Soluzione GPU per l'identificazione di segnali gravitazionali nei dati dei detector interferometrici

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MaCGO Project - **Einstein Telescope** Project
INFN Perugia

CCR Workshop 2011 - Stato e Prospettive del Calcolo Scientifico

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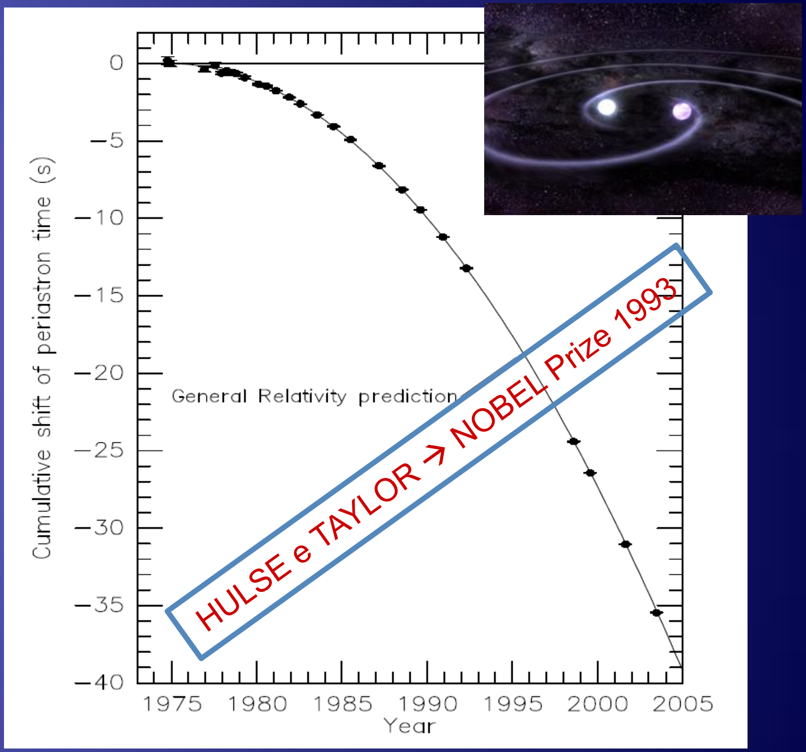
Gravitational Waves: experimental observations

Hulse and Taylor made experimental observation between 1973-1983 about a stellar binary system composed by two compact objects. They recorded an orbital period variation in agriment with the Einstein general relativity. The system lose energy via GW!!.



Osservazioni Sperimentali

$$\dot{P}_{b,corr} = -(2.4056 \pm 0.0051) \times 10^{-12} s/s.$$

Previsioni teoriche

$$\dot{P}_{b,GR} = -\frac{192\pi G^{5/3}}{5c^5}\left(\frac{P_b}{2\pi}\right)^{5/3}(1-e^2)^{7/2}\left(1+\frac{73}{24}e^2+\frac{37}{96}e^4\right) m_p m_c (m_p+m_c)^{-1/3}$$

$$\dot{P}_{b,GR} = -(2.40242 \pm 0.00002) \times 10^{-12} s/s.$$

$$\frac{\dot{P}_{b,corr}}{\dot{P}_{b,GR}} = 1.0013 \pm 0.0021$$

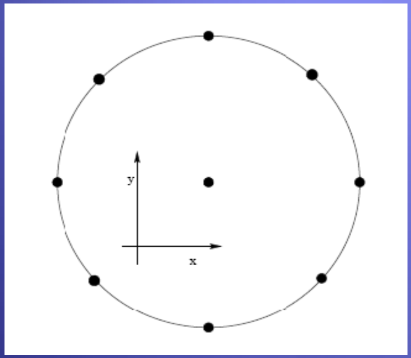
Accuratezza 0.13 %

GW Signal Effects

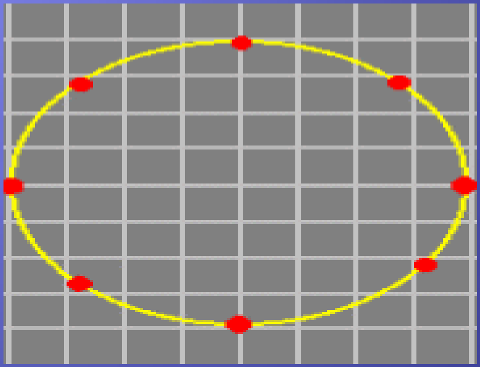
GW signal is composed by two polarizations: h+, hx

$$h_{\mu\nu}^{TT} = h_+ \mathbf{e}_{\mu\nu}^{+} + h_\times \mathbf{e}_{\mu\nu}^{\times}$$

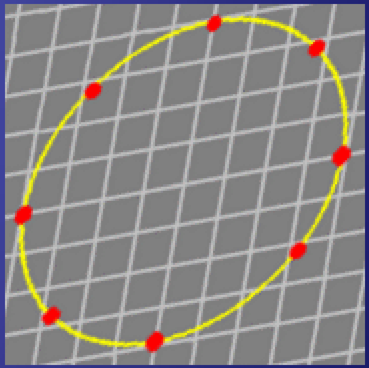
Particelle a riposo



Polarizzazione +



Polarizzazione x



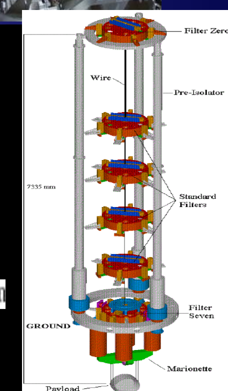
"Allungamento"

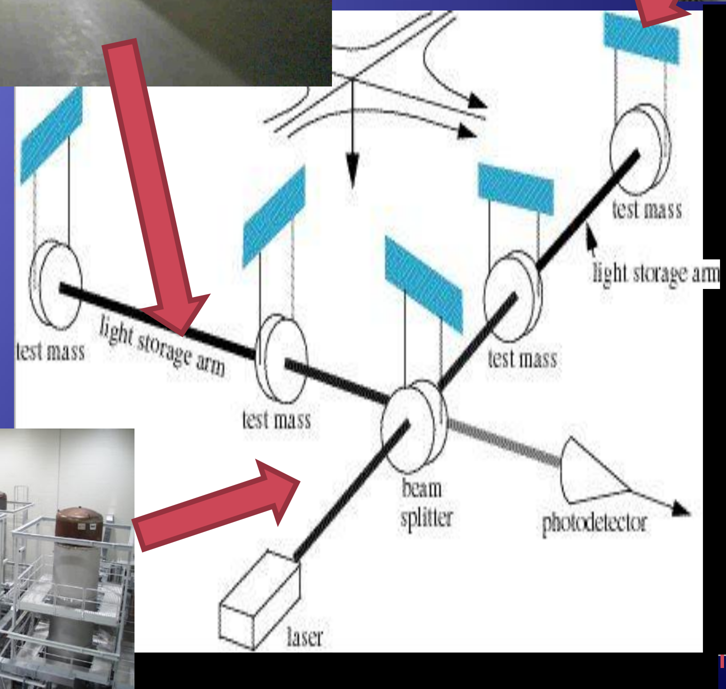
$$L(t) = \sqrt{(1 + h_+(t))x_0^2 + (1 - h_+(t))y_0^2}$$

"Allungamento"

Interferometric GW Detector: VIRGO

VIRGO goal is the direct detection of gravitational waves, as predicted by Einstein's general relativity theory.





VIRGO is an INFN/CNRS experiment. It is located in Cascina (PI).

