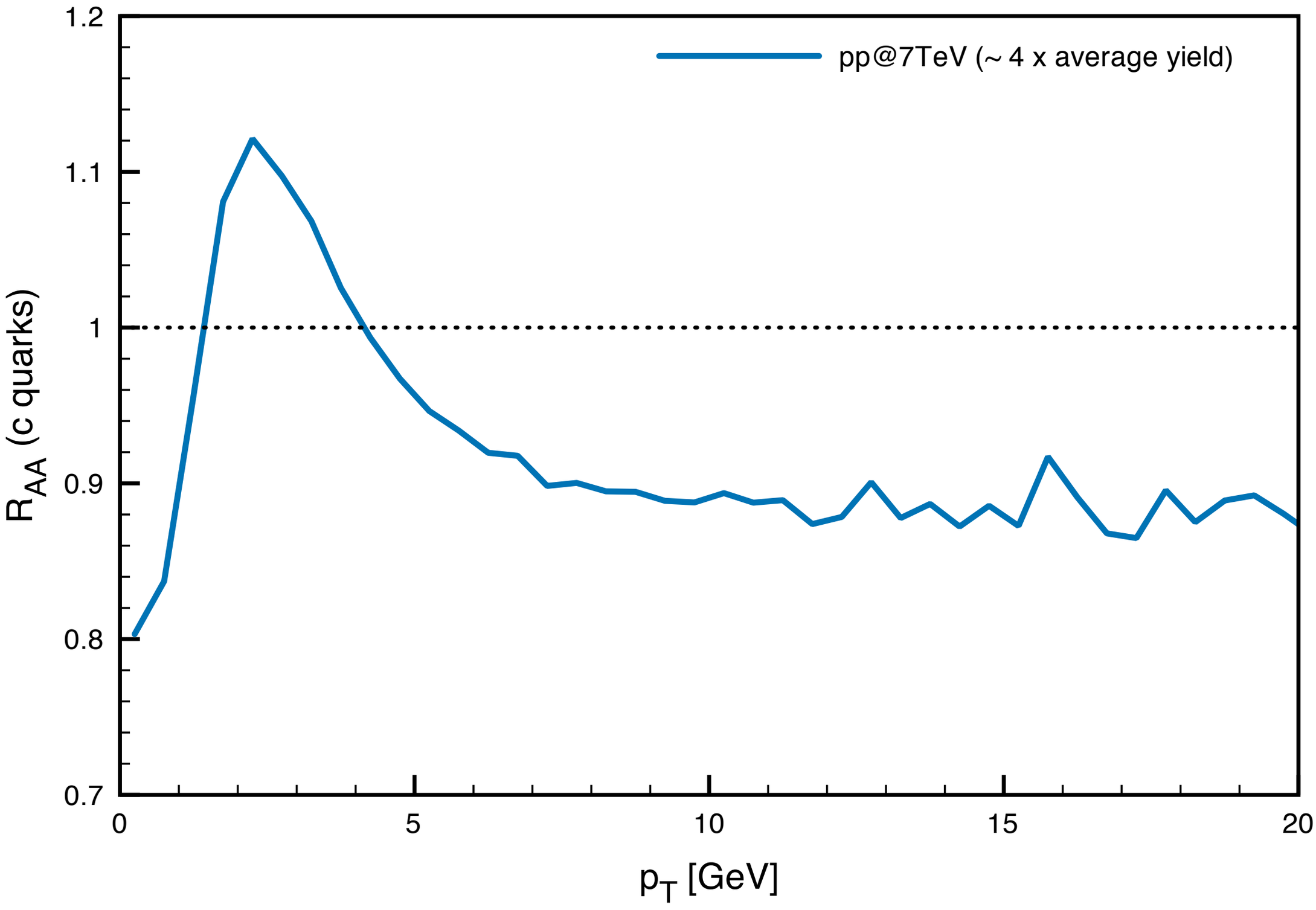
Heavy quark energy loss in pp @ LHC

Sascha Vogel

in collaboration with
Pol-Bernard Gossiaux, Jörg Aichelin and Klaus Werner

26.10.2010, ReteQuarkonii Workshop 2010, Nantes

HQ energy loss in pp roughly 10%!



The next 30 minutes...

- Why care?
- Why pp?
- The tools: EPOS and MC@sHQ
- Does it work?
- Conclusions + Outlook

Why Heavy Quarks?

Heavy quarks are heavy...

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➜ **produced in the initial collisions**

➜ **number is roughly conserved**

➜ **late time evolution has little effect on HQ spectra**

➜ **allows for some pQCD calculations**

➜ **interesting decay topologies (dileptons, hadrons...)**

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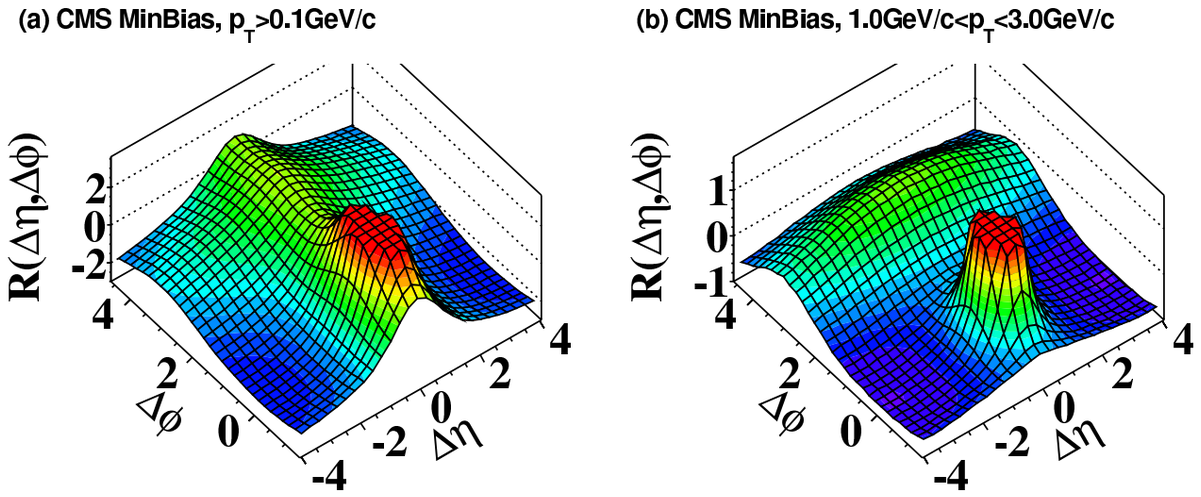
➜ interesting decay topologies (dileptons, hadrons...)

➜ It seems we found ourselves a nice probe!

Why pp?



CMS collaboration
arXiv:1009.4122

Avsar, Flensburg,
Hatta,Ollitrault, Ueda,
arXiv:1009.5643

Why pp?

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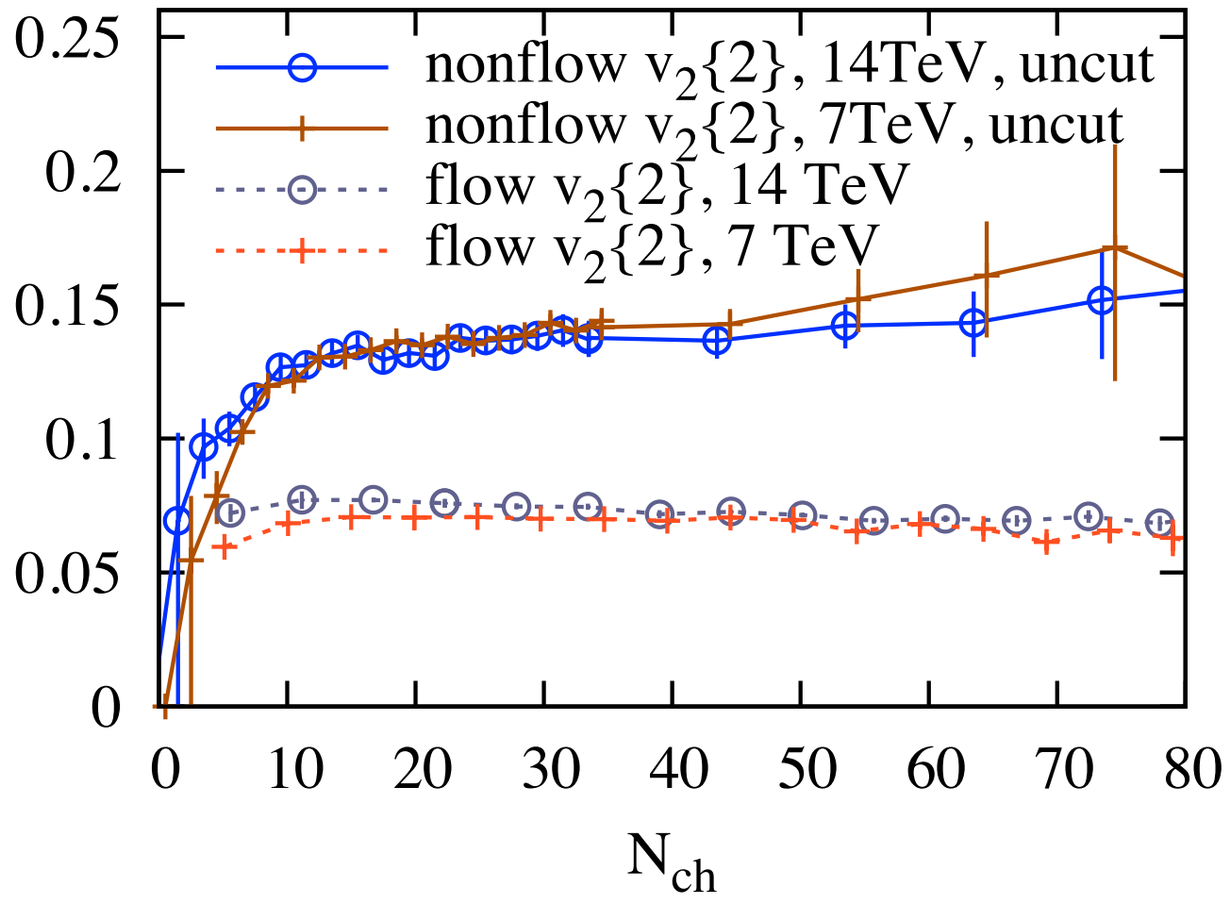

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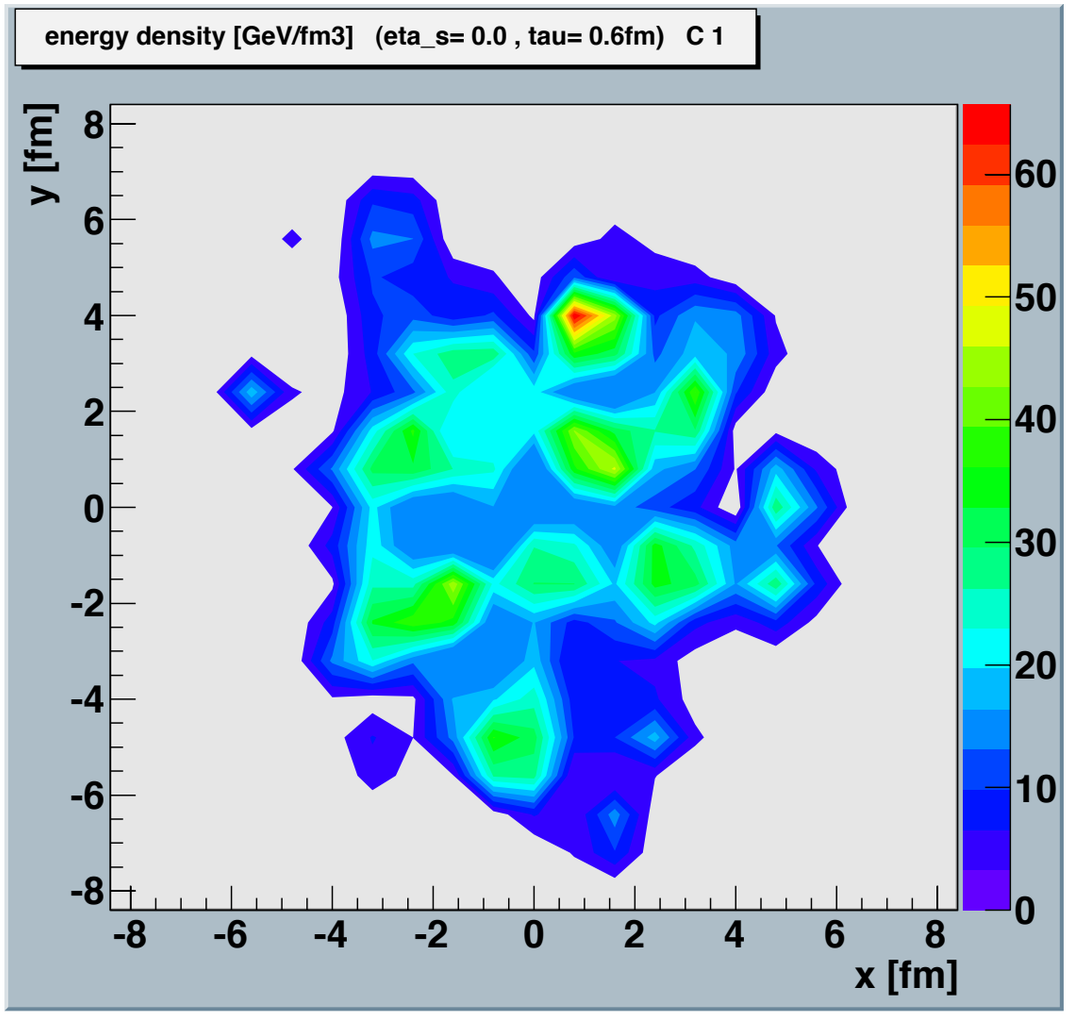
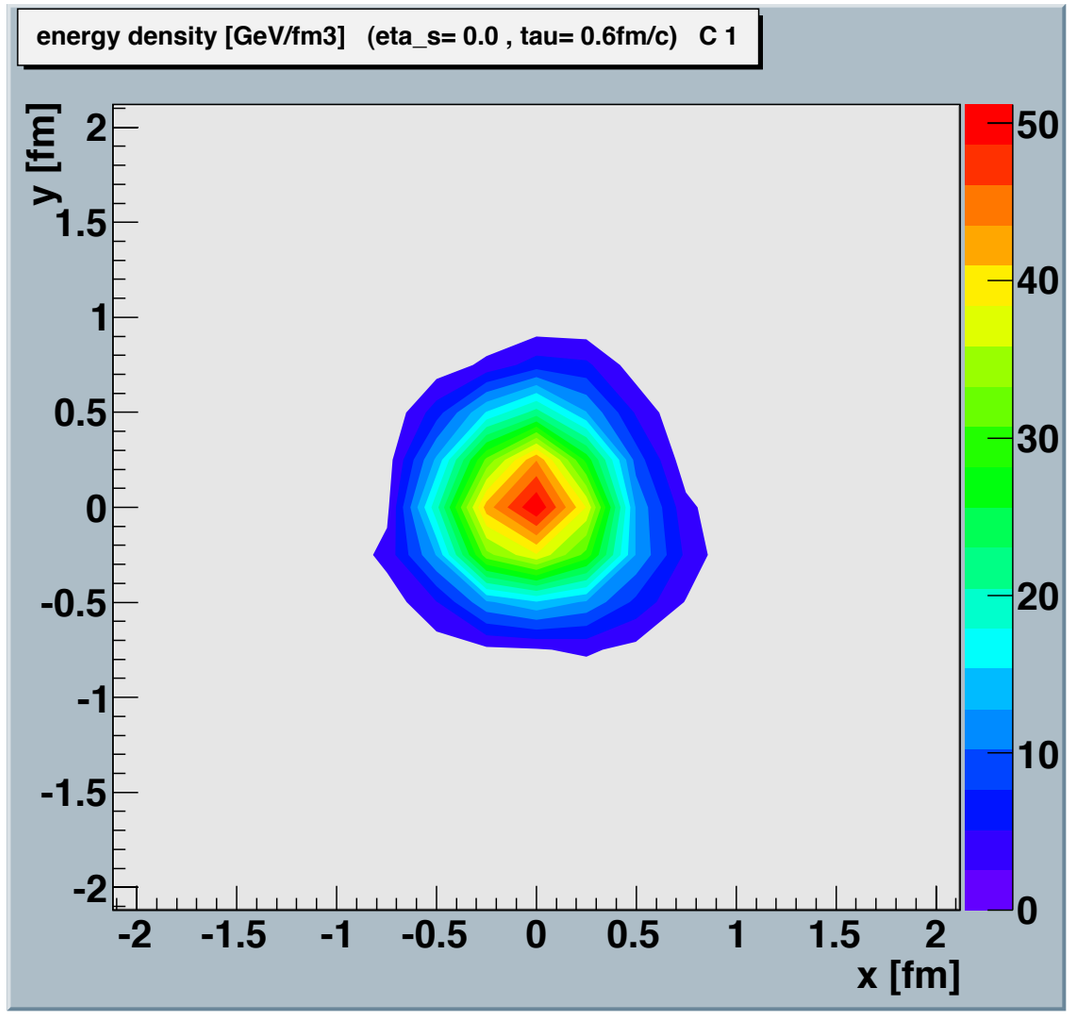
Energy densities comparable!





