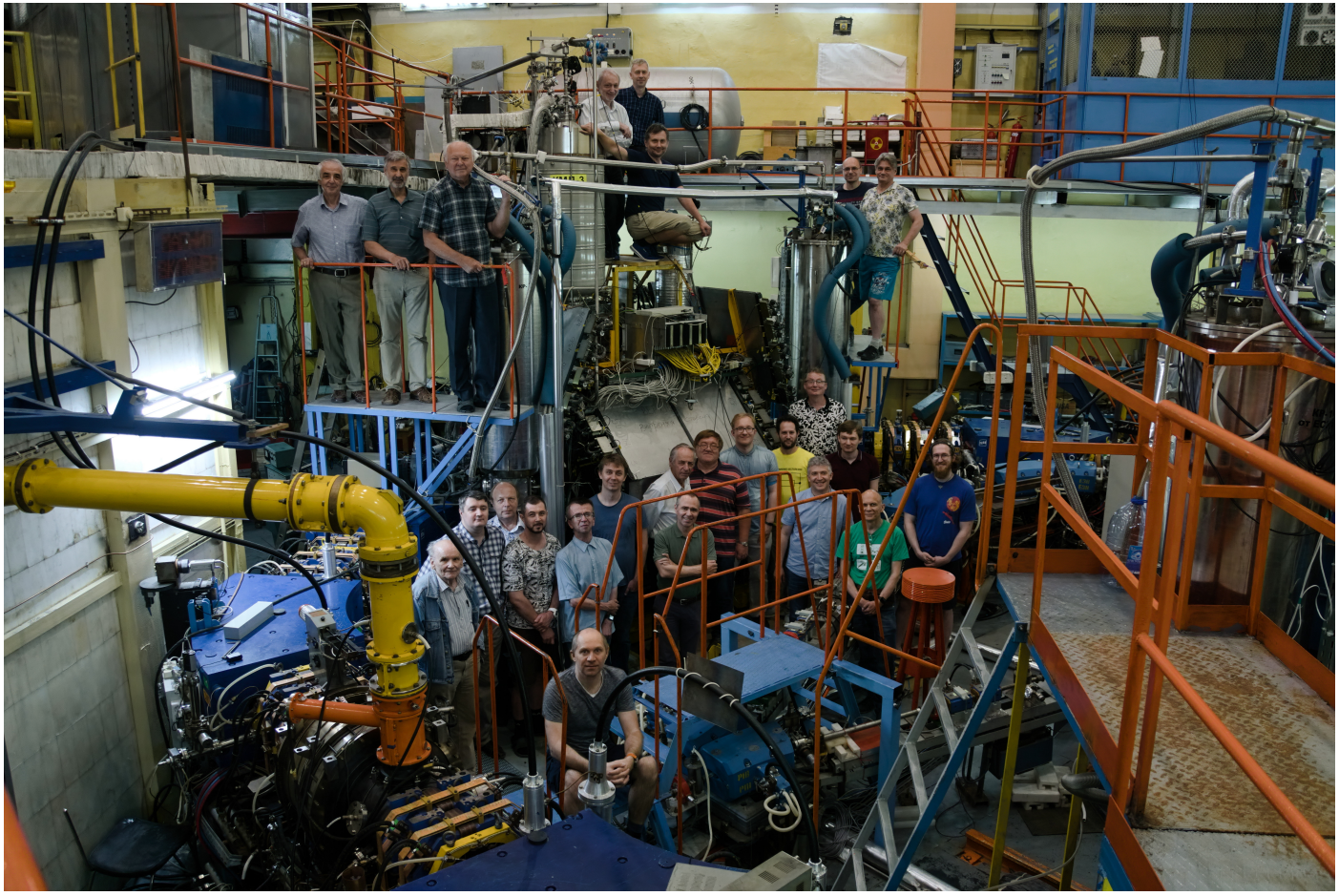

Budker INP
Novosibirsk

# Study of the $e^+e^-$-> hadrons cross sections at the NNbar threshold with CMD-3 at VEPP2000

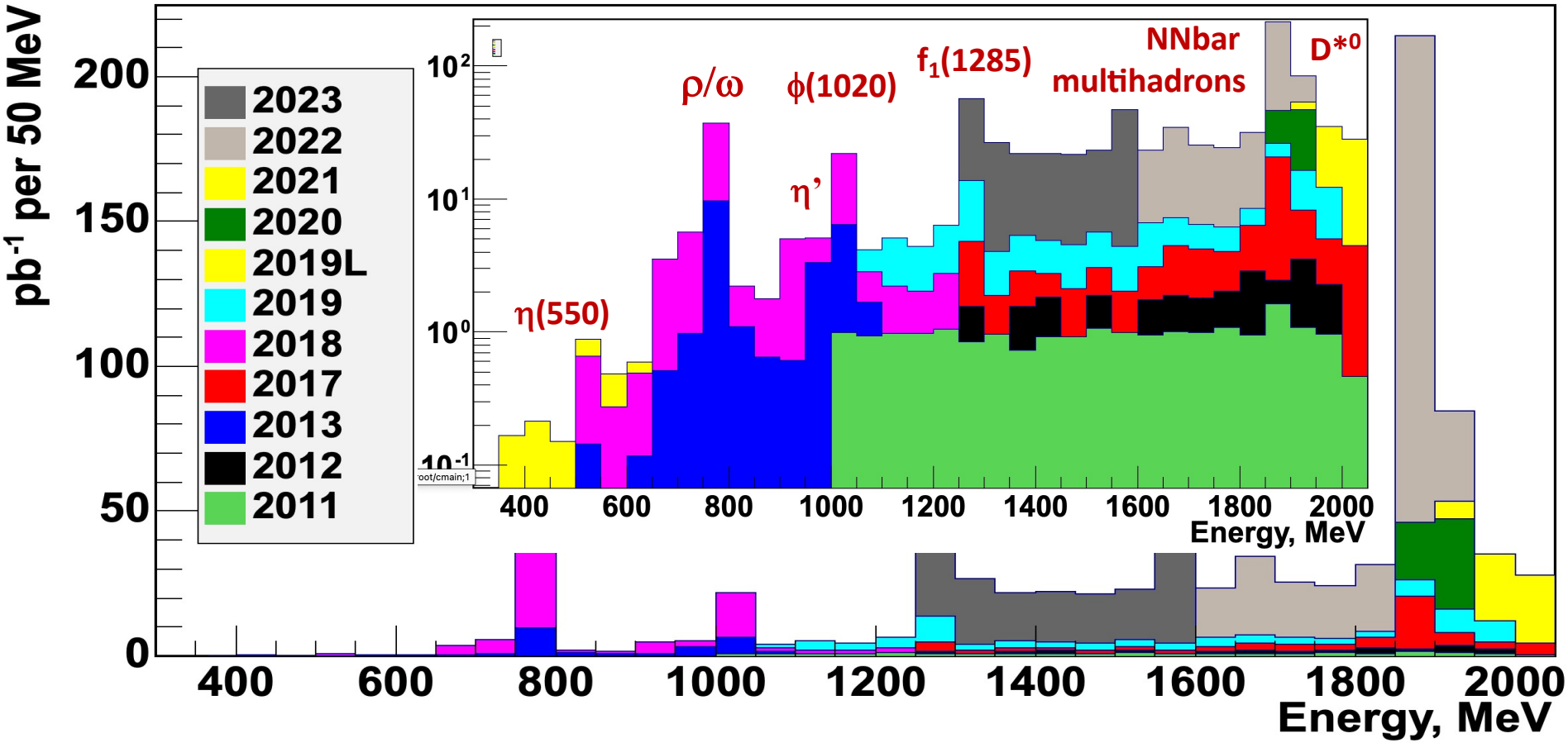
E. P. Solodov, CMD-3 Collaboration

BudkerINP, Novosibirsk, Russia

# CMD-3 Collaboration at VEPP2000 collider

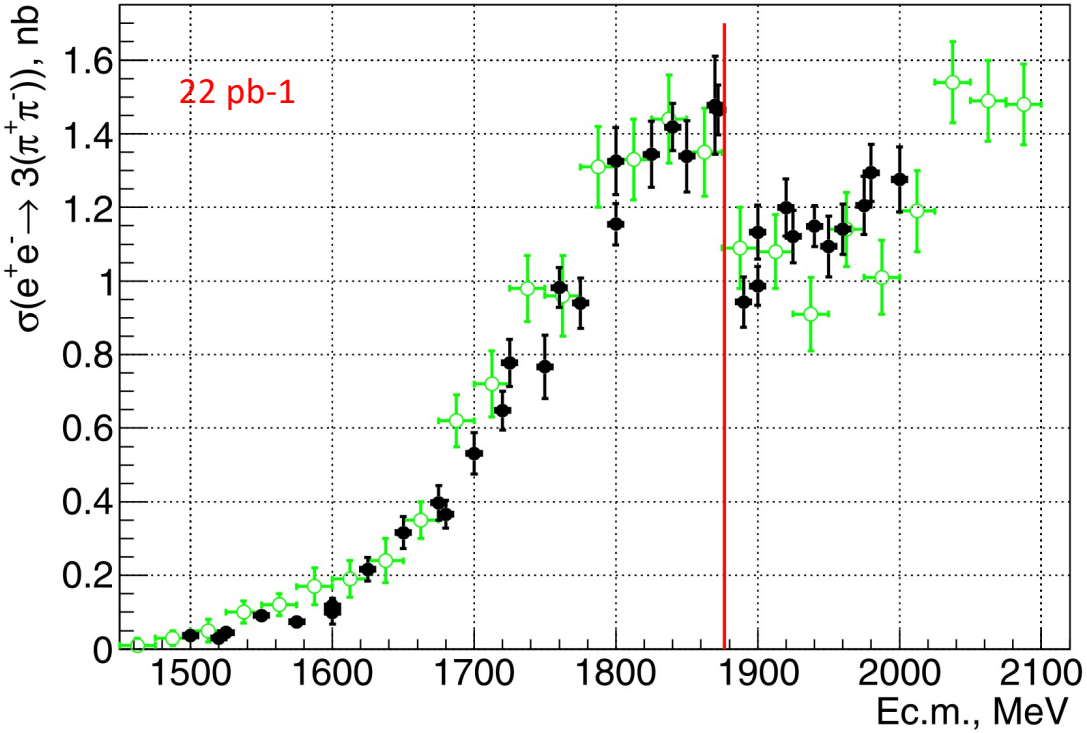


# CMD-3 integral ~1000 1/pb !




About 10 papers are published. More than 20 exclusive e+e- -> hadrons cross sections are under study.

# First energy scan 2010-2012



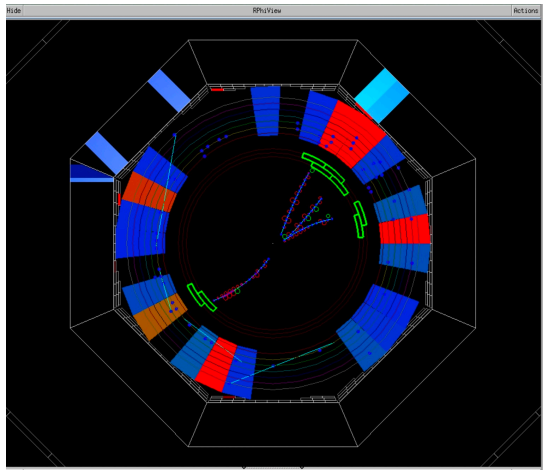

Physics Letters B 723 (2013) 82–89

-- Confirm structure in the $e^+e^-$ -> $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ reaction at the NNbar threshold
-- It does not look like an interfrrence of an under-threshold resonance with continum
-- First look to the production dynamics

The $e\,e \rightarrow 3(\pi\,\pi)$ cross section measured with the CMD-3 detector at VEPP-2000 (dots).
