Exploratory feasibility study on dielectron flow analysis with CBM

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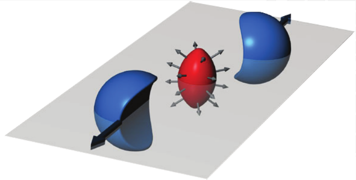
Flow

- Describes azimuthal anisotropy relative to event plane (angle Ψ)
- Event plane: plane including momentum vector of projectile and center of both nuclei
- Feasibility study of reconstructing dilepton flow in CBM
  - Sensitive to anisotropies in early stages of heavy-ion collision
  - First study in CBM (similar analysis done in HADES)

Heavy-Ion-Collision with spectators in blue, overlapping region in red and event plane in gray.

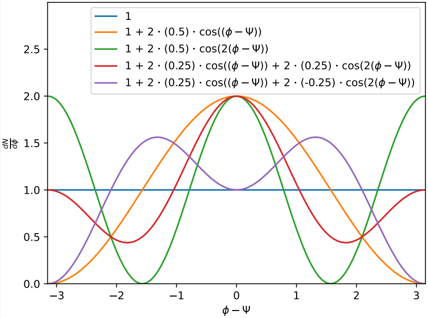


Source: R. Snellings, *"Elliptic flow: a brief review"*, New Journal of Physics 2011 p.055008.

- $\frac{\mathrm{d}N}{\mathrm{d}\phi} \propto 1 + 2 \cdot \sum_{n=1}^{\infty} v_n \cdot \cos\left(n \cdot (\phi - \Psi)\right)$
- Two methods for determine flow coefficients:
  - Fit above formula to $\phi - \Psi$ distribution
  - Calculating mean of n$^{\text{th}}$-order cosines: $v_n = \left\langle \cos\left(n \cdot (\phi - \Psi)\right) \right\rangle$
    - All order flow coefficients independent from each other
    - Independent from binning

    $\Longrightarrow$ Lower statistics sufficient
  - Often one only interested in lowest orders (v_1 and v_2)

Expected ϕ distribution for different flow coefficients.



Methodology

- Using SMASH as nuclei-collision event generator **including dileptons**
- Randomly rotate events to mimic physical Ψ distribution

$\rightarrow$ Rotation suppresses ϕ-dependent detector effects

- First use MC true data to study ideal case

$\rightarrow$ Later apply realistic reconstruction constraints

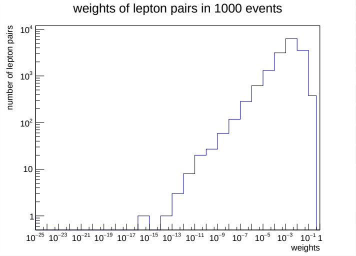
- Reconstructing correct event plane from data is topic for its own, and requires additional forward detector FSD

$\rightarrow$ Not part of this study

$\rightarrow$ True event plane angle is used (later apply smearing)

- "Standard" SMASH output: Oscar format
- Converted to Root format as input for CBMRoot simulation
- "Standard" output: only hadrons, but optional dileptons in extra file
- Dilepton produced in SMASH via "Shining" mechanism
  - Weighted emission from resonances in each time step
  - Continue to propagate resonances instead of decay products
- Challenge: large number of dileptons with negligible weights increases simulation time
  - Number of leptons has to be reduced to run simulation in reasonable time

Distribution of lepton pair weights from SMASH output.



Data-reduction approach

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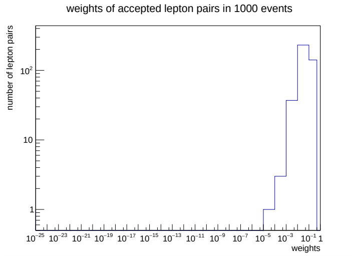
- Aims:
  - Preserve realistic phase space coverage for leptons
  - Every electron pair must have a chance to be selected
- Strategy:
  - Compare individual weight with random number from uniform number generator
  - If random number smaller than the weight, keep electron pair
  - Number of accepted leptons can be adjusted by choosing an appropriate upper limit for the random number
- Currently, only electrons from $\pi^0 \to e^+ e^- \gamma$ are used (based on my settings)

Distribution of accepted lepton pair weights after reduction step.



