Isospin dynamics and thermodynamics in n-rich heavy-ion induced reactions

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for the FAZIA NUCL-ex collaboration

people

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- 49 proponents + engeneers and technicians
- Groups active in the field of reaction mechanisms and multifragmentation at and below Fermi energies
- Largest contributions from **Nuclex-FAZIA and INDRA** collaborations; participation from Poland and US
- Support from theorists (Italy, Russia)
- Overlapping interests with other groups both in Italy (LNS) and outside
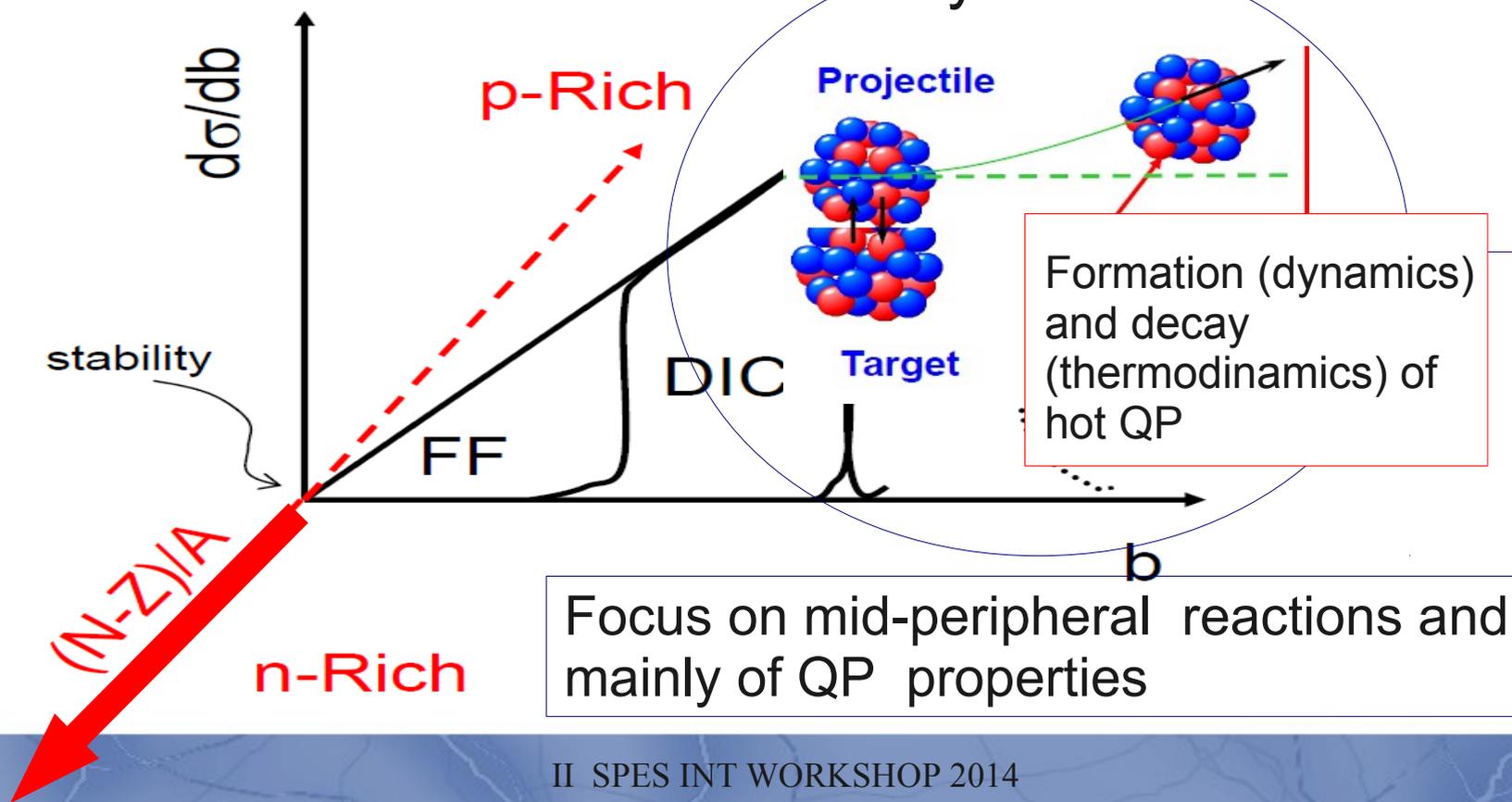- Open-mind LOI: towards joint efforts @SPES   (cfr. Eric Bonnet's talk)

