THE STUDY OF FOUR CHARGED PIONS PRODUCTION WITH CMD-3 DETECTOR AT VEPP-2000 COLLIDER

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Outline

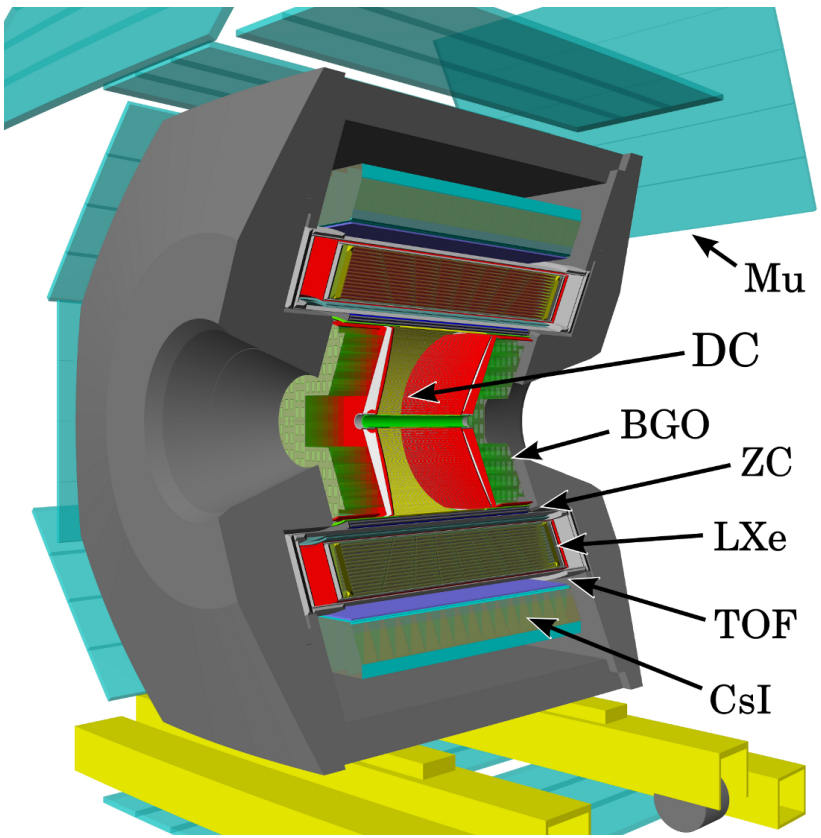
- Introduction
- Selection criteria
- e/π separation procedure
- Detection efficiency
- Preliminary results
- Conclusion

Motivation

- Cross-section measurement $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ at $\sqrt{s}$ <1.06 GeV
- Study of $\pi^+\pi^-\pi^+\pi^-$ internal dynamic
- Measurement of $\rho \to \pi^+\pi^-\pi^+\pi^-$ and $\phi \to \pi^+\pi^-\pi^+\pi^-$ branching fractions
- $(\mathrm{g}-2)_\mu$ contribution
- To compare with theory predictions

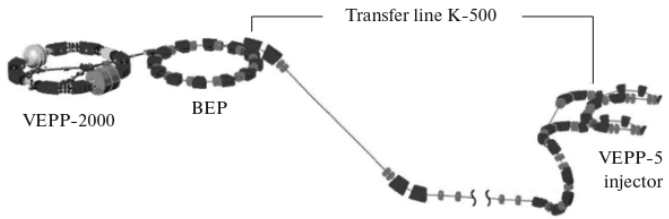
CMD-3 and VEPP-2000

CMD-3 detector



VEPP-2000 collider

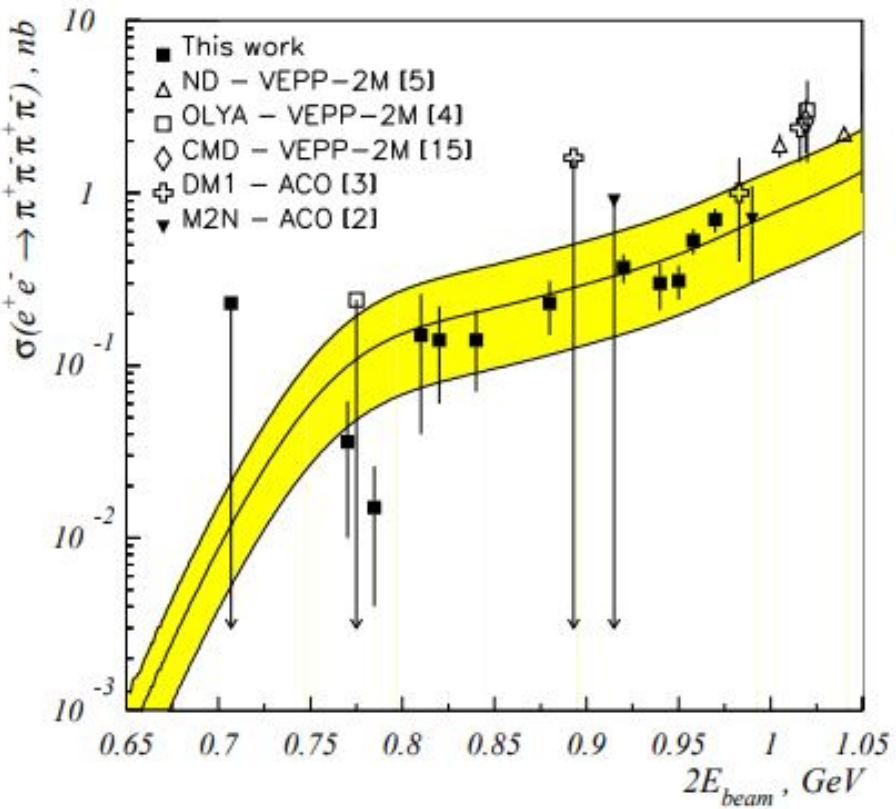
$L=8*10^{31}cm^{-2}c^{-1}$ at 2.0 GeV



Luminosity at
$\sqrt{(s)}$=660–1060 MeV

$L=84.7\ pb^{-1}$

Previous experiments



This work is CMD2(R.R. Akhmetshin et al. (CMD-2 Collab.), Phys. Lett. B **475**, 190 (2000).) 3000 nb^{-1}

Primary selection criteria $\pi^+\pi^-\pi^+\pi^-$

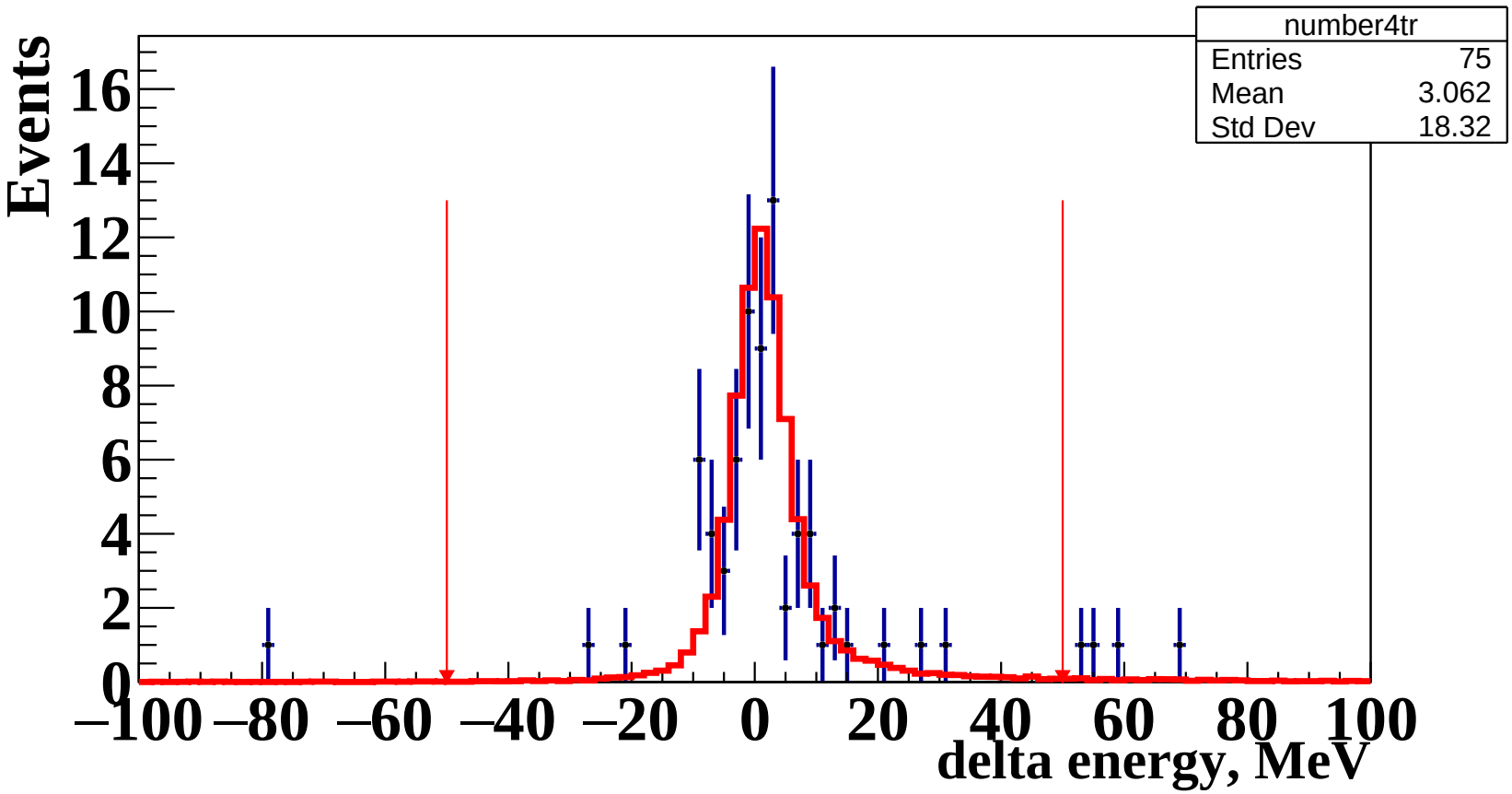
"Good" track:

