Current and Future Directions to Improve AMPT

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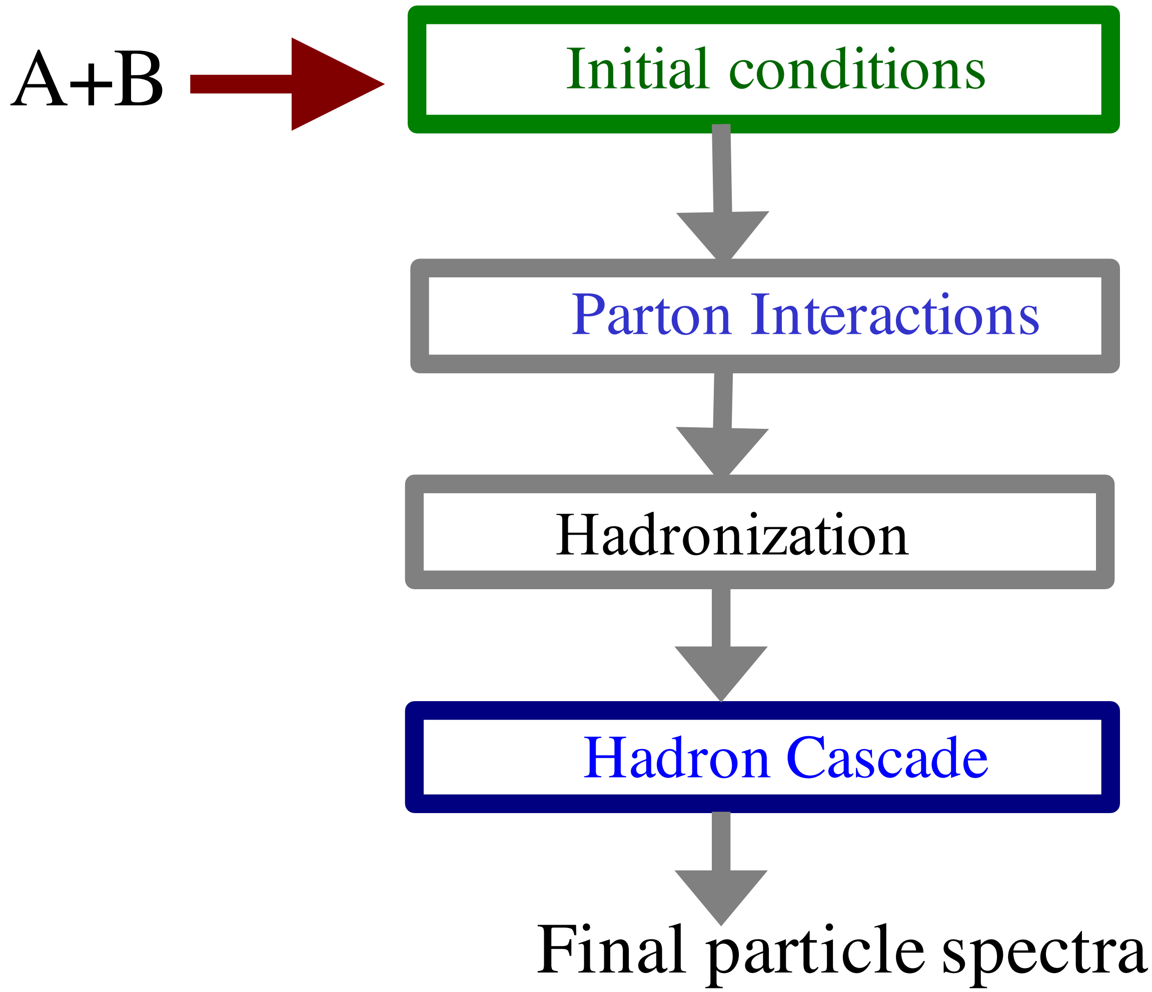
- Main goals of A Multi-Phase Transport model
- Current efforts to improve AMPT
- Challenges & future directions

A Multi-Phase Transport Model (AMPT)

aims to provide a comprehensive kinetic description of essential stages of high energy heavy ion collisions



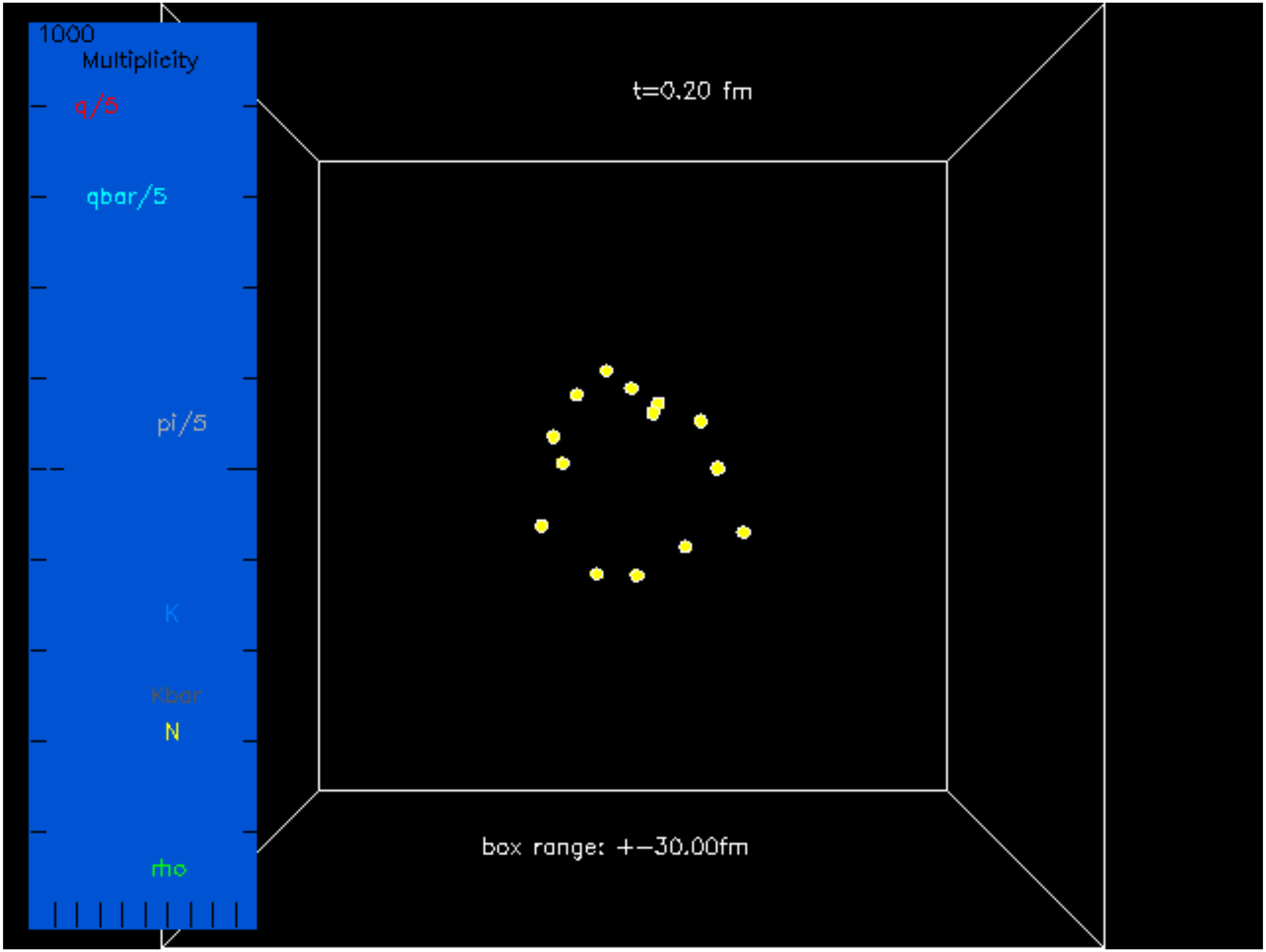
Long paper: ZWL, Ko, Li, Zhang and Pal, PRC 72 (2005);
source codes at the ECU website *http://myweb.ecu.edu/linz/ampt/*

