# Undergraduate physics research at ILP

*Rainer Grobe*

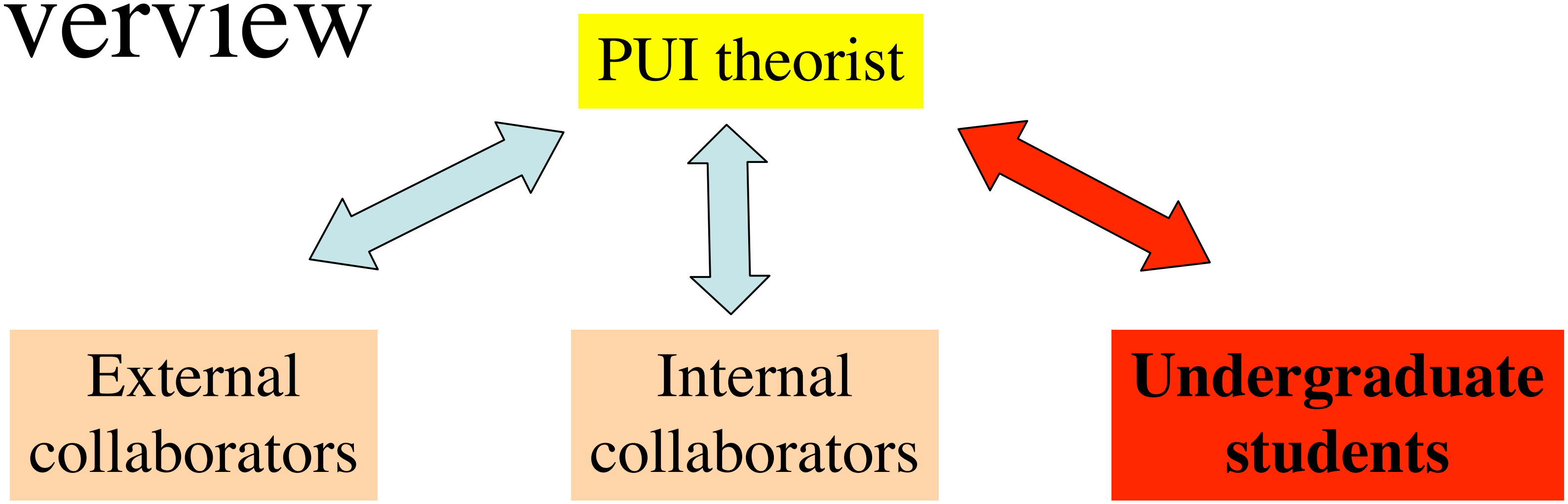
Intense Laser Physics Theory Unit

Illinois State University

www.phy.ilstu.edu/ILP


July 21-25 2003
"Second row rule" ???

# Overview




- where — Institutional environment
- why — My opinion on undergraduate research
- what — Examples of undergraduate projects

# Illinois State University


Location: Normal/ Bloomington

(2h south of Chicago)

students: 18000 Ugrads    2000 Grads

In the middle of nowhere …    (in the center of everything)

# The small-large department

- Undergraduate only

- 12 Faculty

    Smallest in CAS (of 16 depts.)

- 15-20 Graduates / year

    Top Five in the US (of 515 phys. depts.)











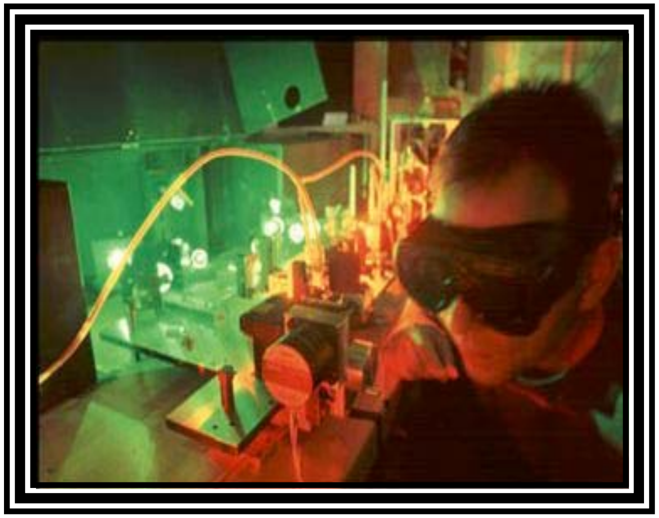







# ISU Physics Department

- ≈ 130 physics majors
  - I Physics
  - II Engineering Physics
  - III Computer Physics
  - IV Phys.Teacher Education



- Funding: NSF, DOE, NASA, Res. Corp.

# Computer Physics Degree at ISU

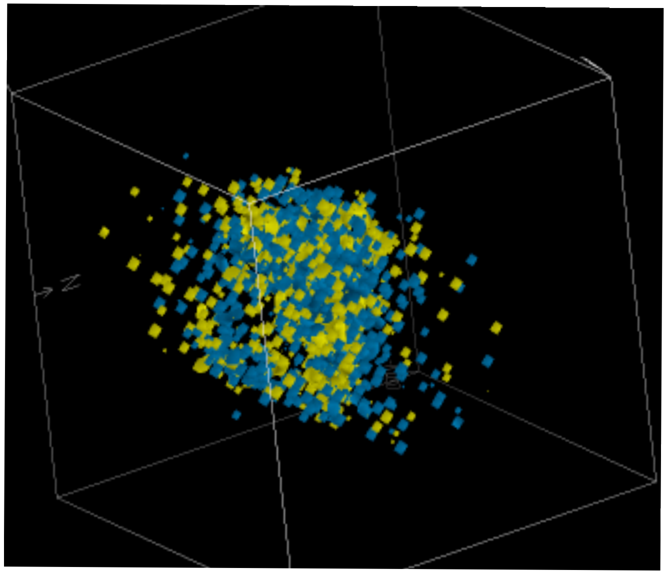
- 9/12 faculty are computational physicists
- early 1970's: first computer course
- 1997: entire degree sequence created
- 1990: numerical challenges incorporated into each class
- class objective: prepare students for research work

Research is integrated component of curriculum

# My **opinion** on educational needs

## Irrelevant:

- Physics “knowledge” and “facts”
- Classes with passive learning experience



## Relevant:

- Problem solving skills
- Communication skills
- Experience in team work
- Realize: real problems do not have solutions

# The perfect fit: teaching & research

Institutional support is crucial:

- credit in teaching category
- out-of-class work with students equally important as in-class work

# **When** to involve Ugrads in research

Common wisdom:

- Beginning Junior year

| | |
|---|---|
| advantages: | • sufficient background and maturity |
| disadvantages: | • good students join other groups |
| | • once prepared they graduate |

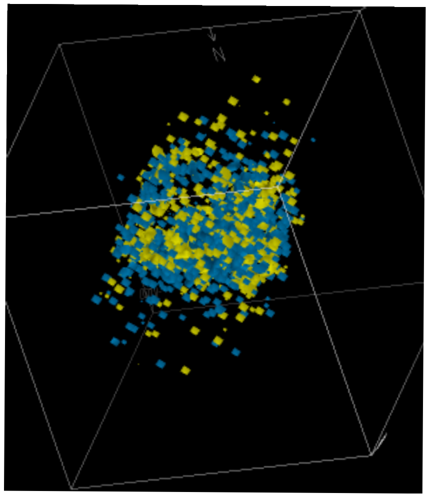
My approach:

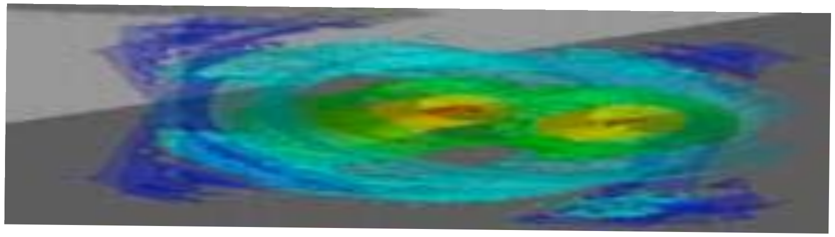
- Directly out of high-school

| | |
|---|---|
| advantage: | • no competition, pick the smartest |
| | • they contribute for 4 years |
| disadvantages: | • no background requires lots of work |
| | • highest risk as no track record |

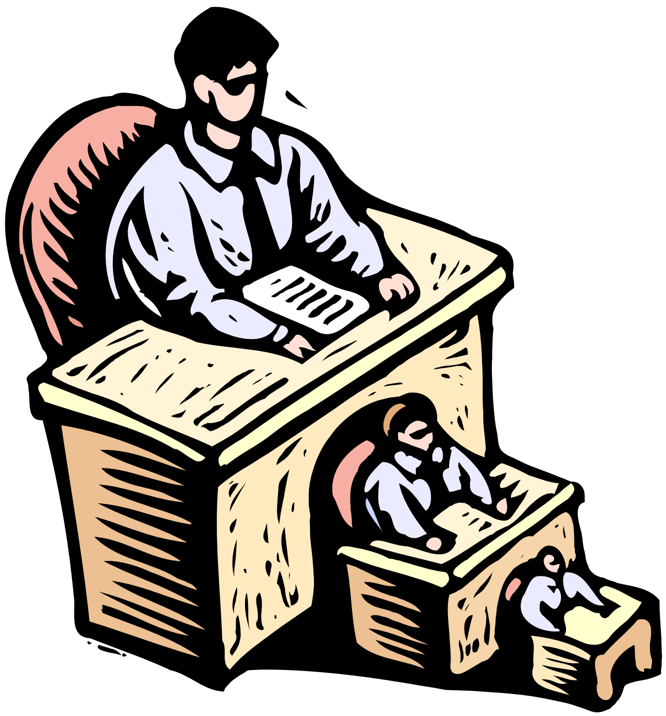
# What to do with Freshmen ??

- They know computers
- Teach them programming
- Simple differential equations
- Teach them graphical display of data
- Teach them the physics
- Tell them what is all not known
- Student are equal partners in research





# Form well-structured subgroups



- Students can teach and help each other
  mix new with older students

Project A:
Leader: Junior
Members: 2 Freshmen

# Frequent student presentations are **a must**

- Communication skills
- Feeling of having something accomplished
- Structure your results
- Presentations look good on resume
- Lots of travel support available
    - Presentation awards

# ILP student presentations

last year 2006:

"Symposium for undergraduates in science, engineering and mathematics", Argonne IL (5 talks)

"Illinois State Undergraduate Research Symposium", Normal IL (5)


"IS-AAPT Conference", East Peoria IL (5)

"APS-DAMOP meeting", Knoxville TN (1)

since 1997: ≈ 165 student presentations in
Illinois, Nebraska, Colorado, Indiana, Canada, Georgia, Michigan, Arizona, Tennessee …

extensive web archive (www.phy.ilstu.edu/ILP/studentachievements)
with details of about all 165 ILP-student presentations, 40 ILP-student publications, and 21 national ILP-student awards.

