Large Scale Polarization Explorer - LSPE

Presentazione preventivi 2016

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INFN Sezione di Pisa

10 Luglio 2015

Outline

- Introduzione
- LSPE
  - SWIPE
- Contributi di Pisa
- Attività svolta nel 2015
- Attività prevista per il 2016.

Inflazione

- Il connubio tra fisica delle particelle e cosmologia sembra fornire una delle spiegazioni più convincenti di come l'universo si sia formato
  - Inflatone e suo potenziale

- La teoria dell'inflazione fa tre previsioni chiare:
  - L'Universo è piatto
  - Perturbazioni quasi-invarianti di scala, adiabatiche e gaussiane
  - Presenza di onde gravitazionali
- Le prime due sono verificate da qualsiasi modello cosmologico sensato
- Le onde gravitazionali sono qualcosa di veramente nuovo e specifico.
- Di più: la loro ampiezza è direttamente collegata con
  - L'epoca dell'inflazione

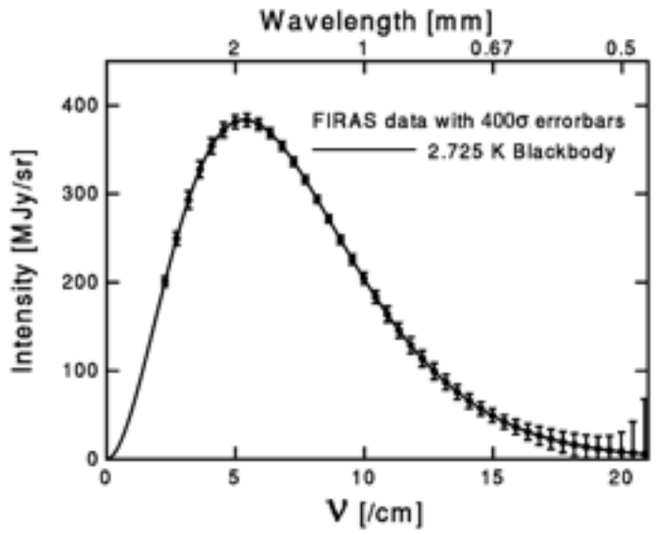
$$H_I^{-1} = \frac{2 \times 10^{-39} \mathrm{sec}}{\sqrt{T/S}}$$

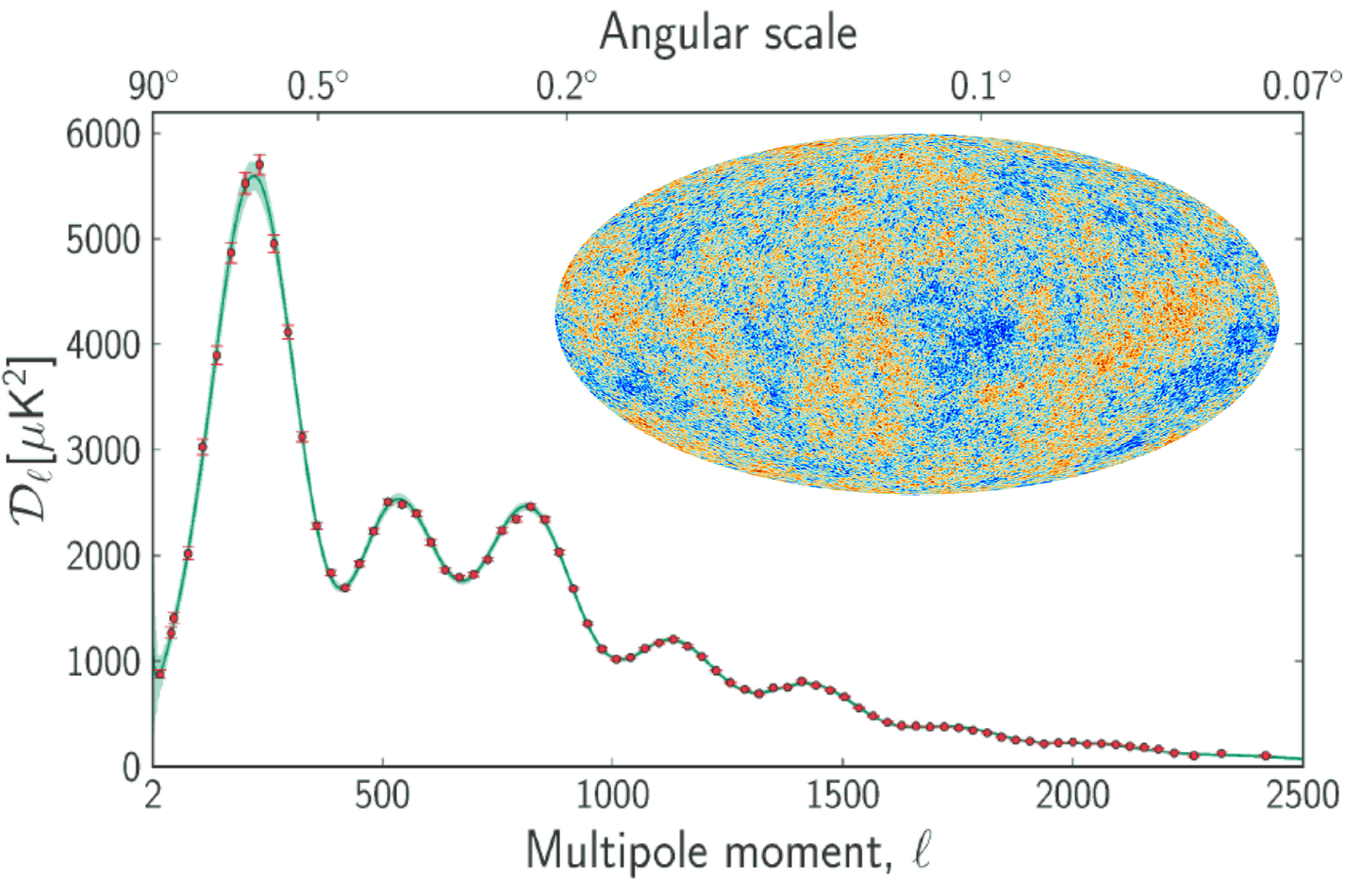
  - La sua scala in energia

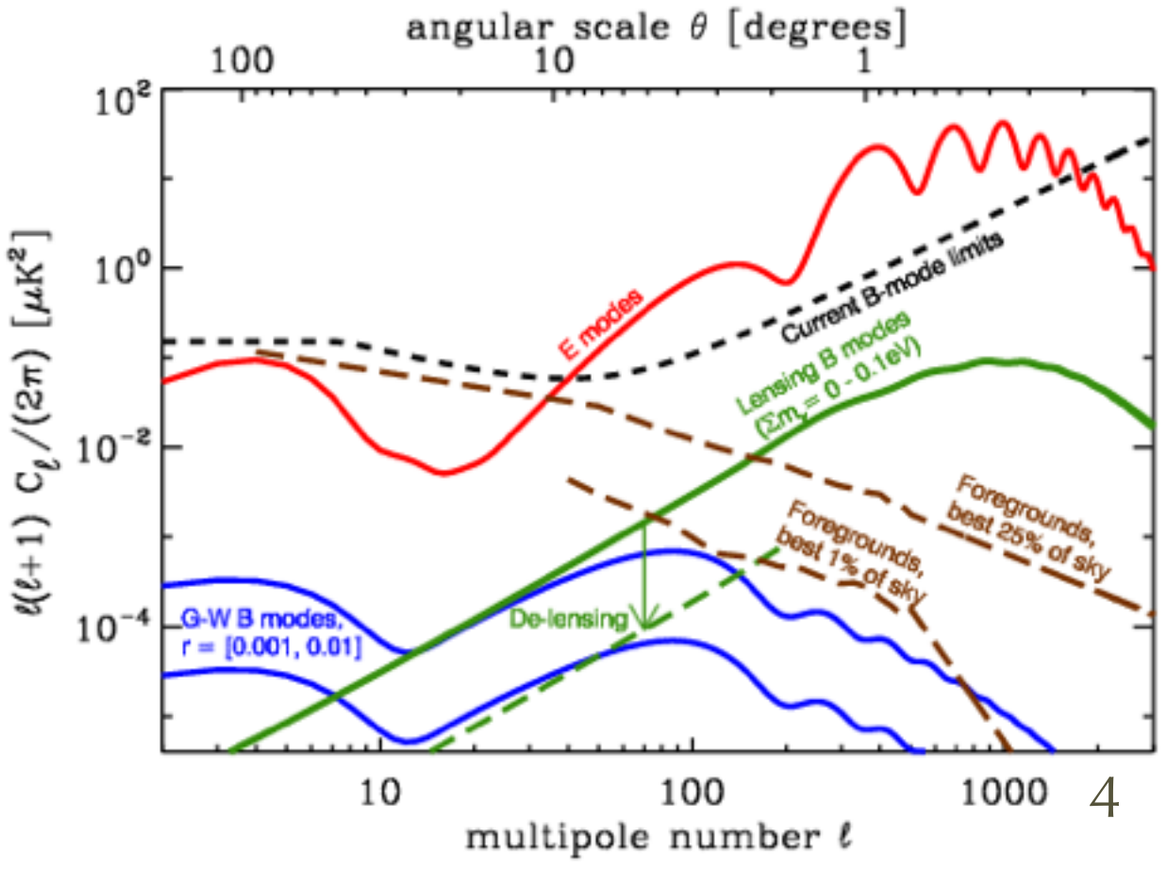
$$V^{1/4} = 3 \times 10^{16} \mathrm{GeV} \, (T/S)^{1/4}$$

CMB Observables

- Monopole term: 2.725 K blackbody
- Dipole term: 3.355 mK
- Anisotropy: 100 μK rms
- E-mode polarization: 3 μK rms
- B-mode polarization: <500 nK rms $\quad O(10^{-8} \div 10^{-8})$
  - depends on lensing of E-modes
  - depends on the inflation process and the background of primordial gravitational waves
  - Kamionkowski et al. PRD 55 (1997) 7368







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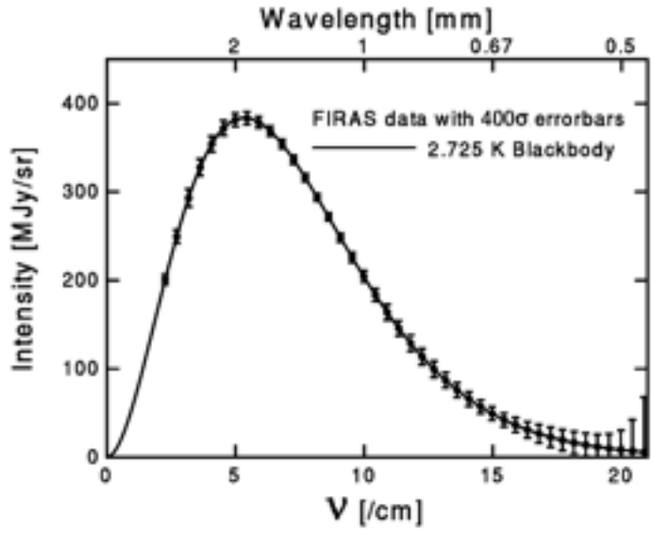
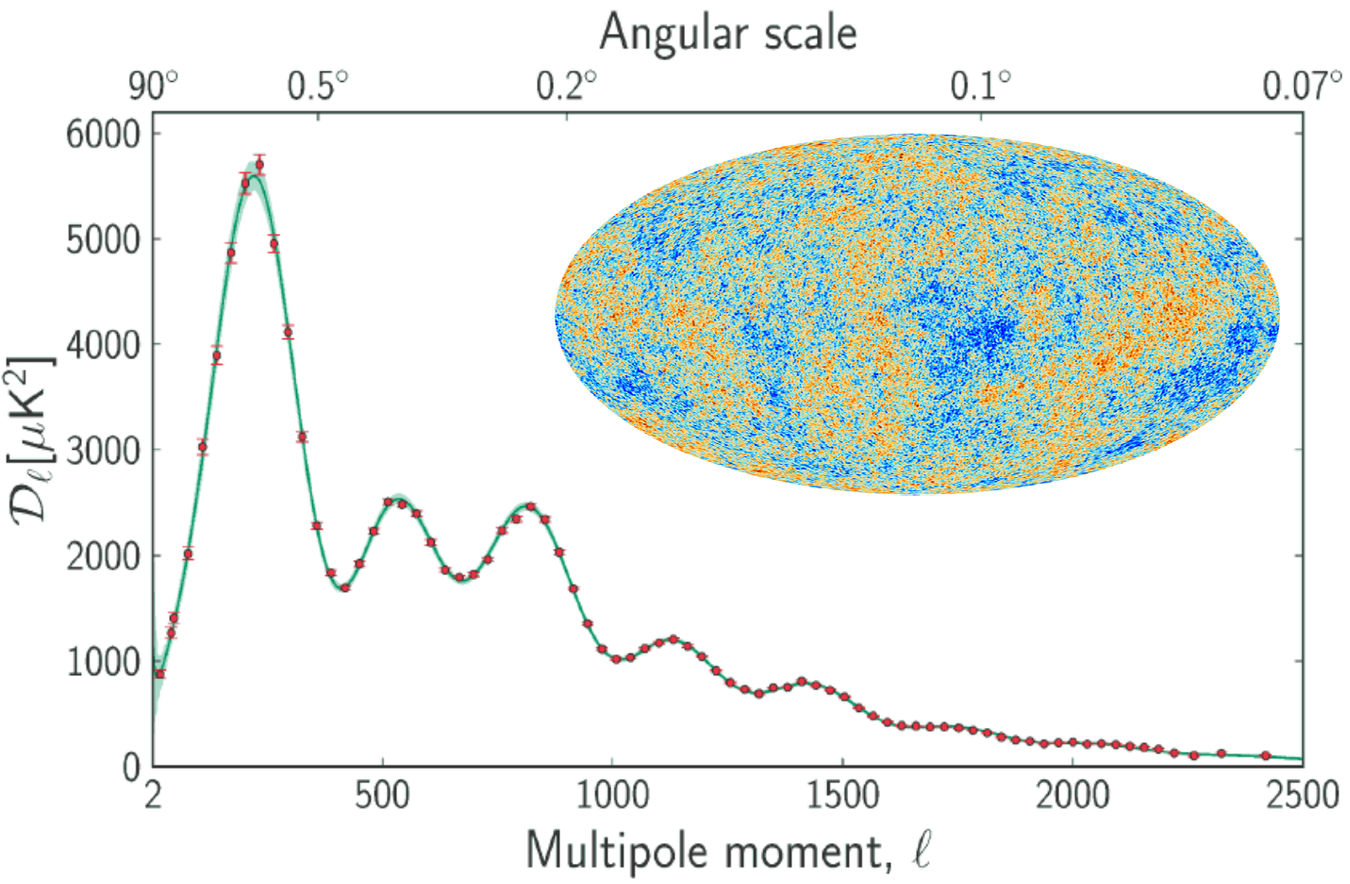
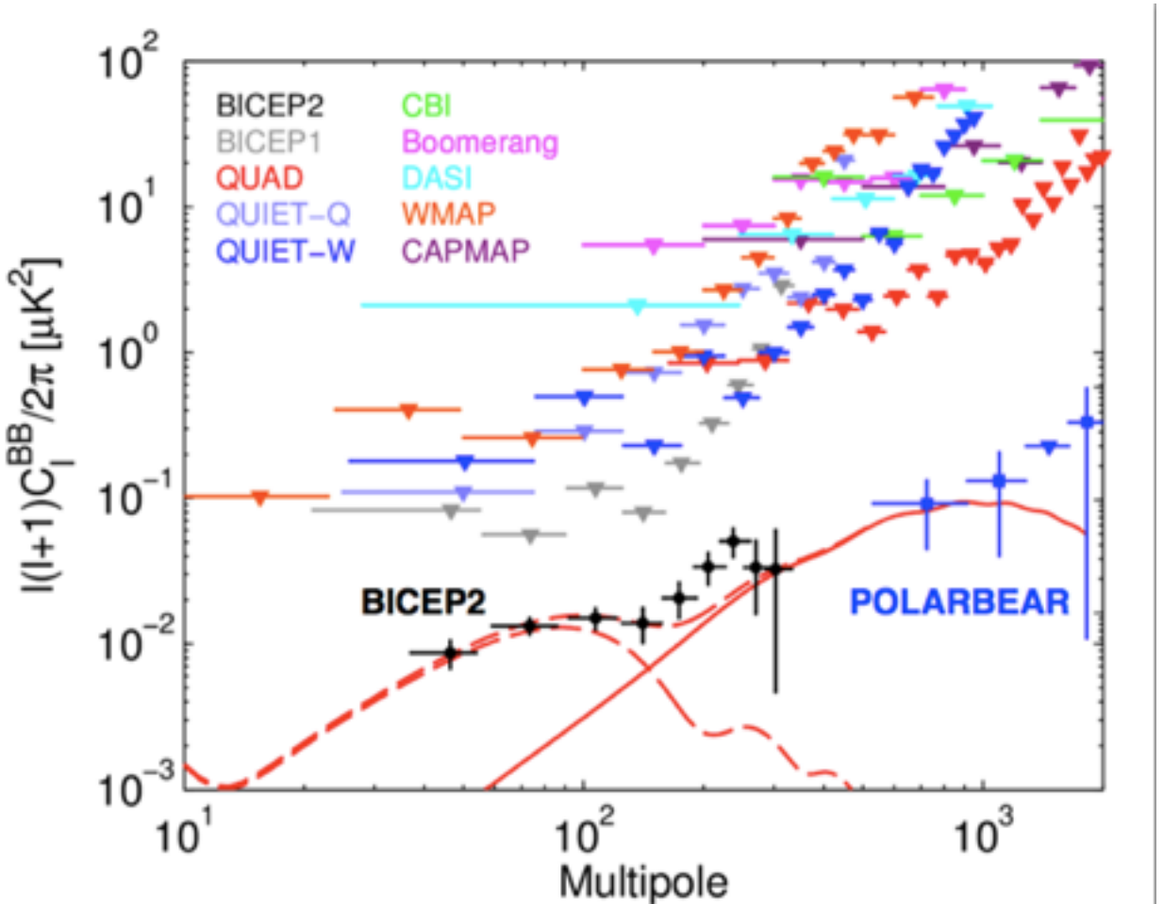


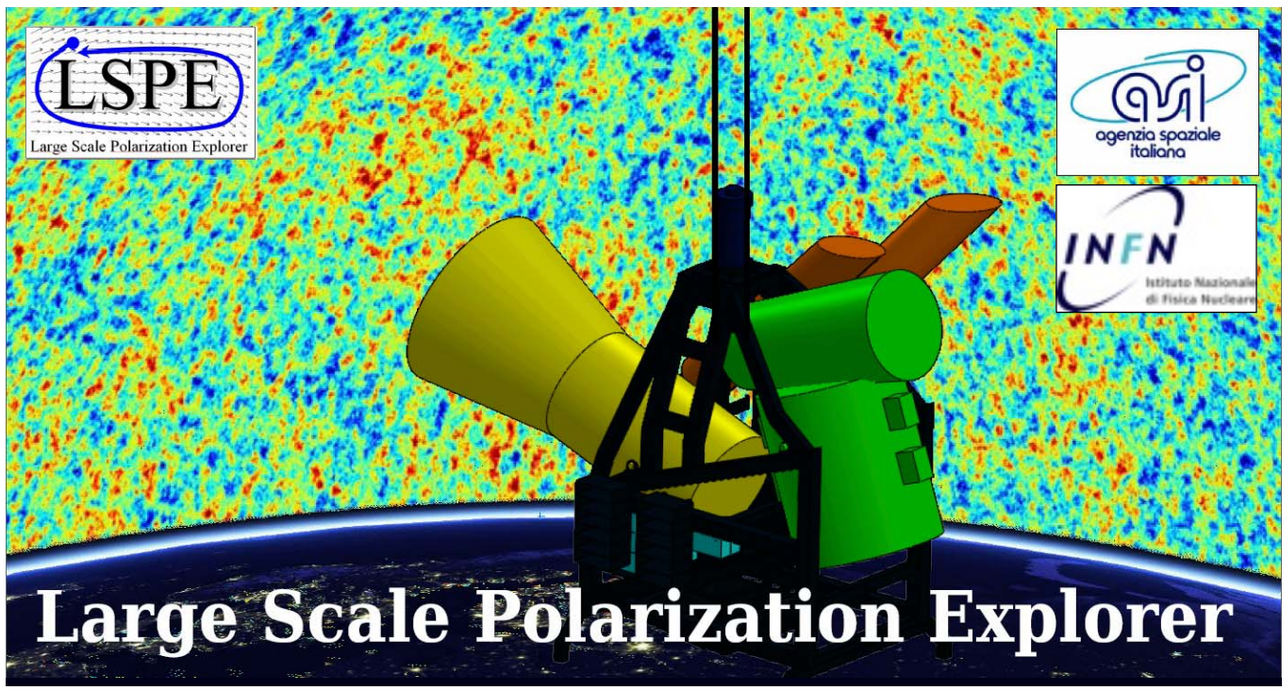
$O(10^{-8})$

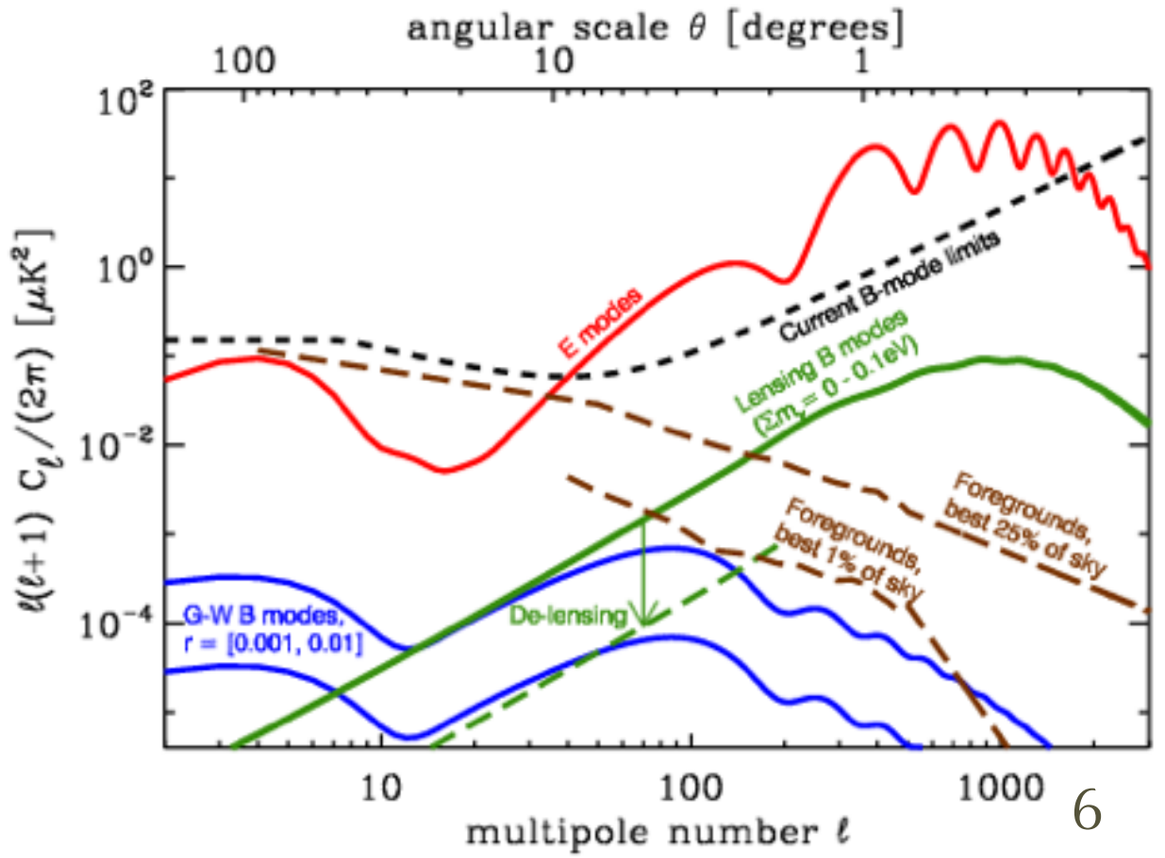




The LSPE experiment

- The Large-Scale Polarization Explorer is a stratospheric balloon to validate some technical choices towards a space mission + physics results
  - P.I. Paolo de Bernardis
- Balloon experiments can use the latest technology to be proved for space experiments
  - All Italian technology
- Two instruments to be sensitive to different frequency bands
  - STRIP (44 and 90 GHz, M. Bersanelli) and SWIPE (140, 220 and 240 GHz, P. de Bernardis)
  - goal → R= $(T/S)^{1/4}$=0.03 @95% CL





