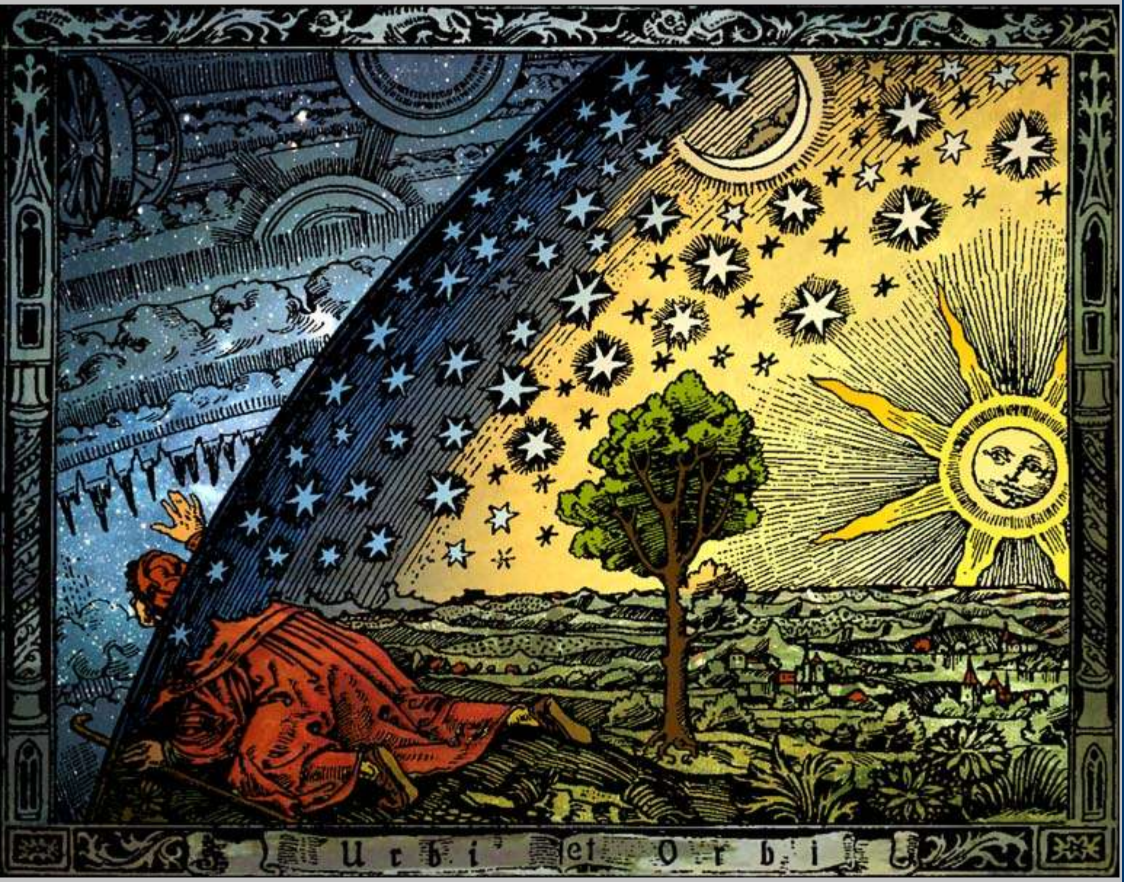
The ELISE project at FAIR
-- electron scattering off RIBs

Electron-radioactive ion collisions: theoretical and experimental challenges
April 25th-27th, 2016
CEA Saclay, France



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

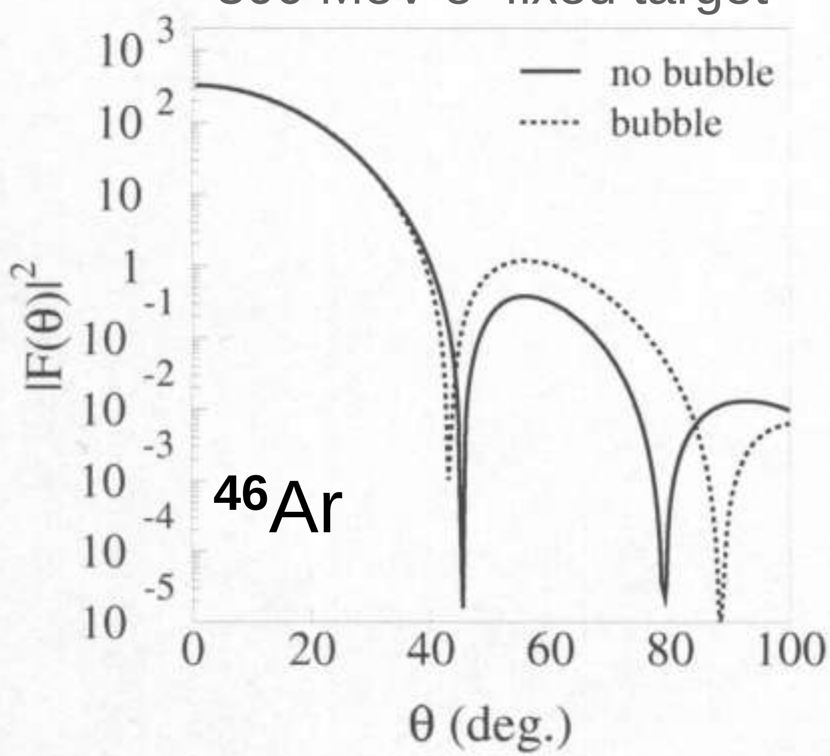
     (not accessible in conventional methods)

3. Transition form factors
   - additional information to plain spectroscopy

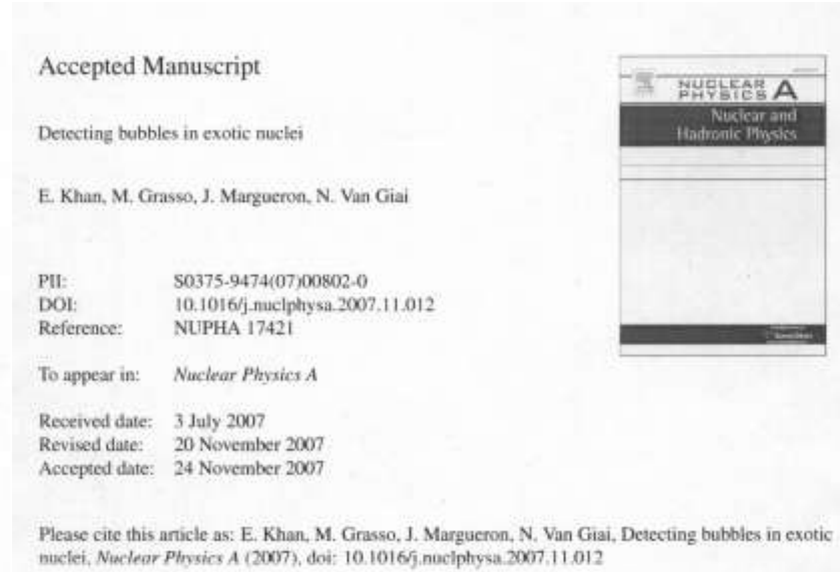
Elastic Scattering

change in interior…

300 MeV e$^-$ fixed target



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*

Received date: 3 July 2007
Revised date: 20 November 2007
Accepted date: 24 November 2007

Please cite this article as: E. Khan, M. Grasso, J. Margueron, N. Van Giai, Detecting bubbles in exotic nuclei, *Nuclear Physics A* (2007), doi: 10.1016/j.nuclphysa.2007.11.012

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

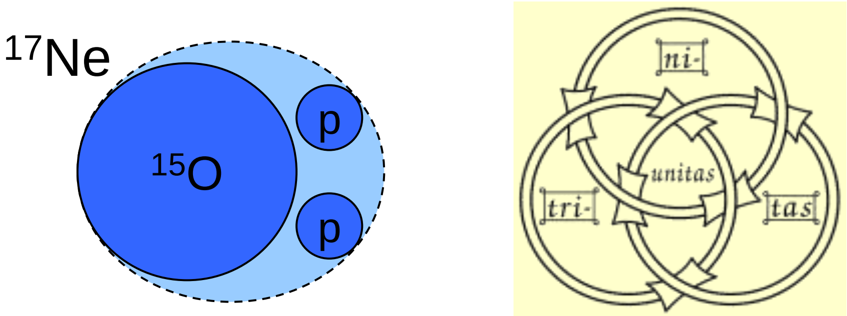
L=2.7 × 10^{28} cm^{-2} s^{-1}

➔Absolute measurement
➔Charge distributions

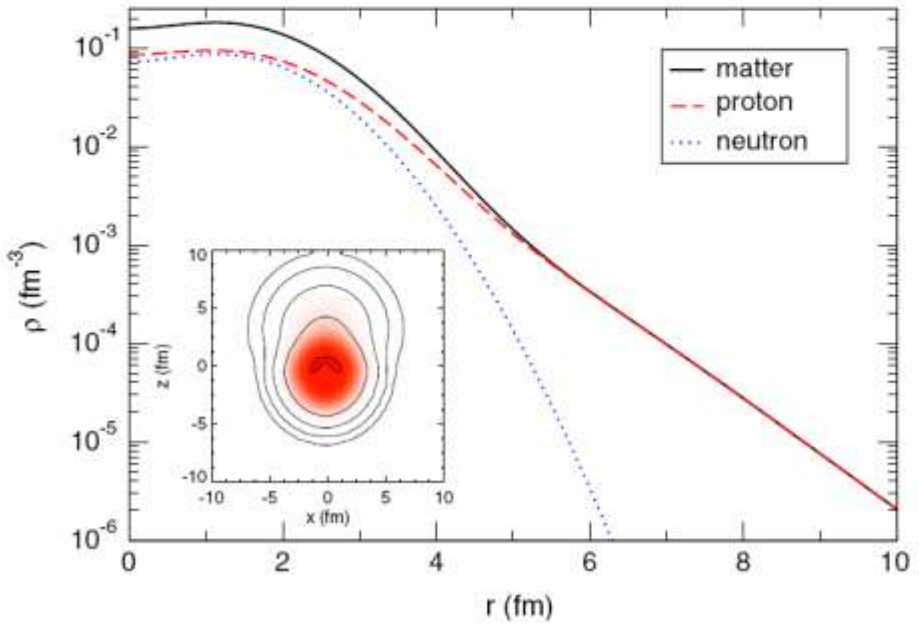
… vs. valence or surface structure.

