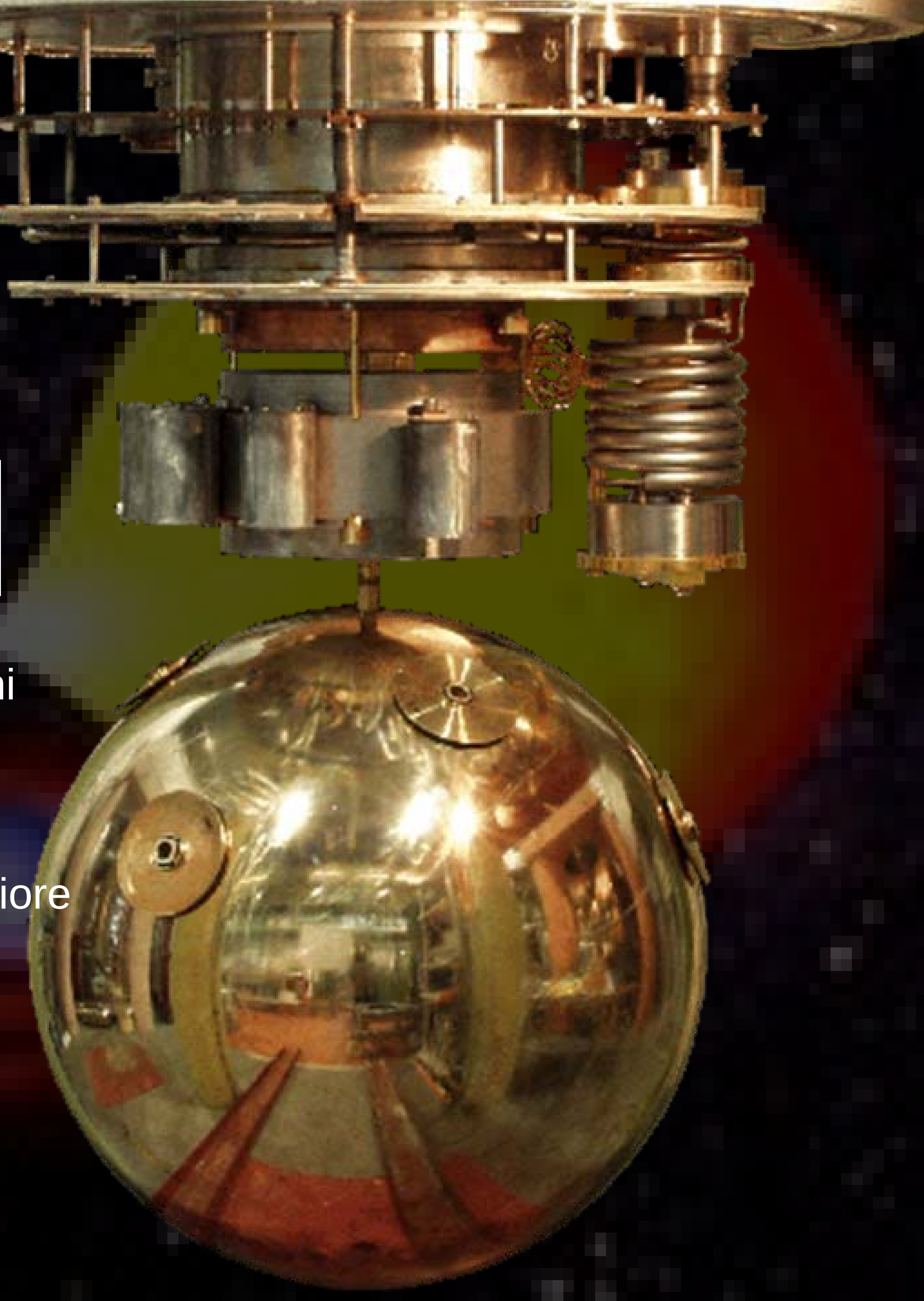


Overview and status of MiniGRAIL

Universiteit Leiden

Giorgio Frossati
Arlette de Waard
Sasha Usenko

UNIVERSITÉ DE GENÈVE

Dr. Stefano Foffa
Dr. Riccardo Sturani
Filipe Da Silva

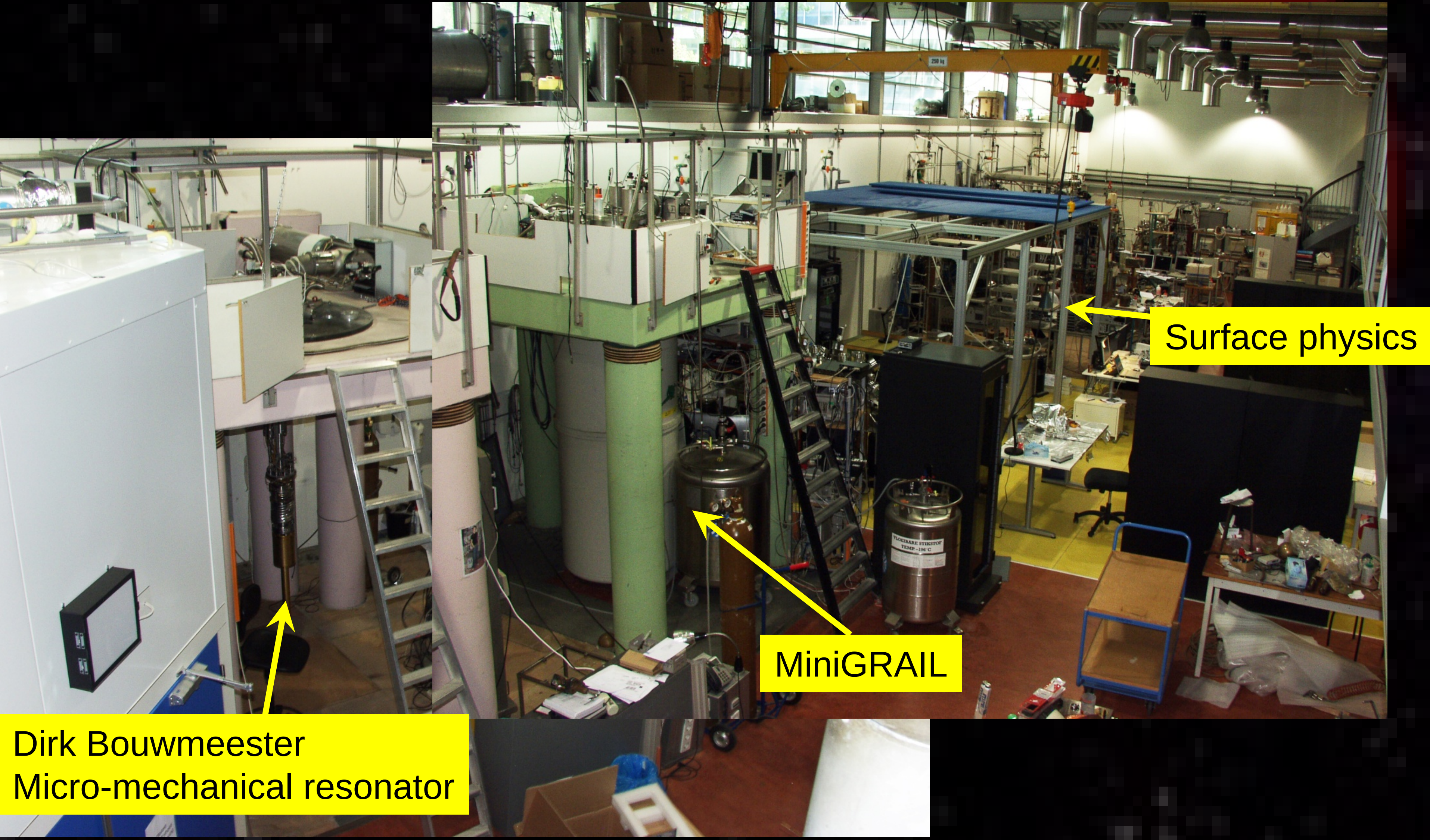
group of
Prof. Michele Maggiore
Prof. Martin Pohl

Kamerlingh Onnes Laboratory
Ultra-low temperature division

MiniGRAIL cryostat

Kamerlingh Onnes Laboratory now

Main research: surface physics



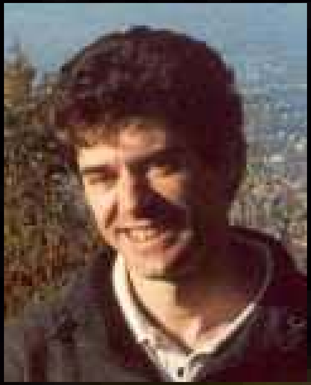
Surface physics

MiniGRAIL

Dirk Bouwmeester
Micro-mechanical resonator

New possibilities for MiniGRAIL: collaboration with Bouwmeester and Oosterkamp

Giorgio Frossati



Michele Maggiore

Dirk Bouwmeester

Tjerk Oosterkamp

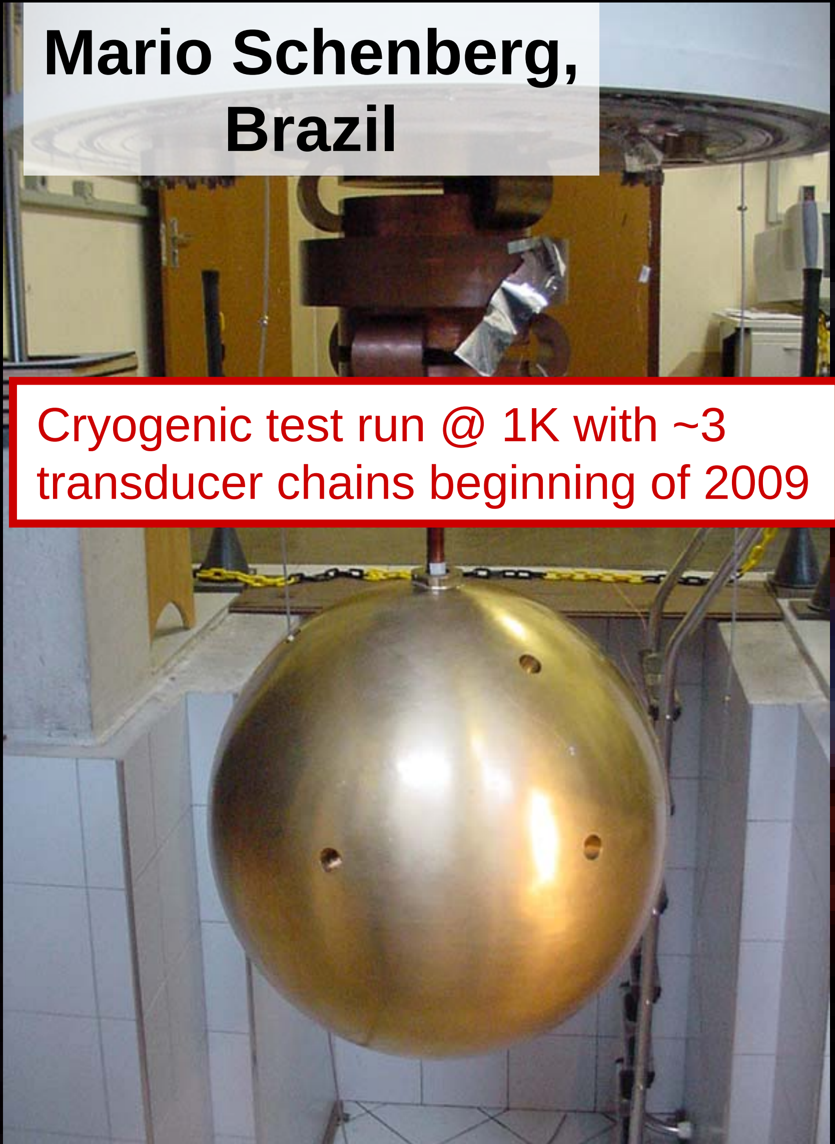
1 PostDoc + Helium

1 PostDoc + Helium

1 PhD + Helium

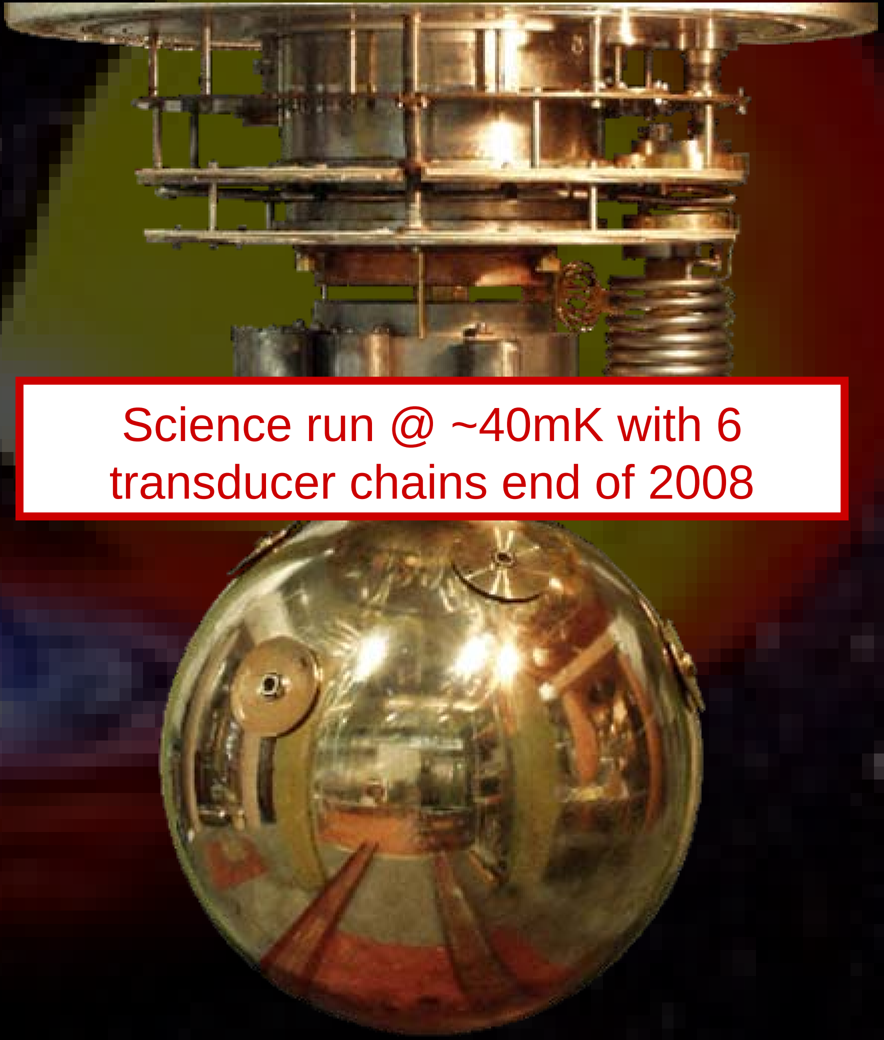
⇒ At least 1 year of data taking possible in 2009 !!

