AGATA experiments performed with EXOTIC RIBs

Anna Togni

for the **ASFIN** and **GAMMA** collaborations

UNIVERSITÀ DEGLI STUDI DI PADOVA

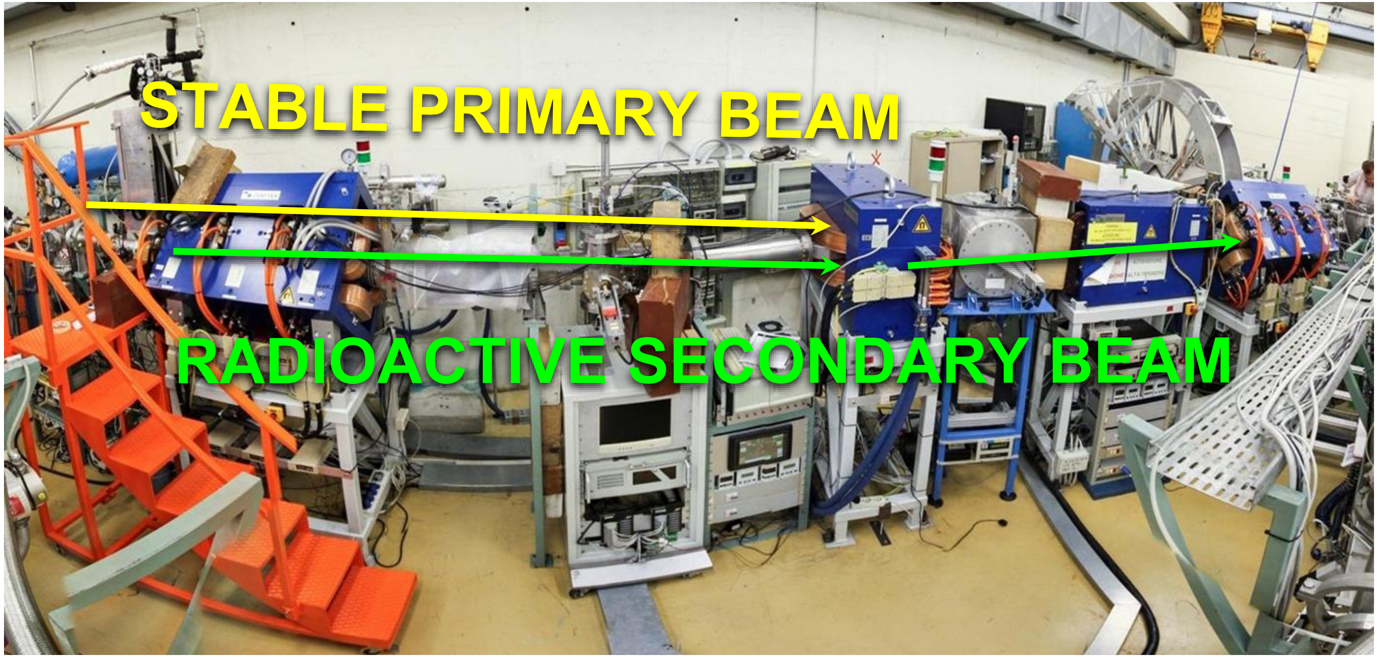
INFN

EXOTIC

Radioactive Nuclear Beams

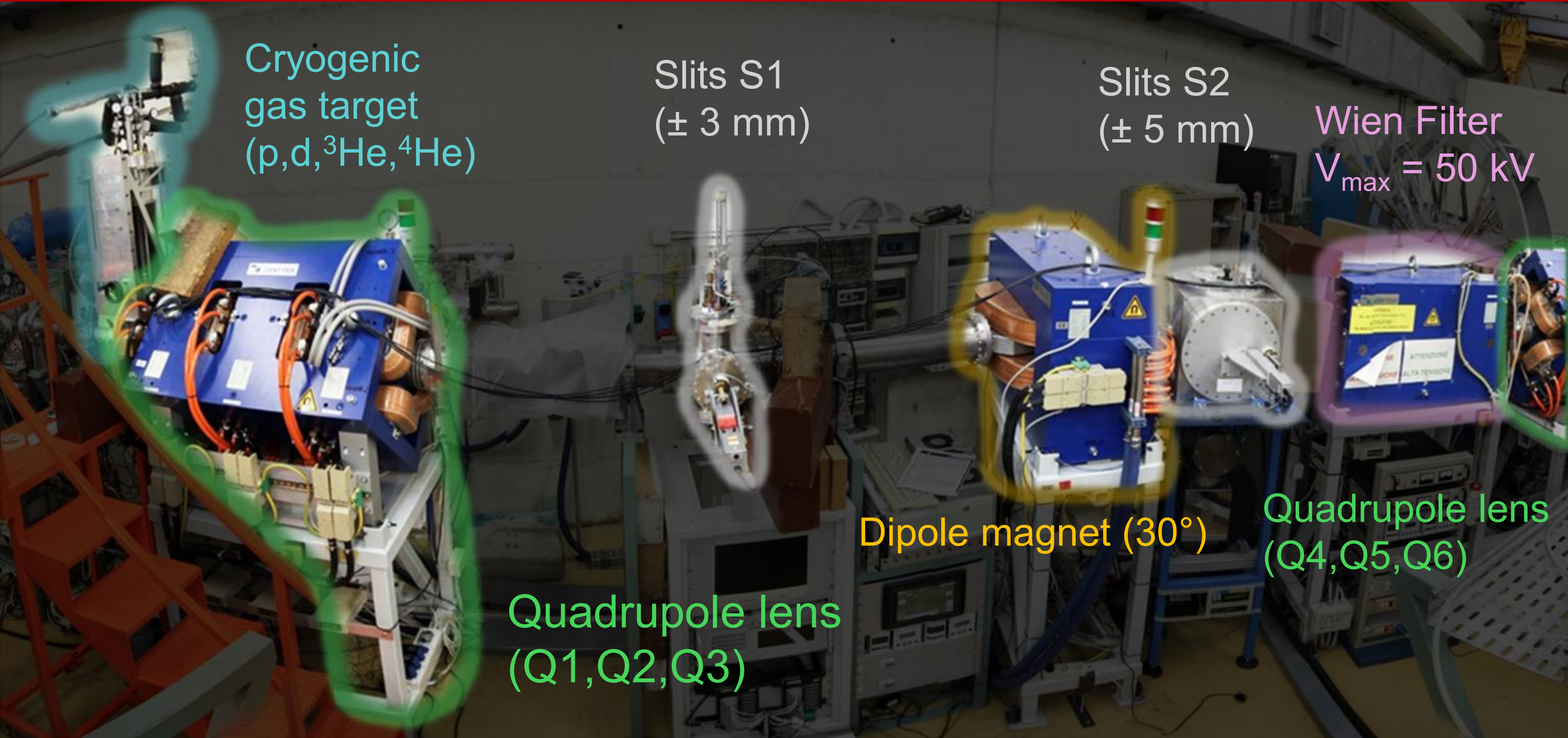
The EXOTIC facility

In-flight production of **light weakly-bound** radioactive ion beams (RIBs), using two-body **inverse kinematic reactions** with the ions from the primary beam delivered by the XTU tandem accelerator impinging on a **gas target**.

