Electron scattering projects: Advent of the leptonic probe

NUSTAR Week
2016 09 26-30
Jorviks Universitet,
King's Manor
UK

H. Simon ● GSI Darmstadt

Electron scattering off RIBs
-a few good reasons

1. Clean pointlike electromagnetic probe
   - no nuclear background
     (as in conventional scattering experiments)

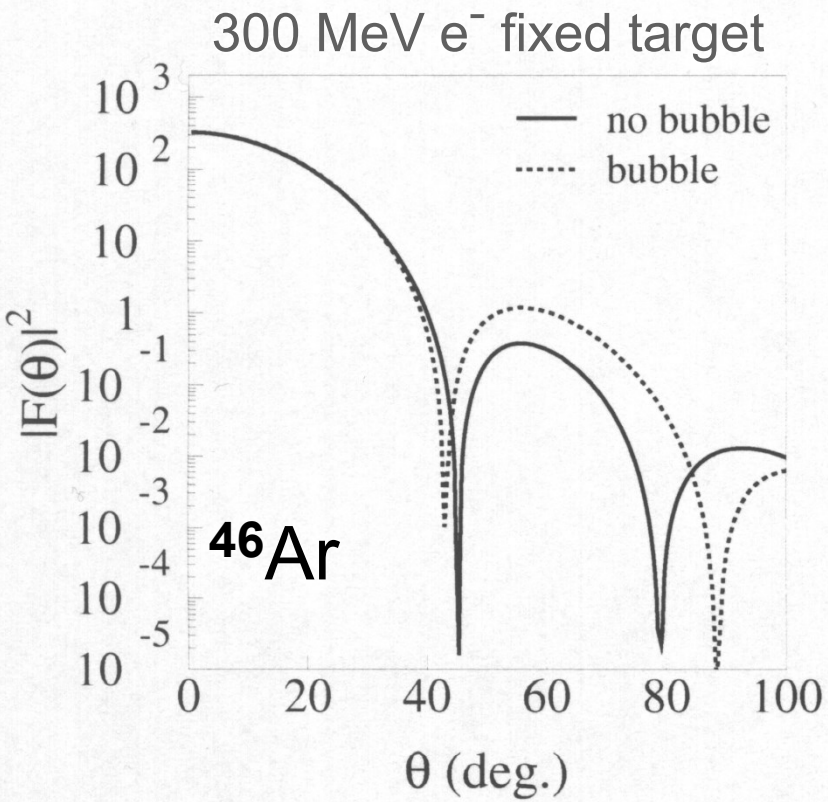
2. Sensitivity to charge distributions
   - higher moments of charge distributions (density ↔wf.)
   - absolute charge radii (ab initio calculations)

   → Deformation vs. Clustering for (very) proton-neutron asymmetric nuclei
   (facilitated access compared to conventional methods)

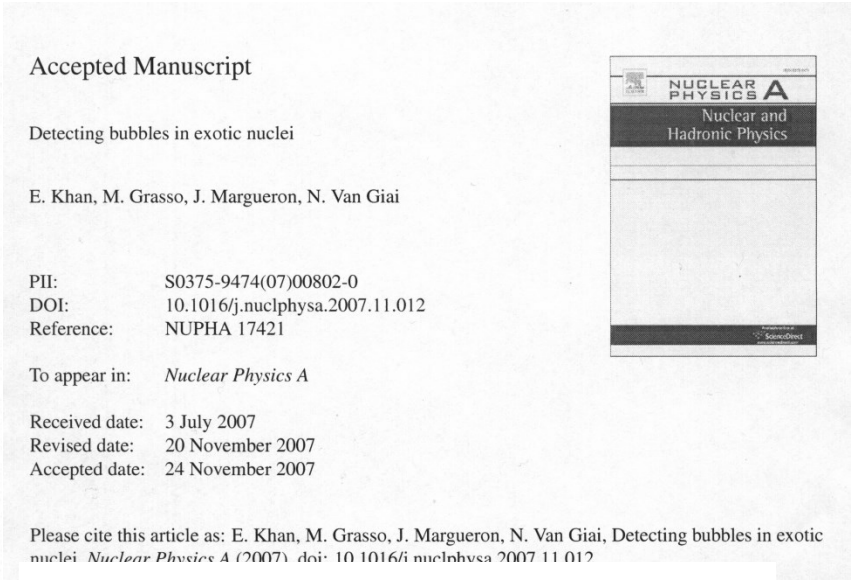
3. Transition form factors
   - additional information to plain spectroscopy

Elastic Scattering

change in interior…



Ar: inversion ($2s_{1/2}$, $1d_{3/2}$)



Accepted Manuscript

Detecting bubbles in exotic nuclei

E. Khan, M. Grasso, J. Margueron, N. Van Giai

PII: S0375-9474(07)00802-0
DOI: 10.1016/j.nuclphysa.2007.11.012
Reference: NUPHA 17421

To appear in: *Nuclear Physics A*

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Nucl. Phys. A800(2008)37
Phys. Rev. C79(2009)034318
[nucl-th] 1311.4412 (2013)

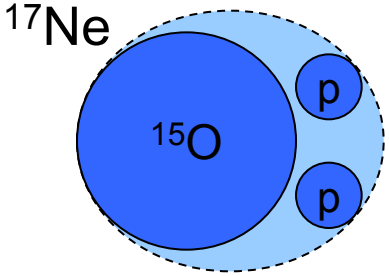
$L=2.7 \times 10^{28}$ cm^{-2} s^{-1}

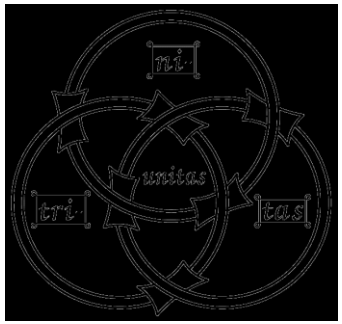
➔Absolute measurement
➔Charge distributions

… vs. valence or surface structure.

"^{17}Ne is a proton-dripline nucleus,
with strong indications of having a 2p – halo"

