



experiments on VEPP-2 e^+e^- collider in Novosibirsk

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(for CMD-3 collaboration)

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SB RAS, Novosibirsk, Russia***

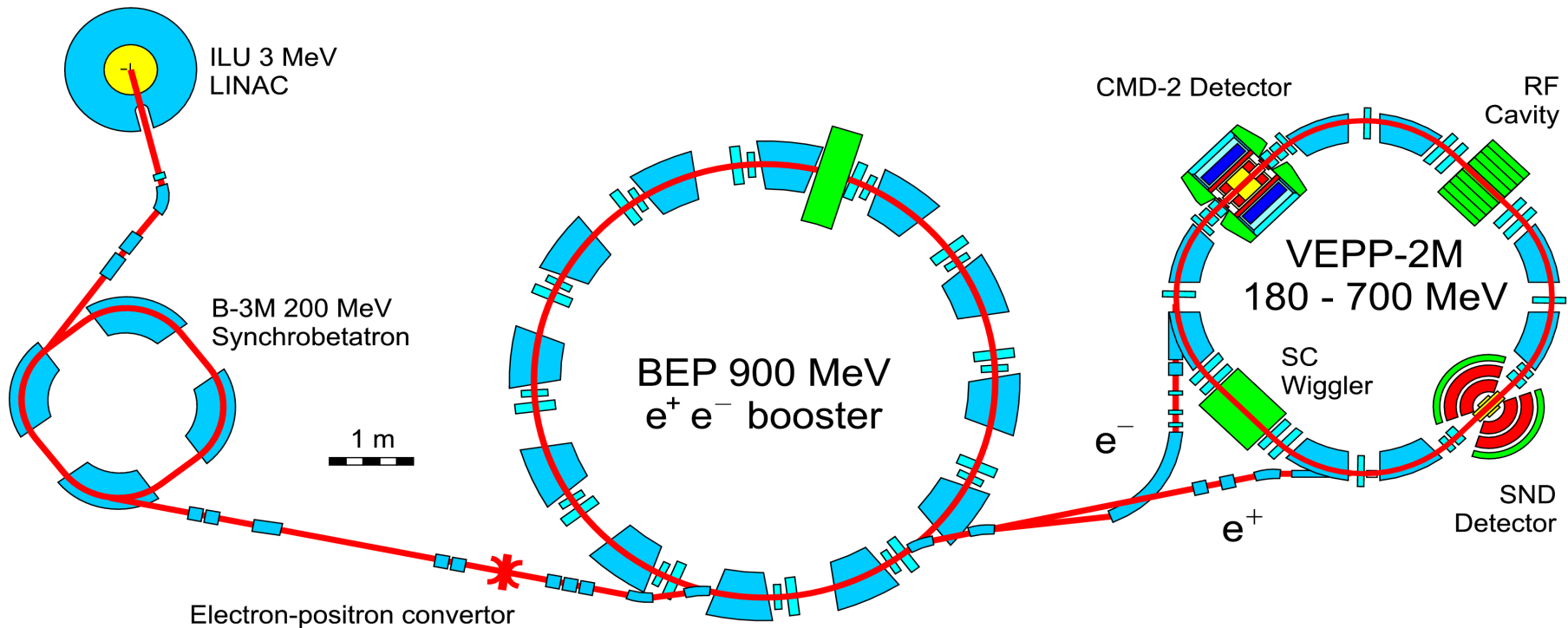
Pisa, September 2011



OUTLINE

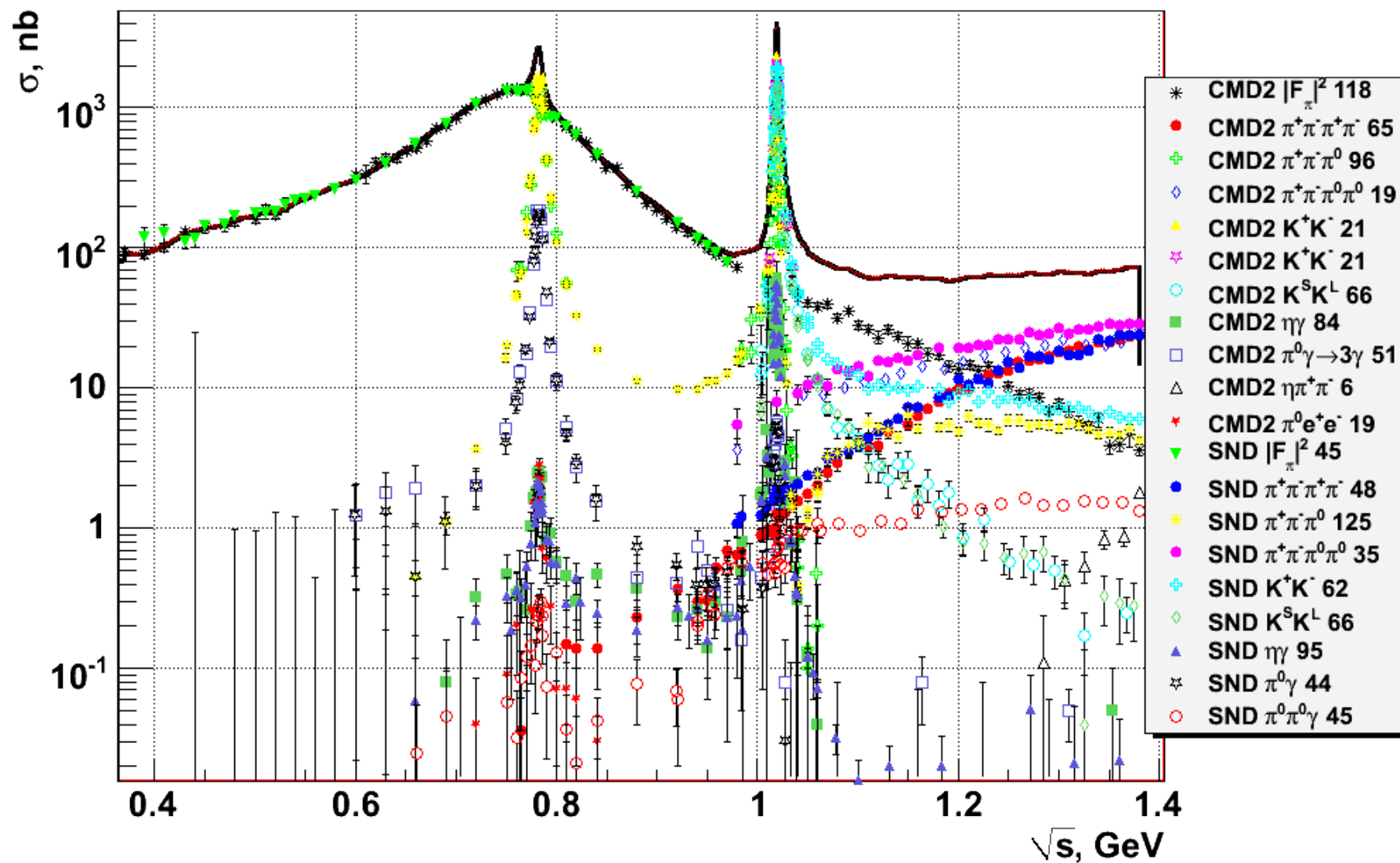
- 1 - VEPP-2000 collider, motivation, construction, performance
- 2 - Physics program
- 3 - SND and CMD-3 detectors
- 4 - first preliminary results
- 5 - status of $(g-2)/2$ calculations

VEPP-2M collider complex (1974-2000)



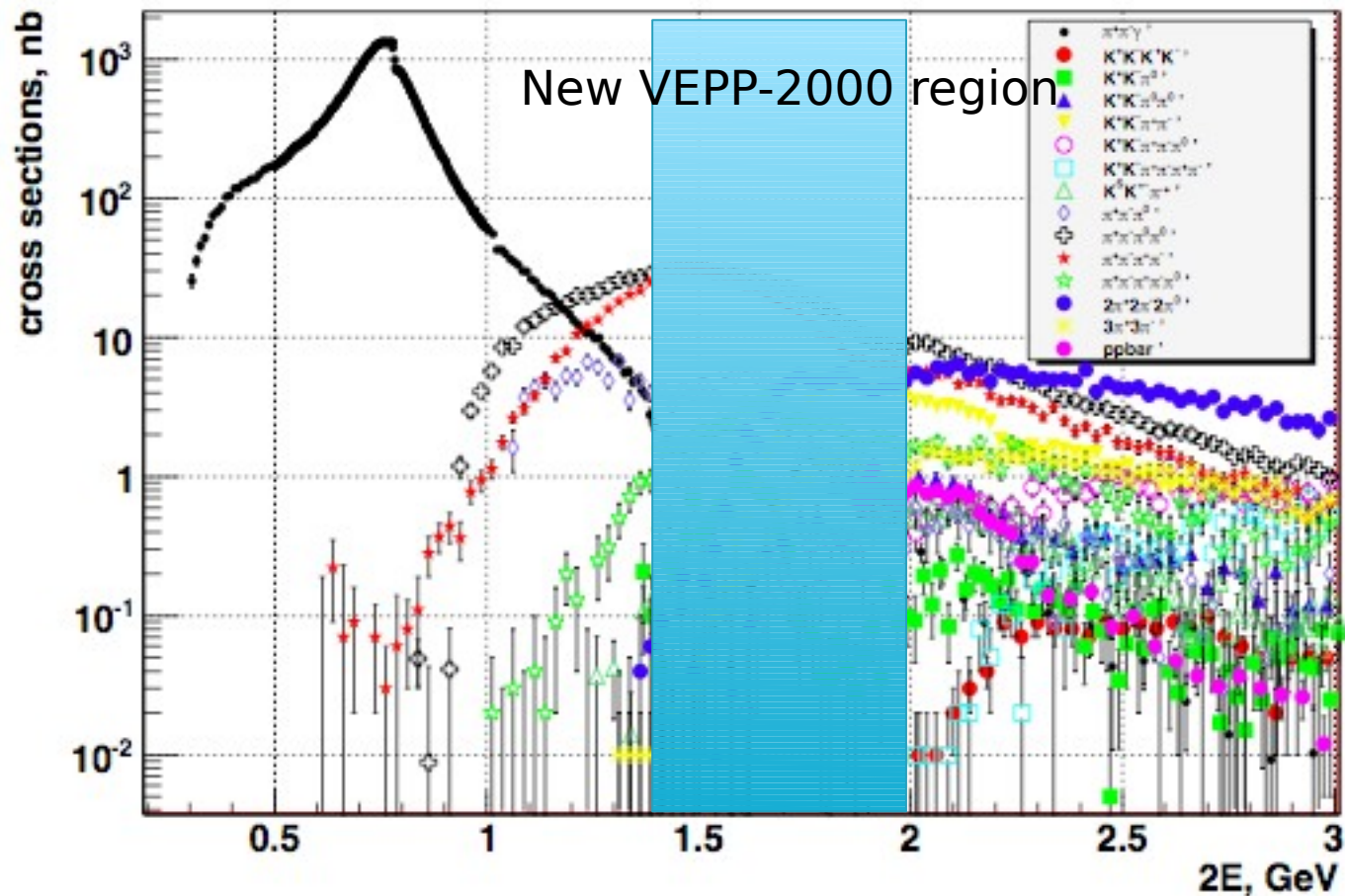
- High luminosity: $L=3 \times 10^{30} \text{ cm}^{-2}\text{s}^{-1}$:
- Energy range 360 - 1400 MeV
- Method of resonant depolarization - precise value of energy beam
- $\rho, \omega, \phi, K^{\pm}, K^0$ mass measurements
- e⁺e⁻ anomalous magnetic moment comparison (10-11)

Overview of VEPP-2M results



1-5% systematic error for major channels

More BaBar data are available



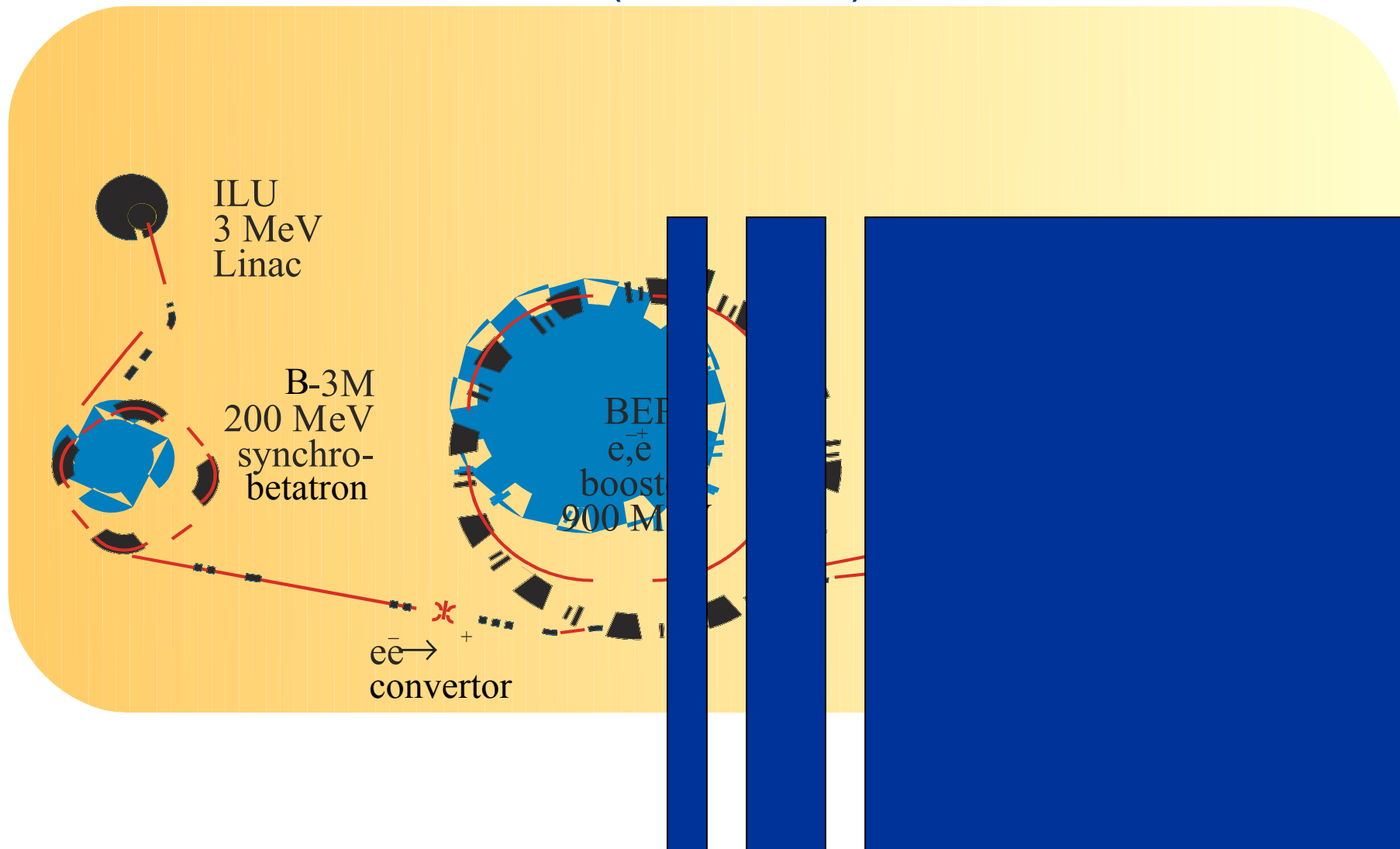
1-5% systematic errors

to obtain R in the energy range 1-2 GeV the processes $\pi^+\pi^-3\pi^0$, $\pi^+\pi^-4\pi^0$, K^+K^- , $K_S K_L$, $K_S K_L \pi\pi$, $K_S K^+ \pi^-\pi^0$ remain to be measured

VEPP-2M

VEPP-

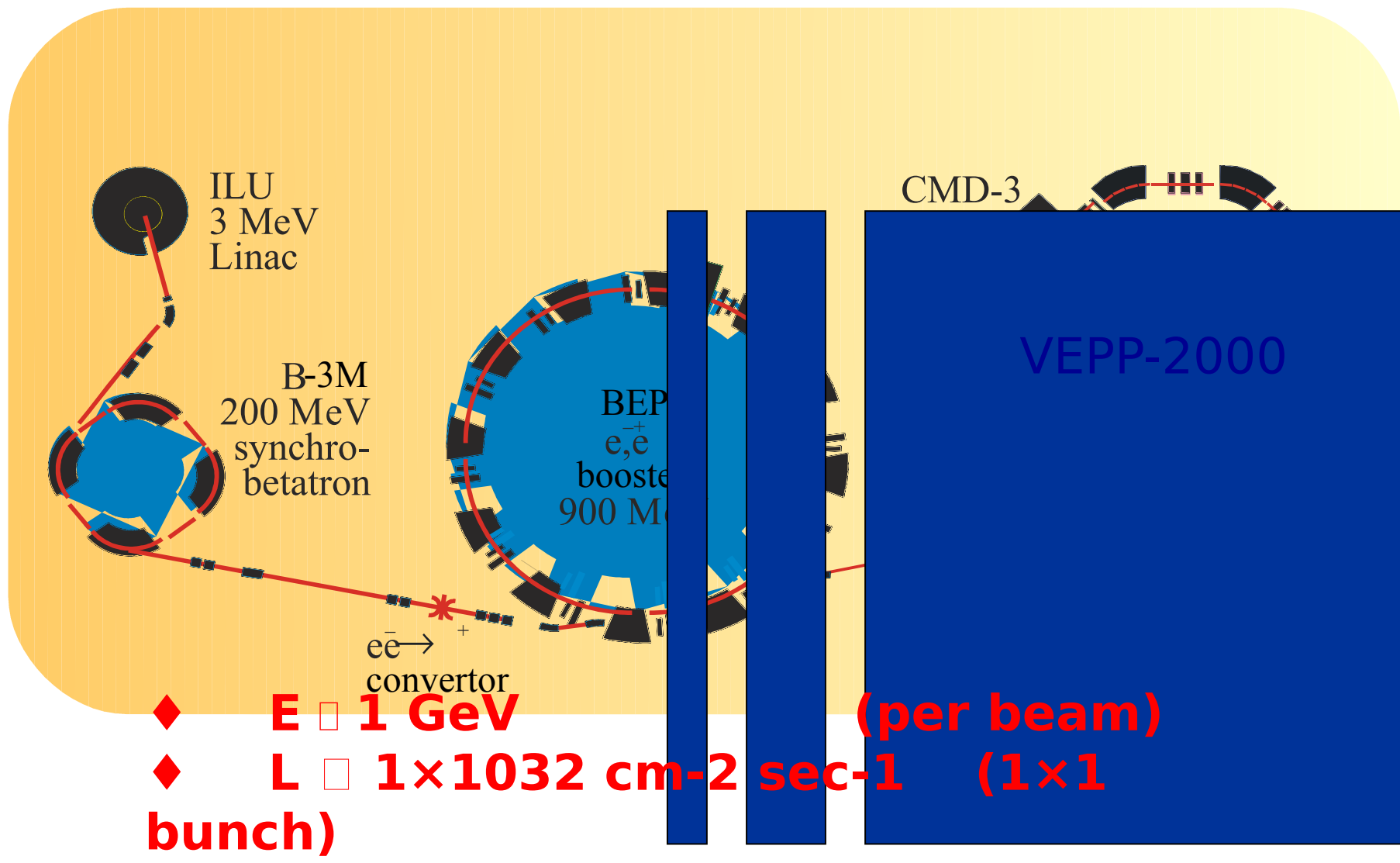
2000
(2000-2007)



VEPP-2M

VEPP-

2000
(2000-2007)



Round beams design



□ Bunch-by-bunch luminosity

$$L = \frac{\pi \gamma^2 \xi_x \xi_y \varepsilon_x f}{r_e^2 \beta_y^*} \left(1 + \frac{\sigma_y}{\sigma_x} \right)^2$$

Round Beams:

$$L = \frac{4\pi \gamma^2 \xi^2 \varepsilon f}{r_e^2 \beta^*}$$

• Geometric factor (gain=4)

• Beam-beam limit enhancement (gain~4)

revolution time -	82 ns
beam current -	200 mA
beam length -	3.3 c
energy spread -	0.7 MeV
circumference -	24.4 m
beta function in IP	$\beta_x = \beta_z = 4.3 \text{ cm}$
$L = 1032 \text{ cm}^{-2}\text{s}^{-1}$	at $2E = 2.0 \text{ GeV}$
$L = 1031 \text{ cm}^{-2}\text{s}^{-1}$	at $2E = 1.0 \text{ GeV}$

