V annual scientific conference of young scientists and specialists, devoted to the 60th anniversary of JINR «Алушта-2016», Alushta, Crimea

ACCULINNA-2: new RIB facility at JINR

The report is presented by
Kostyleva Daria [a,b]
a – FLNR JINR
b – Dubna University

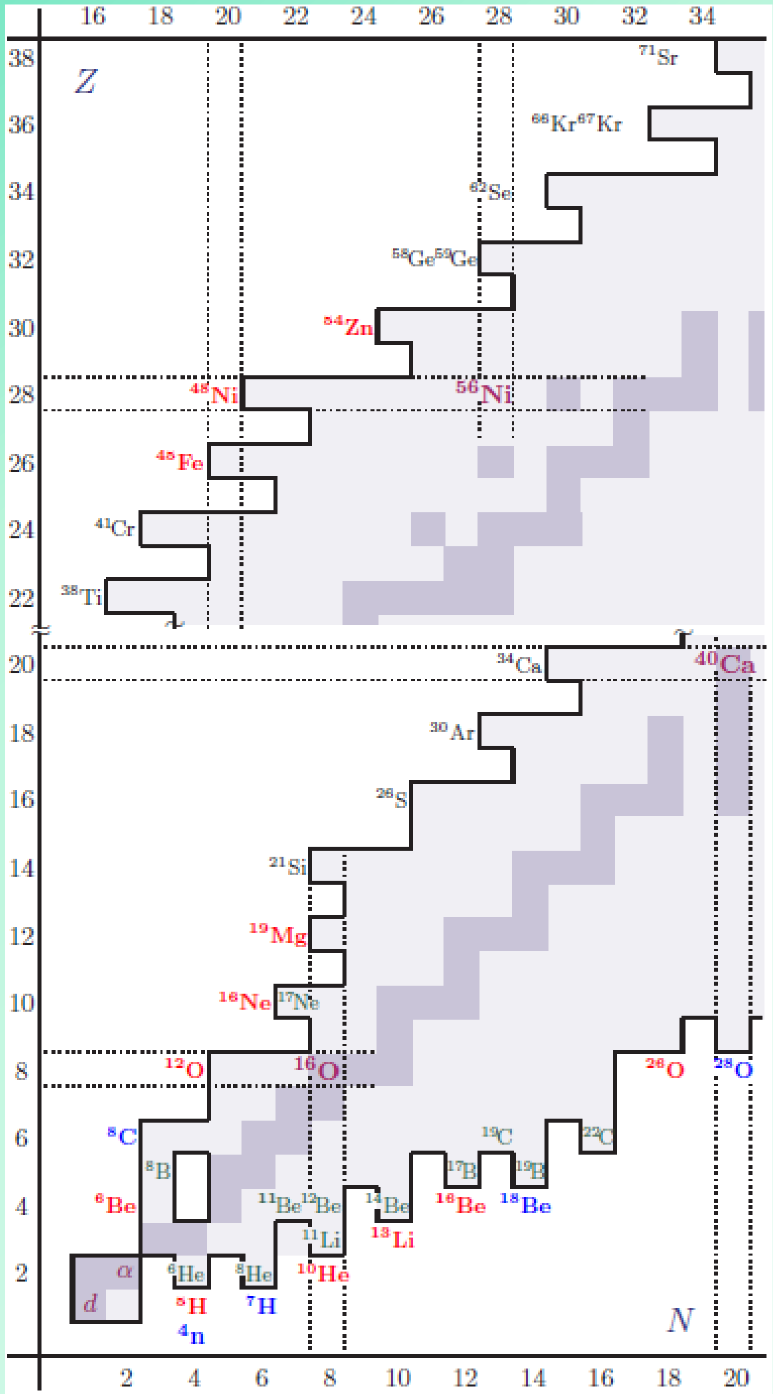
Introduction

- **Investigation and studies of exotic nuclei**

- **Exotic nuclei are located far from beta stability valley and close to neutron and proton drip lines***

- **Unusual characteristics comparing to the ones of the nuclei in the stability valley.**

* Drip line - near the proton or neutron drip lines the separation energy of a nucleon comes close to zero value, becomes negative at some point and nucleon “drips” out of the nucleus.

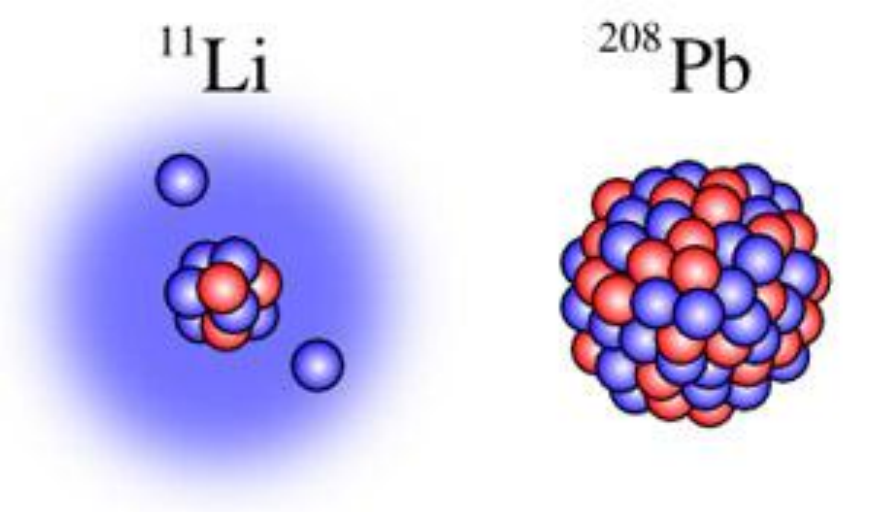


Report content

- Problems of exotic nuclei
- Separation techniques
- ACCULINNA @ FLNR JINR
- ACCULINNA-2 @ FLNR JINR
- Conclusions

