NUSYM 2017
7th international symposium on nuclear symmetry energy
SEPTEMBER 4TH - 7TH / GANIL, CAEN, FRANCE

ASY-EOS II: perspectives for investigating high-density Symmetry Energy @ GSI

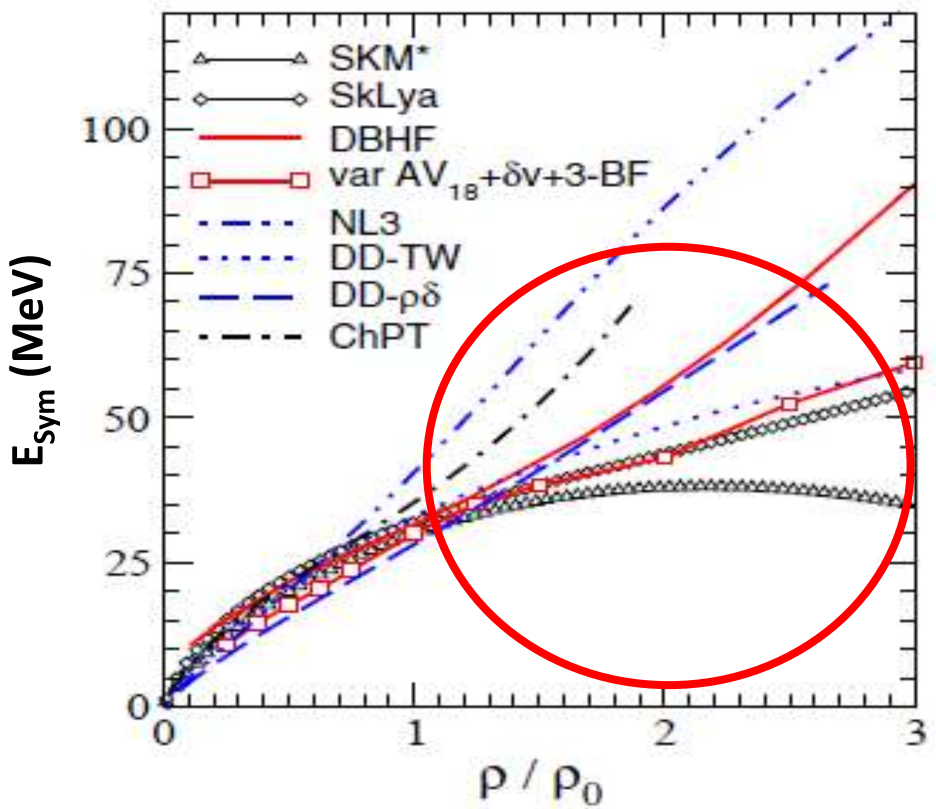
P. Russotto, INFN-LNS, Catania, Italy

for

ASY-EOS II & NewCHIM collaborations

INFN

Symmetry Energy at supra-saturation densities



Fuchs and Wolter, EPJA 30 (2006)

Why high-density?

- Huge divergences
- Few constraints
- Astrophysical interest

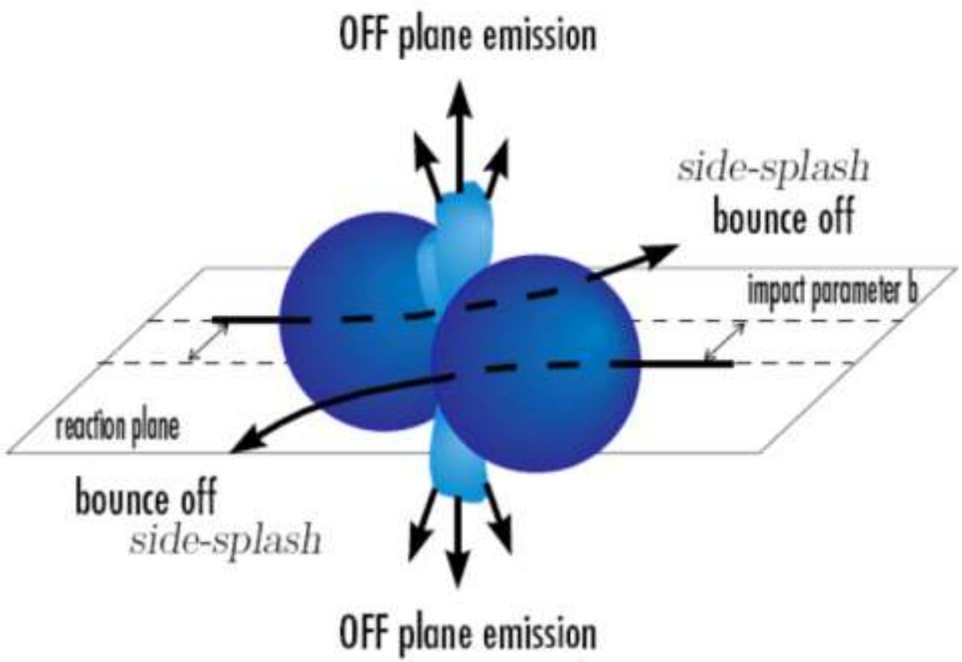
High densities observable: flows
(pions discussed elsewhere)

$$\frac{dN}{d(\phi-\phi_R)}(y,p_t)=\frac{N_0}{2\pi}\left(1+2\sum_{n\geq 1}v_n\cos n(\phi-\phi_R)\right)$$

Y = rapidity
pt = transverse momentum

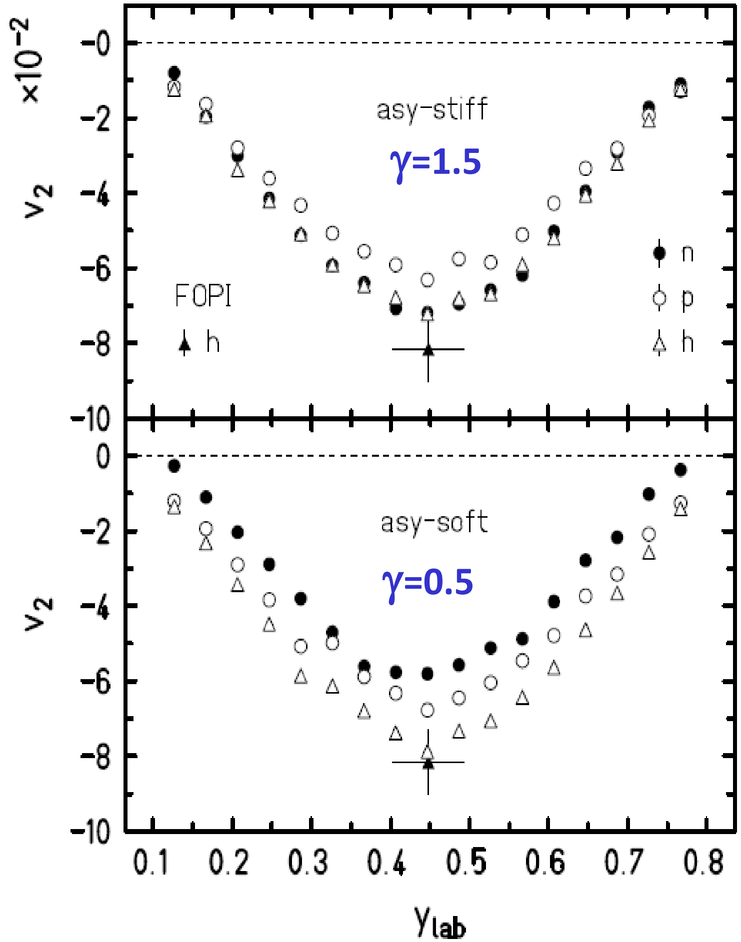
$$V_2(y,p_t)=\left\langle\frac{p_x^2-p_y^2}{p_t^2}\right\rangle$$

Elliptic flow: competition between in plane ($v_2>0$) and out-of-plane ejection ($v_2<0$)



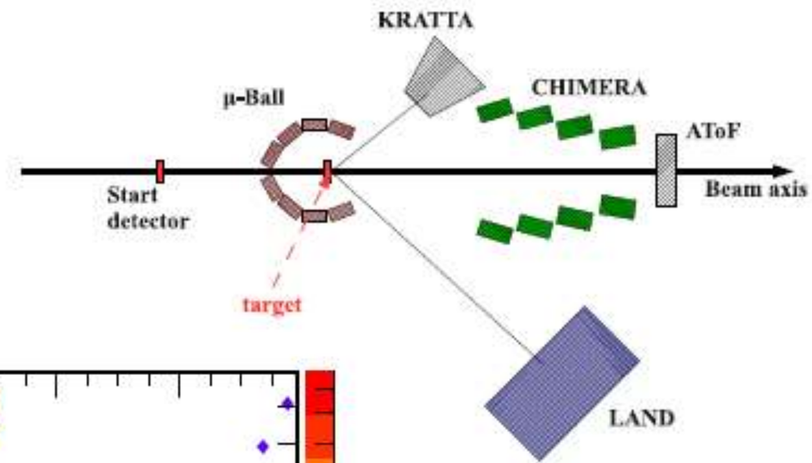
$$E_{sym}=E_{sym}^{pot}+E_{sym}^{kin}$$
$$=22\,\text{MeV}\cdot(\rho/\rho_0)^{\gamma}+12\,\text{MeV}\cdot(\rho/\rho_0)^{2/3}$$

