Imaging of LAr scintillation light with segmented UV photodetector coupled with Coded Mask

Matteo Tenti
(INFN - BO)

XVII edizione di IFAE – Incontri di Fisica delle Alte Energie

Milano, 04 – 06 Aprile 2018

Liquefied Noble Gases TPC

- Liquefied noble gases are excellent **scintillators** and, if properly purified, allow the collection of the drifting **charges** over large distances

- Ideal for particle detectors if requiring:
  - **large target mass**
  - **low energy threshold**
  - **good spatial resolution**
  - **low radioactive background**

- Like those needed for:
  - **neutrino physics**: ICARUS, ArgoNeuT and DUNE
  - **dark matter** detection: XENON, LUX and DARKSIDE

- **LAr-TPC** key technology in particle and astroparticle physics for the next decades:
  - ICARUS and SBND at Short Baseline Neutrino Program
  - Far and Near detector at DUNE

Liquefied Noble Gases TPC

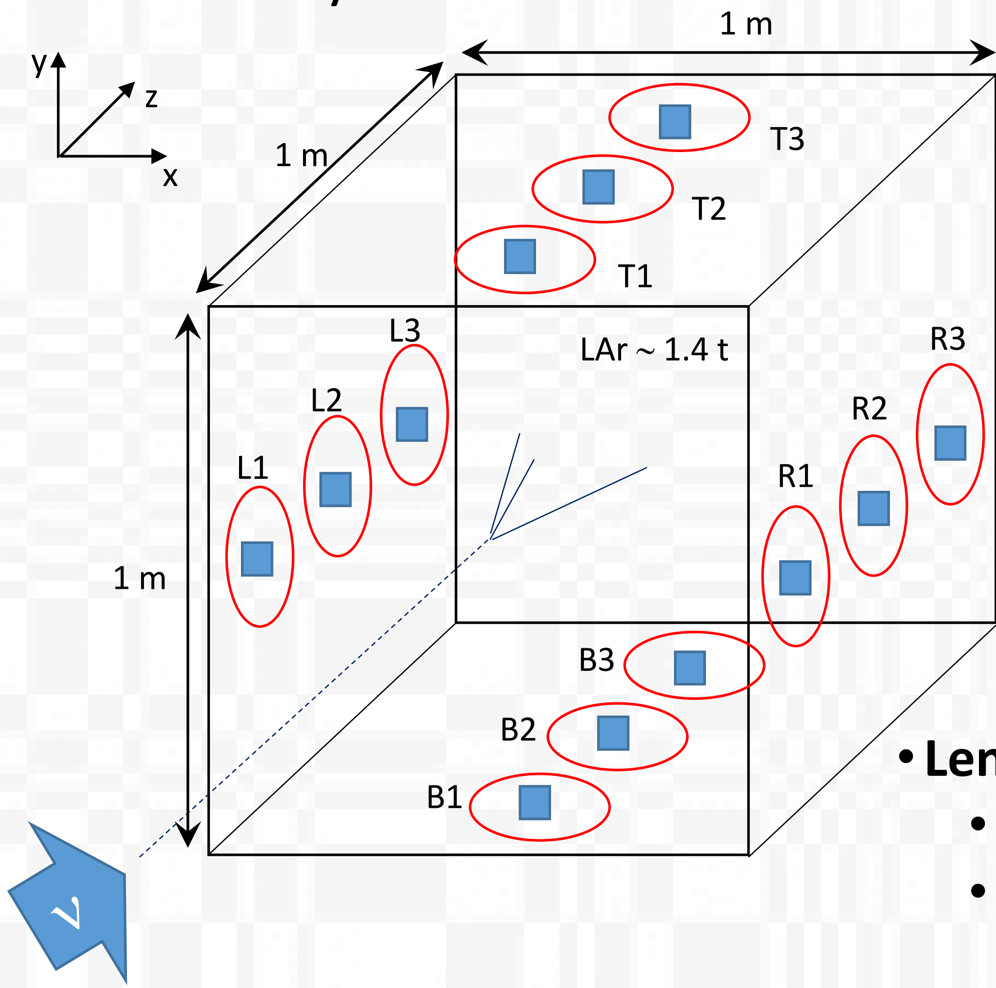
- Both prompt **scintillation light** and the **charge ionisation** signals are used
- The prompt emitted light is in the **far UV region** for both Argon and Xenon
  - Argon: λ = 128 nm; τ_S = 6 ns
- UV sensitive photosensors have **low efficiency**
  - Use of wavelength shifter deposited on the detector walls or on the photosensors themselves
- Event spatial and topological reconstruction only with **ionisation charge**
- **Limitation** for large TPCs due to slow drift velocity of charges
  - Not suitable for intense fluxes of particles.
- **Near detectors** of next generation neutrino long base line experiments may face this limitation
- Up to now, the prompt scintillation light signal is used to:
  - provides a fast signal, for self-triggering applications and off-beam background rejection
  - identify particles, in combination with charge ionization signal

