Fedor V. Ignatov

New Data on $e^+e^- \to \pi^+\pi^-$ cross section with CMD-2 in energy range $\sqrt{s}$=0.37 - 1.38 GeV

Collaboration CMD-2

The Budker Institute of Nuclear Physics
Novosibirsk, Russia

e-mail: ignatov@inp.nsk.su

Why is it interesting?

- π meson internal structure
- physics of ρ, ρ', ρ'' resonances
- major contribution to hadronic part of the vacuum polarization (muon anomalous magnetic moment $a_\mu = (g-2)/2$)

$$a_\mu^{had,1} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} \frac{R(s)K(s)}{s^2} ds \qquad R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

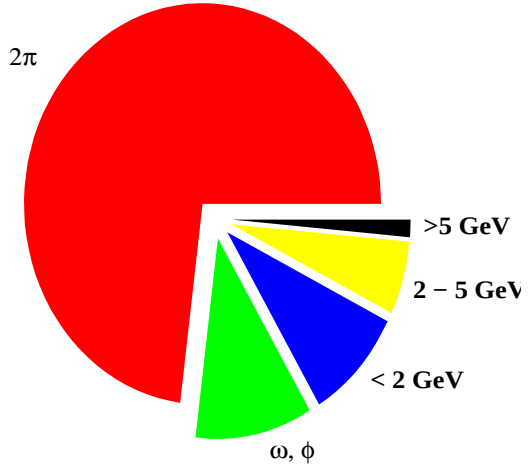
About 91% of the total contribution to a_μ^{had} comes from $\sqrt{s} < 1.8$ GeV

73% to a_μ^{had} comes from two pion final state

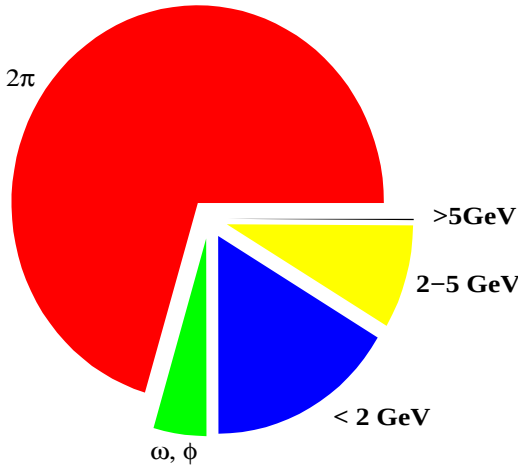
$$a_\mu^{theory} = a_\mu^{QED} + a_\mu^{had} + a_\mu^{weak}$$

a_μ^{SM}	11 659 180.9	$\pm$	8.0
a_μ^{QED}	11 658 470.6	$\pm$	0.3
$a_\mu^{had,1}$	696.3	$\pm$	7.2
$a_\mu^{had,2}$	-10.0	$\pm$	0.6
$a_\mu^{had,lbl}$	8.6	$\pm$	3.5
a_μ^{weak}	15.4	$\pm$	0.2
		10^{-10}	

