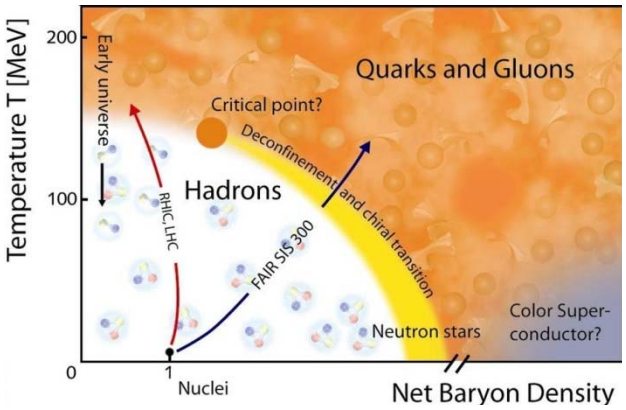


Symmetry energy at high energies Perspectives at GSI/FAIR

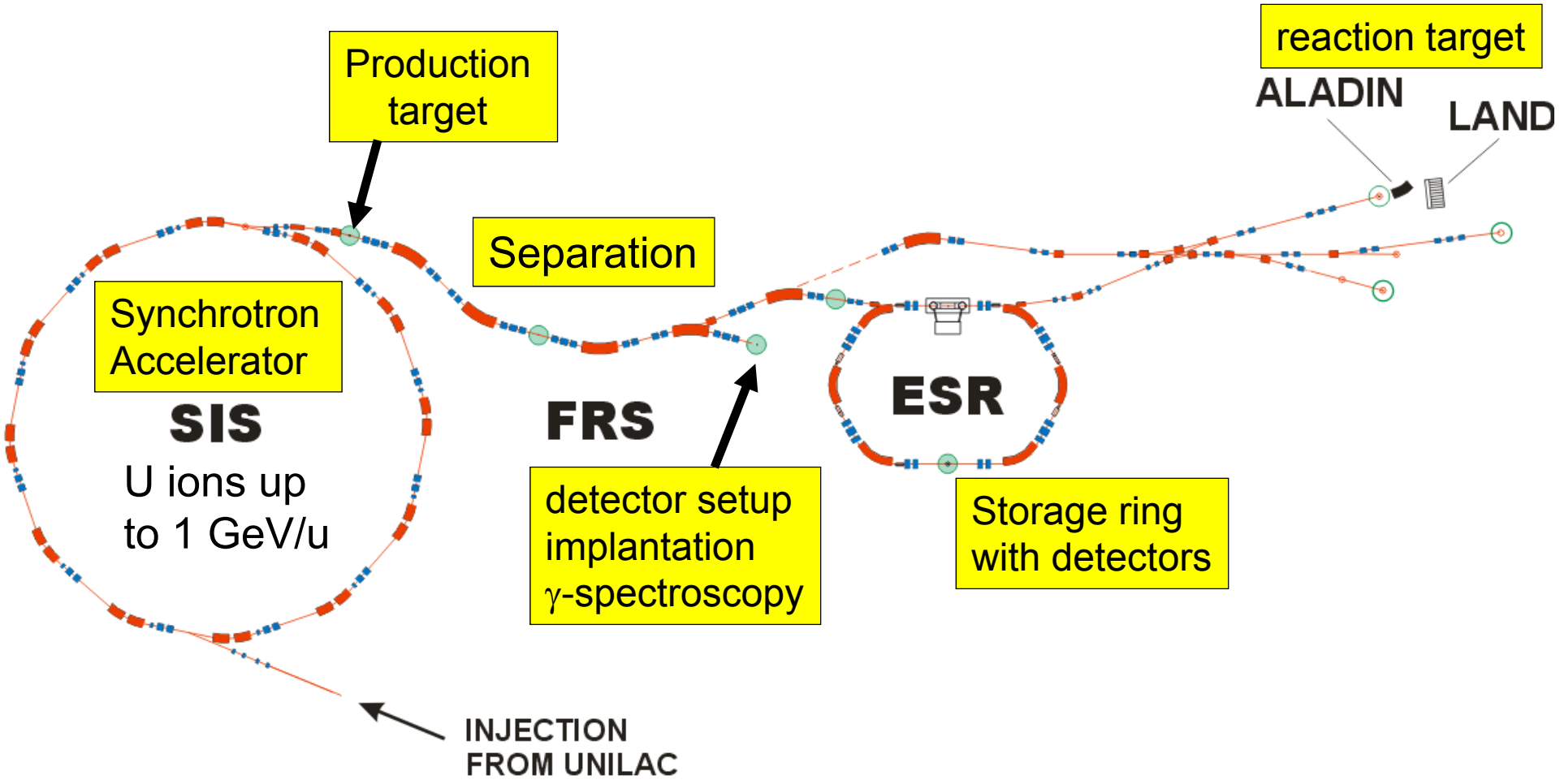
Y. Leifels

FOPI/ASYEOS collaborations

GSI Helmholtzzentrum für Schwerionenforschung GmbH Darmstadt

NUSYM 2014
Liverpool
7.-9. July, 2014

High energy facilities at GSI@SIS18




The Facility for Antiproton and Ion Research

The Facility for Antiproton and Ion Research

Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- 10^{10}/s $^{238}U^{73+}$ up to 35 GeV/u
- 3x10^{13}/s 30 GeV protons

Secondary Beams

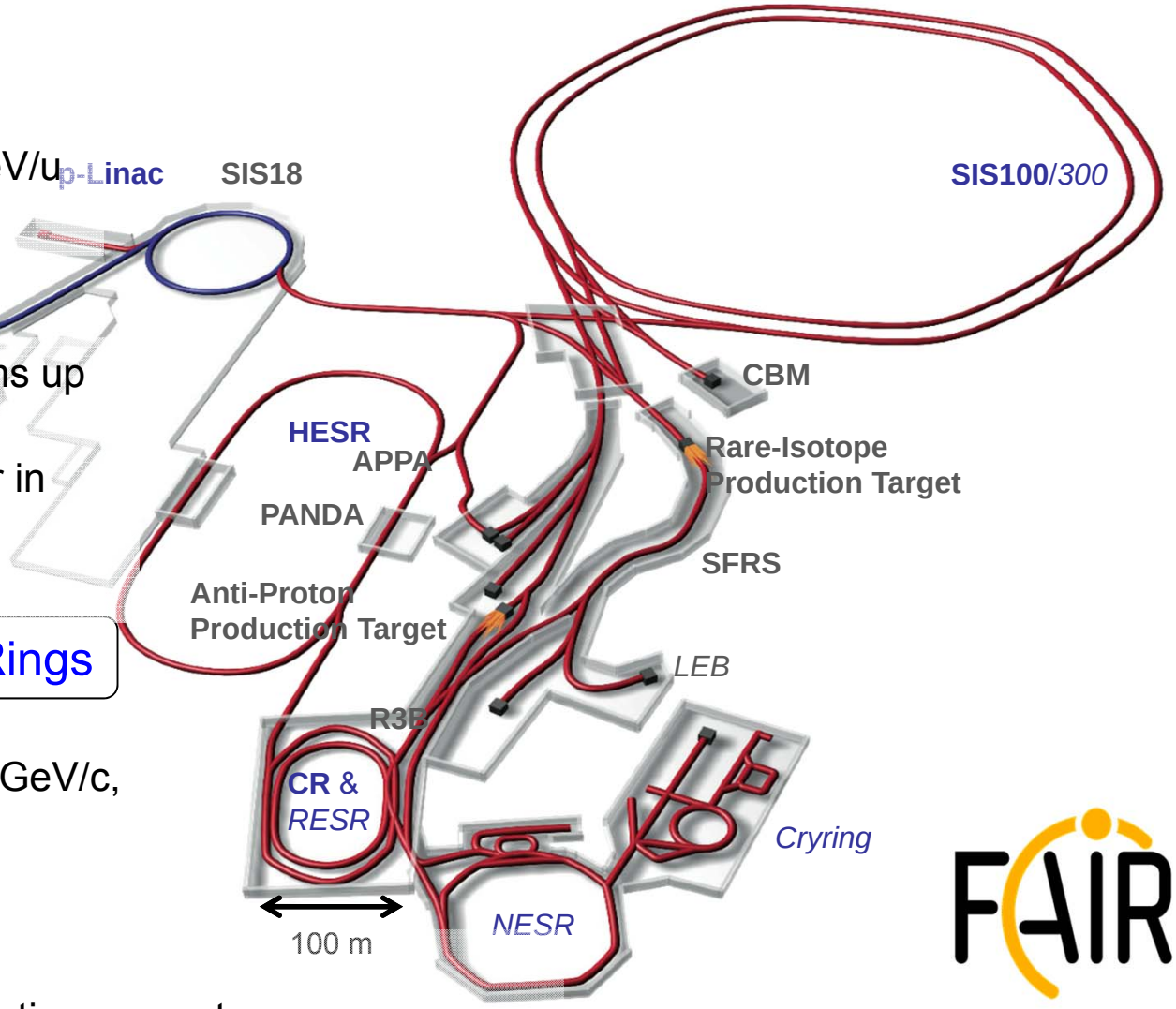
- range of radioactive beams up to 1.5 - 2 GeV/u; up to factor 10 000 higher in intensity than presently
- antiprotons 3 - 30 GeV