*Zhukov & Thompson, PR**C** 52 (1995) 3505*

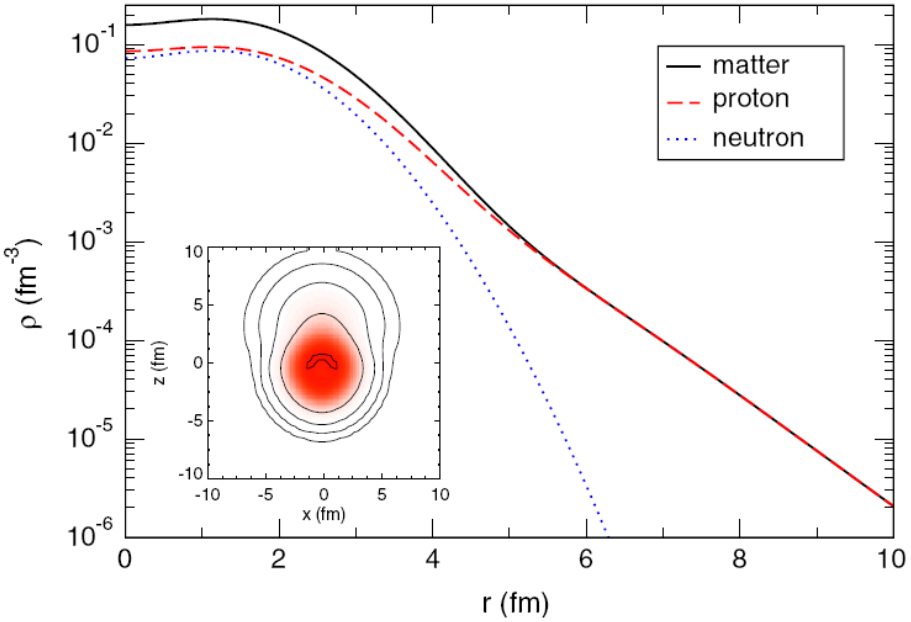




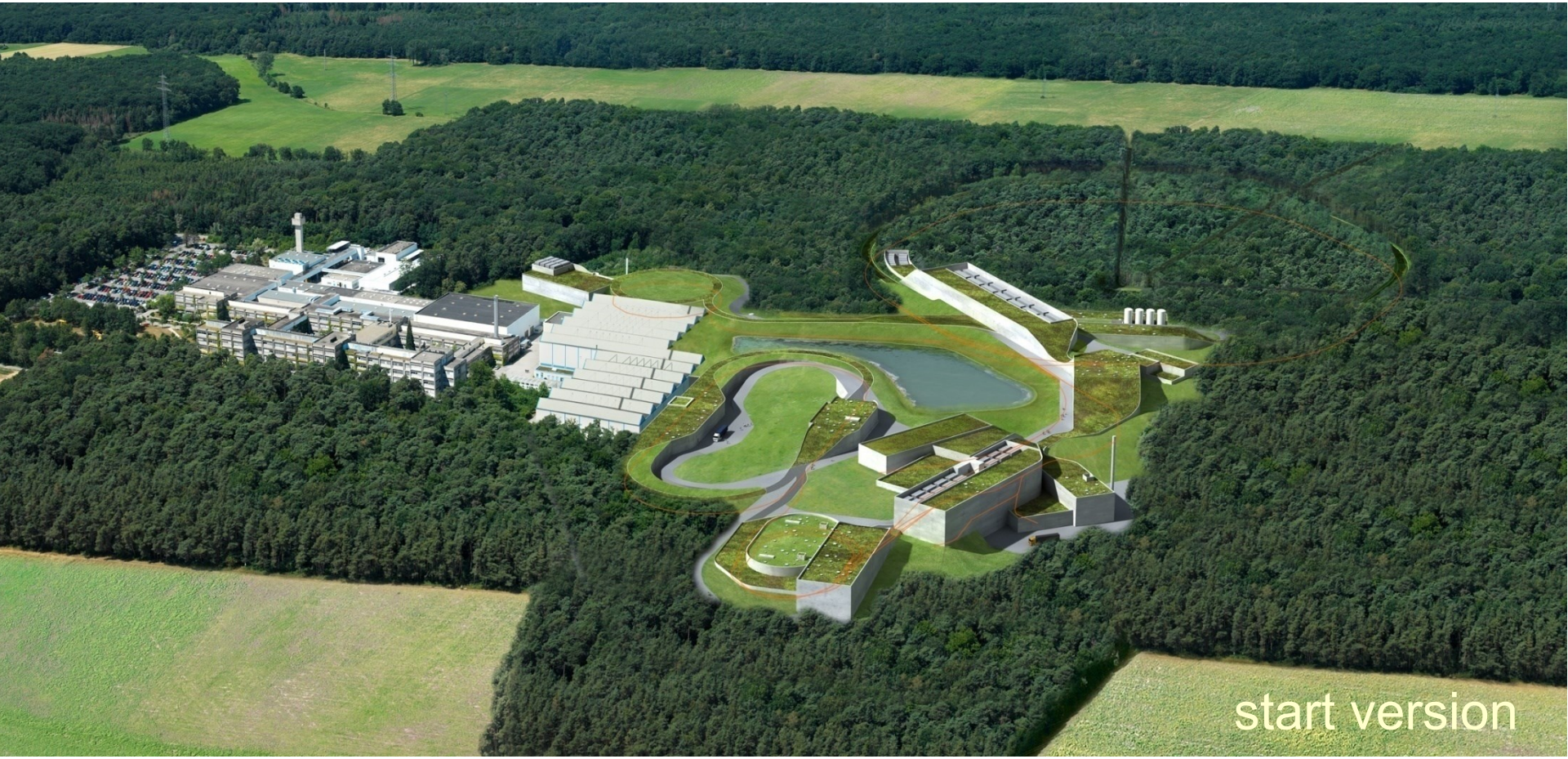
- S_{2p} = 943 keV, S_p = 1479 keV
- $T_{1/2}$ = 109.2 ms (β^+ to ^{17}F)
- Groundstate $J^\pi=1/2^-$; no bound exc. States

~50% Probability
outside classical forbidden region
- Indirect measurements not always conclusive

*W. Geithner, T.Neff et al, PRL **101** 252502 (2008)*



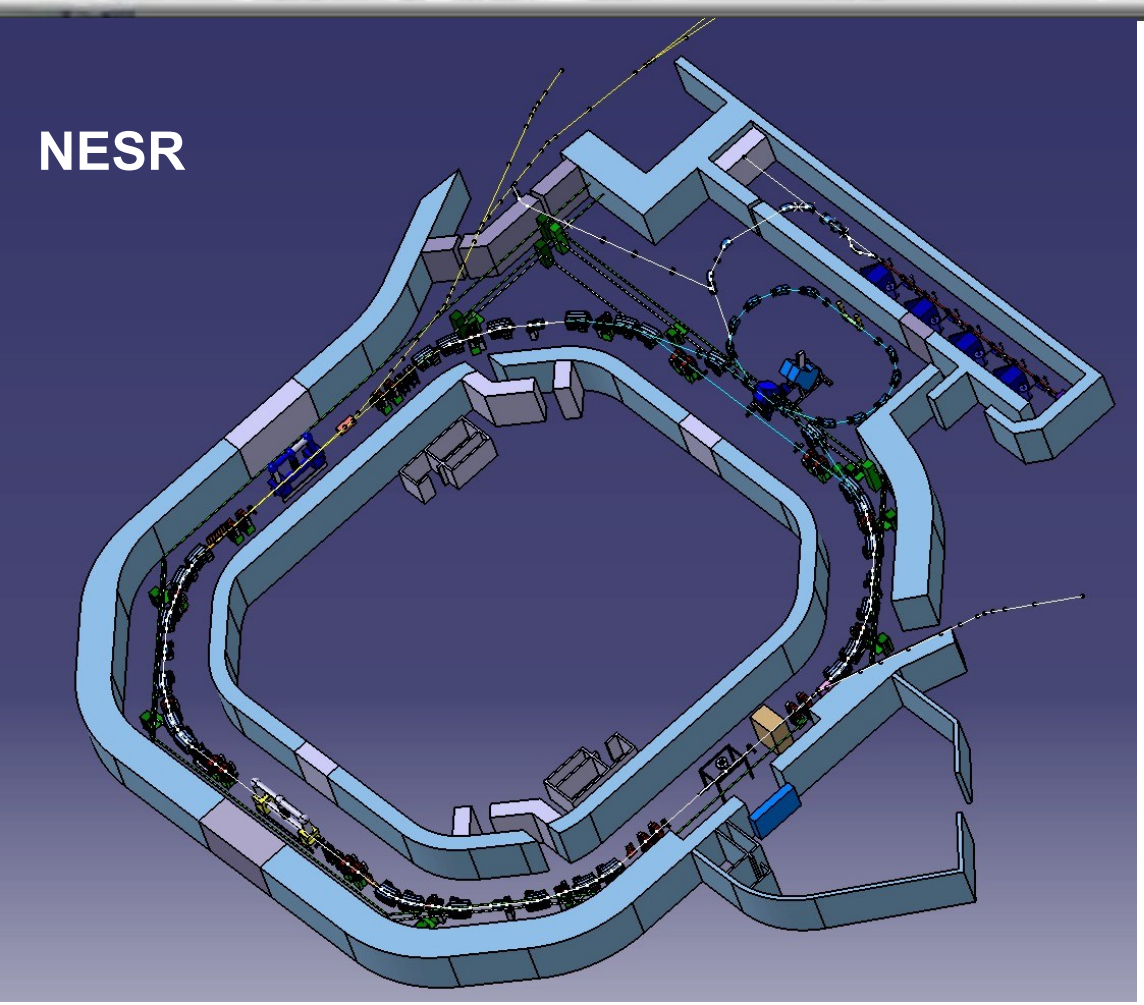
Novel Opportunities @ FAIR, RIKEN, GANIL



Intensity increase 3-4 orders of magnitude !

Realization of an RIB electron collider setup

The ELISe experiment



- 125-500 MeV electrons
- 200-740 MeV/u RIBs

➔ up to 1.6 GeV CM energy

- Original plans K4-K10 Dubna (1992)
Footnote: „We anticipate a possibility to extend in future the K4-K10 complex by installing over the K10 ring a 0.5-1.0 GeV electron storage ring. The very long straight section of the K10 ring will be suitable for arranging electron-ion collisions. This would add a new important dimension to the K4-K10 complex"

- Part of the core facility

http://www.gsi.de/fair/reports/btr.html

AIC option:

- 30 MeV antiprotons

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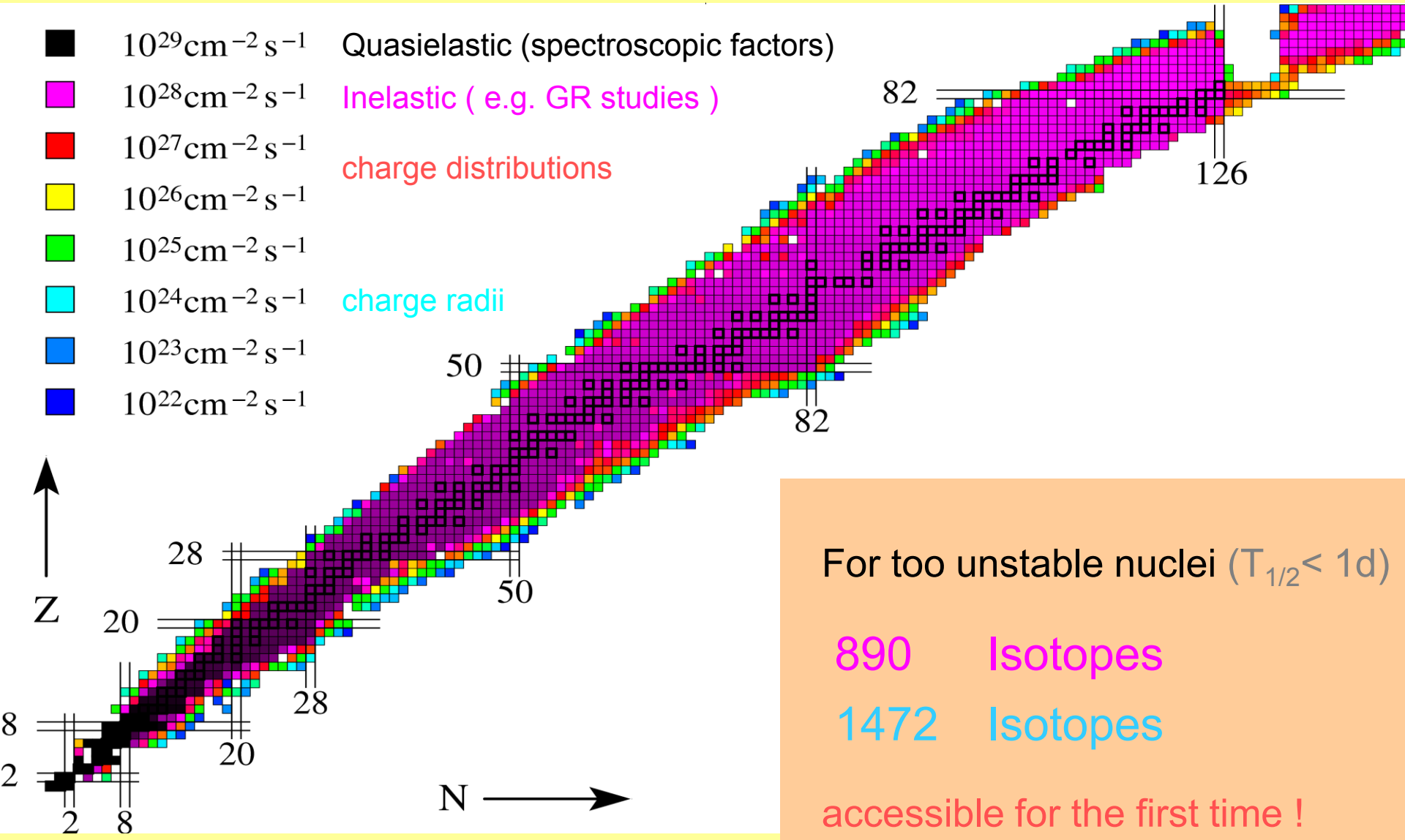
Expected Luminosities (NESR)

