On Instrumenting a Nuclear Physics Program

What does one do with an intense beam?

Emanual Pollacco

IRFU/SPhN, CEA Saclay, Fr

SPhN Instrumentation in the Last 10-15 years

- Solid State
  - Large Area Telescope Arrays
- Gas Detectors
  - Beam Trackers
  - Focal Plane & Recoil Detectors
  - Time Projection Chambers
- Gamma
  - AGATA & EXO-GAMME
- Generic Micro Electronics
  - Front-end – ASIC based (*Analogue & Numeric*)
  - Back-end – FPGA based
- DAQ

*Remodel: Technology for **Particle** and **Astro** Physics for **Nuclear** Physics.*

*Still far to reach Particle Physics **Rates** with Nucl. Phys. specs.*

➔ *Engineering Funding (see VMM2 for example)*

Objective of the Last 10-15 years

- From Stable to Radio Active Beams
  $10^{8\text{-}10}$ pps to $10^{0\text{-}5}$ pps

➔Luminosity ⬏

➔➔Target thickness ⬏ ➔ Resoln. ⬎

➔Phase Space Cover

➔Solid Angle ⬏

➔Highly Segmented Devices ⬏

➔Wide Energy & Momentum Dynamic Range ⬏

Challenge Stable Beam

- Radio Active Beams to Stable/Quasi-Stable.

  $10^{0\text{-}5}$ pps ➔ $10^{6\text{-}13}$ pps

- Present our Instruments: Incapable to cover the increase in rates.

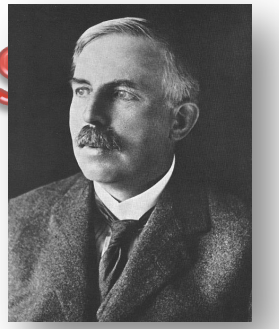
- **BUT**
  - Better Stable Beam characteristics
    - Emittance & Time structure
  - Knowhow exists in Particle hysicsP for some of the challenges.
  - Develop SPESIFIC/NOUVELLE physics program ➔ SPESIFIC instrument.

To accomplish physics
With low X-section
measurement (eg DCE)

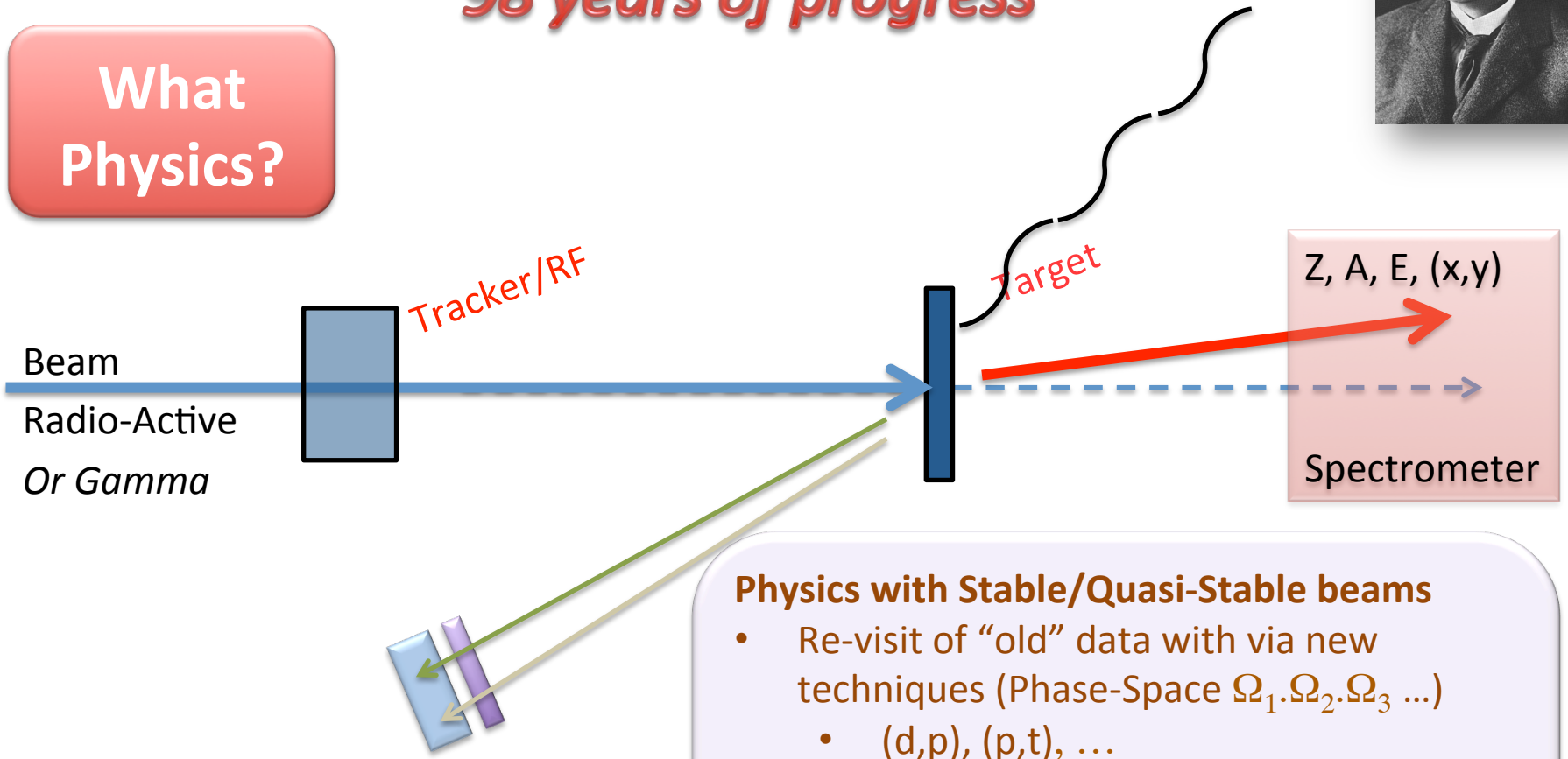
Ultra-High selectivity with
-Magnetic Spectrometers
-High Segmentation
-Radiation hard
-Engineering Knowhow

Spectroscopy In Nuclear Physics

98 years of progress



What Physics?

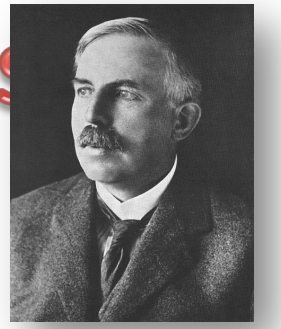


Physics with Stable/Quasi-Stable beams

- Re-visit of "old" data with via new techniques (Phase-Space $\Omega_1.\Omega_2.\Omega_3$ …)
  - (d,p), (p,t), …
  - Particle-Gamma selectivity
  - Multi-Particle final states
- Very low x-section reactions (astro-physics, Sup-Heavy, …)

Spectroscopy In Nuclear Physics

98 years of progress

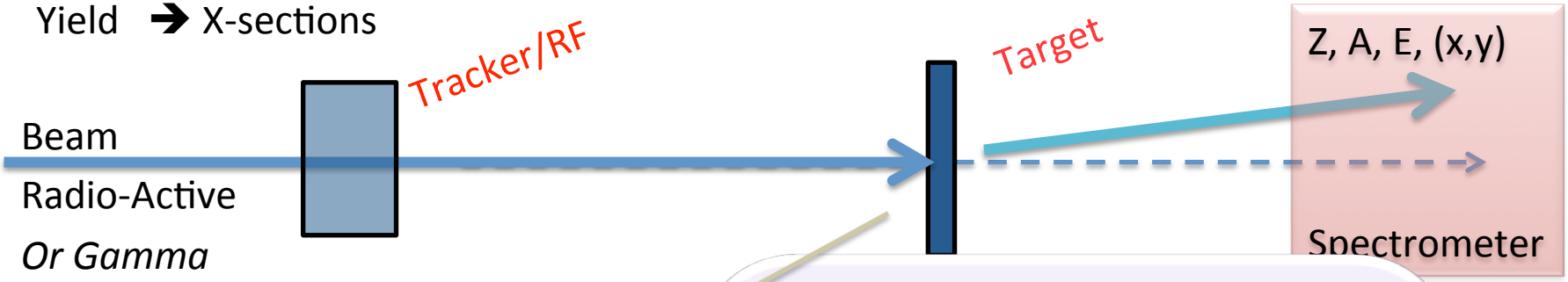


Spectroscopy *(direct or resonant reactions)*

Energy➔ Energy Levels E*

Angles ➔ L^{π}, β (**BE**(L))

Yield ➔ X-sections



Telescope- eg: Si+CsI

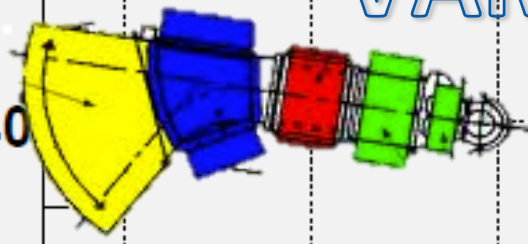
Energy
Position
Charge
Mass
Angle

High Rate Options

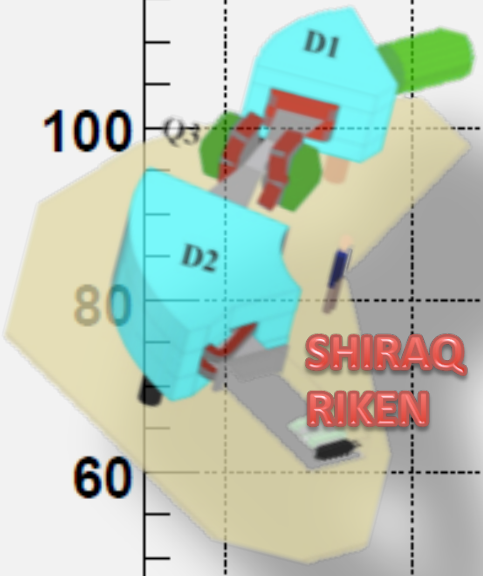
- Target development
- Detectors
  - Fast
  - Highly Segmented
  - Hardened/Fluid
- Adopted Electronics
  - Fast electronics
  - Powerful Trigger
- Multi-coincident /Time/Energy/ Position/
- High Magnet selectivity

Small N° of channels 100+100 max

VAMOS – Se-D & DRIFT

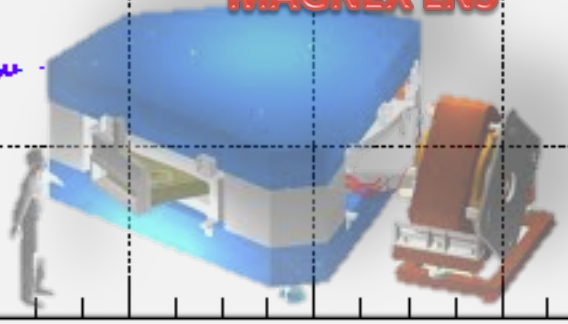


VAMOS



SHIRAQ
RIKEN

All-Elec. Approach
Catania-Saclay
Connection



MAGNEX LNS

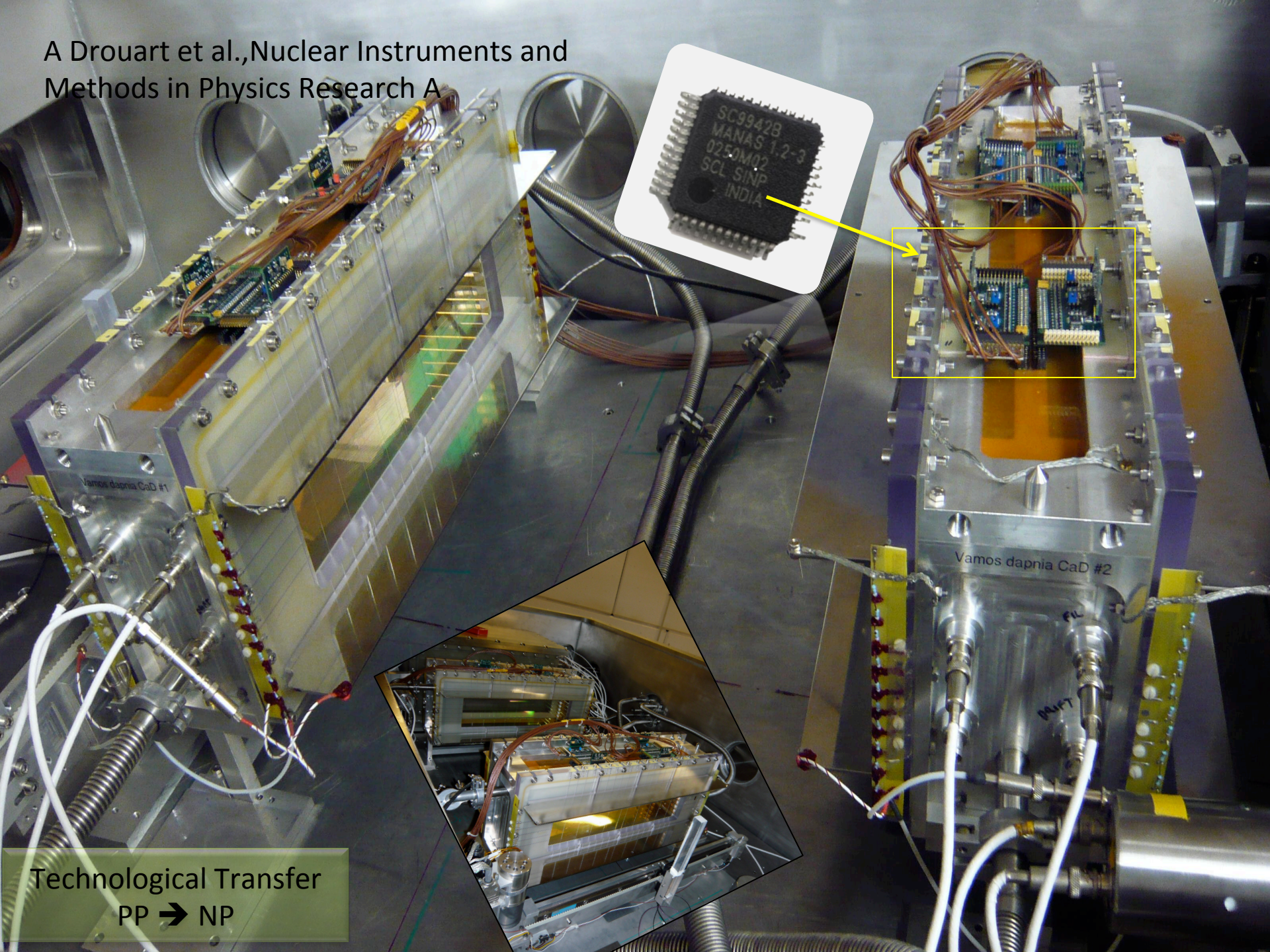
M

160
140
120
100
80
60
40
20

2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6

M/Q

A Drouart et al.,Nuclear Instruments and Methods in Physics Research A



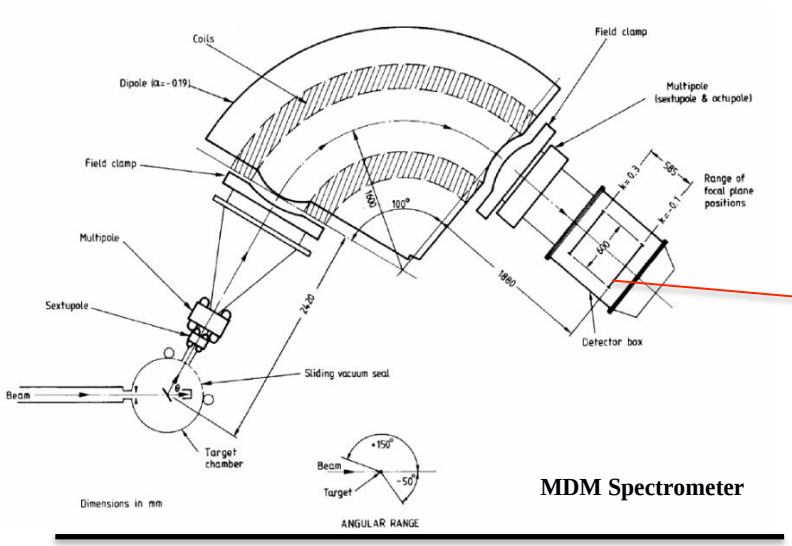
Technological Transfer
PP ➔ NP

Upgrade of the TAMU MDM-Focal Plane Detector with MicroMeg

A. Spiridon, E. Pollacco[1], R. Chyzh, M. Dag,B.T. Roeder, A. Saastamoinen, R.E. Tribble, L. Trache[2], G. Pascovici[2], R. d