Storage and Cooler Rings

- radioactive beams
- 10^{11} antiprotons 1.5 - 15 GeV/c, stored and cooled

Technical Challenges

- cooled beams,
- rapid cycling superconducting magnets,
- narrow bunching

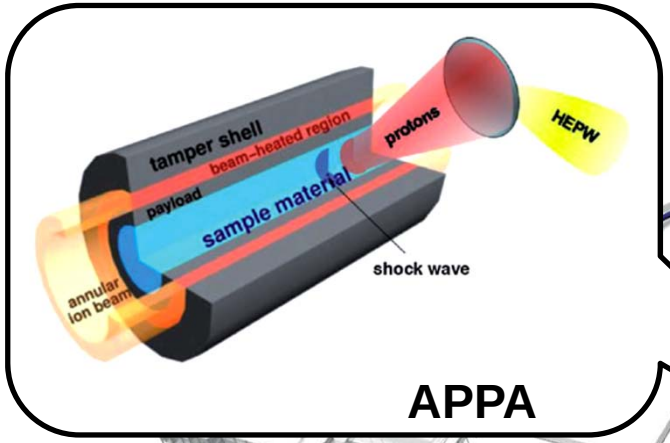


FAIR Civil construction

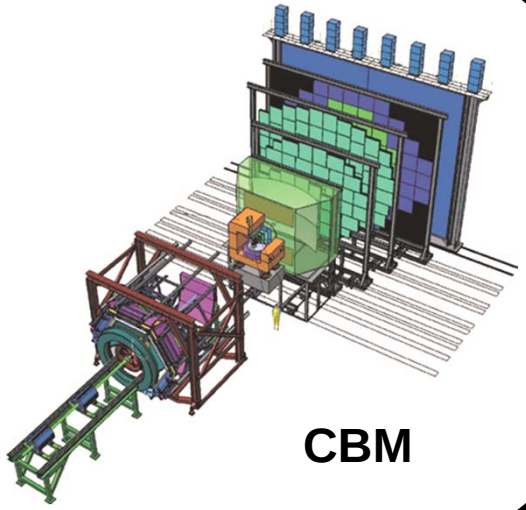
FAIR civil construction

- ground stabilization going to be finished (summer 2014)
- all permits (construction, safety, radiation protection) obtained
- start of tendering October 2014
- start of construction Q2 2015 -> 2019

