The GASPARD Project

GAmma SPectroscopy and PArticle Detection

D. Beaumel, IPN Orsay

Spiral2

Physics case of GASPARD

"Flagship reactions" discussed during collaboration meeting at Huelva

- ✓ ***Representative of our Physics program***
- ✓ ***Relevant to define our specs (simulations)***

Two main topics :

- ***Shell structure evolution using 1-nucleon transfer reactions***
  - ***Provide E_x , l (j), S***
  - ***Various probes (p,d,t, $^{3,4}He$, $^{6,7}Li$)***
  - ***No need go very far from stability***
  - ***Good probe of strength fragmentation***
  - ***Proton shell occupation (d,^3He) → (^7Li,^8Be)***

- ***Study of pairing far from stability***
  - ***Using (p,t) and (t,p) reactions***
  - ***Energies of 0+ (and 2+) states, enhancement factors, …***

Determine the evolution of s.p.e's around N=82

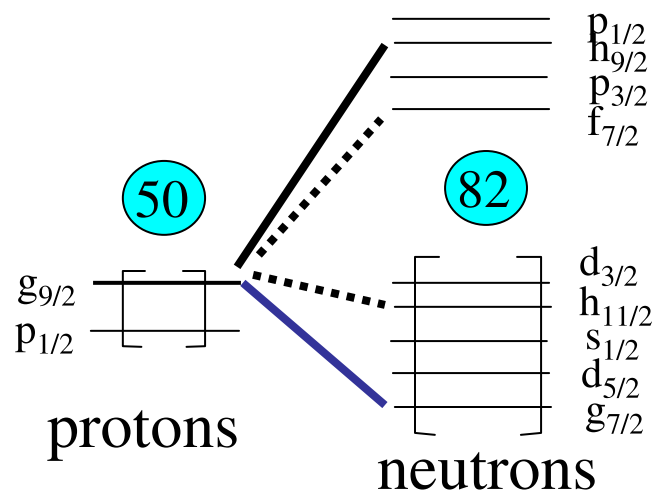
(Cf LoI by O.Sorlin & K.L. Kratz)

How to proceed ?

Compare the s.p.e's between ^{132}Sn (Z=50) and ^{130}Cd (Z=48)

→ np monopole matrix elements + occupancies
properties of nuclear force

→ **predict evolution of s.p.e. down to ^{122}Zr (Z=40)**
location of the astrophysical r process



Experimental tools

Transfer : (d,p) (α,^{3}He) for valence states / (d,t) or (p,d) for occupied states

Beam : energy : from 5 to ~10 A.MeV
intensity : > 10^4pps
isotopes **^{132}Sn, ^{130}Cd, ^{128}Pd !**
divergence ~ mrad
energy resolution < 1%

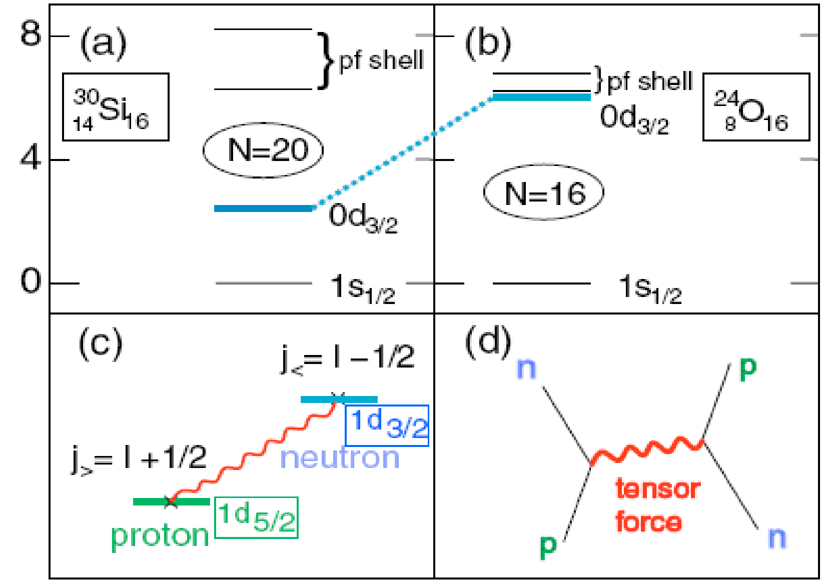
Tracking : beam position ~ 0.5mm accuracy, min. straggling, high freq, good timing

Detector : highly segmented Si detector 4π coverage/ see LOI Gaspard
with γ-ray detection

Spectrometer : in principle not mandatory/ separate mass, charge states, beam rejection

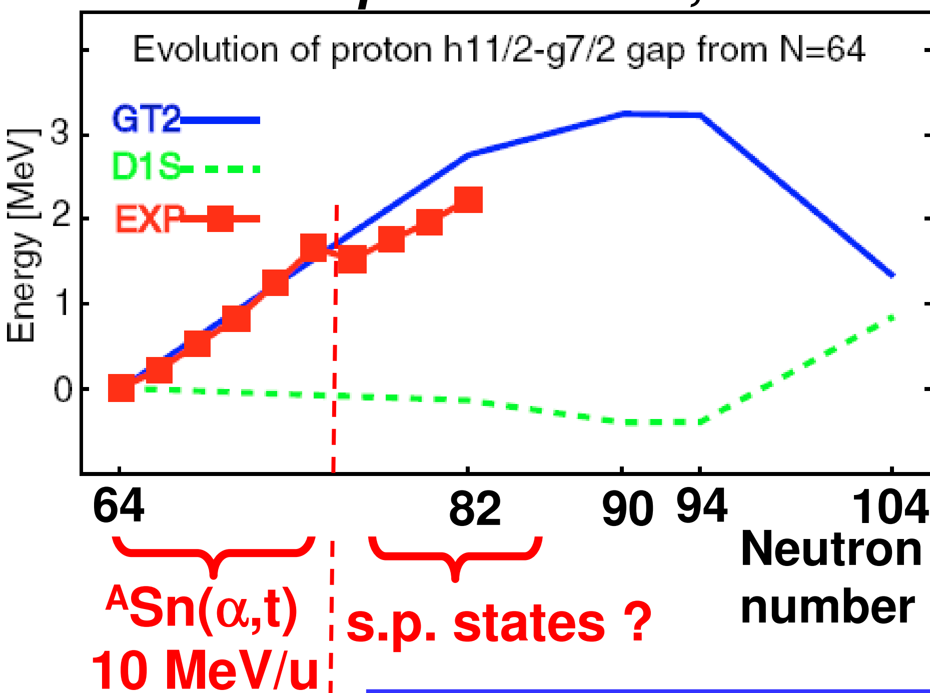
Shell structure evolution - II

Appearance/disappearance of magic numbers: ^{24}O



How about in heavier nuclei ?

Case of proton orbits, Z=51



MF calculation with tensor force (T.Otsuka et al, PRL2006)

- **Tensor force needed**
- **TF effect ~ S.O. splitting change due to n-skin**

Possible study: $^{126\text{-}134}$Sn(α,t)(^{3}He,d) at ~10MeV/u

Recent study: $i_{13/2}$-$h_{9/2}$ gap in (stable) N=83 isotones using (α,^{3}He) 12MeV/u

Probing pairing evolution through pair transfer

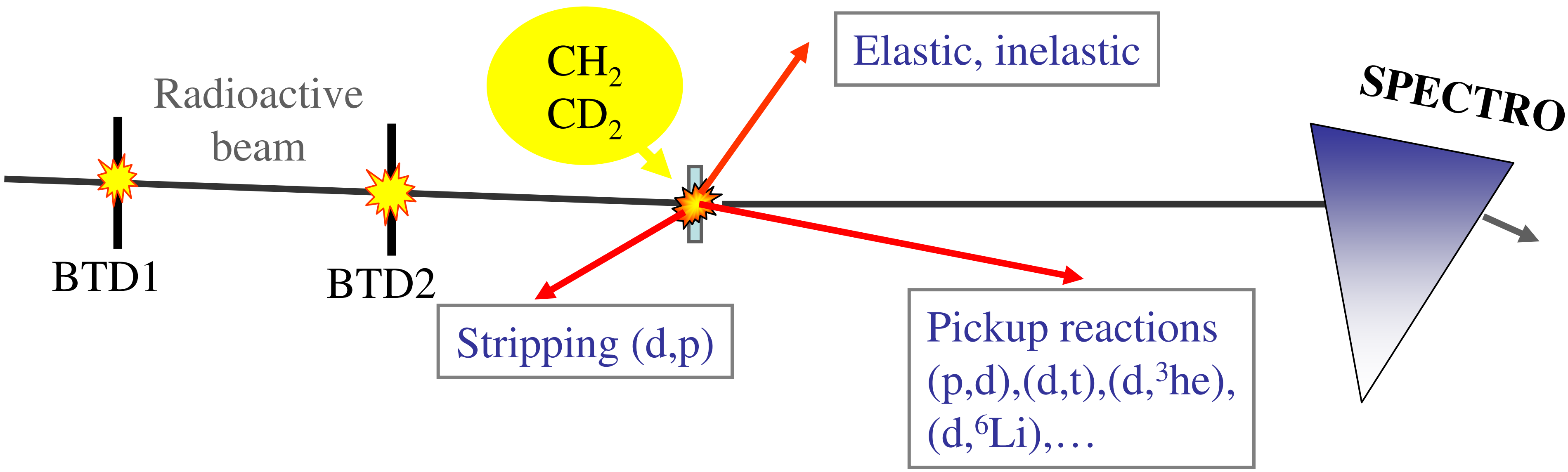
- **2-neutron (and 2-proton) transfer have been used to probe pairing**
  <u>EX</u>: Early work by Broglia et al. (~ 70's)
  What are the dynamical implications of pairing correlations ?
  Similarity between pairing field and 2-body transfer operator
  → use (p,t) and (t,p) reactions (L=0,S=0,T=1 transfer)
  "pairing model"
  Shape deformations ↔ Pairing distortions
  - ✓ **Pairing rotations and vibrations**
  - ✓ Superfluid phase transitions
  - ✓ Particle-pairing coupling
  - ✓ GPV

  Evolution of pairing with Isospin ?

