Feasibility Studies for Di-Electron Spectroscopy with CBM

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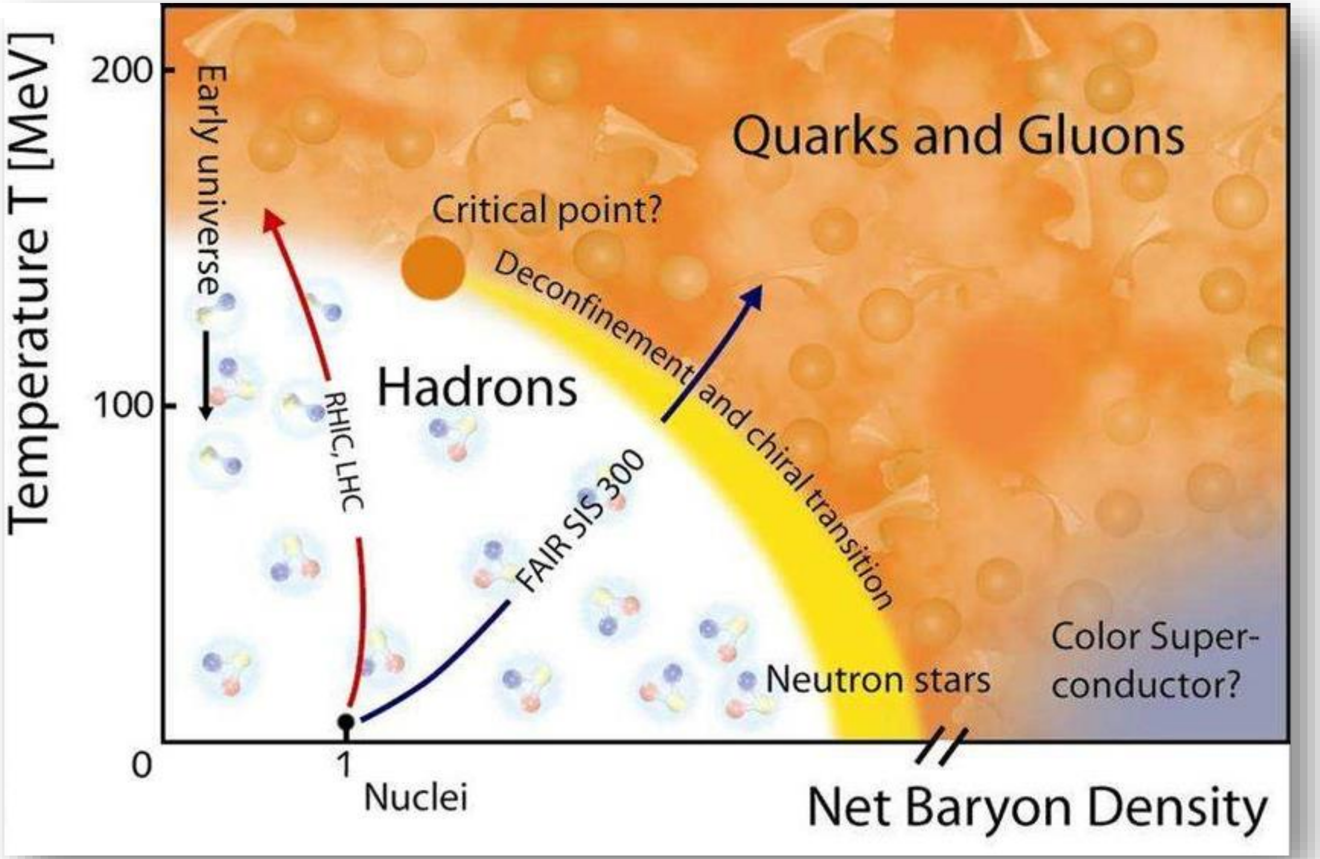
Motivation

[https://theory.gsi.de/~friman/trento_06.html]

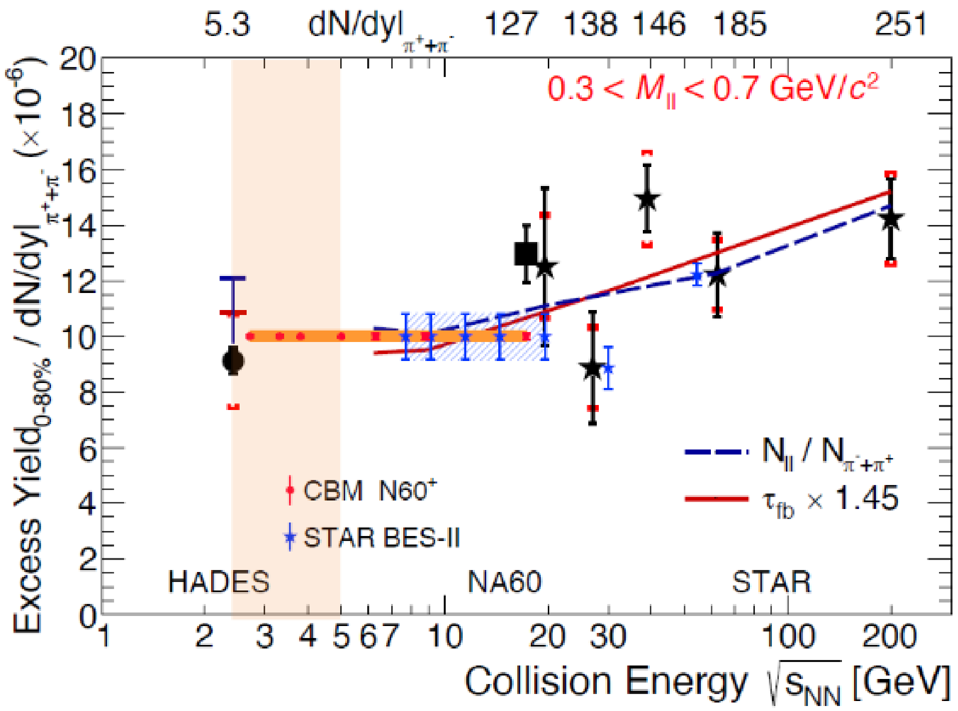


- **CBM: Compressed Baryonic Matter**
- **Explore QCD phase diagram at high densities and moderate temperatures**
- **Di-lepton spectroscopy: determine temperature and lifetime of fireball**