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

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



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



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

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

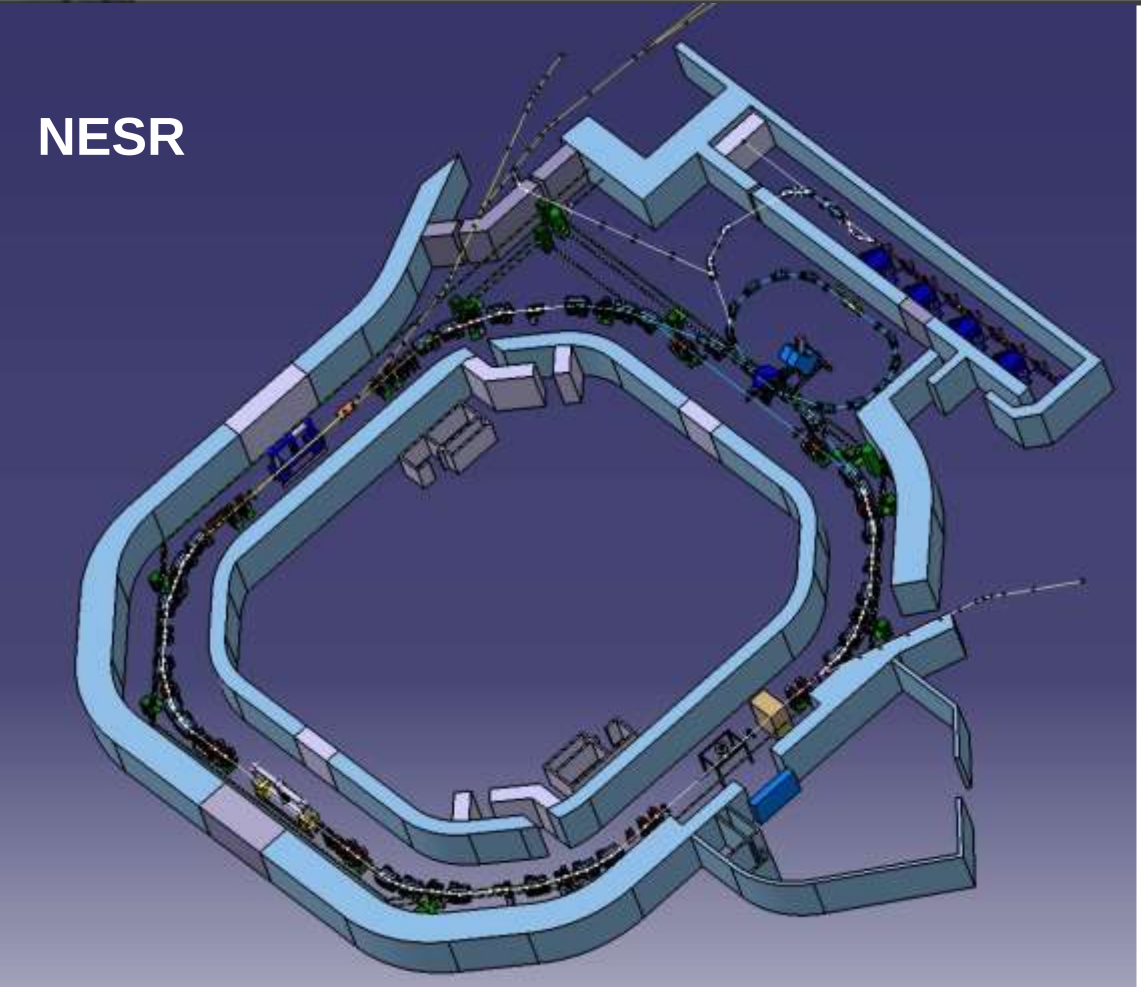
Novel Opportunities @ FAIR

Intensity increase 3-4 orders of magnitude !

Realization of an RIB electron collider setup

The **ELISe** experiment

Haik Simon • GSI / Darmstadt



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

➔ up to 1.6 GeV CM energy

- spectrometer setup at the interaction zone & detector system in ring arcs

- Part of the core facility

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

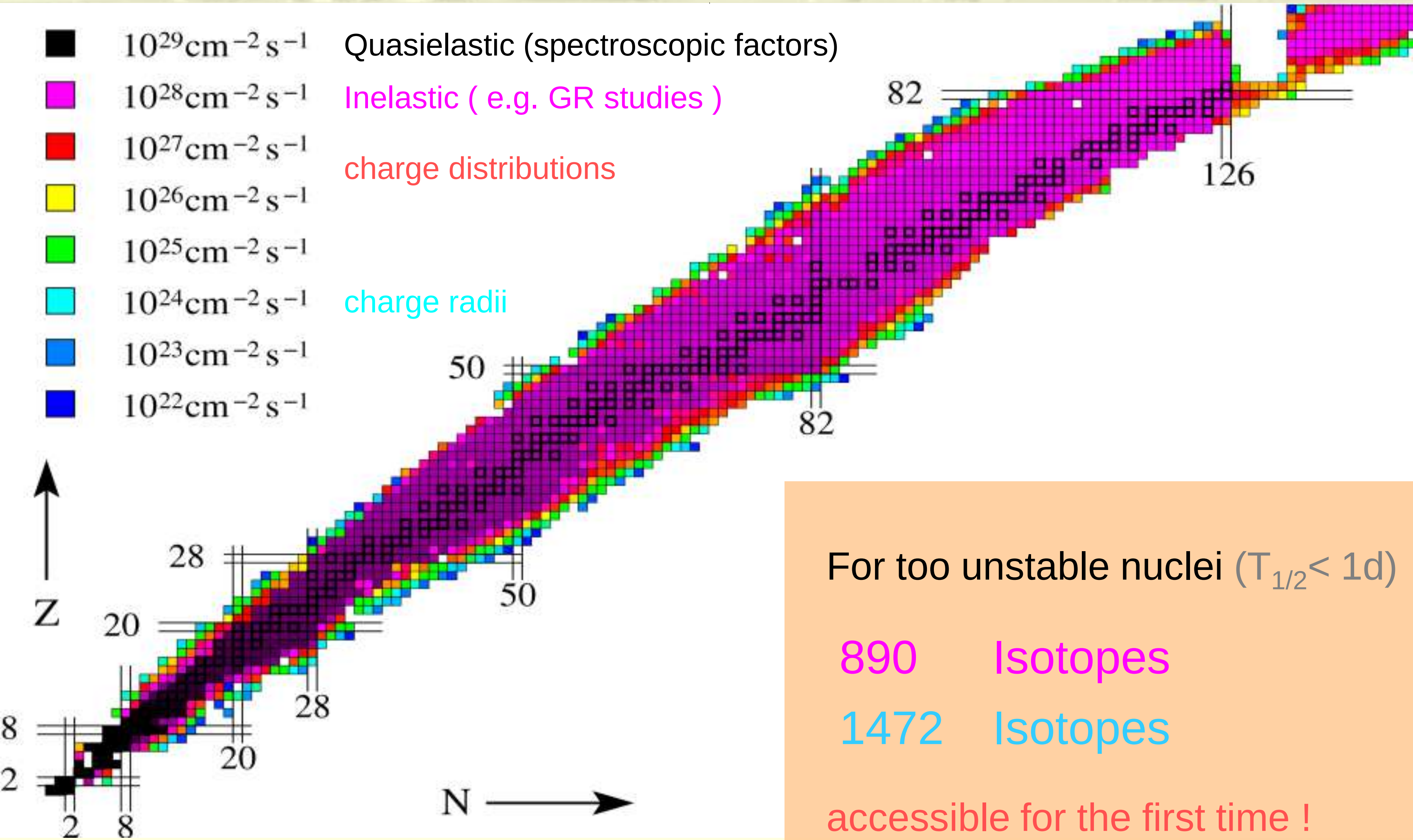
AIC option:

- 30 MeV antiprotons

- detector system in ring arcs
- schottky probes

Expected Luminosities (NESR)

➔ Full simulation of production, transport and storage



Quasielastic (spectroscopic factors)

Inelastic (e.g. GR studies)

charge distributions

charge radii

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}

Why should one try to collide beams ?

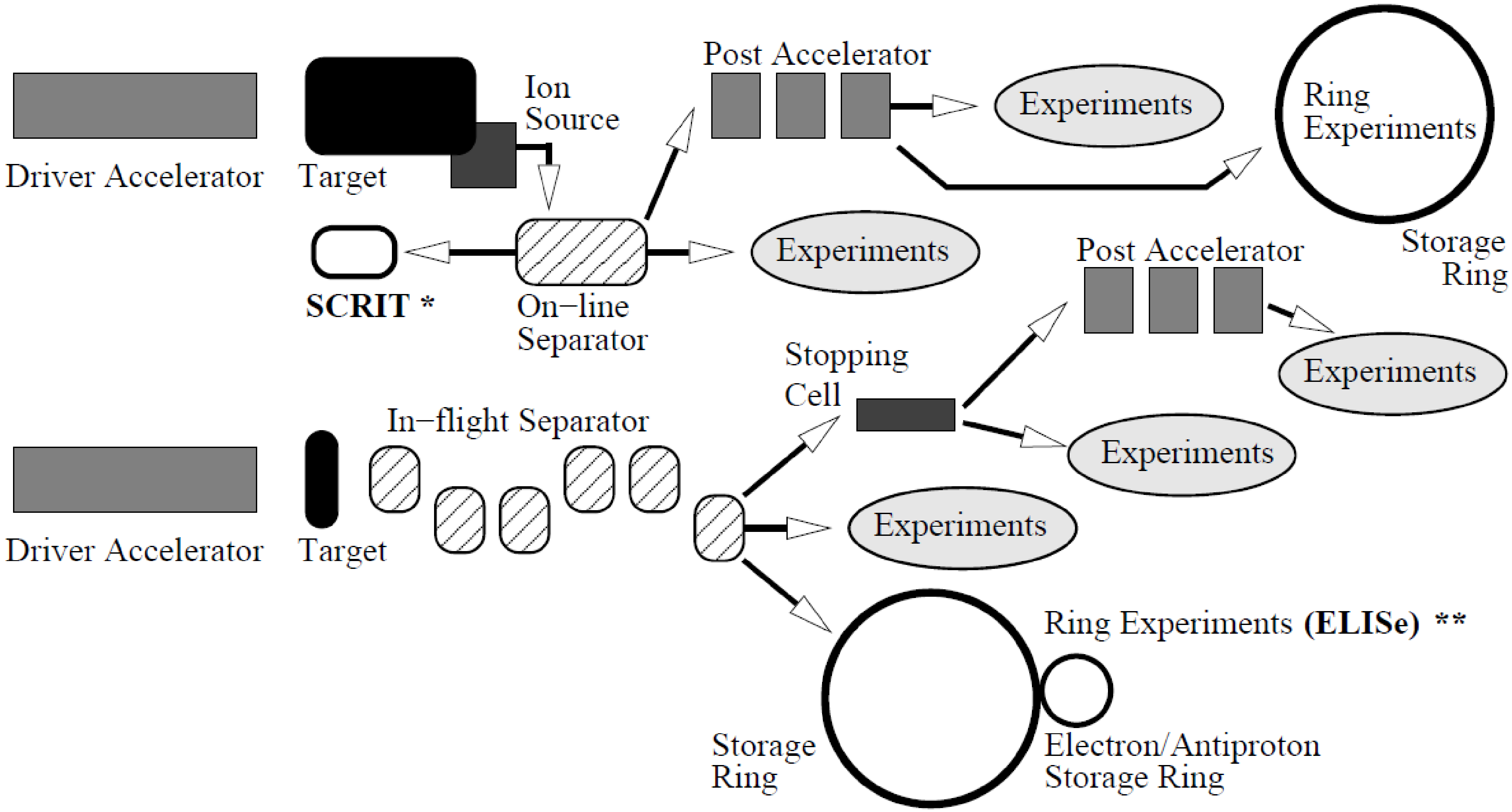
- trying to get through the eye of the needle

