Welcome to NUMEN2015

Challenges in the investigation of double charge exchange nuclear reactions: towards neutrino-less double beta decay

Catania, December, 1-2, 2015

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F. Cappuzzello
Università di Catania and INFN LNS

The nuclear matrix elements of $0\nu\beta\beta$ decay and the NUMEN project at INFN-LNS

The NUMEN collaboration

INFN – LABORATORI NAZIONALI DEL SUD, CATANIA, ITALY
DIPARTIMENTO DI FISICA E ASTRONOMIA, UNIV. DI CATANIA, CATANIA, ITALY
INFN – SEZIONE DI CATANIA, CATANIA, ITALY
UNIV. DEGLI STUDI DI ENNA "KORE", ENNA, ITALY
INFN – SEZIONE DI GENOVA, GENOVA, ITALY
INFN – SEZIONE DI TORINO, TORINO, ITALY
INSTITUT FÜR THEORETISCHE PHYSIK, GIESSEN UNIVERSITY, GERMANY
DEP. OF PHYSICS AND HINP, THE UNIV. OF IOANNINA, IOANNINA, GREECE
INSTITUTO DE FISICA DA UNIVERSIDADE DE SAO PAULO, BRAZIL
INST. DE FISICA DA UNIV. FEDERAL FLUMINENSE, NITEROI, BRAZIL
AKDENIZ UNIVERSITY, ANTALYA, TURKEY

Forthcoming collaborations

Other INFN sections
INSTITUTO DE CIENCIAS NUCLEARES, UNAM, MEXICO
CICANUM, UNIVERSIDAD DE COSTA RICA, SAN JOSE, COSTA RICA
DÉPARTEMENT DE PHYSIQUE, UNIVERSITÉ HASSAN II – CASABLANCA, MOROCCO
CERN
BROKHAVEN NATIONAL LABORATORY
INSTITUTE OF MODERN PHYSICS, CHINESE ACADEMY OF SCIENCES, LANZHOU, CHINA
RCNP, OSAKA UNIVERSITY, OSAKA, JAPAN
BOCHUM UNIVERSITY, GERMANY

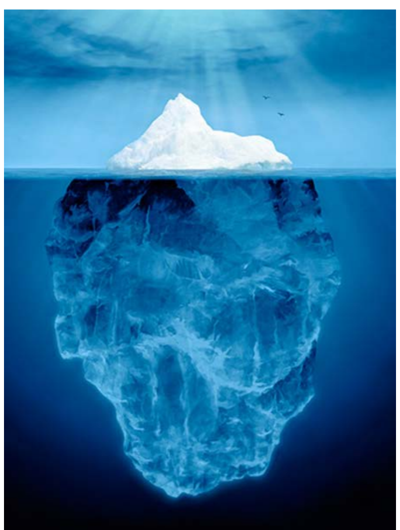
$$1/T^{0\nu}_{1/2}(0^+ \rightarrow 0^+) = G_{01}\left|M^{\beta\beta\,0\nu}\right|^2 \left|\frac{\langle m_\nu \rangle}{m_e}\right|^2$$

Spokespersons: F. Cappuzzello (cappuzzello@lns.infn.it) and C. Agodi (agodi@lns.infn.it)

