Dilepton Production in p+p with the GiBUU Model

Janus Weil, Ulrich Mosel

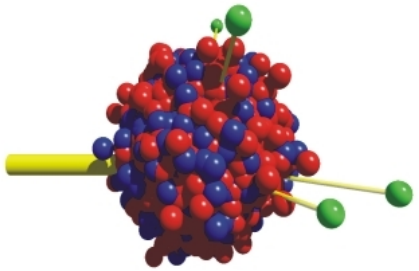
(in collab. with K. Gallmeister & H. van Hees)

Institut für Theoretische Physik, JLU Giessen

AdHoc Workshop on NN collisions with HADES
GSI, August 2011

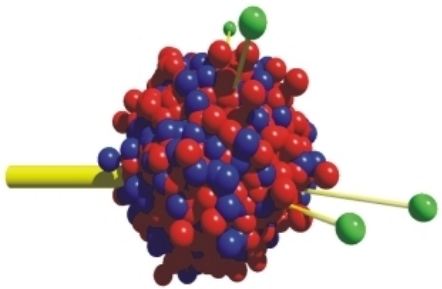
Outline

1. GiBUU - the transport approach
2. resonance model (Teis and beyond)
3. dileptons from NN collisions:
   p + p @ 1.25 GeV
   p + p @ 3.5 GeV
   p + p @ 2.2 GeV
4. outlook, conclusions



The GiBUU Transport Model

- BUU-type hadronic transport model
- unified framework for various types of reactions (pA, πA, γA, eA, νA, AA) and observables
- modular and well-documented Fortran code (F95/03)
- collaborative effort, version control via Subversion
- publicly available releases (open source)
- http://gibuu.physik.uni-giessen.de
- review paper: arXiv:1106.1344 [hep-ph]



GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

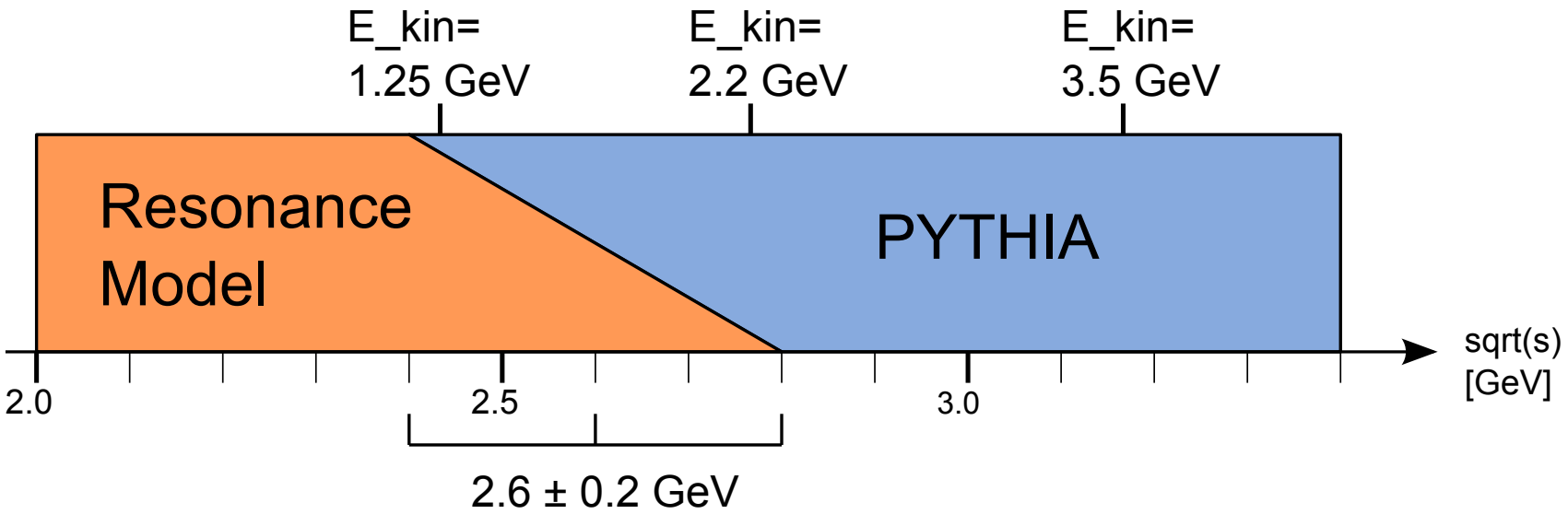
The BUU Equation

- BUU equation describes space-time evolution of phase space density $f_i(\vec{r}, t, \vec{p})$ for each particle species i ($i = N, \Delta, \pi, \rho, ...$):

$$\left(\partial_t + (\nabla_{\vec{p}} H_i)\nabla_{\vec{r}} - (\nabla_{\vec{r}} H_i)\nabla_{\vec{p}}\right) f_i(\vec{r}, t, \vec{p}) = I_{coll}[f_i, f_j, ...]$$

- Hamiltonian H_i:
  - hadronic mean fields, Coulomb, "off-shell potential"
- collision term I_{coll}:
  - decays and scattering processes (2- and 3-body)
  - depends on all $f_i \Rightarrow$ coupled-channel problem
  - low energy: resonance model
  - high energy: PYTHIA
- model includes 61 baryons and 21 mesons
- solve numerically via test-particle method:
  $f = \sum_i \delta(\vec{r} - \vec{r}_i)\delta(p - p_i)$

GiBUU: Collision Term



Resonance Model:

- Teis et al.
- all processes go via Res. prod.
- $NN \to NR, \Delta\Delta$
- $R \to \pi N / 2\pi N / \eta N / \rho N$

PYTHIA:

- Lund String Model
- high energy event generator
- few GeV up to TeV region
- only non-strange res.: Δ
- no N^* or Δ^*

The Teis resonance model

Teis et al., Z. Phys. A 356 (1997)

- all processes assumed to go via Res. prod.
  (some non-res. BG in excl. π prod.)
- $NN \to NR, \Delta\Delta$
- limited set of resonances: 6 N^*s and 7 Δ^*s
- phase-space resonance production (constant matrix elements)

$$\sigma_{NN\to NR} = \frac{1}{64\pi^2 p_i s} \int \mathrm{d}\Omega p_f |\mathcal{M}|^2$$

- OBE models for $N\Delta$ and $\Delta\Delta$ (Dmitriev)
- $R \to \pi N/\eta N/\rho N$ (branching ratios from PDG)
- exclusive π, η, ρ production fitted to data
- 2π production via two-step processes (also fitted to data)

Manley/Saleski, Phys. Rev. D 45 (1992)

	rating	M_B [MeV]	Γ_0 [MeV]	branching ratio in % $N\pi$	$N\eta$	$\Delta\pi$	$N\rho$	$N\sigma$	$N^*\pi$	$\Delta\rho$
$P_{11}(1440)$	****	1462	391	69	—	22	—	9	—	—
$S_{11}(1535)$	***	1534	151	51	43	—	3	1	2	—
$S_{11}(1650)$	****	1659	173	89	3	2	3	2	1	—
$D_{13}(1520)$	****	1524	124	59	—	20	21	—	—	—
$D_{15}(1675)$	****	1676	159	47	—	53	—	—	—	—
$P_{13}(1720)$	*	1717	383	13	—	—	87	—	—	—
$F_{15}(1680)$	****	1684	139	70	—	11	7	12	—	—
$P_{33}(1232)$	****	1232	118	100	—	—	—	—	—	—
$S_{31}(1620)$	**	1672	154	9	—	62	29	—	—	—
$D_{33}(1700)$	*	1762	599	14	—	78	8	—	—	—
$P_{31}(1910)$	****	1882	239	23	—	—	10	—	67	—
$P_{33}(1600)$	***	1706	430	12	—	68	—	—	20	—
$F_{35}(1905)$	***	1881	327	12	—	1	87	—	—	—
$F_{37}(1950)$	****	1945	300	38	—	18	—	—	—	44

$$\Gamma_{R\to ab}(m) = \Gamma^0_{R\to ab}\frac{\rho_{ab}(m)}{\rho_{ab}(M^0)}$$

$$\rho_{ab}(m) = \int \mathrm{d}p_a^2 \mathrm{d}p_b^2 \mathcal{A}_a(p_a^2)\mathcal{A}_b(p_b^2)\frac{p_{ab}}{m}B^2_{L_{ab}}(p_{ab}R)\mathcal{F}^2_{ab}(m)$$

GiBUU: dilepton decays

- $V \to e^+e^-$ (with $V = \rho, \omega, \phi$) via strict VMD: $\Gamma(\mu) \propto \mu^{-3}$
- $P \to \gamma e^+e^-$ (with $P = \pi^0, \eta, \eta'$) from Landsberg (1985):

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\mu} = \frac{4\alpha}{3\pi} \frac{\Gamma_{P\to\gamma\gamma}}{\mu} \left(1 - \frac{\mu^2}{m_P^2}\right)^3 |F_P(\mu)|^2,$$

- $\omega \to \pi^0 e^+e^-$ (Bratkovskaya et al., 1997):

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\mu} = \frac{2\alpha}{3\pi} \frac{\Gamma_{\omega\to\pi^0\gamma}}{\mu} \left[\left(1 + \frac{\mu^2}{\mu_\omega^2 - m_\pi^2}\right)^2 - \frac{4\mu_\omega^2\mu^2}{(\mu_\omega^2 - m_\pi^2)^2}\right]^{3/2} |F_\omega(\mu)|^2$$

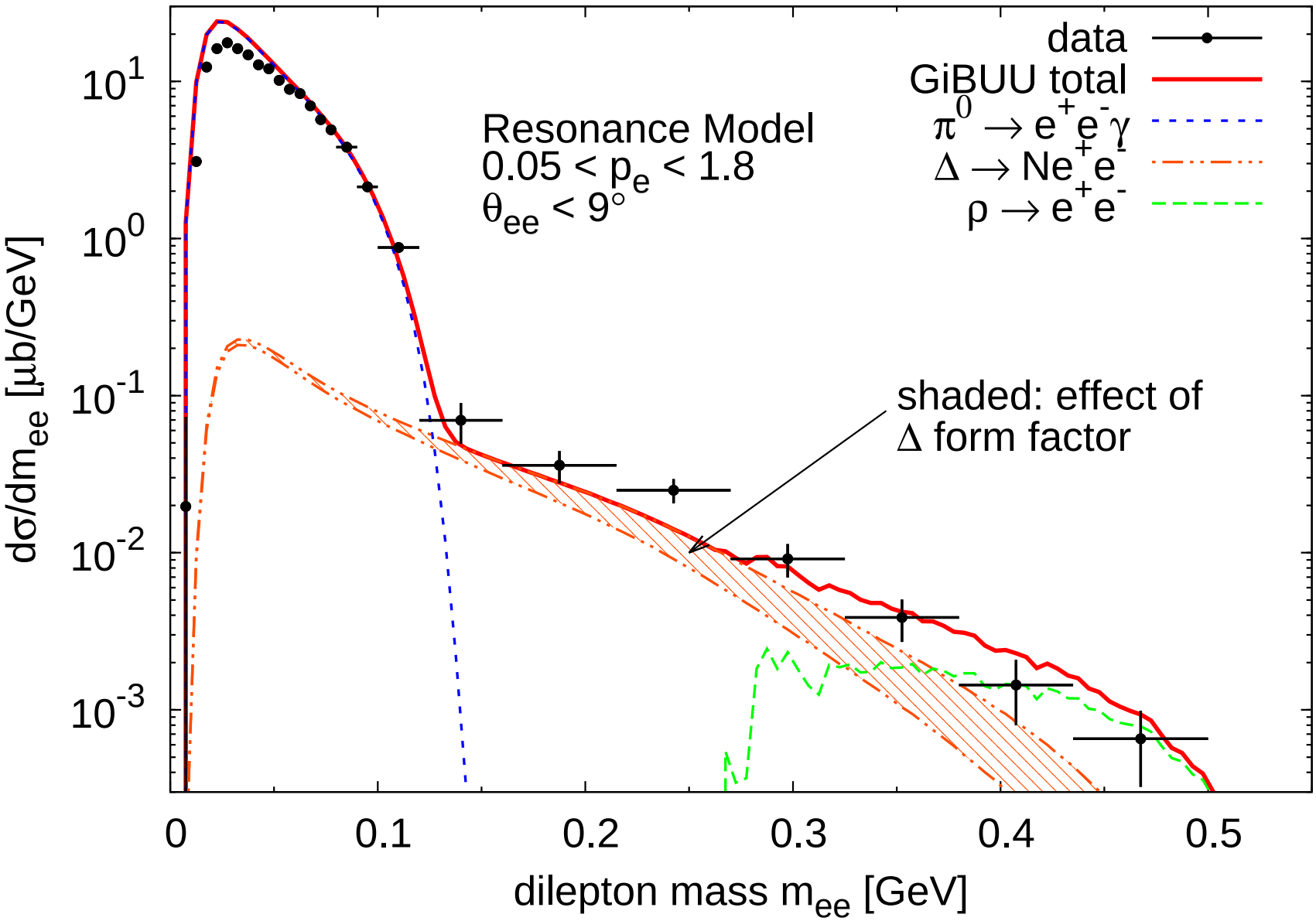
- $\Delta \to N e^+e^-$ (Krivoruchenko et al., 2002):

