Budker Institute of Nuclear Physics, Novosibirsk

Prospects of experimental study of neutron-antineutron production at VEPP-2000

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Talk at LNF experimental seminar

April 3, 2003

OUTLINE

VEPP-2000 collider

SND detector upgrade

Nnbar production cross section

Neutron and proton timelike form factor

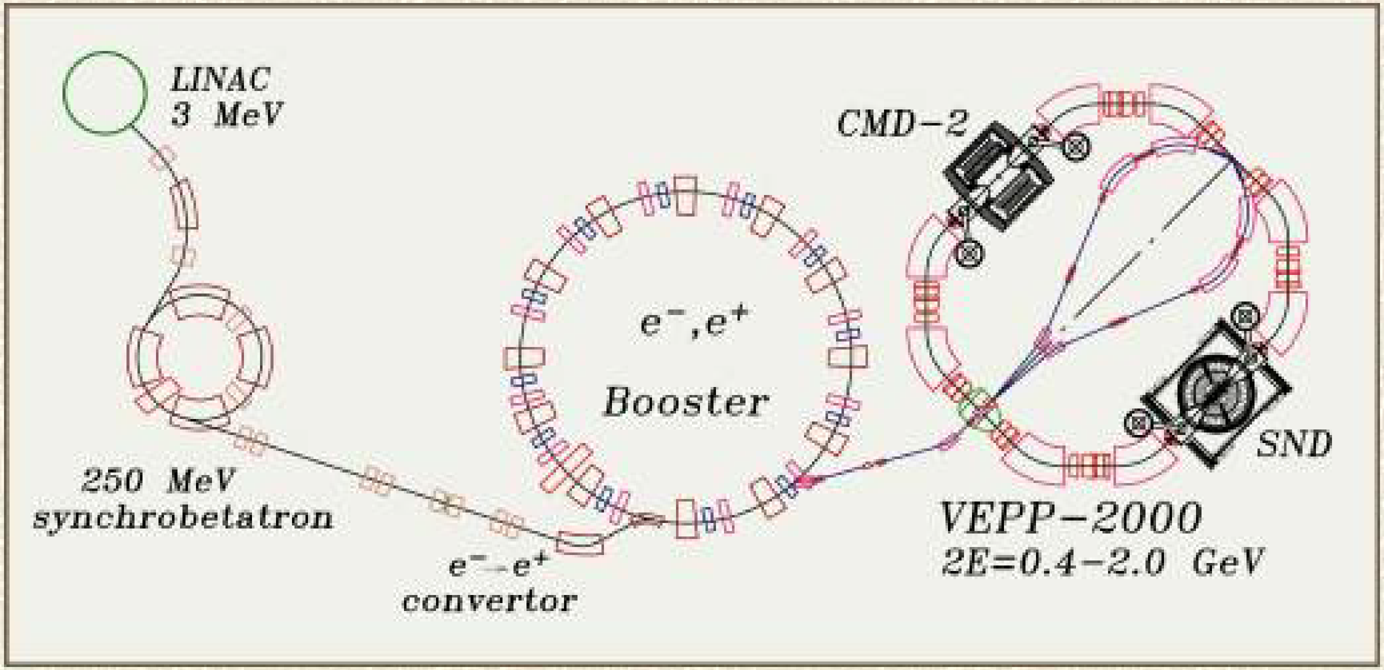
Antineutron and neutron interaction

Options of antineutron detector

Consideration of SND as antineutron detector

Present status

General View of VEPP-2000 Complex



- VEPP-2M (1974 – 2000)
- $2E_{max}$=1400 MeV
- $L=4 \cdot 10^{30} cm^{-2}s^{-1}$ at E=510 MeV

- VEPP-2000
- $2E_{max}$=2000 MeV
- $L=10^{31} cm^{-2}s^{-1}$ at E=510 MeV
- $L=10^{32} cm^{-2}s^{-1}$ at E=1000 MeV

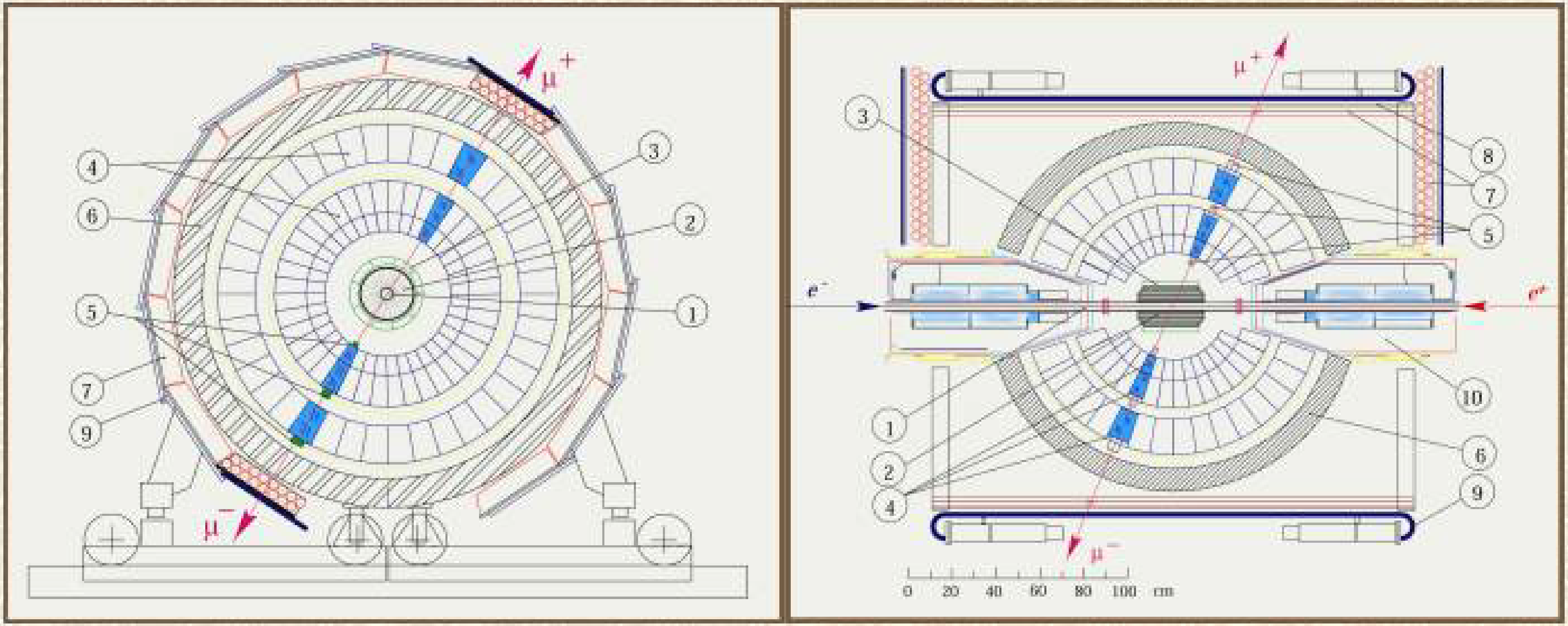
Refs for VEPP-2000:

1. In: Proc.Frascati Phys.Series,v XVI, p.393,Nov.16-19,1999
2. In: Proc. 7-th Europ.Part.Accel.Conf.,EPAC 2000, p.439, Vienna,2000

VEPP-2000 hall view

SND detector

Ref.: NIM A449 (2000) 125-139



1 – VEPP-2000 beam pipe, 2 – tracking system, 3 – aerogel cherenkov counter, 4 – NaI(Tl) counters, 5 – vacuum phototriodes, 6 – absorber, 7-9 – muon system, 10 – VEPP-2000 s.c focusing solenoids.

Most important SND physical results

- Electric dipole radiative decays $\phi(1020) \to f_0(980)\gamma$ and $\phi(1020) \to a_0(980)\gamma$
- were observed at the first time. Relatively large rate of these processes supports
- the model of 4-quark structure of the lightest scalars a_0 and f_0.
- The measured $\rho,\omega \to \pi^0\pi^0\gamma$ branching ratios in 3-4 times exceed VDM
- predictions. The decay $\rho \to \pi^0\pi^0\gamma$ was observed for the first time. Its branching
- ratio can be explained by σ-meson contribution. For the $\omega \to \pi^0\pi^0\gamma$ decay
- there is no theoretical explanation.
- The branching ratios of radiative magnetic dipole decays $\phi, \rho, \omega \to \pi^0\gamma$, $\eta\gamma$ were measured with high accuracy - test of VDM and quark model.
- The branching ratios of $\phi \to \omega\pi^0$, $\pi^+\pi^-$ decays were measured. $\phi \to \omega\pi^0$ decay was observed for the first time - study of OZI and isospin violation.
- In the cross section of the $e^+e^- \to \pi^+\pi^-\pi^0$ process the structure near 1200 MeV was observed, which is direct manifestation of $\omega(1400)$ resonance.
- The $e^+e^- \to 4\pi$, $\omega\pi^0$ cross sections were measured with highest accuracy – $(g-2)_\mu$ and CVC test.

Work in progress:

- $e^+e^- \to \pi^+\pi^-$, $\pi^+\pi^-\pi^0$ in ρ,ω region - $(g-2)_\mu$ and CVC tests;
- $e^+e^- \to \eta\pi^+\pi^-$, K_SK_L, K^+K^-, ... in the range $2E < 1.4$ GeV;
- Study of $\rho, \omega \to \pi^+\pi^-\gamma$ decays

Physical program at VEPP-2000

1. Precise measurement of the quantity
   $R=\sigma(e+e^{-} > \text{hadrons}) / \sigma(e+e^{-} > \mu+\mu^{-})$
2. Study of hadronic channels:
   $e+e^{-} > 2h, 3h, 4h \ldots, h= \pi, K, \eta$
3. Study of 'excited' vector mesons: $\rho', \rho'', \omega', \varphi', ..$
4. CVC tests: comparison of $e+e^{-} >$ hadr. (T=1) cross section with τ-decay spectra
5. Study of nucleon-antinucleon pair production – nucleon electromagnetic formfactors, search for NNbar resonances, ..
6. Hadron production in 'radiative return' (ISR) processes
7. Two photon physics
8. Test of the QED high order processes 2->4,5

For details see the talk of S.S. at Photon-2003

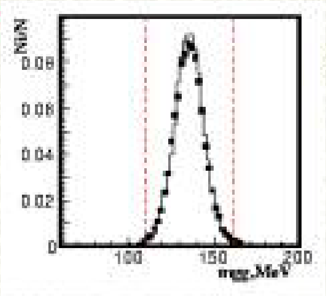
SND subsystems

- NaI(Tl) calorimeter - ~50% new phototriodes
- _racking system – new
- _erogel cherenkov detector – new subsystem
- Electronics – ~50% new
- Data acquisition system – 90% new
- Data processing – 90% new
- Antineutron detector –new subsystem

NaI(Tl) calorimeter

Calorimeter parameters

- 1680 crystals
- VPT readout
- 3 spherical layers
- 3.5 tons
- 13.5 X_0
- 90% 4π
- $\Delta\varphi \times \Delta\theta = 9^0 \times 9^0$



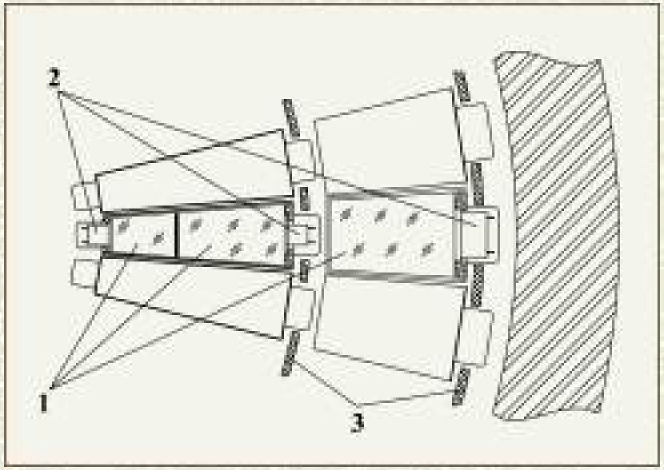
π_0 - mass
σ=8,6 MeV

Energy resolution:

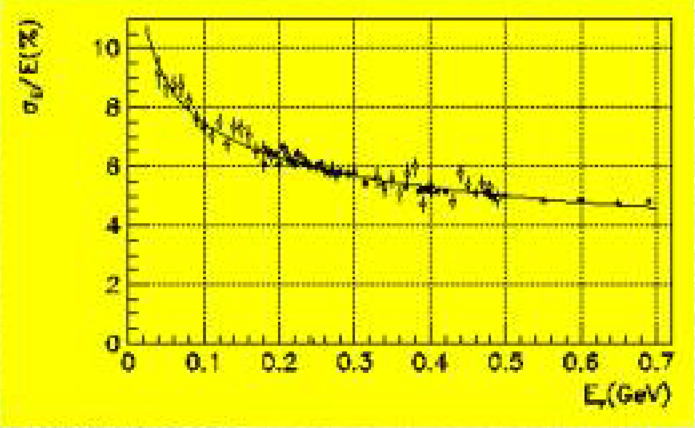
$$\frac{\sigma E}{E} = \frac{4.2\%}{\sqrt[4]{E(GeV)}}$$

Angular resolution:

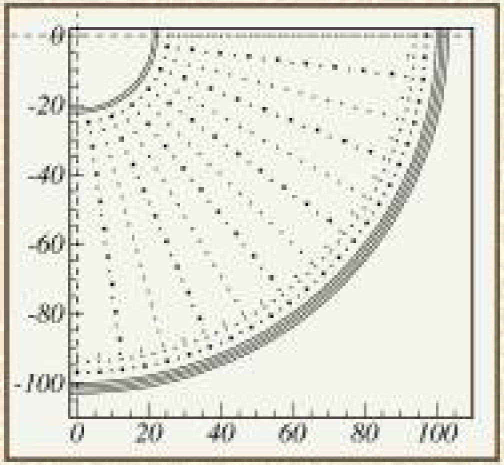
$$\sigma_\phi = \frac{0.82^0}{\sqrt{E(GeV)}} \oplus 0.63^0$$

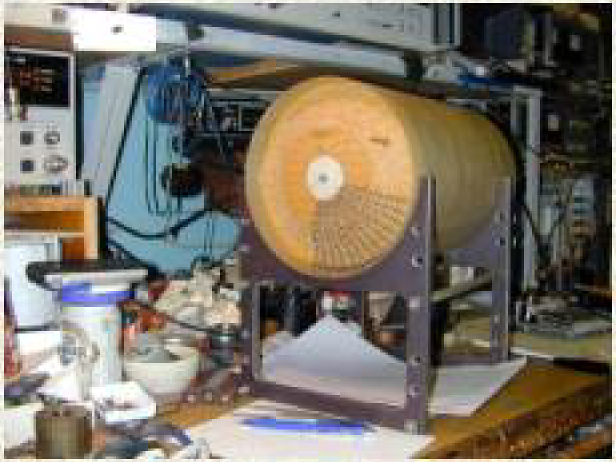


1 – NaI(Tl) crystals
2 – phototriodes
3 – supporting Al hemispheres

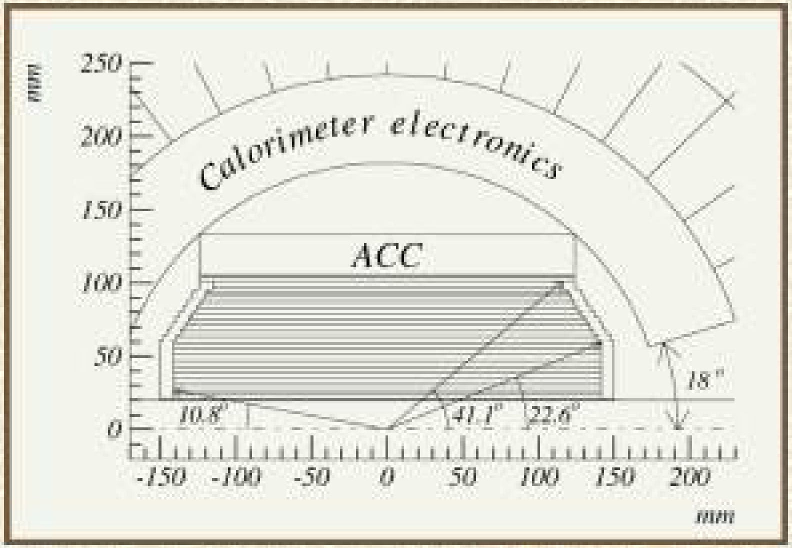


New SND tracking system



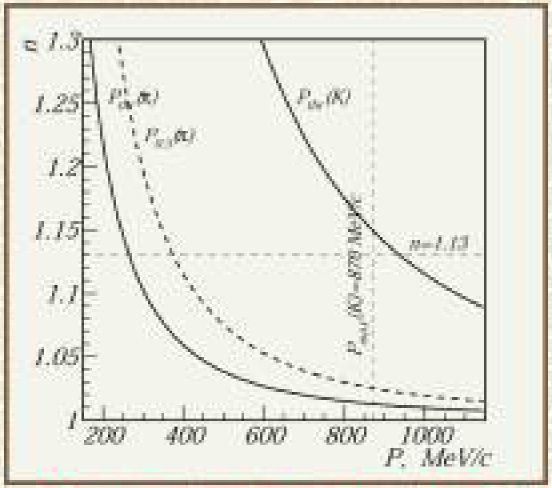


View of DC prototype

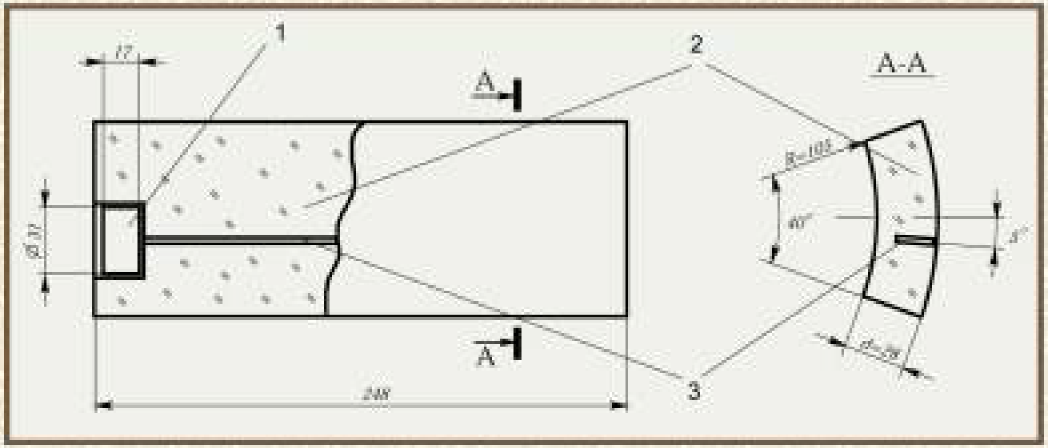


Structure	Jet*24
R_{min}, R_{max} mm	24, 90
L_{wires}, mm	240 – 280
N_{layers}	9+1
$\Delta\Omega/4\pi$	0.94
Gas	Ar+10% CO_2
$\sigma_{R\text{-}\varphi}$ mm	0.2
σ_Z ch.div. mm	1.5
σ_Z strips, mm	0.3 – 0.6
σ_φ	0.18°
σ_θ	0.30°

Aerogel cherenkov detector



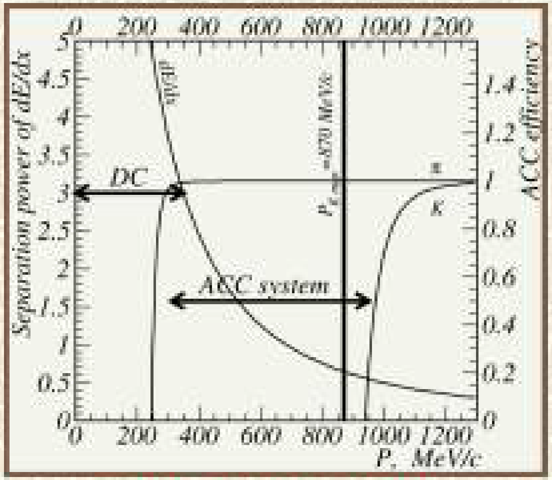
π/K-momentum threshold



1 (of 9) aerogel sector view:

1 – MCP PMT, 2 – aerogel,

3 – WLS bar



π/K-separation

Aerogel refr. index n=1.13

Solid angle – 0.6×4π

WLS bar – PMMA/BBQ

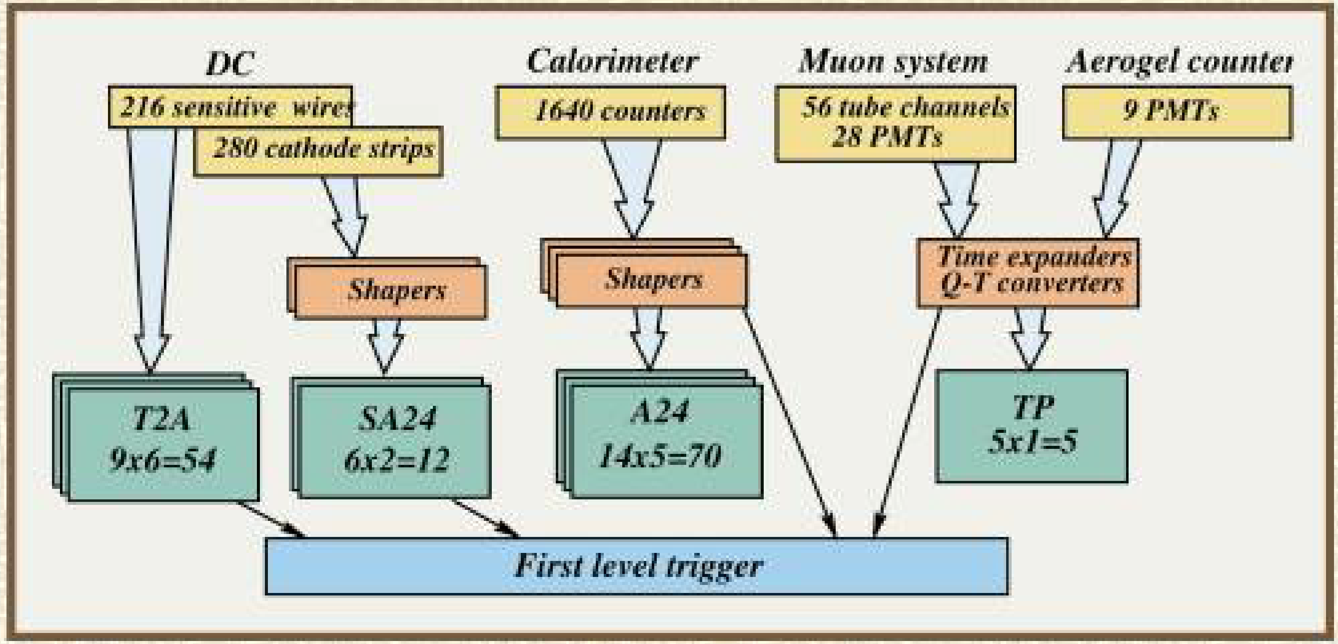
Number of ph. el. ≈ 8

SND electronics

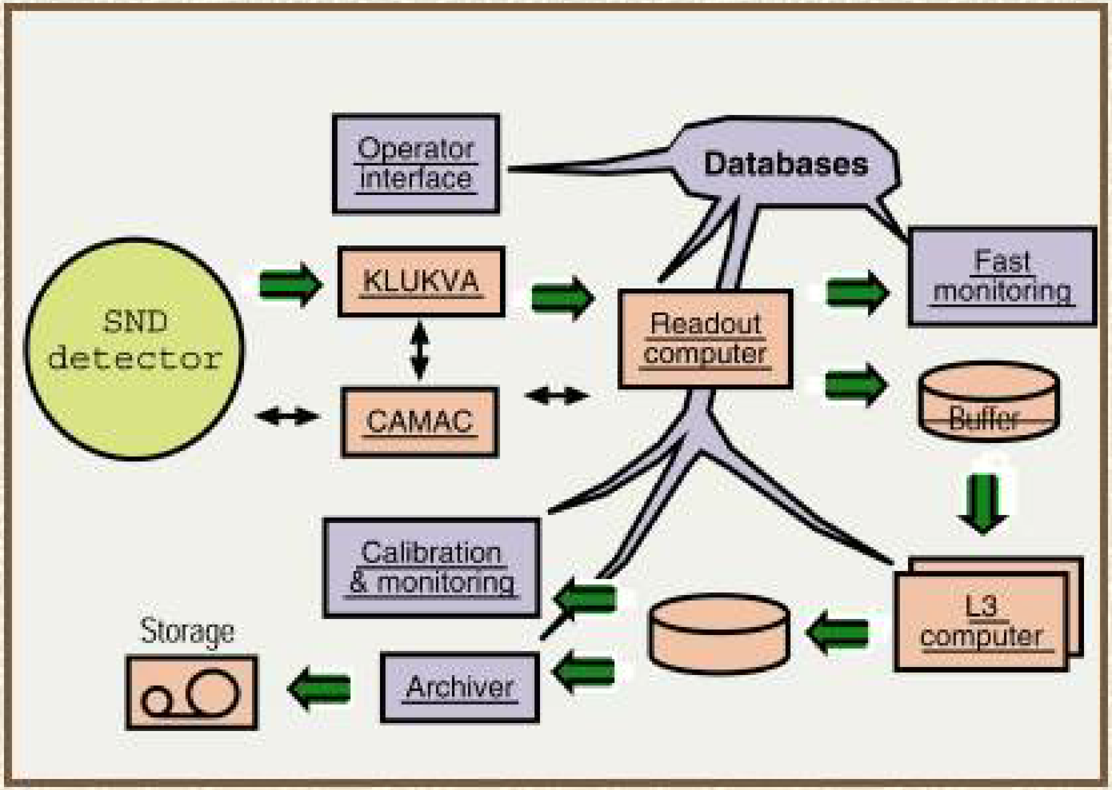
Data acquisition hardware is based on KLUKVA standard, developed in BINP.

Goals of upgrade:

- **Improvement of event rate capability of DAQ system**
- **Improvement of the electronics reliability**
- **Increase in event readout rate from 100 to 1000 Hz: new**
- **crate I/O processors, intelligent digitizing boards**

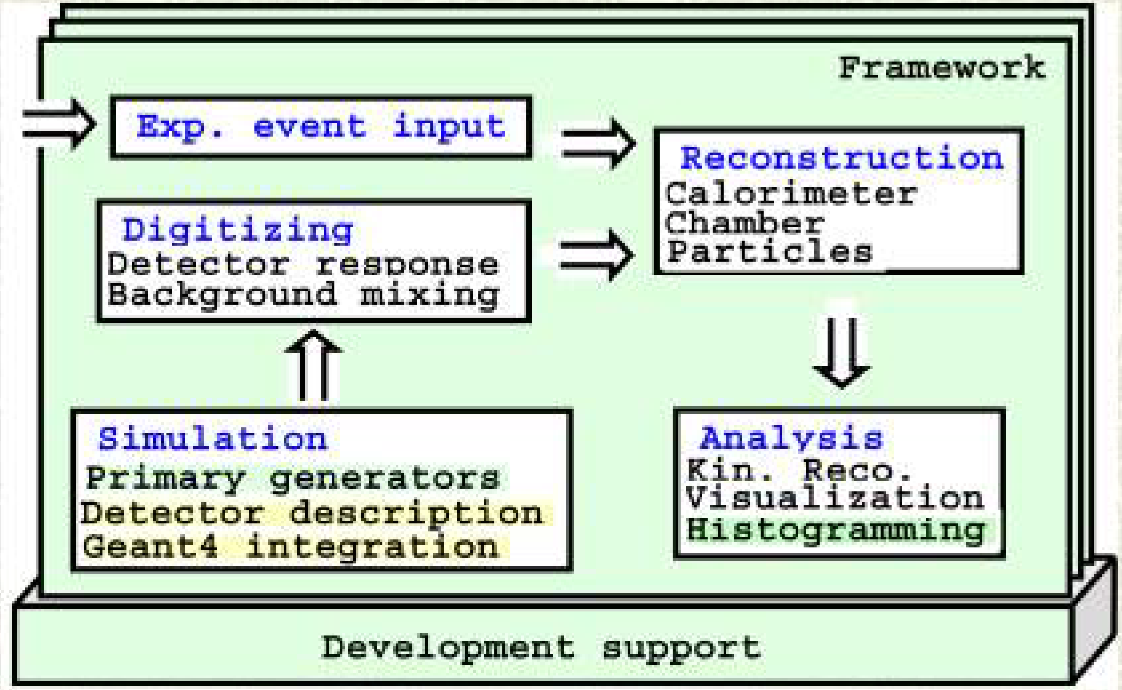


Data acquisition system



Input event rate – up to 1 kHz of 3 kByte events

SND Data Processing



- New reconstruction code for the drift chamber
- New GEANT4 based simulation
- Compatibility with the new data acquisition hardware
- C++ object oriented programming

N Nbar production cross section

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

$$\frac{dƒD}{dƒ¶} = \frac{ƒ¿^2 ƒÀÇ}{4s}\{|G_M(s)|^2(1+\cos^2\vartheta) + \frac{4M_N^2}{s}|G_E(s)|^2 \sin^2\vartheta\}$$

$$\sigma = \frac{4\pi\alpha^2\beta C}{3s}\{|G_M(s)|^2 + \frac{2M^2{}_N}{s}|G_E(s)|^2\}$$

For e+e→p pbar: $C \approx \frac{\pi\alpha}{\beta}/(1-e^{-\frac{\pi\alpha}{\beta}})$ **C~1 at $T_{kin.} \leq 1$ MeV**

At the threshold we have $s=4M_N^2$ and $G_E=G_M$,

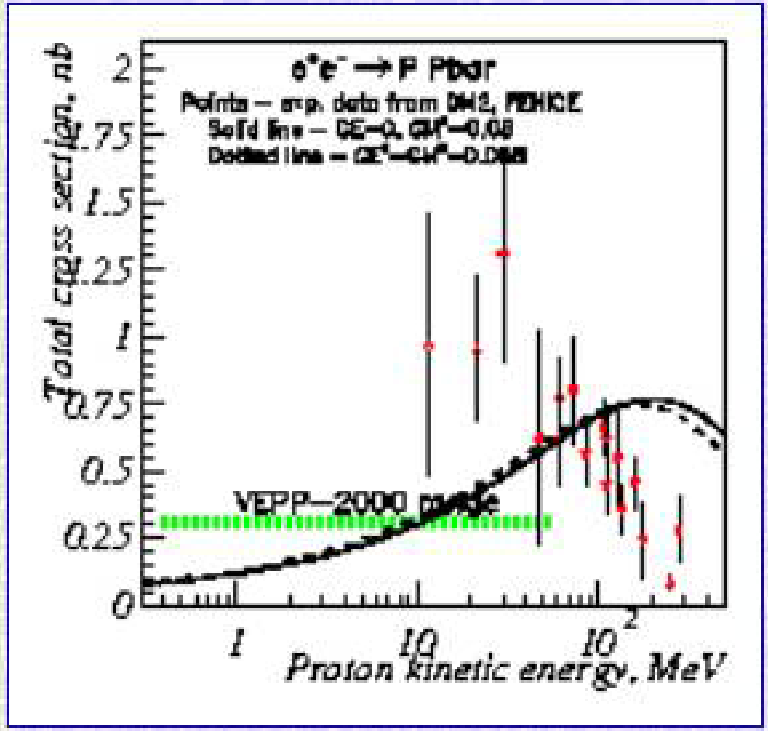
if $G_E = G_M = 0.3$, then $\sigma = \frac{\pi^2\alpha^2}{2M^2{}_N}|G_E(4M^2{}_N)|^2 \approx 0.08\text{nb}$

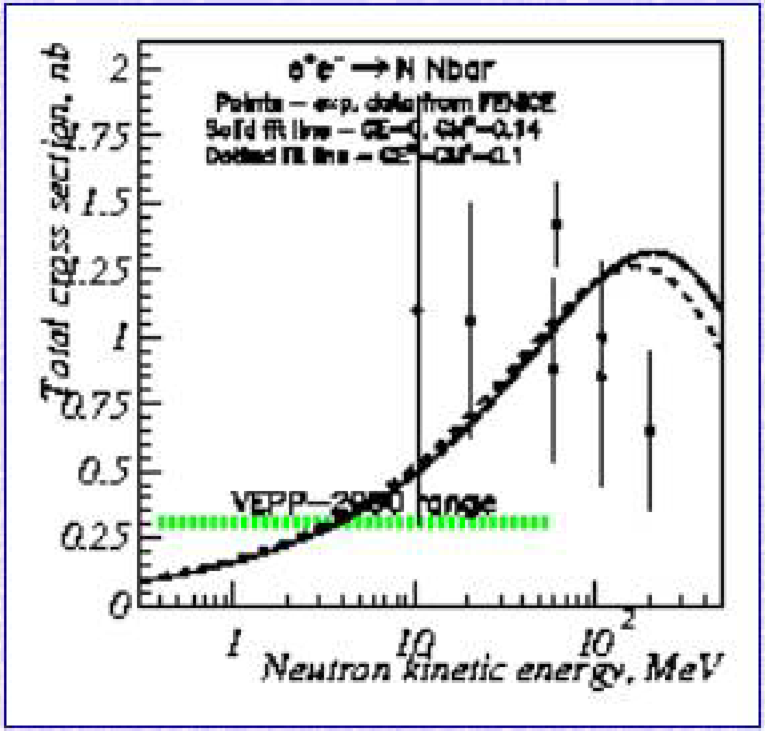
At $s=0$: $G_E^p(0)=1$, $G_E^n(0)=0$, $G_M^p(0)=2.79$, $G_M^n(0)=-1.79$

Radiative correction: $d\sigma = d\sigma_0 e^{-n}, n = \frac{4\alpha}{\pi}\ln\frac{E}{m_e}\ln\frac{E}{T_{kin}},$

For T=1Mev $e^{-n}=0.62$;
For T=50 Mev $e^{-n}=0.82$;

