Report on LNS theory group (GR4) activity

Istituto Nazionale di Fisica Nucleare

Danilo Gambacurta
Laboratori Nazionali del Sud (Catania)

Presentazione Attività e Preventivi 2024
18 e 19 Luglio 2024

Iniziative Specifiche di CSN4:

- MONSTRE
- SIM

MOdeling
Nuclear
STructure and
REactions

MONSTRE

*Unità: **LNS**, Bologna, CT,Milano, Padova, Trento*
FTE totale: ≈30, **FTE (LNS)** *≈4.5*

Responsabile Nazionale: Danilo Gambacurta (LNS)

Responsabile Locale: Maria Colonna

Collaborazioni: LNS+CT (Chimera, Medea, NUMEN, ASFIN), Firenze, Napoli, Genova,IPN-Orsay, GANIL, GSI, Monaco, Bucharest, Giessen, Darmstadt, Siviglia, MSU, Pechino, Lanzhou, Rio de Janeiro, RIKEN, ...

Obiettivi generali:

Modeling nuclear structure and reaction properties

Four WorkPackages (WPs)

- WP1: ***Ab initio* many body methods for nuclei and nuclear matter**: increasing the accuracy and predictive power
- WP2: **Advanced theoretical studies of nuclear phenomena:** addressing the experimental challenges
- WP3: **Nuclear matter under extreme conditions:** from nuclear dynamics to compact objects
- WP4: **Emerging computational technologies:** quantum information and machine learning techniques

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LNS Activities: Nuclear Structure Studies

Theoretical Models and Techniques

- ✓ ***Energy Density Functional** Framework (**Skyrme, Gogny, Covariant**)*
- ✓ ***Ground state:** HF, HF+BCS, HFB*
- ✓ ***Excited states:** RPA, QRPA, Second RPA, TDHF*
- ✓ ***Transport theories based on EDF***
- ✓ ***Extending models:** including clusters d.o.f. , short range correlations, bridge with ab-initio theories, …*

Main Physical Cases of Interest

- ✓ ***Collective nuclear excitations,** especially in neutron-rich and exotic nuclei (Giant Resonances, Pygmy Dipole Resonance, …)*
- ✓ ***EoS of asymmetric matter** (symmetry energy, …)*
- ✓ ***Charge exchange excitations** (Gamow-Teller, Fermi, etc,) and **Beta Decay** (single and double)*
- ✓ ***Interdisciplinary aspects between nuclear and neutrino physics***

LNS activities: Nuclear Reaction Studies

Theoretical Models and Techniques

- ✓ ***Semi-classical transport theories,*** *incorporating many-body correlations*
- ✓ ***DWBA and/or coupled channel calculations***
- ✓ ***Formulation of scattering theories*** *and methods*

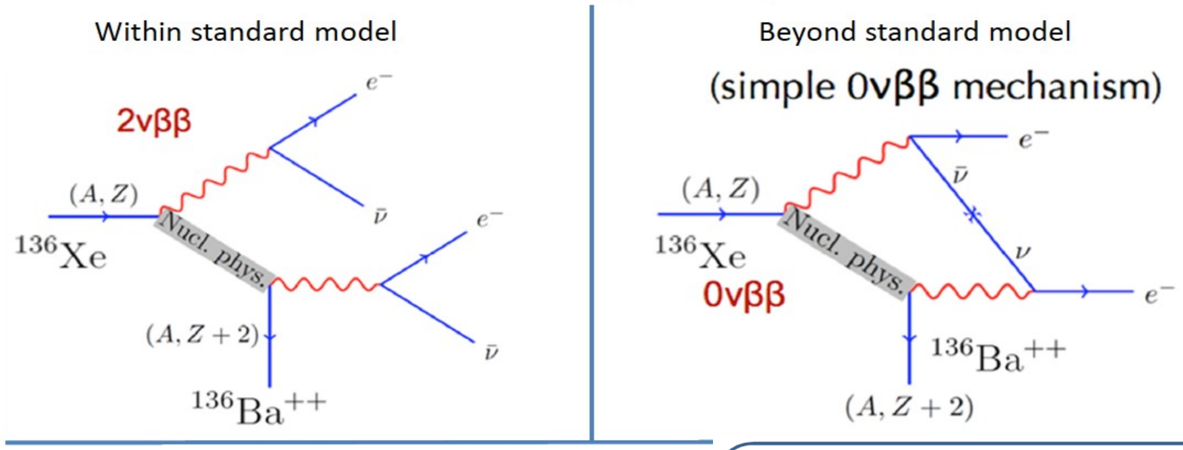
Main Physical Cases of Interest

- ✓ ***Nuclear reactions at Fermi/intermediate energies***
- ✓ ***Direct reaction*** *(transfer, charge exchange, probing spin-isospin channels)*
- ✓ **Fragmentation reactions,** also for medical applications
- ✓ ***Impact of Eos on nuclear reactions***
- ✓ ***Double Charge Excitations*** *and the connection to double beta decay*
- ✓ ***Reactions for astrophysical studies*** *(light systems, cluster structure)*

Theoretical part of NUMEN project (Resp. M. Colonna)

For *single charge exchange* (**SCE**) Nuclear Reactions are a well tested approach to probe single β decay… MAGNEX at LNS allow to access *double charge exchange* (**DCE**)

Double β-decay



$$1/T^{0\nu}_{1/2}(0^+ \rightarrow 0^+) = G_{0\nu}\left|M^{\beta\beta 0\nu}\right|^2 \left|\frac{\langle m_\nu \rangle}{m_e}\right|^2$$

Nuclear Matrix Element (NME)!

$$\left|M_\varepsilon^{\beta\beta 0\nu}\right|^2 = \left|\left\langle \Psi_f \middle| \hat{O}_\varepsilon^{\beta\beta 0\nu} \middle| \Psi_i \right\rangle\right|^2$$

$$T^{(2)}_{\beta\alpha} = \langle \chi_\beta^{(-)} | (b | V_{res}\, G_c\, V_{res} | a) | \chi_\alpha^{(+)} \rangle =$$

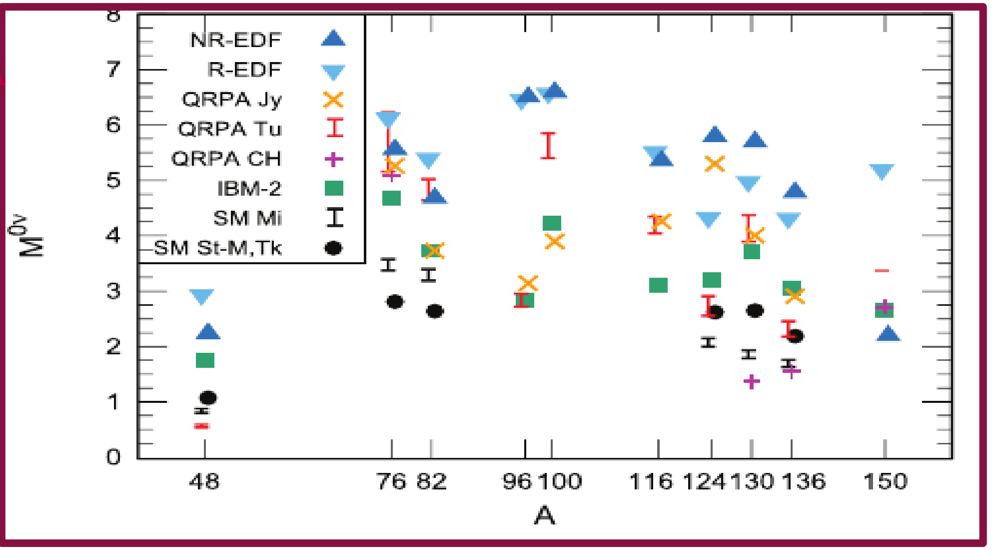
Double

$$= \sum_c \int \frac{d^3k_\gamma}{(2\pi)^3} \langle \chi_\beta^{(-)} | (b | V_{res} | c) | \chi_\gamma^{(+)} \rangle \cdot \frac{1}{E_\alpha - E_\gamma + i\eta}$$

Single

$$\cdot \langle \tilde{\chi}_\gamma^{(+)} | (c | V_{res} | a) | \chi_\alpha^{(+)} \rangle$$

Single



- ➔ Modellizzazione meccanismo di reazione
- ➔ Sviluppo di Codici numerici
- ➔ Multi-Channel approach
- ➔ Modelli di struttura nucleare per meccanismi SCE/DCE

Modelizzazione e studi formali di reazioni di doppio scambio di carica

universe

MDPI

Article

Theory of Majorana-Type Heavy Ion Double Charge Exchange Reactions by Pion–Nucleon Isotensor Interactions

Horst Lenske [1,*,†], Jessica Bellone [2,†], Maria Colonna [2,†] and Danilo Gambacurta [2,†]

universe

MDPI

Article

Induced Isotensor Interactions in Heavy-Ion Double-Charge-Exchange Reactions and the Role of Initial and Final State Interactions

Horst Lenske [1,*,†], Jessica Bellone [2,†], Maria Colonna [2,†], Danilo Gambacurta [2,†] and José-Antonio Lay [3,4,†]

The role of **initial state (ISI) and final state (FSI)** ion–ion interactions for double single-charge-exchange (DSCE) reactions has been investigated.

Virtual pion–nucleon charge exchange interactions are investigated as the source for induced isotensor interactions, giving rise to the **Majorana DCE (MDCE) reactions** in the projectile and target nucleus.

Connections to neutrinoless Majorana double beta decay (MDBD) are also discussed at various levels of the dynamics, from the underlying fundamental electro-weak and QCD scales to the physical scales of nuclear MDBD and MDCE physics**.**

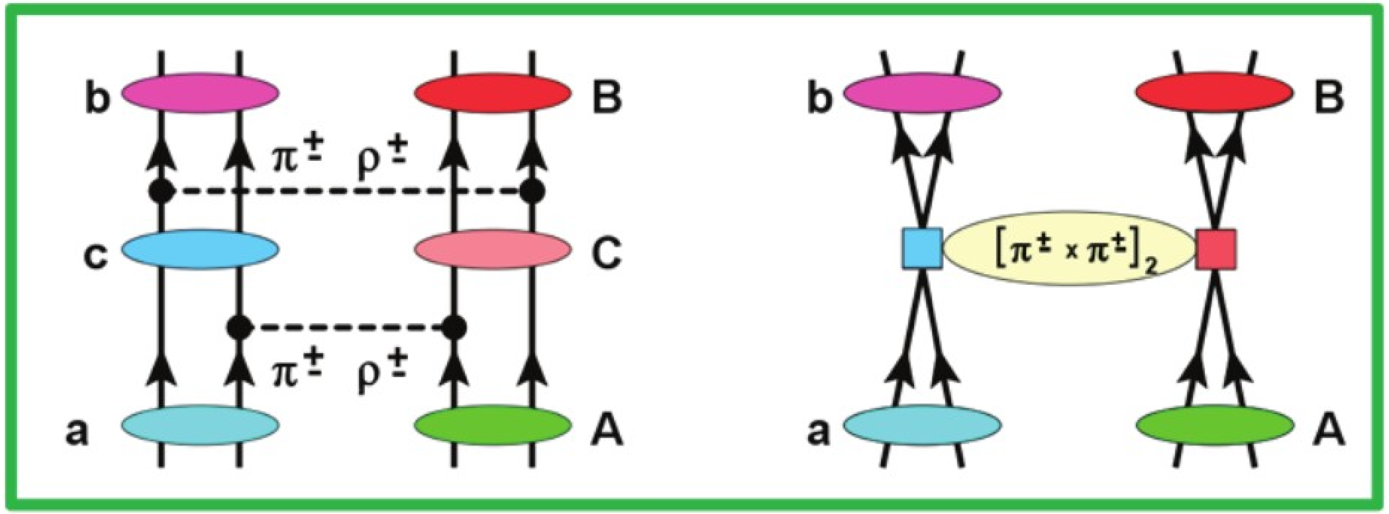
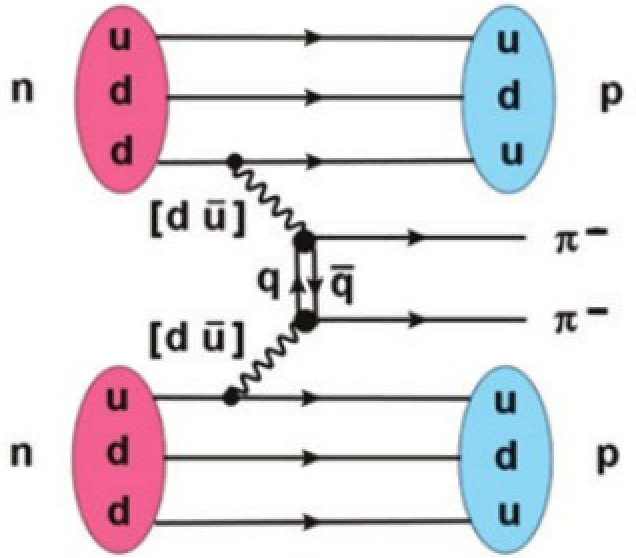
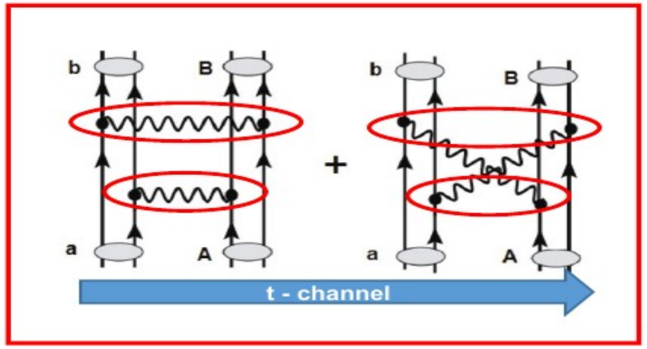
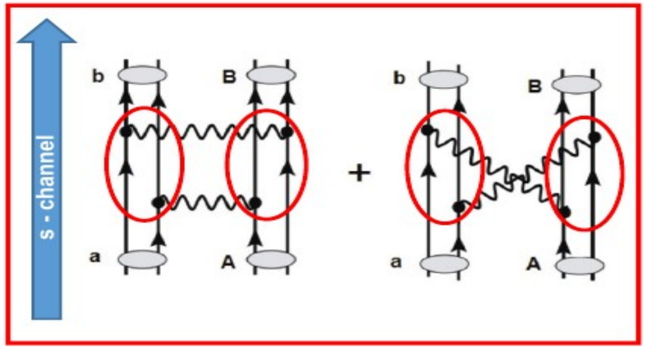


Figure 1. Schematic representation of the collisional processes contributing to a DCE reaction $A(Z,N) \to B(Z \pm 2, N \mp 2)$. The DSCE reaction scenario of second-order in the isovector NN T-matrix (left) competes with the direct MDCE mechanism proceeding by an isotensor interaction induced by off-shell pion–nucleon DCE scattering.