physics

The general subject is: how the σ_{reac} and its contributions evolve with n-rich systems?
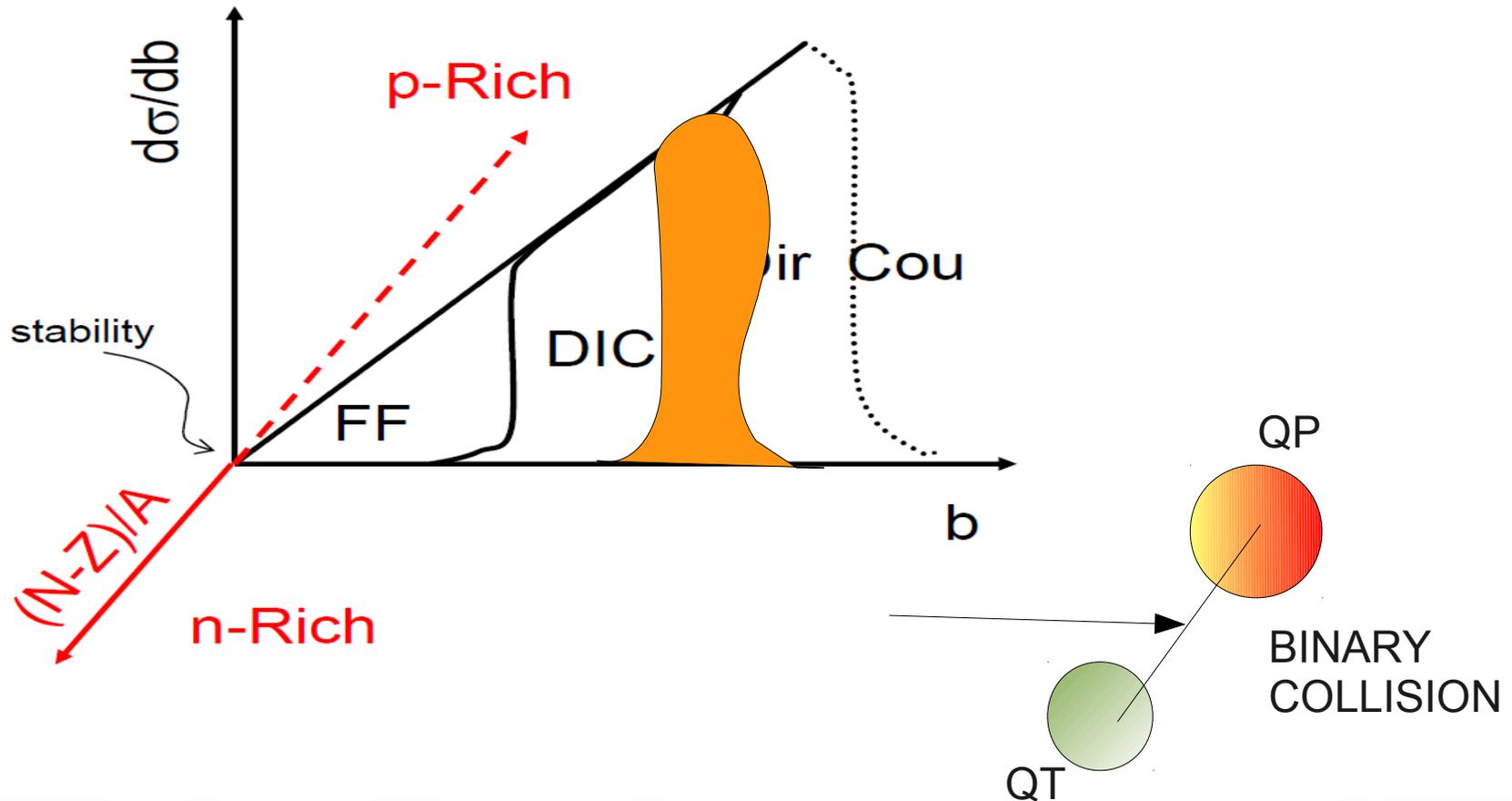
physics

The general subject is: how the σ_{reac} and its contributions evolve with n-rich systems?

