





U.S. DEPARTMENT OF  
**ENERGY**

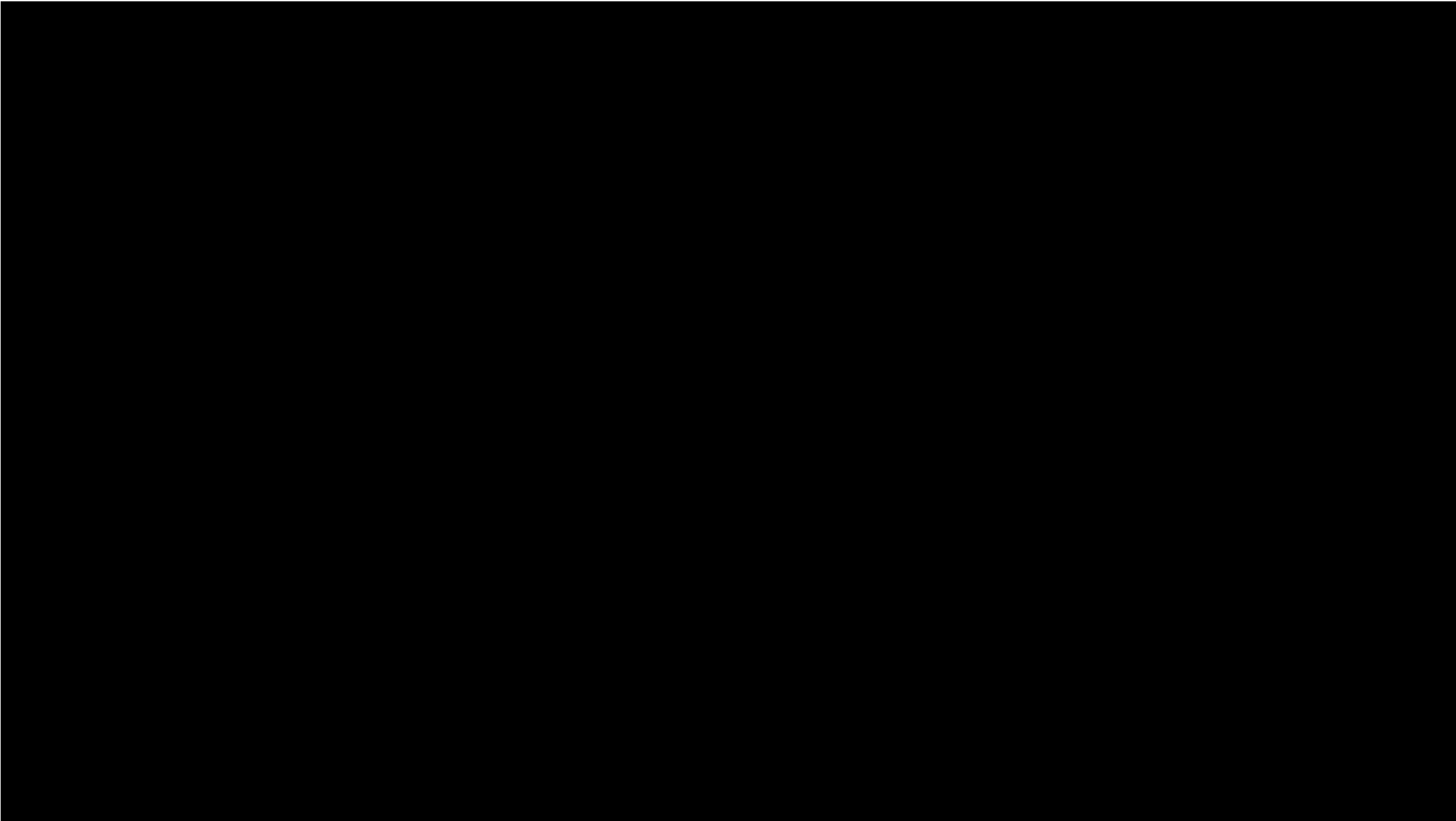
Office of  
Science

# **World Quantum Day: QIS at the Office of Science's User Facilities and Infrastructure Capabilities**

---

Speakers:

Dr. Suji Park, Dr. Zhi-Xun Shen, Dr. Pranav Gokhale,  
and Dr. Kathleen Hamilton



# Dr. Pranav Gokhale

## Inflection



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

# Dr. Kathleen Hamilton

## Oak Ridge National Laboratory



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

# Dr. Suji Park

## Brookhaven National Laboratory



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

# “Graphene exfoliation with Scotch tape”



2010 Nobel Prize in Physics



Andre Geim

Konstantin Novoselov



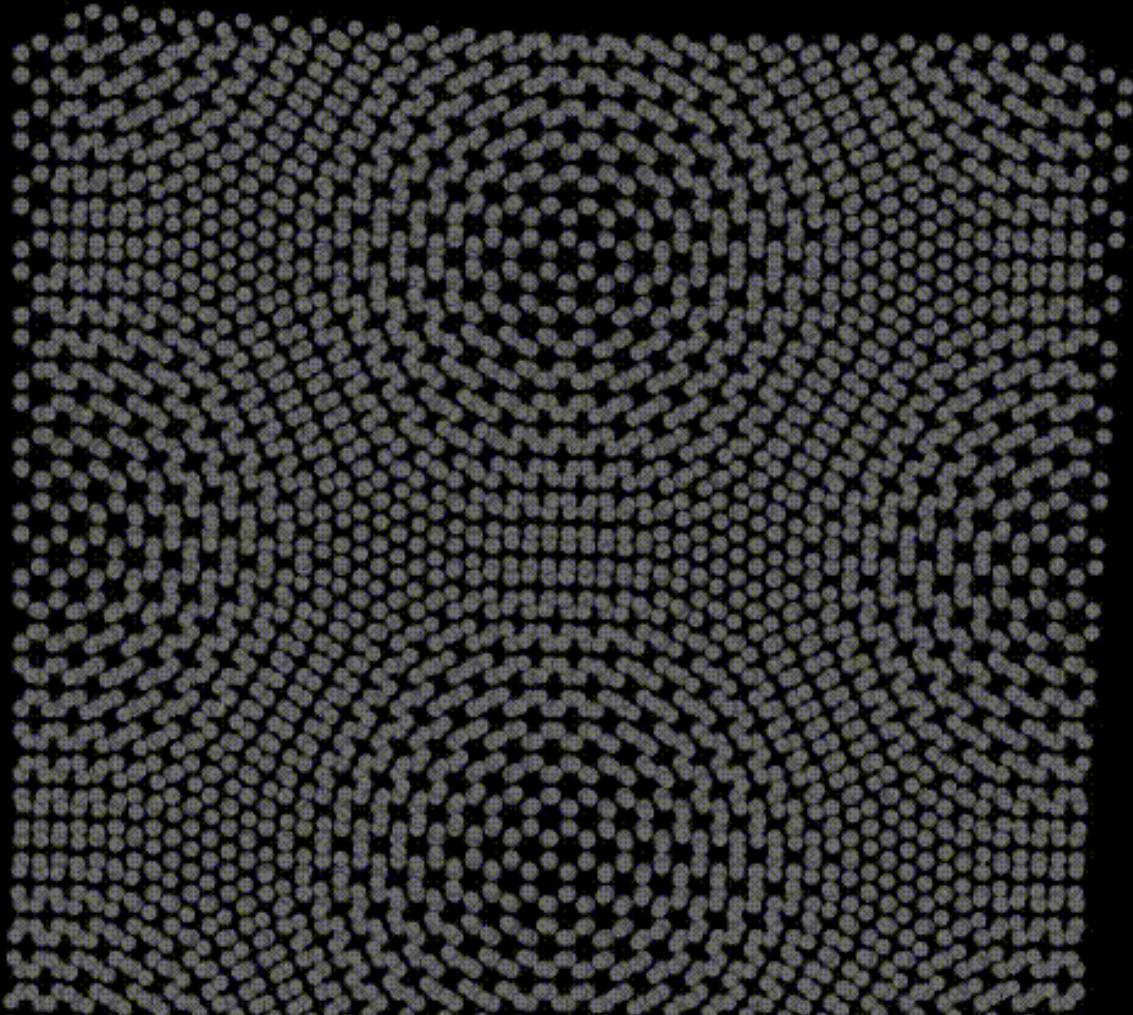
U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