Motivation

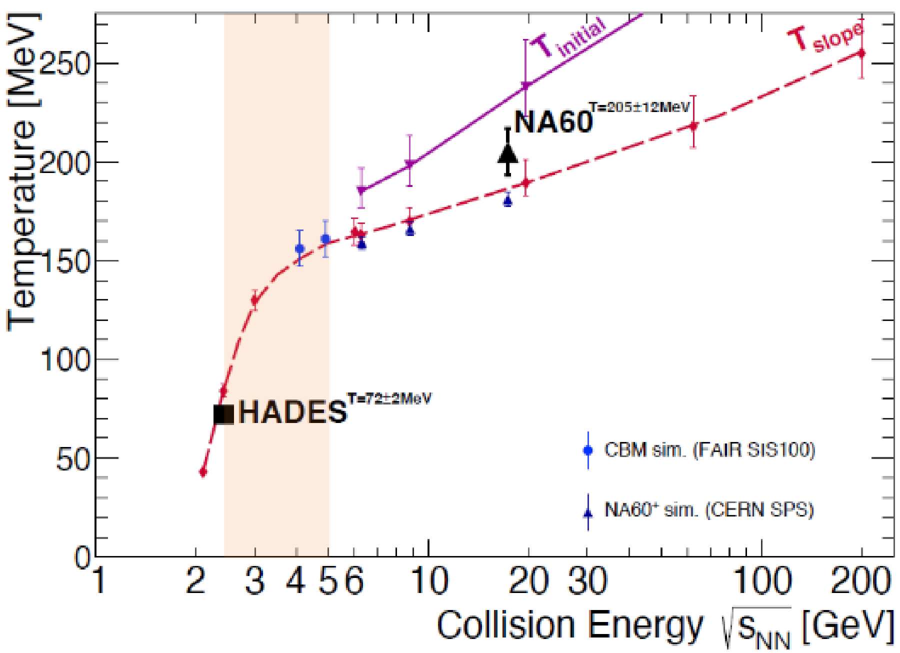
- Excess yield in LMR → fireball lifetime: extra radiation due to latent heat around PT (& CEP?)?
- Invariant mass slope (LMR & IMR) → flattening of caloric curve due to PT ?

* one year 5 days beam on target, 6 energies Au+Au, $2 \cdot 10^{10}$ ev. each, 100kHz



T. Galatyuk, JPS Conf. Proc. 32 (2020) 010079k

Tripolt et al., NPA 982 (2019) 775
Li and Ko, PRC 95 (2017) no.5, 055203
Seck et al., PRC (2022), arXiv:2010.04614 [nucl-th]
O. Savchuk et al., arXiv:2209.05267 [nucl-th]

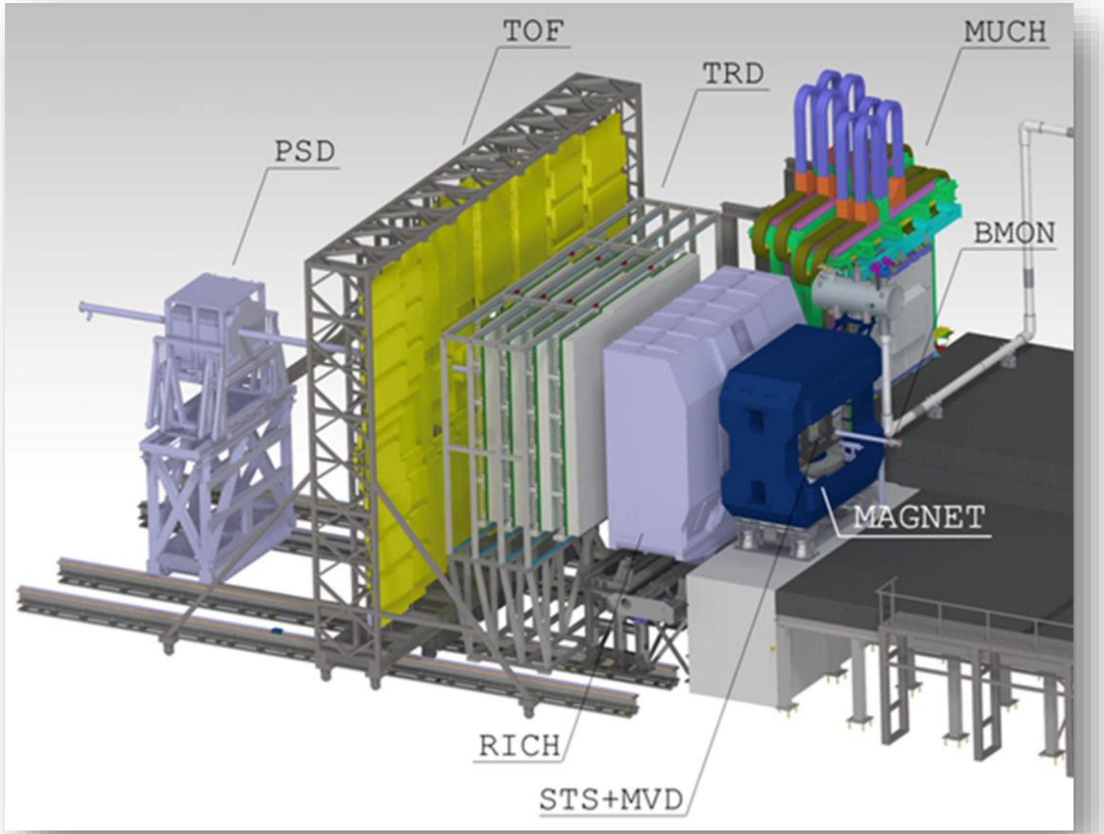


Slide taken from Claudia Höhne

A rise in the excess yield and constancy in Temperature would be an indication of a 1st order phase transistion.

Track Selection for Di-Electron Analysis at CBM

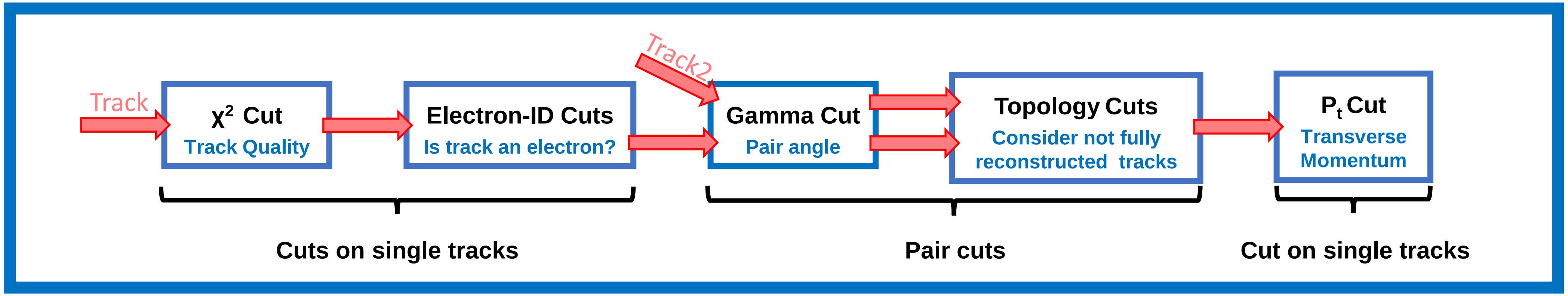
[Peter Senger, CBM Collaboration Meeting; Mar 24]



Problems we have to deal with:

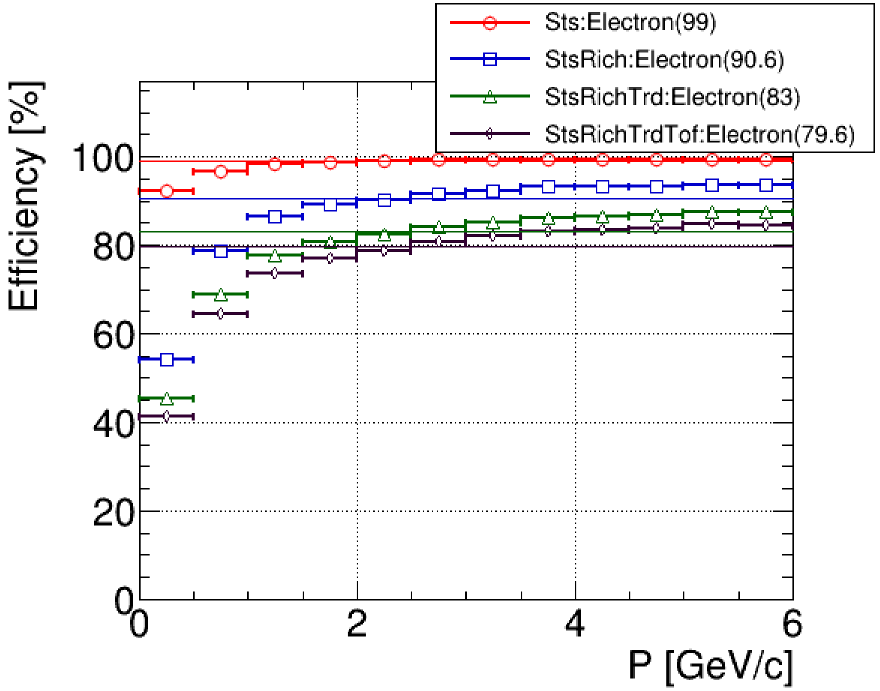
- **Many π^0 are created, decaying into 2γ or γe+e-**
- **A lot of material is deposited before the RICH**
  - **→ enhancement of γ conversion and secondary electrons**
- **Secondaries are seen in RICH and TRD and can easily be matched to tracks of charged pions**
- **Suppression of background is difficult → good tracking is essential for background suppression**

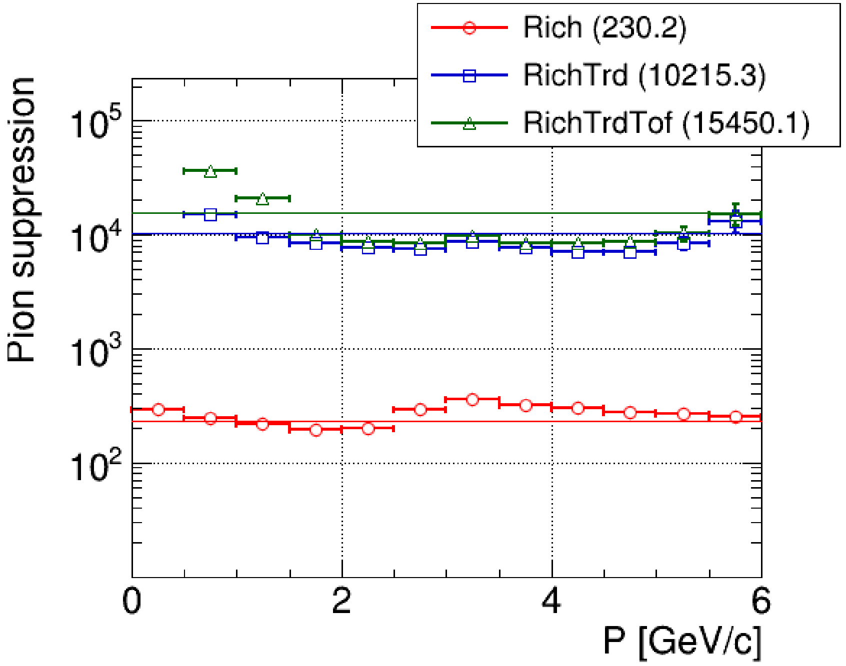
Track Selection for Di-Electron Analysis at CBM

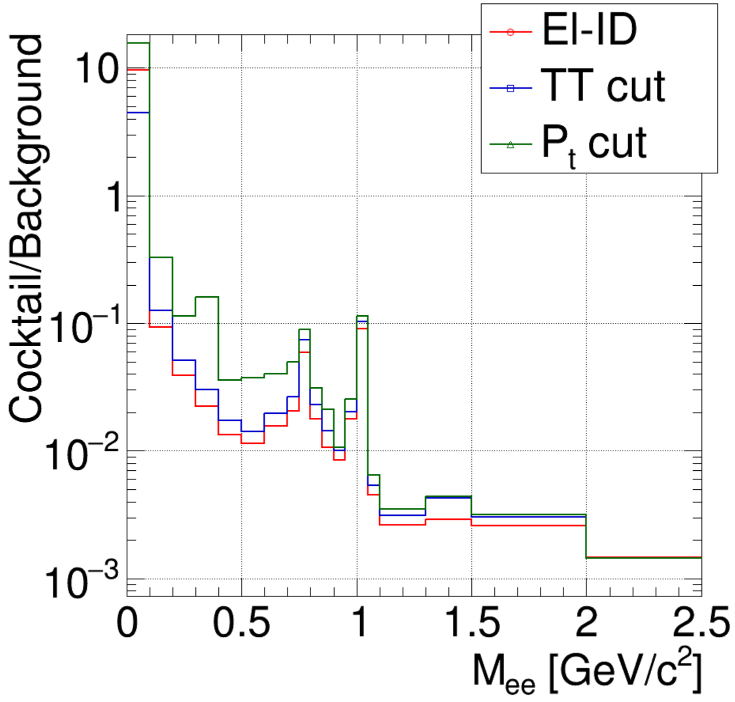


Sequence of Analysis cuts used for Di-Electron Analysis.