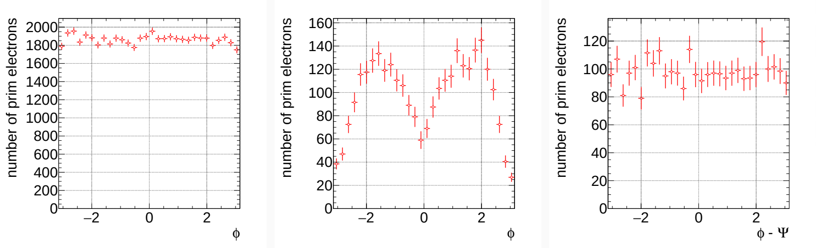
Compensate for detector ϕ-dependence

- Event plane from SMASH always at 0
- Rotate all events in transport step by a uniform distributed random number between 0 and 2π

MC true primary electrons.

Primary electrons identified as electron.

Primary electrons identified as electron after subtracting event plane angle.



- Acceptance and Efficiency have ϕ dependent detector effects
- Random rotation and subtracting angle of the event plane compensate this effects
- Low acceptance and efficiency due to low momentum of electrons

Injecting artificial flow into SMASH dileptons

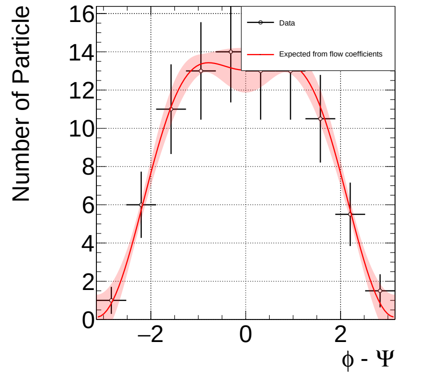
- Standard SMASH simulations do not include collective flow
- Strategy:
  - Apply flow-like weight in the lepton selection to electron pairs based on ϕ of their mother particle
  - Example: introduce π^0 mother particle flow $v_1 \approx 0.5$ and $v_2 \approx 0$: modulate dilepton selection probability with $1 + \cos(\phi_{\pi^0} - \Psi)$
  - In example (after detector simulation):

$$v_{1,e^+e^-} = 0.364 \pm 0.041$$

$$v_{2,e^+e^-} = -0.128 \pm 0.052$$

  - This true flow later used as reference for reconstructed flow

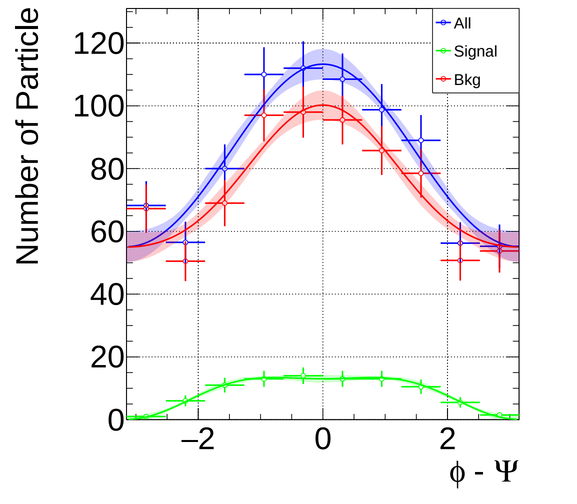
Reconstructed ϕ-distribution of primary electrons (using MC true) with artificial flow modulation



Sources of background

- Combinatorial background
  - Caused by combining uncorrelated electrons and positrons to pairs
  - Impossible to avoid
  - Strategy: to estimate and subtract this background from data
  - Two methods for estimation
    - Event mixing
    - Same sign charged pairs
- Secondary background
  - Caused by photons converting in detector material
  - Partly suppressed by detector acceptance and efficiency
  - Strategy: remove secondaries with basic cuts
  - Hope for further suppression by better identification algorithm
  - **Most important background**
  - Remaining background must be subtracted based on simulations
- Misidentification background
  - Caused by hadrons (pions) misidentified as electrons
  - Hope for suppression by better identification algorithm