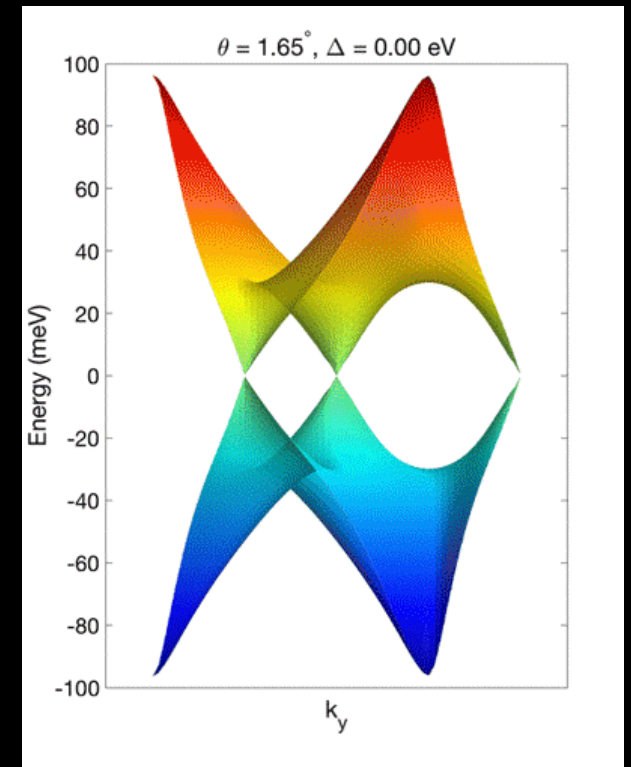


Brookhaven  
National Laboratory

# TWISTRONICS: TUNE material properties.



*“Magic angle”*



Y Cao et al, Nature (2018)

[https://upload.wikimedia.org/wikipedia/commons/d/d5/Graphene\\_Moire\\_3.gif](https://upload.wikimedia.org/wikipedia/commons/d/d5/Graphene_Moire_3.gif)