From t- to s-channel representation

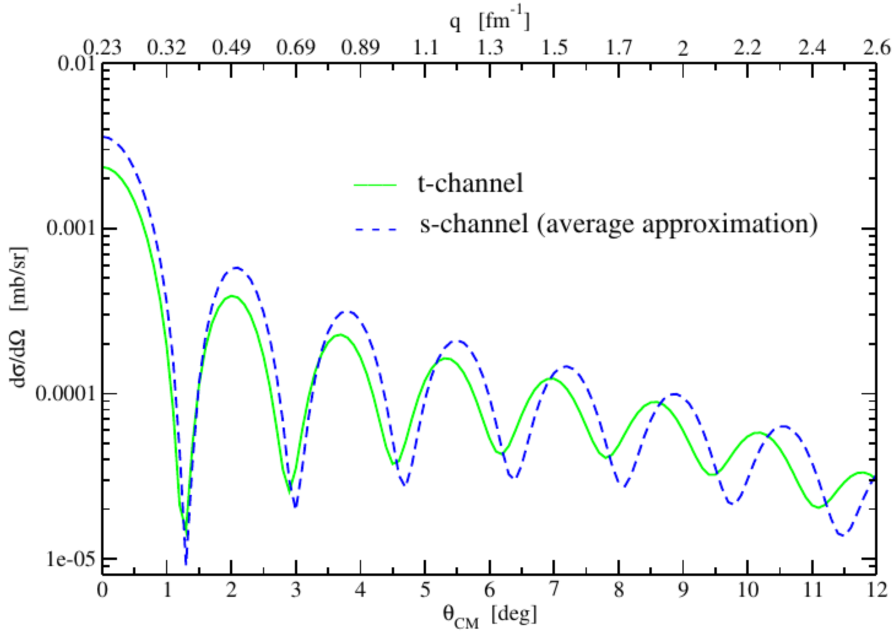




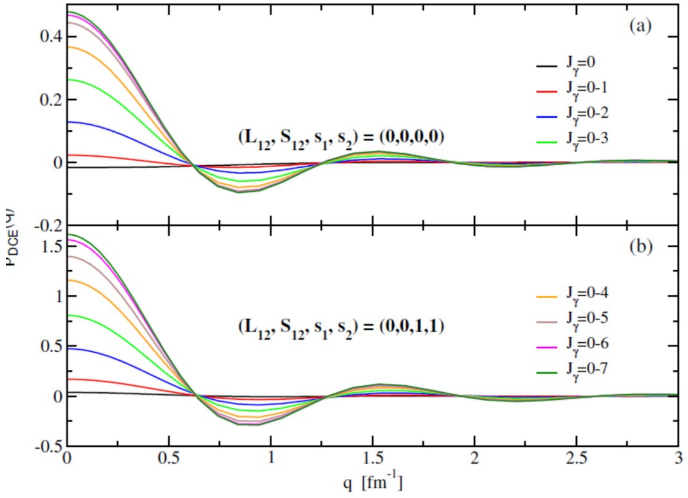
S-channel: separation and factorization of the 2-step process in target and projectile => Selective information on target and projectile

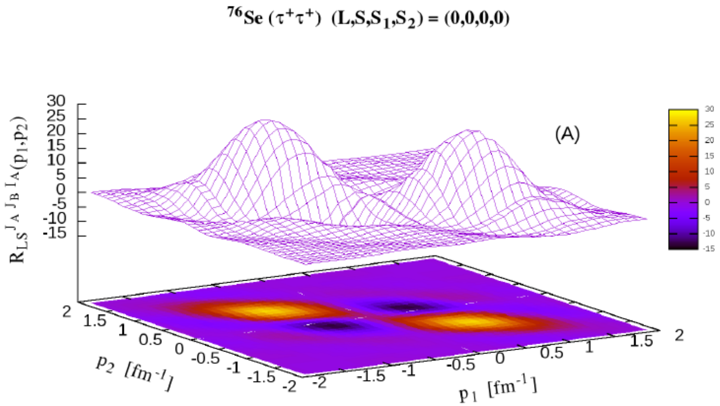
Two-body transition densities

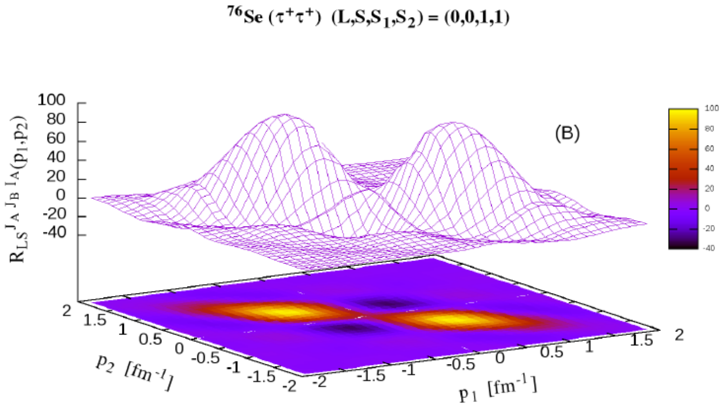
➢ DSCE Cross Section - $^{76}Se(^{18}O,^{18}Ne_{g.s.})^{76}Ge_{g.s.}$ vs. $^{76}Ge(^{20}Ne,^{20}O_{g.s.})^{76}Se_{g.s.}$



2BTDs $^{76}Se \rightarrow {}^{76}Ge_{g.s.}$



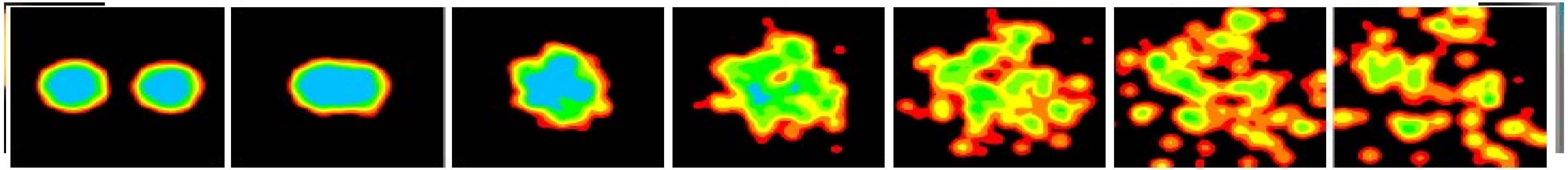




J.I. Bellone, M. Colonna, D. Gambacurta,H. Lenske, submitted

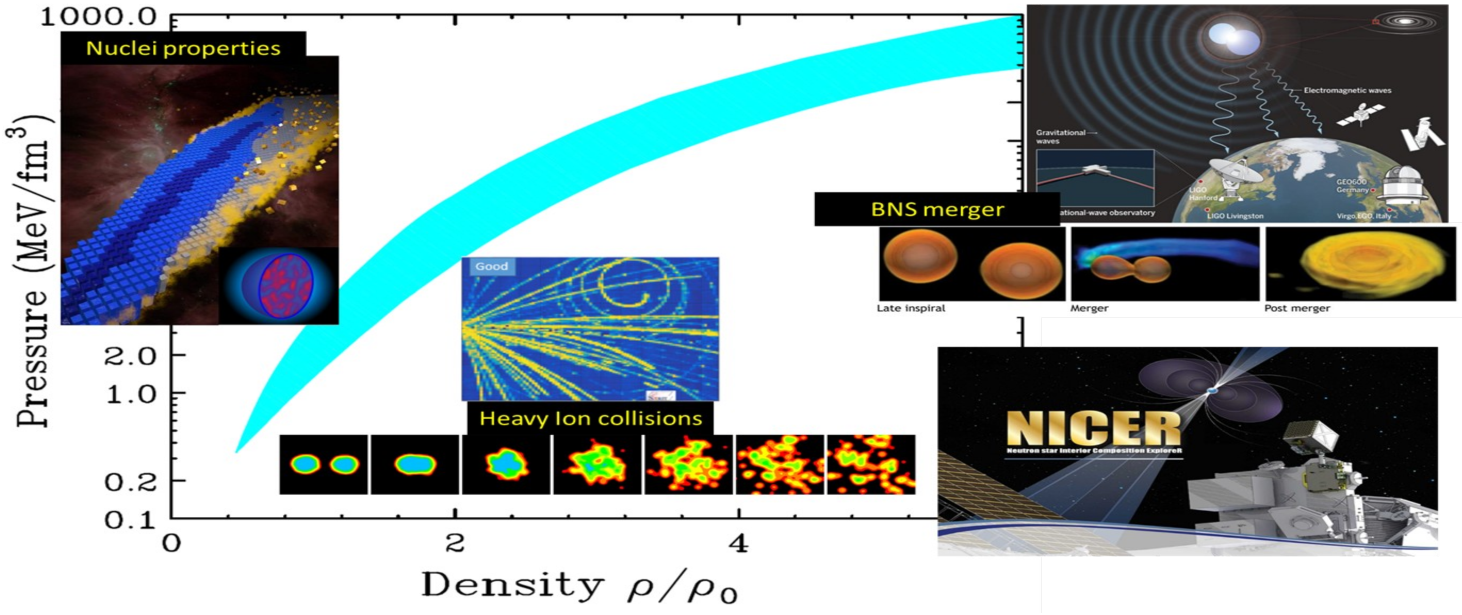
Dissipative reactions provide a unique opportunity to create nuclear matter in several conditions of density and temperature in laboratory

Femto-nova explosion created by heavy ion collisions !



from A. Ono

- Explore the nuclear matter **phase diagram** and access the nuclear **Equation of State (EOS)**



The EOS of asymmetric nuclear matter

Semi-classical approx: from ETDHF to *transport theories*

Challenges for transport theories: TMEP

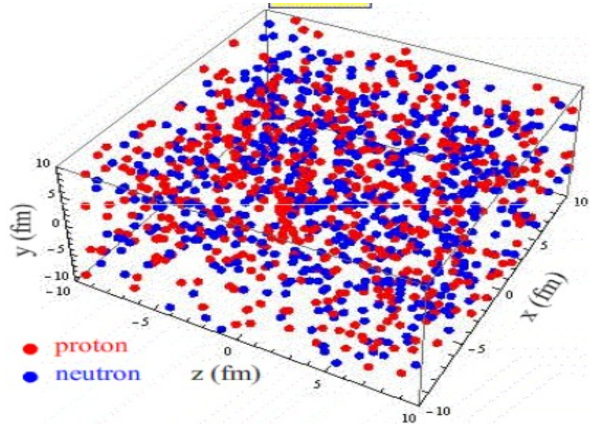
physical input (EOS, σ_{inmed}, $\pi\Delta$ physics, ..) → **transport code** → observables

- Quite complex: simulations with many technical details
- Model dependence for some observables

→ Establish a sort of systematical theoretical error

→ Transport Model Evaluation (Comparison) Project -- **TMEP**

- About 30 participants



Core group:
MC (Catania)
Dan Cozma (Bucharest)
Pawel Danielewicz & Betty Tsang (MSU)
C-M Ko and Z.Zhang (Texas A&M)
Akira Ono (Sendai)
Jun Xu (Shanghai)
Herman Wolter (Munich)
Yingxun Zhang (Beijng)

Calculations of **Nuclear Matter**
(box with periodic boundary conditions)

test separately ingredients in a transport approach:
a) collision term without and with blocking (Cascade)
Y.X. Zhang, et al., Phys. Rev. C 97, 034625 (2018)
b) mean field propagation (Vlasov)
c) pion, Δ production in Cascade
} A.Ono et al., PRC 100, 044617 (2019)
M. Colonna et al., PRC, 104, 024603 (2021)
d) instabilities , fragmentation
e) momentum dependent fields
} pl in progress
......

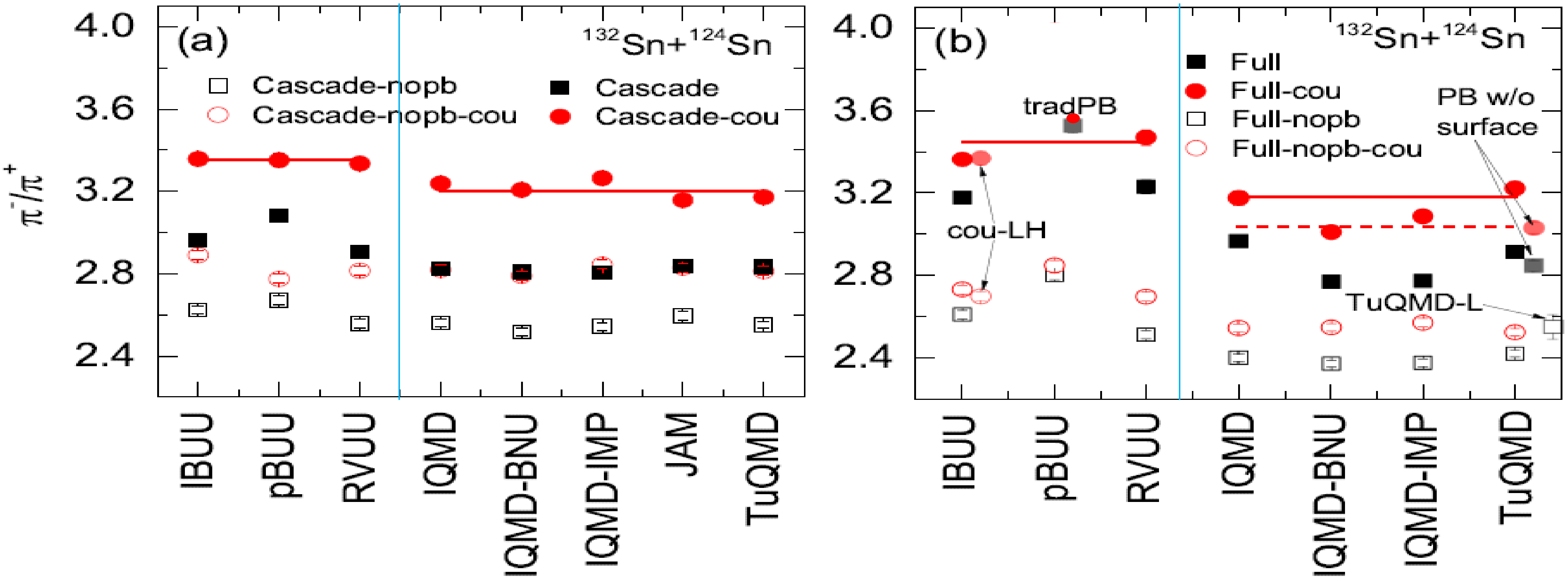
H.Wolter et al, PPNP 125 (2022)

PHYSICAL REVIEW C **109**, 044609 (2024)

Comparing pion production in transport simulations of heavy-ion collisions at 270*A* MeV under controlled conditions

Jun Xu,[1,*] Hermann Wolter,[2,†] Maria Colonna,[3,‡] Mircea Dan Cozma,[4,§] Pawel Danielewicz,[5,6,‖] Che Ming Ko,[7,¶] Akira Ono,[8,#] ManYee Betty Tsang,[5,6,**] Ying-Xun Zhang,[9,10,††] Hui-Gan Cheng,[11] Natsumi Ikeno,[12,13] Rohit Kumar,[5] Jun Su,[14] Hua Zheng,[15] Zhen Zhang,[14] Lie-Wen Chen,[16] Zhao-Qing Feng,[11] Christoph Hartnack,[17] Arnaud Le Fèvre,[18] Bao-An Li,[19] Yasushi Nara,[20] Akira Ohnishi,[21,‡‡] and Feng-Shou Zhang[22,23]
(TMEP Collaboration)

^{132}Sn + ^{124}Sn, b=4 fm E/A = 270 MeV/A



- **CASCADE**: difference **BUU**/**QMD** due to better treatment of Pauli-Blocking in **BUU**
- **FULL**: difference **BUU**/**QMD** due to «softer» effective interaction in **QMD**