Gravitational wave direct observation and the VIRGO experiment

- Similarly to Hertz experiment for the electromagnetic field, a ground based detectors want **realize a gravitational wave antenna**

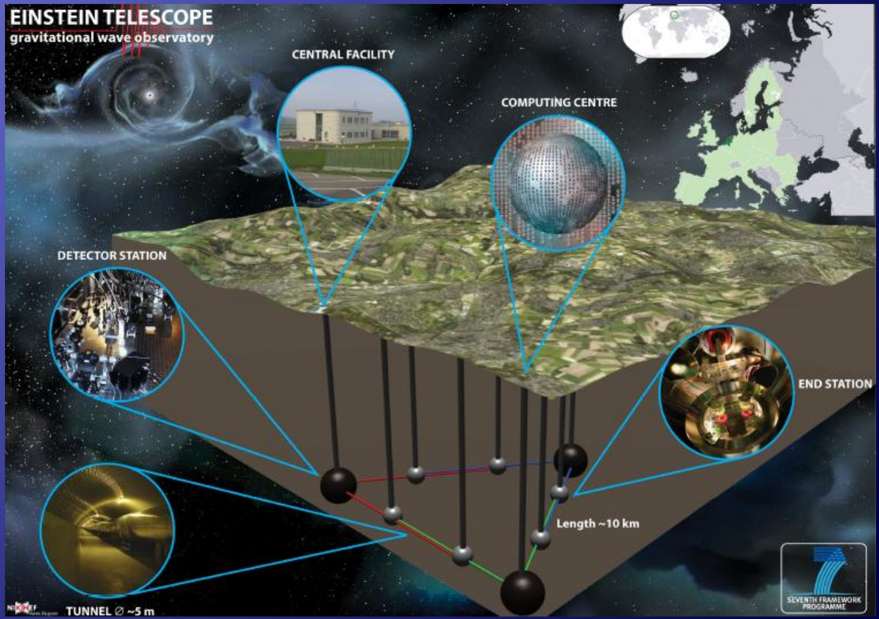
- There are many different gravitational wave sources
- There are many different gravitational wave signals
- We change detection algorithms and strategies with the type of signals

Einstein Telescope Project

❖ Einstein Telescope is a design study supported (2008-2011) by EC within FP7, concerning the study and the conceptual design of a new infrastructure for Gravitational Wave science and to open the era of gravitational wave astronomy. 2 order of magnitude more sensible respect actual detectors.

❖Personal activity:

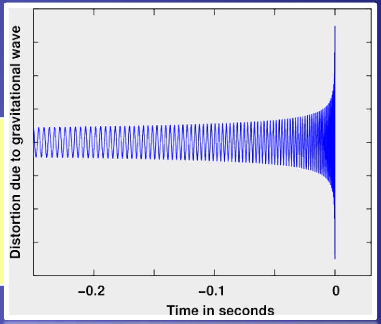
analysis, test and design of the expected computational infrastructure.



CB Signal detection method:
Matched Filtering & Templates bank

Matched filtering:

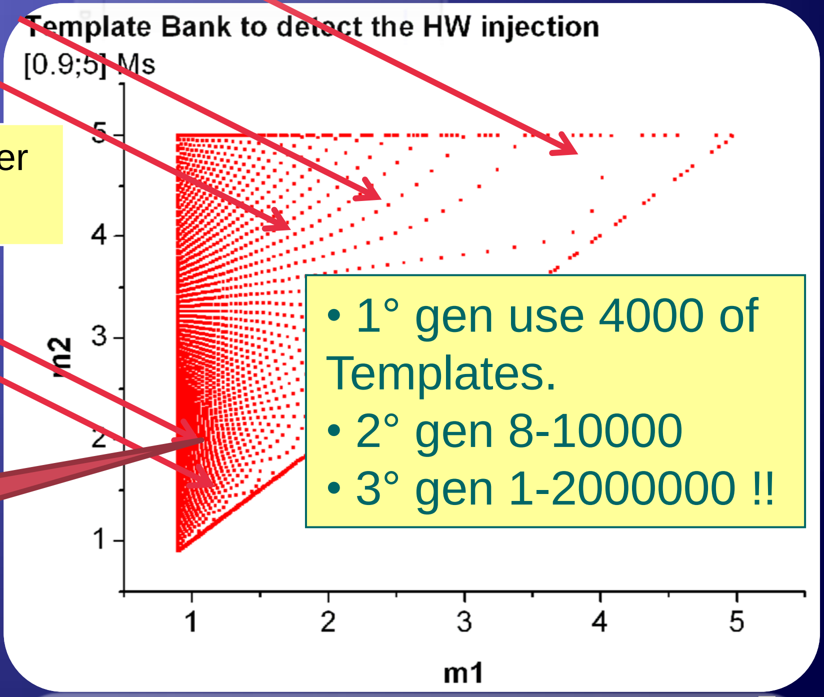
Reference signal, called ***template*** in freq. domain



$$z(t) = 4\int_0^\infty \frac{\tilde{s}(f)\ \tilde{h}^*(f)}{S_n(f)}\ e^{2\pi i f t}\ df$$

FFT (Detector Data)

One-sided noise power spectral density



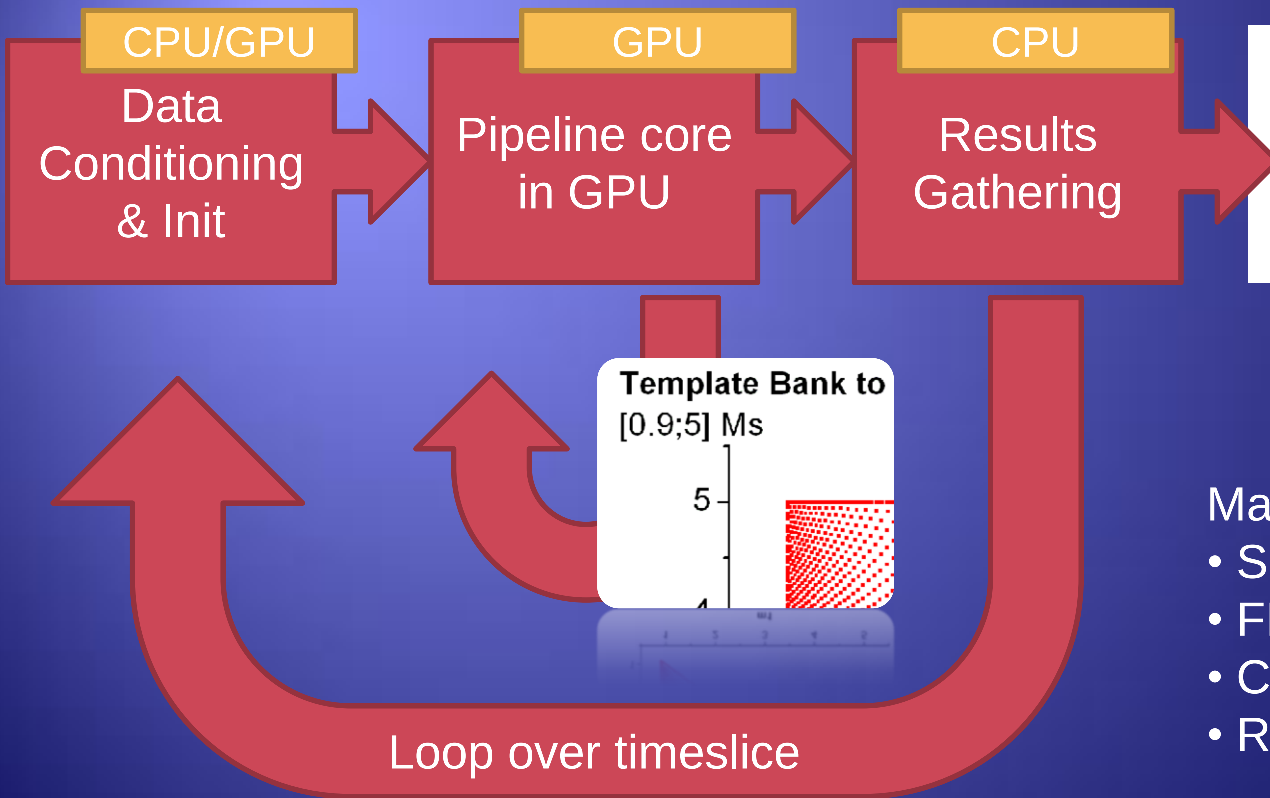
- 1° gen use 4000 of Templates.
- 2° gen 8-10000
- 3° gen 1-2000000 !!