<https://als.lbl.gov/wp-content/uploads/2020/09/428utama2.gif>



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

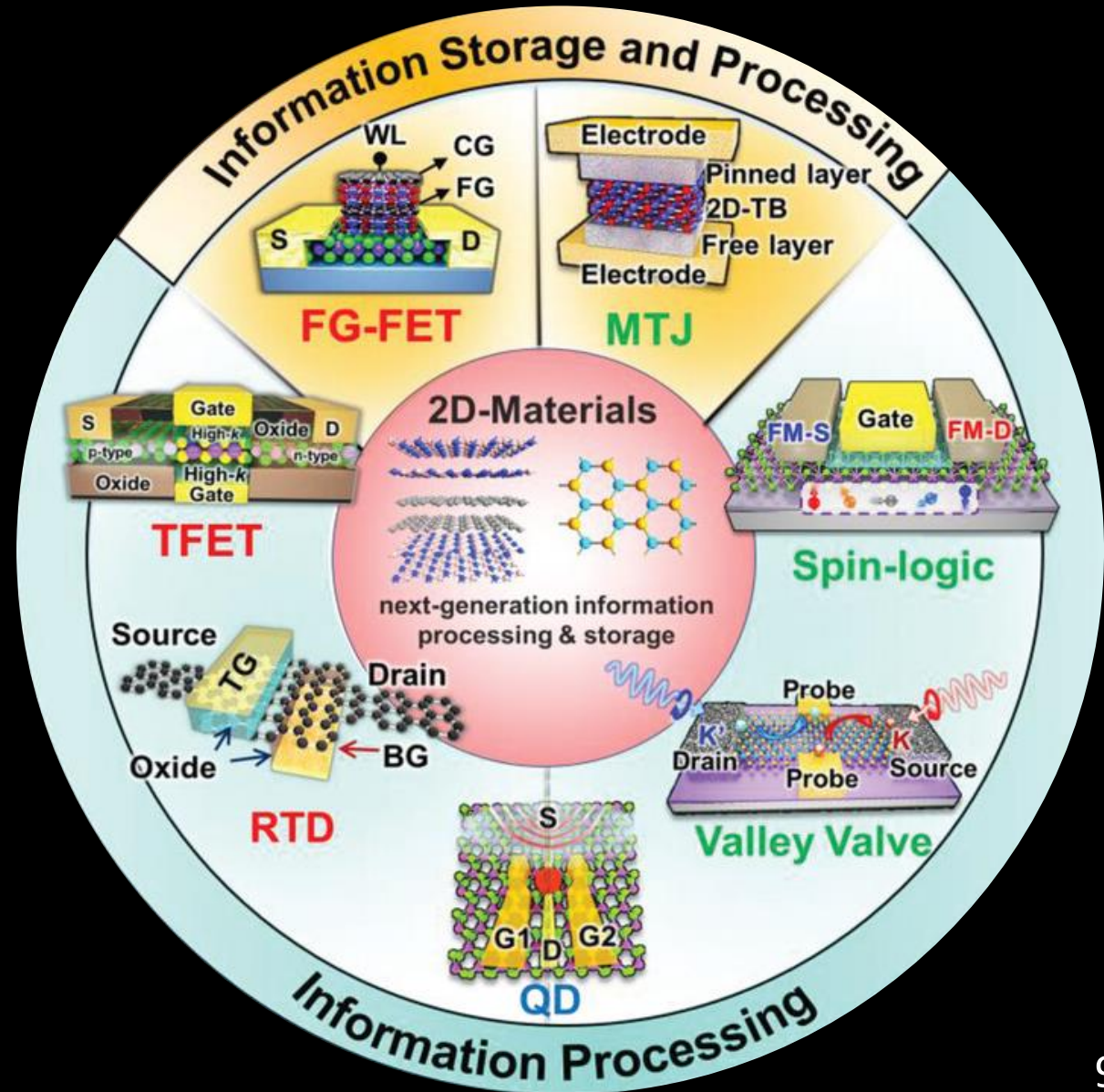
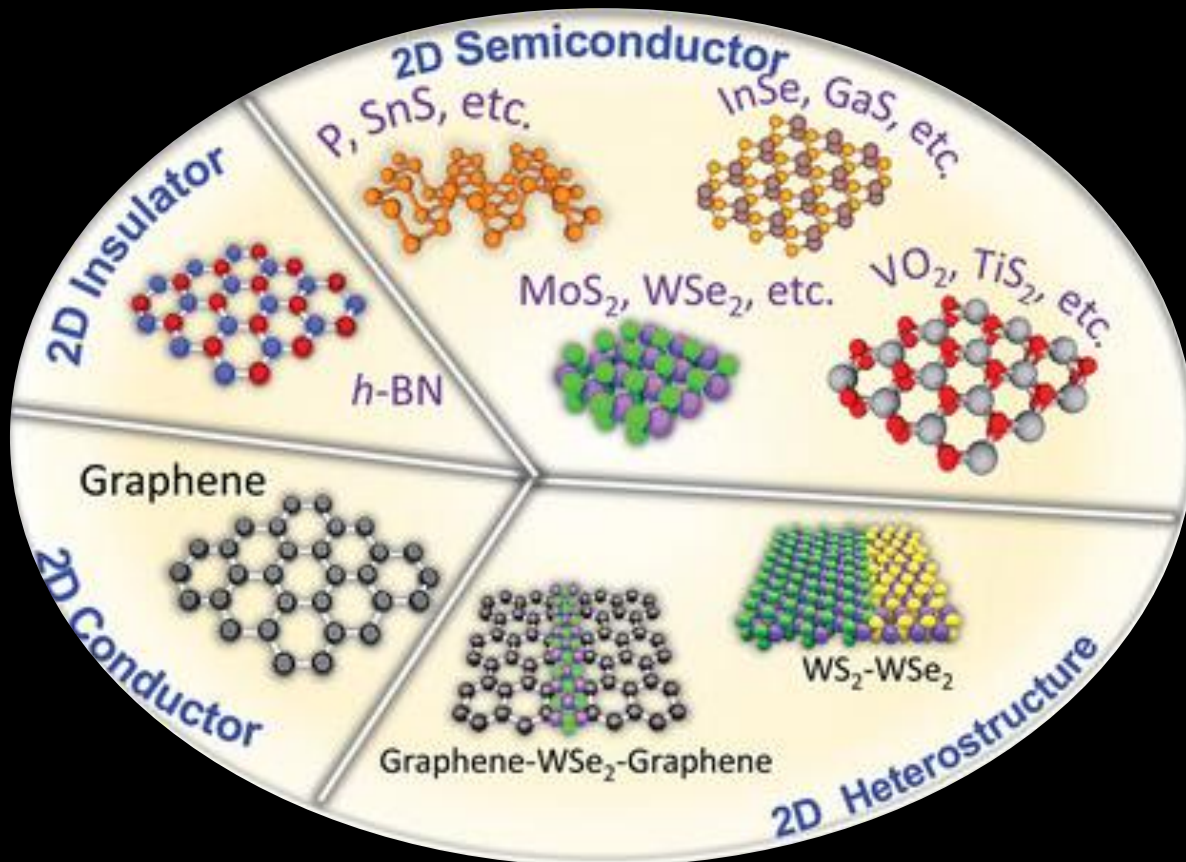


