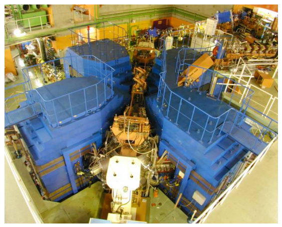
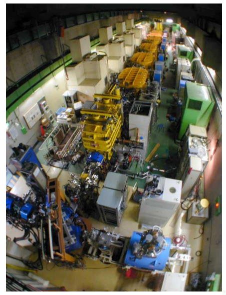
Layout of RIKEN RI beam factory (RIBF) in 2007

RIPS

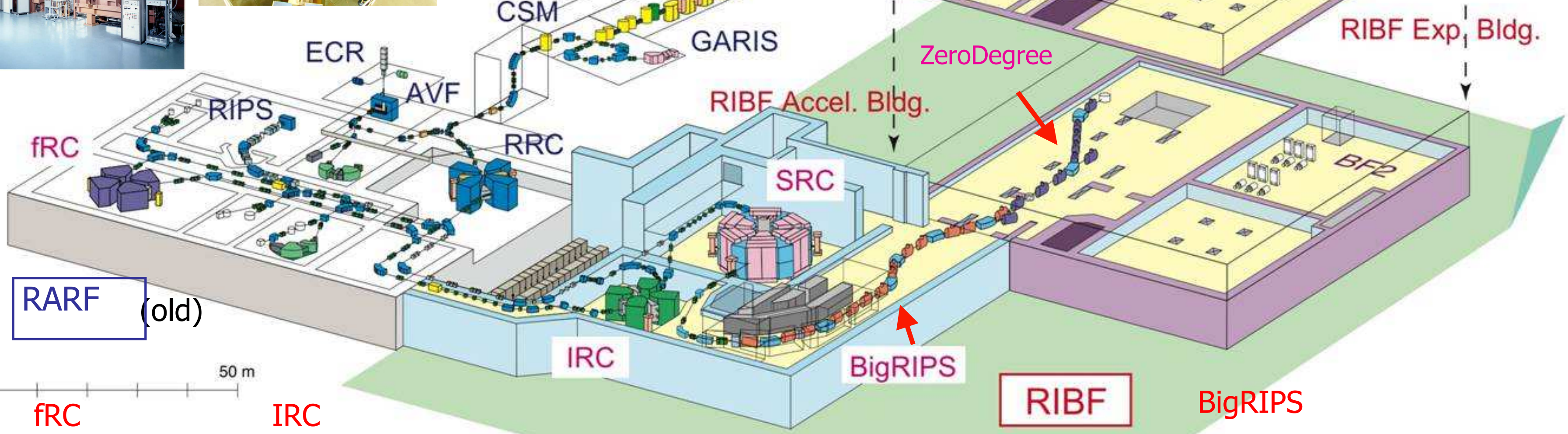
RRC



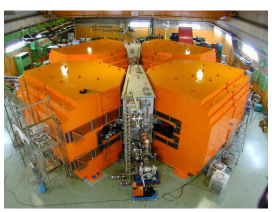


RILAC

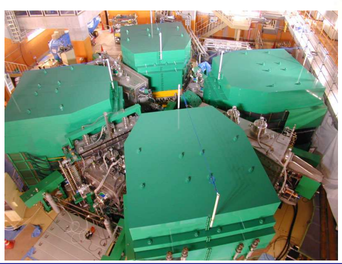
ZeroDegree



fRC

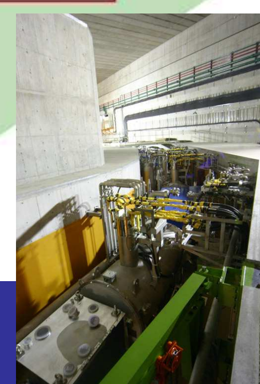


IRC

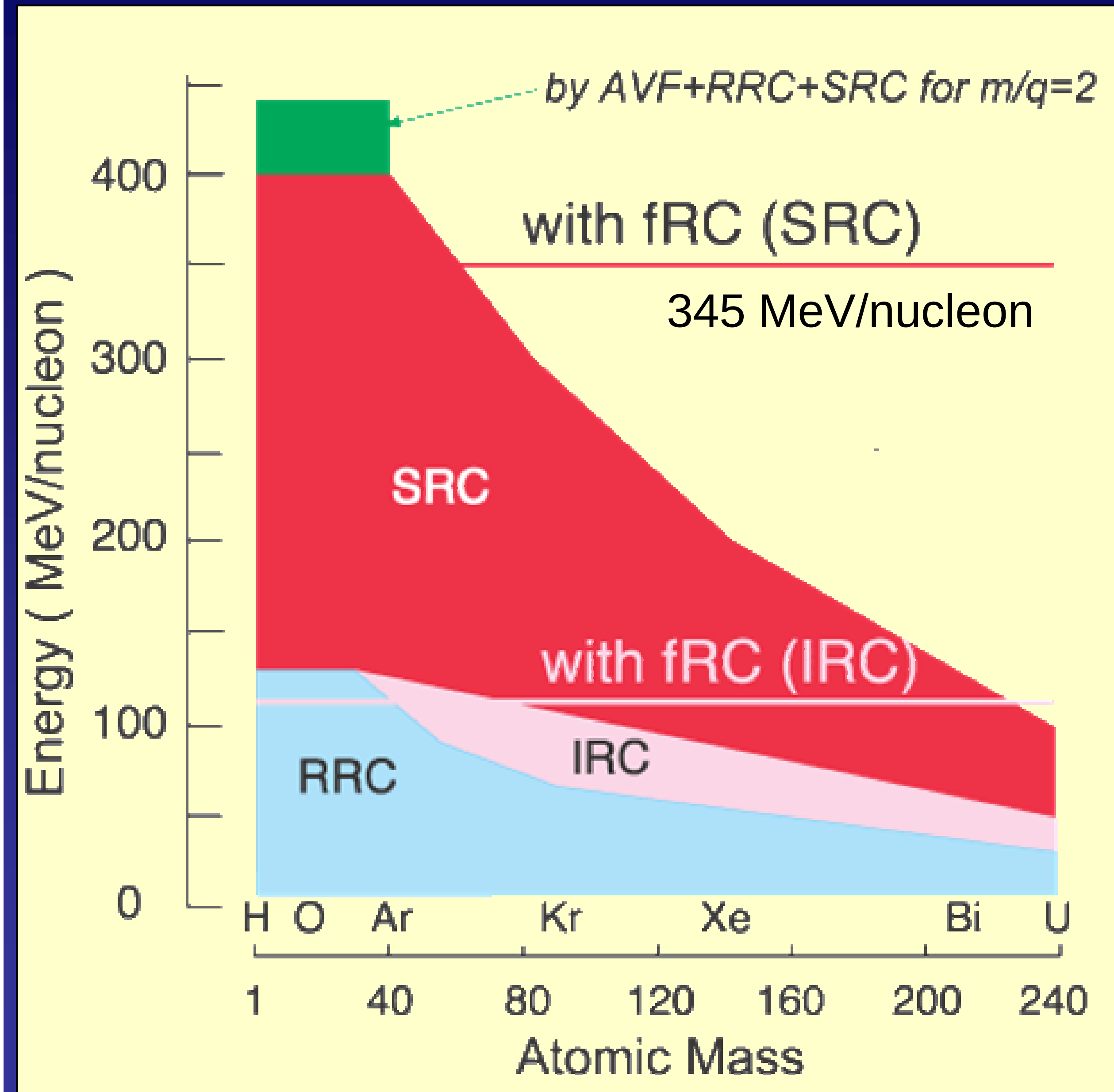


SRC

BigRIPS



Performance of RIBF



p~U
345 MeV/u
1 pμA ($6x10^{12}$ /sec)
(goal)

Projectile fragmentation
In-flight fission of U

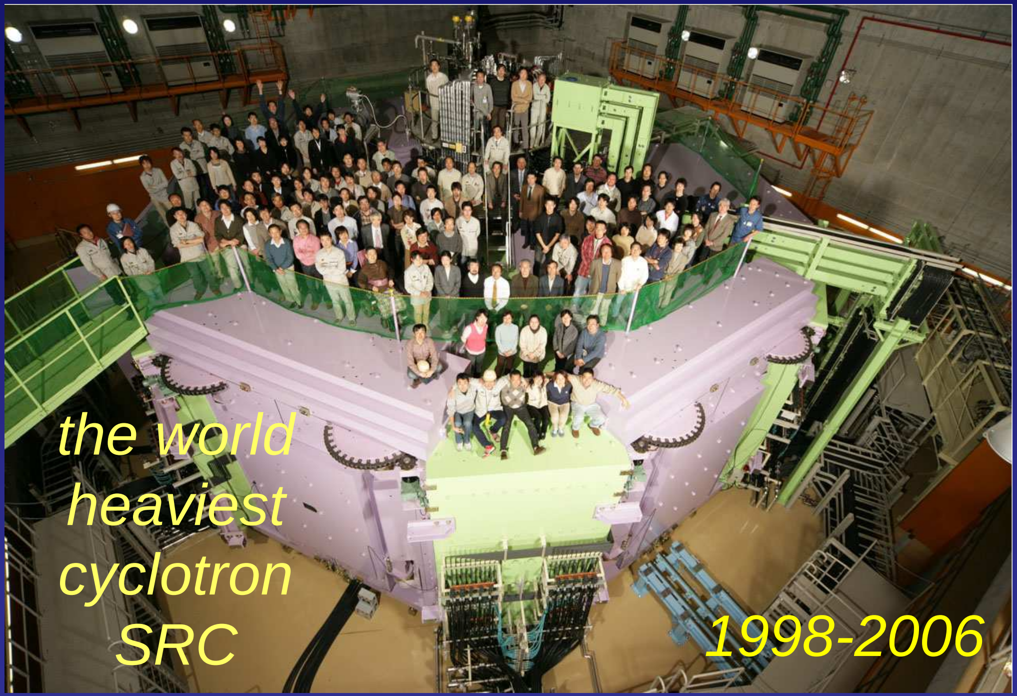
γ–ray spectroscopy at RIBF

2008/1/23-25

Joint JUSTIPEN-LACM Meeting

@Oak Ridge

AOI Nori, RIKEN



* RIKEN RIBF, BigRIPS, ZeroDegree
* γ–spectroscopy at RIBF
* Beam Intensity

γ-ray spectroscopy at RIBF

2008/1/23-25

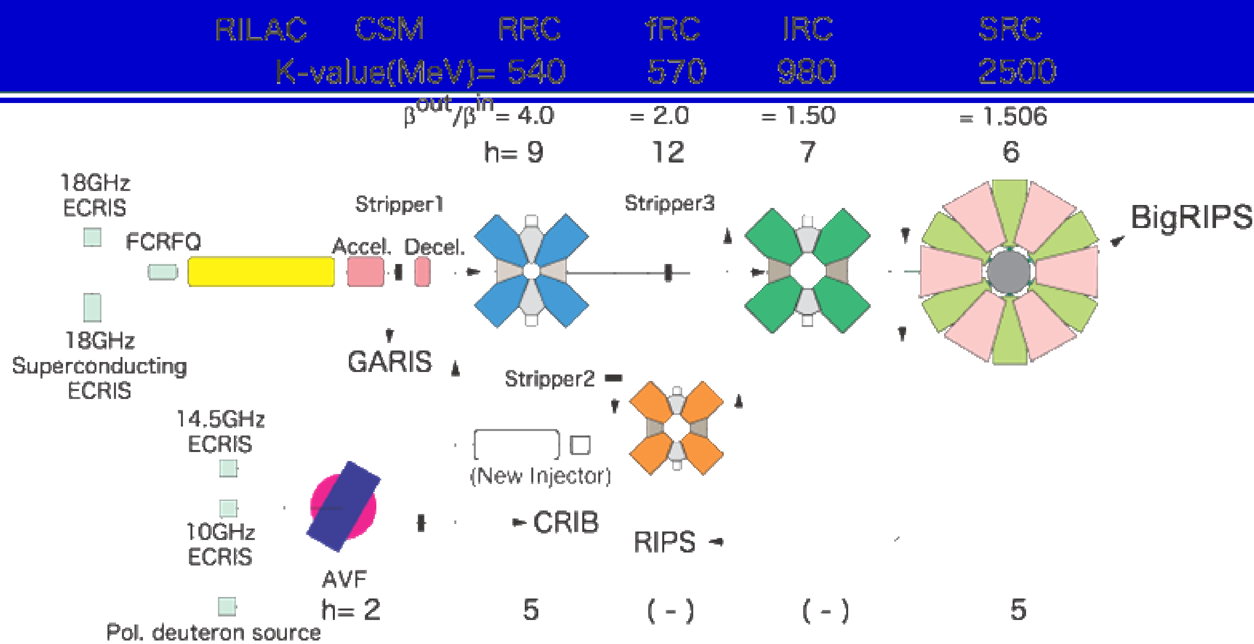
Joint JUSTIPEN-LACM Meeting

@Oak Ridge

AOI Nori, RIKEN

- RIKEN RIBF, BigRIPS, ZeroDegree
- γ-ray spectroscopy at RIBF
- Expected Primary and Secondary Beam Intensity

Configuration of the RIBF accelerator complex



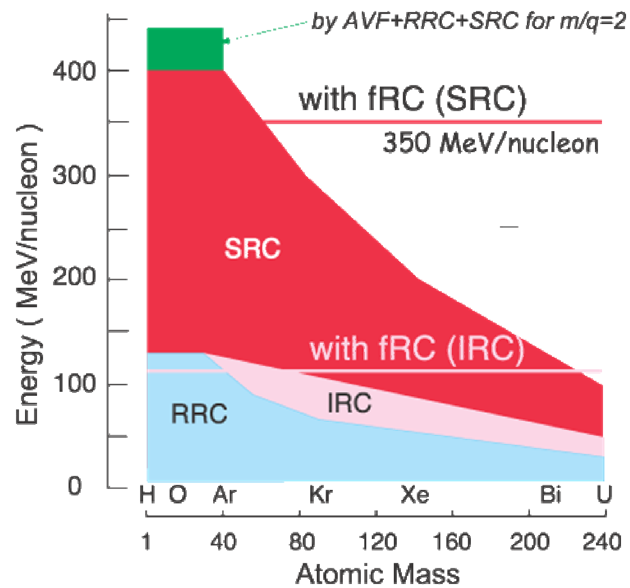
Several modes in the cascade operation

Goal performance of RIBF cyclotrons

- Energy= 345 MeV/u up to U ions
  400 MeV/u for light A ions
- Intensity= 1 pμA up to U ions (6×10^{12} par./sec)

  -> Production reaction: in-flight fission of U beams as well as projectile fragmentation

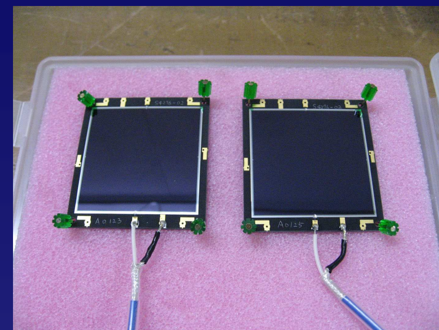
- Max. beam power= 83.3 kW (^{238}U at 350MeV/u)



Standard beam-line detectors at BigRIPS/ZeroDegree focuses

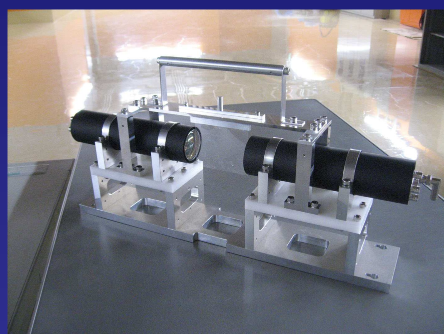
DL-PPAC (position)

Si (ΔE) @F7, F2, F3

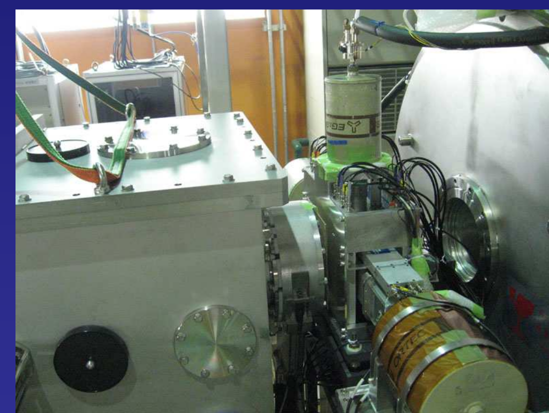


NaI (E) @F7

Plastic scinti. (TOF)



Ge @F7 for isomer γ-decay measurement (Isomer PID)



MUSIC (ΔE) @F7, (F2, F3)

Intensity monitor (primary beams) @F0

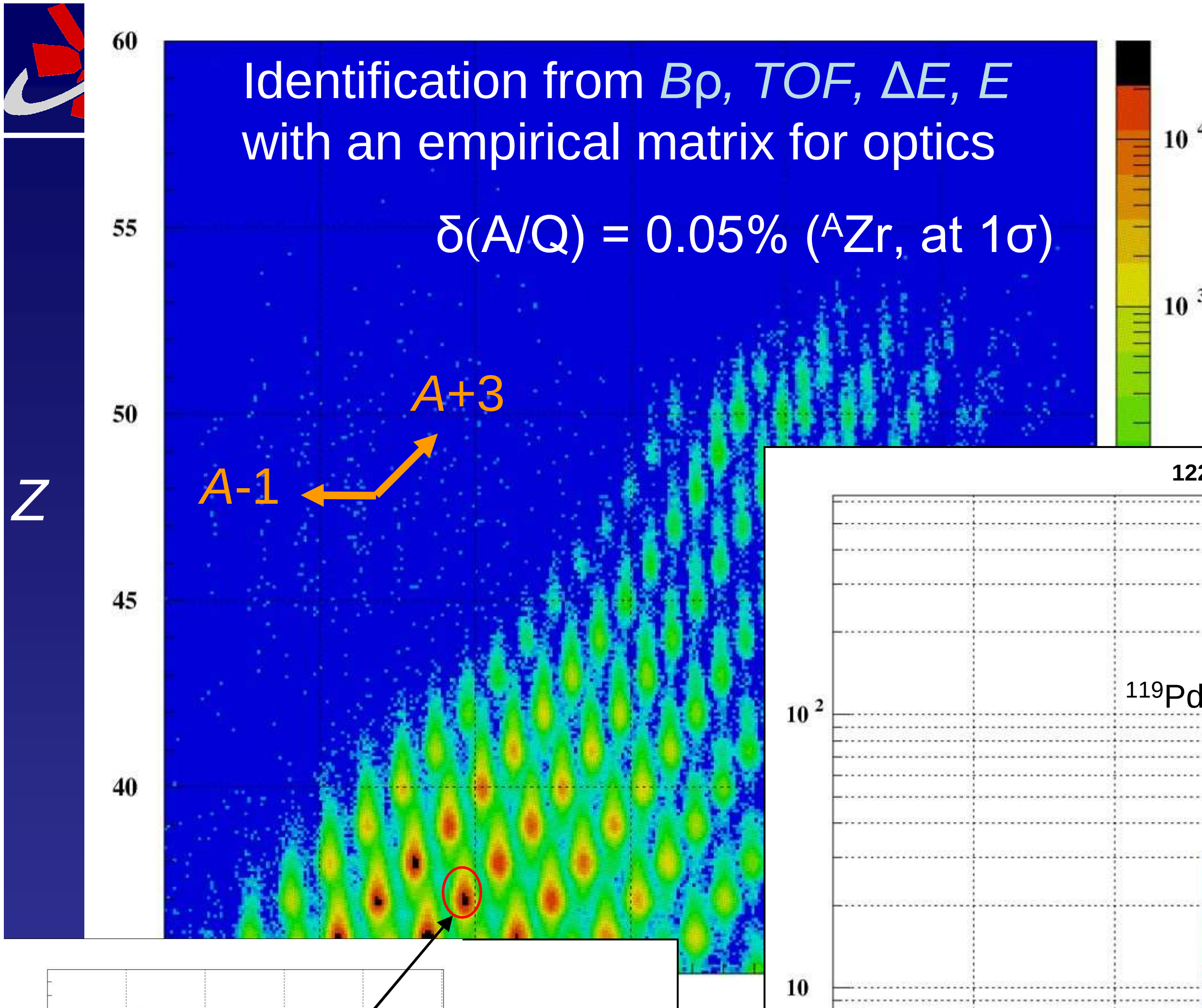
Plastic

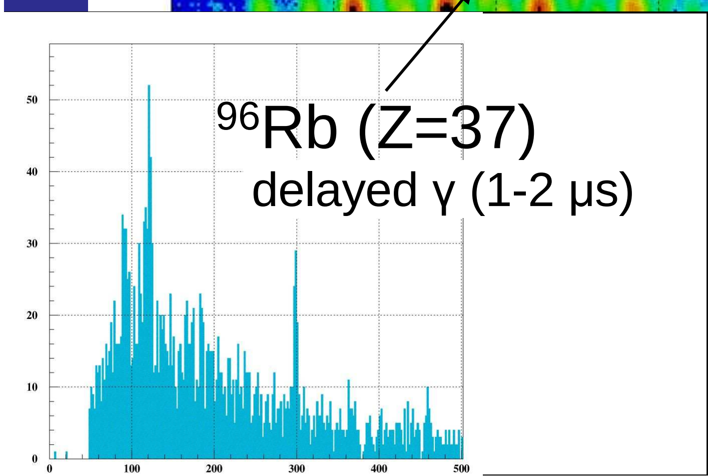
Si

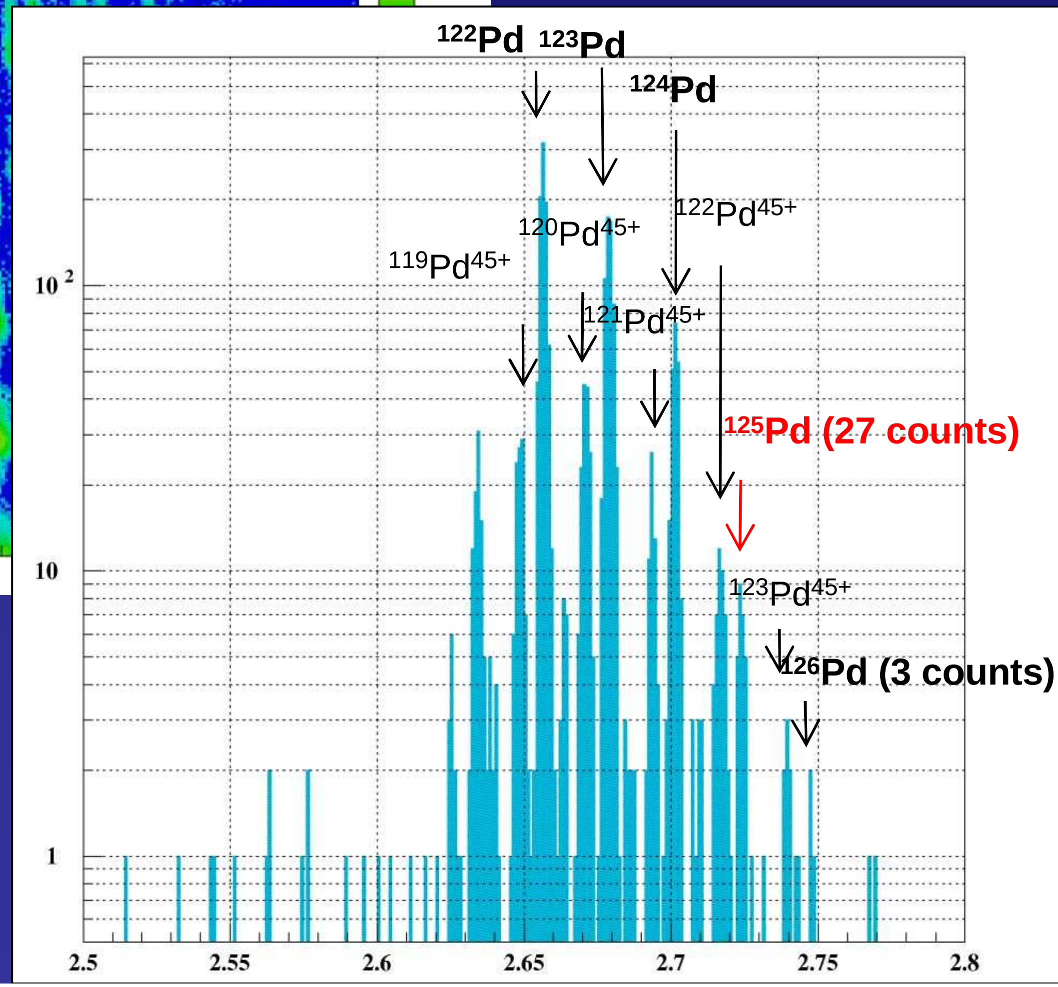
FCT

June 2007

3.6×10^{12} $^{238}U^{86+}$ beam
(4x10^{7} s^{-1}, -1day)
- 10^{-5} of the goal







Recent Achievements and Commissioning Runs at BigRIPS

- Dec. 28th, 2006 — First beam from SRC

  $^{27}Al^{10+}$ at 345 MeV/u

- Mar. 13th, 2007 — First RI-beam production at BigRIPS using 345*A* MeV ^{86}Kr beam
- Mar. 24th — First ^{238}U beam 345 MeV/u
- Mar. 27th — First RI-beam using U in-flight fission at RIBF
- May 16-Jun. 3 — ^{238}U ~ 0.03 pnA max