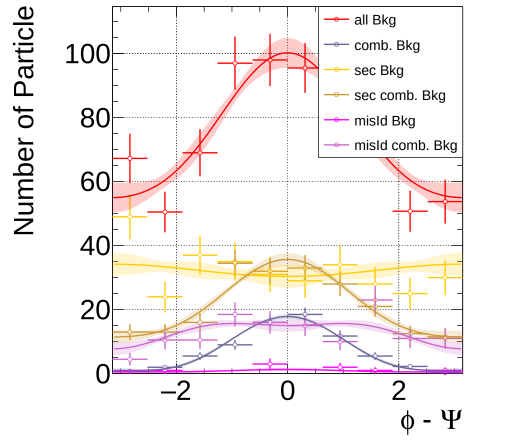
ϕ distribution of dileptons.



- All electron pairs:
  - Number of pairs: 834.5
  - v_1: 0.174 ± 0.020
  - v_2: 0.004 ± 0.021
- Signal (our reference):
  - Number of pairs: 88.5
  - v_1: 0.363 ± 0.041
  - v_2: -0.128 ± 0.052
- Background:
  - Number of pairs: 746
  - v_1: 0.151 ± 0.022
  - v_2: 0.019 ± 0.023

True background flow

ϕ distribution of background dileptons.



- Combinatorial background:
  - Number of pairs: 71.5
- Secondary background:
  - Number of pairs: 322
- Secondary comb. background:
  - Number of pairs: 214.5
- Misidentification background:
  - Number of pairs: 8
- Misidentification comb. background:
  - Number of pairs: 130

- First dilepton flow feasibility study in CBM
- Using SMASH as event generator (with "Shining")
- **Able to reconstruct artificially added flow** in only primary electron pairs
- Next step: Reducing and estimate secondary background
- Later, assess impact of improved electron reconstruction scheme

- First dilepton flow feasibility study in CBM
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Thank you for your attention.
Any Questions?

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Backup

$$N^{\text{tot}} = N^{\text{sig}} + N^{\text{bkg}}$$

$$v_n^{\text{sig}} = \frac{N^{\text{tot}}}{N^{\text{sig}}} v_n^{\text{tot}} - \frac{N^{\text{bkg}}}{N^{\text{sig}}} v_n^{\text{bkg}}$$

Event mixing method

$$N^{\text{bkg}} = N^{\text{diff}\,+\,-} \cdot \frac{\sqrt{N^{\text{same}\,+\,+} \cdot N^{\text{same}\,-\,-}}}{\sqrt{N^{\text{diff}\,+\,+} \cdot N^{\text{diff}\,-\,-}}}$$

$$v_n^{\text{bkg}} = v_n^{\text{diff}\,+\,-} + \frac{1}{2} v_n^{\text{same}\,+\,+} + \frac{1}{2} v_n^{\text{same}\,-\,-} - \frac{1}{2} v_n^{\text{diff}\,+\,+} - \frac{1}{2} v_n^{\text{diff}\,-\,-}$$

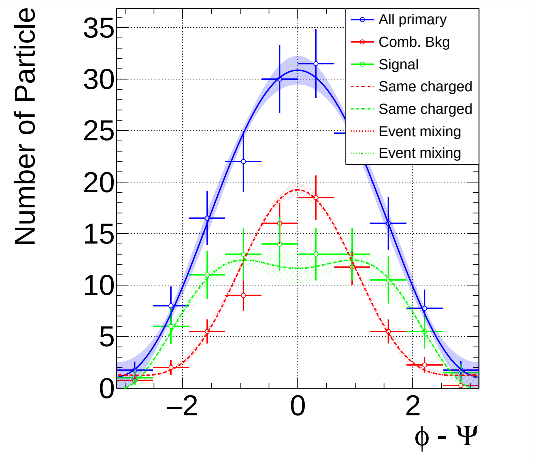
Same sign charged pairs method

$$N^{\text{bkg}} = \sqrt{N^{\text{same}\,+\,+} \cdot N^{\text{same}\,-\,-}}$$

$$v_n^{\text{bkg}} = \frac{1}{2} v_n^{\text{same}\,+\,+} + \frac{1}{2} v_n^{\text{same}\,-\,-}$$