- $\rho < 0.25$ cm; $|\mathrm{Z_{tr}}| < 12$ cm; $\mathrm{N_{hit}} > 5$; $\chi^2_{\mathrm{tr}} < 30$
  $\mathrm{p_i} < 1.5 * \mathrm{E_{beam}}$

Two class of events: 4 tracks and missing track events
Common selection criteria for 2 classes:

- Each track should correspond π according to e/π separation procedure
- ψ is angle between tracks: min $\psi_i > 0.2$; max $\psi_i < \pi - 0.2$
- θ is track polar angle: $0.7 < \theta_{\mathrm{i}} < \pi - 0.7$
- Event should not contain K_S particles

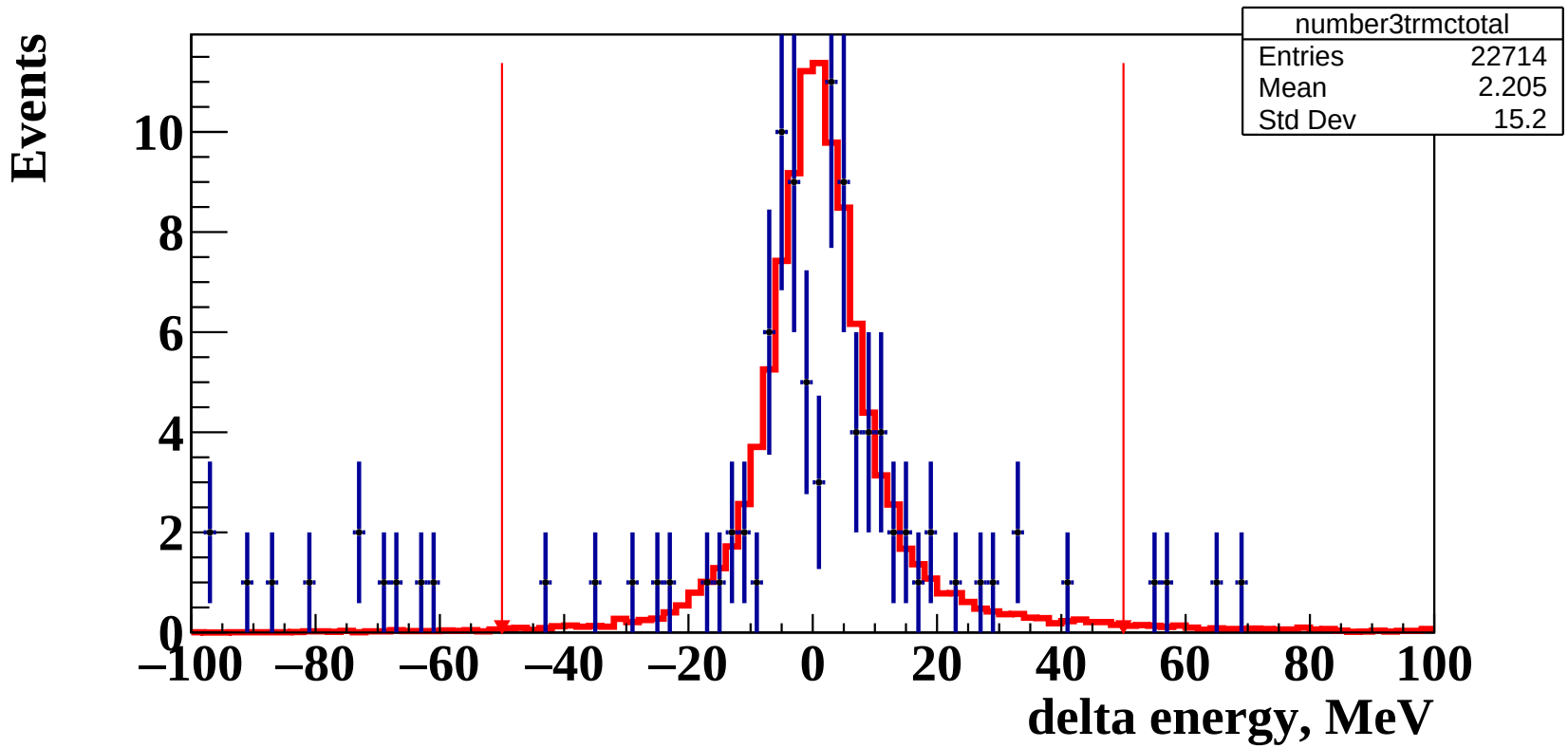
δE distribution in 4 track class



red for MC; black for EXP $\mathrm{E_{beam}} = 460$ MeV

$$50 > \delta \mathrm{E} = 2\mathrm{E_{beam}} - \sum_{\mathrm{i}=1}^{4} \sqrt{\mathrm{p_i^2} + \mathrm{m_\pi^2}} > -50 \text{ MeV}$$

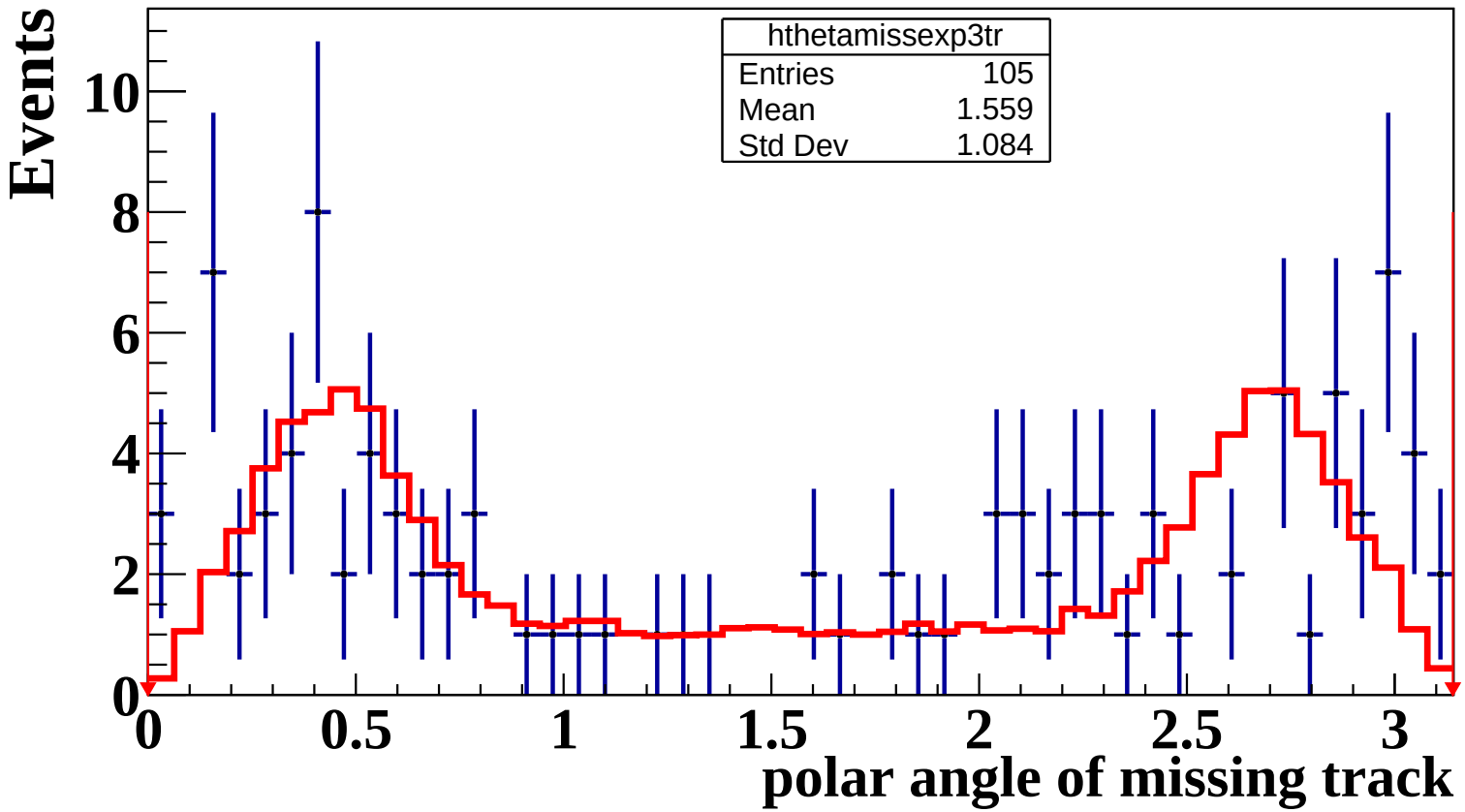
δE distribution in missing track class



red for MC; black for EXP $\mathrm{E_{beam}} = 460$ MeV

$$50 > \delta \mathrm{E} = 2\mathrm{E_{beam}} - \sum_{\mathrm{i}=1}^{3} \sqrt{\mathrm{p_i^2} + \mathrm{m_\pi^2}} - \sqrt{\mathrm{p_{miss}^2} + \mathrm{m_\pi^2}} > \text{-50 MeV}$$

