

# Hauptseminar **Quantum Computing: Principles and physical platforms**

**SS 2024**

**Michael Fleischhauer**

# Goals of the seminar:

- Learn how to **inform** yourself about a specific research subject from original literature
- Learn how to **prepare** a presentation on the subject
- Practice to give a **talk** and answer questions in the subsequent discussion

# Rules:

- Active participation in all seminar talks; in person
- Preparation of talk from given literature & own literature search
- Presentation of scientific talk (35 – 45 min) (english preferred)
- Subsequent scientific discussion (15 – 30 min)
- Oral & written feedback about presentation (15 min)

# 1. Inform yourself about the subject

- Start reading given material approx. 4 weeks before presentation !
- Additional sources or if no material given:
  - Review articles / thesis are a good starting point
  - Wikipedia good for more general subjects; beware: can be biased if topic is more specialized
  - Google scholar; web of Science; Scopus
- Discuss / ask supervisor or colleagues

- The more prepared you are the more confident you'll be !
- Always know much more than you actually talk about!



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Die freie Enzyklopädie

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Artikel Diskussion

Nicht angemeldet Diskussionsseite Beiträge Benutzerkonto erstellen Anmelden

Lesen Bearbeiten Quelltext bearbeiten Versionsgeschichte

Wikipedia durchsuchen



## Quantencomputer

Ein **Quantenprozessor** bzw. **Quantencomputer** ist ein **Prozessor**, der die Gesetze der **Quantenmechanik** nutzt. Im Unterschied zum klassischen **Computer** arbeitet er nicht auf der Basis **elektrischer**, sondern **quantenmechanischer Zustände**. Hierbei sind erstens das **Superpositionsprinzip** (d. h. die **quantenmechanische Kohärenz**, analog zu den **Kohärenzeffekten**, siehe z. B. **Holographie**, in der sonst **inkohärenten Optik**) und zweitens die **Quantenverschränkung** von Bedeutung.

Theoretische Studien zeigen, dass unter Ausnutzung dieser Effekte bestimmte Probleme der Informatik, z. B. die Suche in extrem großen **Datenbanken** (siehe **Grover-Algorithmus**) und die **Faktorisierung** großer Zahlen (siehe **Shor-Algorithmus**) effizienter gelöst werden können als mit klassischen Computern. Dies würde es ermöglichen, die Berechnungszeit für viele mathematische und physikalische Problemstellungen deutlich zu verringern.

Der Quantencomputer war lange ein überwiegend theoretisches Konzept. Es gab verschiedene Vorschläge, wie ein Quantencomputer realisiert werden könnte, in kleinem Maßstab wurden einige dieser Konzepte im Labor erprobt und Quantencomputer mit wenigen **Qubits** realisiert. Der Rekord lag im November 2021 bei 127 Qubits für den Prozessor.<sup>[1]</sup> Neben der Anzahl der Qubits ist aber auch zum Beispiel eine geringe Fehlerquote beim Rechnen und Auslesen wichtig und wie lange die Zustände in den Qubits fehlerfrei aufrechterhalten werden können.

Seit 2018 investieren viele Regierungen und Forschungsorganisationen sowie große Computer- und Technologiefirmen weltweit in die Entwicklung von Quantencomputern, die von vielen als eine der entstehenden **Schlüsseltechnologien** des 21. Jahrhunderts angesehen werden.<sup>[2][3][4]</sup>

Inhaltsverzeichnis [Verbergen]

- 1 Mögliche Anwendungsgebiete
- 2 Technologie

≡ Google Scholar

quantum computer



### Artikel

Ungefähr 169.000 Ergebnisse (0,09 Sek.)

Beliebige Zeit

Seit 2022  
Seit 2021  
Seit 2018  
Zeitraum wählen...

Nach Relevanz  
sortieren

Nach Datum sortieren

Beliebige Sprache  
Seiten auf Deutsch

Alle Typen

Übersichtsarbeiten

✉ Alert erstellen

#### The universe as quantum computer

[S Lloyd - A Computable Universe: Understanding and exploring ...](#), 2013 - World Scientific

... giant **computer**, and if so, just what kind of **computer** it is. I will show that the universe can be regarded as a giant **quantum computer**. ... In particular, the model shows that the **quantum** ...

☆ Speichern 99 Zitieren Zitiert von: 104 Ähnliche Artikel Alle 14 Versionen

[PDF] arxiv.org

#### [HTML] Architecture for a large-scale ion-trap quantum computer

[D Kielpinski, C Monroe, DJ Wineland - Nature, 2002](#) - nature.com

... communication to link a number of small ion-trap **quantum** systems. Developing the ... **quantum computer**, based on techniques already demonstrated for manipulating small **quantum** ...

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[HTML] nature.com

Full View

#### Quantum machine learning with D-wave quantum computer

[F Hu, BN Wang, N Wang, C Wang - Quantum Engineering, 2019](#) - Wiley Online Library

... principle and **quantum** computing models of the **quantum computer**. ... to **quantum** spin models and the QA-based **quantum** ... the **quantum** annealer and further analyzes the prospects of ...