Formation (dynamics) and decay (thermodinamics) of hot QP
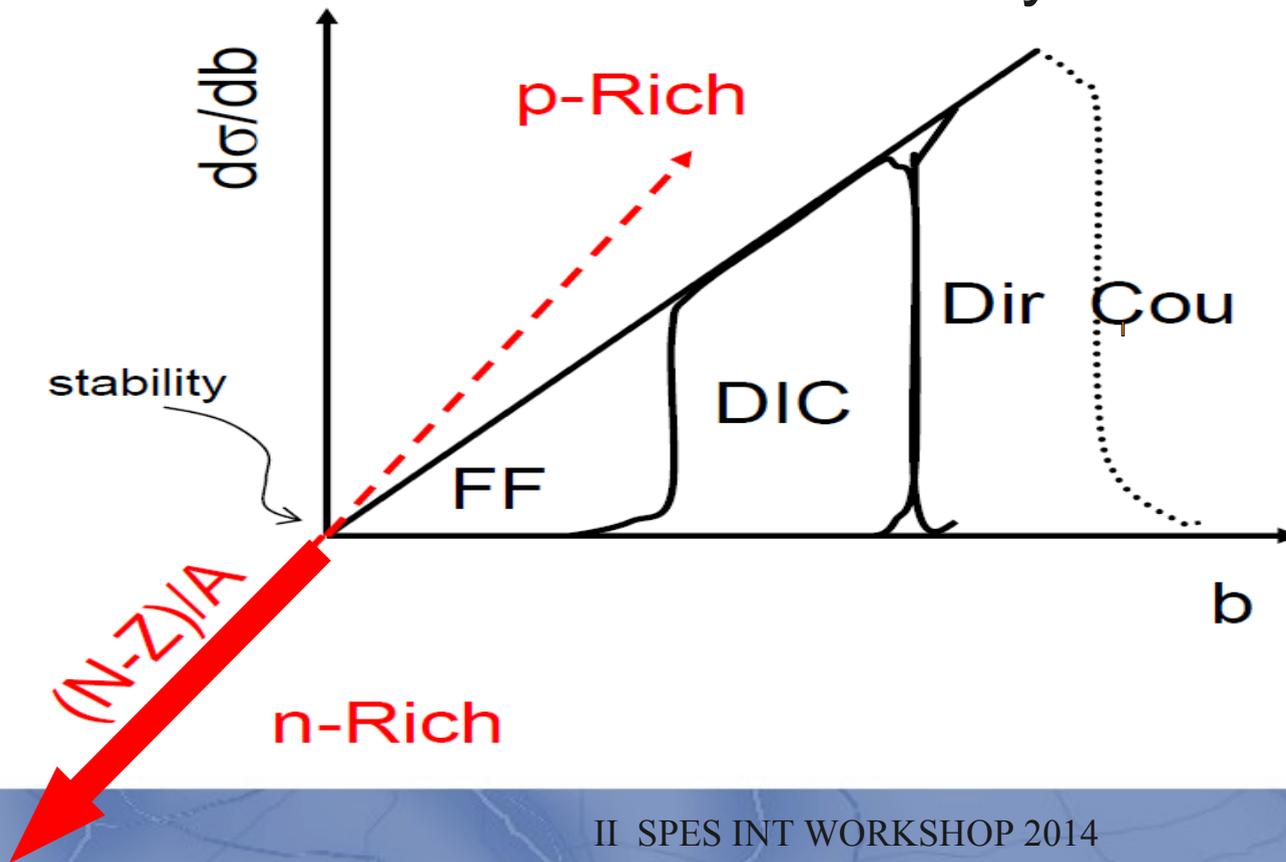
Focus on mid-peripheral reactions and mainly of QP properties
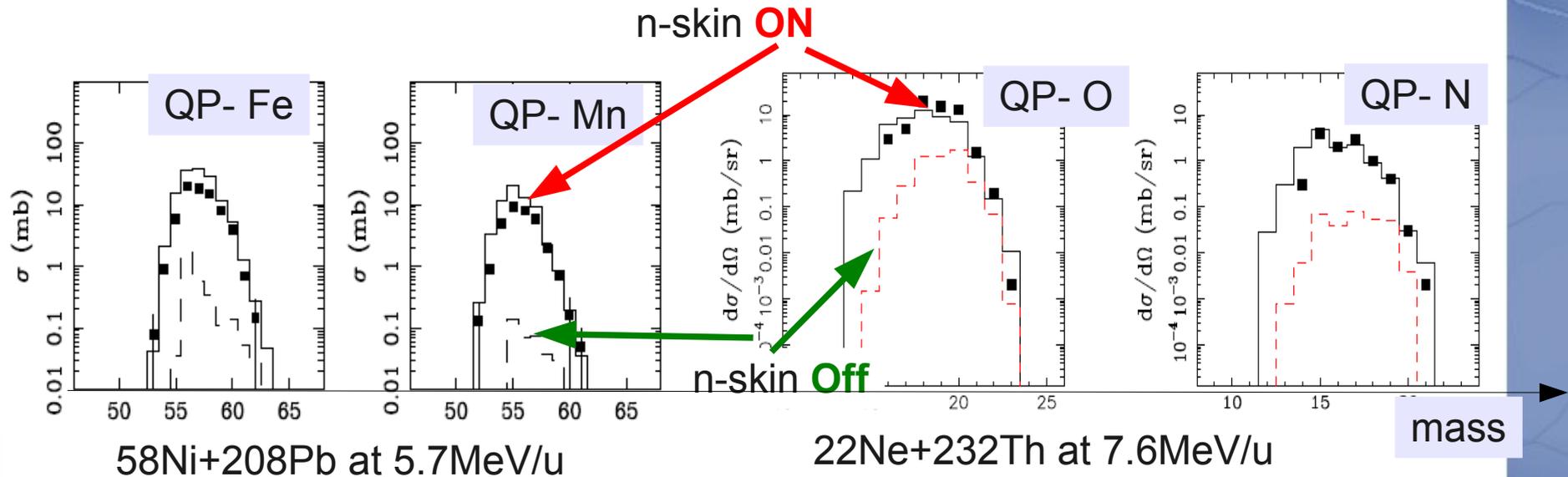
peripheral collisions

Charge equilibration in semi-peripheral collisions

Surface-related effects

Nucleon exchanges ruled by Mean Field →

surface effects
 introducing in transport models an extended neutron density profile improves agreement→ **skin?**

n-skin **ON**

QP- Fe

QP- Mn

QP- O

QP- N

n-skin **Off**

mass

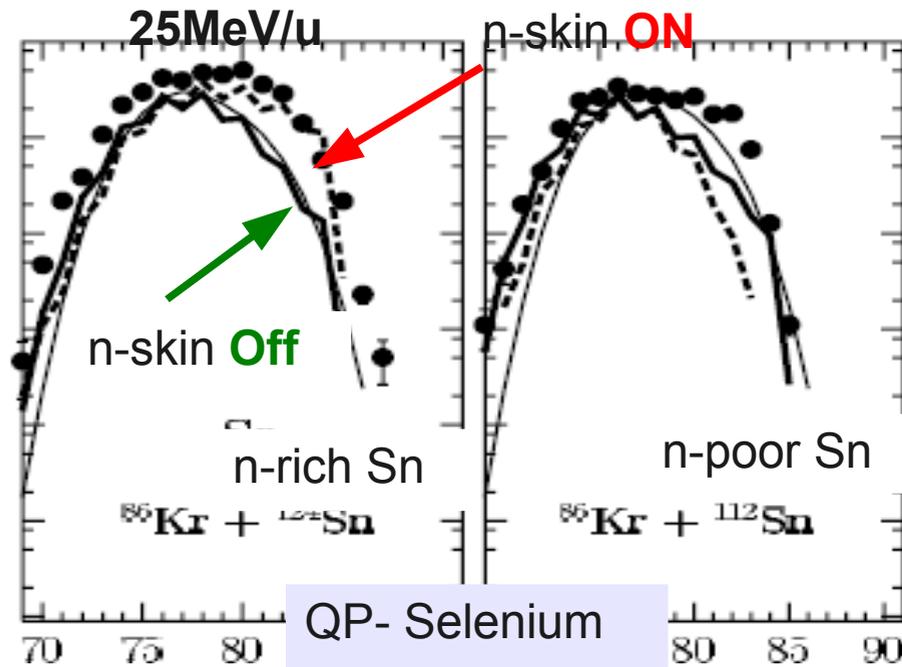58Ni+208Pb at 5.7MeV/u

22Ne+232Th at 7.6MeV/u

M.Veselsky NP A872(2011)
M.Veselsky NP A781 (2007)

