieste finanziarie per gli anni successivi

Anno 2		k€
Test CERN PS (4 persone x 10 gg)		6.0
Metabolismo di laboratorio		1.5
Sistema di condizionamento	SJ	2.0
Test CERN SPS (4 persone x 10 gg)		6.0
TOT		**15.5**

Anno 3		k€
Inizio campagna misure (4 persone x 2 settimane)		8.0
Preparazione campagna misure (consumo)		2.0
TOT		**10.0**

TOTALE PROGETTO (DURATA 3 ANNI)	**59.5**