Brookhaven  
National Laboratory

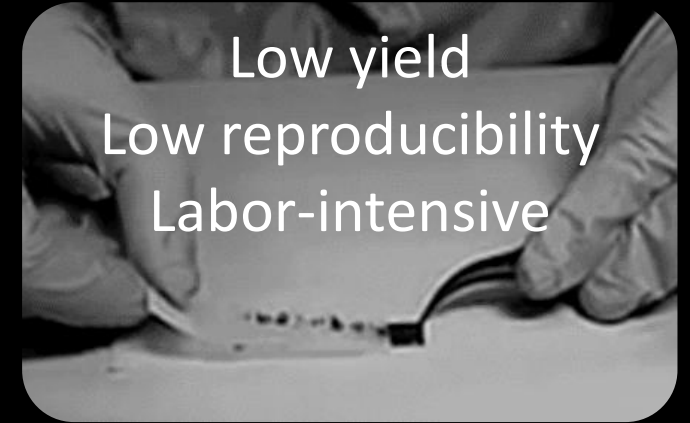


# STACK next-generation of QIS materials.

from *transistors* to *qubits*!  
Broad range of applications



# QPress: robotic fabrication **beyond handcraft**



Low yield  
Low reproducibility  
Labor-intensive



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science



Brookhaven  
National Laboratory

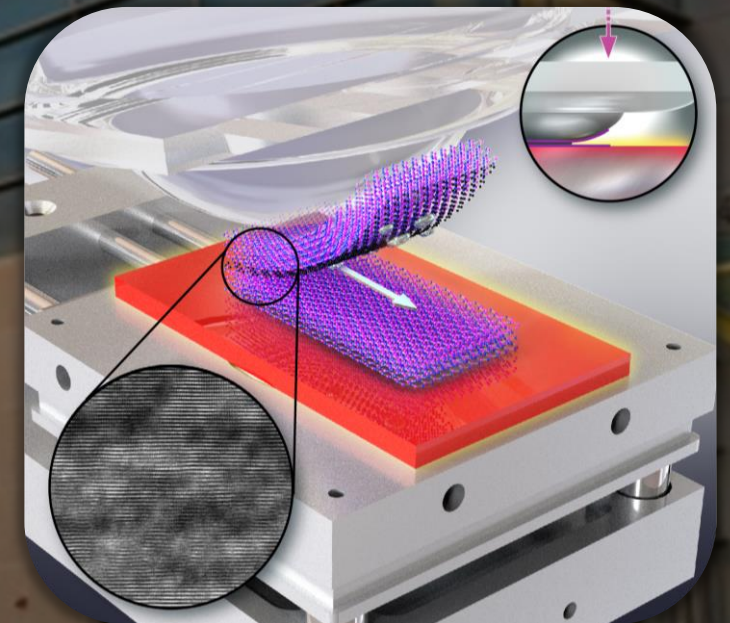
# Bring your ideas!

<https://www.bnl.gov/qpress/>

## Science commissioning started from FY22

- Supported **+30** users  
(**17** groups from **11** institutions)
- Tested with **+10** materials  
(including Graphene, hBN, TMDs, etc.)
- Demonstrated quality & efficiency

Z. Huang *et al.*, *Small* 2022, 2201248



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science



Brookhaven  
National Laboratory

# Dr. Zhi-Xun Shen

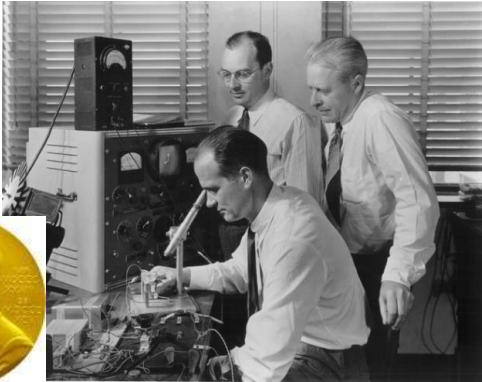
## Stanford University



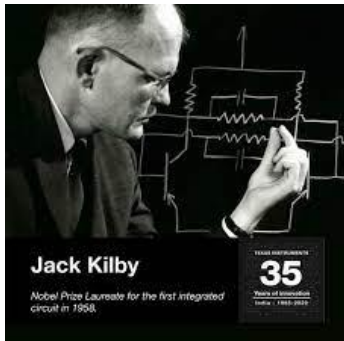
U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

# Scientific foundation for next generation quantum materials



Invention of transistor (1957 Nobel Prize)



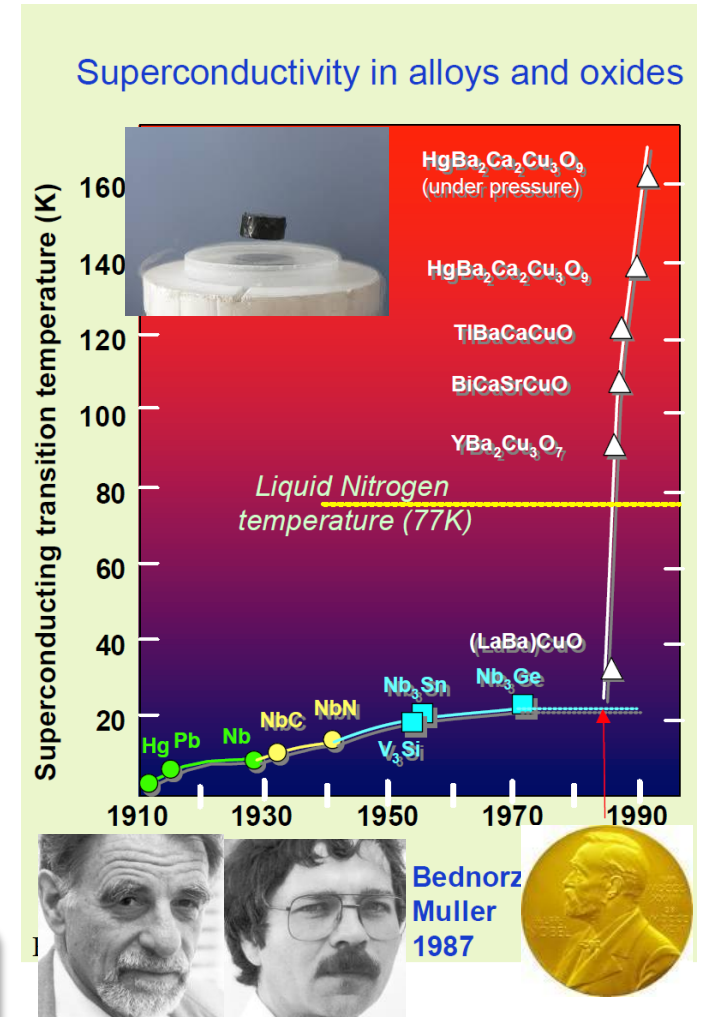
Invention of Integrated circuit (2000 Nobel Prize)