For comprehensive simulations of high energy heavy ion collisions

We need:	**Choices:**
Initial particle/energy production	***Soft+hard model (& string melting)***, *CGC, pQCD, ...*
↓	↓
Pre-equilibrium interactions: *equilibration, thermalization, initial flow*	*Parton cascade (**ZPC**, MPC, BAMPS), NJL, CGC, AdS/CFT, …*
↓	↓
Space-time evolution of QGP	*Parton cascade (**ZPC**, MPC, BAMPS), NJL, (ideal, viscous, anisotropic) hydrodynamics, ...*
↓	↓
Hadronization /QCD phase transition	***Quark coalescence/parton recombination, string fragmentation**, Cooper-Frye, statistical hadronization, independent fragmentation, rate equations, ...*
↓	↓
Hadronic interactions	*Hadron cascade (**ART**, RQMD, UrQMD, ...), thermal model (w/ freezeout temperatures), …*

The AMPT model currently includes the ***green*** components for each phase.

A central Au+Au event at 200AGeV from the String Melting AMPT



σ_p=3mb

60fm-long box

E.g. middle region (near mid-rapidity):
coalescence of
q (red) and
qbar (cyan)

AMPT is also a test-bed of different ideas:

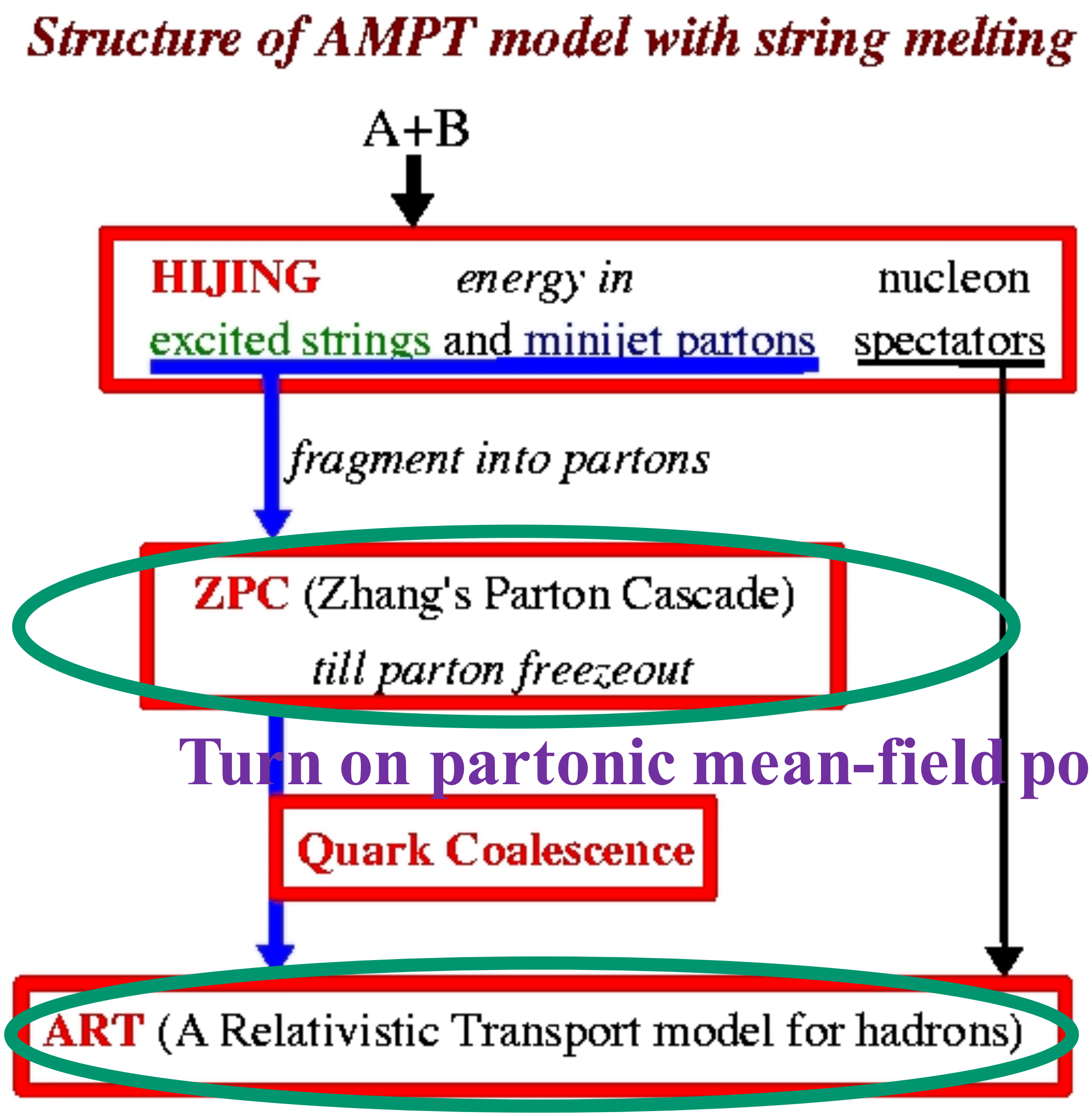
- Discovery of the triangular flow v_3 — Alver & Roland, PRC 81 (2010)
- Longitudinal (de)correlations of flows — Pang et al. PRC 91 (2015), EPJA52 (2016)
- v_2 may be dominated by anisotropic escape but has strong flavor dependence — He et al. PLB753 (2016); ZWL et al. NPA 956 (2016); talk by Hanlin Li
- CME signal and background — Ma, Deng et al., Huang et al., talks by Guo-Liang Ma and Xin-Li Zhao
- Polarization observables — Li et al., arXiv:1704.01507, talk by Hui Li

The current AMPT model needs to be improved with better & new physics, in order to better describe the dense matter evolution and extract its properties.