CMB B-mode timeline

- Ground → Balloon → Space

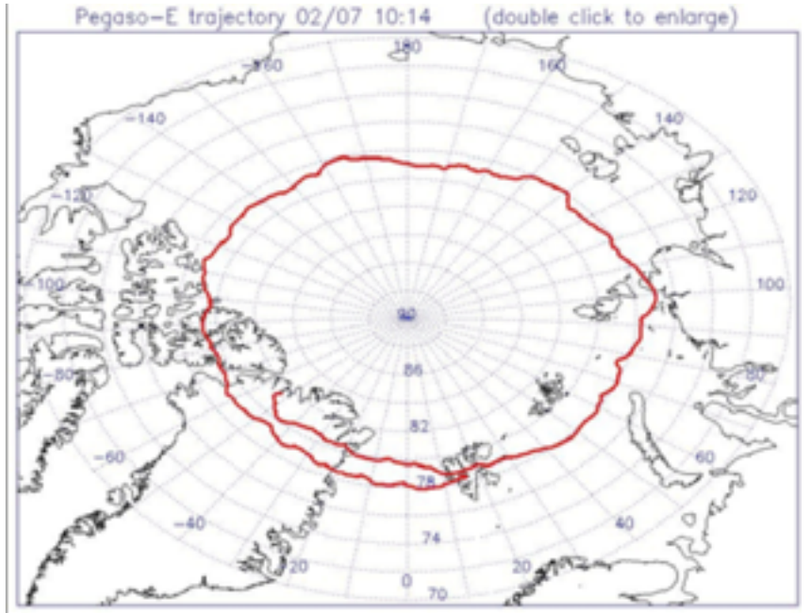
  - 2009: r < 0.7 (BICEP) Chiang et al, 0906.1181

  - 2013: Stage II experiments detect lensing B-modes
  - 2014: r ≲ 0.1 from Inflationary B-modes (BICEP 2) ?
  - 2013-2016: Stage II experiments
    $\sigma(r)\sim0.03$, $\sigma(N_{eff})\sim0.1$, $\sigma(\Sigma m_\nu)\sim0.1$eV
  - 2016-2020: Stage III experiments
    $\sigma(r)\sim0.01$, $\sigma(N_{eff})\sim0.06$, $\sigma(\Sigma m_\nu)\sim0.06$eV;

  - 2020-2025: Stage IV experiment, **CMB-S4**
    $\sigma(r) = 0.001$, $\sigma(N_{eff}) = 0.020$, $\sigma(\Sigma m_\nu) = 16$ meV

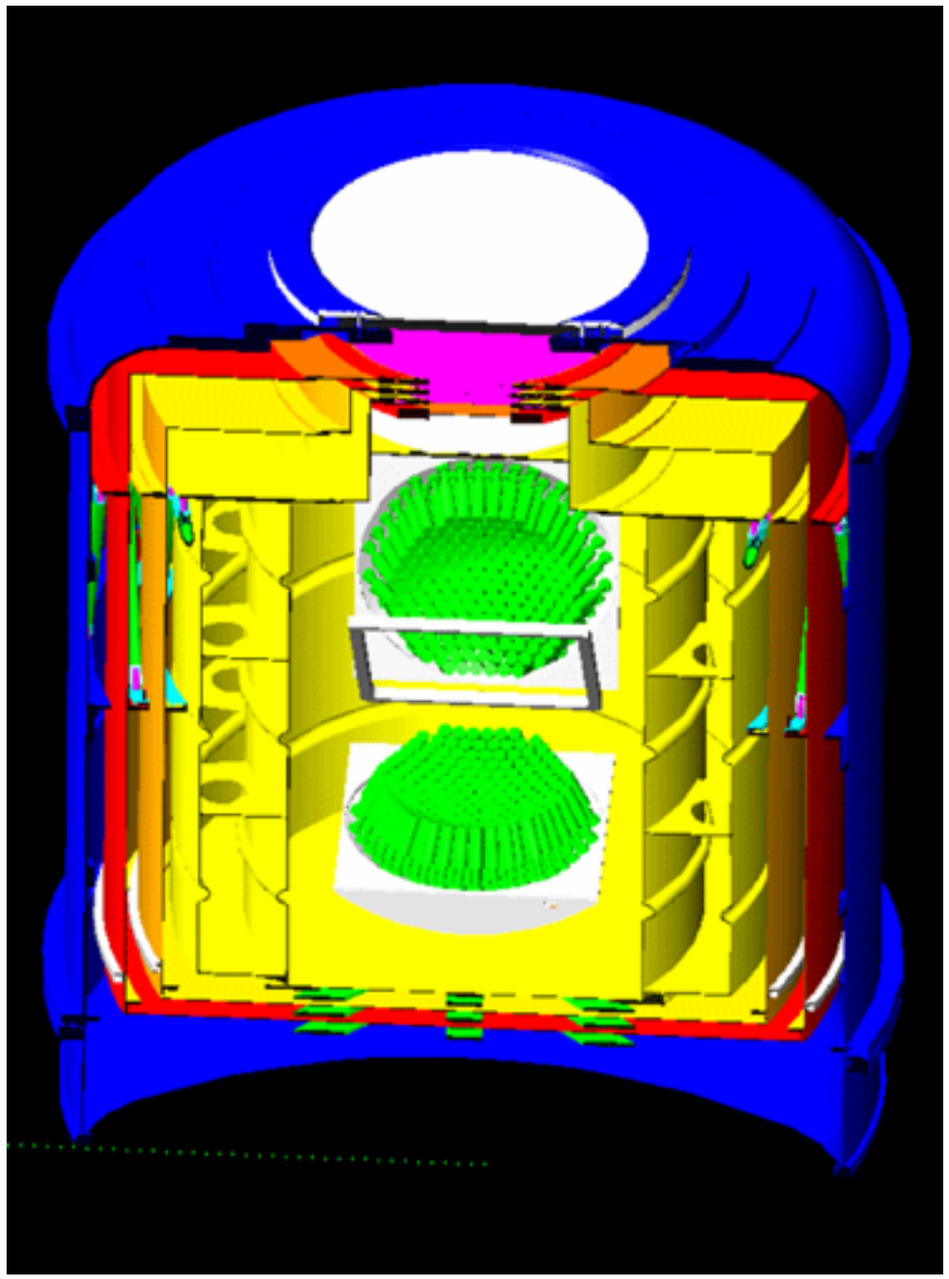
La missione LSPE

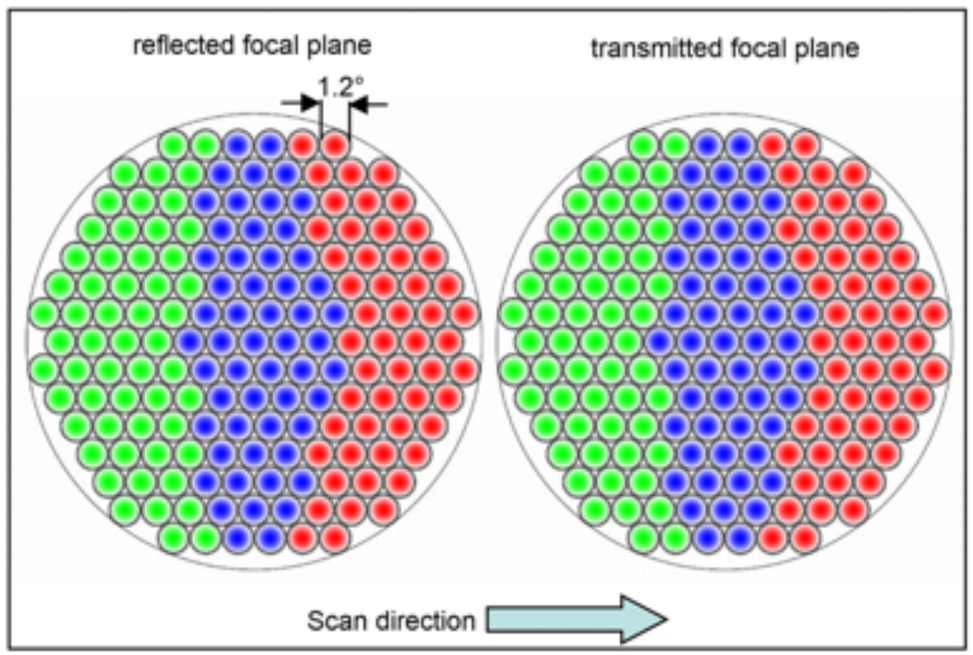
- Volo nella stratosfera
  - (37 km, p=3 mbar, T= –80°C)
- Volo notturno
  - batterie termostatate per 3 settimane
  - circa 700 kg di batterie
- Volo intorno agli 80°N
- pallone 800 000 m^3 elio
- ASI responsabile lancio e volo
- Gruppo di lavoro coordinato da E. Flamini per utilizzo expertise di altre agenzie alle Svalbard con personale italiano in training
- La data di lancio (Gennaio 2016) è spostata a Dicembre 2016-Gennaio 2017

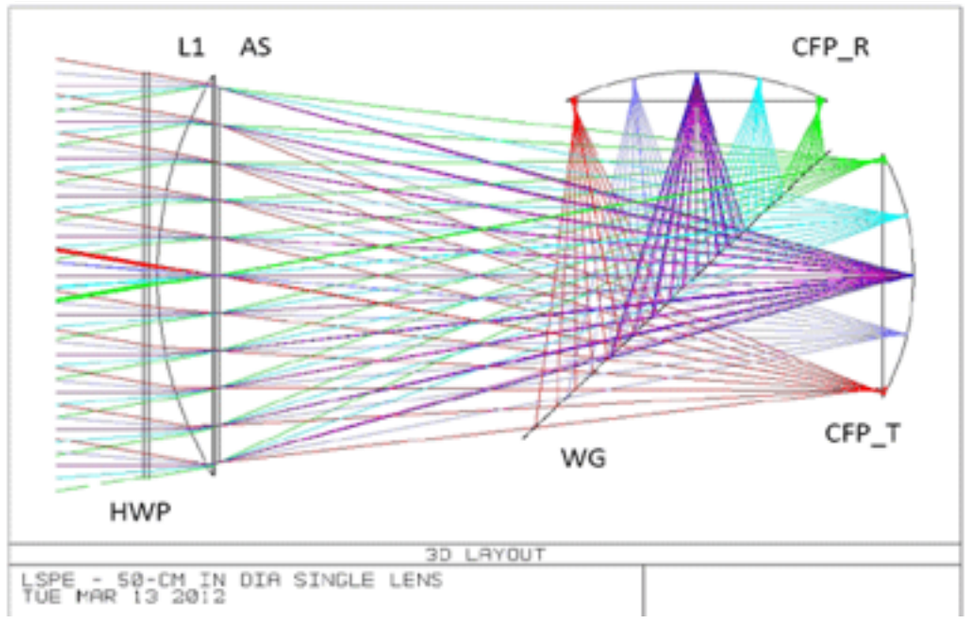


Lo strumento SWIPE

- Short Wavelength Instrument for the Polarization Explorer
- It is a Stokes Polarimeter, based on a cold (4K) HWP polarization modulator, a simple 50 cm aperture refractive telescope, a beamsplitting polarizer, and two large focal planes, hosting 326 multi-moded bolometers at 140, 220, 240 GHz.
- Everything is cooled by a large ^{4}He cryostat and a ^{3}He refrigerator, for operation of the bolometers at 0.3÷0.5K

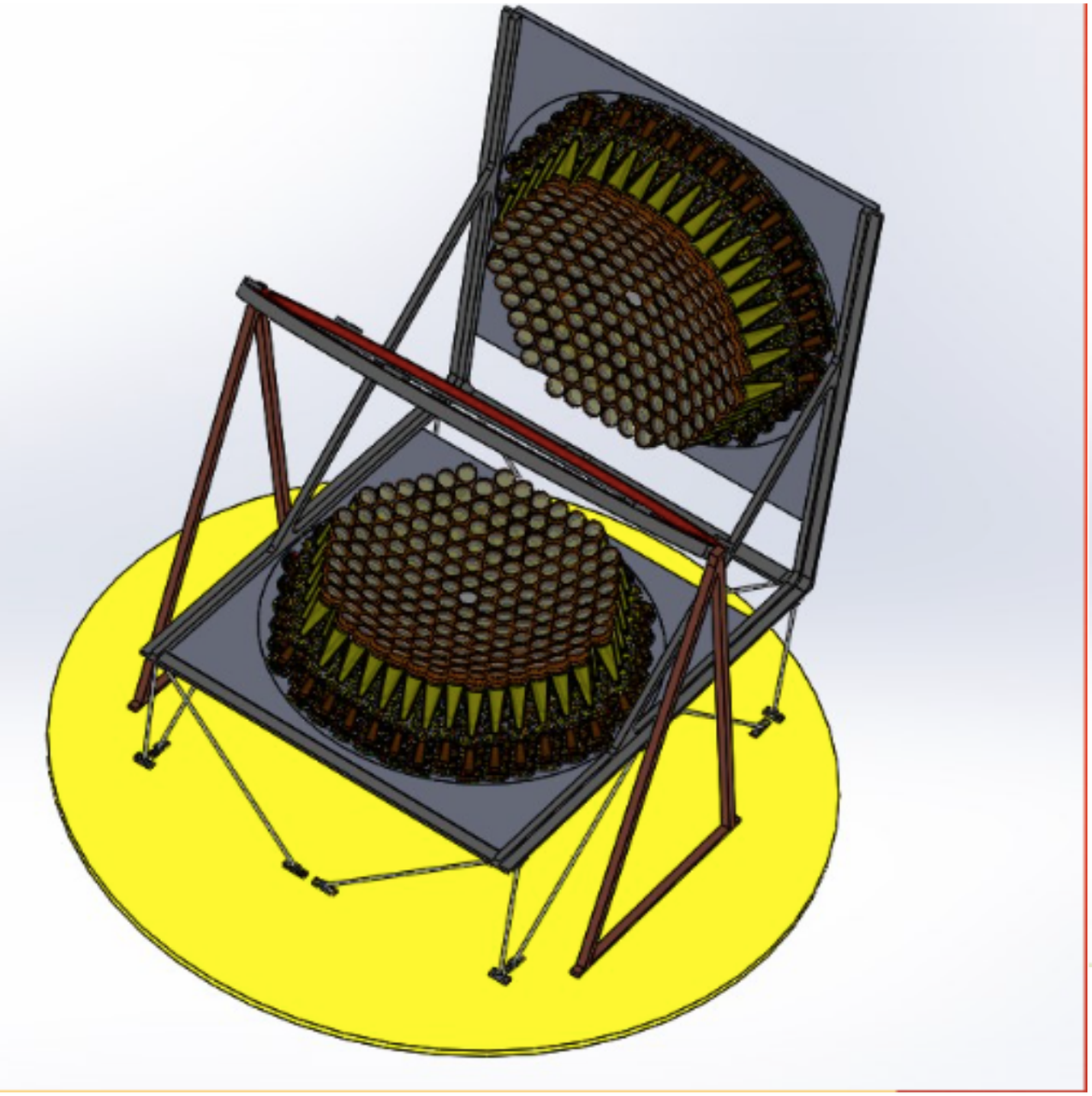




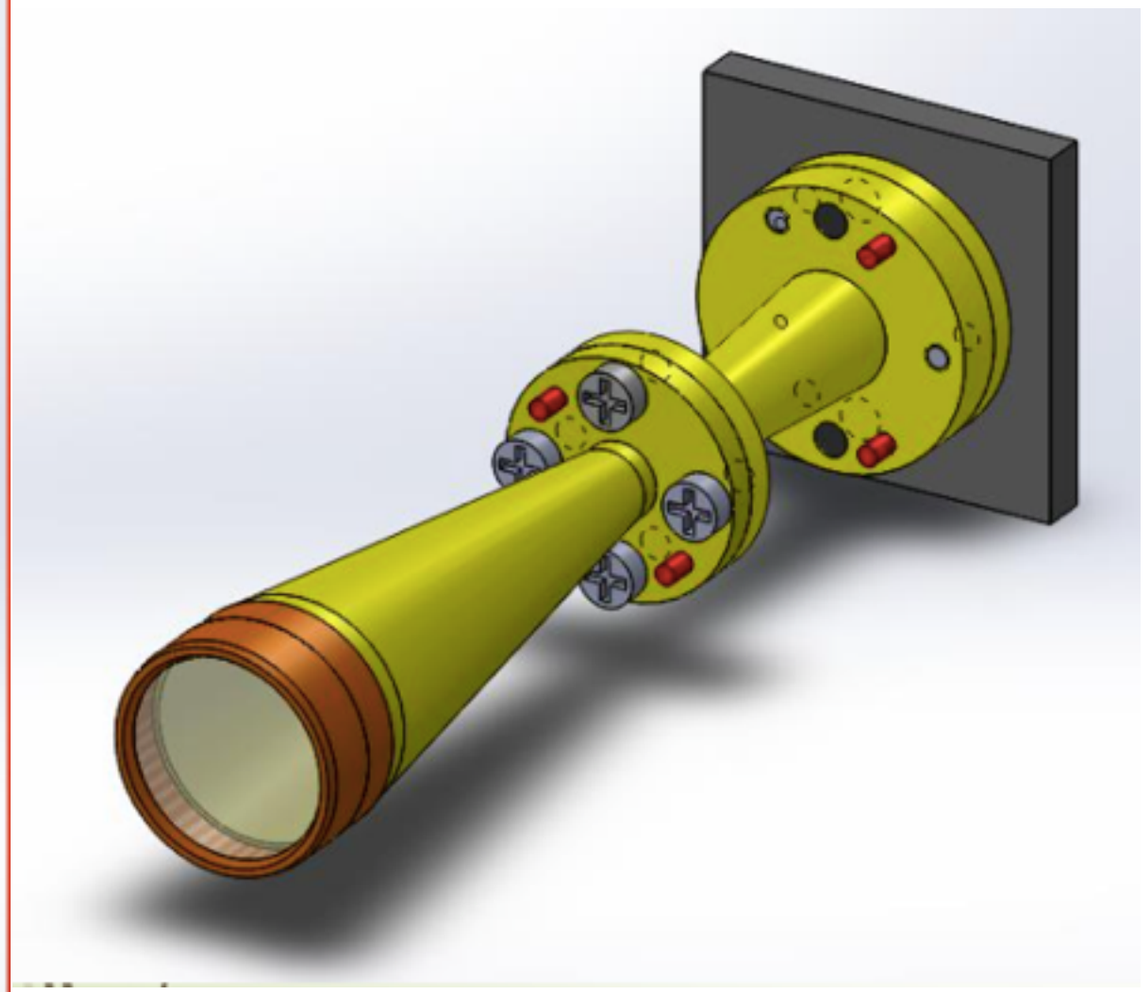


Coni multimodo

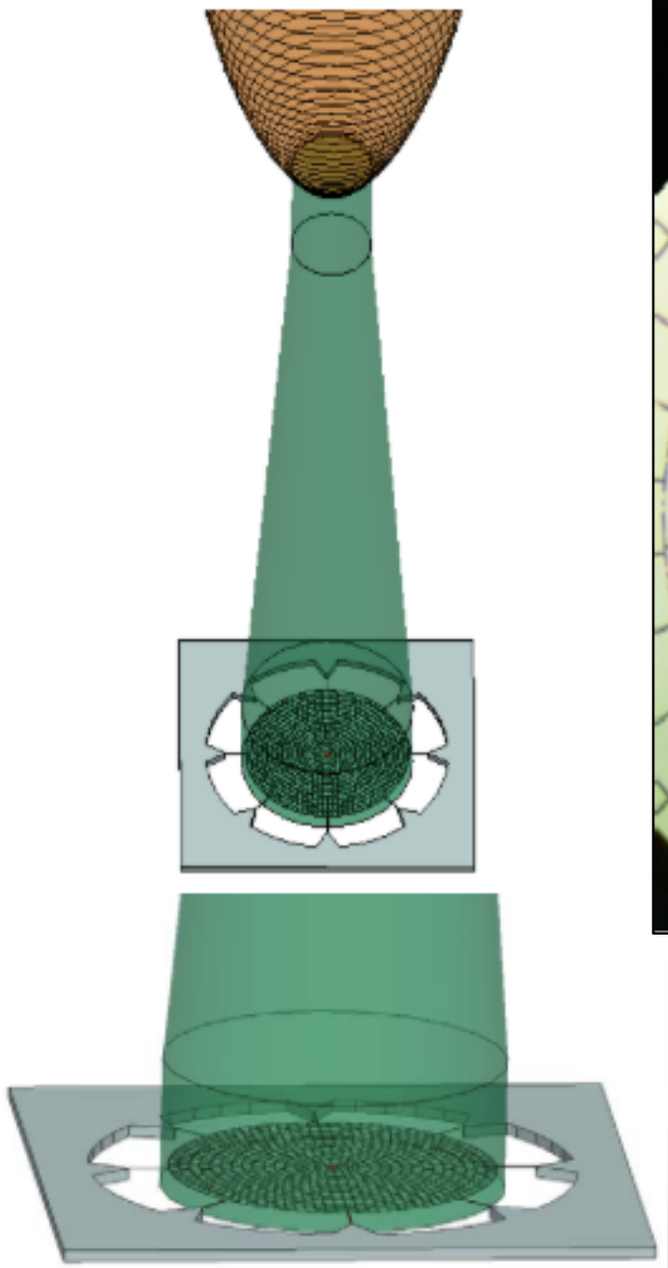
- Ottimizzati per raccogliere maggior potenza sacrificando angolo solido
  - 10→17 (140 GHz) 28→31 (220) 32→35 (240)

