GASPARD-TRACE: recent progresses

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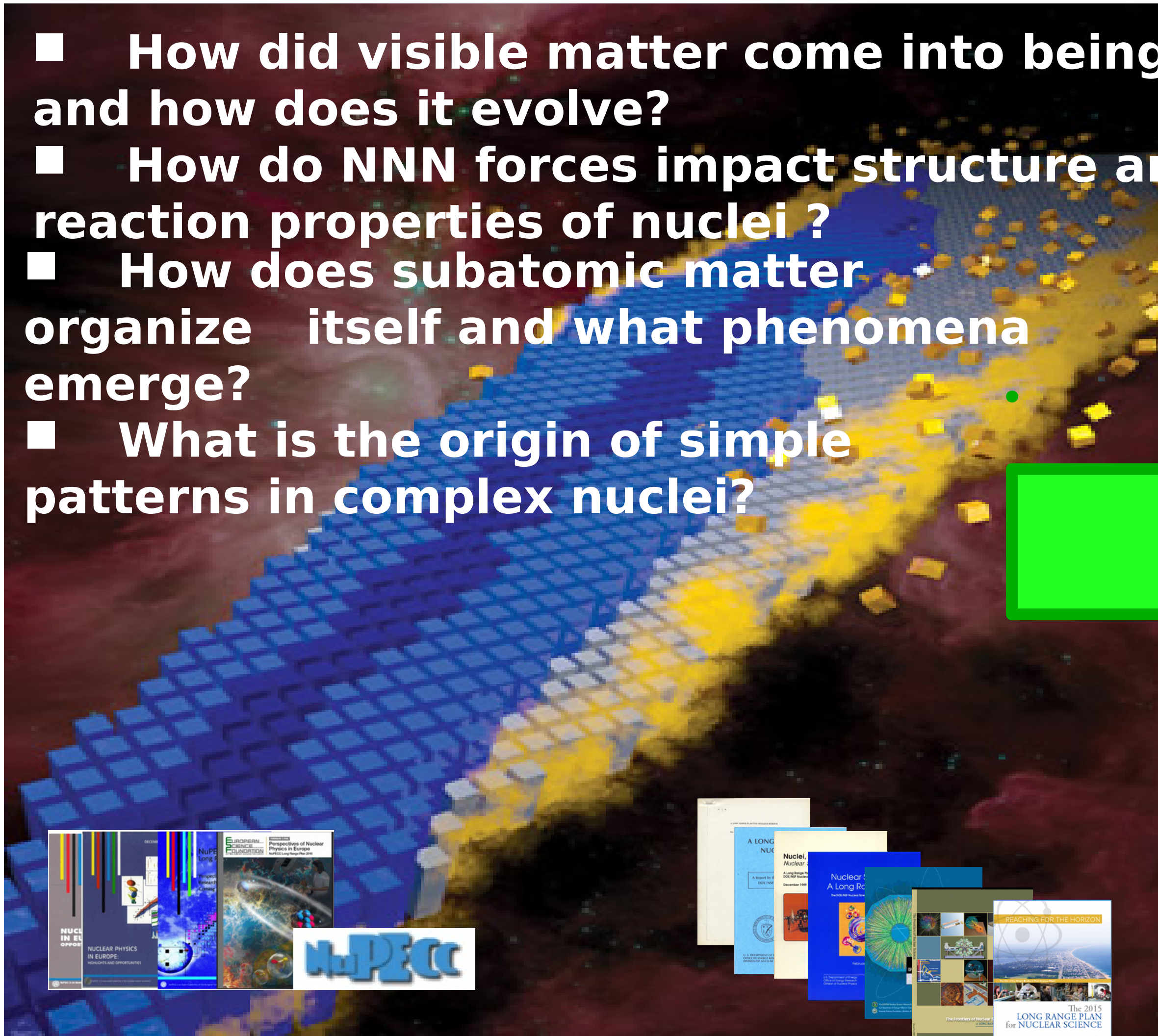
[1]University of Padova, INFN Padova

GASPARD TRACE

Nuclear physics at the frontier



- How did visible matter come into being and how does it evolve?
- How do NNN forces impact structure ar reaction properties of nuclei ?
- How does subatomic matter organize itself and what phenomena emerge?
- What is the origin of simple patterns in complex nuclei?

SPIRAL

Spiral2

SPES exotic beams for science

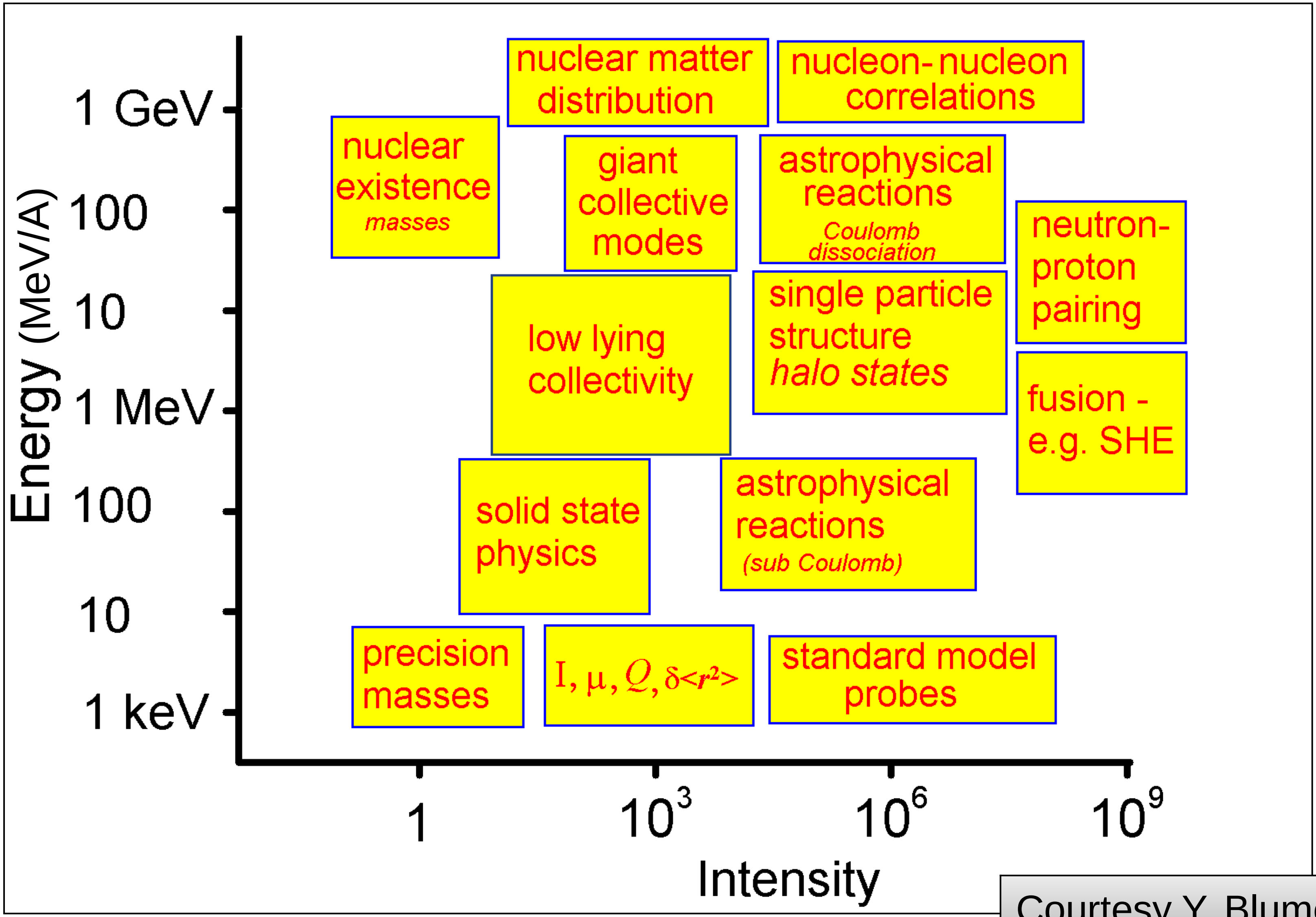
ISOLDE

RIKEN

FRIB

FAIR

RIB Physics Reach

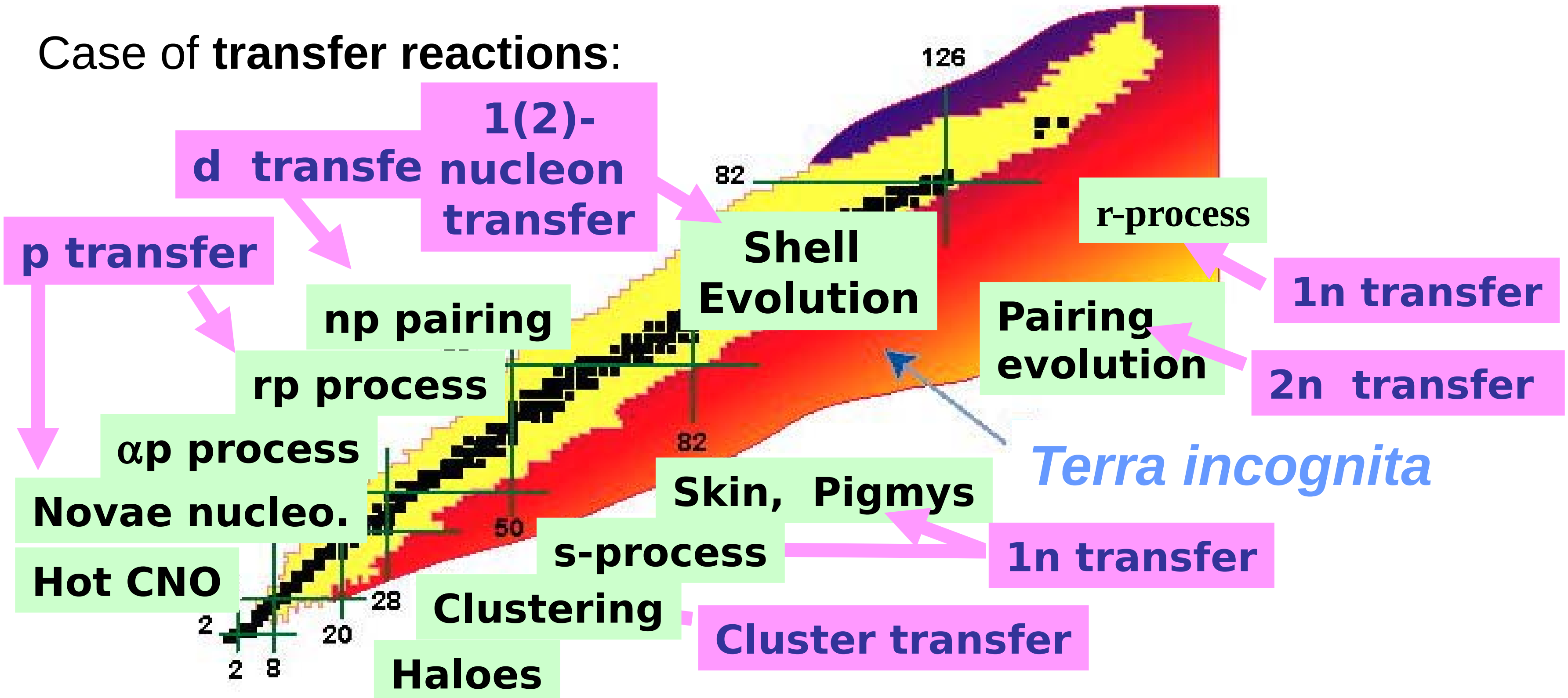


Courtesy Y. Blumenfedl

Direct Reactions

A great tool to investigate Exotic Nuclei and Nucleosynthesis

Case of **transfer reactions**:

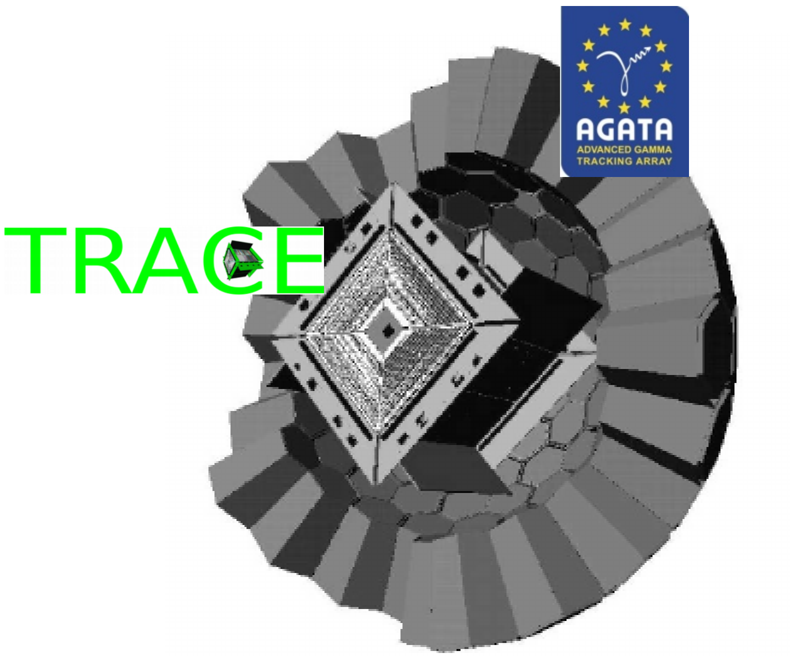


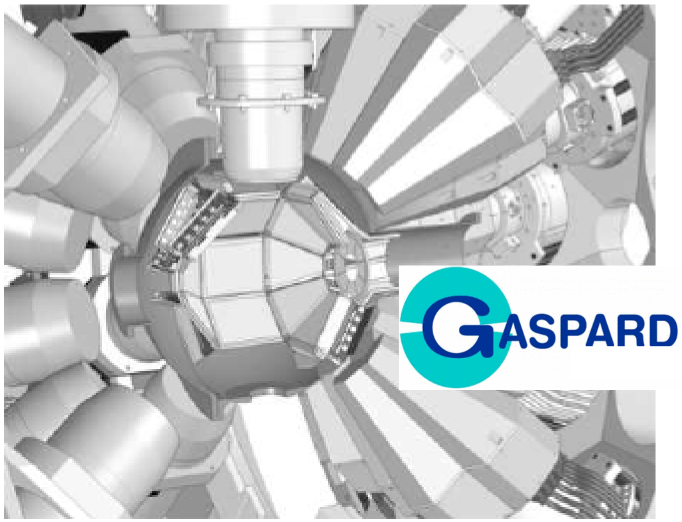
Good energy regime : few MeV/u → few tenths of MeV/u

Methodology : **Radioactive Ion Beam** ⇒ **Light target (H,He…)**
Detect the recoil particle with high accuracy

Silicon technology

Project and Collaboration





GHT Collaboration Agreement

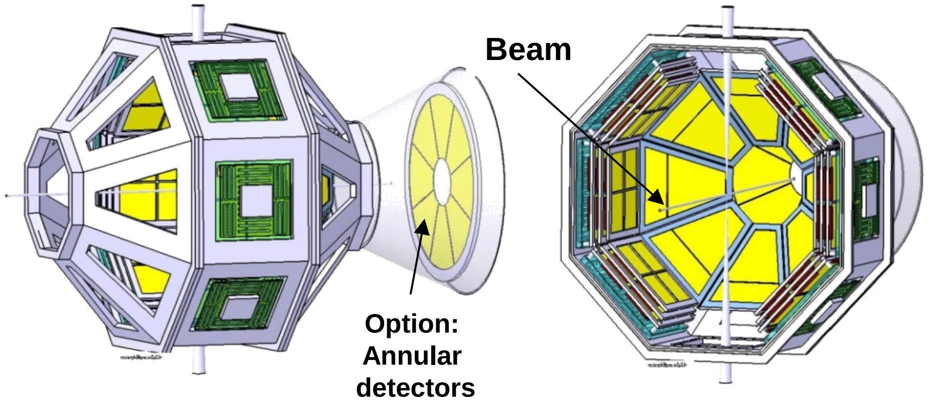
- **Introduction**

GHT (acronym for GASPARD, HYDE and TRACE, in reference to the corresponding initial projects) is an international collaboration aimed to develop a new detector for optimal study of reactions using low and intermediate energy beams at existing and forthcoming radioactive ion beam facilities. It consists in a new type of compact, highly segmented, silicon array, fully integrable within next generation gamma detectors such as AGATA and PARIS. Such new type of Silicon-based array is also meant to offer state-of-the art particle identification to

- Highly-uniform nT detectors
- Digital electronics to embed PSA capability
- Trigger-less system

