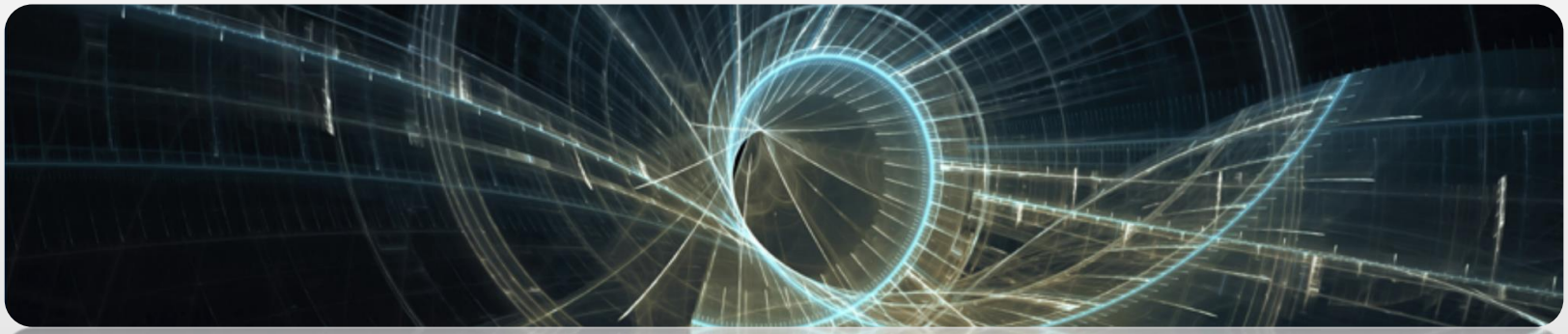
Dark Matter 2025: From the Smallest to the Largest Scale

2-6 June 2025, Santander, Spain.



Constraining Dark Photon Kinetic Mixing in Heavy-Ion Collisions from SIS to LHC energies

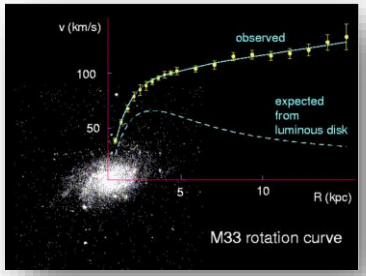
Adrian William Romero Jorge (Goethe Uni. Frankfurt & FIAS & HFHF)

Supervisor: **Elena Bratkovskaya** (GSI, Darmstadt & Uni. Frankfurt & HFHF)

Collaborators: **Taesoo Song** (GSI, Darmstadt) & **Laura Sagunski** (Uni. Frankfurt)

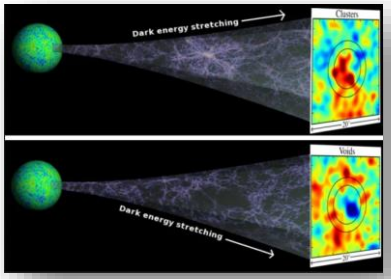
Motivation

Galaxy Rotation Curves



arxiv.org/abs/physics/0007025

Structure Formation

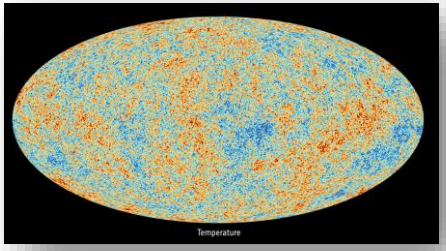


Granett, Neyrinck, Szapudi

Gravitational lensing

NASA

Cosmic Microwave Background (CMB)



ESA and the Planck Collaboration.

Dark Matter Detection

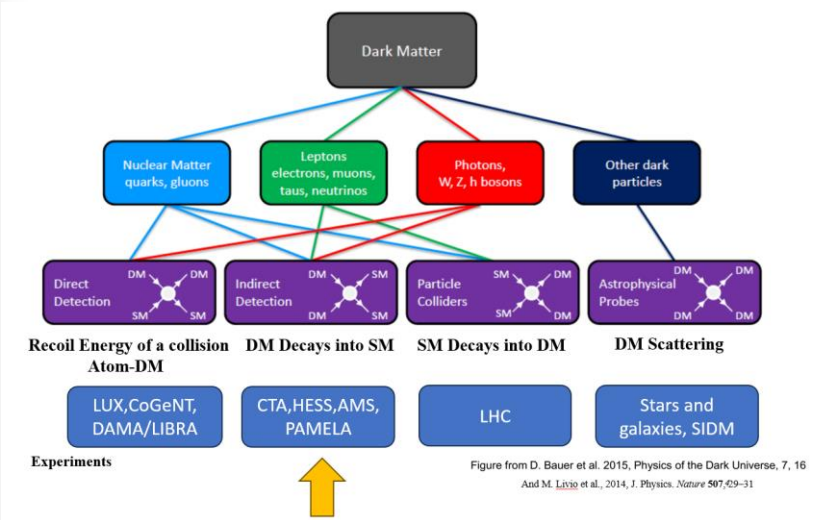


Figure from D. Bauer et al. 2015, Physics of the Dark Universe, 7, 16
And M. Livio et al., 2014, J. Physics. *Nature* **507**,29–31

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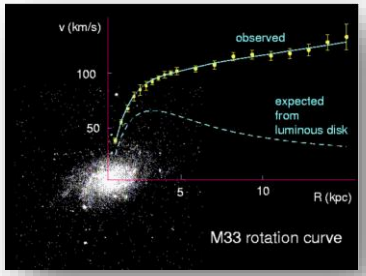

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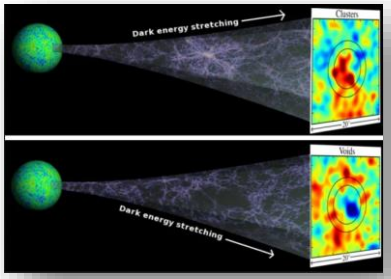

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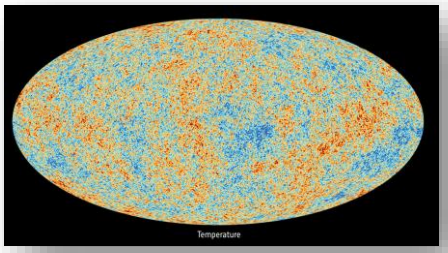

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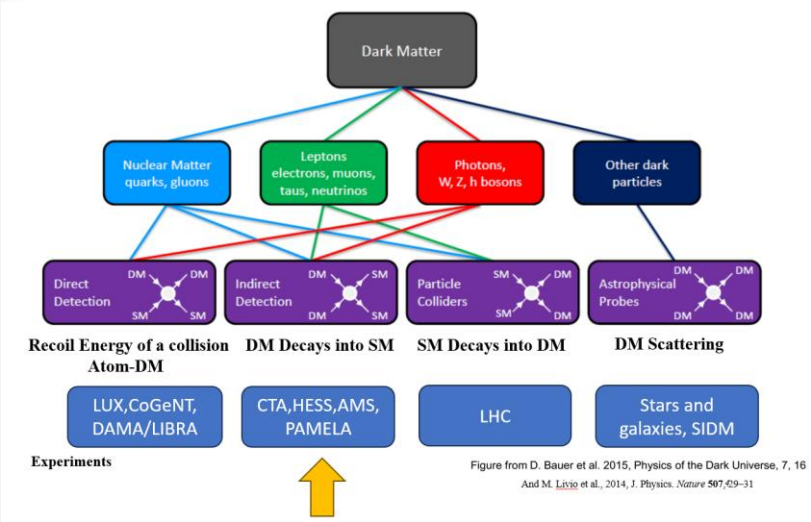

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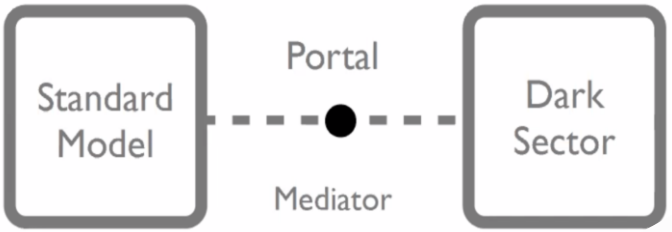
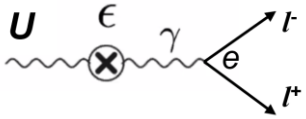


Vector Portal (Dark Photon/U-Boson)

$$\mathcal{L}_U = -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \frac{\varepsilon}{2}B^{\mu\nu}F'_{\mu\nu} - \frac{1}{2}M_U^2 A'^{\mu}A'_{\mu}$$



$\alpha' = \varepsilon^2 \alpha$

L.B. Okun, Sov. Phys. 56 JETP (1982);
B. Holdom, Phys. Lett. B 166, 196 (1986)

Unknown: kinetic mixing parameter ε and mass M_U

Dark photon production in dilepton experiments in HIC

Dalitz Decay

$\pi^0, \eta, \eta' \rightarrow \gamma U$

$\Delta \rightarrow N U$

$\omega \rightarrow \pi^0 U$

$K^+ \rightarrow \pi^+ U$

Direct Decay

$\rho, \phi, \omega \rightarrow U$

$q\bar{q} \rightarrow U$

$U \rightarrow e^+ e^-$

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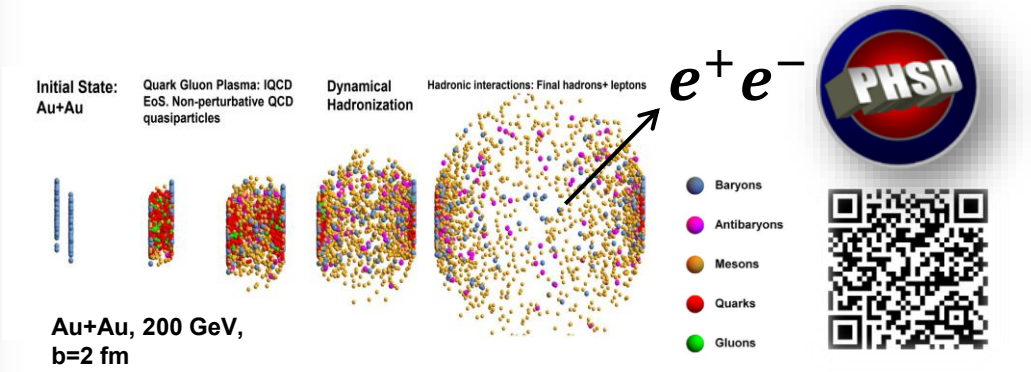
Theoretical modeling of U-boson production