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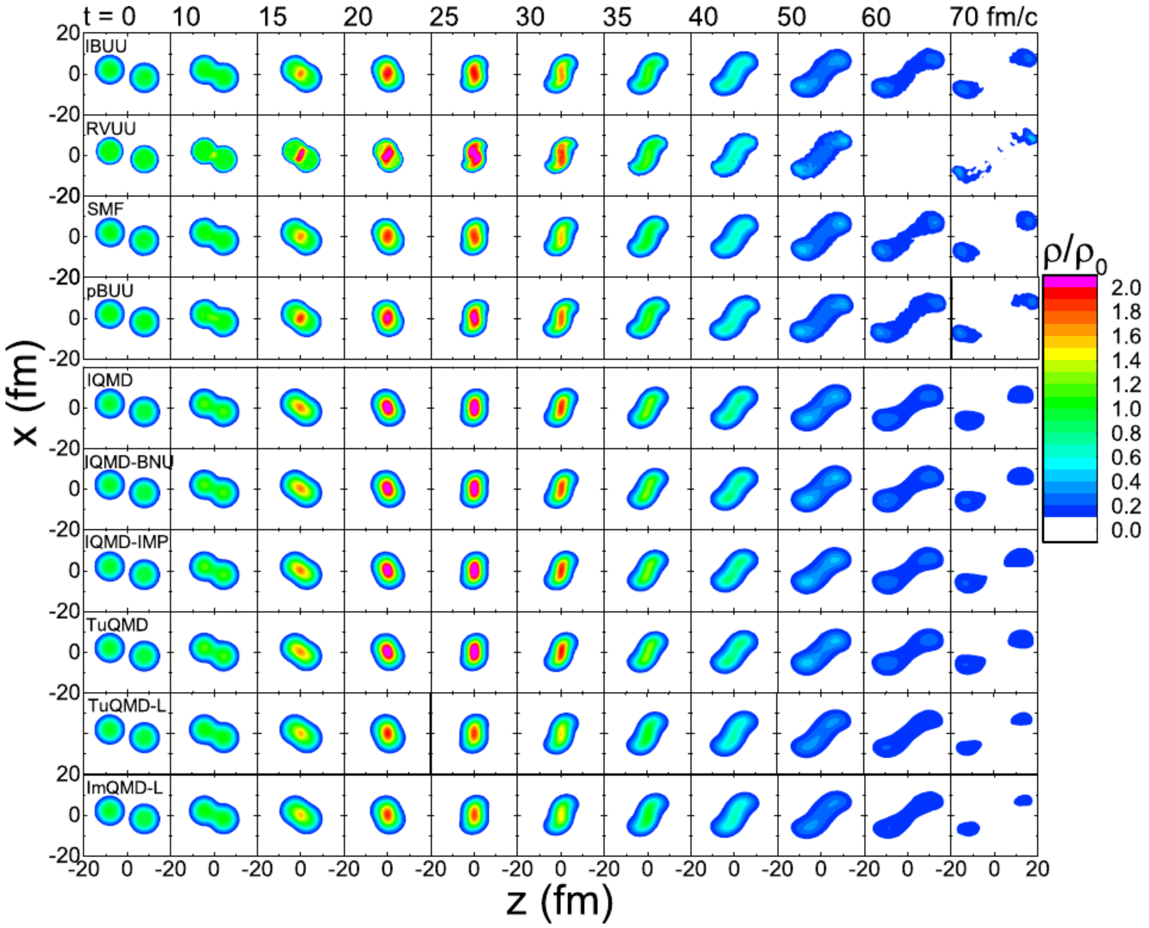


FIG. 2. Contours of reduced densities ρ/ρ_0 in the x-0-z plane at different indicated times in the Full-nopb mode.

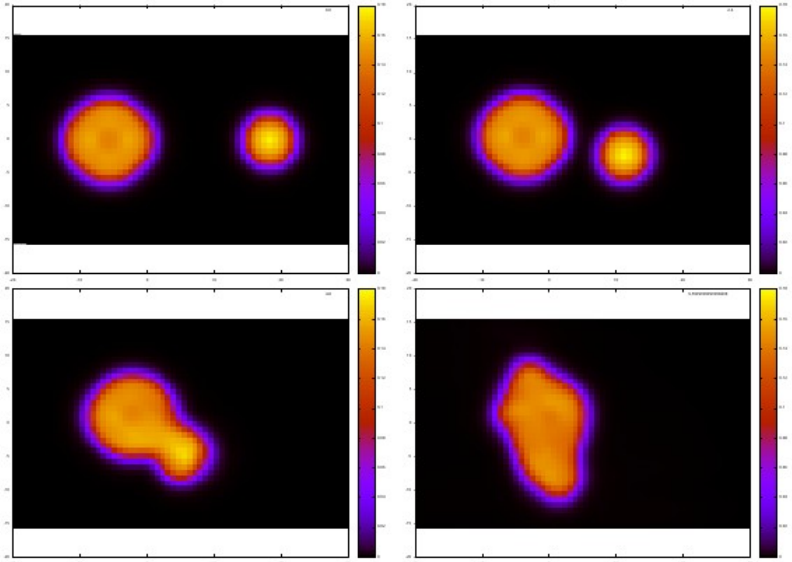
Dynamics of low-energy heavy-ion collisions (HIC)

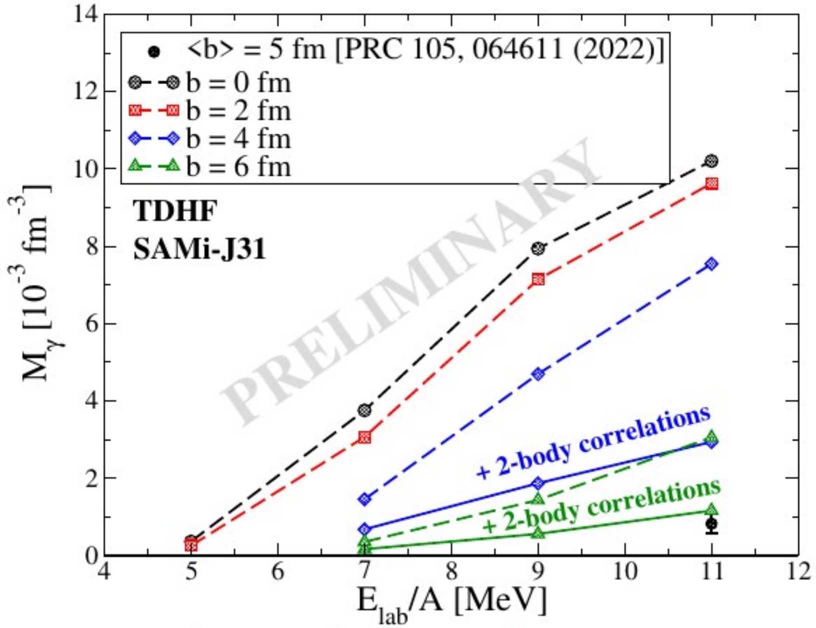
- **Mean-field** models based on (Skyrme-like) energy density functionals (**EDFs**)
  - Time-Dependent Hartree-Fock (TDHF) theory (or semi-classical counterpart)

$$i\hbar\dot{\hat{\rho}}(t) + \left[\hat{\rho}, \hat{H}_{eff}[\rho]\right] = 0$$

- Equilibration mechanisms in **charge-asymmetric** reactions around Coulomb barrier
  - **Pre-equilibrium** emission in ^{40}Ca+^{152}Sm at E_{beam}=11 AMeV⇒ **Dynamical dipole**

[L. Shvedov, S. Burrello, M. Colonna, H. Zheng, in preparation]





- Understanding **microscopic** processes underlying complex HIC dynamics
- Unraveling connection between **effective interaction** and equation of state (EOS)
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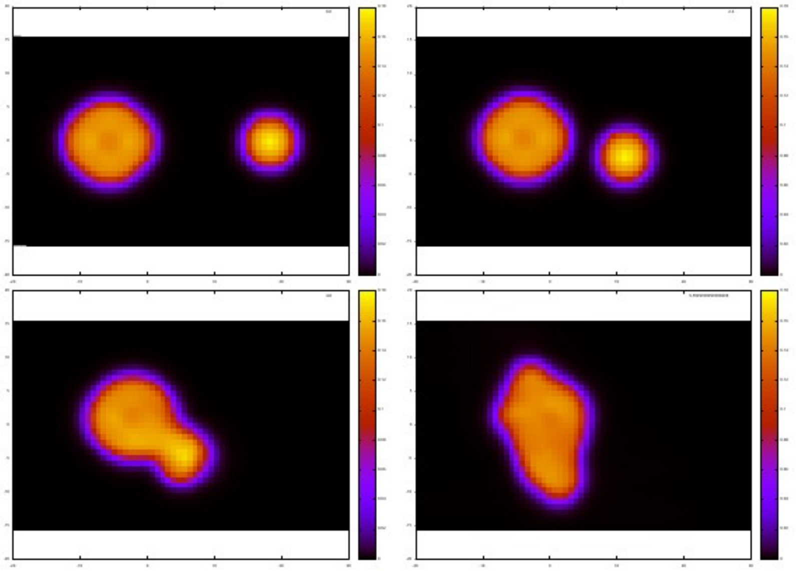

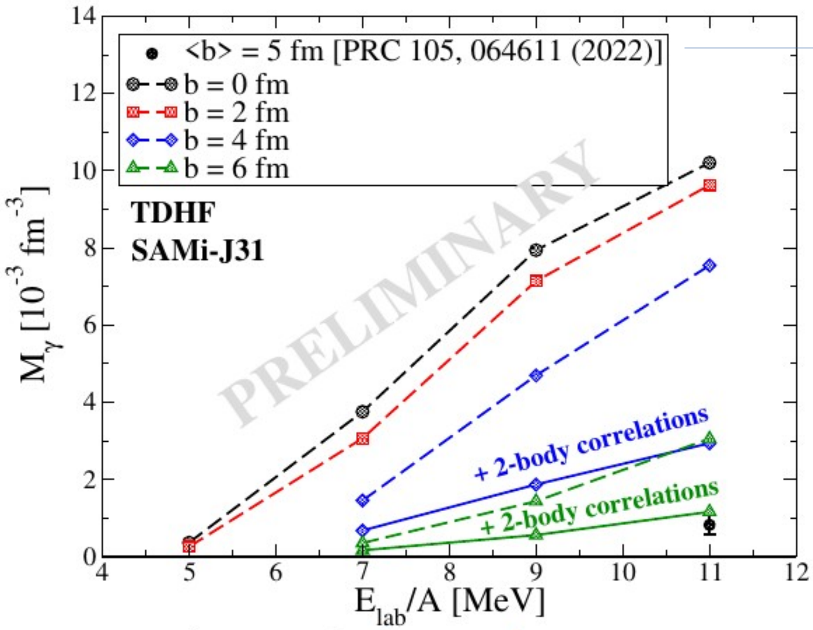

Parascandolo et al., @LNS

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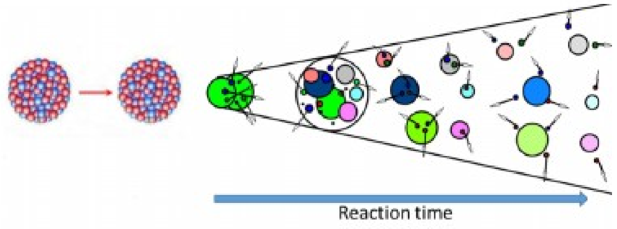
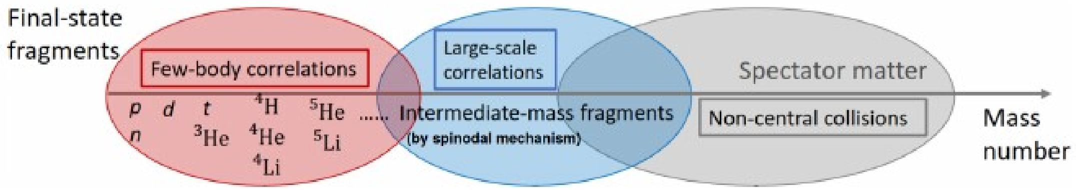
Improving models for HIC at intermediate energies

- Kinetic approach for **HIC** at $E_{\mathrm{beam}} \approx (30 - 300)\,A\mathrm{MeV} \Rightarrow$ (beyond) Boltzmann eqs.

$$(\partial_t + \nabla_{\mathbf{p}}\varepsilon_\tau \cdot \nabla_{\mathbf{r}} - \nabla_{\mathbf{r}}\varepsilon_\tau \cdot \nabla_{\mathbf{p}})\, f_\tau = I_\tau^{\mathrm{coll}}[f_n, f_p, \ldots], \qquad \tau = n, p, d, t, h, \alpha$$

  - Consistent description of light clusters (+ in-medium effects) and **fragments**

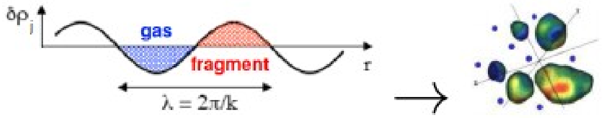


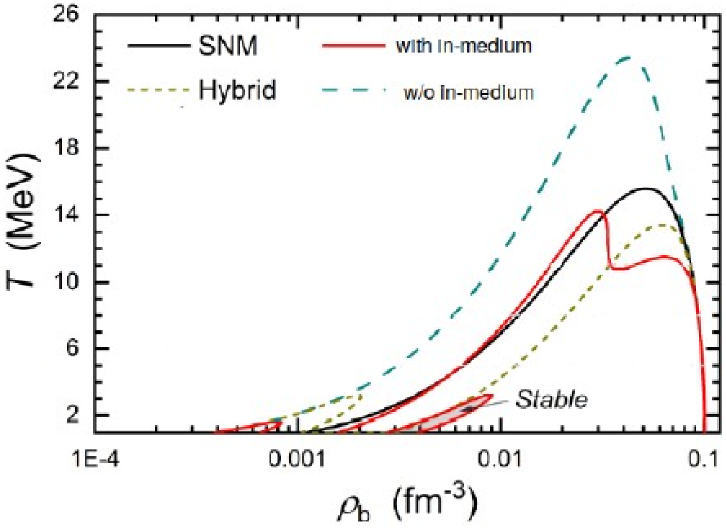


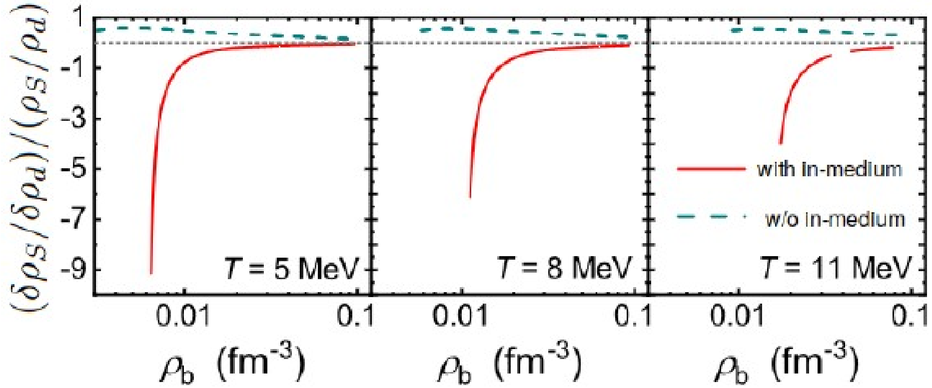
- **Linear** response to collision-less Boltzmann $\Rightarrow$ linearized **Vlasov** eqs. $(\omega = \omega(k))$

[R. Wang, S. Burrello, M. Colonna, F. Matera, arXiv:2405.02157, accepted on PRC Letter]

- $\omega = \mathrm{Im}(\omega) \Leftrightarrow$ unstable mode (**spinodal region**)







- w/o in-medium: clusters **cooperate** to fragments
- **with in-medium:** clusters separately emitted

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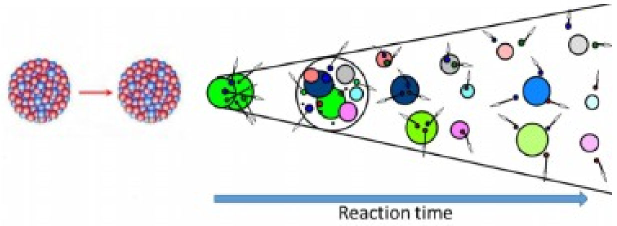

