Description of the GR forward-mode beam line:
physics research by combination of magnetic spectrometers and CAGRA

A. Tamii

Research Center for Nuclear Physics

GRFBL Team:

K. Miki, T. Hashimoto, K. Nagayama, Y. Matsuda, H. Fujita,
C. Iwamoto, H.P. Yoshida, N. Aoi, E. Ideguchi, and A. Tamii

for CAGRA Workshop 2013.12.16-17 at Osaka Univ.

http://www.rcnp.osaka-u.ac.jp/Divisions/np1-a/GRFBL/

GR Forward-Mode Beam Line (GRFBL)

Under construction in this fiscal year (2013)

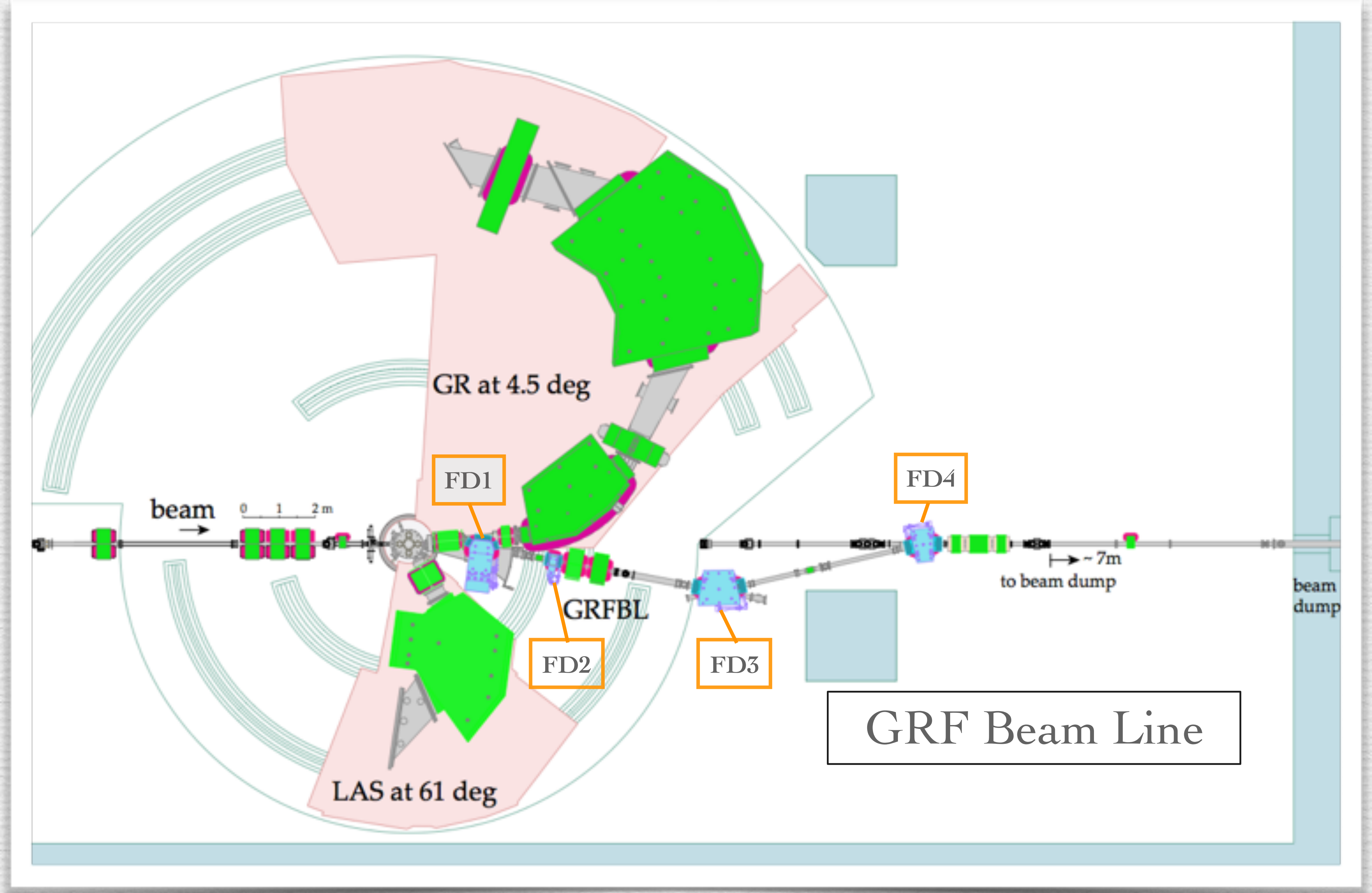
As a part of cyclotron improvement project.

Thanks to:
director of RCNP: Prof. Nakano
accelerator group: Prof. Hatanaka, Prof. Fukuda, and many.

GR Forward-Mode Beam Line (GRFBL)

Adds a beam-transportation mode for spectrometers GR and L

The beam can be transported to a beam dump, located 25 m downstream of the target position, with placing GR at 4.5-19.0 deg.



GR Forward-Mode Beam Line (GRFBL)

Realization of following experiments:

- Coincidence measurement between detectors around the target (especially γ detectors) and Grand Raiden (GR) spectrometer with placing GR at forward angles (4.5-19 deg)

  The beam stop position should be sufficiently far from the detector position.

- Measurements by GR with a high-intensity beam of 10-1000nA. Due to radiation safety, the beam must be stopped in the wall beam-dump.

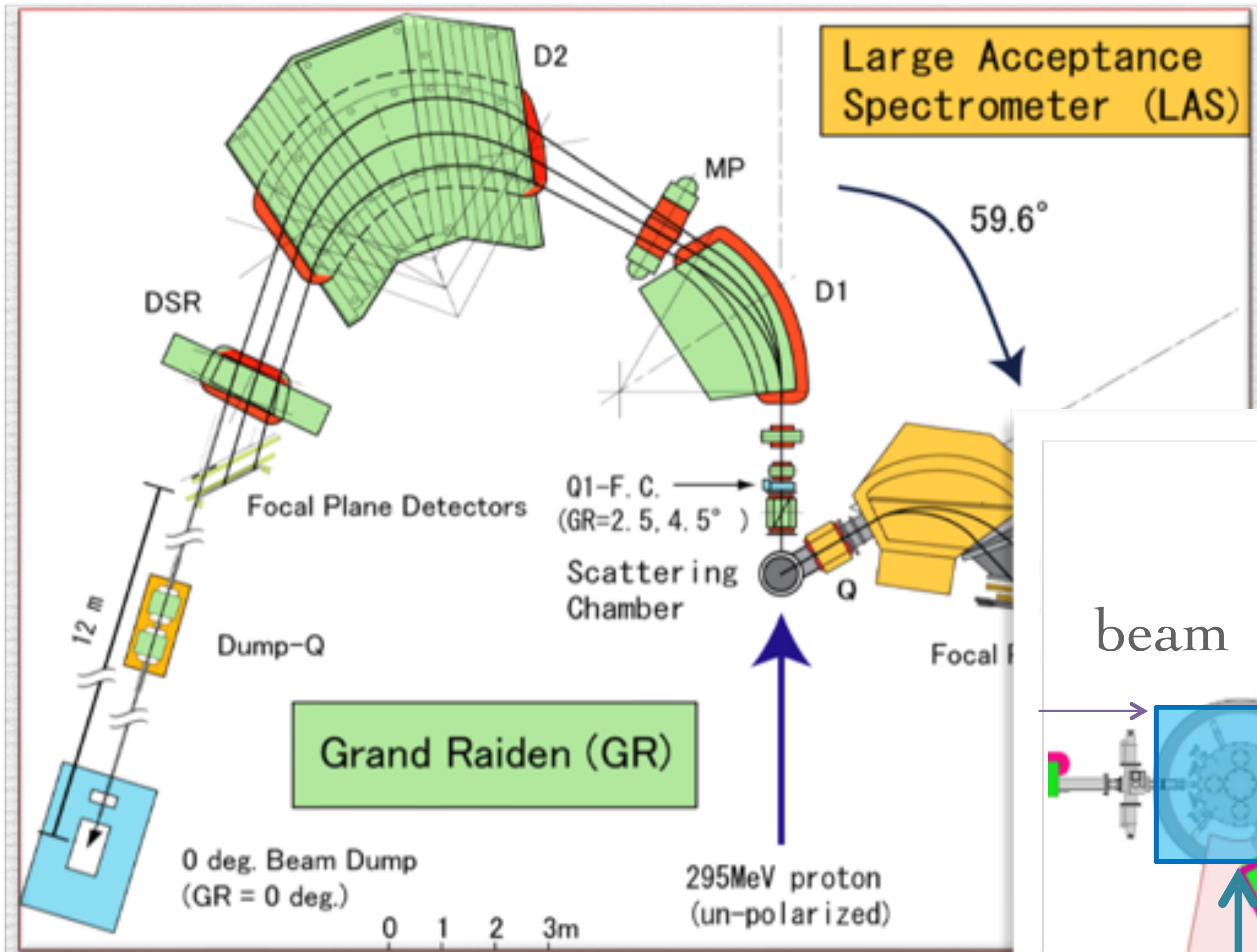
Those measurements have been possible only for GR placed at angles larger than 25.5 deg, and for limited cases at 0 deg.

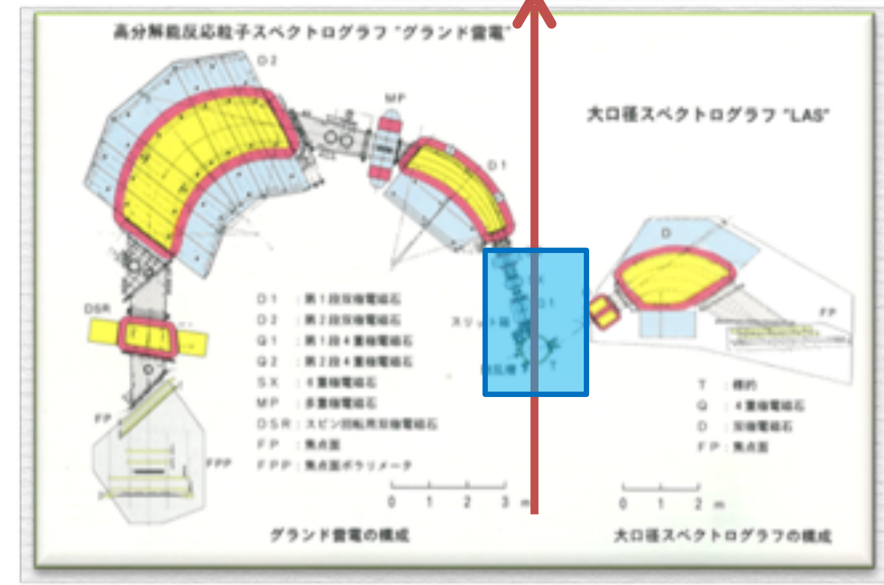
Coin. measurements of high-resolution light-ion reactions and decay γ-rays

Spectrometer

(p,2p) mode > 25.5°

0° mode (0-3 °)





Gamma-Ray Detectors

GR Forward-Mode Beam Line 4.5-19.0°

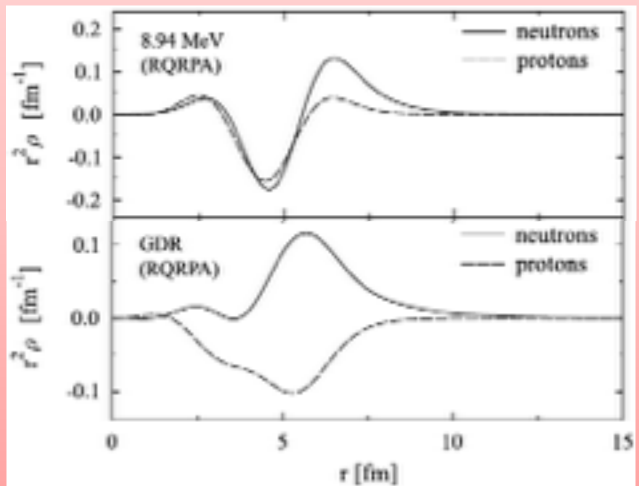
Most of the scattering angles in 0-70 °

three modes.

Coin. measurements of high-resolution light-ion reactions and decay γ

Spectrometer

PDR structure
transition density,
isospin-structure



Rare γ

^{12}C synthesis in stars,
rare γ
giant resonances

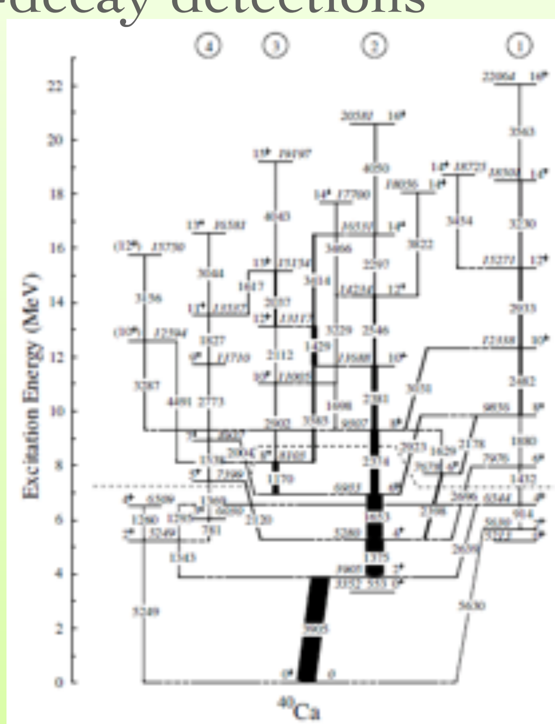
New Probes of Excitation Modes

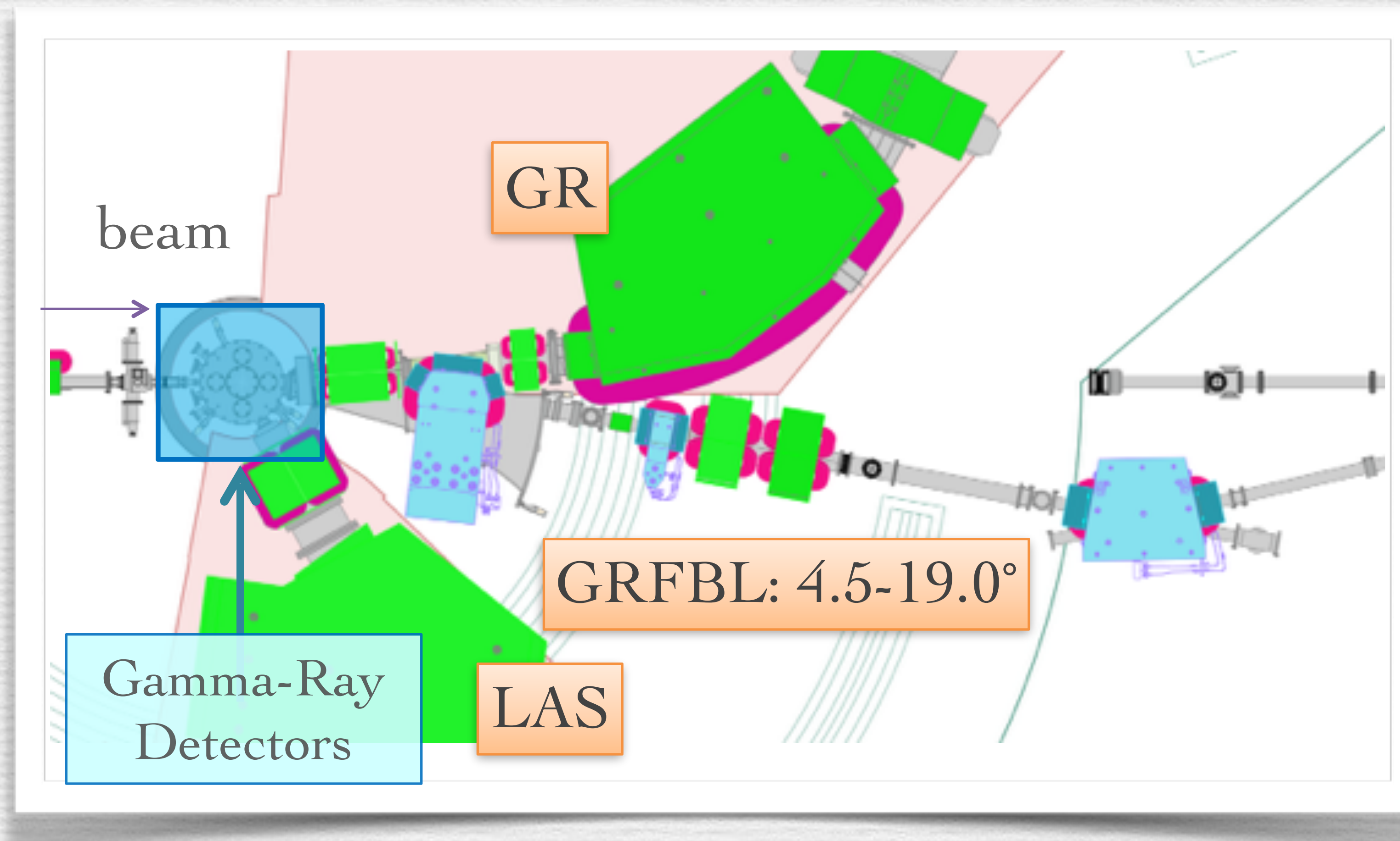
(^{6}Li,^{6}Li'γ): IV spin-flip inelastic scattering