UrQMD :Au+Au @ 400 AMeV
5.5<b<7.5 fm



Qingfeng Li, J. Phys. G31 1359-1374 (2005)
P.Russotto et al., Phys. Lett. B 697 (2011)

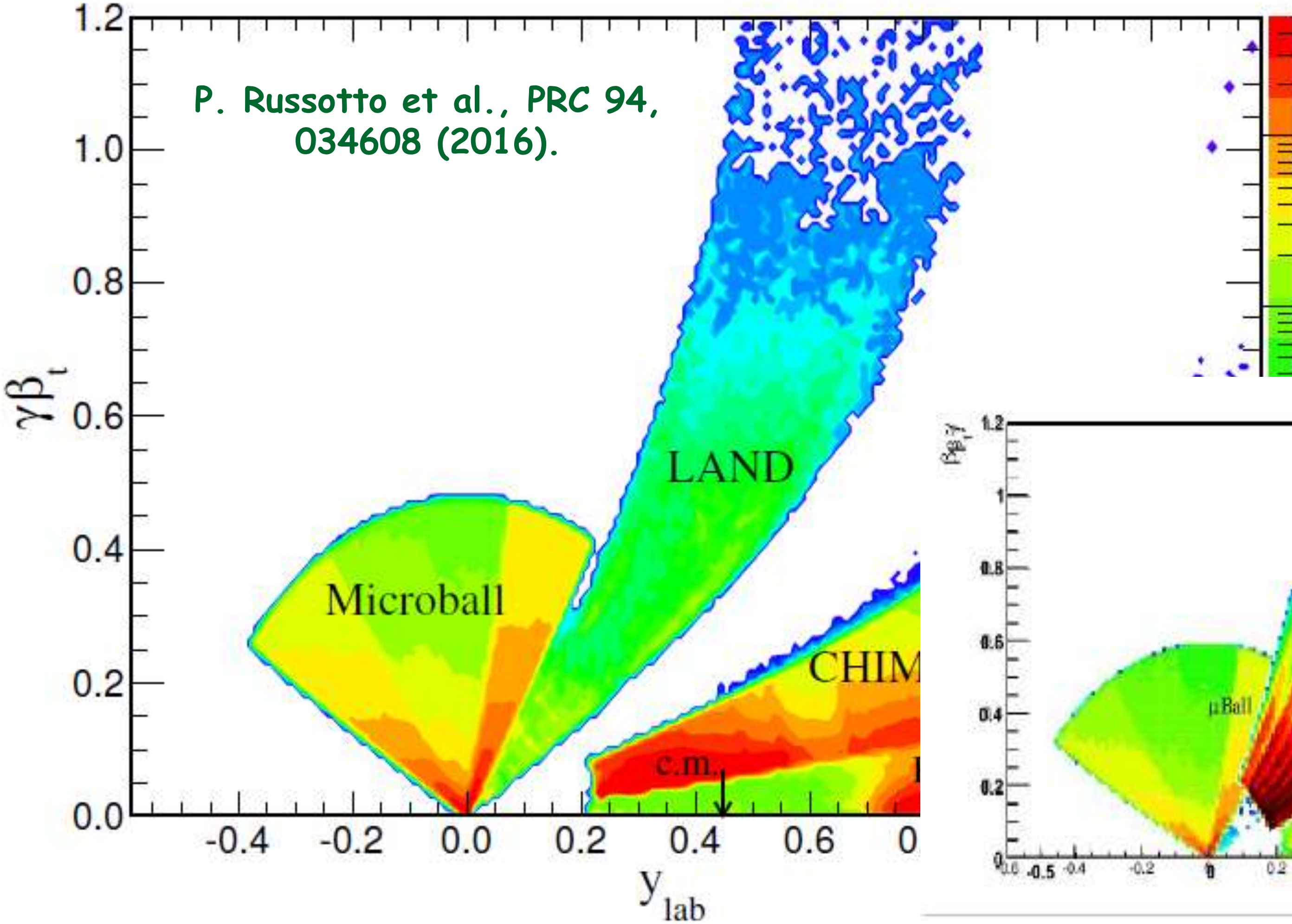
ASY-EOS S394 experiment @ GSI Darmstadt (May 2011)



Au+Au @ 400 AMeV

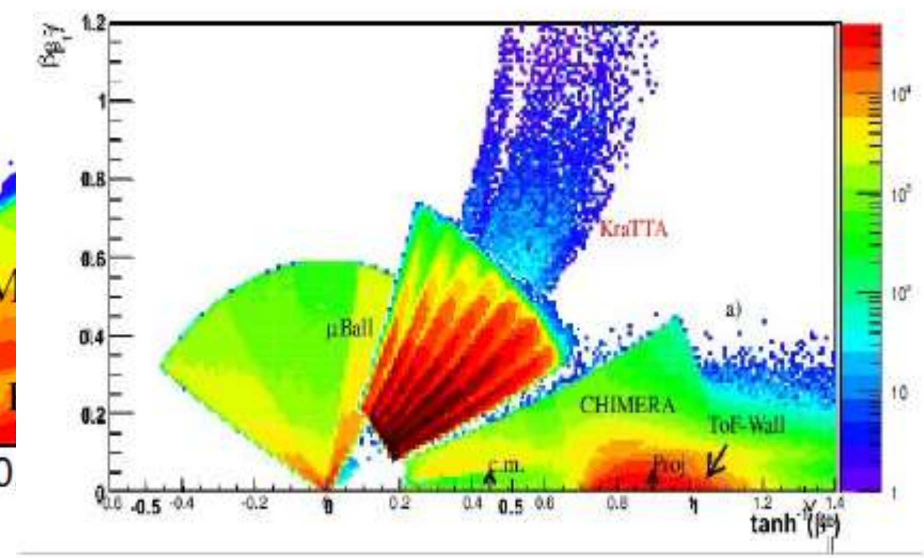
After re-analysis of Au+Au FOPI-LAND data (1991)
P.Russotto et al., PLB 697 (2011)

P. Russotto et al., PRC 94, 034608 (2016).



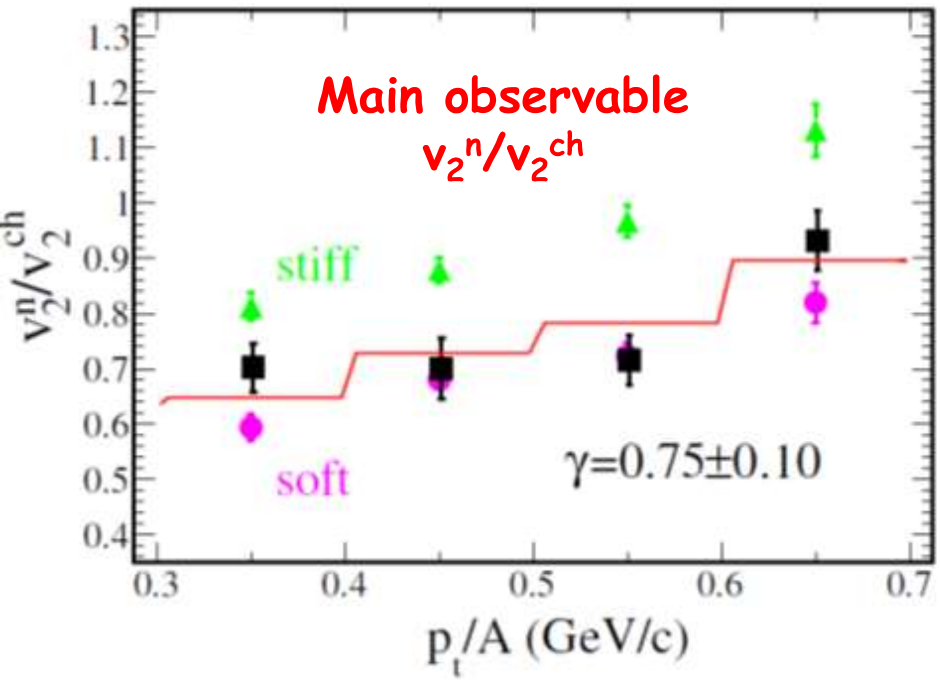
KRATTA:
J. Lukasik et al., Nucl. Instr. Meth. 709 (2013) 120128