Outline

- Main goals of A Multi-Phase Transport model
- Current efforts to improve AMPT
  - Jun Xu's talk on extending with mean-field potentials
  - Yuncun He's talk on improved coalescence in AMPT
  - Chao Zhang's talk on new PDF and nuclear shadowing
  - Zhenyu Xu's talk on modified coalescence
  - Including finite thickness to string-melting AMPT
- Challenges & future directions

from Jun Xu



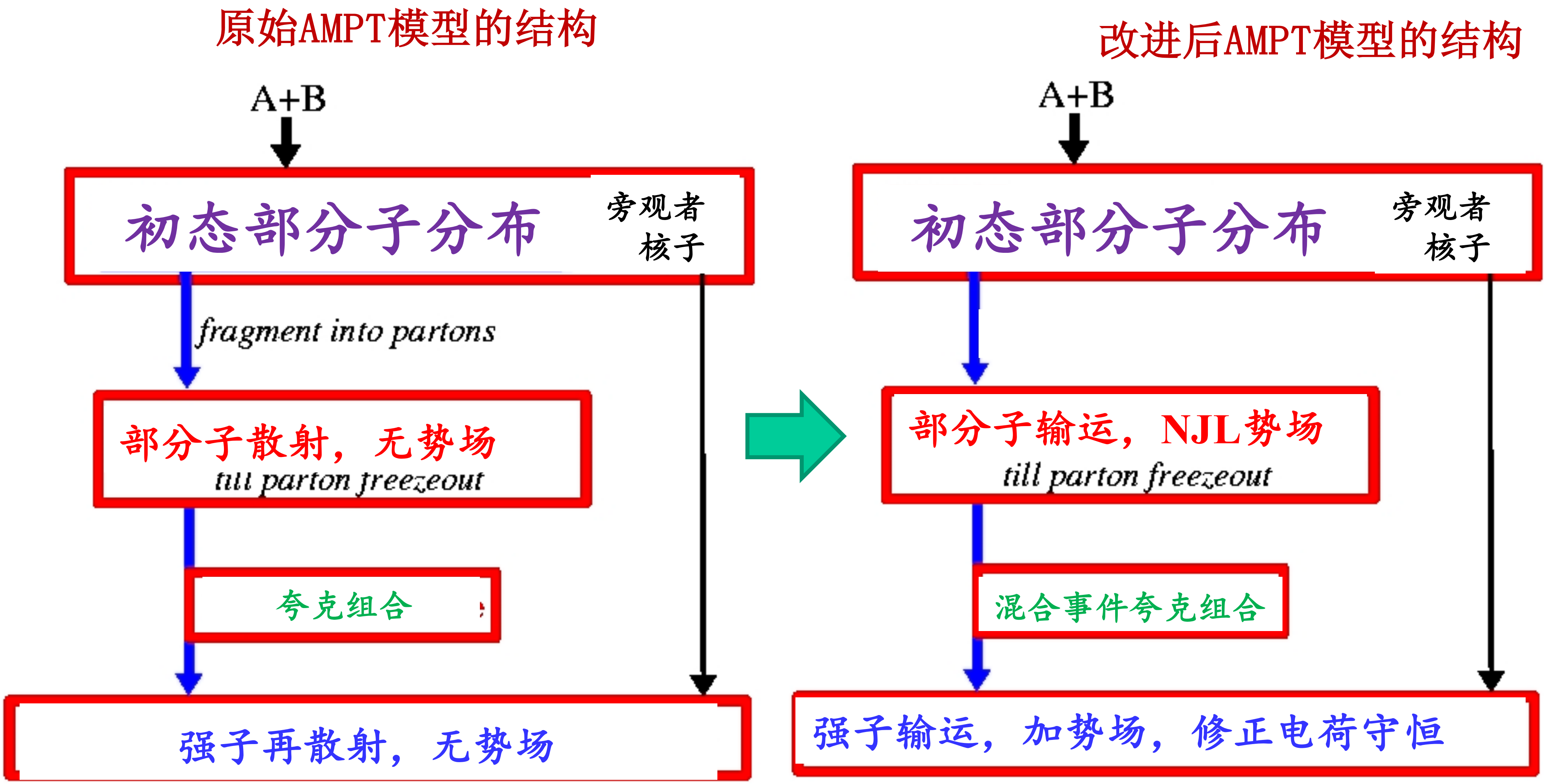
Turn on partonic mean-field potentials

Turn on hadronic mean-field potentials

Jun Xu & Che-Ming Ko, PRC 94 (2016)

from Jun Xu

对多相输运模型(AMPT)的改进



适用于LHC能区、RHIC能区

适用于RHIC束流能量扫描能区、FAIR能区

from Yuncun He

Summary of Improvement

Old coalescence

Numbers of mesons, baryons and antibaryons are forced to be conserved separately for each event.

First, quarks from the melting of mesons search all antiquarks and choose the closest antiquark to form mesons.

Then, quarks from the melting of baryons search all remaining quarks and choose the closest two quarks to form baryons (same for anti-baryons).

New coalescence

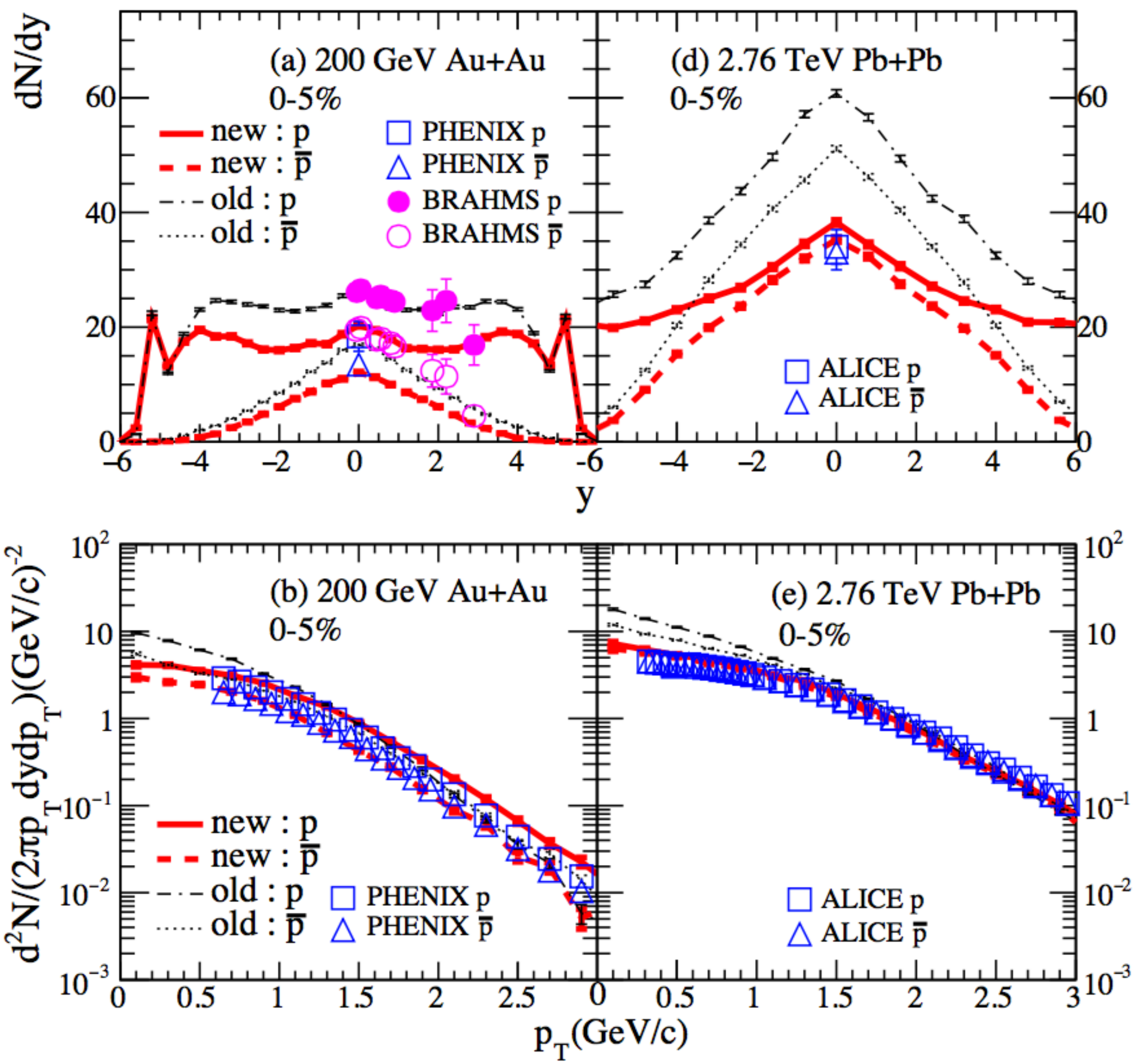
Remove the artificial separate conservation *(conservation of net-baryon number is still automatically satisfied)*.

