Exclusive ϕ production simulation with SPDRoot

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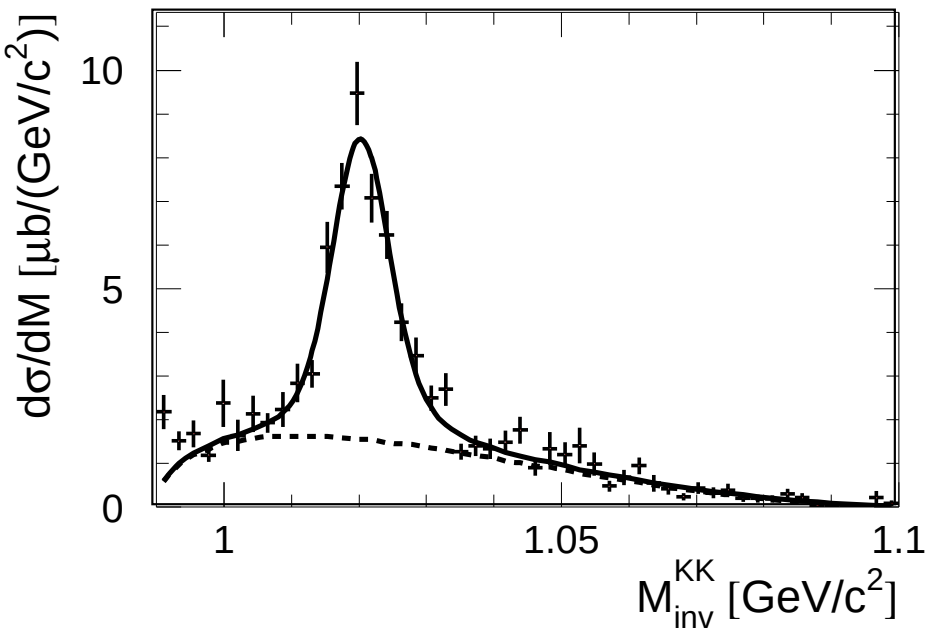
Motivation for $pp \to pp\phi$ study

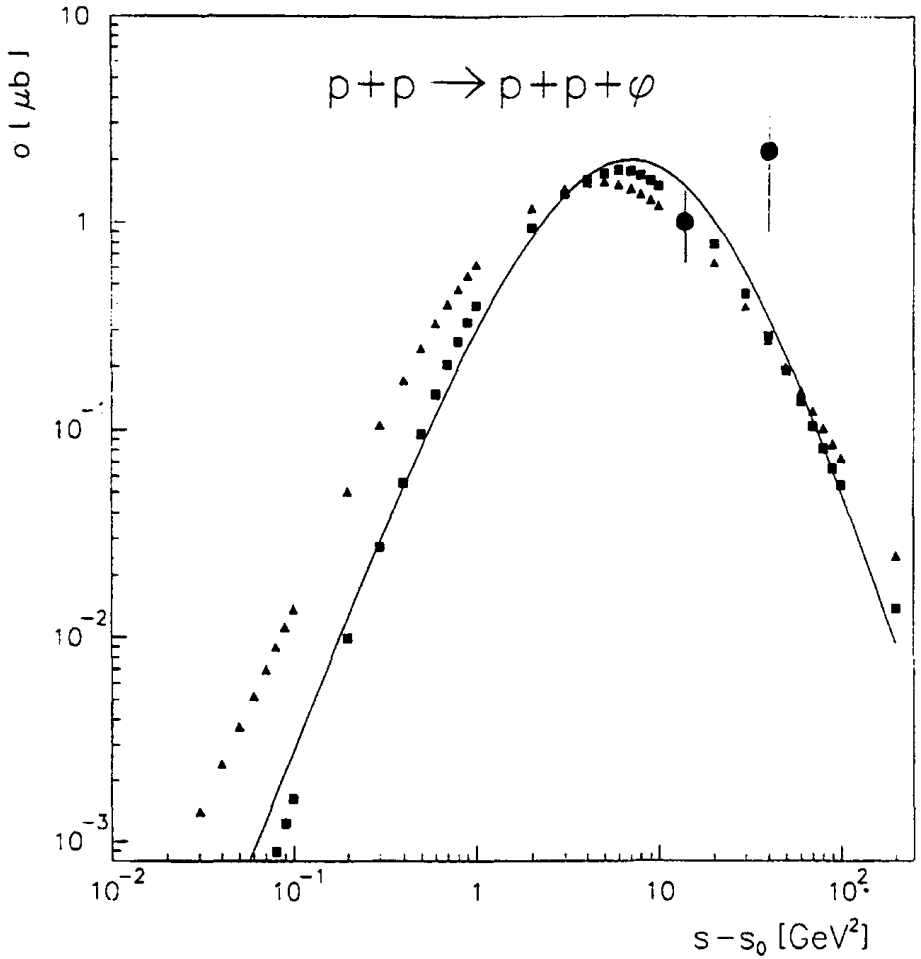
- Probe QCD models at low energy, low Q^2 :
  - production via meson exchange [NewJ.Phys.4:68,2002]
  - v.s. pomeron-odderon meson vertex [Phys.Rev. D101, 094012 (2020)].
- search for pentaquarks with hidden strangeness: $pp \to pP_s^+(\to p\phi)$
- reconstructed ϕ signal to use for detector performance studies



