«Search of E1 strenght around threshold in ^{70}Ni»

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INFN sez. Milano, RIKEN-RIBF, Kyoto Uni., Tokyo IT, et al.

Goal:
Search and Measurement of E1 strength around threshold in 70Ni

Why?:
The Distribution of E1 strenght function is an important nuclear structure information, directly correlated to neutron skin and EOS.

In nuclear astrophysics E1 strength around threshold influences significant the r-process.

It is better known (also with a lot of open problems) in stable nuclei
but practically not in neutron rich nuclei.

PDR states in nuclei

What We know

- Pygmy Dipole States are strongly correlated with the size of the neutron skin (or proton skin)
- Pygmy Dipole Resonance (PDR) is a «collective» excitation of the least bound neutrons (or protons
- PDR is mostly of Electric Dipole (E1) character
- PDR is relevant for astrophysical r-process

What we want to know:

-Level of collectivity ?
-How (collective) properties change with neutron number ?
-How isospin changes mean field ?
-In exotic nuclei: does PDR strength exist also below neutron threshold and to which extend ?
-No High resolution/statistics measurements available
-Present in all nuclei and mass regions ?
-Effect of deformation ?
-Proton Pygmy, still to proof ?
-"Picture" of PDR, toroidal mode
-from pygmy strength deduce dipole polarizability over more nuclei
-Isovector and Isoscalar mode

PDR is measured in stable nuclei
With different probes (in different Labs):
-real photons
(scattering γ,γ, dissociation γ,γ γ,n γ,p)
-p,α,^{17}O,…

LNL, OSAKA, KVI…

ISOSCALAR part of Pygmy
(n & p behave similar)

(p,p'); (α, α'); (^{17}O, ^{17}O') …
(p,p',γ); (α, α',γ); (^{17}O, ^{17}O',γ) …

But in unstable nuclei relevant for the r-process ?

«Search of E1 strenght around threshold in ^{70}Ni»

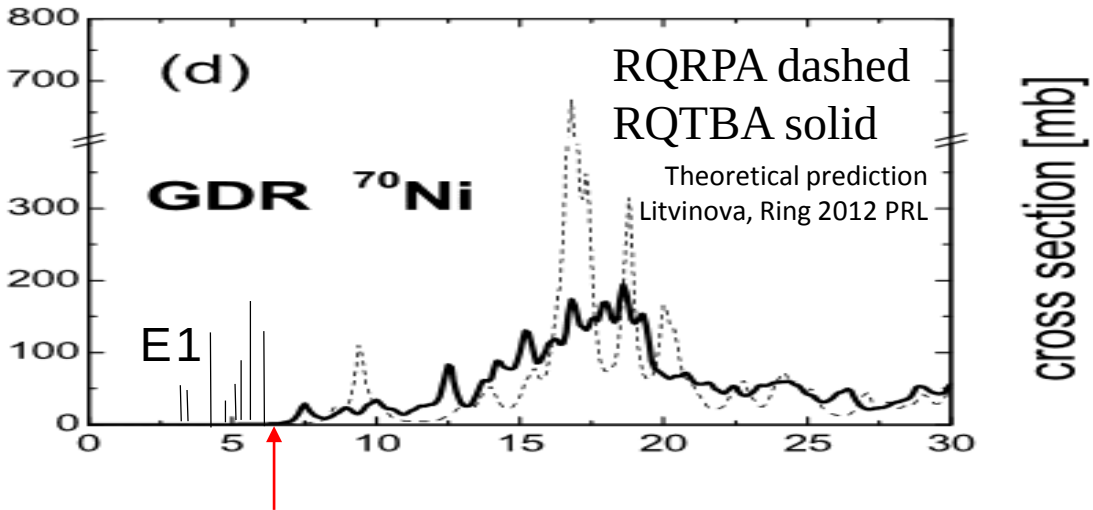
Experimental Method @ RIBF:
Relativistic Virtual Photon Scattering under coulomb excitation conditions

Using a fast (260AMeV) ^{70}Ni beam on thick 2g/cm^2 Au target,
we strongly excites E1 IV states,
E2 and other states are much less excited, nuclear contributions are strongly supressed

Alternatives for exotic nuclei (in part):