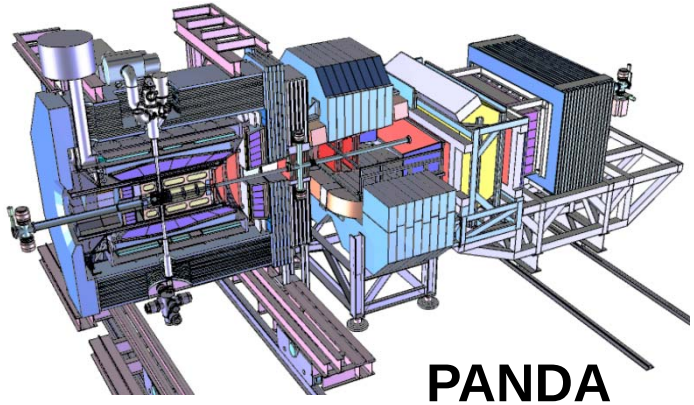
FAIR Experiments



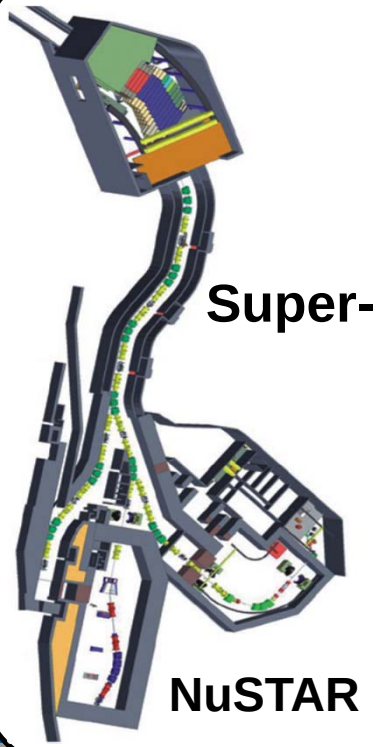
APPA



CBM



PANDA

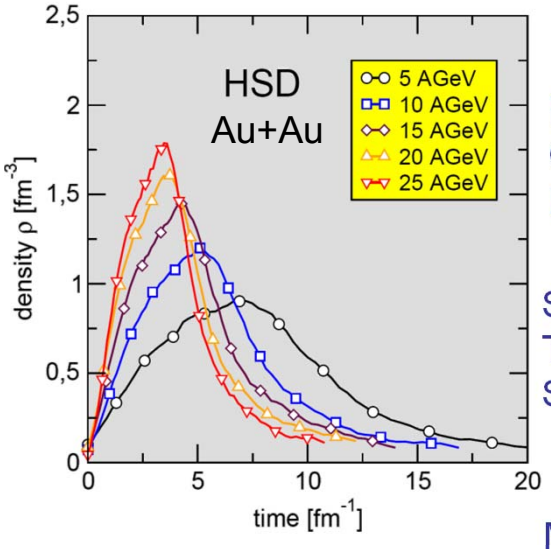


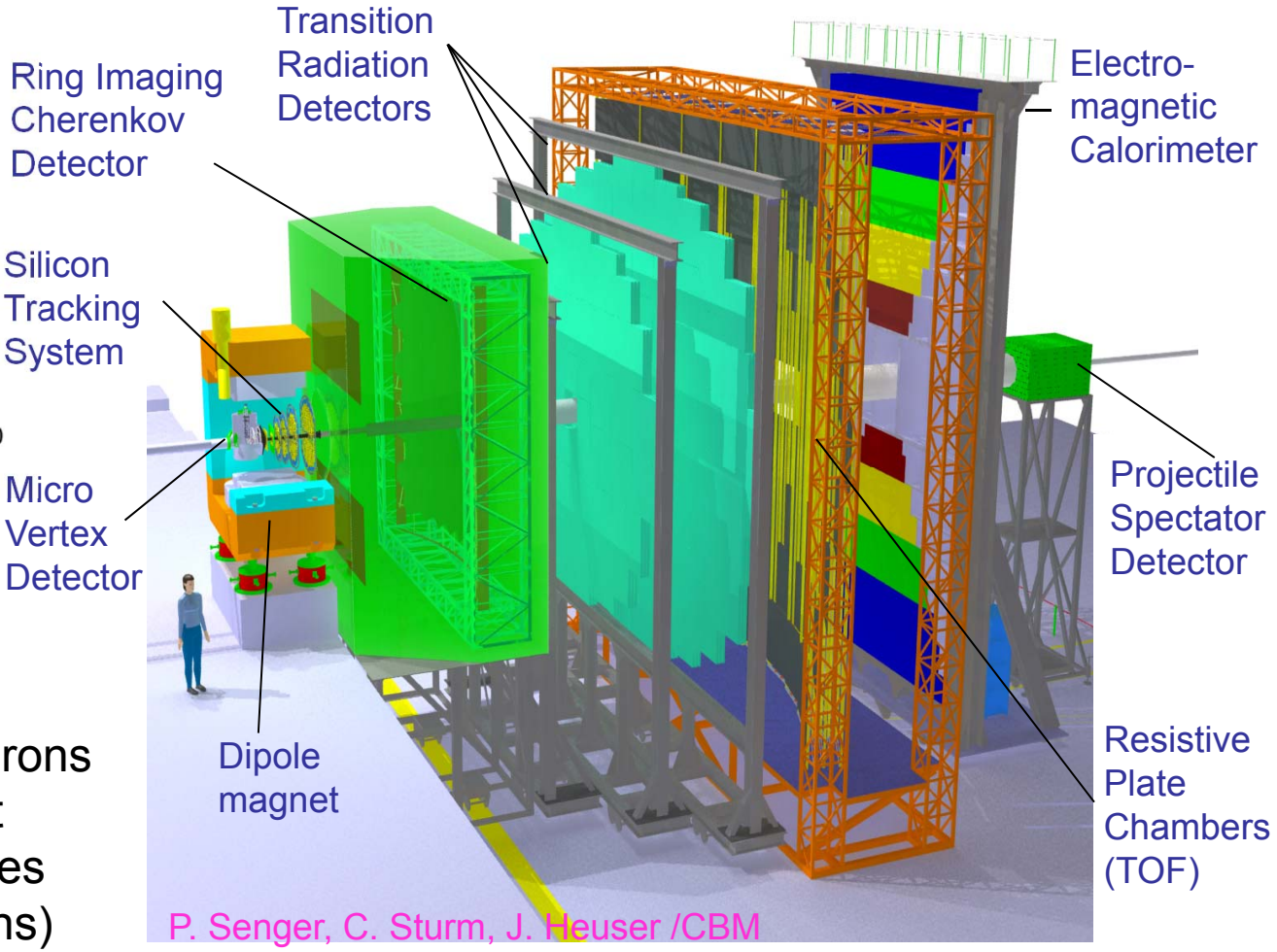
Super-FRS

NuSTAR

CBM – HICs with stable beams @ SIS100

Determination of the nuclear matter phase diagram at highest baryon densities



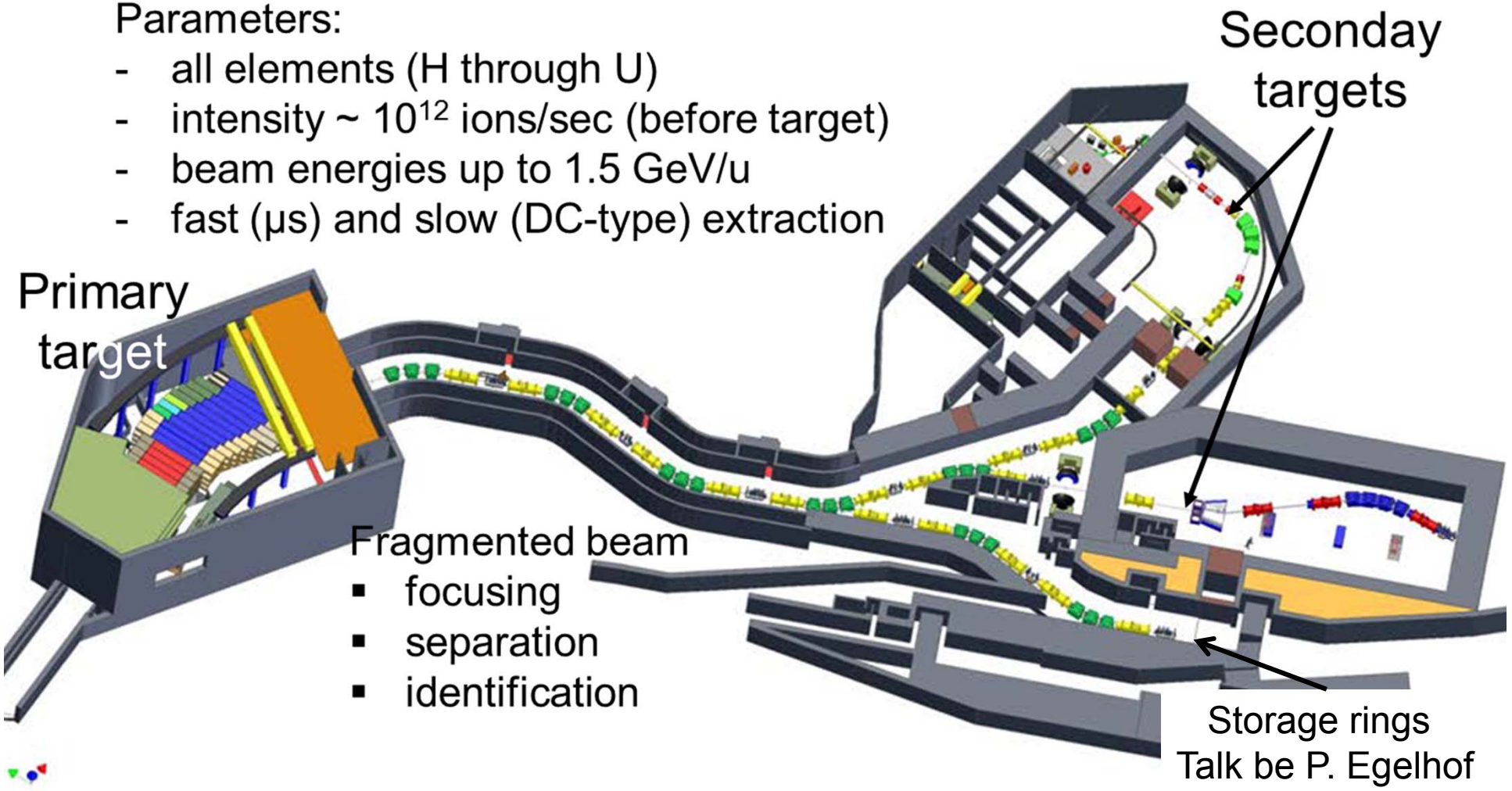


CBM detector

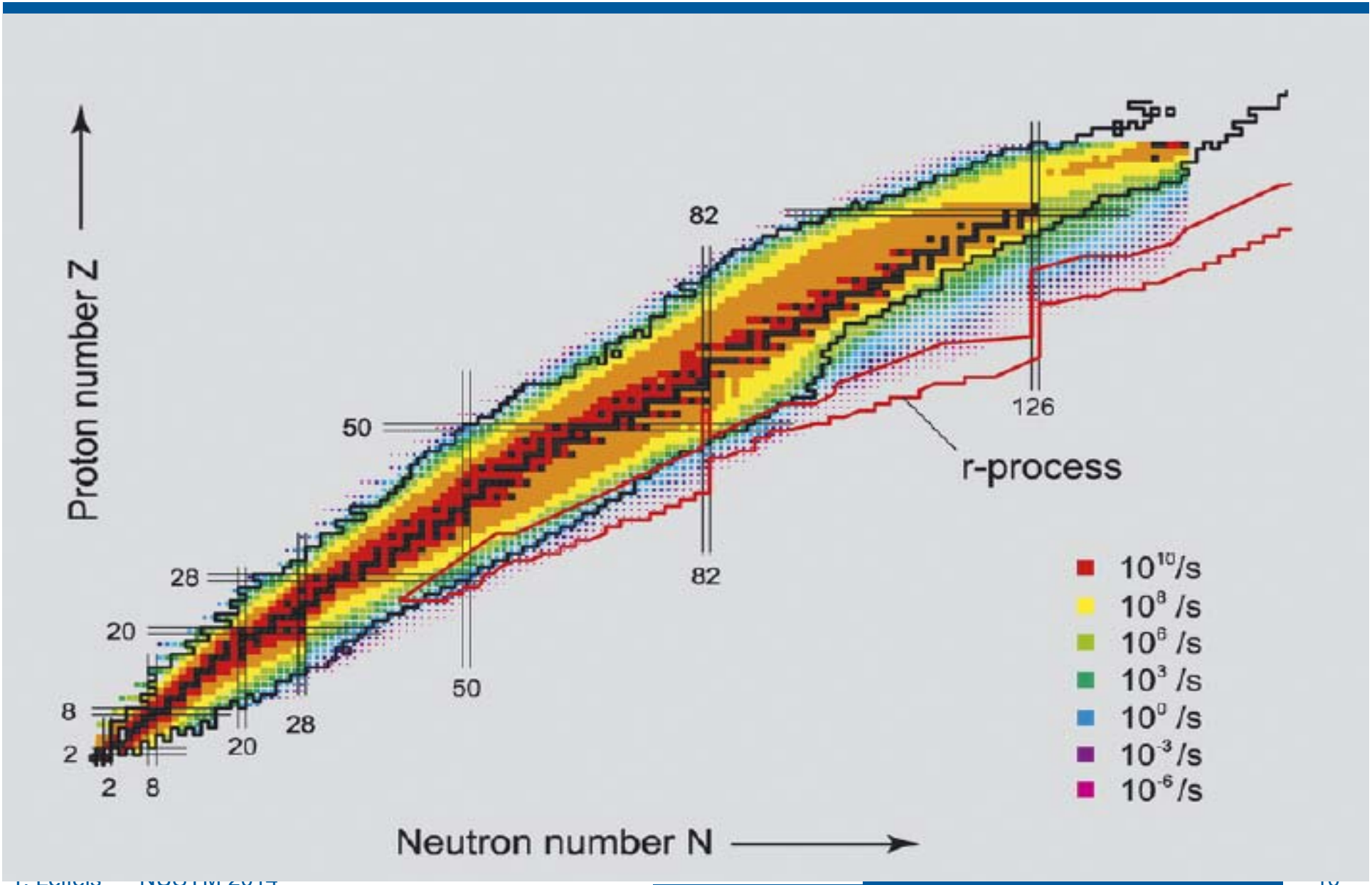
- collective flow of hadrons
- particle production at sub-threshold energies (multi-strange hadrons)

NUSTAR - The Super Fragment Separator

Parameters:
- all elements (H through U)
- intensity ~ 10^{12} ions/sec (before target)
- beam energies up to 1.5 GeV/u
- fast (μs) and slow (DC-type) extraction



