Dielectron physics opportunities with ALICE 3

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on behalf of the ALICE Collaboration

EMMI RRTF – Real and virtual photon production at ultra-low p_T and low mass at the LHC

Online Workshop, 13.9.2021

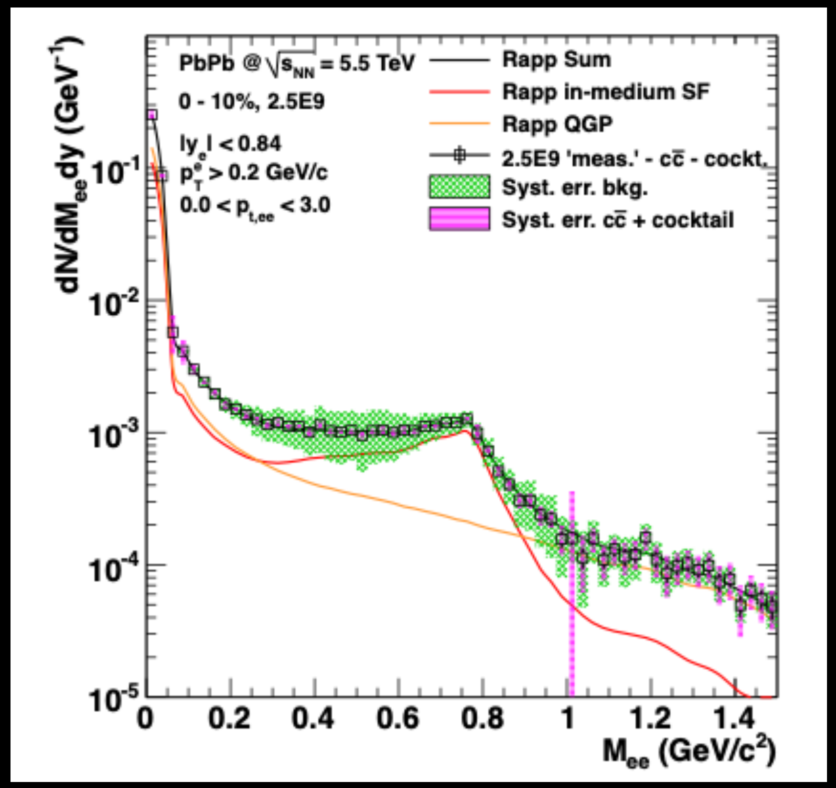
When?

Upgrade time schedule

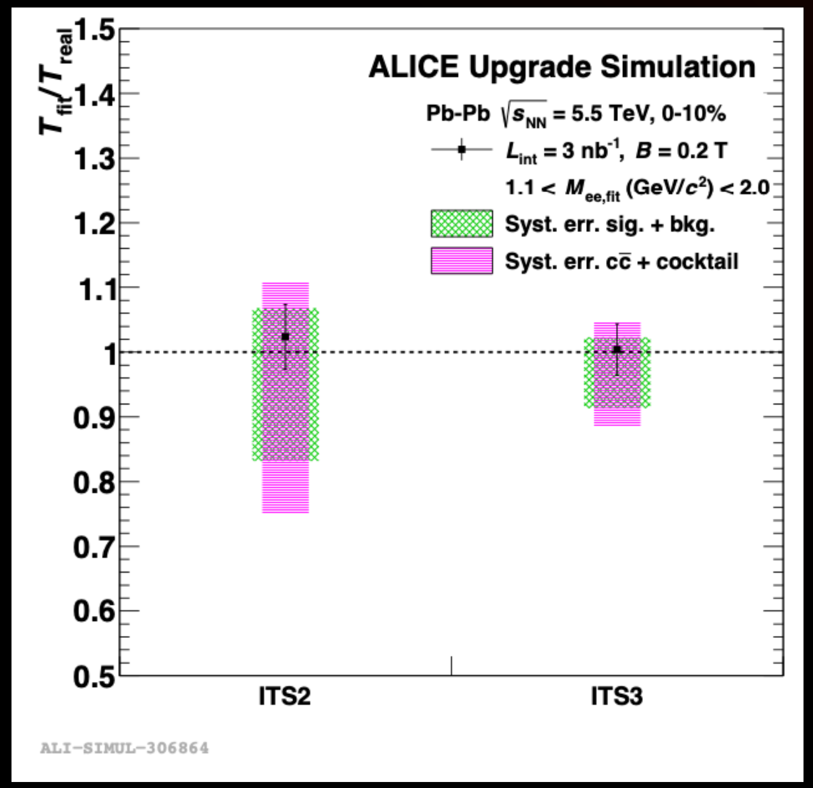
2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033

LS 2 | Run 3 | LS 3 | Run 4 | LS 4 | Run 5

LoI ALICE 2

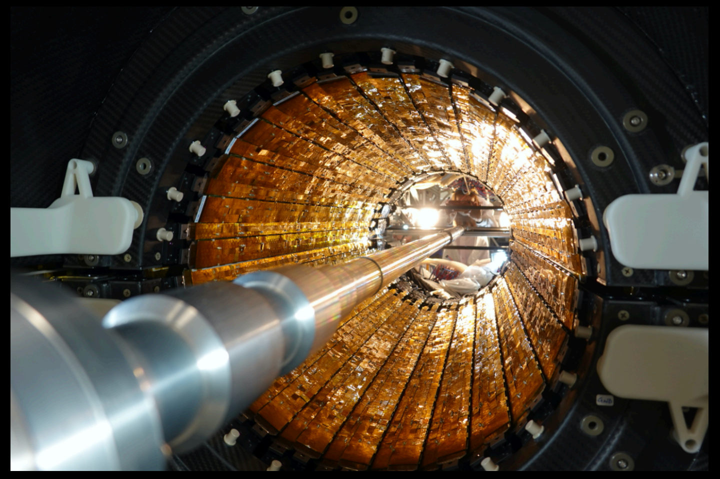


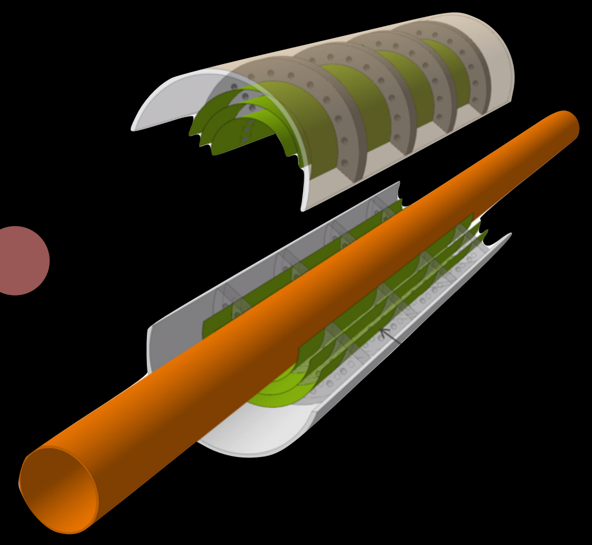
LoI ITS3



Topic of this talk

ITS2 & TPC upgrade → 100x Statistics

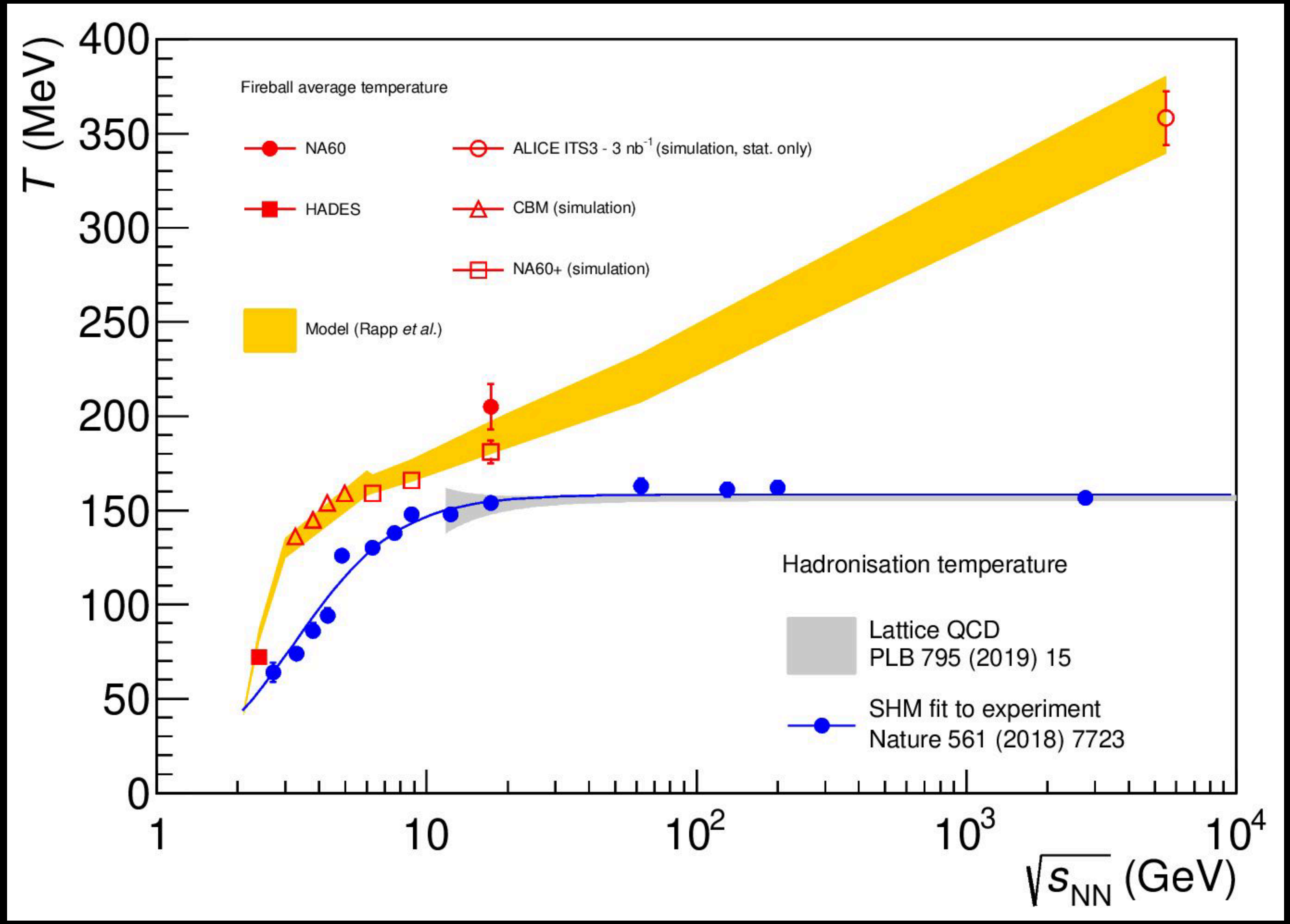




ITS3 → Better charm rejection

Why?

What is still to do after RUN 4



NA60, AIP Conf.Proc. 1322 (2010) 1, 1-10
HADES, Nature Physics 15 (2019) 10, 1040-1045
ALICE, CERN-LHCC-2019-018
CBM, Nucl. Phys. A 982 (2019) 163
NA60+, SPSC-EOI-019
R. Rapp et al., Phys. Lett. B 753 (2016) 568
T. Galatyuk et al., Eur. Phys. J. A52 (5) (2016) 131
Lattice QCD, Phys. Lett. B 795 (2019) 15
SHM, Nature 561 (2018) 7723, 321-330

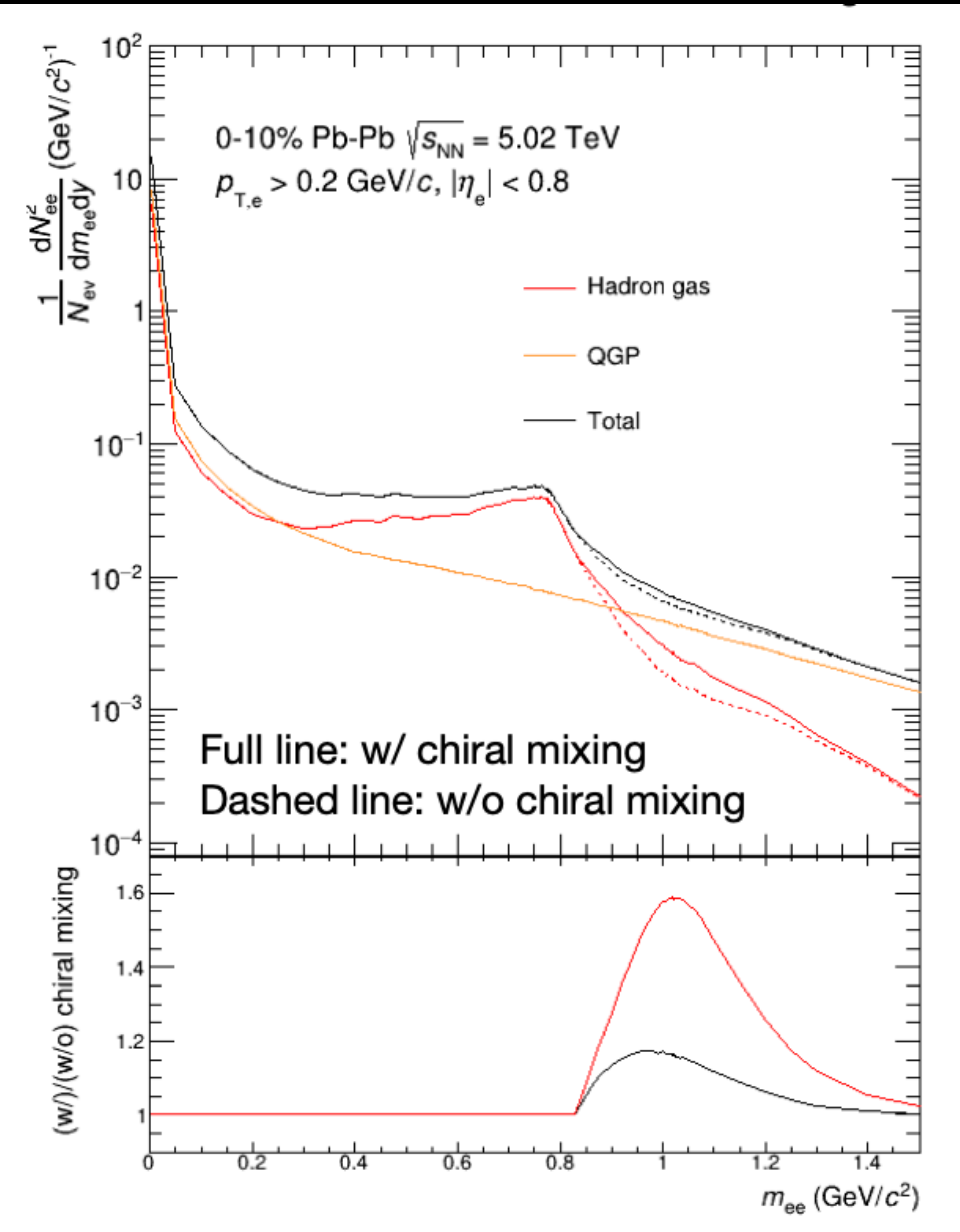
Yield of RUN 3/4 dielectron measurements in ALICE at the LHC:

- Thermal radiation and ρ spectral function measured with 10% uncertainty
- Dielectron v_2 with a precision of $\sigma(v_2)$ = 0.01–0.02 as a function of m_{ee}

Can we learn something from more precision?

Why?

What is still to do after RUN 4



R. Rapp, Adv. High Energy Phys. 2013 (2013) 148253
P.M Hohler and R. Rapp, Phys. Lett. B 731 (2014) 103

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Can we learn something from more precision?

- Chiral mixing of ρ-a_1 changes the shape of dielectron spectrum in 0.9 < m_{ee} 1.4 GeV/c^2
- Measurement with precision higher >10% necessary

Why?