Performance

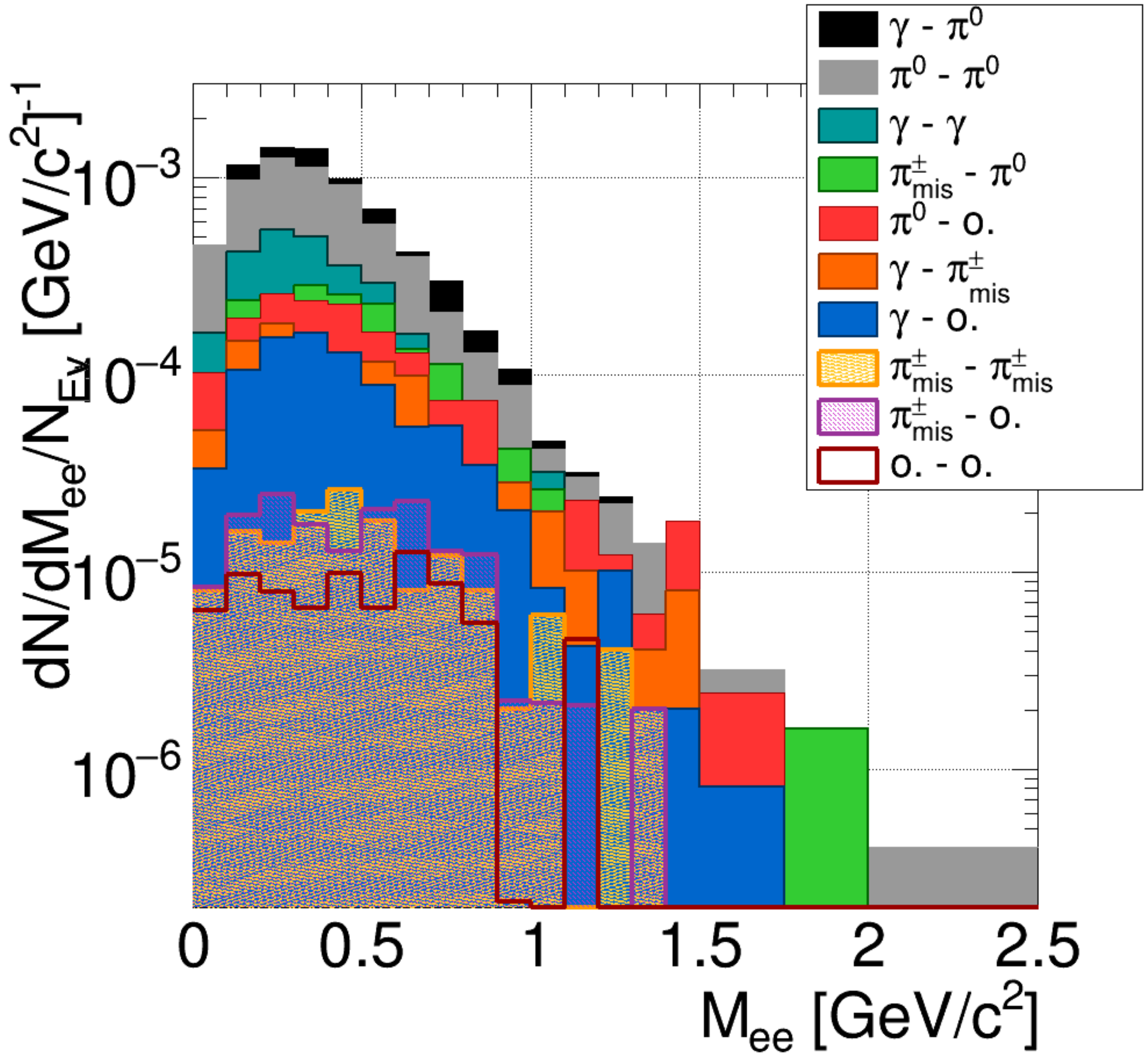






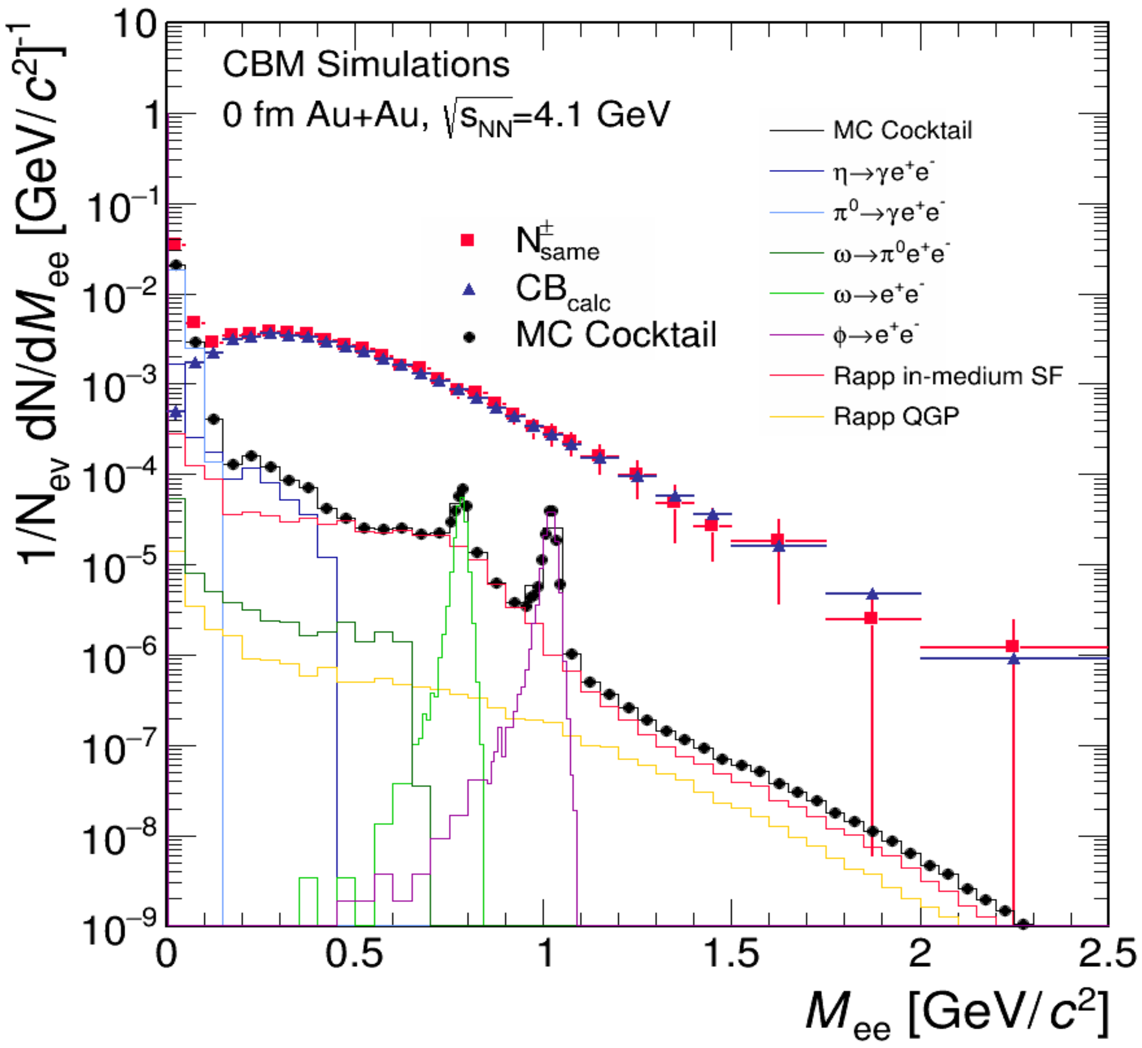
- **Efficiency for electrons (in geometrical acceptance) to be reconstructed in all detectors ε ≈ 80 %**
- **Pion suppression ≈ 15 000** $\left(S_\pi = \frac{\#\text{reconstructed pions}}{\#\text{ rec. pions that passed El-ID step}}\right)$
- **Signal-to-Background ratio S/BG ≈ 1/100**

Current Status of Di-Electron Analysis



- **Contributions to the background are dominated by physical background, i.e. electrons from γ conversion and π^0 decay**
- **Also misidentified pions form a large part of the background**

Current Status of Di-Electron Analysis



- **Ratio S/BG ≈ 1/100 ⟹ not possible to extract signal by means of e.g. see any peaks in $N^{\pm}_{same}$ (= B_{MC} + MC Cocktail) spectrum.**
- **Estimate background with mathematical expression (CB_{calc}, calculated combinatorial background) and subtract it from total e+e- spectra.**