# Precisely articulated projects are a must

- divide problems into many substeps
- better control
- teaches thoroughness - no shortcuts
- progress easier to monitor

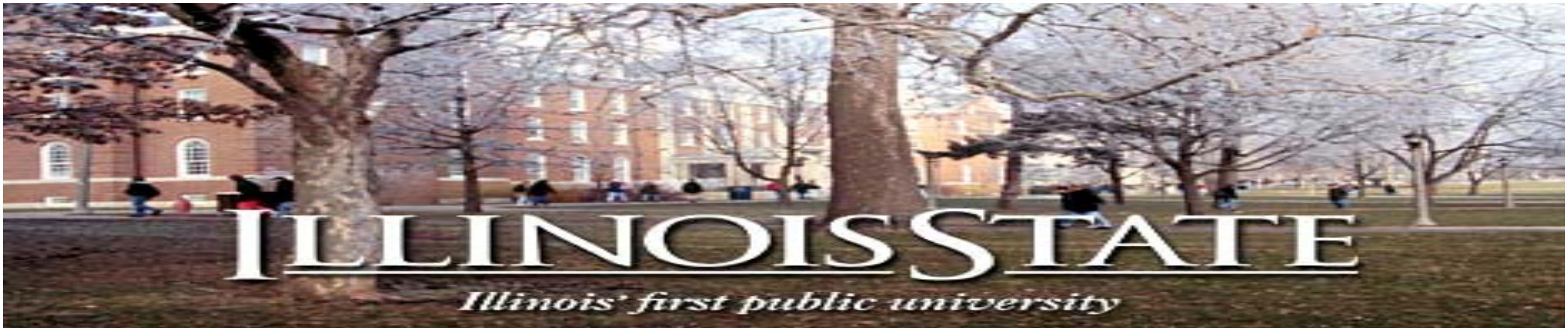
# Student co-authorship is helpful

- qualified when capable to defend work in public

# Summary

- Start as early as possible
- Computational work ideal for students
- Stubbornness, endurance, creativity, don't believe books
- In house collaborations
- Educational aspect is priceless

www.phy.ilstu.edu/ILP

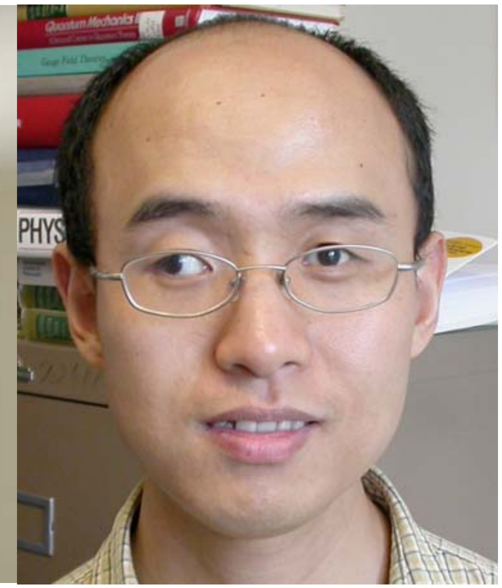


# Collaborators and helpers at ILP

Charles Q. Su

S. Menon

T. Cheng



Experimental colleagues at ISU:

D. Cedeno

B. Clark

J. Dunham

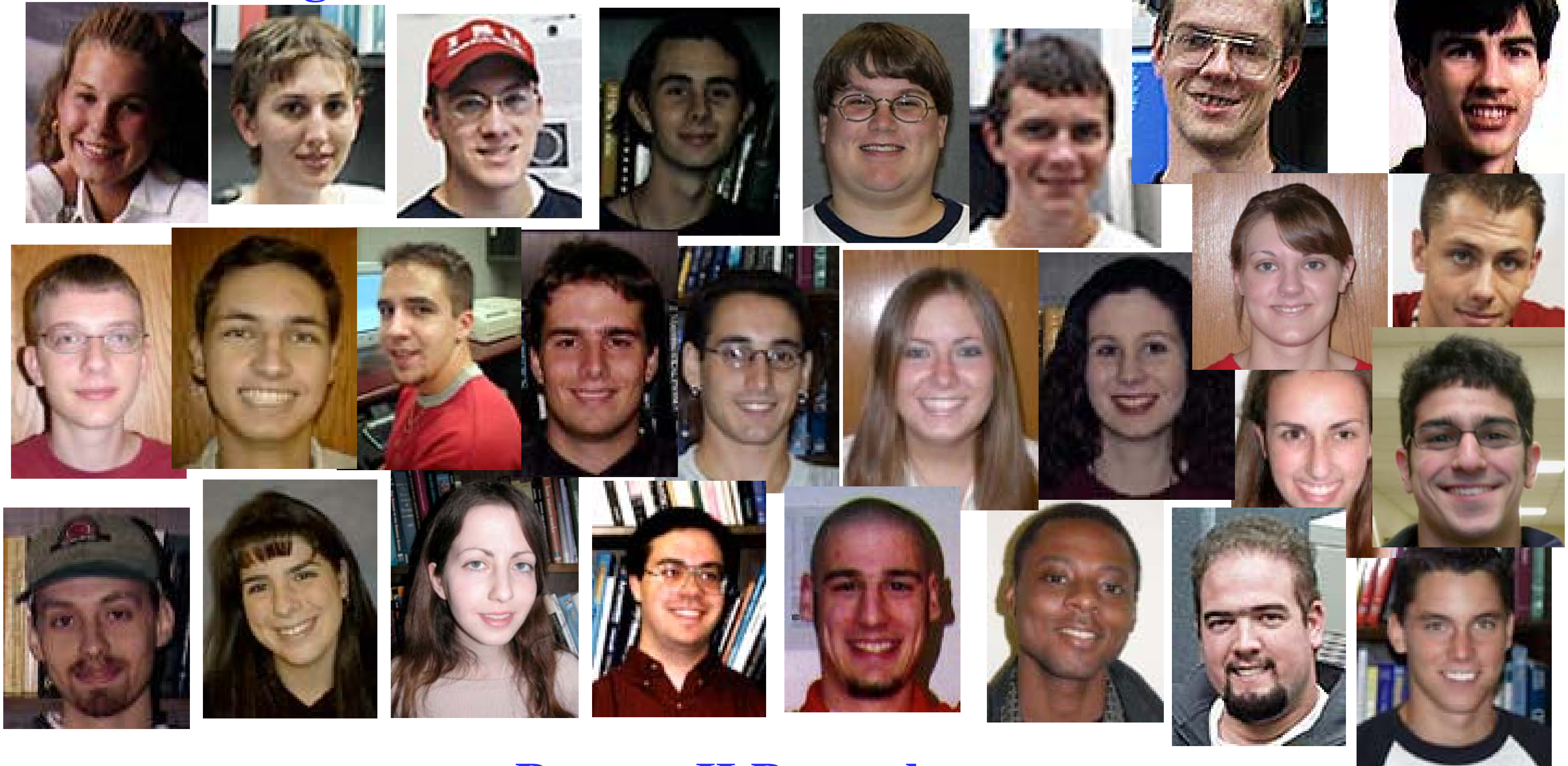
D. Marx

E. Rosa

G. Rutherford

traitors

# Past undergraduate research students at ILP



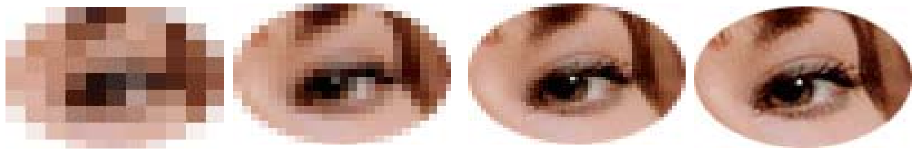
# Present ILP members:

Alison David Isaac Nate Nic Sawyer Sebastian Tim

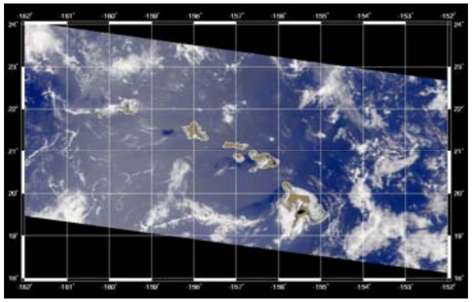
# Three examples of Ugrad. Projects

- seeing through milk (5 students)
    - extrapolation based imaging
    - decomposition based imaging
- destruction of vacuum (2 students)

