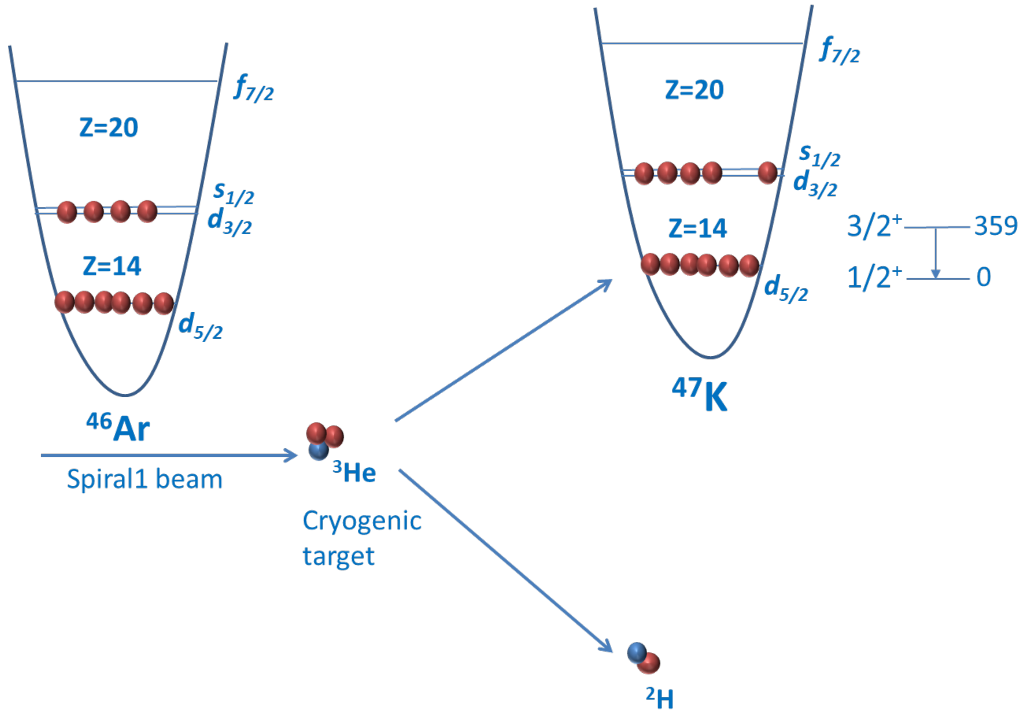
C T A D I R
Cryogenic TArgets for DIrect Reactions