A quark has the freedom to form either a meson or a baryon (*depending on the distance to potential coalescence partners*).

Y. He & ZWL, PRC 96 (2017)

from Yuncun He

Proton yields and spectra



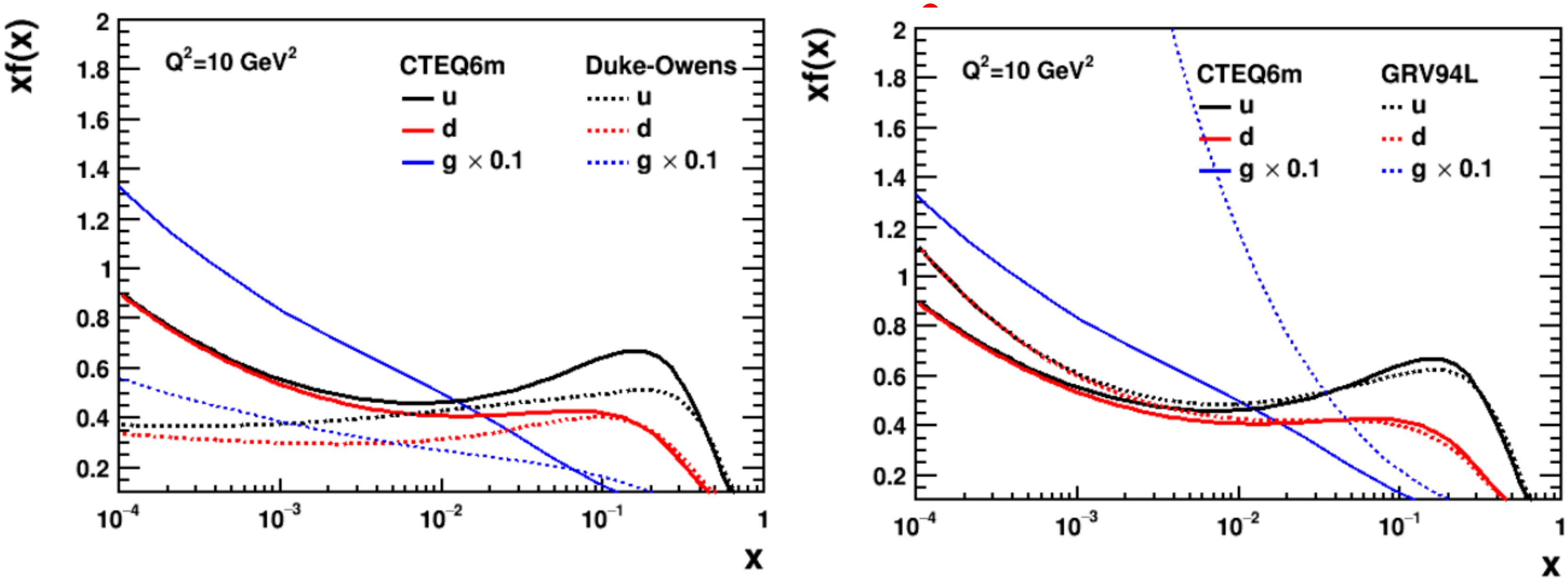
The proton yields at y~0 from the new coalescence (red curves) are more close to the data at RHIC and LHC.

The new coalescence (red curves) better describes the proton p_T spectra.

Anti-particle to particle ratios from new coalescence are also more consistent with data, especially for strange baryons.

from Chao Zhang

PDF: Parton Distribution



- **Duke-Ovens:** adequate for description at RHIC energies. *Outdated*
- **CTEQ6m:** valid for wide energy range, especially LHC energies when minijet production reaches a very small-x region, where gluon distribution is much *higher* than Duke-Owens parametrization.

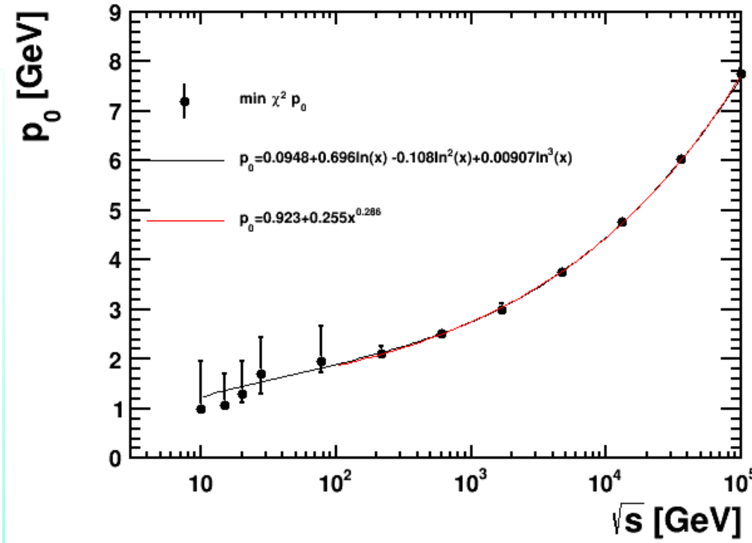
Update the PDF. Zhang Chao, ZWL, Shusu Shi & Liang Zheng

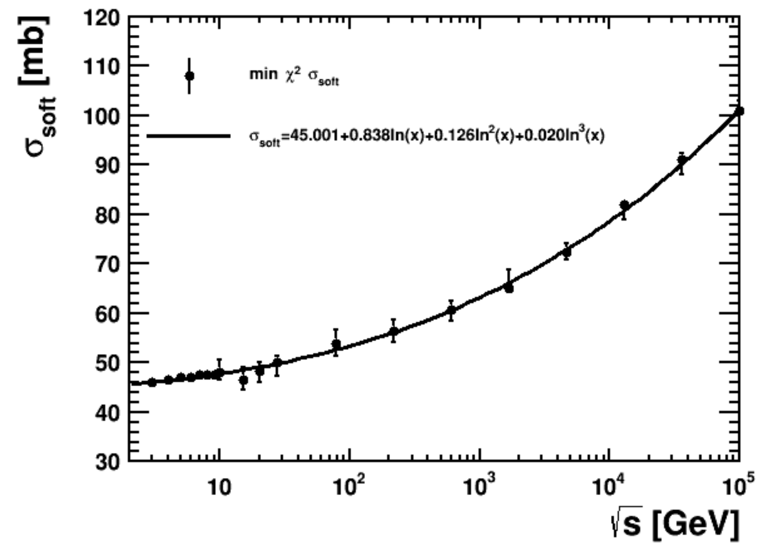
- HIJING 2.0 work : GRV94L PDF.

from Chao Zhang

p_0 and σ_{soft} tuning

- This fit is done for the *Cteq6m* PDF.
- When collision energy $\sqrt{S_{NN}}$ >10 GeV, it is matched with both σ_{tot} and σ_{el}
- When $\sqrt{S_{NN}}$ <10 GeV, we fit the *inelastic* cross section, since the jet cross section is completely switched off below 10 GeV in HIJING.