- **More recently:**
  2n transfer amplitudes are sensitive to the surface enhancement of the pairing – case of $^{132\text{-}138}$Sn (M.Matsuo et al.)
- **Now under study at IPNO :**
  DWBA calculation of $^{124\text{-}136}$Sn(p,t) reaction with HFB-QRPA form factors using various pairing interactions

Methodology: Missing mass measurements

- **Exotic Beam + light target (CH2,CD2)**
- **Detect the light recoiling particle** **$(E,\Theta)^{LAB}$ → (E^*, Θ_{CM})**



With today's detectors (MUST2,TIARA)

ΔX, ΔY~1mm, ΔE ~ 50 keV
- **Good angular distributions !**
- **Energy resolution limited by:**
  - **dE_x/dE_{recoil}**
  - **Target thickness**

→ ***Hardly get better than 300keV***

From SISSI/SPIRAL to Spiral2

Light ions (A≤40) ➔ Heavier ions (Fission fragments)
Increased level densities

Lower Incident energies ➔ shift of (E,Θ) plots

To meet these challenges :

- ***Detect particle & gamma in coincidence with high eff. "Energy tagging"***
  - ***Better than 50 keV energy resolution***
  - ***Use thicker targets***

- ***Improve PID of low energy particles (PSA)***
- ***Improve capability of multi-reaction studies***
- ***Integrate new light-ion targets***

The GASPARD Collaboration

- **France:**
  - CEA-Bruyères-le-Châtel
  - GANIL
  - IPN-Orsay
  - CEA-Saclay
  - IHPC Strasbourg
- **Germany:**
  - GSI
- **Hungary:**
  - ATOMKI Debrecen
- **India:**
  - Saha Institute of Nuclear Physics, Kolkata
- **Italy:**
  - INFN-Catania
- **Netherlands:**
  - KVI
- **Poland:**
  - A. Soltan Institute for Nuclear Studies, Warsaw
- **Spain:**
  - Huelva University
  - Santiago de Compostela University
  - Sevilla University
- **United Kingdom:**
  - CCLRC Daresbury Laboratory
  - Liverpool University
  - Paisley University
  - Surrey University

~ 80 participants

Management:

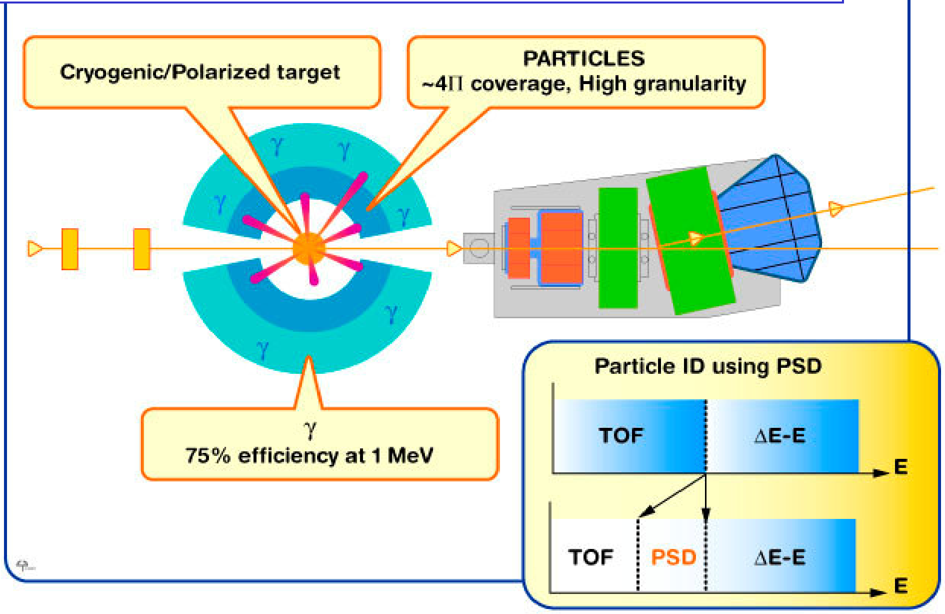
- **Project leader : D. Beaumel (IPNO)**
- **Management Board :**
  D. Beaumel (IPNO)
  W. Catford (Surrey)
  I. Martel (Huelva)
  E. Pollacco (Saclay)
- **Liaison with GANIL: O.Sorlin (GANIL)**

Working Groups

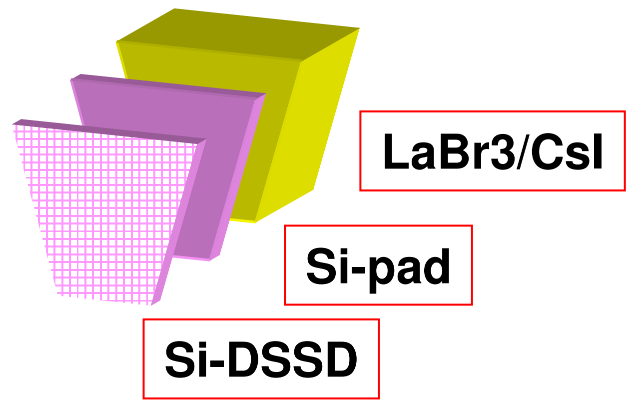
- **Physics case** **O.Sorlin (GANIL)**
- **Physics simulations** **M. Labiche (Daresbury)**
- **Silicon detectors and PSD** **J.Duenas (Huelva)**
- **FEE, C&C and DAQ** **F.Druillole (Saclay)**
- **Targets and beam tracking** **A. Gillibert (Saclay)**
- **Design/Integration - Coupling with other devices**
  W.Catford (Surrey)

Evolution of the GASPARD Concept

INITIALLY :
Fully integrated 4π (particle) + 4π (γ)



3-stage telescopes under vaccum



~ 15000 channels

Stated during the last collaboration meeting:

- ***No need to detect high energy particles with crystals in 4π***

  Possible to decouple the PA and the GA

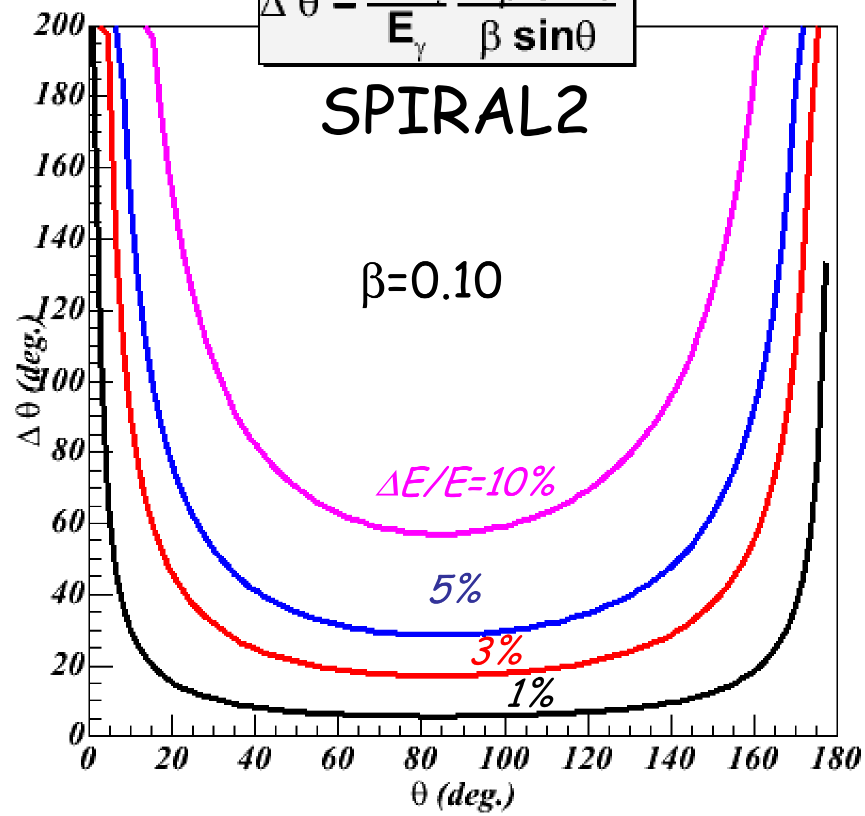
  Road is open to built a PA compatible with EXOGAM2, PARIS and AGATA

Gamma Array Specifications

- **Energie resolution**
  - better than 50 keV (FWHM) for 1 MeV gamma-rays
- **Dynamic range**
  - 0.1 to 5 MeV for gamma-rays
  - Stops high energy light particles (~100MeV)
- **Total detection efficiency**
  - ~ 75% for 1 MeV gammas
- **Granularity**

  NOT determined by Doppler
  - Multiparticle events detection
  - Particle-gamma pile-up
  - Technical aspects (size of APD/PMT,…)

$$\Delta\theta = \frac{\Delta E_\gamma}{E_\gamma}\,\frac{1-\beta\sin\theta}{\beta\sin\theta}$$



Particle Array Specifications

- **Position resolution**
  ~1mm resolution over ~4π
- **Energy resolution – dynamic range**
  < 40 keV ; 100 keV – 1 GeV
  Multidynamic ranges and shaping
  low threshold
  good linearity
- **Particle ID**
  - 0.2-2MeV/u: TOF
  - PSD above 1.5-2 MeV/u
  - E-DE beyond punch-through
- **Low Mass budget**
  Low γ-ray absorption in the mechanics and FEE
  but lots of electronics channels
  → A CHALLENGE !