Integrated luminosity ~ 100 pb⁻¹ per detector/year

Total integrated luminosity with all detectors on VEPP-2M ~ 70 p

First “mile stones” of VEPP-2000

Click to edit Master text style
(14.05.2001)
Second level

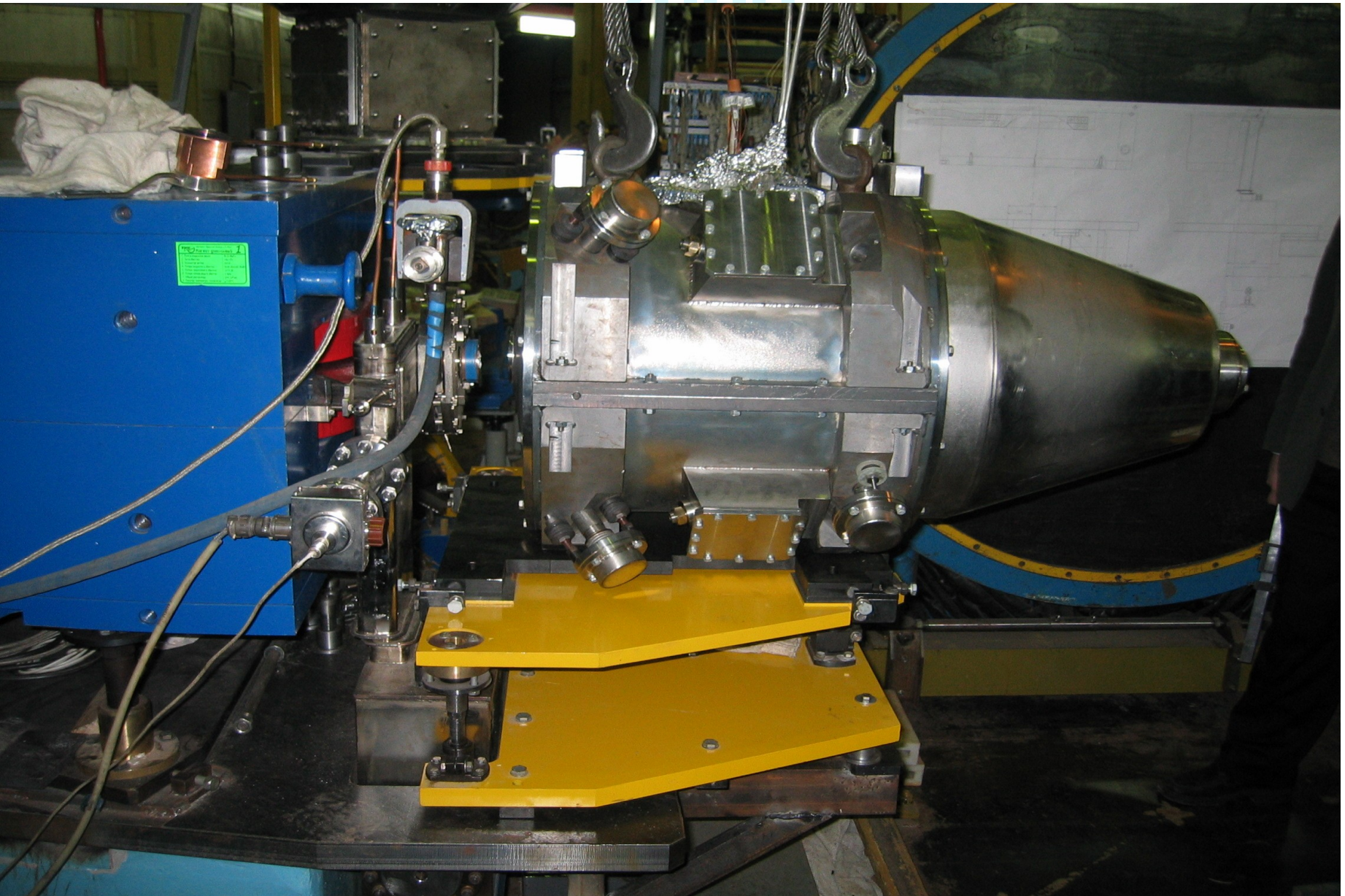
- Third level
- Fourth level
- Fifth level



NOW

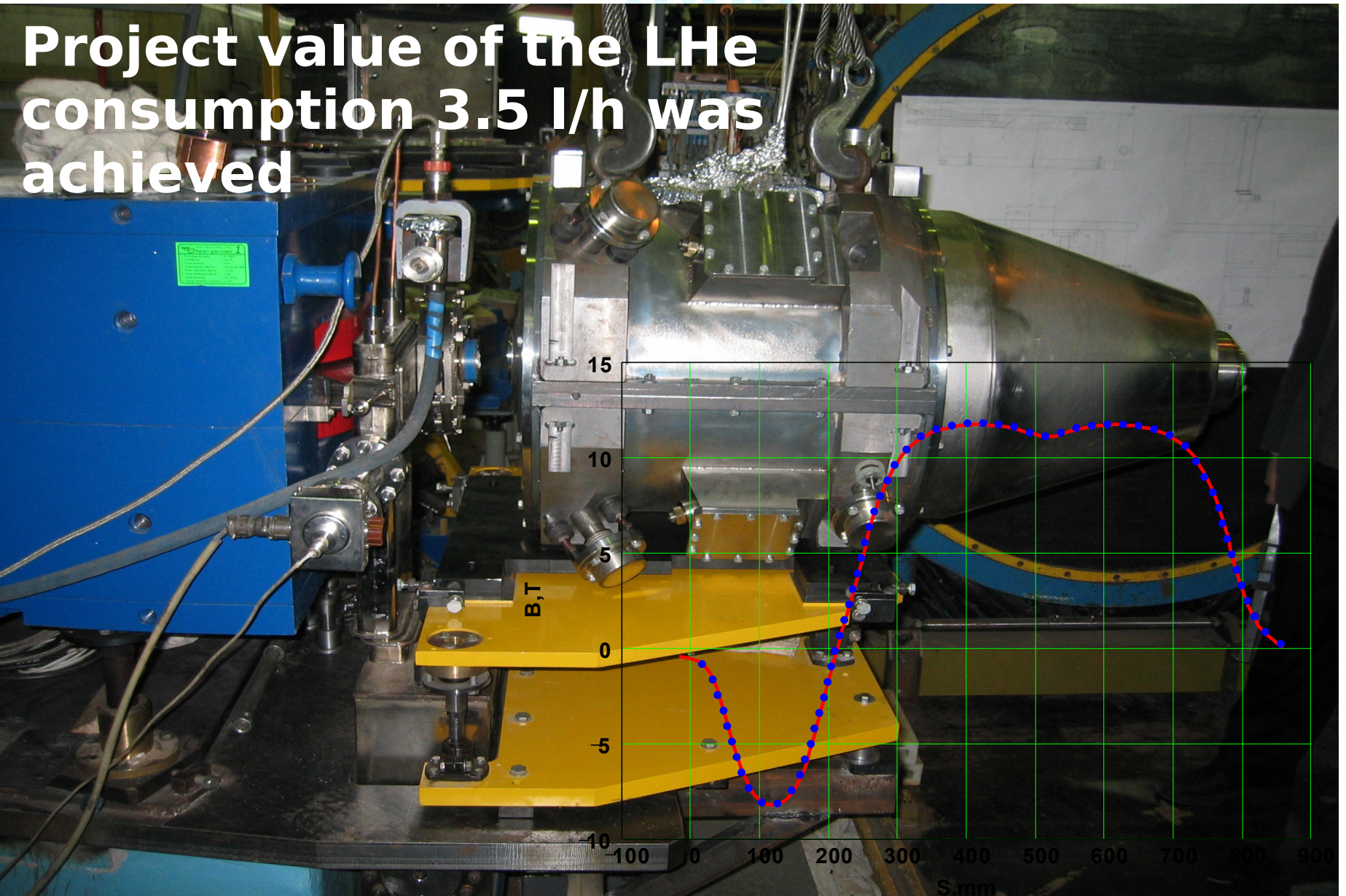


Solenoid 13.0 T at VEPP-2000

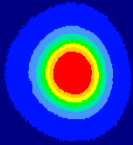


Solenoid 13.0 T at VEPP-2000

Project value of the LHe consumption 3.5 l/h was achieved

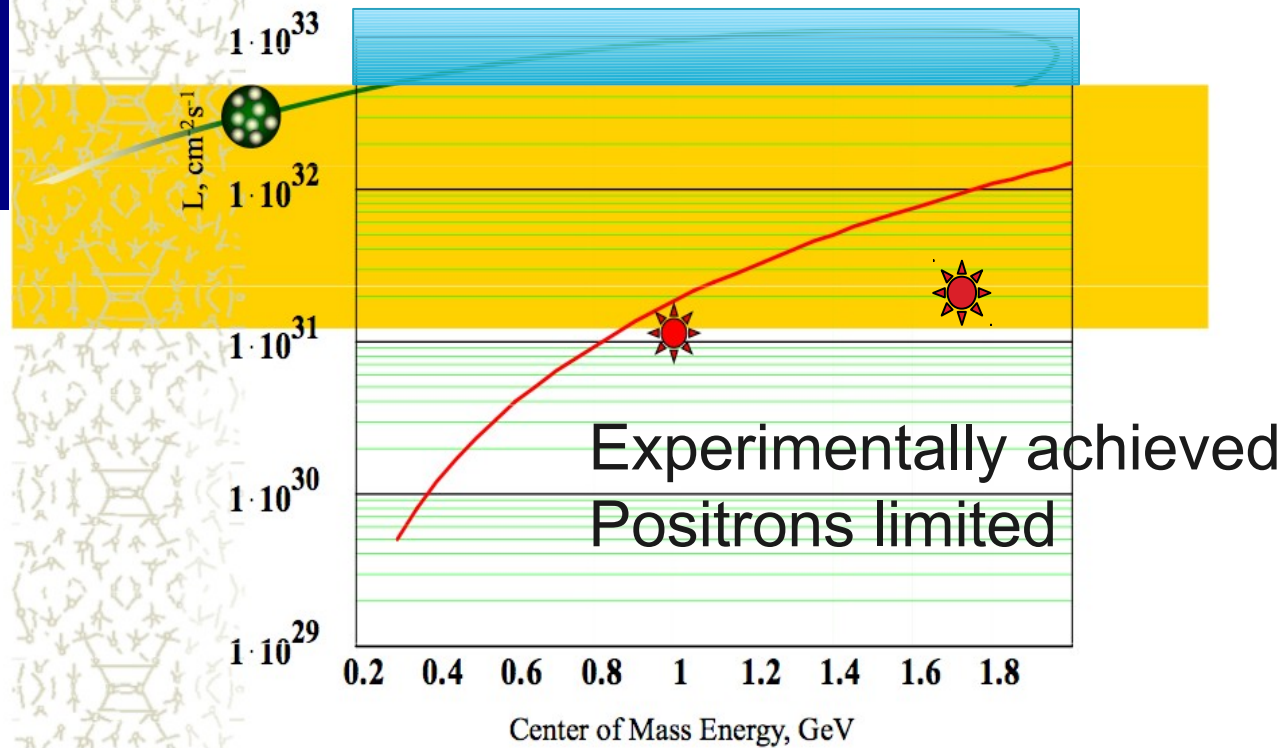


Round beams



#1 (1M2)

VEPP-2000 Luminosity



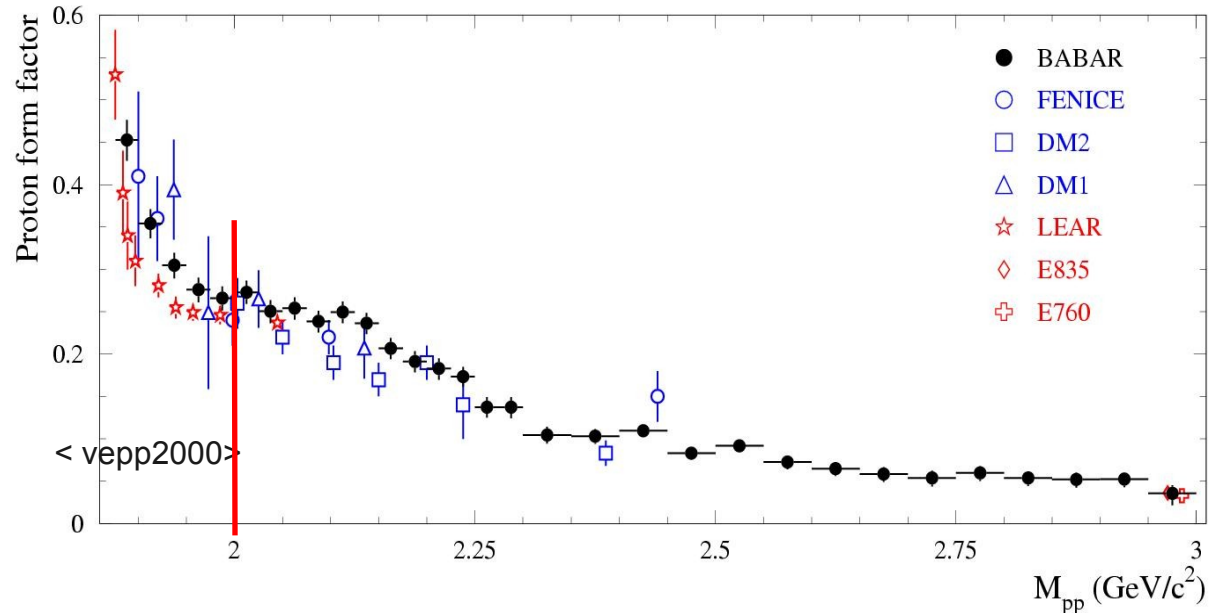
Physics program at VEPP-2000

1. Precise measurement of the quantity
 $R = \sigma(e^+e^- \rightarrow \text{hadrons}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$ - **GOAL <1%** systematic for major channels (now 1 - 5 %)
2. Study of hadronic channels:
 $e^+e^- \rightarrow 2h, 3h, 4h \dots, h = \pi, K, \eta$
3. Study of 'excited' vector mesons: $\rho', \rho'', \omega', \omega'', \dots$
4. CVC tests: comparison of $e^+e^- \rightarrow \text{hadr. (T=1)}$ cross section with π -decay spectra
5. Study of nucleon-antinucleon pair production - nucleon electromagnetic form factors, search for $NN\bar{\text{resonances}}$, ..
6. Hadron production in 'radiative return' (ISR) processes
7. Two photon physics
8. Test of the QED high order processes $2 \rightarrow 4, 5$

Two detectors have been build for the study

Physics program at VEPP-2000

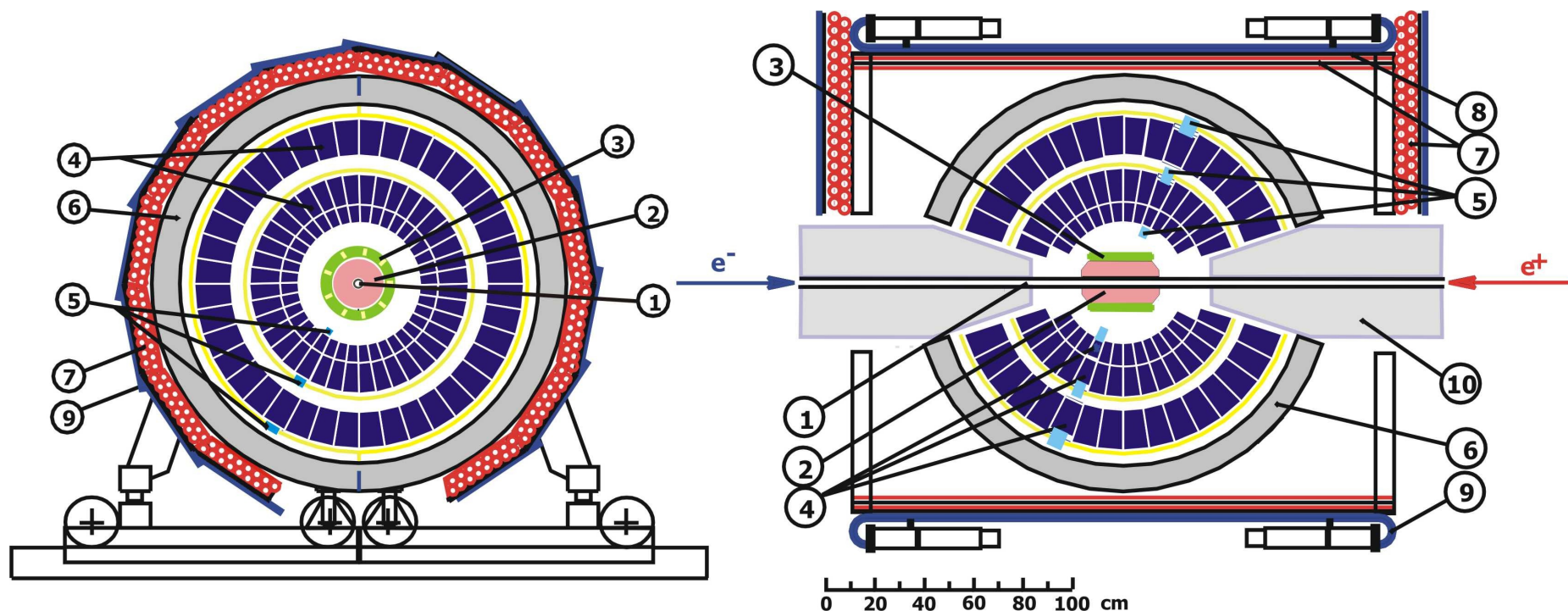
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 nucleon electromagnetic form factors
 search for $N\bar{N}$ resonances
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Two detectors have been build for the study



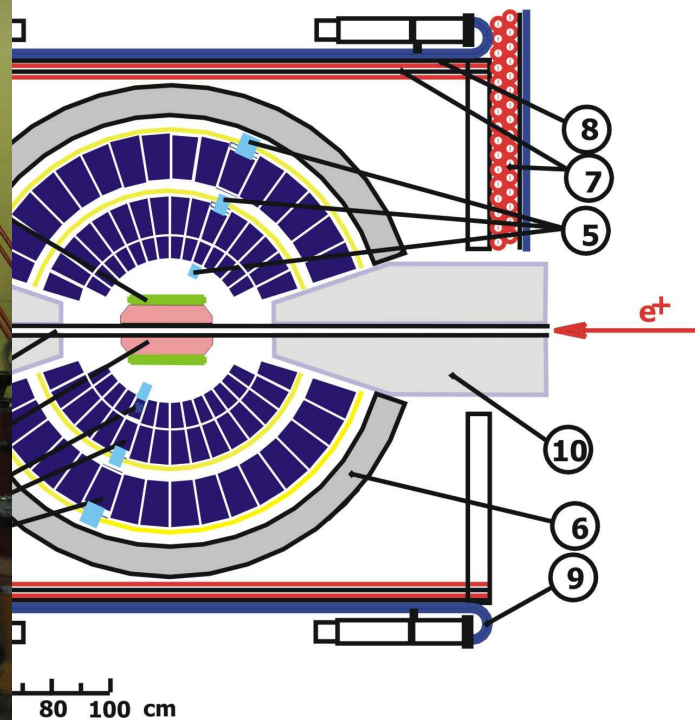
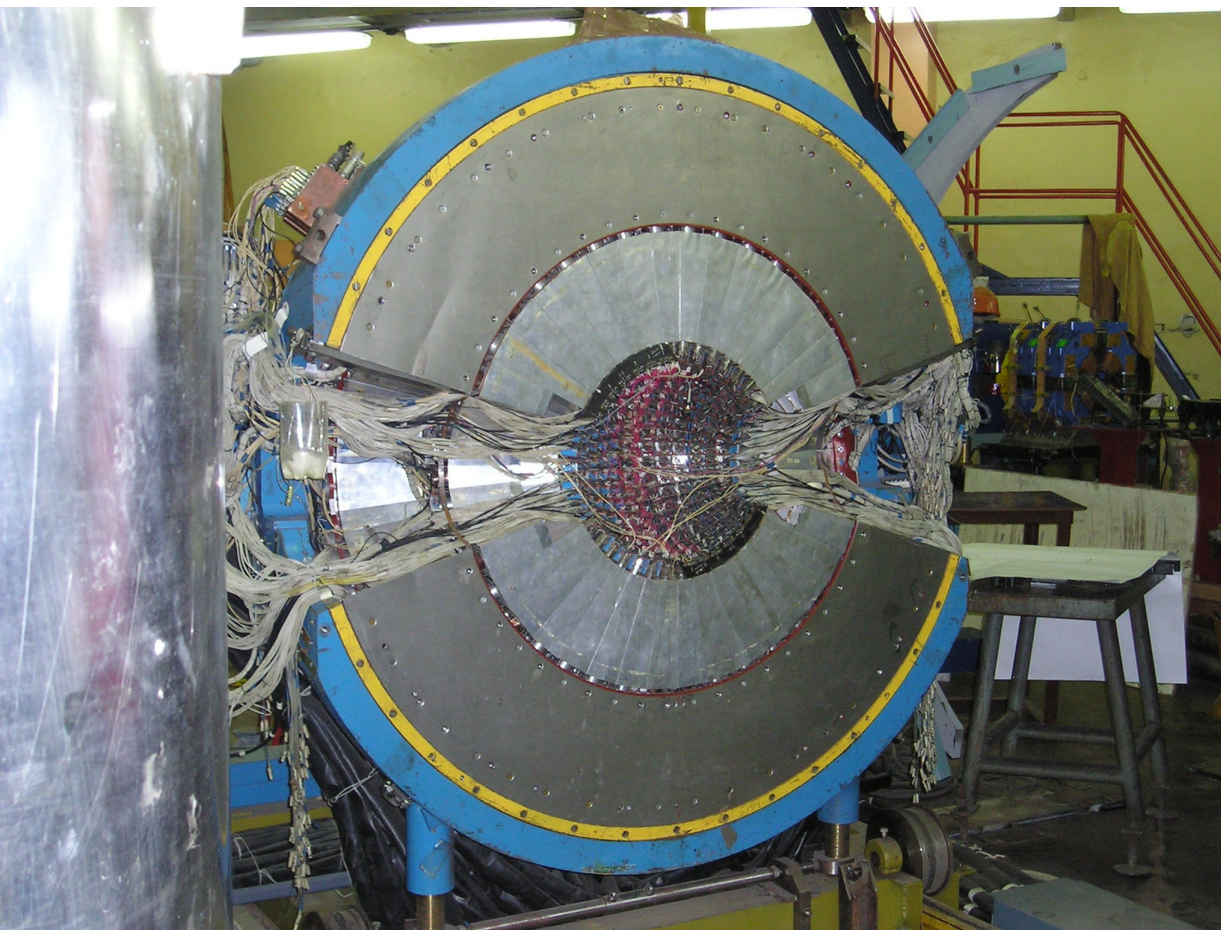
Spherical Neutral Detector



- 1 - VEPP-2000 vacuum chamber, 2 - tracking system,
3 - aerogel counters, 4 - electromagnetic calorimeter NaI(Tl), 5 -
vacuum phototriodes, 6 - absorber, 7-9 - muon system,
10 - VEPP-2000 phocusing solenoid