A new Si array TRACE for structure and reaction study

"GASPARD-TRACE" design

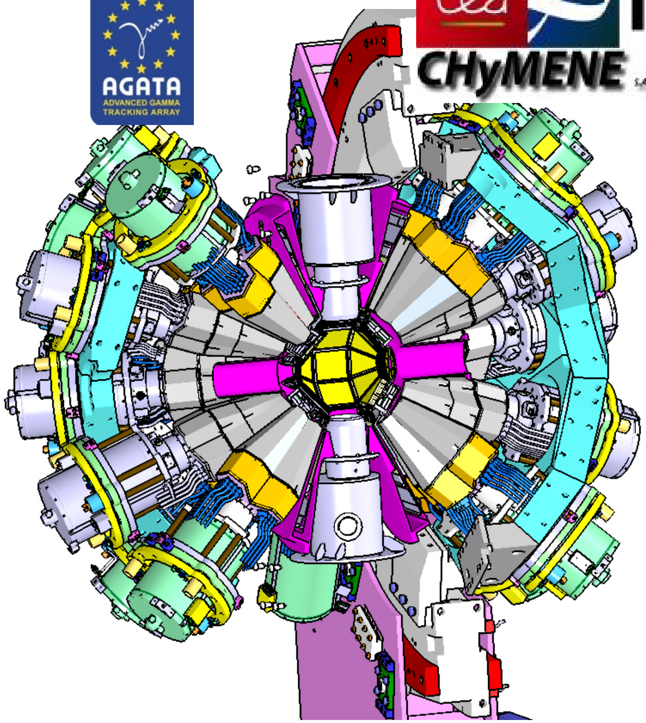


4π, fully integrable in PARIS and AGATA

Layers of Silicon

- 500µm DSSD pitch < 1mm
- 1(or 2) x [1.5 mm DSSD pitch~3mm]

2 main shapes : square & trapezoid, large area



Electronics :

~ 10000 channels (Digital)
high transparency to γ-rays
→ Big integration challenge

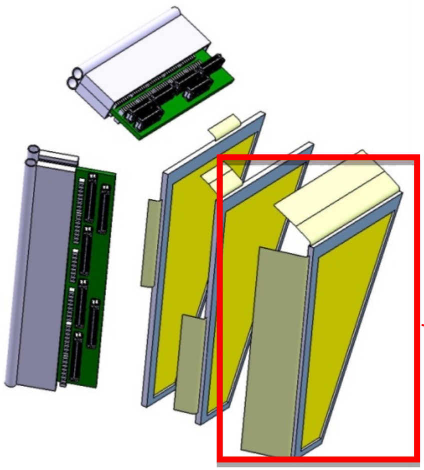
Motivations

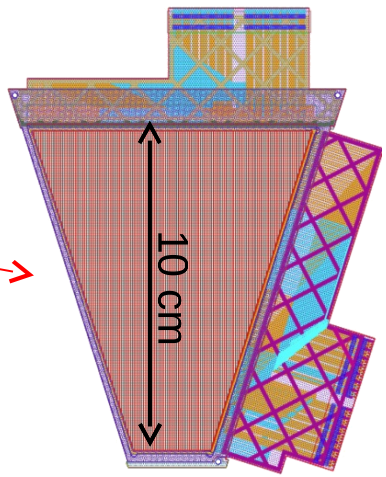
- ❑ Intermediate and heavier masses
- ❑ Higher excitation energies – Low sp strength
- ❑ Sometimes at mid-shell
- ❑ Detect/identify several channels altogether

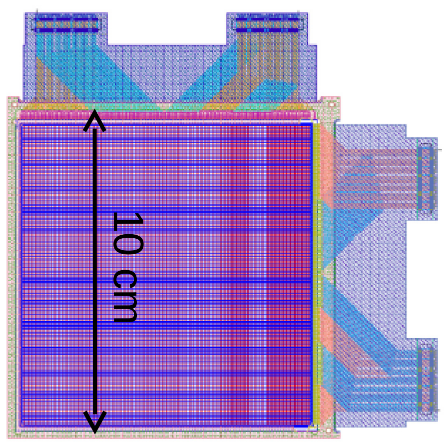
Silicon developments

- New geometries
- New packaging : thin frame, kapton at 90°
- 6”, NTD, random cut, reverse-mount
- Thin (500um) and thick (1.5mm)

M.Assié talk







Si detectors plan

1st layer (500 um, pitch~700 um)

- **Trapezoid shape**
  - **2 prototypes commissioned** [IPNO]
  - **3 pre-serie ordered** [Surrey, Santiago, IPNO] (MICRON SC)
- **Square shape**
  - **2 prototypes ordered** [INFN-Padova]

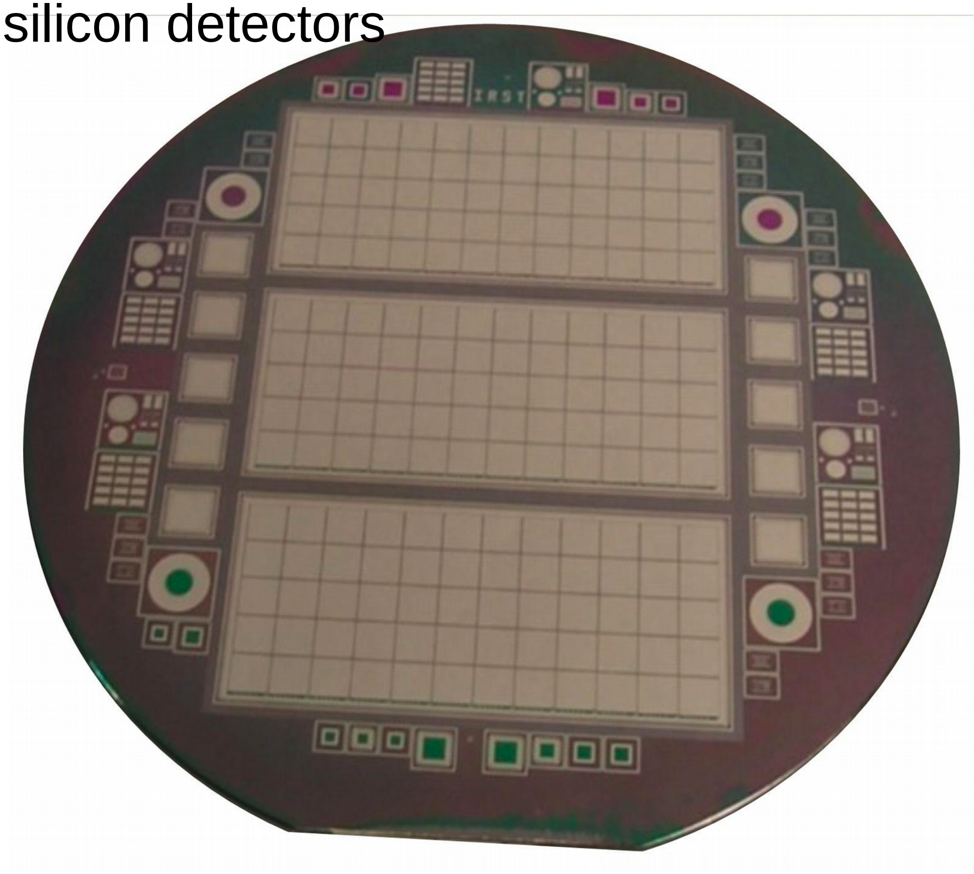
2nd layer (1.5mm, pitch~3mm)

- **2nd layer square**
  - **1 prototype ordered** [INFN-Padova] (MICRON SC)

Collaboration with BARC Mumbai foreseen

Silicon developments: second layer, under discussion

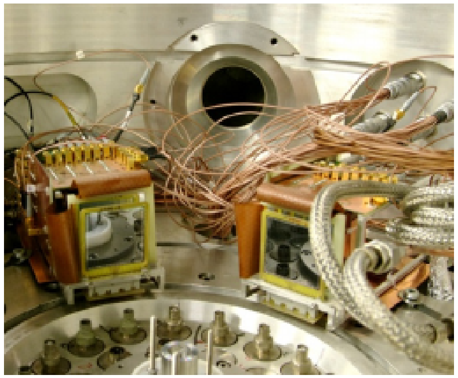
- Option :FBK Trento supplied quality 200-μm and 1.5-mm FZ silicon detectors

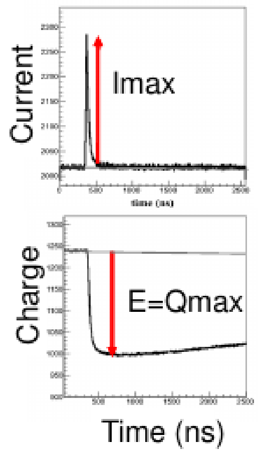


- 1.5 mm thick dets: ~50÷500 nA (200 V FD) chieved on the 4”
- They can deliver DSSD on 6'', but 1-mm thick

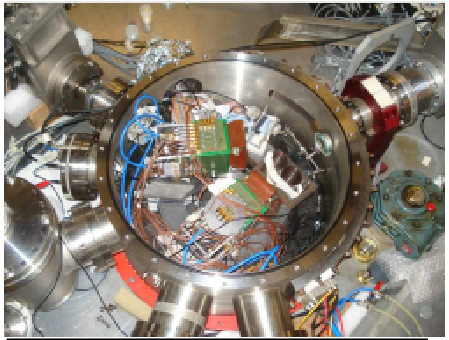
R&D on pulse shape analysis

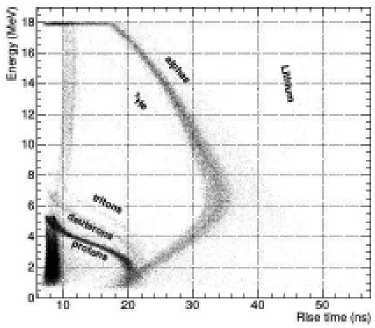
NTD, strips

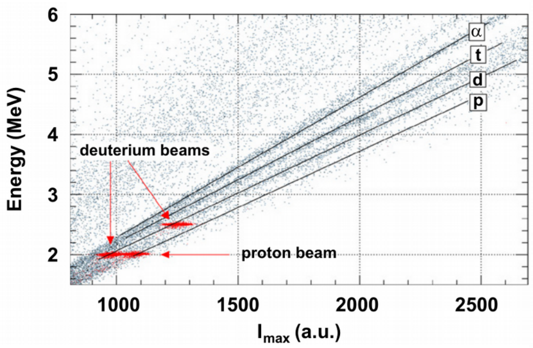


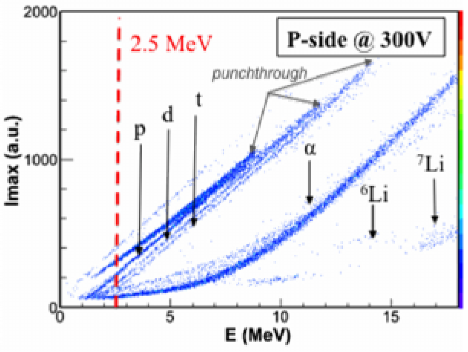


FZ pad

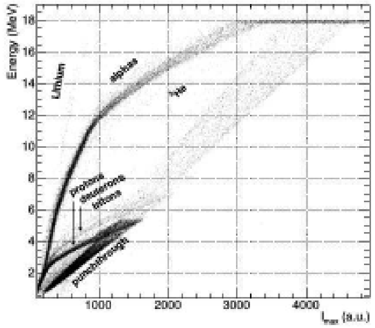








Gamma dets



- NTD Single pad
- Sgmented dets (DSSS&PAD)
- Gamma -ray dets

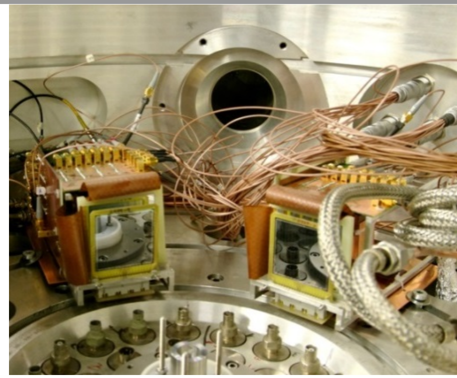
J.Duenas et al., NIMA(2012)

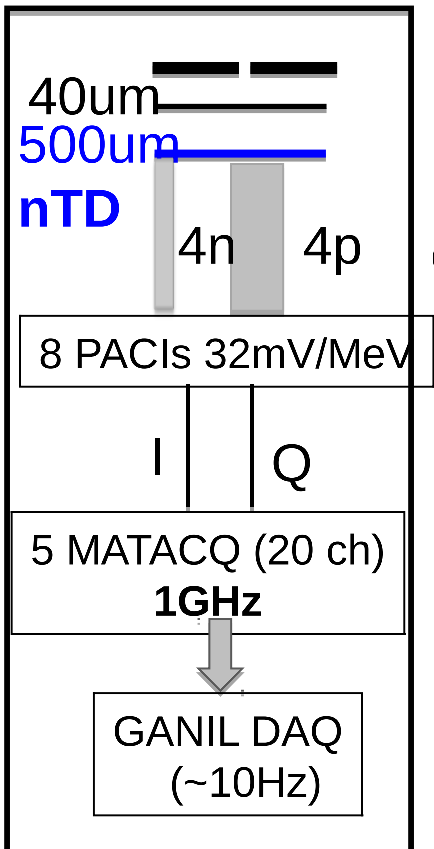
M.Assié et al., EPJA(2015)

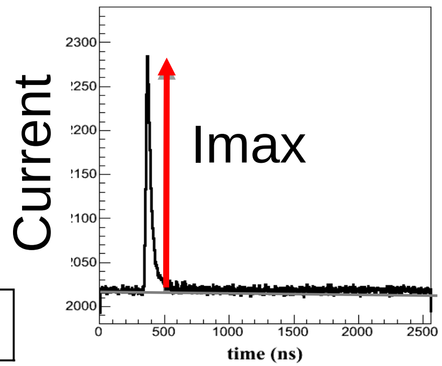
D.Mengoni et al., NIMA(2014)