AuAu @ RHIC

pp @ LHC

Pierog, Porteboeuf,
Karpenko, Werner
arXiv:1005.4526

Ingredients for HQ spectra

Production
(fixed by FONLL)

Medium
(EPOS)

Interaction
(MC@sHQ)

Fragmentation
(fixed by CNV*)

* Cacchiari, Nason, Vogt, Phys.Rev.Lett. 95 (2005) 122001

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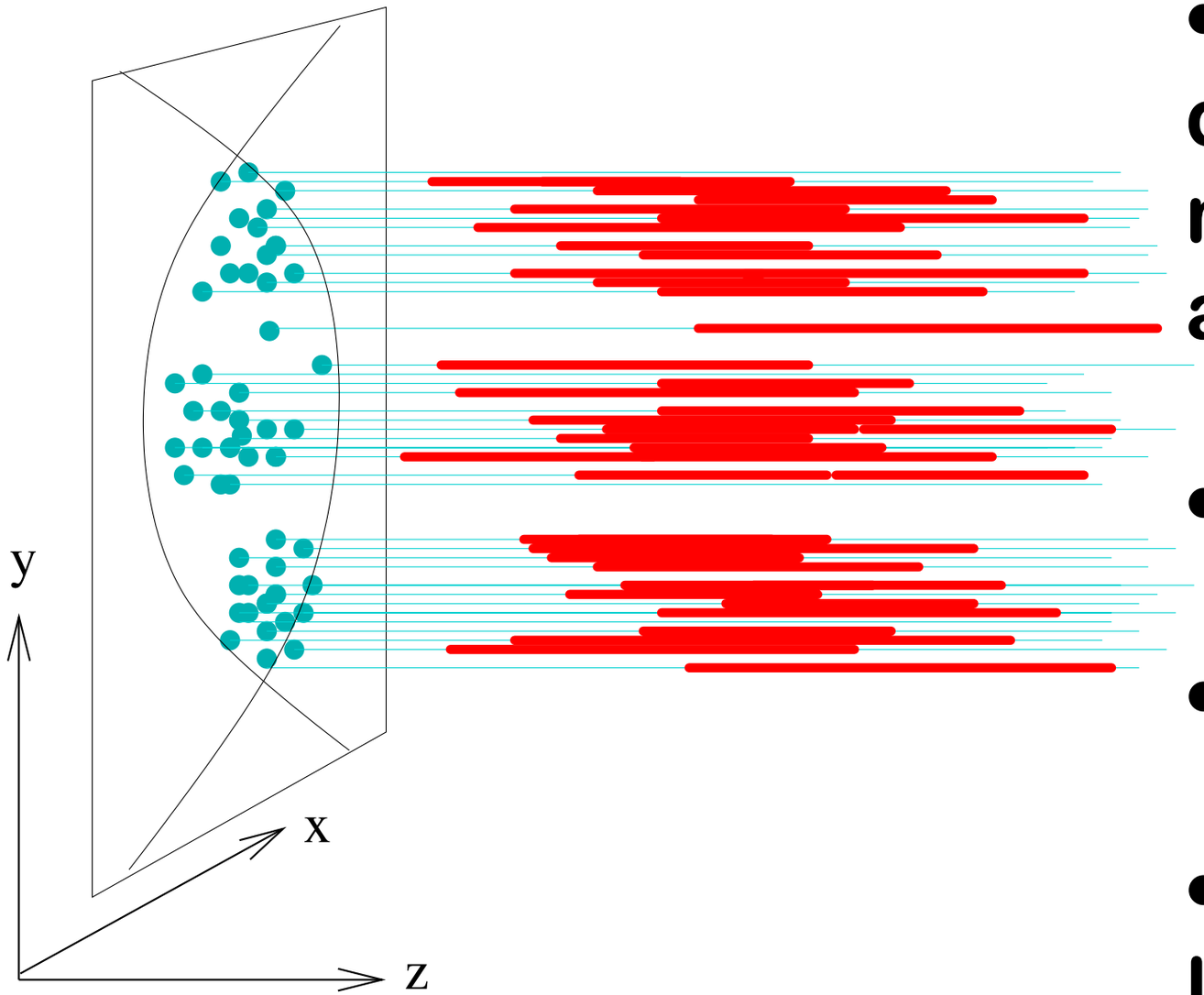
EPOS



- Energy conserving quantum mechanical multiple scattering approach,based on

- Partons (parton ladders)

- Off-shell remnants, and

- Splitting of parton ladders.

EPOS

Fluxtube initial conditions

Event by event calculations

Core/Corona seperation

Corona: EPOS (tuned to elementary reactions)

EPOS+ hydro

3+1D ideal hydro

complete set of hadronic resonances

Hadronic cascade after mixed phase

Lattice EOS with crossover

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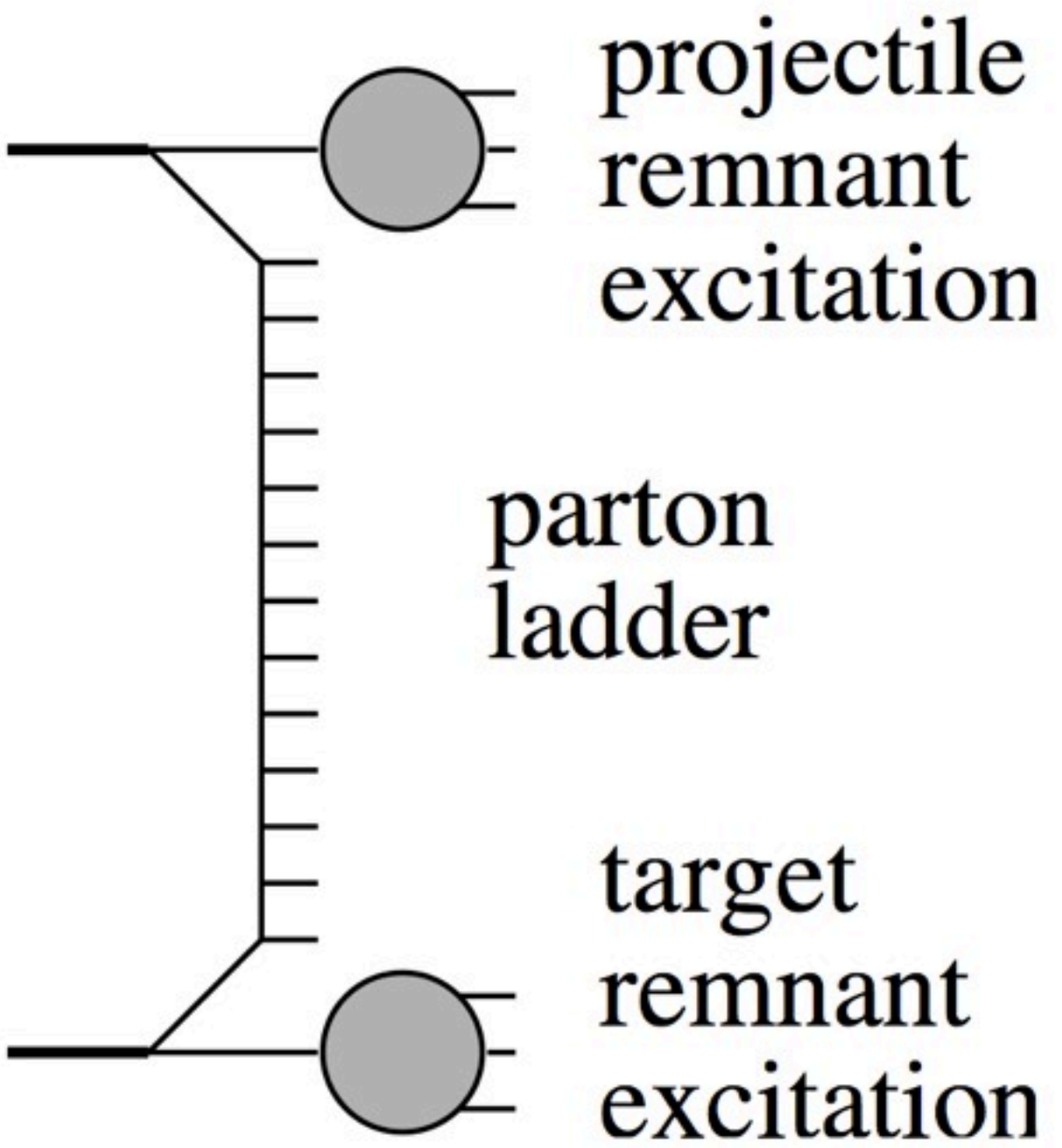
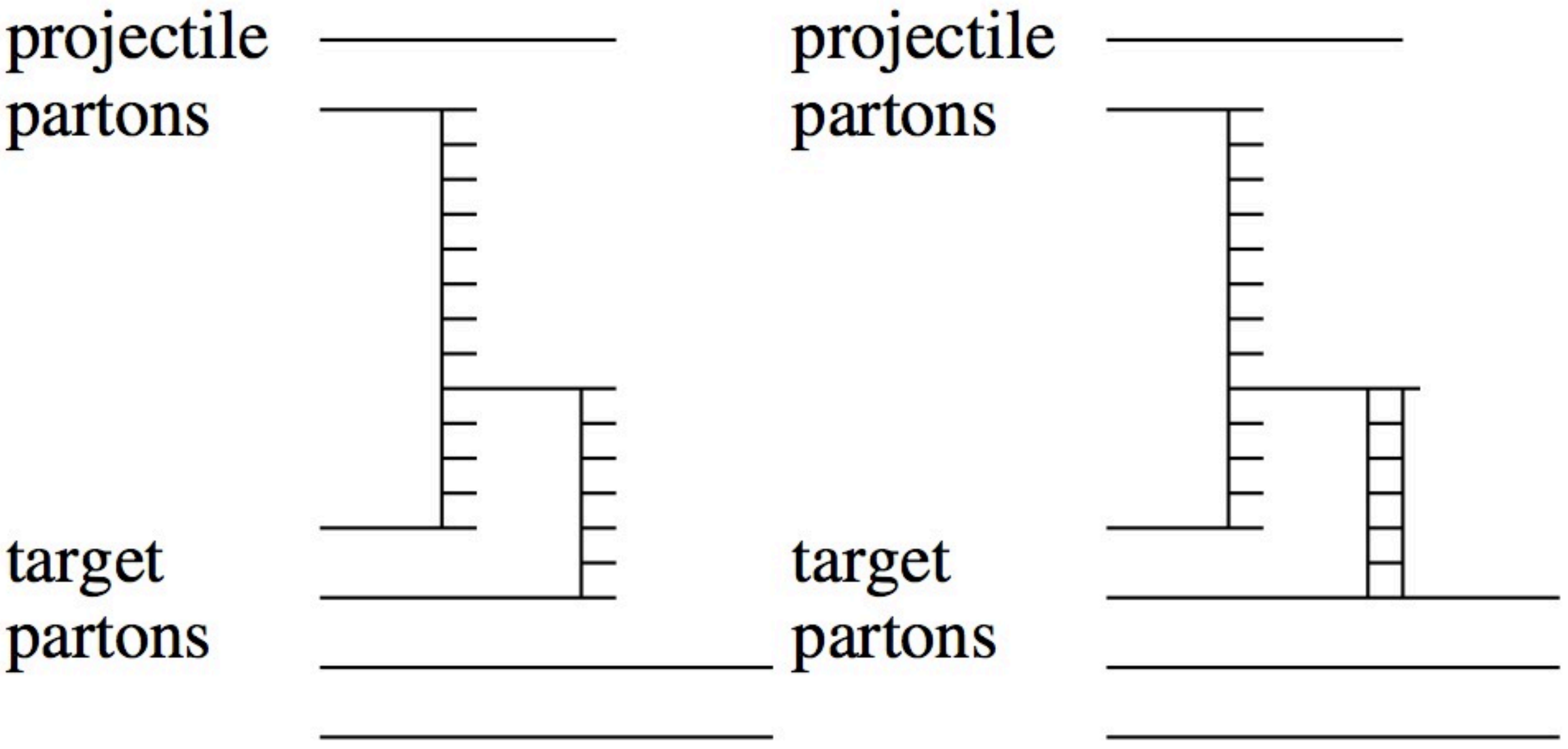


K. Werner, Nuclear Physics B 175, 2008

EPOS



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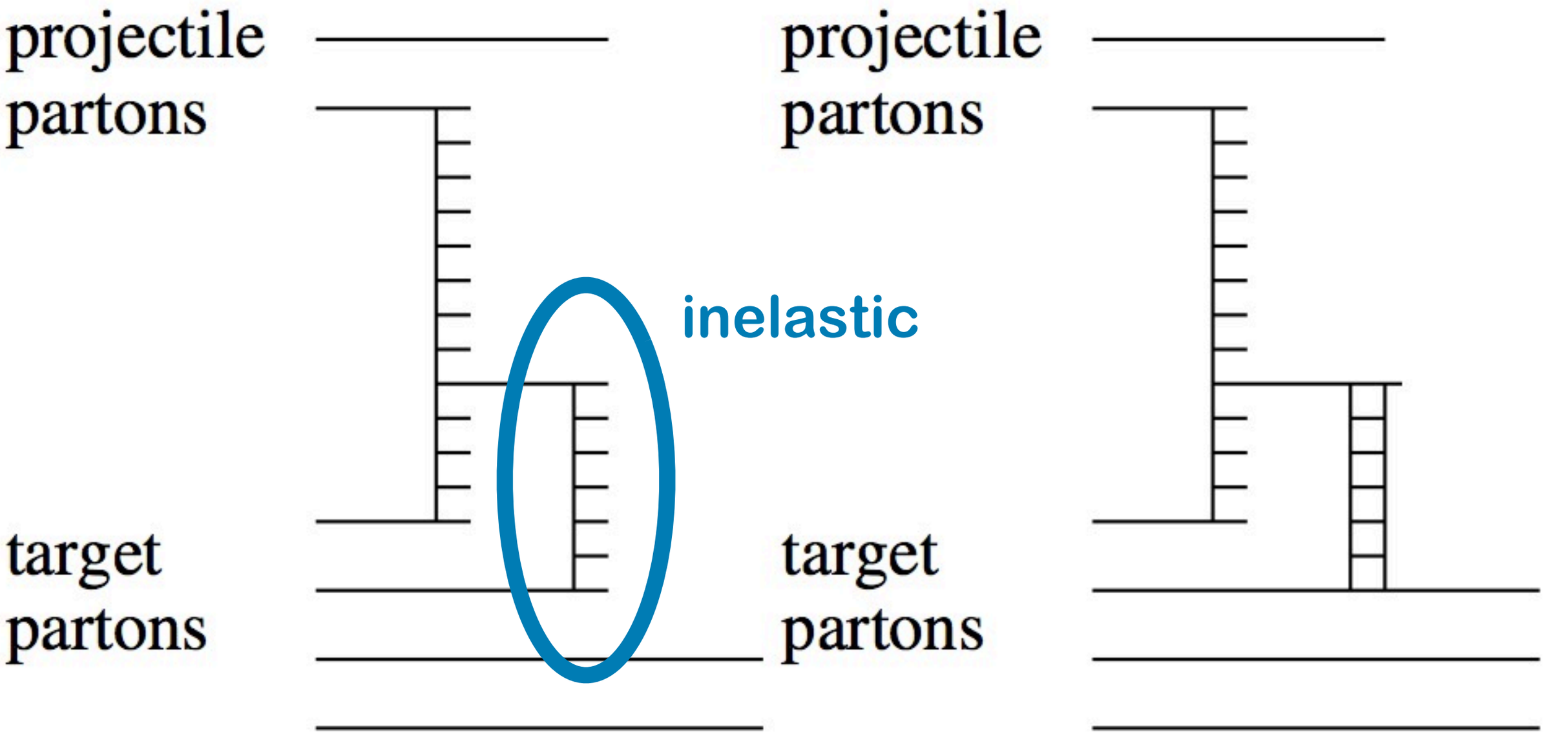