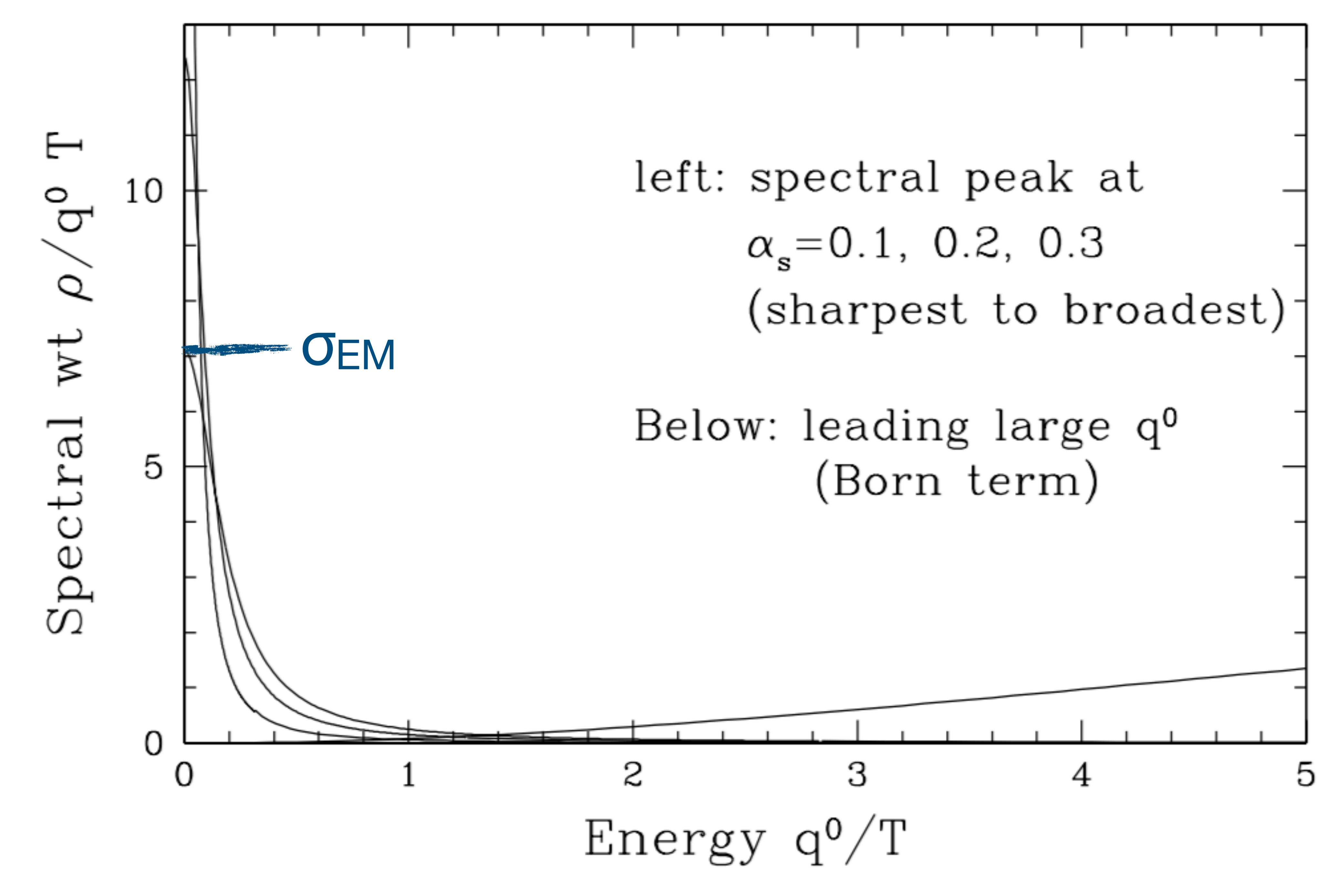
Where to keep looking

Electric conductivity (Ralf Rapp, today)

Dielectron spectral function connected to electric conductivity

$$\sigma_{EM} = -e^2 \lim_{q_0 \to 0} \left(\frac{\partial}{\partial q_0} \mathrm{Im}\Pi(q_0, q = 0, T) \right)$$

Transport peak in the limit of very low mass and p_T



G. D. Moore and J.-M. Robert, arXiv:hep-ph/0607172

Anomalous Soft Photons (Klaus Reygers, tomorrow)

Several experiments measured excess of soft photons over inner Bremsstrahlung calculated based on Low theorem

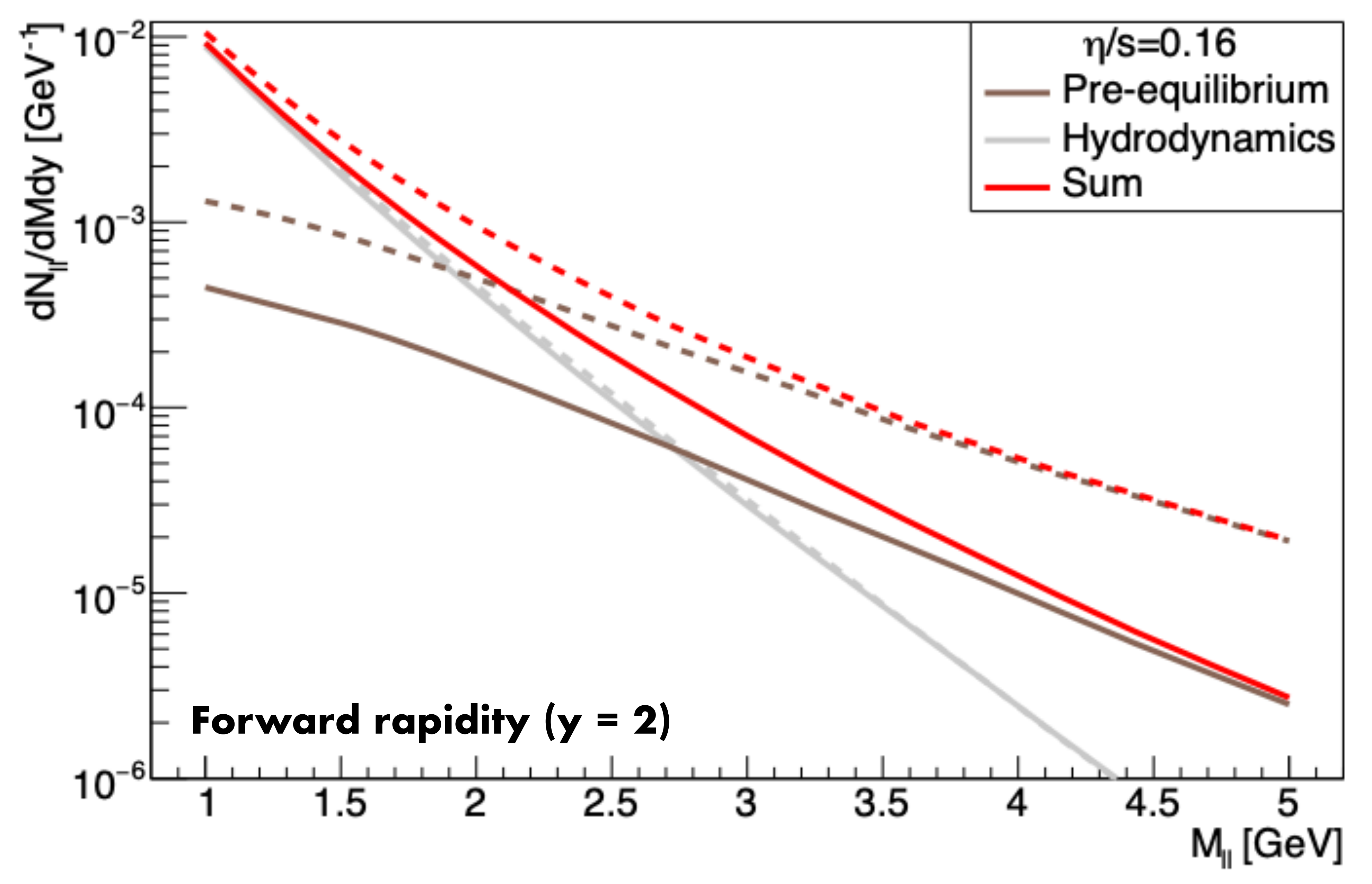
- Dielectrons as complementary measurement to the photon channel

Why?

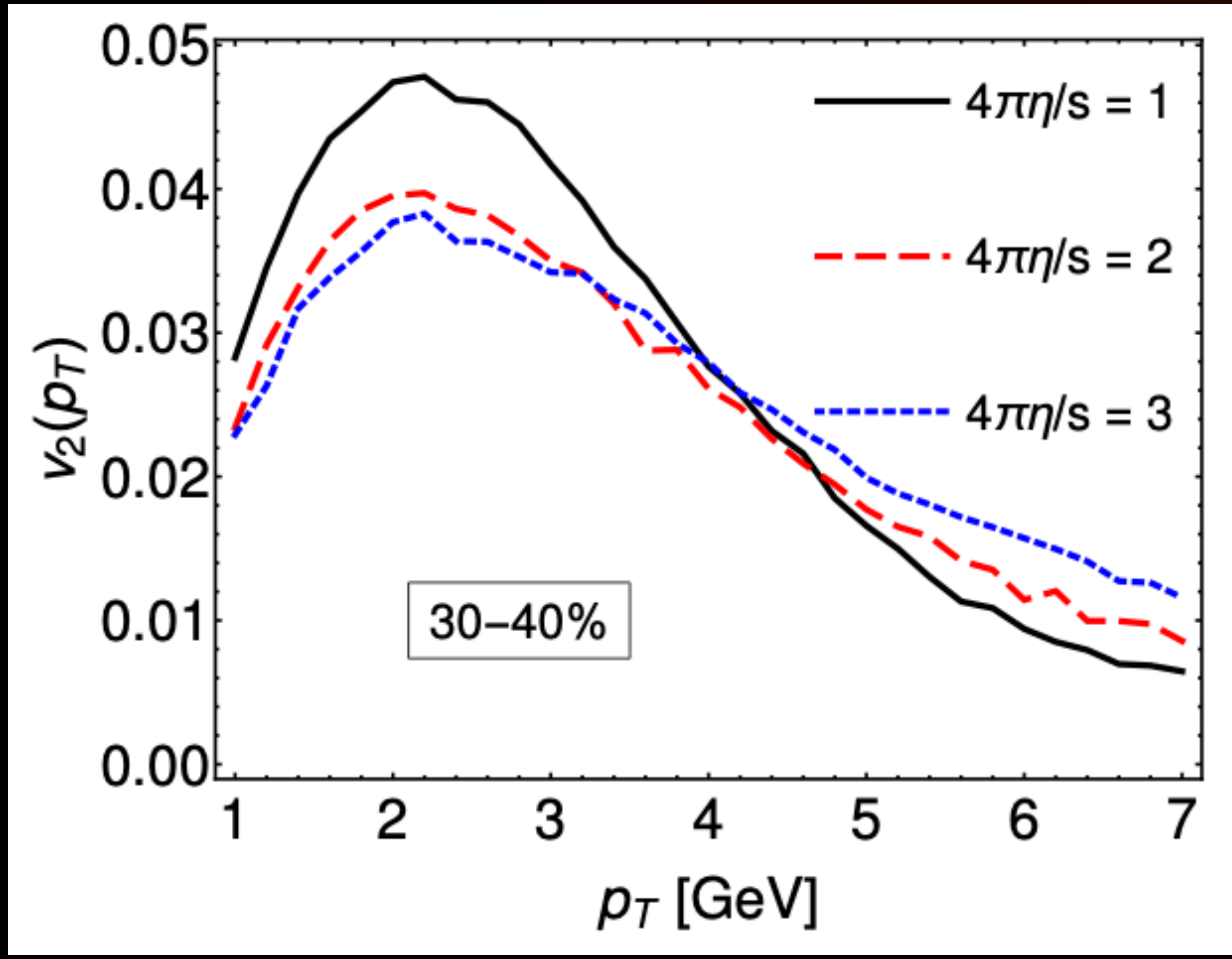
Where to keep looking

Dileptons from earliest collision stage more abundant than the QGP contribution at higher masses

Sensitivity to initial anisotropies and η/s, not accessible with hadronic probes
→ Sensitivity not reached in RUN 3/4

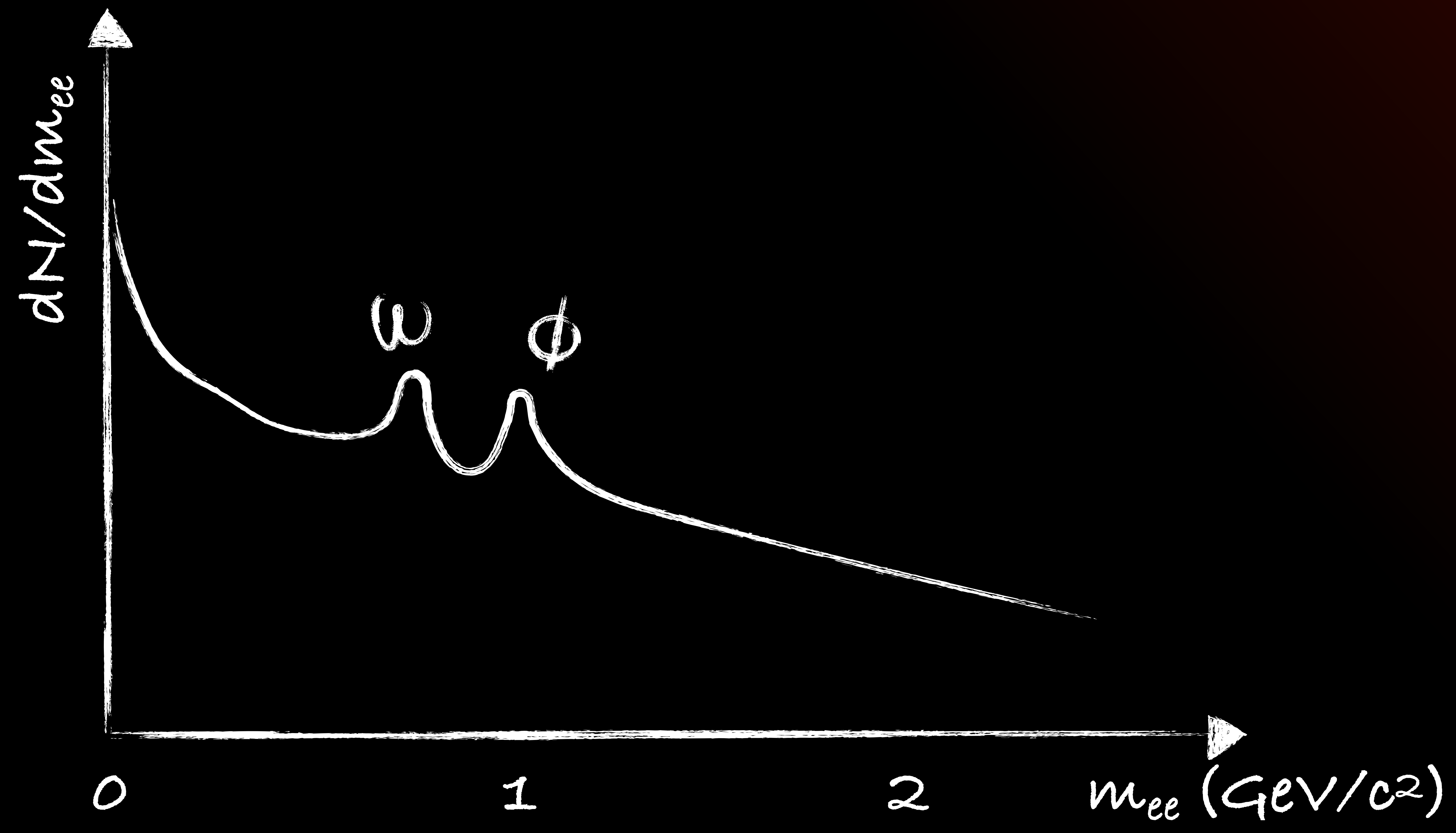


M. Coquet, *et al*, PLB 821 (2021) 136626

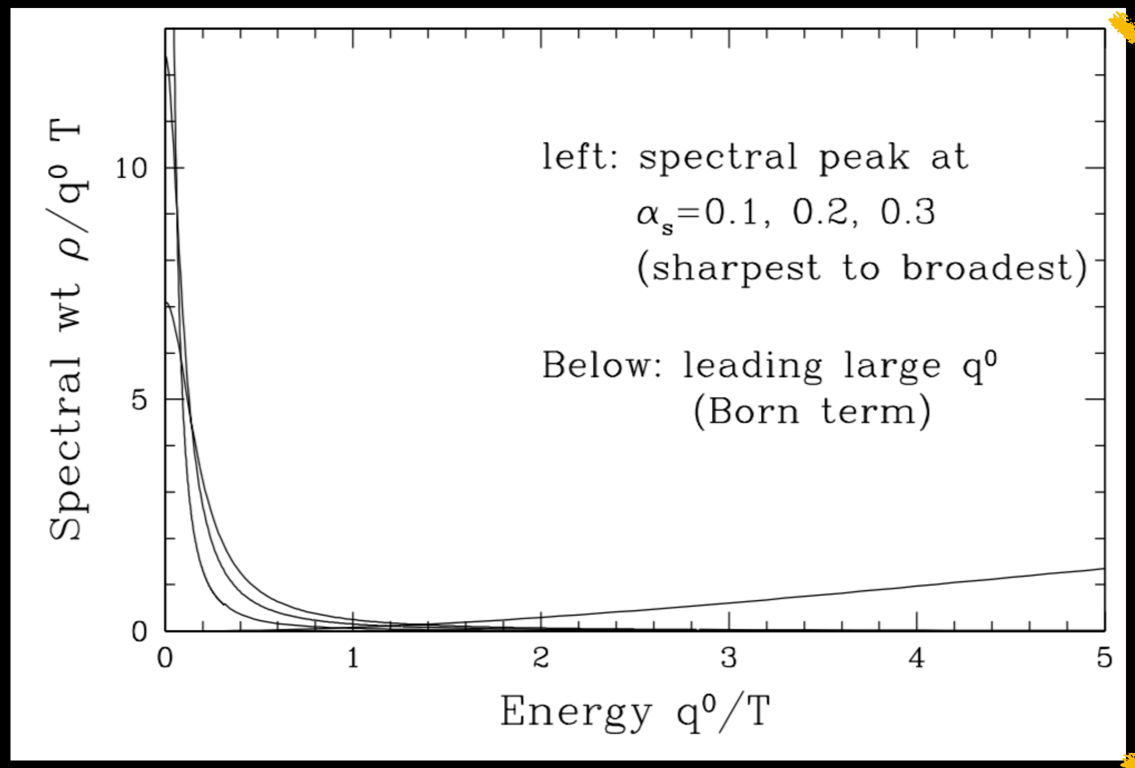


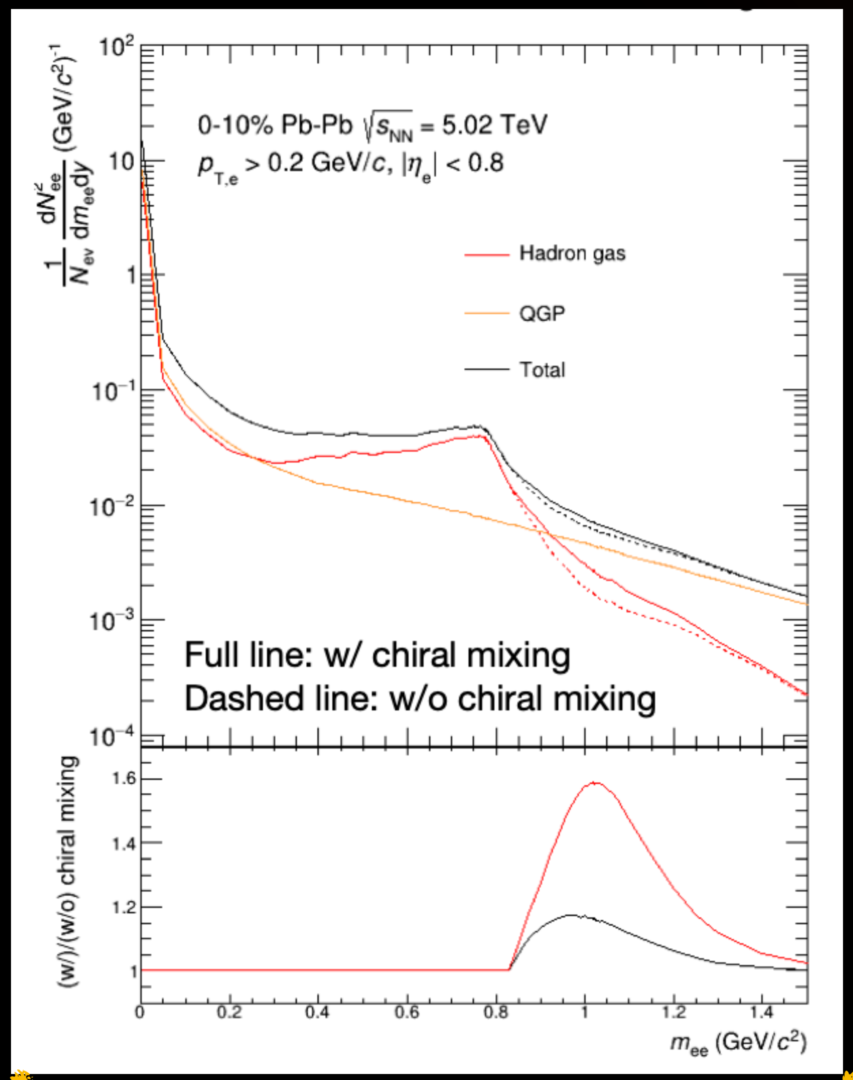
B. S. Kasmaei and M. Strickland, PRD 99 (2019) 3, 034015