Nucleon transfer in MF affected by neutron skin

Charge equilibration in semi-peripheral collisions
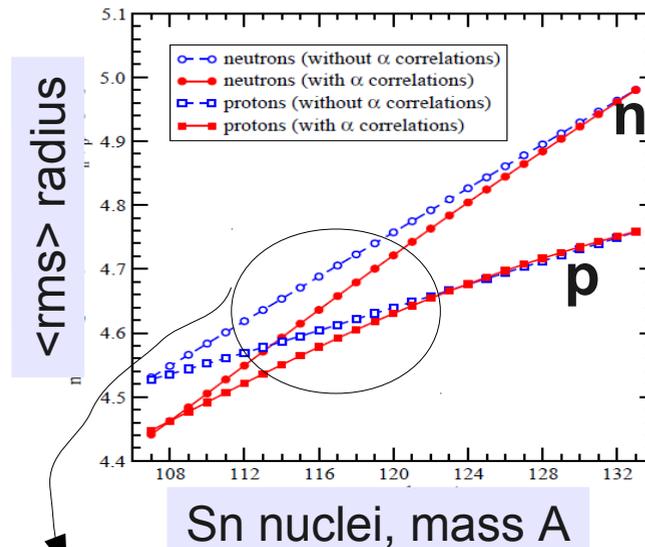## Surface-related effects

Nucleon transfer
affected by neutron rich surface

25MeV/u   n-skin **ON**

n-skin **Off**

n-rich Sn

n-poor Sn

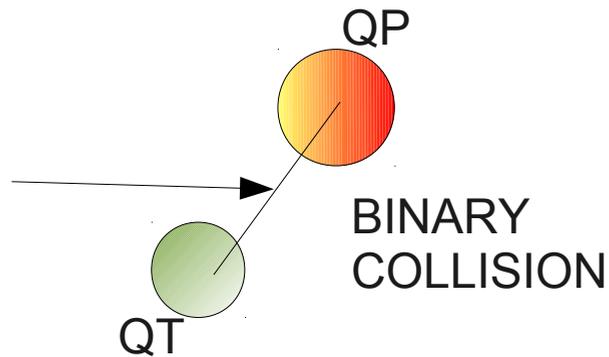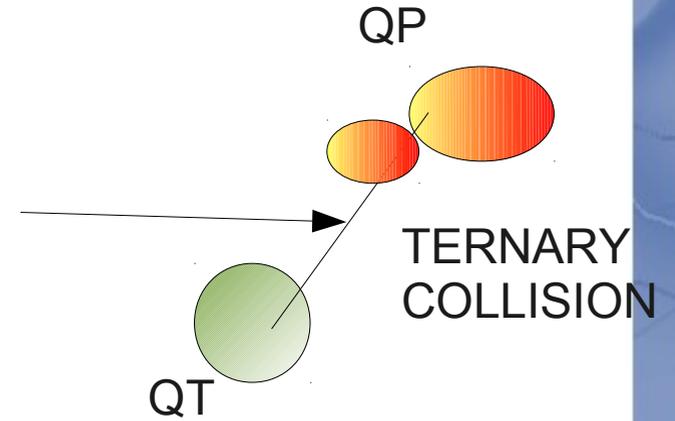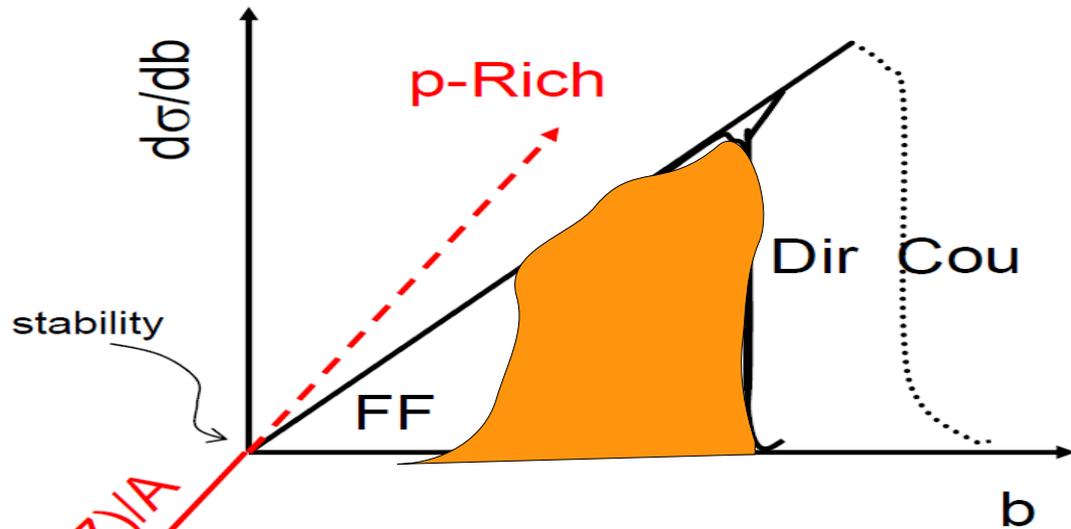$^{86}Kr + ^{124}Sn$ $^{86}Kr + ^{112}Sn$

QP- Selenium

Souliotis PRL91(2003)

S.Typel ArXiv 1403-2851v1 (2014)
neutron skin is influenced by
the alpha-clusterization

Formation of α-clusters at surface
modifies the radii vs. neutron number

More central collisions

Hints from Stochastic MeanField (SMF)

SMF good to explore dynamics. Sensitivity of MeanField to the Esym term of the EOS for semiperipheral reactions

Recent applications to low energy (n-rich) beams

Some sensitivity to Asy-EOS choices of the branching between **fusion vs. break-up**