from Zhenyu Xu

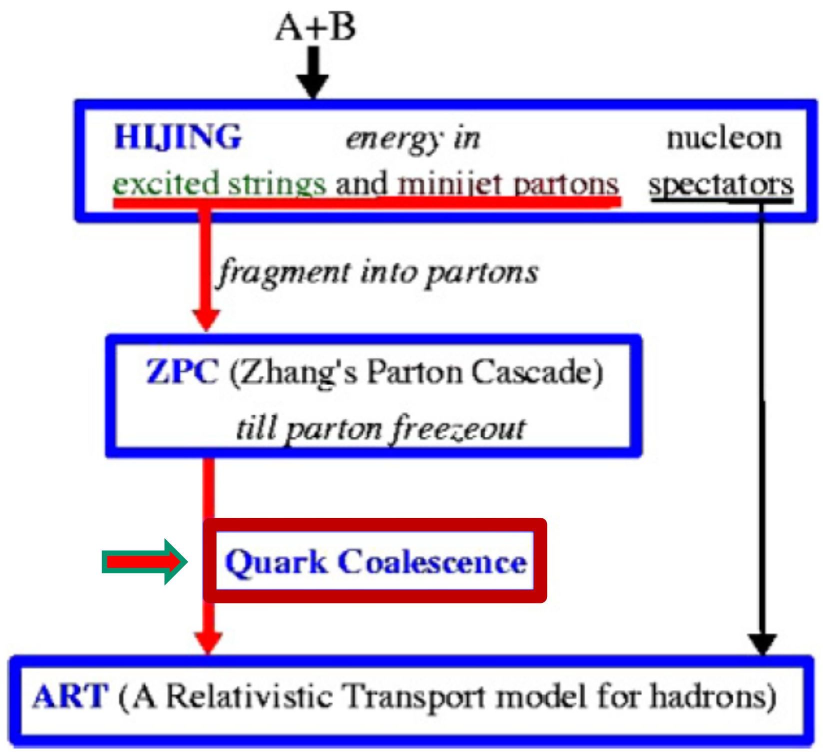
The Change of Quark Coalescence model

- "The current quark coalescence model in AMPT searches for a meson partner before searching for baryon or antibaryon partners"

He Y, Lin Z W. PRC 96, 014910 (2017)

- Do some change on the quark coalescence model
  - Mesons and (anti)baryons are formed under the competition
  - "coordinate coalescence" but with momentum limit Δp_0

$$\begin{cases} \Delta r_{\text{new}} < \Delta r_{\text{old}} \\ \Delta p_{\text{new}} < \Delta p_0 \end{cases}$$



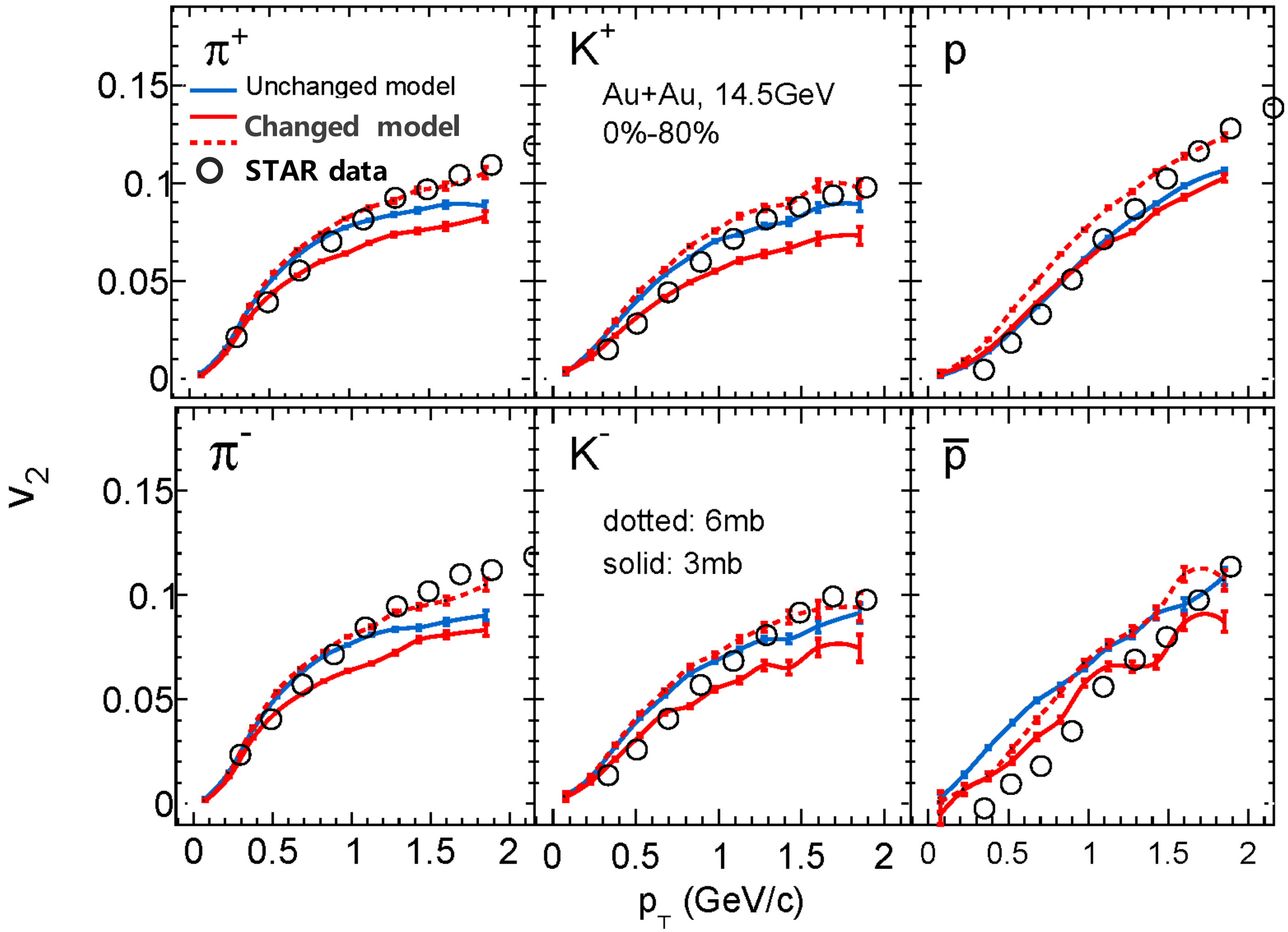
Structure of the AMPT model with string melting

Zhenyu Xu & Lei Huo

from Zhenyu Xu

Results -- Elliptic flow

- Elliptic flow become small when quark coalescence model is modified
- v_2 results for charged pions and kaons from the changed model (6mb) are generally consistent with the experimental data