DISTO Collaboration, Phys.Rev.C63:024004,2001

Exclusive ϕ cross section production

- $\sigma(pp \to pp\phi(\rho, \omega))$ calculated the one-pion exchange model, Ref. [Sibirtsev, Nucl.Phys.A 604 (1996) 455]
- max($\sigma(pp \to pp\phi)$) was found at $\sqrt{s} \sim 4.5$ GeV
- But we cannot reduce MB energy in Pythia below 10 GeV. Using of FTF generator was proposed but not (yet) implemented.



$pp \to pp\phi$ process on generator level

- Pythia: Exclusive processes like $pp \to pph$ are not implemented (see "An Introduction to PYTHIA 8.2").
- The specialized SuperChic generator can be used (A Monte Carlo for Central Exclusive and Photon-Initiated Production, https://superchic.hepforge.org)
- For the sake of simplicity the TGenPhaseSpace class within the ROOT environment is used in current research.

To get the process uniformly filling available phase space:

```
do {
        weight = fGenPhaseSpace.Generate();
        coin = rnd.Uniform(0., fMaxWeight);
} while ( coin > weight);
```

Particle identification: dE/dx

- The previous analysis on di-ϕ uses Particle ID (or PID) based on TOF measurements. But TOF will not be availavle at the first stage.
- Only dE/dx PID will be available. It is based on the measurement of the ionisation energy loss.
- In the SpdRoot it is accessible through the class SpdTsParticle and has the same way of getting Likelihoods as in SpdTofParticle (TOF).
- As dE/dx PID is not reliable for the track momenta above 0.6 GeV, make an assumption: all tracks identified as pions or kaons are assigned to be kaons. (around 40% of signal increase)

Micromegas-based Central Tracker

- The vertex detector based on MAPS technology (or DSSD as a backup option) will not be installed during the first stage of the SPD operation.
- This was taken into the account by changing SpdIts to SpdMvd.

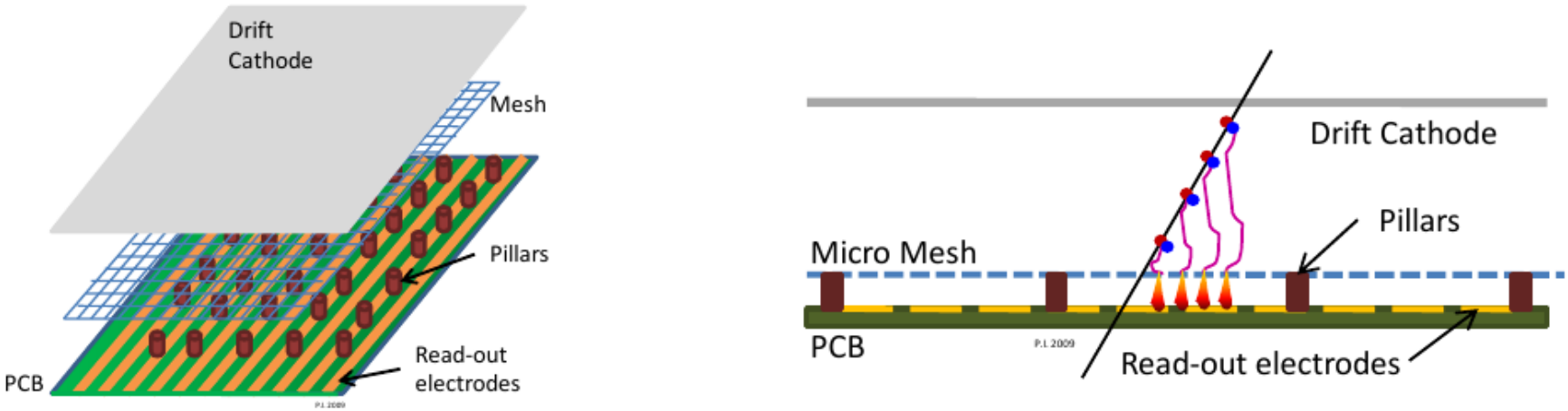


Figure 12.1: Sketch of the layout and operating principle of a Micromegas detector.