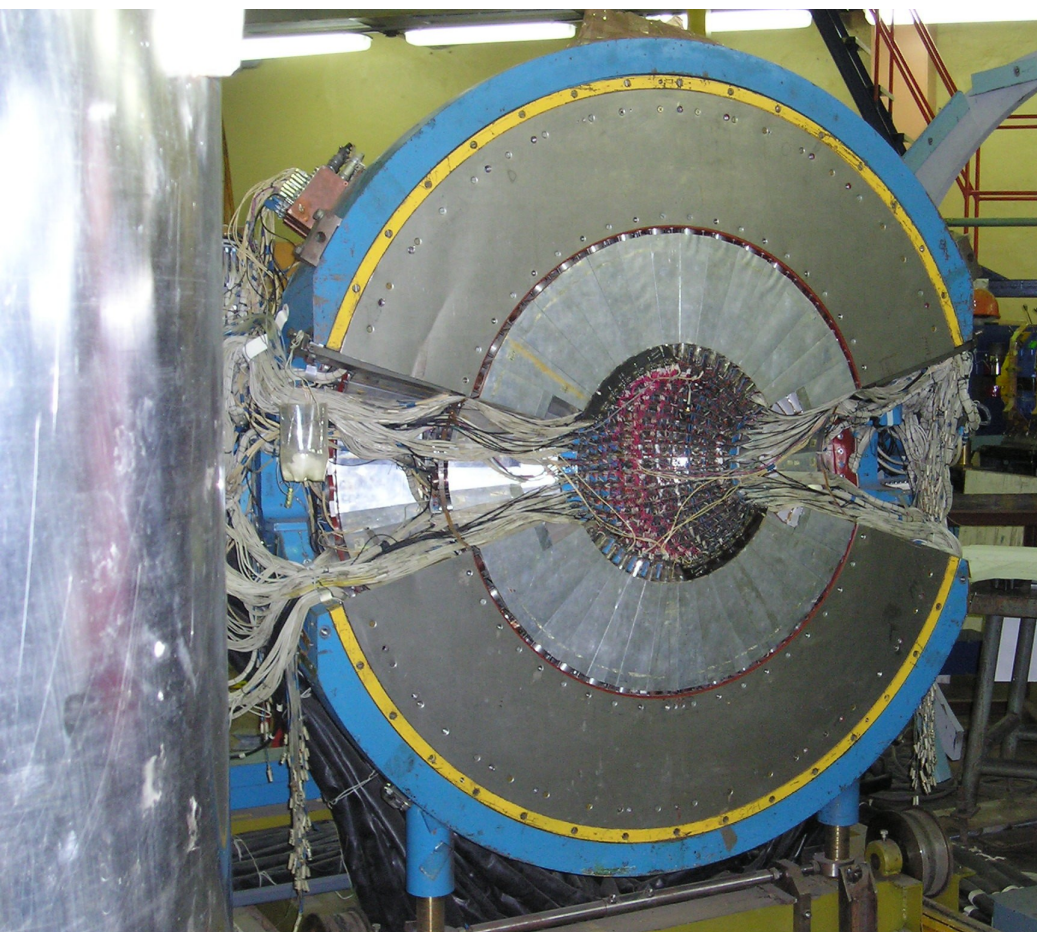
Spherical Neutral Detector



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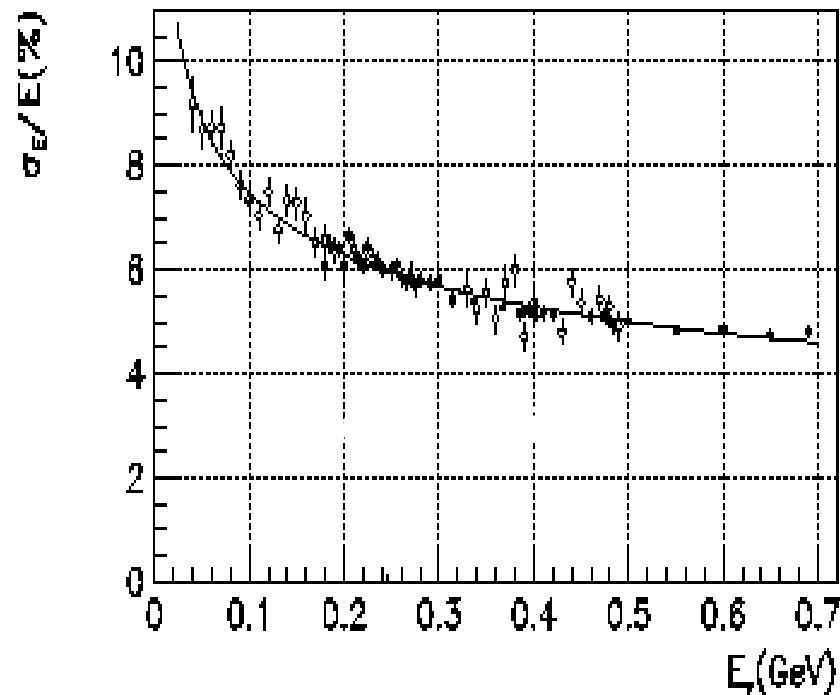


Spherical Neutral Detector



$$\frac{\sigma E}{E} = \frac{4.2\%}{\sqrt[4]{E(\text{GeV})}}$$

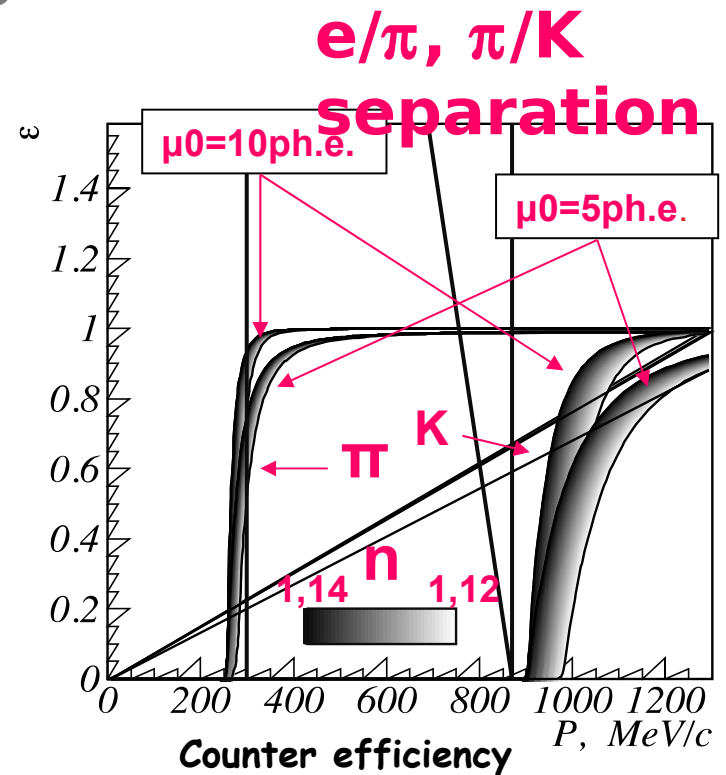
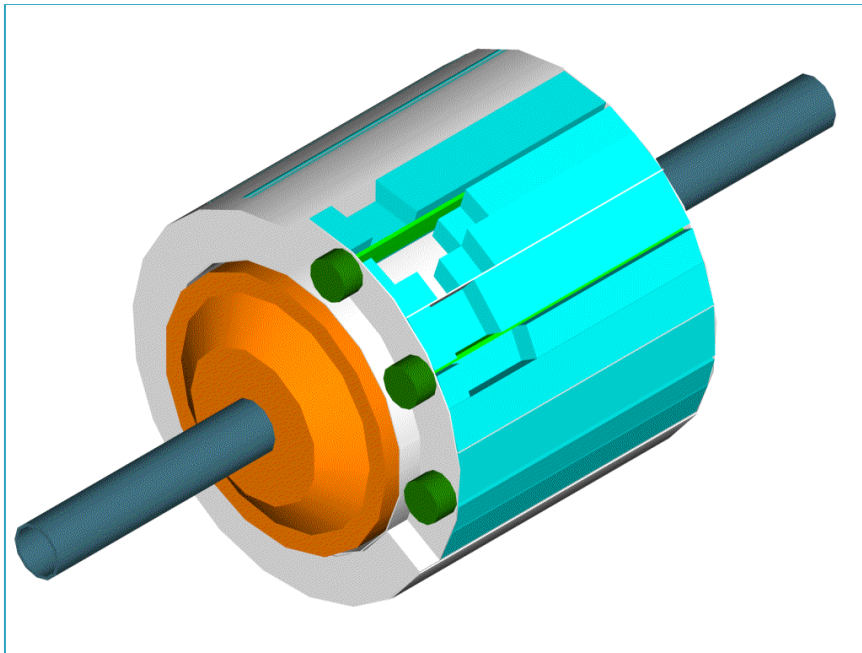
$$\sigma_\phi = \frac{0.82}{\sqrt{E(\text{GeV})}} \oplus 0.63^\circ$$



vacuum phototriodes, 6 - absorber, 7-9 - muon system,
10 - VEPP-2000 focusing solenoid

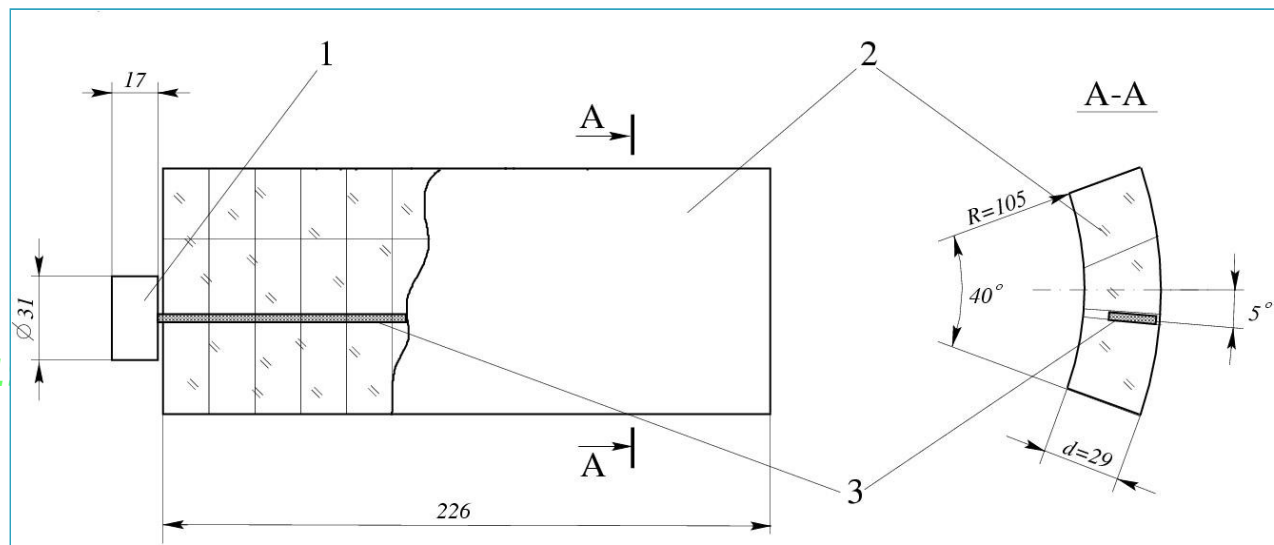


Counters

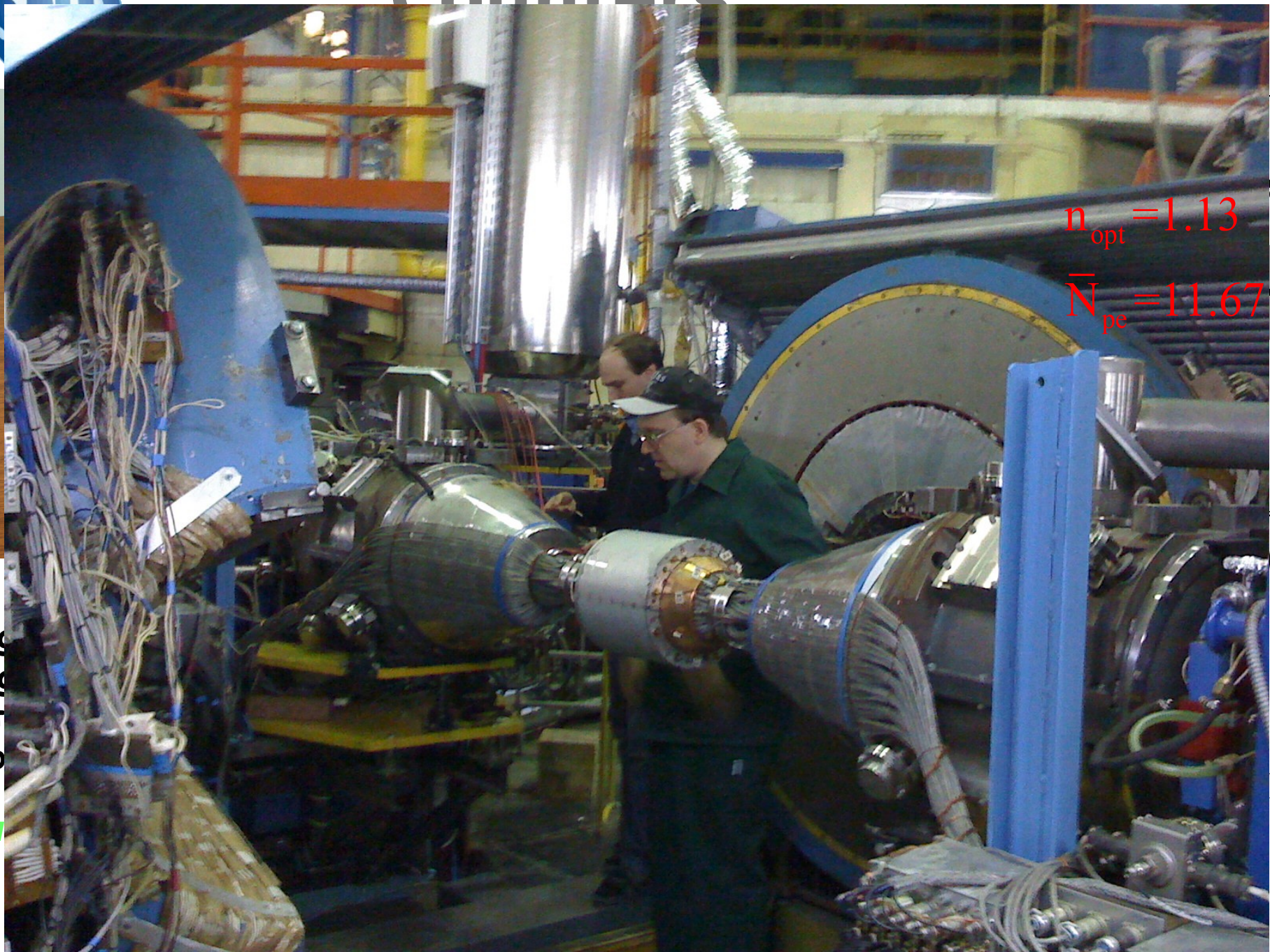


ogel + shifter + PMT
ogel thickness 31 mm
fter turned by 5°
lon coverage ($R=0.98$)

Instrum.Meth.A315:517-520,1



Counters



$$n_{\text{opt}} = 1.13$$

$$\bar{N}_{\text{pe}} = 11.67$$

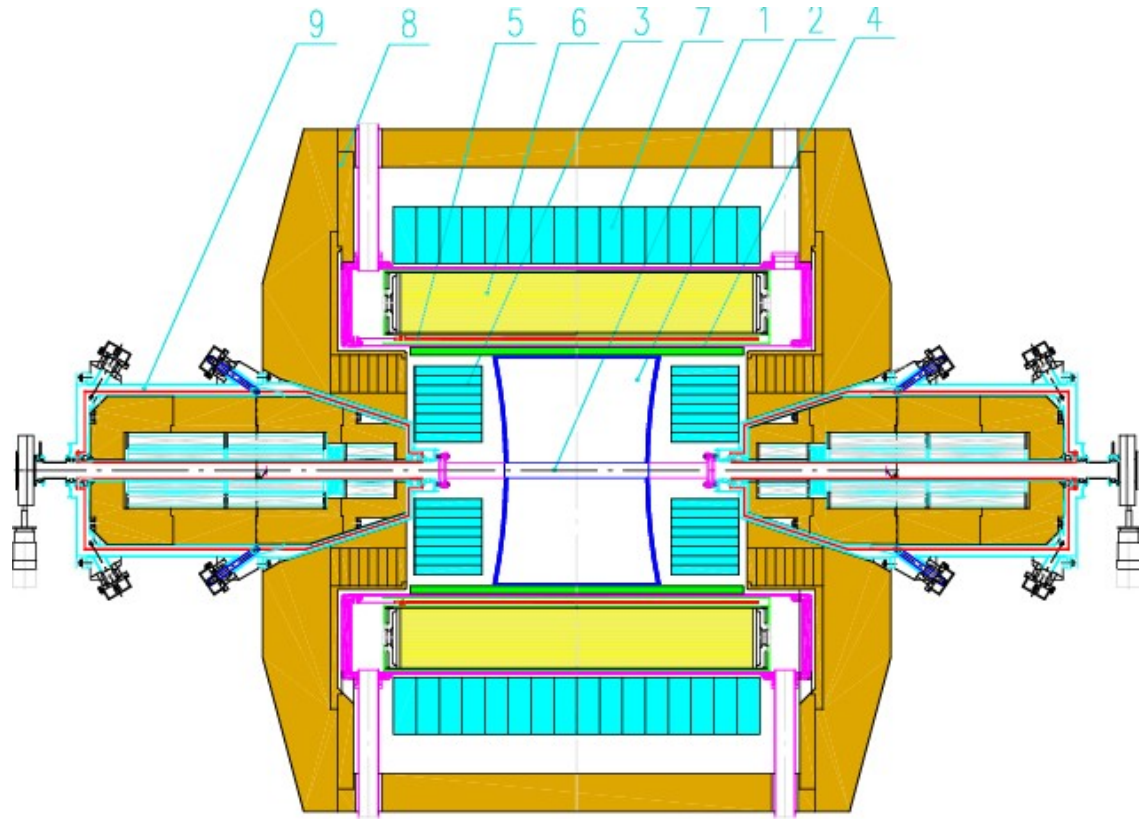
ph.e

5°

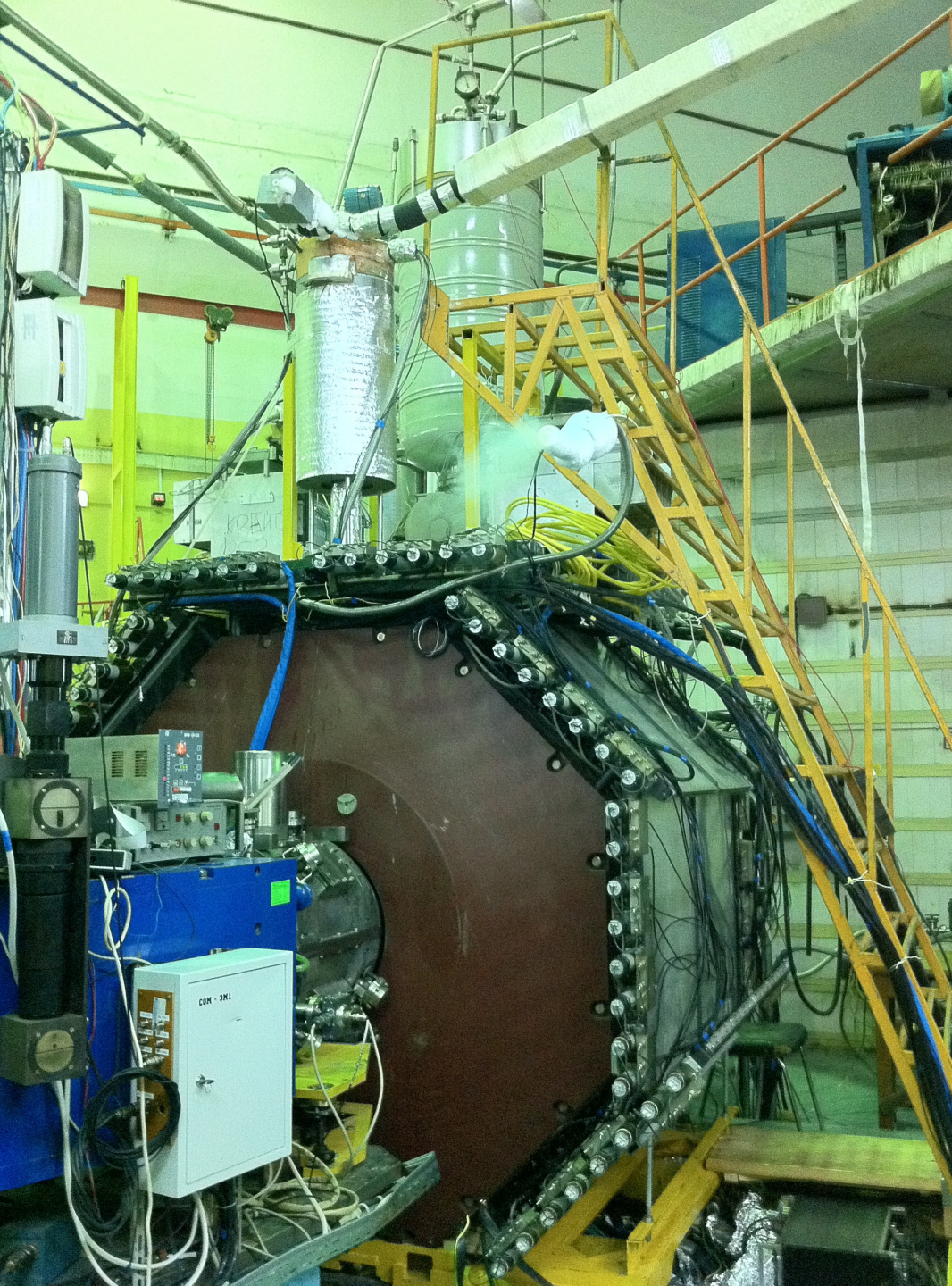


Hyrogenic Magnetic Detector-3

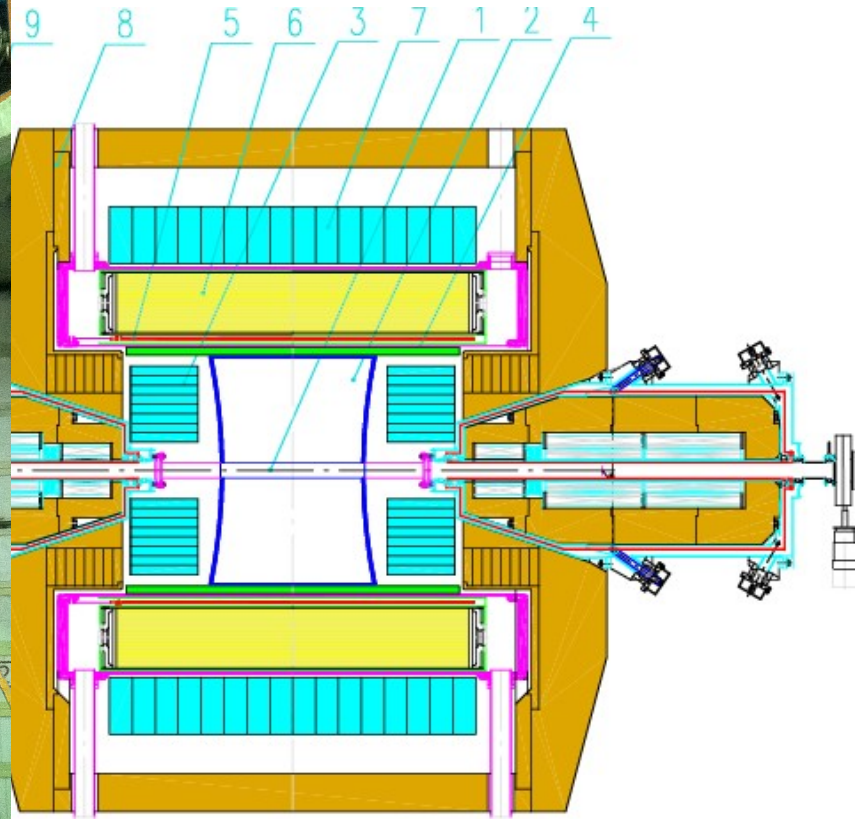
- vacuum chamber
- drift chamber
- electromagnetic calorimeter BGO
- Z - chamber
- CMD SC solenoid