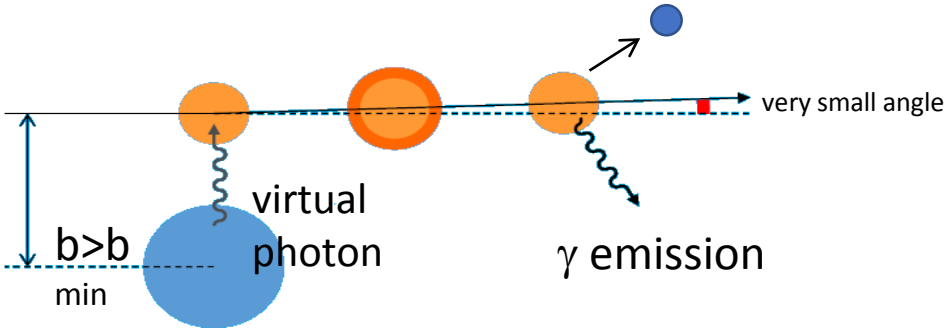
- C. break-up/missing mass (R3B, Samurai) Talk of *K*. Boretzky
- Oslo/MSU beta method

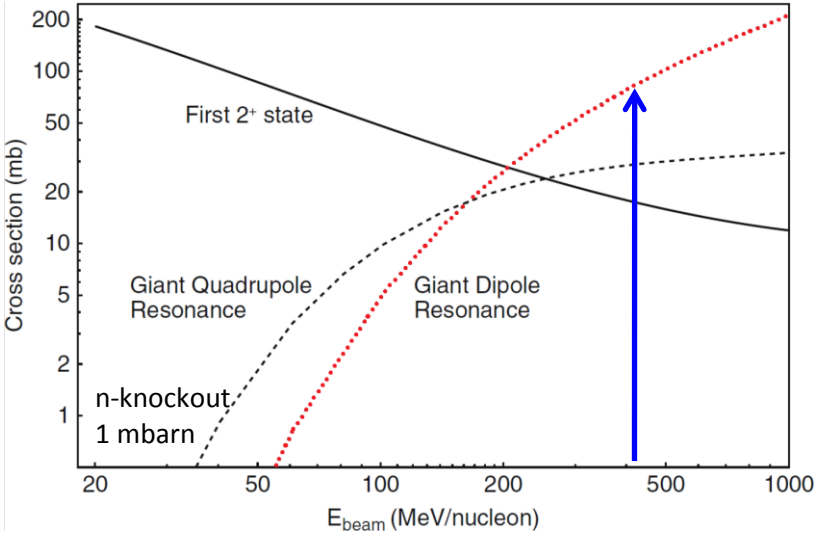
Theoretical
Predictions in exotic nuclei ….. In ^{70}Ni



Relativistic **Virtual photon scattering** for PDR search in n-rich nuclei

high selectivity for dipole E1 excitation

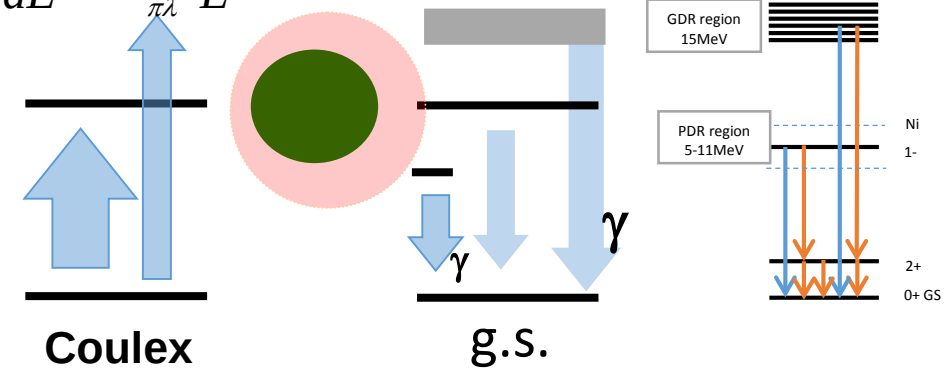




Virtual photon excitation

and decay of **GDR + PYGMY + E1 states**

$$\frac{d\sigma_C}{dE^*} = \sum_{\pi\lambda} \frac{1}{E^*} N_\gamma^{\pi\lambda}(E^*) \cdot \sigma_\gamma^{\pi\lambda}(E^*)$$



<u>To excite</u> Dipole states one needs:

- High beam energy
  - **Large cross sections**
  - Large $\sigma_{GDR}/\sigma_{GQR}$ **ratio**

<u>To Select</u> projectile PDR one needs:

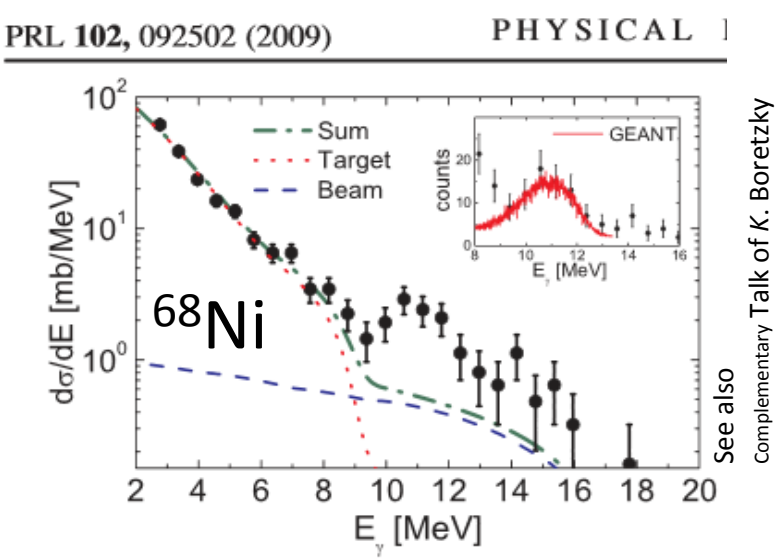
- High beam energy
  - Large **Doppler** effects
    → <u>Background REDUCTION</u>
  - Good Z_{proj}/Z_{target} ratio

VPS-Coulex experiments

Euroball+BaF_2

GSI

400 MeV/u ^{68}Ni + ^{197}Au (May 2004)
600 MeV/u ^{68}Ni + ^{197}Au (April 2005)



See also Complementary Talk of *K.* Boretzky

AGATA*+$LaBr_3$:Ce

GSI

400 MeV/u ^{64}Fe + ^{208}Pb (October 2012)
430 MeV/u ^{62,64}Fe + ^{197}Au (April 2014)

Talk of R. Avigo

* With half of HPGe material as EB and 5 times less intense beam

DALI2+$LaBr_3$:Ce

RIKEN

280 MeV/u ^{70}Ni + ^{197}Au (October 2014)
280 MeV/u ^{72}Ni + ^{197}Au (future)
...

This presentation

VPS-Coulex experiments give important (complementary) informations on existence, position, shape and strenght of PDR

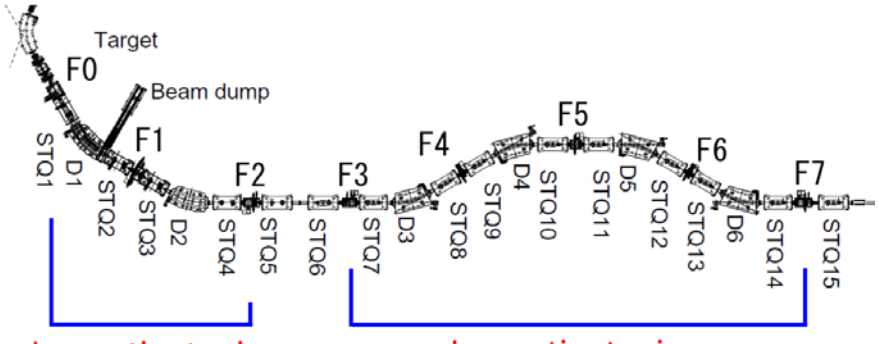
HECTOR+ & DALI2 @ RIKEN (Tokyo)

CAMPAIN of 3* experiments in 2014

- Inelastic alpha scattering on $^{128/132}$Sn (T. Aumann,…)
- Inelastic alpha scattering + coulomb excitation on $^{20/22/24}$O (H. Baba, N. Nakatsuka,…) POSTER
- Coulomb excitation on ^{70}Ni (O. Wieland,…)

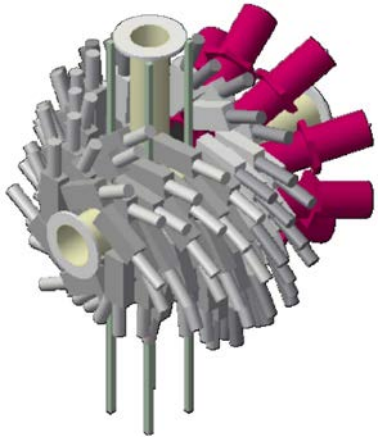
BigRips DALI2 setup (1)

RIBF setup in Riken laboratory allows to produce radioactive beams at relativistic energies and **select in flight (fragmentation)** the isotopes of interest (BigRips)