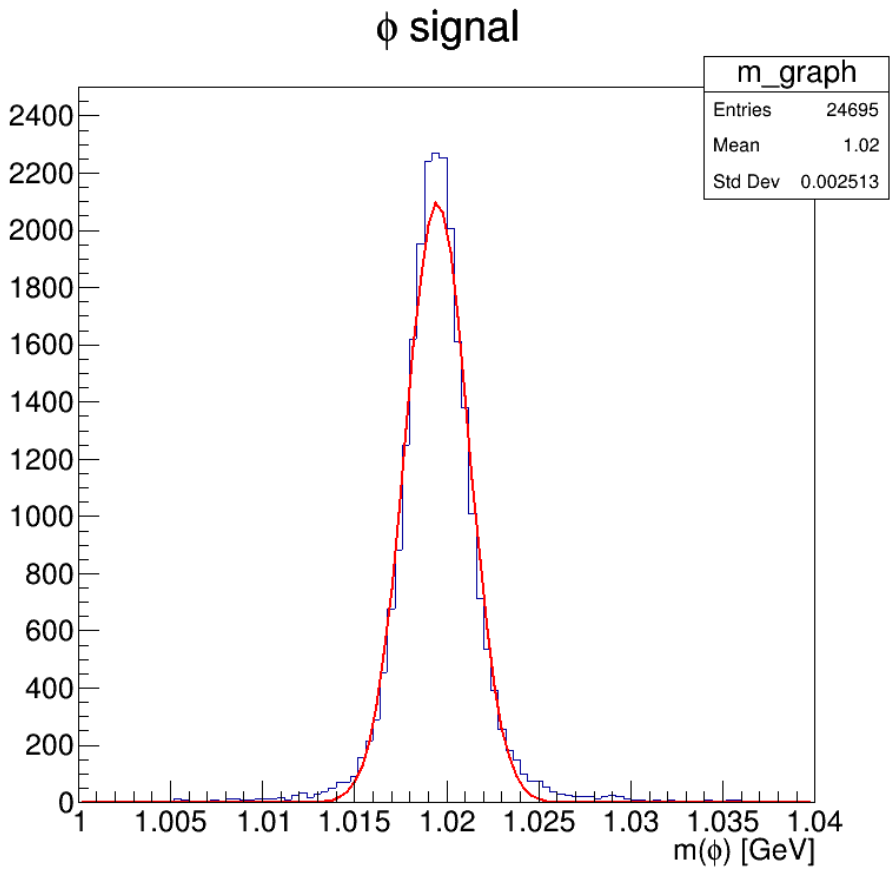
Selection Criteria

To identify the exclusive process $pp \to pp\phi \to ppK^+K^-$ it was required:

- 4-momentum conservation
- only four tracks in the event

It was proposed by Igor Denisenko that we will be able to see all four tracks of the particles concerned. Some previous researchers (from the LHCb) identified only the resulting mesons expecting protons to remain in the tube.

excl-ϕ signal (Gaussian function)



FUNCTION:

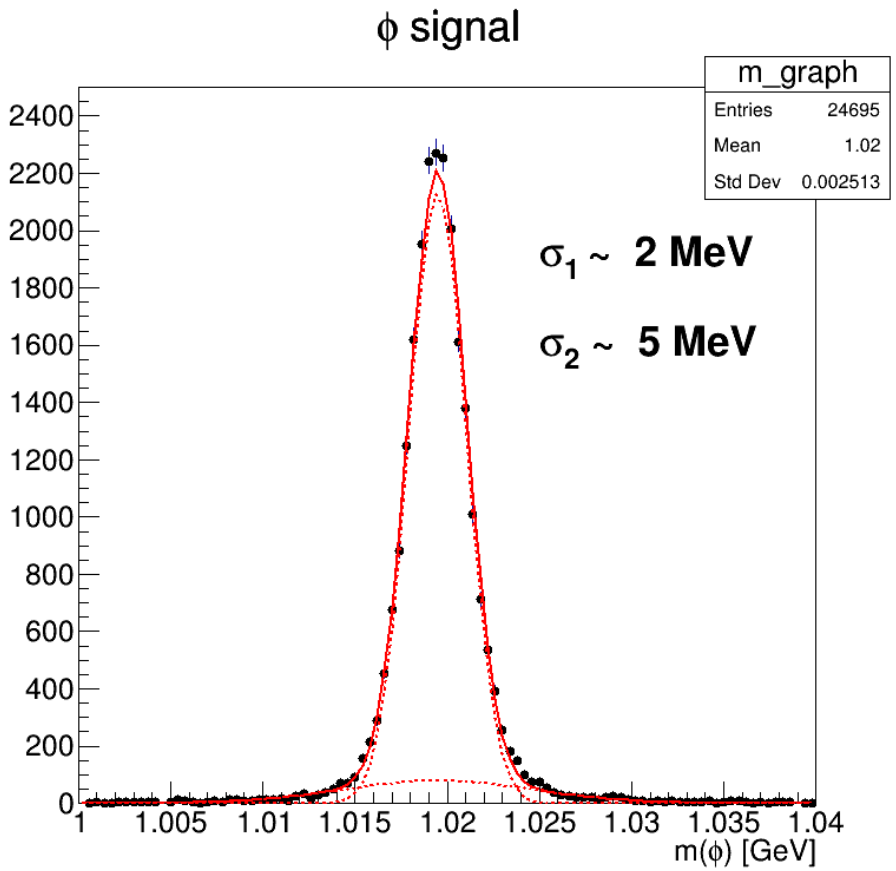
Gaussian function

FIT OUTPUT:

$\mu = 1.019482 \pm 0.000011$ [GeV]

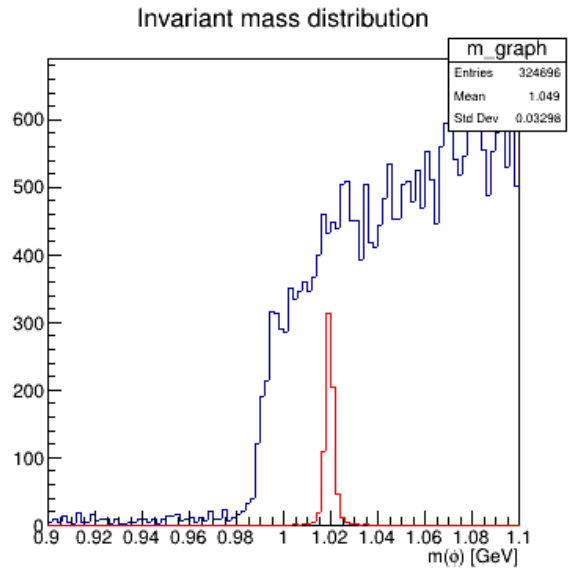
$\sigma = 1.724 \pm 0.011$ [MeV]

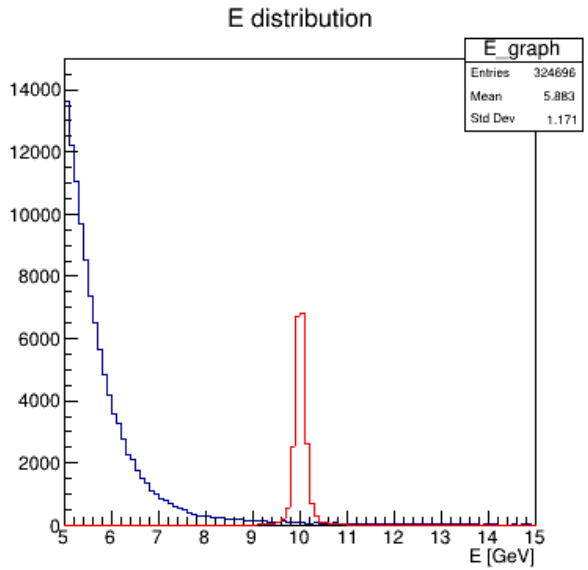
excl-ϕ signal (double Gaussian function)

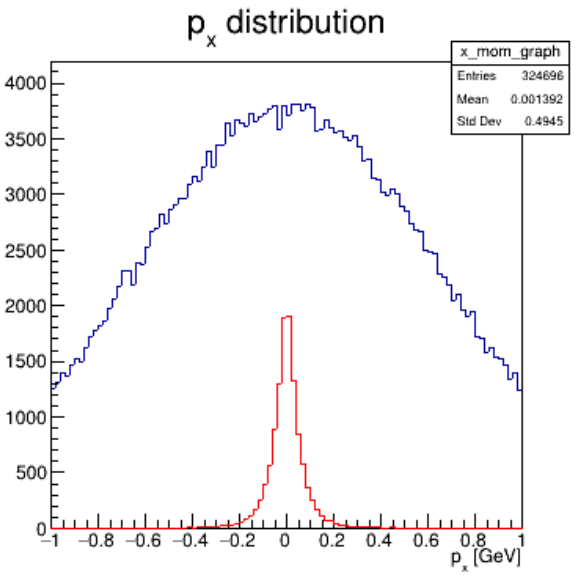


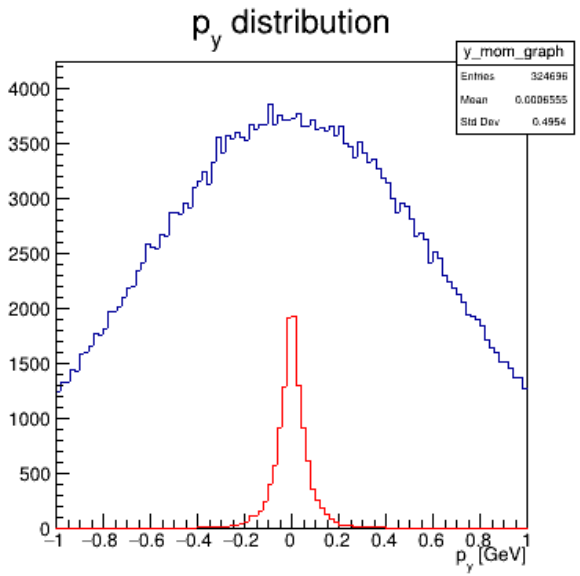
FUNCTION:
double Gaussian function
FIT OUTPUT:
$\mu = 1.019482 \pm 0.000012$ [GeV]
$\sigma_1 = 1.571 \pm 0.014$ [MeV]
$\sigma_2 = 5.18 \pm 0.18$ [MeV]