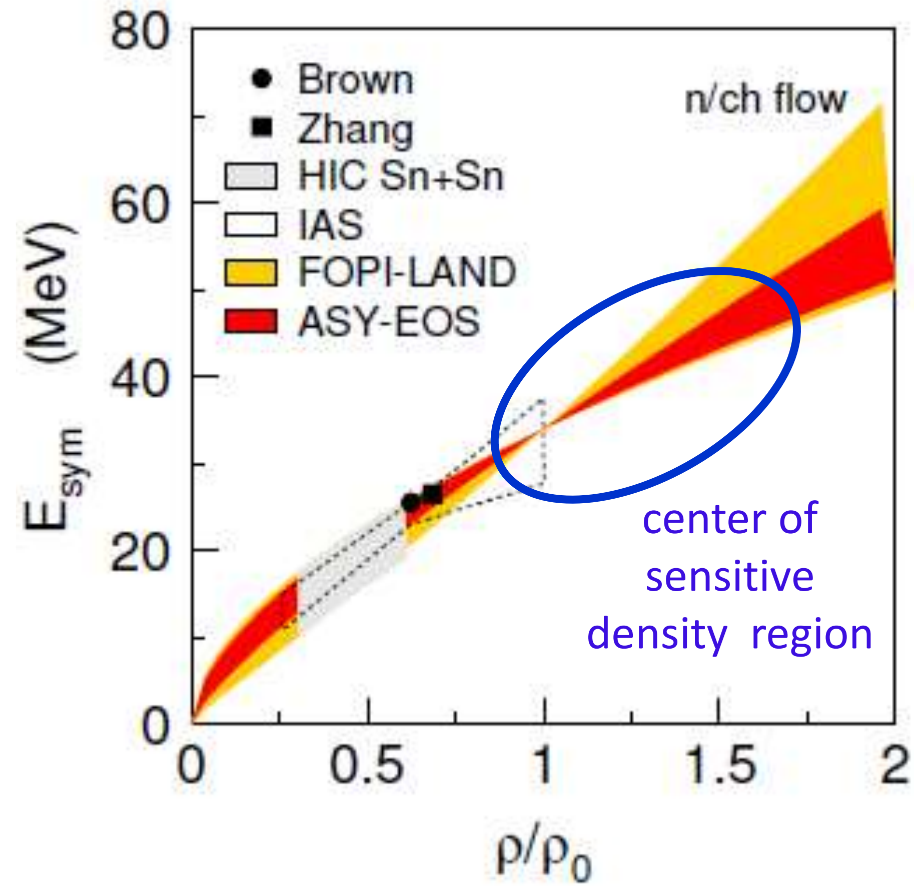
see J. Lukasik talk



ASY-EOS results:

Au+Au @ 400 AMeV b<7.5 fm





FOPI-LAND DATA : P.Russotto et al., Phys. Lett. B 697 (2011)

γ = 0.9 ± 0.4 ; L=83±26 MeV

ASY-EOS DATA: P. Russotto et al., PRC 94, 034608 (2016)

γ = 0.72± 0.19 ; L=72±13 MeV

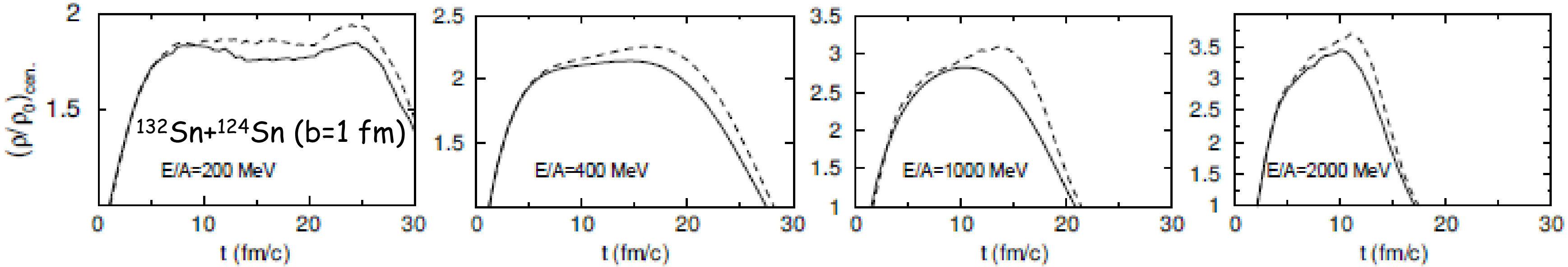
HIC: (mainly Isospin diffusion for Sn+Sn):
M.B. Tsang et al., PRC 86, 015803 (2012)

neutron skin thickness, binding energies,….:
Brown, PRL 111, 232502 (2013); Zhang & Chen, Phys. Lett. B 726 (2013), Danielewicz & Lee, NPA922 (2014).

Next step?

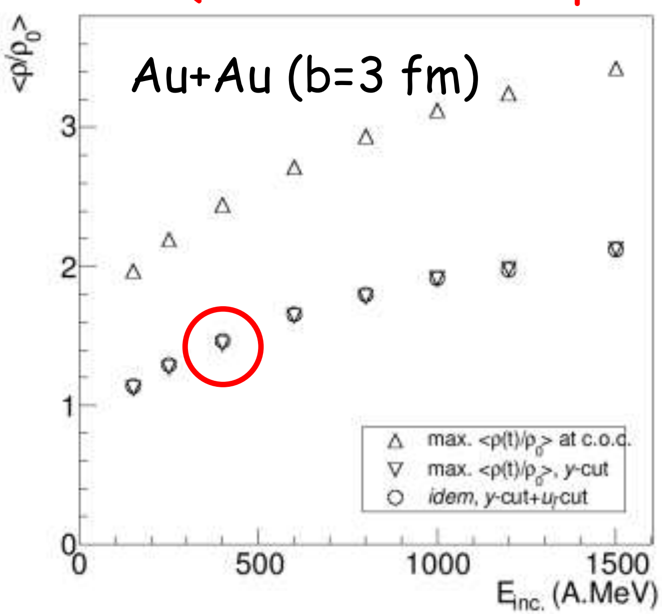
Symmetry energy @ higher density

Which densities can be explored in the early stage of the reaction ? (BUU calculations)



Bao-An Li, NPA 708 (2002)

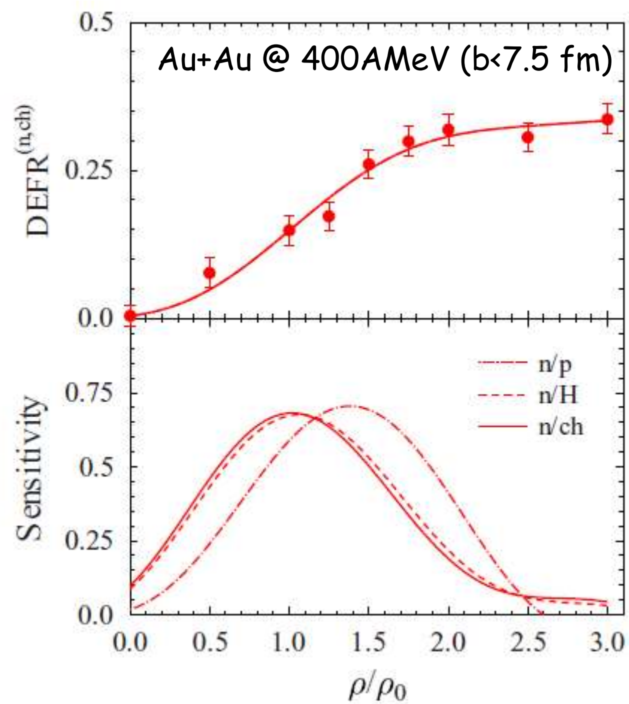
Which densities are explored by the flow?
IQMD calculations for p



A. Le Fevre et al., NPA 945 (2016)

Sensitivity of DEFR to density

$$\mathrm{DEFR}^{(n,Y)}(\rho) = \frac{v_2^n}{v_2^Y}(x=-1,\rho) - \frac{v_2^n}{v_2^Y}(x=1,\rho)$$



P. Russotto et al.,PRC 94, (2016)

M.D. Cozma TuQMD calculations

To explore higher densities:
1) raise the beam energy
2) use n-p observable

ASY-EOS II proposal

PROPOSAL FOR BEAM-TIME IN 2018/2019

FOR

DETERMINATION OF SYMMETRY ENERGY AT SUPRA-NORMAL DENSITIES: A FEASIBILITY STUDY

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THEORY SUPPORT: J. Aichelin[6], M. Colonna[1], M.D. Cozma[10], P. Danielewicz[8], Ch. Hartnack[6], Q.F. Li[17] and Y. Wang[17]