AGATA-MUGAST-VAMOS Experiment

Andrea Gottardo

INFN-LNL, Italy

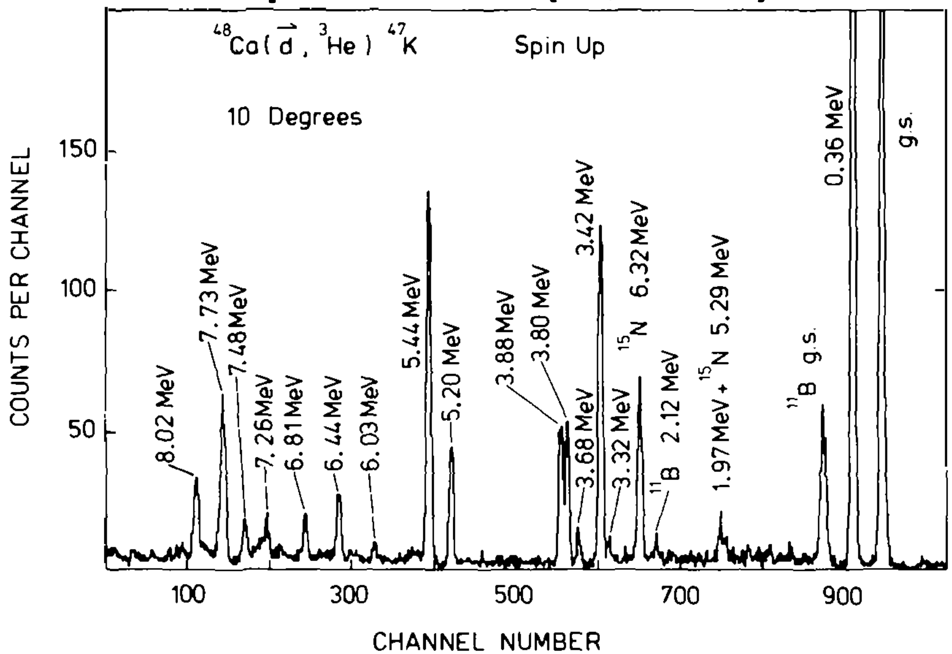
Direct reactions for nuclear structure

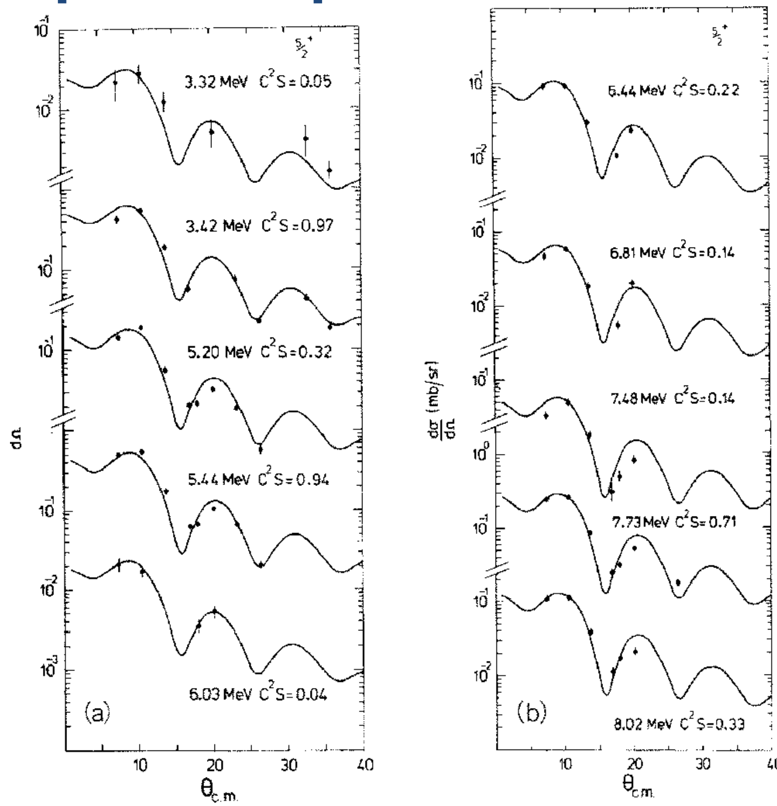


Direct reactions provide a unique access to the observables linked to single-particle structure

Direct reactions with stable targets: direct kinematics, split-pole spectrometer

Example: $^{48}Ca(d,^{3}He)^{47}K$



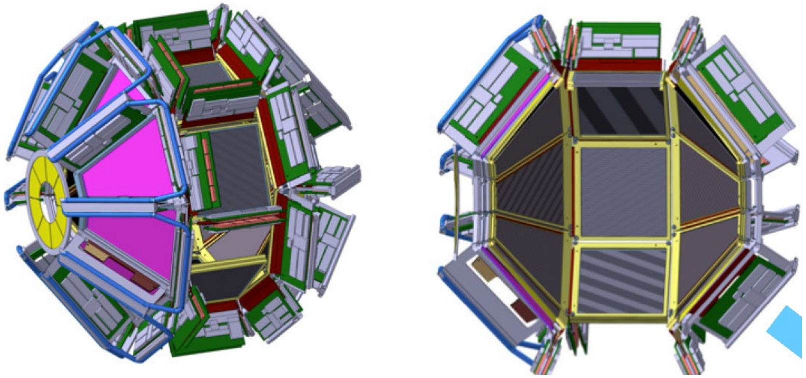


1. High-intensity light beams
2. Excellent energy resolution (few tens keV)
3. Large and precise angular coverage

Direct reactions with exotic beams: inverse kinematics, Si strip detectors

GRIT (GASPARD+TRACE) project

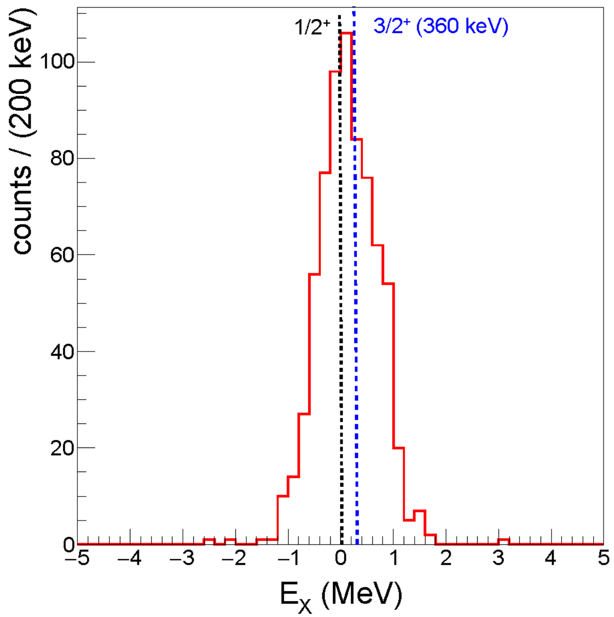
Need for 4π Si detectors: pickup reactions (d,p), (3He, d) typically at backward angles



1. Low-intensity light beams (down to 10^4-10^3 pps)
2. Mediocre energy resolution (few hundreds keV) for thick target, kinematic compression
3. Challanging light targets (gaseous !)