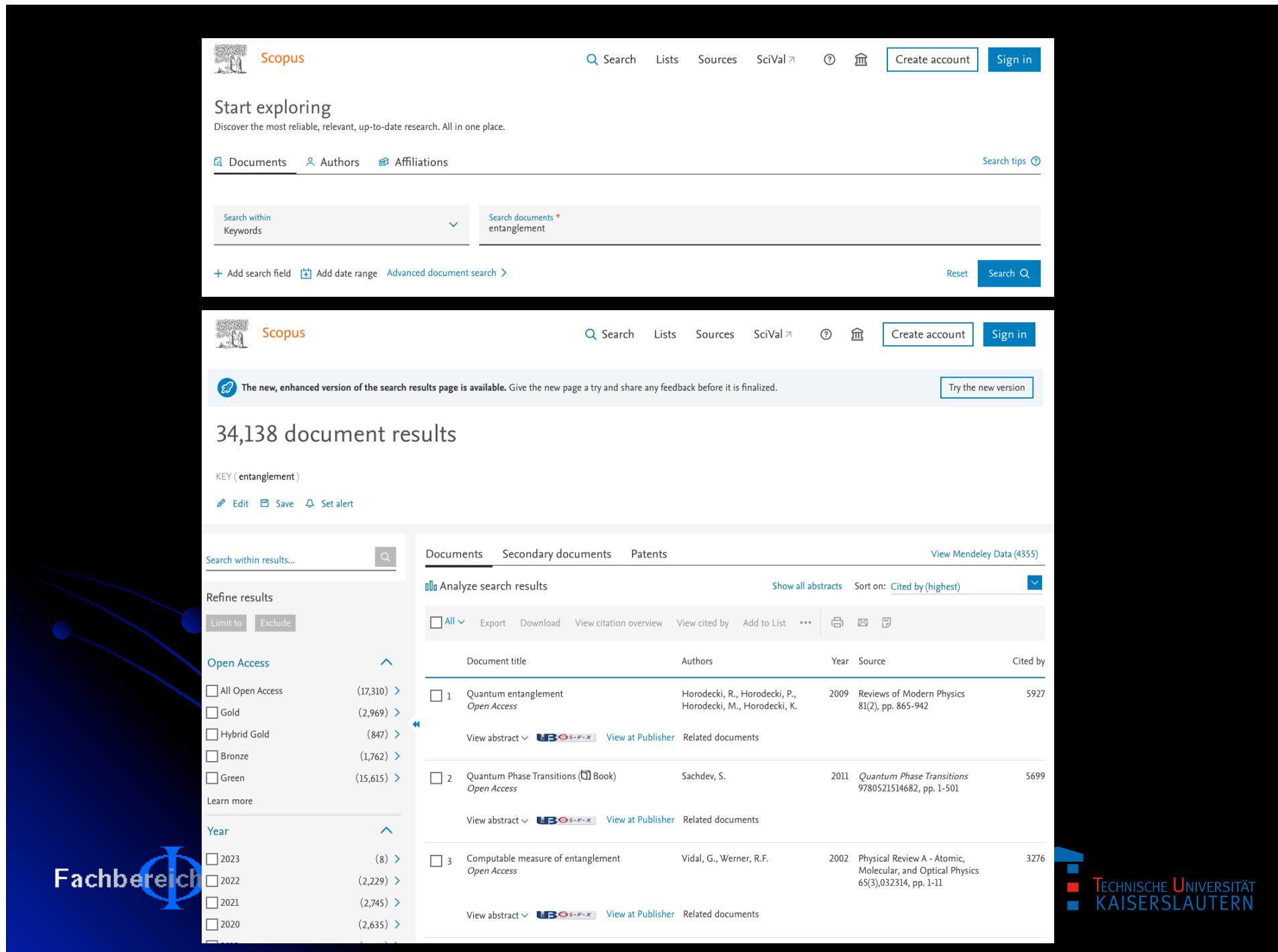
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[PDF] wiley.com

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Fach

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Keywords

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Search within results...

Refine results

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- All Open Access (17,310) >
- Gold (2,969) >
- Hybrid Gold (847) >
- Bronze (1,762) >
- Green (15,615) >

Learn more

Year

- 2023 (8) >
- 2022 (2,229) >
- 2021 (2,745) >
- 2020 (2,635) >

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Analyze search results

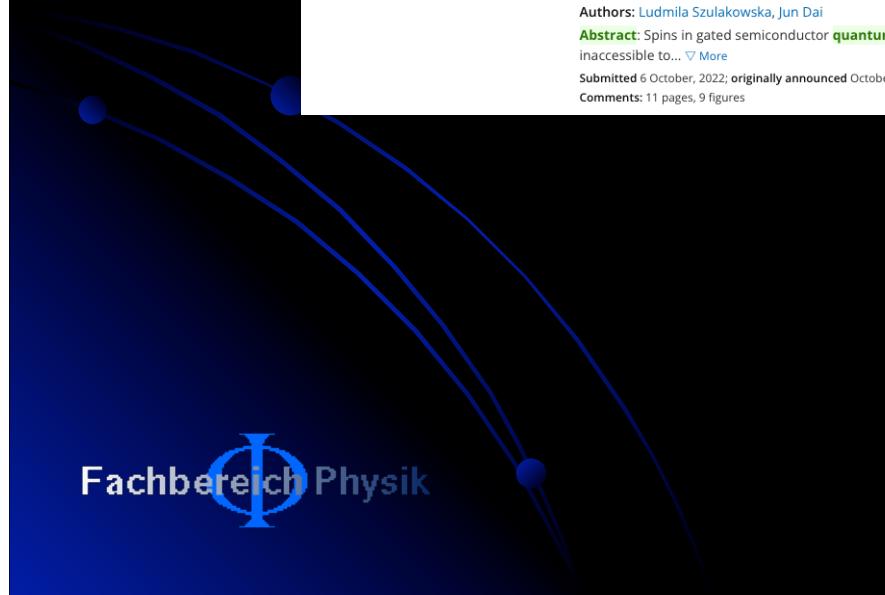
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All Export Download View citation overview View cited by Add to List ...

Document title	Authors	Year	Source	Cited by
1 Quantum entanglement <i>Open Access</i>	Horodecki, R., Horodecki, P., Horodecki, M., Horodecki, K.	2009	Reviews of Modern Physics 81(2), pp. 865-942	5927
2 Quantum Phase Transitions (Book) <i>Open Access</i>	Sachdev, S.	2011	Quantum Phase Transitions 9780521514682, pp. 1-501	5699
3 Computable measure of entanglement <i>Open Access</i>	Vidal, G., Werner, R.F.	2002	Physical Review A - Atomic, Molecular, and Optical Physics 65(3),032314, pp. 1-11	3276

Fachbereich

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 Cornell University

We gratefully acknowledge support from the Simons Foundation and member institutions.

**arXiv**

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50  Sort results by

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1. [arXiv:2210.02455](#) [pdf, other] hep-ph hep-lat nucl-th

**Form factor and model dependence in neutrino-nucleus cross section predictions**

Authors: Daniel Simons, Noah Steinberg, Alessandro Lovato, Yannick Meurice, Noemi Rocco, Michael Wagman

**Abstract:** ...the nuclear many-body problem and in the determination of the single- and few-nucleon quantities taken as input by many-body methods. To quantify both types of uncertainty, we **compute** flux-averaged double-differential cross sections using the Green's function Monte Carlo and spectral function methods as well as different parameterizations of the nucleon...

Submitted 5 October, 2022; originally announced October 2022.