Missing track polar angle



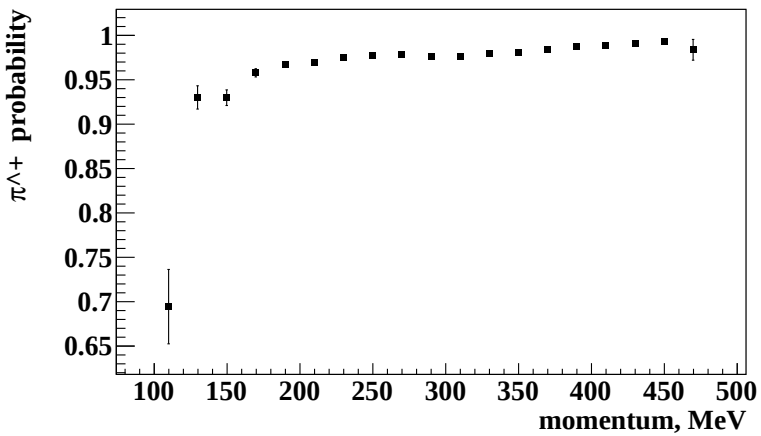
red for MC; black for EXP $\mathrm{E_{beam}} = 460$ MeV

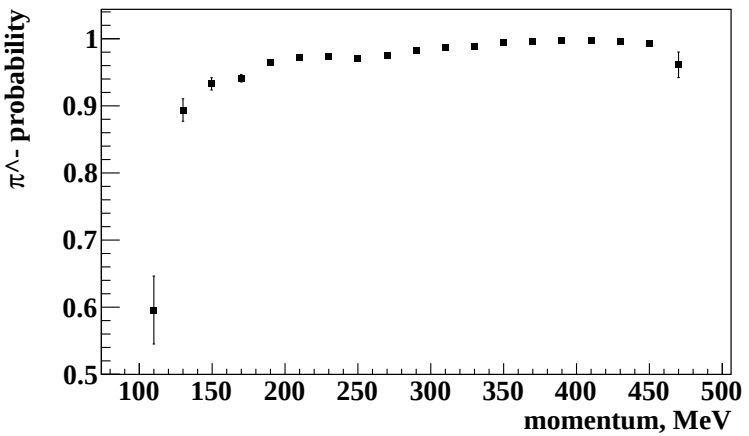
Background

- $e^+e^- \to \pi^+\pi^-\pi^0$, где $\pi^0 \to e^+e^-\gamma$
- $e^+e^- \to e^+e^-e^+e^-$
- $e^+e^- \to e^+e^-\gamma$
- Selected events in 4 track class: N_4=12758
- Selected events in missing track class: N_3=12245

$\pi^+\pi^-\pi^0$:PID π^+,π^- as π

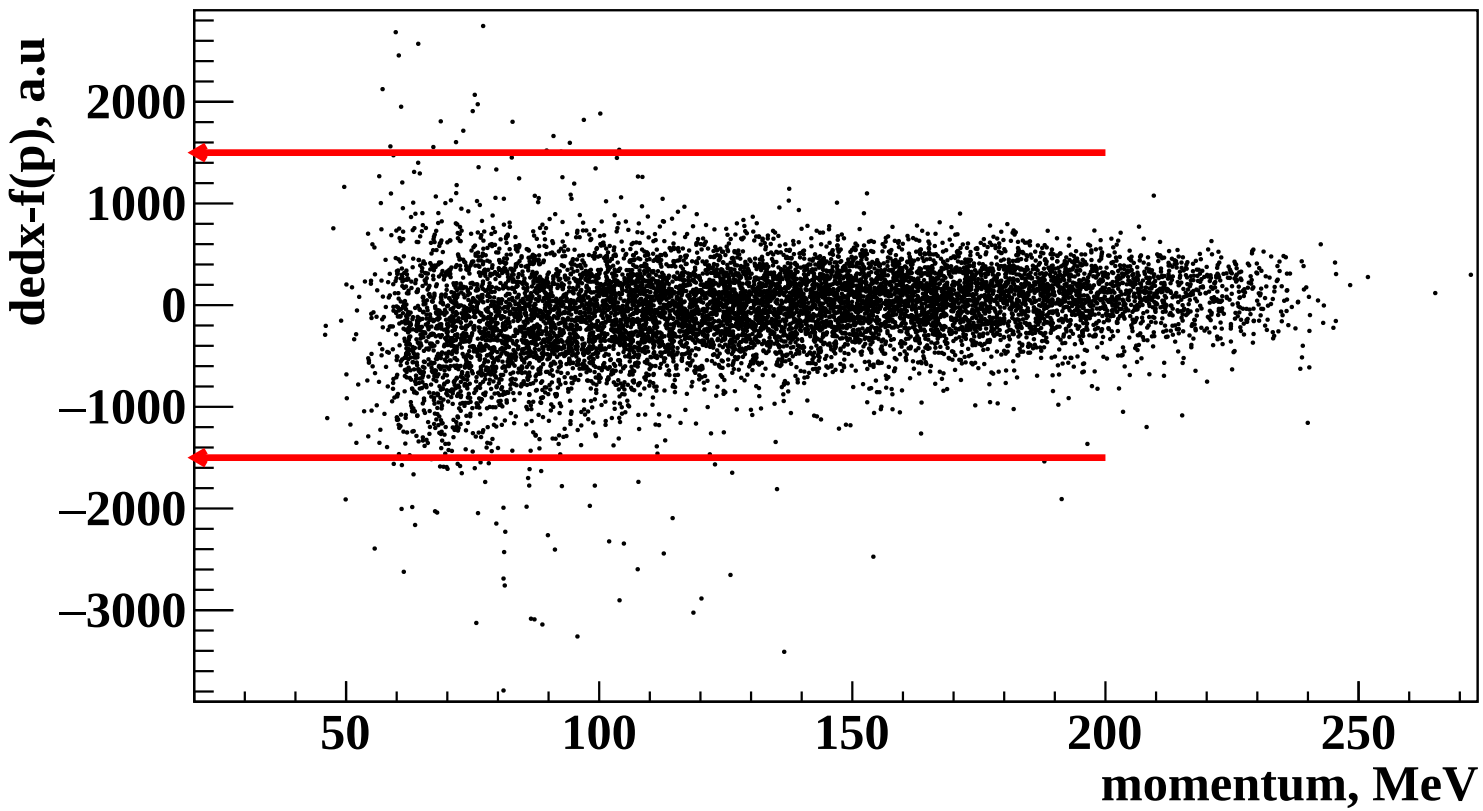
We selected pions from $e^+e^- \to \pi^+\pi^-\pi^0$ process; energy range 100-480 MeV/c, 19 bins; Probability is ratio between event number after this cut $\mathrm{E_{cal}} - 12/11 * \mathrm{p} + 70 < 0$ to all selected events. It is calculated for each bin