➔ Full simulation of production, transport and storage



For too unstable nuclei ($T_{1/2}$< 1d)

890 Isotopes

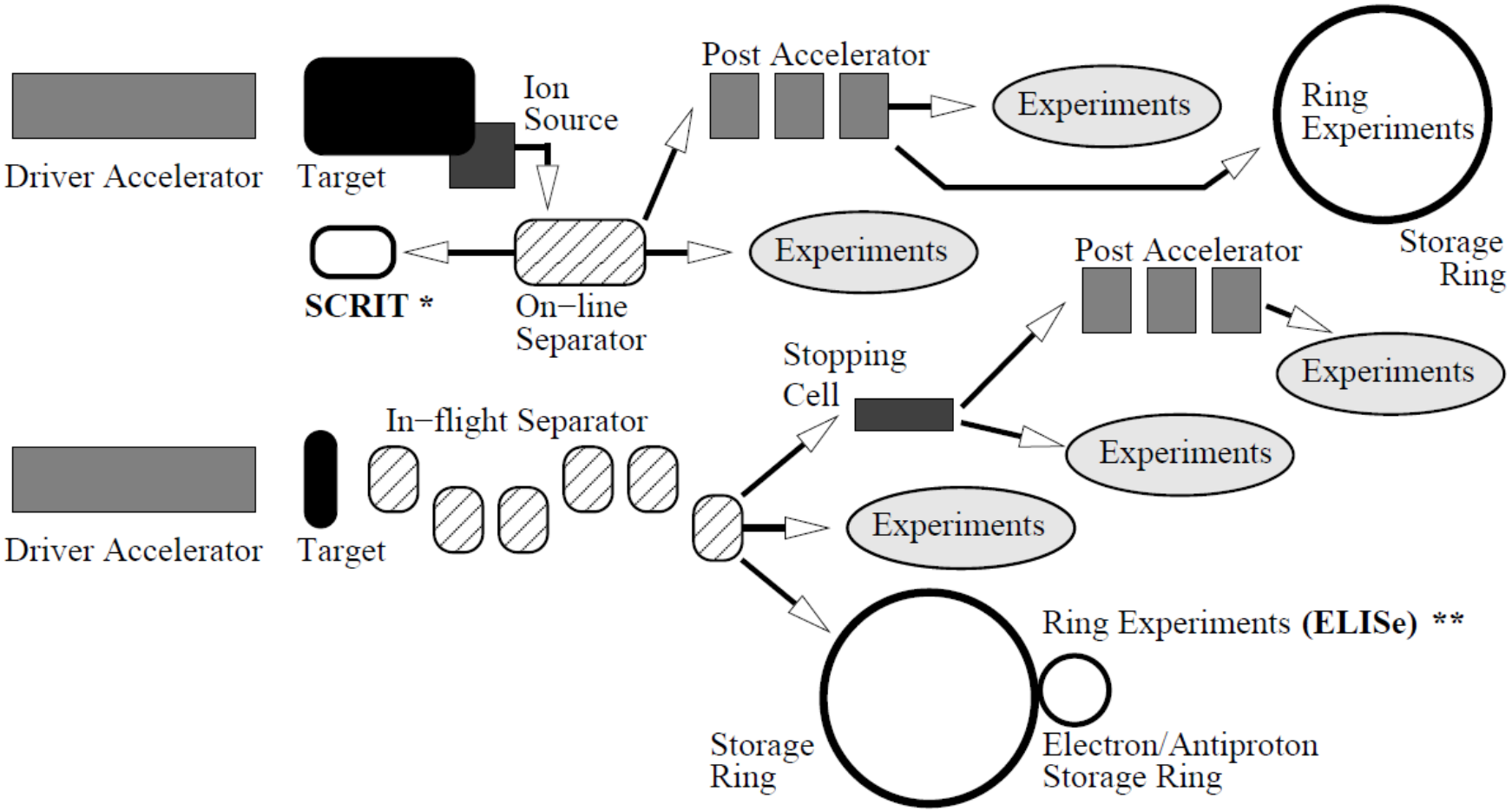
1472 Isotopes

accessible for the first time !

Selected isotopes…

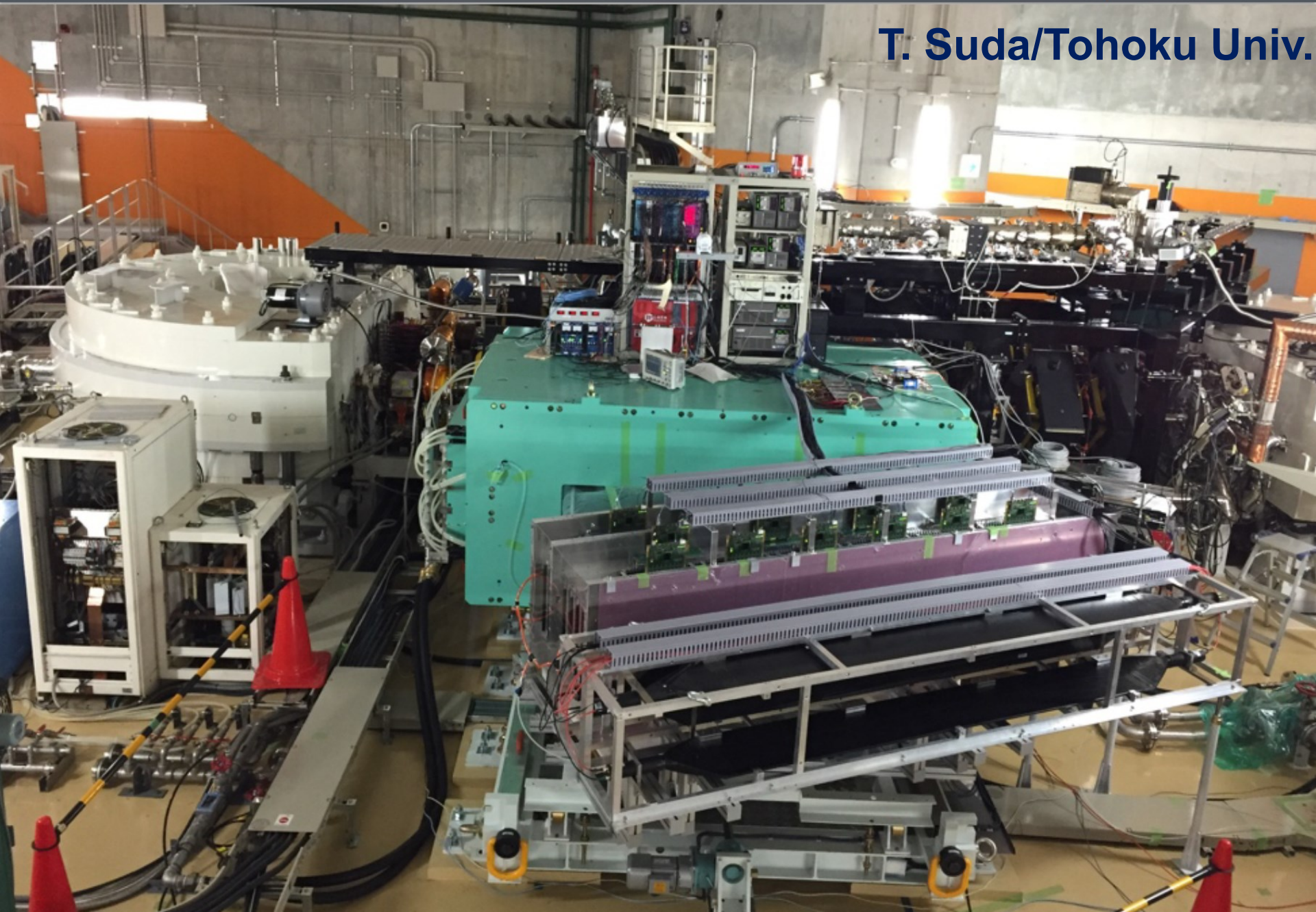
Element	$T_{1/2}$ (s)	τ (s)	N	L ($cm^{-2}\,s^{-1}$)
^{11}Be	13.8	35.6	8.3×10^{9}	2.4×10^{29}
^{35}Ar	1.75	4.5	5.9×10^{7}	1.7×10^{27}
^{55}Ni	0.21	0.5	2.0×10^{7}	4.0×10^{27}
^{71}Ni	2.56	6.5	3.8×10^{7}	1.1×10^{27}
^{93}Kr	1.29	3.3	6.2×10^{6}	1.8×10^{28}
^{132}Sn	39.7	68.2	6.5×10^{8}	1.9×10^{28}
^{133}Sn	1.4	3.5	6.9×10^{6}	2.0×10^{26}
^{224}Fr	199	59.2	3.0×10^{8}	8.6×10^{27}
^{238}U	10^{17}	60	3.4×10^{8}	1.0×10^{28}