- 6 - electromagnetic calorimeter LXe
- 7 - electromagnetic calorimeter CsI
- 8 - yoke
- 9 - VEPP-2000 solenoid



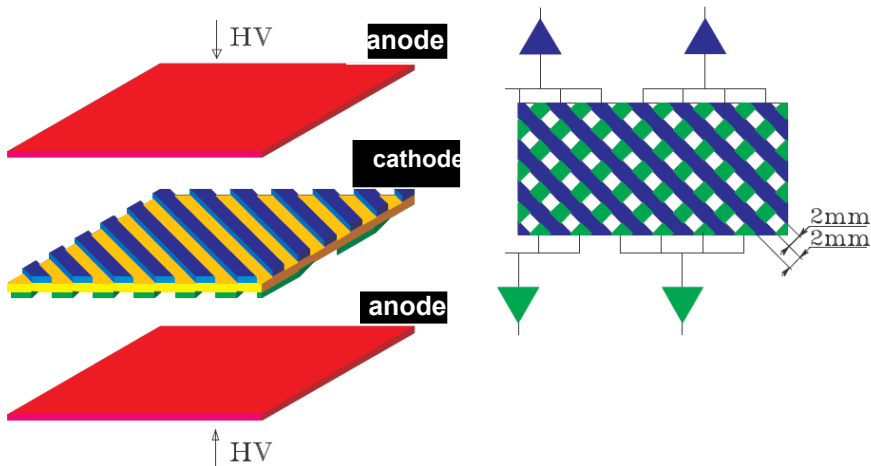
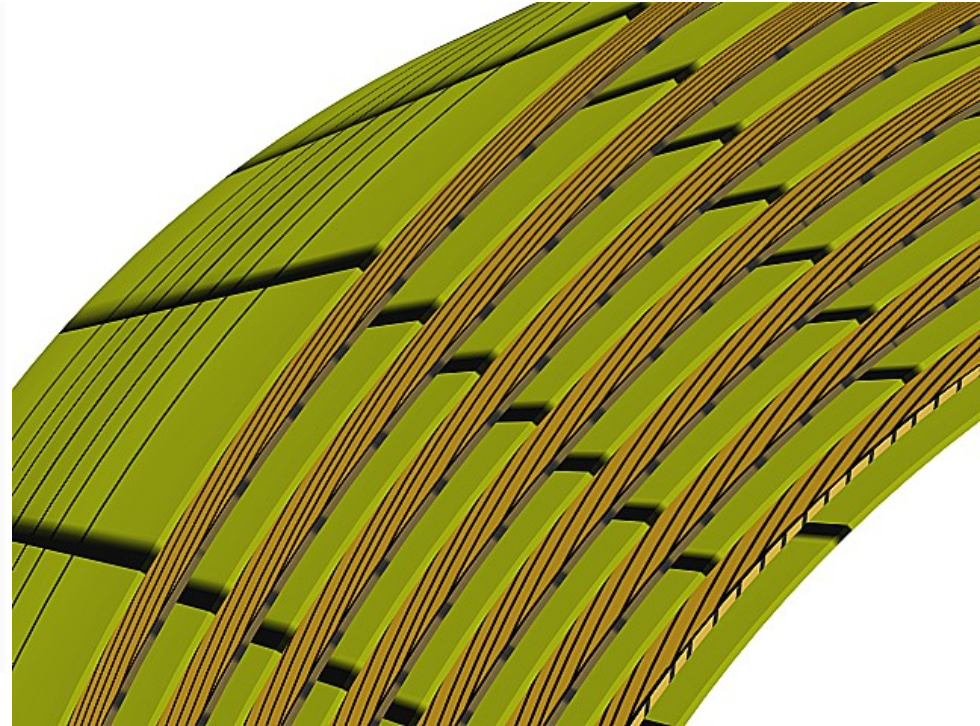
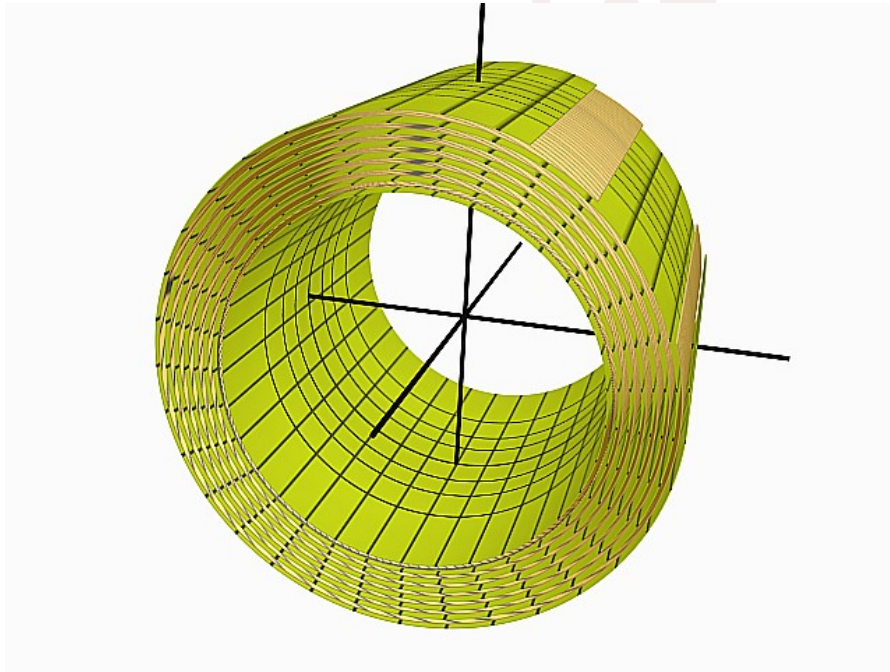
ic Detector-3



- 6 - electromagnetic calorimeter LXe
- 7 - electromagnetic calorimeter CsI
- 8 - yoke
- 9 - VEPP-2000 solenoid

Calorimeter

LXe



5.7 X0 of LXe (400 liters, 1.2 tons)
14 gaps by 10.2 mm
2124 coordinate strips
264 towers

Calorimeter LXe

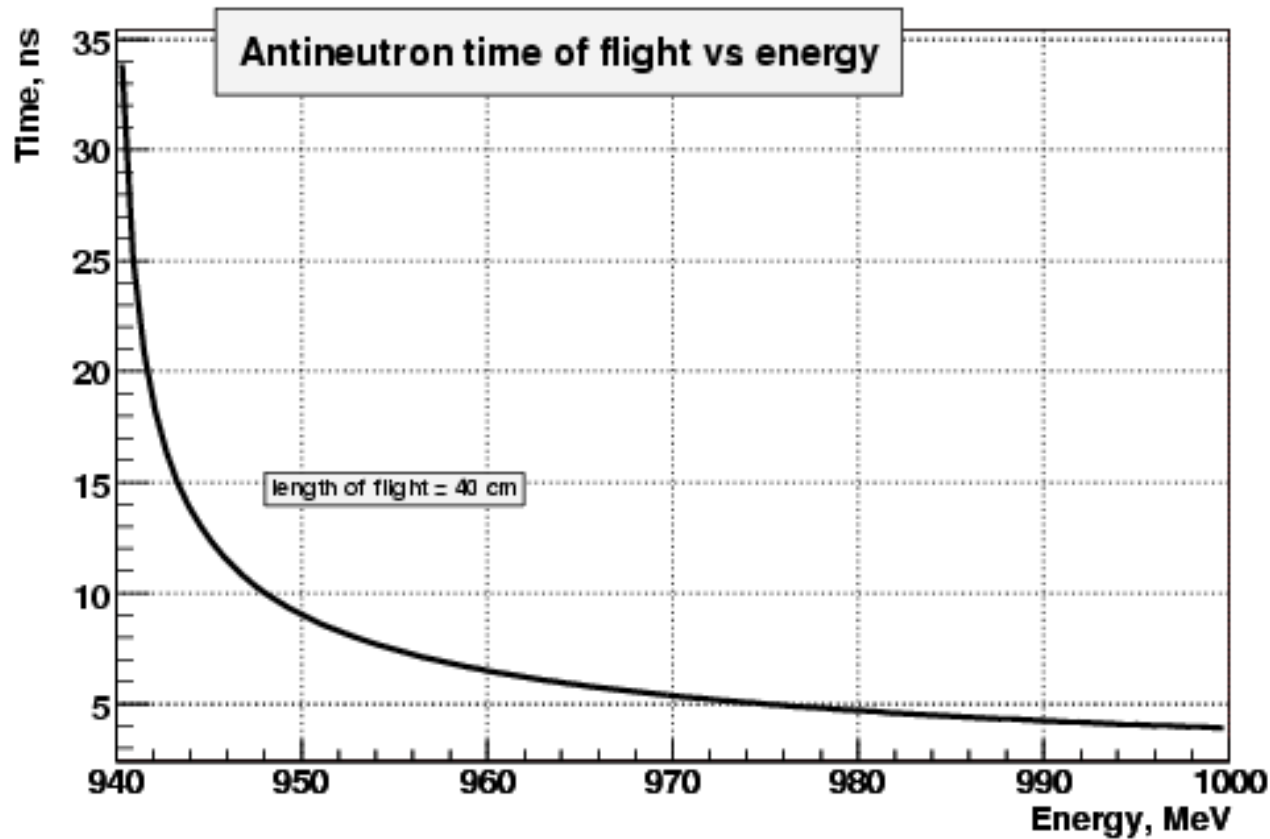


tons)

Particle ID Timing Counter (SCiG)



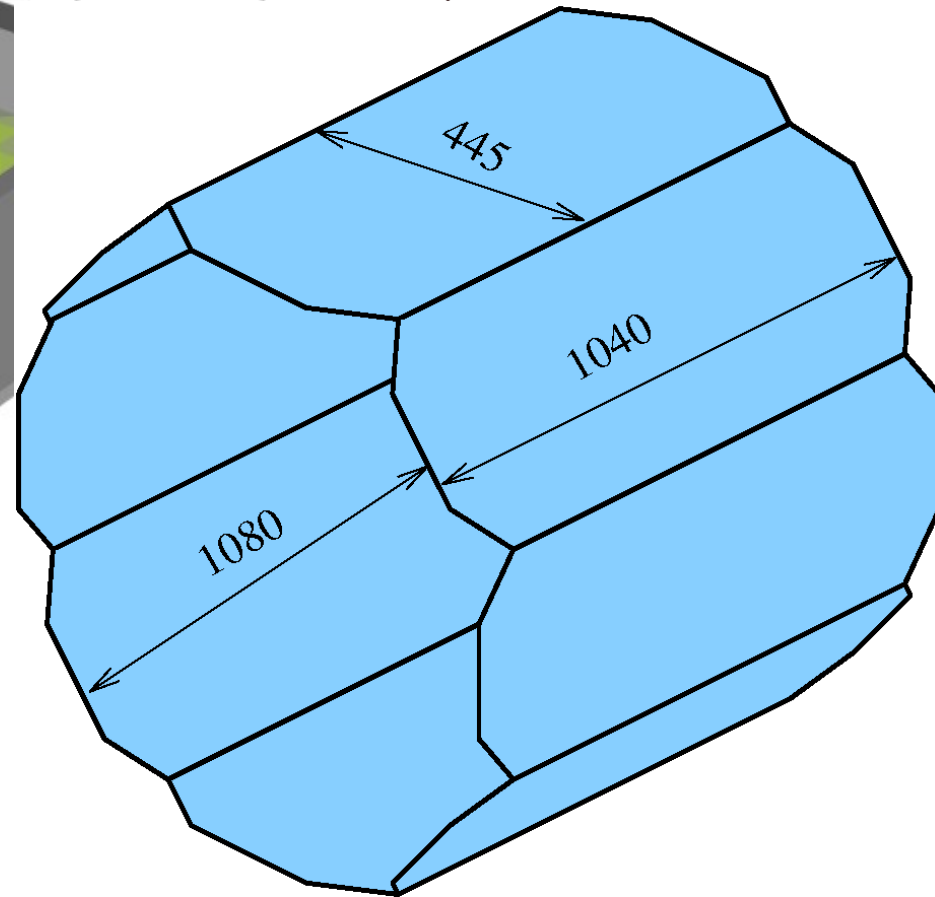
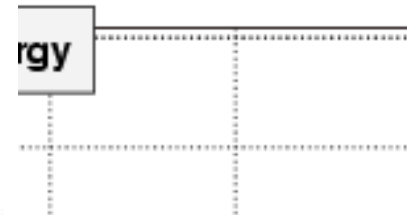
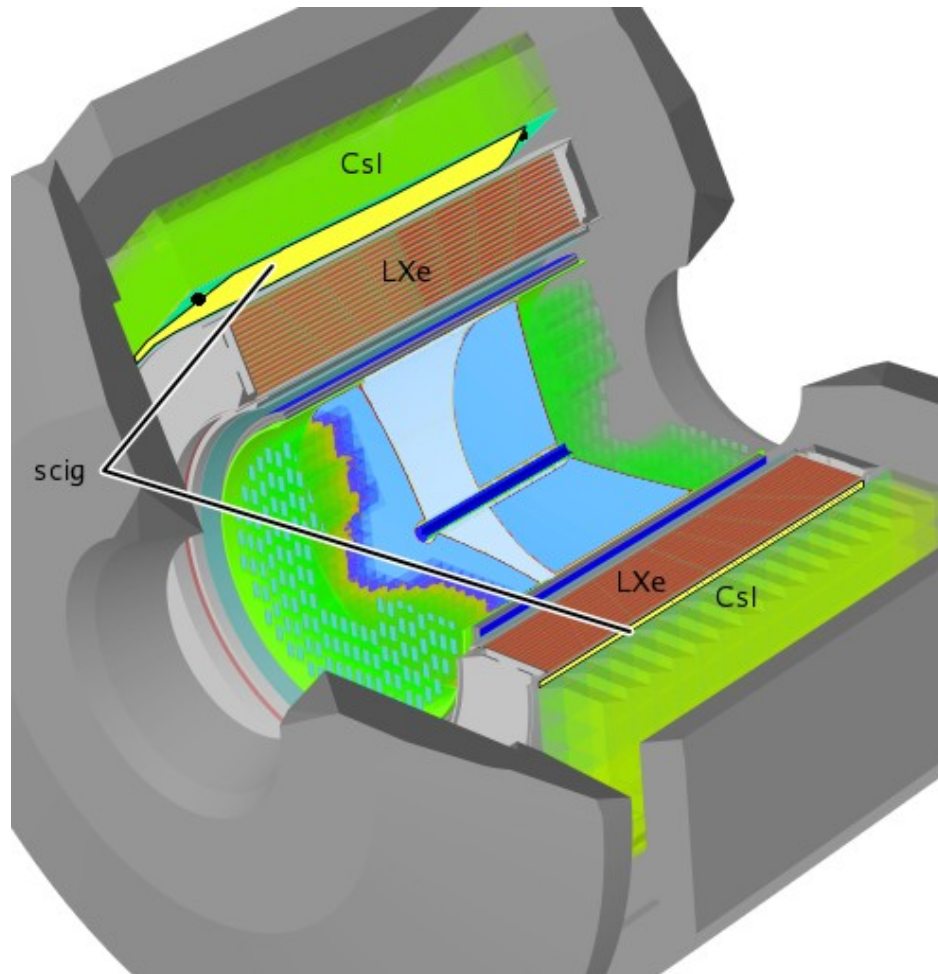
Antineutron identification
in $e^+e^- \rightarrow n \bar{n}$



Particle Identification Counter (SCiG)



Antineutron identification
in $e + \bar{e} \rightarrow n \bar{n}$

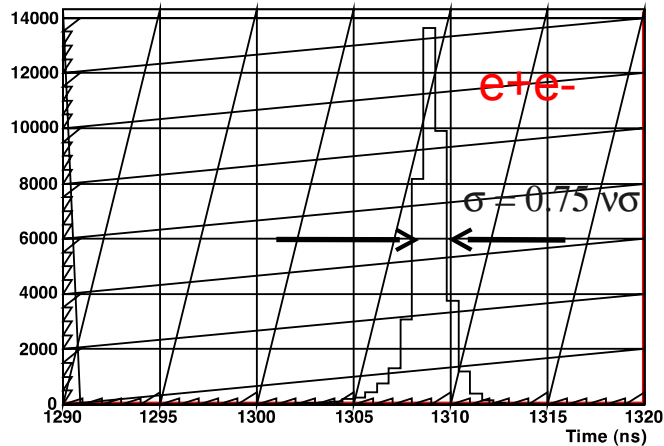
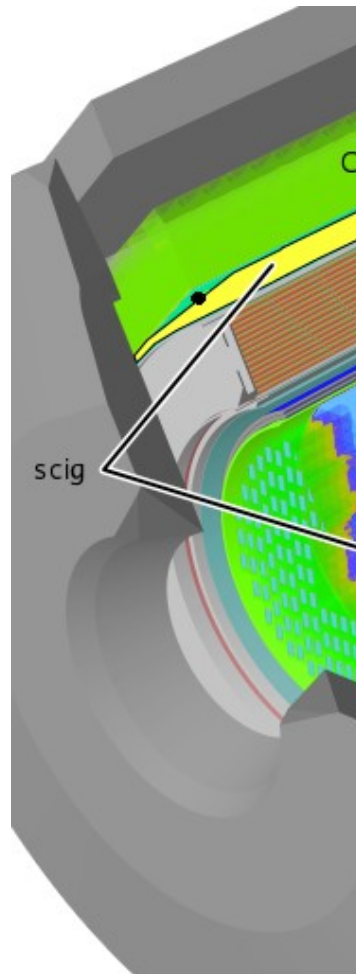


Counter (SCiG)

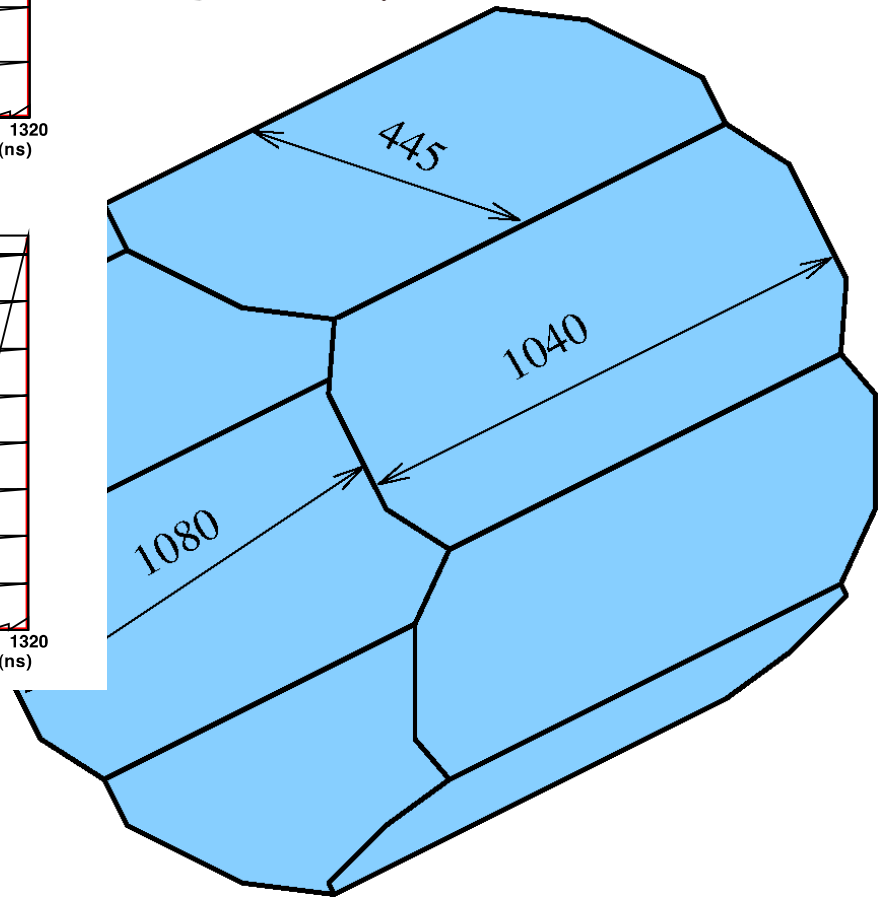
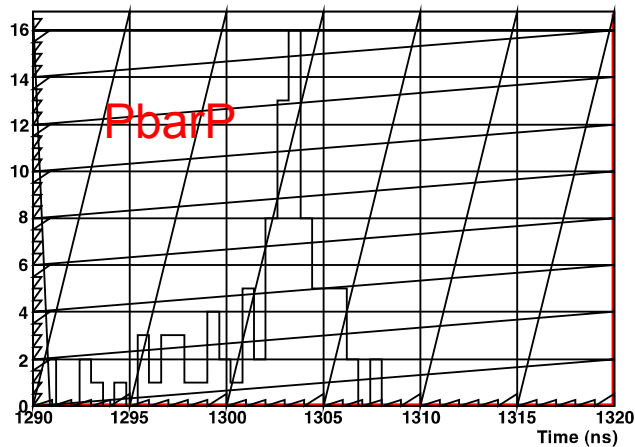