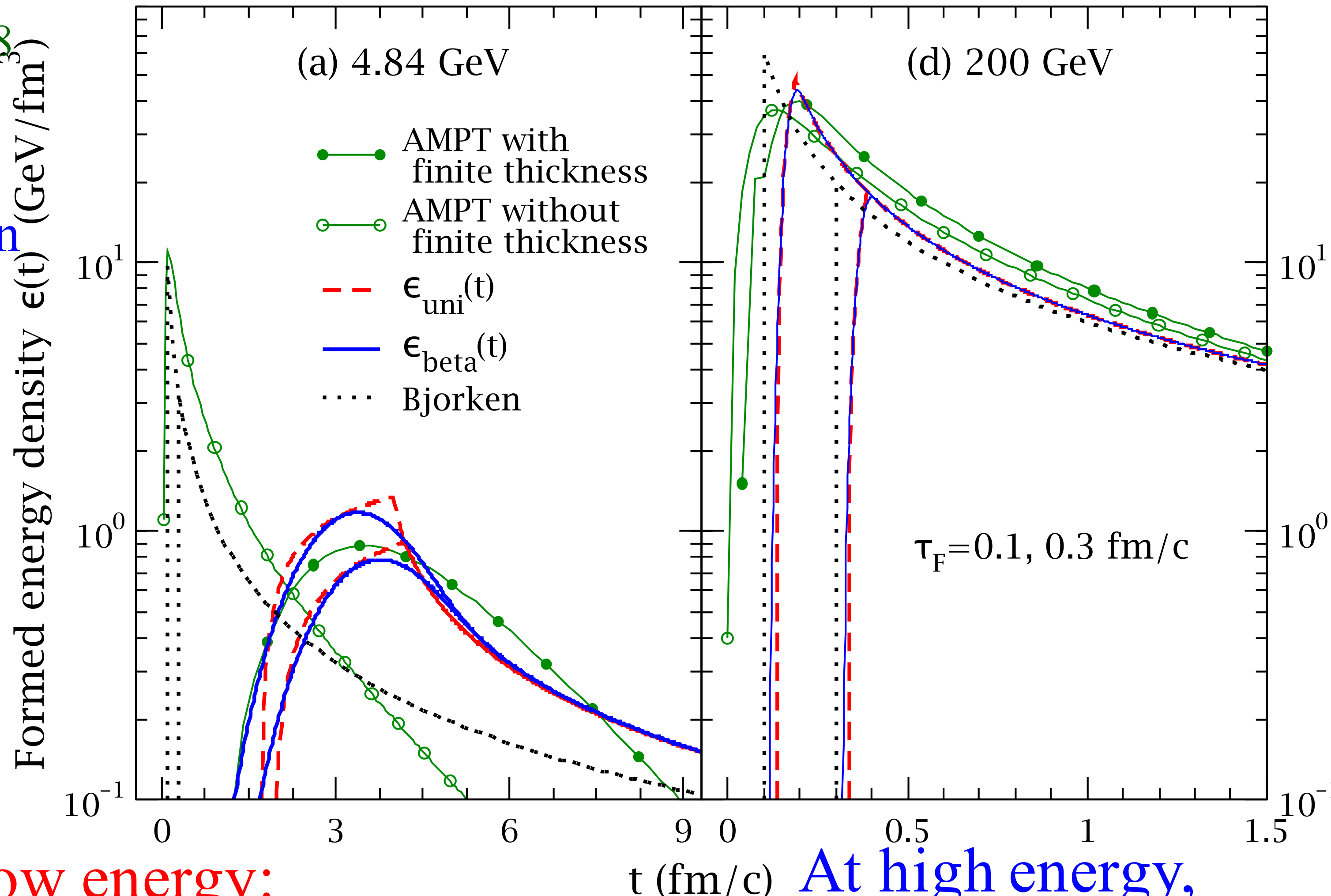


Including Finite Thickness to String-Melting AMPT

ZWL, arXiv:1704.08418

- AMPT with F.T. ~analytical extension of Bjorken formiula
- AMPT w/o F.T. ~ Bjorken formula.
- *Small F.T. effect at 200 GeV.*

F.T.=finite thickness



At low energy: ε^{max} << Bjorken value, is much less sensitive to τ_F :

factor of 2.1 or 2.5 change (not factor of 9) when τ_F changes from 0.1 to 0.9 fm/c.

At high energy, solution ~ Bjorken.

We are testing the effect of finite thickness on SM AMPT. Y He et al., in progress

Outline

- Main goals of A Multi-Phase Transport model
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Challenges and future directions

Outstanding physics problems for AMPT:

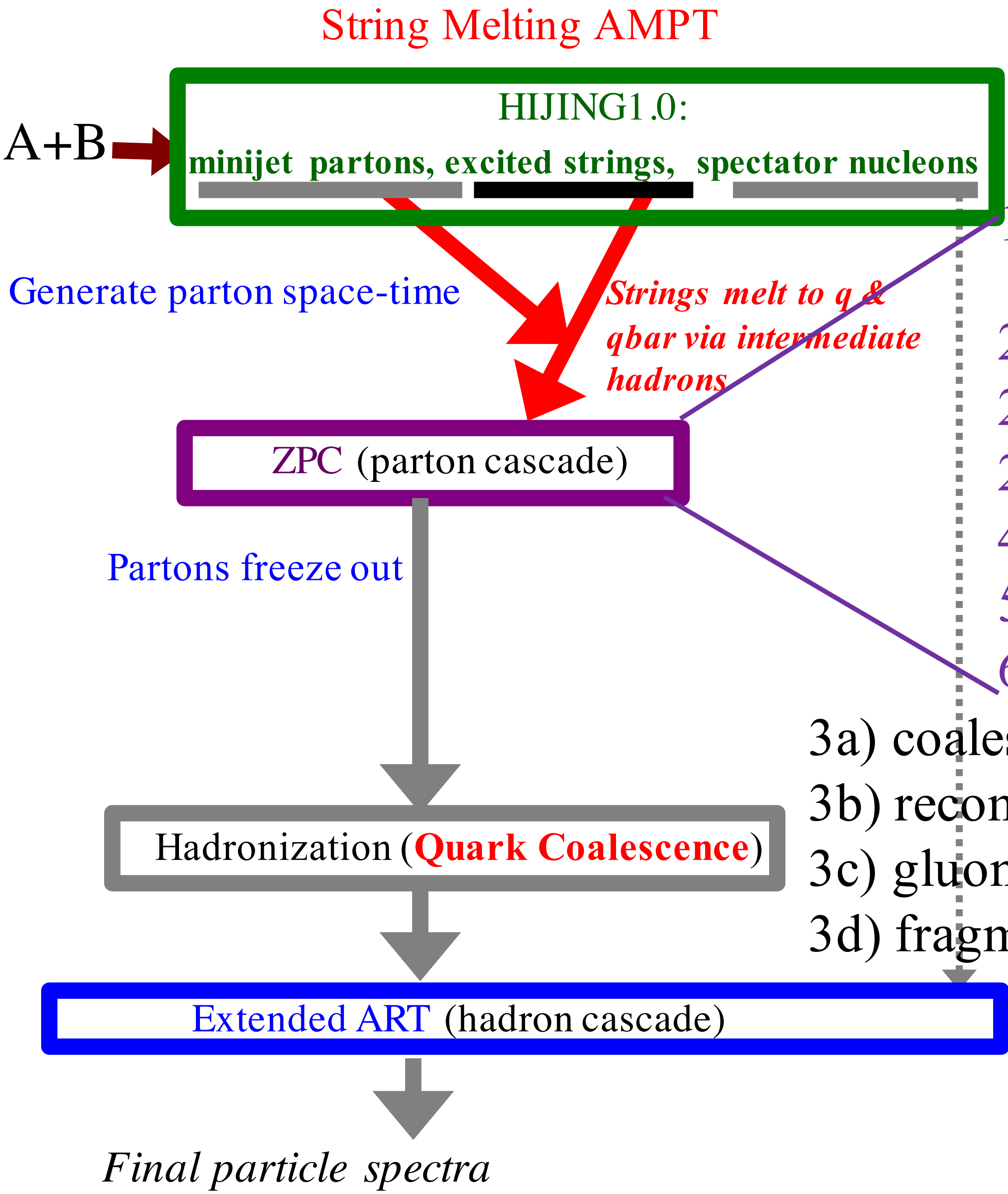
1) equation of state of the dense/partonic matter
2) initial gluons & inelastic parton reactions (*QGP chemical composition*), including jet radiative energy loss
3) hadronization (*parton recombination/quark coalescence/fragmentation*)
4) potentials (*partonic and hadronic*)
5) coupling with vorticity
6) coupling with the critical point

*) other problems

➔ **Outstanding problems for AMPT applications / data comparisons:**

1) extraction of QGP properties like η/s, escape vs collective flow
2) leptons and photons, R_{AA}, flow at high p_T
3) reliable bulk matter (*background for signals*), escape vs collective flow
4) v_2 splitting at low energies, v_1
5) prediction of polarization observables
6) fluctuation signatures from the critical point

Challenges and future directions



**) new PDF & shadowing*

2a) gluons in initial condition

1) QCD equation of state
(dynamical parton mass / NJL?)