2 combinations under study:

- "with thin layer"
  40 μm, ~3mm pitch, PSA
  300 μm, 1mm pitch
  1500 μm
- "Full digital"
  300 μm, 1mm pitch, PSA
  1500 μm

~ 15000 channels

R&D for the Si array

PULSE SHAPE ANALYSIS

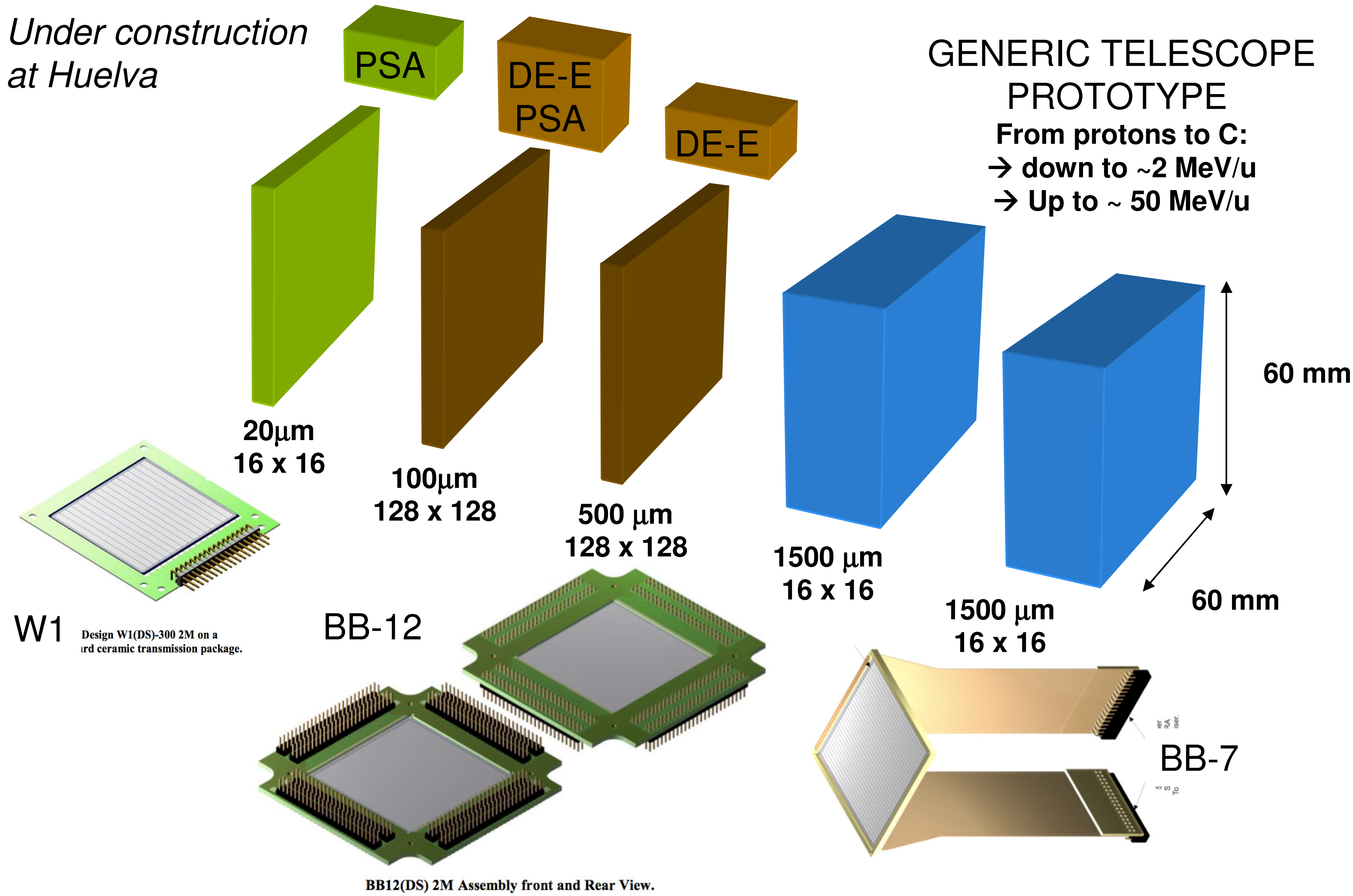
1) **The use of strips**
2) Energy limits
3) Homogeneity of the silicon wafers
4) Channeling effects
5) Charge/current input
6) Sampling rate/resolution
7) Detector thickness dependence
8) PSA and radiation damage…

Within GASPARD the program is lead by the Huelva group (Including V. Parkar, postdoc from SPIRAL2PP)

IPNO in charge of simulations of detector's response

Collaboration with the FAZIA group

Si test telescope for GASPARD/HYDE



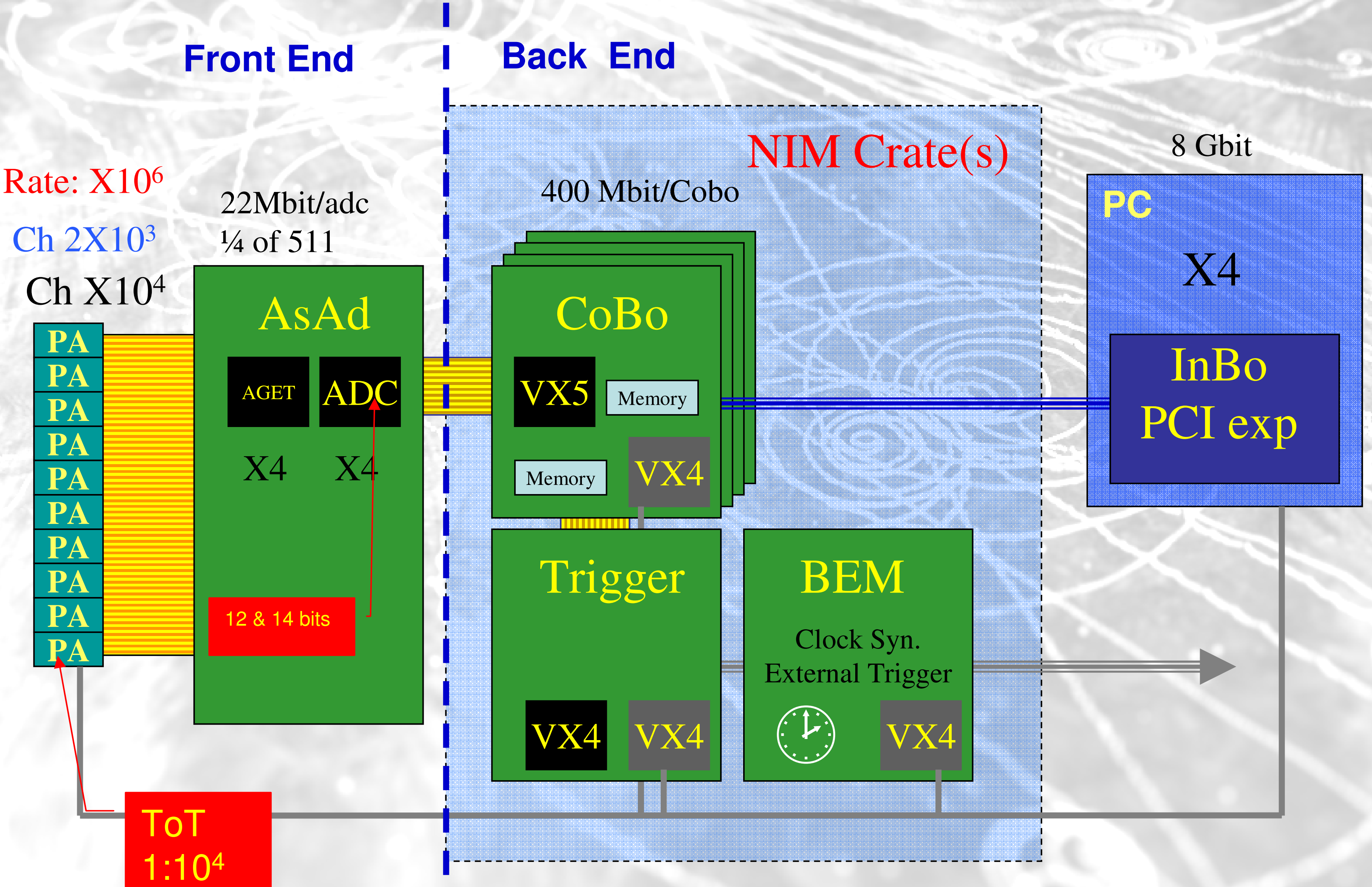
Possible test bench: (MUFEE+MUVI) + (PACI+MATAQ) + GANIL DAQ