(^{14}C,^{14}C'γ) : parity transfer inelastic scattering

Excitation of high-spin states by nuclear interaction and γ-decay detections

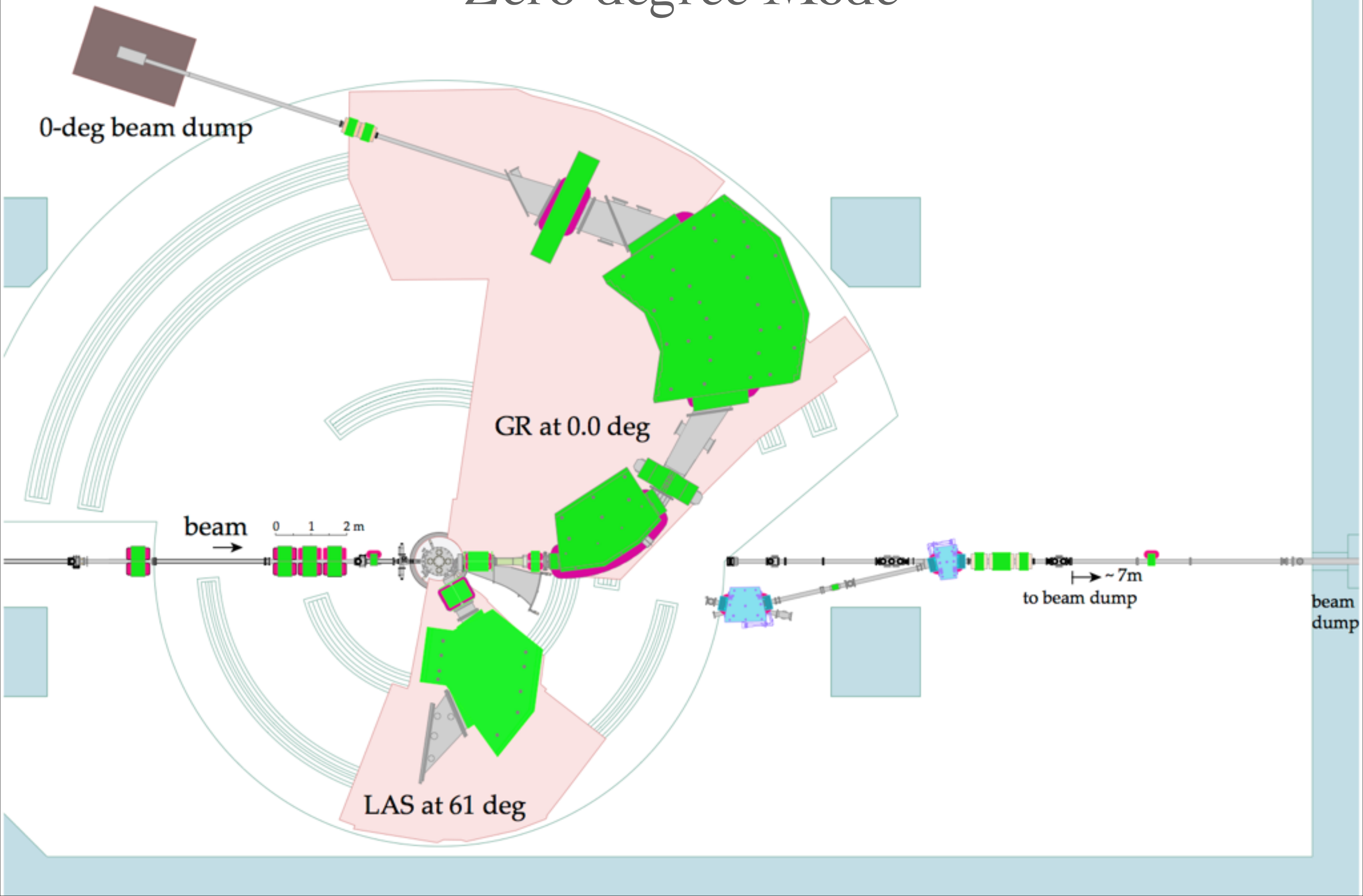
excitation mechanism, excitation on high-spin states, high-spin frontier