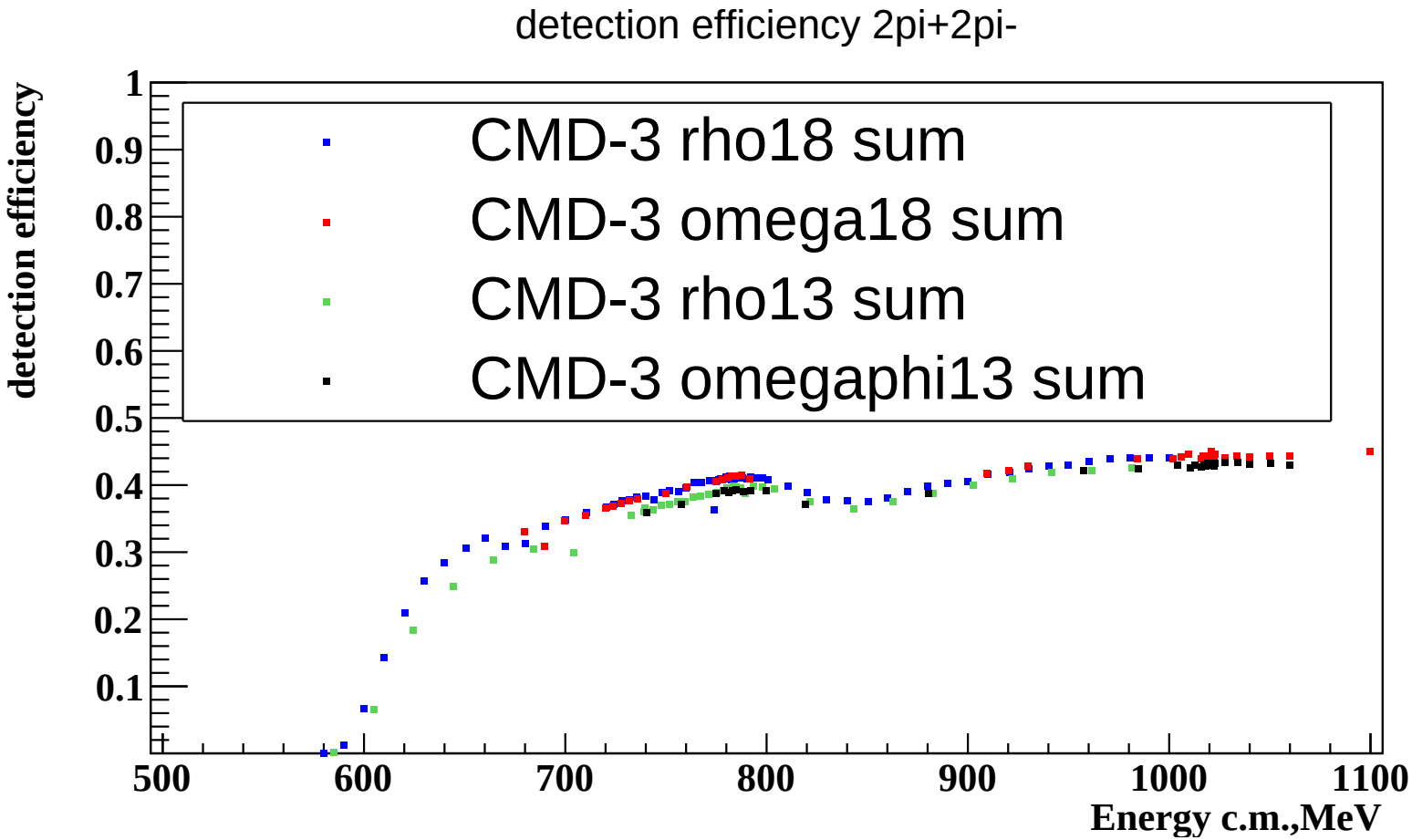


EXP:PID probability of π as π dependence on momentum. Left fig. for π^+ ; right fig. for π^-

Cut on $\frac{de}{dx}$ vs P if P<100 MeV



Detection efficiency of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ before corrections

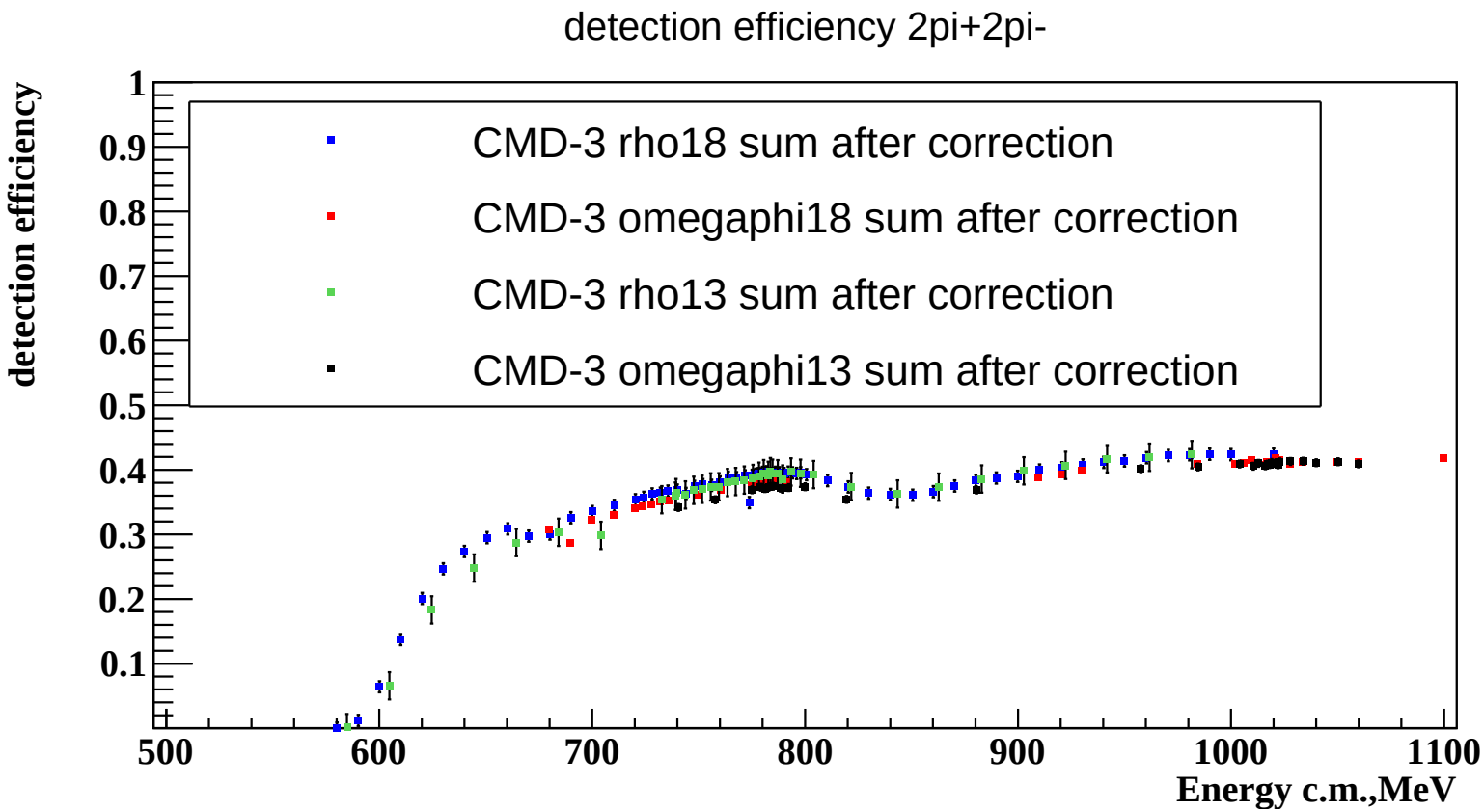


Detection efficiency dependence on c.m.s. energy.

Formula

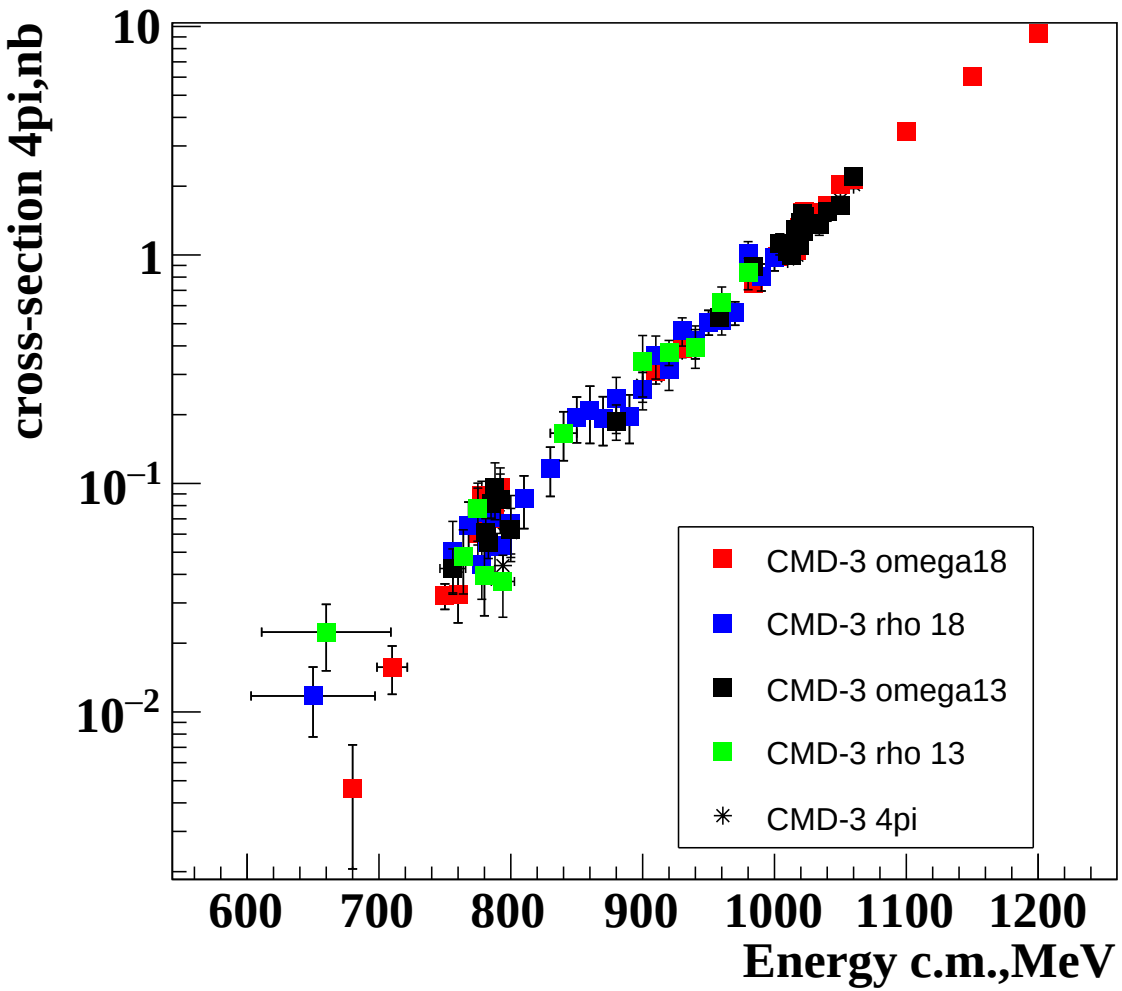
$$\sigma = \frac{N_3 + N_4}{L * (\epsilon_3 + \epsilon_4) * (1 + \delta_{dc}) * (1 + \delta_{outdc}) * (1 + \delta_{rad})}$$

Detection efficiency of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ after corrections



Detection efficiency dependence on c.m.s. energy.