Heavy-ion DCE

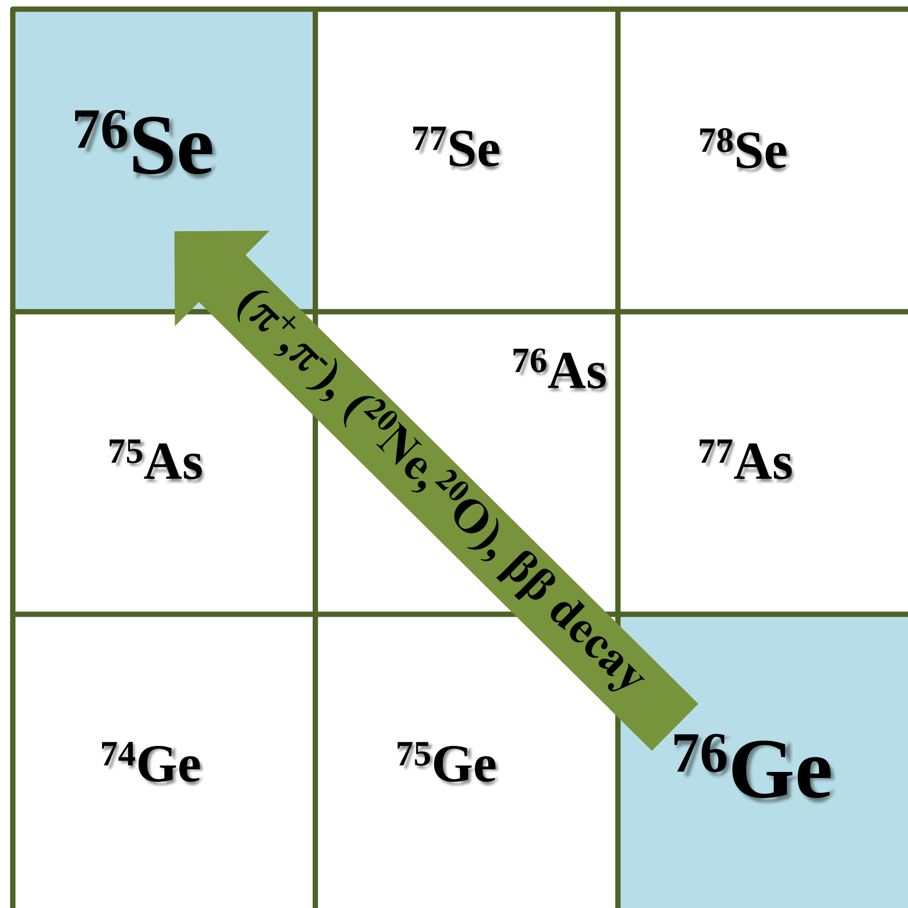
- ✓ ${}^{a}_{z}x_{n} + {}^{A}_{Z}X_{N} \rightarrow {}^{a}_{z-2}y_{n+2} + {}^{A}_{Z+2}Y_{N-2}$
- ✓ Induced by strong interaction
- ✓ Sequential nucleon transfer mechanism 4th order:
- ✓ Meson exchange mechanism 2nd order
- ✓ Possibility to go in both directions

From T. Uesaka talk at NN2015



Tiny amount of DGT strenght in low lying states

Sum rule almost exhausted by DGT Giant Mode



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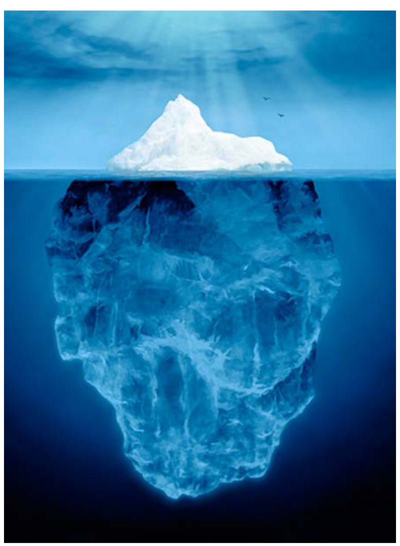