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\mu} = \frac{2\alpha}{3\pi\mu} \frac{\alpha}{16} \frac{(m_\Delta + m_N)^2}{m_\Delta^3 m_N^2} \sqrt{(m_\Delta + m_N)^2 - \mu^2} \left[(m_\Delta - m_N)^2 - \mu^2\right]^{3/2} |F_\Delta(\mu)|^2$$

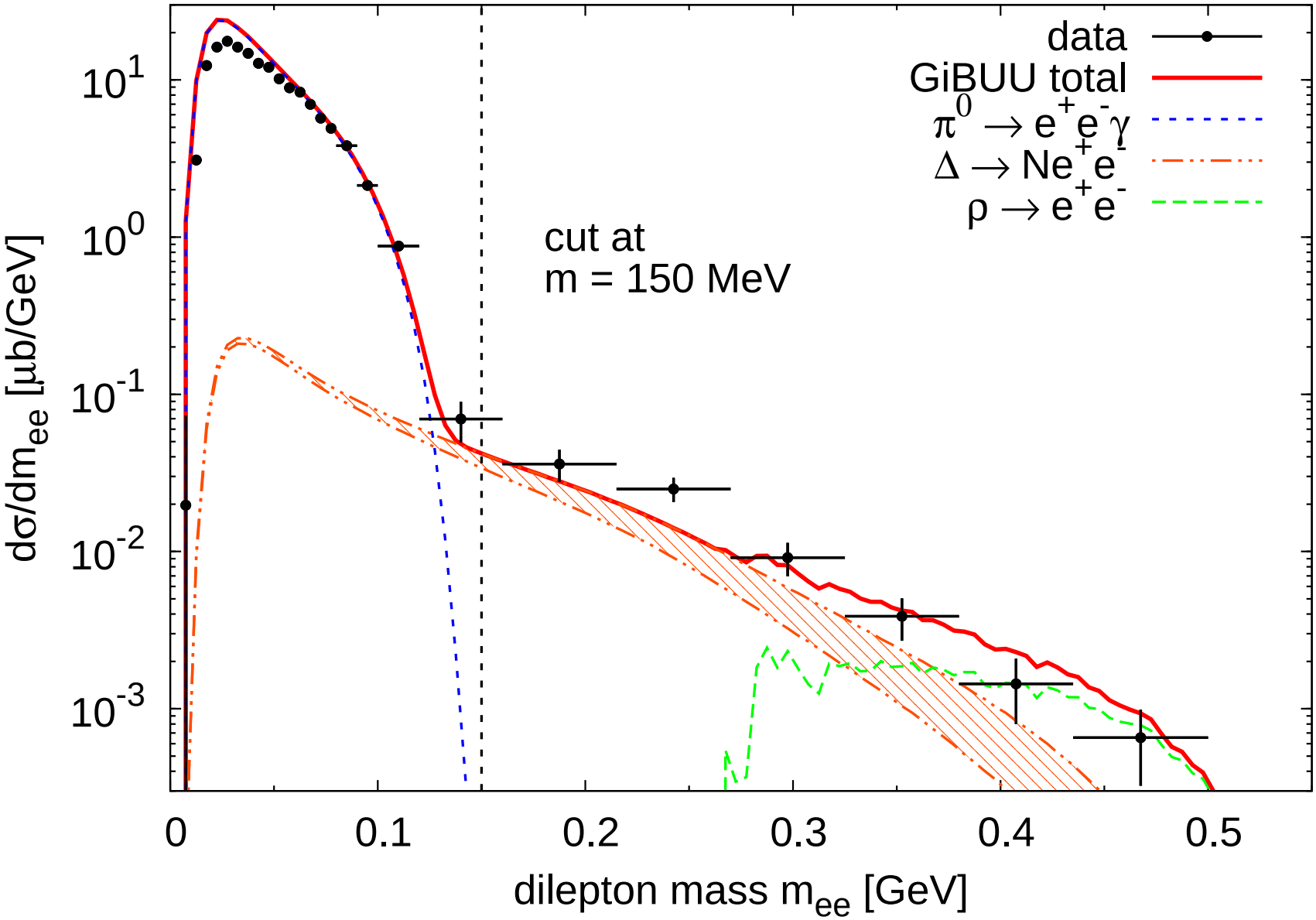
- but no $N^* \to N e^+e^-$ or $\Delta^* \to N e^+e^-$! (to avoid double counting)

