Measurements of dielectron production in Au+Au collisions at $\sqrt{s_{NN}}$ = 27, 54.4 and 200 GeV with the STAR experiment

Florian Seck (TU Darmstadt)

for the STAR Collaboration

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

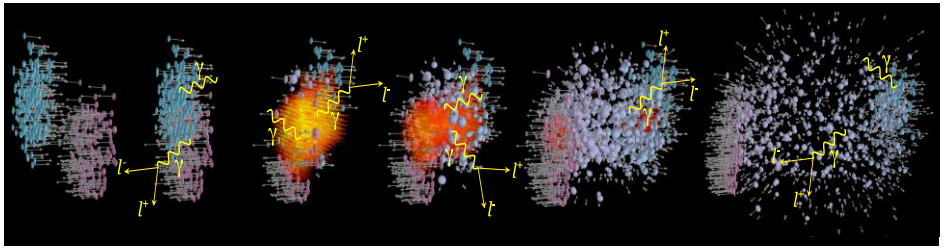
TECHNISCHE UNIVERSITÄT DARMSTADT

In part supported by

U.S. DEPARTMENT OF ENERGY | Office of Science

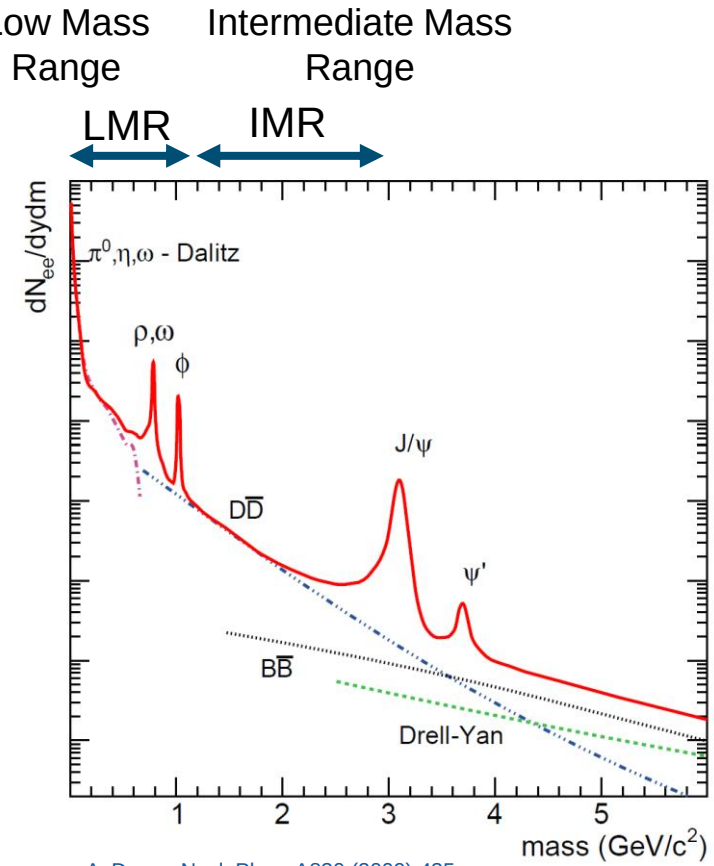
FAIR Phase 0 Research Program

SOURCES OF LEPTON PAIRS



time

- Different sources of correlated lepton pairs contribute at different stages of the collision
- Relative strength of sources depends on collision energy, species, centrality

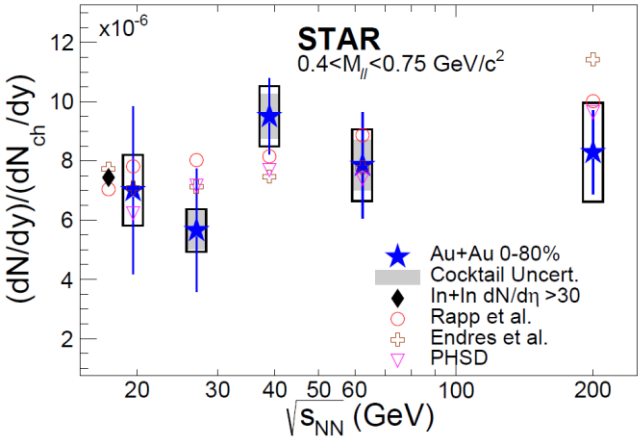


A. Drees: Nucl. Phys. A830 (2009) 435

MAPPING THE QCD PHASE STRUCTURES WITH DILEPTONS

Excess yield in low mass window tracks fireball lifetime

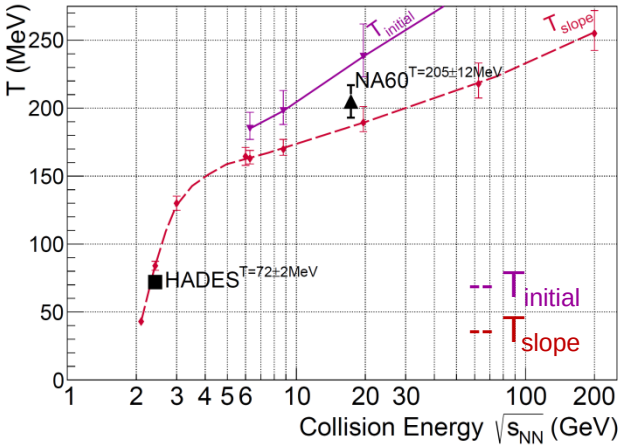
Search for "**extra radiation**" around **phase transition** (& **critical point**?)