Exotic nuclei phenomena

- Nucleon halos
- Exotic decays
- Soft excitation modes
- Shell breakdown

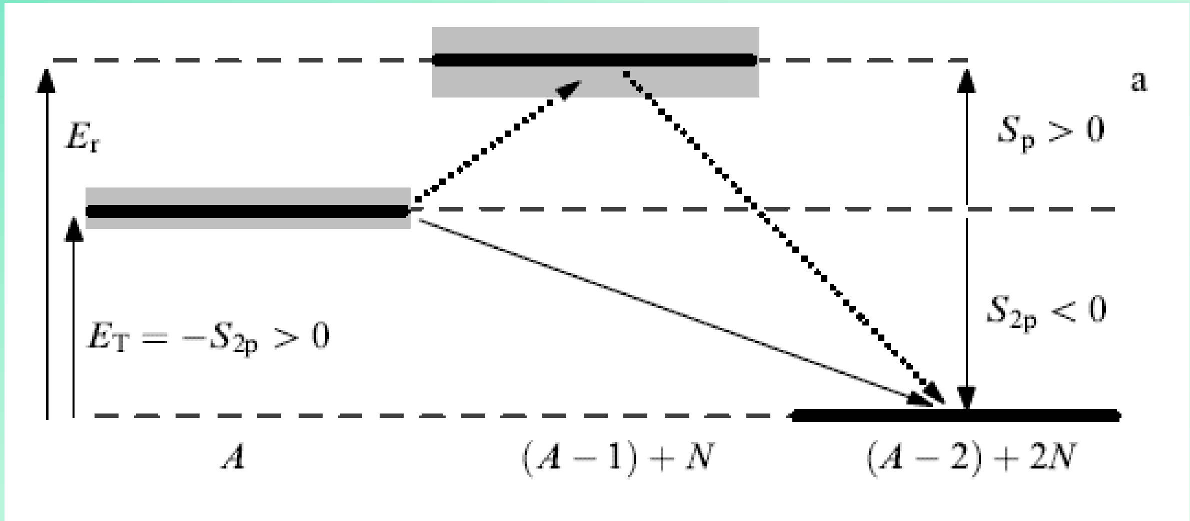


Other halo nuclei: ^{6}He, ^{8}He, ^{11}Be, ^{14}Be, ^{17}B, ^{19}B, ^{19}C, etc.

Exotic nuclei phenomena

- Nucleon halos
- Exotic decays: possible 2n and 4n radioactivity
- Soft excitation modes
- Shell breakdown

Two-proton radioactivity: discovery in 2002, ^{45}Fe

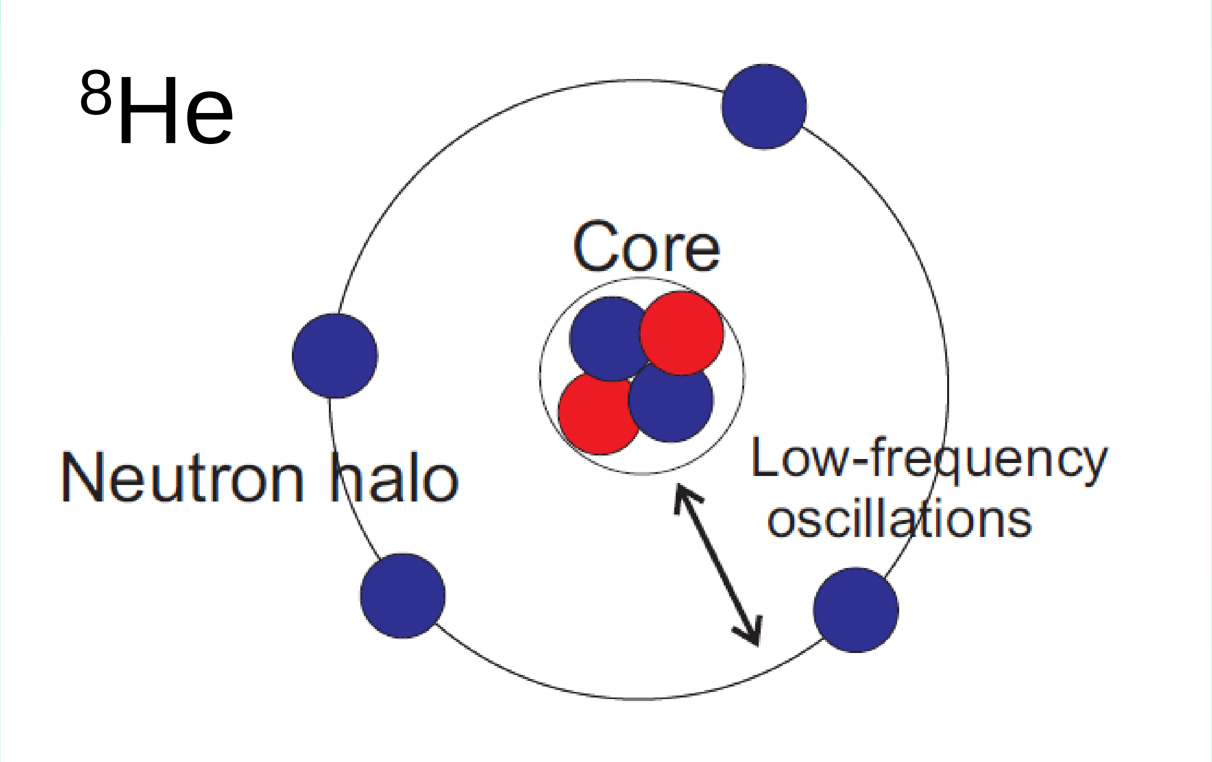


Now are also known: ^{19}Mg, ^{48}Ni, ^{54}Zn

Exotic nuclei phenomena

- Nucleon halos
- Exotic decays
- Soft excitation modes: low-lying dipole excitations
- Shell breakdown