• 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

Main use cases SCRIT vs. eA collider

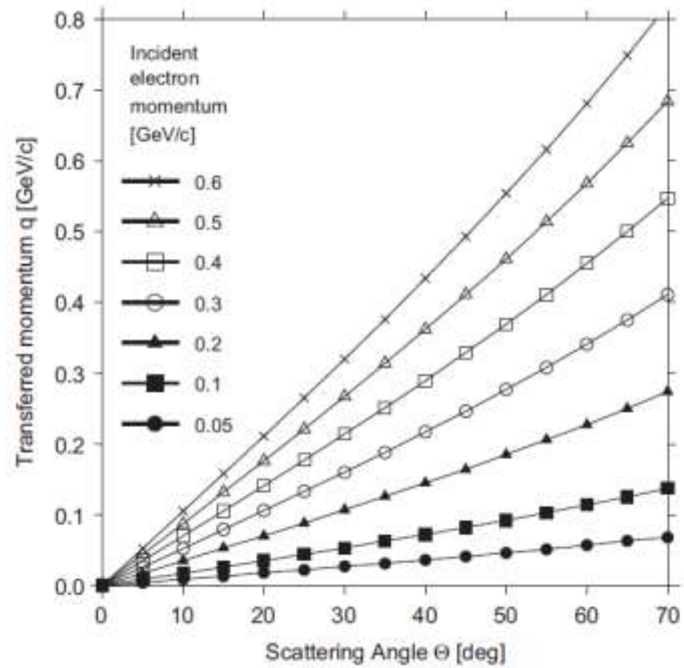


Kinematics

$\beta = p_A / E_A, \ \delta = \sqrt{(1-\beta)/(1+\beta)},$ = 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 ?

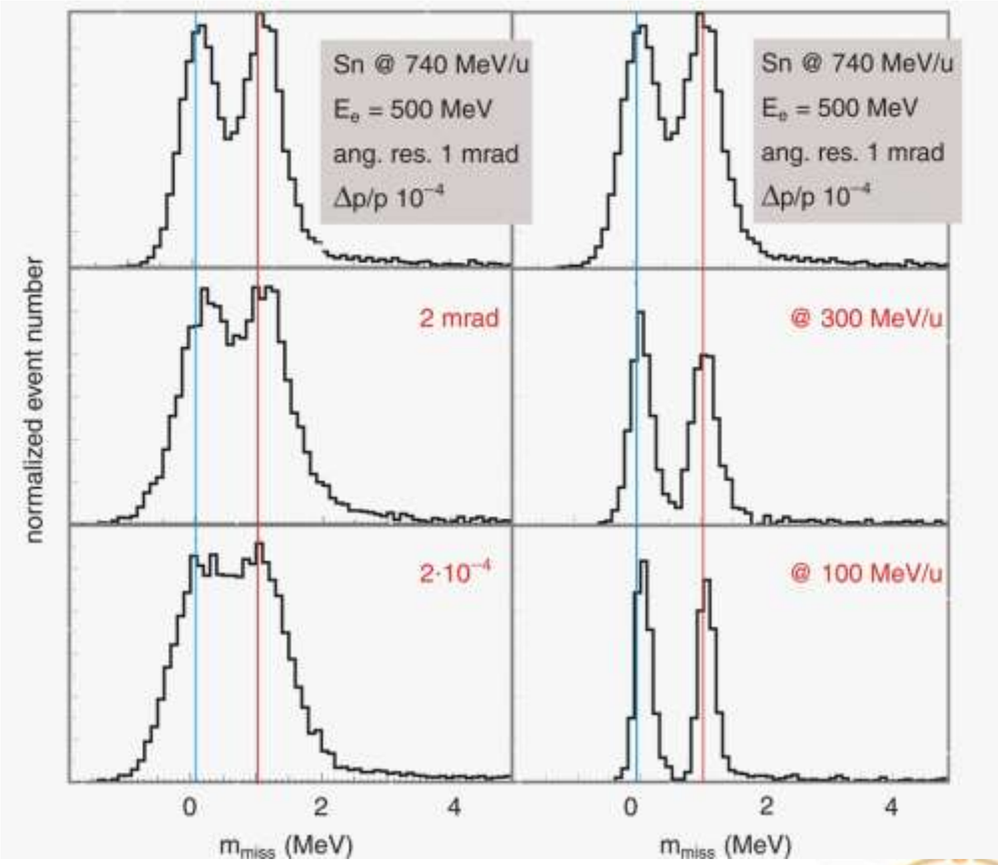
Monte Carlo Simulation: $\Delta E^* = 1$ MeV

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

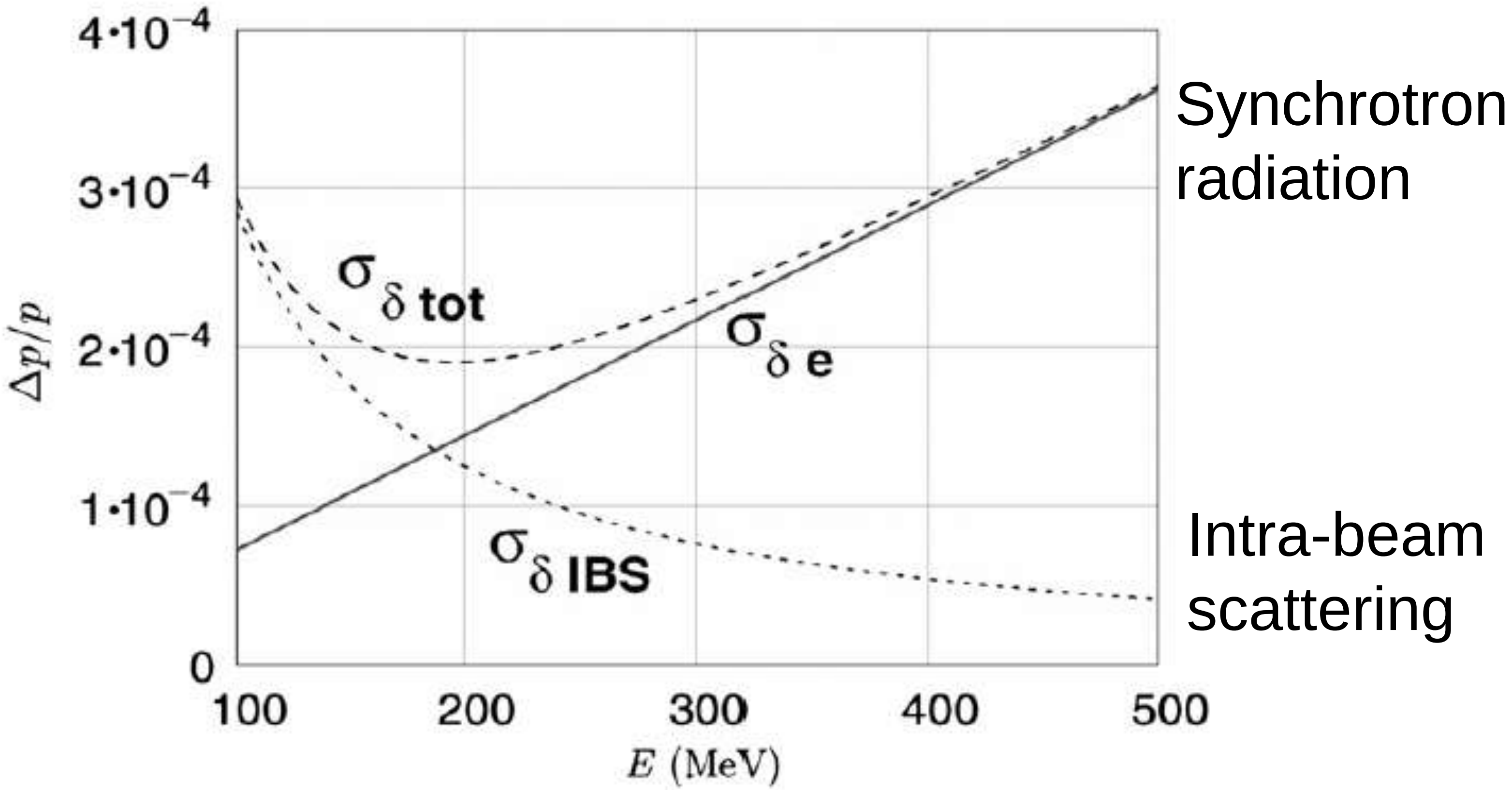
Pure kinematics calculus:

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

➔ reduced luminosity



Electron beam properties



➔ Trade resolution vs. rate

System design:
- preparation for TDRs

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

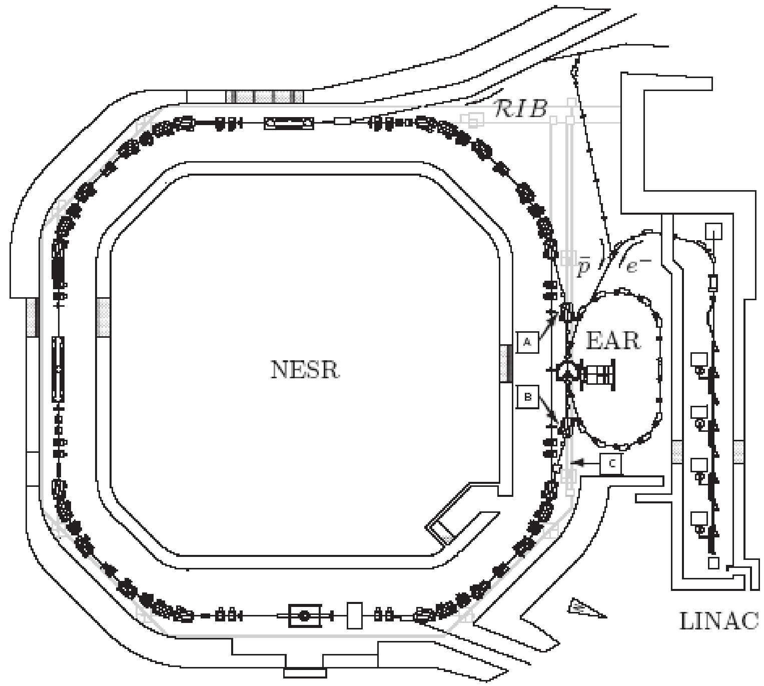
M. Aïche, G. Barreau, S. Czajkowski, B. Jurado

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

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

CEA Bruyères-le-Châtel - France

...