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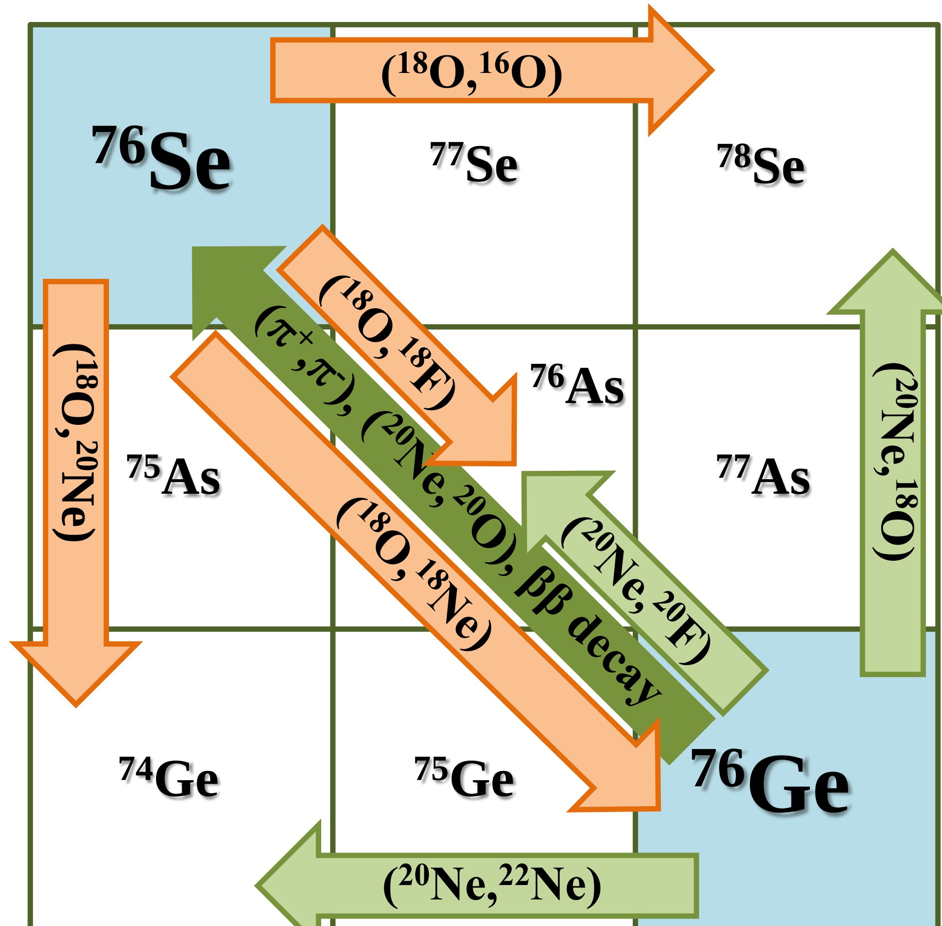


$0\nu\beta\beta$ vs HI-DCE

1. **Initial and final states:** Parent/daughter states of the $0\nu\beta\beta$ are the same as those of the target/residual nuclei in the DCE;

2. **Spin-Isospin mathematical structure** of the transition operator: Fermi, Gamow-Teller and rank-2 tensor together with higher L components are present in both cases;

3. **Large momentum available:** A linear momentum (100 MeV/c or so) is characteristic of both processes;

4. **Non-locality**: both processes are characterized by two vertices localized in two valence nucleons. In the ground to ground state transitions a pair of protons/neutrons is converted in a pair of neutrons/protons so the non-locality can be affected by basic pairing correlation length;

5. **In-medium** processes: both processes happen in the same nuclear medium, thus **quenching** phenomena are expected to be similar;

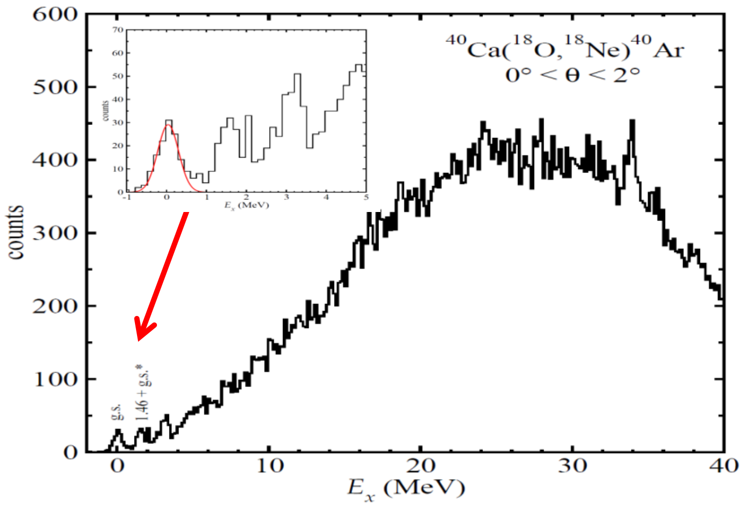
6. Relevant **off-shell propagation** in the intermediate channel.