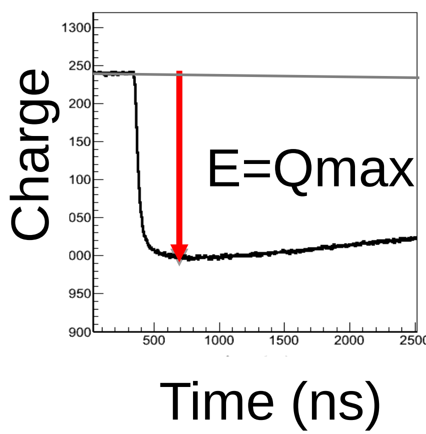
PSD for Z=1 particles

Test experiment
(IPNO tandem)
^{7}Li + ^{12}C @ 35 MeV

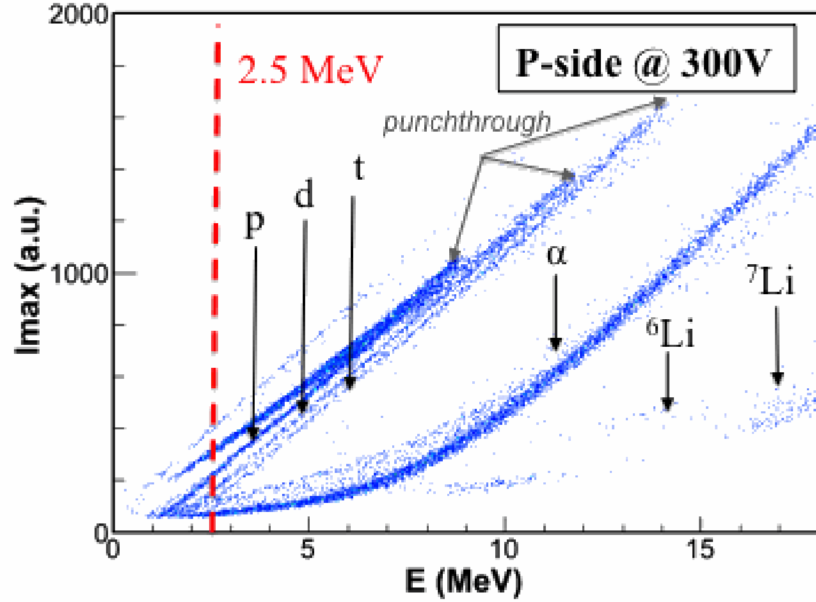


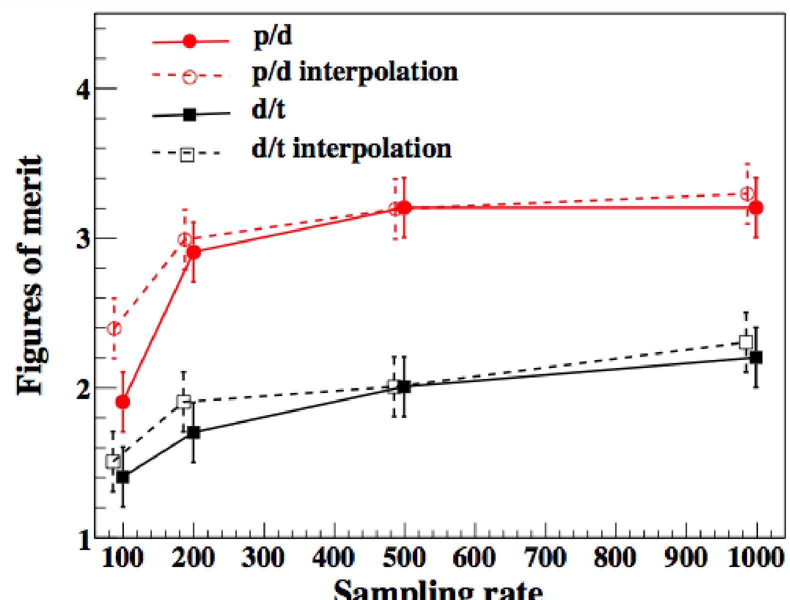






RESULTS



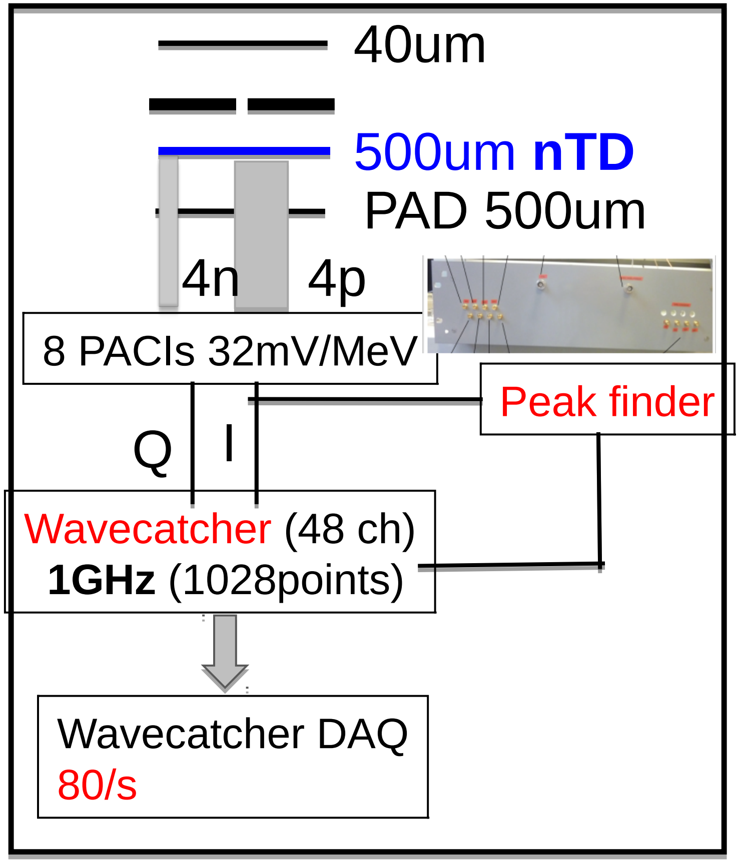


M.Assié et al., EPJA(2015)

PSD for Z=2 particles

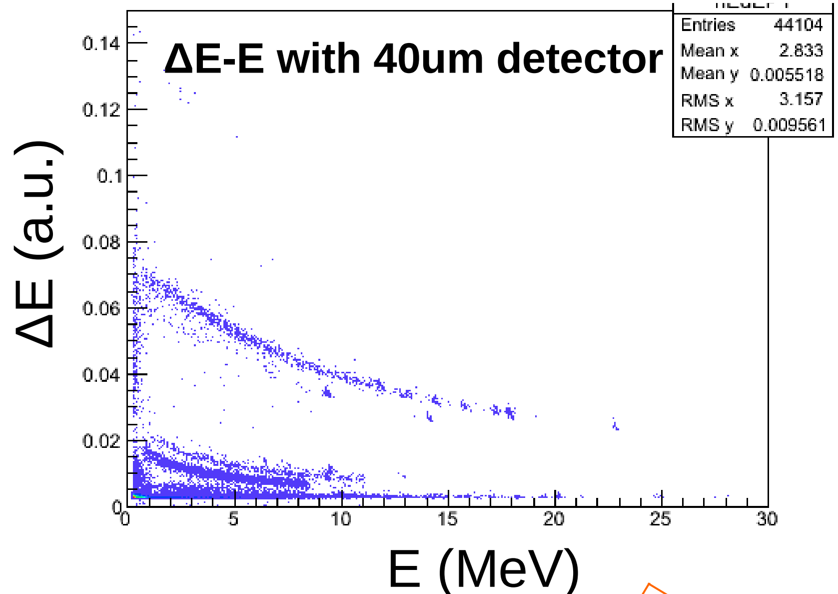
(d,^{3}He) on mylar @ 26 MeV (IPNO tandem)

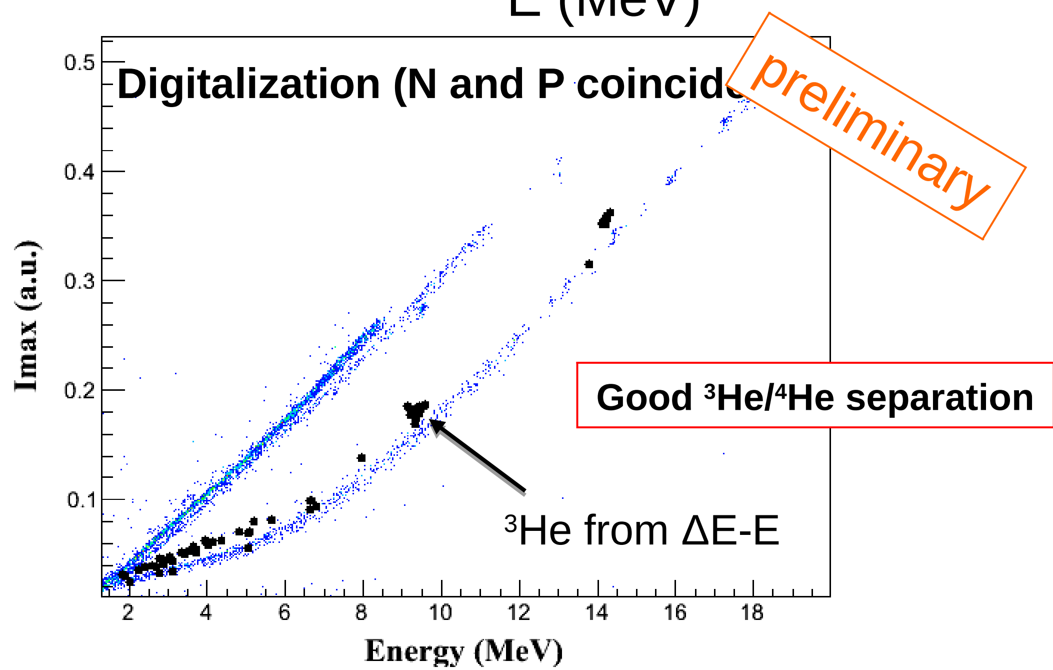
- ^{3}He/^{4}He discrimination
- test of analog peak finder on current



Under analysis

Add a ΔE detector for PID

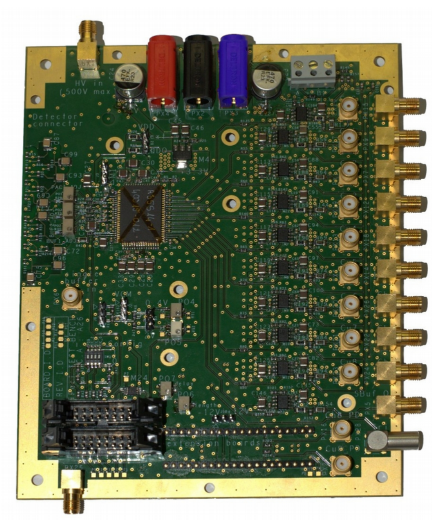




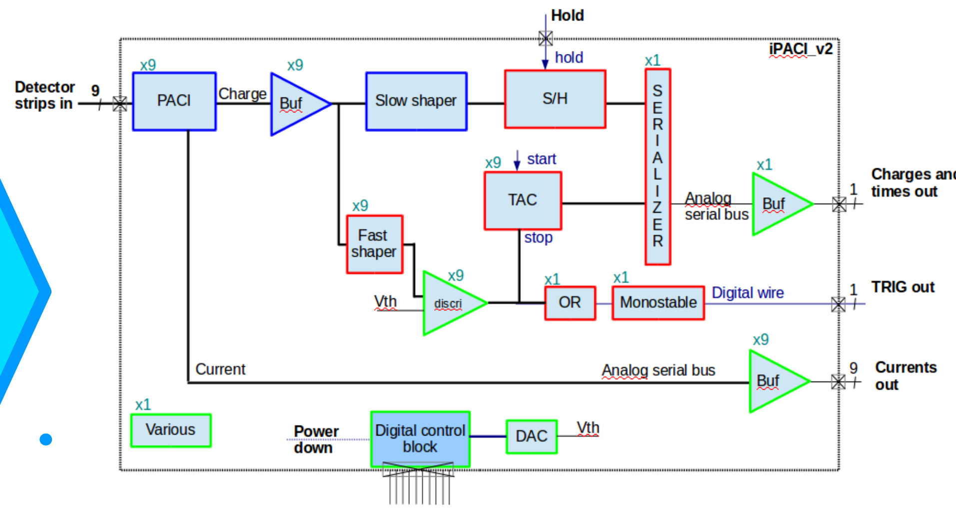
iPACI

JJ Dormard talk

- 9-channel integrated Charge and Current output preamplifier intending 50MeV with 10keV FWHM resolution on charge output



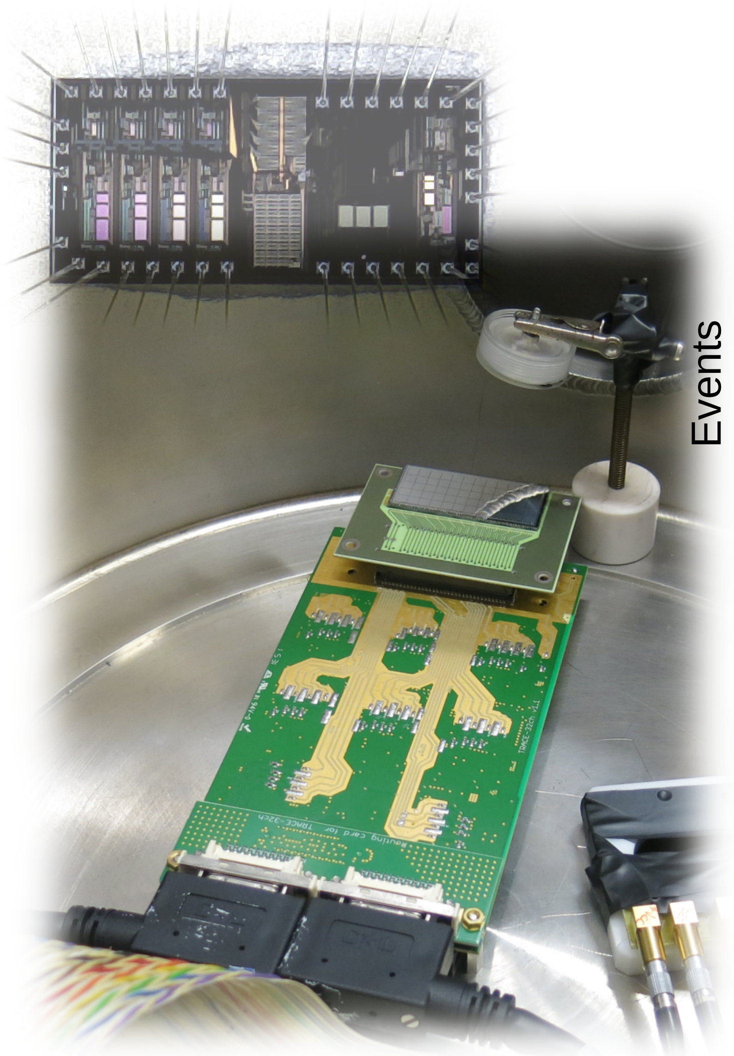
1st release

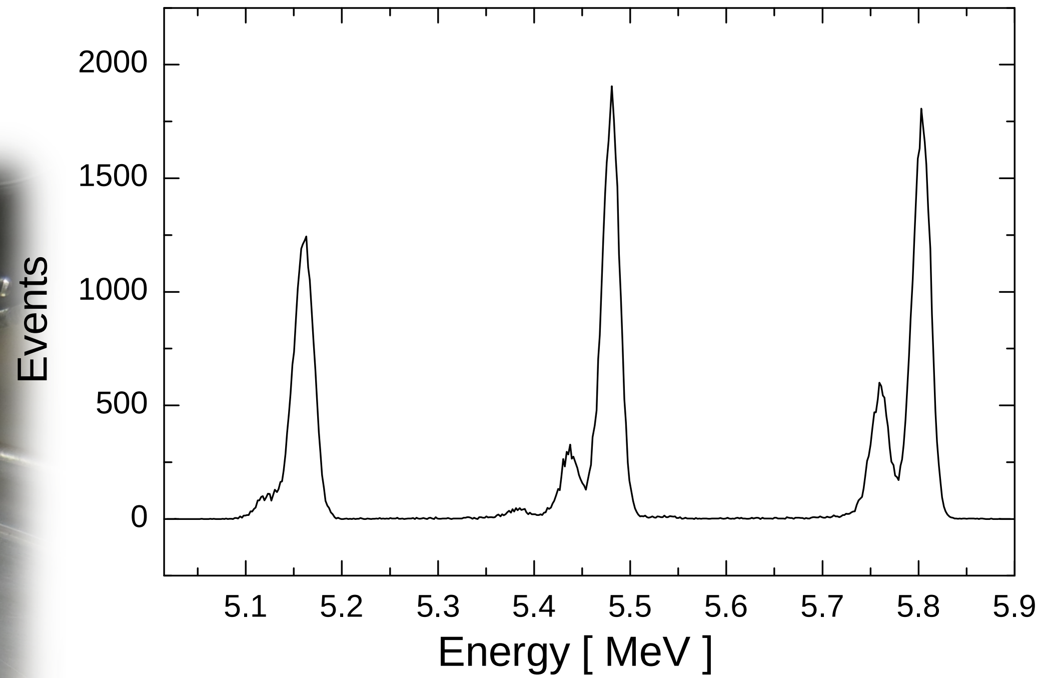


2nd release

Low-Noise High-Dynamic-Range VLSI CSP

S.Capra talk



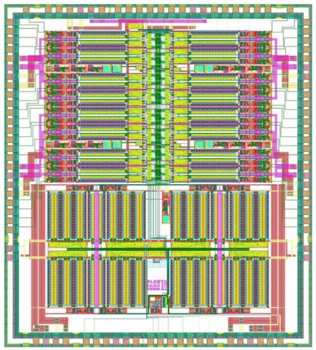


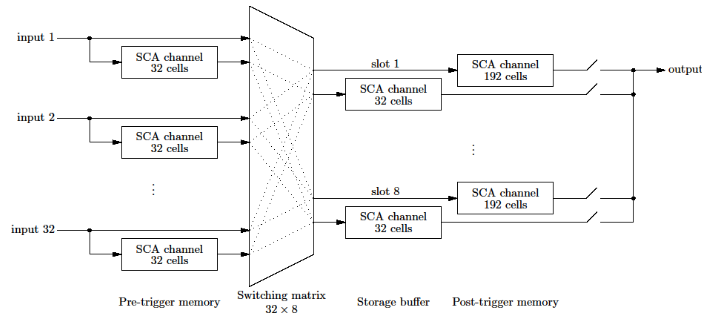
Source test:
sise time, resolution (soon ToT)

PLAS: ANALOG MEMORY ARRAY

R.J.Aliaga et al., NIMA 800 (2015)

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS





R.Aliaga talk

Pulse capture:

- Located after preamplifiers
- Admits different input polarities and signal ranges
- Needs 1 external resistor per channel
- 32 inputs with independent trigger
  Samples pulses @ 200 MSPS
  Both edges of 100 MHz clock
- 224 samples from each pulse: 32 before trigger (30 valid), 192 after trigger
- Generates common Trigger Request signal
- No deadtime:
  Limited by readout rate

Pulse readout:

- Single analog output (differential)
- Serial readout @ 50 MSPS
- External ADC located at back-end
- Generates timestamp for pulses
- Synchronizable with each other and/or GTS
- Low noise (11.5 ENOB spec)

