Event statistics needed for open charm correlations

NA61++ workshop

Ivan Pidhurskyi <ivan.pidhurskyi@cern.ch>

Jan Kochanowski University in Kielce

16 Dec 2022

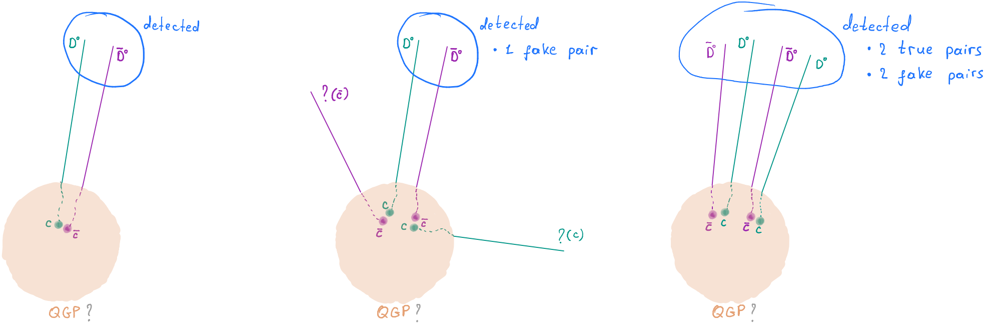
Overview

1. Requirement from the measurement
2. $\langle c\bar{c} \rangle$ yield in central Pb+Pb @ 158A GeV/c
3. Rough estimate of required statistics
4. Summary

Requirement from the measurement

Requirement from the measurement

- Measuring correlations of c and $\bar{c}$ quarks from the same pair forces one to seek for events with only a single $c\bar{c}$-pair.



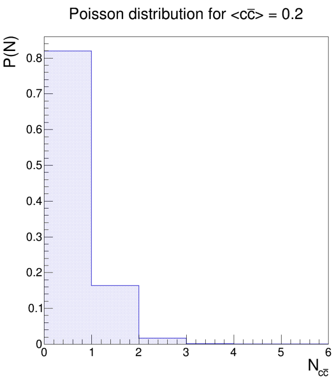
Requirement from the measurement

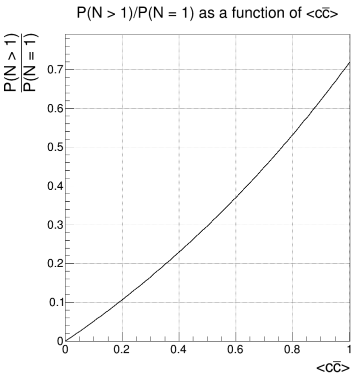
- Measuring correlations of c and $\bar{c}$ quarks from the same pair forces one to seek for events with only a single $c\bar{c}$-pair.
- We need to ensure that this scenario is the dominant one.
  Thus the requirement:

$$\frac{P(N_{c\bar{c}} > 1)}{P(N_{c\bar{c}} = 1)} \ll 1$$

Requirement from the measurement

- Measuring correlations of c and $\bar{c}$ quarks from the same pair forces one to seek for events with only a single $c\bar{c}$-pair.
- We need to ensure that this scenario is the dominant one.
- Assuming that $c\bar{c}$ multiplicity distribution follows Poisson statistics, we have:





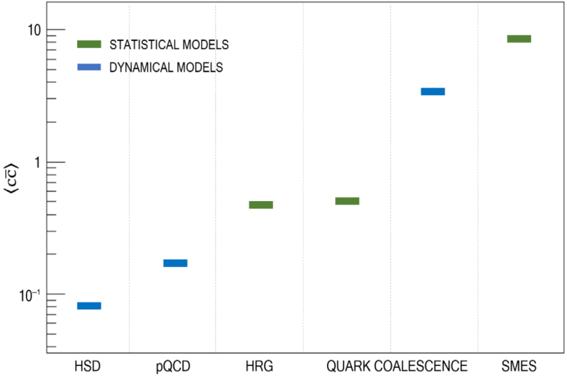
Note that we can't lower the $\langle c\bar{c}\rangle$ to zero as it will skyrocket the statistics needed for any measurement.

Thus some compromise is needed here.

$\langle c\bar{c} \rangle$ yield in central Pb+Pb @ 158A GeV/c

$\langle c\bar{c}\rangle$ yield in central Pb+Pb @ 158A GeV/c

Predictions form theoretical models



- Predictions from theoretical models vary by two orders of magnitude.
- Considering only the most trusted ones (HSD, pQCD, HRG, Coalescence) the yield is expected to be from about 0.1 to about 0.5.