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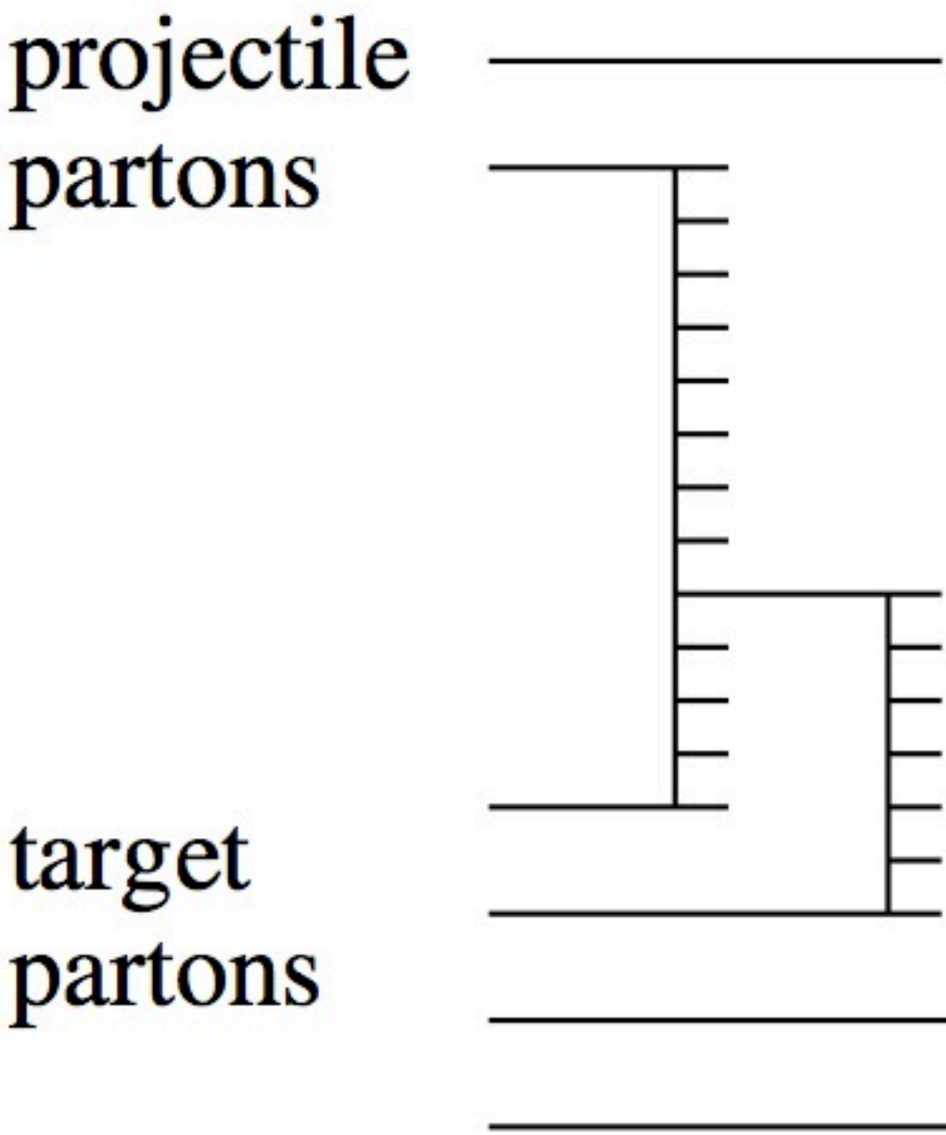

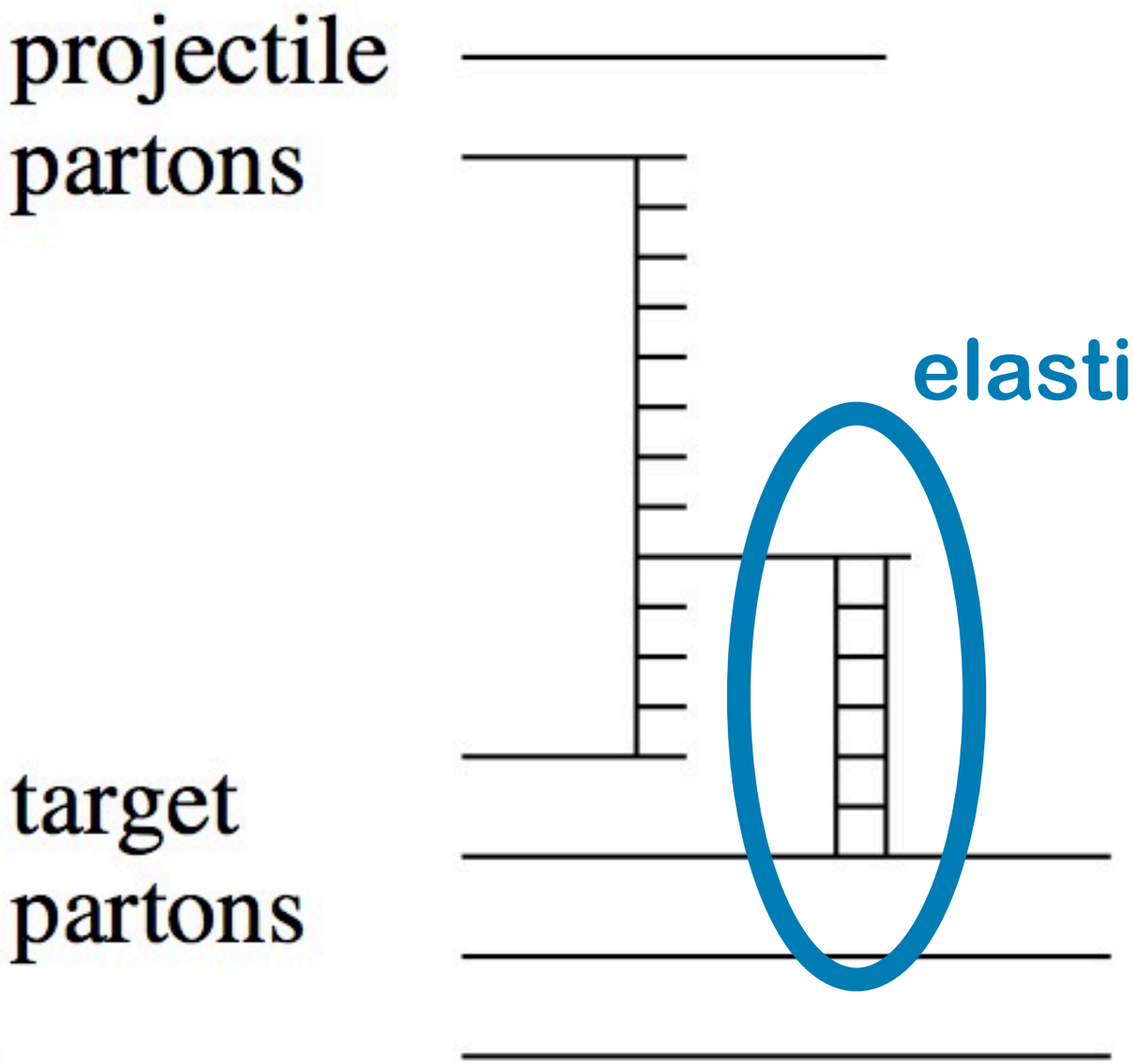

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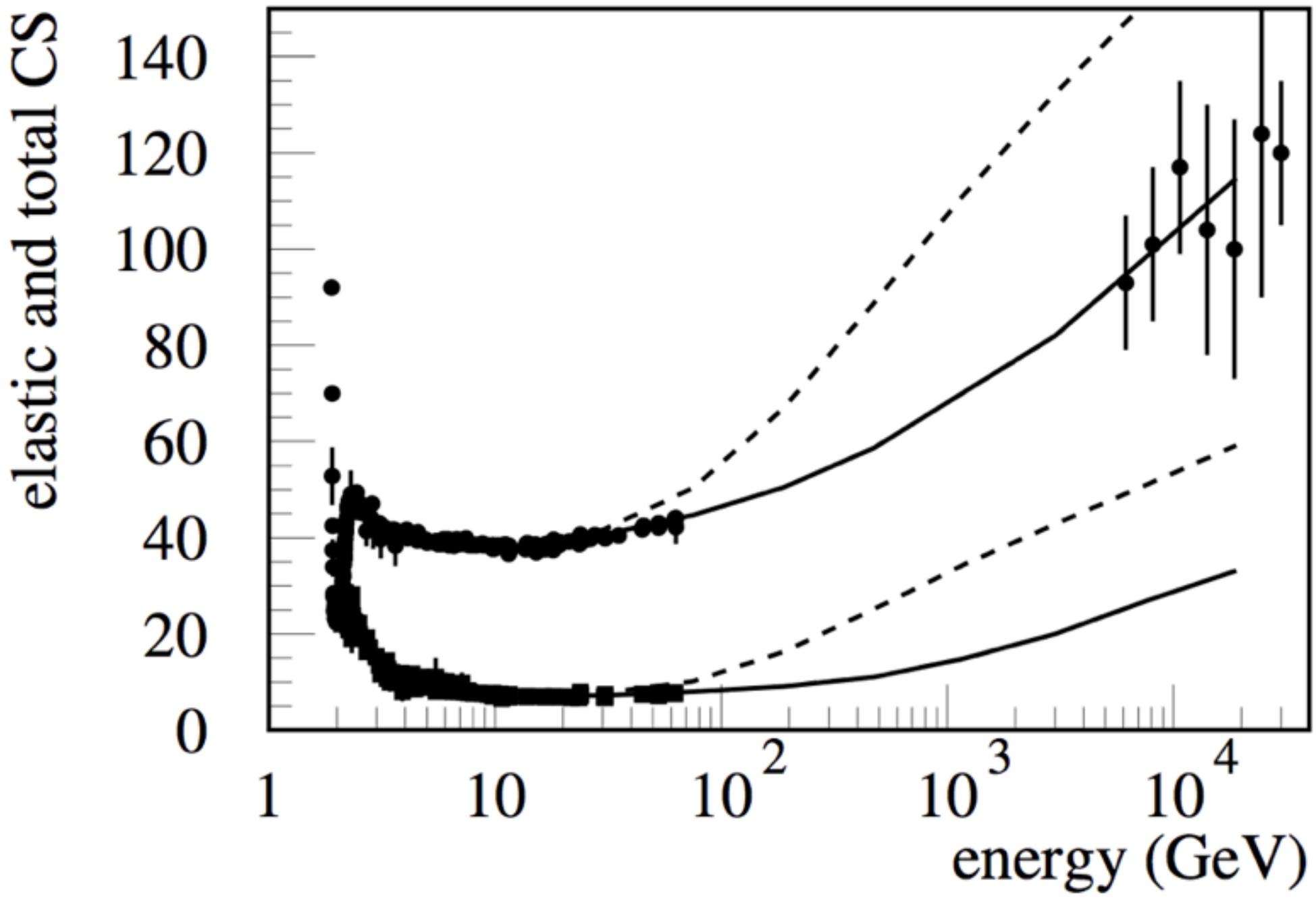
EPOS - pp cross section



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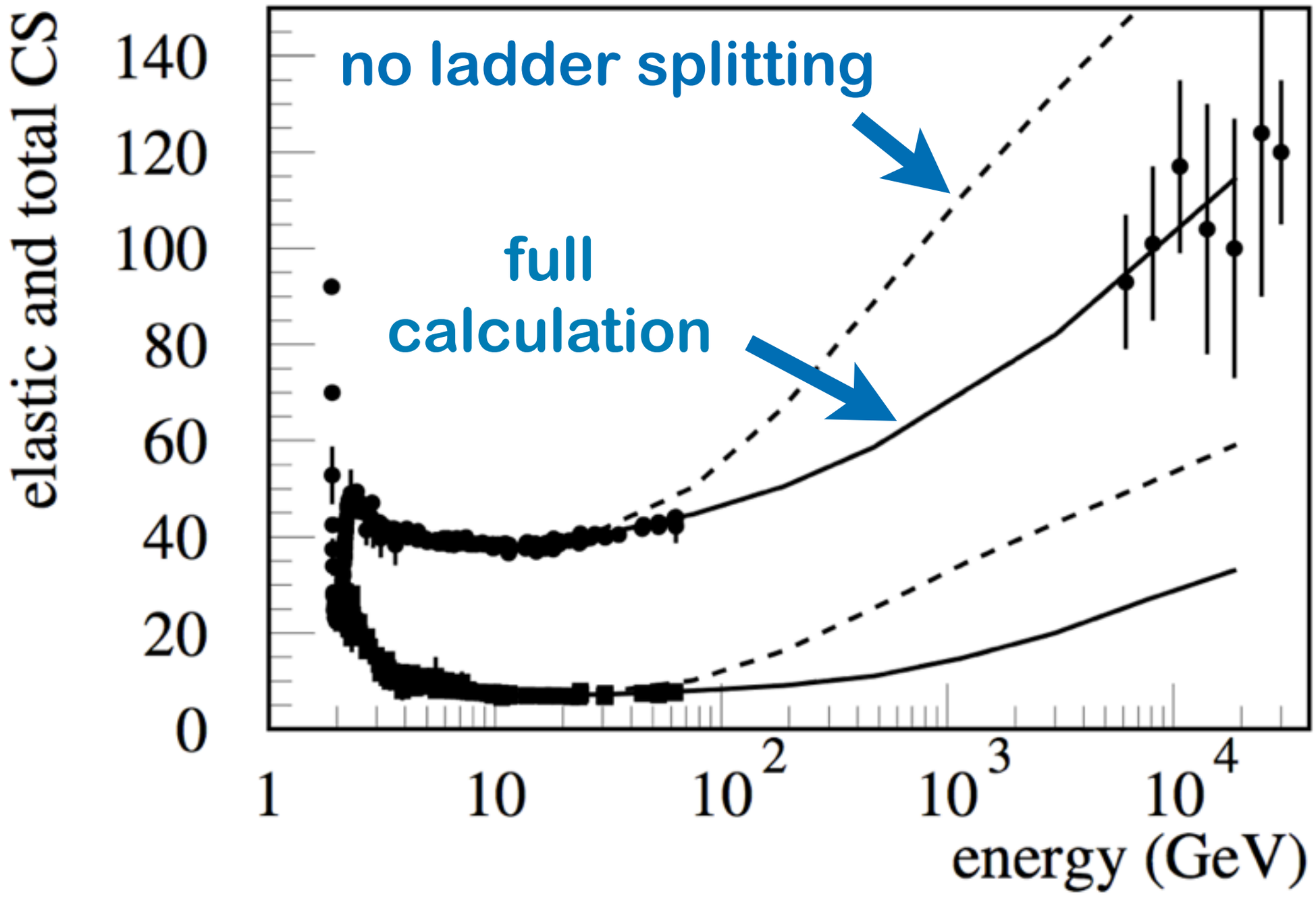
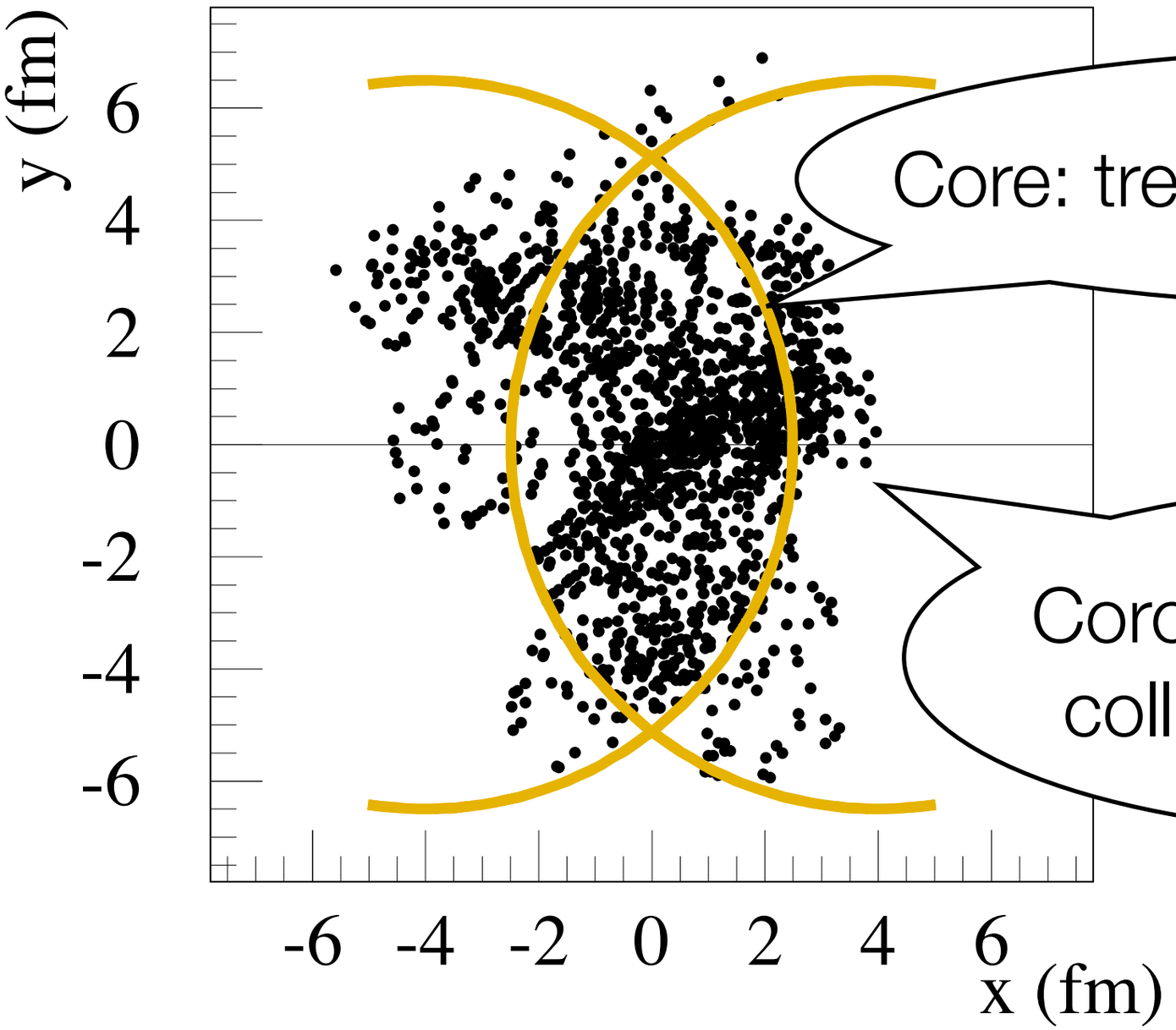


