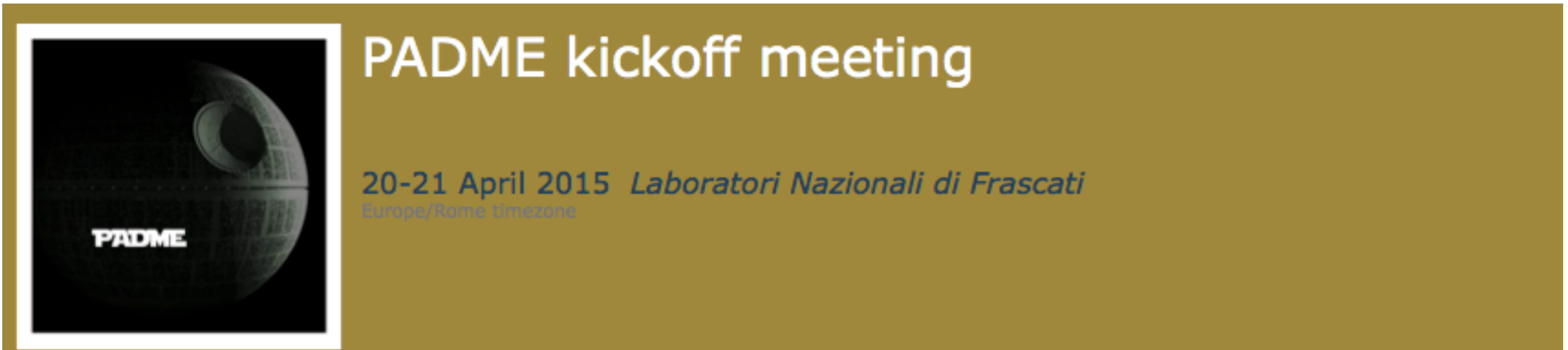
Calorimeter for BDX@LNF

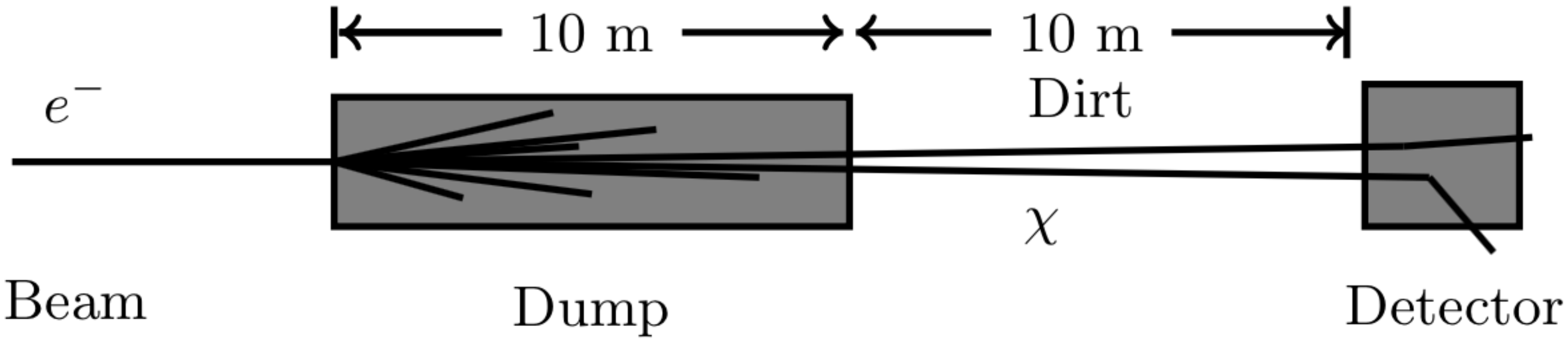
Marzio De Napoli
INFN - Sezione di Catania



PADME kickoff meeting

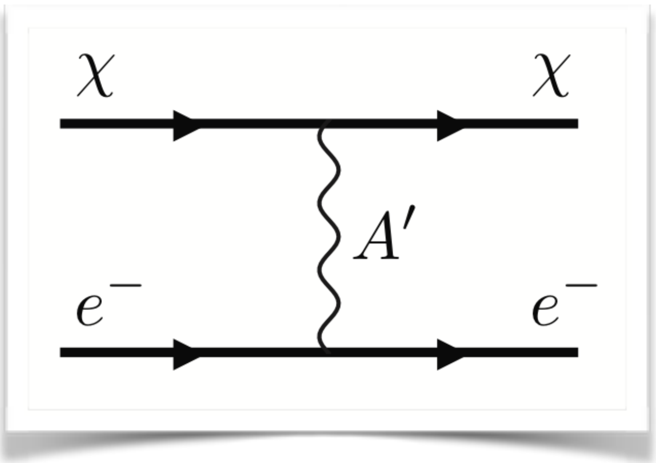
20-21 April 2015 *Laboratori Nazionali di Frascati*
Europe/Rome timezone

Detecting Accelerated Light Dark Matter



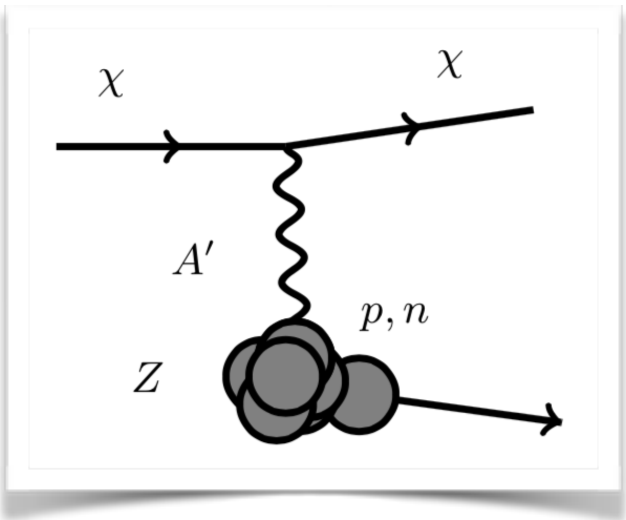
SCATTERING OF χ TROUGH A' EXCHANGE INSIDE THE DETECTOR -> DETECT THE RECOIL

χ - electron scattering



Production of an high energy (~ GeV) recoil electron

χ - nucleon scattering



Production of a low energy (~ MeV) recoil nucleon

Different signals depending on the scattering process

\+

Low interaction probability

BDX inner detector: concept design

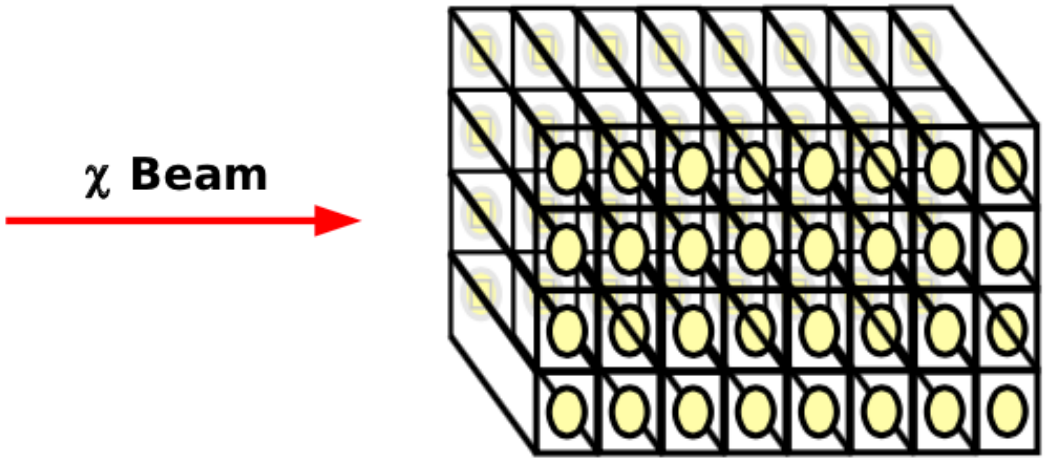
Requirements

✓ Sensitivity to GeV electrons → EM showers detection capability

✓ Sensitivity to MeV nucleons → Low energy thresholds

✓ Compact detector → High density material

ELECTROMAGNETIC CALORIMETER OF SCINTILLATOR CRYSTALS

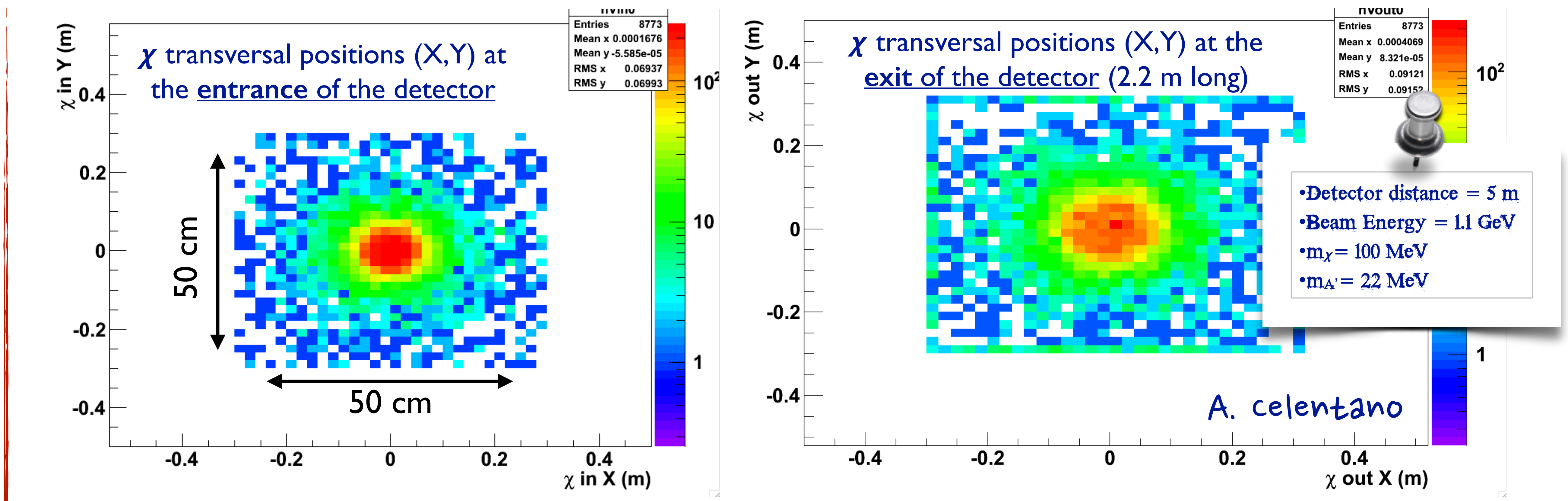


Easy-handling and very well known detection technology

Detector size for BDX@LNF

The front face dimensions depend on how large is the χ-beam at the entrance of the detector → Closely related to the kinematics governing the χ production

Kinematics is strongly peaked forward: compact detector front face



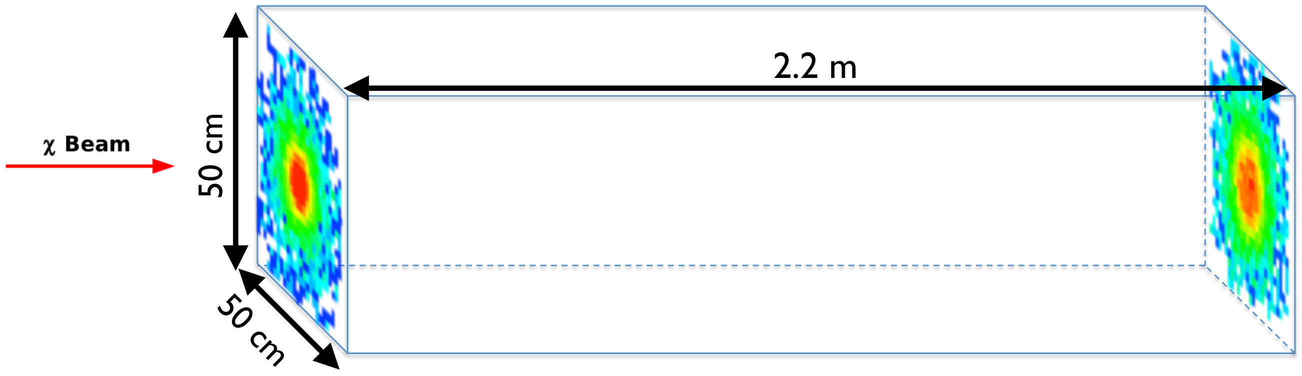
χ transversal positions (X,Y) at the **entrance** of the detector

χ transversal positions (X,Y) at the exit of the detector (2.2 m long)

- Detector distance = 5 m
- Beam Energy = 1.1 GeV
- m_{χ} = 100 MeV
- $m_{A'}$ = 22 MeV