  New Isotope Search

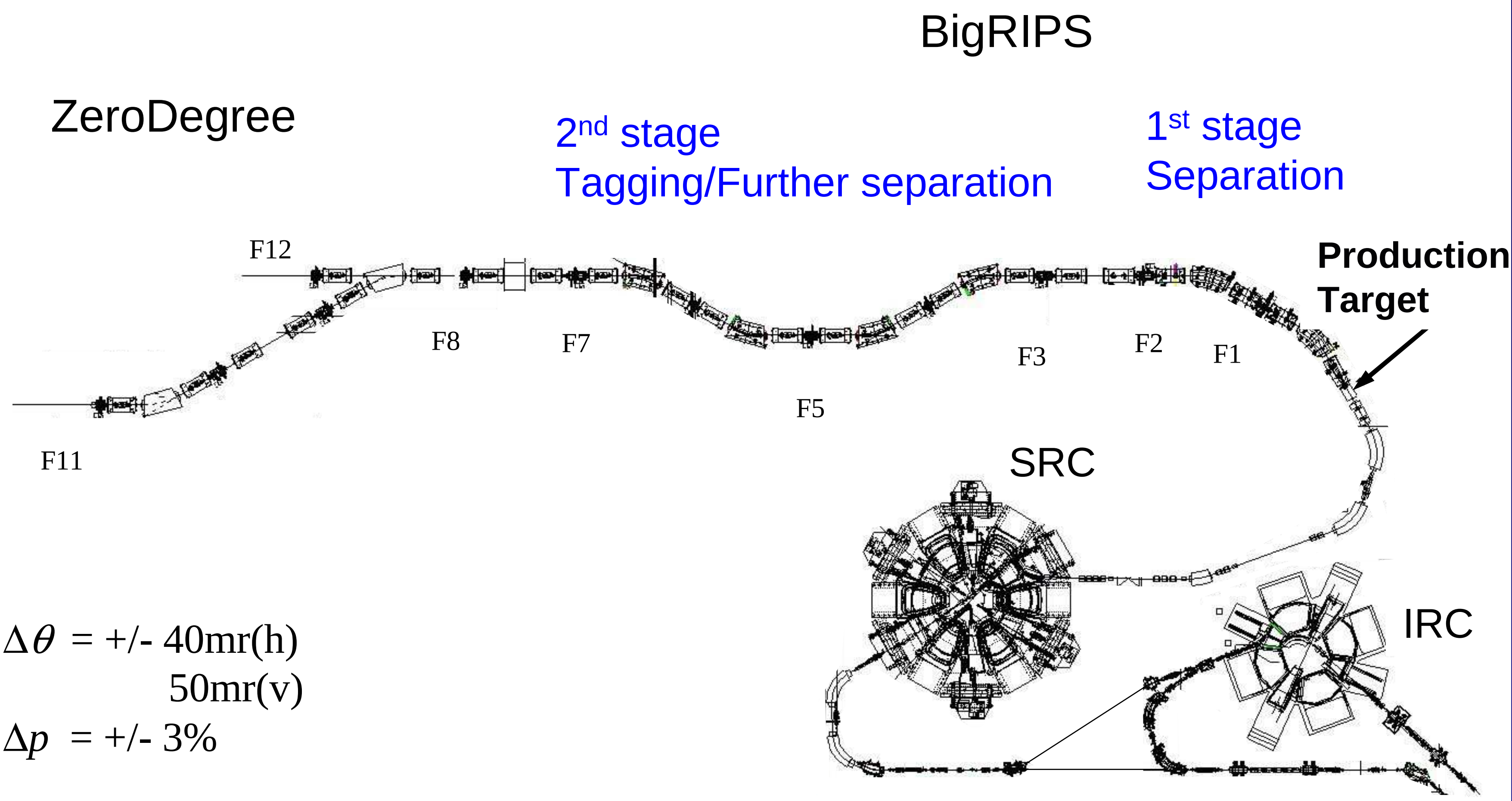
  Optics / Detector performance, etc

- Jun. 29-Jul. 2 — ^{238}U

  Detector tests (IC, NaI), etc

  Yield survey for ^{80}Zn, ^{130}Cd, etc

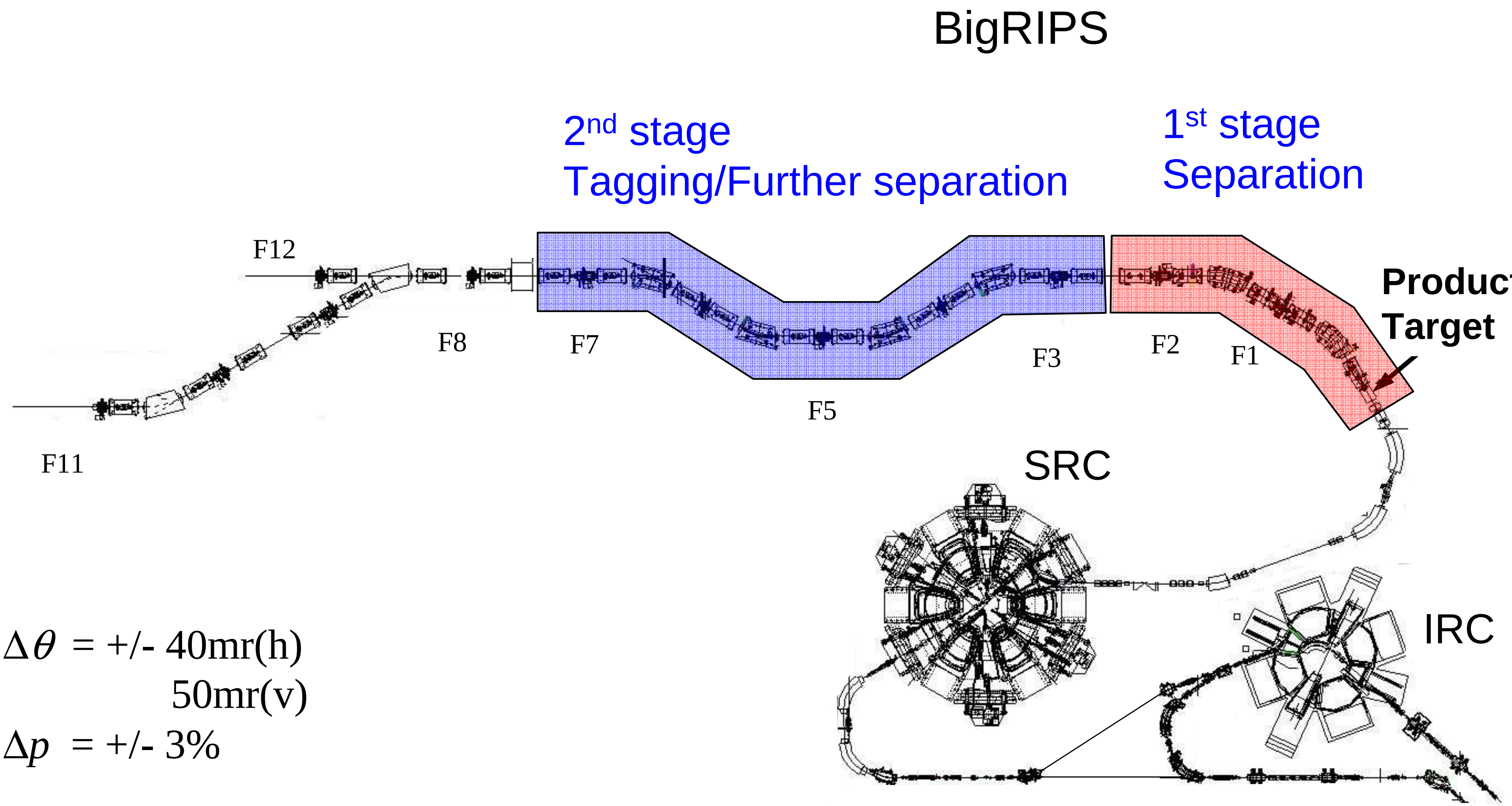
BigRIPS and ZeroDegree spectrometer



$\Delta\theta$ = +/- 40mr(h)
50mr(v)
Δp = +/- 3%

Large Acceptance
→ Projectile fragmentation
Projectile fission

BigRIPS and ZeroDegree spectrometer



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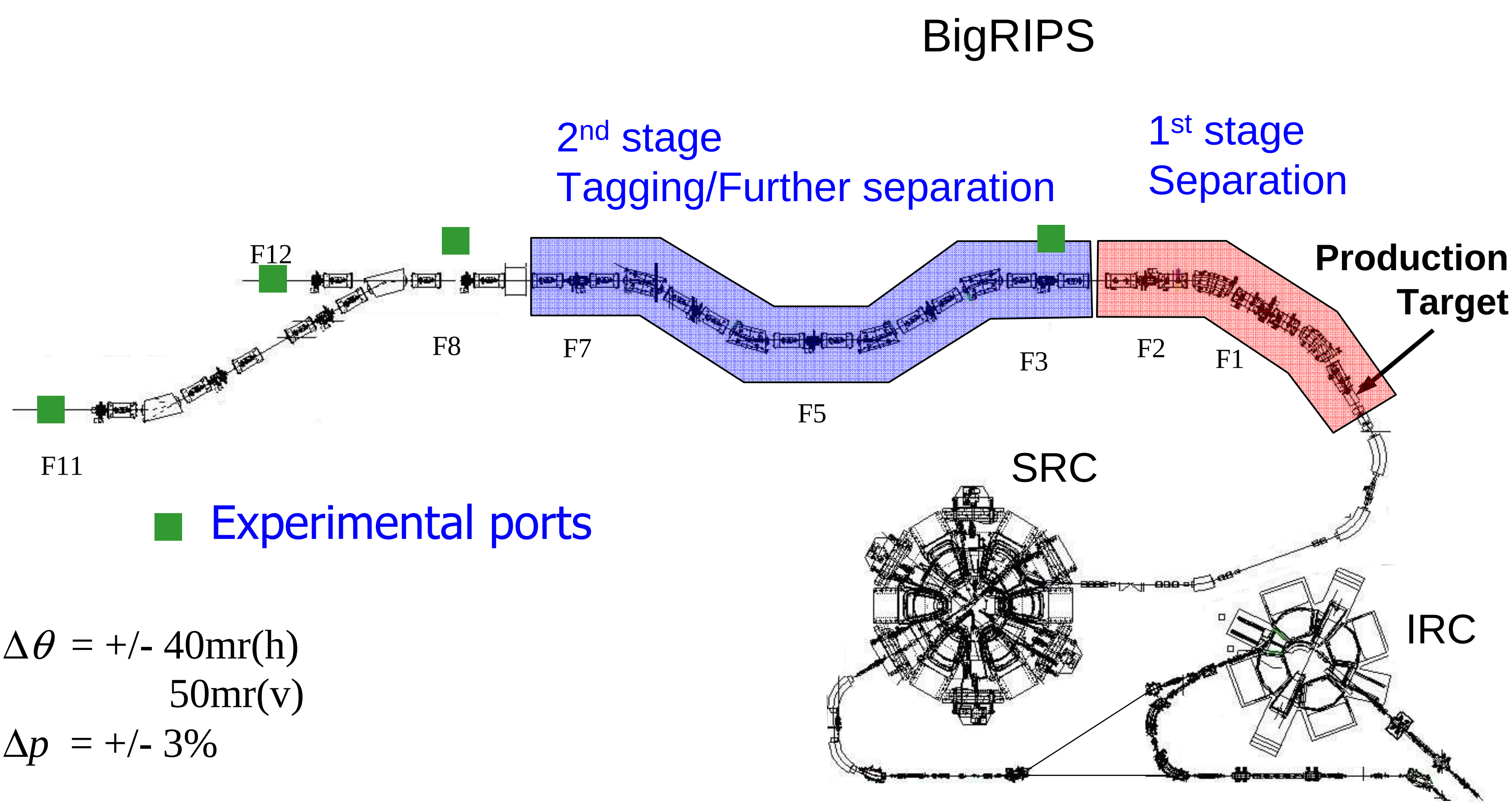


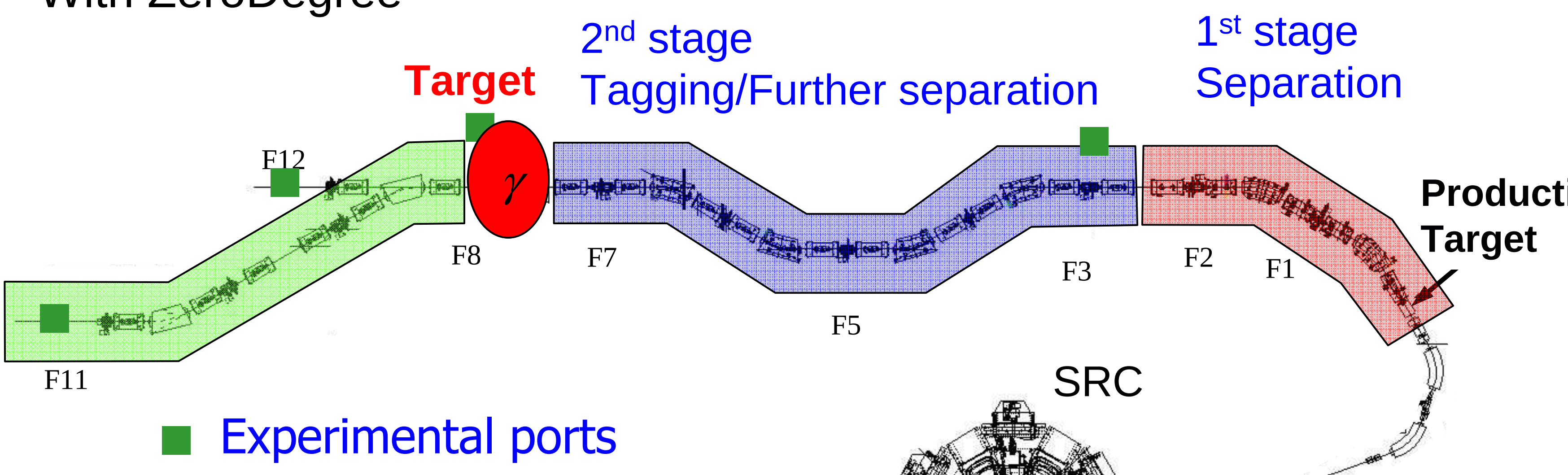
$\Delta\theta$ = +/- 40mr(h)
50mr(v)
Δp = +/- 3%

Large Acceptance
→ Projectile fragmentation
Projectile fission

BigRIPS and ZeroDegree spectrometer

Reaction Residue Tagging
With ZeroDegree

BigRIPS



$\Delta\theta$ = +/- 40mr(h)
50mr(v)
Δp = +/- 3%

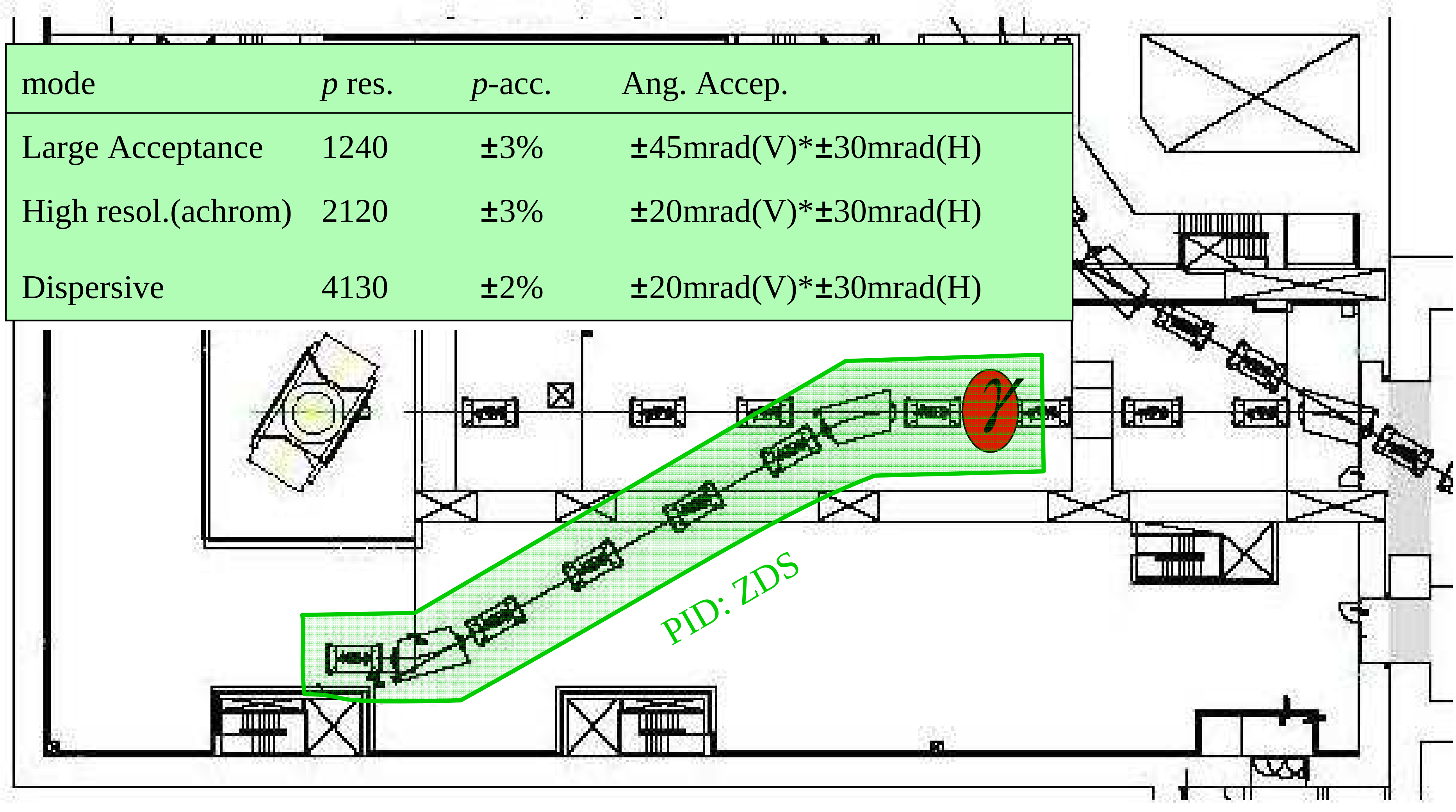
mode	*p* res.	*p*-acc.	Ang. Accep.
Large Acceptance	1240	±3%	±45mrad(V)*±30mrad(H)
High resol.(achrom)	2120	±3%	±20mrad(V)*±30mrad(H)
Dispersive	4130	±2%	±20mrad(V)*±30mrad(H)

Large Acceptance
→ Projectile fragmentation
Projectile fission

γ spectroscopy with ZeroDegree

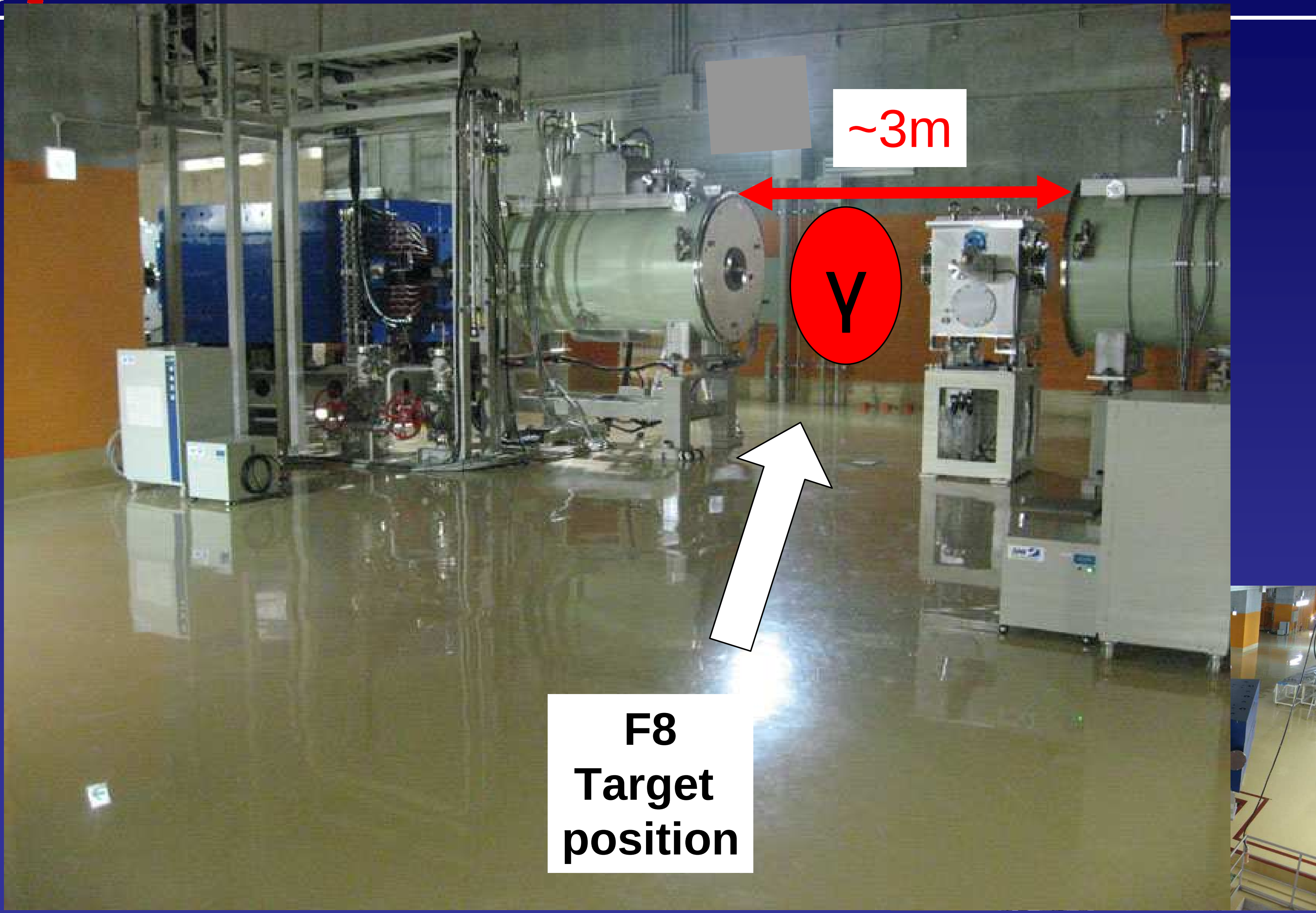
- High resolution
- Large maximum $B\rho$

mode	*p* res.	*p*-acc.	Ang. Accep.
Large Acceptance	1240	±3%	±45mrad(V)*±30mrad(H)
High resol.(achrom)	2120	±3%	±20mrad(V)*±30mrad(H)
Dispersive	4130	±2%	±20mrad(V)*±30mrad(H)



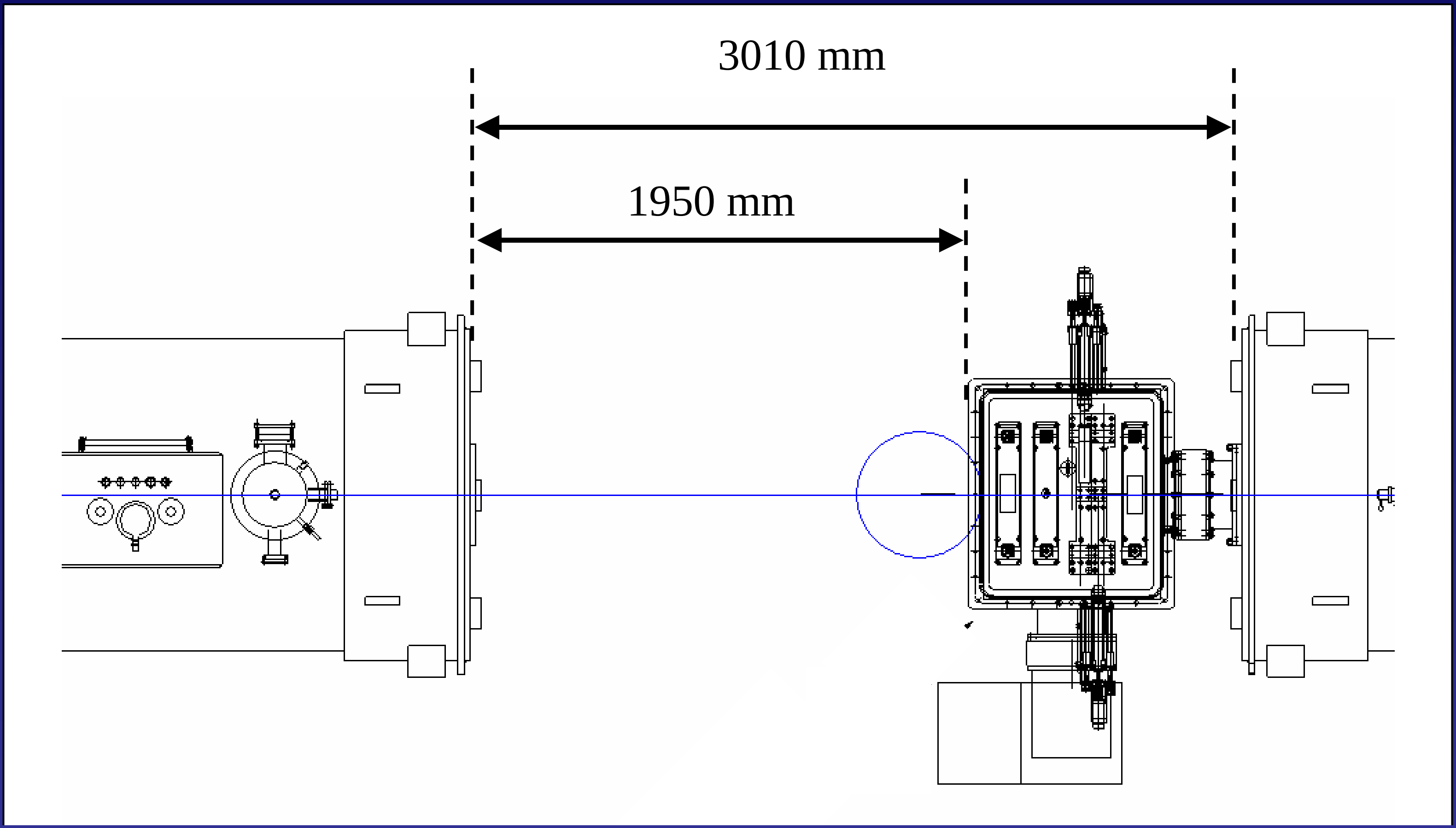
ZeroDegree Spectrometer

ZeroDegree Spectrometer

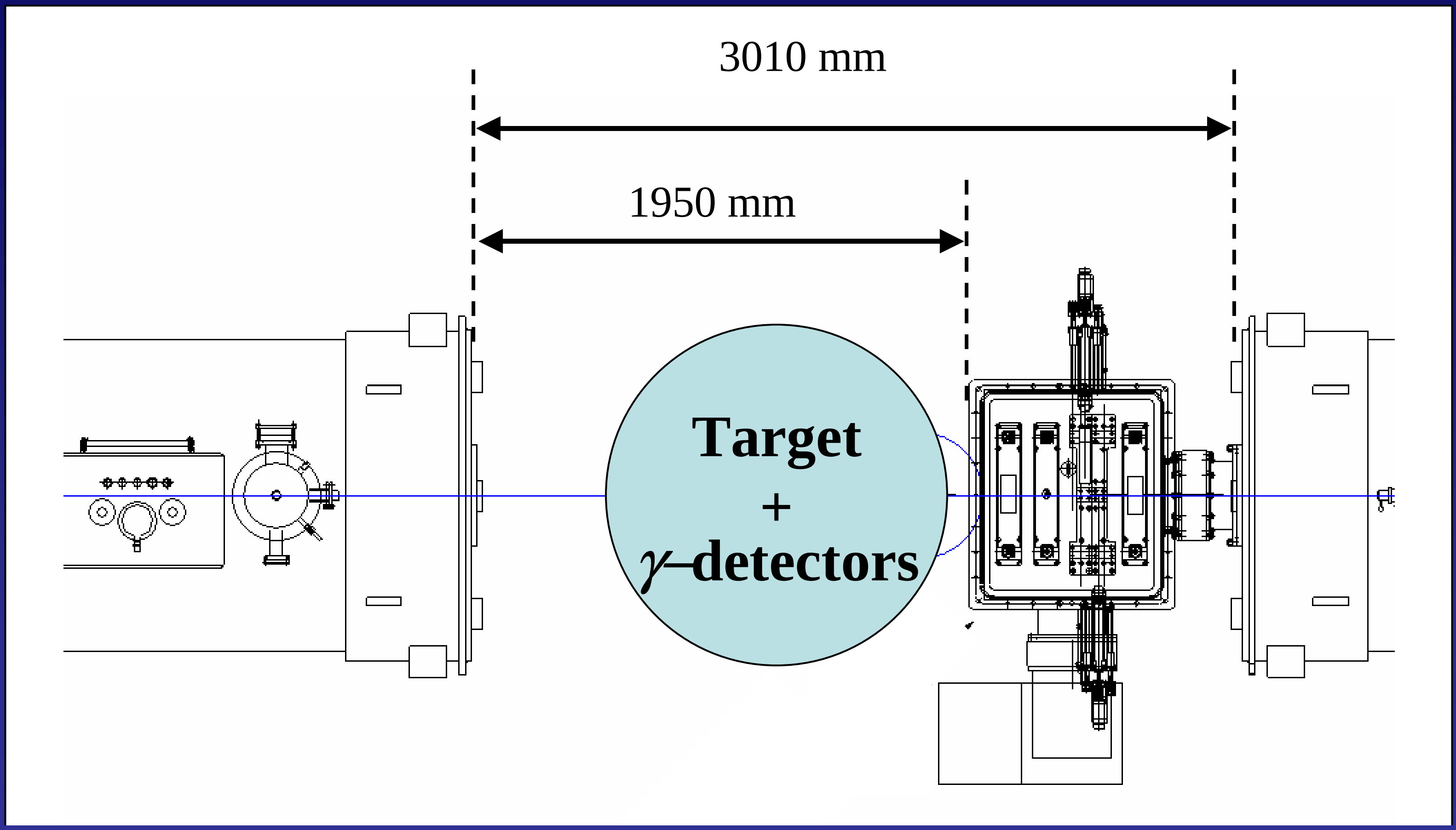


ZeroDegree Spectrometer

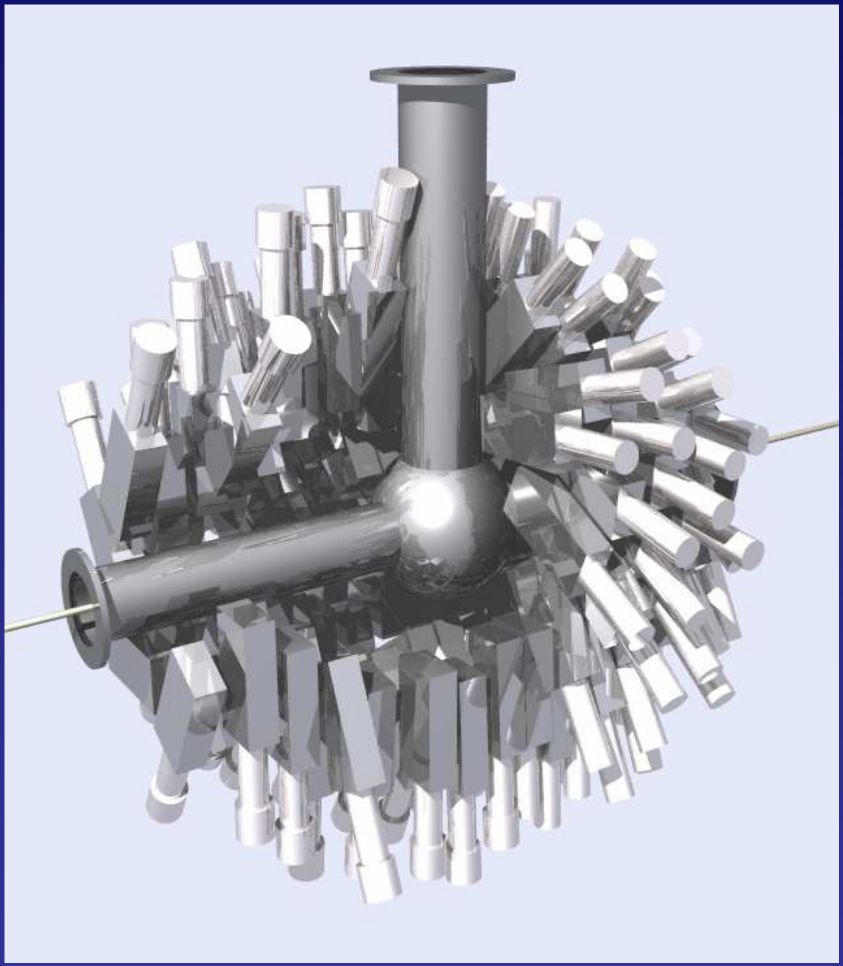
Target position of ZeroDegree/BigTOFspe(tentative name)



Target position of ZeroDegree/BigTOFspe(tentative name)