Antineutron identification

$\bar{p} + e^- \rightarrow n + \bar{n}$



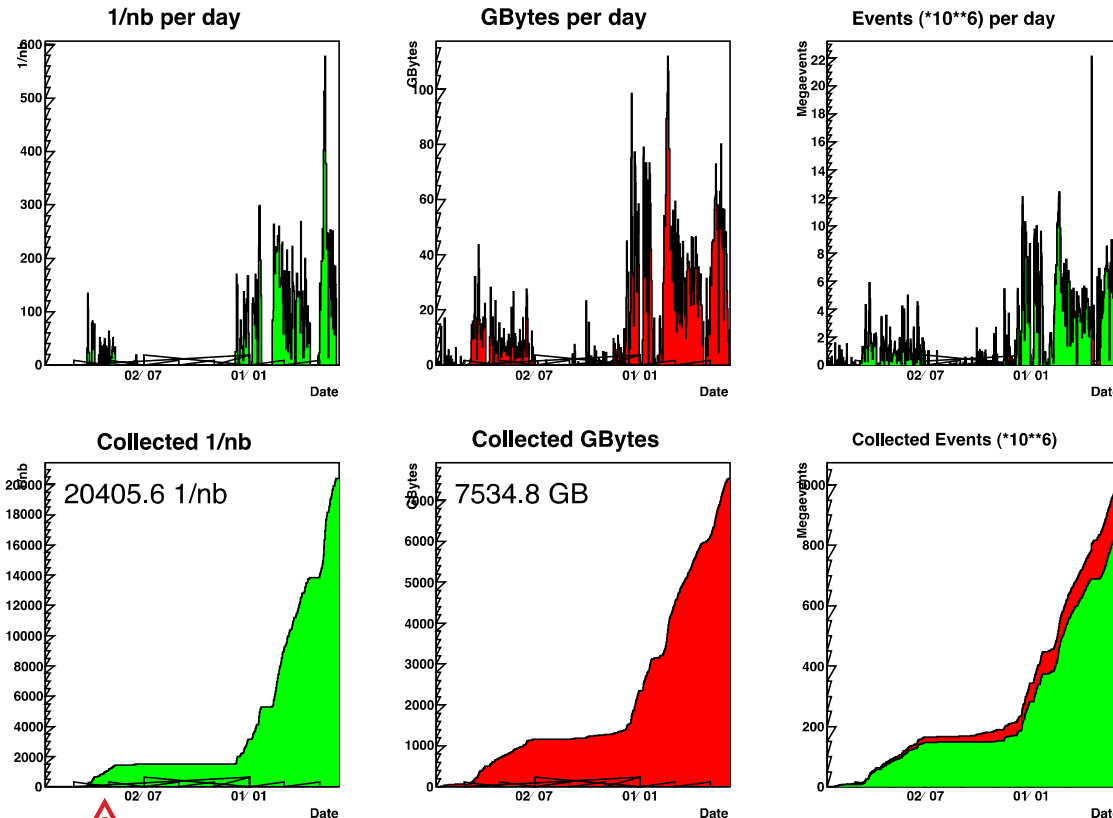
Ec.m. = 1.925 GeV



Successful physics run 2010/2011

CMD-3 data collection

■ - all data, ■ - cosmic and beam data

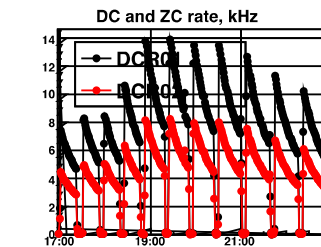
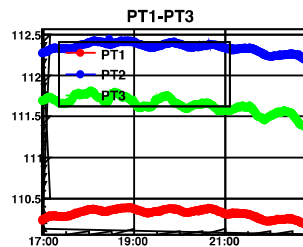
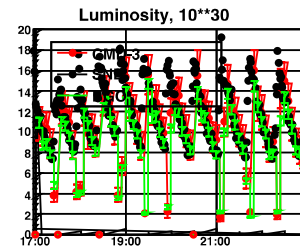
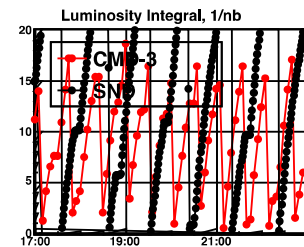
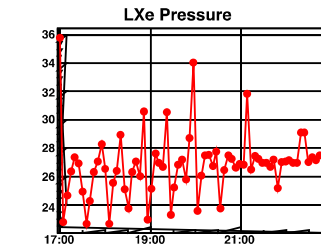
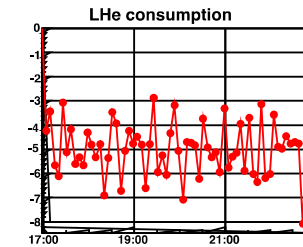
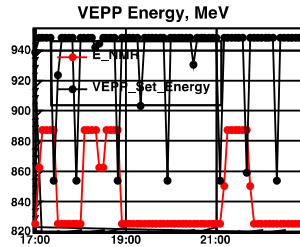
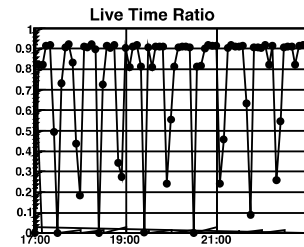
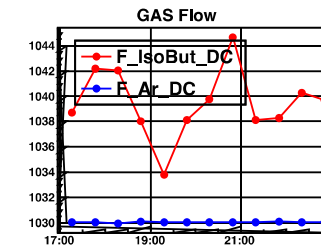
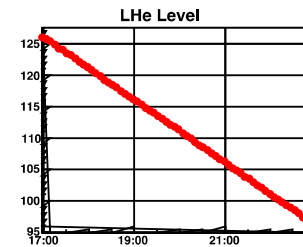
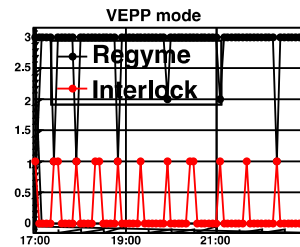
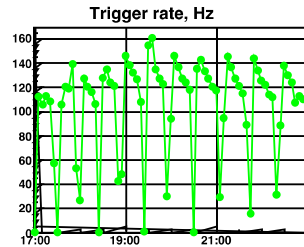
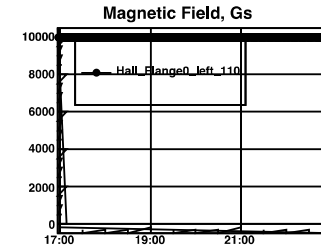
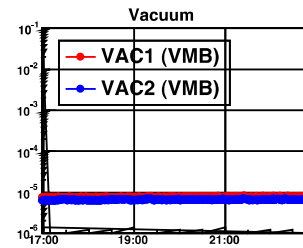
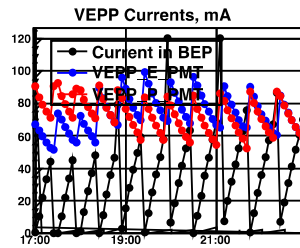
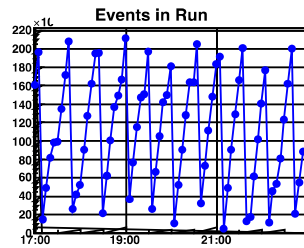


First technical run last year

Two scan (up and down) were performed from ϕ to 2 GeV energy range with 25 MeV step is and about 500 nb⁻¹ per point

We gather
~22 pb⁻¹/detector
~x10 times to previous e⁺e⁻ experiments, and comparable to ISR data from B-factories.

CMD-3 on-line monitor



On-line events monitor for SND

HIGZ_02 @ sndbc4.inp.nsk.su

$e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$
candidate

FLT1-10/0111111111
Calc.Trig/1111111111 Br/000000 B1/000000

5 MeV R-Phi projection
10 MeV T 69/0/0 0/00/00
20 MeV Run 16 Typ 5 LRec 0
50 MeV Ev MT 122731 Ev F 1
100 MeV
E= 800.0MeV E(Nal)/2E= 0.000
ETOT= 423.3MeV

Reconstructed particles N= 5
NT E(MeV) X,Y,Z(cm) Phi,Theta(D)
1 1 0139 0.0 0.0 2.6 159 152
2 1 0129 0.0 0.0 2.4 14 78
3 1 0055 0.1 0.1 1.6 322 121
4 1 0043 0.1 -0.1 2.8 204 25
5 0 0053 0.0 0.0 0.0 62 148

000000 B1/000000

5 MeV R-Phi projection
10 MeV T 69/0/0 0/00/00
20 MeV Run 16 Typ 5 LRec 0
50 MeV Ev MT 122731 Ev F 1
100 MeV
E= 800.0MeV E(Nal)/2E= 0.000
ETOT= 423.3MeV

Reconstructed particles N= 5
NT E(MeV) X,Y,Z(cm) Phi,Theta(D)
1 1 0139 0.0 0.0 2.6 159 152
2 1 0129 0.0 0.0 2.4 14 78
3 1 0055 0.1 0.1 1.6 322 121
4 1 0043 0.1 -0.1 2.8 204 25
5 0 0053 0.0 0.0 0.0 62 148

HIGZ_04 @ sndbc4.inp.nsk.su

FLT1-10/0111111111
Calc.Trig/1111111111 Br/000000 B1/000000

5 MeV R-Theta projection
10 MeV T 69/0/0 0/00/00
20 MeV Run 16 Typ 5 LRec 0
50 MeV Ev MT 122731 Ev F 1
100 MeV
E= 800.0MeV E(Nal)/2E= 0.000
ETOT= 423.3MeV

Reconstructed particles N= 5
NT E(MeV) X,Y,Z(cm) Phi,Theta(D)
1 1 0139 0.0 0.0 2.6 159 152
2 1 0129 0.0 0.0 2.4 14 78
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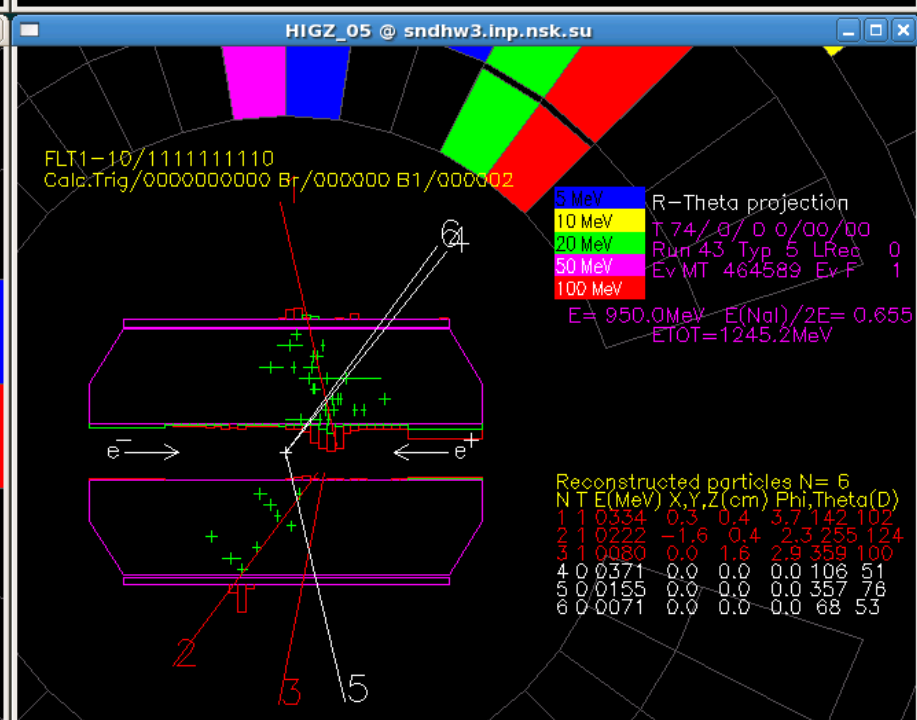
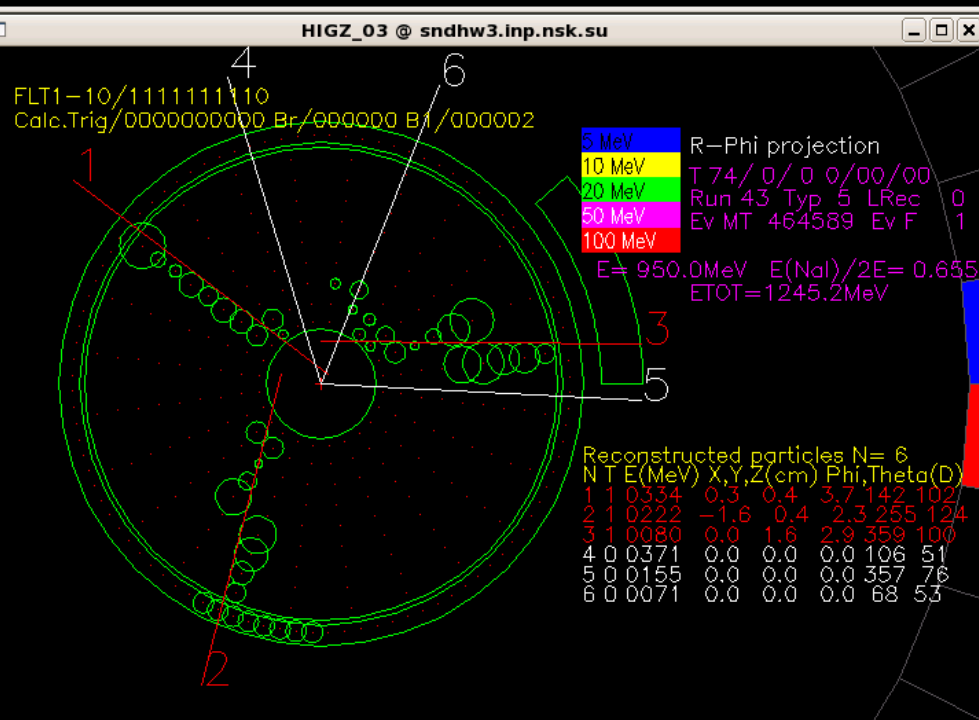
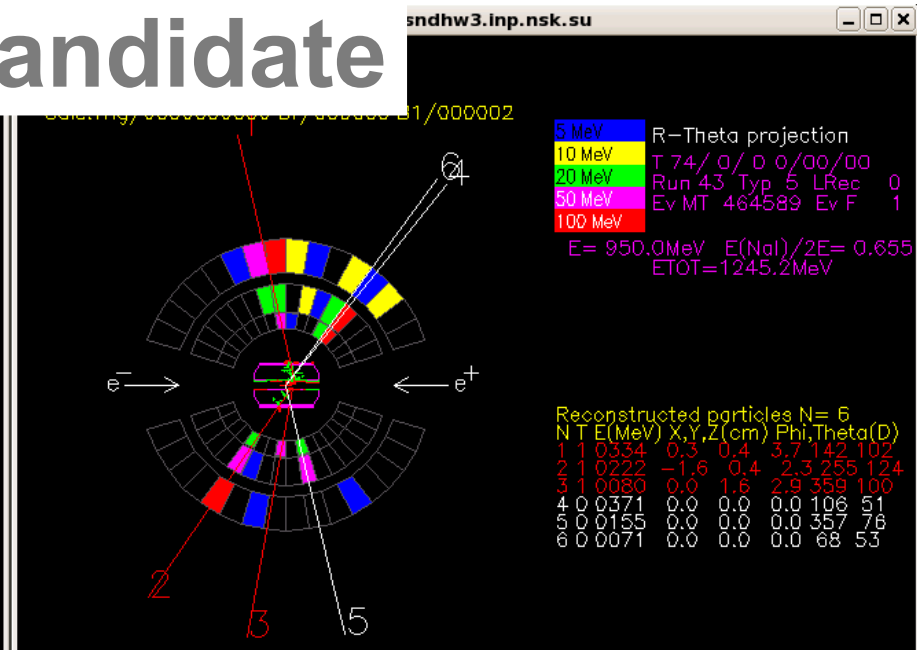
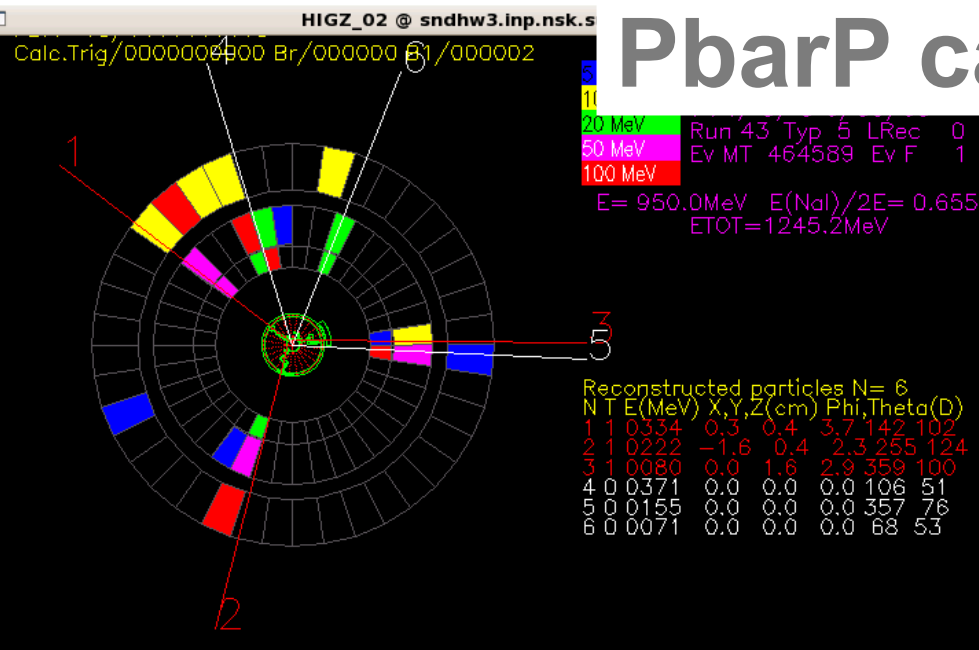
HIGZ_05 @ sndbc4.inp.nsk.su

FLT1-10/0111111111
Calc.Trig/1111111111 Br/000000 B1/000000

5 MeV R-Theta projection
10 MeV T 69/0/0 0/00/00
20 MeV Run 16 Typ 5 LRec 0
50 MeV Ev MT 122731 Ev F 1
100 MeV
E= 800.0MeV E(Nal)/2E= 0.000
ETOT= 423.3MeV

Reconstructed particles N= 5
NT E(MeV) X,Y,Z(cm) Phi,Theta(D)
1 1 0139 0.0 0.0 2.6 159 152
2 1 0129 0.0 0.0 2.4 14 78
3 1 0055 0.1 0.1 1.6 322 121
4 1 0043 0.1 -0.1 2.8 204 25
5 0 0053 0.0 0.0 0.0 62 148