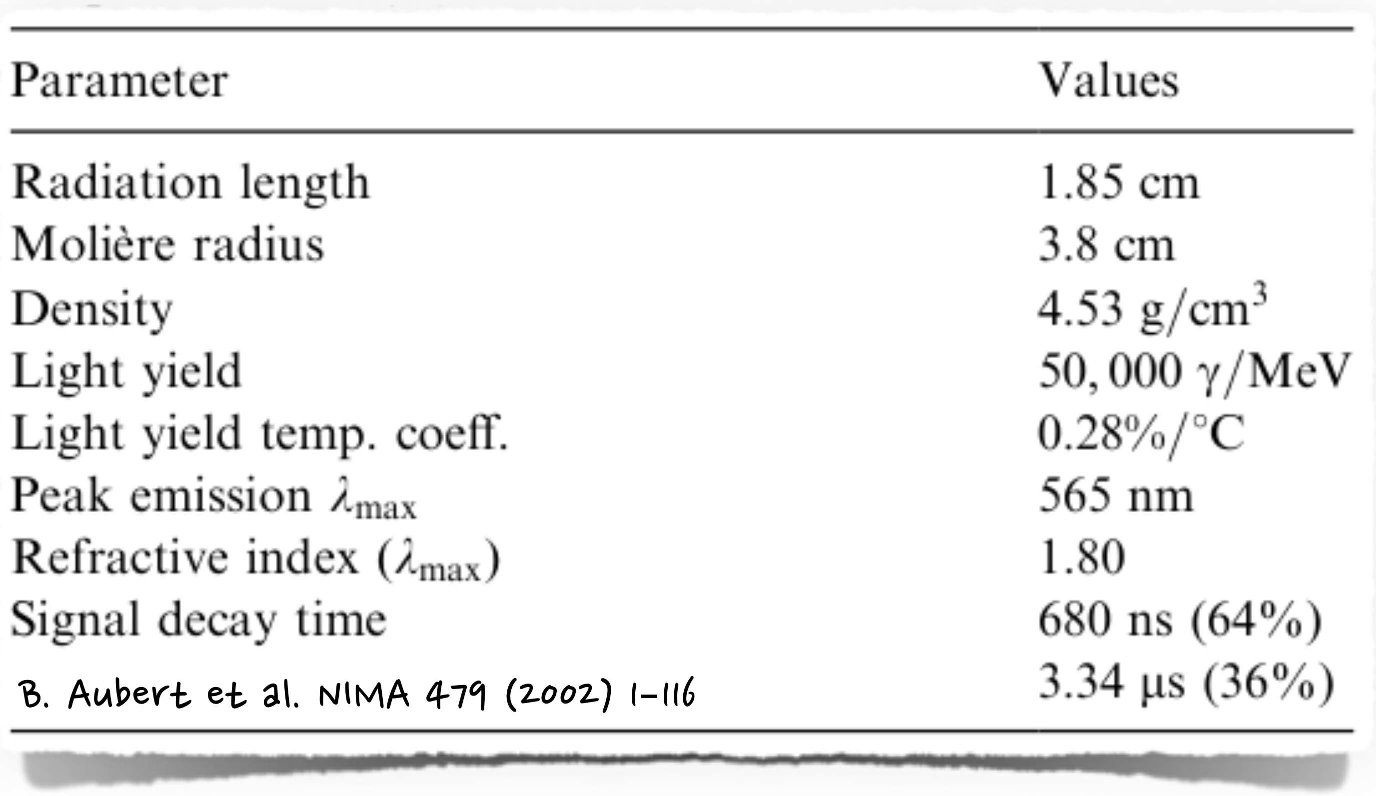
A. celentano

Most of the produced χ cross entirely a detector 2.2 m long with a 50x50 cm^2 front face



MODULAR DETECTOR : POSSIBILITY TO OPTIMIZE ITS DIMENSIONS DEPENDING ON BEAM ENERGY / PARAMETER SPACE ($M_{A'}$;M_{χ}) TO EXPLORE

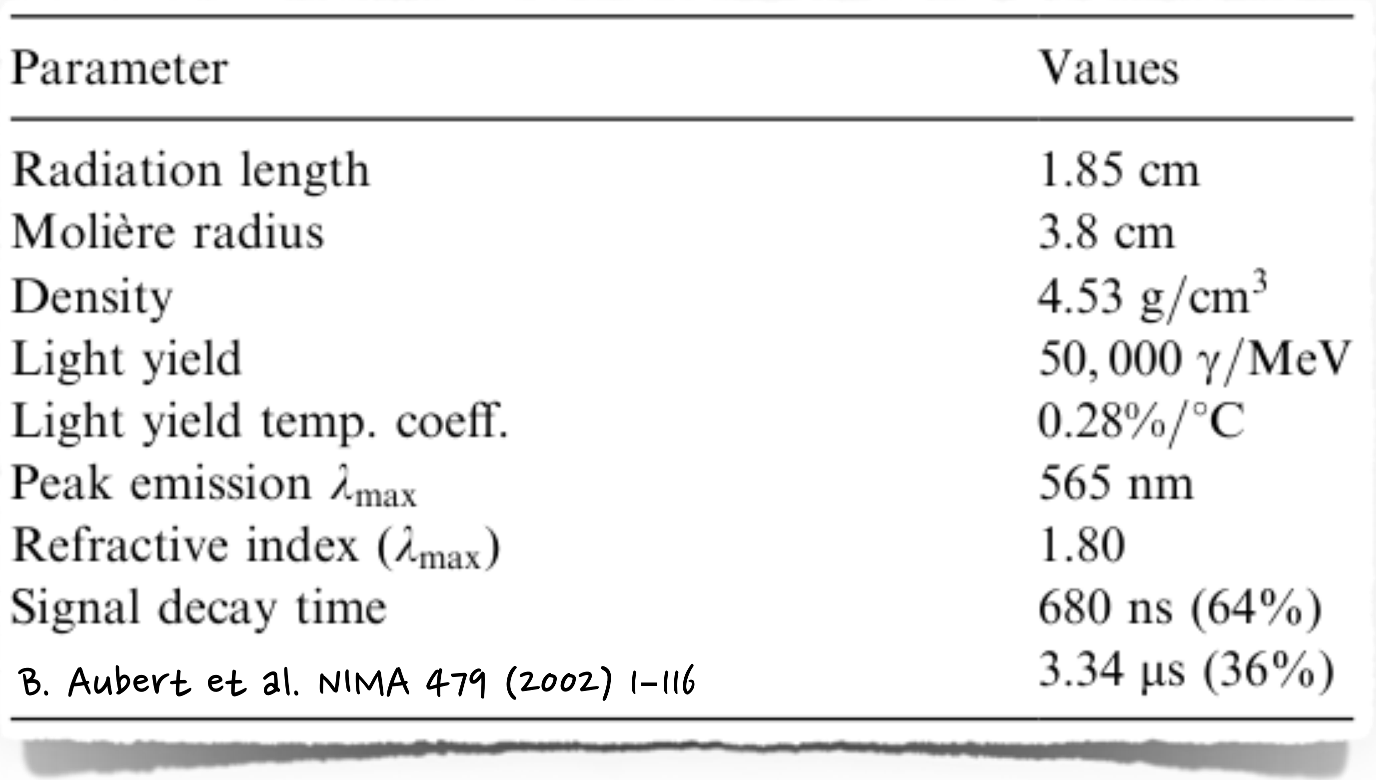
EMC@LNF with CsI(Tl) crystals



Parameter	Values
Radiation length	1.85 cm
Molière radius	3.8 cm
Density	4.53 g/cm^3
Light yield	50,000 γ/MeV
Light yield temp. coeff.	0.28%/°C
Peak emission $\lambda_{\max}$	565 nm
Refractive index ($\lambda_{\max}$)	1.80
Signal decay time	680 ns (64%) 3.34 µs (36%)

B. Aubert et al. NIMA 479 (2002) 1-116

EMC@LNF with CsI(Tl) crystals

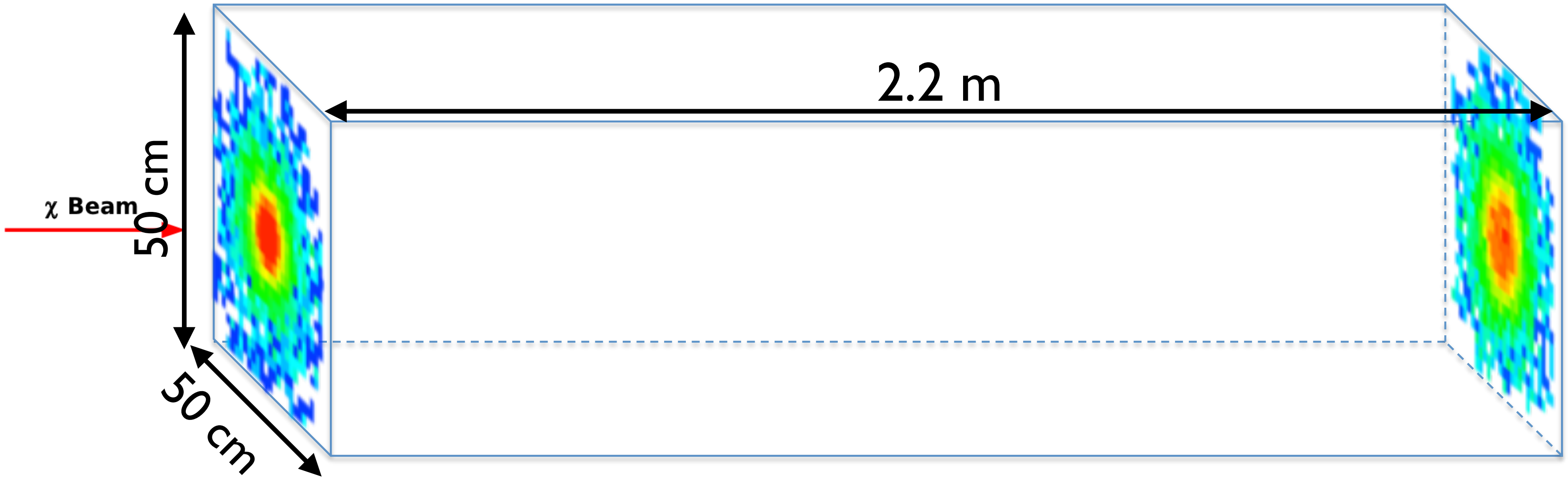


Parameter	Values
Radiation length	1.85 cm
Molière radius	3.8 cm
☺ Density	4.53 g/cm^3
Light yield	50,000 γ/MeV
Light yield temp. coeff.	0.28%/°C
Peak emission $\lambda_{\max}$	565 nm
Refractive index ($\lambda_{\max}$)	1.80
Signal decay time	680 ns (64%) 3.34 μs (36%)

B. Aubert et al. NIMA 479 (2002) 1–116

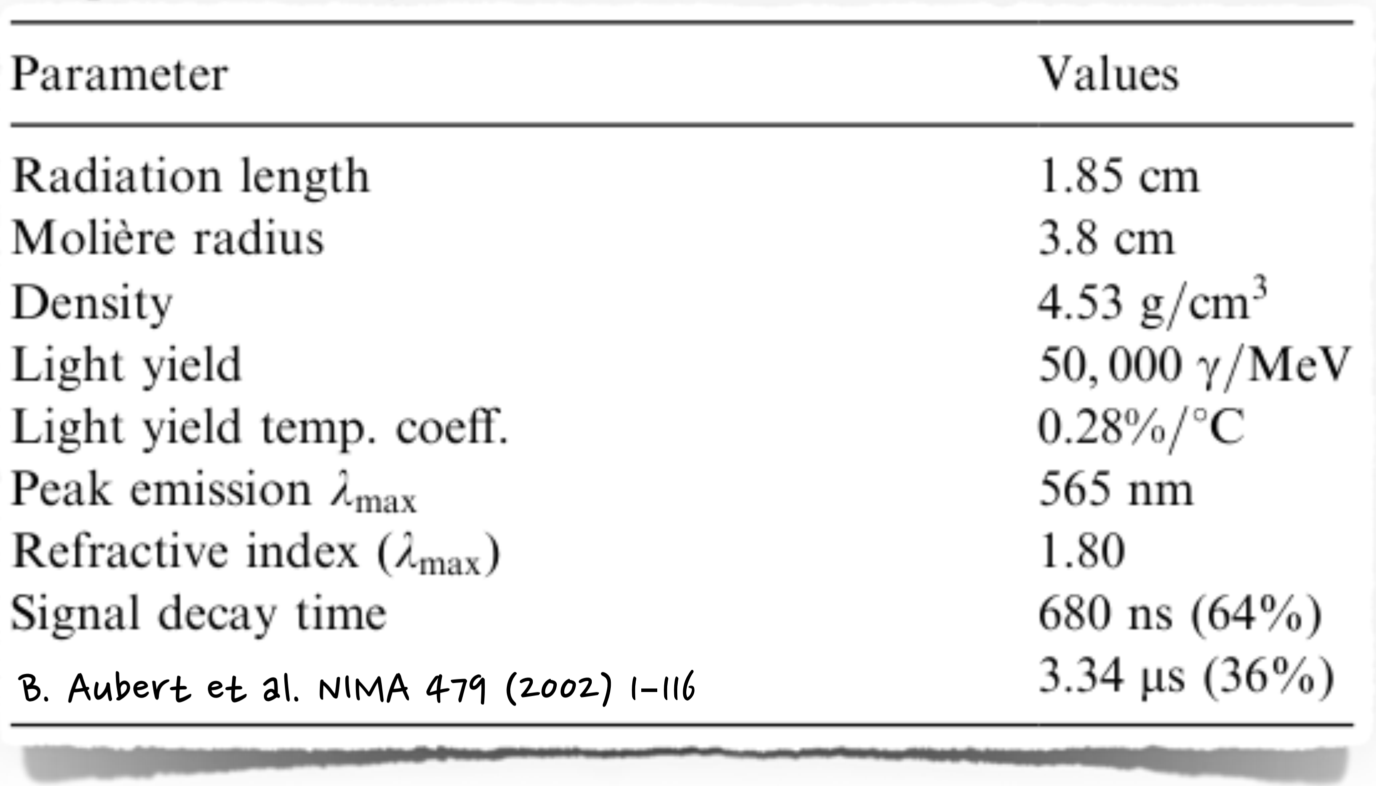
The detector length depends on the density of the scintillating material