Primary flow after combinatorial background subtraction

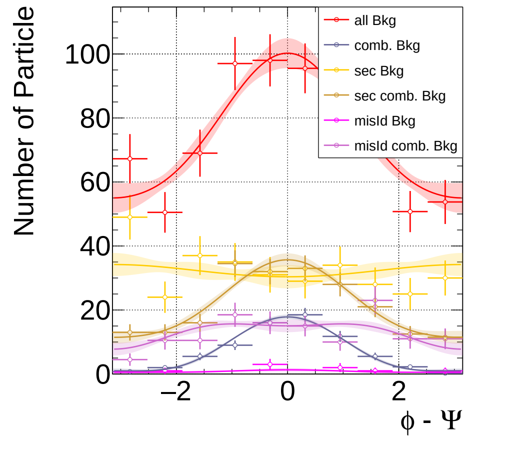
ϕ distribution of primary dileptons.



- Both primary electron pairs:
  - Number of pairs: 160
  - v_1: 0.464 ± 0.026
  - v_2: -0.001 ± 0.035
- Same charged method:
  - Estimated background:
    - Number of pairs: 78
    - v_1: 0.575 ± 0.029
    - v_2: 0.157 ± 0.040
  - Estimated signal:
    - Number of pairs: 82
    - v_1: 0.359 ± 0.058
    - v_2: -0.151 ± 0.078
- Event mixing method:
  - Estimated background:
    - Number of pairs: 78.1
    - v_1: 0.575 ± 0.029
    - v_2: 0.154 ± 0.040
  - Estimated signal:
    - Number of pairs: 81.9
    - v_1: 0.358 ± 0.058
    - v_2: -0.149 ± 0.078

True background flow

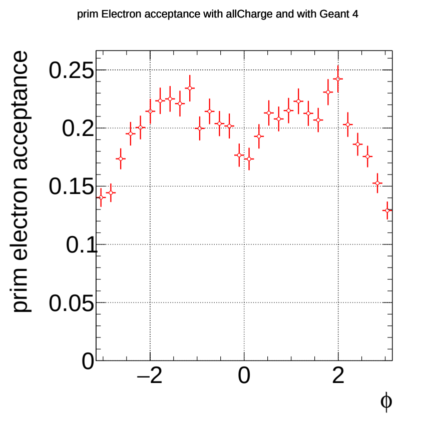
ϕ distribution of background dileptons.



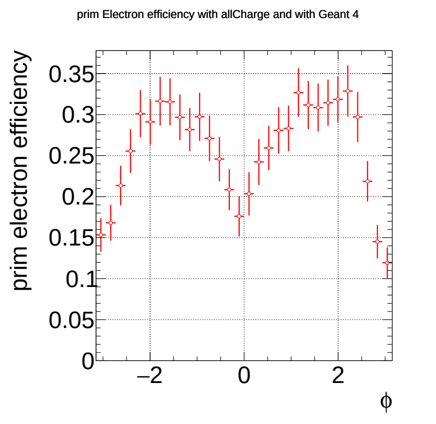
- Combinatorial background:
  - Number of pairs: 71.5
  - v_1: 0.588 ± 0.029
  - v_2: 0.158 ± 0.041
- Secondary background:
  - Number of pairs: 322
  - v_1: -0.030 ± 0.039
  - v_2: 0.001 ± 0.040
- Secondary comb. background:
  - Number of pairs: 214.5
  - v_1: 0.282 ± 0.032
  - v_2: 0.049 ± 0.034
- Misidentification background:
  - Number of pairs: 8
  - v_1: 0.227 ± 0.248
  - v_2: 0.140 ± 0.052
- Misidentification comb. background:
  - Number of pairs: 130
  - v_1: 0.140 ± 0.052
  - v_2: -0.062 ± 0.055