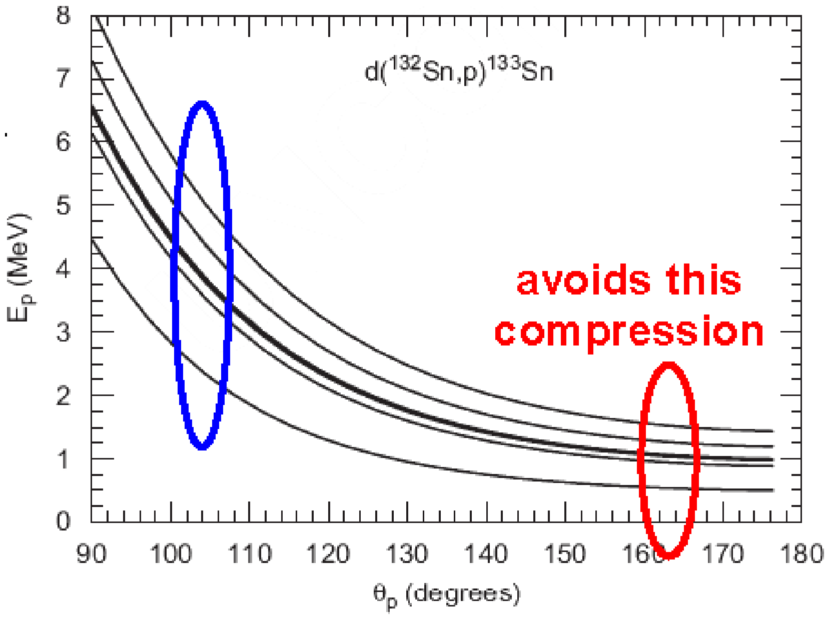
Inverse kinematics: energy resolution

$^{46}Ar(^{3}He,d)^{47}K$: 1 mg/cm^2, Havar windows

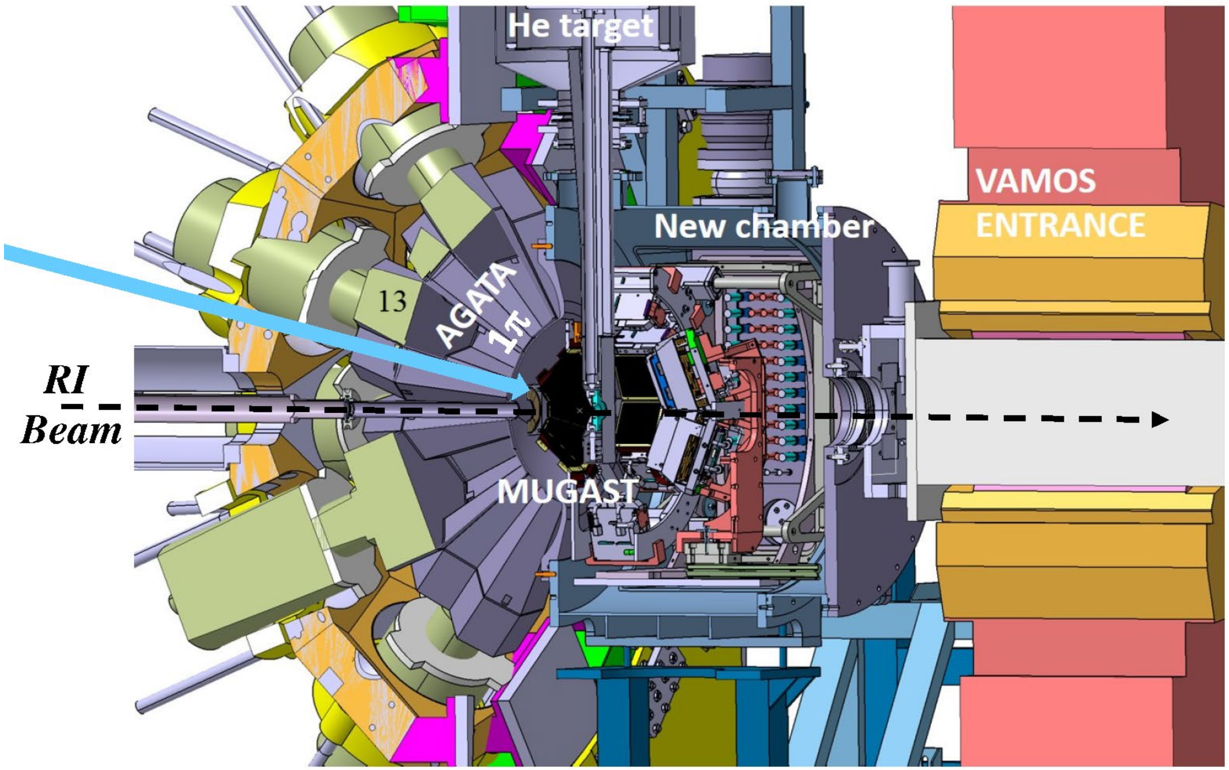


Need to have targets of several 100 µg/cm^2 at least, composite targets.... Difficult to separate states !