STAR: PLB 750 (2015) 64, arXiv:1810.10159 [nucl-ex]

Invariant mass slope measures radiating source temperature (no blue shift)

Flattening of caloric curve (T vs $\sqrt{s_{NN}}$) → evidence for a **phase transition**



R. Rapp, H. van Hees: PLB 753 (2016) 586
FS *et al.*: EPJ A 52 (2016) 131
NA60: Chiral 2010, AIP Conf.Proc. 1322 (2010) 1
HADES: Nature Phys. 15 (2019) 1040

- **Ongoing**
  - STAR
  - HADES
  - ALICE
- **In addition**
  - CBM
  - MPD
  - NA60+
  - J-PARC HI

COMPONENTS OF EM PROBES

- **Phenomenological tools** → excitation functions
  - T_{slope}, excess yield and shape, T_{eff} vs. mass, v_2 vs. mass, polarization

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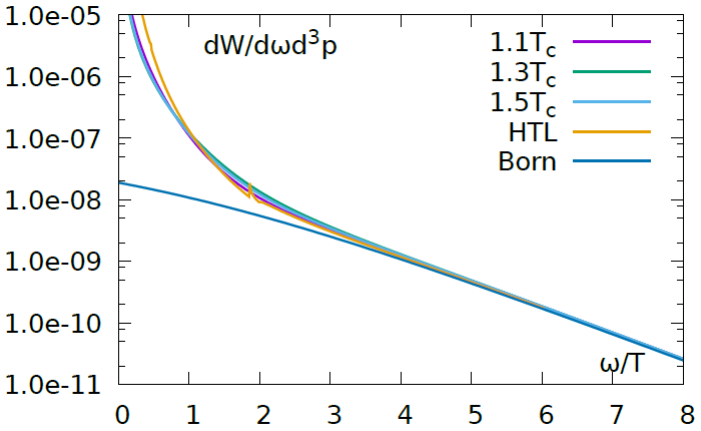

- **Phenomenological tools** → excitation functions
  - T_{slope}, excess yield and shape, T_{eff} vs. mass, v_2 vs. mass, polarization
- **Degrees of freedom** of the medium
  - Spectral function merges into QGP description
    - → Direct evidence for transition from hadrons to quarks & gluons

H. Ding, et. al: PRD 94 (2016) 034504

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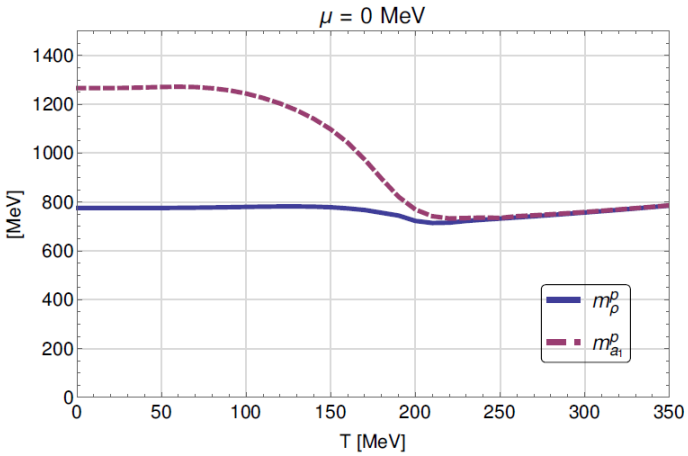

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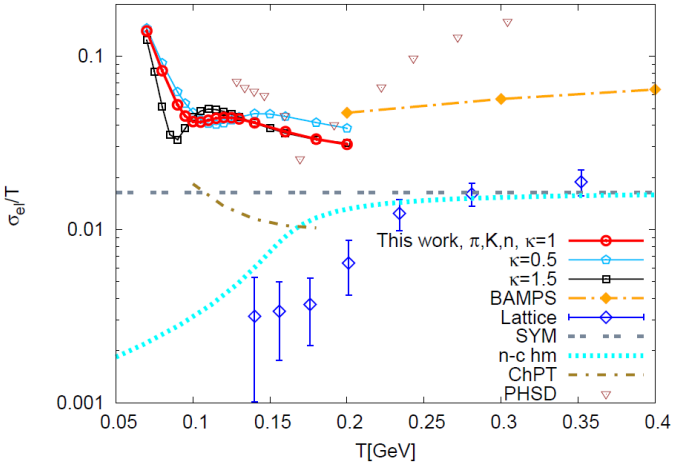
- **Restoration of chiral symmetry** $\int \frac{ds}{\pi s}(\mathrm{Im}\Pi_V - \mathrm{Im}\Pi_A) = -m_q \langle 0|\bar{q}q|0\rangle$
  - Mixing of vector and axial-vector correlators

C. Jung, L. v. Smekal: arXiv: 1909.13712 [hep-ph]
R.-A. Tripolt, et. al: Nucl. Phys. A982 (2019) 775
C. Jung, et al.: PRD 95 (2017) 036020

COMPONENTS OF EM PROBES



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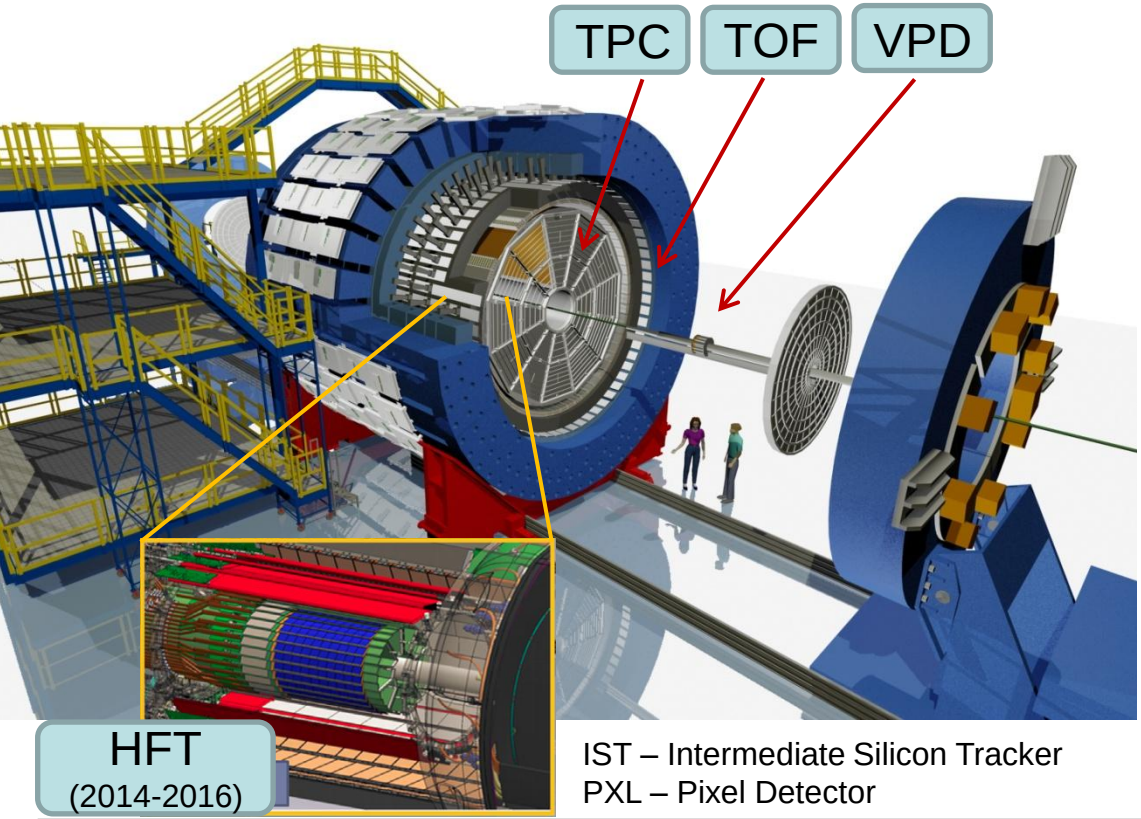
  - Mixing of vector and axial-vector correlators
- **Transport properties** $\sigma_{EM}(T) = -e^2 \lim_{q_0 \to 0}\left[\frac{\partial}{\partial q_0}\mathrm{Im}\Pi_{EM}(q_0, q=0;T)\right]$
  - Electric conductivity → probes soft limit of EM spectral function