The results of the BaBar measurement [2] are shown by open circles.
The line shows the $p\bar{p}$ threshold.

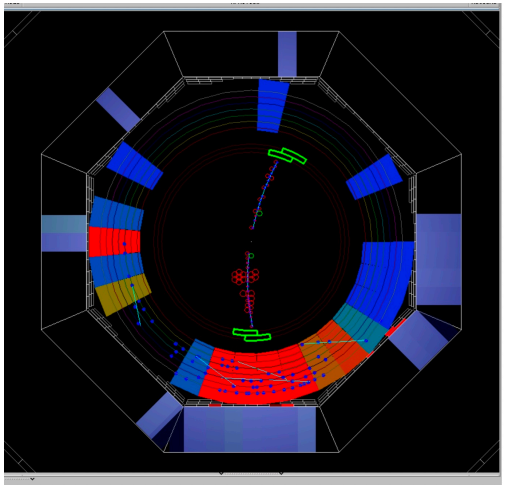
# NNbar threshold scan - 2017 data

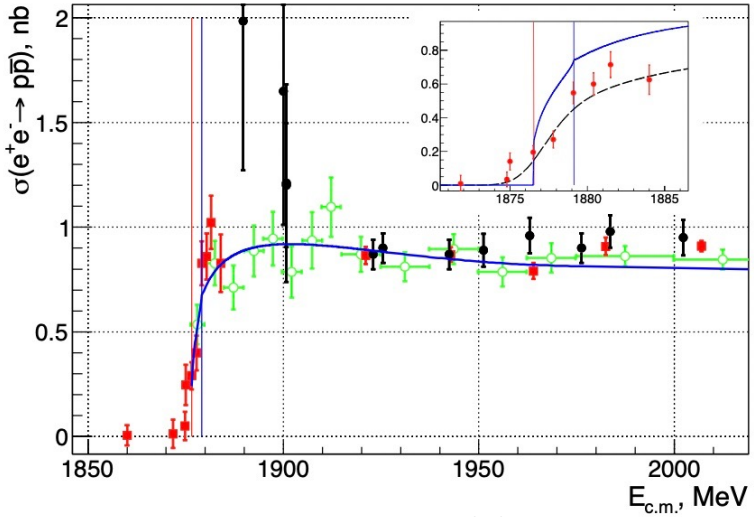
20+50 pb $^{-1}$ ~2 pb$^{-1}$/point



Anti-protons close to the production threshold are seen as an annihilation star at the vacuum beam pipe (or in the DC inner wall)+ large energy deposition in the calorimeters.

Above 1900 we see collinear PPbar tracks in DC





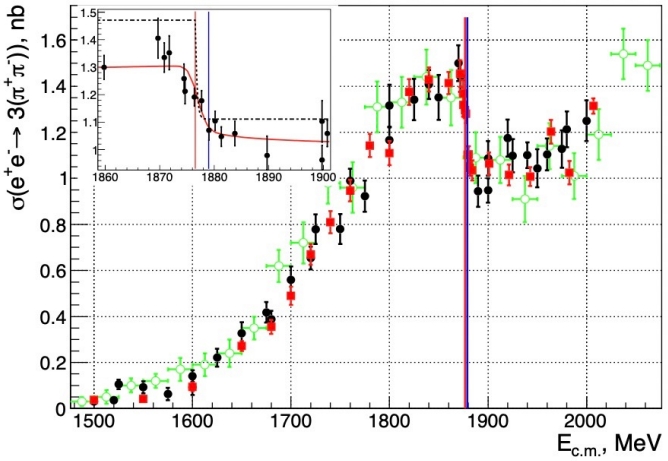

Geen points – BaBar data

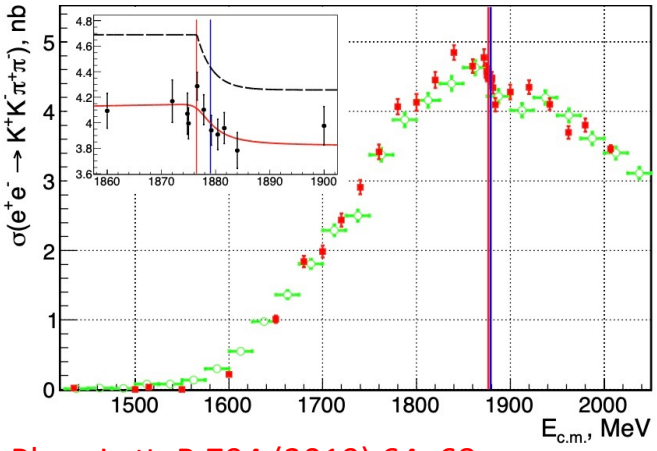
Phys. Lett. B 794 (2019) 64–68

Theory:
A.I. Milstein, S.G. Salnikov,
Nucl. Phys. A 977 (2018) 60.

Nucleons are formed from the quarks in e+e- -> NNbar and at the threshold are slow, and the production is influents by a final state strong interactions at small distances.

