Tau-Charm Factory in Novosibirsk

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Outline

1. Physics case
2. Detector
3. Machine
4. Conclusions

What is Super-Tau-Charm Factory?

A Super-Tau-Charm Factory is an accelerator complex for high-precision measurements between 2 and 5(7) GeV with luminosity up to $10^{35}\text{cm}^{-2}\text{s}^{-1}$ and longitudinal polarization

Integrated luminosity of 1.5 ab^{-1} could be collected in 5-10 years

τ Lepton Physics

- $\sigma_{\tau\tau}$ grows from 0.1 nb near threshold to 3.5 nb at 4.25 GeV
- 10^{10} $\tau^+\tau^-$ pairs can be collected
- Near threshold an additional kinematic constraint $2M_\tau E_h = M_\tau^2 + M_h^2$ suppresses background, with 1 ab^{-1} about 10^8 $\tau^+\tau^-$ pairs can be produced
- LFV, suppression of $e^+e^- \to \tau^+\tau^-\gamma$
- M_τ, M_{ν_τ}, lepton universality, a_τ
- $V-A$ structure of the weak current in leptonic decays
- Rare hadronic decays
- Second class currents
- CP violation in τ decays

Study of Charmonium-(like) States – I

State	J/ψ	$\psi(2S)$	$\psi(3770)$	$\psi(4040)$
M, GeV	3.097	3.686	3.771	4.039
Γ, MeV	0.093	0.337	23	80
σ, nb	1450	400	6	10
$\int Ldt, \text{fb}^{-1}$	800	250	400	10
N	10^{12}	10^{11}	$2 \cdot 10^9$	10^8

- 20 (25) fb^{-1} needed to produce 10^8 $\psi(4160)$ ($\psi(4415)$) mesons
- $\sim 10^{10}$ χ_{cJ} and $\eta_c(1S)$ in radiative decays of the J/ψ and $\psi(2S)$
- About 10^8 h_c mesons in $\psi(2S) \to h_c\pi^0$
- $\eta_c(2S)$ mesons can be produced in $\psi(2S) \to \eta_c(2S)\gamma$ or $\gamma\gamma$ collisions

Study of Charmonium-(like) States – II

- All Y states with $J^{PC} = 1^{--}$ will be directly produced at $\sqrt{s} = M_Y$: $Y(4260),\ Y(4360),\ Y(4660)$
- Charged Z_c states can be produced by scanning the $\sqrt{s}$ range and studying the $J/\psi\pi\pi,\ h_c\pi\pi,\ D^{(*)}\bar{D}^{(*)}$ final states
- Neutral $c\bar{c}$ states with other quantum numbers can be studied in the recoil to $\pi\pi,\ \pi^0,\ \eta,\ \omega$ final states
- Between 6 and 7 GeV double $c\bar{c}$ production?

Charm Physics

- 10^9 pairs of $D^{\pm,0}$ and $2 \cdot 10^7$ D_s mesons can be collected in the reaction $e^+e^- \to D^+D^-,\ D^0\bar{D}^0,\ D_s^+D_s^-$
- More precise results can be expected at the $\psi(3770)$ with a data sample lower than at the $\Upsilon(4S)$
- The multiplicity of final particles is lower by a factor of 2
- Clean $D\bar{D}$ events are produced near threshold, additional kinematic constraints are possible (ν reconstruction), double-tagging: one D is fully reconstructed and for the other D absolute $\mathcal{B}$ are measured
- At threshold D and $\bar{D}$ are produced in QM coherent state, e.g., in $e^+e^- \to D\bar{D}(J^{PC} = 1^{--})$ making possible studies of $D - \bar{D}$ mixing, CP violation, with determination of strong phase shifts and probabilities for decays to CP-pure states
- 50 fb^{-1} between 4.3 and 5 GeV to study spectroscopy of D_J and D_{sJ} states produced in $e^+e^- \to D_0^*\bar{D}^*,\ D_1^{(\prime)}\bar{D}^{(*)},\ D_2^*\bar{D}^{(*)}$ with $\sigma \sim 1$ nb

