Photon Production in a Hadronic Transport Approach

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in collaboration with:

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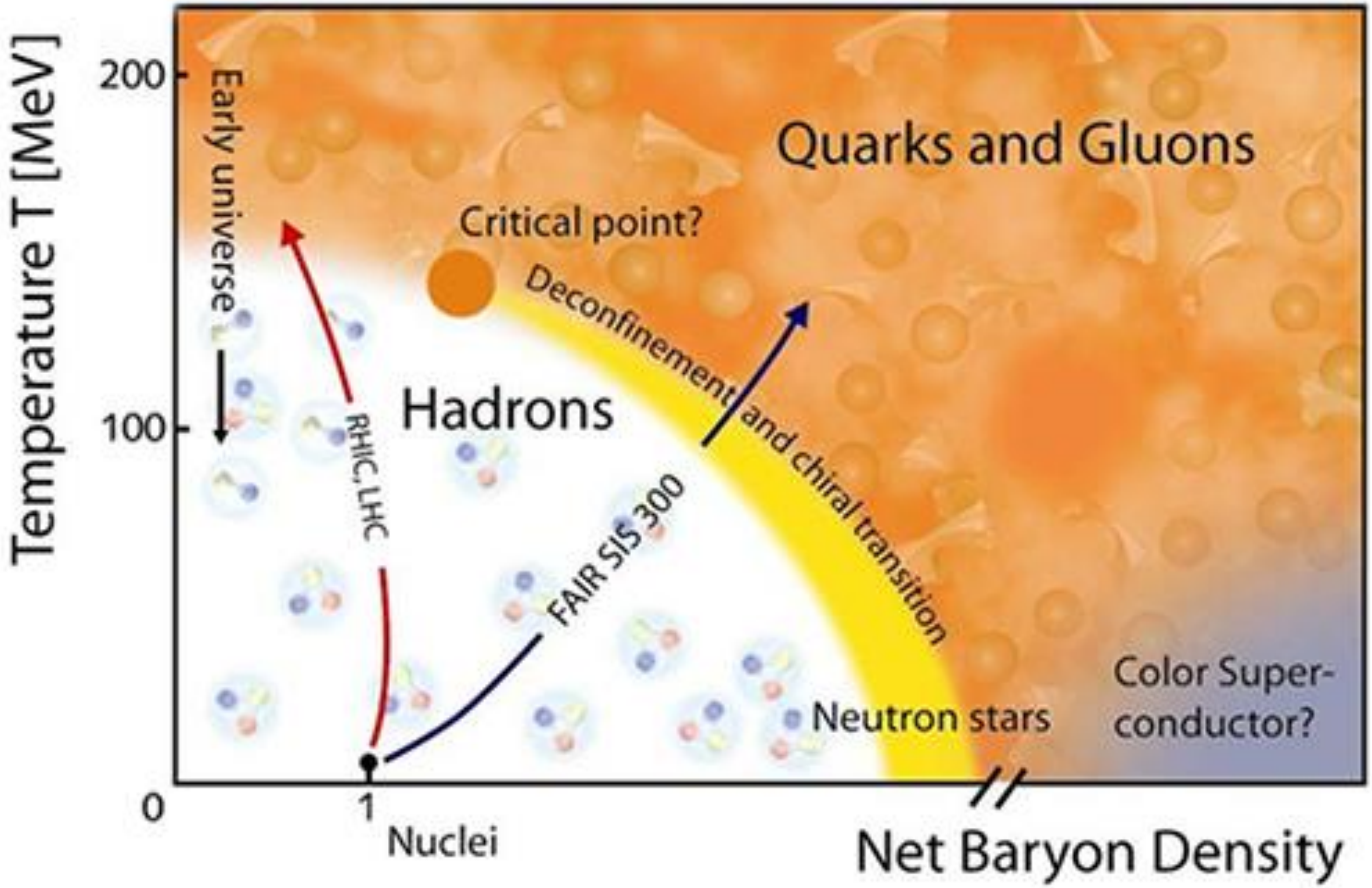
Transport Meeting,   July 12, 2016

Outline

- Introduction and motivation
- Photon production: a simple mesonic system
- Direct photons in SMASH
- Photon production in equilibrium
- Summary
- Outlook

Probing the QCD phase diagram



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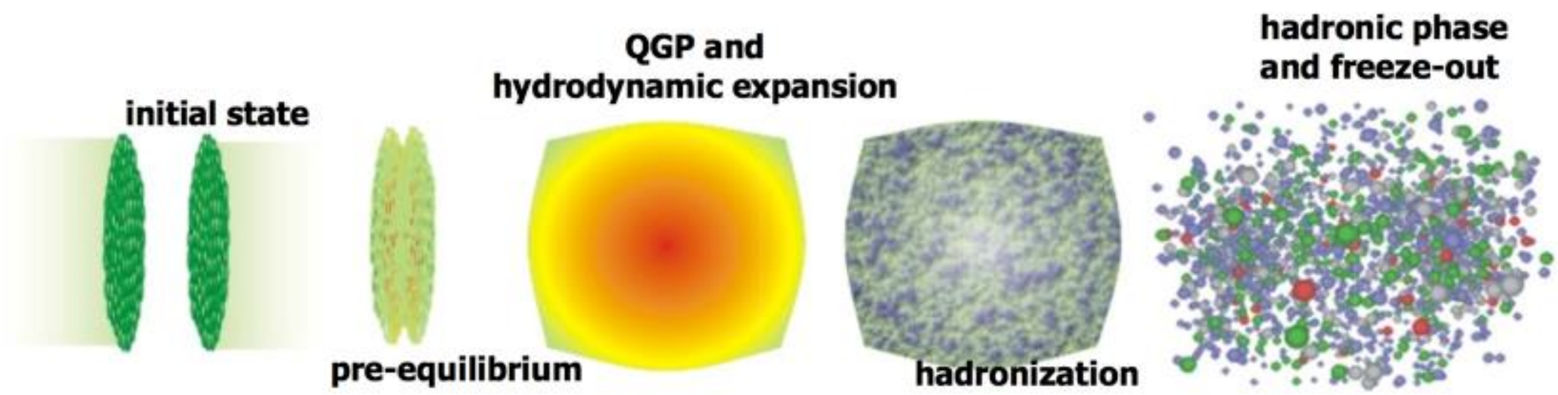
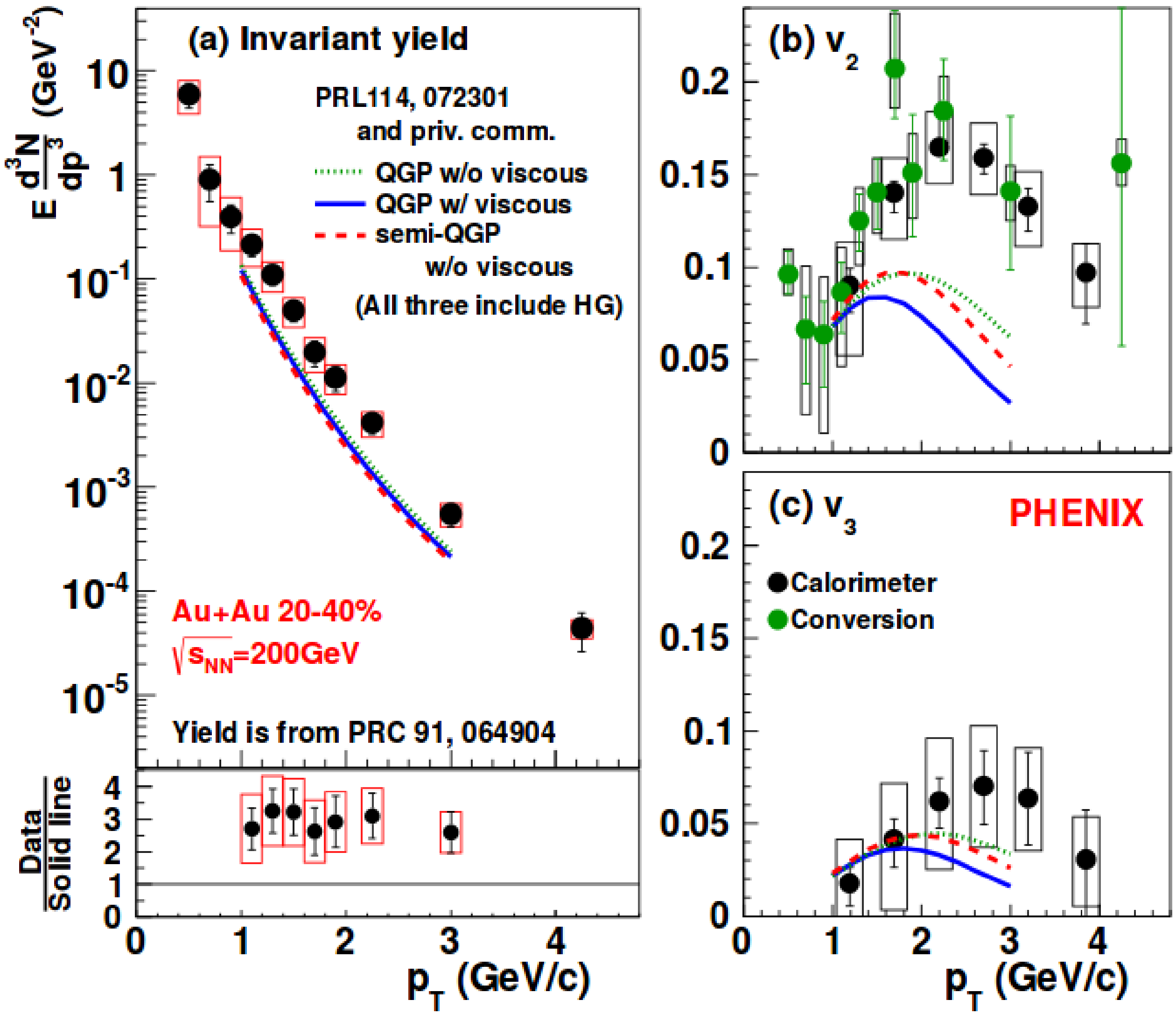


by: S.A. Bass

- photons
  - background
    - decay photons
  - direct photons
    - prompt photons
    - thermal photons
    - bremsstrahlung

Direct photons



- theoretical predictions undershoot measured spectrum and flow
- maybe not dominated by early hot QGP?