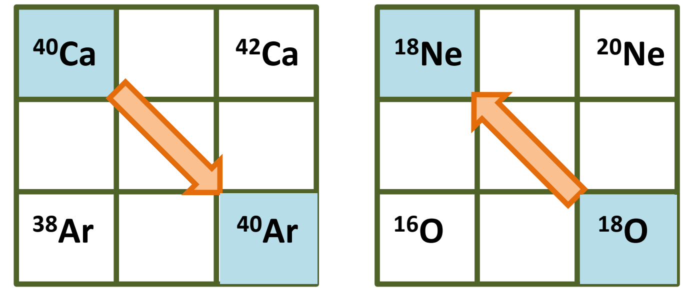
Qualitative is not enough

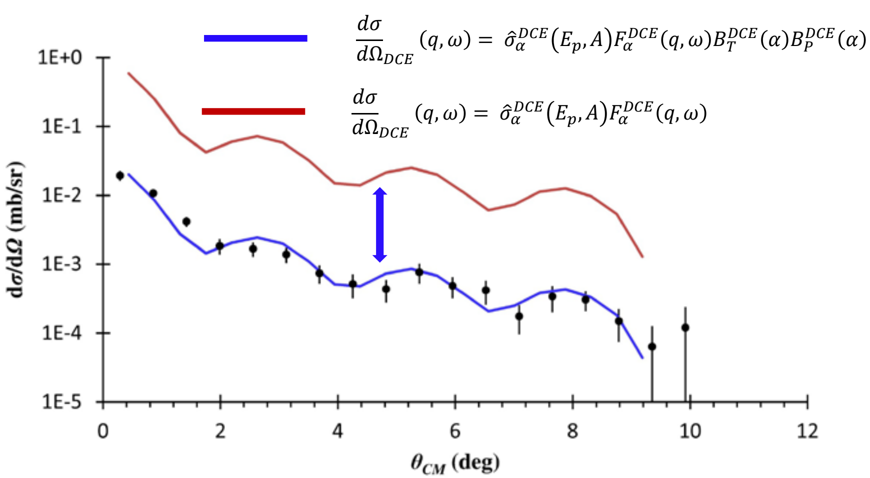
We need to access quantitative information with control of the error bars!

How far we are from that goal?

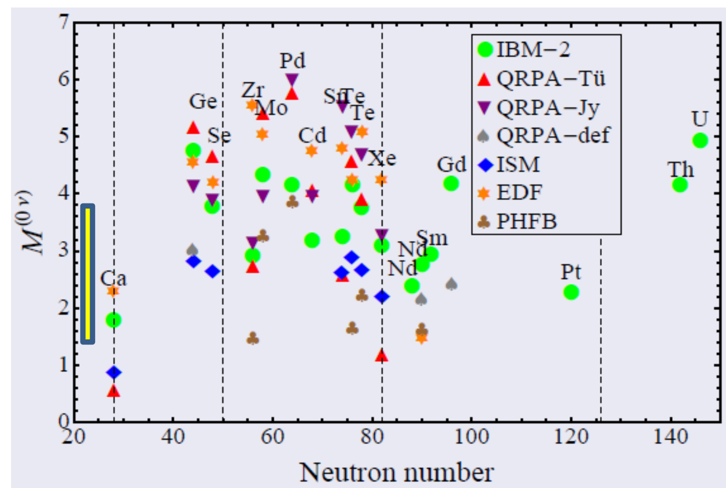
$^{40}Ca(^{18}O,^{18}Ne)^{40}Ar$ @ 270 MeV