Other specs:

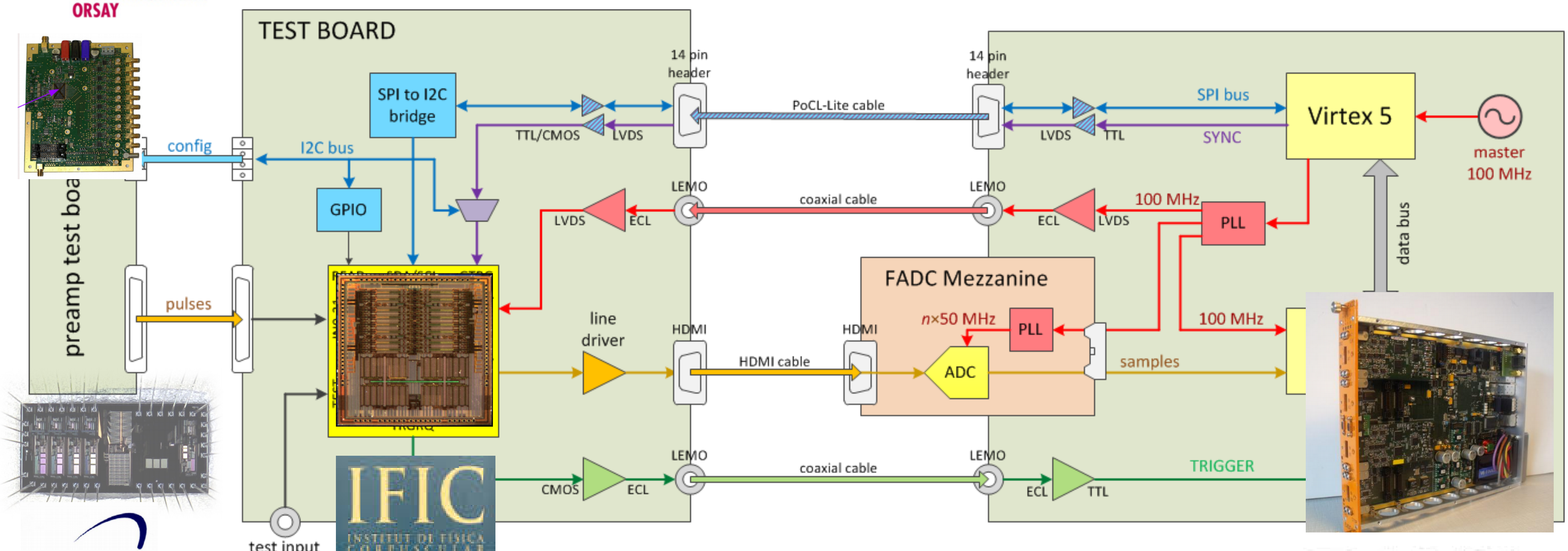
- 0.18um CMOS technology
- 1.8V power supply
- Low power (10 mW/channel spec)
- I2C configuration interface

Test bench: Det. Board + RO unit

- Current and charge output (IPN)
- Charge + extended dynamics (INFN)

- different input polarities and signal Ranges
- 32 inputs with independent trigger
- Samples pulses @ 200 MSPS
- 224 samples from each pulse: 32 beforetrigger (30 valid) 192 after trigger
- Generates common Trigger Request signal
- No deadtime

A.Gadea talk



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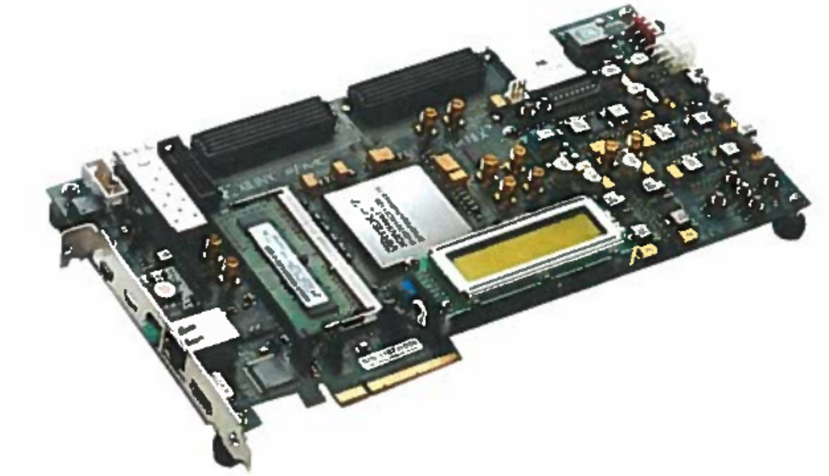
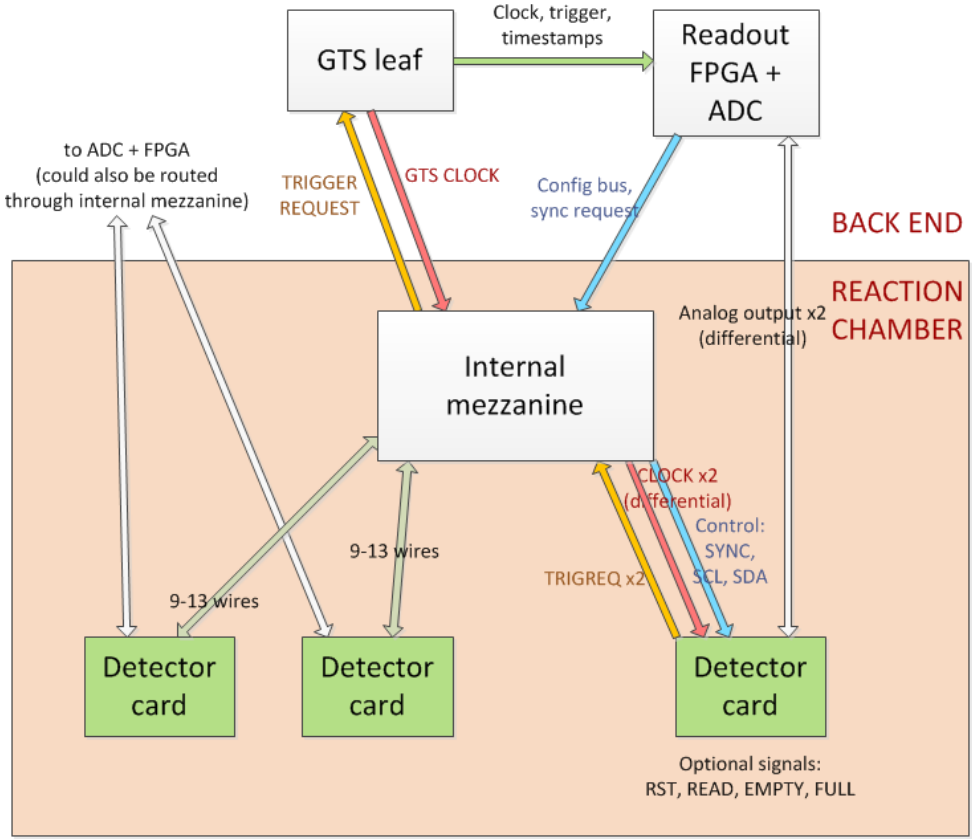
GANIL GRAND ACCELERATEUR NATIONAL D'IONS LOURDS

Trigger processor & sync

TP is optically linked at the top of the GTS tree.



- One or few partitions,
- Multiplicity threshold
- (anti)coincidence
- Possibility to read out partition even if not in the trigger

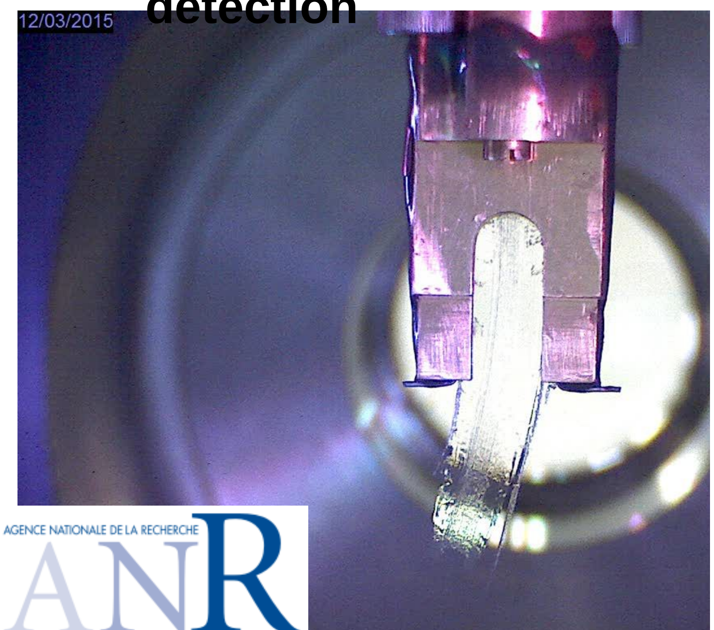


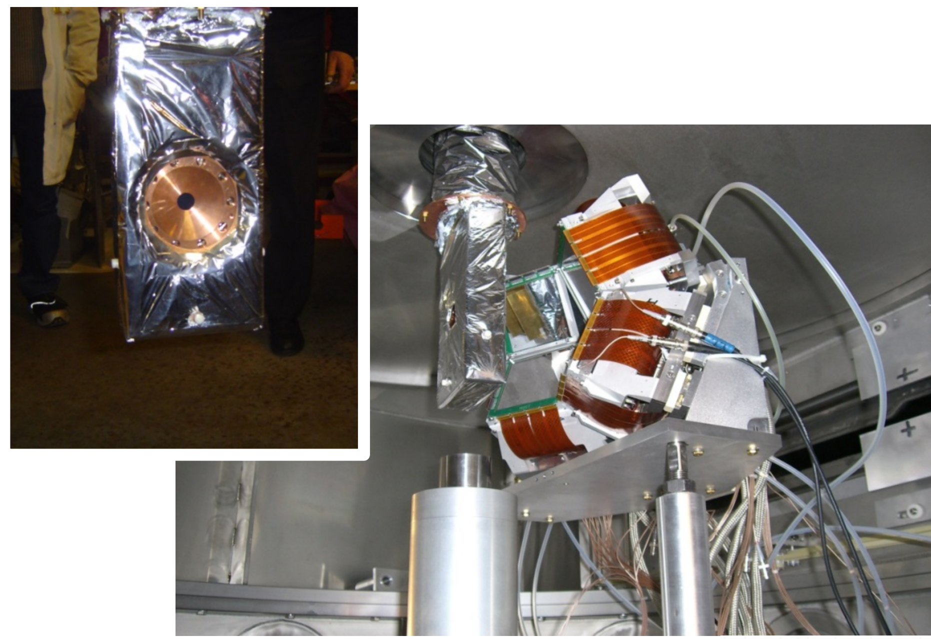
- One MEZZANINE per blocks of detectors.
- GTS mezzanine (FPGA...) embedded in the ADC card : receive the TS both from the GTS leaf, coming from the trigger processor (TP), and also from the PLAS

Special targets

- Hydrogen (h,d) target in a solid phase near triple point (~17K)
- Thickness 50 – 200 µm
- No window - C free
- Continuous flow in vacuum 2-10mm/sec
- Compatible with particle detection

- He gas target
- cooled gas cell at 5~8 K to maximize density
- Havar windows, 3.8 microns
- Used at SPEG – GANIL
- 3He version under study





IRFU-IPNO-DAM

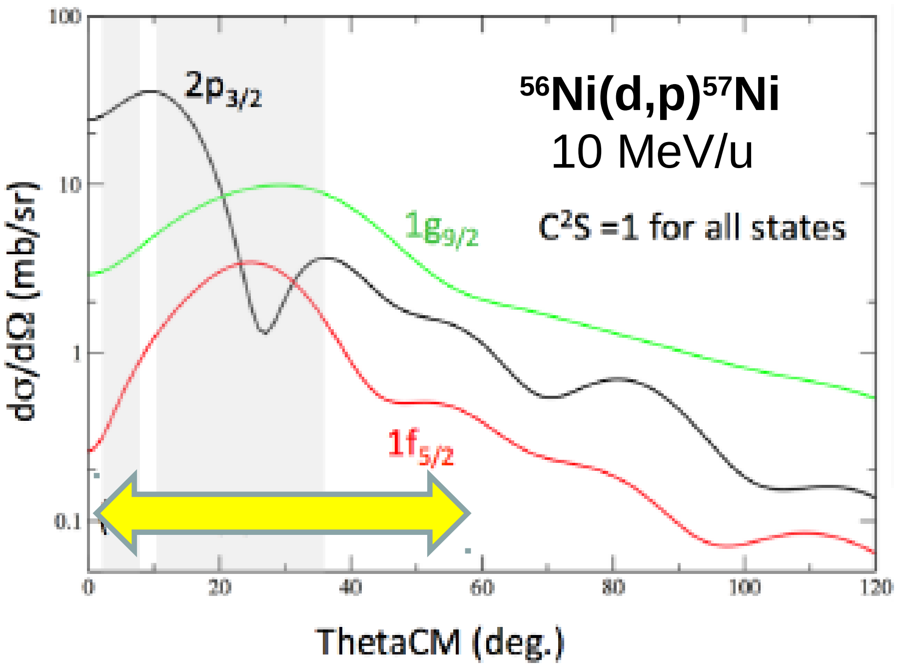
A.Gillibert talk

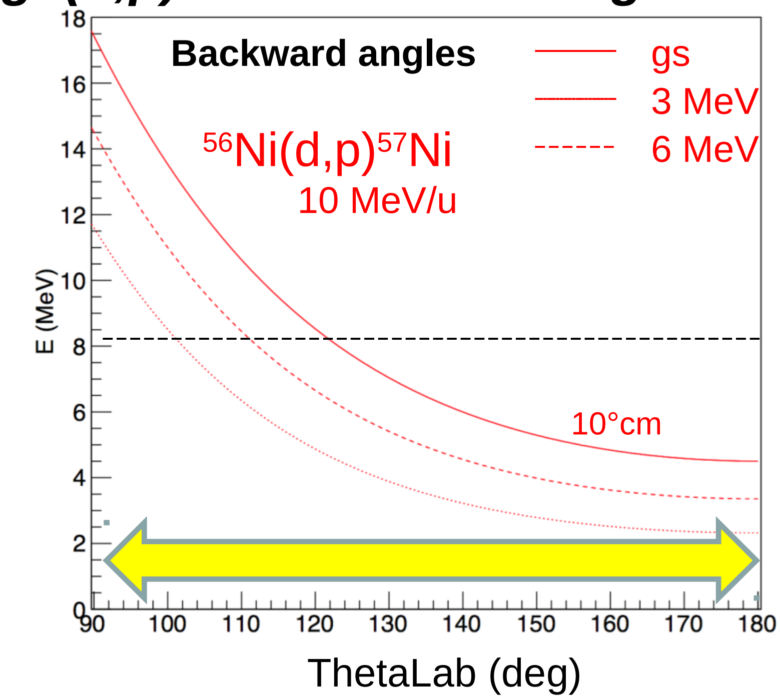
MUGAST: motivations
MUST2+GASPARD+TRACE

To perform ***high resolution reaction and spectroscopy studies*** using

- ❑ **AGATA**@ VAMOS – GANIL for some years
- ❑ The new SPIRAL1 beam + upgrade
- ❑ Some Si dets of future array progressively available

Focus on ***stripping reactions*** ***e.g. (d,p)*** ⇨ ***backward angles***





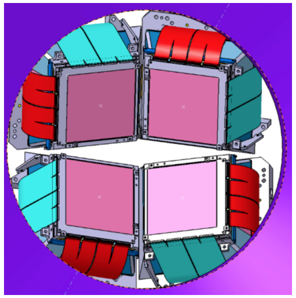
MUGAST: configuration
MUST2+GASPARD+TRACE

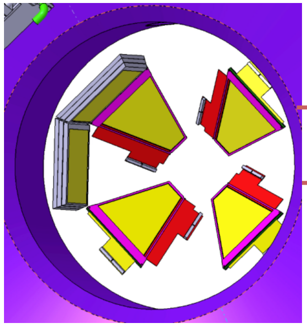
■ **Intermediate configuration: MUGAST (MUST2-GASPARD-TRACE)**

Particle detection:

- 4 GASPARD trapezoid DSSSD (backward/AGATA side)
- 1 Annular (S1-like) (backward close to 180°)
- 2 TRACE square detectors (@90°)
- 4 MUST2 Telescope (forward)

- Existing electronics (MUFEE+MUVI)