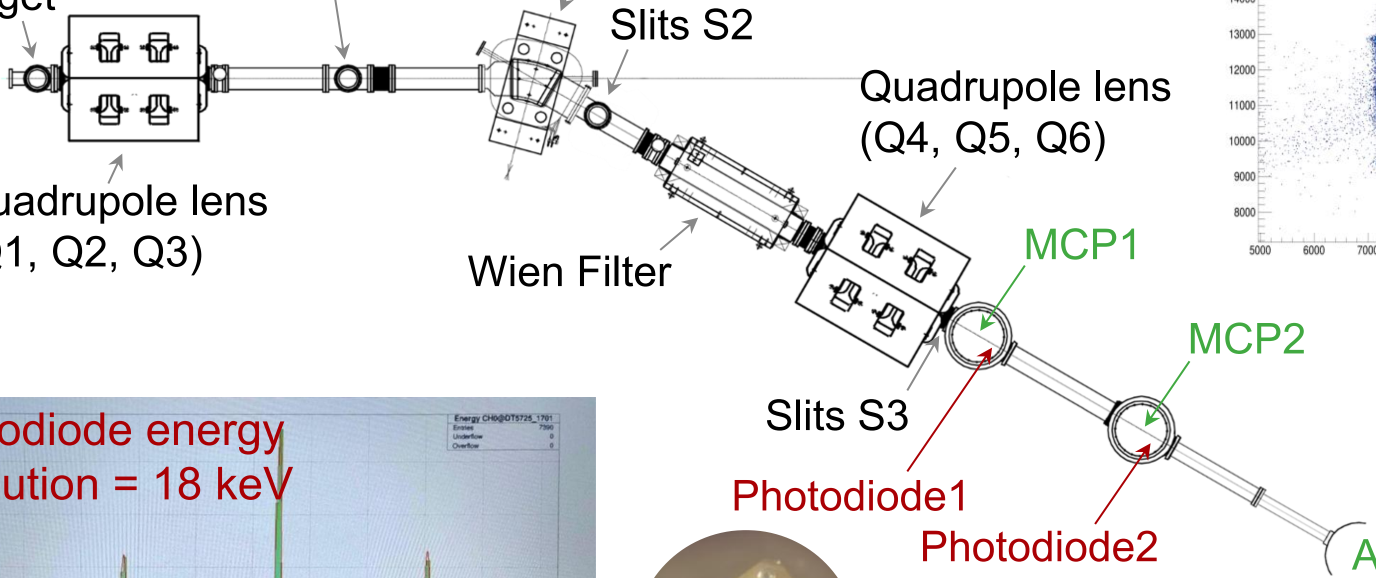


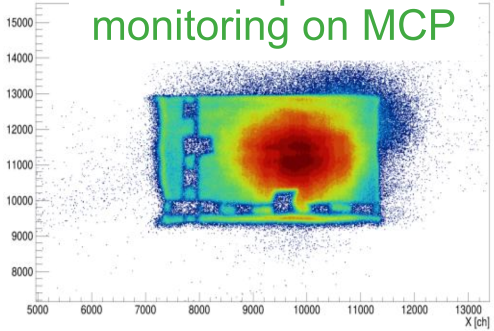
Università degli Studi di Padova

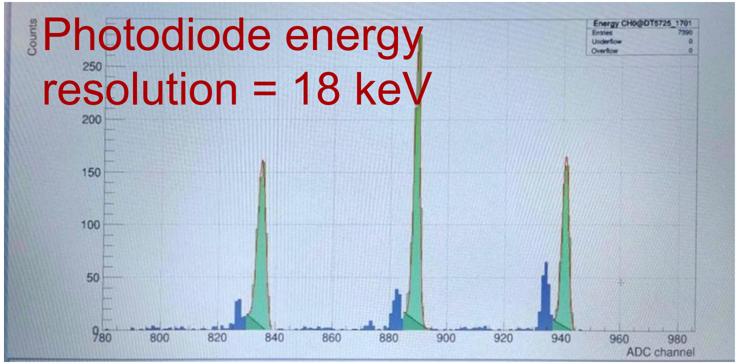
The EXOTIC facility

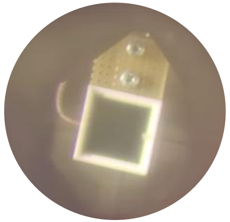


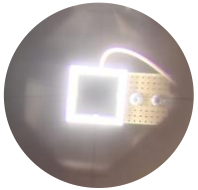
The EXOTIC beam line





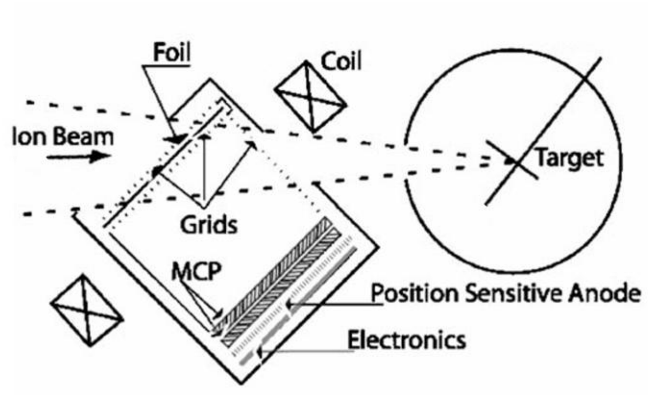


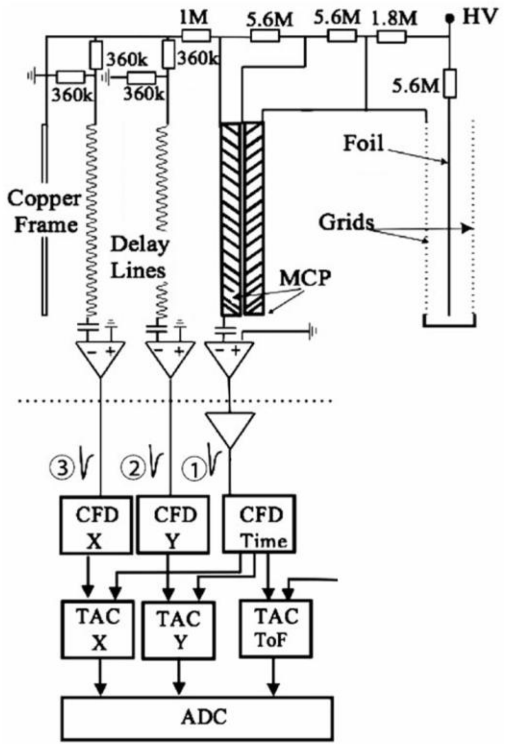




New Tracking System: MCP

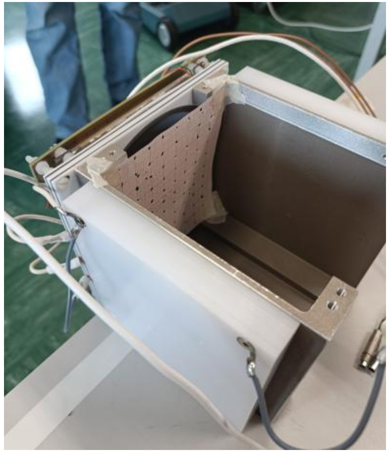
The new system comprises two large-area (104 mm diameter) x-y sensitive **Micro Channel Plate** (MCP) detectors, that replace the previously installed tracking system consisting on Parallel Plate Avalanche Counters (PPACs).

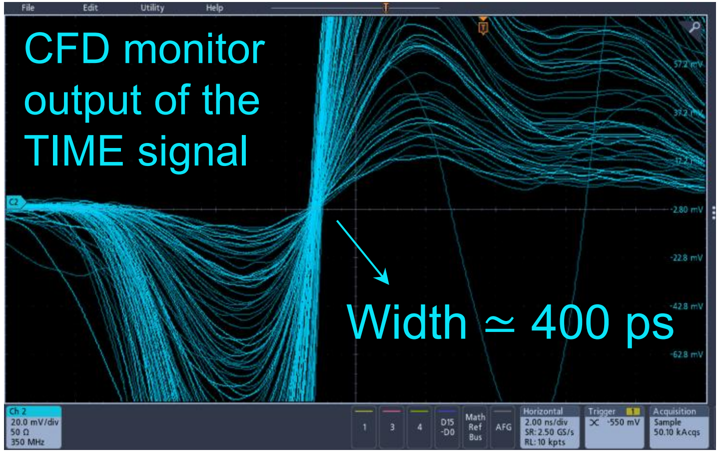




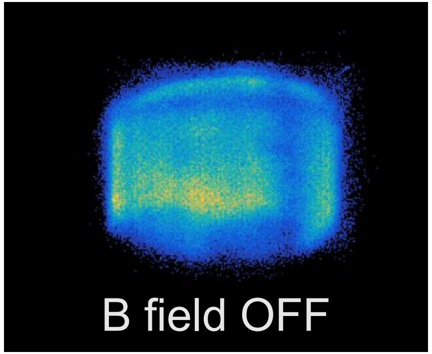
MCP Characteristics

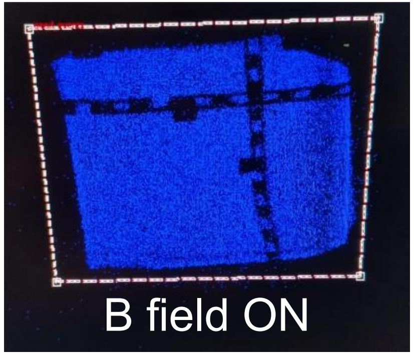
Position resolution: ~**2 mm**
Intrinsic time resolution: **400 ps**





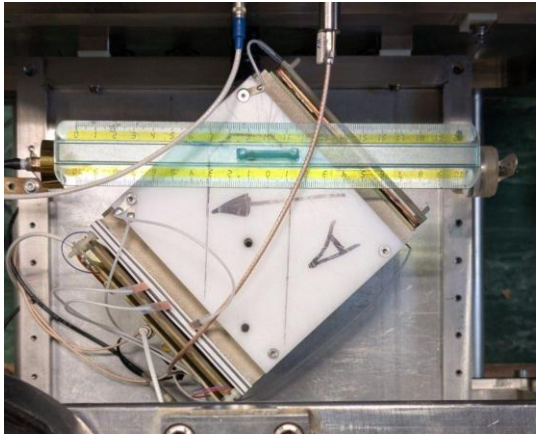
Importance of the **magnetic field**:
MCP profile without and with the magnetic field

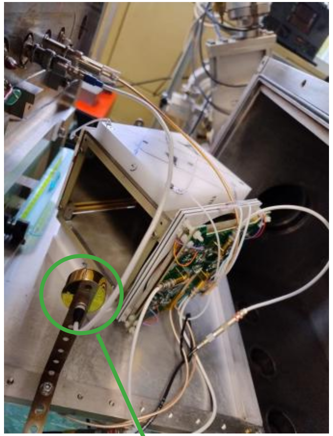




UNIVERSITÀ DEGLI STUDI DI PADOVA

MCP Optimization

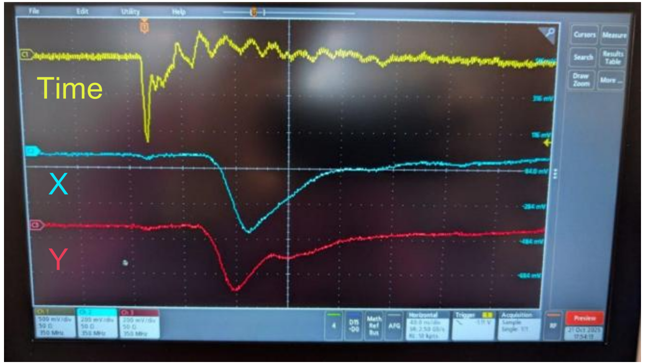




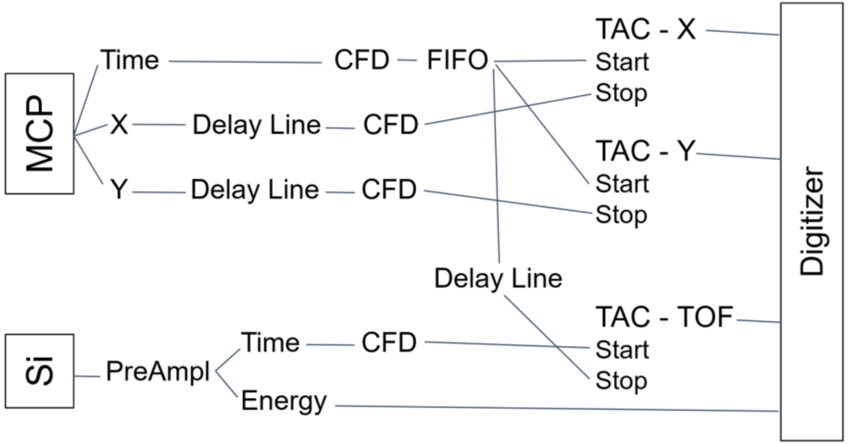
In preparation for the experimental campaign:

- Optimization of the **efficiency**
- Optimization of the **TAC read-out**

Output signals from the MCP



Electronic chain:



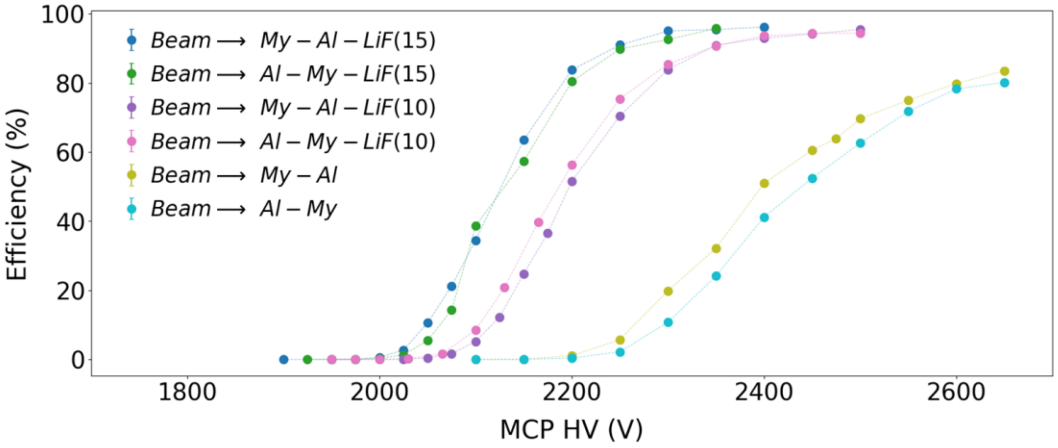
MCP Efficiency

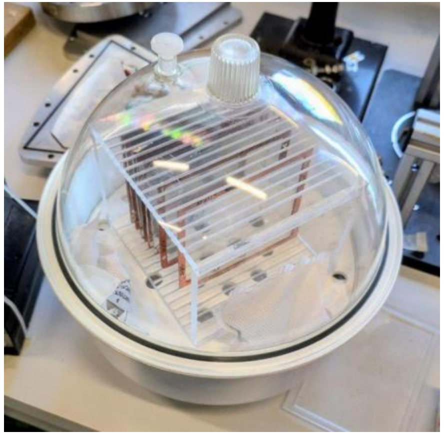
Using α-sources we studies the efficiency of different foils:

- Plain Al-Mylar
- Al-Mylar with evaporation of 10 and 15 μg/cm^2 of LiF

➞The efficiency is greater with the evaporation of **15 μg/cm^2 of LiF**

In the experiment we used foils: **Al-Mylar-LiF**, the LiF is evaporated on the Mylar to ensure the electric contact between the Al and the Cu frame





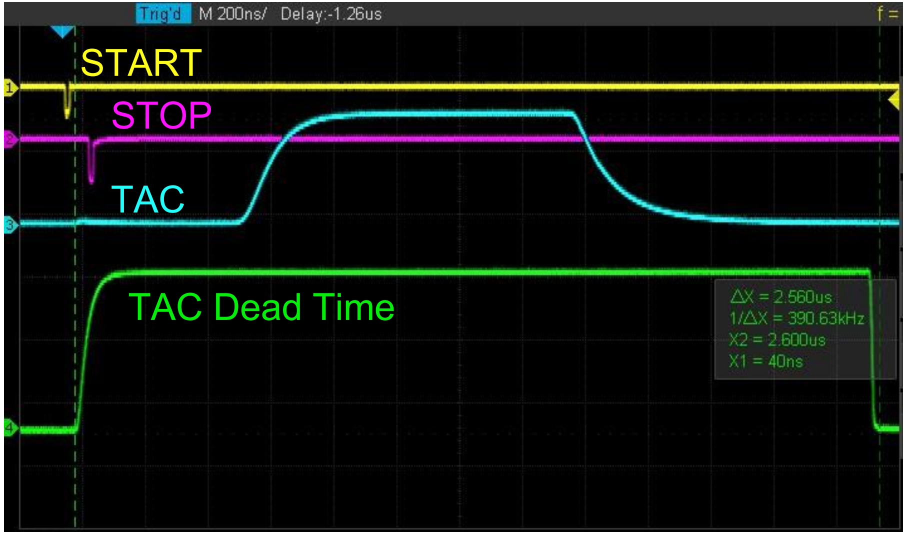
TAC read out

Digital Peak Sensing ADC CAEN module V1741

→ The Dead Time is set by the intrinsic Dead Time of the TAC modules which is **2.56 μs**

The START signals of the TAC are abilitated by the ancillary detectors within the AGATA reaction chamber with rates < 1 kHz

→ Dead Time effects are negligible

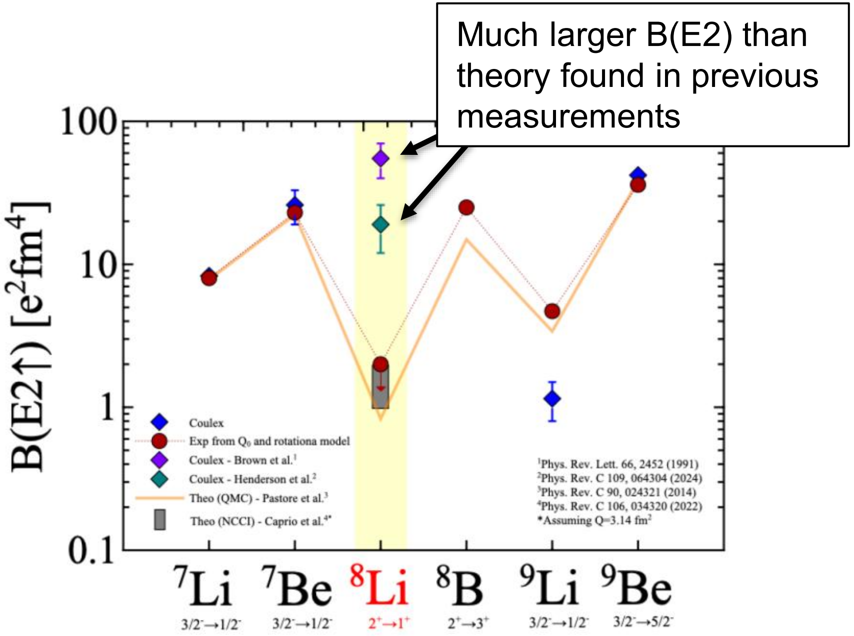


EXOTIC – AGATA Experiments

Solving the puzzle of quadrupole strength in ^{8}Li to benchmark *ab initio* predictions in few-body nuclei

Spokepersons:

- **Simone Bottoni** – INFN sezione di Milano
- **Franco Galtarossa** – INFN sezione di Padova
- **Marco Rocchini** – INFN sezione di Firenze



Large discrepancy in ^{8}Li

→ No theoretical interpretation of such a large E2 strength

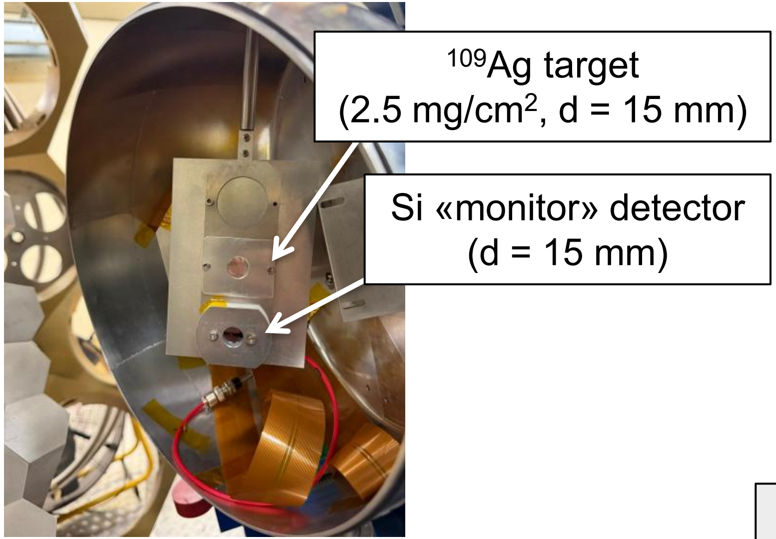
- Experiment goal: Investigation of the possible ^{8}Li anomaly

Coulomb excitation of ^{8}Li

RIB: ^{8}Li at 20 MeV ($5 \cdot 10^{4}$ pps)

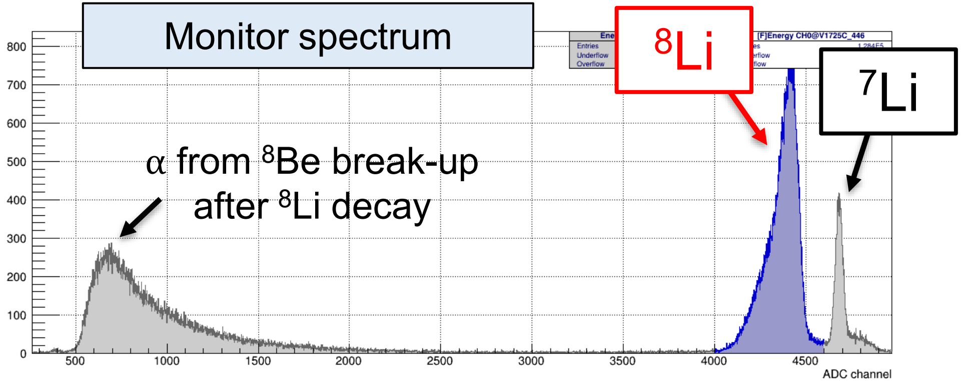
Target: ^{109}Ag 2.5 mg/cm^{2}

EXOTIC – AGATA Experiments

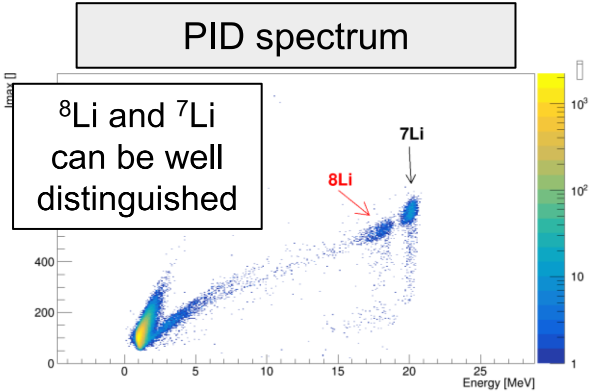


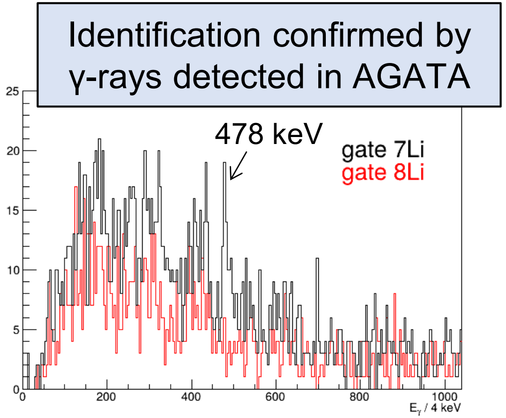
- Set-up: AGATA + Annular DSSSD detector covering forward angles (~ 30° to 50°)
- Large shielding to prevent beam ions to reach directly the detector
- Surface barrier silicon detector in target position to monitor the beam