DALI2



160 NaI(Tl) detectors

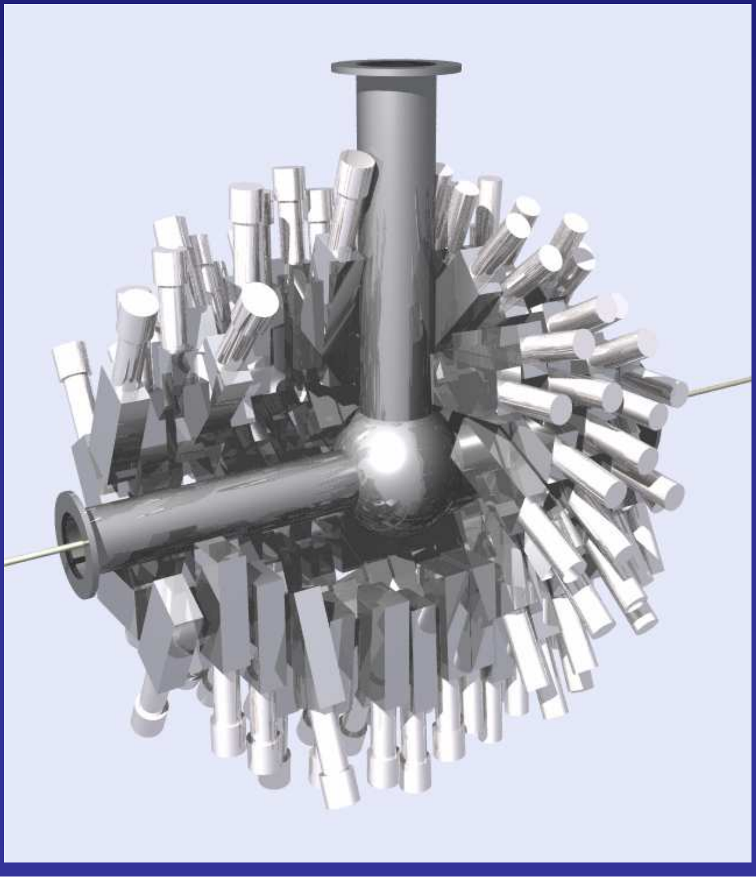
Each detector
- 4.5 x 8 x 16 (cm^3)
  $\Delta E/E$ ~ 9% @ 662keV

Array
- 16 layers
- 6~14 detectors in each layer

γ-detector array

DALI

160 NaI(Tl) detectors
Efficiency : 17% (FWHM)
E resolution: 150keV
(@ 1MeV, β~0.3)



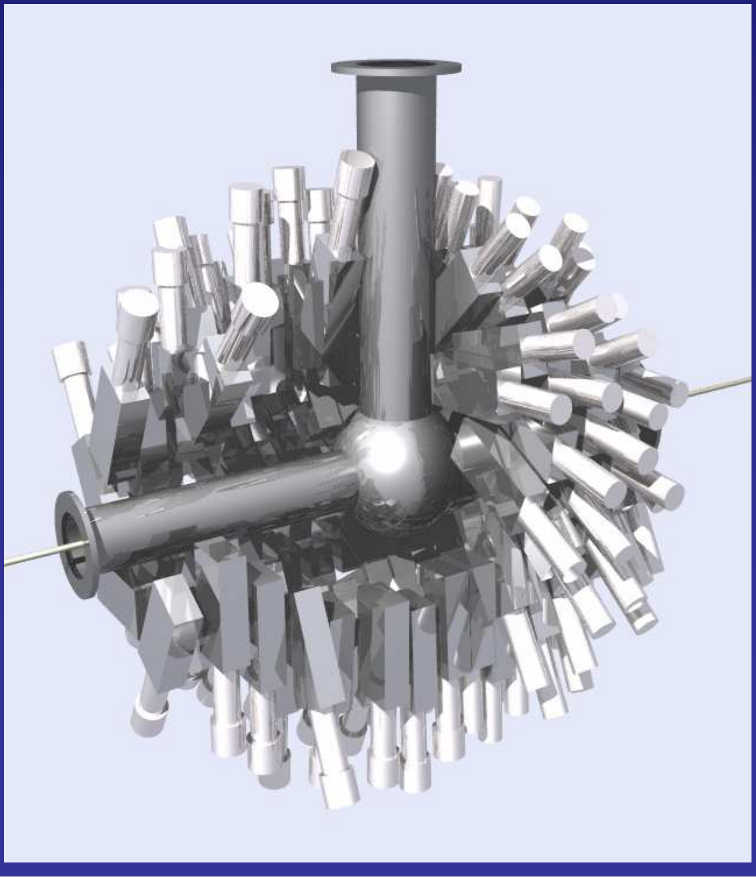
GRAPE --- 18 Ge detectors
S. Shimoura, E. Ideguchi(CNS)

Efficiency 5%
Pos. resolution 2mm
E resolution 10keV
(@2.1MeV, β=0.3)

γ-detector array

DALI

160 NaI(Tl) detectors
- Efficiency : 18% (FWHM)
- E resolution: 100keV
  (@ 2.1MeV, β~0.6)



GRAPE --- 18 Ge detectors

S. Shimoura, E. Ideguchi(CNS)

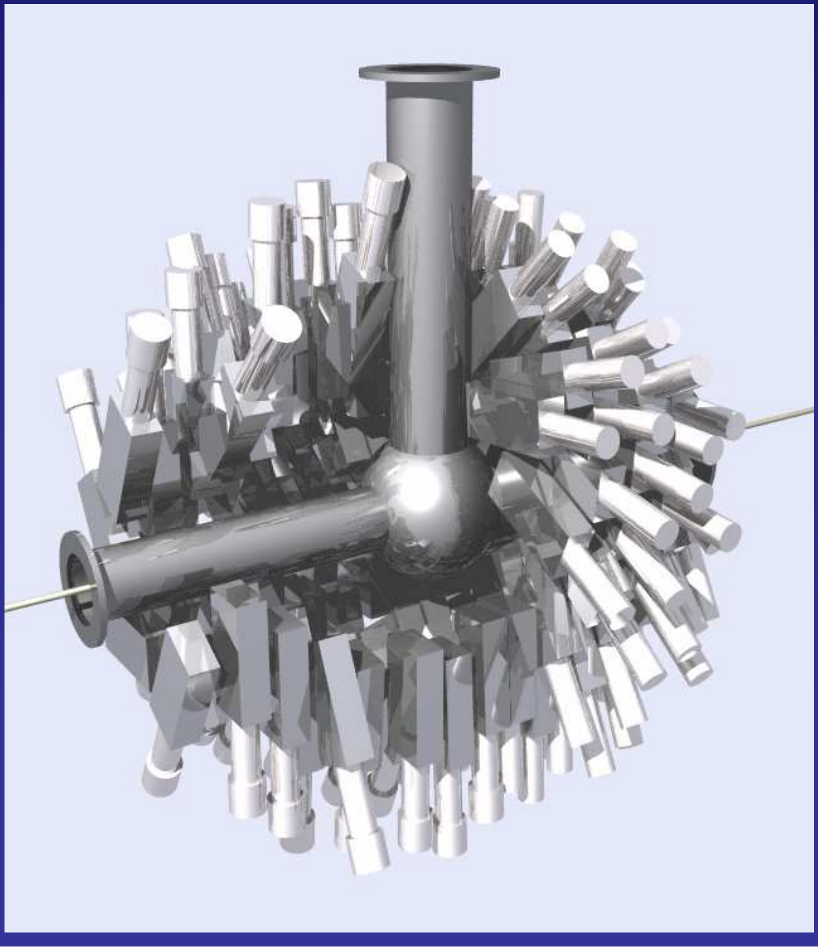
- Efficiency 3%
- Pos. resolution 2mm
- E resolution 40keV
  (@1MeV, β=0.6)

DALI vs GRAPE

	GRAPE	DALI2
ΔE (FWHM@1MeV)	25 keV	100 keV
εΩ (@1MeV)	3 %	18 %
FOM@ 1 MeV (sqrt(εΩ)/ΔE)	**~ 7**	**~ 4**
Peak/Total	Small	Large
Good for	Low E γ (<1MeV) Odd mass Rotational etc.	High E γ (>0.5MeV) γ-γ

DALI2 (**Detector Array for Low Intensity radiation 2**)

160 NaI(Tl) detectors
- Each detector
  - 4.5 x 8 x 16 (cm^3)
  - *ΔE/E* ~ 9% @ 662keV
- Array
  - 16 layers
  - 6~14 detectors in each layer

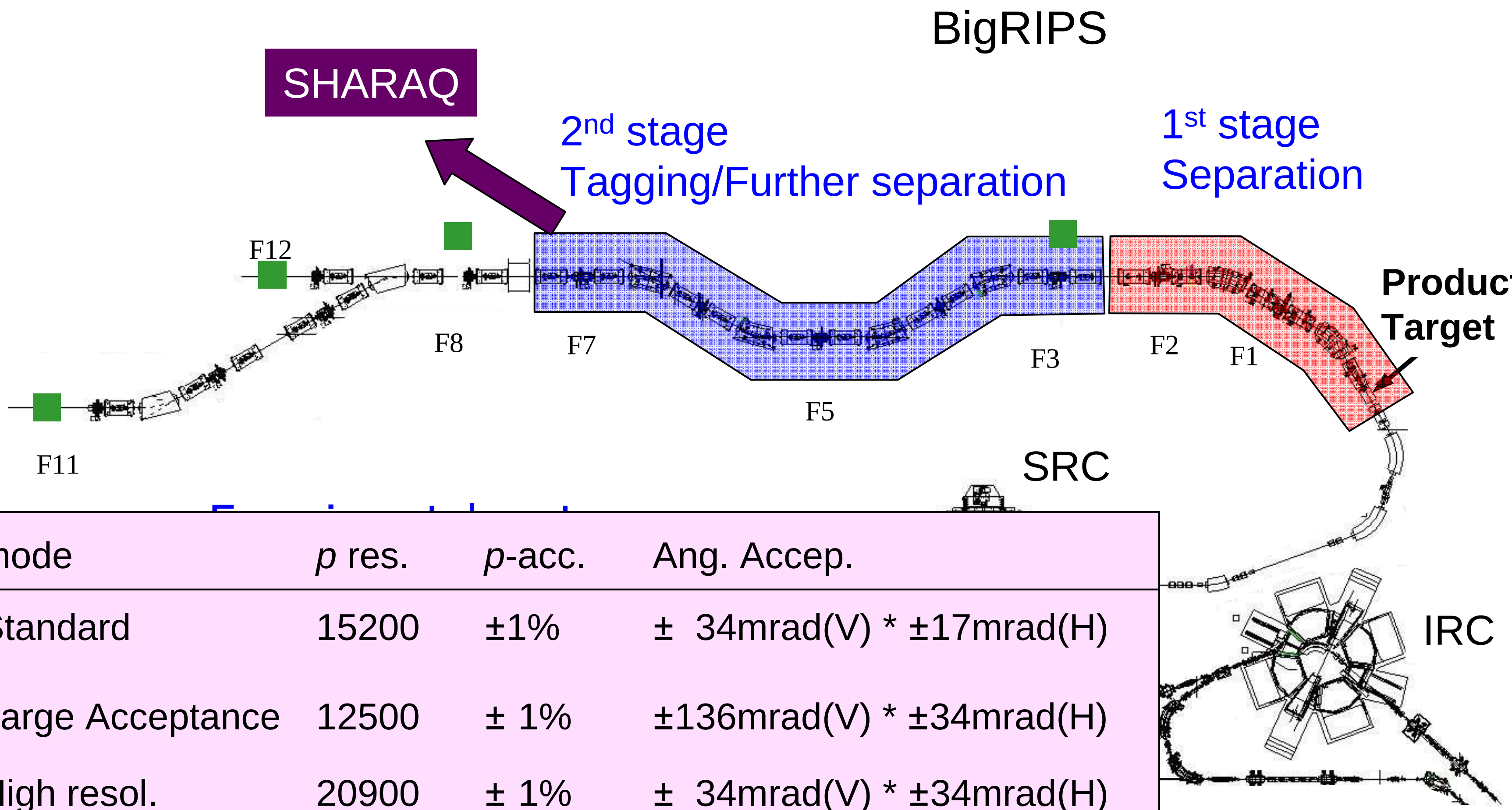


CNS GRAPE (Gamma-Ray detector Array with Energy and Position sensitivity)

CNS, Univ. Tokyo --- S. Shimoura, E. Ideguchi *et al*.

Efficiency	5%	(4%; achieved)
Pos. resolution	2mm	(5mm; achieved)
E resolution	10keV	(16keV @ 2.1MeV, β=0.3; achieved)

BigRIPS and ZeroDegree spectrometer



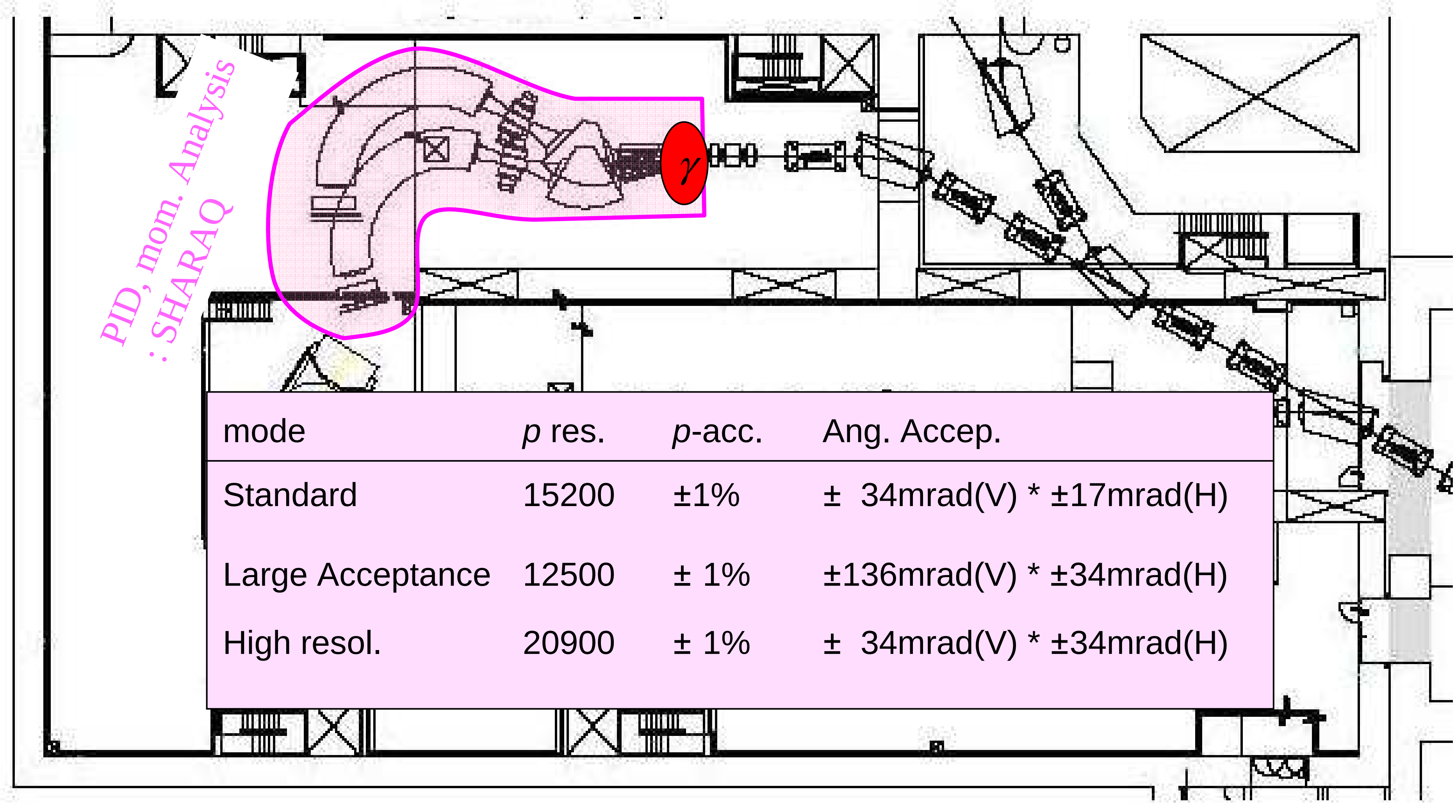
mode	*p* res.	*p*-acc.	Ang. Accep.
Standard	15200	±1%	± 34mrad(V) * ±17mrad(H)
Large Acceptance	12500	± 1%	±136mrad(V) * ±34mrad(H)
High resol.	20900	± 1%	± 34mrad(V) * ±34mrad(H)

→ Projectile fragmentation
Projectile fission

γ spectroscopy with SHARAQ*

Very high resolution
(Relatively small *p* acceptance)

* SHARAQ is being developed by ICHOR project, Univ. of Tokyo



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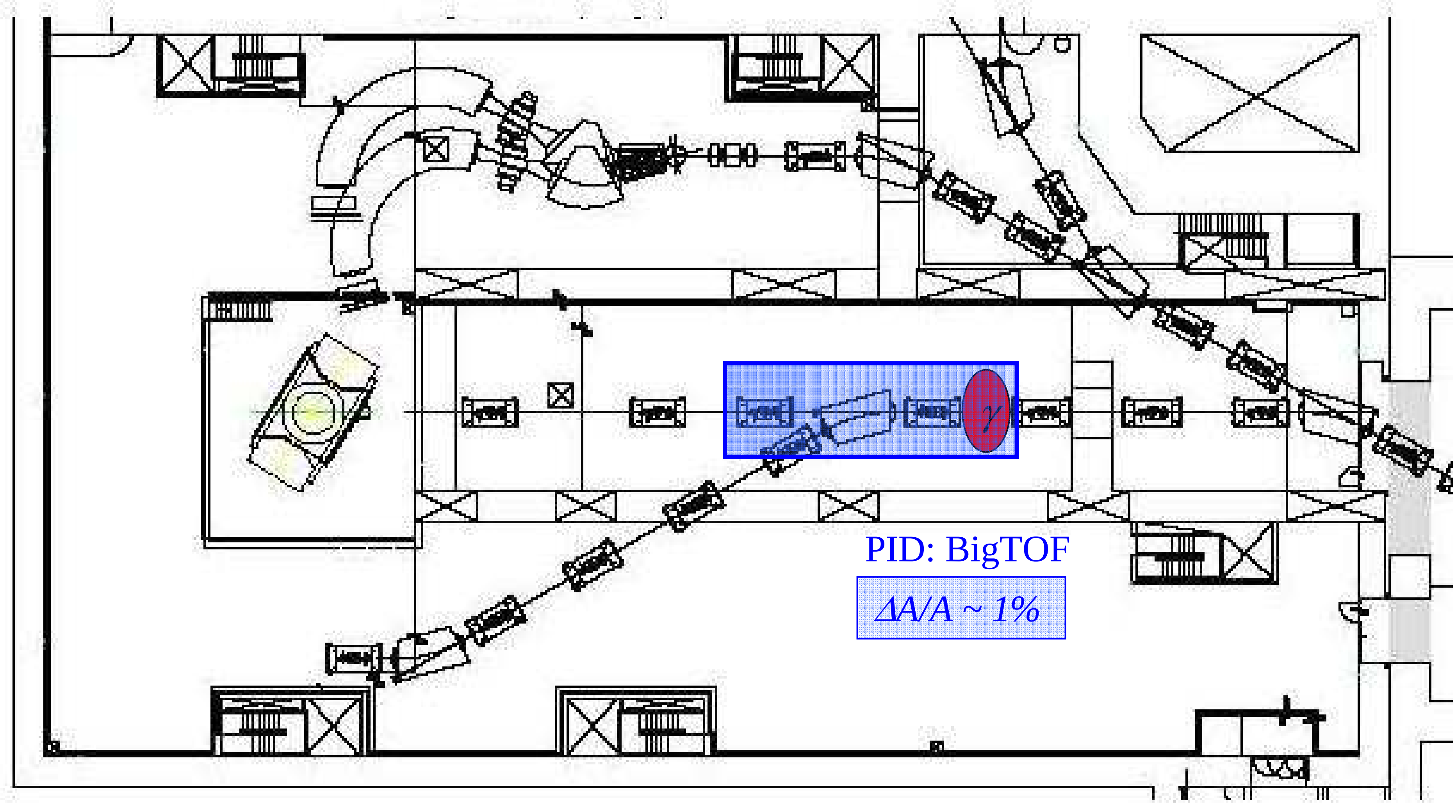
Large Acceptance	12500	± 1%	±136mrad(V) * ±34mrad(H)
High resol.	20900	± 1%	± 34mrad(V) * ±34mrad(H)

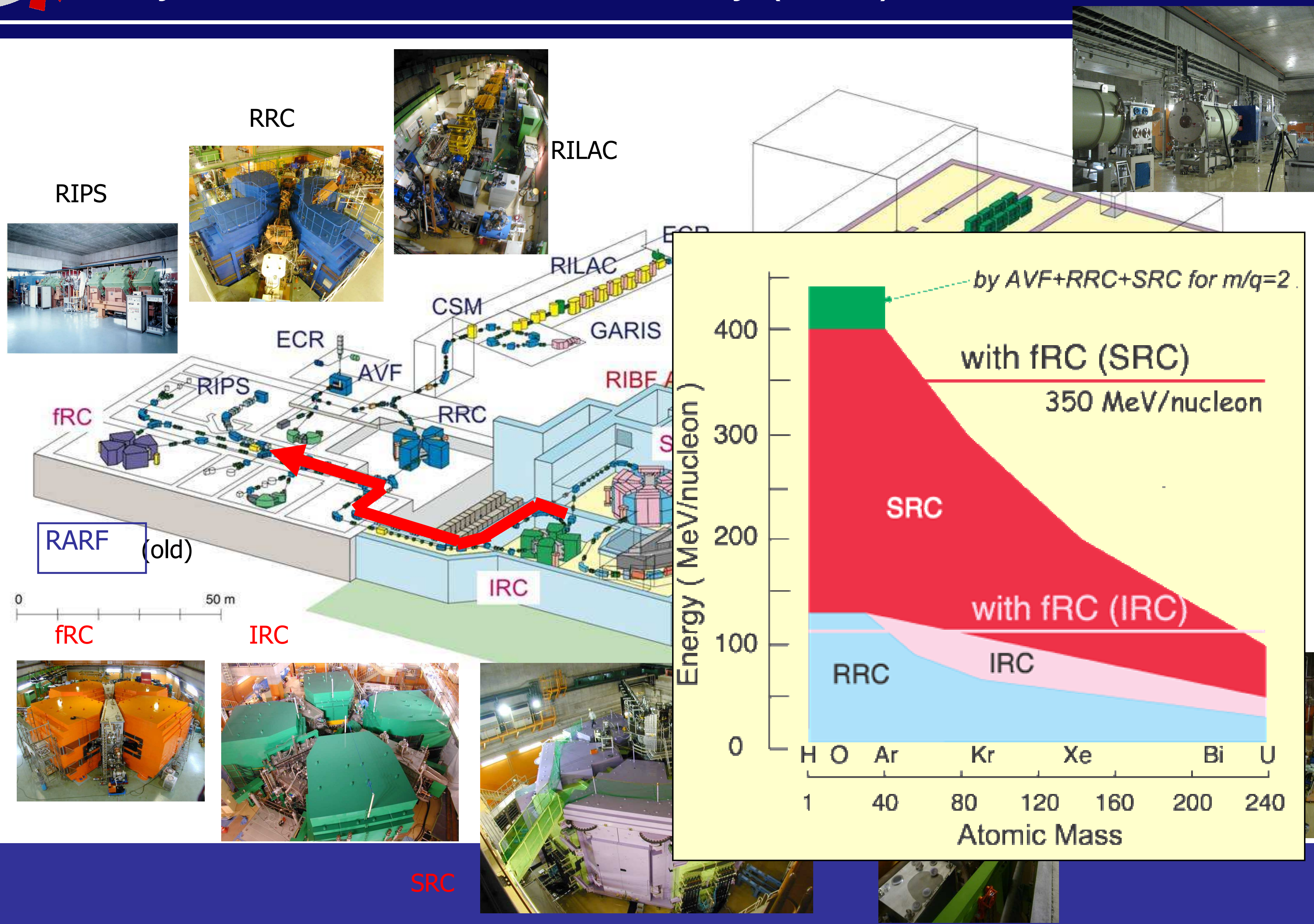
γ spectroscopy with BigTOF (Tentative name…)

Sufficient PID resolution for $A \leq 100$

High "particle species" acceptance (good for cocktail beam)