p + p @ 1.25 GeV

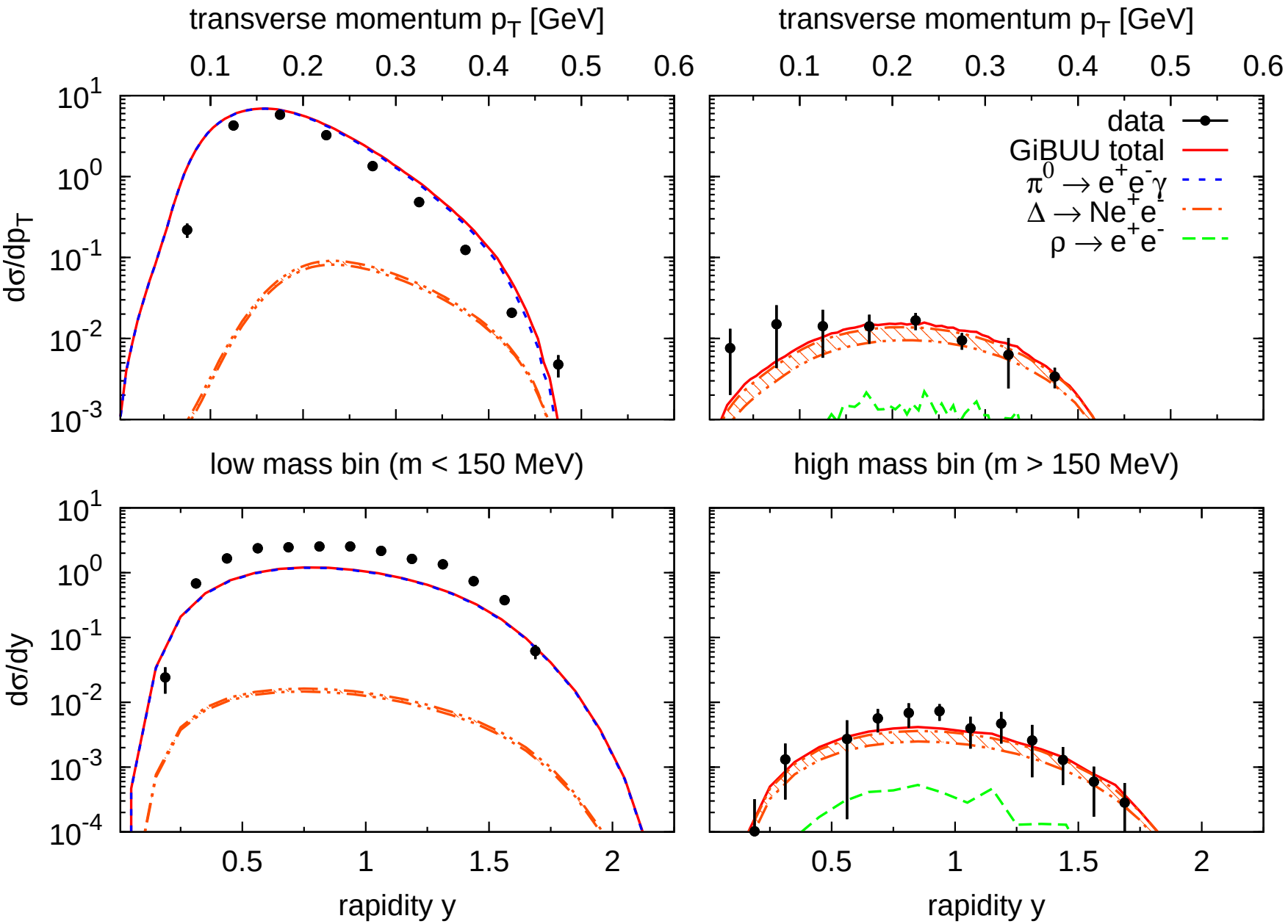
p+p @ 1.25 GeV, mass spectrum



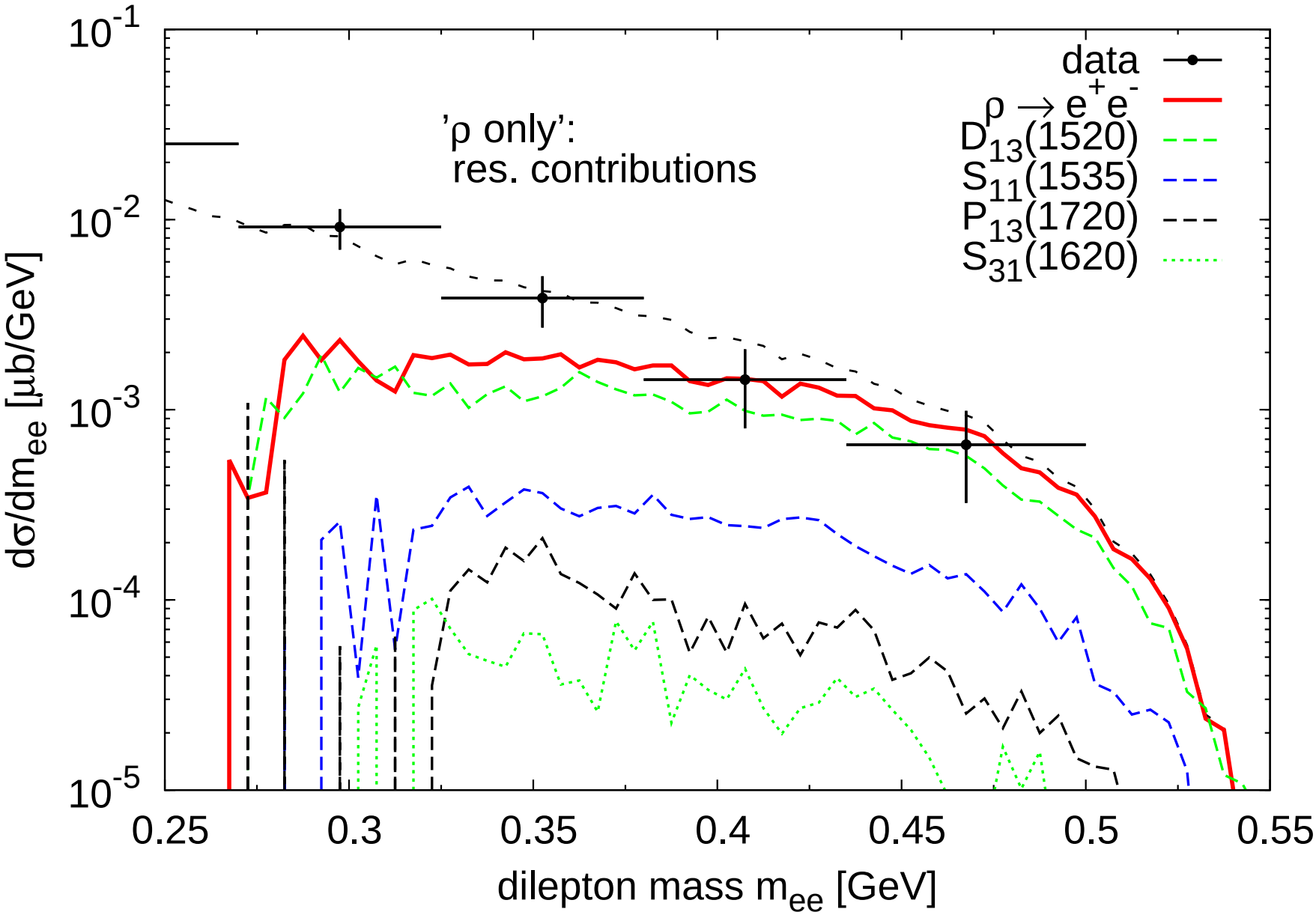
p+p @ 1.25 GeV, mass spectrum



p+p @ 1.25 GeV, p_T and rap. spectra

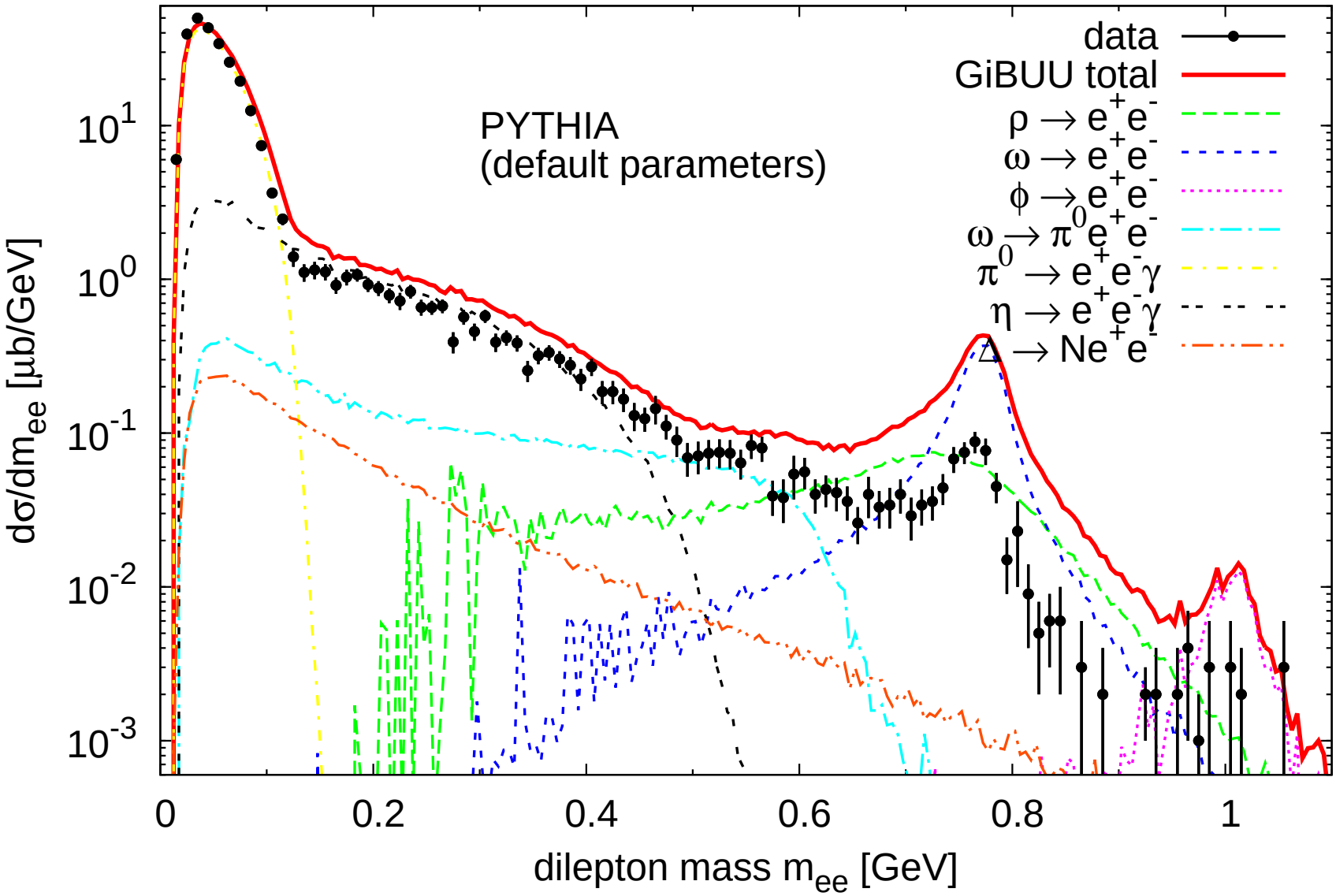


p+p @ 1.25 GeV, mass spectrum

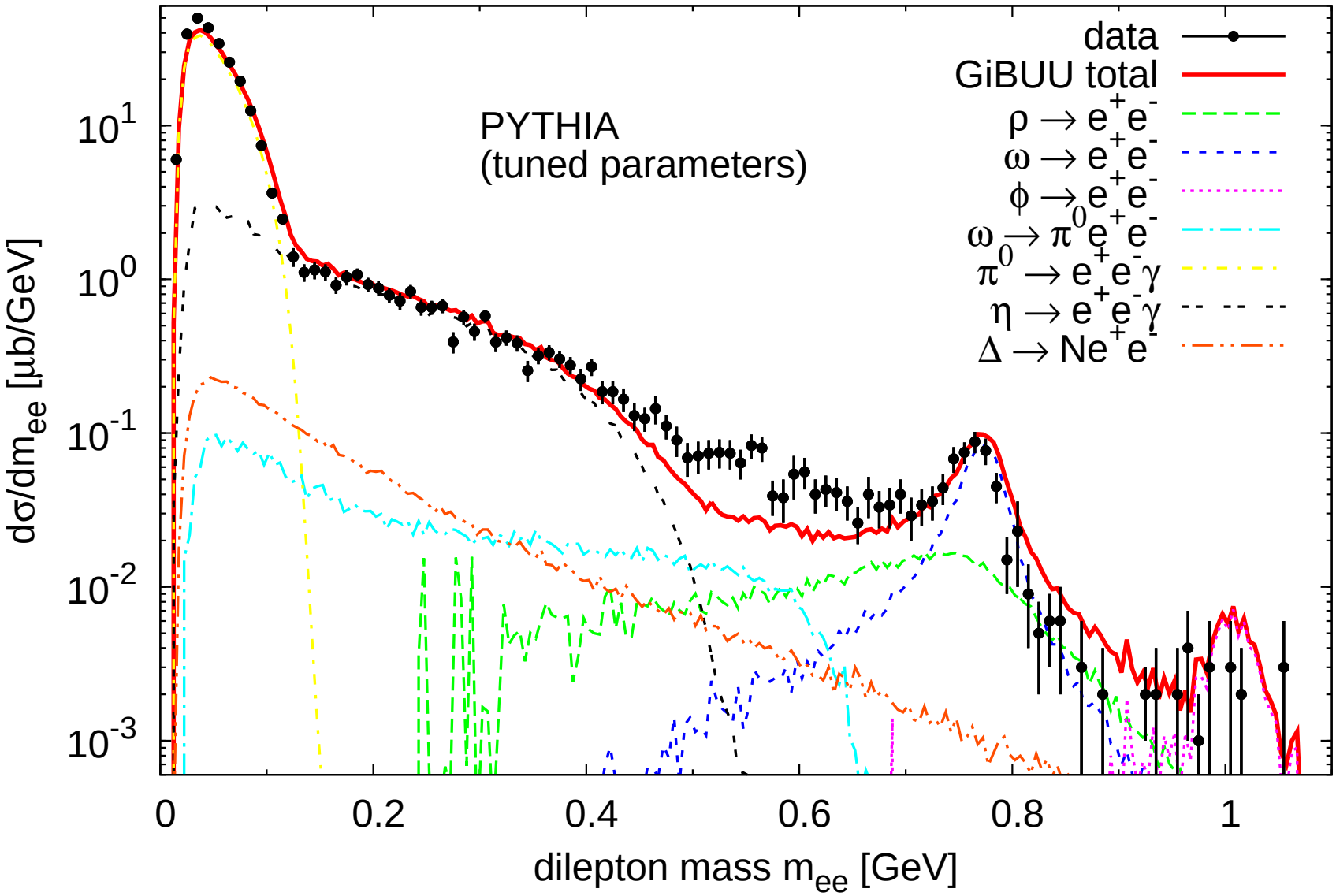


p + p @ 3.5 GeV

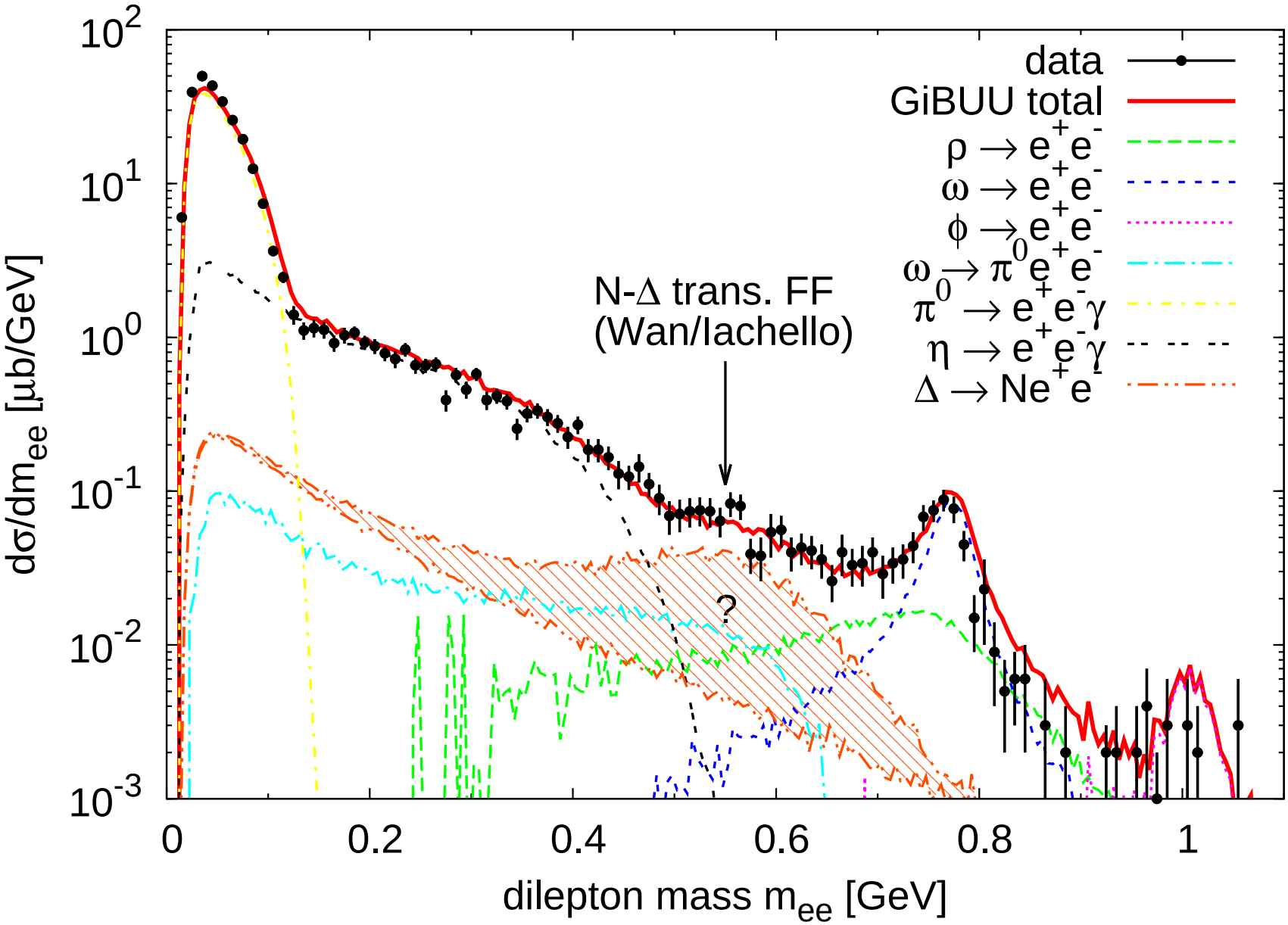
p+p @ 3.5 GeV via Pythia



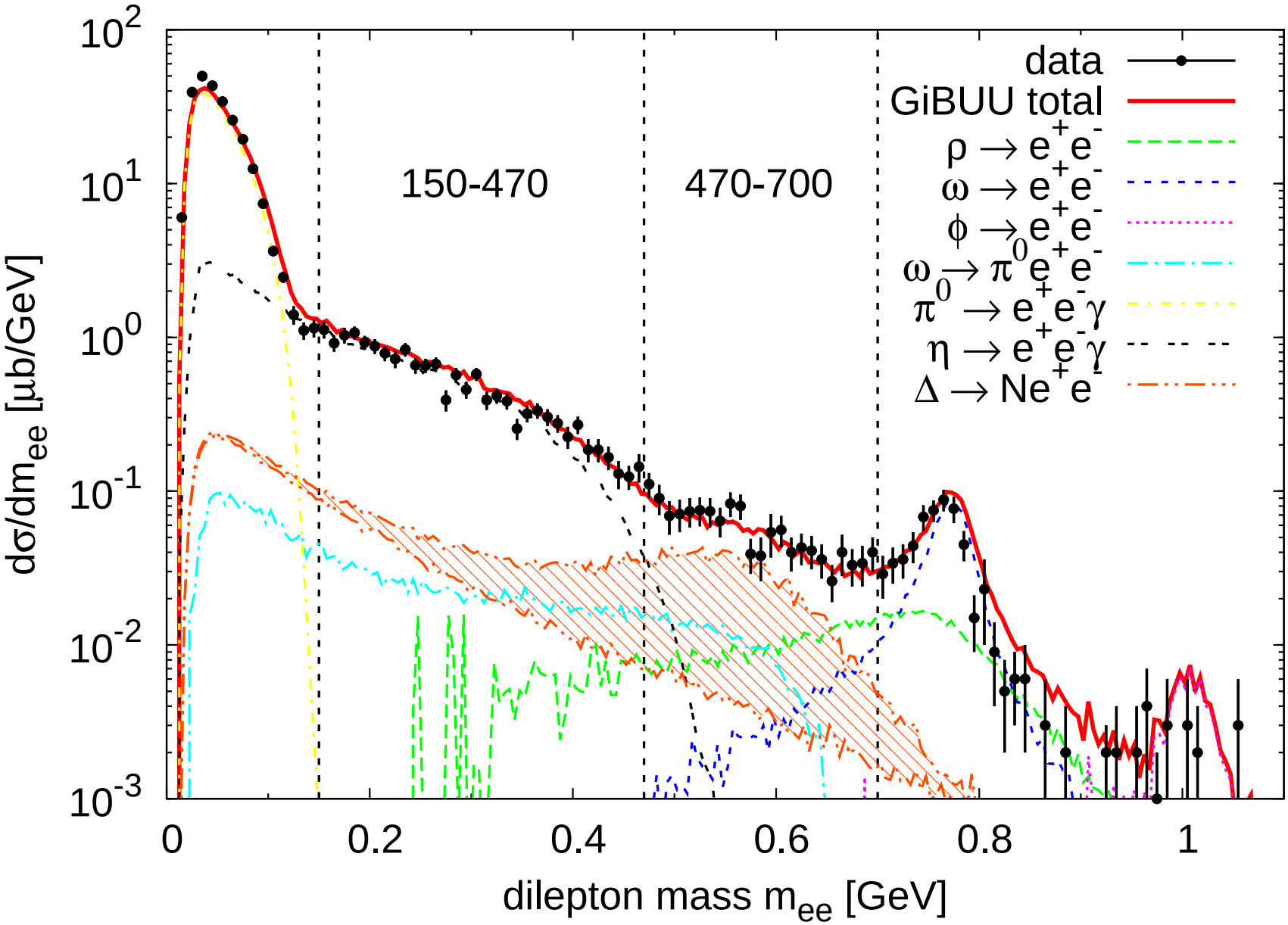
p+p @ 3.5 GeV via Pythia



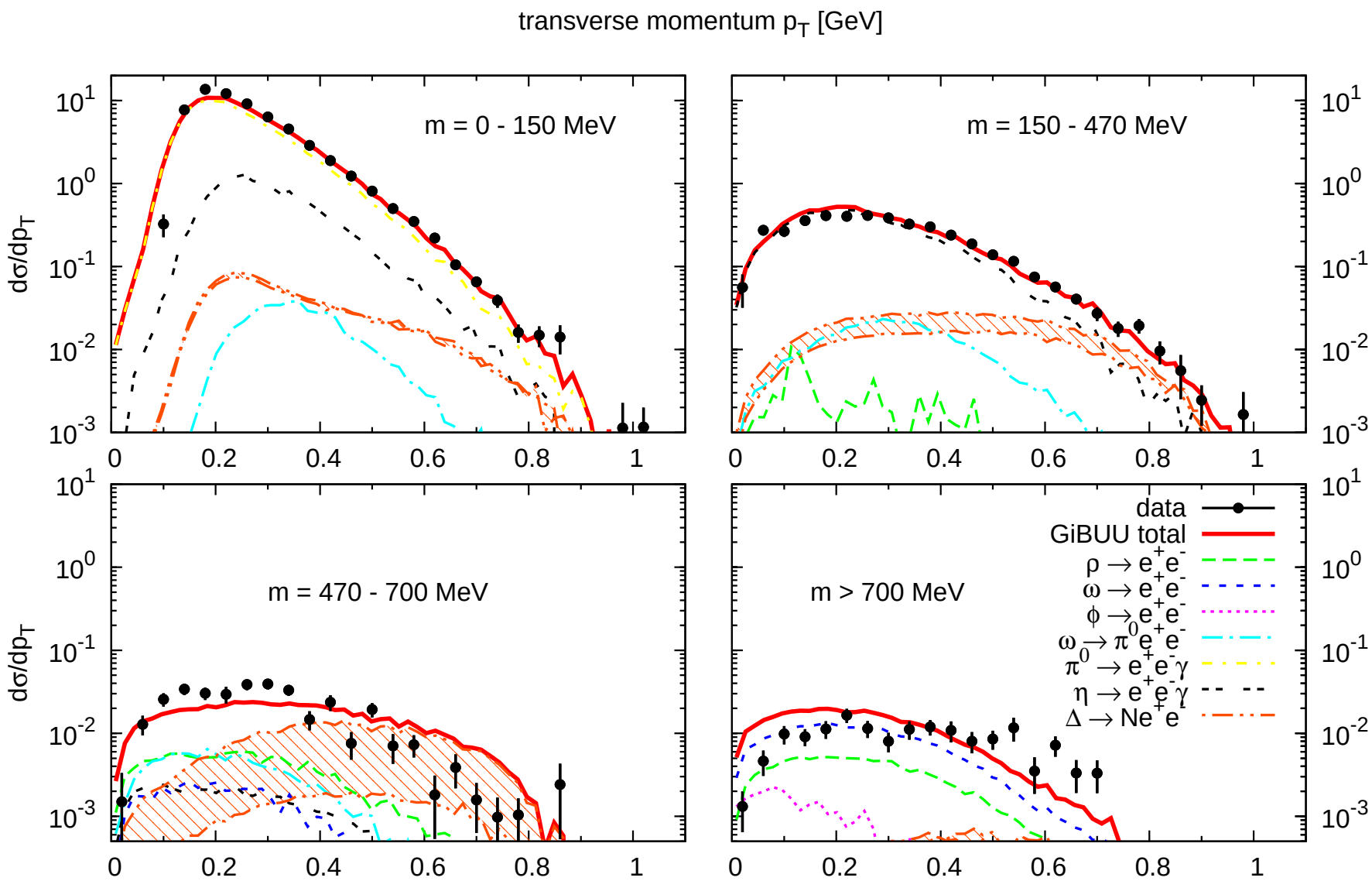
Pythia with Δ form factor



Pythia with Δ form factor



p_T SPECTRA WITH Δ FORM FACTOR

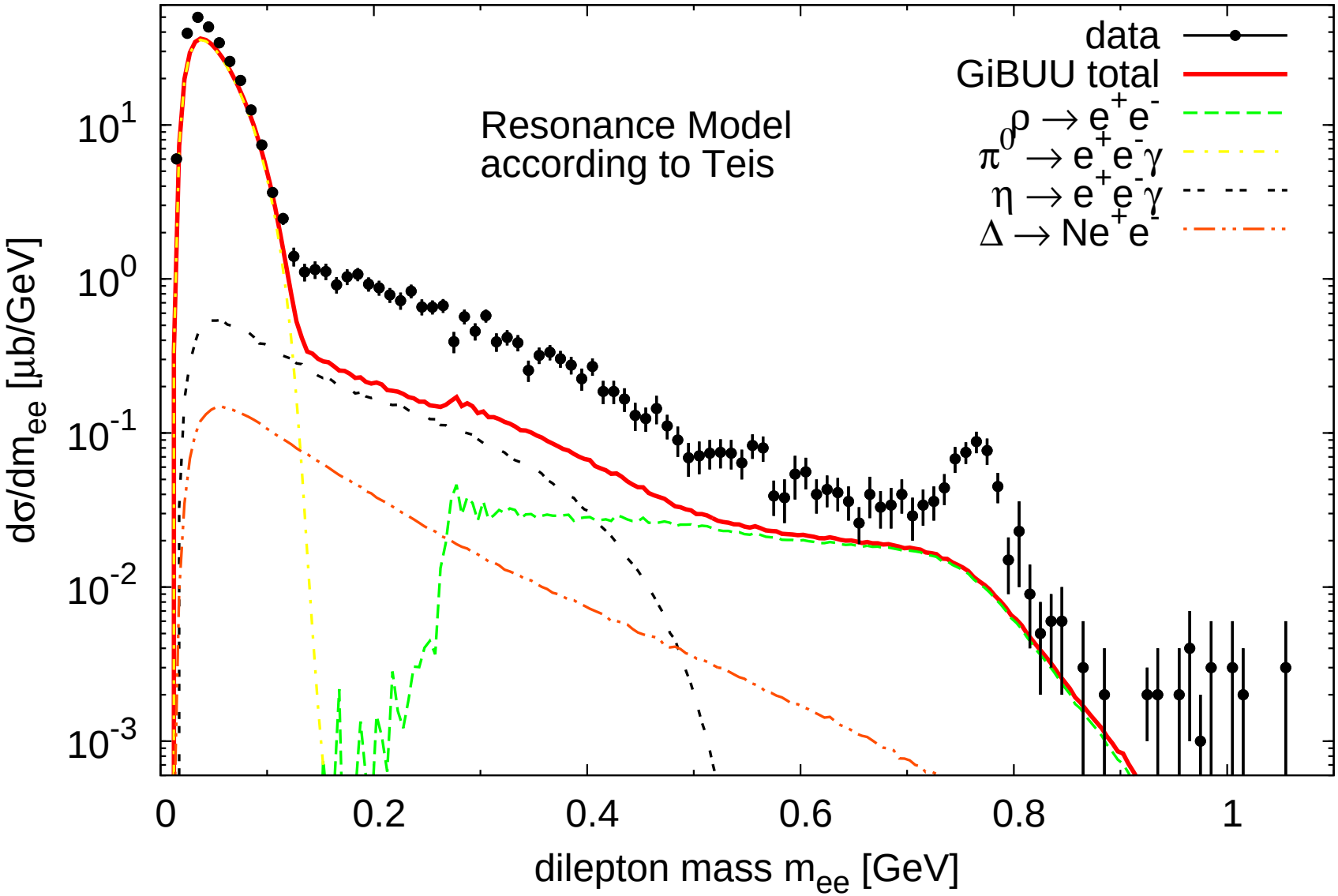


Δ form factor: issues

- stunning observation: (tuned) Pythia + Wan/Iachello FF
  $\Rightarrow$ close-to-perfect fit!
- but: FF experimentally unknown in time-like region
- constraints from space-like region (not enough!)
- Wan/Iachello: peak position not at nominal ρ mass?!?
- 600 MeV dilepton pairs come from very off-shell Δs
- pT spectrum not satisfactory
- mass spectrum: still trouble above m_ω

In the end: not a convinving solution!
Let's see how good we can do with a resonance model ...

p + p @ 3.5 GeV via Res. Model (Teis)



GiBUU: Extending the Teis ansatz

the current GiBUU implementation ...

