Possible experiments on reaction dynamics at intermediate energies

Rome,
april 29th, 2010

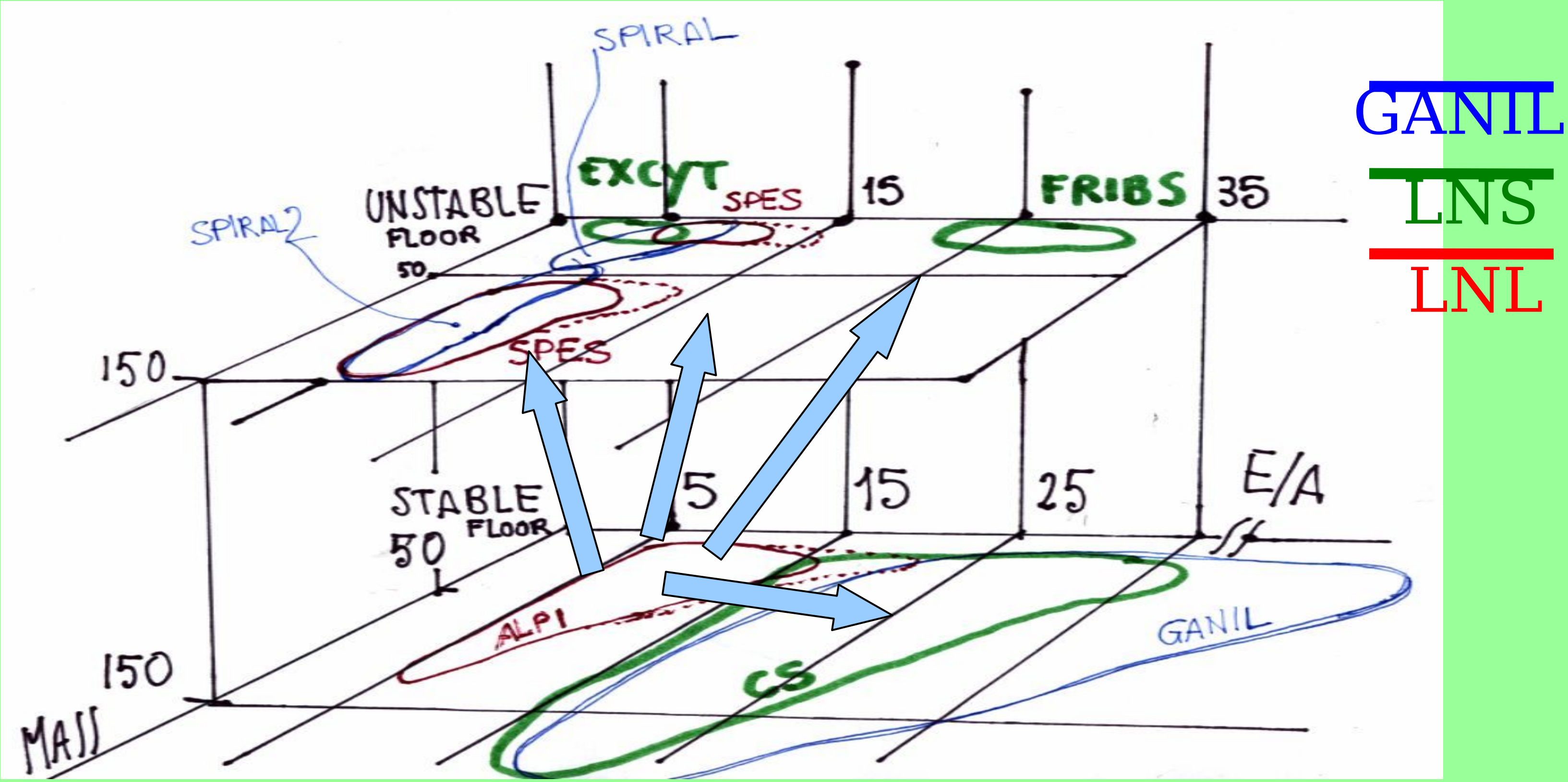
? REX ......?

Physics Motivation: testing the Esym

Expansion of Nuclear Energy in asymmetry, I=(N-Z)/A, yields to:

$$E(\rho, I) = E(\rho, I=0) + I \underbrace{(\delta E/\delta I)_{I=0}}_{=0} + I^2 \underbrace{1/2(\delta^2 E/\delta I^2)_{I=0}}_{\text{SYMMETRY ENERGY}} + O(4)$$

- E does not change under (n,p) interchange, odd terms=0 (charge invariance of strong interaction).
- The Symmetry Energy is the curvature around I=0.
- O(4) are negligible (microscopic calculations), E parabolic form.



Physics Motivation

There are various interesting aspects; some of them have to do more with **nuclear structure** some others with **nuclear dynamics and EOS**

Related to dynamics and EOS

-change of relevance of reaction channels

-energy and angular momentum dissipation (coupling of intrinsic and collective d.o.f.) (cfr Fusion-fission, Emanuele)

-**low density neck region**

-charge equilibration in deep-inelastic

-isospin and Multifragmentation (cfr. Mauro)

see e.g.:

M.Colonna et al. LOI for Spiral2 october 2006

J.Rizzo et al. NPA806 (2008) 79

C.Rizzo et al. NUFRA2009 Kemer sept.2009

Physics Motivation: the model perspective

Transport theories: Stochastic Mean Field (SMF) ⟺ Nuclear EOS

hydrodynamical picture

proton vs. neutron currents

$$j_n = D_n^{\rho} \nabla \rho + D_n^{I} \nabla I$$

$$j_p = D_p^{\rho} \nabla \rho + D_p^{I} \nabla I$$

drift

diffusion

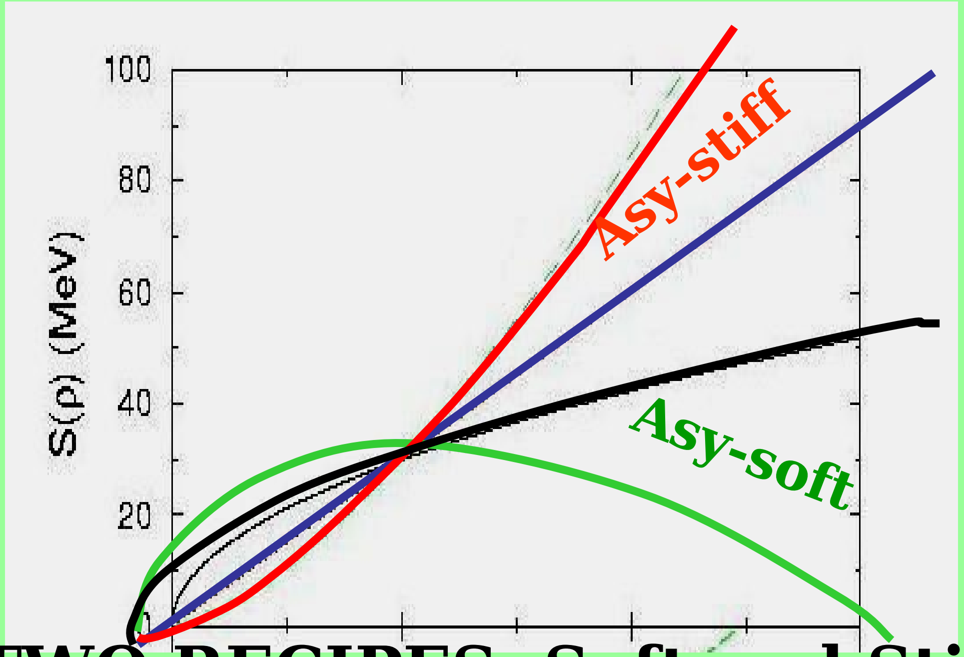
coefficients

$$j_n - j_p \propto E_{sym}(\rho) \nabla I + \frac{\partial E_{sym}(\rho)}{\partial \rho} I \nabla \rho$$

Diffusion

Drift

E/A (ρ) = Es(ρ) + Esym(ρ)*I²



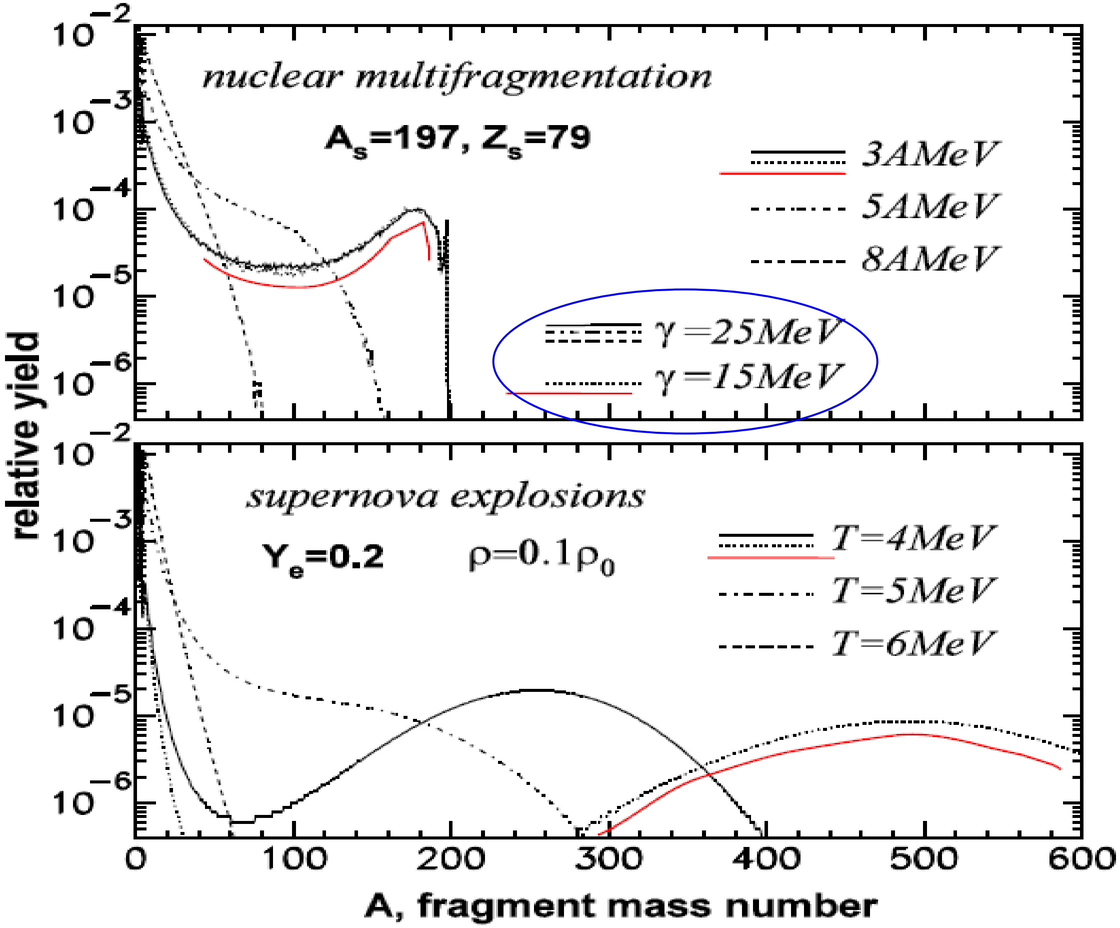
TWO RECIPES: Soft and Stiff

Reactions at intermediate and low energies: information on the EOS below normal density

E_{sym} and the death of stars

Energy evolution of mass distributions of fragments in multifragmentation reactions and in stellar mater

SMM calculations with different Esym values (and temperatures)



EXPLODING NUCLEI

$2*10^{-22}$ g

Esym=2γ

EXPLODING STARS

$\sim 10^{34}$ g

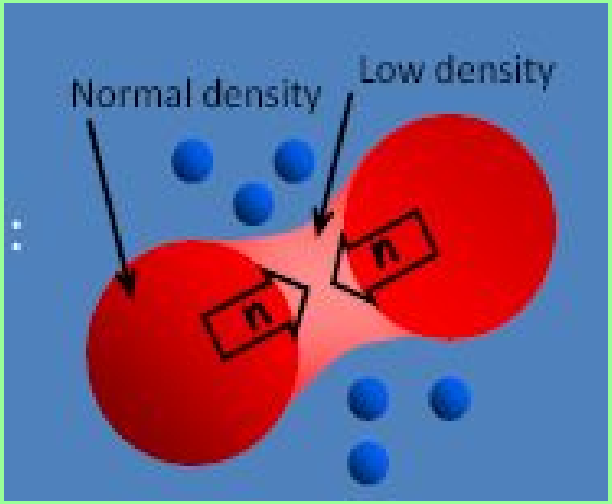
adapted from A.Botvina
NUFRA09 Kemer 2009

Physics aspects:

isospin migration (or drift) <-> neck composition

Neck phenomena and ternary breakings

cluster emission from the neck region, supposed to be at lower density, can depend on the isospin dynamics



Beyond Coulomb repulsion and angular momentum, also isospin can contribute to the formation of surface instabilities.