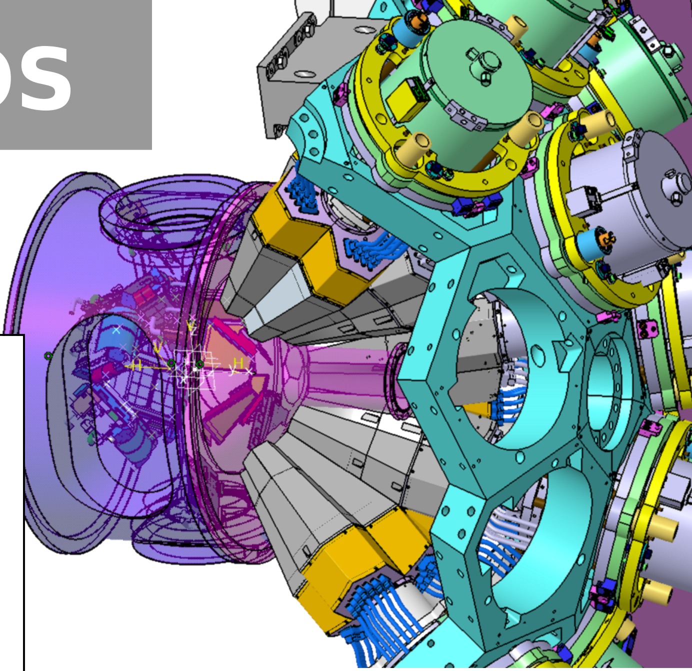


γ-detection (AGATA):

- Maximize eff: ≈ 8% @1 MeV @ 18cm *(for 11 triples)*

- Benefit from very good energy resolution (≈ 5 keV)

MUGAST+AGATA @ VAMOS



 LoI for AGATA+MUGAST+VAMOS for the PAC @ GANIL

Reaction studies using the MUGAST+AGATA setup at VAMOS

Letter of Intent to the AGATA collaboration

D.Beaumel, IPN Orsay
D.Mengoni, University and INFN Padova

1. Introduction

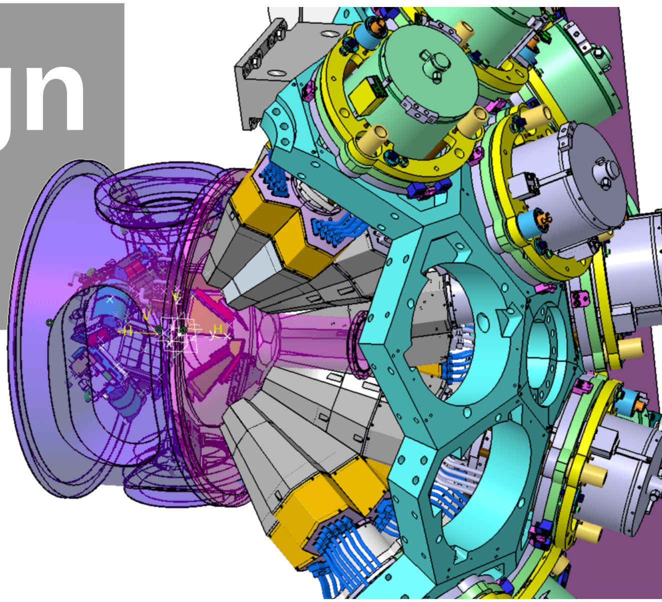
The GASPARD and TRACE high granularity Silicon arrays have been natively designed for optimal integration in new generation gamma detectors such as AGATA with the aim of performing high-resolution reaction studies. Indeed, the coupling to AGATA allows a very large gain in excitation energy resolution, in comparison with the case where the excitation energy is deduced from the recoil charged-particle measurement. The GASPARD and TRACE collaboration are now converging to build such new-generation Si ensemble in common, with a timeline of 2019-20 for completion of the final 4π array, ready for the emerging ISOL facilities, like SPES and SPIRAL1. A view of such ultimate GASPARD-TRACE setup sitting inside AGATA is shown in Fig.1.

The PAC found the proposition of combining MUGAST+AGATA with VAMOS compelling, and it was clear that much progress had already been made in realising this ambition, with significant development of the instrumentation. The aim to deliver a campaign around transfer reactions (including stripping) was well received as it was believed that this should be a core component of the future scientific programme of GANIL, building on the rich heritage of the programme that the present collaboration has led. The PAC is therefore supportive of this development and it would seem that the best course of action is to present this proposition to the GANIL Scientific Council as directed by the GANIL Director.

LoIs Science campaign

MUGAST+AGATA@GANIL

Spiral 1 beams



About 20 LoIs concerning:

- **SHELL EVOLUTION**
- **PAIRING**
- **NUCLEAR ASTROPHYSICS**
- **REACTION DYNAMICS**

AGATA ADVANCED GAMMA TRACKING ARRAY

GANIL GRAND ACCELERATEUR NATIONAL D'IONS LOURDS LABORATOIRE COMMUN DSM/CEA-IN2P3/CNRS

and other **stripping**, pickup, incomplete fusion, Coulex, etc possible considering the disposable angle coverage

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Third International SPES Workshop

SPES exotic beams for science

October 10-12, 2016

Laboratori Nazionali di Legnaro (Padova), Italy

INFN Istituto Nazionale di Fisica Nucleare

Dipartimento di Fisica e Astronomia Galileo Galilei

Under the patronage of

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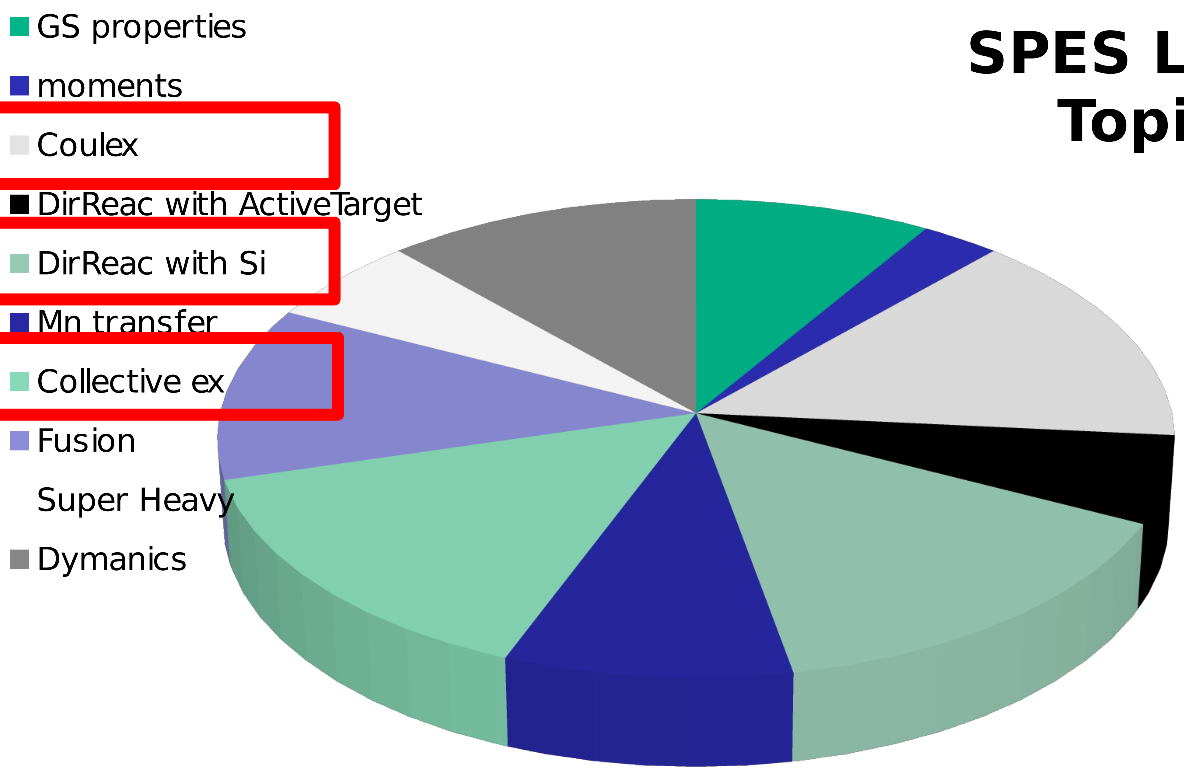
CAEN Tools for Discovery · Strumenti Scientifici CINEL s.r.l. · Oerlikon leybold vacuum · Pfeiffer Vacuum · 5Pascal · E.Zanon S.p.A.

42 LoI presented from around the world



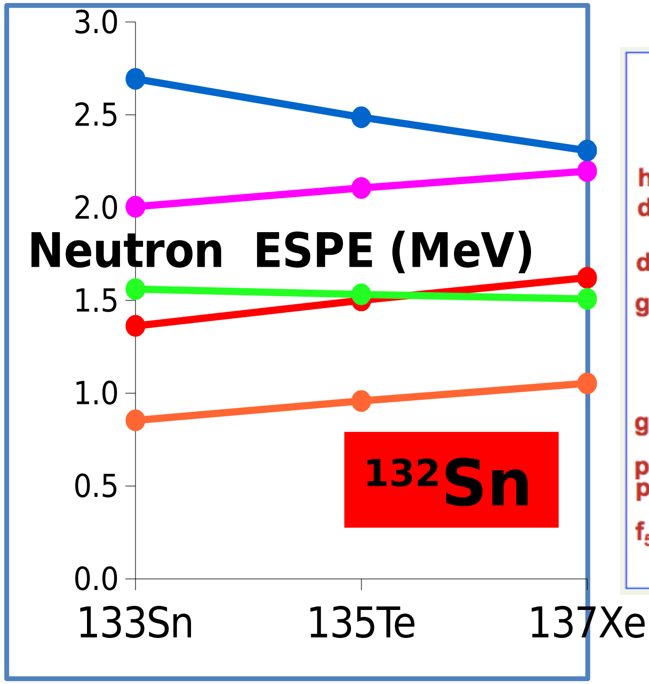
SPES LOIs Topics

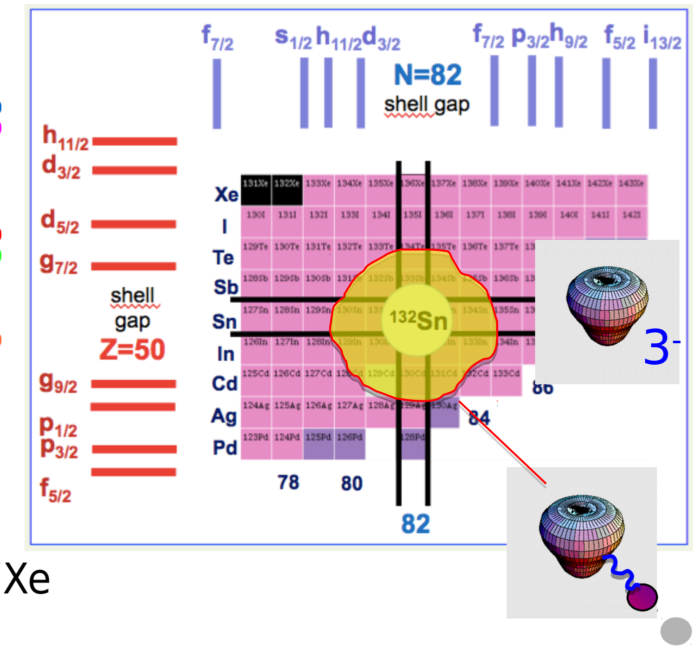
Shell evolution

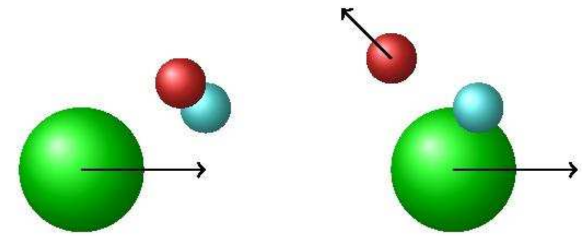
Collective modes

TRANSFER

Evolution of the single-particle states



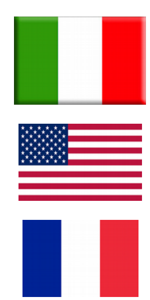




- Energy
- J^π via AD
- Spectroscopic factors → SPE

Spectroscopic factors around and beyond magic nuclei

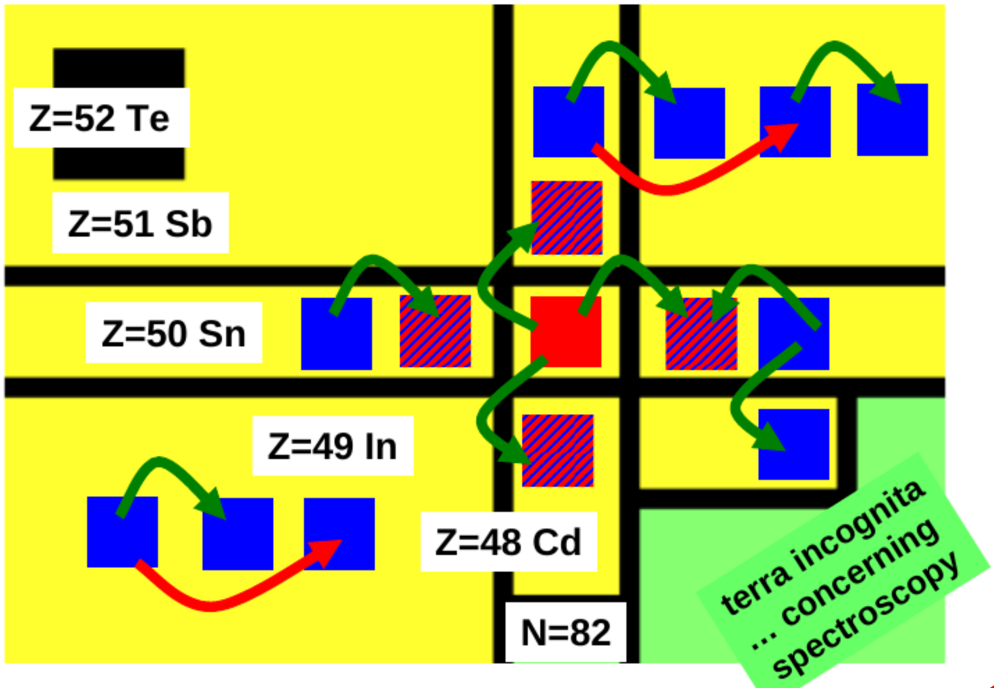
- D. Mengoni et (Uni. - INFN Pd)
- J.J.Valiente-Dobon et al. (INFN LNL)
- S.Leoni et al. (Uni. - INFN Mi)
- S.Pain et al. (ORNL)
- Lozeva et al.. (IPHC Strasbourg)
- ....