contribution to a_μ^{had}

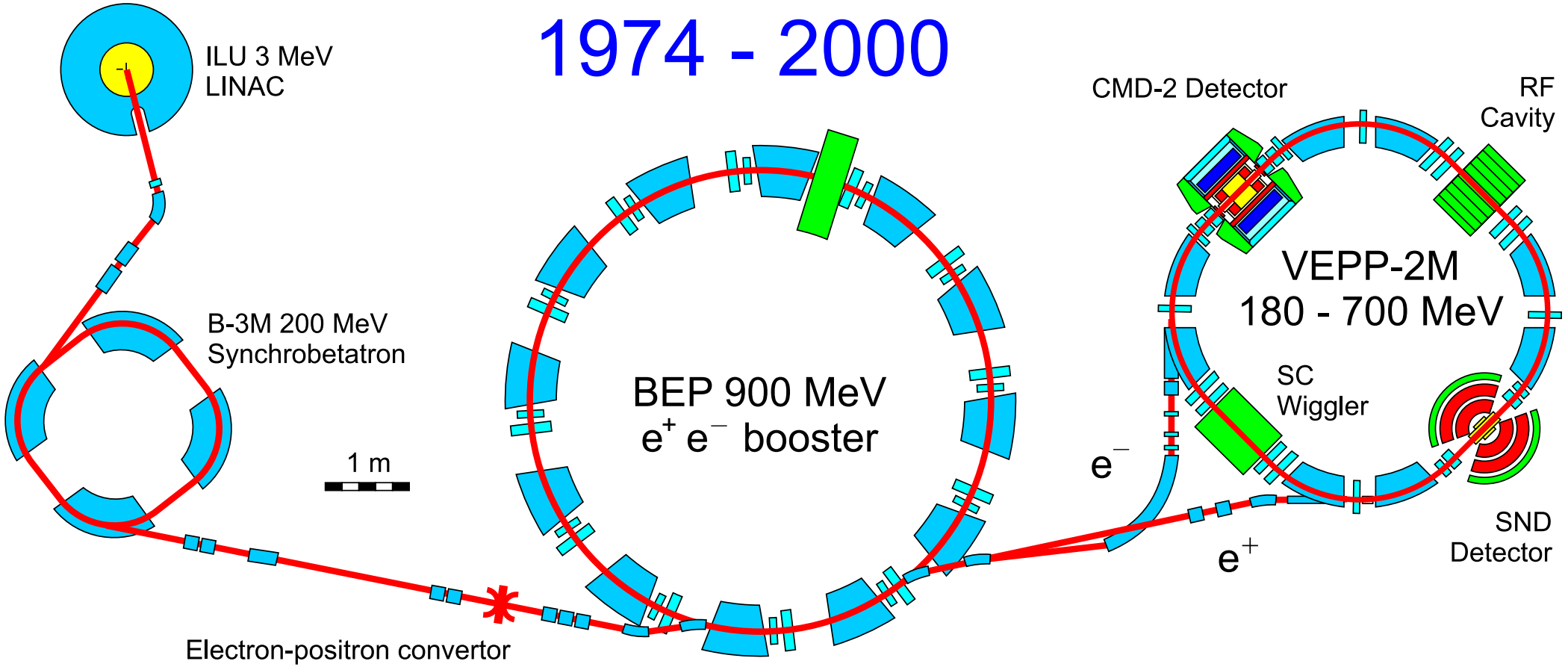


contribution to error of a_μ^{had}



VEPP-2M Collider

Beam Energy 180-700 MeV



With $L_{peak} \approx 3 \cdot 10^{30} cm^{-2} sec^{-1}$

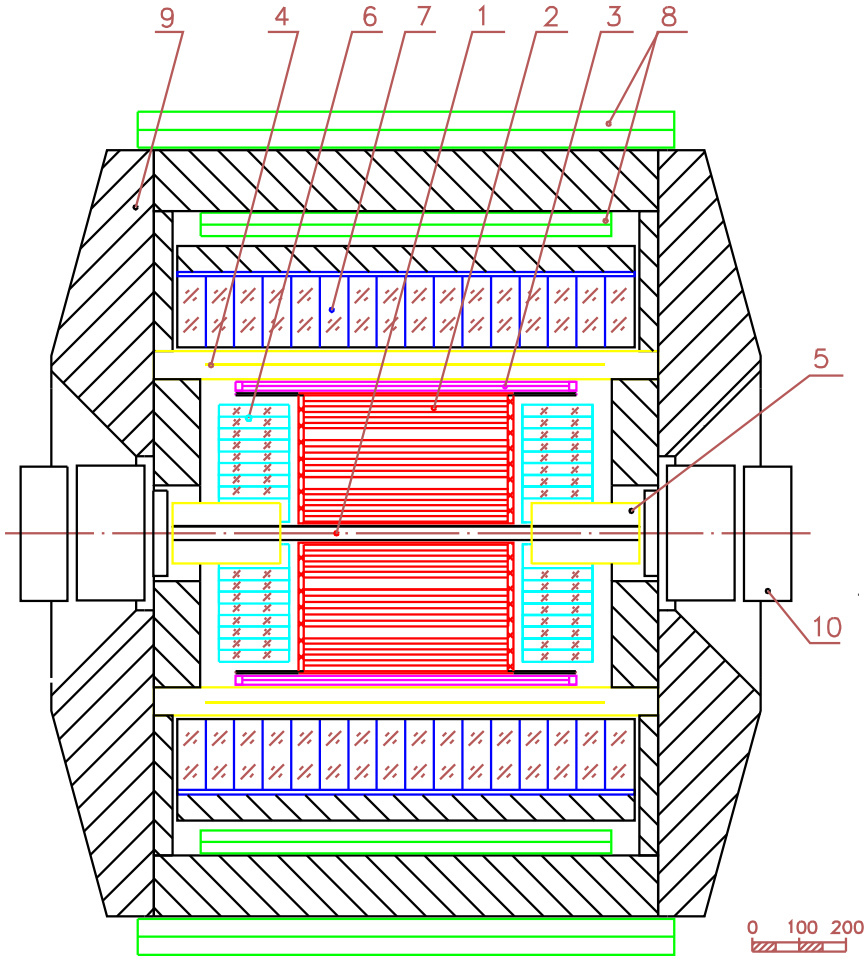
Time between collisions 60 ns

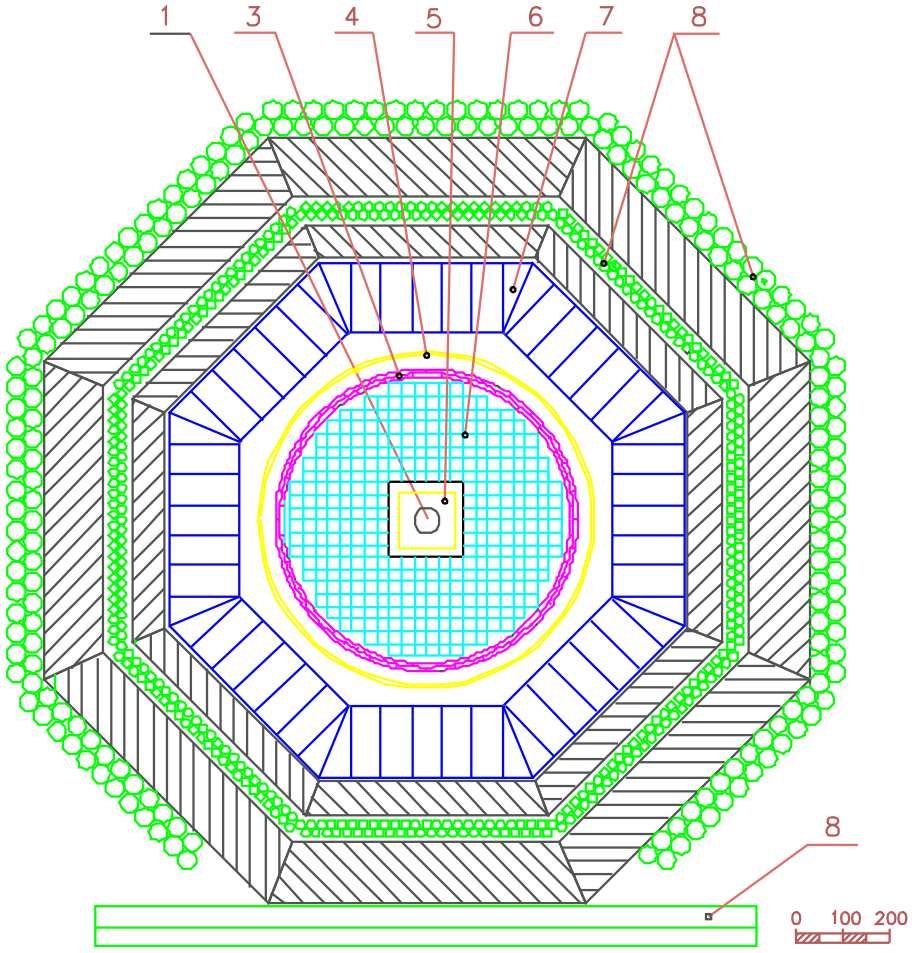
Circumference 18 m

Beam current 50 mA

CMD-2 detector (1992-2000)

Cryogenic Magnetic Detector

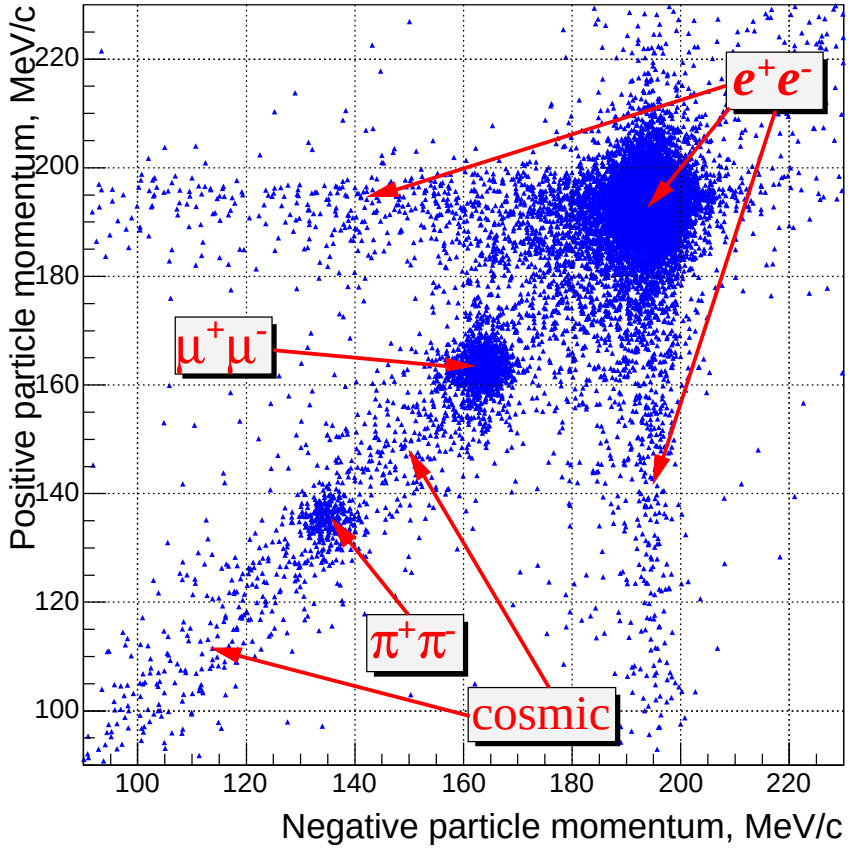




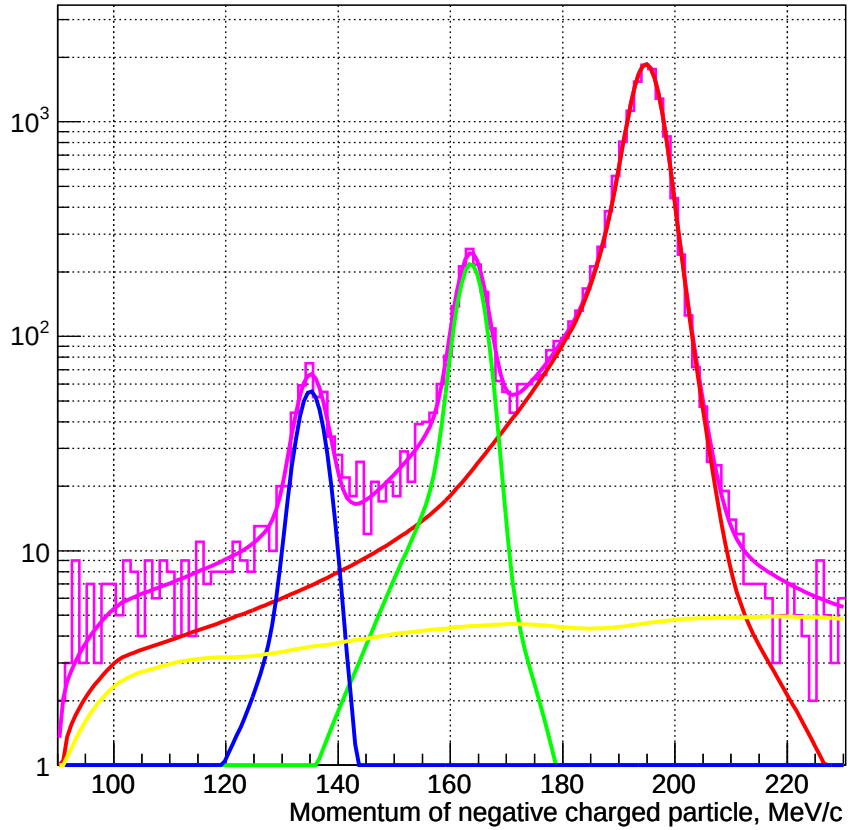
1 — beam pipe, 2 — drift chamber, 3 — Z-chamber, 4 — superconductive solenoid, 5 — focusing solenoid 6 — BGO endcap calorimeter, 7 — CsI barrel calorimeter, 8 — muon system, 9 — magnet yoke, 10 — quadrupole lenses.