Paradox: **local n-enrichment of neck cluster even starting from iso-symmetric systems (due to density gradient effects)**

Predictions

- more deformed neck for Asystiff
- the long-lived n-rich neck emits small clusters (n-rich)

NOTE: at low energies, small neck production but fragments are colder, thus evaporation distorsions should be small.

Physics aspects:

isospin migration (or drift) <-> neck composition

Do some neck-like structures appear at low energies?

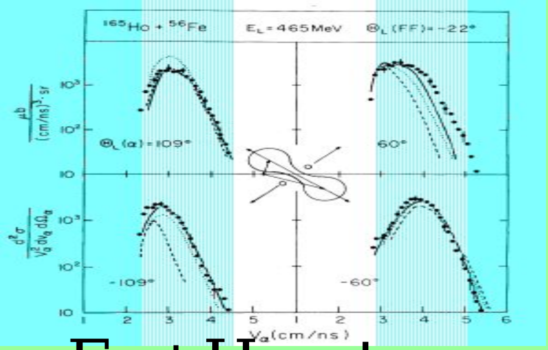
EXPERIMENT

1) Wilcke et al PRL51(1983)99
Fe+Ho at 8.3AMeV
10% alphas from neck for fusion-fission channel

2) Boger et al PRC49(1994)1576
Kr+Cu at 7.4AMeV
sizeable emission of p and alphas before fission or quasi-fission speak of a long-lived elongated system

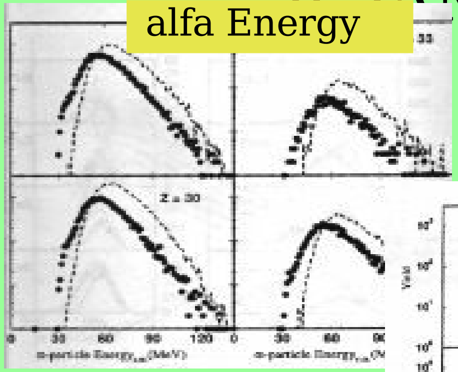
3) Bredeweg et al PRC66(2002)014608
C+Th at 16,22AMeV
IMF emitted with low velocity orthogonal to scission-axis; flat Z distributions as the 'thermal' usual barriers were not valid

4) D.Shapira et al PRC 55 (1997),2448
^{58}Ni+^{24}Mg at 11MeV/u
alpha spectra explained only assuming elongated shapes

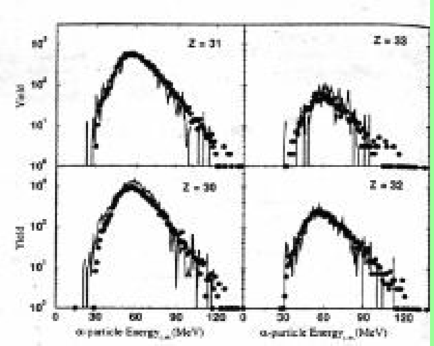


Fe+Ho at 8.3AMeV

alfa Energy



^{58}Ni+^{24}Mg at 11MeV/u



THEORY

-Davies et al PRC20(1979)1372 Kr+La at 8.3AMeV
TDHF calculations predicted the formation of neck-like structures

-Baran et al PhysRep 410(2005)335
SMF calculations with Asy-soft/stiff EOS

interesting systems: isodrift

Lionti et al. Phys Lett B625 2005:

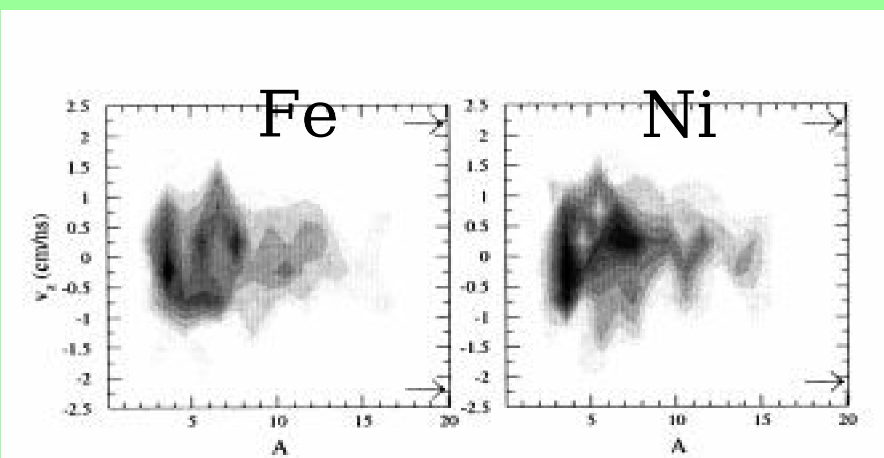
58Fe+58Fe, N/Z=1.23 **58Ni+58Ni 47AMeV N/Z=1.07**

SMF calc. b=4-6fm

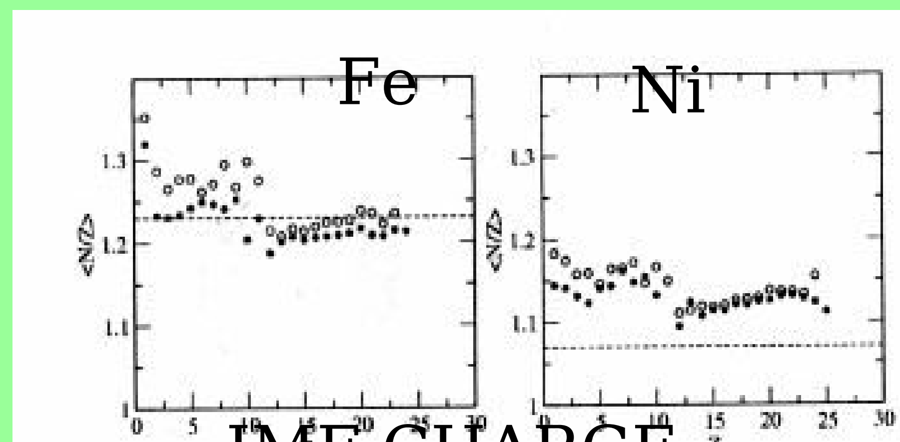
SHORT TIME SCALE <100fm/c

preeq.effects (more n emission in asysoft due to more repuls. meanfield) :
58Fe more n emitted than p : QP,QT tend to lower N/Z
58Ni more p emitted than n : QP,QT tend to higher N/Z --> more isospin to be transferred to the neck (with asystiff the gradient is larger and the migration is stronger)

velocity



N/Z



IMF CHARGE

IMF MASS

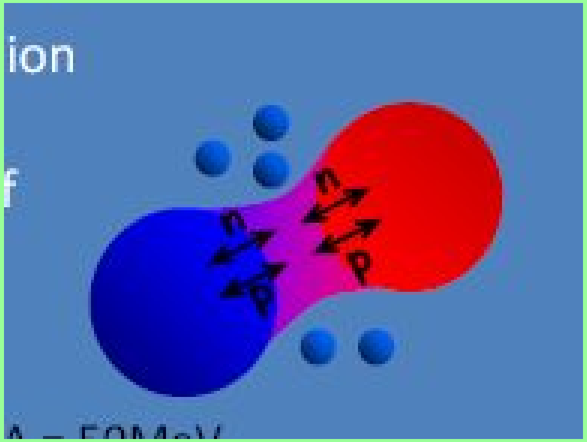
open p. = ASYstiff

full t. =ASY soft

Physics Aspects:

isospin equilibration (or diffusion) <-> n vs. p flows

Charge equilibration in DIC



surface effects appear in the grazing collisions even at medium-high energies

M.Veselsky NP A765(2006) 252, NP A781 (2007))

-how the isospin degree of freedom evolves in collisions as a function of the dissipation

-the charge equilibration is microscopically due to neutron-proton flows between the interacting nuclei

IS THERE ROOM FOR ISOSPIN PHYSICS?

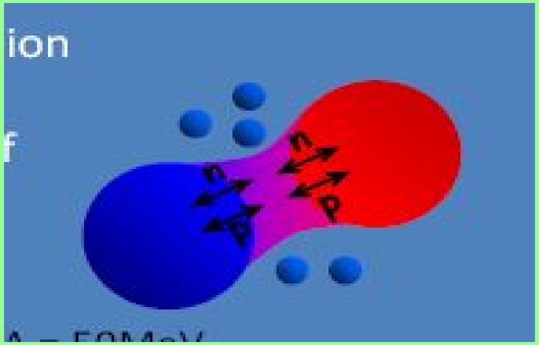
these flows occur in the low-density interface and thus they somewhat depend on the strenght of the Symmetry Energy

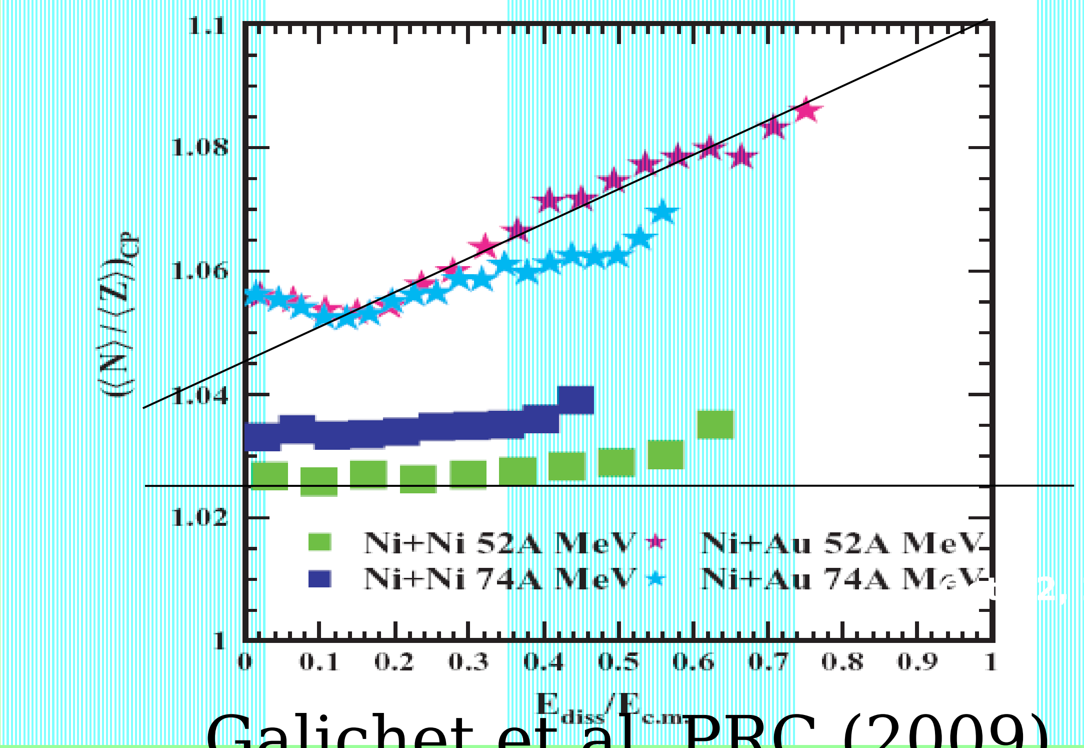
(J.Rizzo NPA806(2008)79)

Physics Aspects:

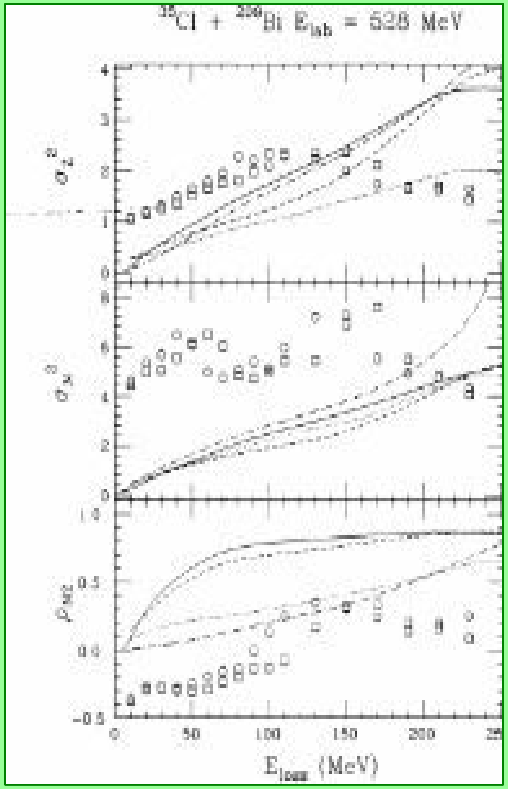
isospin equilibration (or diffusion) <-> n vs. p flows

Charge equilibration in DIC





Galichet et al. PRC (2009)



an 'old' example
Marchetti *PRC 48(1993)*

a modern example
with INDRA

Isospin equilibration: Imbalance ratio an useful variable for mass-symm systems

H: n-rich syst. ^{100}**Mo+** ^{100}**Mo**
L: n-defic. syst. ^{92}**Mo+** ^{92}**Mo**
M : mix system e.g. ^{100}**Mo+** ^{92}**Mo**

SMF simulations

take I=(N-Z)/A or some x = *f*(I)

Phys. Rep. 389 (2004)
Phys.Rep.410(2005)335

$$R_P = \frac{2x_P^M - x_P^{H-H} - x_P^{L-L}}{x_P^{H-H} - x_P^{L-L}}; R_T = \frac{2x_T^M - x_T^{H-H} - x_T^{L-L}}{x_T^{H-H} - x_T^{L-L}}$$

B. Tsang et al. PRL 92 (2004)

for QP fragment **for QT fragment**

$$x^{eq} = \frac{1}{2}(x^H + x^L).$$

R = ± 1 **Full transparency**
R = 0 **Full equilibration**

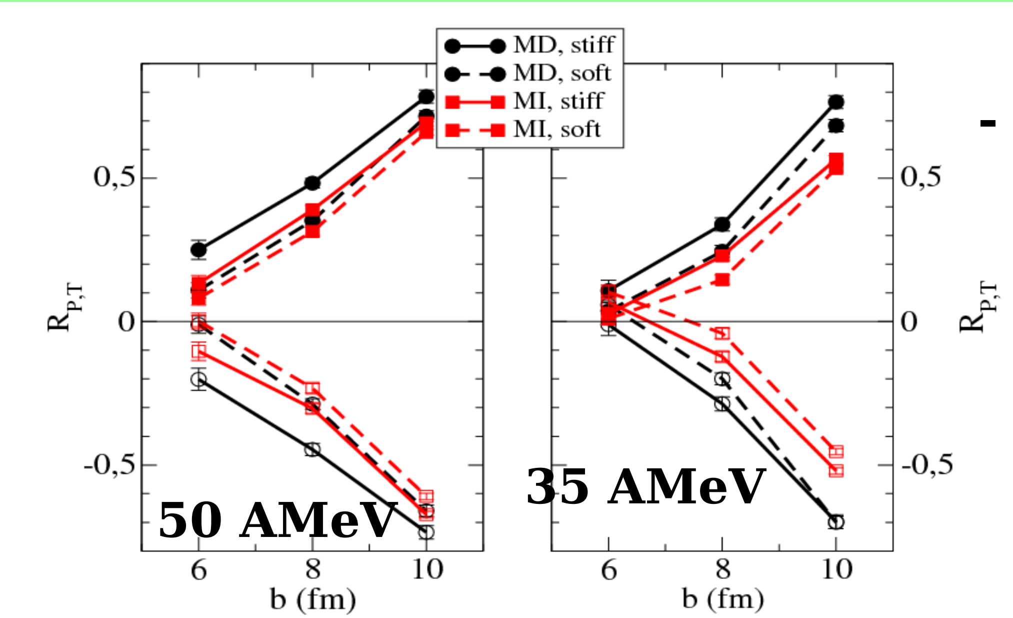
$$R^x_{P,T} = \frac{2(x^M - x^{eq})}{(x^H - x^L)}$$

If: $$x^M = x^{eq} + (x^H - x^{eq})\, e^{-t/\tau} \longrightarrow R^\beta_{P,T} = \pm e^{-t/\tau}$$

(Overdamped dipole oscillation)

τ connected to **symmetry energy** **(restoring force)**
t connected to contact time (**dissipation)**

Imbalance ratios: isoscalar vs. isovector effects



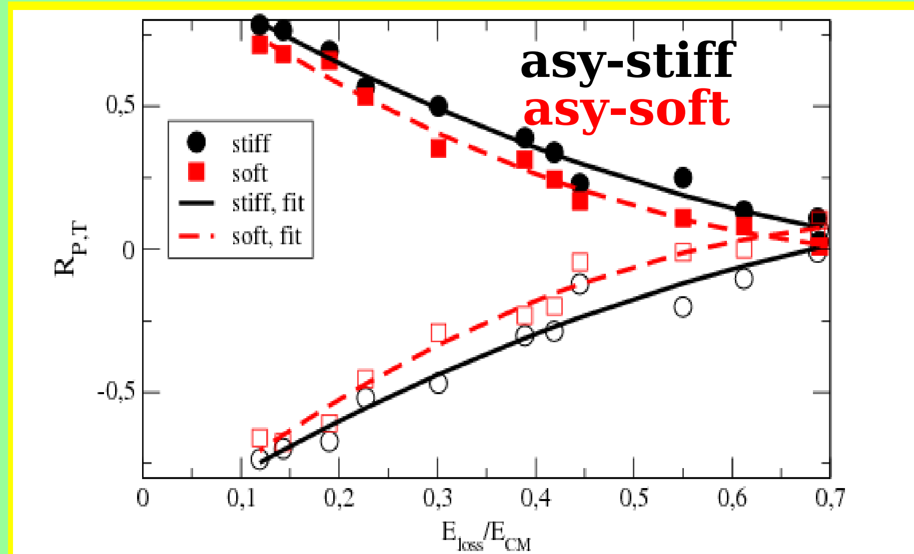
—— **asy-stiff**
- - - **asy-soft**

Faster Iso-equilibration for:
✓- - - Asy-soft (larger Esym)
✓MI interaction
✓Lower beam energies (longer int. times

J.Rizzo et al. NPA806 (2008) 79

Order parameter to select events as a function of b (time of contact)

R dependent only on the isovector part of the interaction !

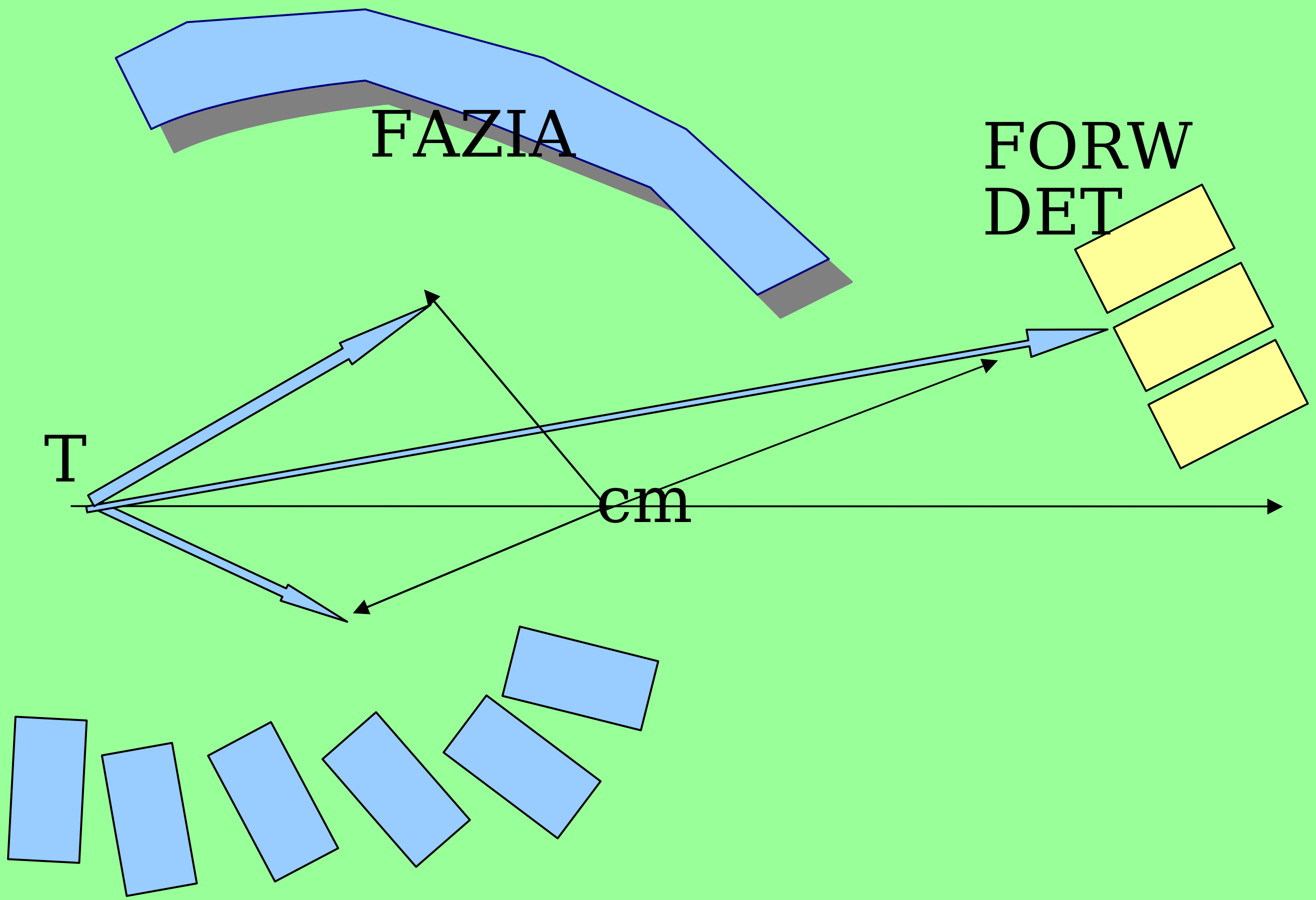


- **Two-body collisions ?**
- **Pre-equilibrium effects ?**
- **Size effects ?**
- **Initial N/Z ?**

An experiment at LNS

- **funding and manpower limitations**
- **The Ciclope chamber is 'free';**
- **The RCO is available and easy to transport;**
- **The FAZIA telescopes will be ready by early 2013;**
- **other detectors could be available: GARFIELD, PHOS (from FIASCO), Telescopes from 8plp.**

An experiment at LNS



- *Midvelocity emissions and (part of) QP,QT emissions*

E from 1 to 50AMeV for all species (300-500μm Si and CsI)

from ΔE-E: Z and A for fast ions (>18-20AMeV)

from Cs-Fast-Slow: Z and A for fast LCP

from Si-PSA, Z for 3 to 18-20 AMeV and A up to Z=8 (?)