2b) 2←→2 inelastic parton reactions

2c) 2 ←→ 3 parton reactions

2d) high-P_T energy loss

4a) parton potentials (NJL?)

5) coupling with vorticity

6) coupling with critical point

3a) coalescence/recombination in both x & p

3b) recombination around ε_c

3c) gluons in recombination

3d) fragmentation

4b) hadron potentials

**) need more resonances*

**) fix charge conservation*

Challenges and future directions: example

Develop parton recombination in the transport model approach as a model of dynamical hadronization

Currently quark coalescence in AMPT only considers relative distance.

We need to further develop the hadronization model in AMPT:

3a) Quark coalescence / parton recombination in full phase-space
by considering both relative distance and relative momentum.
Will extend AMPT to intermediate P_T region.

3b) Start quark coalescence
around a critical energy density ~$\boldsymbol{\varepsilon_c}$ (*onset of confinement*),
not simply after the parton's kinetic freeze-out (*as determined by ZPC*).

3d) hadronization for partons w/o coalescence partner
(*independent fragmentation?)*

Challenges and future directions: example

Include gluons:

2a) Include gluons in the string melting initial condition (in addition to q & qbar)

Include inelastic parton reactions:

2b) gg / qqbar / ssbar / ccbar ←→ gg / qqbar / ssbar / ccbar *partly ongoing*

2c) 2 ←→ 3

3c) Include gluons in parton recombination

High P_T:

2d) Radiative energy loss of fast partons

3d) Independent fragmentation for fast partons without coalescence partner

***) Up-to-date PDF and heavy flavors:**

- Replace Duke-Owens parton distribution function
- Use up-to-date shadowing

ongoing work with Liang He, Shusu Shi, Chao Zhang

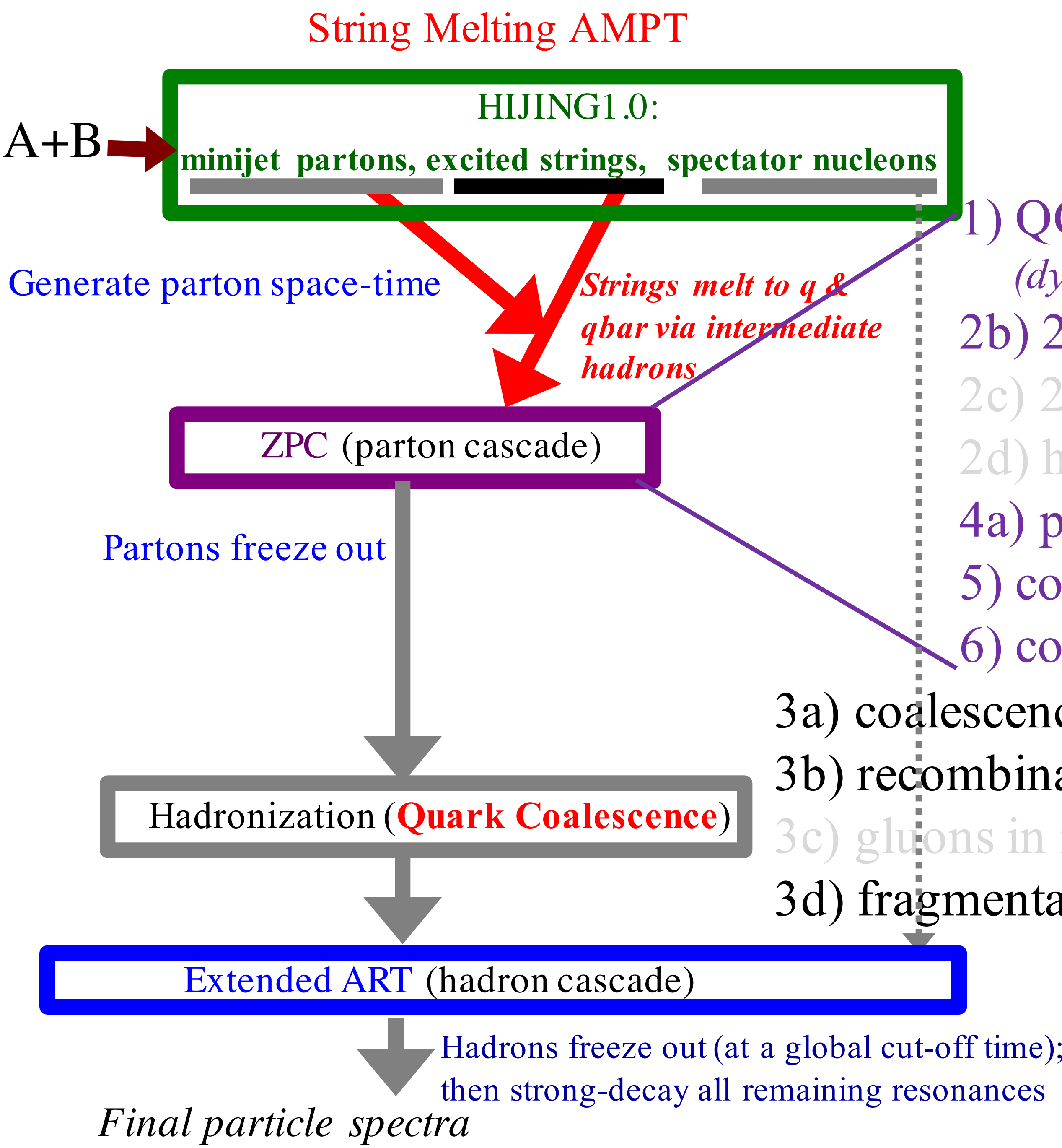
To BE(S) or not to BE(S) ?