The idea

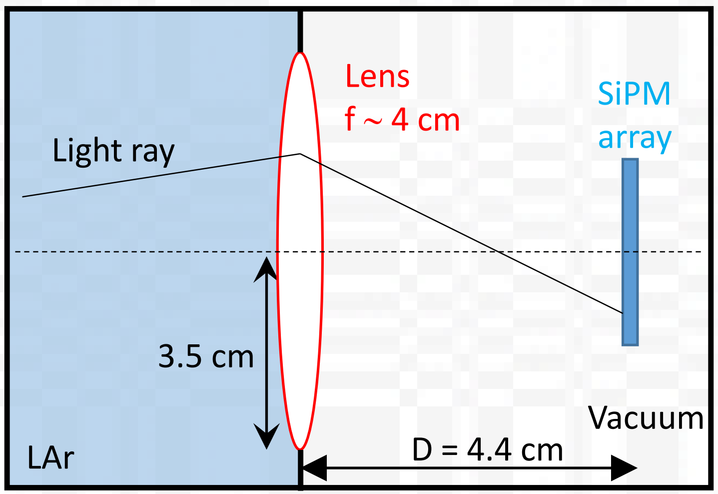
- No attempt to use **imaging technique** with UV light collected by a fast UV sensitive photodetector coupled with a suitable optical system
- Scintillation **signal is very large** (~ 40 UV photons per keV of deposited energy in Argon)
    - corresponding to ~ 1000 photons each 100 microns of track
- The **Rayleigh length is large** (95 cm), making high precision imaging possible
- A set of a few such systems distributed in stereo views can provide a fast and precise reconstruction of neutrino events in LAr, increasing performance and dramatically **reducing complexity and costs**
- A system working at the maximum of its potential, would **outperform** any existing device in terms of 4D (i.e. time and space) reconstruction of the event and maximum operation rate.