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

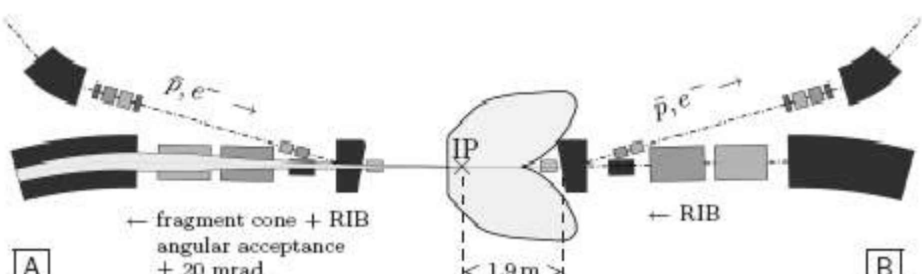


Figure 6: Interaction zone with the interaction point IP in the bypass section of the NESR.

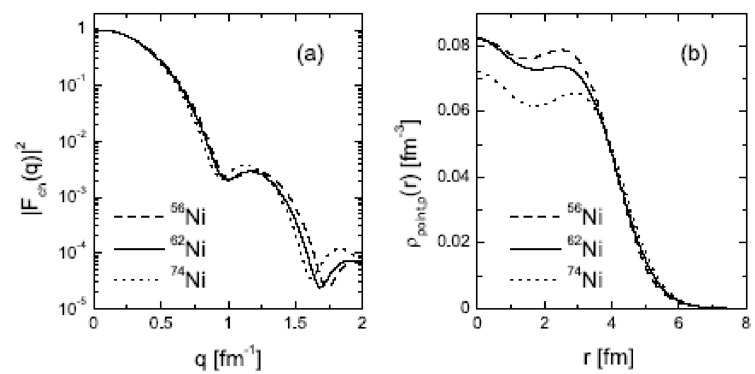
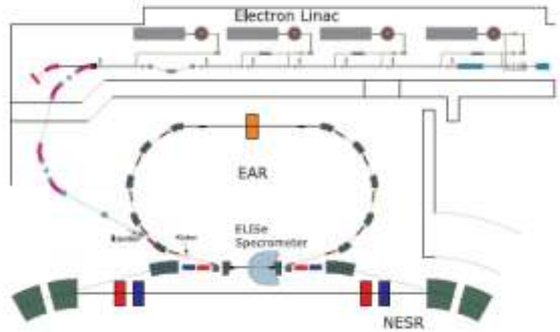


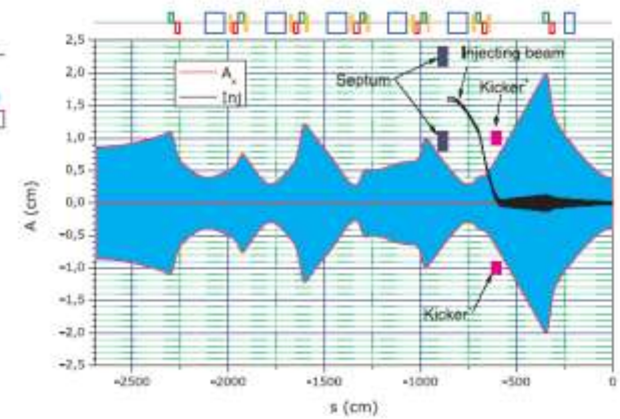
Figure 1: Charge form factors (panel (a)) calculated in DWBA and HF+BCS proton densities (panel (b)) for the unstable doubly-magic ^{56}Ni (dashed line), stable ^{62}Ni (full line) and unstable ^{74}Ni (dotted line) isotopes [7].

Associated LINAC and injection scheme

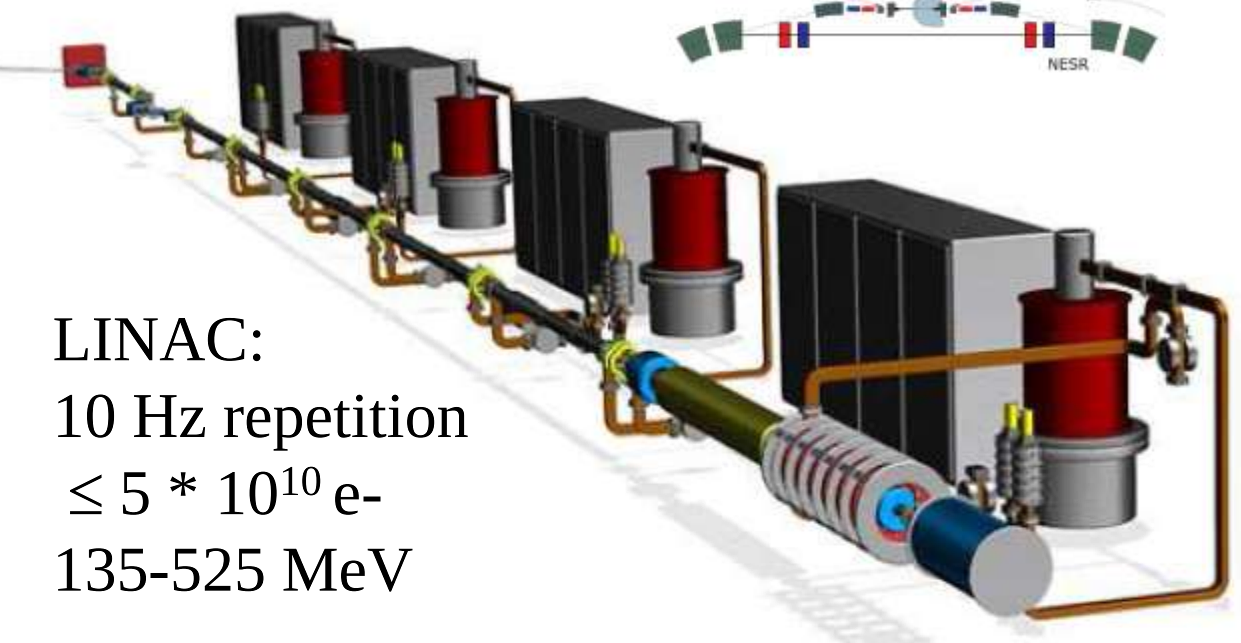
P. V. Logachev, D. Shwartz, P. Shatunov, I. Koop BINP/Novosibirsk

INTAS open call 2005 -2007/ FRRC 2009-

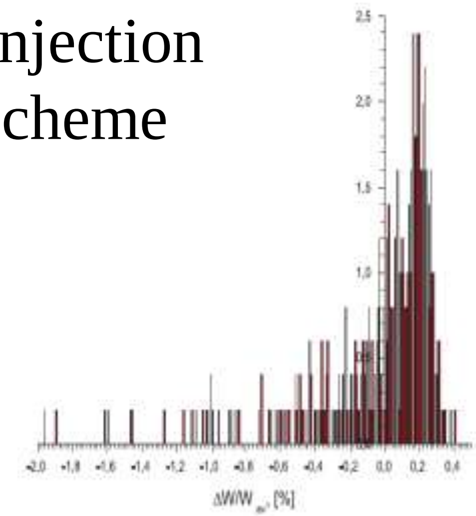




Injection scheme



LINAC:
10 Hz repetition
$\leq 5 * 10^{10}$ e-
135-525 MeV



Paper in preparation

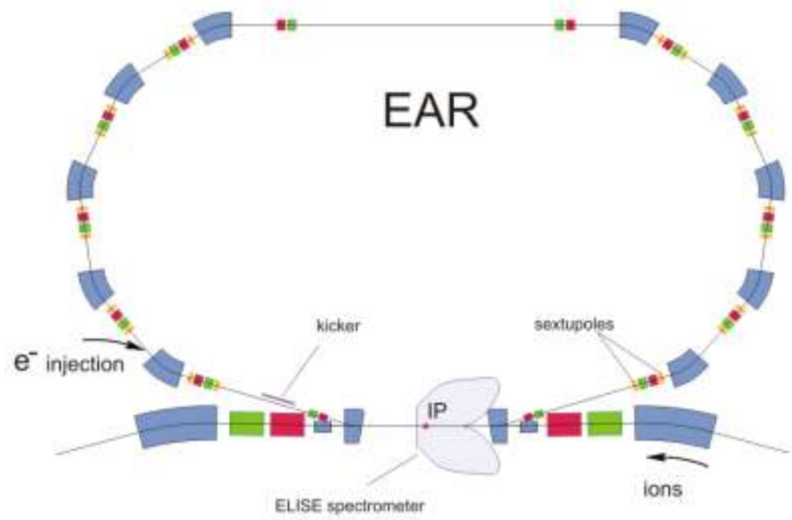
 & Interaction region design

Design of the associated interaction zone

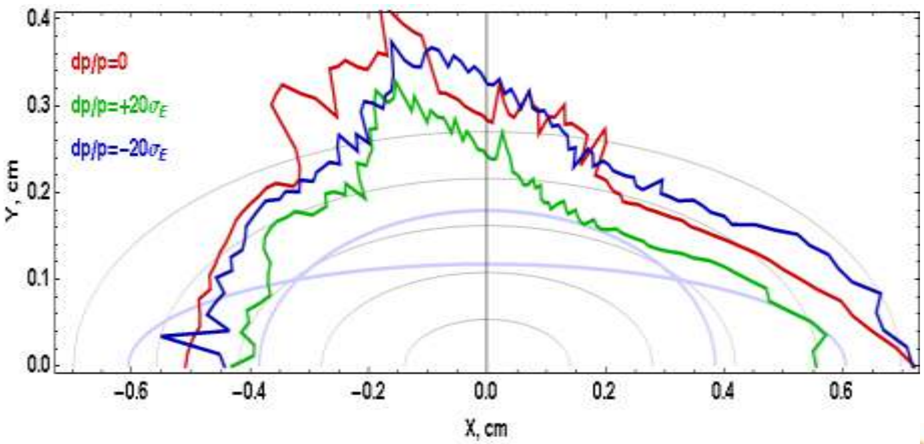
D. Shwartz, P. Shatunov, I. Koop BINP/Novosibirsk