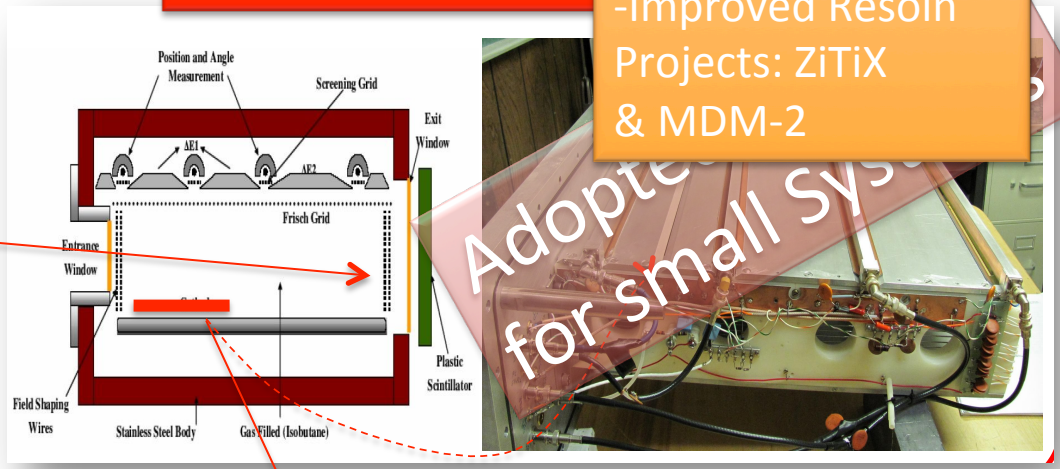
[1]IRFU, CEA Saclay, Gif-sur-Yvette, France
[2]IFIN, Bucharest-Magurele, Romania
[3]CERN, Switzerland

Project
-Front-end for high Counting rates 10^6Hz
-Improved Resoln
Projects: ZiTiX & MDM-2



MDM Spectrometer

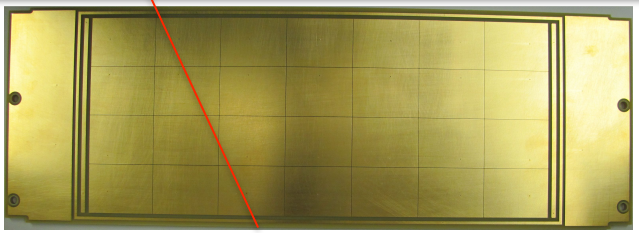
Focal Plane Detector



Adopted for small Sys

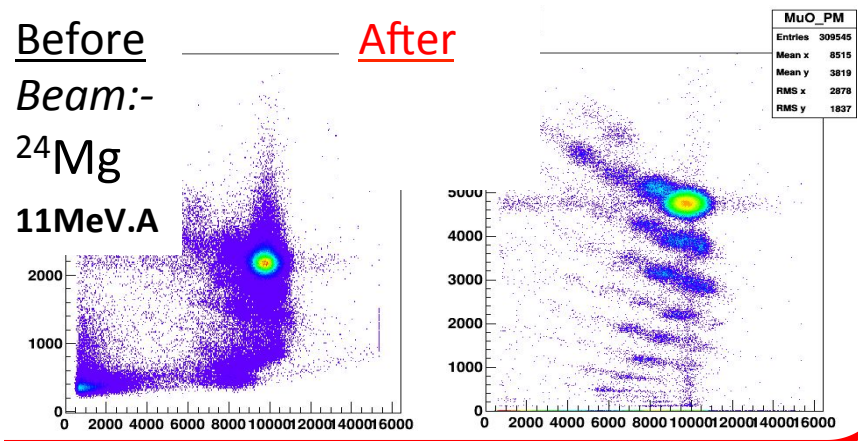
30-100 Torr Iso
6% (FWHM) individual Resoln
3% (FWHM)multi-sampling Resoln

MPGD Replacement by Multi-Pad Anode

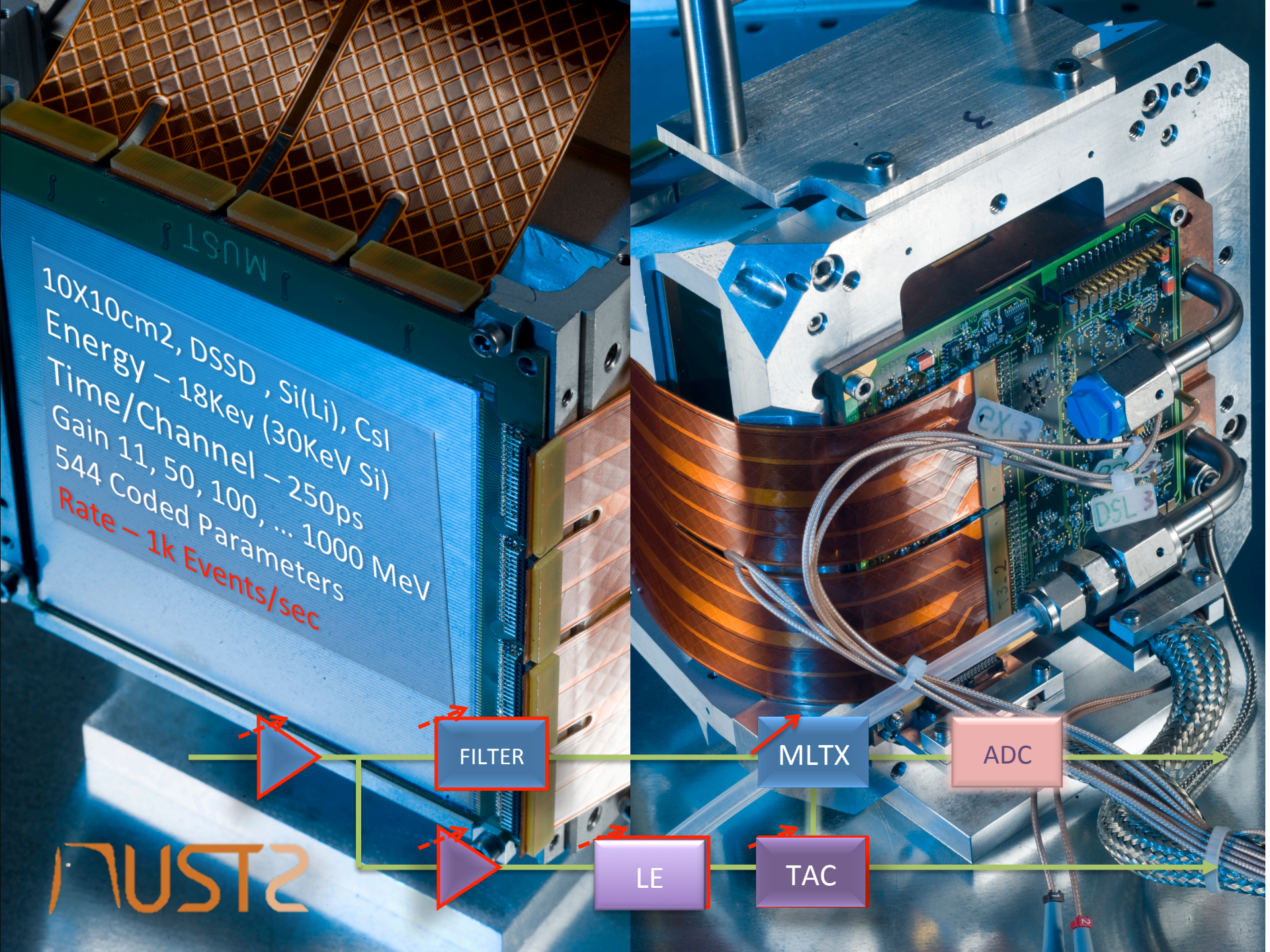


Before — After

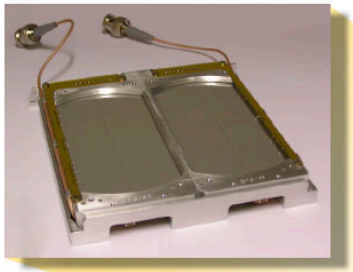
Beam:-
^{24}Mg
11MeV.A



Improvement is still possible to below 2%
Towards higher Z ions, Time, Position & GET electronics:
Recoil Detectors – (x,y)/time/ΔE
Renewal Focal Spectrometers Expected

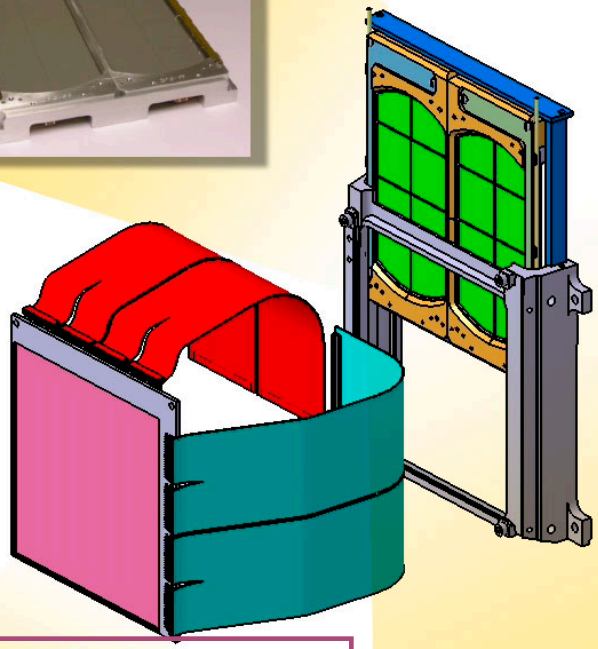

10X10cm2, DSSD , Si(Li), CsI
Energy – 18Kev (30KeV Si)
Time/Channel – 250ps
Gain 11, 50, 100, … 1000 MeV
544 Coded Parameters
Rate – 1k Events/sec
FILTER
MLTX
ADC
LE
TAC

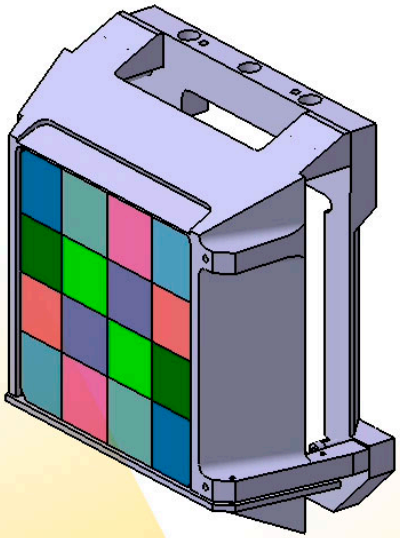
Collaboration: IPNO/SPhN-Saclay/GANIL

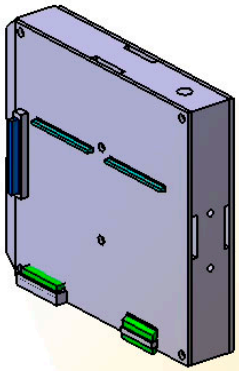


Si(Li) 5mm

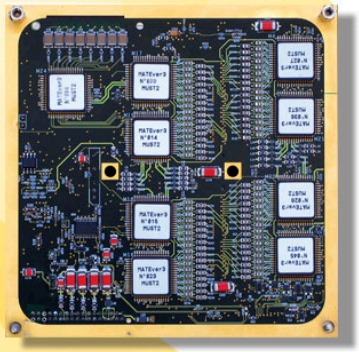
CsI 4cm





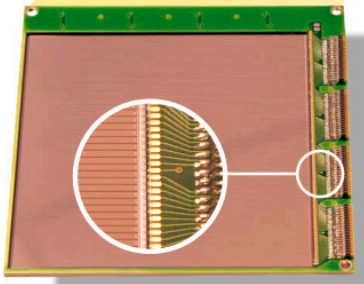


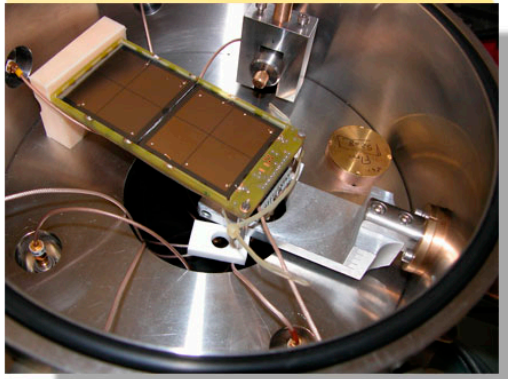
DSSD
10x10cm²
128X+128Y
300µm



Résolution en position 0.7mm

Résolution énergie FWHM ~ 50 keV

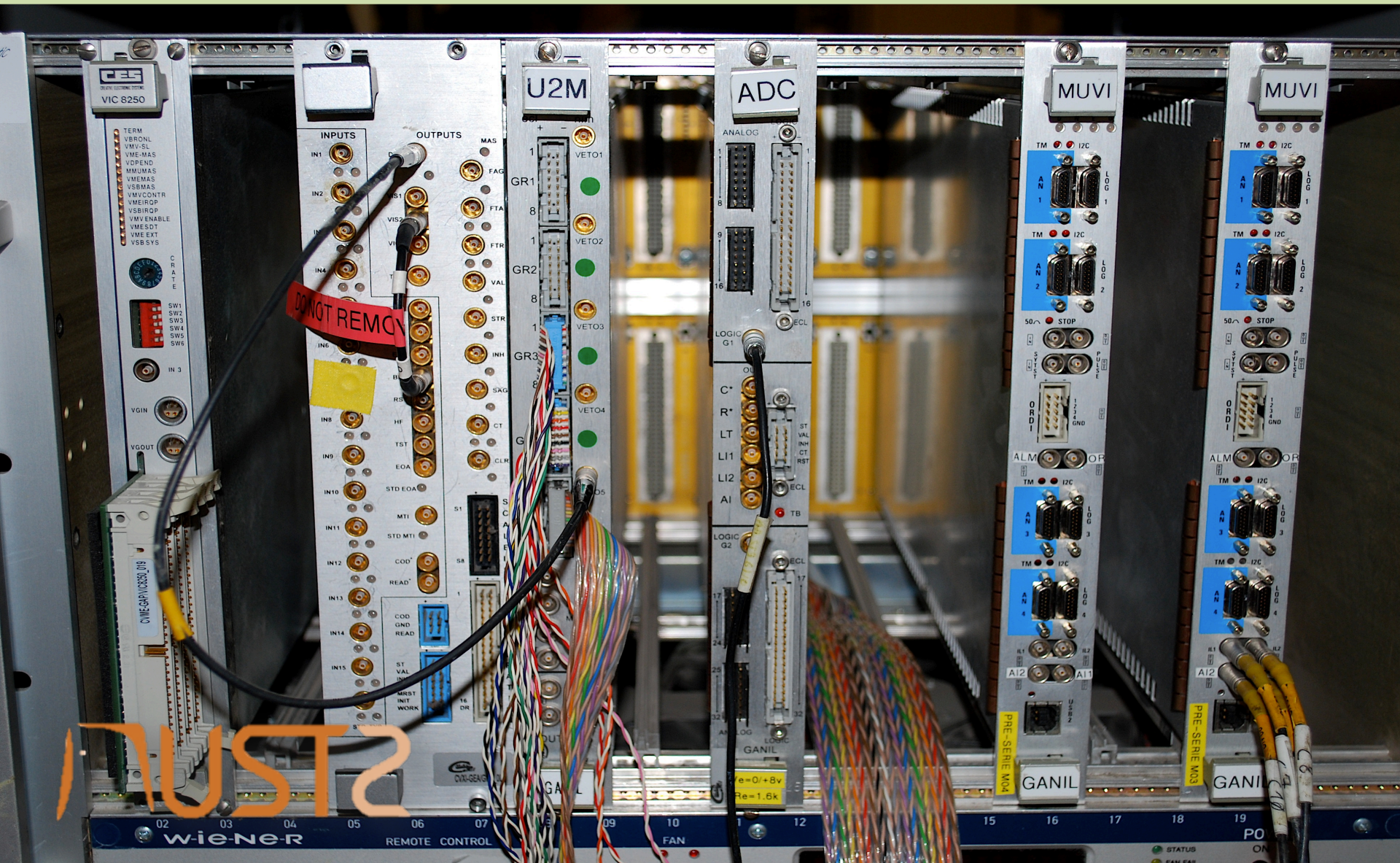




For 8X288 channels of Energy & Time

Project
Can do much better
Concentration X20

Trigger + Scalars +ADC +4MUST2 +4MUST2



Performance

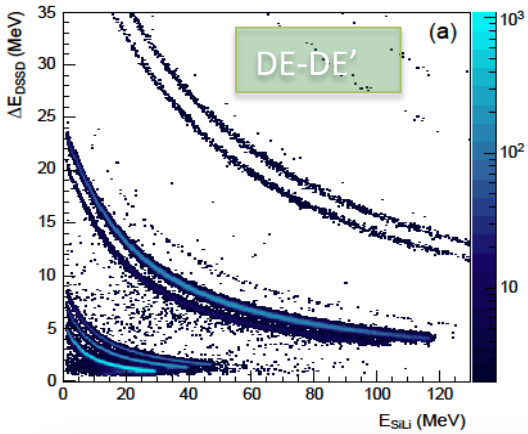
Overlay of 150 channels of MUST2 telescope