The relatively high density of CsI results in a compact detector



- easier to find enough space to install the detector in the proper place
- easier to move the whole setup once in place (e.g. for off-axis measurements)
- more compact passive shielding
- smaller number of internal and external veto detectors (reduced complexity and costs)
- short detector: most of the χ will cross it entirely increasing the possibility of χ-scattering processes

EMC@LNF with CsI(Tl) crystals



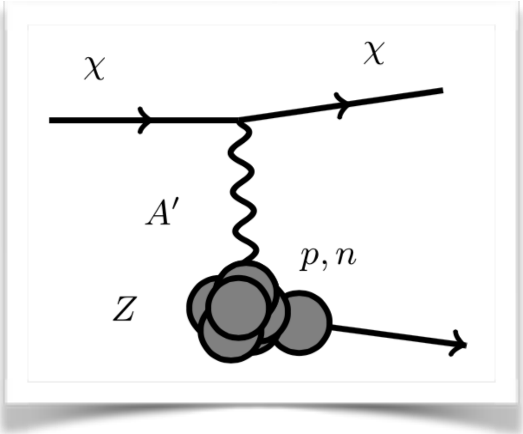
Parameter	Values
Radiation length	1.85 cm
Molière radius	3.8 cm
☺ Density	4.53 g/cm^3
☺ Light yield	50,000 γ/MeV
Light yield temp. coeff.	0.28%/°C
Peak emission λ_{max}	565 nm
Refractive index (λ_{max})	1.80
Signal decay time	680 ns (64%) 3.34 μs (36%)

B. Aubert et al. NIMA 479 (2002) 1-116

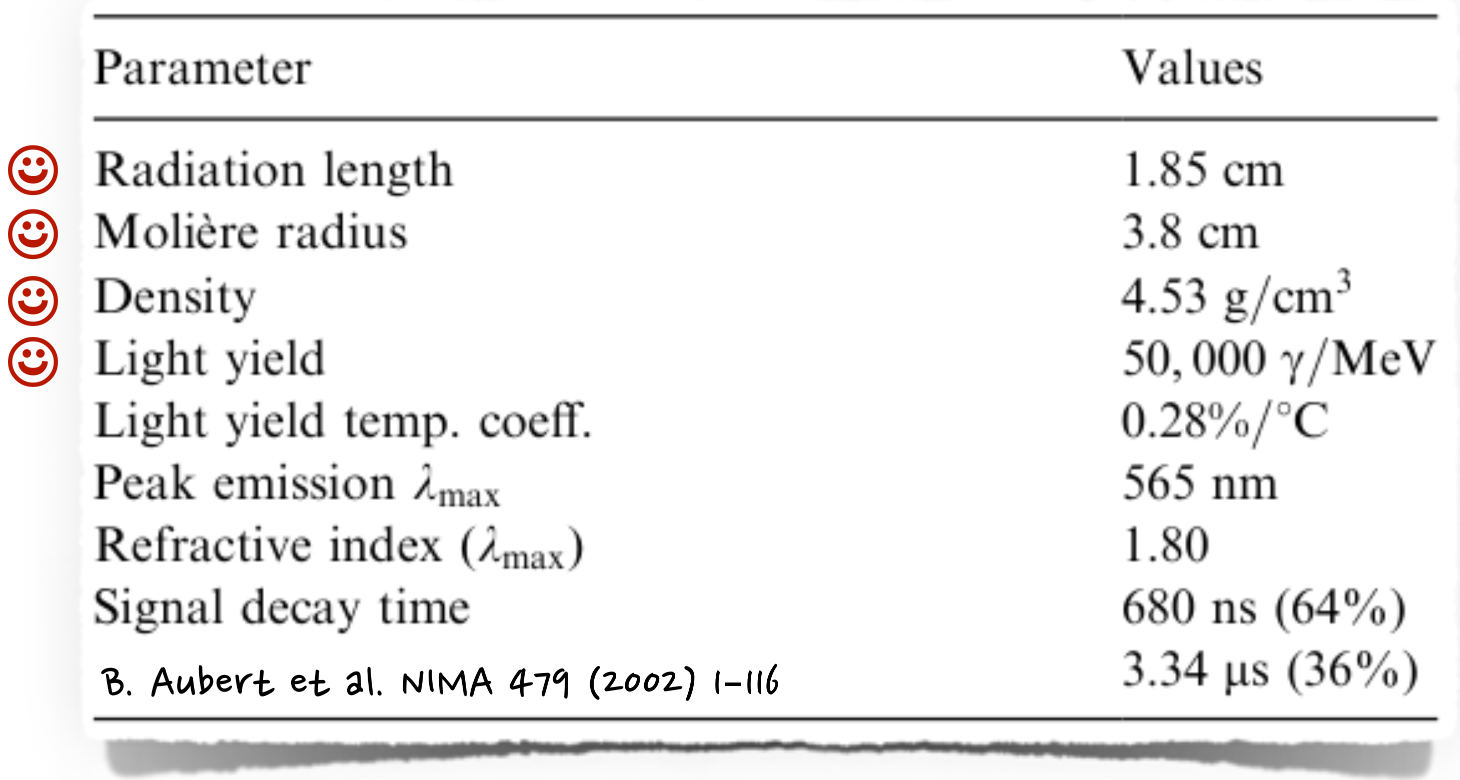
One of the highest Light Yield among scintillating materials

CsI(Tl) has an high efficiency for converting ionization energy to light output : potential advantage for detecting recoil protons at low energies (~ MeV)

χ - nucleon scattering



EMC@LNF with CsI(Tl) crystals



	Parameter	Values
☺	Radiation length	1.85 cm
☺	Molière radius	3.8 cm
☺	Density	4.53 g/cm^3
☺	Light yield	50,000 γ/MeV
	Light yield temp. coeff.	0.28%/°C
	Peak emission λ_{max}	565 nm
	Refractive index (λ_{max})	1.80
	Signal decay time	680 ns (64%) 3.34 μs (36%)

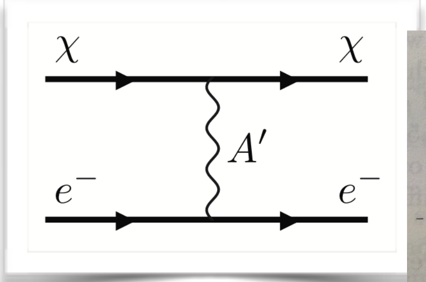
B. Aubert et al. NIMA 479 (2002) 1–116

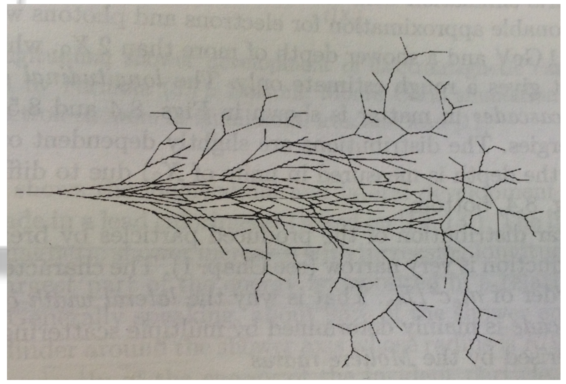
Radiation length and Molière radius

EM showers produced in the χ-electron scattering are contained within a relatively small volume

Advantage: even if the shower is generated near the detector borders a significant fraction of its energy can be likely detected (most of the detector volume is "active")

χ - electron scattering





An upper limit case for LNF: shower produced by 1GeV electron

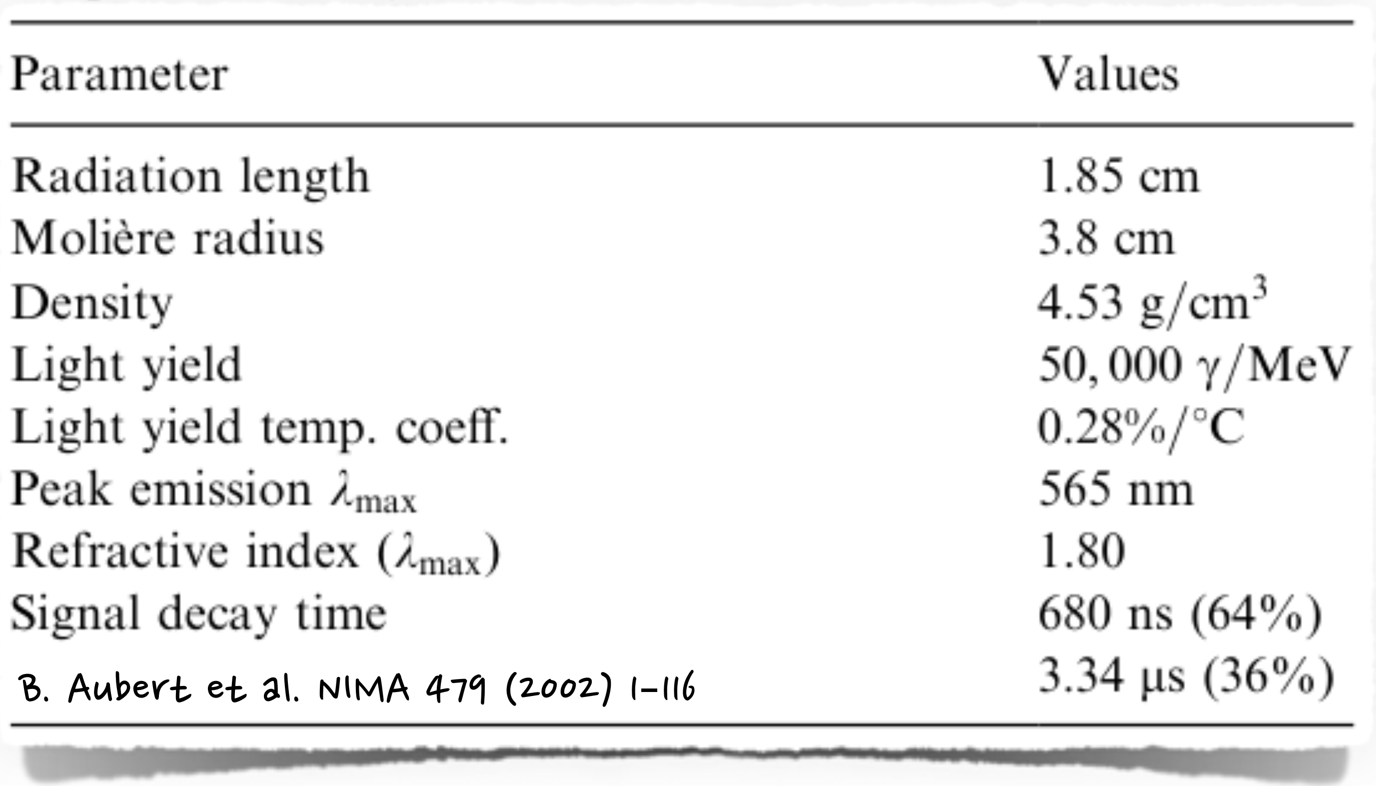
<u>Longitudinal dimension</u>

maximum number of particles at ~ 6.5X$_0$ (~ 12 cm) and **most of the energy absorbed in ~ 15X$_0$ (~ <u>28 cm</u>)**

<u>Transverse dimension</u>

90 % of the shower energy contained in 1 MR = <u>3.8 cm</u>

EMC@LNF with CsI(Tl) crystals

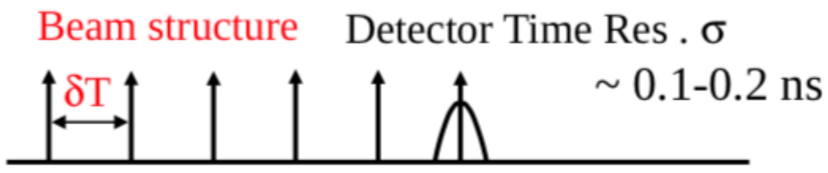


	Parameter	Values
☺	Radiation length	1.85 cm
☺	Molière radius	3.8 cm
☺	Density	4.53 g/cm^3
☺	Light yield	50,000 γ/MeV
	Light yield temp. coeff.	0.28%/°C
	Peak emission λ_{max}	565 nm
	Refractive index (λ_{max})	1.80
	Signal decay time	680 ns (64%) 3.34 µs (36%)

B. Aubert et al. NIMA 479 (2002) 1-116

☹ A potential drawback related to time resolution

Continuous beam: the uncorrelated background reduction factor is dominated by the detector time resolution



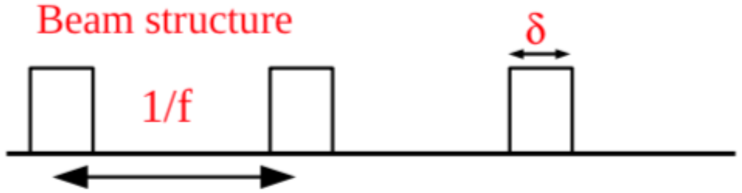
Continuous beam: detector time resolution is a mandatory requirement.

$$R \simeq \frac{\delta T}{3\sigma} <\simeq 100$$

Not a problem for BDX@LNF !