Courtesy of S. Bottoni

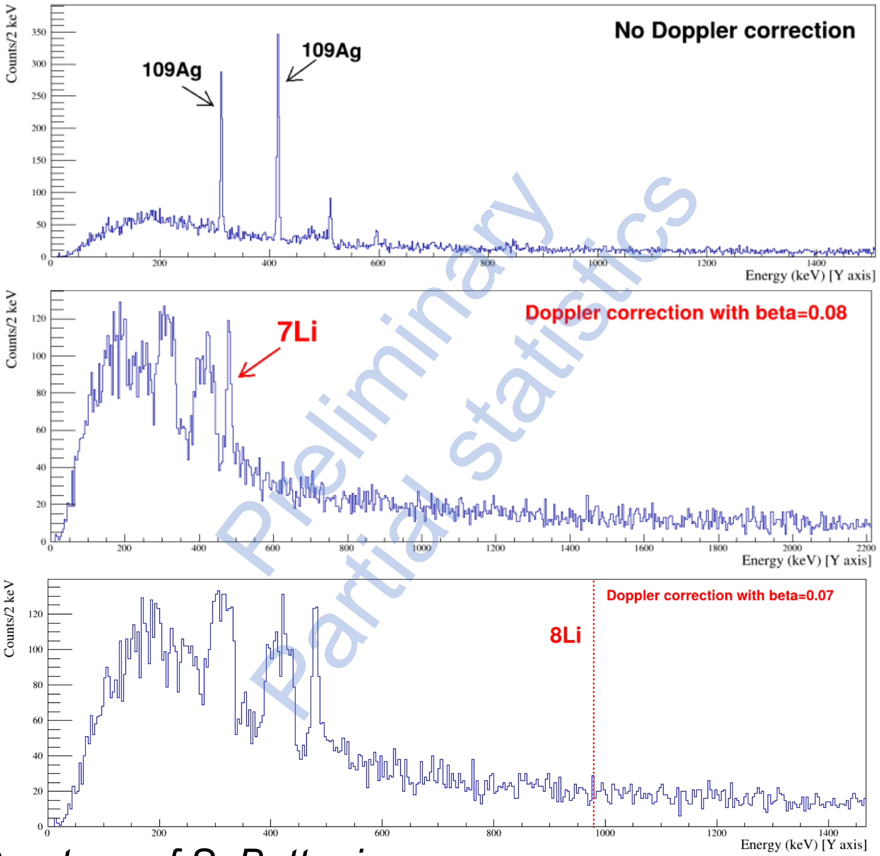


Estimated ^8Li beam intensity on target: ~ 10^5 pps





Preliminary results



Courtesy of S. Bottoni

Excitation of ^{109}Ag by both ^{7}Li and ^{8}Li clearly visible in the non-Doppler-corrected spectra

Inelastic excitation of the first excited state of ^{7}Li [B(E2) ~ 9 e^2fm^4, Ex = 478 keV] clearly visible

Inelastic excitation of the first excited state of ^{8}Li [B(E2) ~ ?, Ex = 981 keV] <u>not visible after few days</u>
→ B(E2) probably below 10 e^2fm^4?

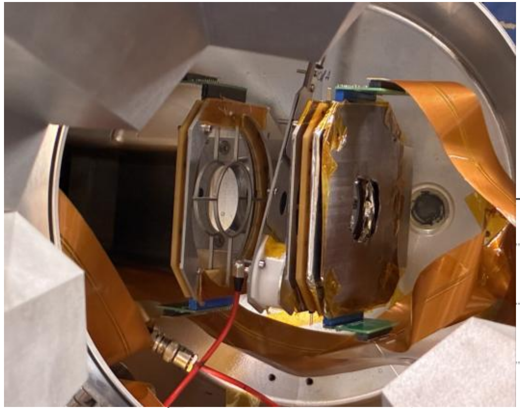
UNIVERSITÀ DEGLI STUDI DI PADOVA

EXOTIC – AGATA Experiments

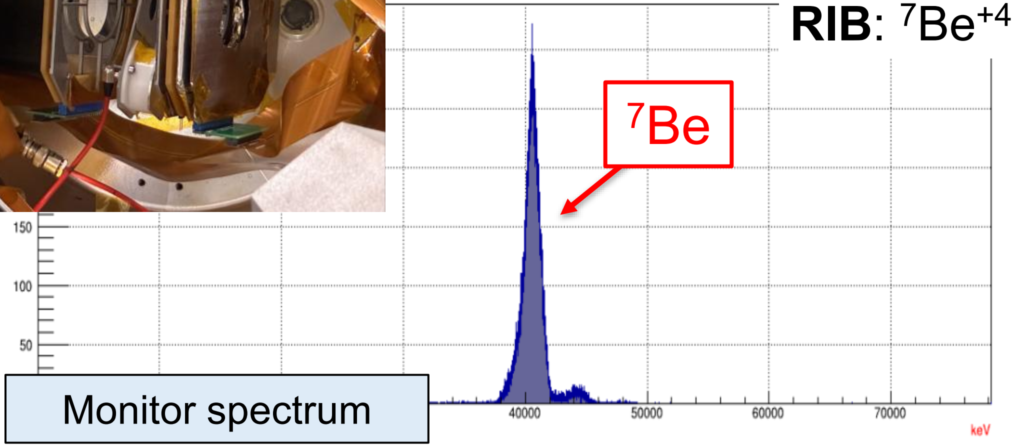
Particle-Gamma Correlation Studies for the System $^{7}Be+^{208}Pb$ at near-barrier Energies

Spokepersons:

- **Marco Mazzocco** – Università degli studi di Padova, INFN sezione di Padova
- **GaoLong Zhang** – Beihang University, Beijing
- **GuangXin Zhang** – Sun Yat-sen University, Guangdong
- **Sara Pigliapoco** – Università degli studi di Padova, INFN sezione di Padova

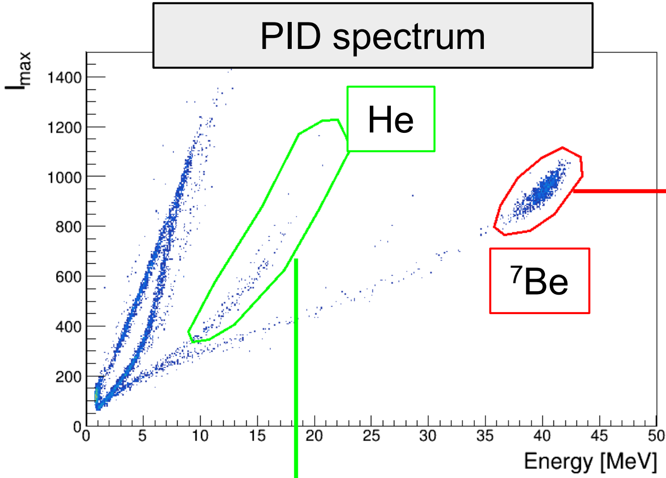


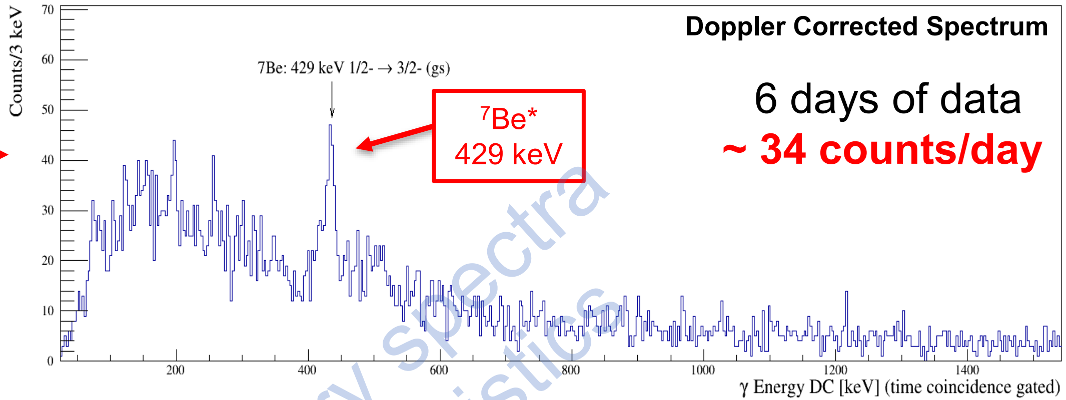
Target: ^{208}Pb 2 mg/cm^2 on ^{12}C backing
Primary beam: $^{7}Li^{+3}$ at 48 MeV
RIB: $^{7}Be^{+4}$ at 40.5 MeV ($1.6 \cdot 10^5$ pps)



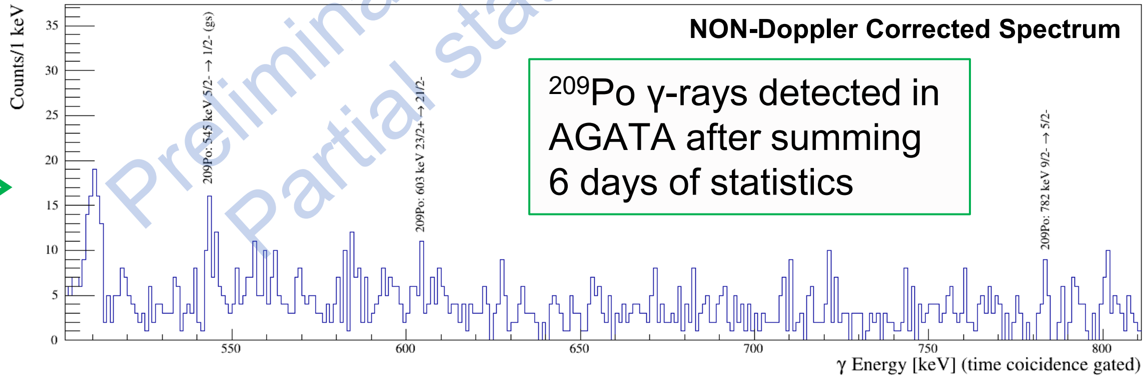
Goal: Investigate the **interplay between break-up and transfer reaction** in the energy range around the Coulomb barrier.