PbarP candidate



First preliminary result from SND

Poster by A. Obrazovsky

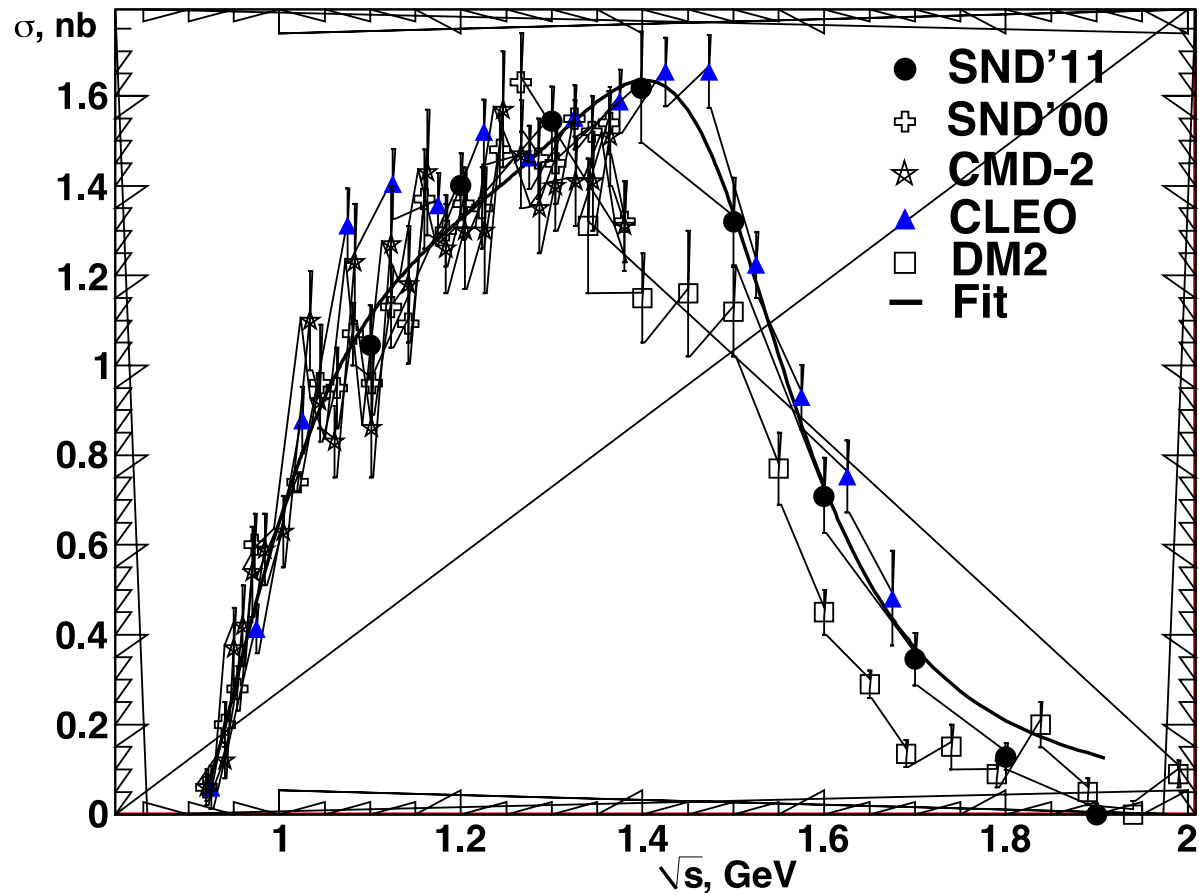
data from 2010 technical run. (20% of available data)

selecting events with 5 photons

looking for $2\pi^0$

looking for $\omega \rightarrow \pi^0\gamma$

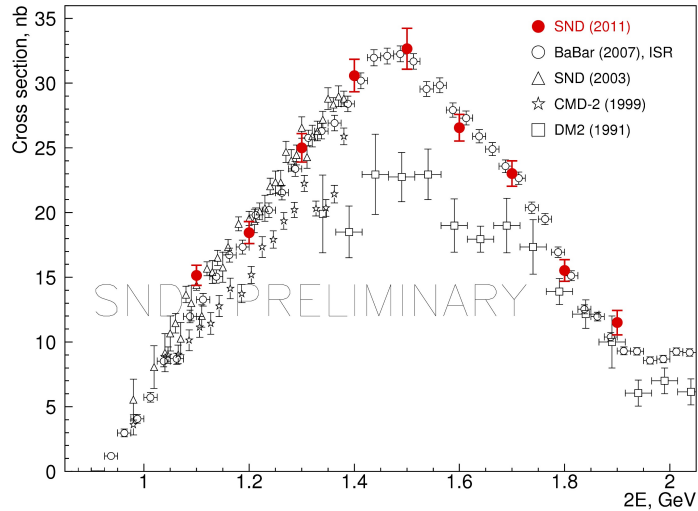
$$e+e^- \rightarrow \omega\pi^0$$



First preliminary result from SND

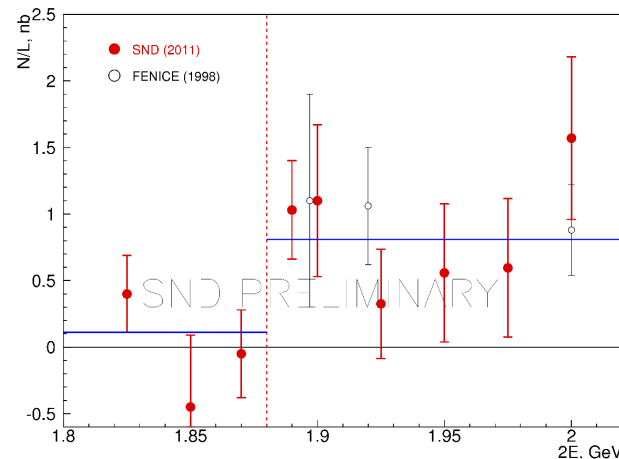
poster by A. Obrazovsk

$$e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$$



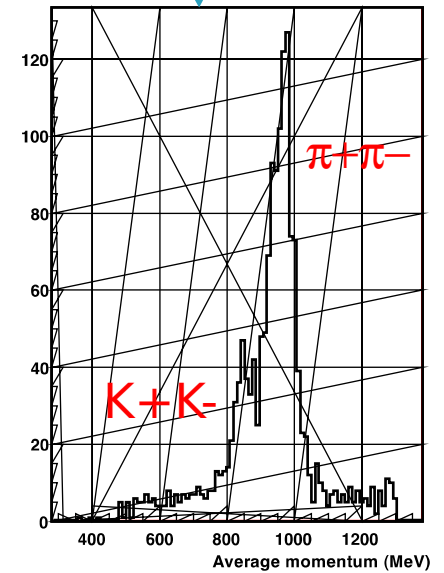
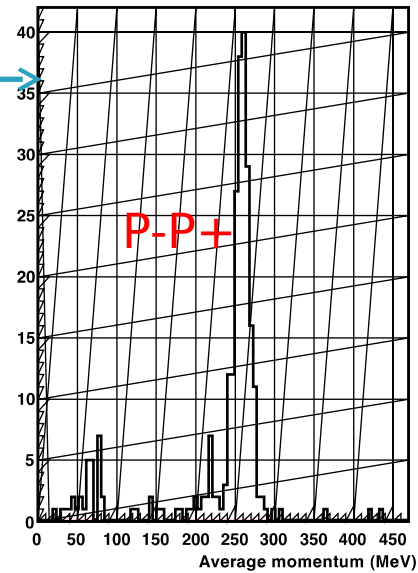
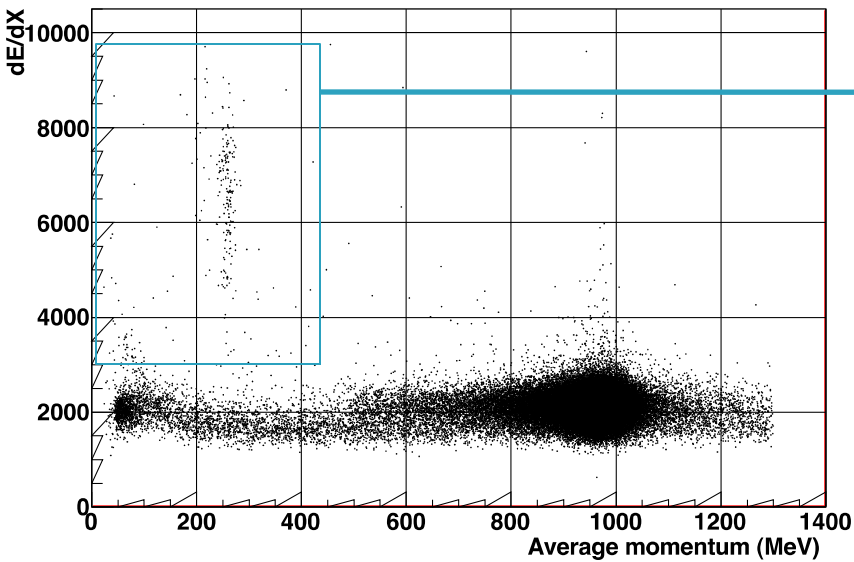
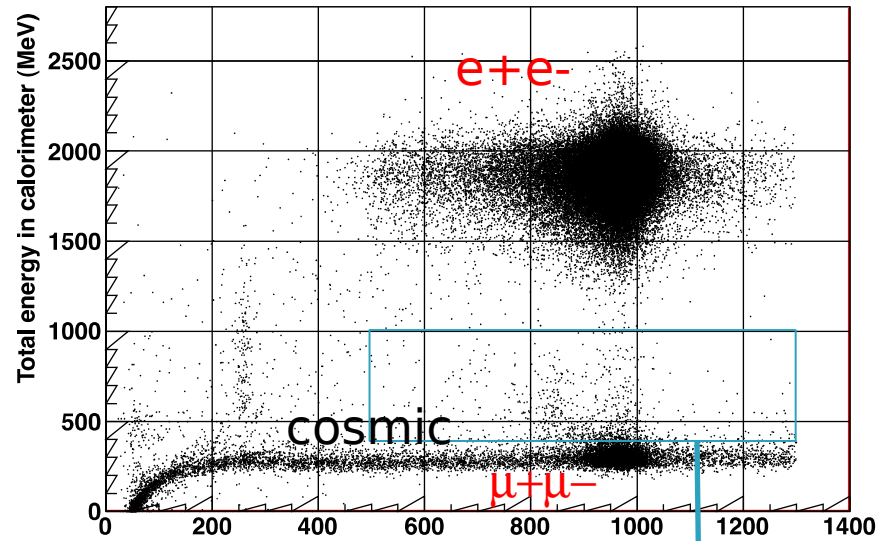
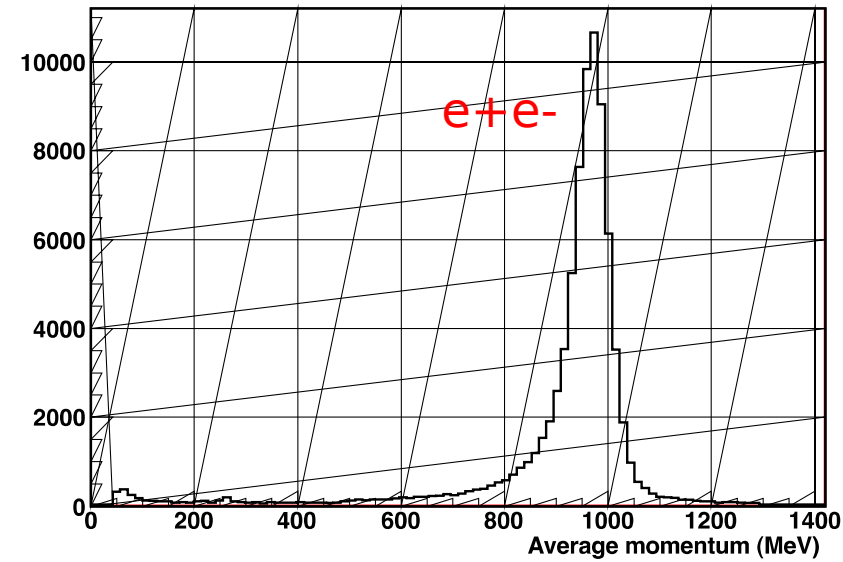
- Scan 2010
- The cross section is dominated by the $\rho(1450)$ and $\rho(1700)$ decays

$$e^+e^- \rightarrow n\bar{n}$$



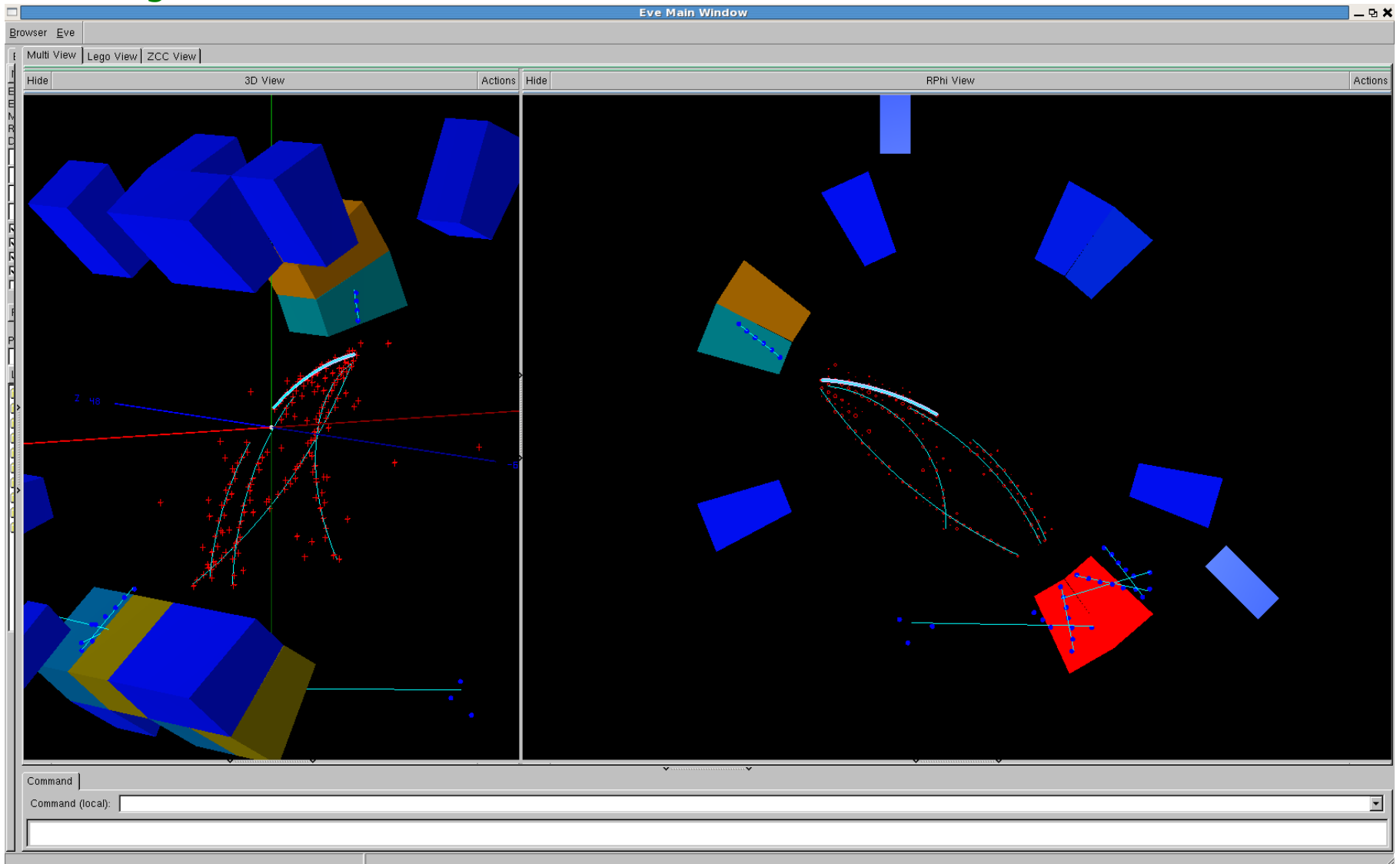
- Scan 2011
- $n\bar{n}$ cross section is presented, efficiency $\sim 30\%$
- $e^+e^- \rightarrow p\bar{p}, \gamma\gamma$ backgrounds are subtracted
- Below the $n\bar{n}$ threshold
 $\sigma = 0.1 \pm 0.2$ nb
- Above the $n\bar{n}$ threshold
 $\sigma = 0.8 \pm 0.2$ nb

near events in CMD-3 ($E_{c.m.} = 1.95$)



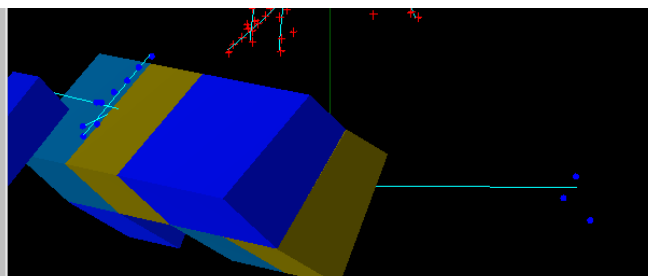
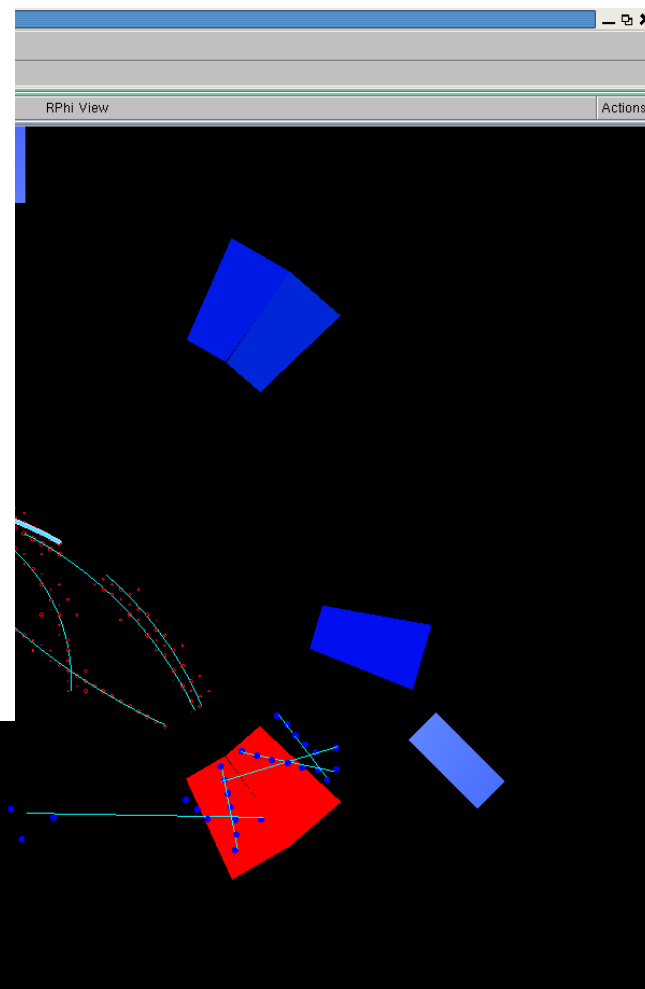
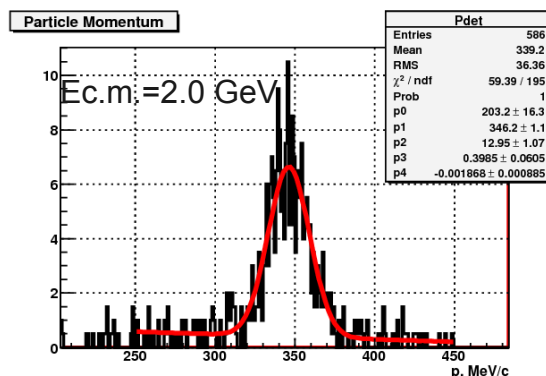
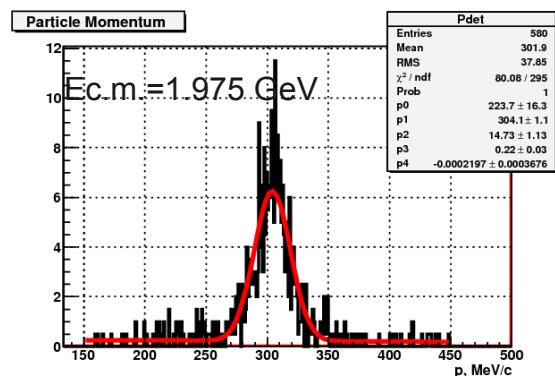
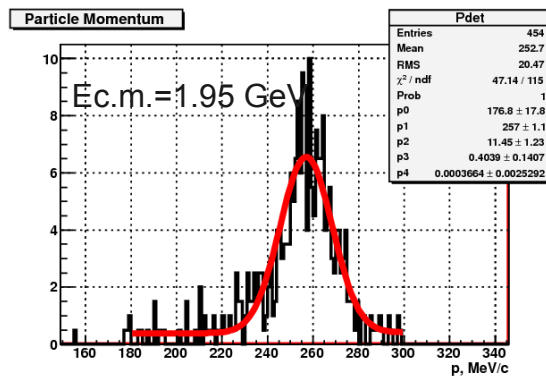
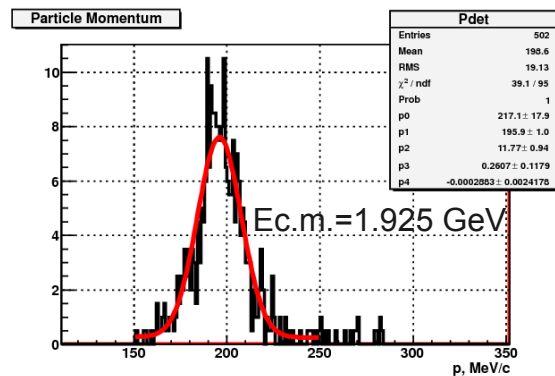
Primary results for the $e^+e^- \rightarrow P\bar{P}$

Clear signature of the $P\bar{P}$ events



Primary results for the $e^+e^- \rightarrow P\bar{P}$

Number of events from momentum distributions

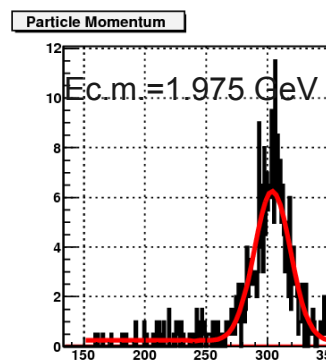
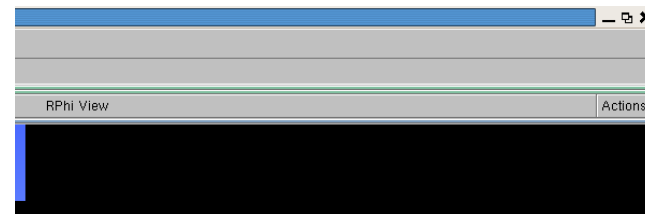
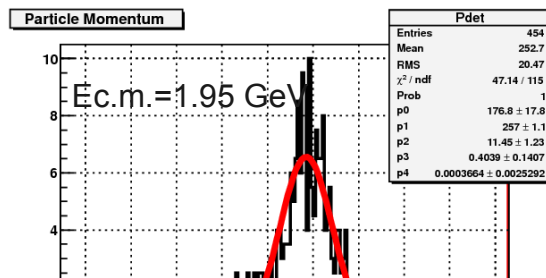
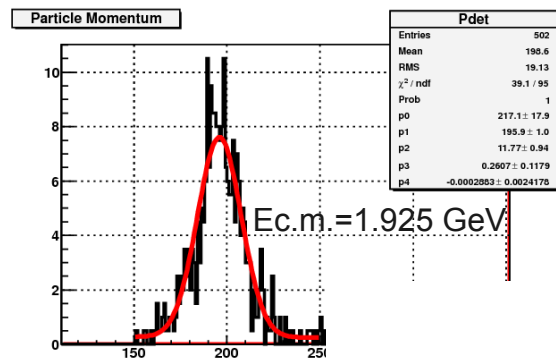