Pulsed beam: detector time resolution is not critical, if smaller than the bunch length.

$$R = \frac{1}{f \cdot \delta} = 2 \cdot 10^5 \ @ \ 50\,Hz, 100\,ns$$



50 Hz @ 10 ns (LNF today)

Background reduction factor = 2*10^6

50 Hz @ 100 ns (possible upgrade)

Background reduction factor = 2*10^5

EMC@LNF with CsI(Tl) crystals

An array of thallium-doped cesium iodide CsI(Tl) crystals meets the needs of BDX@LNF

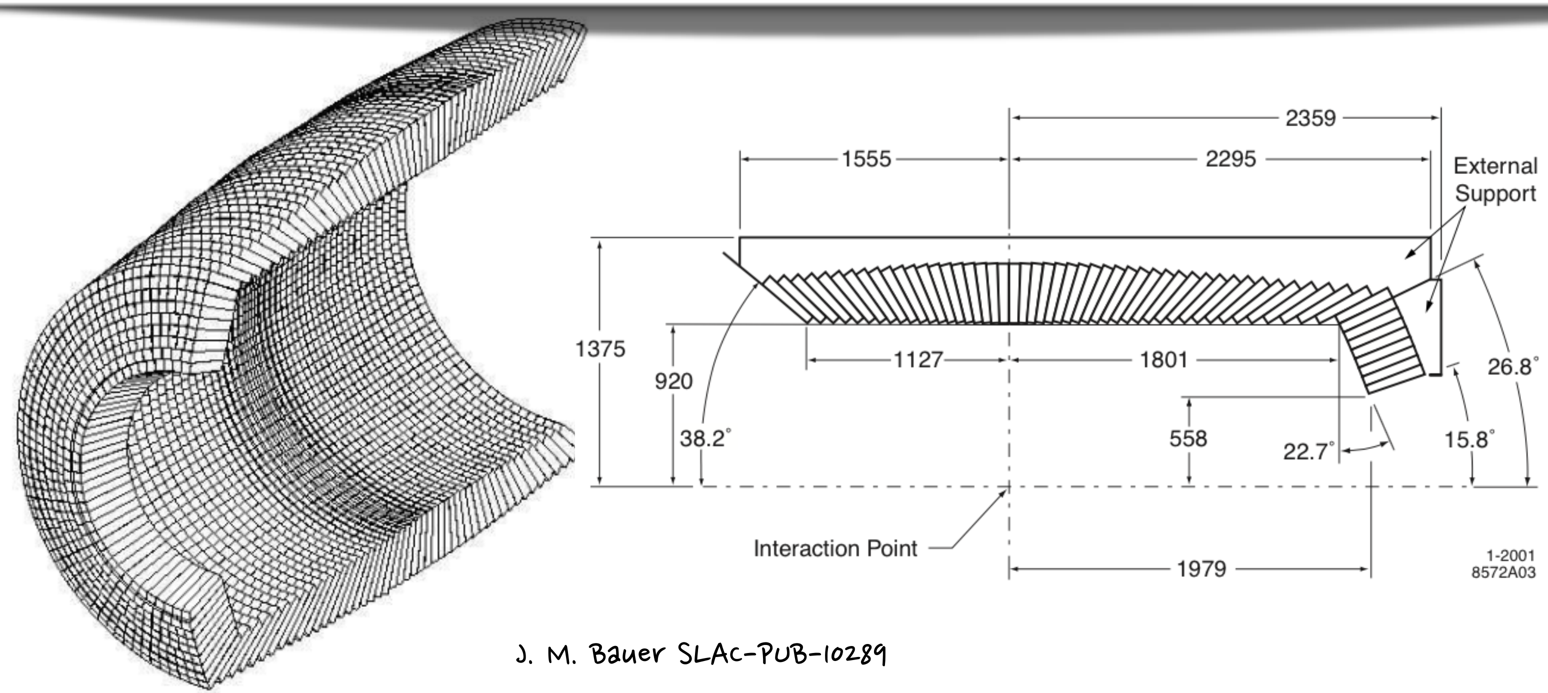
Other scintillating materials with comparable/better performances could be potential candidates however …

☺ The CsI(Tl) solution could allow to save ~ O(M€)

RE-USE PART OF THE BABAR ELECTROMAGNETIC CALORIMETER CRYSTALS

Preliminary contacts with the BaBar management for using the 820 CsI (Tl) crystals from the Endcap

Yesterday one BaBar crystal has been shipped to us: it will be used during the cosmogenic background measurements at LNS-CT



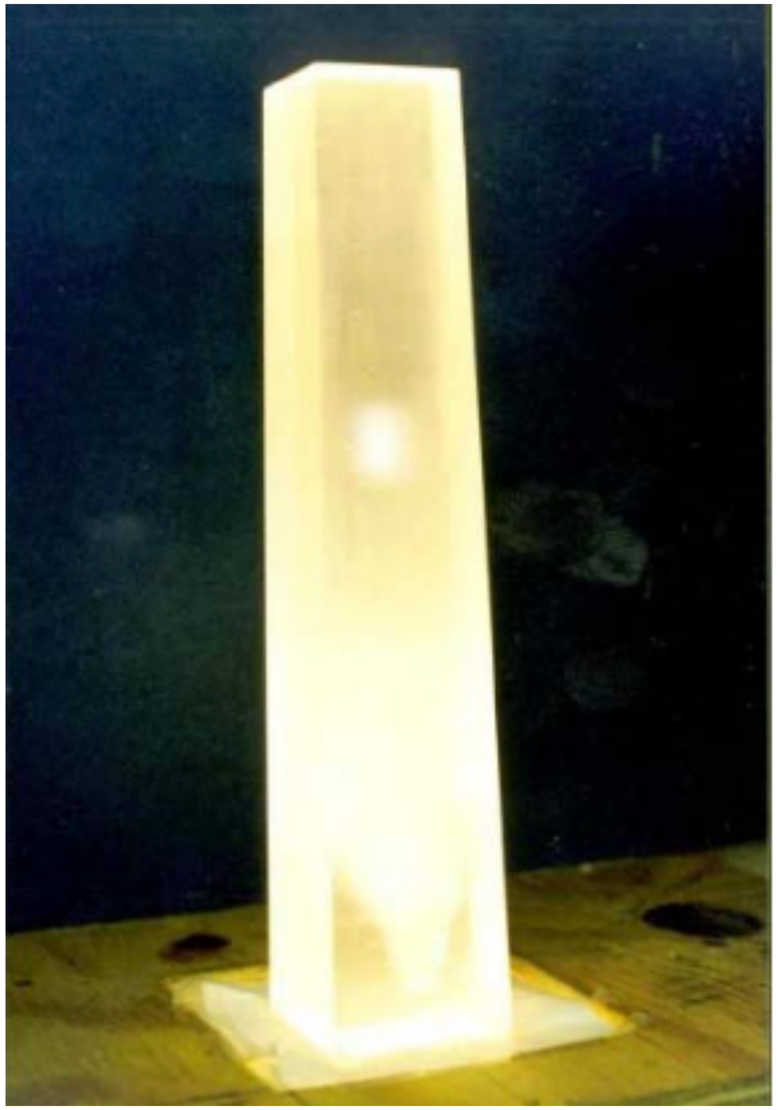
J. M. Bauer SLAC-PUB-10289

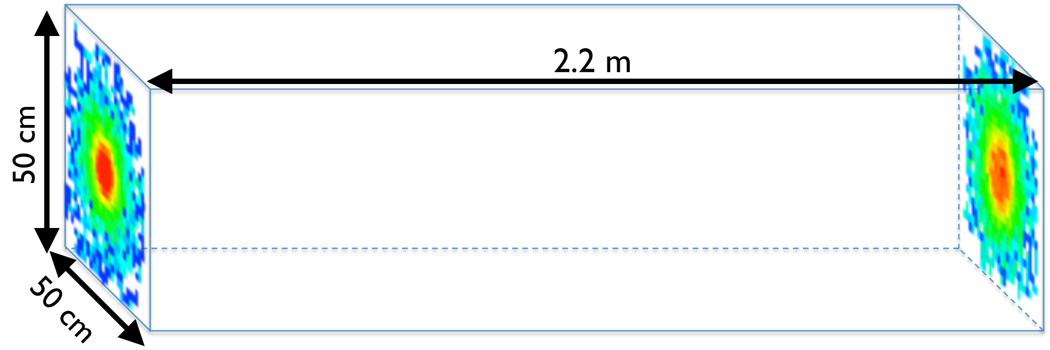
Crystal shape and dimensions

Trapezoidal cross-section

Front face : 4.7 x 4.7 cm^2
Back face : 6 x 6 cm^2

Crystal length (from Endcap): 30.5 cm/16.5 X_0 (80 crystals) and 32.4 cm/17.5 X_0



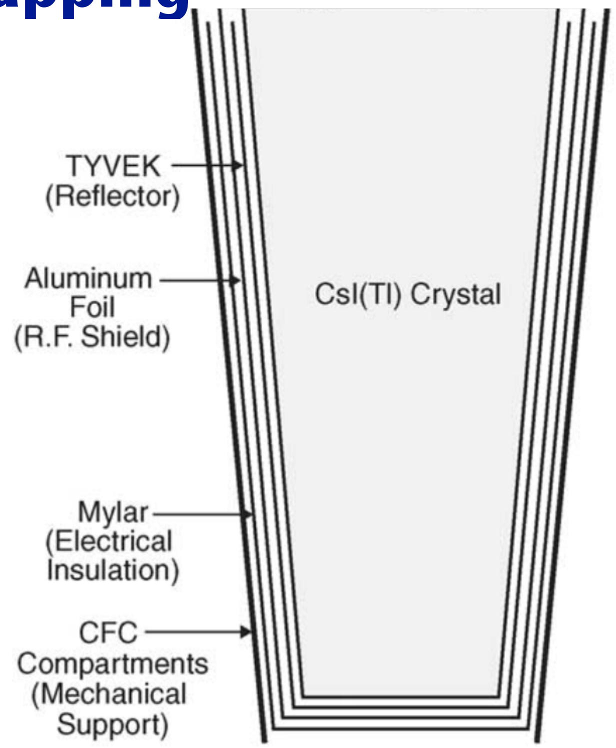


Wrapping

The transmitted light is recovered in part by wrapping the crystal with two layers of diffusive white reflector (Tyvek), 165 μm each.

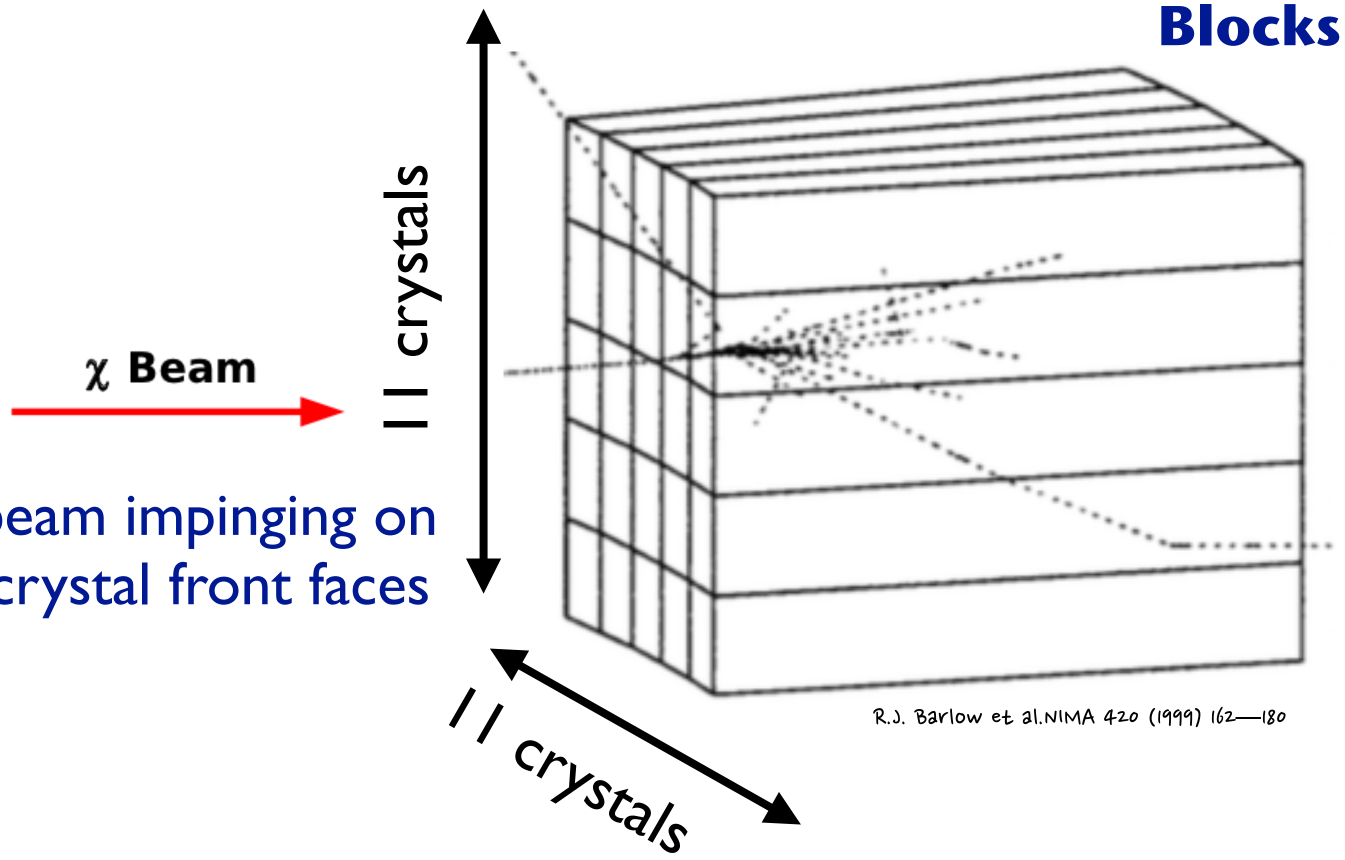
25 μm thick aluminum foil connected to the metal housing of the readout electronics to provide a Faraday shield.