Workplan for PSA R&D (2009-2010)

- Test of BB7-1500 detectors ordered
- Purchase strip detectors BB12 and 20 μm
- Complete prototype telescope: mechanics and connectics
- Setup Bench
- Perform test experiment (Orsay tandem)
- Analyze data
- PSA techniques (signal momentum, average shape, neural networks,…)
- Simulations of detector's response

Electronics/DAQ of GASPARD

An option : use backend of GET (General Electronics for TPC)



Special targets for GASPARD

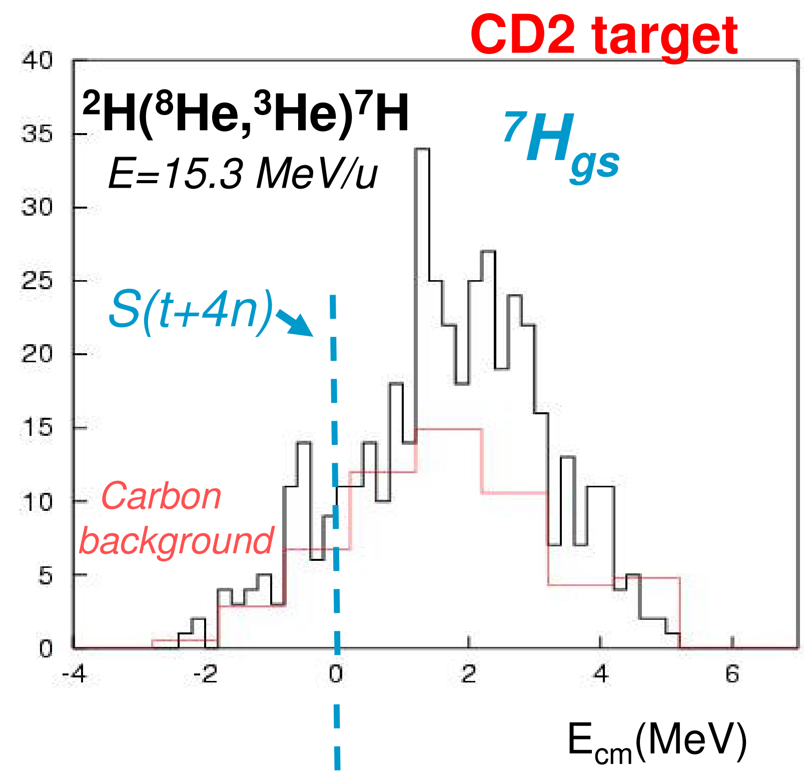
Pure and windowless targets are crucial for :

- ***Density/Energy loss***

^{132}Sn(d,p) at 10 MeV/A
For same ΔE (63 MeV)
CH2,10 µm **N = 7.7 10^{19} at/cm2 H**
H2, 61 µm **N = 2.6 10^{20} at/cm2 H**
factor of 3.5

- ***Use with high intensity beams***
  - ***Less beam scattering***
  - ***Less background reactions***

  (Need of spectrometer)



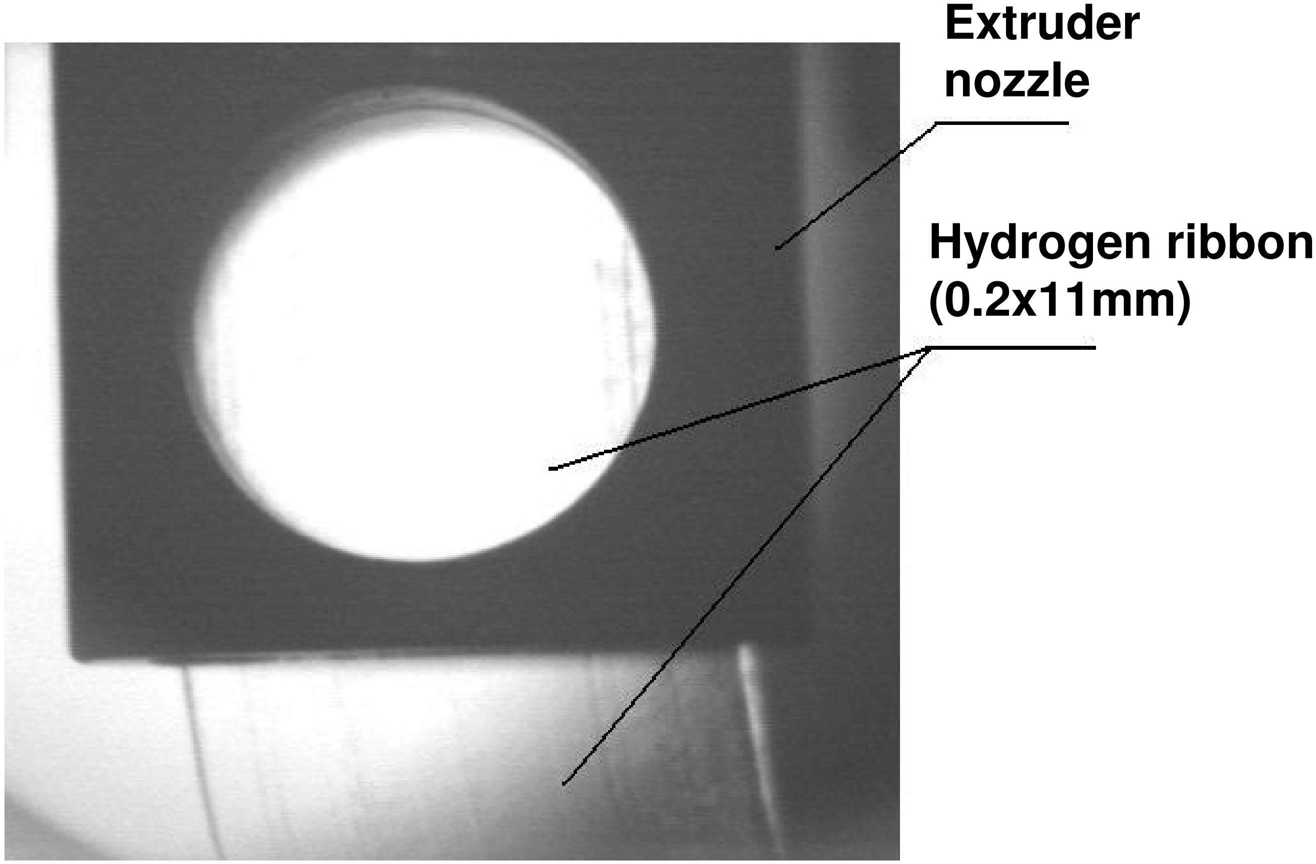
The CHYMENE project

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

A. Gillibert (Saclay)

Collaboration: IRFU/SPhN (Saclay), SBT (Grenoble), PELIN Lab. (St Petersburg)

R&D is funded



Test in June 2007 of a H_2 target → Thickness ≈ 200 μm

AIM: 50 μm or below

Simulations for GASPARD

Angel Sanchez Benitez, University of Huelva
Marc Labiche, STFC Daresbury
Nicolas de Séréville, IPN Orsay

Main framework: GEANT4

- Monte-Carlo simulation code written in C++

Starting point: NPTool

- Initially developped at IPNO for simulating the MUST2 array (Adrien Matta)
- For the moment only charged particles detectors are included, but it can be easily extended to any other detector

NPTool package

NPSimulation:

- Efforts have been put in a flexible design:
  - Few files need to be added/modified in order to include a new detector
  - The same applies for new event generators
- Simple use:

```
./Simulation   60Fe.reaction   gaspardFull.detector
```

- Output is in the ROOT format

NPAnalysis:

- Set of tools (macros, programs) analysing the output file
- Calculate efficiency detection, excitation energy, …