# Seeing through a glass of milk



**Why is this important?**

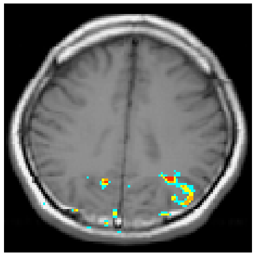


polluted skies
→ meteorology

fog
→ navigation

stellar atmosphere
→ astrophysics

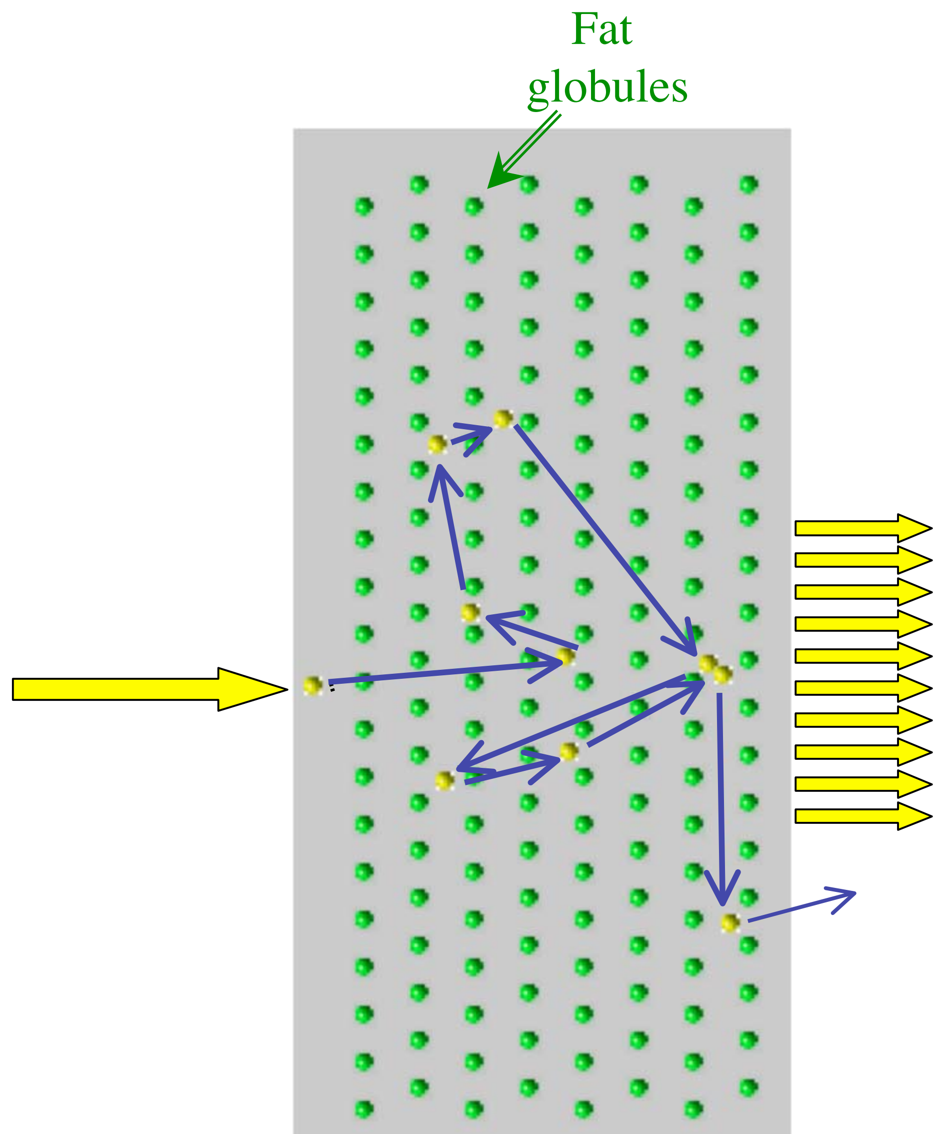
murky water
→ navy



human flesh
→ imaging

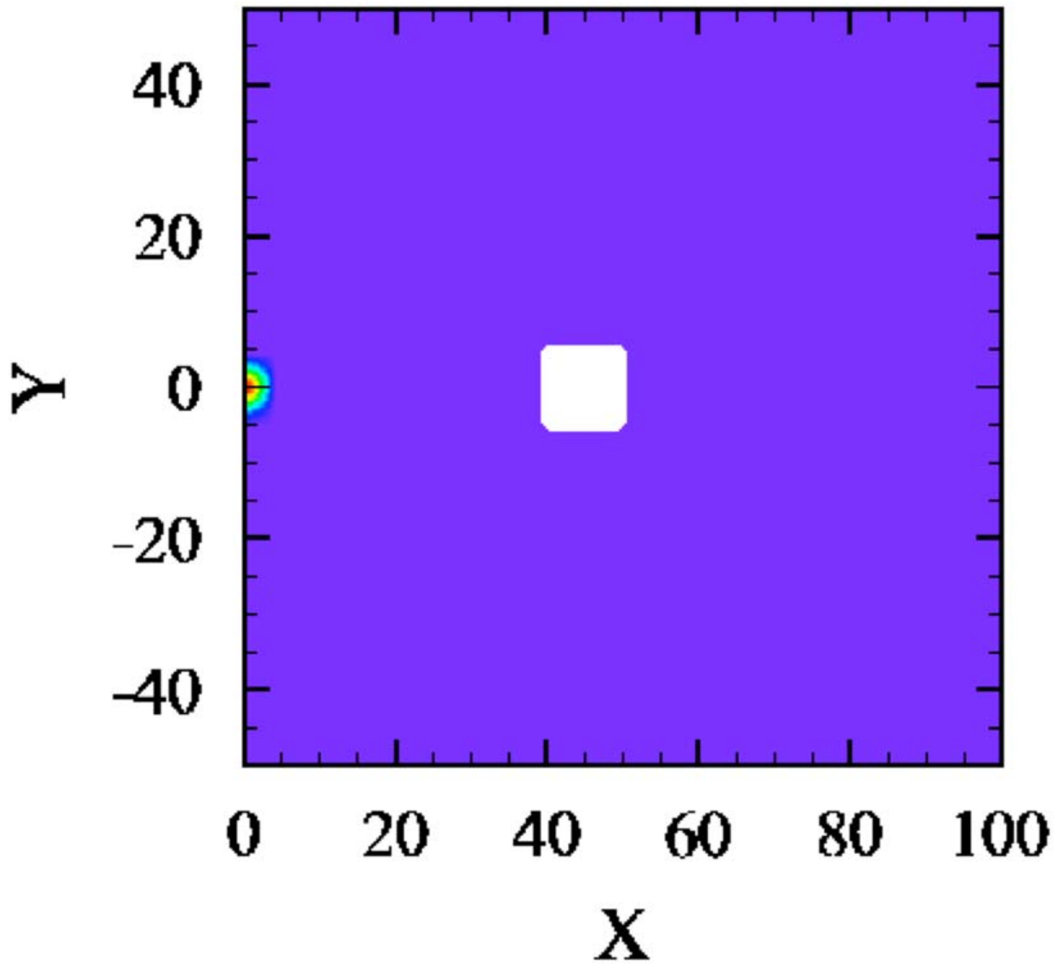
| Reality | Dream |
| --- | --- |
|  |  |
| based on X-rays | based on **lasers** |
| dangerous | **harmless** |