13 μm thick layer of mylar to assure electrical isolation from the external support



BDX@LNF: a possible layout

Blocks of crystals with the χ beam impinging on their front faces

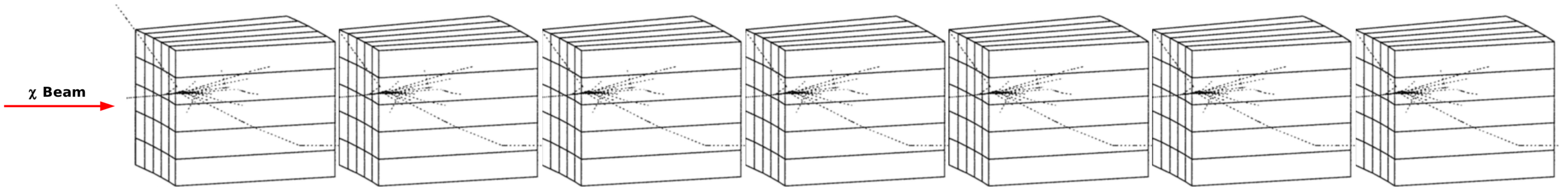


R.J. Barlow et al.NIMA 420 (1999) 162—180

χ - beam impinging on the crystal front faces

1 Block : 11 x 11 crystals = 121 crystals
Front face ~ 50 x 50 cm^2

TOT = 7 Blocks x 121 crystals = <u>847 crystals</u>

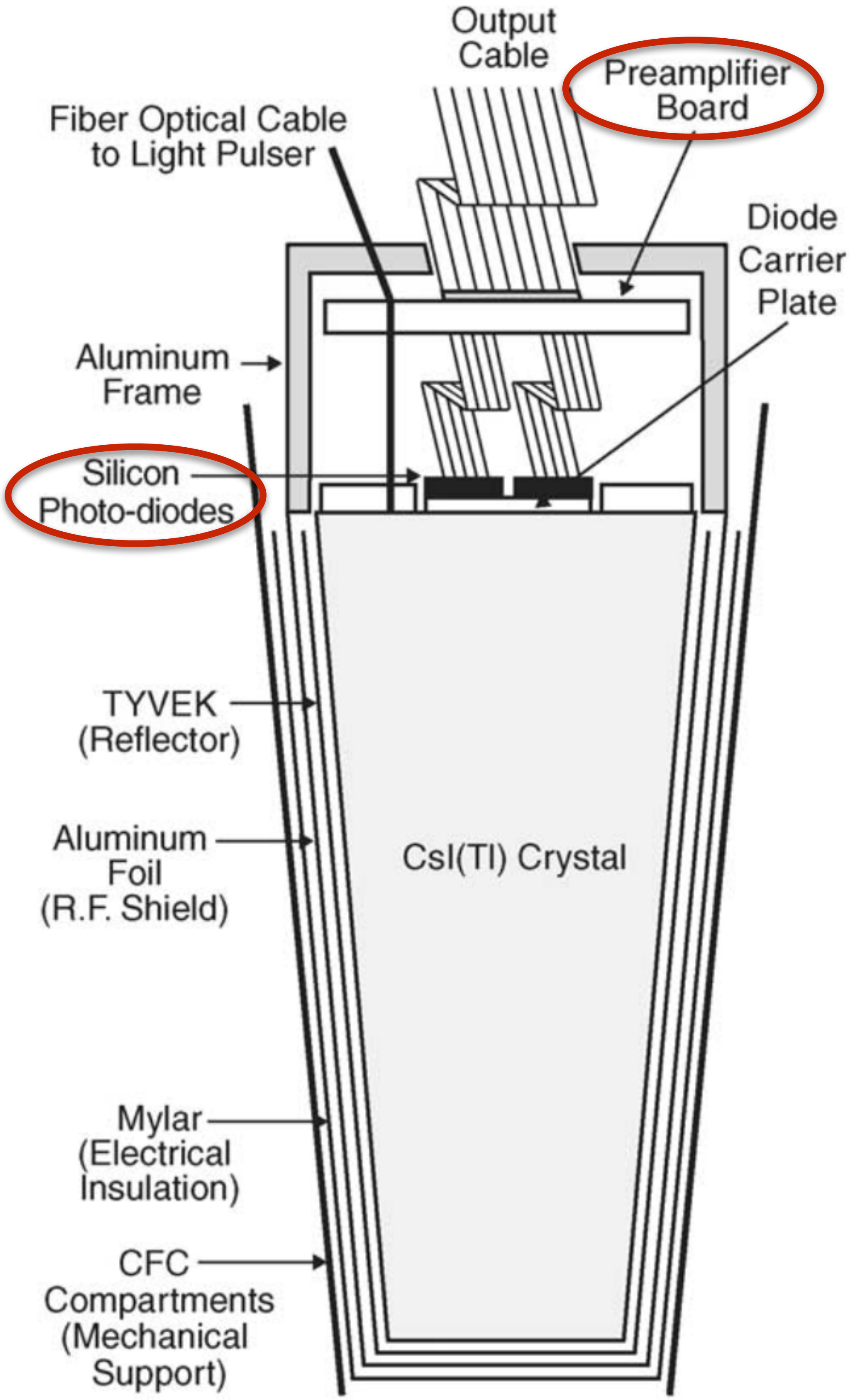


7 blocks ~ 2.2 m of <u>active</u> detector

Layout of the EMC for BDX@LNF

- ✓ ~800 BaBar crystals to make the detector
- ✓ Simple geometry: easy to assemble and simple mechanical supports
- ✓ Modular detector: change front face dimensions and length by easily re-arranging crystals, e.g. 9x9 crystals (~40x40 cm^2) - 10 blocks (~3.2 m)

On-crystal readout



B. Aubert et al. NIMA 479 (2002) 1–116

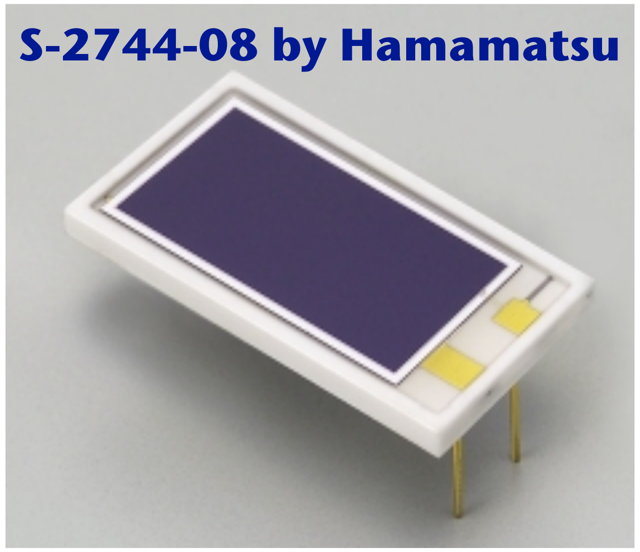
Crystals already equipped with readout electronics

Crystals read out with silicon photodiodes matched to the spectrum of scintillation light

Signals from the diodes amplified and shaped by custom preamplifiers mounted at the rear of each crystal

The entire readout system enclosed by an aluminum frame electrically coupled to an aluminum foil wrapped around the crystal and thermally coupled to the support frame to dissipate the heat load from the preamplifier

Photodiodes


S-2744-08 by Hamamatsu

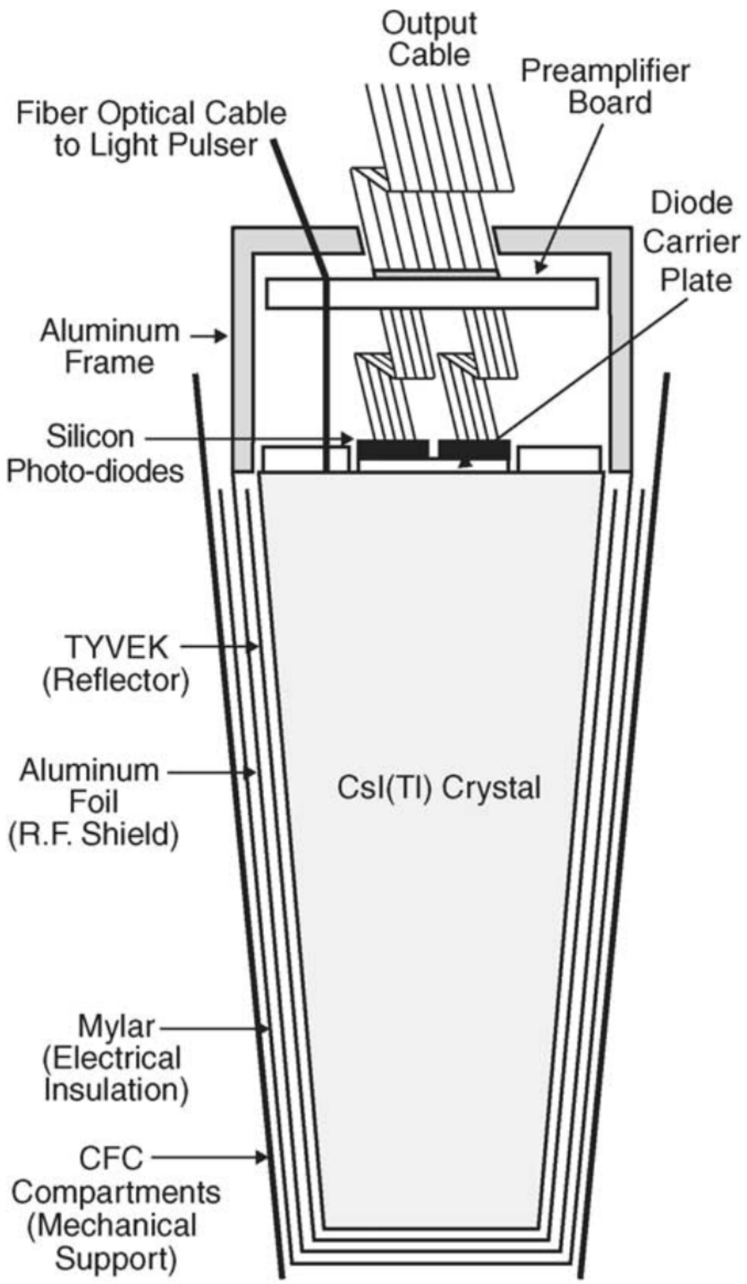
PIN SILICON PHOTODIODES

- Photosensitive area 2 x 1 cm^2
- 85% quantum efficiency at the peak light emission for CsI(Tl) of 565 nm
- Operational voltage : 50 V
- Dark current and capacitance of 4 nA and 85 pF at 70 V
- Light yield crystal+diode 7300 γ/MeV (1.836 MeV ^{88}Y source - 2μs gaussian shaping time)

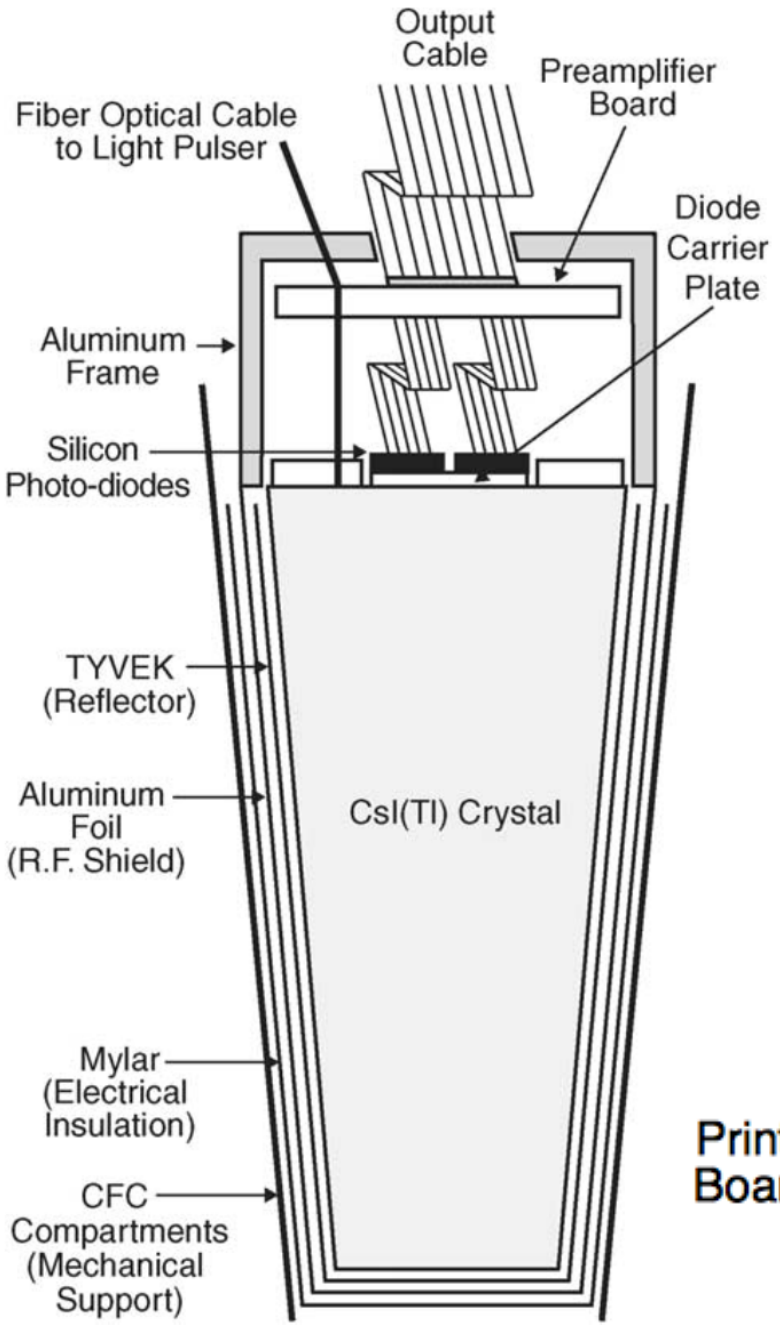
Two identical photodiodes installed on each crystal: to achieve the required operational reliability for the inaccessible front-end readout components

Diodes glued to a transparent 1.2 mm thick polystyrene substrate that in turn is glued to the center of the rear face by an optical epoxy to maximize light transmission.