Other SEM nuclei:
^{6}Be

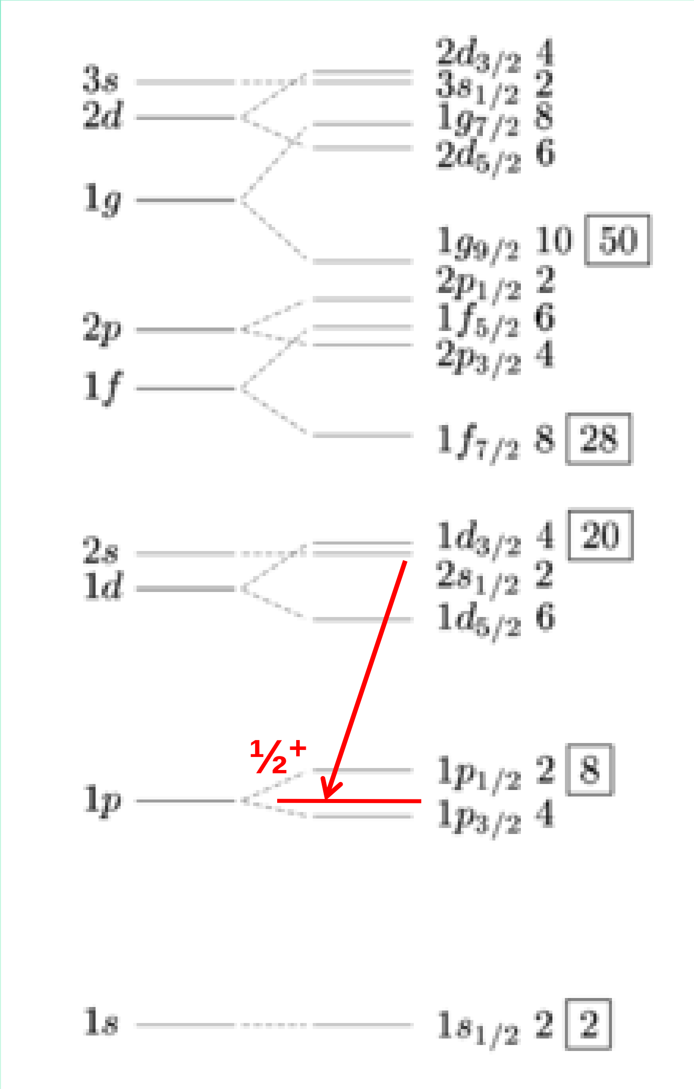


Exotic nuclei phenomena

- Nucleon halos
- Exotic decays
- Soft excitation modes
- Shell breakdown

^{11}Be predicted to have $1/2^-$

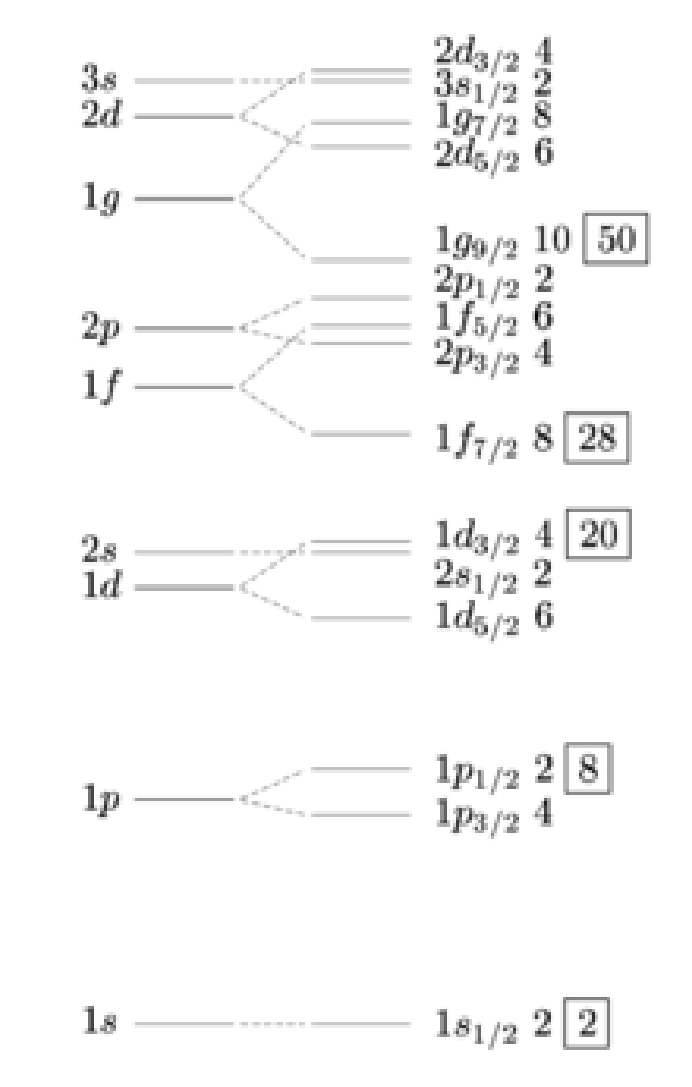
