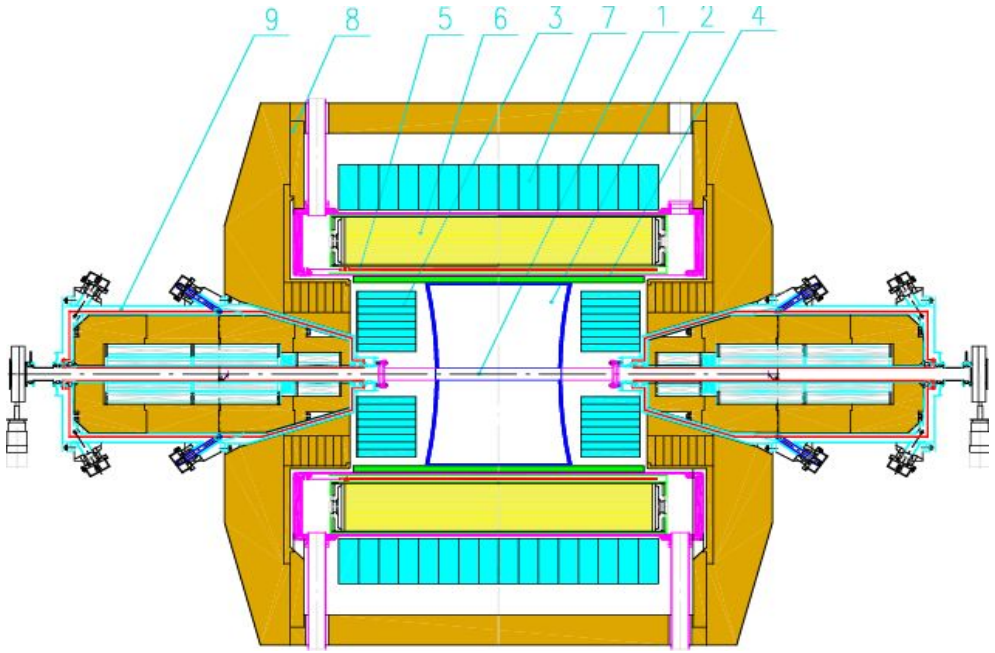
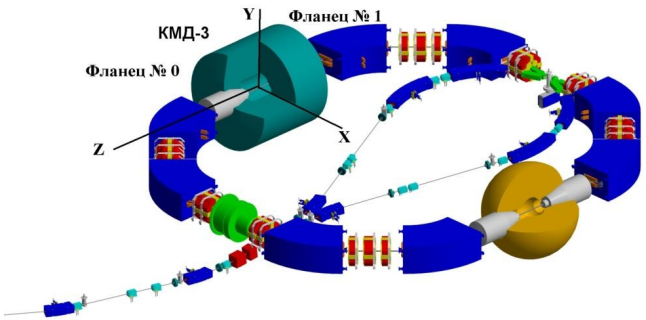
Study of the $e^+ e^- \to \pi^+ \pi^- \pi^0$ process with the CMD-3 detector at the VEPP-2000

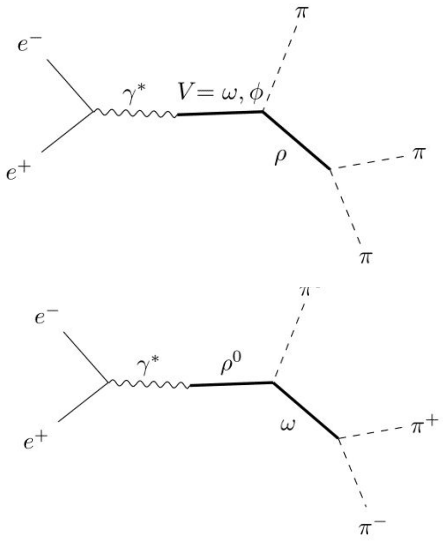




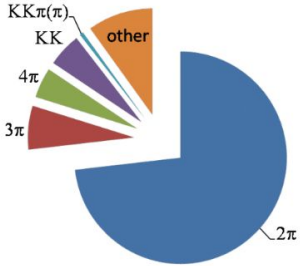
S. Tolmachev on behalf of the CMD-3 collaboration (BINP, Novosibirsk)
21st Lomonosov Conference, Moscow 2023

Motivation, goals, data set

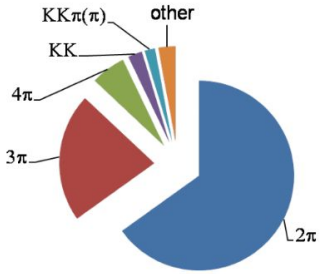
- Cross-section of $e^+ e^- \to \pi^+ \pi^- \pi^0$ is the second significant contribution to the hadronic part of the g-2 and its uncertainty
- Difference between CMD-2 and SND measurements of peak cross-section (~ 130 nb) contributes significantly to uncertainty of hadronic part of g-2



Value



Square of uncertainty



- Measurement of ω-meson parameters
- Study of dynamics, particularly measure ρ-ω interference

Data set:

- $E_{c.m.}$ = 0.66 - 0.97 GeV
- 2 seasons (2013, 2018)
- 4 scans at energy region close to ω-meson mass
- 101 energy points
- $L_{int} \approx 51.4$ pb^{-1} (2013,2018)

Selection criteria

Good track:

- N_{hits} > 10 (Number of hits in DC)
- 1.1 < θ < π - 1.1 [Rad] (Polar angle of track)
- ρ < 0.2 [cm] (Distance to beam axis)
- |z| < 10 [cm] (Distance to interaction point along the beam)
- dEdx < 6000 (Energy loss in DC)
- 0.2 < P/E_{beam} < 0.8

- $N_{good\ tr}$ = 2
- $Q_1 + Q_2 = 0$ (Oppositely charged tracks)
- $N_{good\ \gamma} \geq 2$
- 0.25 < |Δφ| < π - 0.25 (Acollinearity in the azimuthal plane)
- 0.4 < $(P_1 + P_2)/2E_{beam}$ < 0.73

Good γ:

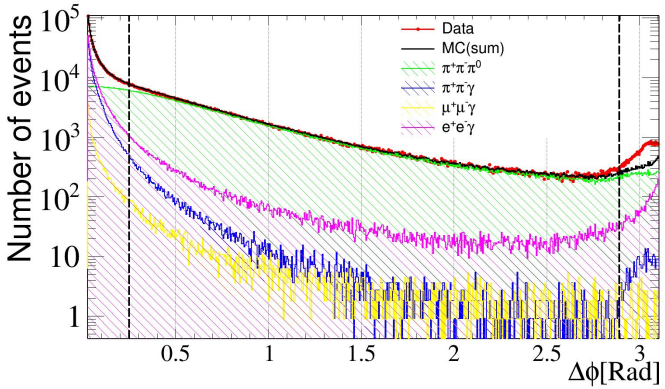
- E_γ > 50 MeV
- 0.5 < θ_γ < π - 0.5

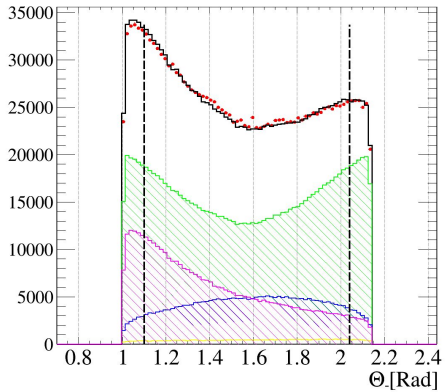
Kinematic fit:

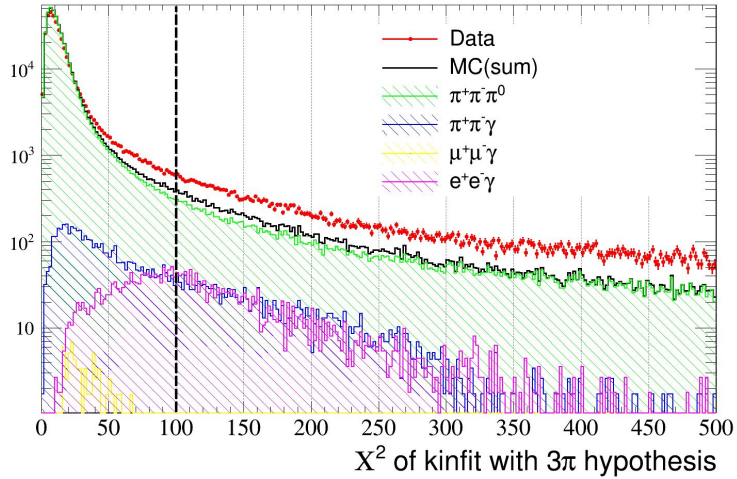
- $X^2_{3\pi} < 100$
- $X^2_{\pi\pi\pi\gamma} > 40$
- $X^2_{ee\gamma} > 200$
- $X^2_{\mu\mu\gamma} > 100$

Background:

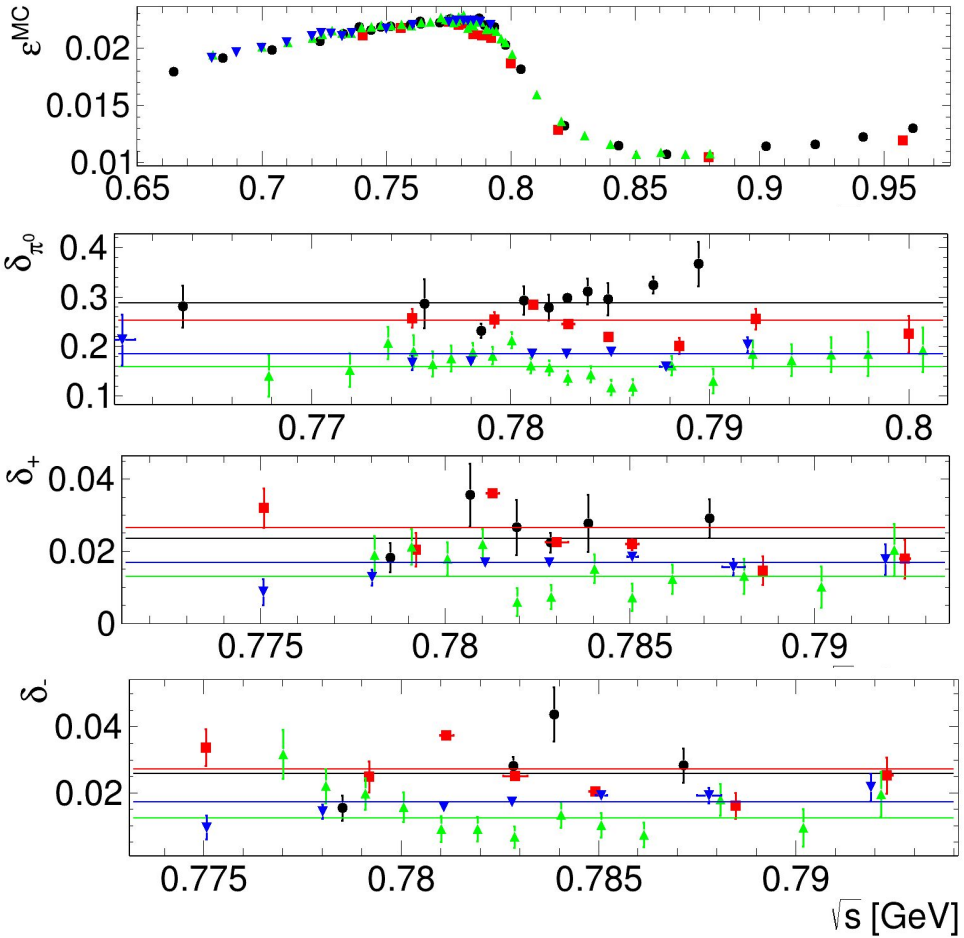
- $\pi^+\pi^-\gamma$
- $e^+e^-\gamma$
- $\mu^+\mu^-\gamma$