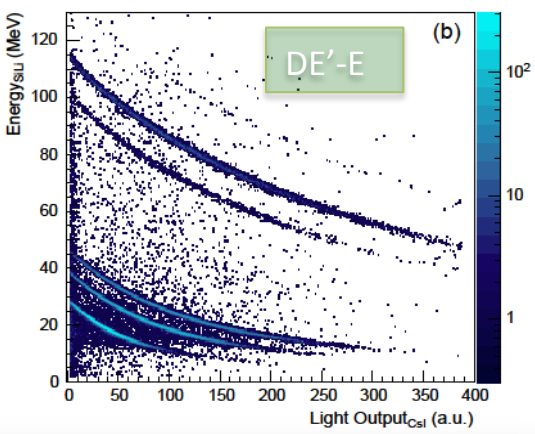
➔Generic approach: ASIC development for M

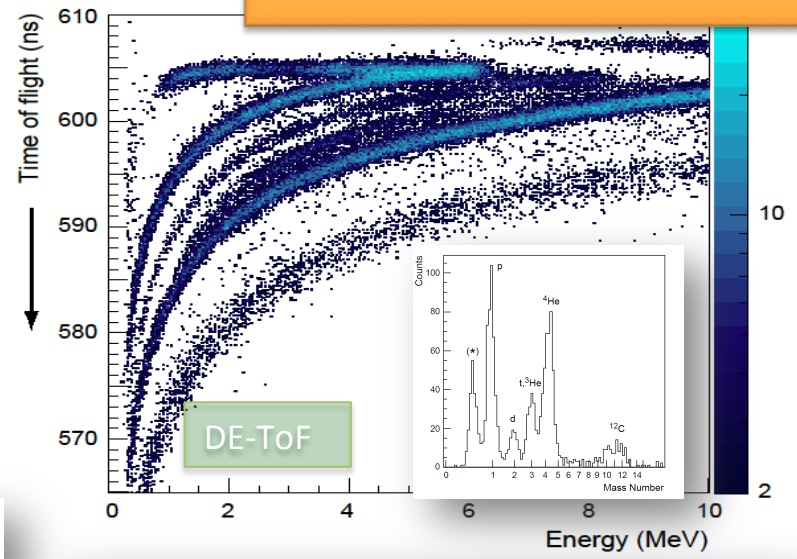
Project

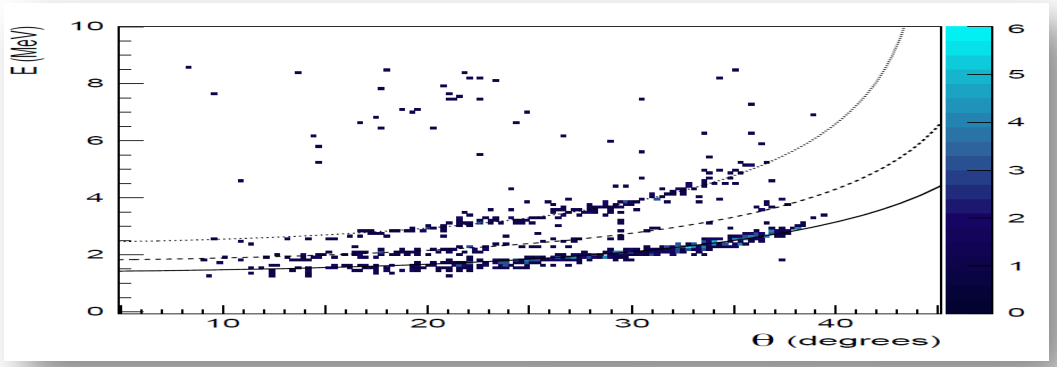
. Pulse Shape - 500MHz sample

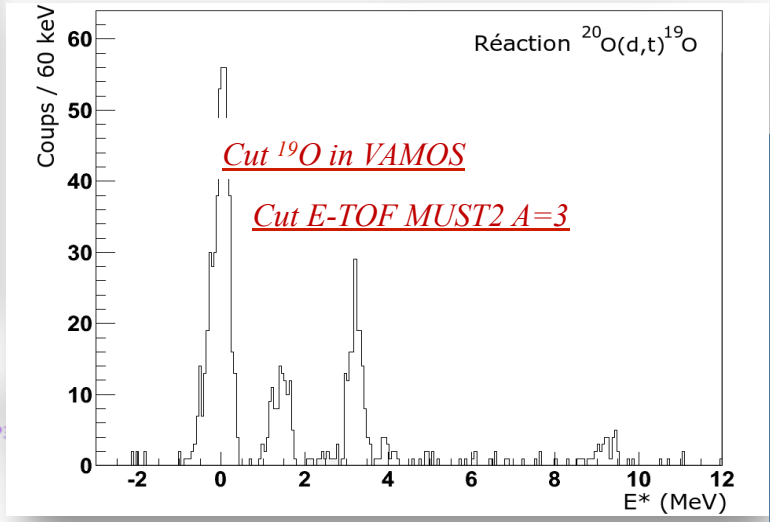
. Improved Back-end 1kHz to 20kHz







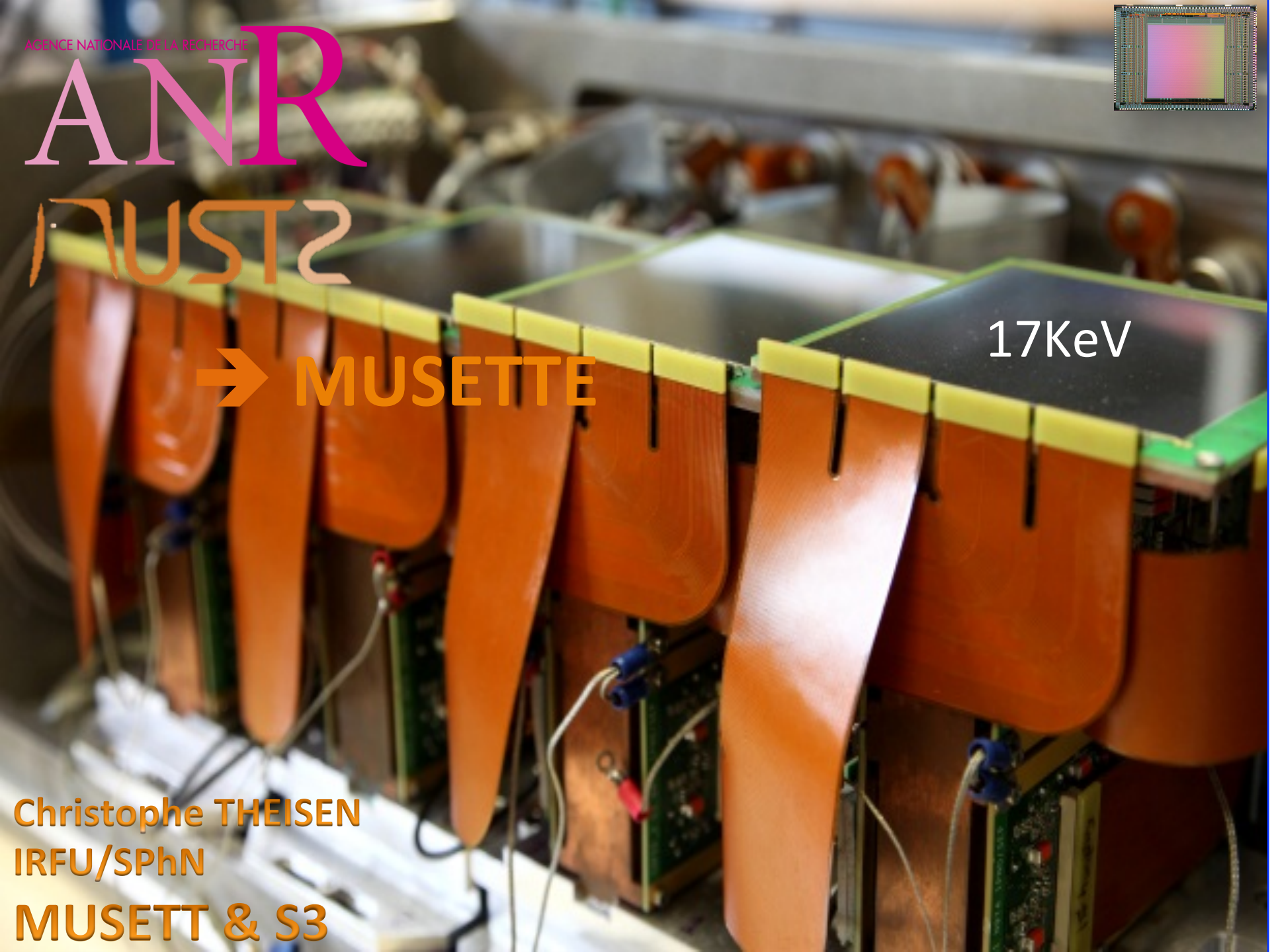


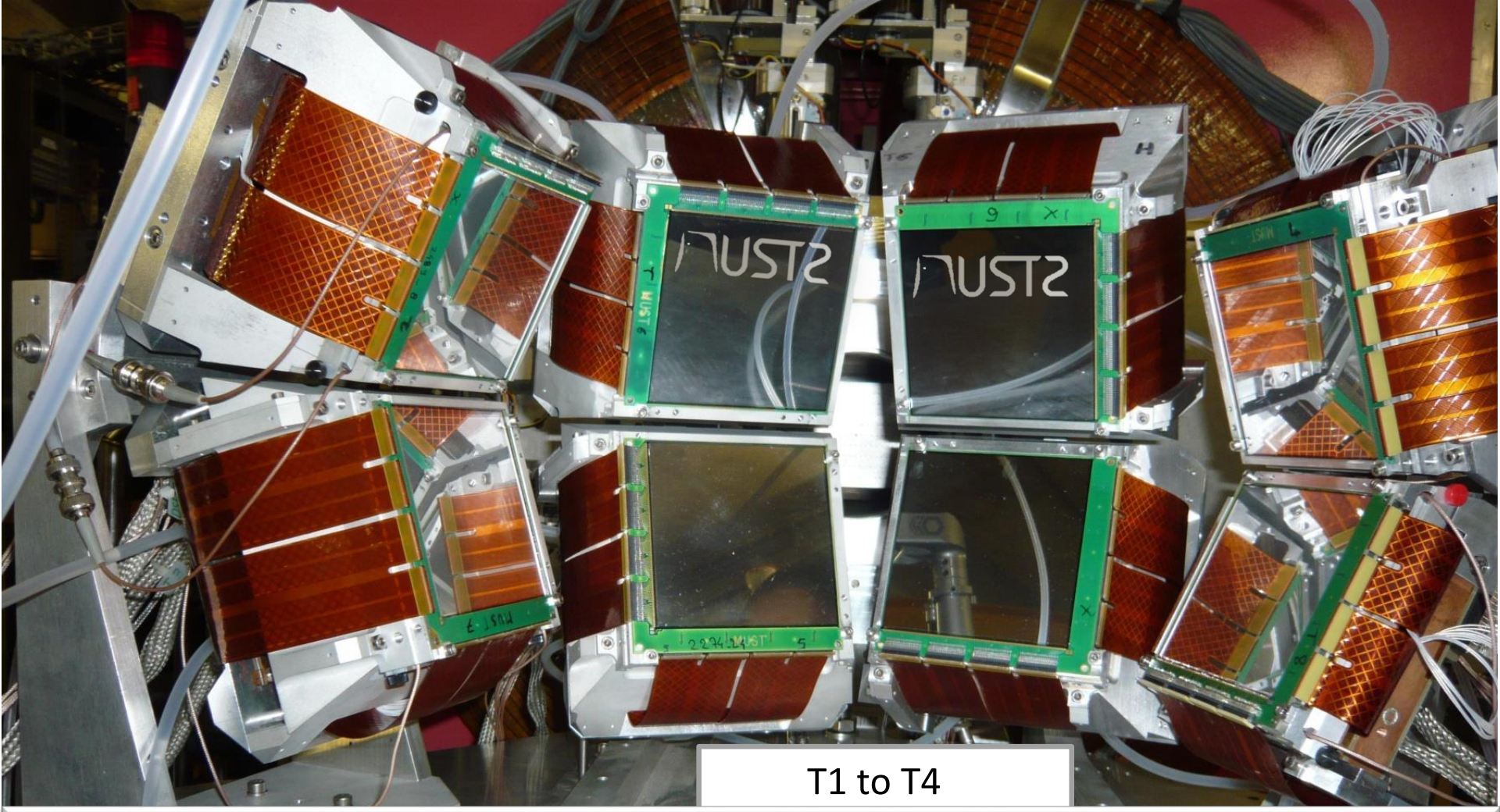


Irfu cea saclay

IPN Orsay

GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3


AGENCE NATIONALE DE LA RECHERCHE
ANR
17KeV
MUSETTE
Christophe THEISEN
IRFU/SPhN
MUSETT & S3



Hodoscopes for Particle Spectroscopy

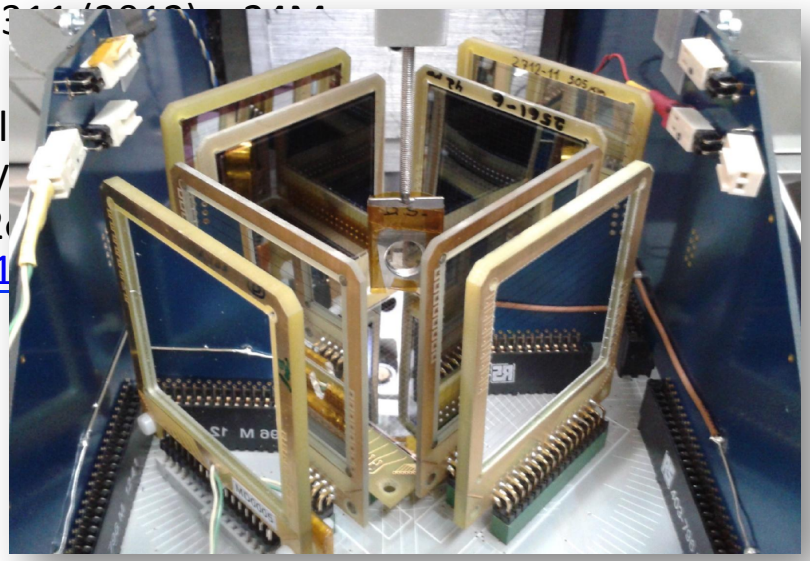
>30 Nucl. Phys Exp. So … what now?

