Exclusive ϕ production simulation with SPDRoot

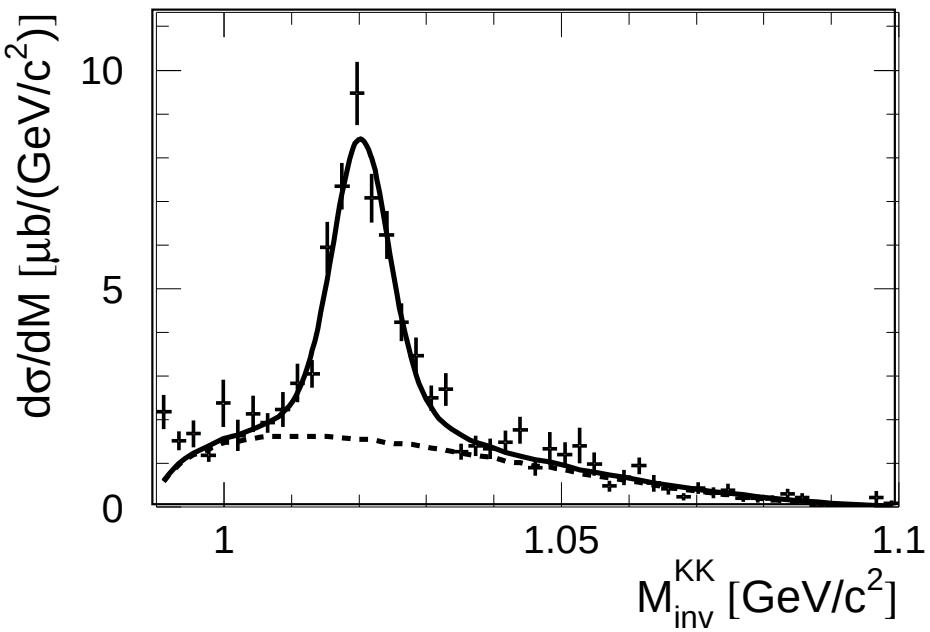
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SPD collaboration meeting, 15 May 2025

Motivation for $pp \to pp\phi$ study

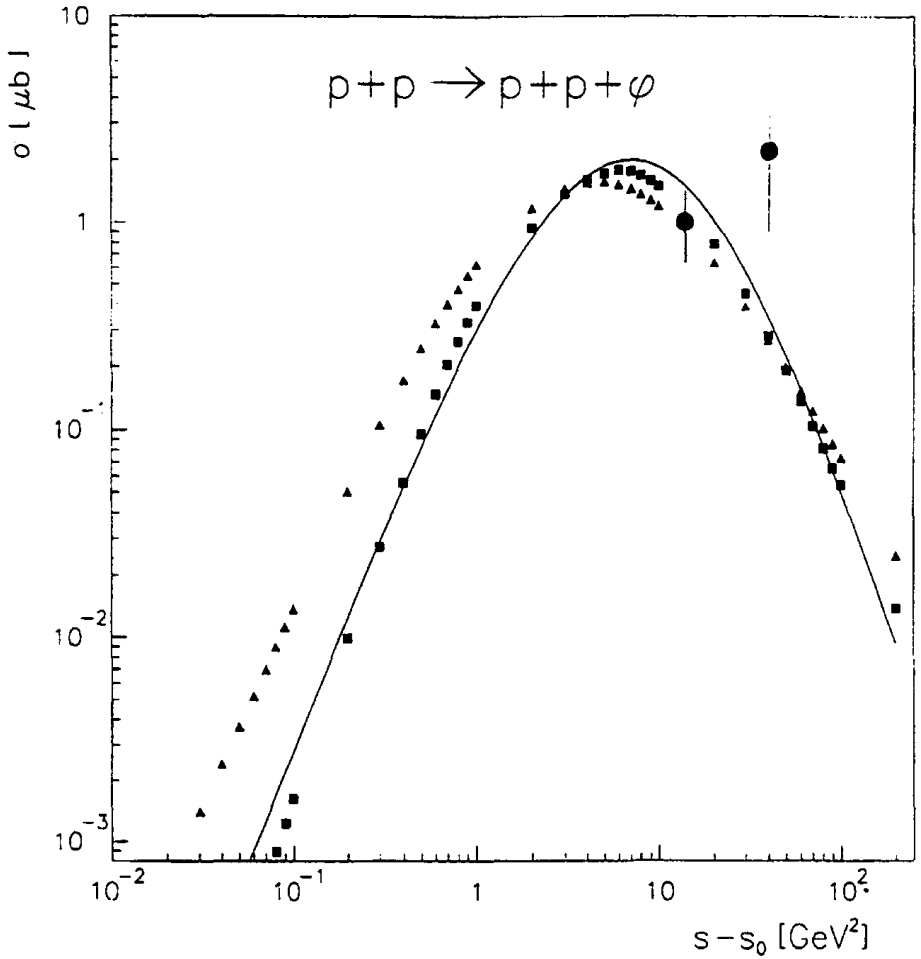
- Probe QCD models at low energy, low Q^2 :
  - production via meson exchange [NewJ.Phys.4:68,2002]
  - v.s. pomeron-odderon meson vertex [Phys.Rev. D101, 094012 (2020)].
- search for pentaquarks with hidden strangeness: $pp \to pP_s^+(\to p\phi)$
- reconstructed ϕ signal to use for detector performance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