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- test of the detectors
- test of RIBs yield in cave C

GSI-PAC in 2 weeks

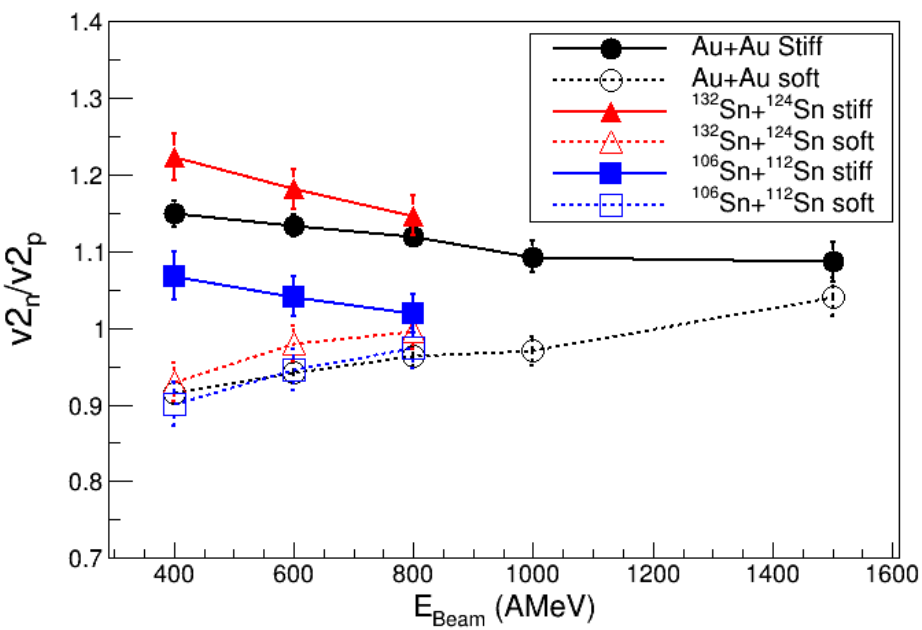
ASY-EOS II proposal: UrQMD predictions

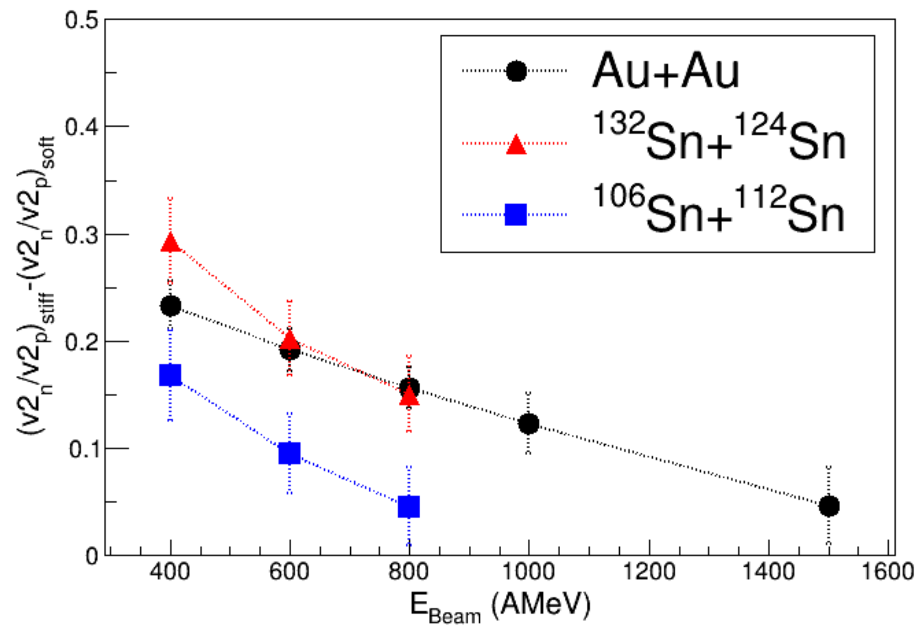
The systems/energies we would like to measure in the future campaign are:

$$
\begin{array}{llll}
{}^{197}\mathrm{Au} + {}^{197}\mathrm{Au} & \mathrm{at} & 400,\ 600,\ 1000\ \mathrm{AMeV} \\
{}^{132}\mathrm{Sn} + {}^{124}\mathrm{Sn} & \mathrm{at} & 400,\ 600\ \mathrm{AMeV} \\
{}^{106}\mathrm{Sn} + {}^{112}\mathrm{Sn} & \mathrm{at} & 400,\ 600\ \mathrm{AMeV}
\end{array}
$$

Measure excitation function to improve resolving power

At midvelocity b/bred <0.53



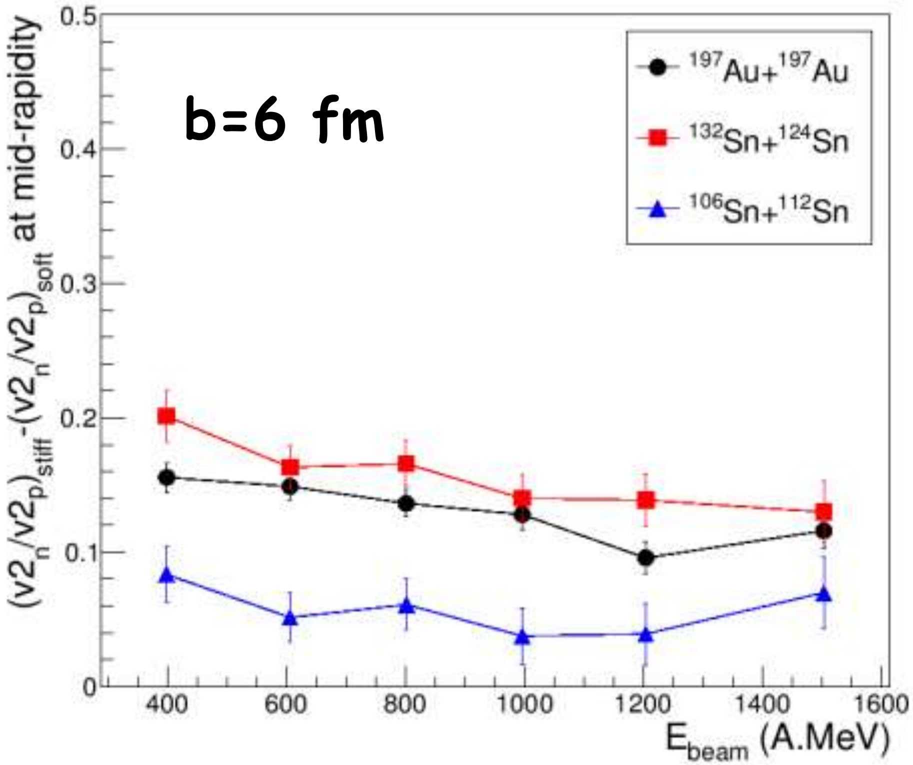


$$E_{sym} = 22\,\mathrm{MeV}\cdot(\rho/\rho_0)^{\gamma} + 12\,\mathrm{MeV}\cdot(\rho/\rho_0)^{2/3}$$

Stiff γ=1.5, Soft γ=0.5

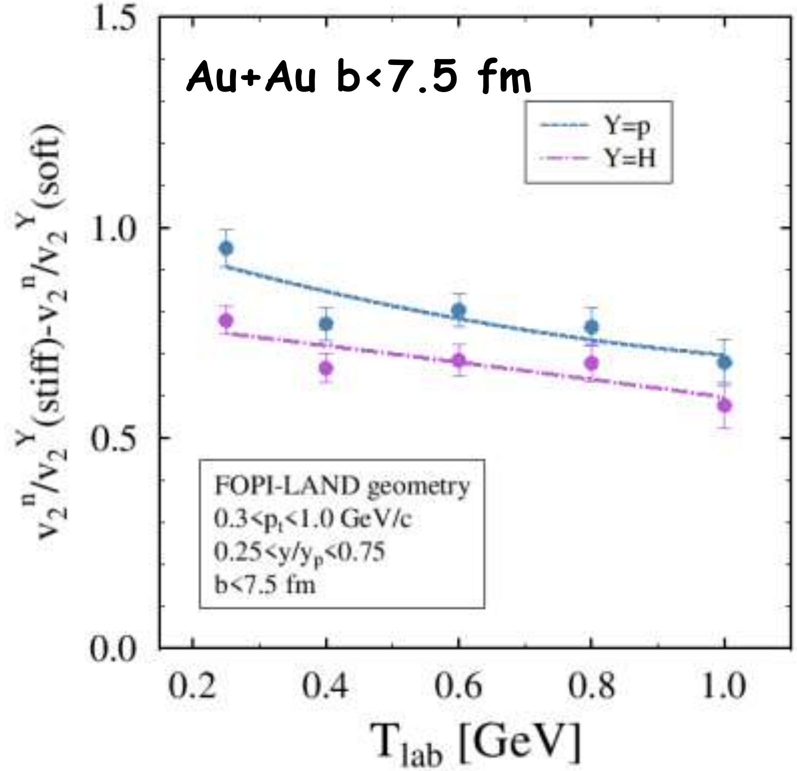
ASY-EOS II proposal: IQMD and TuQMD predictions