Rates available after the SFRS



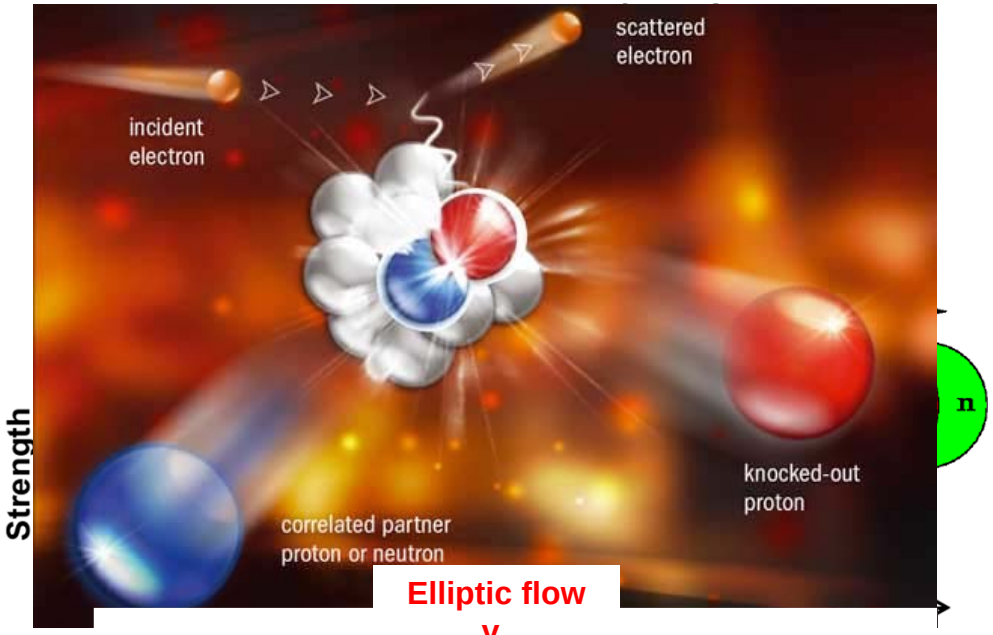
Symmetry energy at high energies in the laboratory

Reactions with no or small nuclear overlap

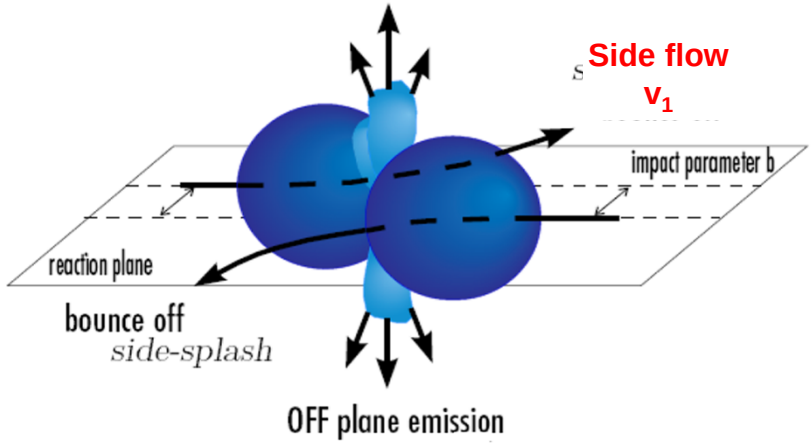
study of short range correlations
neutron skins
GDR & Pygmy resonances
dipole polarizability...
nuclear structure far off stability
masses and radii of nuclei

Reactions with substantial nuclear overlap

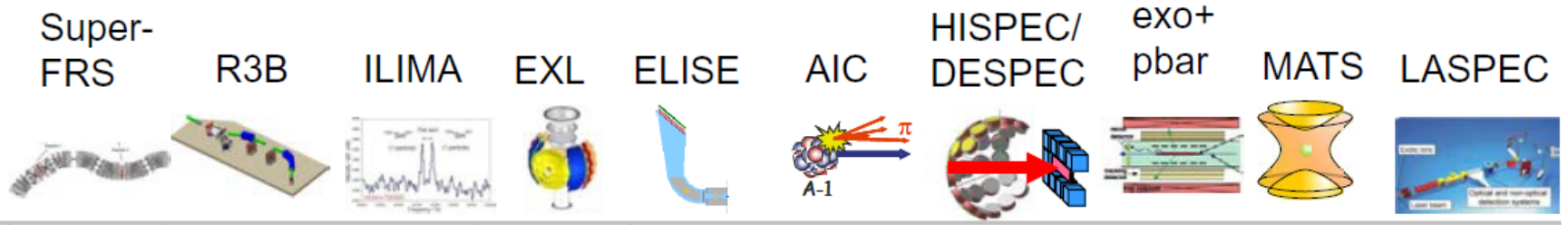
yields of fragment
particle production
flows



Elliptic flow
v_2



NUSTAR experiments

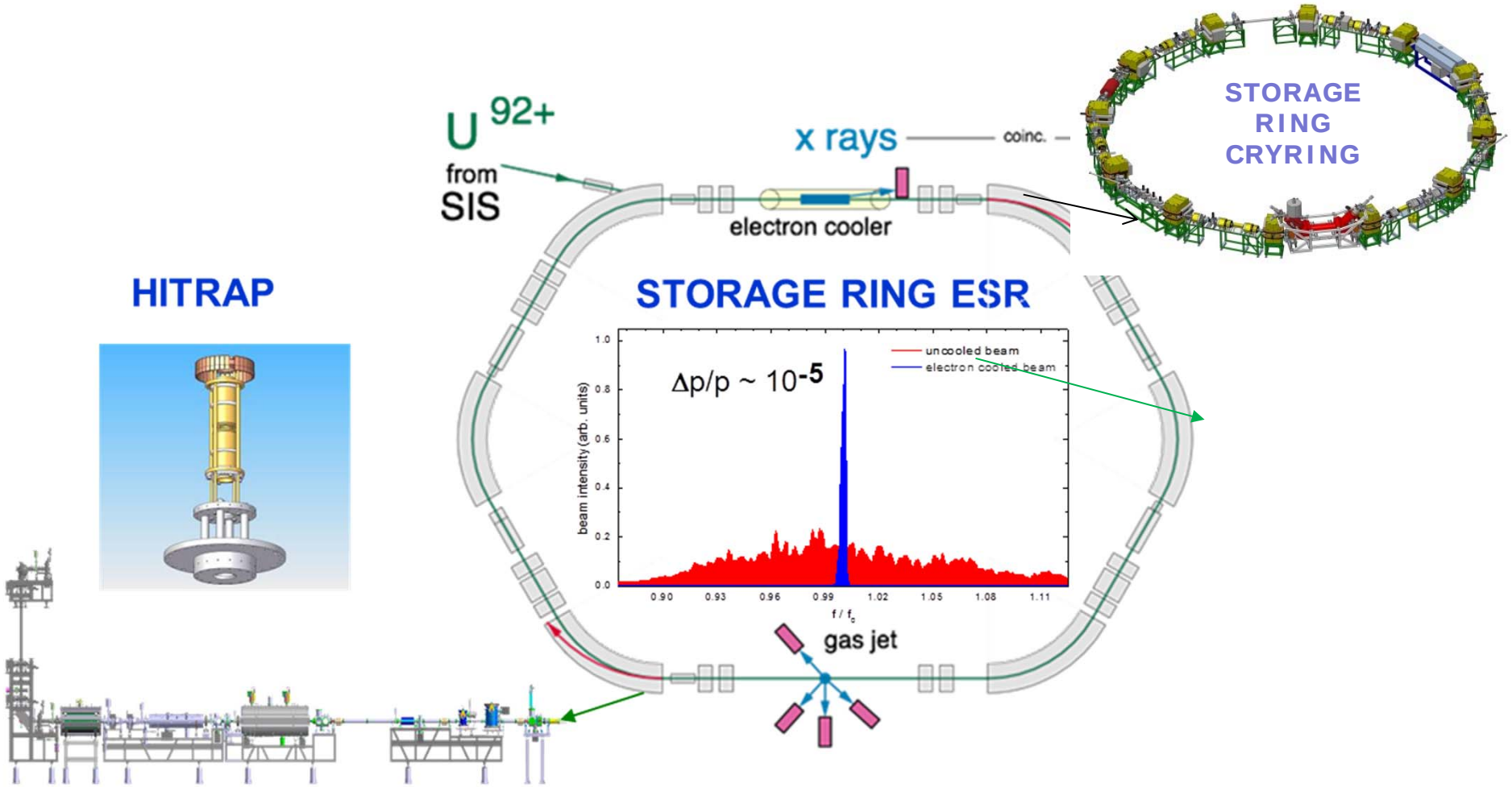


	Super-FRS	R3B	ILIMA	EXL	ELISE	AIC	HISPEC DESPEC	exo+pbar	MATS	LASPEC
Masses			bare ions, mapping study				Q-values, isomers		dressed ions, highest precision	
Half-lives	ps…ns-range		bare ions, s…h				dressed ions, μs…s			
Matter radii	interaction x-sect	matter radii		matter densitiy distributions		matter radii from absorption		nuclear periphery		
Charge radii					charge density distribution					mean square radii
Single-particle structure	high resolution, angular momentum	complete kinematics, neutron detection		low momentum transfers			high-resolution spectroscopy			