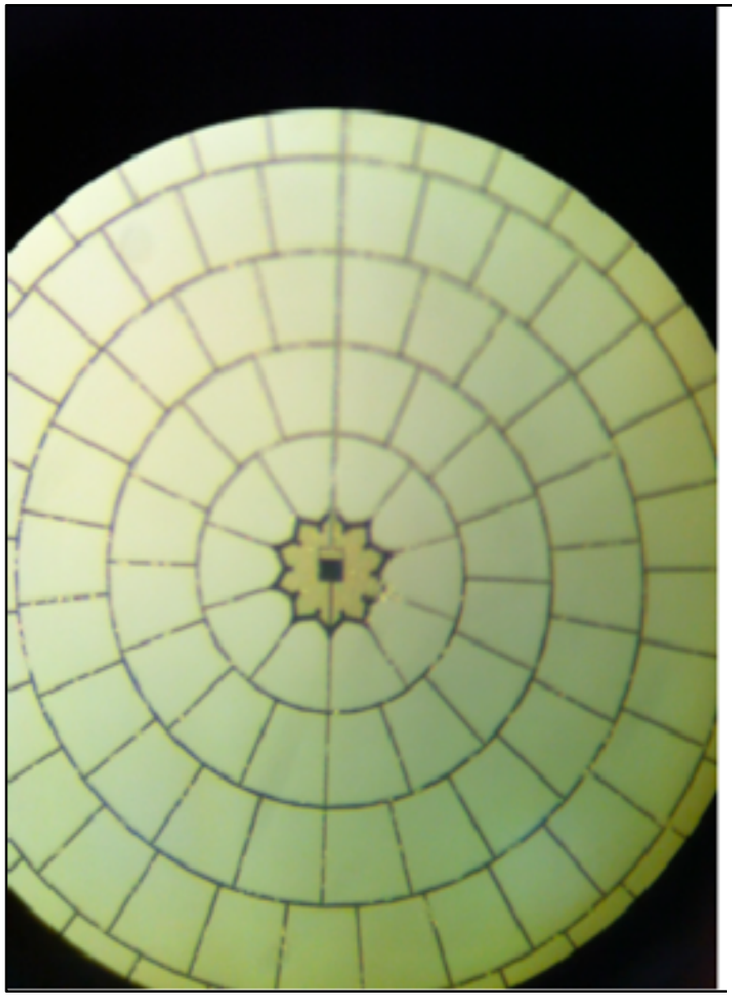


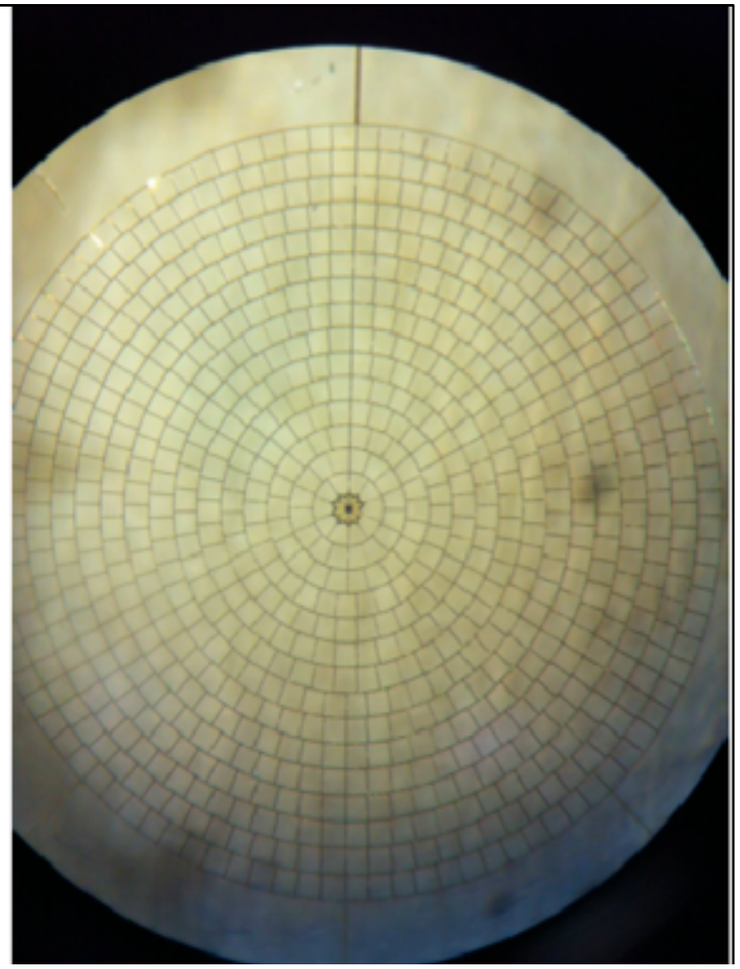
i due piani focali



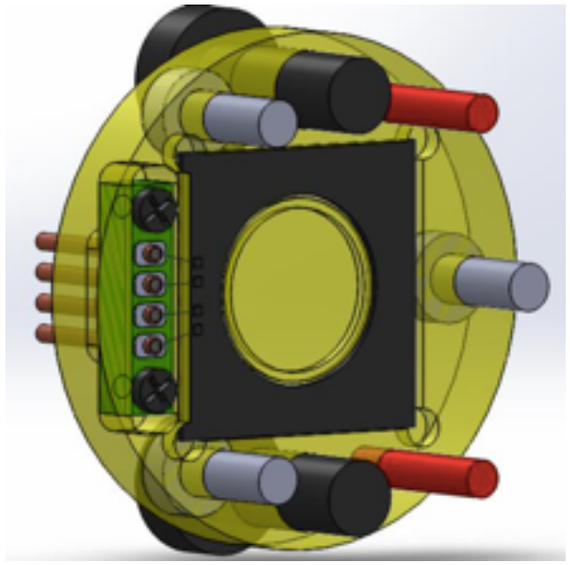
un cono multimodo





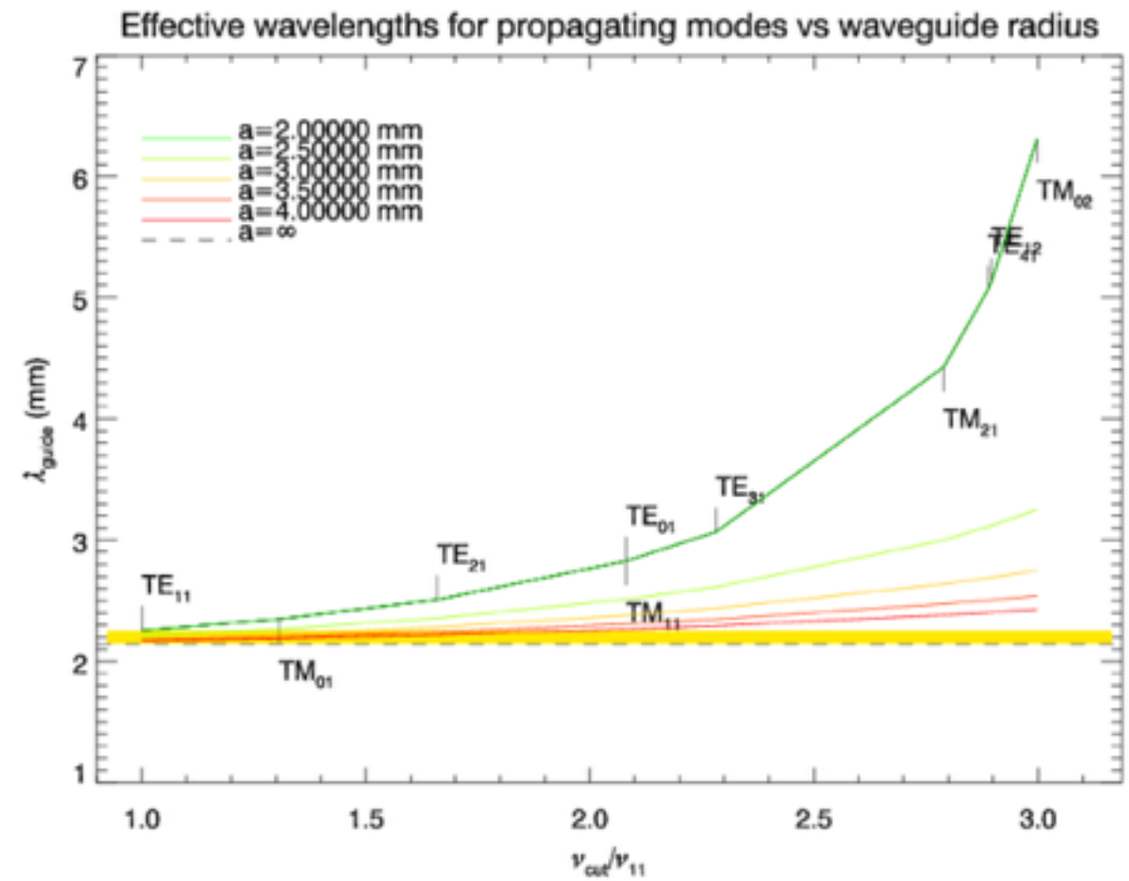


bolometri
TES
spiderweb



Resp: Genova

guida d'onda + cavità risonante



Instrument

- At INFN Genova the first “all Italian” spiderweb bolometer was realized (F. Gatti et al.)
- TiAu TES (superconducting transition edge sensor) technology → MoAu for higher transition temperature
- World’s largest multimode detector

0 – starting from silicon wafer covered with SiO_2 and Si_3N_4

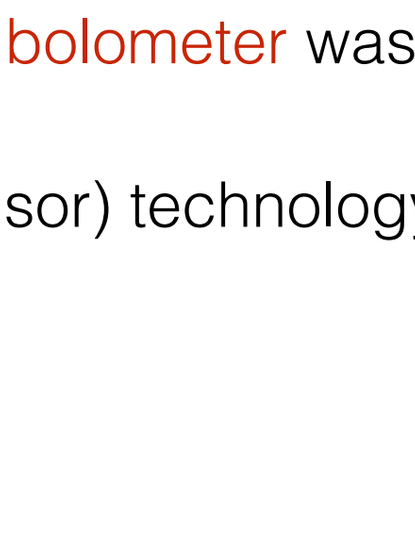
Si_3N_4 thickness 1 μm

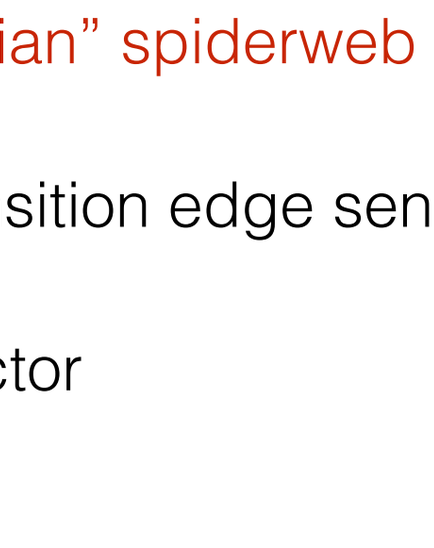
SiO2 thickness 0.5 μm

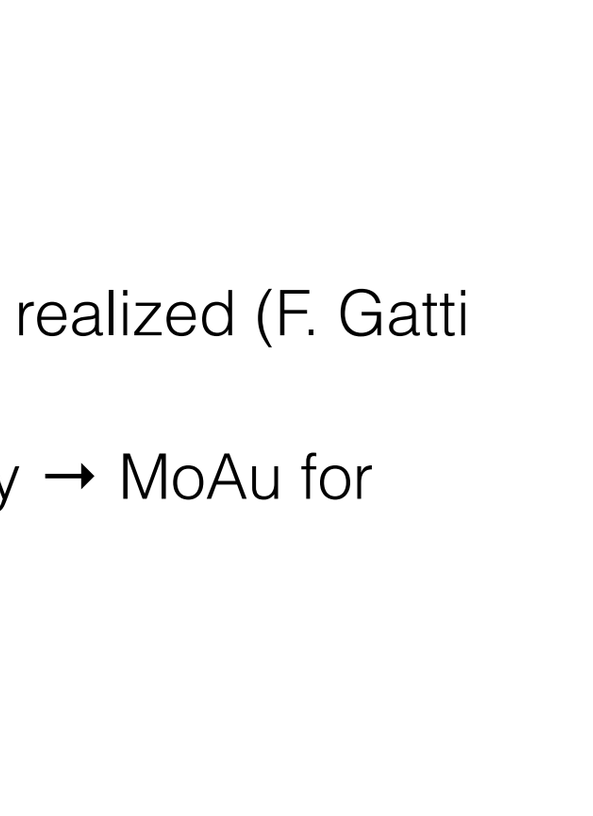
Silicon

4 - Gold absorber deposition with lift-off process (a Ti sticking layer is necessary)

5 - RIE etching after positive photolithography





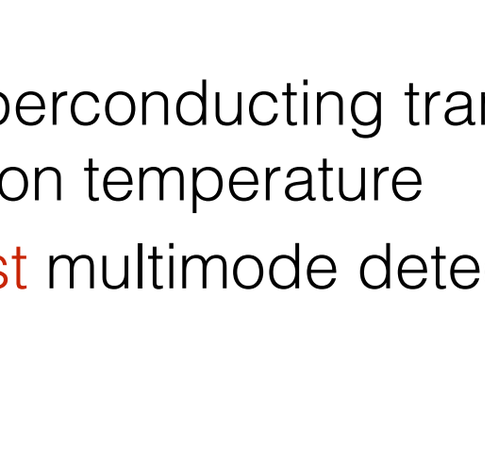


Lithographic masks assembled:

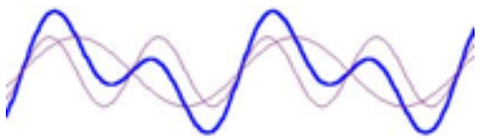
Chip dimension 15 x 15 mm

Absorber diameter 8 mm

Spiderweb mesh size 250 μm



Il "rivelatore"



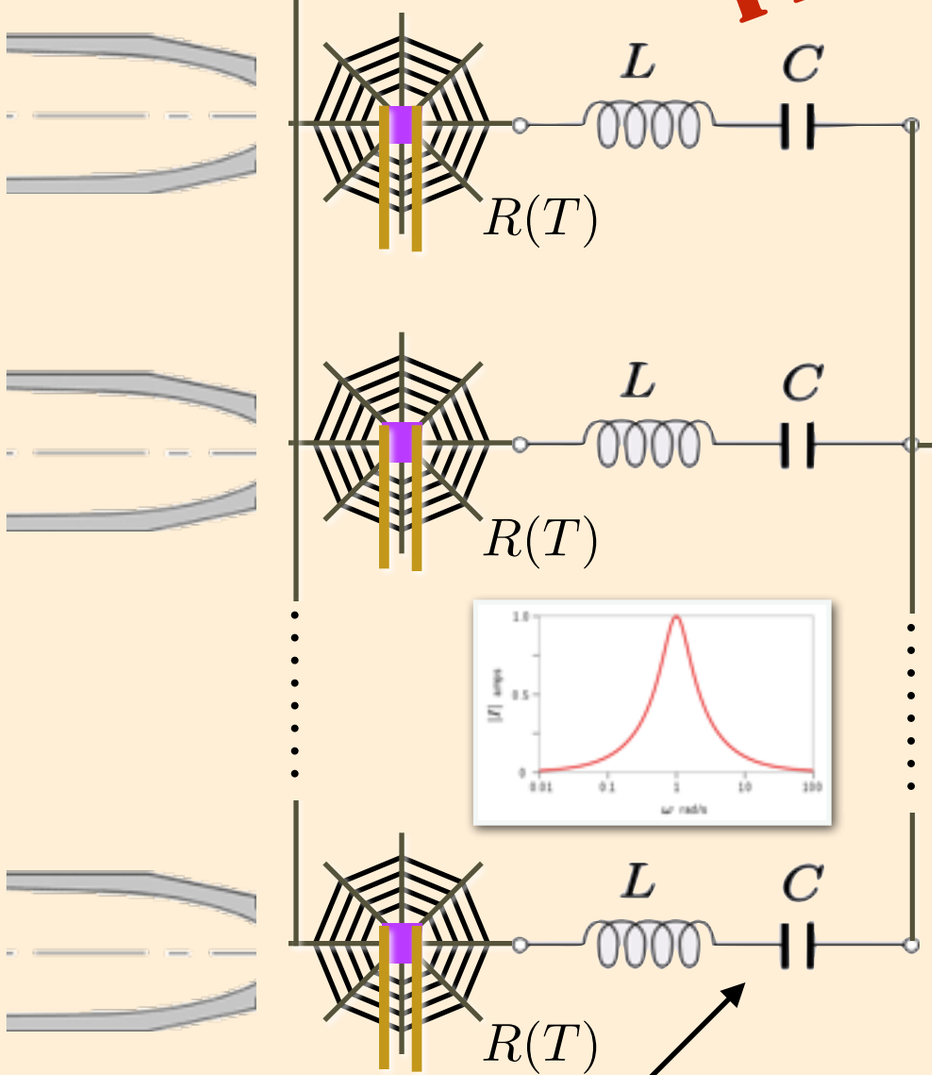
300 mK

4 K

–80 ºC

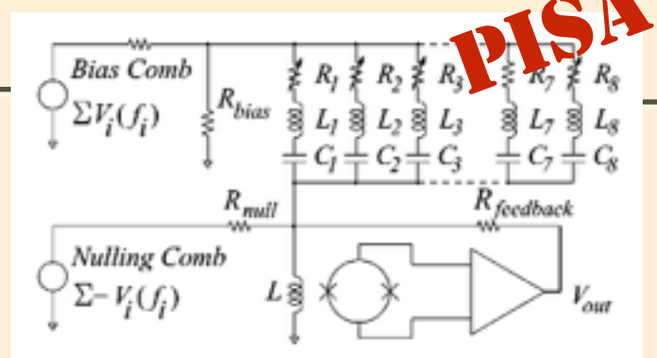
x N bolometers

PISA



x M multiplexing

PISA



SQUID

> –40 ºC

Detector Control

PISA

circuiti risonanti superconduttori

elettronica FDM
(frequency domain modulation)