Charmed Baryons

- Charmed baryons are produced via $e^+e^- \to B_{1c}\bar{B}_{2c}$ with $B_{ic} = n_1 n_2 c$
- From the QF-asymmetric antitriplet 3 spin-1/2 states (Λ_c^+, Ξ_c^+, Ξ_c^0)
- From the QF-symmetric sextuplet 6 spin-1/2 states ($\Sigma_c^{++,+,0}$, $\Xi_c^{\prime +}$, $\Xi_c^{\prime 0}$, Ω_c^0), 6 spin-3/2 states ($\Sigma_c^{*++,+,0}$, Ξ_c^{*+}, Ξ_c^{*0}, Ω_c^{*0}), all 15 S-wave discovered
- The quark model predicts 63 P-wave states, 16 discovered between 2.6 and 3.1 GeV
- Weak decays of the $\Lambda_c^+(2286)$, $\Xi_c^+(2468)$, $\Xi_c^0(2471)$ and $\Omega_c^0(2698)$ are of interest, the required maximum energies are 4.7, 5.1 and 5.5 GeV

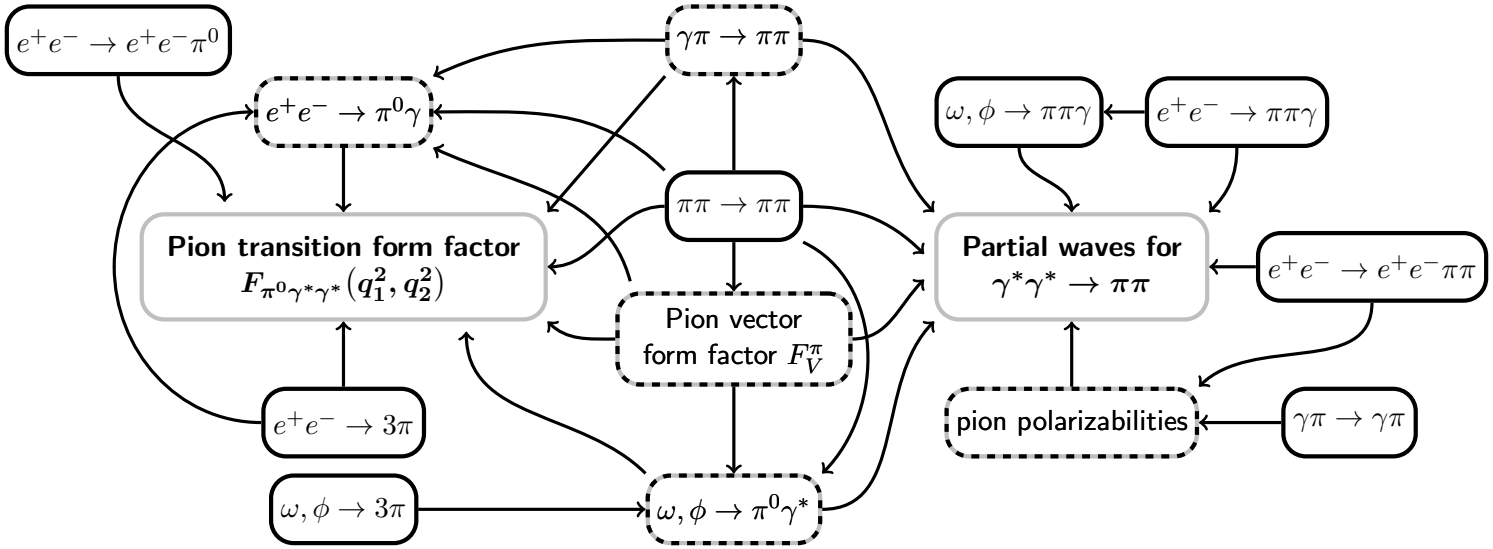
Measurements of e^+e^- Cross Sections

1. Detailed study of exclusive processes $e^+e^- \to (2-10)h, h = \pi, K, \eta, p, \ldots$, scan between 2 and 5 GeV and ISR for $\sqrt{s} < 2$ GeV
   - Meson Spectroscopy
   - Intermediate dynamics
   - Search for exotic states (tetraquarks, hybrids, glueballs)
2. High precision determination of $R = \sigma(e^+e^- \to \text{ hadrons})/\sigma(e^+e^- \to \mu^+\mu^-)$ at low energies and fundamental quantitites
   - $(g_\mu - 2)/2$, 92% from < 2 GeV, 7% for 2-5 GeV
   - $\alpha(M_Z^2)$, 19.0% from < 2 GeV, 18.1% for 2-5 GeV
   - QCD parameters (α_s, quark masses, quark and gluon condensates)

