Brief update: Di-electron inputs from Pluto for MPD

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with
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Input signal from Pluto

- Simulate di-electrons from various low mass mesons.
- Some input parameters are to be set to generate the input signal.
- Source by source simulations are performed: $\pi^0 \rightarrow \gamma\ e^+e^-$, $\eta \rightarrow \gamma\ e^+e^-$, $\omega \rightarrow \pi^0\ e^+e^-$, $\omega \rightarrow e^+e^-$, $\phi \rightarrow e^+e^-$ and $\rho^0 \rightarrow e^+e^-$.
- Values of particle multiplicities can be taken from HSD (Hadron String Dynamics) or thermal sources (CBM di-leptons group).
- Measured p_{T} and rapidity spectra need to be used to restore the shape in Pluto.

Inputs to Pluto

- Stable and broad particles are emitted by so-called "fireball" which is set for each particle; with inputs such as temperature, beam energy.
- These particles are then subsequently decayed in the Pluto framework.
- For stable particle, with fixed masses, sampling of either,
  Case I: m_T-distribution and rapidity distribution,
  $$\frac{dN}{dm_T} \propto m_T^2 \times K1(m_T/T) \quad \& \quad \frac{dN}{dy} \propto \exp^{-(y^2/2\sigma_y^2)} \quad \textbf{OR}$$
  Case II: Energy and polar angle distribution,
  $$\frac{dN}{dE} \propto pEe^{(E/T)} \quad \& \quad \frac{dN}{d\Omega} \propto 1 + A_2\cos^2(\theta^{c.m.}) + A_4\cos^4(\theta^{c.m.})$$
- At the moment, input parameters for Pluto:
  $\Rightarrow$ rapidity width, $\sigma_y = 1.0$ and source temperature $T_\pi = 0.10$ GeV, $T_\eta = 0.14$ GeV, $T_{\omega,\rho} = 0.16$ GeV, $T_\phi = 0.19$ GeV $\Rightarrow$ **may need to update**

Inputs to Pluto

For broad particles, the energy and mass are sampled as:

$$\frac{d^2N}{dEdm} \propto \frac{dN}{dE} \cdot g(m) \cdot \theta(E > m)$$

where, g(m) is Breit Wigner distribution,

$$g(m) = A \frac{m^2 \Gamma^{\rm tot}(m)}{(M_{\rm R}^2 - m^2)^2 + m^2(\Gamma^{\rm tot}(m))^2}$$

- $\Gamma^{\rm tot}(m)$ is mass-dependent/dynamic width used for which models are specified otherwise fixed-width is used (Case II). The partial width of direct decay of vector mesons,

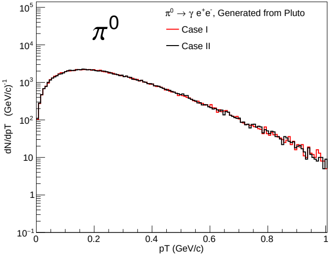
$$\Gamma^{V \to e^+e^-}(m) = \frac{c_V}{m^3} \sqrt{1 - \frac{4m_e^2}{m^2}} \left(1 + \frac{m_e^2}{m^2}\right)$$

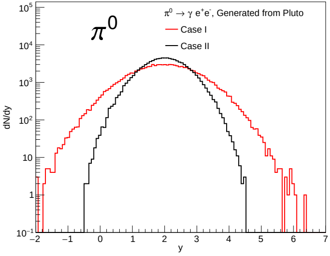
  where the the index V refers to one of ρ^0, ω and ϕ, and c_V is 3.079×10^{-6}, 0.287×10^{-6}, and 1.450×10^{-6} GeV^4 respectively

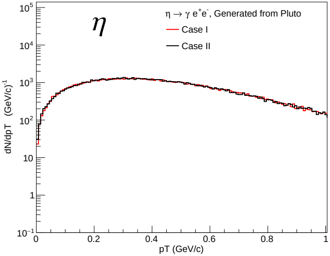
- As an alternative way, $m_{\rm T}$ and rapidity spectra can be also sampled with mass being sampled using fixed-width Breit-Weigner distribution (Case I).