Comments: 20 pages, 10 figures

Report number: FERMILAB-PUB-22-745-T

2. [arXiv:2210.03077](#) [pdf, other] cond-mat.mes-hall

**Bayesian autotuning of Hubbard model quantum simulators**

Authors: Ludmila Szulakowska, Jun Dai

**Abstract:** Spins in gated semiconductor **quantum** dots (QDs) are a promising platform for Hubbard model simulation inaccessible to...

Submitted 6 October, 2022; originally announced October 2022.

Comments: 11 pages, 9 figures

**Fachbereich Physik**

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## 2. Prepare your presentation

step 1: identify your audience

step 2: determine how much time you have

step 3: identify the main points you want to convey  
(2-3 main points in a 20 – 30 min talk)

step 4: create an outline of your talk

step 5: prepare slides (and backup slides)

step 6: practice, practice, practice !!

## 2. Prepare your presentation

### Organizing a 30 min talk ?

no unique recipe (depends on what type: short / long talk; colloquium)

#### I. Background & Introduction

- Title slide
- Outline slide (can be skipped in short talk)
- Overview slide (if appropriate) *why is research important ?*
- 1-2 Background slides (if appropriate) *provides background for non-experts*

#### II. Main body of talk

#### III. Summary

- Summary of key points (2-4 for 20 – 30 min talk)
- Acknowledgement *sources; people involved; funding sources*

**The title slide and outline prepares the audience to listen and shows organization of talk**

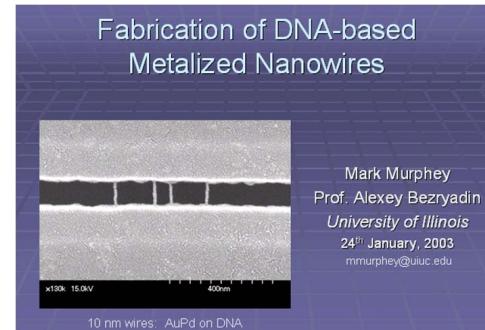
## Title slide

Your names and affiliations

Paper citation (for JC)

Venue and date

Attention-getting graphic



## Outline or overview of presentation

Prepares the audience to listen

Provides a logical structure for your talk

Provides motivation and context

Summarizes key points (limit to two or three for a 20- to 30-minute talk)



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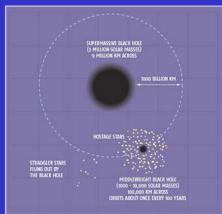
# Overview



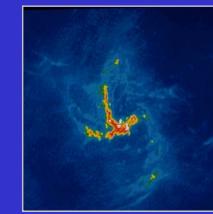
Black holes and star clusters



The galactic center



Intermediate-mass black hole kinematics



Here, we have a **VISUAL** and **WRITTEN** outline and it's not too long !

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# The “body” of your presentation is the intellectual content of your talk

## Problem statement, motivation

~1–2 slides

## Previous work

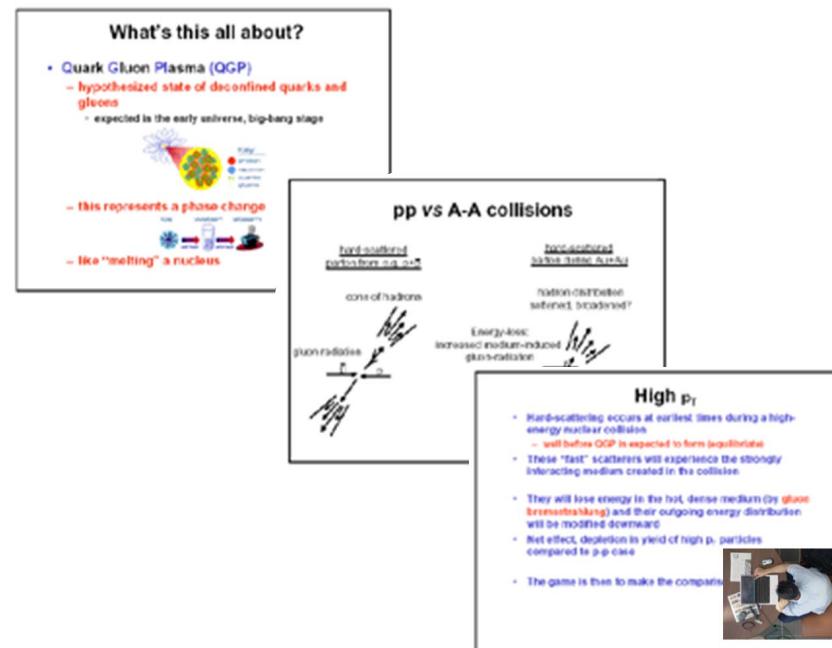
~1–2 slides

## Methods

~1–3 slides

## Key Results

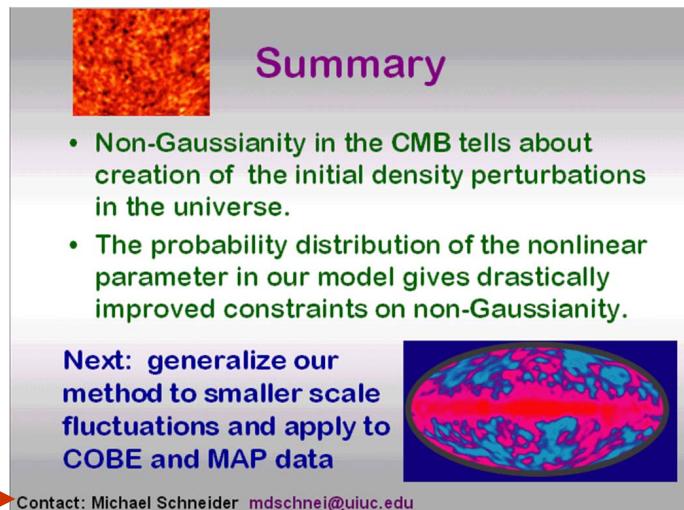
~5–6 slides



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## Provide a “summary” slide

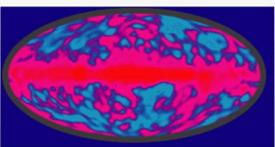
Recap key results and conclusions  
Reiterate main critiques (for JC)



**Summary**

- Non-Gaussianity in the CMB tells about creation of the initial density perturbations in the universe.
- The probability distribution of the nonlinear parameter in our model gives drastically improved constraints on non-Gaussianity.