Main use cases SCRIT vs. eA collider



SCRIT facility as of today

T. Suda/Tohoku Univ.



First Physics Data from the SCRIT facility

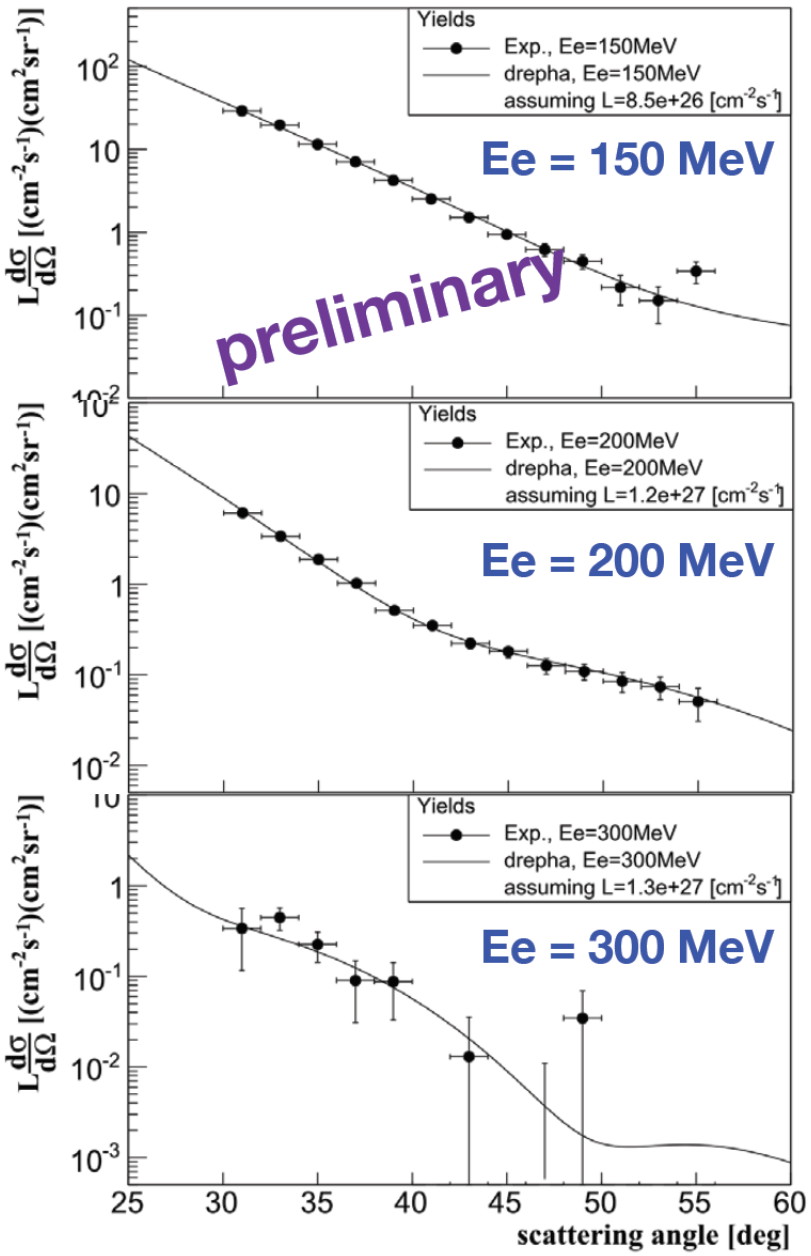
^{132}Xe(e,e')

First electron scattering data
for (stable) Xenon nuclei.

~10^7 ions on the electron beam

(Liq. Xenon for Dark matter search ?)

Switching to unstable ^{138}Xe this summer



Kyo Tsukada

Further Systems

ETIC (Electron-Trapped Ion Collider)

- Working group started at CEA/IRFU within GANIL2025 discussions on a possible electron-ion collider started at CEA/IRFU
- SCRIT concept matches well GANIL settings (continuous injection / low energy)
- ETIC goal: gain a **factor > 100 in luminosity** w.r.t. SCRIT
  - ↘ Greatly expand accessible types of reactions and reach in N/Z
  - ↘ Open up exciting areas of potential physics research

« Retour

SPhN

Séminaires du SPhN

Electron-radioactive ion collisions

Atelier ESNT

du 25/04/2016 au 27/04/2016
Bat 703, p 135 salle visio-conférence, CEA Saclay, Orme des Merisiers

On behalf of the "Espace de Structure et de réactions Nucléaires Théorique" (ESNT), the workshop entitled:
"Electron-radioactive ion collisions: theoretical and experimental challenges"
will be held in April 25-27th at CEA-Saclay, Orme-les-Merisiers site.
The goals of the project are:
1. To review the past achievements with electron scattering on stable nuclei
2. To discuss observables, and state-of-the-art theoretical methods to estimate them
3. To stimulate reflections on new observables that can be measured using electrons as a probe
4. To present the SCRIT machine and its recent results, and the ELISe project
5. To discuss challenges for the ETIC project.

For details about the updated program, see the ESNT Web site http://esnt.cea.fr >> Ateliers 2016
For further information, please contact the local organizer of the project: V. Somà (SPhN).

http://esnt.cea.fr/Phocea/Page/index.php?id=58
Contact : Valerie LAPOUX

$L \sim 10^{30} cm^{-2} s^{-1}$

Antoine Chancé

ER-LINAC

➔15x15 µm²

Electron beam spot

Fixed target vs. colliding beams …

- trying to get through the eye of the needle

- Target and scattered off particles can be detected

➔ excitation and deexcitation process is studied

- kinematical focusing

➔ solid angle

➔ Mott cross section enhanced (small angles)

- luminosity for unstable nuclei (no target)

➔ 100µm x 100µm interaction area

vs e.g. dilute ions in a trap

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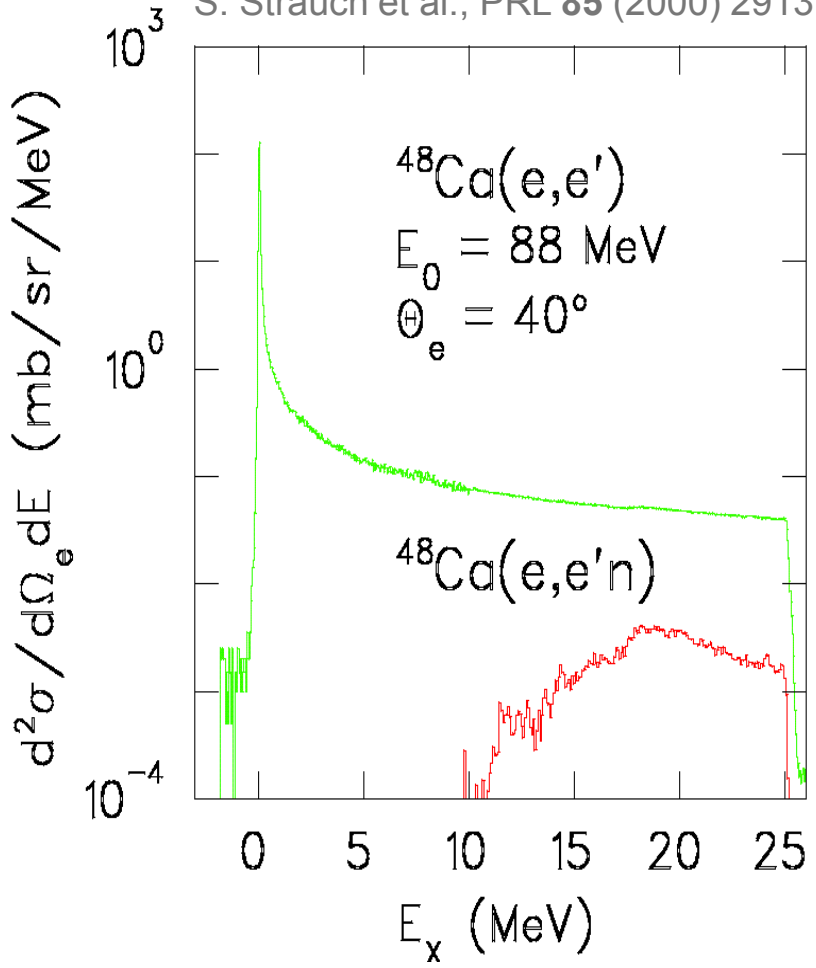
Gain factors through different kinematics

→ compared to conventional (fixed target) experiments (L_{eff} → $10^{32..33}$ $cm^{-2}s^{-1}$)

S. Strauch et al., PRL **85** (2000) 2913



Fixed target		Collider 1.5GeV
^{48}Ca(e,e'n)		^{48}Ca(e,e'A')
Ω_n =100msr	100	Ω_n ~ 4π
n_{eff} =20 %	5	n_{eff} ~ 100 %
$\Theta_{e'}$ = 40 °	50	**$\Theta_{e'}$ = 5 °**
elastic	>10^4	
L=10^{31} – 10^{32}	cm^{-2} s^{-1}	**L ~ 10^{27}**
SCRIT ~10^{28}/ETIC ~10^{30}		ELISe ~10^{28}

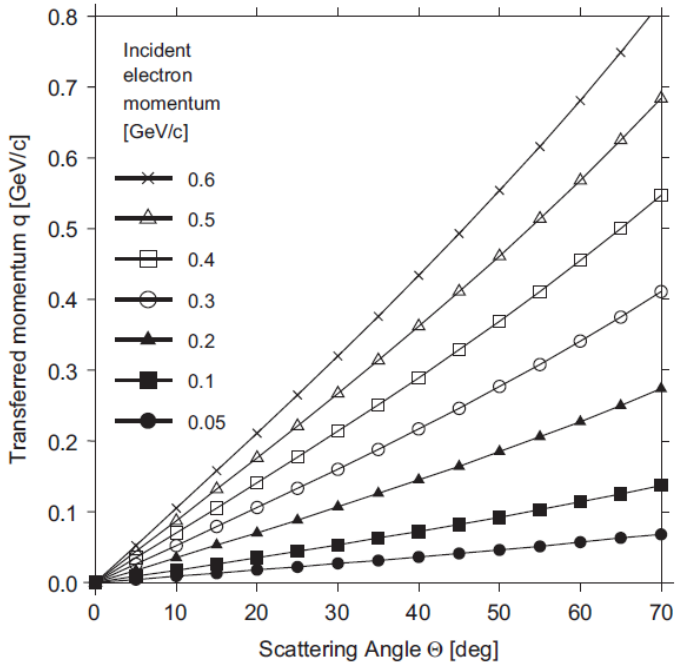
→ Another large gain through kinematics

Kinematics

$\beta = p_A / E_A, \quad \delta = \sqrt{(1-\beta)/(1+\beta)},$ = 0.3 @ 740 AMeV/500MeV