But it is $1/2^+$



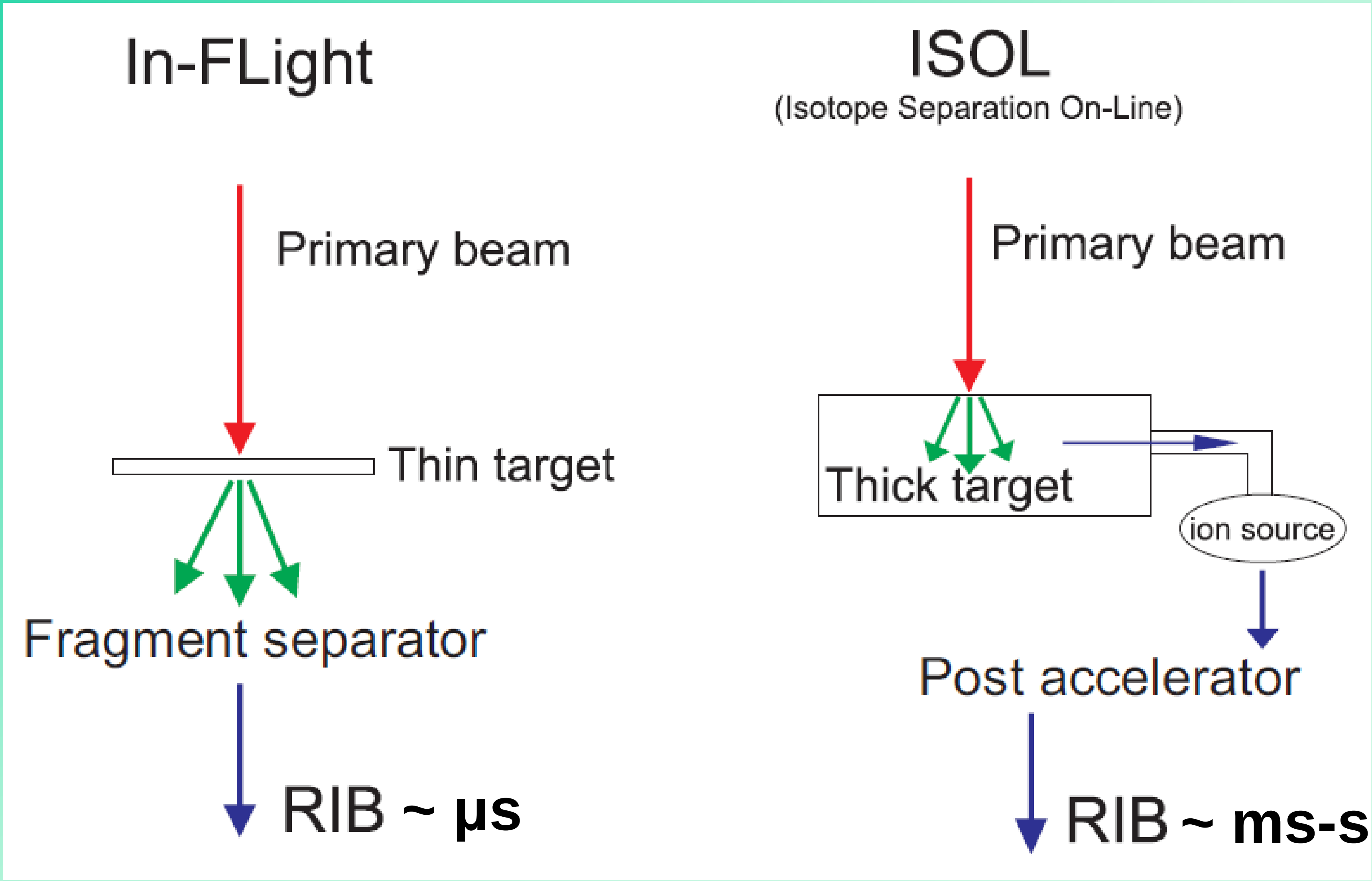
Exotic nuclei phenomena

- Nucleon halos
- Exotic decays
- Soft excitation modes
- Shell breakdown

In order to study these we need Radioactive Ion Beams (RIBs)!!!