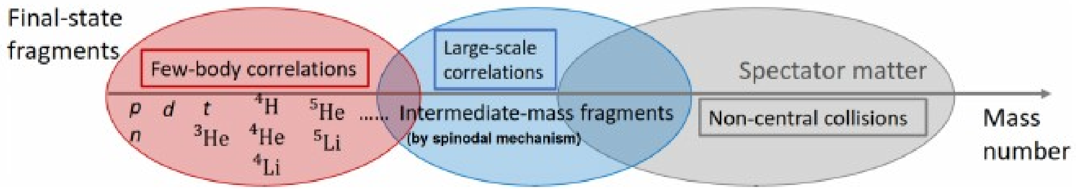

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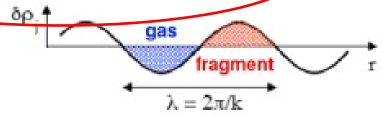
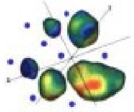
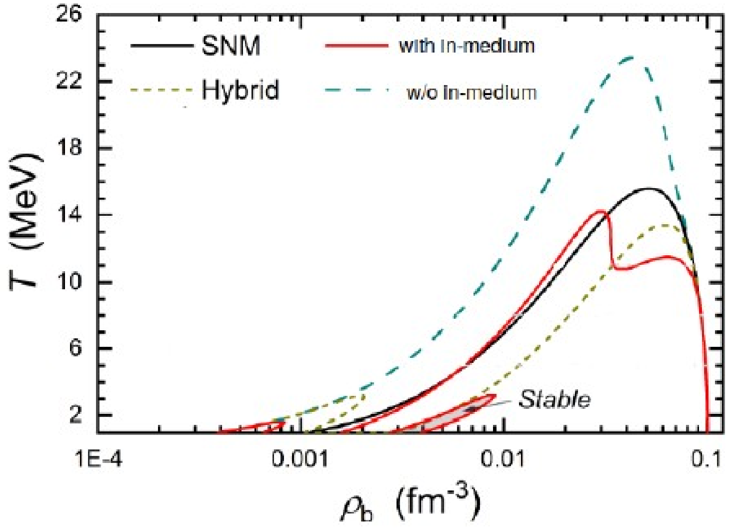
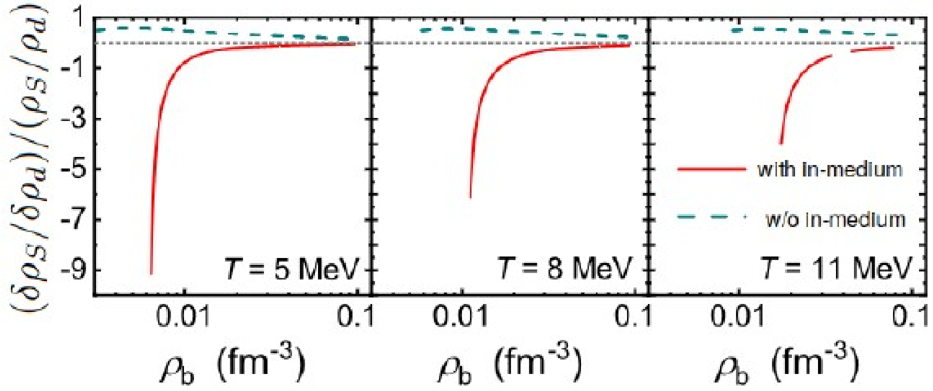






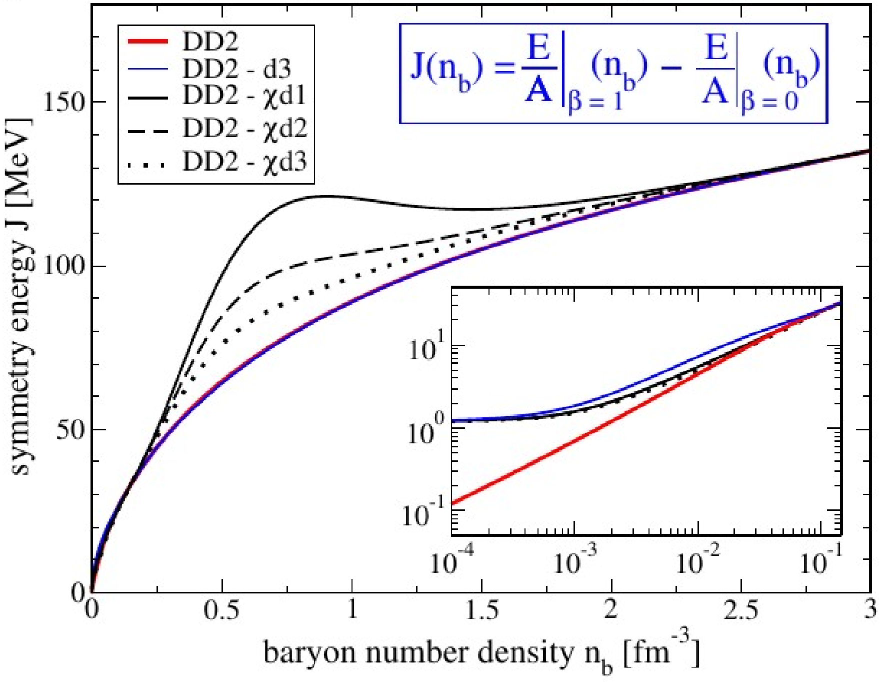


- **w/o in-medium:** clusters **cooperate** to fragments
- **with in-medium:** clusters separately emitted

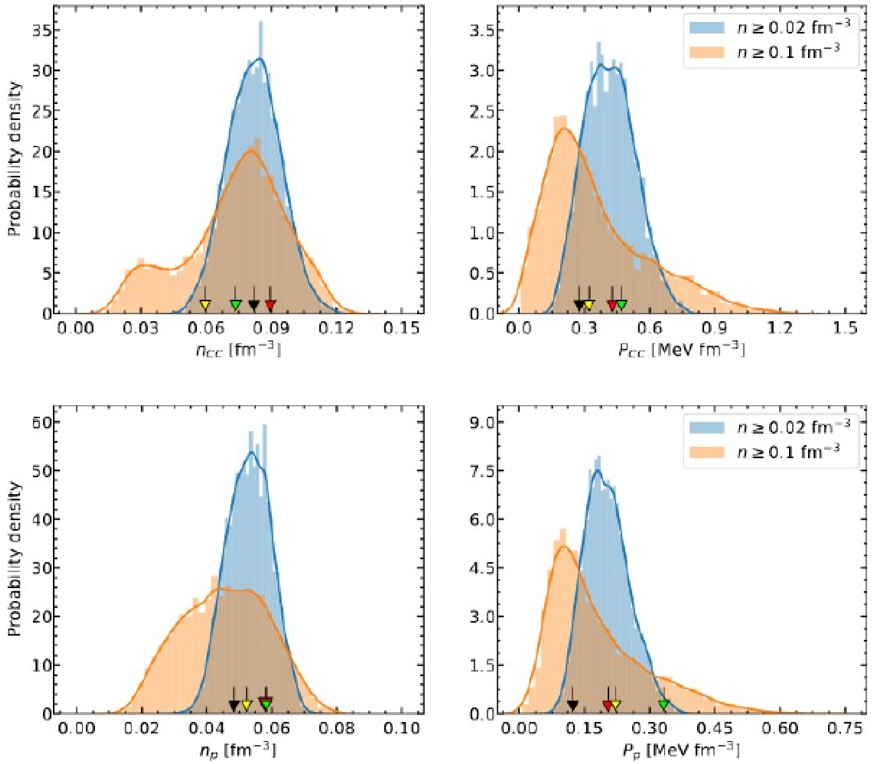
EOS and modelization of compact stellar object

- Embedding clusters and **short-range correlations** in EDFs [coll. G. Röpke & S. Typel]
- Treatment of **low-density** matter in meta-modeling approach [coll. F. Gulminelli]
  - **EFT**-inspired & ab-initio benchmarked **EDFs** [S. Burrello & M. Grasso, EPJA 58:2 (2022)]

[S. Burrello, S. Typel, EPJA 58, 120 (2022)]



[H. Dinh Thi et al., A&A 654, A114 (2021)]



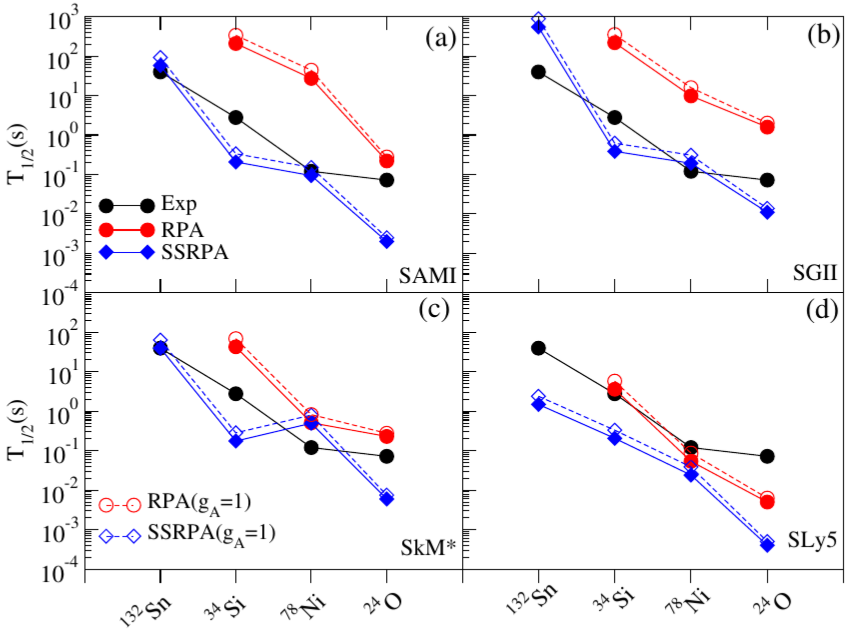
- Development of **emulators** to provide inputs on EOS from **heavy-ion physics**
  - **Theoretical** support for interpretation of GW signals for **Einstein Telescope**

PHYSICAL REVIEW LETTERS **125,** 212501 (2020)

Gamow-Teller Strength in ^{48}Ca and ^{78}Ni with the Charge-Exchange Subtracted Second Random-Phase Approximation

D. Gambacurta,[1] M. Grasso,[2] and J. Engel[3]

Improving beta decay half lives description



D.G and M. Grasso in preparation

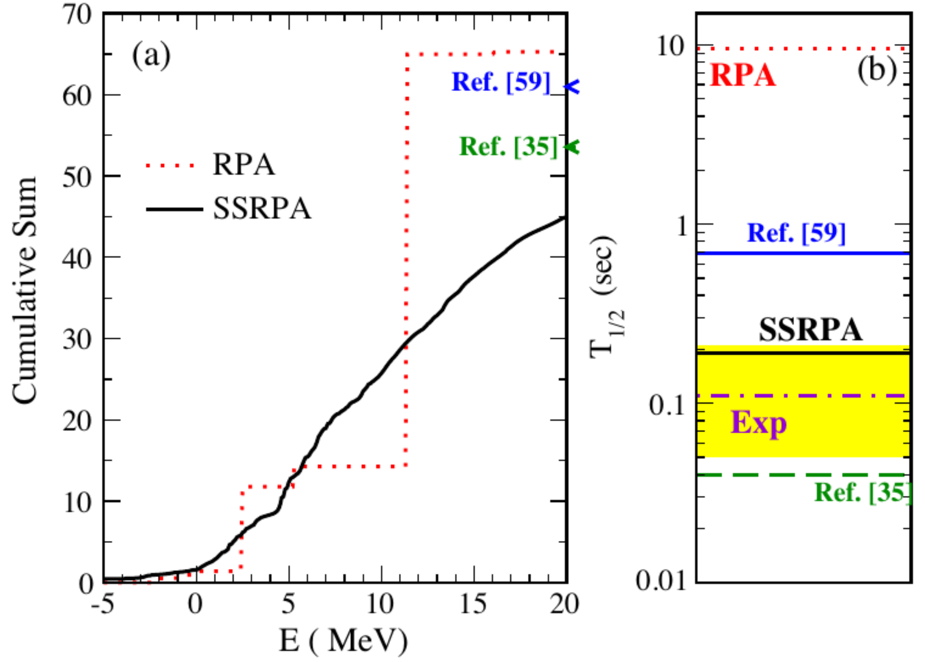


FIG. 4. (a) Cumulative sum for different models (see legend and text) for the nucleus ^{78}Ni; (b) β-decay half-life for ^{78}Ni predicted by SSRPA, compared with predictions of other models and the experimental value [58]. The yellow band represents the experimental uncertainty.

- Implications for NME in **neutrino-less double-β decay, PANDORA** and **NUMEN project**

PHYSICAL REVIEW C **109**, 044315 (2024)

Symmetry-restored Skyrme-random-phase-approximation calculations of the monopole strength in deformed nuclei

A. Porro,[1,2,3,*] G. Colò,[4,5,†] T. Duguet,[1,6,‡] D. Gambacurta,[7,§] and V. Somà[1,‖]

A. Angular momentum projection

$$P^J_{MK} \equiv \frac{2J+1}{8\pi^2} \int d\Omega\, \mathcal{D}^{J*}_{MK}(\Omega)\mathcal{R}(\Omega),$$

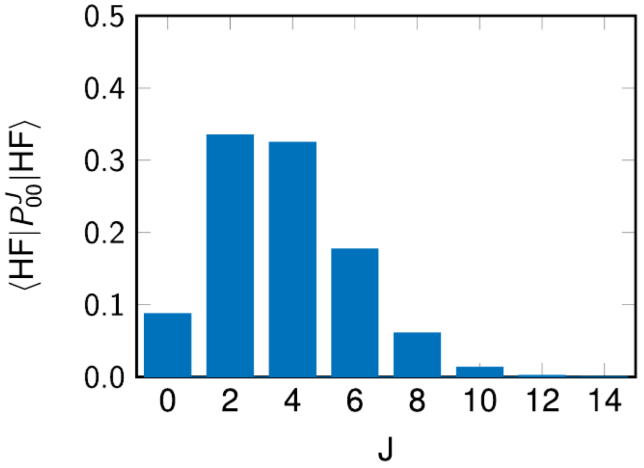
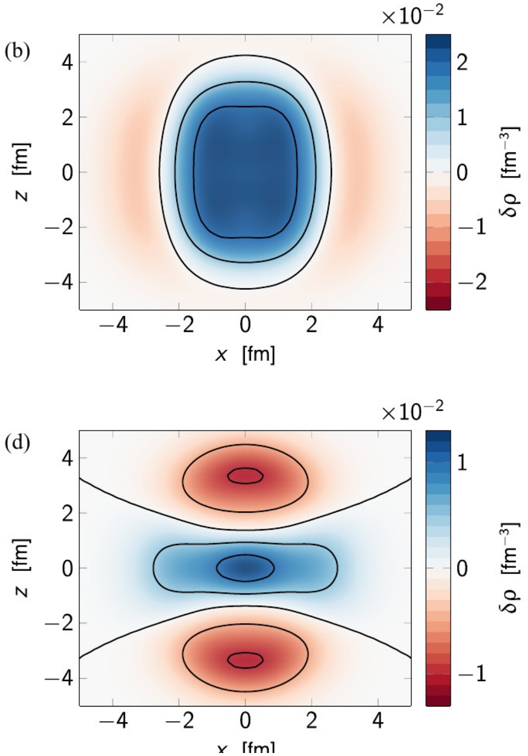
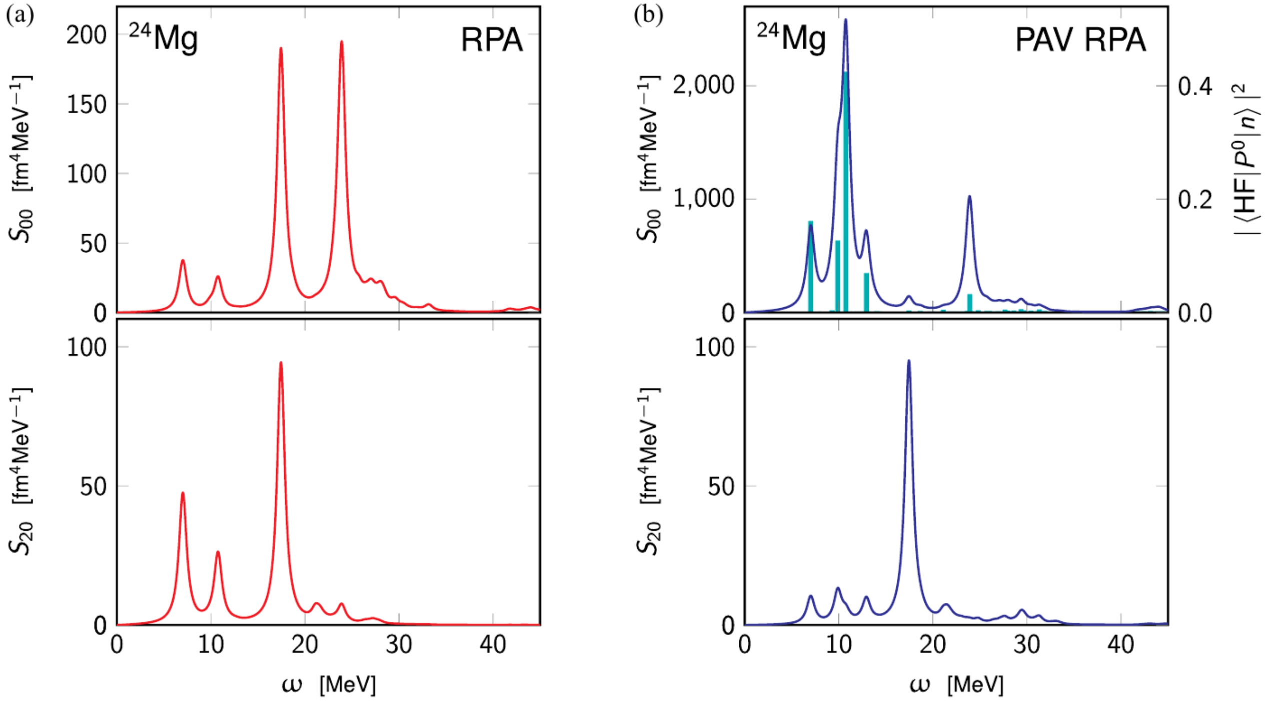


FIG. 2. Angular momentum decomposition of the HF ground state in ^{24}Mg ($N_{sh} = 11$).





