HowTo: CB

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How to subtract the
Combinatorial Background

Outline

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    - → Event mixing
- Overview

The relavant observable

We are looking for the **invariant mass spectrum** dN/dm_{inv} of **e^+e^- -pairs**

the invariant mass is the root of the product of the sum of the four-momenta $p_1^\mu = (E_1, p_1)$, $p_2^\mu = (E_2, p_2)$:

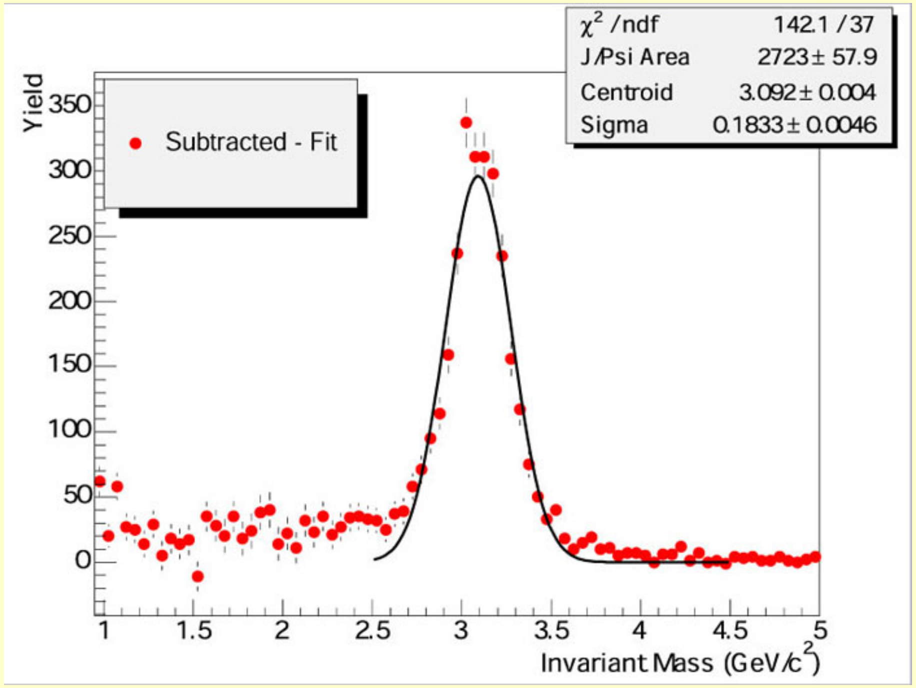
$$m_{inv}^2 = (p_1^\mu + p_2^\mu)(p_{1\mu} + p_{2\mu})$$
$$= 2(m_e^2 + E_1 E_2 - |p_1||p_2| \cos\Theta_{ee})$$

m_e: electron rest mass
Θ_{ee}: angle between momenta

Wanted contributions

Most commonly, one (or several) specific particle species is (are) to be surveyed, e.g. the J/ψ:

$$J/\Psi \rightarrow e^{+}\, e^{-}$$



http://www.interactions.org/sgtw/2006/0503/images/jpsi_phenix_700.jpg

Physical Background

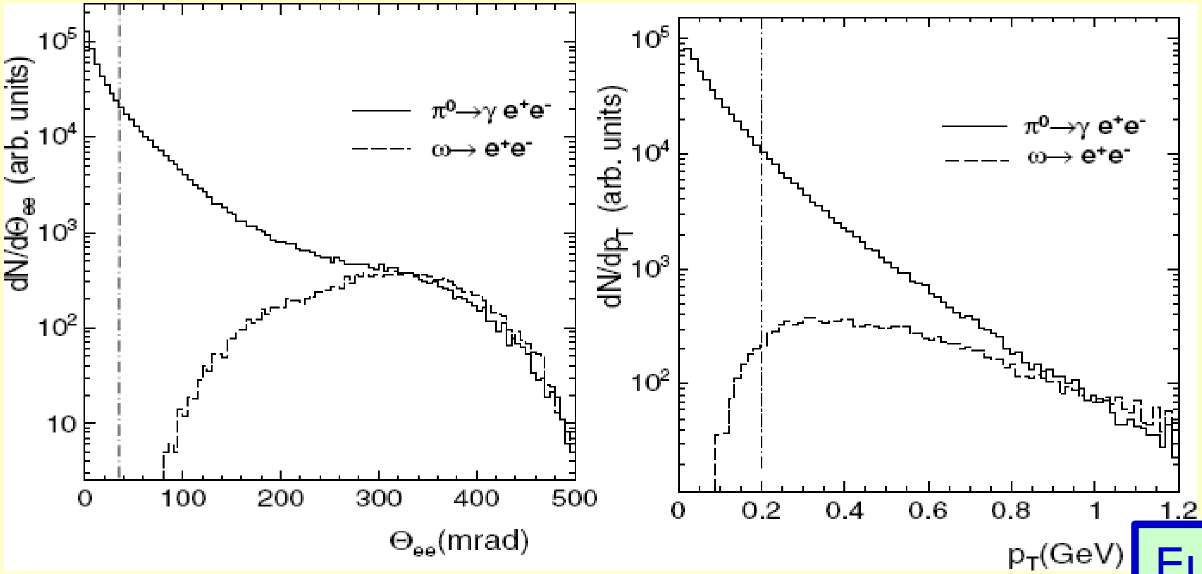
When looking for the spectrum of a given particle, all other particles decaying in **e^+e^- (+X)** must be considered as background
most common sources:

$$\gamma \rightarrow e^+ e^-$$

External Pair Conversion

$$\pi^0 \rightarrow e^+ e^- \gamma$$

Dalitz decay



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Reducing the physical BG

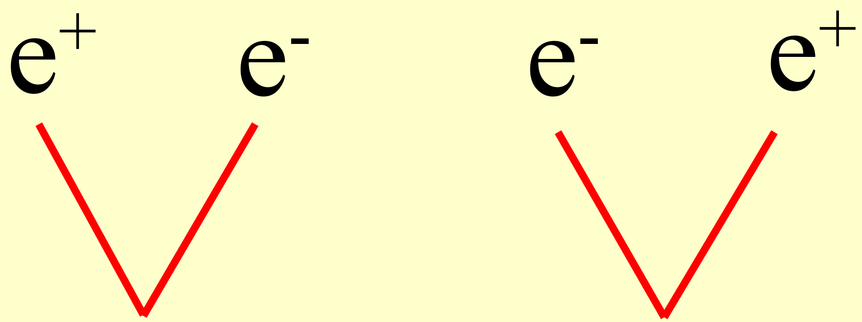
There are a number of things one can do to reduce the contributions from external pair conversions and π/ω-Dalitz-decays

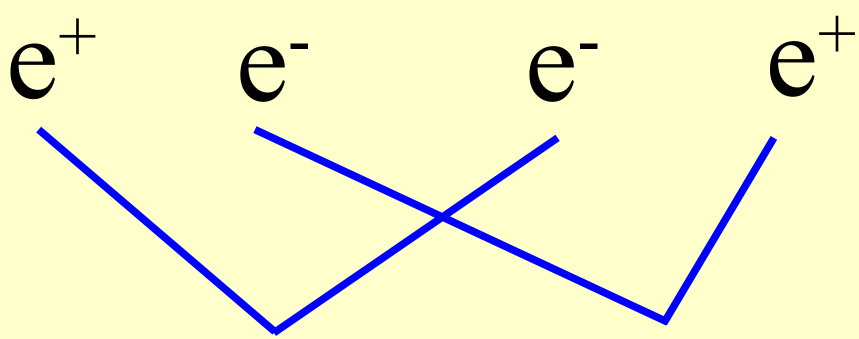
- Rejection of small momentum-particles
- Rejection of pairs with small opening angle
  – look for tracks with too big dE/dx!
- using a segmented target
- using a ”massless“ detector

Combinatorial Background

Spectrum is created from **all possible e^+e^- combinations**.

You cannot know which pairs combine particles from the same decay





There are much more combinations than decays have happened.

Those pairs that combine particles from different decays form the *Combinatorial Background*.

Combinatorial Background

Let`s assume:

- e^+ and e^- come only from pair creation
- all particles are reconstructed
- we have N pairs, so $N^+ = N$ positrons and $N^- = N$ electrons and N^2 possible combinations

The Task:

Extract the signal of N correlated pairs from all combinations:
Obtain shape and size (normalization) of N^2-N uncorrelated e^+e^- -pairs:

→ By like-sign-correlations
→ By event-mixing

Normalization:

$$A = \int \frac{\mathrm{d}A}{\mathrm{d}m} \mathrm{d}m$$

Shape:

$$\frac{1}{A}\frac{\mathrm{d}A}{\mathrm{d}m}$$

Like-sign method

The Background B^{+-}:
B^{+-} = N^2 - N constructed e^+e^--pairs stem from uncorrelated particles.