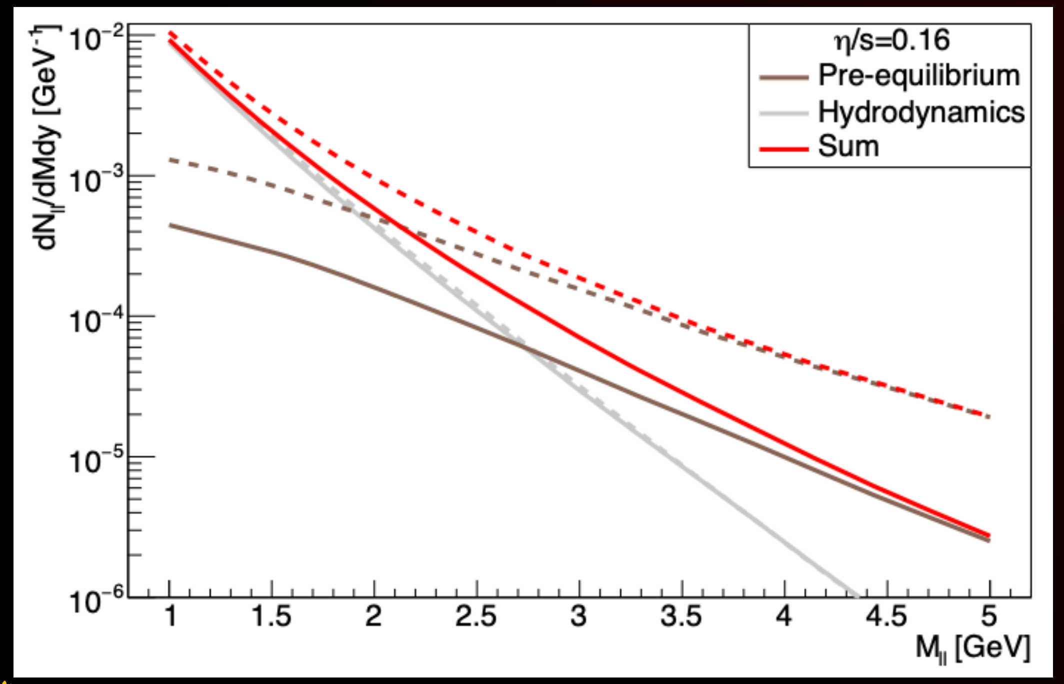
Where to keep looking?

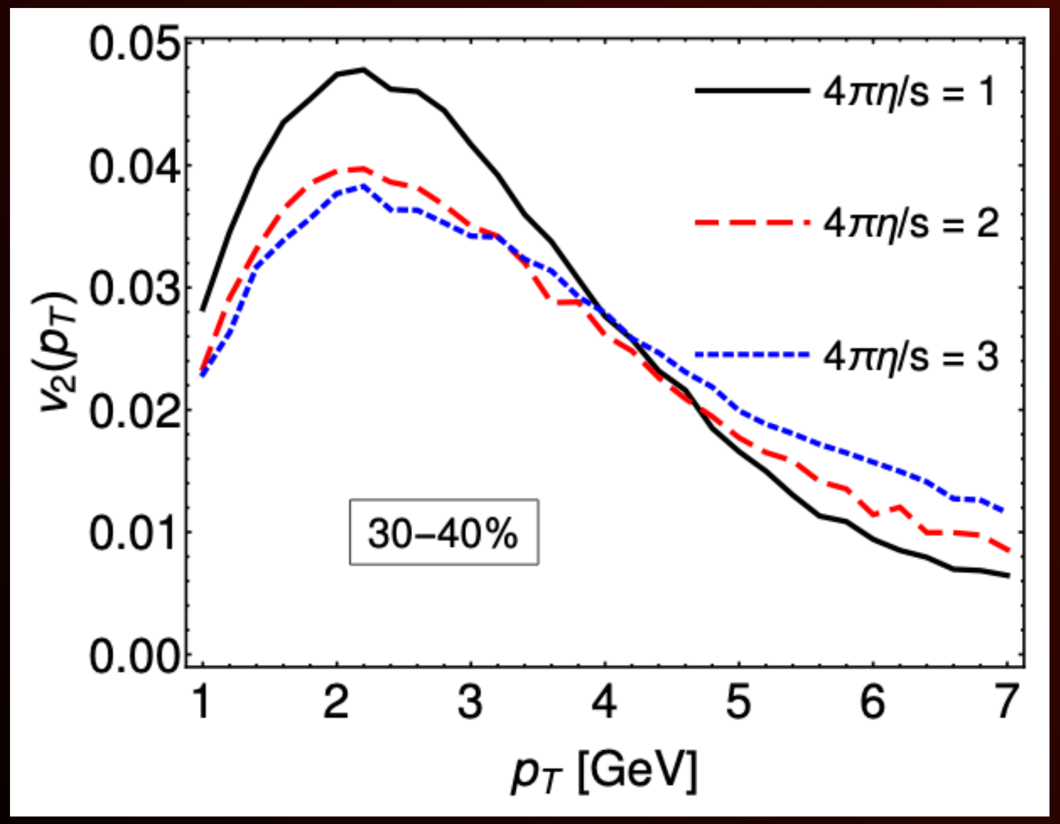


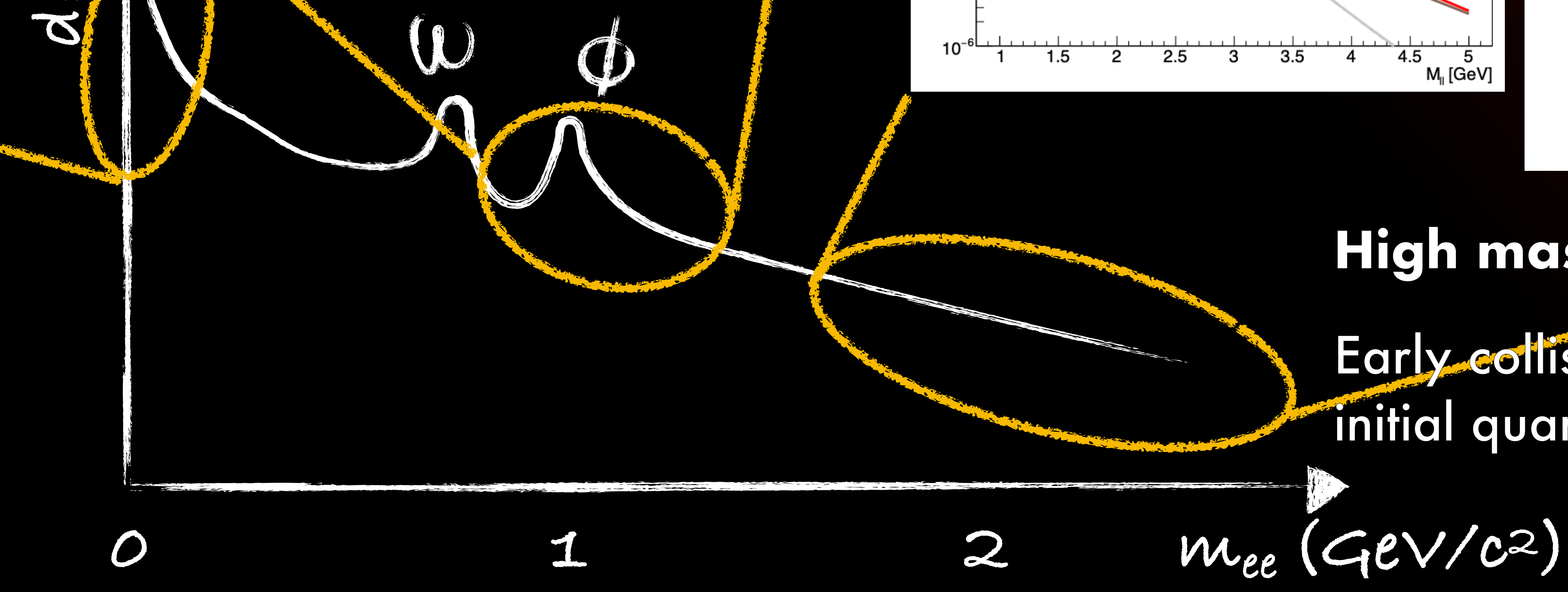
Where to keep looking?











Very low mass and pair p_T

Electric conductivity and soft (virtual) photons

High mass and p_T

Early collision stages & initial quark momentum anisotropy

What?

A possible ALICE 3 setup

High resolution retractable vertex detector

- 1st layer at 5 mm distance from interaction point (pointing resolution 20 µm at p_T = 0.1 GeV/c)

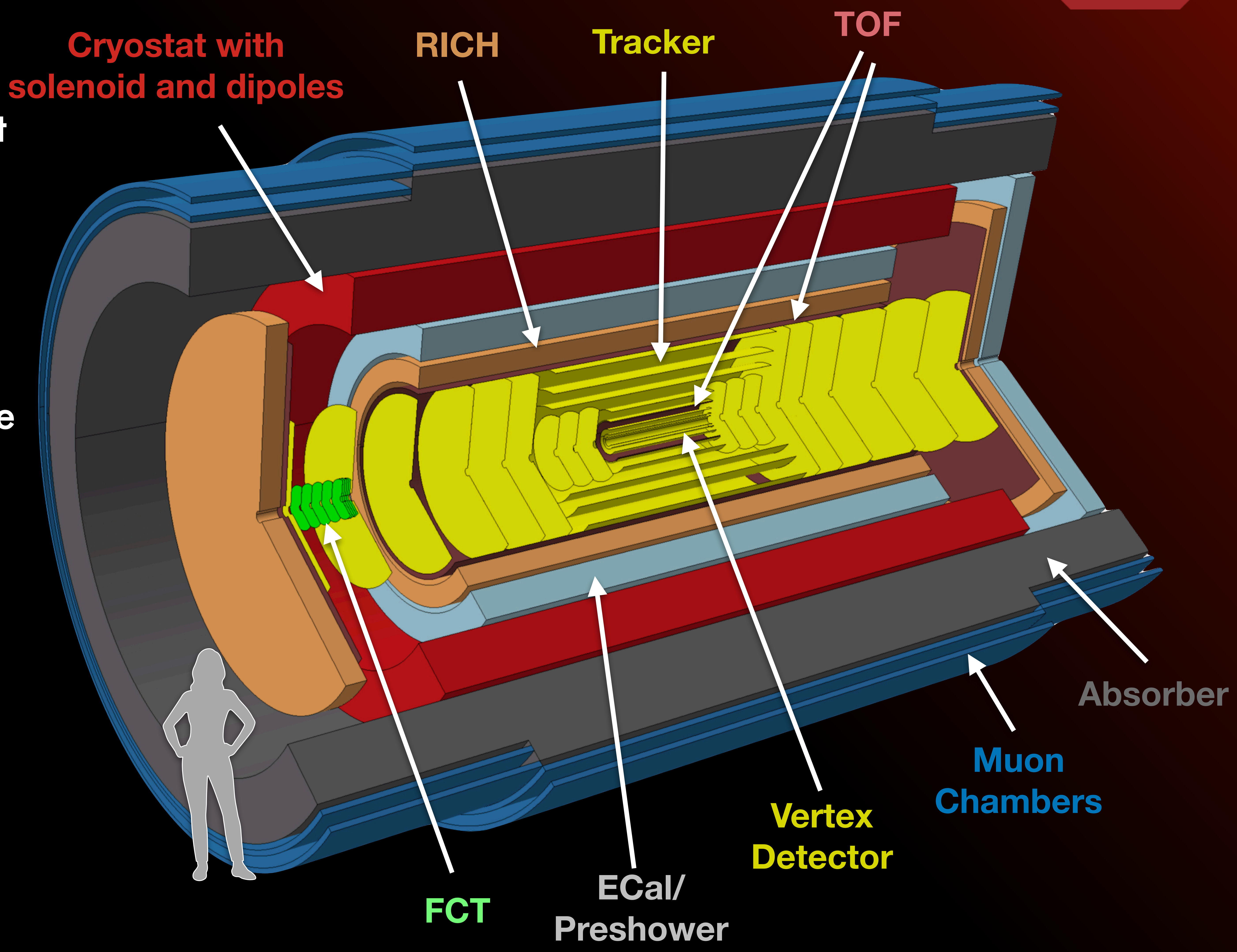
High acceptance silicon tracker

- Barrel + Forward discs

Super-conductiong Magnet system

- Good momentum resolution in whole acceptance

Large coverage for particle identification



Particle Identification

Photons and dielectrons with ALICE 3

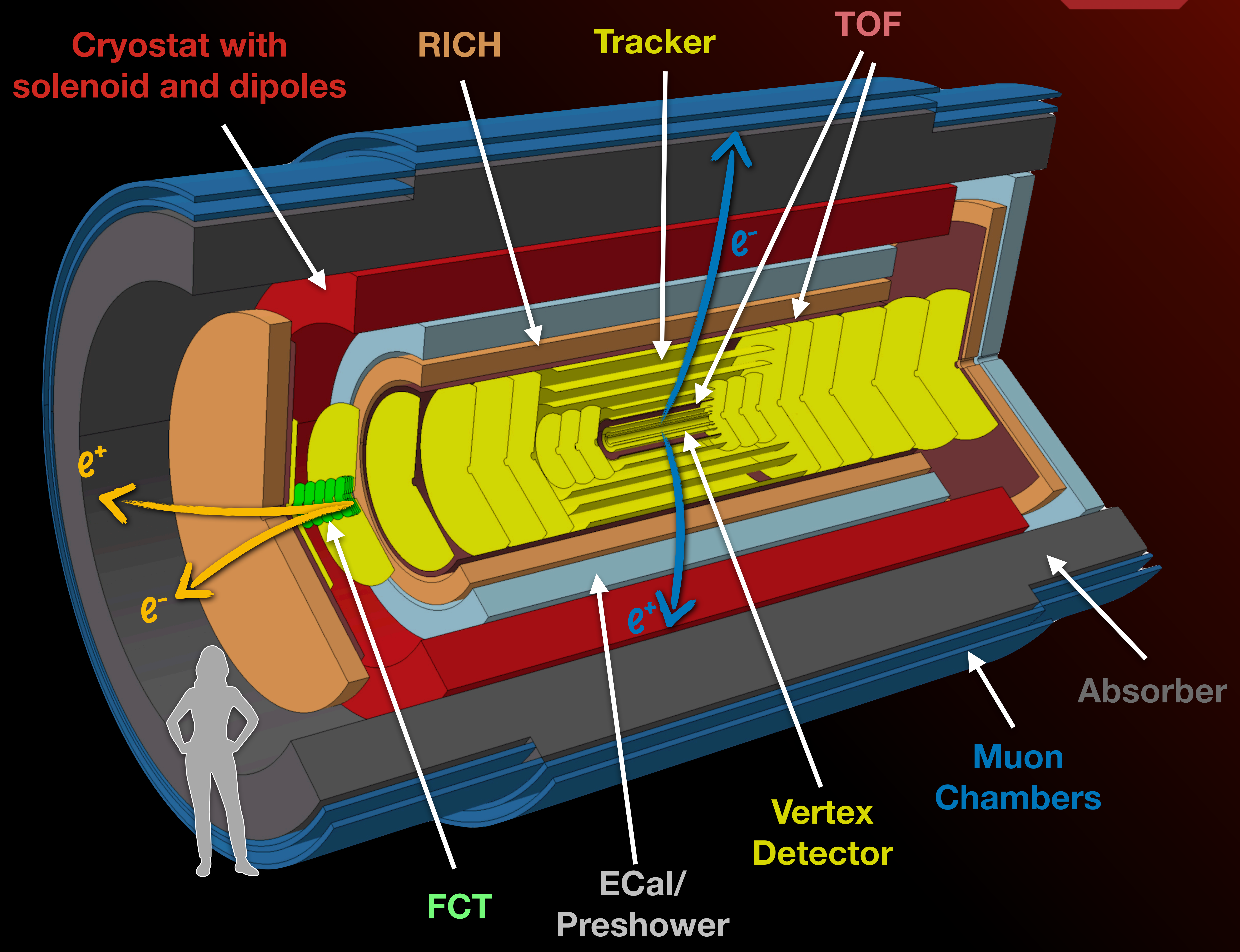
Electron Identification:

- TOF layers (low p_T)
- RICH (intermediate p_T)
- ECal/Preshower (high p_T)