Layout of RIKEN RI beam factory (RIBF) in 2007

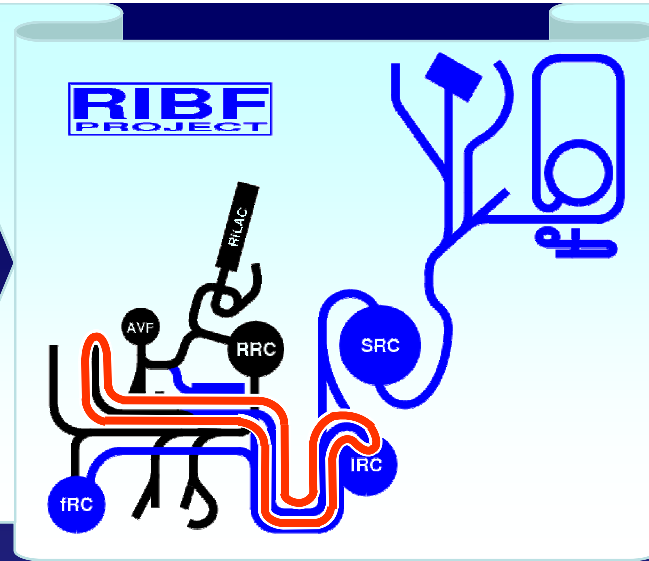


RI spin lab. *Phase 2*

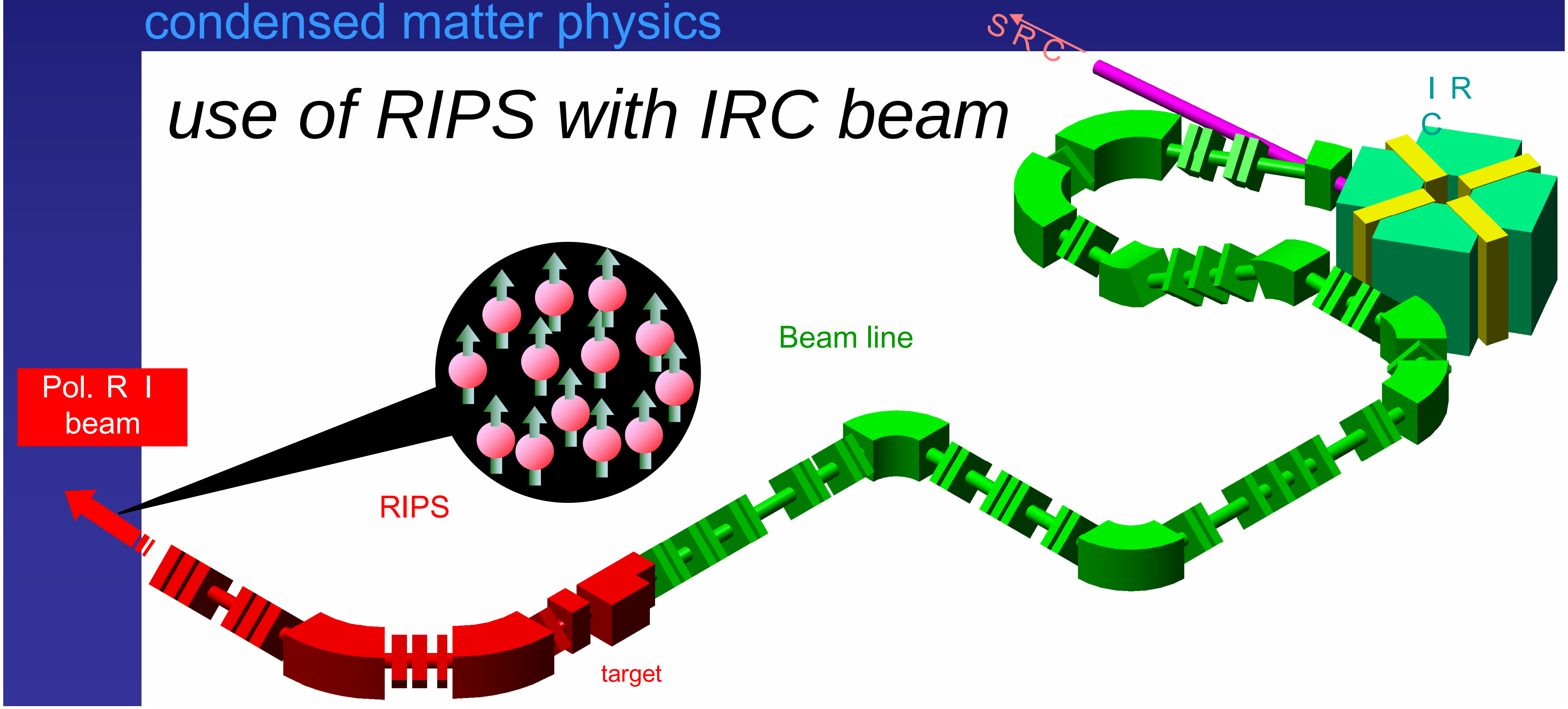
H. Ueno et al

Spin polarized RI beam
- IRC-based production

- nuclear moment
- condensed matter physics



use of RIPS with IRC beam

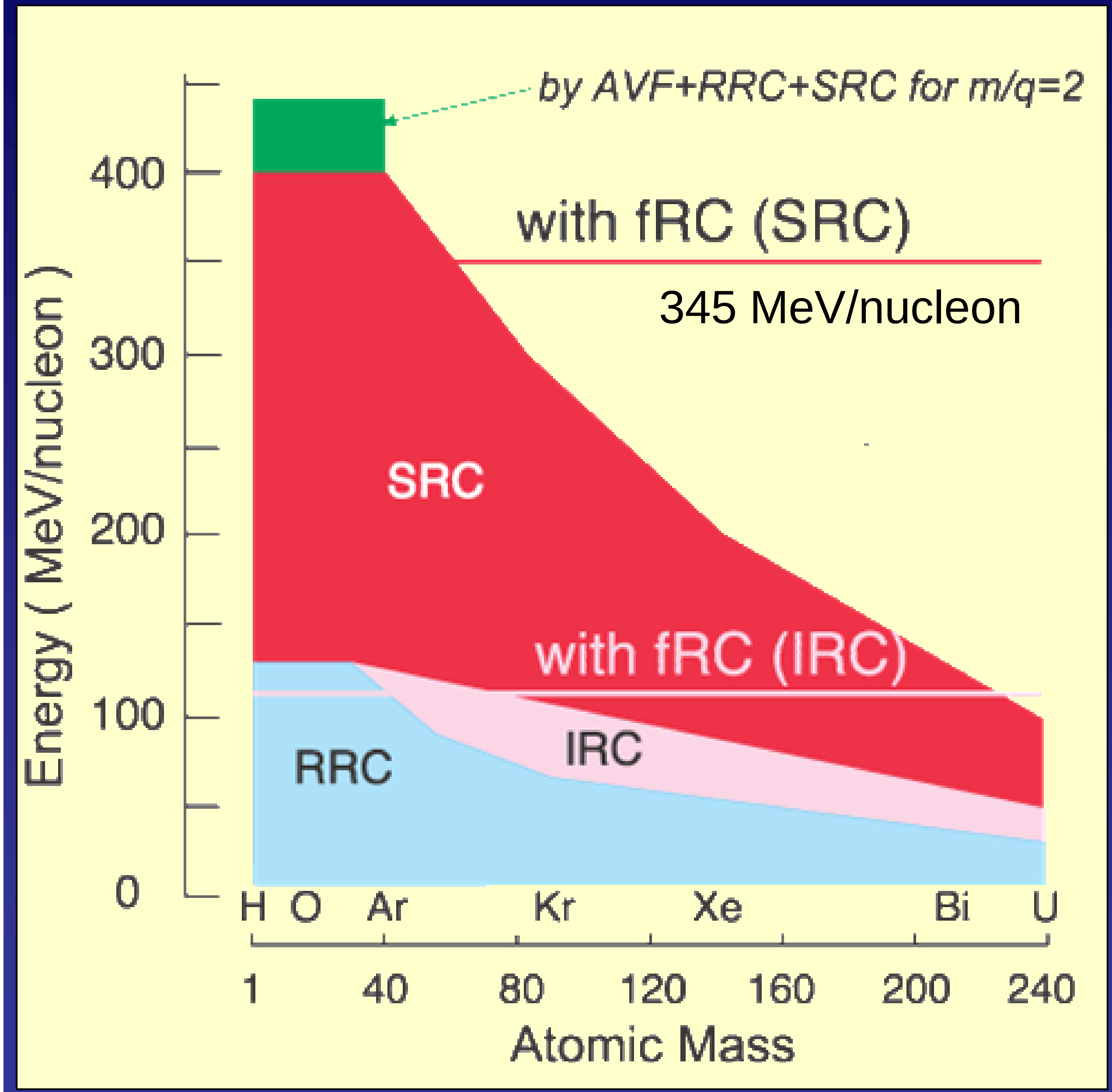


Performance of

Primary and

Secondary Beams

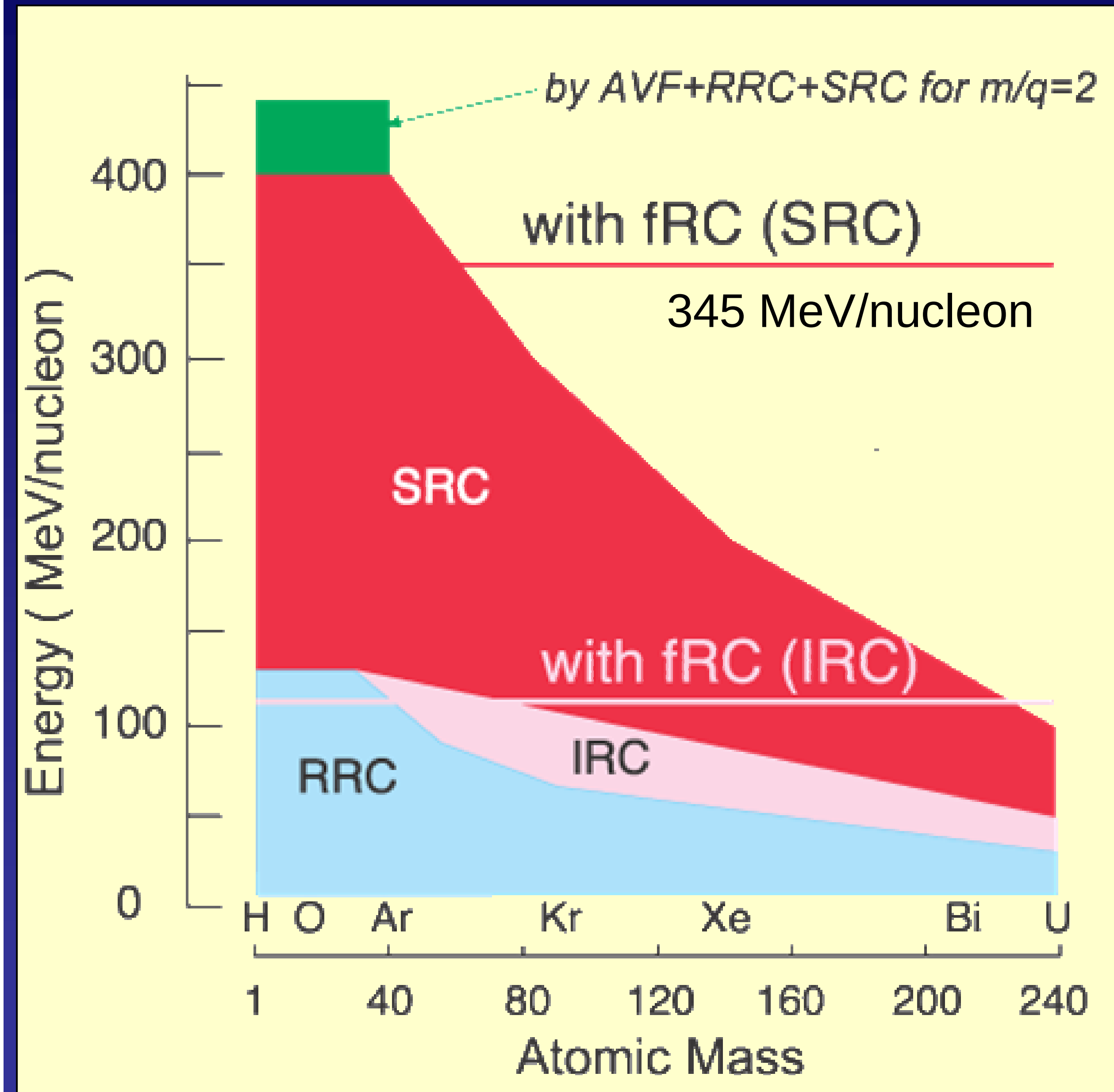
Performance of RIBF



p~U

345 MeV/u
1 pμA (goal)

Performance of RIBF



p~U
345 MeV/u
1 pμA ($6x10^{12}$ /sec)
(goal)

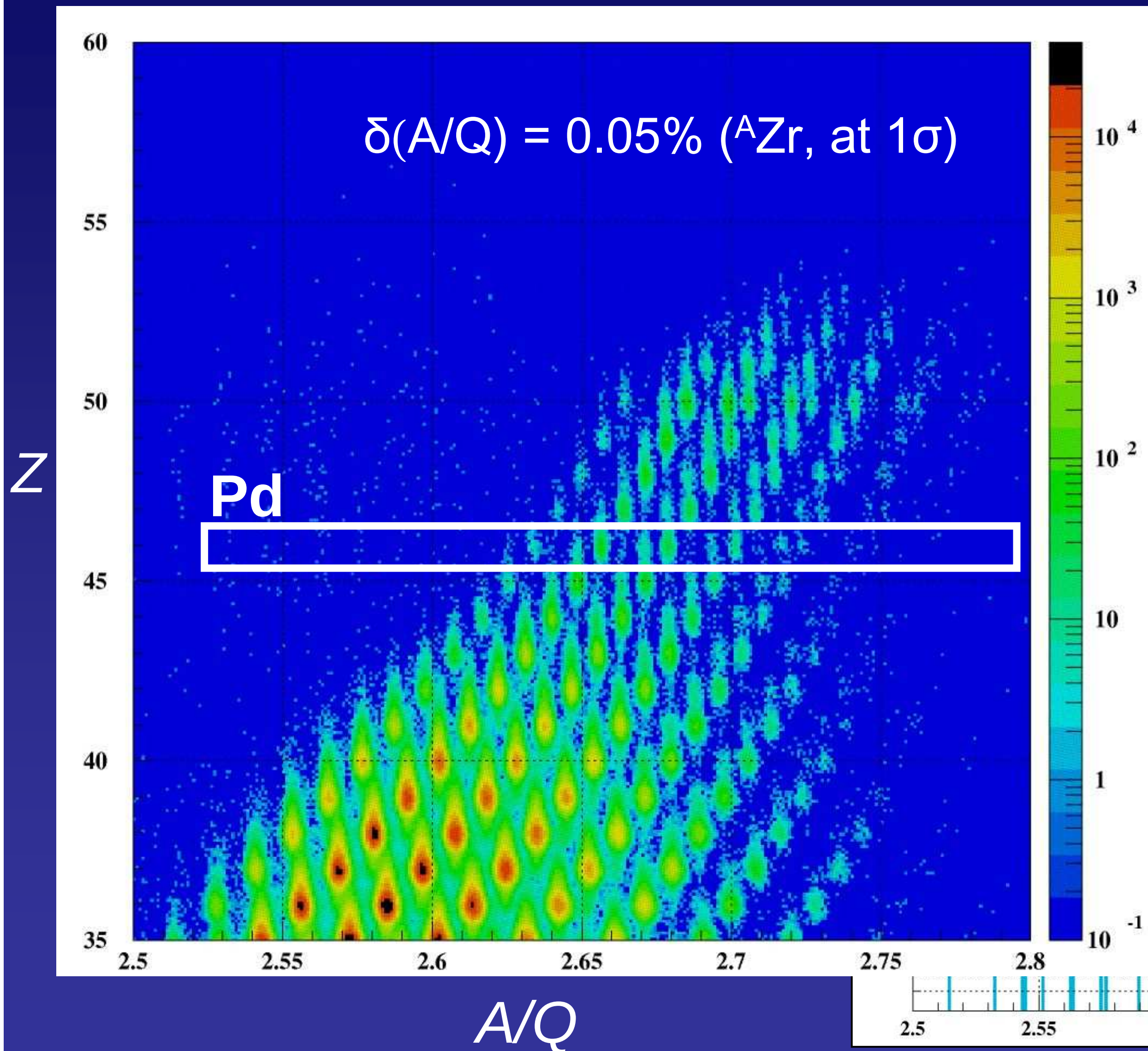
Projectile fragmentation
In-flight fission of U

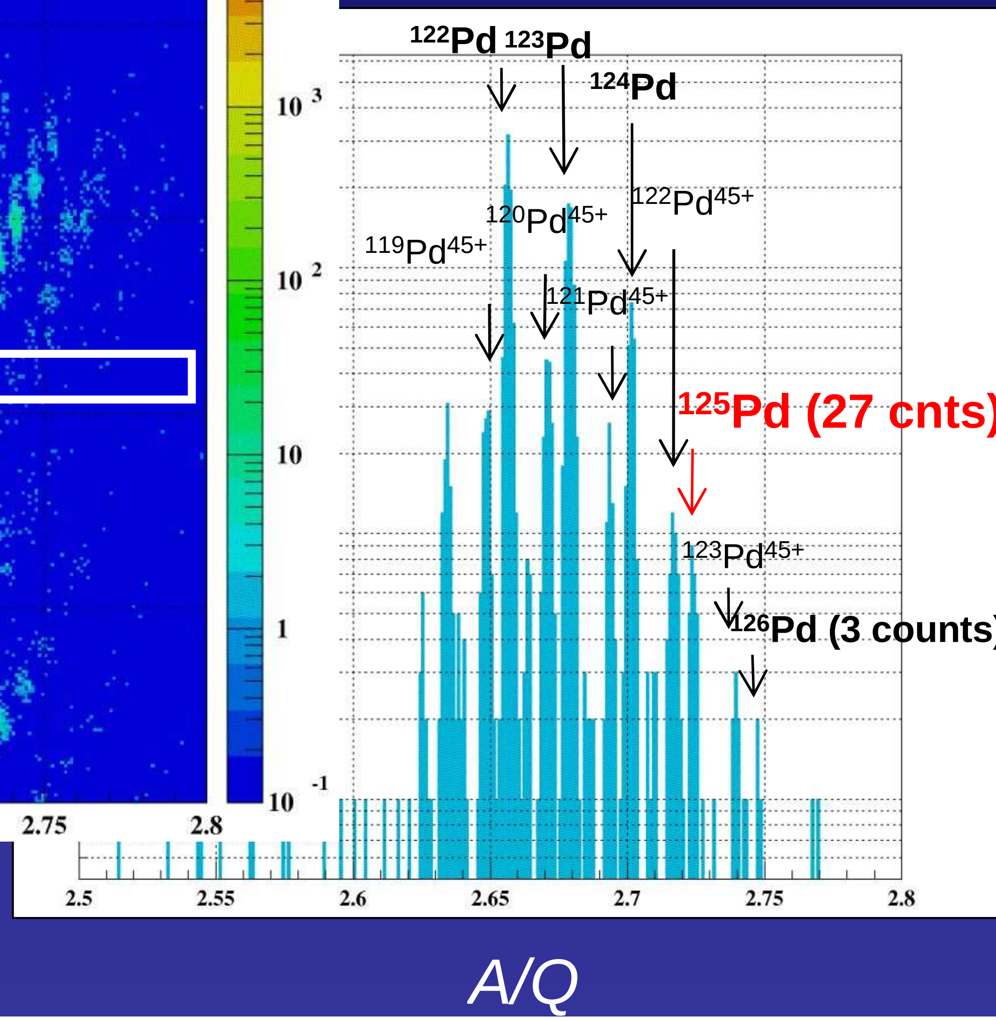
Beam Intensity

$^{86}Kr^{34+}$	345 MeV/u	30 pnA	Achieved
$^{238}U^{86+}$	345 MeV/u	0.04 pnA	Achieved

June 2007

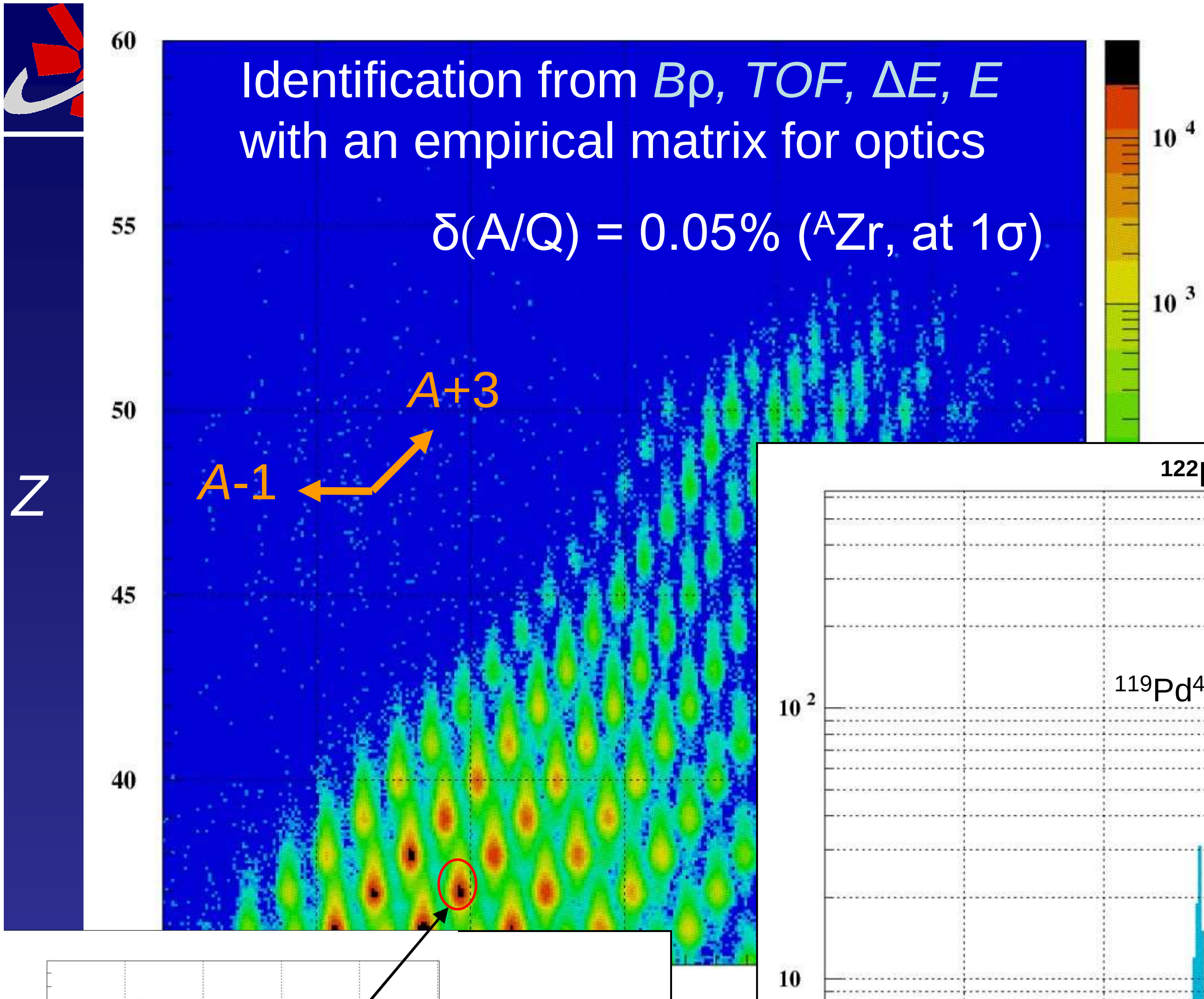
3.6×10^{12} $^{238}U^{86+}$ beam
($4x10^7$ s^{-1}, -1day)
- 10^{-5} of the goal

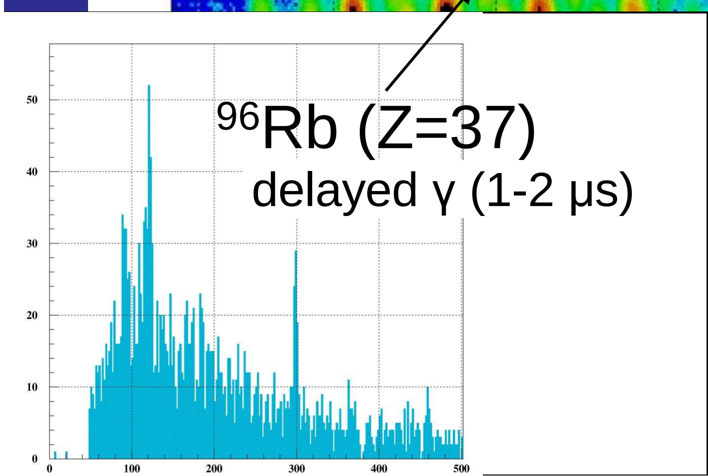


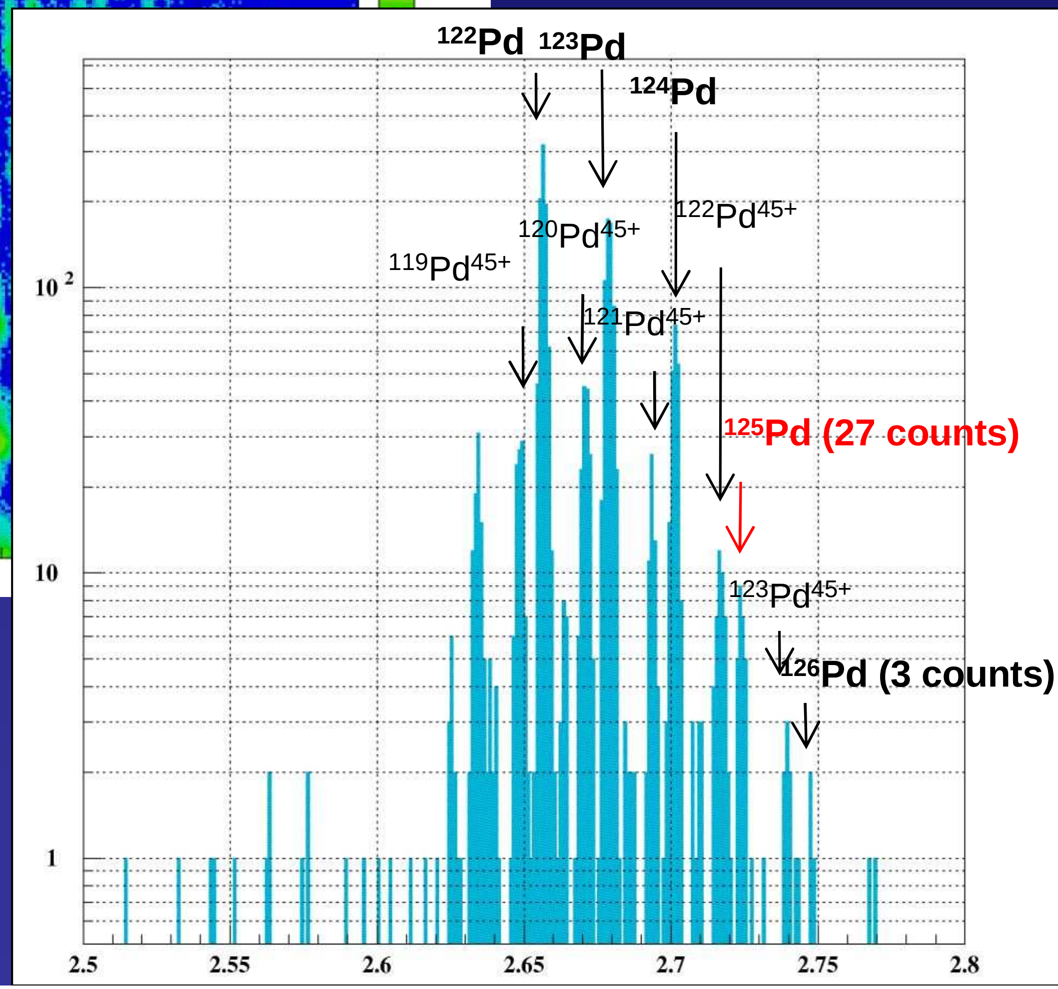


June 2007

3.6×10^{12} $^{238}U^{86+}$ beam
(4×10^{7} s^{-1}, -1day)
- 10^{-5} of the goal







Beam Intensity (near future)

$^{86}Kr^{34+}$	345 MeV/u	30 pnA	Achieved
→	~100 pnA *feasible in coming year*		
$^{238}U^{86+}$	345 MeV/u	0.04 pnA	Achieved
→	10 pnA *feasible in coming year*		

Beam Intensity (near future)

$^{86}Kr^{34+}$ 345 MeV/u 30 pnA Achieved

→ ~100 pnA

feasible in coming year

$^{238}U^{86+}$ 345 MeV/u 0.04 pnA Achieved

→ 10 pnA

feasible in coming year

1 pμA

need more investigation, investment

present accelerator performance

$^{86}Kr^{34+}$ 1.1 eμA (30 pnA) 345 MeV/u

Nov. 10th

$^{238}U^{86+}$ ~5 enA (0.04 pnA) 345 MeV/u

Jun. 29th

ε_{trans} <3% (~50%)^5

$\varepsilon_{stripper\ (RRC\text{-}SRC)}$ <5% (15% * 30%)

I_{RRC} ~15 pnA

Tuning of Accelerators, BT
Flat-Top operation
Stripper,
New Injector, New IS *x100*