Next: generalize our method to smaller scale fluctuations and apply to COBE and MAP data



Contact: Michael Schneider [mdschnei@uiuc.edu](mailto:mdschnei@uiuc.edu)

This slide will probably stay on the screen during the question period and will thus get the longest audience exposure—make it count!



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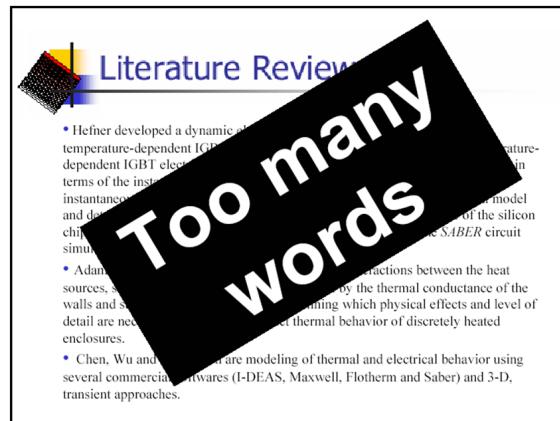
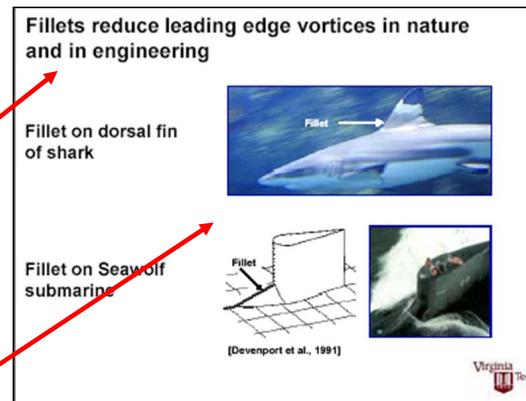
## Tips for preparing slides

## Have only 1 idea per slide

Use the header to state the main idea of the slide, and use the body of the slide to support that idea

Use well-labeled graphs and figures to illustrate your key points this makes the slide more real and interesting to the audience

## Avoid too much text



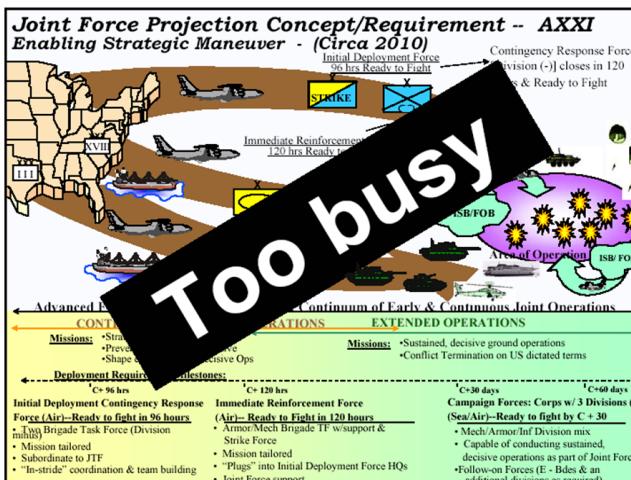
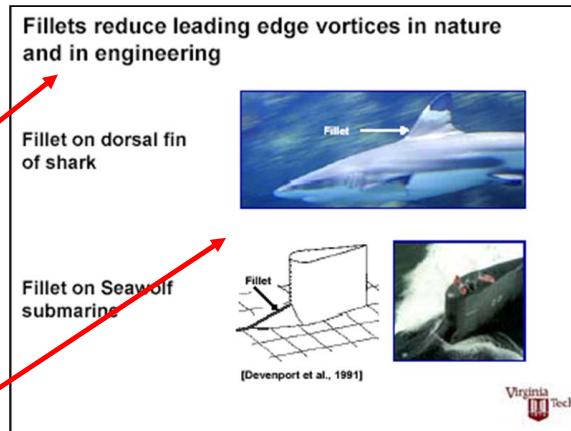
## Tips for preparing slides

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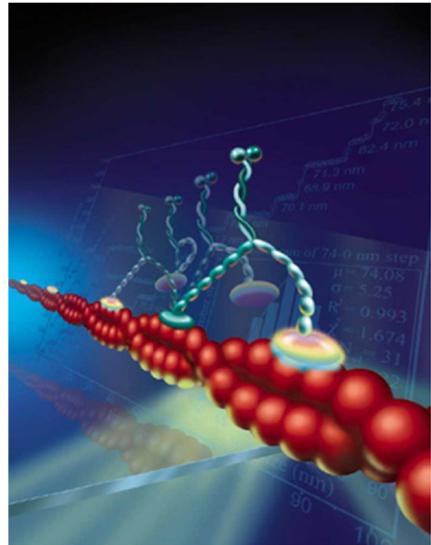
Use well-labeled graphs and figures to illustrate your key points this makes the slide more real and interesting to the audience

.or too many distracting images



## Tips for preparing slides

### Use figures to illustrate your key points



Myosin “walking” on actin  
*Courtesy of P. Selvin*

#### Figures:

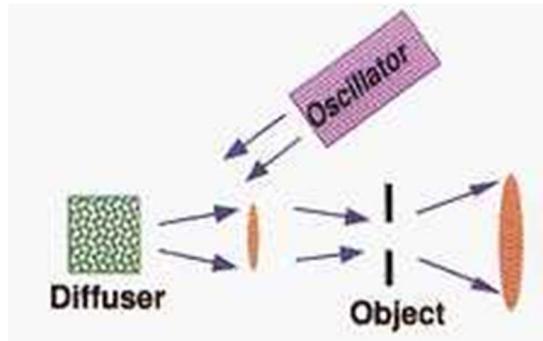
- enliven slides
- promote audience interest
- provide supporting evidence for key points
- help explain complex ideas and relationships quickly
- show how things work, etc.