Predictions of the final evolution of the transient system from its initial (<300 fm/c) phase-space
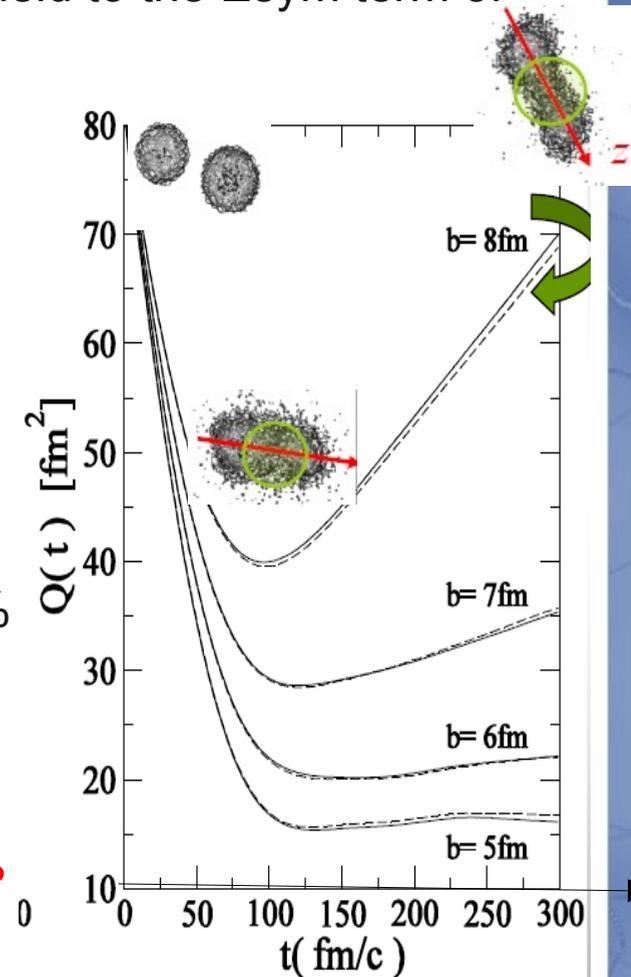
Soft asyEOS favours fusion 4-5% effect, for n-rich systems

$$Q(t) = < 2z^2(t) - x^2(t) - y^2(t) >$$

$$QK(t) = < 2pz^2(t) - px^2(t) - py^2(t) >$$

$^{132}Sn + ^{64}Ni$ E_{lab} = 10 AMeV
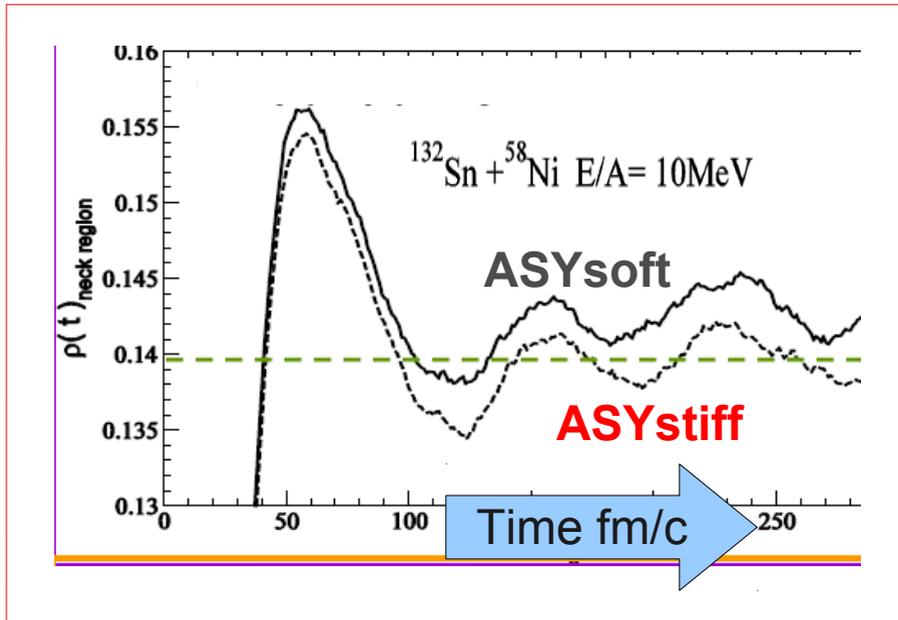Mid-central

m.colonna THIS WORKSHOP
c.rizzo PRC83 2011
c.rizzo Eurisol Krakow 2013
m.colonna Spiral2 LOI 2006

Hints from SMF

**Asysoft** favours fusion and slight suprasaturation phases for the interacting systems.
Asystiff favours more diluted phases which means more IMF and neck-like formation (more fission-like events)