Preliminary spectra





One of the reaction of interests is the transfer reaction of ^{3}He (from the break-up of ^{7}Be into ^{4}He and ^{3}He) to ^{208}Pb producing ^{211}Po that evaporates 2n leaving ^{209}Po



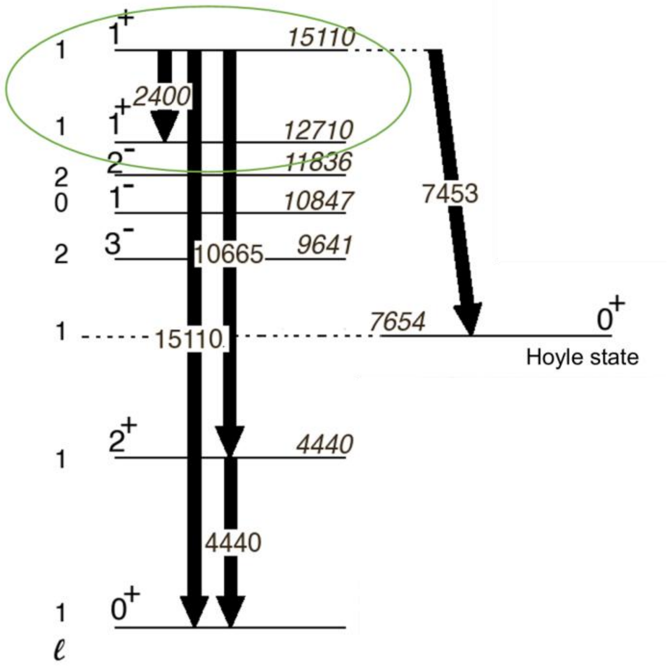
EXOTIC – AGATA Experiments

Università degli Studi di Padova

Isospin Mixing and Cluster Configurations in ^{12}C

Spokepersons:

- **Luca Zago** – Università degli studi di Milano, INFN sezione di Milano
- **Andrea Gottardo** – INFN Laboratori Nazionali di Legnaro



Reaction $^{11}C(d,p)^{12}C$

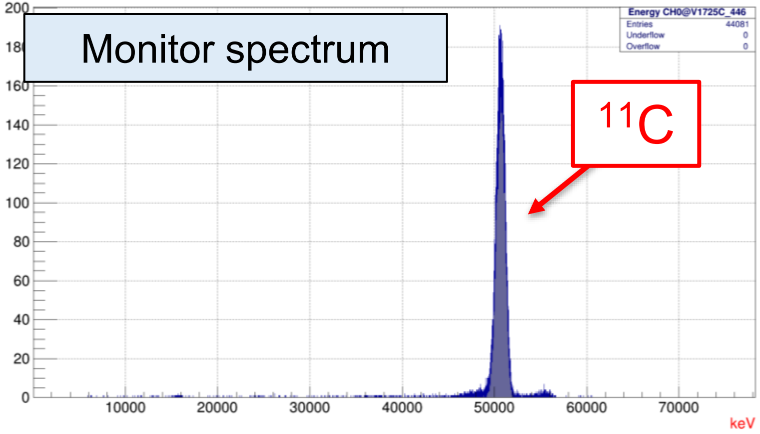
Goals:

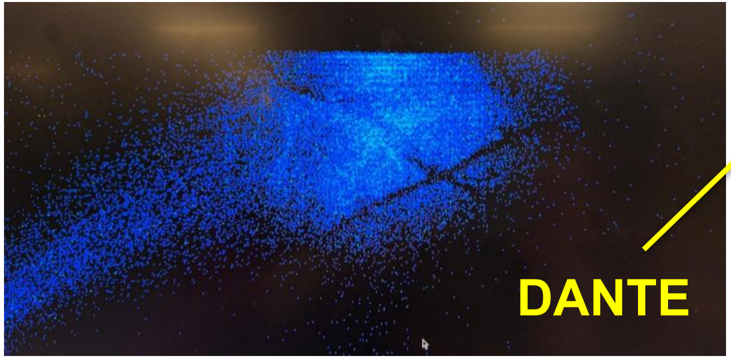
1. **Hoyle state**: studying the angular distributions and comparing the results with the DWBA calculations of the reaction populating the Hoyle state and the first few excited states of ^{12}C
2. **Isospin doublet**: investigating the isospin mixing of the 1^+ isospin doublet by measuring the spectroscopic factors of these two states

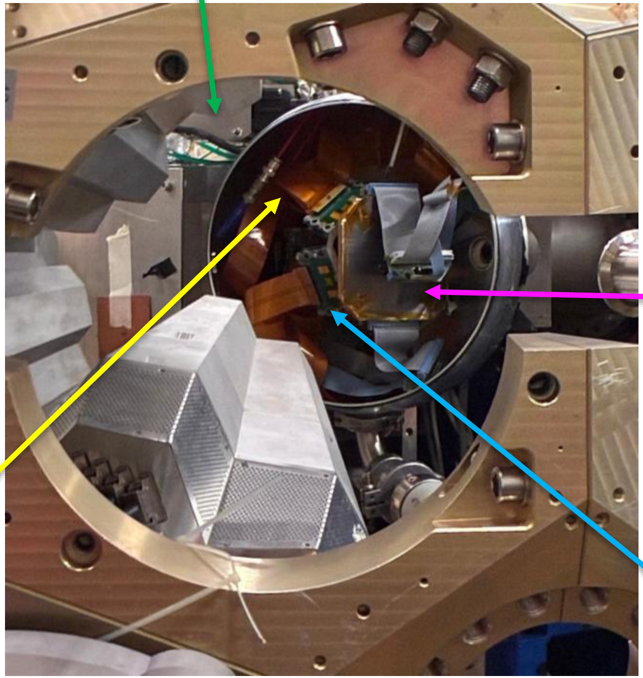
Target: CD_2 2 mg/cm^2 on Au backing 4 mg/cm^2
Primary beam: $^{11}B^{+6}$ at 70 MeV (35 pnA)
RIB: $^{11}C^{+7}$ at 54 MeV (10^5 pps)

Università degli Studi di Padova

EXOTIC – AGATA Experiments

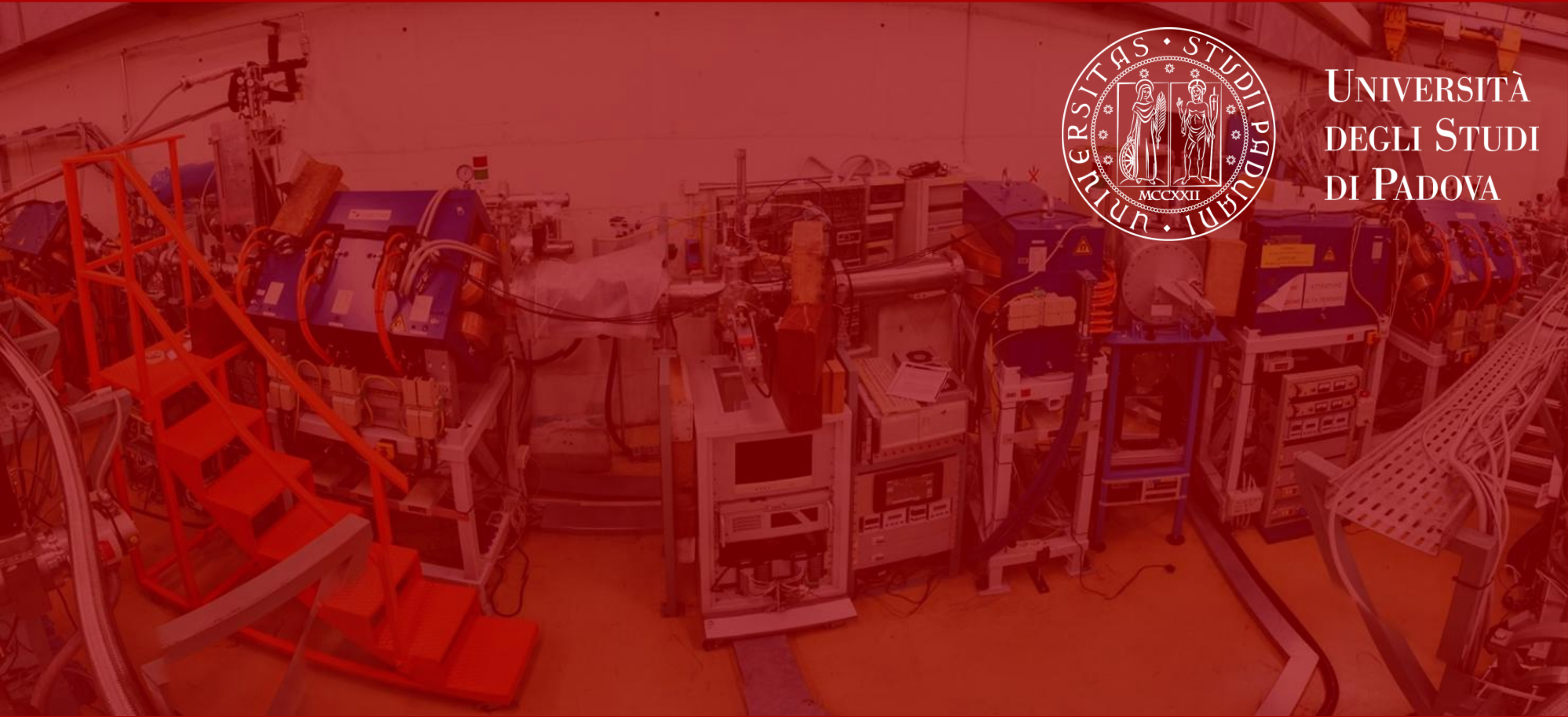




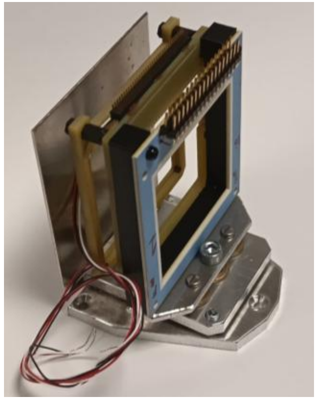


Summary

- **Upgrades** performed to couple EXOTIC to AGATA:
  - Change in beam diagnostic
  - Development of a new tracking system
- **Optimization** of the new tracking system based on MCP
  - Efficiency
  - Read Out
- **Preliminary results** of the performed experiments

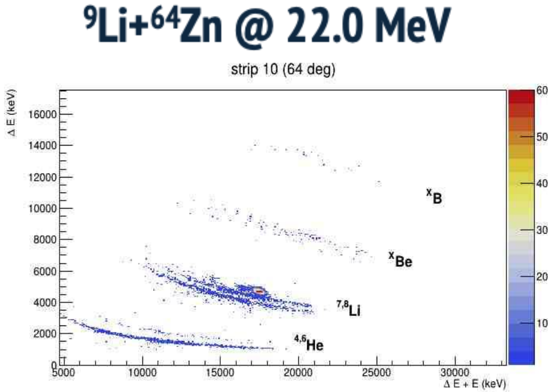

Università
degli Studi
di Padova

Future: The ASFIN Si Strip Detection System



Up to **8 Segmented 3ple Si telescopes**
DE: 20 um Single Sided 16 strip detector 5x5 cm^2
ER1: 1000 um Double Sided 32x32 detector 5x5 cm^2
ER2: 1500 um Si detector not segmented

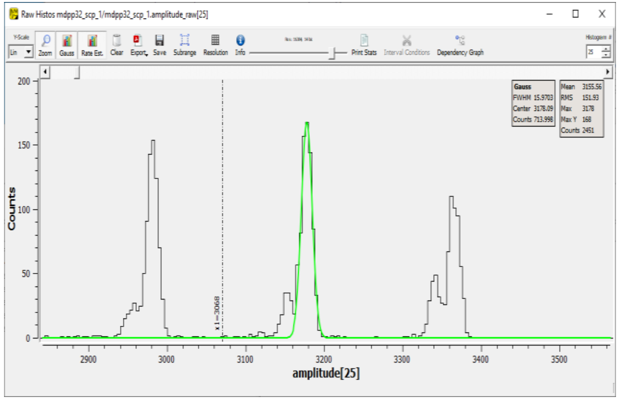
Compact support, **can be mounted in various configurations** according to the experimental needs including very compact ones. Allows 3D fine adjustments of the detector position