Parton-Hadron-String Dynamics (PHSD) is a non-equilibrium microscopic transport approach for the description of strongly-interacting hadronic and partonic matter created in heavy-ion collisions

Dynamics: based on the solution of generalized off-shell transport equations derived from Kadanoff-Baym many-body theory



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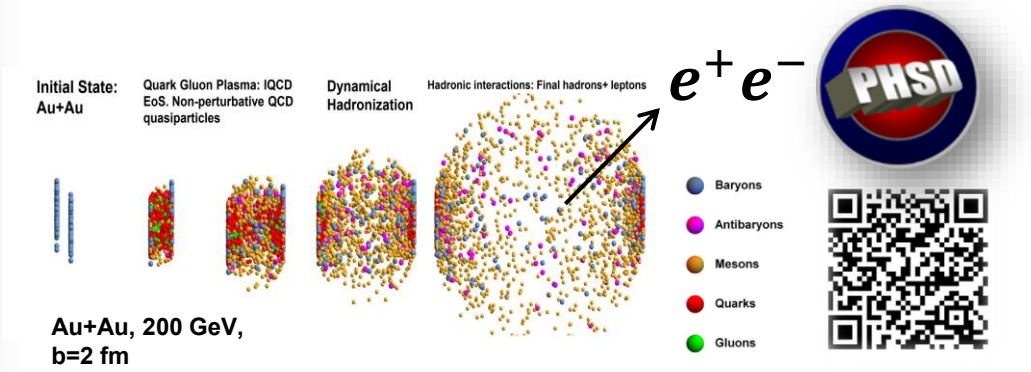


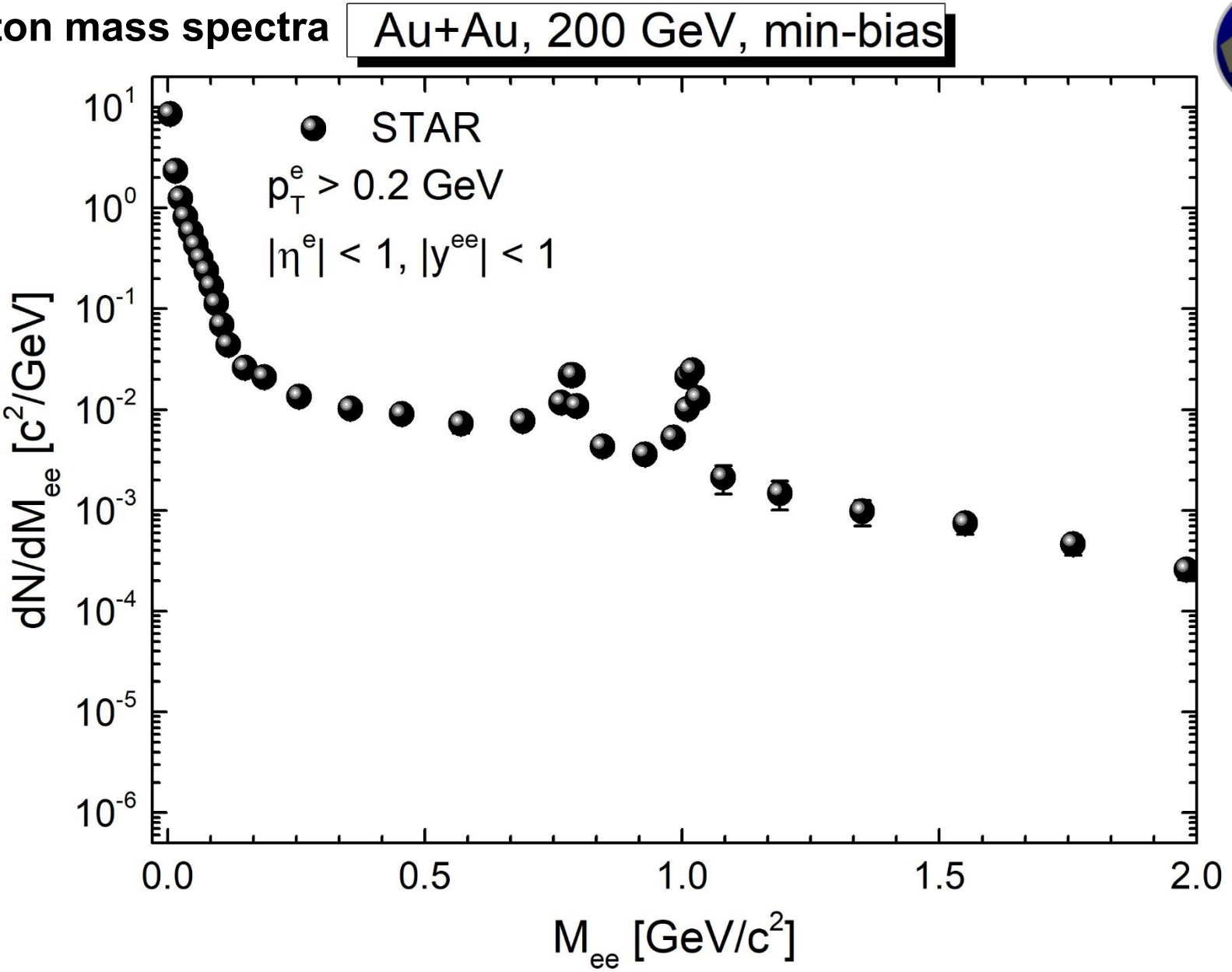
Theoretical constraint on ε^2

$$\frac{dN^{sumU}}{dM} = \varepsilon^2 \frac{dN^{sumU}_{\varepsilon^2=1}}{dM}$$

$$\frac{dN^{sumU}}{dM} = C_U \frac{dN^{sumSM}}{dM}$$

$$\varepsilon^2(M_U) = C_U \cdot \left(\frac{dN^{sumSM}}{dM}\right) \Big/ \left(\frac{dN^{sumU}_{\varepsilon^2=1}}{dM}\right)$$

Dilepton mass spectra



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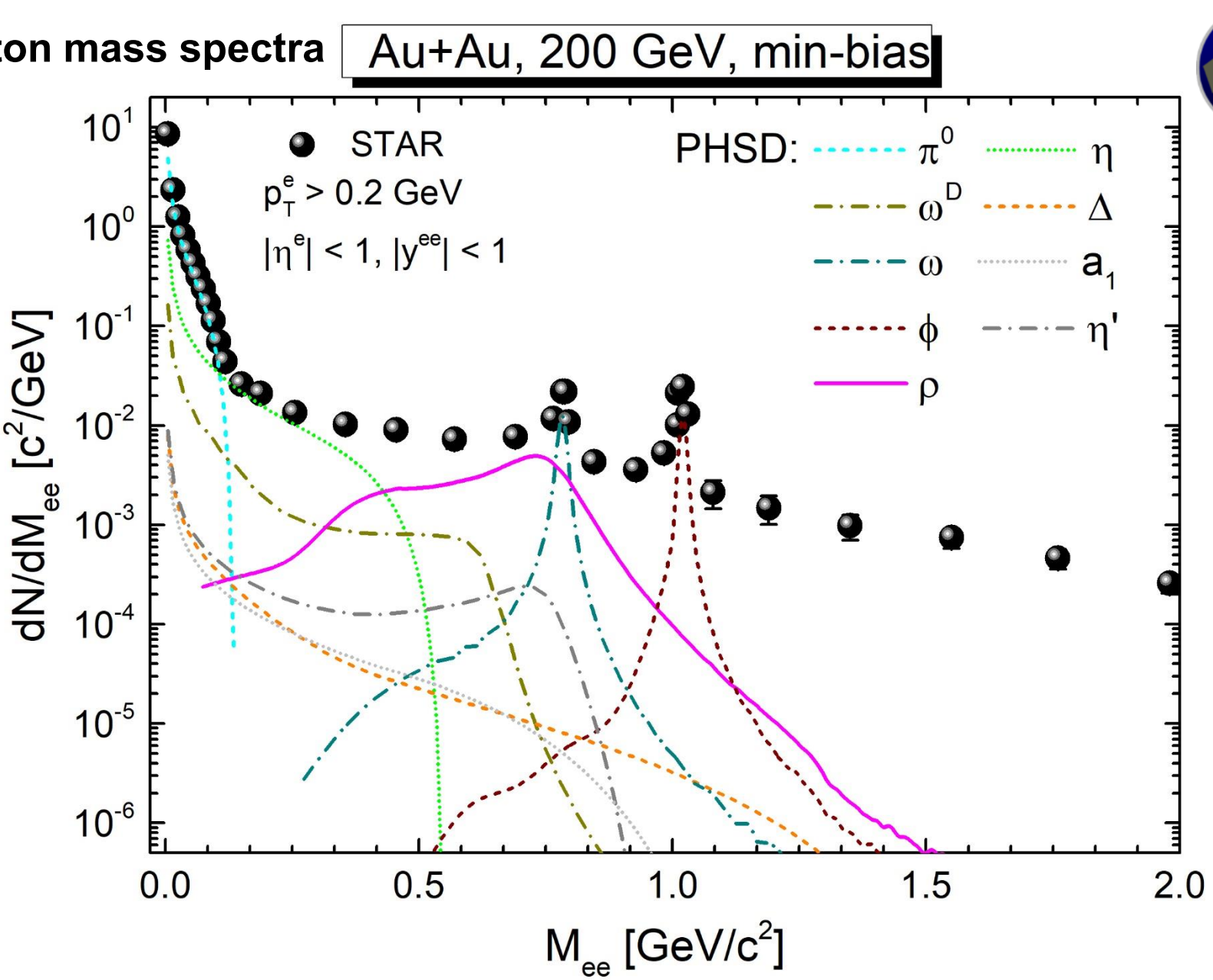