- Highest intensity and transmission
- "High" energy (unambigous identification)
- World-wide unique storage-ring complex
- Exotic nuclei **and** antiprotons
- New isotopes (r-nuclides)
- Neutron radioactivity, neutron dripline
- Modification of shell structure, new excitation modes
- Unexpected observations and phenomena

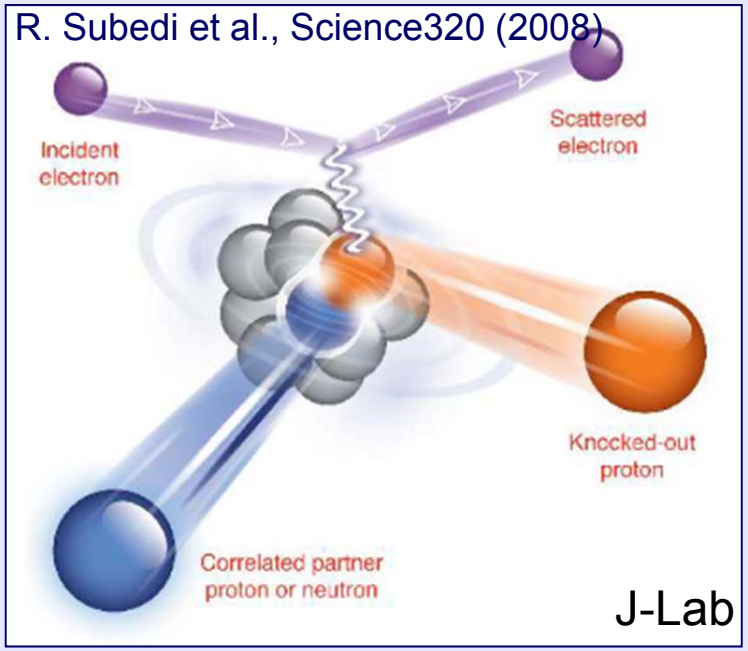
B. Sharkov / FAIR

Nuclear physics with storage rings @ ESR



Tensor force

R. Subedi et al., Science320 (2008)

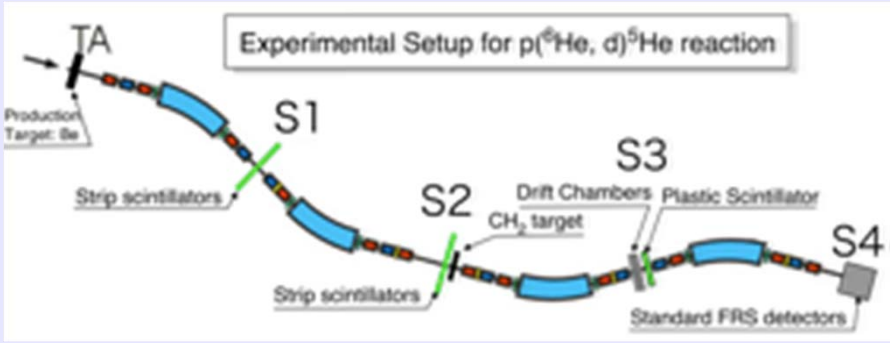


short range correlations in ^{12}C(e,e')

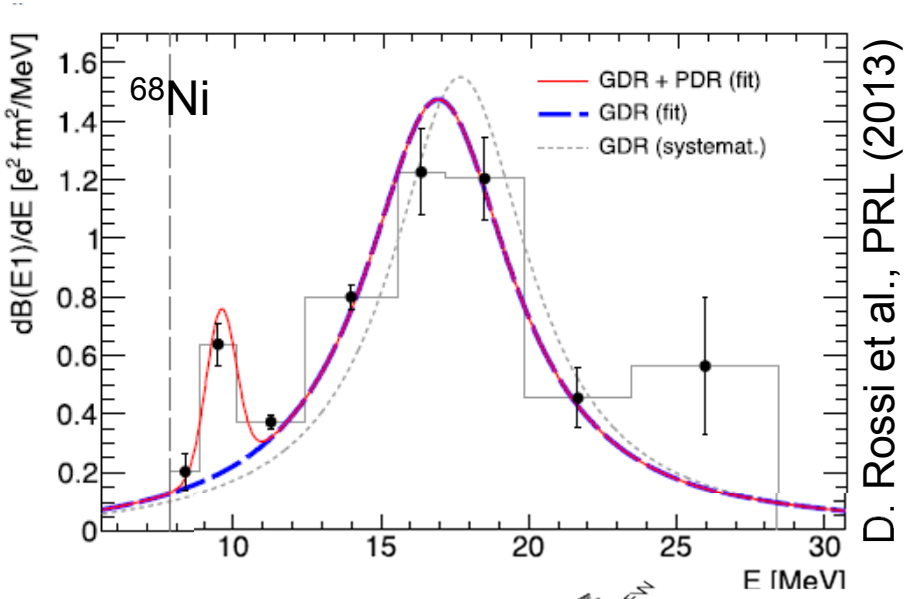
- ✓ neutron-proton pairs nearly twenty times as prevalent as proton-proton pairs
- ✓ modifies momentum distributions in asymmetric matter and confirms the role of the tensor force acting in neutron-proton isosinglet pairs .

measurement at FRS/GSI at SIS18

- ✓ p(^{6}He, d), p(^{6}Li, d) reaction at *E/A*=200, 400, 800 MeV
- ✓ at 0 degree scattering angle of deuteron
  - 0 degree in cm of p+^{6}X -> d + ^{5}X reaction; pick up of high momentum neutron in ^{6}X nucleus.