A from E-tof for all ions (e.g. A/ΔA=4 at 35AMeV and A/ΔA=7 at 10AMeV, L=60cm, Δt=1ns)

An experiment at LNS

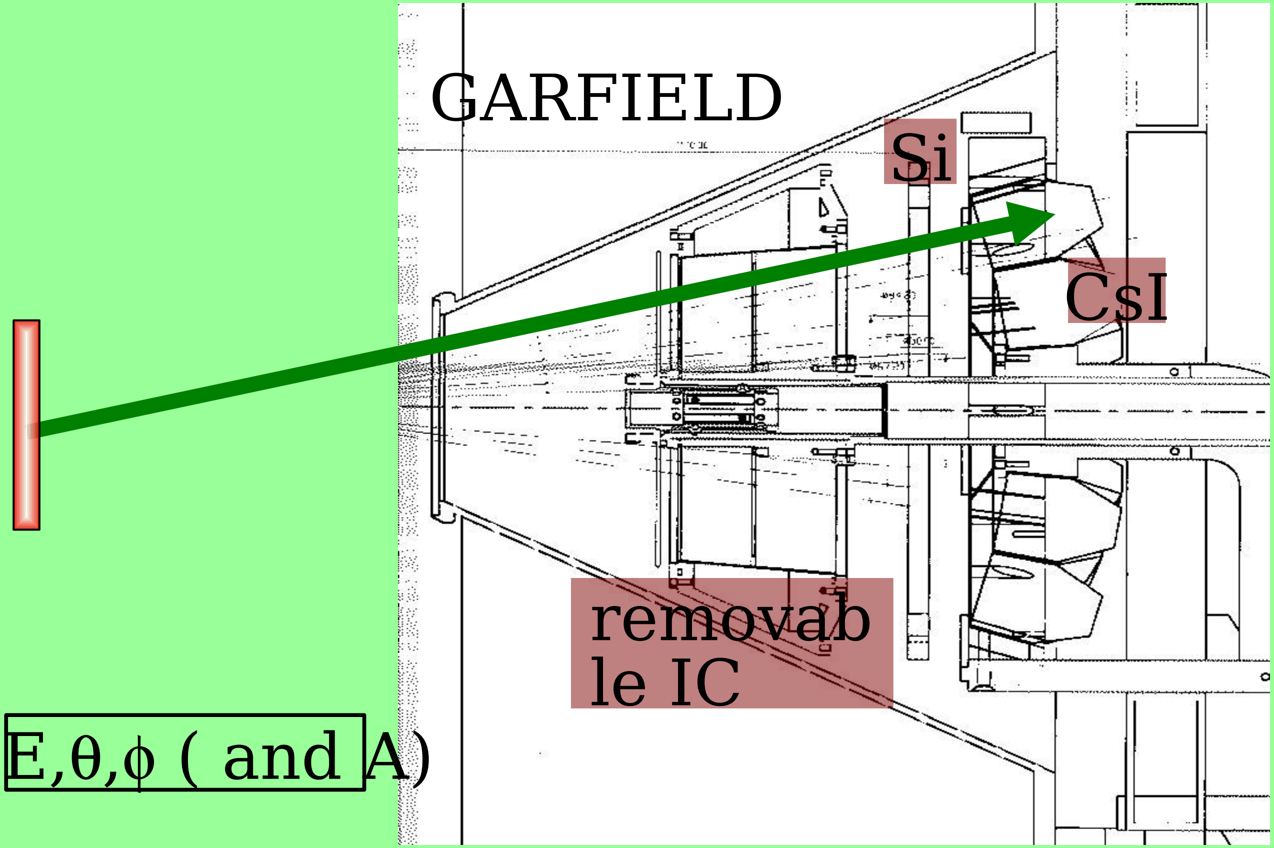
Basically, the idea, for this collisions, could be:

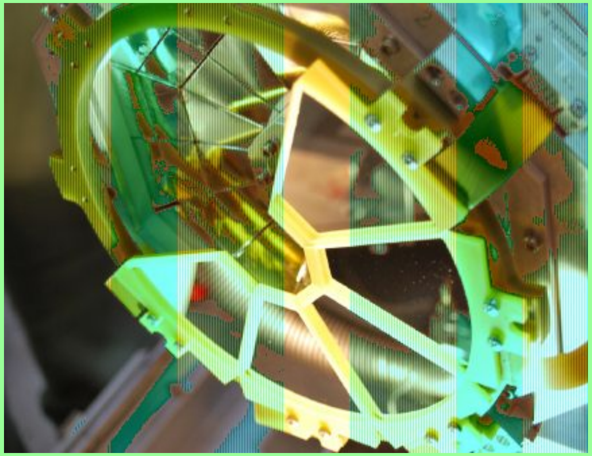
- **not to build a 4p detector!**
- **to concentrate on DIC (peripheral – semiperipheral, say b>5fm)**
- **to select a 'reaction plane' (binary collisions)**

- **to detect QP as precisely as you can**
  Z from DE(300micron-Si)-E(40mm-CsI)
  Z for stopped species (PSA E-risetime)
  A from DE(300micron-Si)-E(40mm-CsI) up to Z=10 (check!)
  A for fast LCP and IMF via PSA in CsI
  A for light stopped ions (QT decay at small theta)
  E from DE+E(scint) ---> estimate of VEL if ansatz on A
- **to detect QT in the way you can**
  position detector only (?)
  position and velocity and 'energy' via PHOSWICH (?)
  position and E (and Z from PSA) from Telescope (8plp?)
- **to detect lcp and imf from midvelocity emissions with FAZIA**

The Garfield Ring Counter (RCO)

The RCO is an array made of (gas)-Si-CsI detectors. Following recent results from FAZIA-Nucl-ex group we upgraded the RCO (commissioning july,2009).





Z,$\boxed{\text{E},\theta,\phi\text{ (and }}$A)

$\delta\theta=2.7^{o}$

coverage: 5 to 17deg

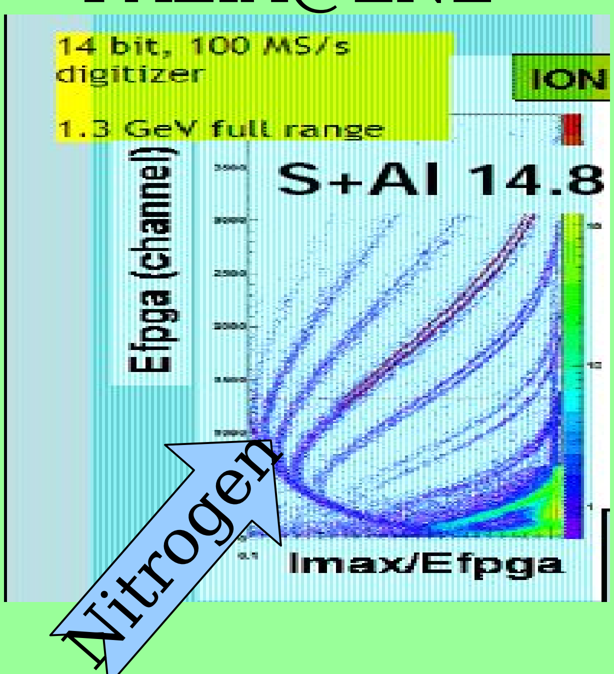
Issues at LNS:
-remove IC?
-no tof
-enough pos. precision?

The digitized RCO

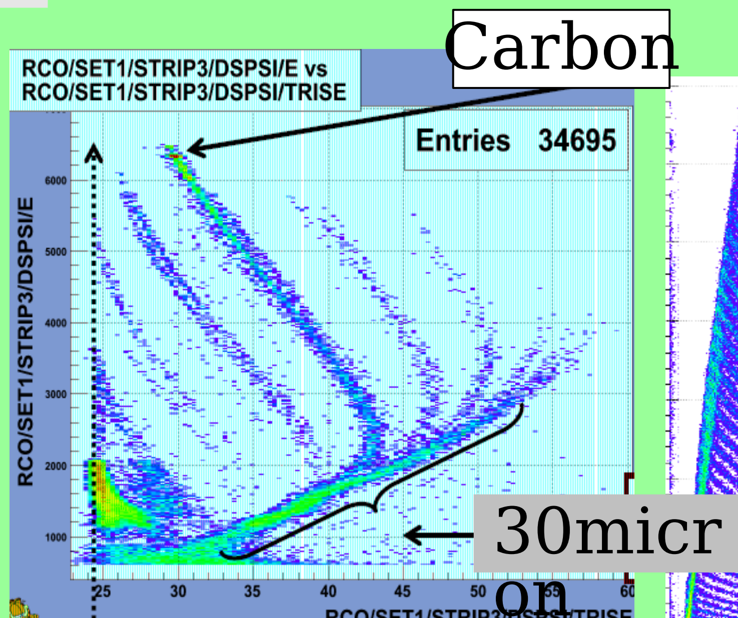
RELEVANT ISSUES FOR PULSE SHAPE ANALYSIS

- **nTD Si with uniform resistivity in the bulk**
- **reverse mounting for low-electric-field injection**
- **fast digital sampling Electronics (Si and CsI) and l.n. Preamp**

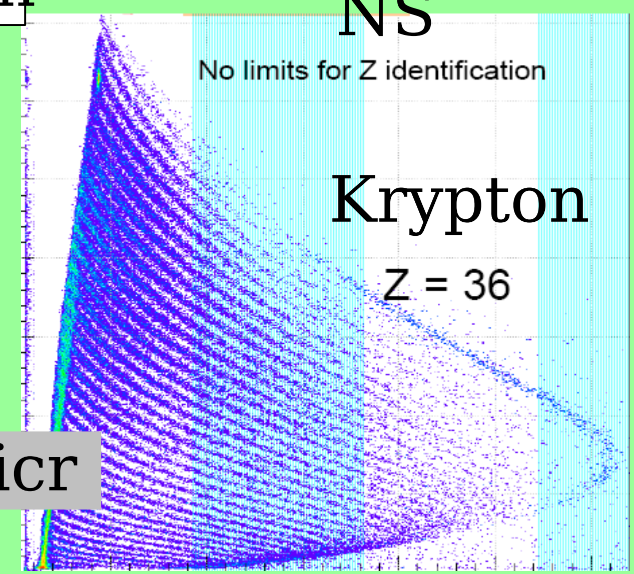
PSA in Silicon FAZIA@LNL



RCO@LNL



FAZIA@LNS



The FAZIA PhaseII-bis: (almost) fixed facts

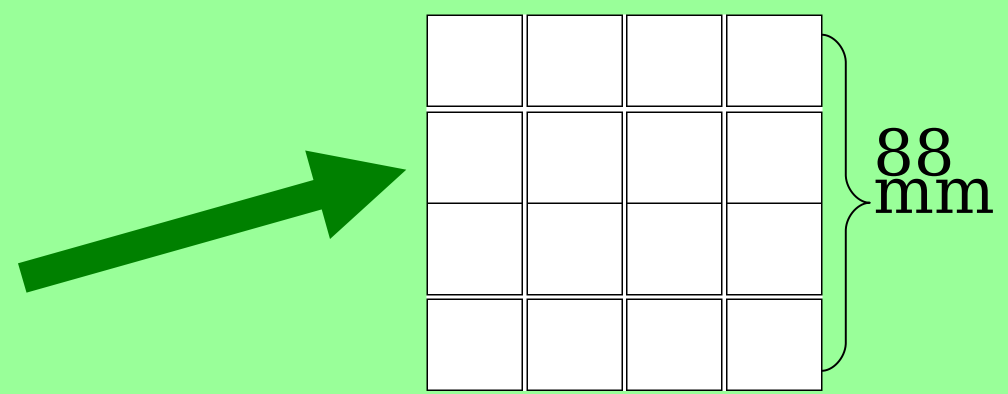
Silicons: 20x20 mm2; Thickness: 300 and 500 micron; special production process for homogeneity, orientation, metal deposition

CsI(Tl): 20.5x20.5x40mm3 OR
20.5x20.5x100mm3 slightly tapered (see later)
Tl-doping between 1500 and 2000ppm
readout: PD-coupling or/and SCT

Unit-Module (Stand-Alone Module, SAM): 4x4 telescope matrix, about 88x88mm2 front face package;
This is the elementary Telescope Group as far as mechanics, electronics, cooling, fine orientation tuning of the 2x2 subgroups)