# NNbar threshold in hadronic reactions




Phys. Lett. B 794 (2019) 64–68

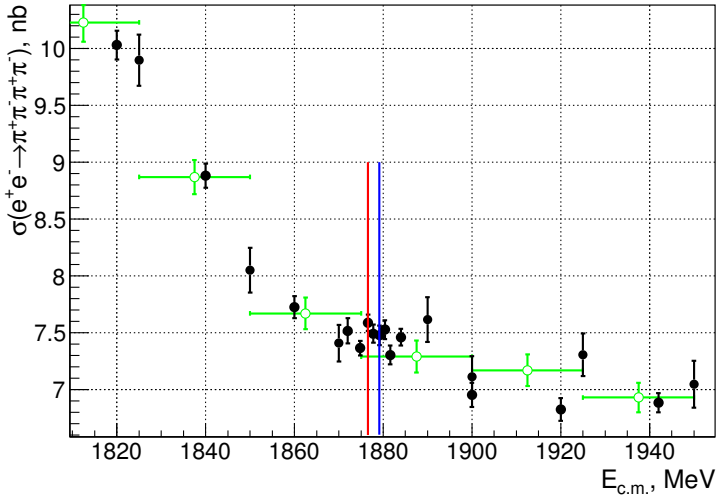
Openning NNbar real reaction reflects in XS drop in multihadron productions

Energy spread ~ 1 MeV

Simultanious fit with PPbar by exponentialy rising (drop) functions gives:

$\sigma^{thr}$ = 0.18±0.27 MeV

Consistent with zero within uncertainty in energy due to beam spread and radiative corrections.




No signal for the $e^+e^-$ -> $\pi^+\pi^-\pi^+\pi^-$ reaction

The idea, that signal in the hadronic cross section is propotional to the annihilation rate of NNbar to this final state does not work!?

Are there any indications for other hadronic cross sections?

# New scans

- Scan 2019 – from 1.4 to 2.0 GeV c.m. 28 points with ~2 $pb^{-1}$/point — 40.462 $pb^{-1}$
- Scan 2020 – from 1.870 to 1.935 GeV – 5 points with 10 $pb^{-1}$/point — 46.870 $pb^{-1}$
- Scan 2021 – from 1.935 to 2007 GeV – 4 points with 10$pb^{-1}$/point (24 $pb^{-1}$ at 2007) — 48.400 $pb^{-1}$
- Scan 2021-2022 at NN threshold and below to 1.600 Gev: — 282.844 $pb^{-1}$

  18 point at the threshold with ~1 MeV step – 10 $pb^{-1}$/point (x5 to 2017 scan)

  13 points below threshold with 10 MeV step – 5-10 $pb^{-1}$/point
- Scan 2023 – from 1.600 down to 1.400 GeV – with ~10$pb^{-1}$/point — 176.860 $pb^{-1}$

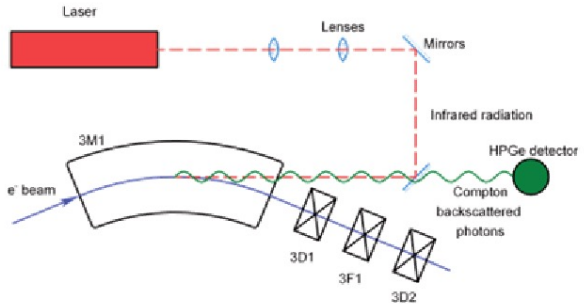
595.4 $pb^{-1}$

We plan to study the energy behavior of many hadronic reactions

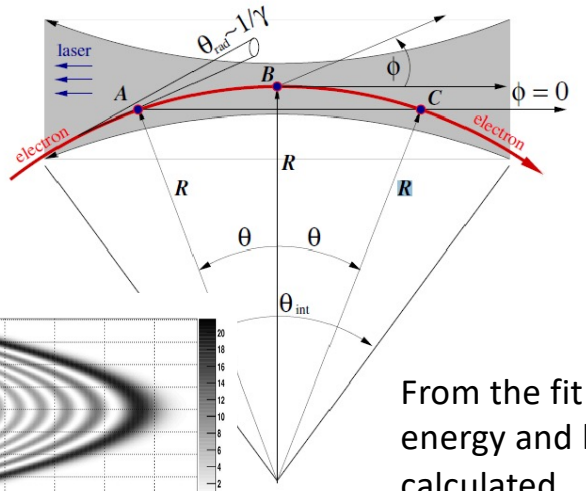
And in particular at the NNbar threshold

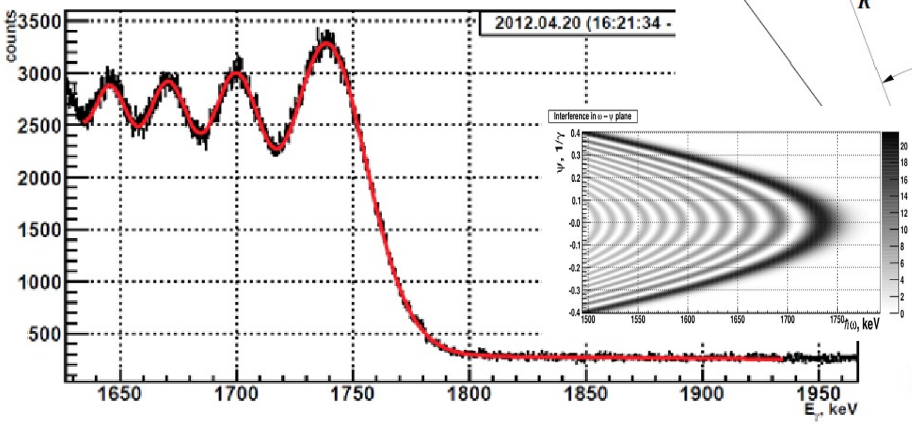
# Energy measurement

Starting from 2012, energy is monitored continuously using Compton backscattering




Light from A and B interferes



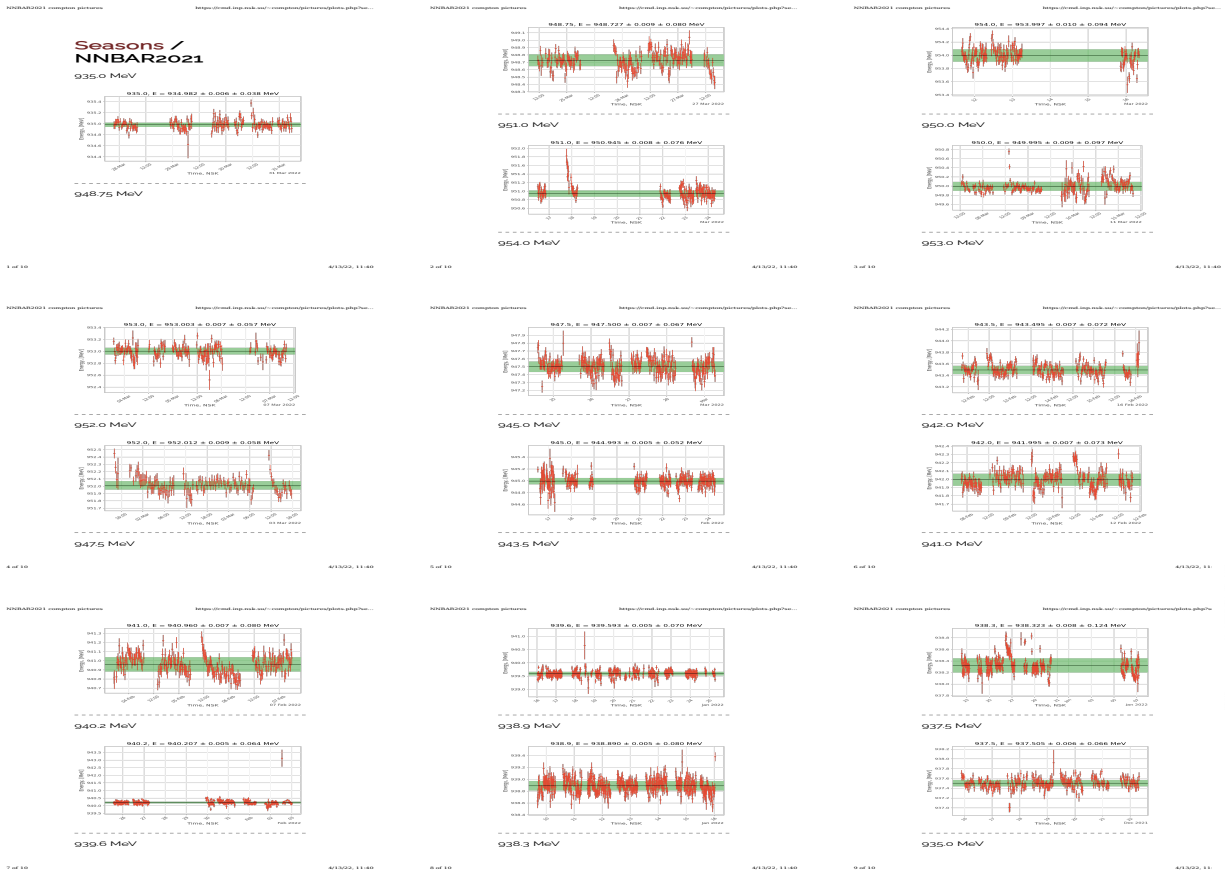

From the fit parameters, the beam energy and beam energy spread are calculated.