Expectations Spherical Detectors 2009



Mario Schenberg, Brazil

Cryogenic test run @ 1K with ~3 transducer chains beginning of 2009

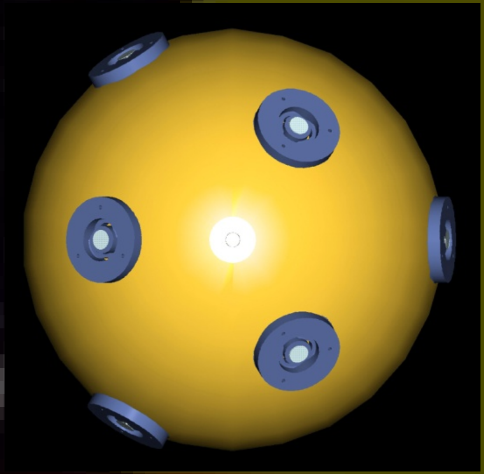


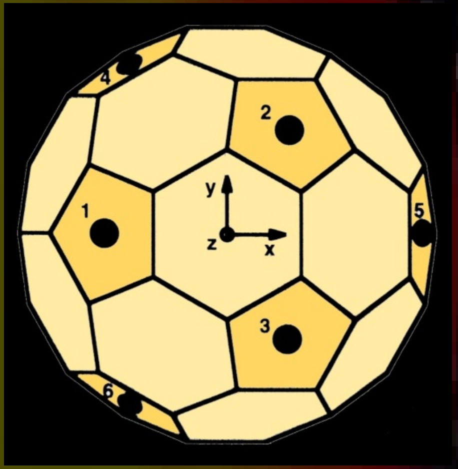
Science run @ ~40mK with 6 transducer chains end of 2008

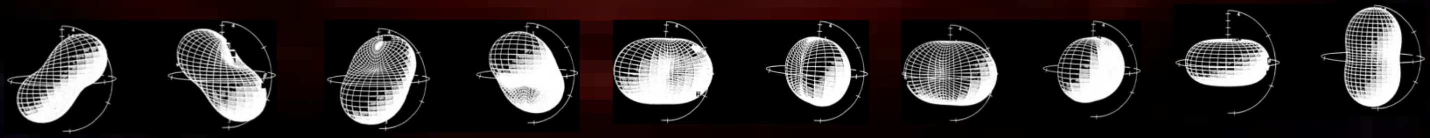
MiniGRAIL, Leiden

Sphere advantages

- Omni-directional
- Determine direction and polarization (TIGA)
- Veto with Toroidal modes







Sensitivity spherical detectors

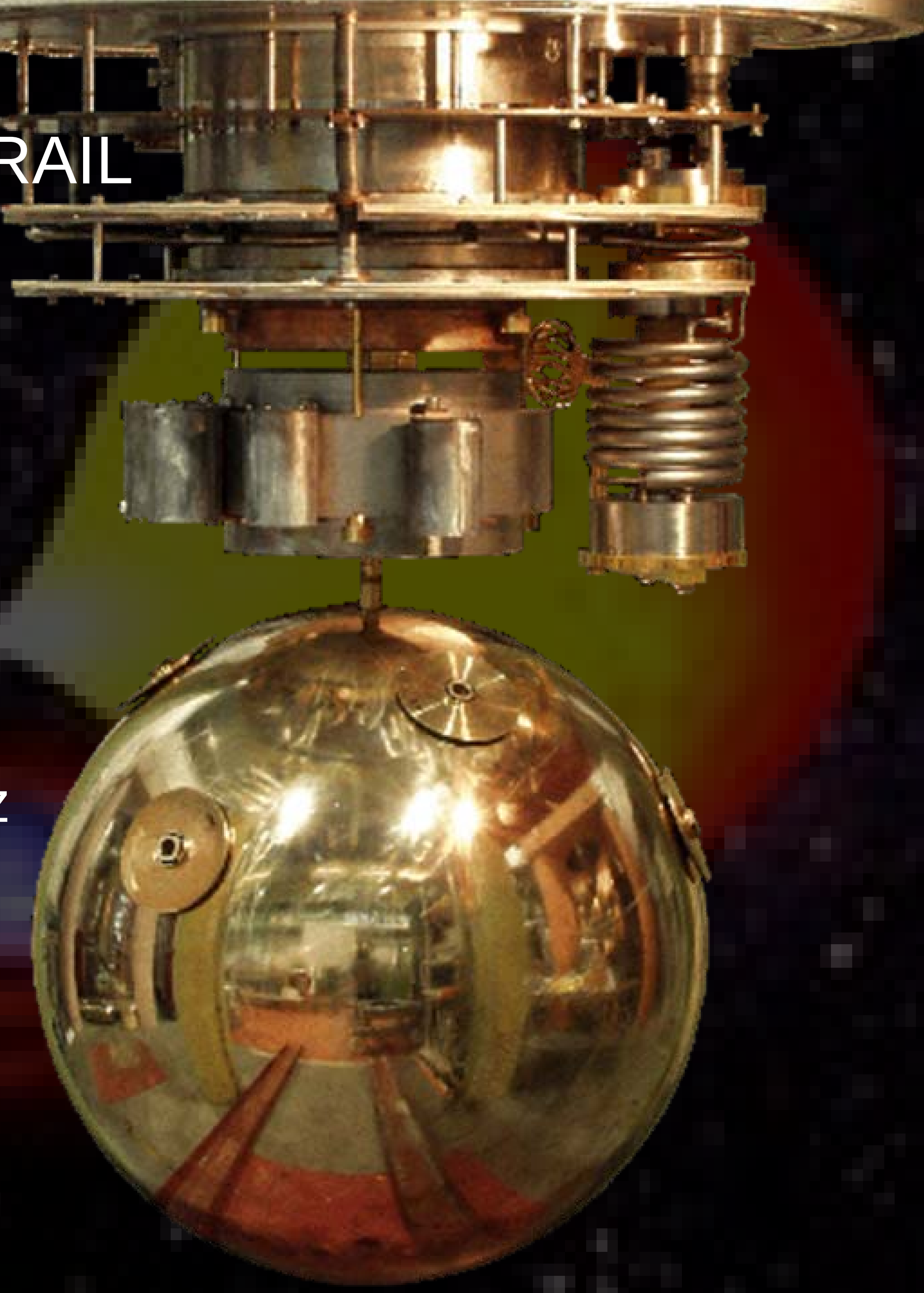
Aim MiniGRAIL 2009: Towards the quantum limit

$$T_{eff} \cong \frac{T}{\beta Q} + 2T_N$$

$$\frac{T}{\beta Q} << 2.6\times 10^{-7} \qquad @\ 2.9\mathrm{kHz}$$

$$\left.\begin{array}{l}\beta \sim 0.1\\ Q \sim 2\times 10^{6}\end{array}\right\} \qquad \text{T<50mK}$$

Properties MiniGRAIL



Material CuAl6%

Diameter $\Phi = 0.68$ m

Mass $M = 1300$ kg

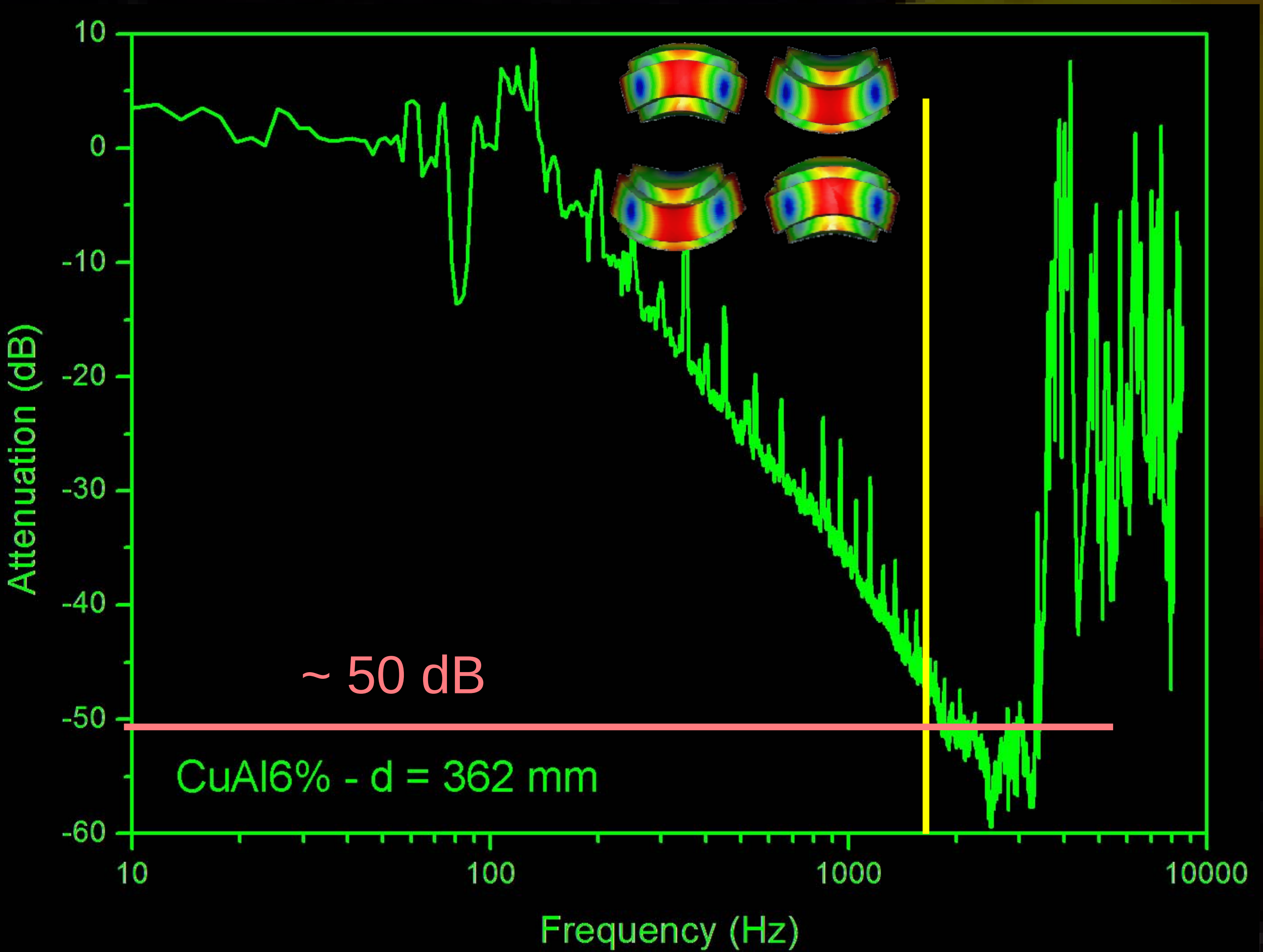
Resonance freq. $f = 2900$ Hz

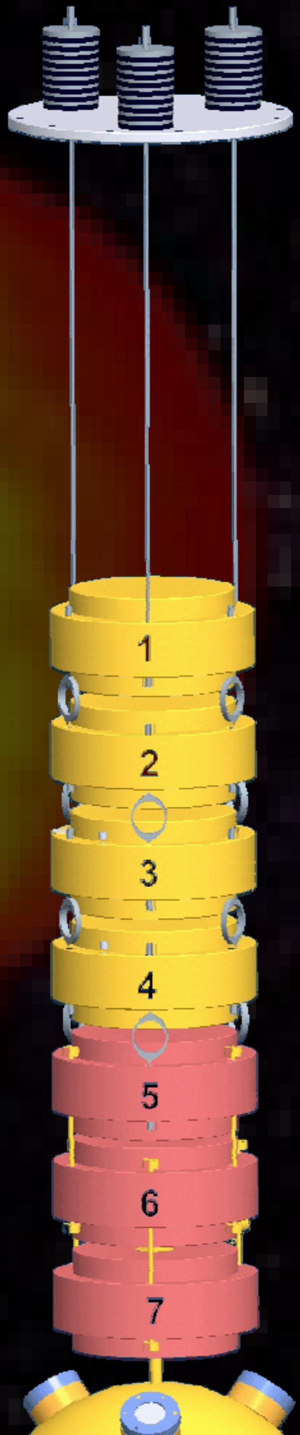
Temperature < 50 mK

NF sensitivity $4\text{x}10^{-22}$ $\text{Hz}^{-1/2}$

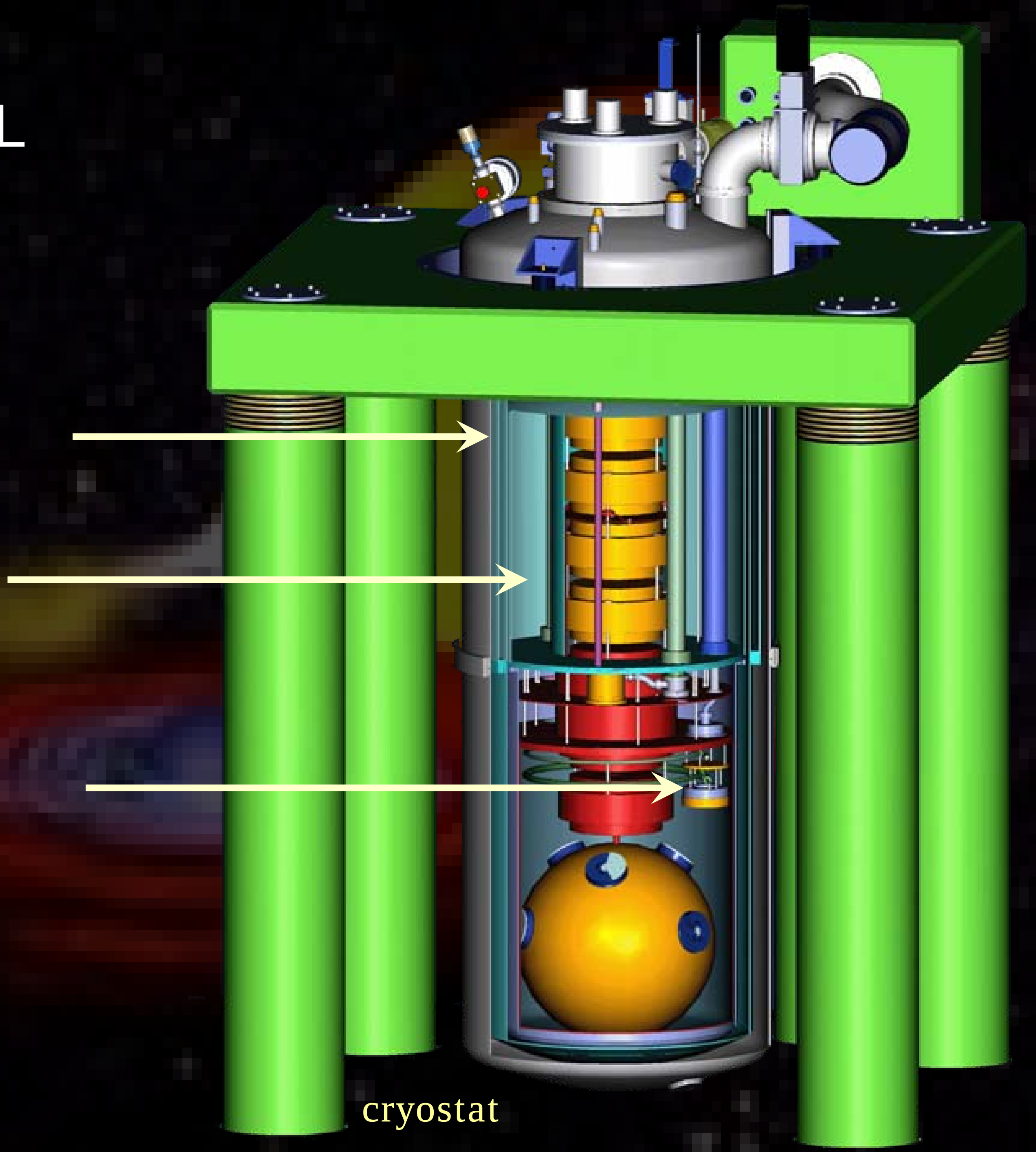
QL sensitivity $4\text{x}10^{-23}$ $\text{Hz}^{-1/2}$

MiniGRAIL
Seismic isolation





MiniGRAIL



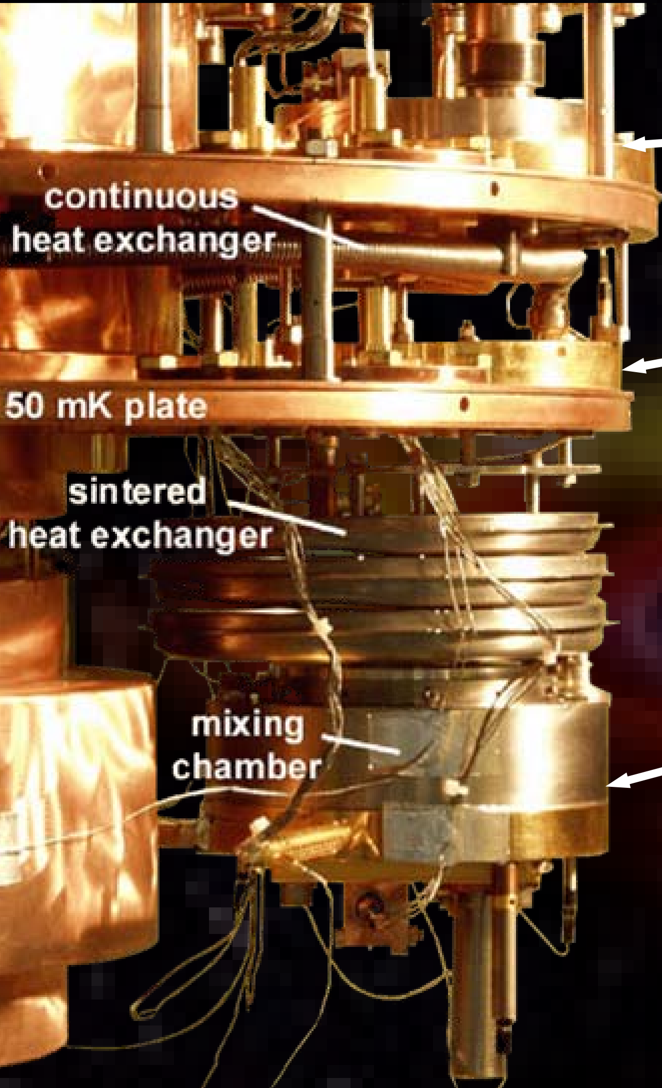
Liquid N_2
77K (-196 ºC)