First generation quantum theory played a vital role in the development of “1<sup>st</sup> generation of quantum technologies” like semiconductors.

Adequate quantum theory is yet to be developed for other classes of quantum materials, for example cuprate high temperature superconductors.

Precision measurement of key quantum parameters is imperative to the development of “next generation quantum theory” – in the search for the next “magic material”

DOE facilities enable precision measurements not possible any other way

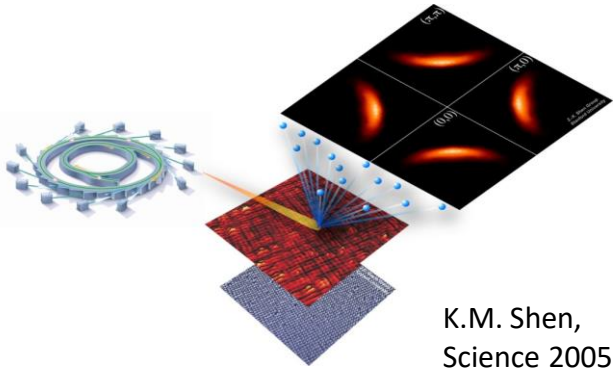


# Probing important quantum numbers of electrons

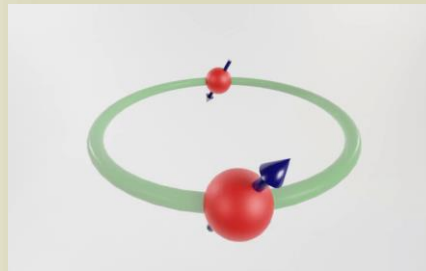
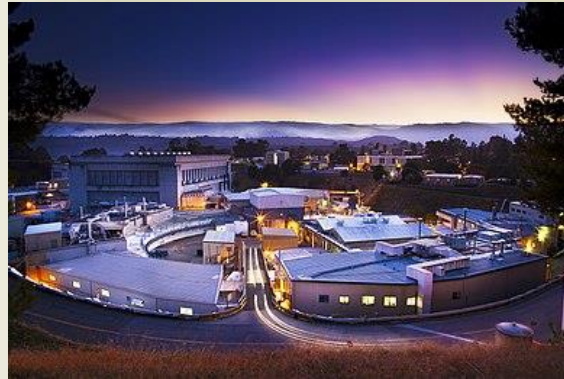
## Angle-resolved photoemission spectroscopy (ARPES)