E = 993.662 ± 0.016 МэВ

MeV

M.N. Achasov et al. arXiv:1211.0103v1 [physics.acc-ph] 1 Nov 2012

# Energy control during data taking at each point

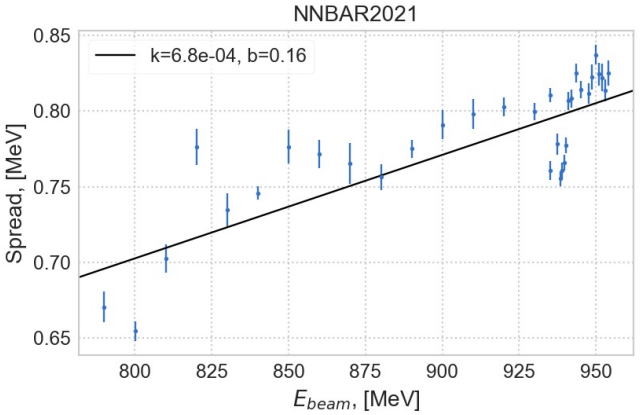



Energy measurement each 20 minutes

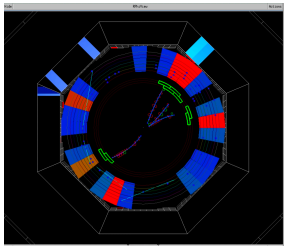
Green bands – are the estimated uncertainty in the energy ~50-60 keV

Excelent ! machine stability

The energy spread is also measured for each energy point

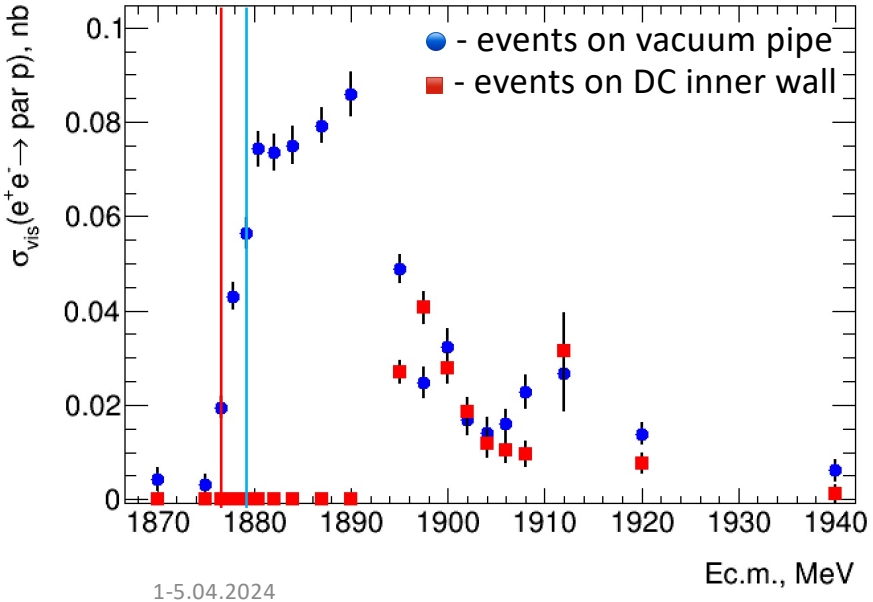


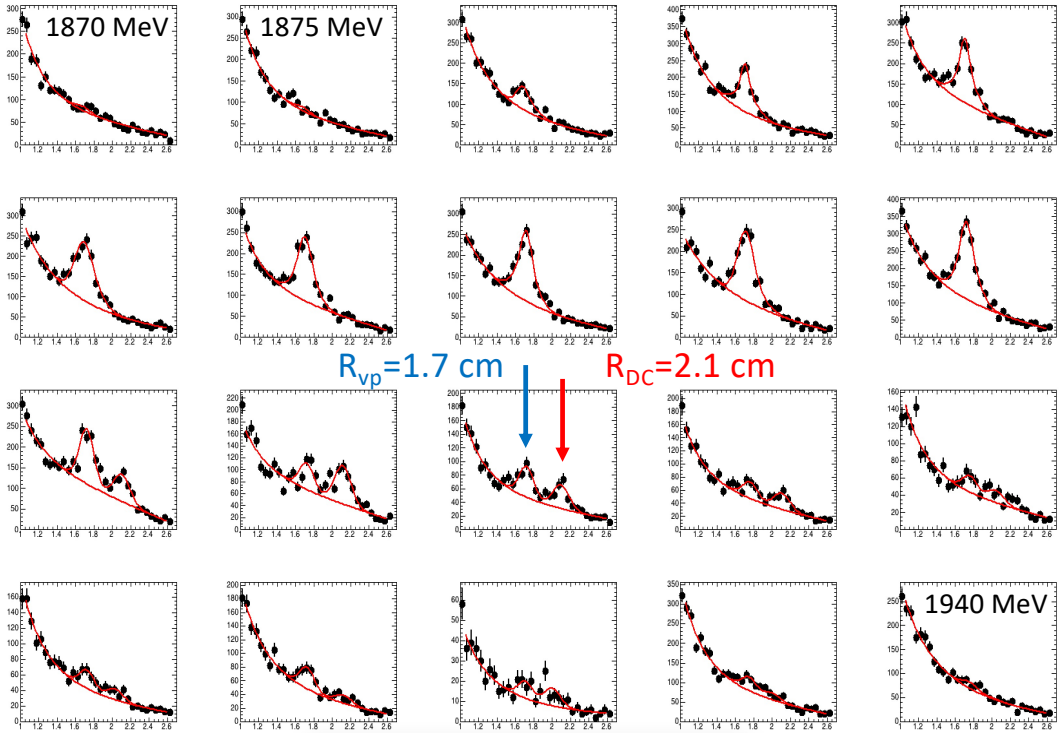
# New ppbar detailed threshold scan



Anti-protons close to the production threshold are seen as an annihilation star at the vacuum beam pipe (or in the DC inner wall)+ large energy deposition in the calorimeters.

We plot radius of the vertex with >2 tracks and energy deposition > 500 MeV



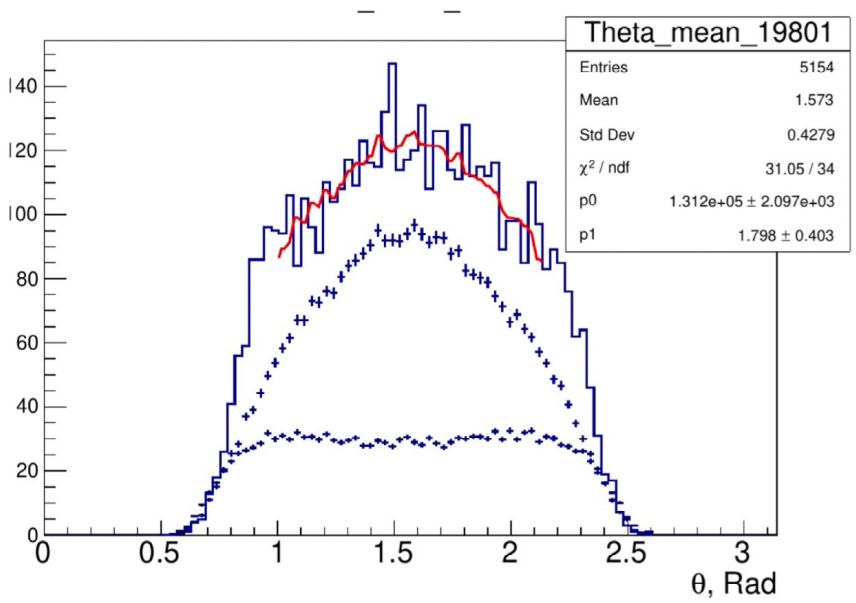




First peak – radius of the aluminum vacuum pipe $R_{vp}$ = 1.7 cm, (0.5 mm)
Second peak – inner wall of the DC carbon fiber $R_{DC}$ = 2.1 cm (0.25mm)