Photon measurements

- Forward conversion tracker (very low p_T)
- Photon conversion
- ECal

The layout not finalised yet



Electron efficiency and purity

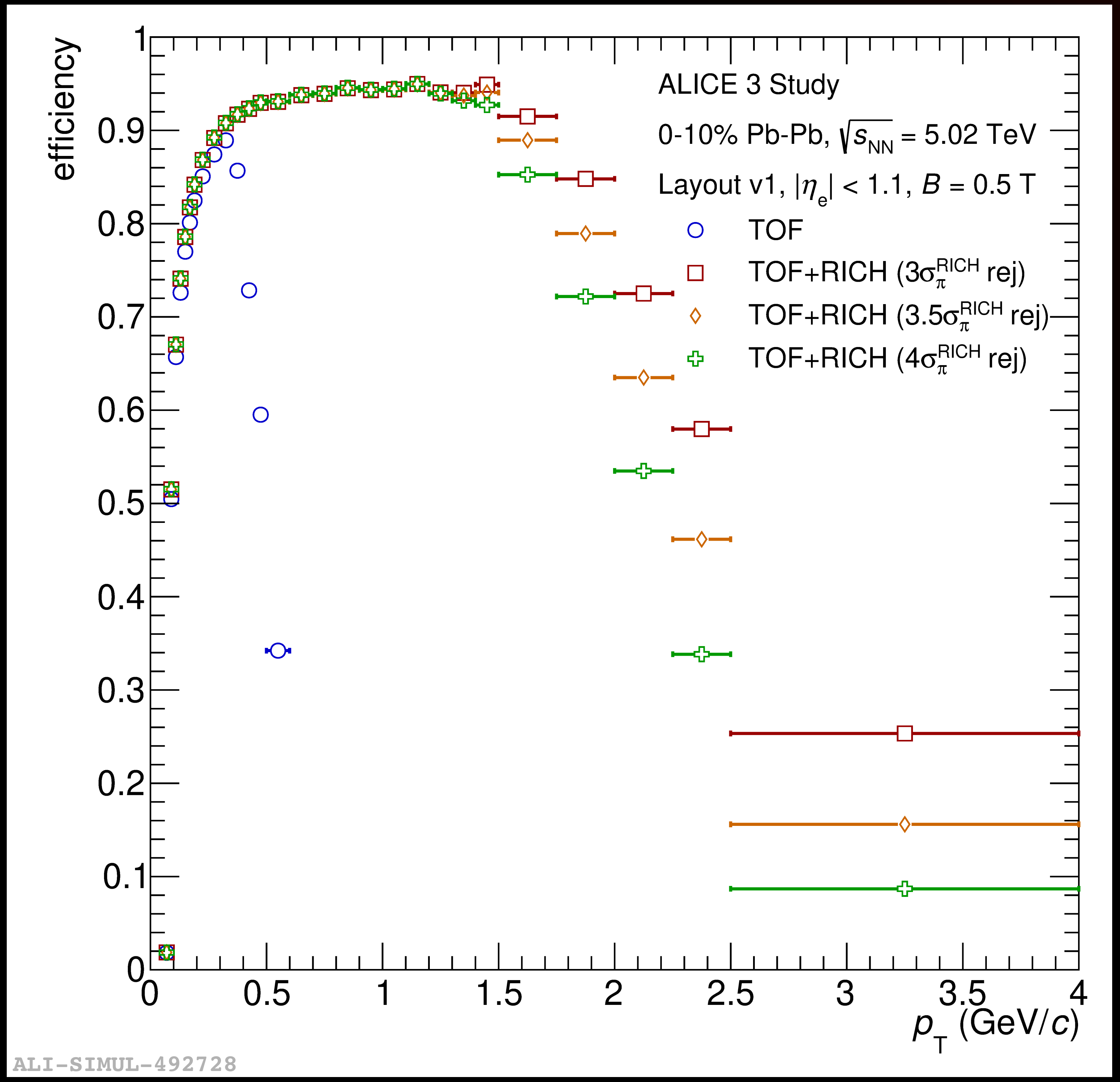
Electron identification with TOF and RICH at 1m distance from the interaction point

Effect of tracking efficiency included

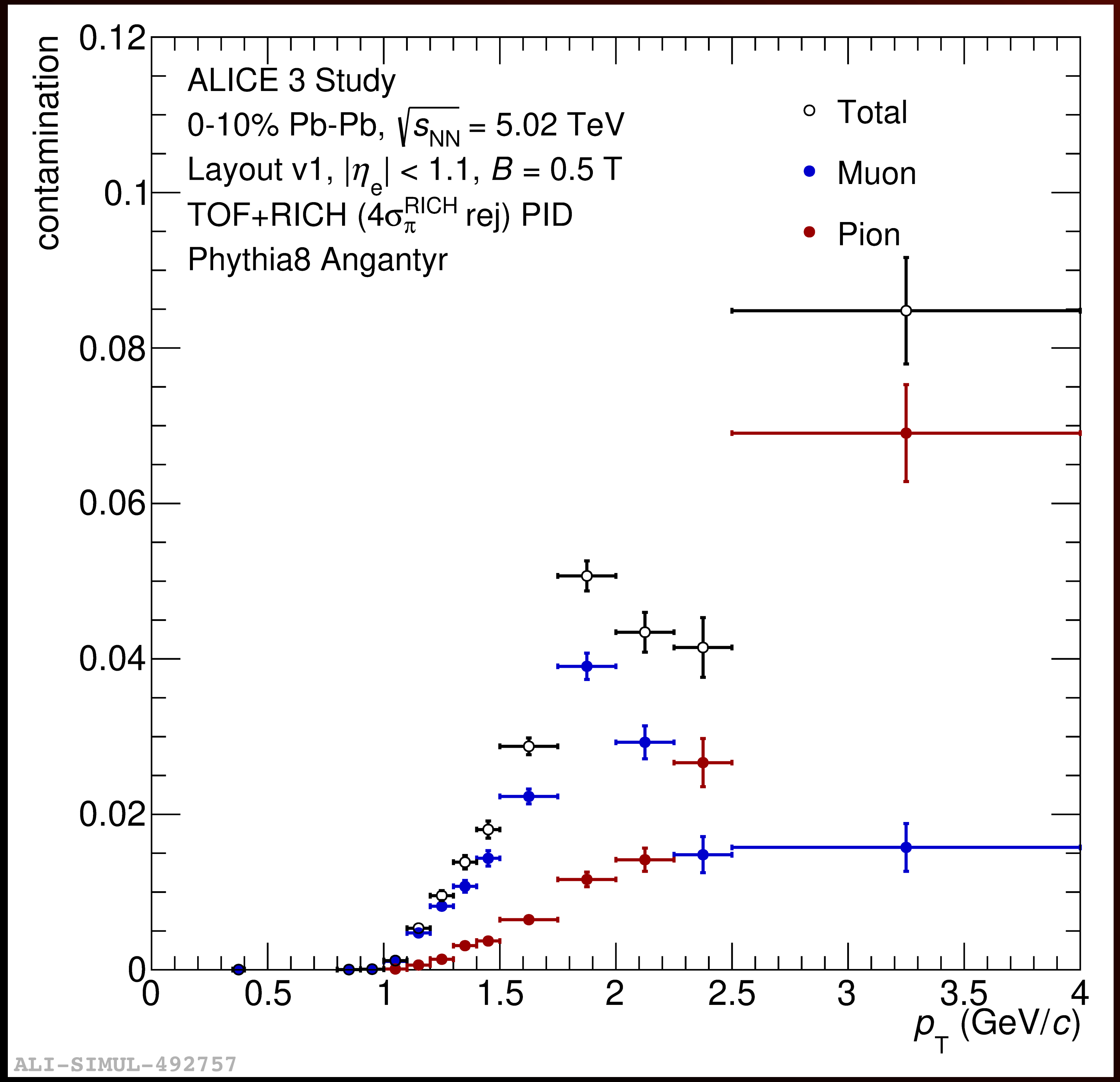
TOF alone limited to narrow p_T region

TOF+RICH achieve high efficiency with negligible contamination up to 2 GeV/c

Electron efficiency



Hadron contamination



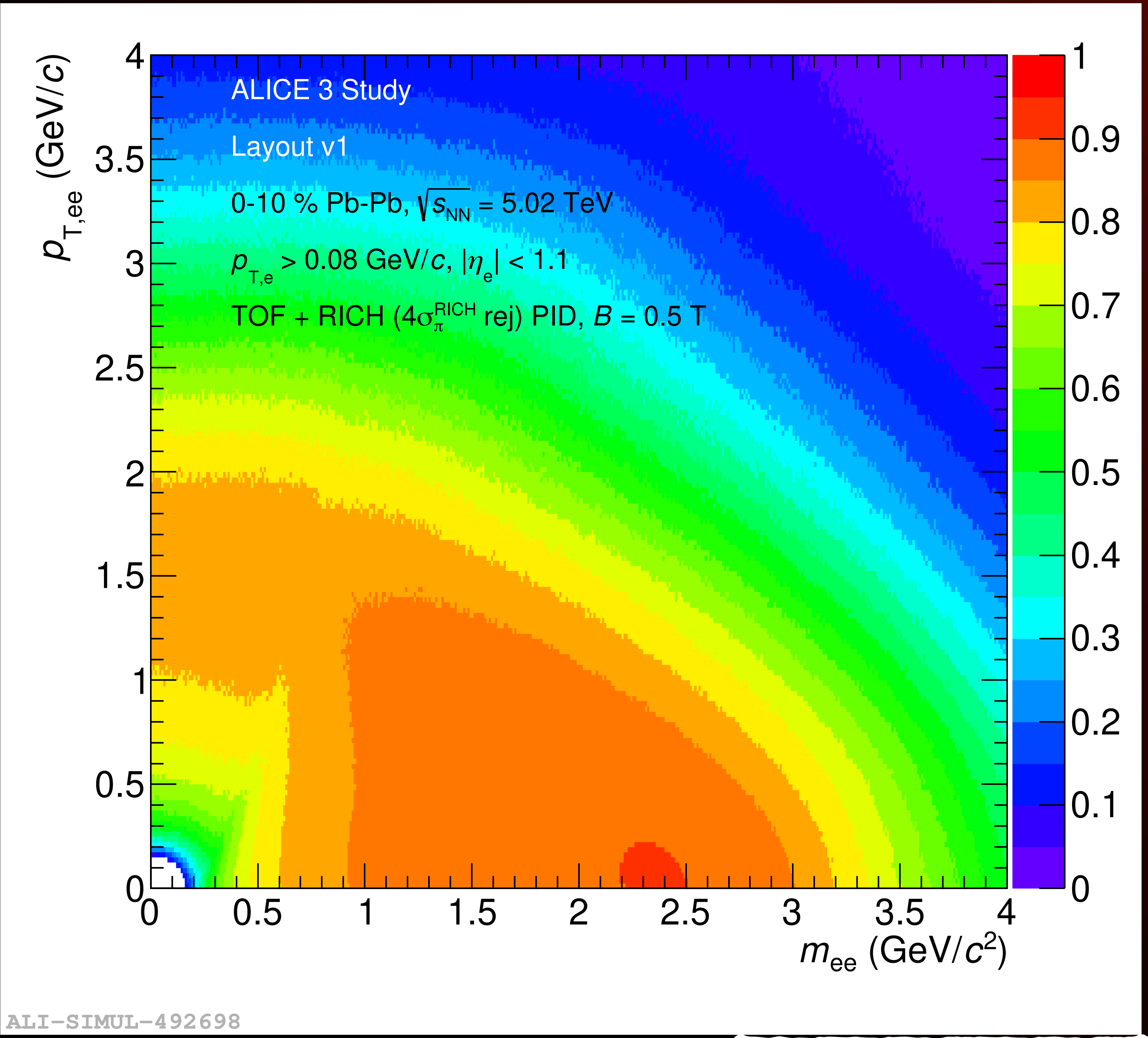
Ongoing studies

Dielectron efficiency

Pair efficeincy from single electron efficiency using toy MC

Mass/$p_{T,ee}$ threshold already close to ALICE 2 with low magnetic field configuration (p_T > 75 MeV/c)

- Extend p_T reach with smaller B-Field or PID layer closer to the beampipe (TOF foreseen at 20 cm)



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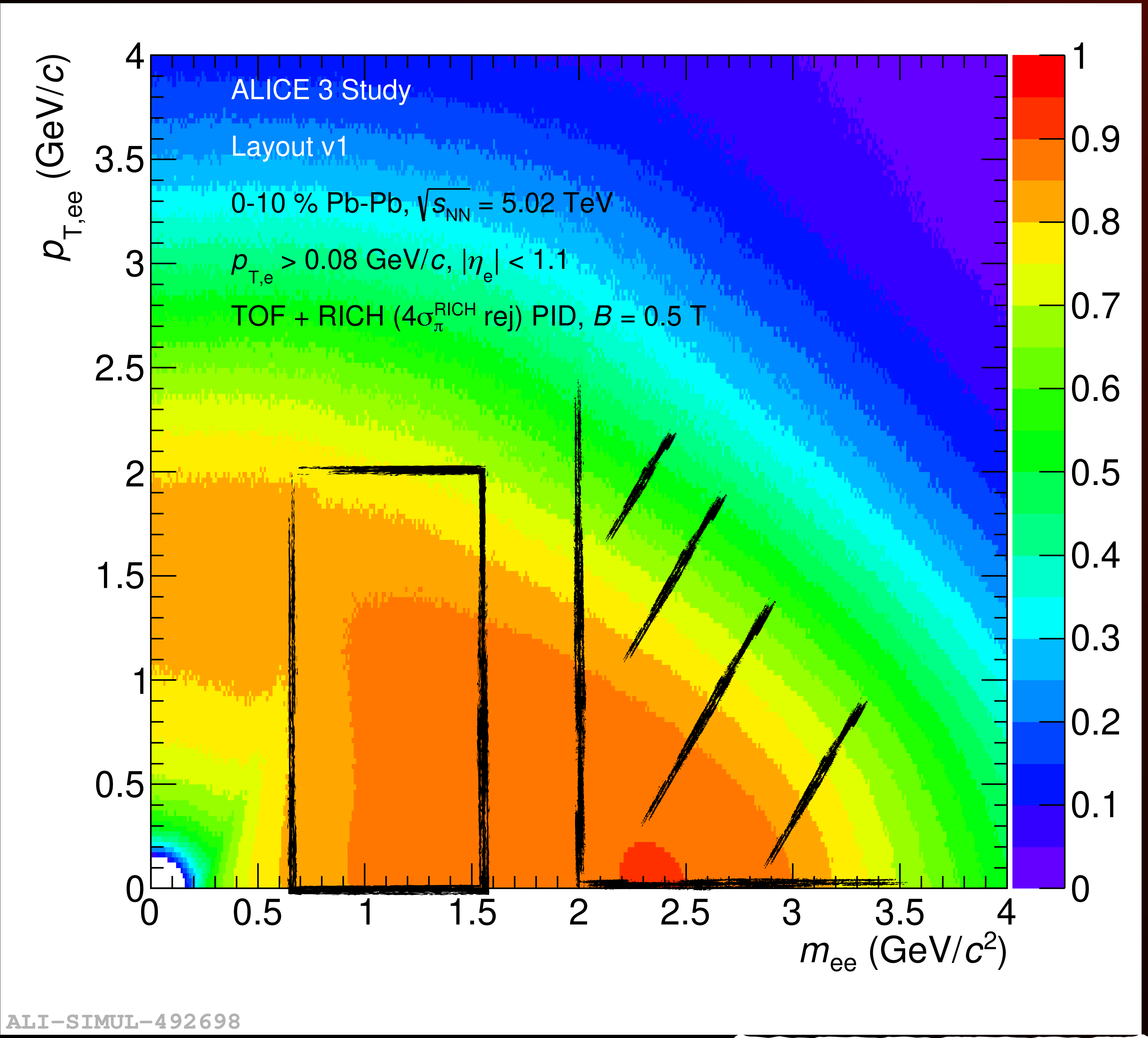
Limited particle identification at high p_T leads to efficiency loss at high mass/$p_{T,ee}$