Fazia PhaseII-bis foresees 12-14 SAM i.e. 192 telescopes

SAM

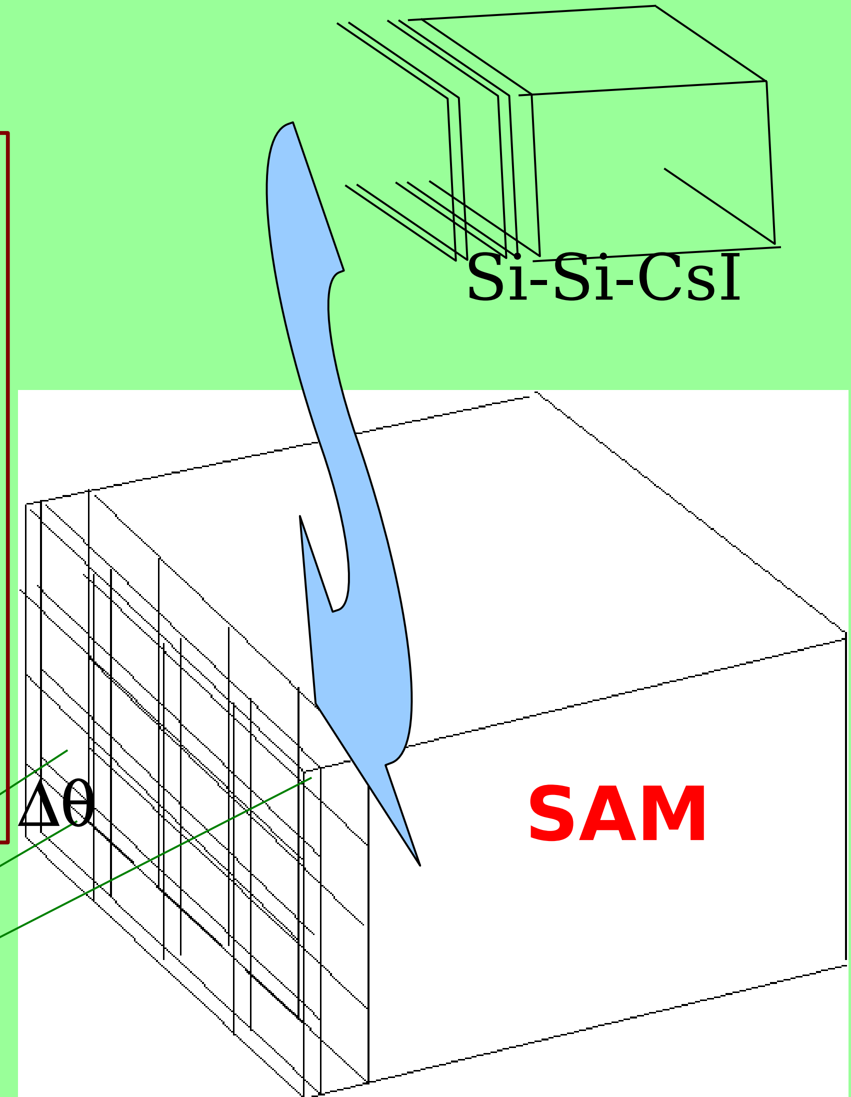


Please note:
all telescopes cover
768cm^2 corresponding to **77msr at 100cm** (0.6% of 4π)

Some Numbers

distance from target mm	$\Delta\alpha$ deg	$\Delta\theta$ deg	$\Delta\Omega$ pad/sam msrad
600	**7.6**	**1.9**	**1.1/17.6**
1000	**4.4**	**1.1**	**0.4/6.4**
1700	**(max val for Garfield chamber forw. mounting)**		
	2.8	**0.7**	**0.14/2.2**
2000	**(possible value for Indra)**		
	2.4	**0.6**	**0.1/1.6**

start to be interesting for particle correlation function studies



Present performances

ENERGY pulse height for ALL IONS
E from 1 to 50AMeV for all species (300+500μm Si)

CHARGE and MASS usual ΔE-E tech. for FAST IONS
Z for fast ions (>18-20AMeV) (300-500μm Si) up to Z=54
A for fast ions (>18-20AMeV) (300-500μm Si) up to Z=20
Z,A for very fast and light ions(800μmSi +CsI)

CHARGE and MASS pulse shape analysis; for SLOW IONS
Z from 3 AMeV (for light ions) to 18/20 AMeV (300μm) up to Z=54
A up to Z=5-7 (300μm) (to be confirmed; thresholds?)

for the slowest species a partial recovery of masses comes from E-TOF.
Hp) L=70cm, Δt=1ns overall FWHM (negligible ΔE contribution)

A/ΔA=8 at 10AMeV ion vel= 4.4 cm/ns stopped 300
A/ΔA=11 at 5AMeV ion vel= 3.1 cm/ns stopped 300
A/ΔA=18 at 2AMeV ion vel= 2.0 cm/ns stopped 300

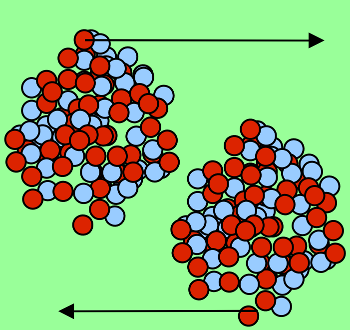
Hipse: an event generator for nuclear reactions *(Lacroix et al. PRC69(2004))*

statistical approach
(a few global variables)

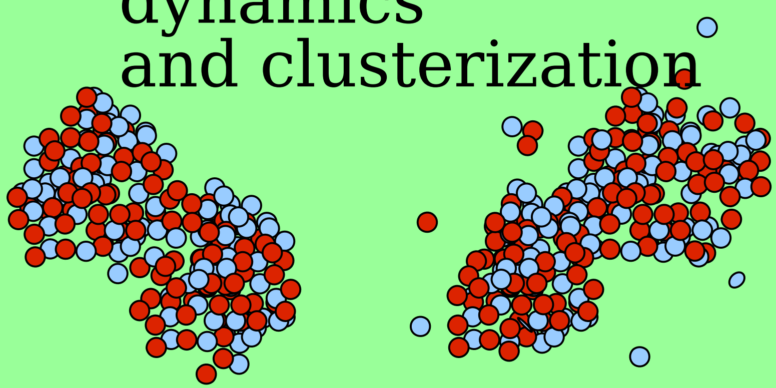
microscopic transport approach
(n-n Xsection + mean field)

macroscopic-microscopic Phenomenology

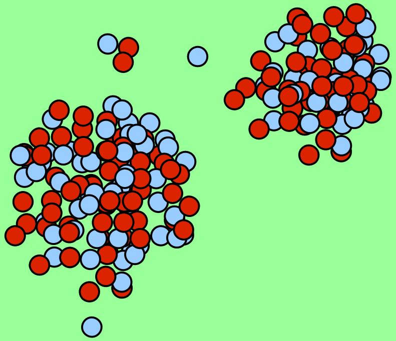
approaching



dynamics
and clusterization



decay



- nucleon ensembles in g.s.
- boosted in momentum
- classical trajectories

- overlap region (vs. b)
- nucleon rearrangement in phase-space.
- clustering of LCP and IMF (coealescence recipe)

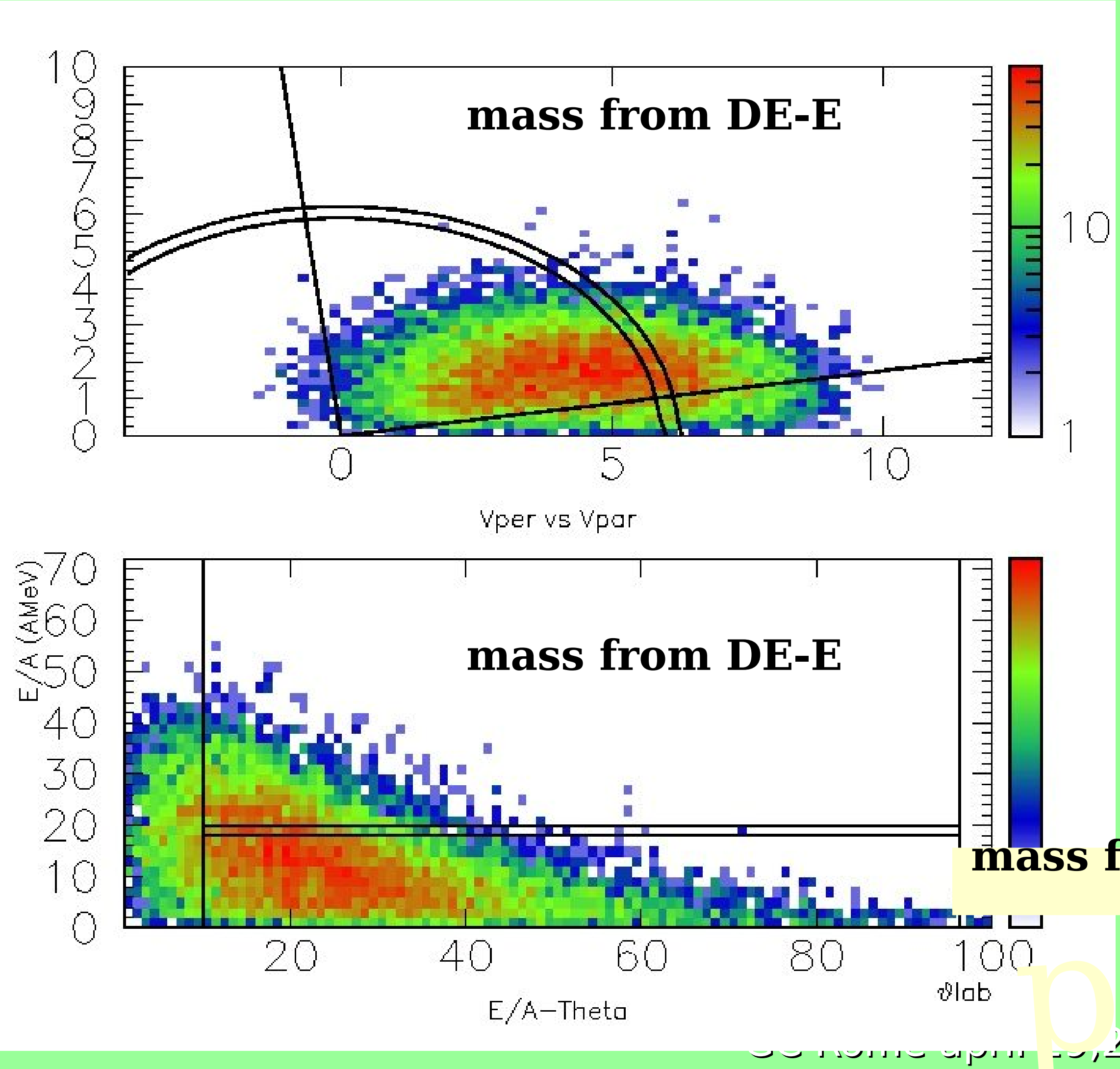
statistical decay
via SIMON code

note: HIPSE mainly tested at Fermi energies

ISOSPIN ARRAY

HIPSE model predictions for **48Ca+40Ca at 35AMeV**

FAZIA located at 70cm; a belt 10 to 96deg (reaction plane)