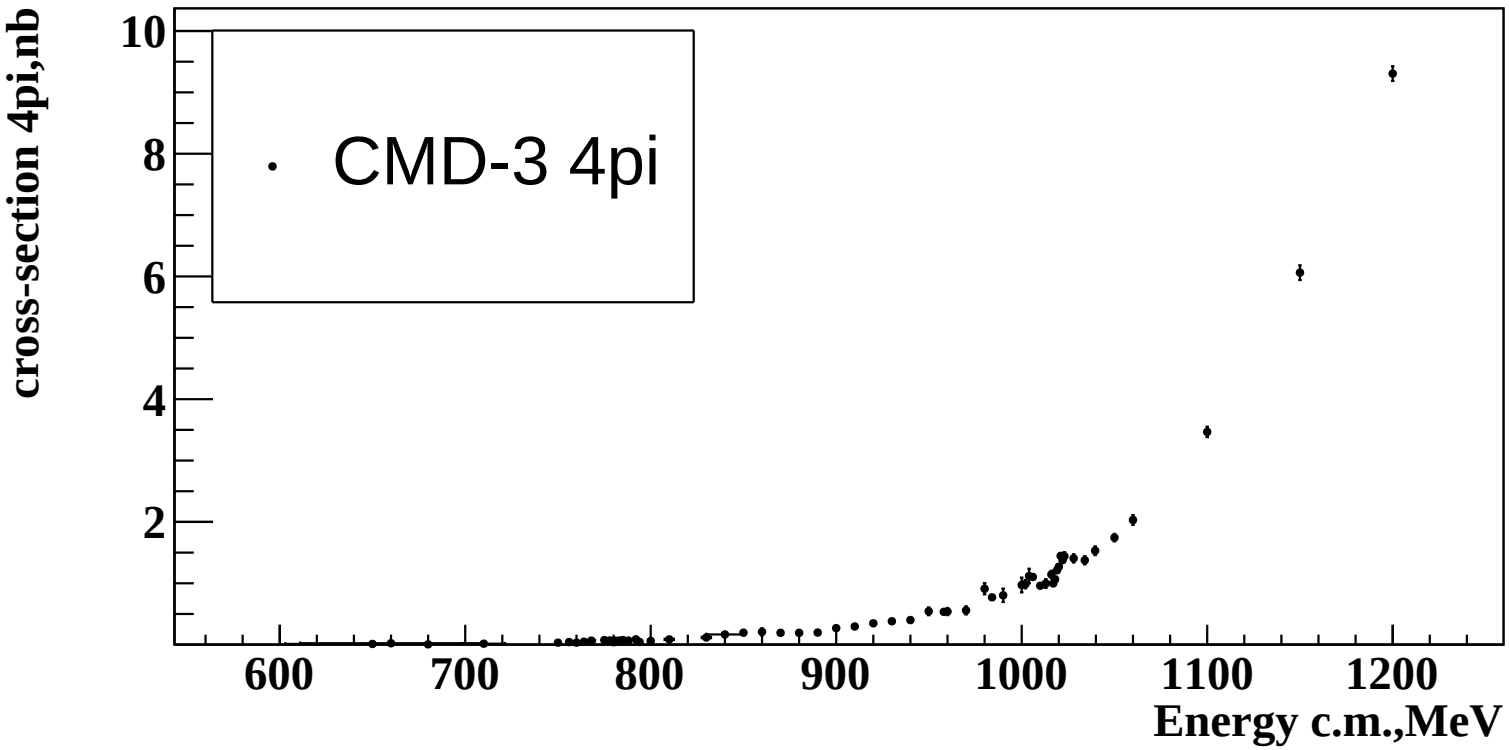
$e+e- \to \pi^+\pi^-\pi^+\pi^-$ cross-section: runs comparison



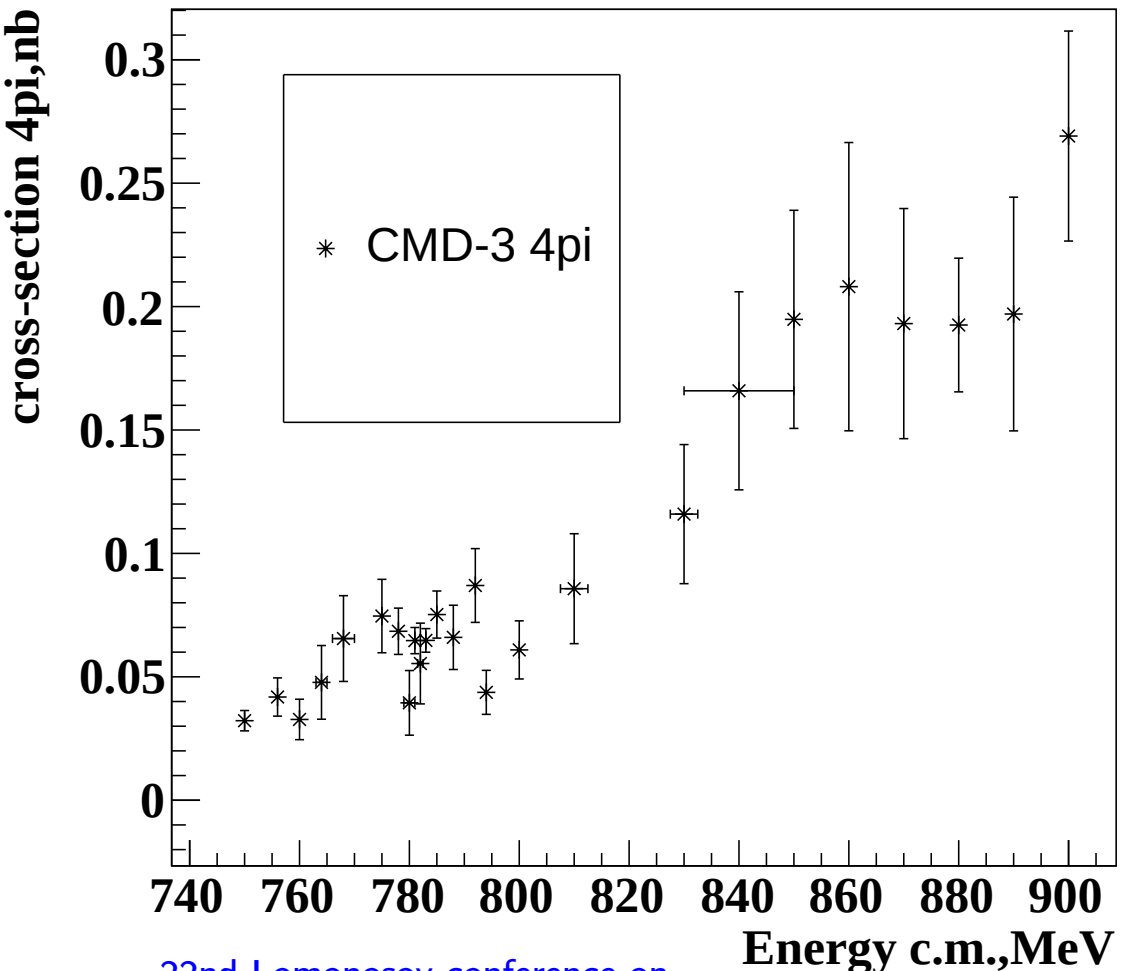
Preliminary:

$e + e- \to \pi^+\pi^-\pi^+\pi^-$ cross-section: linear scale

Preliminary:



$e + e- \to \pi^+\pi^-\pi^+\pi^-$ cross-section: ω meson energy range



Preliminary:

Fit Formula and results

$\sigma(\mathrm{E_{c.m.}}) = \sigma_0 \mathrm{f}(\mathrm{E_{c.m.}})|1 - \xi \frac{\mathrm{m_\phi} * \gamma_\phi}{\mathrm{m_\phi^2} - \mathrm{E_{c.m.}^2} - \mathrm{i E_{c.m.}} \gamma_\phi}|^2$, where σ_0 is a non-resonant cross-section at ϕ resonance mass $\mathrm{m_\phi}$=1019.456 MeV/c^2 with γ_ϕ=4.24 MeV; $\mathrm{f}(\mathrm{E_{c.m.}}) = \mathrm{e}^{\mathrm{B}(\mathrm{E_{c.m.}} - \mathrm{m_\phi})}$, B is slope parameter describes of the energy dependence of the non-resonant cross-section, and ξ is a complex amplitude of the $\phi(1020) \to \pi^+\pi^-\pi^+\pi^-$ transition