A. Adare et al. [PHENIX Collaboration], arXiv:1509.07758 [nucl-ex].

Photons from a hadron gas

$$\mathcal{L} = |D_\mu \Phi|^2 - m_\pi^2 |\Phi|^2 - \frac{1}{4}\rho_{\mu\nu}\rho^{\mu\nu} + \frac{1}{2}m_\rho^2 \rho_\mu \rho^\mu - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$

$$\pi^\pm + \pi^\mp \to \rho^0 + \gamma$$
$$\pi^\pm + \pi^0 \to \rho^\pm + \gamma$$
$$\pi^\pm + \rho^0 \to \pi^\pm + \gamma$$
$$\pi^\pm + \rho^\mp \to \pi^0 + \gamma$$
$$\pi^0 + \rho^\pm \to \pi^\pm + \gamma$$
$$\pi^\pm + \pi^\mp \to \eta + \gamma$$
$$\pi^\pm + \eta \to \pi^\pm + \gamma$$
$$\pi^\pm + \pi^\mp \to \gamma + \gamma$$

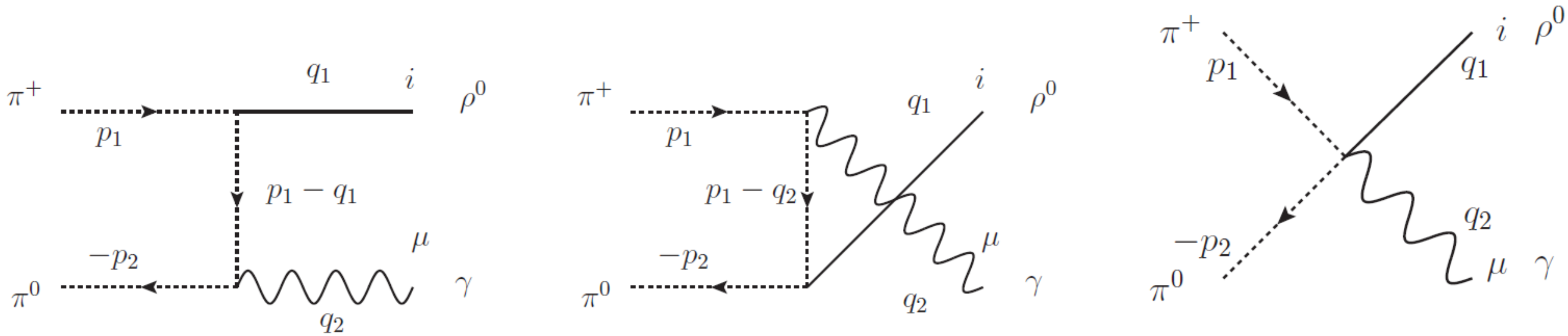
$$\begin{aligned} |D_\mu \Phi|^2 &= (\partial_\mu \Phi^\dagger + ieA_\mu \Phi^\dagger + ig_\rho \rho_\mu \Phi^\dagger)(\partial^\mu \Phi - ieA^\mu \Phi - ig_\rho \rho^\mu \Phi) \\ &= -ie[\partial_\mu \Phi^\dagger A^\mu \Phi + \Phi^\dagger A^\mu \partial_\mu \Phi] - ig_\rho[\partial_\mu \Phi^\dagger \rho^\mu \Phi + \Phi^\dagger \rho^\mu \partial_\mu \Phi] \\ &\quad + e^2 A_\mu A^\mu \Phi^\dagger \Phi + g_\rho^2 \rho_\mu \rho^\mu \Phi^\dagger \Phi + 2eg_\rho A_\mu \Phi^\dagger \rho^\mu \Phi \end{aligned}$$

- simple hadron resonance gas
- only pi-, rho- and eta-mesons
- evaluated via Scalar Field Theory

[KAP91]

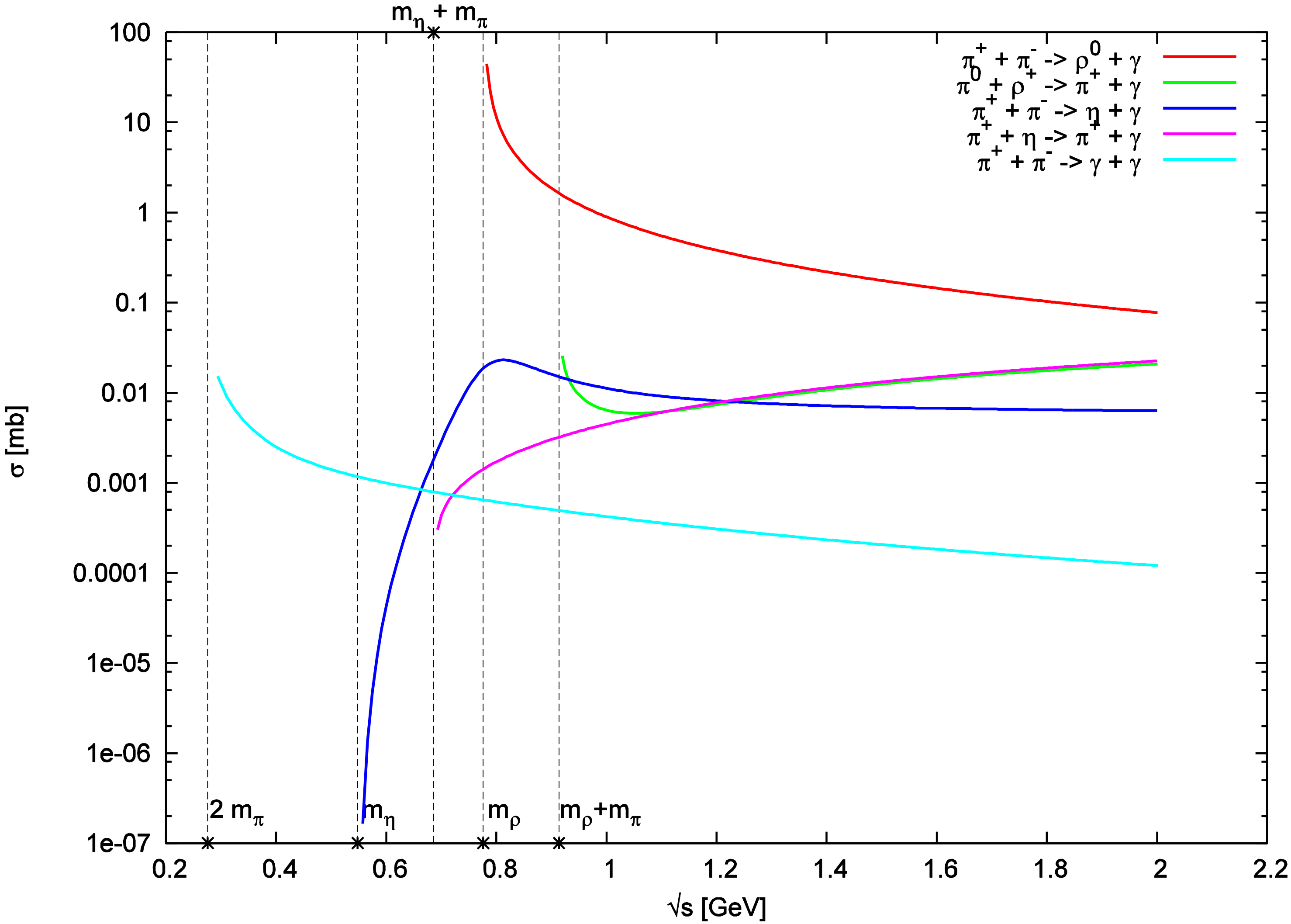
Deriving cross sections from scalar field theory

example: $\pi^{\pm} + \pi^{\mp} \rightarrow \rho^0 + \gamma$

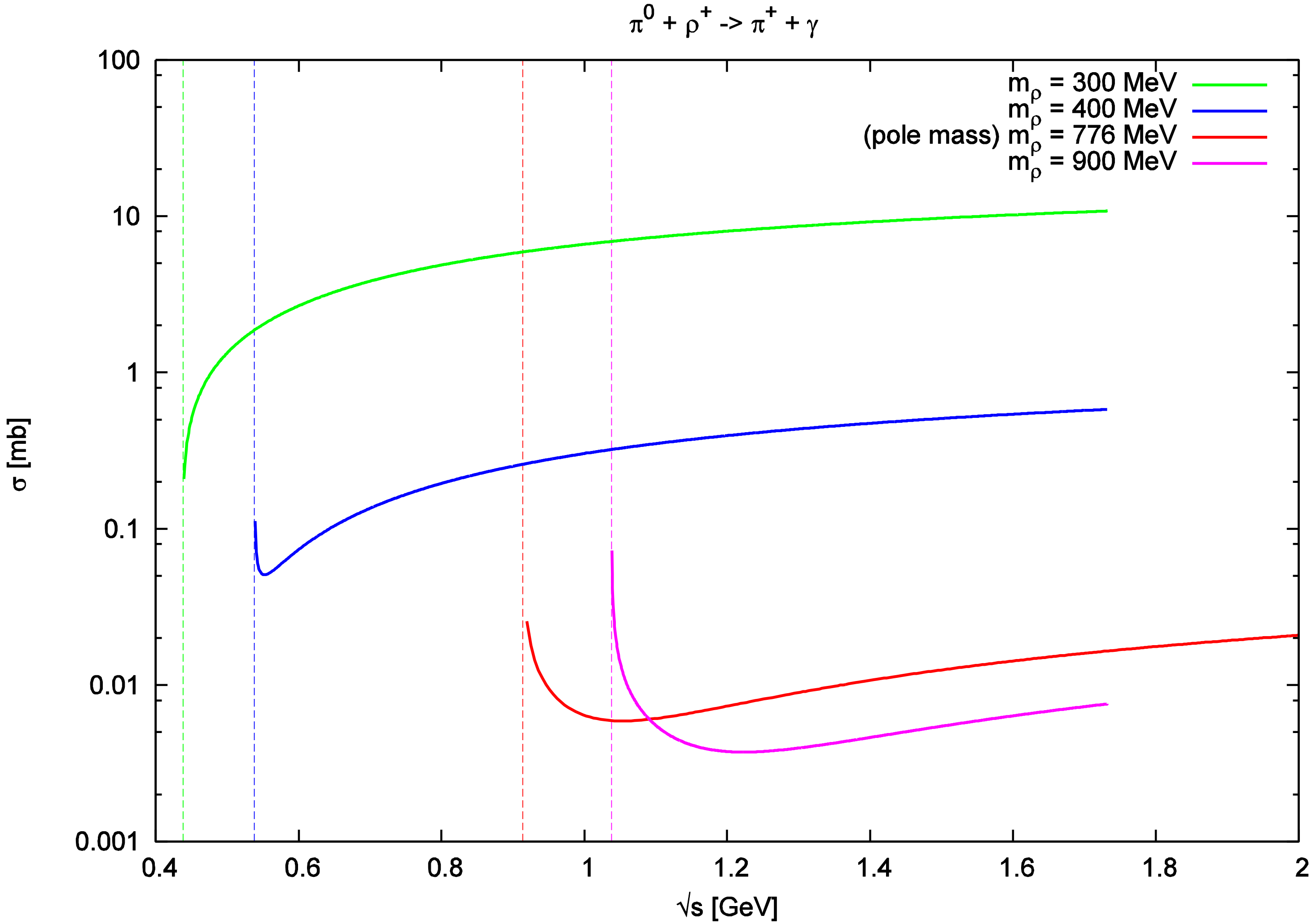


$$\sigma(\pi^{\pm} + \pi^{\mp} \rightarrow \rho^0 + \gamma)$$
$$= \frac{\alpha g_\rho^2}{4s|p_{c.m.}|^2} \left\{ 2\Delta t - \Delta m^2 \left[\frac{m_\pi^2 \Delta t}{\tilde{t_1} \tilde{t_2}} - \frac{m_\pi^2 \Delta u}{\tilde{u_1} \tilde{u_2}} + \frac{s - 2m_\pi^2}{s - m_\rho^2} \ln \left(\frac{\tilde{t_2} \tilde{u_1}}{\tilde{t_1} \tilde{u_2}} \right) \right] \right\}$$