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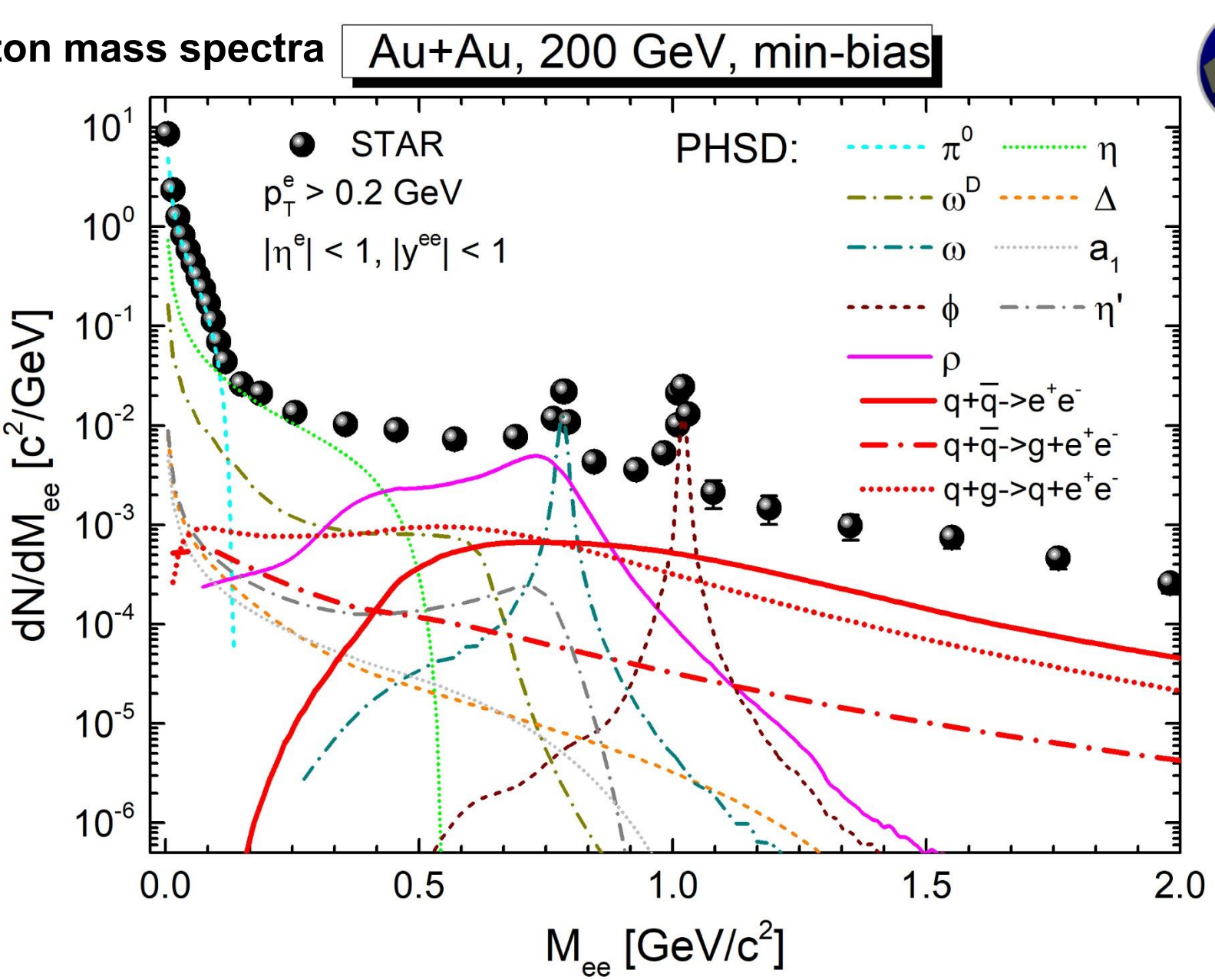

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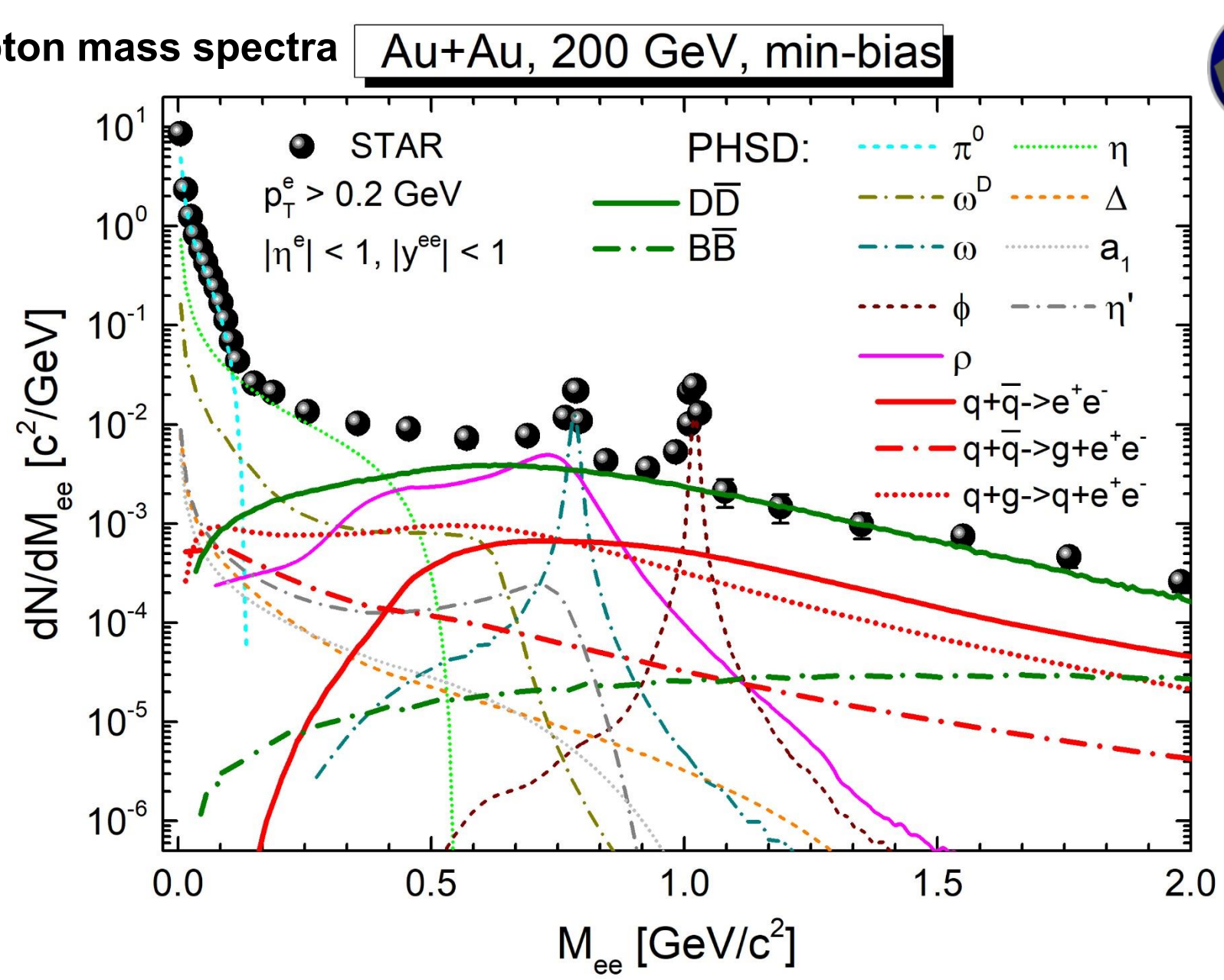
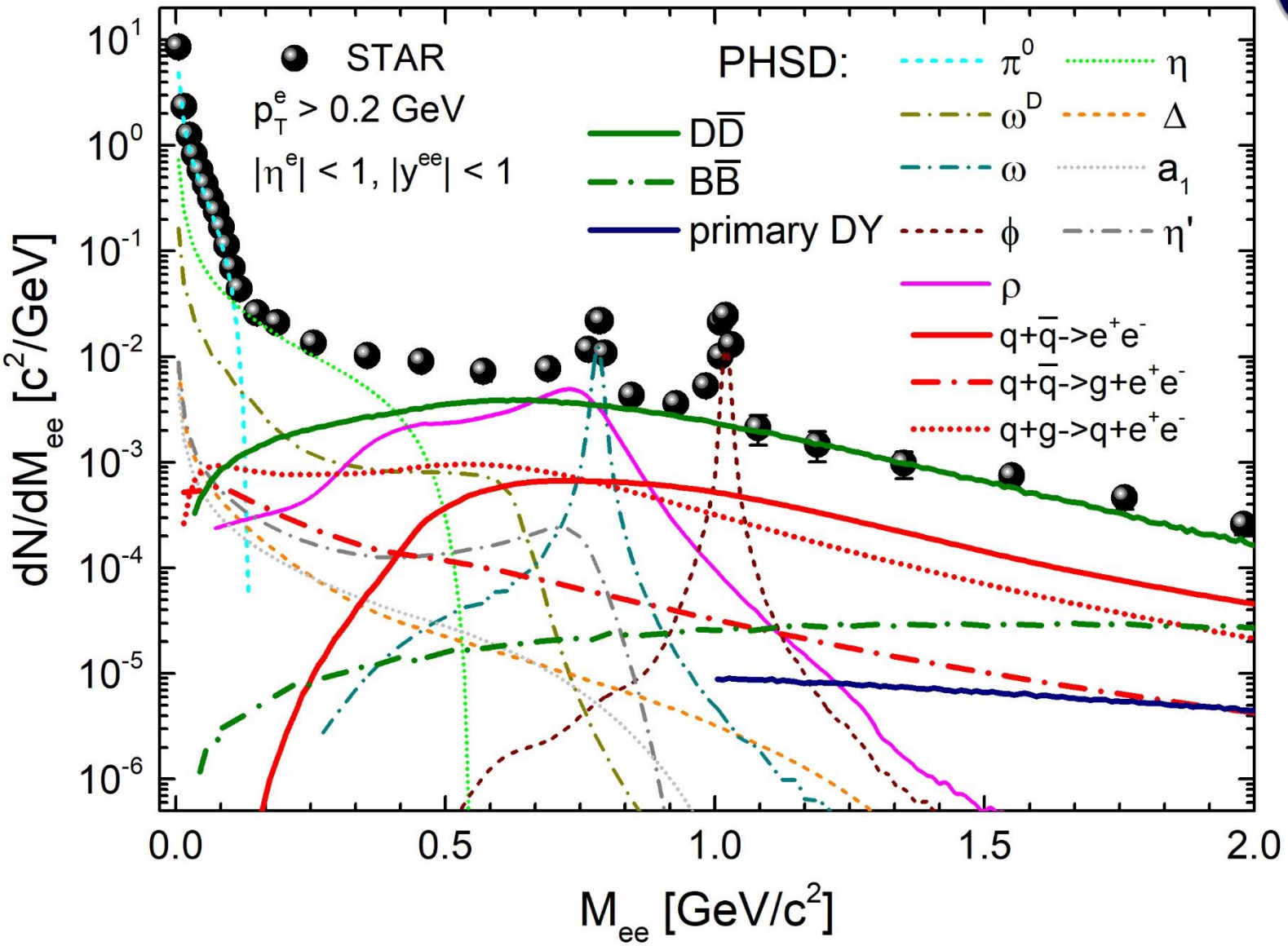