M. Greif, et al.: PRD93 (2016) 096012
J. Atchison and R. Rapp: J. Phys. Conf. Ser. 832 (2017) 012057

STAR – SOLENOIDAL TRACKER AT RHIC

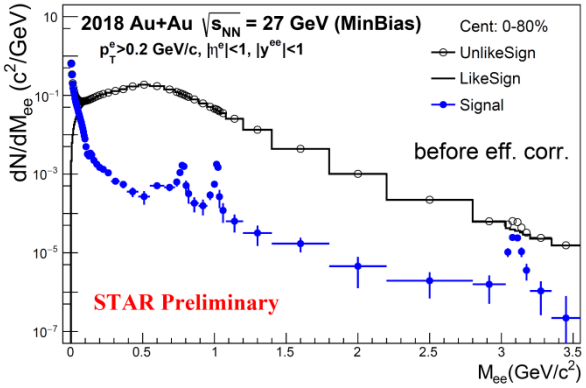


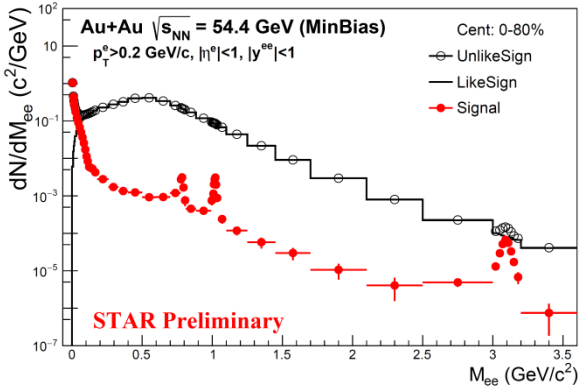
IST – Intermediate Silicon Tracker
PXL – Pixel Detector

- 27 GeV
  - Larger data set compared to submitted BES-I results
- 54.4 GeV
  - New energy for dielectron excitation function
- 200 GeV with HFT
  - Suppress $c\bar{c}$ contribution to the IMR
  - DCA resolution better than 50μm at p_T = 1 GeV/c

Year	$\sqrt{s_{NN}}$ (GeV)	Analyzed events (M)
2018	27	500
2017	54.4	875
2014	200	860

RAW SPECTRA



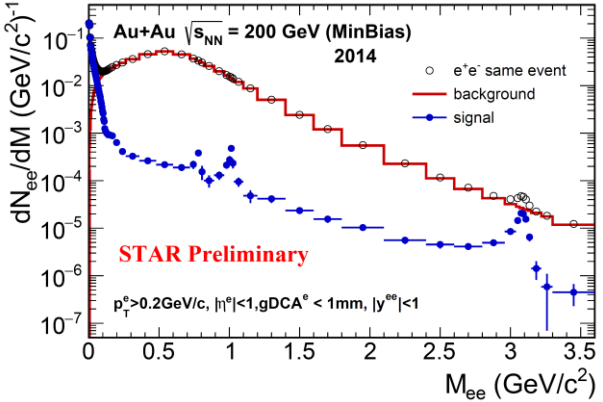


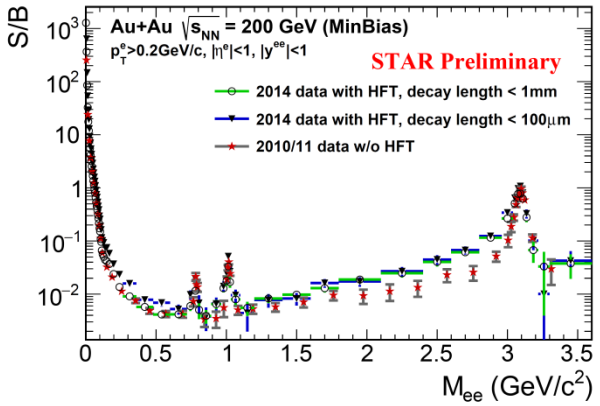
- Raw spectra in 0-80% centrality (MinBias)

  at 27, 54.4 and 200 GeV

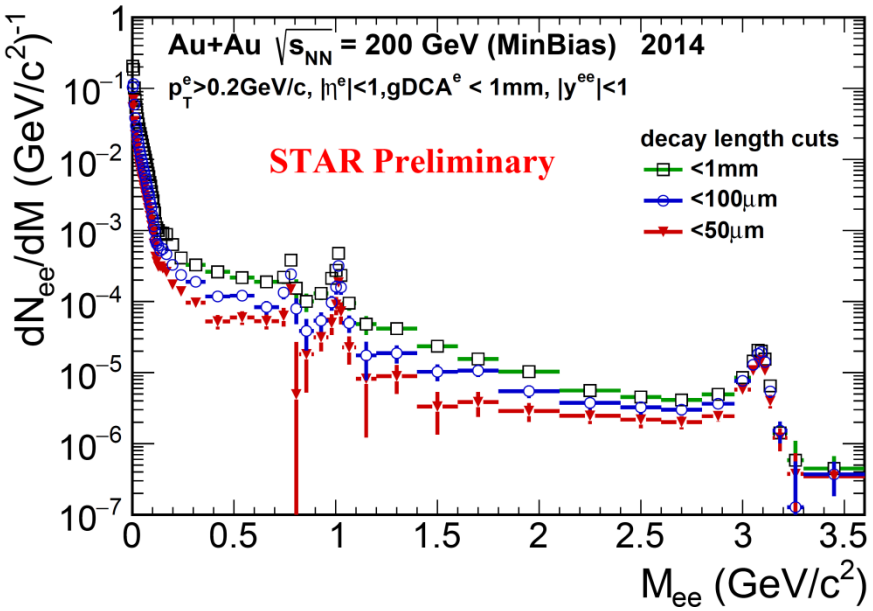
- For 200 GeV:
  - Additional material close to beam pipe