ϕ dependence of acceptance and efficiency

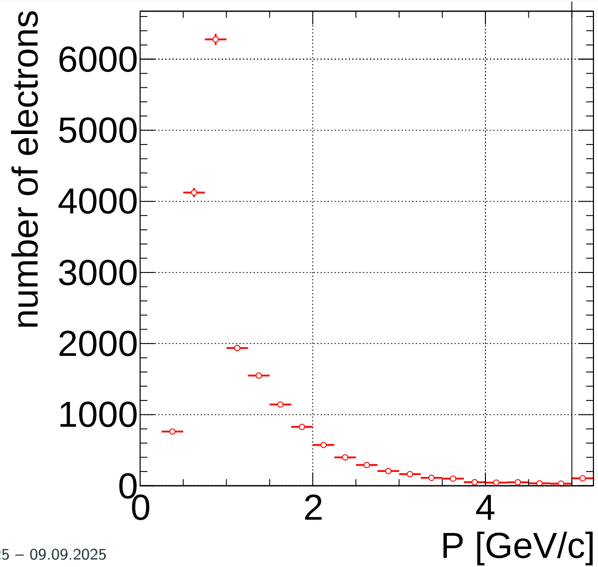
Acceptance



Efficiency



as electron identified $e^{\pm}$ MC tracks.



Criteria of acceptance

- At least three hits in STS
- At least seven hits in RICH
- At least two hits in TRD
- At least one hit in Tof

Criteria for identification as electron

- IsRichElectron (Ann output > 0.0)
- IsTrdElectron ($p < 1\,\text{GeV}$ or Pidlikeel > 0.8)
- IsTofElectron ($m < 0.01\,\text{GeV}^2$, if $p < 1.3\,\text{GeV}$ or $m < 0.01\,\text{GeV} \times (p - 0.3\,\text{GeV})$, if $p \geq 1.3\,\text{GeV}$)
- Chi2Prim < 3.0
- Number of Mvd Hits ≥ 3

Calculation for background suppression

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$$N^{\text{tot}} = N^{\text{sig}} + N^{\text{bkg}}$$

$$\frac{dN}{d\phi} = N \cdot \sum_{n=1} v_n \cdot \cos(n \cdot (\phi - \Psi))$$

$$v_n^{\text{sig}} = \frac{N^{\text{tot}}}{N^{\text{sig}}} v_n^{\text{tot}} - \frac{N^{\text{bkg}}}{N^{\text{sig}}} v_n^{\text{bkg}}$$

Problem 1: need of estimation for v_n^{bkg}

$$\Delta v_n^{\text{sig}} = \sqrt{(\frac{N^{\text{tot}}}{N^{\text{sig}}} \Delta v_n^{\text{tot}})^2 + (\frac{N^{\text{bkg}}}{N^{\text{sig}}} \Delta v_n^{\text{bkg}})^2}$$

Problem 2:

$$\Delta v_n^{\text{sig}} \overbrace{\propto}^{N^{\text{bkg}} >> N^{\text{sig}}} \frac{N^{\text{bkg}}}{N^{\text{sig}}}$$

$$N^{\text{bkg}} = N^{\text{diff}\,+\,-} \cdot \frac{\sqrt{N^{\text{same}\,+\,+} \cdot N^{\text{same}\,-\,-}}}{\sqrt{N^{\text{diff}\,+\,+} \cdot N^{\text{diff}\,-\,-}}}$$