INTAS open call 2005 -2007/ FRRC 2009-

- Overlap of the two beams 150µm × 60µm
- Emittances 50 µm·mrad

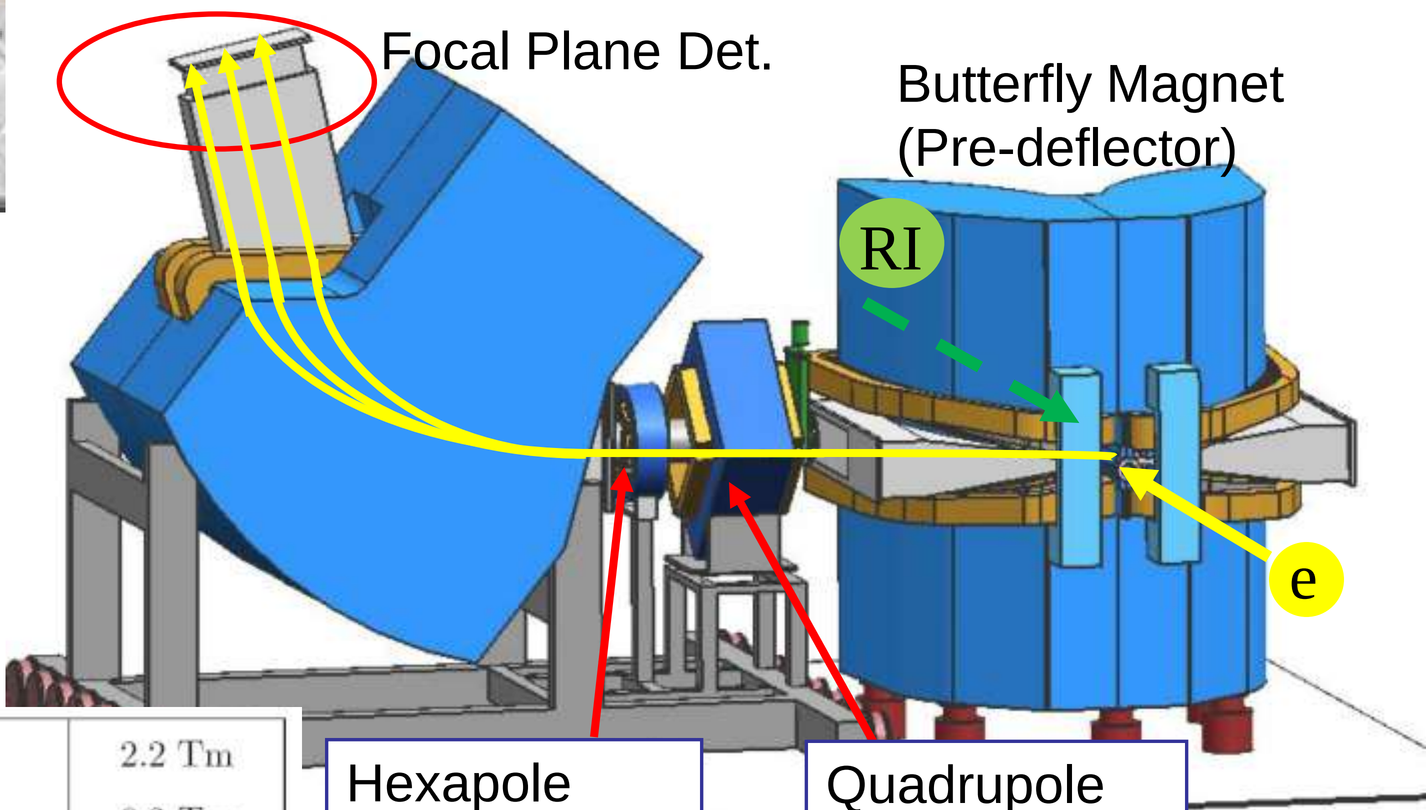


- +- 1.5% momentum acceptance and dynamic apperture
- Accepted cone
  +- 20 mrad for fission fragments …



… and a suitable magn. high resolution spectrometer

GPA Berg et al.



Maximum rigidity $B\rho$	2.2 Tm
Minimum rigidity $B\rho$	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

FAIR

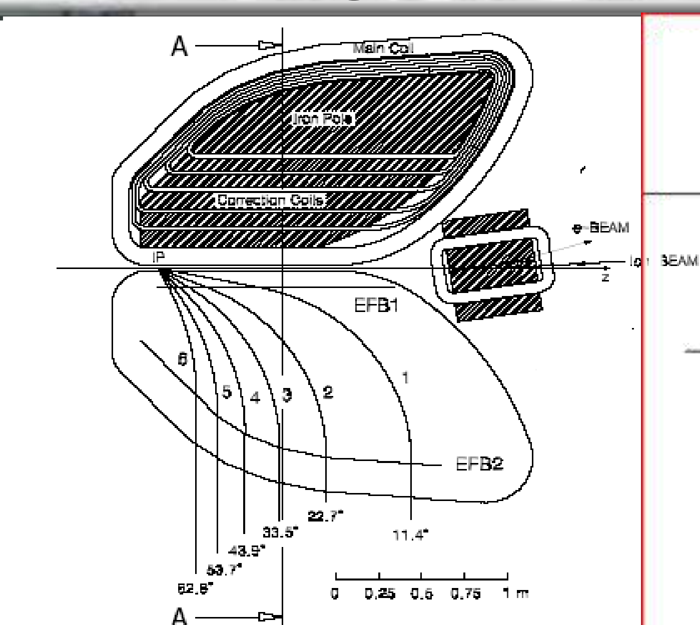
Resolution (clamp shell)

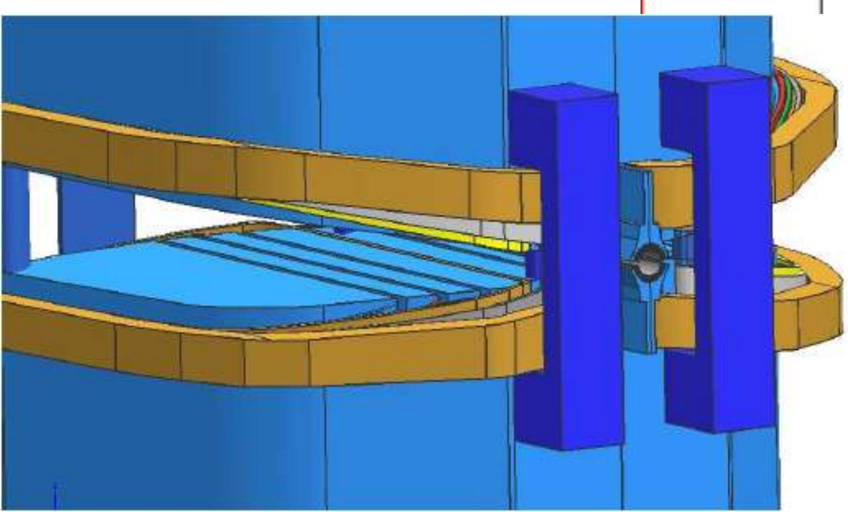
GPA Berg et al.