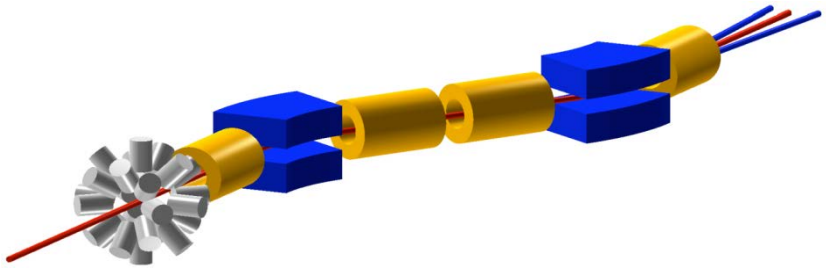
Ion-optics tuning → Good separation

Ion-optics tuning → Good PID($B\rho$) resolution
Good separation
(in two-stage separation mode)



DALI2 coupled with LaBr3:Ce scintillators provide a very large angular coverage and also efficiency at high energies

Zero degree Spectrometer allows to select reaction products outcoming from secondary target

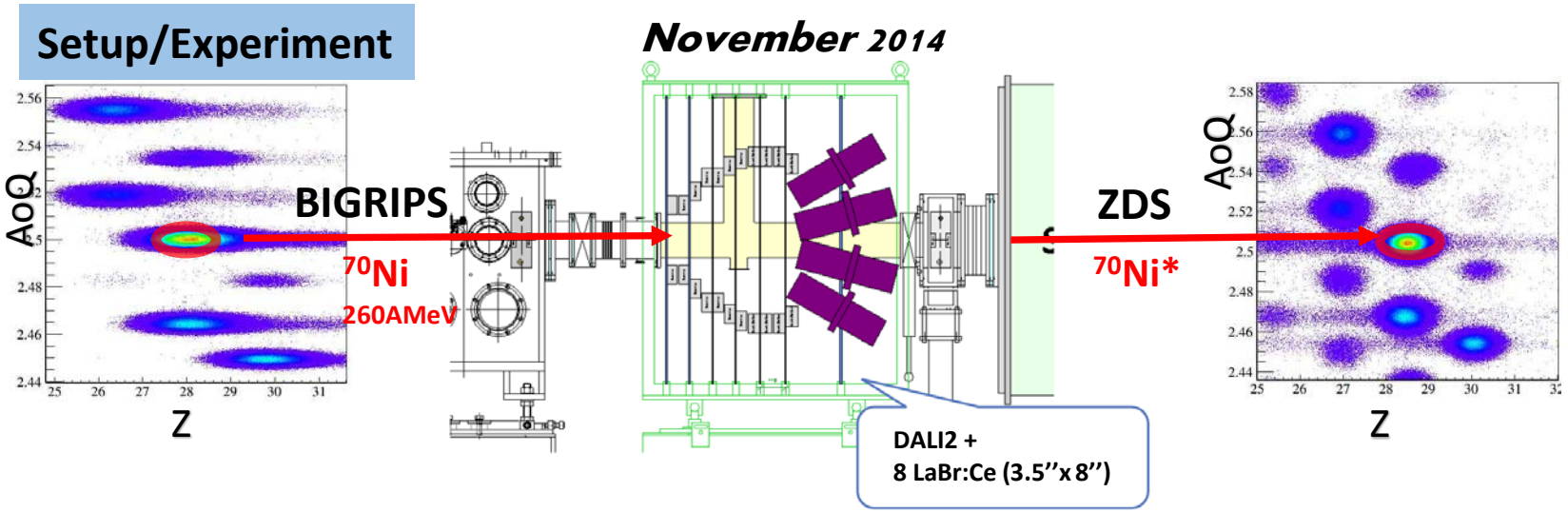


Experiment at RIKEN-RIBF
BIGRIPS Parameters: 238U Primary Beam -> 70Ni secondary Beam at 260AMeV
@F3 48 kcps SECONDARY BEAM PRODUCED
@F7 30 kcps SECONDARY BEAM SELECTED with 40% PURITY 70Ni
@F11 27 kcps AFTER TARGET AND REGISTERED IN ZERODEGREE SPECTROMETER
→ $1.3*10^9$ «good ^{70}Ni» events recorded in **34** hours measurement

^{70}Ni measurement @ Riken setup(2)

Primary Beam ^{238}U with 82GeV total kinetic energy

Experiment at Riken laboratory to measure PDR in **^{70}Ni** with NaI (DALI) and $LaBr_3$:Ce detectors