PHYSICAL REVIEW C **109**, 044315 (2024)

Symmetry-restored Skyrme-random-phase-approximation calculations of the monopole strength in deformed nuclei

A. Porro[1,2,3,*] G. Colò[4,5,†] T. Duguet[1,6,‡] D. Gambacurta[7,§] and V. Somà[1,‖]

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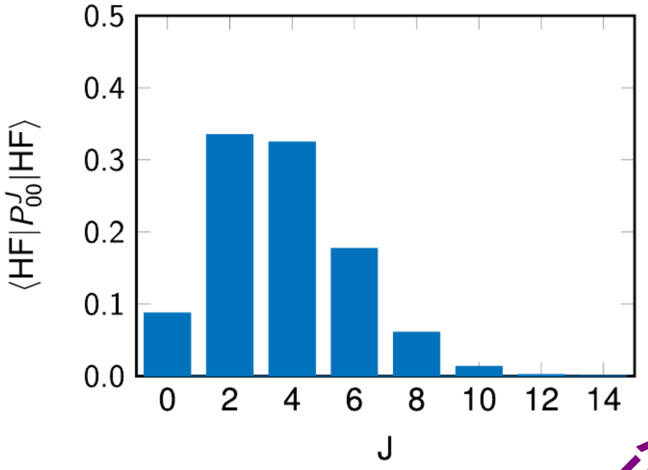

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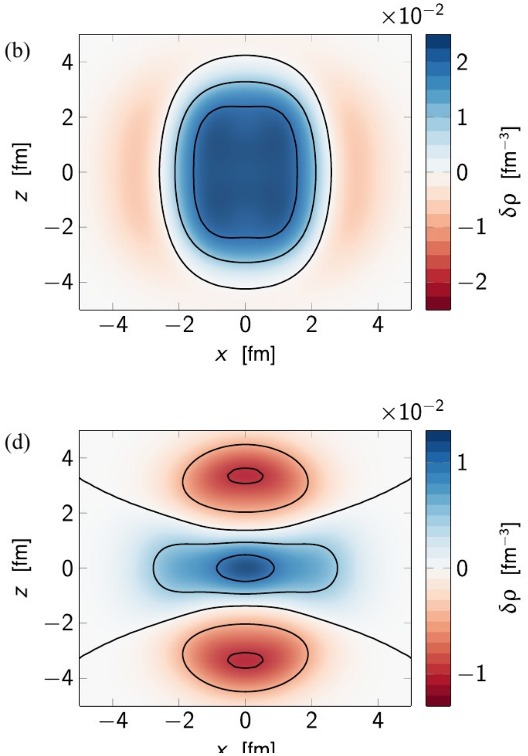

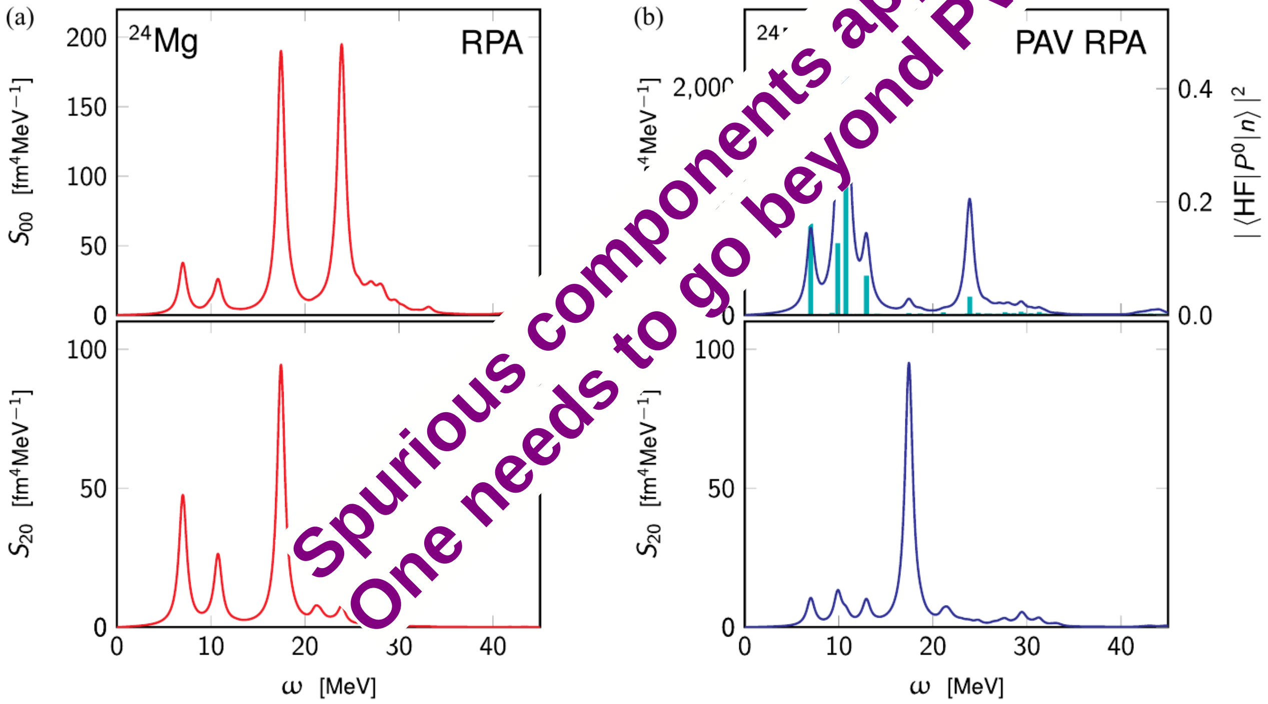

Spurious components appear =>
One needs to go beyond PVA-RPA

Attività 2025: MONSTRE

Nuclear Structure

- Single and double beta decay studies (RPA, QRPA and Second RPA), *in progress*
- Nuclear excitations in deformed nuclei and link with Equation of State
- Transport theories**:** formation of light clusters, treated as explict degrees of freedom
- Equation of State including light clusters, *Short Range Correlations*
  (important also for the modeling of compact stellar objects=>Einstein Telescope physics)

Nuclear Reactions

- Charge Exchange: Compare the results of different structure models (shell model vs. QRPA), *in progress*
- Consistent description of competing channels (multi-nucleon transfer) and, more in general, of all open reaction channels (multi-channel approach)
- Correlated Double Charge Echange mechanism (*short-range correlations*) and interference with DSCE

- **Theoretical support** to LNS experiments (Numen project, ASFIN, PANDORA, ...)

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FTE: MONSTRE (4.4) *4.7 in 2023*

cognome	nome	contratto	profilo	perc	sezione
Bonaccorso	**Angela**	Associato	Associazione Senior	0%	Pisa
Bonasera	**Aldo**	Associato	Associazione Senior	50%	LNS
Burrello	**Stefano**	Dipendente	Ricercatore	70%	LNS
Colonna	**Maria**	Dipendente	Dirigente di Ricerca	60%	LNS
Gambacurta	**Danilo**	Dipendente	Primo Ricercatore	80%	LNS
Greco	**Vincenzo**	Associato	Prof. Ordinario	10%	LNS
Gargano	**Angelina**	Dipendente	Primo Ricercatore	70%	Napoli
Shvedov	**Leonid**	Dipendente	Assegno di Ricerca	100%	LNS

SIM: Strongly Interacting Matter at high density and temperature

*Units: Catania, Firenze, **LNS**, Torino,*

FTE totale: ≈20

FTE (LNS) ≈*6.6*

Responsabile Nazionale: Andrea Beraudo (TO)

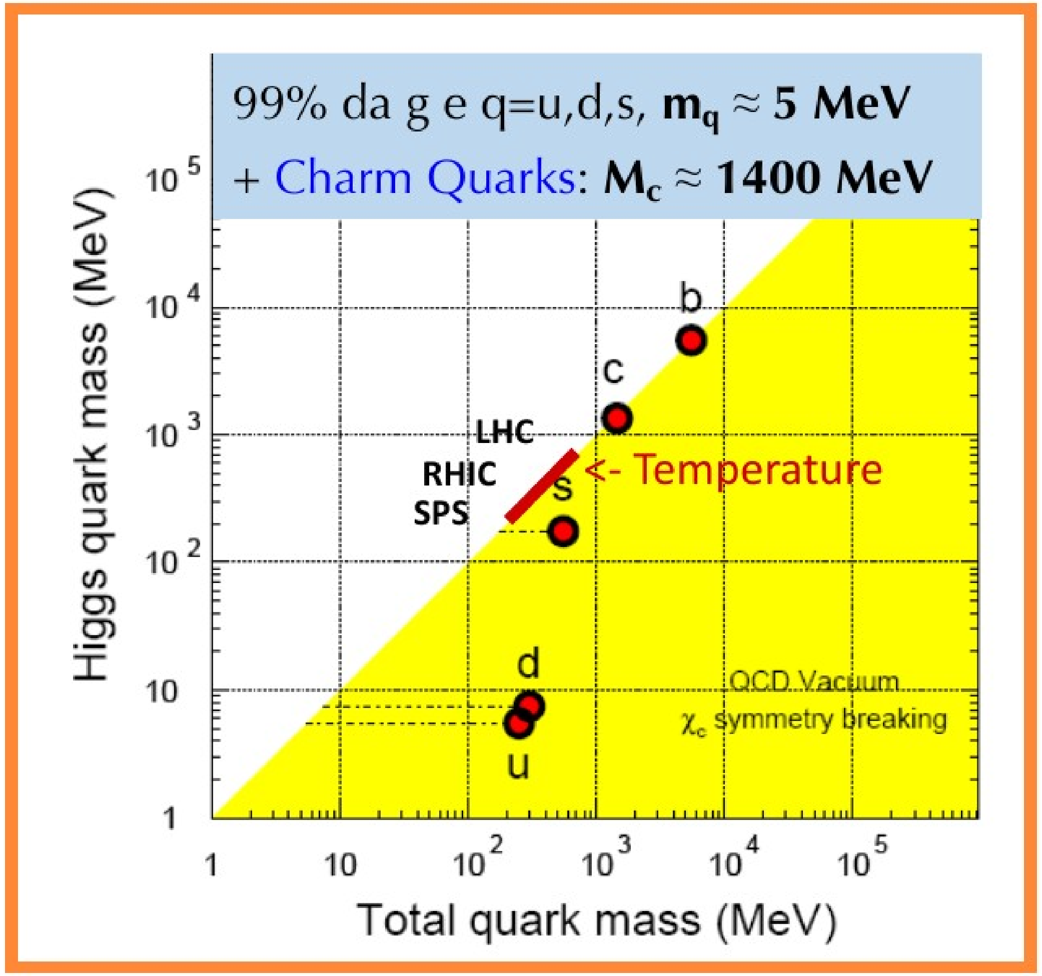
Responsabile Locale: Enzo Greco

Collaborazioni: CT, TO, Francoforte, Nantes, CERN, Berkeley LBL, Texas A&M, Duke U., Lanzhou University, University of Barcellona, IIT Ghoa,Jyväskylä , ...

Obiettivi generali: Study of strongly interacting matter at high density and temperature

- Fenomenologia del Quark Gluon Plasma (QGP)
- Dinamica dei quarks e meccanismi di adronizzazione
- Equazioni del trasporto per i partoni (beyond hydrodynamics):
- Dinamica dei quark pesanti: charm e bottom
- Early stage, dinamica di non-equilibrio AA, pA e pp

An elephant in the liquid: Heavy Charm Quark



Heavy because:

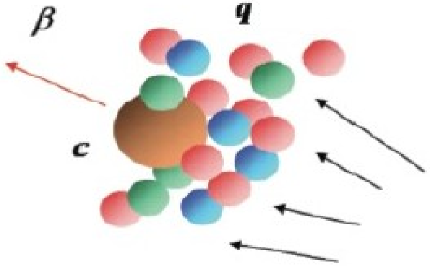
✧ **$M >> \Lambda_{QCD}$ (particle physics)**

✧ **M >> T (plasma physics)**

Fokker-Planck Equation – Brownian motion

$$\frac{\partial f_{c,b}}{\partial t} = \gamma \frac{\partial (p f_{c,b})}{\partial p} + D \frac{\partial^2 f_{c,b}}{\partial p^2}$$

<p> Drag — <Δp²> Diffusion



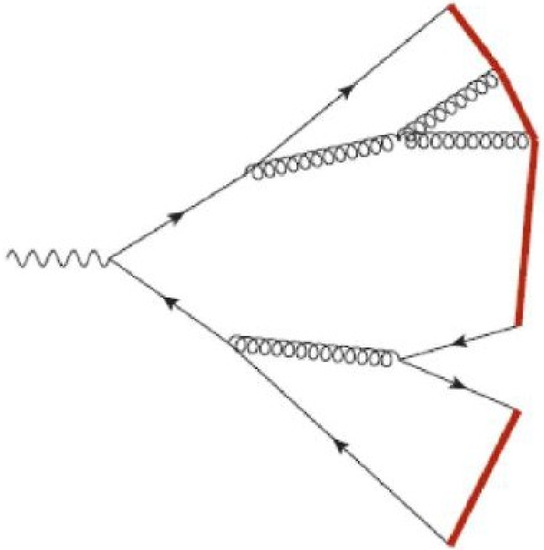
→ Poorly dragged & long thermalization time (!?)