Core / Corona

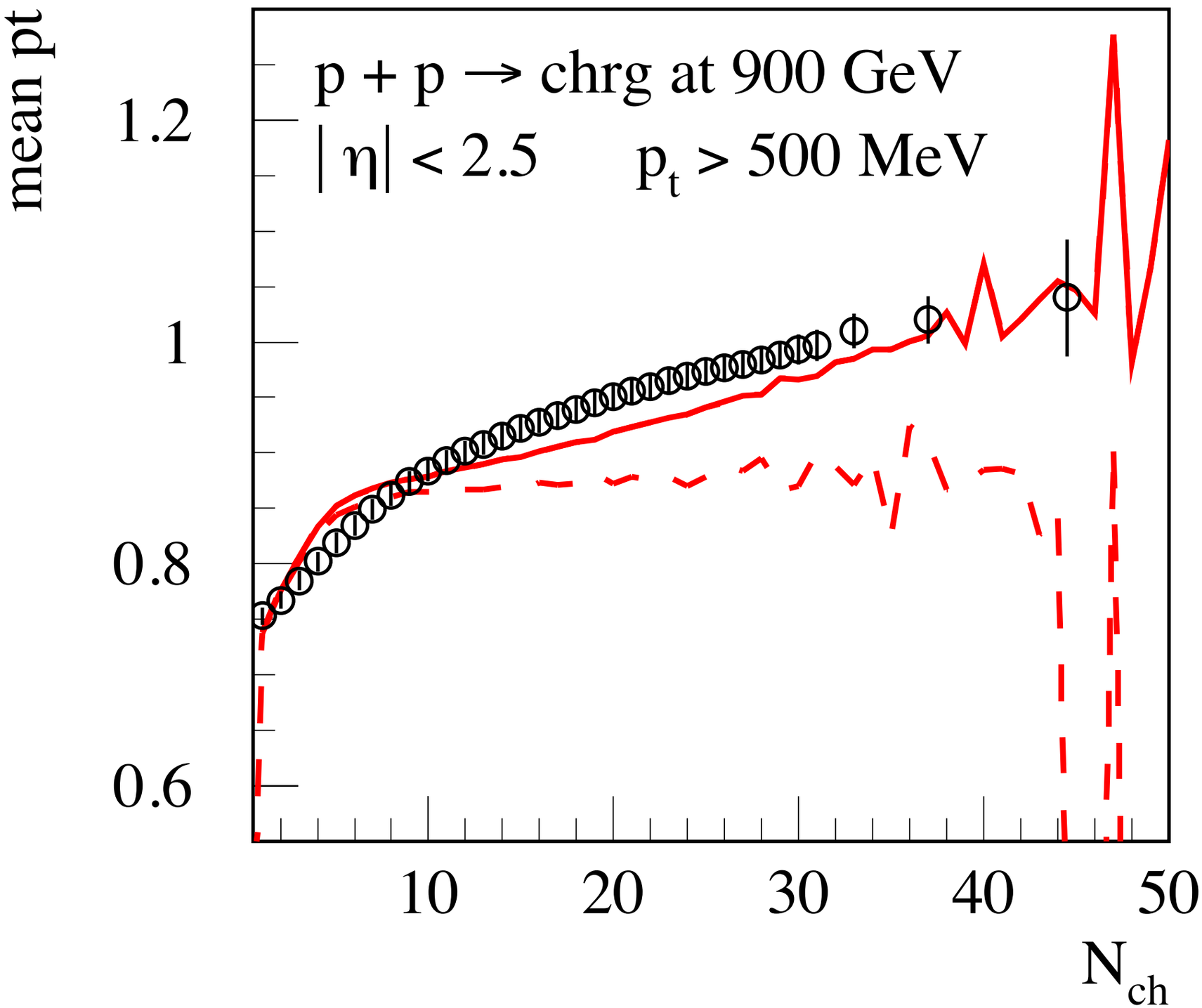


Core: treated hydrodynamically

Corona: treated as pp collisions with EPOS

Werner, Karpenko, Pierog, Bleicher, Mikhailov
arXiv:1004.0805

EPOS



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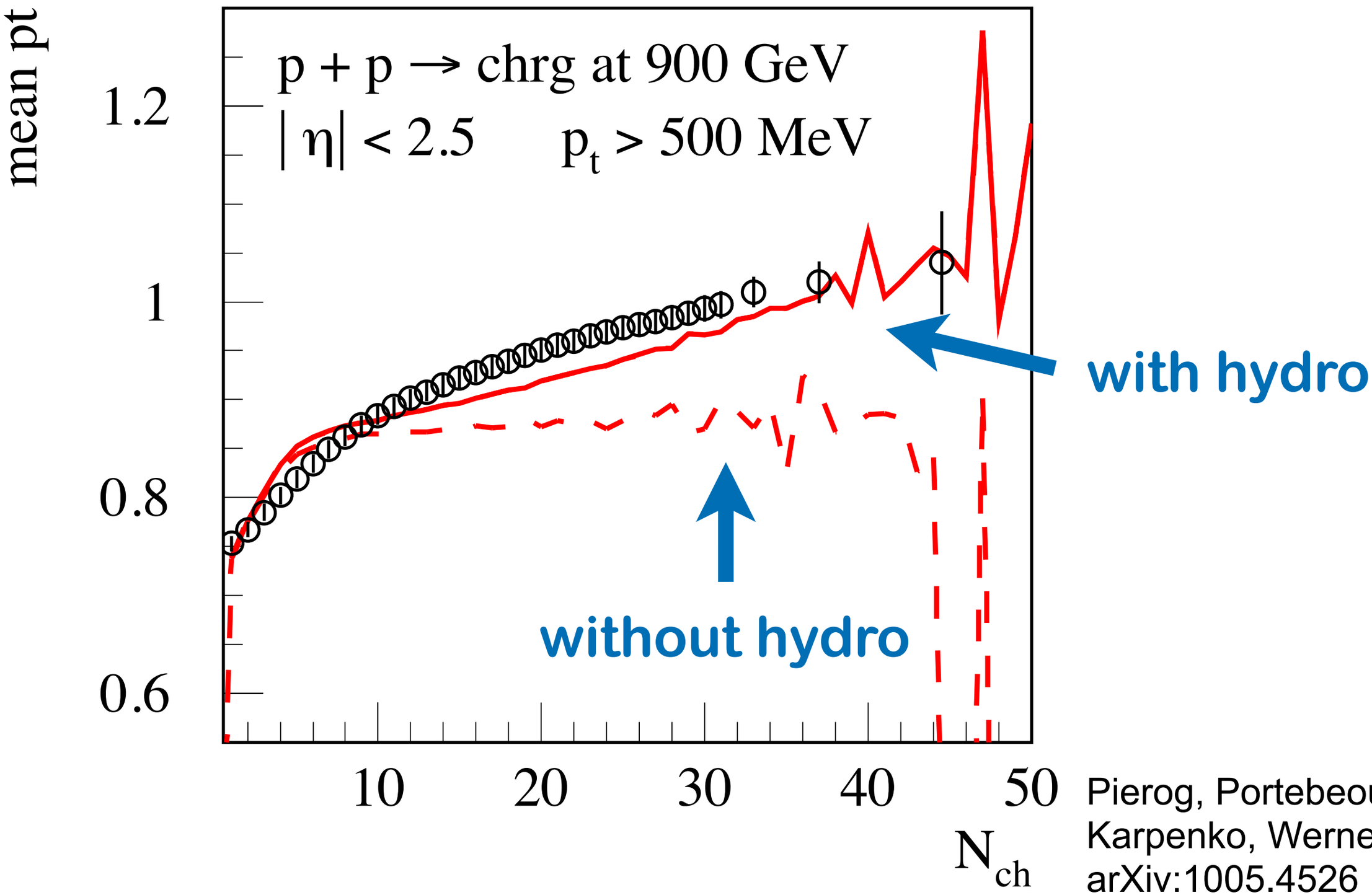

Pierog, Portebeouf, Karpenko, Werner
arXiv:1005.4526

EPOS - hydro

Pressure:

$$p = p_Q + \lambda(T)\,(p_H - p_Q)$$

Entropy density:

$$S = \frac{\partial p}{\partial T} = S_Q + \lambda\,(S_H - S_Q) + \frac{\partial \lambda}{\partial T}\,(p_H - p_Q)$$

Flavor densities:

$$n^i = \frac{\partial p}{\partial \mu^i} = n^i_Q + \lambda\,(n^i_H - n^i_Q) + \frac{\partial \lambda}{\partial \mu^i}\,(p_H - p_Q)$$

Energy density:

$$\varepsilon = TS + \sum_i \mu^i n^i - p$$

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EPOS - hydro

one free parameter (in T dependence)

Pressure:

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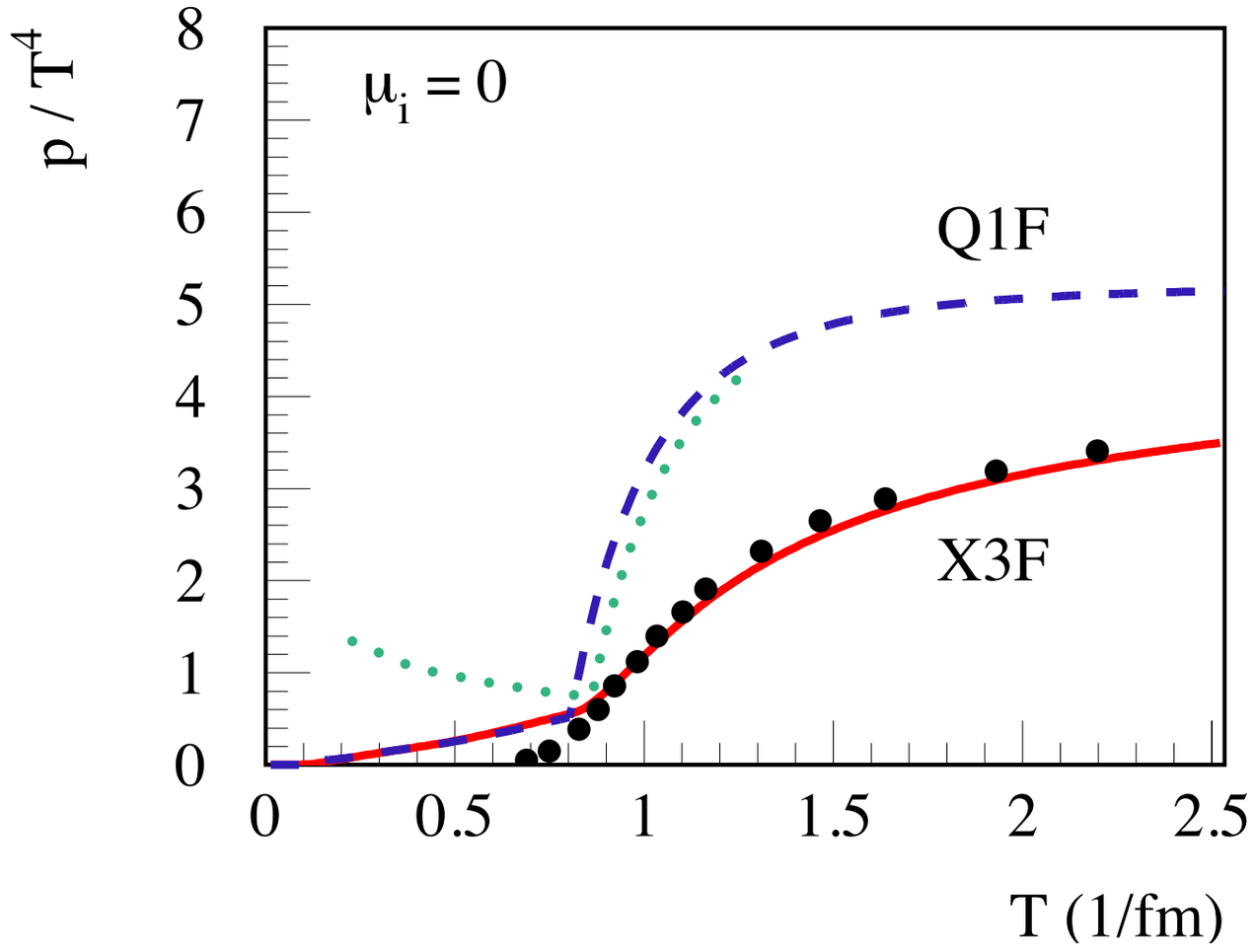
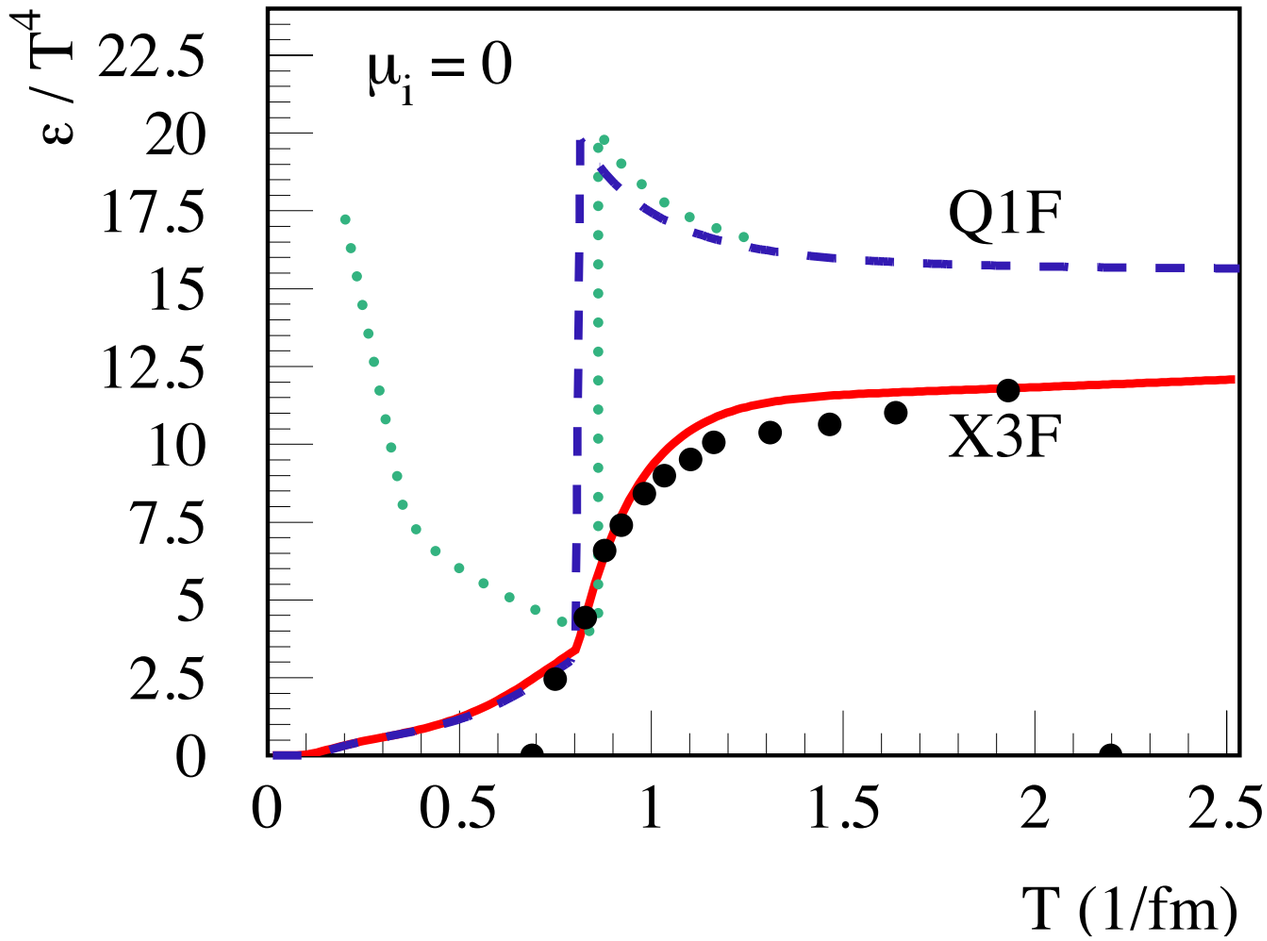
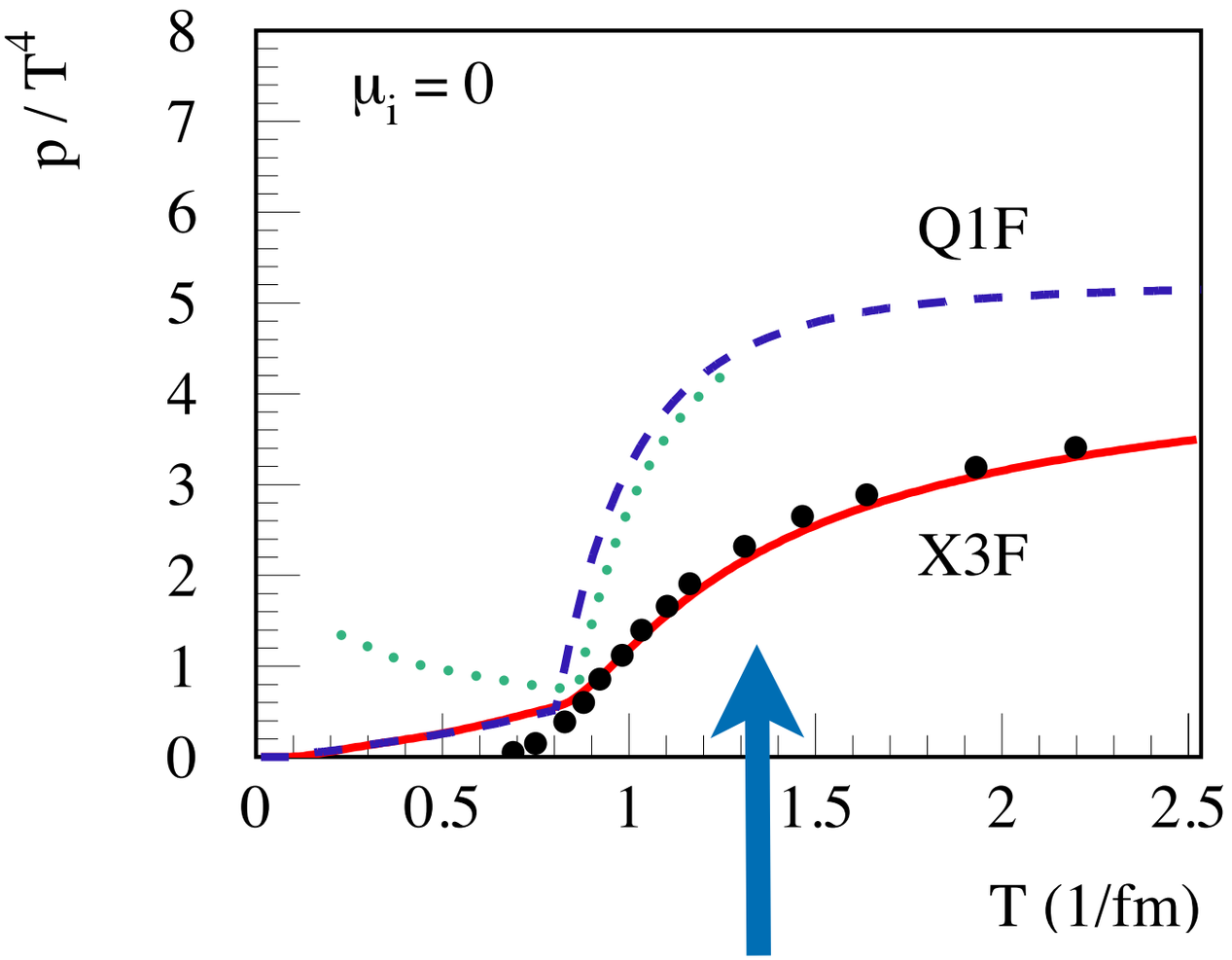
EPOS - EOS