    → Increased photon conversion background
  - Utilizing HFT data on the tracks gives similar S/B ratio as 2010/11 data without HFT

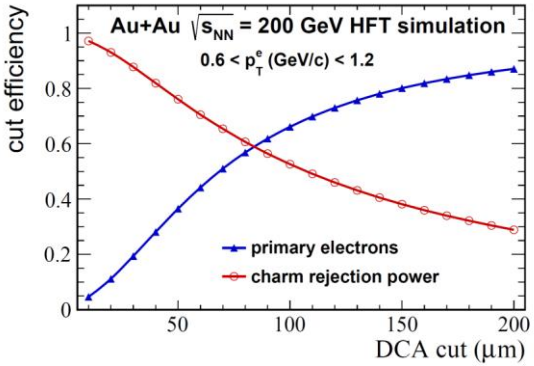




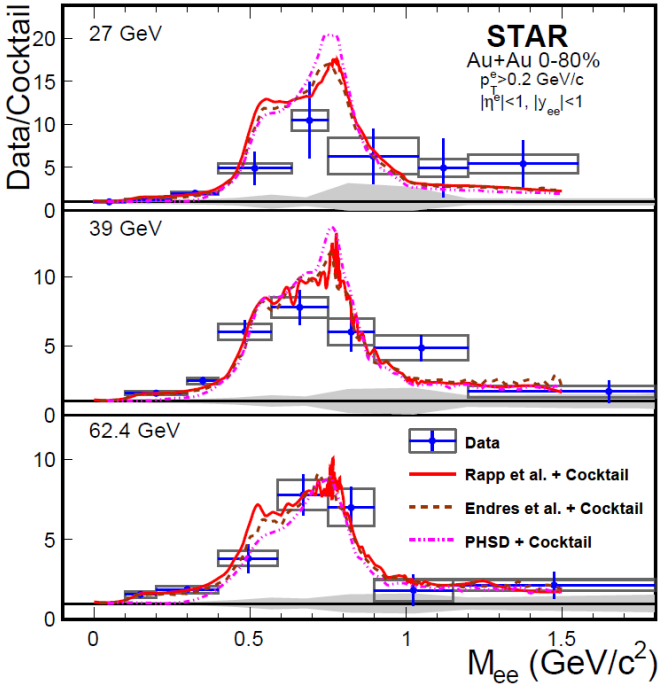
DECAY TOPOLOGY CUTS



- Decay topology cuts show strong effect on the IMR
  - Slope change ⟶ hint to $c\bar{c}$ contribution
  - MC studies of topological selections to reduce semi-leptonic charm decay contribution ongoing
  - Unfolding with DCA resolution & momentum
  - More Au+Au data with HFT (2016) on tape



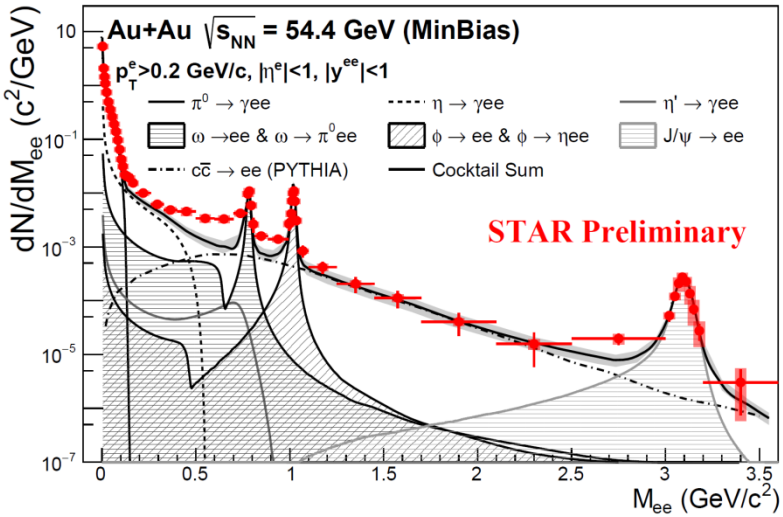
BES-I DATA COMPARISON TO THEORY

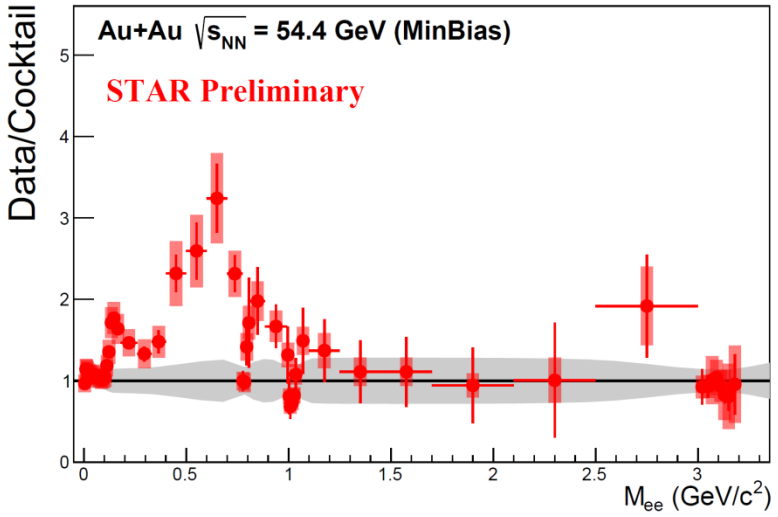


- Data / cocktail ratio in STAR acceptance
  - ω and ϕ subtracted from data and cocktail
  - Theory calculations consistent with data
- Reduce data uncertainties with new measures at 27 and 54.4 GeV
  - Factor ~10 more data compared to BES-I in 2010/11