# Light's random walk through milk

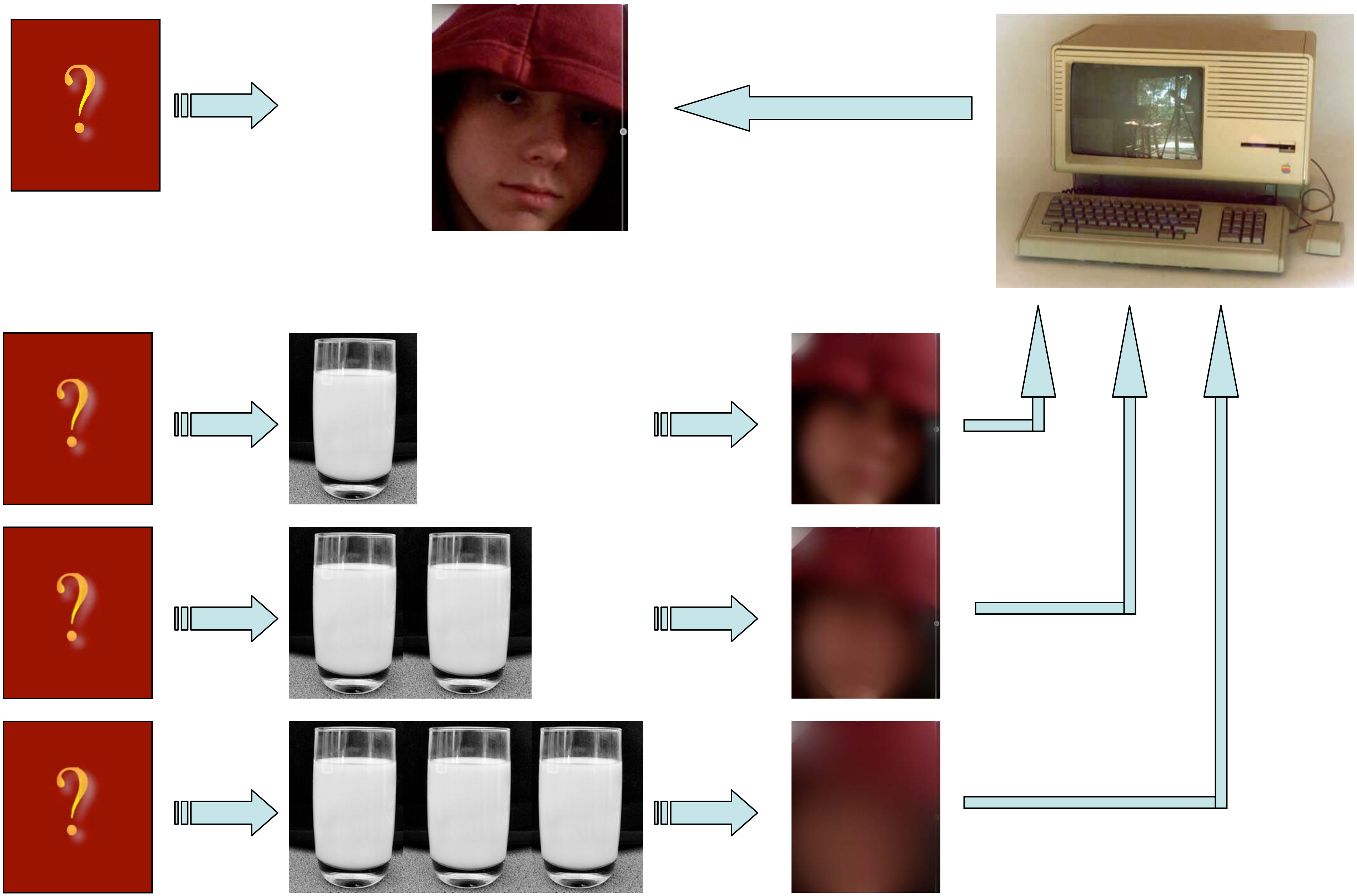


# Laser pulse interacting with a turbid medium

Robert Wagner
13 pubs, Apker

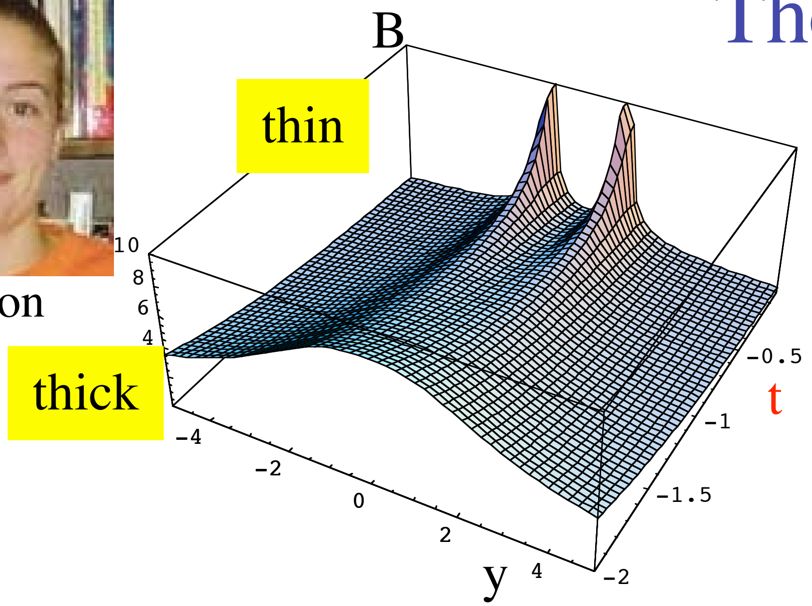


# I Extrapolation based imaging



# Theoretical example for EBI

Alison

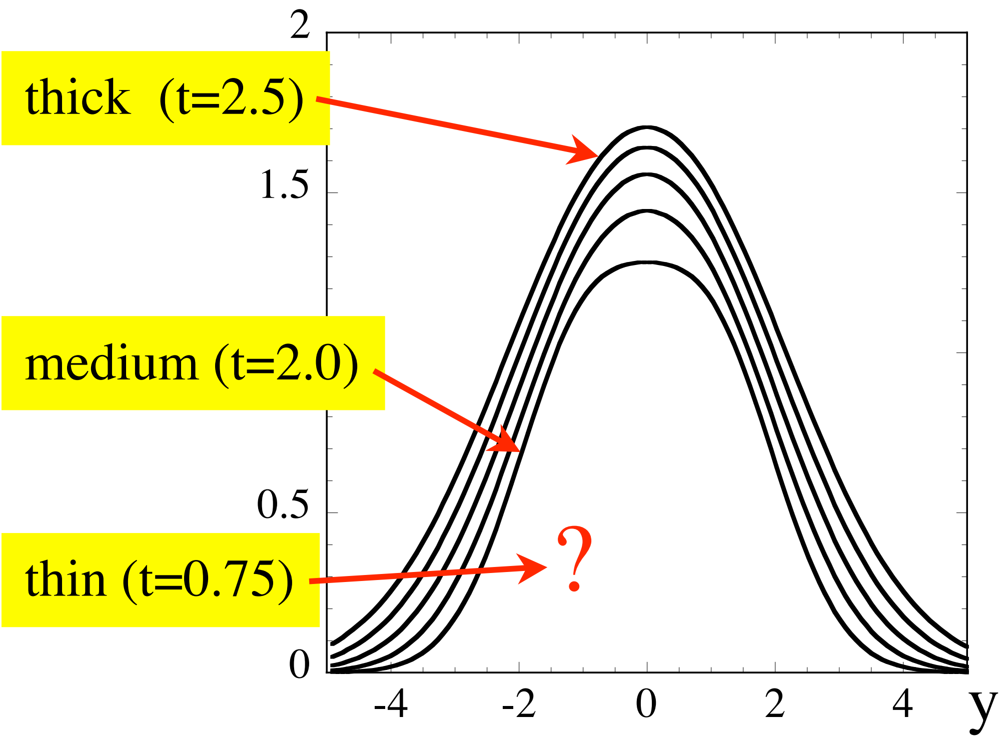


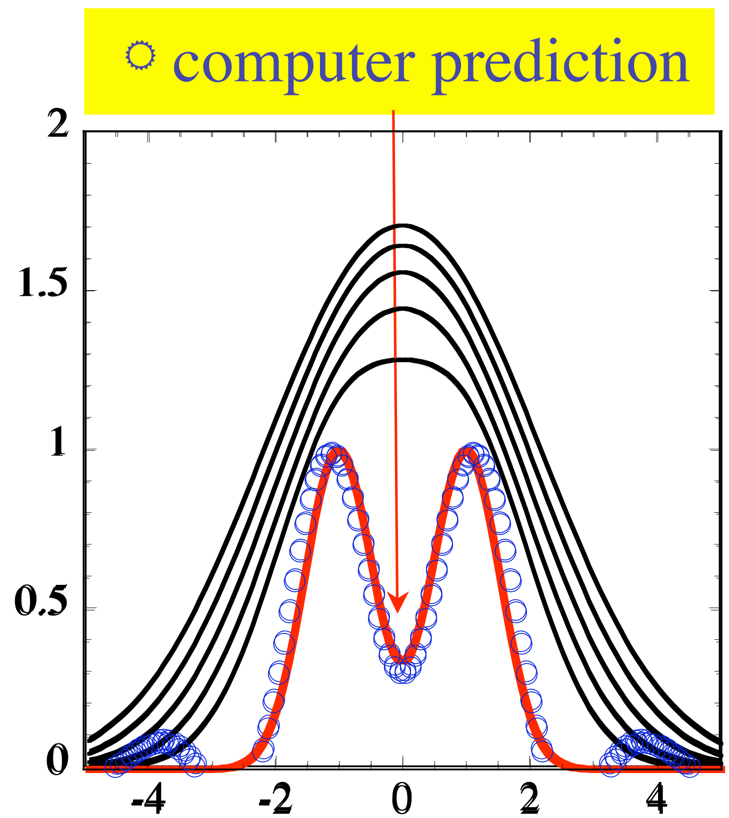

$$B(y) = e^{-[(y-1)/t]^2} + e^{-[(y+1)/t]^2}$$

B: brightness

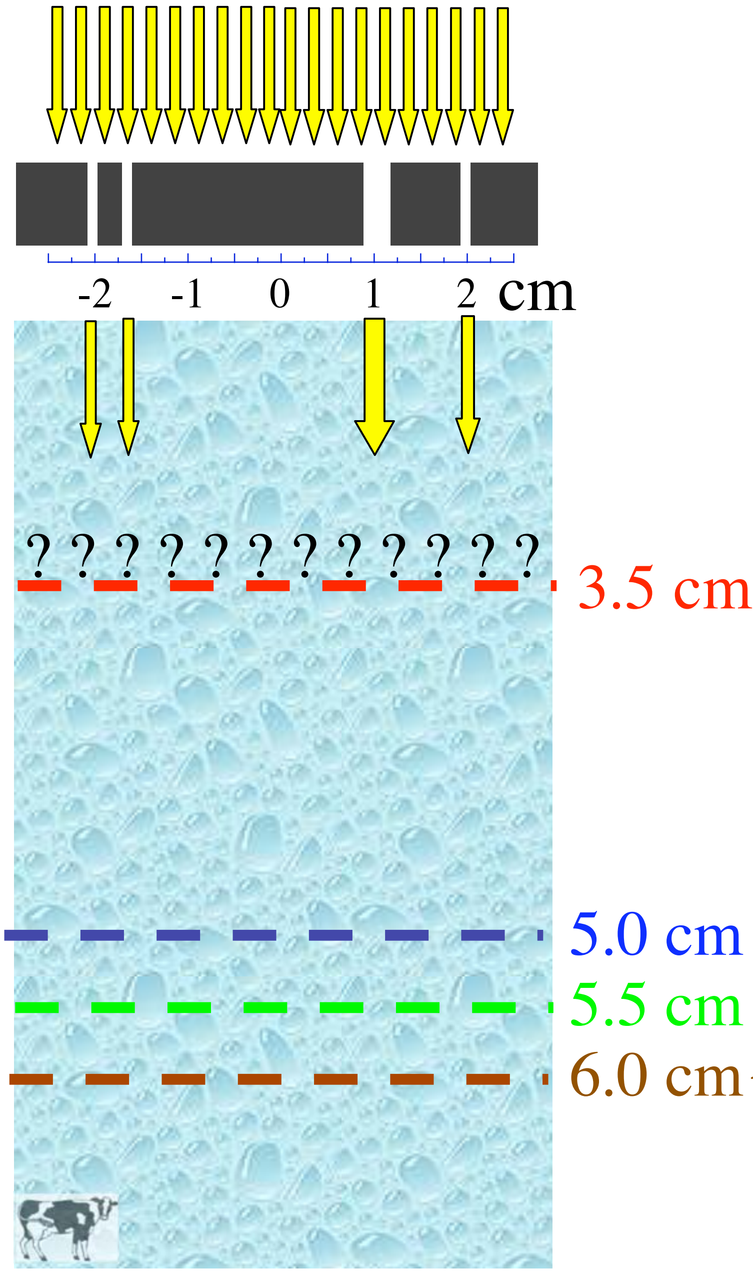
y: transverse length

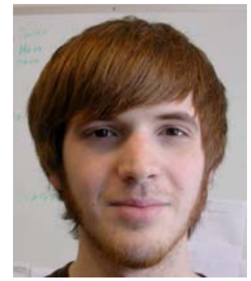
t: medium's thickness



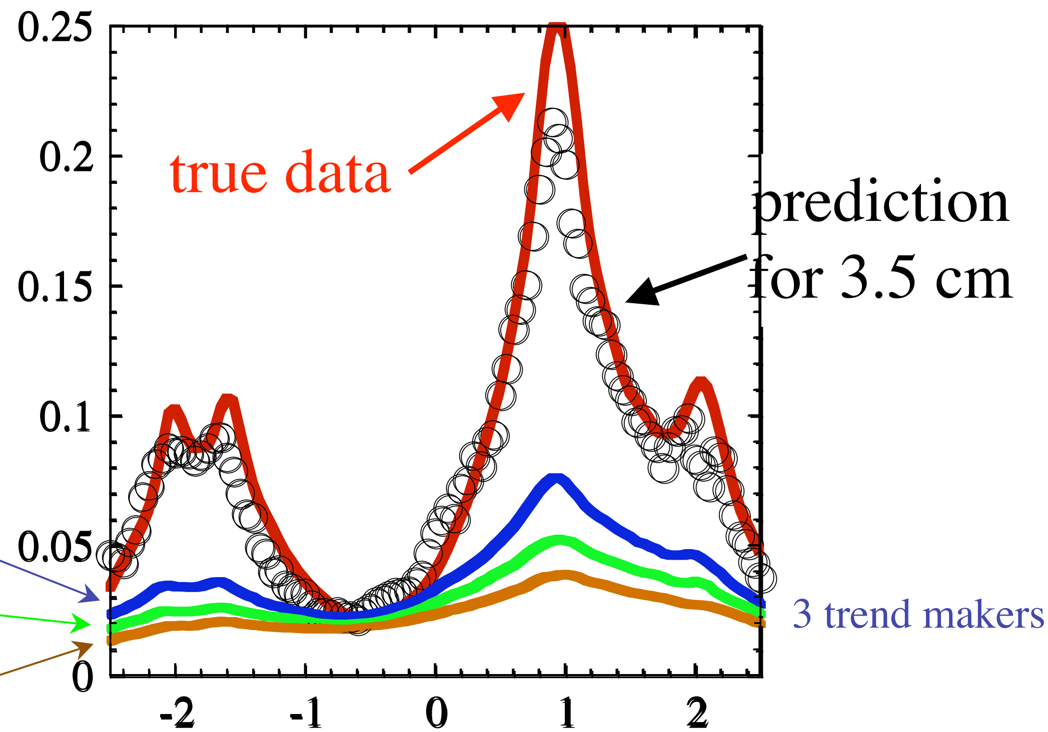



# Experimental example for EBI

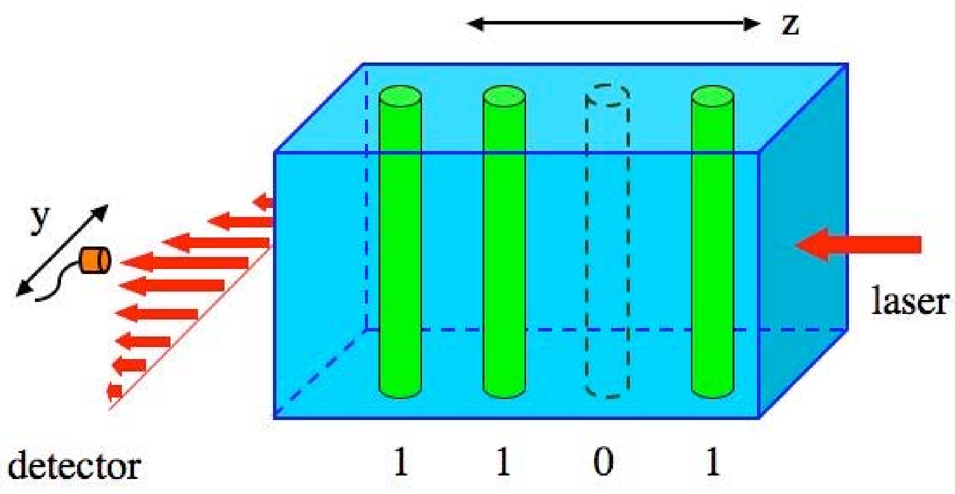


Isaac



# Can one use scattered light to recover positions of the rods ??




(1) create shadow data S(y) for one-rod configurations:

$S_{1000}(y)$ $S_{0100}(y)$ $S_{0010}(y)$ $S_{0001}(y)$

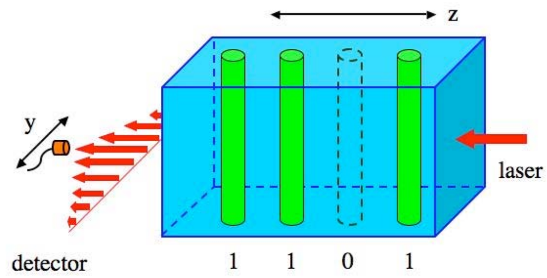
(2) decompose:

$$S_{1101}(y) = \lambda_1 S_{0100}(y) + \lambda_2 S_{0100}(y) + \lambda_3 S_{0100}(y) + \lambda_4 S_{0100}(y)$$

| If | $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\lambda_4$ | |
|---|---|---|---|---|---|
| | 1 | 1 | 0 | 1 | then it works |

Theory:

create shadow patterns




Sebastian

L(y) = transverse light distribution for incoming light

Abs = action of absorption:

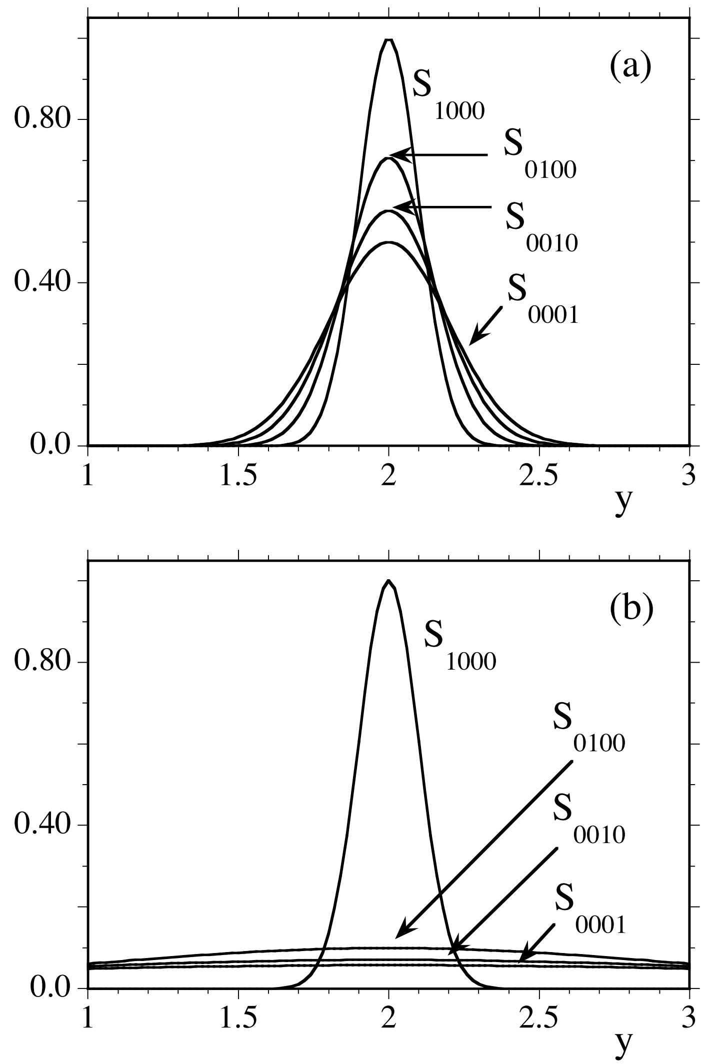
$$L(y) = [1-\exp(-y^2)]\, L(y)$$

Scat = action of scattering:

$$L(y) = \int dy'\, \exp(-(y-y')^2)\, L(y')$$

$$B_{1101}(y) = \text{Scat} \otimes \text{Abs} \otimes \text{Scat} \otimes \text{Abs} \otimes \text{Scat} \otimes \text{Scat} \otimes \text{Abs}\, L(y)$$

# The four single-rod shadow basis states




weak scattering

strong scattering

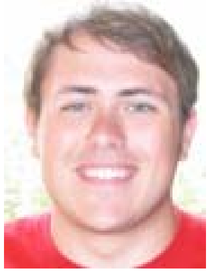
Shadow point spread function

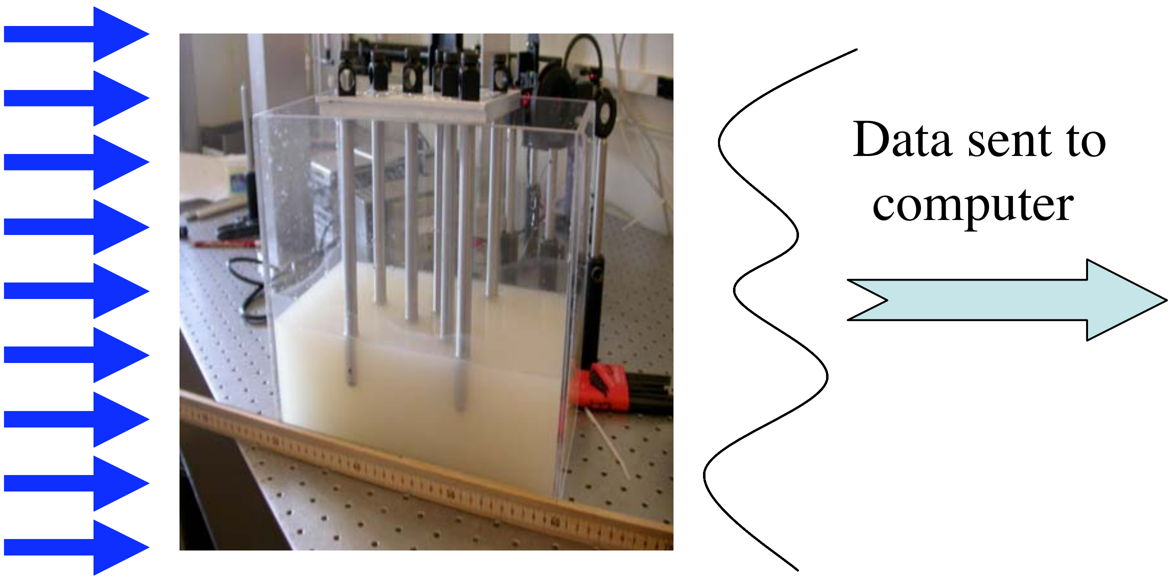
# Model data for eleven different arrangements of rods

| $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\lambda_4$ |
|---|---|---|---|
| 0.901 (1) | 1.003 (1) | -0.006 (0) | 0.004 (0) |
| 0.930 (1) | 0.001 (0) | 0.998 (1) | 0.001 (0) |
| 0.942 (1) | 0.001 (0) | -0.001 (0) | 1.001 (1) |
| 0.000 (0) | 0.901 (1) | 1.000 (1) | 0.000 (0) |
| 0.000 (0) | 0.930 (1) | 0.000 (0) | 1.000 (1) |
| 0.000 (0) | 0.000 (0) | 0.901 (1) | 1.000 (1) |
| | | | |
| 0.840 (1) | 0.905 (1) | 0.992 (1) | 0.005 (0) |
| 0.850 (1) | 0.933 (1) | -0.007 (0) | 1.004 (1) |
| 0.879 (1) | 0.002 (0) | 0.898 (1) | 1.002 (1) |
| 0.000 (0) | 0.840 (1) | 0.901 (1) | 1.000 (1) |
| | | | |
| 0.795 (1) | 0.844 (1) | 0.893 (1) | 1.005 (1) |

# Experimental reconstruction of hidden objects

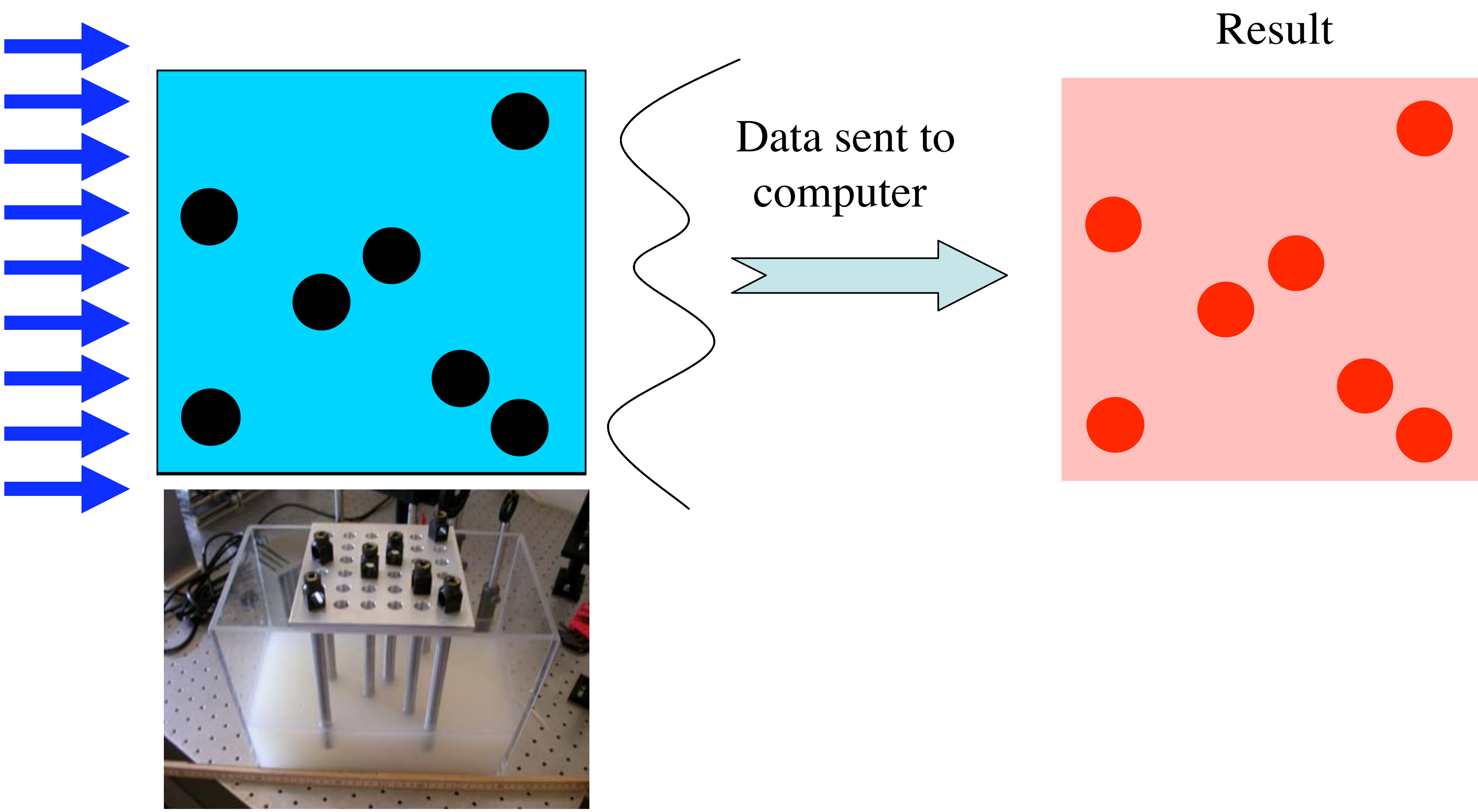
Sawyer



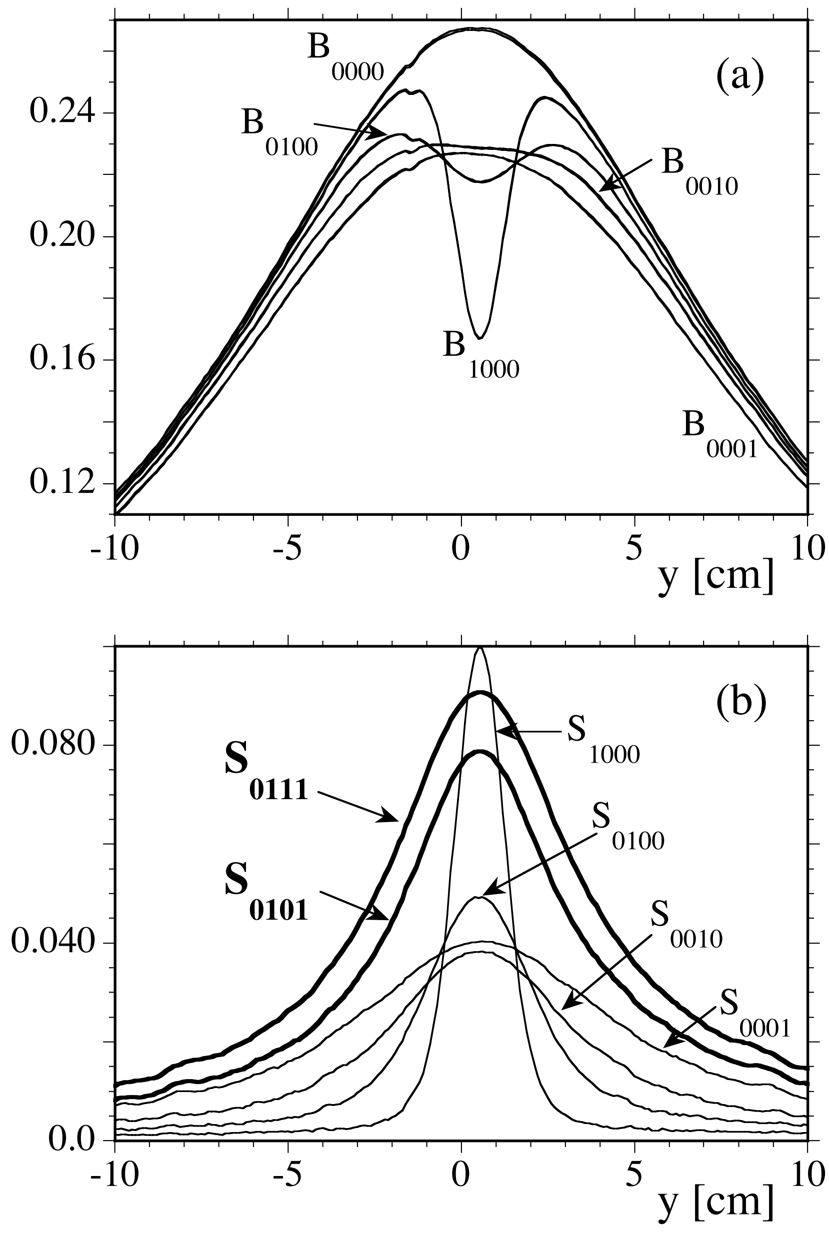



?????