- has resonance production channels from Teis
- but: slightly different decay branchings (Manley, not PDG)
- still roughly compatible with data, no re-fitting done
- 16 N^* and 13 Δ^* resonances (not all produced in pp, though)

missing ...

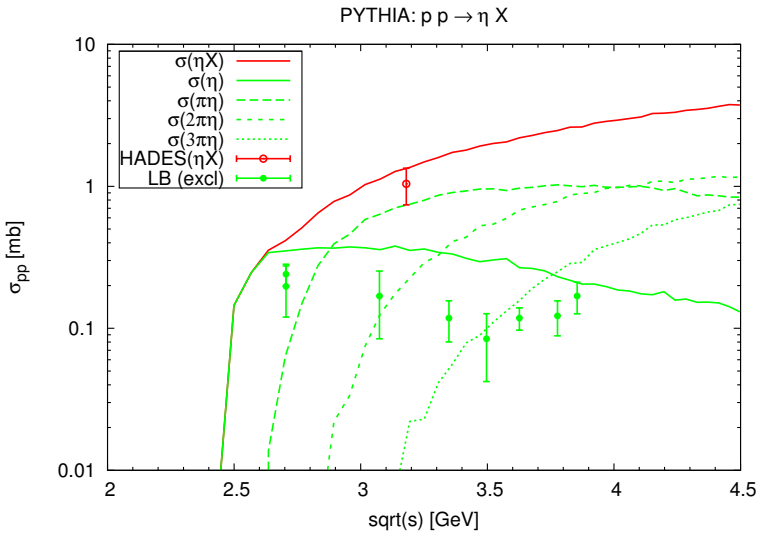
- in the Teis model: $NN \to \Delta R$ (present e.g. in UrQMD)
- in Teis and UrQMD: $NN \to RR'$

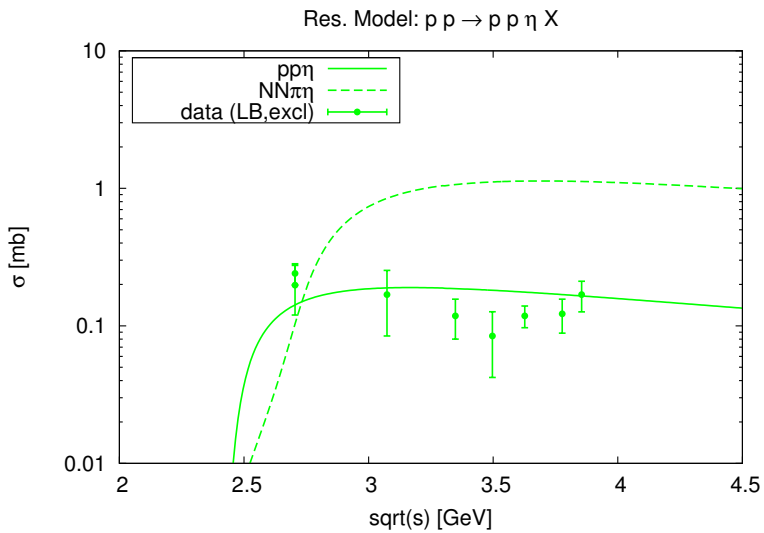
for pp@3.5GeV we need ...

- multi-meson final states: $NN \to NN\pi\eta, NN\pi\rho, NN\pi\pi\pi, ...$
- omega production: $NN \to NN\omega, NN\pi\omega$

EXTEND η PRODUCTION

- Teis: excl. η production goes via $NN \to NN^*(1535)$
- now: add new channel $NN \to \Delta(1232)N^*(1535)$
- fit matrix element to Pythia's $pp \to pp\pi\eta$: $|\mathcal{M}|^2/16\pi \approx 60\,\text{mb}\,\text{GeV}^2$
- will also contribute to $\pi\rho$
- $2\pi\eta$ channel still missing, but negligible at $\sqrt{s} = 3.2 GeV$





ω / ρ PRODUCTION

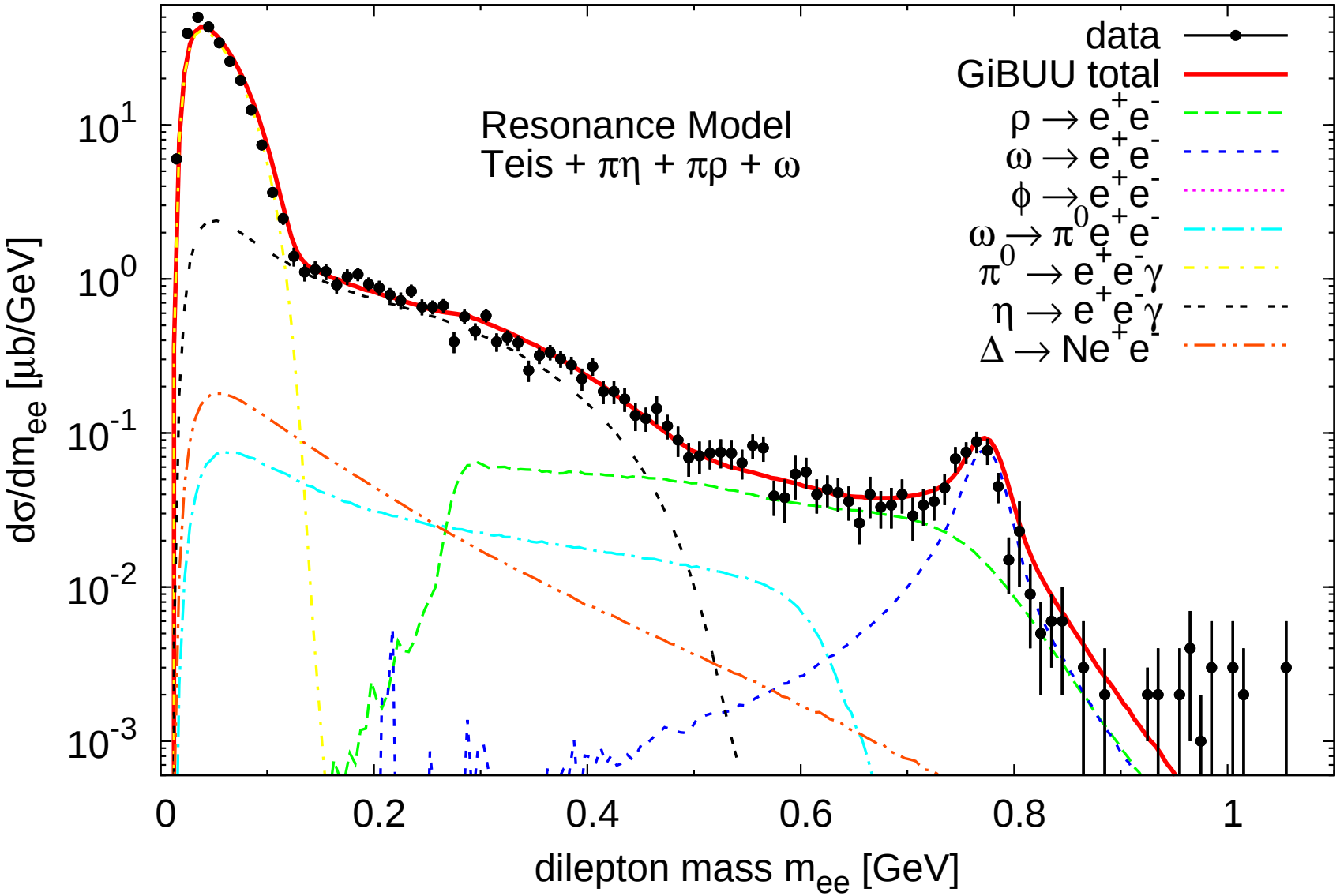
- ω: no significant resonance contributions found in p+p
- assume simple phase space production for now

- Teis: 5 N^*s and 4 Δ^*s contributing to excl. ρ production
  $NN \to NN^* \to \rho NN$: $|\mathcal{M}|^2/16\pi = 4$ mb GeV^2
  $NN \to N\Delta^* \to \rho NN$: $|\mathcal{M}|^2/16\pi = 7$ mb GeV^2

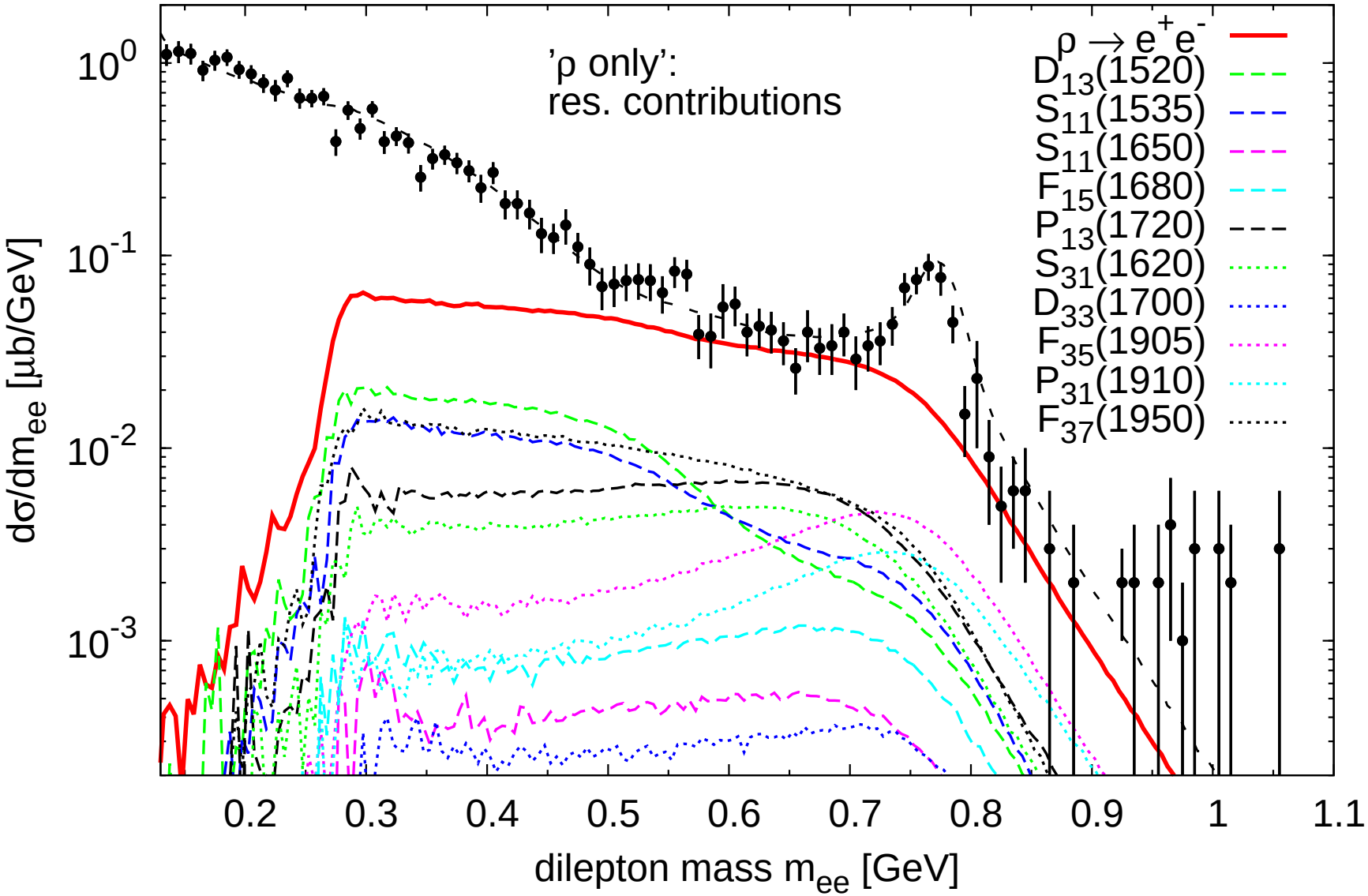
- now: add ΔN^* and $\Delta\Delta^*$ to get $\pi\rho$ final states
  $NN \to \Delta N^* \to \pi\rho NN$: $|\mathcal{M}|^2/16\pi = 8$ mb GeV^2
  $NN \to \Delta\Delta^* \to \pi\rho NN$: $|\mathcal{M}|^2/16\pi = 14$ mb GeV^2