F. Cappuzzello et al. Eur. Phys. J. A (2015) 51: 145



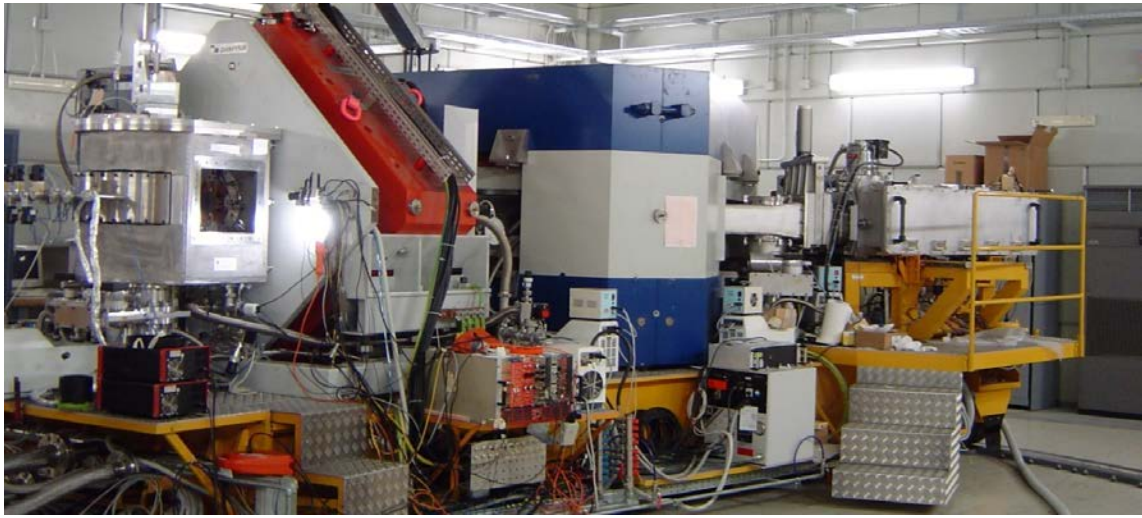
$$\left|M^{0\nu\beta\beta}\left(^{40}Ca\right)\right|^2 = 0.37 \pm 0.18$$

Pauli blocking about 0.14 for F and GT

Tools for DCE at LNS

The Superconducting Cyclotron

MAGNEX



Moving towards hot-cases:

Caveat

- The $(^{18}\mathrm{O},^{18}\mathrm{Ne})$ reaction is particularly advantageous, but it is of $\beta^+\beta^+$ kind;
- None of the reactions of $\beta^-\beta^-$ kind looks like as favourable as the $(^{18}\mathrm{O},^{18}\mathrm{Ne})$.
  $(^{18}\mathrm{Ne},^{18}\mathrm{O})$ requires a radioactive beam
  $(^{20}\mathrm{Ne},^{20}\mathrm{O})$ or $(^{12}\mathrm{C},^{12}\mathrm{Be})$ have smaller B(GT)
- The reaction Q-values are normally more negative than in the $^{40}\mathrm{Ca}$ case
- In some cases gas or implanted target will be necessary, e.g. $^{136}\mathrm{Xe}$ or $^{130}\mathrm{Xe}$
- In some cases the energy resolution is not enough to separate the g.s. from the excited states in the final nucleus $\rightarrow$ Coincident detection of γ-rays