# Experimental work



# Experimental data




Transverse brightness patterns

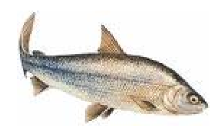
Shadow functions patterns

compare: $S_{0111}(y)$ and $S_{0101}(y)$

# Experimental data for eleven arrangements of rods

| $\lambda_1$ | $\lambda_2$ | $\lambda_3$ | $\lambda_4$ |
|---|---|---|---|
| 0.613 (1) | 1.113 (1) | -0.081 (0) | 0.035 (0) |
| 0.757 (1) | 0.182 (0) | 0.736 (1) | 0.116 (0) |
| 0.790 (1) | 0.034 (0) | 0.059 (0) | 0.949 (1) |
| -0.040 (0) | 0.798 (1) | 0.777 (1) | 0.121 (0) |
| -0.019 (0) | 0.818 (1) | -0.028 (0) | 1.022 (1) |
| -0.025 (0) | 0.131 (0) | 0.287 (1) | 1.206 (1) |
| | | | |
| 0.571 (1) | 0.615 (1) | 1.094 (1) | 0.011 (0) |
| 0.582 (1) | 0.556 (1) | 0.427 (0) | 0.836 (1) |
| 0.683 (1) | 0.046 (0) | 0.532 (1) | 1.049 (1) |
| -0.015 (0) | 0.458 (1) | 0.662 (1) | 1.090 (1) |
| | | | |
| 0.480 (1) | 0.509 (1) | 0.594 (1) | 1.155 (1) |

Real time functional imaging possible



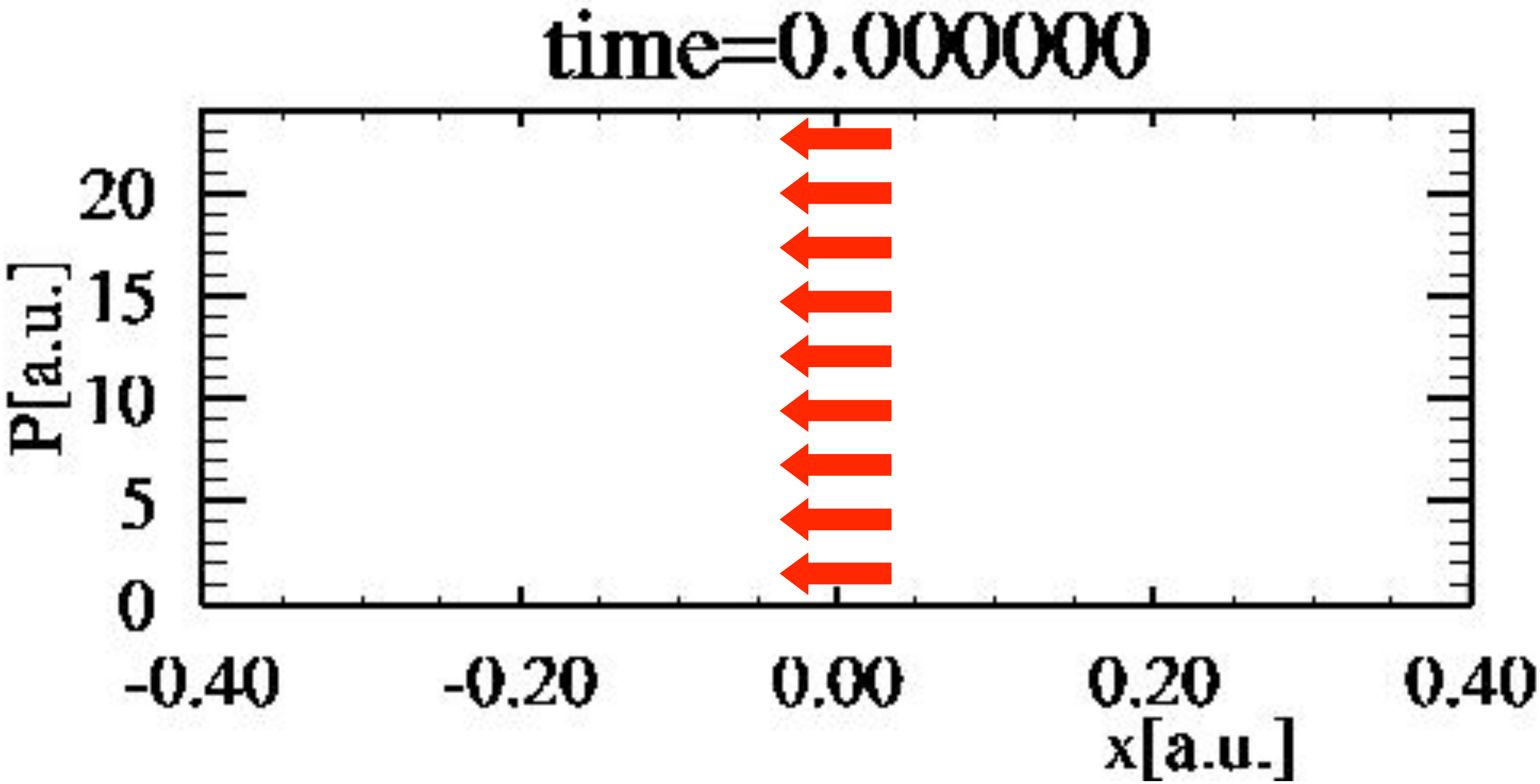
# How to break down the vacuum?

Required: **huge forces** $E \approx 10^{18}$ V/m

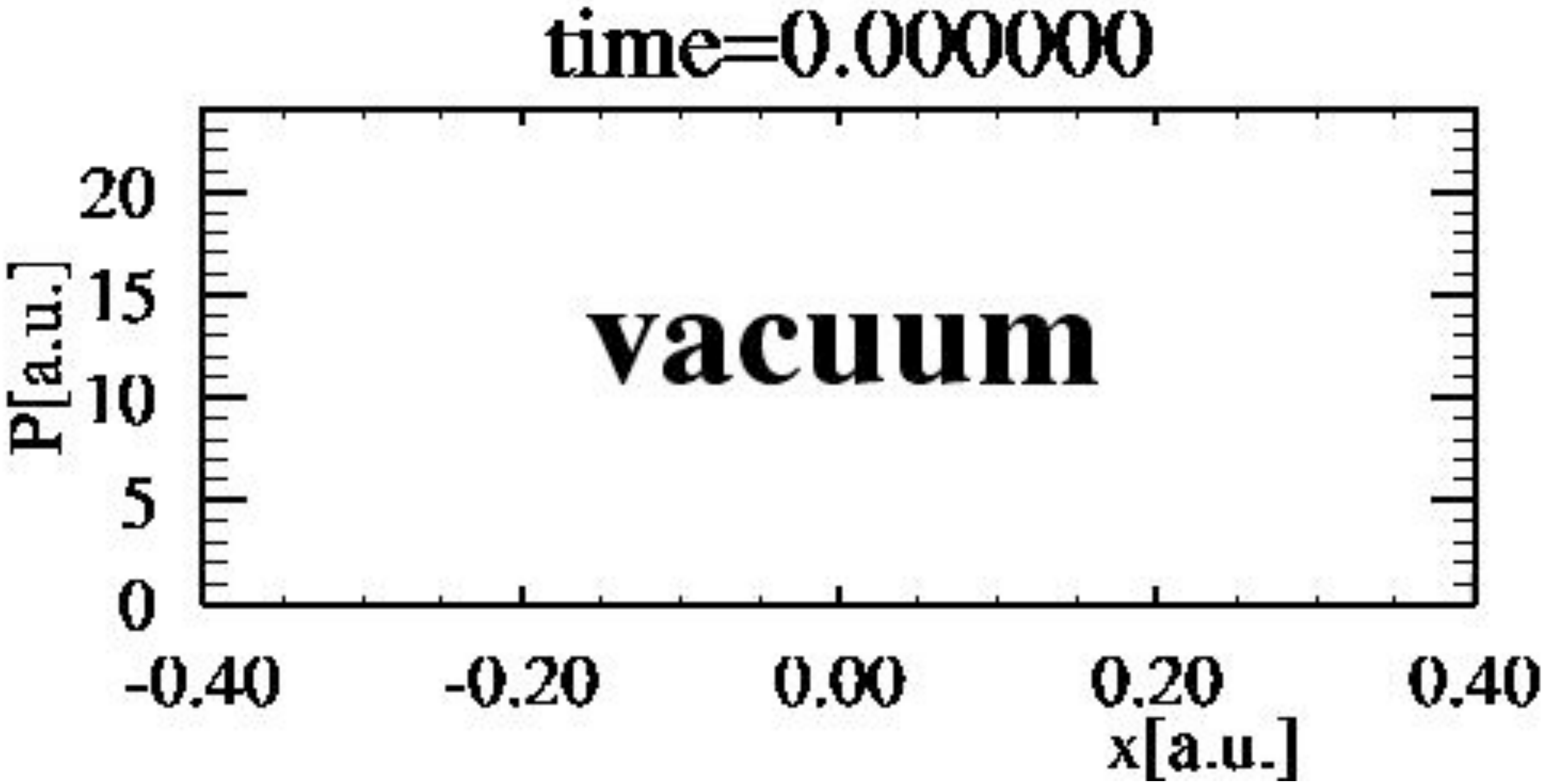
- Collision of two ions in accelerators

- Focus a laser beam


The birth of an electron-positron pair



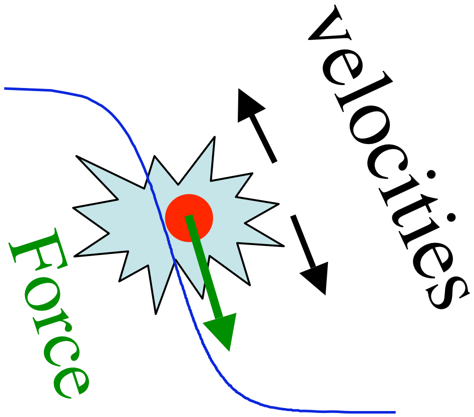
The birth of an electron-positron pair



# Model the electron motion

Questions:

- Are the particles born with an initial velocity?
- Do they gain velocity due to rolling down?
- Can an interpretation help based on classical mechanics?