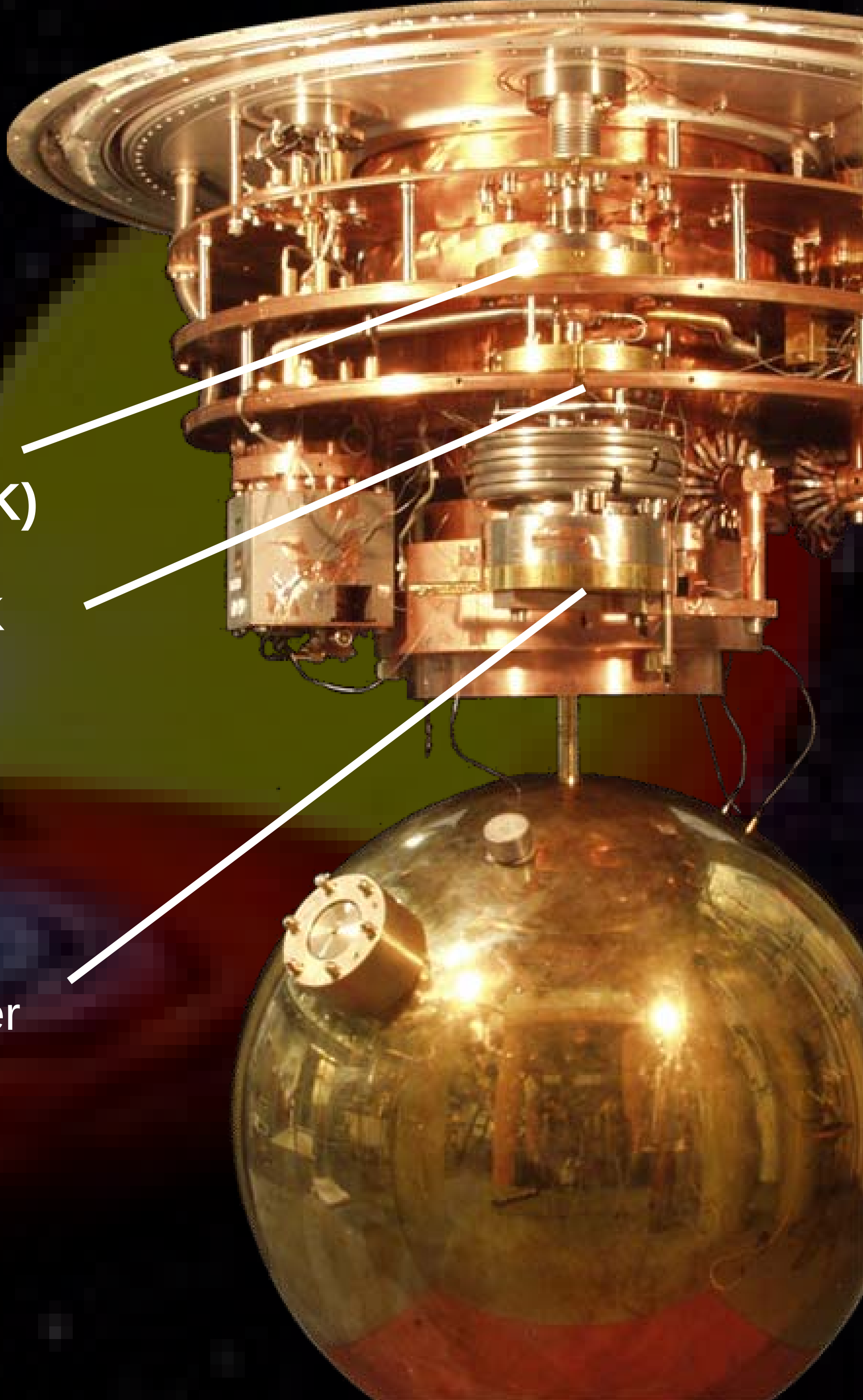
Liquid He
4K (-269 ºC)

Dilution refrigerator
(17 mK)

cryostat

MiniGRAIL *Cryogenics;* *The dilution refrigerator*



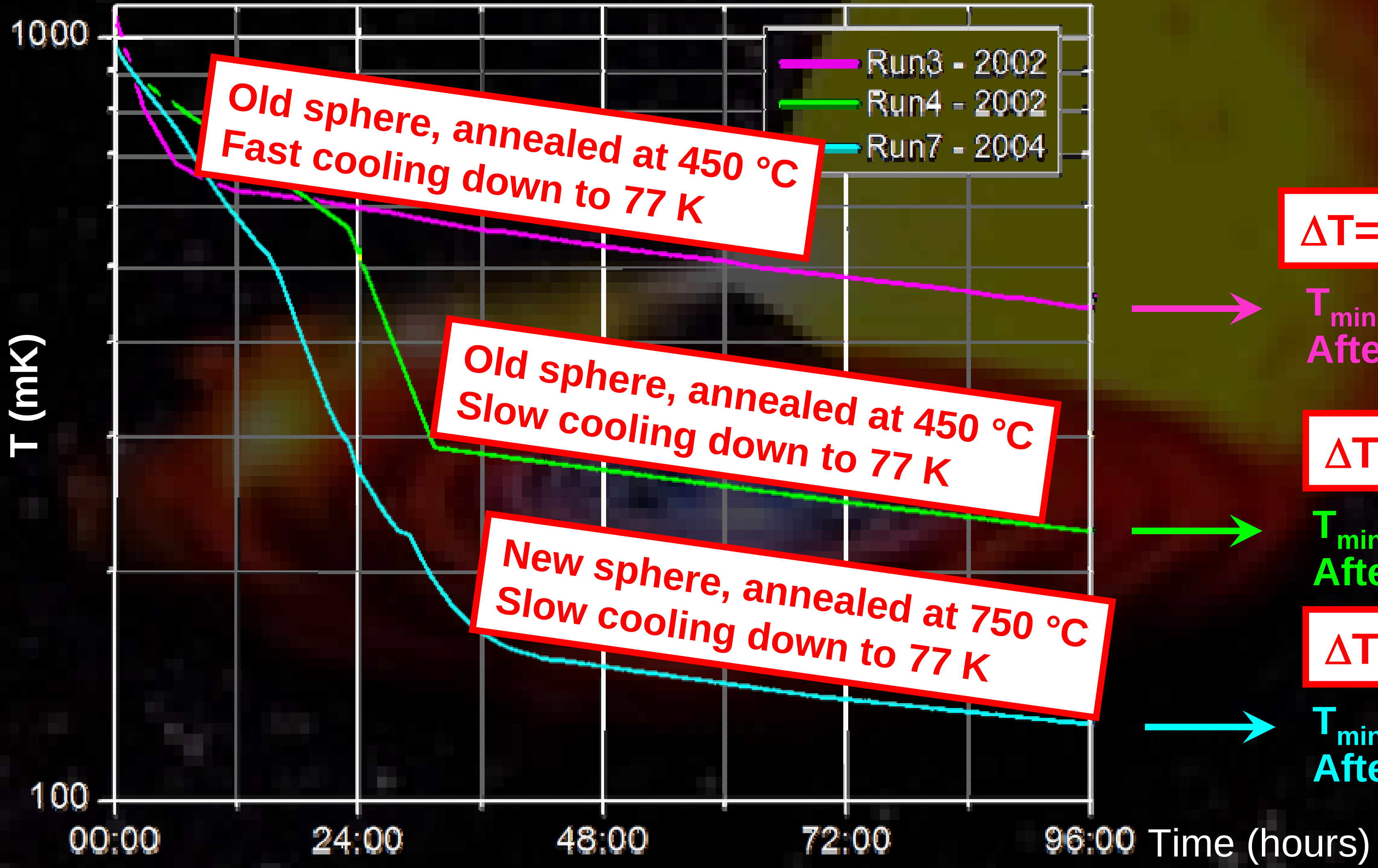


still
(700 mK)

50 mK
plate

mixing
chamber

Cryogenic improvements during engineering runs



Old sphere, annealed at 450 °C
Fast cooling down to 77 K

Old sphere, annealed at 450 °C
Slow cooling down to 77 K

New sphere, annealed at 750 °C
Slow cooling down to 77 K

ΔT= 200 mK

T_{min}= 294 mK
After 1 week

ΔT= 59 mK

T_{min}= 79 mK
After 6 weeks

ΔT= 20 mK

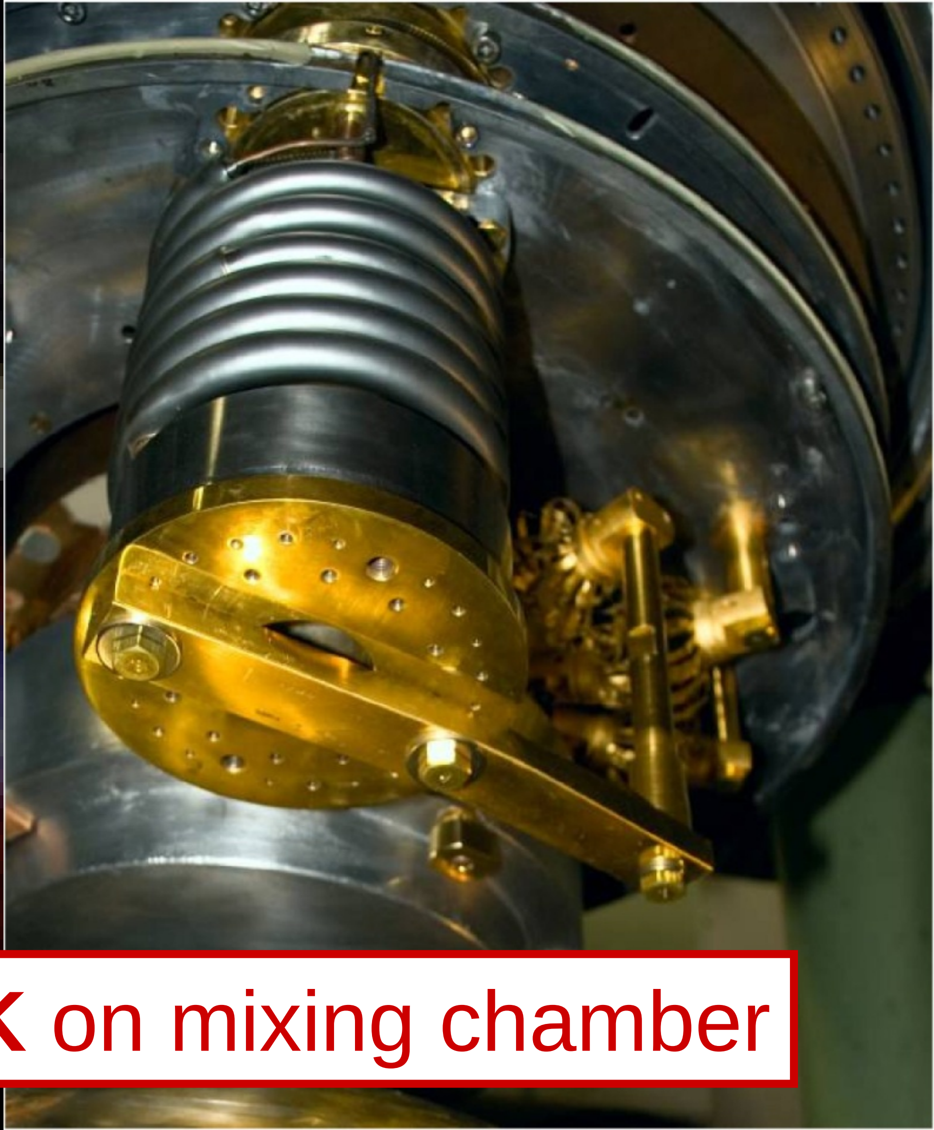
T_{min}= 65 mK
After 2 weeks

Improvements; Cryogenics

The dilution refrigerator was completely changed from the 50mK plate down to the mixing chamber

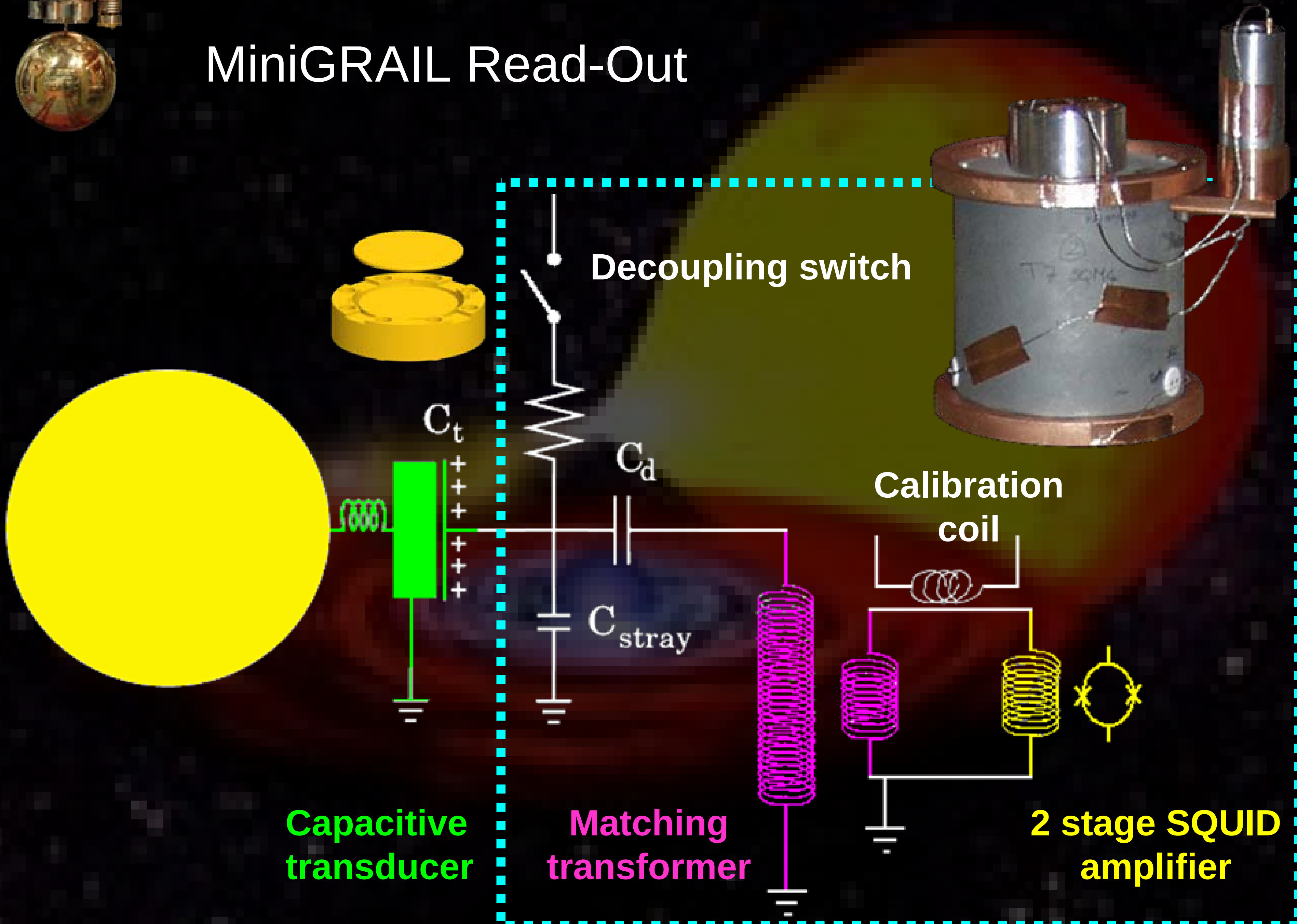
New sintered heat exchangers were installed, having 7 convolutions instead of three. A new enlarged mixing chamber was assembled as well.

Larger cooling power and lower base temperature



Result: **17 mK** on mixing chamber

MiniGRAIL Read-Out



Decoupling switch

Calibration coil

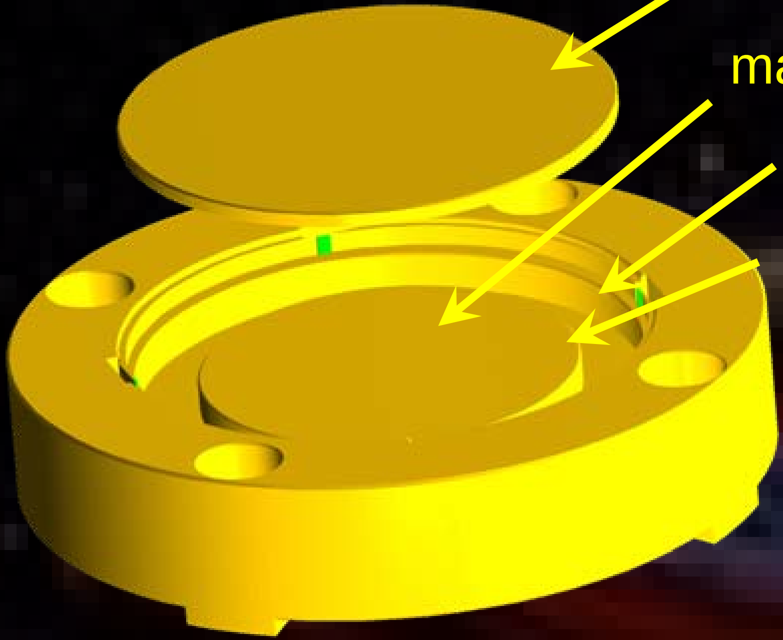
Capacitive transducer

Matching transformer

2 stage SQUID amplifier

MiniGRAIL Read-Out; Capacitive Transducer

CuAl6%



electrode

mass (~ 200 g)

spring

membrane

Advantages:

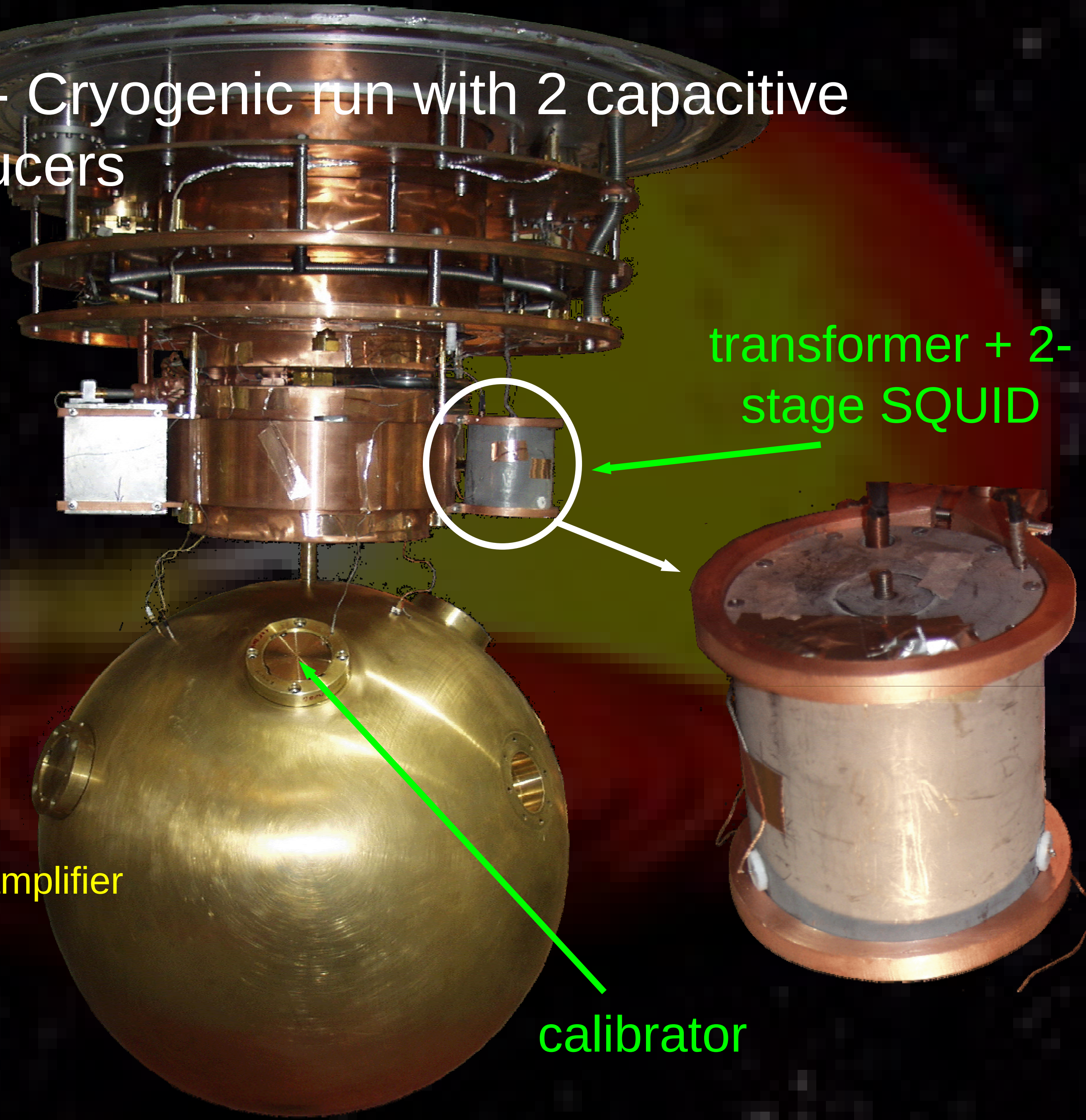
- Compact design
- Easy to make

d~30 micro m

V_{BIAS} up to 500 V

Run 6 - Cryogenic run with 2 capacitive transducers

Tmin=4.5K



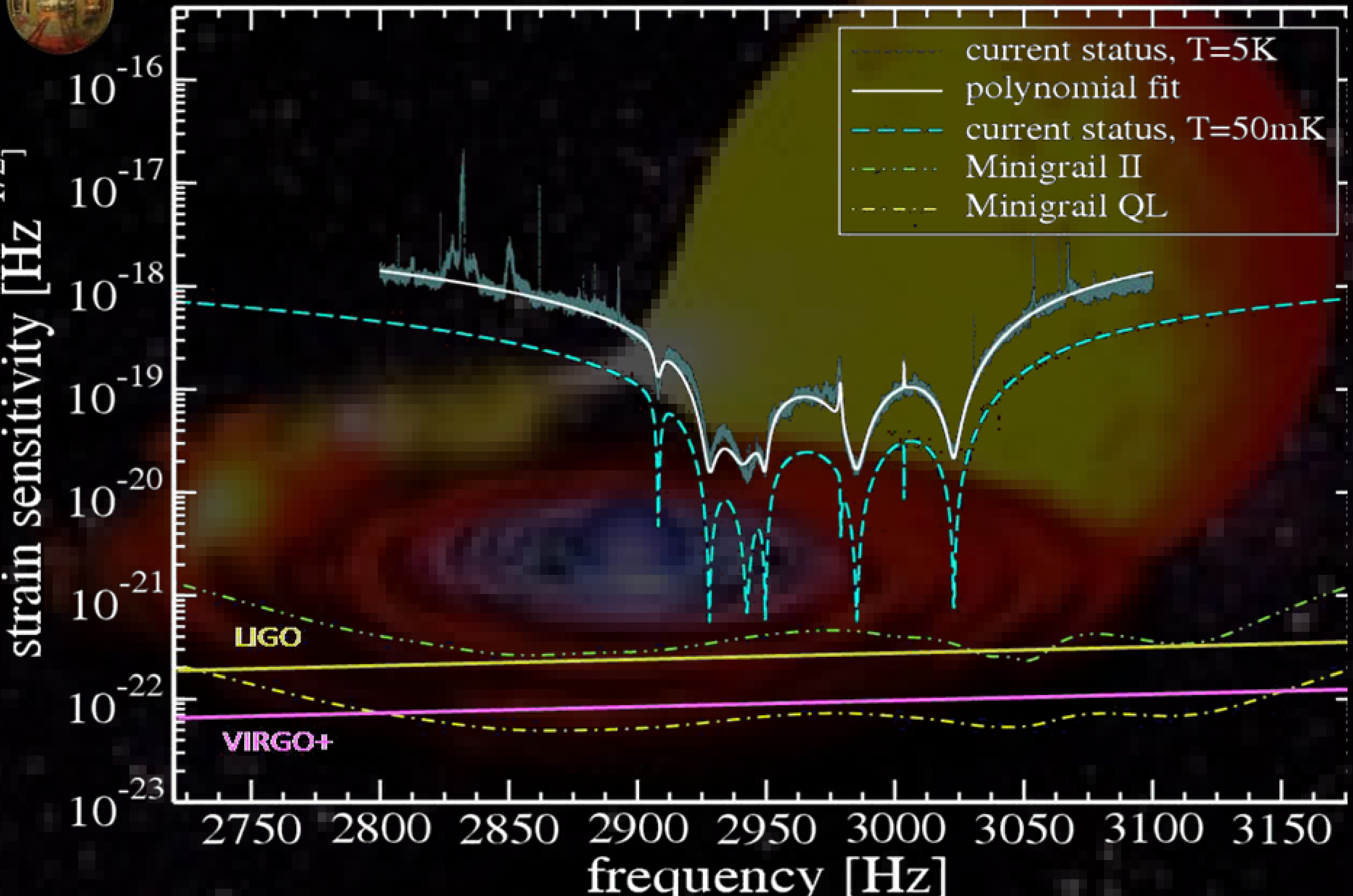
transformer + 2-stage SQUID

calibrator

2 transducer chains:

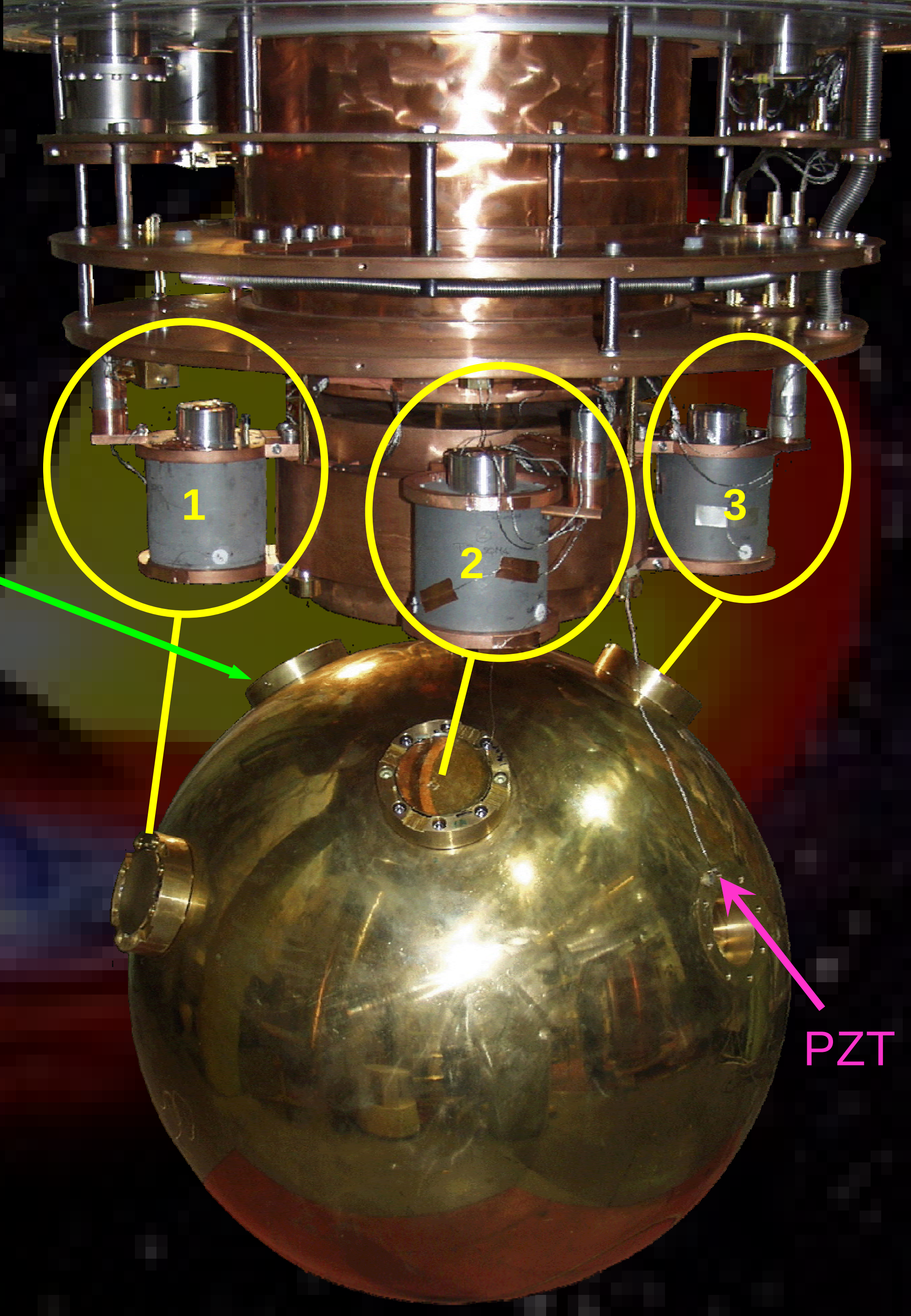
Capacitive transducer
Transformer
Calibration coil
1 and 2 stage SQUID amplifier
Decoupling switches

Sensitivity MiniGRAIL run 6



MiniGRAIL; run 8

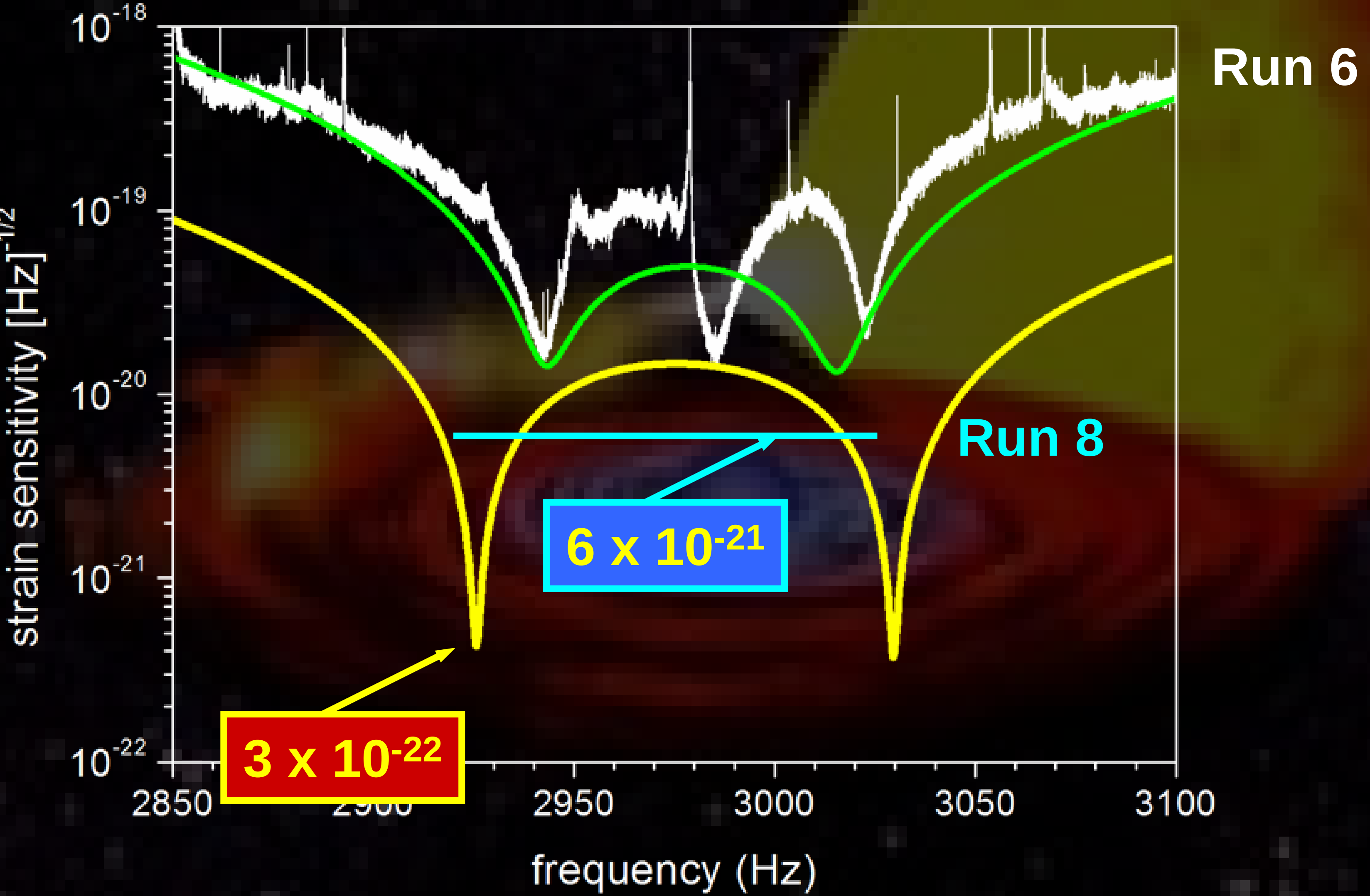
Tmin=65mK



3 identical transducer chains:

Capacitive transducer
Transformer
Calibration coil
2 stage SQUID amplifier
Decoupling switches