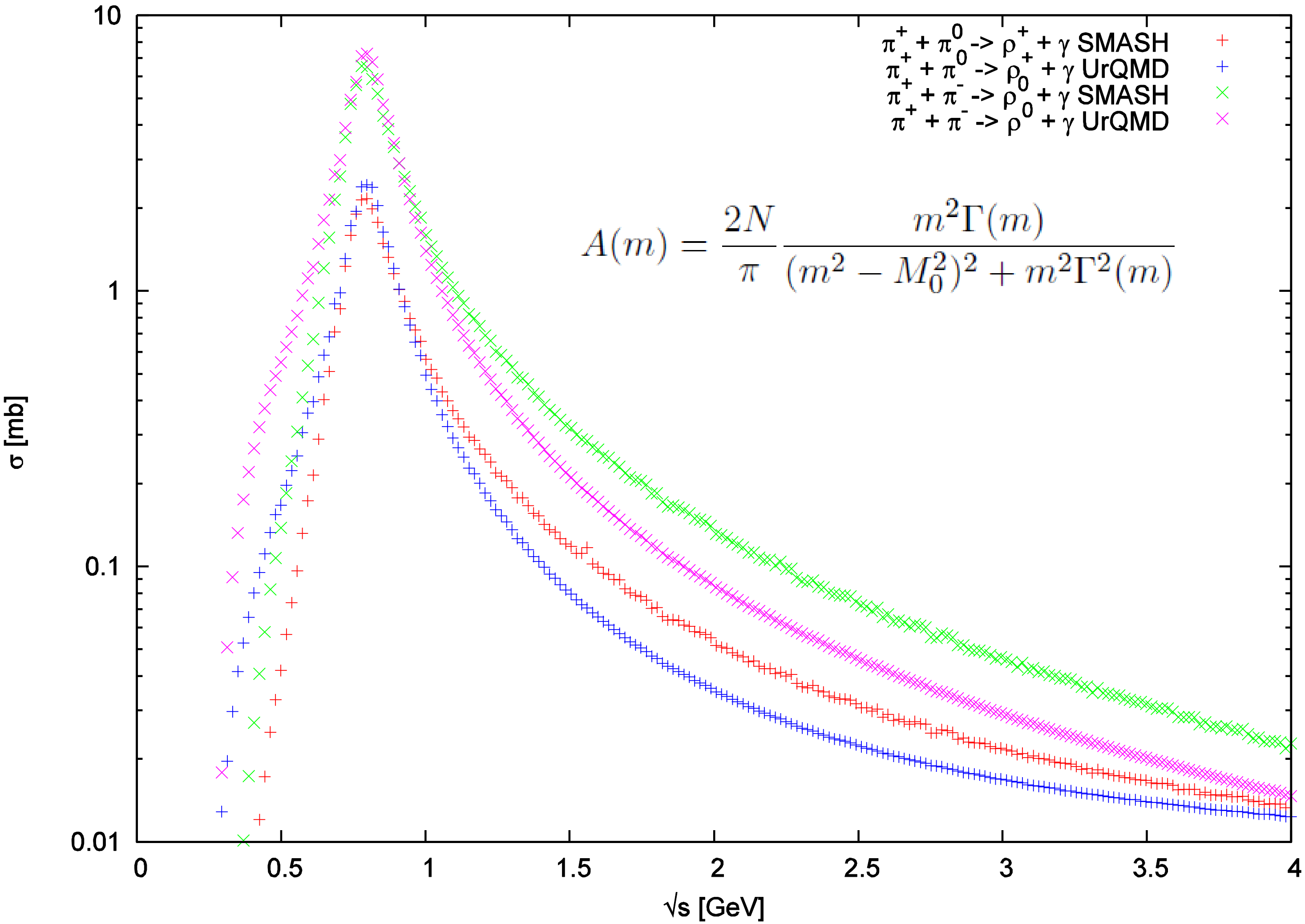
Total cross section comparison



Mass dependence of initial rho cross sections



Width dependence of final rho cross sections



[WEIL16], [BAU10]

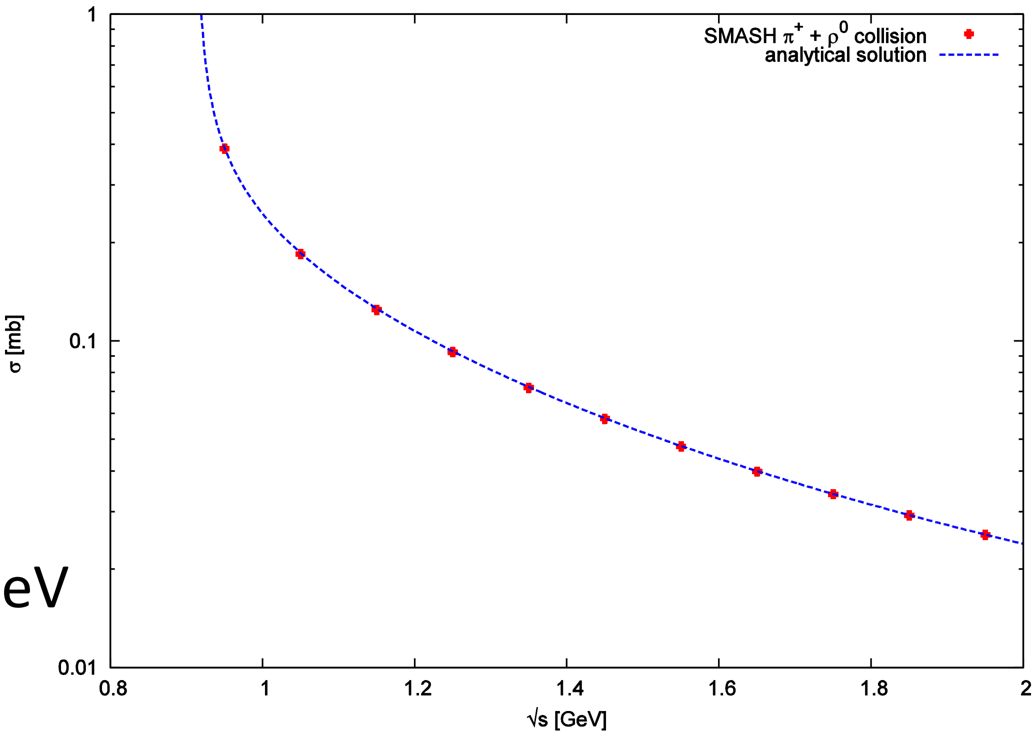
SMASH

(Simulating Many Accelerated Strongly-interacting Hadrons)

$$p^\mu \partial_\mu f_i(x,p) + m_i F^\alpha \frac{\partial}{\partial p^\alpha} f_i(x,p) = C_{coll,i}$$

<u>In the following:</u>

- box simulations with pions, rhos and etas
- thermal and chemical equilibrium
- box sizes: 10^3 to 40^3 fm^3
- temperature: 100 to 200 MeV



Perturbative photon production

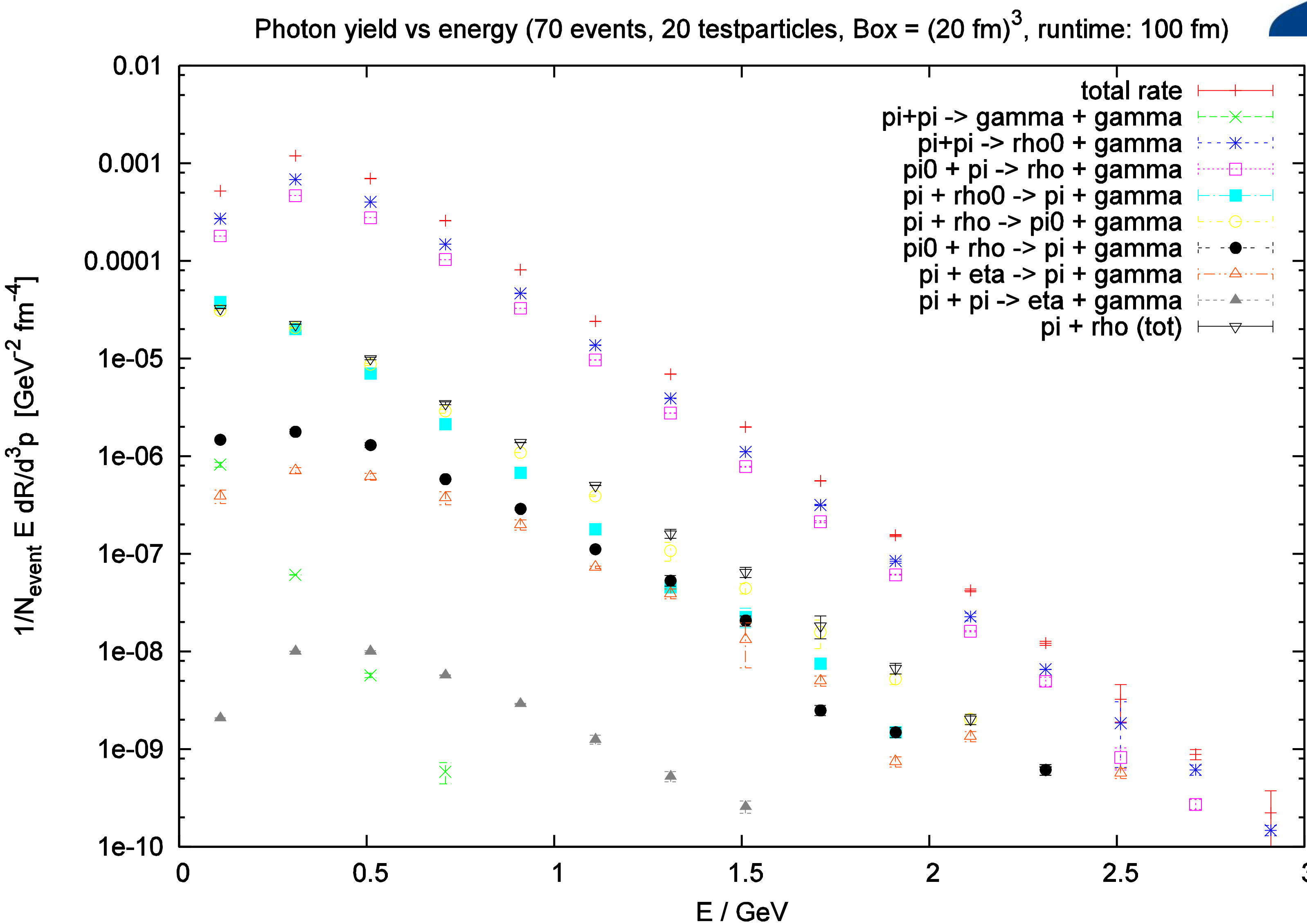
LOOP

1. check for collisions: $d_{trans} < d_{int} = \sqrt{\frac{\sigma_{tot}}{\pi}}$
2. determine $\sqrt{s}$ and p_{cm}
3. sample outgoing mass, find limits for Mandelstam t from effective masses
4. sample t according to $\frac{d\sigma}{dt}(s,t)$ and calculate θ
5. get ϕ from uniform distribution
6. <u>include weighting factor:</u>