LC

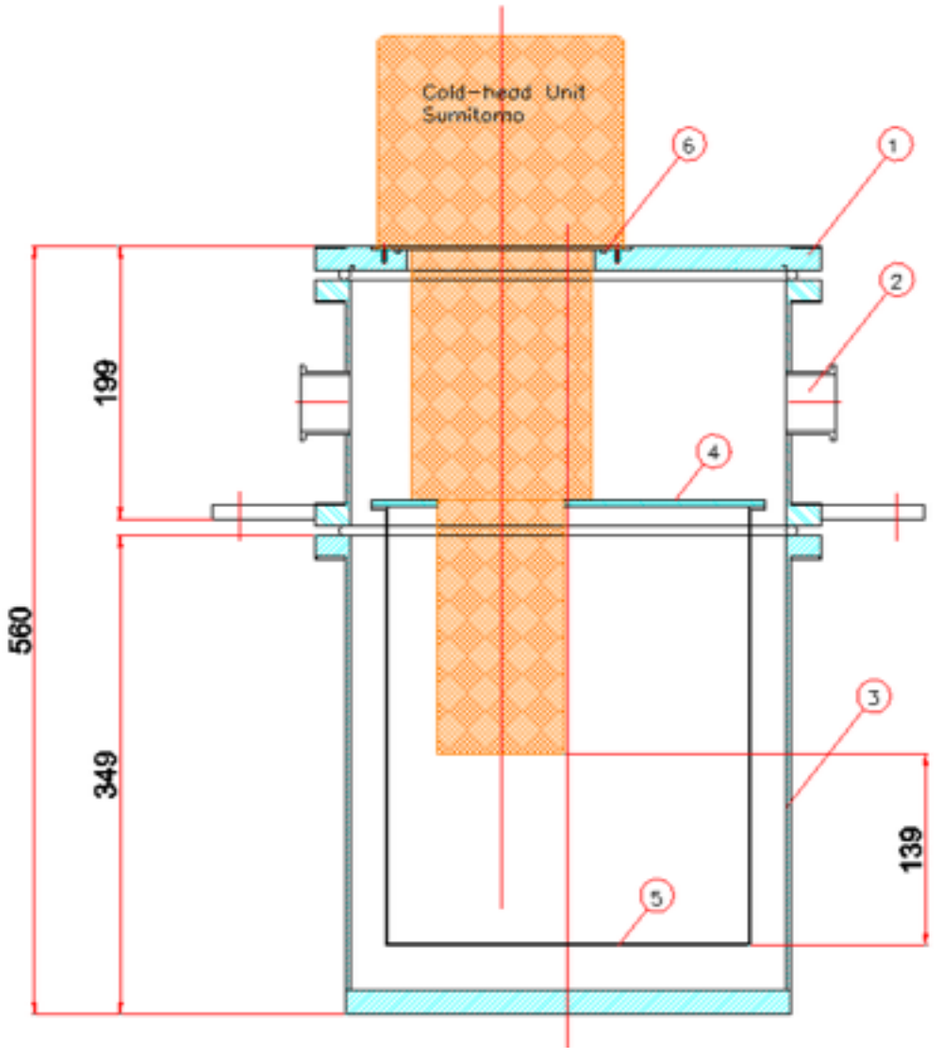
esempio di piano focale (EBEX)
350 mK

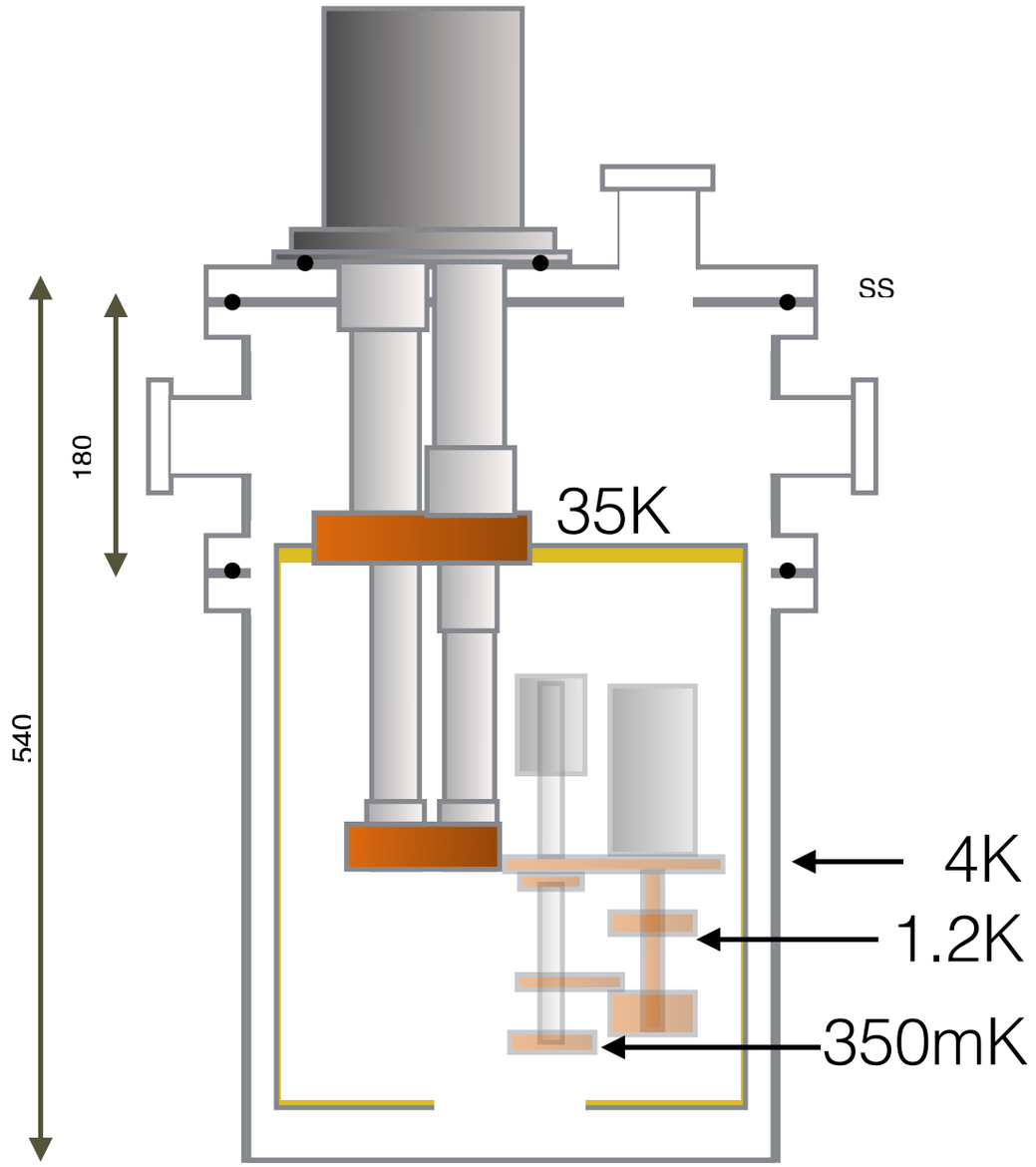
Le Sezioni INFN Partecipanti

- Rivelatore complesso e che necessita di integrazione “fine”
  - ⇒ Divisione “fluida” ⇒ Singola responsabilità ma collaborazione su tutti gli items
- Genova (F. Gatti, R. Naz.)
  - Costruzione e test elettrico sensori bolometrici e dell’elettronica fredda (SQUID)
- Roma I (P. de Bernardis)
  - Accoppiamento ottico e test ottico sensori bolometrici
- Roma Tor Vergata (A. Rocchi)
  - Integrazione navicella e test pre-volo
- Pisa (G. Signorelli)
  - Costruzione e collaudo elettronica di lettura sensori bolometrici → data flow
    - meccanica, crate, integrazione in esperimento
  - disegno e realizzazione dei filtri superconduttori risonanti
    - integrazione nel piano focale
  - Studio dell’effetto dei raggi cosmici sui rivelatori
  - Facility di test criogenica
- Ferrara (P. Natoli)
  - map-making e analysis schooling

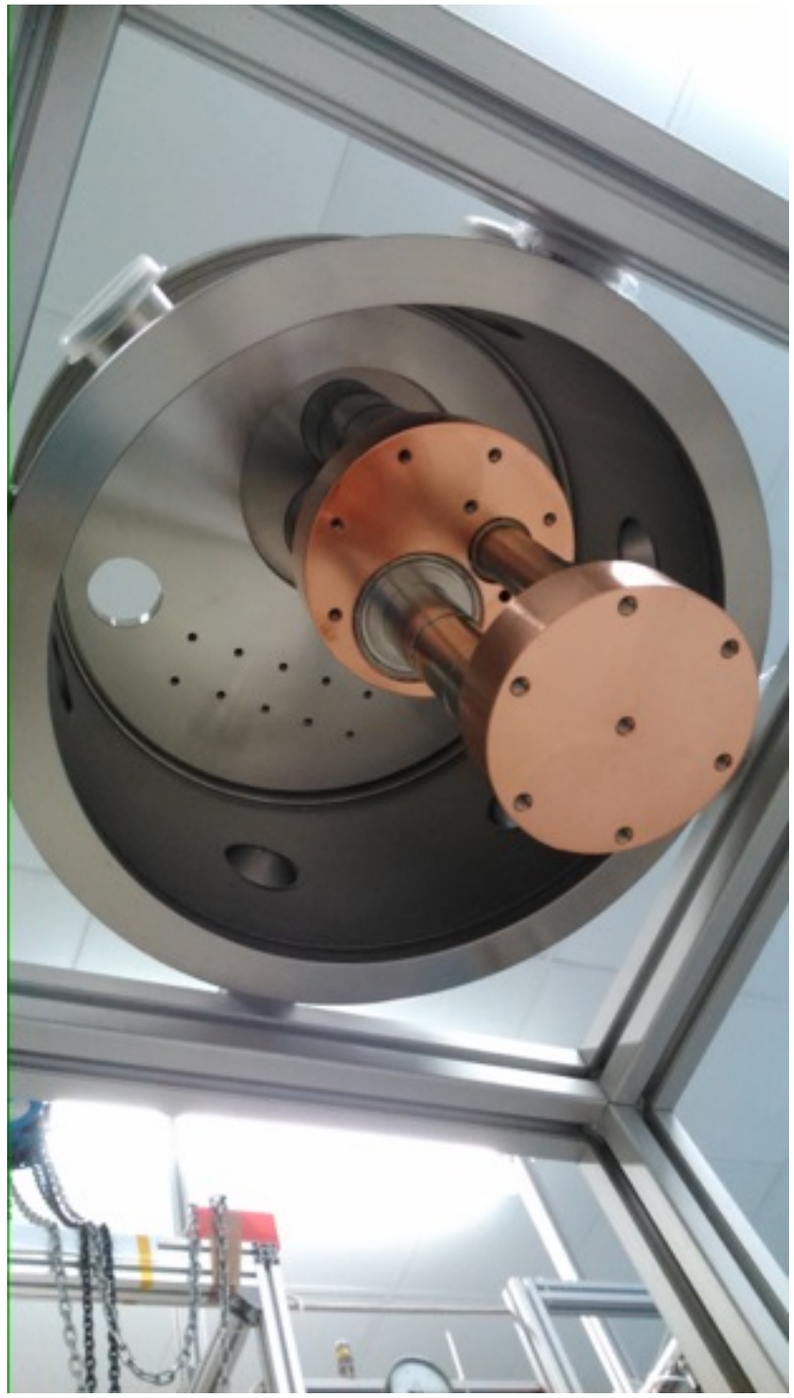
4K test facility

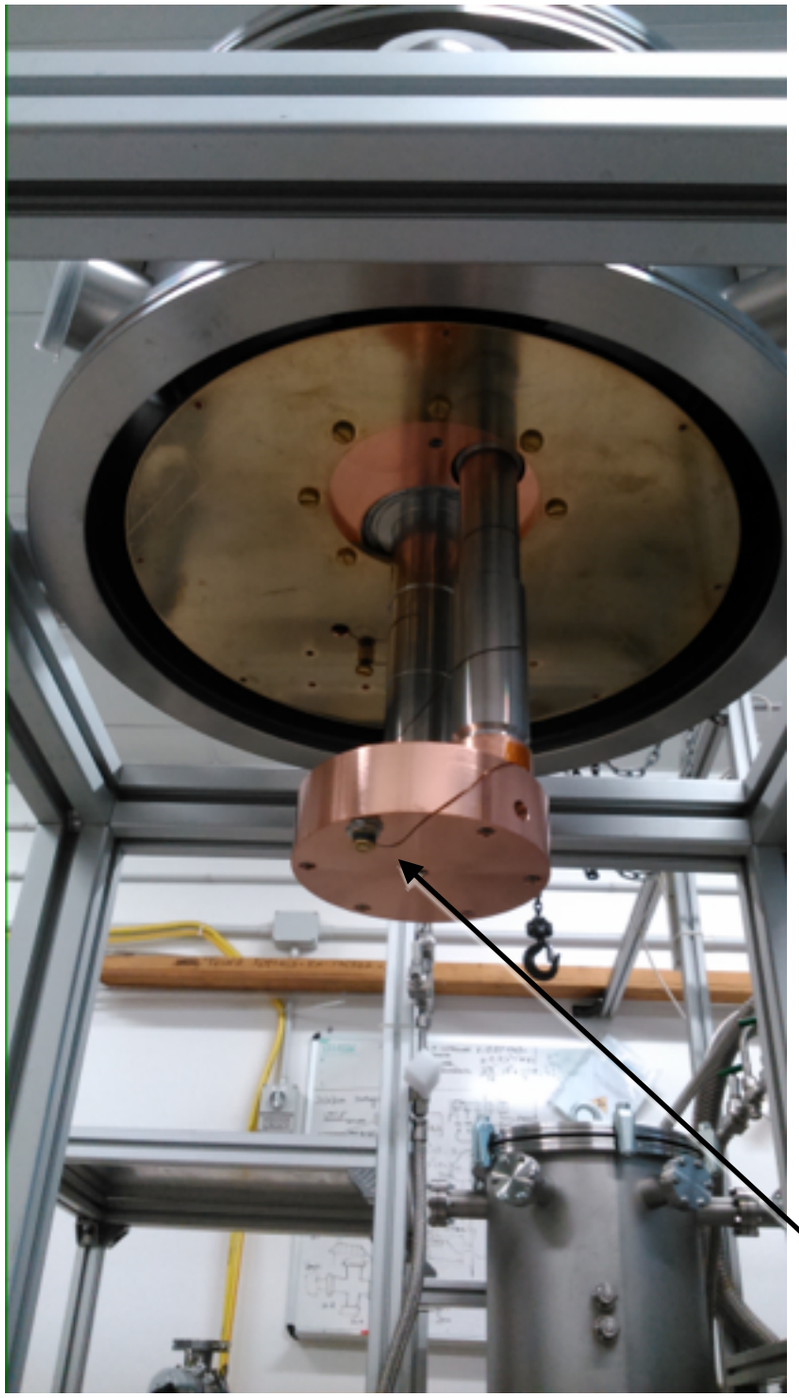
- Costruita su anticipi al 2014 → ordini effettuati su DTZ2
- Materiale ricevuto a partire da Marzo
  - SUMITOMO SRP-082B2-F70H dual stage pulse tube 0.9 W @4K, 35W @45
- Some delay on assembly due to power and water cooling requirements
  - Stadio a 350 mK non ancora finanziato