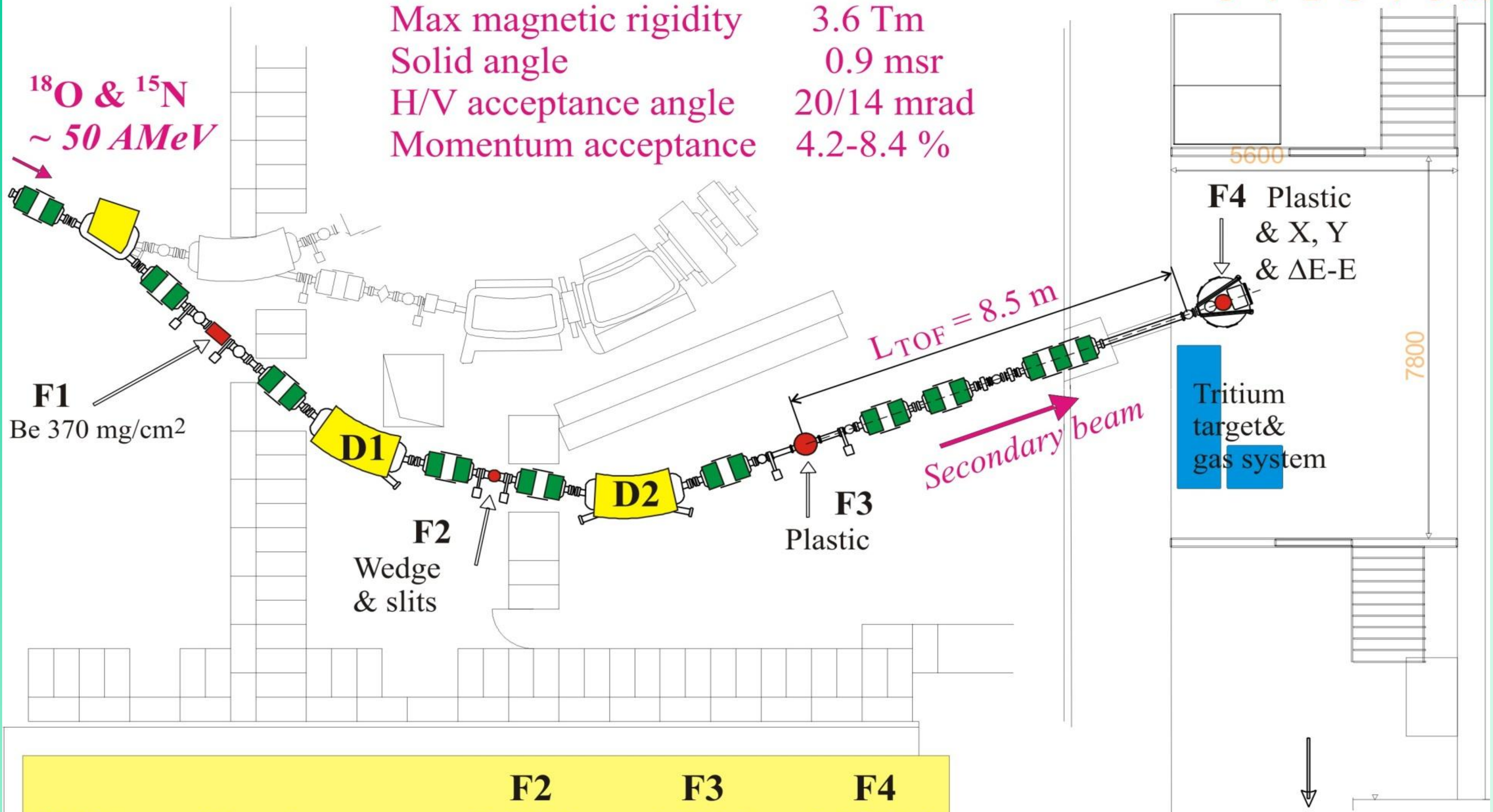
Separation techniques



In-Flight method is faster, but requires additional beam diagnostics!