Much higher beam current is needed

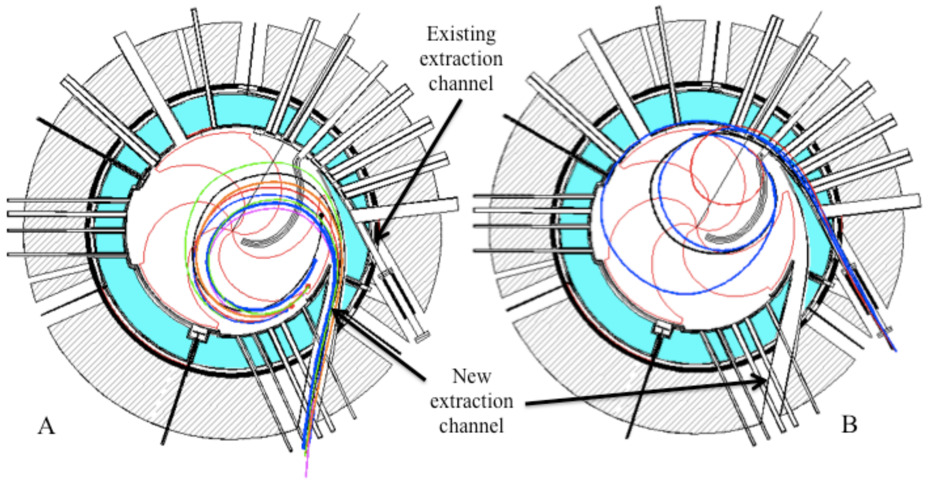
Present technology is not enough

We need to measure at very high rates of heavy ions!

How far we are from that goal?

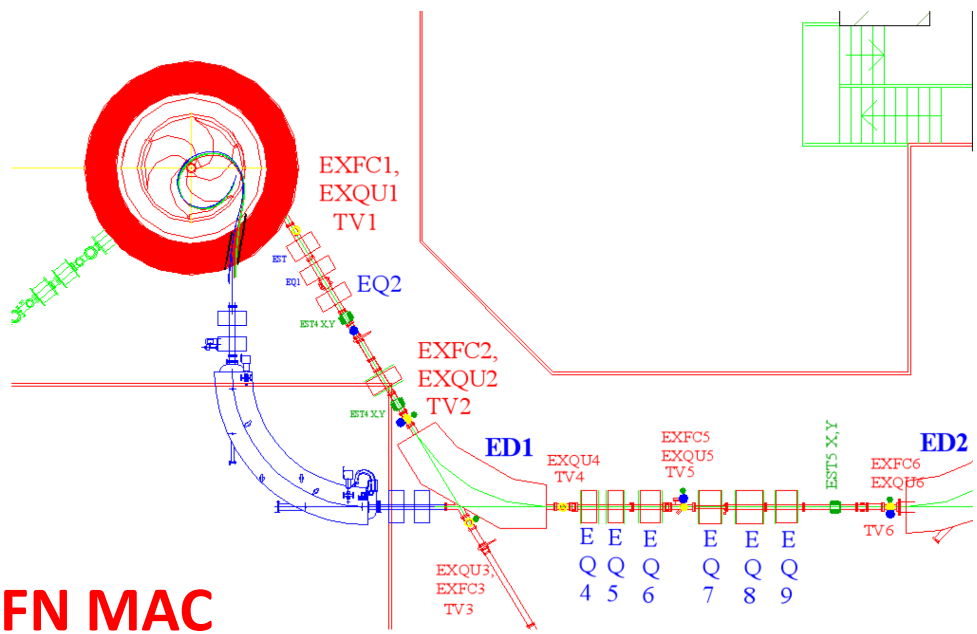
Major upgrade of LNS facilities: The CS accelerator

- The **CS** accelerator current (from 100 W to 5-10 kW);