p / T^4
μ_i = 0
Q1F
X3F
0
1
2
3
4
5
6
7
8
0
0.5
1
1.5
2
2.5
T (1/fm)

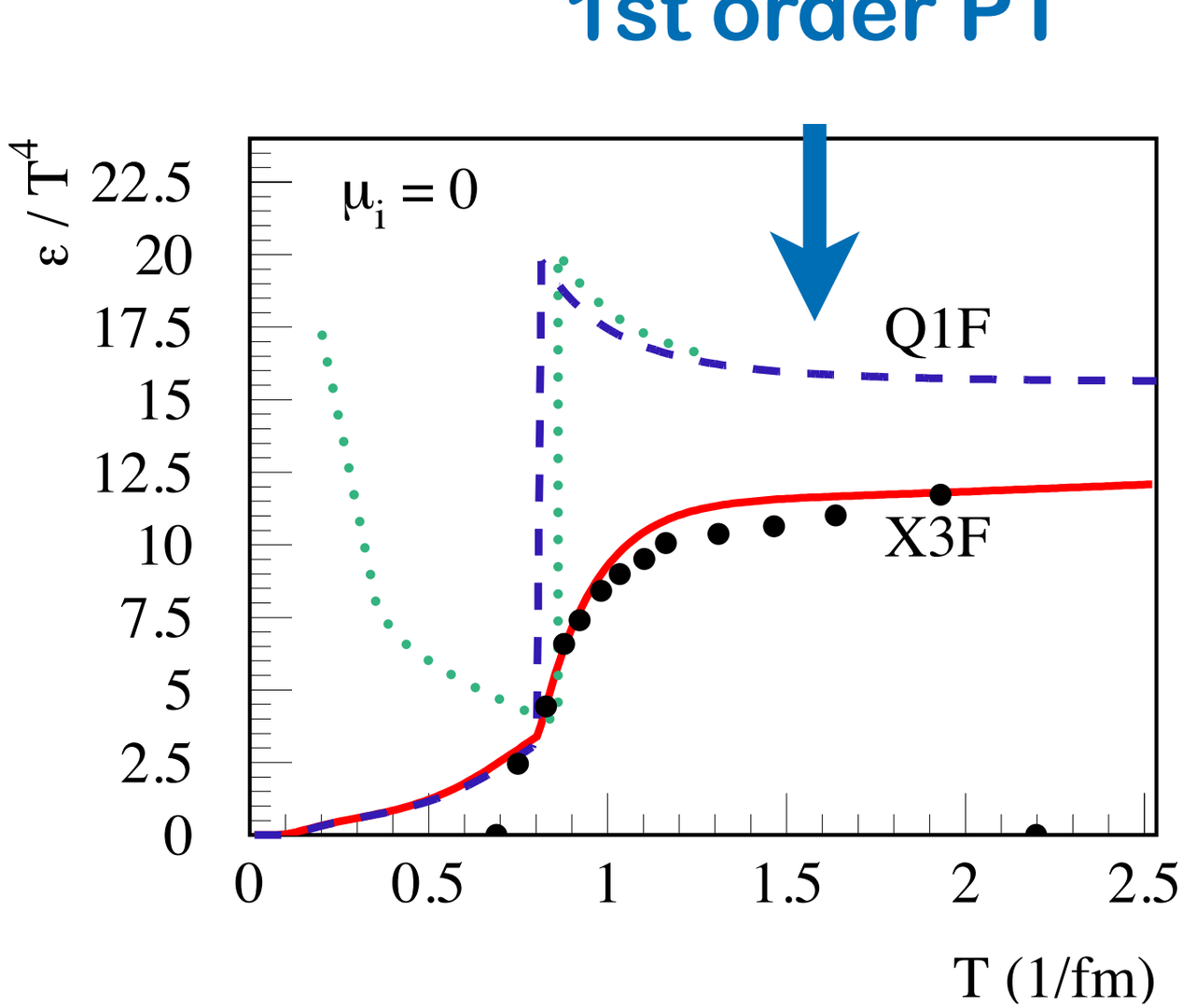

ε / T^4
μ_i = 0
Q1F
X3F
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
0
0.5
1
1.5
2
2.5
T (1/fm)