Beam Transportation Modes

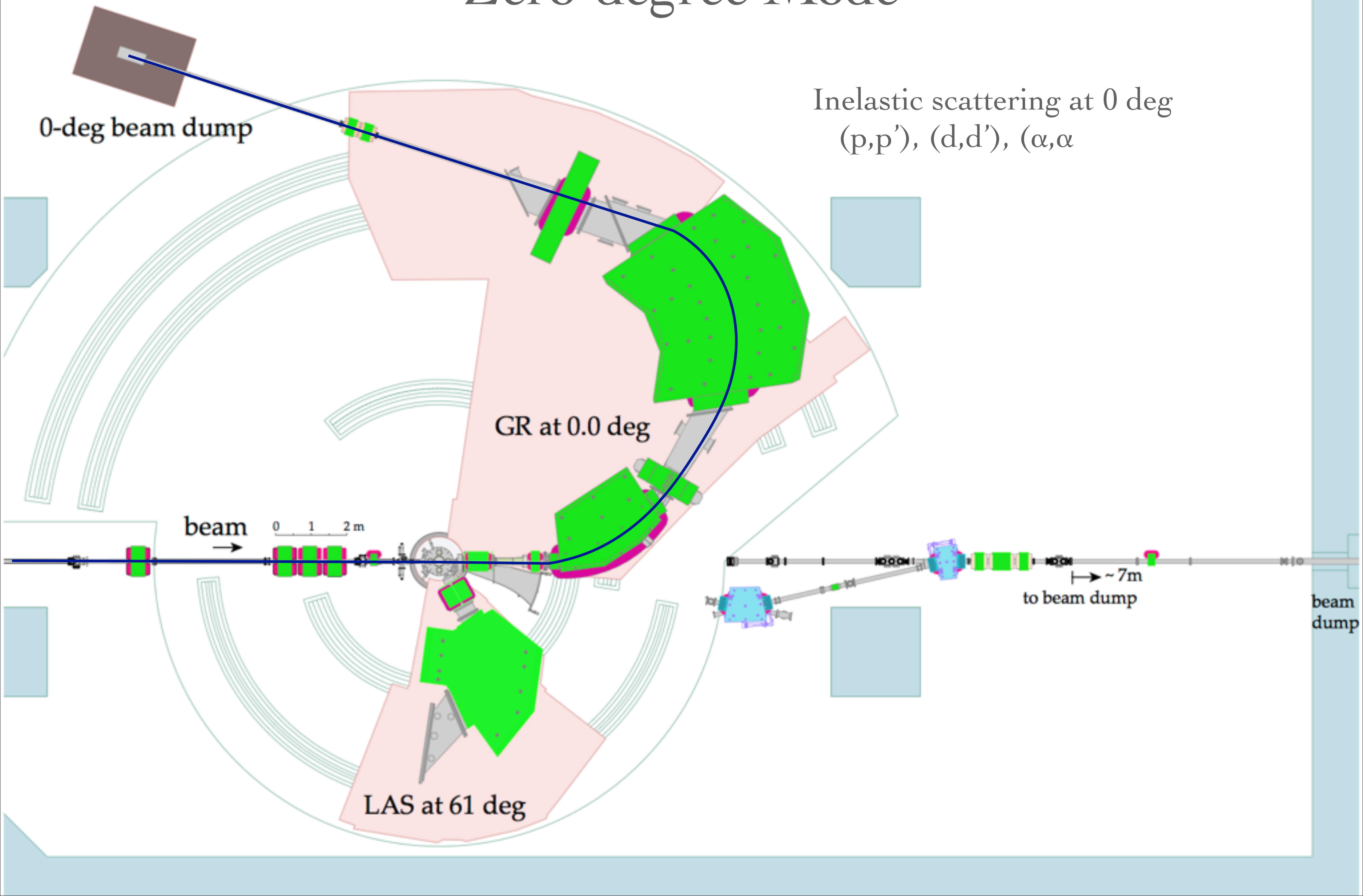
Zero-degree Mode



Beam Transportation Modes

Zero-degree Mode

Inelastic scattering at 0 deg
(p,p'), (d,d'), (α,α

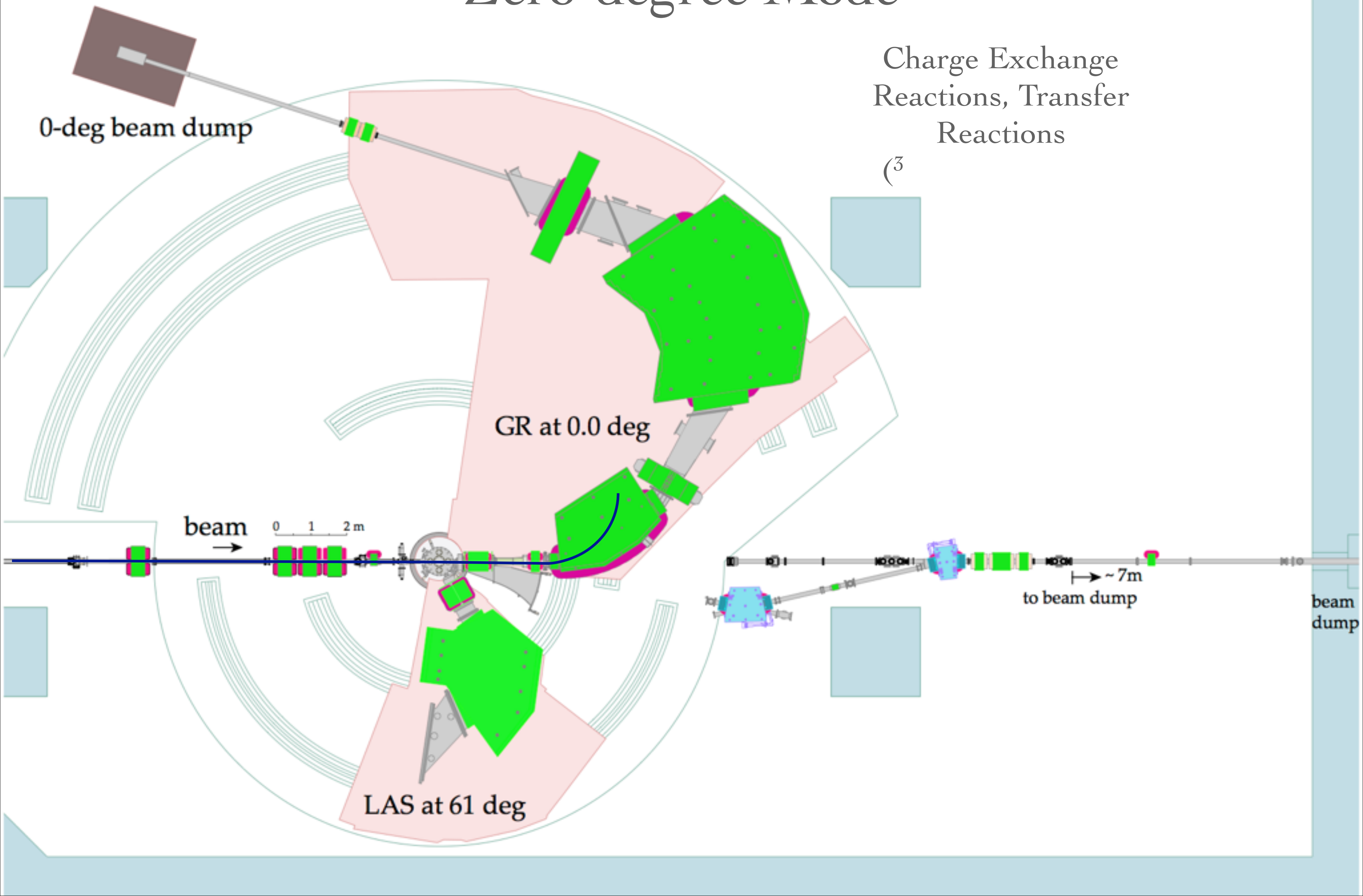


Beam Transportation Modes

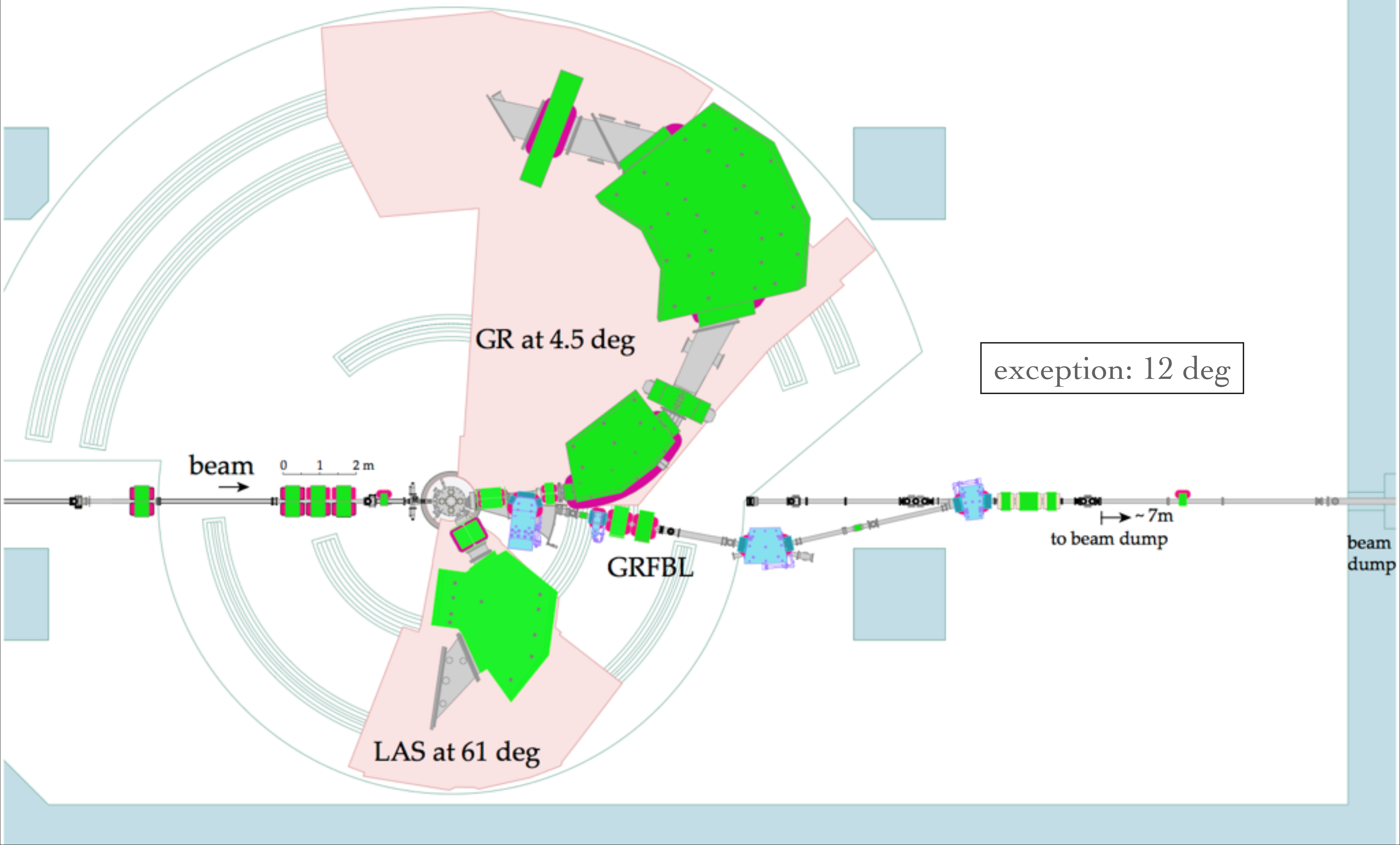
Zero-degree Mode

Charge Exchange Reactions, Transfer Reactions

(³

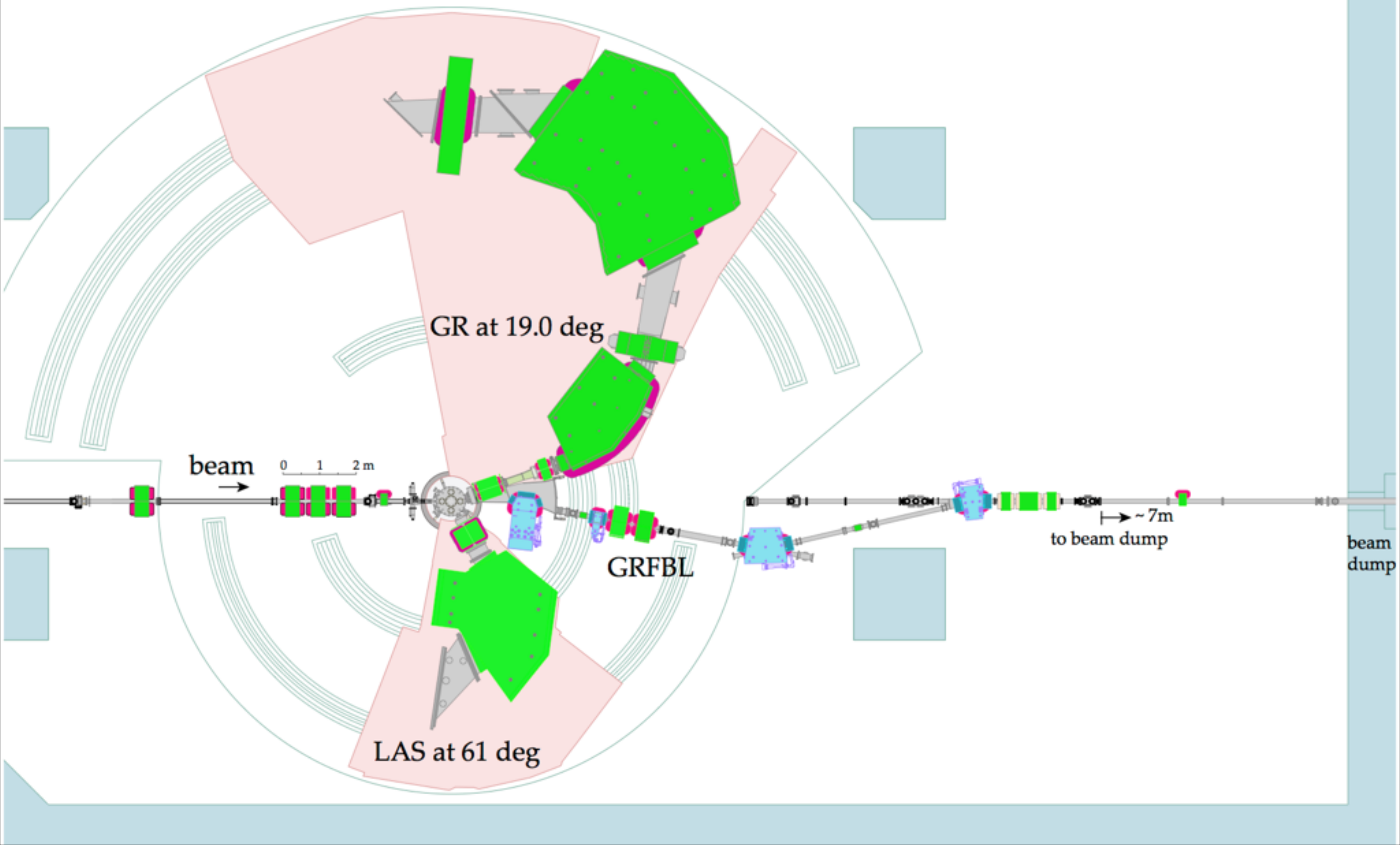


Beam Transportation Modes
GRFBL Mode



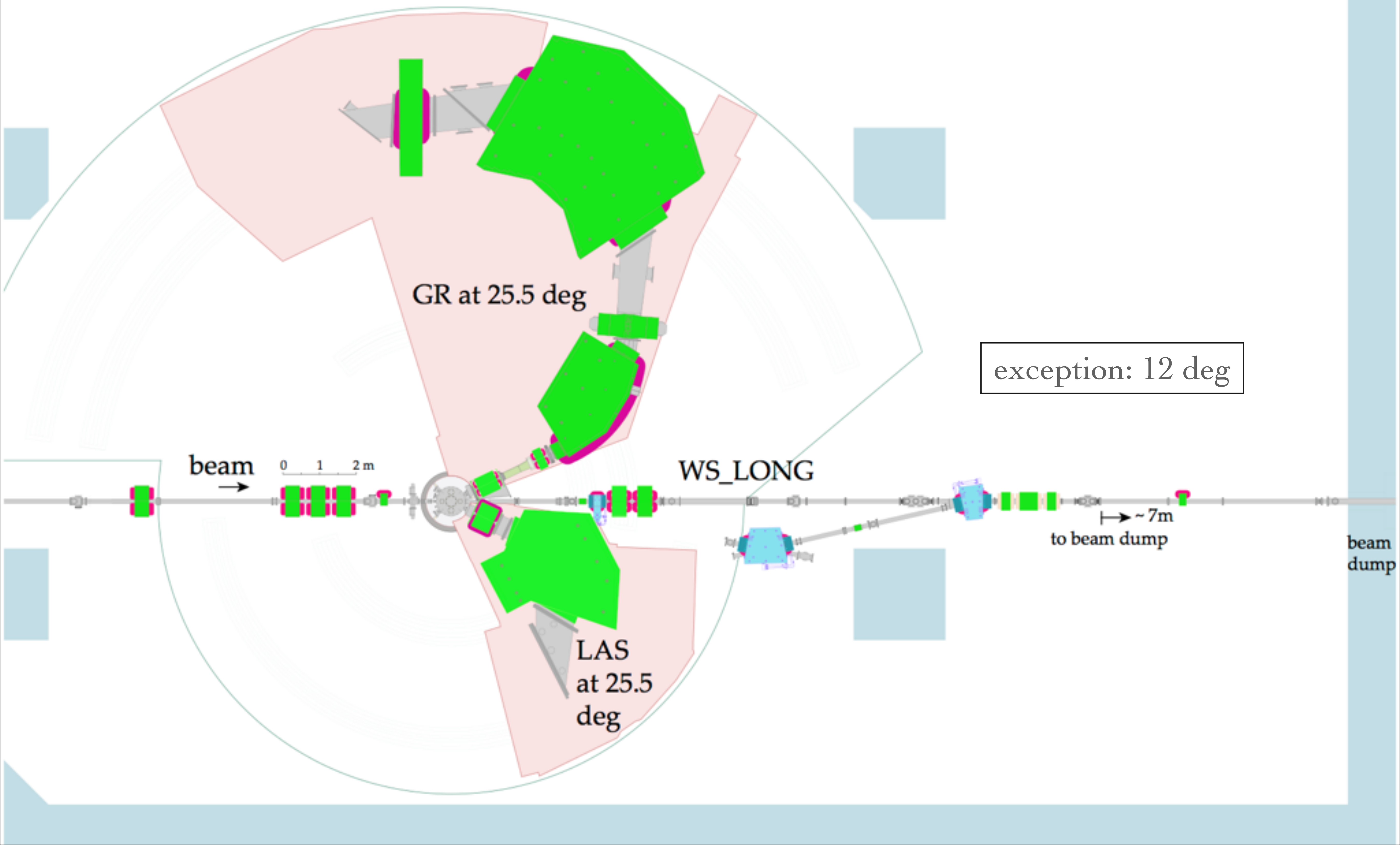
exception: 12 deg

Beam Transportation Modes
GRFBL Mode

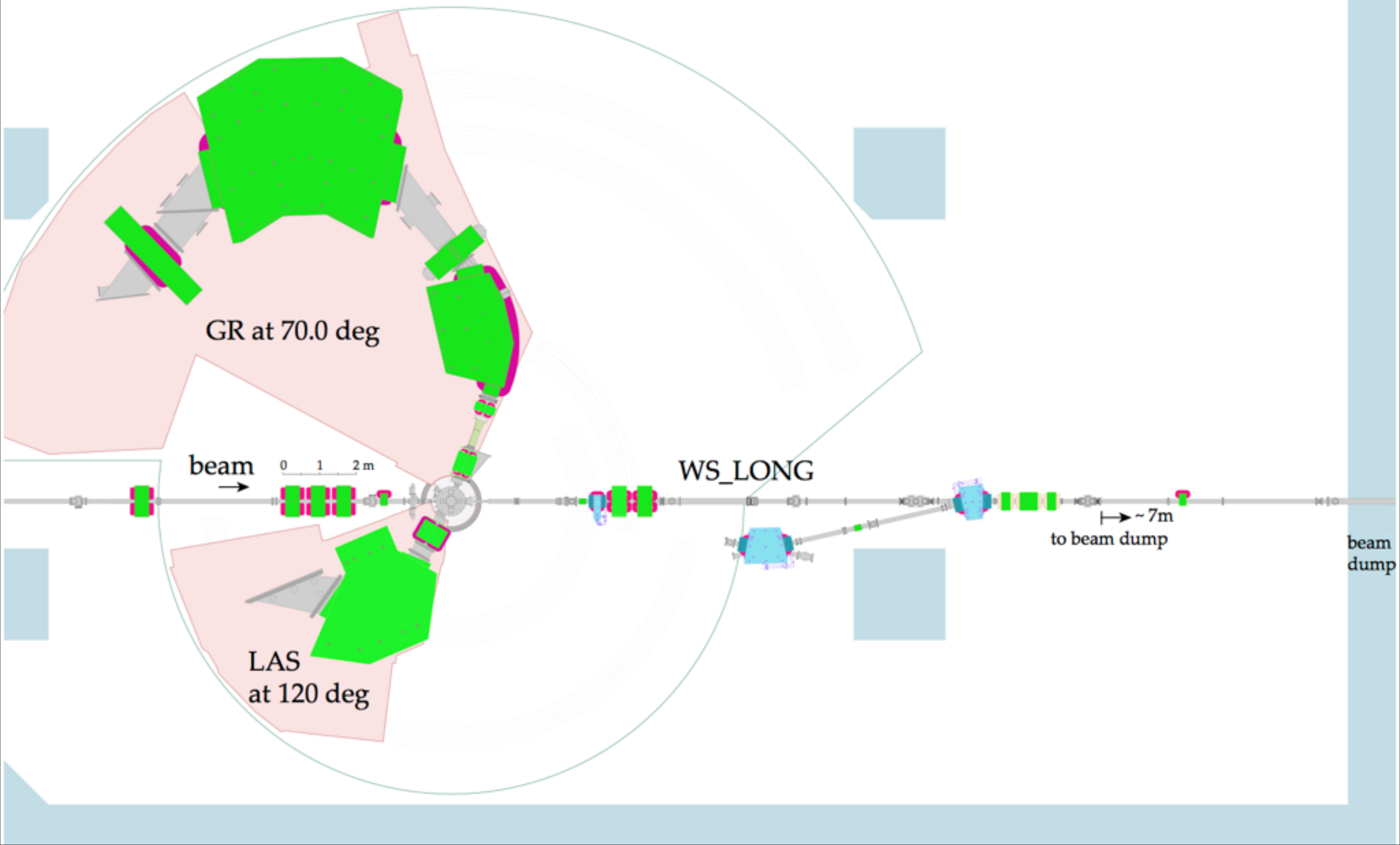


Beam Transportation Modes

WS_LONG Mode



Beam Transportation Modes
WS_LONG Mode

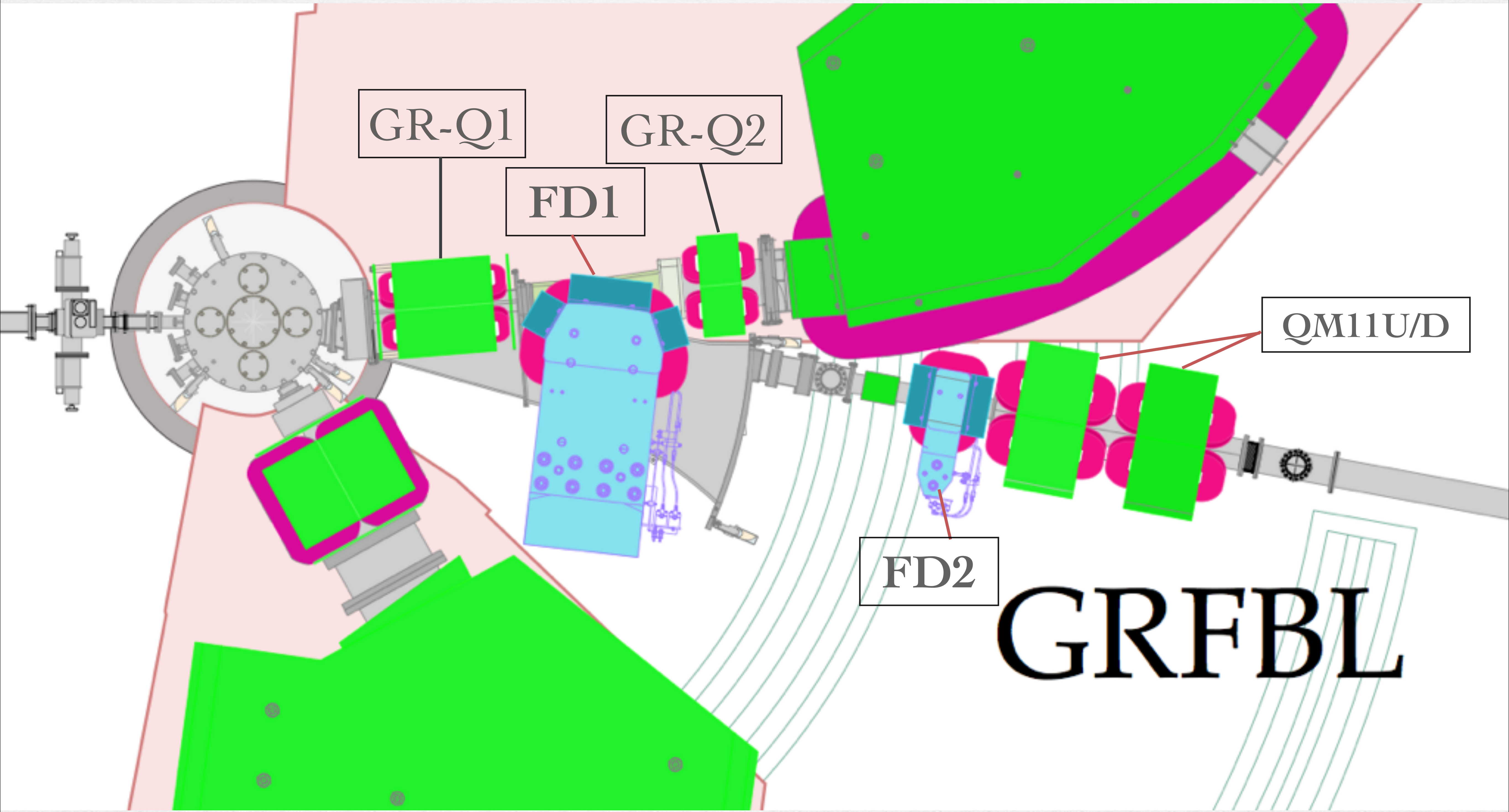


Beam Transportation Modes

Table 1. Summary of the three spectrometer modes

mode	beam stopper	Max. beam intensity	GR angle (coverage)	LAS angle (coverage)
Zero-deg inel. scatt.	0-deg beam dump	~10 nA	0 deg (0-~3 deg)	61-120 deg (58-123 deg)
Zero-deg CEX or transfer	In GR-D1	~10-100 nA	0 deg (0-~3 deg)	61-120 deg (58-123 deg)
GRFBL	wall beam dump	1000 nA	4.5-19.0 deg (3.5-20.0 deg)	61-120 deg (58-123 deg)
WS_LONG	wall beam dump	1000 nA	25.5-70.0 deg (24.5-71.0 deg)	25.5-120 deg (22.5-123 deg)

GR Forward-Mode Beam Line (GRFBL)



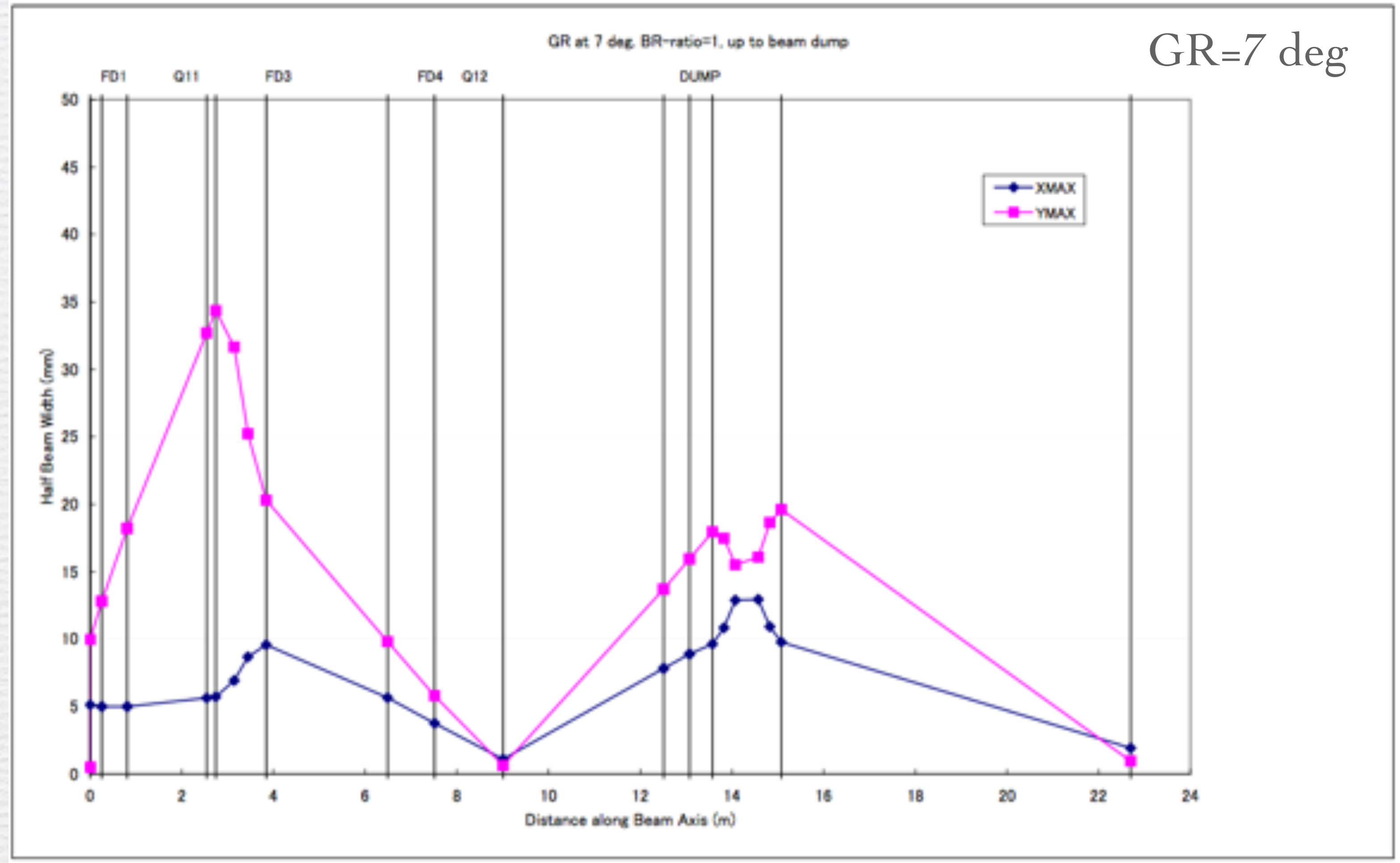
The Bρ ratio: Bρ

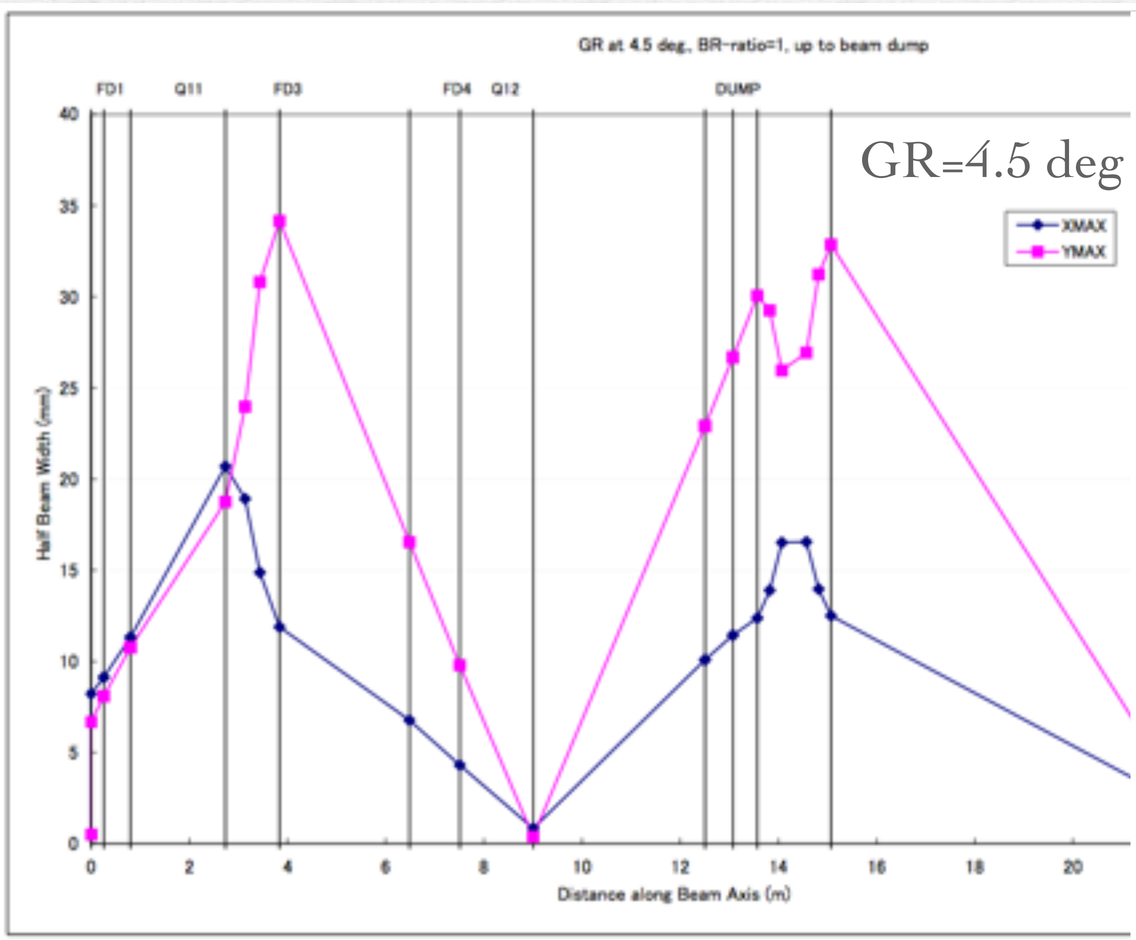
The angular coverage has some limitation for reactions with Bρ out of the above region.