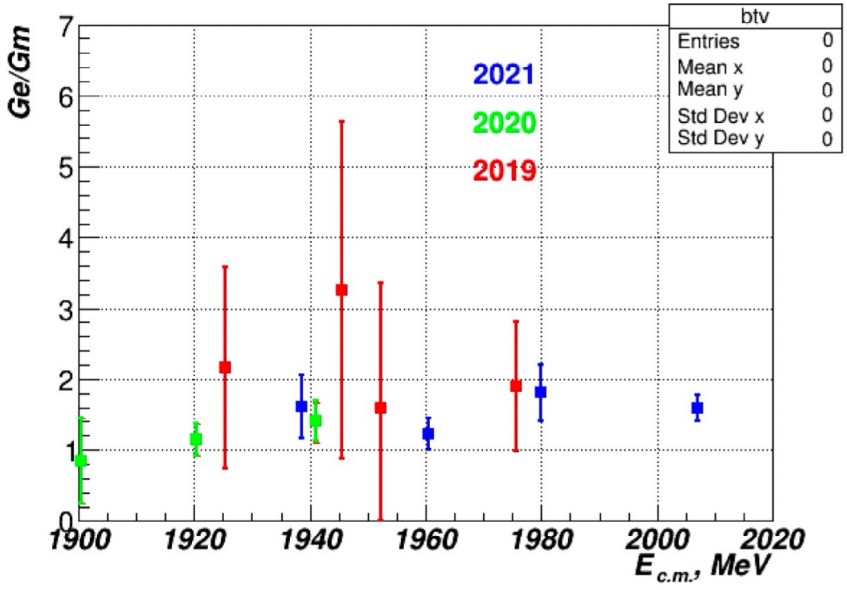
In progress…

# GE/GM measurement

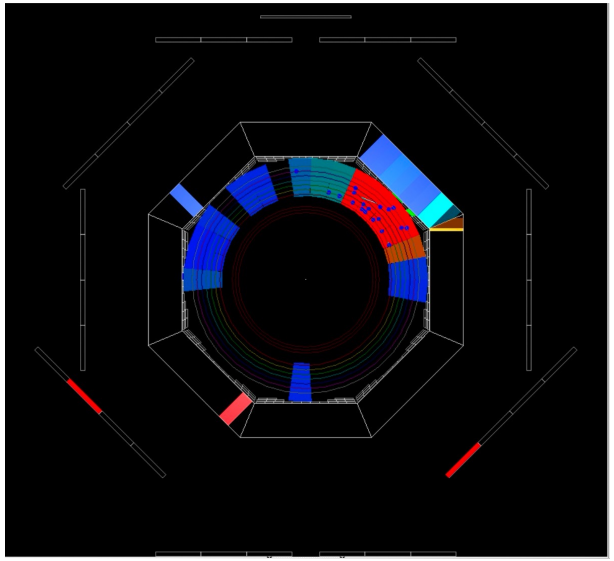
ppbar events polar angle distribution for Ec.m. = 1980 MeV,
and fit with sum of expected distributions with GE=0 and GM=0




PRELIMINARY

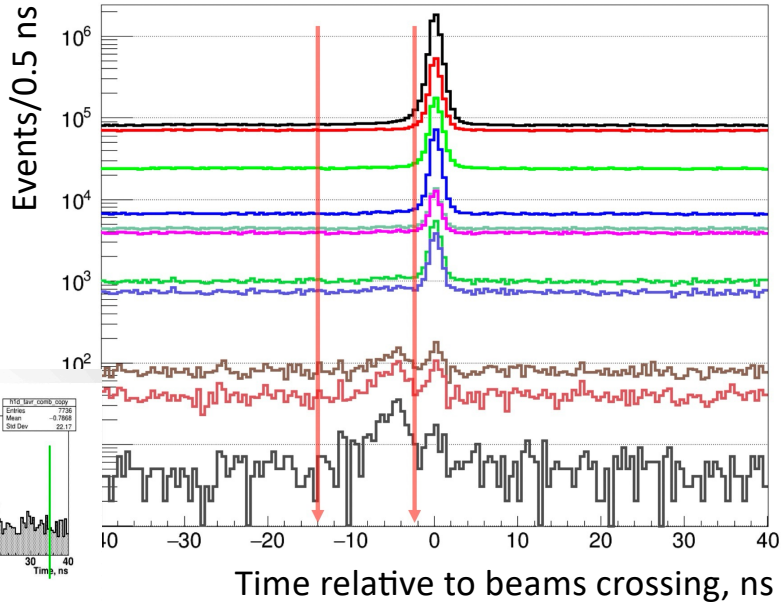


# nnbar production

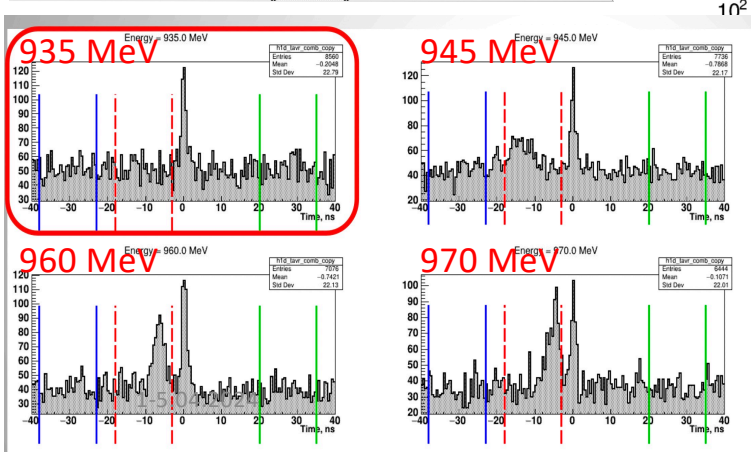


nnbar events are detected as a large energy single cluster in the calorimeters with delay timing in the TOF system, relative to the beam crossing.

Cross section is small and selections should suppress 5 orders of magnitude of backgrounds, mainly from the cosmic events.