Kinematic compression at backward angles (solenoid)

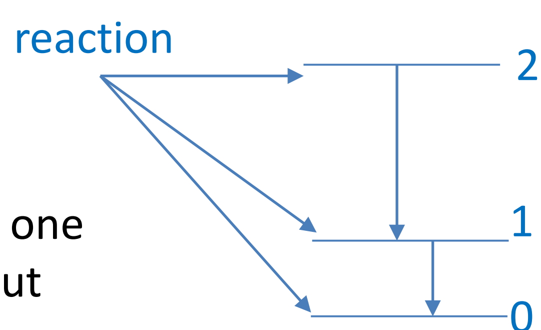


Inverse kinematics : γ-ray spectroscopy



Gating on gamma rays de-populating a level can provide selection of states otherwise impossible.

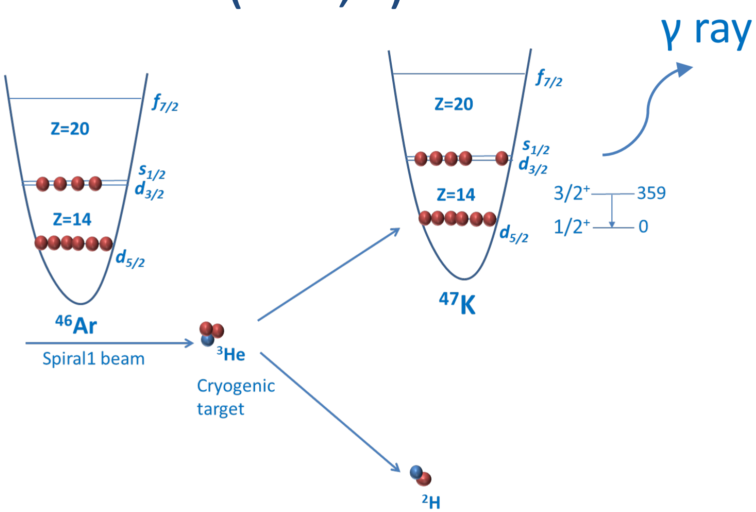
Triple coincidence: γ rays, heavy-ions, light particles



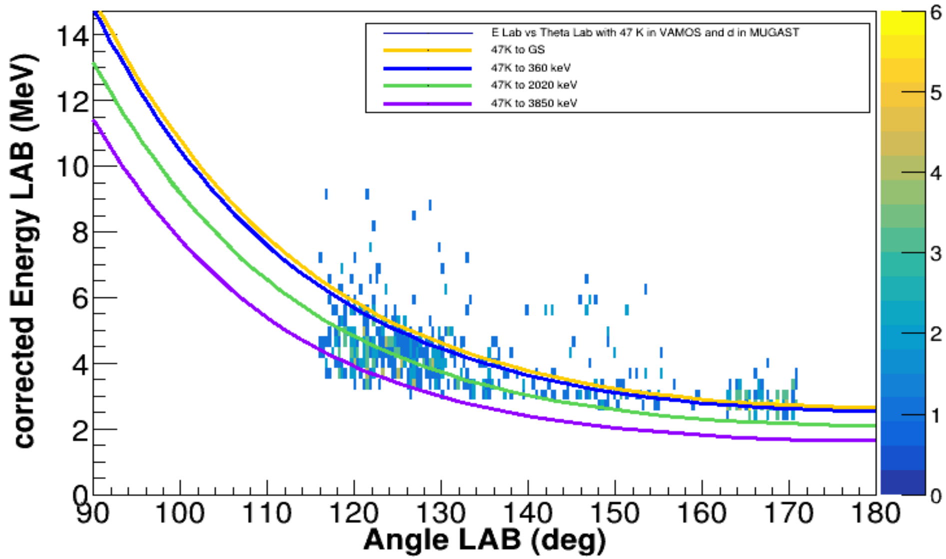
By gating on a γ ray one can select a level, but there are ambiguities