# Tips for preparing slides

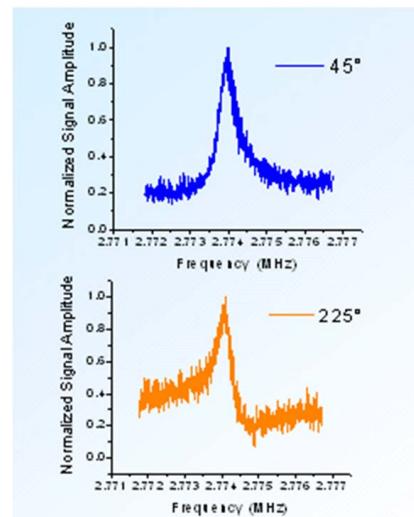
## Label all elements in a figure

- Point out important features
- Label both axes of graphs and show units
- Provide a brief caption
- Give credit to source



The Nike laser system  
uses discharge pre-  
amplifiers.  
(Courtesy US Navy)

Fachbere



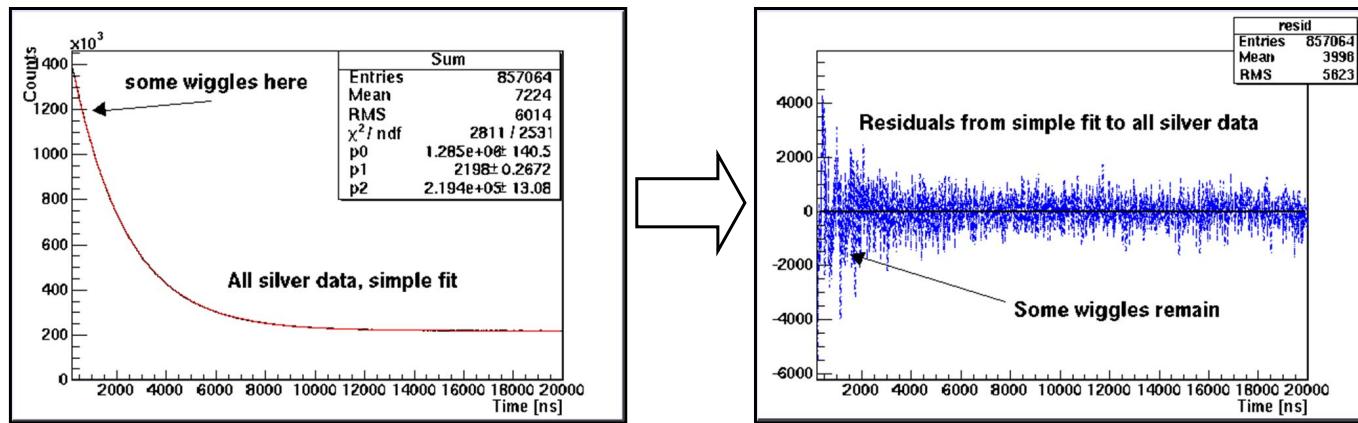
Sample normalized  
signals from the two-  
beam optical drive.  
(Courtesy C. Michael)



# Tips for preparing slides

## Presenting data is your most important and challenging task

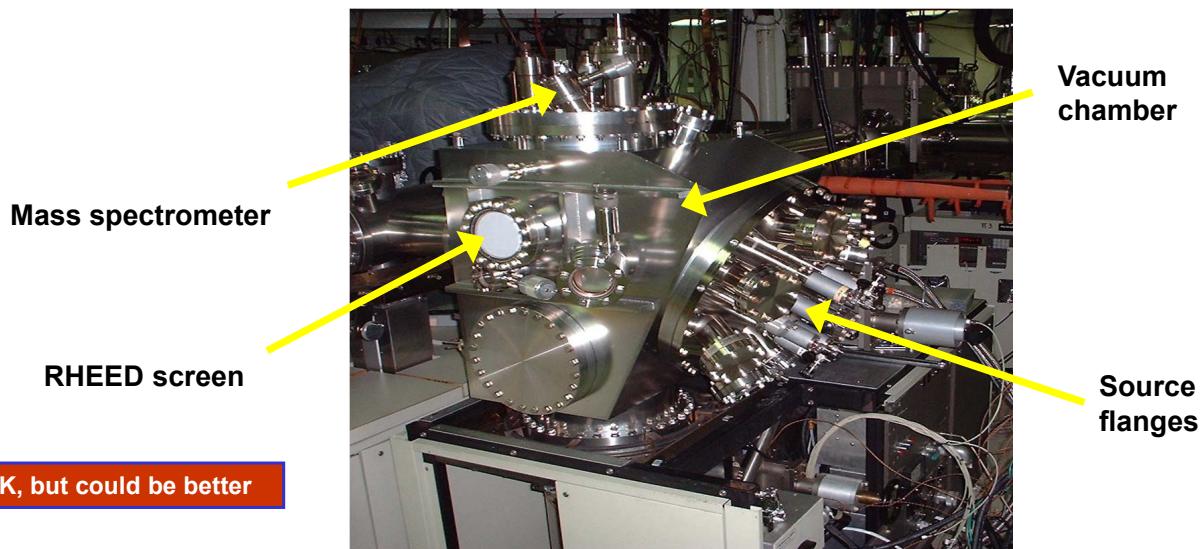
- Avoid copying a graph from a formal article – they have a different style, e.g., labels are too small
- Use color and make lines thick, labels legible
- Label axes and annotate important points with arrows and add words
- Use tables sparingly – if used highlight important parts



## Tips for preparing slides

**Show the equipment IF it helps as part of your proof – but sparingly, not just because you love it**

- **Photographs** give scale and reality – but add labels
- **Schematics** provide concept
- **Diagrams** strip away unnecessary details
- **ALL OF THESE** can be useful in combination



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## Tips for preparing slides