$pp \to pp\phi$ 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)
- Matrix element was implemented by adjusting previous code

To get the process filling available phase space according to matrix element:

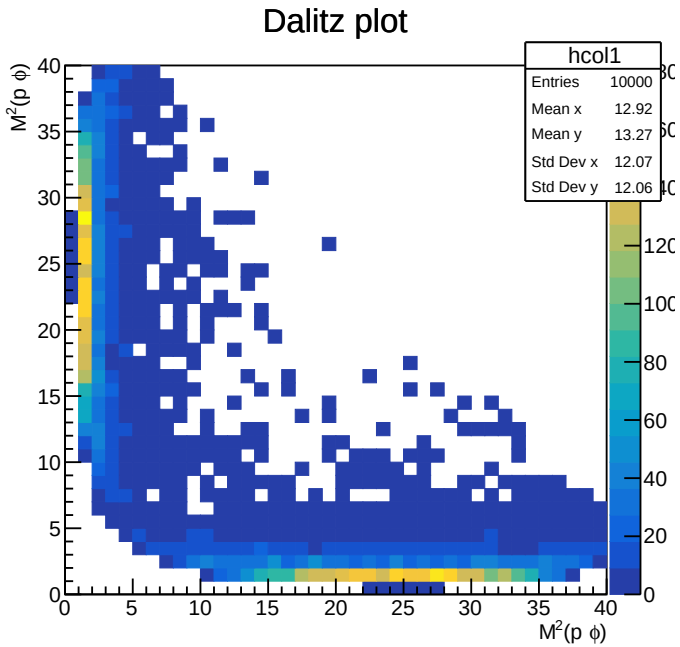
```
do {
      weight = fGenPhaseSpace.Generate();
      weight = weight * MatrixElement2( ...  );
      coin = rnd.Uniform(0., fMaxWeight);
} while ( coin > weight);
```