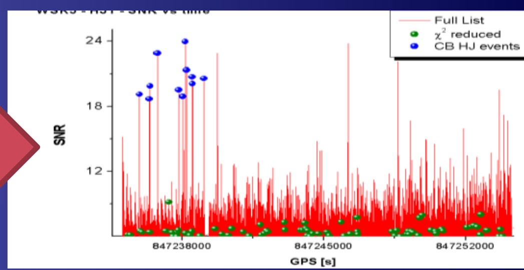
Looping over ALL templates for each timeslice of data.

MaCGO Project activities

- Next 10-15 years CPU architecture will change deeply, introducing a manycore organization, where thousands scalar processors will be embedded in the same die. Right now major vendors are starting to implement this new technology on Graphic Processing Unit. Modern GPUs can provide more than 200 cores, permitting to realize computational node with roughly 1000 cores.
- Data analysis for ET generation of GW observatories involve a wide set of algorithms:
  - Signal processing: FFT, correlation, convolution, ..
  - matrix-vector algebra
  - minimization problems
- These algorithms are of interest on many others research field
- The goal of the project is:
  - Study of these new technology and programming paradigm for science purpose.
  - Porting data analysis algorithms on these new architecture, producing a manycore data analysis library.

Problems parameters: data vector size + N template

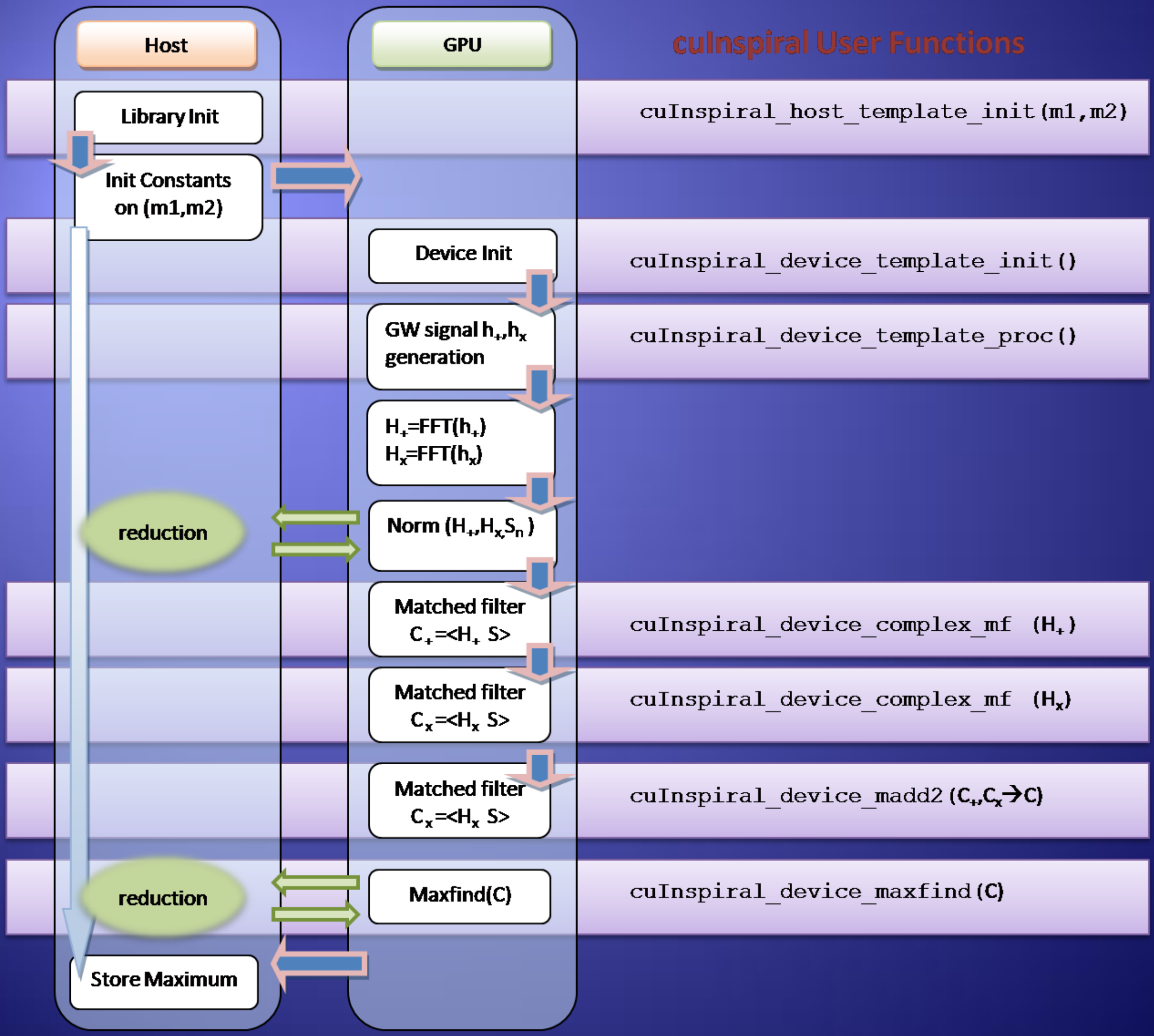




Main critical functions:

- Signal generator
- FFT
- Complex Vect op.
- Results gathering

GPU CB detection pipeline

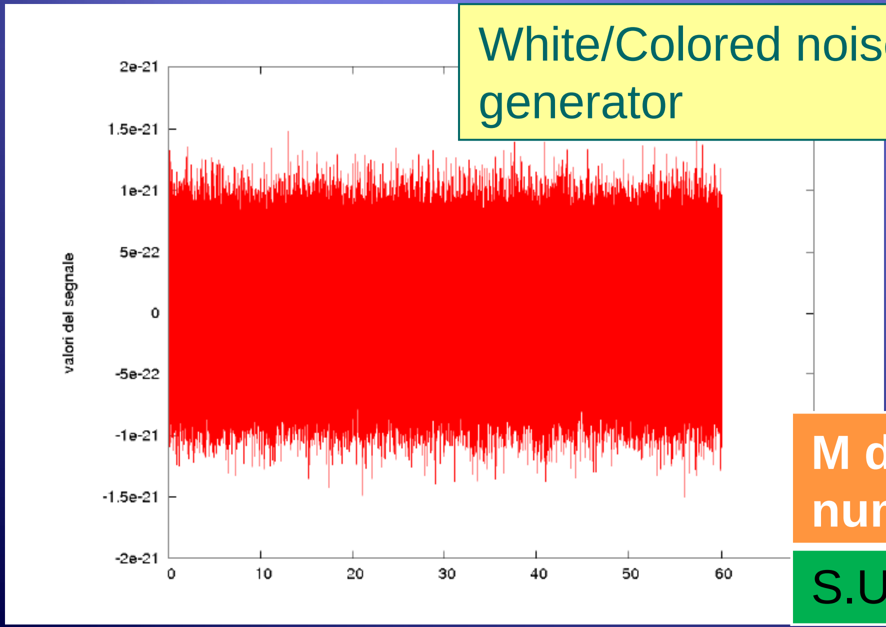


Random Numbers and Noise Generators on GPU (MT, MWC, RAND)

e.s.Mercenne Twister

Vector size	48 M	96 M	192 M	384 M
Speed up no copy	35.69	34.81	34.60	34.31
Speed up with copy	3.70	3.54	3.84	3.88