### Use equations sparingly

Use equations only when necessary

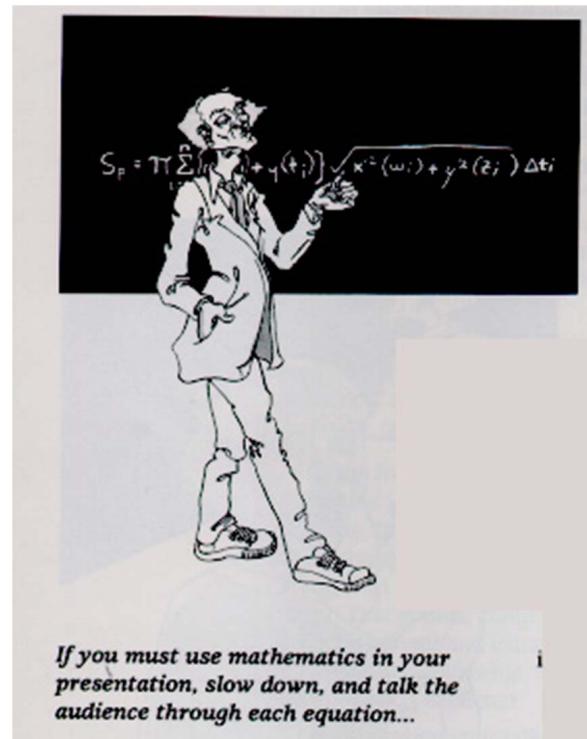
If you use equations

Slow down

Talk through step by step

Explain relevance

Combine with a picture  
that illustrates the  
physical principle  
involved



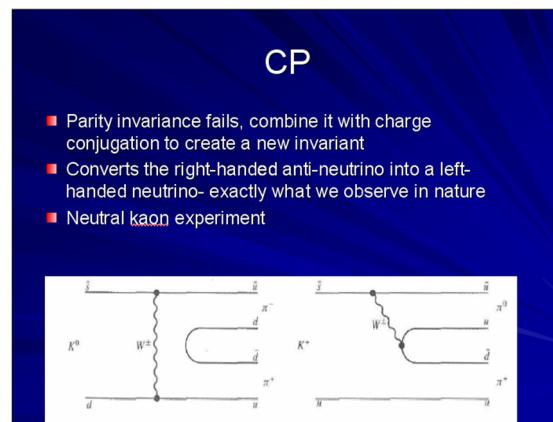
# Tips for preparing slides

Remember, your goal is to convey your ideas, so avoid distracting text and effects!

Don't overuse PowerPoint animations and sounds!

Make sure there is good contrast between text and background

Use simple (or no) backgrounds on slides



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## Tips for preparing slides

**Eschew weird fonts**

Don't use *calligraphy*  
or serif fonts

**USE THE SAME FONT  
THROUGHOUT THE TALK**

Make all text at least 20 pt

# Tips for preparing slides

## Use “normal” colors

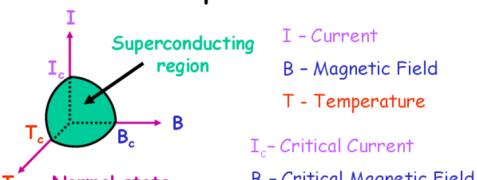
DON'T use red/green or red/blue as contrasting colors

Make sure colors looks the way you expect using an LCD projector!

Avoid neon colors and pastels

Don't use many random colors; people expect color to *mean* something

Superconductivity is an electronic state of matter that exists below certain currents, magnetic fields, and temperatures.



The diagram shows a 3D coordinate system with axes for Current (I), Magnetic Field (B), and Temperature (T). A central green sphere represents the 'Superconducting region'. A dashed line extends from the center of this sphere to the axes, marking the critical values:  $I_c$  on the current axis,  $B_c$  on the magnetic field axis, and  $T_c$  on the temperature axis. The region outside this boundary is labeled 'Normal state of matter'.

I - Current  
B - Magnetic Field  
T - Temperature  
 $I_c$  - Critical Current  
 $B_c$  - Critical Magnetic Field  
 $T_c$  - Critical Temperature

Strive for easy reading

Strive for easy reading

Strive for easy reading



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### 3. Tips for giving a good talk

#### **Maintain eye contact with audience**

Don't stare at screen or monitor

#### **Do not read your talk!**

#### **Avoid nervous mannerisms**

Pacing, bobbing, waving arms, jingling coins

#### **Use laser pointer or stick directed at screen**

Don't point directly at overhead on projector

Don't block the screen

#### **Train yourself to speak slowly and distinctly— practice!**

#### **Avoid “fillers”: “uh”, “like”, “um”, “okay”**

#### **Be enthusiastic!**

If you don't act excited by your results,  
don't expect the audience to be!



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### 3. Tips for giving a good talk

**Don't show any material on slides (e.g., figures, equations, text, etc.) you can't explain!!**

**Rehearse how you'll end your talk**

Don't end with "Well, I guess  
that's it "

Don't just stop and let the committee guess that you're  
done

Thank the audience!

**Focus on communicating not performing**

(humor is good but don't overdo it)

**Keep it simple**

**Prepare key phrases**

(it is o.k. to write out some important statements first)

### 3. Tips for giving a good talk

#### Rehearse Your Talk!

##### A few days before

Practice in front of friends  
and check timing

Rehearse likely questions

Solicit feedback about  
logic and clarity

Revise (*shorten*)

##### The night before

Go over one more time

Put all materials *in order*  
(number your slides!)



Prof. Per Ahlberg delivering the Presentation Speech for the 2001 Nobel Prize in Chemistry at the Stockholm Concert Hall.