➔ Electron scatt. @1.64 GeV

Fixed target	Collider
Conventional kinematics ($\beta = 0$)	Counter-propagating beams ($\beta > 0$)
Scattered electron momentum	
$p_{e'} = \frac{p_e - E^*}{1 + 2\frac{p_e}{M}\sin^2\frac{\theta}{2}}$	$p_{e'} = \frac{p_e - \delta E^*}{1 + 2\frac{p_e - p_A}{M}\delta\sin^2\frac{\theta}{2}}$
Momentum transfer	
$q^2 = \frac{4p_e^2\sin^2\frac{\theta}{2}}{1 + 2\frac{p_e}{M}\sin^2\frac{\theta}{2}}$	$q^2 = \frac{4p_e^2\sin^2\frac{\theta}{2}}{1 + 2\delta\frac{p_e - p_A}{M}\sin^2\frac{\theta}{2}}$
Resolution (momentum dependence)	
$\Delta E^* \approx -\left(1 + 2\frac{p_e}{M}\sin^2\frac{\theta}{2}\right)\Delta p_{e'}$	$\Delta E^* \approx -\left(\frac{1}{\delta} + 2\frac{p_e - p_A}{M}\sin^2\frac{\theta}{2}\right)\Delta p_{e'}$
Resolution (angular dependence)	
$\Delta E^* \approx -\frac{p_e p_{e'}}{M}\sin\theta\Delta\theta$	$\Delta E^* \approx -\frac{(p_e - p_A)p_{e'}}{M}\sin\theta\Delta\theta$



Where's the challenge ?

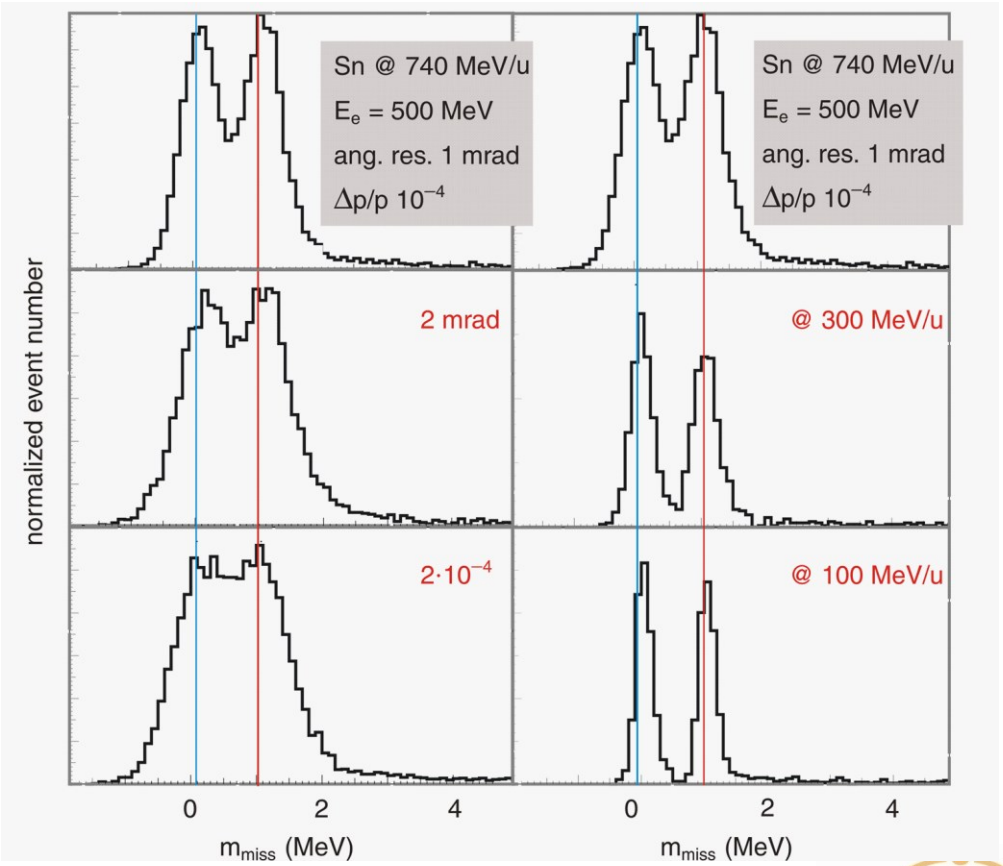
Monte Carlo Simulation: $\Delta E^* = 1$ MeV

Cola++, Simul++ (H. Merkel, Univ. Mainz)

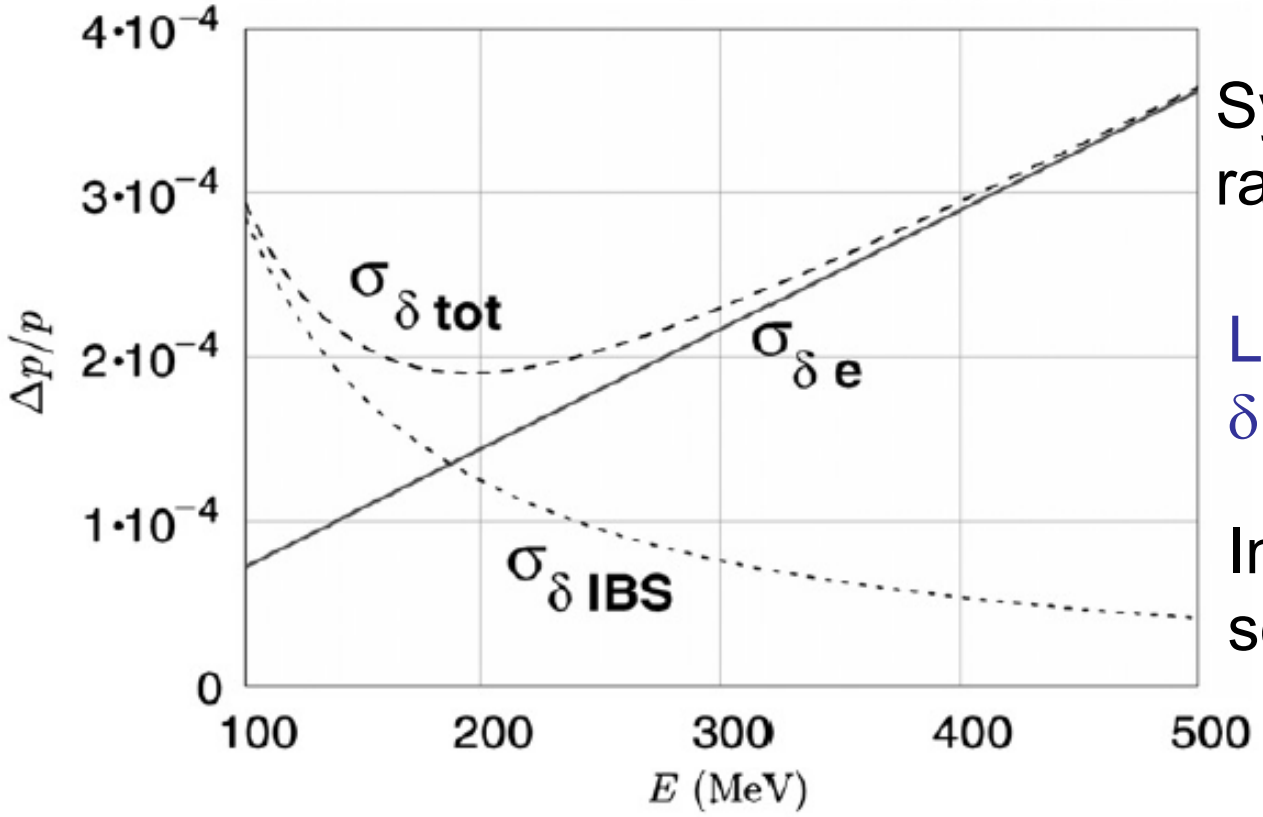
Pure kinematics calculus:

- colliding beam kinematics
- angular and energy resolution coupled
- achievable resolution can be improved by getting the "target" to "rest"

  ➔ reduced luminosity



Electron beam properties



Synchrotron radiation

Loss with $\delta = 0.3$ (first order)

Intra-beam scattering

➔ Trade resolution vs. rate

System design:
-TDR

The Electron-Ion Scattering experiment ELISe at the International Facility for Antiproton and Ion Research (FAIR) - a conceptual design study

A.N. Antonov, M.K. Gaidarov, M.V. Ivanov, D.N. Kadrev

INRNE-BAS Sofia - Bulgaria

M. Aïche, G. Barreau, S. Czajkowski, B. Jurado

Centre d'Etudes Nucléaires Bordeaux-Gradingnan (CENBG) - France

G. Belier, A. Chatillon, T. Granier, J. Taieb

CEA Bruyères-le-Châtel - France

...