Experimental data on ppbar and nnbar cross sections



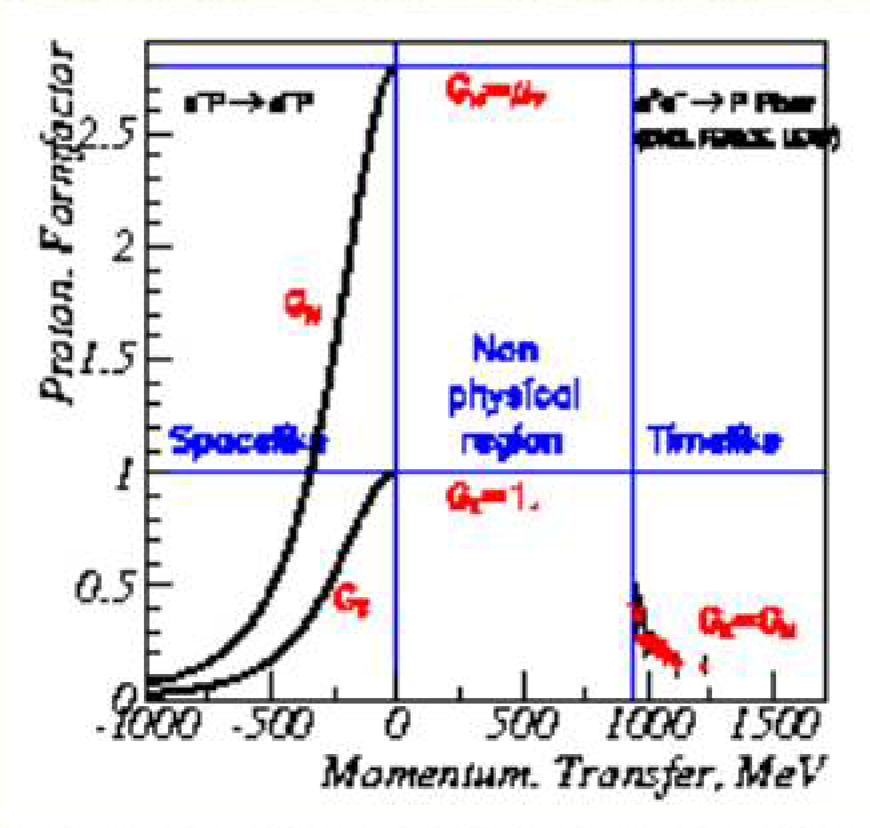


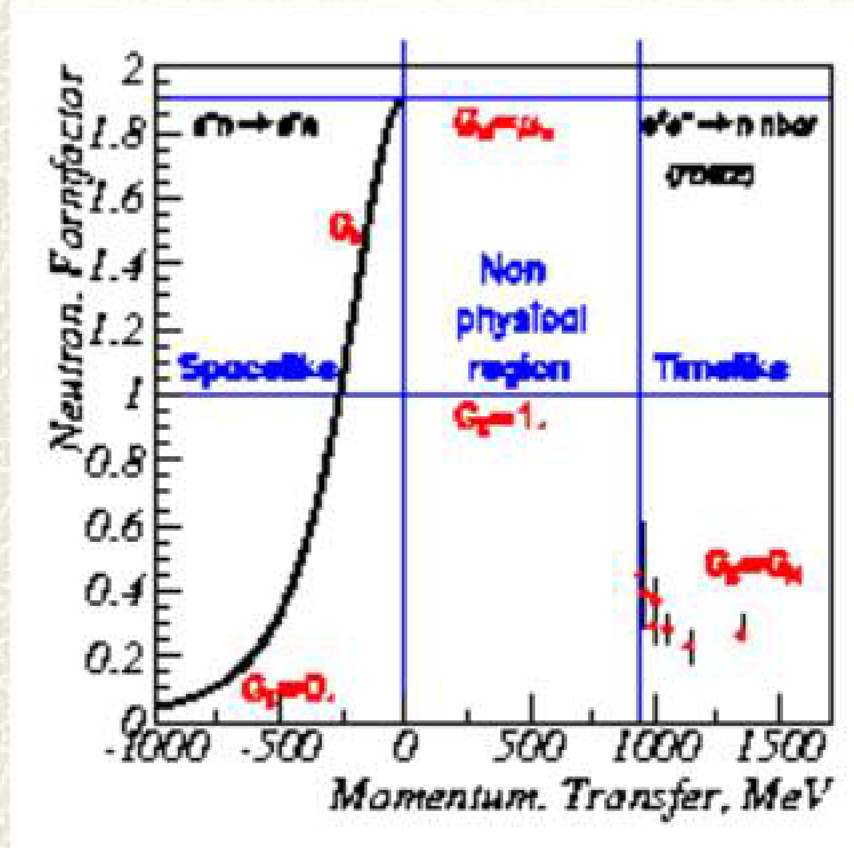
- Curves correspond to GE=0.3 and GM=0.3
- **No radiative corrections applied**;
- VEPP-2000 range is shown by green line
- Data are mainly from DM2, FENICE
- There is no data below 10 MeV (kin.en.)
- The cross section in the maximum is 1 nb
- The cross section at the threshold is 0.1 nb if GE=GM=0.3

Estimates of statistics at threshold :

- Instant luminosity - 0.1/(nb.sec)
- Time – 10^7 sec
- Integrated luminosity - 1/fb
- Detection efficiency – 0.1
- Number of events: 10^4

General View of Nucleon Formfactors





Spacelike region:

Dipole formula:

$F \sim 1/(1+q^2/M^2)^2$

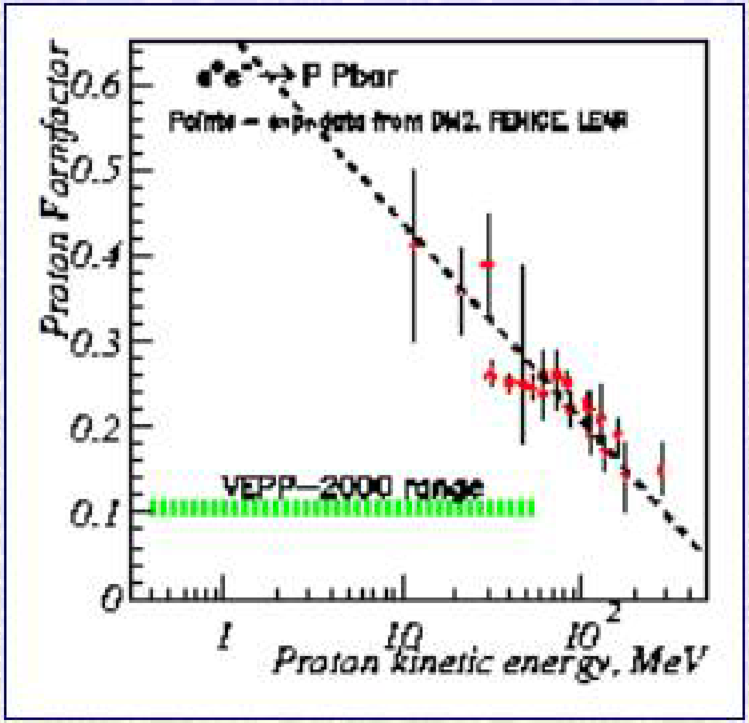
$G_{Mp} = \mu_p$, $G_{Mn} = \mu_n$,

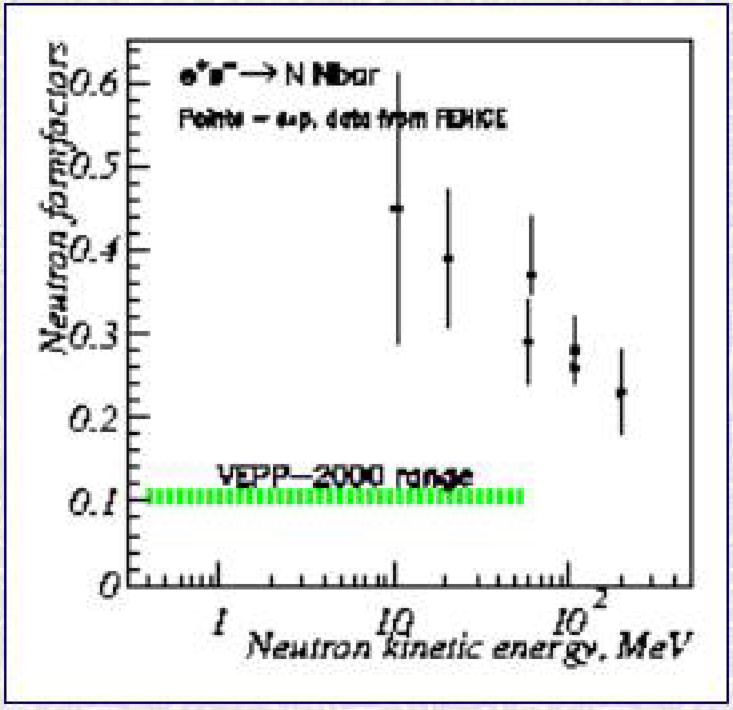
$G_{Ep} = 1$, $G_{En} = 0$.

Timelike region:

$G_M(4M^2_N) = G_E(4M^2_N)$

Experimental data on proton and neutron timelike e.m. formfactor





Value $r = \frac{\sigma(ee->nn)}{\sigma(ee->pp)}$; From exp. data: r ~1

Models: PQCD: r=0.25 (not supported)
EVDM: r=1-100;
Skyrme: r ~1

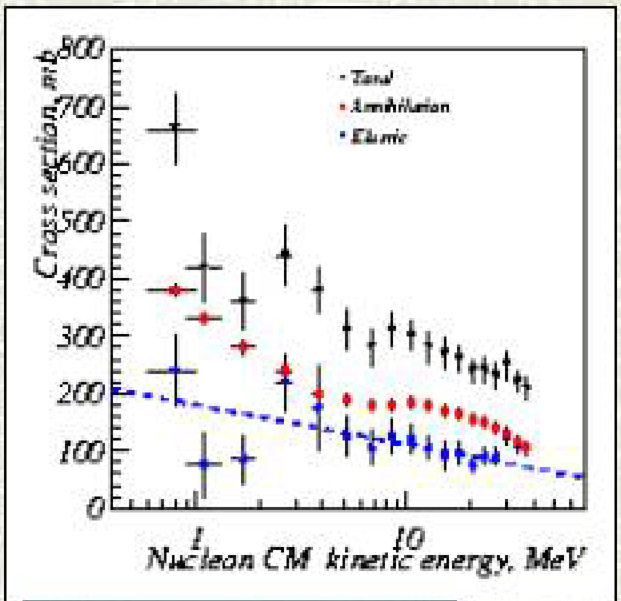
Accurate measurement of r is challenge for VEPP-2000

The goals at VEPP-2000:

- -- separate measurement of G_M and G_E ;
- -- check the rise of FF to threshold;
- -- check the relation $|G_M|=|G_E|$ at threshold;

Indications on possible resonance structure near NNbar threshold

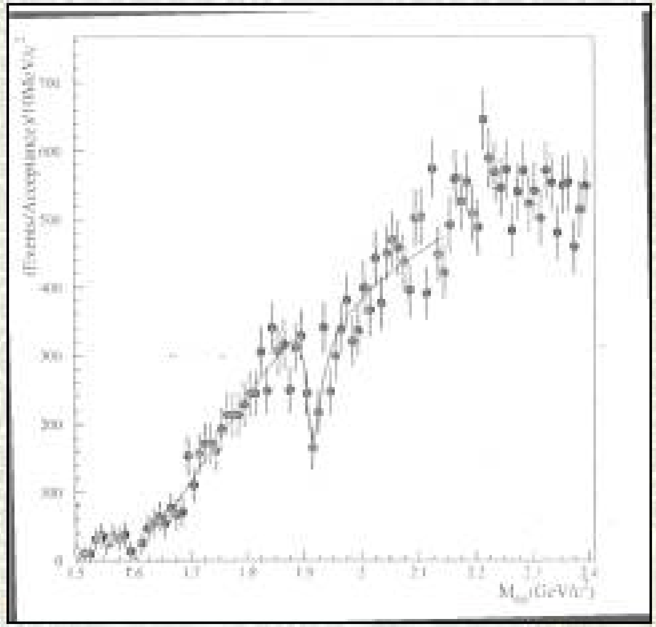
Antineutron-proton cross section



Fitting results:
M ≈ 1881 (+- 1MeV)
Γ≈ 4+- 2 MeV
Above threshold !!
Isovector (nbar p) !
If L=0 (S-wave)
S(spin)=0,1
J^{PC} = 0^{-+} or 1^{--}
If 1^{--} -> VEPP-2000

~ 3σ!