EPOS - EOS



cross-over, 3 flavor

1st order PT

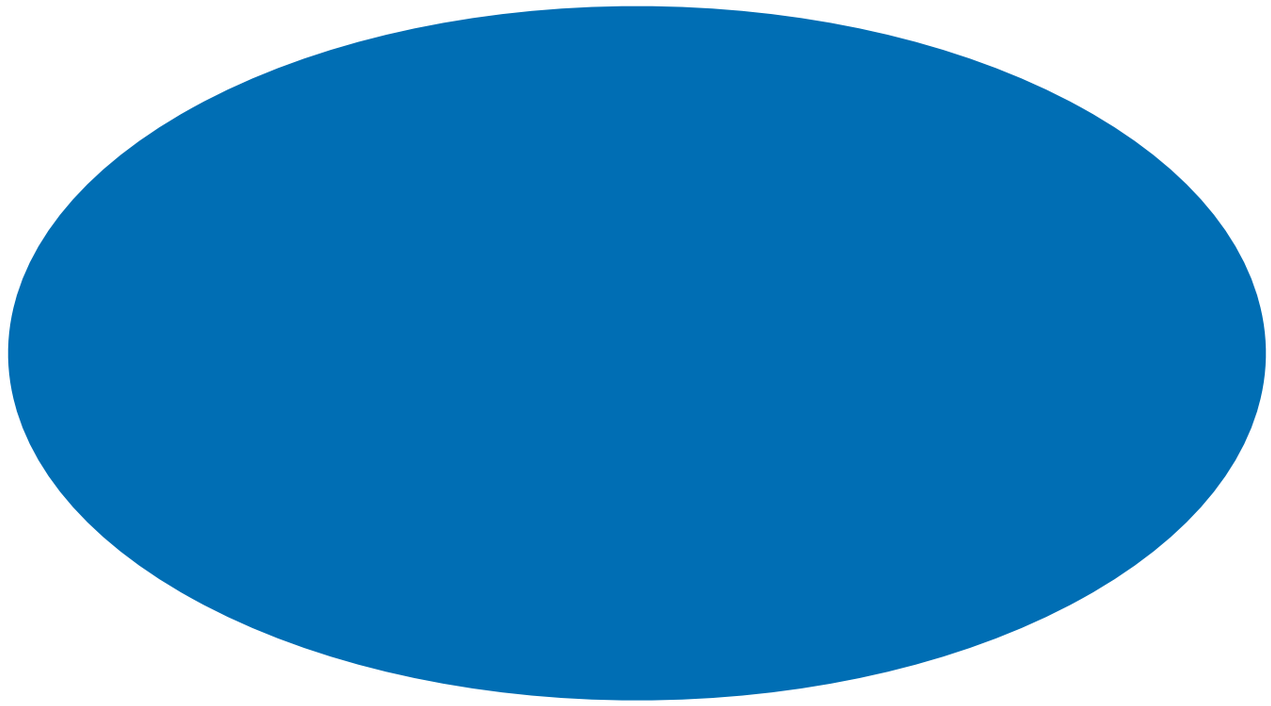


MC@sHQ - as a cartoon

Monte **C**arlo with running α_S for **H**eavy **Q**uarks

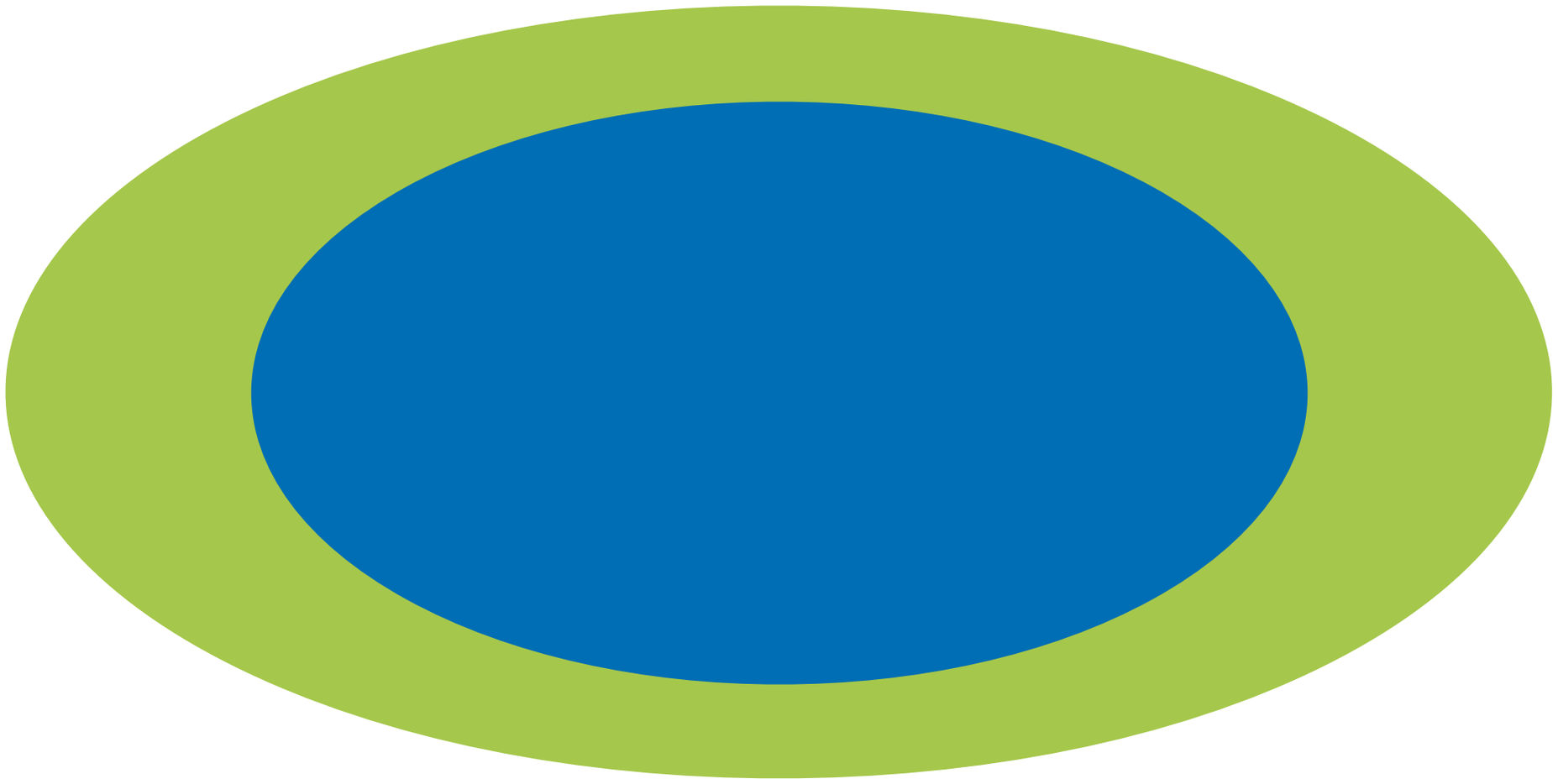
MC@sHQ - as a cartoon

Monte Carlo with running α_S for Heavy Quarks



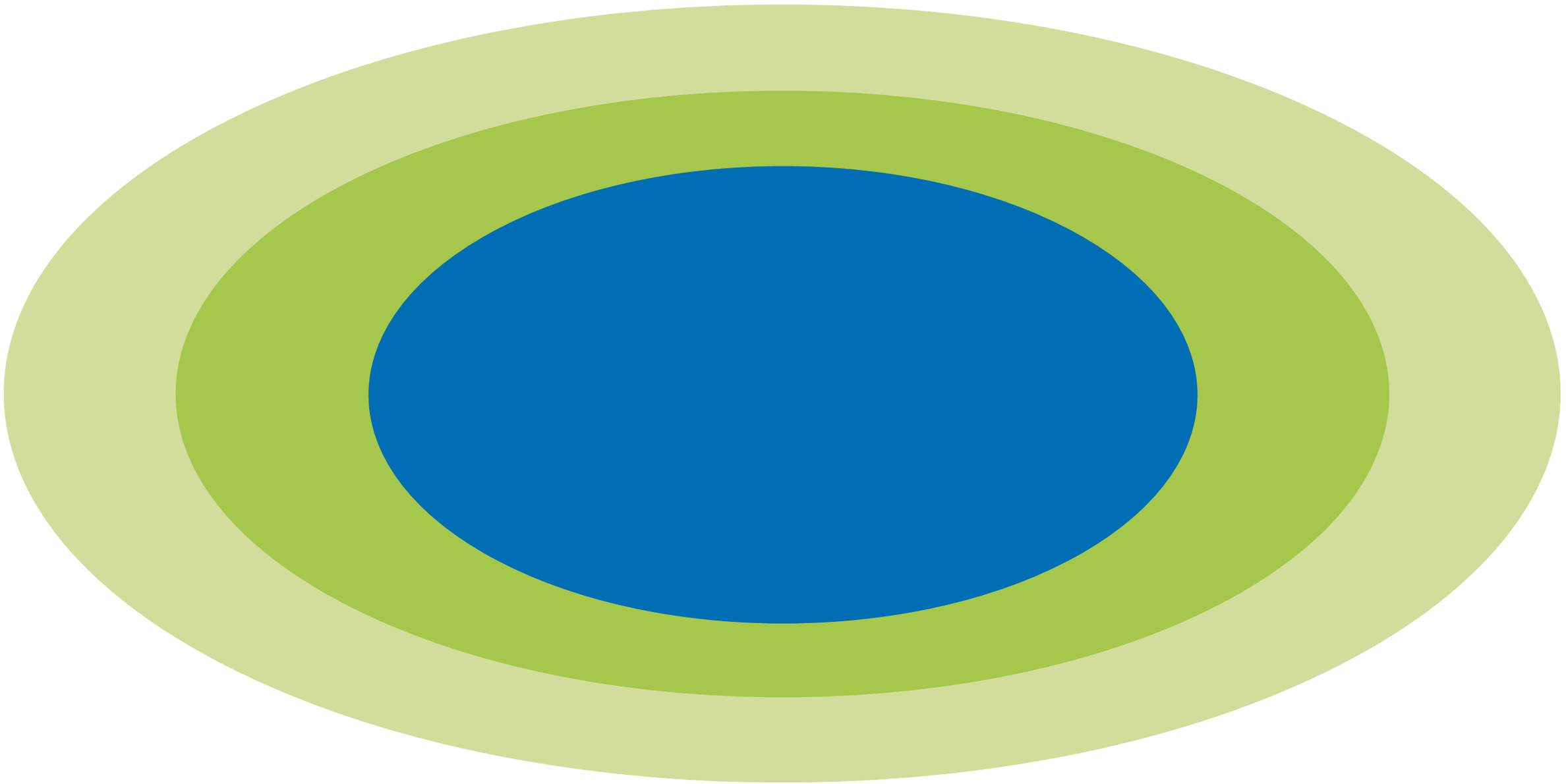
: QGP

MC@sHQ - as a cartoon



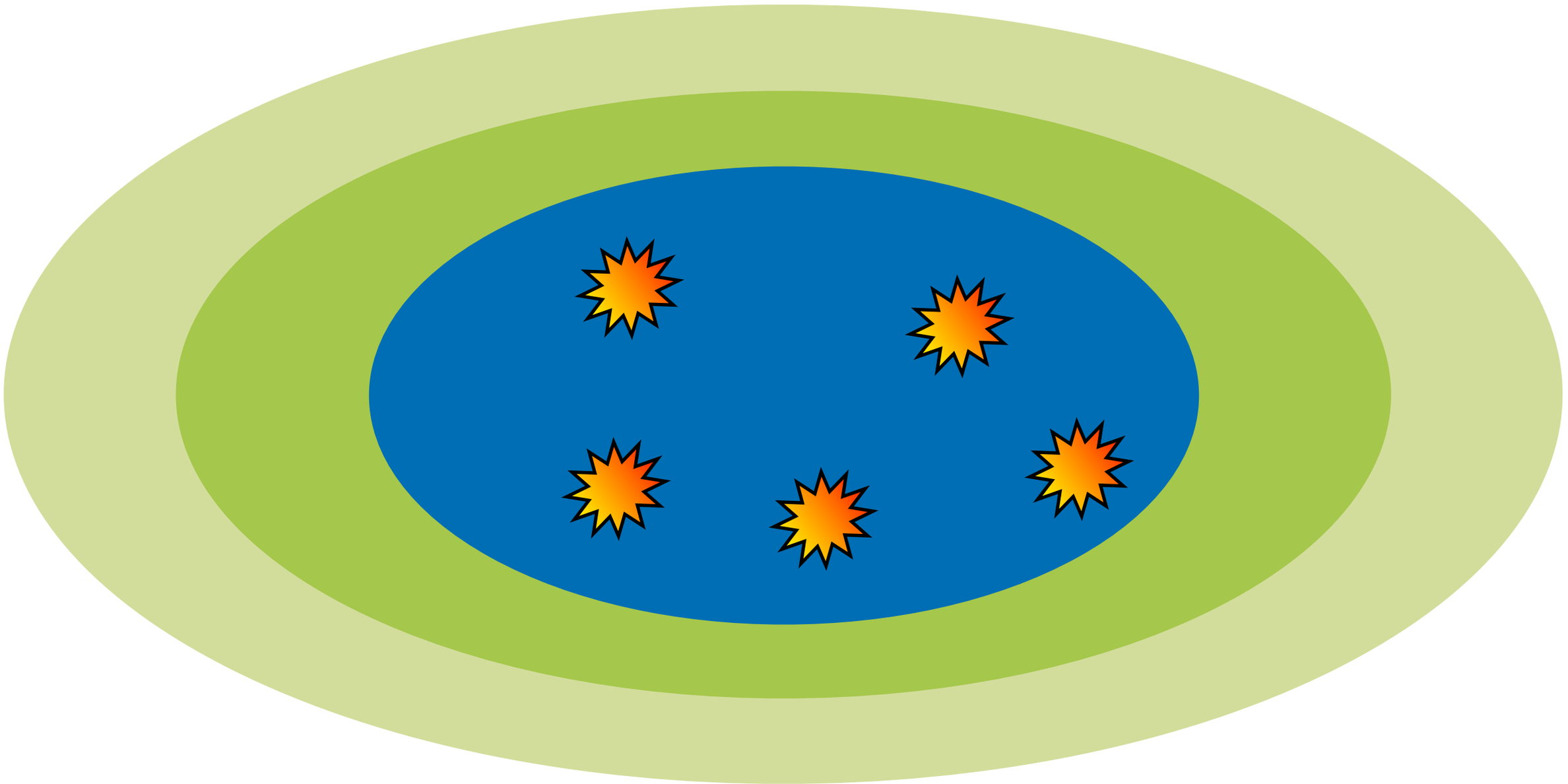
: mixed phase

MC@sHQ - as a cartoon



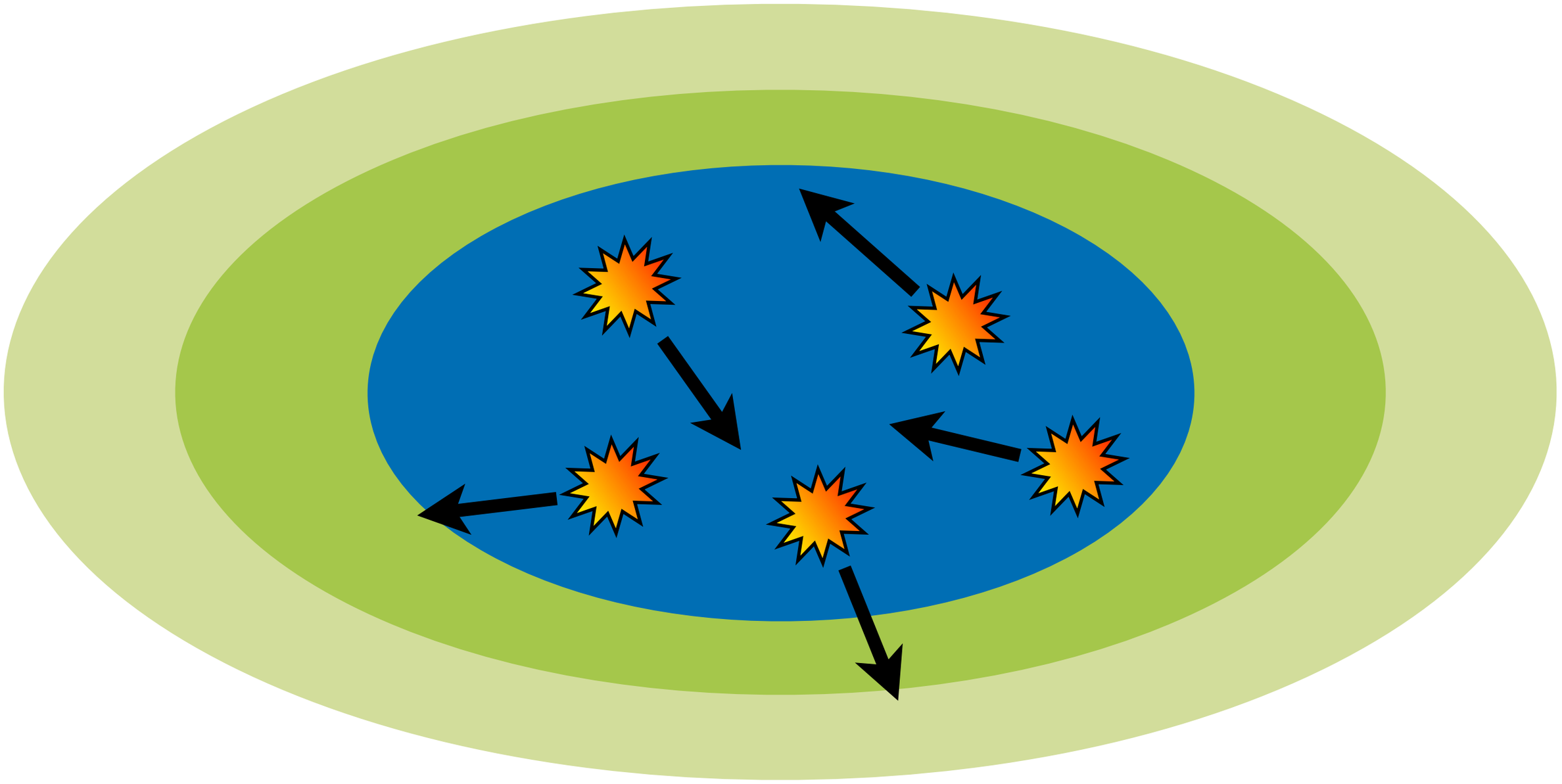
: hadronic phase (not taken into account)

MC@sHQ - as a cartoon



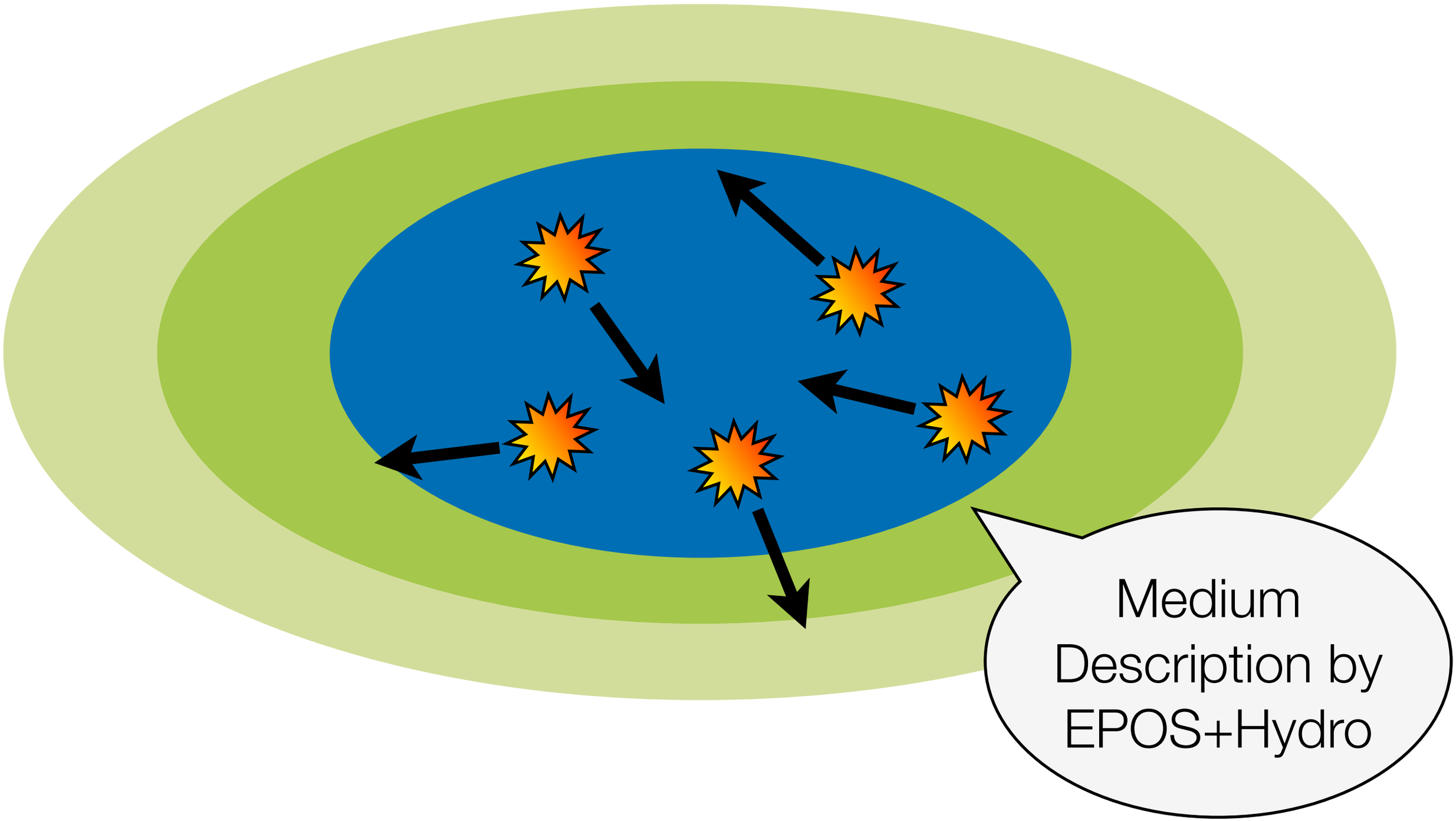
: hard collisions in initial NN collisions

MC@sHQ - as a cartoon



: HQ evolution according to Boltzmann equation

MC@sHQ - as a cartoon



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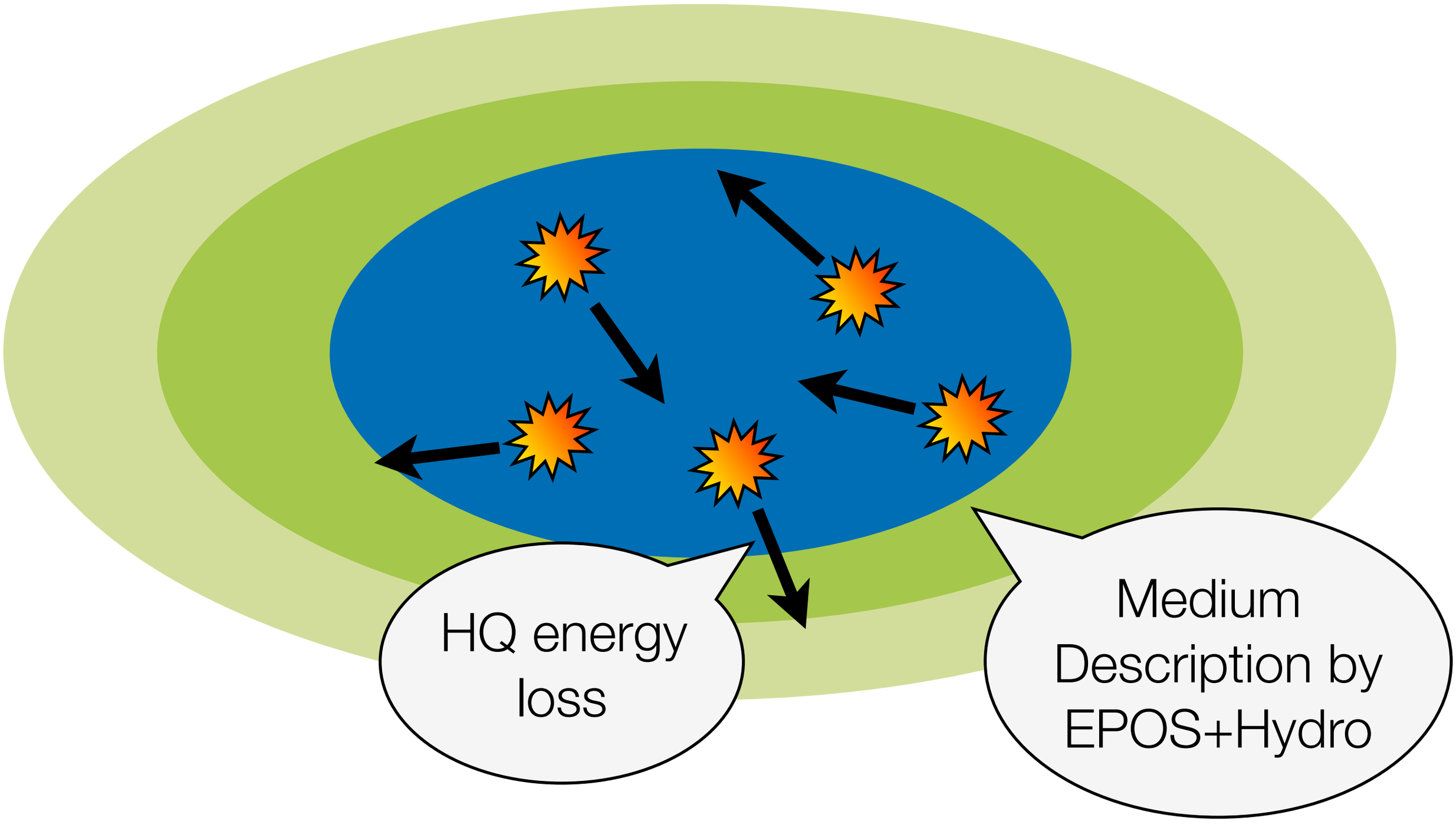