γ-ray spectroscopy: an example

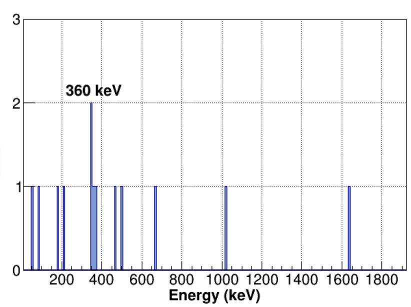
$^{46}Ar(^{3}He,d)^{47}K$

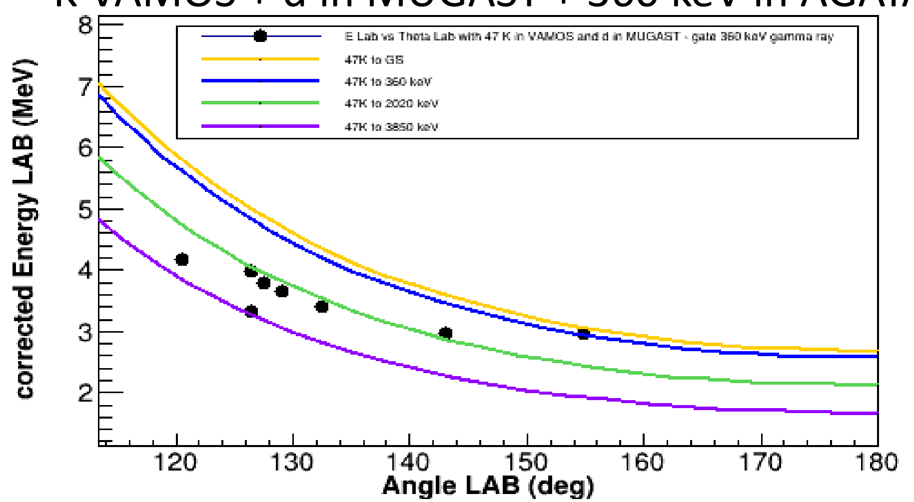


Kinematic plot: ^{47}K VAMOS + d in MUGAST



^{47}K VAMOS + d in MUGAST + 360 keV in AGATA

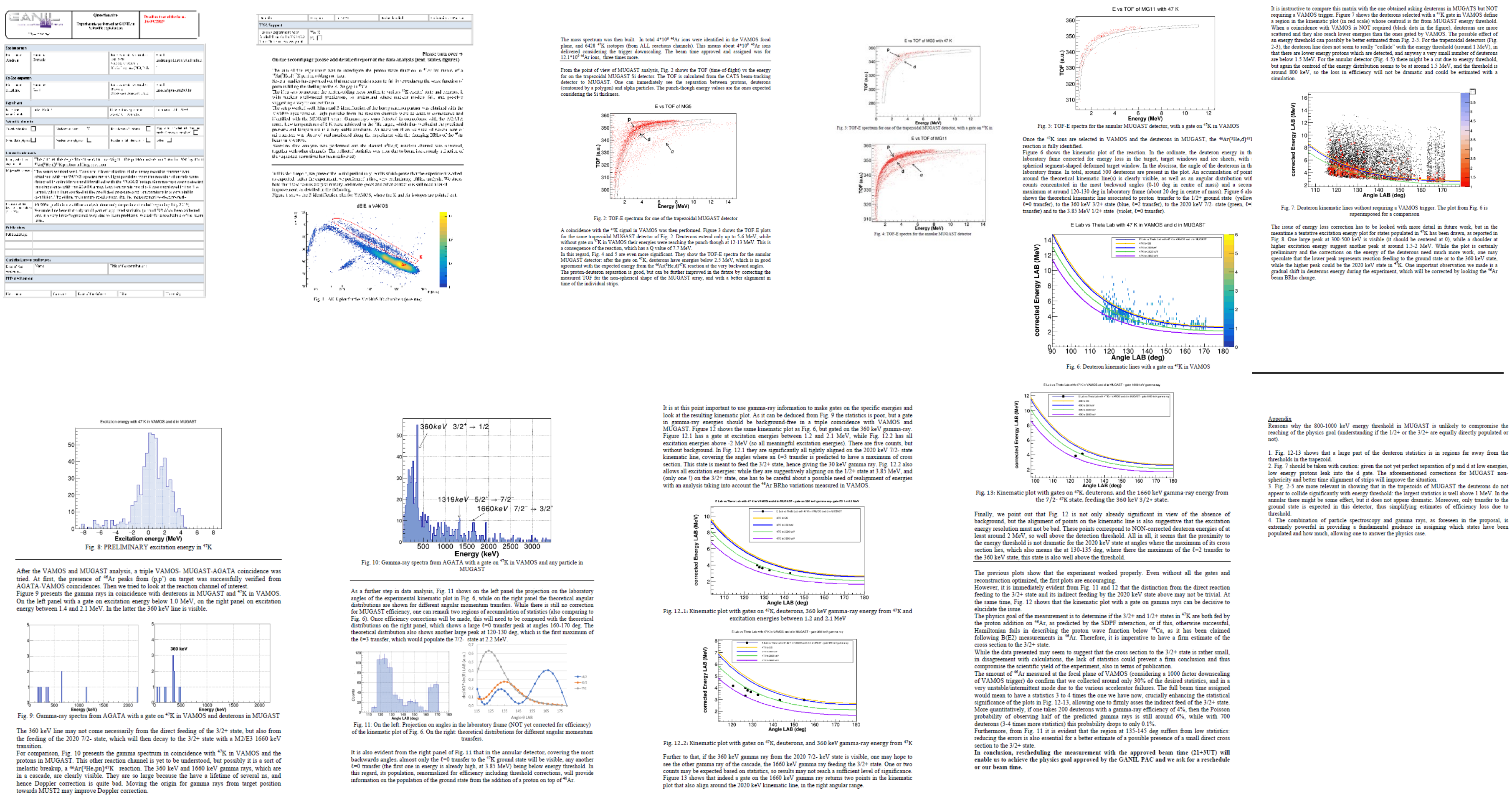




Triple coincidence: γ rays, heavy-ion product,

Digression (1)