Dilepton mass spectra

Au+Au, 200 GeV, min-bias



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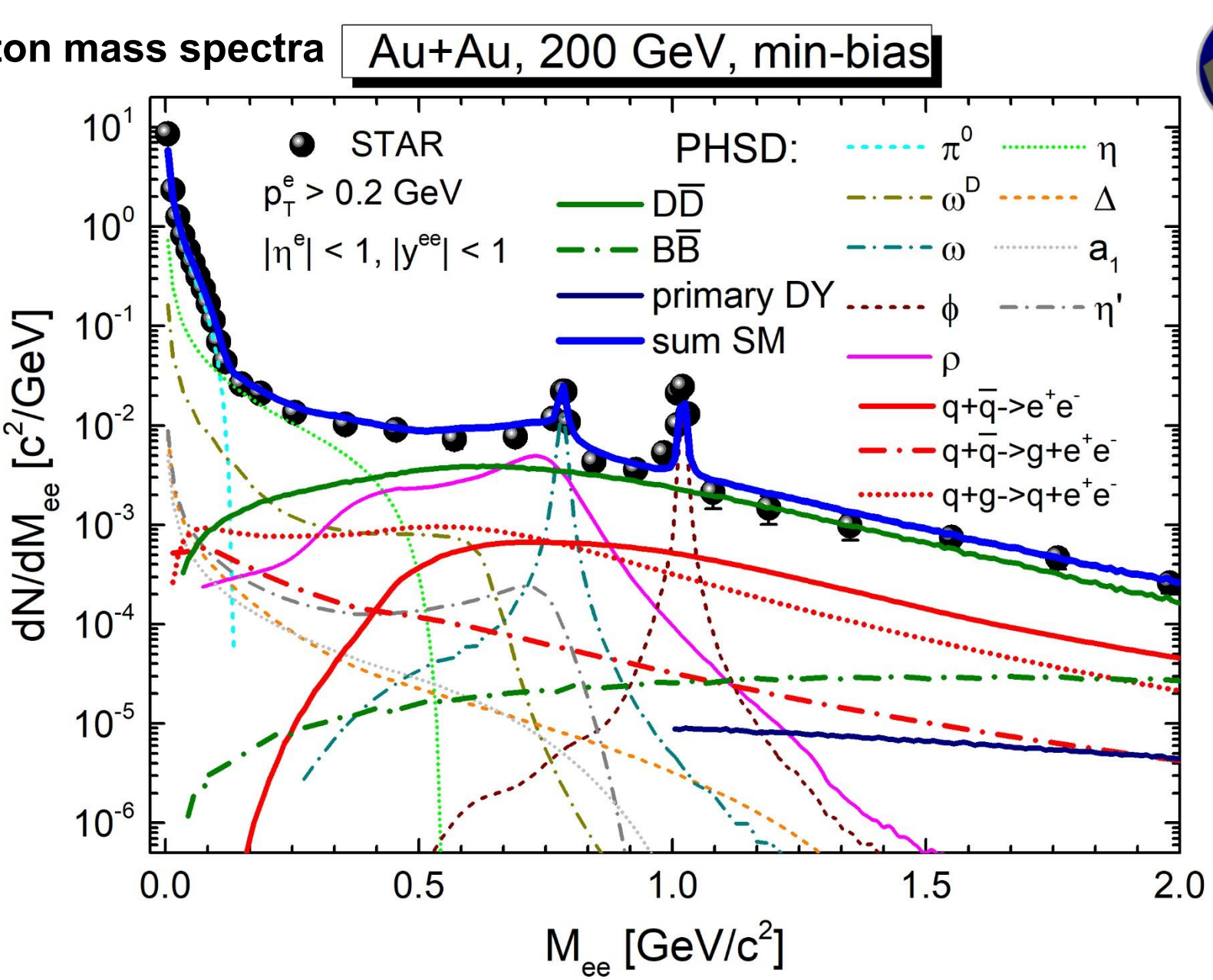
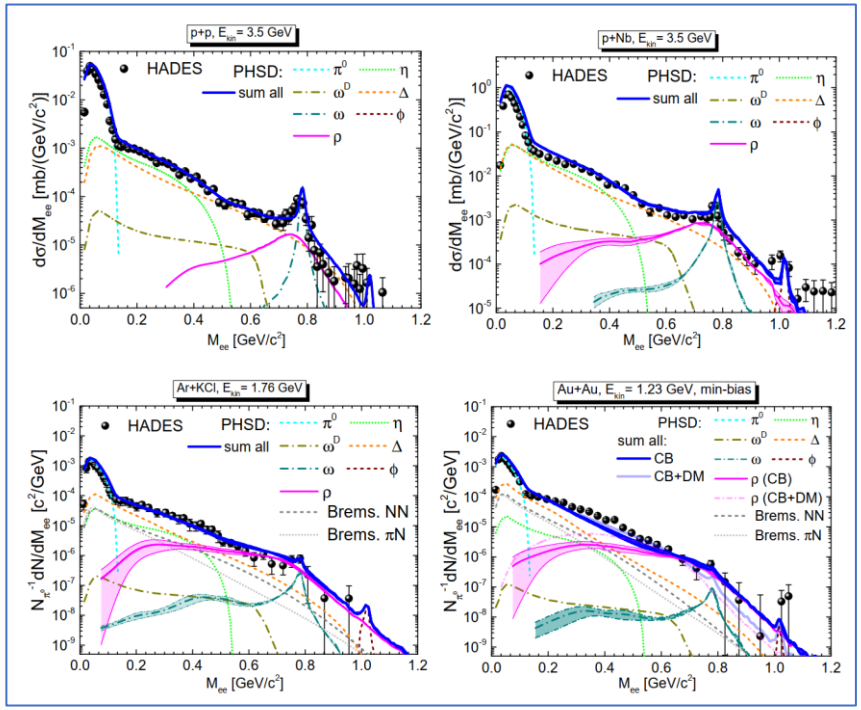
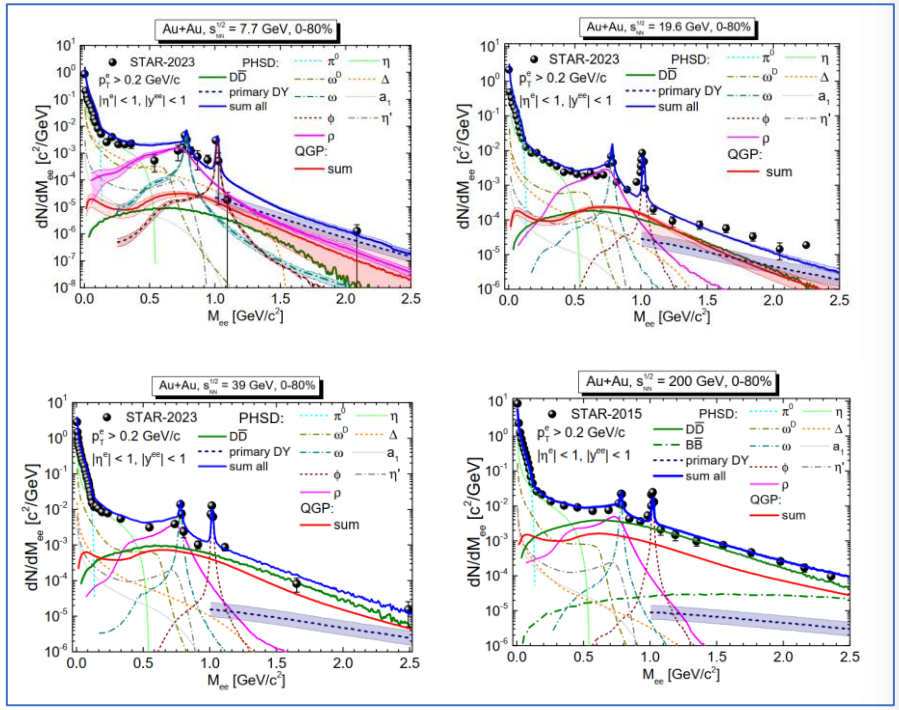