$$R = \frac{\sigma_\gamma}{\sigma_{tot}} \longrightarrow \boxed{\Delta R(s,t) = \frac{\frac{d\sigma_\gamma}{dt}(s,t)\frac{\Delta t}{N}}{\sigma_{tot}(s)}}$$

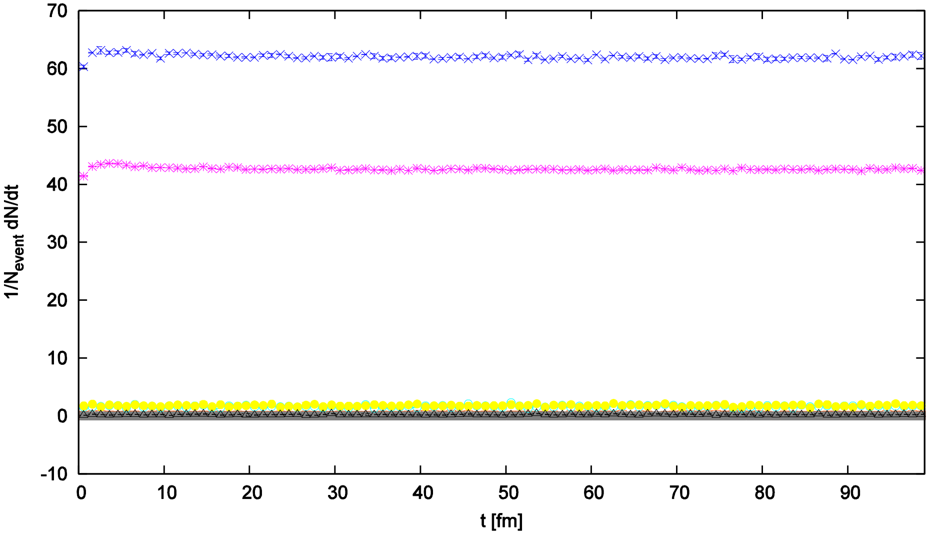
7. boost to initial frame

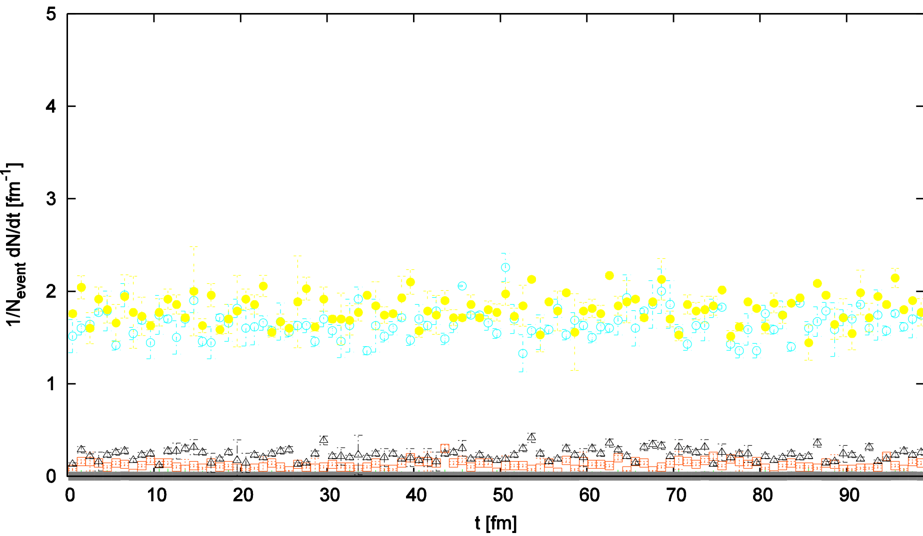
Basic tests

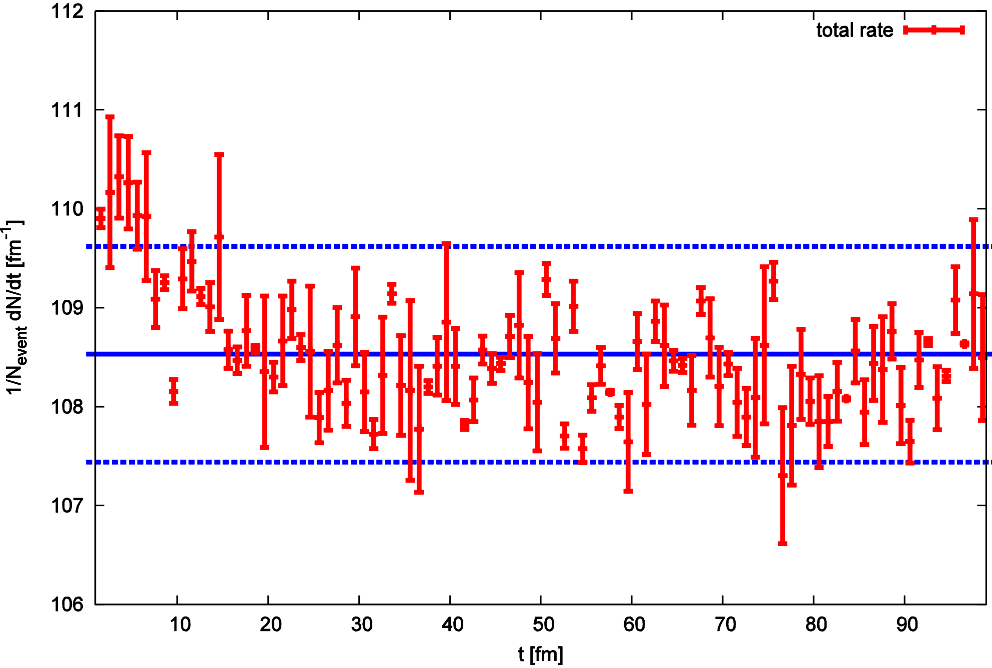


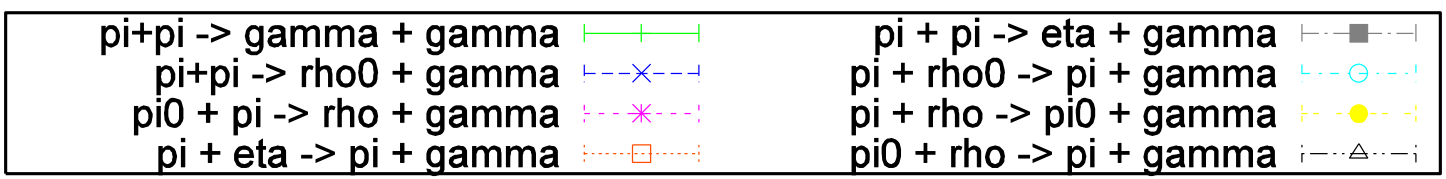
Photon yield vs energy (70 events, 20 testparticles, Box = (20 fm)^3, runtime: 100 fm)
1/N_event E dR/d^3p [GeV^-2 fm^-4]
E / GeV
0.01
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
0
0.5
1
1.5
2
2.5
3
total rate
pi+pi -> gamma + gamma
pi+pi -> rho0 + gamma
pi0 + pi -> rho + gamma
pi + rho0 -> pi + gamma
pi + rho -> pi0 + gamma
pi0 + rho -> pi + gamma
pi + eta -> pi + gamma
pi + pi -> eta + gamma
pi + rho (tot)