Challenges and future directions:

- Some are more relevant for
  lower energies / **BES** energies,
- Some are more relevant for
  higher energies / **top RHIC & LHC** energies

- *May be beneficial to have coordinated efforts to improve AMPT along multiple directions*

Challenges and future directions 1: BES



other) new PDF & shadowing

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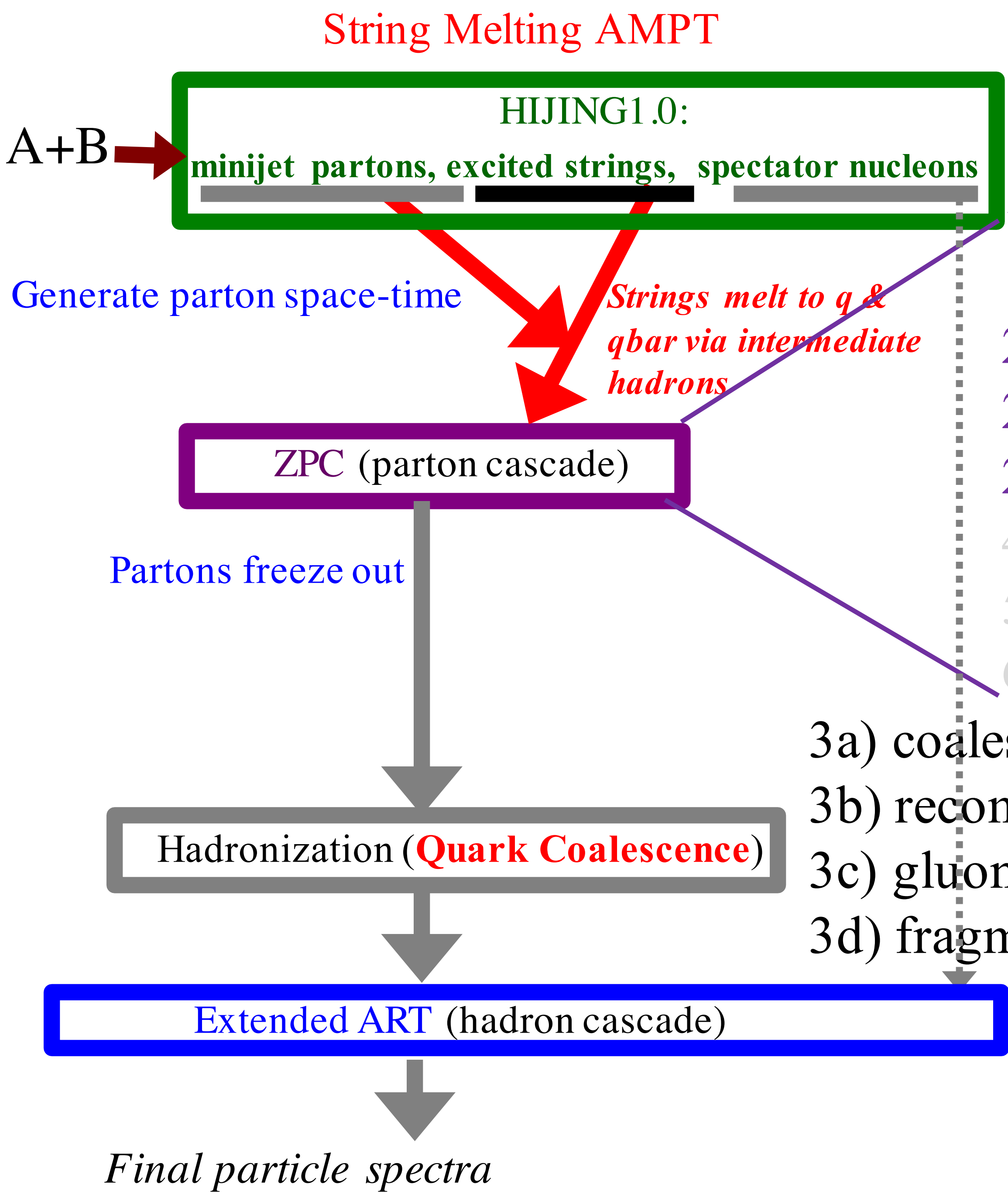
other) need more resonances

other) fix charge conservation

Challenges and future directions 2: topRHIC&LHC



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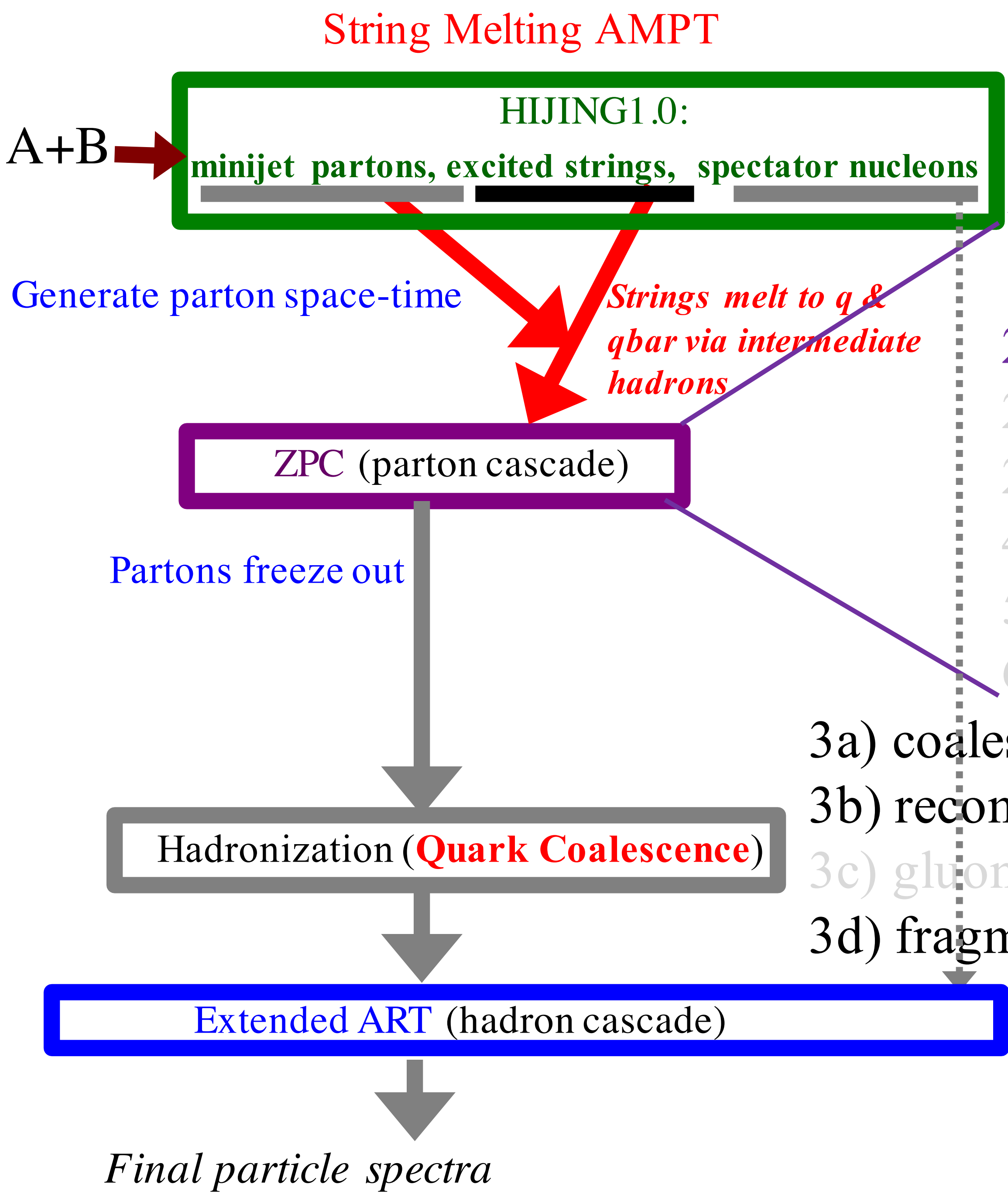
Challenges and future directions: common areas of 1)&2)



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other) need more resonances

other) fix charge conservation

Thank you!

Let the discussion party begin ...