$\langle c\bar{c}\rangle$ yield in central Pb+Pb @ 158A GeV/c

Estimate from data

NA61/SHINE Pb+Pb @ 158A GeV/c (A. Merzlaya, et.al)

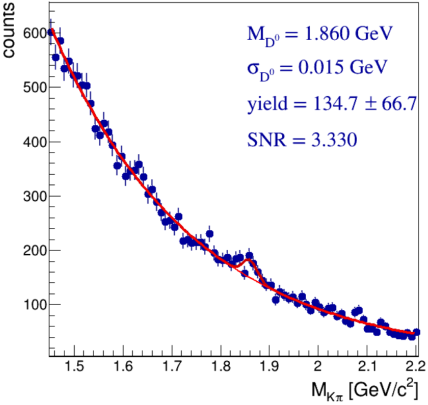
- Mean multiplicity of $D^0 + \bar{D}^0$ mesons:

$$\langle D^0 + \bar{D}^0 \rangle_{\text{Pb+Pb}} = 0.39 \pm 0.21.$$

- 95% CL limit:

$$\langle D^0 + \bar{D}^0 \rangle_{\text{Pb+Pb, 95\% CL}} = 0.82.$$

central collisions, acceptance corrections included



Invariant mass distribution of unlike-charge sign π, K decay track candidates for Pb+Pb

$\langle c\bar{c}\rangle$ yield in central Pb+Pb @ 158A GeV/c

Estimate from data

NA61/SHINE Pb+Pb @ 158A GeV/c (A. Merzlaya, et.al)

- Mean multiplicity of $D^0 + \bar{D}^0$ mesons:

$$\langle D^0 + \bar{D}^0\rangle_{\text{Pb+Pb}} = 0.39 \pm 0.21.$$

- 95% CL limit:

$$\langle D^0 + \bar{D}^0\rangle_{\text{Pb+Pb, 95\% CL}} = 0.82.$$

central collisions, acceptance corrections included

$$\langle c\bar{c}\rangle_{\text{exp}} \approx \frac{\langle D^0 + \bar{D}^0\rangle_{\text{exp}}}{P(c \to D^0)_{\text{PHSD}} + P(\bar{c} \to \bar{D}^0)_{\text{PHSD}}} = 0.63 \pm 0.34$$

$$\langle c\bar{c}\rangle_{\text{exp}} \approx \langle c\bar{c}\rangle_{\text{PHSD}} \cdot \frac{\langle D^0 + \bar{D}^0\rangle_{\text{exp}}}{\langle D^0 + \bar{D}^0\rangle_{\text{PHSD}}} = 0.74 \pm 0.4$$

$$\langle c\bar{c}\rangle_{\text{exp, avg}} = 0.68$$
$$\langle c\bar{c}\rangle_{\text{exp, 95\% CL}} \approx 1.4$$

$\langle c\bar{c}\rangle$ yield in central Pb+Pb @ 158A GeV/c

Summary on $\langle c\bar{c}\rangle$ yield:

- Theory doesnt provide us with a conclusive prediction on the $\langle c\bar{c}\rangle$ yield.
- Neither do we have a conclusive results from the experiment side at the moment.
- All we can conclude is that expected yield can be from about 0.1 up to about 1.
- **Fortunately the newly collected data by NA61/SHINE during November this year should provide a better insight into the problem.**

Rough estimate of required statistics

Rough estimate of required statistics

- For now lets consider only D^0 and $\bar{D}^0$ mesons.
- Measuring any correlation between them implies that **both D^0 and $\bar{D}^0$ mesons have to be reconstructed** within an event.

Average number of reconstructed $D^0\bar{D}^0$-pairs

$$\langle D^0\bar{D}^0\rangle_{rec} \approx \langle c\bar{c}\rangle \cdot \left(P(c \to D^0) \cdot \mathrm{BR}(D^0 \to K\pi) \cdot P(\mathrm{acc.}) \cdot P(\mathrm{bkg.\ cuts}) \cdot P(\mathrm{rec.})\right)^2$$

assuming that processes considered inside brackets are uncorrelated between D^0 and $\bar{D}^0$

Rough estimate of required statistics

Average number of reconstructed $D^0\bar{D}^0$-pairs

$$\langle D^0\bar{D}^0\rangle_{rec} \approx \langle c\bar{c}\rangle \cdot \left(P(c \to D^0)\cdot \mathrm{BR}(D^0 \to K\pi)\cdot P(\mathrm{acc.})\cdot P(\mathrm{bkg.\ cuts})\cdot P(\mathrm{rec.})\right)^2$$

assuming that processes considered inside brackets are uncorrelated between D^0 and $\bar{D}^0$

Estimates for the terms:

- $P(c \to D^0)$ – probability for c-quark to hadronise into D^0-mesons: 31% (PHSD).
- $\mathrm{BR}(D^0 \to K\pi)$ – probability of the measurable decay: 3.89%.
- $P(\mathrm{acc.})$ – probability for D^0 to be in the acceptance region: 50%.
- $P(\mathrm{bkg.\ cuts})$ – probability for D^0 to pass background suppression cuts: 20%.
- $P(\mathrm{rec.})$ – probability for D^0 to be reconstructed: $\approx (95\%)^2 = 90\%$.