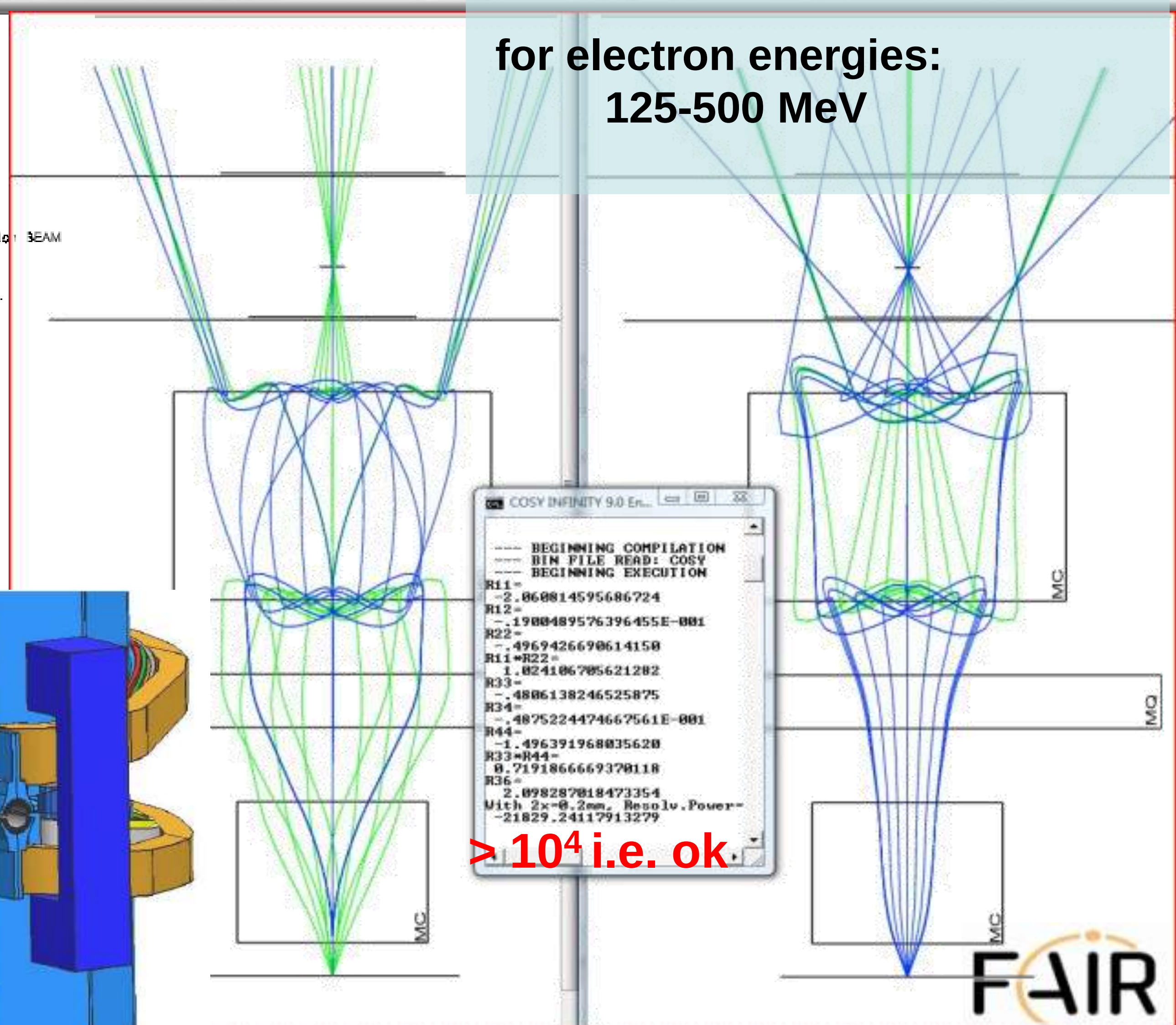
Θ_{Lab}: 10-60°

q: 20-600 MeV/c

for electron energies: 125-500 MeV





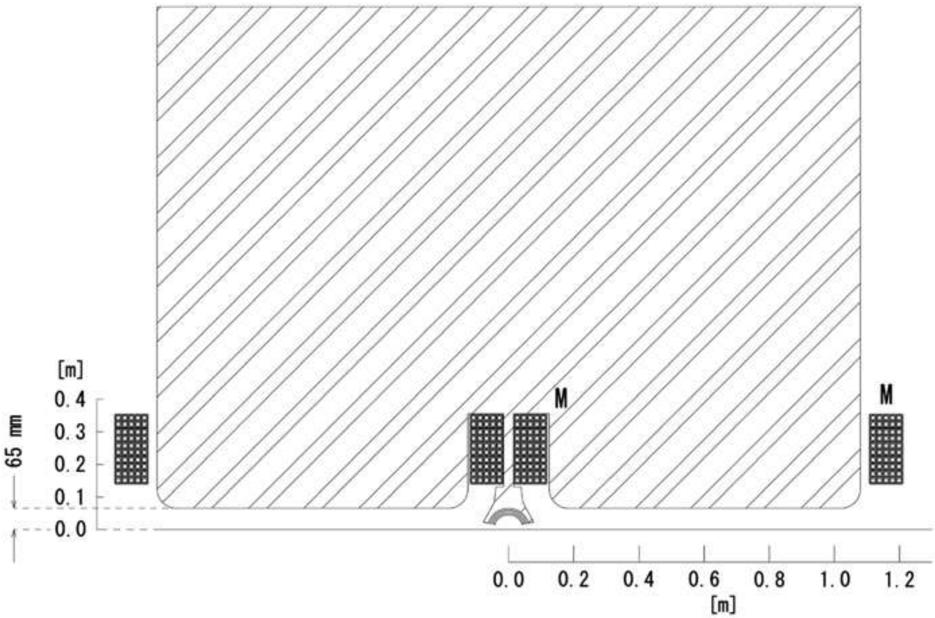


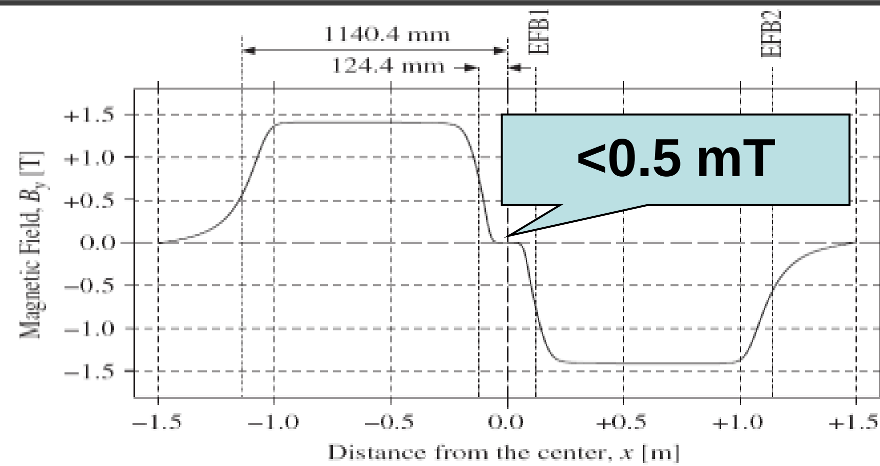
> 10^4 i.e. ok

FAIR

Further improvements …

T. Adachi, GPA Berg, et al.



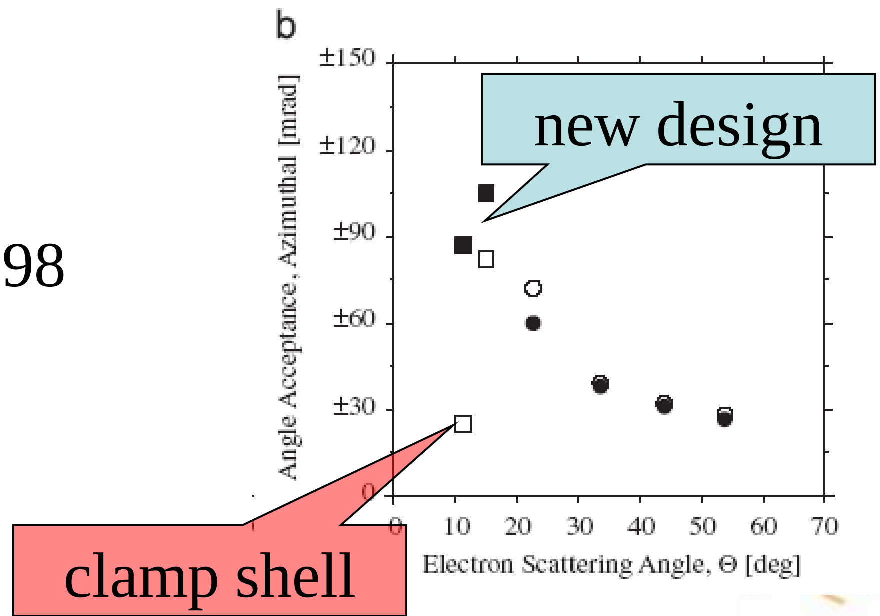


T. Adachi et al.,

Nucl. Inst. Meth. **A659** (2011) 198

doi:10.1016/j.nima.2011.06.081

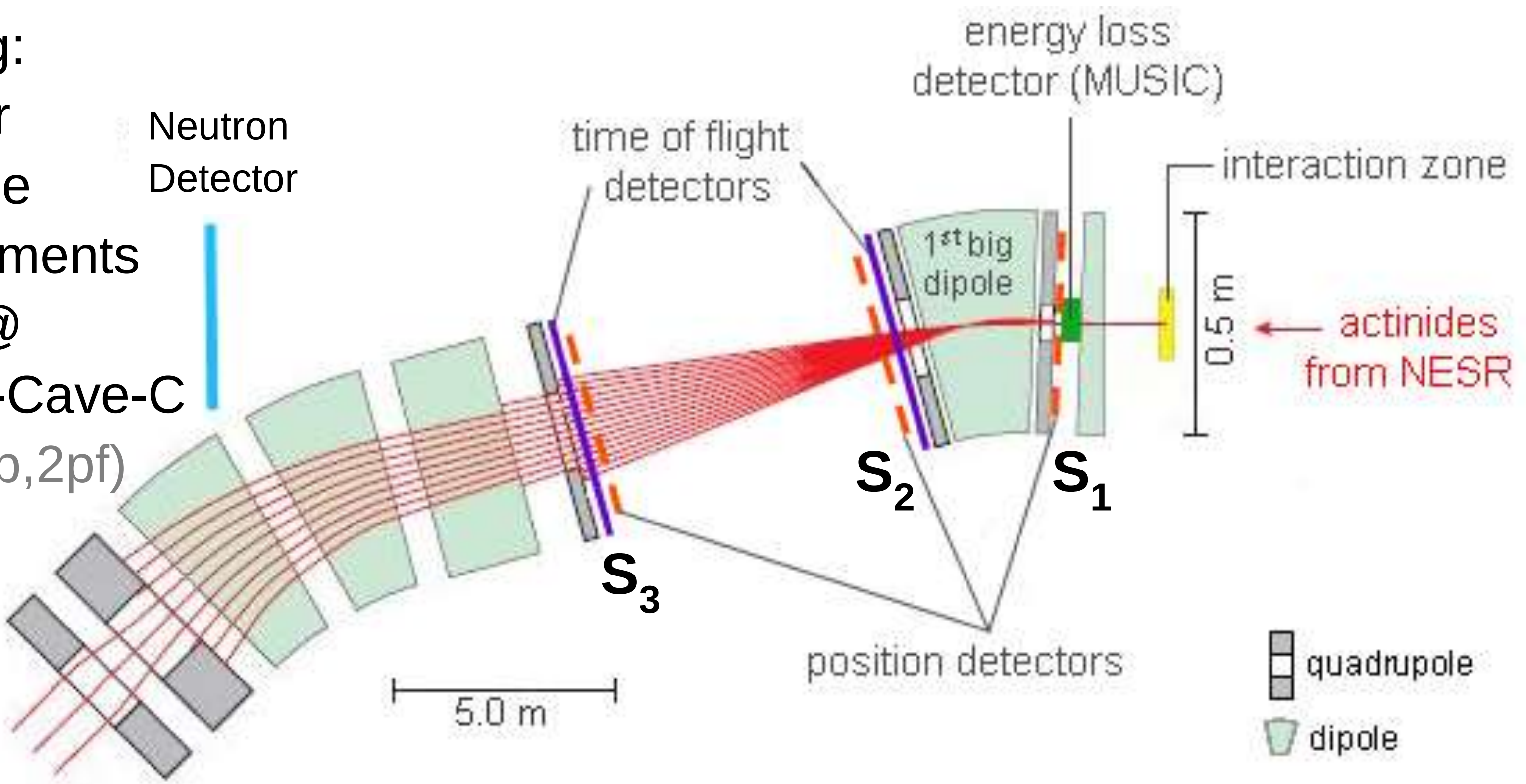
➔no correction coils needed



In-Ring spectrometer in the Bypass

CEA-DAM Bruyères-le-Châtel, JINR Dubna, GSI

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



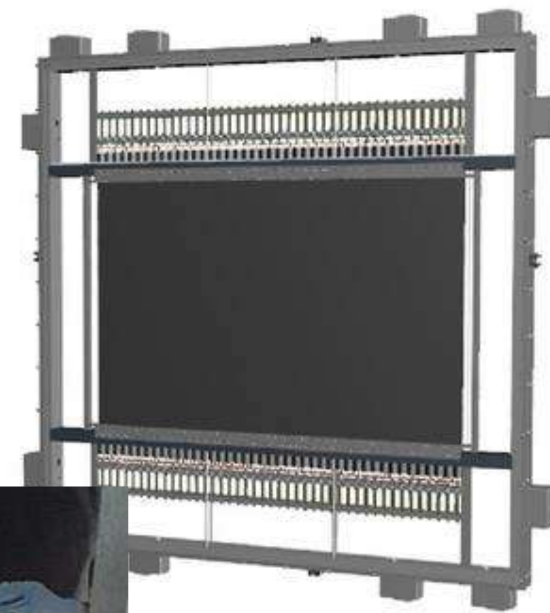
Most demanding physics case: Electrofission studies (FELISe)
-coincident identification of both fission fragments
-prefragment excitation energy directly accessible (e,e'f)

E.g.
R³B Time-of-flight detector prototyping

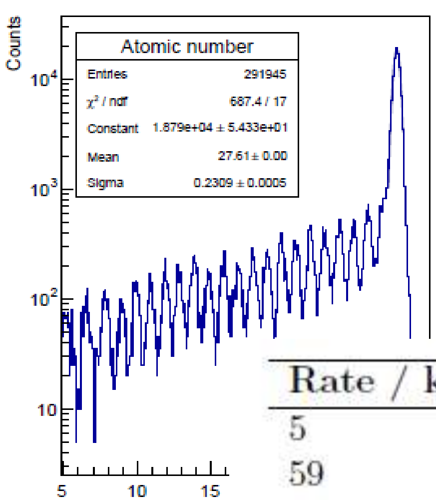
Performance goals:

- Time resolution σ_t/t = 2E-4
  (⇔ σ_t =20 ps for 20 m flight path at 1 *A*GeV)
- Energy resolution σ_E /E = 1%
- High-counting rate capabilities (~1 MHz)
- Large dynamic range (up to Pb-U).
- FPGA based TDC readout (ΔE via ToT Techniques)