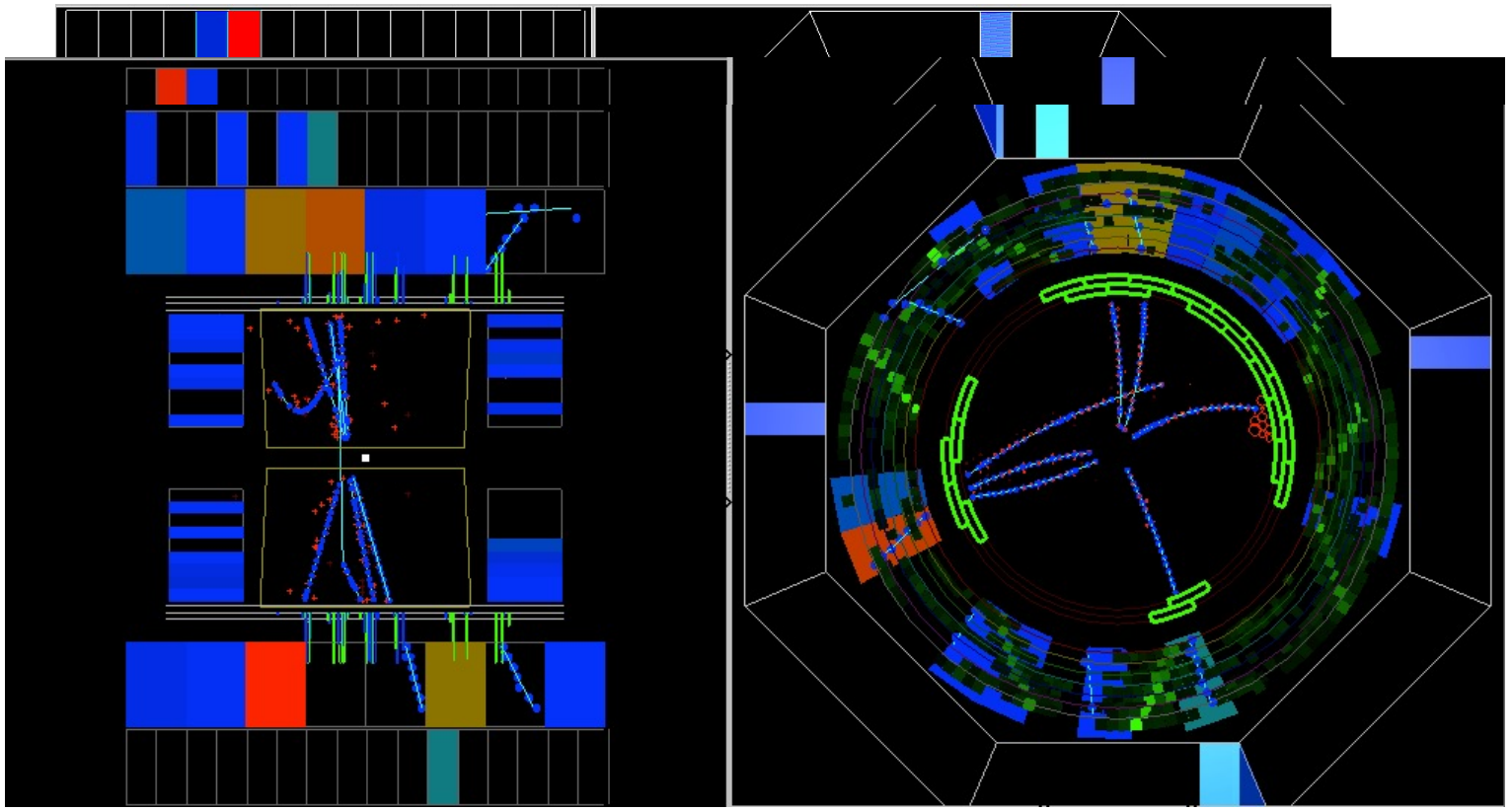



Peak at 0 is from Bhabha events



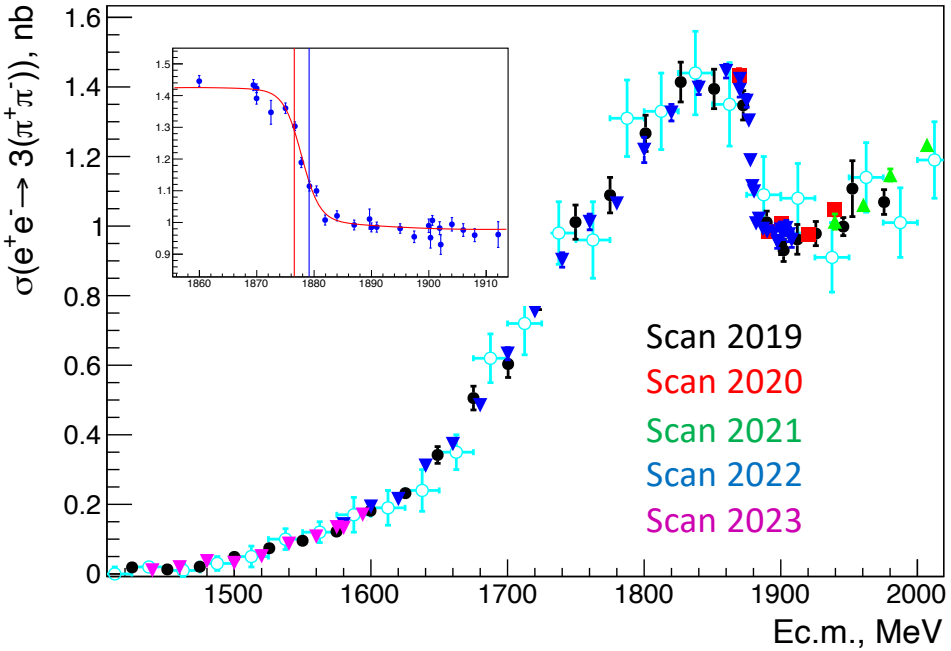

Analysis is in progress. Major problem comes from the efficiency calculation

# Example of $e^+e^-$ -> $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ from CMD-3

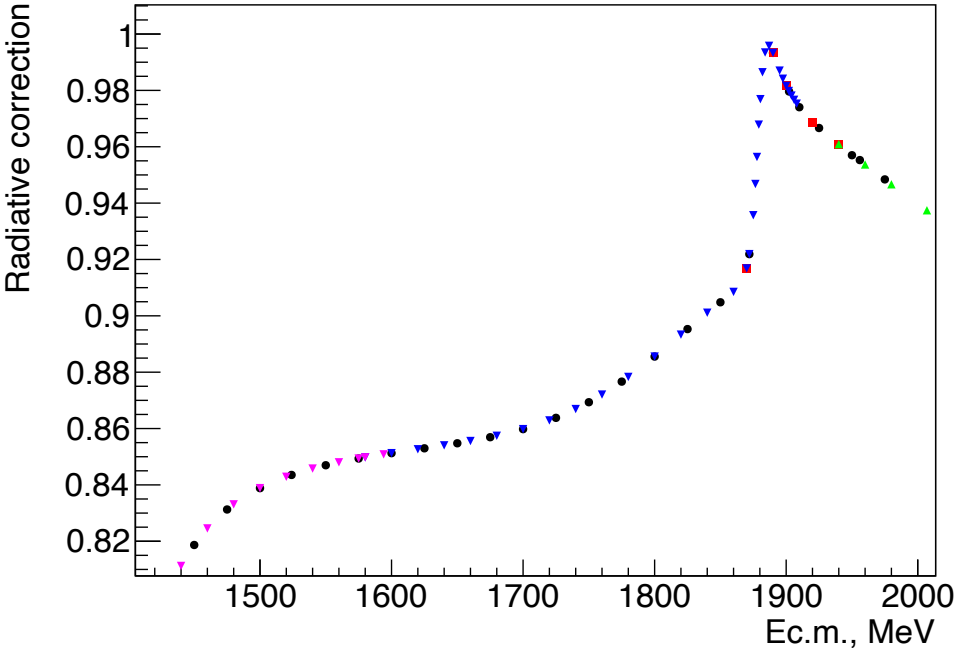


# First look to $e^+e^- \to 3(\pi^+\pi^-)$ reaction (new data)

PRELIMINARY




Unfolding of beam energy spread and radiative effects

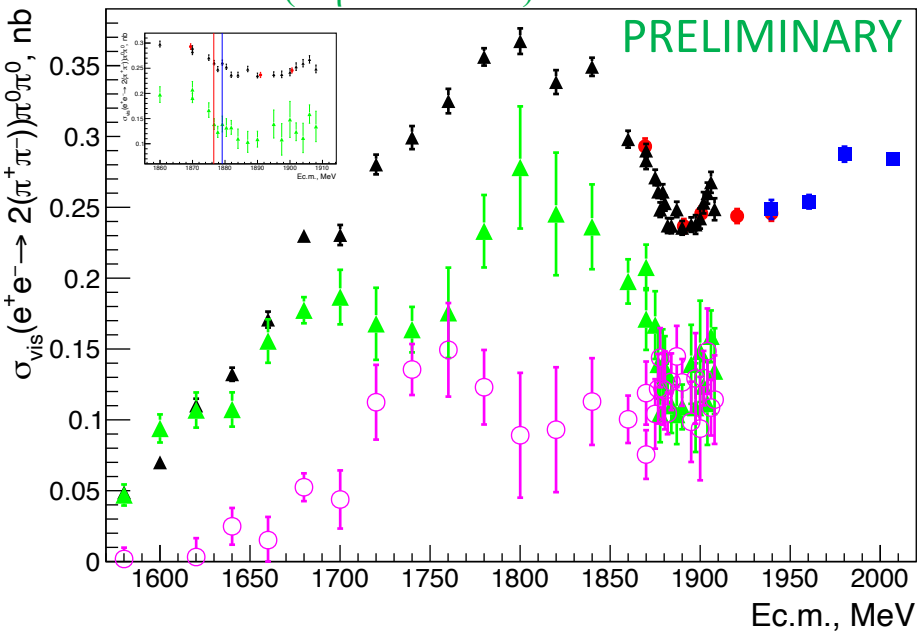


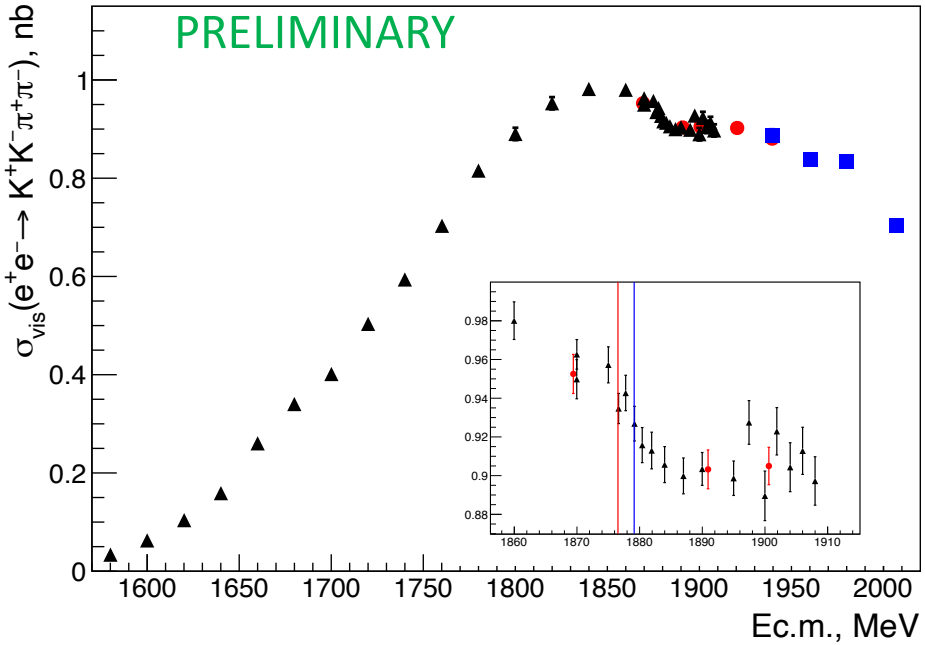

30% drop with 1.91+-0.15 MeV shape at 1877.9+-0.13 MeV

# How about other reactions?

First look to visible (number of events/luminosity) cross sections (no corrections)

e+e- -> ω3π (ωη – excluded)




We confirm, that e+e- -> $4\pi 2\pi^0$ (is dominated by e+e- -> ω3π !) and e+e- -> $K^+K^-\pi^+\pi^-$ reactions demonstrate structure in the cross sections at the NNbar threshold

# Expect signal in other reactions?



**THE ANTINUCLEON–NUCLEON INTERACTION AT LOW ENERGY: ANNIHILATION DYNAMICS**

Eberhard Klempt
Helmholtz-Institut für Strahlen- und Kernphysik
der Rheinische Friedrich-Wilhelms Universität
Nußallee 14-16, D–53115 Bonn, Germany

Chris Batty
Rutherford Appleton Laboratory
Chilton, Didcot
Oxon, OX11 OQX, United Kingdom

Jean-Marc Richard
Laboratoire de Physique Subatomique et Cosmologie
Université Joseph Fourier–CNRS–IN2P3
53, avenue des Martyrs, F–38026 Grenoble Cedex, France