STAR: arXiv:1810.10159 [nucl-ex]
Rapp et al.: PRC 63 (2001) 054907, PRL 97 (2006) 102301
Endres et al.: PRC 91 (2015) 054911, PRC 94 (2016) 024912
PHSD: Nucl. Phys. A831 (2009) 215, Prog. Part. Nucl. Phys. 87 (2016) 50

EFFICIENCY CORRECTED SPECTRA: 54.4 GeV

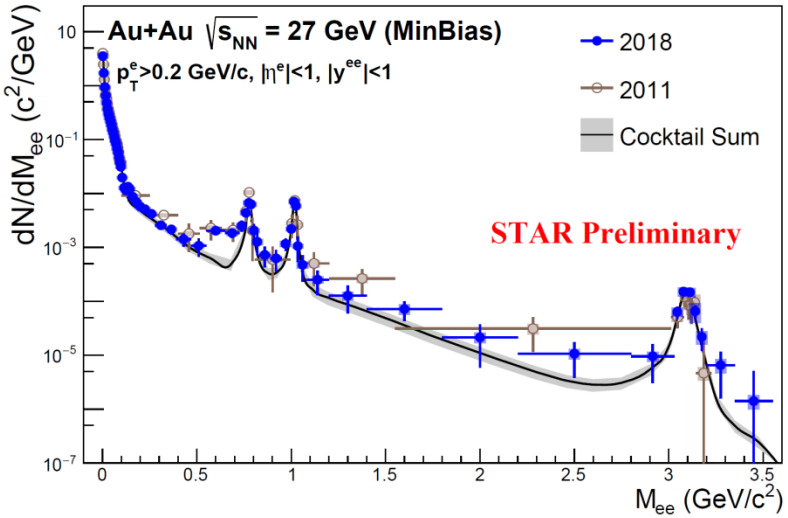


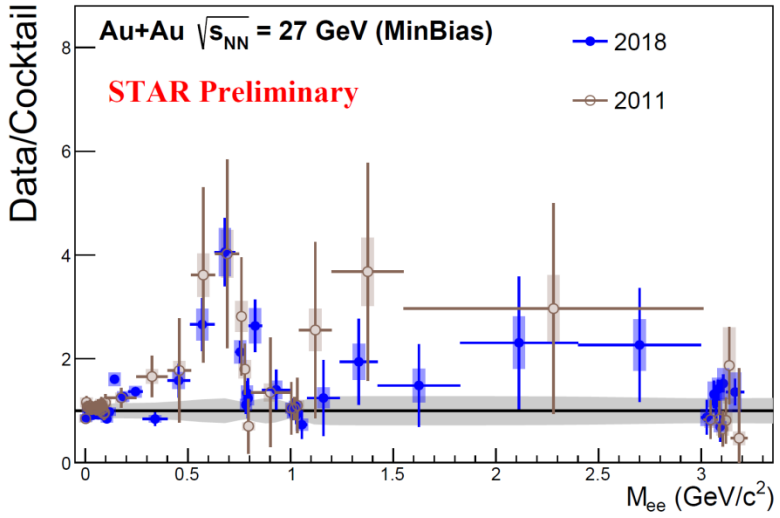


- 54.4 GeV: first e^+e^- measurement at this energy
  - Excess over the cocktail in the LMR with increased significance compared to 62.4 GeV
  - IMR consistent with cocktail
- Enough statistics for differential measurements vs p_T, centrality, etc.

Poster 329 (EM8) by Zhen Wang

EFFICIENCY CORRECTED SPECTRA: 27 GeV

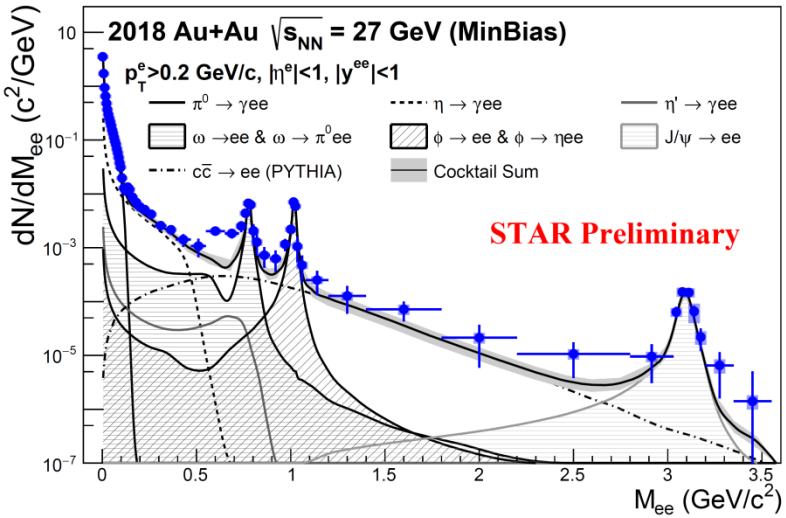


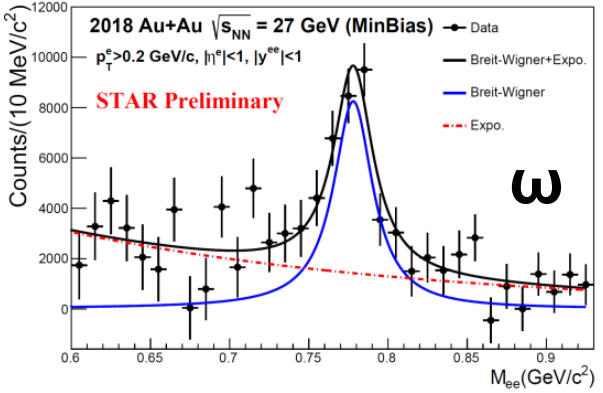


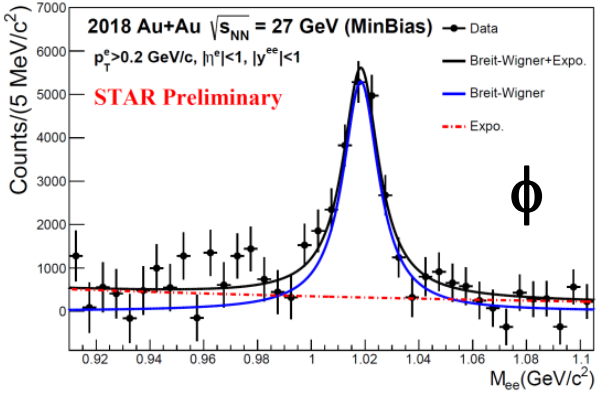
- 27 GeV: improved statistics consistent with submitted data (2011)
  - Lower charm cross section → hint of excess in the IMR at 1.7 σ level
  - Correlated $c\bar{c}$ gives upper limit on charm contribution