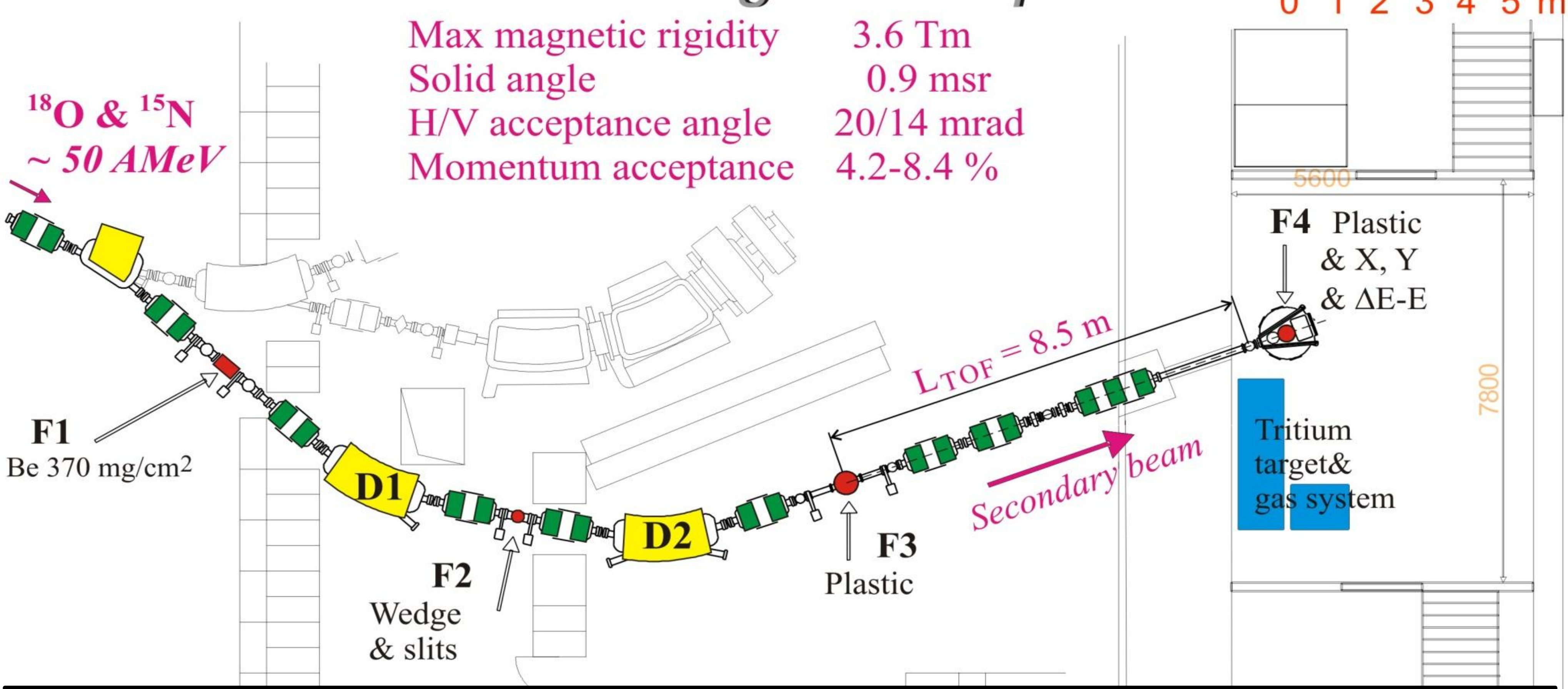
ACCULINNA Fragment Separator

Max magnetic rigidity	3.6 Tm
Solid angle	0.9 msr
H/V acceptance angle	20/14 mrad
Momentum acceptance	4.2-8.4 %



	F2	F3	F4
H/V magnification	0.5/2.0	1.0/1.0	2.25/1.6
Mom. dispersion, mm/%	4.0-18.0	–	–
Mom. resolution	0.003		
H/V RIB size, mm		8/10	20/16

ACCULINNA Fragment Separator



In-Flight

RIB energy ~ 20-35 MeV/A - direct reaction investigations:

- Elastic and inelastic scattering
- Transfer reactions (d,p), (t,p), (d,3He)
- Charge exchange (p,d), (p,t), (3He,d)
- QFS (α,2 α), (α,t α)

ACCULINNA important results

- **2n halo** configuration **in ^{6}He** (^{6}He at 151 MeV, 2n exchange with ^{4}He) [Ter-Akopian G et al. Phys Lett. B 426 251 (1998)]
- **^{5}H discovery** in p(^{6}He,2p)^{5}H and **ground state identification** in ^{3}H(^{3}H,p)^{5}H [Golovkov M S et al. Phys. Rev. C 72 064612 (2005)]
- **The lowest resonant state of ^{9}He** at energy ~ 2 MeV ($1/2^{-}$) above ^{8}He+n threshold in ^{2}H(^{8}He,p)^{9}He at 25 MeV/nucleon [Golovkov M S et al. Phys. Rev. C 76 021605(R) (2007)]
- **The ground state of ^{10}He** at energy ~ 2.1 MeV (0^{+}) in ^{3}H(^{8}He,p)^{10}He [Sidorchuk S I et al. Phys. Rev. Lett/ 108 202502 (2012)]

ACCULINNA important results

- **2n halo** configuration **in ^{6}He** (^{6}He at 151 MeV, 2n exchange with ^{4}He) [Ter-Akopian G et al. Phys Lett. B 426 251 (1998)]
- **^{5}H discovery** in p(^{6}He,2p)^{5}H and **ground state identification** in ^{3}H(^{3}H,p)^{5}H [Golovkov M S et al. Phys. Rev. C 72 064612 (2005)]
- **The lowest resonant state of ^{9}He** at energy ~ 2 MeV ($1/2^{-}$) above ^{8}He+n threshold in ^{2}H(^{8}He,p)^{9}He at 25 MeV/nucleon [Golovkov M S et al. Phys. Rev. C 76 021605(R) (2007)]
- **The ground state of ^{10}He** at energy ~ 2.1 MeV (0^{+}) in ^{3}H(^{8}He,p)^{10}He [Sidorchuk S I et al. Phys. Rev. Lett/ 108 202502 (2012)]

ACCULINNA important results

- **2n halo** configuration **in ^{6}He** (^{6}He at 151 MeV, 2n exchange with ^{4}He) [Ter-Akopian G et al. Phys Lett. B 426 251 (1998)]
- **^{5}H discovery** in p(^{6}He,2p)^{5}H and **ground state identification** in ^{3}H(^{3}H,p)^{5}H [Golovkov M S et al. Phys. Rev. C 72 064612 (2005)]
- **The lowest resonant state of ^{9}He** at energy ~ 2 MeV ($1/2^{-}$) above ^{8}He+n threshold in ^{2}H(^{8}He,p)^{9}He at 25 MeV/nucleon [Golovkov M S et al. Phys. Rev. C 76 021605(R) (2007)]
- **The ground state of ^{10}He** at energy ~ 2.1 MeV (0^{+}) in ^{3}H(^{8}He,p)^{10}He [Sidorchuk S I et al. Phys. Rev. Lett/ 108 202502 (2012)]

ACCULINNA important results

- **2n halo** configuration **in ^{6}He** (^{6}He at 151 MeV, 2n exchange with ^{4}He) [Ter-Akopian G et al. Phys Lett. B 426 251 (1998)]
- **^{5}H discovery** in p(^{6}He,2p)^{5}H and **ground state identification** in ^{3}H(^{3}H,p)^{5}H [Golovkov M S et al. Phys. Rev. C 72 064612 (2005)]
- **The lowest resonant state of ^{9}He** at energy ~ 2 MeV (1/2$^-$) above ^{8}He+n threshold in ^{2}H(^{8}He,p)^{9}He at 25 MeV/nucleon [Golovkov M S et al. Phys. Rev. C 76 021605(R) (2007)]
- **The ground state of ^{10}He** at energy ~ 2.1 MeV (0$^+$) in ^{3}H(^{8}He,p)^{10}He [Sidorchuk S I et al. Phys. Rev. Lett/ 108 202502 (2012)]