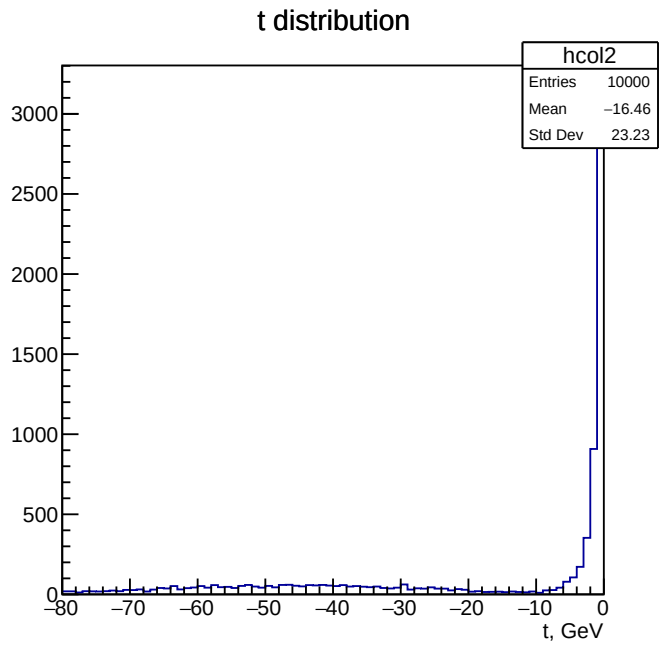
Matrix element

- The matrix element was taken from the Sibirtsev's article

$$|M|^2 = \sum_{i=1}^{4} \frac{k}{|p'_f|} F^2(t) D^2(t) \sigma(w) w^2 t =$$

$$= \sum_{i=1}^{4} \frac{\lambda^{1/2}(w^2, m_p^2, m_\pi^2)}{\lambda^{1/2}(w^2, m_p^2, m_\phi^2)} F^2(t) D^2(t) \sigma(w) w^2 t$$





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.

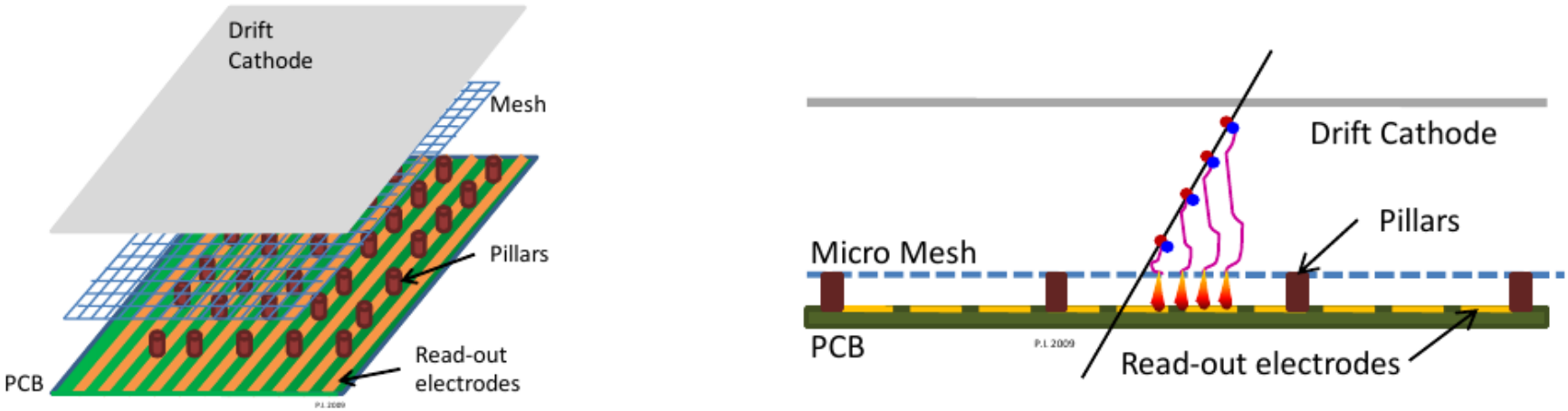


Figure 12.1: Sketch of the layout and operating principle of a Micromegas detector.