Synchrotron based photoemission records energy and momentum of electrons

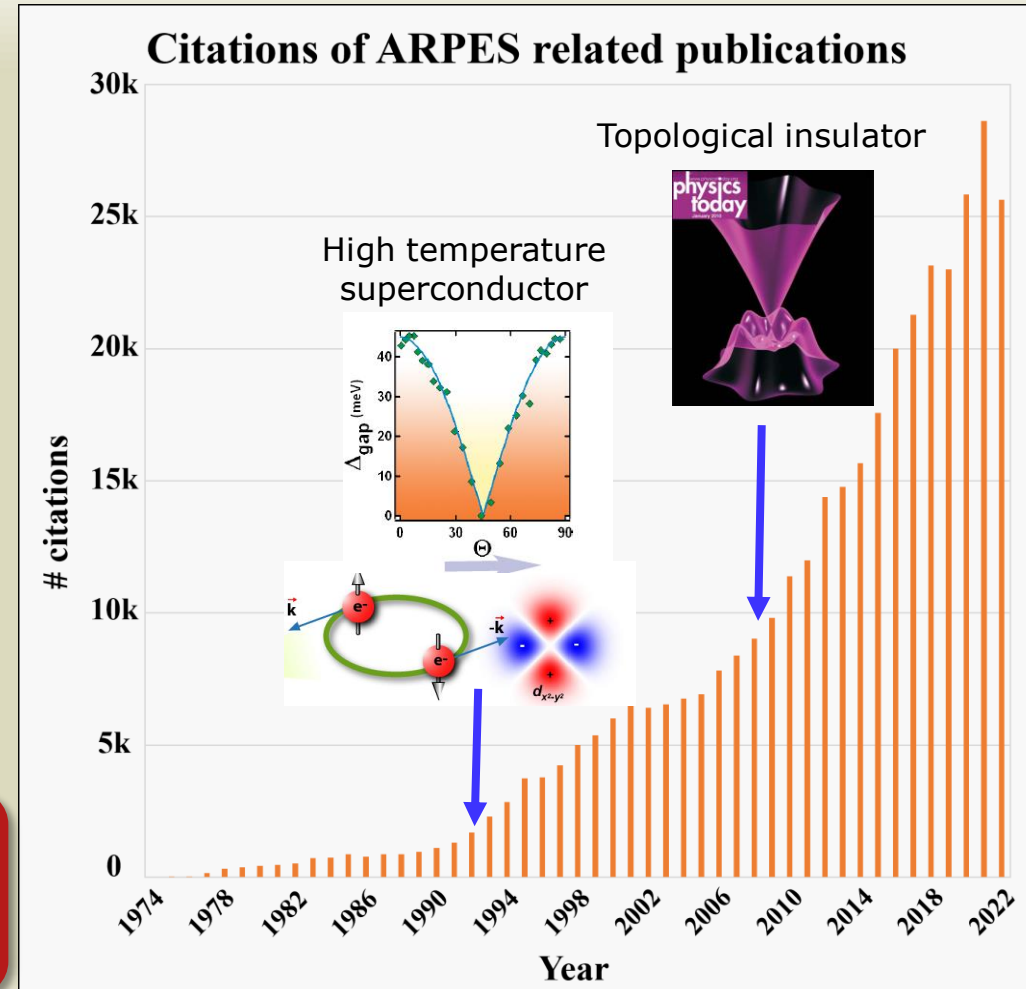


K.M. Shen, Science 2005



Dessau et al., Phys. Rev. Lett. **66**, 2160 (1991)  
 Z.X. Shen, et al, Phys. Rev. Lett. **70**, 1553 (1993)  
 B.O. Wells et al., Phys. Rev. Lett **74**, 964 (1995)  
 Z.X. Shen et al., Science **267**, 343 (1995)  
 A.G. Loeser et al., Science, **273**, 325 (1996)  
 A. Lanzara et al., Nature, **412**, 510 (2001)  
 N.P. Armitage et al., Phys. Rev. Lett. **87**, 147003 (2001)  
 K. Tanaka et al. Science, **314**, 1910 (2006)  
 D. Hsieh et al., Nature **452**, 970 (2008)  
 Y. L. Chen et al., Science **325**, 178 (2009)  
 Y. He et al., Science, **362**, (2018)  
 S.D. Chen et al., Science, **366**, 6469 (2019)  
 Z.Y. Chen et al., Science, **373**, 1235 (2021)  
 S.D. Chen et al., Nature, **601**, 562 (2022)

A quantitative tool to address key questions in materials where reliable quantum theory has yet to be developed



**SSRL**

**SIMES**

**SLAC**



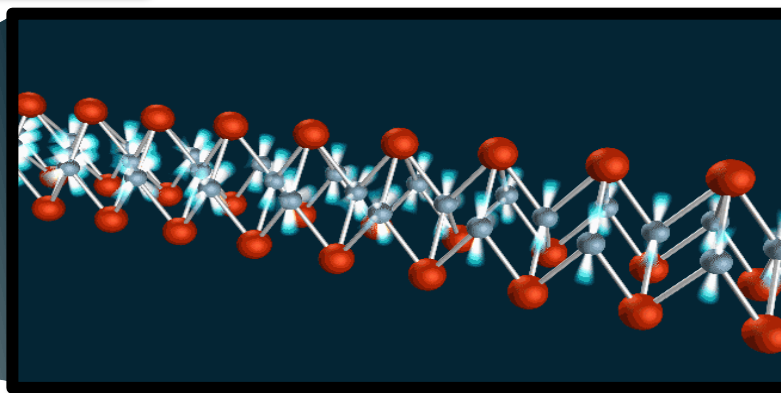
# Understanding and controlling matter

## How do electrons and atoms behave on their natural length and time scales?

Ultra-bright & ultra-fast x-ray laser for recording movies of electrons and atoms in motion