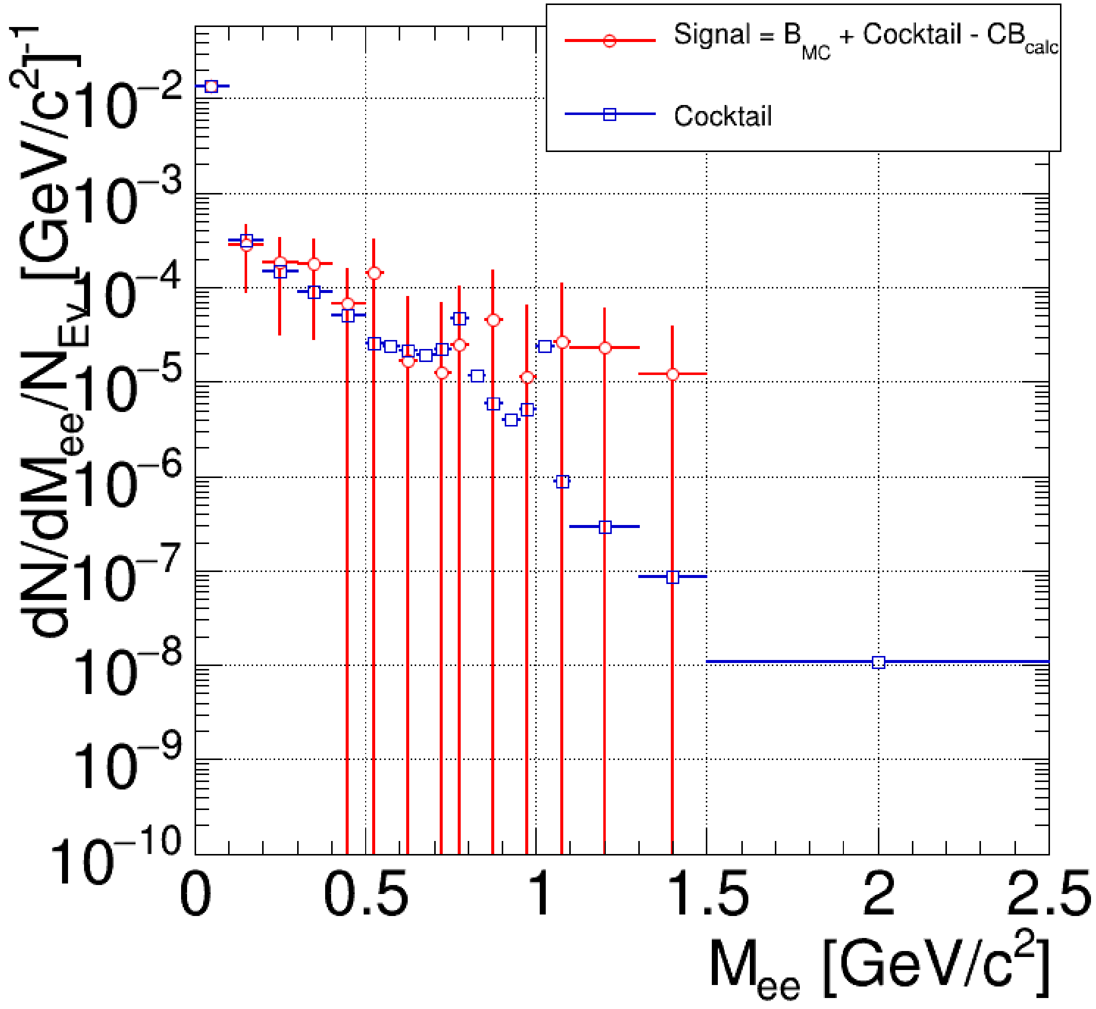
$$CB_{calc} = 2\,k\,\sqrt{B^{++}B^{--}}, \quad B^{++} = e^+e^+ \text{ yields from same events}$$

$$k = \frac{b^{\pm}}{2\sqrt{b^{++}b^{--}}}, \quad b^{++} = e^+e^+ \text{ yields from mixed events}$$

- **Problem in our simulations:**
  - **Two large numbers are subtracted to get a small number as result**
  - **not sufficient statistics (5x10^6 events)**

⟹ **large fluctuations in calculated signal**

Current Status of Di-Electron Analysis

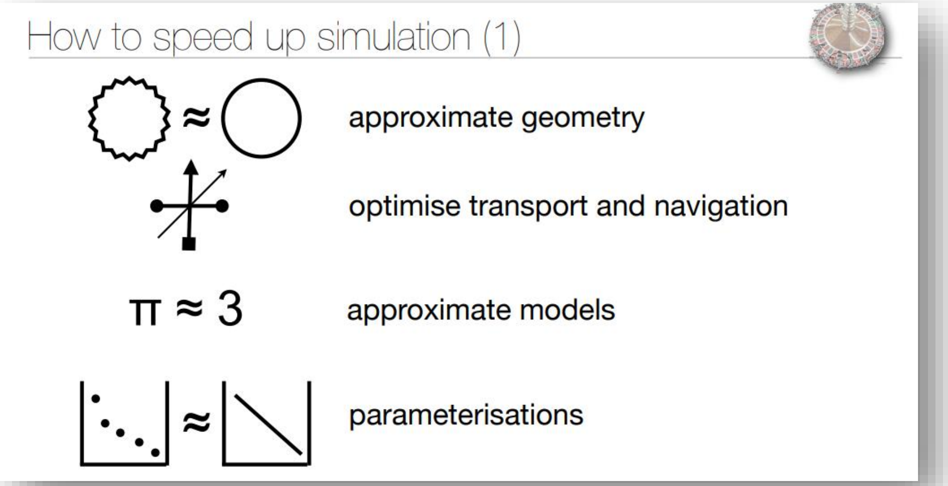


➡ **Large fluctuations in calculated signal**

- **Result does not reflect the true signal**
- **Idea: Enhance statistics by implementing Fast Simulation techniques (Random Events) to enable large statistics for constructing a background with small fluctuations**

Implementation of a Fast Simulation (Random Event) Procedure

[Andreas Salzburger: *Fast Simulation in ATLAS*; talk; 2013]



- **Fast Simulations are based generally on approximations of geometry / models and parametrisations of outputs.**

- **Here: use output of „Slow Simulations“ as basis to create large numbers of randomly generated events (via using `GetRandom()`), seperately for each particle or charge**

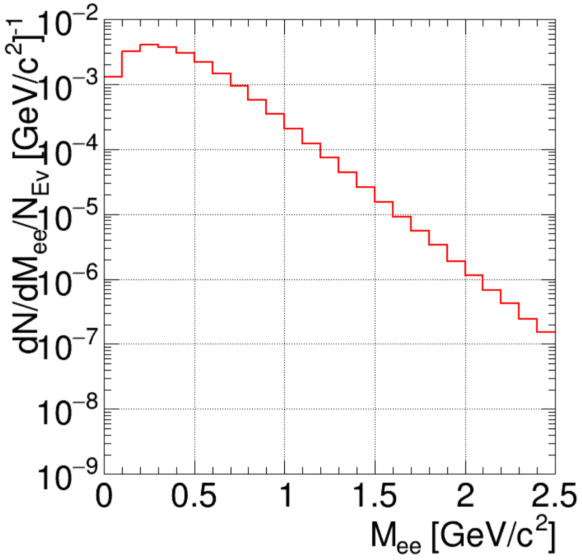
- **Which parameters are needed to construct the background?**

$$M_{\mathrm{ee}} = 2\sqrt{P_+ \cdot P_-} \cdot \sin\left(\frac{\vartheta}{2}\right)$$