Poster 387 (EM10) by Zaochen Ye

EFFICIENCY CORRECTED SPECTRA: 27 GeV



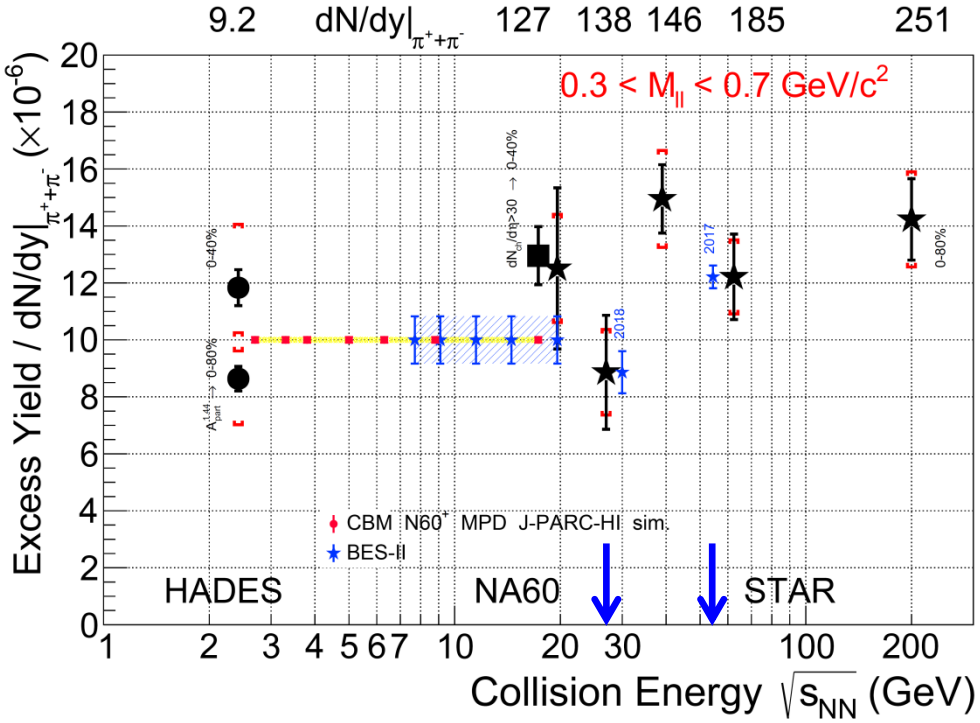




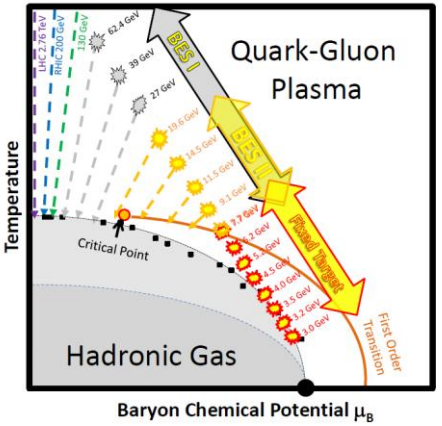
- Constrain cocktail with direct measurement of ω, ϕ, (J/Ψ) in e^+e^- channel

Poster 387 (EM10) by Zaochen Ye

FILLING IN THE EXCITATION FUNCTION



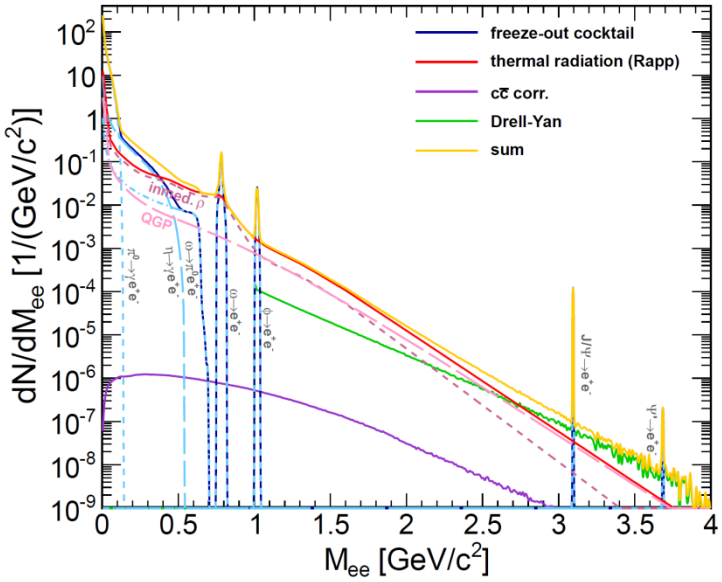
- Excess yield scaled by $dN/dy|_{\pi^+\pi^-}$ from SIS to top RHIC energy
- Expected statistical precision for new measurements at 27 & 54.4 GeV added
- Projections for BES-II program



NA60: Chiral 2010, AIP Conf.Proc. 1322 (2010) 1
STAR: PLB 750 (2015) 64, arXiv:1810.10159 [nucl-ex]
HADES: Nature Phys. 15 (2019) 1040

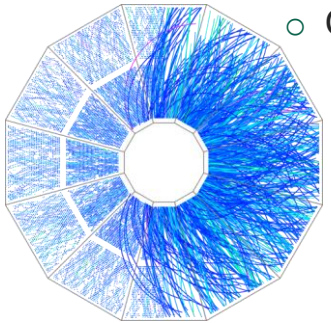
FUTURE

example spectrum at $\sqrt{s_{NN}}$ = 7 GeV



Freeze-out : A. Andronic, et. al: PLB 673 (2009) 142
Thermal radiation: R. Rapp, J. Wambach: Adv. Nucl. Phys. 25 (2000) 1
Drell-Yan & charm: P. Bhaduri, et. al: PRC 89 (2014) 044912