Extraction by stripping

- The **beam transport line** transmission efficiency to nearly 100%

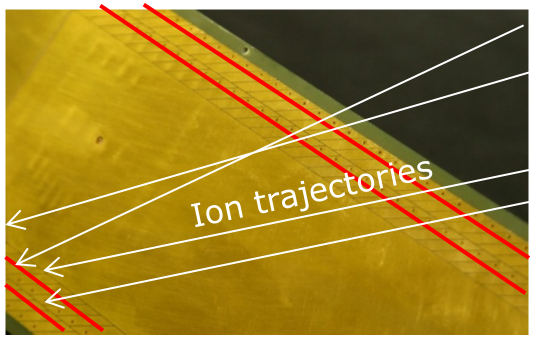


Project submitted to INFN MAC

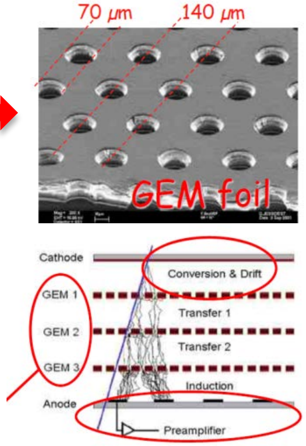
Major upgrade of LNS facilities: the MAGNEX spectrometer

- The **MAGNEX focal plane** detector rate (from 2 kHz to several MHz)

From multi-wire tracker

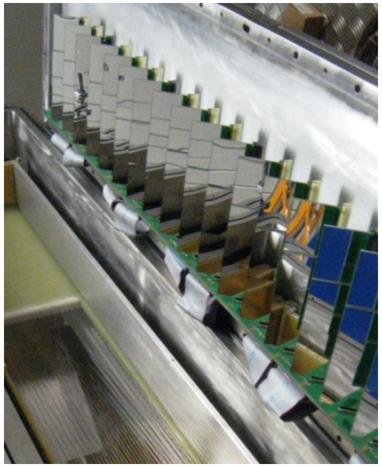


To micro-pattern tracker

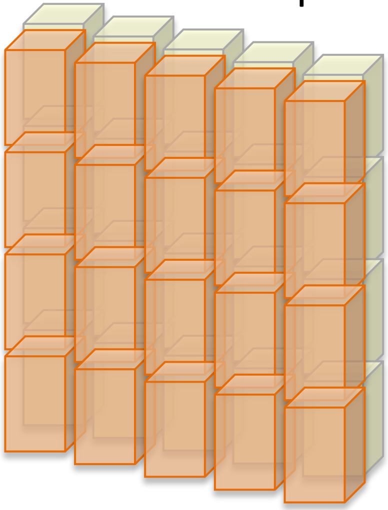


- **R&D key issue : GEM-based tracker at low pressure and wide dynamic range**
- **Collaboration with LNF and CERN**

From wall of **60** Si pad



To wall of **2500 SiC-SiC** pad **telescopes**



A big challenge!

0.9 M€ call approved by INFN CSN5 (SICILIA)
in collaboration with
CNR
STM microelectronics
FBK

The Phases of NUMEN project

- **Phase1**: The experimental feasibility
- **Phase2**: "hot" cases optimizing the experimental conditions and getting first results (approved)
- **Phase3**: The facility Upgrade (Cyclotron, MAGNEX, beam lines, …..):
- **Phase4** : The systematic experimental campaign

Preliminary time table

year	2013	2014	2015	2016	2017	2018	2019	2020	2021
Phase1	done								
Phase2				Approved					
Phase3									
Phase4									

Challenging some hot cases in Phase 2

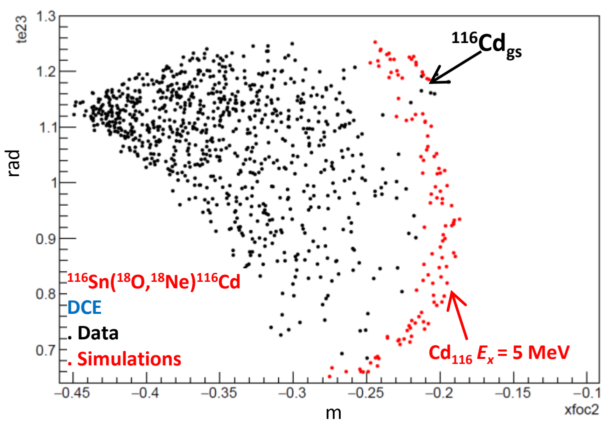
		2016				2017				2018			
Reaction	**Energy (MeV/u)**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
^{116}Sn (^{18}O,^{18}Ne) ^{116}Cd	15-30	**Approved experiment**											
^{116}Cd (^{20}Ne,^{20}O) ^{116}Sn	15-25	**Approved test**											
^{130}Te (^{20}Ne,^{20}O) ^{130}Xe	15-25												
^{76}Ge (^{20}Ne,^{20}O) ^{76}Se	15-25												
^{76}Se (^{18}O,^{18}Ne) ^{76}Ge	15-30												
^{106}Cd(^{18}O,^{18}Ne) ^{106}Pd	15-30												