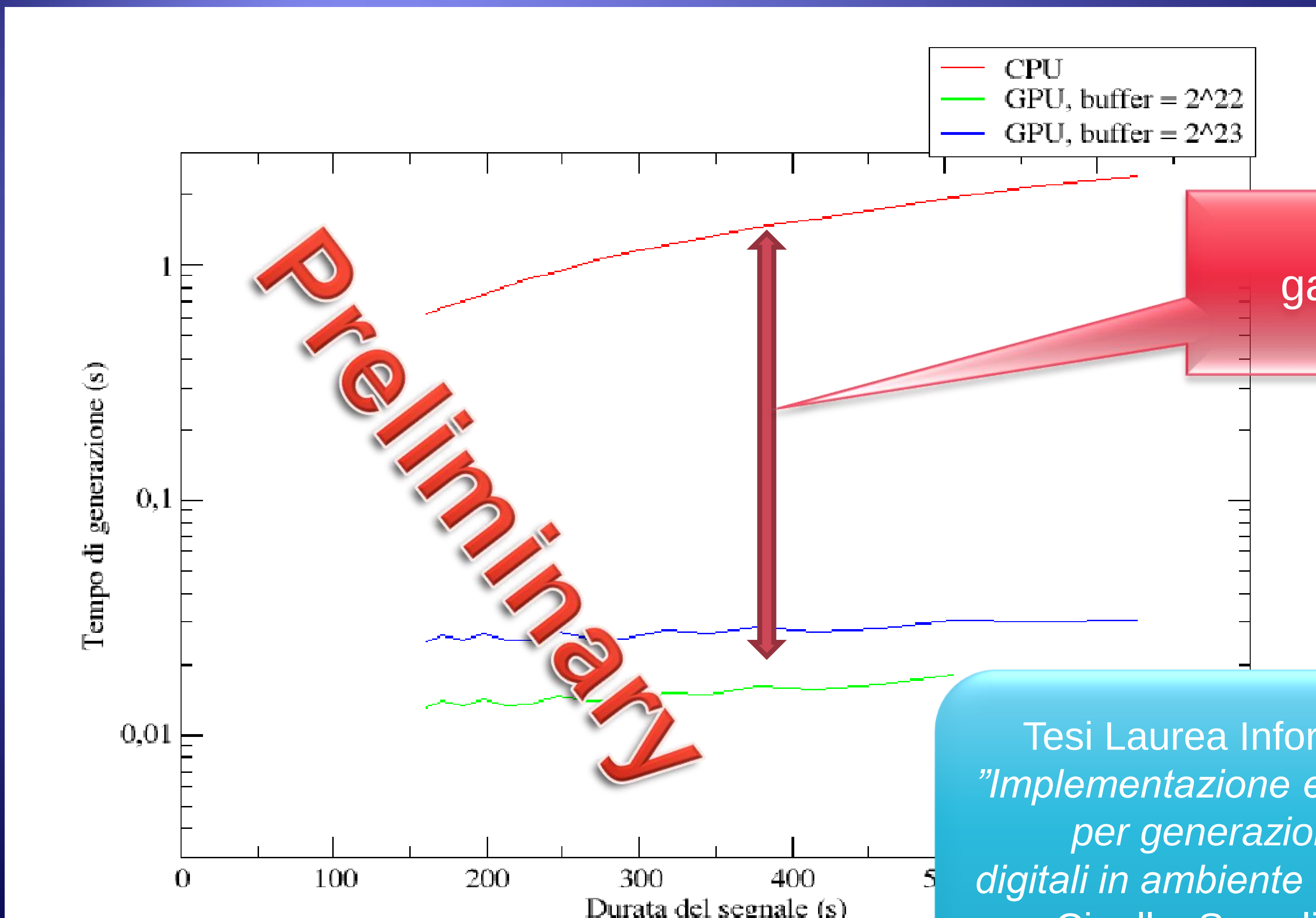
White/Colored noise generator



Tesi Laurea Informatica, Uni.PG: "**Generatori di numeri Pseudo-Random su GPU**" M. De Bonis, Servoli, Bosi, Storchi @ MaCGO & ET Projects

M di num.	48 M	96 M	192 M	384 M
S.Up	39.00	38.25	38.00	38.00

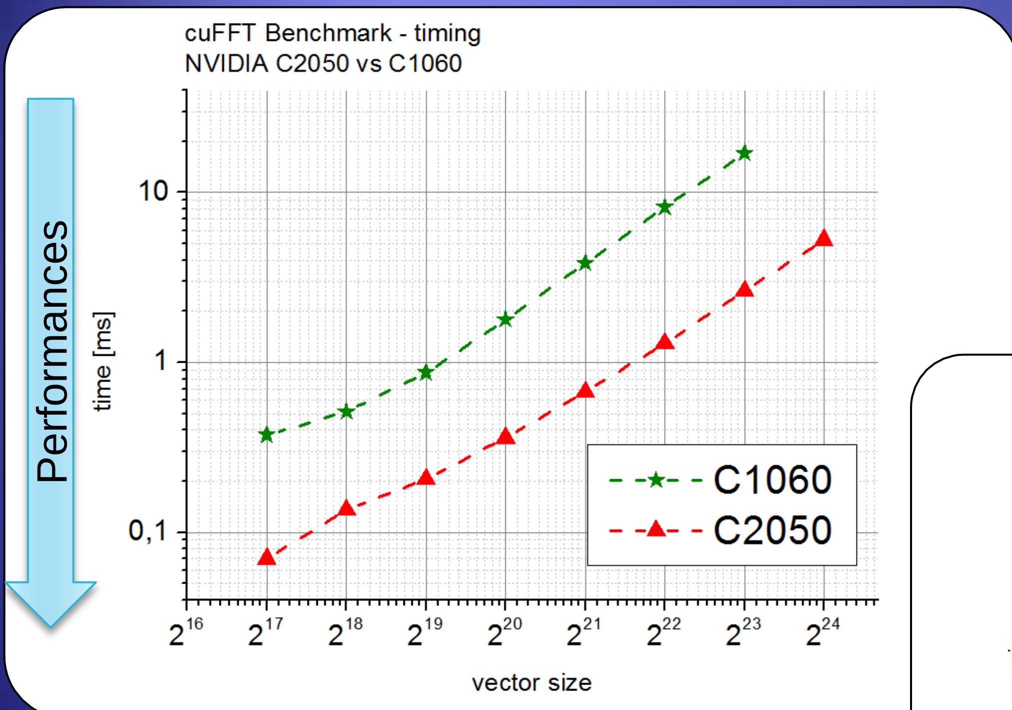
Template Signal Generation function:GPU vs CPU