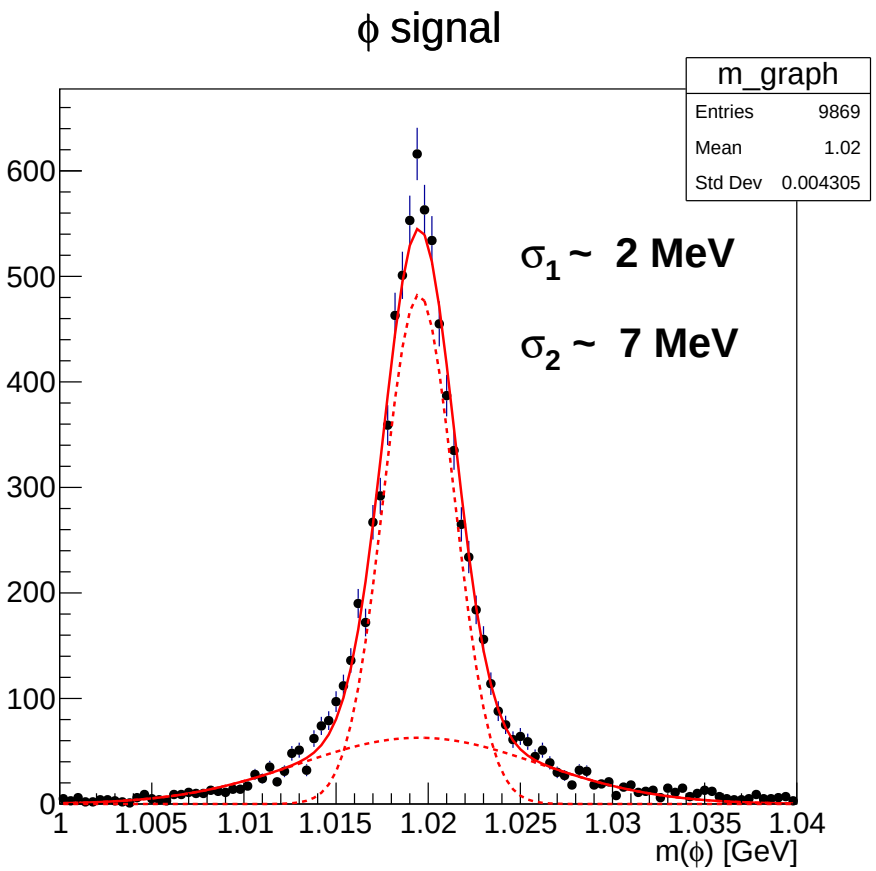
Selection Criteria

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

- ~~4-momentum conservation~~
- only three tracks in the event

Due to the appearance of the matrix element, one of the protons remains in the tube. The condition of the presence of four protons in the event is replaced by the presence of three protons in the event.

excl-ϕ signal (double Gaussian function)



FUNCTION:

double Gaussian function

FIT OUTPUT:

$\mu = 1.019503 \pm 0.000029$ [GeV]

$\sigma_1 = 1.918 \pm 0.042$ [MeV]

$\sigma_2 = 6.52 \pm 0.20$ [MeV]

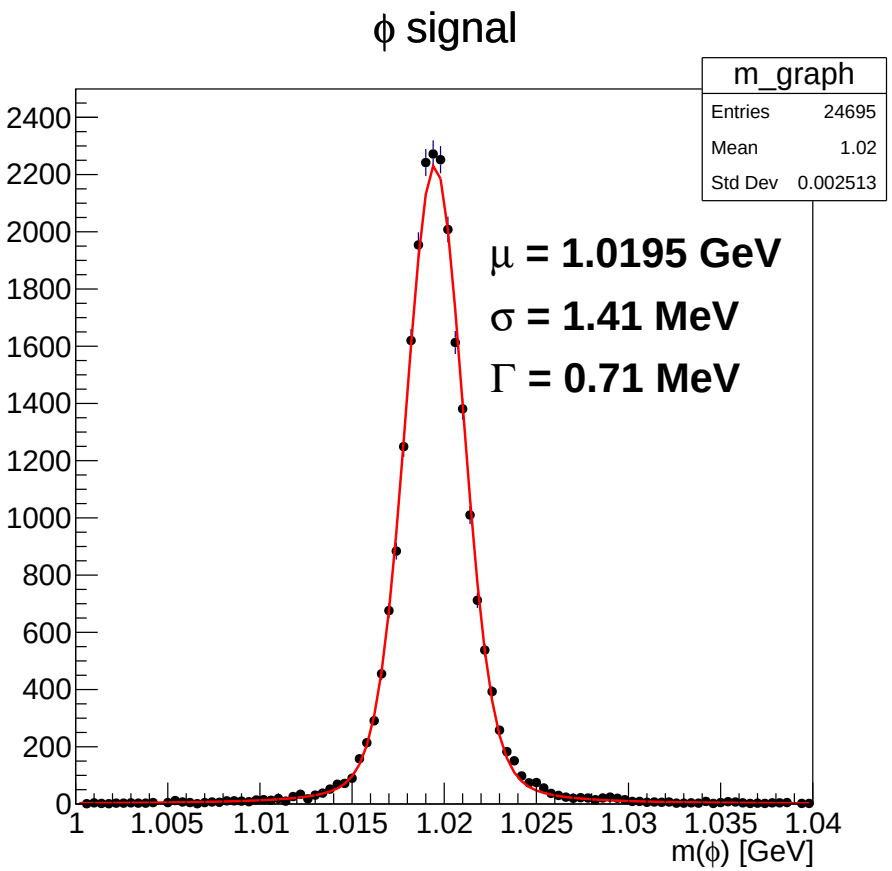
PREVIOUS FIT OUTPUT:

$\mu = 1.019482 \pm 0.000012$ [GeV]

$\sigma_1 = 1.571 \pm 0.014$ [MeV]

$\sigma_2 = 5.18 \pm 0.18$ [MeV]

excl-ϕ signal (Voigt profile)



FUNCTION:
Voigt profile
(convolution of a Breit-Wigner distribution and a Gaussian distribution)

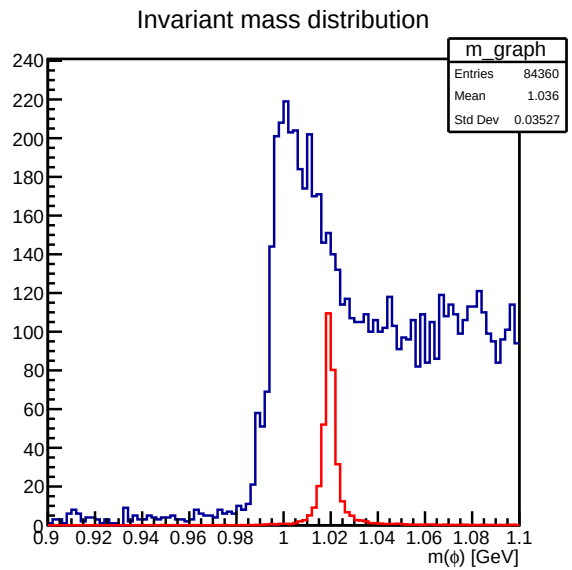
FIT OUTPUT:

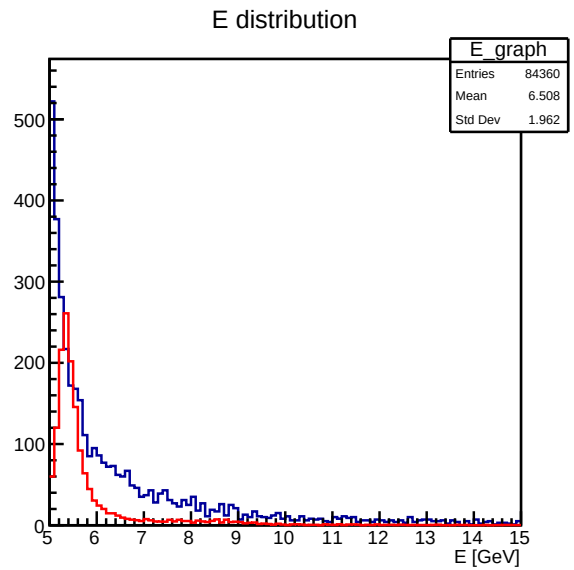
$\mu = 1.01948 \pm 0.000012$ [GeV]