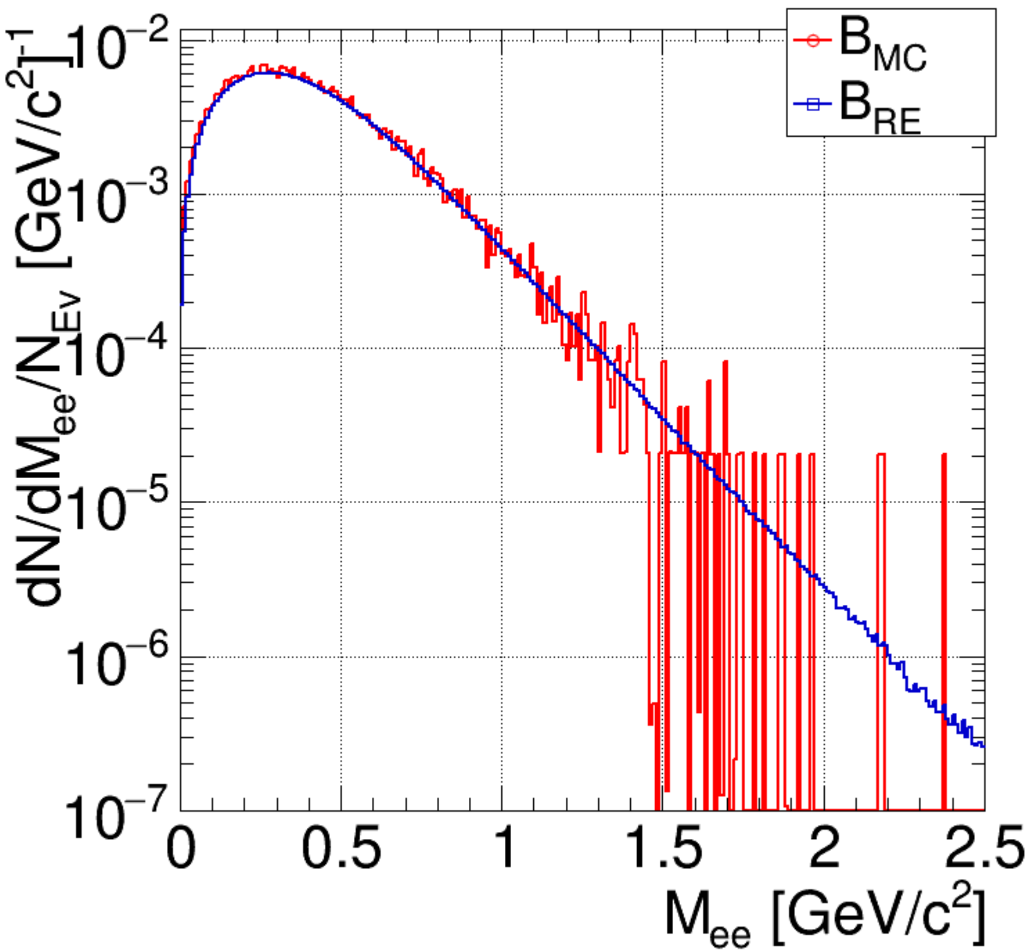
→ Hence, only two parameters are needed:

- **Multiplicity: Occurence of a particle per event after electron-identification**
- **3D Momentum distribution of that particle**

Background

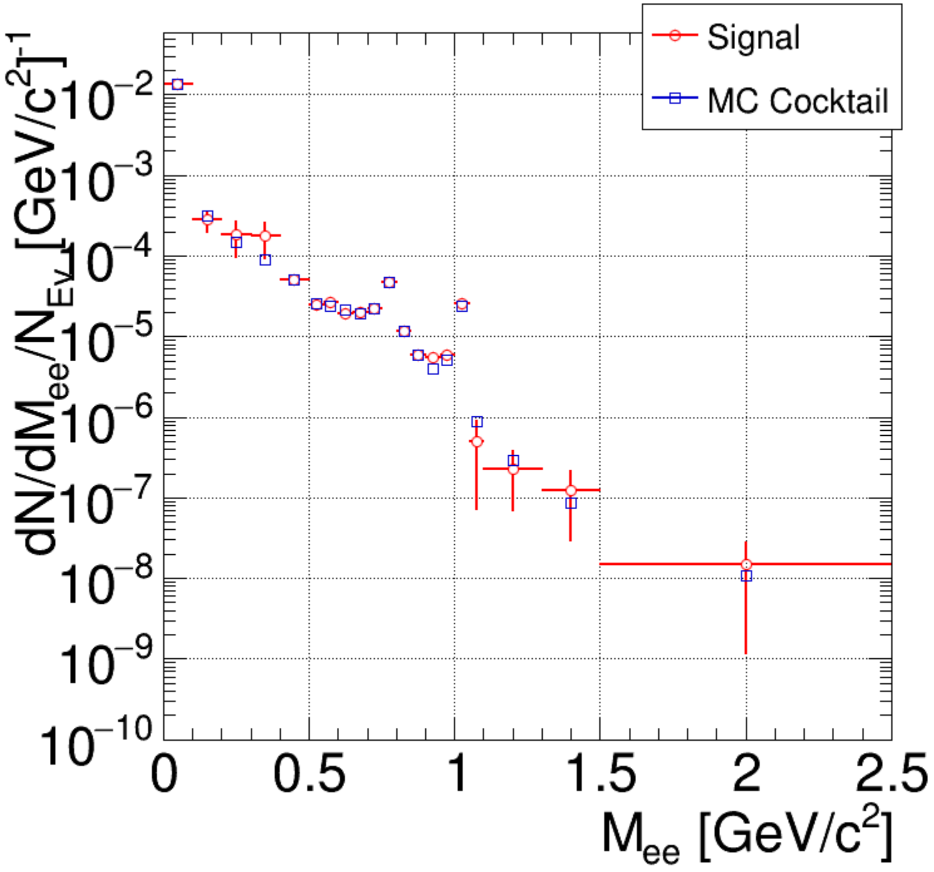


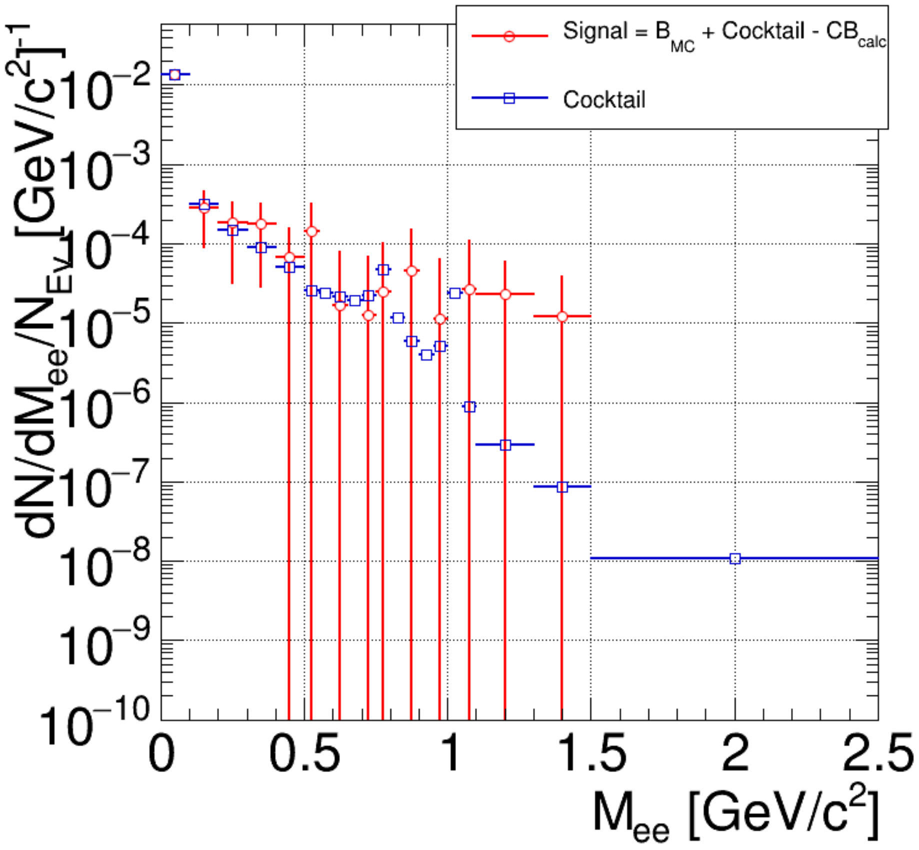
Implementation of a Fast Simulation (Random Event) Procedure



Conventional Background B_{MC} with a statistics of $5x10^6$ compared to the background obtained by Random Event Techniques (B_{RE}) with a statistics of $20x10^9$ events.