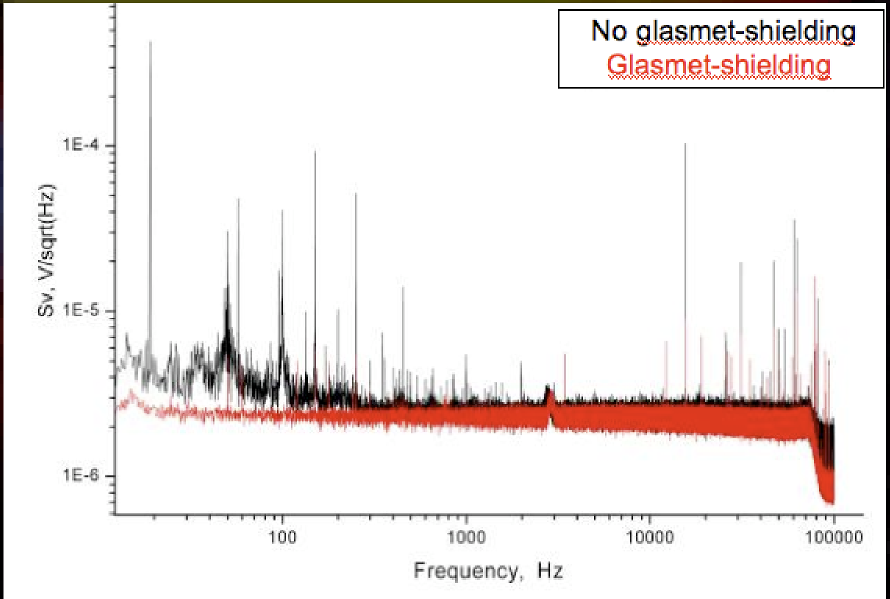
MiniGRAIL sensitivity run 8 @ 75mK



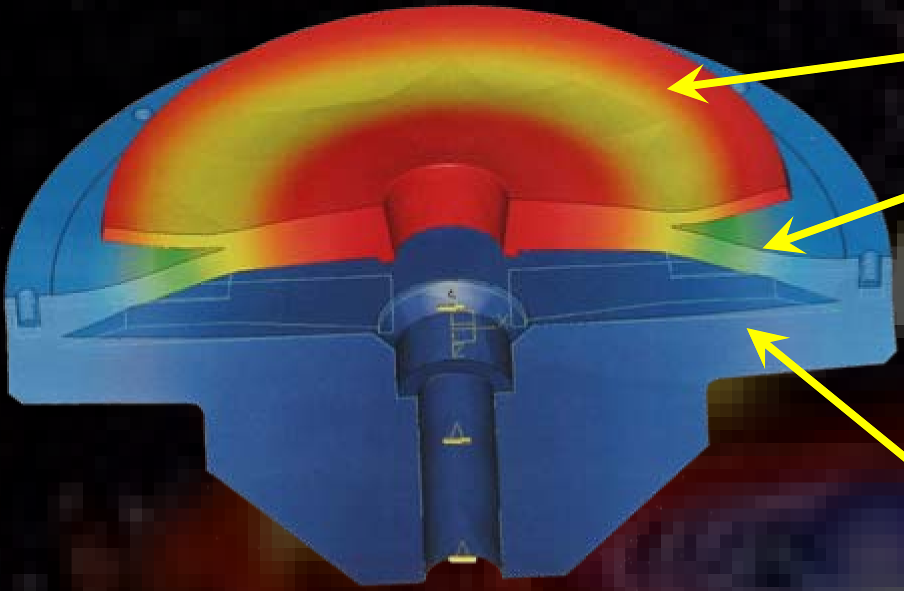
6×10^{-21}

3×10^{-22}

Improvements; Shielding



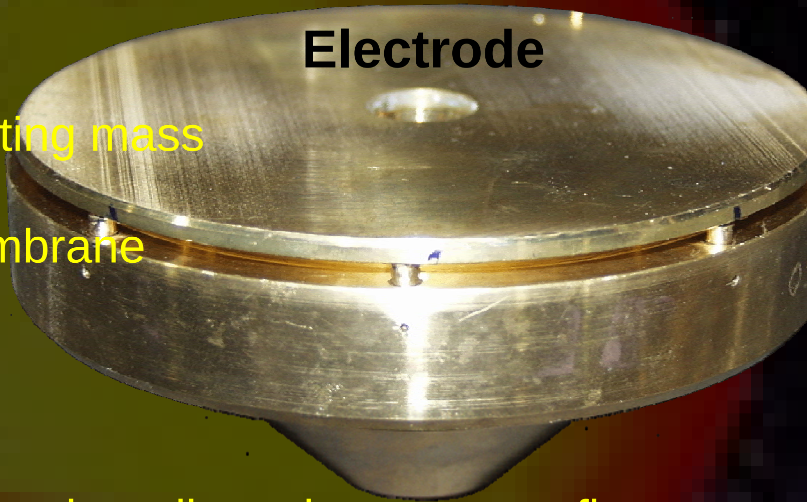
Improvements; New transducer design



resonating mass

membrane

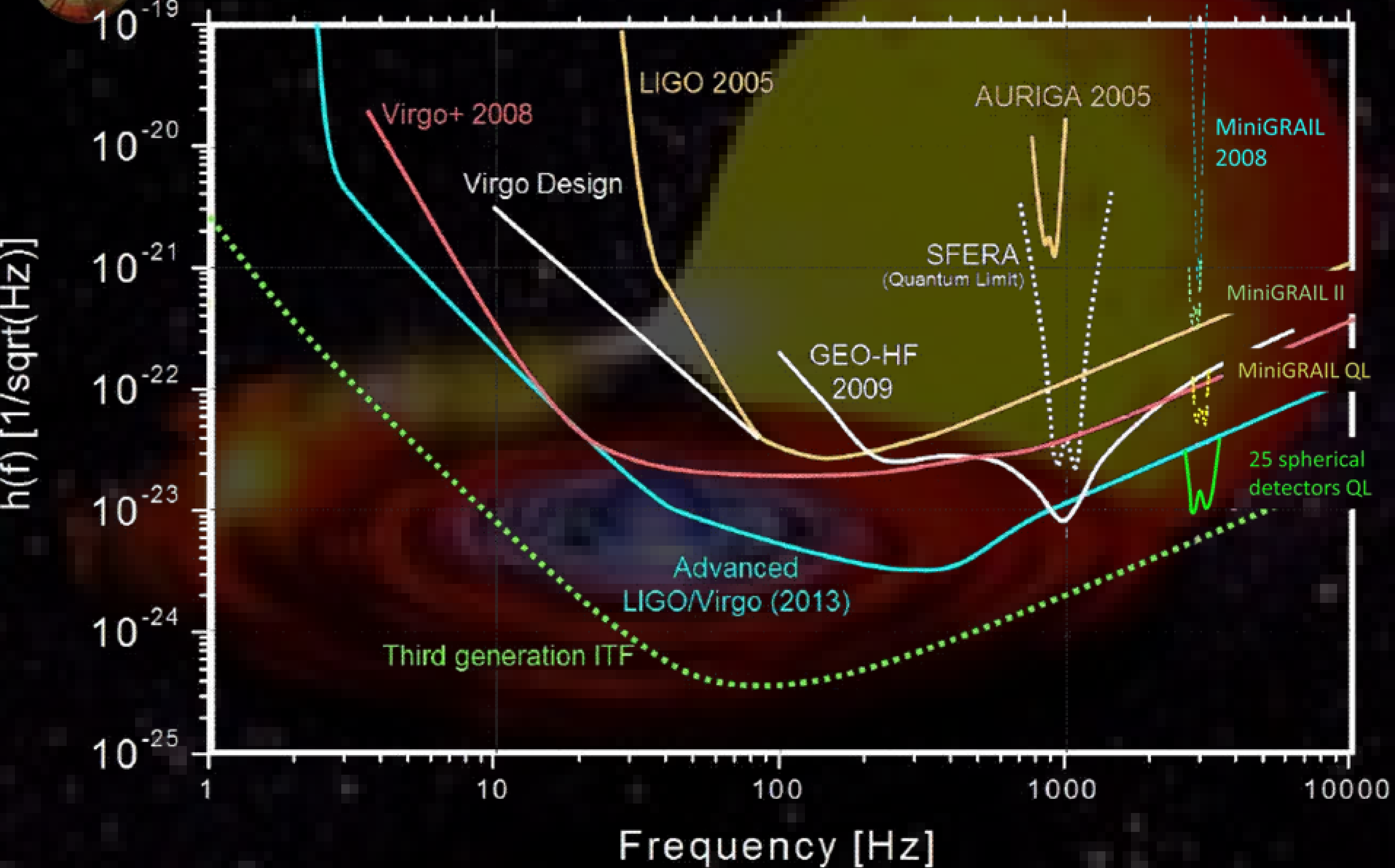
Base can be adjusted to use as a first mass for 2-mode transducer



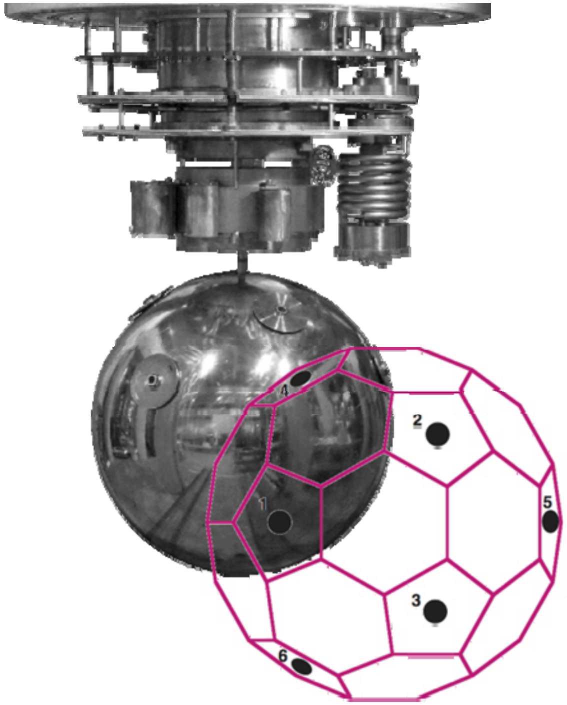
Improvements:

- Surface area increase to A=85 cm^2
  (maximum, because of restriction due to radiation shields)
- Easier to polish flat because mass surface and supports are at the same level
- Estimation of capacitance : C ~ 8 nF

Expectations MiniGRAIL 2009 (MiniGRAIL 2)



miniGRAIL data analysis pipeline

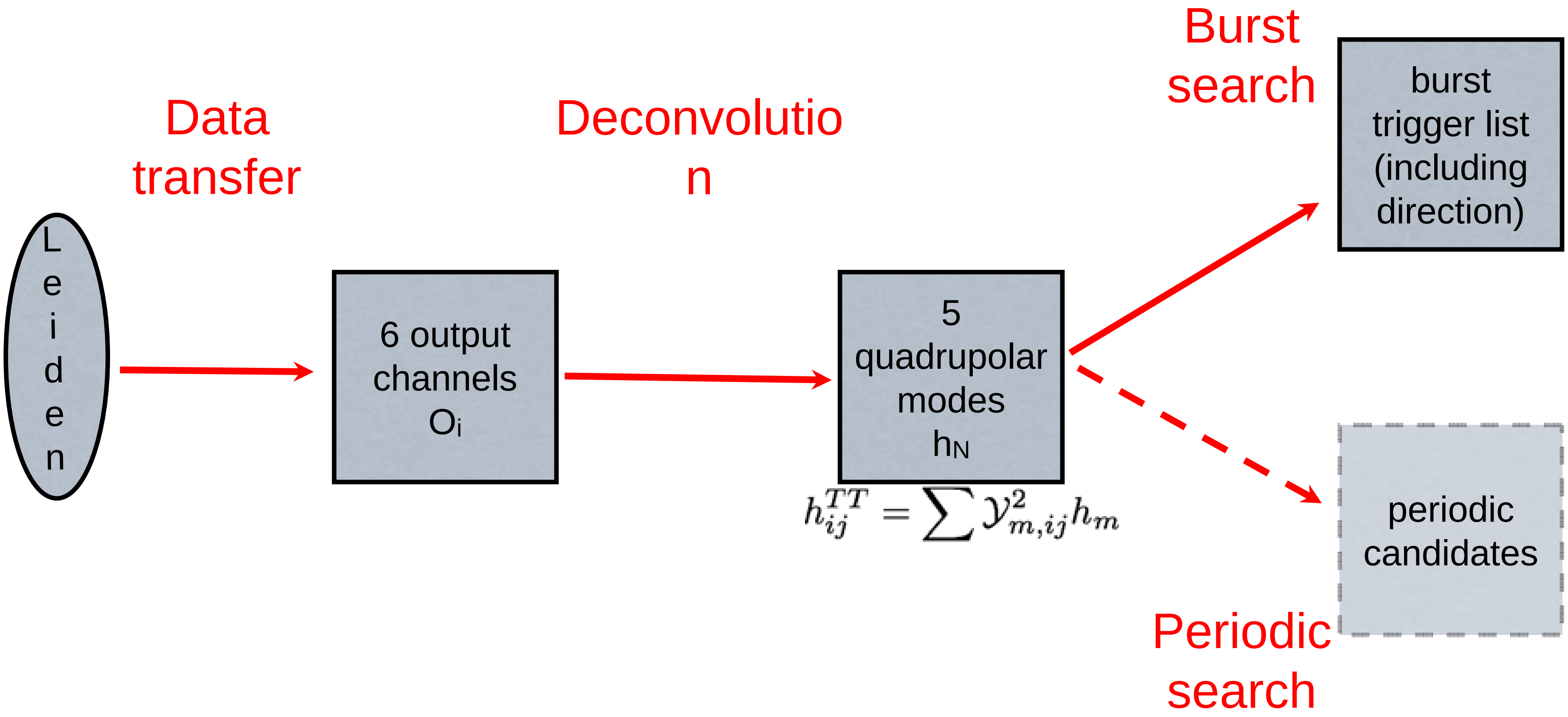


Dr. Stefano Foffa
Dr. Riccardo Sturani
Filipe Da Silva

group of
Prof. Michele Maggiore
Prof. Martin Pohl

University of Geneva (Switzerland)

UNIVERSITÉ
DE GENÈVE



Leiden

Data transfer

6 output channels O_i

Deconvolutio
n

5 quadrupolar modes h_N

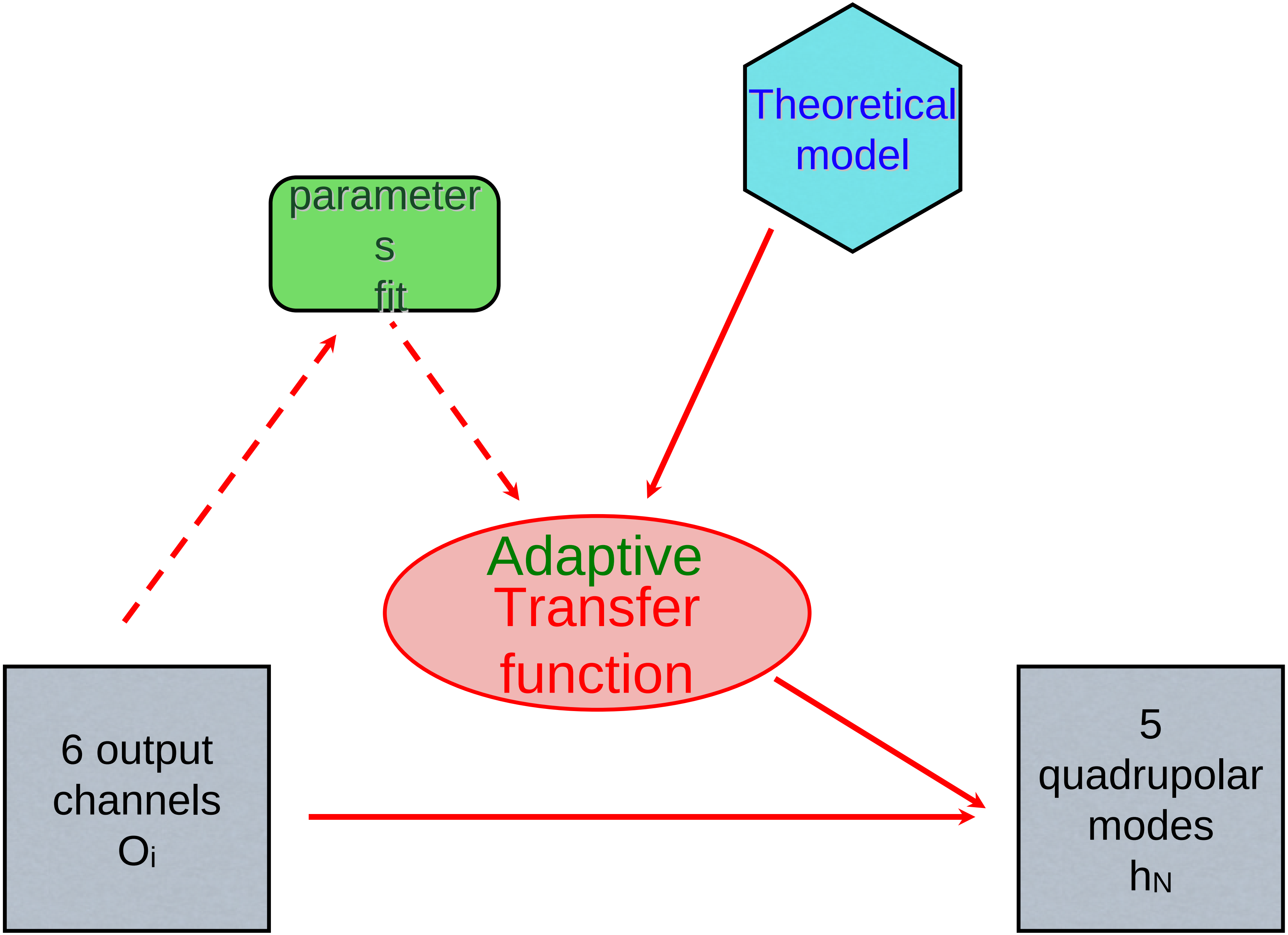
$$h_{ij}^{TT} = \sum \mathcal{Y}_{m,ij}^{2} h_m$$

Burst search

burst trigger list (including direction)