Dilepton spectra from PHSD from SIS to RHIC energies

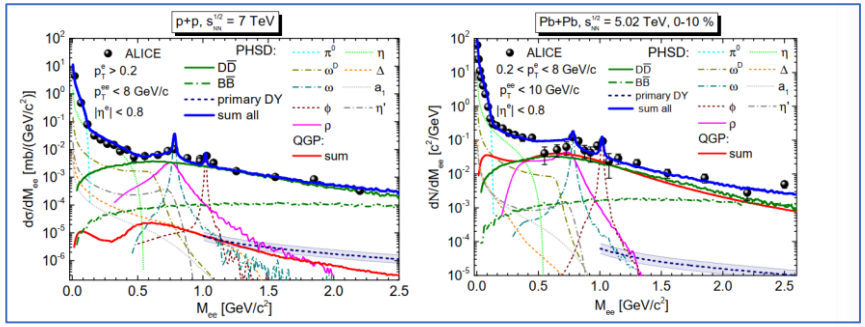
SIS-HADES



BES-RHIC-STAR

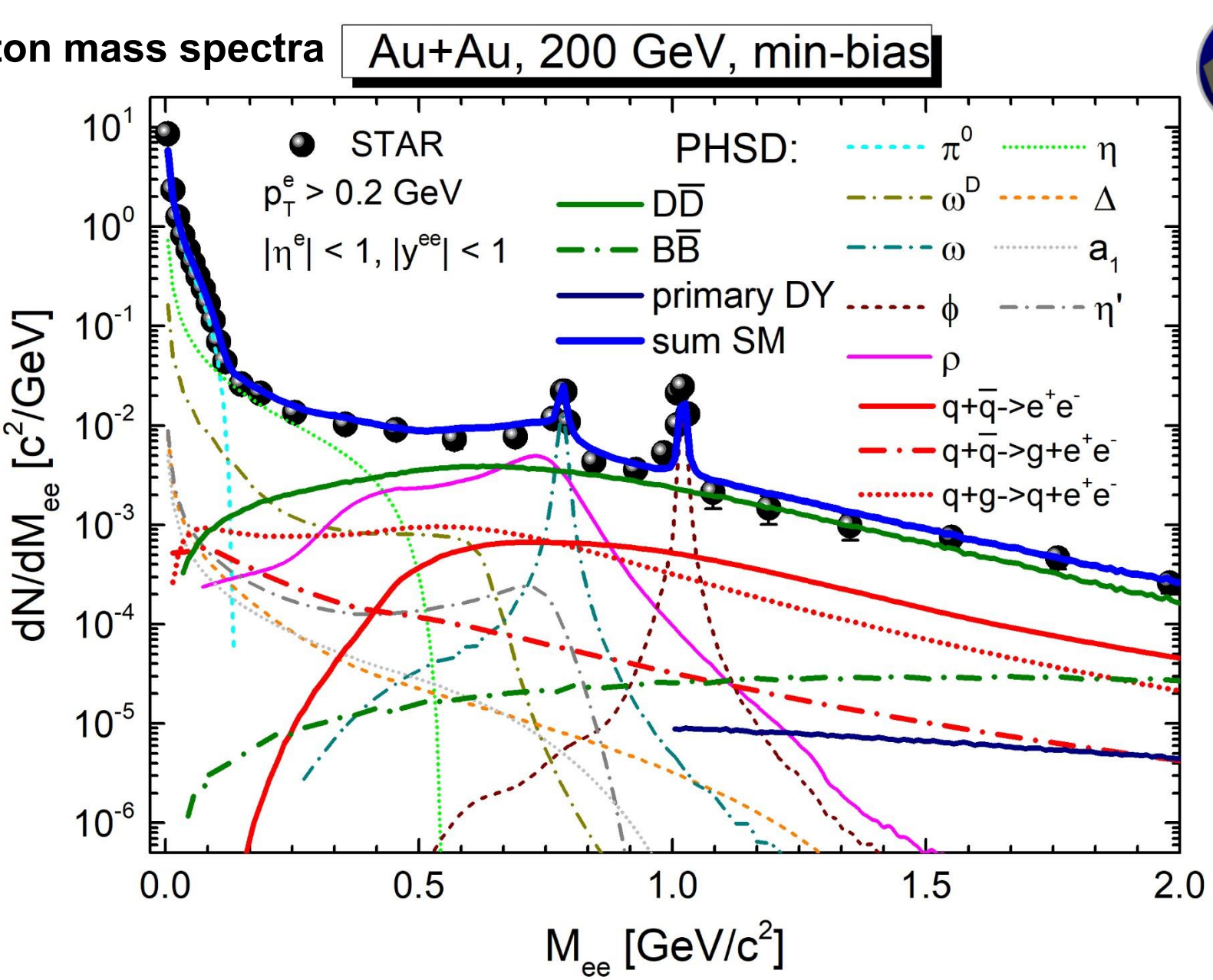


LHC-ALICE



- **The STAR/HADES/ALICE data, i.e. SM contributions (including exp. acceptance) are well described by the PHSD**

Dilepton mass spectra



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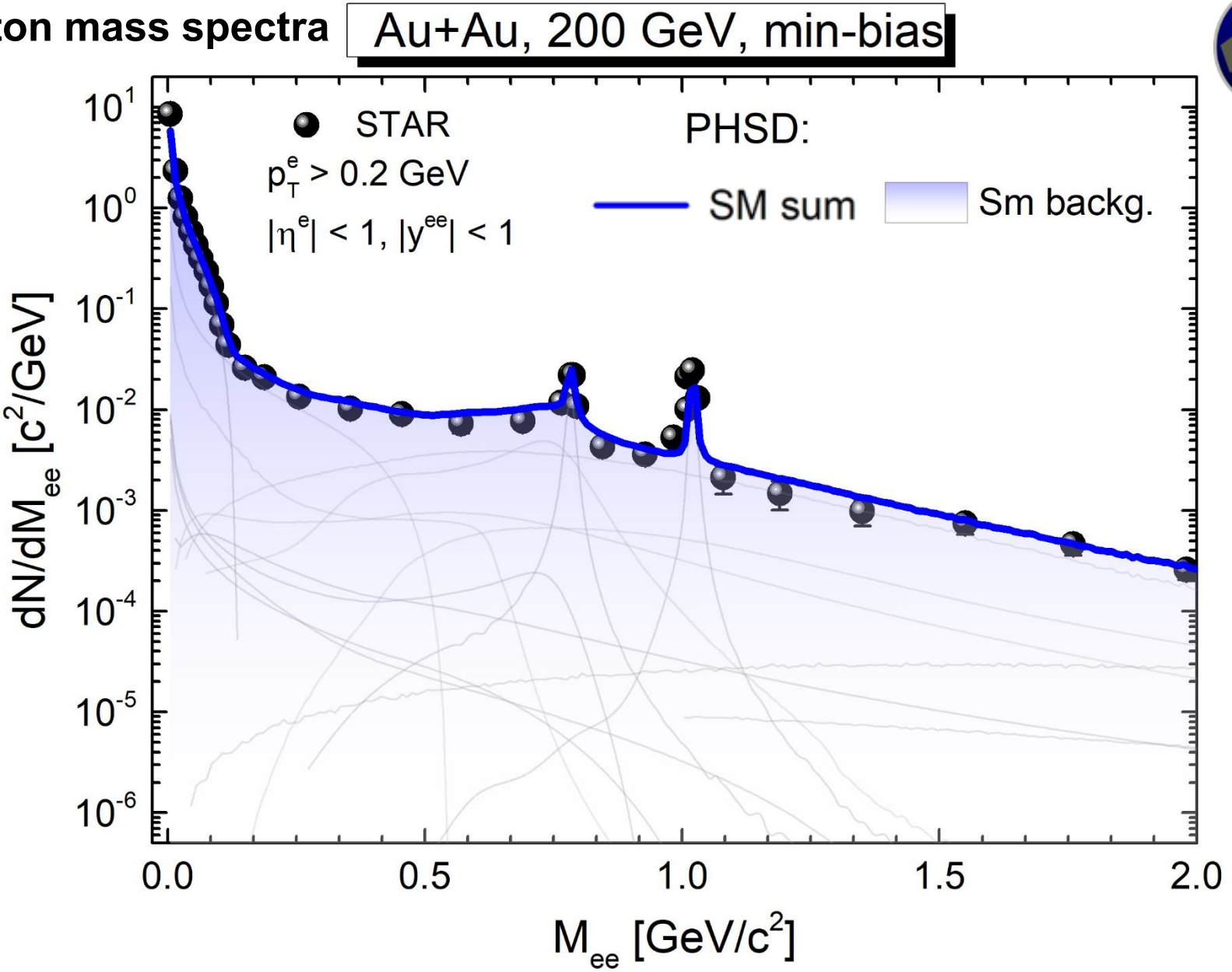