Toy simulation of neutrino event

Geometry Sketch



Lens + SiPM array

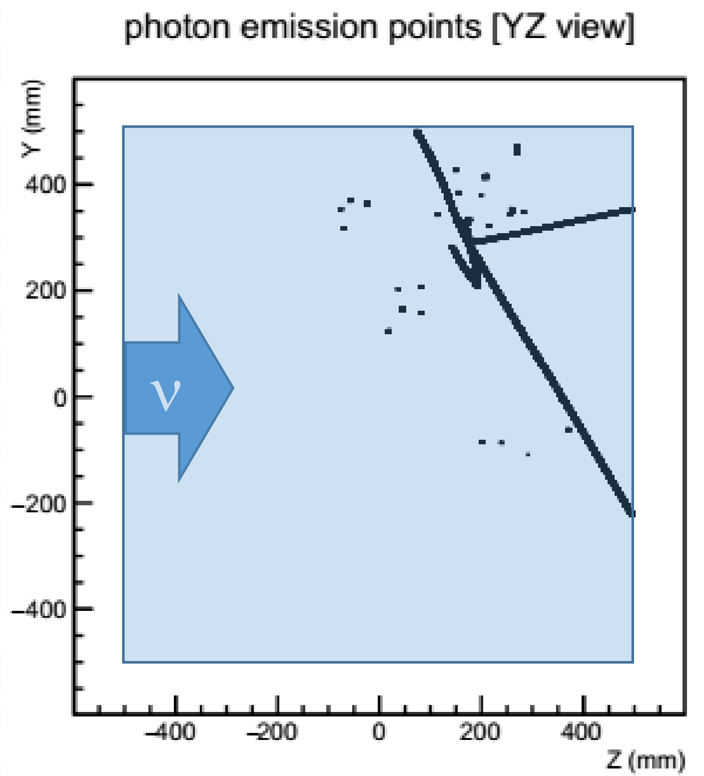


- **Lens Simulation**:
  - Paraxial Approximation
  - Thin Lens Approximation

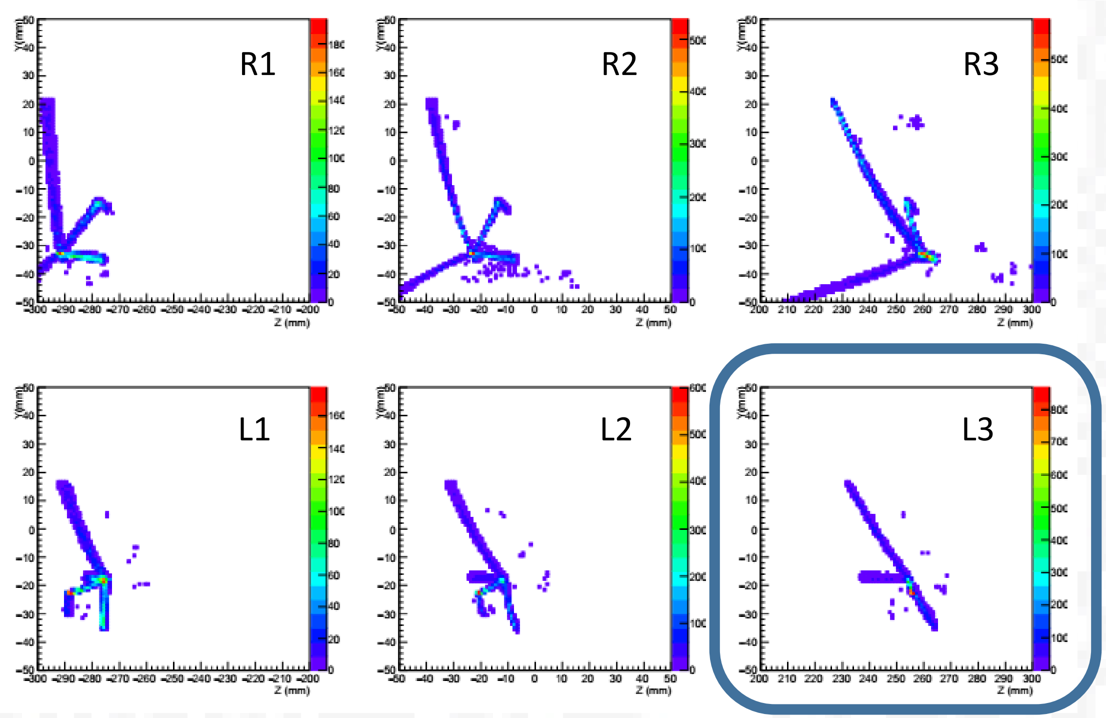
- **No lens transmittance** taken into account

Toy simulation of neutrino event

Example: ν_μCC with E_ν = 2.44 GeV [YZ view]