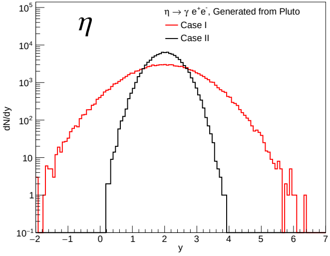
π^0 and η meson: Generated from Pluto

p_T-distribution | **rapidity distribution**



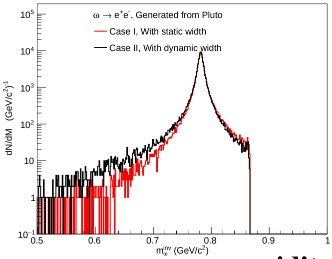




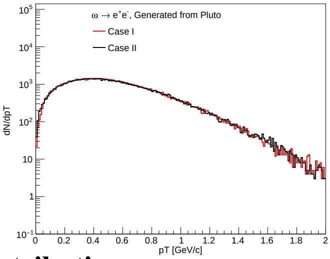


ω-meson: Generated from Pluto

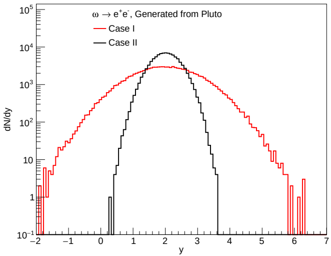
invariant mass distribution



p_T-distribution

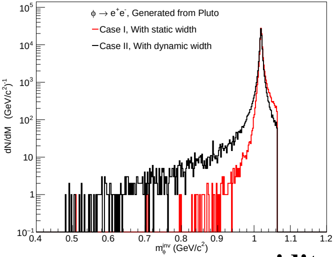


rapidity distribution

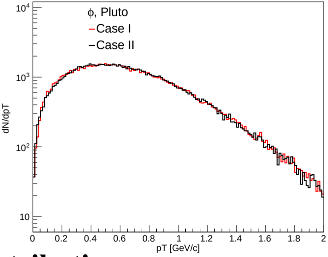


ϕ-meson: Generated from Pluto

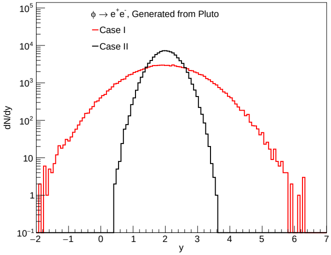
invariant mass distribution



p_T-distribution

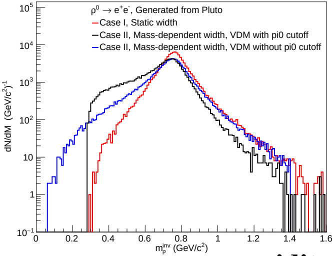


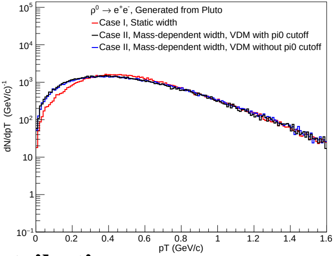
rapidity distribution



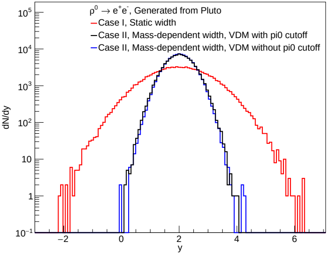
ρ^0-meson: Generated from Pluto

invariant mass distribution **p_T-distribution**





rapidity distribution



Multiplicities from HSD

particles	mass (MeV)	10 (AGeV)	15 (AGeV)	20 (AGeV)	25 (AGeV)	30 (AGeV)	35 (AGeV)
π^0	135	221	264	300	337	361	382
π^-	140	233	293	333	368	397	423
π^+	140	201	261	298	332	361	386
η	550	16	23	29	33	37	40
K^0	498	21	31	37	42	47	52
$\bar{K}^0$	498	3	7	9	12	14	17
K^+	494	20	28	35	40	45	48
K^-	494	3	7	9	13	16	18
ρ^0	775	9	15	19	23	25	26
ω^0	783	19	27	34	38	42	46
ϕ	1020	0.12	0.50	0.83	1.28	1.24	1.50
Λ	1115	20	26	30	32	34	35
Σ^0	1193	5.99	8.09	9.20	10.06	10.56	10.76
Σ^+	1189	4.19	5.69	6.55	7.18	7.72	8.74
Σ^-	1197	3.30	4.04	4.61	5.46	5.37	5.67
Ξ^0	1315	0.13	0.20	0.34	0.40	0.45	0.45
Ξ^-	1321	0.18	0.22	0.32	0.48	0.33	0.42
D^0	1864	$1.15 \cdot 10^{-11}$	$2.72 \cdot 10^{-7}$	$6.67 \cdot 10^{-6}$	$3.74 \cdot 10^{-5}$	$1.11 \cdot 10^{-4}$	$2.49 \cdot 10^{-4}$
