Characteristics of midvelocity emissions in peripheral and semi-peripheral HI collisions at Fermi Energies

Giovanni Casini
S.Piantelli, P.R.Maurenzig, A.Olmi, L.Bardelli, M.Bini, G.Pasquali, G.Poggi, A.A.Stefanini

INFN - Sezione di Firenze and Dipartimento di Fisica - Università di Firenze
Outlook

- Physics
- Experimental setup
- Impact parameter estimate
- Emission pattern in peripheral collisions
- Separation of the sources
- Features of midvelocity and evaporated particles
- Conclusions
**What is well assessed for (semi-)peripheral collisions?**

- **Binary character (2body)** with two main remnants (Quasi-Projectile (QP) and Quasi-Target (QT)) in the exit channel \((\sigma_{2body} > 50\% \text{ of total reaction } \sigma)\)
- QP and QT are **excited** and deexcite by **evaporating** neutrons, Light Charged Particles (LCP), gammas and Intermediate Mass Fragments (IMF)
- Large production of **midvelocity particles and fragments**


**What is not well assessed in (semi-)peripheral collisions?**

- Origin and characteristics of midvelocity emissions
- Relationship with low-energy preequilibrium phenomena (fast oriented fission, pre-scission emission) and with high-energy processes (fireball, participant-spectator scenario)
- Strong deformation of QP,QT (surface vs. volume energies)
- What about the nuclear density and the Isospin in the midvelocity region?
- Excitation of QP,QT: is it so large that they enter the instability region? How much excitation does the midvelocity emission take away from the system?
- Relationship with more central collisions (when do we get one source and Multifragmentation?)
An Experimental Setup for peripheral collisions

- A suitable apparatus for **HEAVY** fragments: detection of QP (fast, close to 0°) and QT (slow and emitted up to 90°)
- A large-acceptance array for **LIGHT** ejectiles: LCP and IMF identification and velocity (momentum) determination

QP-QT coincident detection with very low E-threshold (0.1AMeV)
Experimental Setup
The Fiasco conceptual sketch

Experiment at LNS

\( 93^\text{Nb} + 93^\text{Nb} \) at 17, 23, 30, 38 AMeV
\( 116^\text{Sn} + 116^\text{Sn} \) at 23, 30, 38 AMeV
\( 93^\text{Nb} + 116^\text{Sn} \) at 23, 30, 38 AMeV
(in direct and reverse kinematics)

M.Bini et al., NIMA 515 (2003) 497
Experimental Setup

The Fiasco conceptual sketch

M.Bini et al., NIMA 515 (2003) 497
TKEL as a good order parameter

SELECTED binary exit channel (QP, QT+ LCP, IMF)

\[ TKEL = E_{\text{cm}} - (\mu v_{\text{rel}}^2 / 2) \]

Under the hypothesis of two-body kinematics

Model calculation (QMD code CHIMERA)


Experimental estimate:
integration of the cross-section starting from elastic events


CONCLUSION:
even at Fermi energies TKEL remains a good centrality scale
RELEVANT ISSUES FOR HIGH QUALITY DATA

• precise event-by-event determination of separation axis;
• good velocity measurements of LCP and IMF;
• corrections for the limited efficiency of the detectors and for possible analysis biases via Montecarlo simulations

The experimental velocity (or momentum) correlations give direct evidence of the complexity of the emissions

• Coulomb ring: standard emission from QP, QT well after their separation

• Intensely populated midvelocity region, revealing a 'fast' emission coming from different phase-space zones
The world of midvelocity

**Ni+Ni at 30AMeV**

Milazzo et al. P Lett. B09(01)204

**alpha PERIP. COLLISIONS Xe+Sn at 50AMeV**

Lukasik et al PLB566(03)76

**Ni+C,Au at 34.5 AMeV**

Hudan et al PRC 71(05)054604

LCP from Ni+C,Au at 34.5 AMeV

Toke et al. PRL75(95)2920

Yanez PRC68(03)011602R

**HOW TO SEPARATE THE DIFFERENT SOURCES?**

Gingras et al. PRC65(02)061604R

**IMF**

**LCP**
Separation of the emission components

for a given TKEL and for a given particle, experimental velocity correlations $A$ (Vperp vs Vpar)
evaluation of inefficiency corrections $C$

for SYMMETRIC systems we can limit to CM forward region; we obtain total emission pattern $T$ by correcting $A$ with $C$: $T = A^*C$

In the QP reference frame, we estimate the (total) evaporative QP emission $E$, starting from the forward (0-45deg) emission region and taking into account the angular momentum

obtaining total midvelocity (midvel) emission $M$ via subtraction of $E$ from $T$: $M = T - E$

Nb+Nb at 38AMeV FIASCO at LNS

*A. Mangiarotti et al., PRL 93 (2004) 232701*

- velocity correlation using the separating axis and not the beam axis frame
- no reflection at 90° to estimate evaporation

Phys. Rev. C 56(97)2003

Landau-Vlasov Calc.