Result

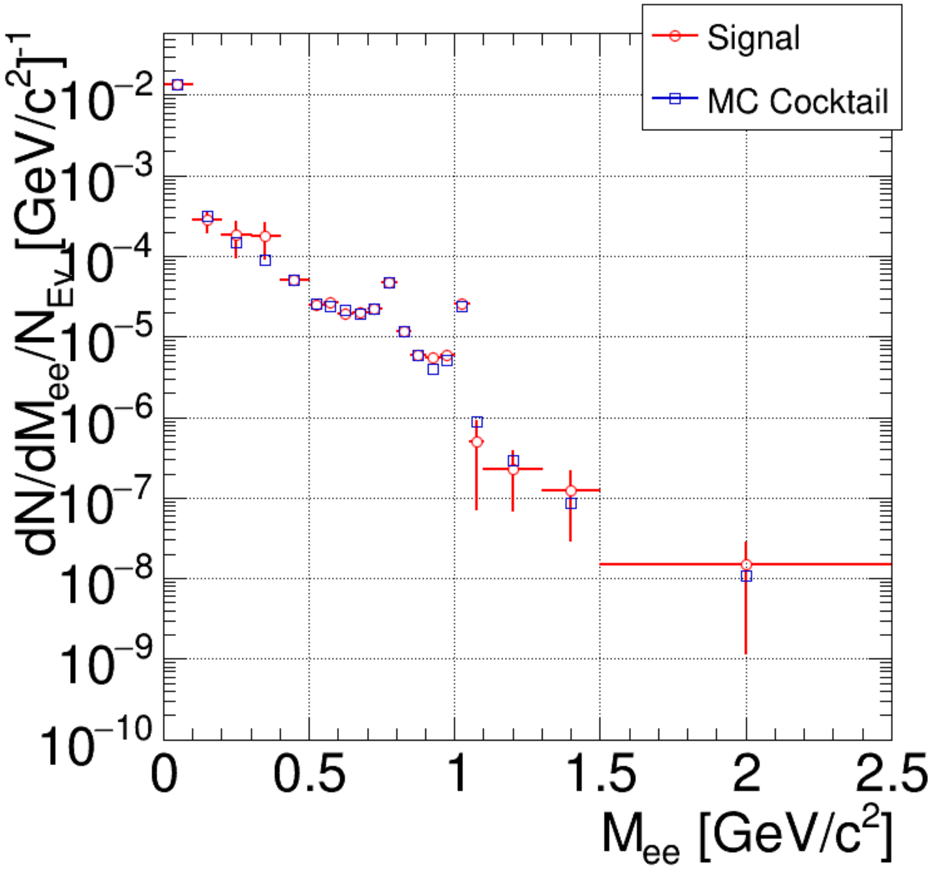




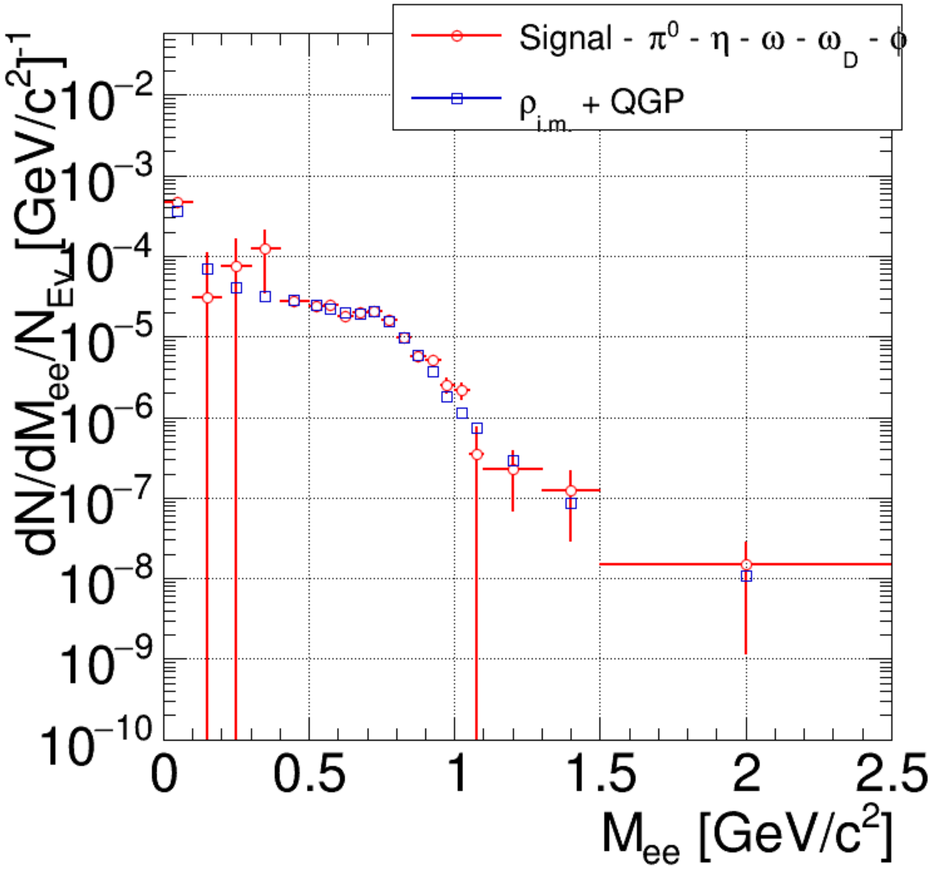
Signal (red), calculated by subtracting the Calculated Combinatorial Background (CB_{calc}) from the e+e- yield, obtained by Random Event techniques (left) and conventional methods (right), in comparison to the MC cocktail (blue).