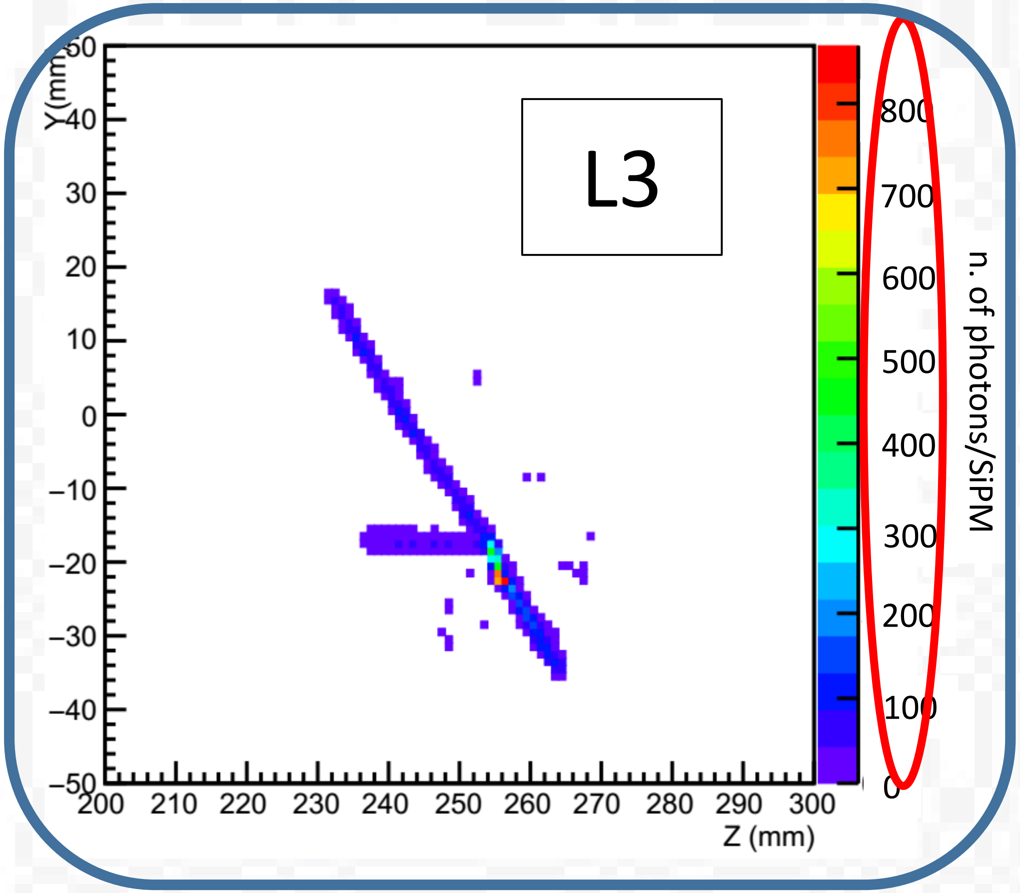


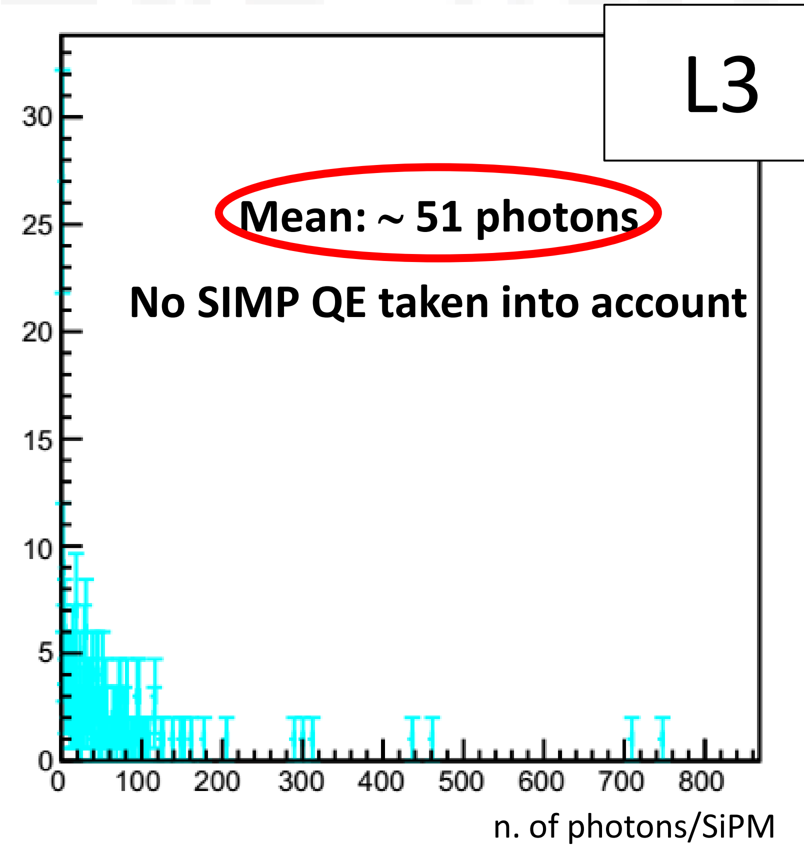
n. of photons/SiPM



SiPM array: **10 x 10**