Eudes et al. Ar+Al 95AMeV
Mass and Energy balances for the QP and the midvelocity region

After the separation of the two components one can measure the properties of the QP (QT) sources and the MIDVEL “source”.

WE OBSERVE THE FOLLOWING:

• Proportionality between TKEL and the excitation energy of QP

• QP average energy density < 4 MeV/u; the QP is moderately hot (at least in semiperipheral collisions)

• Almost equal energy sharing: $E^*_{Q\ell} \approx E^*_{mid}$

• Large amount of energy is deposited in the contact region: does the system enter in the multifragmentation regime?

The midvelocity emission could be an example of multifragmentation limited to the contact region.
Looking more precisely at the velocity pattern one can distinguish two MIDVEL regions:

2) a region very close to the CM zone with particles emitted just in between QP and QT velocities

3) a “Coulomb-related” region, resembling a fast emission from the separating fragments (similarity with fast oriented fission)

ENERGY SPECTRA in the QP frame

Study of the second component in the most favourable zone, i.e. the region perpendicular to the QP flight direction; here we have: almost no central region midvelocity, no contamination from standard QT evaporation.

S. Piantelli et al., preprint Los Alamos 2007
Apart from the phase-space distribution, this component shows other differences with respect to 'normal' QP evaporation.

DIFFERENT SLOPE PARAMETER

The properties of the Coulomb-related emission

Fit with Maxwell function(s)

Only one Maxwell source at small emission angles: the apparent temperature for the standard evaporation component doesn't depend on the emission direction and is around 2-4MeV consistent with other studies on QP decay.

Two Maxwell functions at 90°: one component corresponds to standard evaporation and is quite similar to the previous one. A second component (tail) presents a higher apparent temperature.

S. Piantelli et al., preprint Los Alamos 2007
Other evidences of this hard component

A HARD component in semiperipheral collisions close to 90° in the QP-frame has been observed in other systems

$^{114}$Cd + $^{92}$Mo at 50AMeV

LCP between 40° and 75° in QP reference frame.

- The QP heats up with increasing centrality as shown by the increase of the slope temperatures
- A hard component is observed at large QP angles
The properties of the Midvel emission

high neutron content for bound species

For Z=1 isotopes we found a strong neutron enrichment in the midvel component with respect to N/Z for evaporated hydrogen (well reproduced by GEMINI)

Comparison of TOTAL MIDVEL and Coulomb related 90° emissions: the N/Z for this second part is intermediate between the evaporation value and the total MIDVEL


S.Piantelli et al., preprint Los Alamos 2007
Already in the past we suggested that non-evaporative emission pattern was reproduced with two “sources”:

- a prompt emission ($t < 100 \text{ fm/c}$) from the very middle region (fireball participant nucleons)
- a later (but fast!) emission ($t \approx 200 \text{ fm/c}$) from the surface of excited, deformed and rotating QP/QT (evolution of the fast oriented fission or i.e. aligned asymmetric break-up) (*)

(*): Gingras et al. PRC65(02)061604R Ni+C,Au at 34.5AMeV
DeFilippo et al. PRC71(05)044602 Sn+Ni at 35AMeV
Papa et al PRC75(07)054616 Sn+Ni at 35AMeV
Anisotropic emission

Is this an evidence of the production of strongly deformed QP?

Relevant subjects for further investigation:
- Deformation of the systems (strong surface energies) to be included also in models
- Proximity effects and Coulomb distortions
- Role of the fast decay of hot fragments in producing midvelocity light particles (e.g. α oriented emission)

S. Piantelli et al., PRC 74 (2006) 034609

S. Hudan et al. PRC 70(04)031601R

S. Hudan et al. PRC 73(06)054602
Conclusions

- Emission of LCP and IMF from semiperipheral collisions has been studied at Fermi energies with a dedicated apparatus.
- A careful analysis has been carried out to estimate the QP evaporation and to obtain, by subtraction, the total MIDVEL emission.
- The QP (QT) emission is consistent with evaporation from an equilibrated source at normal density.
- High energy densities seem to be reached in the contact region, with values greater than the threshold for multifragmentation (a small multifragmenting systems?)
- The midvelocity emission can be naively split in two components: a prompt emission from a central source (t<100fm/c) and a later emission (t~200-300fm/c) from the deformed QP/QT (evolution of the fast oriented fission).
- The fast Coulomb-related emission has features different from standard evaporation; it presents high apparent temperatures and high neutron content for light particles.
- Dynamics strongly influences the observables on a timescale which overlaps with their short decay times: doubts on the ‘standard’ theoretical approach where the dynamical stage AND the statistical stage are separately treated.