## 4. Tips for question & answers session

### **Handling questions is an essential part of giving a talk**

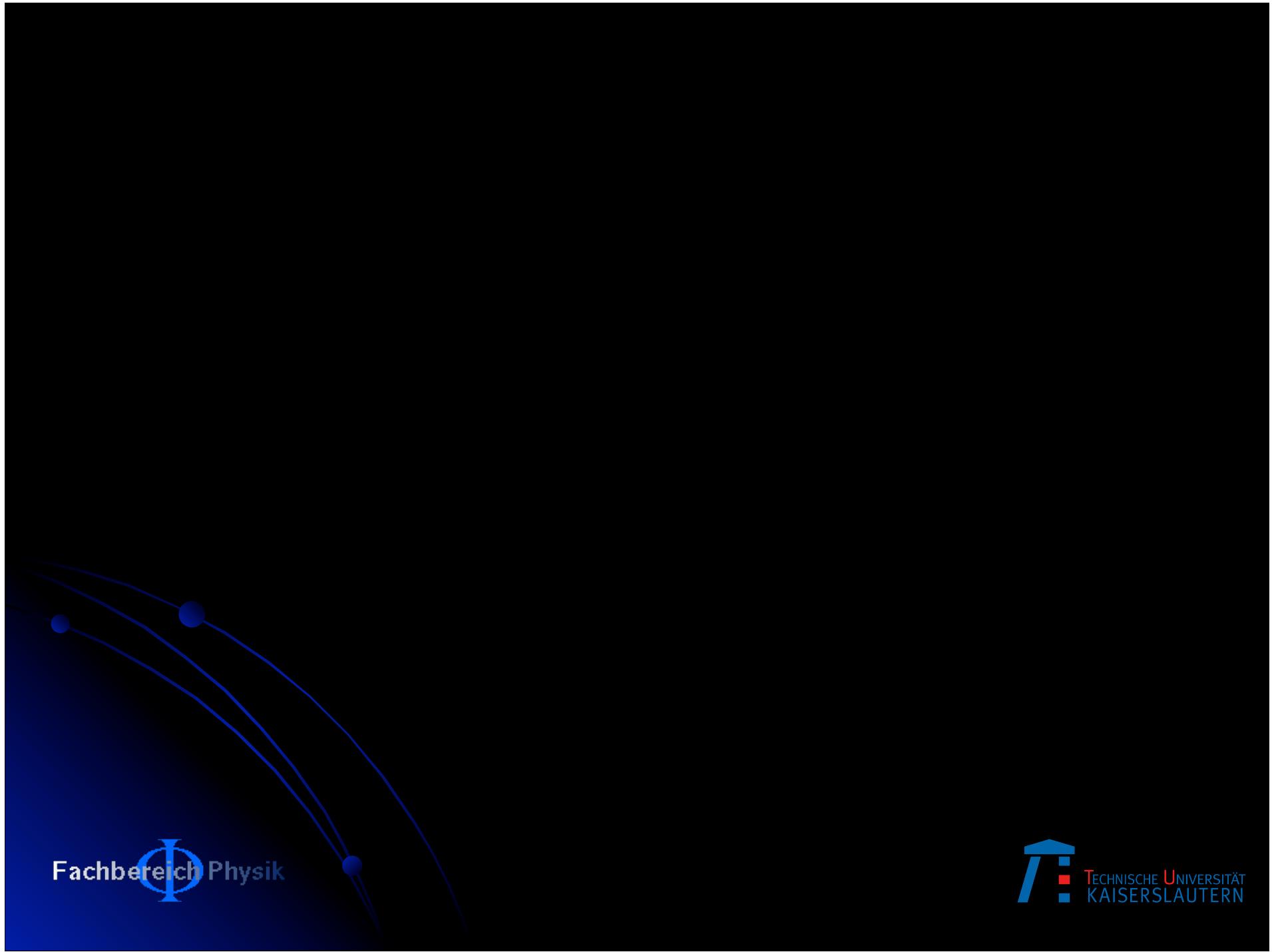
**As part of preparing your talk, try to anticipate questions you might get**

In each slide, try to identify what the weak points are, what questions you might ask, etc.

**Be prepared to repeat simple derivations of equations or estimates presented on your slides**

**If you don't know the answer?**

Say "That's an excellent question. I'm not sure; I'll have to look into it" or "Let's talk about it afterward"