High pair efficiency in phase space relevant for chiral mixing studies

Focus on intermediate mass



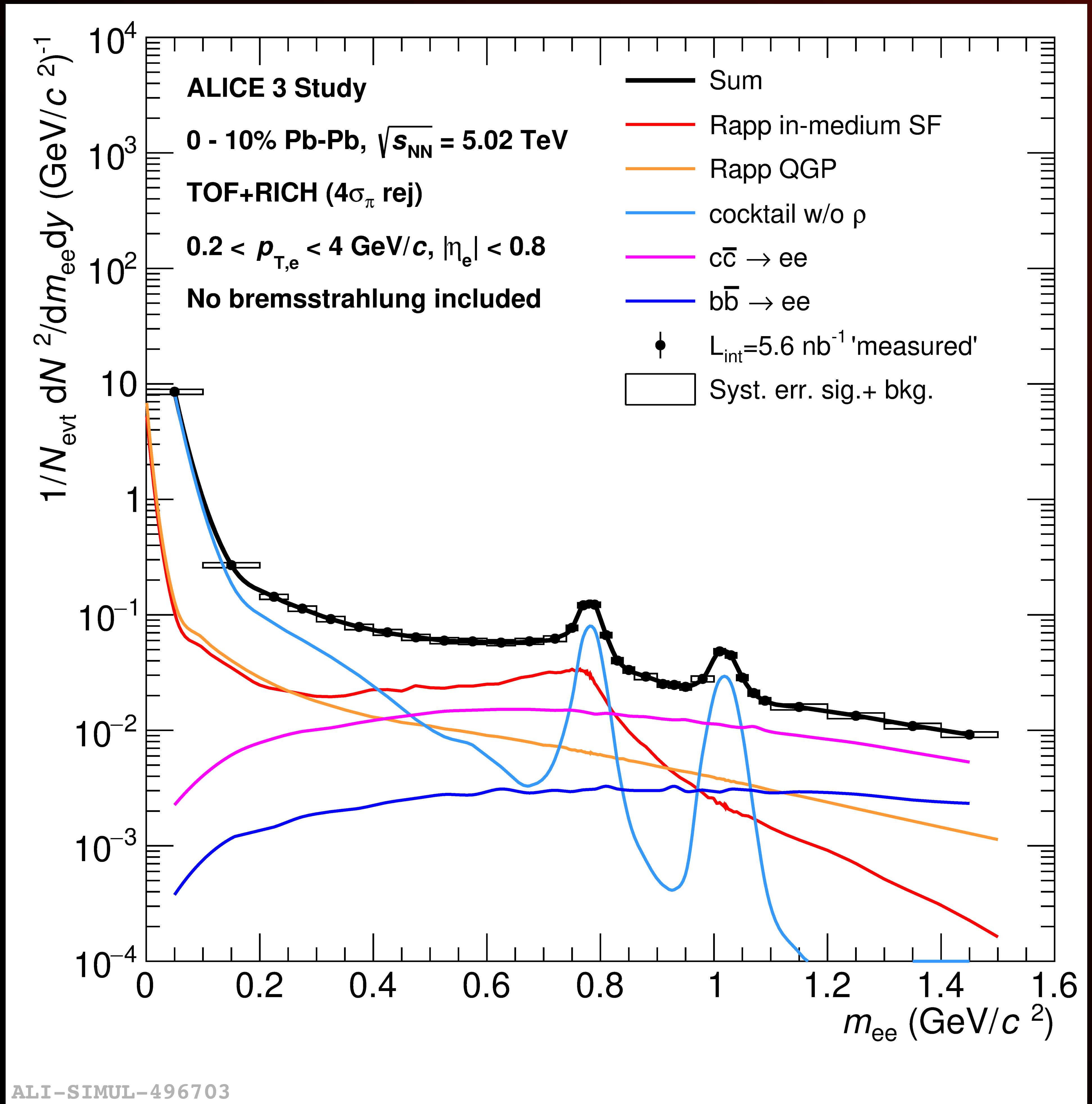
Ongoing studies

Dielectron cocktail

Hadronic cocktail calculations based on RUN 2 data

Charm and beauty cross sections based on pp measurements

Large charm contribution of wide mass range
→ dominant m_{ee} > 0.9 GeV/c^2



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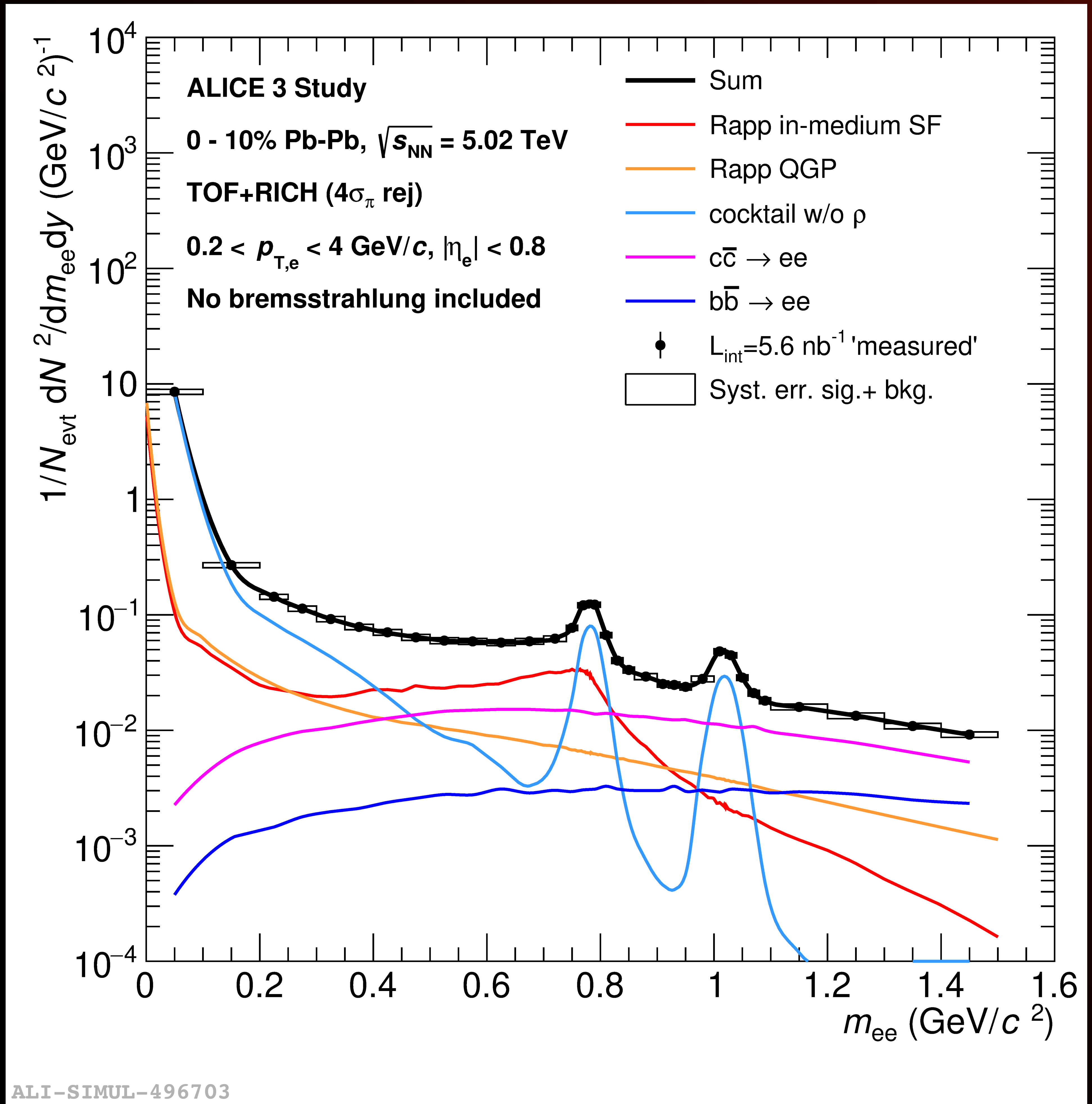
But Wait! Why are there Data point!?



Ongoing studies

From Cocktail to measurement

Hadronic cocktail calculations based on RUN 2 data

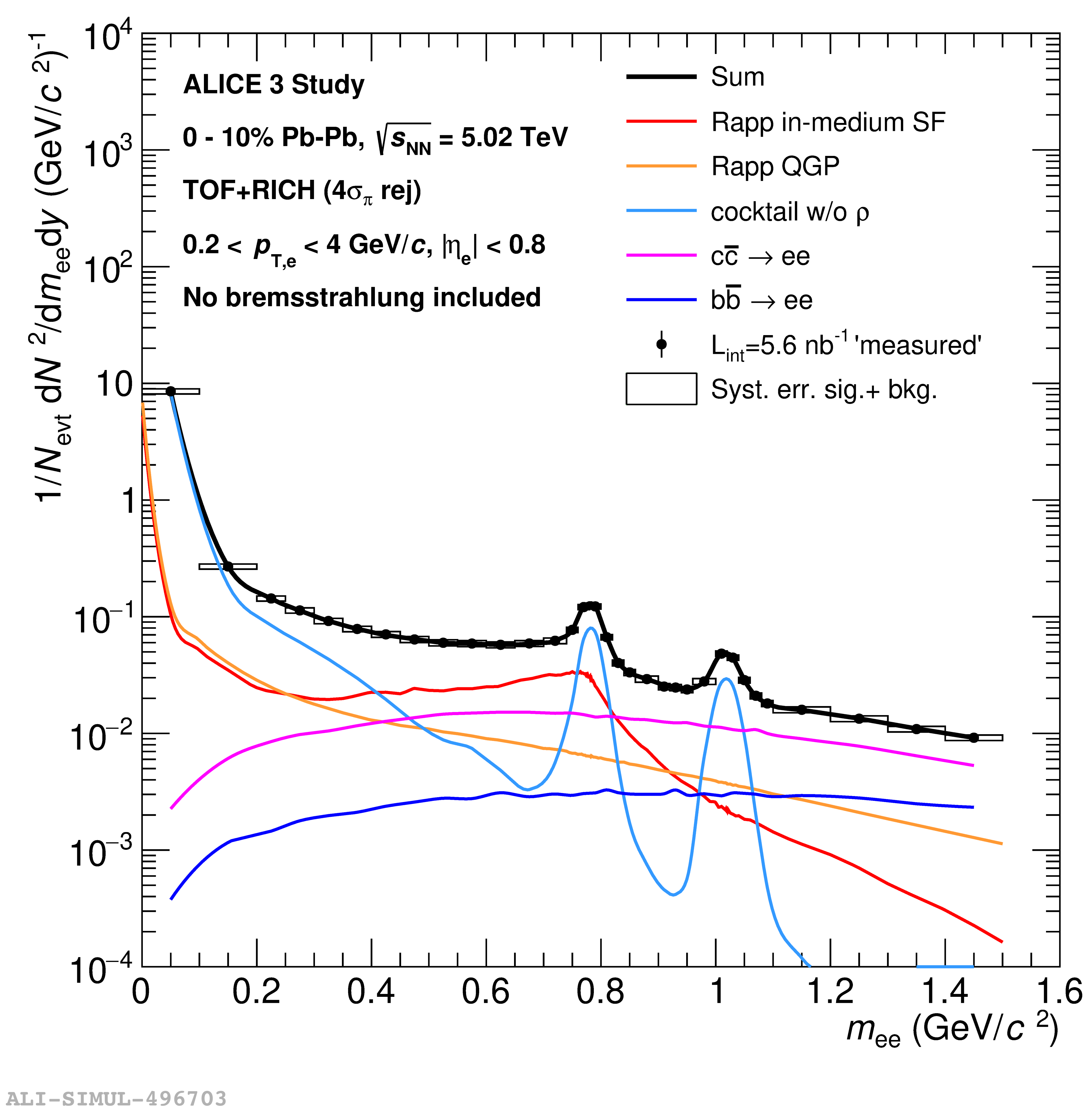
Charm and beauty cross sections based on pp measurements

Large charm contribution over wide mass range
→ dominant $m_{ee} > 0.9$ GeV/c^2

Dielectron signal (S) from hadronic cocktail plus calculations by Ralf Rapp
→ Electron identification and tracking efficiency included

Combinatoric pairs from Pythia8 Angantyr
+ weighting to describe measurements in Pb–Pb collisions

Statistical uncertainty given by Significance $\frac{S}{\sqrt{S + 2B}}$



Ongoing studies

From Cocktail to measurement

Hadronic cocktail calculations based on RUN 2 data

Charm and beauty cross sections based on pp measurements

Large charm contribution over wide mass range
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We have a really nice tracker at hand

Dielectron signal (S) from hadronic cocktail plus calculations by Ralf Rapp
→ Electron identification and tracking efficiency included

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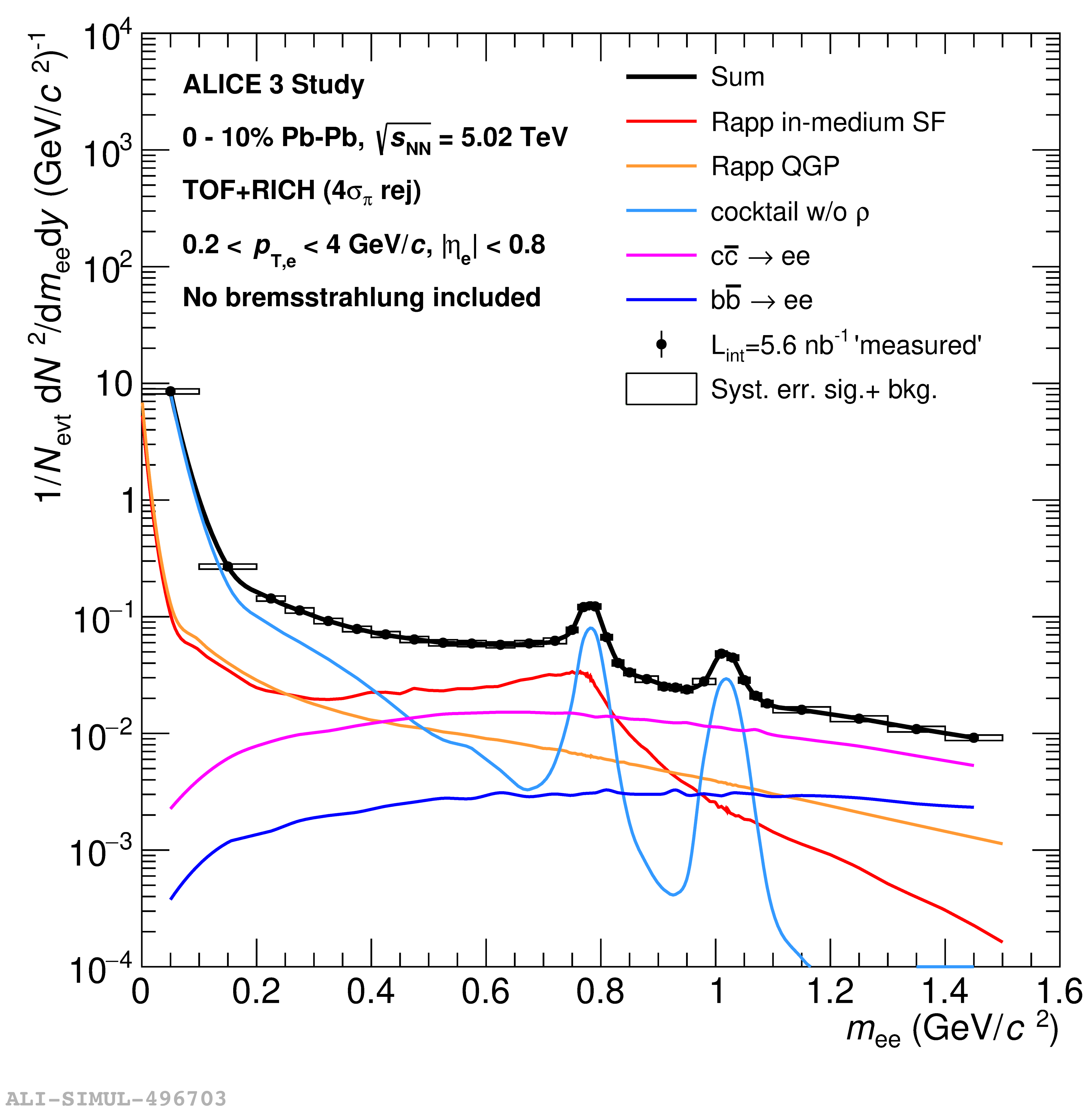


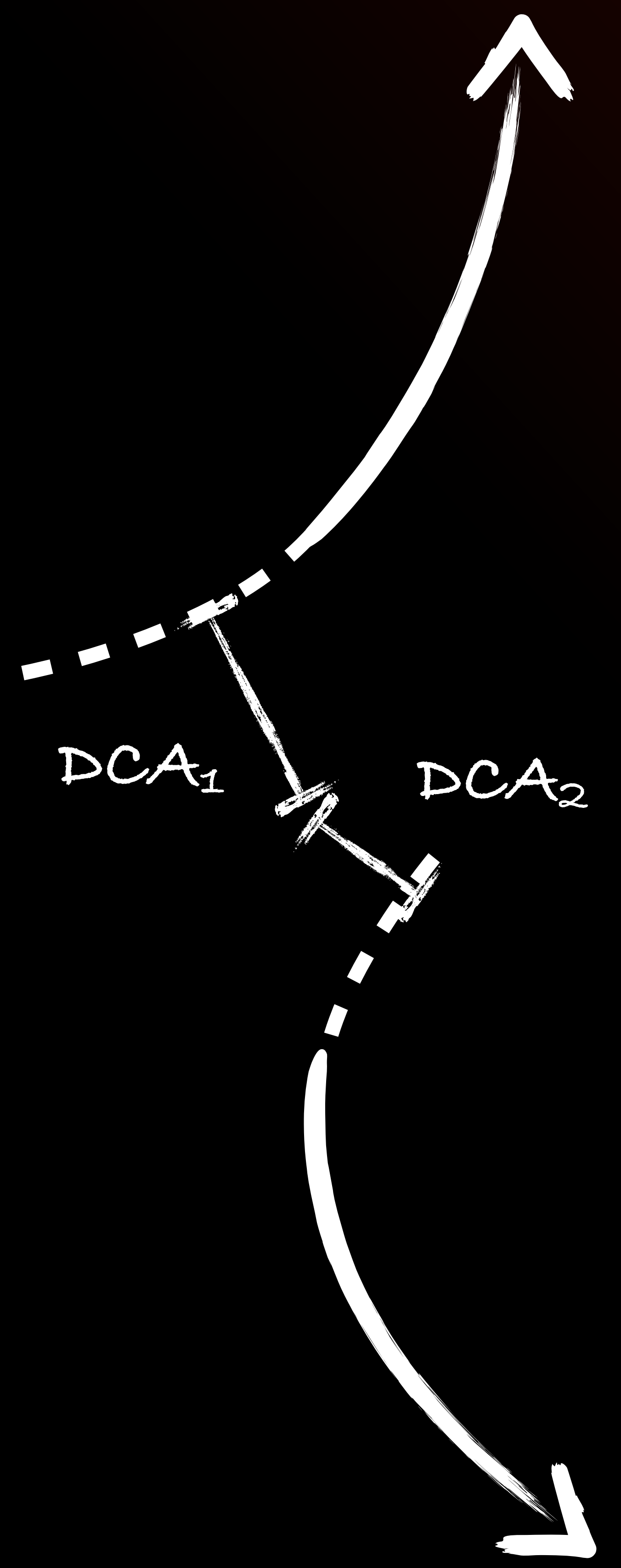
Ongoing studies

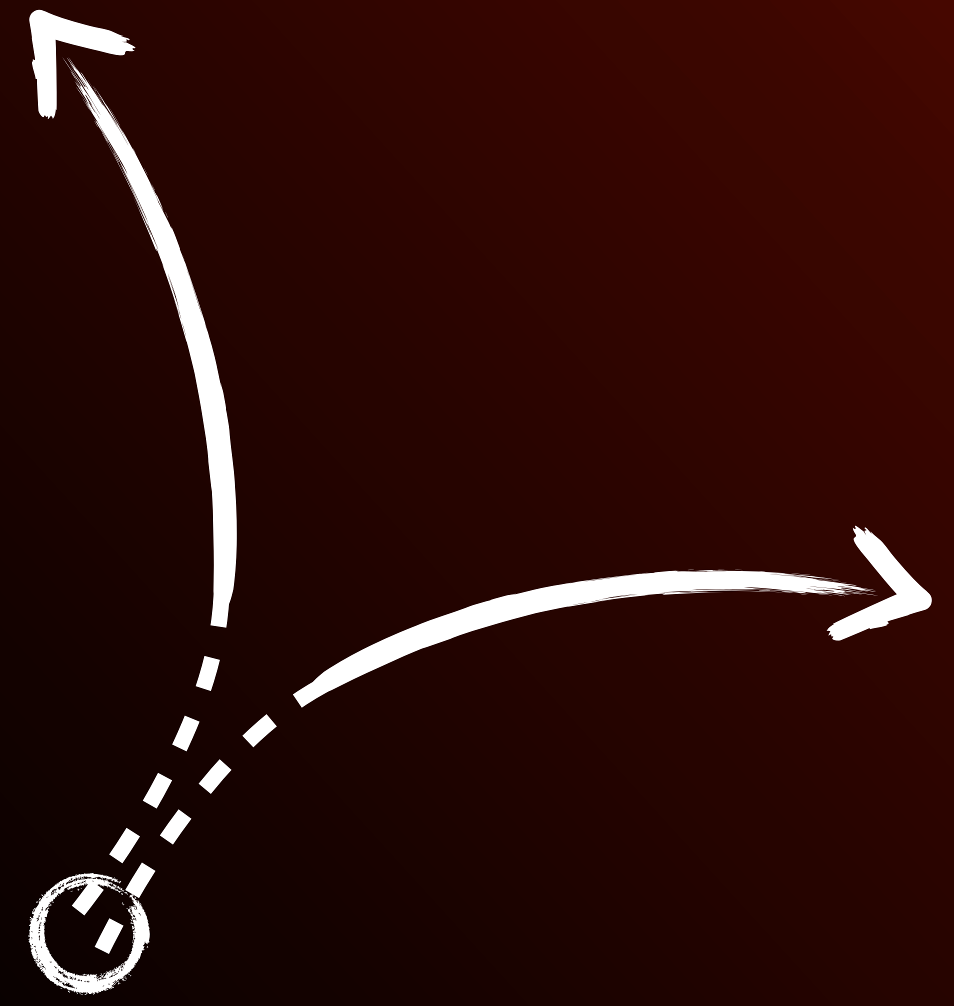
Distance of Closest Approach

Topological separation of prompt and non-prompt heavy flavour pairs via pair Distance-of-Closest-approach DCA_{ee}

$$DCA_{ee} = \sqrt{\frac{DCA_1^2 + DCA_2^2}{2}}$$

with $DCA_{1/2}$ normalised to respective resolution





Expectation:

$DCA_{ee}(\text{prompt}) < DCA_{ee}(\text{HF})$

Separation power driven by resolution

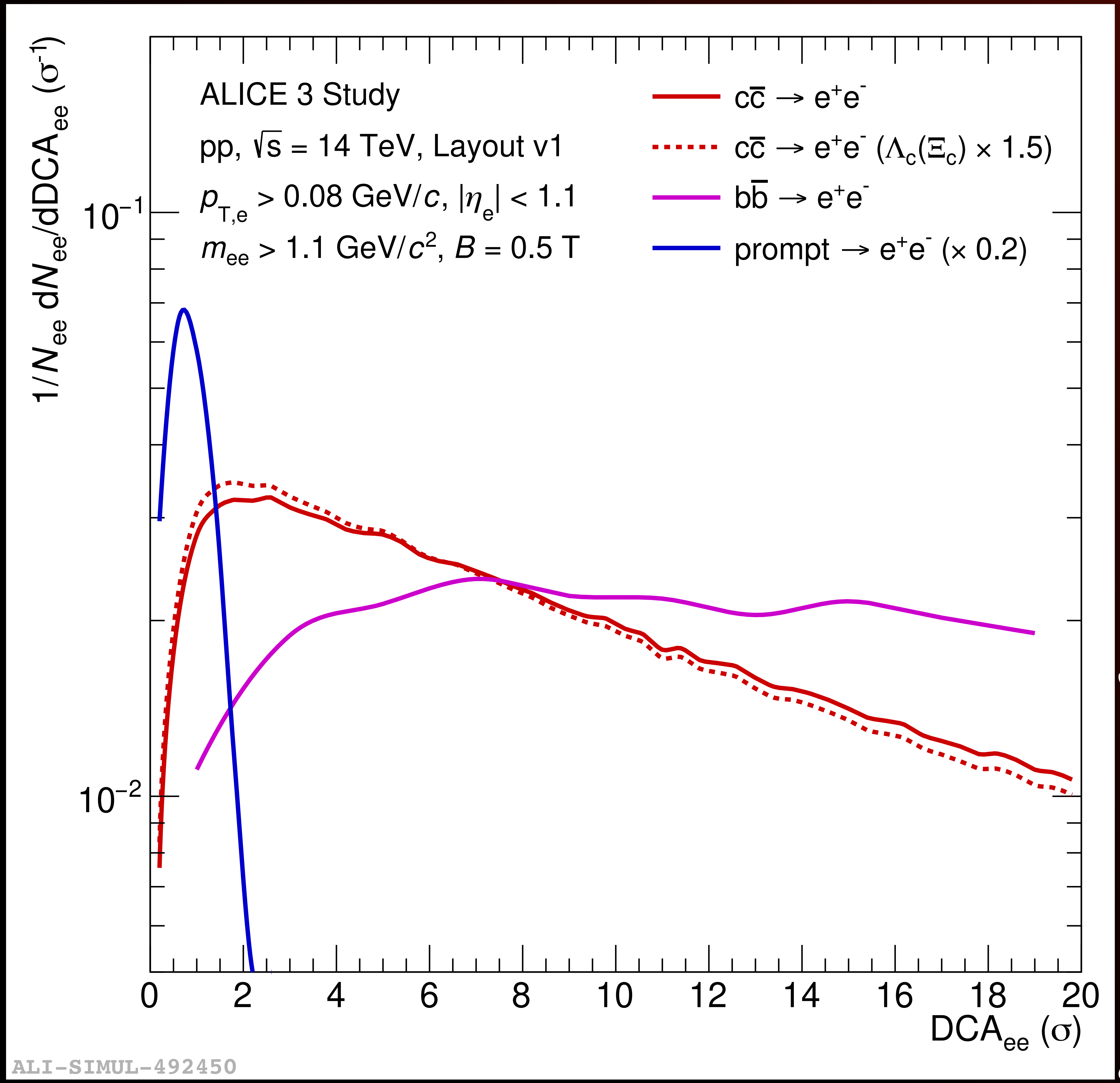
Distance of Closest Approach

DCA_{ee} templates for prompt, charm and beauty contributions

Ordering by decay length of mother particles as expected:

Prompt < Charm < Beauty

Changing hadron chemistry in the charm sector can change the shape of the template



Ongoing studies

Distance of Closest Approach

Expected DCA_{ee} spectrum

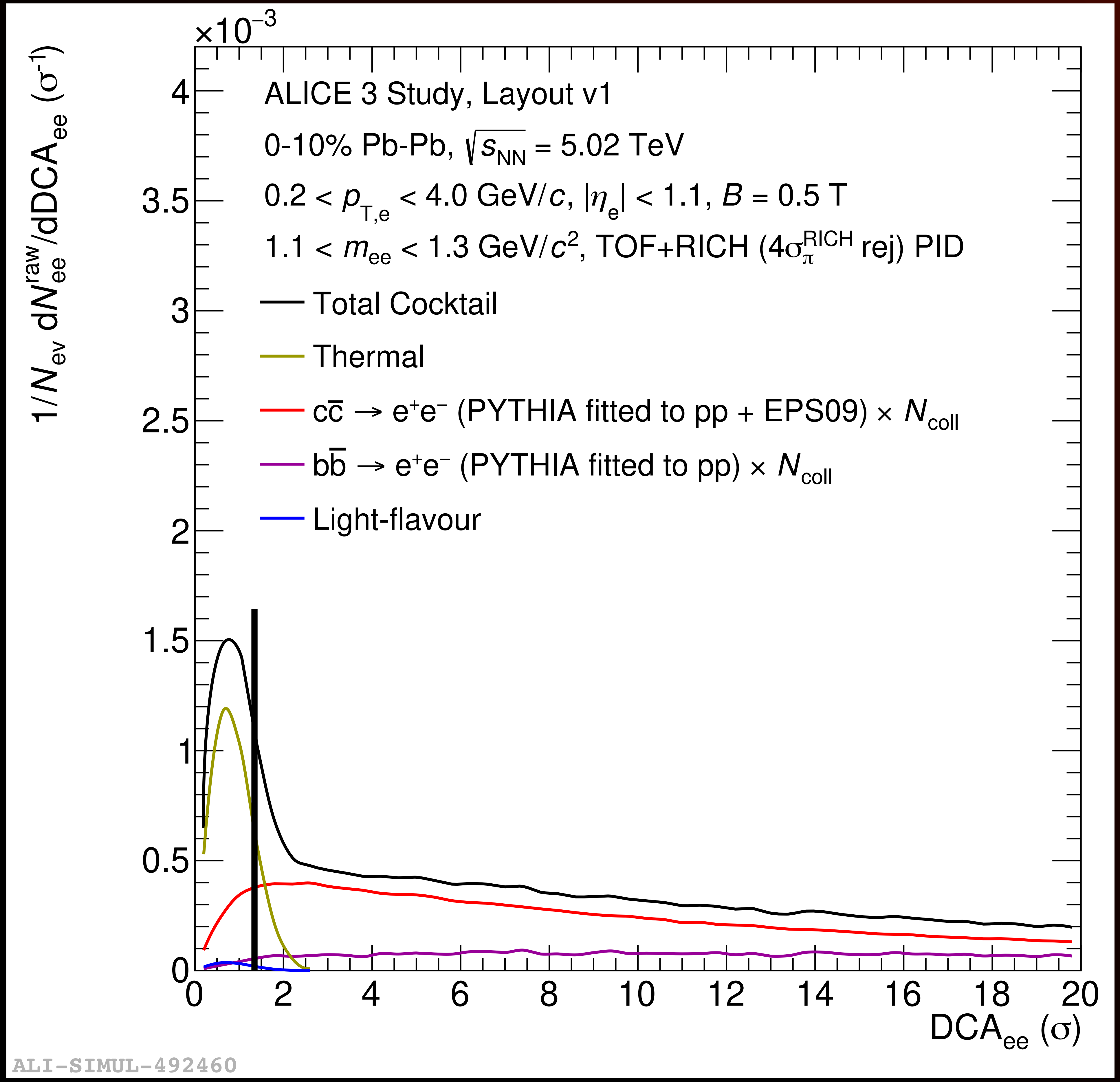
DCA_{ee} contributions based on cocktail expectations and calculations by Ralf Rapp

Good separation

- Large suppression of HF contribution
- Small systematic uncertainty from HF background
- Possibility for precise HFe measurement further reduces uncertainty

Selection at 1.2σ rejects:

27% prompt, 94% charm, and 98% of beauty



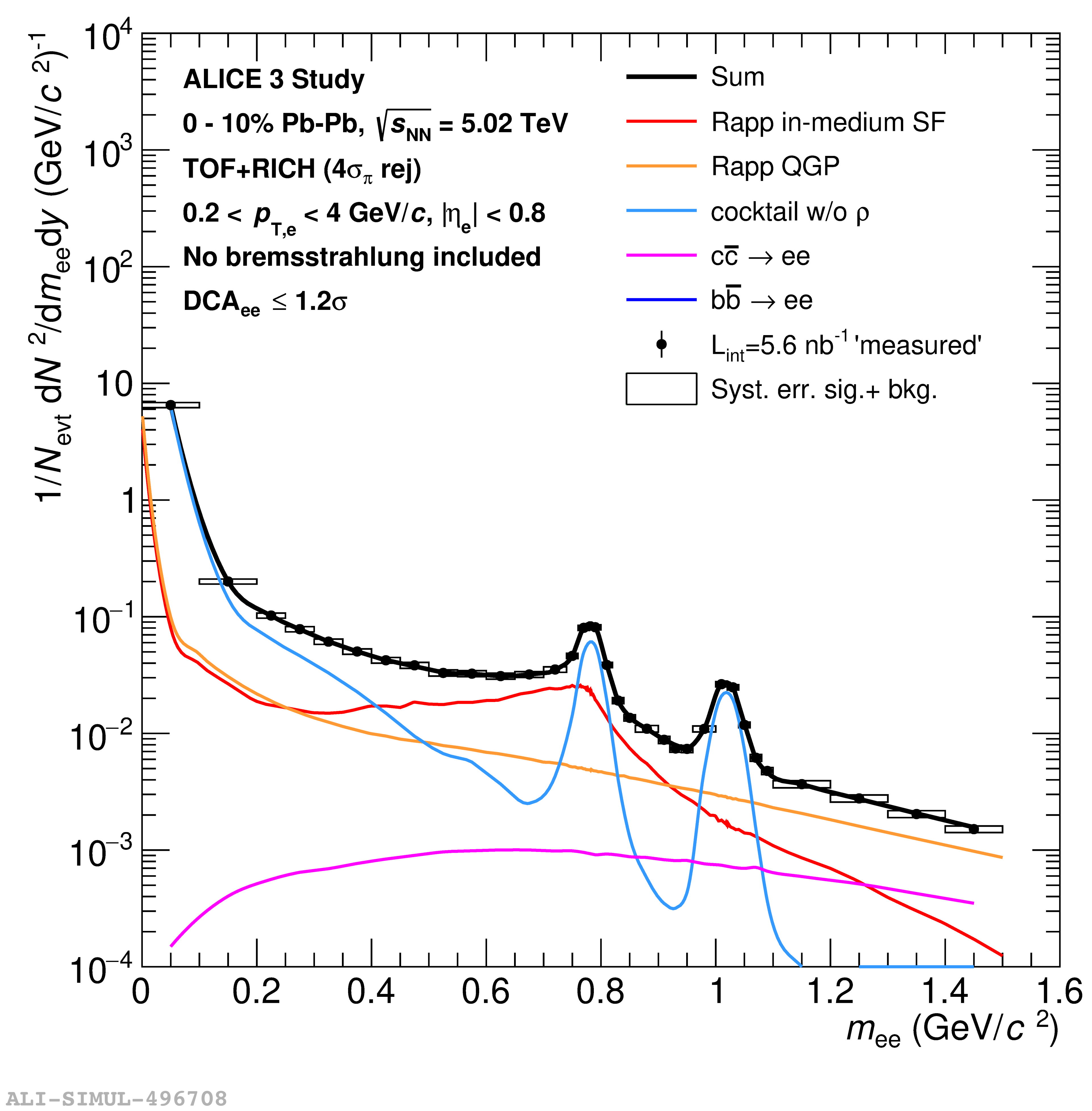
Ongoing studies

Dielectron signal

Expected contributions to the dielectron spectrum after selecting only DCA_{ee} < 1.2σ

Thermal dielectron contributions dominant at m_{ee} > 400 MeV/c^2 (except peak of ω/ϕ)

Possibility to subtract residual charm with small uncertainties (after charm/beauty fit in DCA_{ee})



Ongoing studies

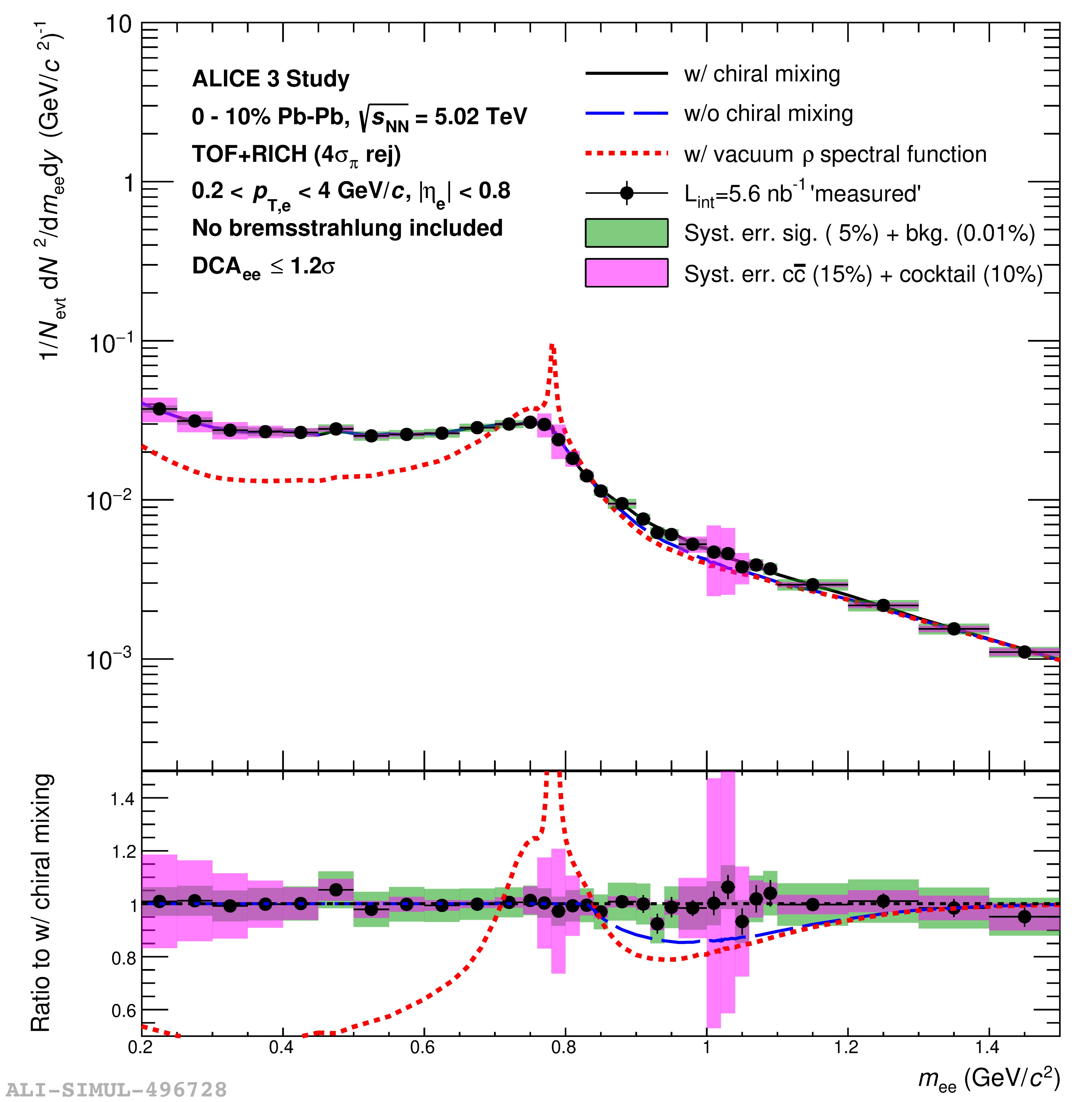
Excess yield

Thermal spectrum from QGP and hadron gas after subtraction of hadronic components

Compared to different ρ spectral functions:

- Including ρ-a1 mixing (reference)
- Without mixing of ρ and a1
- Vacuum ρ spectral function

Statistic uncertainties smaller than systematic uncertainties over the whole mass range