- roughly fixed to Pythia's $pp \to \pi\rho pp$ (analogous to η case)

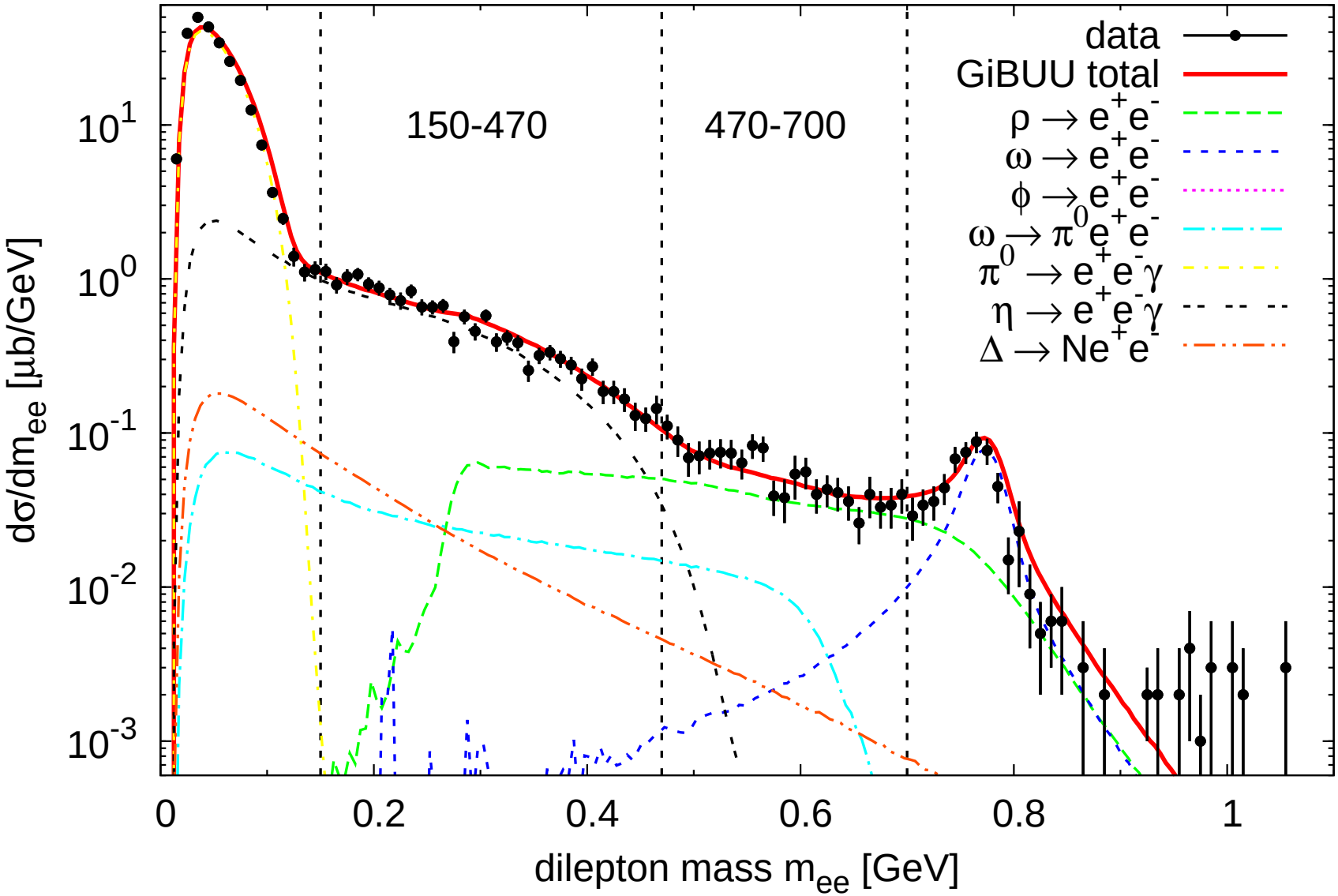
p + p @ 3.5 GeV via Res. Model



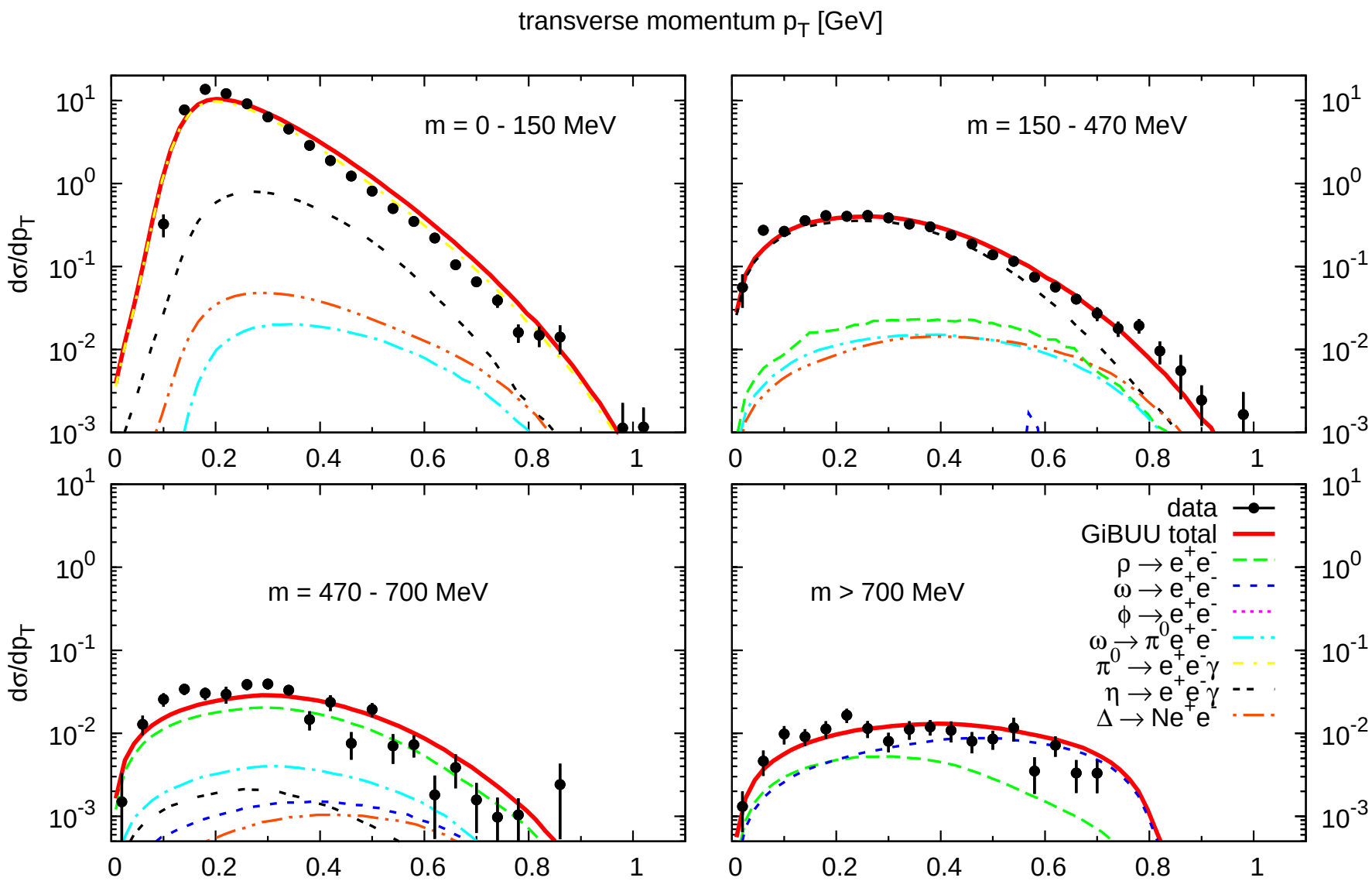
p + p @ 3.5 GeV via Res. Model



p + p @ 3.5 GeV via Res. Model

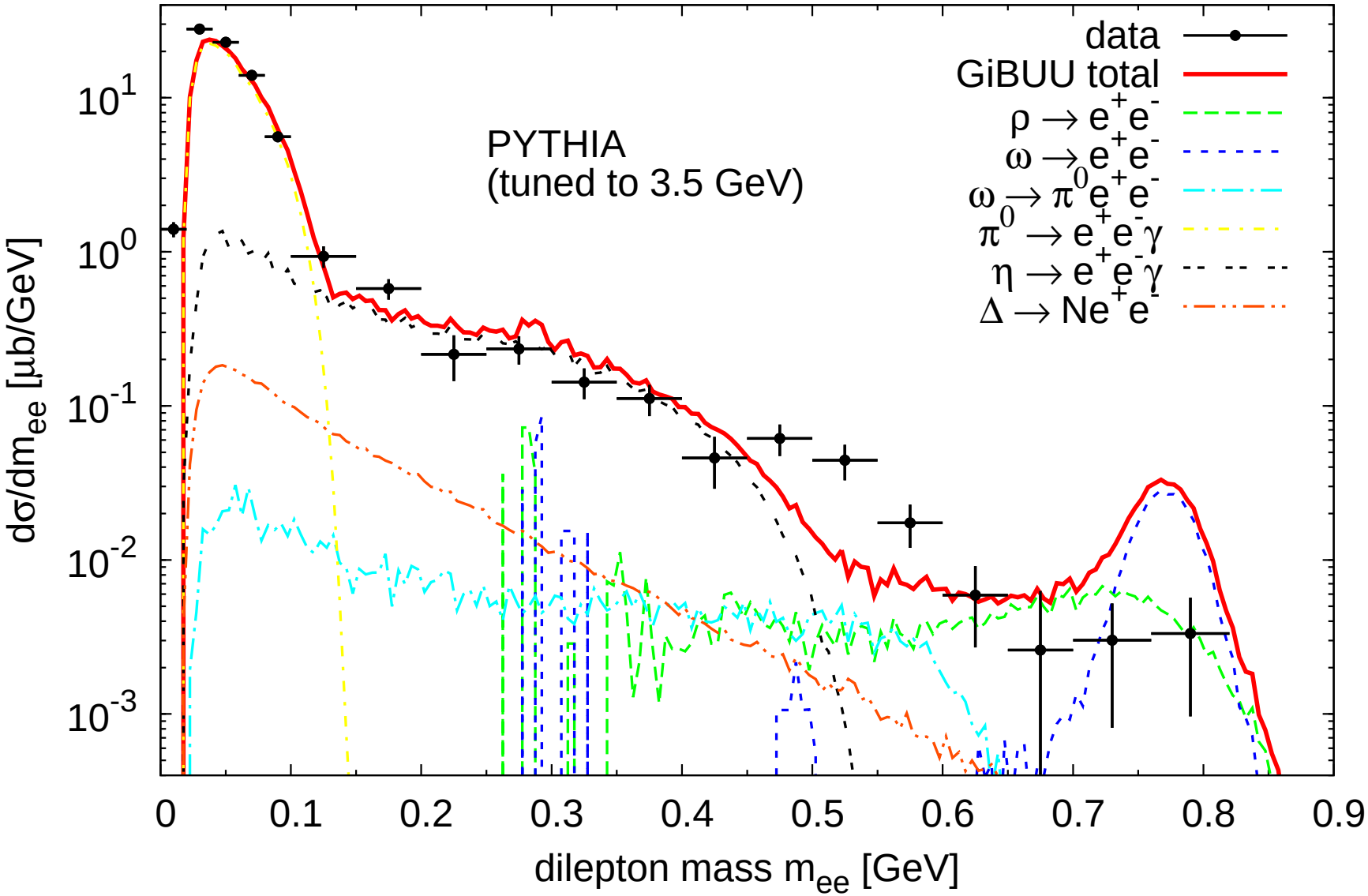


p + p @ 3.5 GeV via Res. Model: p_T spectra

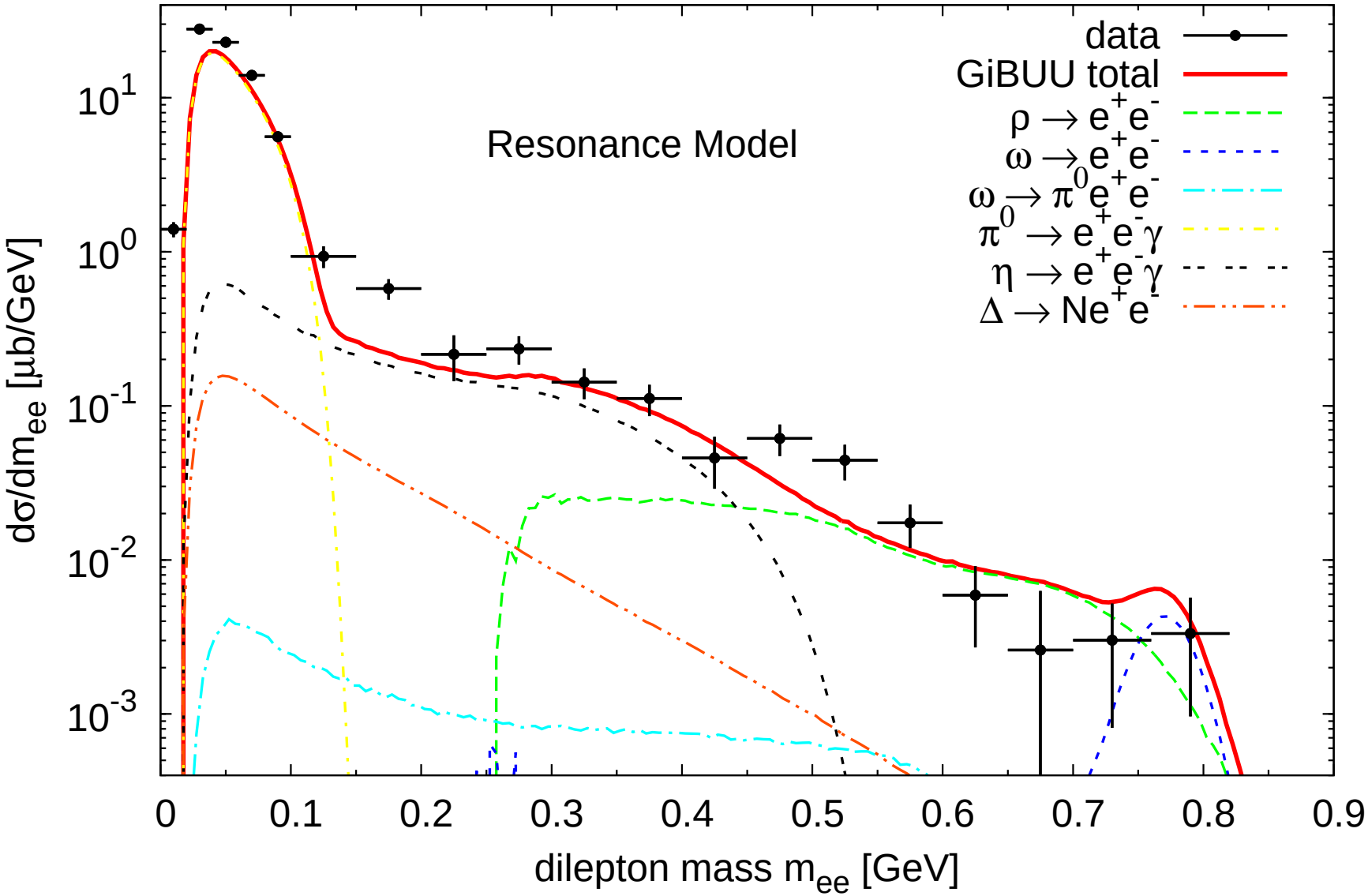


p + p @ 2.2 GeV

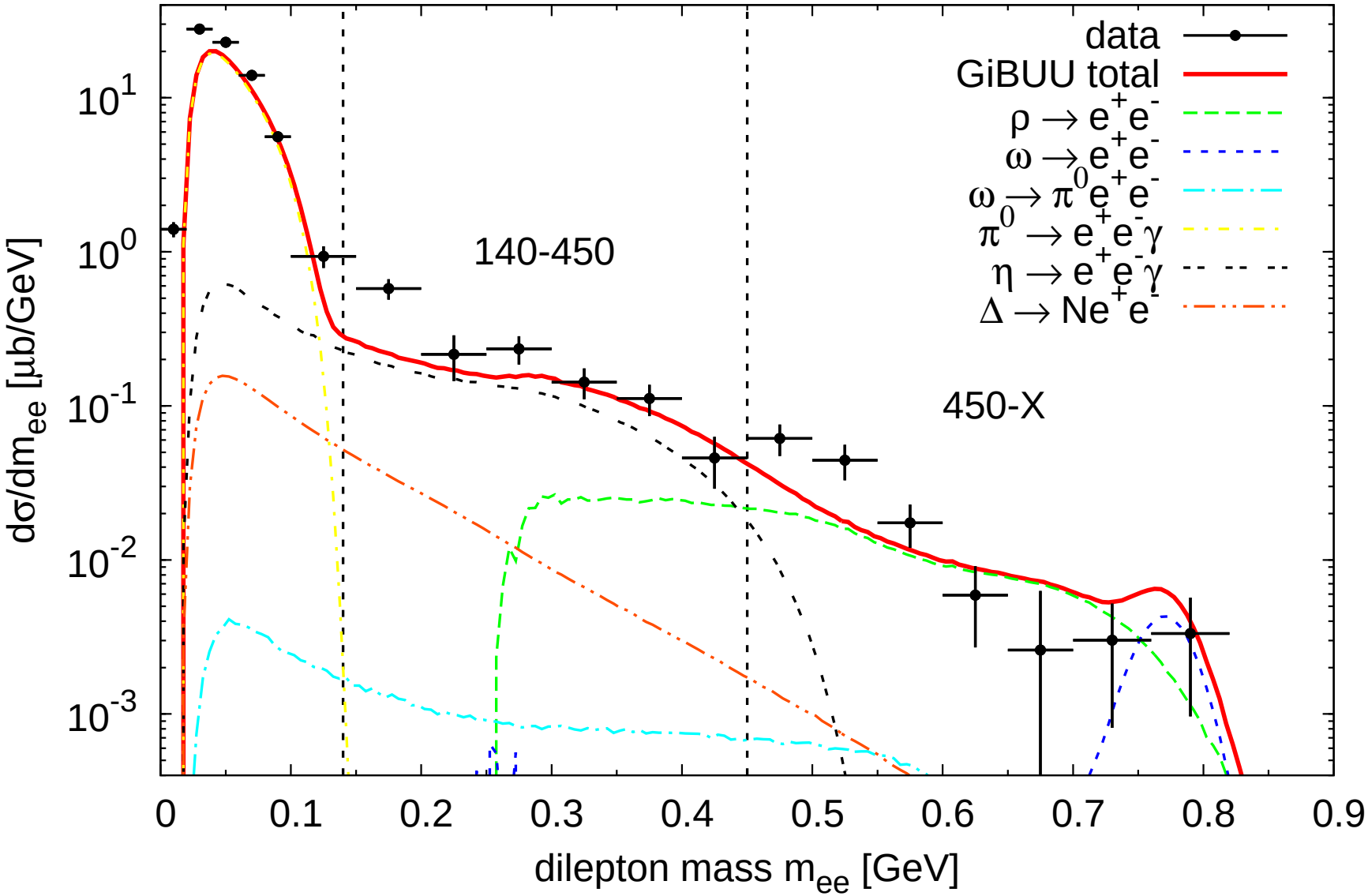
p + p @ 2.2 GeV via Pythia