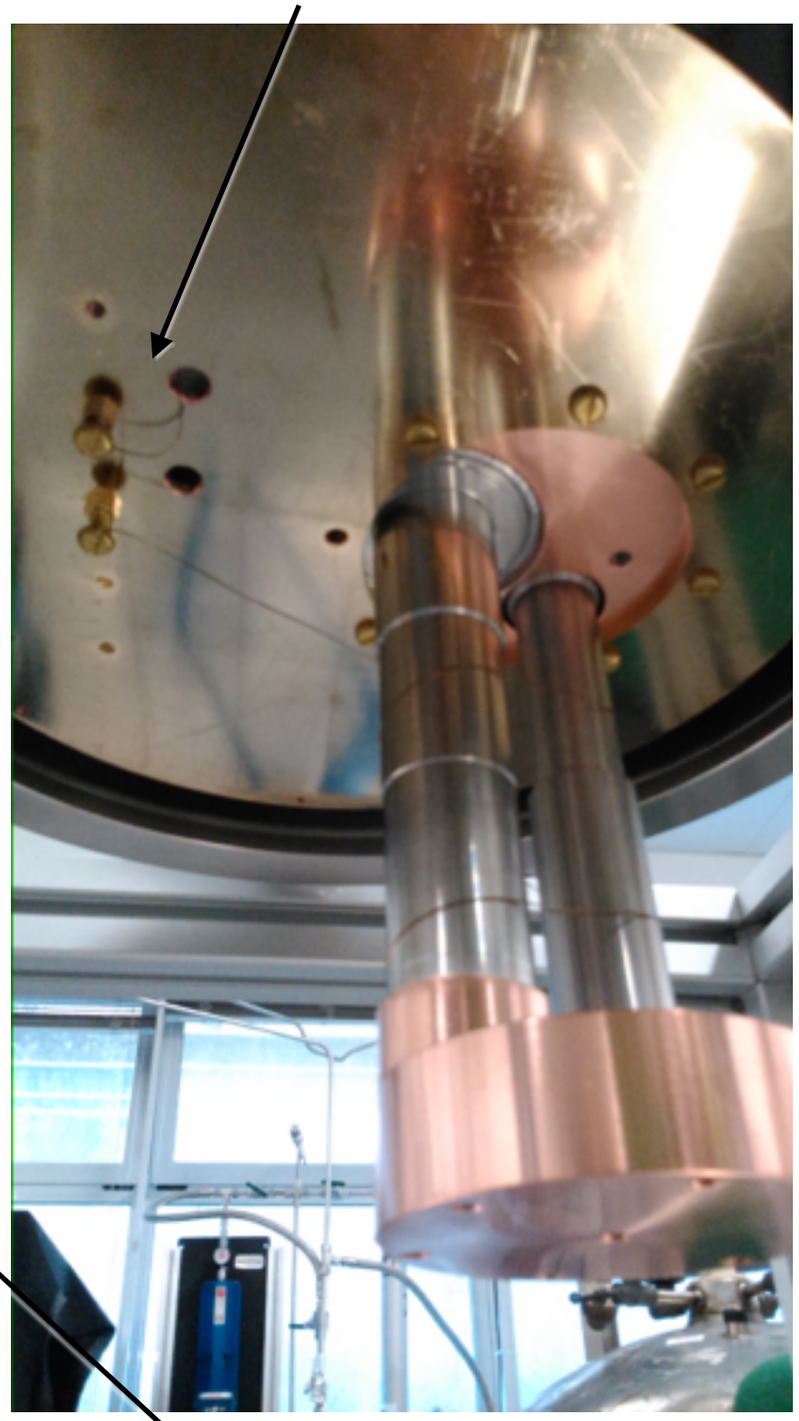




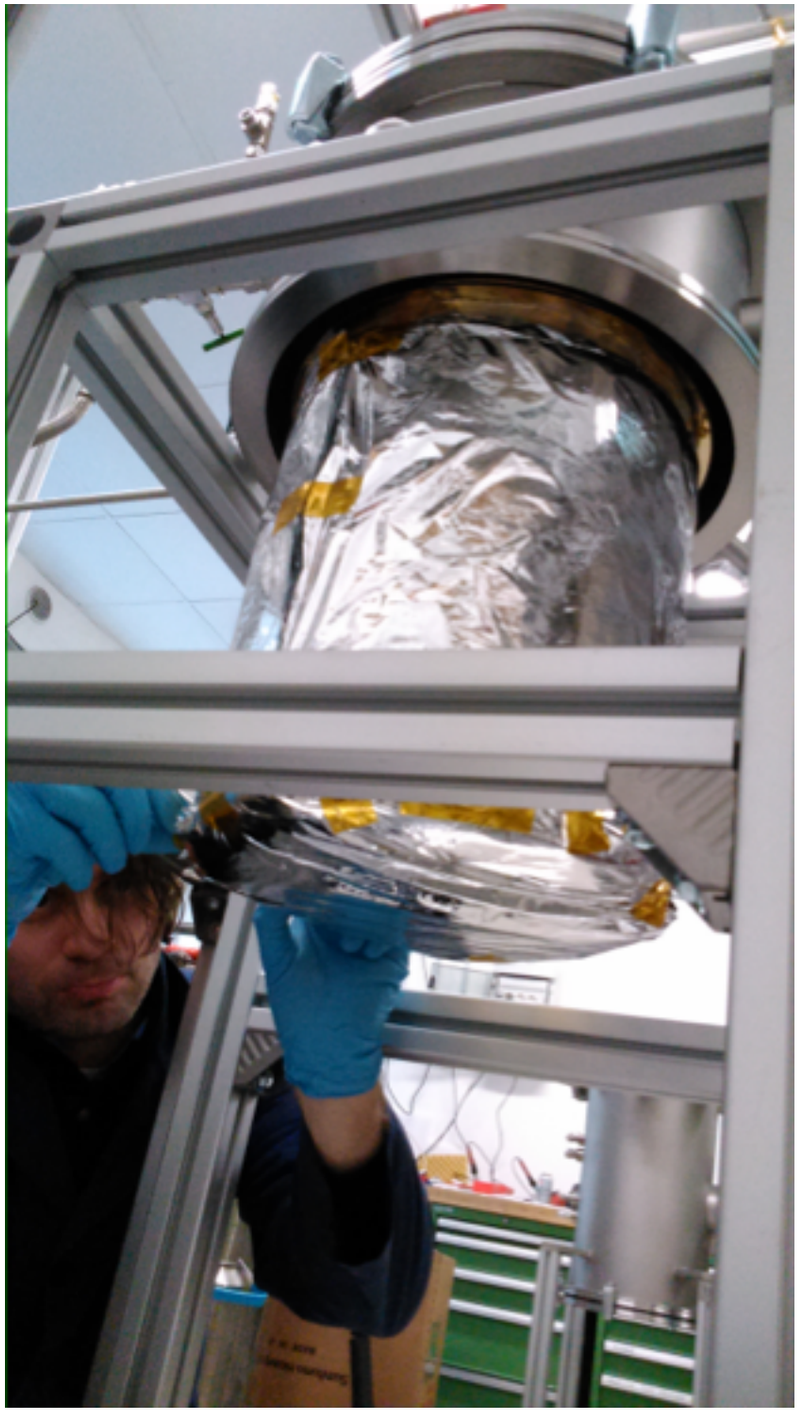
Sensor installation

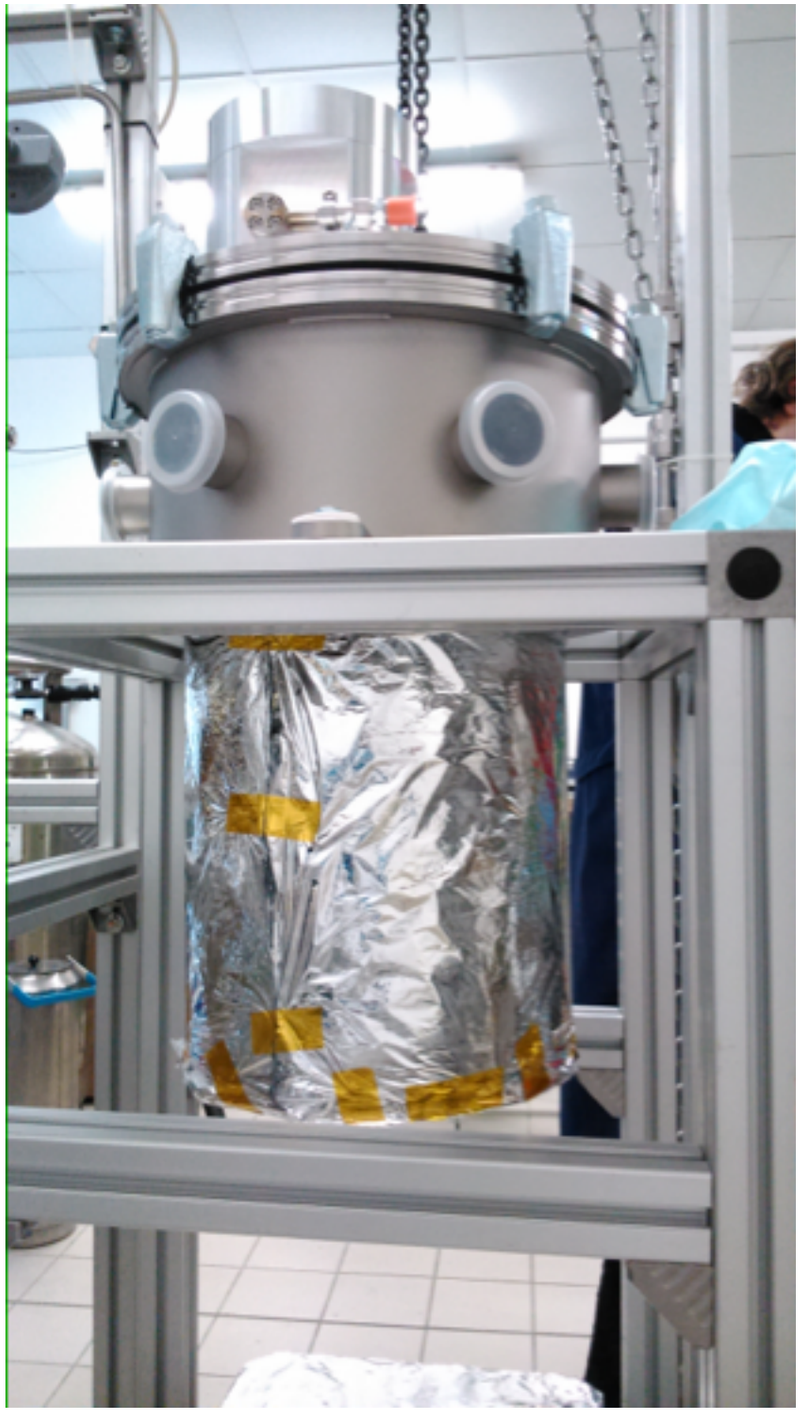






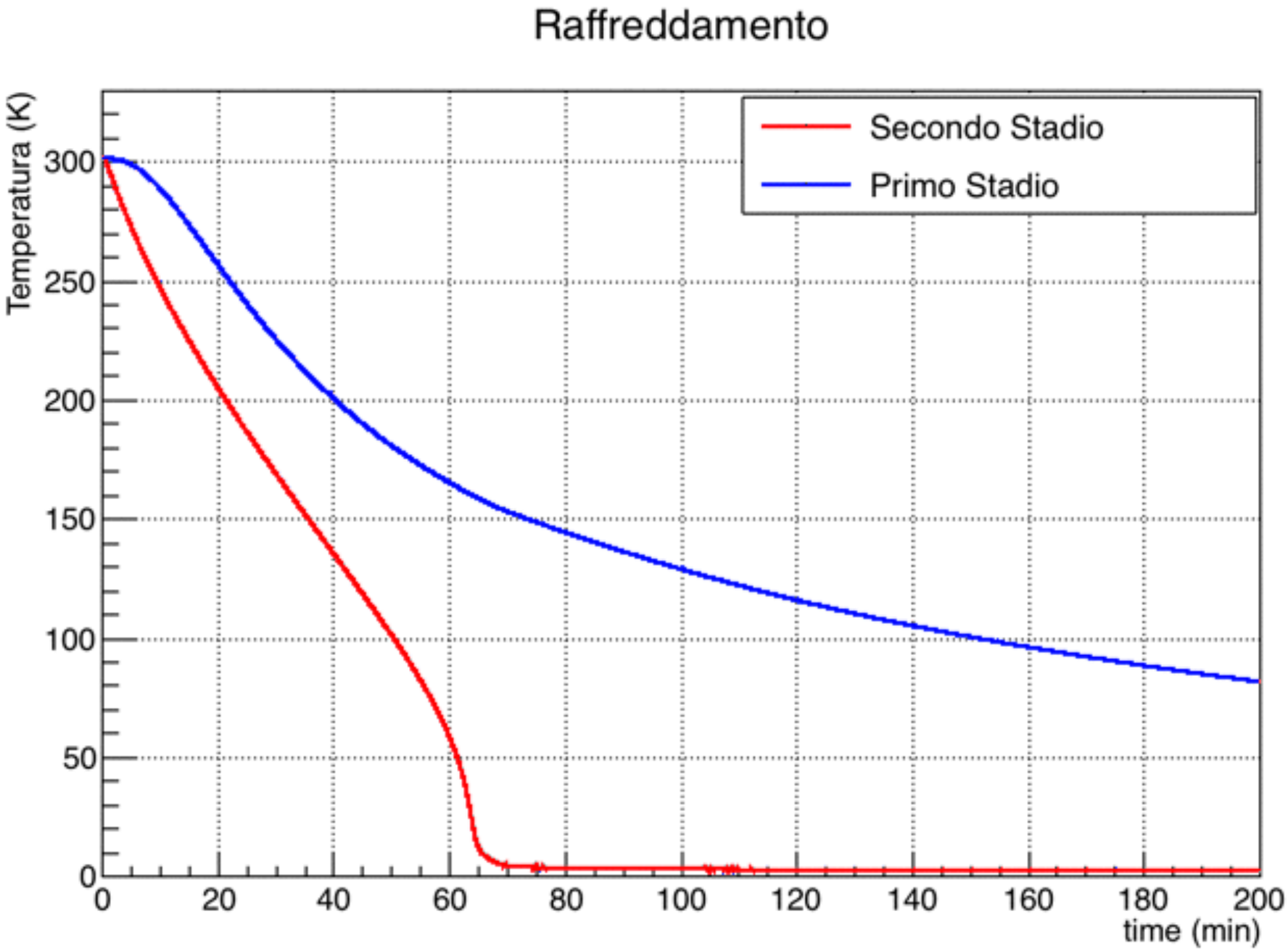
Superinsulation





Facility criogenica

- Primo e secondo stadio funzionanti
  - necessità di auto-provvedere all'acqua di raggraddamento
- Raggiungiamo <4K in 1 ora.

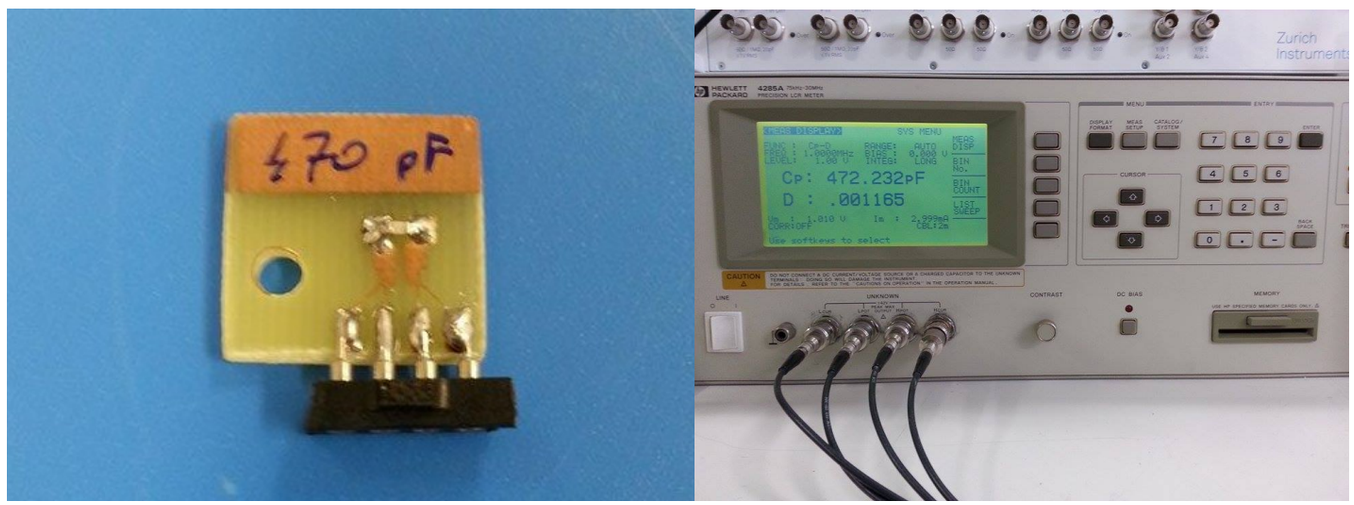


Measurement of SMD capacitors

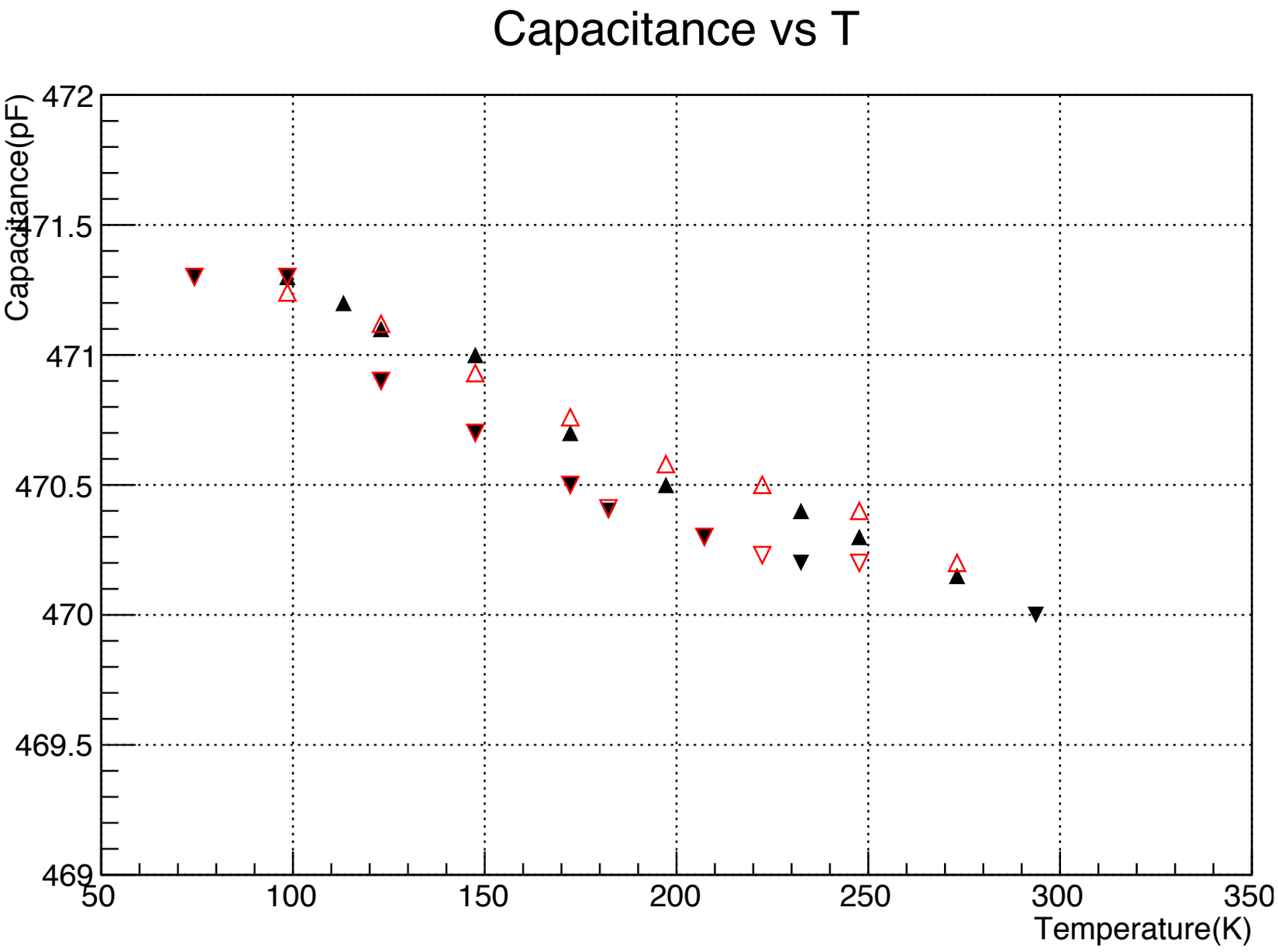
Capacitances must range from $\simeq$ 100 pF to $\simeq$ 20 nF.
Selected C0G/NP0 dielectric:

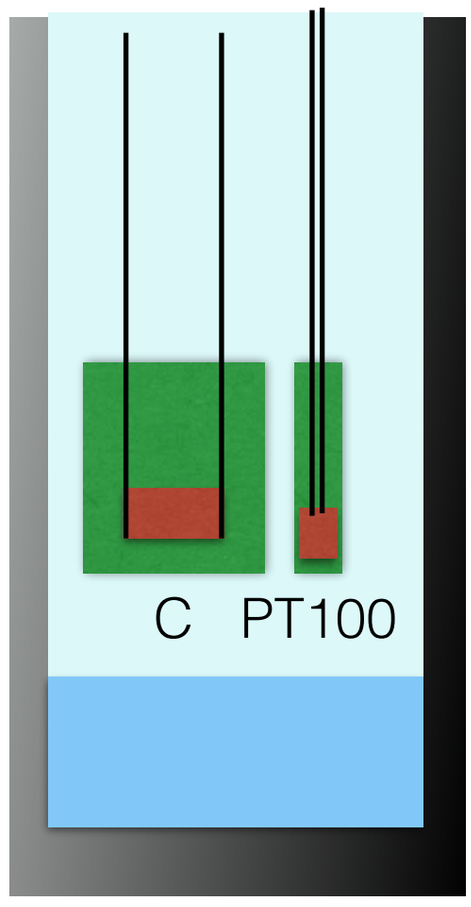
- Ultra Stable
- Negligible dependance of C and DF from t, V, f, T
- DF $\lesssim$ 0.15%

Capacitors tested in liquid N_2.
4-terminal measurements performed using an HP 4285A LRC Meter.



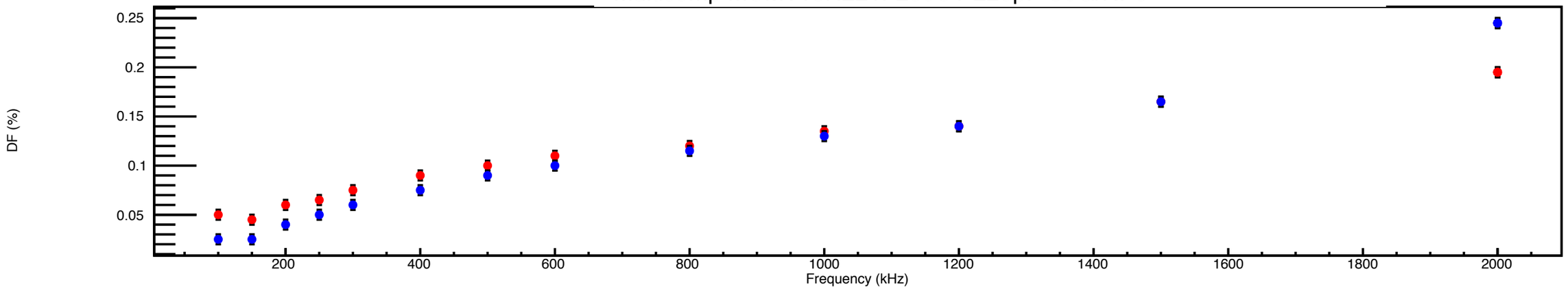
Tested 220pF, 470pF, 1nF, 2.2nF, 7.5nF capacitors.

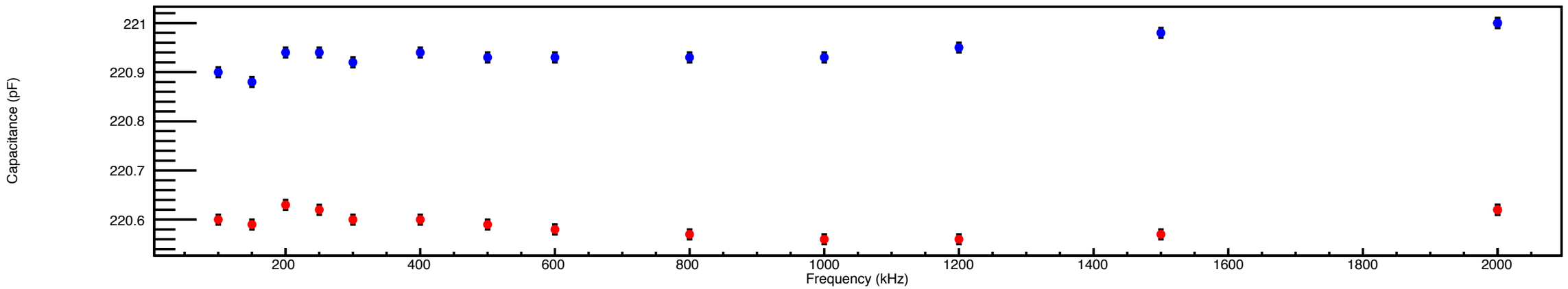


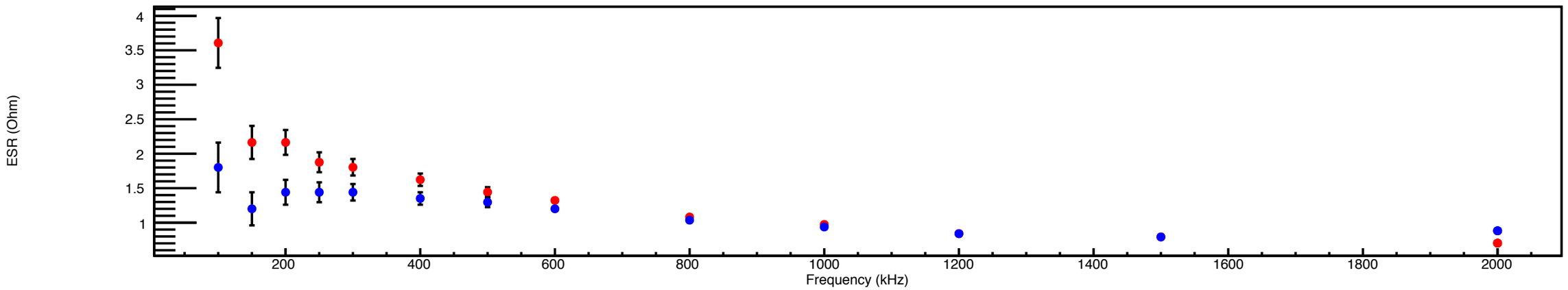


- Hysteresys due to temperature readout
- Condensatori commerciali selezionati per caratteristica

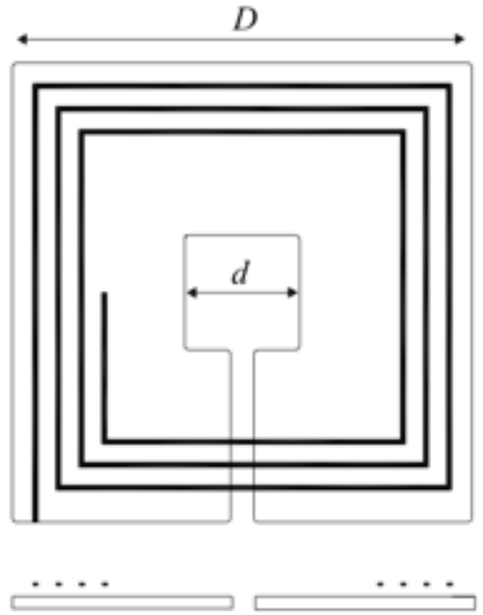
Multicomp MCMT18N221F250CT 220pF C0G/NP0



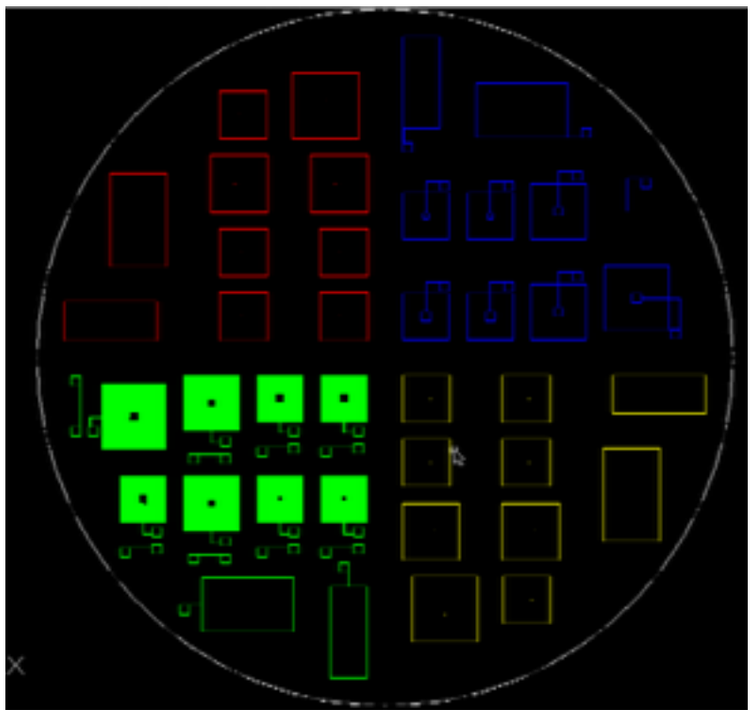


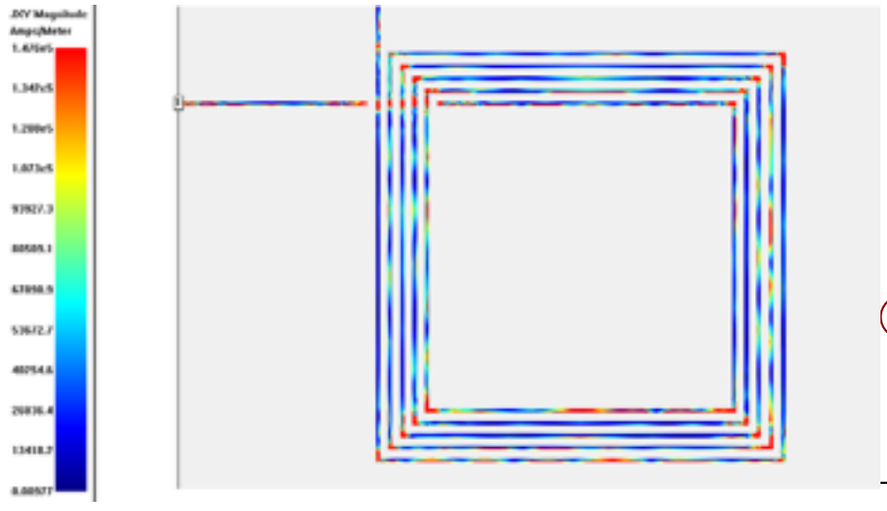


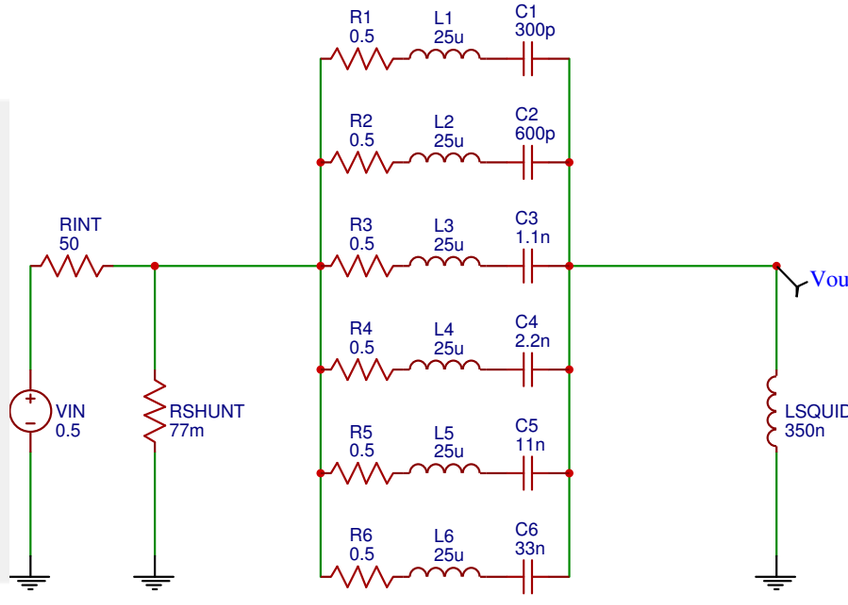
Risuonatori

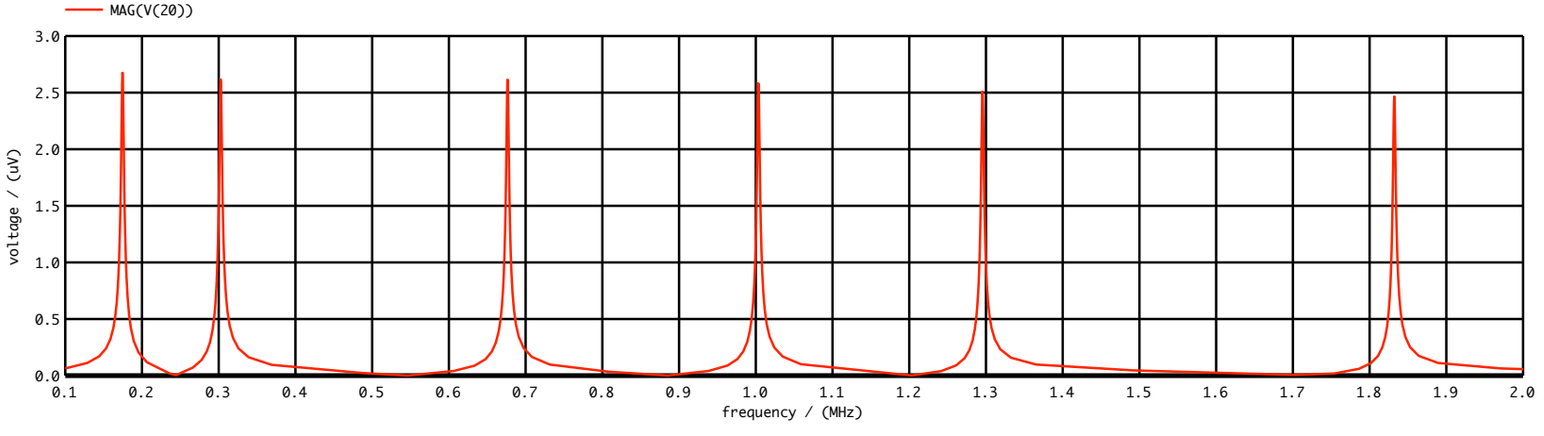


- L litografate a spirale-su-rondella
- L ~ 30 μH → BW ~ 3 kHz @ 1 Ohm
- Disegno della maschera
  - spirale: ~140 giri, 5 μm Nb, pitch 15 μm
  - insulation: SiO (ε=3.5) rondella: Nb, floating
- Possibilità di realizzare Si-rondella-isolamento-spirale o vice versa
- Simulazione - disegno - realizzazione - test