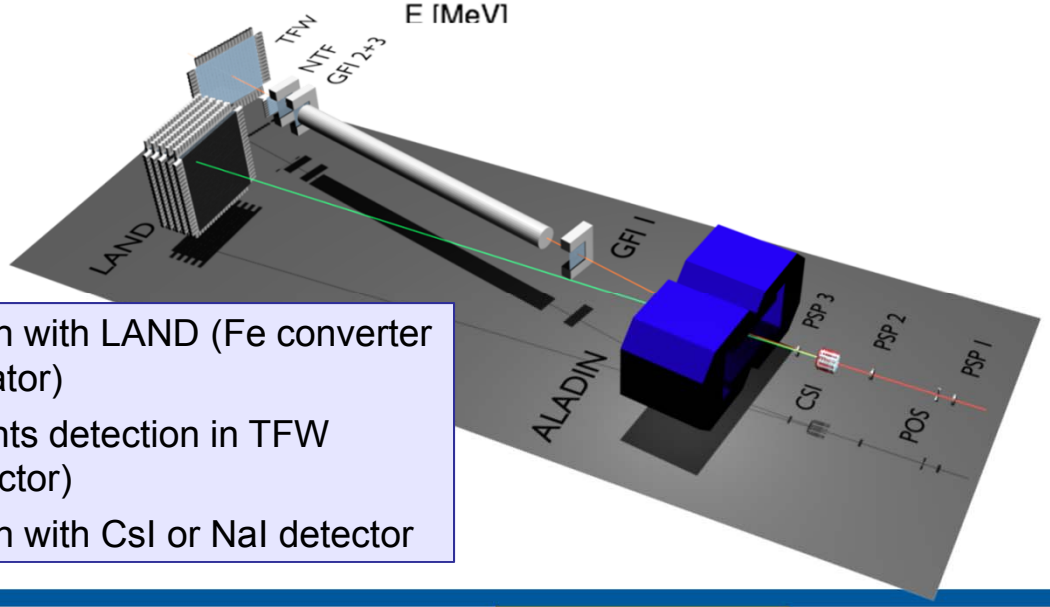


R3B – for kinematically complete measurements



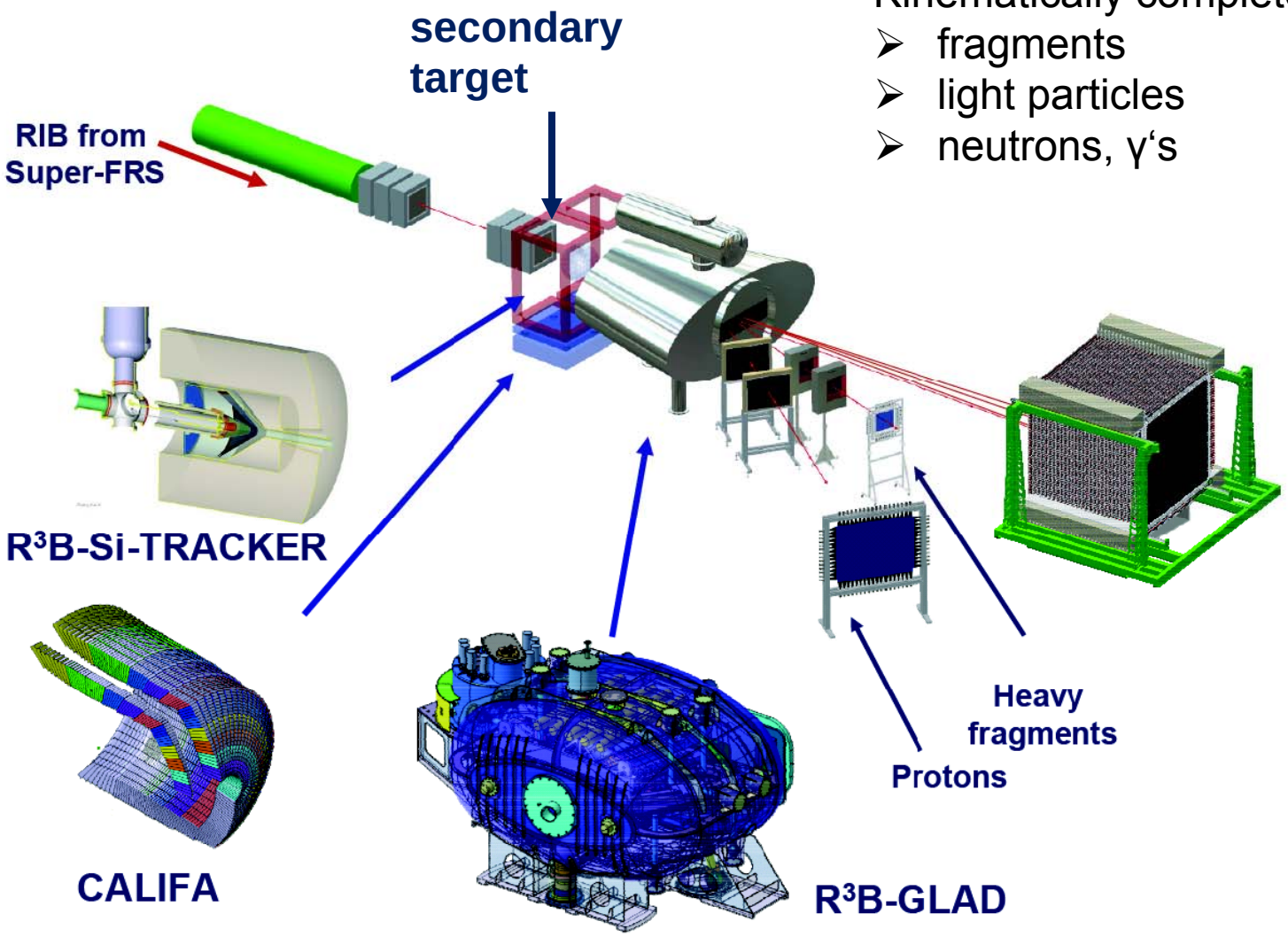
Next-generation experiments – Goals:

- extraction of full dipole strength function (below and above threshold, extracting E2 contribution, (-cacade) and neutron channels)
- development of strength with neutron excess
- relation to symmetry energy
- characteristic of low-lying strength (isospin structure, decay properties)



- Neutron detection with LAND (Fe converter + organic scintillator)
- Charged fragments detection in TFW (scintillation detector)
- Gamma detection with CsI or NaI detector

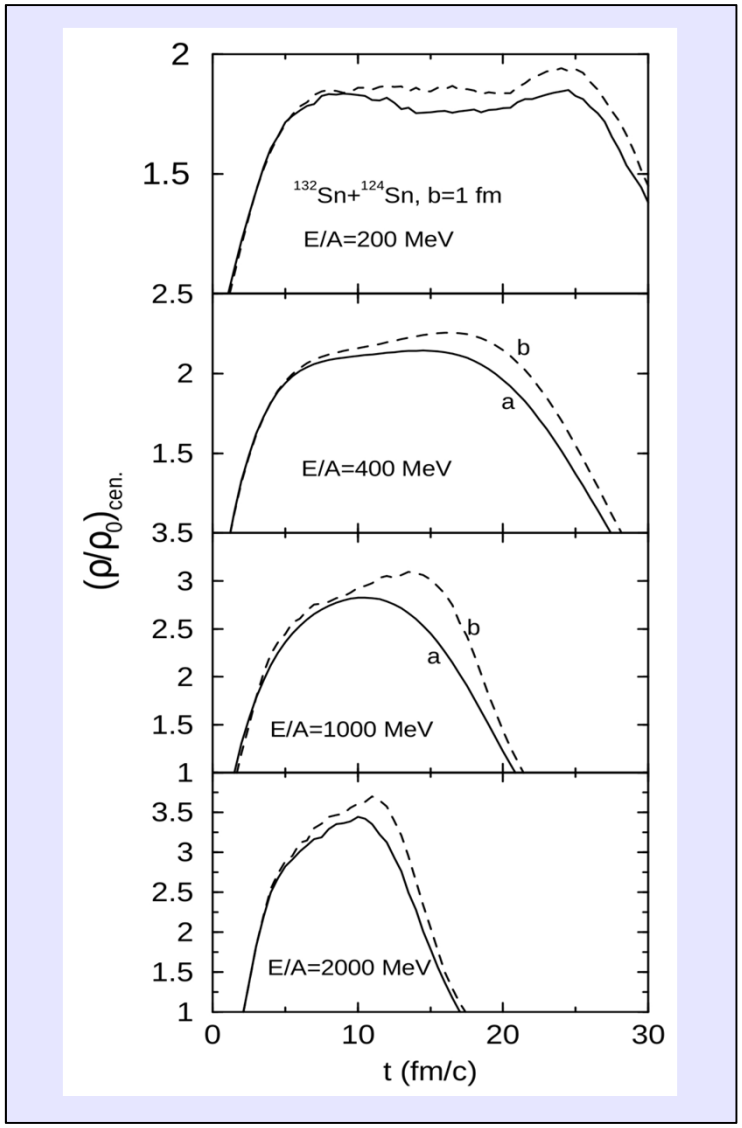
R3B Reactions with Relativistic Radioactive Beams



Kinematically complete measurement

- fragments
- light particles
- neutrons, γ‘s

HI collisions - Relevant observables



The optimum ρΔt obtained at ~400AMeV in the dense region of ^{132}Sn+^{124}Sn central collisions according to the isospin dependent transport model of Bao-An Li, NPA 708(2002)

Relevant observables:

Flows of isospin pairs

- i.e. n/p, t/^{3}He
- ratios n/p, t/^{3}He
- isospin diffusion (nucleons, cluster and produced particles)