Momentum distribution for particle separation is used at $\sqrt{s} < 0.6\text{GeV}$

Momentum scatter plot

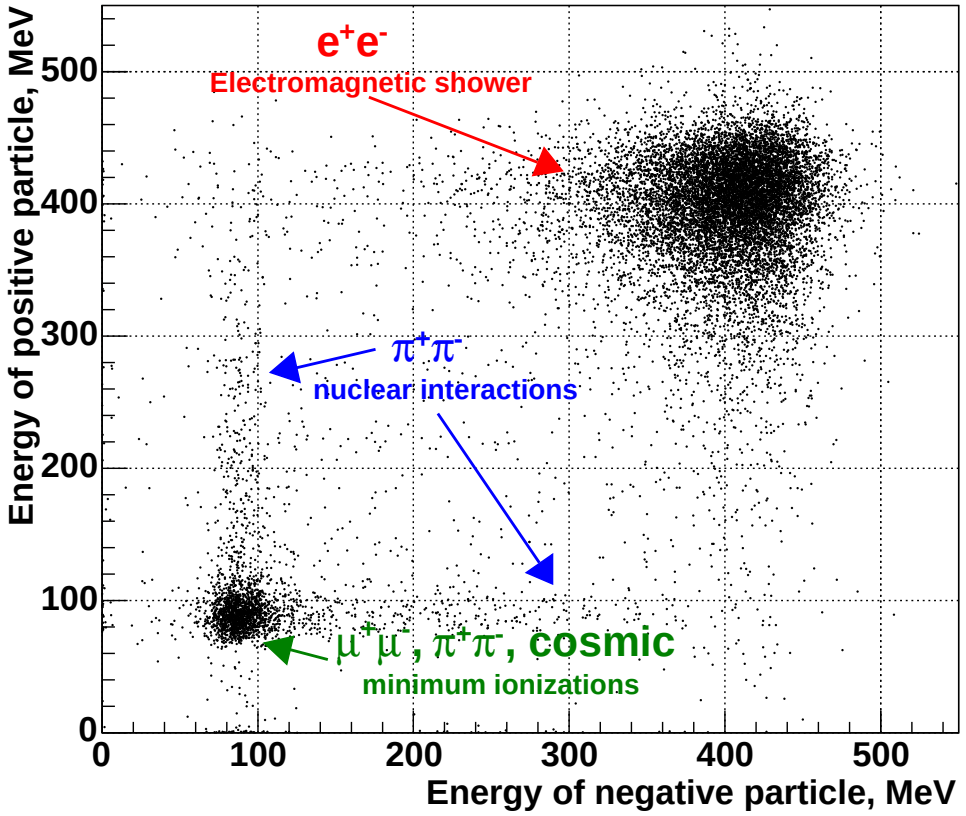


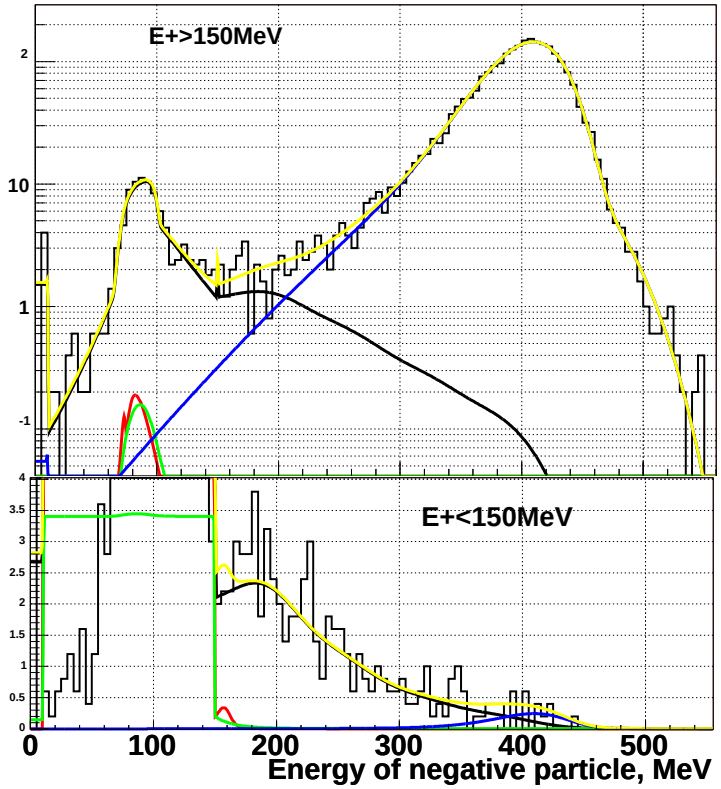
Negative momentum projection



$$\mathcal{L} = -\sum_{events} \ln\left(\sum_{e,\mu,\pi,bg} \omega_{type} \cdot f_{type}(P^+, P^-)\right), \qquad \sum_{type} \omega_{type} = 1$$

Energy deposition in CsI calorimeter for particle separation is used at $\sqrt{s} > 0.6$GeV