Efficiency and corrections



$$\varepsilon_{MC} = \frac{N_{MC}^{sel}}{N_{MC}^{tot}}$$

$$\delta_{\pi^0} = 1 - \frac{\varepsilon_{\pi^0}^{Data}}{\varepsilon_{\pi^0}^{MC}}$$

$$\varepsilon_{\pi^0} = \frac{N_{\pi^+\pi^-\pi^0}}{N_{\pi^+\pi^-}}$$

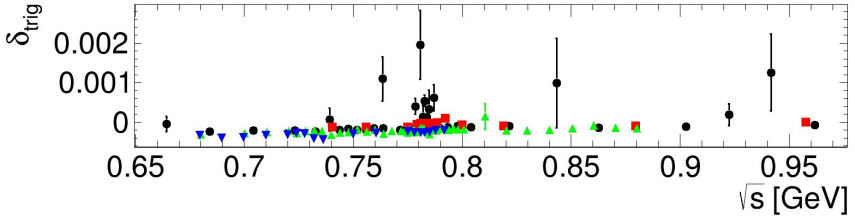
$$\delta_{\pm} = 1 - \frac{\varepsilon_{\pm}^{Data}}{\varepsilon_{\pm}^{MC}}$$

$$\varepsilon_{\pm} = \frac{N_{2tr,\pi^0}}{N_{2tr,\pi^0} + N_{1tr\pm,\pi^0}}$$

scan2013_rho
scan2013_omphi
scan2018
scan2018_omphi

$$\sigma_{vis} = \frac{N_{3\pi}}{L\varepsilon_{MC}(1-\delta_{\pi^0})(1-\delta_+)(1-\delta_-)(1-\delta_{trig})}$$

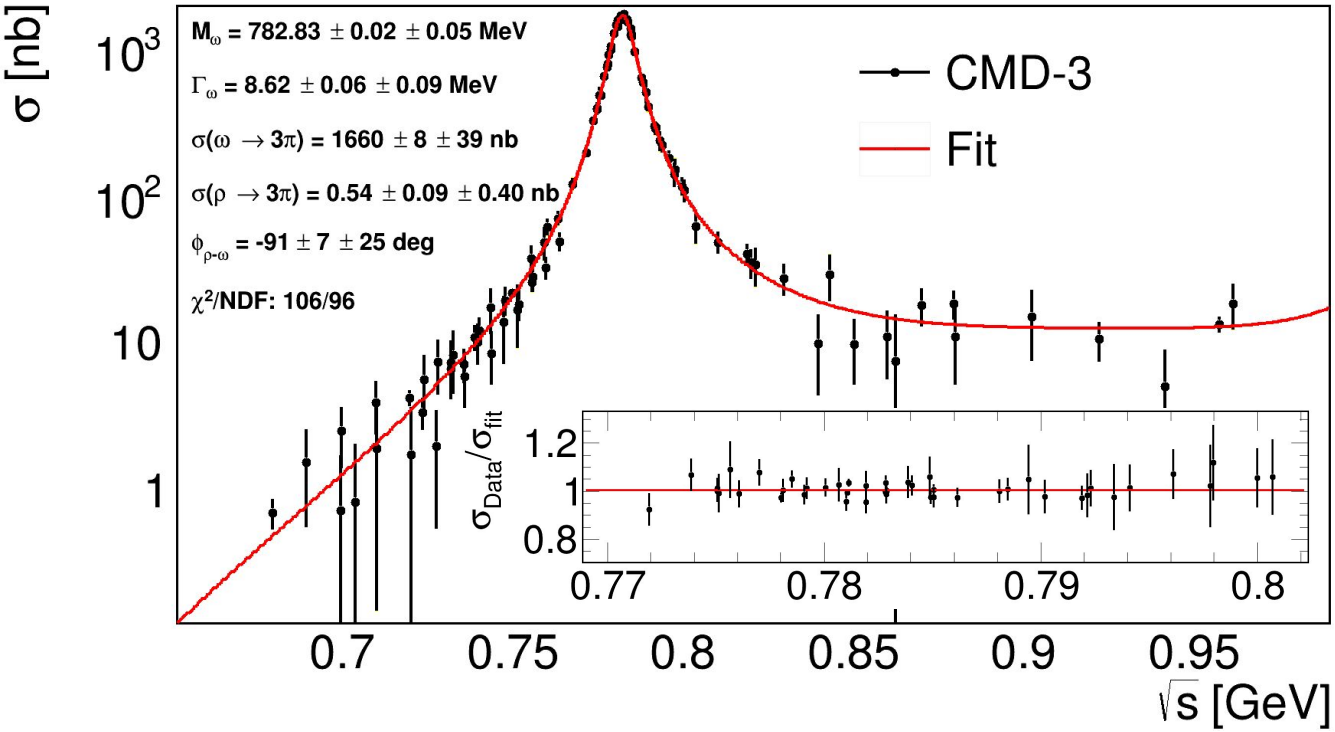
- Number of signal was determined from the missing mass distribution fit
- Detection efficiency ~ 2%
- π^0 reconstruction correction 15 - 30 %
- Track reconstruction correction 1.5 - 3%
- Trigger correction less than 0.1%
- At points where there were not enough statistics to determine the corrections, the average for the scan was taken



Cross-section approximation

$$\sigma(s) = \frac{F_{3\pi}(s)}{s^{3/2}} \left| \sum_{V=\rho,\omega,\phi,\omega',\omega''} e^{i\phi_{\omega V}} \sqrt{\frac{\sigma(V \to 3\pi) M_V}{F_{3\pi}(M_V^2)}} \frac{\Gamma_V M_V^2}{D_V(s)} \right|^2 \qquad F_{3\pi}(s) = \frac{(4\pi\alpha)^2 \sqrt{s}}{12\pi} \int \left[\vec{P}_+ \times \vec{P}_- \right]_\perp^2 \left| \sum_{i=0,+,-} \frac{g_{\rho^i \pi\pi}}{D_{\rho^i}(P_{\rho^i}^2)} \right|^2 d\Phi_{3\pi}$$