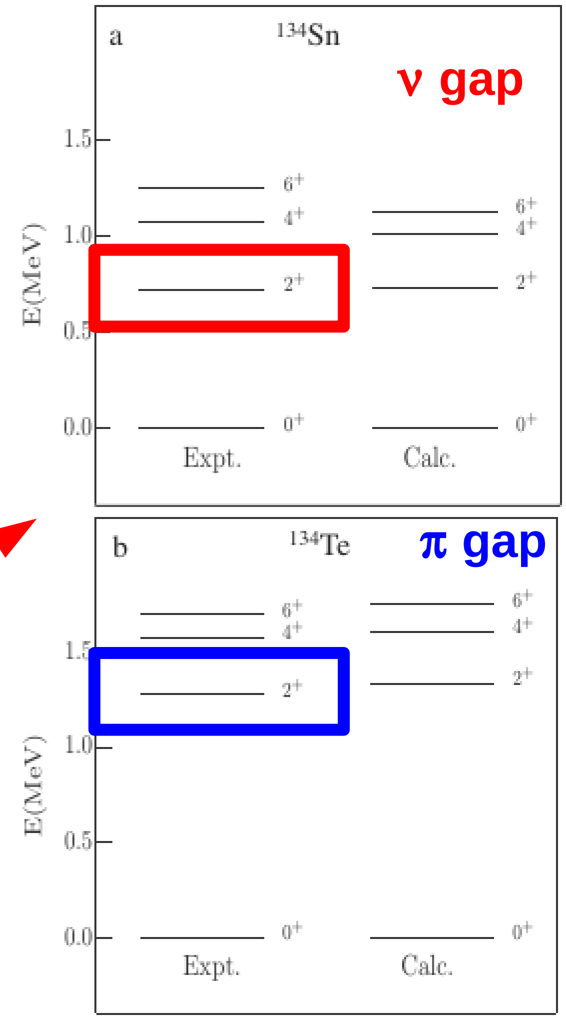


SPES
exotic beams for science

TRANSFER

Probe of the nuclear effective interaction

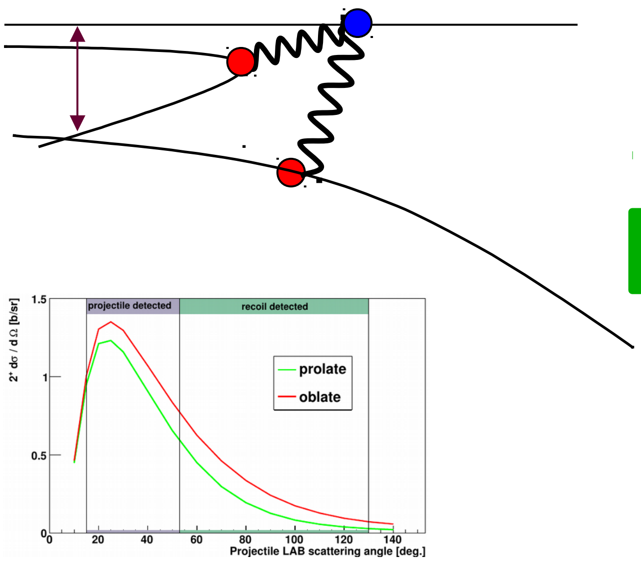


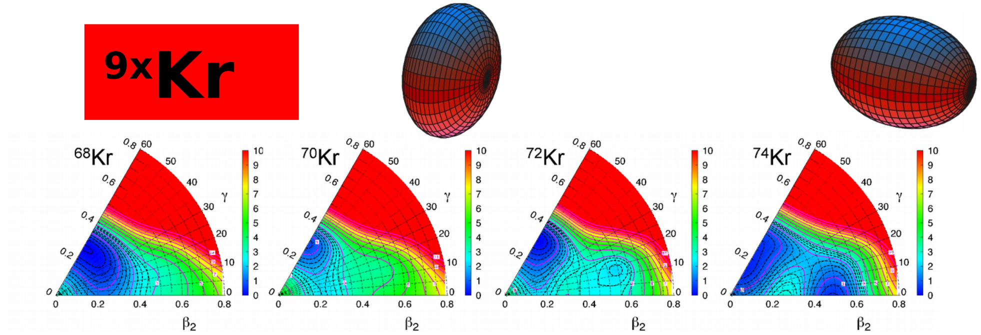


- SF → **single particle energies**
- 134Sn, 134Te → ππ, νν **pairing** term
- 137Xe → νπ **tensor force** tailoring
- Collective **excitation** from the **core**
- ν,π holes below 132Sn → erosion of shell closure? Island of inversion?
- 128Cd, 130In → trimmer the interaction ν,π holes configurations

Coulomb Excitation

Nuclear shapes and collectivity

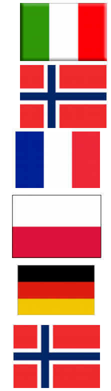




- Deformation
- Intrinsic shape
- Shape coexistence

Spectroscopic quadrupole moment

- B. Melon et al. (Uni. - INFN Fi)
- V. Modamio et al. (Univ Oslo)
- M.Zielinska et al (CEA Saclay)
- M. Kmiecik et al (IFJ PAN, Krakow)
- N.Pietralla et al. (IKP, Darmstadt)
- E.Sahin et al. (Uni Oslo)
- ....

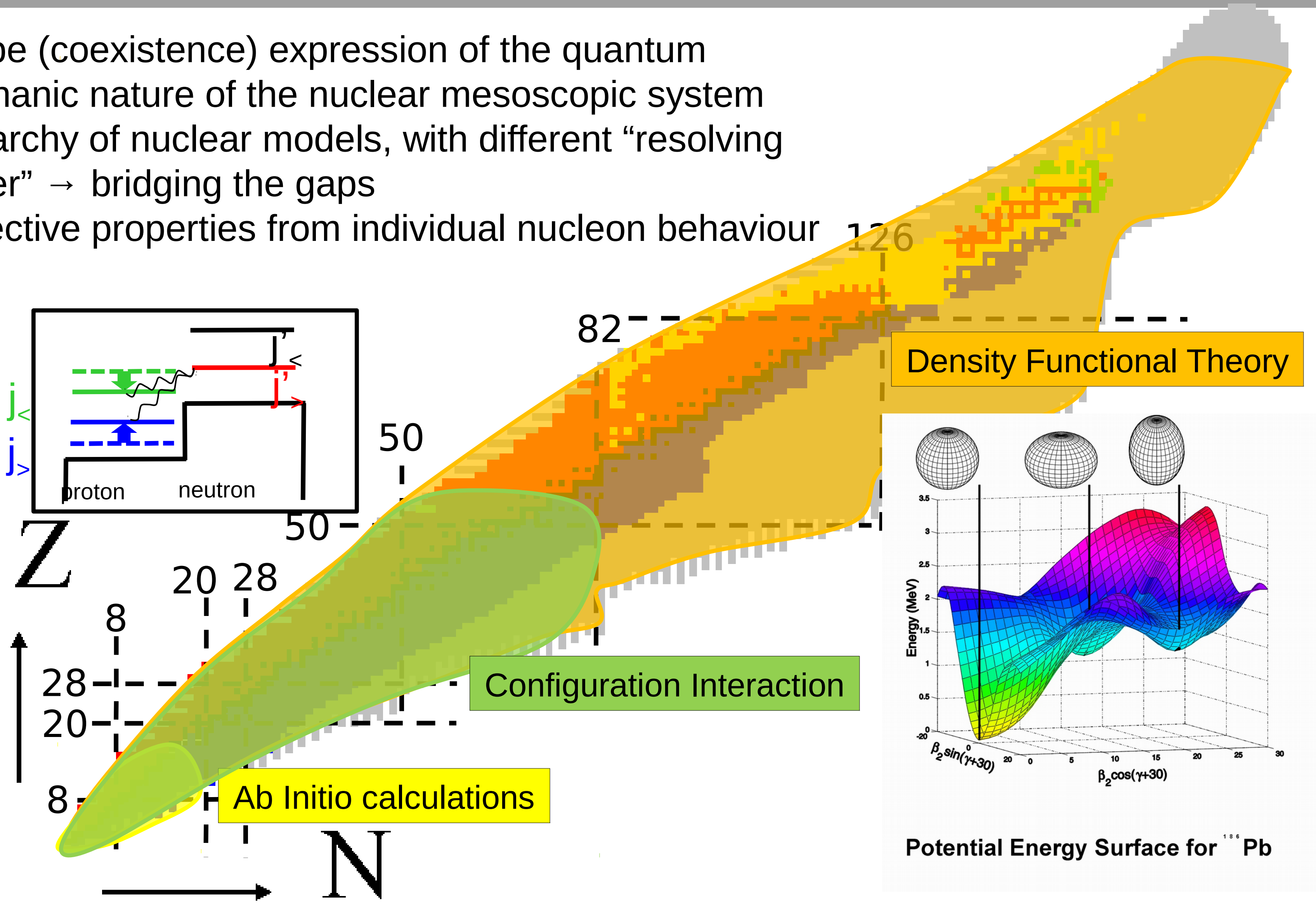


SPES
exotic beams for science

Coulomb Excitation

Microscopic underpinning of collective model

- Shape (coexistence) expression of the quantum mechanic nature of the nuclear mesoscopic system
- Hierarchy of nuclear models, with different “resolving power” → bridging the gaps
- Collective properties from individual nucleon behaviour



Potential Energy Surface for ^{186}Pb

Summary & Conclusions

- Structure and reaction studies using transfer reactions at 2nd generation ISOL facilities
- MUGAST array
- Physics program at GANIL using AGATA @ VAMOS
- in the future ….

Collaboration

- IPN Orsay , CEA Saclay, GANIL, LPC Caen
- INFN Univ. of Padova, INFN-LNL Legnaro , INFN Univ. of Milano
- Univ. of Huelva, Univ. of Santiago de Compostella, Univ. of Valencia
- Univ. of Surrey, STFC Daresbury
- BARC, Mumbai

Struttura nucleare alla frontiera

Spettroscopia γ a tracciamento

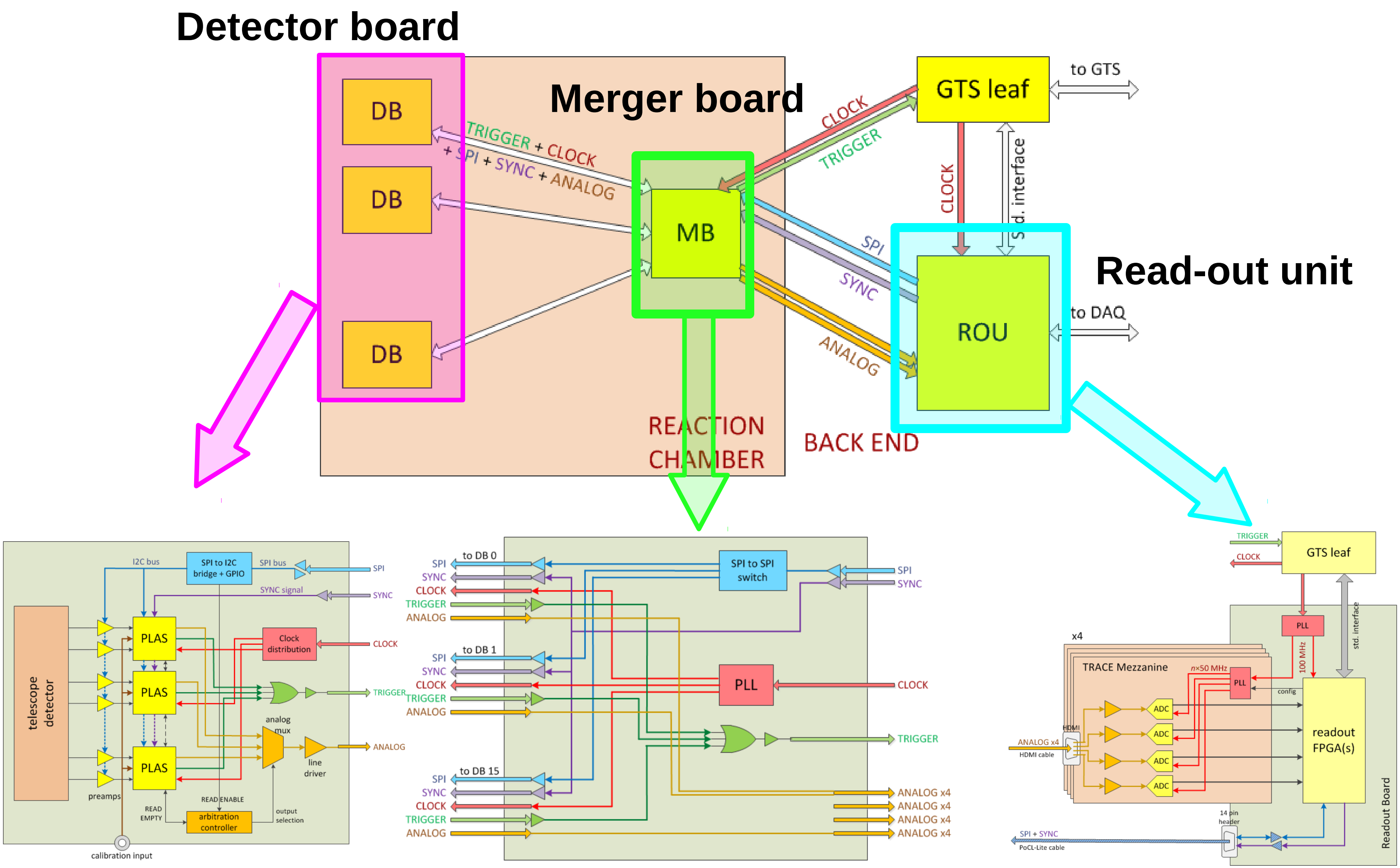
INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Legnaro

GSI

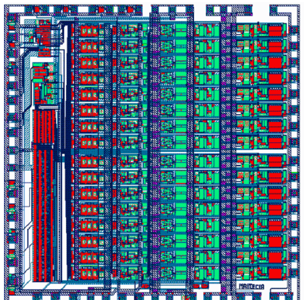
GANIL GRAND ACCELERATEUR NATIONAL D'IONS LOURDS LABORATOIRE COMMUN DSM/CEA-IN2P3/CNRS

SPES exotic beams for science

Electronics architecture



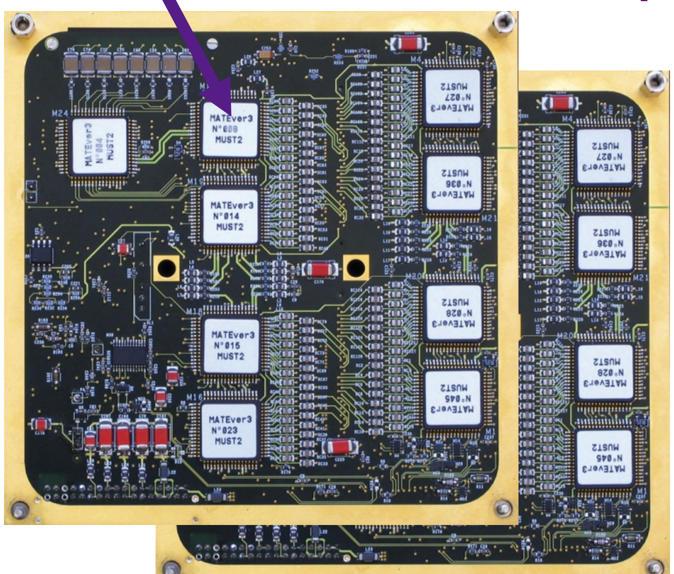
MUGAST Electronics : MUFFEE + MUVI



- 16 channels 28 mW/ch
- Energy & Time
- Si, Si(Li) and CsI
- Multiplexer
- I2C interface

- High linear. pulser
- T sensor

MOTHER BOARDS (IPNO)



VACUUM

AIR

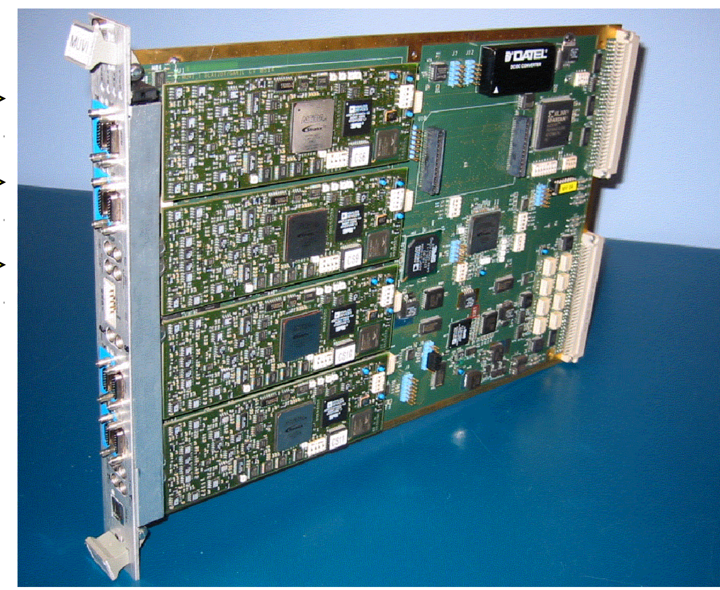
4 analog bus

Control signals

I2C bus

VXI board (GANIL)