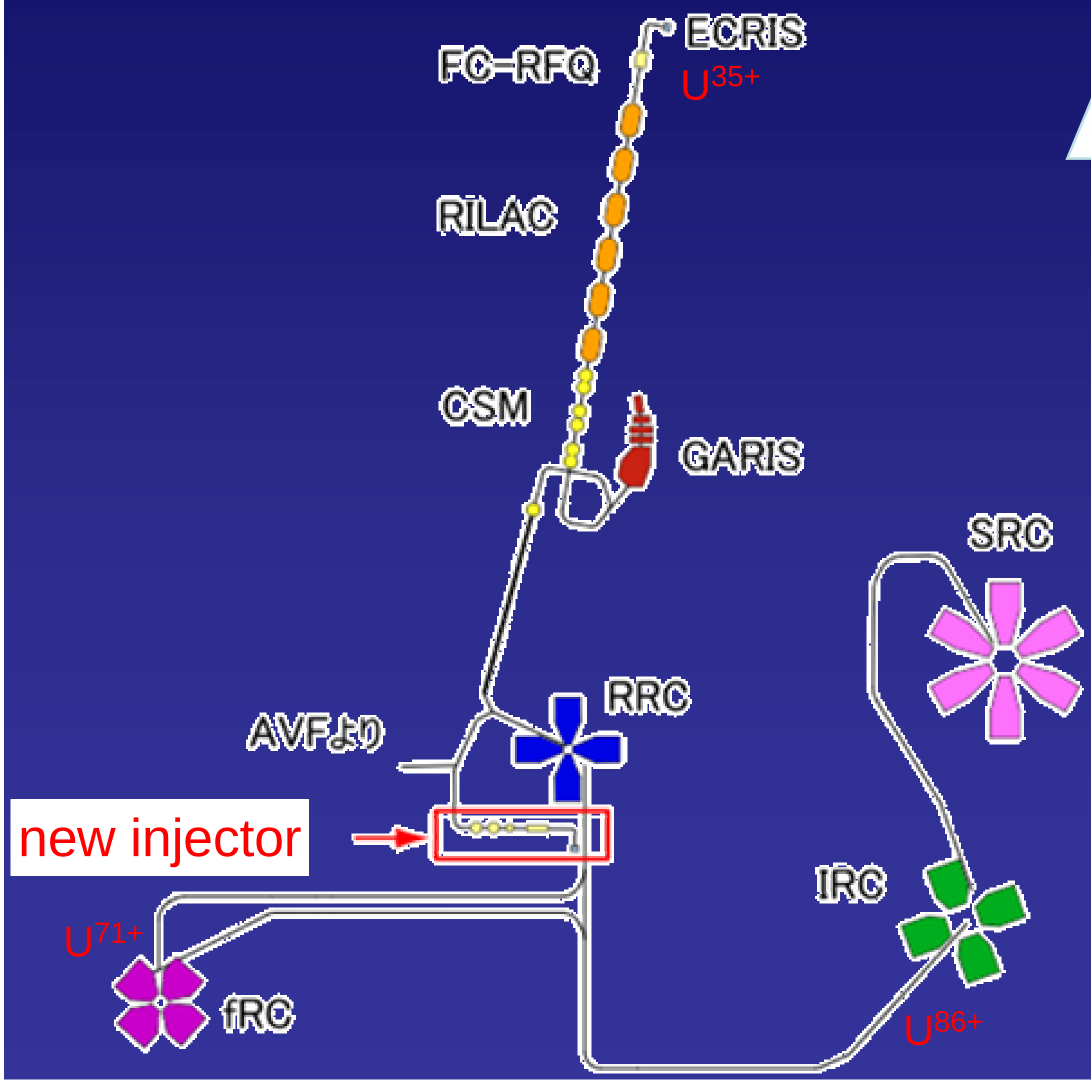
10 pnA U

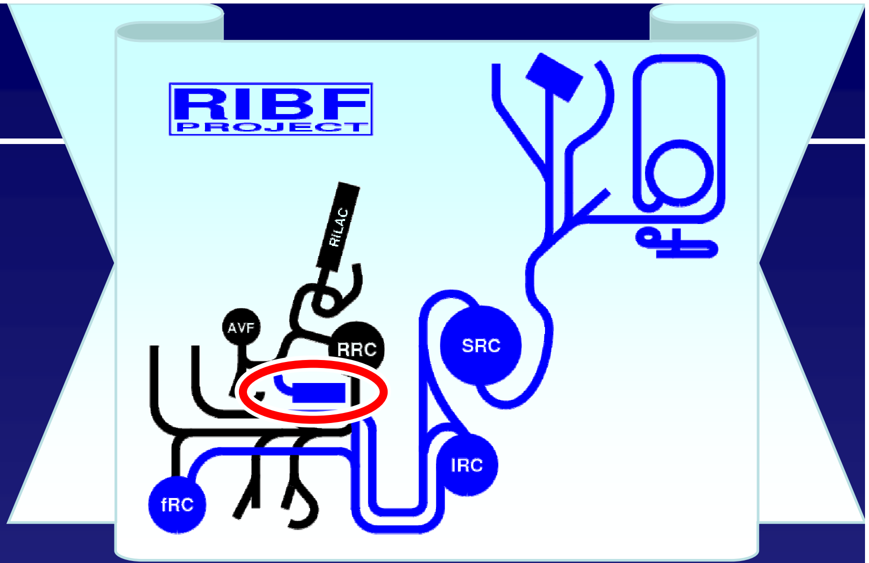
feasible in coming year

1 pμA U

need more investigation, investment

Injector system dedicated for RIBF

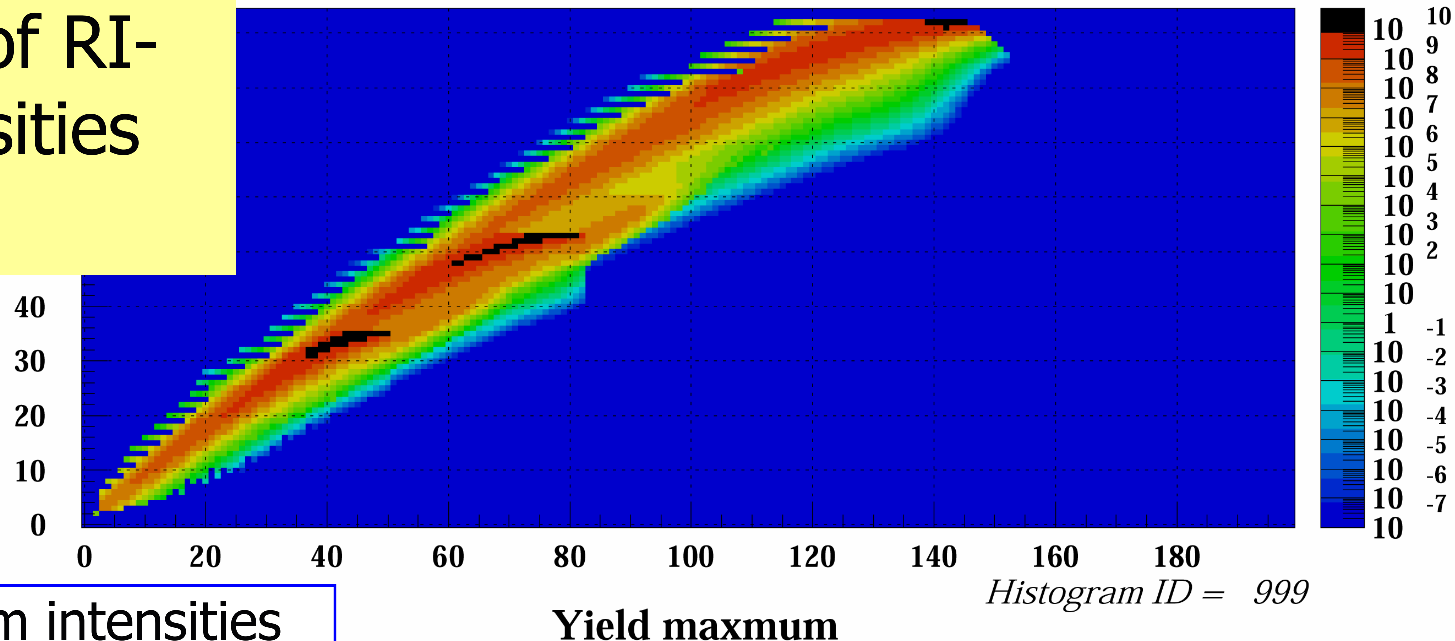




Independent operations of RILAC-GARIS (SHE, ..) and RIBF

Estimation of RI-beam intensities @BigRIPS

Courtesy of T. Suda



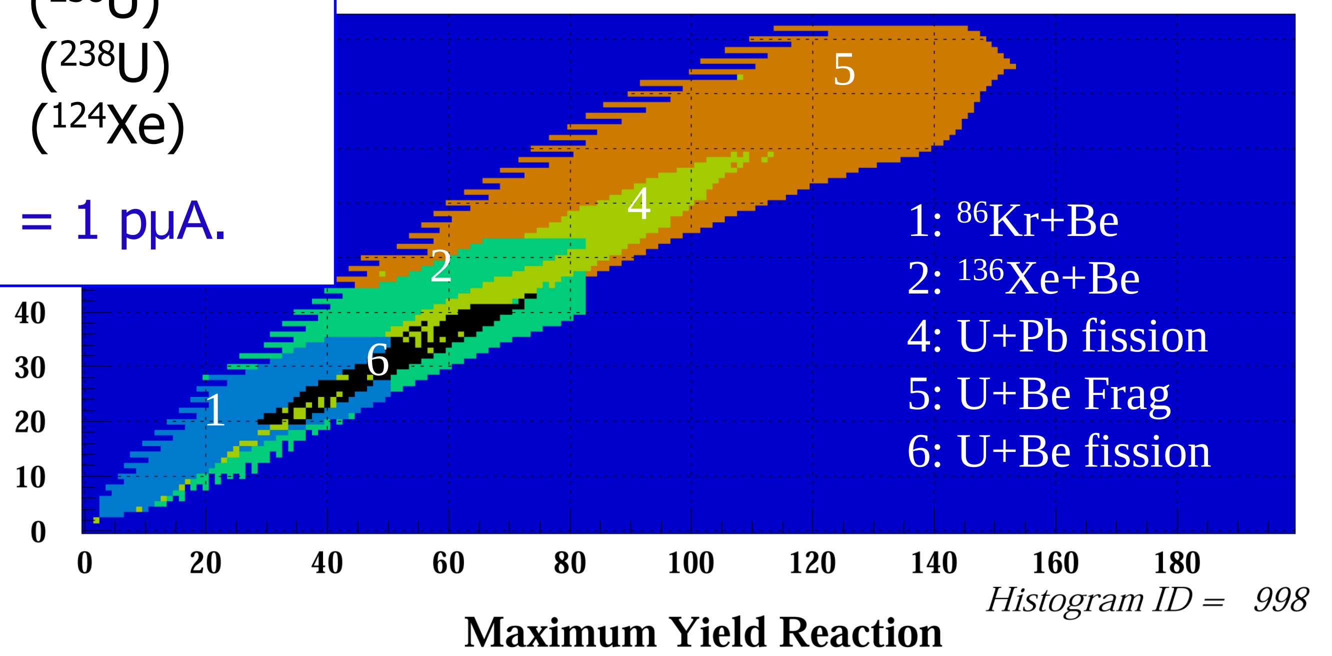
Expected RI-beam intensities

^{78}Ni ~10 pps (^{238}U)

^{132}Sn ~10^7 pps (^{238}U)

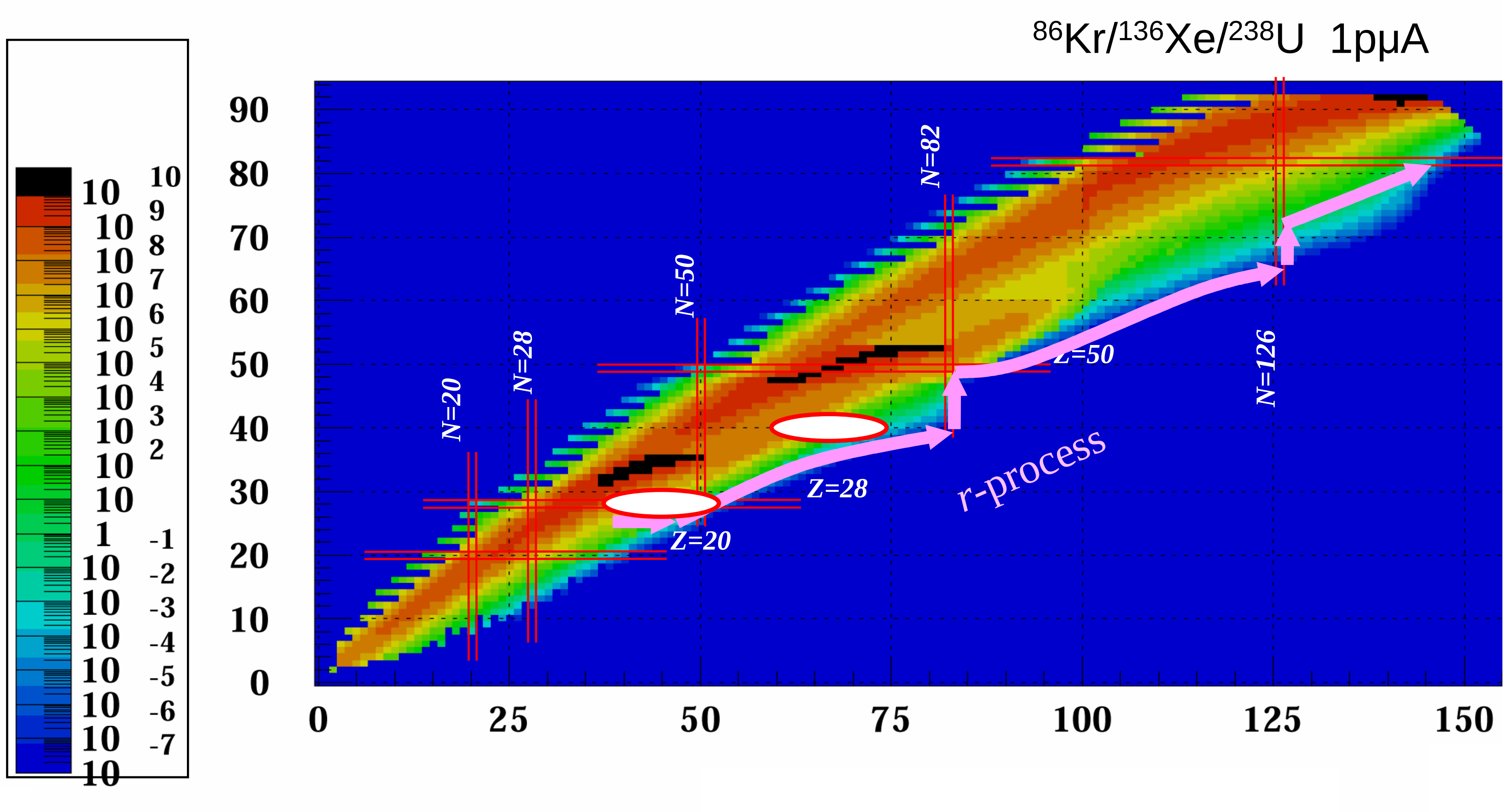
^{100}Sn ~1 pps (^{124}Xe)

I(primary beam) = 1 pμA.



Estimation based on the GSI data and the ABLABRA and EPAX2 formula

Estimated beam intensity at BigRIPS



Estimated beam intensity at BigRIPS

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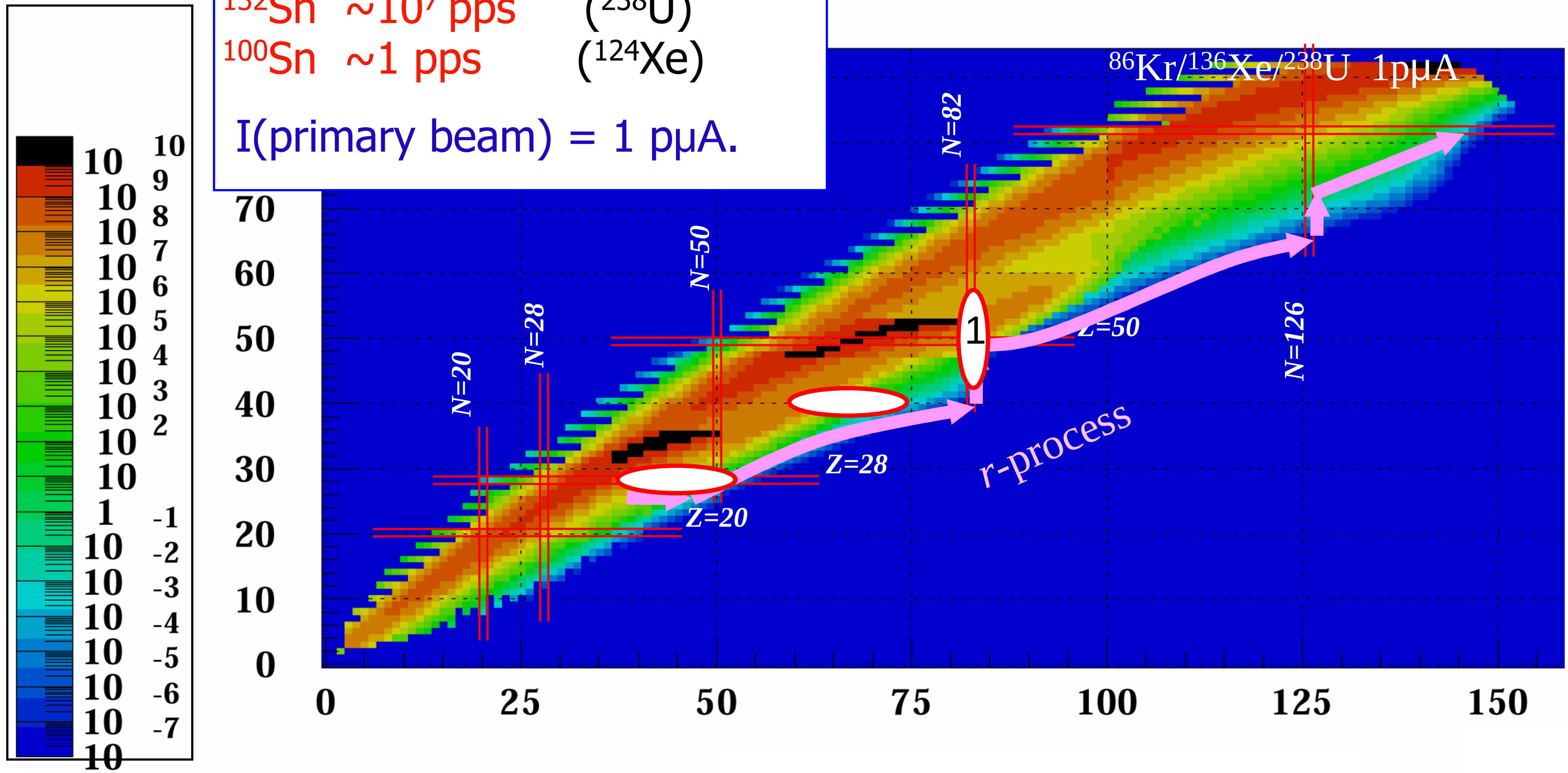
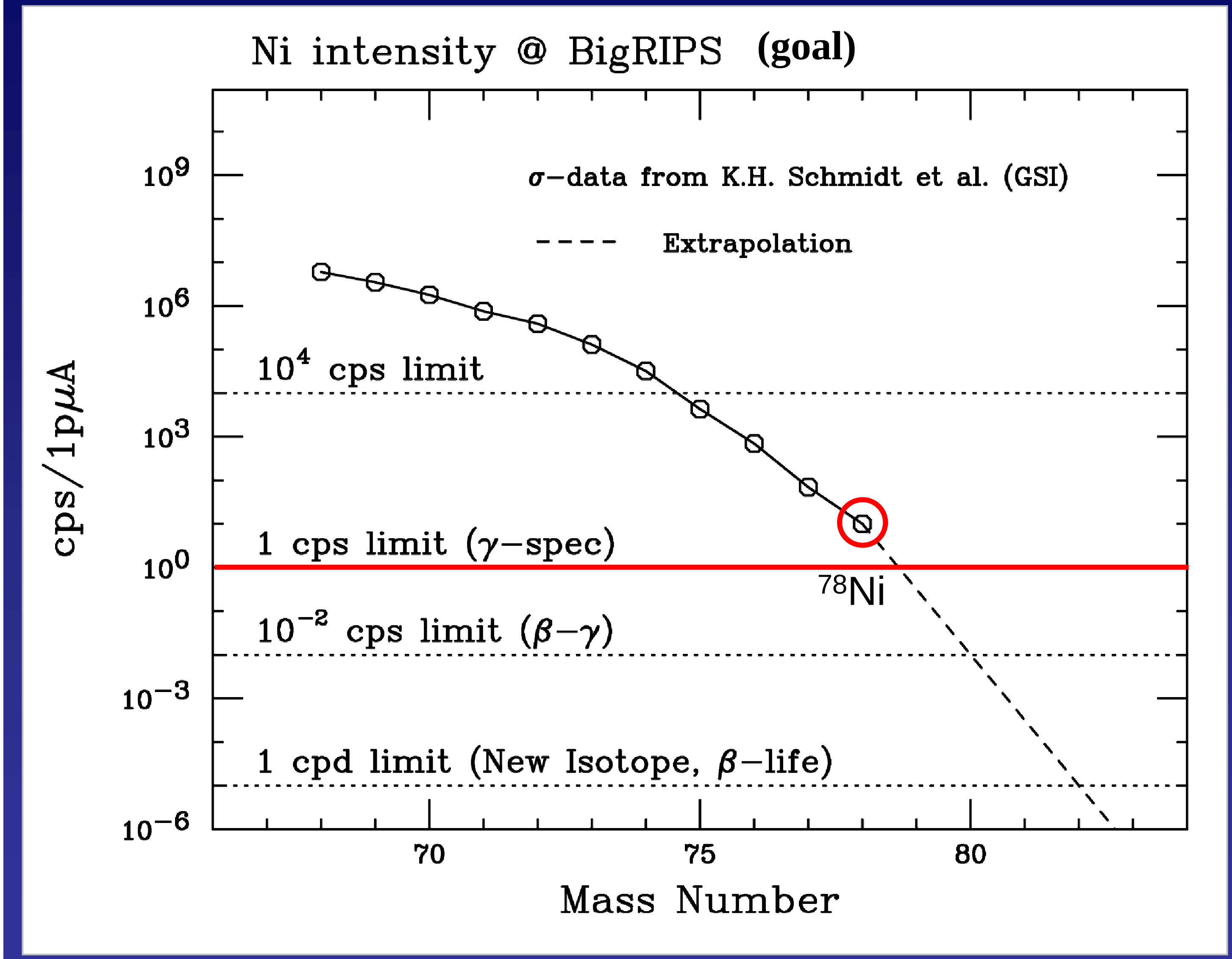
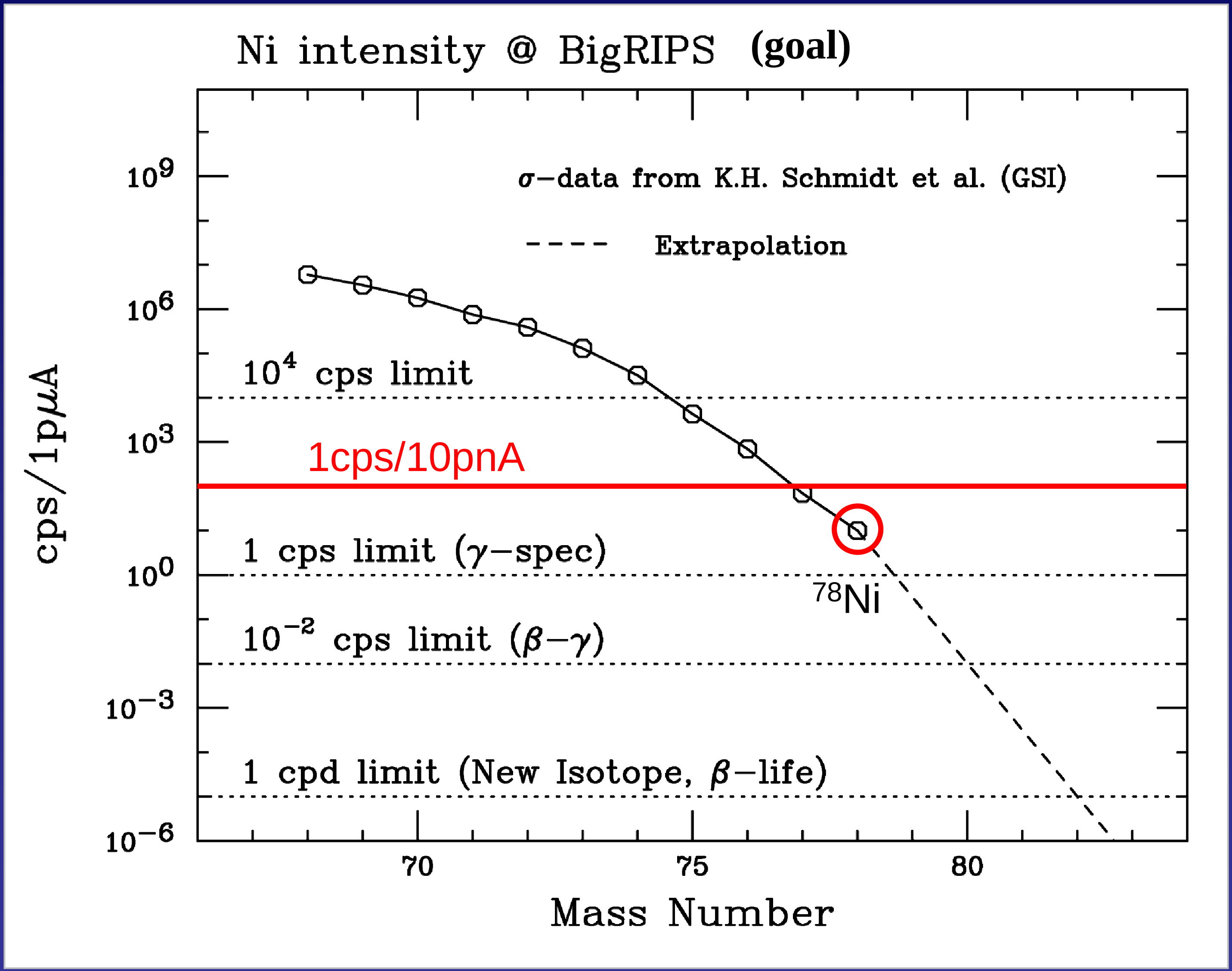




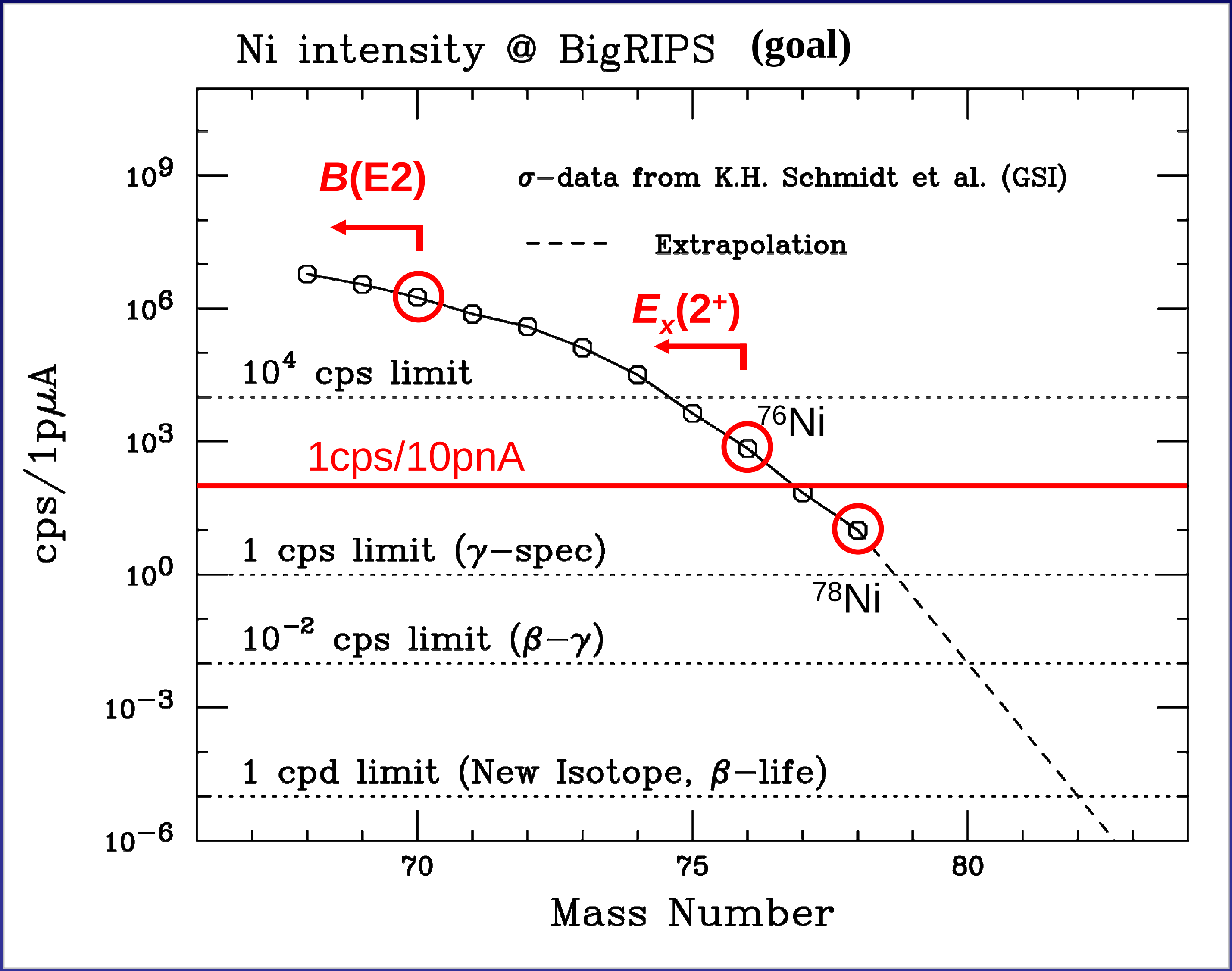
at present:

- $T_{1/2}$: up to ^{78}Ni
- $E(2^{+})$: up to ^{76}Ni
- B(E2): up to ^{70}Ni



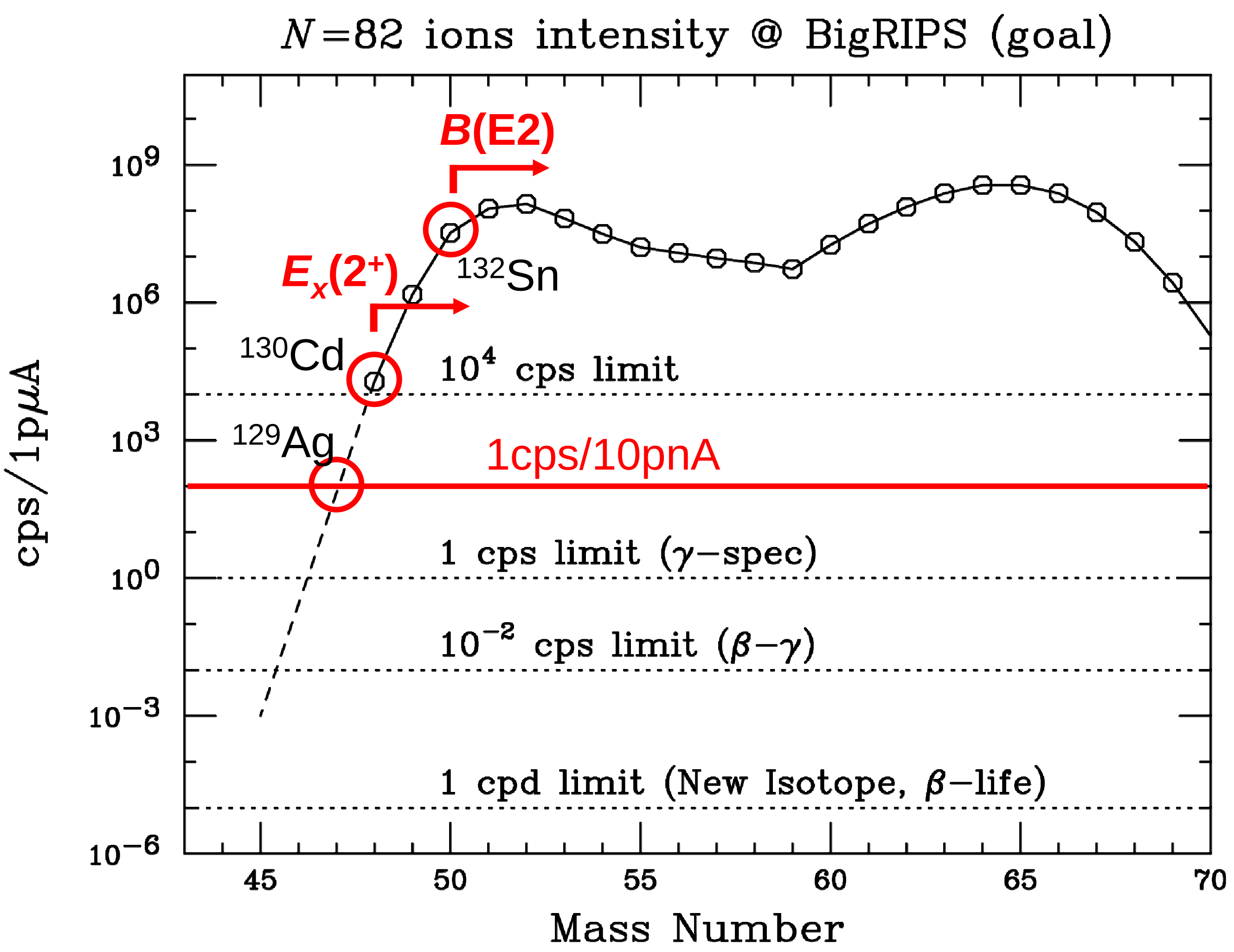
at present:

- $T_{1/2}$: up to ^{78}Ni
- $E(2^+)$: up to ^{76}Ni
- B(E2): up to ^{70}Ni

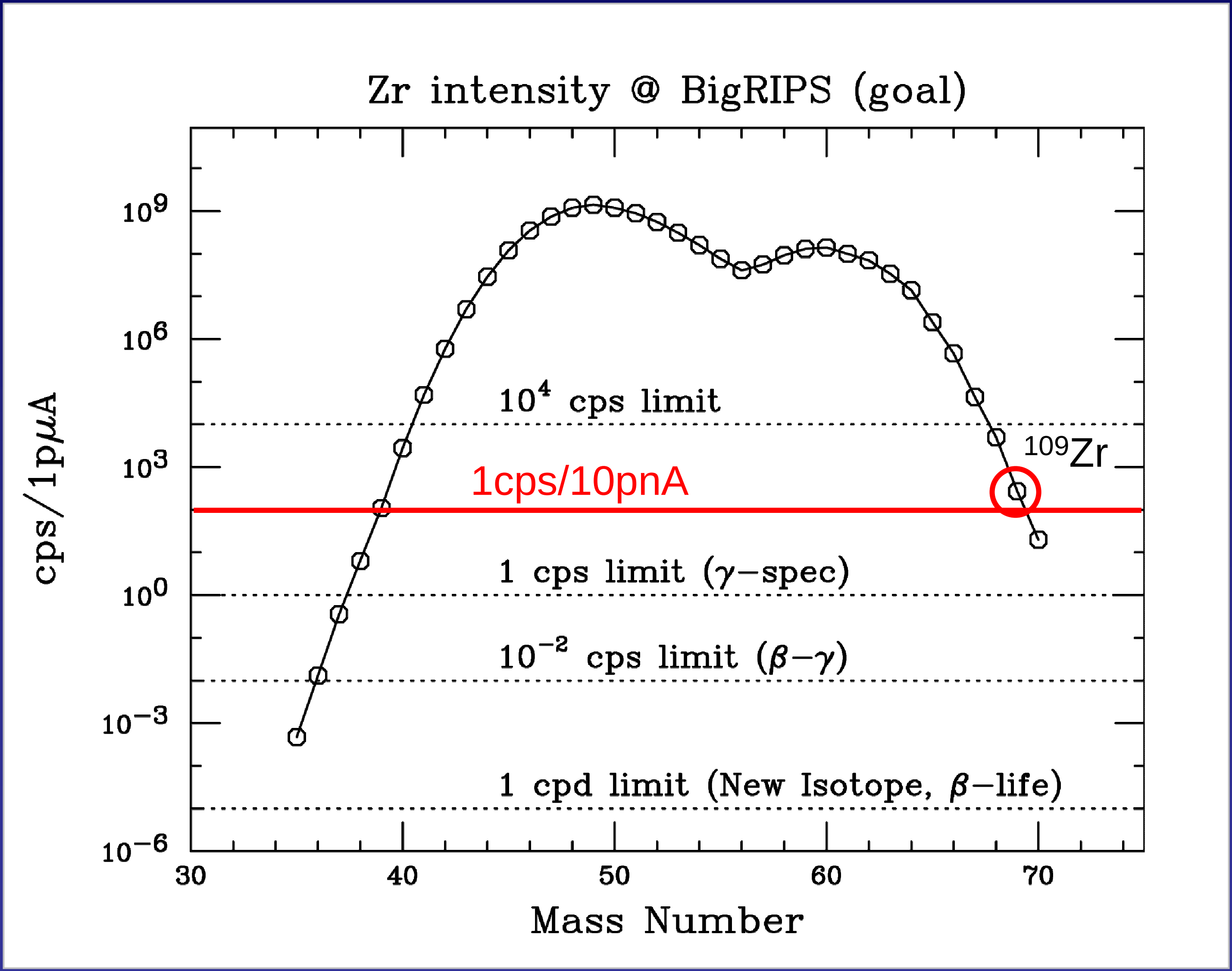


at present:

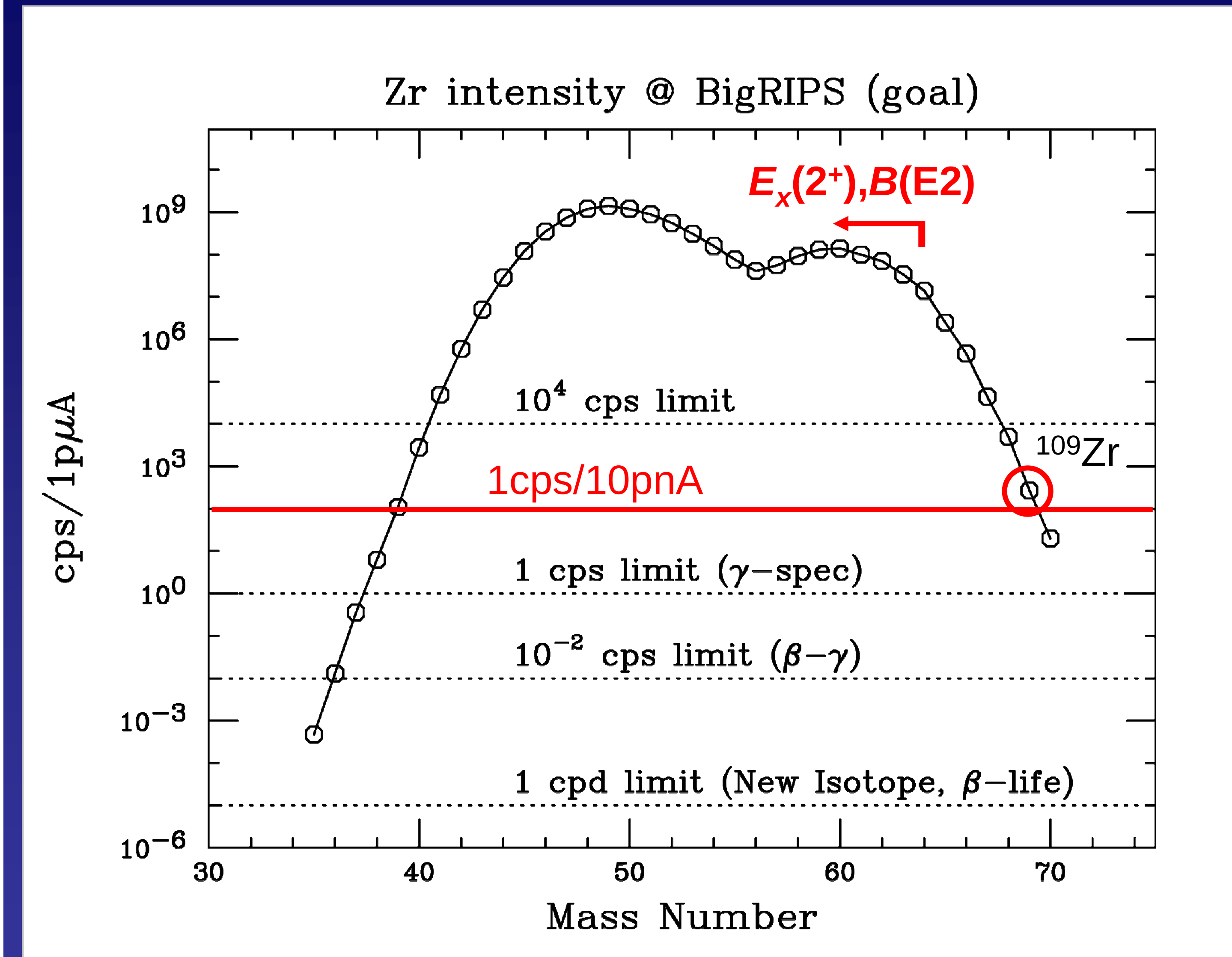
- $T_{1/2}$: up to ^{78}Ni
- $E(2^{+})$: up to ^{76}Ni
- $B(E2)$: up to ^{70}Ni



N=82 ions intensity @ BigRIPS (goal)
B(E2)
Ex(2+)
132Sn
130Cd
129Ag
10^4 cps limit
1cps/10pnA
1 cps limit (γ−spec)
10^−2 cps limit (β−γ)
1 cpd limit (New Isotope, β−life)
10^9
10^6
10^3
10^0
10^−3
10^−6
cps/1pμA
45
50
55
60
65
70
Mass Number



Zr intensity @ BigRIPS (goal)
cps/1pμA
Mass Number
10^9
10^6
10^3
10^0
10^−3
10^−6
30
40
50
60
70
10^4 cps limit
1cps/10pnA
109Zr
1 cps limit (γ−spec)
10^−2 cps limit (β−γ)
1 cpd limit (New Isotope, β−life)



Zr intensity @ BigRIPS (goal)
$E_x(2^+)$,B(E2)
10^4 cps limit
^{109}Zr
1cps/10pnA
1 cps limit (γ–spec)
10^{-2} cps limit (β–γ)
1 cpd limit (New Isotope, β–life)
cps/1pμA
Mass Number
10^9
10^6
10^3
10^0
10^{-3}
10^{-6}
30
40
50
60
70

Use of RIPS

LINIAC + RRC

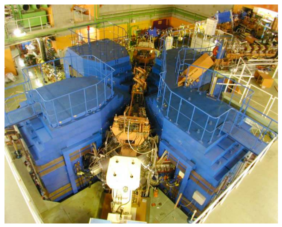
^{86}Kr 80pnA@63AMeV

^{70}Zn 150pnA@63AMeV

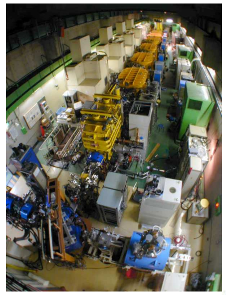
- Lower energy
- Higher intensity
- No magnetic spectrometer for reaction residue

Layout of RIKEN RI beam factory (RIBF) in 2007

RRC

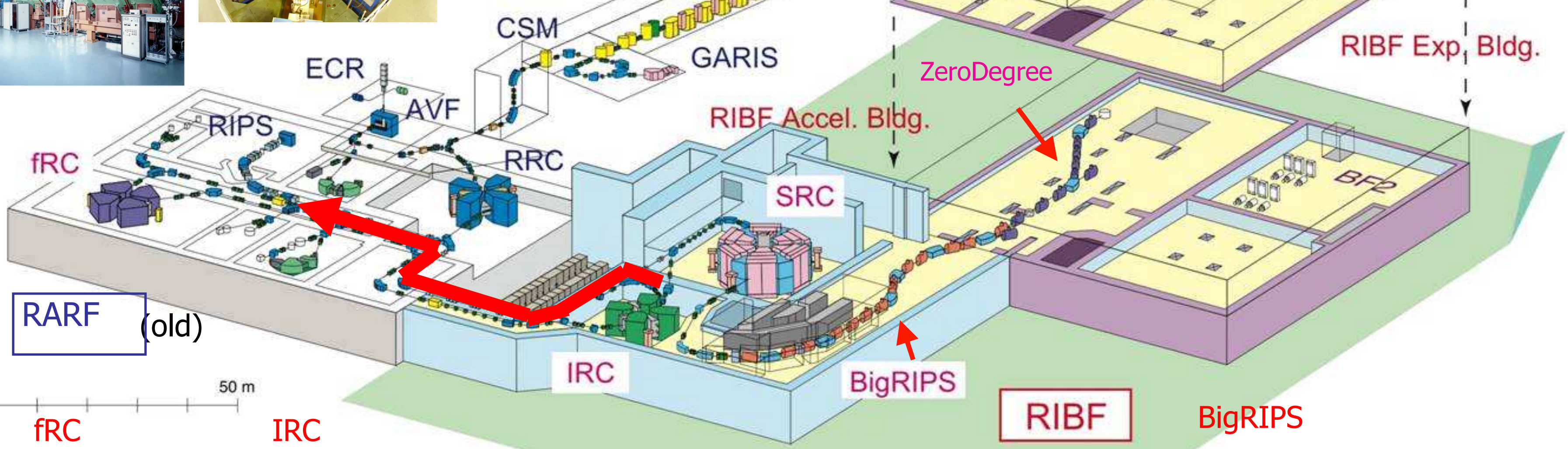


RILAC

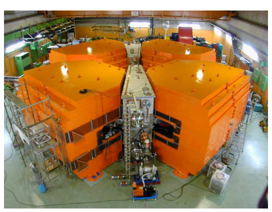


RIPS

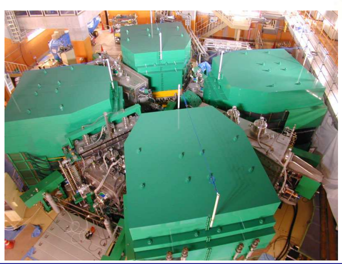
ZeroDegree



fRC

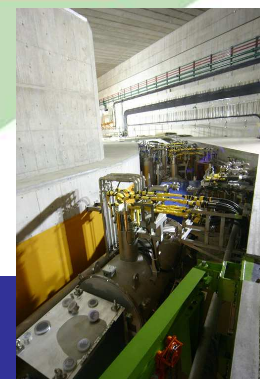


IRC

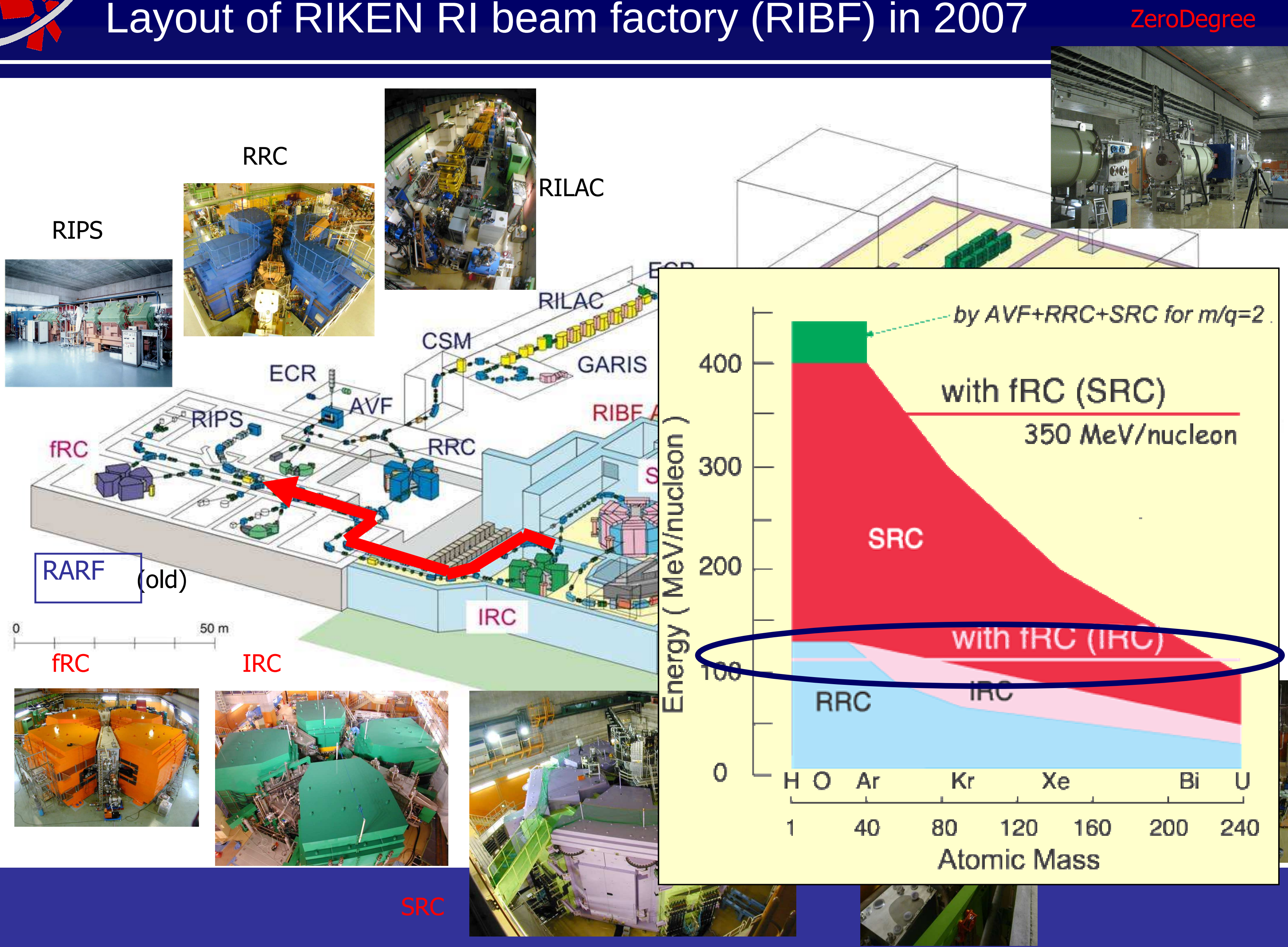


SRC

BigRIPS



Layout of RIKEN RI beam factory (RIBF) in 2007



Use of RIPS

LINIAC + RRC

^{86}Kr 80pnA@63AMeV

^{70}Zn 150pnA@63AMeV

LINAC + RRC + (fRC) + IRC

<Pb ~100pnA@115AMeV

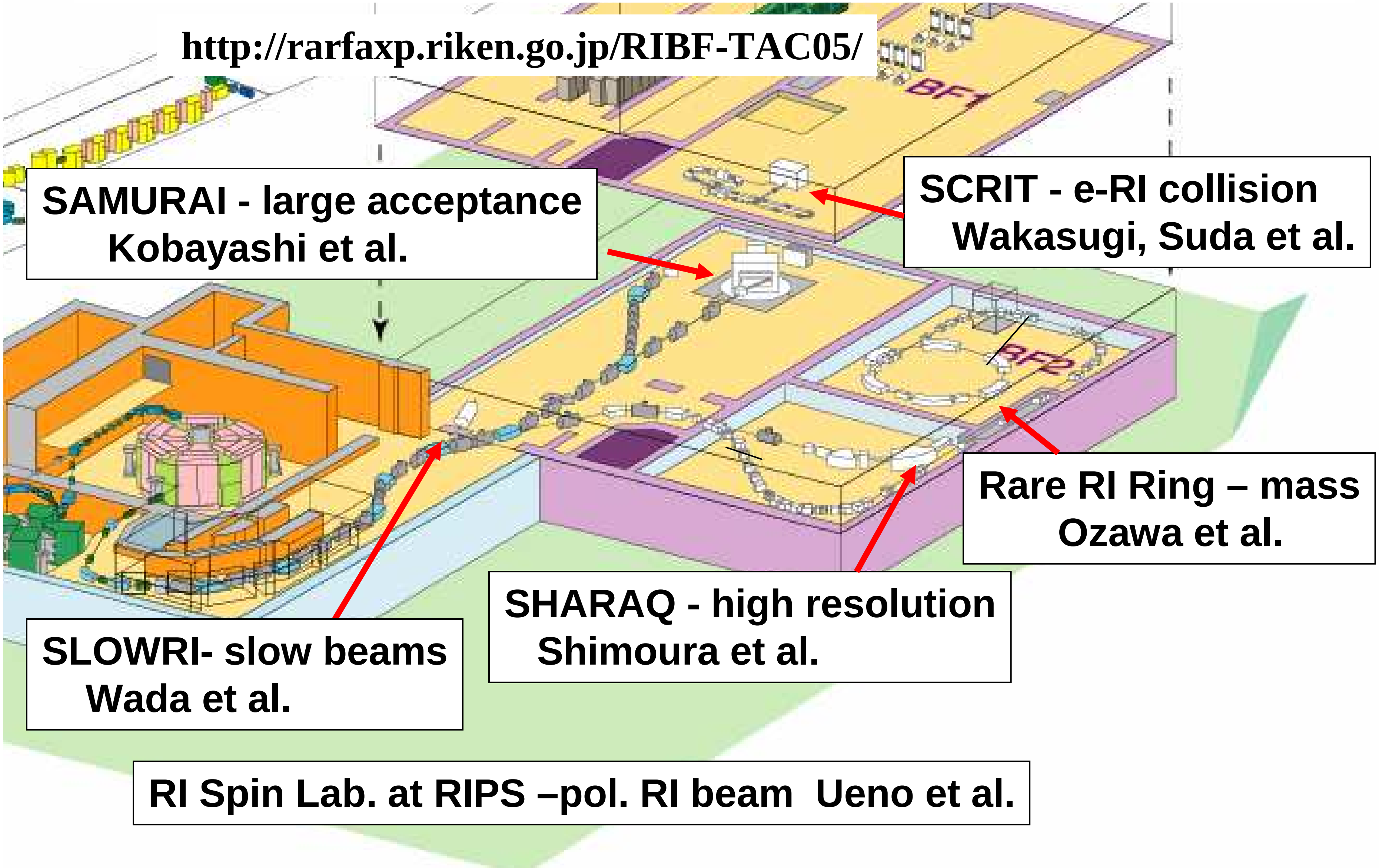
1pμA@115AMeV (goal)

- Lower energy
- Higher intensity
- No magnetic spectrometer for reaction residue

Phase-II construction 2007-2010

To maximize the potentials of intense RI beams available at RIBF

http://rarfaxp.riken.go.jp/RIBF-TAC05/



Expected beam list in 2007-2008

Expected intensities of 350 MeV/nucleon beams at RIBF

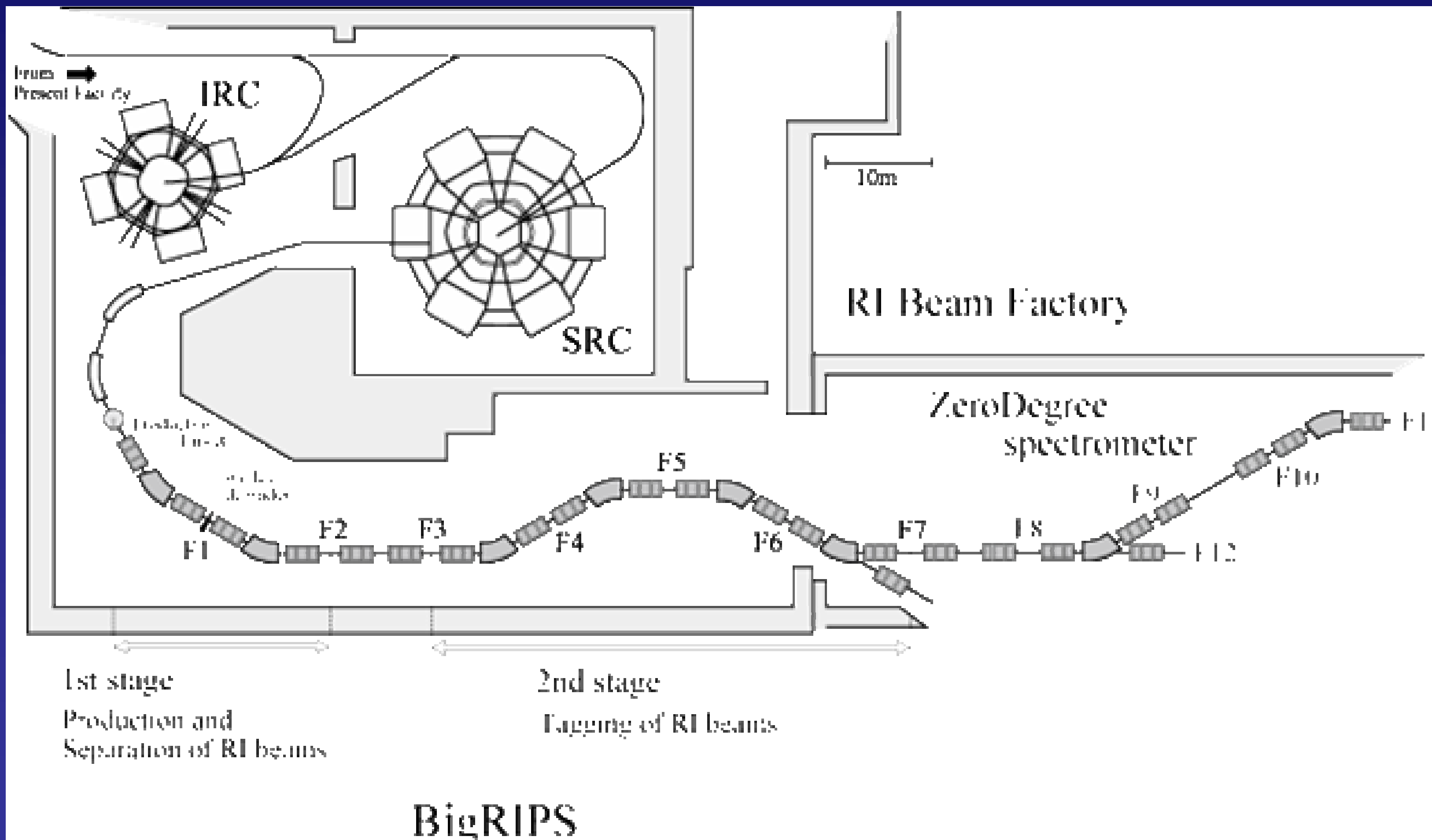
	Ca	Kr	Xe	^{238}U
Intensity (pnA)	200	100	10	2

Note
1. The intensities of Xe and U beams for the first one-year are expected to be lower than the values in the table by one order.
2. Xe beams at lower energies are available with higher intensities: 100 pnA at 200 MeV/nucleon, for example.

2 pnA = 1.2×10^{10} particles/sec

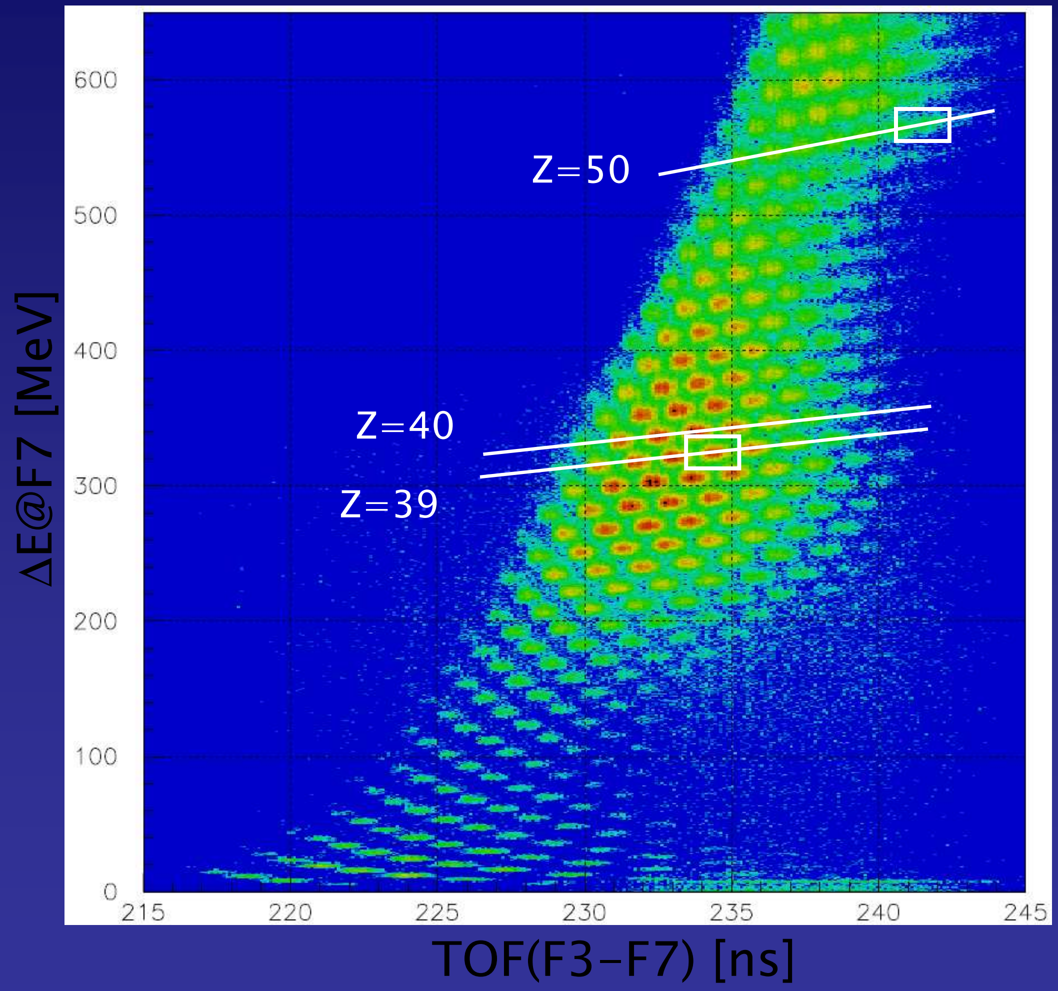
http://ribfwww.riken.go.jp/exp/pre/accelerator/concept.html

→ The construction project of a new injector linac with a new superconducting 28-GHz ECR ion source is beginning, aiming at upgrading the intensity.