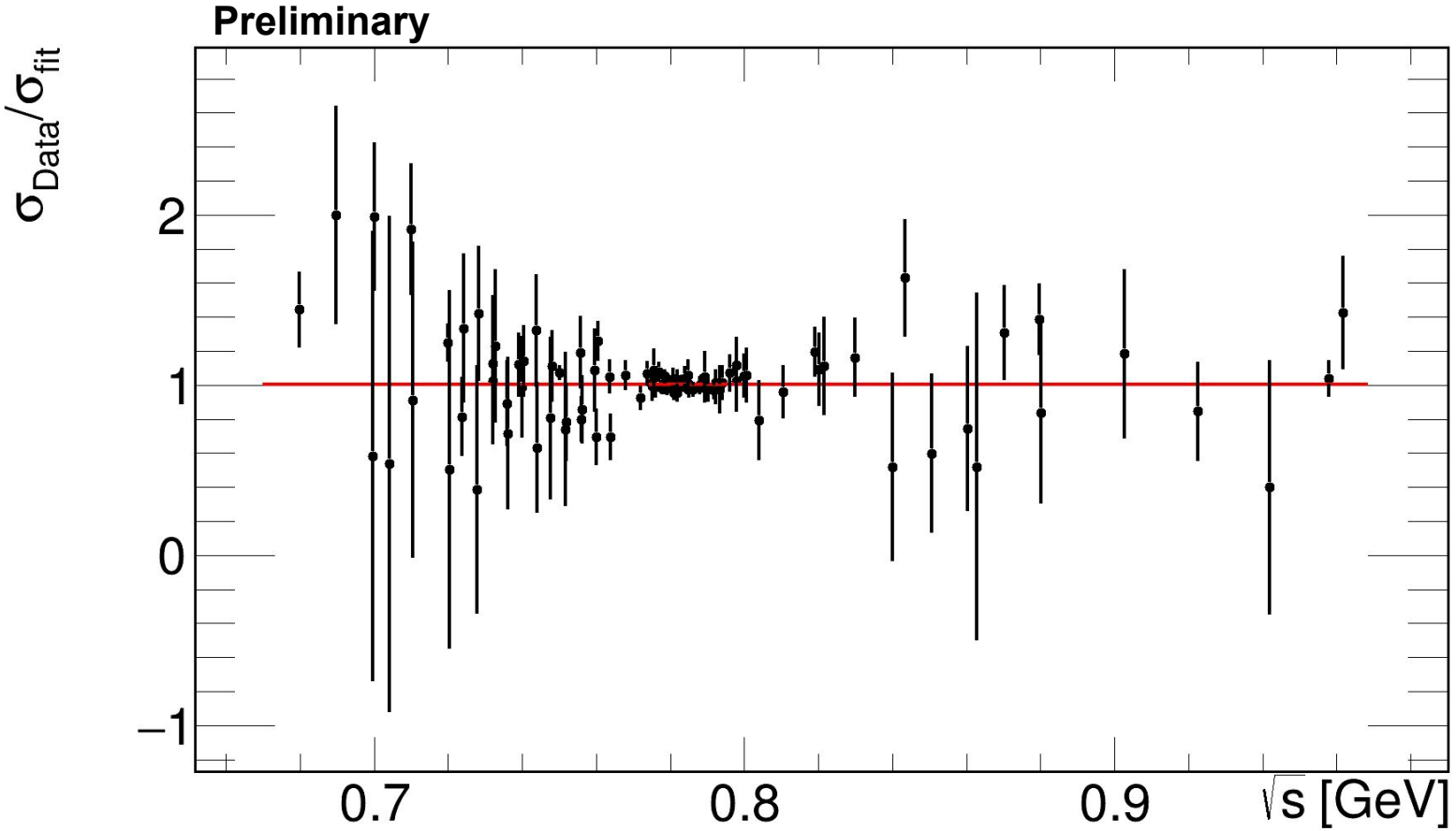
Preliminary fit ($E_{c.m.}$ = 0.66 - 0.97 GeV)



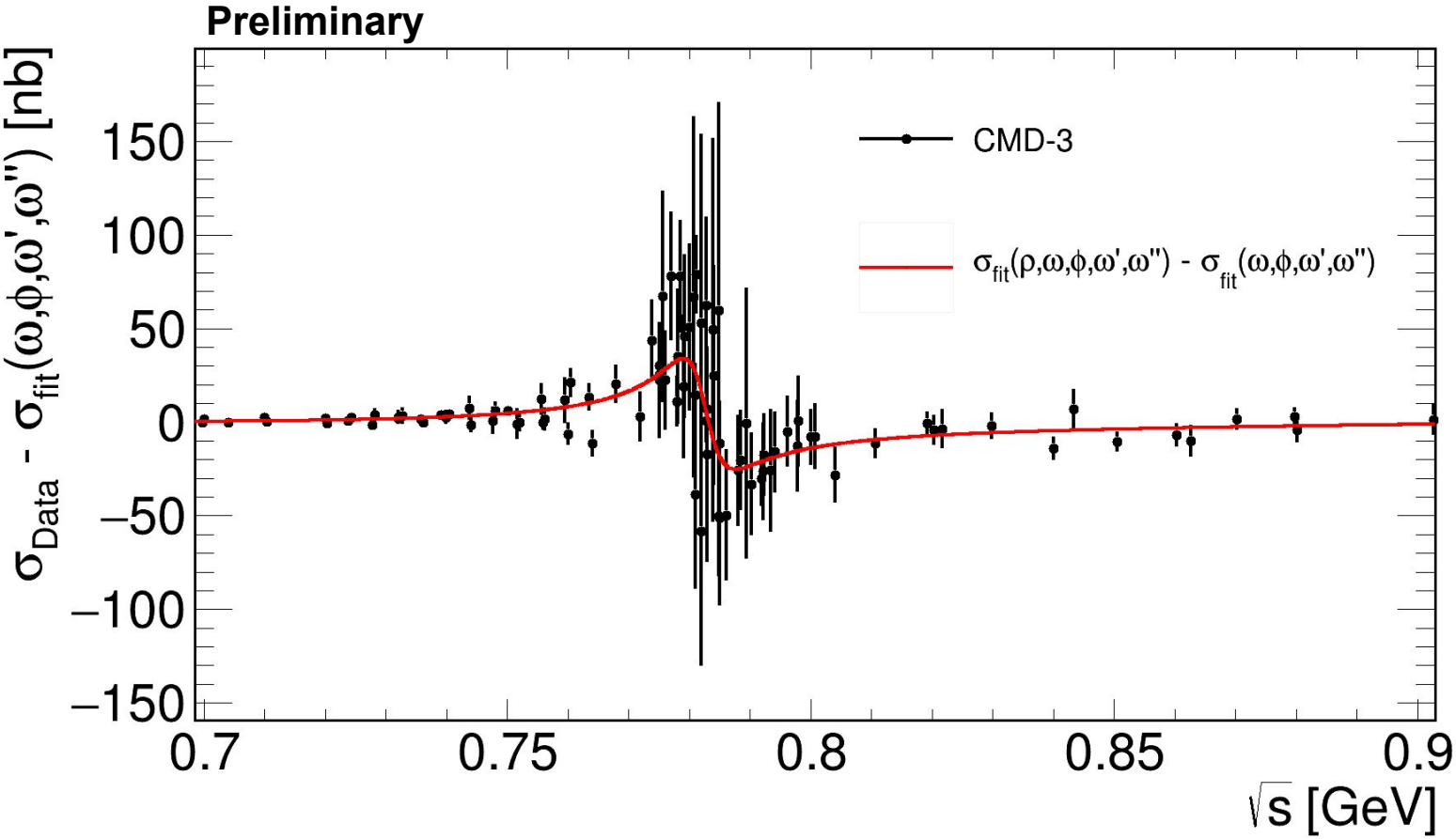
- Phase space includes only ρπ mechanism
- The energy dependence of the widths is included
- In the approximation ρ, φ, ω', ω" masses and widths were fixed at their PDG values.
- ω - φ phase was fixed at 167°
- ω - ω' phase was fixed at 90°
- ω - ω" phase was fixed at 180°