IQMD



A. Le Fevre calculations

TuQMD
but using x=-2 (super-stiff) and x=2 (super-soft)



M.D Cozma calculations

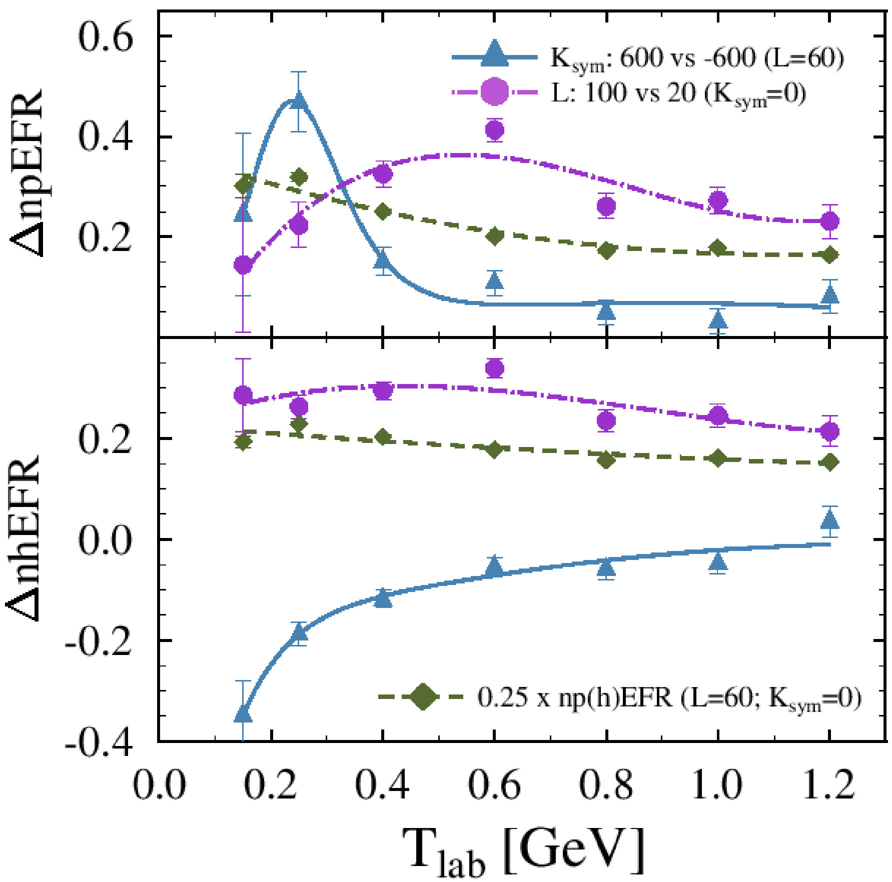
ASY-EOS II proposal: TuQMD predictions

L and KSym sensitivities

$$S(\rho) = S_0 + \frac{L}{3}\left(\frac{\rho-\rho_o}{\rho_o}\right) + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_o}{\rho_o}\right)^2 + \ldots,$$

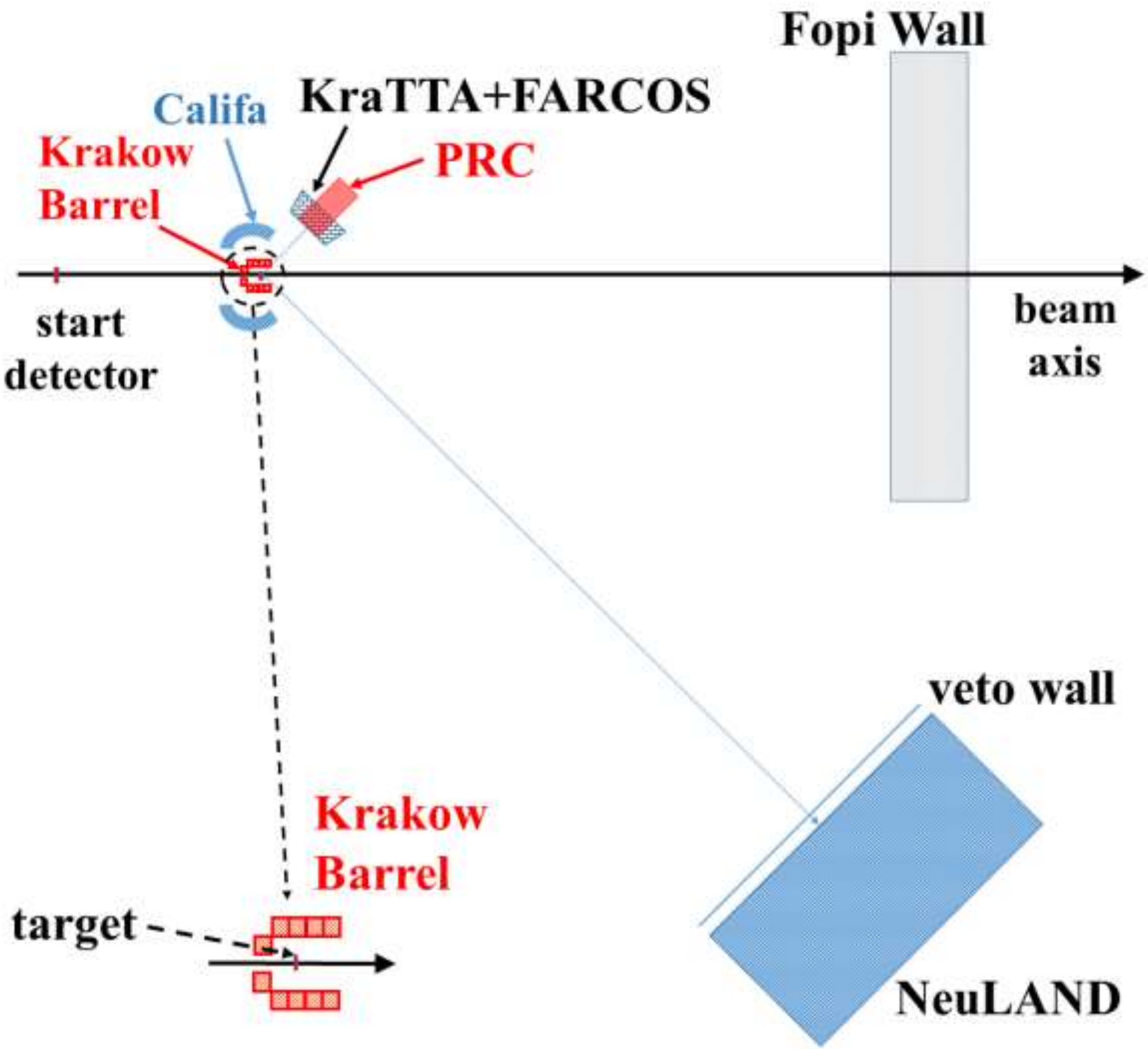
Au+Au b<7.5 fm

$$\Delta np(h)EFR = \left[\frac{v_2^n}{v_2^{p(h)}}\right]_{(a)} - \left[\frac{v_2^n}{v_2^{p(h)}}\right]_{(b)}$$



M.D Cozma submitted to EPJA
arXiv:1706.01300

ASY-EOS II proposal: the set-up



KraTTA (Si-Si-Csi-CsI-Si):
Flows and yields of LCP at mid-rapidity
(see J. Lukasik talk)

FARCOS (2xDSSSD-CsI):
LCP at mid-rapidity
(high angular resolution)