Oscillations: Dynamical Dipole modes
See LOI Pierroutsakou and LOI Barlini

$^{132}Sn + ^{58}Ni$ E/A= 10MeV

ASYsoft

ASYstiff

Time fm/c

c.rizzo PRC83 2011
c.rizzo Eurisol Krakow 2013
m.colonna Spiral2 LOI 2006

Asy-stiff: more dissipative neck dynamics

$b = 7 fm$

ASYsoft
ASYstiff

qua(a.u.)
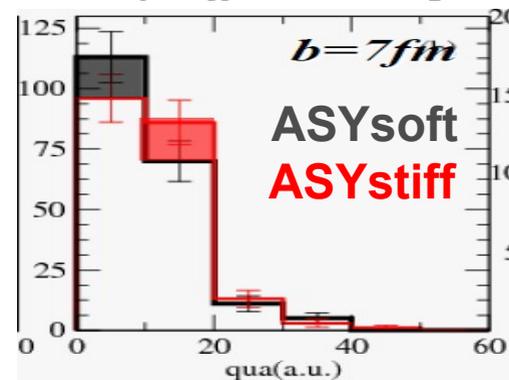
quadrupole

A neutron rich intermediate neck can more easily survive

observables

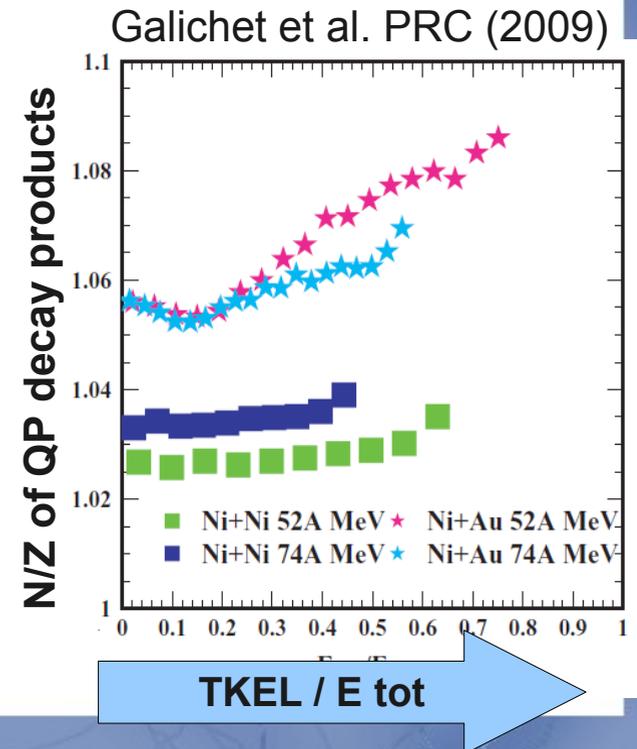**Sensitive variables to isospin equilibration and neck decay**
- N/Z of LCP and fragments from QP decay
- LCP and fragments yields
- Fission probability and angular distributions of fragments
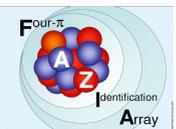- TKEL or other ordering parameters (dissipation scale)

Problems/difficulties
- Z,A identification of QP is extremely challenging (a part from using spectrometres);
- Asy-EOS effects less pronounced at low E (gentler dynamics)
- Sources less separated in phase-space than at Fermi energies

Advantages/opportunities
- Longer reaction times → extended evolution
- Colder fragments: primary-secondary states closer
- Initial large N/Z thanks to SPES beams

Galichet et al. PRC (2009)

N/Z of QP decay products

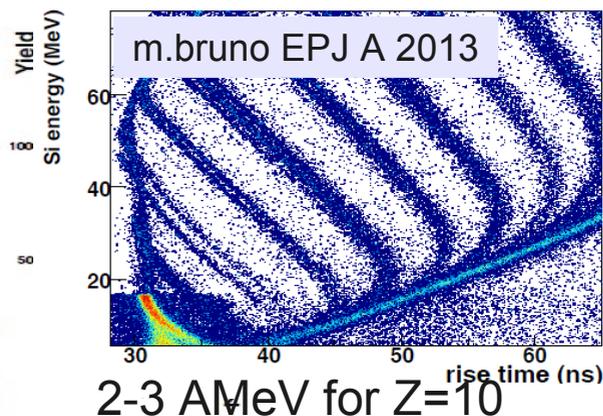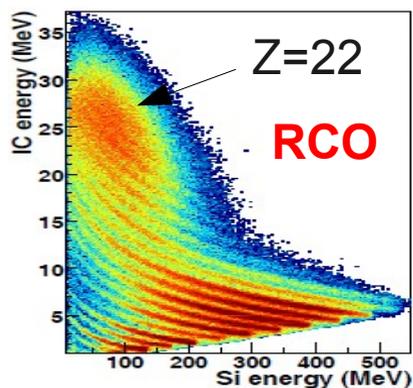| Ni+Ni 52A MeV | Ni+Au 52A MeV |
| Ni+Ni 74A MeV | Ni+Au 74A MeV |

TKEL / E tot

Tools and equipments

Full detection of QP (up to Z=50-60) and its decay products in a wide solid angle is a challenge at low energies (max 12MeV/u)

- **Fazia-Nuclex** collaboration pushed fragment identification with low-threshold Si-Si-CsI (FAZIA) and gas-Si-CsI (Nuclex) telescopes
- Intense R&D on preamplifier+ fast sampling electronics, with wide dynamics (1 to 6000 MeV)
- Deep experience on Pulse Shape Analysis and shaping/filtering algotithms

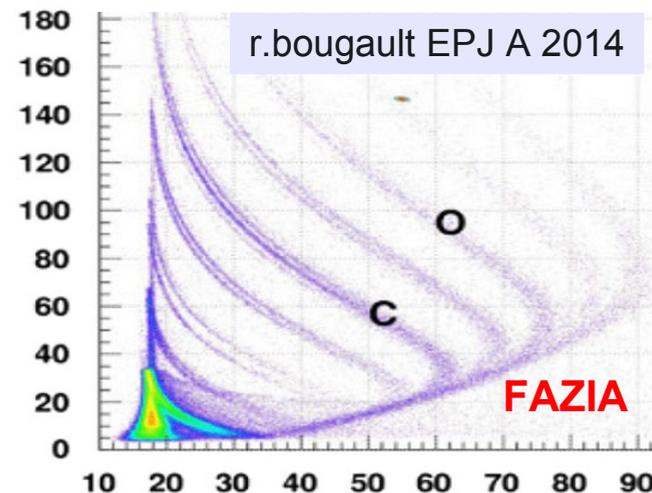Exploring possible cooperations...e.g.
Farcos (talk E.V.Pagano)
Prisma (talk L.Corradi)

See Bonnet talk, on FAZIA

Z=22

RCO

m.bruno EPJ A 2013

2-3 AMeV for Z=10

r.bougault EPJ A 2014

O

C

FAZIA

SPES beams (full power UCx)

- Very specific isotopes are not needed
- Long isotopic projectile chains: systematics and comparison play a key role
- Purity is an issue