Fit results:

$\sigma_0 = 1.242 \pm 0.016$ nb

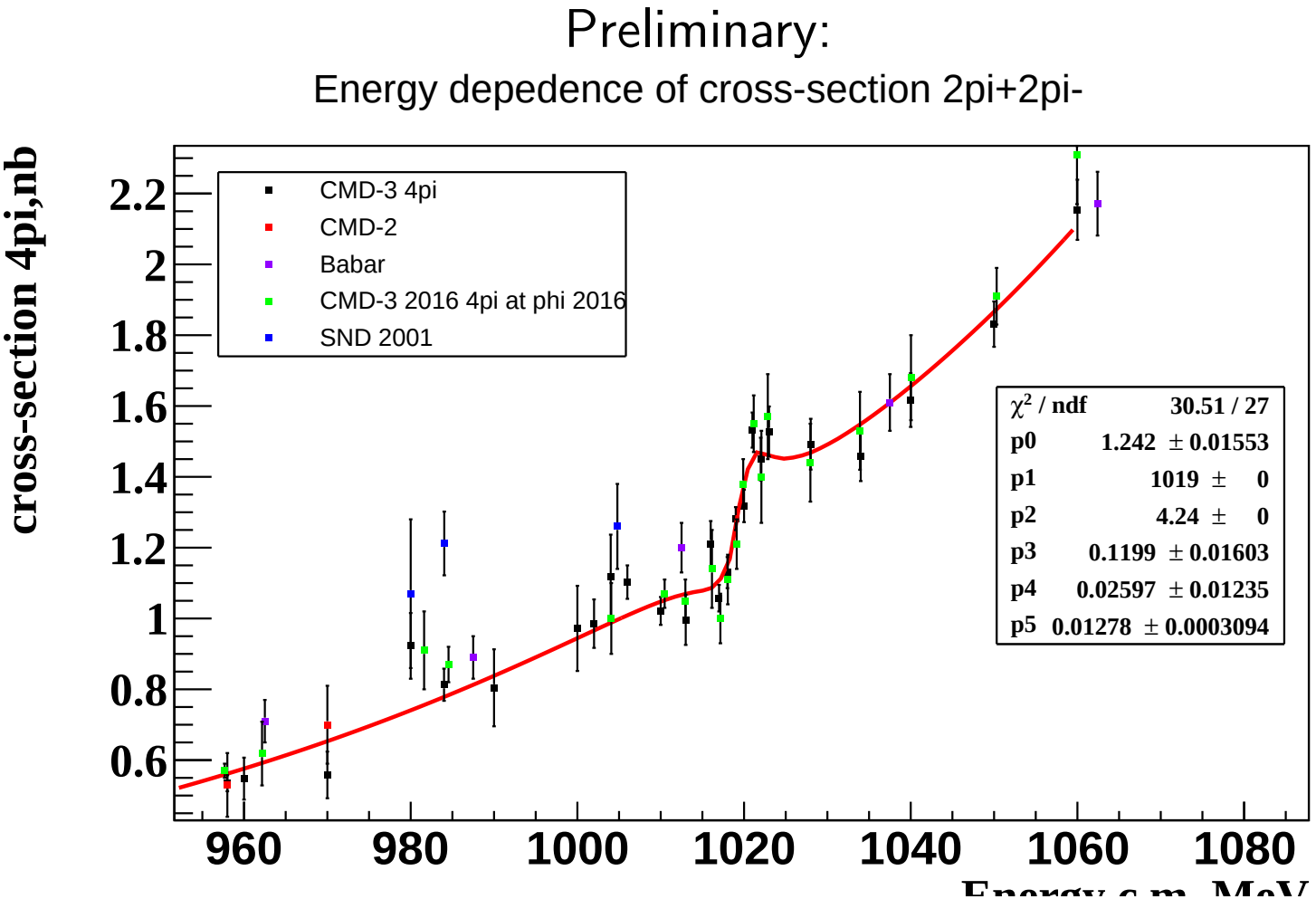
Re $\xi = 0.120 \pm 0.016$

Im $\xi = 0.026 \pm 0.012$

Preliminary:

$$\mathrm{B}(\phi \to \pi^+\pi^-\pi^+\pi^-) = (4.5 \pm 1.3) * 10^{-6}$$

$e + e- \to \pi^+\pi^-\pi^+\pi^-$ cross-section: ϕ meson energy range



Conclusion

- Preliminary result of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ cross-section measurement at c.m.s. energy below 1.060 GeV is obtained
- Selection criteria for background suppression are developed
- Preliminary result of $\mathrm{B}(\phi \to \pi^+\pi^-\pi^+\pi^-) = (4.5 \pm 1.3) * 10^{-6}$ is obtained and agrees with PDG data $(3.9^{+2.8}_{-2.2}) * 10^{-6}$ and with previous CMD-3 measurement: $(6.5 \pm 2.7 \pm 1.6) * 10^{-6}$
- e/π separation procedure is developed
- Detection efficiency corrections are calculated
- Systematic uncertainty study is in progress

Backup

Selection criteria

Criteria for 4 track class:

- Events with 4 "good" tracks, $\sum_{i=1}^{4} q_i = 0$, where q_i track charge
- $50 > 2\mathrm{E}_{\mathrm{beam}} - \sum_{\mathrm{i}=1}^{4} \sqrt{\mathrm{p}_{\mathrm{i}}^2 + \mathrm{m}_{\pi}^2} > -50$ MeV

Criteria for missing track class:

- Events with 3 "good" tracks, $|\sum_{i=1}^{3} q_i| = 1$, where q_i track charge
- $50 > 2\mathrm{E}_{\mathrm{beam}} - \sum_{\mathrm{i}=1}^{3} \sqrt{\mathrm{p}_{\mathrm{i}}^2 + \mathrm{m}_{\pi}^2} - \sqrt{\mathrm{p}_{\mathrm{miss}}^2 + \mathrm{m}_{\pi}^2} >$-50 MeV, where p_{miss} missing track momentum
- min $(P_{beam} - P_+ - P_-)^{\mu}(P_{beam} - P_+ - P_-)_{\mu} > 50000$ MeV^2

e/π separation

EXP:

Particle is a pion if:

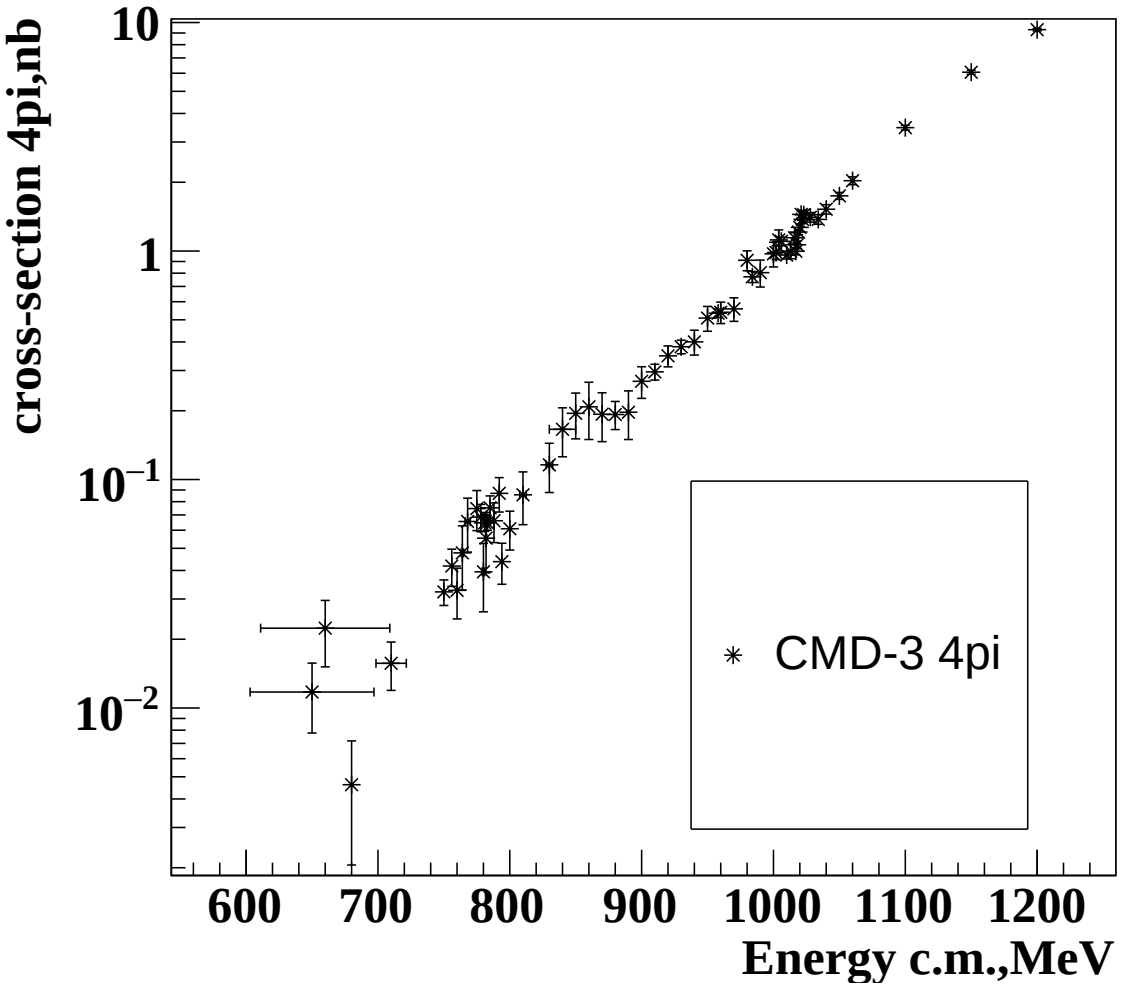
- $p < 100$ MeV/c and $|f(p) - \frac{dE}{dx}| < 1500$, where $f(p) = \frac{5.58*10^9}{(p+40)^3} + 2.21 * 10^3 - 3.77 * 10^{-1} * p$
- $p > 100$ MeV/c and $\mathrm{E_{cal}} - 12/11 * \mathrm{p} + 70 < 0$