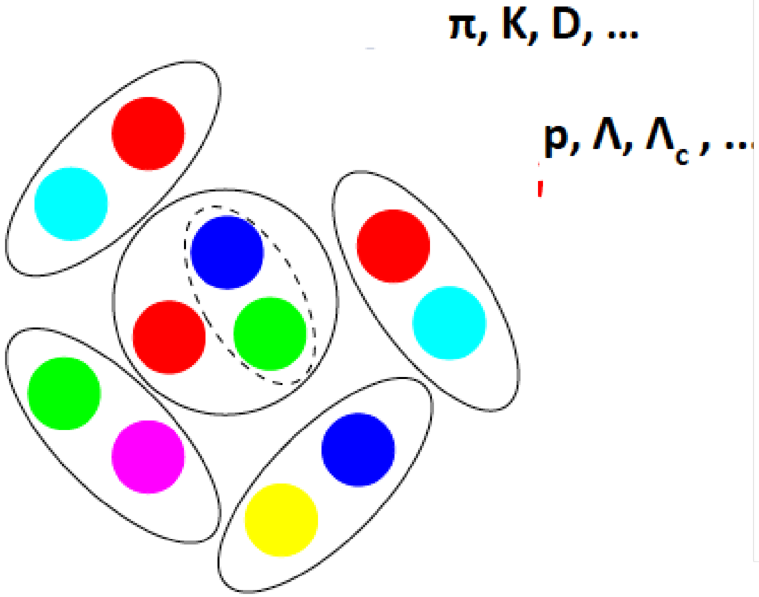
$\tau_{C,therm} \approx O(10^2) >> \tau_{QGP} >> \tau_{q,therm} \approx O(1)$ fm/c

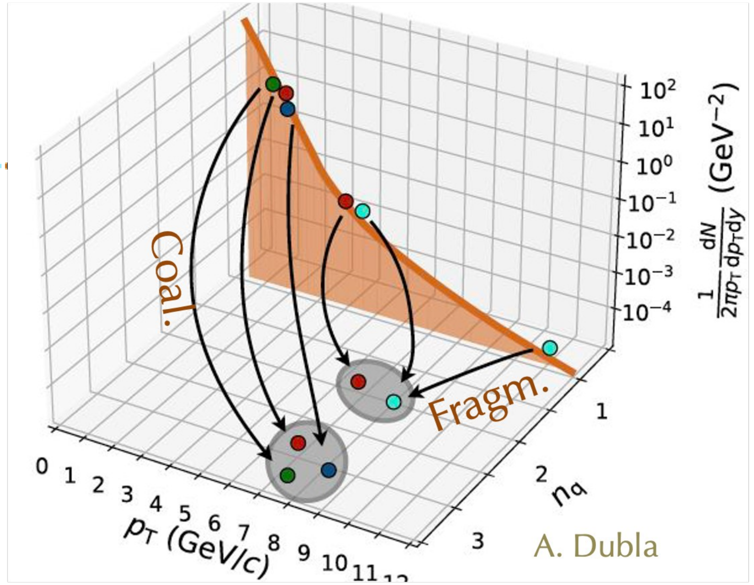
Goal : determine strength of QCD interaction and thermalization time of Heavy quarks

Long stand problem → reproduce both p_T spectra (R_{AA}) and elliptic flow (v_2)

Hadronization from e^+e^- to pp and AA







Fragmentation

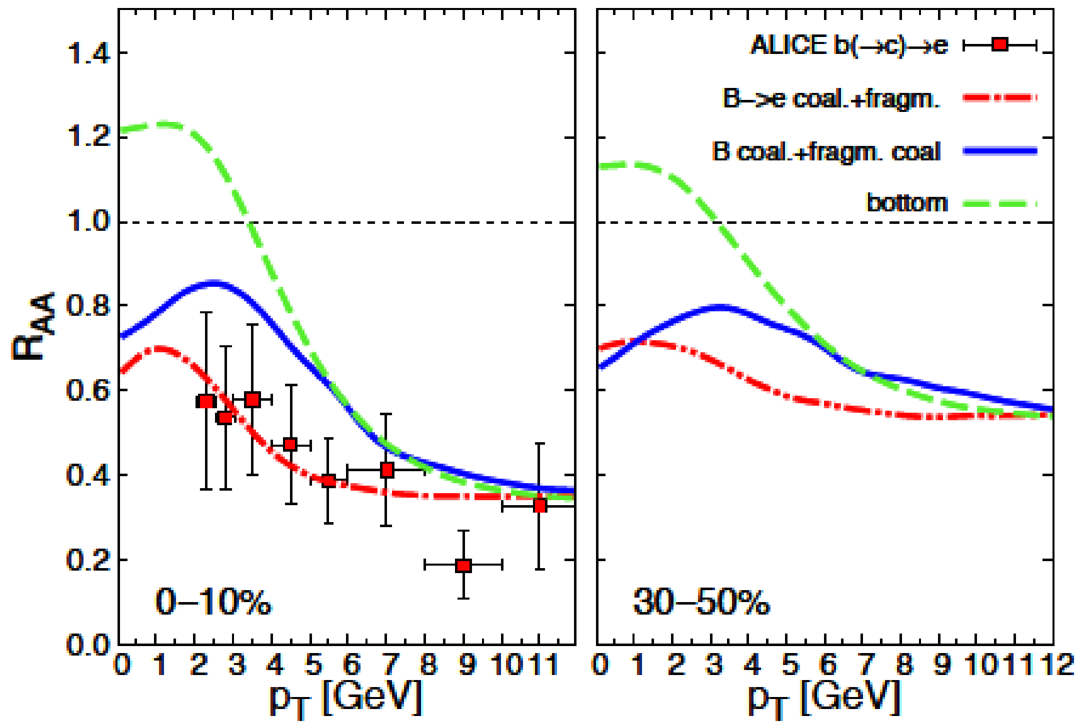
$$f_H(P_H = zp_T) = f_{q,g}(p_T) \otimes D_{q,g\to H}(z) \quad , z<1$$

Coalescence

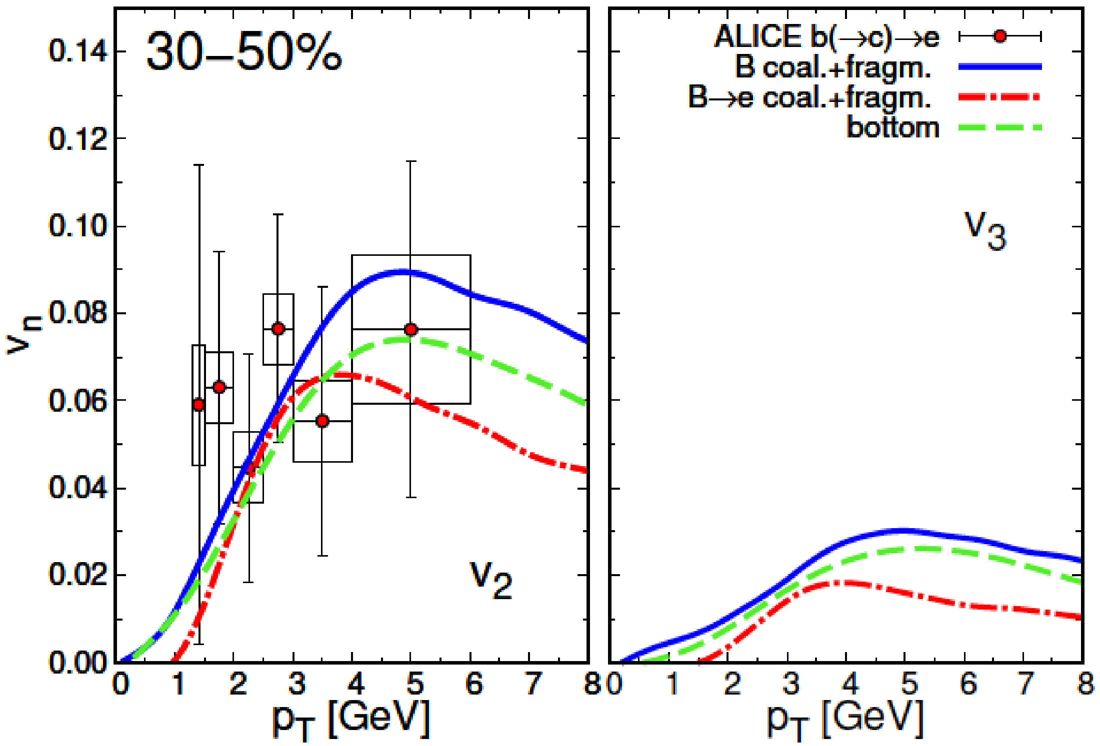
$$f_M \approx f_q \otimes f_{\bar{q}} \otimes \Phi_M \cdot \delta(\vec{p}_M - \vec{p}_q - \vec{p}_{\bar{q}})$$

Extension to b quark dynamics

Ratio p_T spectra AA/pp collision



Ellitpic v_2 and triangular v_3 flow



- Extension of QPM-Catania model employed for charm quarks to bottom quarks: no parameter adjustment!
- Comparison to electrons for semileptonic decays of B mesons: OK! (large error bars)

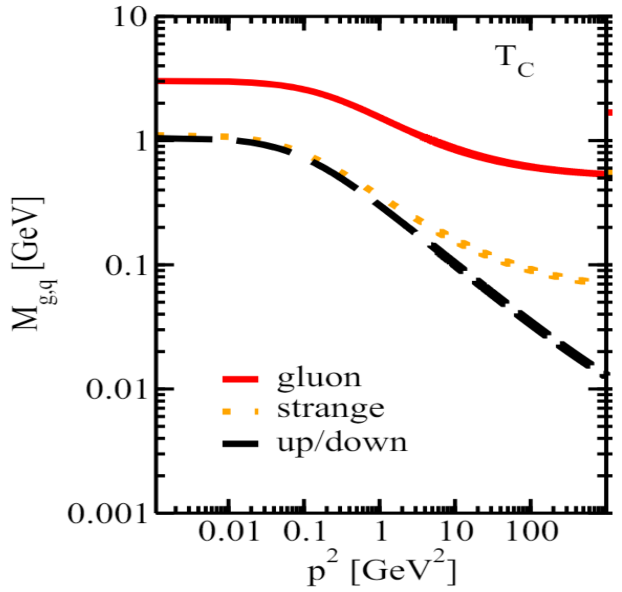
ML Sambataro et al., PLB849(2024) [hep-ph]

New: QPM (N_f=2+1) extension to QPMp (N_f=2+1+1)

Momentum dependent masses : p >> Λ_{QCD} $m_{u,d,s}$ → current masses

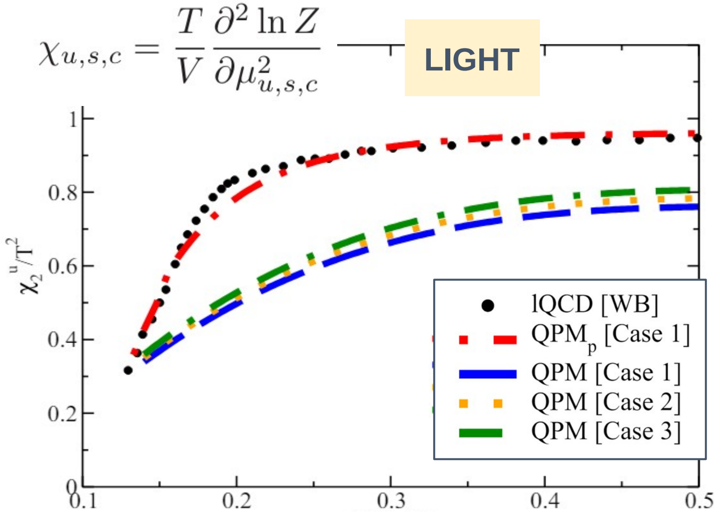
$$M_g(T,\mu_q,p) = \left(\frac{3}{2}\right)\left(\frac{g^2(T^\star/T_c(\mu_q))}{6}\left[\left(N_c+\frac{1}{2}N_f\right)T^2+\frac{N_c}{2}\sum_q\frac{\mu_q^2}{\pi^2}\right]\left[\frac{1}{1+\Lambda_g(T_c(\mu_q)/T^\star)p^2}\right]\right)^{1/2} + m_{\chi g}$$

$$M_{q,\bar{q}}(T,\mu_q,p) = \left(\frac{N_c^2-1}{8N_c}g^2(T^\star/T_c(\mu_q))\left[T^2+\frac{\mu_q^2}{\pi^2}\right]\left[\frac{1}{1+\Lambda_q(T_c(\mu_q)/T^\star)p^2}\right]\right)^{1/2} + m_{\chi q}$$



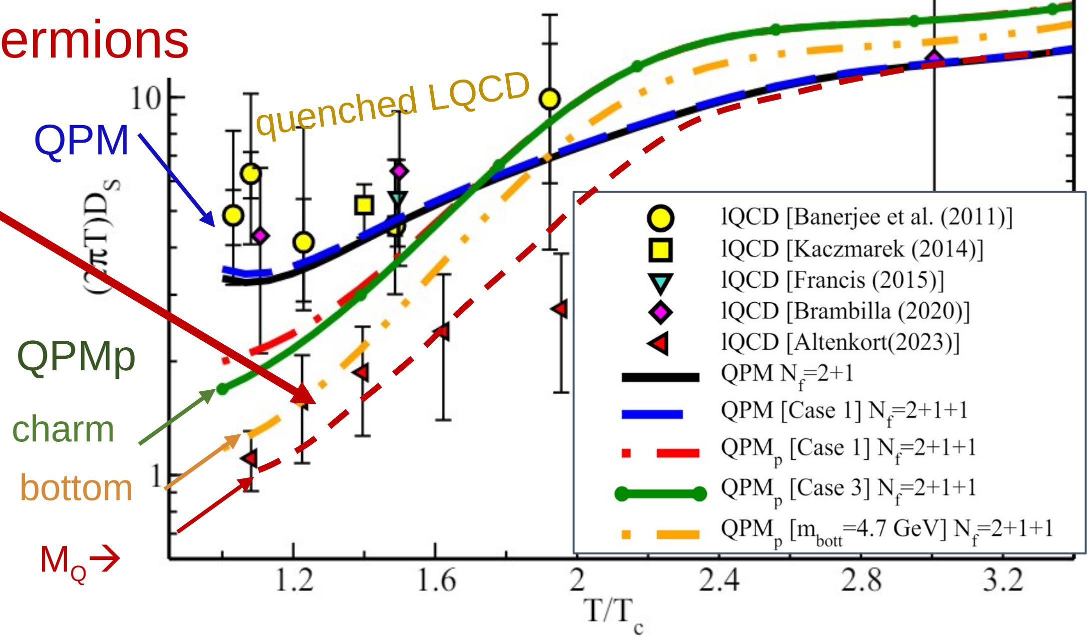
$m_{u,d,s}(p)$ expected on theoretical ground → susceptibilities…

$$\chi_{u,s,c} = \frac{T}{V}\frac{\partial^2 \ln Z}{\partial \mu_{u,s,c}^2}$$



- **QPMp** describes **ε,P, χ_q, χ_s ofLQCD**
  + closer than QPM to D_S to **new LQCD** with dynamical fermions