16 ADC14 bits
2.3K parameters
2MHz
Slow Control I2C
Pedestal substraction
DNL correction



1 telescope

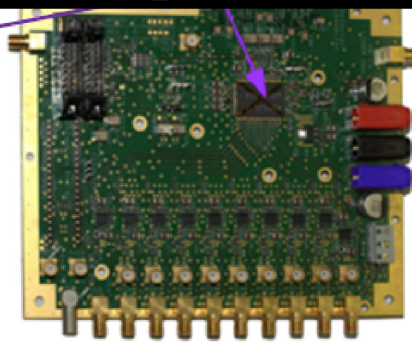
4 telescopes

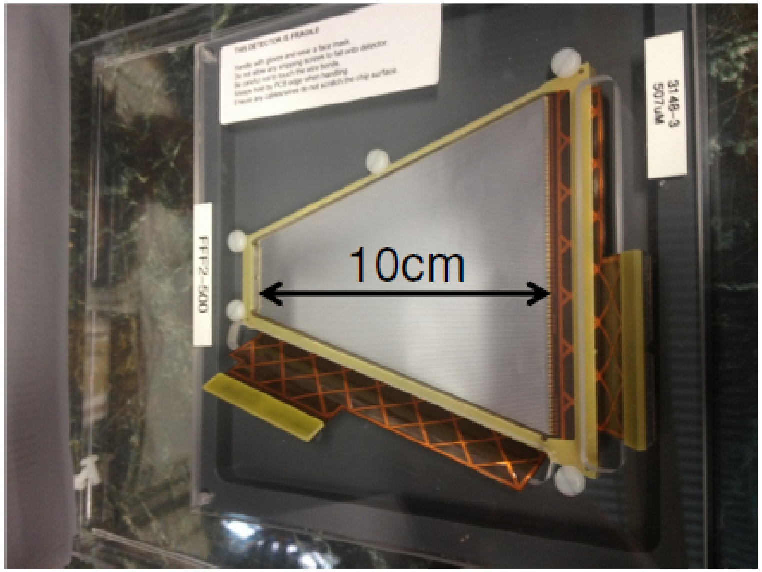
Commissionig of the trapezoid

Test bench at IPNO

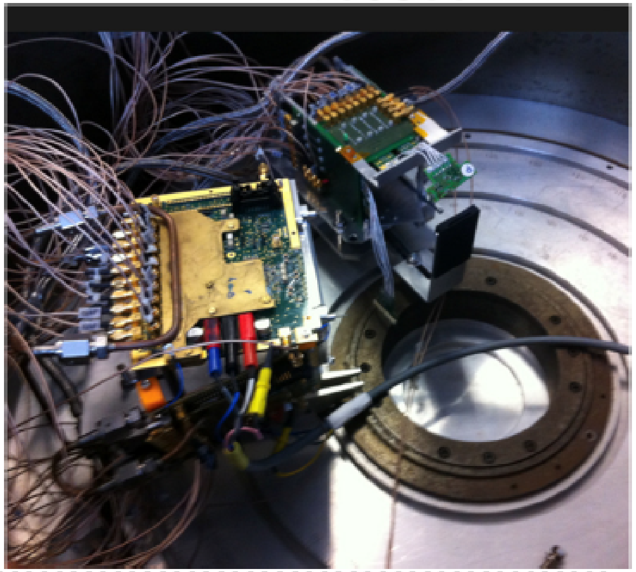
>> 2 numerical test bench : PACI & iPACI

- PACI : 4X+4Y voies
- iPACI : 9X+9Y voies (short and long strips)





Kaptons will be modified



>> Analogic test bench (MUST2 electronics & GANIL DAQ) now being implemented

256 channels

- test of new detectors (prototypes)
- test of new MUFEE boards for MUGAST

Physics with MUGAST

2 dedicated workshops organized at Orsay and Padova

- Shell structure evolution & deformation
  - Mapping of neutron orbitals around N=28 — *F.Flavigny, O.Sorlin et al.*
  - Oblate driving force in n-deficient nuclei above ^{56}Ni — *A.Goasduff, D.Mengoni, et al.*
  - Shape transition along and across N=28 — *L.Fortunato, D.Mengoni et al.*
  - Interplay of single-part and collective structures in ^{46}Ca — *S.Leoni et al.*
  - Shell evolution toward the island of inversion — *A.Matta, W.Catford, N.Orr, et al.*
  - Island of Inversion and shape coexistence in ^{30,31}Mg — *B.Fernandez-Dominguez et al.*
  - 75Kr: Shape coexistence in characterisation in light Kr — *A.Matta, W.Catford, N.Orr, et al*
- Neutron-proton pairing
  - np-pairing in fp-shell — *M. Assié et al.*
- Astrophysics
  - Breakout from hot CNO to rp process — *C.Diget et al.*
  - Explosive H-burning in Novae — *N.de Sereville, F.Hammache et al*.
  - s-process ^{79}Se(n,γ) — *G.de Angelis et al*.
  - s-process ^{60}Fe(n,γ) — *A.Matta, W.Catford, N.Orr, et al.*
- Reaction dynamics
  - Space-time characterization of emitting sources in HI collisions — *G. Verde, A.Chbihi, Q.Fable*

"Reaction and structure studies using the MUGAST+AGATA setup at VAMOS"
D.Beaumel & D. Mengoni

"Umbrella" LoI submitted to the coming GANIL PAC

Trapezoid detectors and test bench

Ordered to Micron semiconductors :

- **2 trapez**. prototypes nTD DSSSD ordered by IPN
(delivered end of june 2015)

- **3 more trapezoid « series » ordered**
(1 Surrey, 1 Santiago University, 1 IPN)

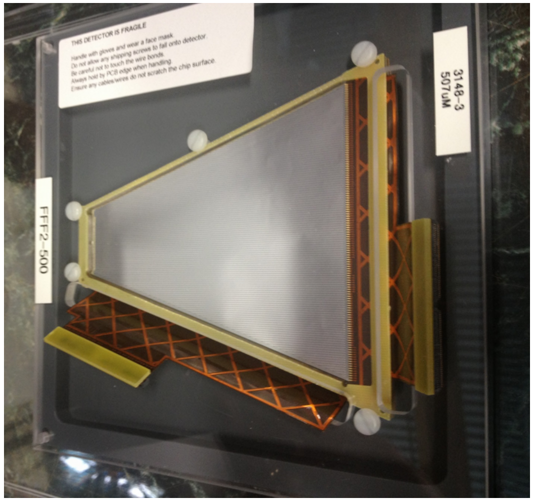
- **2 square** proto. nTD DSSSD **+ 1 thick sq. DSSSD**
*(ordered by INFN end of 2014***,** *under fabrication)*

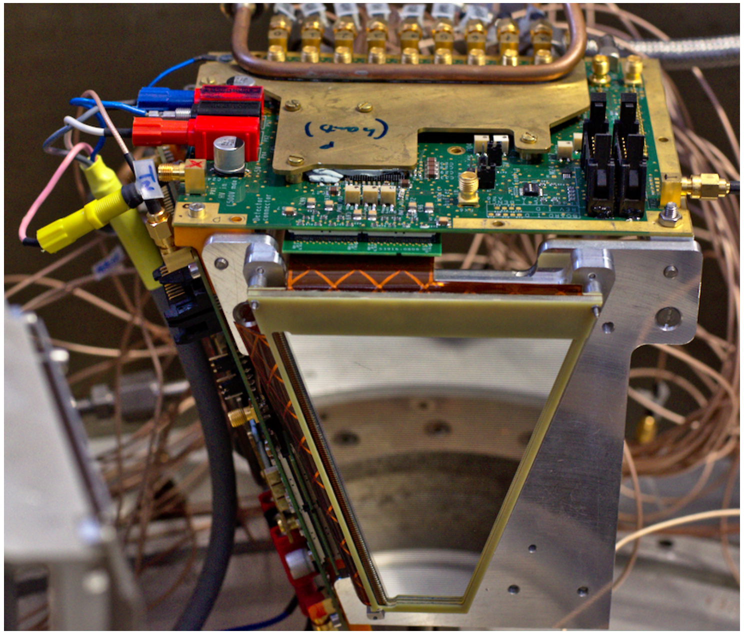
Test bench mounted @ Orsay :

- Digital test bench (GASPARD purposes)

- **Analog test bench** (256 channels) : Trapezoid + MUFEE + MUVI + GANIL acq.

Aim End of 2016 validation of prototypes

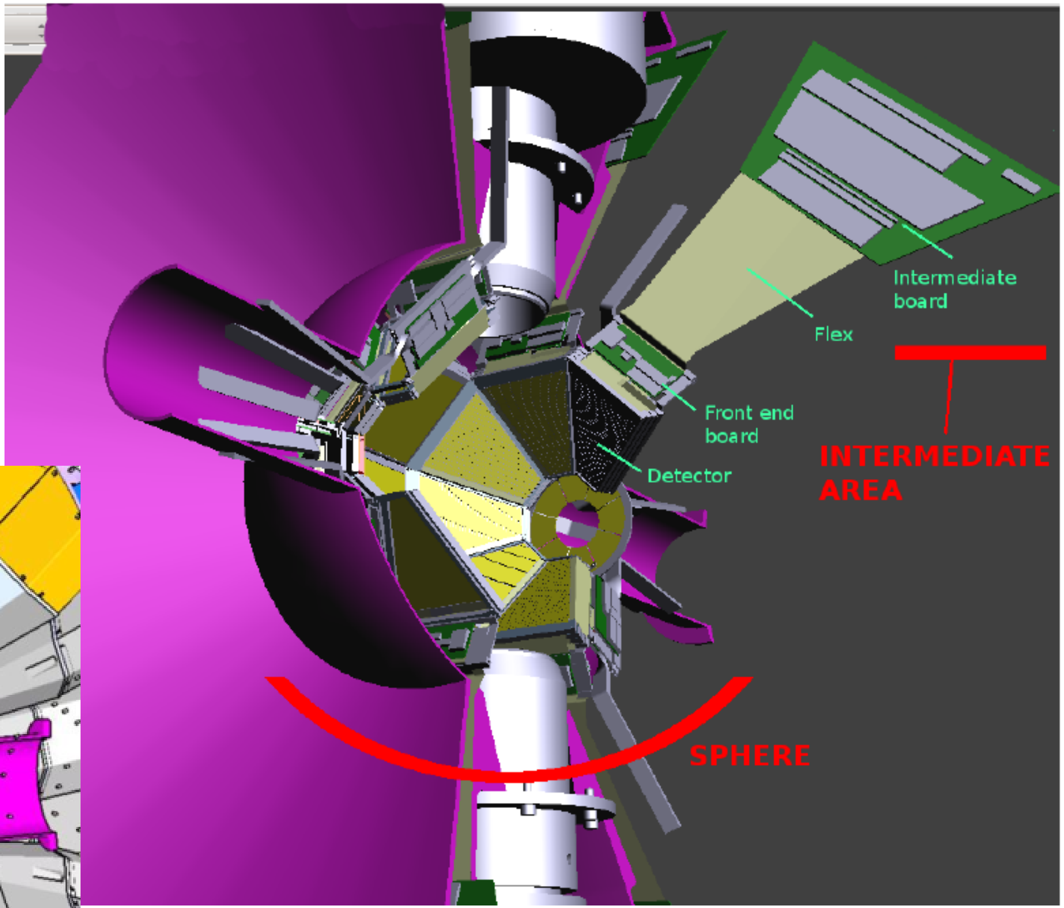


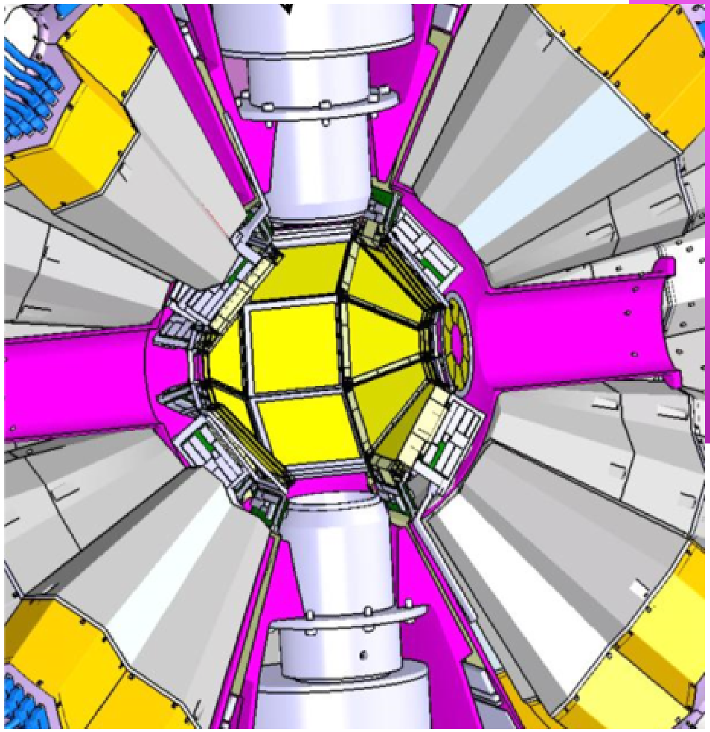


Electronics / Integration

Our challenge:

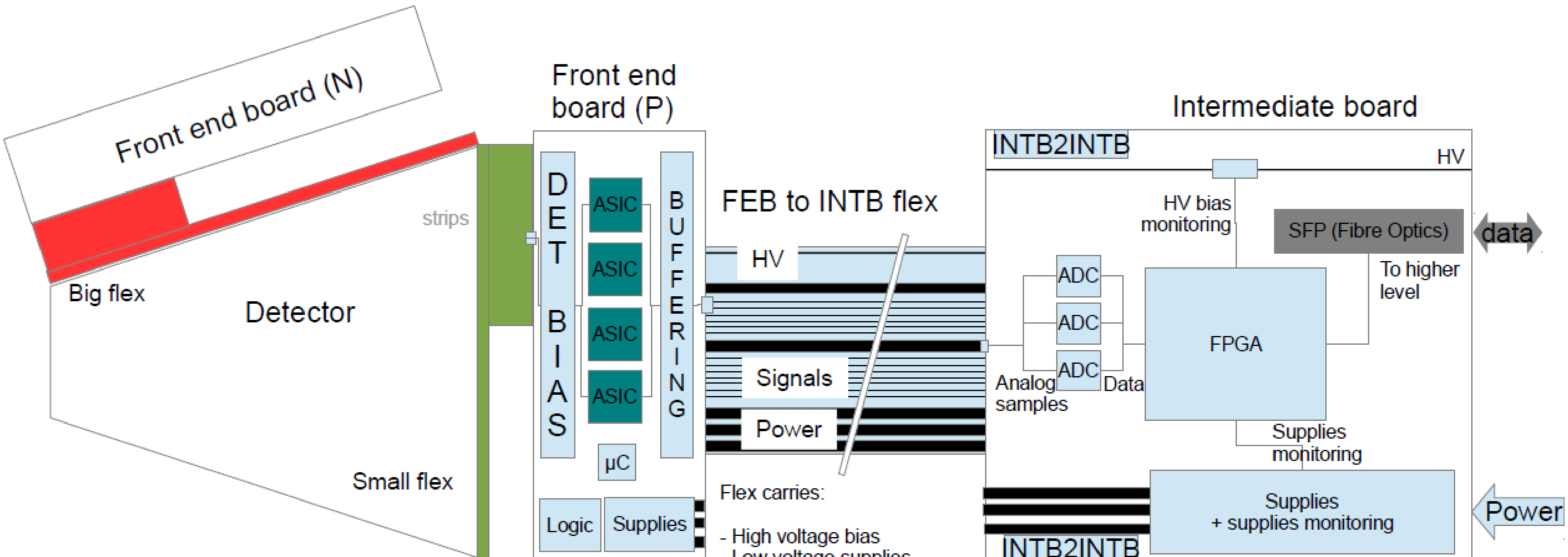
- ~ 10.000 channels
- Transparency to γ-rays





Detailed design under elaboration (IPNO)

Electronics architecture



FEB carries:

- Detector bias
- ASICs
- Buffering
- Supplies
- Logic
- µC ?

Flex carries:

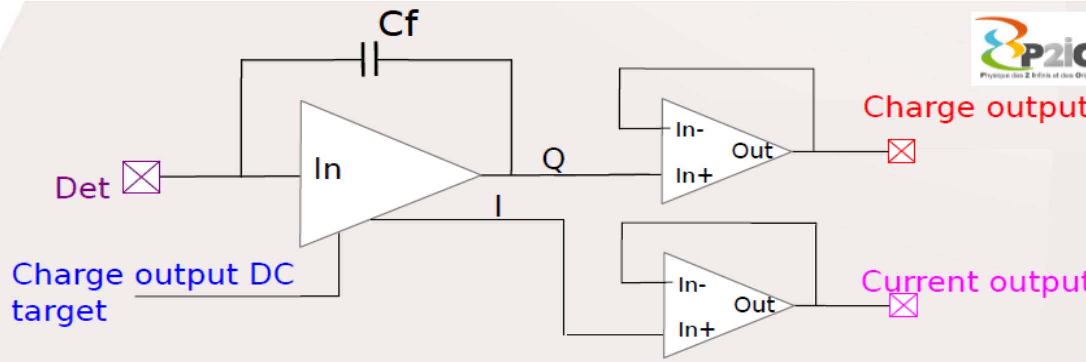
- High voltage bias
- Low voltage supplies
- PACI slow control
- Analog memory digital control
- Analog memory analog outputs
- Various : House keeping, indicators, T°

INTB carries:

- ADCs
- FPGA
- Suppies + Supply voltage/current monitoring
- HV bias + HV voltage/current monitoring
- SFP (Optical link to higher level)
- Connectors to other intermediate boards (INTB2INTB)

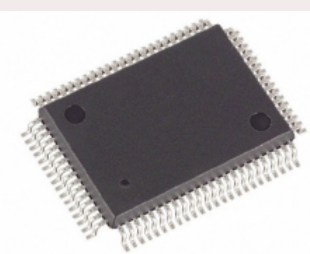
iPACI : 9 channel integrated *charge* and *current* output preamplifier

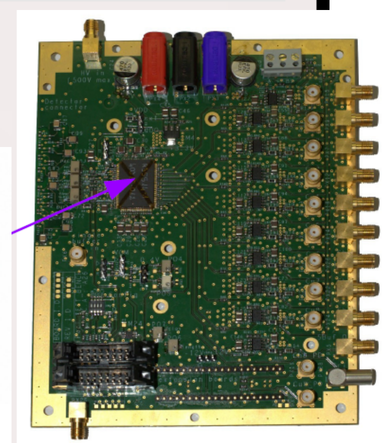
1-Channel performance (simulated!)