$\bar{D}^0$	1864	$8.76 \cdot 10^{-9}$	$2.97 \cdot 10^{-6}$	$3.05 \cdot 10^{-6}$	$1.15 \cdot 10^{-4}$	$2.78 \cdot 10^{-4}$	$5.43 \cdot 10^{-4}$
D^+	1869	$1.67 \cdot 10^{-11}$	$3.34 \cdot 10^{-7}$	$7.71 \cdot 10^{-6}$	$4.17 \cdot 10^{-5}$	$1.21 \cdot 10^{-4}$	$2.67 \cdot 10^{-4}$
D^-	1869	$6.76 \cdot 10^{-9}$	$2.28 \cdot 10^{-6}$	$2.34 \cdot 10^{-5}$	$8.91 \cdot 10^{-5}$	$2.16 \cdot 10^{-4}$	$4.23 \cdot 10^{-4}$
D_s^+	1969	$2.13 \cdot 10^{-14}$	$1.71 \cdot 10^{-8}$	$7.50 \cdot 10^{-7}$	$5.43 \cdot 10^{-6}$	$1.84 \cdot 10^{-5}$	$4.53 \cdot 10^{-5}$
D_s^-	1969	$2.18 \cdot 10^{-11}$	$6.67 \cdot 10^{-8}$	$1.26 \cdot 10^{-6}$	$6.59 \cdot 10^{-6}$	$1.92 \cdot 10^{-5}$	$4.29 \cdot 10^{-5}$
J/Ψ	3097	$1.74 \cdot 10^{-7}$	$2.44 \cdot 10^{-6}$	$8.37 \cdot 10^{-6}$	$1.92 \cdot 10^{-5}$	$3.45 \cdot 10^{-5}$	$5.49 \cdot 10^{-5}$
Ψ'	3686	$1.07 \cdot 10^{-10}$	$1.69 \cdot 10^{-8}$	$9.09 \cdot 10^{-8}$	$2.56 \cdot 10^{-7}$	$5.66 \cdot 10^{-7}$	$9.96 \cdot 10^{-7}$

Table 12.2: Particle multiplicities calculated for central Au+Au collisions (impact parameter of b = 0.5 fm) at different beam energies using the HSD code

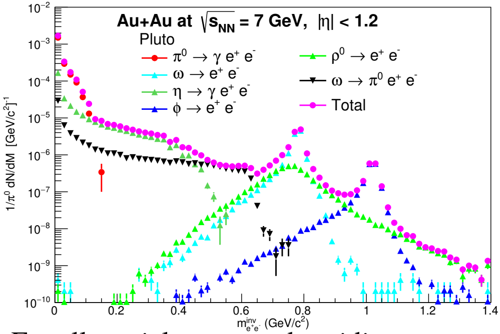
Comparison of multiplicities

- Multiplicities from CBM dilepton group: `https://cbm-wiki.gsi.de/foswiki/bin/view/PWG/CbmDileptonInfoMult`.
- For b = 0.5 fm, $< N_{part} > \approx 388$ using Monte Carlo Glauber model (`https://github.com/jbernhard/glauber-model.git`)
- The π^0 multiplicity per participant nucleon (fit to central Au+Au data).
- η, ρ, ω, ϕ multiplicities from a thermal model.