SiPM size: 1 x 1 mm^2

Toy simulation of neutrino event





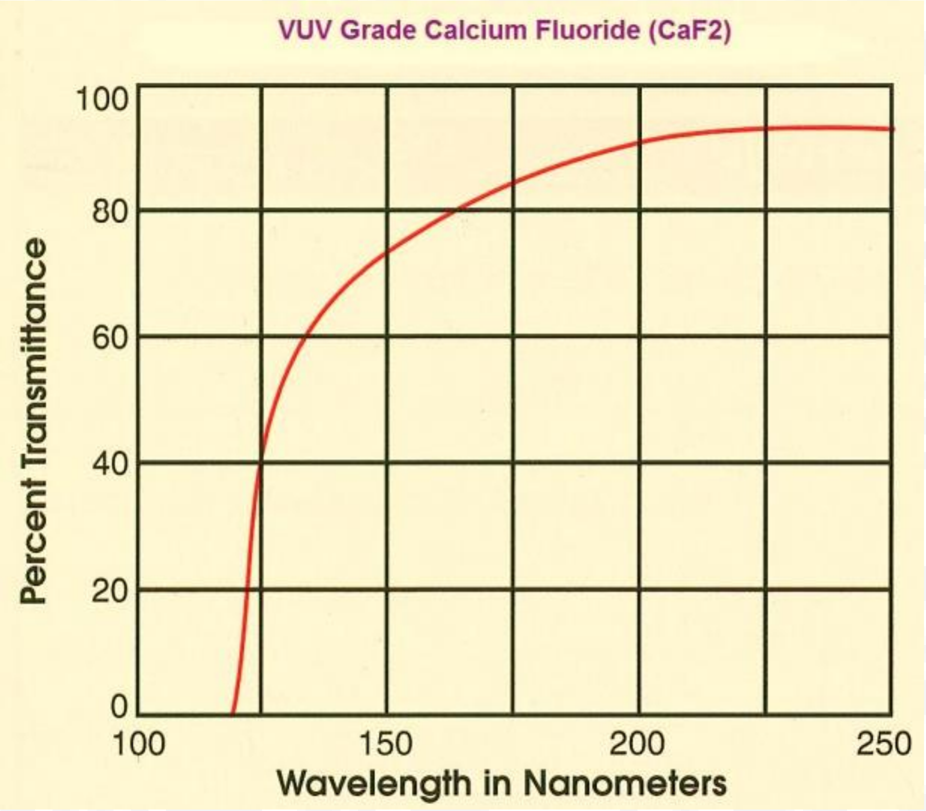
The idea is **feasible**.