February 5, 2008

**Abstract**

The general properties of antiproton–proton annihilation at rest are presented, with special focus on the two-meson final states. The data exhibit remarkable dynamical selection rules: some allowed annihilation modes are suppressed by one order of magnitude with respect to modes of comparable phase-space. Various phenomenological analyses are reviewed, based on microscopic quark dynamics or symmetry considerations. The role of initial- and final-state interaction is also examined.

PbarP annyhilation rates

Table 8: Pionic multiplicity distribution.

| | From Table 7 | From [262] |
|---|---|---|
| 2 pions | $0.38 \pm 0.03\%$ | $0.38 \pm 0.03\%$ |
| 3 pions | $7.4 \pm 0.3\%$ | $7.8 \pm 0.4\%$ |
| 4 pions | $18.1 \pm 1.8\%$ | $17.5 \pm 3.0\%$ |
| 5 pions | $35.2 \pm 3.7\%$ | $45.8 \pm 3.0\%$ |
| 6 pions | $23.3 \pm 2.8\%$ | $22.1 \pm 1.5\%$ |
| 7 pions | $3.3 \pm 0.3\%$ | $6.1 \pm 1.0\%$ |
| 8 pions | | $0.3 \pm 0.1\%$ |

$$\mathrm{BR}(\bar{\mathrm{p}}\mathrm{p} \to \text{kaons} + \text{anything}) = (5.4 \pm 1.7)\% . \qquad (5.11)$$

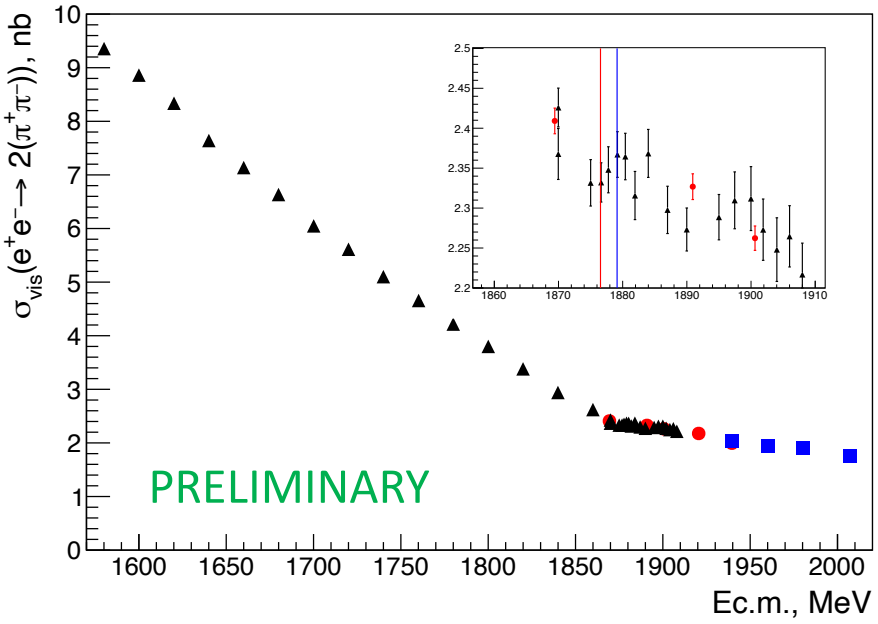
In short, one event out of 20 contains strange particles in the final state.

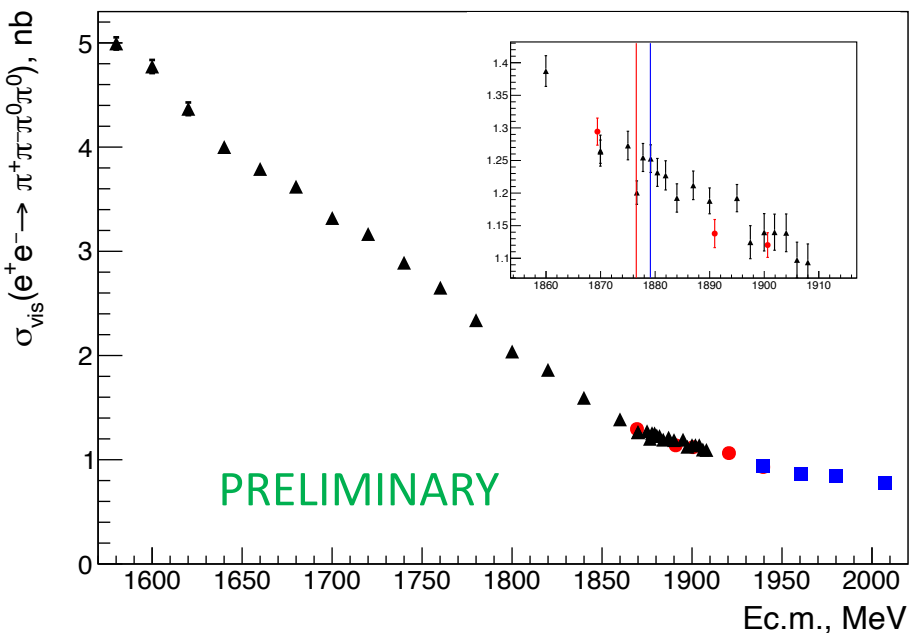
It is natural to expect signal in other hadronic reactions
to be proportional to the NbarN annyhilation rate to this final state

Shown – the annyhilation rate to $1^{--}$ (photon QNs) is relatively small,
But not negligible!