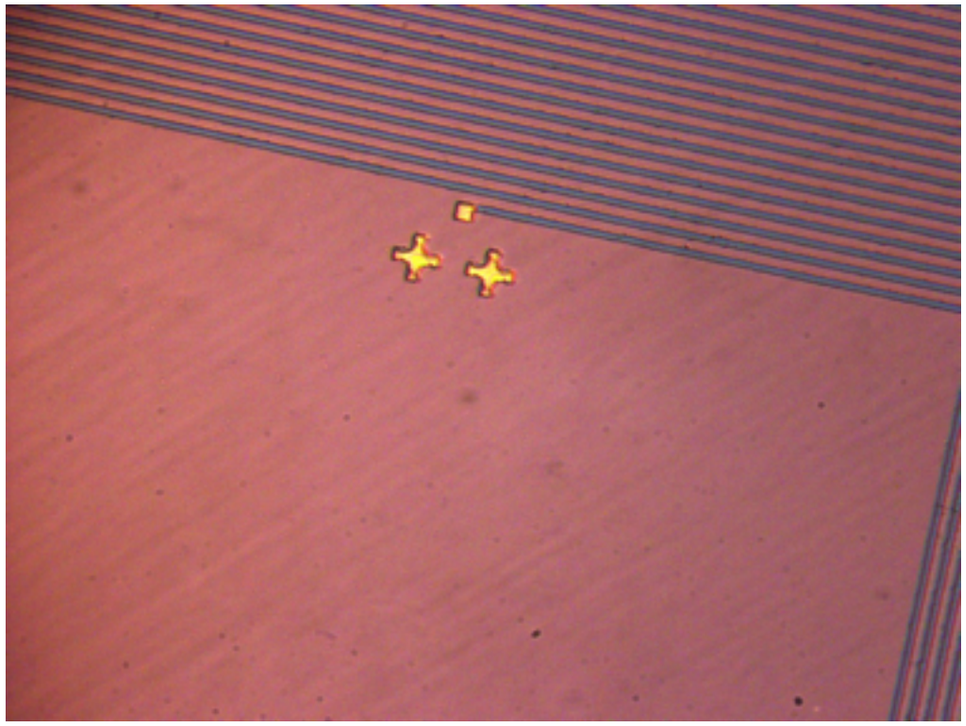


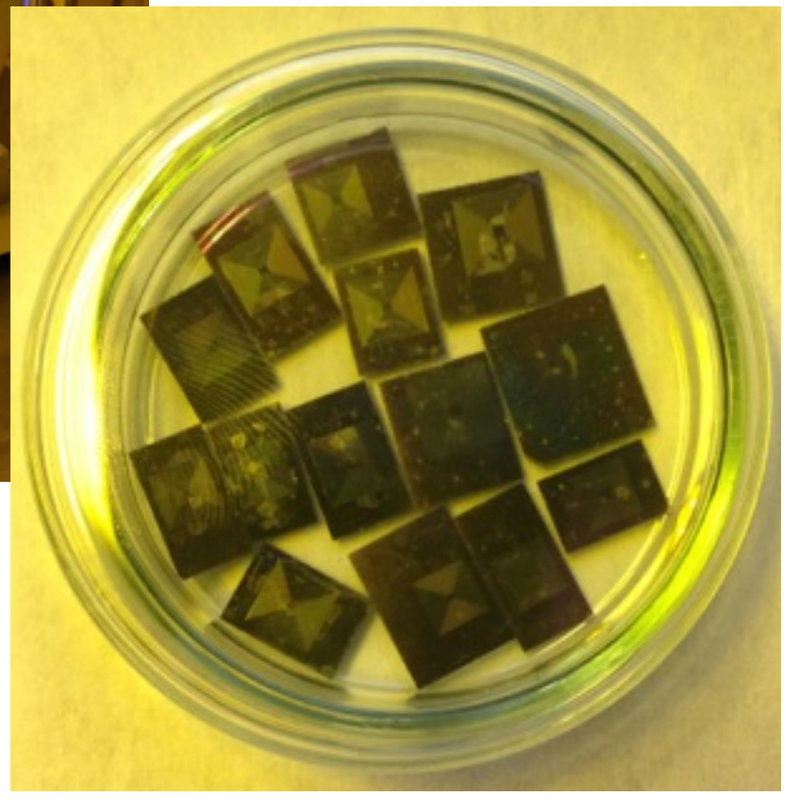


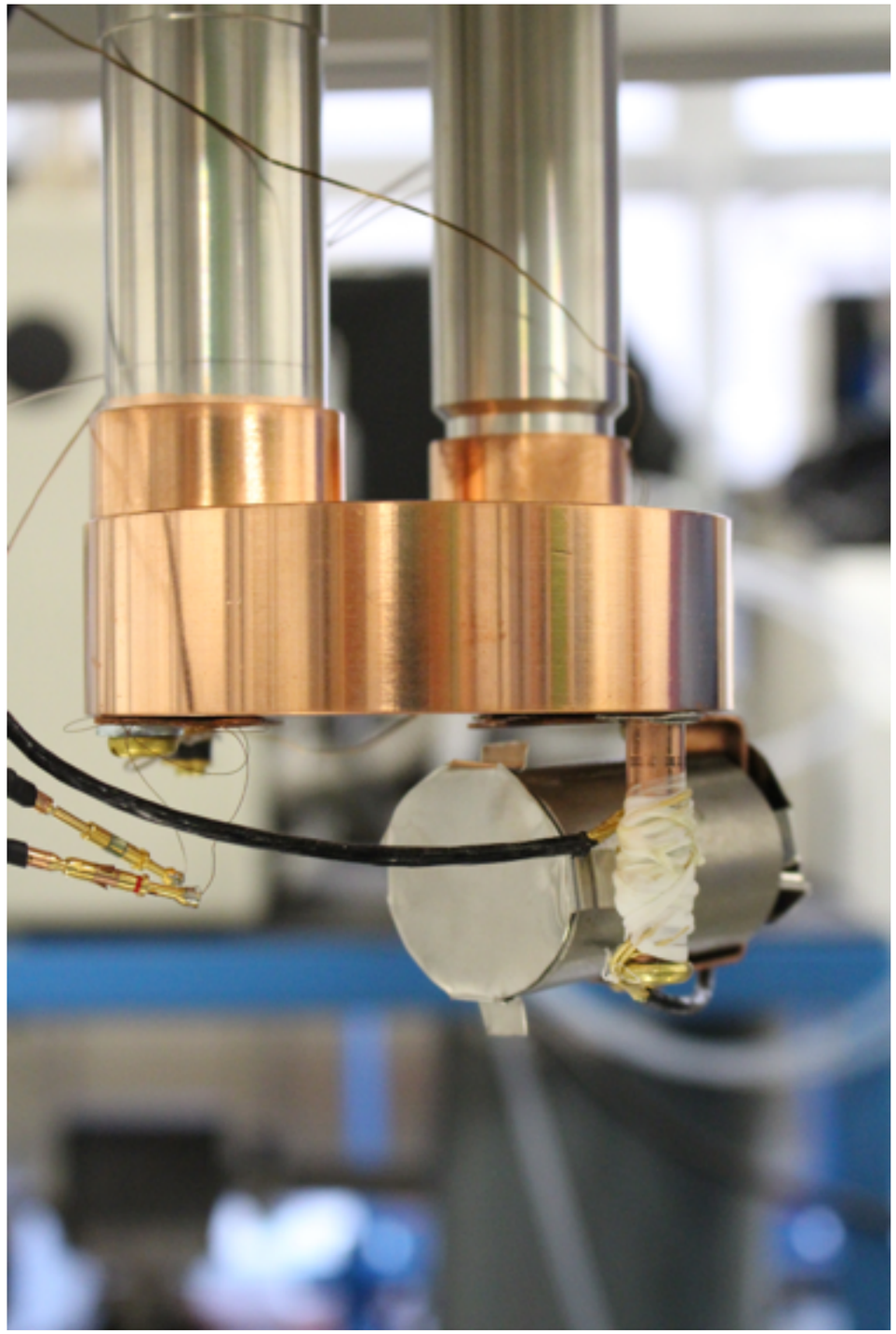


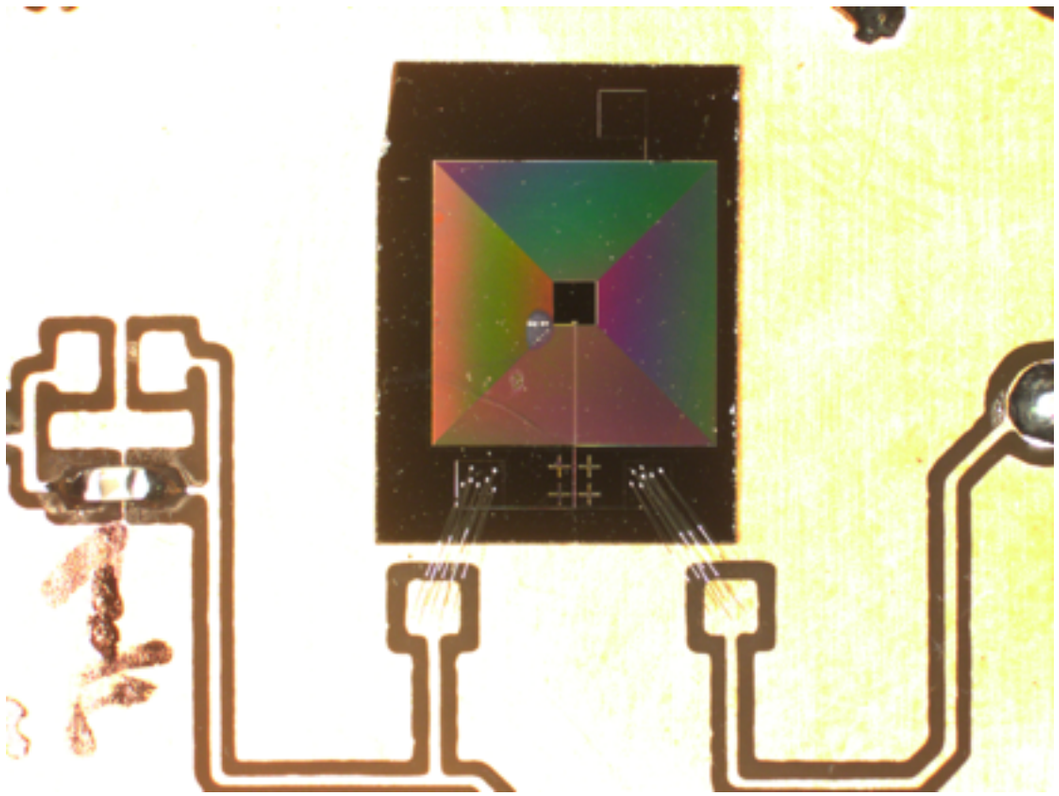
Realizzazione presso INFN Genova

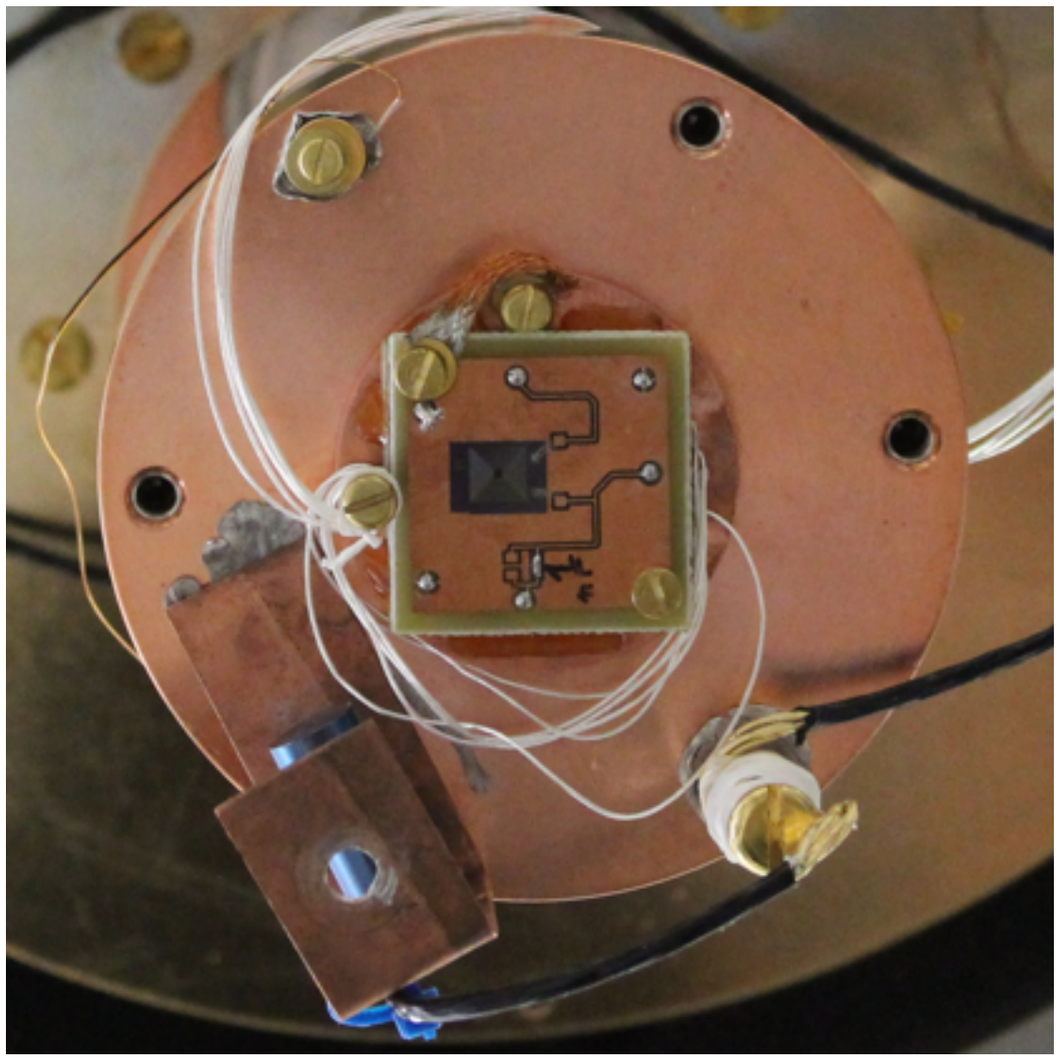
- Davide Vaccaro (laureando)
  - produzione per sputtering di niobio su silicio
- Collaborazione con NEST Pisa











Un grazie particolare ai servizi:

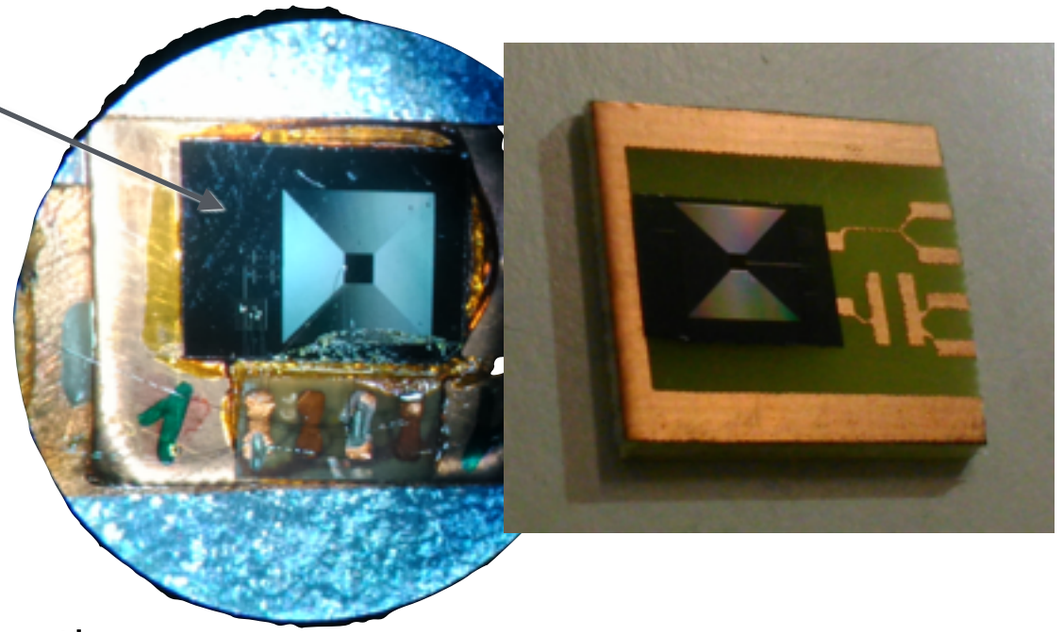
- officina meccanica
- elettronica
- alte tecnologie

Assemblaggio facility e primi test

4K head

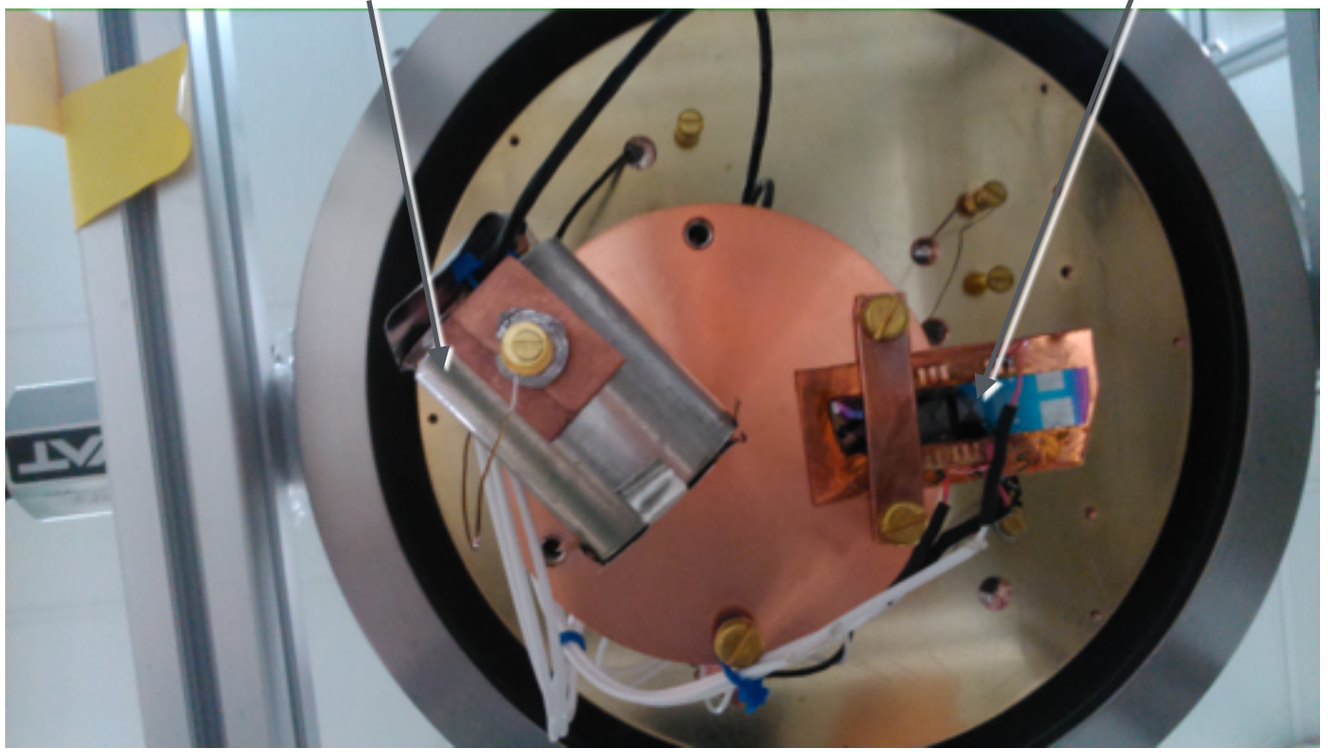
SQUID

Nb square spiral inductance



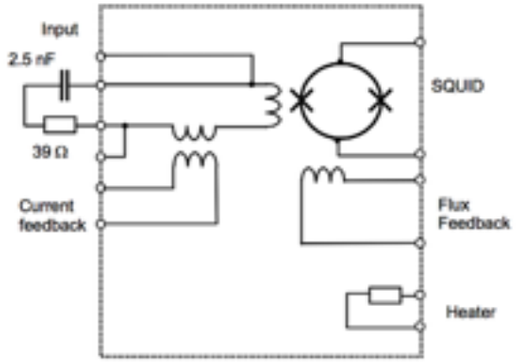
Magnetic screen

LC Chain



Test dello SQUID

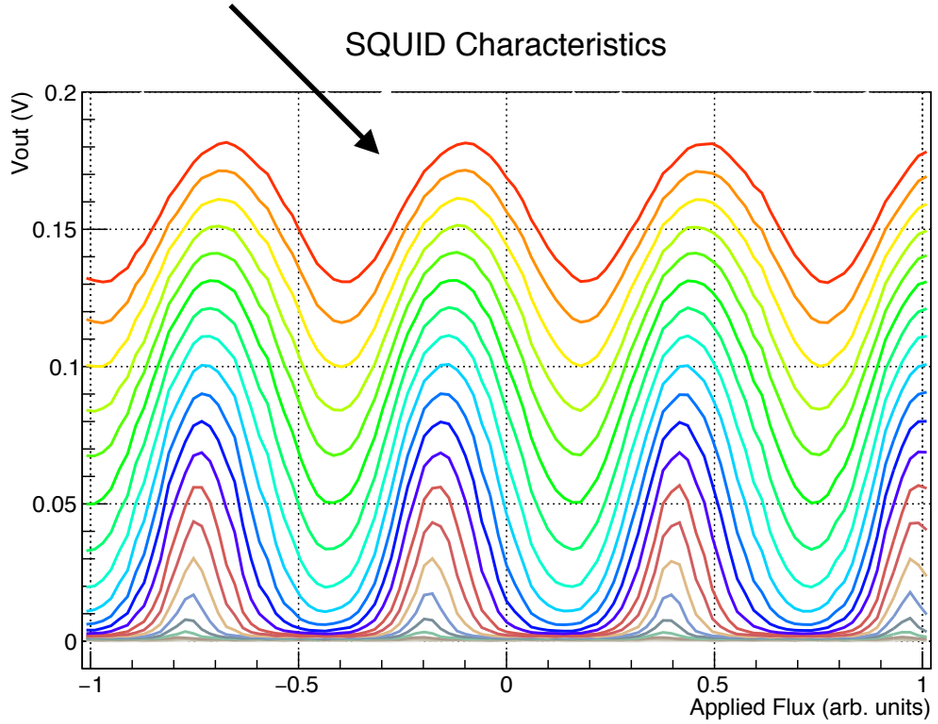
- Superconducting Quantum Interference Device
- SUPRACON CE1-blue



Parameter (open input coil)	Value
Chip size	2.5 mm × 2.5 mm
Working temperature	1...5 K
SQUID-Inductance L_S	≈ 180 pH
Input coil inductance L_{IN}	≈ 160 nH
Input coil – to – SQUID mutual inductance M_{IN}	4.8 nH
Input coupling $1/M_{IN}$	0.44 μA/Φ_0
Flux feedback coil – to – SQUID mutual inductance	80 pH
Flux feedback coupling	26 μA/Φ_0
Current feedback coil – to – input coil mutual inductance	4.2 nH
Current feedback coupling with short on the input coil	18 μA/Φ_0

- Transimp. 400 V/A (mis. 120)
- typical noise 1.5 pA/sqrt(Hz)

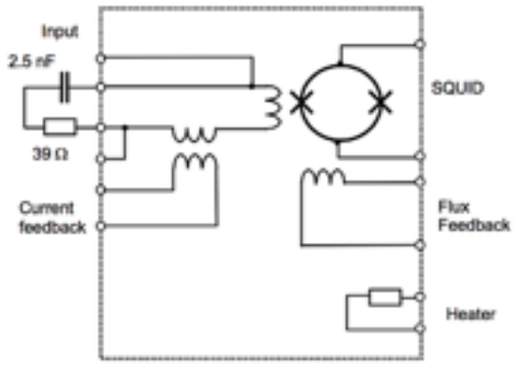
Nostre misure sperimentali



- Estremamente sensibile a noise e campi magnetici
  - Essenziale averne dimostrato il funzionamento
- Misure di banda, noise etc in corso.