Detector layout



375kHz



Rate / kHz	σ_t / ps	σ_t^{det} / ps
5	41	14
59	41	14
375	45	16
1000	64	23

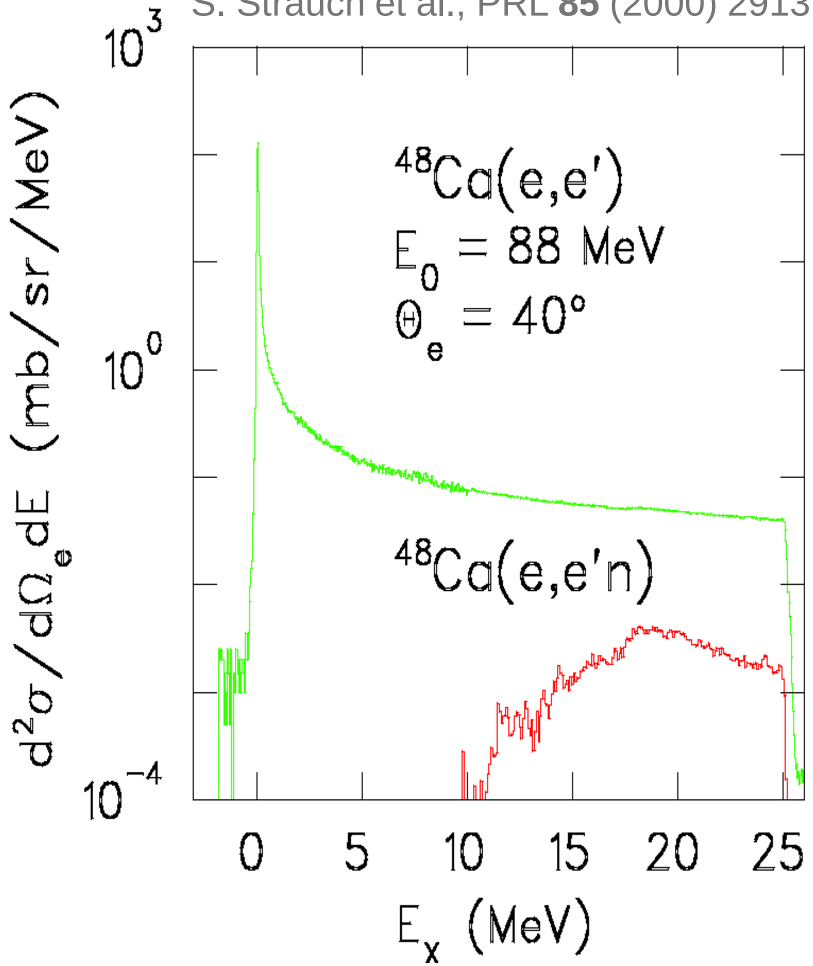
Excellent time and energy resolution at high rates

Prototype studies @ Cave-C 08/2014 10/2014

Inelastic Scattering @ forward angles

→compared to conventional (fixed target) experiments

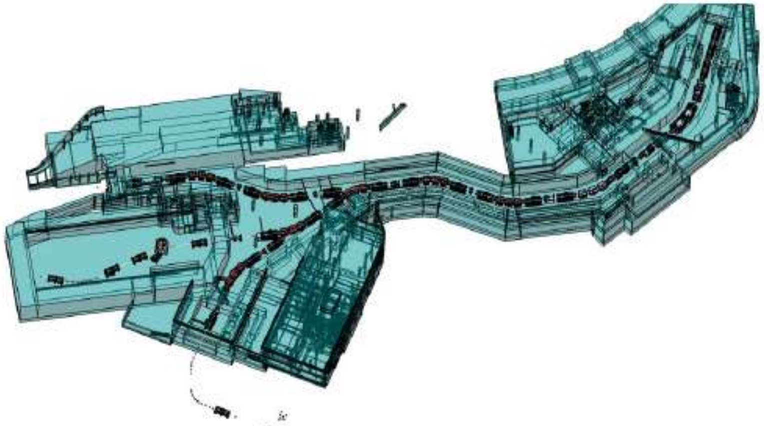
S. Strauch et al., PRL **85** (2000) 2913

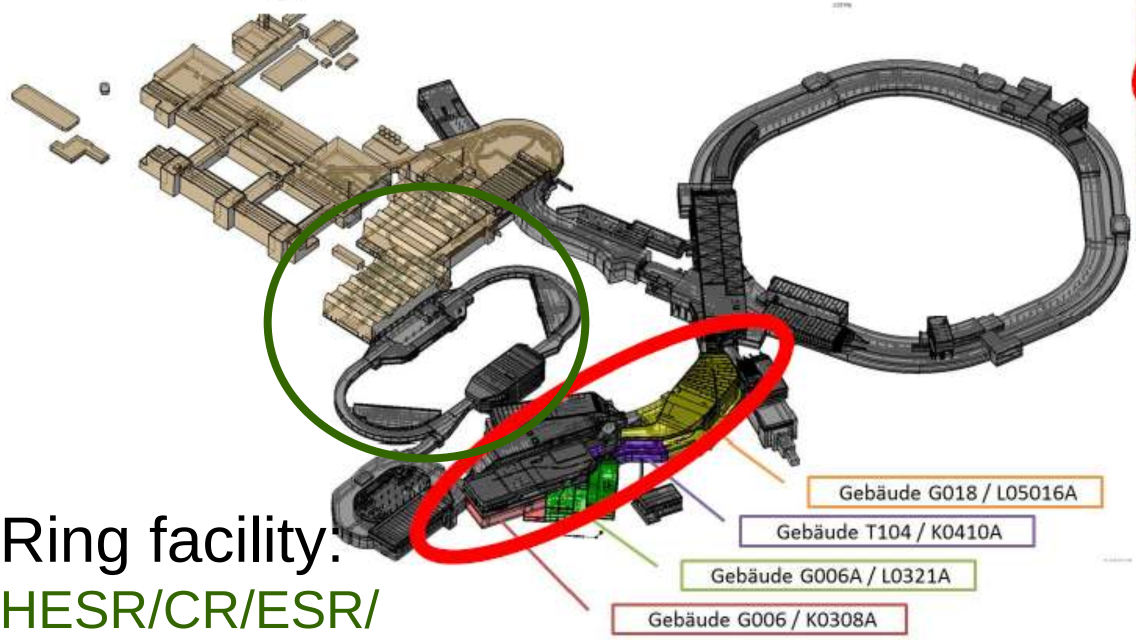


Fixed target		Collider 1.5GeV
^{48}Ca(e,e‘n)		^{48}Ca(e,e‘A‘)
Ω_n =100msr	**100**	Ω_n ~ 4π
n_{eff} =20 %	**5**	n_{eff} ~ 100 %
$\Theta_{e'}$ = 40 °	**50**	**$\Theta_{e'}$ = 5 °**
	>10^4	
L=10^{31} - 10^{32}	cm^{-2} s^{-1}	**L ~ 10^{27}**

➔ Large gain through kinematics

Current status with respect to the MSV - NESR is delayed





Ring facility:
HESR/CR/ESR/
Cryring complex

NESR is postponed ...

still …

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s.richter@gsi.de

February 26, 2010

Dear Dr. Simon,

We hereby reconfirm your designation as Machine Coordinator for the following FAIR-Accelerator/Accelerator-related Experiment-Infrastructure:

ER

In spite of the fact that the accelerator/accelerator-related experiment-infrastructure ER is not part of the FAIR Modularized Start Version, the FAIR Management would like to keep all machine coordinators in charge.

We want to keep you fully informed about the next planning steps, so when any of the modules 4 – 6 can be realized, the planning can continue.

Kind regards,

Prof. Boris Sharkov — Dr. Simone Richter — Dr. Dieter Krämer

Prof. Zbigniew Majka

cc: Dr. Thomas Aumann, Prof. Dr. Karlheinz Langanke

HELMHOLTZ GEMEINSCHAFT

Possible realization of the ELISe experiment at the ESR

Paper in preparation

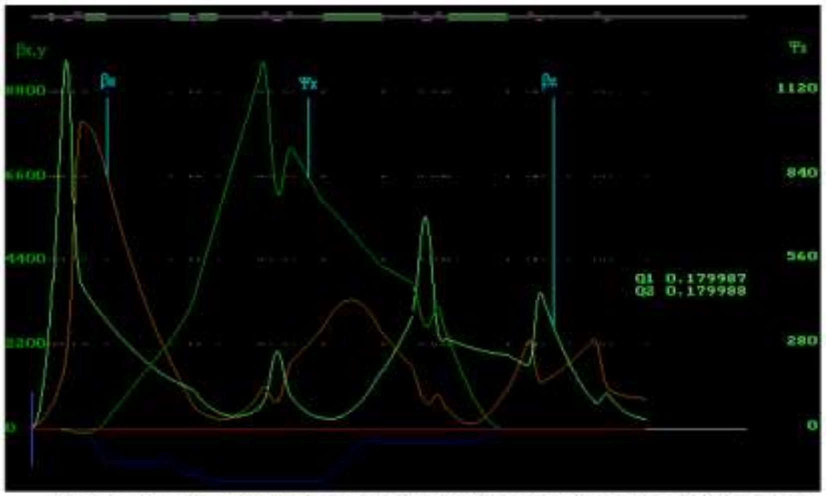
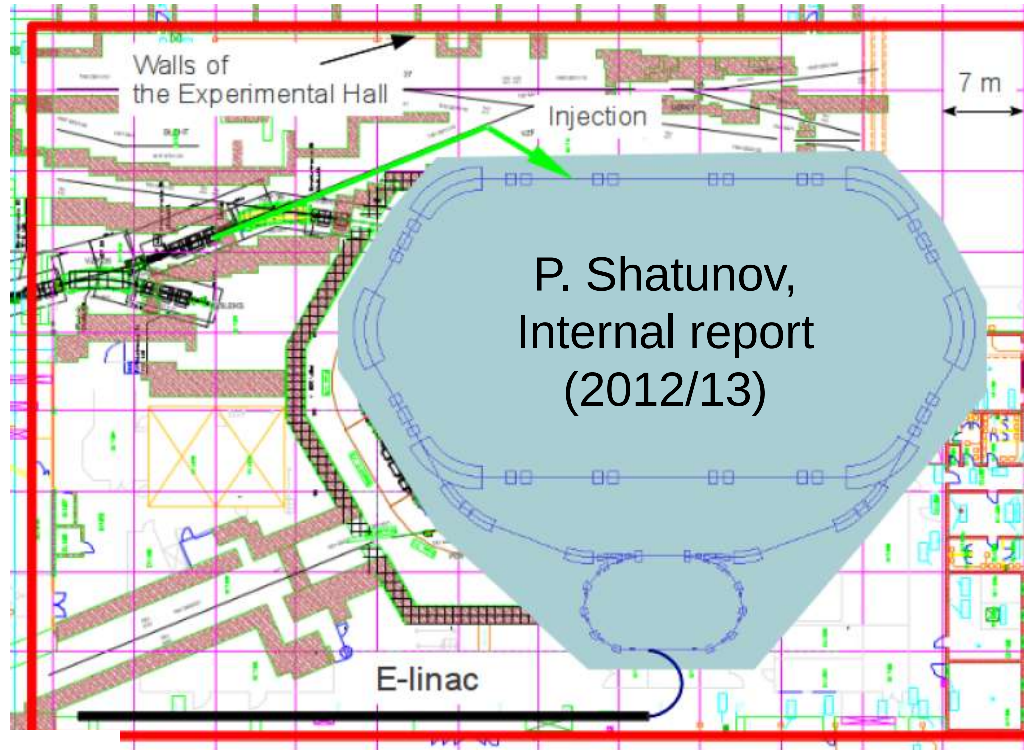
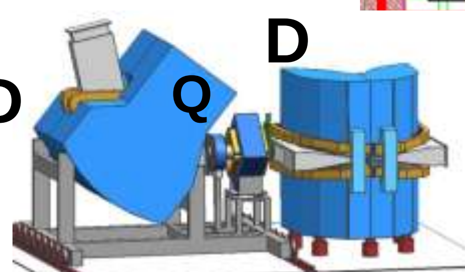


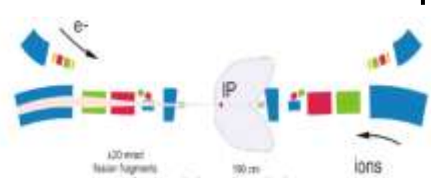
Figure 9. Beta (β, cm) and dispersion (Ψ, cm) functions of stretched ESR (1 half) in the collider mode.