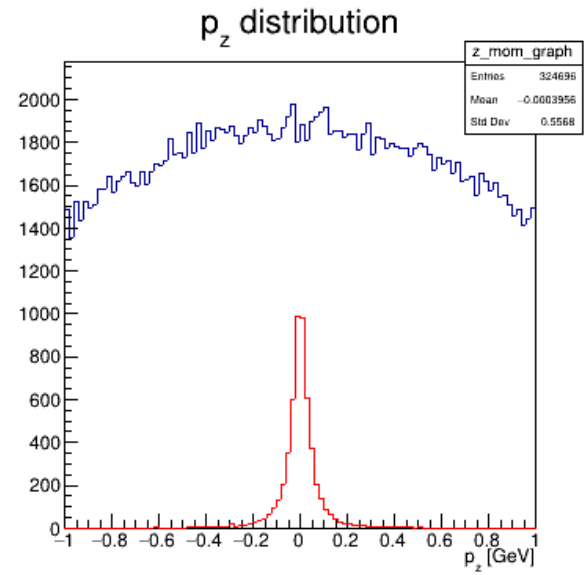
Plots (10 GeV, no selection)



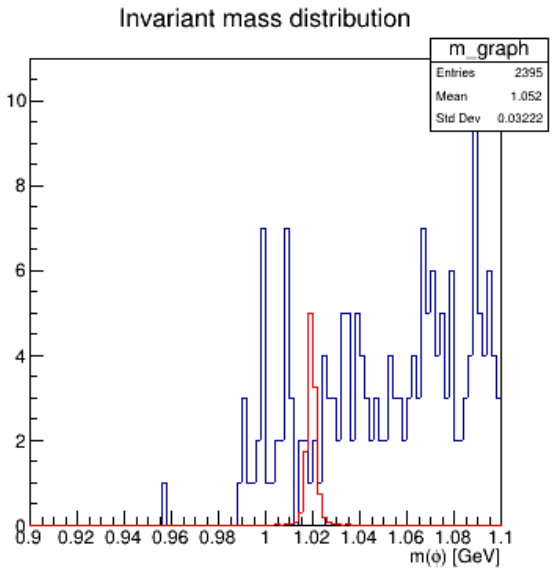


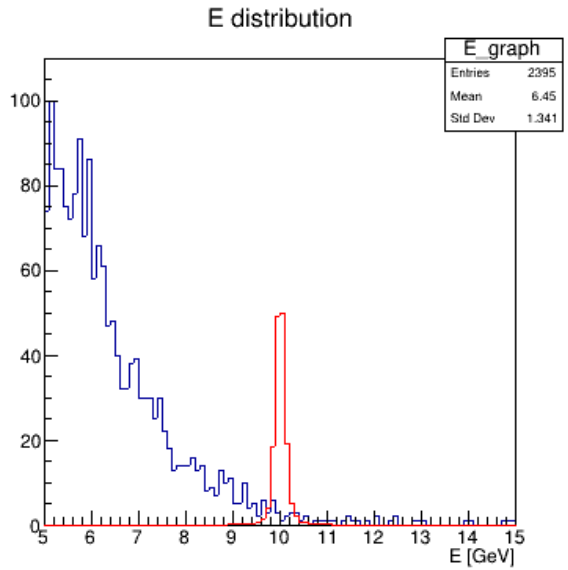


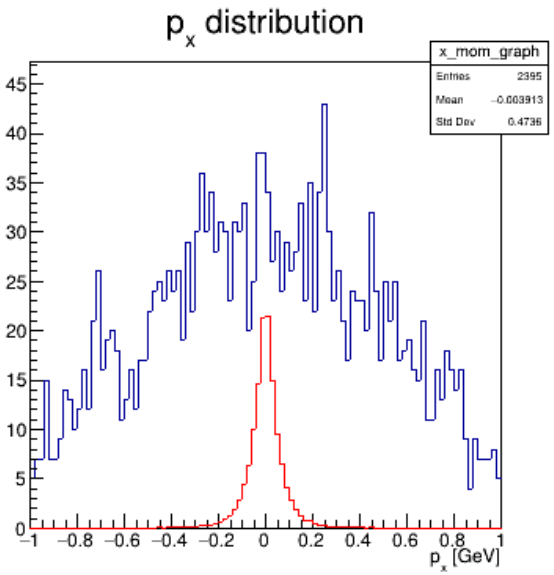


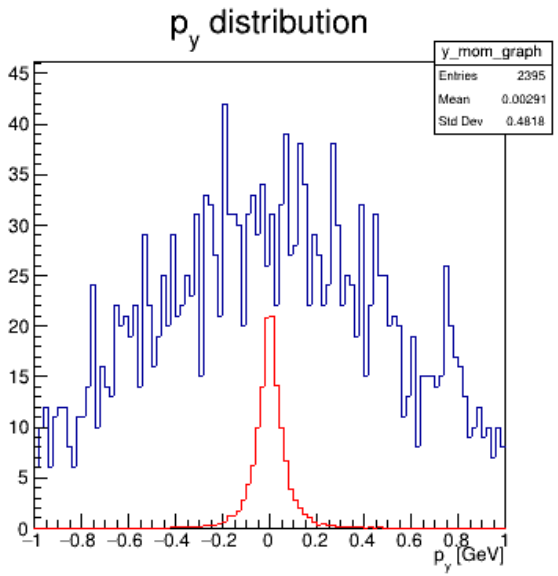


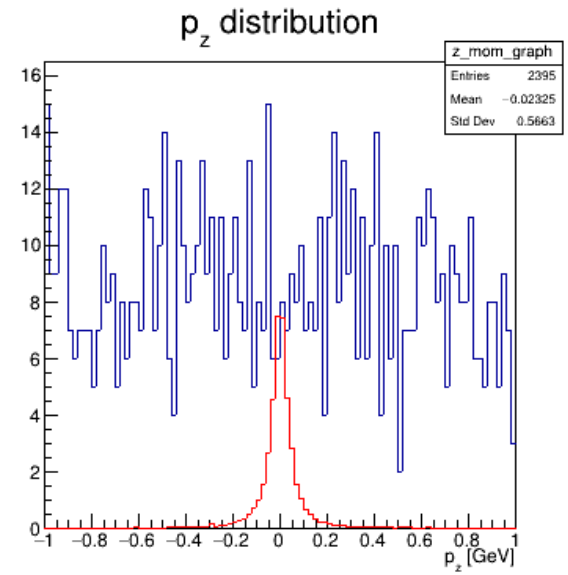
Plots (10 GeV, only 4 tracks in the event)