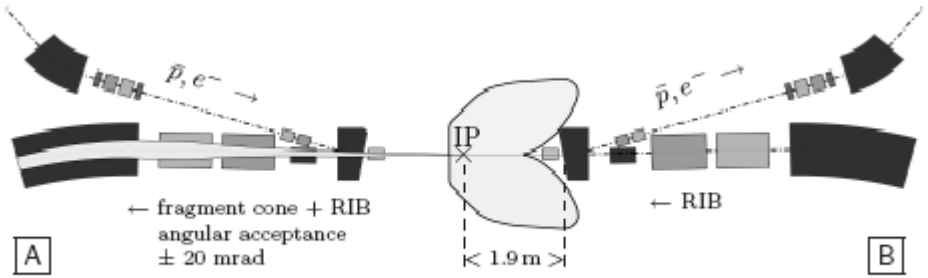
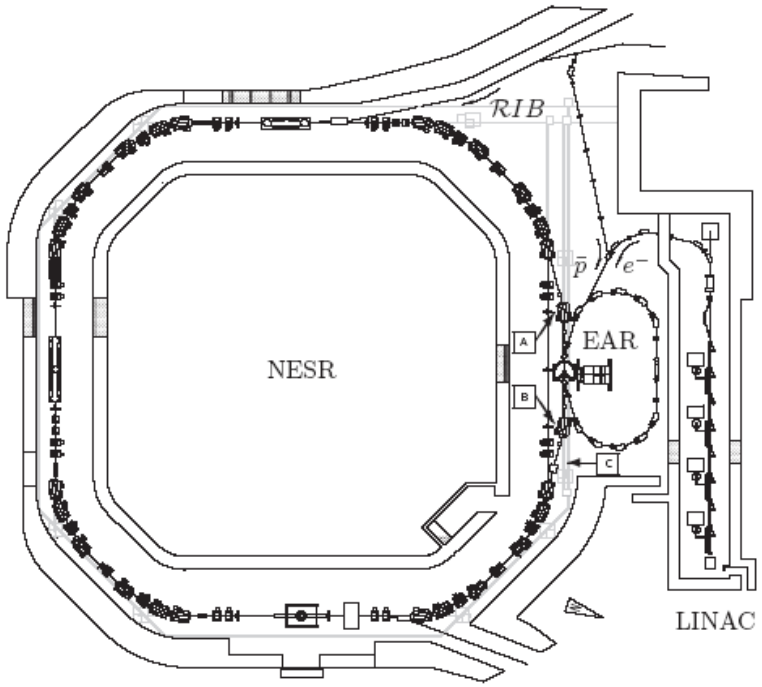


Figure 6: Interaction zone with the interaction point IP in the bypass section of the NESR.



ELISe collaboration,
NIM **A637** (2011) 60

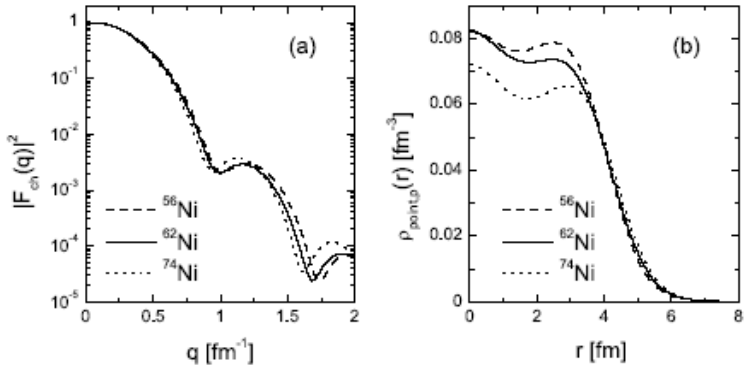


Figure 1: Charge form factors (panel (a)) calculated in DWBA and HF+BCS proton densities (panel (b)) for the unstable doubly-magic ^{56}Ni (dashed line), stable ^{62}Ni (full line) and unstable ^{74}Ni (dotted line) isotopes [7].

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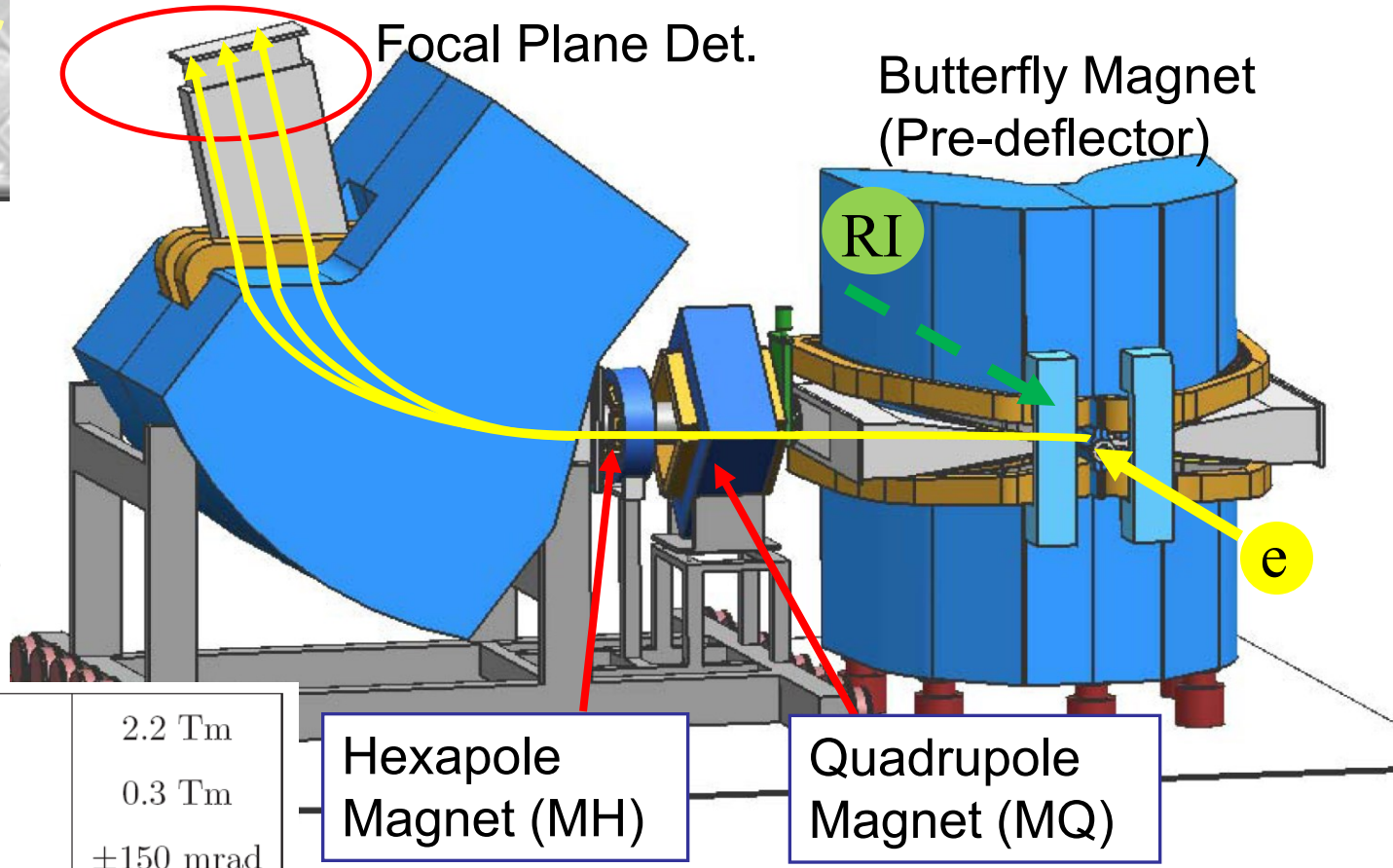
… and a suitable magn. high resolution spectrometer

GPA Berg et al.



Maximum rigidity Bρ	2.2 Tm
Minimum rigidity Bρ	0.3 Tm
Angle acceptance, azimuthal	±150 mrad
Angle acceptance, polar at 11.4°	±24 mrad
Angle acceptance, polar at 22.7°	±70 mrad
Energy acceptance	± 5 %
Resolving Power E/ΔE	$\approx 10^4$
Angle resolution	1 mrad
Kinematic compression factor	0.3 - 0.6

GPA Berg et al.,
NIM **A640** (2011) 123

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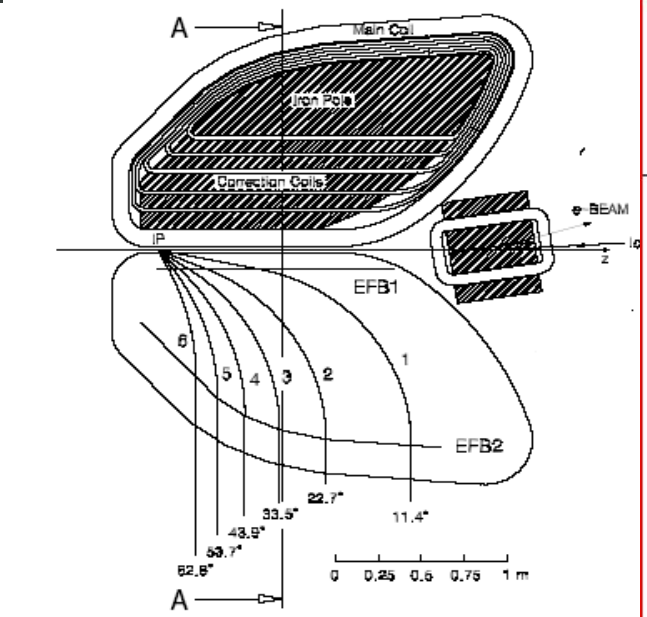
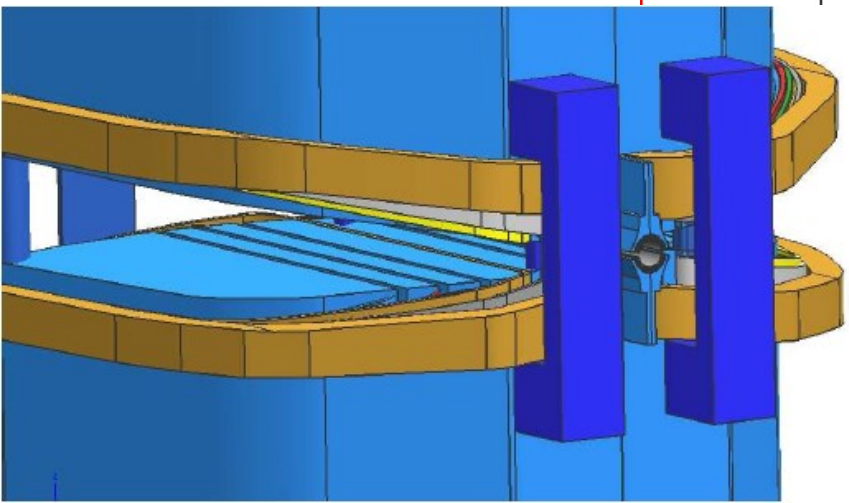
Resolution