Diffr.photoproduction, E687, BNl, 2001 γ+Be->6π+Be

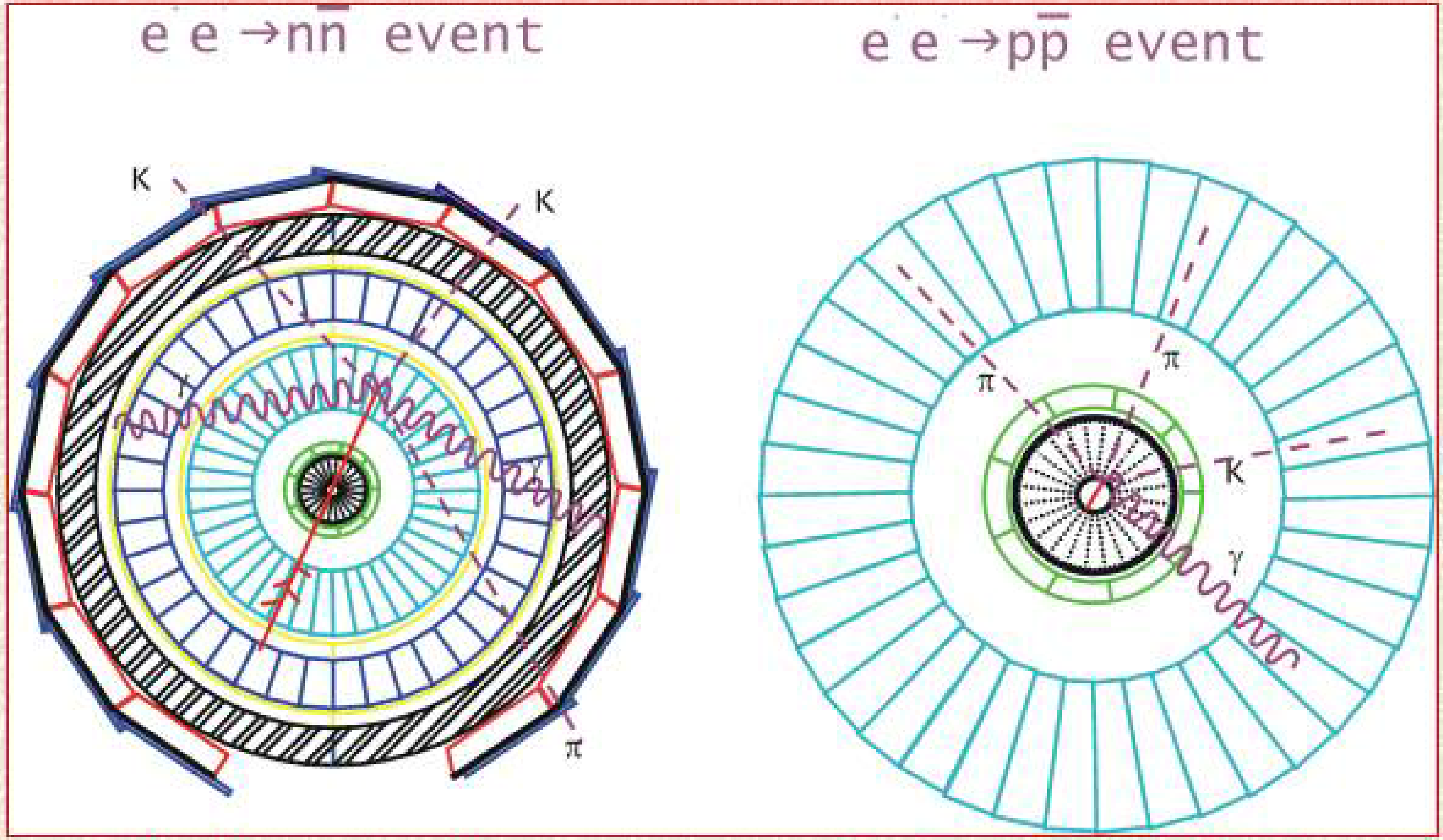


Models:
1. vector hybrid ~1.9 GeV,
2. vector glueballs >> 2 GeV,
3. NNbar resonance
4. Nnbar threshold effect

Fitting of 6π mass spectrum
M = 1911 +- 4 MeV,
Γ= 29 +- 11 MeV,
φ= 62 +- 12 deg.
A_{res}/A_{nres}=0.31+-0.07
χ^2/ND = 1.1

$J^{PC}I^G = 1^{--}\,1^+$

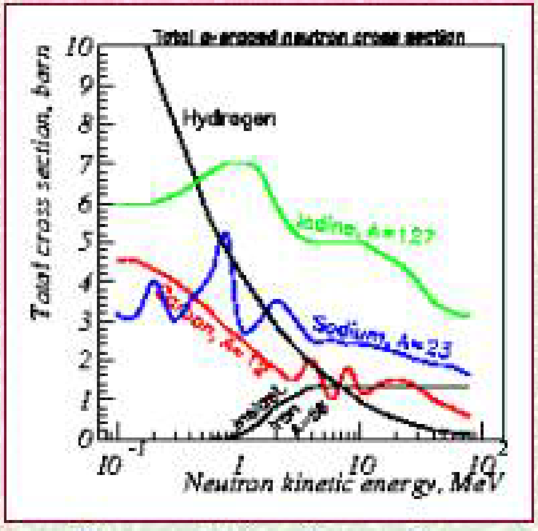
Typical signature of ppbar and nnbar events in SND



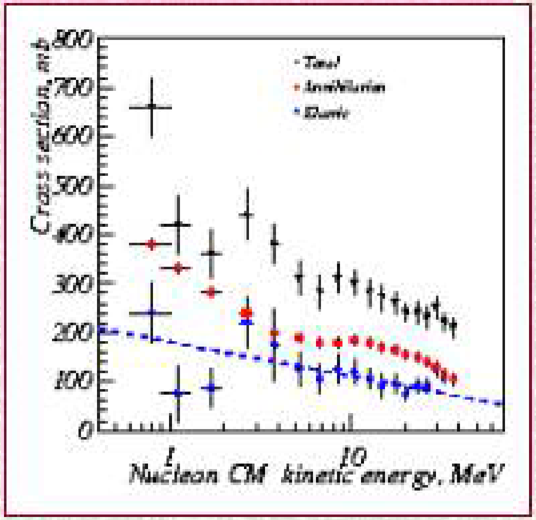
Antineutrons give stars inside calorimeter

Antiprotons annihilate in material before drift chamber

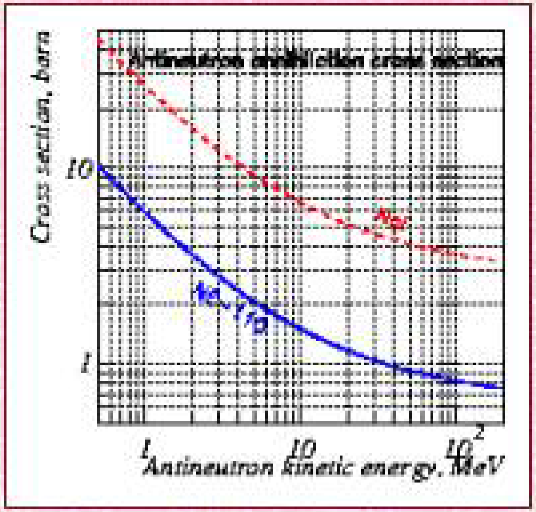
Antineutron/neutron interaction with detector material



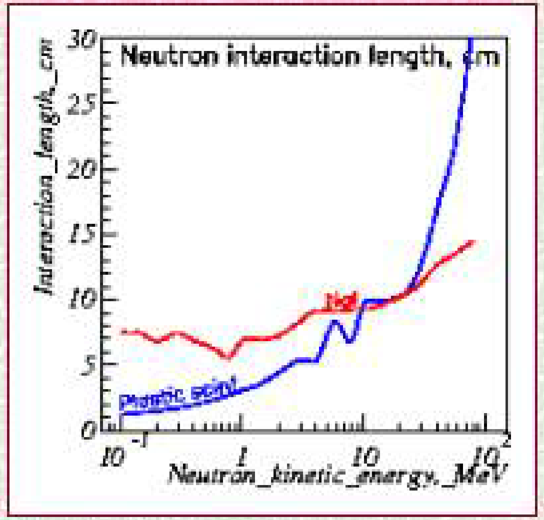
Curves obtained from old neutron interaction Tables



Experimental data from Obelix:

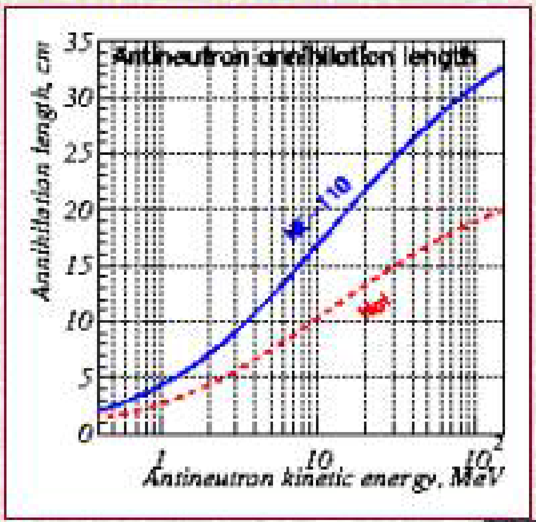


Fit curves obtained from Obelix data: NP A692 (2002) 39 -46



General conclusions:

- **the antineutron annihilation length ~ 10 cm is ~calorimeter thickness;**
- **neutrons and antineutrons have similar interaction length**



3 options of antineutron detector

1 - SND (as it is) as antineutron detector – antineutron annihilates in NaI(Tl) calorimeter, which works as antineutron absorber. The annihilation products are detected in all SND elements

2 - modified SND (SnD)
('n' means antineutron)
- first and second NaI layers are replaced by plastic scintillator with PMT readout. Annihilation time can be measured, which allows to suppress background

3 - completely new anti-neutron detector (AnD) : a la FENICE or with KLOE-type calorimeter or something else. This option is beyond the scope of the talk.

Problem of background in n nbar detection

3 types of background:

Atmospheric showers:
- they are suppressed by cosmic veto system;
- the survived events can fake the n nbar events;
- time measurements can separate the effect from cosmic background

Beam background:
- is inverse proportional to the beam life time
- can be monitored by measurements with one beam in the ring;
- can be suppressed by nbar annihilation time measurements

Physical background

$e^+ e^- \to K_S K_L$, $\sigma \sim 0.1$ nb
$e^+ e^- \to K_S K_L \pi^0$, $\sigma \sim 1$ nb
$e^+ e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$, $\sigma \sim 0.1$ nb
$e^+ e^- \to \omega\gamma, \varphi\gamma \to$ neutrals, $\sigma \sim 10$ pb
$e^+ e^- \to$ hadrons $\to$ neutrals, $\sigma < 0.1$
$e^+ e^- \to 4\gamma, 5\gamma$, (QED), $\sigma \sim 0.1$ nb

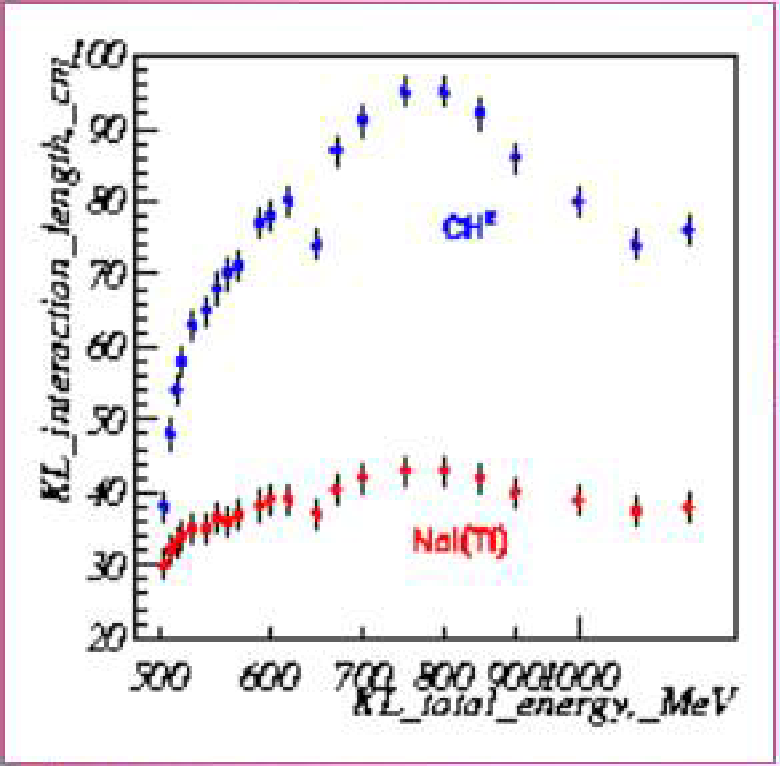
For comparison $e^+e^- \to n\,\bar{n}$ cross section $\sigma \sim 0.1$ nb