Example: Inside the PISOLO chamber at LNL June 2025

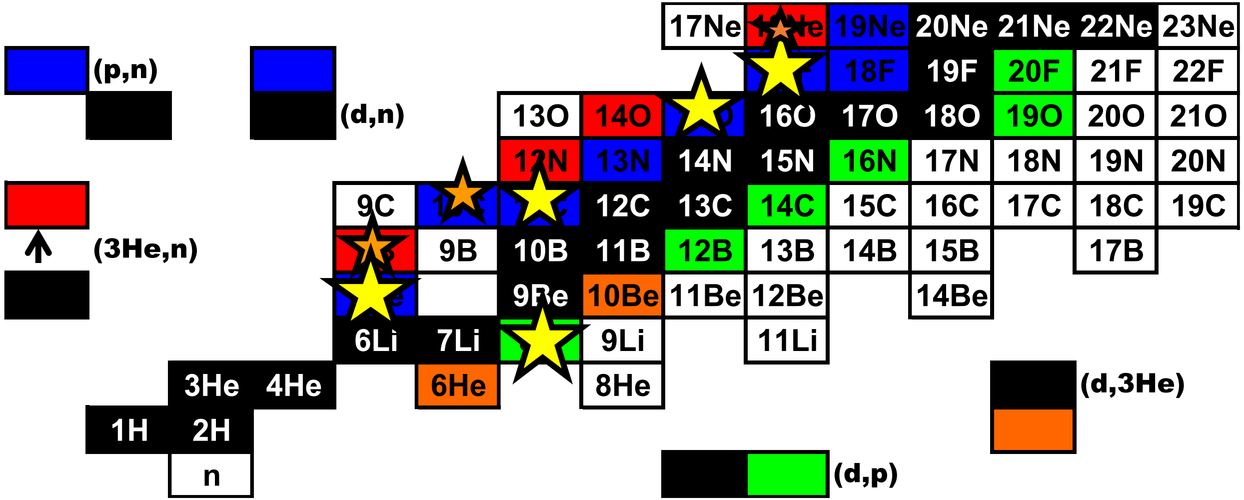
Readout via Mesytec electronics :
32 channel preamps MPR32
followed by
32 channel digitizers MDPP32

Typical DSSSD resolution 30-40 KeV FWHM for 5.48 MeV Alpha particles



Università degli Studi di Padova

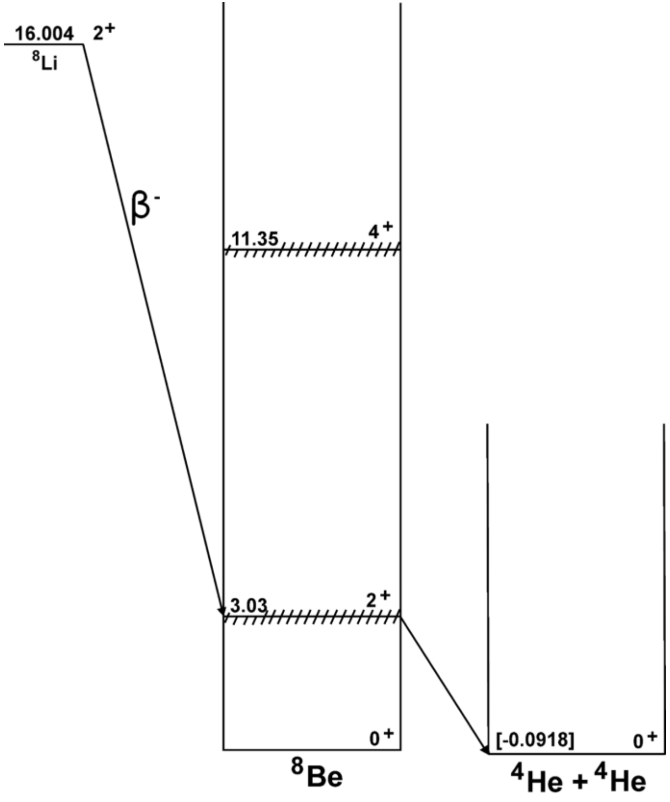
RIBs with EXOTIC

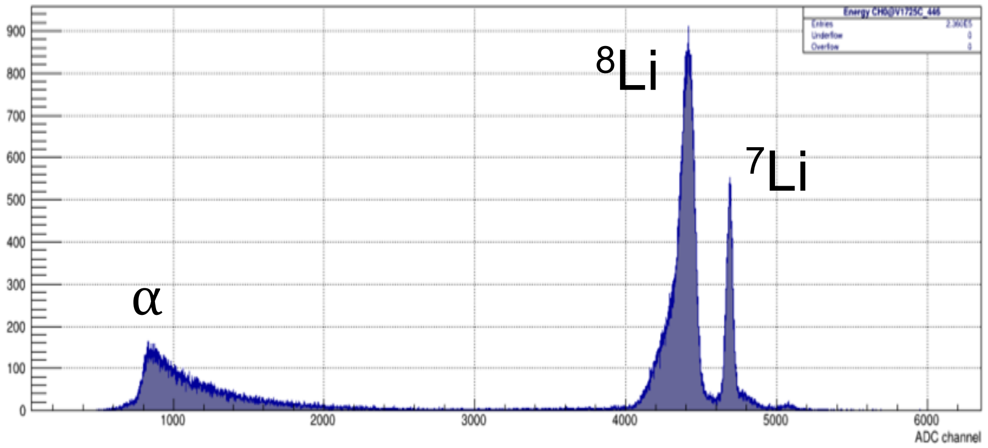


^{17}F	E = 3 - 5 MeV/u	Purity: **93-96 %**	Intensity: **10^5 pps**
^{8}B	E = 3 - 5 MeV/u	Purity: **30-43 %**	Intensity: **~ 10^3 pps**
^{7}Be	E = 2.5 - 6 MeV/u	Purity: **99 %**	Intensity: **10^6 pps**
^{15}O	E = 1.3 MeV/u	Purity: **97-98 %**	Intensity: **$4*10^4$ pps**
^{8}Li	E = 2 - 2.5 MeV/u	Purity: **99 %**	Intensity: **10^5 pps**
^{10}C	E = 4 MeV/u	Purity: **99 %**	Intensity: **$5*10^3$ pps**
^{11}C	E = 4 MeV/u	Purity: **99 %**	Intensity: **$2*10^5$ pps**
^{18}Ne	E = 1.3 MeV/u	Purity: **95 %**	Intensity: **$6*10^3$ pps**

Università degli Studi di Padova

^{8}Li beam profile





The **2 α-particles** are emitted in coincidence back-to-back resulting in a **single events**

→ We expect the ^{8}Li peak-integral to be the same as the α-particles one

Particle-Gamma Correlation Studies for the System $^{7}Be+^{208}Pb$ at near-barrier Energies

Goal: Investigate the **interplay between break-up and transfer reaction** in the energy range around the Coulomb barrier.

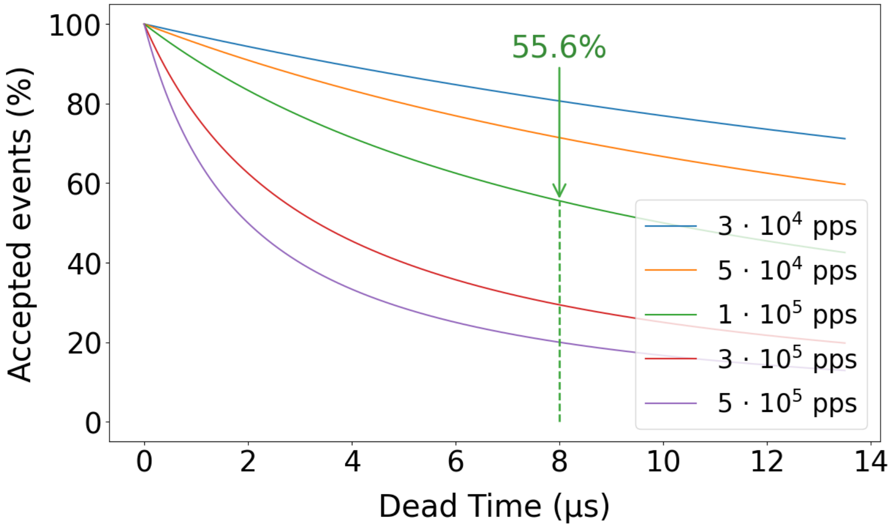
The EXOTIC+AGATA+SAURON set-up allows to detect in coincidence charged particle reaction products and γ-rays:

- Transer/incomplete fusion of ^{3}He with ^{208}Pb
  → Production of $^{211}Po^{*}$ + emission of energetic ^{4}He
- Transer/incomplete fusion of ^{4}He with ^{208}Pb
  → Production of $^{212}Po^{*}$ + emission of energetic ^{3}He
- Inelastic scattering events → detection of ^{7}Be with it's characteristic γ-ray

Target: ^{208}Pb 1 mg/cm^{2} on ^{12}C backing
Primary beam: $^{7}Li^{+3}$ at 48 MeV
RIB: $^{7}Be^{+4}$ at 41 MeV

Dead Time

Percentage of **accepted events** considering only the dead time, without considering the detectors efficiencies.



$$\frac{\text{Accepted events}}{\text{Delivered events}} = \frac{1}{1 + \text{Delivered events} \cdot \text{Dead Time}}$$