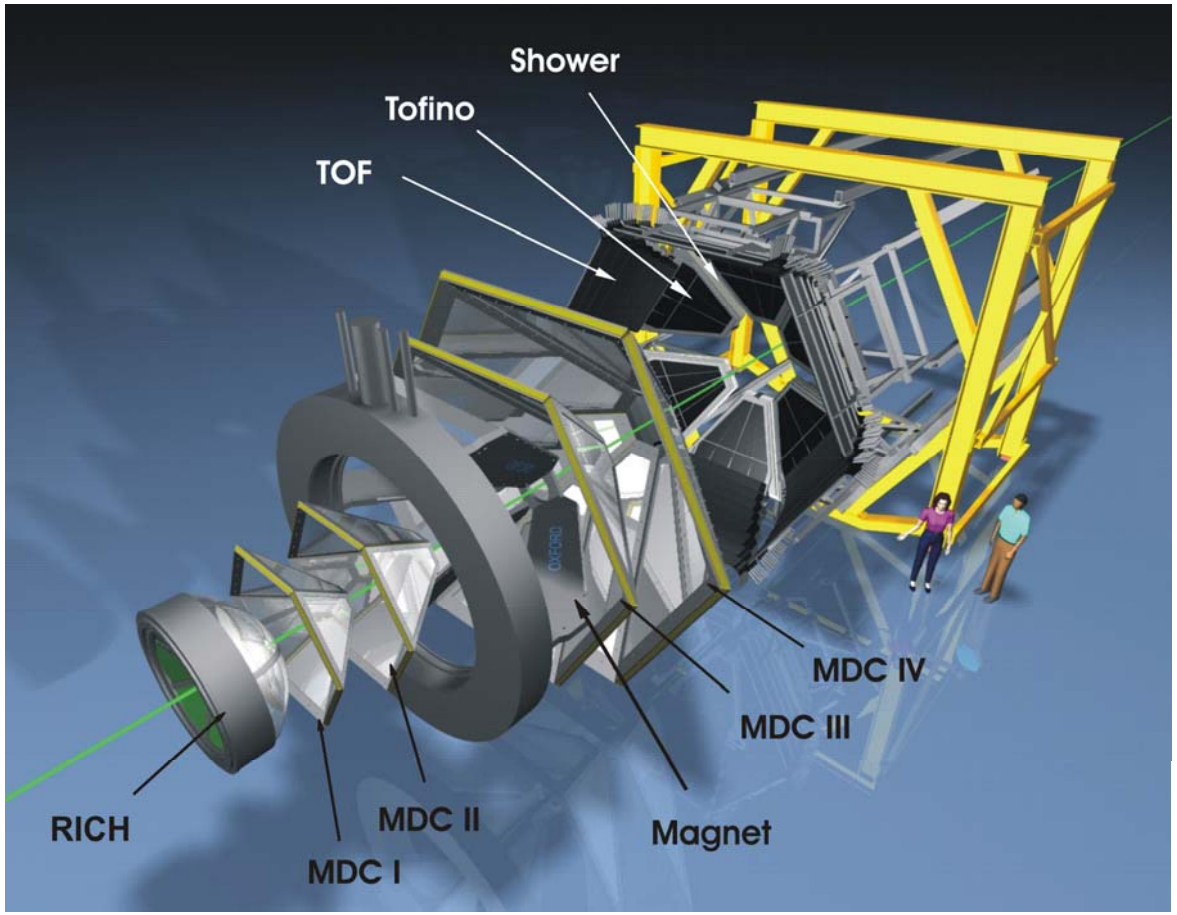
Particle production

- K^+/K^0 ratio below threshold

Experiments with stable beams @ SIS18/SIS100

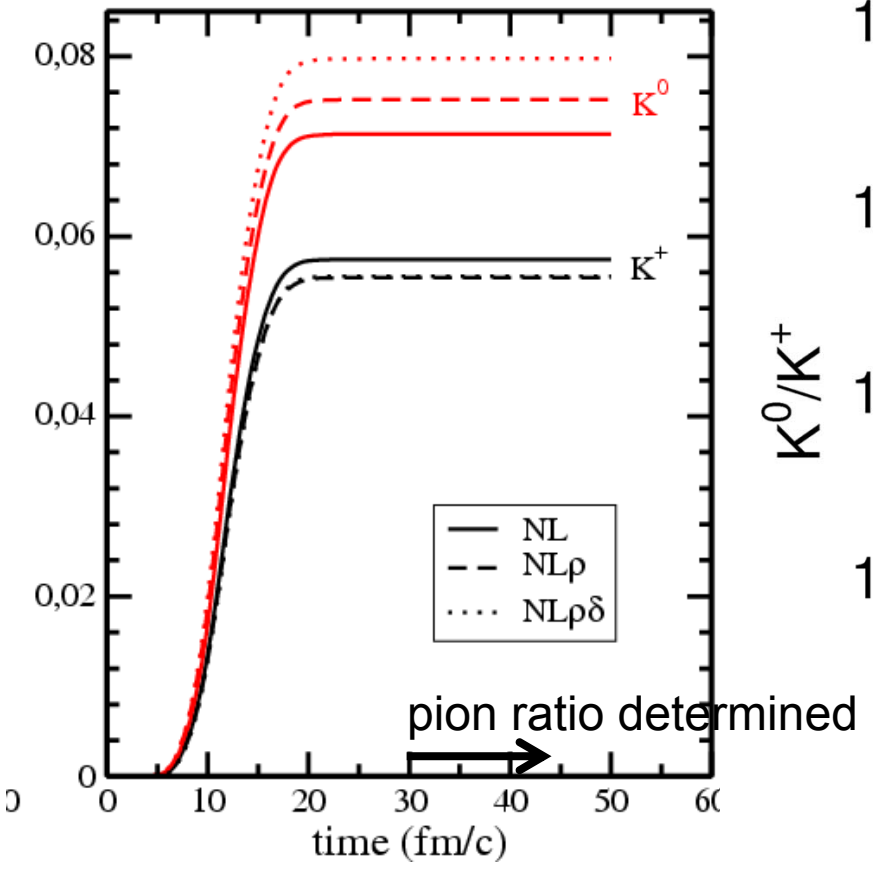
HADES

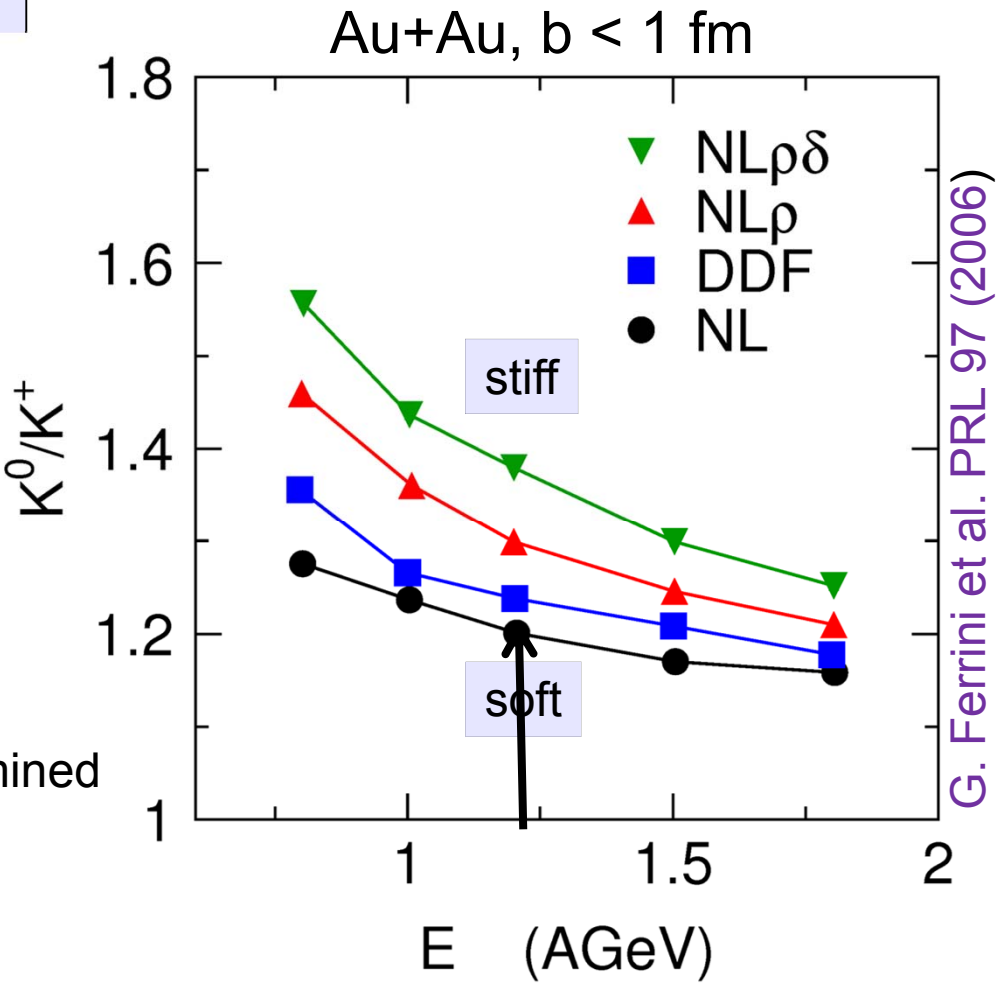
- Systematic studies of dilepton and hadron production
- upgraded with an electromagnetic calorimeter (η detection)



Kaon production

- Kaons produced early
- originating from high densities
- do not interact with matter





Elliptic flow of neutron/protons/charged particles

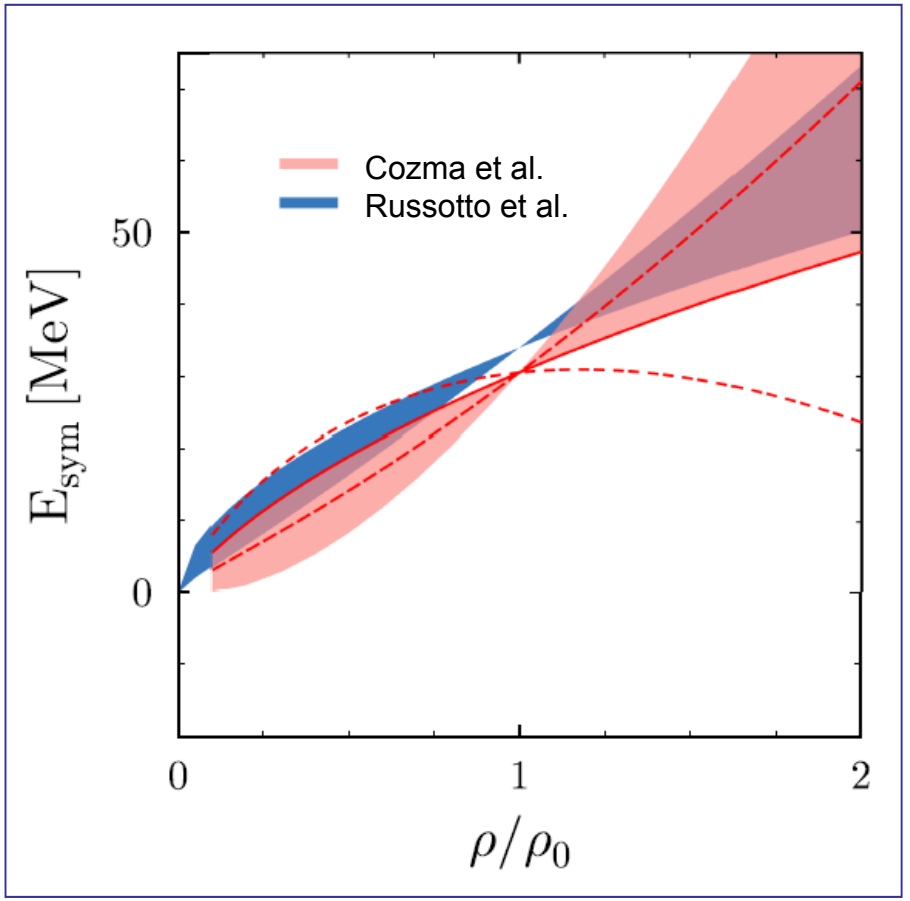
Towards model independence
Tested stability of results:

- soft vs. hard **190<K<280 MeV**
- density dependence of $\sigma_{NN,elastic}$
- asymmetry dependence of $\sigma_{NN,elastic}$
- optical potential
- momentum dependence of isovector potential

Cozma et al. (Tübingen-QMD) :
L = 106±46 MeV
Russotto et al. (UrQMD):
L = 85±40 MeV

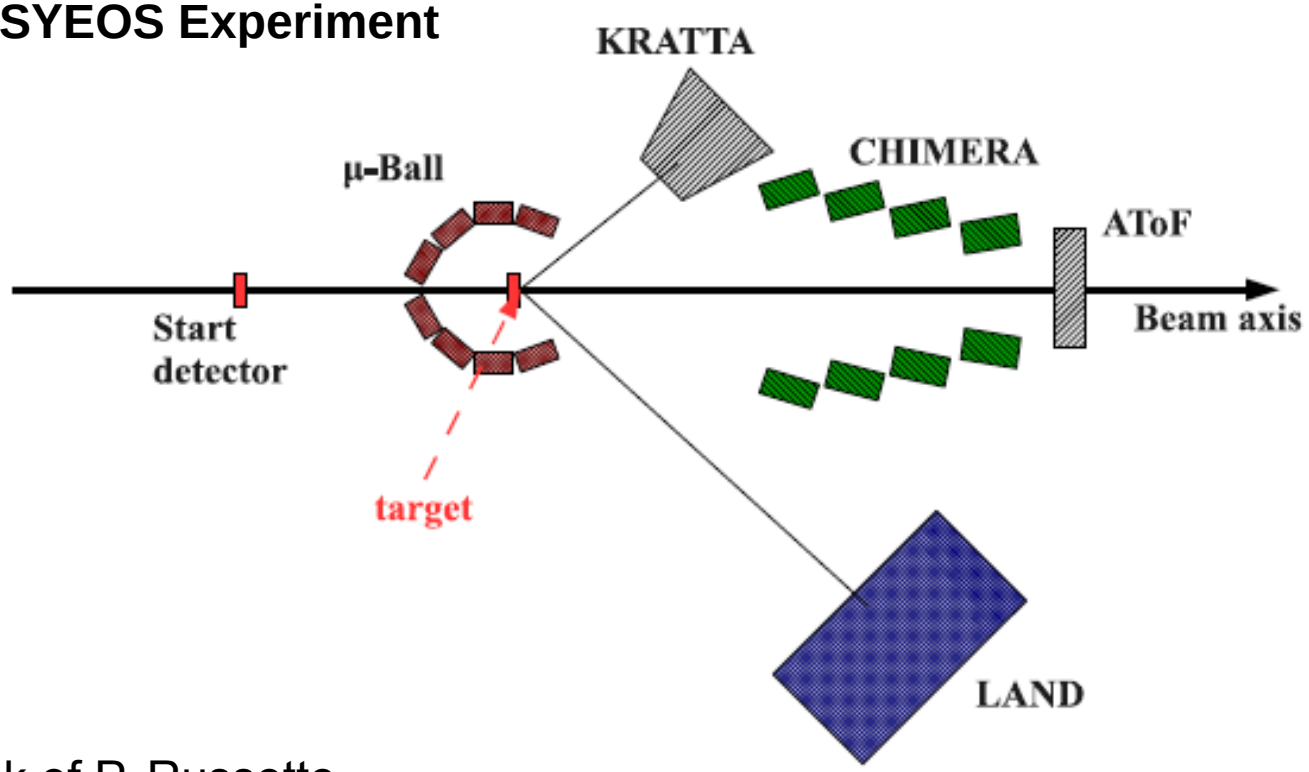
- ruling out particular hard or soft E_{sym}
- other experiments obtain smaller L
- statistics unsatisfactory
  - **ASYEOS experiment**
- other observables?

M.D. Cozma et al., arXiv:1305.5417
P. Russotto et al., PLB 267 (2010)



Experiments with stable beams

ASYEOS Experiment



Talk of P. Russotto

studied reactions:

^{197}Au + ^{197}Au @ 400 A MeV

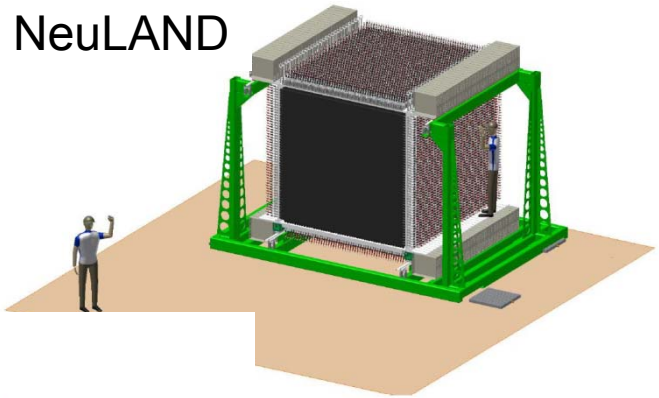
^{96}Ru + ^{96}Ru @ 400 A MeV

^{96}Zr + ^{96}Zr @ 400 A MeV

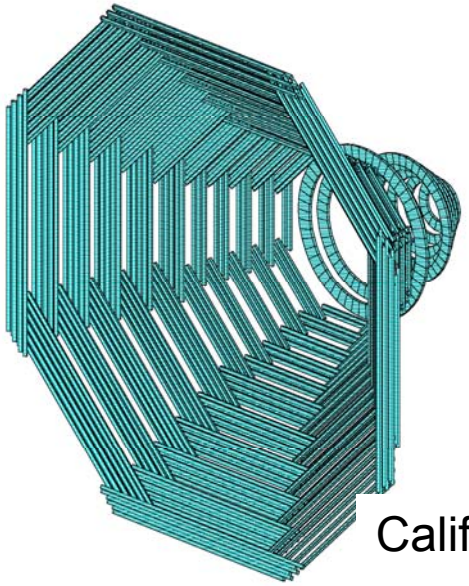
CHIMERA, ALADIN Tof-wall, μ-ball, for impact parameter orientation and modulus

Prospects at GSI/FAIR

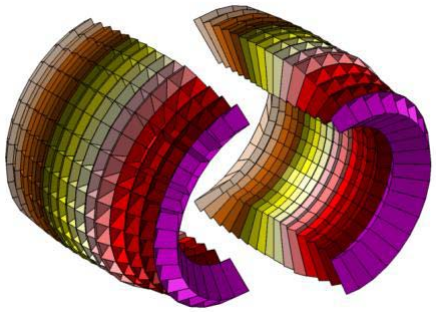
NeuLAND



PLAWA



Califa



Symmetry energy at supra-normal densities

- Radioactive beams at the highest rigidities
- Study of momentum dependence of symmetry energy
- Extend studies to higher densities
- Pion ratio sensitive at 250-400A MeV -> complete systematics
- Kaon ratio requires dedicated detector (magnet + tracking + ToF)
  - Feasibility needs to be proven -> HADES stable beams
- n/p and t/3He ratio
  - neutron + charged particle detectors
  - detectors for reaction plane and impact parameter determination

Summary

- Grounding works finished
- All relevant permits obtained (building, radiation)
- Civil construction starting Q2/2015
- Perspectives for research on Symmetry energy
  - investigation of ingredients (tensor force/3-body forces) by direct reaction (e.g. quasi free proton knockout
  - GDR and PDR studies with high resolution in Coulomb excitation
  - determination of masses of neutron rich nuclei in traps and storage rings
  - determination of radii by electron and anti-proton scattering
  - experiments at supra-saturation densities still need to be designed
    - Strategy
      - HADES for particle production at stable beams
      - dedicated experiment for n/p, t/3He flow at radioactive beams