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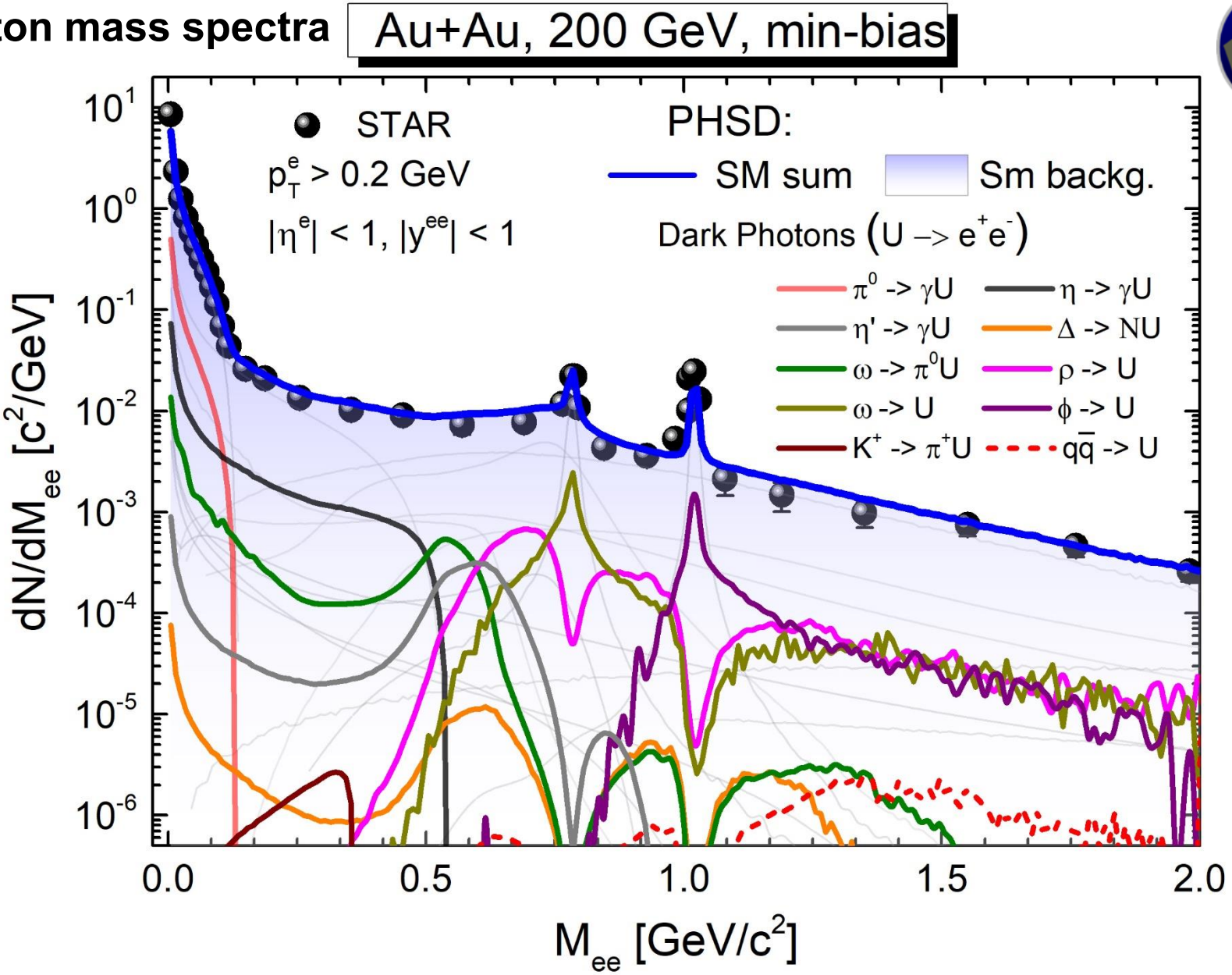

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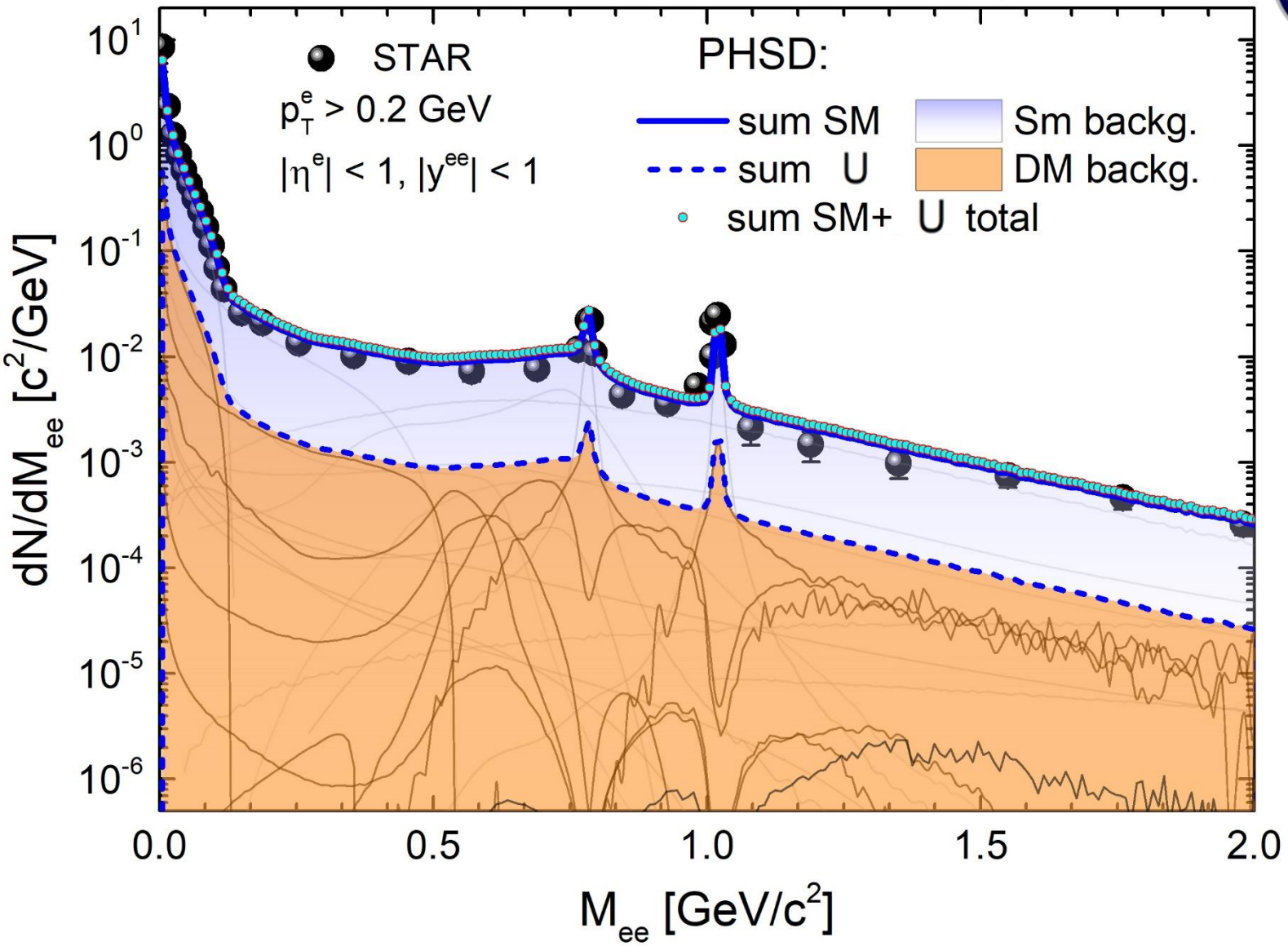