Input files (1): Detector

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%1
GeneralTarget
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%1
Target
        THICKNESS= 309.278350515
        RADIUS= 7.5
        MATERIAL= CD2
        X= 0
        Y= 0
        Z= 0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Gaspard
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%1 Barrel
GPDSquare
        X1_Y1=          [illegible]   66.08    -135.41
        X128_Y1=        [illegible]   66.22    -135.41
        X1_Y128=        [illegible]   135.51   -66.1
        X128_Y128=      49.2          135.36   -66.1
        FIRSTSTAGE= 1
        SECONDSTAGE= 0
        THIRDSTAGE= 0
        VIS= all
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%2
GPDSquare
        X1_Y1=          -66.04   61.23    -130.4
        X128_Y1=        -135.4   12.32    -81.4
        X1_Y128=        -65.94   130.51   -61.09
        X128_Y128=      -135.3   81.6     -12.1
        FIRSTSTAGE= 1
        SECONDSTAGE= 0
        THIRDSTAGE= 0
        VIS= all
```

QuickTime™ and a decompressor are needed to see this picture.

Target keyword

Target foil

→ Cryogenic target also exists

GASPARD keyword

Square element detector

Coordinates from CATIA

→ Detector can also be placed with (Θ, Φ) coordinates

Only first stage is considered here

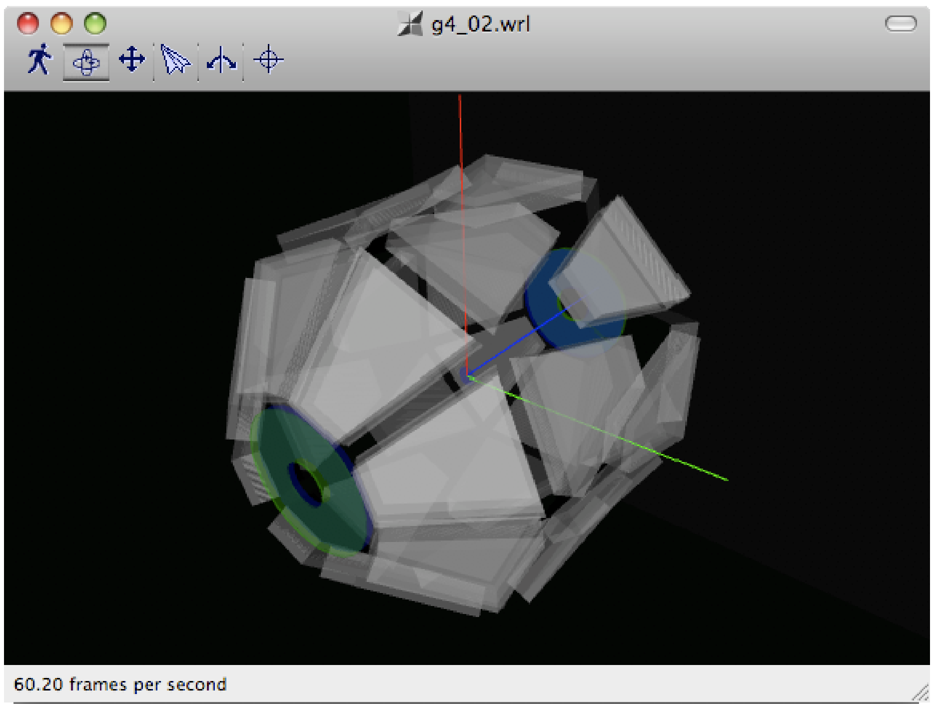
Adding a new geometry is creating a new xxx.detector file

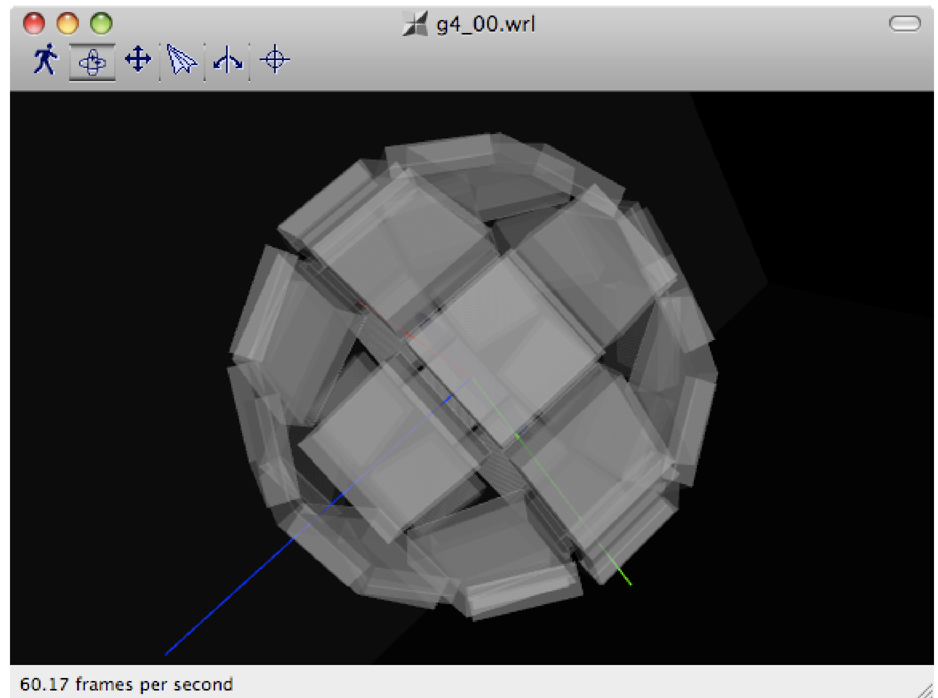
Input files (2): Event generator