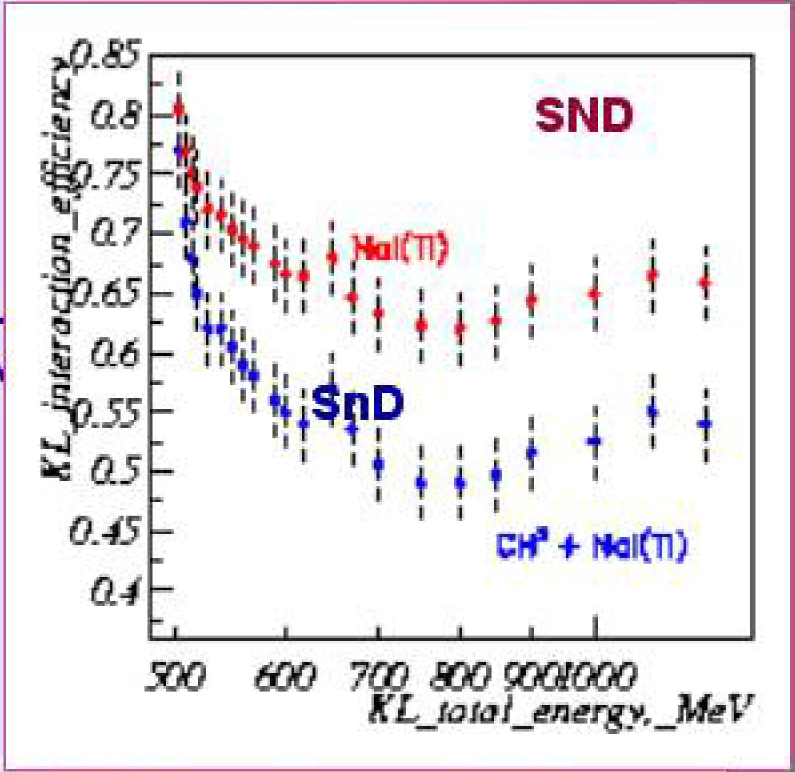
The most physical background comes from the reactions with production of K_L.

K_L interactions and decays in flight look similar to nbar annihilation, because they give ‘stars’ outside the detector center.

Estimation of K_L interaction probability

KL is the main source of physical background



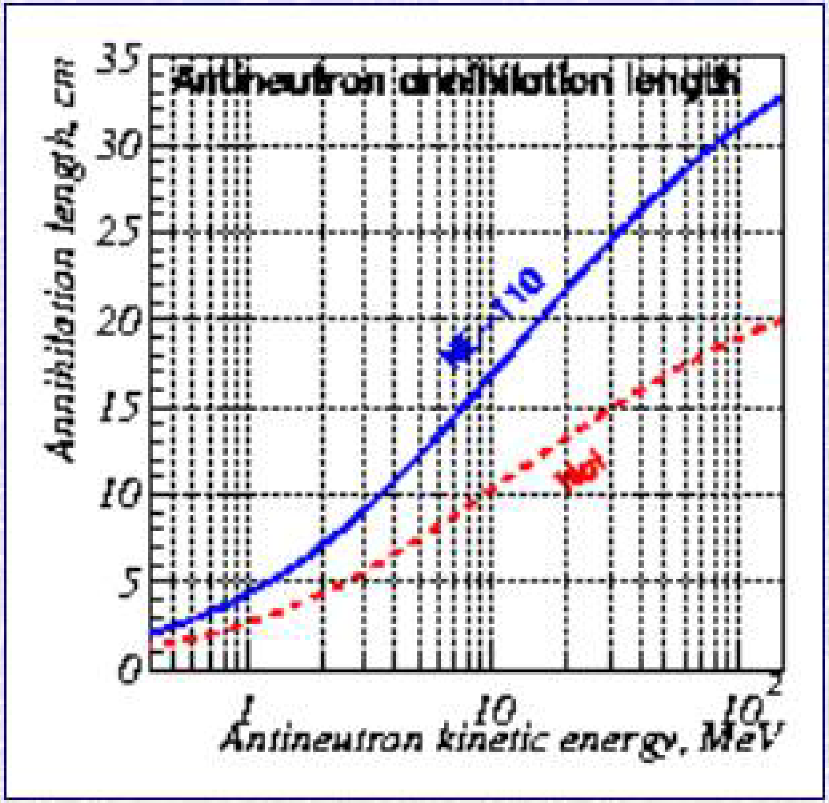


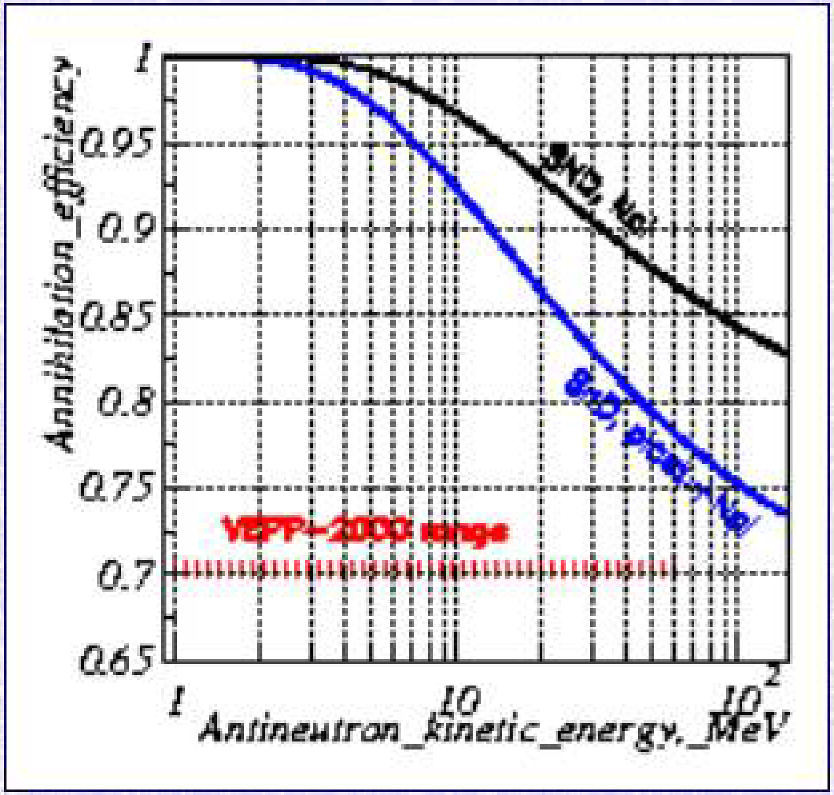
KI interaction length (incl. decays)
Red: SND NaI(Tl) detector
Blue: SnD (with plastic insert)

KL interaction probability:
Red: SND NaI(Tl) detector
Blue: SnD (with plastic insert)

Conclusion: K_L detection efficiency in SnD is ~50% of that of nbar.

Estimation of nbar detection efficiency in SND and SnD





Detection efficiency $\varepsilon = \varepsilon_a \varepsilon_{Tr} \varepsilon_{Rec}$,
where ε_a = annihilation probability,
ε_{Tr} = trigger efficiency ~0.8?
ε_{Rec} = reconstruction eff. ~0.5?

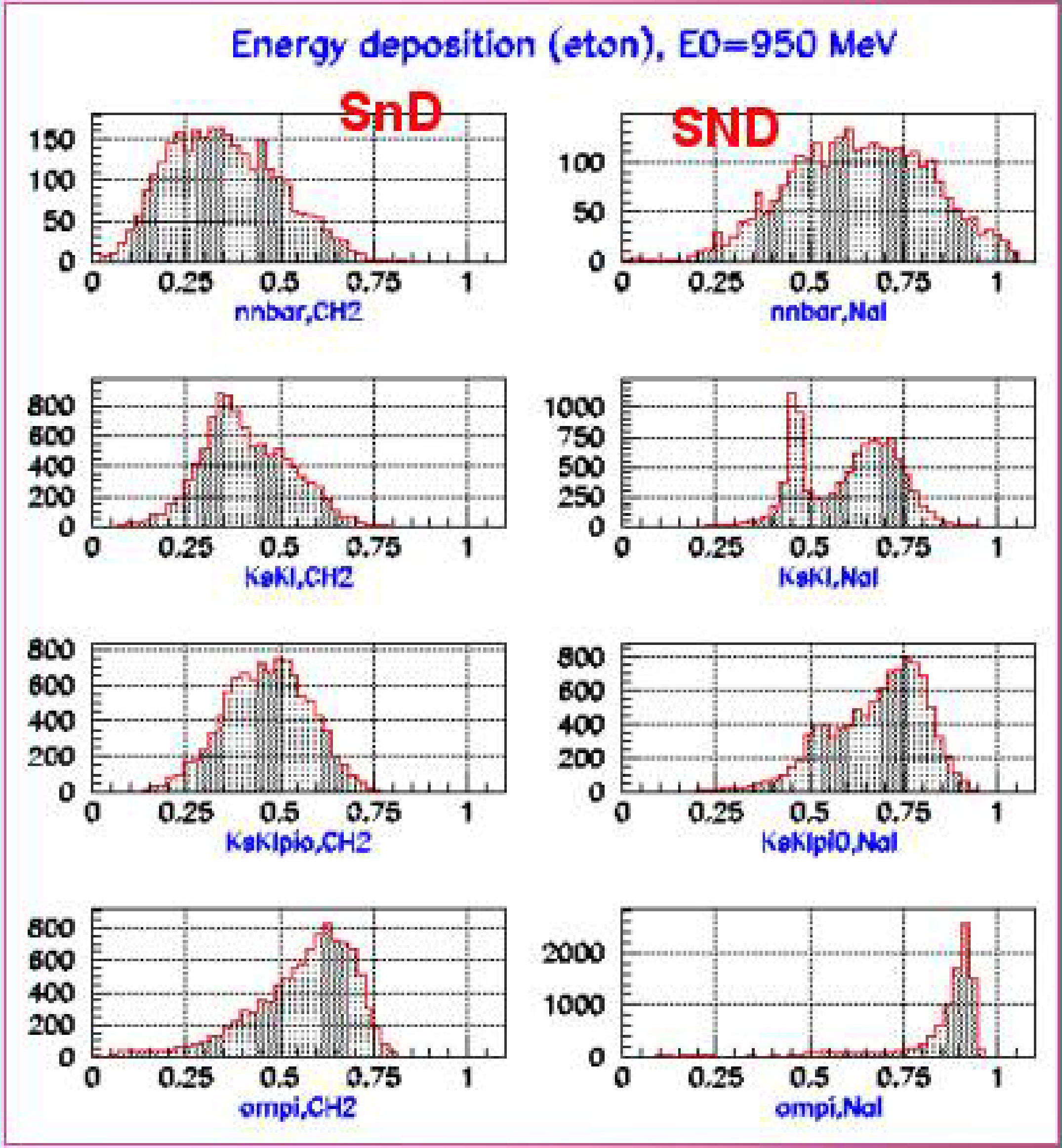
Estimate of detection efficiency at T=10 MeV:
ε ~0.3 - 0.4

MC study of different e+e- processes (based on total energy deposition)

