CANDLE - A New Synchrotron Light Source Project in Armenia

Vasili Tsakanov

DESY, 7 Dec 2004
Contents

• Introduction
• The Project Overview
• Scientific Program
• Laboratory Activity
• International Collaboration
• Summary
**Why Synchrotron Light Source?**

- **Science**
  - Biology
  - Physics
  - Material Science
  - Medicine
  - Chemistry
  - Environments

- **Industry**
  - Biotechnology
  - Electronics
  - New material
  - Pharmacy
  - Nanotechnology
  - Microfabrication

Diagram:
- Electron source
- X-Rays
- Sample
- Detector
- Cell
- Virus
- Protein
- Molecule
- Atom
Why Synchrotron Light Source?

- High Brightness
- Continues Spectrum
- Tunability
- Coherency

User Demands
3-10 times exceeds

<table>
<thead>
<tr>
<th>Projects</th>
<th>Country</th>
<th>$E$ (GeV)</th>
<th>$L$ (m)</th>
<th>$\varepsilon$ (Nm)</th>
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<tbody>
<tr>
<td>SPEAR3</td>
<td>USA</td>
<td>3.0</td>
<td>240</td>
<td>18</td>
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<tr>
<td>CANDLE</td>
<td>Armenia</td>
<td>3.0</td>
<td>216</td>
<td>8.4</td>
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<tr>
<td>DIAMOND</td>
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<td>560</td>
<td>2.0</td>
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<td>SOLEIL</td>
<td>France</td>
<td>2.5</td>
<td>354</td>
<td>3.1</td>
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<td>Boomerang</td>
<td>Australia</td>
<td>3.0</td>
<td>184</td>
<td>11.5</td>
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<td>CLS</td>
<td>Canada</td>
<td>2.9</td>
<td>170</td>
<td>18</td>
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</table>

Brilliance of the X-ray beams
(photons/s/mm²/mrad²/0.1% BW)

3rd generation sources
- CANDLE
- X-Ray Tubes

2nd generation sources
- Dipole
- Wiggler

1st generation sources
- Undulator

1900 1920 1940 1960 1980 2000
Year
Why in Armenia?

1967- ARUS 6 GeV synchrotron in Armenia

Brain Drain

HEP Database-2000

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Papers</th>
<th>Population (mln)</th>
<th>Papers/1mln</th>
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</thead>
<tbody>
<tr>
<td>USA</td>
<td>150,738</td>
<td>270.3</td>
<td>558</td>
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<tr>
<td>Germany</td>
<td>51,142</td>
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<td>France</td>
<td>27,937</td>
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<td>UK</td>
<td>27,664</td>
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<td>Sweden</td>
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<td>Italy</td>
<td>33,307</td>
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<td>Japan</td>
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<td>Finland</td>
<td>31,18</td>
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<td>611</td>
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<td>Switzerland</td>
<td>33,876</td>
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<td>Israel</td>
<td>6,236</td>
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<td>Armenia</td>
<td>2,929</td>
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<td>813</td>
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<td>Russia</td>
<td>48,577</td>
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<td>Georgia</td>
<td>1,626</td>
<td>5.7</td>
<td>285</td>
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<td>Estonia</td>
<td>180</td>
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<td>112</td>
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<td>Belarus</td>
<td>883</td>
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<td>4,241</td>
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<td>Kazakhstan</td>
<td>943</td>
<td>17.3</td>
<td>55</td>
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<td>Azerbaijan</td>
<td>422</td>
<td>7.8</td>
<td>54</td>
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<tr>
<td>Uzbekistan</td>
<td>887</td>
<td>23</td>
<td>38</td>
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<tr>
<td>Tadzhikistan</td>
<td>99</td>
<td>6.1</td>
<td>16</td>
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<tr>
<td>Turkey</td>
<td>893</td>
<td>63.4</td>
<td>14</td>
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<tr>
<td>Iran</td>
<td>416</td>
<td>64</td>
<td>7</td>
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</table>
CANDLE will serve scientists of 2000km radius region.
3 GeV CANDLE Light Source