The surrounding area of the back face covered by a plastic plate coated with white reflective paint

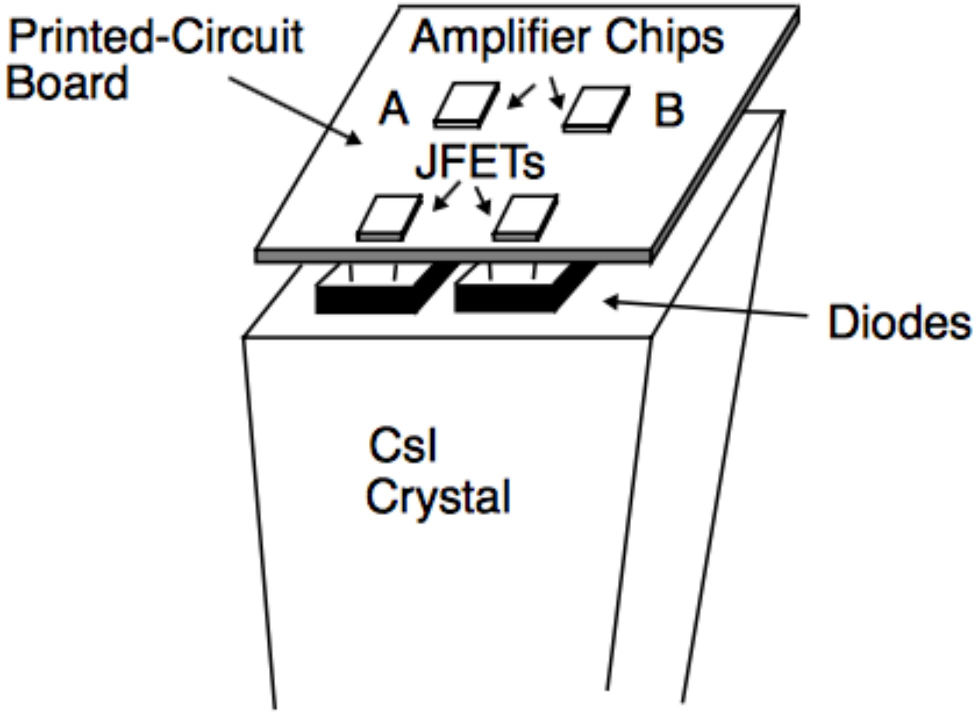


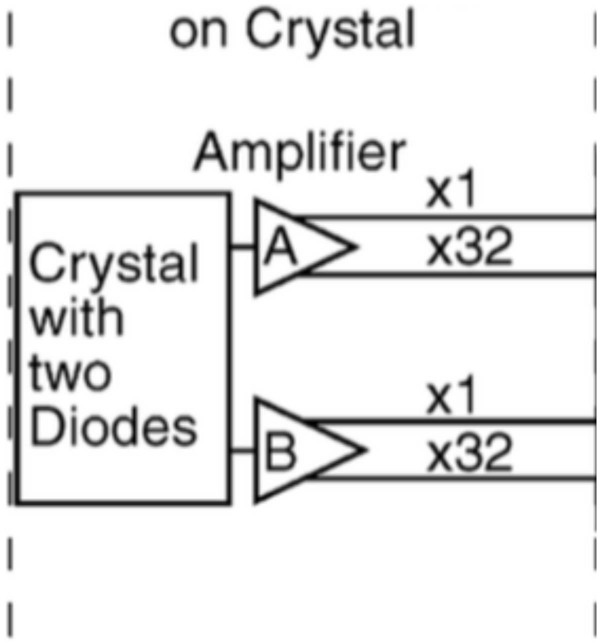
Preamplifiers



CUSTOM AMPLIFIER INTEGRATED CIRCUIT

- Custom amplifier chips mounted on a printed circuit board which comprises also biasing resistors for the diodes and filters for the supply voltages
- Low-noise charge sensitive preamplifiers acting as band-pass filter to remove high- and low-frequency noise component
- Shaping time <1µsec
- Two independent signal channels (A and B) are instrumented for each crystal.
- A and B provide EACH amplification factors of x1 and x32





What else ?

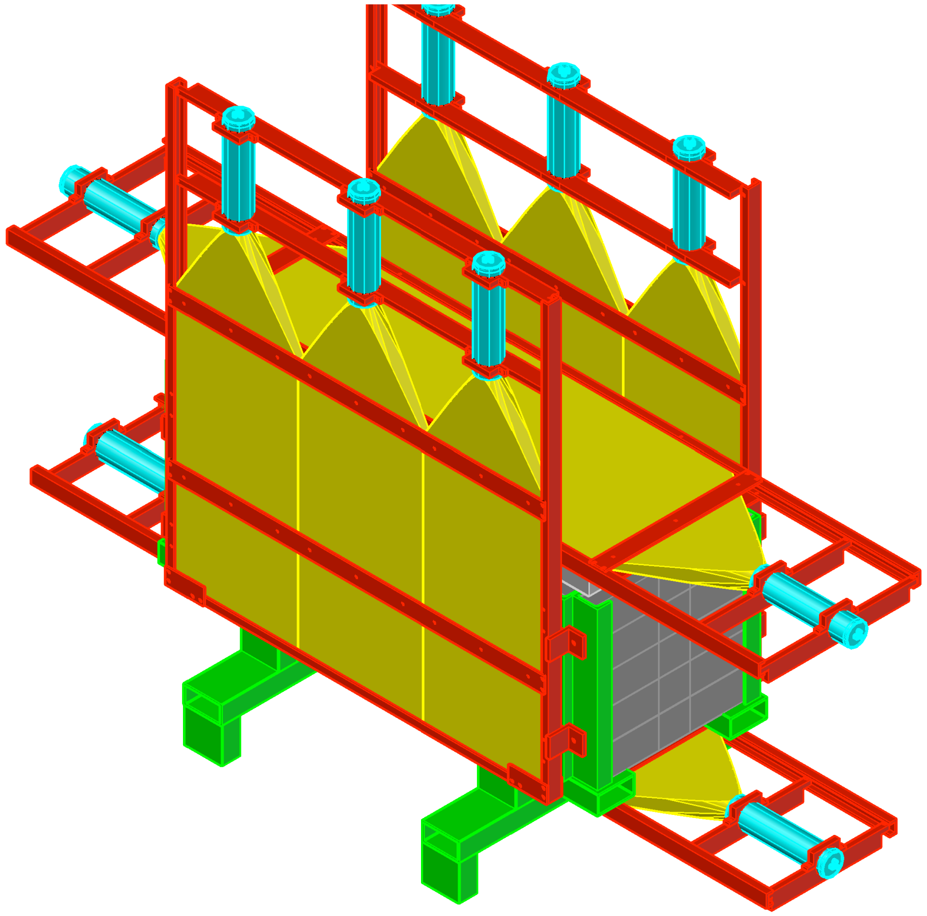
Apart from crystals many other components of the experimental setup needed

- **Mechanical structure for the whole setup: supports for crystals, internal shielding, veto detectors**
- **Cooling system**
- **If for some reasons we can't use the existing on-crystal readout we need to replace it with other solutions (e.g. SiPM)**
- **Electronics after the preamps up to the front-end**
- **Internal and the external veto detectors + readout electronics**
- **....**

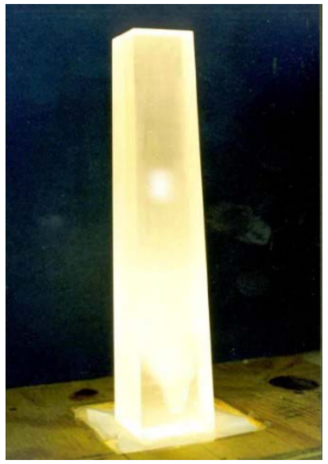
Measurements with a BDX prototype @ LNS

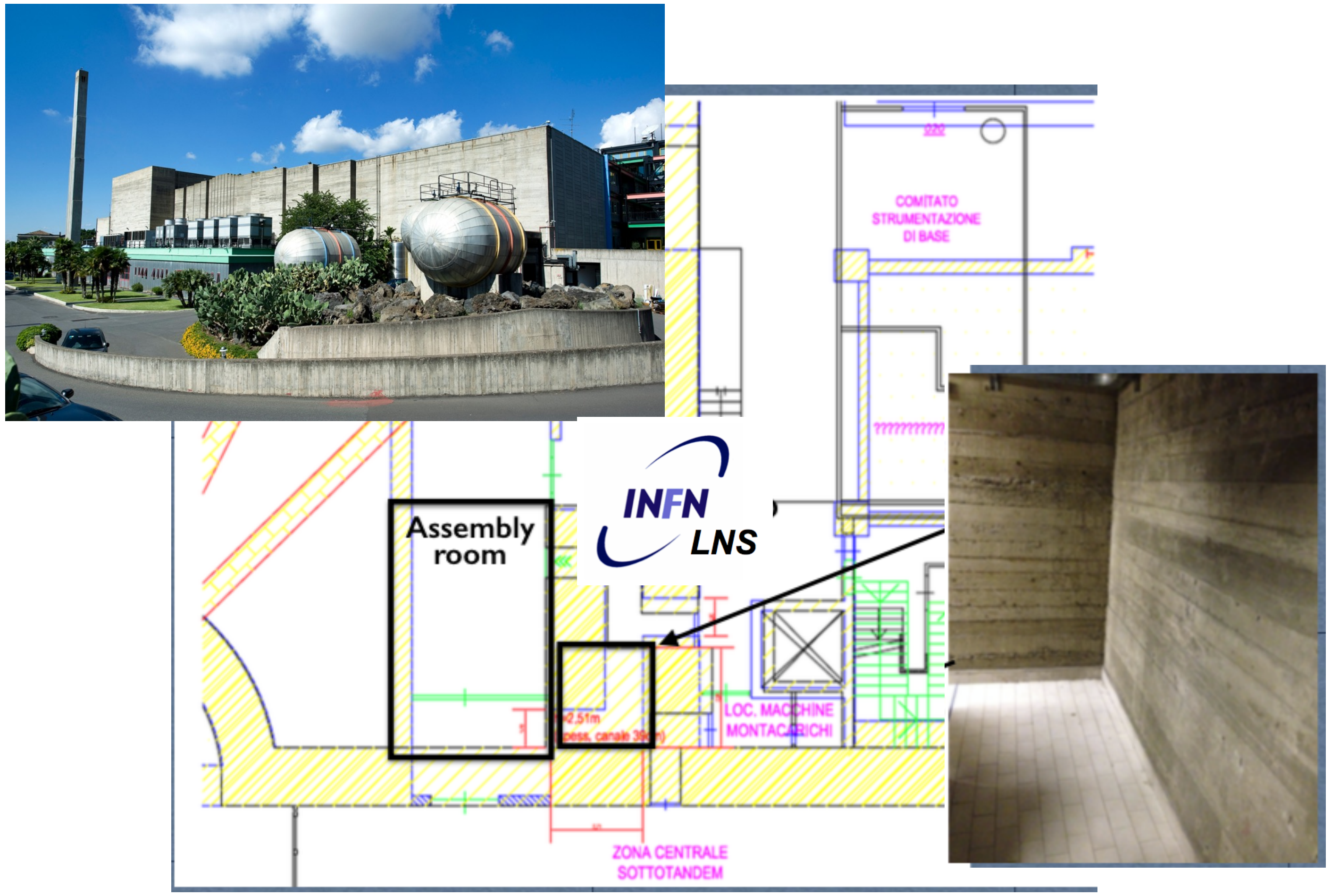
A campaign of cosmogenic background measurements will start this year at LNS: test of BaBar and other crystals for backup solutions