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



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



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

Other ideas …

ELSEVIER Nuclear Instruments and Methods in Physics Research A 516 (2004) 228–236
Section A
www.elsevier.com/locate/nima

e.g. New SUBARU/Spring-8

High-energy photon beam production with laser-Compton backscattering

K. Aoki[a], K. Hosono[a,*], T. Hadame[a], H. Munenaga[a], K. Kinoshita[a], M. Toda[a], S. Amano[b], S. Miyamoto[b], T. Mochizuki[b], M. Aoki[c], D. Li[c]

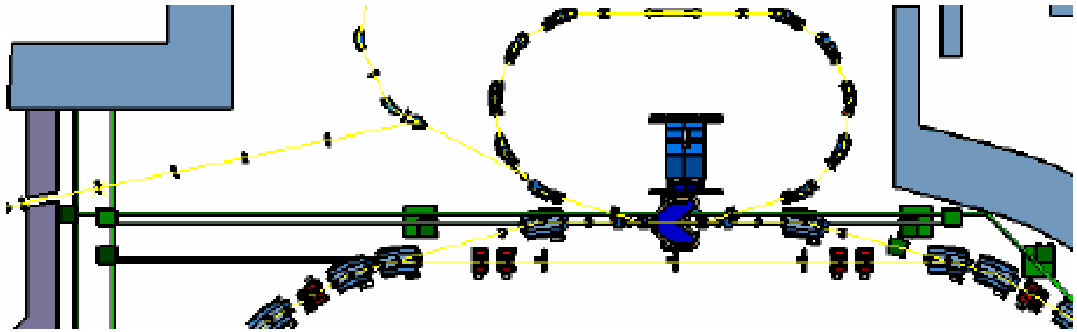
[a] Graduate School of Engineering, Himeji Institute of Technology, 2167 Shosha Himeji, Himeji, Hyogo 671-2201, Japan
[b] LASTI, Himeji Institute of Technology, Kamigori-Kouto, Hyogo 678-1205, Japan
[c] Institute for Laser Technology, Honmachi, Osaka 550-0004, Japan

Received 25 June 2003; received in revised form 12 August 2003; accepted 26 August 2003

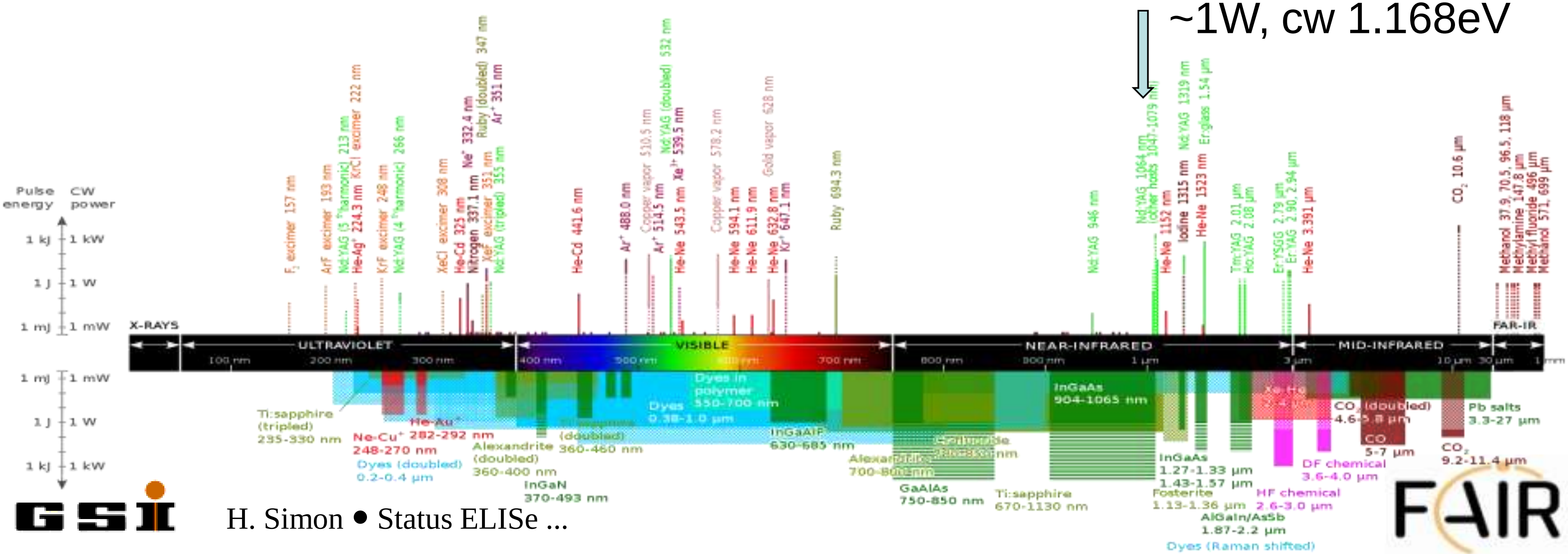
- Laser systems

➔ Compton backscattering

$E_{max} = 4\,\gamma^2\,E_{LASER}$

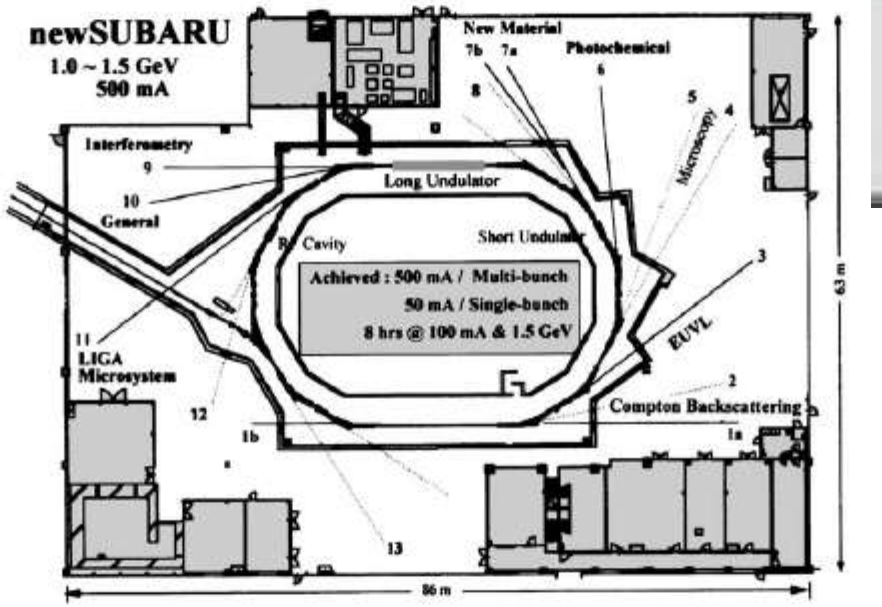


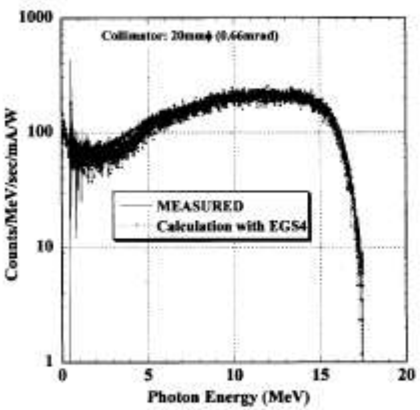
~1W, cw 1.168eV

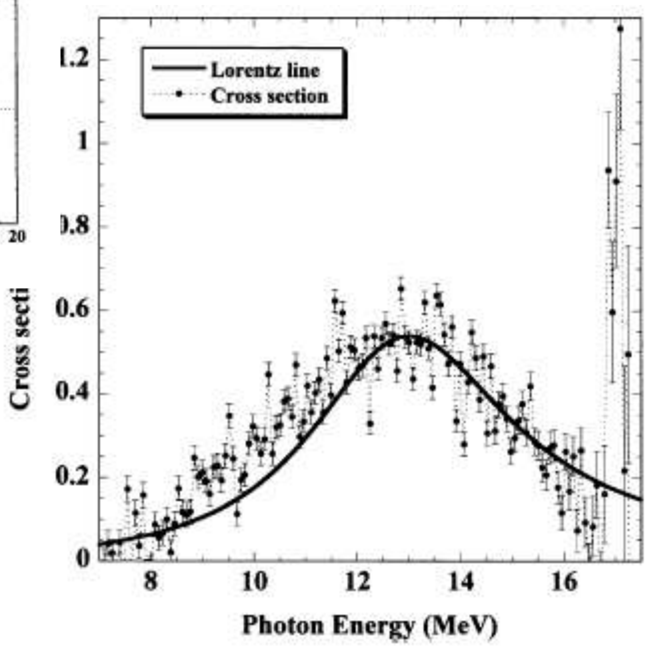


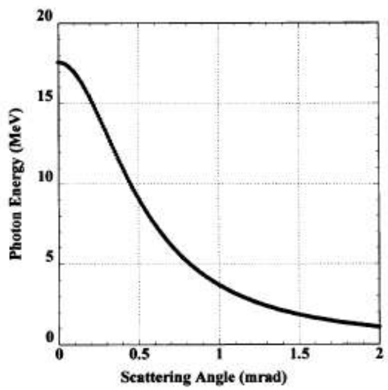
Direct comparison
➔ looks promising

- beam current (425 mA @ 500MeV)
- laser intensity (~1 W cw / 1-6 eV)
- overlap/angular spread straight sec. **?**
- shown: 10mA/1GeV on 0.5 W/1.168eV Nd:YVO_4









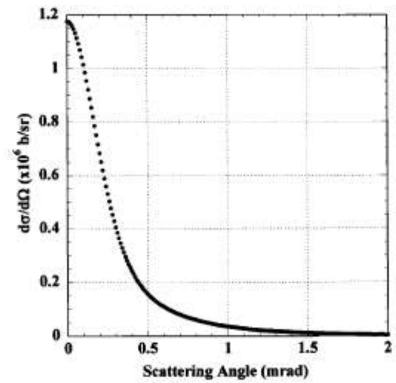


Photo-nuclear reaction
E1 (GDR) ^{197}Au

H. Sim

Summary

- Electron(Antiproton)-RIB Collider is feasible - collider mode provides optimal use for RIBs.
- Design of a Challenging spectrometer and demanding interaction zone is possible
- 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 RIB facilities)

➔ Not only for nuclear physics studies ?

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

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