Ongoing studies

Excess yield

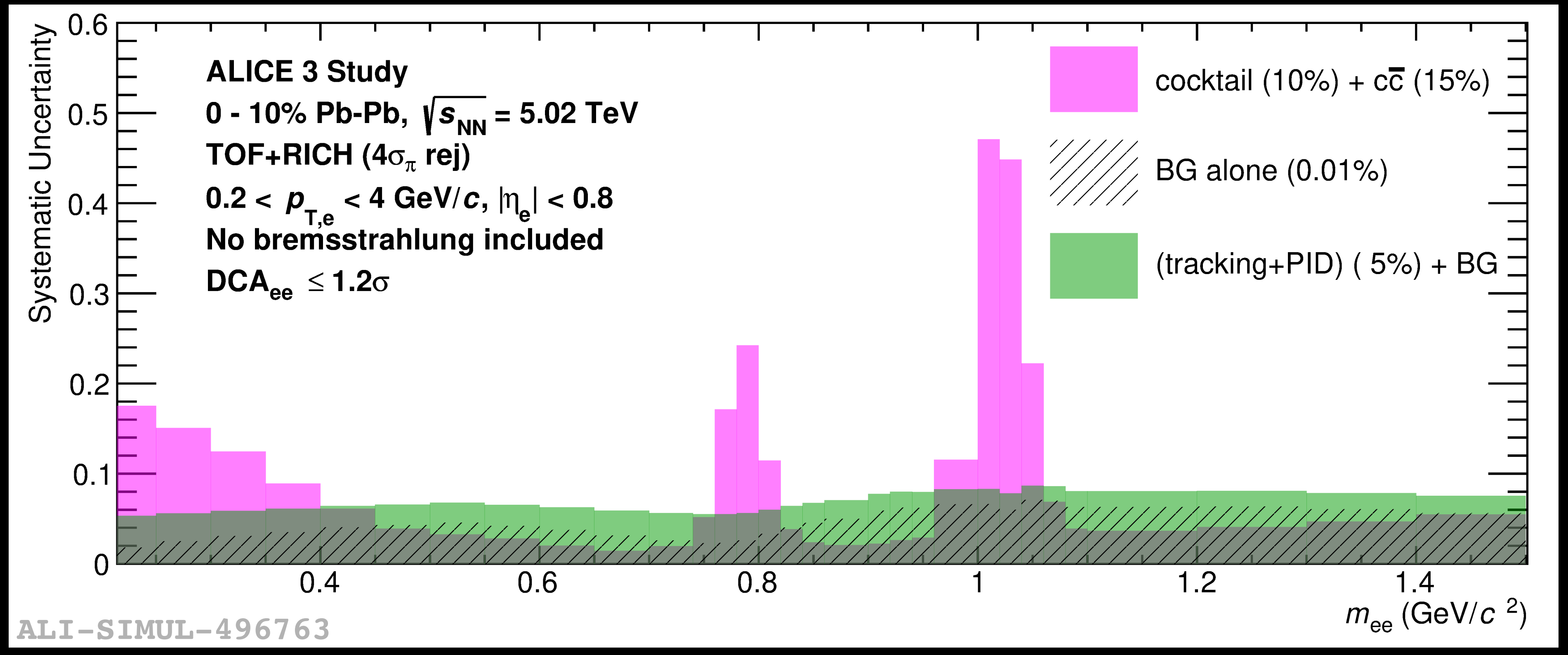
Systematic Uncertainties

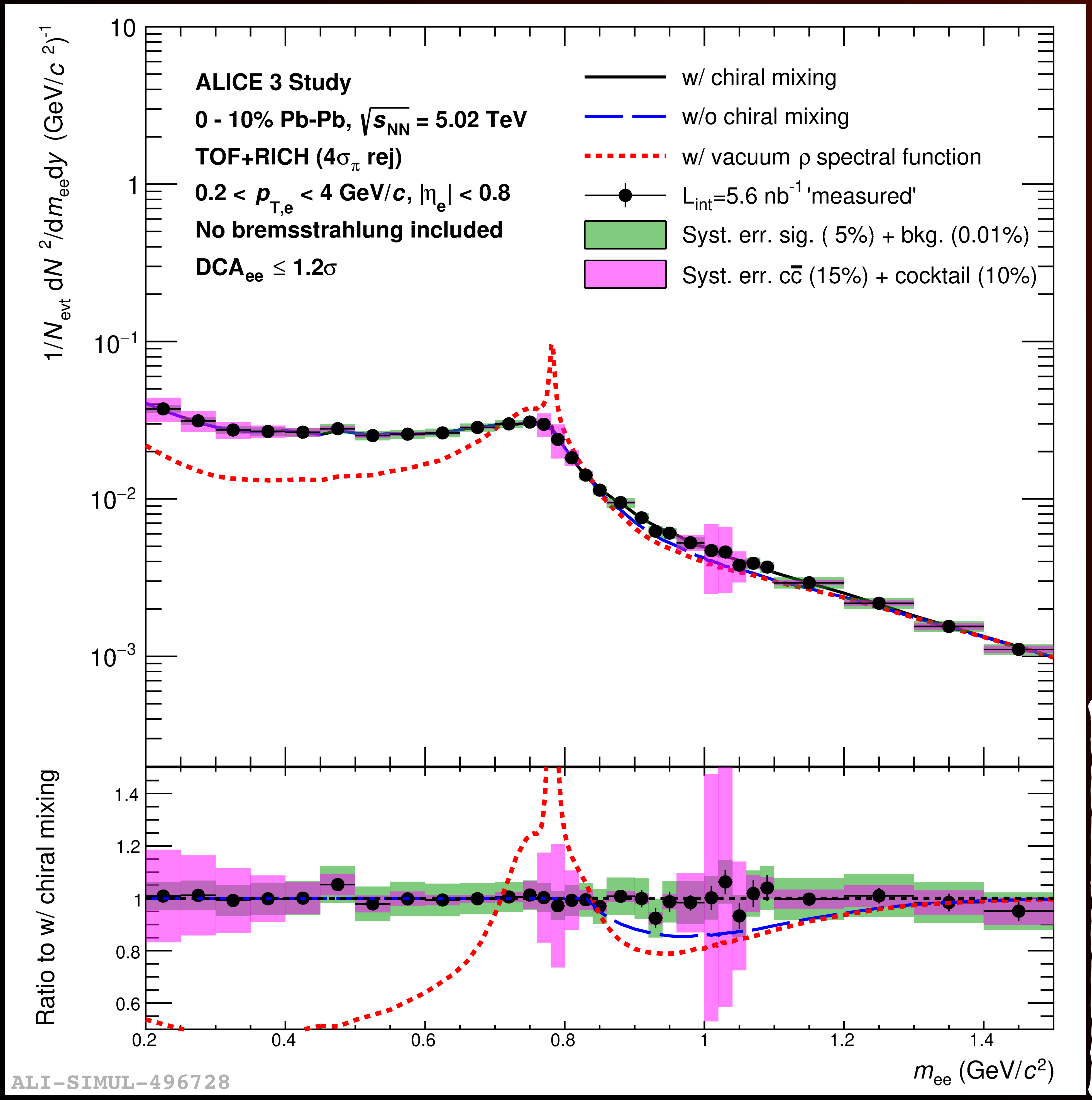
Assumed systematic uncertainties:

- Tracking and PID (5%)
- Combinatoric background estimation (0.01%)
- light-flavour (10%) and heavy flavour (15%) cocktail subtraction

Outside peak regions background, tracking, and PID are dominating source of uncertainty (< 10%)

- Total systematic uncertainties below 10%





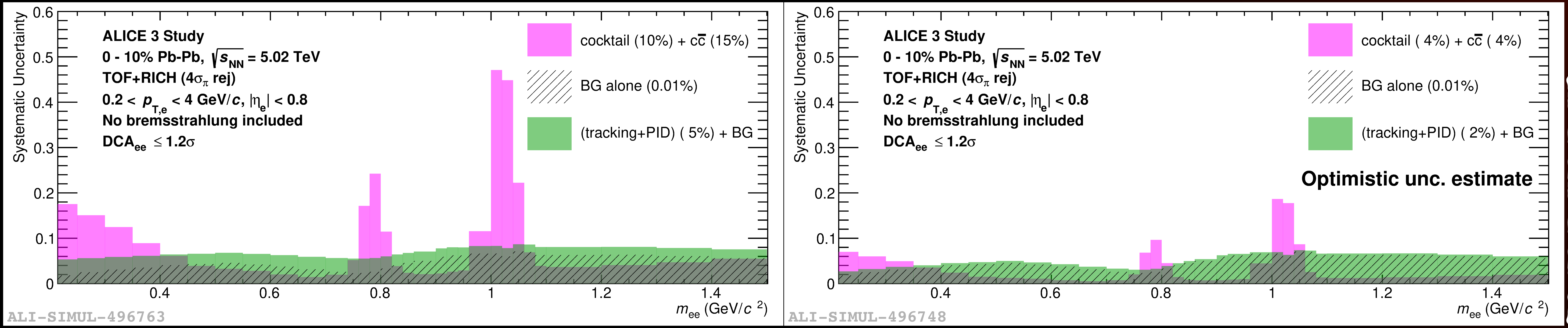
Ongoing studies

Excess yield

Systematic Uncertainties

What if we can reduce the uncertainties?

- Tracking and PID will be better in a all silicon tracker (2%)
- (More) Data driven cocktail estimation for LF and HF contributions (4% each)

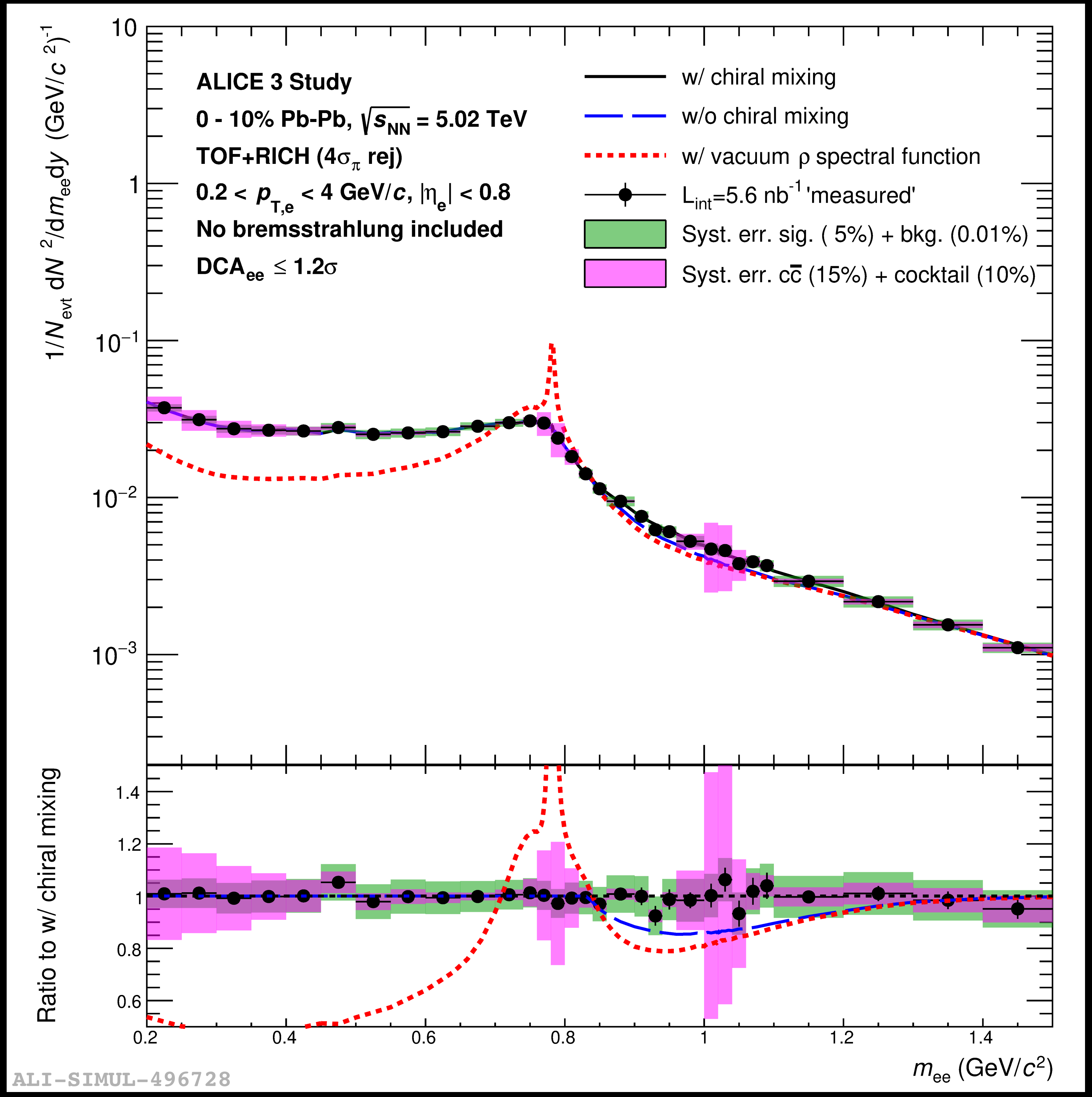


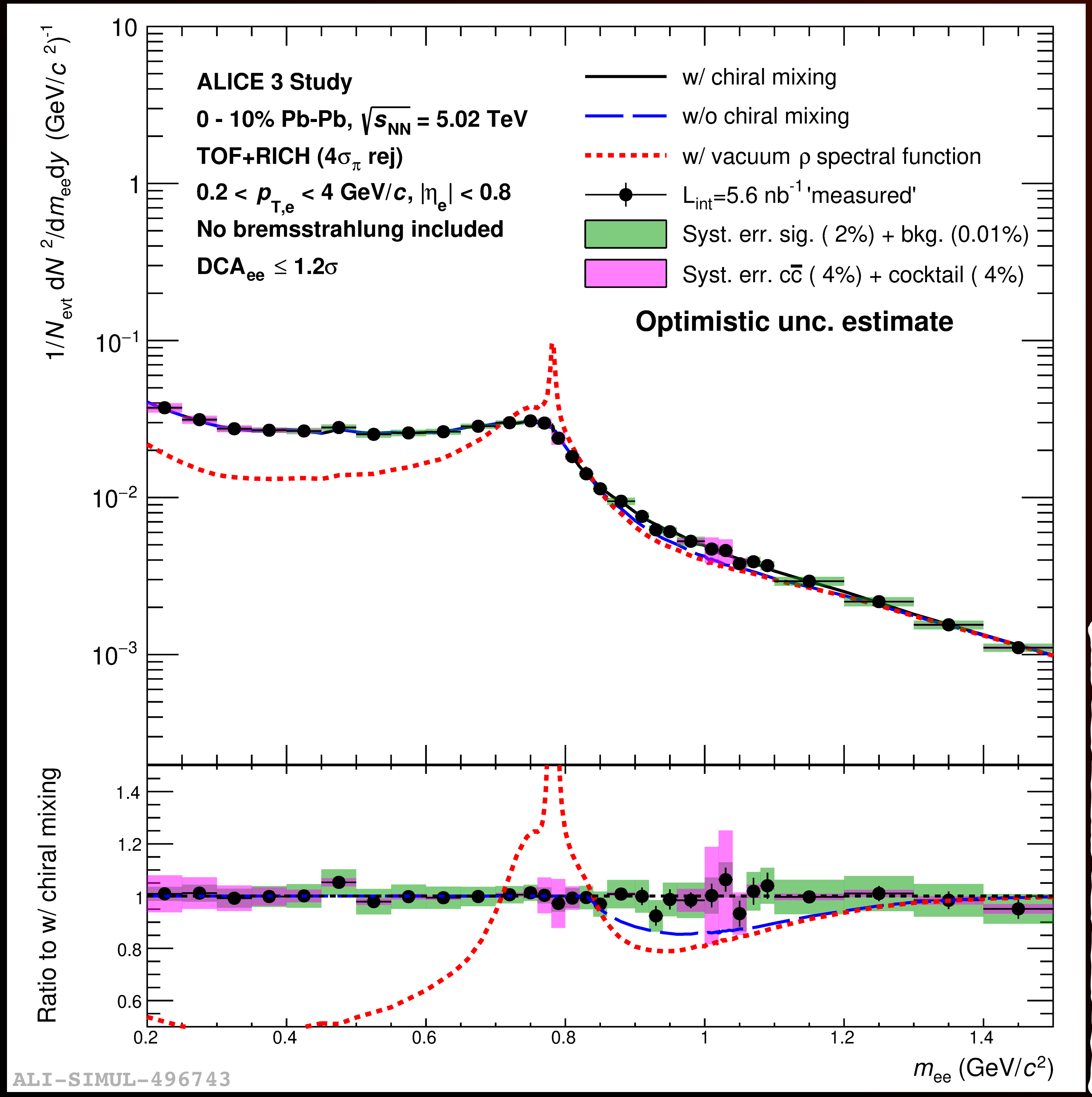
Ongoing studies

Combinatoric background becomes dominant source
→Possible suppression with pre-filter under investigation

Excess yield

Systematic Uncertainties





Ongoing studies

Combinatoric background becomes dominant source
→Possible suppression with pre-filter under investigation

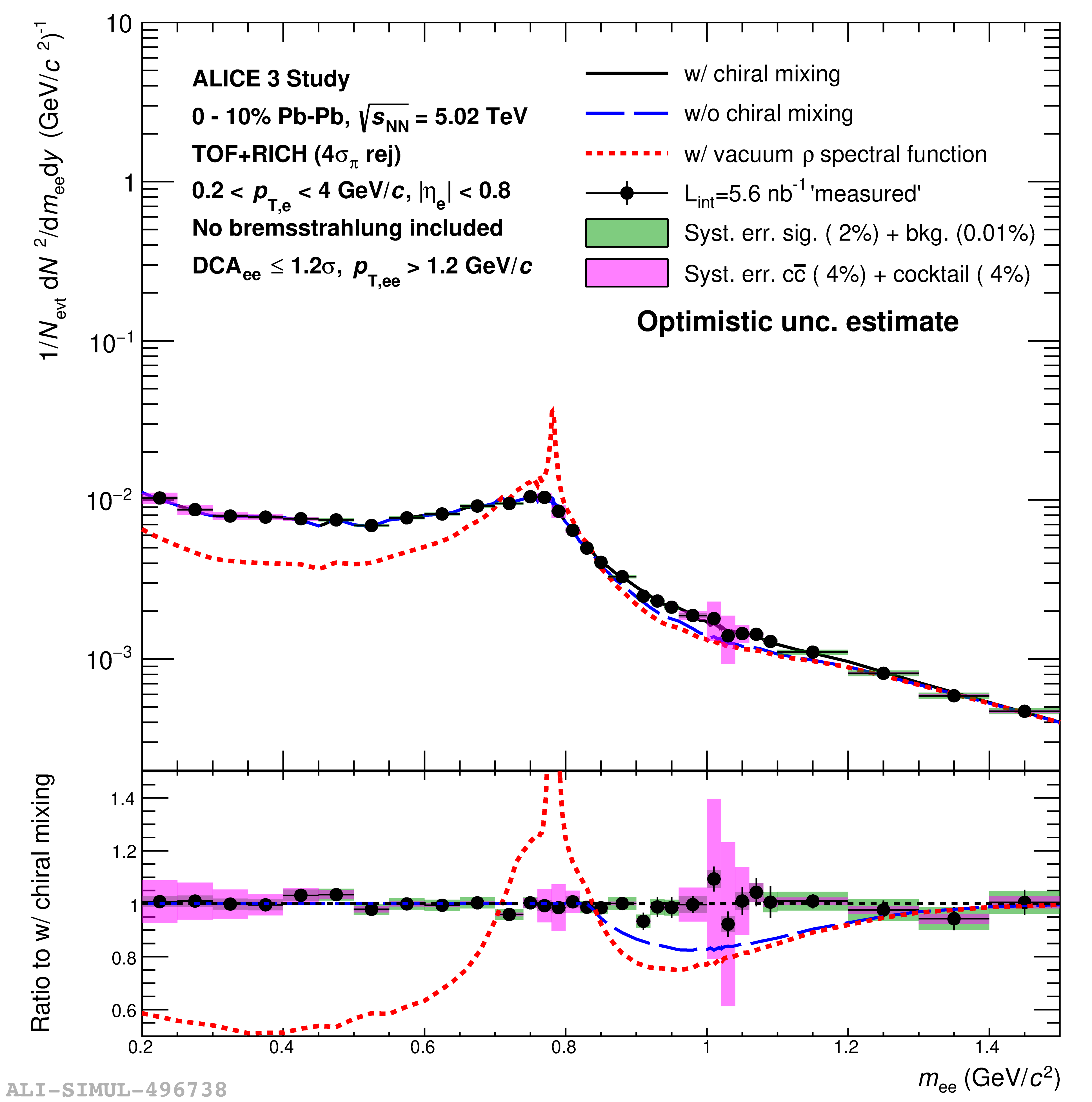
Another possibility: Signal to background ratio is better at higher $p_{T,ee}$