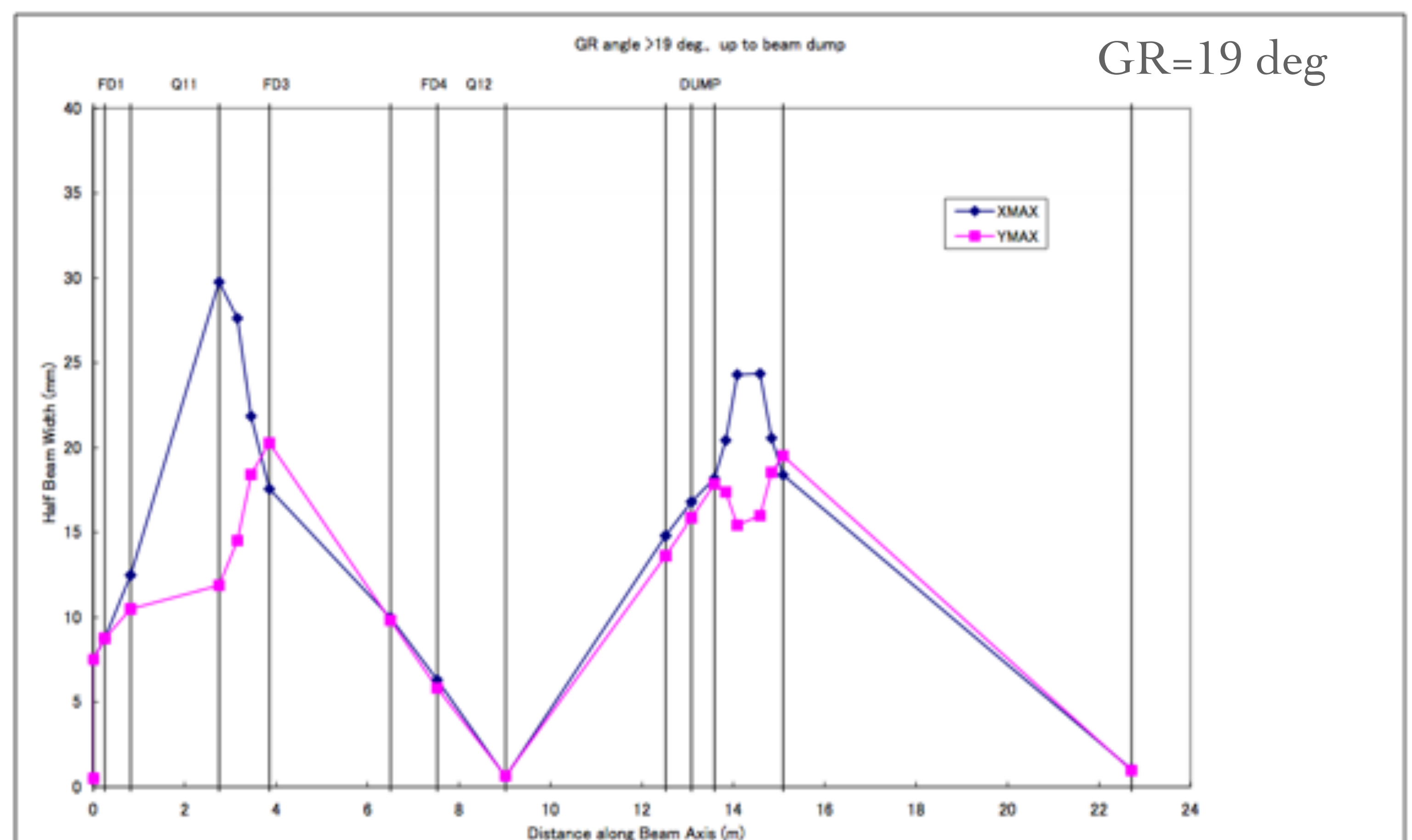
Ion Optics

by S. Morinobu

for Bρ



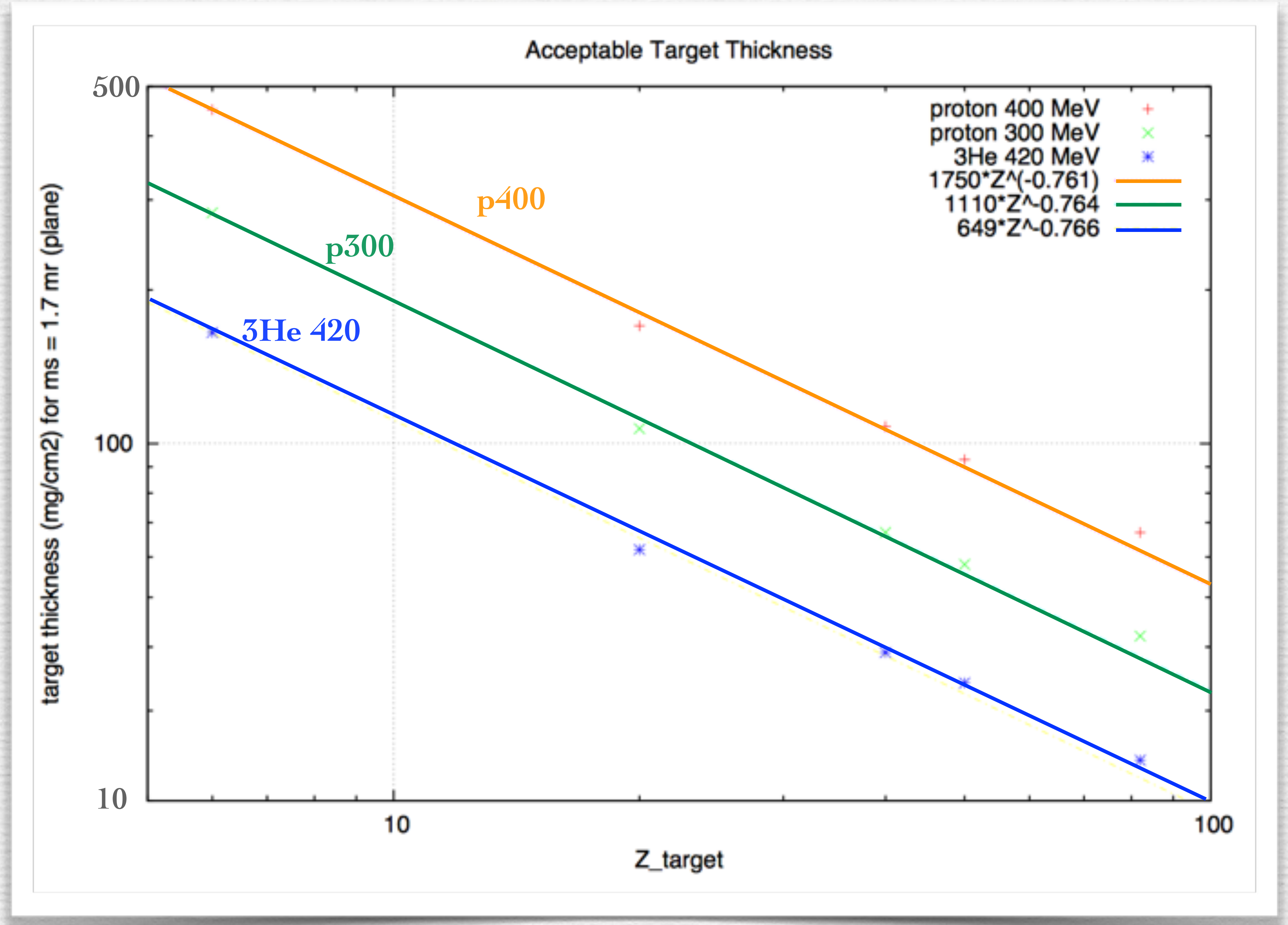




Limitation of Target Thickness

GRFBL Acceptance: < 5 mr after target

Rough estimation of acceptable target thickness to have >99% transmission.



GRFBL Schedule

by Sumitomo Heavy Industries (SHI) Company

year 2013

✦ Nov-Dec	production of parts, assembling of magnets

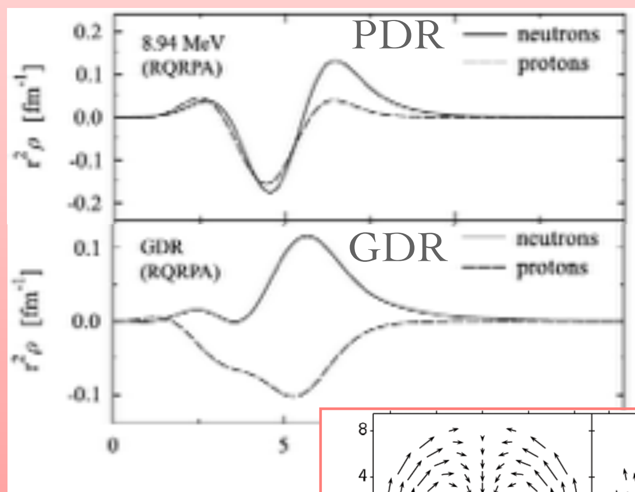
year 2014

✦ Jan-Feb	assembling and test in Niihama (SHI company)
✦ Mar	construction at RCNP, adjustments, performance tests
✦ Apr	adjustments, performance tests
✦ May or later	beam commissioning (by RCNP)

Coin. measurements of high-resolution light-ion reactions and decay γ

Spectrometer

PDR structure
transition density,
isospin-structure



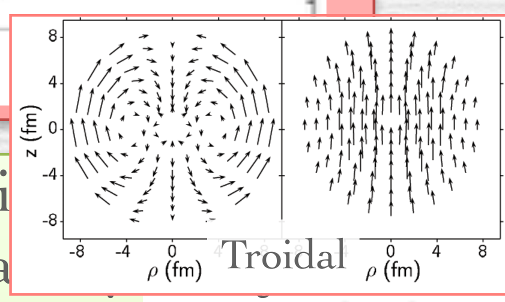
Rare γ

^{12}C
dilute α cluster states,
rare γ
giant resonances

New Probes of Excitation Modes

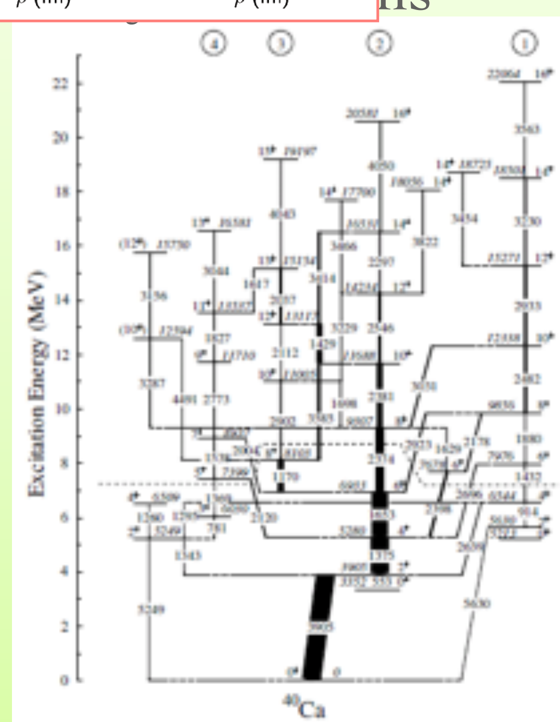
(^{6}Li,^{6}Li'γ): IV spin-flip inelastic scattering

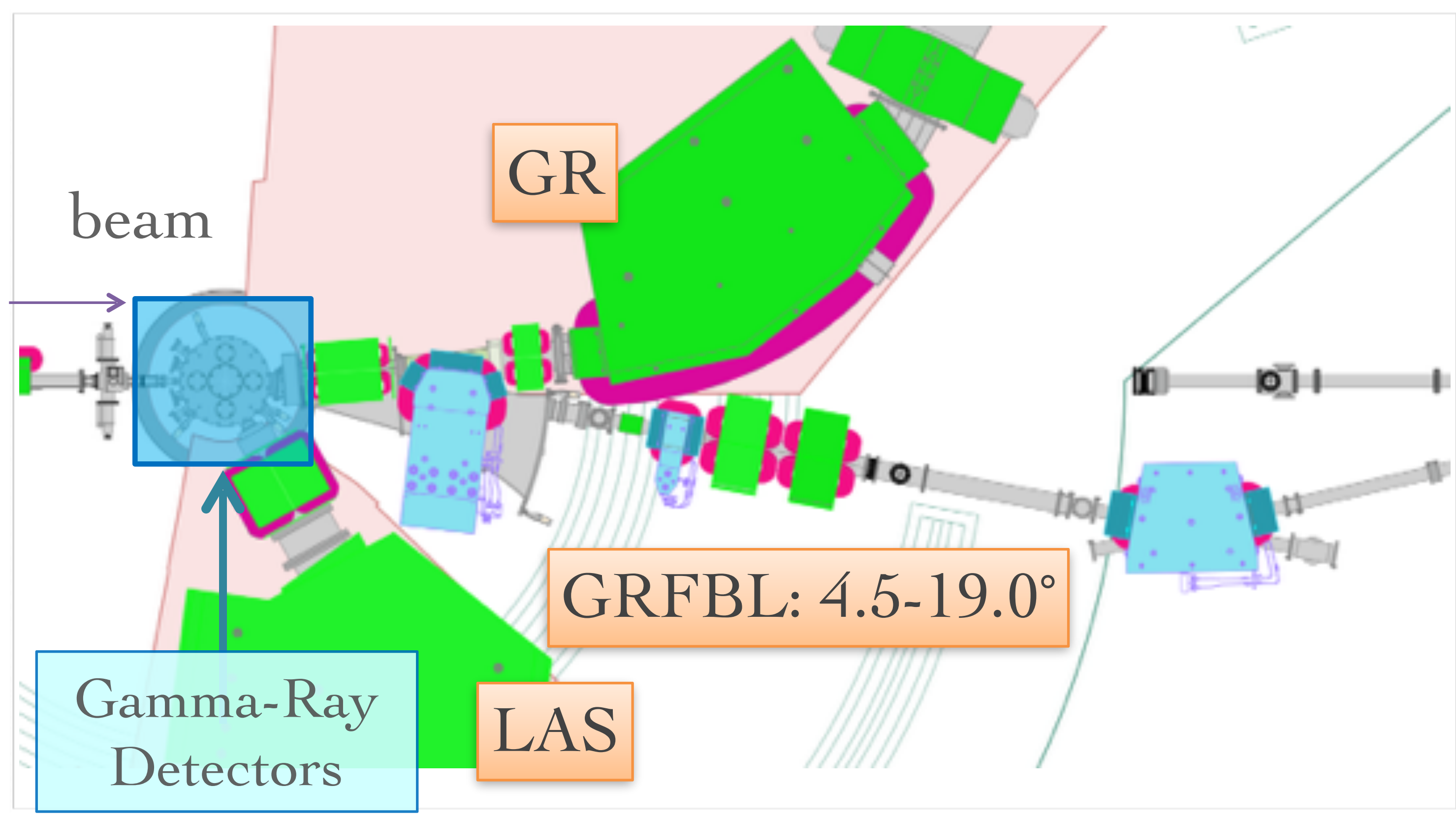
(^{14}C,^{14}C'γ) : parity transfer inelastic scattering



Excitation of hi … clear
interaction a … ns

excitation mechanism,
excited states on high-spin,
high-spin frontier

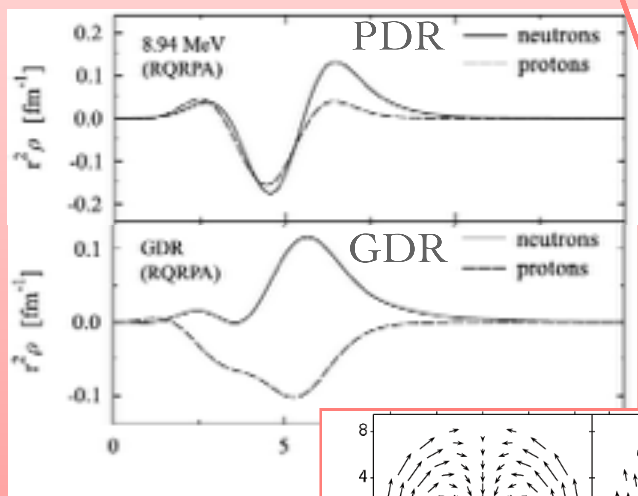


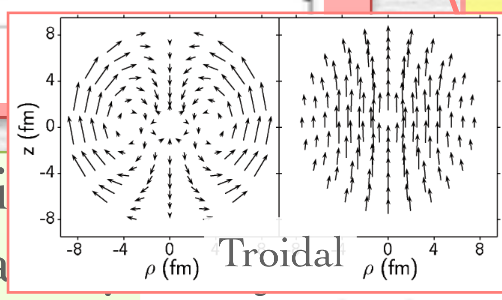


Coin. measurements of high-resolution light-ion reactions and decay γ

Spectrometer

PDR structure
transition density,
isospin-structure





Rare γ

^{12}C
dilute α cluster states,
rare γ
giant resonances

C. Iwamoto
D. Savran
A. Bracco
P. Papka

New Probes of Excitation Modes
(^{6}Li,^{6}Li'γ): IV spin-flip inelastic scattering
(^{14}C,^{14}C'γ) : parity transfer inelastic scattering