On Monday, within the deadline, we sumbmitted an 11 page report asking a reschedule



Ongoing discussion with people from the collaboration on data quality/statistics needed to achieve objective

Digression (2)

GANIL official feedback/answer (yesterday):

Dear Andrea,
Thank you for the detailed report you sent. Unfortunately we will not be able to reschedule your experiment.

With my best regards,

Beam coordinator

Inverse kinematics : H and He cryogenic target density

	H semisolid	^{3}He cryogenic
Atoms/cm^2	$4 \cdot 10^{20}$	$4 \cdot 10^{20}$
mg/cm^2	0.7	2.1
Thickness (mm)	0.1	3

For reference: σ = 1mbarn, beam = 10^4 pps, ^{2}H target= 1mg/cm^2

260 reactions/day, 1800 reactions/week

Solutions for H, He targets

Gel-like targets: CHyMENE

Cryogenic target that extrudes a semi-solid state paste for ^{1}H and ^{2}H

- Thickness: several 10^{20} atoms/cm^2
- No windows needed
- Impossible for ^{3}H (radioprotection)

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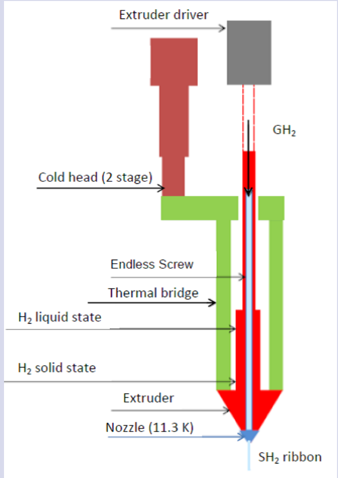
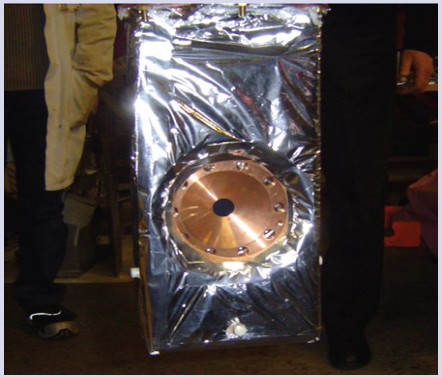


Cryogenic gas: $^{3,4}He$

Cryogenic target in the gas phase but at low temperature: high density gas for ^{3}He and ^{4}He

- Thickness: 1-2 mg/cm^2, several 10^{20} atoms/cm^2
- windows needed: secondary reactions, energy straggling
- ^{3}He very expensive



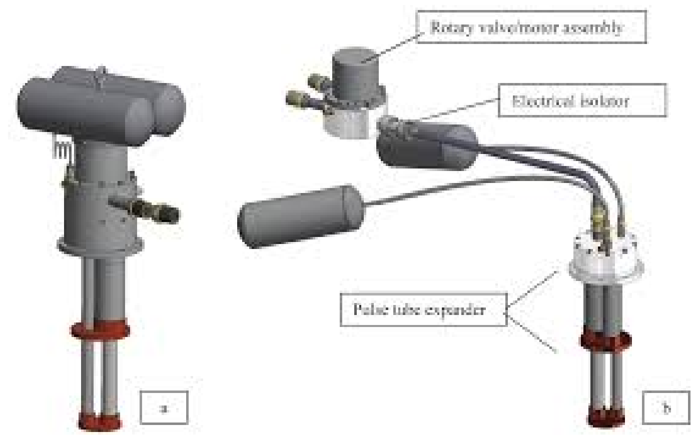
The CTADIR project (1)

Project structure

Project financed by MIUR with 750 k€ 2019-2022

- Three research units: INFN (LNL-CT), University of Milano, University of Padova
- At least four personnel units to be hired
- Two main axis:
  1. Integration with experimental setups at LNL of a CHyMENE-like windowless target
  2. Prototype of a cryogenic target for $^{3,4}He$ with windows
- Development of a direct reaction community linked to SPES beams, with devices like AGATA, GRIT, TRACE…