Left column: SnD (plastic insert)
Right column: SND NaI(Tl)

Top row – n nbar process
2-nd row – KsKL(Ks->2pi0),
3-rd row – KsKLpi0((Ks->2pi0),
Except KsKL and nnbar we check in
bottom row– ωπ->5γ

Conclusion: n nbar and KsKLpi0 events have different distribution

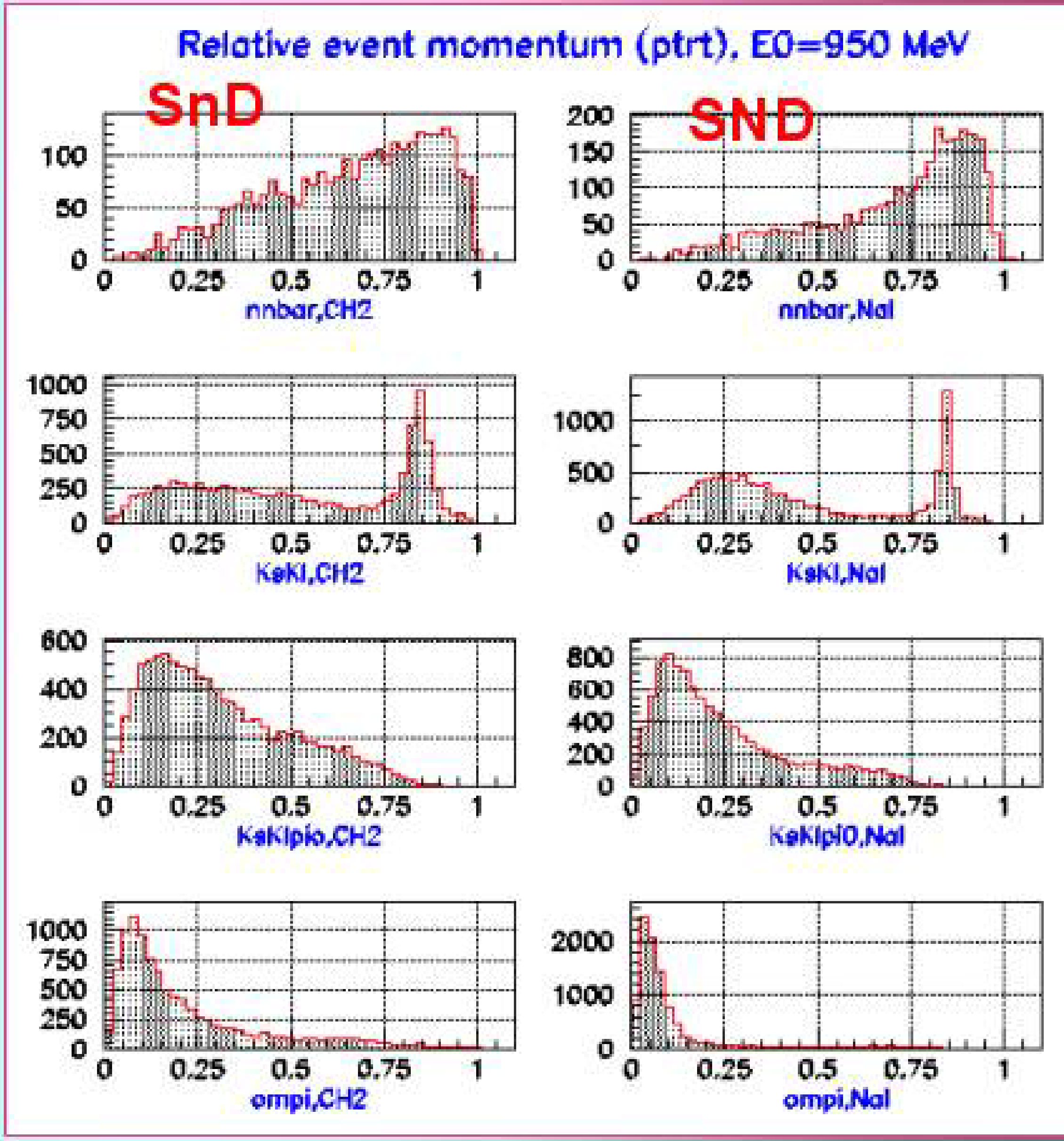


MC study of different e+e- processes (based on total event momentum)

Left column: SnD (plastic insert)
Right column: SND NaI(Tl)

Top row – n nbar process
2-nd row – KsKL(Ks->2pi0),
3-rd row – KsKLpi0((Ks->2pi0),
Bottom row– ωπ->5γ

Conclusion: n nbar and KsKLpi0 events have different distribution

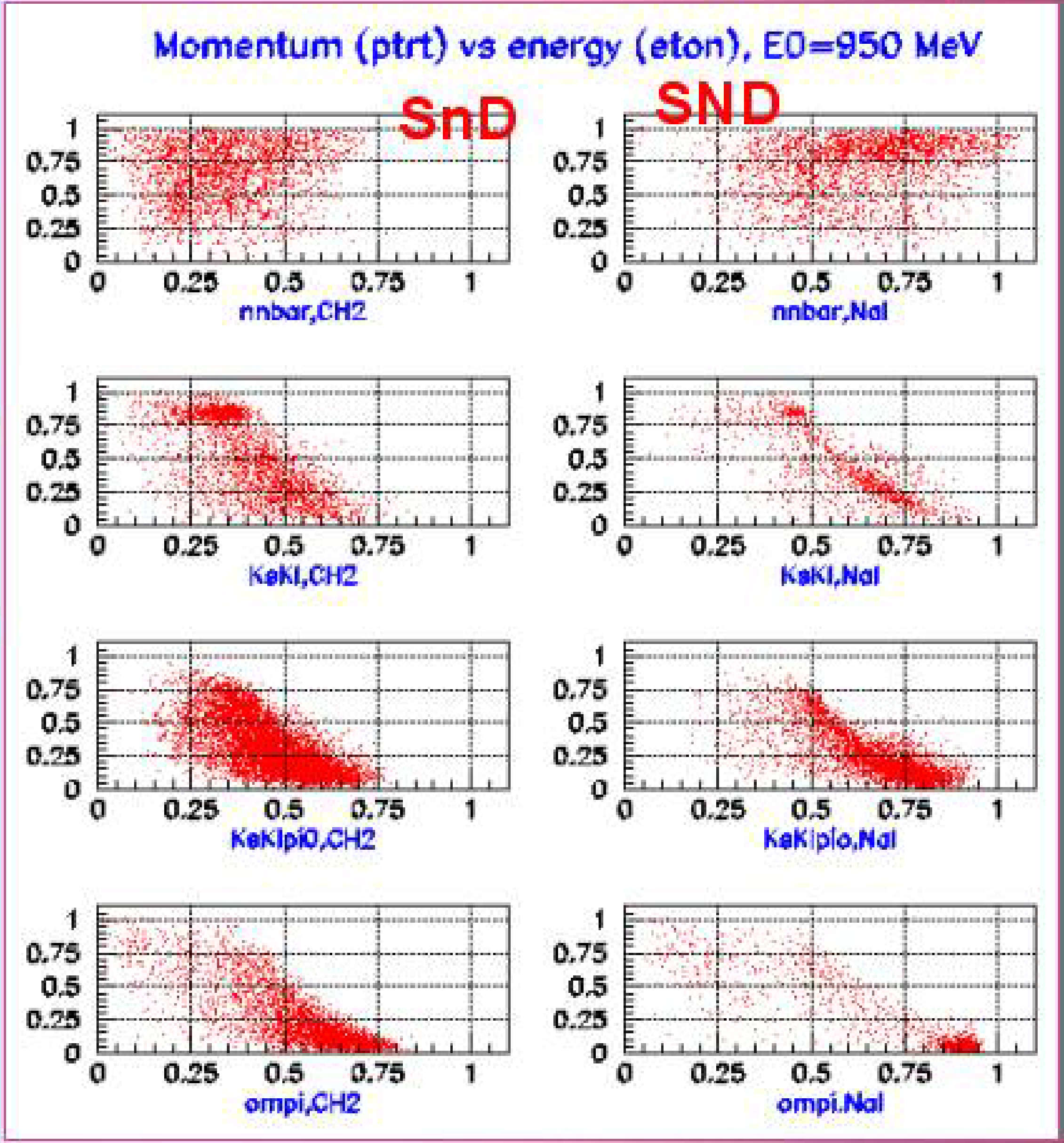


MC study of different e+e- processes (based on total event energy and momentum)

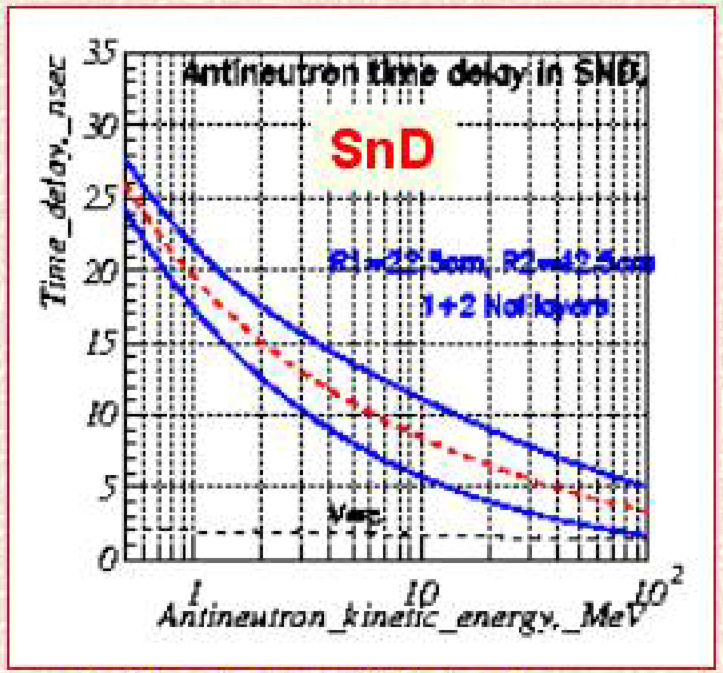
Left column: SnD (plastic insert)
Right column: SND NaI(Tl)

Top row – n nbar process
2-nd row – KsKL(Ks->2pi0),
3-rd row – KsKLpi0((Ks->2pi0),
Bottom row– ωπ->5γ

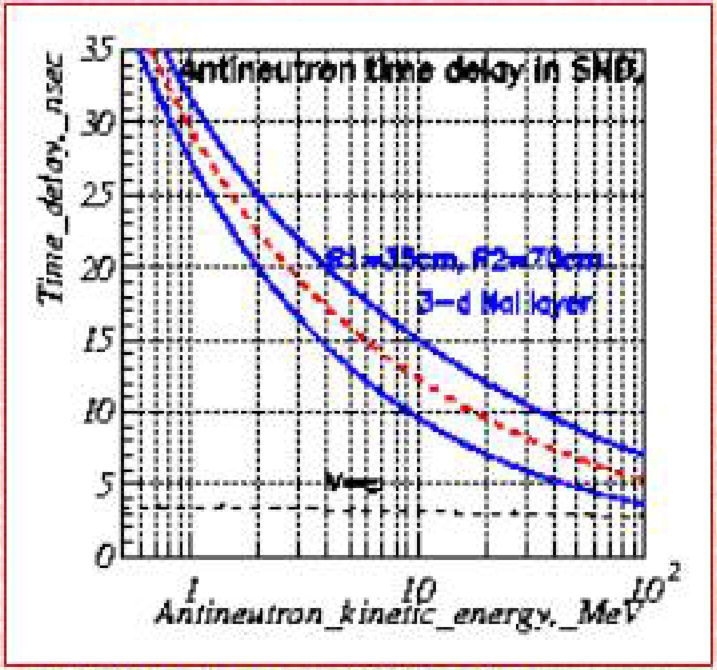
Conclusion: n nbar and KsKLpi0 events have different distribution, which allows their effective separation