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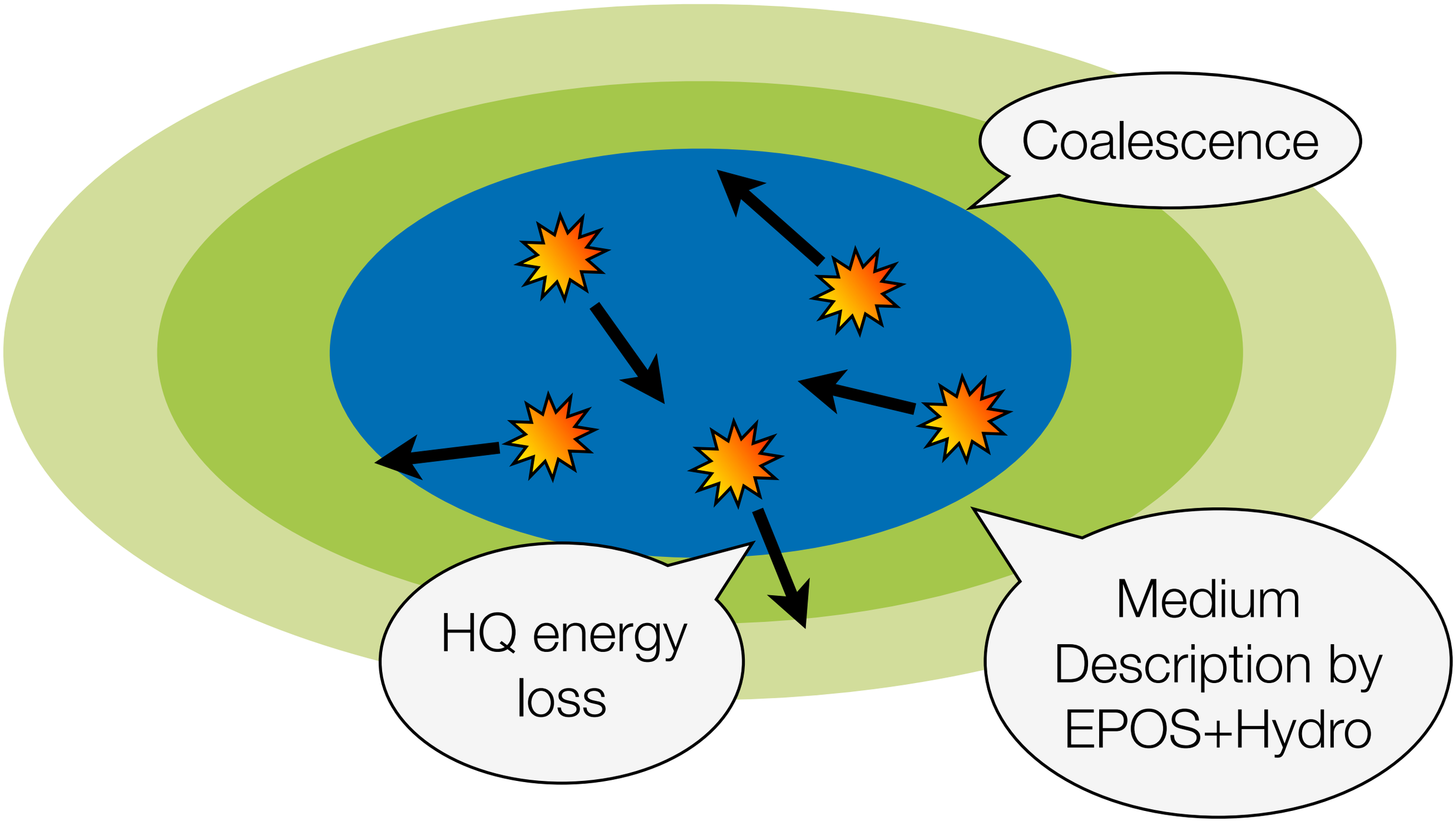

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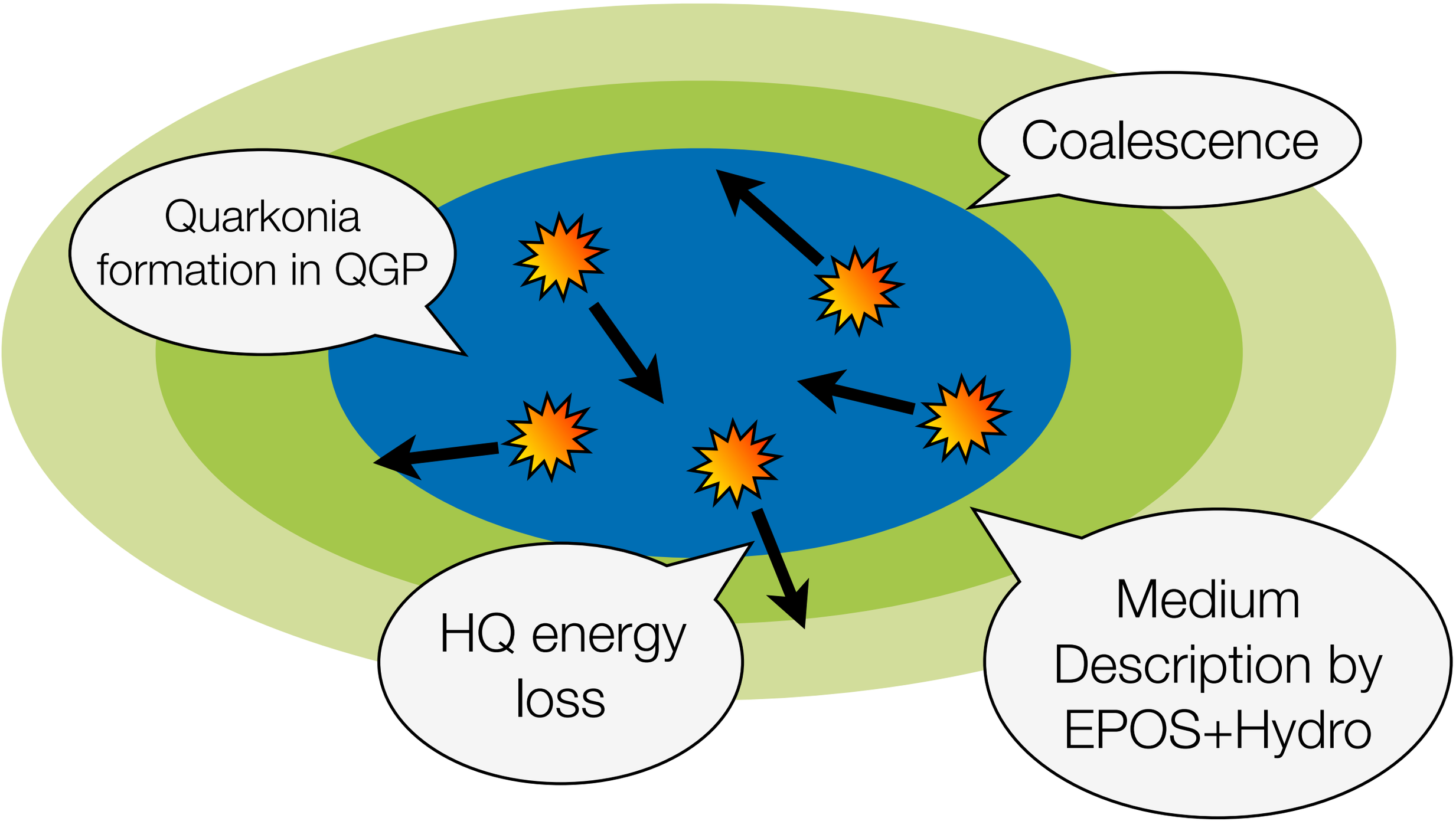

MC@sHQ - energy loss

collisional energy loss

infrared regulator

running coupling

infrared regulator

gluon propagator

$$\frac{\alpha}{t} \to \frac{\alpha}{t-\mu^2}$$

usual choices:

thermal gluon mass

$$\mu^2 = \frac{m_D^2}{3} = \frac{N_c}{9}\left(1+\frac{1}{6}n_f\right)4\pi\alpha_S T^2 \approx \frac{(g_S T)^2}{3}$$

infrared regulator

gluon propagator

$$\frac{\alpha}{t} \rightarrow \frac{\alpha}{t-\mu^2}$$

usual choices:

thermal gluon mass

$$\mu^2 = \frac{m_D^2}{3} = \frac{N_c}{9}\left(1+\frac{1}{6}n_f\right)4\pi\alpha_S T^2 \approx \frac{(g_S T)^2}{3}$$

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infrared regulator

gluon propagator

$$\frac{\alpha}{t} \to \frac{\alpha}{t-\mu^2}$$

usual choices:

thermal gluon mass (not from first principles!)

$$\mu^2 = \frac{m_D^2}{3} = \frac{N_c}{9}\left(1+\frac{1}{6}n_f\right)4\pi\alpha_S T^2 \approx \frac{4\pi\alpha_S T^2}{3}$$

infrared regulator

assume:

$$\frac{\alpha}{t - \kappa m_D^2(T)}$$

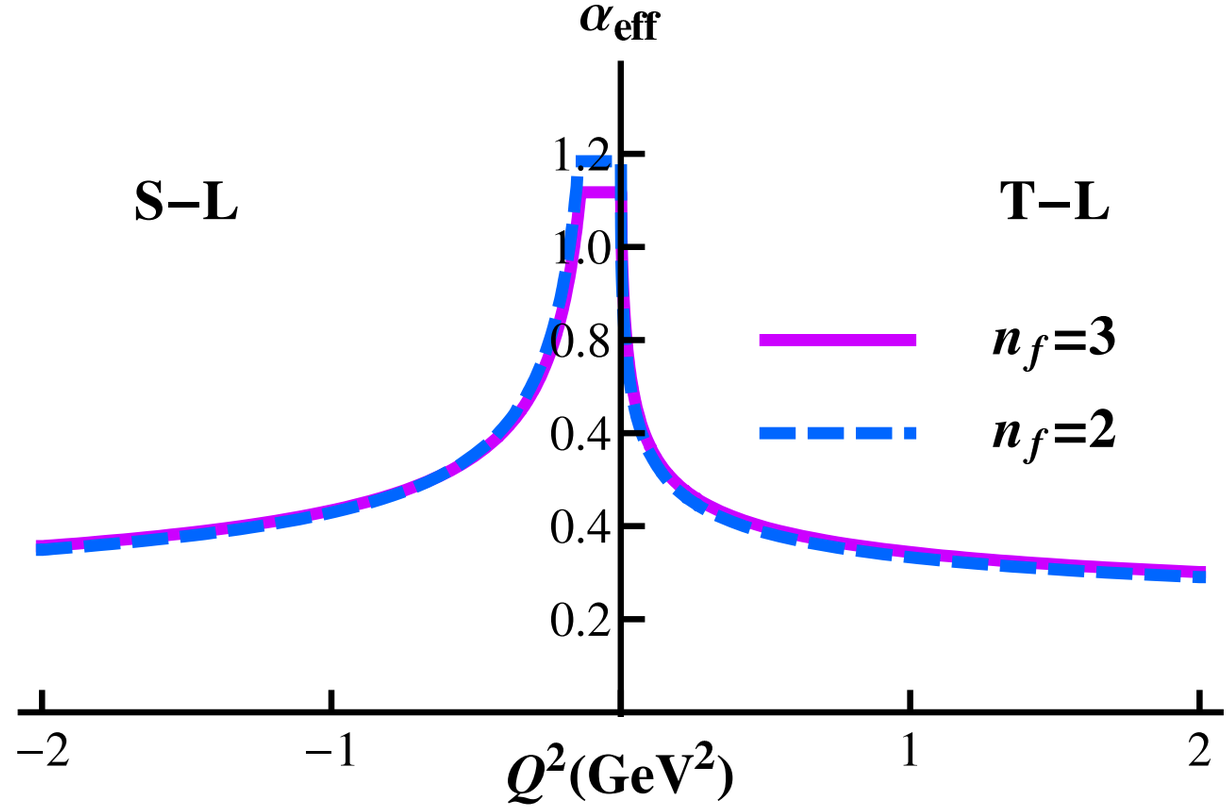
determine parameters in agreement with HTL+hard dE/dx calculations

$$\kappa \sim 0.2$$

Gossiaux, Aichelin, Phys.Rev. C78 (2008) 014904

running coupling

possibility to define an infrared finite running coupling



Dokshitzer, Marchesini, Webber, NPB469, 1996

running coupling

$$\alpha \to \alpha_{\rm eff}(Q^2)$$

$$\alpha_{\rm eff} = \frac{4\pi}{\beta_0}\left[\ln\left(\frac{-Q^2}{\Lambda^2}\right)\right]^{-1}$$

$$\alpha_{\rm eff} = \frac{4\pi}{\beta_0}\left[\frac{1}{2} - \pi^{-1}{\rm atn}\left(\frac{\ln(Q^2/\Lambda^2)}{\pi}\right)\right]$$

Dokshitzer, Marchesini, Webber, NPB469, 1996

MC@sHQ - collisional energy loss

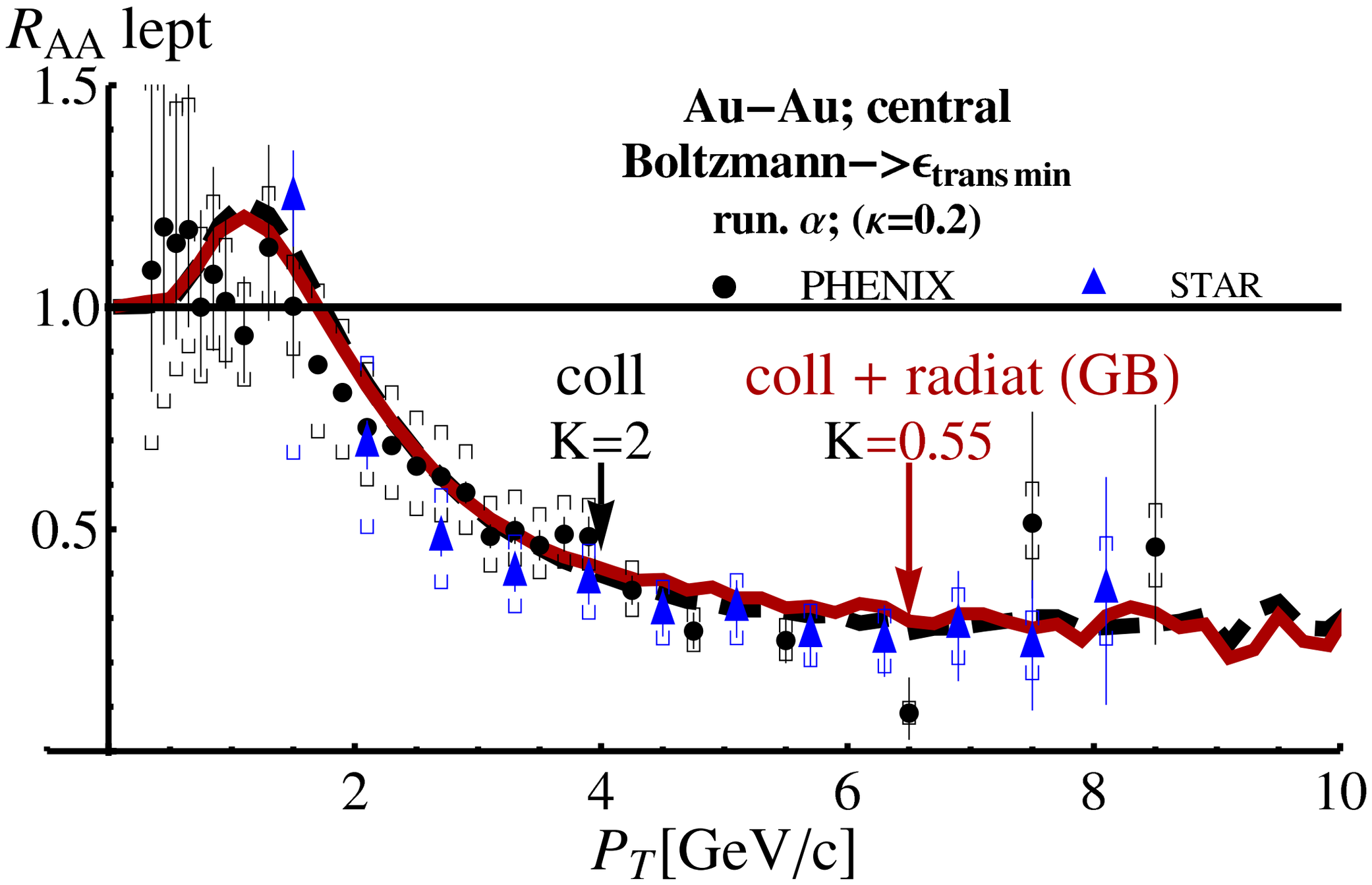
$$\frac{\alpha_{\mathrm{eff}}(t)}{t - \kappa \tilde{m}_D^2(T)}$$

ingredients:

- **running coupling**
- **self-consistent Debye mass**
- **infrared regulator adjusted to HTL+hard**
- **radiative energy loss (not covered here)**