IRC
SRC
10m
RI Beam Factory
ZeroDegree
spectrometer
F1
F2
F3
F4
F5
F6
F7
F10
F11
F12
1st stage
Production and
Separation of RI beams
2nd stage
Tagging of RI beams
BigRIPS

First observation of in-flight fission at BigRIPS

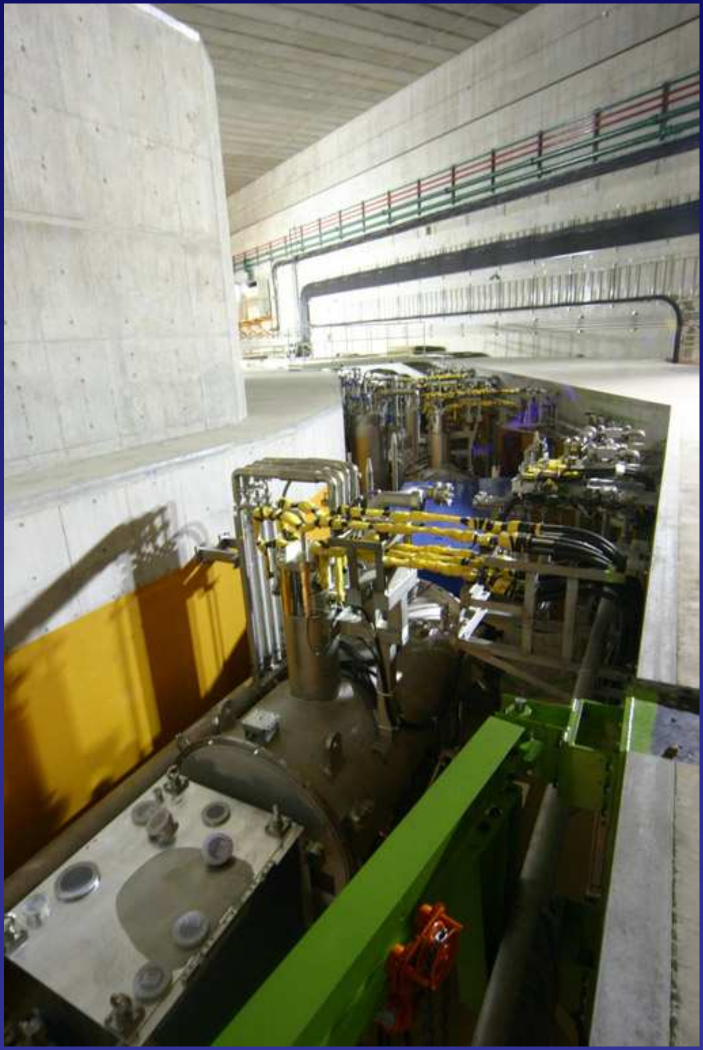
^{238}U + Be @ 345AMeV



PID using
tagging section

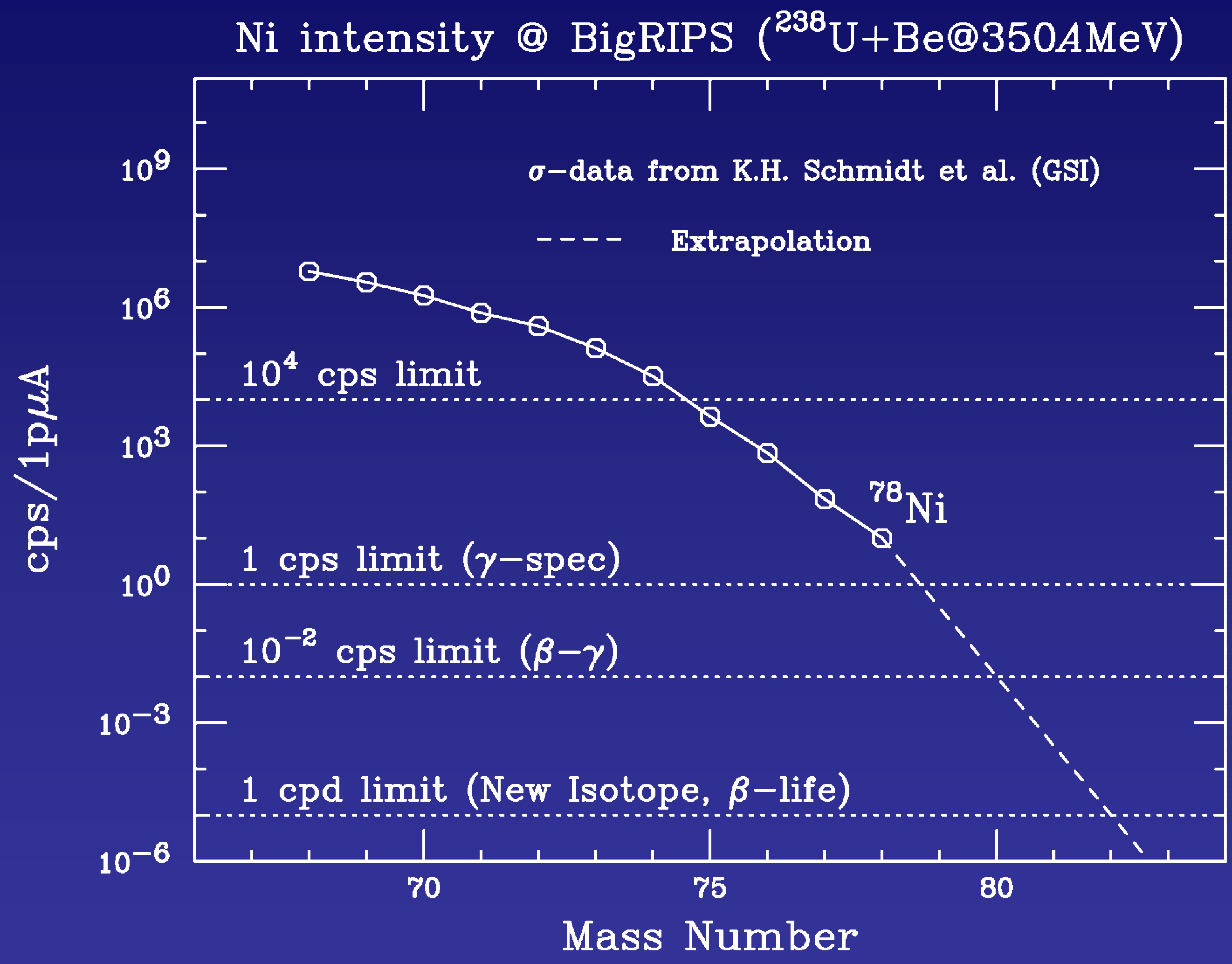
2007/3/27: T.Kubo, T. Ohnishi, and
BigRIPS Commissioning team

BigRIPS first-stage

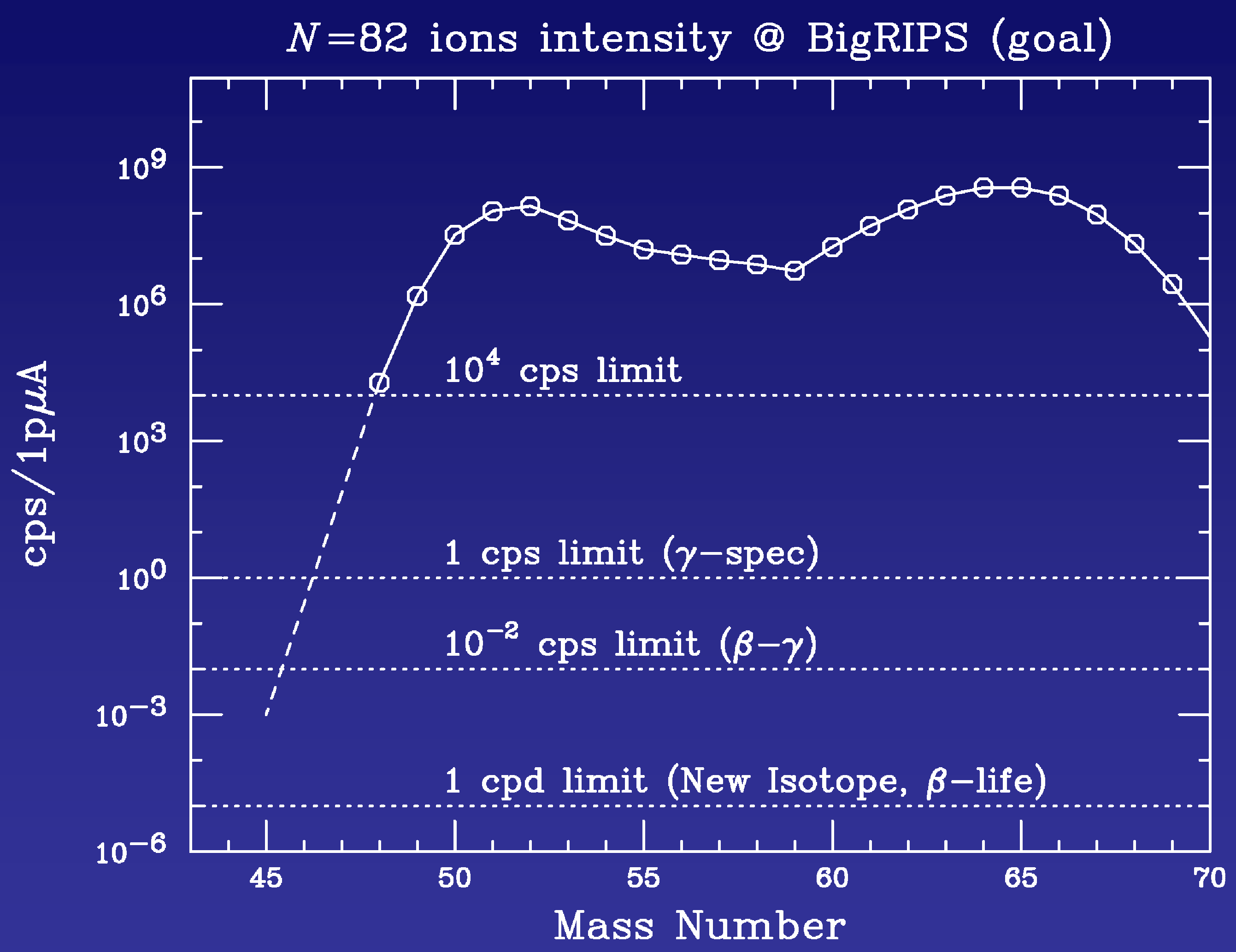


Courtesy of S. Bishop (left) & A. Saito (right), Oct. 2, 2006

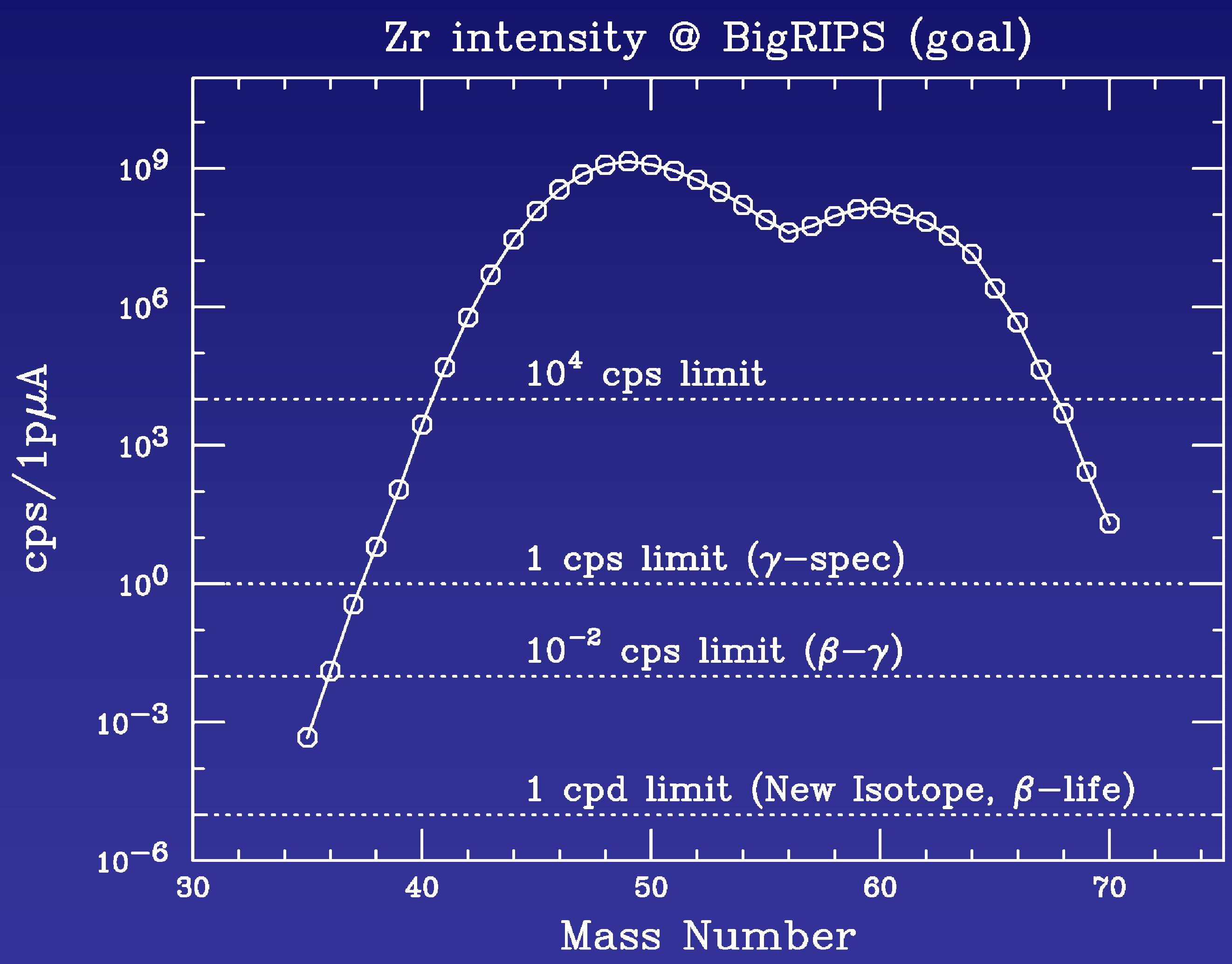
BigRIPS second-stage



Ni intensity @ BigRIPS (238U+Be@350AMeV)
σ−data from K.H. Schmidt et al. (GSI)
Extrapolation
10^4 cps limit
78Ni
1 cps limit (γ−spec)
10^−2 cps limit (β−γ)
1 cpd limit (New Isotope, β−life)
10^9
10^6
10^3
10^0
10^−3
10^−6
cps/1pμA
70
75
80
Mass Number



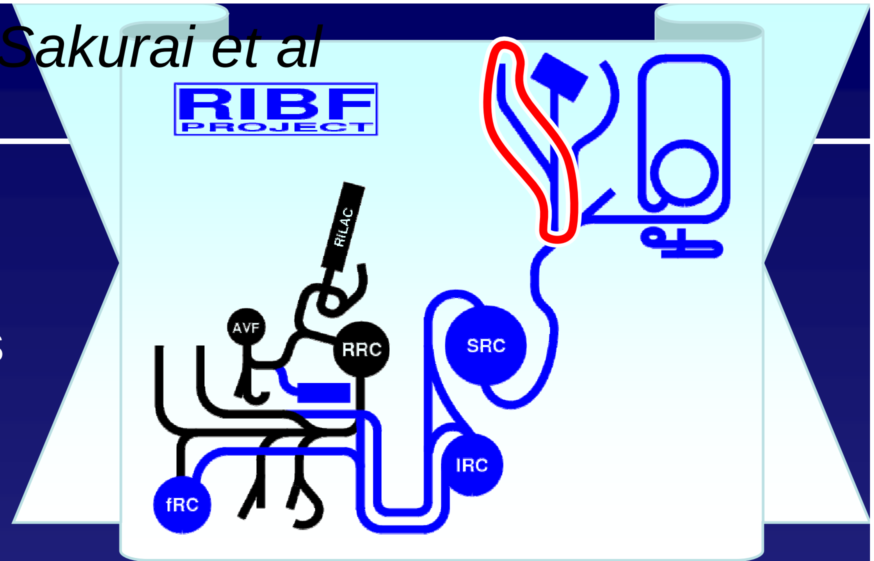
N=82 ions intensity @ BigRIPS (goal)
10^9
10^6
10^3
10^0
10^−3
10^−6
cps/1pμA
10^4 cps limit
1 cps limit (γ−spec)
10^−2 cps limit (β−γ)
1 cpd limit (New Isotope, β−life)
45
50
55
60
65
70
Mass Number



Zr intensity @ BigRIPS (goal)
cps/1pμA
Mass Number
10^9
10^6
10^3
10^0
10^−3
10^−6
30
40
50
60
70
10^4 cps limit
1 cps limit (γ−spec)
10^−2 cps limit (β−γ)
1 cpd limit (New Isotope, β−life)

Zero-degree spectrometer

H. Sakurai et al

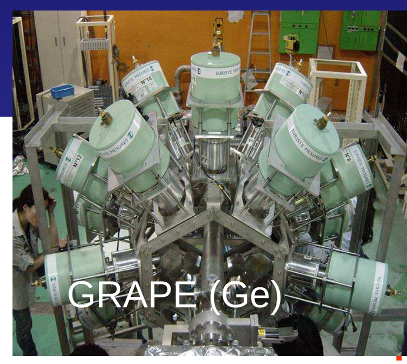


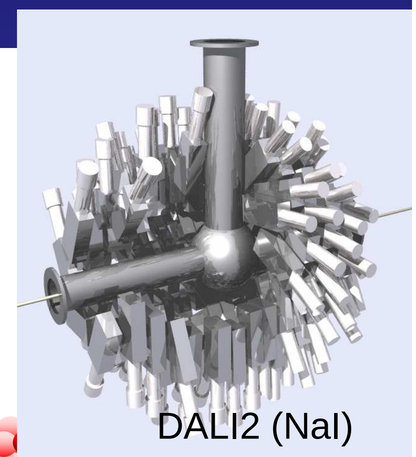
particle ID / momentum analysis

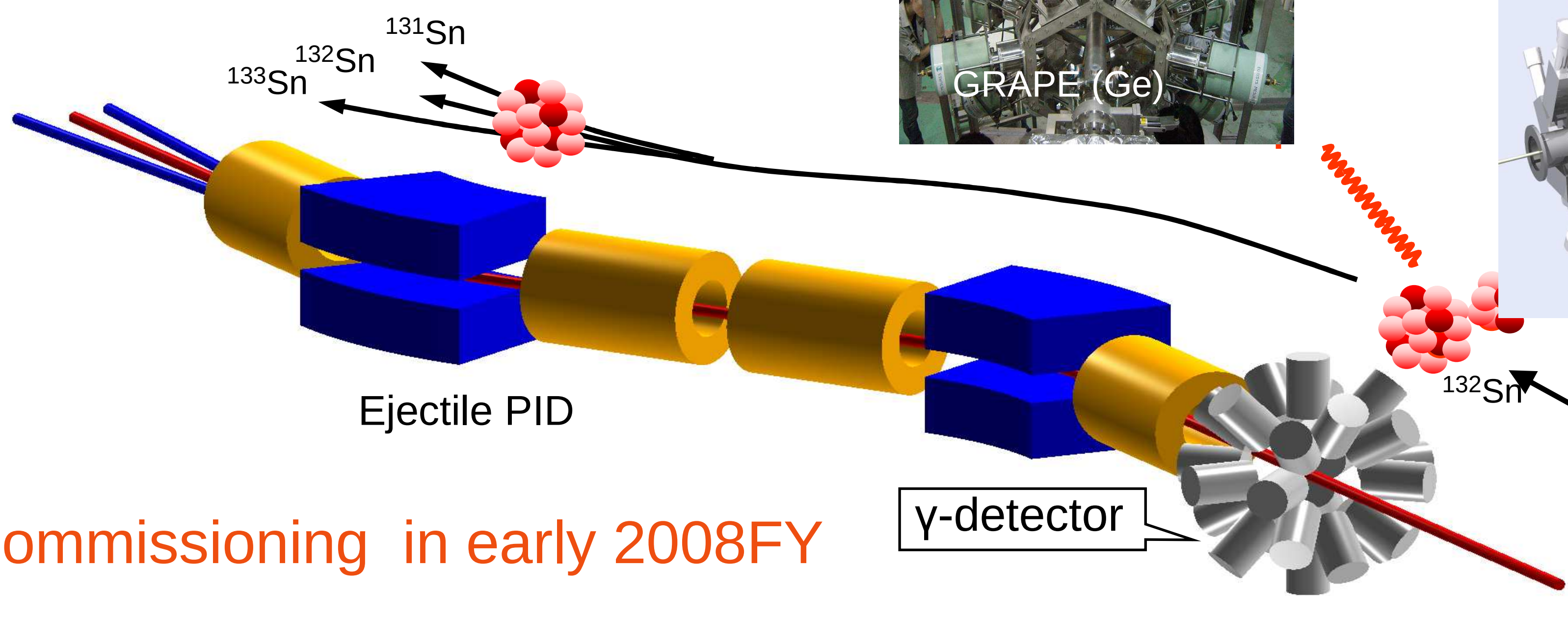
e.g. Doppler shifted γ-ray measurements
with identification of products
(angle-integrated cross section)

p/dp = 2000 ~ 4000

p_{acc} = ±3%





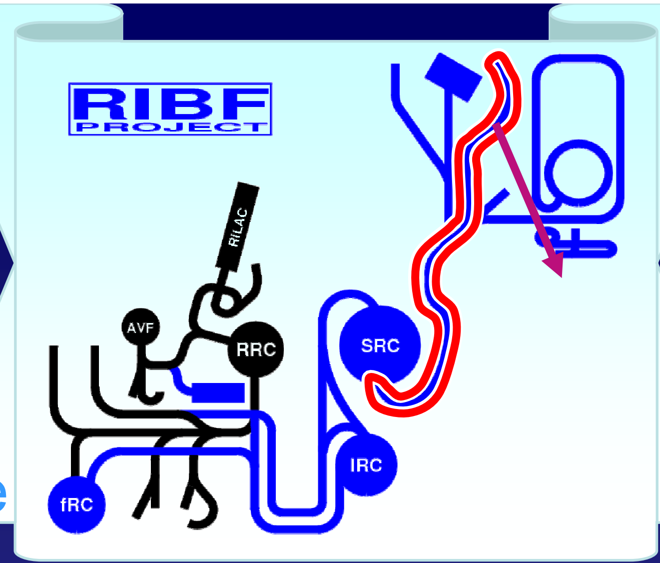


ommissioning in early 2008FY

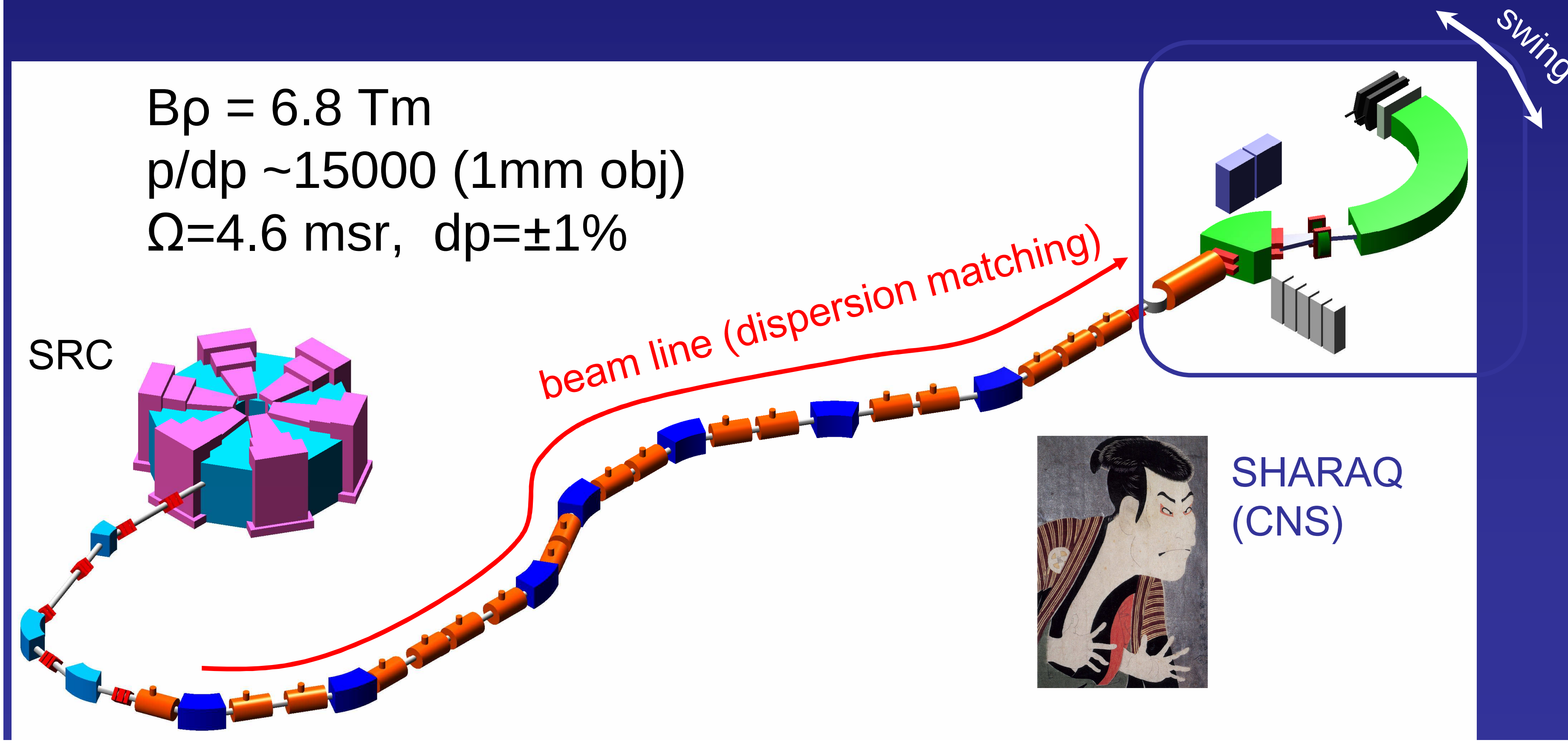
SHARAQ *S. Shimoura et al*

High-resolution spectrometer
with dispersion-matched beam line

RI beam as probes
e.g. double charge exchange

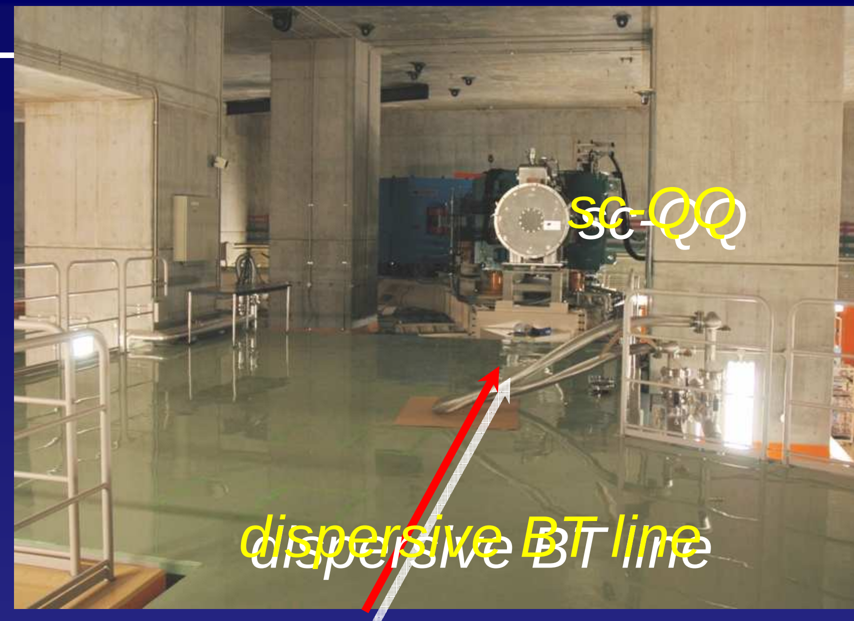


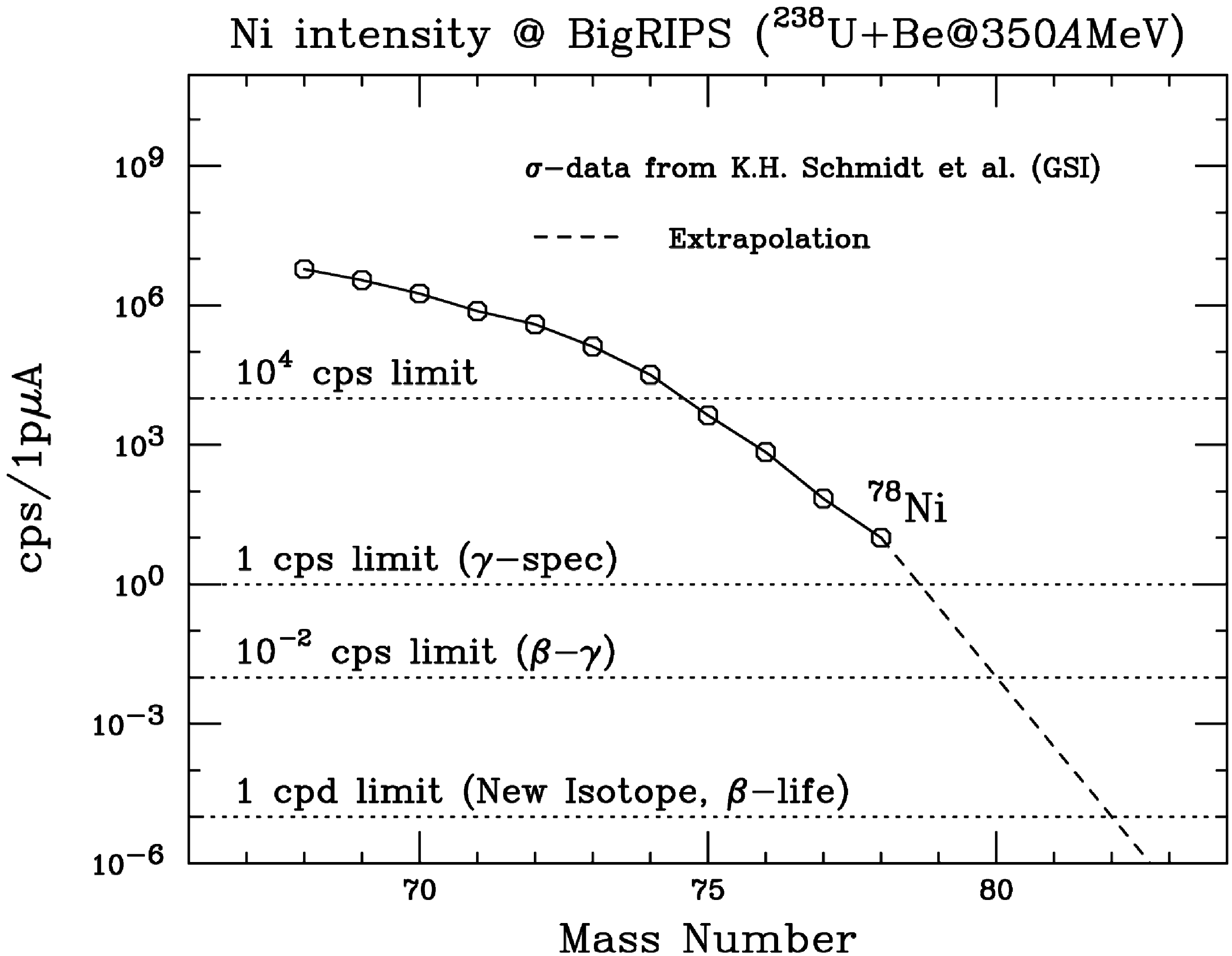
Bρ = 6.8 Tm
p/dp ~15000 (1mm obj)
Ω=4.6 msr, dp=±1%



SHARAQ construction

Magnets installed in 2007
Dispersive BT in 2008
Commissioning in 2008?