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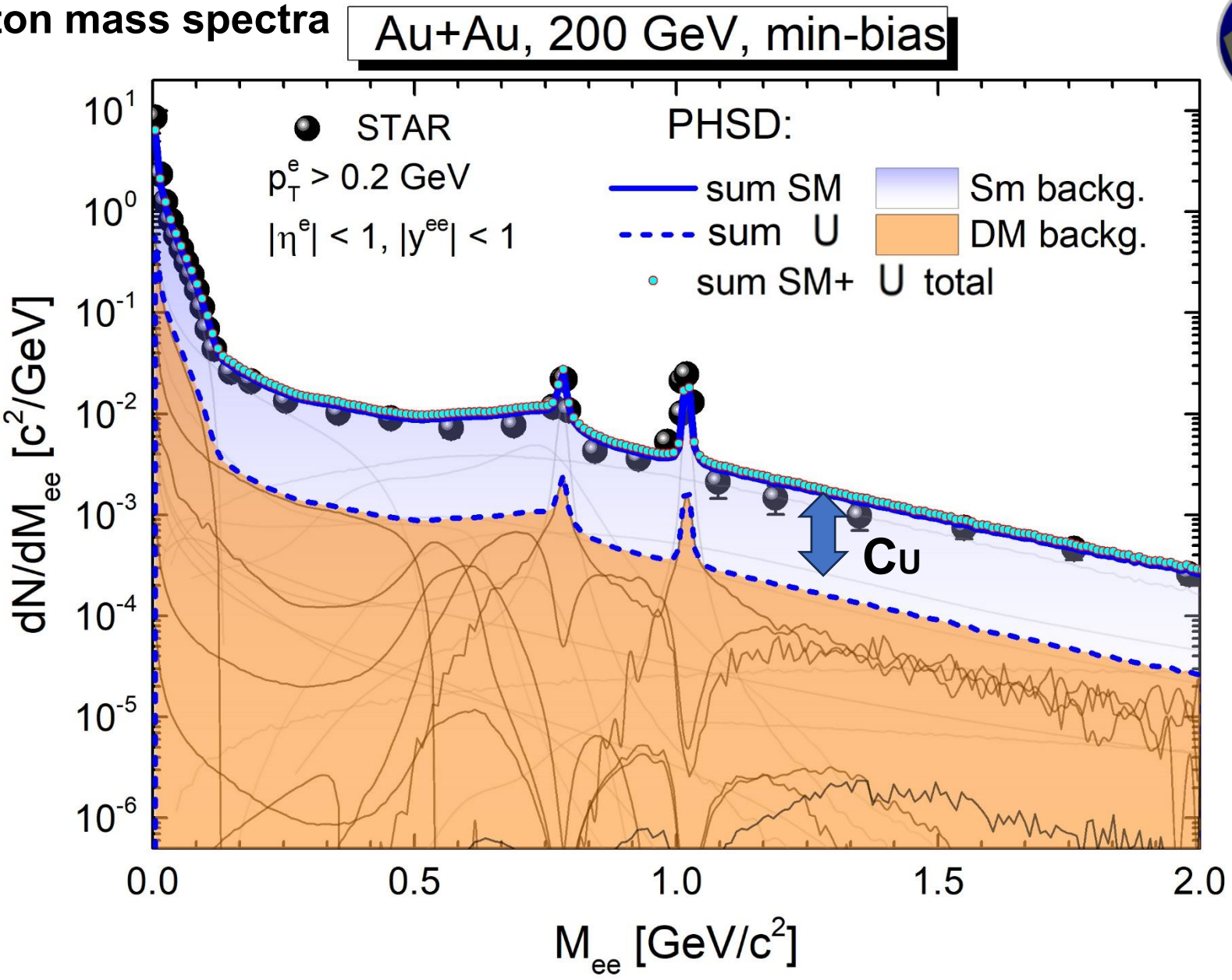
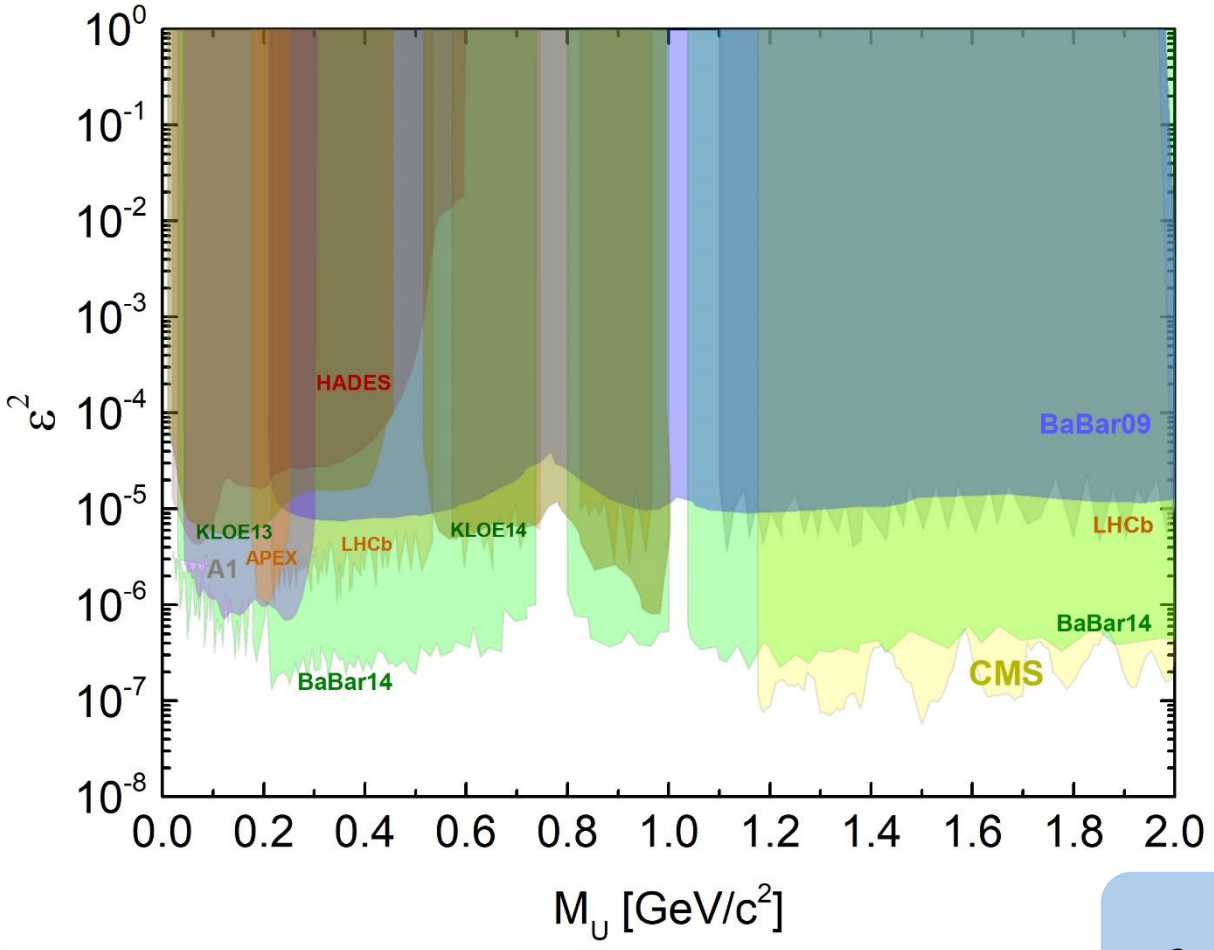
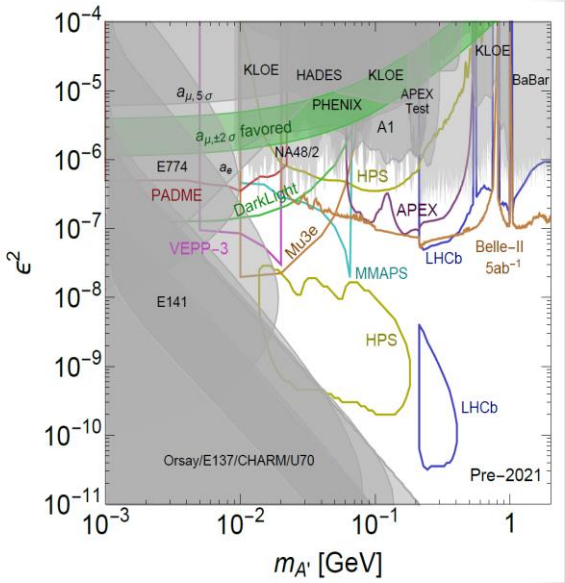


Kinetic Mixing parameter $\varepsilon^2(M_U)$

The upper limit for the kinetic mixing parameter $\varepsilon^2(M_U)$ of dark photons extracted from the PHSD dilepton spectra - with C_U allowed surplus of the total SM yield





J. Alexander et al. (2016), 1608.08632

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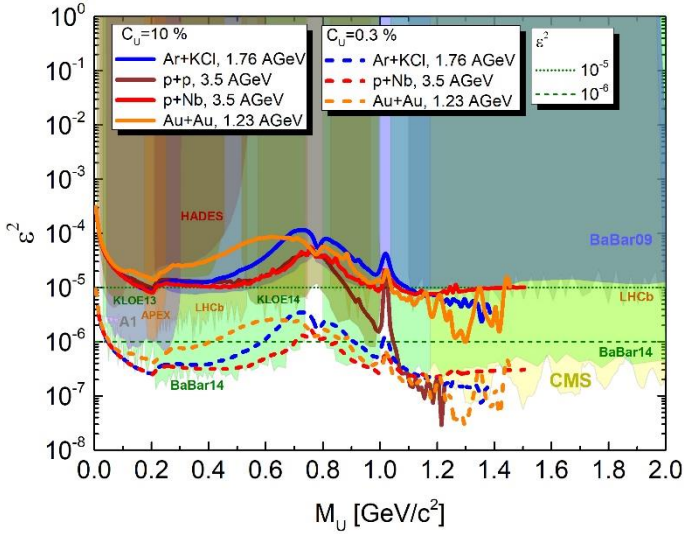