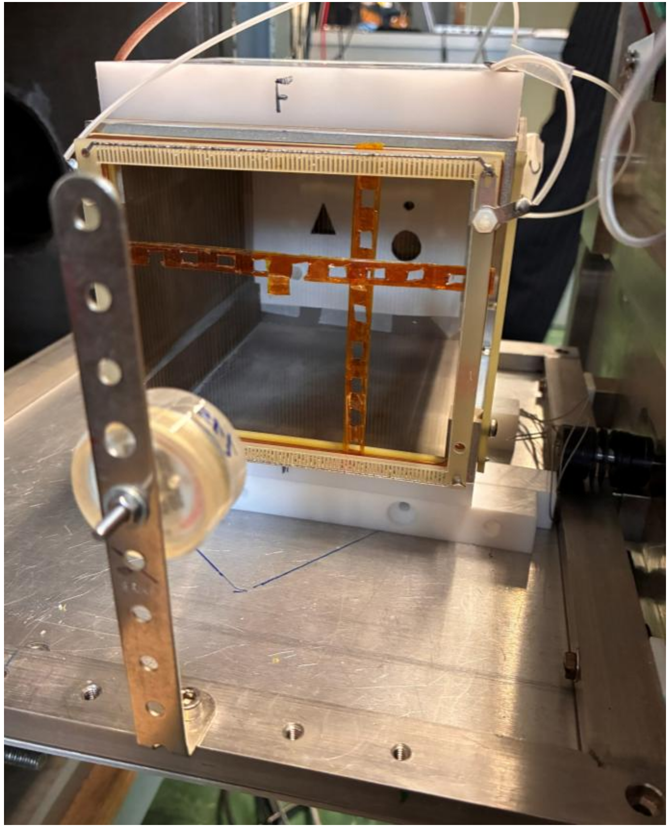
RIBs Production

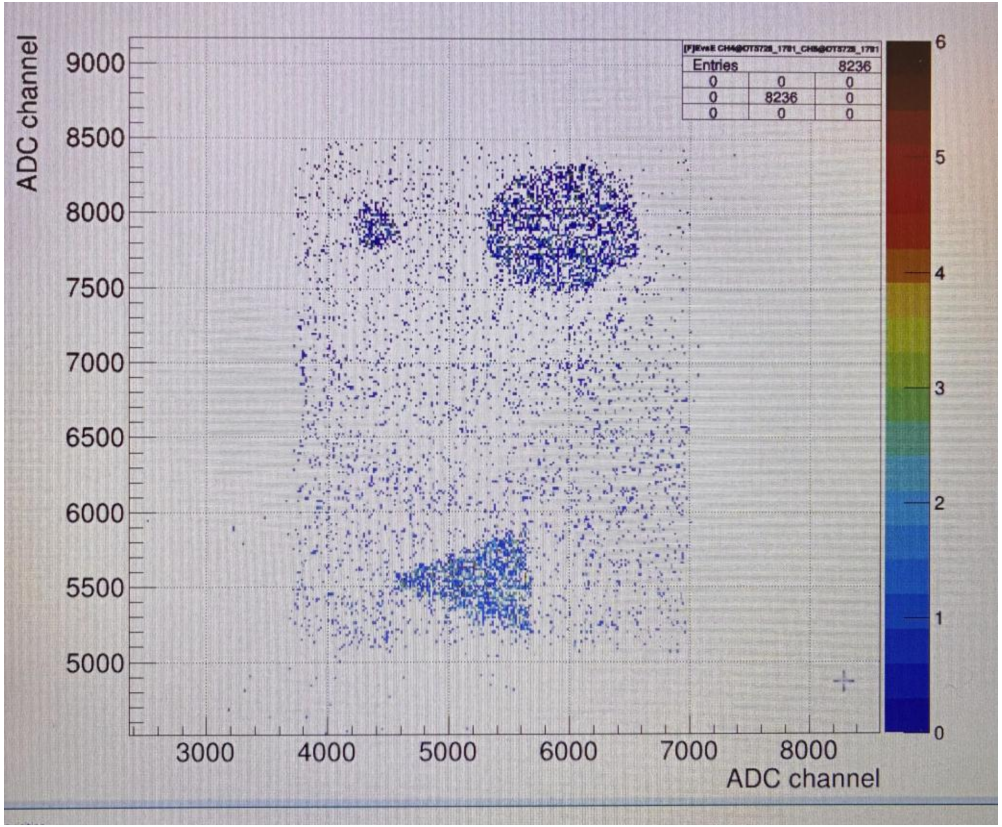
The simulations showed that shifting the final focus downstream would require lower magnetic fields for the second quadrupole triplet compared to the original EXOTIC stand-alone configuration. This ensures that **RIBs can be delivered without exceeding the limitations of the existing power supplies and magnets**.

These simulations were performed considering the highest primary beam energy achievable or the maximum secondary beam magnetic rigidity. The calculations indicates a potential **reduction in transmission of approximately 50%**.

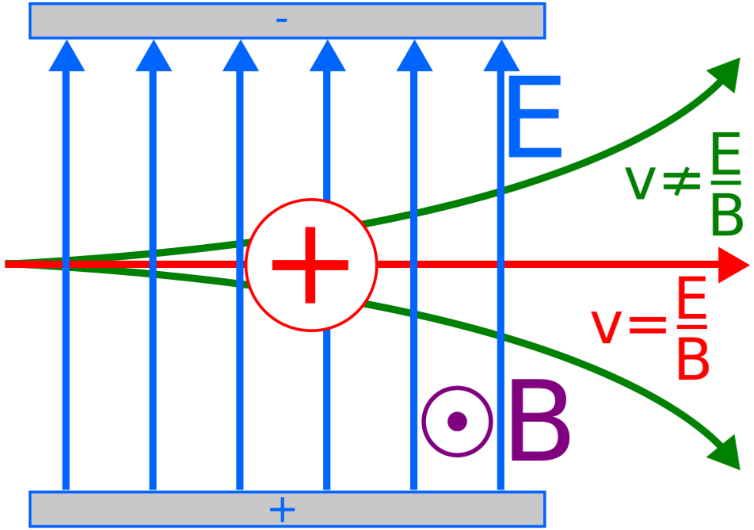
RIB	Reaction	RIB E_{max} (MeV)	EXOTIC Conf. (pps)	AGATA Conf. (pps)
$^{7}Be^{+4}$	p(^{7}Li, ^{7}Be)n	44.2	10^{6}	5×10^{5}
$^{8}Li^{+3}$	d(^{7}Li, ^{8}Li)p	21.7	10^{5}	5×10^{4}
$^{11}C^{+6}$	p(^{11}B, ^{11}C)n	54.2	2×10^{5}	10^{5}

MCP Characteristics





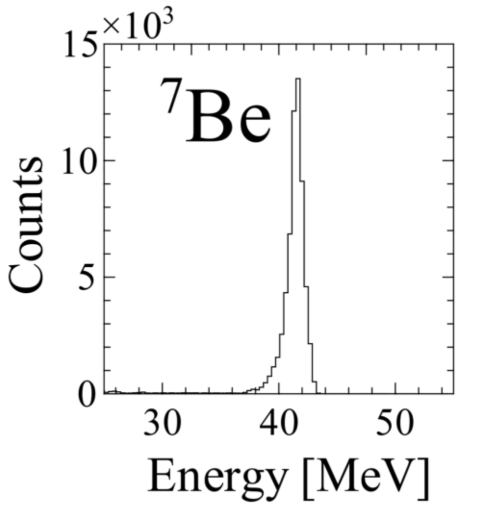
Wien Filter

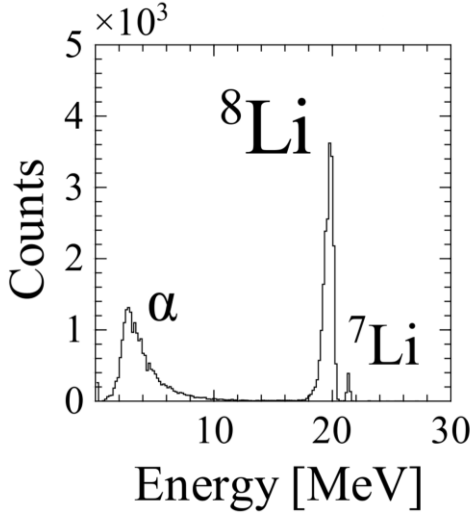


A **Wien filter** also known as a **velocity selector** is a device consisting of perpendicular **electric** and **magnetic** fields that can be used as a velocity filter for charged particles.

The filter is such that particles with the correct speed will be unaffected while other particles will be deflected.

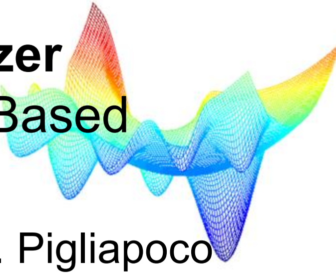
RIBs Production and Transport





Bayesian Optimazer

Sequential Model-Based Optimization



Work by: D. Genna, S. Pigliapoco

References:

https://bayesian-optimization.github.io/BayesianOptimization/3.1.0

- Ryan Roussel *et al.*, Physical Review Accelerators and Beams 24, 062801 (2021)
- Chenran Xu *et al.*, Physical Review Accelerators and Beams 26, 034601 (2023)
- Y. K. F. Ong *et al.*, "ADVANCED ALGORITHMS FOR LINEAR ACCELERATOR DESIGN AND OPERATION"

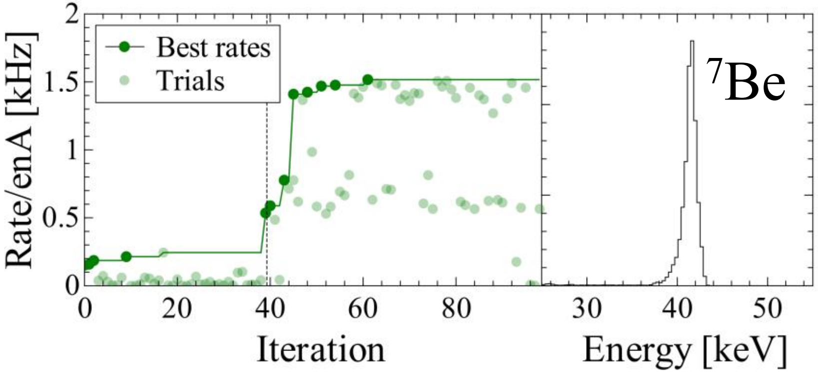
RIB	Reaction	RIB E (MeV)	Rate (pps/enA)	Primary (pnA)*	Secondary (pps)
$^8Li^{+3}$	d(^{7}Li, ^{8}Li)p	21.7	470	39	5×10^4
$^7Be^{+4}$	p(^{7}Li, ^{7}Be)n	41.3	1520	39	2×10^5
$^{11}C^{+6}$	p(^{11}B, ^{11}C)n	54.2	780	25	8×10^4