R. Zegers

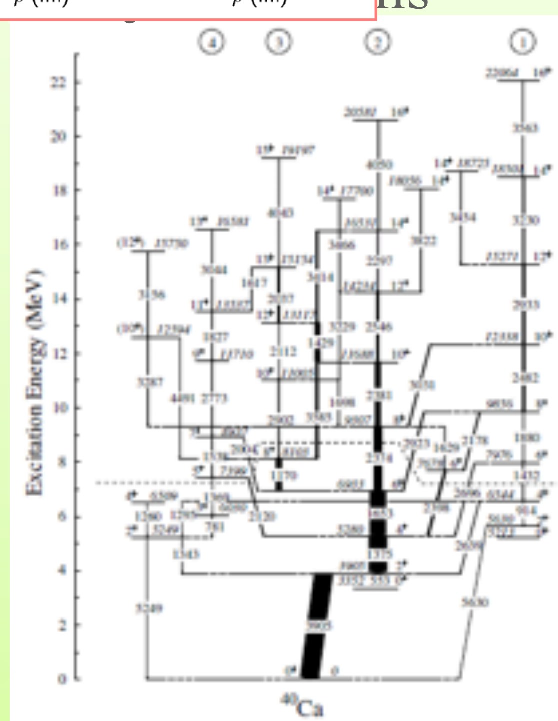
T. Hashimoto

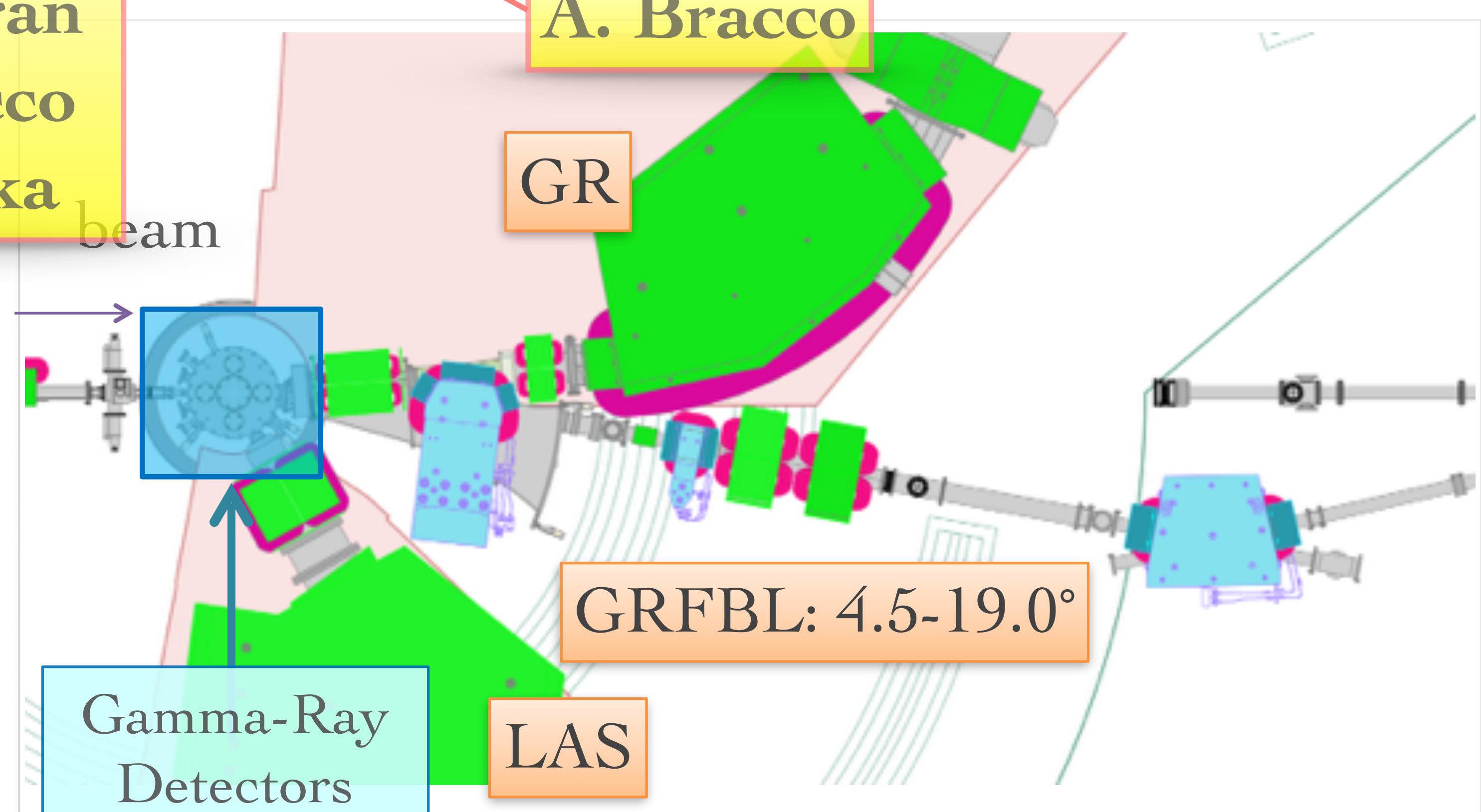
A. Bracco

Excitation of hi... interaction a... nuclear ...ns

excitation mechanism,
excited states on high-spin,
high-spin frontier

A. Tamii





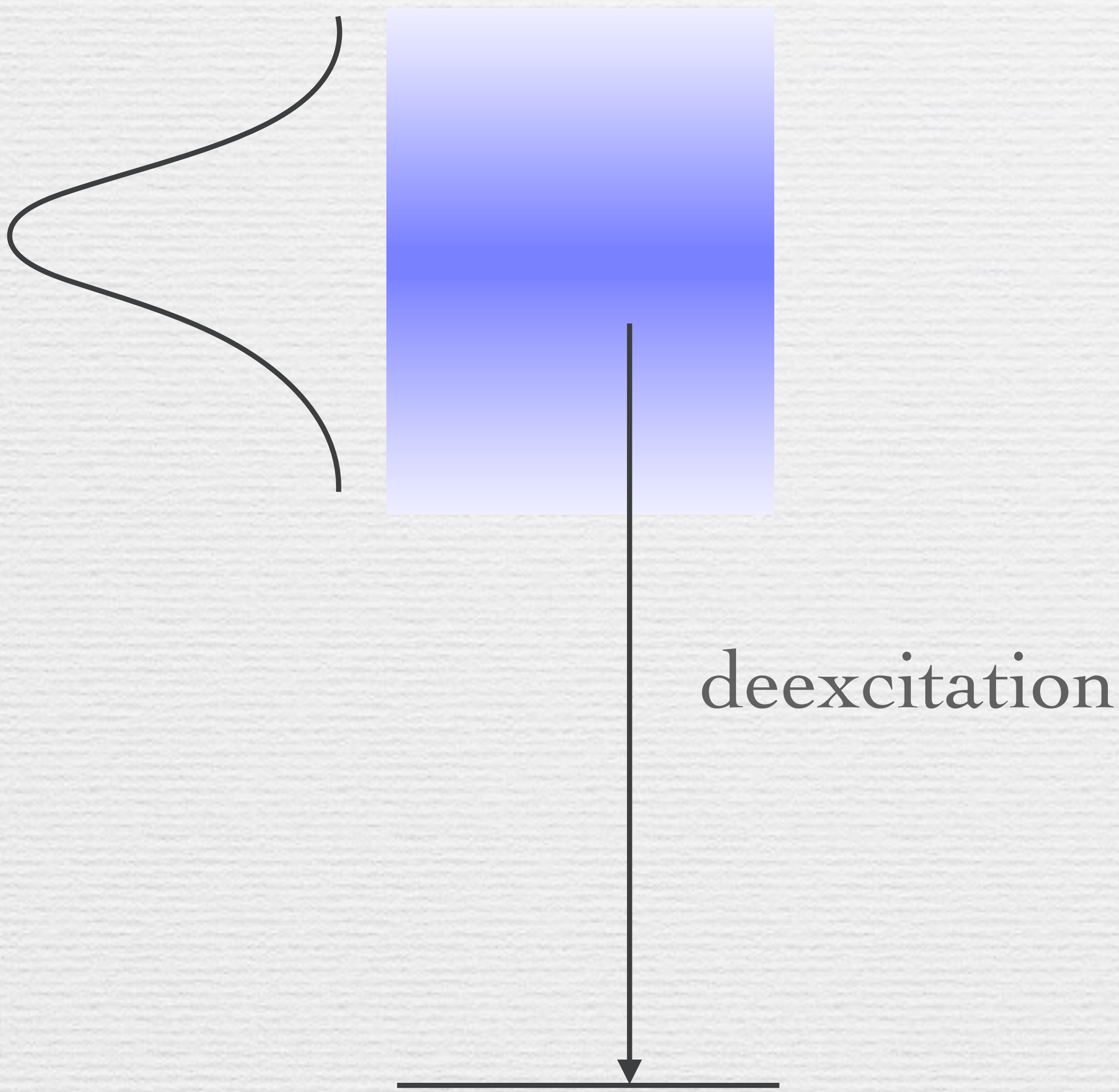
From GRFBL Workshop in Nov. 2013

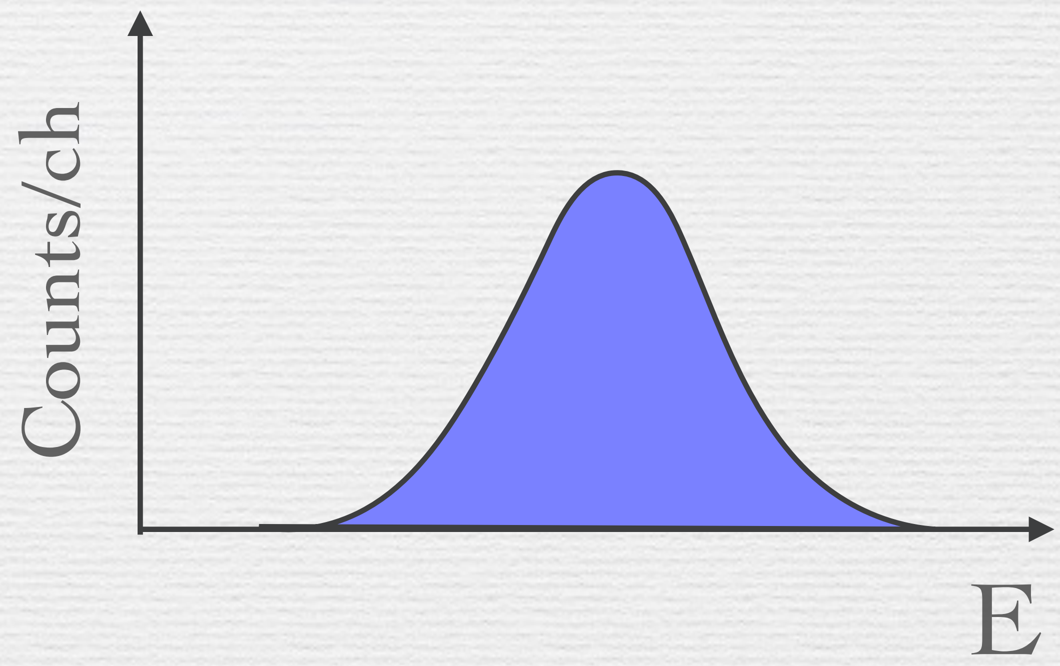
●	T. Hashimoto	^{12}C(α,α' γ)		dilute cluster states, γ rare-decay	HPGe and LaBr3
	M. Tsumura	^{3}He(^{14}N, t ^{14}O)		nuclear synthesis	High Intensity
○	H.G. Ong, K. Miki	^{4}He,^{12}C,^{16}O(p,dp), (p,dn)	Ge for proton detection	tensor correlation in nuclei	Ge for proton detection
	A. Tamii	Reactions with implanted stable/unstable target		new method	High Intensity 1pμA
●	Michimasa	^{50}Cr(p,tγ), (^{3,4}He,^{6,8}He γ) astrophysics		nuclear astrophysics	HPGe 3-4 MeV
	T. Kawabata	^{4}He(p(pol),p(pol))		tensor correlation	polarized beam, high intensity
●	H. Ejiri	74,72Ga,122Sn(^{3}He,tγ)	HPGe 1% ang. correlation	study of SDR (double beta-decay)	HPGe
●	I. Ou, M. Sakuda	^{16}O, ^{12}C(p,p'γ)	HPGe (NaI)	GDR, SDR for neutrino detection, supernova	HPGe (or scintillator)
●	Dozono	(^{16}O,^{16}N(0-))		new probe: parity transfer	HPGe for tagging reaction channel
○	Takaki	(^{12}C,^{12}Be(0^{+})		new probe: double charge exchange	Gamma detectors at the focal plane
●	T. Itoh	32S(α,α'γ) 12C(α,αN)	HPGe	super-deformed band, dilute cluster state	HPGe

● HPGe
○ related

Some of New? Ideas

for a broad resonance state





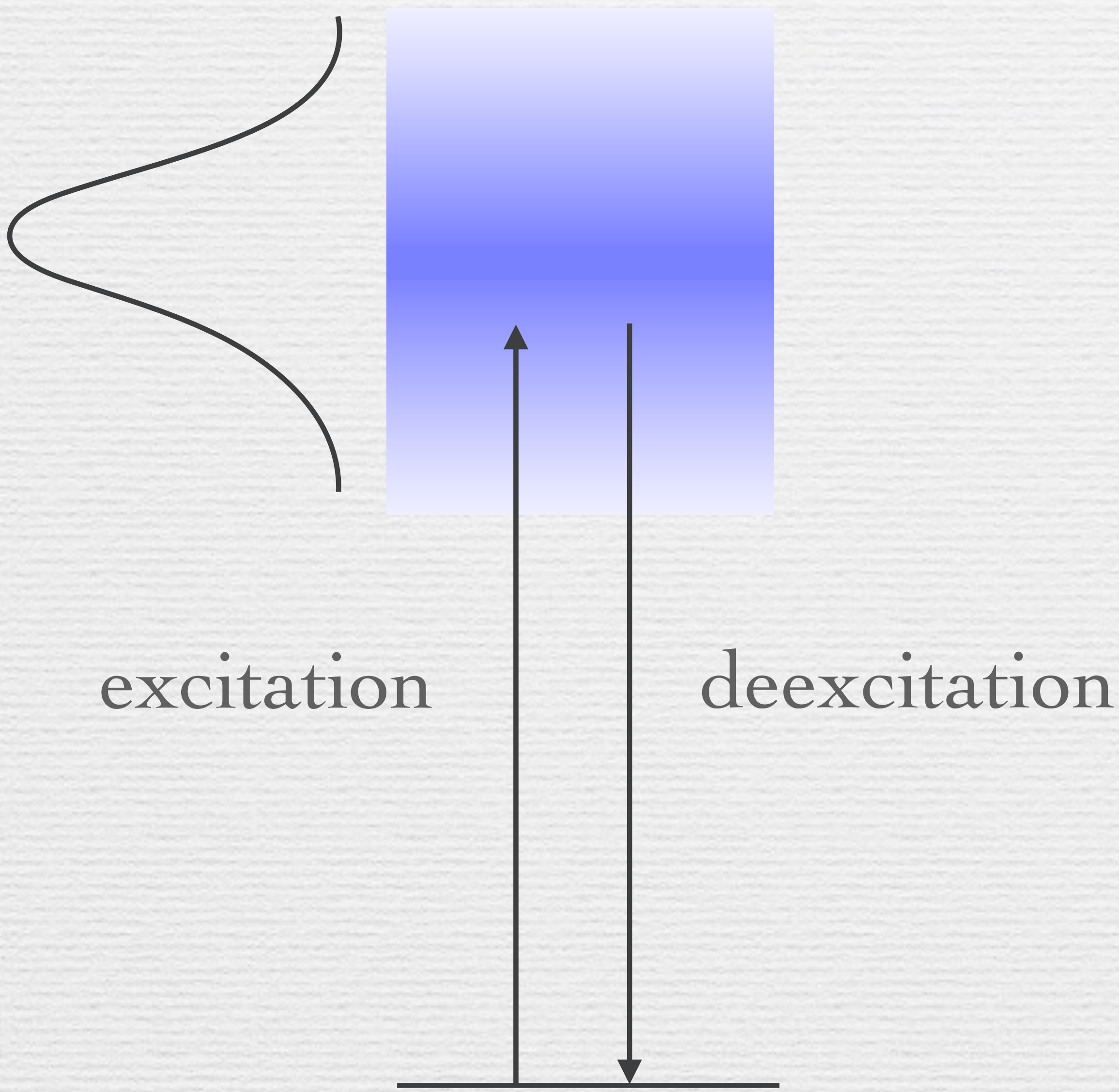
The measured resonance state is broad with its physical decay width.