# How about other reactions?

First look to visible (number of events/luminosity) cross sections (no corrections)

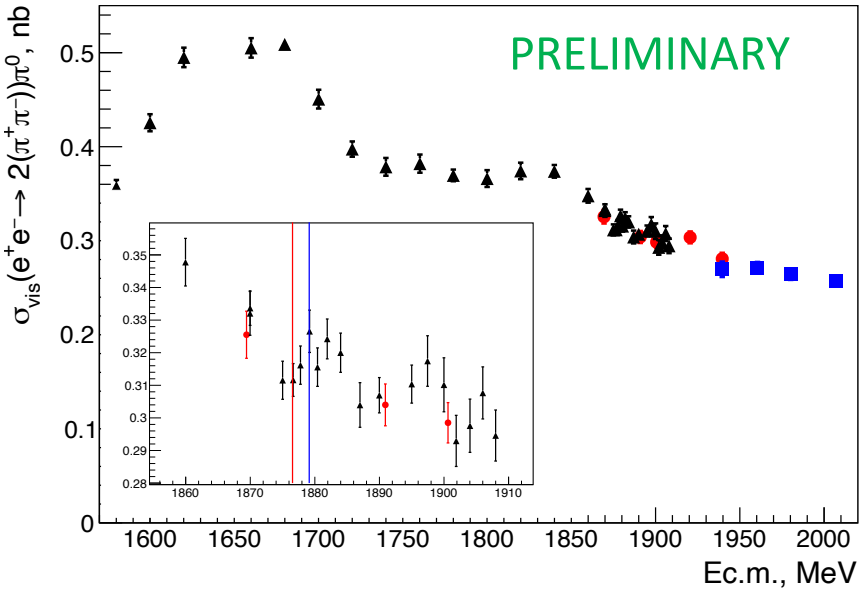


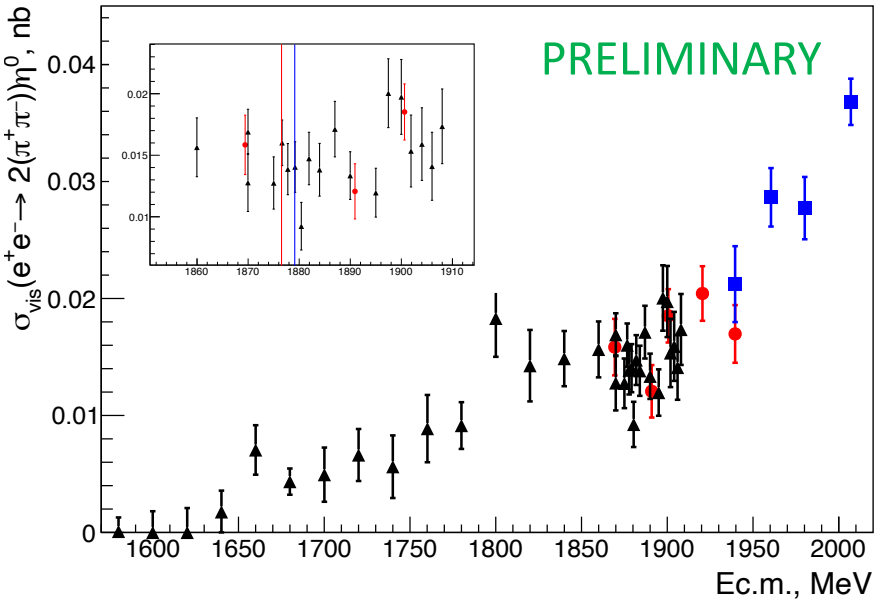




Nothing is seen for the e+e- -> $\pi^+\pi^-\pi^+\pi^-$ and e+e- -> $\pi^+\pi^-\pi^0\pi^0$ reactions !!

# How about other reactions?

First look to visible (number of events/luminosity) cross sections (no corrections)

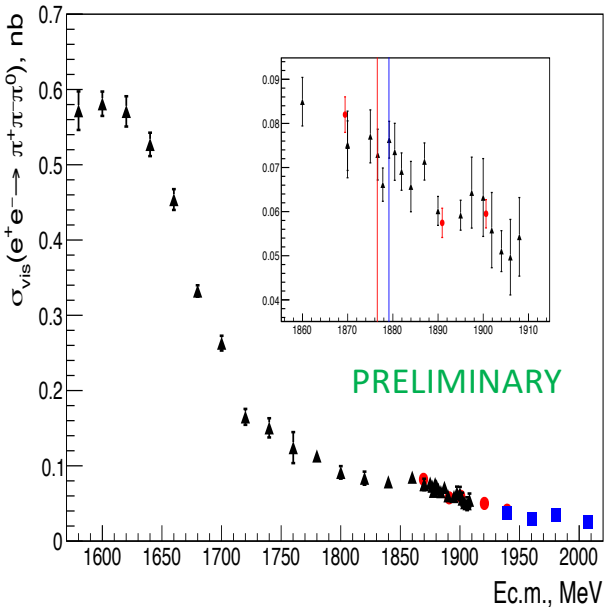


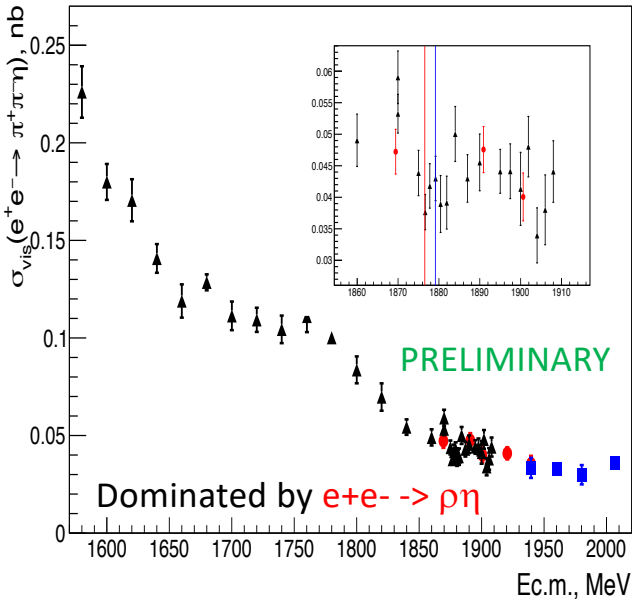



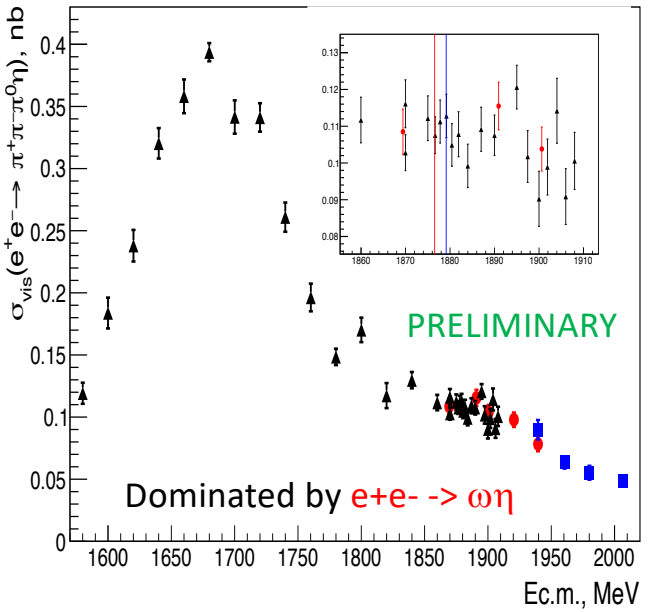

Nothing is seen for the e+e- -> $\pi^+\pi^-\pi^+\pi^-\pi^0$ and e+e- -> $\pi^+\pi^-\pi^+\pi^-\eta$ reactions !!

# How about other reactions?

First look to visible (number of events/luminosity) cross sections (no corrections)




Nothing is seen for the e+e- -> $\pi^+\pi^-\pi^0$ , e+e- -> $\pi^+\pi^-\eta$, and e+e- -> $\pi^+\pi^-\pi^0\eta$ reactions !!

# CONCLUSION

- New small-step energy scans have been performed at the VEPP2000 $e^+e^-$ collider with the significantly increased (x5) integrated luminosity.
- First preliminary results from CMD-3 confirms a fast cross section changing in the $e^+e^-$ ->ppbar, $e^+e^-$ -> $3(\pi^+\pi^-)$, $2(\pi^+\pi^-)2\pi^0$ and $K^+K^-\pi^+\pi^-$ reactions at the NNbar threshold. Explained by theory. Can we extract any useful parameters?
- NO other hadronic reactions exhibit structure at the NNbar threshold in the $e^+e^-$ collisions. Why? Ideas are needed.
- May be the question is – why step is so large in the $e^+e^-$ -> $3(\pi^+\pi^-)$ reaction?
- We plan to investigate this effect, study the cross section and production dynamic for the hadronic reactions.

THANK YOU