Optical system: **Vacuum UV lens** (CaF_2)

- Not so expensive

But:

- **Small radius** (few cm)
- **Low efficiency**
  - (transmittance ≤ 50%)
- Which **Focal Length**?
  - Resolution?
  - Depth of field?

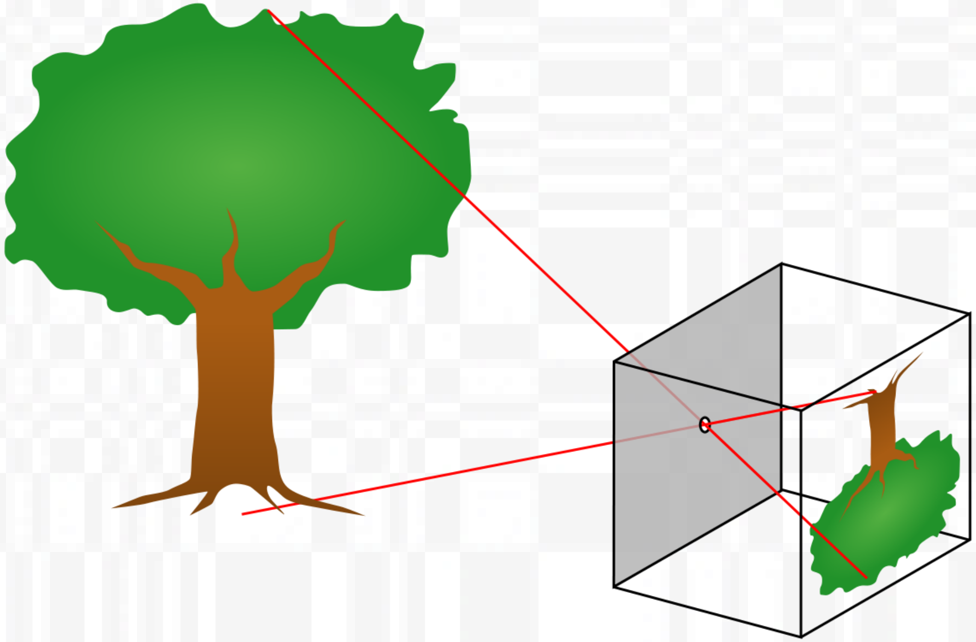


Optical System: Pinhole

- Works with any wavelengths shorter than pinhole size
- Virtually infinite Depth of Field