Pairs constructed from two e^- or two e^+ (like-sign-pairs) are **always uncorrelated**.
N^{++} + N^{--} = N^2 - N pairs can be constructed

The **Signal S** will be:
$S = N = N^{+-} - (N^{++} + N^{--})$

actually, the signal is:

$$\frac{\mathrm{d}S}{\mathrm{d}m} = \frac{\mathrm{d}N^{+-}}{\mathrm{d}m} - \left(\frac{\mathrm{d}N^{++}}{\mathrm{d}m} + \frac{\mathrm{d}N^{--}}{\mathrm{d}m} \right)$$

N: Number of pair-decays

N^{+-}: Number of constructed e^+e^--pairs
$N^{\pm\pm}$: Number of constructed $e^{\pm}e^{\pm}$-pairs
B^{+-}: Background from e^+e^--pairs
S: Signal

The like-sign-contribution should have the same shape as the contribution from the uncorrelated unlike-sign-pairs

Like-sign method

Watch Out!

Efficiency is not arbitrarily good

Cuts may leave more electrons or more positrons: $N^+ \neq N^-$

$$\Rightarrow N^{+-} - (N^{++} + N^{--}) \neq N$$

N: Number of pair-decays
$N^{\pm}$: Number of $e^{\pm}$-tracks
N^{+-}: Number of constructed e^+e^- -pairs
$N^{\pm\pm}$: Number of constructed $e^{\pm}e^{\pm}$ -pairs

Like-sign method

But there is a connection between N^{++}, N^{--} and B^{+-}:
$B^{+-} = 2\sqrt{(N^{++}N^{--})}$, so
$$\langle S\rangle = \langle N^{+-}\rangle - 2\langle\sqrt{N^{++}N^{--}}\rangle$$
(also if efficiency is imperfect)

If all e^+ and e^- are created as singles, the correct normalization is
$$\langle S\rangle = \langle N^{+-}\rangle - \langle N^{+}\rangle\langle N^{-}\rangle$$

N: Number of pair-decays

N^{+-}: Number of constructed e^+e^- -pairs
$N^{\pm\pm}$: Number of constructed $e^\pm e^\pm$ -pairs
B^{+-}: Background from e^+e^- -pairs
S: Signal

Mixed events techniques

Instead of like-sign pairs from the same event, uncorrelated signals may be extracted from particles from different events.

Statistics is much better: from E events, E(E-1) mixtures can be made

But: **Normalization is more complicated**

Square-root-normalization:

As in single-event analysis

Divide mixed event-background by its integral and multiply by the normalization from single-events $2\sqrt{N^{++}N^{--}}$

$$\frac{\mathrm{d}\,B^{+-}}{\mathrm{d}\,m_{\mathrm{inv}}} = \frac{1}{M^{+-}} \frac{\mathrm{d}\,M^{+-}}{\mathrm{d}\,m_{\mathrm{inv}}} 2\sqrt{N^{++}N^{--}}$$

N: Number of pair-decays
$N^{\pm}$: Number of $e^{\pm}$-tracks
$N^{\pm\pm}$: Number of constructed $e^{\pm}e^{\pm}$ -pairs
B^{+-}: Background from $e^{+}e^{-}$ -pairs
M^{ab}: Number of $e^{a}e^{b}$ -pairs from different events

Mixed events techniques

Empirical method for normalization:

(like sign data) / (like sign mixed)

Get mixed background (M^{+-} pairs), and scale with the number of like sign pairs in single-event analysis devided by the number of like sign pairs in mixed events

$$\frac{B^{+-}}{M^{+-}} = \frac{N^{\text{like}}}{M^{\text{like}}}$$

$$\frac{dB^{+-}}{\mathrm{d}\, m_{\text{inv}}} = \frac{dM^{+-}}{\mathrm{d}\, m_{\text{inv}}} \left(\frac{N^{++}}{M^{++}} + \frac{N^{--}}{M^{--}} \right)$$

$$B^{+-} = \frac{1}{2} \left(\frac{N^{+}}{N^{-}} \left(N^{+2} - N^{+} \right) + \frac{N^{-}}{N^{+}} \left(N^{-2} - N^{-} \right) \right)$$

N: Number of pair-decays
$N^{\pm}$: Number of $e^{\pm}$-tracks
$N^{\pm\pm}$: Number of constructed $e^{\pm}e^{\pm}$ -pairs
B^{+-}: Background from $e^{+}e^{-}$ -pairs
M^{ab}: Number of $e^{a}e^{b}$ -pairs from different events