If you measure only decay γ-rays

Discussion with T. Kawabata, T. Hashimoto

Some of New? Ideas

for a broad resonance state



excitation energy
= deexcitation energy

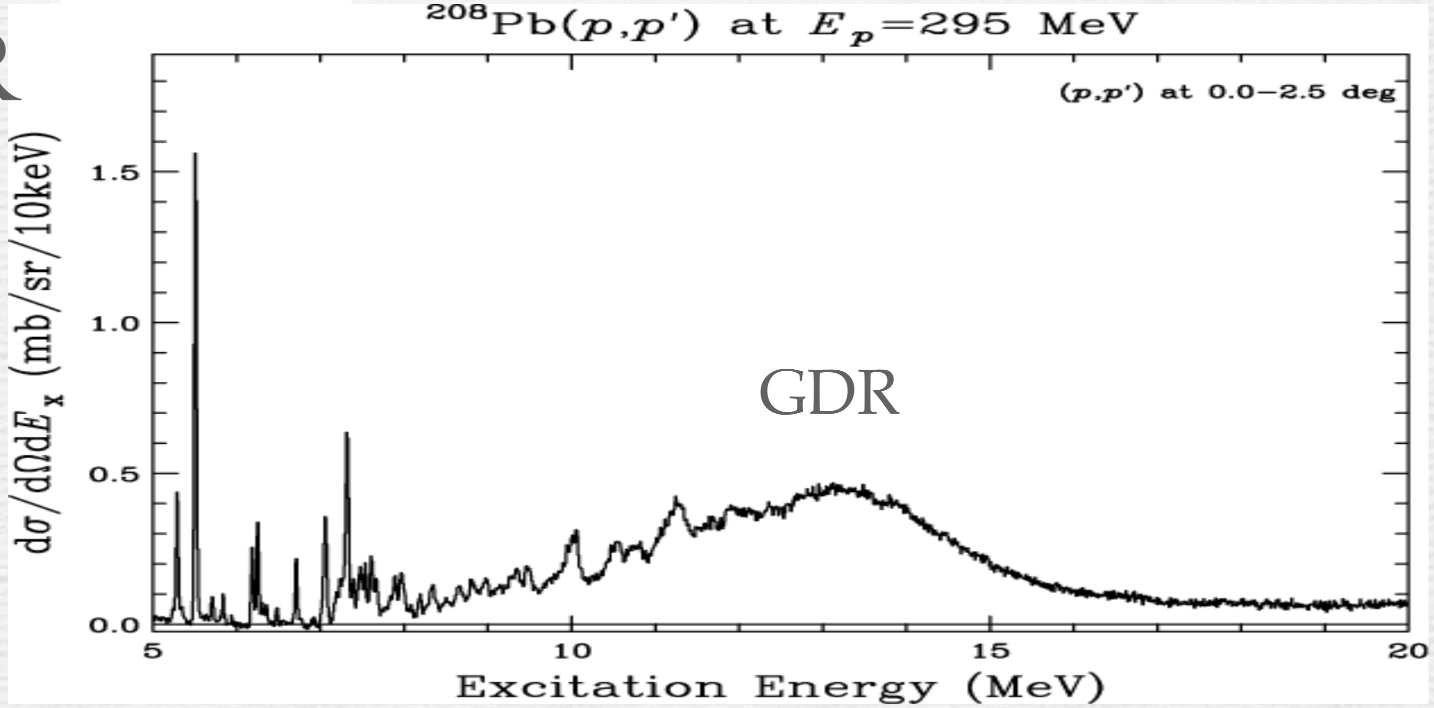
If you measure both the excitation and deexcitaion with high-resolution

That enables us to
- study each part of a broad resonance
- greatly improve the signal/noise ratio

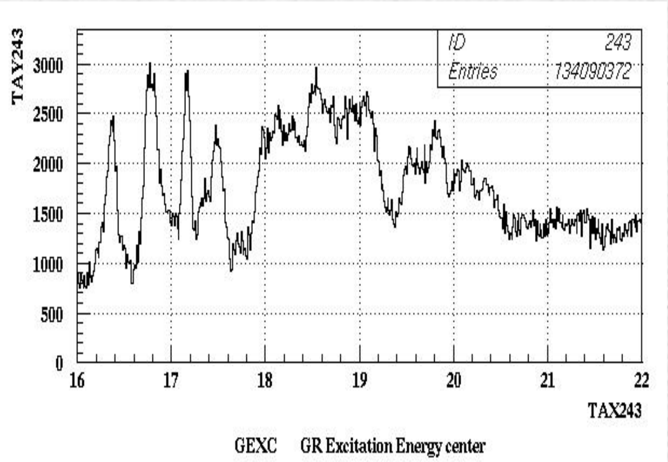
Discussion with T. Kawabata, T. Hashimoto

Some of New? Ideas

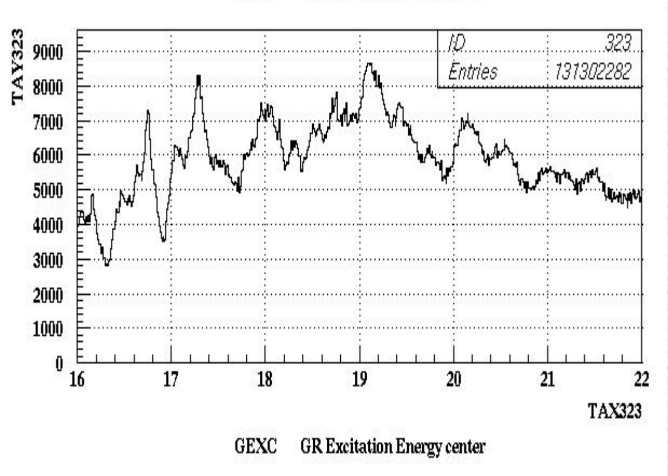
fine structure of GDR



^{24}Mg(p,p′)

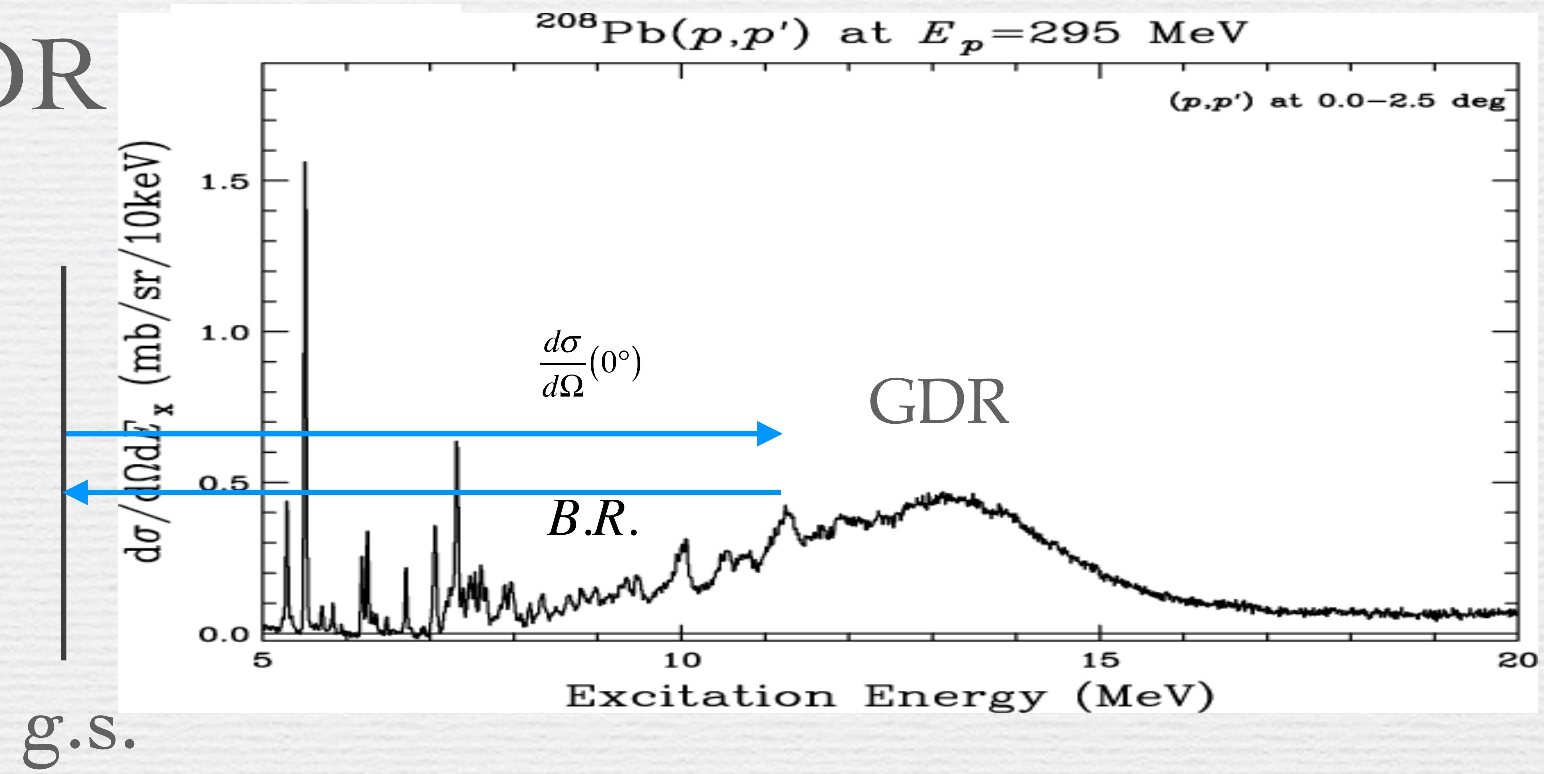


^{32}S(p,p′)



Some of New? Ideas

fine structure of GDR



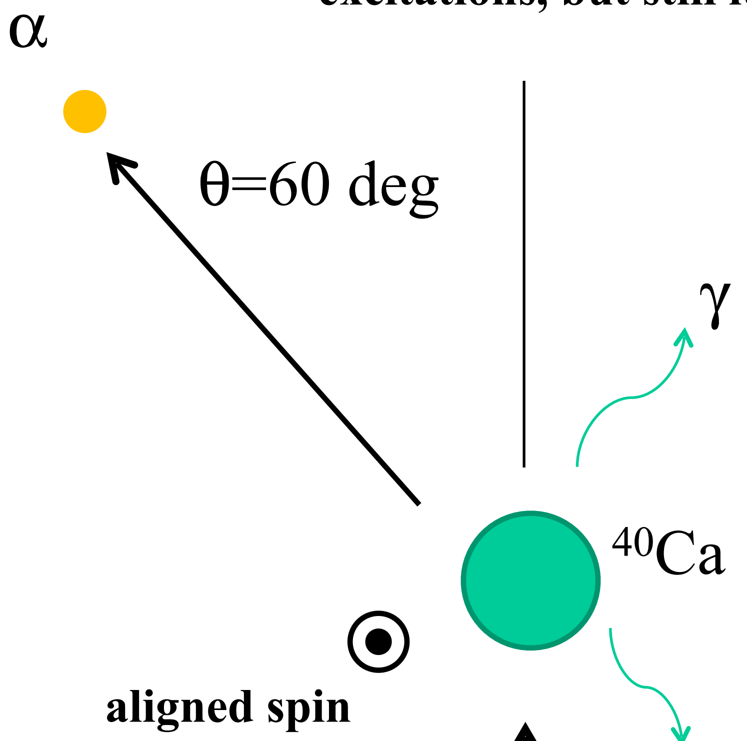
$$\frac{d\sigma}{d\Omega}(0°) \rightarrow B(E1) \rightarrow \Gamma_0$$

$$B.R. = \frac{\Gamma_0}{\Gamma}$$

The total decay width (Γ~neutron decay width) of each part of GDR can be measured as a function of E_x.

Excitation of high-spin states with gamma-ray tagging

Direct reaction usually doesn't favor many-particle many-hole excitations, but still it might have sizable cross section.



- **Spin parity assignment of low-lying states. (excitation and decay)**
- **Isospin determination**
- **Excited states above the yrast line**
- **Transition strength from the ground state**

also
•Life-time measurement with Doppler shift attenuation?

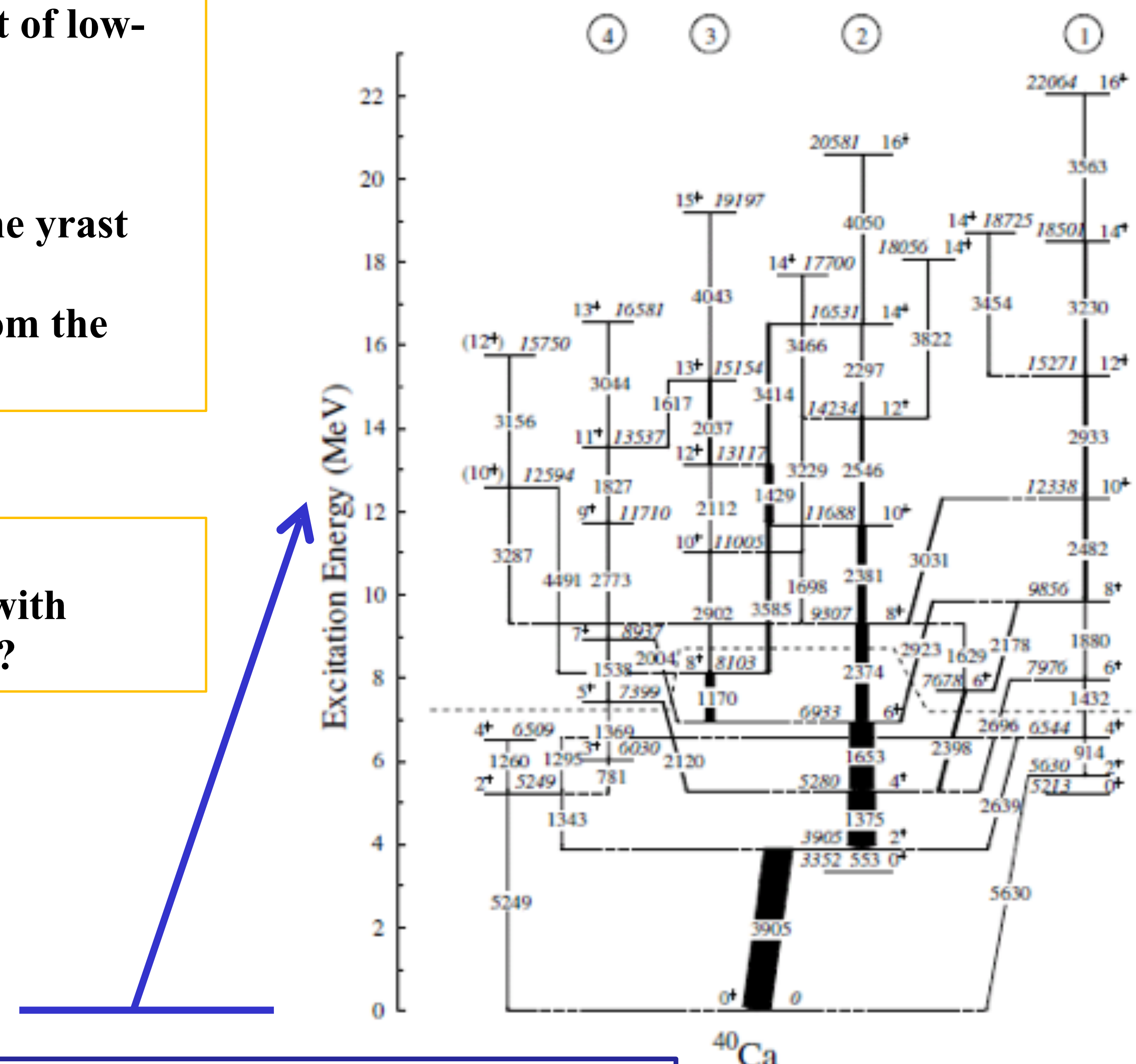
R~4 fm
q=1700 MeV/c
qR = 34 h-bar

Target spin is fully aligned in the normal direction of the scattering plane.

q=1700 MeV/c, β=0.05 at 60 deg

q=2800 MeV/c, β=0.08 at 120 deg

α at 100 MeV/U



Excitation of high-spin states from the ground state

E. Ideguchi et al., PRL87,222501(2001)

for ^{12}C at 80 MeV/U
q = 4200 MeV/c, β=0.09 at 60 deg
qR = 85 h-bar
(LAS spectrometer has larger acceptance)

Detection of large angle ion scattering (for high-q) with gamma-ray detection.

Transfer reactions can also be used.

Excitation of high-spin states with gamma-ray tagging

$^{12}C(^{16}O,\alpha)$ at 8.9 MeV/U, θ_α=5.5 deg

T. Shimoda, S. Shimoura et al., J. Phys. G 9, L199 (1983)

Y. Fujita et al., PLB247, 219(1990)

$^{208}Pb(p,p')$ E_p=80MeV q=64 deg

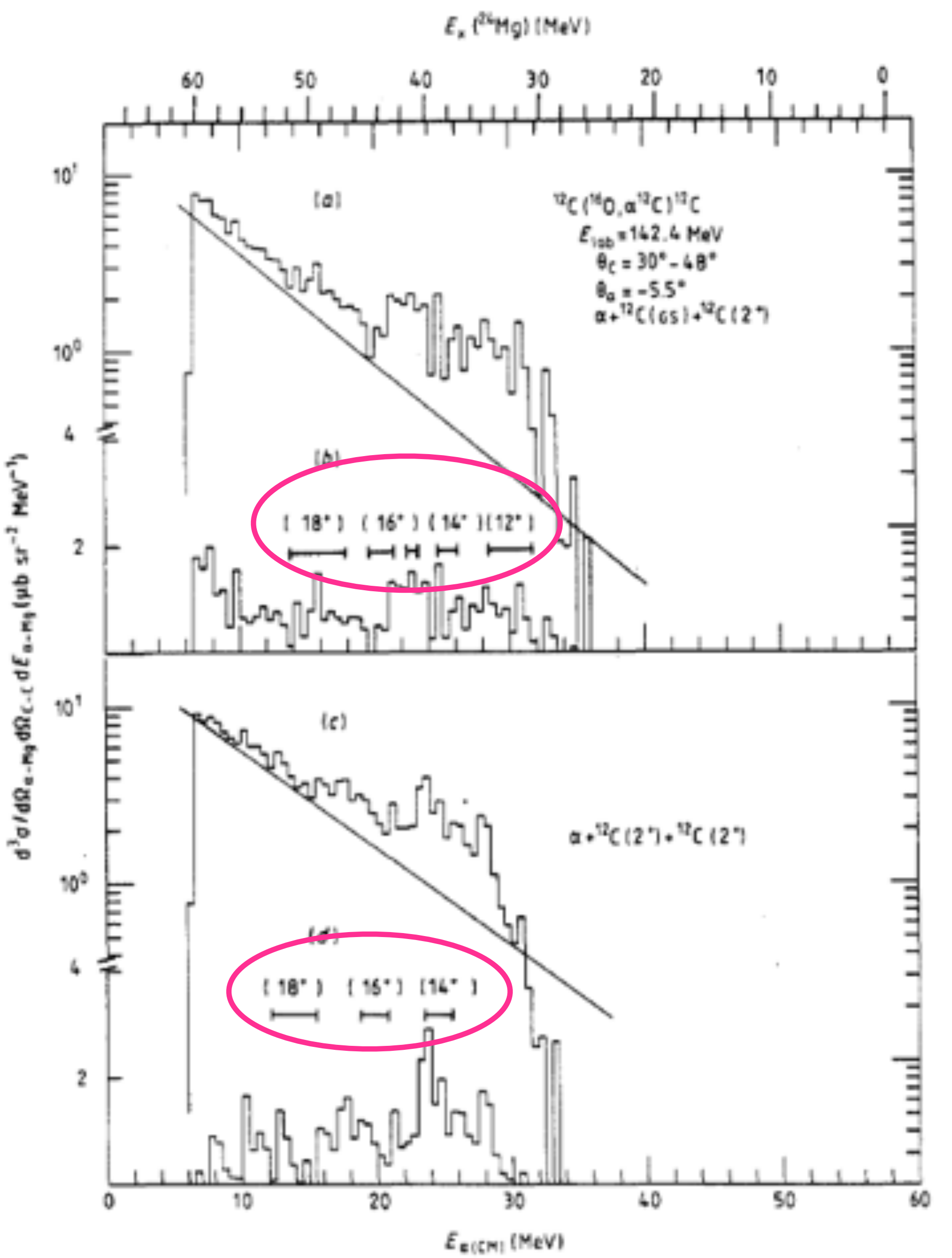


Figure 3. The alpha spectra coincident with ^{12}C particles detected at $\theta_{^{12}C}$(lab) = 30°–48° for (a) the $\alpha + {}^{12}C(GS) + {}^{12}C(2^+)$ channel and (c) the $\alpha + {}^{12}C(2^+) + {}^{12}C(2^+)$ channel. Straight lines show the background cross sections assumed. The background-subtracted spectra from (a) and (c) are shown in (b) and (d), respectively. The energies and total widths of the $^{12}C + {}^{12}C$ molecular resonance states observed in the inelastic excitation function measurements (Cormier et al 1978) are shown by horizontal lines (FWHM) in (b) and (d).