Test dello SQUID

- Superconducting Quantum Interference Device
- SUPRACON CE1-blue



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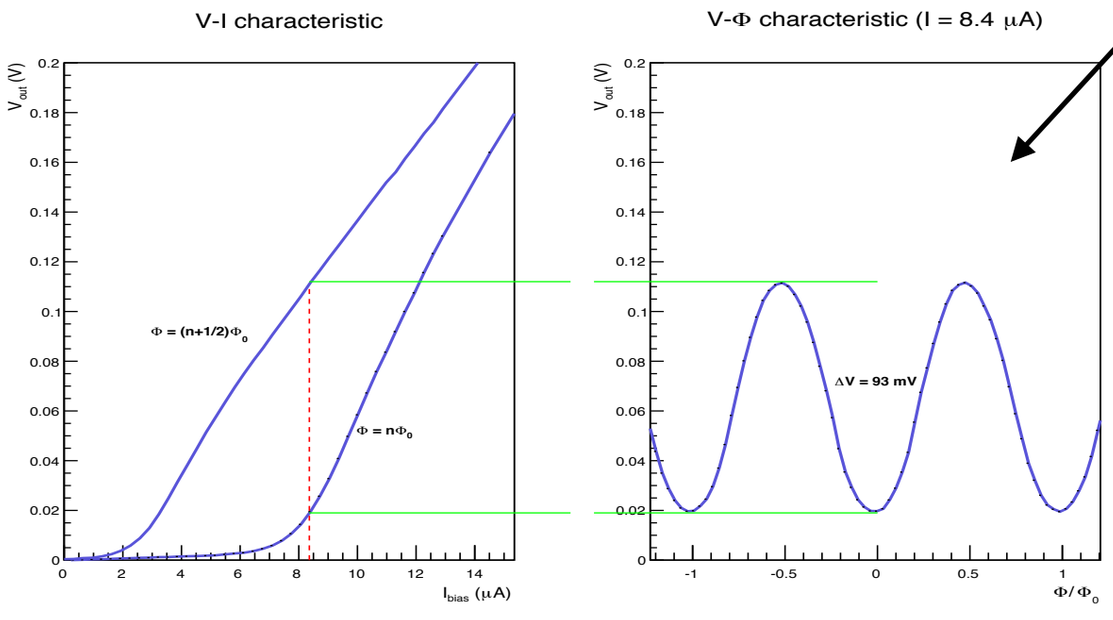
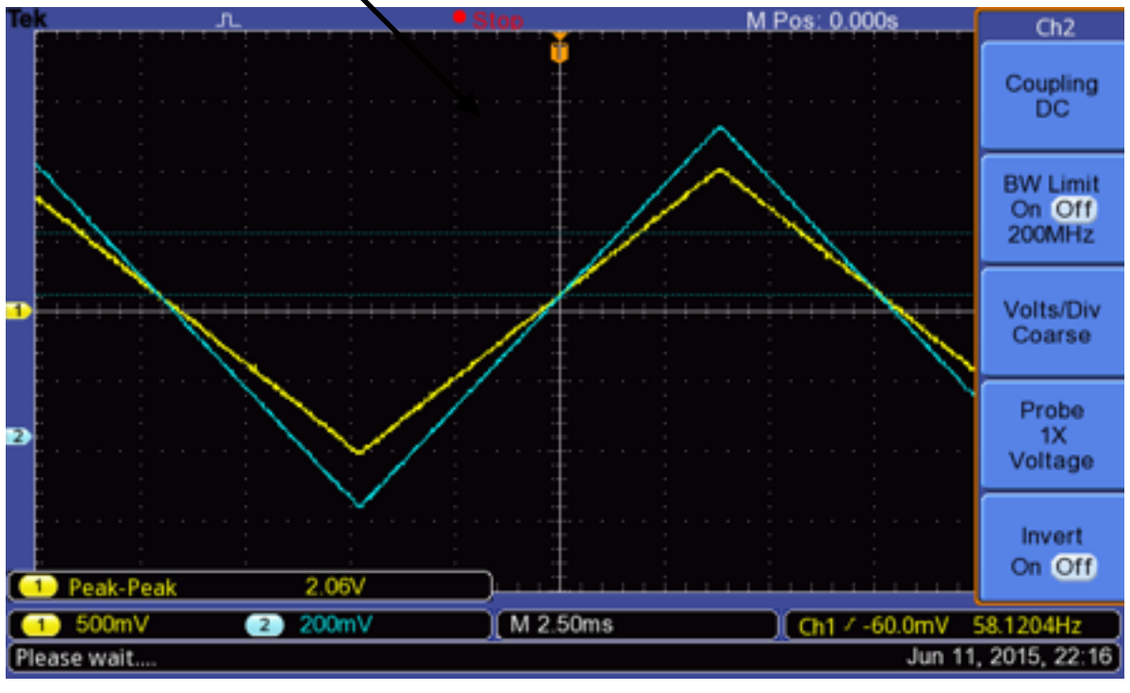
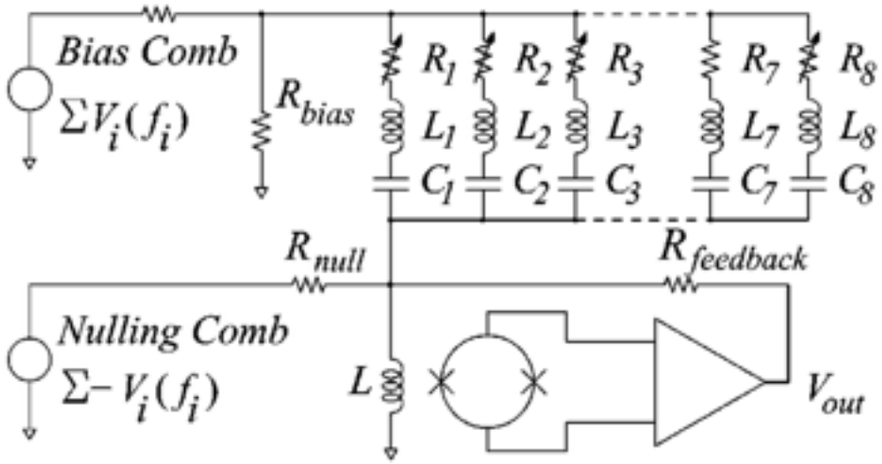


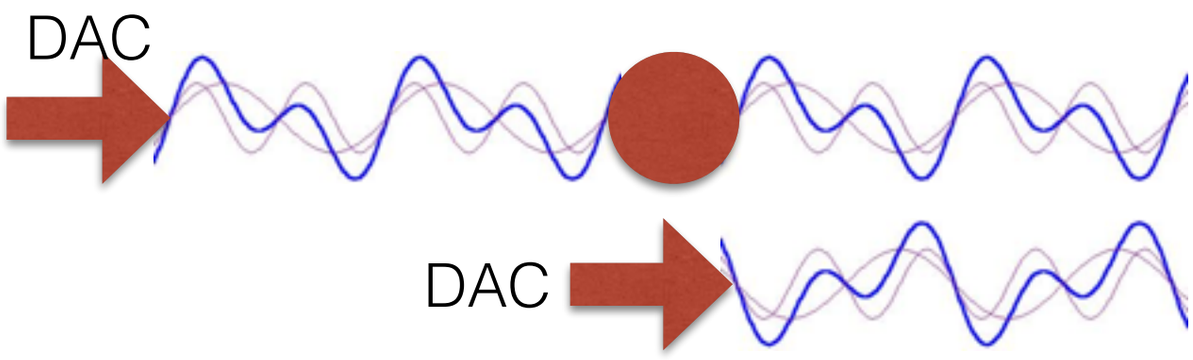


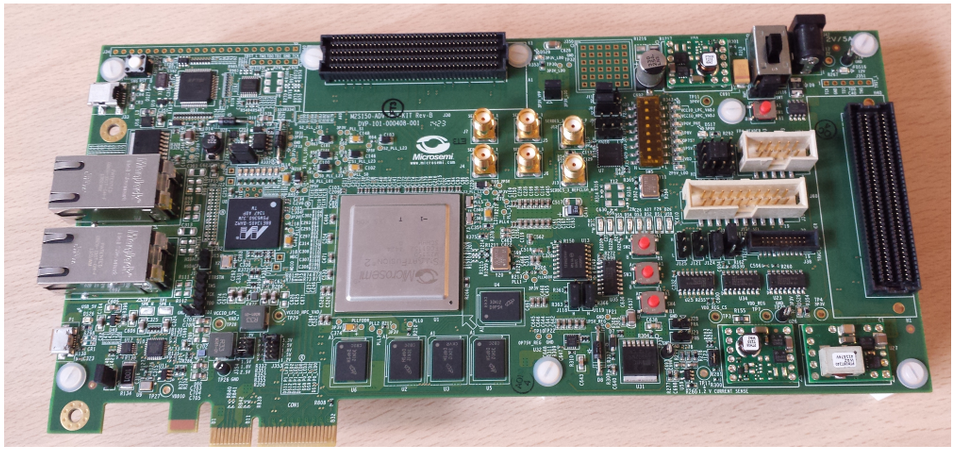
- Estremamente sensibile a noise e campi magnetici
  - Essenziale averne dimostrato il funzionamento
- Misure di banda, noise etc in corso.

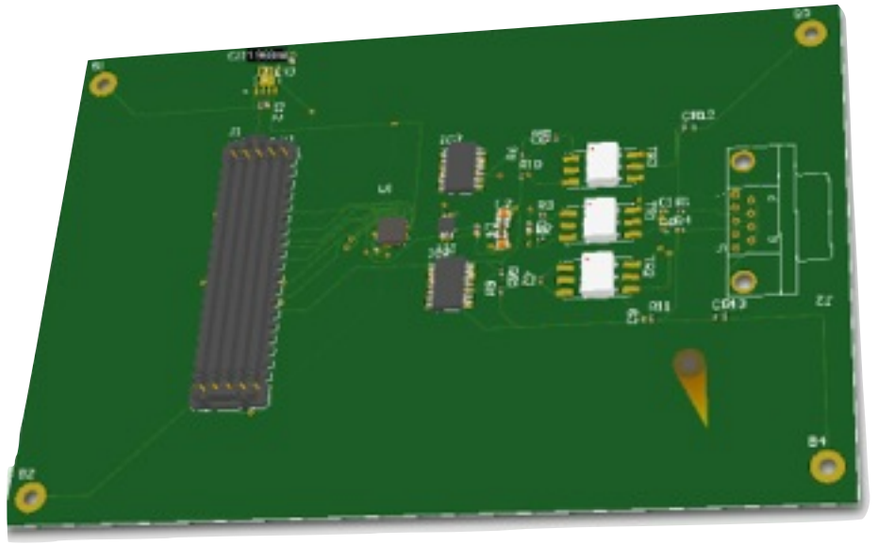
Scheda di sviluppo SMART FUSION2

- Scheda di sviluppo SMART FUSION2
- Progetto di un mezzanino con ADC + 2 DAC (bias + nulling)
  - Componenti selezionati
    - DAC LT668
    - ADC AD9266-20 (-40 -65 -80, bw)
  - In fase di produzione
- Misura con rete RLC in facility criogenica





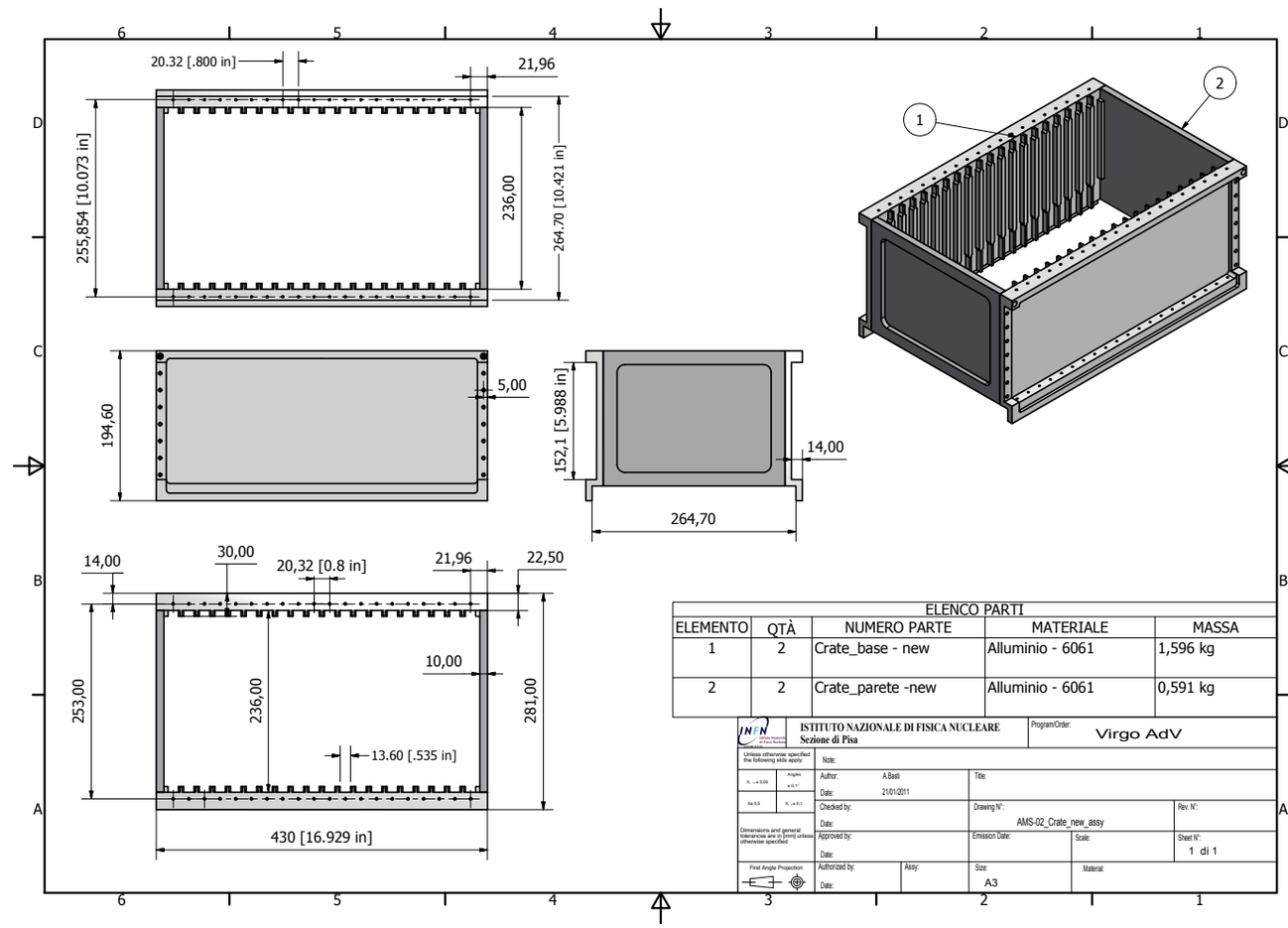




F. Spinella, resp. WG FDM

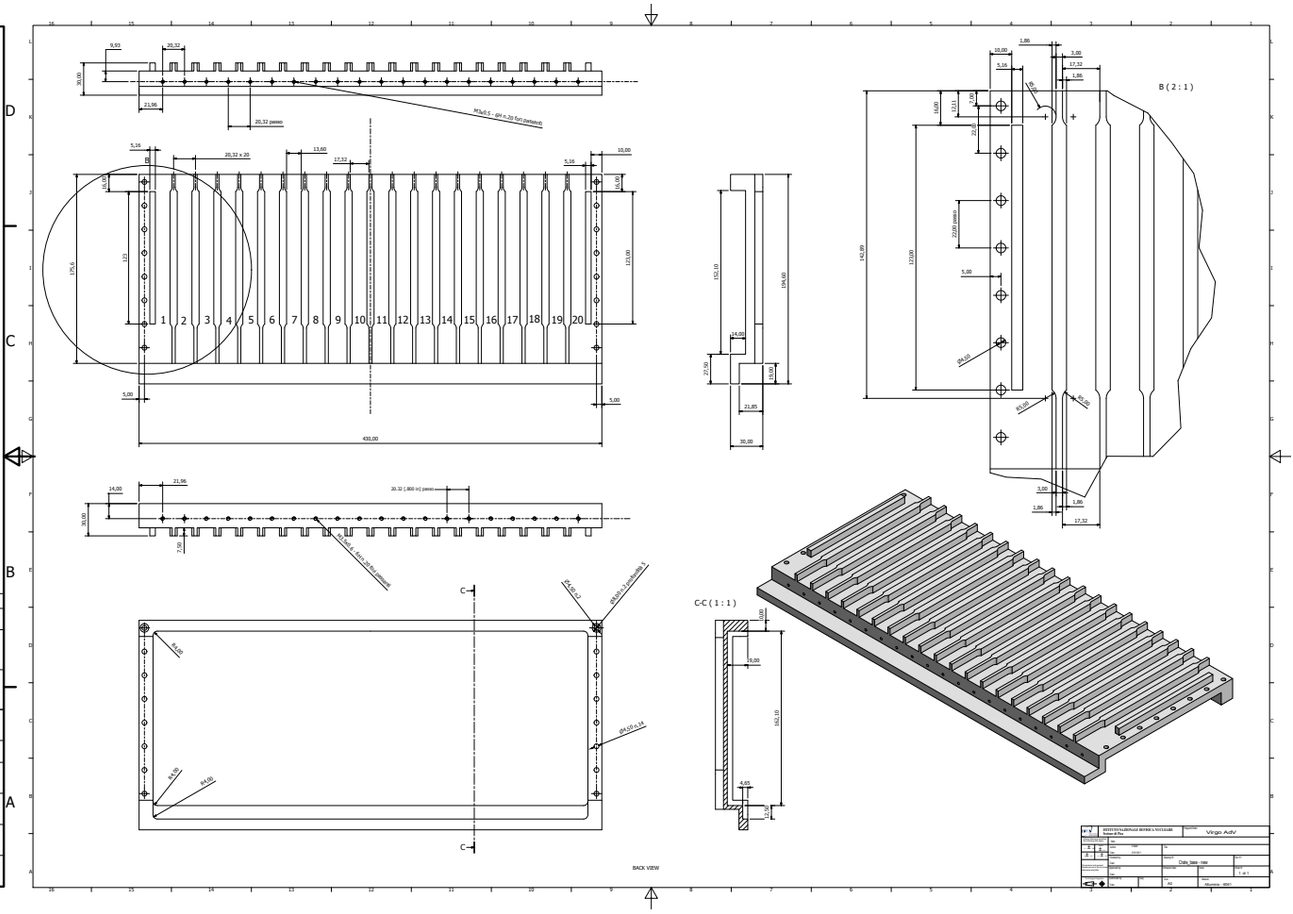
Meccanica per elettronica

- vernice riflettente per limitare il riscaldamente dovuto alla radiazione solare
- assenza di spigoli
- struttura modulare
- termalizzazione delle schede attraverso un piano di massa non connesso elettricamente
- termalizzazione del crate attraverso *card-loks* (prossima slide) montati sulla scheda
- peso limitato (4.8kg per 11 schede)