CTADIR

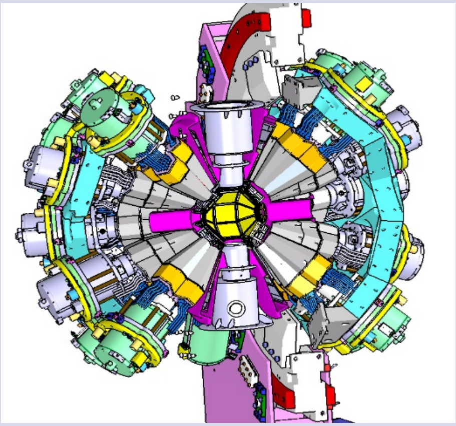


Pulse tube cryocooler for T=2K

The CTADIR project (2)

Main technical points to address

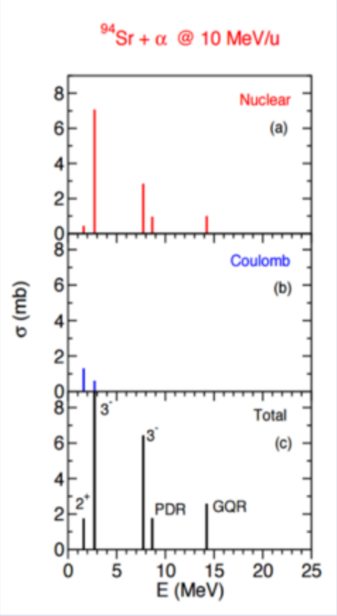
- Vacuum in reaction chamber with a windowless target (down to 10^{-3} mbarn): connection with beam line, Si detectors, coupling to PRISMA…
- Mechanical integration (pumps…)



- For He targets: window thickness as much as possible, ice accumulation on the windows

Physics aims

1. Direct reactions for s.p. nuclear structure (d,p), (^{3}He,d), (p,d) …
2. Molecular states in light nuclei ^{10}B,^{13}C+H breakup, (^{3}He,d) for stellar nucleosynthesis…
3. Study of pygmy and giant resonances via transfer (d,pγ) or inelastic scattering (α, α’γ)



Conclusions

1. Development of cryogenic targets for direct reactions (pickup or stripping) and inelastic scattering, sequential breakup…

2. Energy resolution from light particles (thin target) vs statistics (thick target) compromise

3. The presence of a large γ-ray array poses further constraints: transparency to γ-rays, mechanical compatibilities with vacuum pumps and target infrastructure (dewar, etc…)

4. Triple coincidence among γ rays, light particles, and heavy partners provides a unique tool to work with radioactive beams down to 10^4 pps intensity.

5. The CTADIR project aims at studying the integration of such targets with a typical AGATA-GRIT (PRISMA?) setup

Direct reactions for nuclear structure

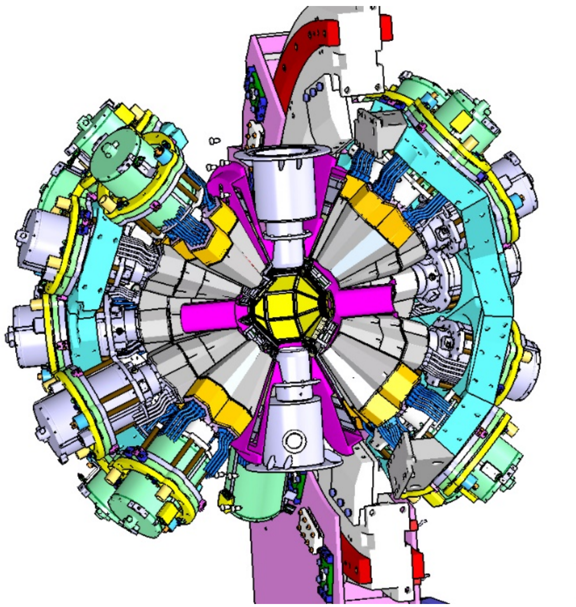
Direct reactions for nuclear structure

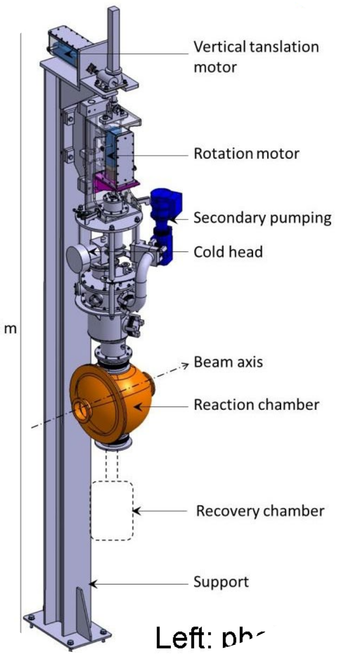
The CTADIR project (2)