→ Full Particle-Gamma → GASPARD

Possible Measurements With MUST2

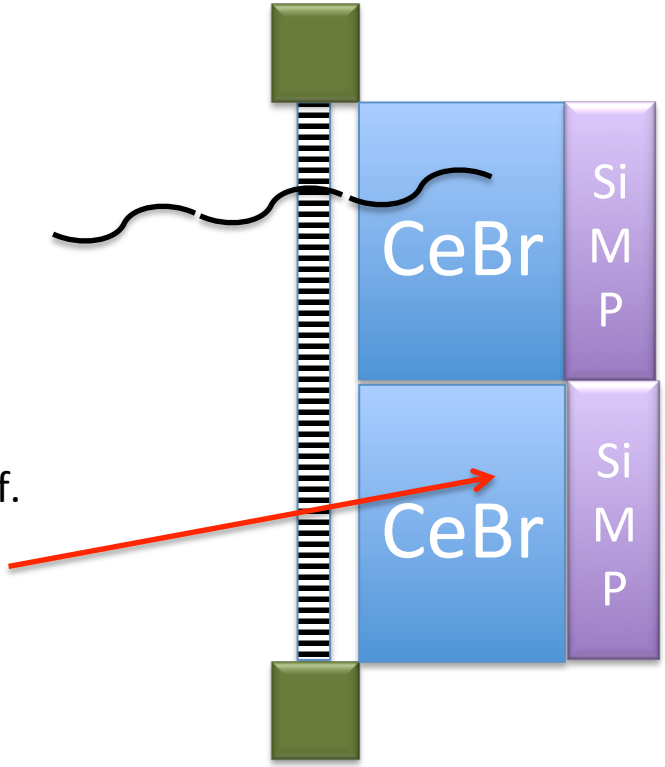
- MUST2 has
  - a large solid angle (x50 higher than most existing system & x10,000 of 1980 data sets)

- Experiment prospects:-
  - (t,p), (d,p), (^{3}He,d) … done in 1970's: Solid Angles 1/10,000 of 4xMUST2.
  - Can perform particle-γ measurements to establish decay schemes for particle states in stable or quasi-stable nuclei.
  - Multi-Particle final States
    - E. S. Diffenderfer et al., Phys. Rev. C 85, 034
    - Low lying resonances in light nuclei
    - Investigations of three, four, and five-particl nuclei created using a ^{9}C beam; R. J. Charity
    - Decay of ^{10}C excited states above the 2p + 2 Curtis, N. *et al.* Phys.Rev. C77 (2008) 021301



Particle-Gamma Physics Instrumentation Project

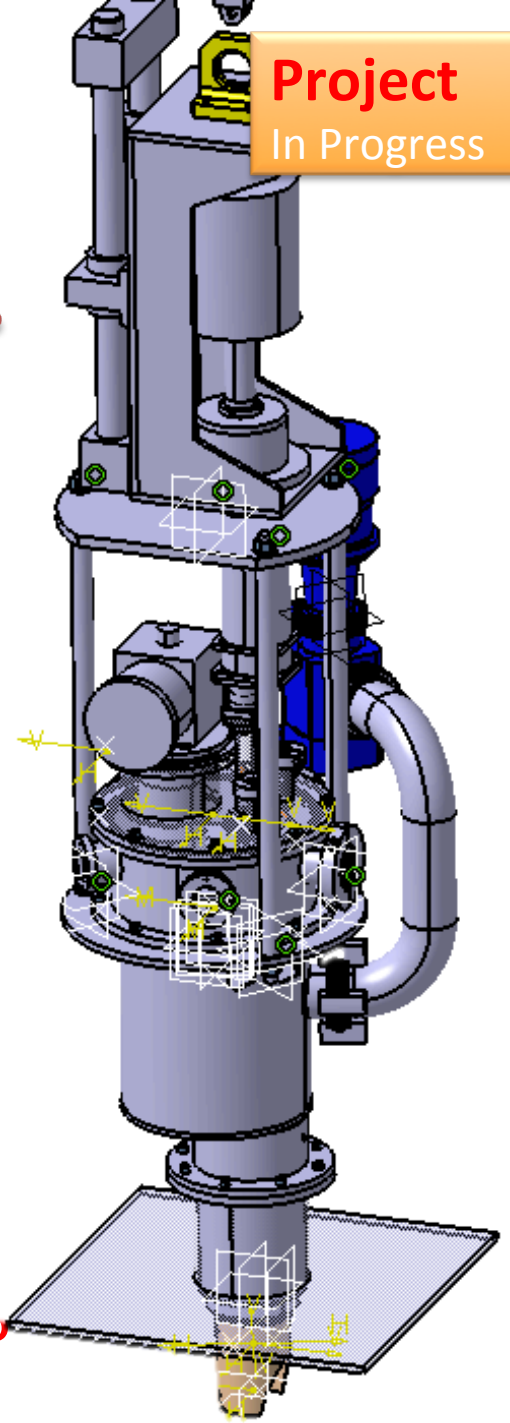
- **Telescope (Particles & Gamma) 25% of 4π**
  - **ΔE** - DSSSD ➔ 40KeV & 500nsec resol^n
    - 6 DSSSDs of 10cmx10cm
  - **E** - $CeBr_3$ ➔ 5% & 4mm resol^n
    - 24 crystals of 5cmx5cm
- **Gamma 12% of 4π**
  - E - $CeBr_3$ ➔ 5% & 4mm resol^n & high eff.
    - 12 crystals of 5cmx5cm
- **High Phase Space**
  - Ωγ x Ωp approx 25%
    - Large Phase Space Cover
      - Needs review of electronics for high counting rates.
      - High dynamic range for particles & gammas



An exotic Target

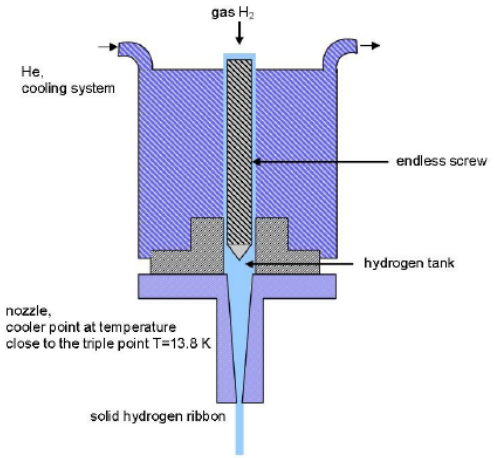
CHyMENE – the super thin BUT expensive Lasagne Machine

Project
In Progress



Challenge - how thin 100μm, 50μm, …?

CHyMENE hydrogen target



- 50-200 micron solid H_2/D_2 film

- no C and mylar window
  - ⇒ no C background
  - ⇒ atoms.cm^{-2} x 5
  - ⇒ less energy loss

- experiments at SPIRAL1 and SPIRAL2
  - ⇒ 5-15 MeV/u and thin target (<0.5 mm)

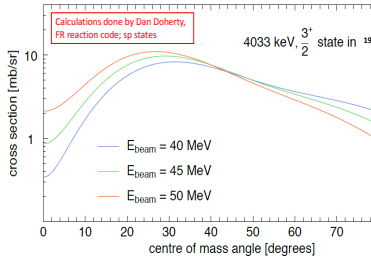
Developments:

- Early 2010: production test at Saclay
- June 2010: in-beam test at Bruyères-le-Châtel
- 2011: ANR
- Towards below 40μm

If DCE then this exp!

Possible Measurements With MUST2

- Astro-Physics Reactions (Ph Woods)
  - ^{20}Ne(p,d)^{19}Ne ➔ Branching 10^{-4} ➔ α + ^{15}O
  - ^{21}Ne(p,t)^{19}Ne ➔ α + ^{15}O
  - Need To populate ^{19}Ne(E*=4.033MeV - mbarn)

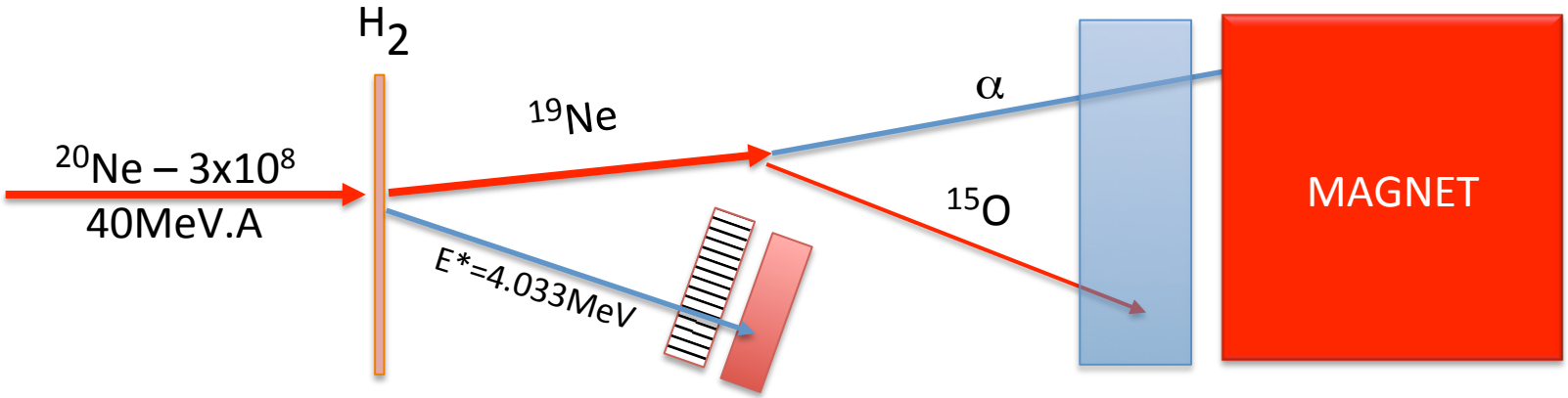


➔High intensity ^{20}Ne (10^{12}pps)

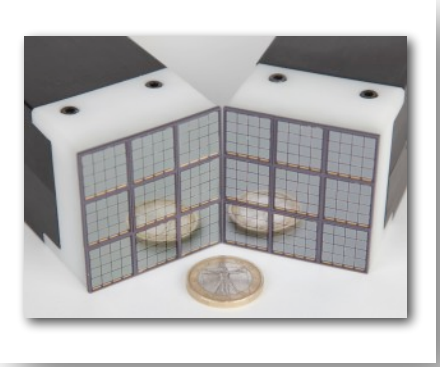
➔Target no Contaminant (C, O, N … kills the DSSSDs)

➔Spectrometer approx 0°.

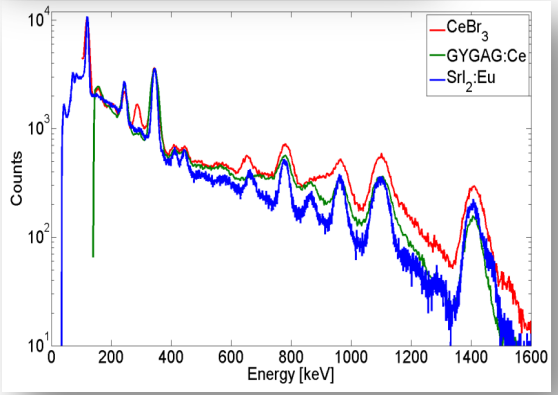
➔Detect α + ^{15}O & p



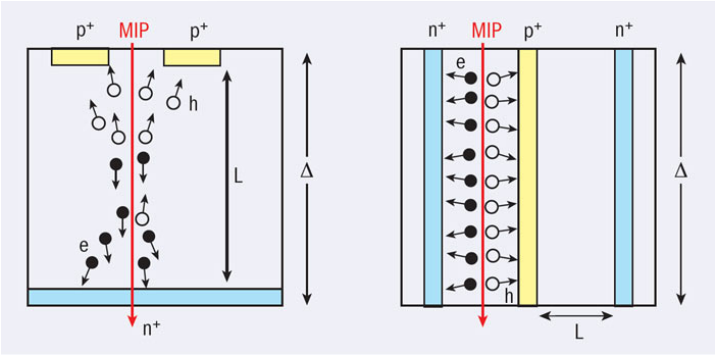
Other Si frontiers:-



- ***SiPM – Fast crystals with fast "PMs"***
  - ***100psec & resoln 6.5% for CeBr3***
  - ***Developments in progress (noise)***
  - ***Nucl. Phys. Being tested***



- ***GAIN mode*** *in Si detectors (Not APVs)*
  - ***Low-Gain Avalanche Detectors (LGAD)***
    - ***X10 gain***
    - ***Very fast timing (<30psec)***
  - *Nucl. Phys. Not trying ?*



- ***3-D Si for tracking***
  - ***Ultra fact Si***
  - ***Radiation hard***
  - *Nucl. Phys. Not trying ?*

Fast Growing ZOO in Particle Physics

FAMILY TREE:

TIME PROJECTION CHAMBER

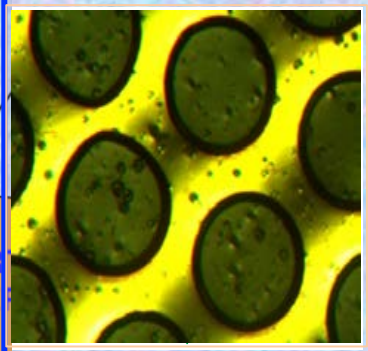
CHERENKOV RING IMAGING

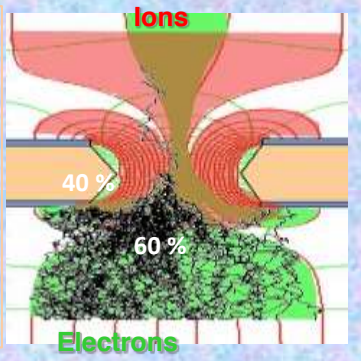
WIRE ORTIONAL CHAMBER

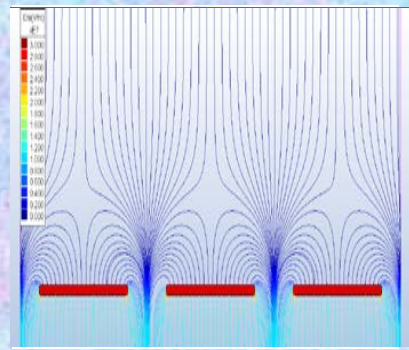
THGEM

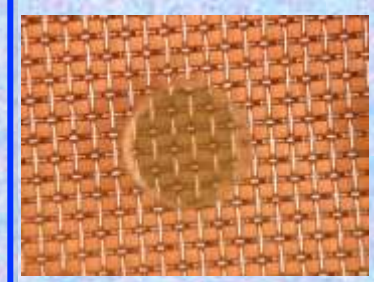
GEM

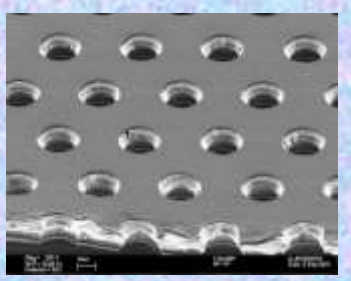
Micromegas | GEM | THGEM

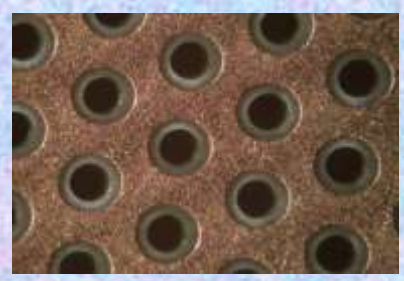












PROPOR COUNTE

COUTER

Gas Electron Multiplier

MICROME GAS

BULK

μ- BULK

AVALANCHE CHAMBERS

PESTOV COUNTER

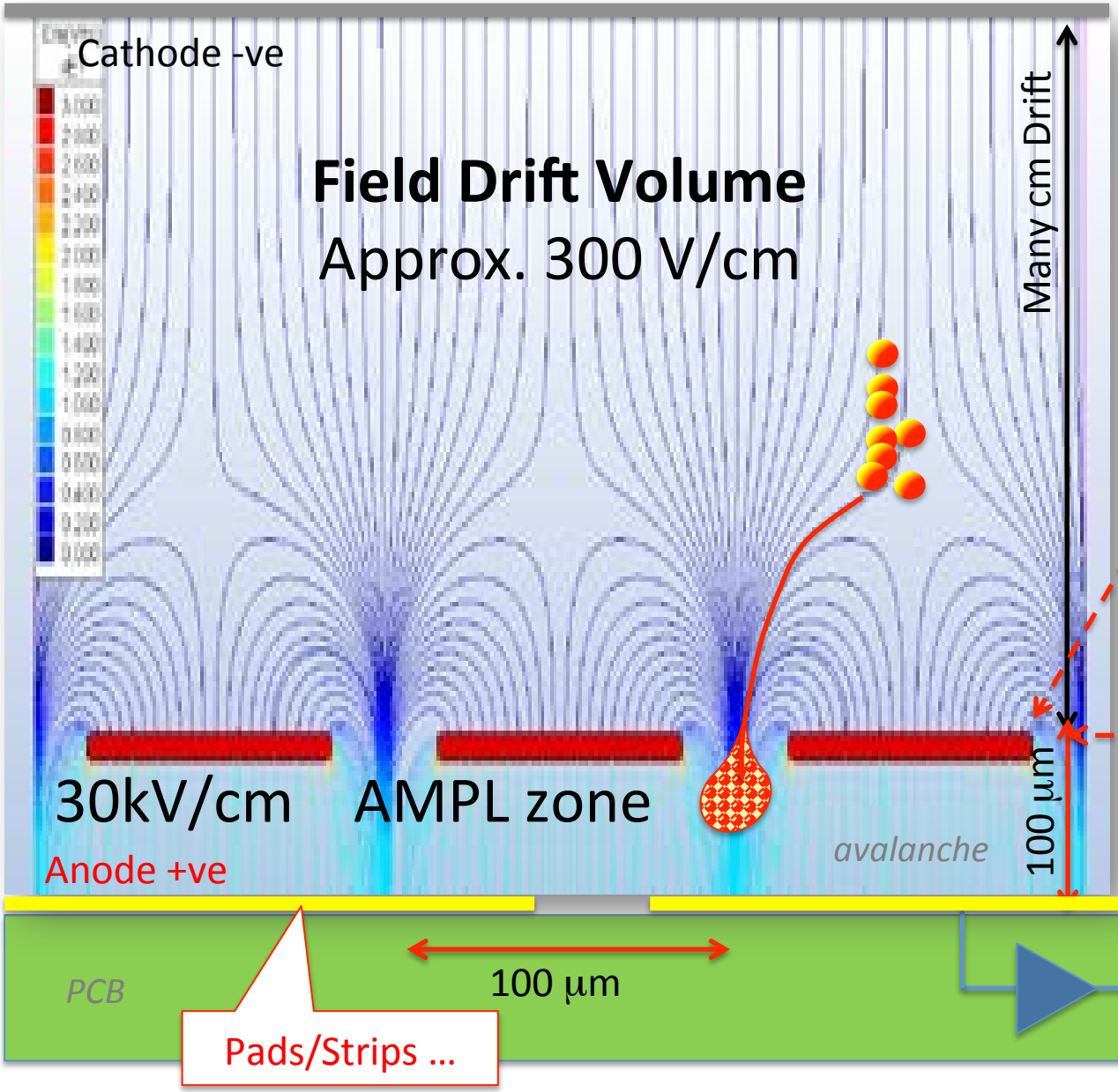
RESISTIVE PLATE CHAMBERS

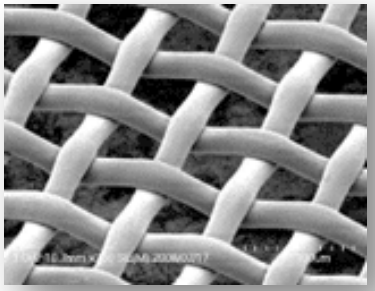
Maxim Titov, CEA Saclay, France

Mico-Patter Gas Det.