Combinatorial Background

Like sign data

- Normalization is (comparatively) easy
- depends on assumption that different decays in one event are independent
- e.g. CERES (NA 45)

Mixed events data

- Normalization is difficult
- much better statistics
- e.g. NA 60, KEK-PS E325

Thank you very much

for your attention

Reducing Physical BG

momentum cut

Pair-conversions from γ‘s can be largely **excluded** by cutting out small momenta, because the spectra are much steeper

energy loss

If two electrons too close to distinguish, dE/dx is twice the normal value

Reducing Physical BG

Pairs with small invariant mass can be largely removed by excluding all pairs with small opening angle Θ_{ee}:

$$m^2_{inv} = 2(m_e^{\,2} + E_1E_2 - |p_1||p_2|\cos\Theta_{ee})$$

$m_e \ll |p_i|$:

$$m^2_{inv} = 2|p_1||p_2|(1-\cos\Theta_{ee})$$

if m_{inv} is small, either

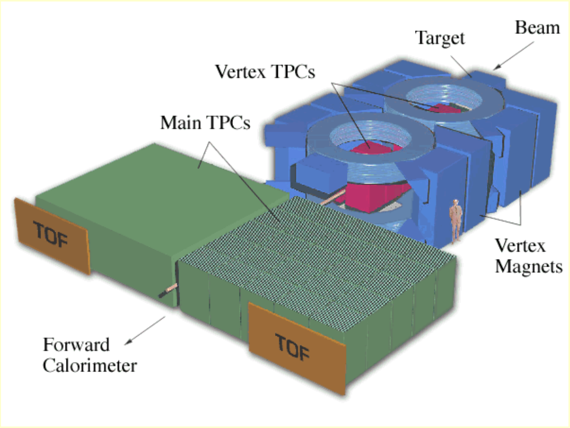
- $\cos(\Theta_{ee}) \rightarrow 1$ ($\Theta_{ee} \rightarrow 0$) or
- $|p_1| \rightarrow 0$ or
- $|p_2| \rightarrow 0$

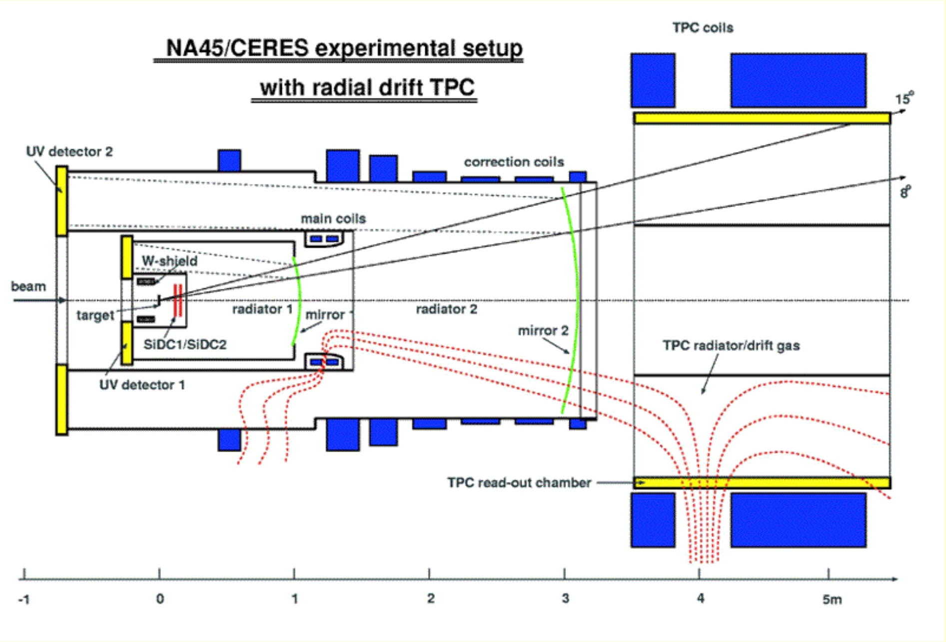
those cases are covered by low-p-cut

Reducing Physical BG

Detector issues

Pair-conversions from real γ's within the detector can be **prevented** by using a „massless" detector (*small Z*-materials, e.g. Mylar)





Reducing Physical BG

target design

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(fixed target experiments only): Pair-conversions at other nuclei within the target can be excluded by using **segmented targets** with corresponding cuts in the acceptance

We need **big interaction length** but **small radiation length**