```
Transfert
          Beam= 60Fe
          Target= 2H
          Light= 1H
          Heavy= 61Fe
          ExcitationEnergy= 2.0
          BeamEnergy= 800
          BeamEnergySpread= 0
          BeamFWHMX= 0.6232
          BeamFWHMY= 0.9069
          BeamSpreadX= 0
          CrossSectionPath= ni69_g7_01.n
          ShootLight= 1
          ShootHeavy= 0
```

- Event generator keyword → Isotropic case also exist
- Reaction definition
- Beam properties
- Cross-section $\frac{d\sigma}{d\Omega} = f(\Theta_{C.M.})$
- Particle to be fired

Available geometries

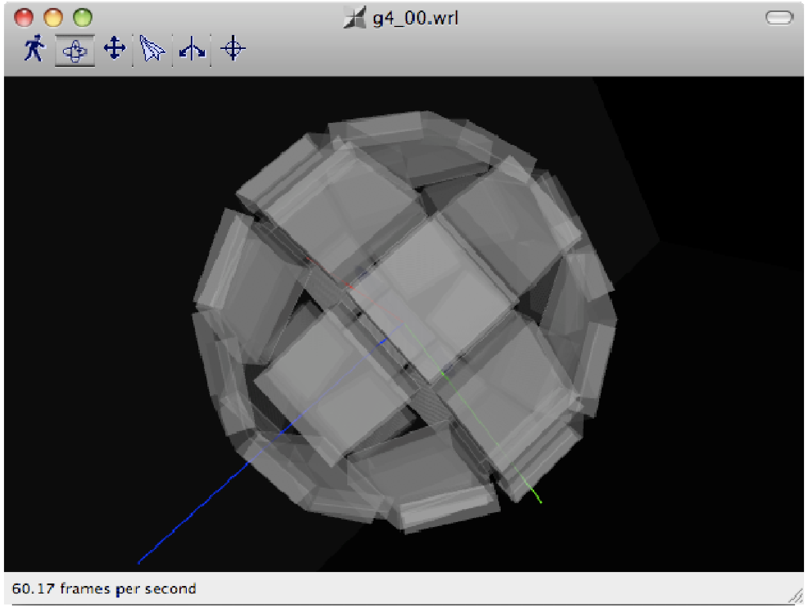




Barrel with trapezoid detectors
+
End-caps with trapezoid and annular detectors

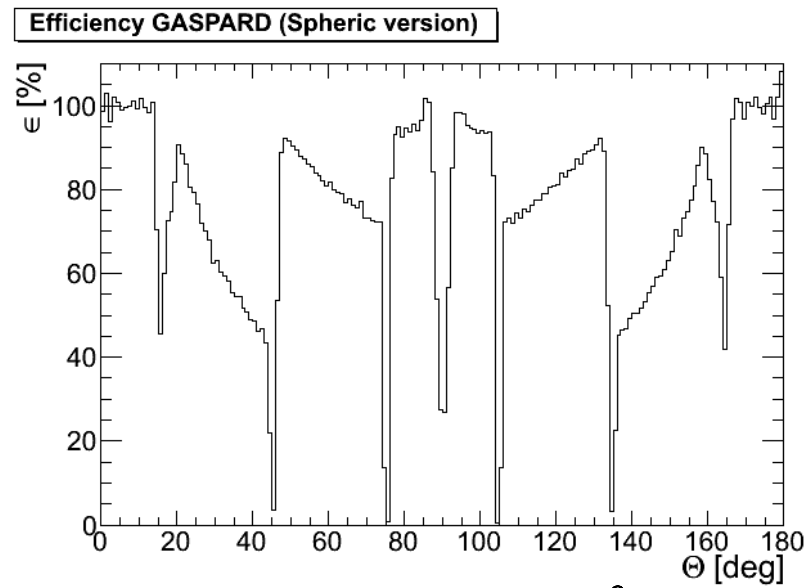
Sphere paved with 40 5x5 cm^2 square detectors

d(^{132}Sn,p)^{133}Sn @ 10 MeV/A

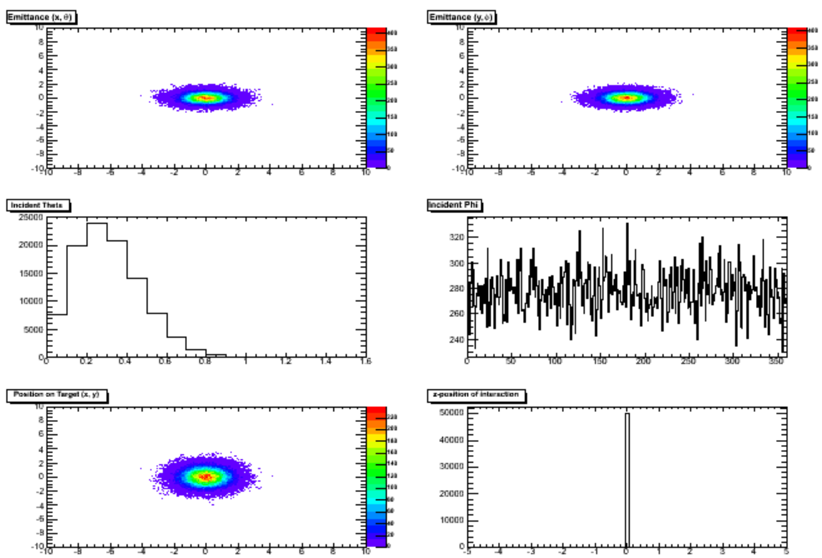


3-layer telescopes (S=5x5cm^2)
- 300 μm, 2mm pitch
- 2 layers of 1000 μm

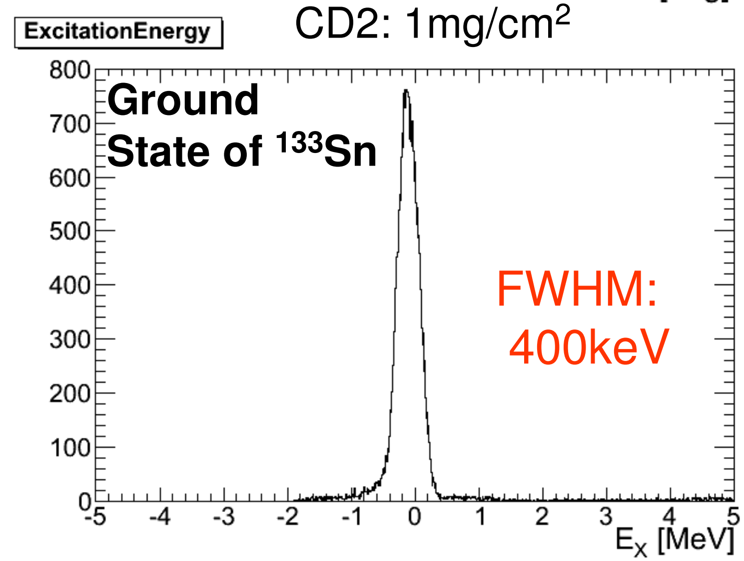
D_{Target} = 10cm



BEAM



CD2: 1mg/cm^2



Studies in the near future

- Study of detector granularity for different physics cases and effect on excitation energy, angular resolution,…

- Acceptable target thicknesses with SPIRAL2 beams

- Effect on excitation energy when no beam tracking (high intensity beams @ SPIRAL2)

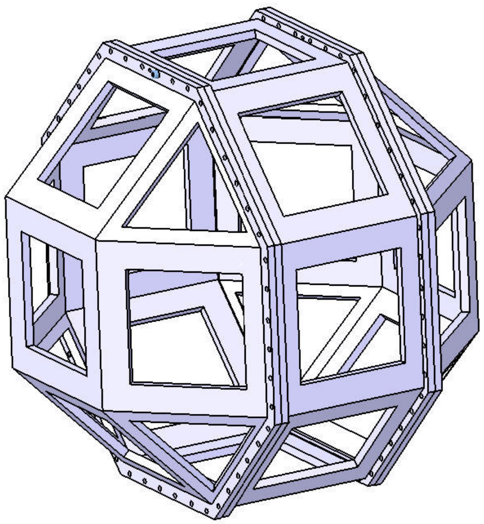
- Integrate gamma detectors / upgrade event generator
  Compare efficiency of MUST2+Exogam versus GASPARD + AGATA/PARIS

- ....

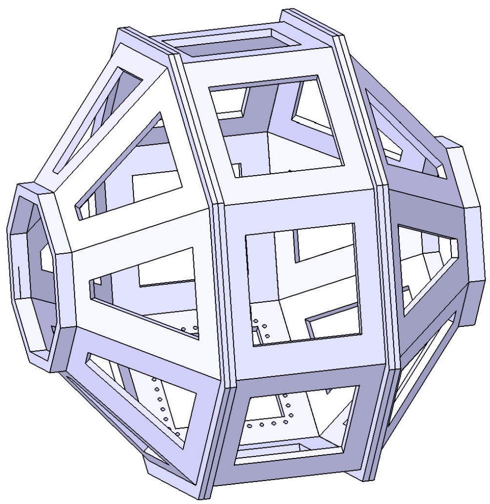
Mechanical design

- Fit inside the Agatha diameter (R 230mm)
- Use 4 inches silicon detectors