MC:

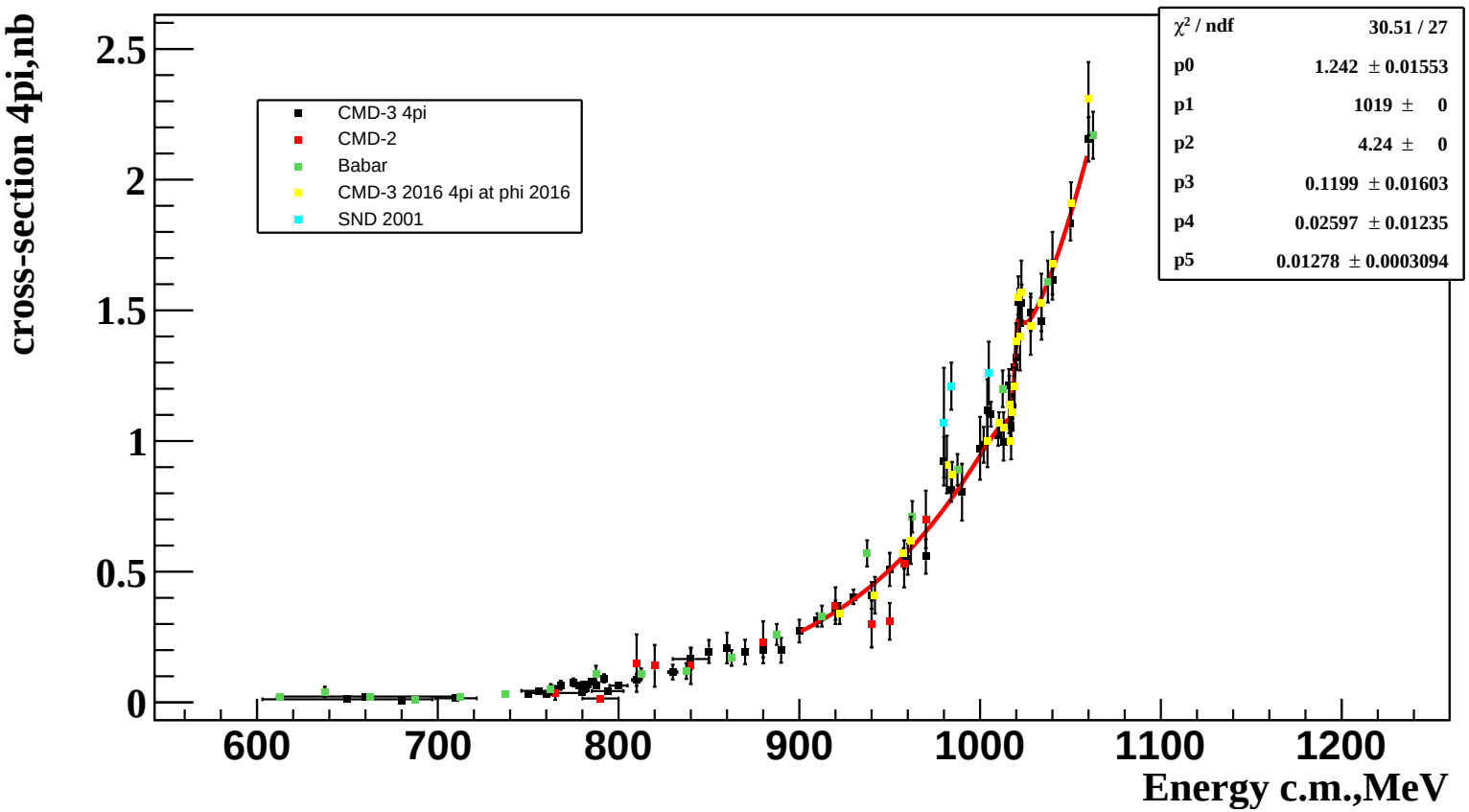
Particle is a pion if

- $p < 100$ MeV/c and $|f(p) - \frac{dE}{dx}| < 1500$, where $f(p) = \frac{5.58*10^9}{(p+40)^3} + 2.21 * 10^3 - 3.77 * 10^{-1} * p$
- $p > 100$ MeV/c We do not use MC energy deposition distribution. We use PID probability dependence from previous slide

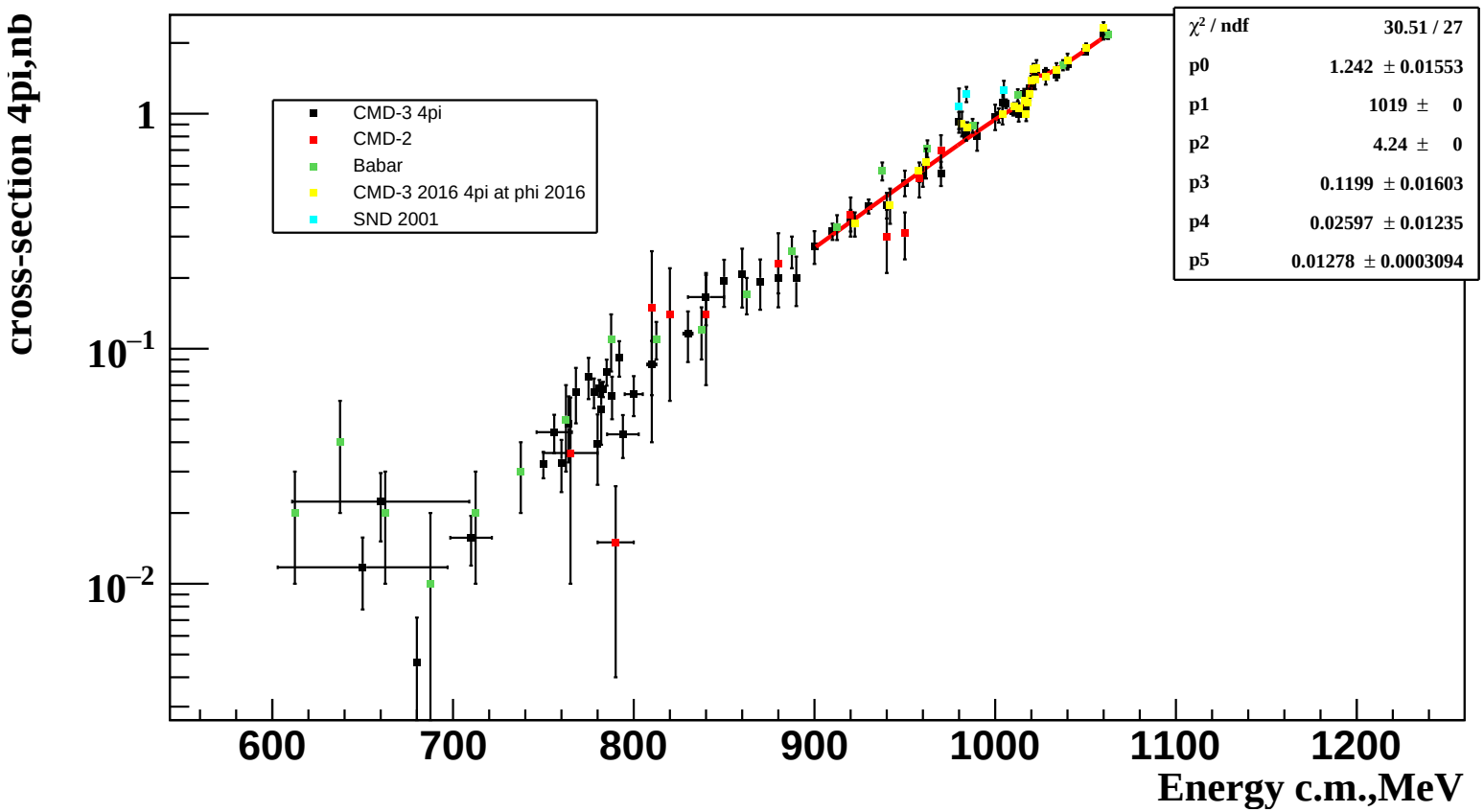
$e + e- \to \pi^+\pi^-\pi^+\pi^-$ cross-section: log. scale