Time (in)dependence

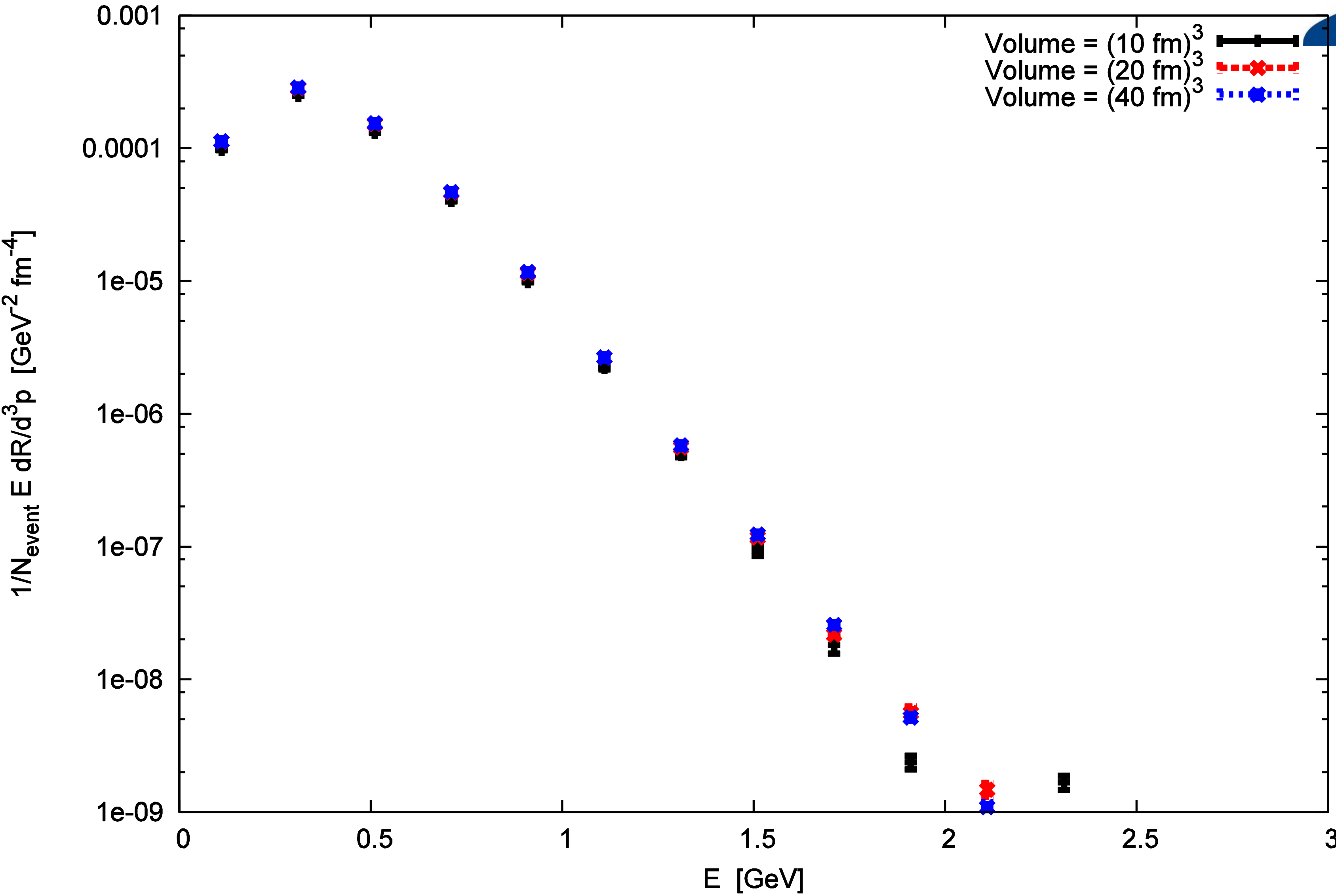




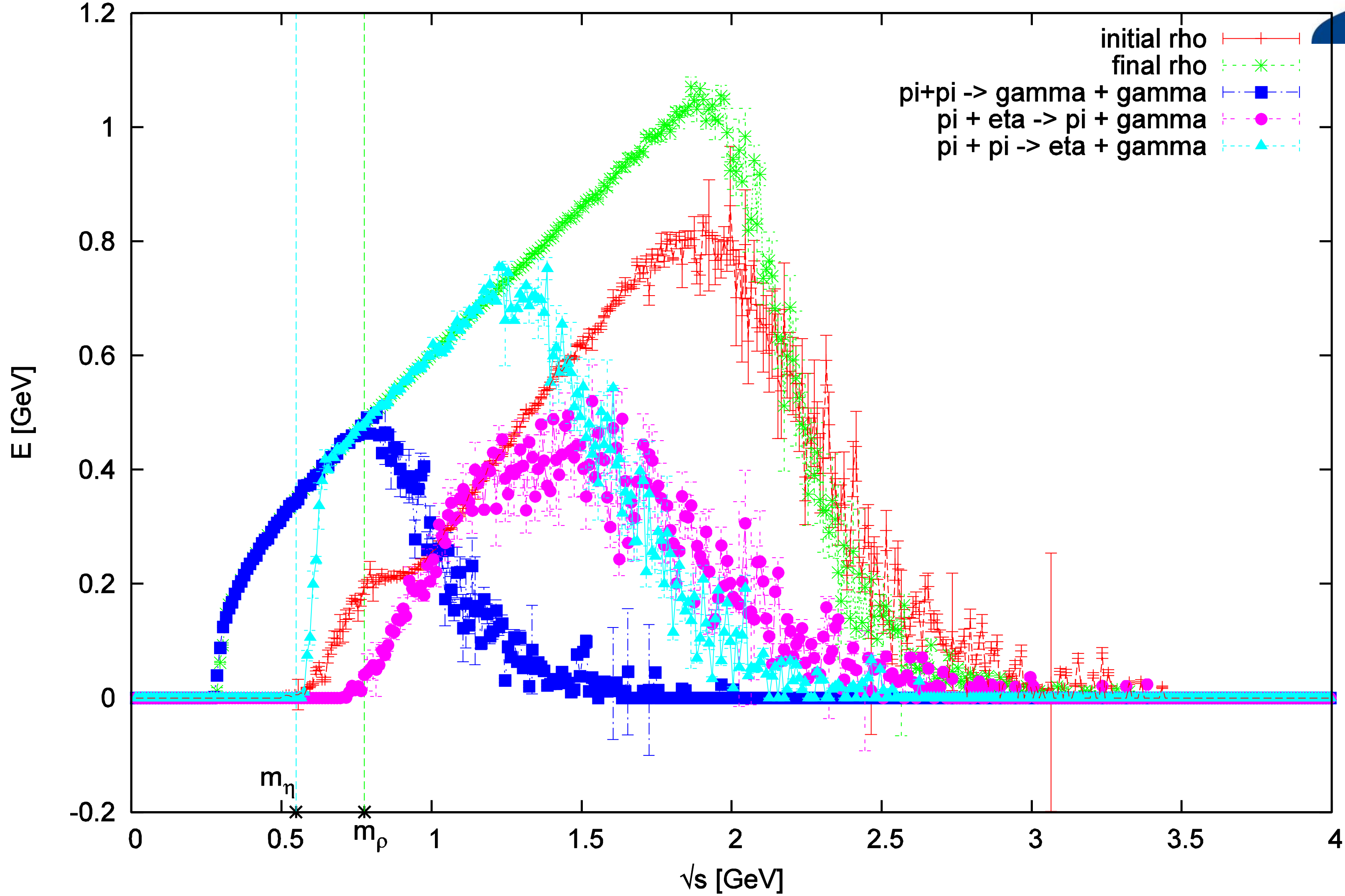




Volume (in)dependence



Average photon energy vs. $\sqrt{s}$



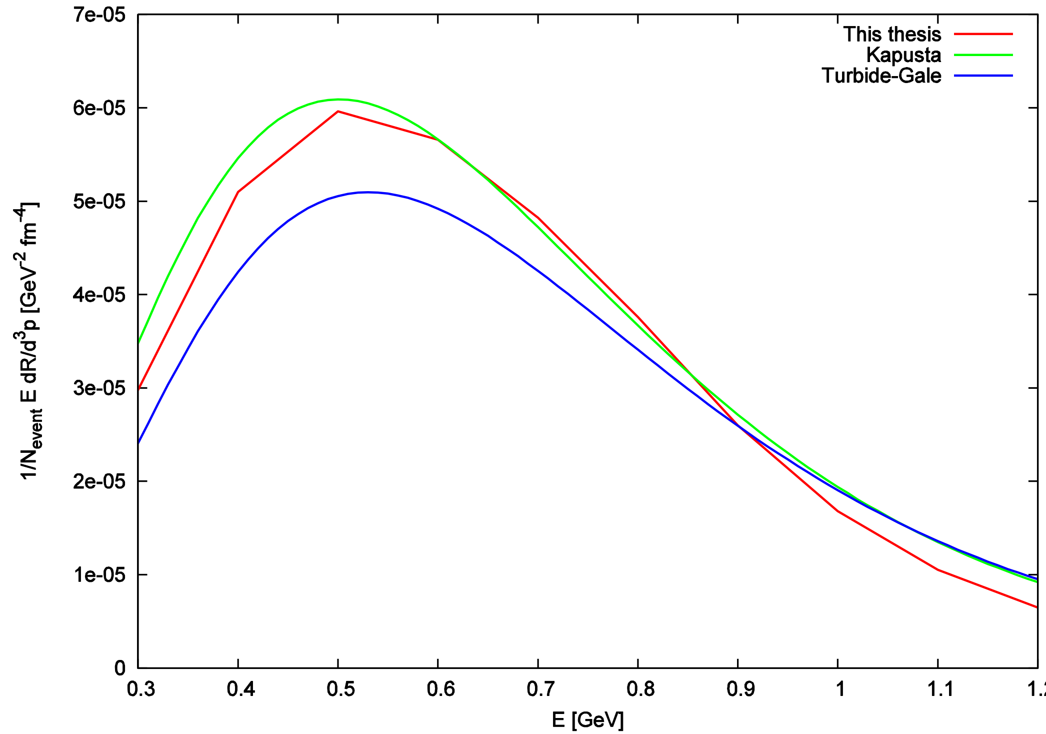
Thermal photon rates

$$R_i = N \int \frac{d^3p_1}{2E_1(3\pi)^3} \frac{d^3p_2}{2E_2(3\pi)^3} \frac{d^3p_3}{2E_3(3\pi)^3} \frac{d^3p}{2E(3\pi)^3} (2\pi)^4 \delta(p_1^\mu + p_2^\mu - p_3^\mu - p^\mu) |\mathcal{M}_i|^2 f_1(E_1) f_2(E_2) [1 \pm f_3(E_3)]$$

[KAP91], [TUR13]