- Energy: 3 GeV
- Current: 350 mA
- Circumference: 216 m
- Frequency: 499.65 MHz
- Harm. Number: 360
- Periods No: 16
- Straight section: 4.8 m
- Lattice type: DBA
- Emittance: 8.4 nm
- Beam lifetime: 18.4 hours

Time structure:
- Beam: 2 nsec
- Bunch: 40 psec
## Radiation Characteristics

### Dipole beamline

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Dipole field $B$ (T)</td>
<td>1.354</td>
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<tr>
<td>Critical ph. energy (keV)</td>
<td>8.1</td>
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</table>

### Wiggler type I

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Magnetic field (T)</td>
<td>1.98</td>
</tr>
<tr>
<td>Period length (cm)</td>
<td>17</td>
</tr>
<tr>
<td>Critical ph. energy (keV)</td>
<td>11.97</td>
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</table>

### Undulator

<table>
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<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Magnetic field (T)</td>
<td>0.3</td>
</tr>
<tr>
<td>Period Length (cm)</td>
<td>5</td>
</tr>
<tr>
<td>Photon energy $n=1,3,5$ (keV)</td>
<td>0.85/ 2.6 /4.3</td>
</tr>
</tbody>
</table>
Storage Ring – Figure of Merit

**Brightness**

\[ B = \frac{N_{ph}}{4\pi^2 S_x S_y} \]

\( \eta = 0.18 \, m \)

\( \beta_{x,y} = 7.9m / 4.8m \)

V. Tsakanov et al, Rev. Sci Instr., 2002
M. Ivanian et al, Nucl. Inst. Meth. (A) 2004

High Brightness & Stable Beams
Storage Ring - Optics

Resonance Diagram

Betatron Functions

\[ Q_x = 13.22 \quad Q_y = 4.26 \]

\[ \varepsilon_x = 8.4 \, \text{nm} \cdot \text{rad} \]
Storage Ring – Dynamics

Dynamical Aperture

Horizontal

Vertical
Non-stable ions

<table>
<thead>
<tr>
<th>Stable ion mass</th>
<th>Residual gas species</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>( H_2 )</td>
</tr>
<tr>
<td>16</td>
<td>( CH_4 )</td>
</tr>
<tr>
<td>28</td>
<td>( N_2, CO )</td>
</tr>
<tr>
<td>32</td>
<td>-</td>
</tr>
<tr>
<td>33</td>
<td>-</td>
</tr>
<tr>
<td>37</td>
<td>-</td>
</tr>
<tr>
<td>42</td>
<td>-</td>
</tr>
<tr>
<td>44</td>
<td>( CO_2 )</td>
</tr>
</tbody>
</table>

Traped ions

- \( CO_2(44) \)
- \( N_2, CO (28) \)
- \( CH_4 (16) \)
- \( H_2(2) \)
Ring impedance

Longit. Impedance - 0.314 Ω

Trans. Impedance - 12.5 kΩ/m

Small Gap undulator Impedance

\[ Z(k) = -\frac{jZ_0}{\pi k} \left( a^2 + 2 \frac{a e_3}{\varepsilon_0 \chi_3} \times \frac{1 + \alpha \theta(\chi_3 d_3) \theta(\chi_4 d_4)}{\theta(\chi_3 d_3) + \alpha \theta(\chi_4 d_4)} \right)^{-1} \]

M. Ivanian et al, Phys. Rev STAB-2004
Storage Ring – Instabilities

ANKA, Transverse, Horizontal

Ring Impedance = $0.314 \Omega$

Threshold Current

Bunch Current

$1 /[ sec^{-1} ]$

Radiation Damping Rate $1/\tau = 299 \ sec^{-1}$

$1/\tau$ [ sec$^{-1}$ ]

Relative mode index, $n$

Single bunch Instability

Multi-bunch Instability
Beam Lifetime

- Elastic scattering: 91.4
- Inelas. Scattering: 55.4
- Touschek Lifetime: 39.5
- Quant. Lifetime: $10^{38}$