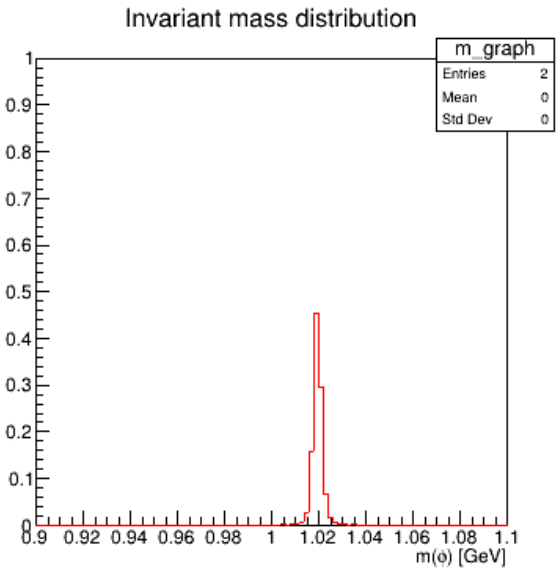


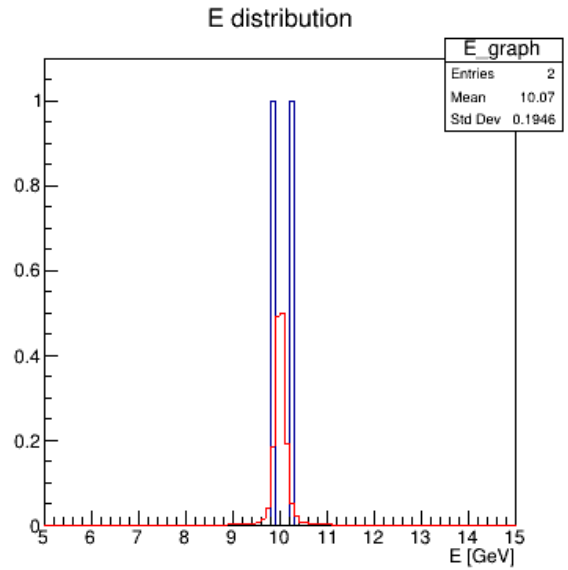


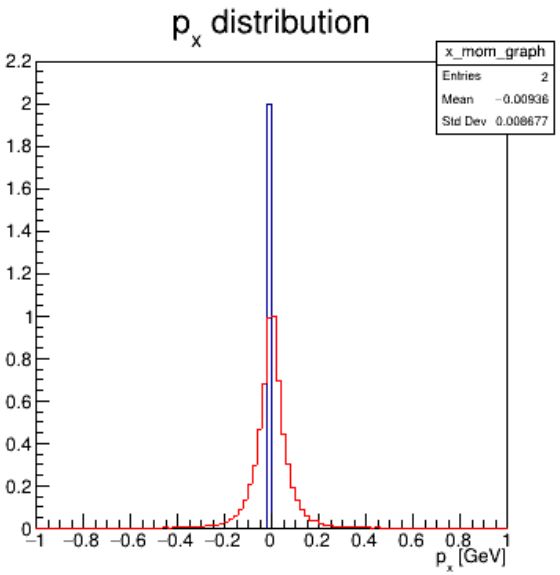


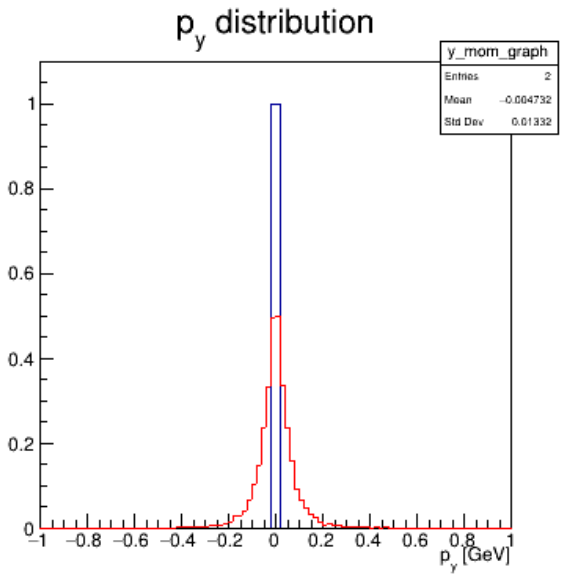


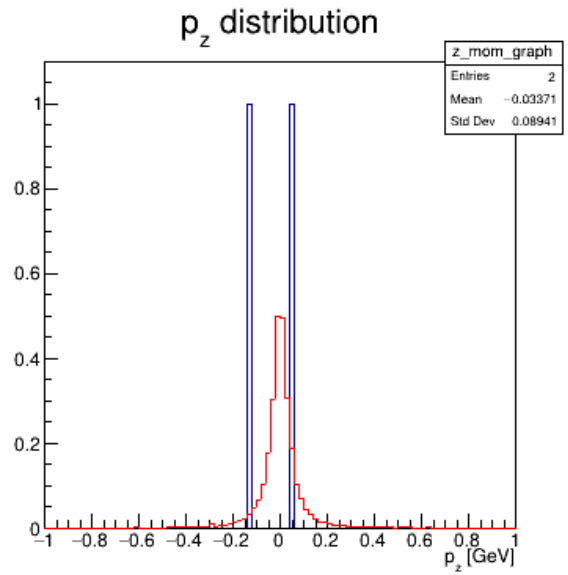
Plots (10 GeV, 4-momentum constraint)