- Distance to target ~150 mm

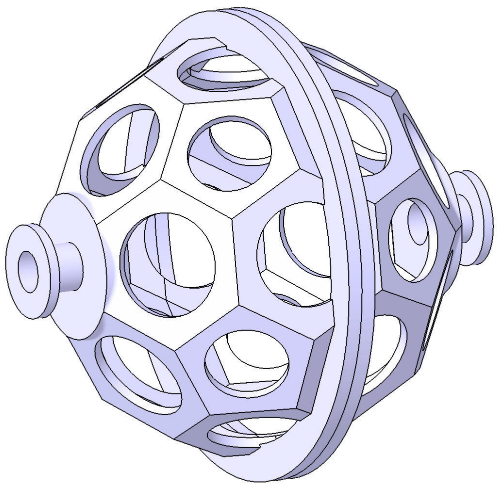
Isolde ball
(Barrel + 2 end-caps)



Hyde
(Same barrel but 2 different end-caps)

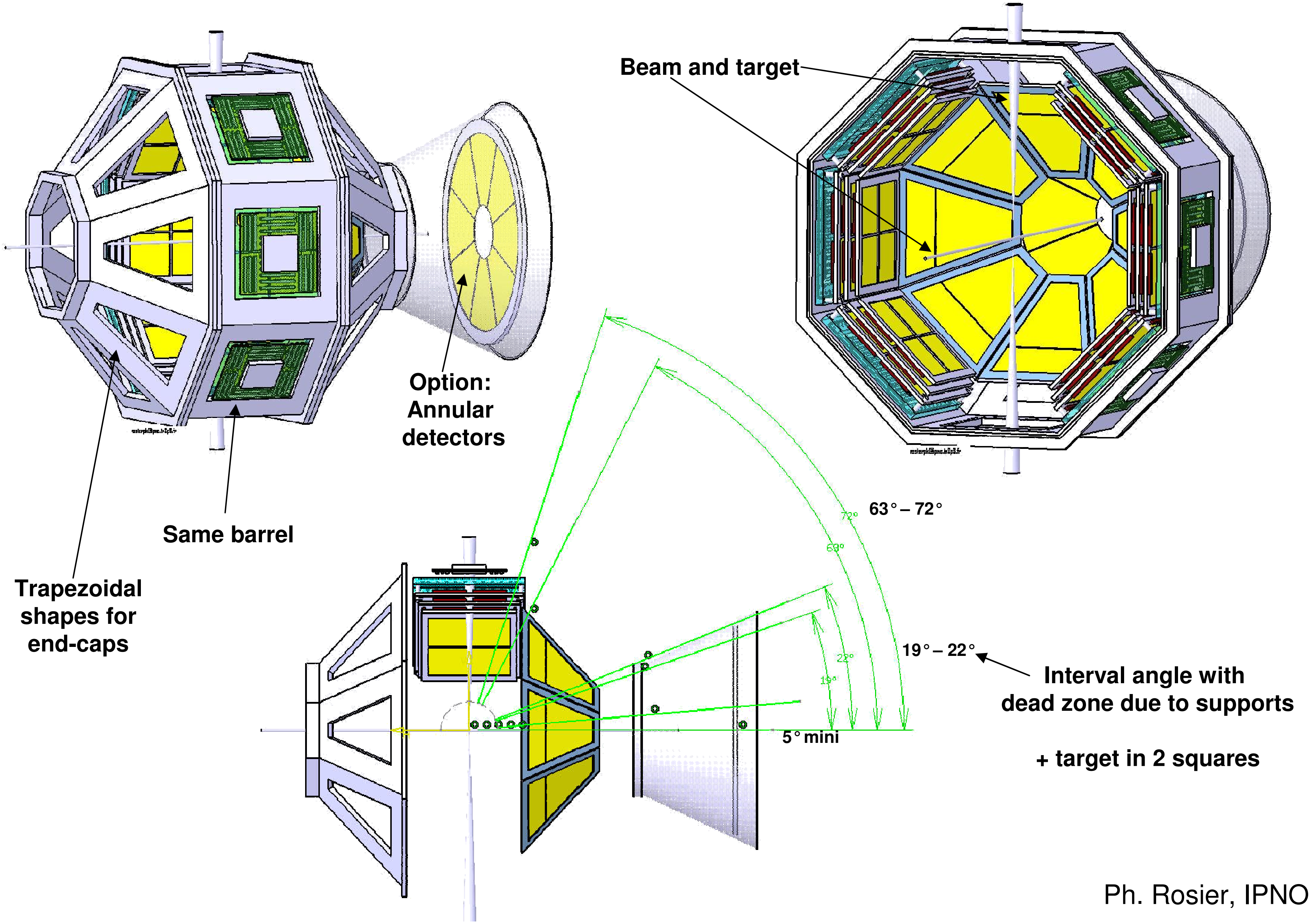


Truncated icosahedra



Ph. Rosier, IPNO

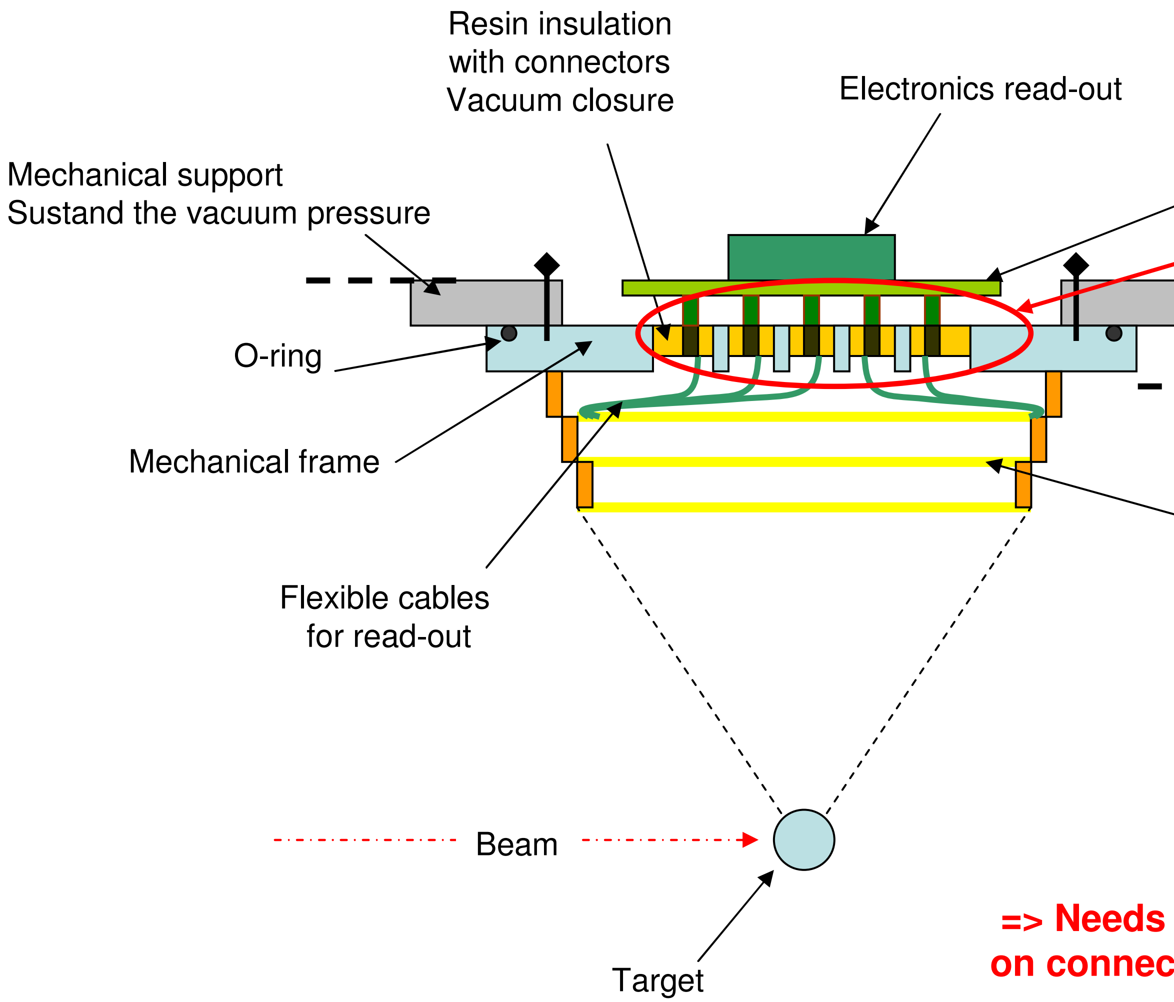
Towards a “GaspHyde” proposal

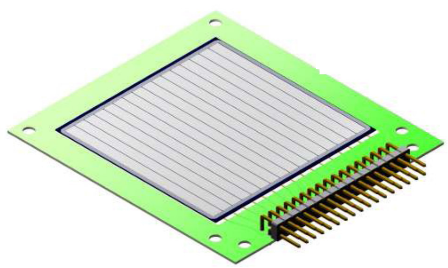


Ph. Rosier, IPNO

Integration principle

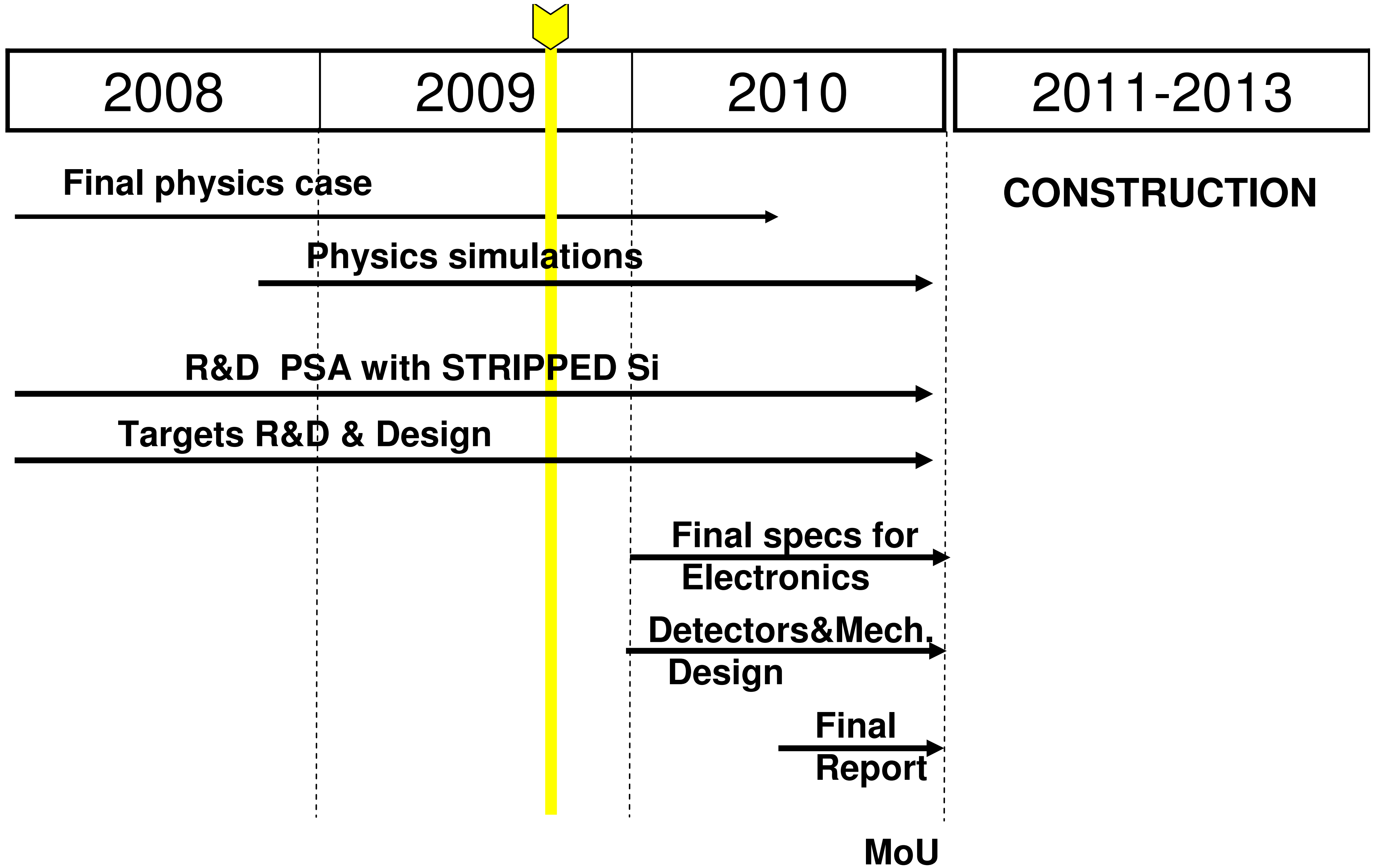
Integrate silicon detectors inside a vacuum 4π detector with electronics outside





=> Needs serious R&D
on connectors feedthroughs integration

GASPARD *Timescales*



PARIS-GASPARD meeting - Feb 2008

- **Points discussed:**
  - **Timescales and specifications of the the two calorimeters**
  - **How to concert the two projects ?**
  - **Can the arrays be made compatible ?**
  - **How to make both compatible with AGATA whose design is already fixed ?**
  - **Could PARIS go under vacuum and be particle detector of GASPARD ?**
  - **Joint simulations of PARIS and GASPARD**

PARIS-GASPARD synergy group
(J.A. Scapaci (chair) D. Jenkins, A. Maj, J.P. Wieleczko (PARIS)
D. Beaumel, W. Catford, M. Labiche)

Comparison specs of PARIS/GASPARD (minutes of meeting)

E_γ = 0.1 – 5 MeV for GASPARD c.p. 0.1 – 50 MeV for PARIS

ε ~ 75 % for GASPARD c.p. > 75% for PARIS

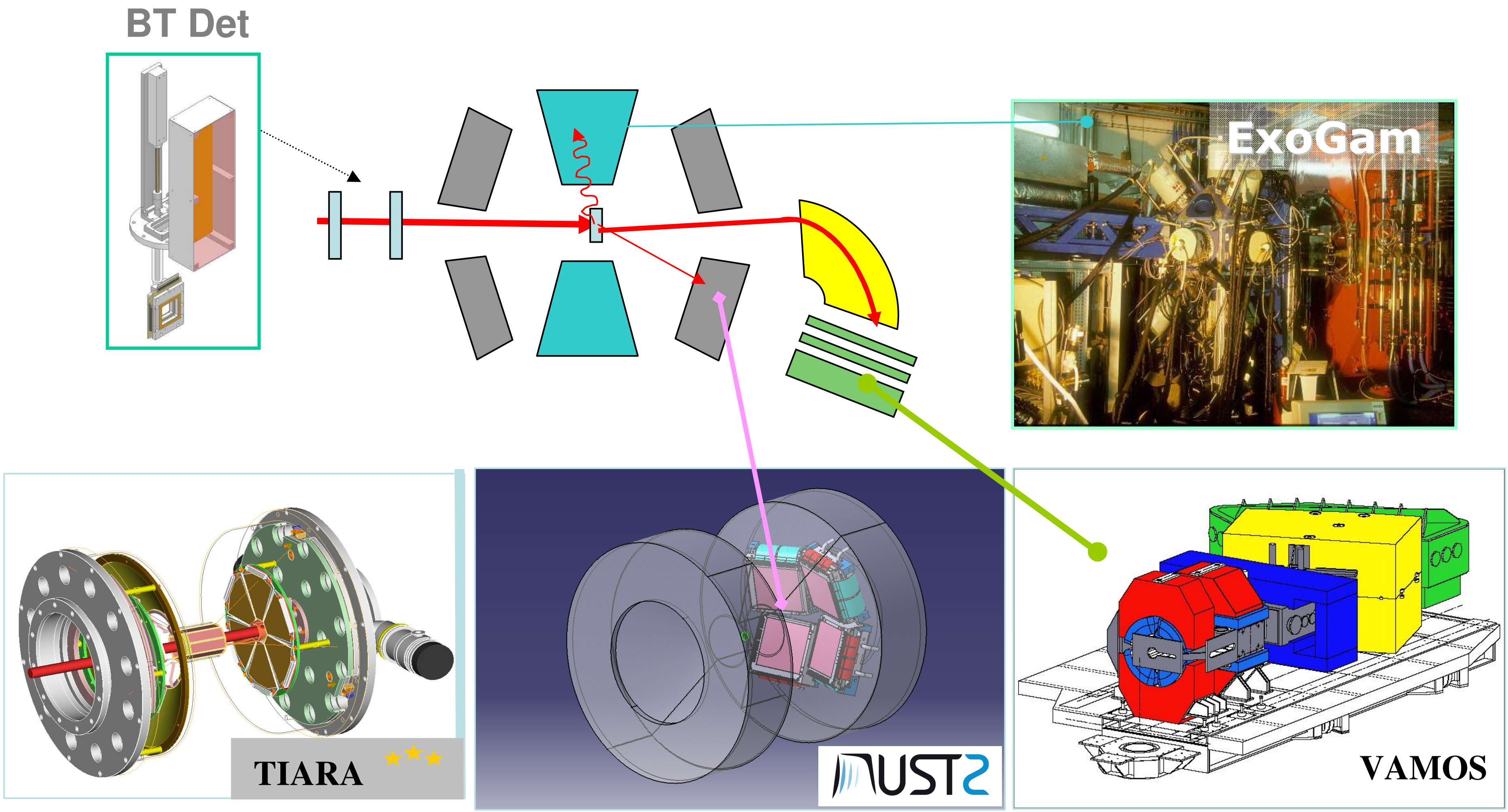
Resolution better than 50 keV for 1 MeV (COMMON)

Granularity 100- 200 elements (COMMON)

Inner radius ~20 cm (COMMON)

***Key issue*: For GASPARD shall the crystals be used to detect high energy particles (under vacuum) ?**

Today's "best setup" for Direct reactions