Results from a test run on $^{116}Sn(^{18}O,^{18}Ne)^{116}Cd$ October 2015

- ✓ E_{beam}=15MeV/u, target thickness 400 μg/cm²
- ✓ 150μC integrated charge in 50 hours at 1 enA (including dead time 50%)
- ✓ Detector and beam transport performances studied up to 6 enA
- ✓ Realistic cross section estimate for DCE

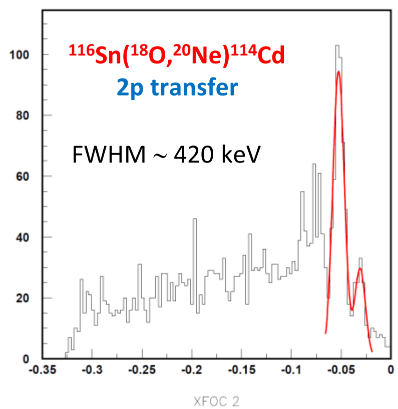
Preliminary

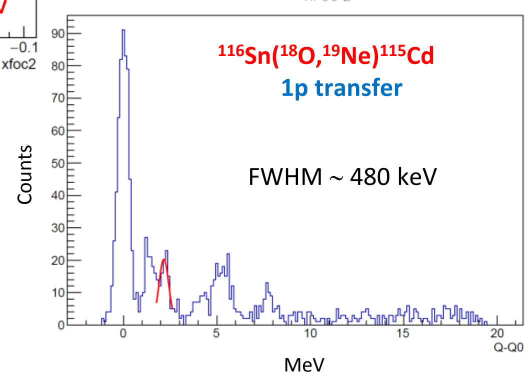
Good sensitivity for DCE



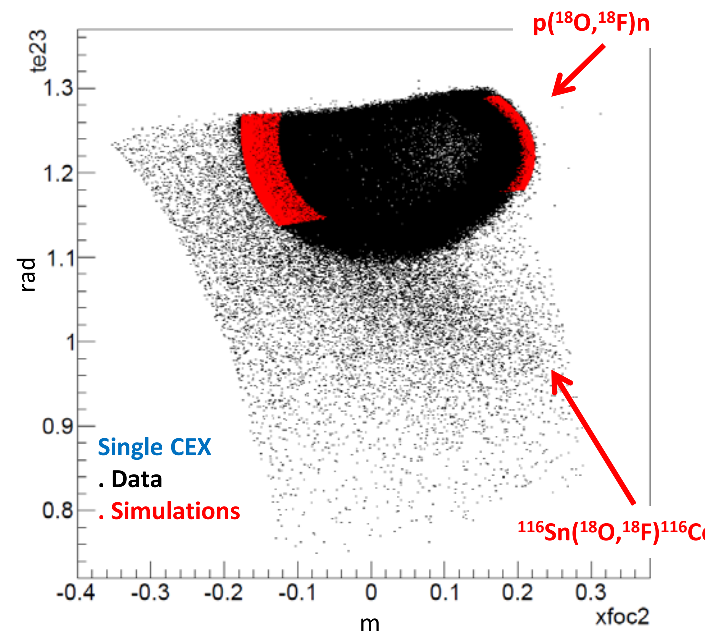
Perhaps 3 counts for

$^{116}Sn_{gs} \rightarrow ^{116}Cd_{gs}$





Good energy resolution and accuracy



Let’s enjoy the workshop