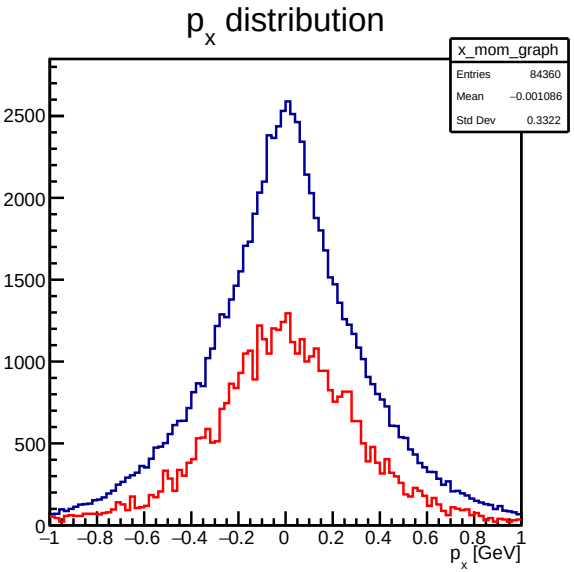
$\sigma = 1.413 \pm 0.016$ [MeV]

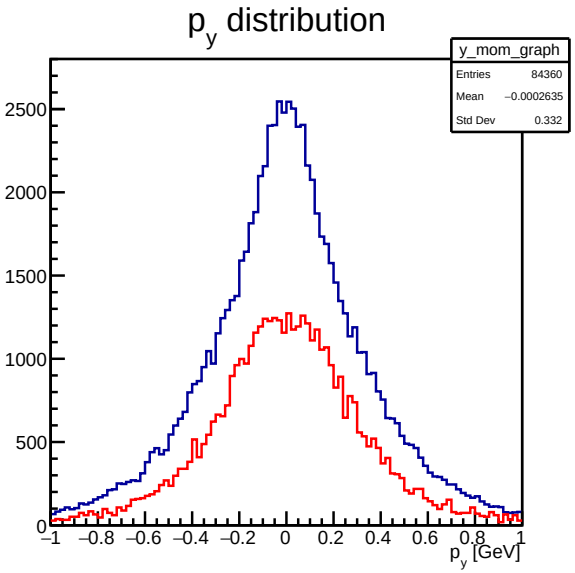
$\Gamma = 0.709 \pm 0.024$ [MeV]

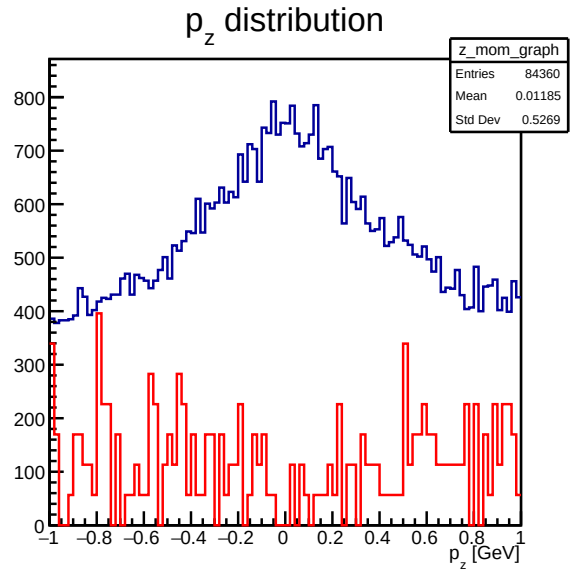
Plots (5 GeV, only 3 tracks in the event)











Calculations

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

The yield of the signal:
$N_{signal} = 10\ 000 \times \frac{L \times \sigma_{signal} \times T}{200\ 000} \approx 8.4 \times 10^6$

The yield of the Minimum-Bias (inside 3σ):
$N_{bg} = 815 \times \frac{L \times \sigma_{bg} \times T}{2.8 \times 10^7} \approx 3.9 \times 10^7$
$\sqrt{N_{bg}} = 6200$

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

Summary

To summarize the status of the analysis:

- The more realistic signal generator has been constructed.
- The preliminary signal fit parameters have been extracted.

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

- Calculate the detector resolution
- Update the analysis using recoil mass
- Make generator work more efficiently

Many thanks to Igor Denisenko for help and fruitful discussions.

Thank you for your attention!