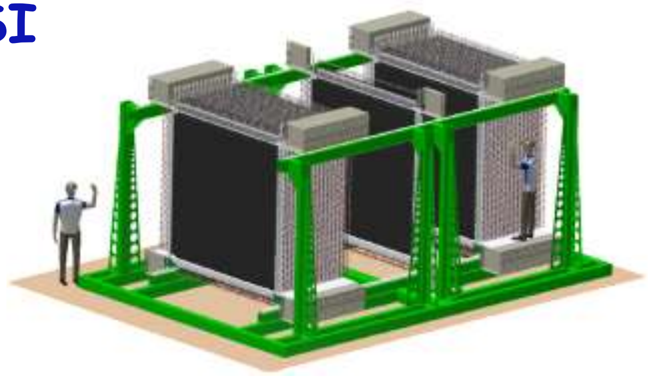
Califa (CsI):
LCP at target-rapidity

Pion Range Counter (stack of plastics):
π^+ and π^- at mid-rapidity

NeuLAND @ FAIR/GSI

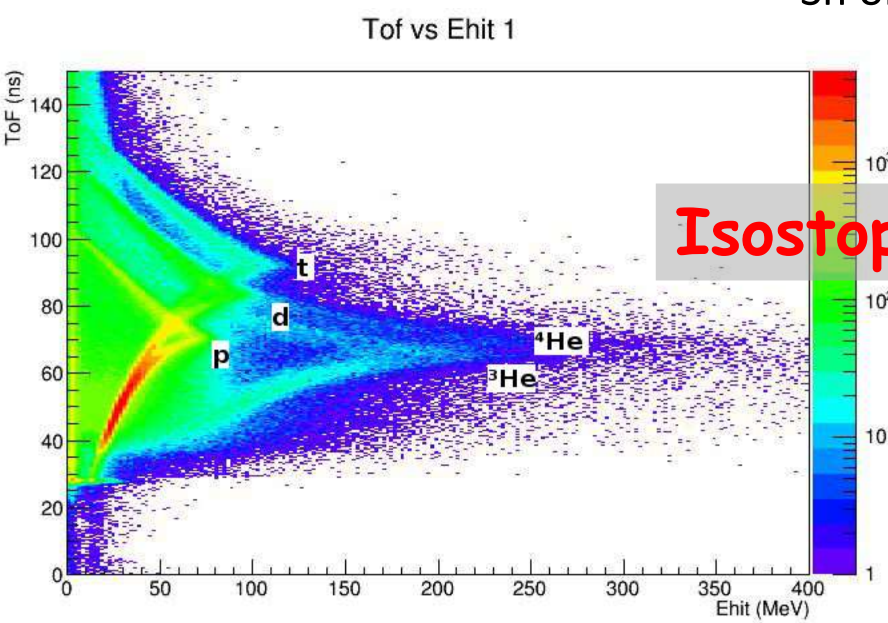
TDR finalized in Oct 2011 and submitted

- total volume 2.5x2.5x3 m^3
- each bar readout by two PMT
- 3000 modules (plastic scintillator bars) 250x5x5 cm^3
- 30 double planes with 100 bars each, bars in neighboring planes
- mutually perpendicular
- $\sigma_t \leq 150$ ps and $\sigma_{x,y,z} \leq 1.5$ cm
- one-neutron efficiency ~95% for energies 200-1000 MeV
- multi-neutron detection capability

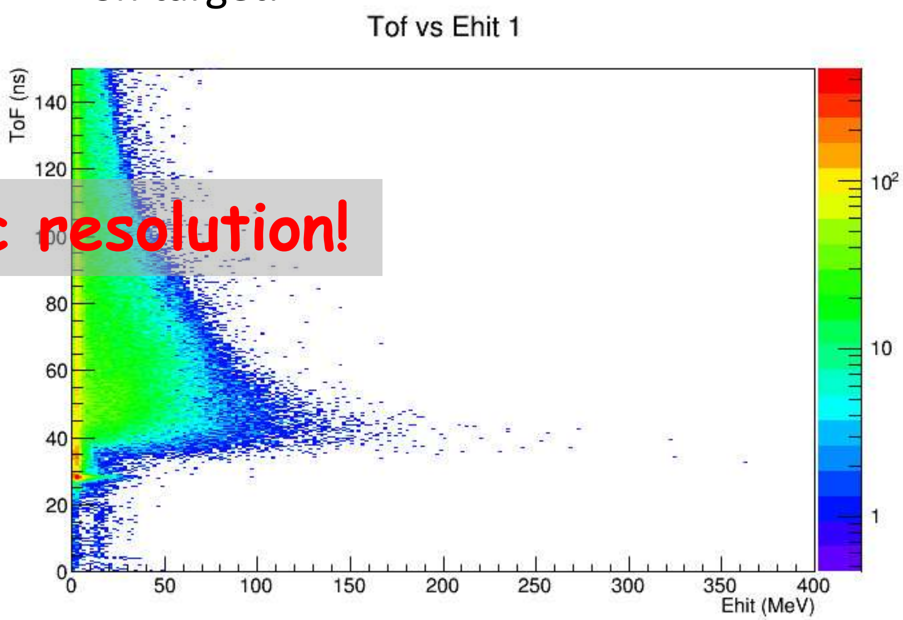


I. Gasparic AsyEOS2012 workshop, 6.9.2012, Siracusa, Italy

The NeuLAND demonstrator was part of the Sπrit TPC experiment carried out at RIKEN. Charged particles and neutrons stemming from central collisions of $^{108,112,124,132}Sn$ on ^{112,124} Sn target.



Isotopic resolution!



Particle ID plot from the 1st NeuLAND plane

including a condition that no VETO hit was registered in the event

FOPI forward wall

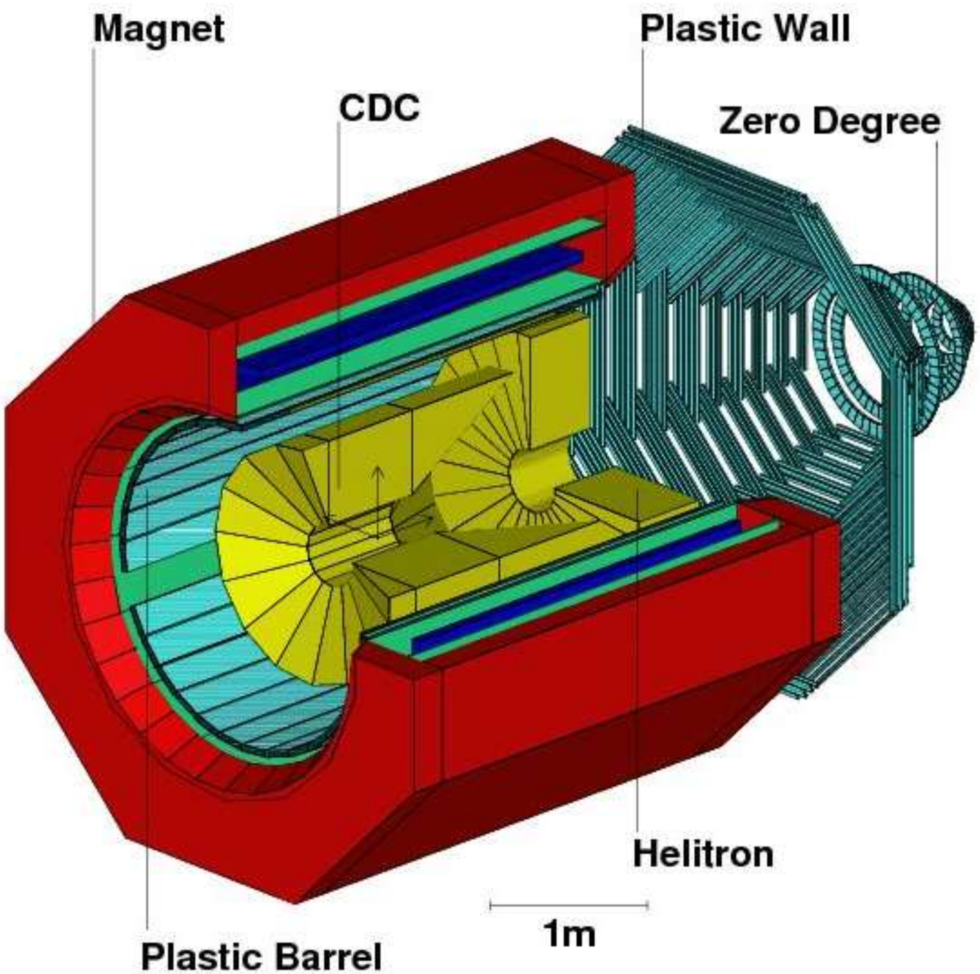


Figure 2.1: Schematic drawing of the FOPI detector.

2.10 The Forward Wall

The forward wall covers polar angles from 1.2 ° to 30 ° and the full azimuthal range. It consists of two parts: the outer wall called "Plastic Wall" (PLAWA) and the inner wall called "Zero Degree" (ZD).