Periodic search

periodic candidates



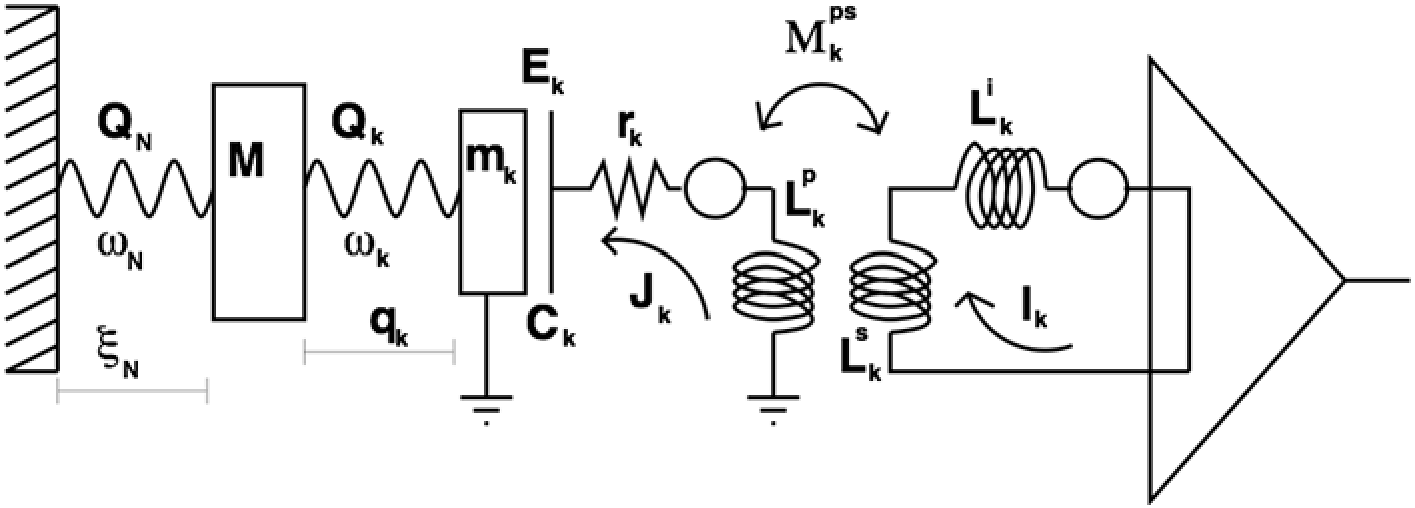
Theoretical model

parameters fit

Adaptive Transfer function

6 output channels O_i

5 quadrupolar modes h_N

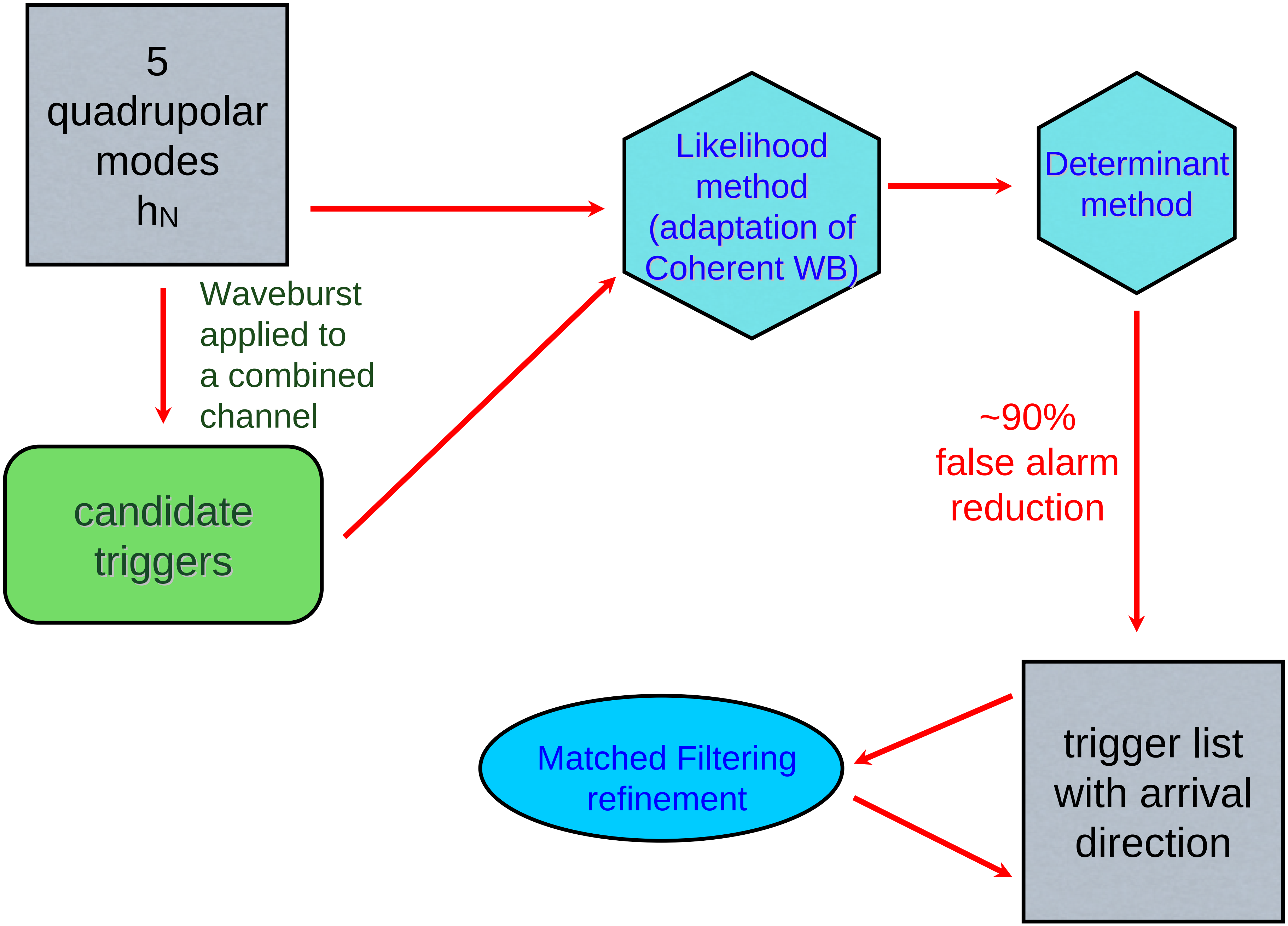


$$\left(\omega_N^2 - \omega^2 + i\frac{\omega_N\omega}{Q_N}\right)\xi_N - \alpha_N\sum_k B_{Nk}\left[\left(\omega_k^2 + i\frac{\omega_k\omega}{Q_k}\right)\frac{m_k}{M}q_k - i\frac{E_k}{M\omega}J_k\right] = f_N - \alpha_N\sum_k B_{Nk}\frac{m_k}{M}f_k^t$$

$$-\omega^2\sum_N B_{kN}\alpha_N\xi_N + \left(\omega_k^2 - \omega^2 + i\frac{\omega_k\omega}{Q_k}\right)q_k - i\frac{E_k}{m_k\omega}J_k = f_k^t$$

$$E_k q_k + \left[r_k + i\left(\omega L_k^p - \frac{1}{\omega C_k}\right)\right]J_k - i\omega M_k^{ps}(I_k - f_k^i) = f_k^p$$

$$-i\omega M_k^{ps}J_k + i\omega\left(L_k^s + L_k^i\right)\left(I_k - f_k^i\right) = f_k^s$$



5 quadrupolar modes h_N

Waveburst applied to a combined channel

candidate triggers

Likelihood method (adaptation of Coherent WB)

Determinant method

~90% false alarm reduction

trigger list with arrival direction

Matched Filtering refinement

- Look for power excess in

$$H = \sum_{mn} h_m h_n < h_m h_n >^{-1}$$

- Reconstruct h_{ij} and arrival direction via Likelihood method: maximization of

$$\Lambda(h_{+,\times}, \theta, \phi) = \frac{p(\{h_m\}|H_{h_{+,\times},\theta,\phi})}{p(\{h_m\}|H_0)}$$

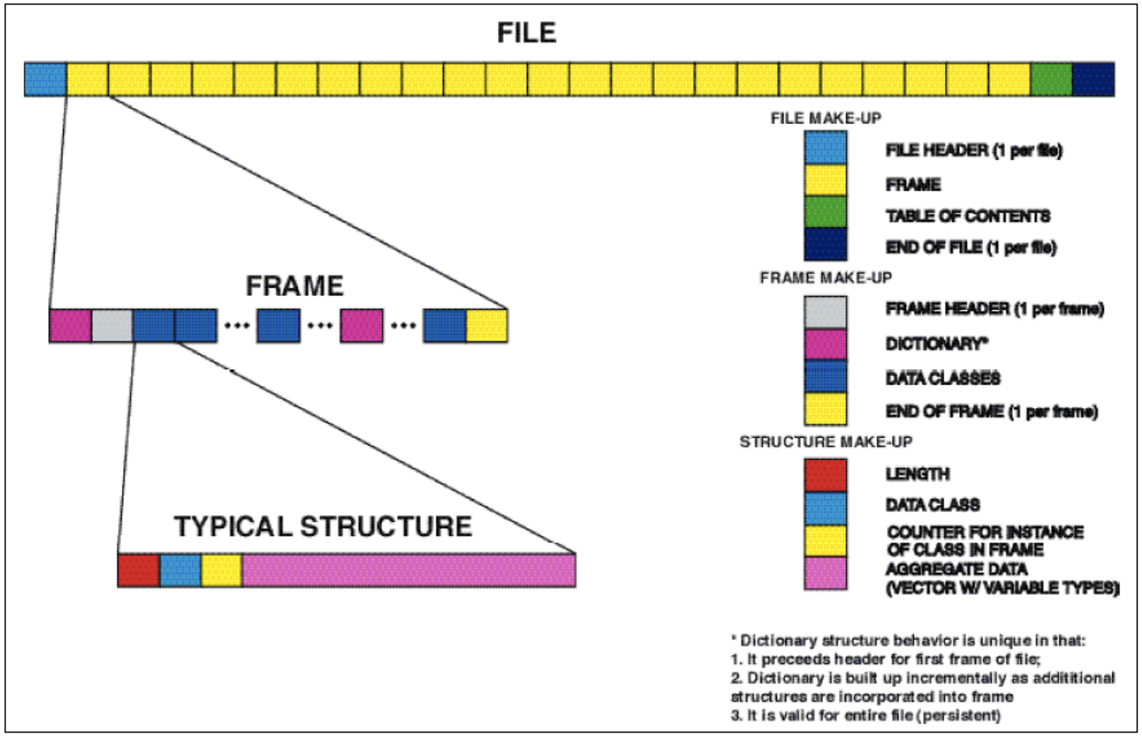
- Check de eigenvector is compatible

Open libraries/

- FFTW-3.1.2: To do the discrete Fourier transform
  - http://www.fftw.org/
- GSL-1.11: GNU scientific library, for matrix and vector operations
  - http://www.gnu.org/software/gsl/
- Wave Burst
- root libraries 5 v16 or v19
  - http://root.cern.ch/
- Frame v6r24: For the format of the files.
  - http://lappweb.in2p3.fr/virgo/FrameL/

Frames/

Figure 1: **Schematic representation of data organization within a file.**


FILE
FRAME
TYPICAL STRUCTURE
FILE MAKE-UP
FILE HEADER (1 per file)
FRAME
TABLE OF CONTENTS
END OF FILE (1 per file)
FRAME MAKE-UP
FRAME HEADER (1 per frame)
DICTIONARY*
DATA CLASSES
END OF FRAME (1 per frame)
STRUCTURE MAKE-UP
LENGTH
DATA CLASS
COUNTER FOR INSTANCE OF CLASS IN FRAME
AGGREGATE DATA (VECTOR W/ VARIABLE TYPES)
* Dictionary structure behavior is unique in that:
1. It preceeds header for first frame of file;
2. Dictionary is built up incrementally as addititional structures are incorporated into frame
3. It is valid for entire file (persistent)

Ref.: Specification of a Common Data Frame Format for Interferometric Gravitational Wave Detectors

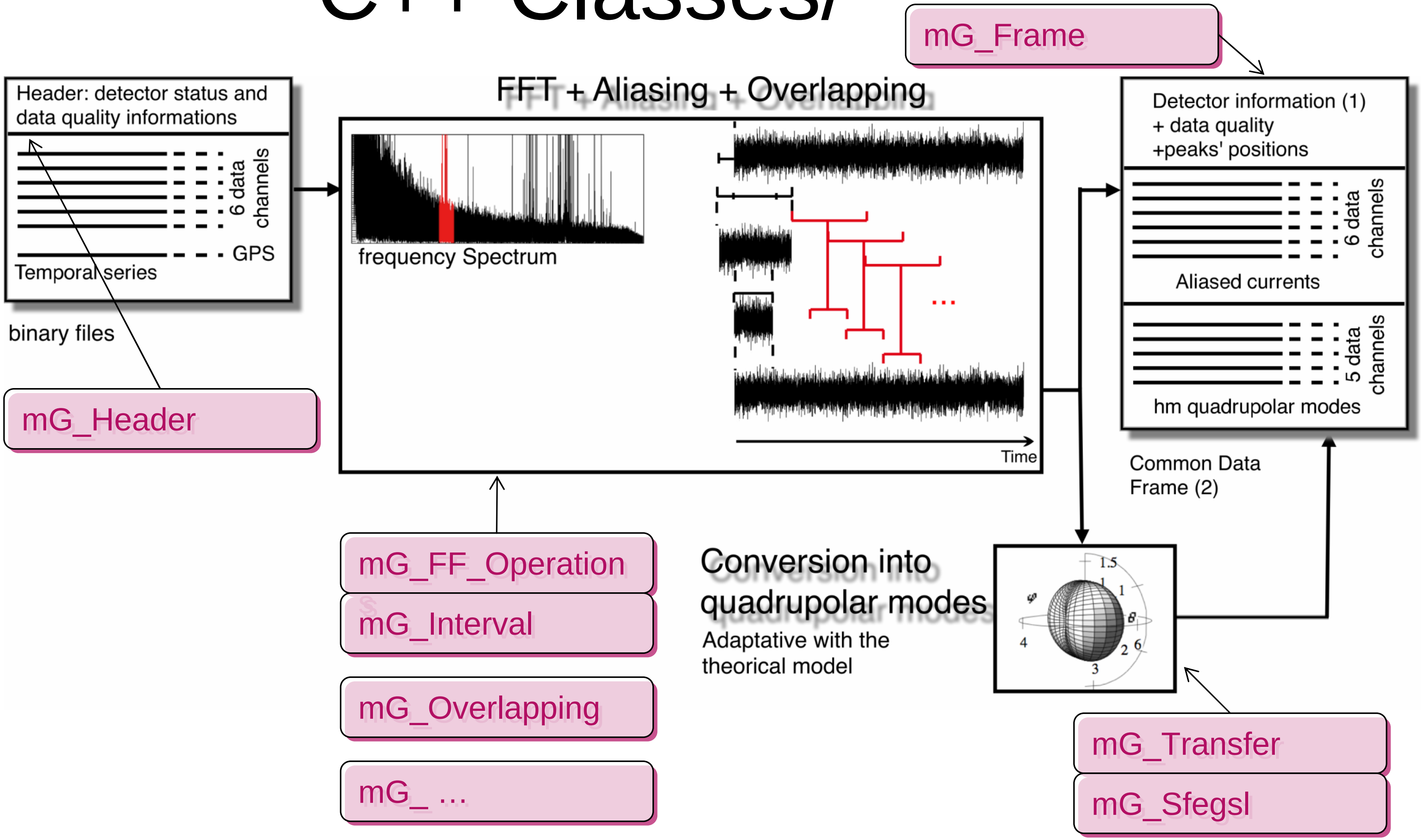
-Information of the data kind
-data
-Internal information to build “C struct”
-we use only one frame per file.

The frames are based in “C structures”.
We use FrADC, FrProcData, FrEvent,…

The library includes the declaration of all the structures and many functions to manage them.

mG_Frame: includes functions that fill automatically fields with our parameters: numbers of channels, our abbreviation mG etc

C++ Classes/



mG_Frame

Header: detector status and data quality informations

Temporal series

binary files

mG_Header

FFT + Aliasing + Overlapping

frequency Spectrum

mG_FF_Operation

mG_Interval

mG_Overlapping

mG_ …

Detector information (1)
+ data quality
+peaks' positions

Aliased currents

hm quadrupolar modes

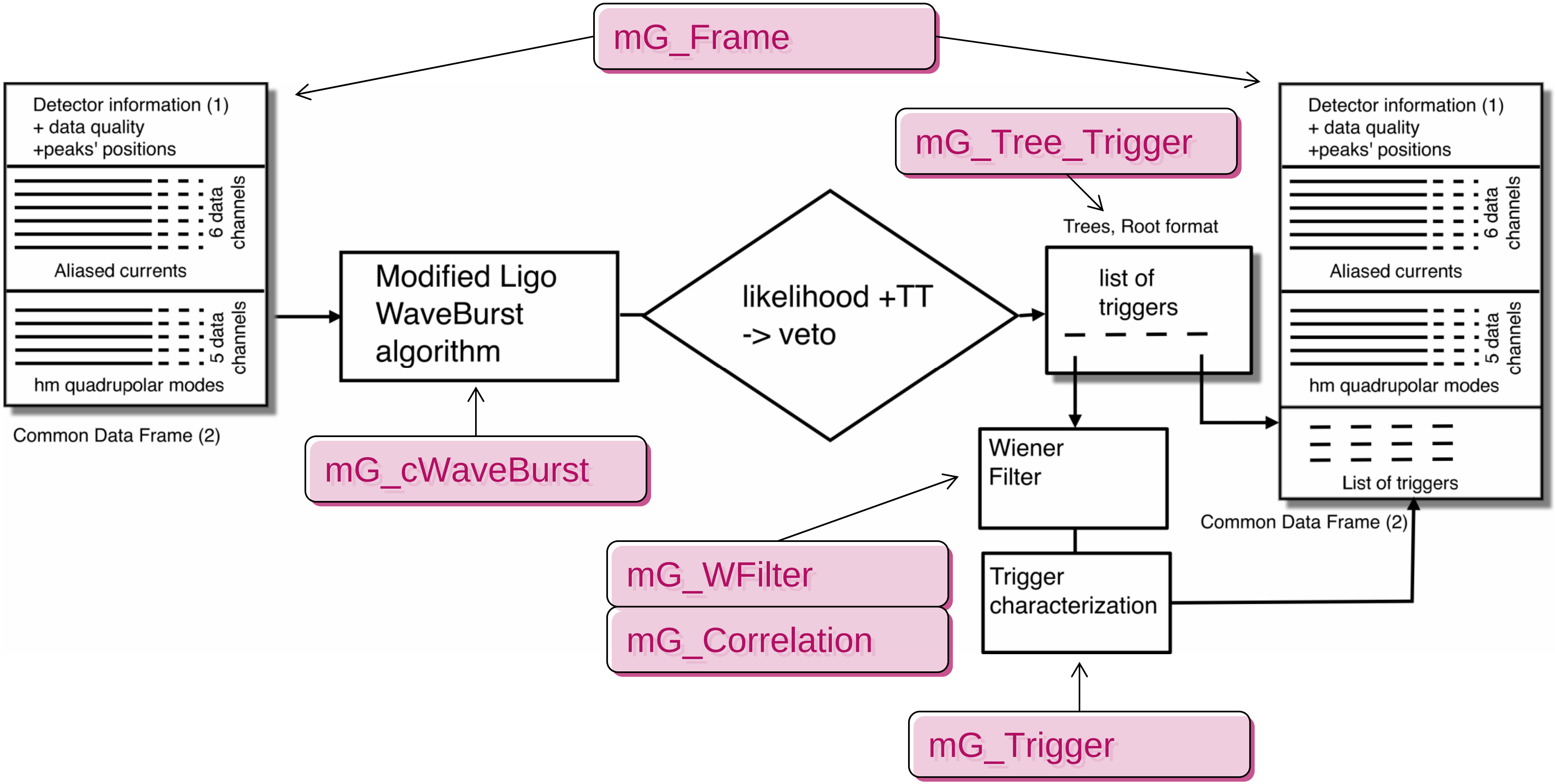
Common Data Frame (2)