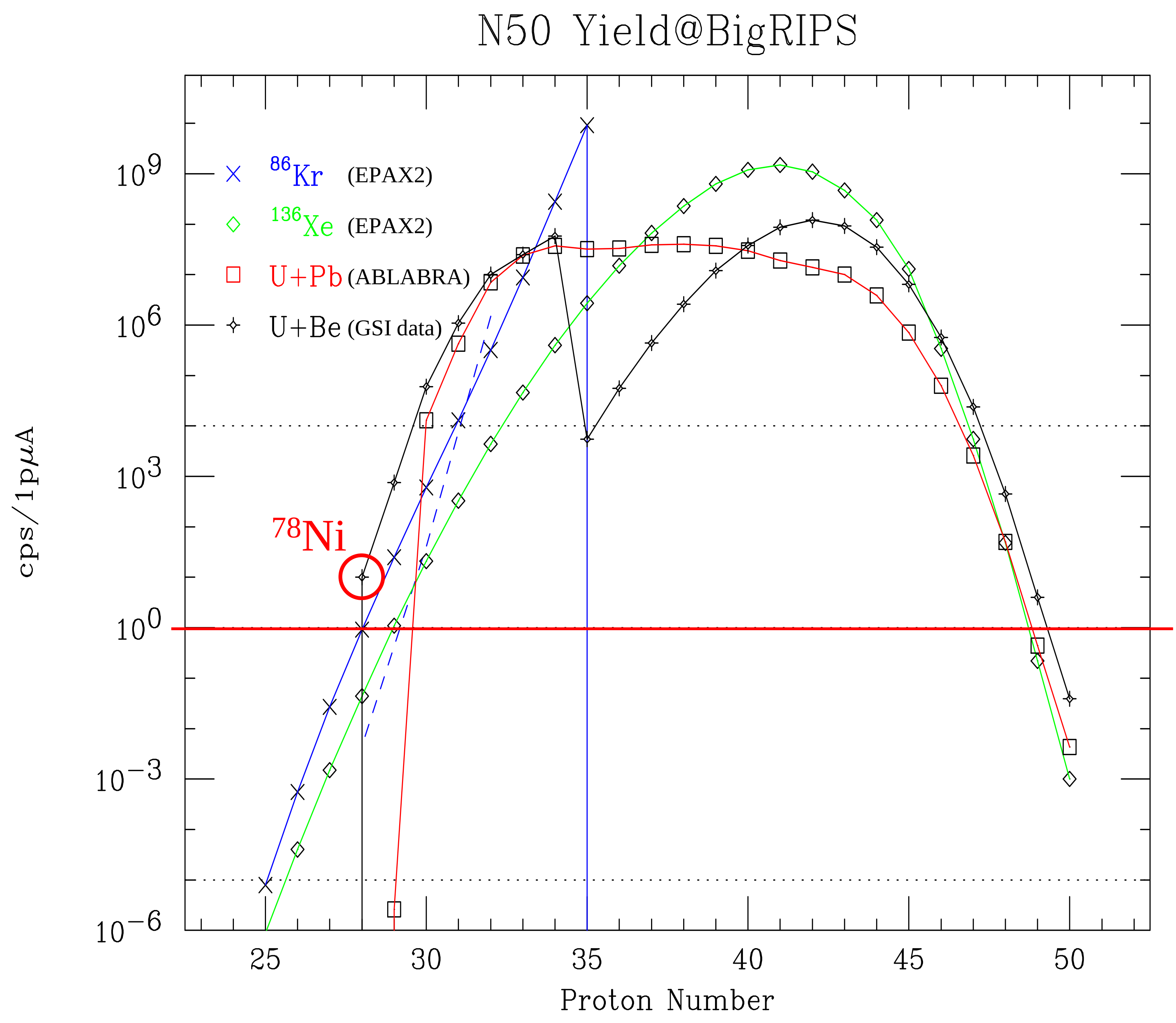
at present:

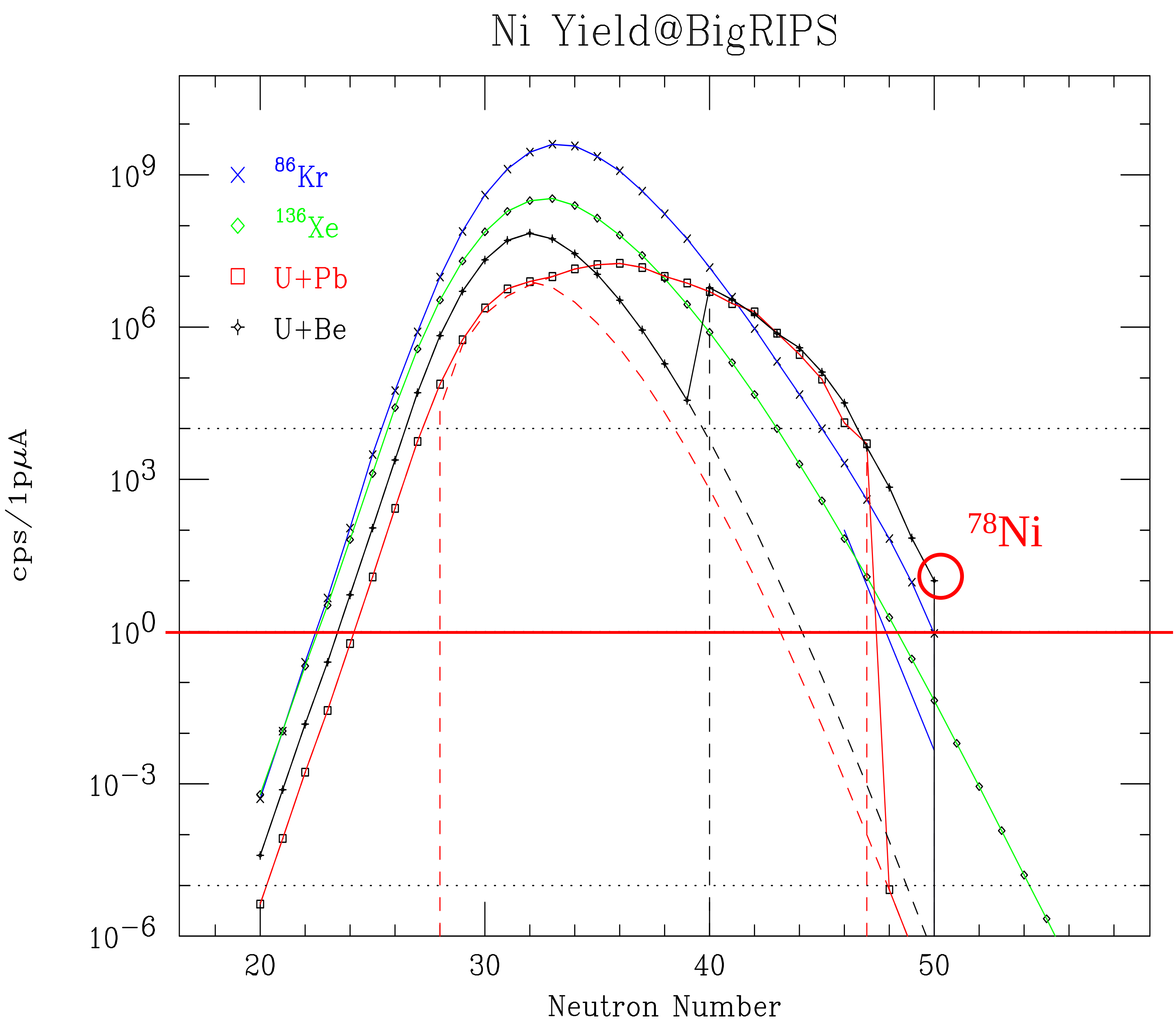
$T_{1/2}$: up to ^{78}Ni

$E(2^+)$: up to ^{76}Ni

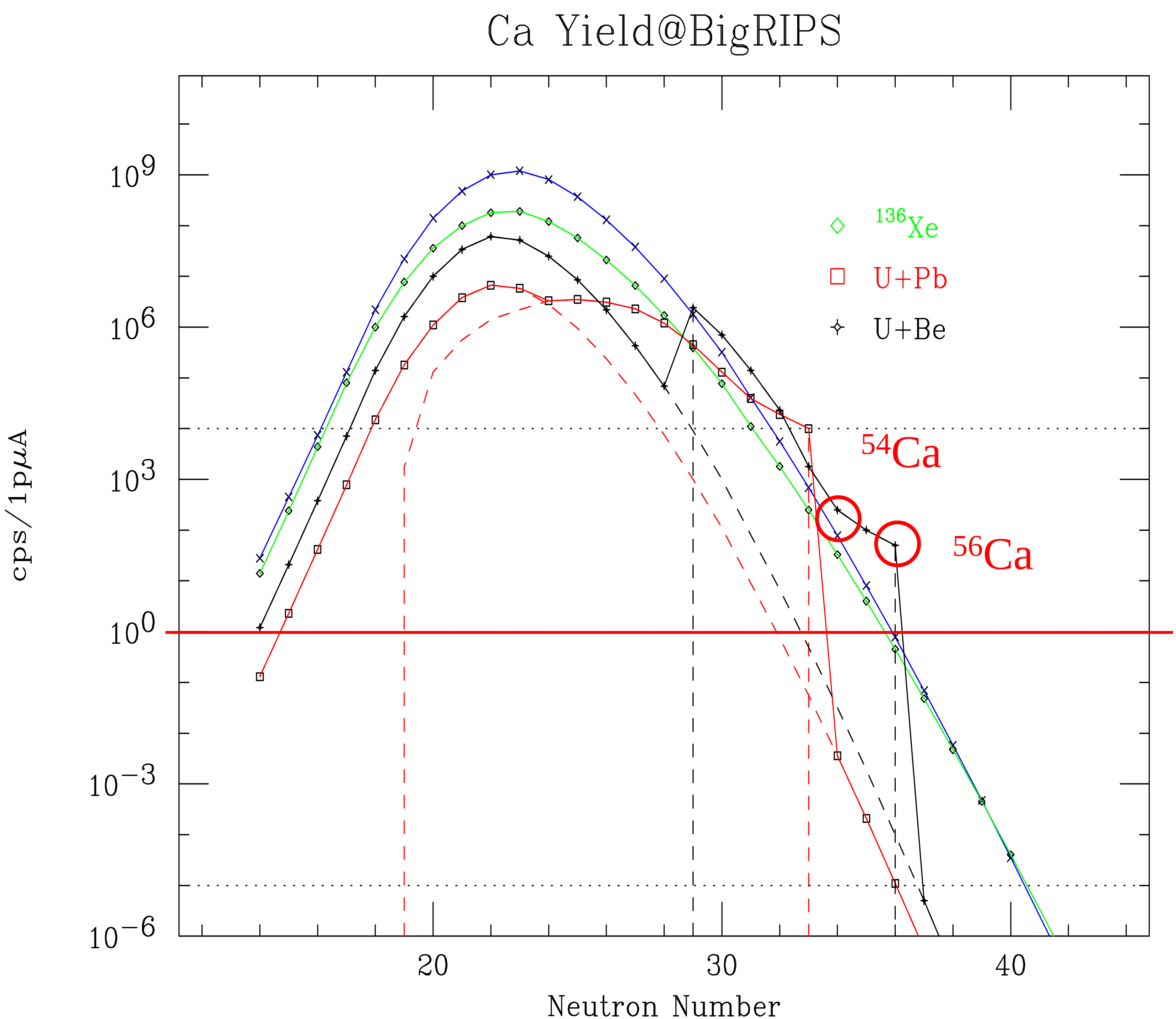
B(E2): up to ^{70}Ni

β_2(pp') for ^{74}Ni

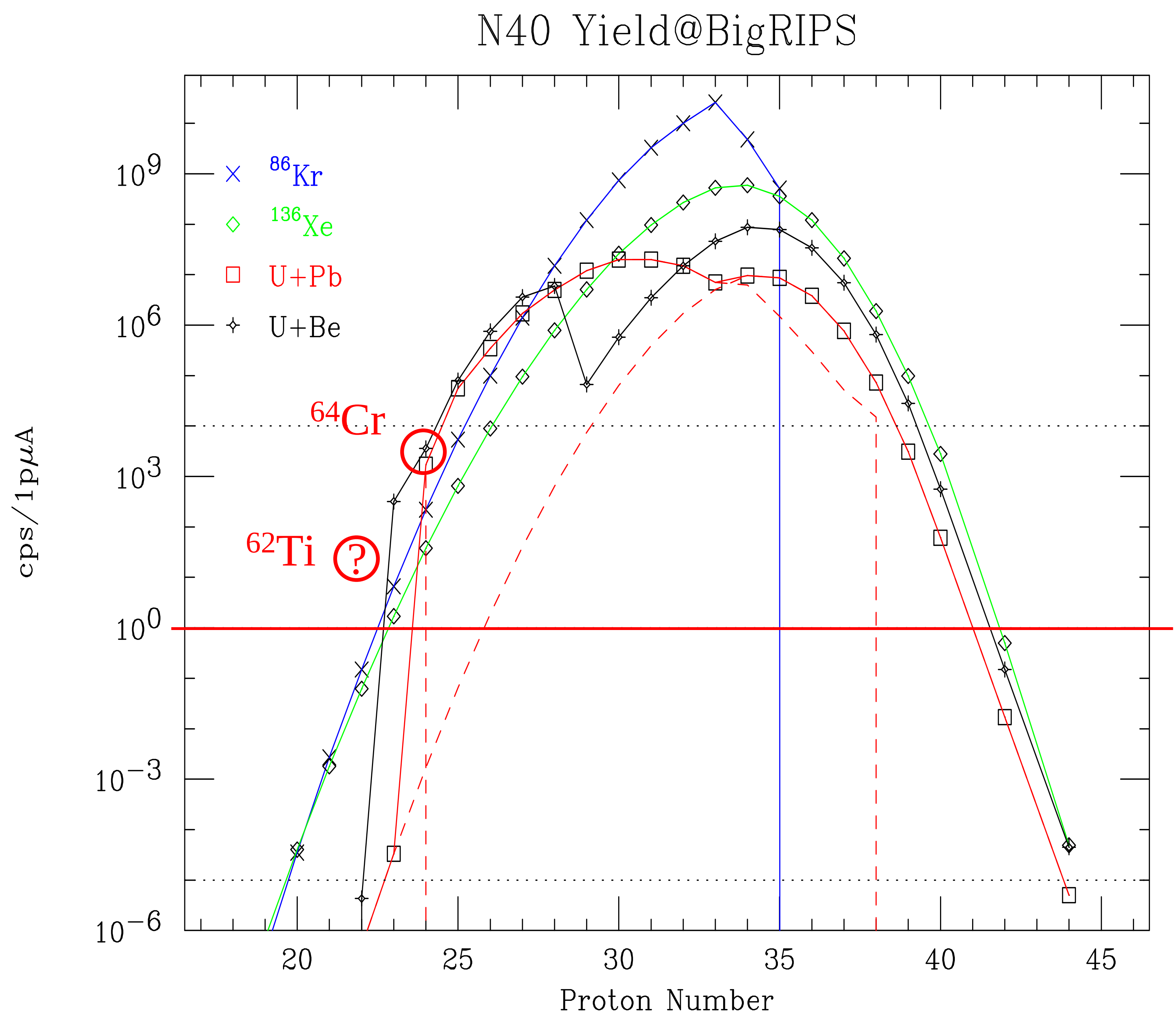

N50 Yield@BigRIPS
86Kr (EPAX2)
136Xe (EPAX2)
U+Pb (ABLABRA)
U+Be (GSI data)
78Ni
cps/1pμA
10^9
10^6
10^3
10^0
10^−3
10^−6
25
30
35
40
45
50
Proton Number



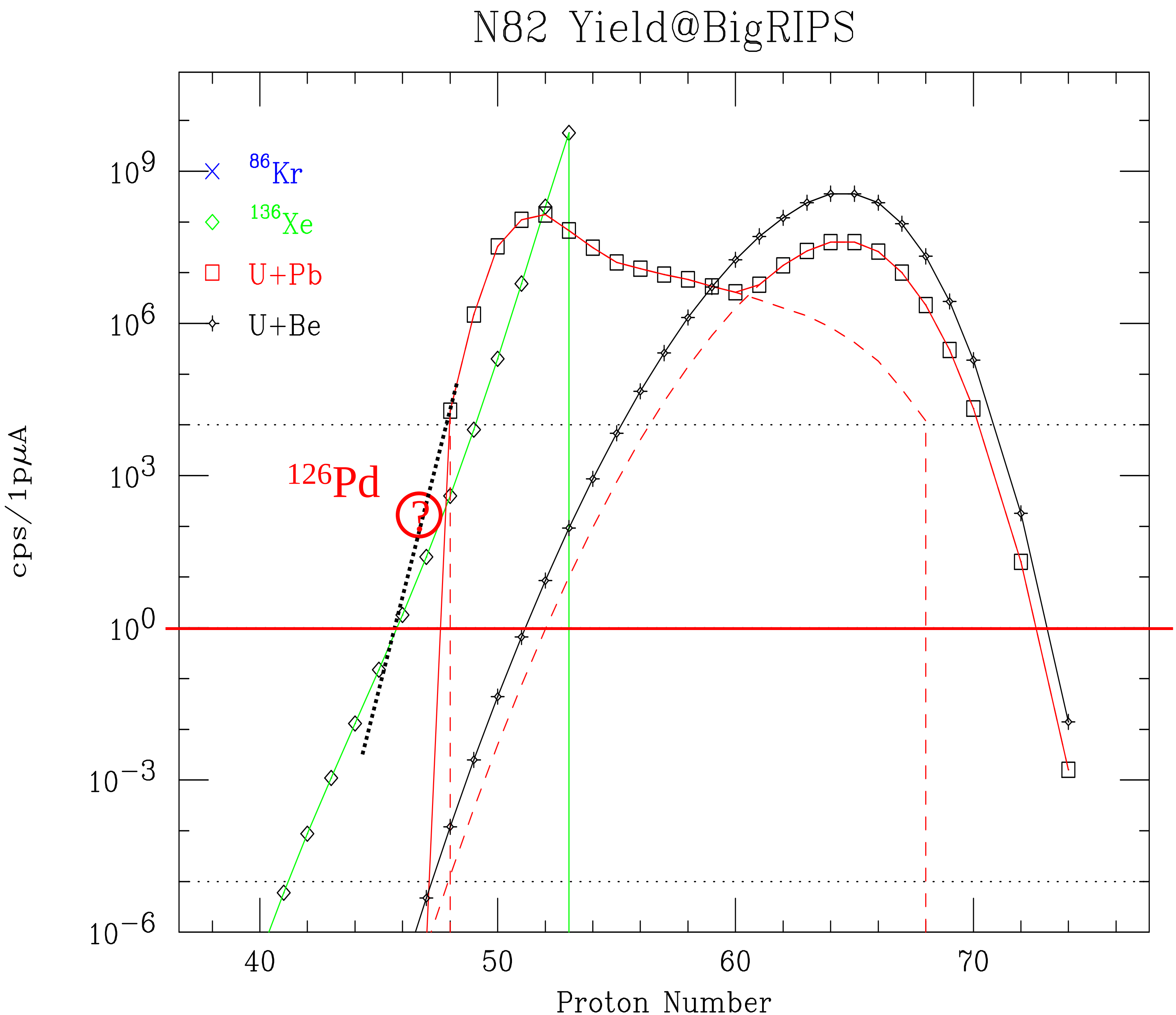
Ni Yield@BigRIPS
86Kr
136Xe
U+Pb
U+Be
78Ni
cps/1pμA
10^9
10^6
10^3
10^0
10^-3
10^-6
20
30
40
50
Neutron Number



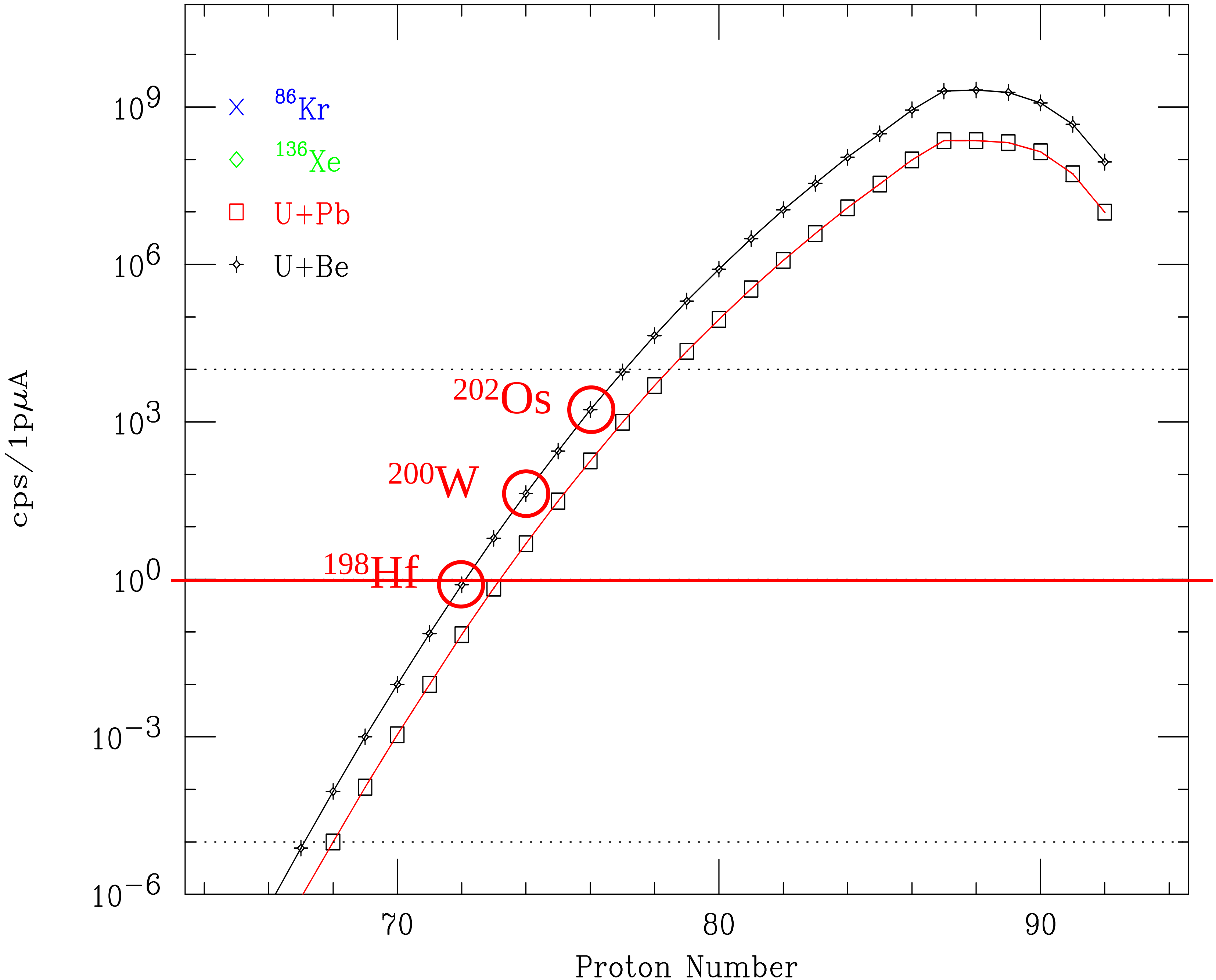
Ca Yield@BigRIPS
136Xe
U+Pb
U+Be
54Ca
56Ca
10^9
10^6
10^3
10^0
10^-3
10^-6
cps/1pμA
20
30
40
Neutron Number

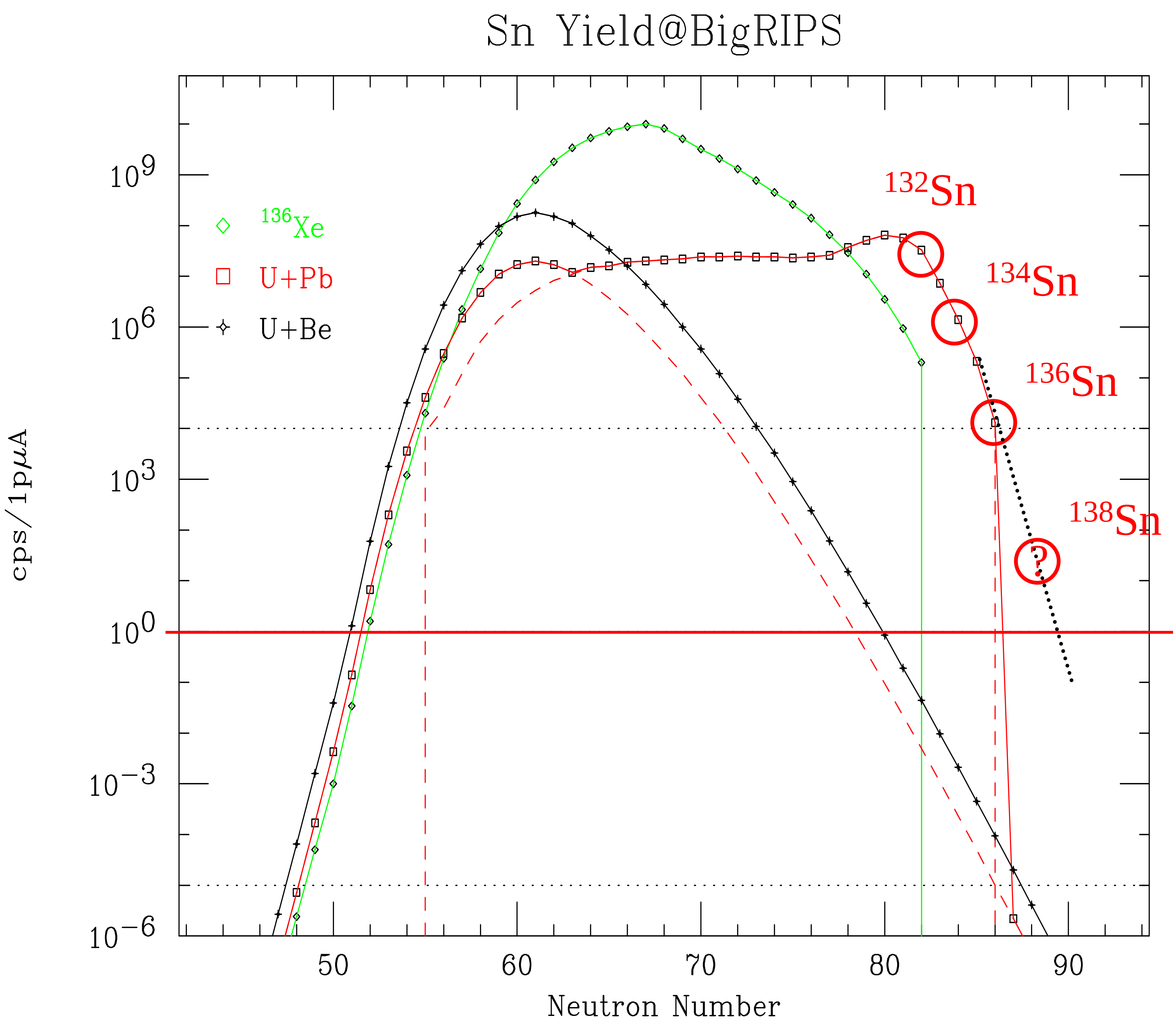


N40 Yield@BigRIPS
cps/1pμA
Proton Number
86Kr
136Xe
U+Pb
U+Be
64Cr
62Ti
?
10^9
10^6
10^3
10^0
10^−3
10^−6
20
25
30
35
40
45


N82 Yield@BigRIPS
^{86}Kr
^{136}Xe
U+Pb
U+Be
^{126}Pd
?
cps/1pμA
Proton Number
10^{9}
10^{6}
10^{3}
10^{0}
10^{-3}
10^{-6}
40
50
60
70

N126 Yield@BigRIPS





Sn Yield@BigRIPS
^{136}Xe
U+Pb
U+Be
^{132}Sn
^{134}Sn
^{136}Sn
^{138}Sn
?
cps/1pμA
10^{9}
10^{6}
10^{3}
10^{0}
10^{-3}
10^{-6}
50
60
70
80
90
Neutron Number