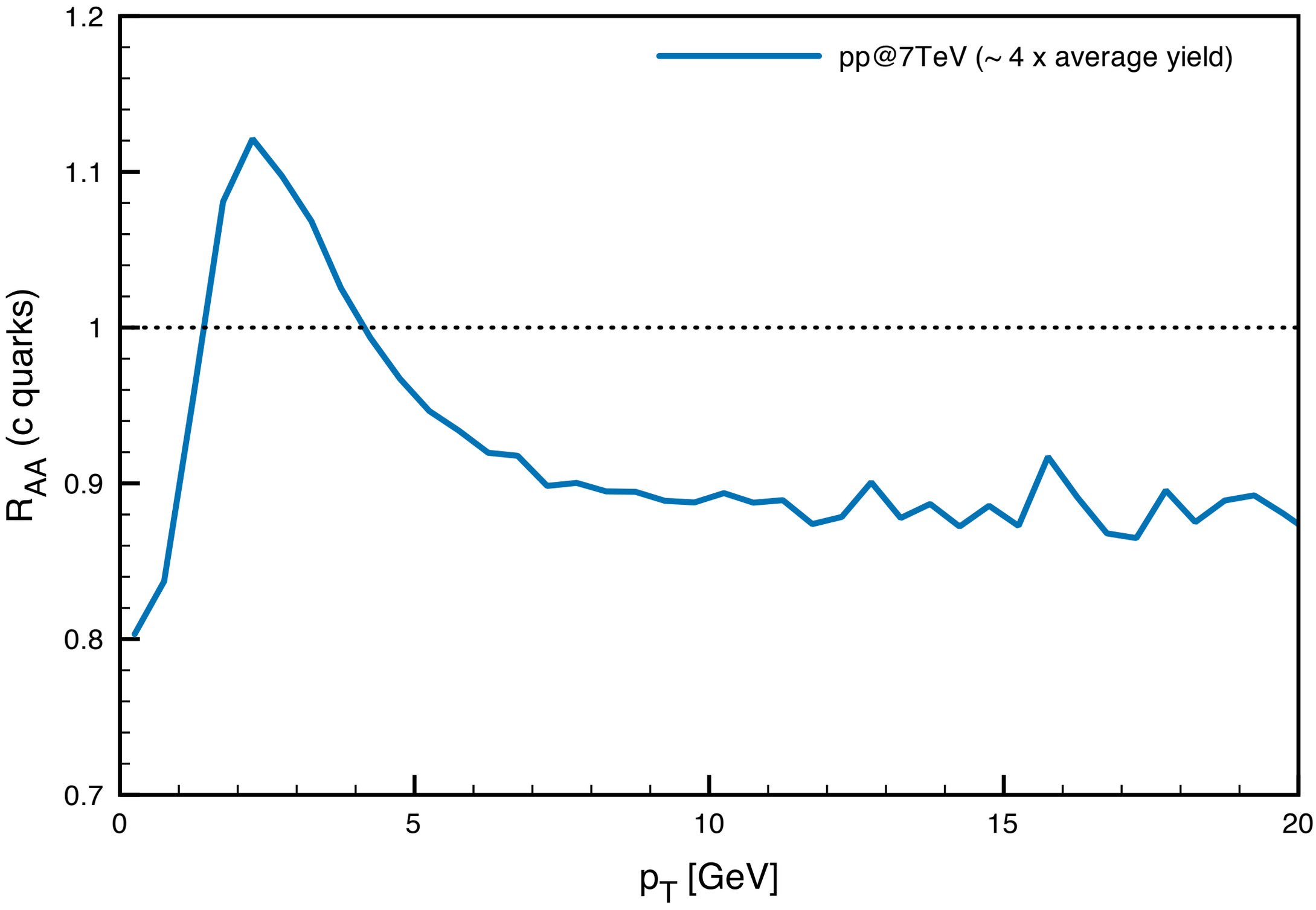
Gossiaux, Aichelin, Phys.Rev. C78 (2008) 014904

MC@sHQ in AuAu @ RHIC

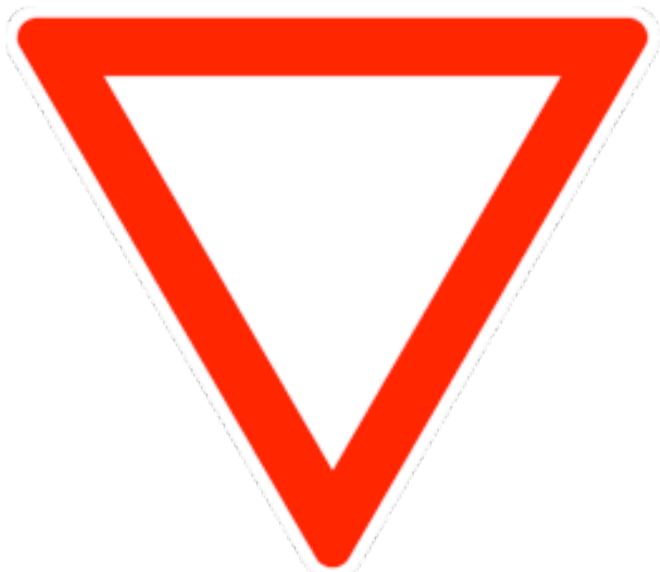


Gossiaux, Aichelin, Gousset, Guiho, J.Phys.G **37** 094019 (2010)

HQ energy loss in pp roughly 10%!



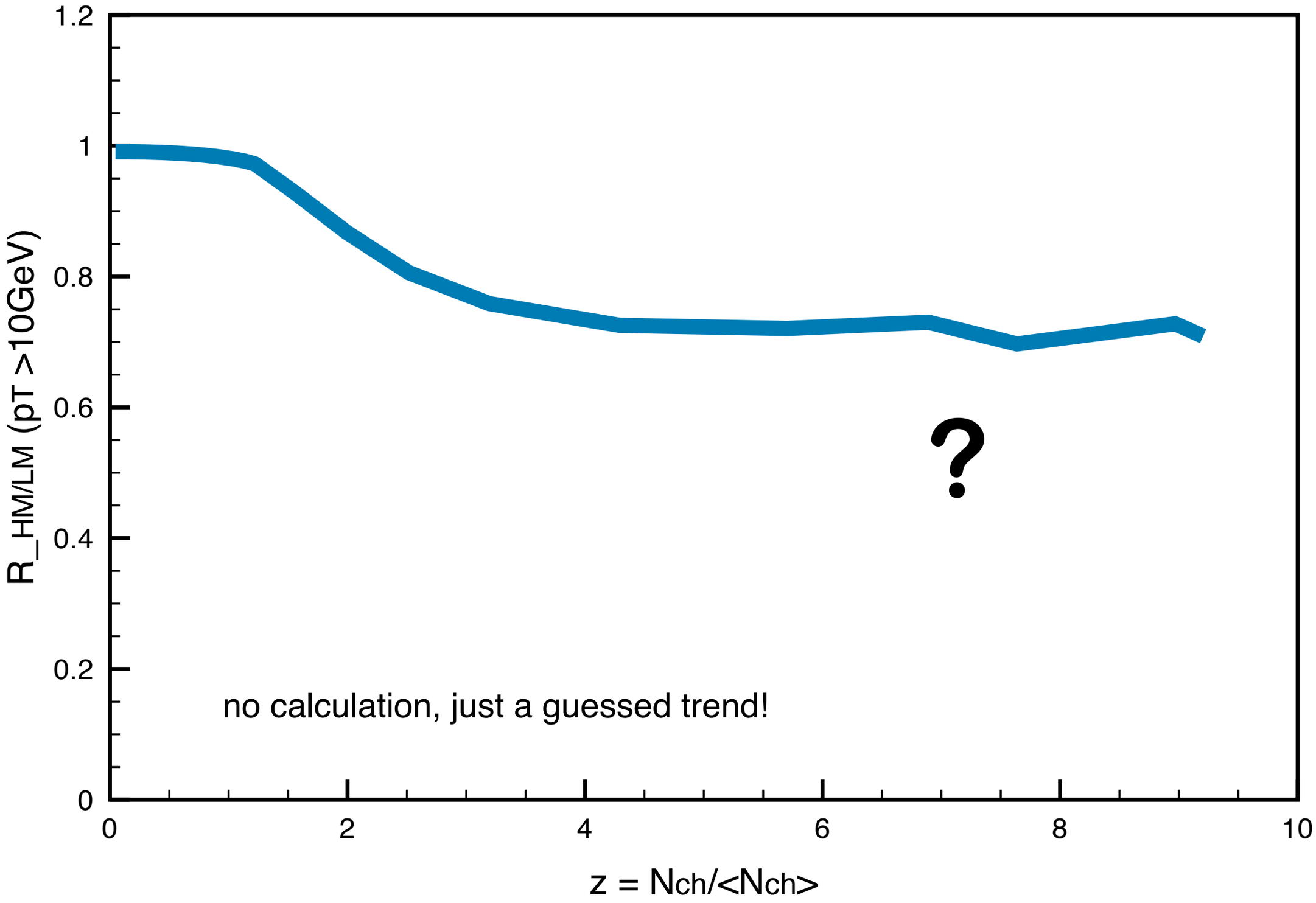
Link to experiment



Problem: Experimental reference is not well defined!

$$R_{HM/LM} = \frac{dN/dp_{T,HM}}{< N_{HM} > \frac{dN/dp_{T,LM}}{<N_{LM}>}}$$

Link to experiment



Take home messages

- **Heavy Quark energy loss in pp @ LHC is a measurable effect**

- **$R_{HM/LM}$ could be used as an experimental observable**

- **Multiplicity dependent studies are a valuable tool for pp@LHC**

Outlook

- Dynamically generate the HQ in EPOS

- Further model adjustments (e.g. HQ production, coherence ...)

- Tune the medium description to light quark data

  ⇒ learn about HQ interaction

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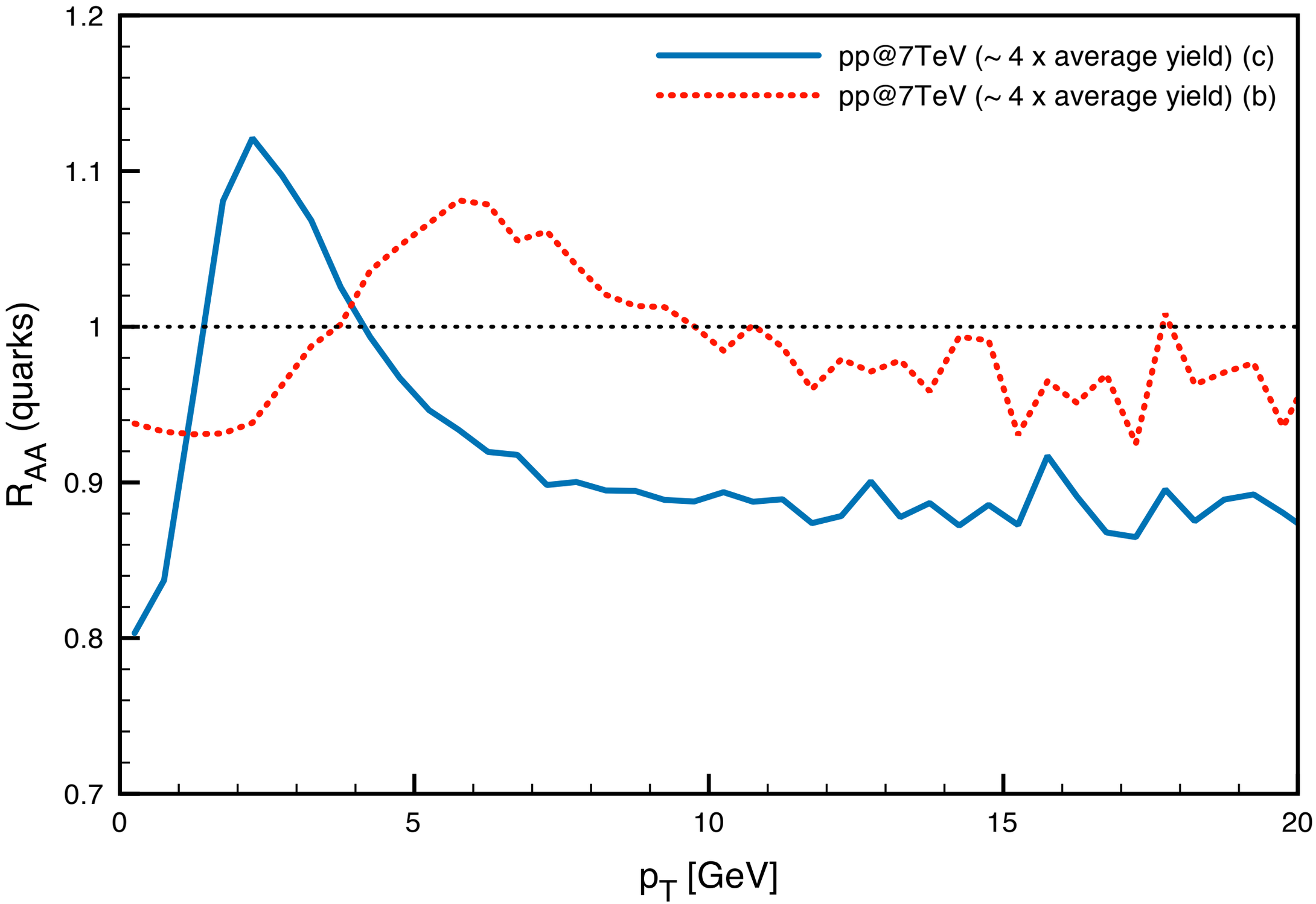
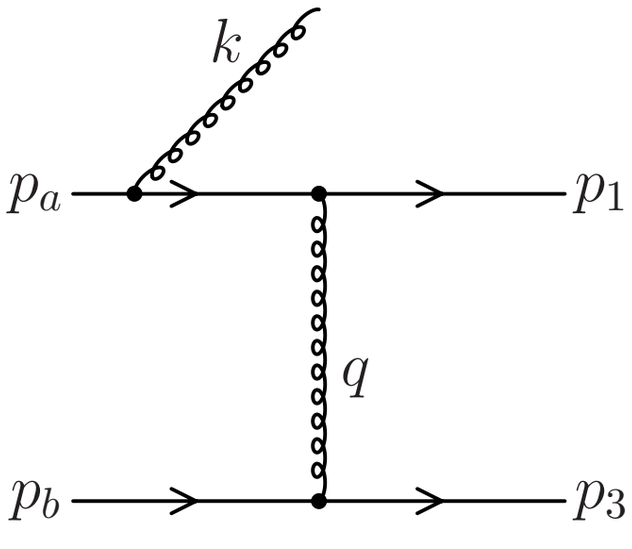
Thanks!

BACKUP SLIDES

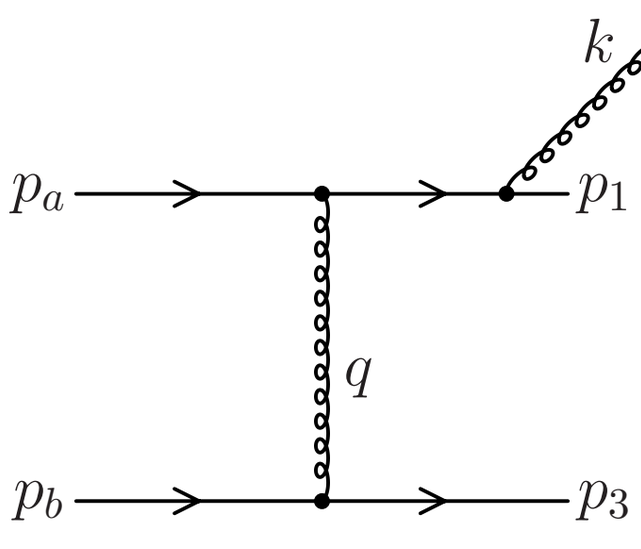
energy loss of bottom



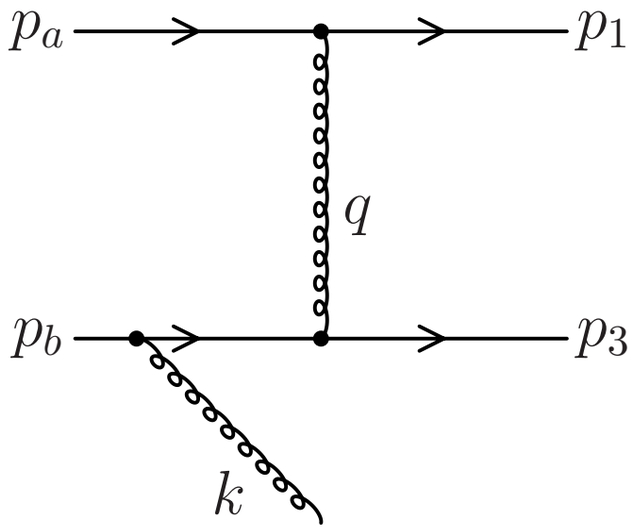
Matrix elements - radiative



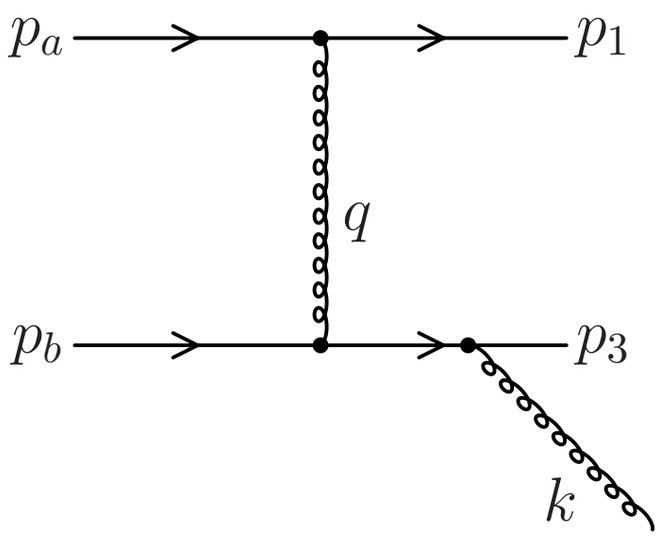
M_1



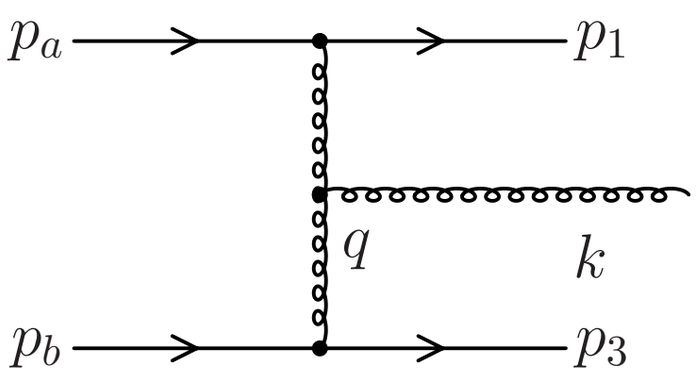
M_2



M_3



M_4



M_5

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