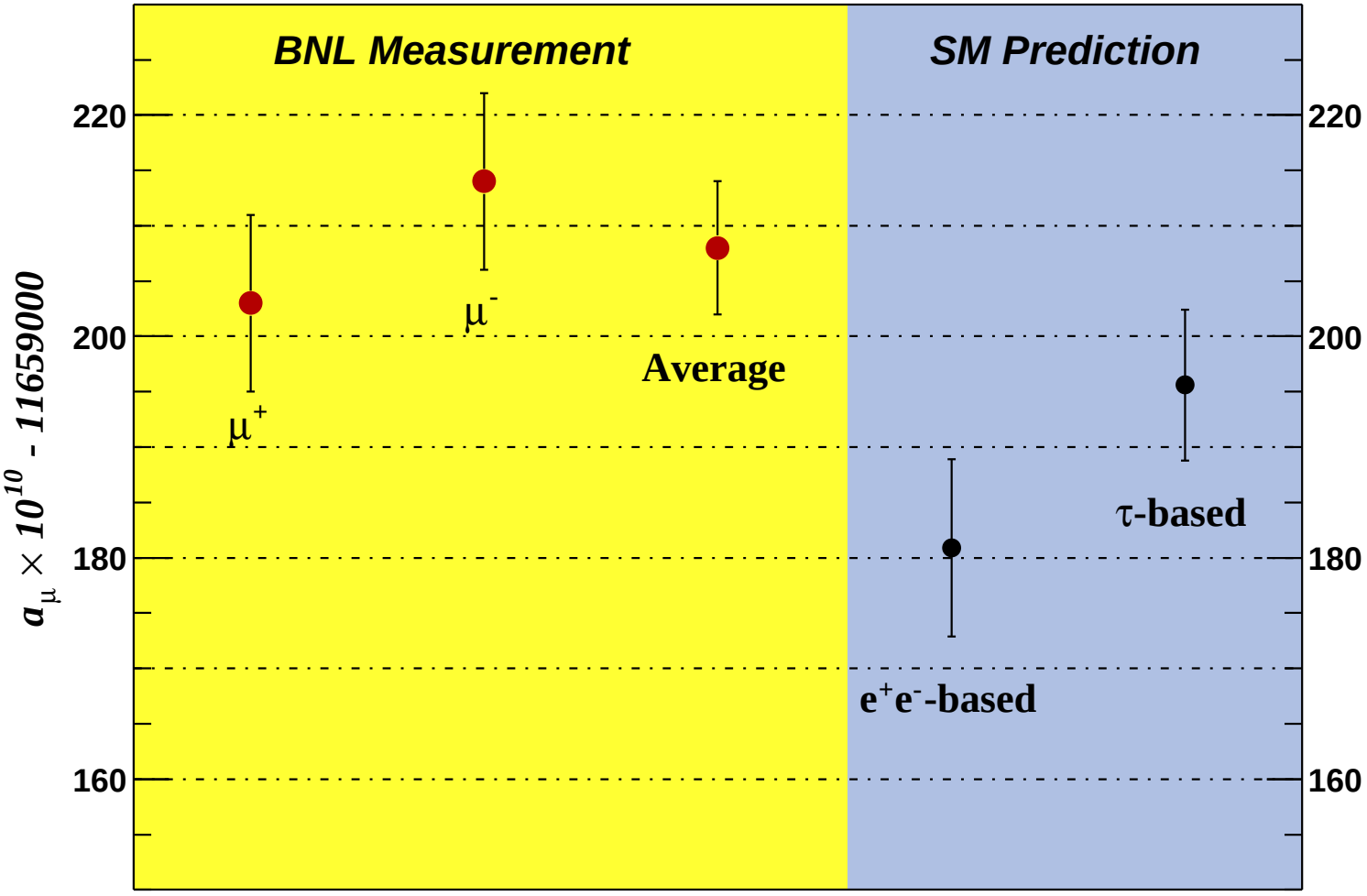


$$\frac{N_\mu}{N_e+1} = \frac{\sigma^B_{ee\to\mu\mu}\cdot(1+\delta_\mu)\cdot\epsilon_\mu}{\sigma^B_{ee\to ee}\cdot(1+\delta_e)\cdot\epsilon_e}$$ fixed from QED

Number of cosmic events from distribution of vertex position

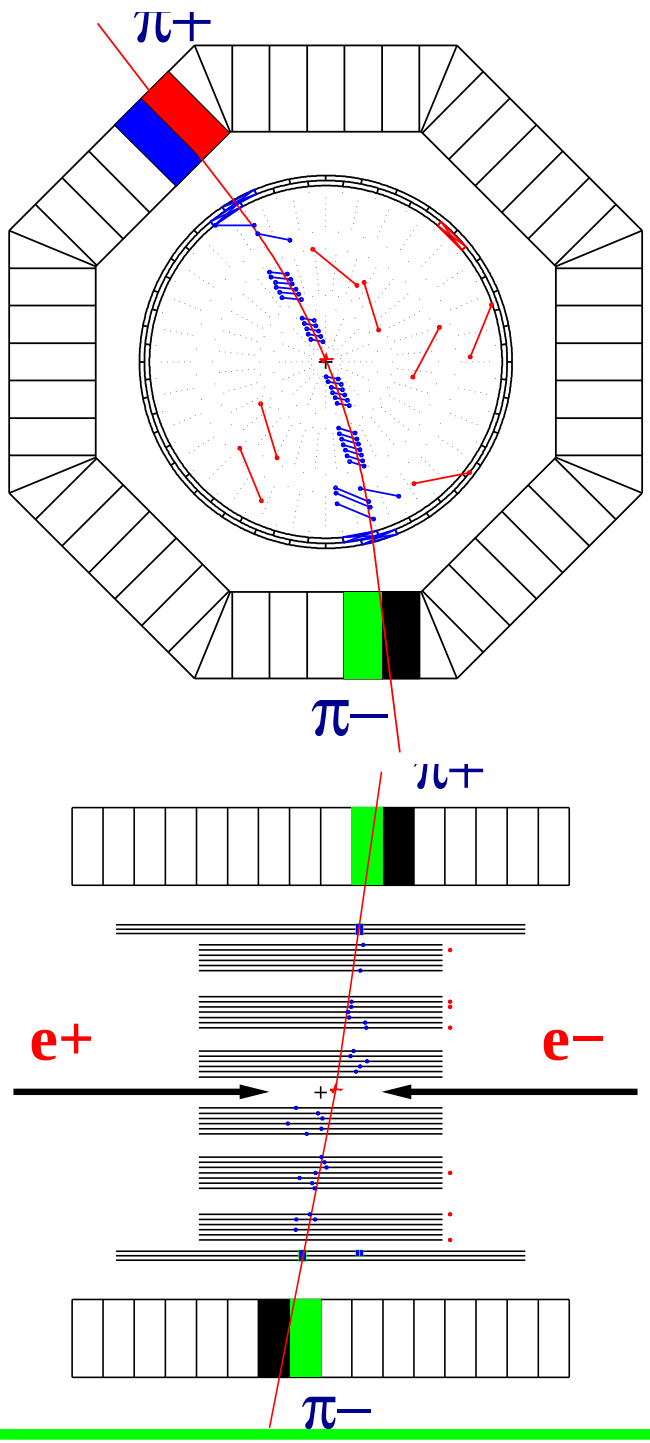
$$\mathcal{L} = -\sum_{events} \ln\left(\sum_{e,\mu,\pi,bg} N_{type}\cdot f_{type}(E^+,E^-)\right) + \sum_{e,\mu,\pi,bg} N_{type}$$

Anomalous Magnetic Moment ($a_\mu = (g_\mu - 2)/2$) results



$$a_\mu(Exp) - a_\mu(Theory, e^+e^-) = (27.1 \pm 10.0) \cdot 10^{-10}\ (2.7\sigma)$$

DEHZ'02 M.Davier, S.Eidelman, A.Hocker, Z.Zhang, hep-ph/0208177,hep-ph/0308213

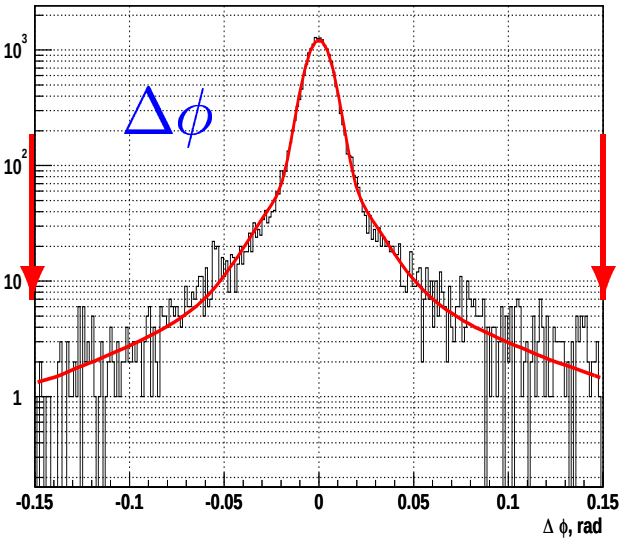


Collinear Event selection

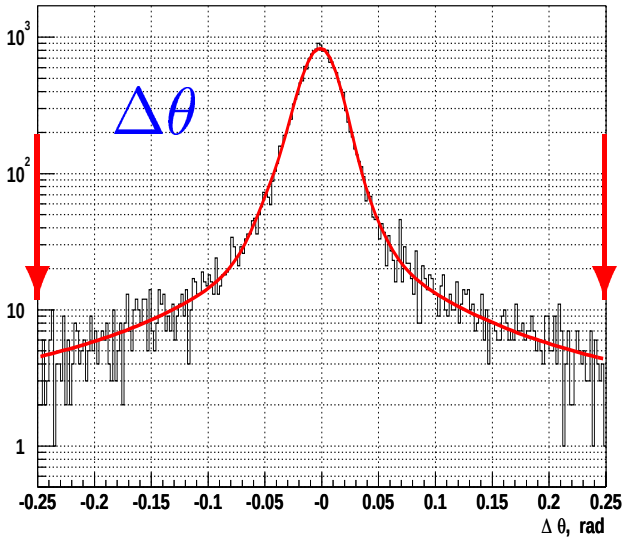
1. One vertex with two tracks,
   $Q_1 + Q_2 = 0$
2. Vertex position:
   $\rho_{vtx} < 0.15$ cm , $|Z_{vtx}| < 10$ cm
3. Tracks collinearity:
   $|\Delta\phi| < 0.15$, $|\Delta\theta| < 0.25$
4. Minimum Average Momentum:
   $(p^+ + p^-)/2$ >90 MeV/c at $\sqrt{s} < 0.6$ GeV
   >200 MeV/c at ρ-region
   And for Charge Kaons Rejection at $\sqrt{s} > 1$ GeV:
   $>\max(1.3 \cdot P_K, 325)$MeV/c
5. Average polar angle:
   $1.1 < (\pi + \theta^- - \theta^+)/2 < \pi - 1.1$