- Intensity is (can be) an issue; chosen beams are expected **with > 10^7 pps**

ion	Z	N/Z	Max Energy	notes
82–92Kr	36	1.28 - 1.56	11-12	HRMS needed
112-132/133Sn	50	1.24 - 1.66	10-11	Laser source; SPES reference beams
85-96Rb	37	1.30 - 1.60	11-12	"Easy" beams
133-144Cs	55	1.41 -1.62	11-12	"Easy" beams

possible SPES reactions

**Charge equilibration and 2body/3body competition
in dissipative collisions**

Stable and unstable Cs beams

1. ^{133}Cs+^{40}Ca E/A=6-10.5 MeV (N/Z_P=1.42 N/Z_T=1.0, $(N/Z)_{sys}$=1.3)
2. ^{143}Cs+^{40}Ca E/A=6-10.5 MeV (N/Z_P=1.60 N/Z_T=1.0, $(N/Z)_{sys}$=1.4)
3. ^{133}Cs+^{48}Ca E/A=6-10.5 MeV (N/Z_P=1.42 N/Z_T=1.4, $(N/Z)_{sys}$=1.41)
4. ^{143}Cs+^{48}Ca E/A=6-10.5 MeV (N/Z_P=1.60 N/Z_T=1.4, $(N/Z)_{sys}$=1.55)

System 1 the most n-poor
System 4 the most n-rich
Systems 2,3 the same global N/Z
System 3 charge symmetric in entrance channel
System 2 the most charge asymmetric

**IMPORTANT: Pre-SPES training to evaluate technical
solutions and sensitivity for this physics**

spare

Kinematic parameters

Reac: 10.00 AMeV   (A=133.,Z=55.) ---> (A= 40.,Z=20.)
Ecm : 307.51 MeV
 Vcm : 3.379 cm/ns ;   Vrel : 4.396 cm/ns;   Vrel_cont : 3.35 cm/ns
R12 : 12.25fm Thetagr=7deg

 Reac: 10.00 AMeV   (A=143.,Z=55.) ---> (A= 40.,Z=20.)   Ecm : 312.57 MeV
 Vcm : 3.435 cm/ns ;   Vrel : 4.396 cm/ns;   Vrel_cont : 3.38 cm/ns
 R12 : 12.43fm Thetagr=6.4deg

Reac: 10.00 AMeV   (A=133.,Z=55.) ---> (A= 48.,Z=20.)   Ecm : 352.71 MeV
Vcm : 3.230 cm/ns ;   Vrel : 4.396 cm/ns;   Vrel_cont : 3.52 cm/ns
R12 : 12.56fm Thetagr=6.6deg

 Reac: 10.00 AMeV   (A= 92.,Z=36.) ---> (A= 48.,Z=20.)   Ecm : 315.43 MeV
 Vcm : 2.889 cm/ns ;   Vrel : 4.396 cm/ns;   Vrel_cont : 3.74 cm/ns
 R12 : 11.86fm Thetagr=6.2deg

Does Fissility play?

$$X = \frac{E_c^0}{2E_s^0} = \frac{(Z^2/A)}{(Z^2/A)_c}$$

$$(Z^2/A)_c = 40\pi r_0^3 \sigma/(3e^2) \simeq 50$$

$$\sigma = a_2/(4\pi r_0^2)$$ Surface tension

133Cs X133=0.455

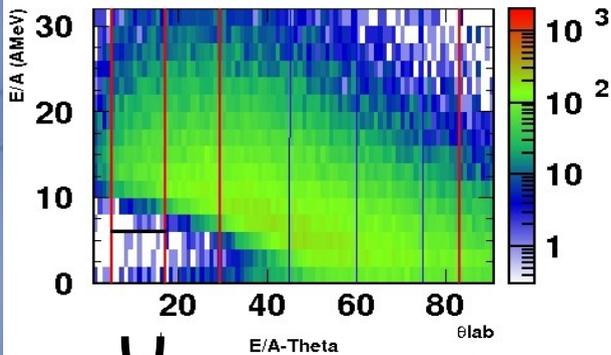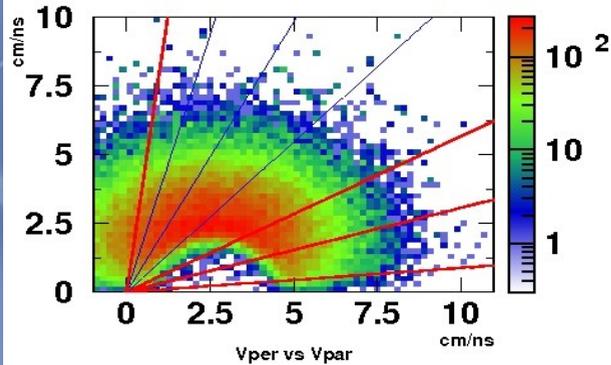143Cs X143=0.423

82Kr X82=0.316

92Kr X92=0.281

If 'standard' fission prevails fissility X is meaningful:
Less fission for n-rich

If 'dynamic' fission prevails neck effects can produce larger
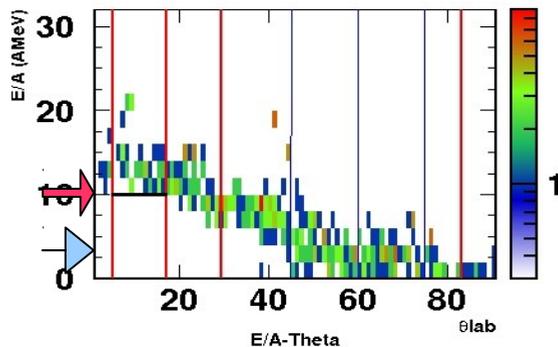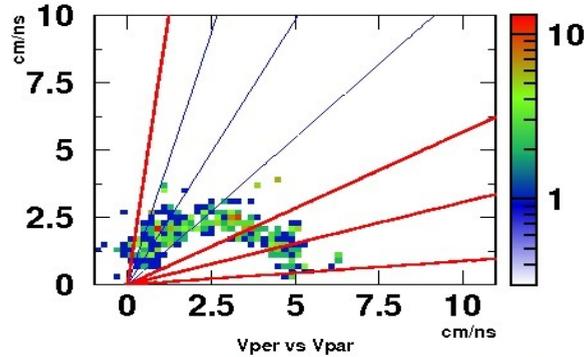fission for n-rich