2.10.1 The Plastic Wall (PLAWA)

Like the Plastic Barrel the Plastic Wall is made of 512 plastic scintillator strips divided into eight sectors. Each sector is composed of 64 strips. The light produced by a charged particle on a given strip is read out at both ends of the strip via photo multipliers. Each strip delivers four signals, two energies (E_L,E_R) and two times (t_L,t_R). The energy loss ΔE of a particle is proportional to $\sqrt{E_L \cdot E_R}$ and its time of flight is proportional to $\frac{1}{2} \cdot (t_L + t_R)$. The position of a particle hitting the PLAWA is given by the angular position of the strip which fired. The time resolution is linked to the active length of the scintillator strip, thus it varies from 80 ps for strips in the inner sector to 120 ps for strips in the outer sector. The resolution of the hit position varies from 1.2 cm to 2.0 cm [74, 75].

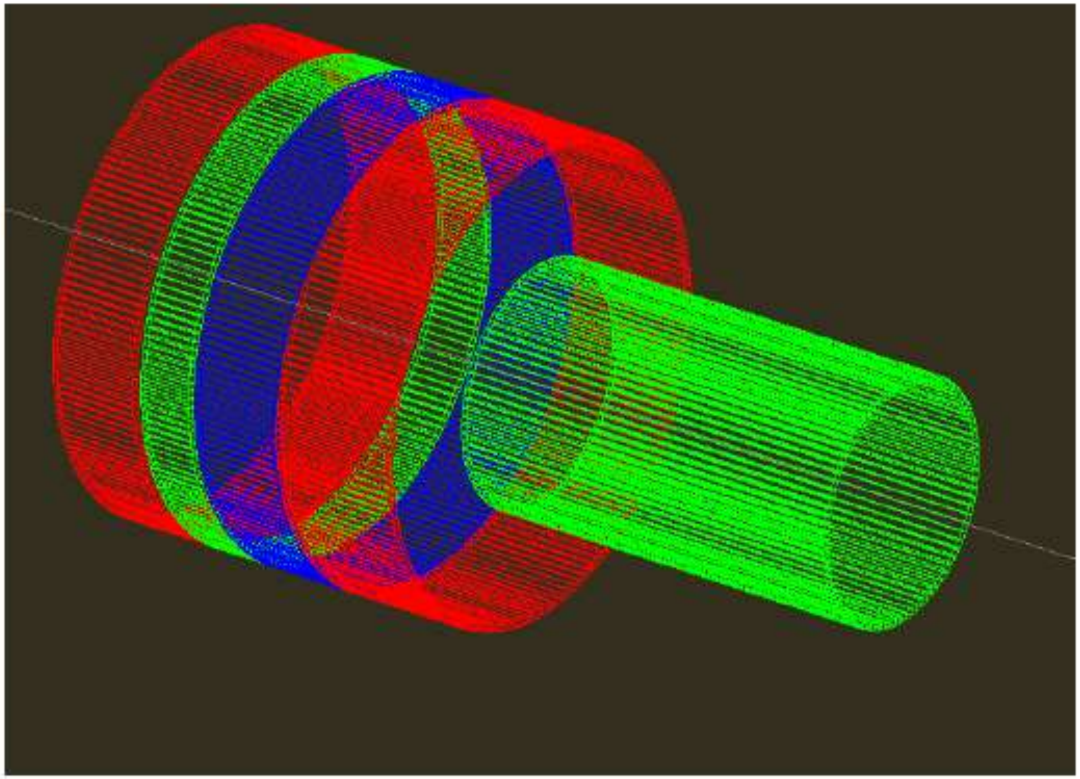
2.10.2 The Zero Degree Detector

This detector covers polar angles from 1.2 ° to 7.0 ° and consists of 252 plastic scintillator strips grouped into 7 concentric rings. Each module is read out by only one photo multiplier and delivers the energy loss (ΔE) and the time of flight of charged particles. The time resolution of this detector is about 200 ps.

Study for the new Krakow Barrel See J. Lukasik talk

Trigger/Reaction Plane detector around the target:

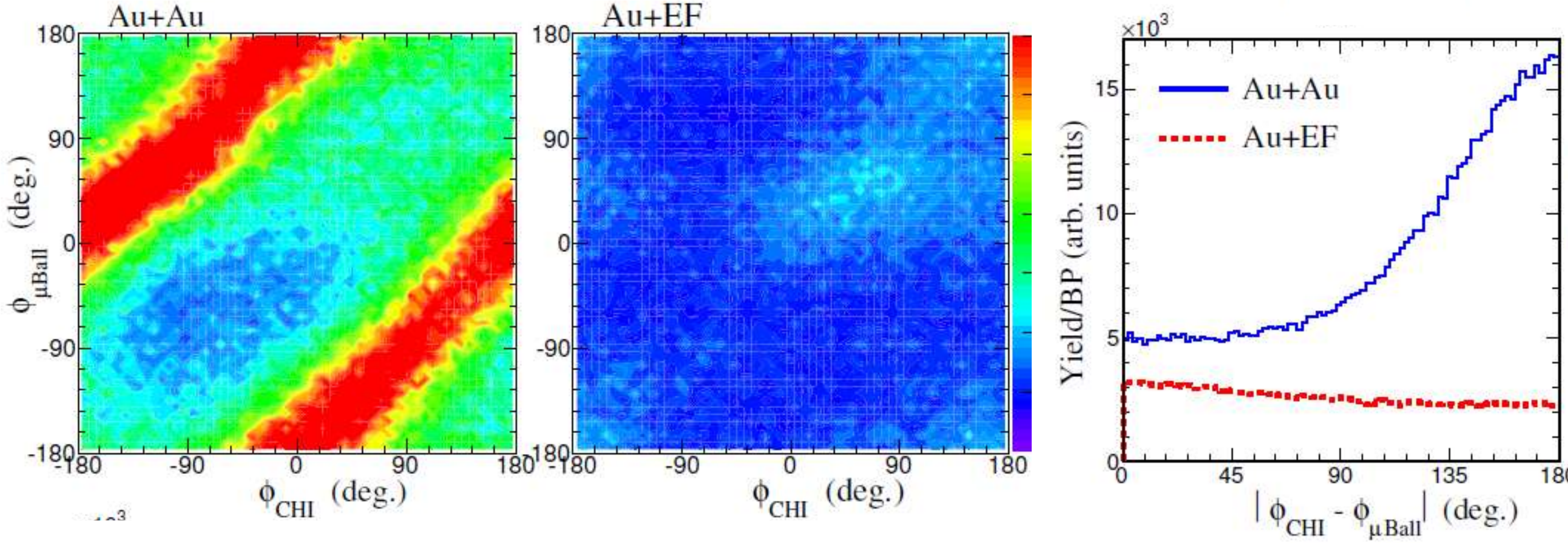
- 5 rings of 4x4 mm^2 fast scintillating fibers (e.g. BCF-20) read out by SiPMs
- covers angles from 30° to 165°,
- segmentation assures more or less uniform count rates for Au+Au at 1 AGeV,
- geometrical efficiency ~95%
- ~10% of charged particles involved in multihits,
- ~5% multihit probability
- sufficiently large for radioactive beams
- sufficiently small and lightweight not to disturb neutrons
- min radius - 6 cm,
- max radius - 12 cm
- length 43 cm
- 180 segments in forward rings
- 90 segments in backward ring
- 810 channels



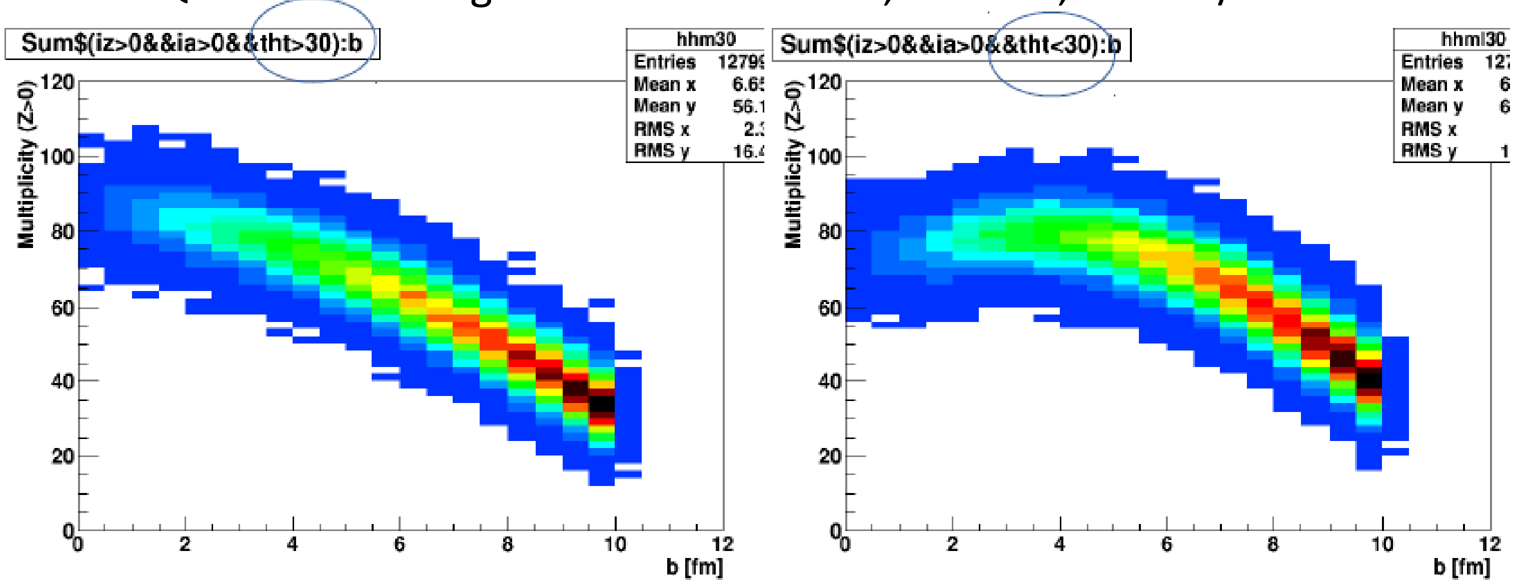
- **Fast enough to trigger**
- **Transparent to neutrons**
- **Highly segmented**
- **Background reduction**