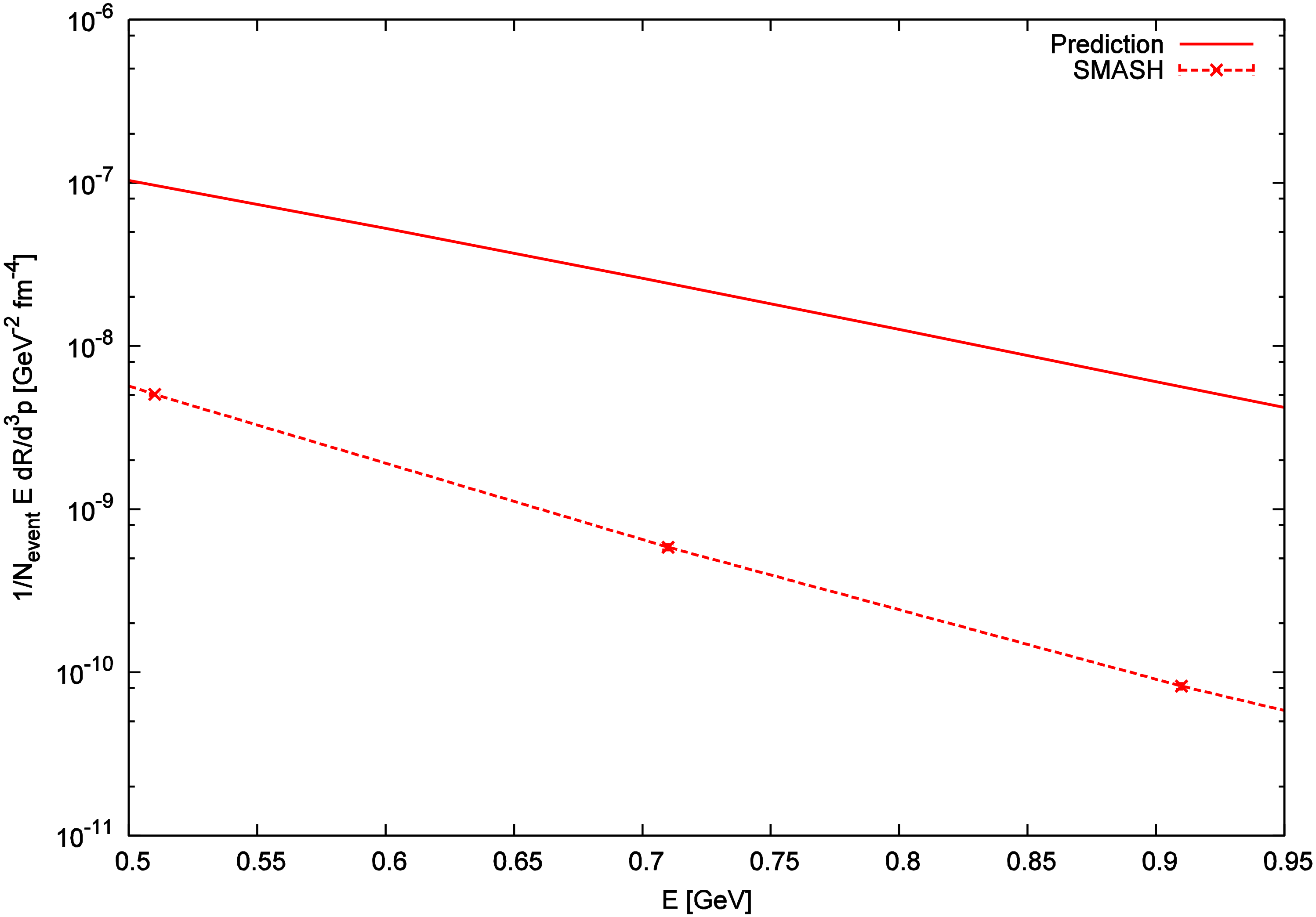
$$f_1(E_1)f_2(E_2) \to \exp\left(\frac{E_1+E_2}{T}\right)$$
$$E_1 + E_2 > E \gg T.$$

$$\frac{d\sigma}{dt} = \frac{|\mathcal{M}_i|^2}{64|p_{cm}|^2 \pi s}$$

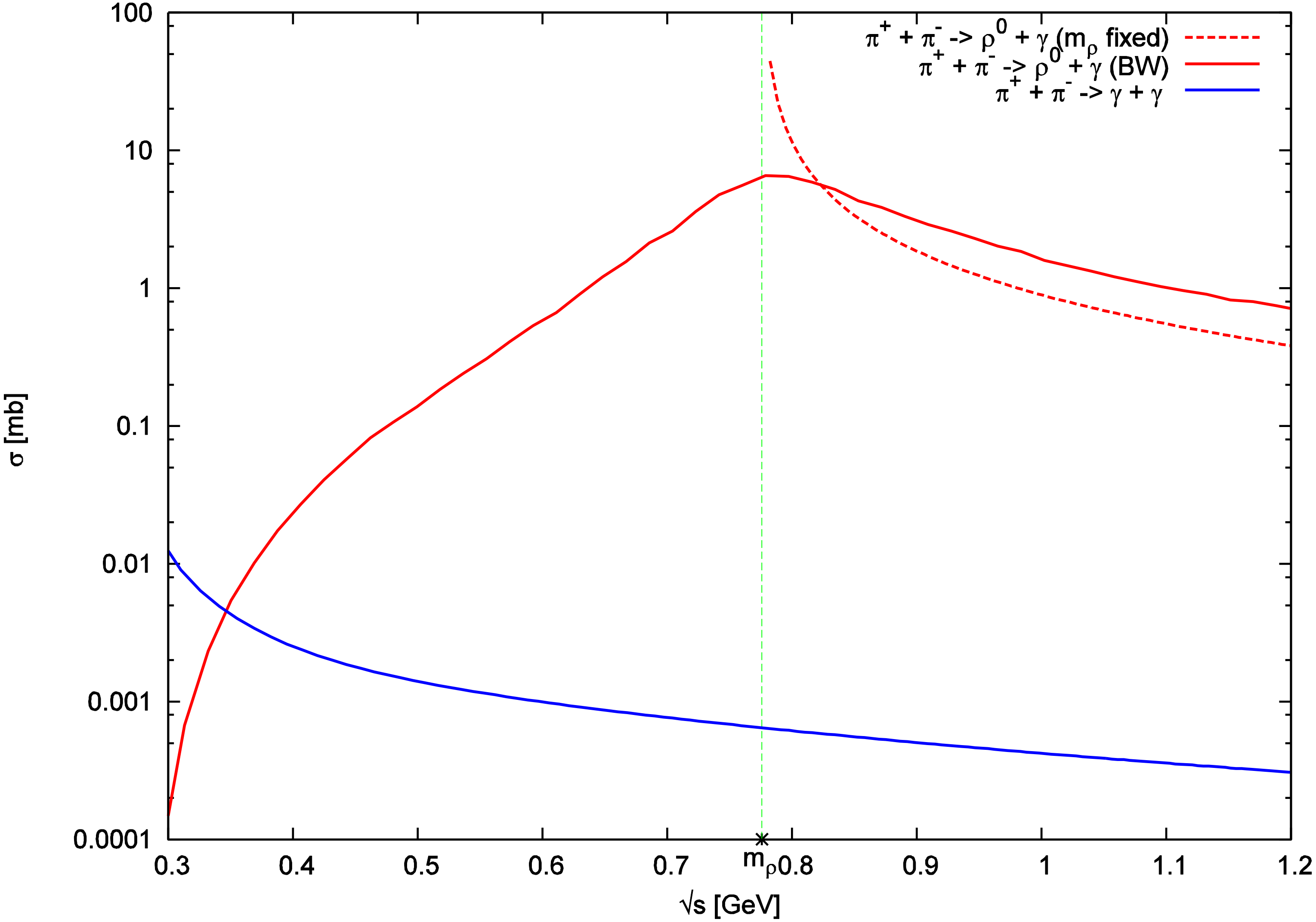


$$E\frac{dR_i}{d^3p} = \frac{N}{(2\pi)^5}\frac{T}{E}e^{-E/T}\int ds \ln\left(1 \pm e^{-\frac{s}{4ET}}\right)^{\pm 1} |p_{cm}|^2 \sigma(s)$$

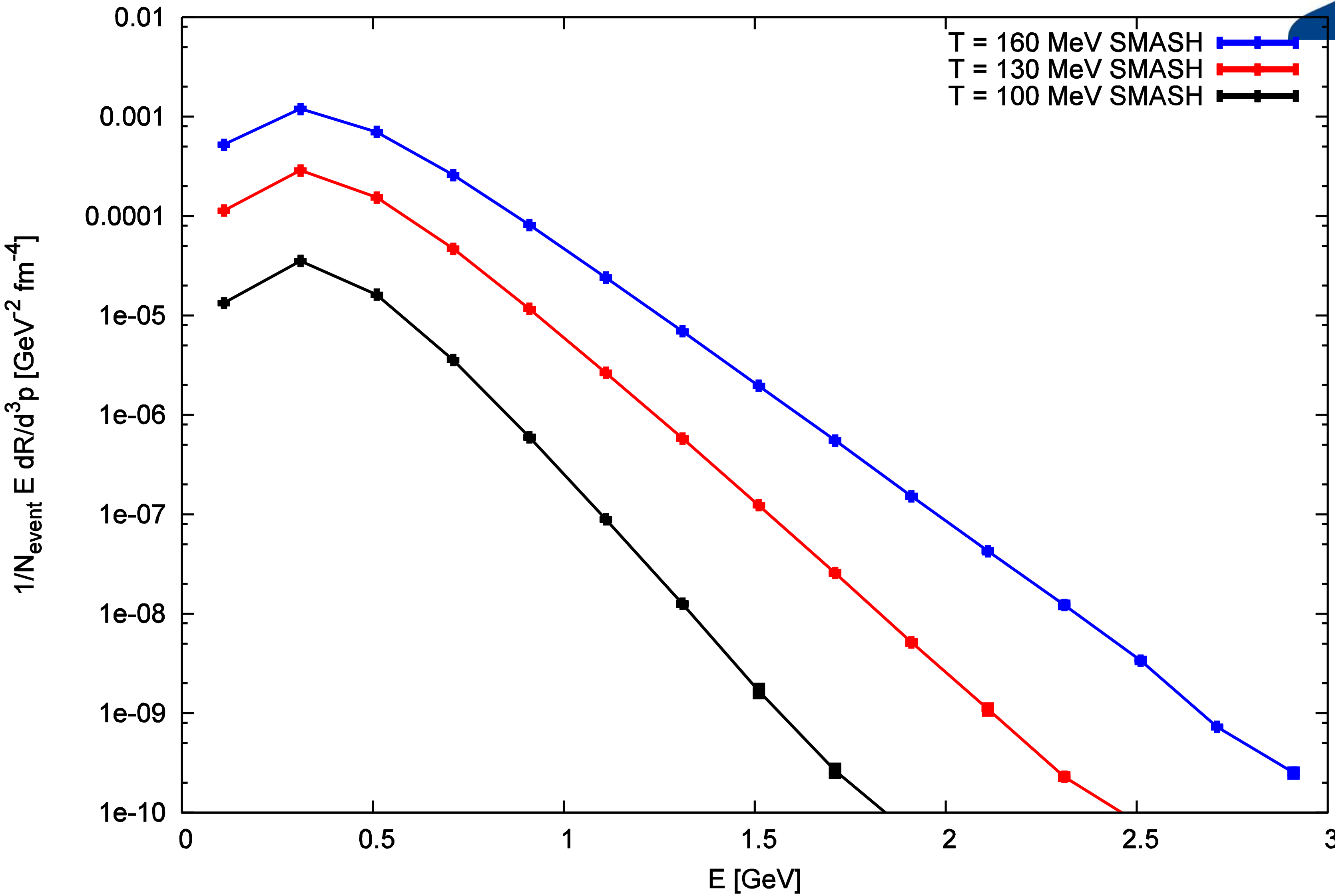
Suppression of: $\pi^{\pm} + \pi^{\mp} \rightarrow \gamma + \gamma$



Suppression of: $\pi^{\pm} + \pi^{\mp} \to \gamma + \gamma$



Temperature scaling



Conclusion

- thermal direct photon production from a simple mesonic system has been implemented successfully in SMASH

Outlook

- add several other production channels
- calculate p_T-spectra for very low p_T
- merge with hybrid-hydro model
- calculate flow and other observables
- compare to experimental data

Thank you
for your attention!