Total - 18.4 hours
Storage Ring – Magnets

Dipole

B=1.354 T,   G=3.3T/m  
aperture=44mm

Quadrupole

G=20 T/m  
aperture=50mm
Magnet supports
Material – Stainless Steel
Vacuum – 1 nTorr
Fore-vacuum - 2
Turbo-molecular – 16
Titan-sublimation – 80
Ion pumps - 64
Storage Ring – RF

ELETTRA cavity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ELETTRA</th>
<th>SORISCA</th>
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<tbody>
<tr>
<td>Energy loss/turn</td>
<td>0.97 MeV</td>
<td>1.39 MeV</td>
</tr>
<tr>
<td>Shunt Impedance</td>
<td>6x3.4 MΩ</td>
<td></td>
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<tr>
<td>Total RF power</td>
<td>660 kW</td>
<td>830 kW</td>
</tr>
<tr>
<td>Gap Voltage</td>
<td>3.3 MV</td>
<td>3.3 MV</td>
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<tr>
<td>Energy acceptance</td>
<td>2.4%</td>
<td>2%</td>
</tr>
<tr>
<td>Energy Spread</td>
<td>0.1%</td>
<td>0.1%</td>
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</tbody>
</table>
Booster synchrotron

Energy 3 GeV
Pulse current 10 mA
Repetition 2 Hz
Circumference 192 m
Emittance 75 nm-rad

Lattice with missing dipole

Quadrupole G=10-13 T/m

Dipole B=0.024 - 0.72 T

Sextupole S=90/110 T/m²
Energy ramp and Injection

Dipole ramping rate and energy gain

Injection bump

Emittance vs energy

Injected beam: 1 and 3 turns

75 nm
Linac

<table>
<thead>
<tr>
<th></th>
<th>Gun</th>
<th>SPB 500 MHz</th>
<th>SWB 1 GHz</th>
<th>TWB 3 GHz</th>
<th>ACC Section 3 GHz</th>
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<tbody>
<tr>
<td>90 kV</td>
<td></td>
<td></td>
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</table>

**Energy** 100 MeV  
**Current** 1-20 mA  
**Pulse length** 2-600 nsec  
**Frequency** 3 GHz  
**Energy Spread** < 1%  
**Emittance** < 1 mm-mrad
Beamlines

1. Diffraction & scattering (dipole)
2. Protein crystallography (dipole)
3. LIGA (dipole)
4. Medical applications (wiggler)
5. Soft X-ray microscopy and spectroscopy (undulator)

Dipoles – 32
Wigglers – 8
Undulators – 4
Exp. Stations ~40
Structural Biology

- Structural Genomic
- Genes and Drugs
- DNA complexes
- Protein Structure
- Drug design
- High Capacity Crystallogr.

Physics

- Macro-molecular physics
- High-Temp superconductivity
- Physics of nano-particles
- Surface physics
- Heavy fermions
Material Science

- 3D structure of new material
- Crystal growth
- New Crystals
- Nano-structures
- Nano-tubes

Chemistry

- Chemical Dynamics
- Polymers
- Nanoscale chemistry
- Biochemistry
- Catalytic Interfaces

Medicine

- Angiography
- Bronchography
- Mammography
- Computed Tomography
- Photon Activation Therapy
- Microbeam Radiation Therapy
Micro-fabrication

X-Ray Lithography - LIGA

Annual Microfabrication Market

- 25 billions doll. in 2002
- 160 billions doll. in 2010

Electronics

λ=308 nm, refraction, lense, scale-130nm

EUV, λ=13 nm, reflection, mirrors, scale-13nm
Site

- Easy Access
- Flatness
- Geology
- Office Building
CANDLE

Design Study of 3 GeV Synchrotron Light Source


CANDLE, Yerevan, Armenia

Yerevan State University YSU, Yerevan, Armenia

Yerevan Physics Institute YerPhI, Yerevan Armenia

Deutches Electronen Synchr. DESY, Hamburg, Germany

Stanford University, Stanford, USA

CAMD, Baton Rouge, USA

Virginia Tech., Blacksburg, USA
“CANDLE is a world-class project enabling frontier research in a whole spectrum of basic and applied sciences. An excellent investment from scientific-technical point of view.”