$N_{3\pi} \approx 480k$

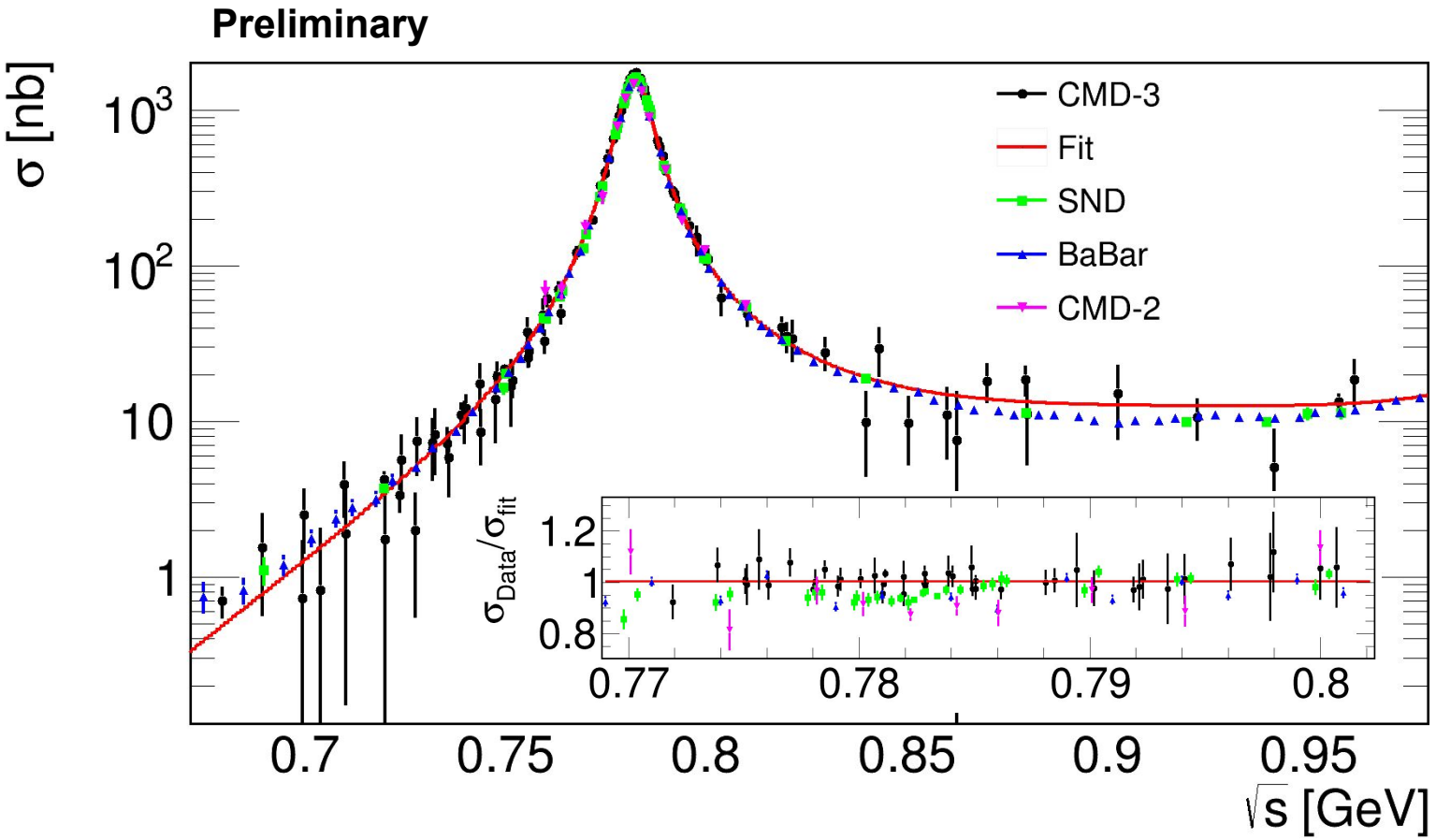
Ratio

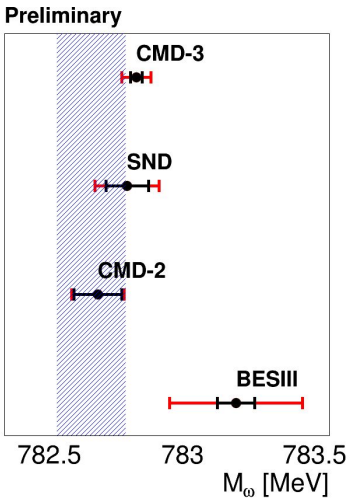


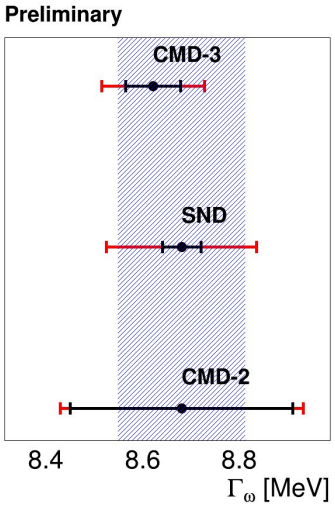
Cross-section without ρ-meson part

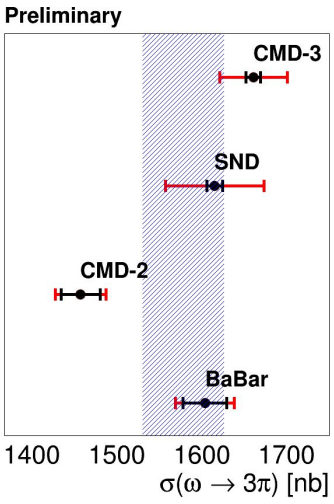


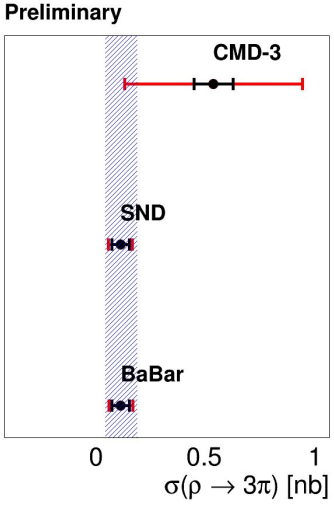
Comparison with other experiments

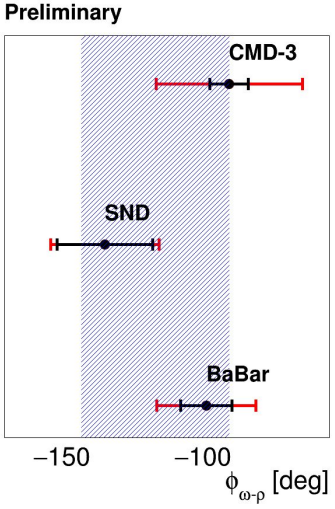


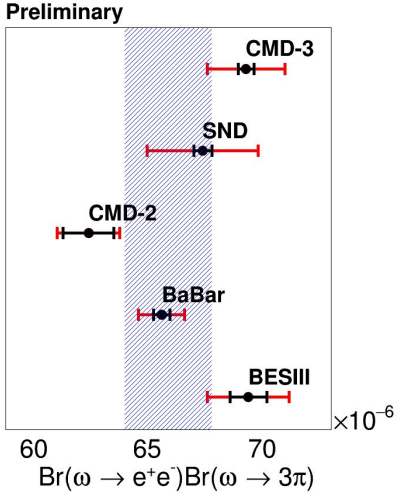












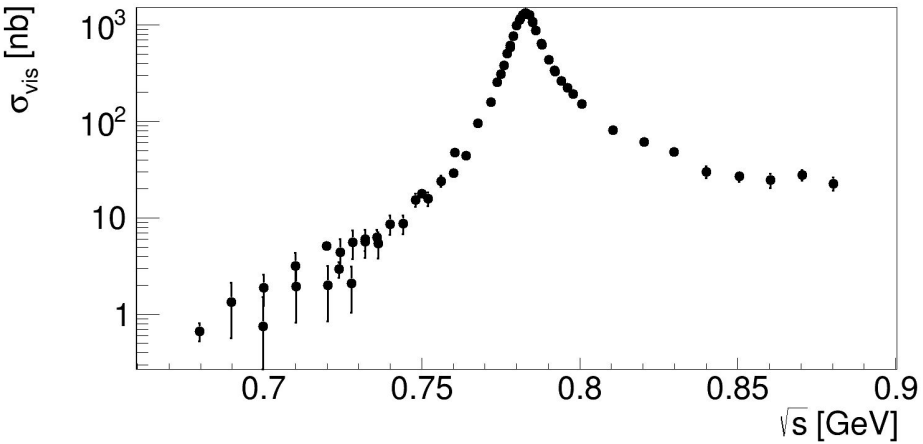
Cross-section systematic uncertainty sources:

Luminosity	1.5 %
θ cuts	~ 1%