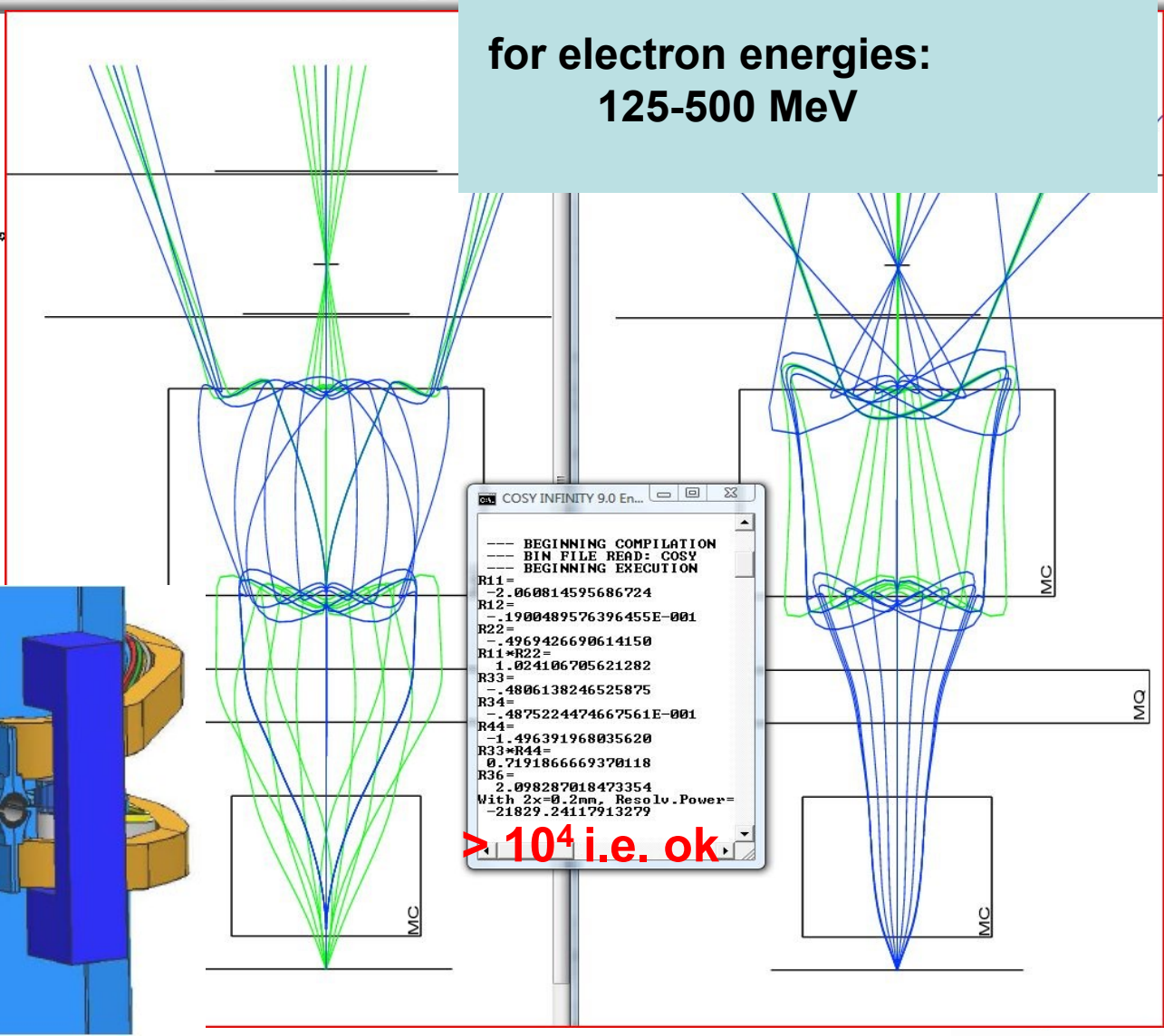
GPA Berg et al. → T. Adachi et al.

Θ_{Lab}: 10-60°
q: 20-600 MeV/c

for electron energies:
125-500 MeV





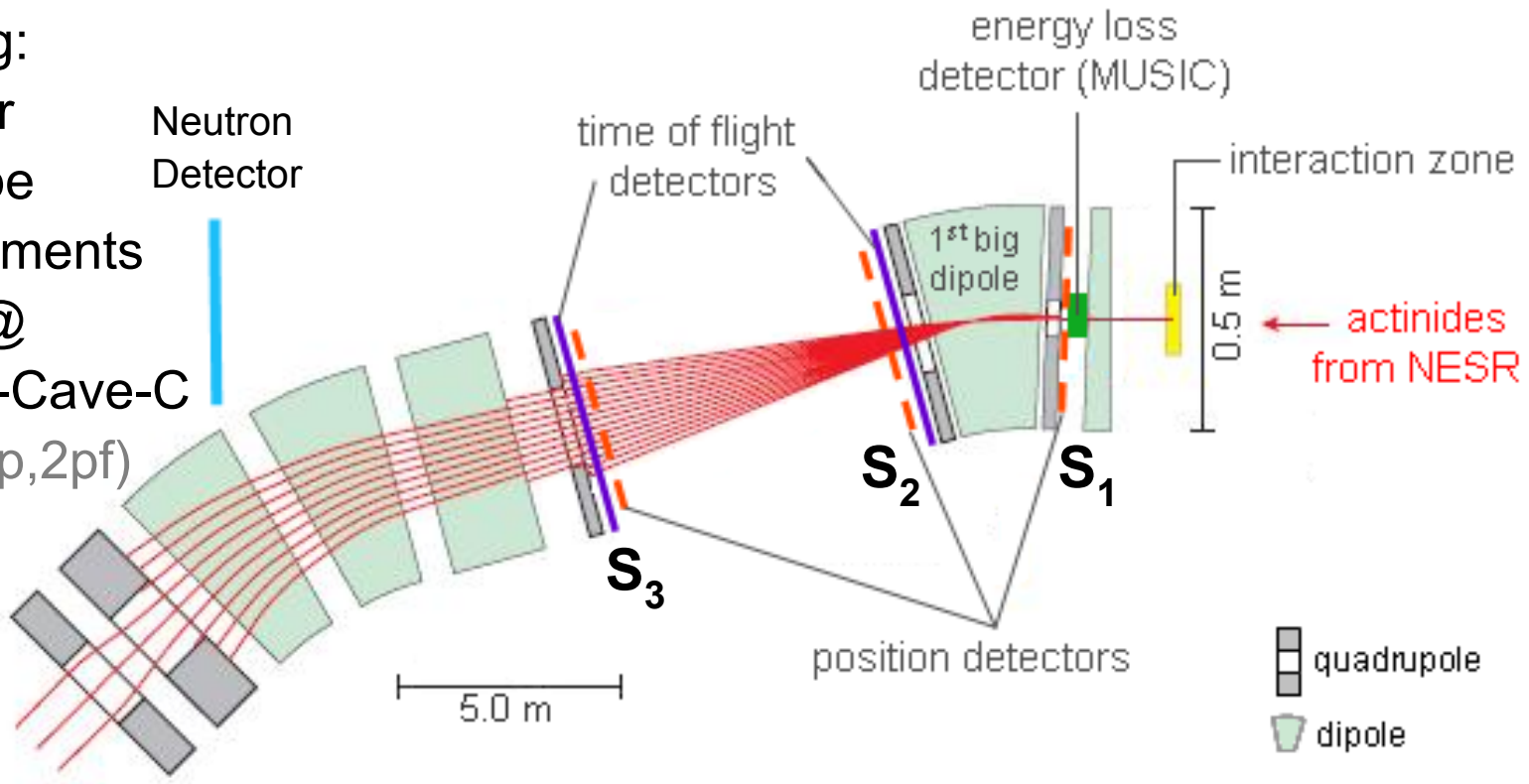


$> 10^4$ i.e. ok

In-Ring spectrometer in the Bypass

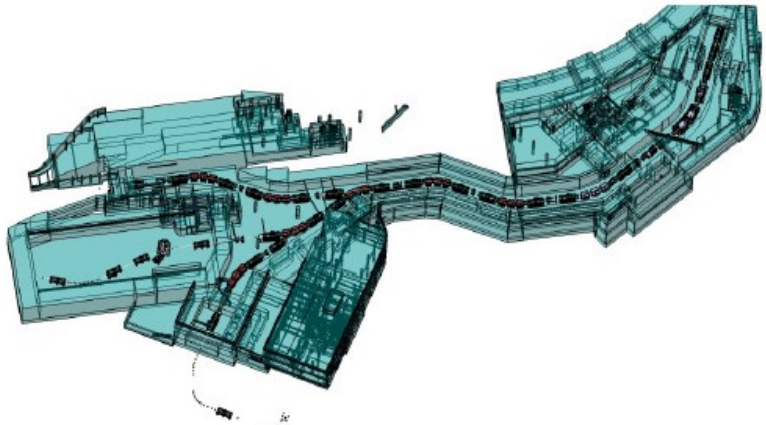
CEA-DAM Bruyères-le-Châtel, JINR Dubna, GSI (FELISe → SOFIA)