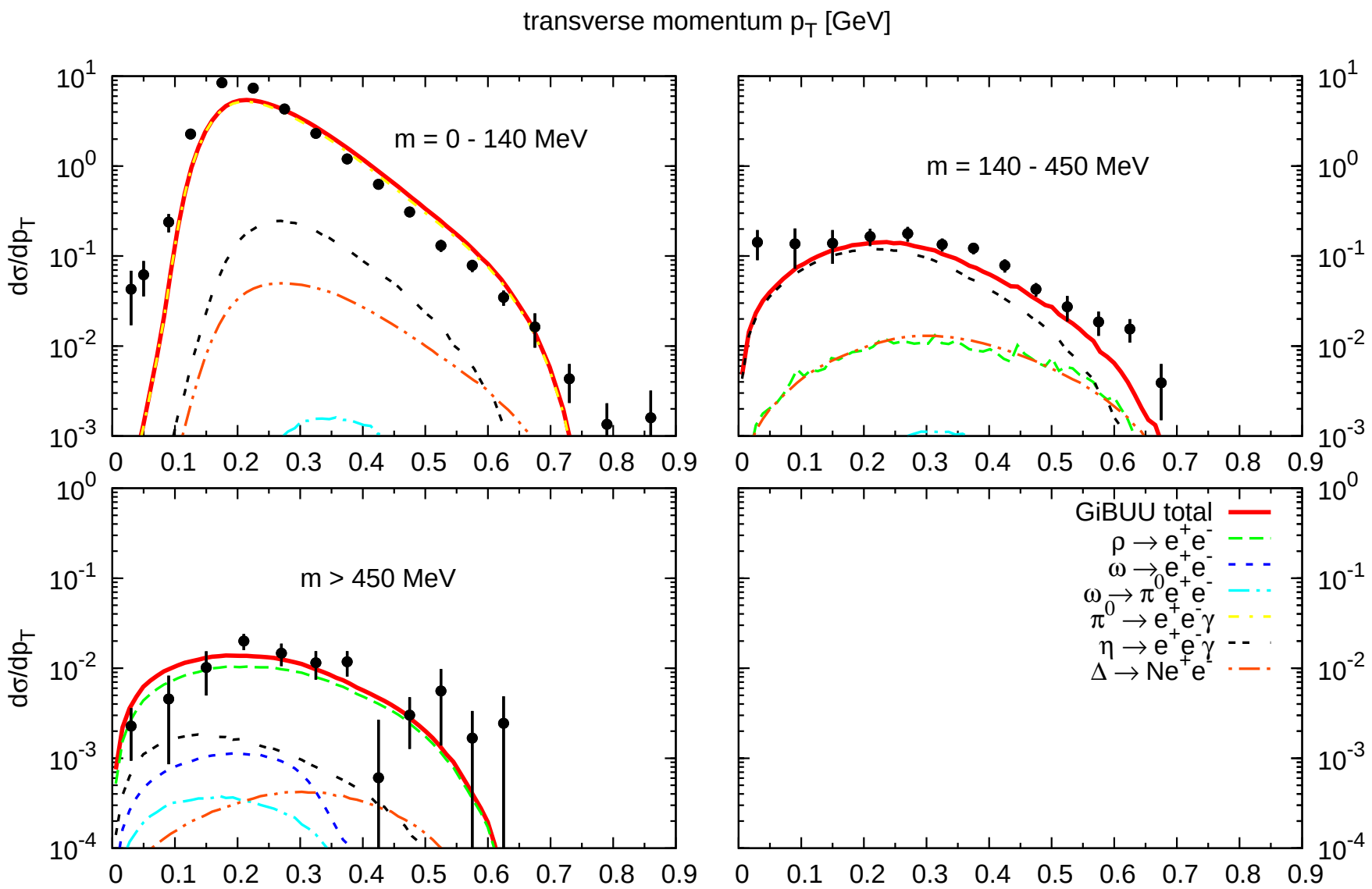
p + p @ 2.2 GeV via Res. Model



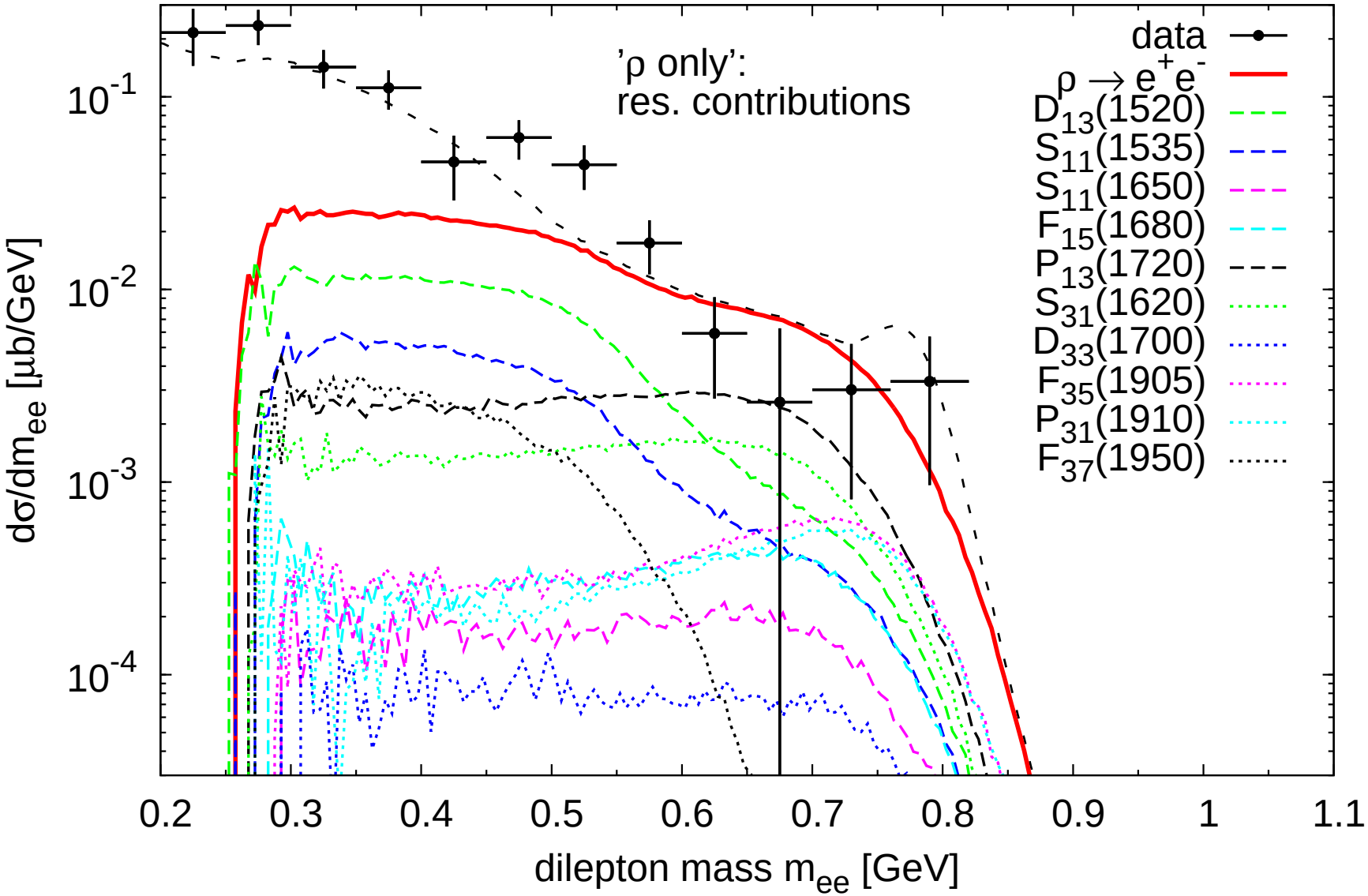
p + p @ 2.2 GeV via Res. Model



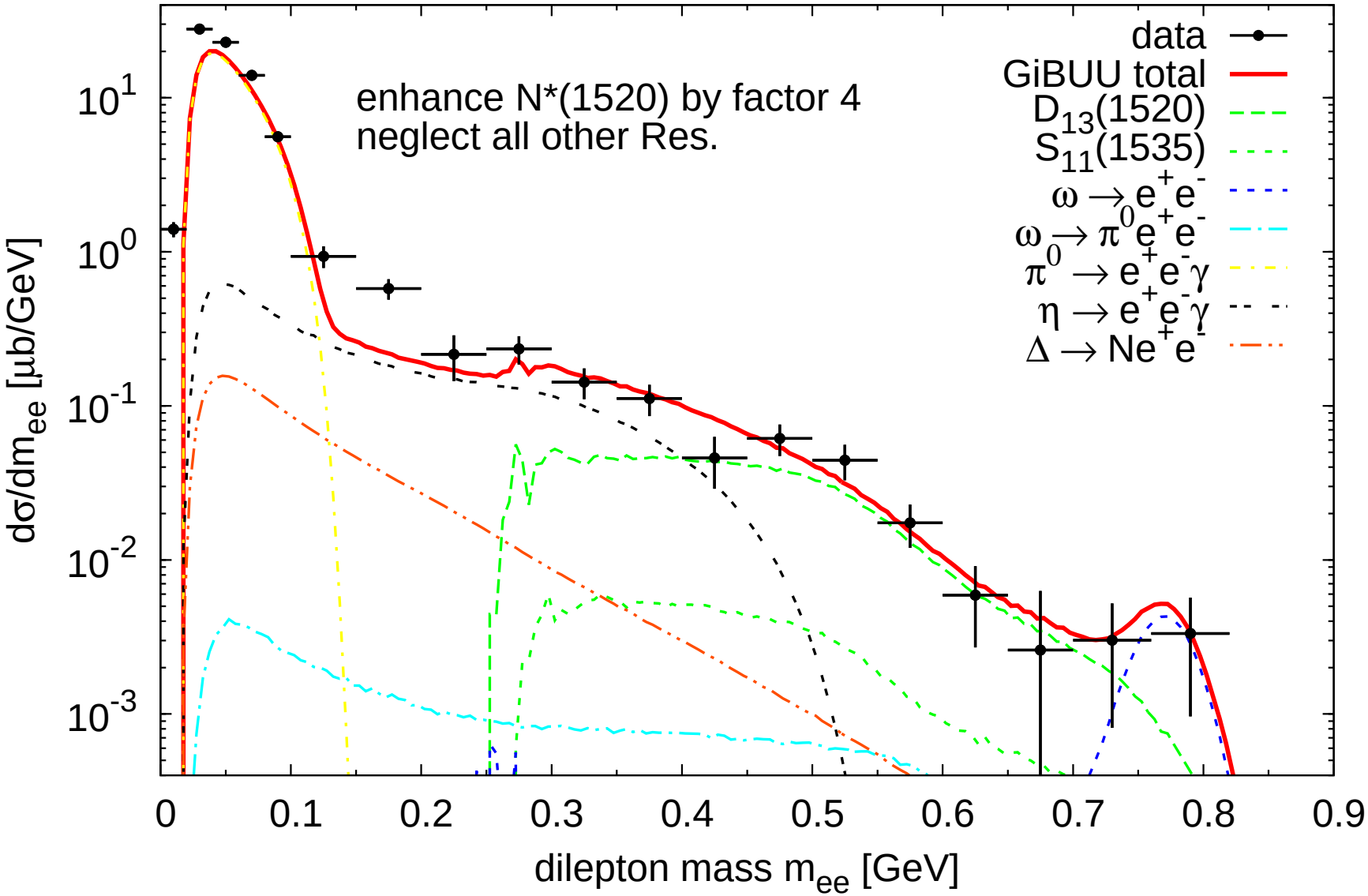
p + p @ 2.2 GeV via Res. Model



p + p @ 2.2 GeV via Res. Model

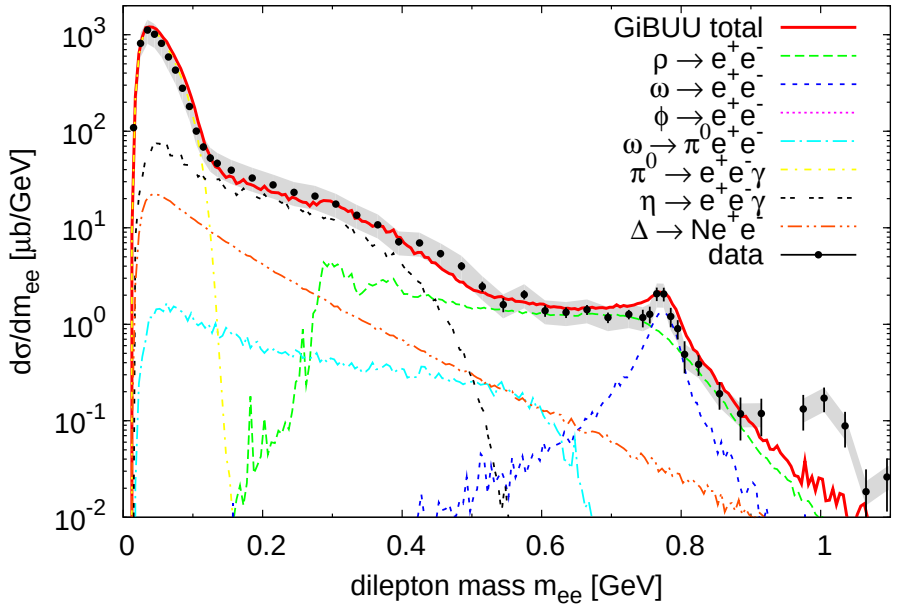


p + p @ 2.2 GeV via Res. Model



Outlook

- p+Nb @ 3.5 GeV



- C+C @ 1 GeV / 2 GeV
- Ar+KCl @ 1.76 AGeV
- Au+Au, ...

Conclusions

1. **p + p @ 1.25 GeV:**
   - reasonable agreement with data
   - (minor deviations in pion channel)
2. **p + p @ 3.5 GeV:**
   - very good agreement with data
   - res. model performs much better than Pythia
   - crucial: shape of ρ channel (res. contributions)
3. **p + p @ 2.2 GeV:**
   - again: ρ shape crucial
   - dominated by $N^*(1520)$ at this energy?
   - check via πN spectra?

$\Rightarrow$ **enhanced resonance model is able to consistently describe $pp \to e^+e^-X$ at all HADES energies**