Kin fit X^2 cuts	~ 1%
Photons cuts	~ 1%
π^0 reconstruction	~ 0.5%
Tracks reconstruction	~ 0.2%
Total	~ 2.4%

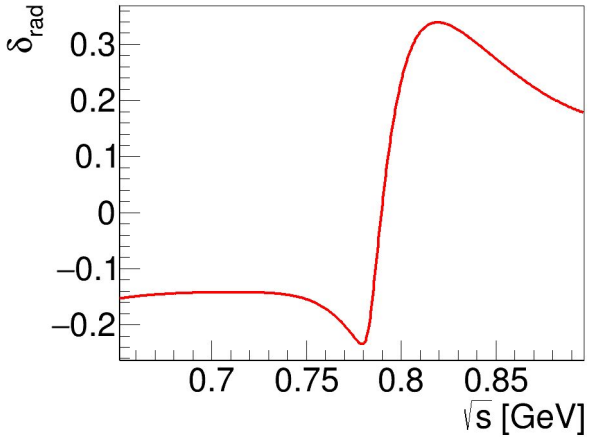
Summary

- Analysis results are in agreement with previous measurement
- Parameter uncertainties are determined by systematics
- Analysis in φ - meson region is in progress
- We are optimistic about reducing the systematics
- The work was supported by grants: the Russian Science Foundation No 23-42-10025; the Belarusian Republican Foundation for Basic Research No. F23RSF-118.