Two-Photon Physics

- Measurement of $\Gamma_{\gamma\gamma}$ for $J^{PC} = 0^{-+},\ 0^{++},\ 2^{-+},\ 2^{++}$ States
- Study of $\gamma\gamma^* \to R$, $J^{PC} = 1^{++}$
- Transition Form Factors in $\gamma^*\gamma^* \to R$
- Total Cross Section of $\gamma\gamma \to$ hadrons
- Exclusive cross sections for $\gamma\gamma \to \rho\rho,\ p\bar{p}, \phi\phi$
- Taggers needed for single- and double-tag measurements

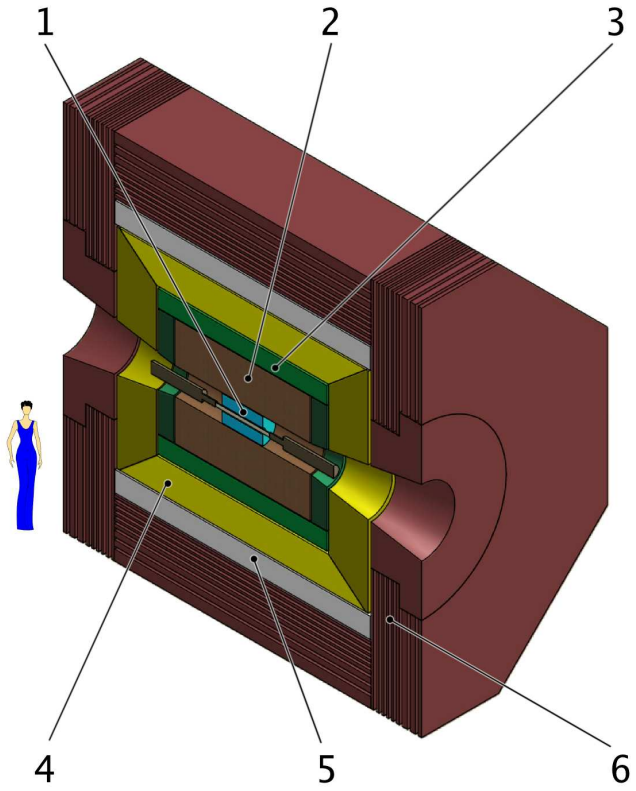
Transition Form Factors and Hadronic LbL



Measurements of various processes are in order

G. Colangelo et al., Phys. Lett. B 738, 6 (2014); JHEP 1409, 091 (2014)

Detector – I



1 – Vertex detector
2 – Drift chamber
3 – FARICH
4 – Calorimeter
5 – Superconducting coil
6 – Muon System