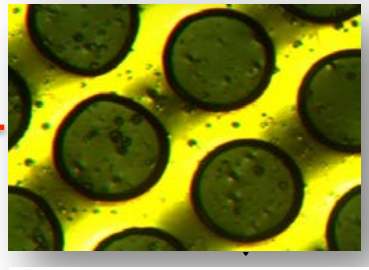
High Resol^{n}

- ☑ Gain: 10^{6}
- ☑ Time: 2-5ns
- ☑ Space: <100μm
- ☑ Charge: <20%/sqrt(E)
- ☑ Rad. Hard
- ☑ Ion Feed-Back

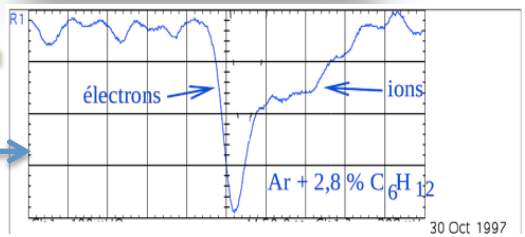




Bulk

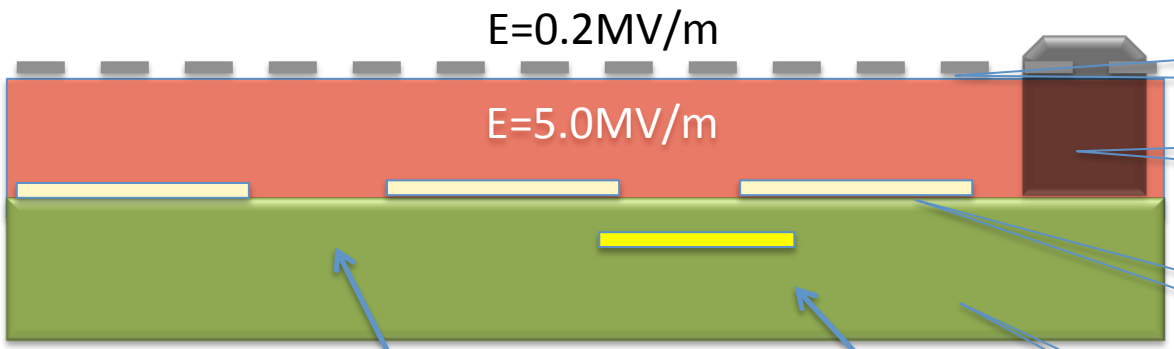


μ-Bulk



Tailoring μ-structure of MPGD.
Zone pad-mesh/kapton: modify the E- behaviour

Project
.High resoln
.High counting
& Ionization
CERN-SPhN
ZiTiX & MDM-2



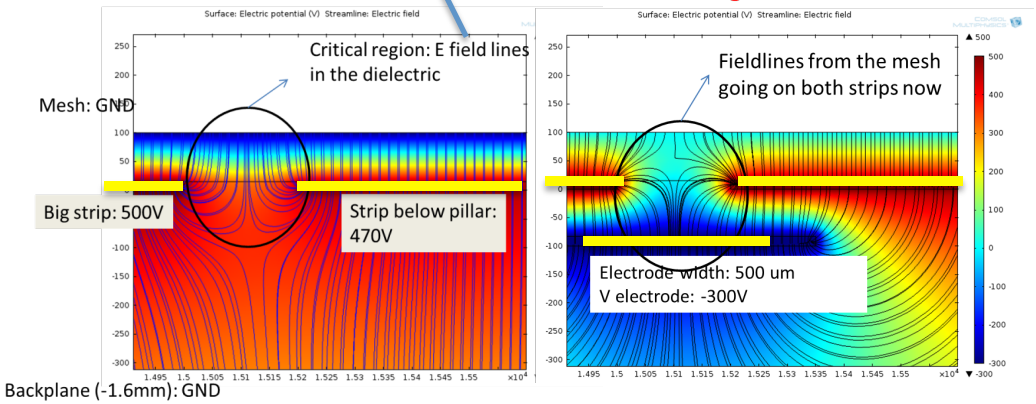
Mesh
Support 300μm

Anode Cu+Au

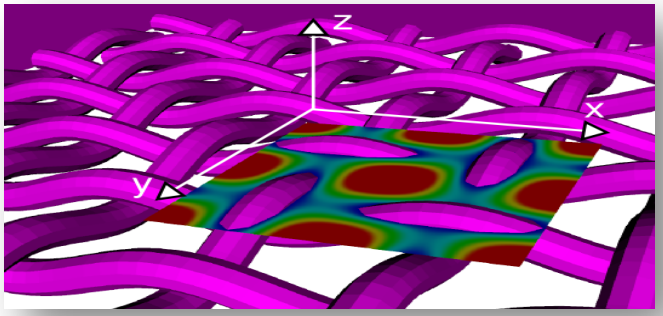
PCB

Without internal electrode:

Internal electrode (100 um below)
V electrode negative



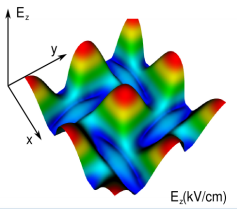
Simulations MIT



Calculations:
S. Franchino, R. de Oliveira & E. Pollacco (ZiTiX Project)

Energy resol^{n} vs. gain

Large P.P. data base (RD51 Collaboration)

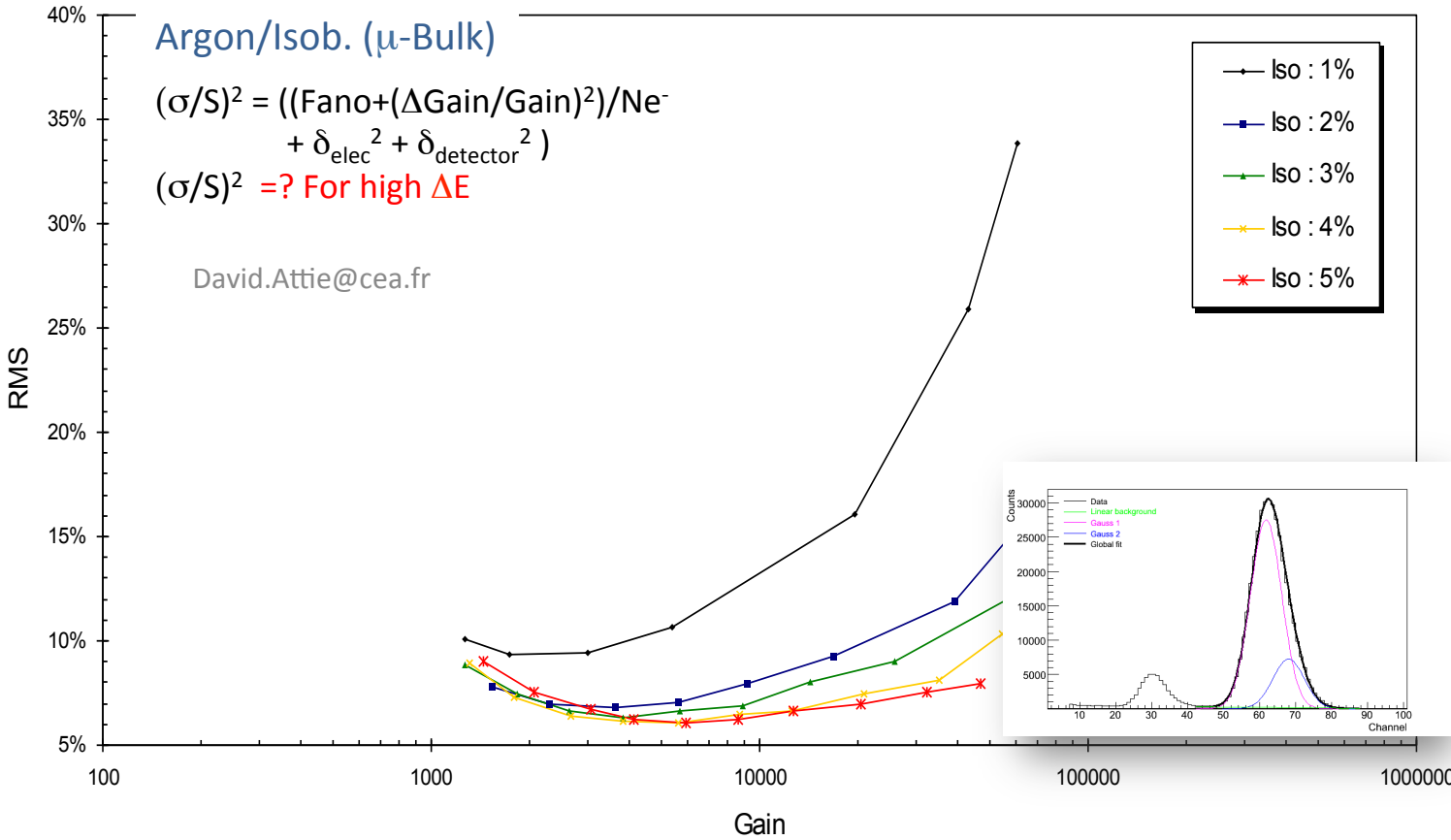


μ-Bulk ^{55}Fe
FWHM = 13.5 %

μ-Bulk ^{241}Am
FWHM = 1.2 %

Bulk ^{55}Fe
FWHM = 16.6 %

Bulk ^{241}Am
FWHM = 3 %



Micromegas/GEM
'Fluid' Radiation Hard
High Rates (mips 10^{7}Hz)
Good Position, Time & Charge Resoln

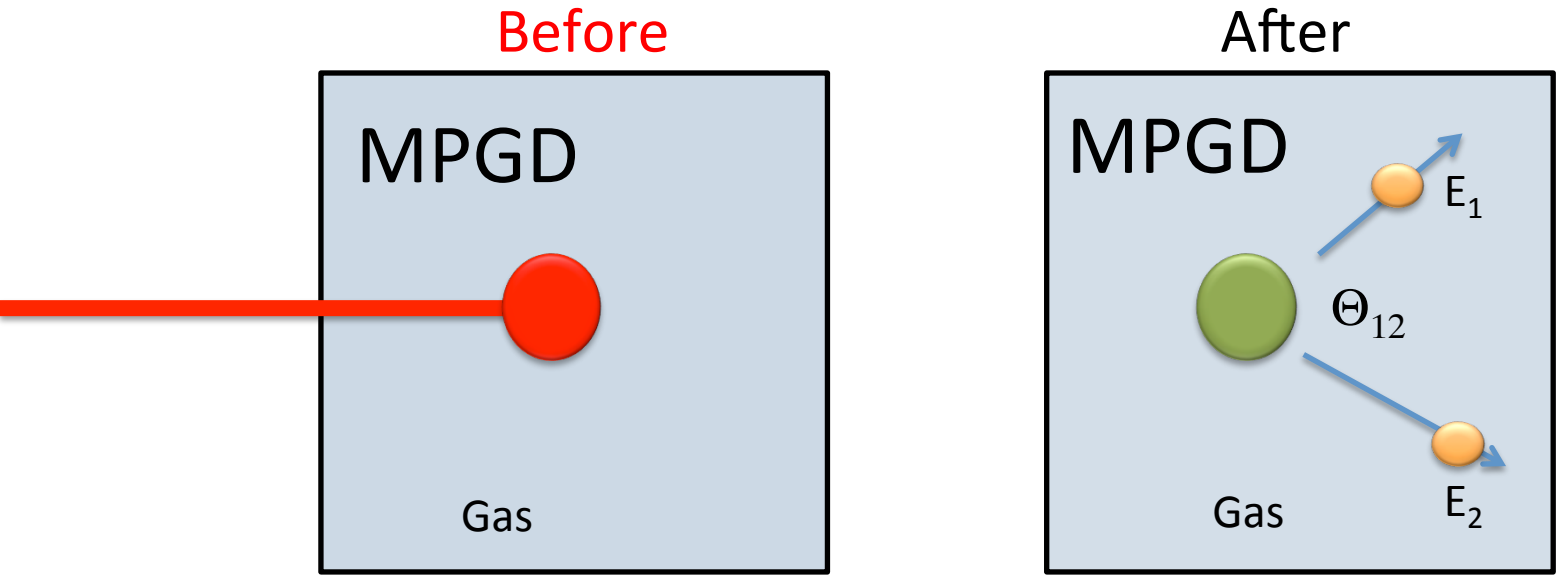
irfu cea saclay

Decay Spectroscopy

Produce A Radio-Active Species

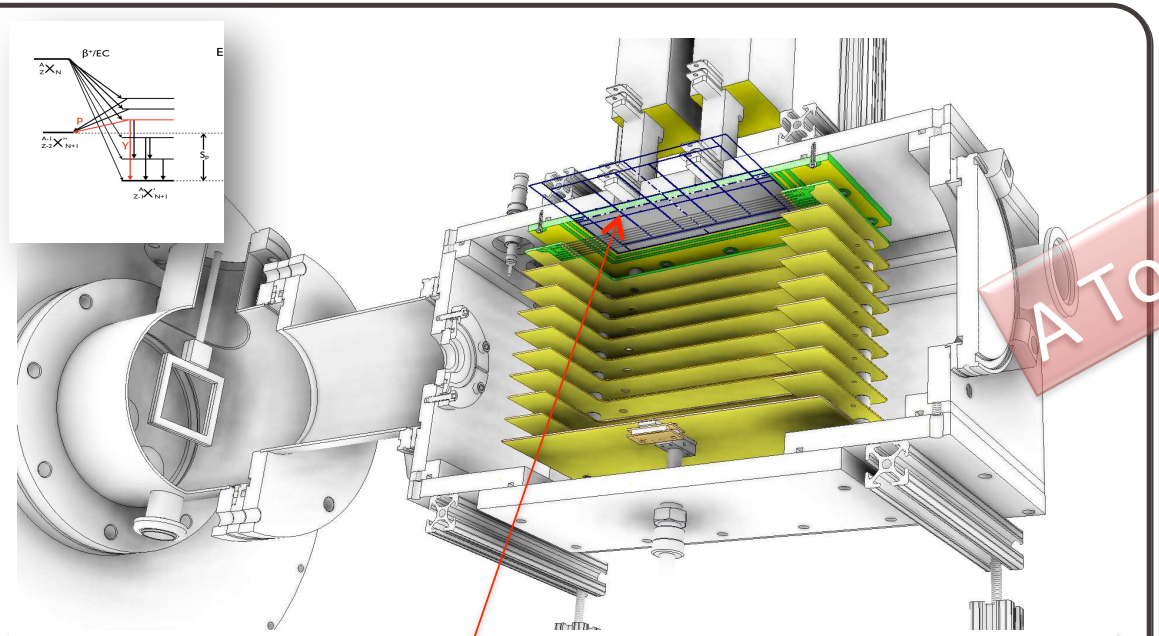
➔ (*then*)

Measure the decay products (p, 2p, 3p, α, αp, …)

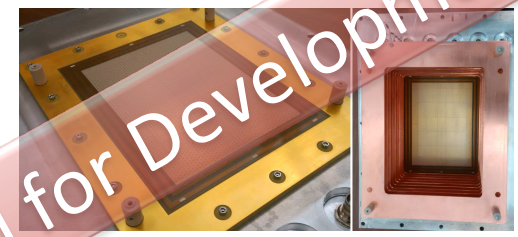


A. Saastamoinen, E. Pollacco, B. Roeder,
A. Spiridon, L. Trache, R. De Oliveira, R. E. Tribble

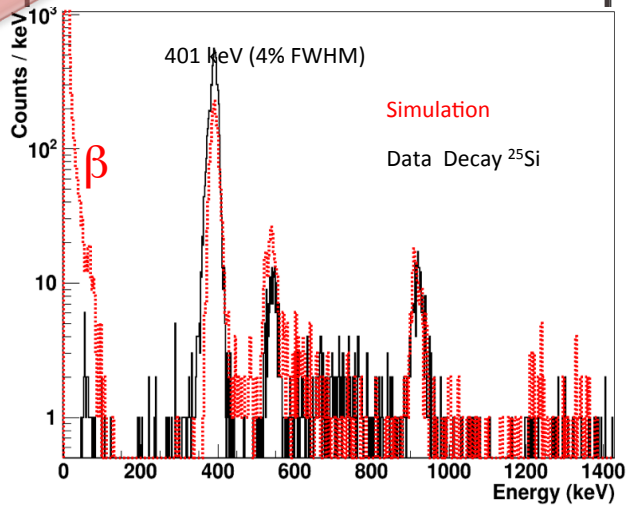
AstroBox2 - Detector for low-energy β-delayed particle detection



AstroBox2 Set-up – Micromegas 256μm P5 gas 900Torr



Left: The AstroBox2 MicroMEGAS mounted on its flange.
Right: The field cage mounted on the detector.