Backslides(Visible cross-section and radiative correction)



- Born cross-section was calculated with the precision 0.2%
- Fadin - Kuraev function

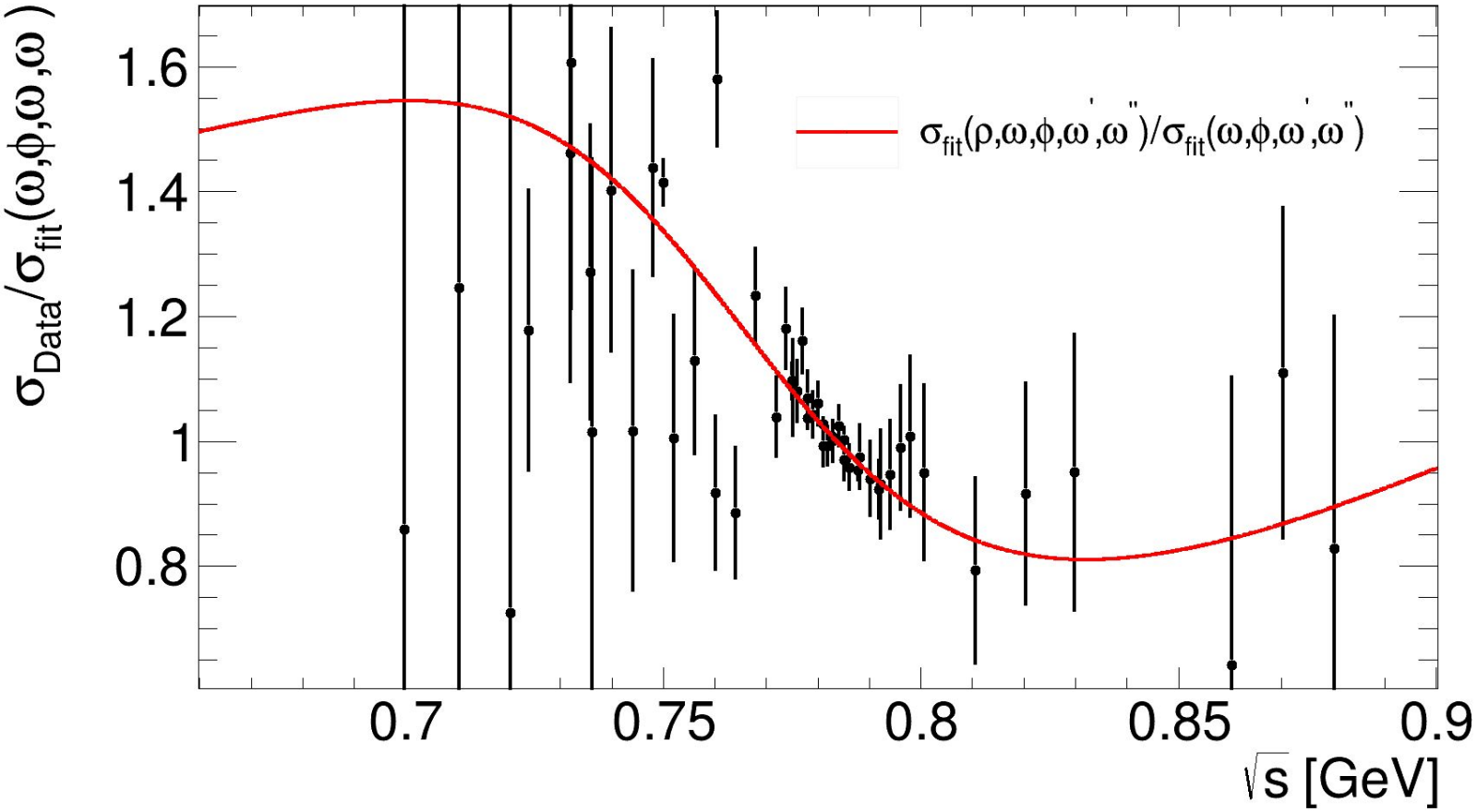


$$\sigma_{vis} = \frac{N_{3\pi}}{L\varepsilon_{MC}(1-\delta_{\pi^0})(1-\delta_+)(1-\delta_-)(1-\delta_{trig})}$$

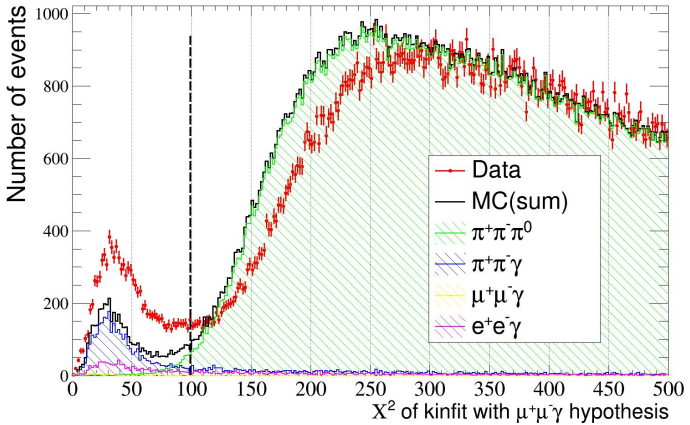
$$\sigma_{vis}(s_0) = \int_{-\infty}^{\infty} e^{-\frac{(s-s_0)^2}{2\sigma_s^2}} ds \int_0^{x_0} \sigma(s(1-x))F(x,s)dx$$