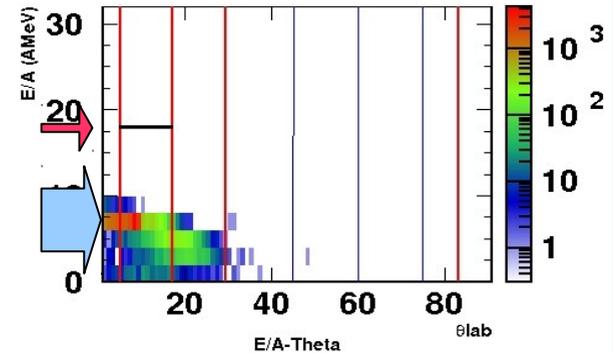# Hipse predictions

86Kr+40Ca at 7.8AMeV   events with b>4 fm

RCO   GARFIELD

IMF 5<A<20

QP 50<A<90
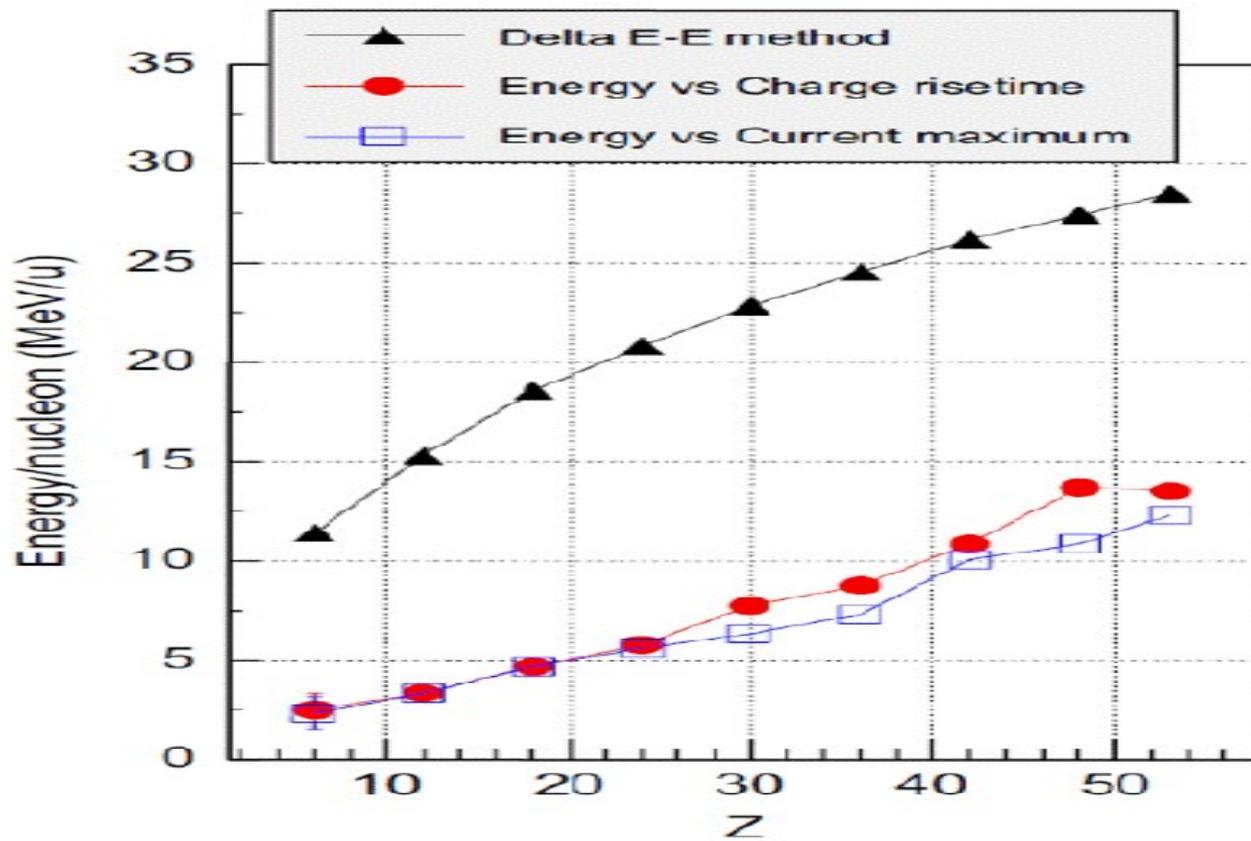
LCP p,d,t,alpha
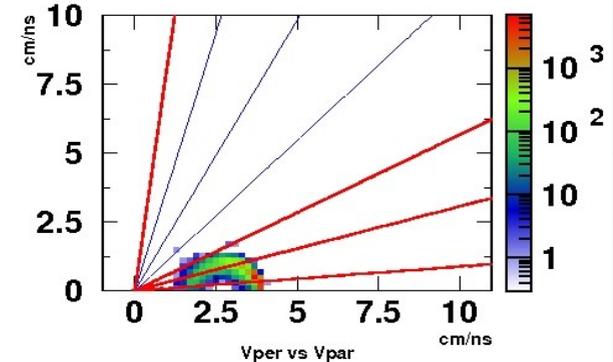
thresh. PSA in Si
thresh. ptru Si

thresholds

PSA: present Z ident. Thresholds for 300micron Silicons (FAZIA)

^{132} Sn+^{58} Ni, 10AMeV : Fast Nucleon Emission vs Symmetry Energy

Asy-Soft: neutrons see a more repulsive Symmetry Potential below ρ_0

By Maria Colonna
SMF calculations

132Sn + 58Ni 10AMeV b=4fm