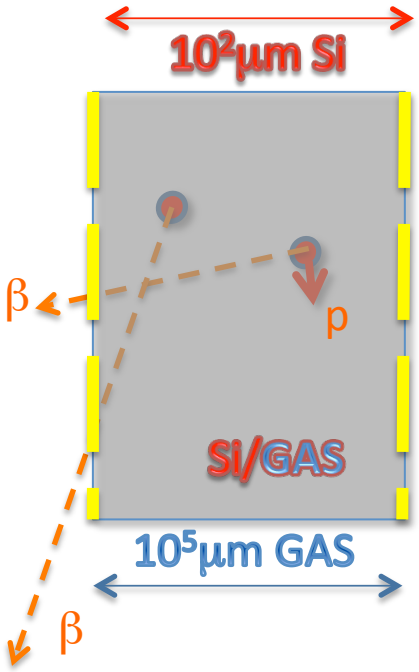
A Tool for Development

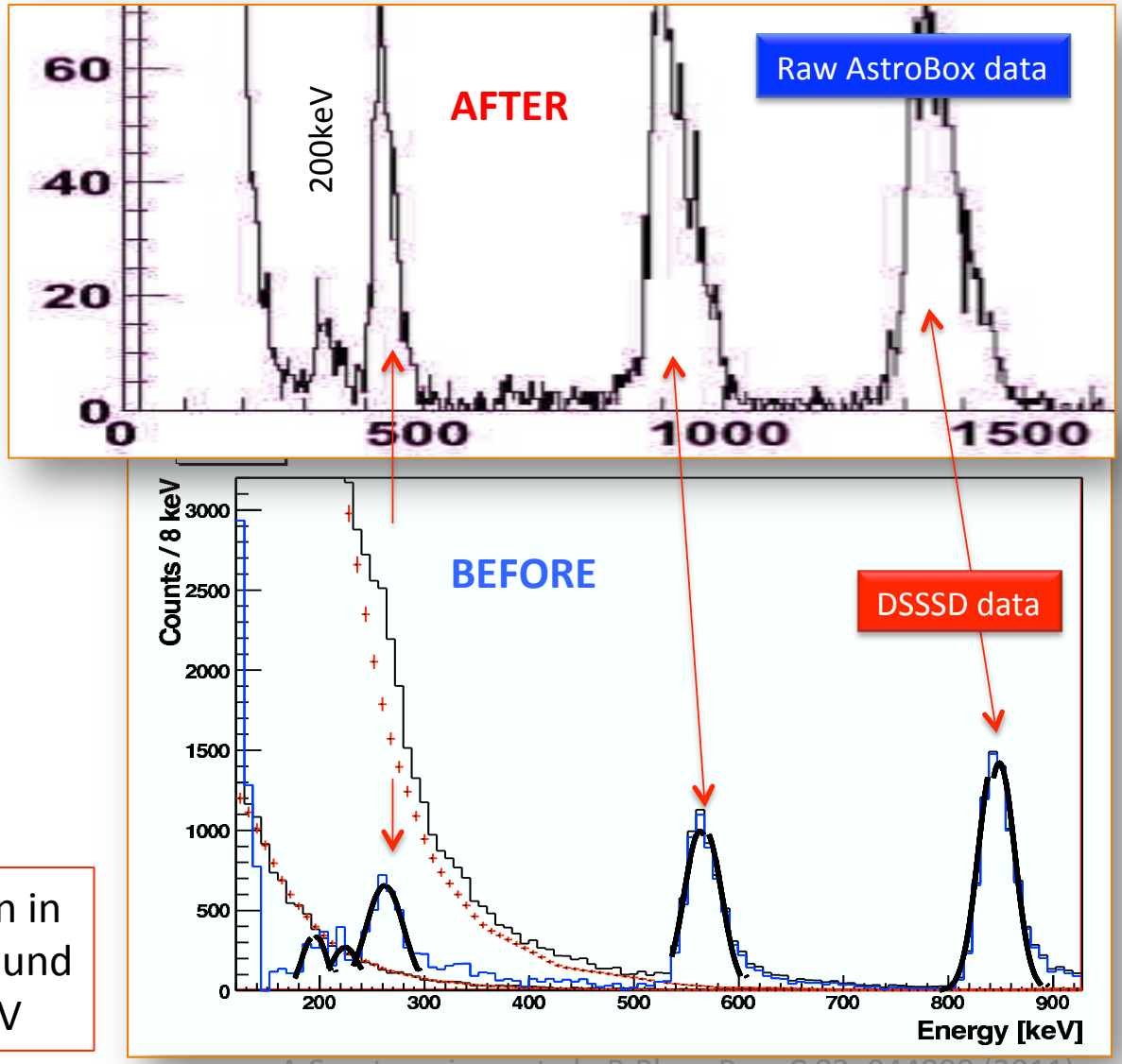
Improvements presently to reach optimum **single pad Q resoln**

Lowering β-background ➔ *Very Low Branching Ratios (10^{-5}) measurement reachable*

Replacing Si by Gas Medium - AstroBox

Making use of dE/dx





10^3:1 gain in Back-Ground @ 200keV

A.Saastamoinen et al., B.Phys. Rev. C 83, 044808 (2011).

irfu
cea
saclay
Cyclotron Institute
Texas A&M University


AGENCE NATIONALE DE LA RECHERCHE
ANR


NSF


Eurotalents

GET


RIKEN
NiSHiNA
CENTER


CENBG


Irfu
cea


GANIL
spiral2
laboratoire commun CEA/DSM
CNRS/IN2P3

GET Collaboration

Faisal Abu-Nimeh[4], Shebli Anvar[1], H. Baba[5], Pascal Baron[1], Daniel Bazin[4], Chiheb Belkhiria[2], Bertram Blank[2], Joël Chavas[1], Patricia Chomaz[1], Eric Delagnes[1], Frederic Druillole[1], Patrick Hellmuth[2], Cedric Huss[2] , Eugene Galyaev[4], Bill Lynch[4], Wolfgang Mittig[4], Tetsuya Murakami[5], Laurent Nalpas[1], Jean-Louis Pedroza[2], Emanuel Pollacco[1],Riccardo Raabe[3], Jérôme Pibernat[2], Bruno Raine[3], Abdel Rebii[2], Atsushi Taketani[5], Frederic Saillant[3], Patrick Sizun[1], Daisuke Suzuki[4], Nathan Usher[4] and Gilles Wittwer[3].

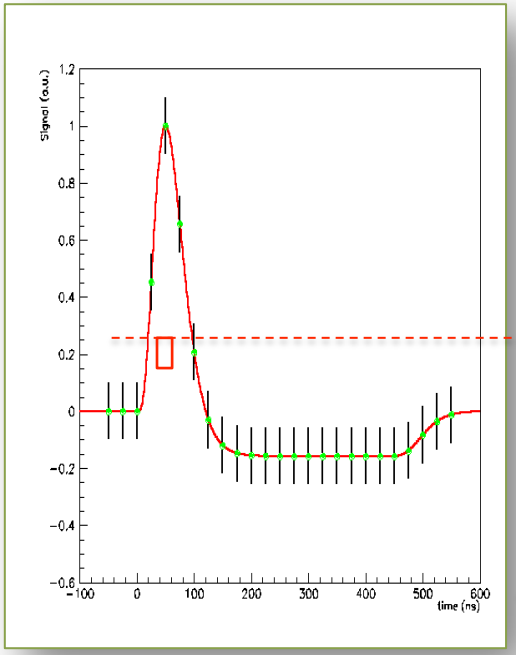
- *[1] IRFU/SPhN, CEA-Saclay, Cedex 91191 Gif-sur-Yvette, France*
- *[2] CENBG, Chemin du Solarium, 33175 Gradignan Cedex, France*
- *[3] GANIL, Bd Henri Becquerel. BP 55027, 14076 Caen Cedex 05. France*
- *[4] NSCL, MSU, 1 Cyclotron, East Lansing, Michigan 48824-1321, US*
- *[5] RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan*

18 Engineers Participated

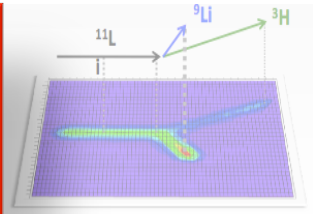
➔ Needs a major effort for a DA

Analogic Memory
Sampled Signal *(1-150MHz)*

32 000 Channels



MASTER
PATTERN
TRIGGER



FAST
L.E. Disc

Register

Trigger Time

Pattern

SLOW
A-MEMORY

Conversion
To Numerics

Useful
Data

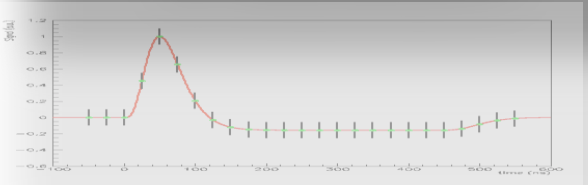


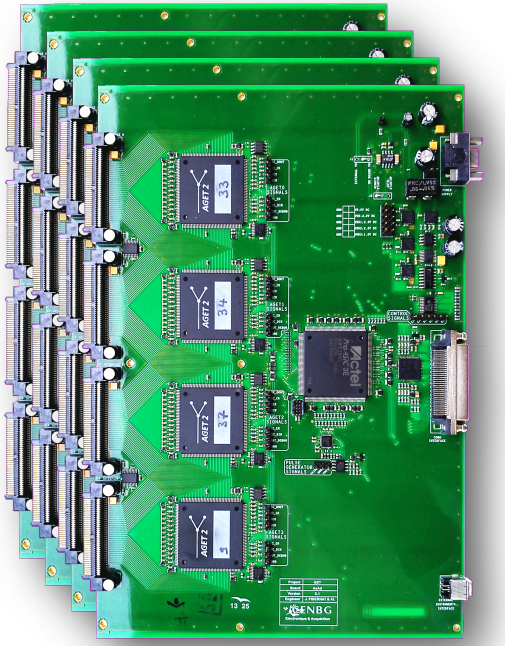
Table of projects

Instrument	N° Ch	Hosting lab.	Funding Agency
SπIRIT,	10k	NSCL, Riken, … , Jp	DOE, RIKEN, …
ACTAR TPC	16k	GANIL, IRFU, IPNO…, Fr	ERC, GANIL, IN2P3,
LAMPS	2.5 -> 20k	IBS Korea, Korea	IBS
AT-TPC	10k	NSCL, …, US	NSF
N_TOF	2.5k	CERN, IRFU, …	IRFU
CNS-AT	2.5k	Univ. Tokyo, Jp	CNS
E-15	6k	J-PARC, … ,Jp	J-PARC
ELI-TPC	1k	Univ. Warsaw, Pl	ELI-NP
FARCOS	5k	INFN-Catania, It	INFN-Catania
TexAT-P	2 - >32k	Texas A&M, US	Texas A&M
ND-TPC	1k	Univ. ND, US	Univ. ND
Shanghai-TPC	1k	CAS, Cn	CAS
NEXT	1 - > 5k	Univ. of Zaragosa, Es	Univ. of Zaragosa
Lanzhou-TPC	2k	IMP, Cn	IMP
S^3	4k	SPIRAL2, Fr	GANIL, IRFU
SpecMAT	2.5k	KU Leuven	ERC
Focal-Plane	256	Orsay, IN2P3, Fr	IN2P3
eTPC	1k	Univ. Warsaw	ELI-NP
SSD	2k	IFNF-Catania, It	INFN-Catania
MINOS	6k	IRFU	ERC

Lots of Thrust
Lots of Responsability

80k Channels Total
20 experiments
4ch to 20k ch

Hardware



AGET + AsAd

1Gb

X4

CoBo

MuTaN

27 Gb

X30

X 3

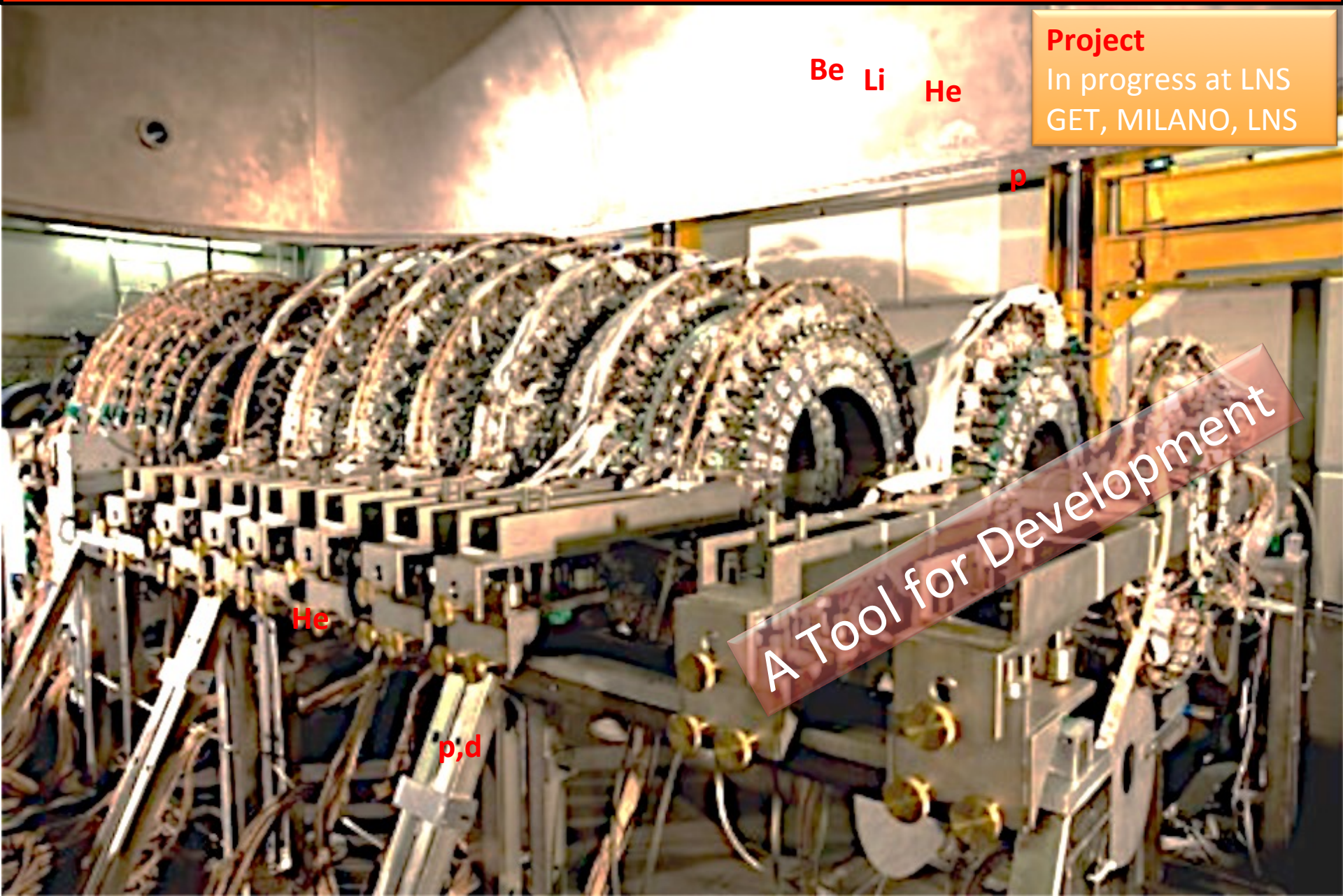
µTCA

30k Channels

27 Gb

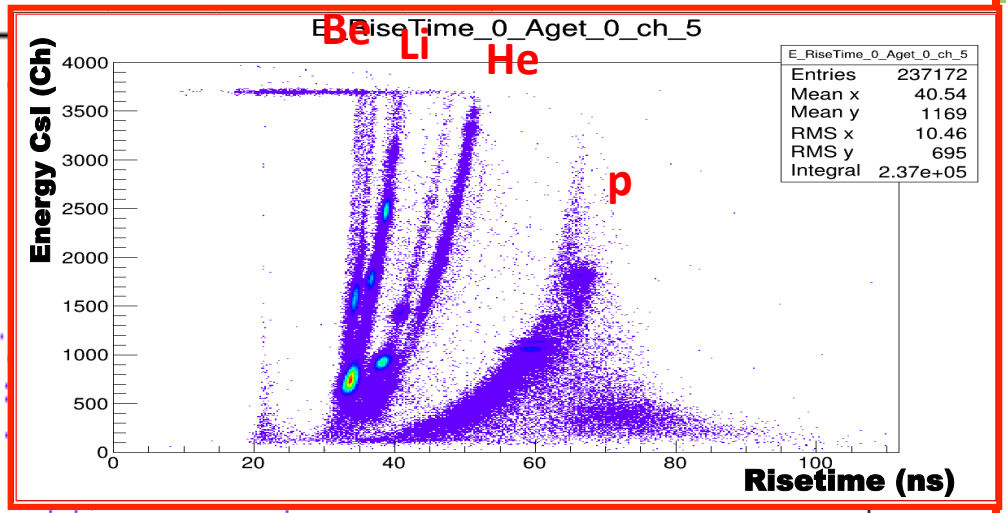
FARM CPU
Disc

INFN – Catania: CHIMERA GROUP - EoS



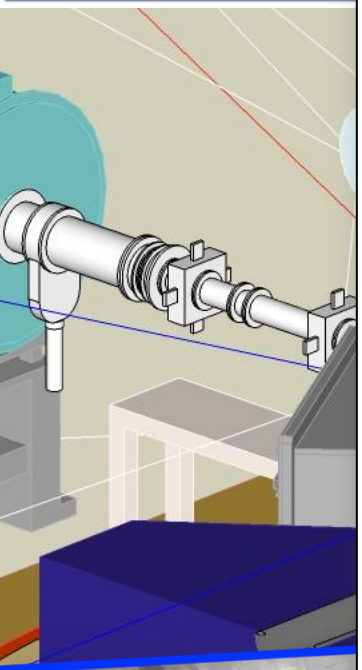
Project
In progress at LNS
GET, MILANO, LNS