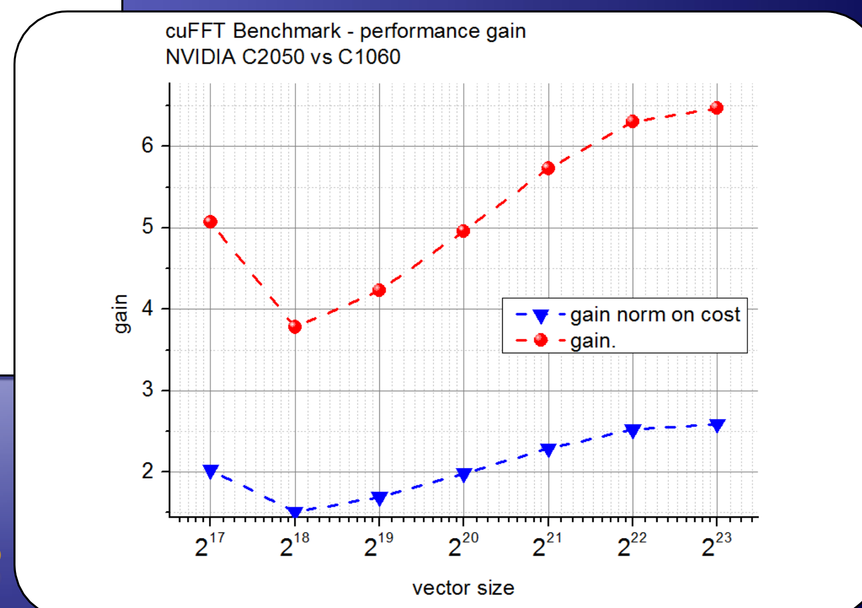


Leone B. Bosi – INFN Perugia

Tesi Laurea Informatica, Uni.PG:
"Implementazione e studio di algoritmi per generazione di segnali digitali in ambiente CUDA e OPENCL"
Cipullo, Servoli, Bosi, Storchi
@ MaCGO & ET Projects