Reduced Signal

Full Signal

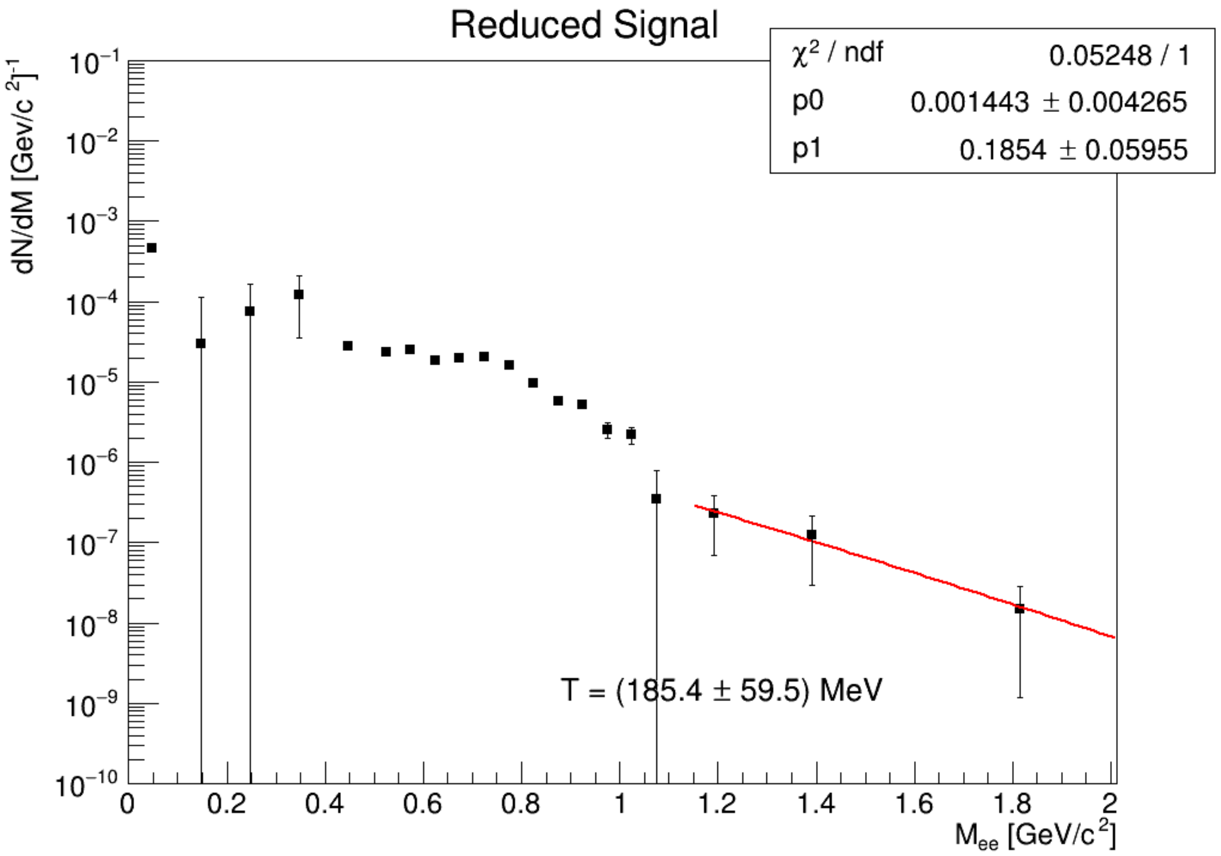


Reduced Signal



Right: „Reduced“ signal: Obtained signal minus electrons from known sources (π^0, η_D, ω, ω_D, ϕ; red). Remain should only electrons from in-medium rho ($\rho_{i.m.}$) and QGP. In blue: MC input $\rho_{i.m.}$+ QGP.
From comparison with NN references at masses below 1 Gev/c^2 the excess yield can be determined.

Temperature of the Medium



Reduced Signal with temperature fit.

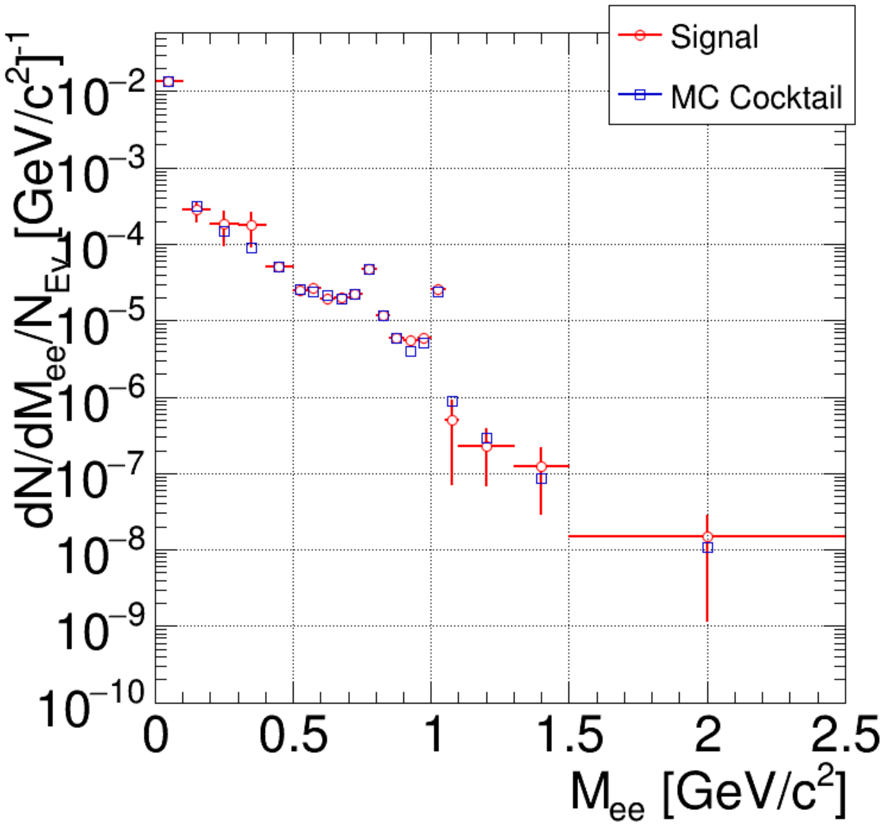
if $M \gg \boldsymbol{T}$:

$$\frac{\mathrm{d}N}{\mathrm{d}M} \propto (M\boldsymbol{T})^{3/2} \exp(-M/\boldsymbol{T})$$

- **Acceptance and efficiency corrections are not applied yet in these results (bias ≈ 8 MeV).**
- **Location of data points is corrected due to asymmetric bin population to get true fit results [1)]**

[1)] G.D. Lafferty, T.R. Wyatt: *"Where to stick your data points: The treatment of measurements within wide bins". Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 355, Issues 2–3, 1995, Pages 541-547, ISSN 0168-9002, https://doi.org/10.1016/0168-9002(94)01112-5.*

Statistical Errors



Calculated signal with statistical error bars. In the IMR, the size of the error is about the size of the signal itself.

- **Statistical errors calculated for quick energy scan at first year of CBM running (4-5 days beam each for 5-6 energies with moderate rate)**
- **In last bin (1.5-2.5 GeV/c²):**

$$\frac{S}{N} \approx \frac{1}{300}$$

$$N \approx 60{,}000^{1)} \quad \rightarrow \Delta N = \sqrt{N} = 245$$

$$S = N - CB_{calc} \rightarrow \Delta S \approx \Delta N^{2)} = 245 \approx S = 200$$

- **Ratio S/BG will be improved: e.g. MVD not included here yet (reduce contributions of γ and π^0); better rejecting of pions and protons; etc.**

1) for full statistics of 20×10^9 events

2) $\Delta CB_{calc} << \Delta S$ because of any wanted mixing depth

Summary and Outlook

- **Feasibility for Di-Electron measurement is shown**
- **Fast Simulatioin procedures were developed to enable realistic studies**
- **Suppression of background is difficult; improvements are ongoing and we are on well that way**
- **First year planned for quick energy scan; Thorough measurements for each energy will follow**

Thank you for your attention!

Thanks to:
Claudia Höhne, Jan-Hendrik Otto, Marten Becker