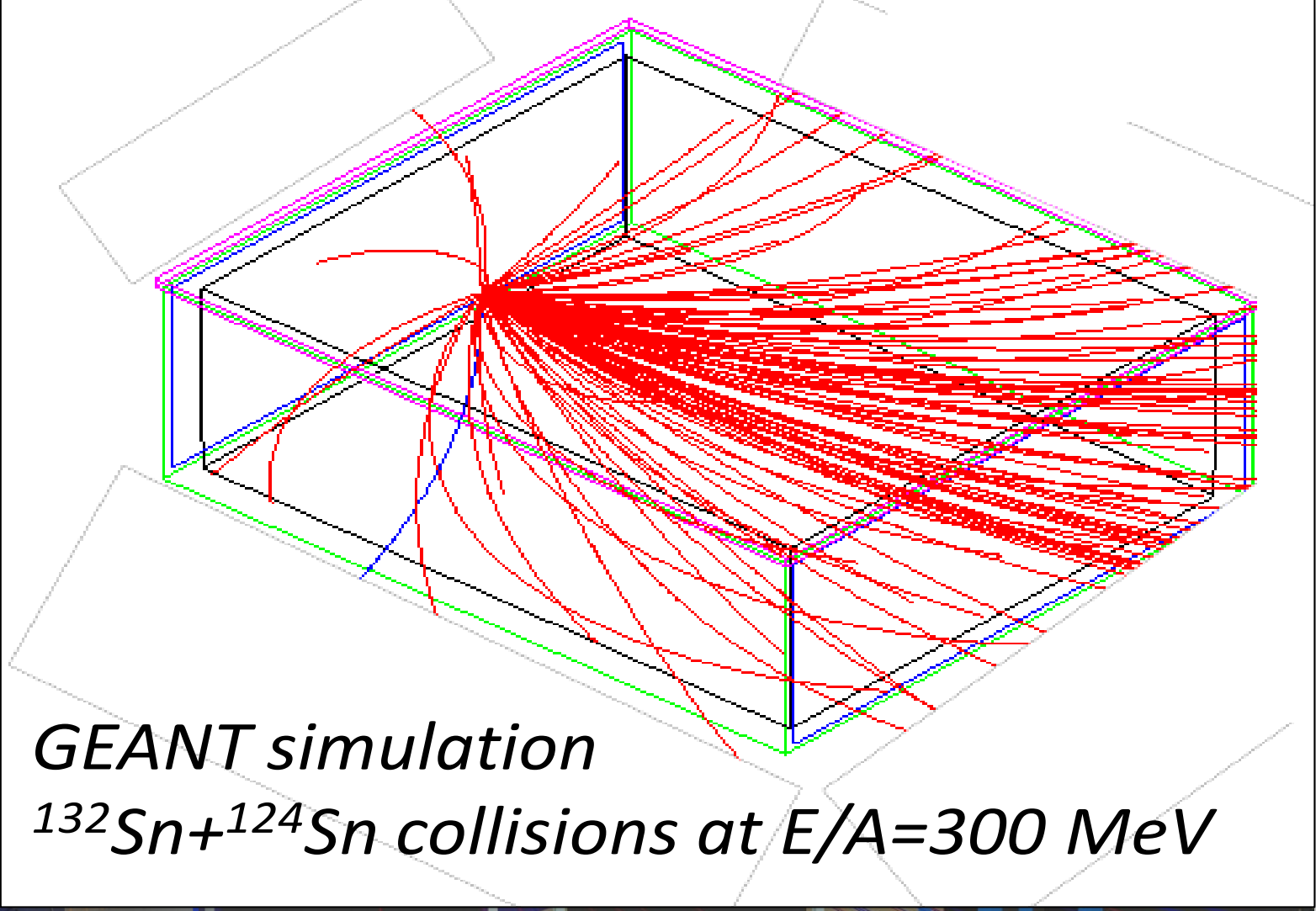
DEEGASP


E_RiseTime_0_Aget_0_ch_5
Be
Li
He
p
Energy CsI (Ch)
Risetime (ns)
E_RiseTime_0_Aget_0_ch_5
Entries 237172
Mean x 40.54
Mean y 1169
RMS x 10.46
RMS y 695
Integral 2.37e+05

Energy Si (Ch)
He
p,d
Energy CsI (Ch)

SπRIT





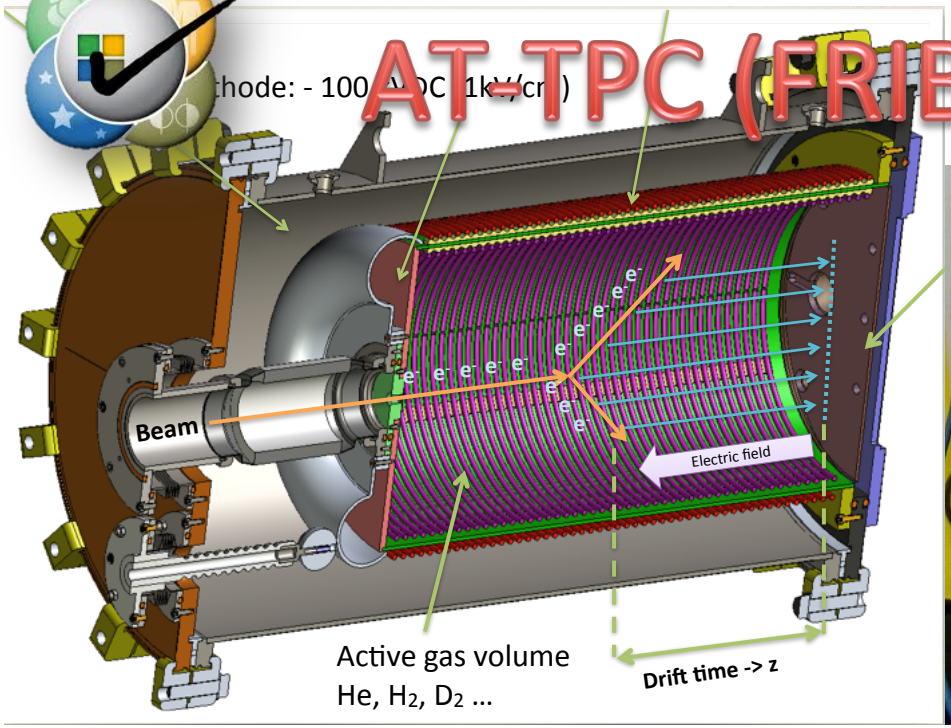
GEANT simulation

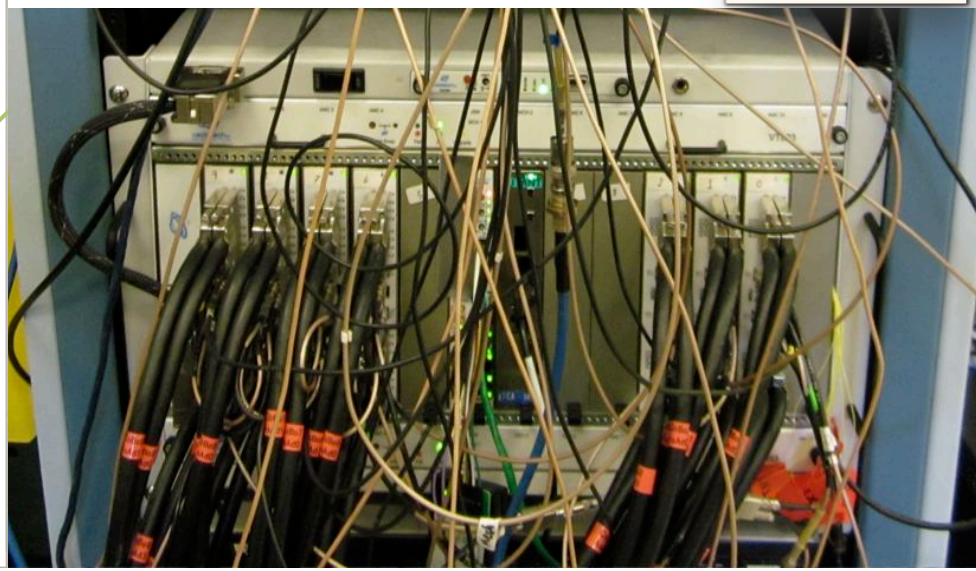
^{132}Sn+^{124}Sn collisions at E/A=300 MeV

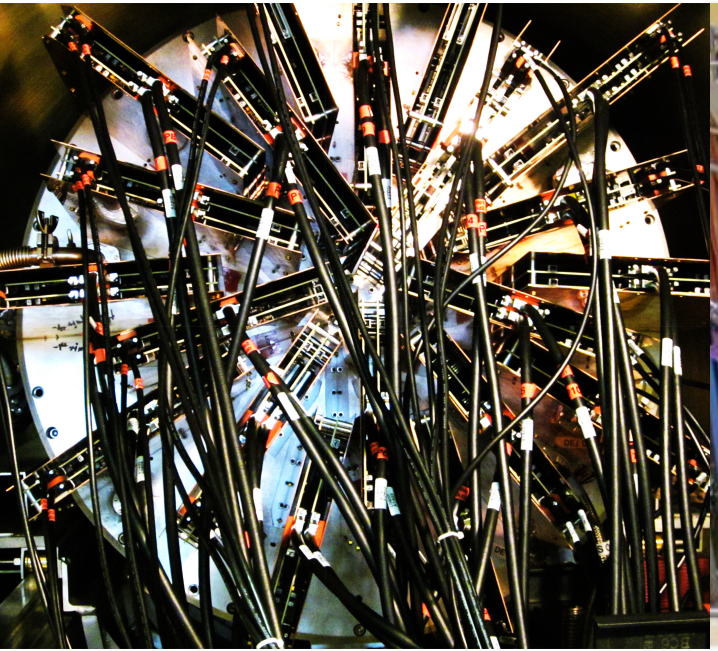
Measure differential flow and yield ratios for (π^+ & π^-), (p & n), (^{3}H & ^{3}He) in Heavy RI Collisions at E/A=300MeV

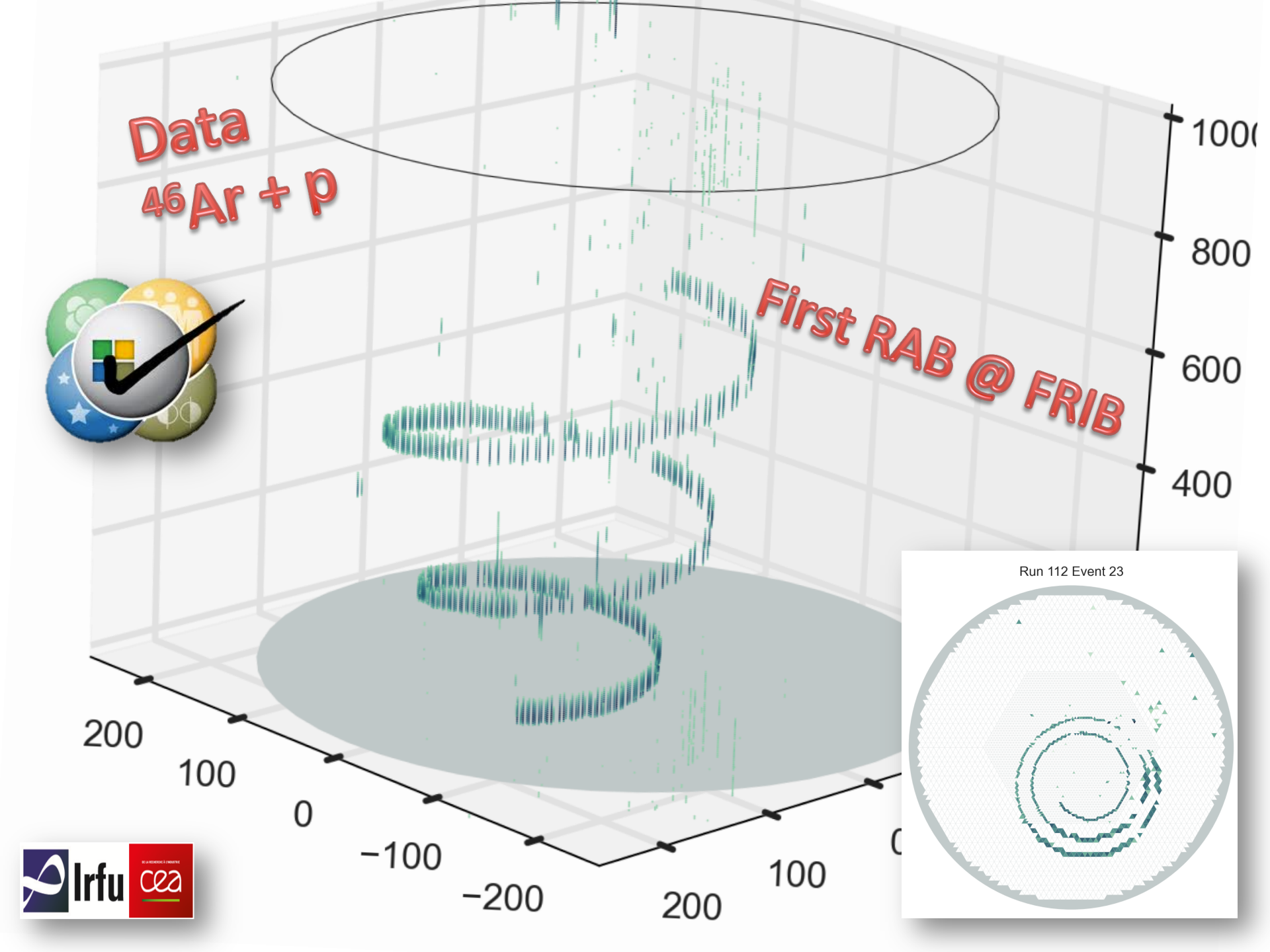

GET
12,288 Channels
of GET electronics
Pad Plane

AT-TPC (FRIB) – 10kChannels





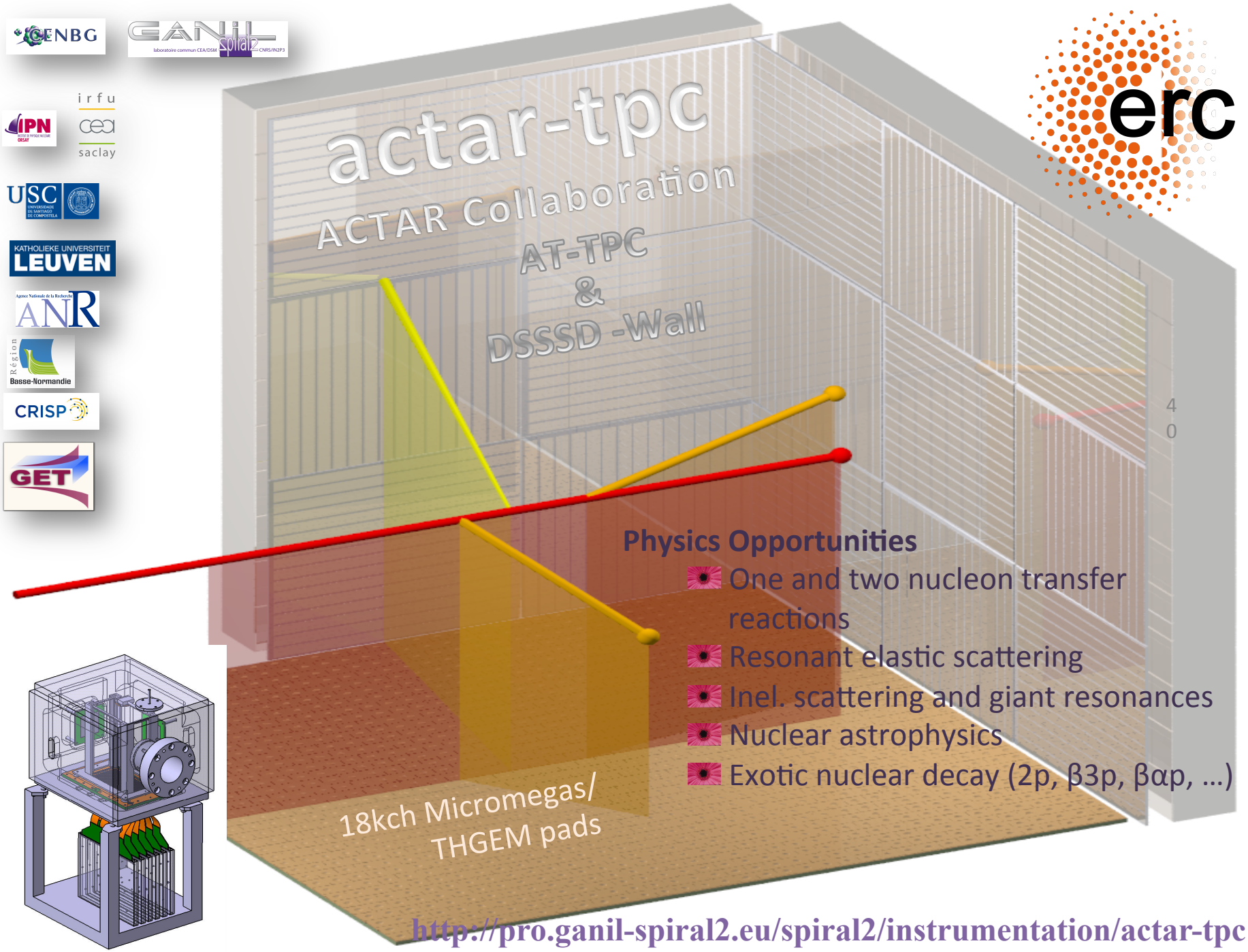



Data
46Ar + p
First RAB @ FRIB
1000
800
600
400
200
100
0
−100
−200
200
100
Run 112 Event 23
Irfu
cea