cuFFT C2050 vs C1060

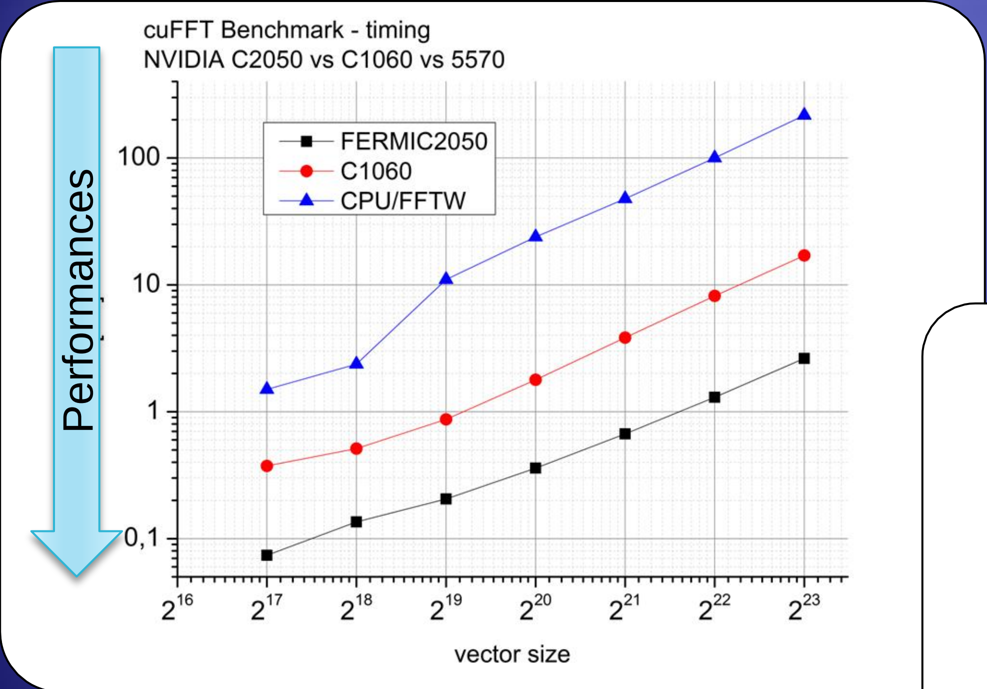


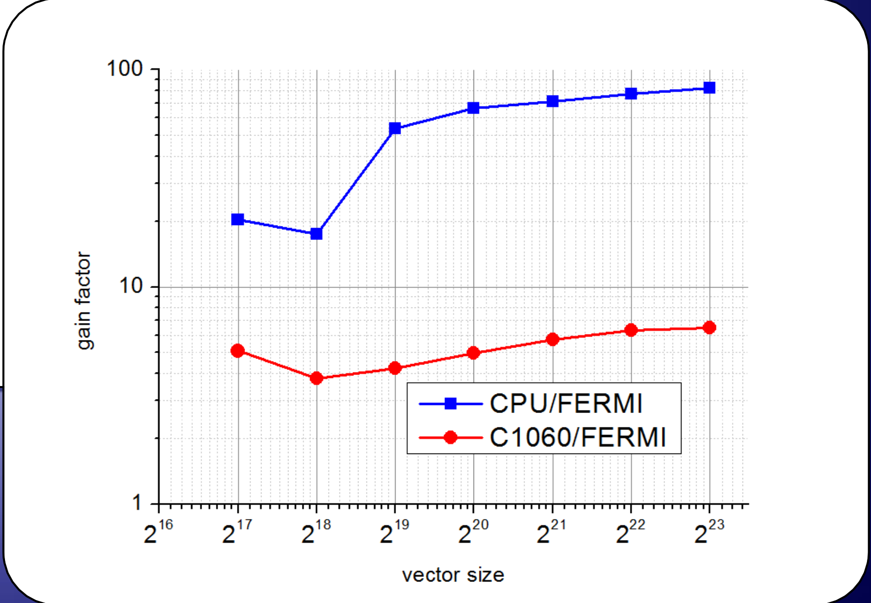


C2050 increases perfrormances with Vector size. **TOP PERF GAIN X7@2^23**

NORMALIZING respect to board price the gain is **BETWEEN 1.5 – 2.5**

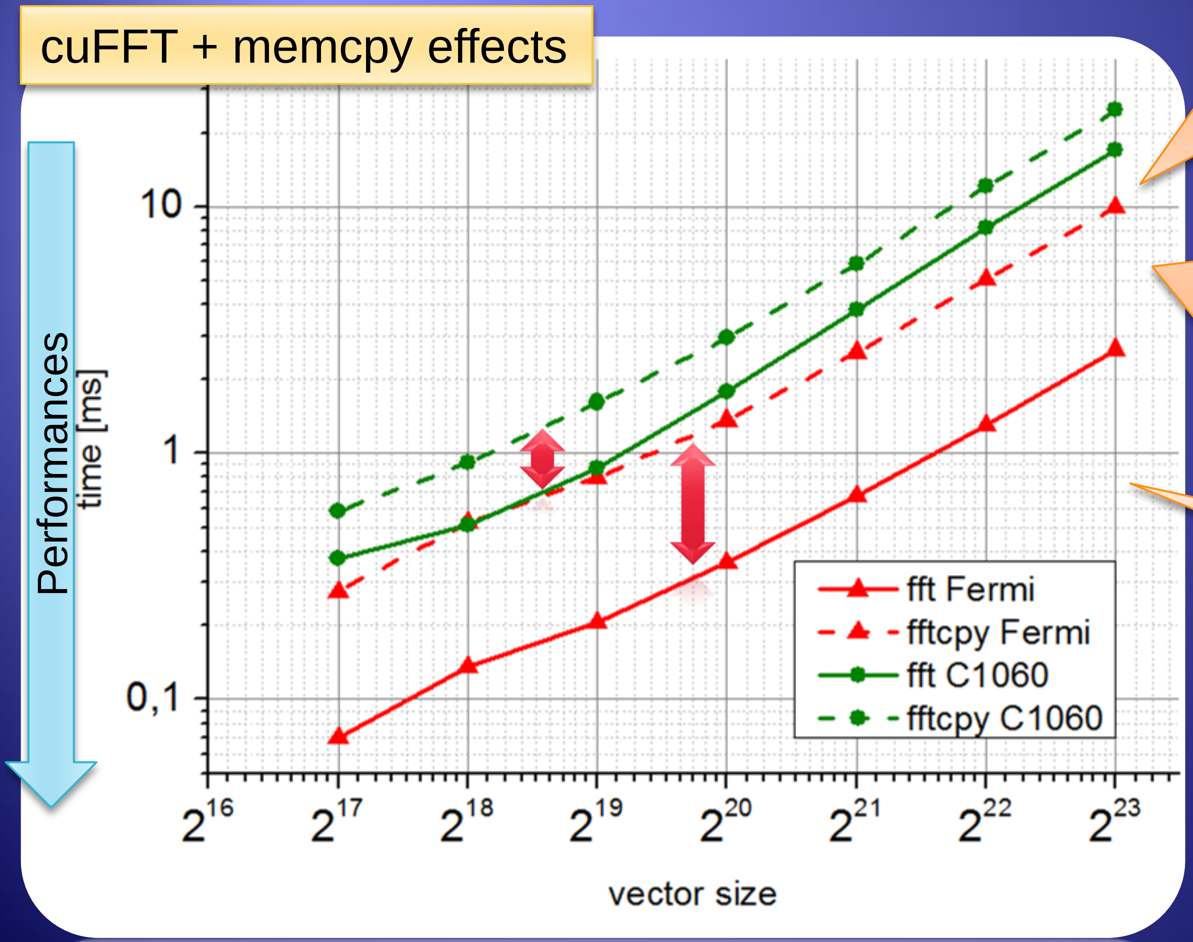
cuFFT C2050 vs C1060 vs FFTW CPU(5570)





Between C1060 and CPU there is a **FACTOR 10**
Between C2050 and CPU there is a **FACTOR 80**

cuFFT C2050 & C1060:
GPU as "Co-Processor" and IO Effects



Test strategy:

1) Only FFT
2) memcpy host->GPU + FFT

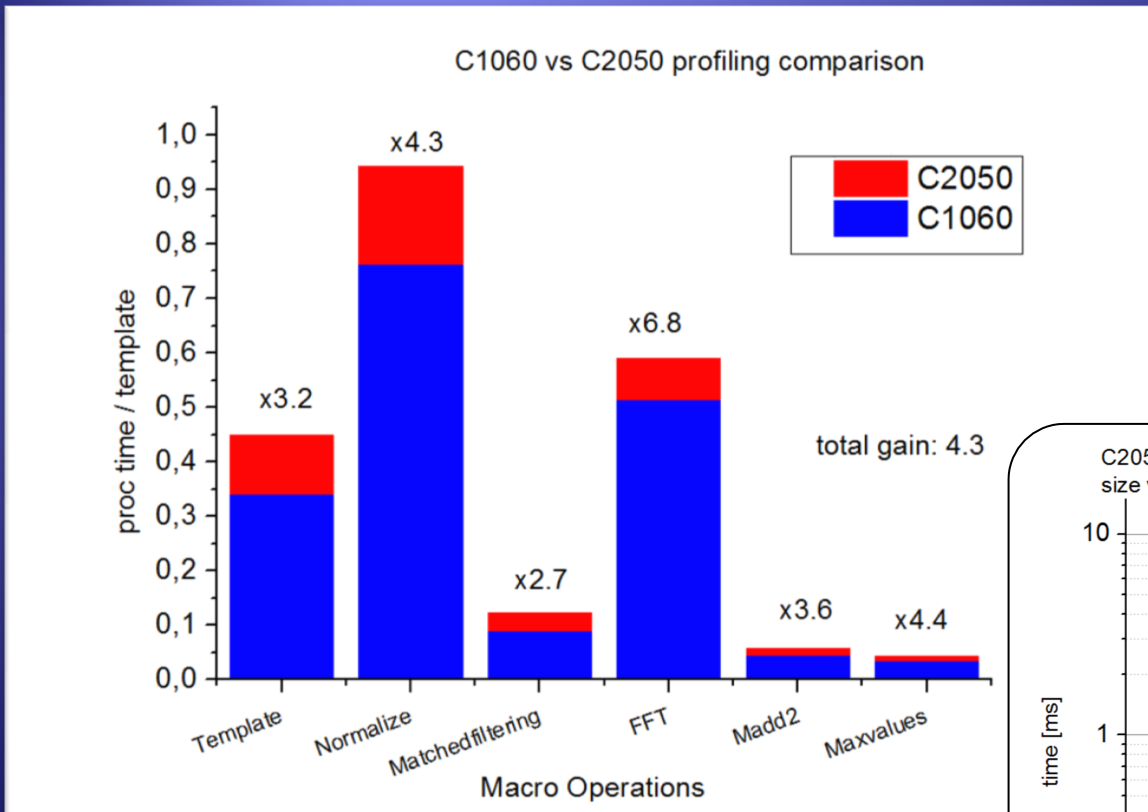
Obviously making continuos IO and using GPU as Co-processors kills GPU benefits.

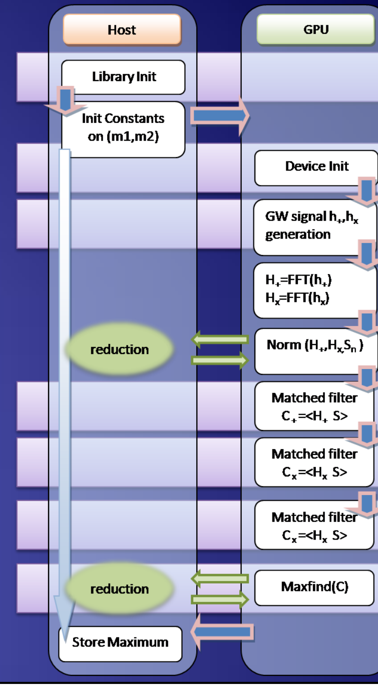
The bottleneck is common, the PCI bandwidth and the final effect is a disaster:

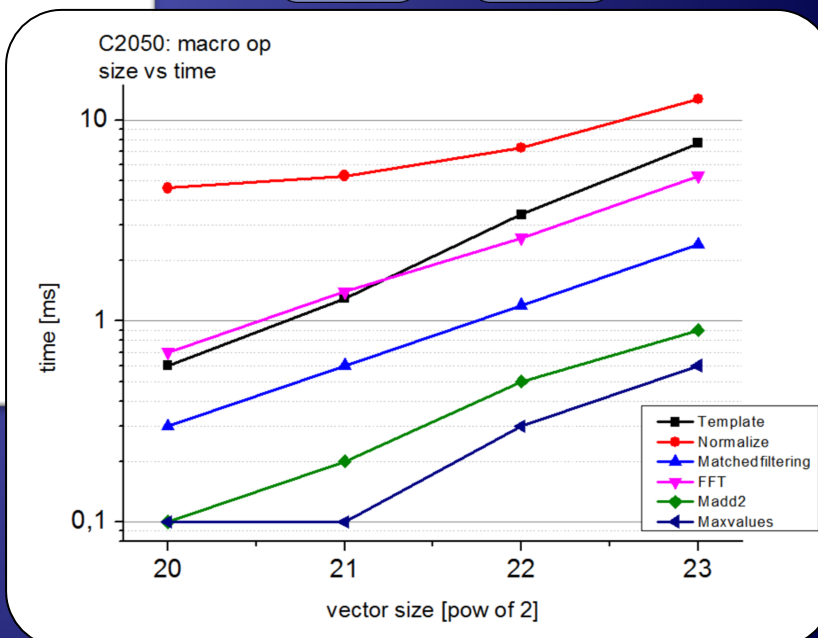
Fermi → -250/300%

C1060→ -55/65%

Pipeline Profiling





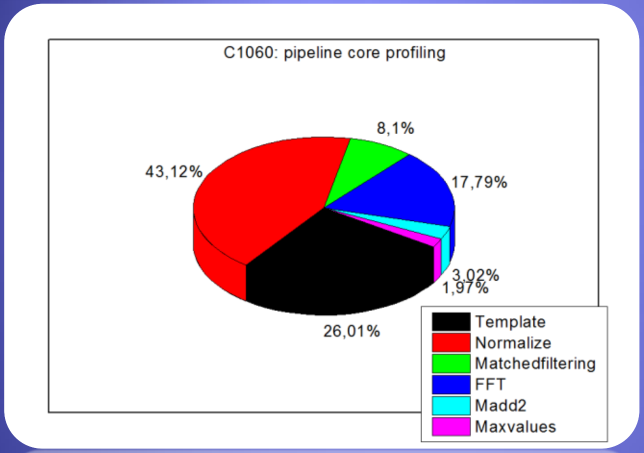


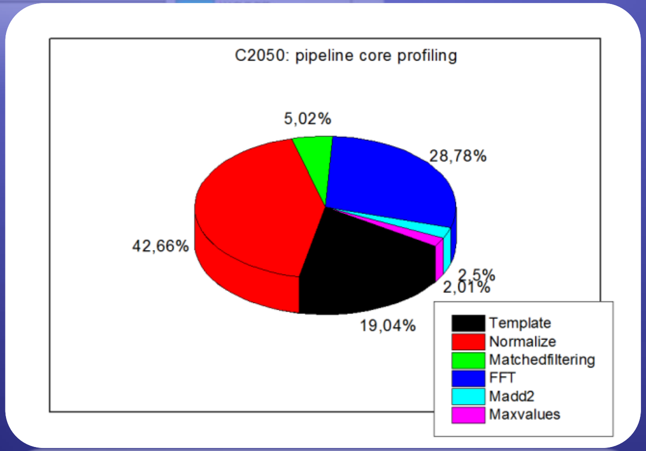
Pipeline C1060/C2050 gain:

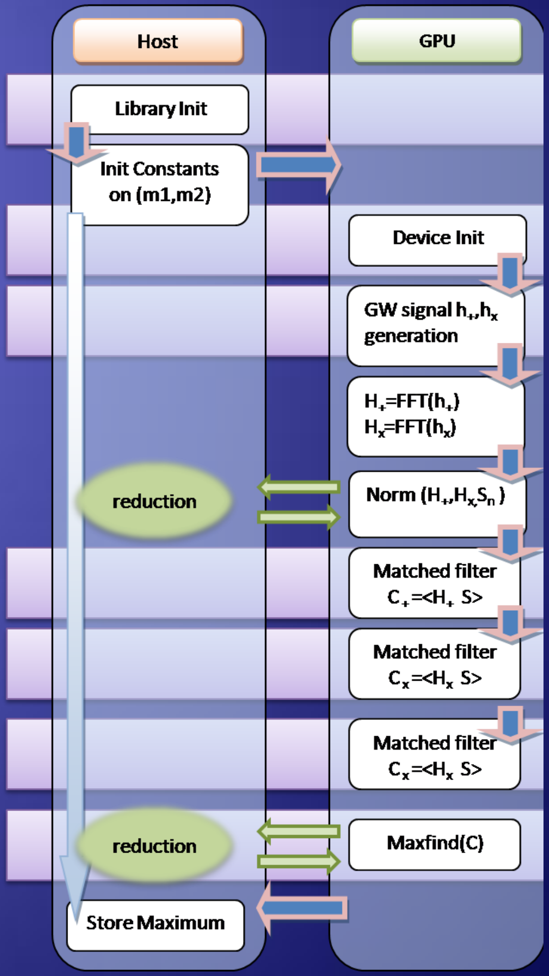
FACTOR 4.3

- **Sign. Gen. x3.2**
- **FFT → x7**
- **Complex Vect. Op →x3.5 - 4**

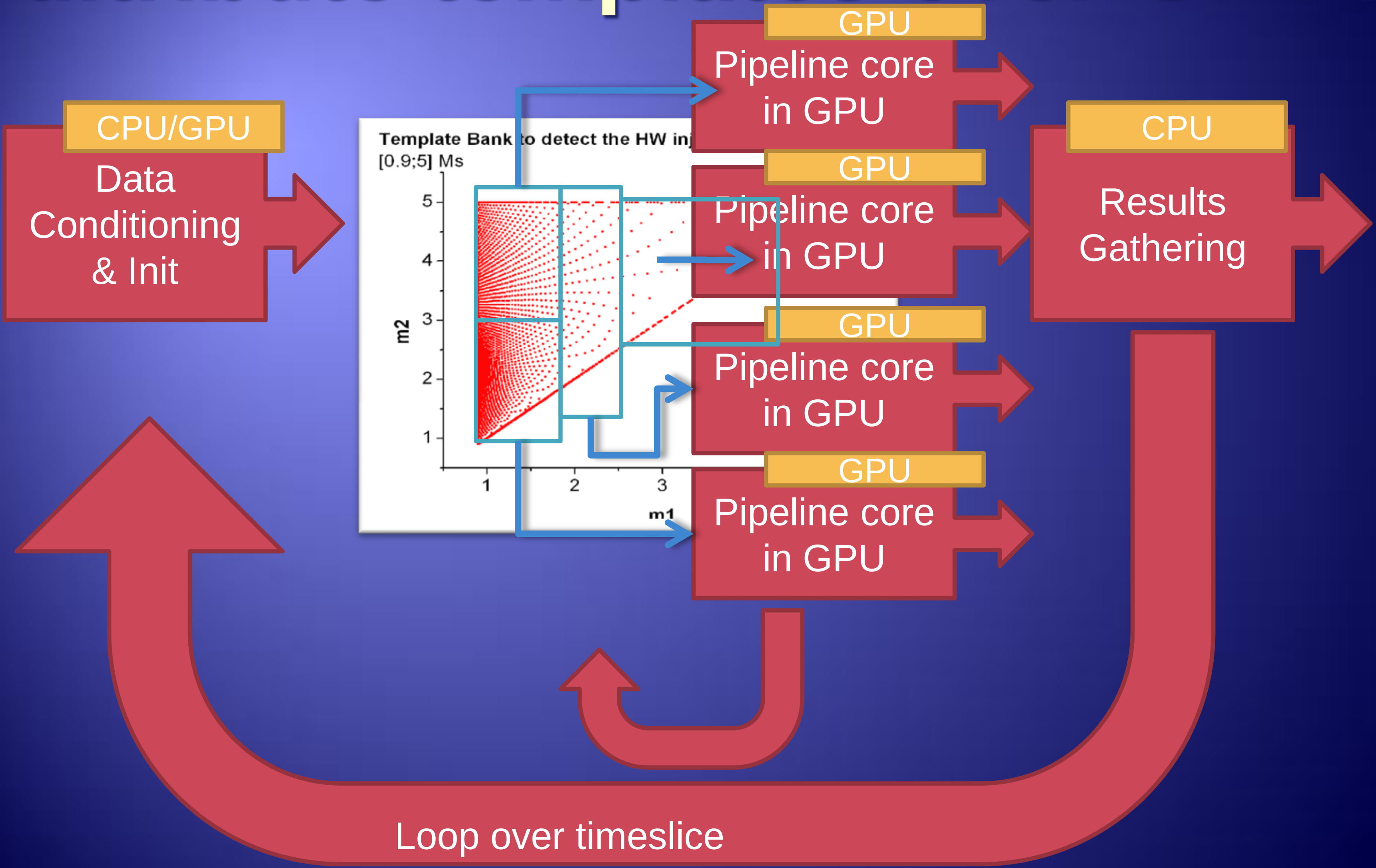
Pipeline Profiling: Macro Op distribution