Species	HSD	CBM Dilepton group
π^0	337	$0.713 * < N_{part} > = 277$
η	33	$0.064 * < N_{part} > = 25$
ω	38	$0.044 * < N_{part} > = 17$
ρ^0	23	$0.069 * < N_{part} > = 27$
ϕ	1.28	$0.010 * < N_{part} > = 3.88$

First result: Au–Au at $\sqrt{s_{NN}} = 7$ GeV

No p_T-cut on daughter electrons



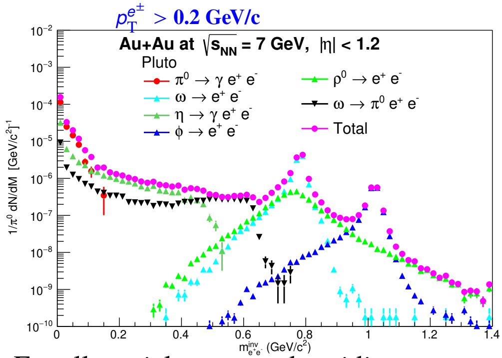
1. $\pi^0 \to \gamma\, e^+e^-$; (3.5M)
2. $\eta \to \gamma\, e^+e^-$; (3.8M)
3. $\omega \to \pi^0\, e^+e^-$; (3.7M)
4. $\omega \to e^+e^-$; (3.9M)
5. $\phi \to e^+e^-$; (2M)
6. $\rho^0 \to e^+e^-$; (3M)

Cuts:

TPC points > 20, $|\eta| < 1.2$
$\mathrm{DCA_r}$ and $\mathrm{DCA_z} < 3\,\sigma$.

- For all particles, m_T and rapidity spectra are sampled (Case I).
- Fixed masses for stable particles and for broad particles, masses are sampled with fixed-width Breit-Weigner distribution.
- Di-electrons from different sources are simulated separately.
- Scaled with multiplicities from HSD and branching ratios.

First result: Au–Au at $\sqrt{s_{NN}} = 7$ GeV



1. $\pi^0 \to \gamma\, e^+e^-$; (3.5M)
2. $\eta \to \gamma\, e^+e^-$; (4.4M)
3. $\omega \to \pi^0\, e^+e^-$; (4.6M)
4. $\omega \to e^+e^-$; (4.4M)
5. $\phi \to e^+e^-$; (3.3M)
6. $\rho^0 \to e^+e^-$; (3.1M)

Cuts:

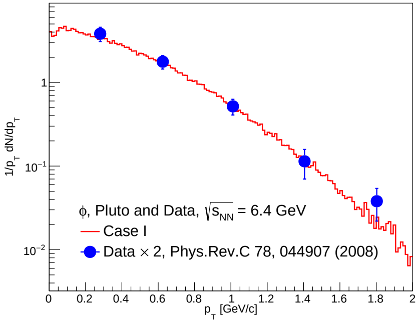
TPC points > 20, $|\eta| < 1.2$

DCA_r and $DCA_z < 3\,\sigma$.

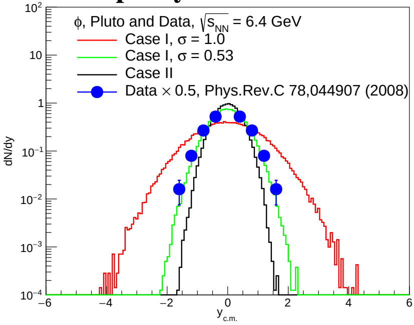
- For all particles, m_T and rapidity spectra are sampled (Case I).
- Fixed masses for stable particles and for broad particles, masses are sampled with fixed-width Breit-Weigner distribution.
- Di-electrons from different sources are simulated separately.
- Scaled with multiplicities from HSD and branching ratios.

Comparison with data: ϕ meson generated from Pluto

p_T-distribution



rapidity distribution



In case I, rapidity width (σ) is given by,

$$\sigma^{sig} = \sigma^{\pi} \times \frac{y_{max}^{sig}}{y_{max}^{\pi}} \Rightarrow \sigma^{\pi} = \sqrt{\log(\sqrt{s}/2m_N)} \quad \& \quad y_{max} = \log(\sqrt{s}/m_0)$$

$\Rightarrow$ Looking for rest of the data for the comparison.