mass from PSA

central collisions
b<5 fm

plotted the **IMF**
4< A < 16

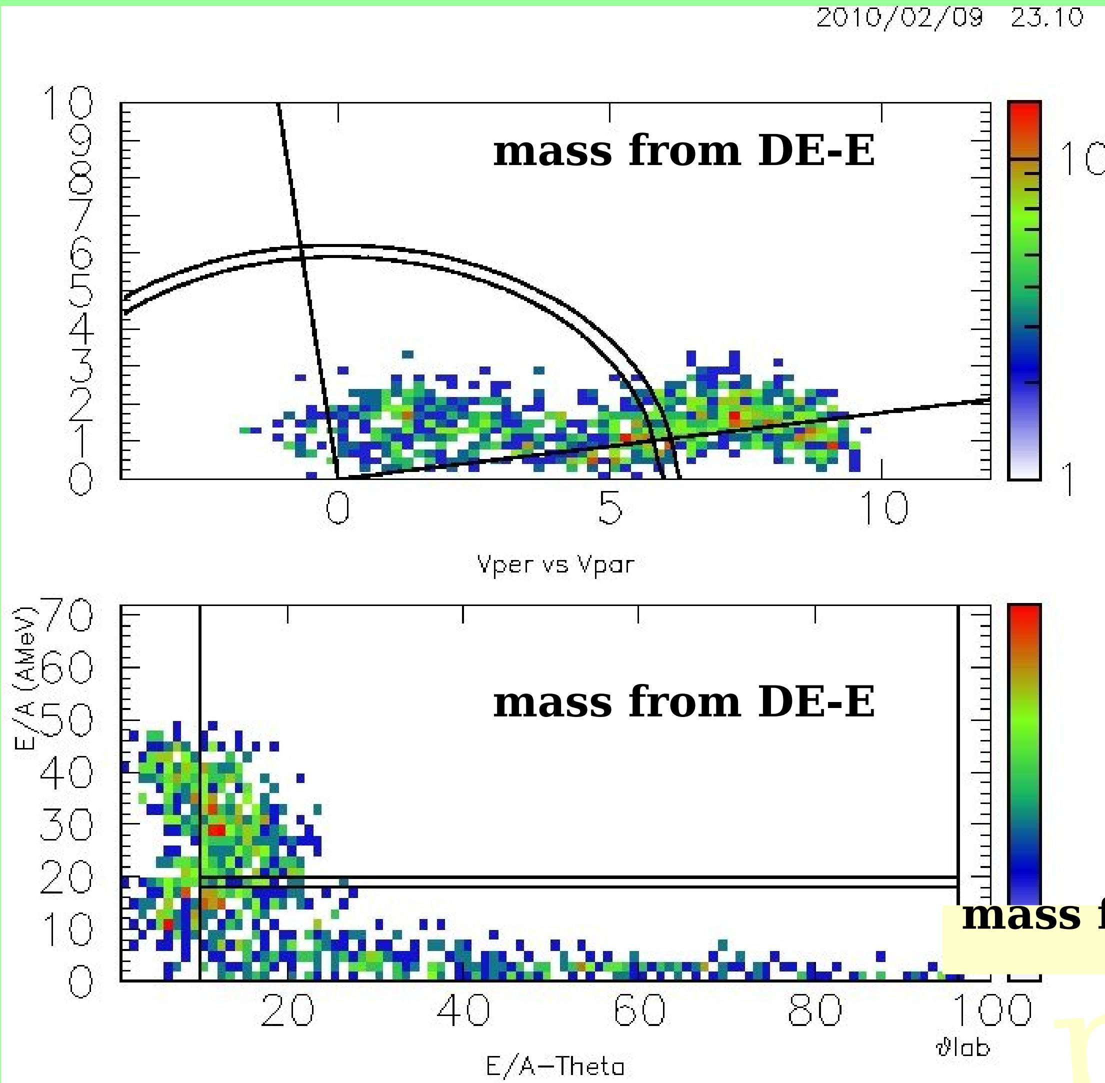
18-20AMeV veloc.
correspond to
pthru 300micron
for many species

preliminary

B) ISOSPIN ARRAY

HIPSE model predictions for **48Ca+40Ca at 35AMeV**

FAZIA located at 70cm; a belt 10 to 96deg (reaction plane)



mass from PSA

peripheral collisions
b>5 fm

plotted the **IMF**
4< A < 16

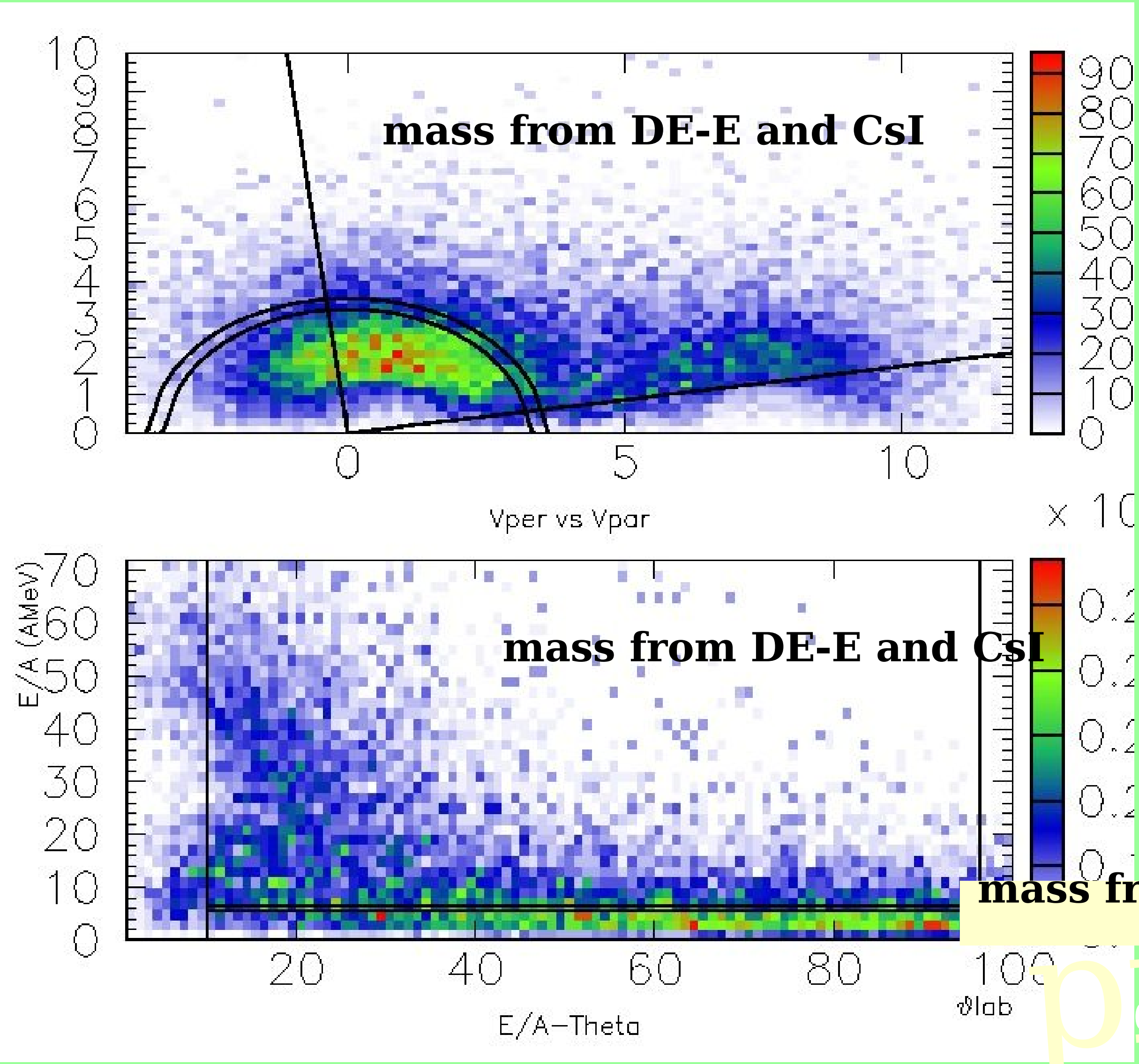
18-20AMeV
correspond to
ptru 300micron
for many species

preliminary

B) ISOSPIN ARRAY

HIPSE model predictions for **48Ca+40Ca at 35AMeV**

FAZIA located at 70cm; a belt 10 to 96deg (reaction plane)

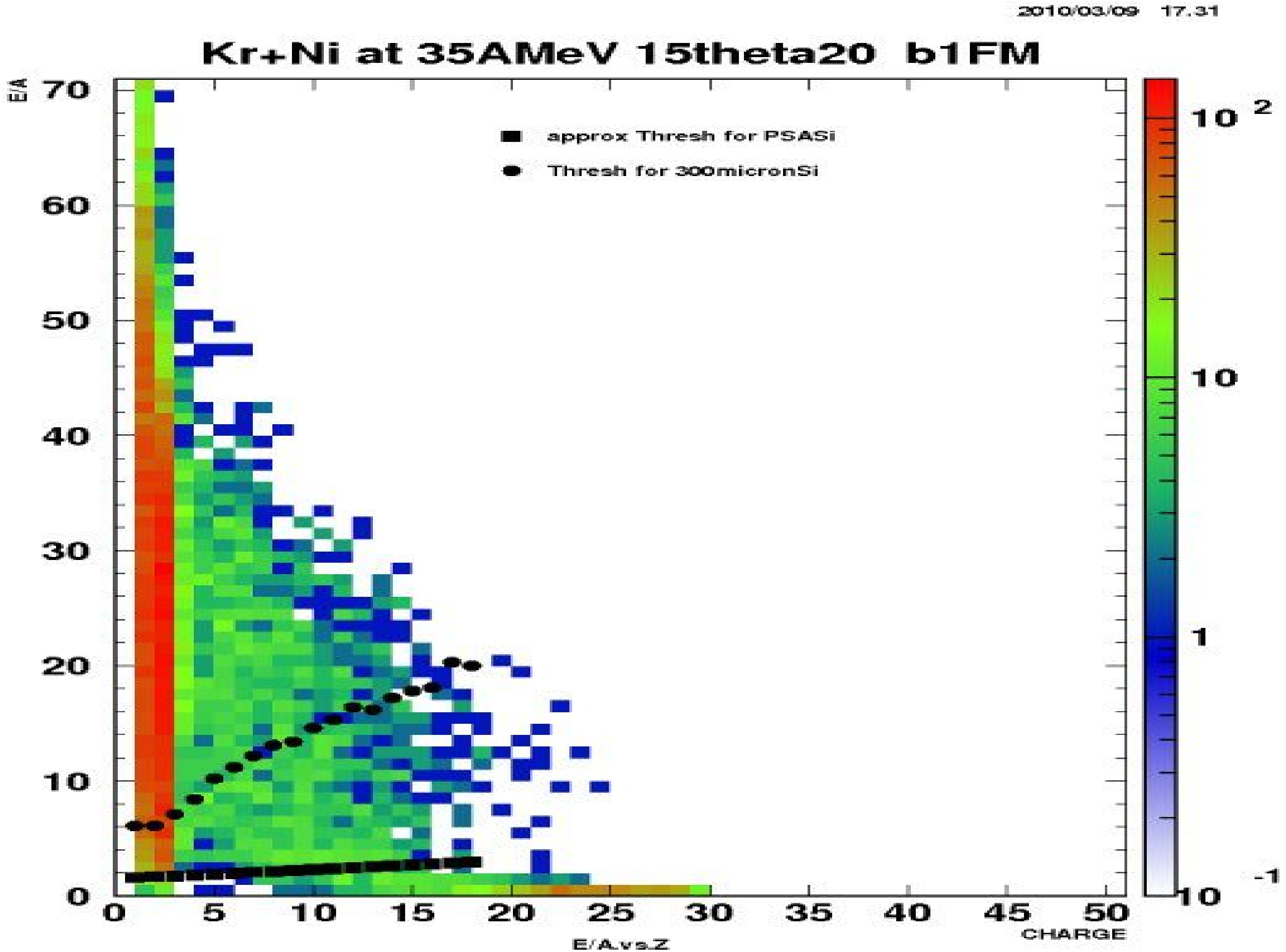


peripheral collisions
b>5 fm

plotted the **LCP**
A < 5

5.5-6.5 AMeV
correspond to
pthru 300micron
proton and Alphas

preliminary

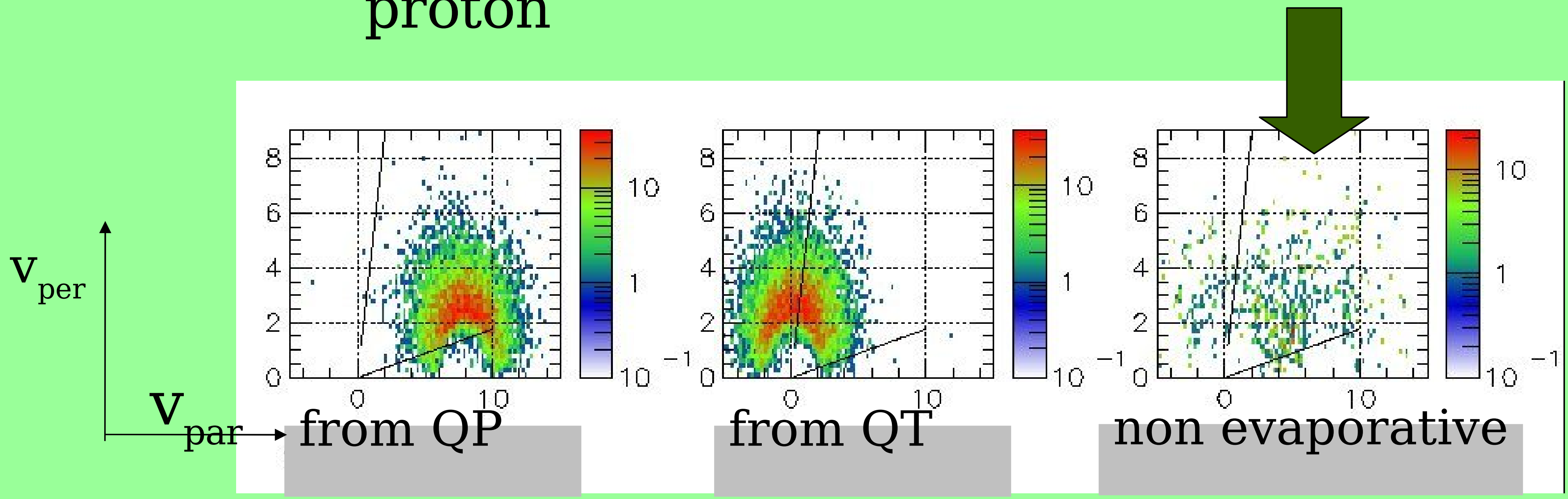

2010/03/09 17.31
Kr+Ni at 35AMeV 15theta20 b1FM
approx Thresh for PSASi
Thresh for 300micronSi
E/A
CHARGE
E/A.vs.Z