Use of nbar annihilation time delay in SnD



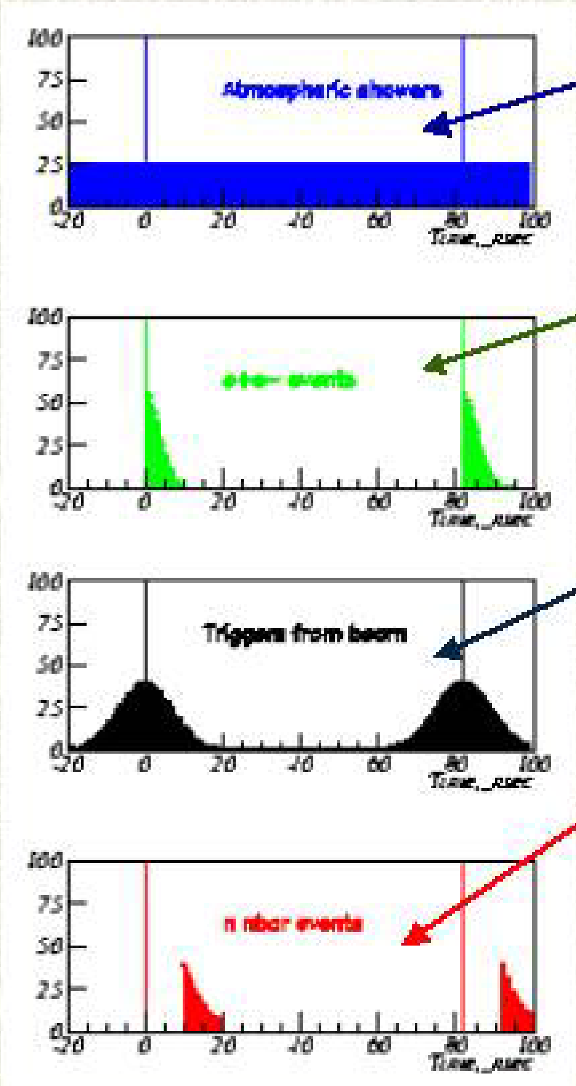
Antineutron annihilates in
1-2 calorimeter layer (NaI is
replaced by plastic scintillator)



Antineutron annihilates in
3-d plastic layer (1-2 layers are
removed)

Conclusion: Effective suppression of physical background is possible using time measurements for antineutrons with energy below 50 MeV.

Trigger time spectra in SnD for different processes



Atmospheric showers give uniform time distribution

e+e- events (like e+e->4π) give peak at t=0

Beam triggers give broad peak around t-0

n nbar events give distribution shifted from t=0 by 5-10 nsec

Conclusions: in search for n nbar events time measurements can improve background suppression

FENICE – the only detector measured e+e->n nbar process (ADONE)

GENERAL

Length – 2.5m, Radius –1.5m
Coverage – 76% 4π,
T=8Xo, λ=1.2-5.0 λo

Neutron detector

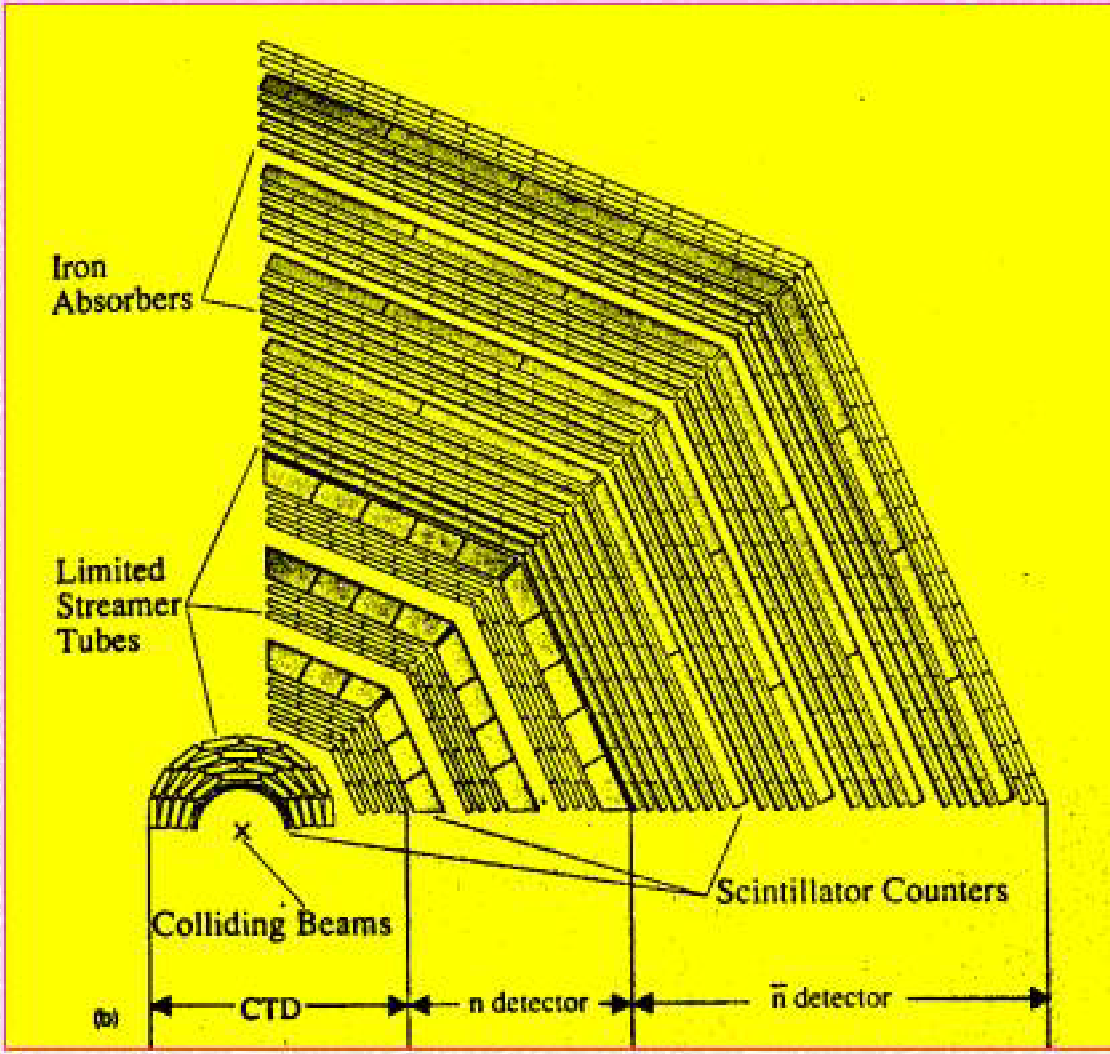
Streamer tubes (LST) – 10 layers
NE-110 (5cm) - 3 layers
Det.efficiency,T>5MeV ~10-40%

Antineutron detector

Streamer tubes (LST) – 20 layers
NE-110 (2cm) – 4 layers
Iron plates – 20 layers

Material along track

LST – 34 layers
NE-110 – 23.5 cm
Iron - 10 cm

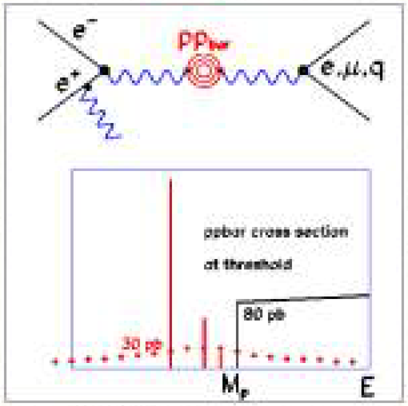


FENICE Experiments:
$\Delta L \approx 400/nb$; $\varepsilon_{nn} \approx 0.22$; $N \approx 74$ ev.;
$\delta_{syst} \approx 15\%$; $\sigma_{nn} \approx 1nb$; $FF_{nn} \approx 0.37$;

trigger rate ≈ 20 Hz

e+e->p pbar process

Formation of ppbar Coulomb state (antiprotonium)



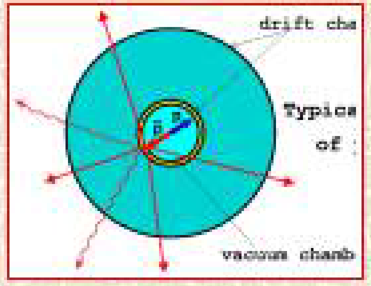
E= $\alpha^2/4$=12.5 KeV,
R=2/ $M_p \alpha$ =0.6 10^{-11}cm >> 10^{-13} cm,
$\Gamma_{ee} = \Gamma_{\mu\mu} = M_p\alpha^5/6$=3.3 meV, $\Gamma_t \cong 4\Gamma_{ee}$,
$\sigma_0 = 3\pi\lambda^2 B_{ee} B_f = 10^{-27}$ cm^2, $\sigma_{vis} = \sigma_0 \Gamma_t / \Delta E$,
$\Delta E \cong 0.5$ MeV, $\sigma_{vis} \cong 30$ pb for E= M_p ,

For comparison σ(e+e->$\mu\mu$) $\cong$ 25 nb,
Then S/N $\cong$ 7.5 pb/25 nb $\cong$1/3000 !

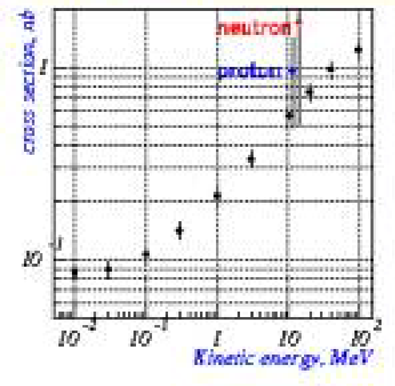
Conclusions: antiprotonium doesn't give visible contribution in e+e- cross section

Collider energy calibration with e+e->pbar process at threshold

Typical signature of Ppbar event:



The ppbar cross section view at the threshold



Conclusions for VEPP-2000:

The cross section at the threshold is 50 pb with radiative correction;
If L=0.1/(nb s), t=10^5sec (1 day), ε=0.3, then we have N=L t ε =150 events/day ~10% accuracy,
Estimated calibration accuracy is ~10^{-4}

Schedule

VEPP-2000 -- beam -- 2004
-- luminosity -- 2005
-- running – 2005–2010

SND -- upgrade -- 2004
– nbar trigger -- 2004
-- data taking -- 2005
-- FF results -- 2007

SnD -- TDR, decision - 2004
– construction –2005-2006
– data taking -- 2007
– FF results -- 2008

AnD -- proposal - 2004?

Conclusions

1. VEPP-2000 provides unique possibility to produce more than 10^5 ppbar and Nnbar events per year at the threshold region 2E<2000 MeV. This exceeds by ~1000 times the world statistics of e+e→n nbar process.

2. Non magnetic SND detector can be used as efficient antineutron detector. To improve n nbar events selection an option with plastic scintillator insert in 1-2 spherical layers is proposed (SnD).

3. The hadronic final states with K_L-meson are the main source of physical background. Simulation shows, that suppression of this background by ~100 times is possible in SND calorimeter. Time measurements in SnD promise more background suppression.

4. The nonphysical background for e+e→n nbar process comes from atmospheric showers and e^+, e^- beams. The time measurements in SnD can facilitate suppression of this background.

5. In near future we suggest to use upgraded SND detector for study of e+e→n nbar and e+e→p pbar processes. The improved SND option (SnD) is being developed in parallel for second run at VEPP-2000.

SND team (March 2003)

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3. Vladimir Druzhinin – general
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10. Yuri Usov – electronics
11. Alexandr Korol – DAQ
12. Alexandr Bogdanchikov – DAQ
13. Sergey Koshuba – DAQ
14. Dima Bukin – software
15. Alexey Berdyugin – simulation
16. Zurab Silagadze – analysis
17. Elena Pakhtusova – analysis
18. Alexandr Bukin - analysis
19. Tanya Dimova - analysis