Future steps

- To use mass-dependent width for resonances instead of fixed-width.
- Collect information about multiplicities, p_{T} and rapidity distributions of all the parent particles of interest at relevant energies.
- Estimate reconstruction efficiency (= reconstructed / generated) as function of m, p_{T} for the different sources.
- Add sources like NN bremsstrahlung and Delta Dalitz decay to the cocktail.

BACK-UP

Inputs to Pluto

For stable particle, either, 1) Energy-distribution,

$$\frac{dN}{dE} \propto p \times E \times e^{(E/T)} \quad \textbf{OR} \quad \frac{dN}{dE} \propto \sqrt{p} \times E \times e^{(E/T)} \quad \textbf{OR} \quad \frac{dN}{dE} \propto p^3 \times E \times e^{(E/T)}$$

OR 2) m_T-distribution and rapidity distribution,

$$\frac{dN}{dm_T} \propto m_T^2 \times K1(m_T/T) \quad \& \quad \frac{dN}{dy} \propto \exp^{-(y^2/2\sigma_y^2)}$$

σ_y is rapidity width which is given by,

$$\sigma_y^{sig} = \sigma_y^{\pi} \times \frac{y_{max}^{sig}}{y_{max}^{\pi}} \Rightarrow \sigma_y^{\pi} = \sqrt{\log(\sqrt{s}/2m_N)} \quad \& \quad y_{max} = \log(\sqrt{s}/m_0)$$

At the moment, input parameters for Pluto: **to be updated if needed**

$\Rightarrow \sigma_y = 1.0$

$\Rightarrow T_\pi = 0.10$ GeV, $T_\eta = 0.14$ GeV, $T_{\omega,\rho} = 0.16$ GeV, $T_\phi = 0.19$ GeV

Inputs to Pluto

The mass dependence of the decay width of Dalitz decay of pseudo-scalar mesons, π^0 and η is,

$$\frac{d\Gamma^{\mathrm{k}}(m)}{\Gamma^{A\to 2\gamma}dm} = \frac{4\alpha}{3\pi m}\sqrt{1-\frac{4m_e^2}{m^2}}\left(1+\frac{2m_e^2}{m^2}\right)\left(1-\frac{m^2}{m_A^2}\right)\left|F_A(m^2)\right|^2$$

and, for vector mesons, ω is,

$$\frac{d\Gamma^{\mathrm{k}}(m)}{\Gamma^{A\to B\gamma}dm} = \frac{2\alpha}{3\pi m}\sqrt{1-\frac{4m_e^2}{m^2}}\left(\left(1+\frac{m^2}{m_A^2-m_B^2}\right)^2-\left(\frac{2m_A m}{m_A^2-m_B^2}\right)\right)^{\frac{3}{2}}\left|F_A(m^2)\right|^2$$

direct decay of vector mesons, ρ, ω and ϕ,

$$\Gamma^{V\to e^+e^-}(m) = \frac{c_V}{m^3}\sqrt{1-\frac{4m_e^2}{m^2}}\left(1+\frac{m_e^2}{m^2}\right)$$

where the the index V refers to one of ρ^0, ω and ϕ, and c_V is 3.079×10^{-6}, 0.287×10^{-6}, and 1.450×10^{-6} GeV^4 respectively

Thermal models

Following the usual Ansatz (see e.g. [8]) we use the relativistic form of the Breit Wigner distribution:

$$g(m) = A\frac{m^2\Gamma^{\rm tot}(m)}{(M_{\rm R}^2 - m^2)^2 + m^2(\Gamma^{\rm tot}(m))^2} \tag{1}$$

where m denotes the running unstable mass, and $M_{\rm R}$ is the static pole mass of the resonance. The mass-dependent width depends on the partial widths:

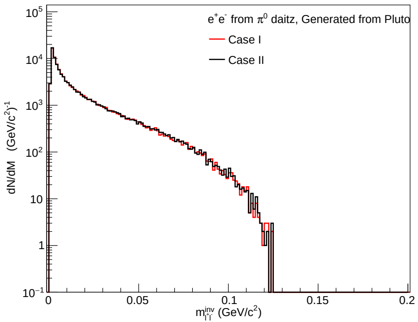
$$\Gamma^{\rm tot}(m) = \sum_{\rm k}^{N} \Gamma^{\rm k}(m) \tag{2}$$

with N the number of decay modes. The factor A has been chosen such that the integral is statistically normalized ($\int dm\, g(m) = 1$).