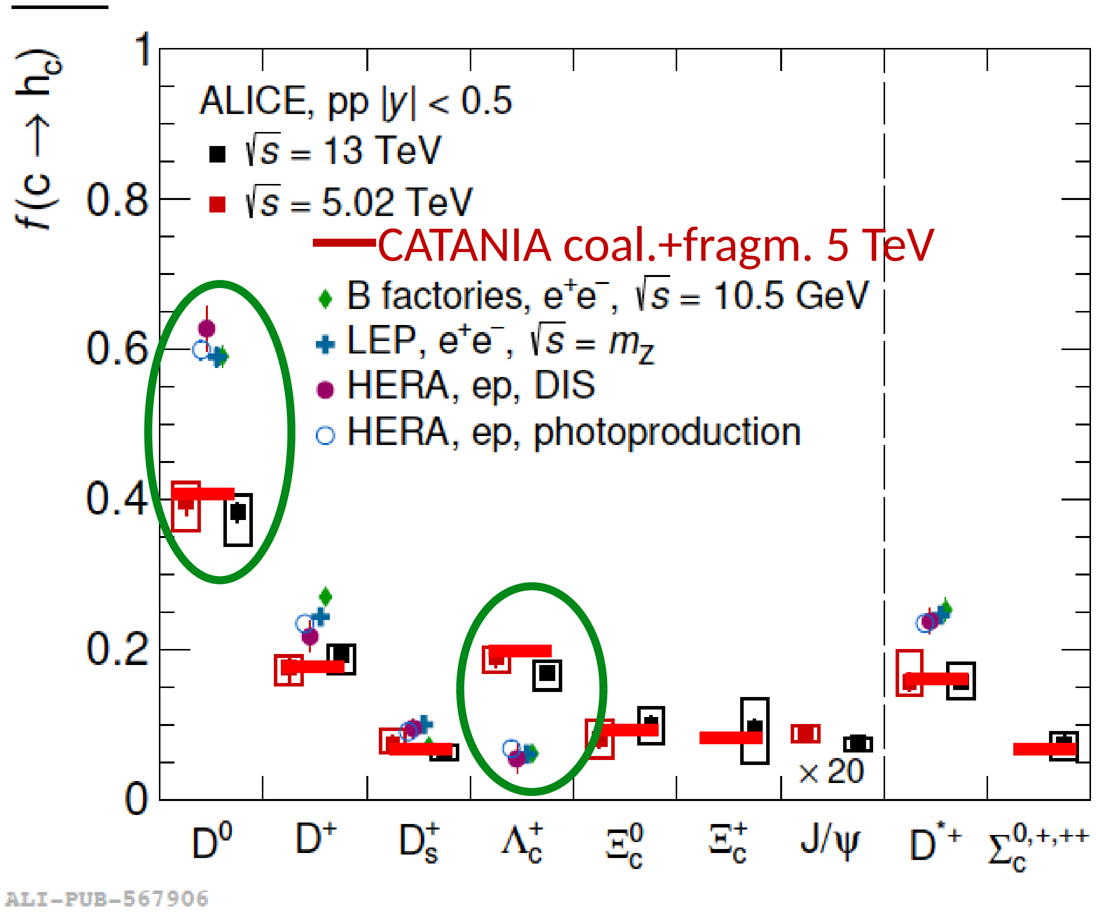
$$D_s = \frac{T}{M\gamma} = \frac{T}{M}\tau_{th}$$



- **Can this new D_s(T) generate predictions for R_{AA}, v_2, v_3 in agreement with experimental data?**

M.L. Sambataro et al. e-Print: 2404.17459

“Fragmentation” Fractions in pp Catania Coalescence



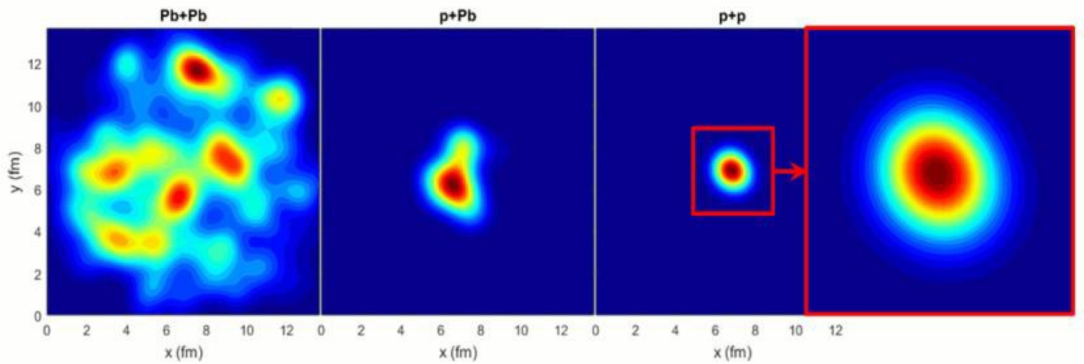
Altmann, Dubla, Greco, Rossi & Skands, arXiv:2405.19137

- Evidence of different “Fragmentation” Fractions in pp at LHC wrt $e^+e^-(e^-p)$ collisions while very similar to AA collisions

- Catania Coal+Fragm. : same approach to pp and AA: pp@TeV like a little drop of AA

Coalescence $f_M \approx f_q \otimes f_{\bar{q}} \otimes \Phi_M \cdot \delta(\vec{p}_M - \vec{p}_q - \vec{p}_{\bar{q}})$

Daring to assume a small fireball according **viscous hydro** applied to pp as in AA, but **size,time, flow given by hydro for pp**



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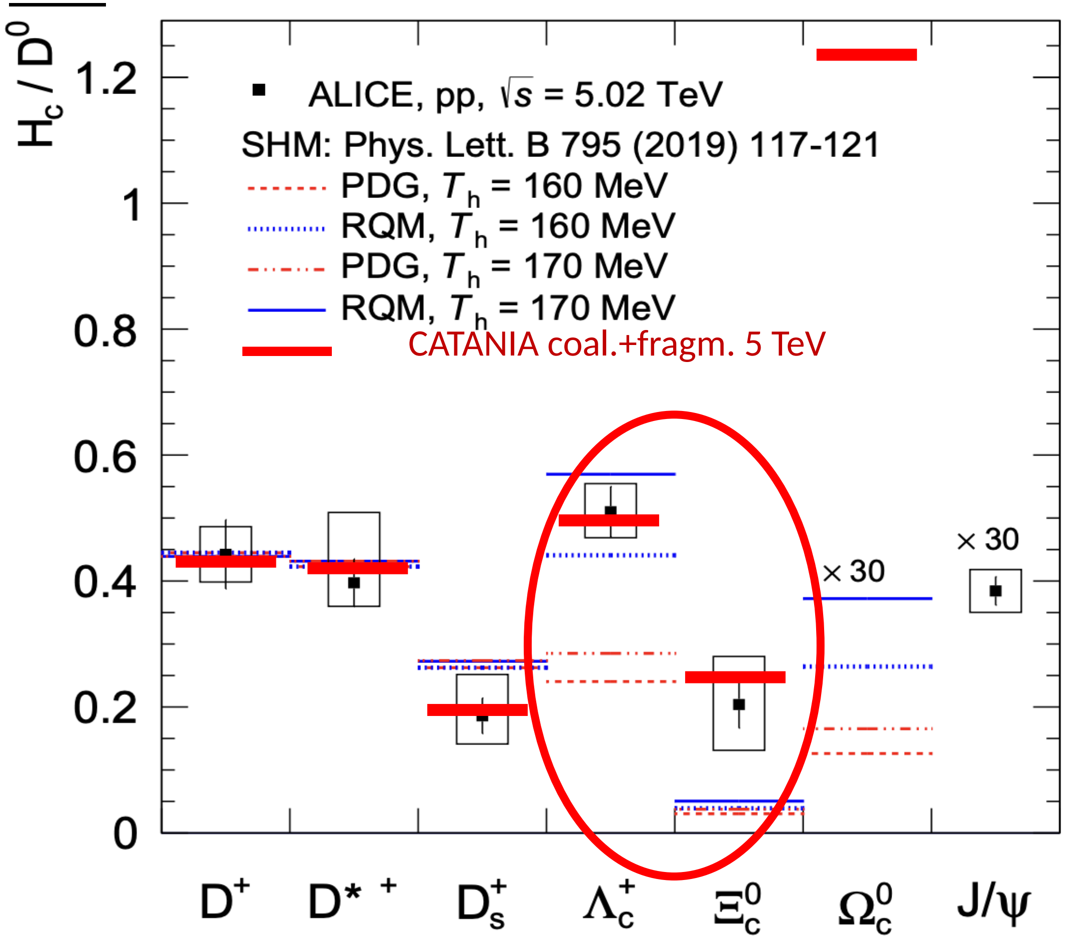

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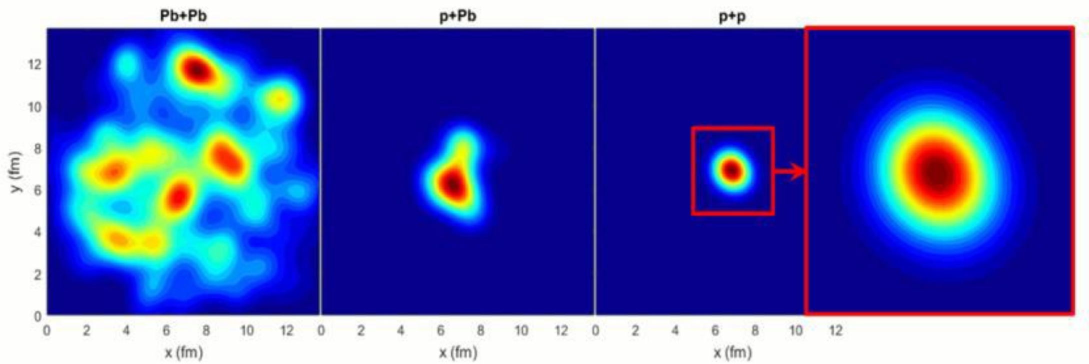
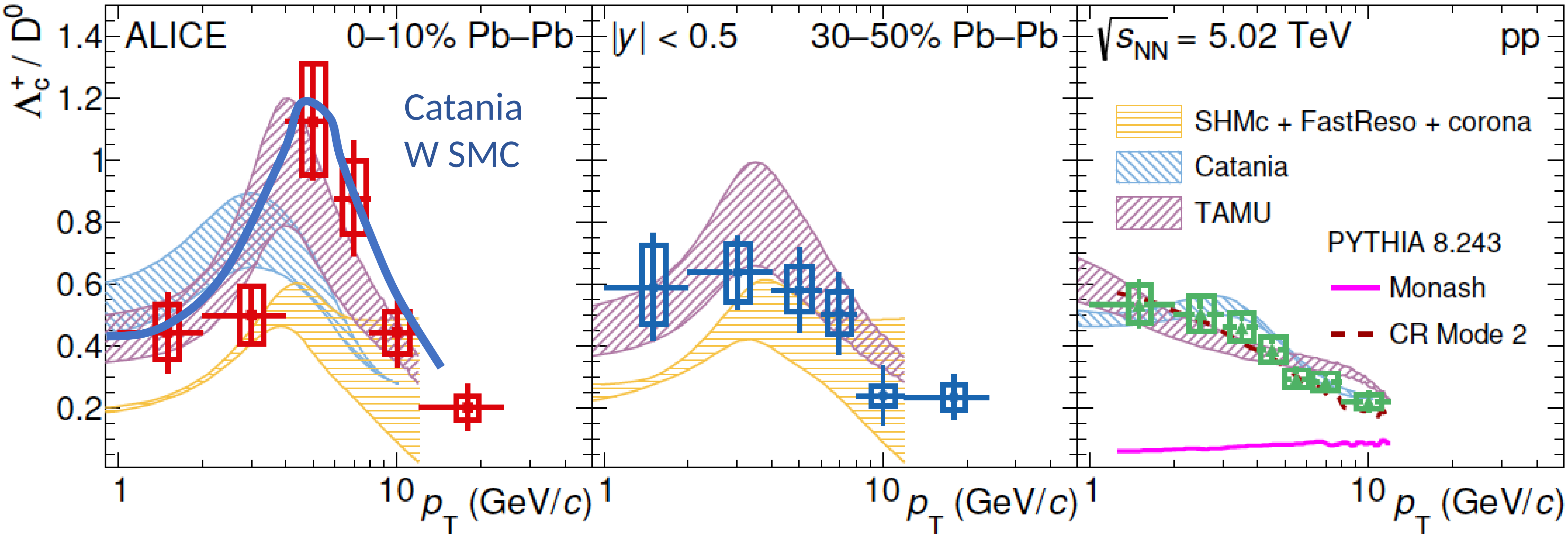
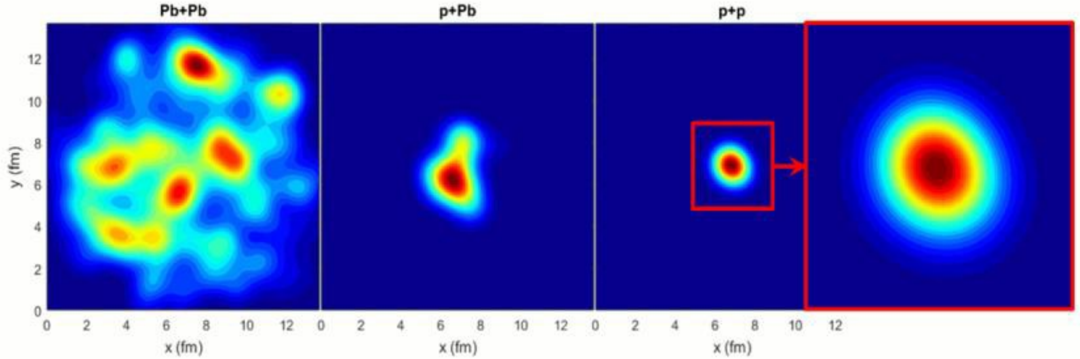


From AA to pp baryon/meson vs p_T



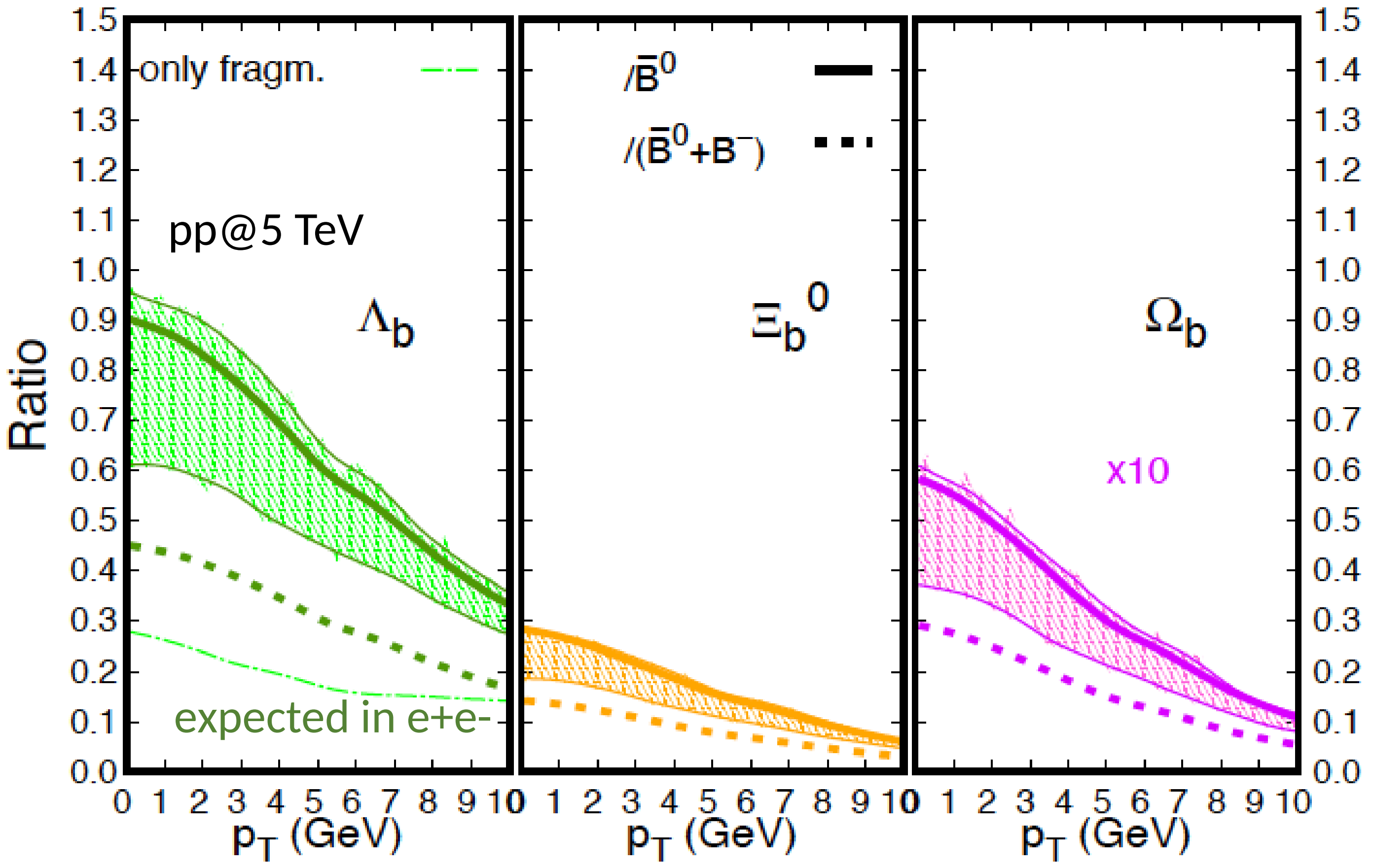
Same hadronization approach in pp and AA:
pp@TeV like a drop of AA with smaller size & radial flow