Conversion into quadrupolar modes

Adaptative with the theorical model

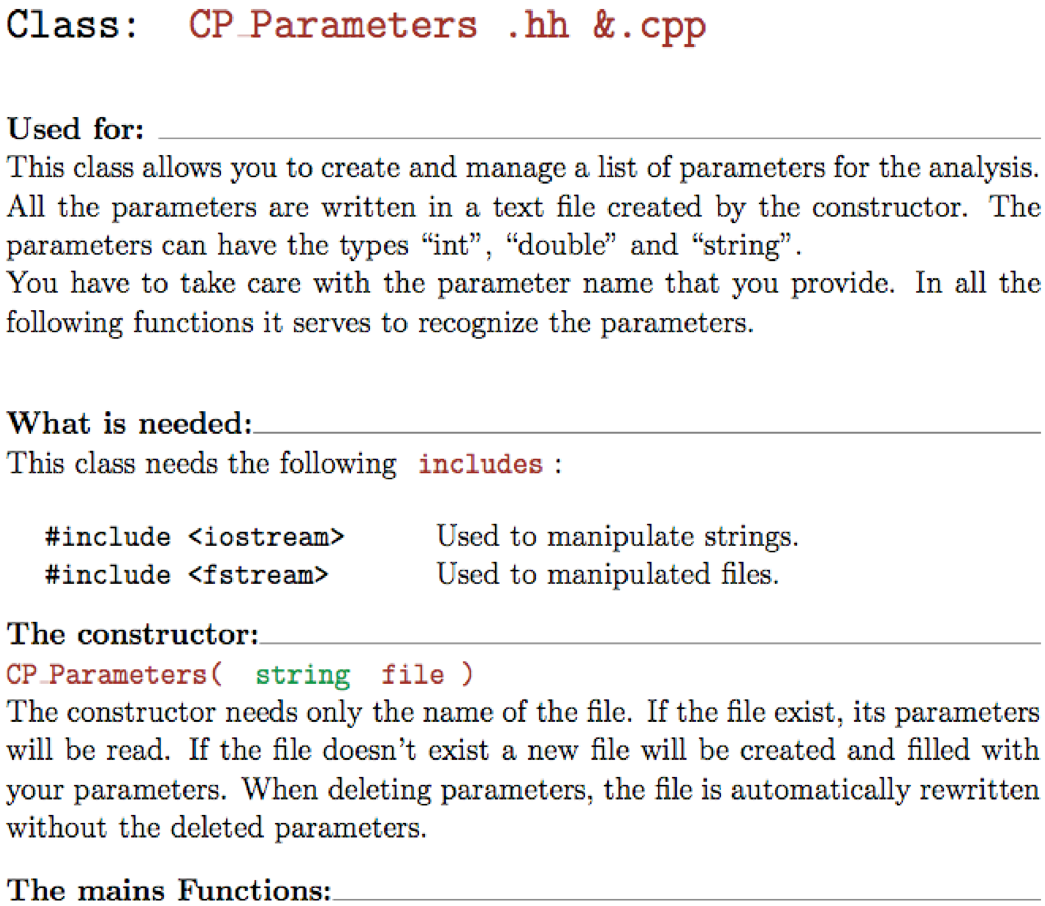
mG_Transfer

mG_Sfegsl


mG_Frame
Detector information (1)
+ data quality
+peaks' positions
6 data channels
Aliased currents
5 data channels
hm quadrupolar modes
Common Data Frame (2)
Modified Ligo WaveBurst algorithm
mG_cWaveBurst
likelihood +TT
-> veto
mG_Tree_Trigger
Trees, Root format
list of triggers
Detector information (1)
+ data quality
+peaks' positions
6 data channels
Aliased currents
5 data channels
hm quadrupolar modes
List of triggers
Common Data Frame (2)
Wiener Filter
mG_WFilter
mG_Correlation
Trigger characterization
mG_Trigger

Documentation/ Read-me

In the Read-me you will find a description of all the programmes, classes and other documents used for the analysis of miniGRAIL



Class: CP_Parameters .hh &.cpp

Used for:

This class allows you to create and manage a list of parameters for the analysis. All the parameters are written in a text file created by the constructor. The parameters can have the types “int”, “double” and “string”.
You have to take care with the parameter name that you provide. In all the following functions it serves to recognize the parameters.

What is needed:

This class needs the following `includes` :

```
#include <iostream>        Used to manipulate strings.
#include <fstream>         Used to manipulated files.
```

The constructor:

`CP_Parameters( string file )`
The constructor needs only the name of the file. If the file exist, its parameters will be read. If the file doesn’t exist a new file will be created and filled with your parameters. When deleting parameters, the file is automatically rewritten without the deleted parameters.

The mains Functions:

- A brief description of the class function.

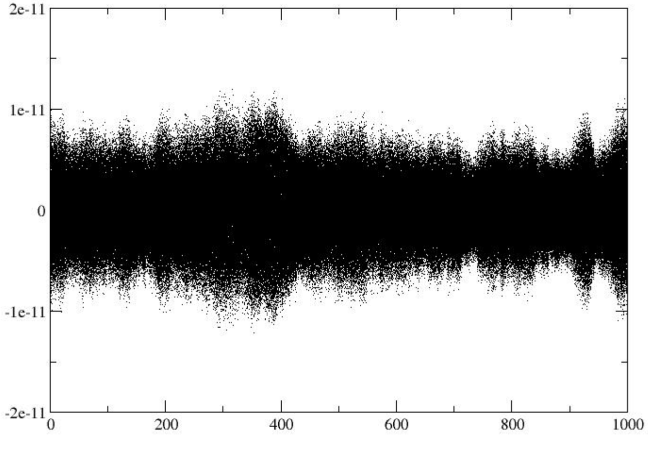
-The includes (the libraries) that we need.

-The constructor

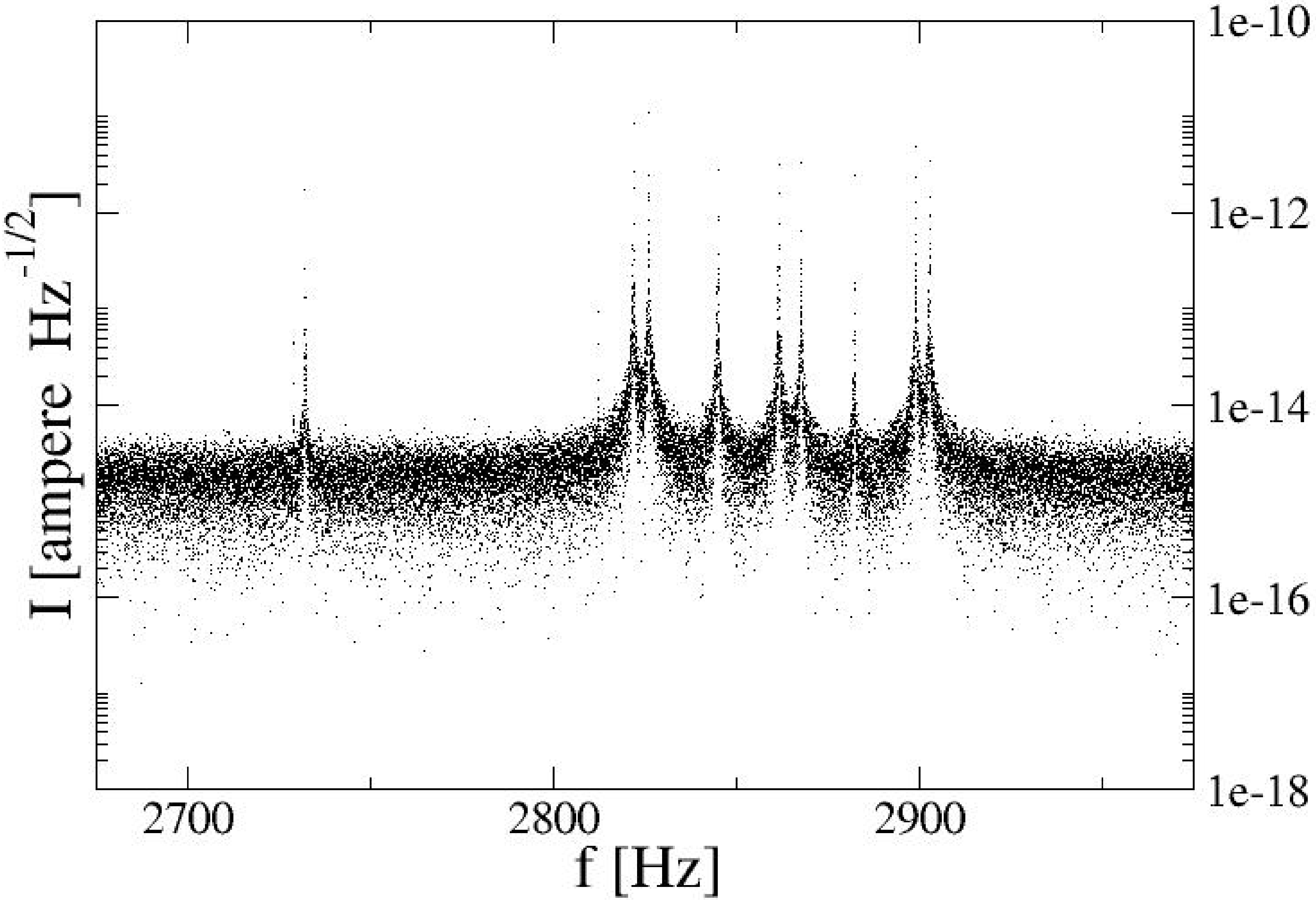
And the functions of the class.

Test of the trigger with mock data

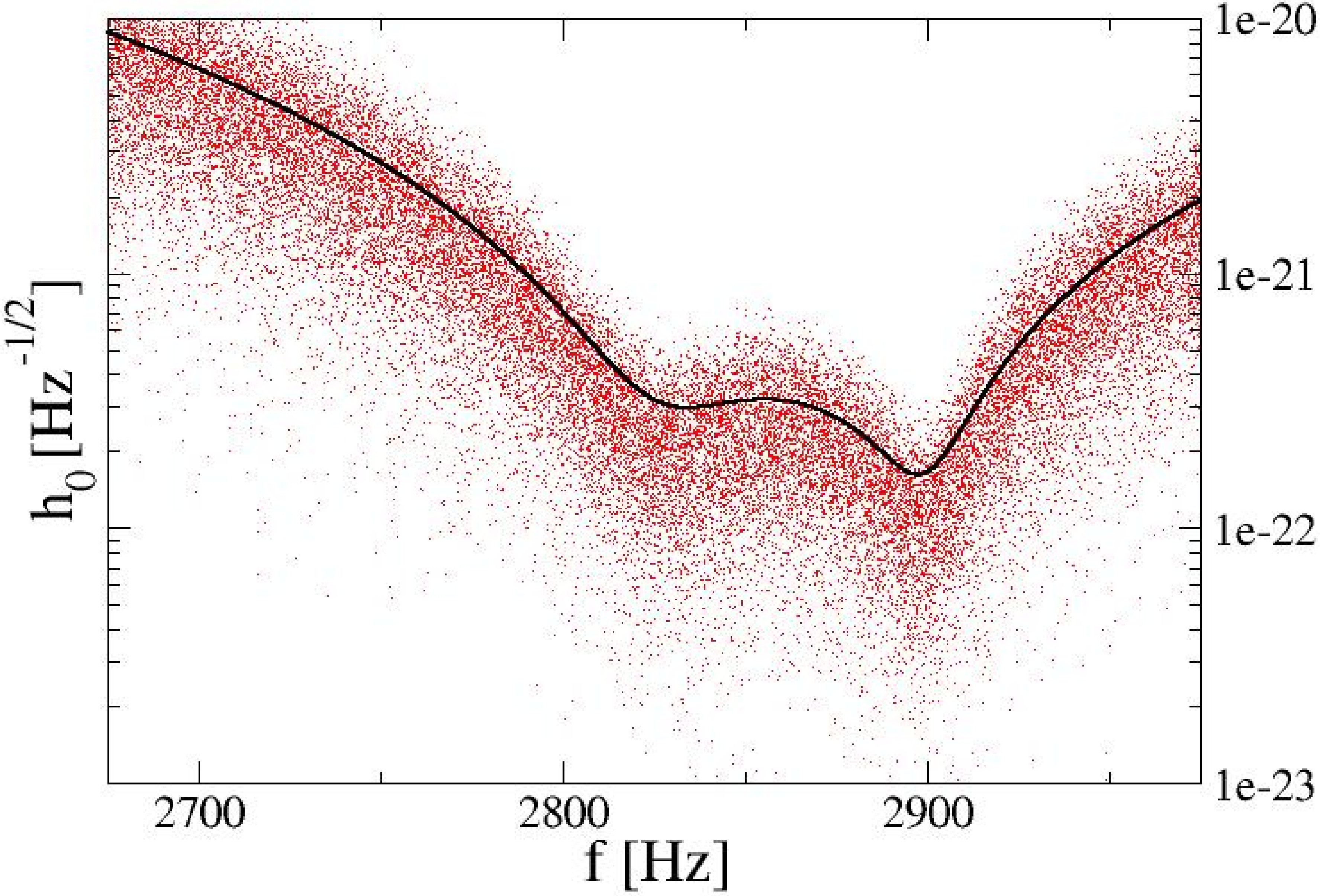
- Prepare several sets of white noise by means of a random number generator
- Transform in Fourier space
- Colour these sets by means of the noise spectral densities of each stochastic force f_x that enters in the model: $$< f_x(f) f_y^*(f') > \equiv S_{xy}(f)\delta(f - f')$$
- Insert in the linear system and solve for $I_k(f)$
- Transform back in time domain:



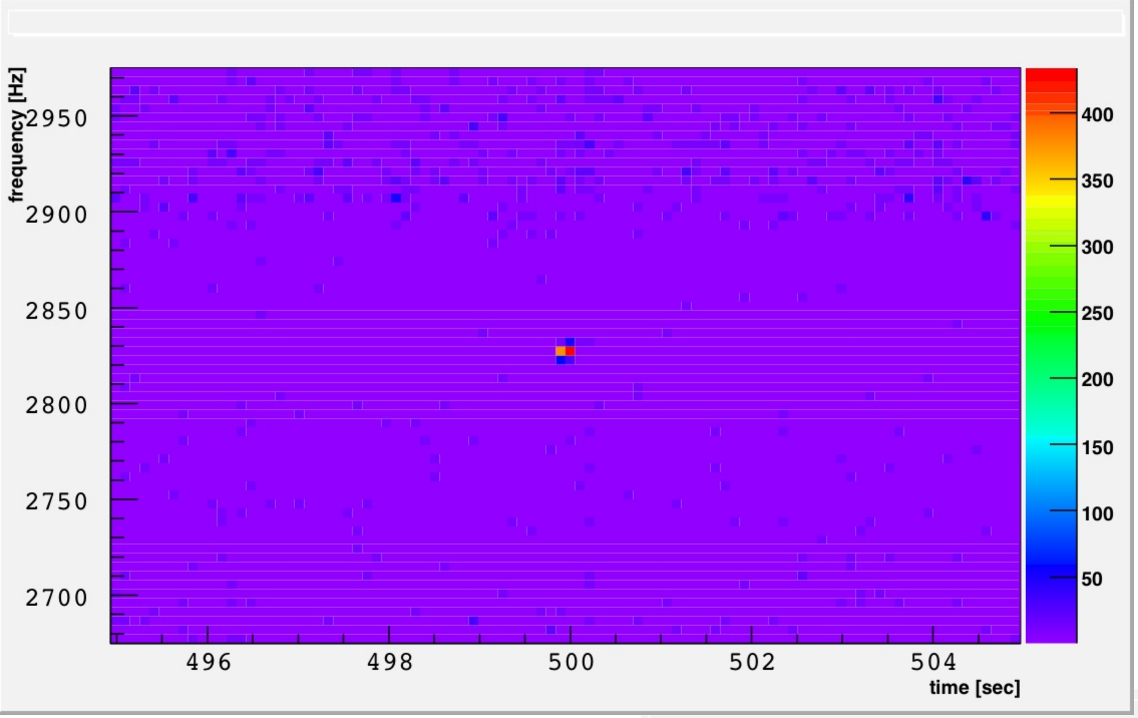
Output of transducer #0 (mock data)