Krakow Barrel See J. Lukasik talk

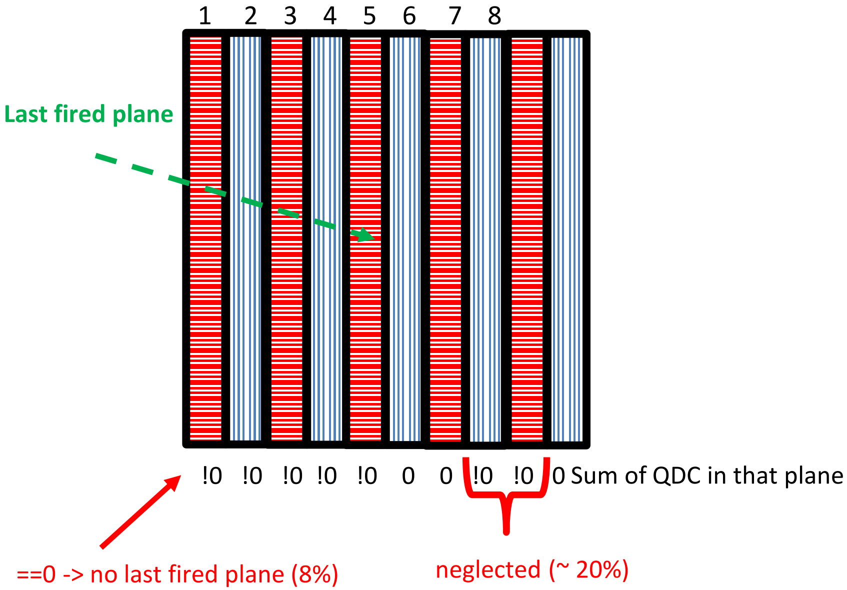
Background reduction: CHIMERA-MicroBall correlation in ASY-EOS exp

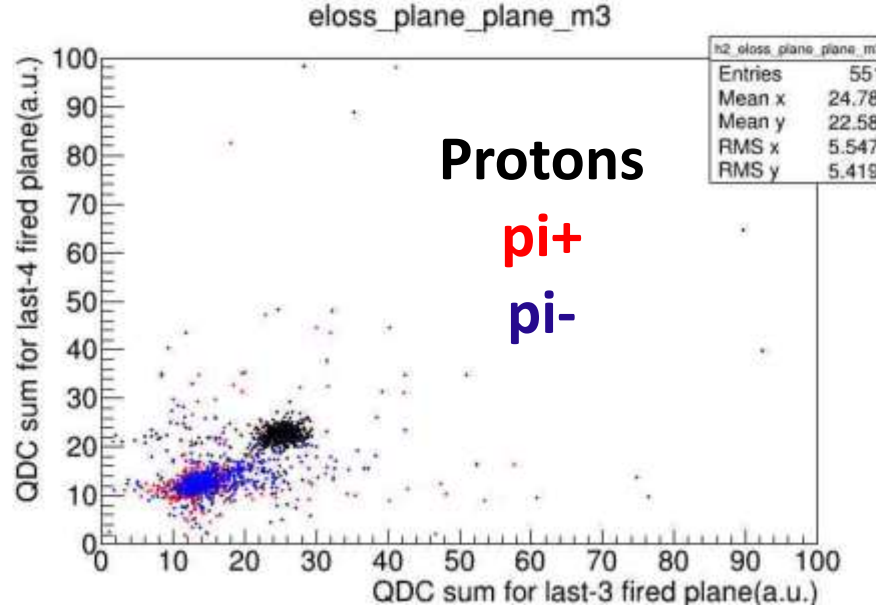


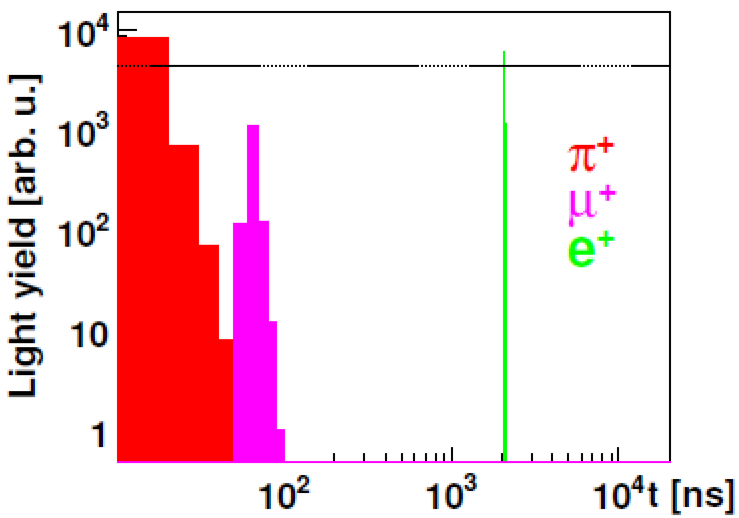
UrQMD + clustering: Au+Au 1000 AMeV, 0-10 fm, 200 fm/c

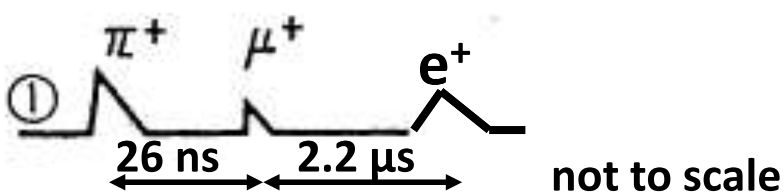


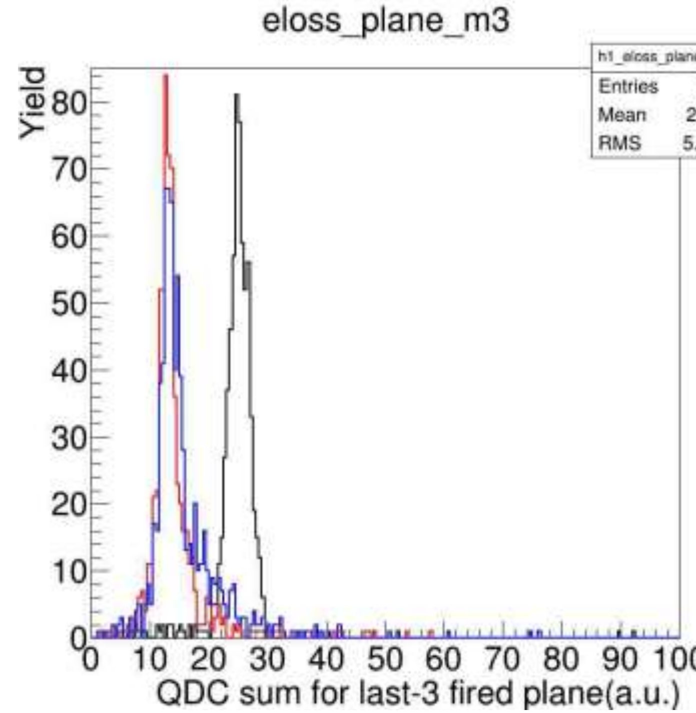
Can NeuLAND measure pi+ and pi-?











Conclusions

Symmetry Energy:

- Low densities: several constraints quite consistent
- High density:
  - n/p flows: "our" observable for constraining the high-density dependence of the symmetry energy
  - ASY-EOS data analysis is done, new constraint obtained
  - pions: Spirit results!
- Work on code consistency needed…everywhere!
- Possibility of new (and better) experiments on n,p flows (& pions?) at @ GSI
- International collaborations and efforts

On the road…..