Sources

[BAU10]: Björn Bäuchle, *Direct Photons in Heavy-Ion Collisions*, PHD Thesis, Johann Wolfgang Goethe-Universität, Frankfurt am Main, Germany, September 2010

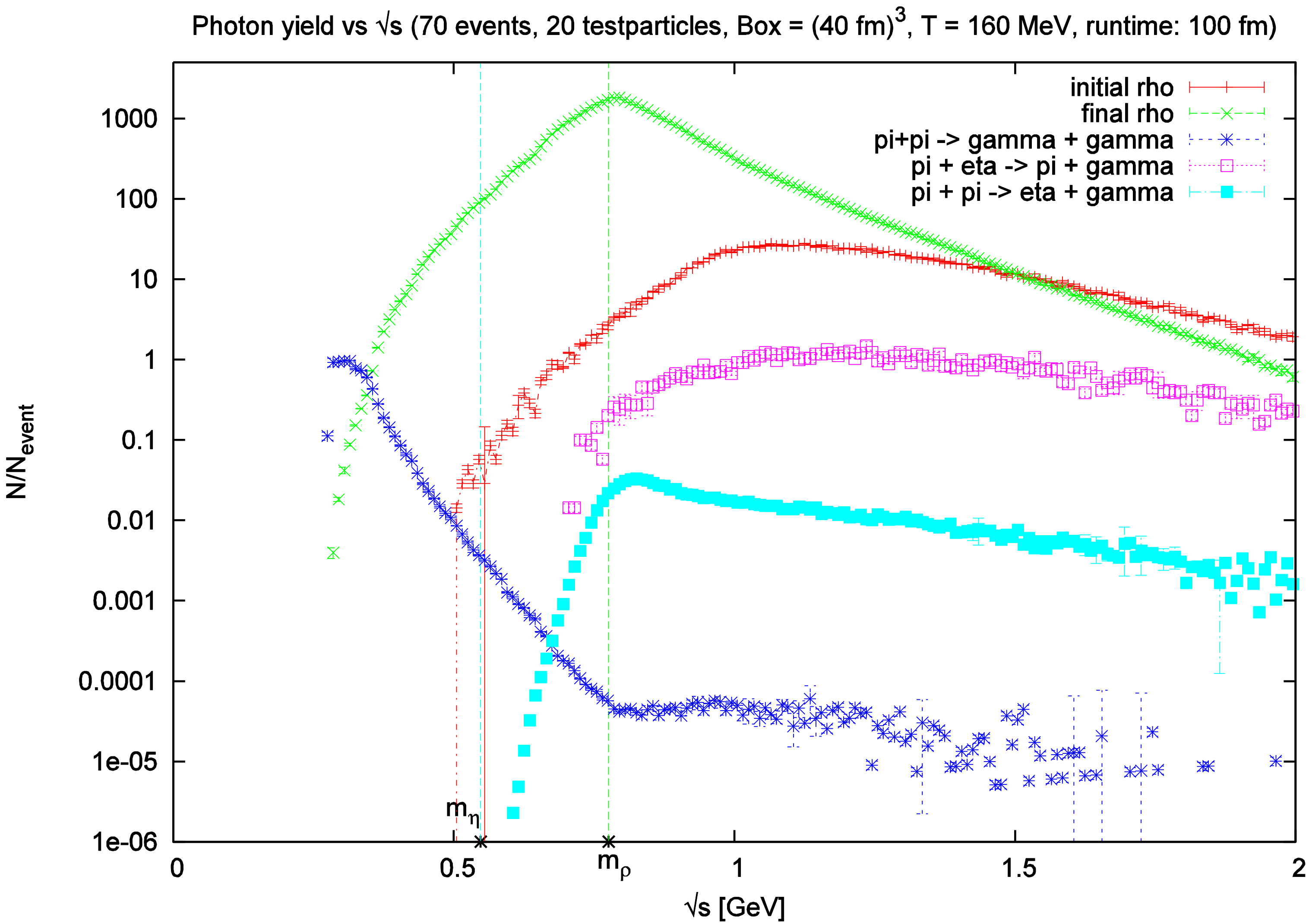
[KAP91]: J. I. Kapusta, P. Lichard and D. Seibert, *High-energy photons from quark gluon plasma versus hot hadronic gas*, Nucl. Phys. A 544, 485C (1992). doi:10.1016/0375-9474(92)90603-H

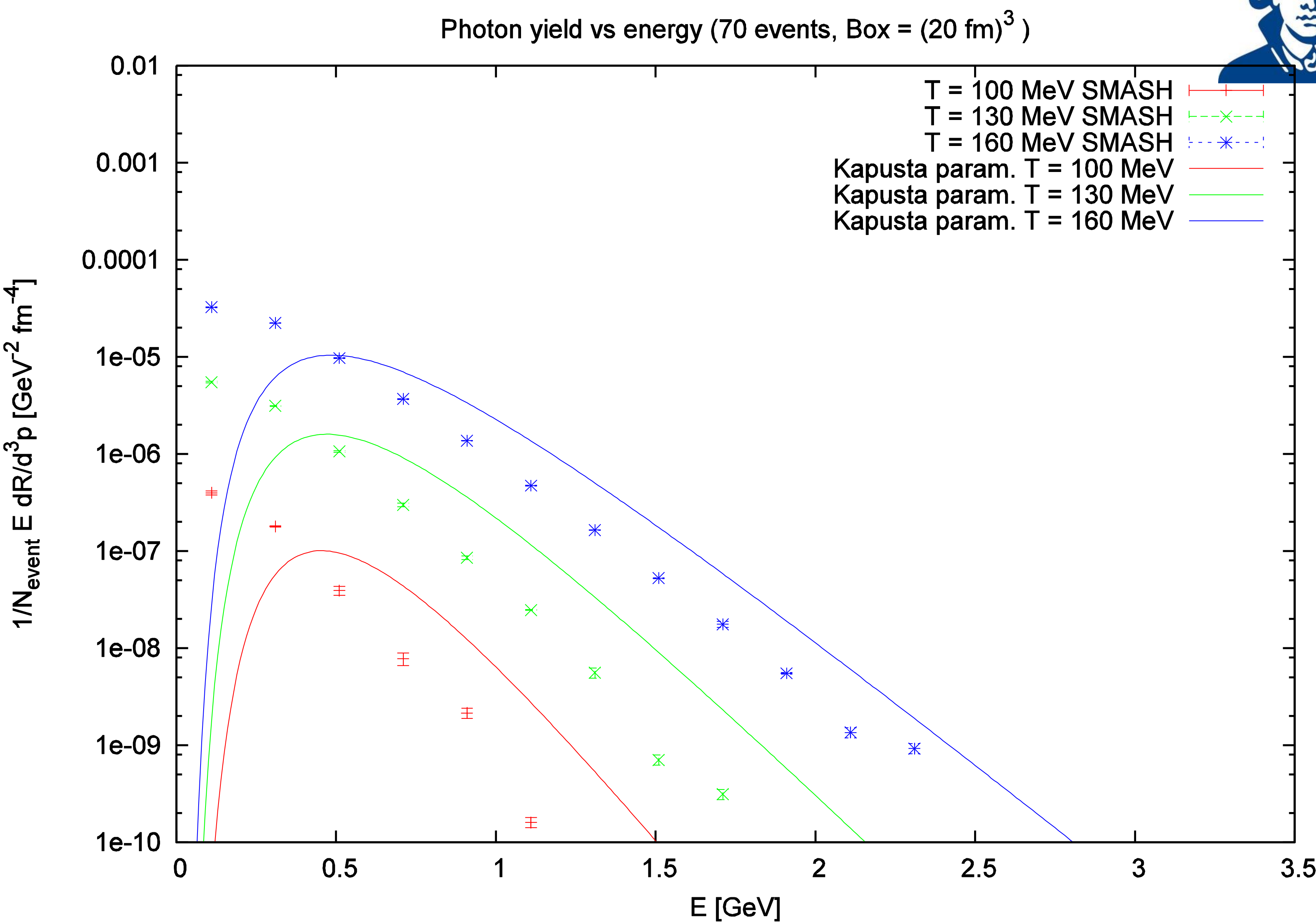
[NAD92]: H. Nadeau, J. I. Kapusta and P. Lichard, *Parametrization of thermal photon emission rates from mesonic matter*, Phys. Rev. C 45, 3034 (1992). doi:10.1103/PhysRevC.45.3034

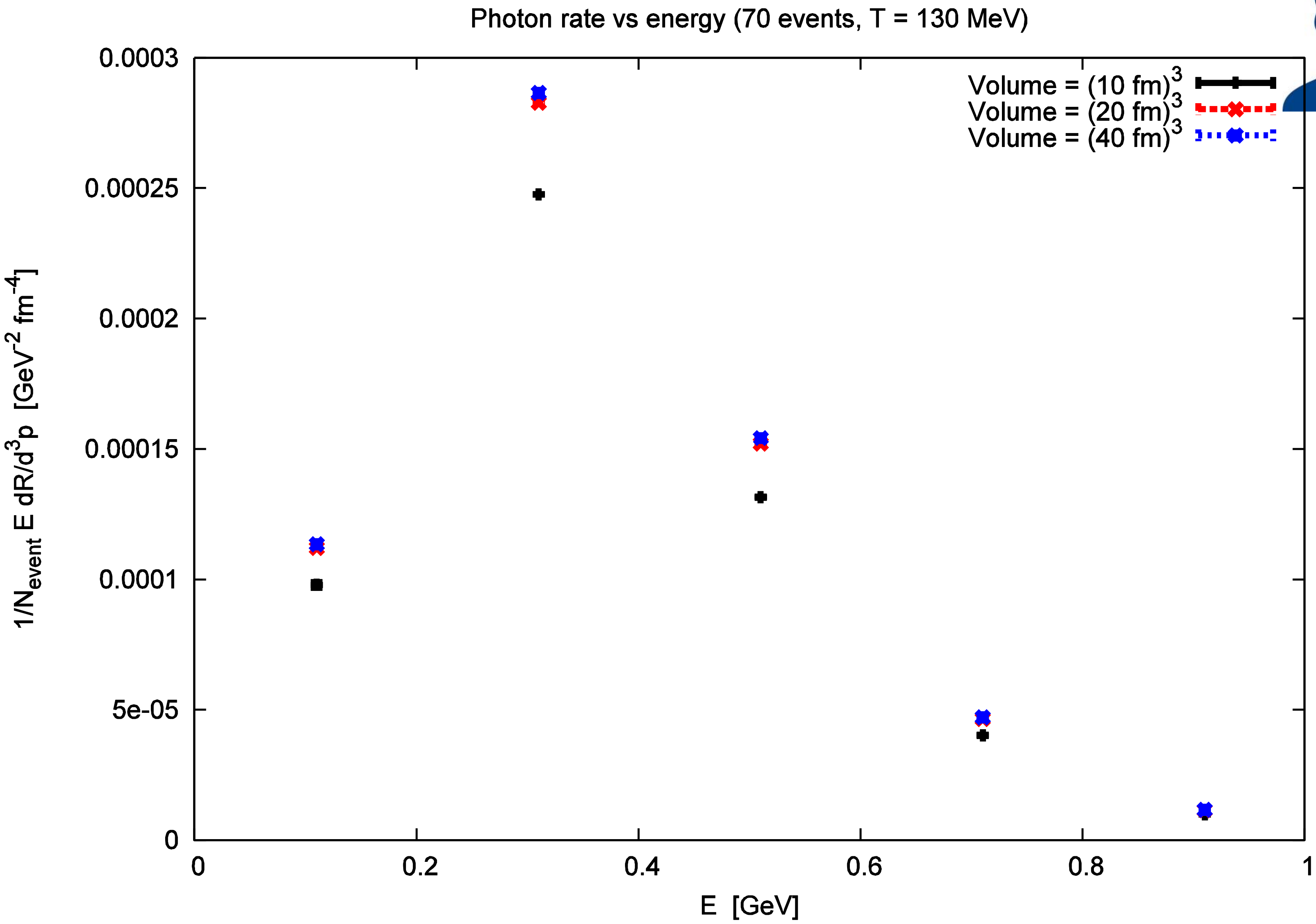
[TUR13]: S. Turbide, R. Rapp and C. Gale, *Hadronic production of thermal photons*, Phys. Rev. C 69, 014903 (2004) doi:10.1103/PhysRevC.69.014903 [hep-ph/0308085].