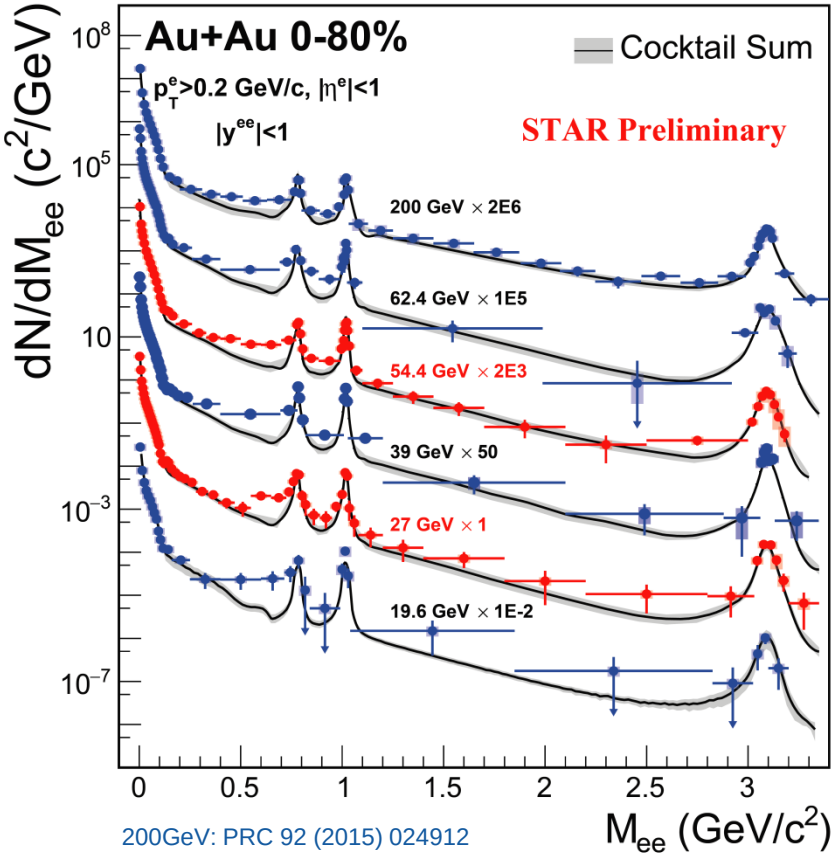
- BES-II in full swing
  - Measurement of e^+e^- spectra at $\sqrt{s_{NN}}$ between 7.7 GeV and 19.6 GeV
  - Reduced charm cross section enhances sensitivity to thermal radiation
  - Data from 19.6 & 14.6 GeV already on tape
  - Enhanced tracking & particle identification capabilities due to iTPC and eTOF upgrades
    - Change the rapidity window
      - → Study total baryon density dependence



Detector upgrade talk by Yi Yang, Tue 16:20

SUMMARY & OUTLOOK

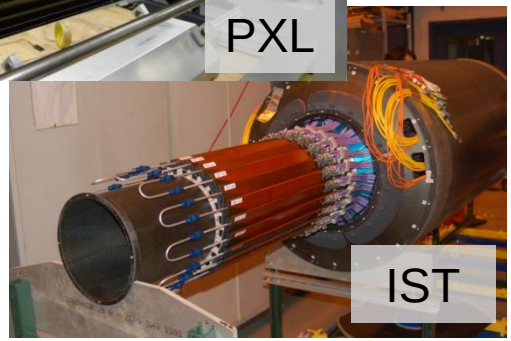
- New measurements for e^+e^- at 27 & 54.4 GeV
  - High statistics will allow differential studies
  - Constrain contribution of thermal radiation to the spectrum
- 200 GeV e^+e^- with HFT
  - Comparable S/B to previously published data without HFT
  - Decay topology cuts increase sensitivity to the thermal QGP radiation in the IMR
- BES-II has started
  - Fill in excitation function of dielectron production between 7.7 and 19.6 GeV

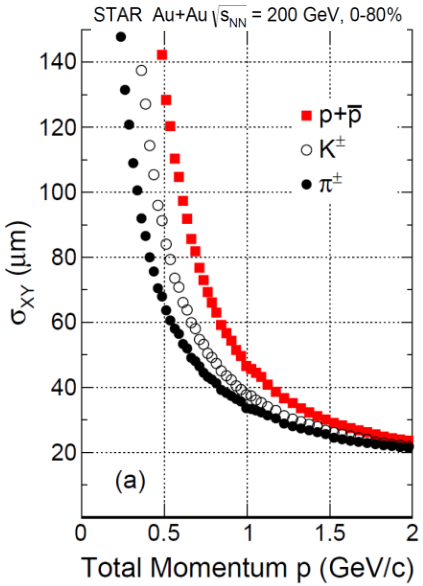


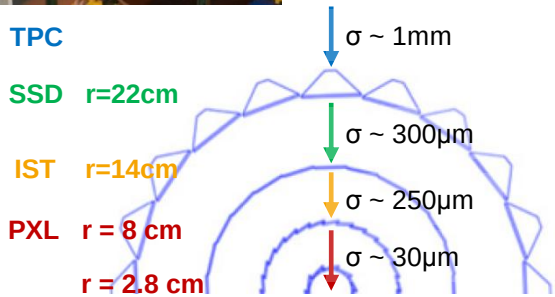
200GeV: PRC 92 (2015) 024912
19.6 GeV: PLB 750 (2015) 64
62.4 & 39 GeV: arXiv:1810.10159 [nucl-ex]