ACCULINNA important results

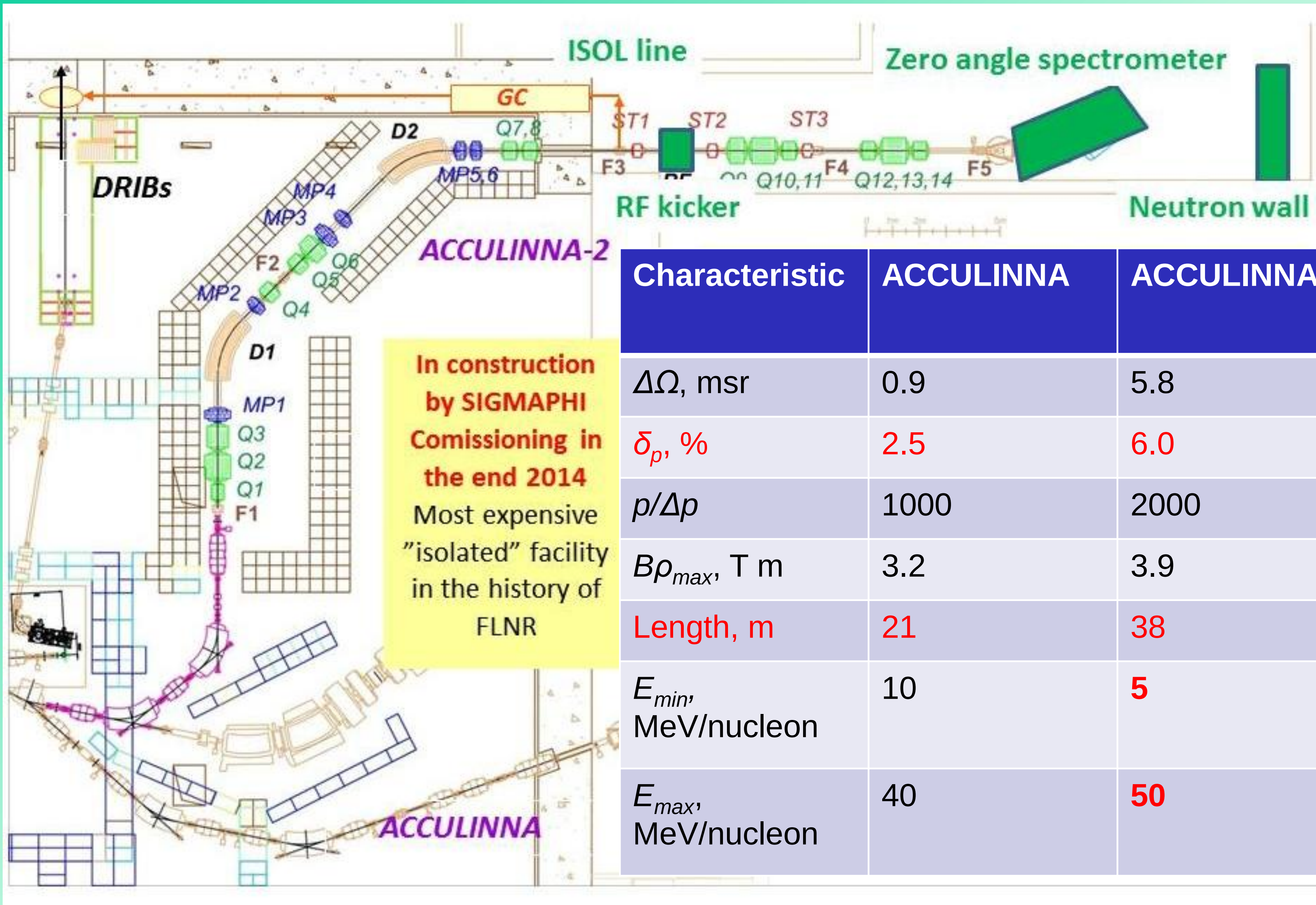
- **2n halo** configuration **in ^{6}He** (^{6}He at 151 MeV, 2n exchange with ^{4}He) [Ter-Akopian G et al. Phys Lett. B 426 251 (1998)]
- **^{5}H discovery** in p(^{6}He,2p)^{5}H and **ground state identification** in ^{3}H(^{3}H,p)^{5}H [Golovkov M S et al. Phys. Rev. C 72 064612 (2005)]
- **The lowest resonant state of ^{9}He** at energy ~ 2 MeV ($1/2^{-}$) above 8He+n threshold in ^{2}H(^{8}He,p)^{9}He at 25 MeV/nucleon [Golovkov M S et al. Phys. Rev. C 76 021605(R) (2007)]
- **The ground state of ^{10}He** at energy ~ 2.1 MeV (0^{+}) in ^{3}H(^{8}He,p)^{10}He [Sidorchuk S I et al. Phys. Rev. Lett/ 108 202502 (2012)]

the results of ACCULINNA scientific group are accepted by the international scientific community!

Continue of investigations? ACCULINNA-2!