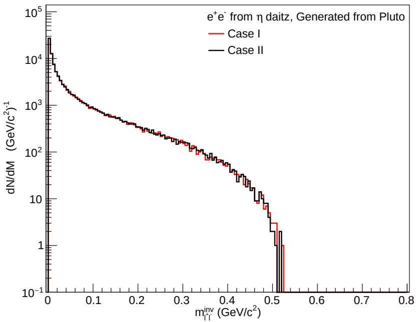
π^0 and η meson: Generated from Pluto

invariant mass distributions

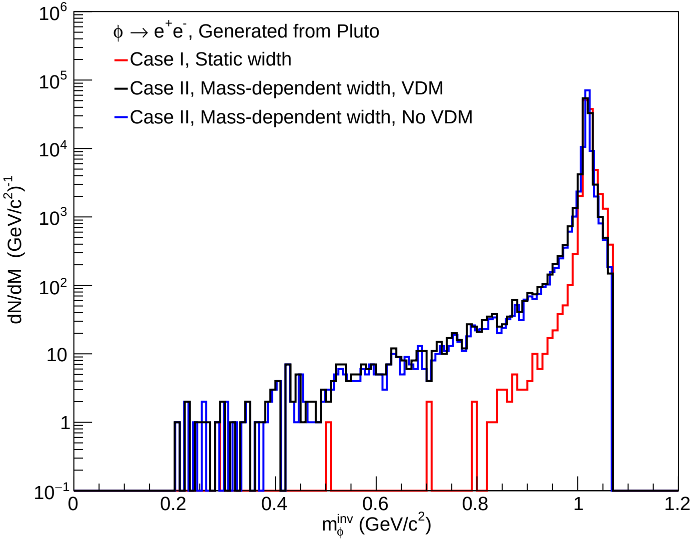
π^0



η



ϕ meson: Generated from Pluto



ρ^0-meson

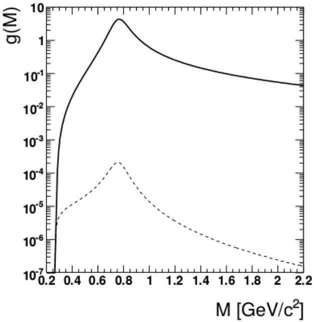


Figure 5: The ρ^0 free spectral shape. Solid line: Full shape, dashed line: $\rho^0 \rightarrow e^+e^-$ with the $\pi\pi$ cutoff as described in the text.

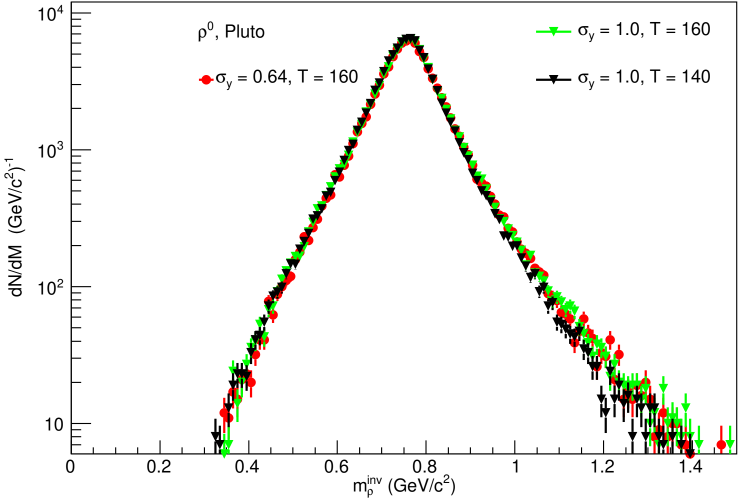
vector-meson dilepton decay width for is given by [20]:

$$\Gamma^{V \rightarrow e^+e^-}(m) = \frac{c_V}{m^3}\sqrt{1 - \frac{4m_e^2}{m^2}}\left(1 + \frac{m_e^2}{m^2}\right) \tag{22}$$

where the the index V refers to one of ρ^0, ω and ϕ, and c_V is $3.079 \cdot 10^{-6}$, $0.287 \cdot 10^{-6}$, and $1.450 \cdot 10^{-6}$ GeV^4 respectively [19].