Nice but:

- ➢ **Poor efficiency for γ-ray detection**
- ➢ **Strong limitation for targets**

Pairing vibrations

Located near closed-shells
Fluctuations of the pairing field → collective oscillations
Basic modes : pair addition/removal phonons

Observables :

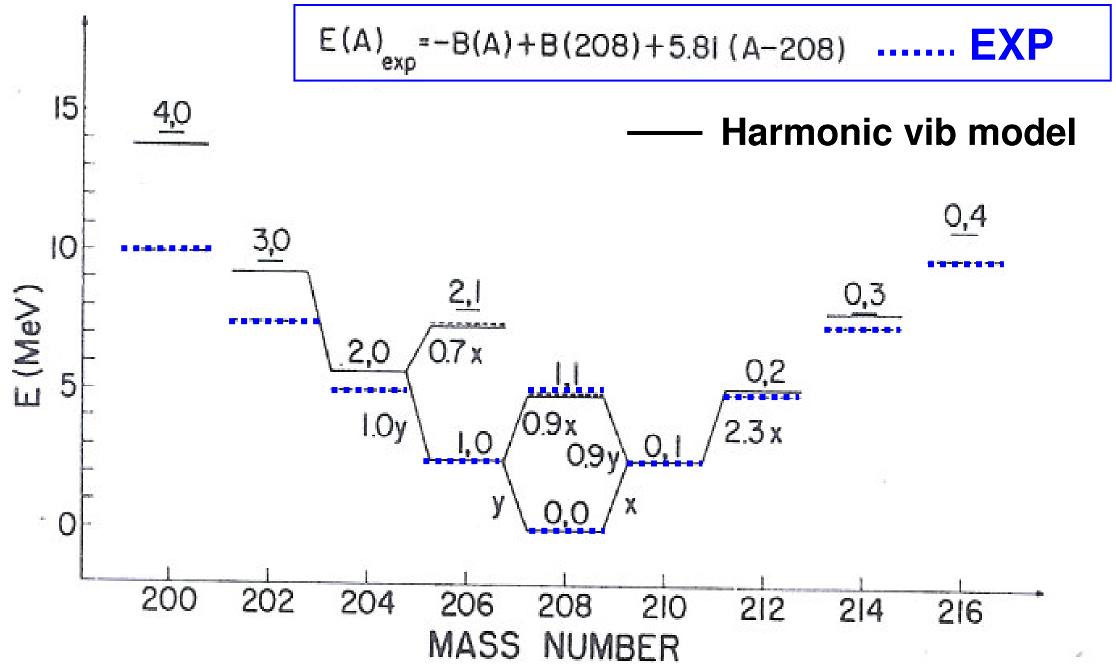
- **G.S. energies**
- **G.S. → G.S. transfer σ**
- **G.S. → second 0^+ transfer σ**

Region around ^{208}Pb (Δ=0)

Model predictions:

- Harmonic spectrum
- Stripping $N_0 \rightarrow N_0+2 \rightarrow N_0+4\ldots$ have enhanced GS transitions with 1:2:3… ratios
- Same for pickup
- 2-phonon at 2xEg.s.
- 2-phonon state with GS/P.V. intensity ratio ~ 1

Good agreement with data



Study around ^{132}Sn using (p,t) and (t,p) reactions

Other reactions discussed

- Radiative captures / Direct measurement /p nuclei
- Resonant elastic scattering
- Resonant inelastic scattering
- Inelastic scattering and angular correlation technique
- Narrow unbound states
- Gamma transitions in unbound nuclei
- Quasi-bound unbound nuclei

GASPARD CONCEPT

GAmma SPectroscopy and PArticle Detection

- ***Particle-gamma coincidences***
  - *Fact ~10 in energy resolution*
  - *Fact ~7 in efficiency*

  (w/r MUST2+TIARA+EXOGAM)

- **Multireaction capababilites**
  - **Coupled-Channels analysis**

- **Improve PID for light particle**

  ToF issue
  - **Tractability**
  - **compactness**
  - **Use with High Int. beams**
  - **t/^{3}He; ^{6}Li/^{6}He**

- **Integrate special targets**

- **Modularity - Coupling with other devices (AGATA,..)**

Integrated 4π (particle) + 4π (γ)