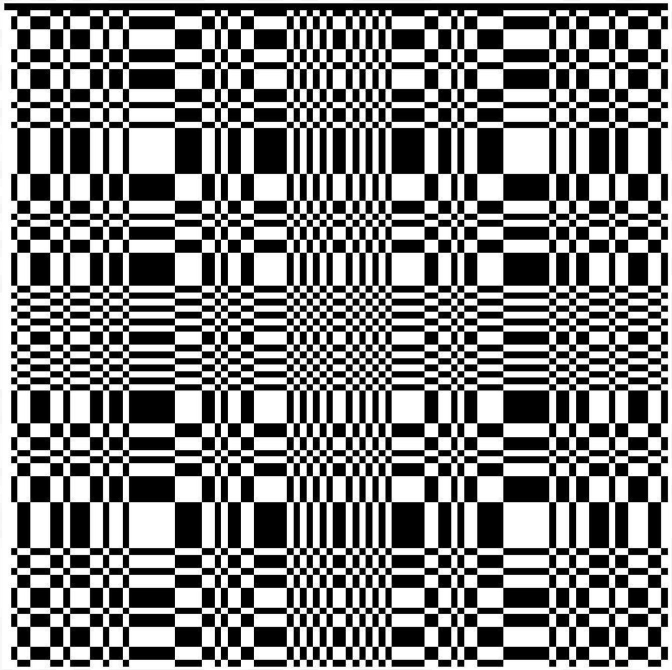
but

- **Little light collection**



Optical System: Coded Aperture

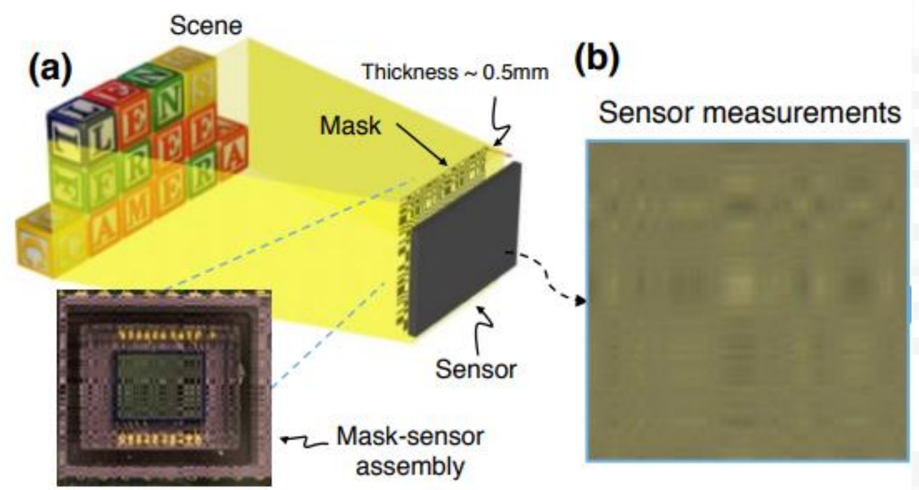
- Blocking light by a known pattern, a **coded "shadow"** is cast upon a plane
- From this shadow the properties of the original light sources can be **mathematically reconstructed**.
- C.A. is extensively used in **X and γ ray imaging** systems
- No limitation on **size**
- **Transmittance ~ 50%**
- **Resolution** equivalent to pinhole's



FlatCam (arxiv: 1509.00116)