Collinear Event selection

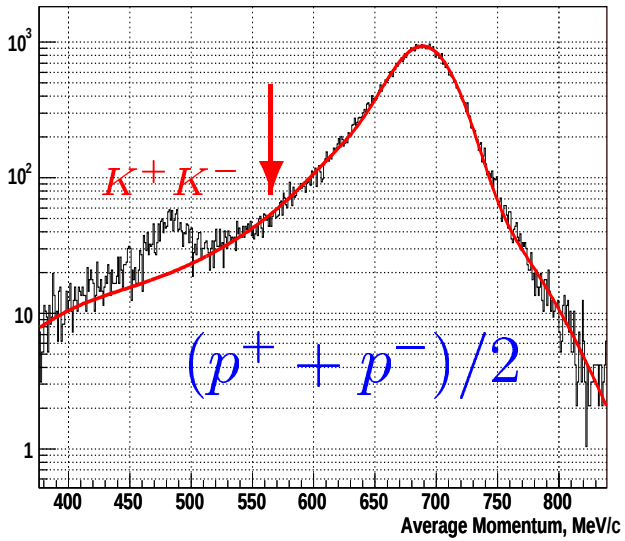
Phi resolution



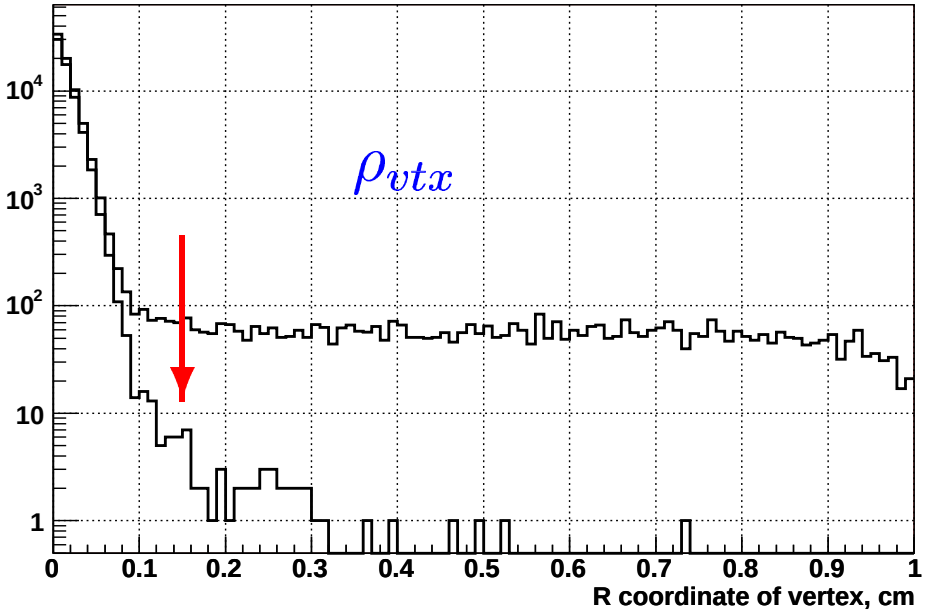
Theta resolution



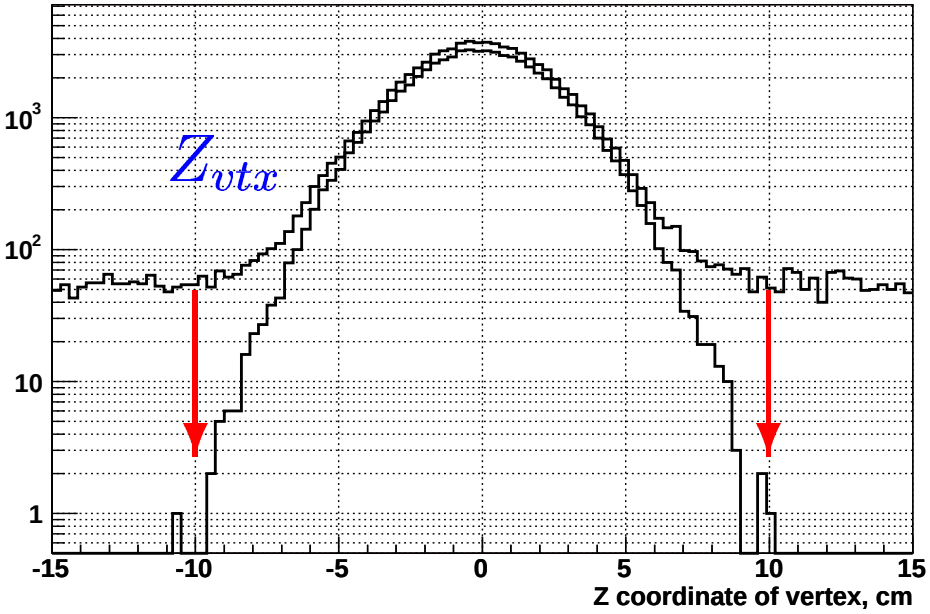
Momentum resolution



Distance to beam



Distance to beam



Formfactor Calculation

$$|F_\pi|^2 = \frac{N_{\pi\pi}}{N_{ee}+N_{\mu\mu}} \cdot \frac{\sigma^B_{ee}\cdot(1+\delta_{ee})\cdot\varepsilon_{ee} + \sigma^B_{\mu\mu}\cdot(1+\delta_{\mu\mu})\cdot\varepsilon_{\mu\mu}}{\sigma^B_{\pi\pi}\cdot(1+\delta_{\pi\pi})(1-\Delta_{lose})\cdot\varepsilon_{\pi\pi}} - \Delta_{3\pi,4\pi,K^+K^-}$$

σ^B -Born Cross-Section

ε - efficiency of reconstruction $\sim 99\%$

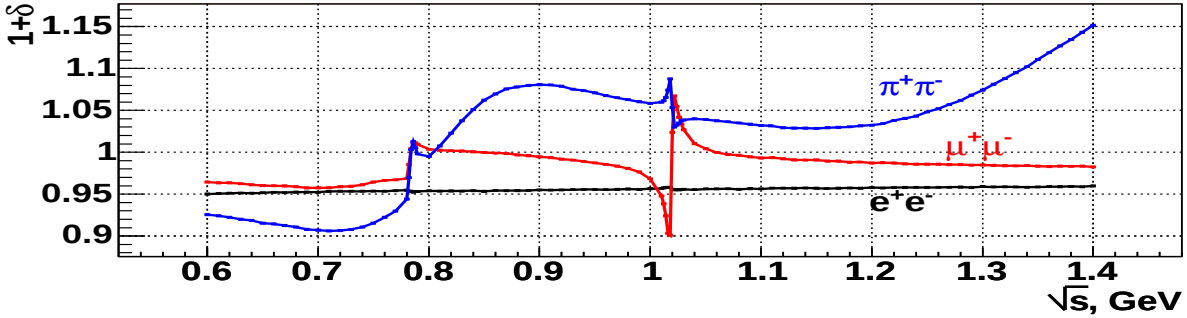
Δ_{lose} - correction from pion lose $\sim 3.5\% \div 0.6\%$