BACKUP

HFT PERFORMANCE



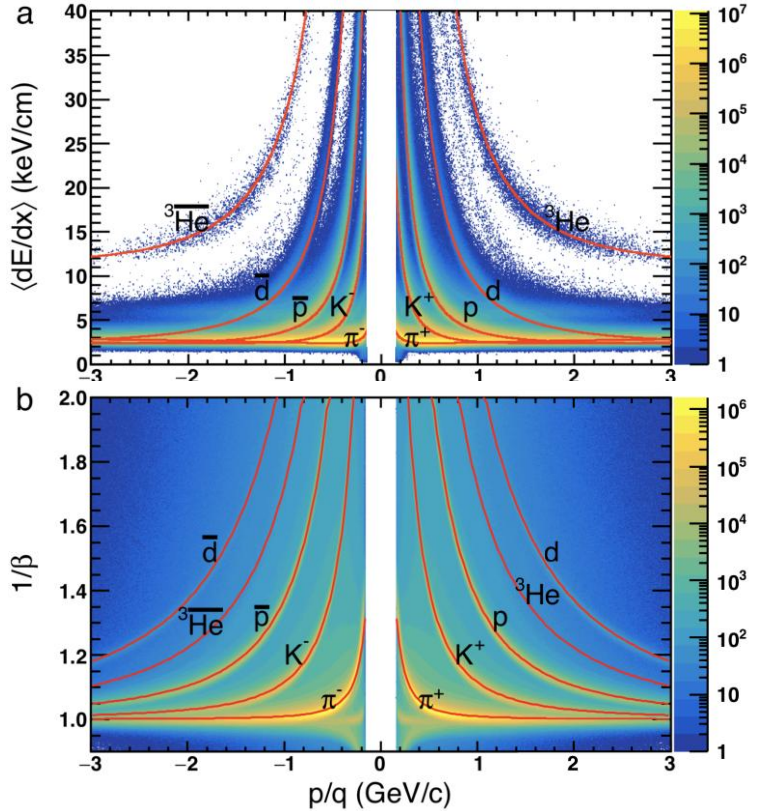




Tracking inwards with gradually improved resolution

- Heavy Flavor Tracker
  - SSD – Silicon Strip Detector
  - IST – Intermediate Silicon Tracker
  - PXL – Pixel Detector
    - First application of MAPS technology in collider experiments
    - Pitch size 20x20 μm^2
    - Thickness of first layer 0.5%X_0 (2014)
- Acceptance
  - $-1 < \eta < 1$
  - $0 < \varphi < 2\pi$
- Good DCA resolution of particle track to collision point

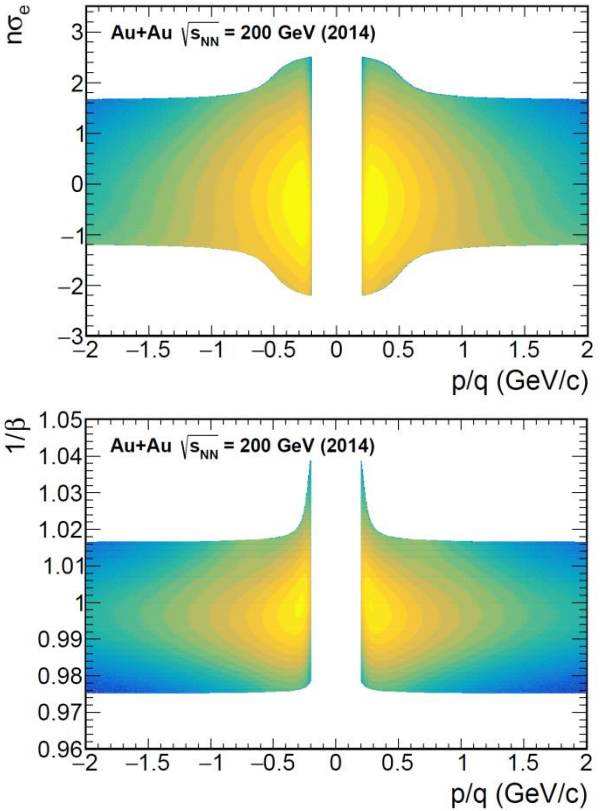
PARTICLE IDENTIFICATION



- High purity electron sample via
  - Mean ionization energy loss

$$n\sigma_e = \frac{1}{R_{dE/dx}} \log \frac{\langle dE/dx \rangle^{measured}}{\langle dE/dx \rangle_e^{theory}}$$

  - Time of flight $\frac{1}{\beta}$



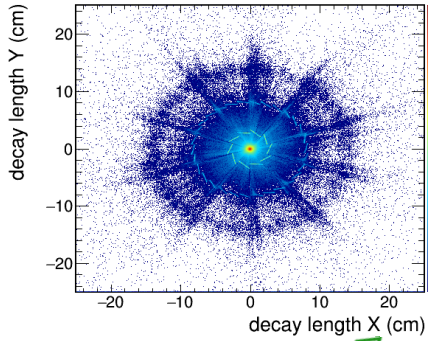
PAIRING OF LEPTONS

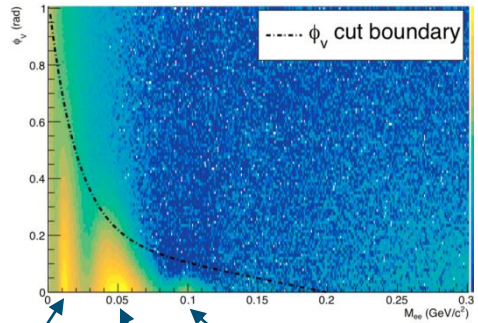
- Combine all electrons/positrons in an event into pairs
  - Signal contained in unlike-sign pairs
  - Combinatorial background estimated via like-sign pairs
  - k corrects for acceptance difference between unlike and like-sign pairs
  - Event mixing with several event pools
    - Vertex Z, centrality, event plane angle
- Photon conversion removal
  - Cut on pair opening angle w.r.t. the magnetic field ϕ_V
  - Decay length cut in case of HFT analysis

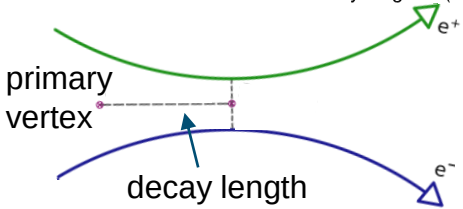
$$S = N_{+-} - N^{corr}_{++\times--}$$

$$N^{corr}_{++\times--} = 2\sqrt{N_{++}(M,p_T)\cdot N_{--}(M,p_T)} \times k$$

$$k = \frac{N^{mix}_{+-}(M,p_T)}{2\sqrt{N^{mix}_{++}(M,p_T)\cdot N^{mix}_{--}(M,p_T)}}$$







beam pipe

supporting structure

TPC inner field cage

COMPARISON DATA / COCKTAIL: 27 & 54.4 GeV