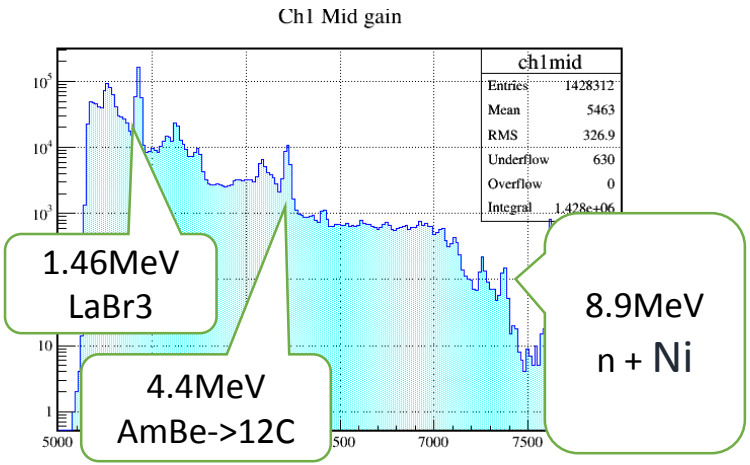
>25%(for E2) >5%(for E1)

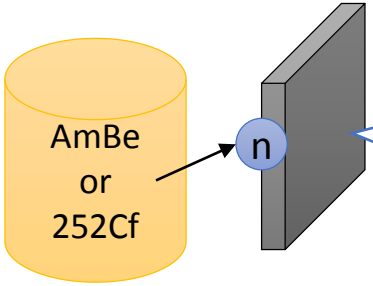
Gamma ray efficiency → select HE gamma ray GS decay