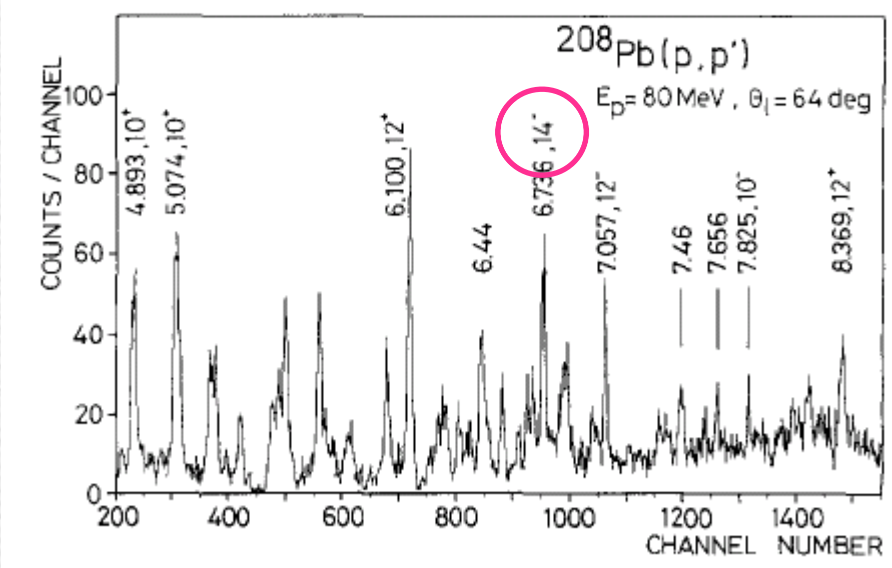
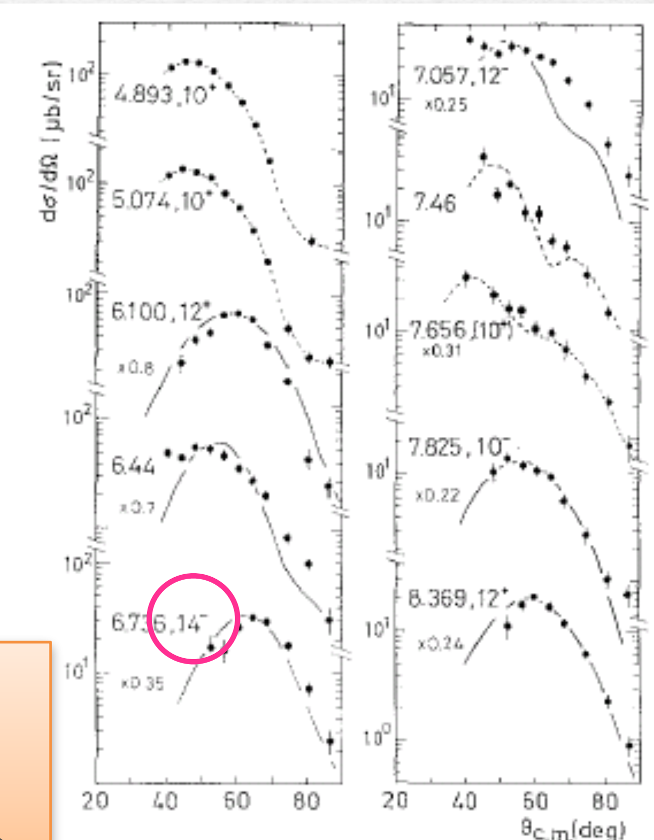
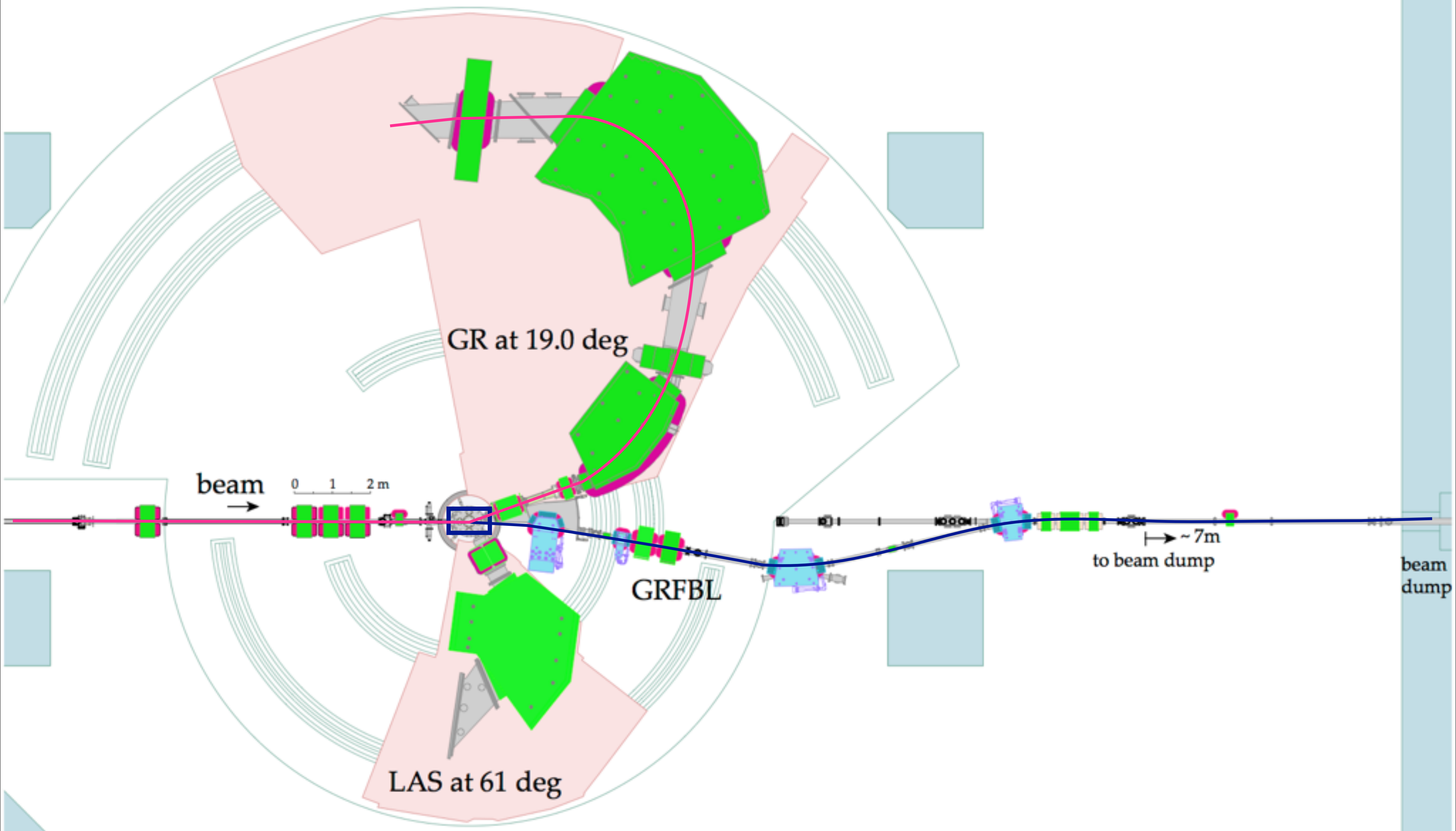


Fig. 1. Inelastic proton spectrum at $\theta_{lab} = 64°$. The estimated error of the excitation energy is ±8 keV.



High-spin states up to ~14-18 could be observed even without γ coincidence.

(p,π



GR at 19.0 deg
beam
0 1 2 m
GRFBL
~ 7m
to beam dump
beam dump
LAS at 61 deg

Some of New? Ideas

From GRFBL Workshop in Nov. 2013

Free Discussion on Wednesday 18th Dec.

- A free discussion is scheduled for the part of GR(spectrometer)+CAGRA projects.

  Place: AVF building 3rd floor lobby
  Time: Wednesday 18th, 9:00am - 12:00?

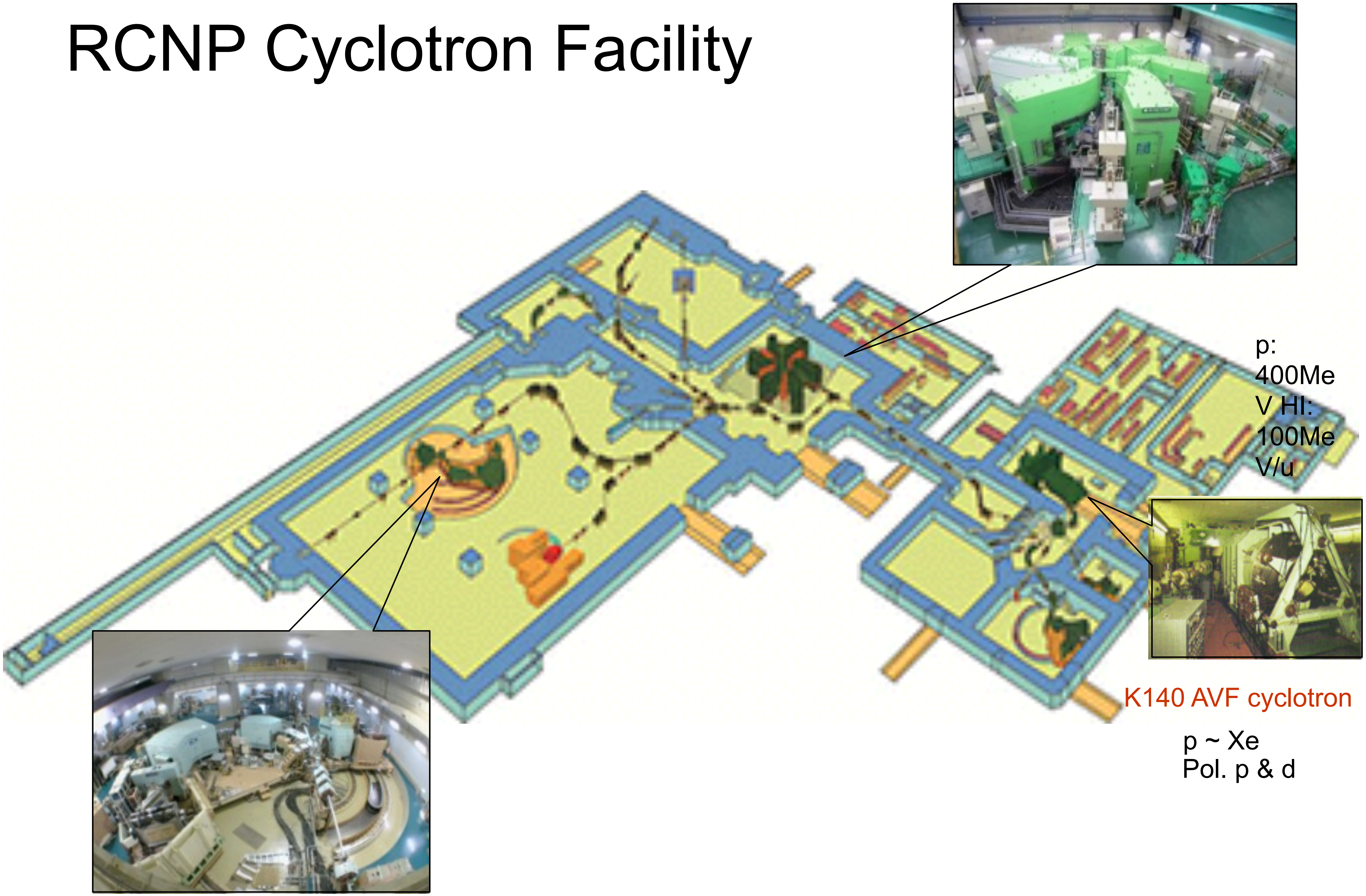
  Meeting room on the 2nd floor is reserved for the case discussion continues in the afternoon.

- Discussions … free (bring your items)
  - Details of planned measurements, ideas
  - Possible configuration of the gamma-ray detectors
  - Requirements from planned measurements
  - Schedule
  - Collaboration
  - etc.

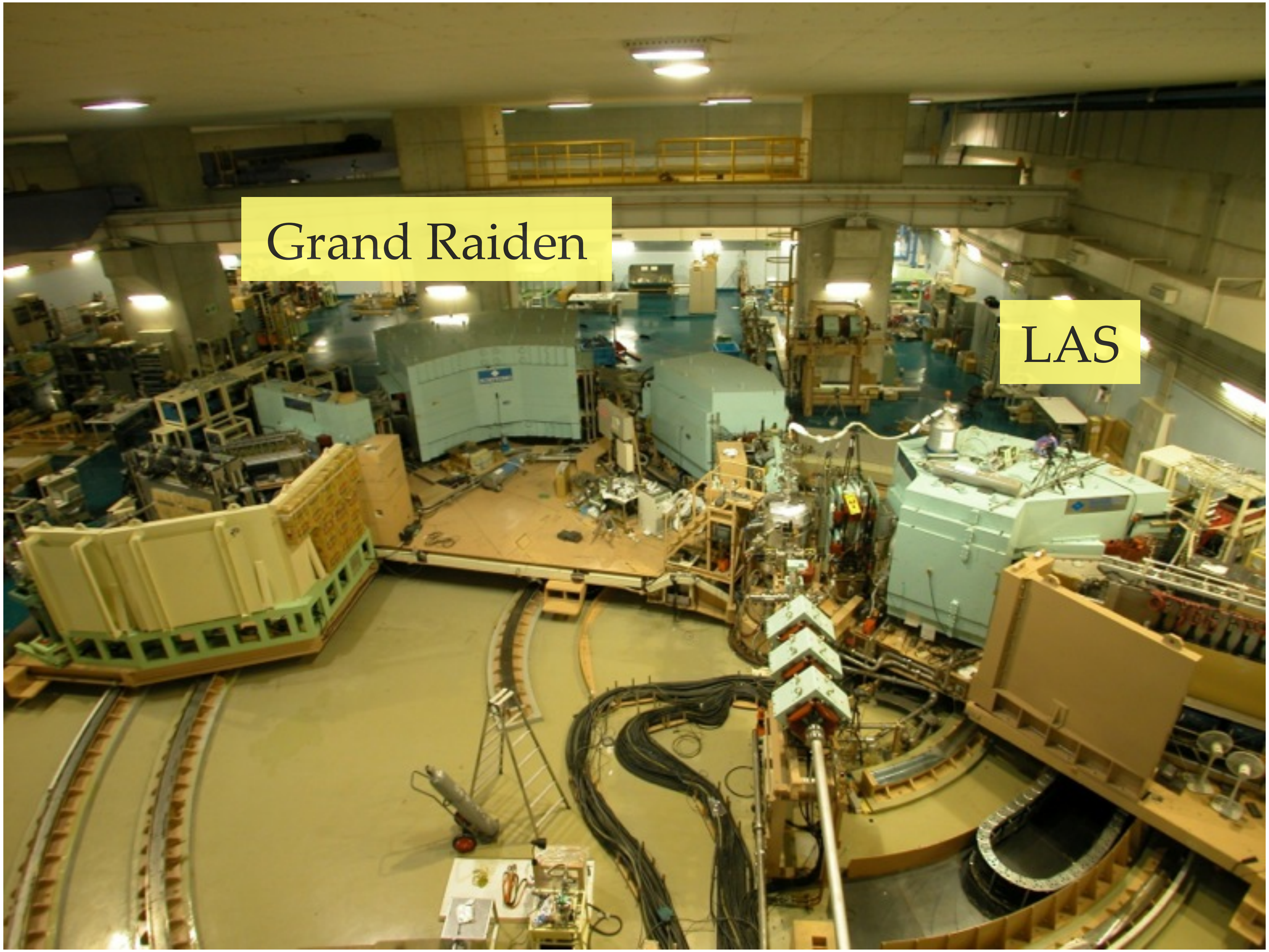
Why don't you join the discussion!

Thank you!