$\Delta_{3\pi,4\pi,K^+K^-}$ - background events

$\sim 0.3\%$ near ω-meson,

$\sim 1\%$ above ϕ-meson

δ - radiation correction

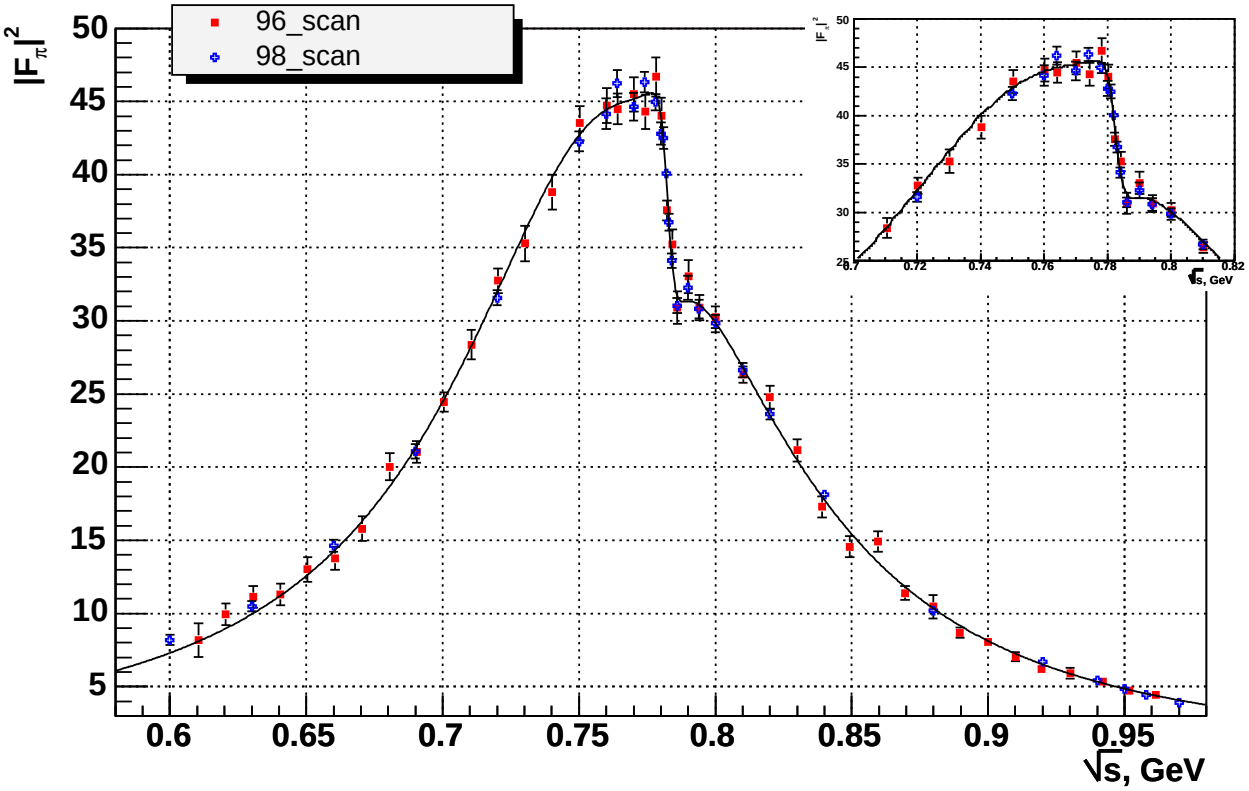


e^+e^-	$\mu^+\mu^-$	$\pi^+\pi^-$	cosmic	number of points	energy range, $\sqrt{s}$	
number of events, 10^3						
164	16	114	17	43	610 ÷ 960 MeV	Phys.Lett B578:285-289,2004
96	9	4	5	10	370 ÷ 520 MeV	
710	65	520	19	29	600 ÷ 960 MeV	
840	81	33	14	36	980 ÷ 1380 Mev	

Systematic Errors

source	value		
	$\sqrt{s}$ =0.37 ÷ 0.52	0.6 ÷ 0.96	1.04 ÷ 1.38 GeV
fiducial volume	0.2 %	0.2 %	0.2÷0.5 %
detection efficiency	0.3 %	0.2 %	0.5÷ 2 %
correction for pion loses	0.2 %	0.2 %	0.2 %
radiative corrections	0.3 %	0.4 %	0.5÷ 2 %
background events	<0.1%	<0.1%	0.6÷1.6 %
energy calibration of collider	0.3 %	0.1 %	0.7÷1.1 %
full event separation	1.0 %	0.2 %	0.5÷3.5 %
	1.2 %	0.6 %	1.3 ÷ 5.0 %
statistic error in point	6 %	1.5 ÷ 4 %	5 ÷ 13 %

Pion Formfactor (CMD2 data)



$600 < \sqrt{s} < 1000$ MeV ρ, ω, ρ' :

$M_\rho = 775.65 \pm 0.64 \pm 0.50$ MeV

$\Gamma_\rho = 143.85 \pm 1.33 \pm 0.80$ MeV

$Br(\omega \to \pi^+\pi^-) = 1.30 \pm 0.24 \pm 0.05\%$

$\arg\delta = 13.3^\circ \pm 3.7^\circ \pm 0.2^\circ$

Phys.Lett B527:161-172,2002

Phys.Lett B578:285-289,2004

all statistic data at CMD-2
only statistic error

$M_\rho = 775.36 \pm 0.46$ MeV

$\Gamma_\rho = 143.5 \pm 1.2$ MeV

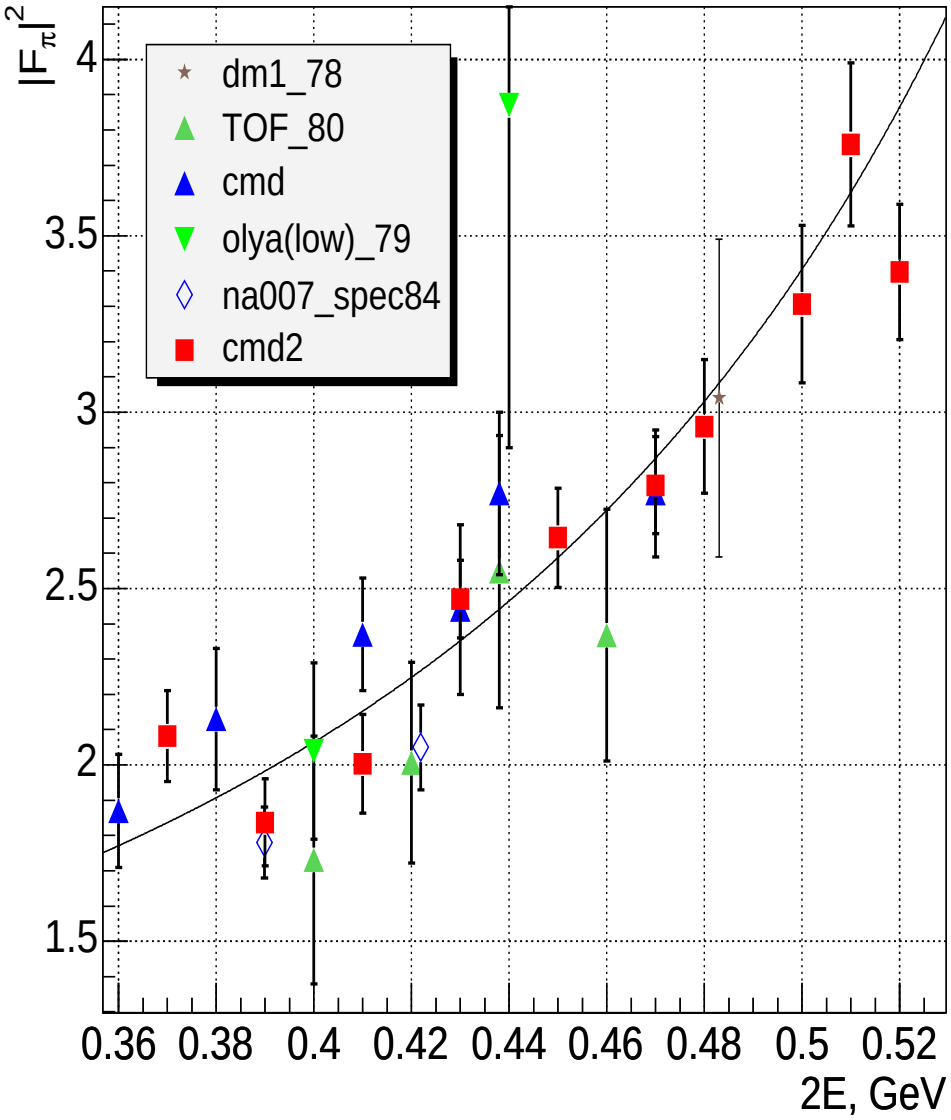
$Br(\omega \to \pi^+\pi^-) = 1.47 \pm 0.12\%$