Energy Calibration for High Energy Gammas

H.Baba, Nakatsuka

- Cover up to 25MeV in C.M. = 40MeV in Lab. @30 deg

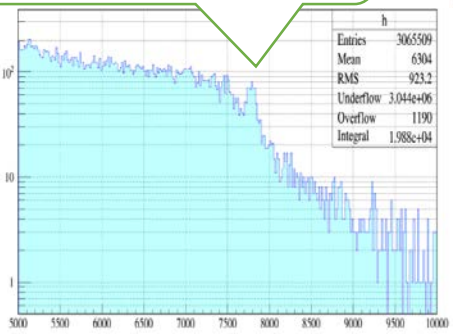


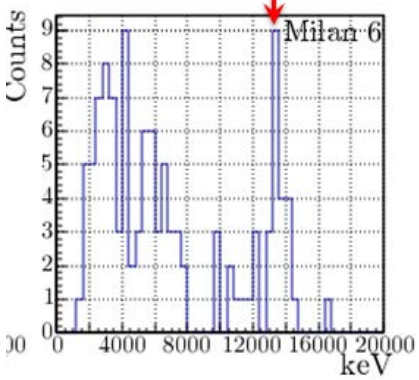


Neutron capture gamma
Ni = 8.9MeV
Al = 7.7 MeV

15.1MeV from 12C(p,p')
test experiment @ RCNP

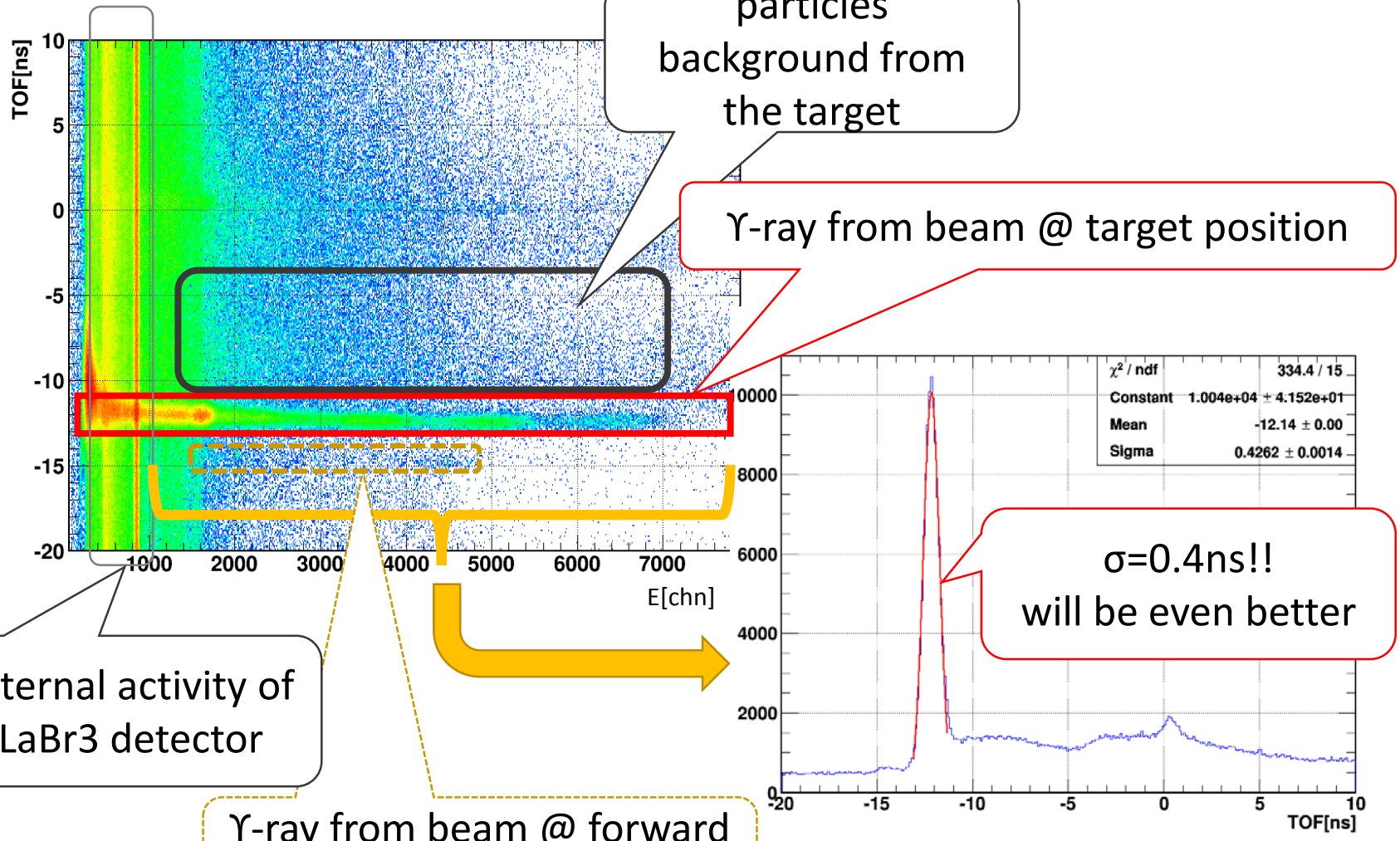
7.7MeV
n + Al (DALI Frame)





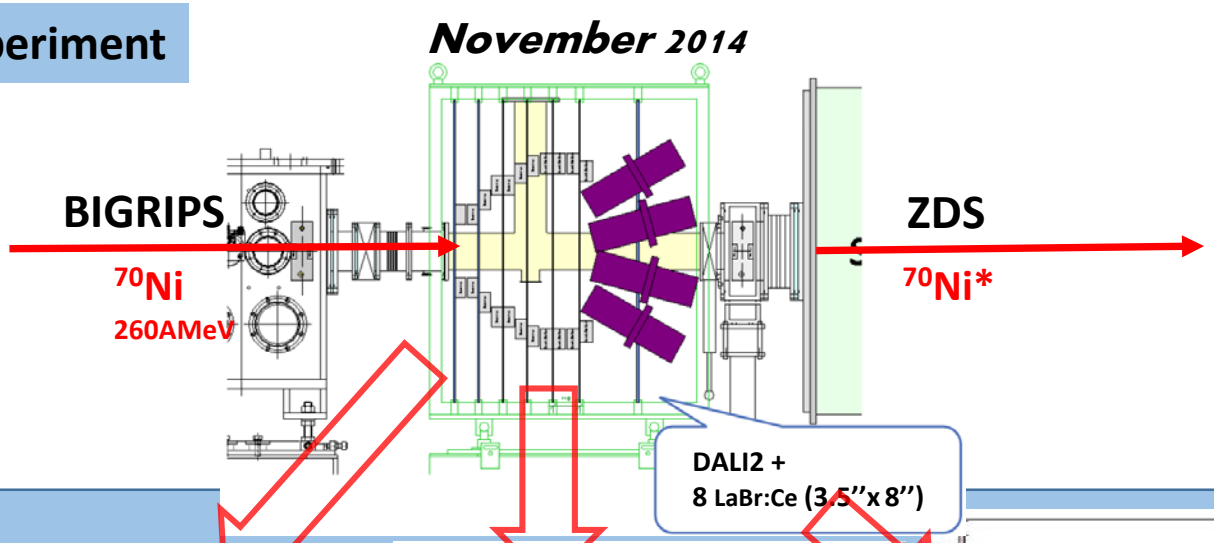
& A.Giaz NIM A729(2013)910
linearity efficiency up to 22MeV (p,γ)