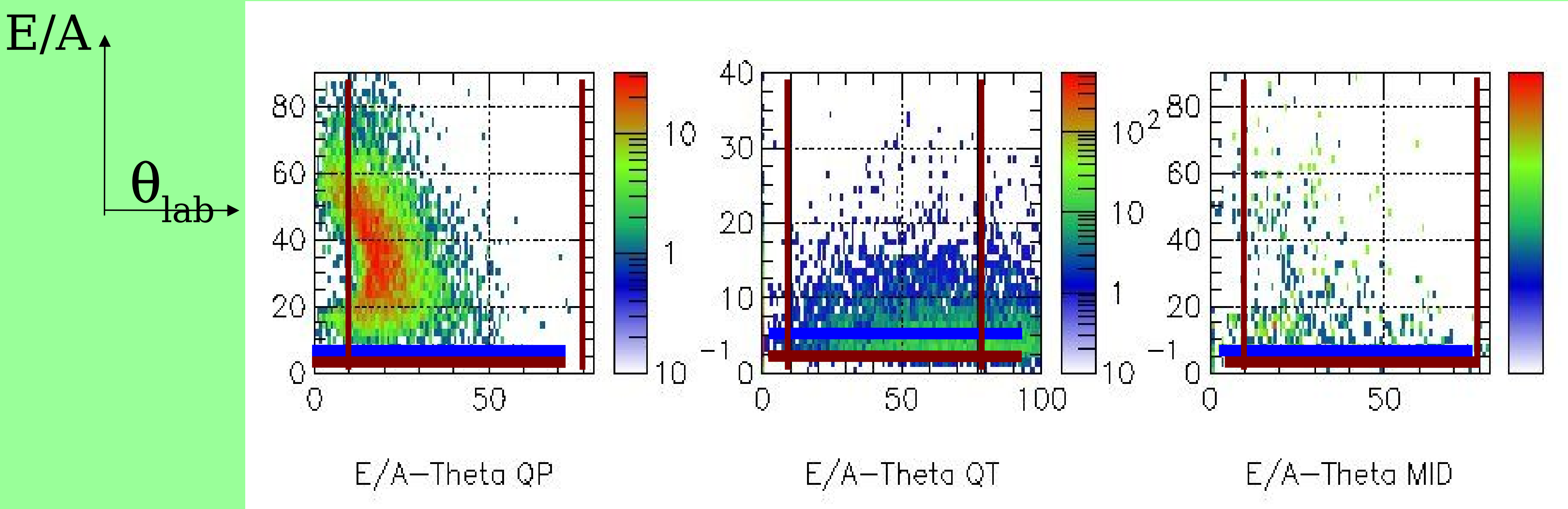
b>6fm

HIPSE **Ni+Ni 35AMeV**

proton

ok

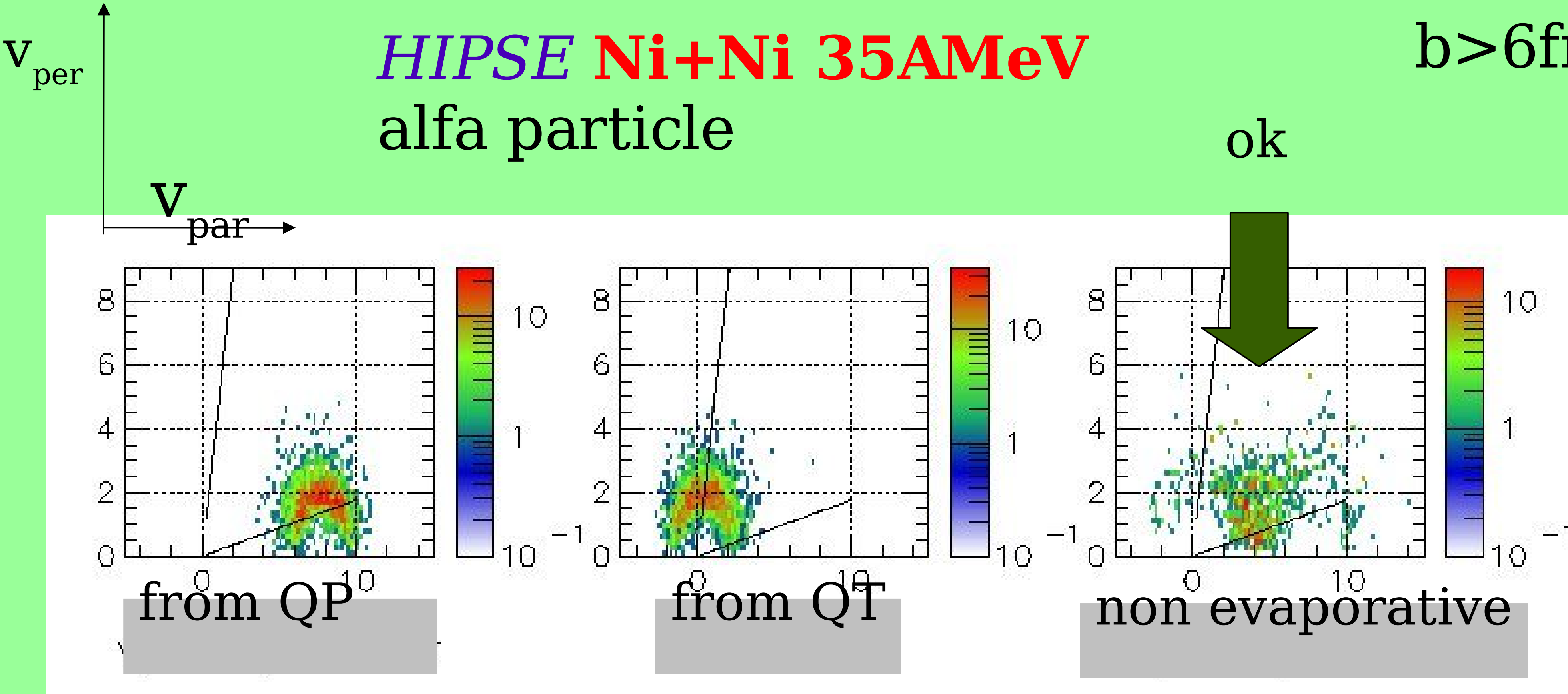


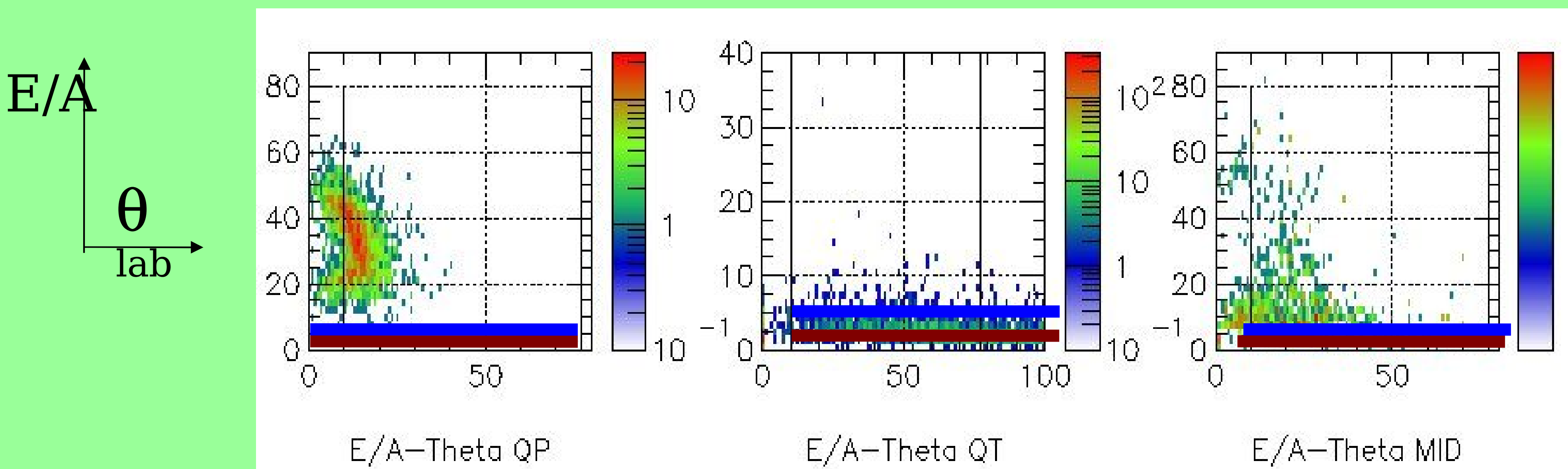


HIPSE **Ni+Ni 35AMeV** b>6fm

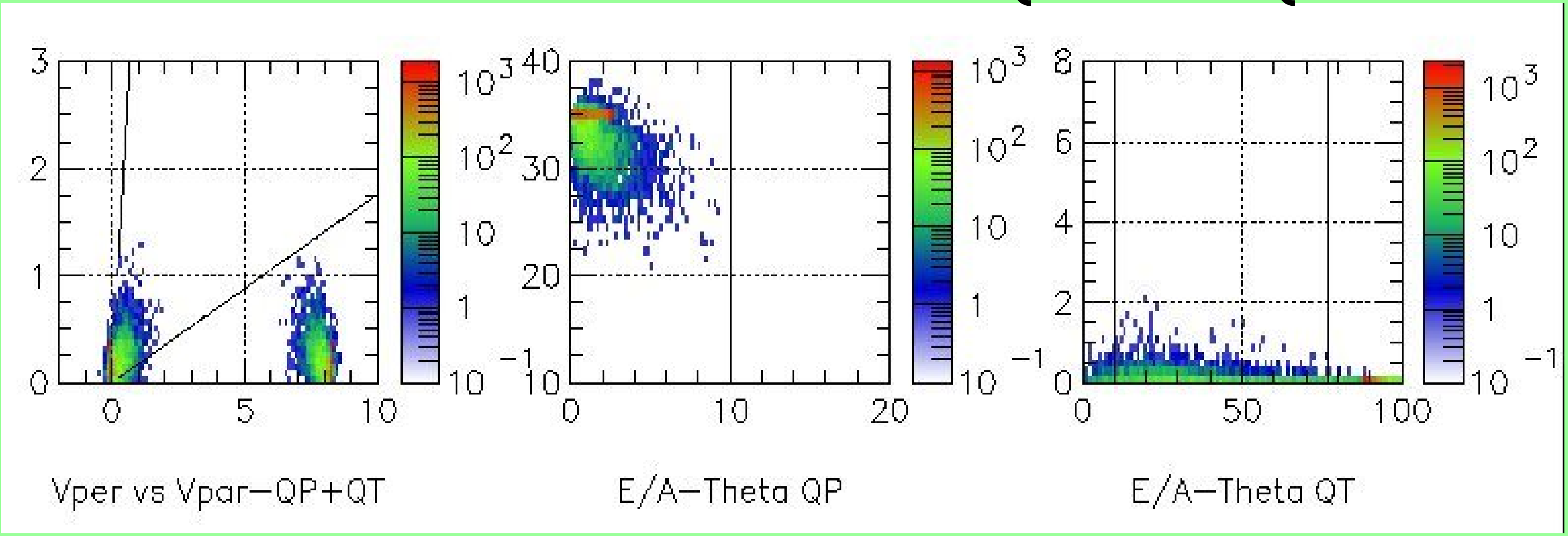
alfa particle

ok



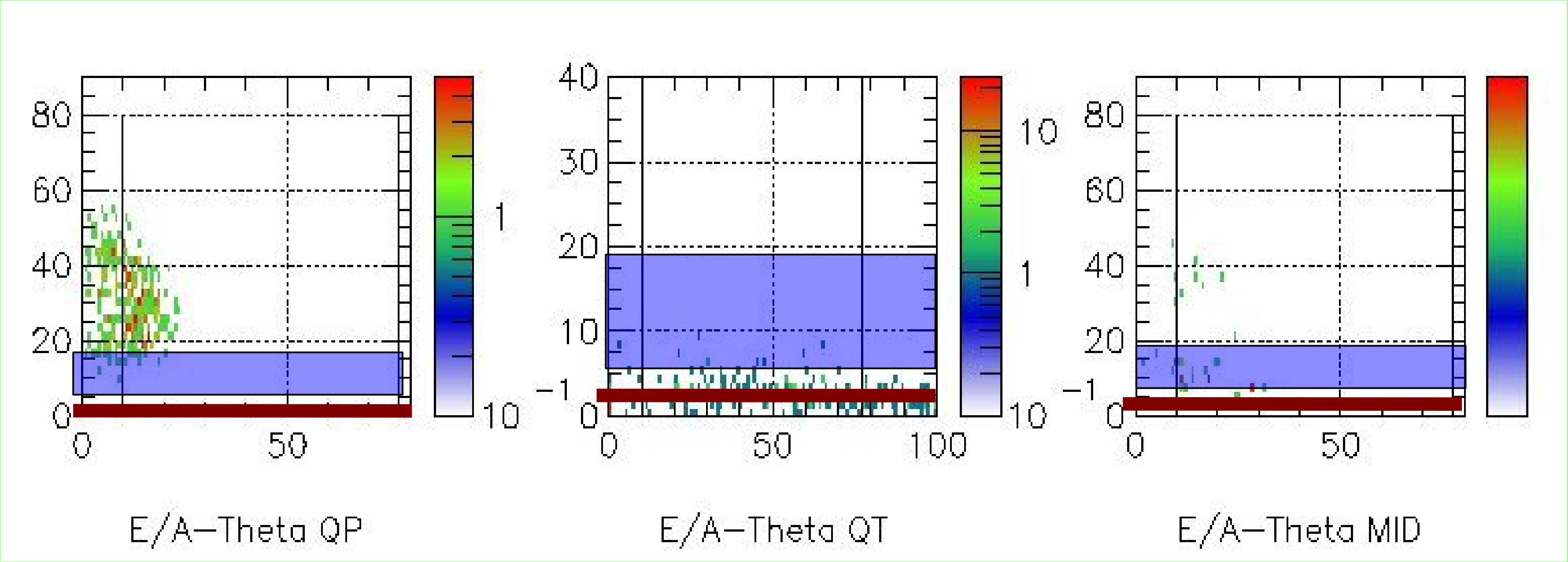


HIPSE **Ni+Ni 35AMeV** QP and QT



HIPSE **Ni+Ni 35AMeV**

IMF from lithium to magnesium

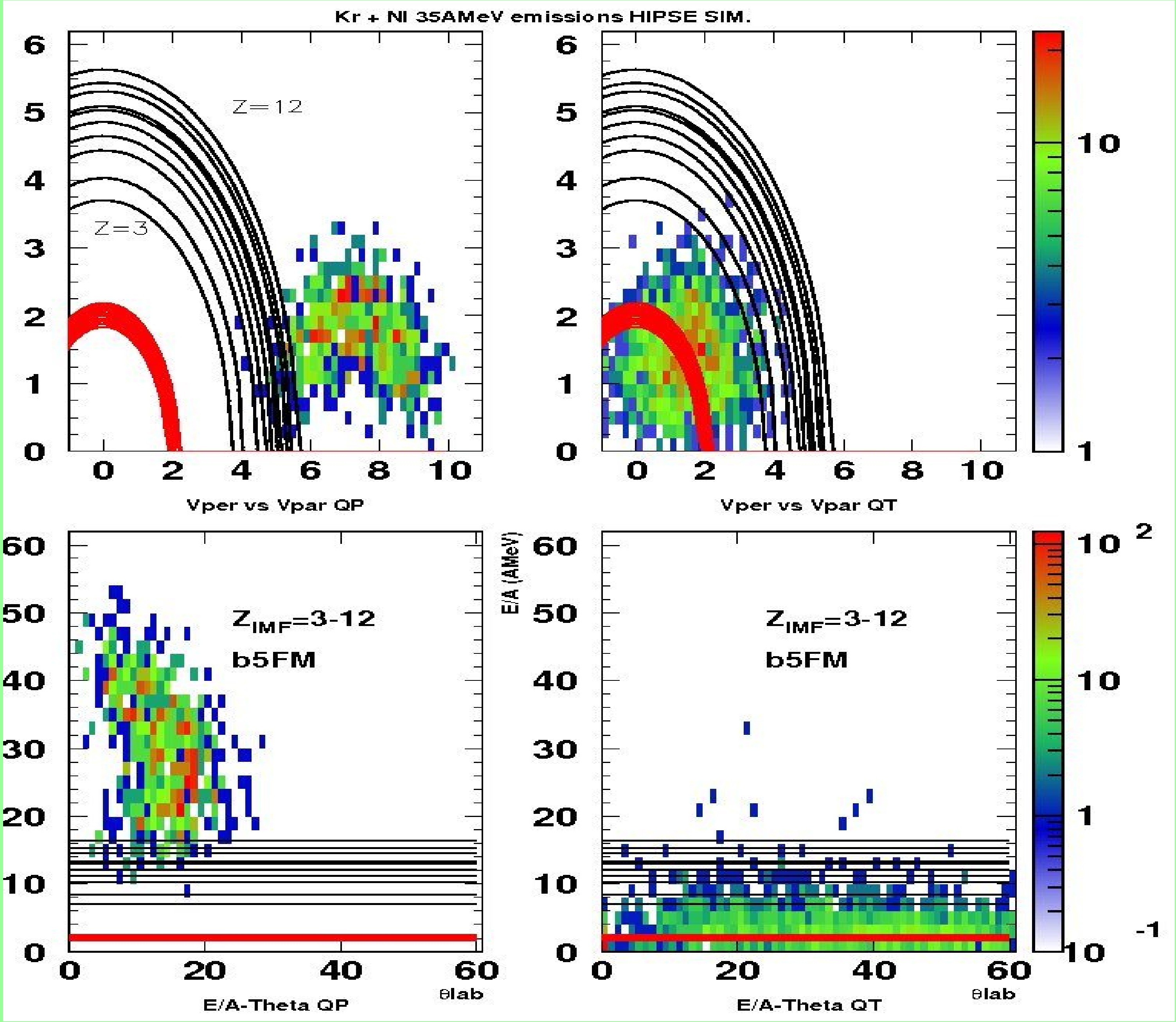


conclusions

Study for dynamics effects and EOS in semiperipheral collisions

-Intermediate energies at CS LNS from 17 to 50 AMeV

Detectors: for QP the RCO and or the PHOS
for QT array of PHOS, or the 8plp BALL
or ….
for MIDVEL emissions
T> two-years FAZIA BELT configuration
T< two-years 8plp Telescopes? PHOS? or….

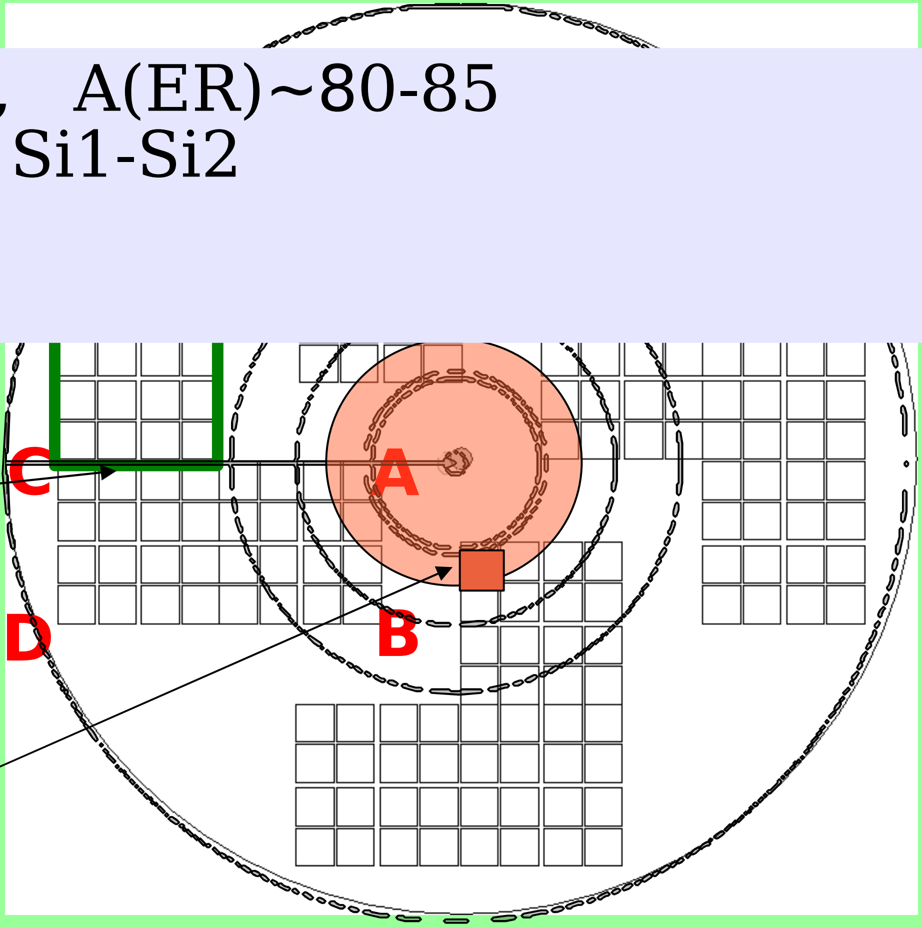


Kr + Ni 35AMeV emissions HIPSE SIM.
Z=12
Z=3
Vper vs Vpar QP
Vper vs Vpar QT
E/A (AMeV)
Z_IMF=3-12
b5FM
Z_IMF=3-12
b5FM
θlab
θlab
E/A-Theta QP
E/A-Theta QT