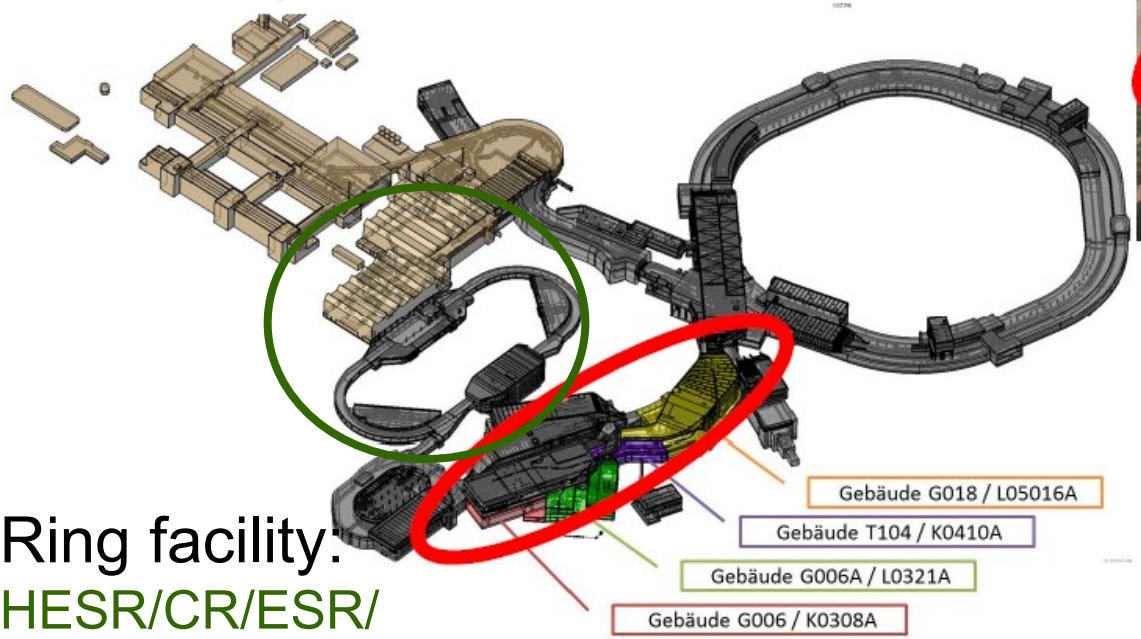
Ongoing:
Detector prototype developments
SOFIA@
R³B-Cave-C
future: (p,2pf)



Most demanding physics case: Electrofission studies (FELISe)
-coincident identification of both fission fragments
-prefragment excitation energy directly accessible (e,e'f)

Current status with respect to the MSV - NESR is delayed





Ring facility:
HESR/CR/ESR/
Cryring complex

Possible realization of the ELISe experiment at the ESR

Paper in preparation

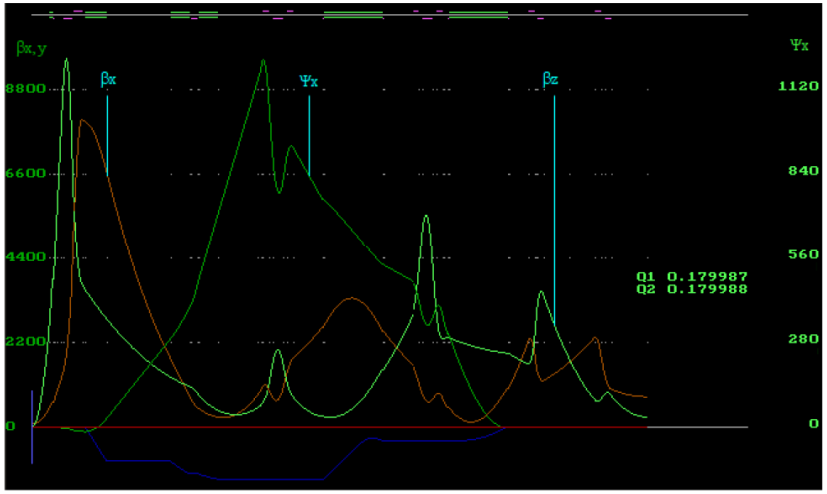
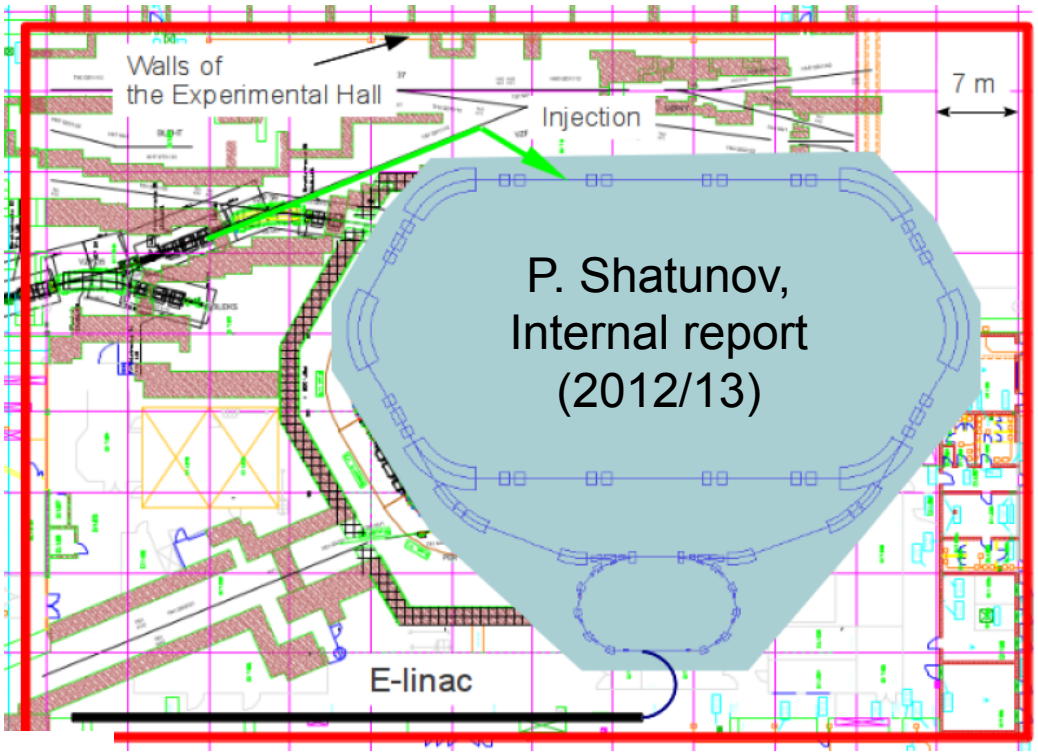
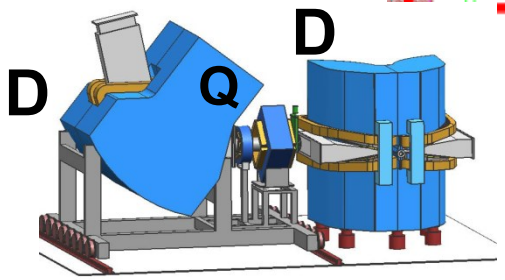
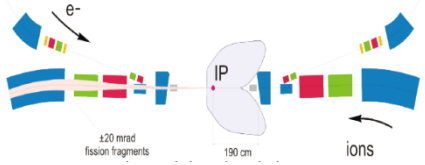


Figure 9. Beta (β, cm) and dispersion (Ψ, cm) functions of stretched ESR (1 half) in the collider mode.



GPA Berg et al.,
NIM **A640** (2011) 123
NIM **A659** (2011) 198





ELISe Collaboration
NIM **A637** (2011) 60

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Main consequences:

- Lower ion energies (340 AMeV vs. 740 AMeV)
  - less maximum luminosity (tune shift ~ factor 3…4)
- Higher resolution / better sensitivity
- No injection from SuperFRS to ESR, bad injection efficiency for non pre-cooled beams

➔ initial programme with ~10^6 less particles for most exotic species at the outskirts of the nuclear chart (flat top for isotopes close to stability)

- All properties of ESR (stability, … to be checked)
- Modifications to prolong straight sections & Cave

Summary

- Electron Scattering becomes first available for RIB studies, main obstacle is the usable rate for studies
- Fixed target setup(s) for use with ISOL type facilities become online
- Electron(Antiproton)-RIB Collider is feasible -
  collider mode provides optimal use for RIBs. Another
  Large gain factors are expected, especially enabling inelastic scattering studies.

➔ Conceptual design for all major systems are done

➔ Options for running at the existing ESR have been studied

Viable physics programme for an initial facility in the HESR/CR/ESR/Cryring complex at FAIR.

- Unique experiment for FAIR (and other in-flight facilities)

http://www.gsi.de/elise/

The ELISe collaboration

BINP Novosibirsk - Russia Koop, I.A., Skrinsky, A.N., Korostelev, M.S., Parkhomchuk, V.V., Shatilov, D.N., Shiyankov, S.V., Valishev, A.A., Shatunov, Y.M., Pavlov, V.M., Otboev, A.V., Nesterenko, I.N., Logatchov, P.V.

CEA Bruyeres le Chatel - France Chatillon, A., Belier, B., Granier, T. , Taieb, J.

CEA Saclay/ IRFU - France Doré, D., Letourneau, A., Ridikas, D. , Dupont, E. , Berthoumieux, E., Panebianco, S.

CEN Bordeaux-Gradingnan - France Czajkowski, S., Jurado, B., Aïche, M., Barreau, G.

CSIC Madrid - Spain Sarriguren, P., Ramirez, C. F. , Borge, M.J.G., Garrido, E., Alvarez, R., Moya de Guera, E.

Chalmers University of Technology – Sweden Nyman, G., Johansson, H., Heinz, A., Jonson, B., Nilsson, T.

Complutense University of Madrid - Spain Udias-Moinelo, J., Fraile Prieto, L.M., Herraiz, J.L., Vignote, J.R.

DAEES Kyushu University - Japan Kadrev, D.N.

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