$$\begin{aligned}
\frac{\mathrm{d}N^{\text{bkg}}}{\mathrm{d}\phi} &= \frac{\mathrm{d}N^{\text{bkg}}}{\mathrm{d}N^{\text{diff}\,+\,-}}\frac{\mathrm{d}N^{\text{diff}\,+\,-}}{\mathrm{d}\phi} + \frac{\mathrm{d}N^{\text{bkg}}}{\mathrm{d}N^{\text{same}\,+\,+}}\frac{\mathrm{d}N^{\text{same}\,+\,+}}{\mathrm{d}\phi} \\
&+ \frac{\mathrm{d}N^{\text{bkg}}}{\mathrm{d}N^{\text{same}\,-\,-}}\frac{\mathrm{d}N^{\text{same}\,-\,-}}{\mathrm{d}\phi} + \frac{\mathrm{d}N^{\text{bkg}}}{\mathrm{d}N^{\text{diff}\,+\,+}}\frac{\mathrm{d}N^{\text{diff}\,+\,+}}{\mathrm{d}\phi} + \frac{\mathrm{d}N^{\text{bkg}}}{\mathrm{d}N^{\text{diff}\,-\,-}}\frac{\mathrm{d}N^{\text{diff}\,-\,-}}{\mathrm{d}\phi} \\
&= \frac{N^{\text{bkg}}}{N^{\text{diff}\,+\,-}}\frac{\mathrm{d}N^{\text{diff}\,+\,-}}{\mathrm{d}\phi} + \frac{1}{2}\frac{N^{\text{bkg}}}{N^{\text{same}\,+\,+}}\frac{\mathrm{d}N^{\text{same}\,+\,+}}{\mathrm{d}\phi} + \frac{1}{2}\frac{N^{\text{bkg}}}{N^{\text{same}\,-\,-}}\frac{\mathrm{d}N^{\text{same}\,-\,-}}{\mathrm{d}\phi} \\
&- \frac{1}{2}\frac{N^{\text{bkg}}}{N^{\text{diff}\,+\,+}}\frac{\mathrm{d}N^{\text{diff}\,+\,+}}{\mathrm{d}\phi} - \frac{1}{2}\frac{N^{\text{bkg}}}{N^{\text{diff}\,-\,-}}\frac{\mathrm{d}N^{\text{diff}\,-\,-}}{\mathrm{d}\phi}
\end{aligned}$$

$$\Longrightarrow \quad v_n^{\text{bkg}} = v_n^{\text{diff}\,+\,-} + \frac{1}{2}v_n^{\text{same}\,+\,+} + \frac{1}{2}v_n^{\text{same}\,-\,-} - \frac{1}{2}v_n^{\text{diff}\,+\,+} - \frac{1}{2}v_n^{\text{diff}\,-\,-}$$

$$\begin{aligned}
\Delta v_n^{\text{bkg}} = \Bigg[&\left(\Delta v_n^{\text{diff}\,+\,-}\right)^2 + \left(\frac{1}{2}\Delta v_n^{\text{same}\,+\,+}\right)^2 + \left(\frac{1}{2}\Delta v_n^{\text{same}\,-\,-}\right)^2 \\
&+ \left(\frac{1}{2}\Delta v_n^{\text{diff}\,+\,+}\right)^2 + \left(\frac{1}{2}\Delta v_n^{\text{diff}\,-\,-}\right)^2\Bigg]^{\frac{1}{2}}
\end{aligned}$$

Background estimation with same sign charged pairs method

$$N^{\text{bkg}} = \sqrt{N^{\text{same}++} \cdot N^{\text{same}--}}$$

$$\frac{\mathrm{d}N^{\text{bkg}}}{\mathrm{d}\phi} = \frac{\mathrm{d}N^{\text{bkg}}}{\mathrm{d}N^{\text{same}++}} \frac{\mathrm{d}N^{\text{same}++}}{\mathrm{d}\phi} + \frac{\mathrm{d}N^{\text{bkg}}}{\mathrm{d}N^{\text{same}--}} \frac{\mathrm{d}N^{\text{same}--}}{\mathrm{d}\phi}$$

$$= \frac{1}{2} \frac{N^{\text{bkg}}}{N^{\text{same}++}} \frac{\mathrm{d}N^{\text{same}++}}{\mathrm{d}\phi} + \frac{1}{2} \frac{N^{\text{bkg}}}{N^{\text{same}--}} \frac{\mathrm{d}N^{\text{same}--}}{\mathrm{d}\phi}$$

$$\implies v_n^{\text{bkg}} = \frac{1}{2} v_n^{\text{same}++} + \frac{1}{2} v_n^{\text{same}--}$$

$$\Delta v_n^{\text{bkg}} = \frac{1}{2} \sqrt{\left(\Delta v_n^{\text{same}++}\right)^2 + \left(\Delta v_n^{\text{same}--}\right)^2}$$