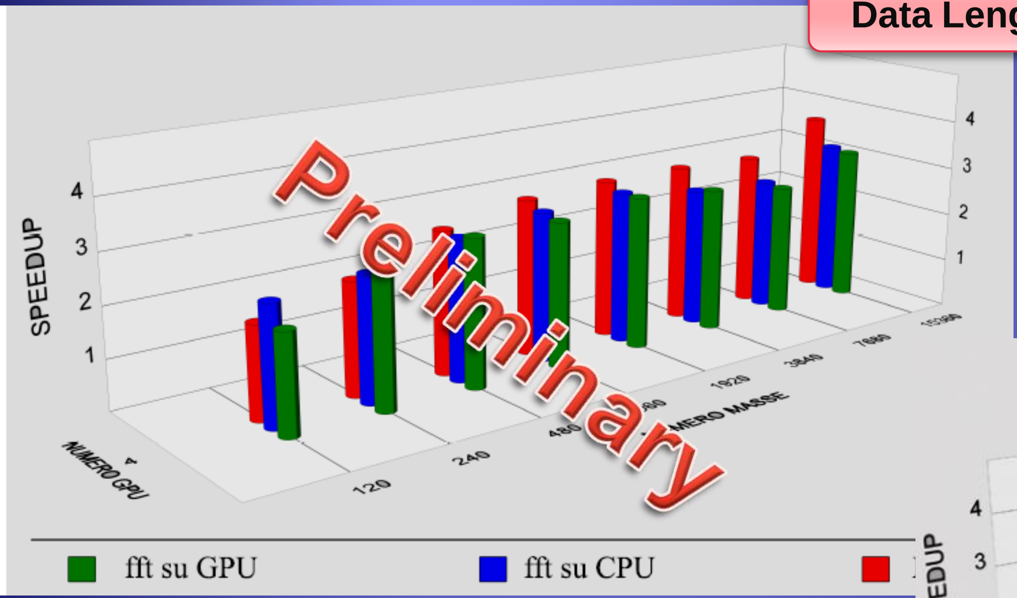


Multi-GPU pipeline: ditribute templates over GPUs

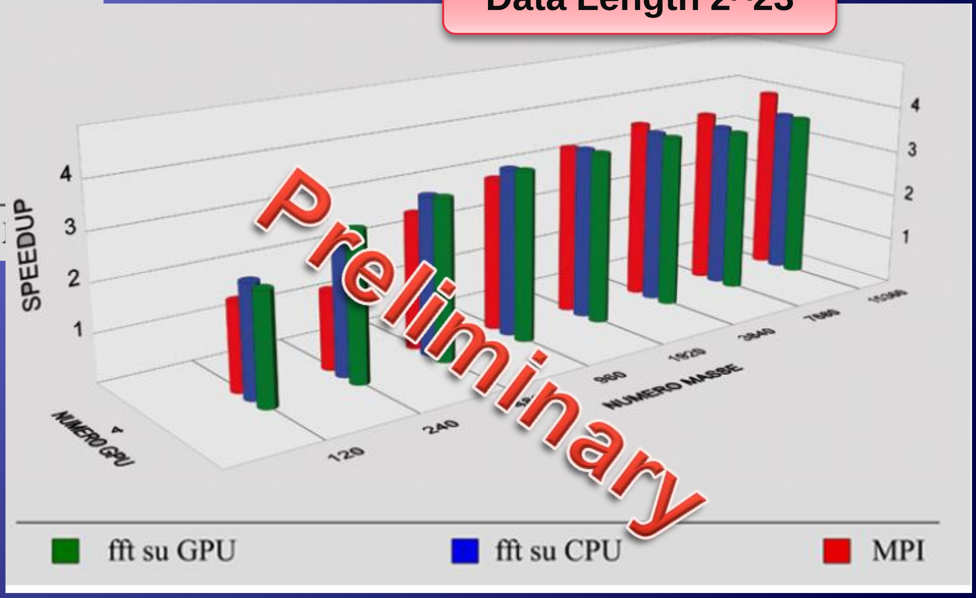


Multi GPU implementation: (MPI and Ptherads case):

Data Length 2^19



Data Length 2^23



Tesi Laurea Informatica, Uni.PG:
"Utilizzo di MPI e Pthread nella parallelizzazione multi-GPU di algoritmi di identicazione di segnali gravitazionali"
*L.*Fontana, Servoli, Bosi, Storchi
@ MaCGO & ET Projects

Effects on GW Data Analysis

- The first set of test made with GTX 275 and with C1060 provided a gain factor respect the CPU implementation of the same algorithms of **X50**
- This means a number of matched filering per seconds of
  - **C1060 →30 TEMPLATES/SEC**
- New preliminary results with Fermi technology report a matching rate **>X4** respect to the previous results, providing:
  - **C2050 → 120 TEMPLATES/SEC**
- The preliminary Multi-GPU version of the pipeline gives another factor **X3** :
  - **4GPU C2050 → 400 TEMPLATES/SEC**

This is a very impressive results, permitting to cover with 4 GPU the Virgo 2° quasi-real-time data analysis, that will involves more than 150 CPUs.

Thanks to:

INFN that supports and funds MaCGO project (http://macgo.pg.infn.it)

Einstein Telescope Project (The research leading to these results has received funding from the European Communitys Seventh Framework Programme (FP7/2007-2013) under grant agreement n 211743 in the context of ET (Einstein Telescope) Design) – http://www.et-gw.eu

Dr. Loriano Storchi

Dr. Leonello Servoli

Dr. Michele Punturo

And E4 Computer Engineering for hardware provided and used in some of our tests.

Cuda vs OpenCL code

C for CUDA Kernel Code:

```
__global__ void
vectorAdd(const float * a, const float * b, float * c)
{
    // Vector element index
    int nIndex = blockIdx.x * blockDim.x + threadIdx.x;

    c[nIndex] = a[nIndex] + b[nIndex];
}
```

OpenCL Kernel Code

```
__kernel void
vectorAdd(__global const float * a,
          __global const float * b,
          __global       float * c)
{
    // Vector element index
    int nIndex = get_global_id(0);

    c[nIndex] = a[nIndex] + b[nIndex];
}
```

Ref: CUDA OpenCL JumpStart guide