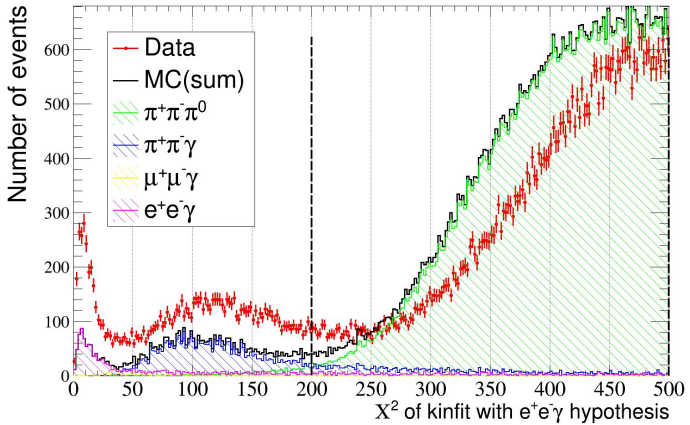
$$\sigma(s) = \frac{\sigma_{vis}(s)}{(1+\delta_{rad})}$$

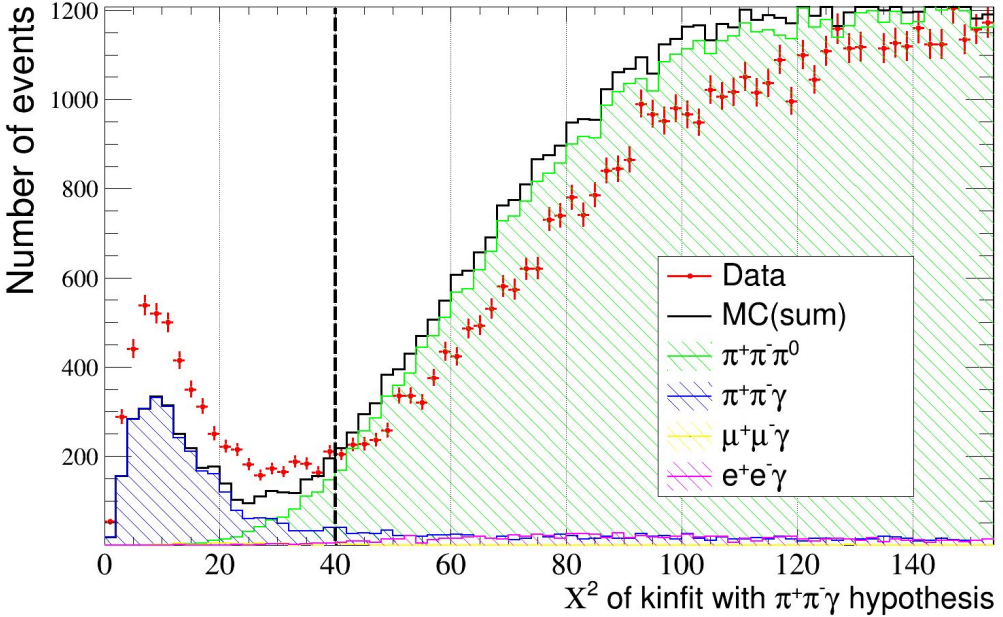
Backslides (Cross-section ratio without ρ)



Backslides (Chi2 cuts)

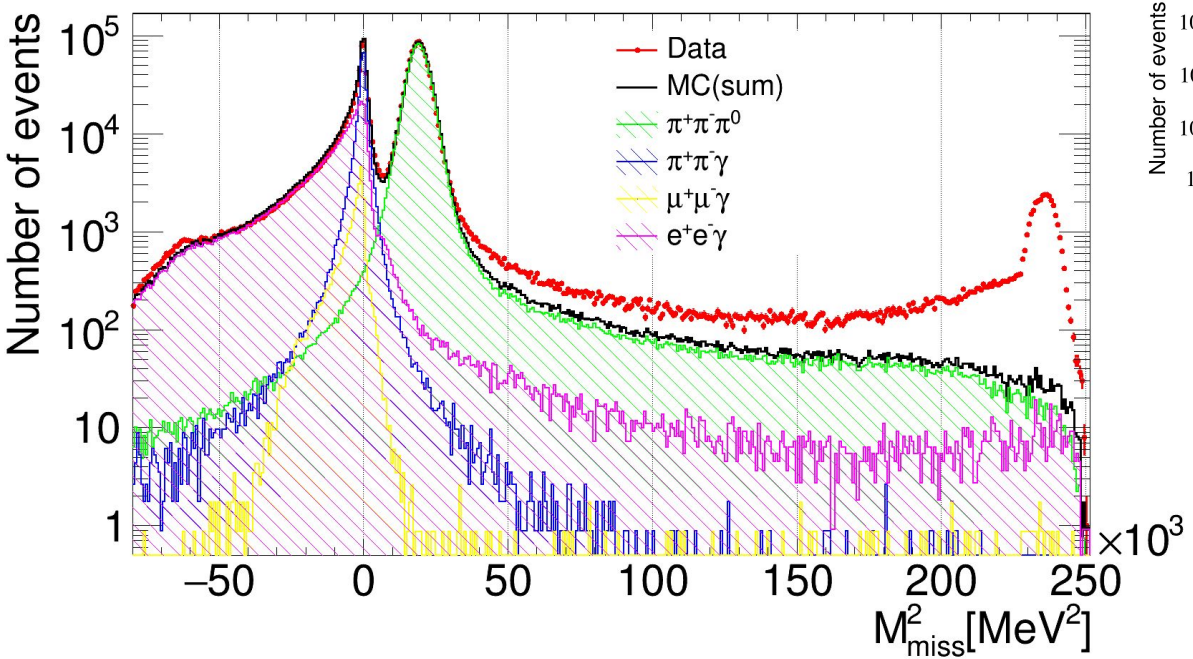




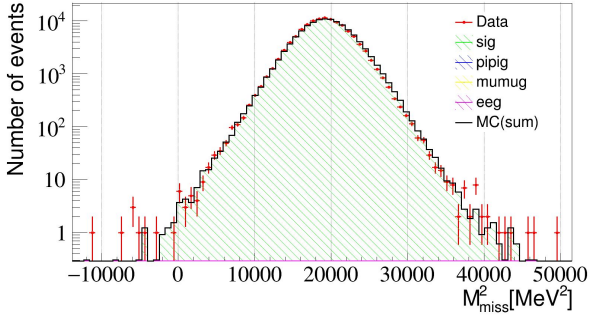


Backslides (Missing mass before cuts)

Only two opposite charged tracks



All selection criteria applied



After selection almost no background but low efficiency