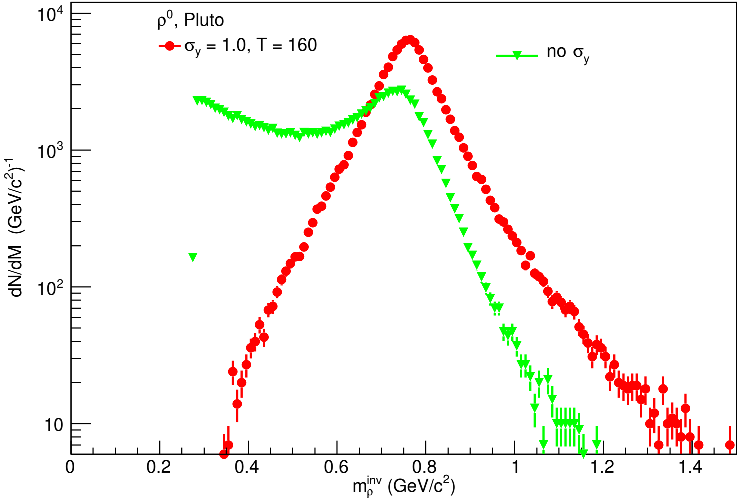
In addition, we follow the ansatz here that the ρ is governed by the 2-Pion phase space in order to be comparable to transport code calculations [22]. This cut-off behavior at $2 \cdot M_{\pi^0}$ can be seen in Fig. 5. However, this is still a question under discussion.

Pluto: QA



ρ^0, Pluto
σ_y = 0.64, T = 160
σ_y = 1.0, T = 160
σ_y = 1.0, T = 140
dN/dM (GeV/c^2)$^{-1}$
m_ρ^{inv} (GeV/c^2)
10^4
10^3
10^2
10
0
0.2
0.4
0.6
0.8
1
1.2
1.4

Pluto: QA

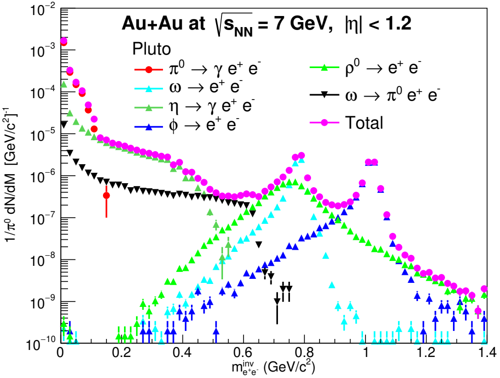


ρ^0, Pluto
σ_y = 1.0, T = 160
no σ_y
10^4
10^3
10^2
10
dN/dM (GeV/c^2)$^{-1}$
0
0.2
0.4
0.6
0.8
1
1.2
1.4
m_ρ^{inv} (GeV/c^2)