From Panel Report
Proposals

- Total number of proposals – 82
- Number of Scientists - 284
- Number of Institutes - 41
- Countries - 7
  Armenia, England, Germany, Georgia, France, Russia, USA

Fields:
- Physics, Biology, Medicine, Chemistry, Environment, Material science,

Vision by 2010

- Scientists ~ 2000/ year
- Institutions > 200
- Industrial Comp. > 30
- Countries ~ 20

ALS, SPEAR3, SLS, BESSY, ELETTRA
“From a review of the 69 experimental proposals, it is clear that strong Armenian user community will emerge as the facility is readied”

From Panel review
CANDLE will drive the country development as a high technology and excellence island in this part of the world.

L. Mkrtchian (Minister of Science and Educat.)

National Academy of Sciences expresses the lasting support for the CANDLE creation and usage.

Resolution of NAS RA

We believe the project is worthy of support by the private sector, the international community, the US and Armenian governments.

Vardan Oskanian (Minister Of FA)
International Collaboration

- Armenia - NAS, YSU, YerPhI
- Bulgaria - Inst. Nucl. Research
- Germany - DESY, ANKA, BESSY, TUD, RU
- France - Provence Univ, ESRF
- Italy - ELETTRA
- USA - DOE, Virginia Tech, SLAC
- Russia - JINR, IMT, FIAN
- Georgia - Tbilisi Univ, NAS
- Tailand - SIAM

- Letter of Supports
- Memorandums of Understanding
- Collaboration Agreements
International Collaboration

Armenia, Germany, France, Italy, USA, Russia, Bulgaria, Greece, Georgia

European Laboratories

European Round Table for SR and FEL

International Atomic Energy Agency

- Letter of Supports
- Memor. of Understanding
- Collaboration Agreements
DESY contribution

3 GHz RF components

Deutsches Elektronen-Synchrotron DESY
in der Helmholtz-Gemeinschaft
Chairman of the Board of Directors

There is no doubt that a scientifically sound project as CANDLE will be an asset for Armenia with its long tradition in basic and applied science. DESY and CANDLE already established a cooperation agreement on accelerator physics and synchrotron radiation usage. Within the framework of this cooperation, DESY expressed its willingness to make an important contribution to the new project by means of the components of the S-band linear accelerator for the injector system of CANDLE.

I am confident that CANDLE upon its completion will enable the Armenian scientists and their foreign colleagues to perform frontier research in a wide spectrum of basic and applied sciences. Please accept my lasting support for this project.

Sincerely Yours,
Prof. Dr. Albrecht Wagner

9 Sept 2003 – Permission by State dept. for technology transfer
University of Region de Provence

Support to the CANDLE project and express of interest in

- Structural biology
- Nanostructures
European Parliament Resolution
26 February 2004

“An Involvement of the Union in the Armenian CANDLE synchrotron project would be a sign of encouragement to this project which concerned chiefly the European scientific teams “

Amendment 102

Armenia

04 June 2004
Meeting of President RA with CANDLE Board
Cost & Schedule

2002 –2003 - Design
2003-2005 – Prototyping
2005-2008 - Construction
2009 - Operation

Cost - $48 mln
with 5 exper. stations

Prototypes, Test stands, Infrastructure

Armenia and CANDLE is ready for construction

Consul, Board, Advisory committees

Development of User Case!

Organizational issue

2006–2009 Construction

Funding Sources

CANDLE is a place where investment to enable the next step might lead to a major improvement in S&T infrastr. in Armenia

Recommendation for allocation of 4 mln $US for 2005
CANDLE Organization (vision)

- International Laboratory
- User Friendly Environment
- World Class Research
Welcome to CANDLE