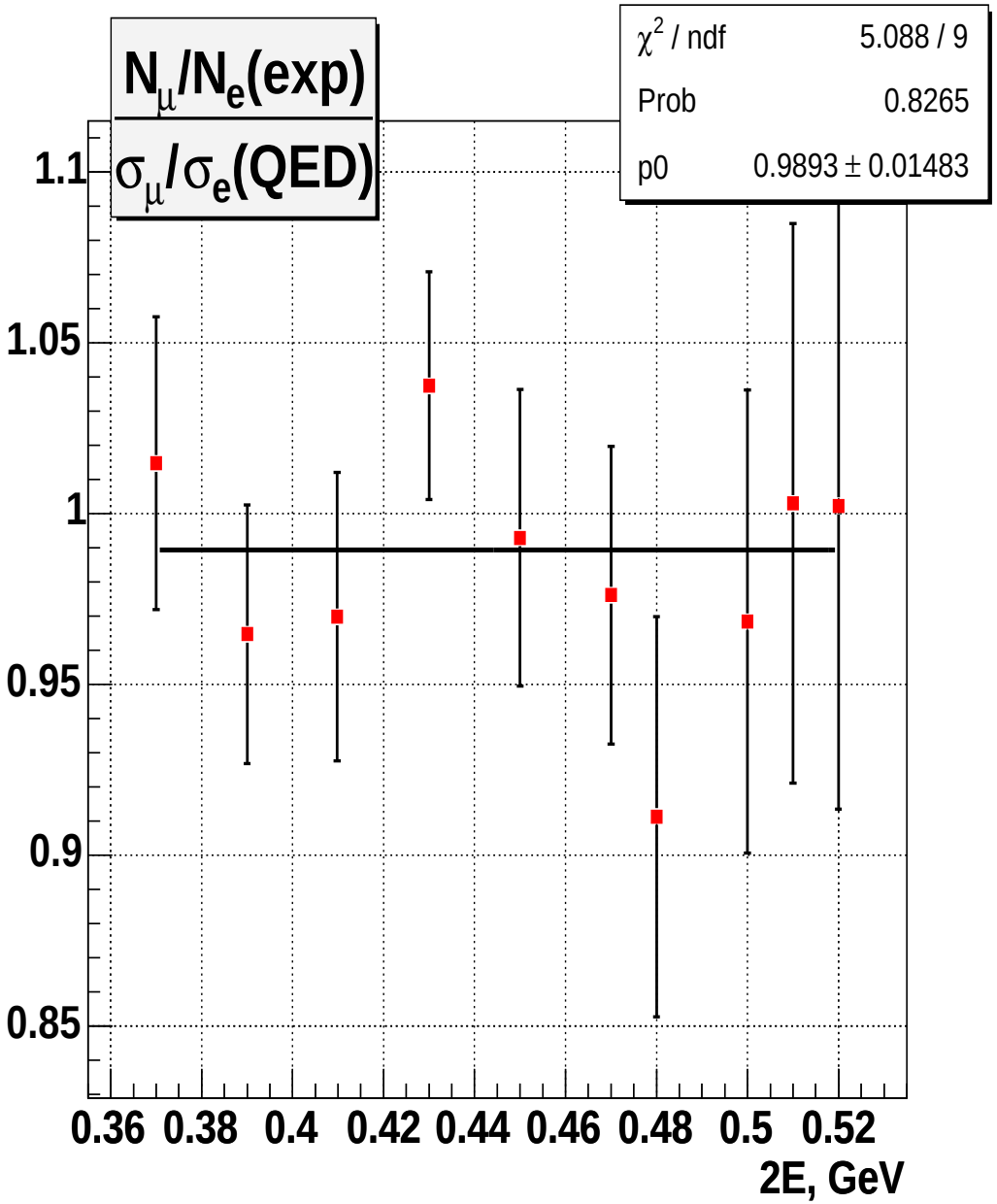
$\arg\delta = 11.0^\circ \pm 1.7^\circ$

The Gounaris-Sakurai parametrization (GS)

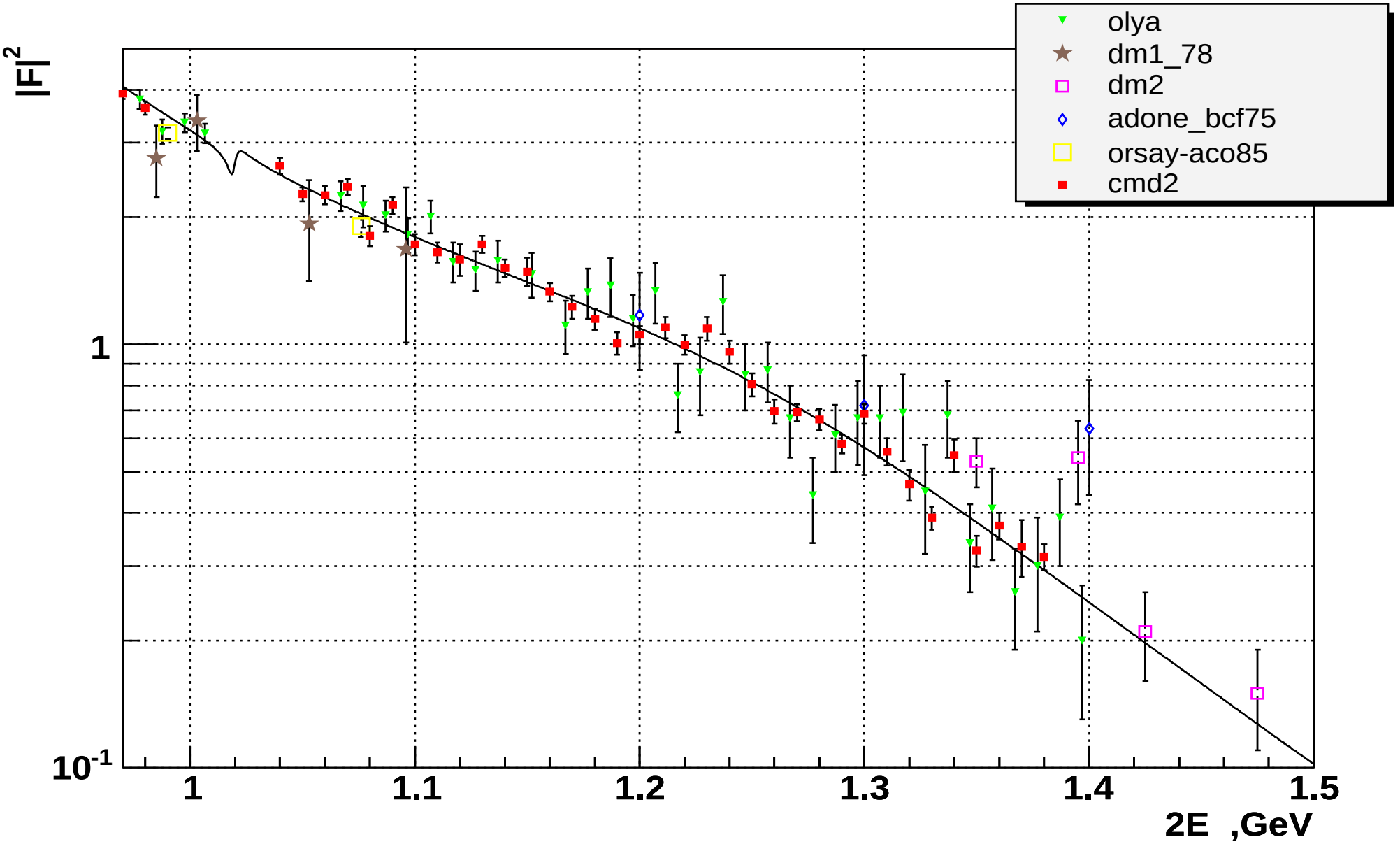
$$F_\pi(s) = \frac{\mathrm{BW}^{\mathrm{GS}}_{\rho(770)}(s) \cdot \dfrac{1 + \delta\,\mathrm{BW}_\omega(s)}{1+\delta} + \beta\,\mathrm{BW}^{\mathrm{GS}}_{\rho(1450)}(s) + \gamma\,\mathrm{BW}^{\mathrm{GS}}_{\rho(1700)}(s)}{1 + \beta + \gamma}$$