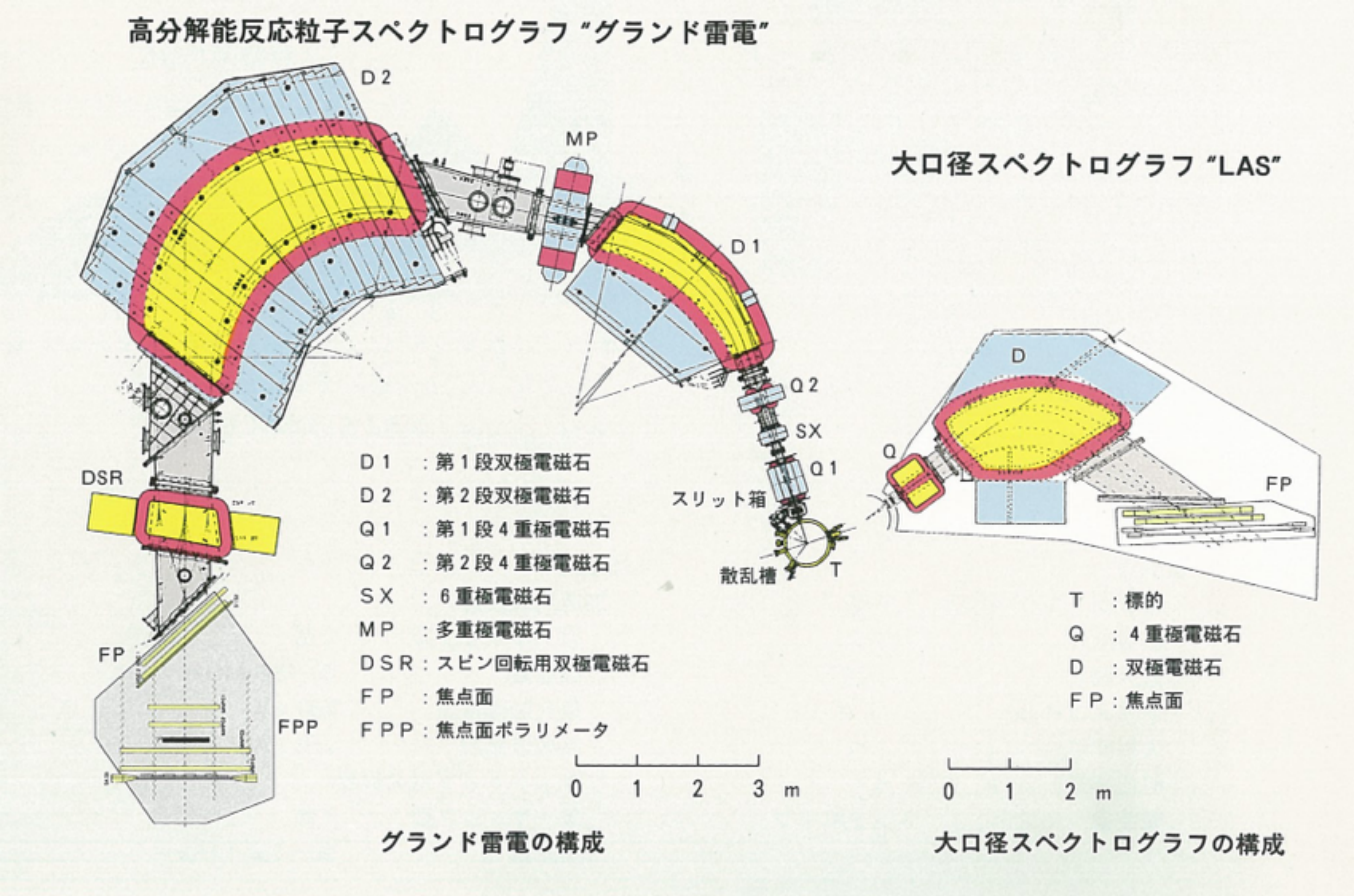
RCNP Cyclotron Facility



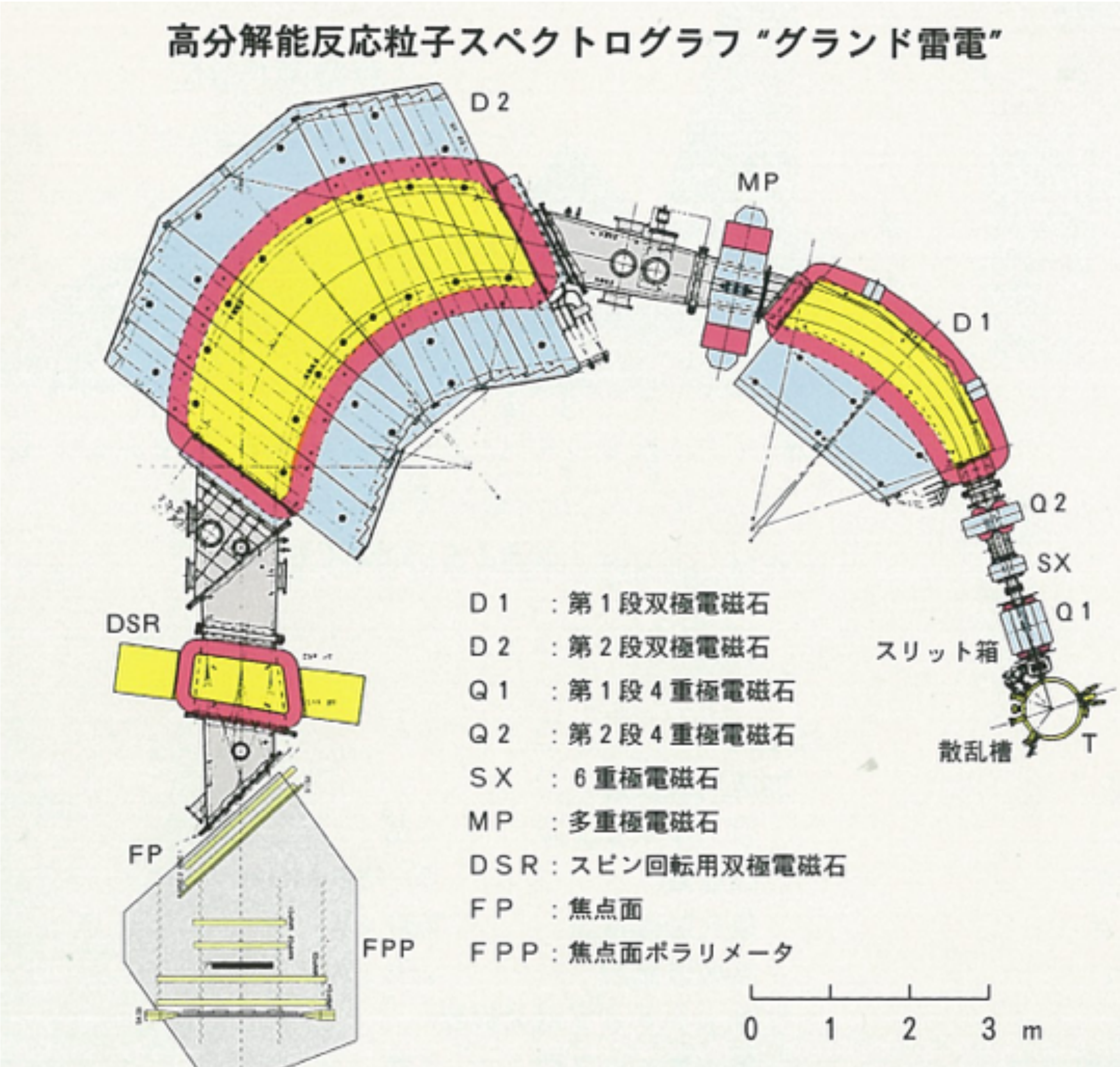
Double Arm Spectrometer: Grand Raiden and LAS



Double Arm Spectrometer: Grand Raiden and LAS



High-Resolution Spectrometer "Grand Raiden (GR)"



M. Fujiwara *et al.*, NIMA422,494(1999)

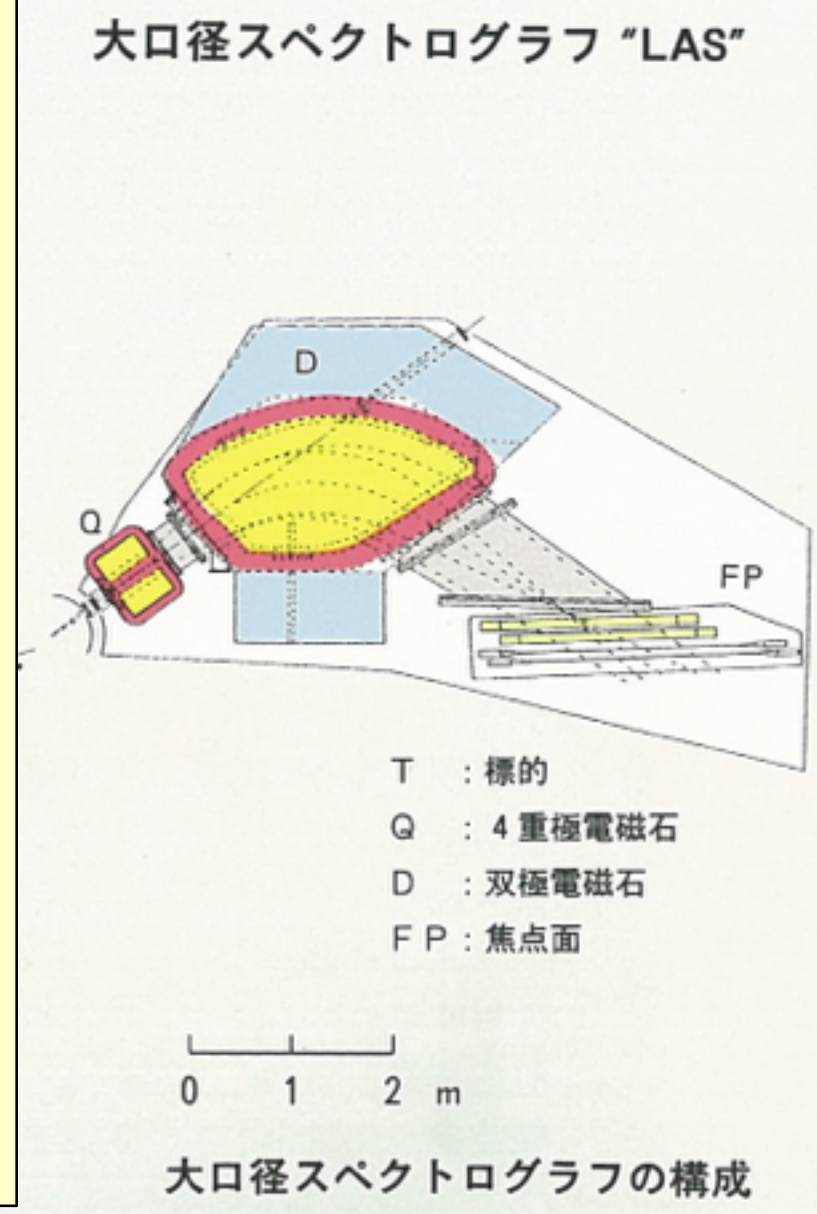
Resolving Power:	37,000
Bending Radius:	3 m
Bending Angle:	162 deg
Bending Power:	5.4 Tm
Dispersion:	15.4 m
Solid Angle:	~4 msr
Momentum Acceptance:	5 %
Horizontal Magnification:	-0.42
Vertical Magnification:	6.0
Angle:	0-70 deg

Two Multi-Wire Drift Chambers
Plastic Scintillators
Focal Plane Polarimeter (for protons)

Large Acceptance Spectrometer (LAS)

Resolving Power:	5,000
Bending Radius:	1.75 m
Bending Angle:	70 deg
Bending Power:	3.22Tm
Dispersion:	2 m
Solid Angle:	~20 msr
Momentum Acceptance:	30 %
Horizontal Magnification:	-0.40
Vertical Magnification:	-7.3
Angle:	0-130 deg

H. Matsuoka et al., RCNP Annual Report 1990



Two Multi-Wire Drift Chambers
Plastic Scintillators

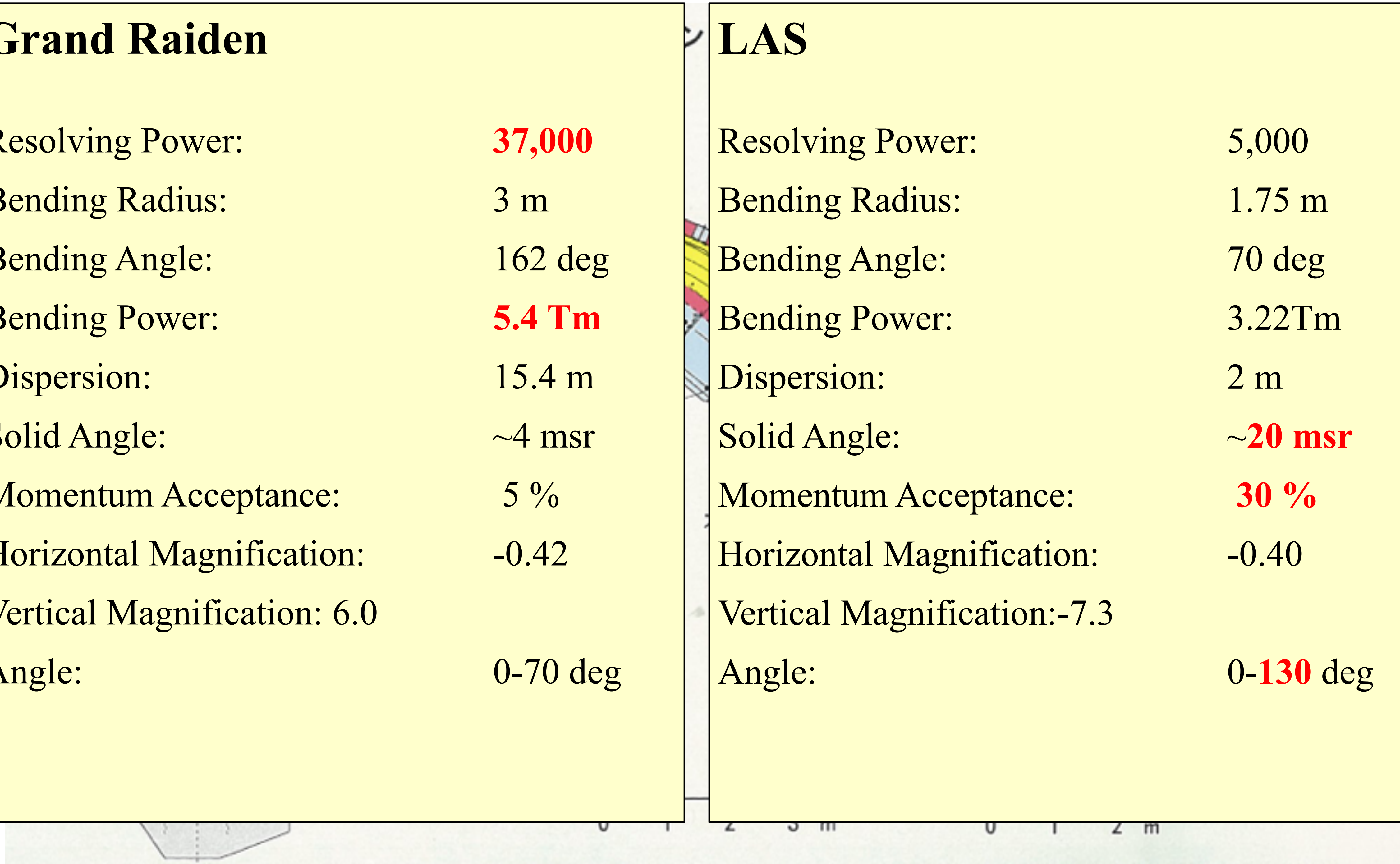
Double Arm Spectrometer: Grand Raiden and LAS

Grand Raiden

Resolving Power:	**37,000**
Bending Radius:	3 m
Bending Angle:	162 deg
Bending Power:	**5.4 Tm**
Dispersion:	15.4 m
Solid Angle:	~4 msr
Momentum Acceptance:	5 %
Horizontal Magnification:	-0.42
Vertical Magnification: 6.0	
Angle:	0-70 deg

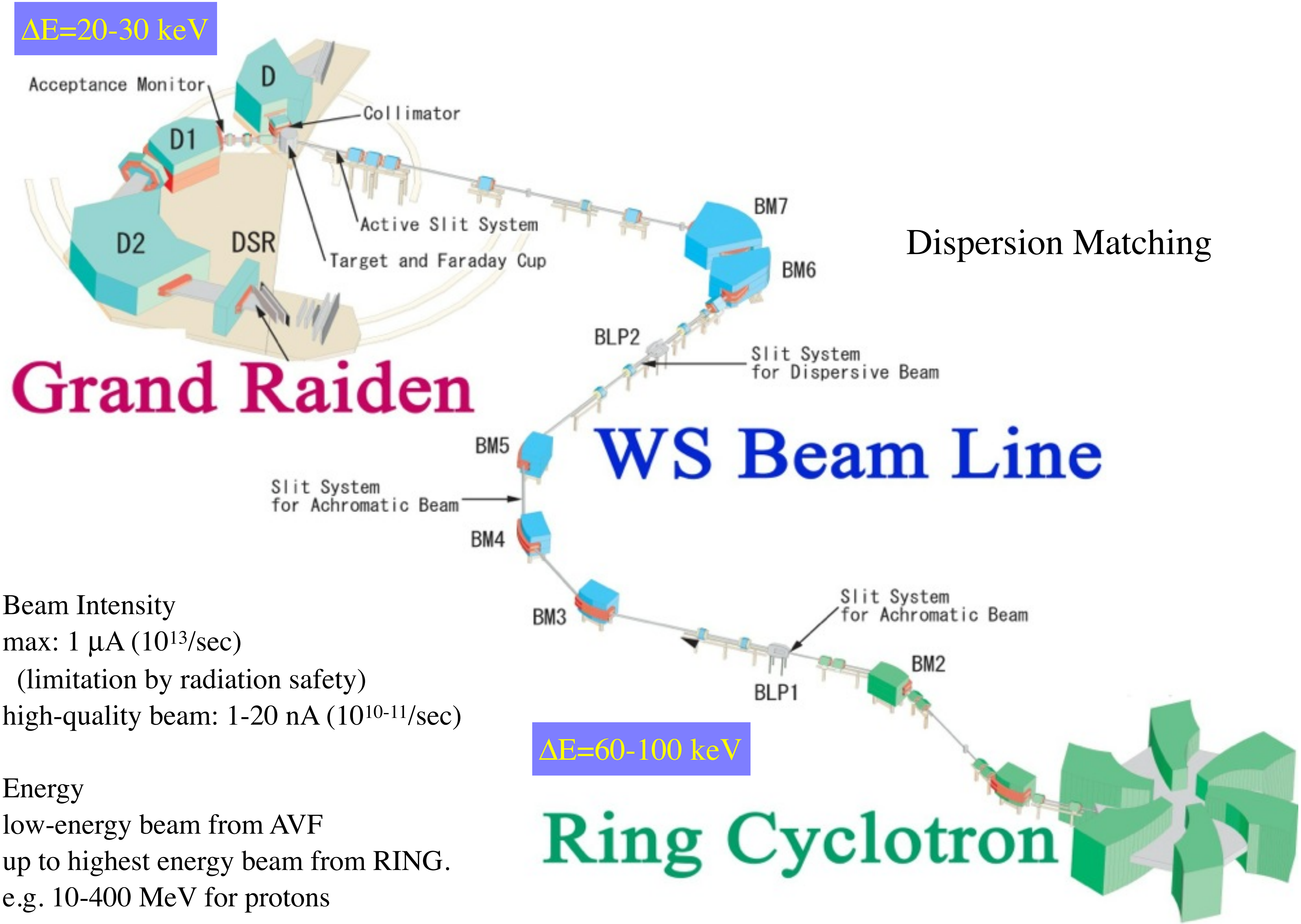
LAS

Resolving Power:	5,000
Bending Radius:	1.75 m
Bending Angle:	70 deg
Bending Power:	3.22Tm
Dispersion:	2 m
Solid Angle:	~**20 msr**
Momentum Acceptance:	**30 %**
Horizontal Magnification:	-0.40
Vertical Magnification:-7.3	
Angle:	0-**130** deg



グランド雷電の構成

大口径スペクトログラフの構成



Beam Intensity
max: 1 μA (10^{13}/sec)
(limitation by radiation safety)
high-quality beam: 1-20 nA (10^{10-11}/sec)

Energy
low-energy beam from AVF
up to highest energy beam from RING.
e.g. 10-400 MeV for protons