Rough estimate of required statistics

Substituting number from the previous slide we get:

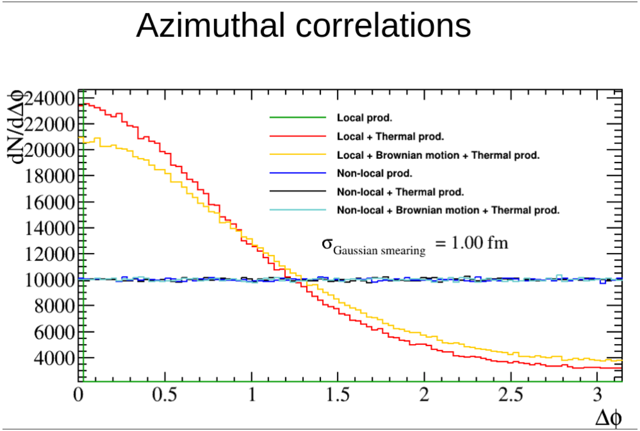
Average number of reconstructed $D^0\bar{D}^0$-pairs

$$\langle D^0\bar{D}^0\rangle_{rec} \approx \langle c\bar{c}\rangle \cdot \left(P(c \to D^0) \cdot \mathrm{BR}(D^0 \to K\pi) \cdot P(\mathrm{acc.}) \cdot P(\mathrm{bkg.\ cuts}) \cdot P(\mathrm{rec.})\right)^2$$
$$\approx \langle c\bar{c}\rangle \cdot (0.31 \cdot 0.0389 \cdot 0.5 \cdot 0.2 \cdot 0.9)^2$$
$$= \langle c\bar{c}\rangle \cdot 1.2 \cdot 10^{-6}$$

assuming that processes considered inside brackets are uncorrelated between D^0 and $\bar{D}^0$

Rough estimate of required statistics

Example of a measurement



- correlation – maximum at zero $\Delta\phi$
- no correlation – flat distribution

$\Rightarrow$ 1000 $D^0\bar{D}^0$ pairs should be sufficient

Rough estimate of required statistics

Statistics needed for 1000 $D^0\bar{D}^0$ pairs

- $\langle D^0\bar{D}^0\rangle_{rec} \approx \langle c\bar{c}\rangle \cdot 1.2 \cdot 10^{-6}$
- Event selection cuts usually accept about 35% of events;
- Thus one would need about $1000/(0.35 \cdot \langle D^0\bar{D}^0\rangle_{\text{rec}}) = 2.4 \cdot 10^9/\langle c\bar{c}\rangle$ events.

$$\langle c\bar{c}\rangle = 1 \Rightarrow 2.4 \cdot 10^9,\ \langle c\bar{c}\rangle = 0.1 \Rightarrow 2.4 \cdot 10^{10}$$

And, finally, we can estimate the time needed to accumulate this statistics (taking into account duty-cycles, i.e. data-taking takes 30% of an actual run-time):

	$\langle c\bar{c}\rangle = 0.1$	$\langle c\bar{c}\rangle = 0.2$	$\langle c\bar{c}\rangle = 0.5$	$\langle c\bar{c}\rangle = 1$
1 kHz	$\sim$ 1000 days	$\sim$ 500 days	$\sim$ 200 days	$\sim$ 100 days
10 kHz	$\sim$ 100 days	$\sim$ 50 days	$\sim$ 20 days	$\sim$ 10 days
100 kHz	$\sim$ 10 days	$\sim$ 5 days	$\sim$ 2 days	$\sim$ 1 day

Summary

Summary

Recall the requirement for a dominance of a single $c\bar{c}$-pair production: $\frac{P(N_{c\bar{c}}>1)}{P(N_{c\bar{c}}=1)} \ll 1$

	$\langle c\bar{c}\rangle = 0.1$	$\langle c\bar{c}\rangle = 0.2$	$\langle c\bar{c}\rangle = 0.5$	$\langle c\bar{c}\rangle = 1$
$P(N_{c\bar{c}} > 1)/P(N_{c\bar{c}} = 1)$	0.05	0.1	0.3	0.7
$N_{\text{true pairs}}/N_{\text{all pairs}}$	91%	83%	66%	50%

	$\langle c\bar{c}\rangle = 0.1$	$\langle c\bar{c}\rangle = 0.2$	$\langle c\bar{c}\rangle = 0.5$	$\langle c\bar{c}\rangle = 1$
1 kHz	$\sim$ 1000 days	$\sim$ 500 days	$\sim$ 200 days	$\sim$ 100 days
10 kHz	$\sim$ 100 days	$\sim$ 50 days	$\sim$ 20 days	$\sim$ 10 days
100 kHz	$\sim$ 10 days	$\sim$ 5 days	$\sim$ 2 days	$\sim$ 1 day

Summary

Q Can one dream of measuring $c\bar{c}$-correlations?

A Yes, **but**:

- Detector must be capable to handle at least 10 times higher event-rate in comparison to what we have now.
  Reaching 100 kHz would be ideal, but, in fact, may be unnecessary.
- Information on $c\bar{c}$ production is too vague at the moment. And it may be an issue:
  - → If it happens to be ≈ 0.1 or below, we have to push the event-rate to up to 100 kHz.
  - → If it is within the range of $(0.2 - 0.5)$, 10 kHz should be sufficient.
    Moreover 10 kHz is very realistic.
  - → If it is closer to 1 or higher, one may need to consider a measurement at a lower energy or with a smaller system.

Fortunately, there is a hope that the data we collected just recently can help to shed some light on this problem. Which is, by the way, the subject of my PhD.

END