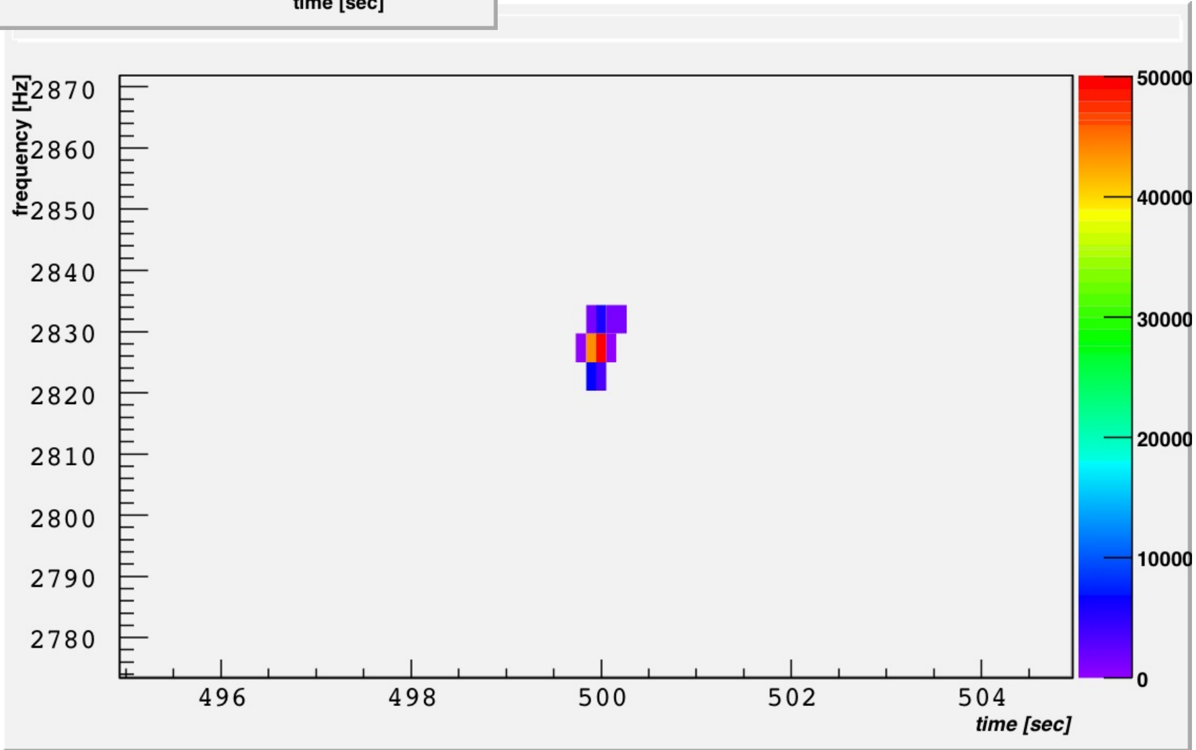


Sensitivity to the quadrupolar mode h_0 (mock data)

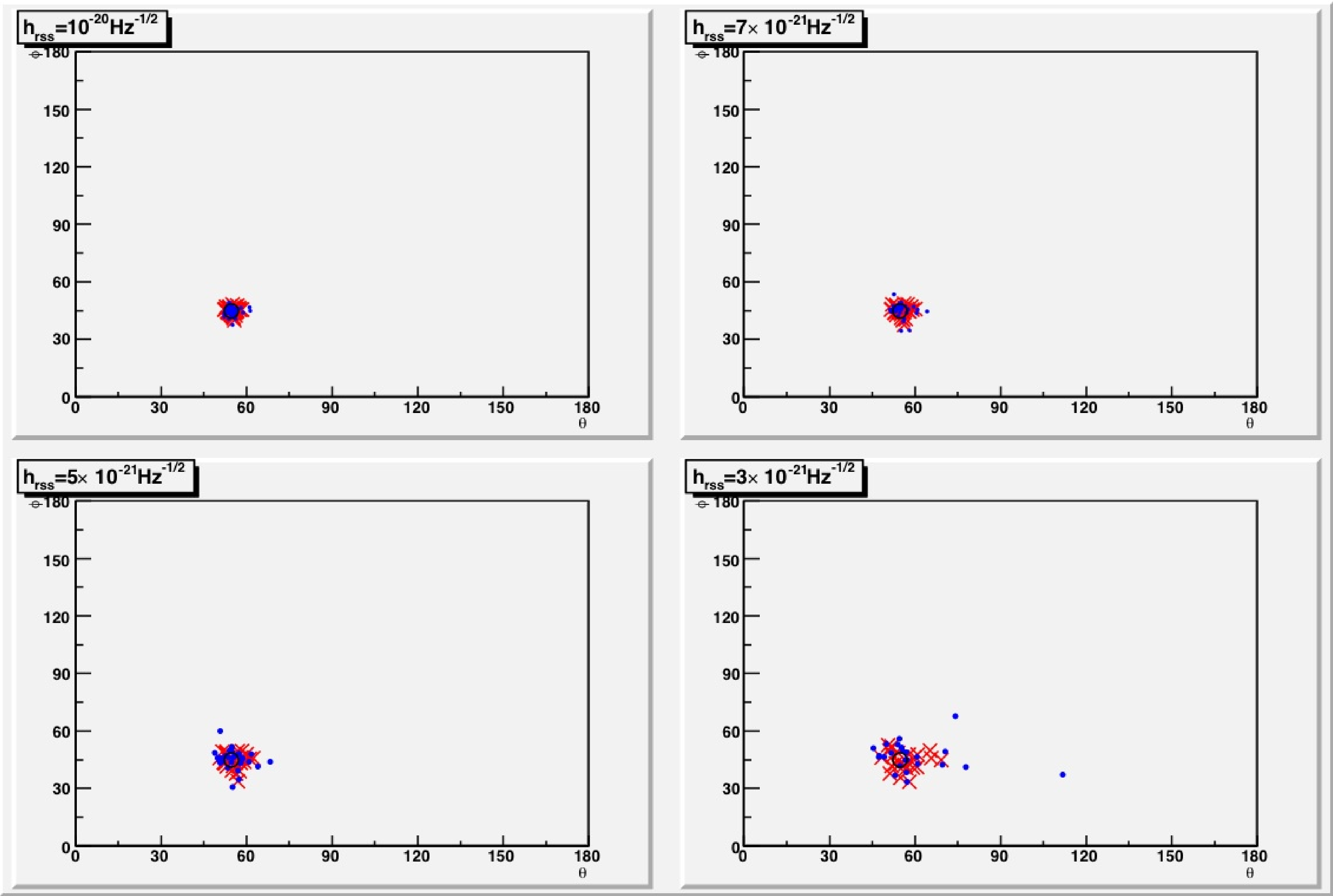


Scalar trigger H

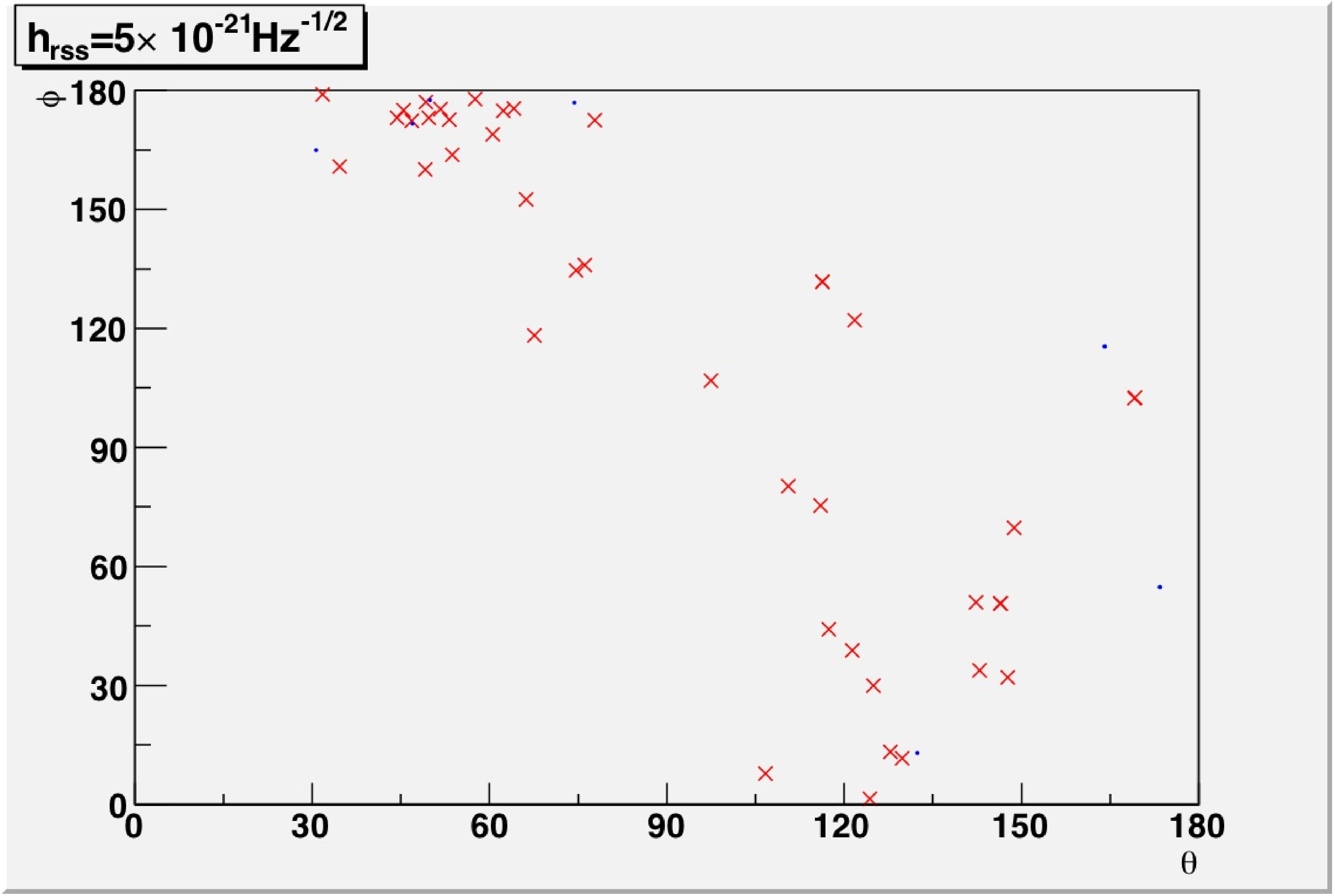




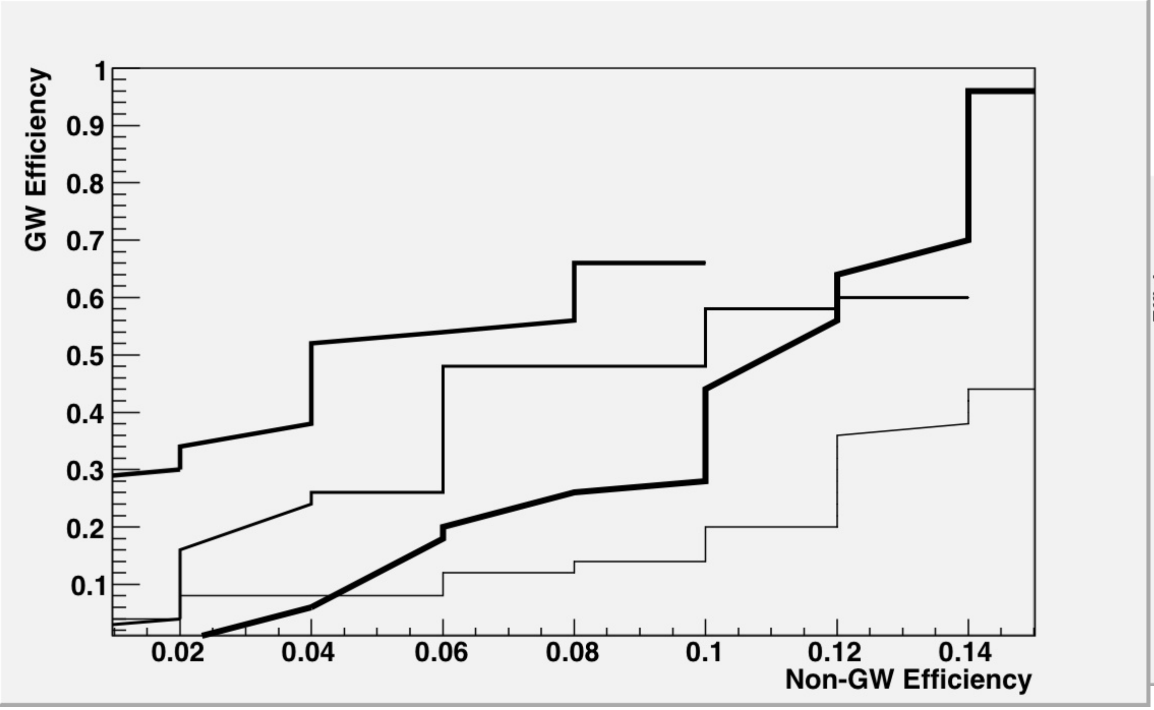
Real GW injections

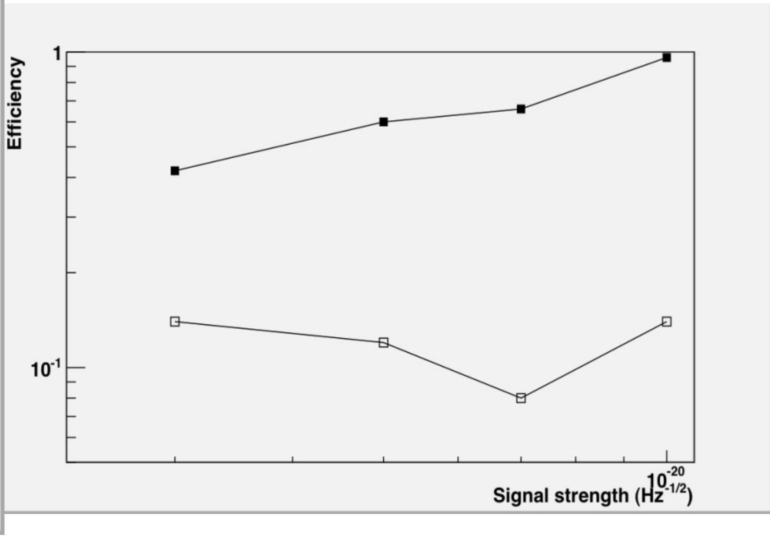


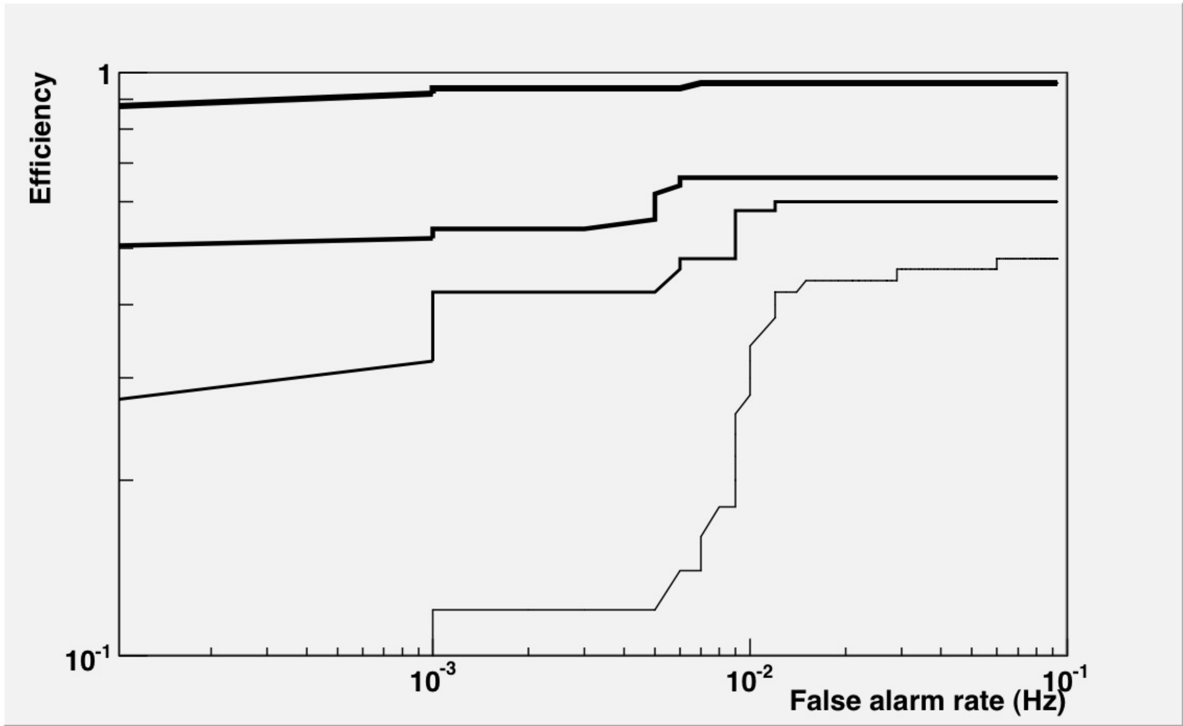
Injection of non-transverse signals



“ROC” curves


GW Efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.02
0.04
0.06
0.08
0.1
0.12
0.14
Non-GW Efficiency


Efficiency
1
10^{-1}
10^{-20}
Signal strength ($Hz^{-1/2}$)


Efficiency
1
10^{-1}
10^{-3}
10^{-2}
10^{-1}
False alarm rate (Hz)

Summary

- A complete set of C++ classes with a dynamic library
  - Adaptive version still to be completed and tested
- We aim to finish soon a first complete version of the burst pipeline
  - Already partially tested on mock data
  - More tests foreseen (also on real data when avaliable)
- The final outcome will be a list of triggers, with arrival direction
  - Geometrical veto allows reduction of false alarm rate by a factor of 10
- If everything works fine, we will attack the analysis of periodic signals at the beginning of next year