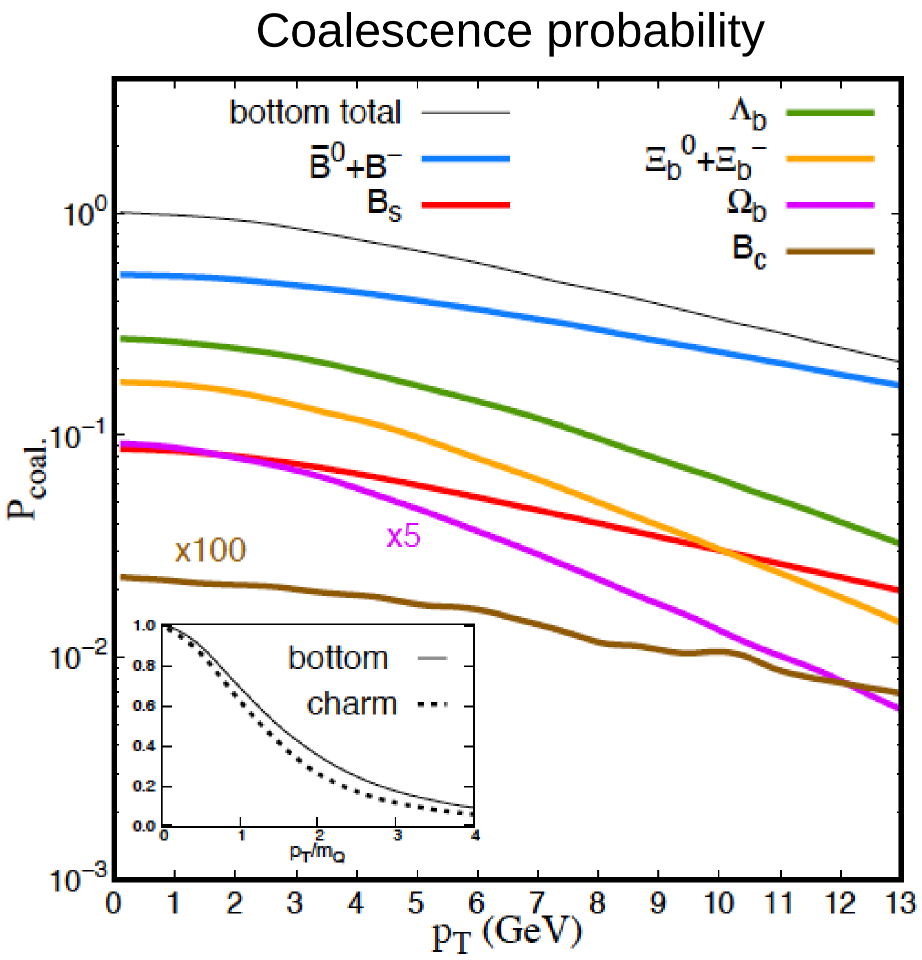
SMC: Space-Momentum correlation



“Extension to bottom baryons

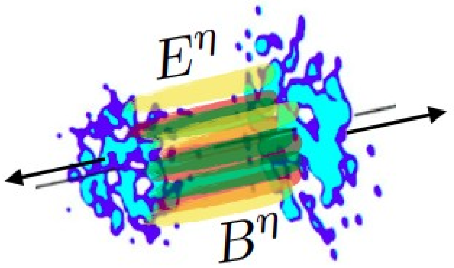
V. Minissale et al., 2405.19244 [hep-ph]





- Similar but even larger Λ_b/B than Λ_c/D
- Extension of coalescence probability in p_T about proportional to the heqvy quark mass

Very early stage dynamics

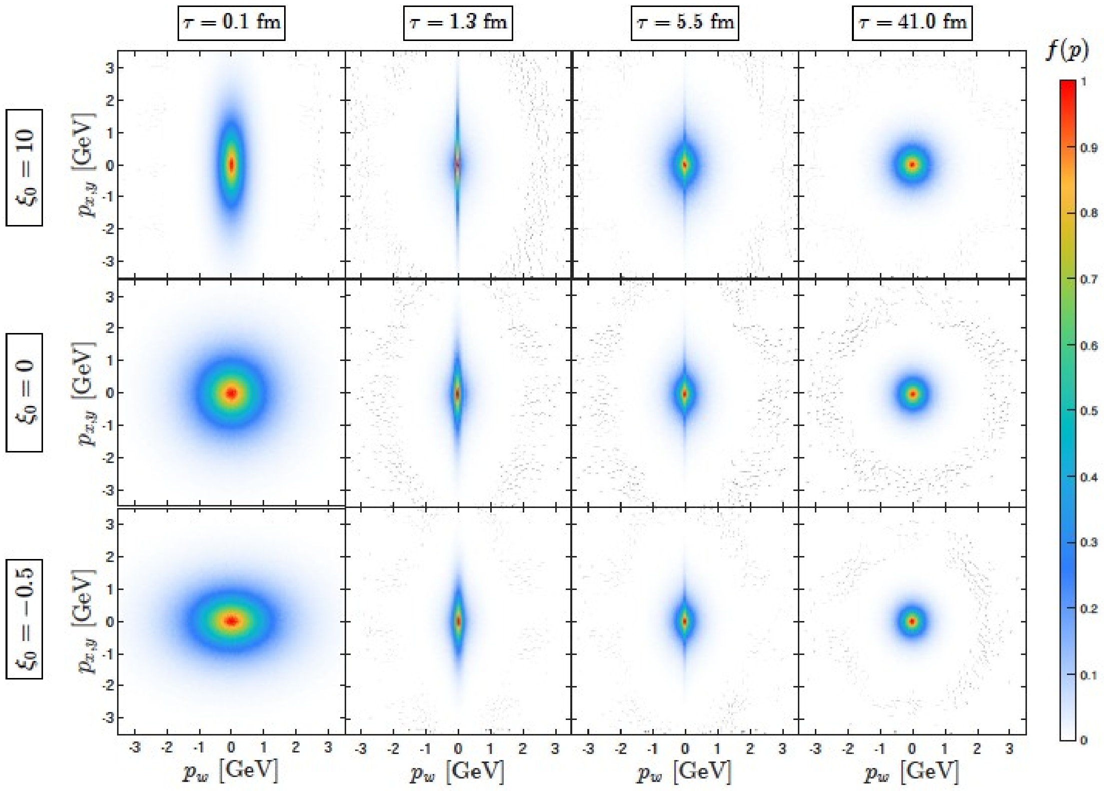


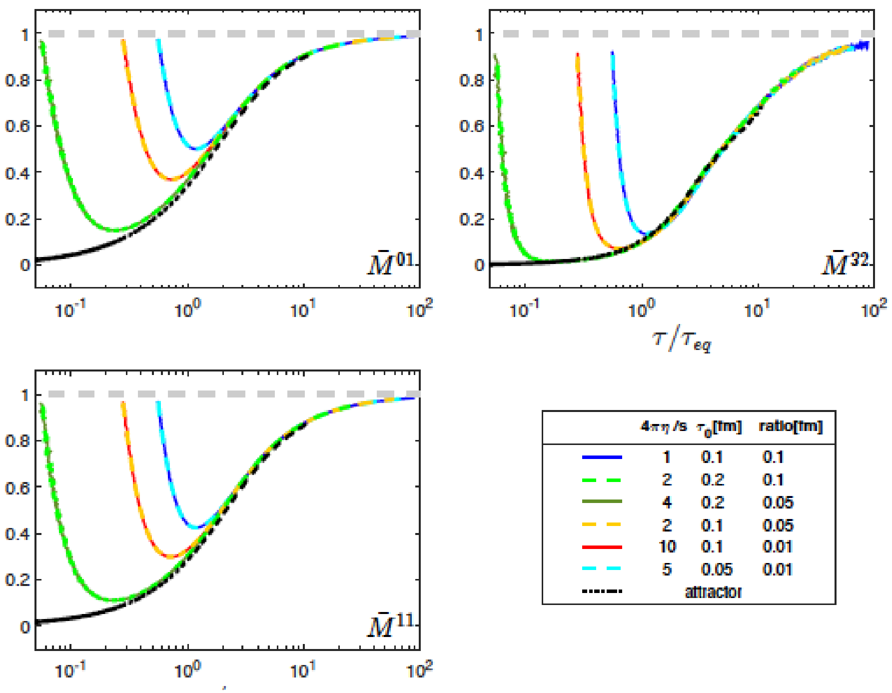
$$p^\mu \partial_\mu f_a(x,p) + m(x)\,\partial^x_\mu m(x)\,\partial^\mu_p f_q(x,p) = C[f_q, f_g]$$

$$\mathcal{M}^{mn}(\tau) = \int dP\, (p\cdot u)^n\, (p\cdot z)^{2m}\, f(\tau,p).$$

transverse to flow* longitudinal

Evolution of the moments
of the distribution function





Simulation
in 1+1D

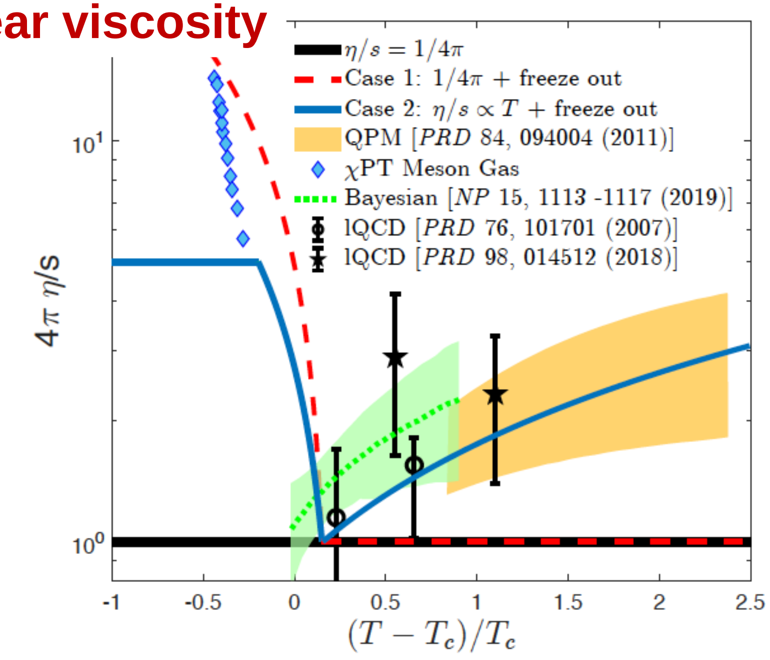
How sensitive we are to "unknown"

initial conditions and early stage attractions?

V. Nugara et al., 2311.11921 [hep-ph]

Impact of transition to hadronic matter

Shear viscosity



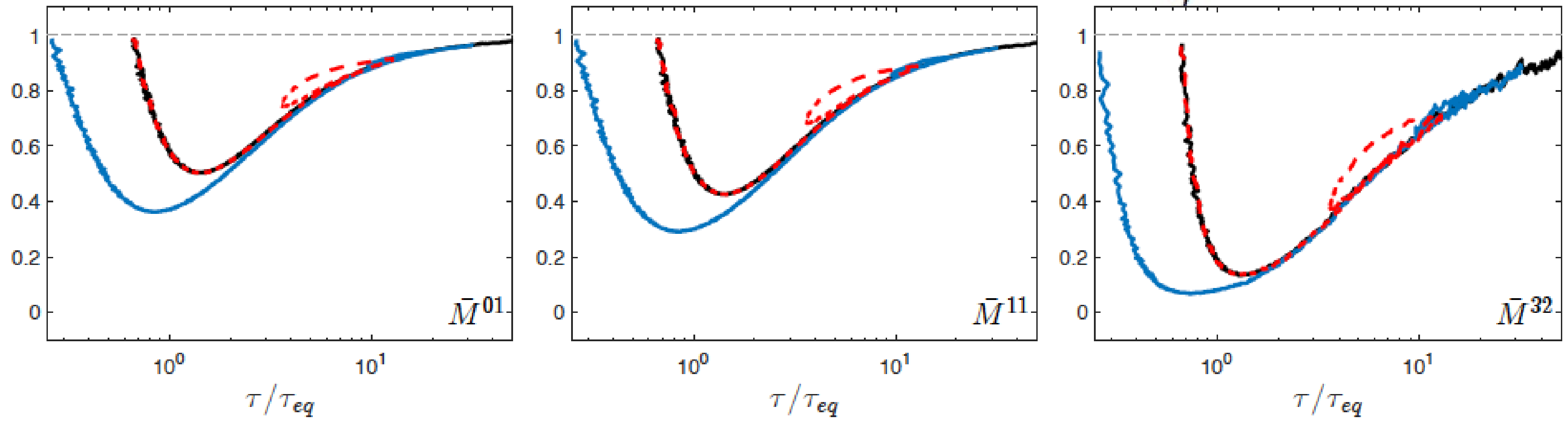
Even the strong rise of the shear viscosity at the transition to hadronic matter (→ increase of equil. time) does not break the evolution toward equilibration

$$\tau_{eq} = 5(\eta/s)/T(\tau)$$

V. Nugara et al., 2311.11921 [hep-ph]

Moments M^{mn} normalized to equilibrium values

$$\mathcal{M}^{mn}(\tau) = \int dP\,(p\cdot u)^n\,(p\cdot z)^{2m}\,f(\tau,p).$$



Attività SIM 2024-26

❖ Develop a relativistic event-by-event transport theory suitable to perform realistic simulations of relativistic HIC's from AA to pA collisions.

→Study the existence of dynamical attractors in 3+1 D

→Heavy Quark dynamics in a unified frameworks in pA and AA(extensiontobquarks)

→ Early stage Heavy Quark in the Glasma (collaboration with INFN-CT)

❖ Hadronization: coalescence+fragmentation to predict different charmed hadrons like D mesons Λc, Ξc and Ωc baryons as well as multi-charm baryons (Ξcc, Ωcc and Ωccc)

→ to different colliding systems from Pb+Pb to Kr+Kr, Ar+Ar and pA collisions (ALICE3)

- Explore impact of open quantum system tecniques in high energy physics on quantum computing (NQSTI – PNRR)

FTE: SIM (6.0) *5.9 in 2023*

cognome	nome	contratto	profilo	perc	sezione
Asta	**Angelo**	Associato	Dottorando III (proroga)	100%	LNS
Coci	**Gabriele**	Associato	RTDA-PNRR	10%	LNS
Greco	**Vincenzo**	Associato	Prof. Ordinario	90%	LNS
Nugara	**Vincenzo**	Associato	Dottorando III	100%	LNS
Parisi	**Gabriele**	Associato	Dottorando III	100%	LNS
Plumari	**Salvatore**	Associato	Prof. Associato	100%	LNS
Sambataro	**Maria Lucia**	Associato	Assegnista	100%	LNS

Budget (in k€)

	Missioni	Inviti	Seminari	Consumi	Inventariabile	Totale
Dotazioni	9	5	4	4	7	29
MONSTRE	9	-	-	-	-	9
SIM	14	-	-	-	-	14
Totale	30	5	4	4	7	52