* Minimum Guaranteed Intensities

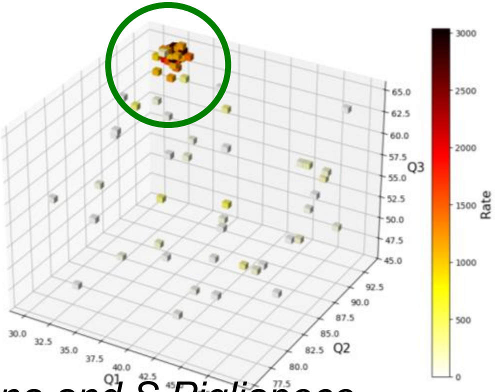
UNIVERSITÀ DEGLI STUDI DI PADOVA

Results of the 7th Commissioning Run: Oct. 3-6, 2025

p(^{7}Li,^{7}Be)n @ 48 MeV

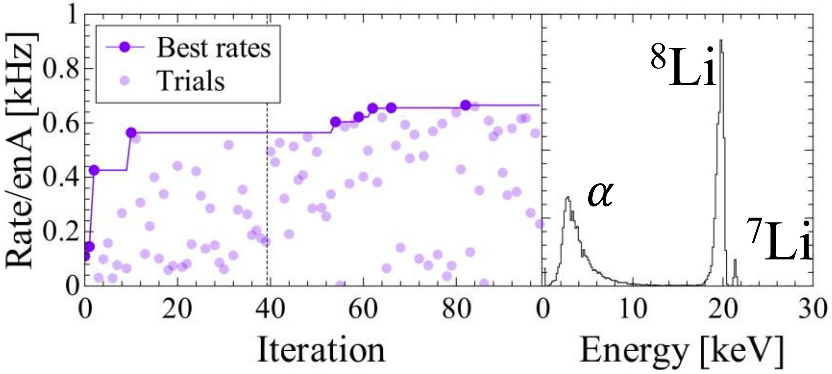


$n_0 = 40$
$n_{BO} = 60$

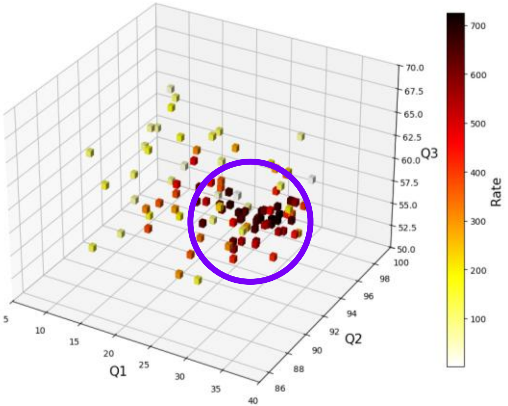


0.5 – 1 h

d(^{7}Li,^{8}Li)p @ 28 MeV



$n_0 = 40$
$n_{BO} = 60$



0.5 – 1 h

Courtesy of D. Genna and S.Pigliapoco

Gaussian Process (GP)

Builds a surrogate statistical model of the unknown target function

$$f(\boldsymbol{x}) \sim GP(\mu(\boldsymbol{x}), k(\boldsymbol{x}, \boldsymbol{x}'))$$

Target function

Mean

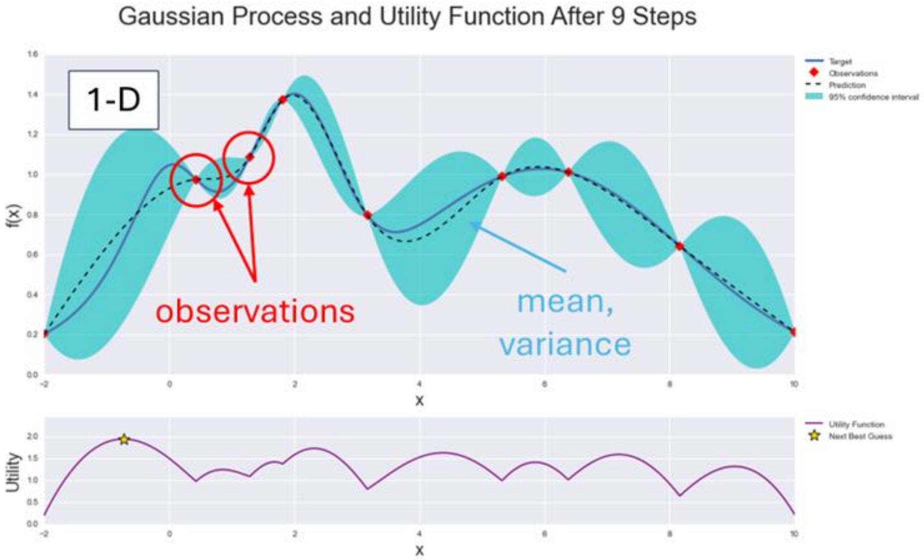
Covariance (similarity between points…)

Set of observations (x_i, y_i), with $y_i = f(x_i) + \epsilon_i$

GP regression to calculate the predicted mean and variance anywhere in input space X

As the number of observations grows, the posterior distribution improves

GP prior $\mu(\boldsymbol{x})$ = initial data's mean



Bayesian Optimizer

Sequential Model-Based Optimization

Acquisition Function

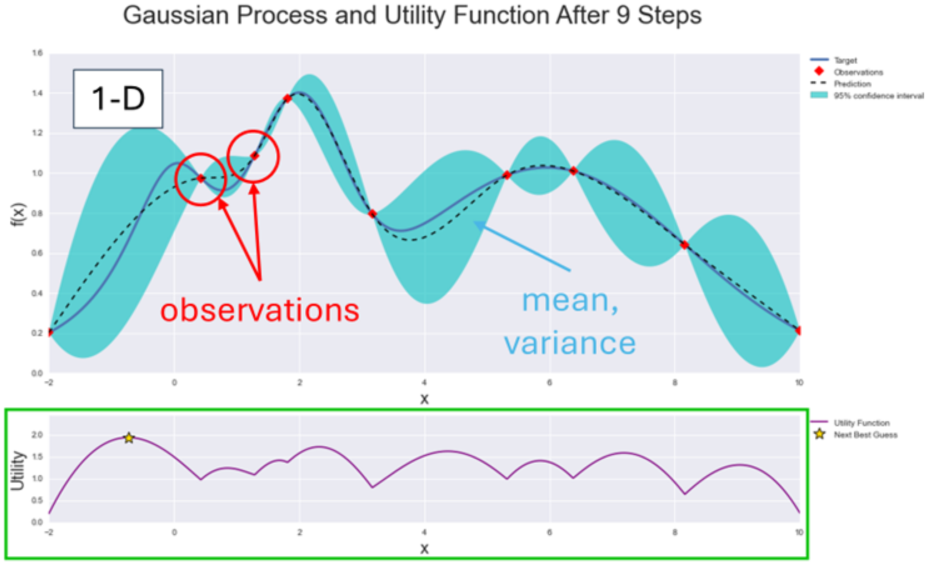
Sets the exploration policy of the algorithm

Upper Confidence Bound (UCB)

Expected improvement value of a proposed point $\boldsymbol{x}$ over the best-observed value f_{best}

$$\alpha_{UCB}(\boldsymbol{x}) = \mu(\boldsymbol{x}) + \kappa\,\sigma(\boldsymbol{x})$$

If $\kappa \ll 1$, UCB prioritizes exploitation;
if $\kappa \gg 1$, UCB prioritizes exploration.



Bayesian Optimizer

Sequential Model-Based Optimization

Acquisition Function

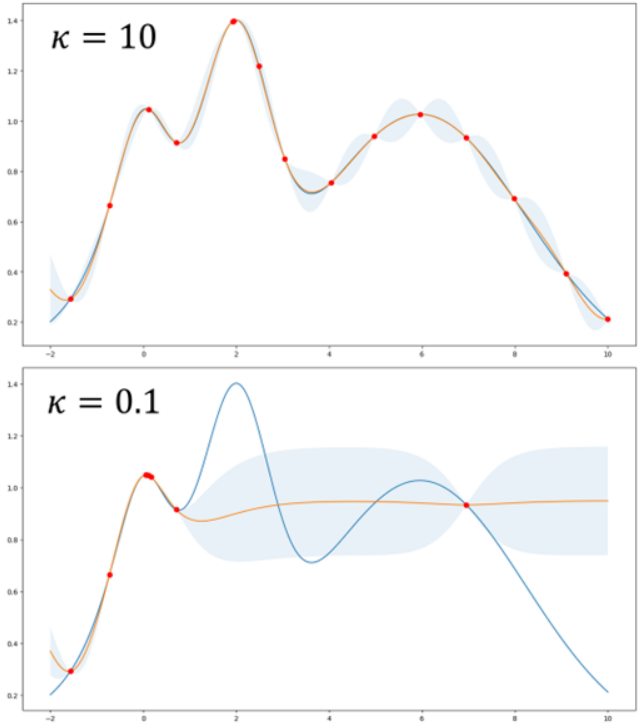
Sets the exploration policy of the algorithm

Upper Confidence Bound (UCB)

Expected improvement value of a proposed point $\boldsymbol{x}$ over the best-observed value f_{best}

$$\alpha_{UCB}(\boldsymbol{x}) = \mu(\boldsymbol{x}) + \kappa\,\sigma(\boldsymbol{x})$$

If $\kappa \ll 1$, UCB prioritizes exploitation;
if $\kappa \gg 1$, UCB prioritizes exploration.



Bayesian Optimizer

Sequential Model-Based Optimization

Acquisition Function

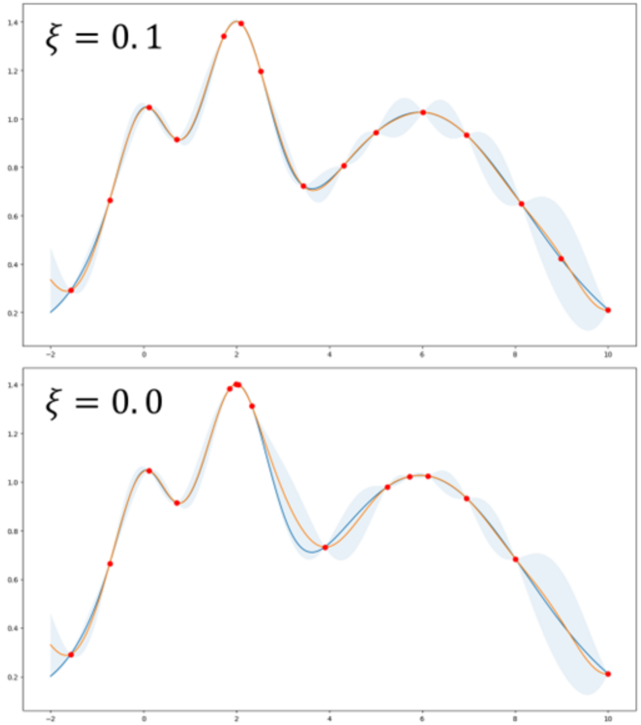
Sets the exploration policy of the algorithm

Expected Improvement (EI)

Average improvement of a proposed point $\boldsymbol{x}$ over the best-observed value f_{best}

$$\alpha_{EI}(\boldsymbol{x}) = \boldsymbol{E}[\max(\mu(\boldsymbol{x}) - (f_{best} - \xi), 0)]$$

The exploration-exploitation trade-off determined by ξ. Higher ξ values lead to more exploration.



Bayesian Optimizer

Sequential Model-Based Optimization