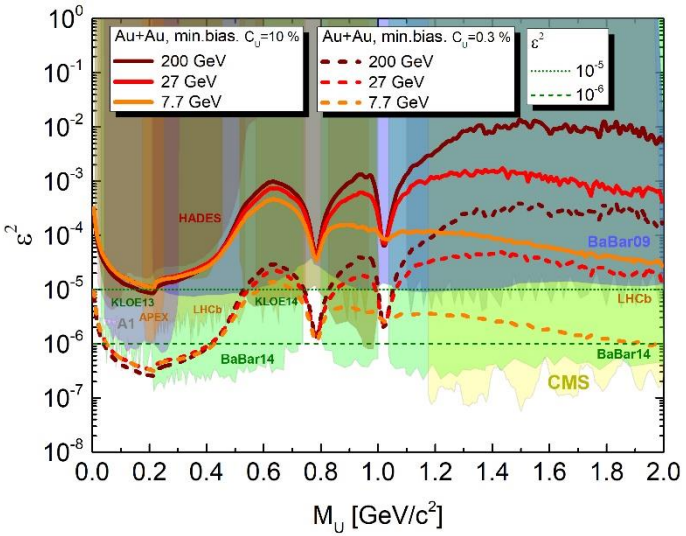

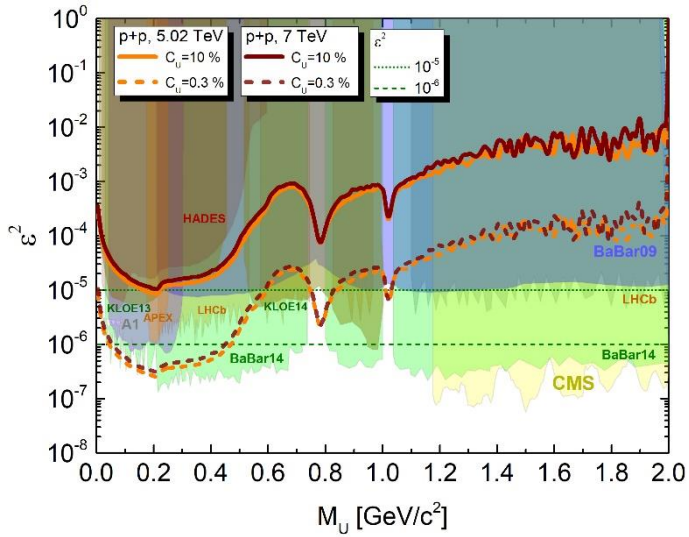

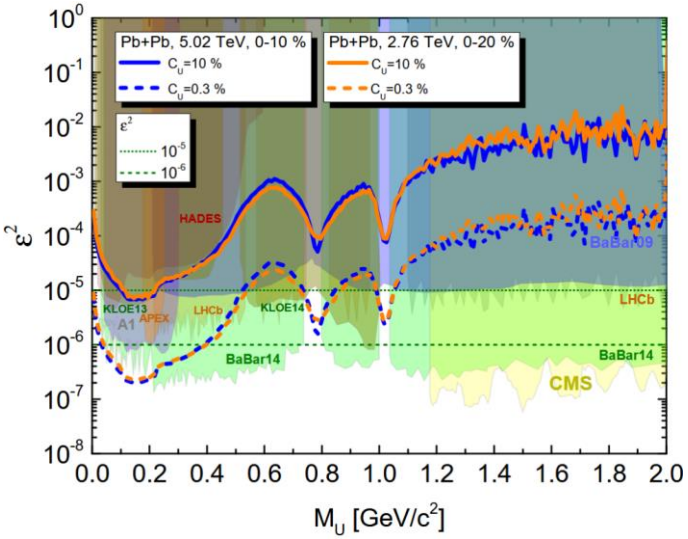

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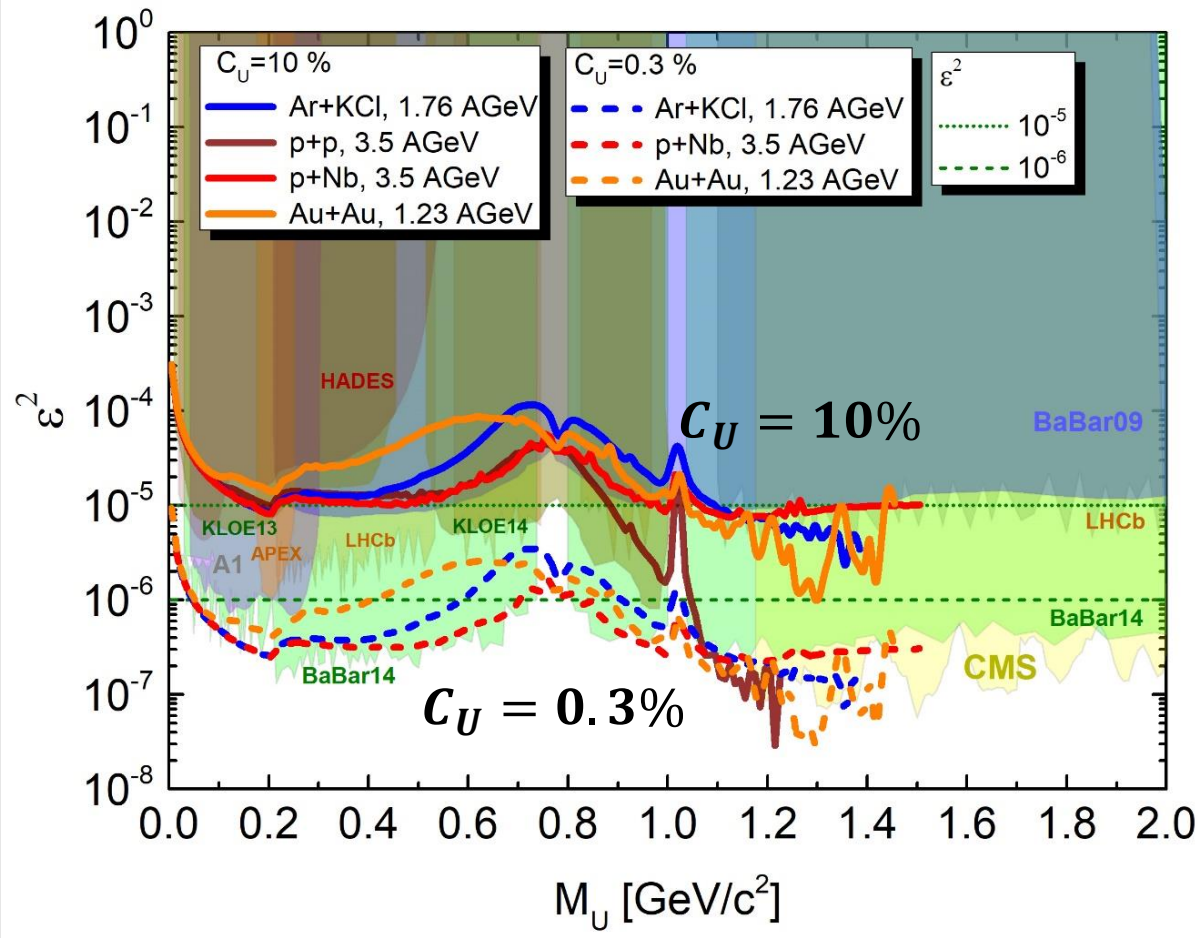

$\varepsilon^2(m_U)$ is consistent with the exp. data from BaBar, KLOE, HADES, A1 for different C_U and $\sqrt{s_{NN}}$ for M_U < 1.2 GeV

Experimental data of high precision are needed to reduce the upper limit for ε^2

Summary

Using C_U = 0.3%, the extracted limits also match BaBar14 results for M_U < 1.5 GeV, indicating a possible 0.3 % dark-photon contribution to the SM dilepton

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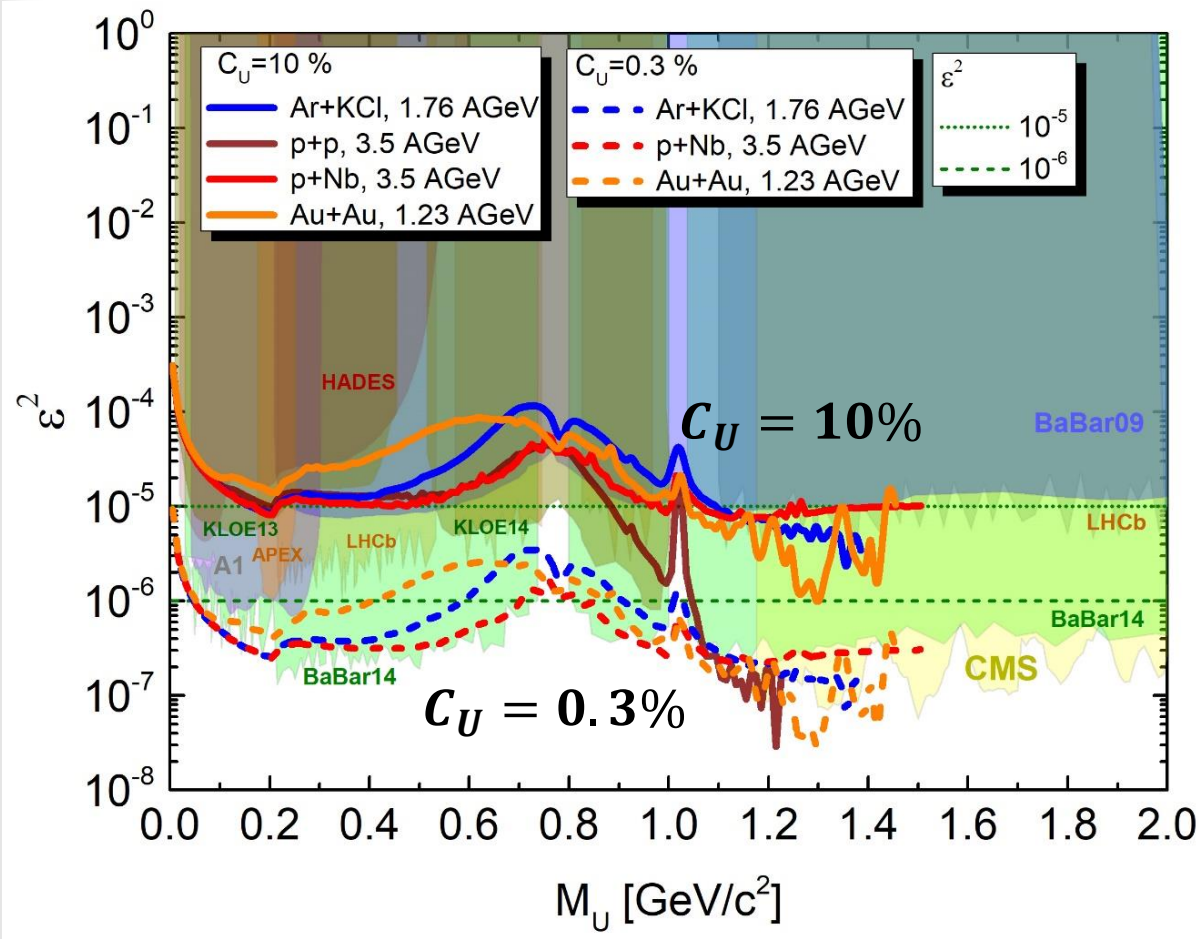

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Thank you for your attention !