actar-tpc

ACTAR Collaboration

AT-TPC
&
DSSSD -Wall



Physics Opportunities

- One and two nucleon transfer reactions
- Resonant elastic scattering
- Inel. scattering and giant resonances
- Nuclear astrophysics
- Exotic nuclear decay (2p, β3p, βαp, …)

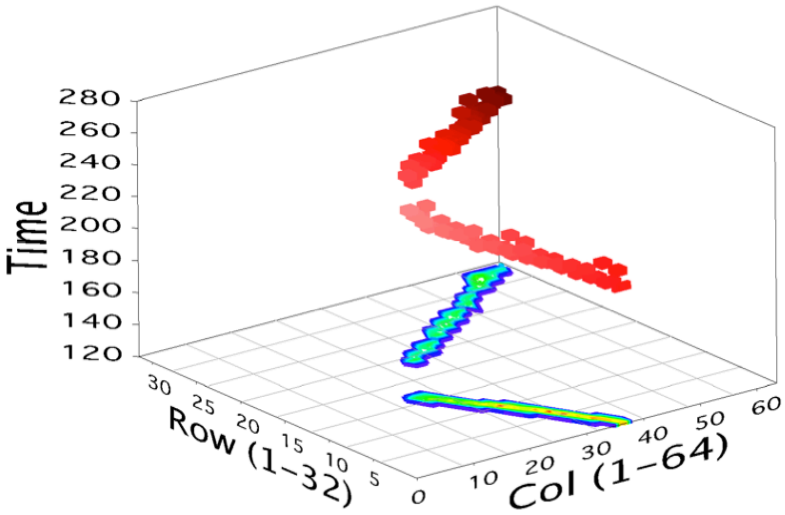
18kch Micromegas/
THGEM pads

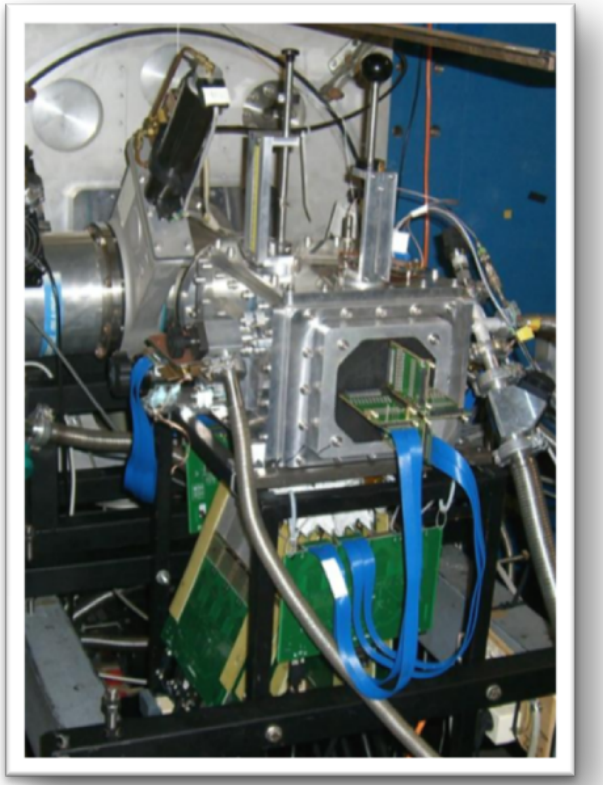
http://pro.ganil-spiral2.eu/spiral2/instrumentation/actar-tpc

ACTAR-TPC

laboratoire commun CEA/DSM GANIL spiral2 CNRS/IN2P3

IPN Orsay

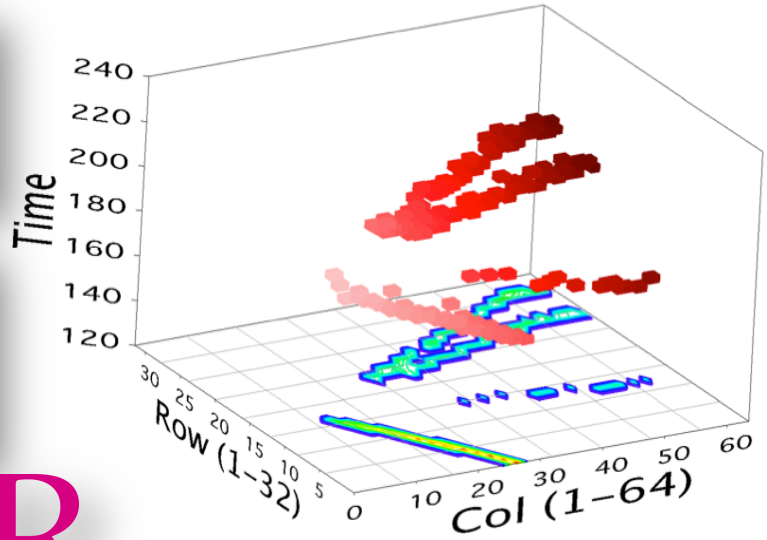




GET

erc

AGENCE NATIONALE DE LA RECHERCHE ANR



ACTAR-TPC_Proto

2k Channels (2015)

ACTAR-TPC

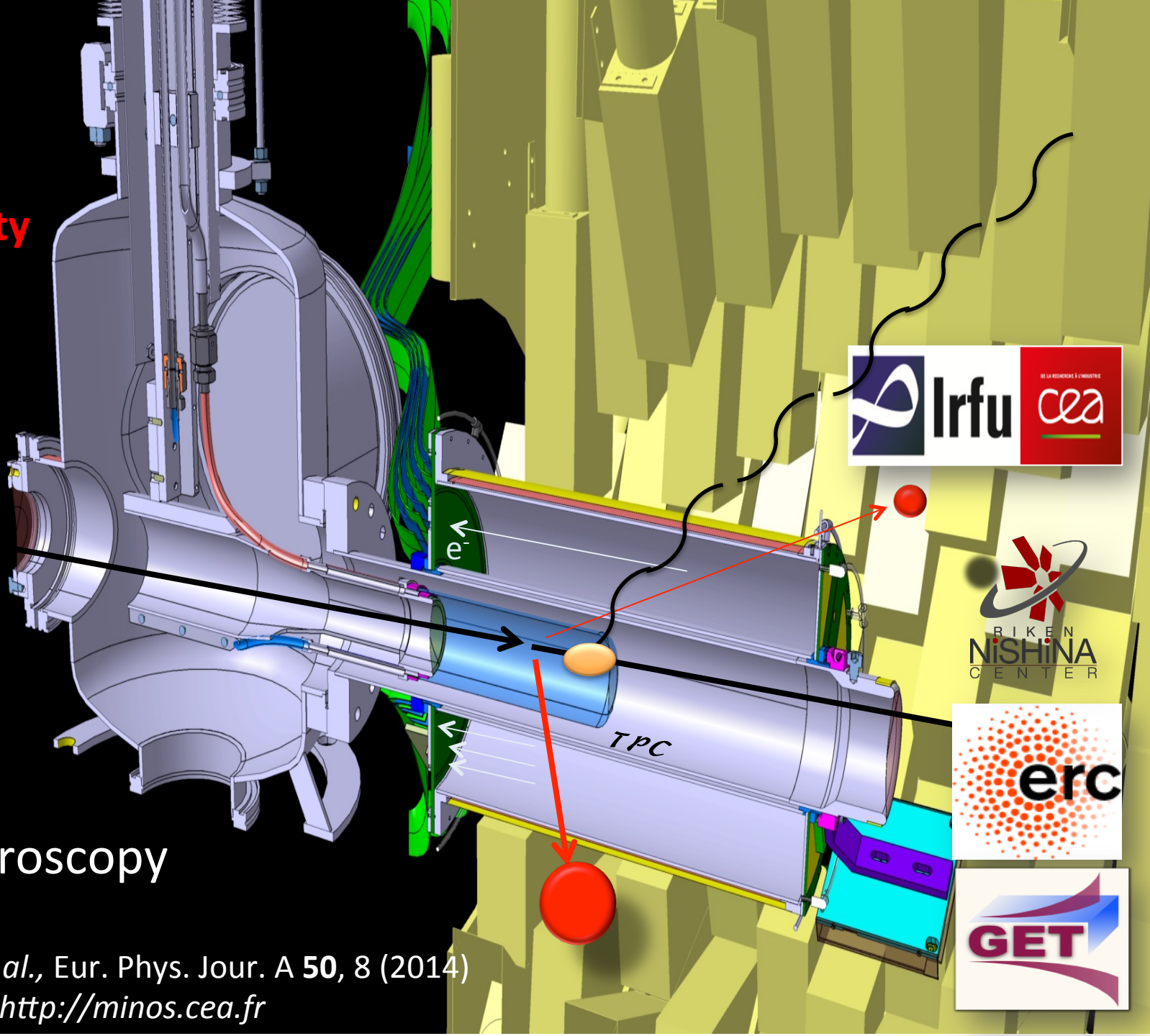
18k Channels (2016)

GANIL & ISOLDE & SPES

MINOS : Magic Numbers Off Stability

In-beam knockout experiments

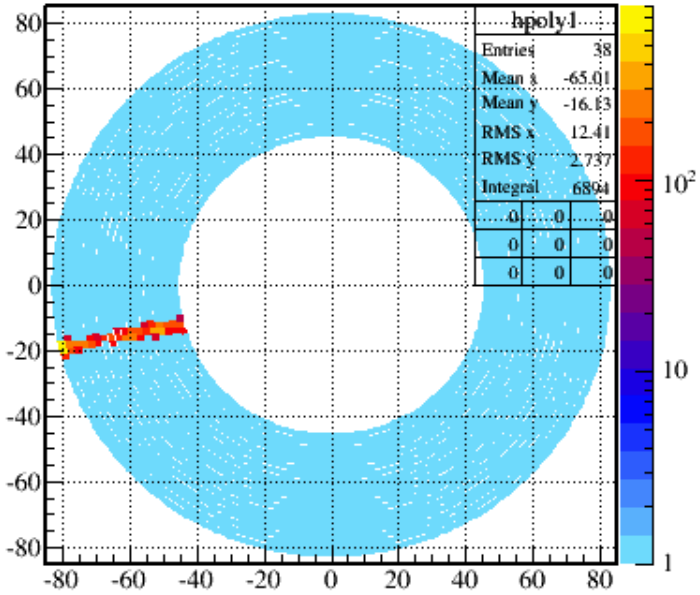
(p,2pγ)
(p,pnγ)
(p,αγ)
…
γ – spectroscopy



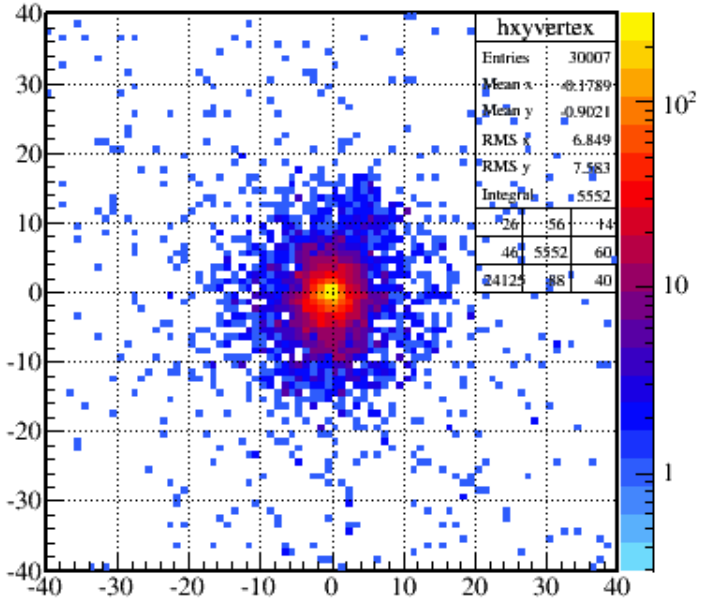
A. Obertelli *et al.*, Eur. Phys. Jour. A **50**, 8 (2014)
http://minos.cea.fr

MINOS: T

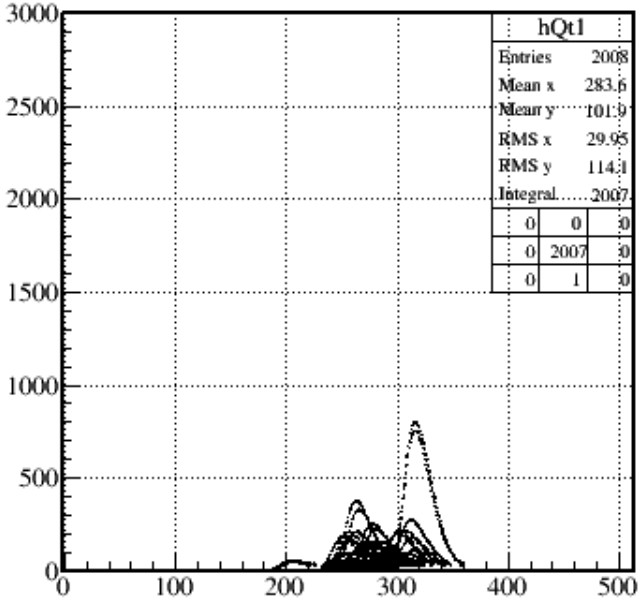
XY view - 1 event



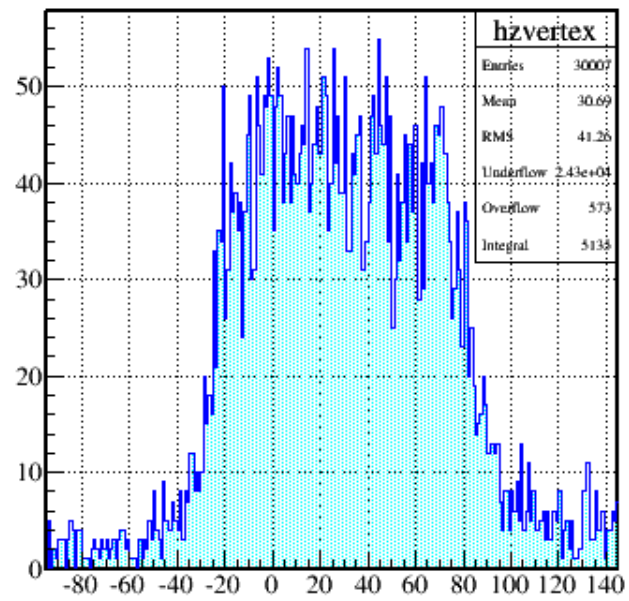
Vertex reconstruction xy



Q(t) signal - 1 event



Vertex reconstruction along beam



DAQ–

RAON

RISP Rare Isotope Science Project

ibs 기초과학연구원 Institute for Basic Science

GET