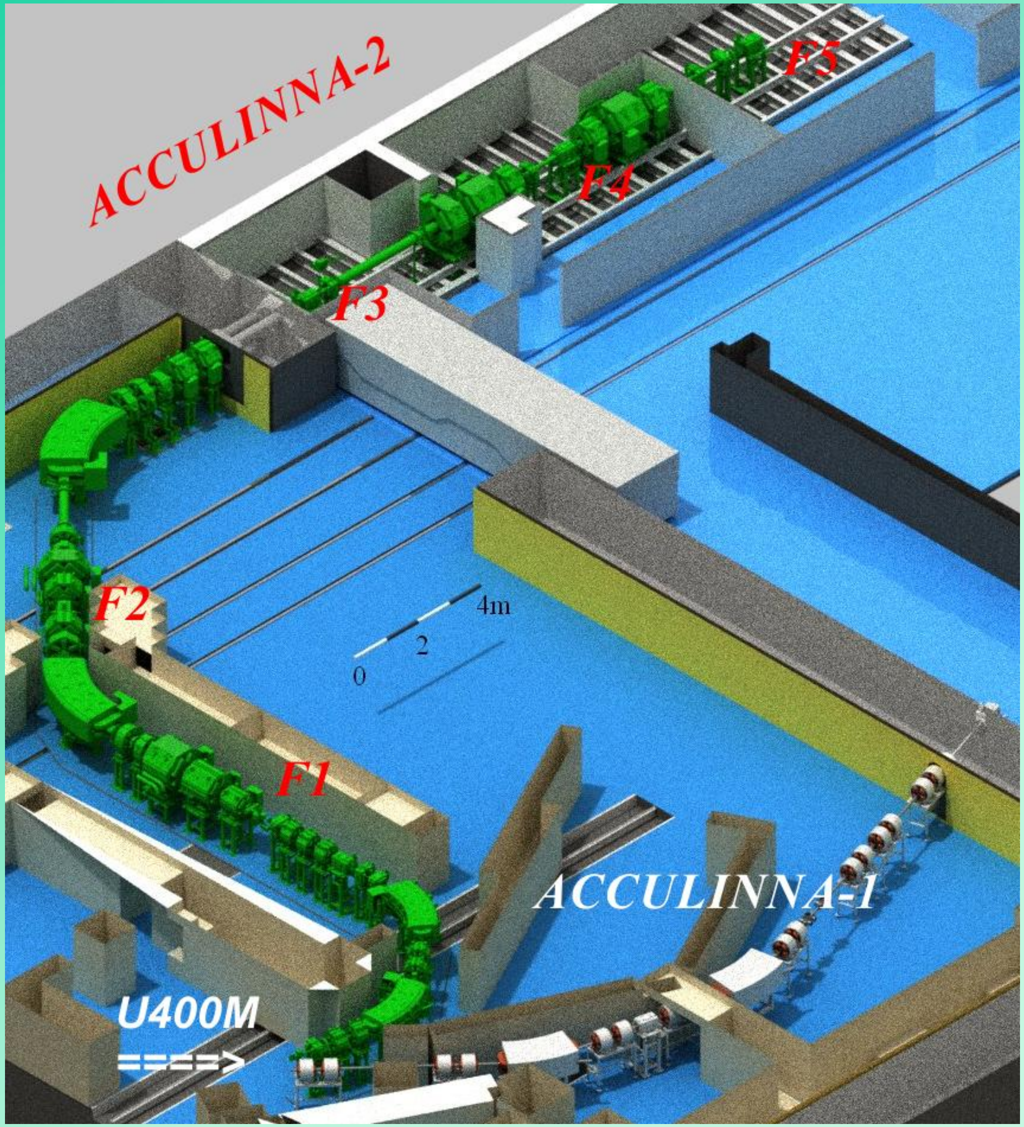
New coming facility ACCULINNA-2 is going to move toward lower energies to facilitate complete kinematics measurements resulting in the observation of very clean, background-free spectra of nuclei lying in the region and beyound the neutron and proton driplines.

ACCULINNA-2



Characteristic	ACCULINNA	ACCULINNA-2
$\Delta\Omega$, msr	0.9	5.8
δ_p, %	2.5	6.0
$p/\Delta p$	1000	2000
$B\rho_{max}$, T m	3.2	3.9
Length, m	21	38
E_{min}, MeV/nucleon	10	**5**
E_{max}, MeV/nucleon	40	**50**

ACCULINNA-2: planned and now



ACCULINNA-2 father development

- Zero-angle spectrometer (dipole magnet D3) – to separate secondary beam from the projectile-like reaction products
- RF-kicker – the velocity filter aimed to purify proton-rich RIBs
- Accelerator upgrade – increase intensity/energy of primary beam

ACCULINNA-2 father development

- Zero-angle spectrometer (dipole magnet D3) – to separate secondary beam from the projectile-like reaction products
- RF-kicker – the velocity filter aimed to purify proton-rich RIBs
- Accelerator upgrade – increase intensity/energy of primary beam

ACCULINNA-2 father development

- Zero-angle spectrometer (dipole magnet D3) – to separate secondary beam from the projectile-like reaction products
- RF-kicker – the velocity filter aimed to purify proton-rich RIBs
- Accelerator upgrade – increase intensity/energy of primary beam

ACCULINNA-2 start up research program

1. **Neutron haloes.**

   Detailed study of the excitation spectra of ^{13}Be, ^{14}Be and heavy carbon nuclei ^{19}C, ^{20}C, ^{21}C via transfer reactions in complete kinematic measurements.

2. **Nuclei close to the doubly magic ^{24}O.**

   Transfer reactions (t,p), (d,p), (p,^{2}He), (d,^{3}He) and charge-exchange reactions (d,2p), (t,^{3}He)

3. **Proton drip-line nuclei in vicinity of atomic numbers Z = 10 – 20.**

Conclusions

- The ACCULINNA-2 facility is planned to occupy a specific "ecological niche" among the world leading facilities providing the unique opportunities for RIBs investigations.