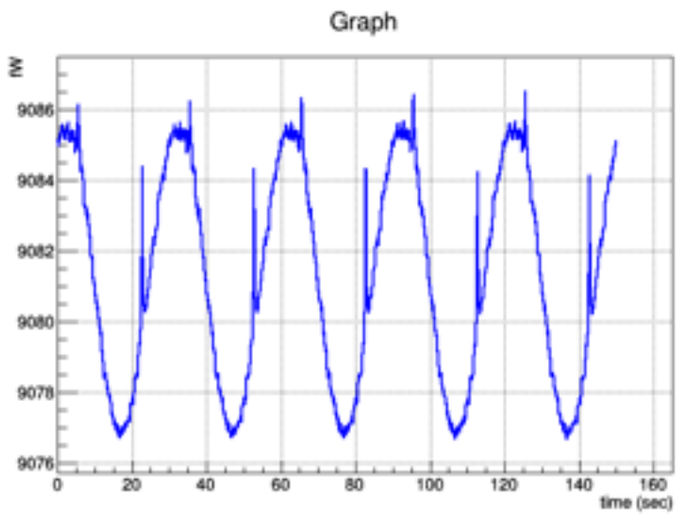
ELENCO PARTI				
ELEMENTO	QTÀ	NUMERO PARTE	MATERIALE	MASSA
1	2	Crate_base - new	Alluminio - 6061	1,596 kg
2	2	Crate_parete -new	Alluminio - 6061	0,591 kg

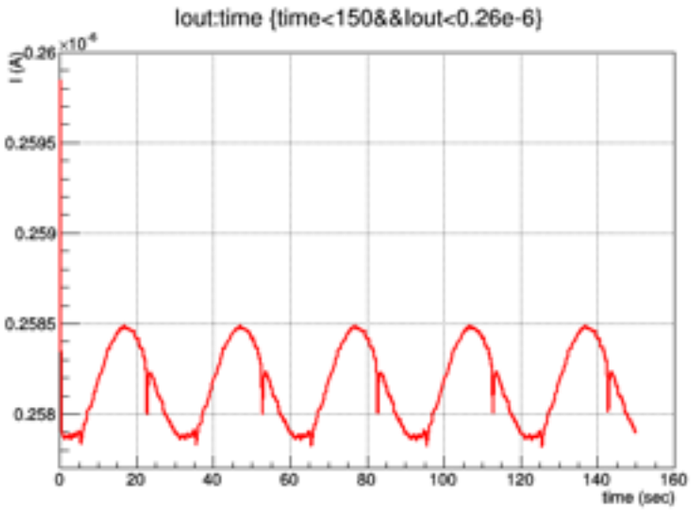
ISTITUTO NAZIONALE DI FISICA NUCLEARE Sezione di Pisa		Program/Order: Virgo AdV	
Unless otherwise specified the following aplly	Note:		
	Author: A.Basti	Title:	
	Date: 21/01/2011		
	Checked by:	Drawing N°: AMS-02_Crate_new_assy	Rev. N°:
	Date:		
Dimensions and general tolerances are in [mm] unless otherwise specified	Approved by:	Emission Date:	Scale: Sheet N°: 1 di 1
	Date:		
First Angle Projection	Authorized by:	Assy: Size: A3	Material:
	Date:		

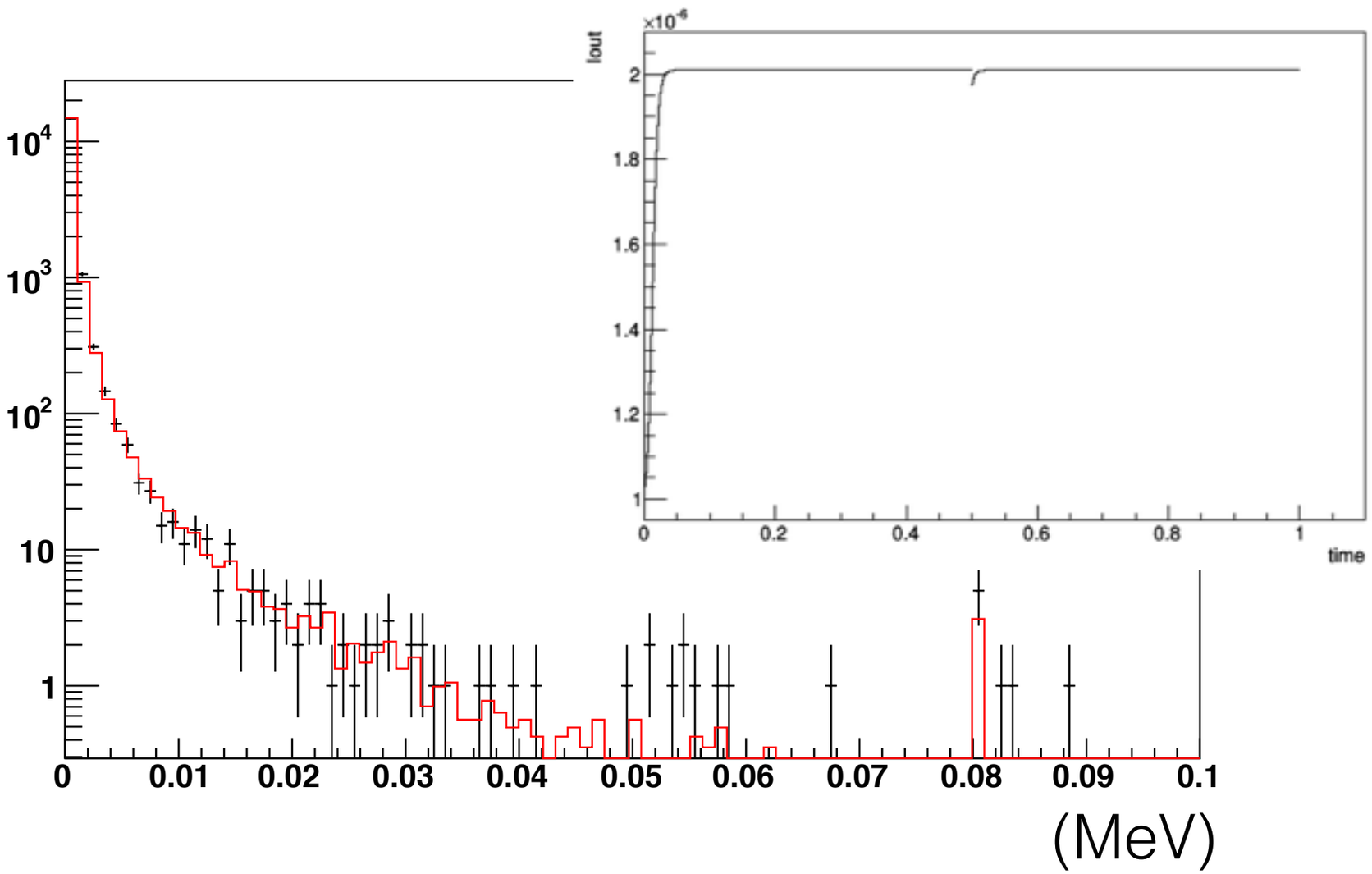


Effetto dei cosmici sui bolometri

- I CR hanno tre effetti principali
  1. accecare il bolometro per un tempo ~ 5τ
  2. modificare la distribuzione del noise (se non riconosciuti) e quindi l'estrazione del segnale
  3. single-event effects sull'elettronica, single event latch-up (distruttivi) oppure single event upset (memory bits, non distruttivi)







Attività di Pisa per il 2015

- Inizialmente prevista la produzione e l'assemblaggio in vista del volo a fine 2015
- Sposteremo la produzione al 2016
- Upgrade ulteriore della facility a 350 mK
- Definizione dell'elettronica di readout e stesura preliminare degli algoritmi firmware/software
- Definizione dei circuiti risonanti LC e finalizzazione del piano focale
- Finalizzazione del progetto termico della meccanica per la warm electronics

Attività previste per il 2016

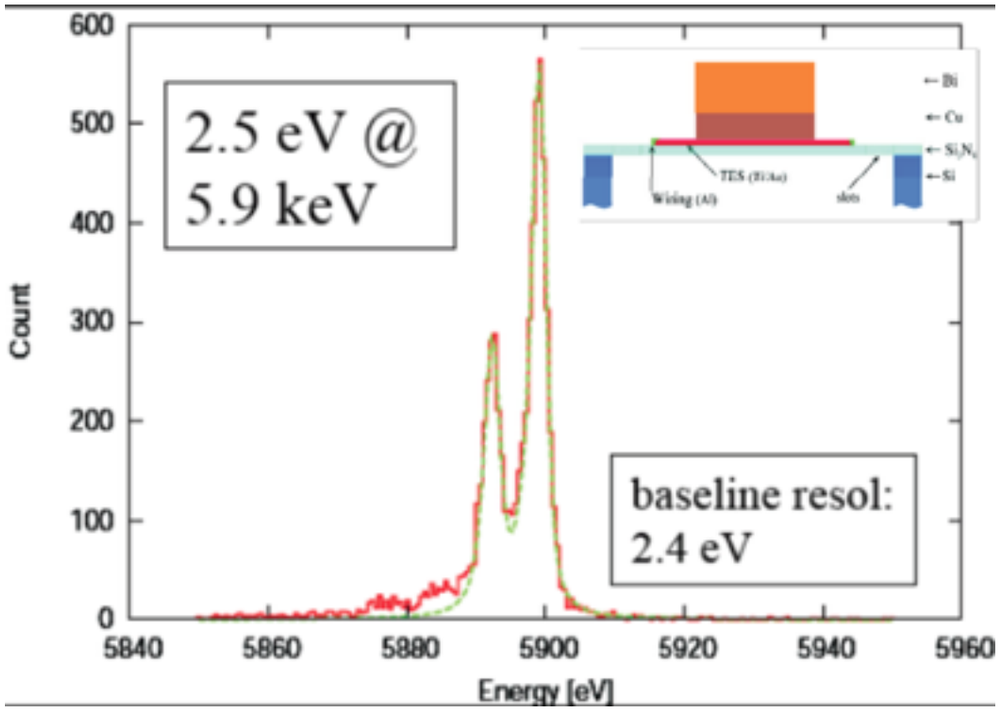
- Produzione dell'elettronica analogica/digitale di controllo, lettura dei ~330 bolometri
- Produzione e test dei risuonatori LC
- Test dei rivelatori criogenici nella configurazione finale
- Assemblaggio del rivelatore (fine estate - autunno)
- Preparazione per il volo (dicembre 2016 - gennaio 2017)
- Sforzo sul map making, simulation e data analysis.

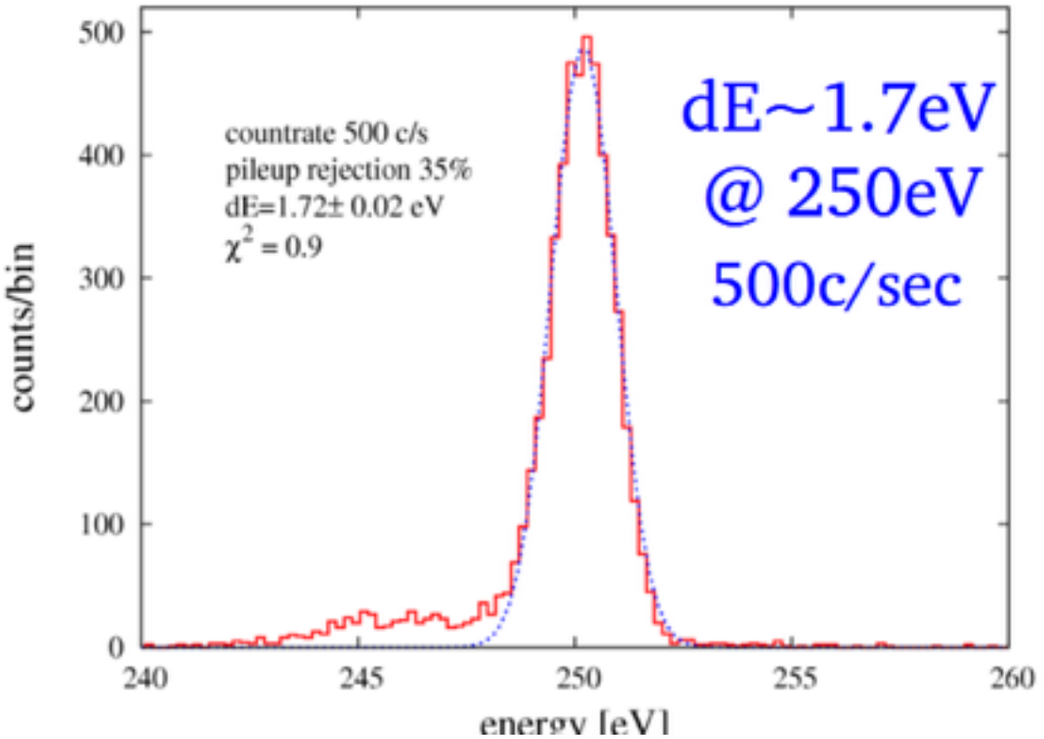
Anagrafica per il 2016

RICERCATORI		
Giovanni Signorelli	R.Loc.	0.7
Alessandro Baldini		0.3
Marco Grassi		0.3
Donato Nicolò		0.25
Fabrizio Cei		0.3
Carlo Bemporad		0
Marco Incagli		0.3
TECNOLOGI		
Franco Spinella		0.25
Ingegnere Meccanico		0.30
TOTALE	FTE	2.7
ALTRI SERVIZI		
Officina meccanica		2 m.u
Sevizio alte tecnologie		0.5 m.u
LAURENDI		
Davide Vaccaro		

Alcuni commenti

- Molta “nuova fisica”
  - Cosmologia - inflazione - CMB
  - Nuovi rivelatori di ultimissima generazione
    - superconduttività
  - Elettronica ultra-fredda e ultra-low noise
  - Preparazione delle mappe
  - Analisi dati
  - …





Richieste 2016

- Dal prospetto di budget 2014
  - 15.0 k€ calcolo
  - 5.0 k€ test prototipi per satellite – consumo
- Re-itero la richiesta per lo stadio a 350 mK
  - 40.0 k€ c.app.
- Missioni (Svalbard + Italia)
  - 22.0 k€ + 12.0 k€

- Con il gentlemen agreement che anticipo lo stadio 350mK a quest'anno e postponiamo 40k€ di costruzione al 2016

- Ricordo che sugli anticipi al 2014 ci hanno tagliato molto e ci siamo dovuti arrangiare con 50k€ per pulse tube + compressore+ chiller + criostato….!!

- Tutte le voci che abbiamo quotato sono assolutamente necessarie a garantire la veloce ed efficiente preparazione dell'elettronica di lettura.

CHASE RESEARCH CRYOGENICS LTD.
WORLD LEADERS IN SUB-KELVIN CRYOGENICS
'UPLANDS', 140 Manchester Road, Sheffield S10 5DL
Tel. & Fax: +44 (0) 114 268 0672
Registered No: 4643351
VAT registration No. GB 763 8558 84

QUOTATION

Attn: Dr. Giovanni Signorelli, PhD
INFN Sezione di Pisa
Largo B. Pontecorvo 3, Edif. C
I-56127 Pisa
ITALY.

Date: 1st July 2015

Quote # CRC010715

For the provision of a 'GL-7' type cryogenic cooler.

Specifications:
Cold stage base temperature T < 280mK.
^{3}He cold stage heat lift: approx. 3μW @ T < 290mK.
Buffer stage heat lift: approx. 150μW @ T < 1K.
Hold time: approx. 8 to 10 hours continuously.
Cycle time (4K to 300mK): approx. 1 to 1.5 hours.
Will run from a ^{4}He cold plate or GM mechanical cooler (with at least 500mW of cooling power at 4K).

Additional features:
RuO_2 thermometers fitted to cold heads.
Diode thermometry to pumps and heat switches supplied by Chase Research.
All wiring carried to an MDM micro-D connector, mounted on unit.

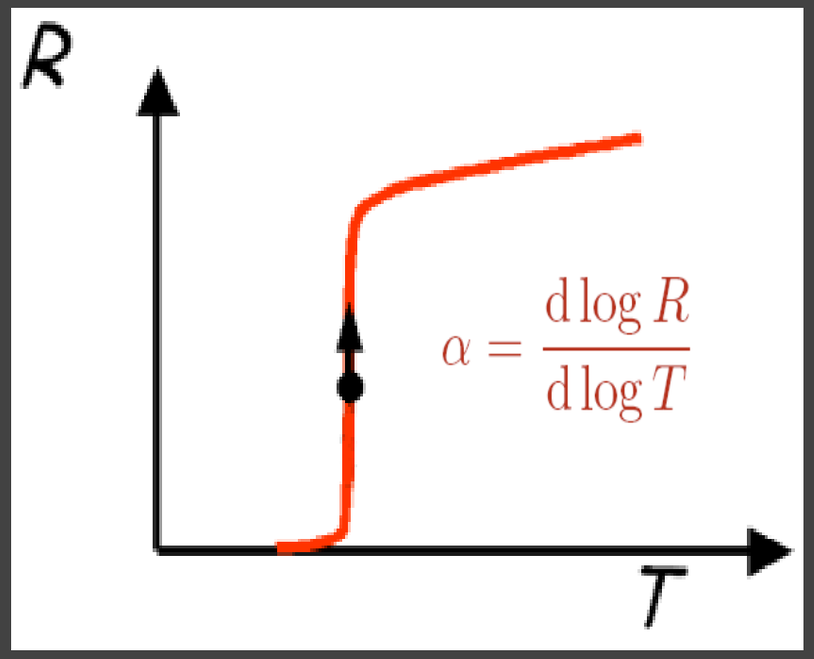
Description	**Unit Price**	**Quantity**	**Total cost**
'GL-7' type cryocooler, excluding ^{3}He gas.	€24,000.00	1 off	€24,000.00
^{3}He gas in ^{3}He cold stage, per STP litre.	€3,000.00	1 litre	€3,000.00
RuO_2 Thermometer supplied by CRC	No Charge	2 off	No Charge
Shipping charge	€500.00	1 off	€500.00
Total price including He3 and thermometers			**€27,500.00**

This quotation is valid until 30th August 2015. Delivery should be around 4 to 6 months from receipt of an order.
Shipping and insurance costs will be added.
Payment in full will become due 30 days after delivery.
Please advise us of your shipping agent's details.

I hope you find this to be satisfactory.

Dr. S.T. Chase. (Director)

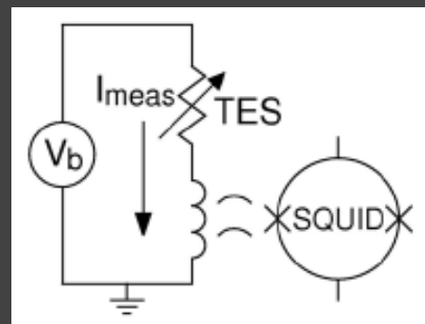
Superconducting Transition Edge Sensors



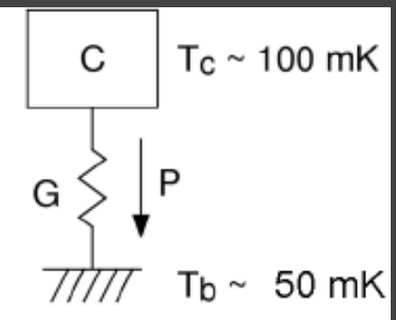
Thin film superconducting bilayer:

Ti/Au
Mo/Au
Mo/Cu

Electrical circuit



Thermal circuit



- **Electro-thermal feedback**
- Heat input from photons:

  → TES temperature and resistance **up**

  → Joule power **down**

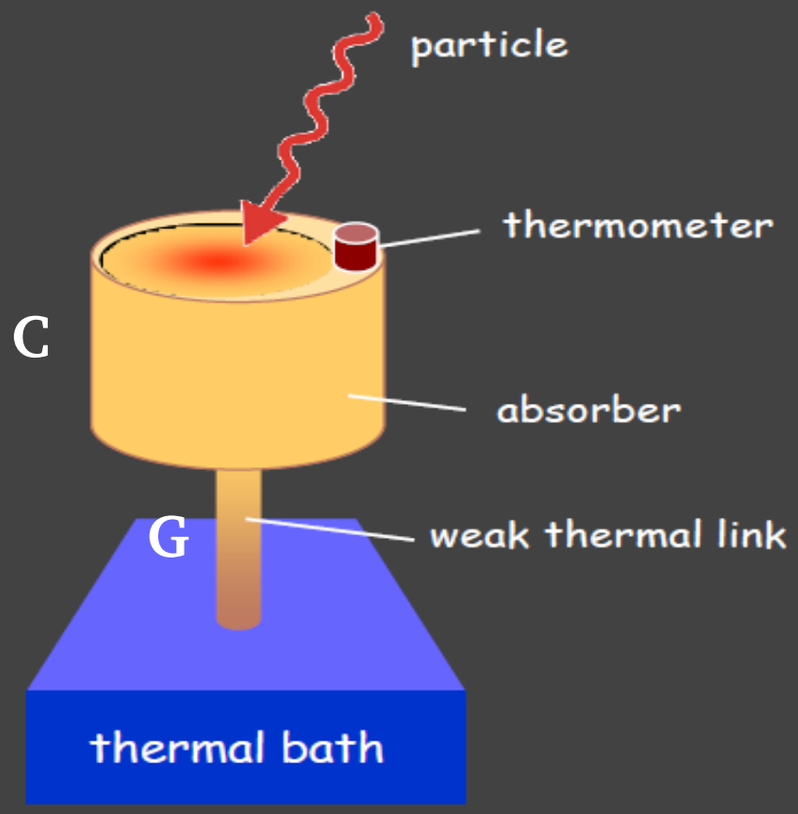
  → fast recovery
- self biasing in the transition

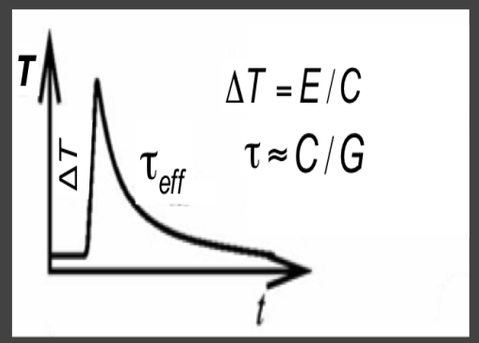
K. D. Irwin, Appl. Phys. Lett. 66, 1945 (1995)

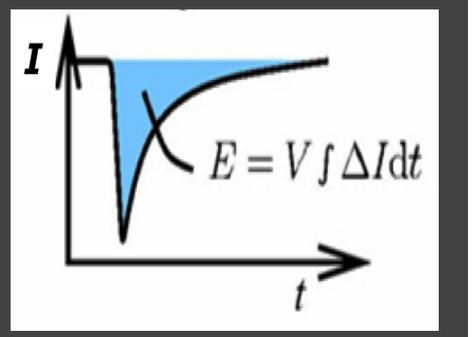
SRON X-IFU

TES micro-calorimeters

Single photon detector







Energy resolution:

$$E_{FWHM} \sim 2.355\sqrt{\frac{4k_B T_c^2 C}{\alpha}}$$

- Low temperature detector Tc~100mK
- Sharp transition α~10-500
- Small pixels, low C absorbers
- Limited dynamic range: $E_{lin} \propto C/\alpha$

SRON X-IFU