Fazia HODO

In this case we have A(QP)~>40,   A(ER)~80-85
QP: Z,A from DE-E even cooked Si1-Si2
ER: Z from PSA for fresh Si1
ER: A not reachable via E-TOF

θ(D,E)=6.8 deg



^{48}Ca+^{40}Ca 35AMeV
thGrazing =2.1 deg.
elastic- quasielastic p.thru in 300micron

total reaction rate 57000s^{-1}
elastic rate 1.5-2deg
each pad   about 2300cps
Xsection measured (efficiency included): 1%
570 cps --> DT 30%   --> 400cps
2exp8 good events in 5.8 days
Pads close to grazing:
not implanted 1.1x10^9 ^{48}Ca ions
+implanted also some 10^7 ER A=80

fixed parameters:
target thickness 0.2mg/cm2
current 1pnA

interesting systems

Baran NPA730(2004)329 **124Sn+64Ni 35AMeV**
SMF calc. b>4fm b/bmax>0.37
58Fe N/Z=1.23 58Ni N/Z=1.07
IMF from neck after about 150fm/c; max yield from neck at 6-7fm

tiff the gradient is larger and the migration is stronger)

guardare neckimf vs. vrel (TKEL) rise and fall?
relative veloc. imf-qp, imf-qt Wilcz2 plot
isoscaling per midvelocity?