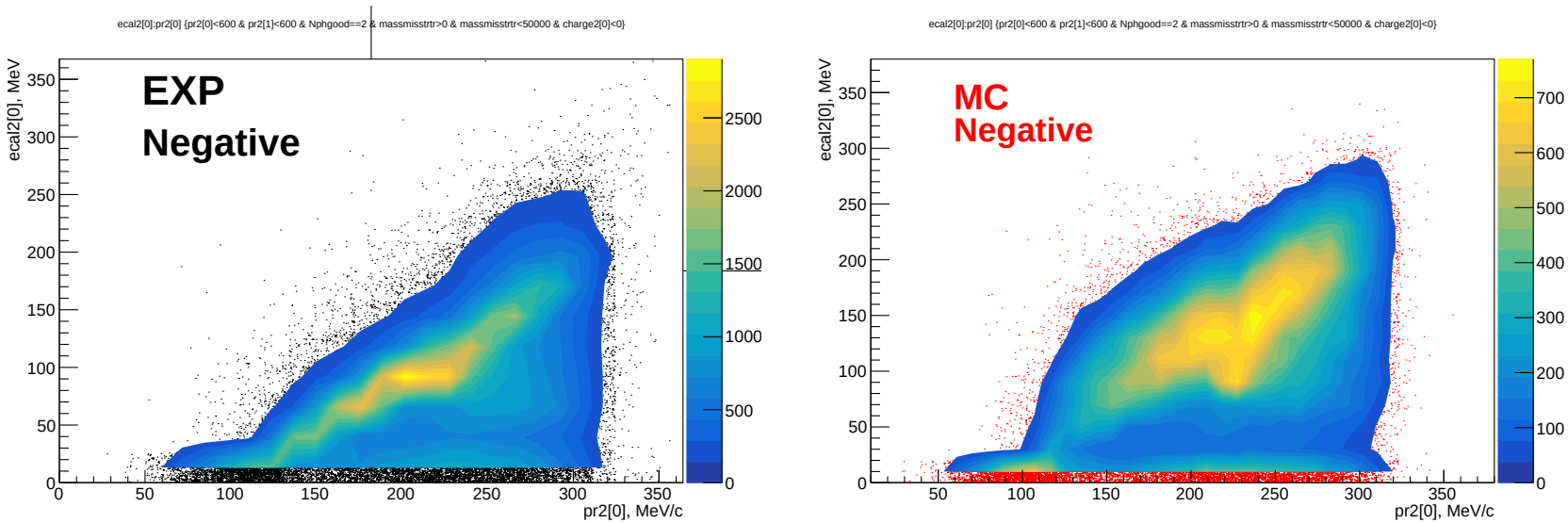
$e + e- \to \pi^+\pi^-\pi^+\pi^-$ cross-section: fit



$e + e- \to \pi^+\pi^-\pi^+\pi^-$ cross-section: fit

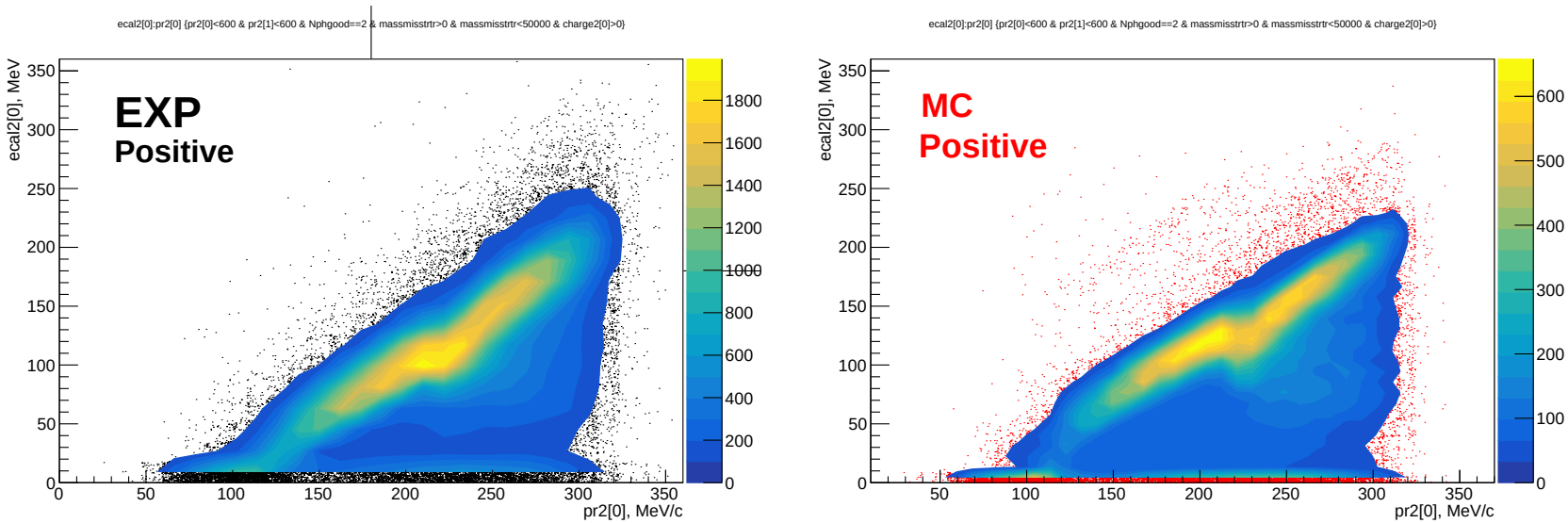


$\pi^+\pi^-\pi^0$: $E_{\rm cal}$ для π^- в EXP&MC



$E_{\rm cal}$ vs p при 2E=782 МэВ Слева: EXP; Справа: MC

$\pi^+\pi^-\pi^0$: $E_{\rm cal}$ для π^+ в EXP&MC



$E_{\rm cal}$ vs p при 2E=782 МэВ Слева: EXP; Справа: MC

Данные о светимости

Таблица: Data

Сезон	Год	$\sqrt{s}$, МэВ	$\int Ldt$, нб$^{-1}$
rho2013	2013	560-980	5000
omegaphi2013	2013	740-1060	18200
rho2018	2018	560-1020	12400
omegaphi2018	2018	680-1060	49200

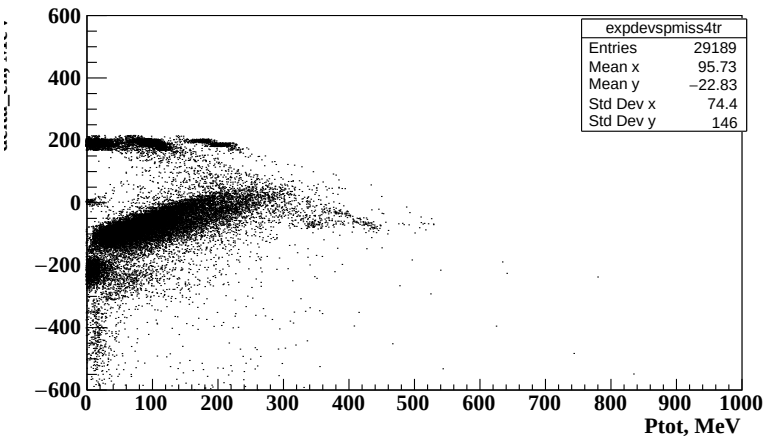
Формулы 3/4

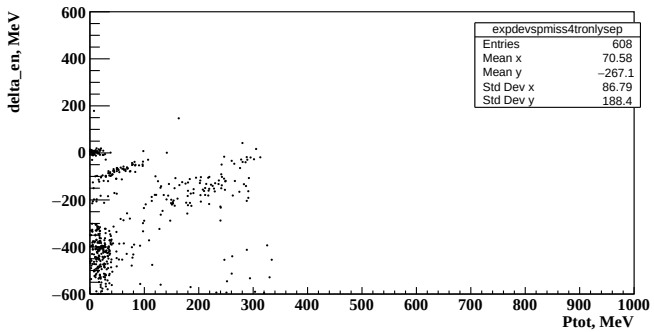
- $R_{34} = \frac{N_{3dc}+N_{3outdc}}{N_4}$; $R_{dc} = \frac{N_{3dc}}{N_4}$;$R_{outdc} = \frac{N_{3outdc}}{N_4+N_{3dc}}$
- $$\epsilon_{dc} = \frac{1}{1 + R_{dc}/4}$$
- $$\epsilon_{outdc} = \frac{1}{1 + R_{outdc}/4}$$
- $$1 + \delta_{dc} = \frac{\epsilon^4_{expdc} + 4 * \epsilon^3_{expdc} * (1 - \epsilon_{expdc})}{\epsilon^4_{MCdc} + 4 * \epsilon^3_{MCdc} * (1 - \epsilon_{MCdc})}$$

Немного об идентификации

Для идентификации трека мы используем ионизационные потери в дрейфовой камере и энерговыделение в калориметре, привязанное к треку. Распределения по ионизационным потерям согласуются в эксперименте и моделировании. Но при одинаковых импульсах энерговыделение в калориметре не совпадает с экспериментом. Поэтому мы решили использовать зависимость энерговыделения от импульса из эксперимента $e^+e^- \to \pi^+\pi^-\pi^0$.

Польза e/π разделения 2E=785 МэВ





Слева до разделения Справа после