Multiplicities from CBM group

Ebeam	s1/2	F	ymid	muB	Tchem	Mπ0/Apart	Mη/Apart	Mρ0/Apart	Mω/Apart	Mφ/Apart	Mη'/Apart
[AGeV]	[AGeV]	[AGeV1/2]	-	[GeV]	[GeV]	-	-	-	-	-	-
1.0	2.309	0.443	0.679	0.802	0.055	0.042 fit	0.0003 exp	?	?	?	?
2.0	2.683	0.673	0.907	0.755	0.070	0.083 fit	0.0047 exp	?	?	?	?
3.0	3.010	0.841	1.059	0.718	0.080	0.126 fit	0.0014	0.00050	0.00019	0.00001	0.00001
4.0	3.305	0.976	1.175	0.688	0.088	0.168 fit	0.0029	0.0013	0.00057	0.00005	0.00003
6.0	3.827	1.186	1.348	0.640	0.100	0.244 fit	0.0089	0.0056	0.0029	0.00032	0.00019
8.0	4.287	1.350	1.475	0.603	0.109	0.312 fit	0.016	0.012	0.0068	0.0010	0.00054
10.0	4.701	1.485	1.577	0.573	0.115	0.374 fit	0.023	0.020	0.011	0.0019	0.0010
15.0	5.605	1.749	1.766	0.517	0.125	0.507 fit	0.039	0.039	0.023	0.0047	0.0023
20.0	6.382	1.950	1.902	0.477	0.132	0.618 fit	0.052	0.055	0.034	0.0075	0.0035
25.0	7.074	2.115	2.010	0.446	0.136	0.713 fit	0.064	0.069	0.044	0.010	0.0046
30.0	7.705	2.255	2.098	0.421	0.140	0.797 fit	0.074	0.081	0.052	0.012	0.0056
35.0	8.287	2.378	2.173	0.401	0.142	0.873 fit	0.084	0.092	0.060	0.014	0.0065
40.0	8.831	2.488	2.238	0.383	0.144	0.940 fit	0.092	0.101	0.067	0.016	0.0073
80.0	12.349	3.109	2.579	0.299	0.153	1.340 fit	0.144	0.156	0.111	0.027	0.012
158.0	17.258	3.813	2.916	0.229	0.159	1.770 fit	0.204	0.217	0.159	0.039	0.018

First result: Au–Au at $\sqrt{s_{NN}} = 7$ GeV



1. $\pi^0 \to \gamma\, e^+e^-$; (3.5M)
2. $\eta \to \gamma\, e^+e^-$; (3.8M)
3. $\omega \to \pi^0\, e^+e^-$; (3.7M)
4. $\omega \to e^+e^-$; (3.9M)
5. $\phi \to e^+e^-$; (2M)
6. $\rho^0 \to e^+e^-$; (3M)

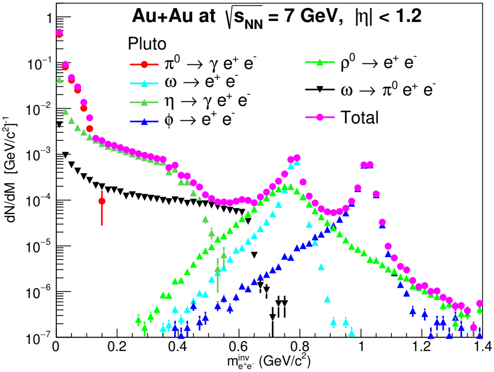
Cuts:

TPC points > 20, $|\eta| < 1.2$

DCA_r and $DCA_z < 3\,\sigma$.

- Di-electrons from different sources are simulated separately.
- Scaled with multiplicities from CBM dilepton group and branching ratios.

First result: Au–Au at $\sqrt{s_{NN}} = 7$ GeV



1. $\pi^0 \rightarrow \gamma\, e^+e^-$; (3.5M)
2. $\eta \rightarrow \gamma\, e^+e^-$; (3.8M)
3. $\omega \rightarrow \pi^0\, e^+e^-$; (3.7M)
4. $\omega \rightarrow e^+e^-$; (3.9M)
5. $\phi \rightarrow e^+e^-$; (2M)
6. $\rho^0 \rightarrow e^+e^-$; (3M)

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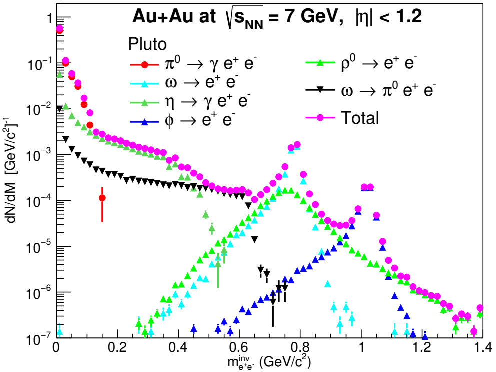

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Cuts:

TPC points > 20, $|\eta| < 1.2$
DCA_r and $DCA_z < 3\,\sigma$.

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