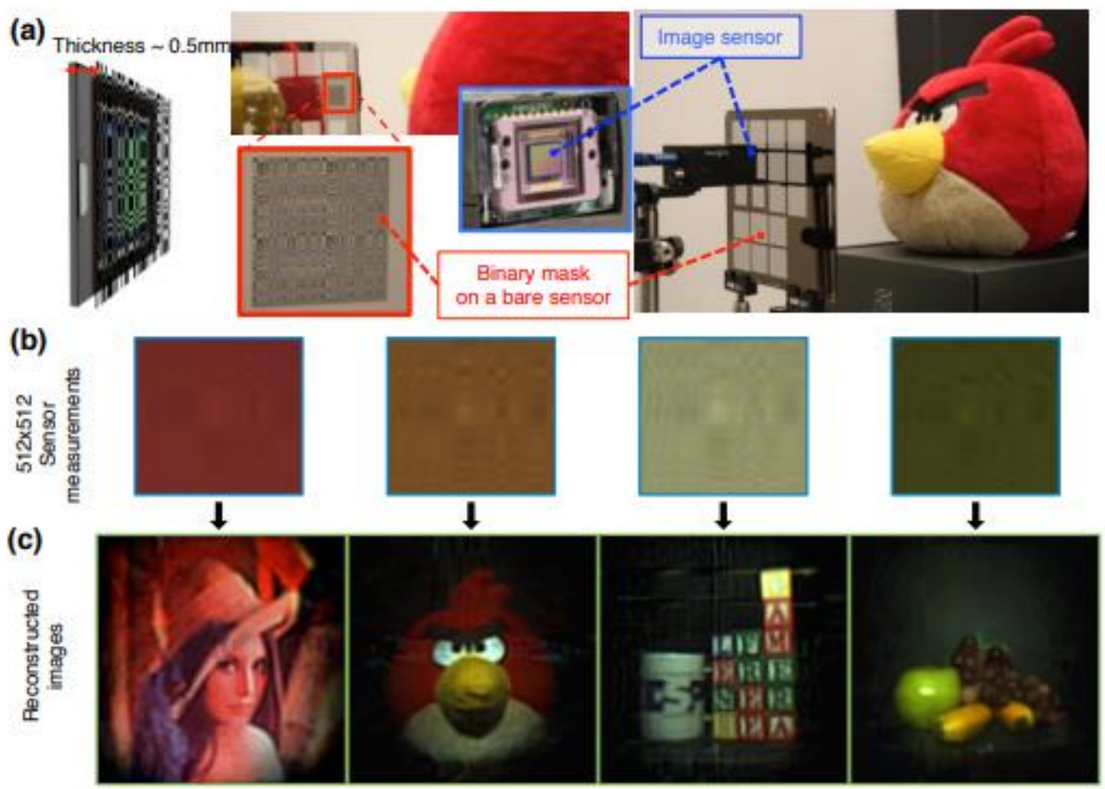
- A very interesting implementation

- Thin, Bare-Sensor Cameras using Coded Aperture and Computation
  - **Coded aperture on top of CCD** (~0.5 mm)



FlatCam/2 (arxiv: 1509.00116)

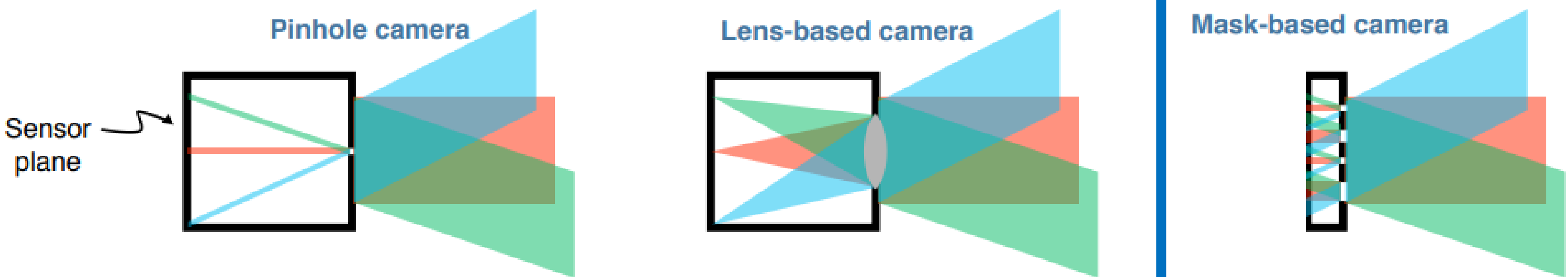
- **Image reconstruction** through post processing computation (75ms on laptop)



Coded images

Reconstructed images

FlatCam/3 (arxiv: 1509.00116)



	Pinhole camera	Lens-based camera	Mask-based camera
Light throughput	Low (~F/22)	High (~F/1.8)	High (~F/2.54)
Fabrication	Requires post-fabrication	Requires post-fabrication	Direct fabrication
Thickness	~10-20mm	~10-20mm	~10-500μm
Infrared and thermal	No wavelength limitations	Costly optics	No wavelength limitations
Cost	$	$$	$
Curved or flexible geometries	Infeasible due to limited field of view	Infeasible due to rigid optics	Adaptable to curved and flexible sensors

UV light read-out

- SiPM array
  - The operation of SiPM at cryogenic temperature
    - reduces dark current by orders of magnitude
    - provides an outstanding signal to noise ratio for the raw (pre-processed) image

- Electron Multiplying CCD (EMCCD) by Andor
  - image sensor capable of detecting single photon events without an image intensifier - unique electron multiplying structure built into the chip

On going activities

- **Mastering the reconstruction technique**
- **FlatCam MC Simulation (toy MC)**
- **Design and Construction of a prototype**
- **Development of high granularity and back illuminated SIPM (in collaboration with FBK)**

Thank you