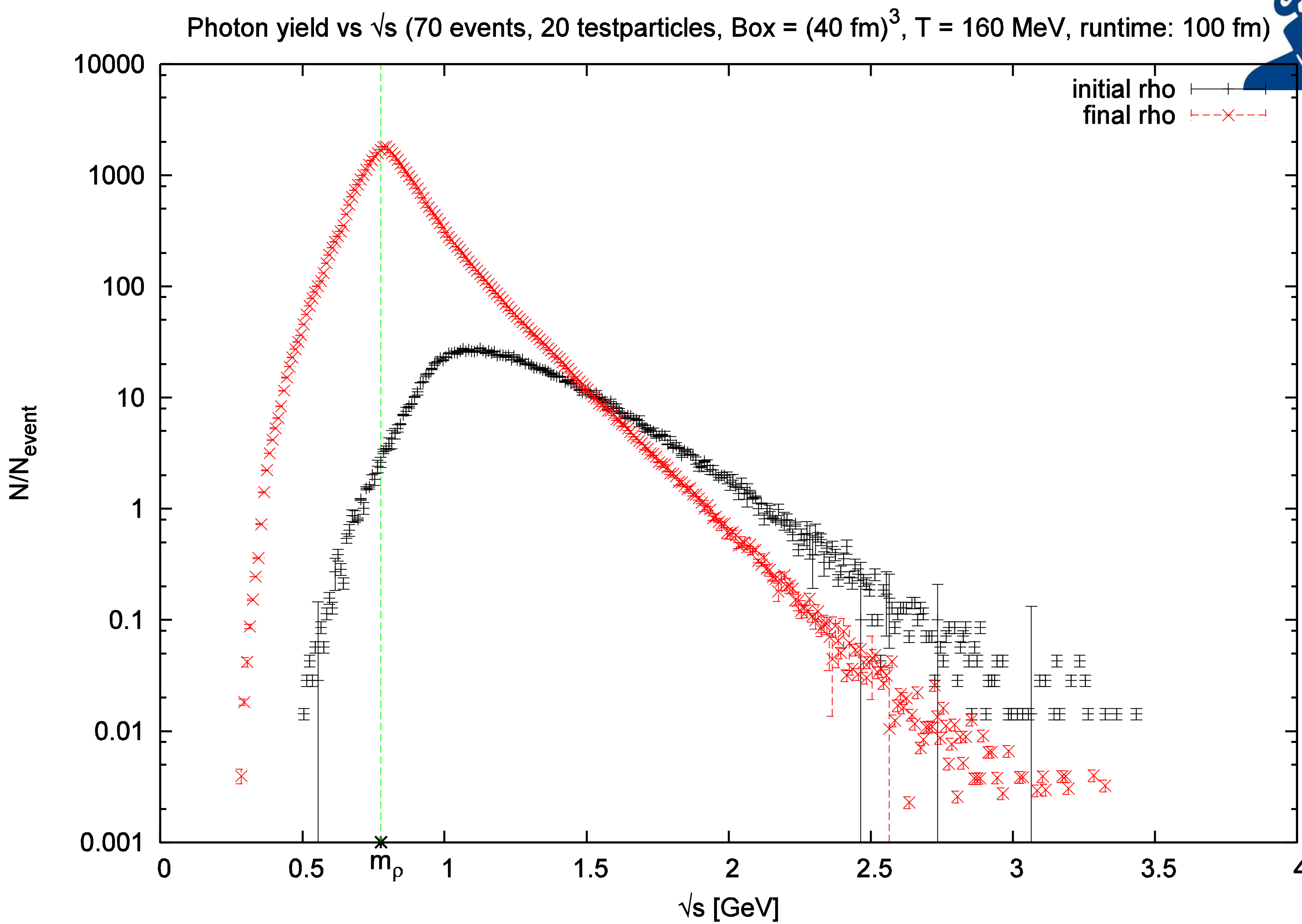
[WEIL16]: J.Weil et al., *Particle production and equilibrium properties within a new hadron transport approach for heavy-ion collisions*, arXiv:1606.06642 [nucl-th].

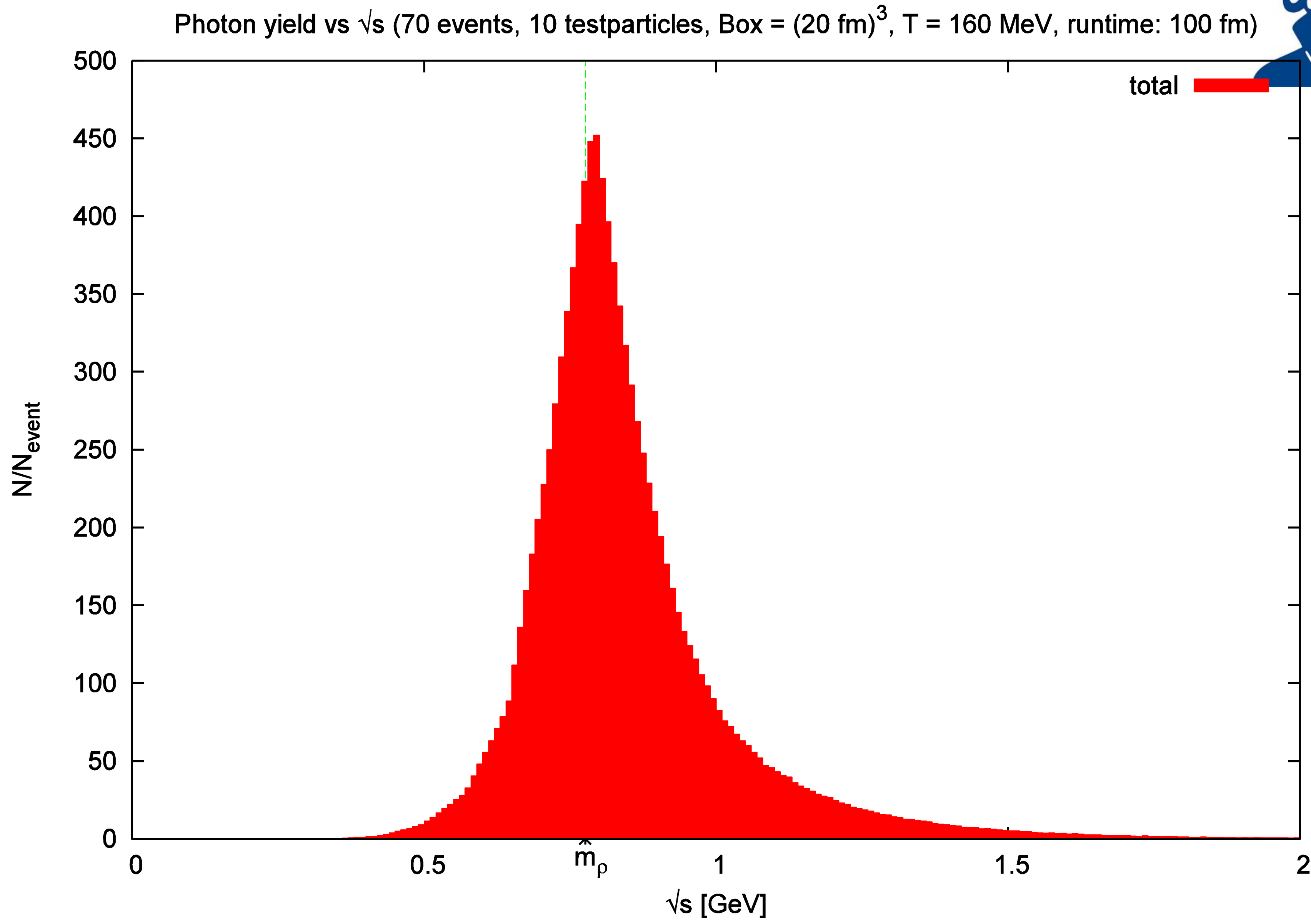
Backup slides




Photon yield vs energy (70 events, Box = (20 fm)^3)
T = 100 MeV SMASH
T = 130 MeV SMASH
T = 160 MeV SMASH
Kapusta param. T = 100 MeV
Kapusta param. T = 130 MeV
Kapusta param. T = 160 MeV
$1/N_{event}$ E dR/d^{3}p [GeV^{-2} fm^{-4}]
E [GeV]
0.01
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
1e-09
1e-10
0
0.5
1
1.5
2
2.5
3
3.5


Photon rate vs energy (70 events, T = 130 MeV)
Volume = (10 fm)^3
Volume = (20 fm)^3
Volume = (40 fm)^3
1/N_event E dR/d^3p [GeV^-2 fm^-4]
E [GeV]
0.0003
0.00025
0.0002
0.00015
0.0001
5e-05
0
0
0.2
0.4
0.6
0.8
1


Photon yield vs √s (70 events, 20 testparticles, Box = (40 fm)^3, T = 160 MeV, runtime: 100 fm)
N/N_event
√s [GeV]
initial rho
final rho
m_ρ
10000
1000
100
10
1
0.1
0.01
0.001
0
0.5
1
1.5
2
2.5
3
3.5
4


Photon yield vs √s (70 events, 10 testparticles, Box = (20 fm)^3, T = 160 MeV, runtime: 100 fm)
total
N/N_event
√s [GeV]
m_ρ
0
0.5
1
1.5
2
0
50
100
150
200
250
300
350
400
450
500