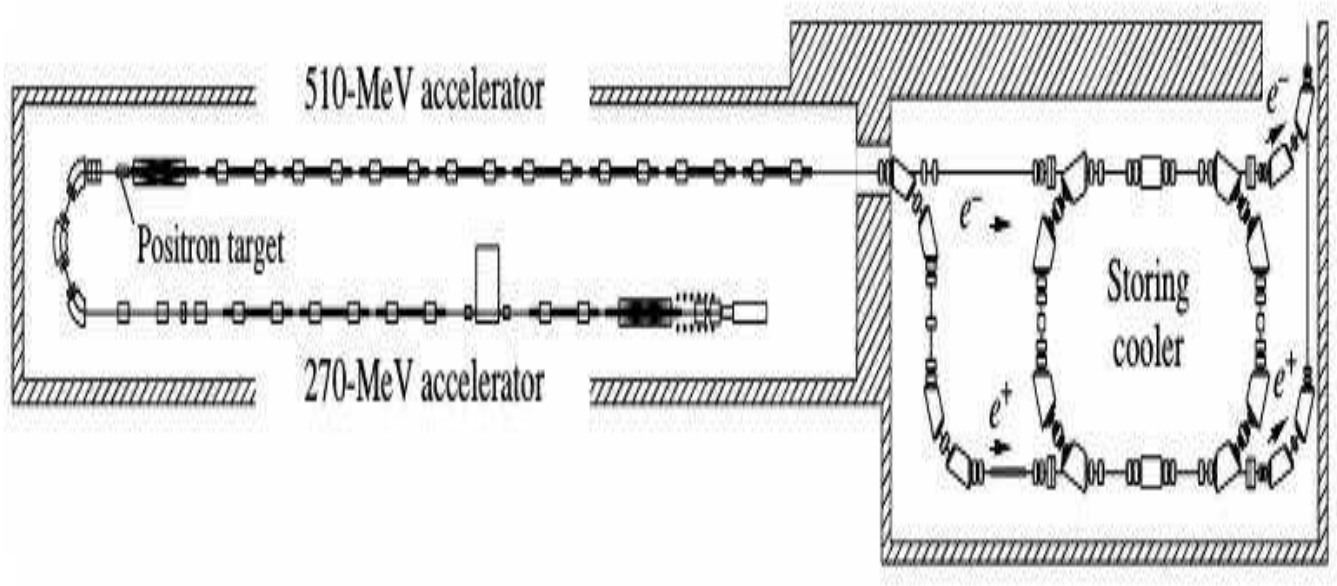
Detector – II

- Vertex detector: $L = 60$ cm, inner/outer D – 5/40 cm,
  TPC or multilayered Si detector considered
- Drift chamber similar to BaBar, $L = 200$ cm, $D = 180$ cm,
  average spatial resolution 125 μm
- E/m calorimeter on pure CsI crystals, 16-18 X_0 (30-34 cm),
  5248 cr. (26-31 t), energy resol. 1.5% at 1 GeV
- Focusing Aerogel RICH (FARICH), radiator of several aerogel layers,
  K/π separation - 10σ, from 1.3 to 2 GeV/c, multipixel APD
- Superconducting coil – (1.0 - 1.2)T
- Muon system – nine layers: localized-discharge counters,
  streamer gas detectors, scintillators

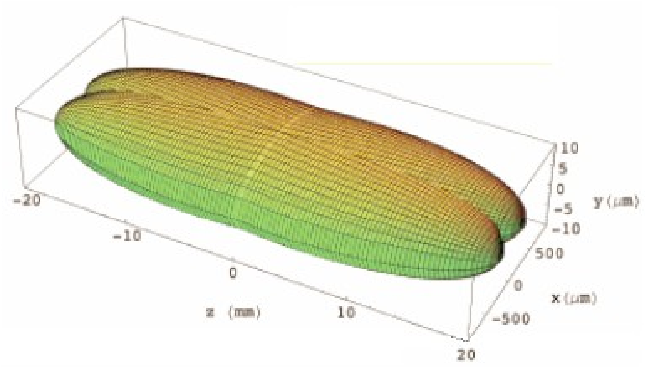
Injection System – I

- A preinjector – two linacs at the energies of 270 and 510 MeV
- After a 180° bend electrons from the first linac
  are sent to a conversion target to produce positrons
- Positrons are accelerated to 510 MeV in the second linac
- The positron beam is passed through a debunching monochromator and is injected into a cooling storage ring
- The system exists and is currently being commissioned
  to start operation in 2015 and feed VEPP-2000 and VEPP-4M with positrons