Pion Formfactor at $\sqrt{s} < 0.6$ GeV

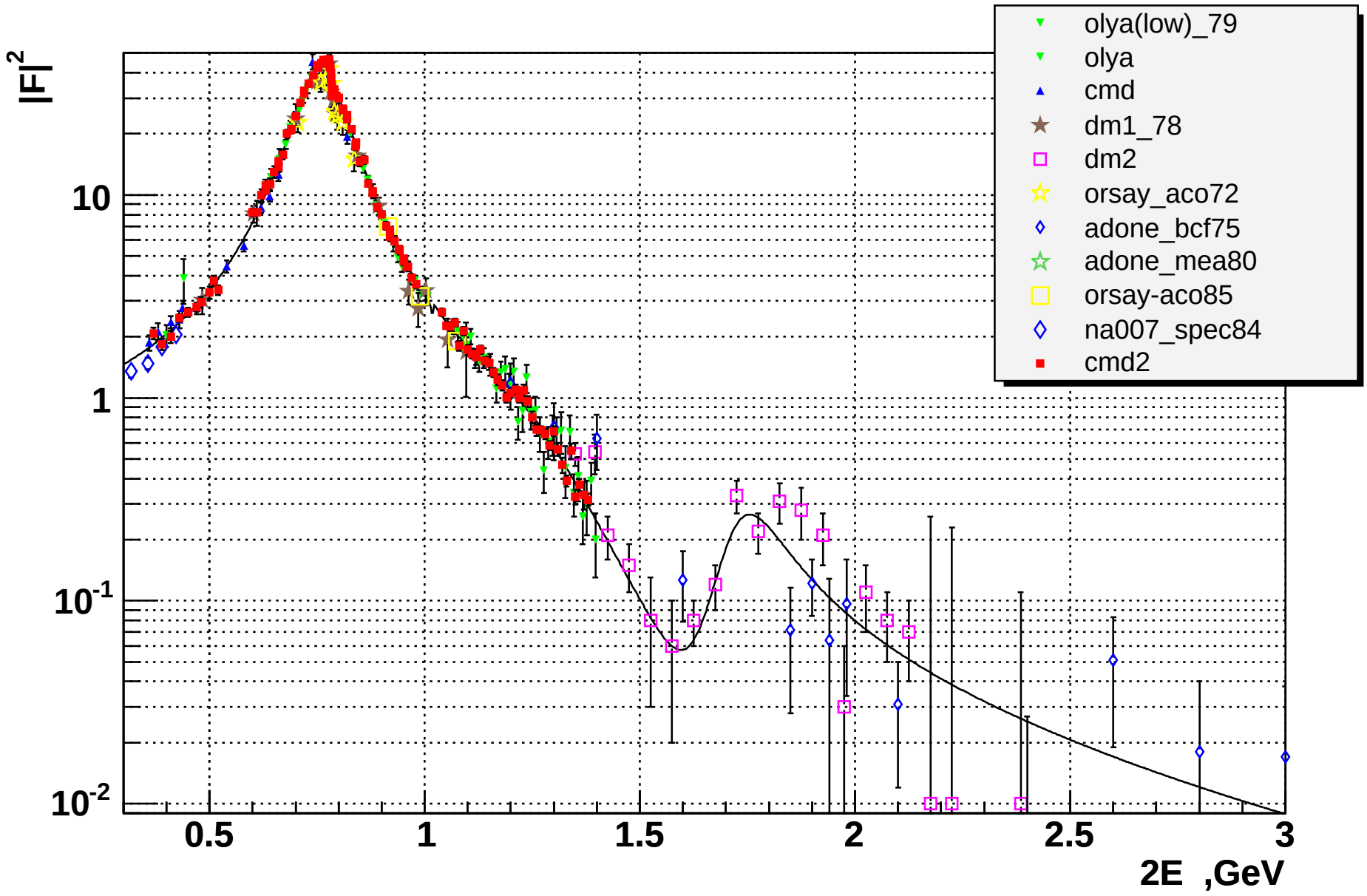




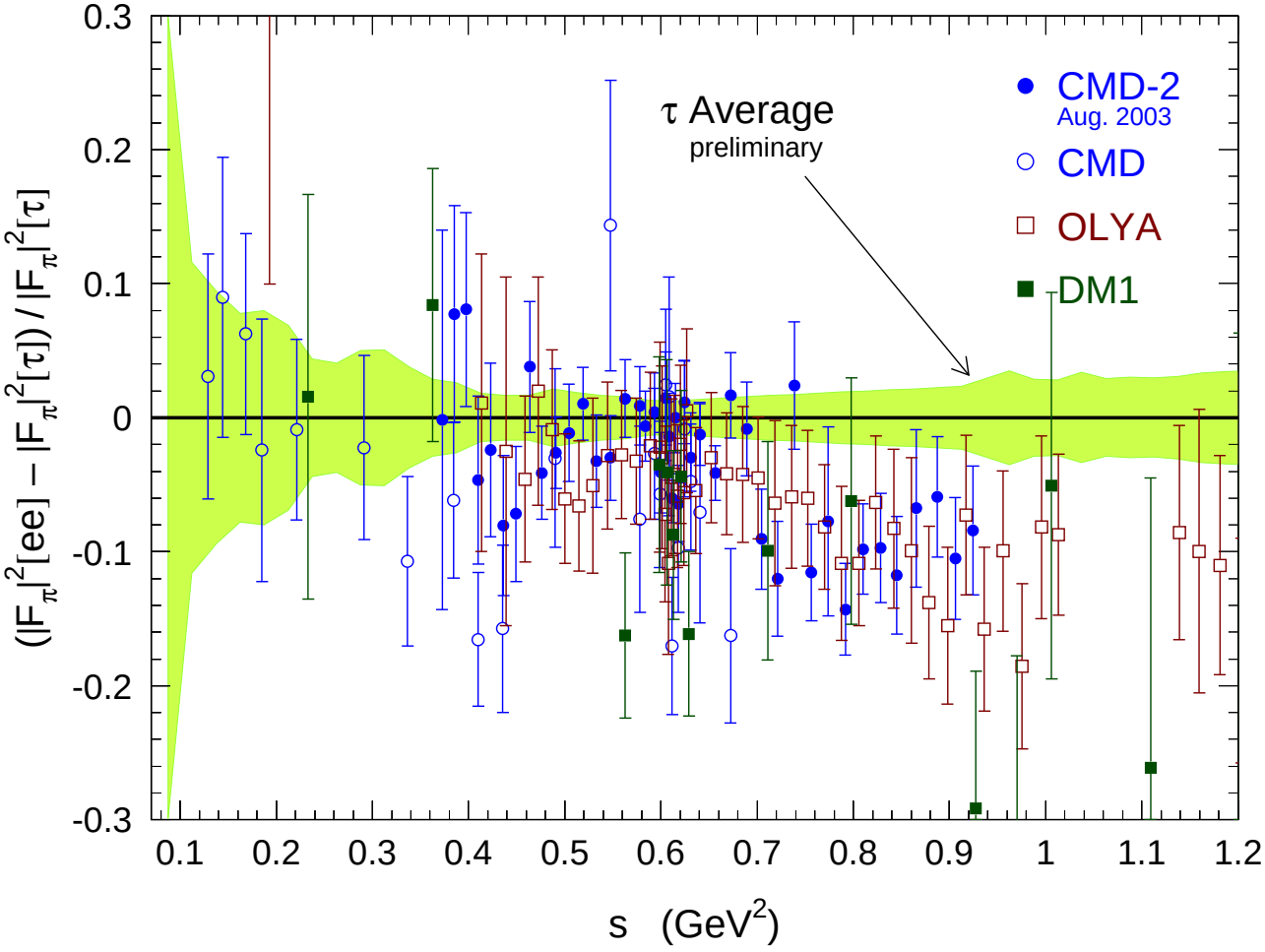
Pion Formfactor at $\sqrt{s} = 1.02 - 1.38$ GeV



Pion Formfactor at $\sqrt{s} = 0.37 \div 3.$ GeV



Relative comparison of the $\pi^+\pi^-$ spectral functions from e^+e^- and isospin beaking-corrected τ data



$\mathbf{a_\mu^{had} = 696.3 \times 10^{-10}}$ **(59.72 ± 0.6 ppm) from** e^+e^-

$\mathbf{a_\mu^{had} = 711.0 \times 10^{-10}}$ **(60.98 ± 0.5 ppm) from** τ **to** 2π **and** 4π

$$a_\mu(e^+e^-) - a_\mu(\tau) = -14.7 \pm 7.9$$

DEHZ'02,hep-ph/0208177,hep-ph/0308213

Conclusion

- Contribution at this energy range of $\pi^+\pi^-$ to $a_\mu = (g-2)/2 = (11659208 \pm 6) \cdot 10^{-10}$: $\Delta a_\mu^{had} = (508.20 \pm 5.53) \cdot 10^{-10}$
- Why spectral function from e^+e^- and τ have different behavior? (possibly due to difference in masses and widths of $\rho^\pm$ and ρ^0 ?)
- The further $2 \div 10$ times improvement of experimental value of a_μ need requies the mprovement of $\pi^+\pi^-$ cross-section knowledge.
- KLOE, BABAR and BELLE results for $e^+e^- \to \pi^+\pi^-(\gamma)$ will give additional information.
- Experiments with CMD-3 at VEPP-2000 will provide new data in expanded energy range $\sqrt{s}$=0.36-2. GeV.