Command

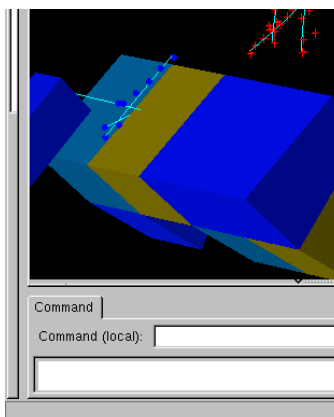
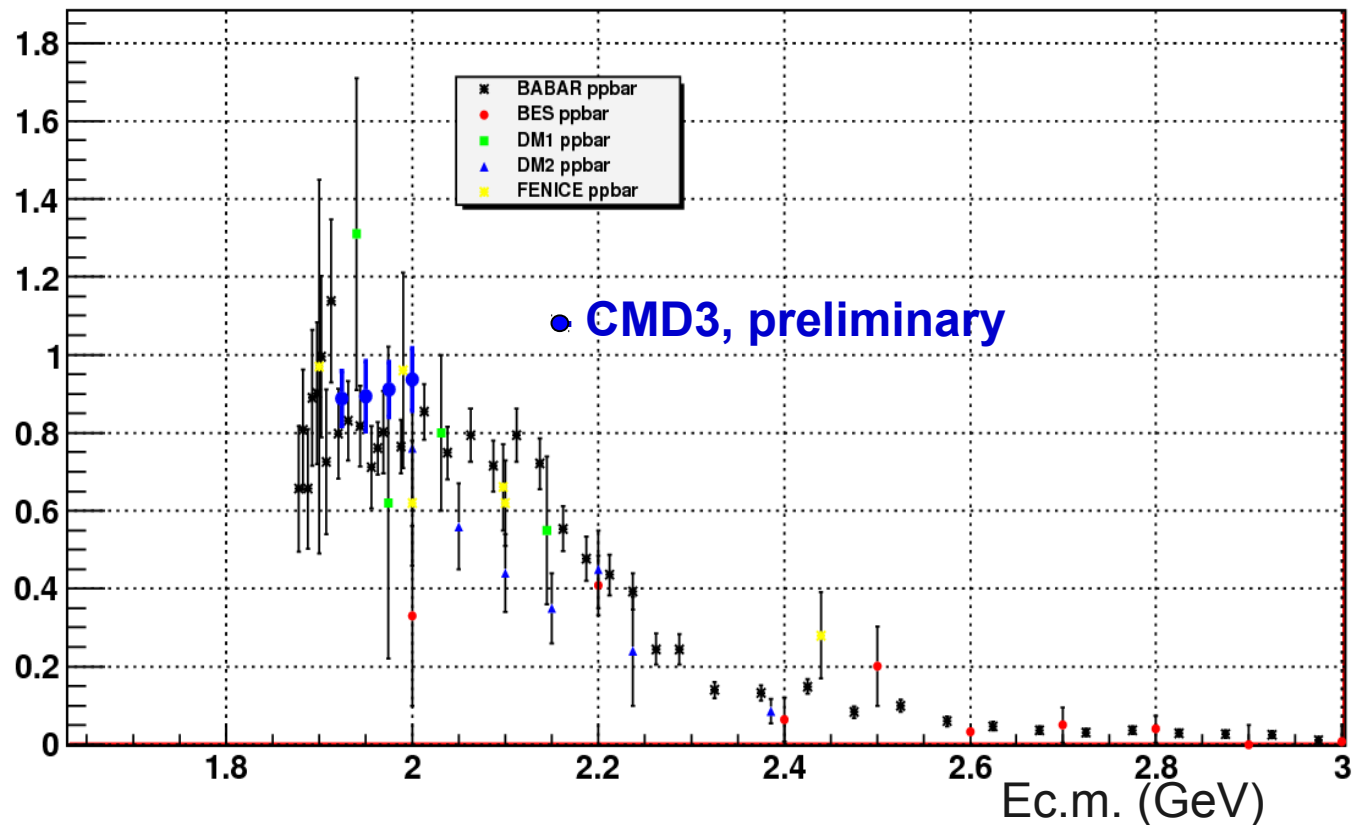
Command (local):

Preliminary results for the $e^+e^- \rightarrow P\bar{p}P$

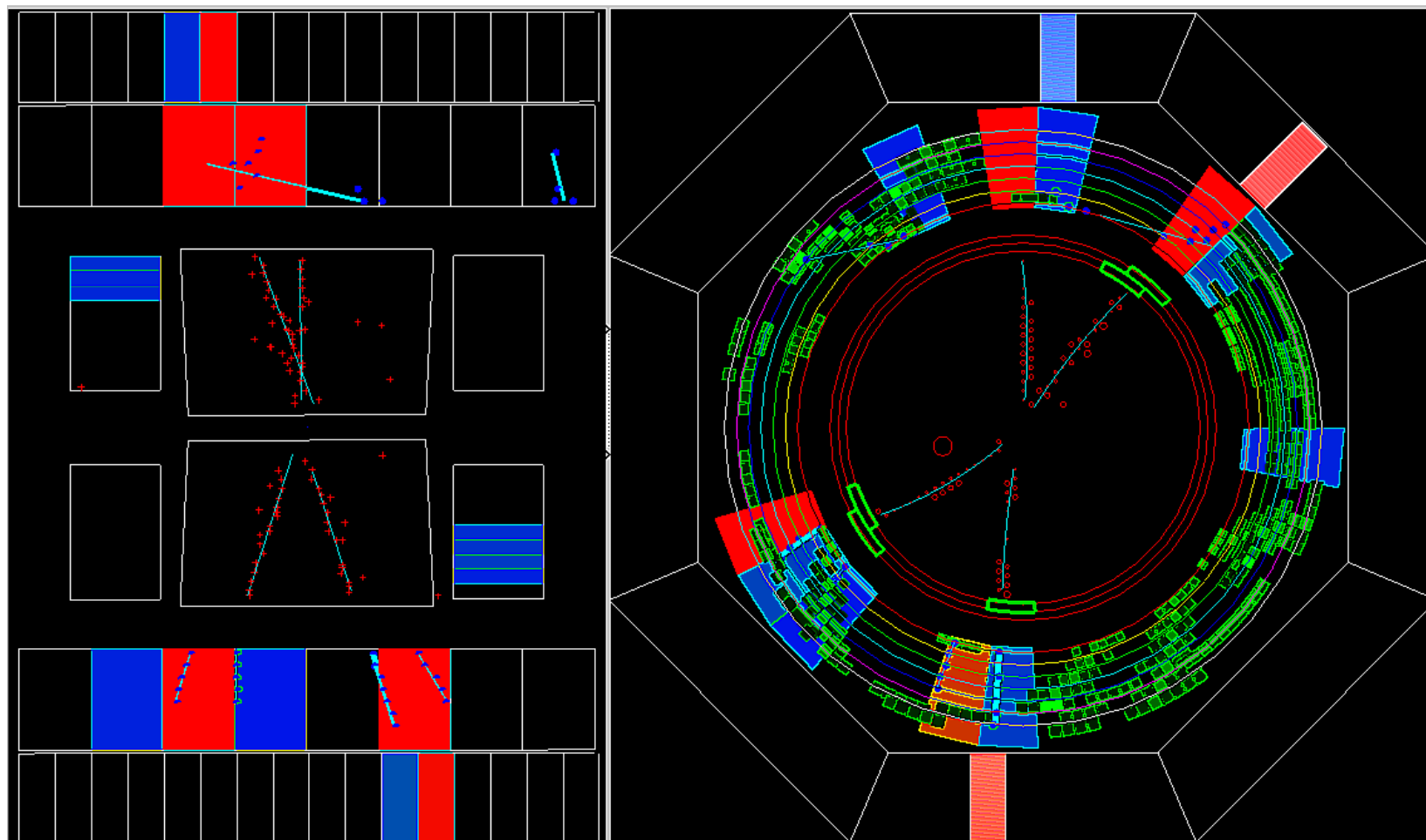
Number of events from momentum distributions



Cross section (nb)

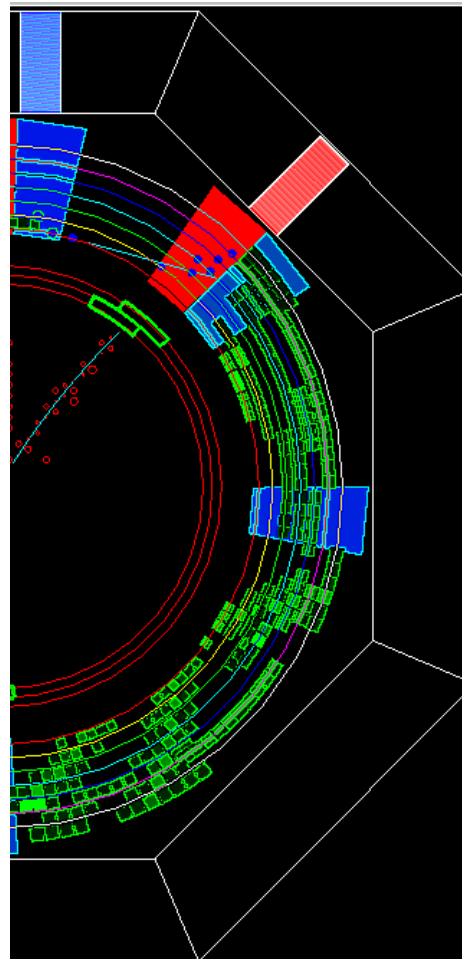
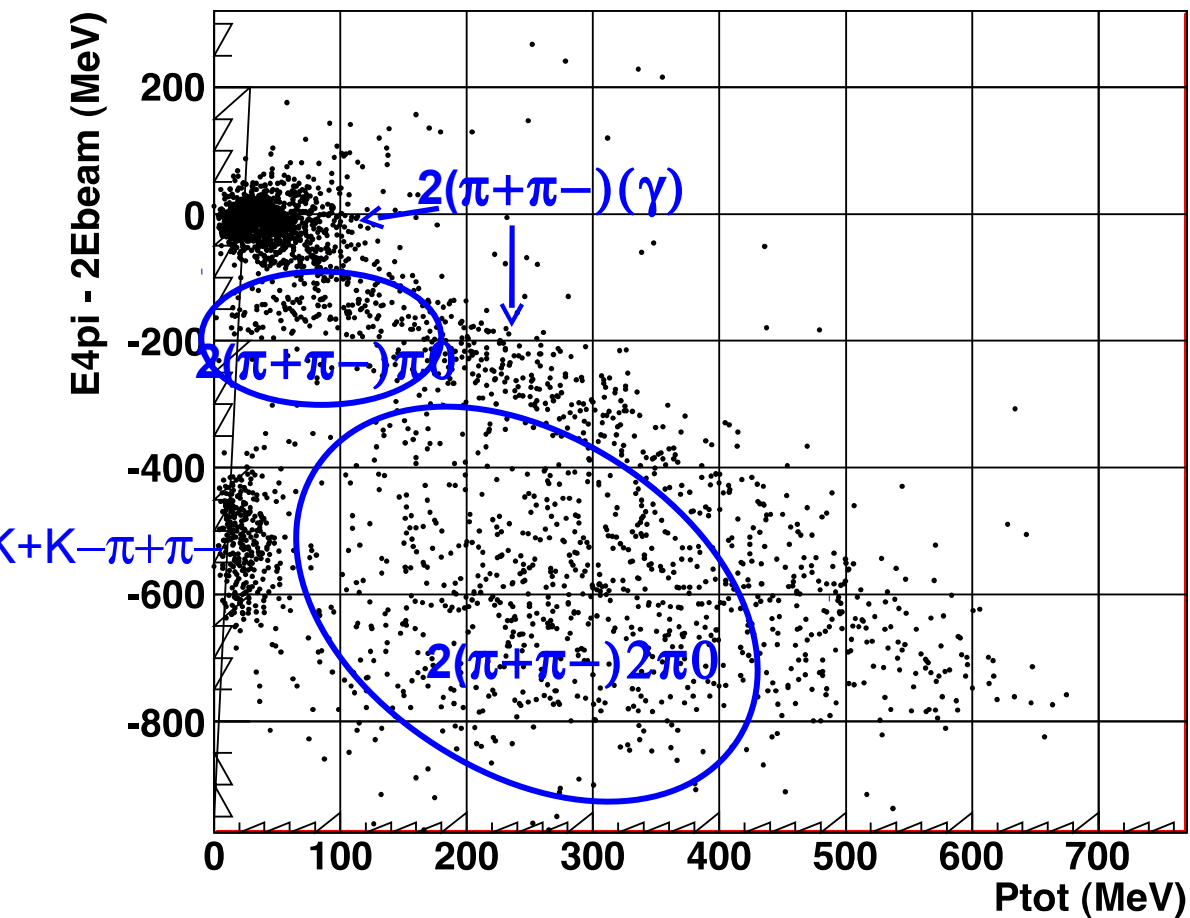


Sample of $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ from CM

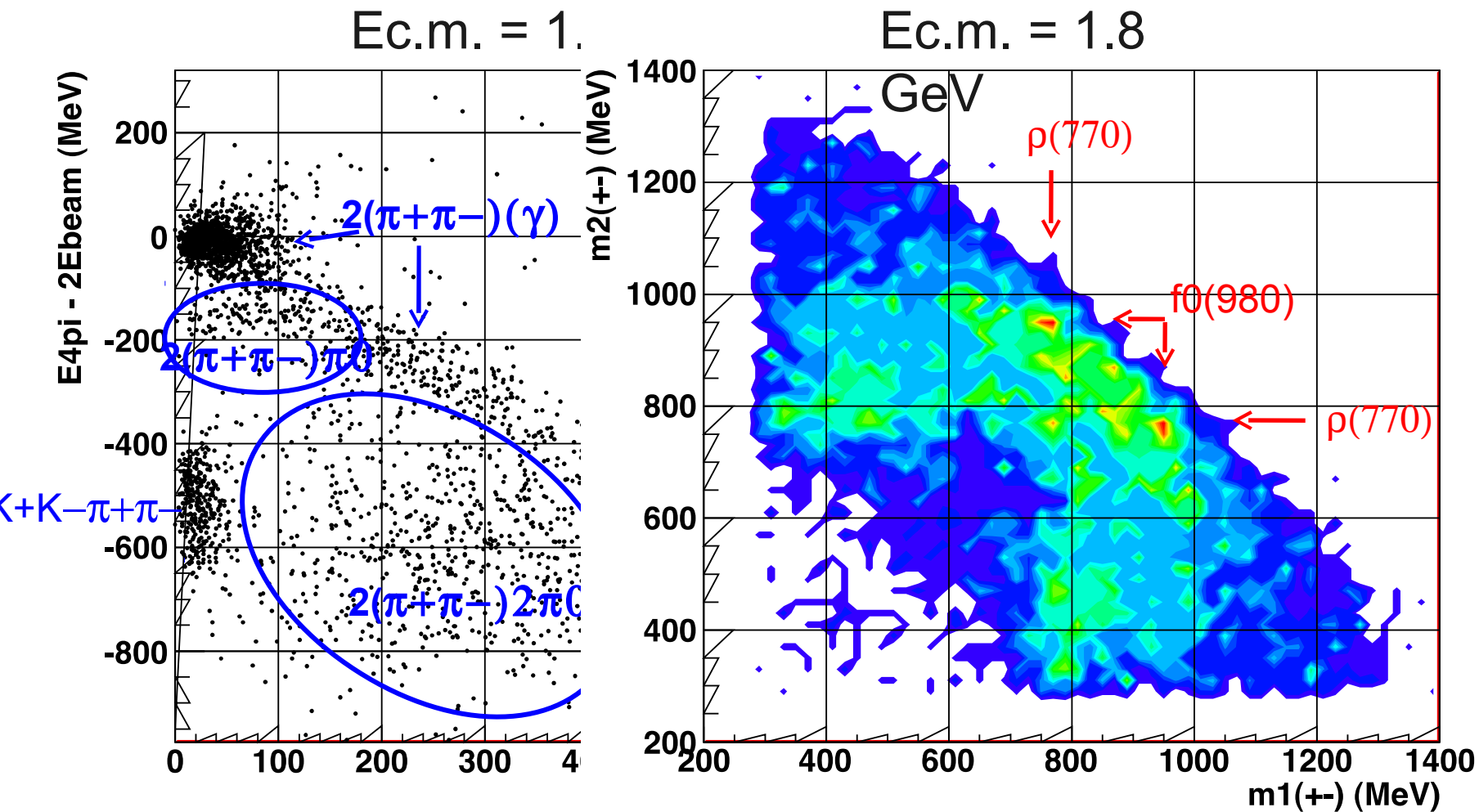


Example of $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ from CM

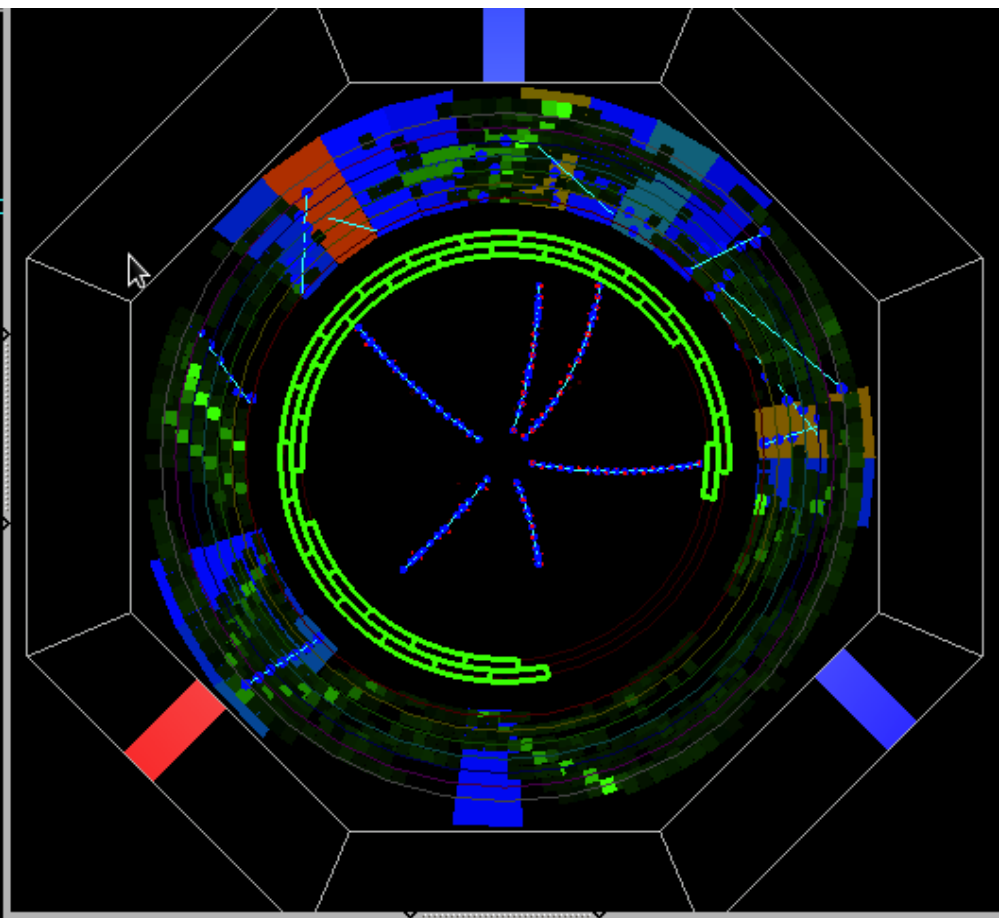
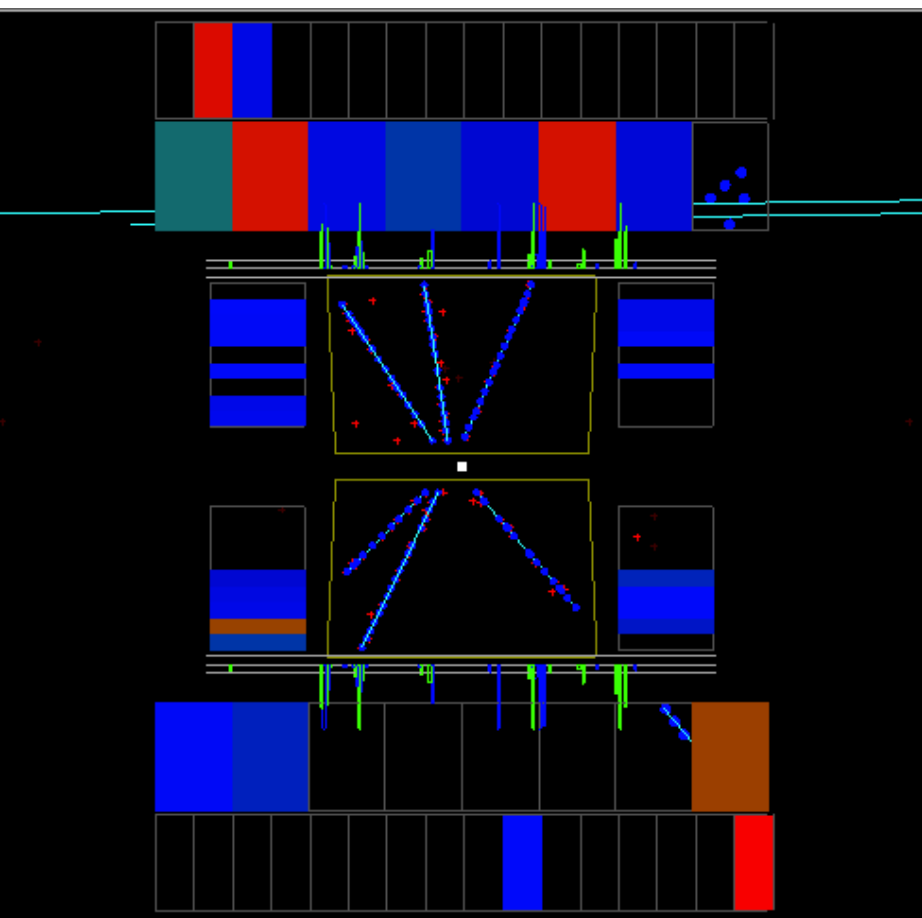
$E_{c.m.} = 1.8 \text{ GeV}$