Excess yield

Higher $p_{T,ee}$ > 1.2 GeV/c

- Smaller systematic uncertainty from combinatoric background due to better S/B
  → now tracking and PID become more relevant
- Larger effect of mixing/no-mixing due to larger relative contribution from HG (radial flow)

Improved discrimination power between scenarios with and without mixing



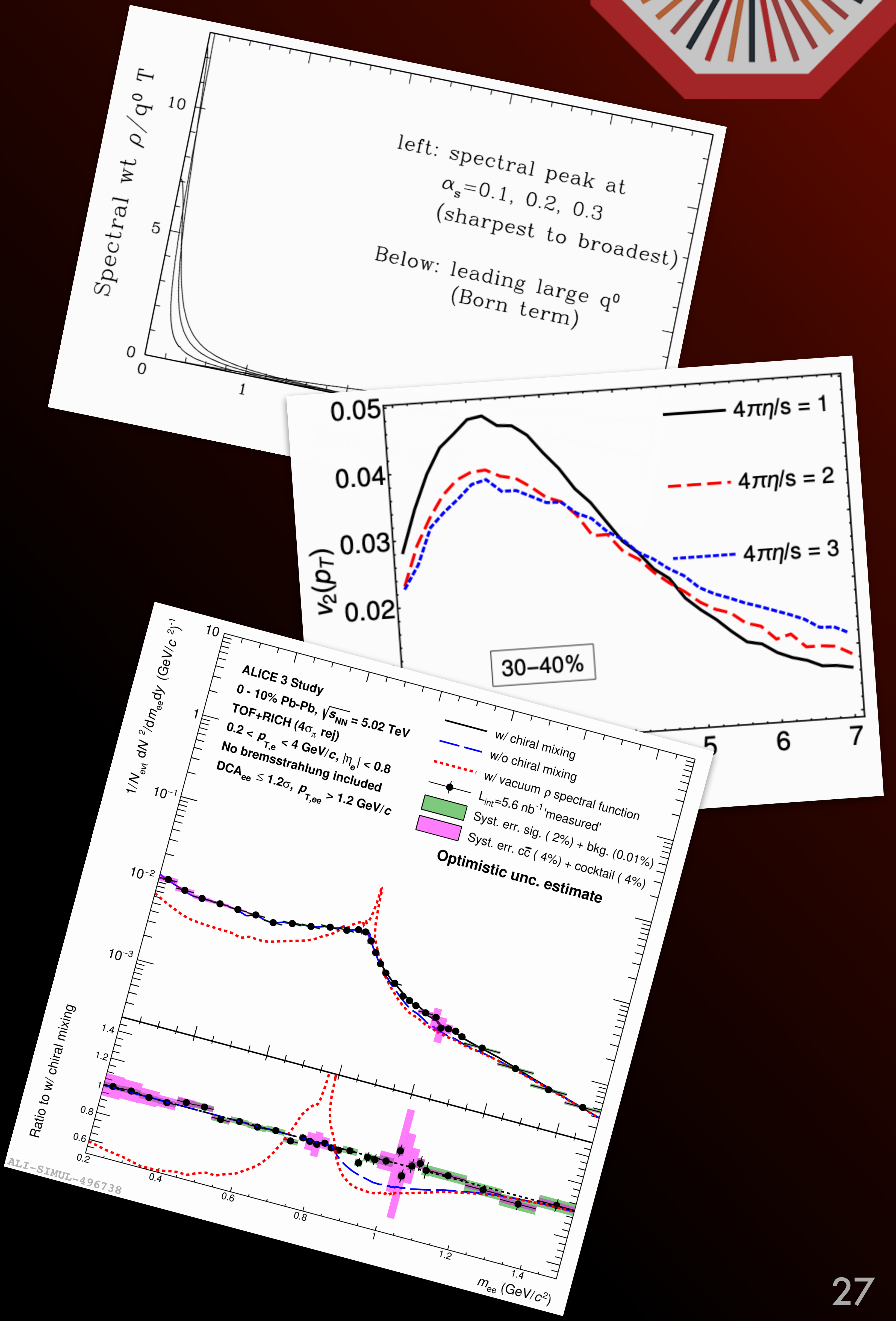
Ongoing studies

Summary

Beyond RUN 3/4 measurements of dielectrons will provide new insights in the physics of strongly interacting matter

- The dielectron spectrum at low masses expected to be sensitive to electric conductivity of the produced medium
- Super soft dielectrons as a complementary probe to the soft photons
- High masses will give access to the dynamics of the very early stages of the heavy ion collision
- Further measurement of ρ spectral function to study chiral mixing in detail

ALICE 3 will provide an excellent detector to study dielectron production with an unprecedented acceptance



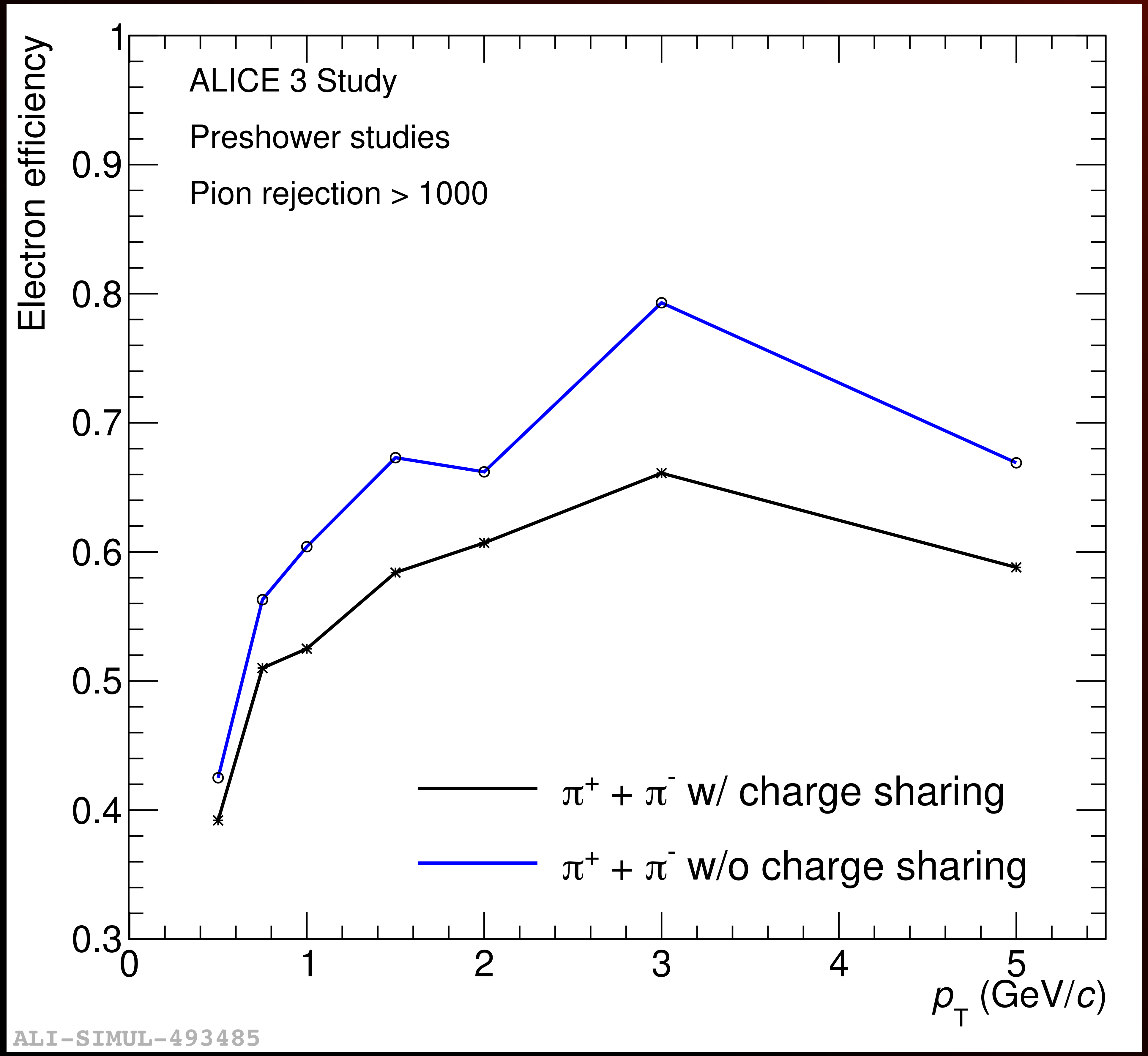
Outlook

Study pre-filter to reduce combinatory background and related systematic uncertainty

Conclude on systematic uncertainties

Explore additional particle identification scenarios

- Pre-shower detector will provide high p_T electron identification and pion rejection
  → enables measurement at high mass/high p_T
  → access to pre-equilibrium dielectrons
- TOF layer at 20 cm will give unprecedented reach for the measurement of super soft dielectron pairs

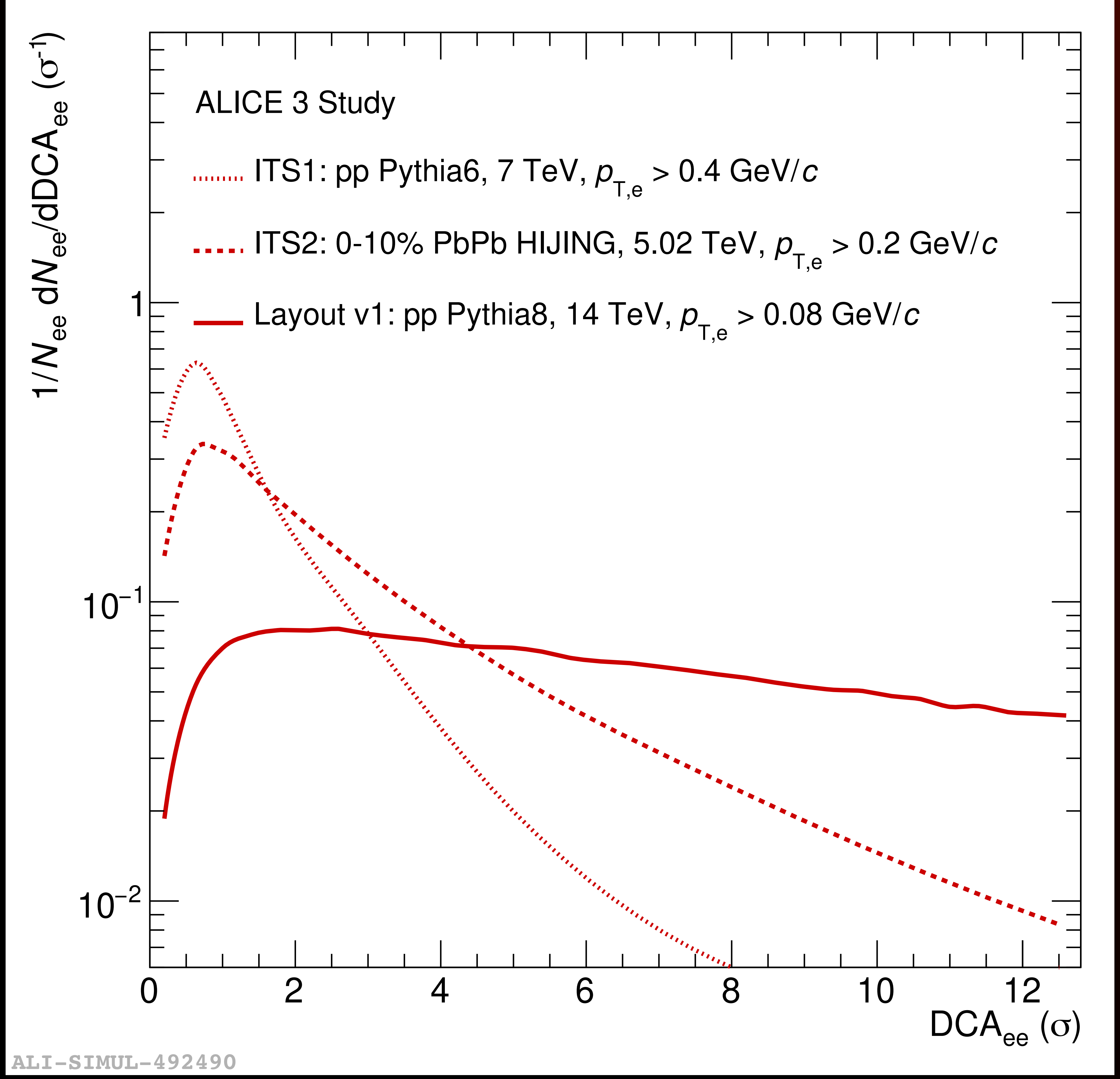


Ongoing studies

Backup

Distance of Closest Approach

Comparison with RUN1/3 performance



Distance of Closest Approach

Charm hadron contributions

Sensitivity can be demonstrated on the level of different decay length of charm hadron species

$c\tau$ (Λ_c) = 60µm

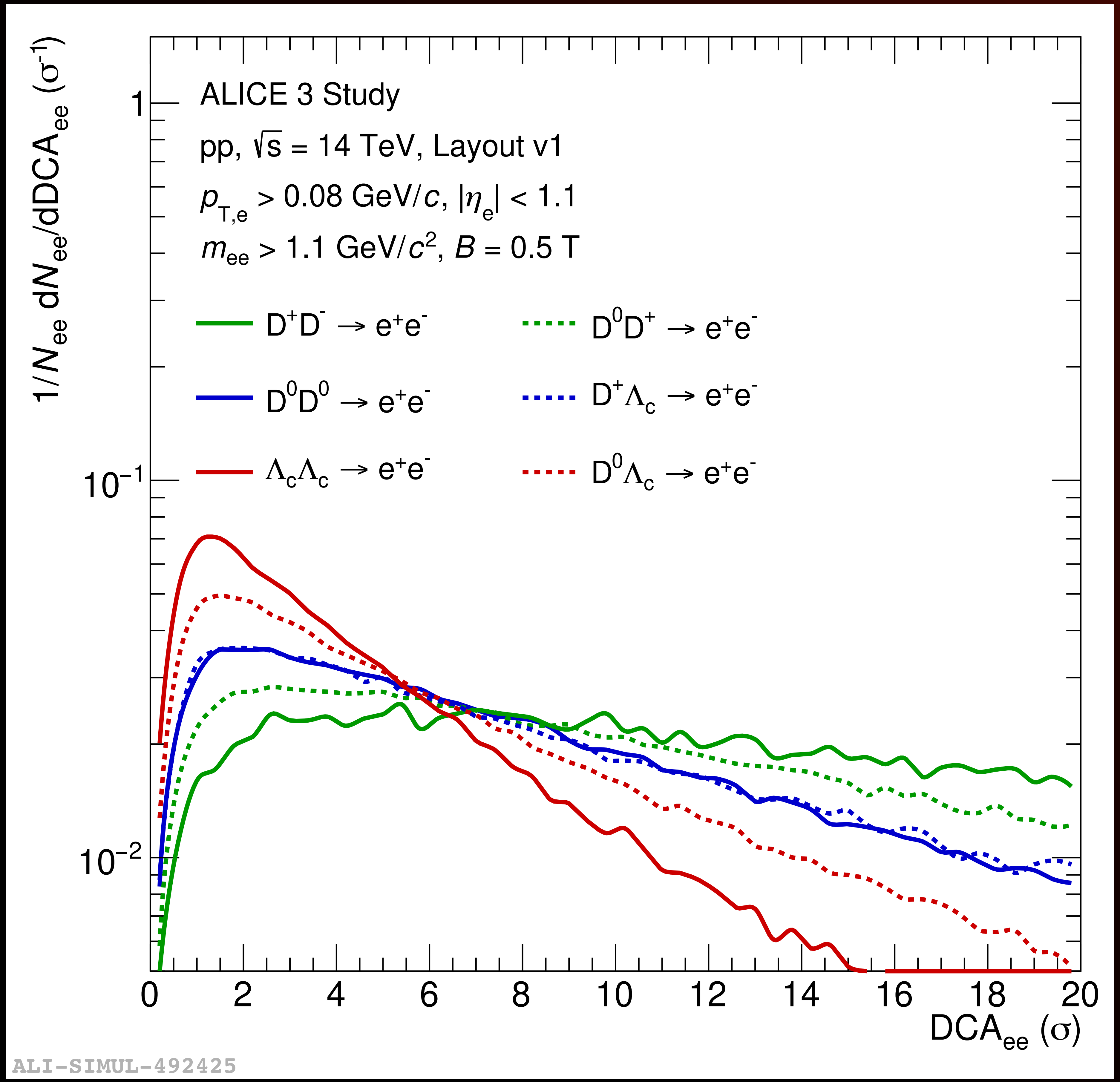
$c\tau$ (D^0) = 150 µm

$c\tau$ (D^+) = 300µm

Final template for charm from weighted sum of single contributions

Input are the measured branching ratios and fragmentation functions

Estimation of uncertainty underinvetigation



Excess yields