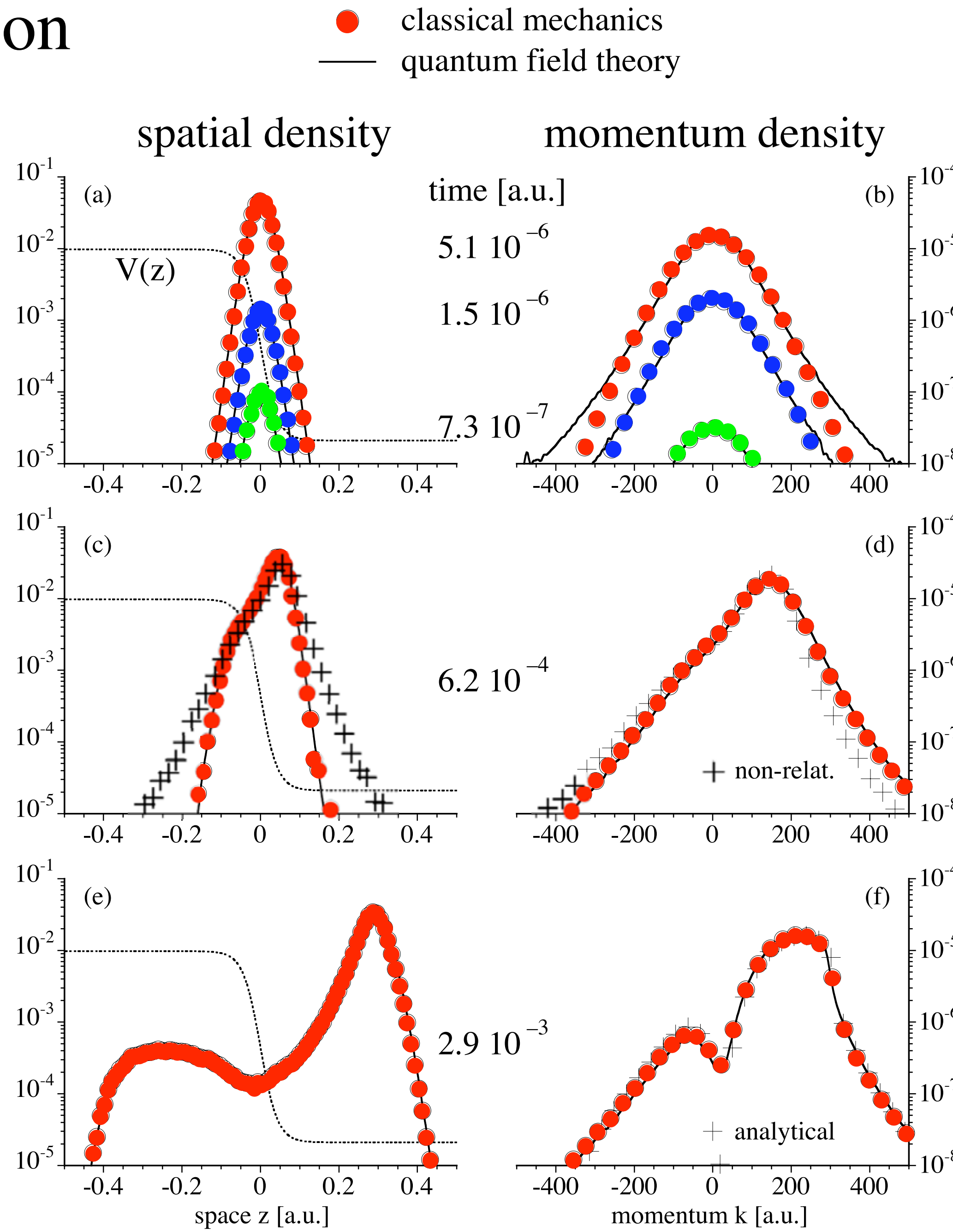
# Classical-QFT comparison

# ρ(z) and ρ(k)

early time

intermediate time

large time



# Impact on $e^{-}+e^{+}$ interaction

Quantum field theory: not possible yet

involving the quantization of light

interaction of photon with matter field → Coulomb attraction

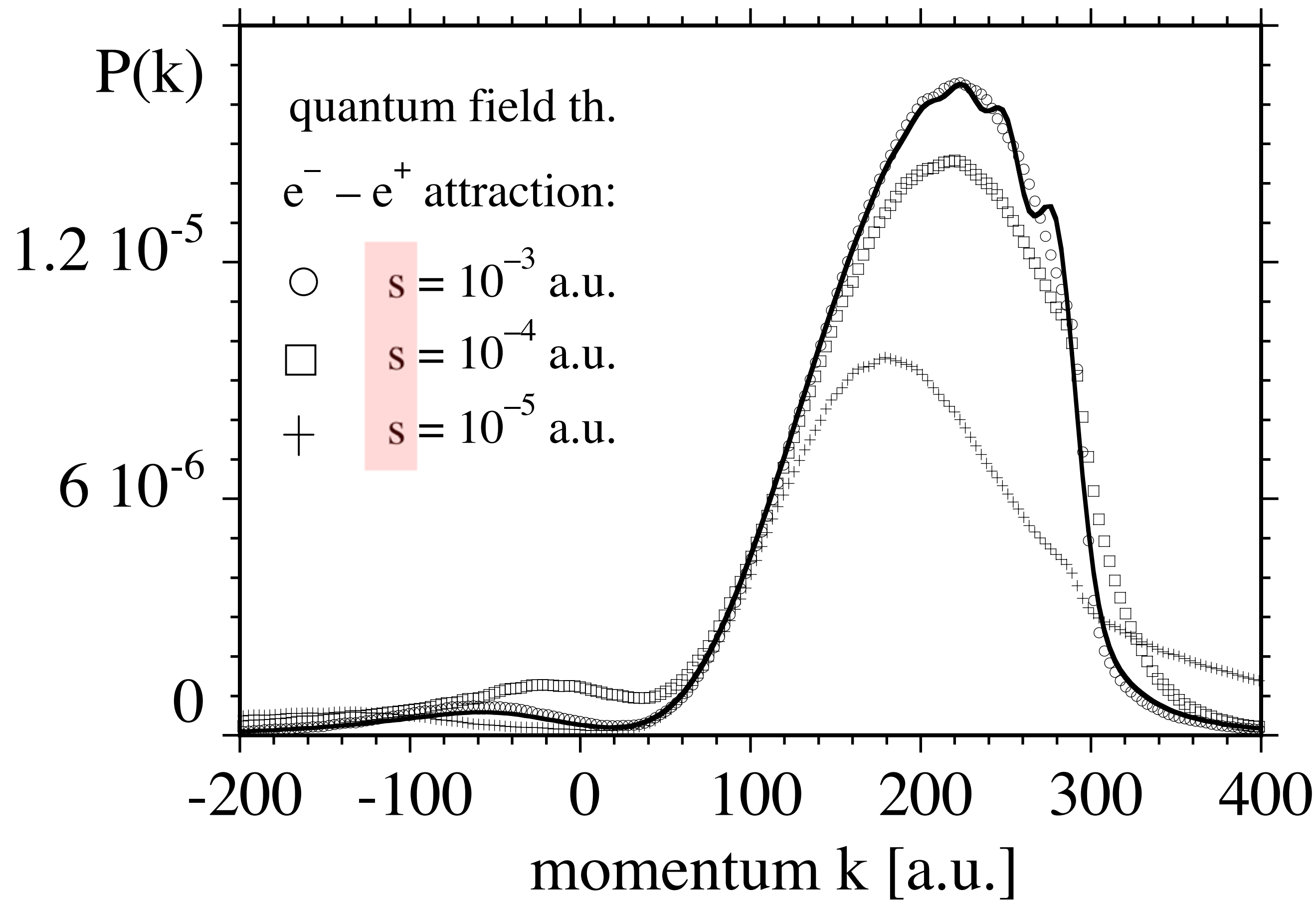
require simulations of both Dirac and Maxwell equations

Classical theory: possible

preliminary result

# Impact of $e^{-}$-$e^{+}$ interaction

$$V(x)=1/\sqrt{(s^2+x^2)}$$



# Impact of "initial state" x-p correlation for $e^-$

Quantum field theory:

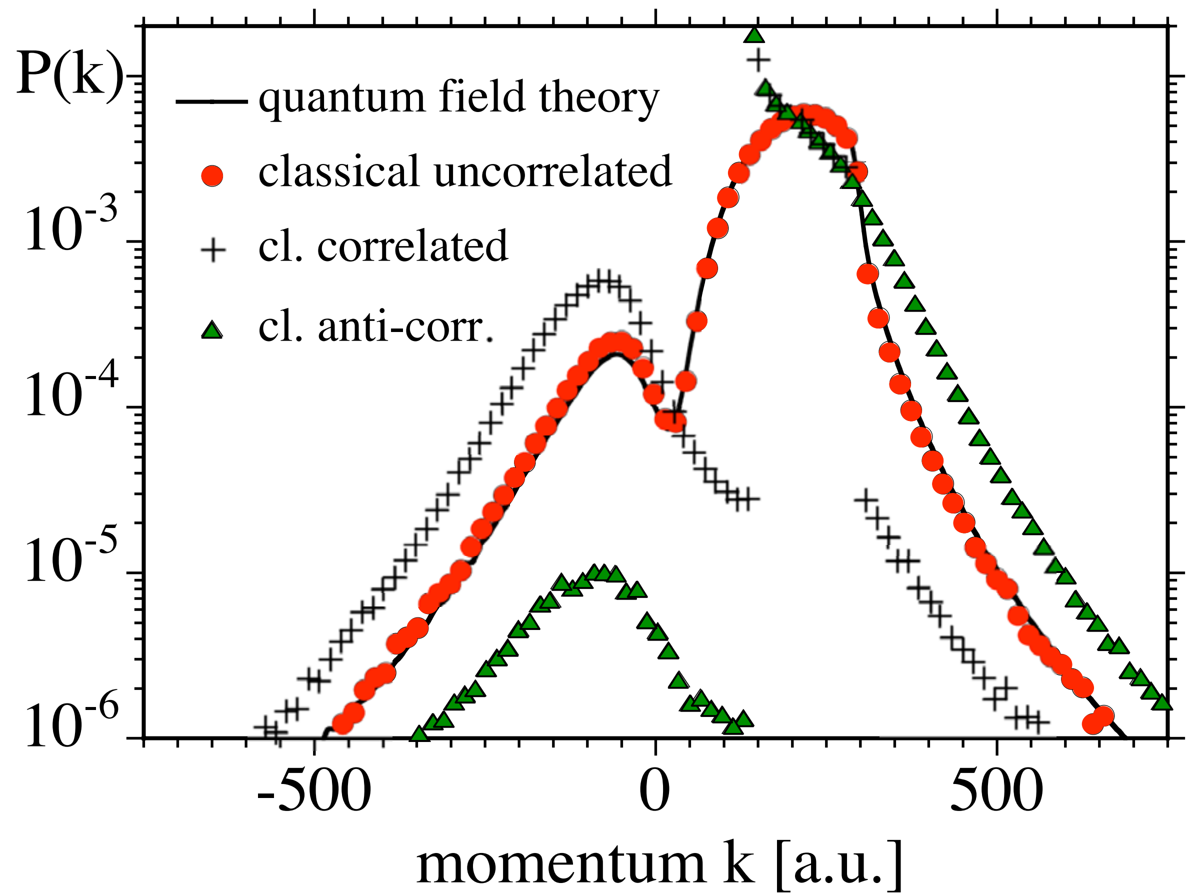
know only $\rho(x)$ and $\rho(p)$ for the electron

don't know $\rho(x,p)$

Classical theory:

let's see the impact

# Impact of "initial state" x-p correlation for e⁻



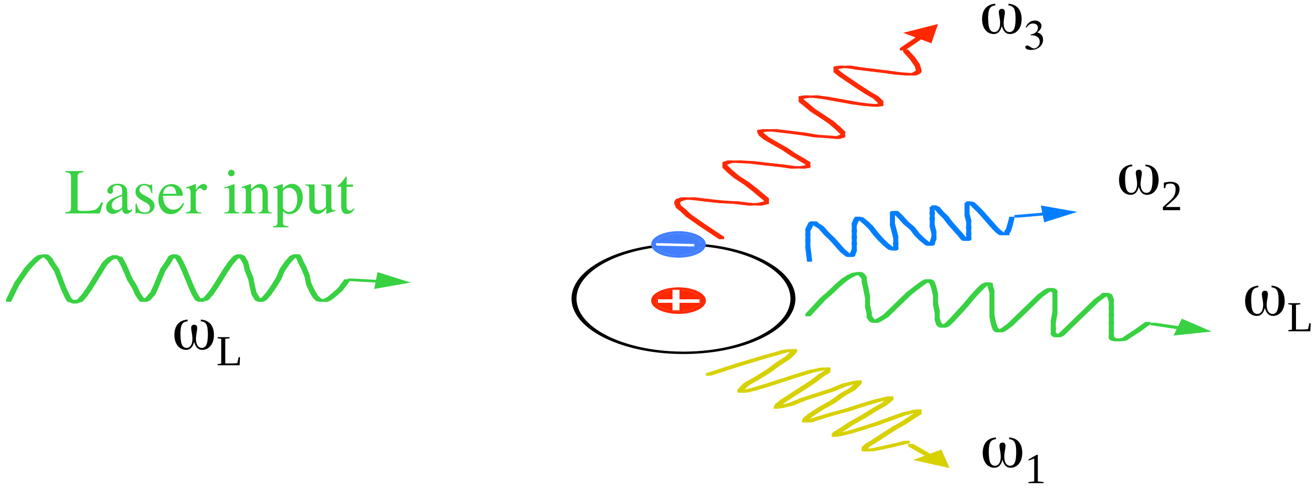
# Summary

- Pair creation was simulated using quantum field theory
- Final velocity distribution was compared with classical model
- Classical mechanics explains QFT