- Quantify background rates vs energy thresholds
- Test of different veto solutions
- Measure of veto efficiencies
- Shielding optimization

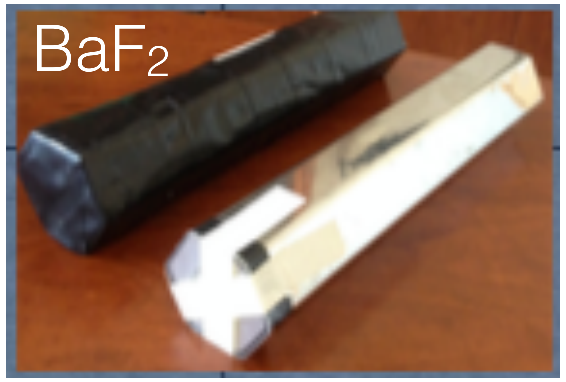


BaBar CsI(Tl)

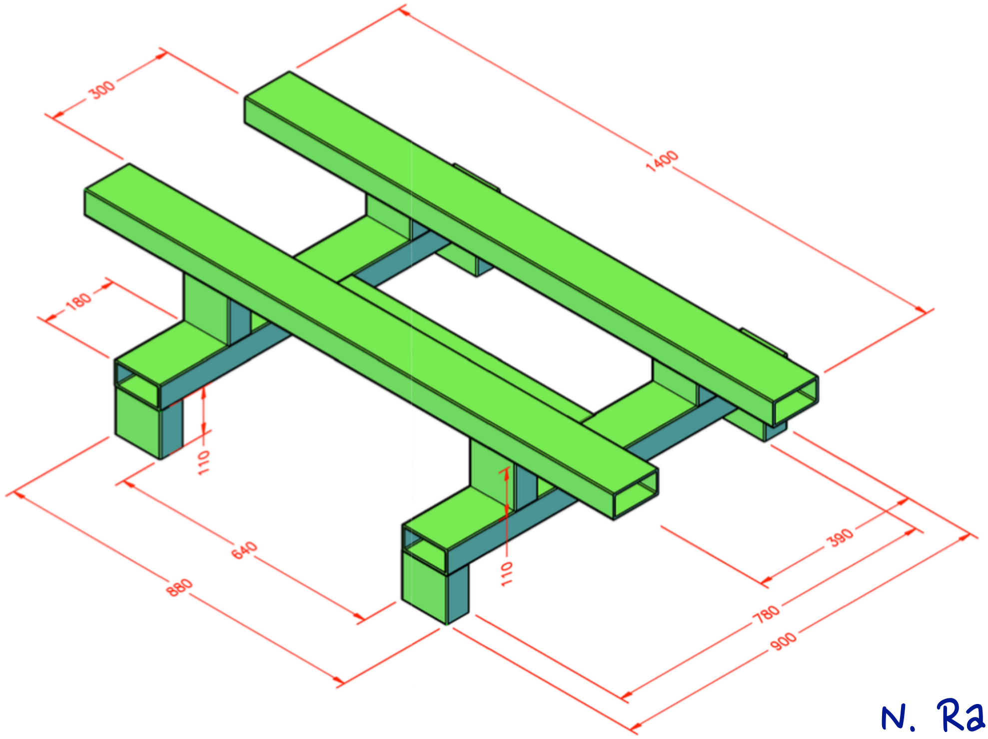




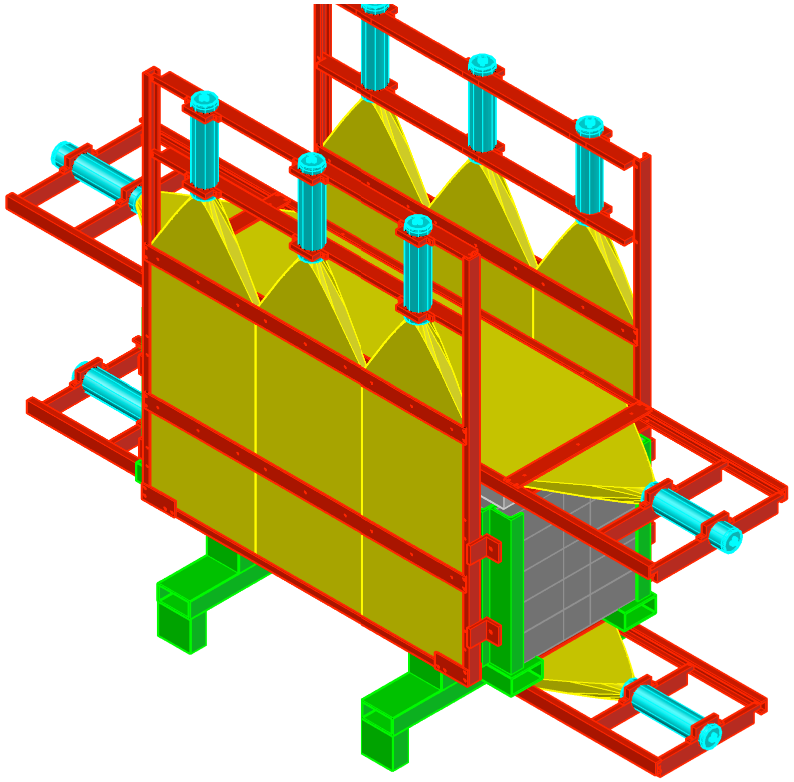
BSO



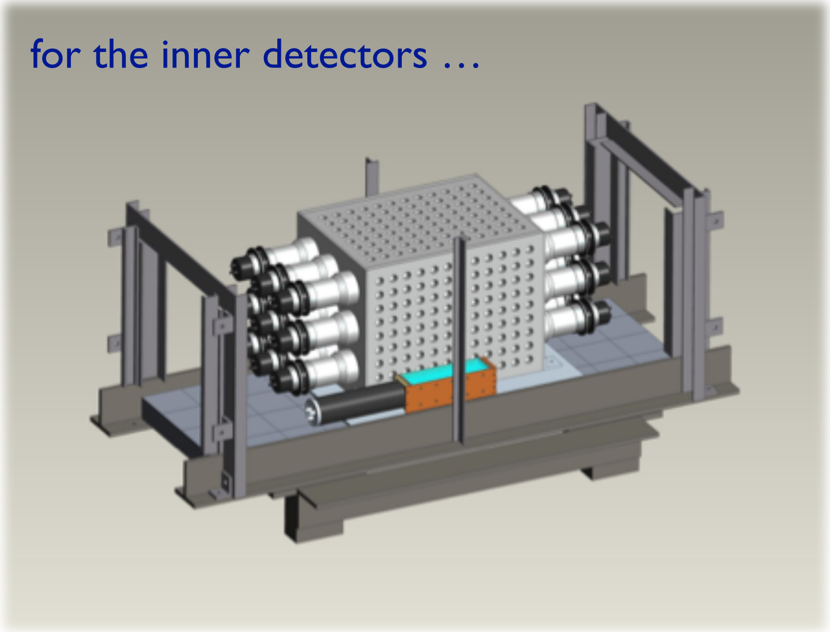
Mechanical structure



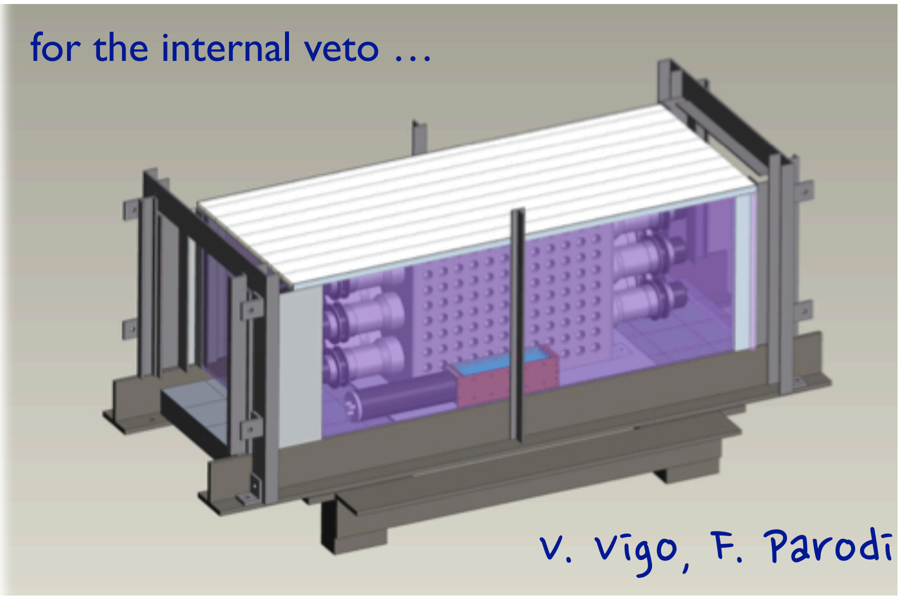
N. Randazzo



for the external veto …

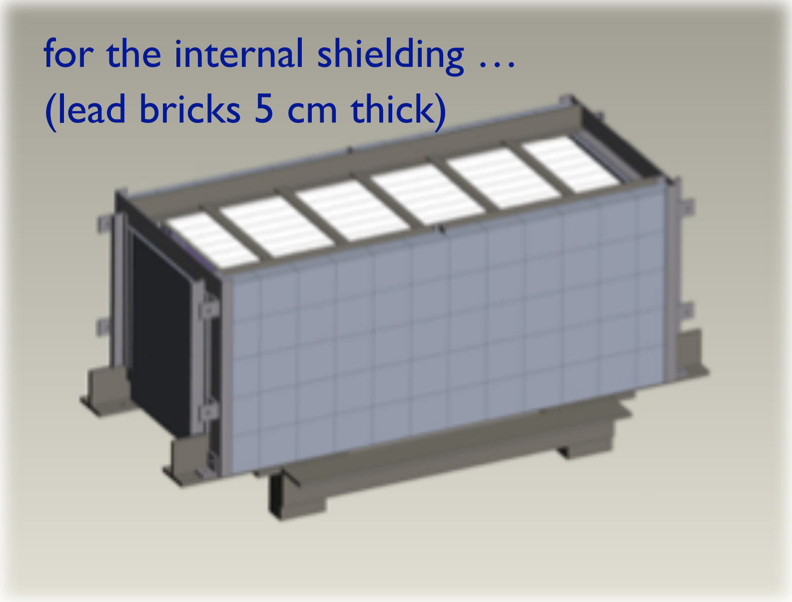


for the inner detectors …



for the internal veto …

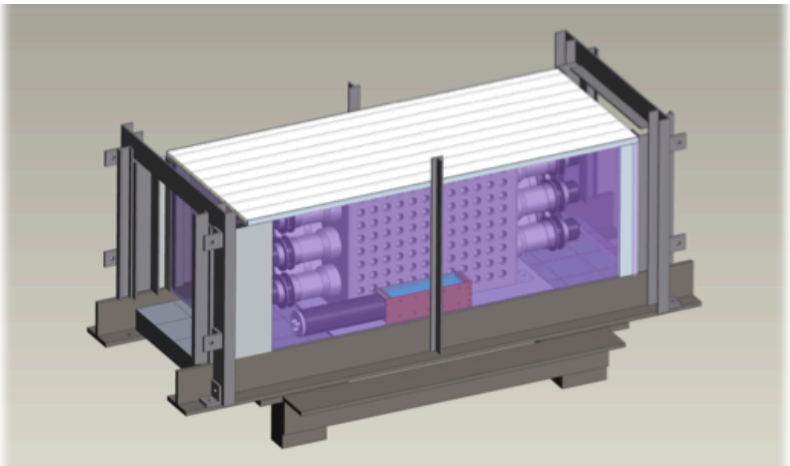
V. Vigo, F. Parodi



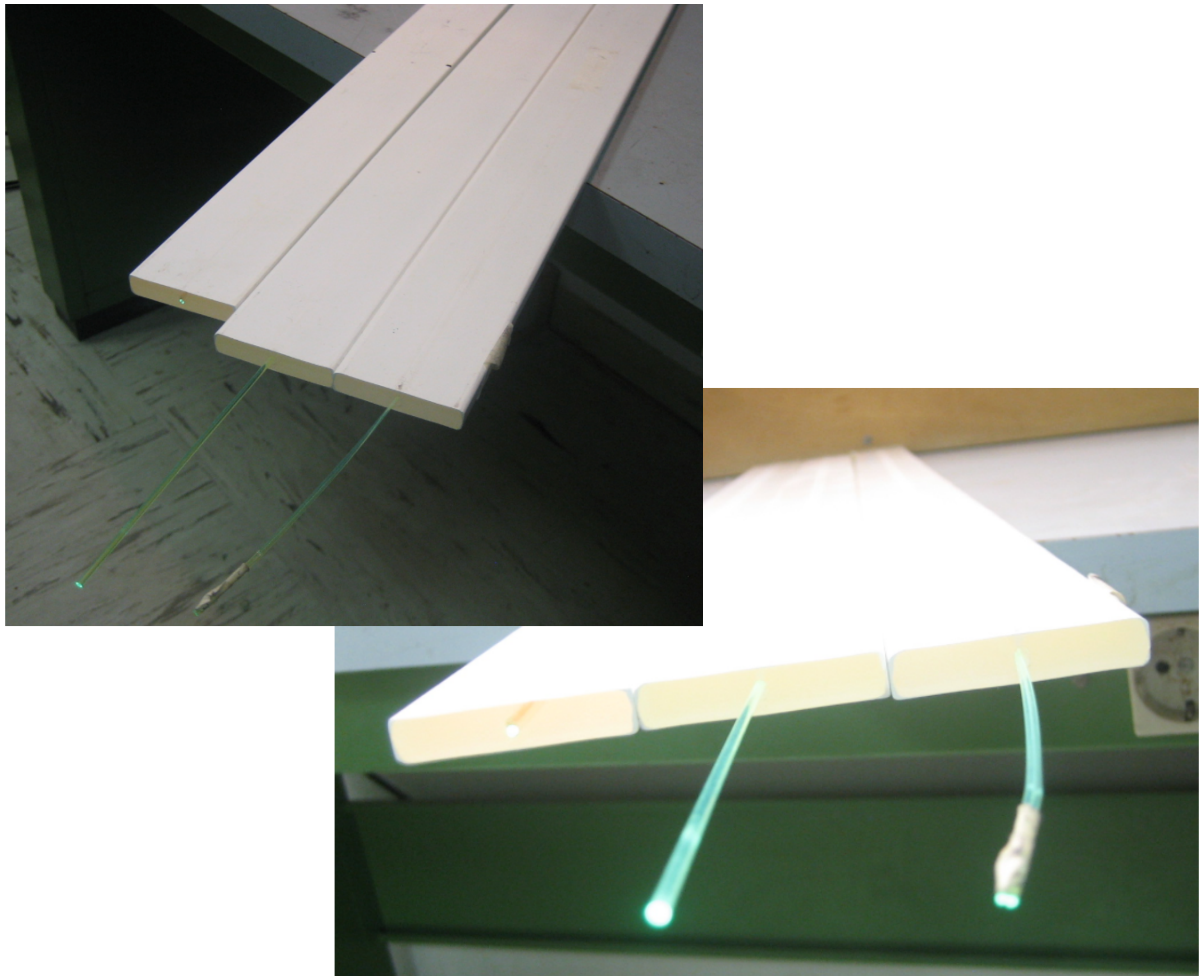
for the internal shielding …
(lead bricks 5 cm thick)

Veto detectors

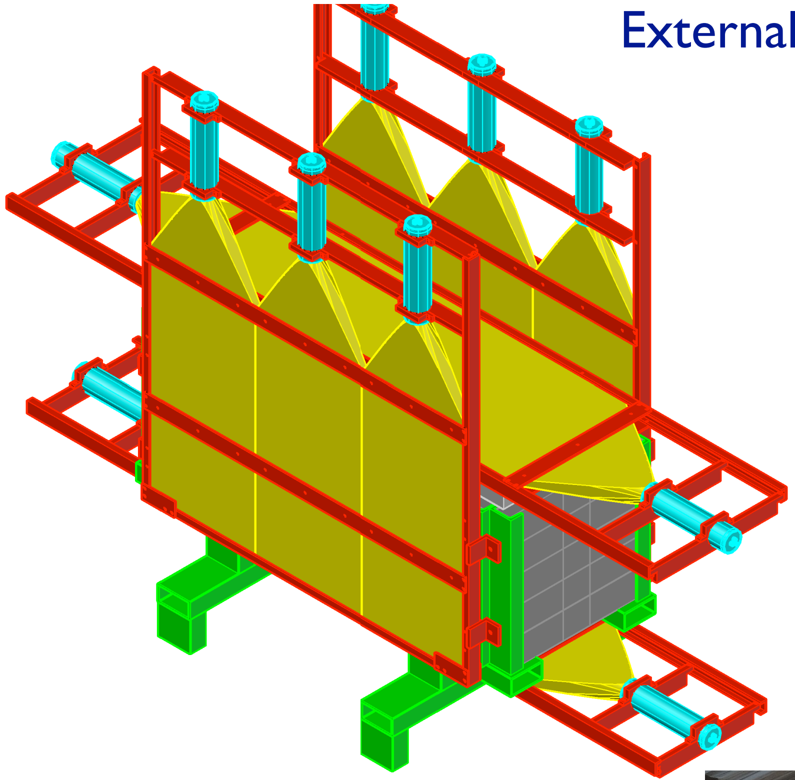
Internal veto: between the inner detector and lead shielding



Extruded plastic scintillator (paddles top and foils lateral) + Wave Length Shift fibers + single SiPM readout



External veto



Plastic scintillator paddles (NE110)
Area: 40x80 cm^2 - Thickness: 2 cm +
light guide + single side PMT readout

Conclusions