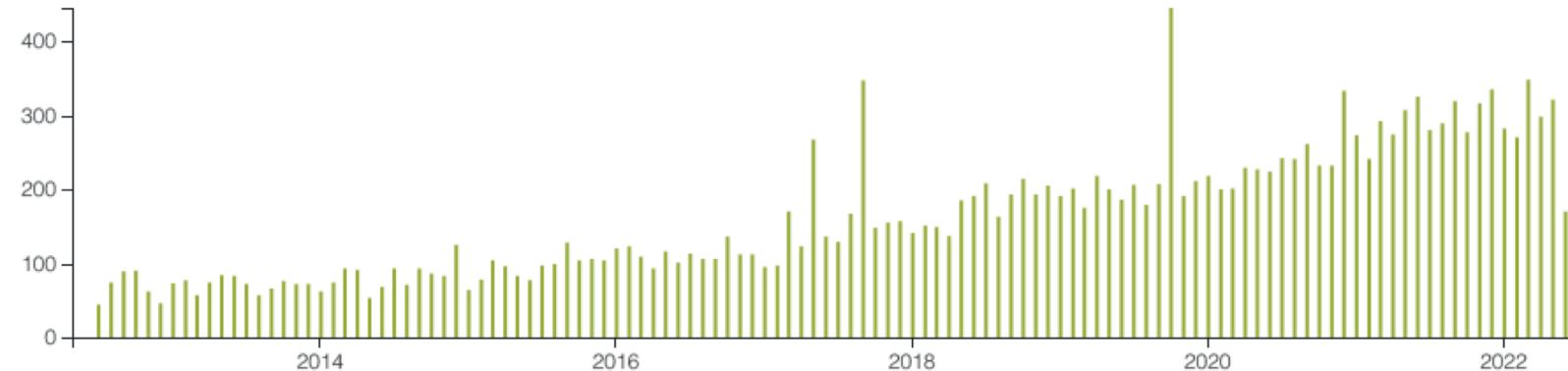


# Why ? „Quantum Information Processing“

# Publications & Venture Capital Investments

## Publications over time

Mergeflow

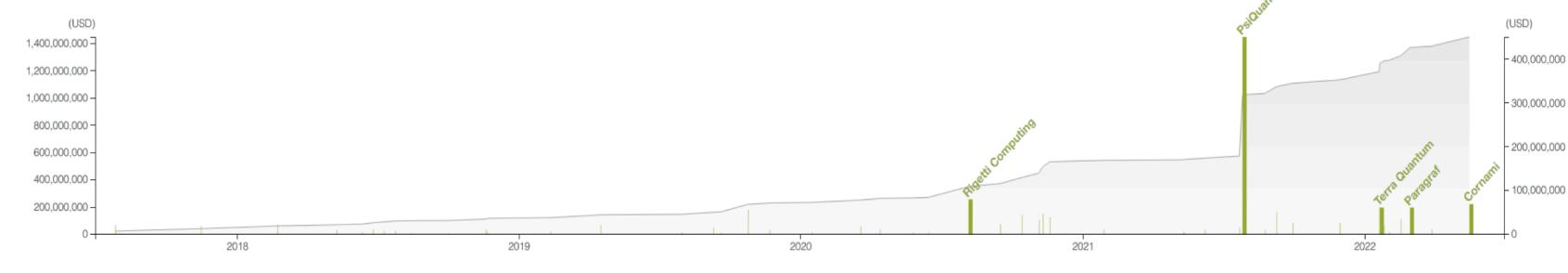


## Venture Capital

Mergeflow

48 funding events from the past 5 years

Running Total Top Funding Events



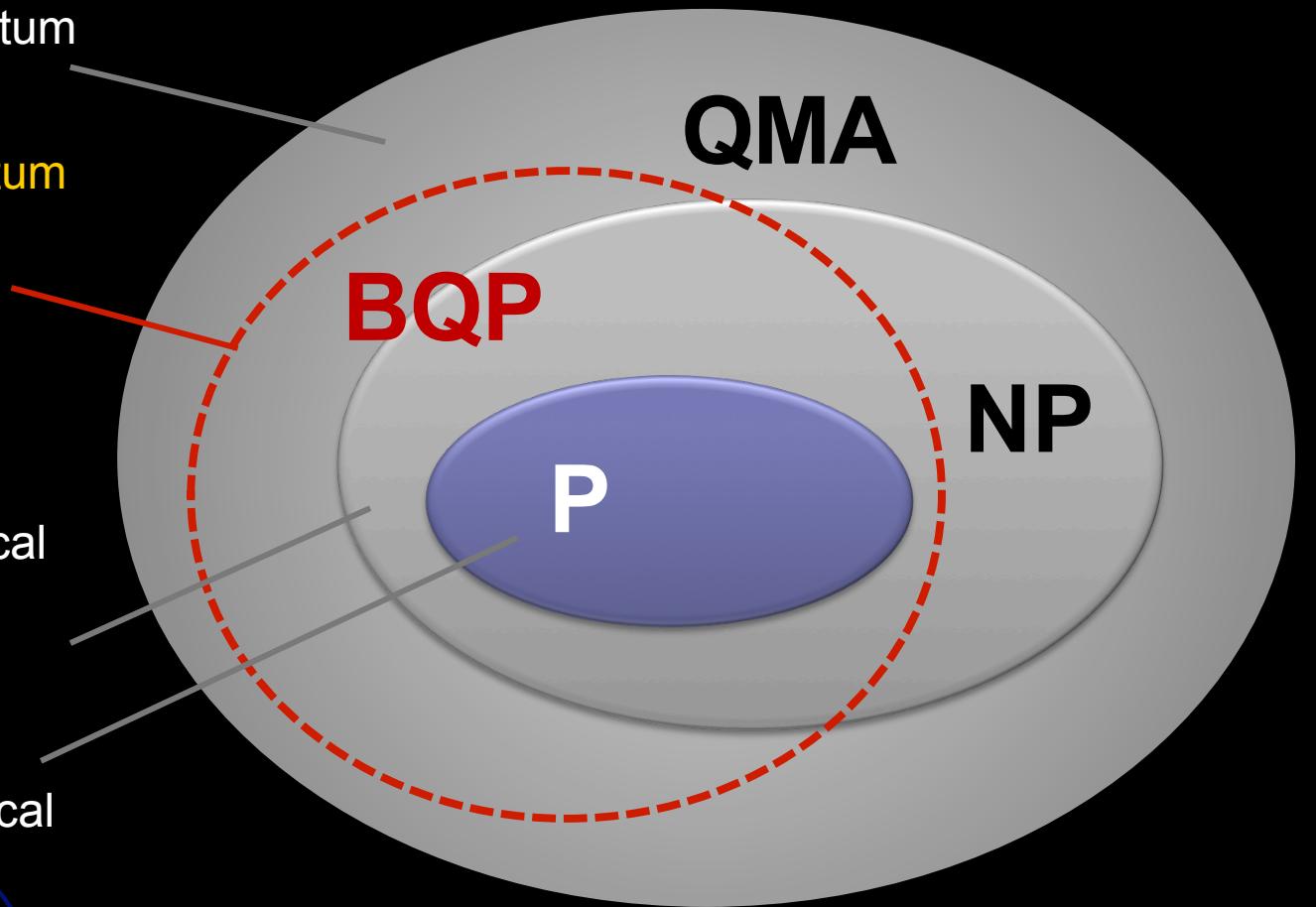
## Mathematical problems:

verifiable with Quantum computer

solvable\* with Quantum computer:

verifiable with classical computer

solvable\* with classical computer



\* with polynomial effort

# Deutsch-Josza algorithm



valid



front

back

invalid



front

back

## Deutsch-Josza algorithm

$$f : \{0, 1\} \longrightarrow \{0, 1\}$$

front      back      head      tail

$$\begin{array}{ll} f(0) = 0 & f(0) = 1 \\ f(1) = 0 & f(1) = 1 \end{array}$$

constant (invalid)

$$\begin{array}{ll} f(0) = 0 & f(0) = 1 \\ f(1) = 1 & f(1) = 0 \end{array}$$

balanced (valid)

To find out if  $f$  constant or balanced  
two inquiries neded!

## Deutsch-Josza algorithm

$$|0\rangle|1\rangle \longrightarrow (|0\rangle + |1\rangle)(|0\rangle - |1\rangle)$$

$f$  encoded in unitary transformation

$$U_f : |x\rangle|y\rangle \longrightarrow |x\rangle|y \oplus f(x)\rangle$$

$$U_f|x\rangle(|0\rangle + |1\rangle) = \begin{cases} |x\rangle(|0\rangle + |1\rangle) & \text{constant} \\ -|x\rangle(|0\rangle - |1\rangle) & \text{balanced} \end{cases}$$

A single inquiry sufficient!

# Topics for talks

## Basics & fundamental experiments

- Bell inequalities: *quantum correlations are stronger than classical one's*
- Quantum teleportation: *how to transport an unknown quantum state from A to B*
- Quantum cryptography: *how to use peculiarities of quantum mechanics to create secure keys?*

# Topics for talks

## Quantum computing principles

- Network quantum computer: *quantum bits and gates (M. Fleischhauer)*
- Measurement-based quantum computation: *how to replace gate operations by measurements on massively entangled states*

# Topics for talks

## Physical platforms for quantum computing

- Ion-trap quantum computers
- Neutral atoms in strongly coupling cavities
- Rydberg atoms & Rydberg polaritons
- Superconducting qubits
- Topological qubits (external lecture)

# Topics for talks

## Physical platforms for quantum networks

- Photon exchange between strongly coupled cavities
- Quantum memories for light based on atomic ensemble
- Duan-Lukin-Cirac-Zoller quantum repeater