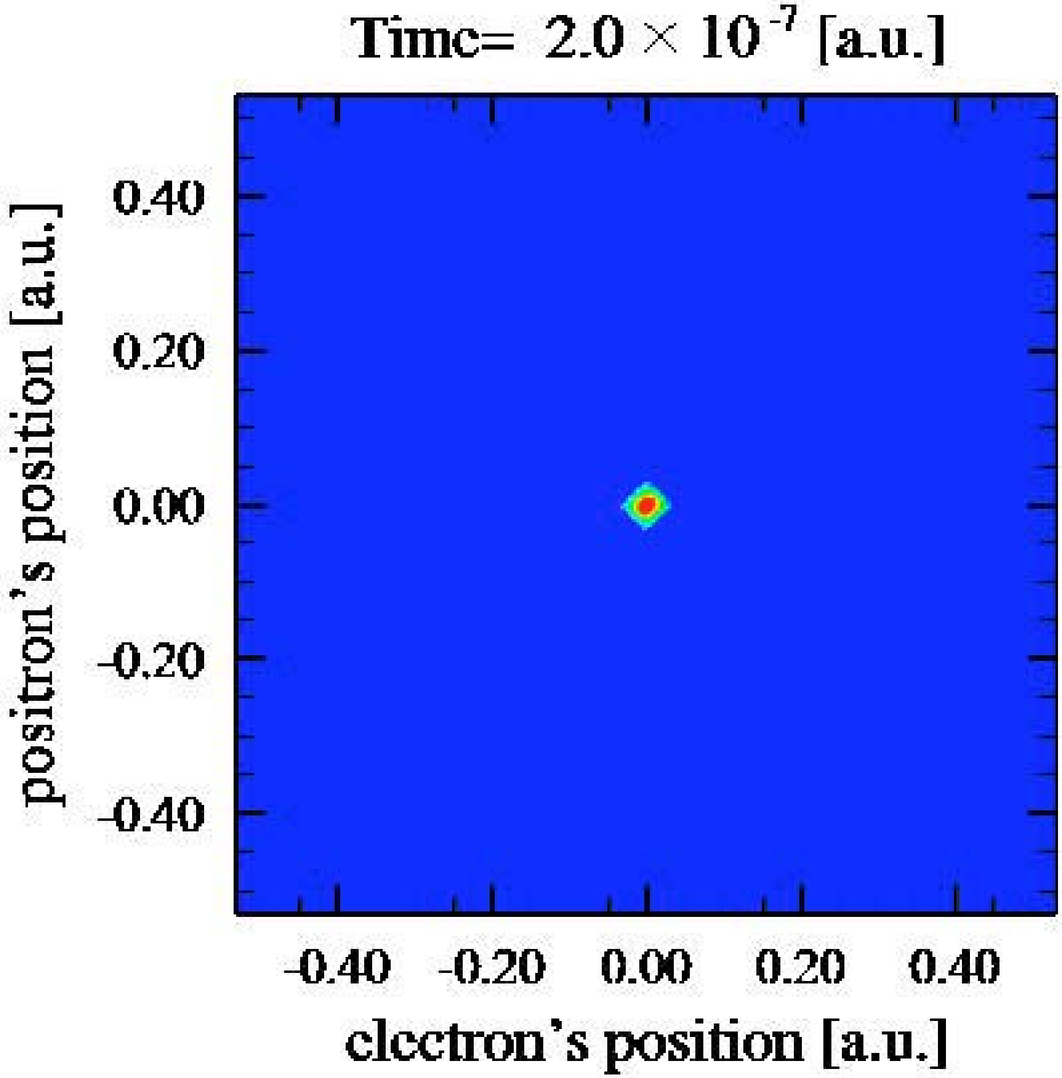
  if electron is born with initial velocity
- What is really quantum mechanical about pair creation?


P. Krekora, Q. Su and R. Grobe, **Phys. Rev. Lett.** 92, 040406 (2004).
P. Krekora, Q. Su and R. Grobe, **Phys. Rev. Lett.** 93, 043004 (2004).
P. Krekora, K. Cooley, Q. Su and R. Grobe, **Phys. Rev. Lett.** 95, 070403 (2005).
N. Chott, Q. Su and R. Grobe, **Phys. Rev. Lett.** (submitted)

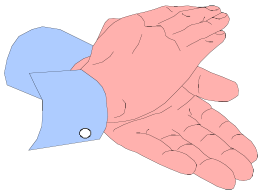

# Atoms in magnetic/laser fields




Resonance: cyclotron frequency = laser frequency




Evolution of electron and positron



Robert Wagner (Computer Physics Major 1998-2002)

- 13 Publications
- 14 Conference presentations
- Barry Goldwater Scholarship
- USA All Academic Team
- **Leroy Apker Award in 2002**

now a graduate student at Princeton

# Level 1: Maxwell equations

laser: E(r,t)     medium: n(r)

Initial field satisfies :

$$\nabla \bullet \mathbf{E} = 0 \quad \text{and} \quad \nabla \bullet \mathbf{B} = 0$$

Time evolution given by :

$$\partial \mathbf{E} / \partial t = 1/n^2 \, \nabla \times \mathbf{B} \quad \text{and} \quad \partial \mathbf{B} / \partial t = -\nabla \times \mathbf{E}$$

**FFT on the grid method**

# Intense Laser Physics Theory Unit

**Present Undergrad Researchers:**

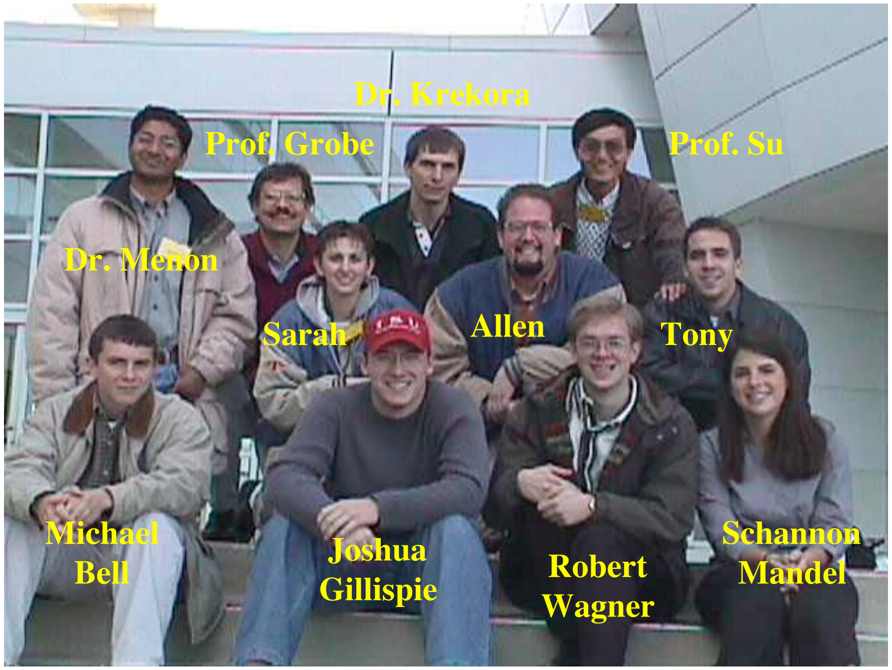
- M. Narter, scattering
- P. Peverly, animations
- J. Henderson, ionization
- M. Bell, experimental
- A. Lewis, simulations
- R. Wenning, scattering
- K. Karim, ionization

**Postdocs:**

P. Krekora, S. Menon

**Faculty:**

Q. Su, RG




Intense Laser Physics Theory Unit

**Support:**

National Science Foundation
Research Corporation
ISU Honor's Program
ISU College of A&S

# Student projects since 1997

| | |
|---|---|
| Kevin M. Paul (**1 publication**) | Adiabaton time evolution |
| Brad A. Smetanko (**2**) | Numerical solution to the Dirac equation |
| Kelly N. Rodeffer | Ionization revivals in classical mechanics |
| Kress M. Shores | One dimensional quantum calculation of the Schrödinger equation |
| Jennifer R. Csesznegi (**4**) | Stability analysis of off-resonant adiabatons |
| Jason C. Csesznegi (**1**) | Relativistic ionization using the Lorenz equation |
| Benjamin P. Irvin (**2**) | Stability of KH-eigenstates in bichromatic fields |
| Joshua W. Braun (**3**) | One-dimensional essential state approach to stabilization |
| Marek M. Jacobs | Computer movie of pulse propagation |
| Robert E. Wagner (**13**) | Cycloatoms |
| Peter J. Peverly (**6**) | Higher-harmonics generation in ionization |
| Tyson R. Shepherd | Animations on the ILP webpage |
| Radka Bach | Laser-assisted positron production for the Klein paradox |
| Chad Johnson (**1**) | Stabilization in one dimension |
| Shannon Mandel (**3**) | Pulse propagation in random media |
| Alexander Bergquist | Stereographic display of three-dimensional data |
| Mathew Nickels | Photon-density waves in turbid media |
| Michael S. Bell (**1**) | Monte Carlo simulations in time-dependent media |
| Allan F. Lewis (**1**) | Traditional Monte Carlo simulations in frozen media |
| Sarah Radovich (**1**) | Classical simulations for Cyclo-helium |
| Joshua Gillespie (**1**) | Classical simulations for Cyclo-helium |
| Travis N. Faust | Cyclo-hydrogen and helium |
| Matthew E. Narter | Monte Carlo simulations in random media |
| John C. Henderson (**1**) | Classical simulations for Cyclo-helium |
| Karim Karr | Relativistic ionization |
| Ryan Balfanz | Web site development |

1.6 publications/per student

Failures: Two ACT = 35/36 students

<u>Journals</u>

Phys. Rev. Lett (2 times)
Phys. Rev. A (6 times)
Phys. Rev. E (1)
Laser Phys. (8)
Opt. Express (2)
Front. Las. Phys. (1)
SPIE journals (3)
Orbit (2)

total ≈ 25 publications

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