Scintillator crystals represent a realistic solution for the calorimeter of BDX@LNF

- **Compact detector**
- **EM shower detection**
- **Low energy thresholds**

A concrete and convenient option is re-using CsI(Tl) crystals from the dismissed BaBar calorimeter (preliminary contacts)

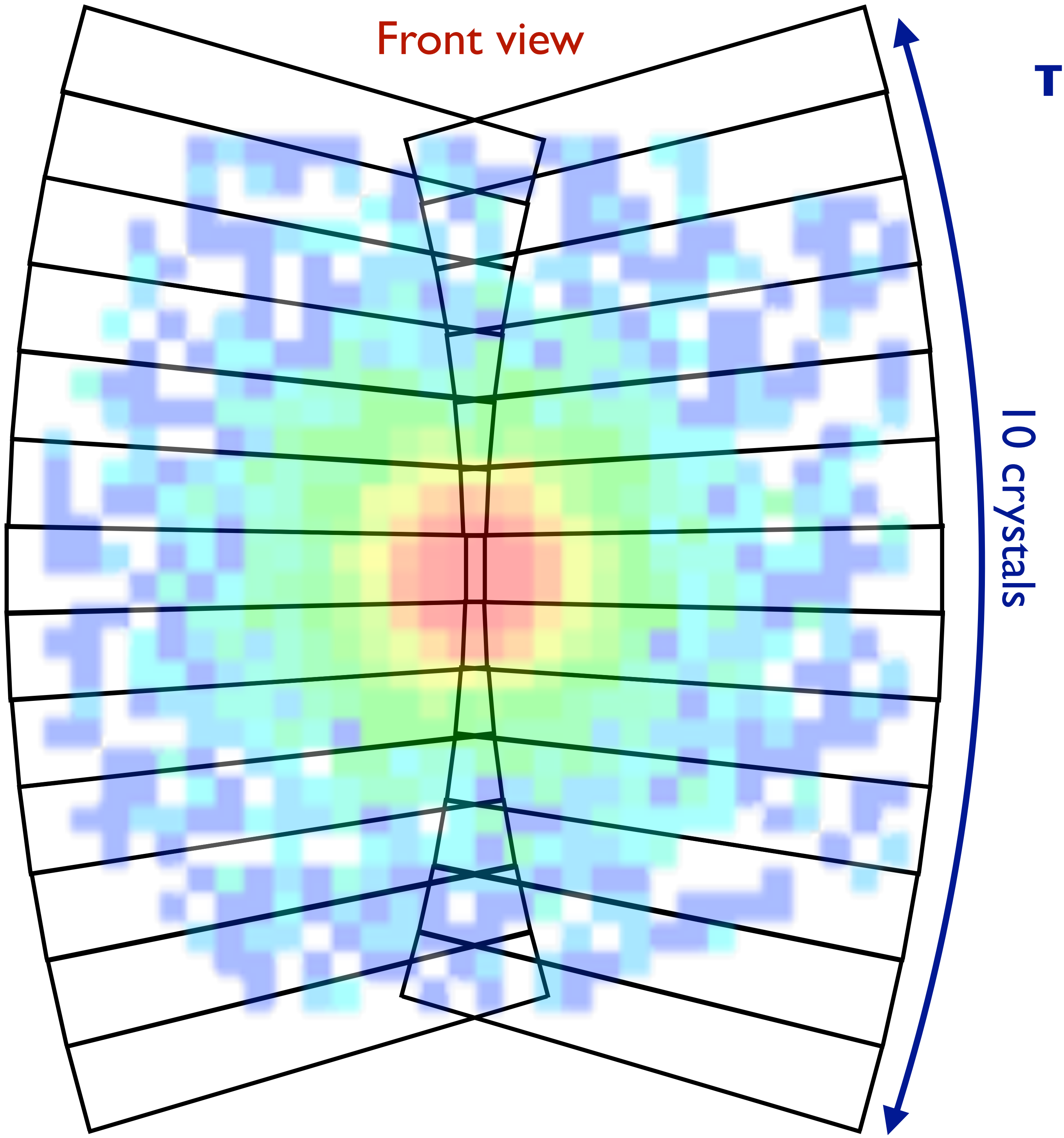
- **CsI(Tl) properties fit well the BDX@LNF needs**
- **O(800 crystals) to build the detector easy to assemble**
- **Crystals already equipped with readout electronics**
- **Minimized costs**
- **Minimized time-line: detector assembled and ready for measurements in O(1 year)**

Yesterday one BaBar crystal has been shipped to us: it will be used during the cosmogenic background measurements at LNS-CT

BDX@LNF: a possible layout I

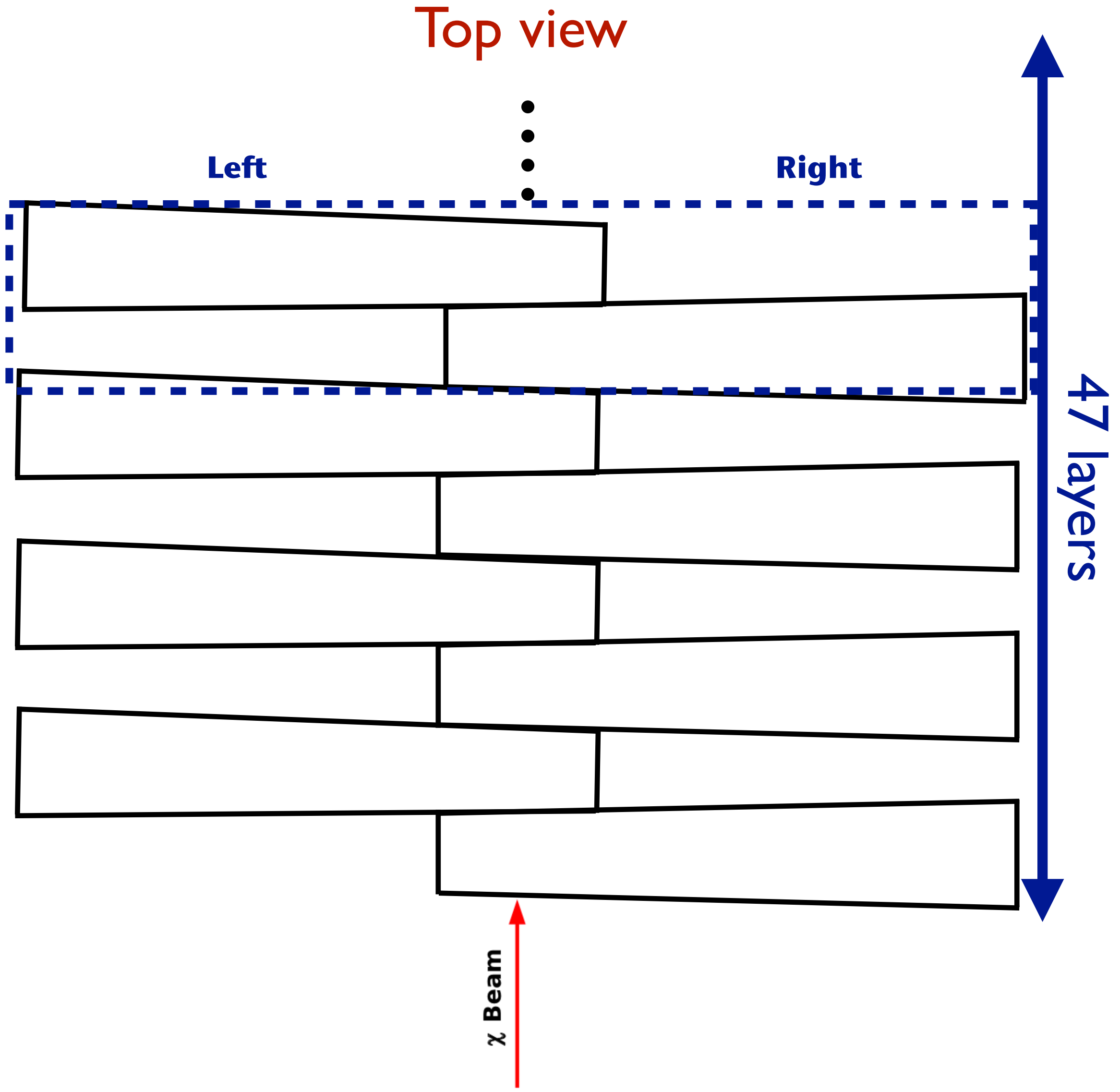
Layers of crystals arranged face-to-face

Single layer: 10 crystals x 2 columns = 20 crystals



2 m of detection material = ~ 41 layers

TOT = 41 layers x 20 crystals = 820 crystals



A potential advantage: χ particles cross a thicker volume of CsI in the middle of the EMC where their flux is maximum