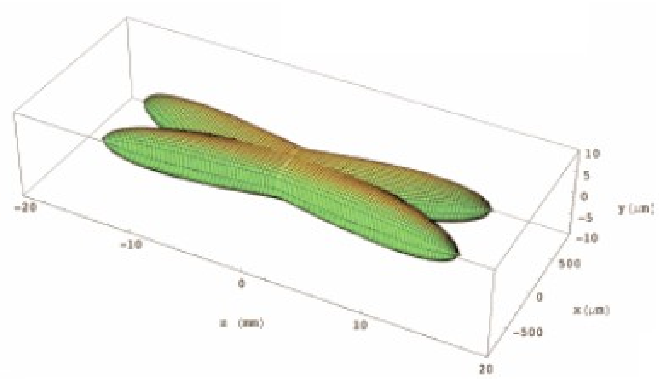
Injection System – II



Beam Collisions



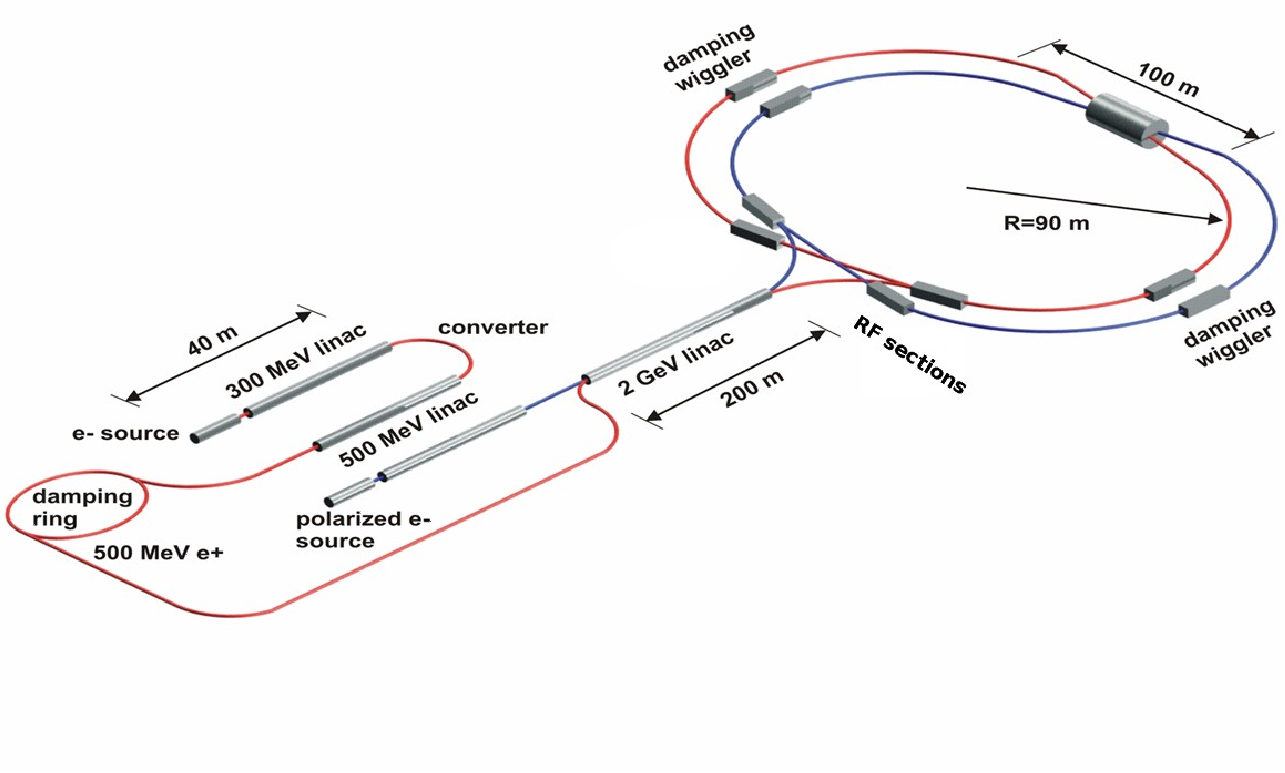
Normal beam collision



Small size beam collision

1

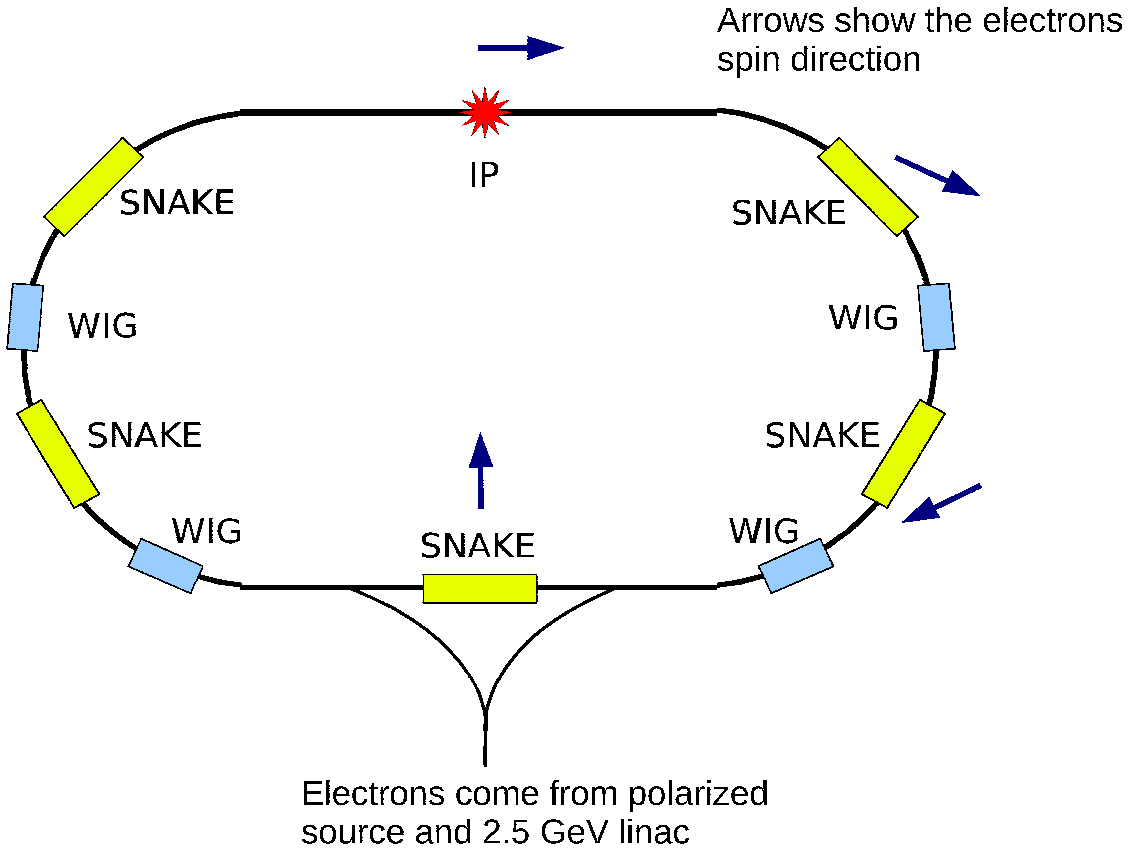
Facility scheme



Parameters

Energy	1.0 GeV	1.5 GeV	2.0 GeV	2.5 GeV
Circumference	780 m			
Emittance hor/ver	8 nm/0.04 nm @ 0.5% coupling			
Damping time hor/ver/long	30/30/15 ms			
Bunch length	16 mm	11 mm	10 mm	10 mm
Energy spread	$10.1 \cdot 10^{-4}$	$9.96 \cdot 10^{-4}$	$8.44 \cdot 10^{-4}$	$7.38 \cdot 10^{-4}$
Momentum compaction	$1.00 \cdot 10^{-3}$	$1.06 \cdot 10^{-3}$	$1.06 \cdot 10^{-3}$	$1.06 \cdot 10^{-3}$
Synchrotron tune	0.007	0.010	0.009	0.008
RF frequency	508 MHz			
Harmonic number	1300			
Particles in bunch	$7 \cdot 10^{10}$			
Number of bunches	390 (10% gap)			
Bunch current	4.4 mA			
Total beam current	1.7 A			
Beam-beam parameter	0.15	0.15	0.12	0.095
Luminosity	$0.63 \cdot 10^{35}$	$0.95 \cdot 10^{35}$	$1.00 \cdot 10^{35}$	$1.00 \cdot 10^{35}$

Polarization scheme



Super-Tau-Charm Factory – I

- The project successfully passed the international expertise
- The cost of the machine is $\sim$ 300 Million Euro plus a detector
- Approved by the Russian government together with 5 other megaprojects, but funding conditions are still unclear ...
- CDR and other details can be found at http://ctd.inp.nsk.su

Super-Tau-Charm Factory – II

BINP is considering alternative projects of
a machine in the existing tunnels of VEPP-3 or VEPP-4M,
at least an order of magnitude cheaper, doable ourselves?

A machine in the VEPP-4 tunnel (360 m circumference):

$E_{\rm beam}$, GeV	0.5	1.0	1.5	2.1
L, $10^{35}{\rm cm}^{-1}{\rm s}^{-1}$	0.92	0.92	1.3	1.3

A machine in the VEPP-3 tunnel (80 m circumference):

$E_{\rm beam}$, GeV	0.5	0.75	1.0	1.2	1.55
L, $10^{34}{\rm cm}^{-1}{\rm s}^{-1}$	0.954	1.49	1.81	1.86	1.60