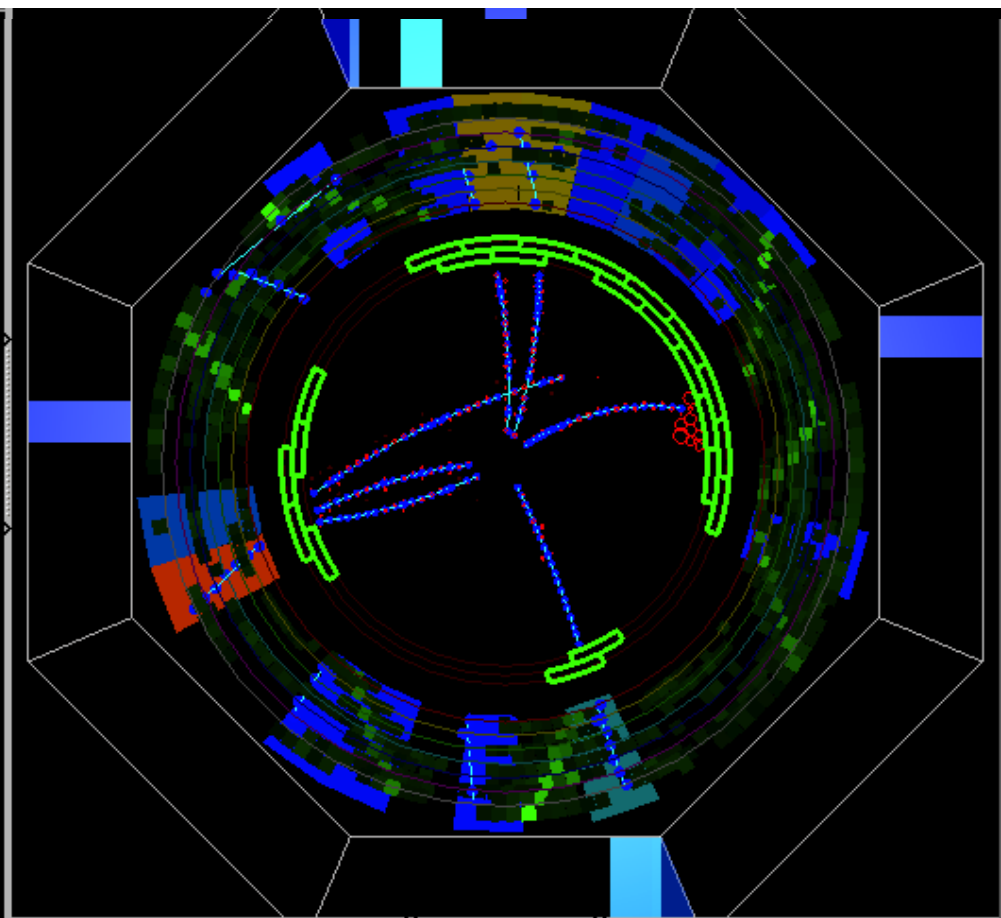
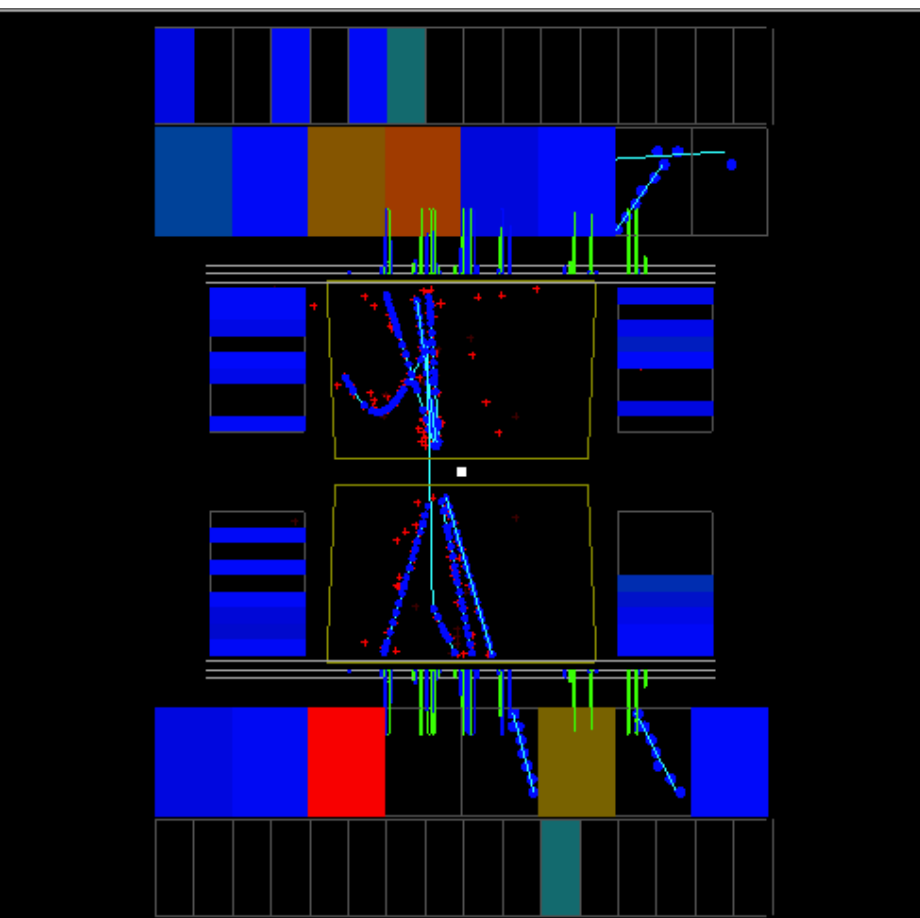
Example of $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ from CM



Example of $e^+e^- \rightarrow 3(\pi^+\pi^-)$ from CMD

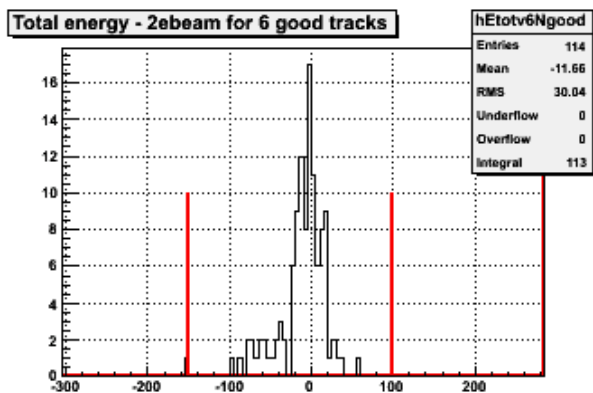


Example of $e^+e^- \rightarrow 3(\pi^+\pi^-)$ from CMD

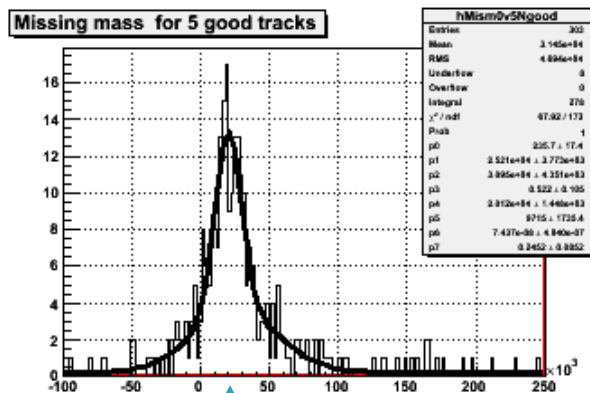


Primary results for the $e^+e^- \rightarrow 3(\pi^+\pi^-)$

have very clean selection of 6 and 5 pions

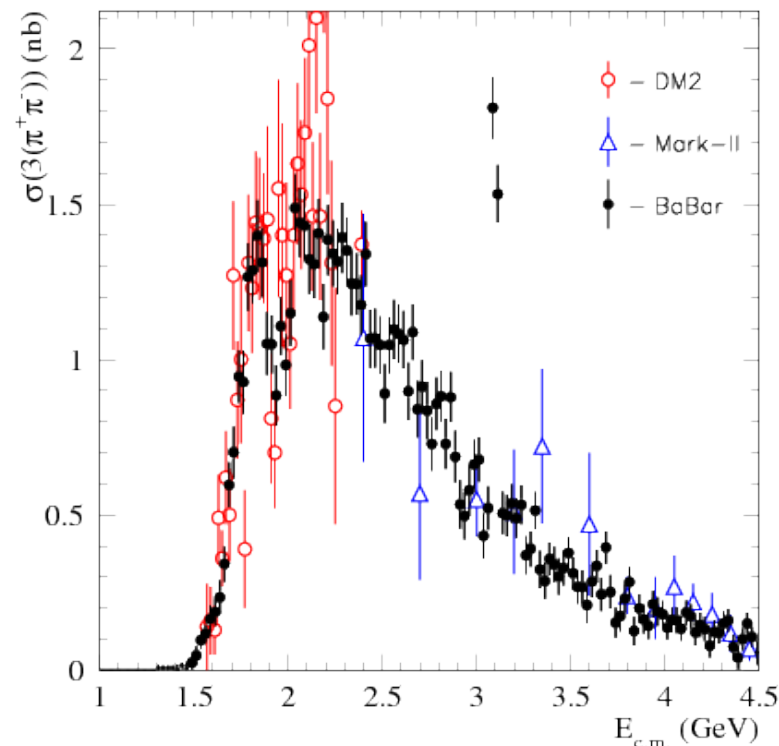
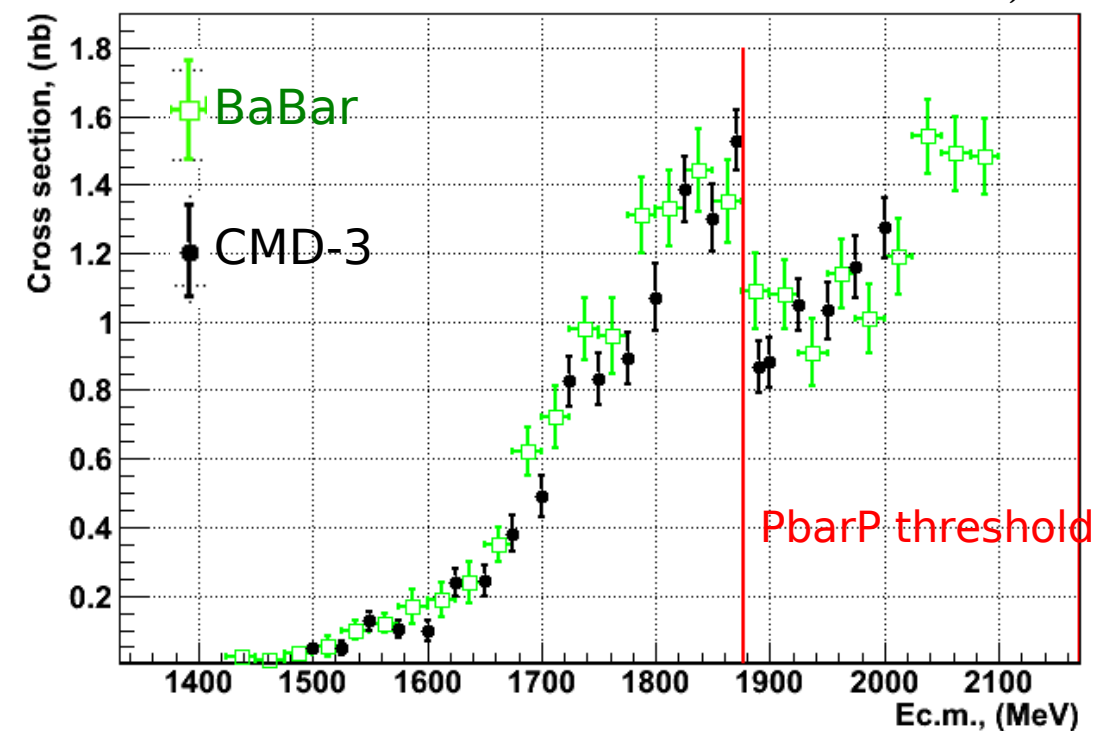


E6tracks - 2*Ebeam, (MeV)

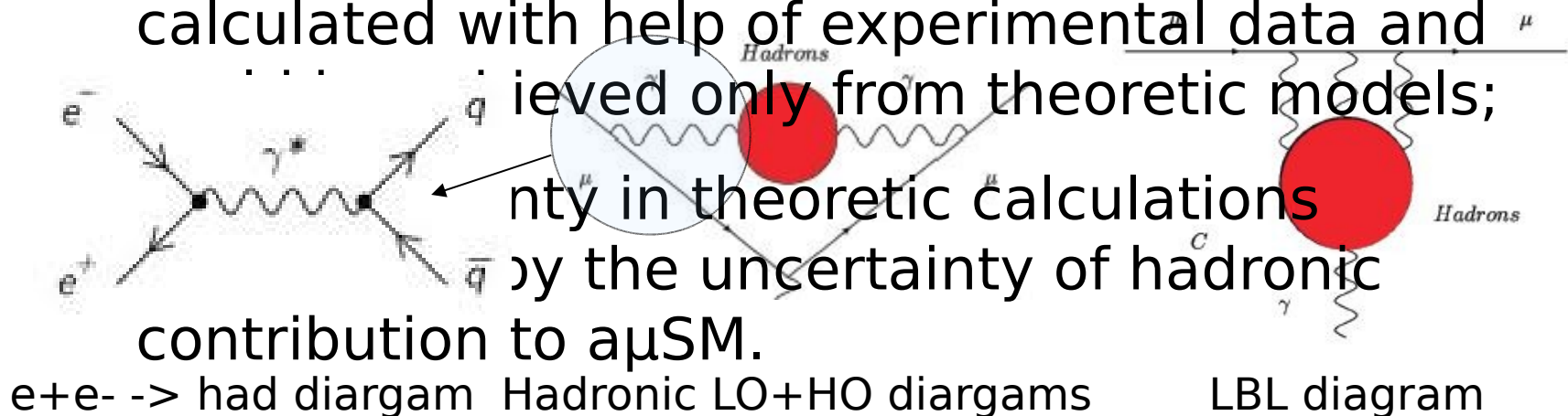


↑ $m_2(\pi)$

Other data for $e^+e^- \rightarrow 3(\pi^+\pi^-)$



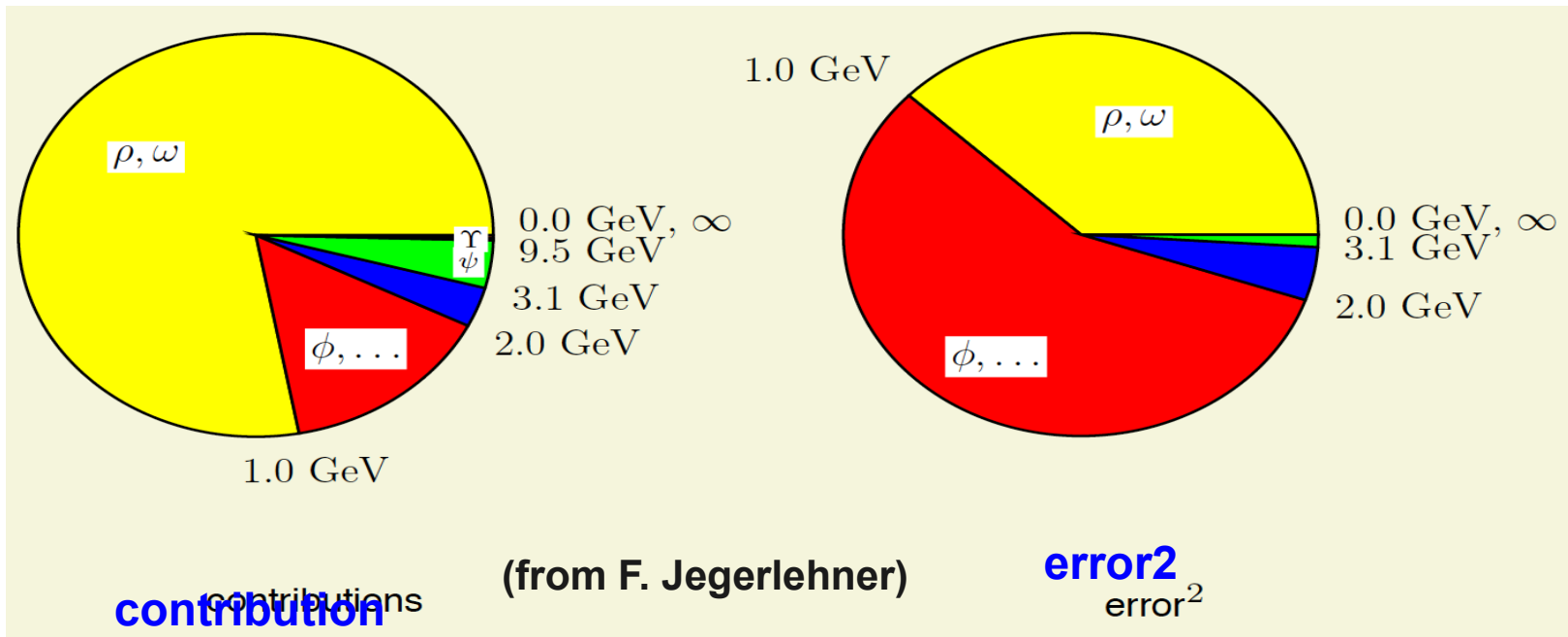
- Measured with highest precision at BNL-E821:
 $a_{\mu}^{\text{exp}} = (11659208.0 \pm 6.3) \times 10^{-10}$;
- The theoretical calculations a_{μ}^{SM} meet the problems with hadronic contribution of radiative corrections but calculations can be done using experimental data: $e^+e^- \rightarrow \text{hadrons}$ or τ -decays – optical theorem;
- An high-order hadronic contribution “light-by-light” (LBL) stands apart – it can not be calculated with help of experimental data and is derived only from theoretic models; uncertainty in theoretic calculations by the uncertainty of hadronic contribution to a_{μ}^{SM} .



$e^+e^- \rightarrow \text{had}$ diargam Hadronic LO+HO diargams

LBL diagram

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



The contribution goes mainly from the small s , the contribution of $\sqrt{s} > 2$ GeV less than 10% of overall ;

The maximal contribution to the error now goes from 1 - 2 GeV region, the energy of VEPP-2000;

Hadronic contributions in terms of 10^{-10} : LO VP: 694.91 ± 4.27 HO VP: -9.84 ± 0.07

LBL: 10.5 ± 2.6 – the recent result (K. Hagiwara et al)

The recent result has difference between a_μ^{SM} and a_μ^{exp} in 3.3σ ;

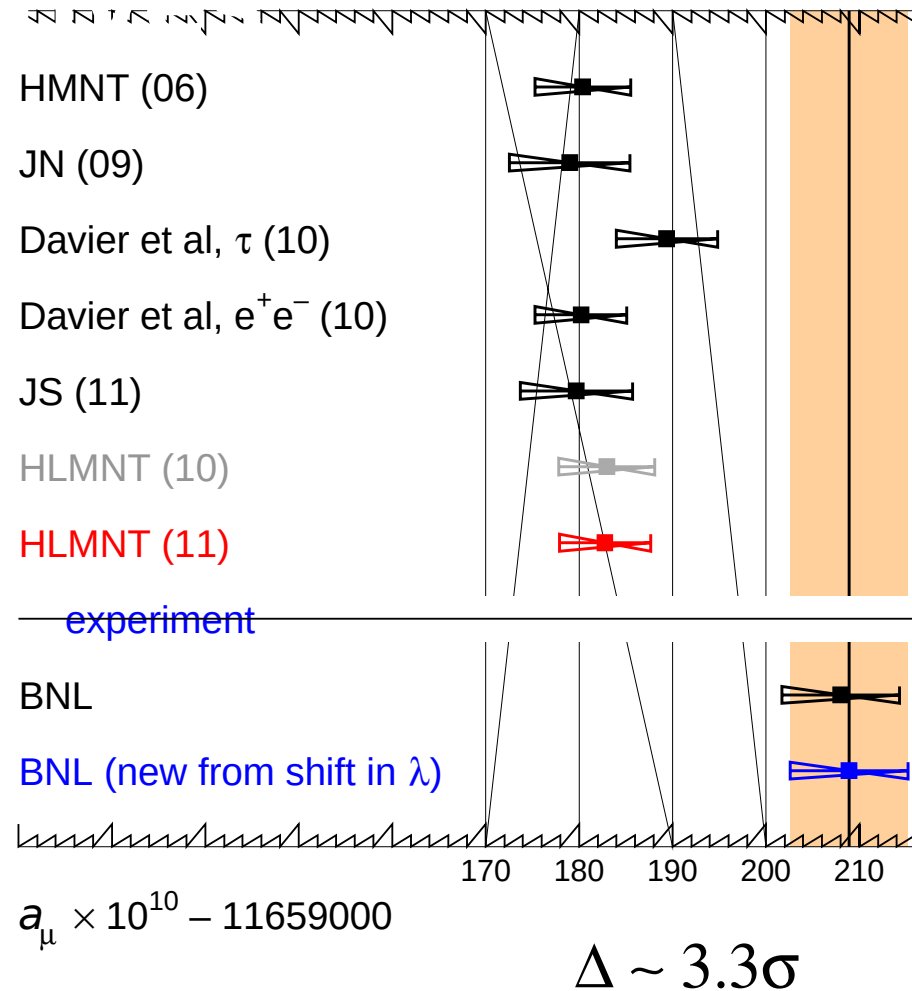
VEPP-2M, BaBar, KLOE significantly reduced errors.

More ISR analysis from KLOE, BaBar, Belle; better R below 4.3 from CLEO-c;

CMD-3, SND at VEPP2000, up to 2 GeV (next 5+ years) with goal $< 1\%$ of systematics for majority of the channels;

By 2014 LO error could reach 2×10^{-10} with LBL 2.6×10^{-10} .

New (g-2) experiment at FLAB with accuracy 3 times better, JPARC hopes for 4 times better accuracy. This corresponds to 0.3% of a_μ^{SM} (bad) — unreachable





Summary

- New generation of detectors perfectly matches the reach physics potential of VEPP-2000;
- $L \sim 2 \times 10^{31} \text{ cm}^{-1} \text{ sec}^{-2}$ has been reached so far – positrons limited. “Unlimited” positron source is in preparation;
- Both detectors are on the beams and are taking data. We start understanding their performance;
- The integrated luminosity collected between 1 and 2 GeV already exceeds the one previously achieved in direct scans with precision close to BaBar;
- In a few years we hope to measure $\sigma(e^+e^- \rightarrow \text{had})$ with high accuracy and significantly improve the precision of all $\text{SM}(\text{had}, LO)$.

**Thank you for your
attention!**