Main points to address

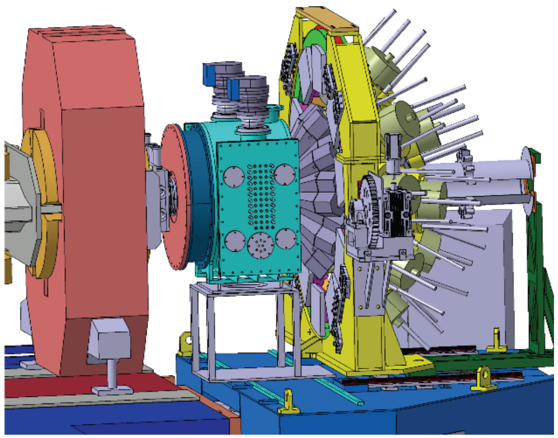
- Vacuum in reaction chamber with a windowless target (down to 10^{-3} mbarn): connection with beam line, Si detectors, coupling to PRISMA…
- Mechanical integration (pumps, device) with large arrays for γ-ray spectroscopy
- For He targets: reducing the window thickness as much as possible, reducing ice accumulation on the windows

AGATA + GRIT+ CHyMENE





AGATA + GRIT+ VAMOS + He Cryotarget @ GANIL



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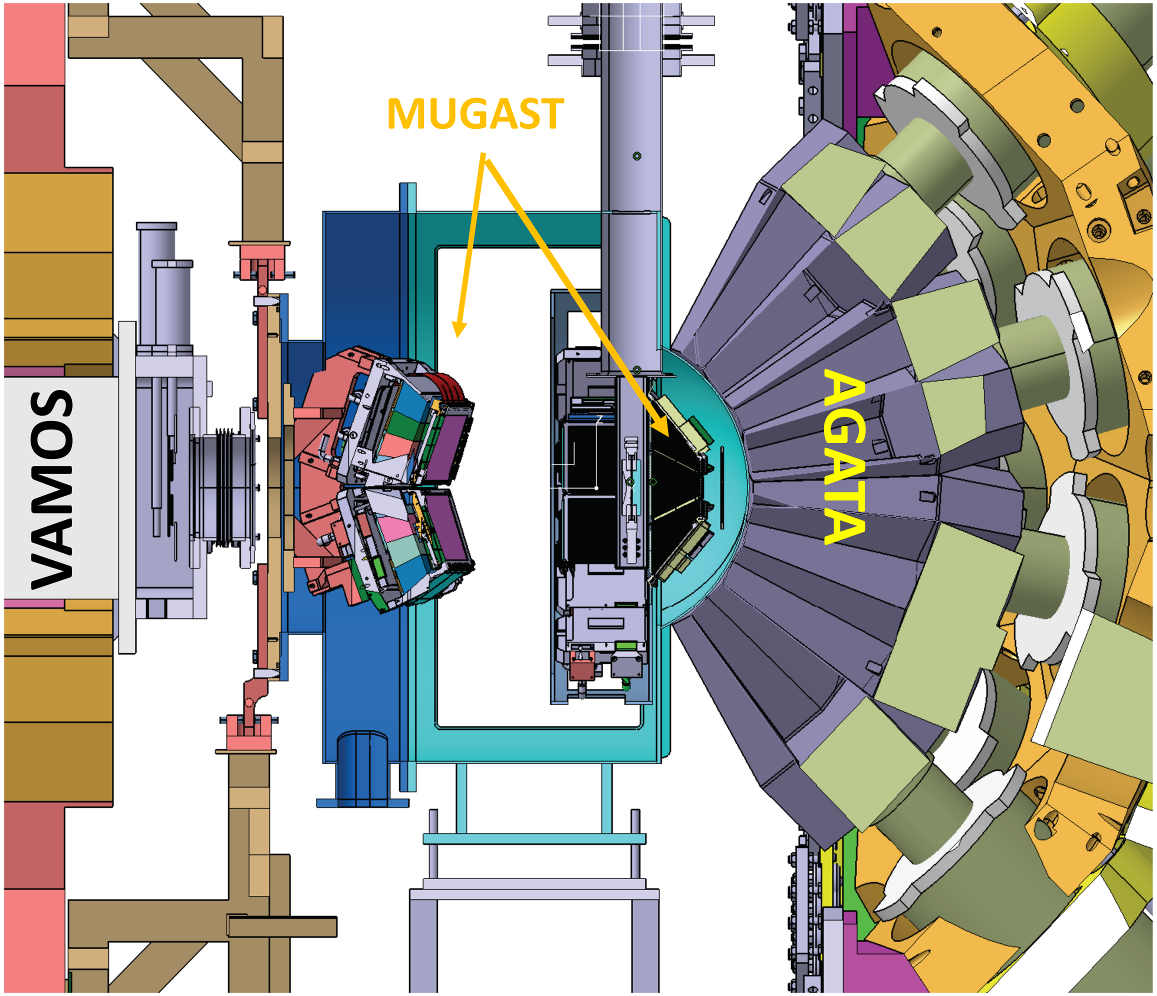

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