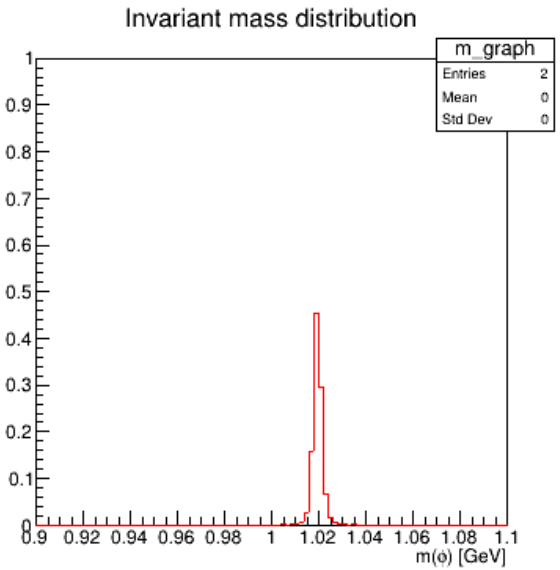


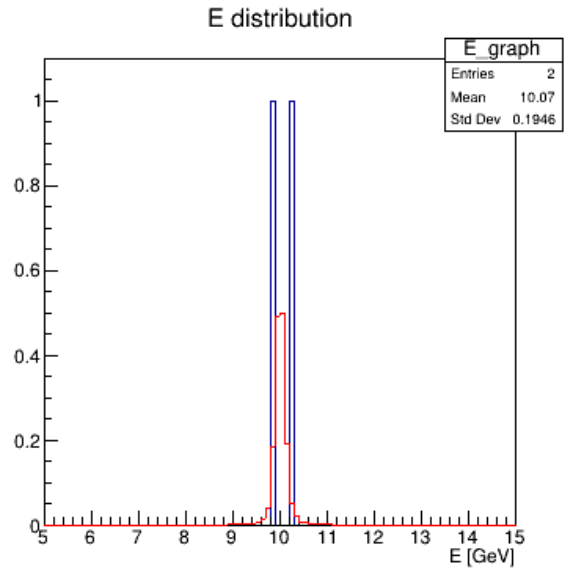


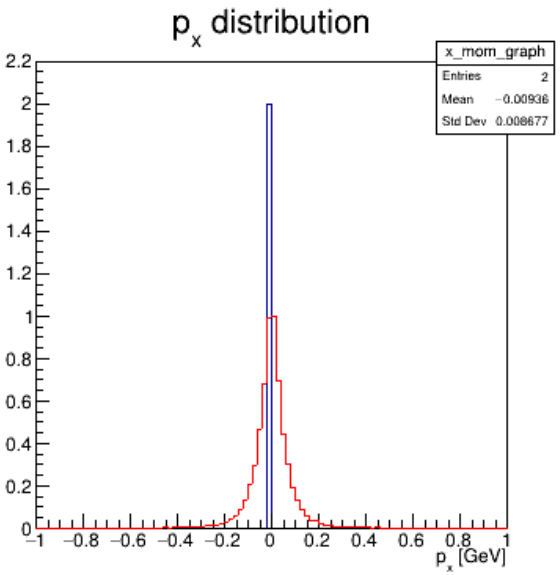


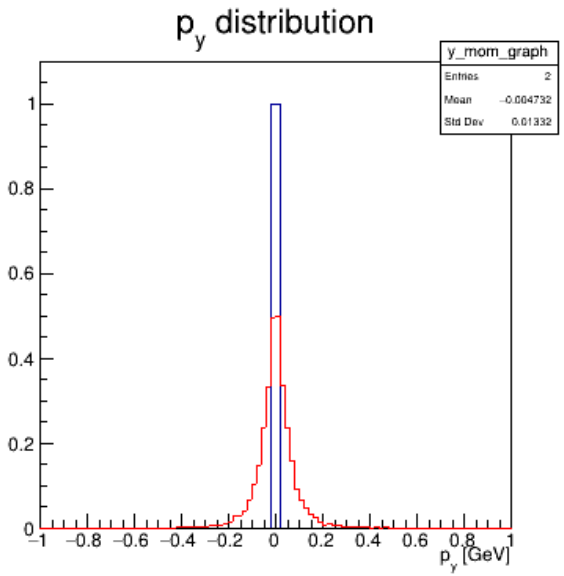


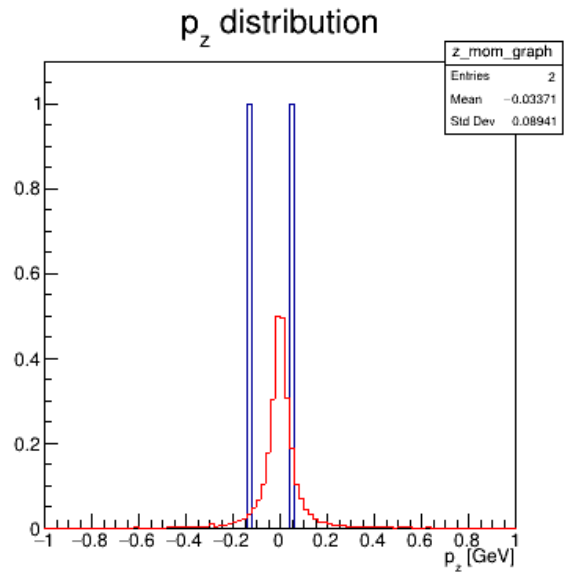
Plots (10 GeV, all constraints)











Preliminary calculations (I)

- The conservation of energy and the presence of four tracks can be considered partially interchangeable (strongly correlated).
- The number of generated MB events is still quite small, hence the estimates presented below are quite preliminary, linear interpolation is used.

Some known parameters:
$L = 10^{31} cm^{-2} s^{-1}$
$\sigma_{MB} = 40 mb$
$\sigma_{signal} = 0.1 \mu b$
$T = \frac{1}{3} 10^7 s \approx \frac{1}{3} year$

Preliminary calculations (II)

The yield of the signal:

$$N_{signal} = 25000 \times \frac{L \times \sigma_{signal} \times T}{200\ 000} \approx 2.1 \times 10^7$$

The number of background events were assessed considering sidebands. We constrain momentum values and invariant mass values. The energy values are left unconstrained. Then we look at number of events smoothly constraining energy. The least number of events (only 1) happen at around 4.9 GeV. Using linear approximation we get 0.08164 at energy constraints at 0.4 GeV. Then

$$N_{bg} = 0.08164 \times \frac{L \times \sigma_{bg} \times T}{1\ 000\ 000} \approx 1.1 \times 10^5$$

$$\sqrt{N_{bg}} \approx 330$$

$$N_{signal} \gg \sqrt{N_{bg}}$$

Summary

To summarize the status of the analysis:

- The simple signal generator has been developed.
- The preliminary signal fit parameters have been extracted.
- The signal of the exclusive ϕ production in SPD detector is feasible to identify with the first stage data

The next items on our (not full) "ToDo list":

- Implement adequate generator of excl-ϕ production
- Use lower energy for MB event sample.
- Generate MB sample with larger statistics

Many thanks to Igor Denisenko for help and fruitful discussions.

This study was carried out within the project "Study of exclusive ϕ-meson production under conditions of the first stage of the NICA SPD experiment".

Thank you for your attention!