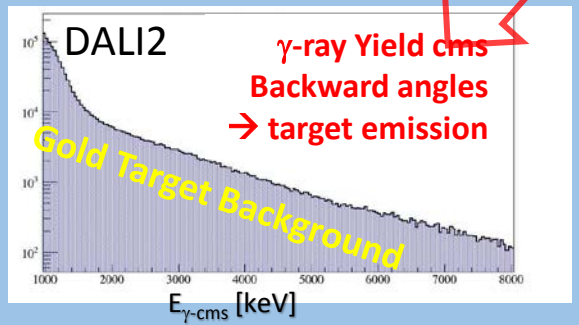
Background for $LaBr_3$:Ce / DALI2

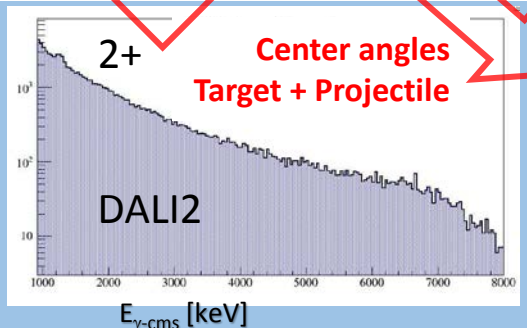


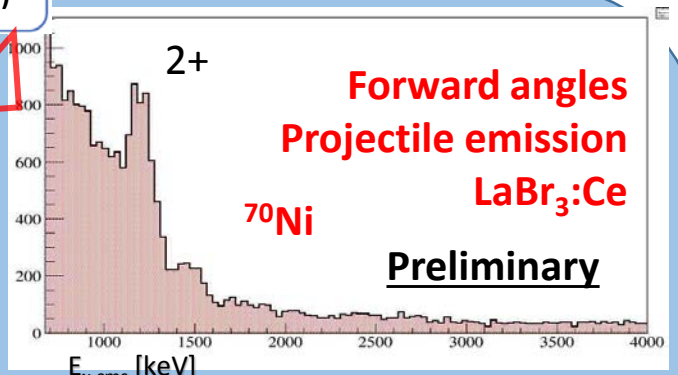
H.Baba, N. Nakatsuka

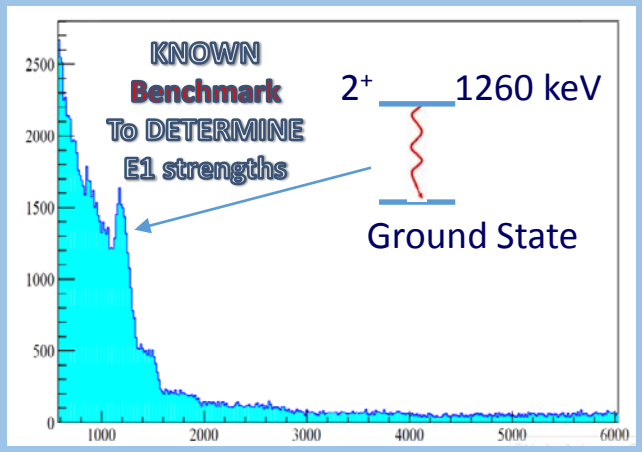
Setup/Experiment

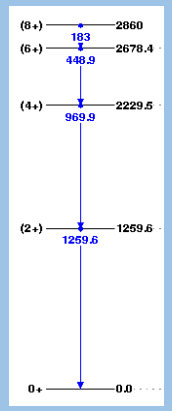


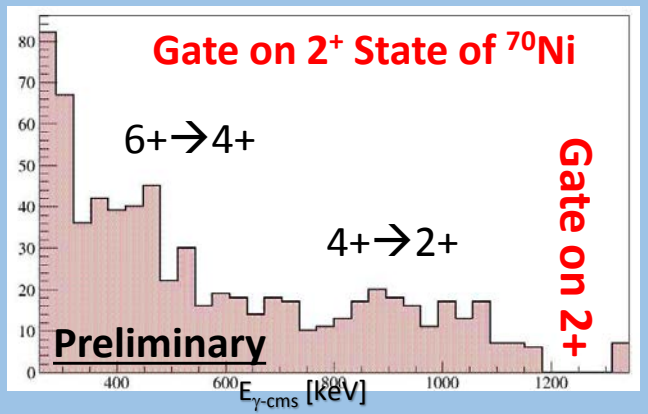




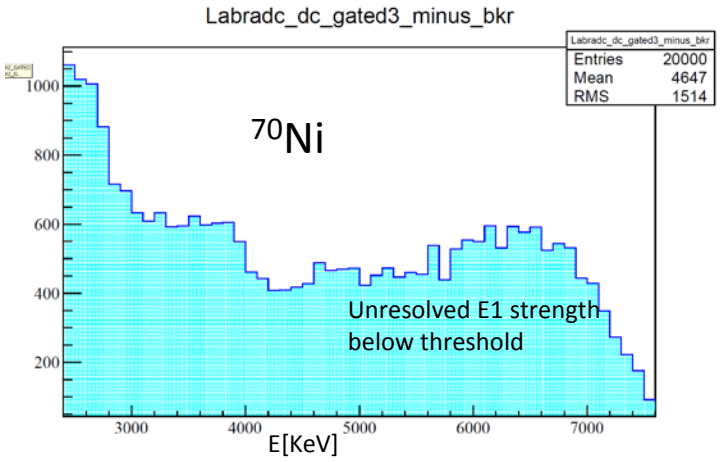


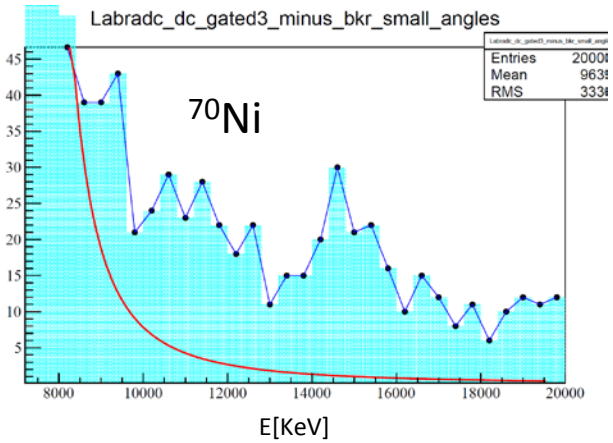


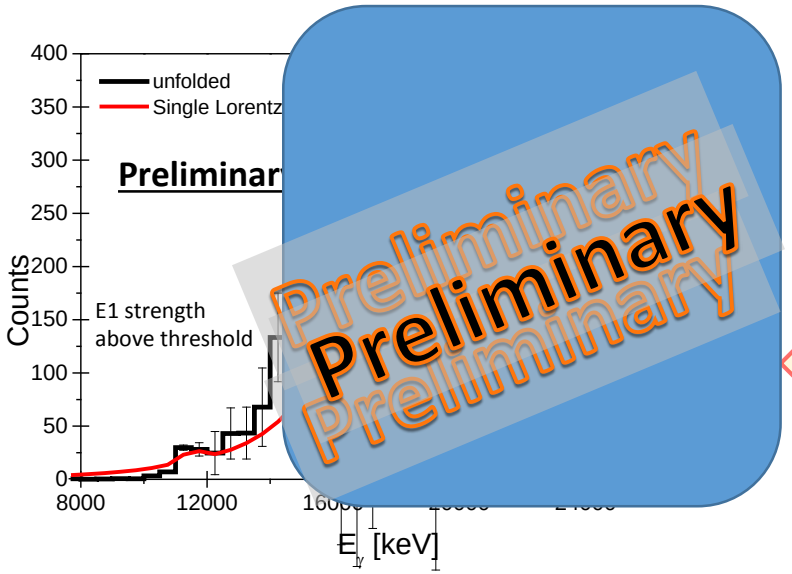




High Energy gamma ray spectra







To Do :
fix (low energy) **tail** of GDR,
target contribution and background
then **unfold** with responsefunction

Summary and Status

- We have measured the E1 strength in ^{70}Ni neutron-rich nuclei around threshold
  - We have used DALI2+ large volume $LaBr_3$:Ce on thick gold target with ^{70}Ni beam @ 260AMeV
- Analysis is ongoing
  - Analysis meeting Milano 2015 Sep.21-25
  - Analysis meeting Darmstadt 2015 Okt.
  - Analysis meeting at Tokyo 2016
- Next nucleus ^{72}Ni (DALI2+Hector+),

Thank you and
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et al. …