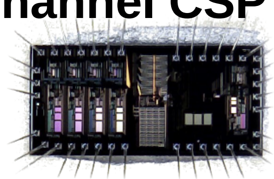
	Charge Output
Energy max (Si)	50 MeV
Charge signal swing (50MeV)	1.6V single ended
Charge gain	32mV/MeV
Equivalent noise charge (Input-refered, FWHM)	7 keV 830 e- Si
Charge resolution	12.8 bits ENOB
Charge non-linearity	< 2%
Charge output recovery time	100µs
	Current Output
Current gain	7kΩ
Current signal swing	1.5V single ended
Current signal BW	[4MHz .. 120MHz]

	System data
Technology	AMS 0.35µm BICMOS
Supply	3.3V
Detector's input capacitance	Compatible with [10pF .. 40pF] range
Compensation cap	Digitally tunneable within [0.5pF .. 2.25pF], step 0.25pF
Current consumption	12mA (40mW) / Channel
Size	220 x 100µm (PACI block) + 130 x 70µm (Buffer ch) + 130 x 70µm (Buffer cu)



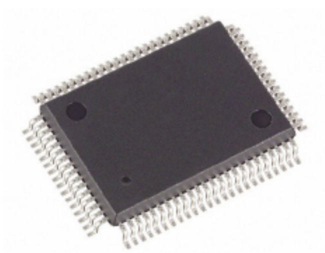


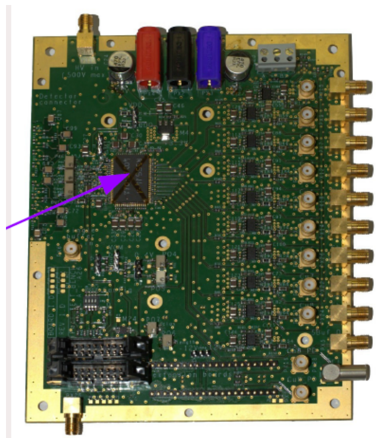
Other development: **multichannel CSP ASIC**
A.Pullia, S.Capra
INFN / Univ. Milano



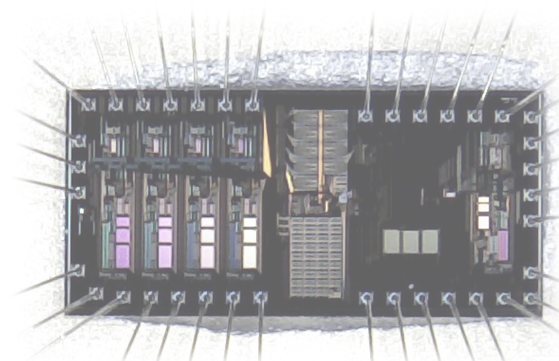
Preamplifier ASIC

- Current and charge output
- Presently 9 ch

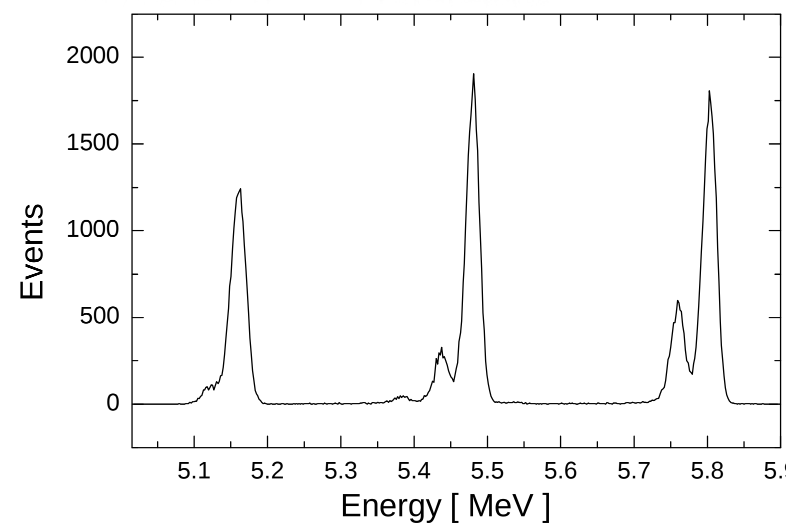




- Charge output and extend dynamics
- Presently 4 ch



Milano



ITEM	STATUS	who
DETECTORS		
Trapezoids proto (x2)	Commissioning	**IPNO**
Trapezoids pre-serie (x3)	Ordered	**Surrey + IPNO + Santiago**
Squared proto (x2) + Thick proto	Ordered	**INFN Padova**
Annular (x1) th = 500um	Available	**--**
MUST2 (x4)	Available	**--**
ELECTRONICS		
MUST2 FEE boards (x10)	Available	**--**
(MUST2 FEE new boards (x5) boards+components+ASICs)	To be ordered	
MUST2 Digital boards (x4)	Available	**--**
Kaptons (x48)	To be designed and ordered	
Cables & feedthroughs	To be ordered	
MECHANICS		
Chamber and supports	Under design	**Surrey**
Cooling blocks	Under design	**Surrey**

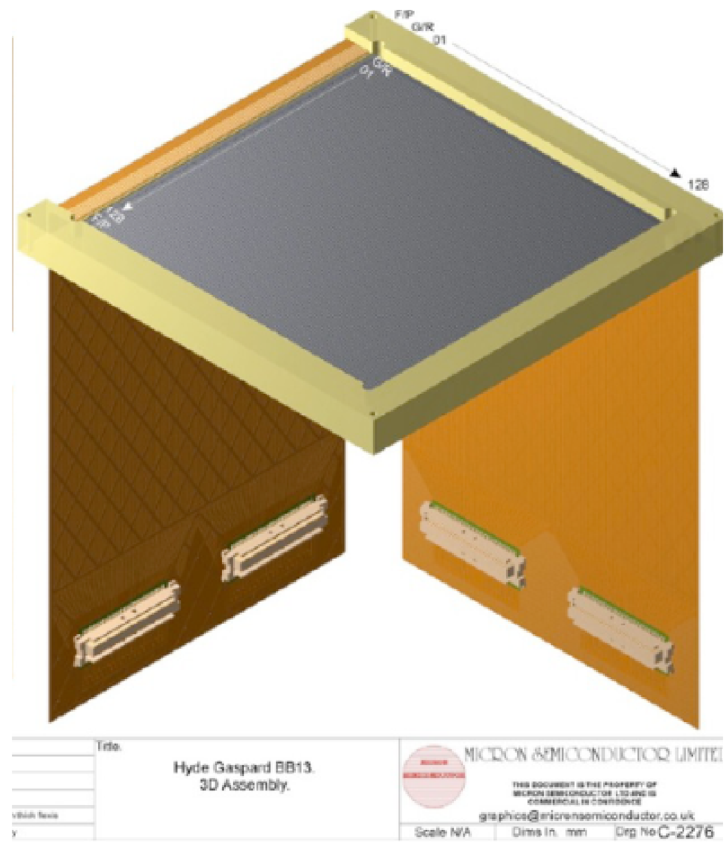
R&D on pulse shape analysis

Goal: establish the method for light particles and highly segmented detectors

- **Effect of segmentation**
- **Lower E threshold for each particle ?**
- **Minimum sampling frequency (Digital elec)**
- n-side or p-side ?
- Filters (e.g. Haar wavelets transform, …)
- Other possible observable : Rise time ?
- Radiation damage
- ….

test experiments
at the IPNO tandem

Detector:
- 500 um nTD DSSD
  BB13 design of MSL
- 8° cut
- 128X+128Y
- pitch<500um
- special package
  90° kapton readout
  high density
  connectors



The CHyMENE H/D target system

Cible d'HYdrogène Mince pour l'Etude des Noyaux Exotiques

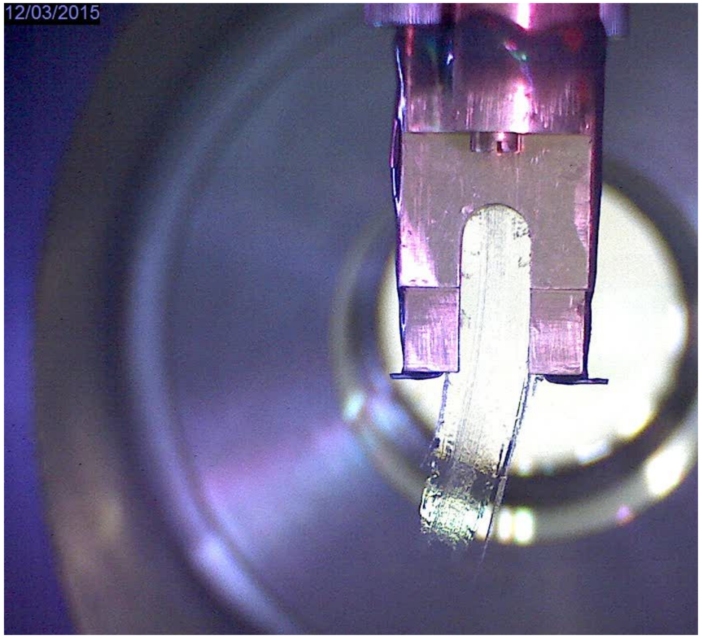
System providing continuous extrusion of ^1H or ^2H through a rectang nozzle defining the target-film thickness

- **Hydrogen target in a solid phase near triple point sH_2 ~ 17 K**
- **Thickness 50 – 200 µm**
- **No window - C free**
- **Continuous flow in vacuum 2-10mm/sec**
- **Compatible with particle detection**

CHyMENE collaboration :

- CEA/IRFU Saclay
  project coordinator: A. Gi
- IPN Orsay
- CEA/DAM Bruyères

Grant from French ANR ~550k€



Tests undergoing using alpha source

IRFU-IPNO-DAM

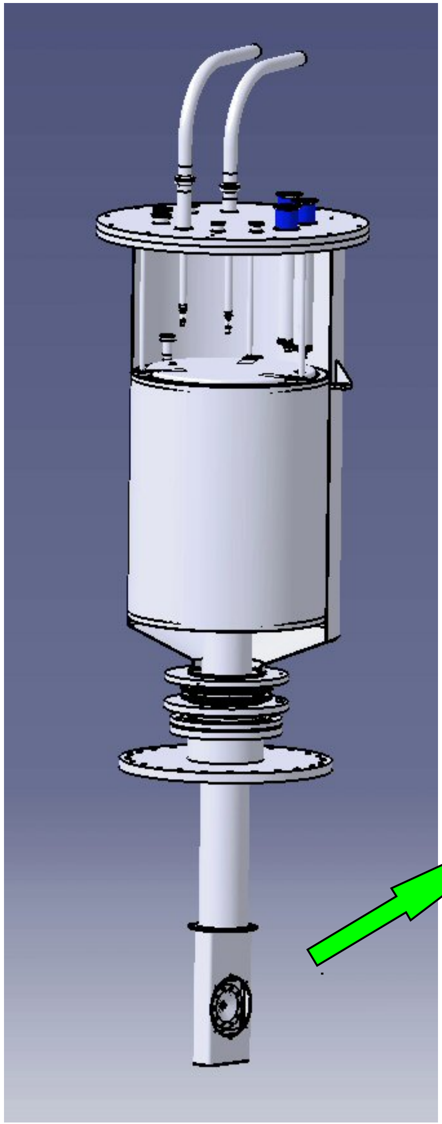
Cooled Helium gas target

IPNO/ Accelerator division

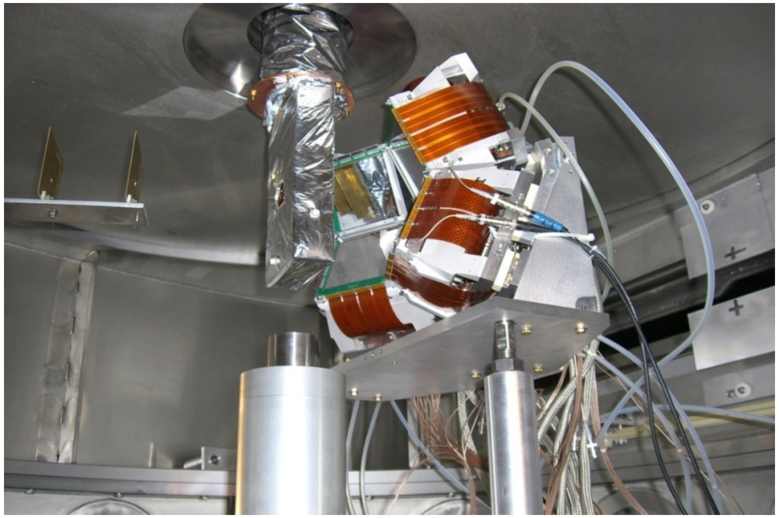
Designed for the use of direct reactions with ^{3,4}He probe in Inverse kinematics

Concept : cooled gas cell at 5~8 K to maximize density

Possible reactions: (α,^{3}He), (α,t), (α,^{6}He),…



Previously used
at SPEG / GANIL



Ø 16 mm, 3mm thick
Havar windows, 3.8 microns
T = 8.5 K
P = 1 bar

Now under study : **^{3}He version**

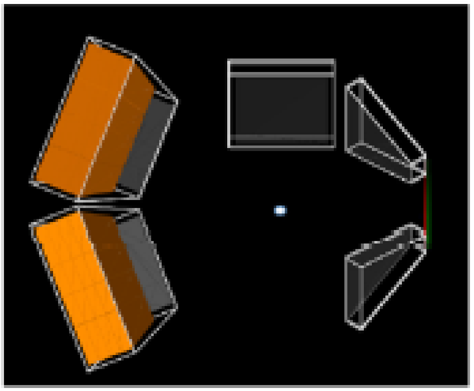
(^{3}He,d) proton stripping

(^{3}He,p) d transfer for np pairing

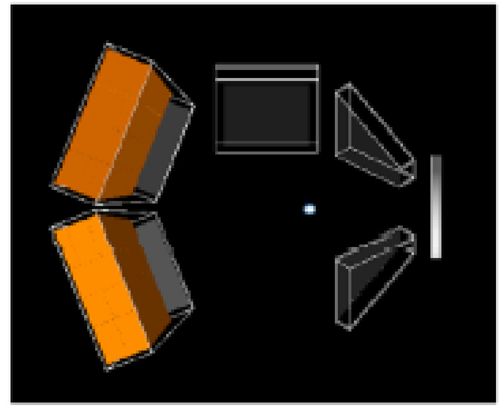
Simulations / Detection efficiency

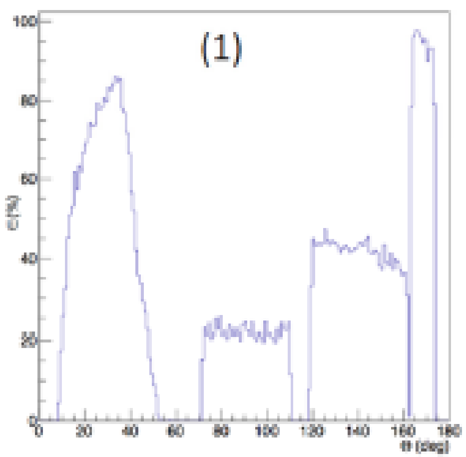
Using NPTool package

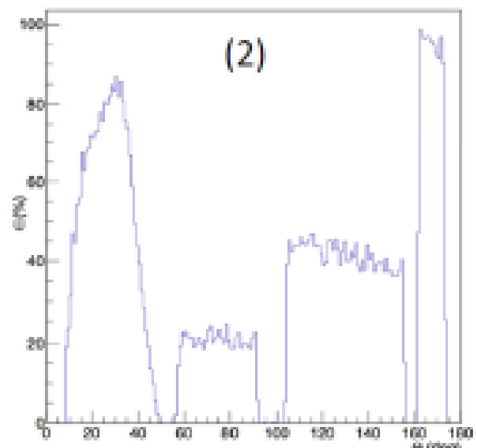
Config Initiale



Translation Trapézes +carrés vers M2 (~4cm)
+ update géométrie carrés







Last geometrical configuration available on demand

MUGAST with EXOGAM & PARIS

« MUGAST » configuration = MUST2 + GASPARD (trapeze) +TRACE (square)
available for AGATA campaign at GANIL **(2017)**
read by **MUST2 electronics (MUFEE+MUVI)**

Possible gamma detector's configurations :

- **6 PARIS clusters (if available)**
- **6 EXOGAM**