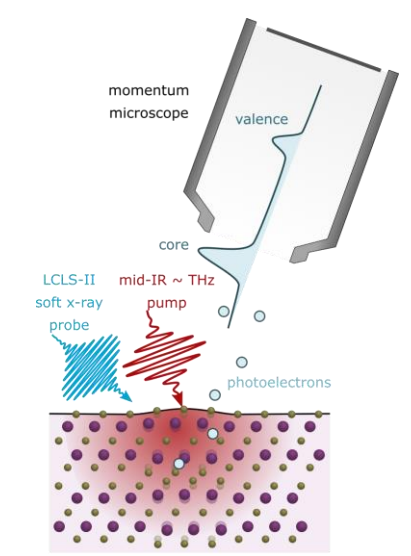
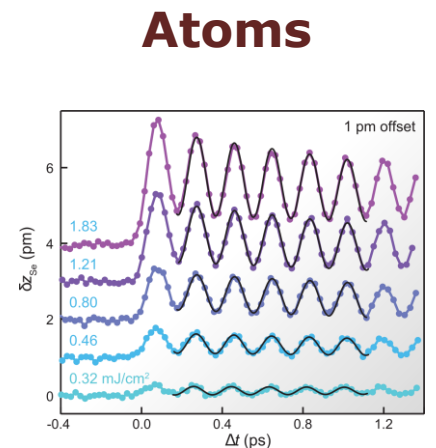
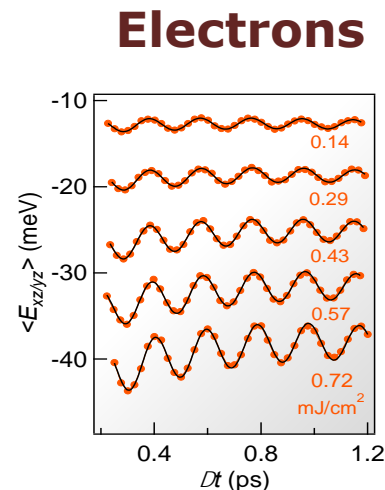
→  $10^{-12-13}$  m      →  $10^{-13-15}$  sec

Linac Coherent Light Source (LCLS)  
SLAC National Accelerator Lab



Harmonious cooperation of electrons and atoms enhances properties in a little-understood superconductor FeSe

J.A. Sobota, et al., Phys. Rev. Lett., **108**, 117403 (2012)  
 S.L. Yang et al, Phys. Rev. Lett. **122**, 176403 (2016)  
 S. Gerber, et al, Science **357**, 71 (2017)  
 J.A. Sobota et al., Rev. Mod. Phys. **93**, 025006 (2021)  
 S. Sakamoto et al, Phys. Rev. B. **105**, L161107 (2022)  
 J.A. Sobota et al, Phys. Rev. B. **107**, 014305 (2023)

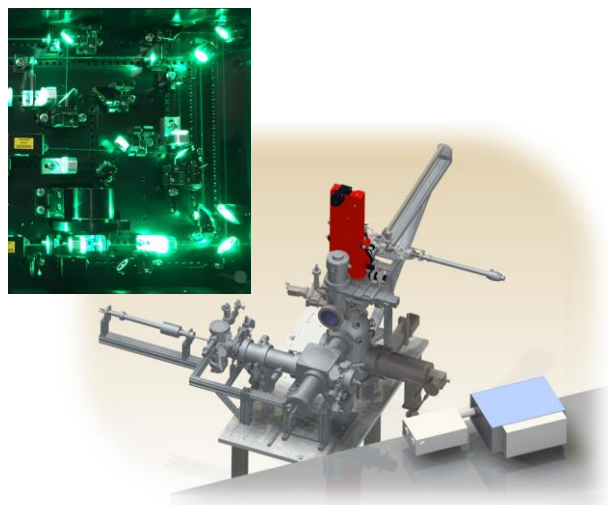
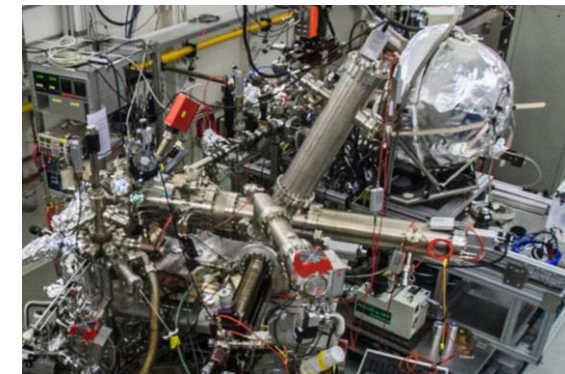
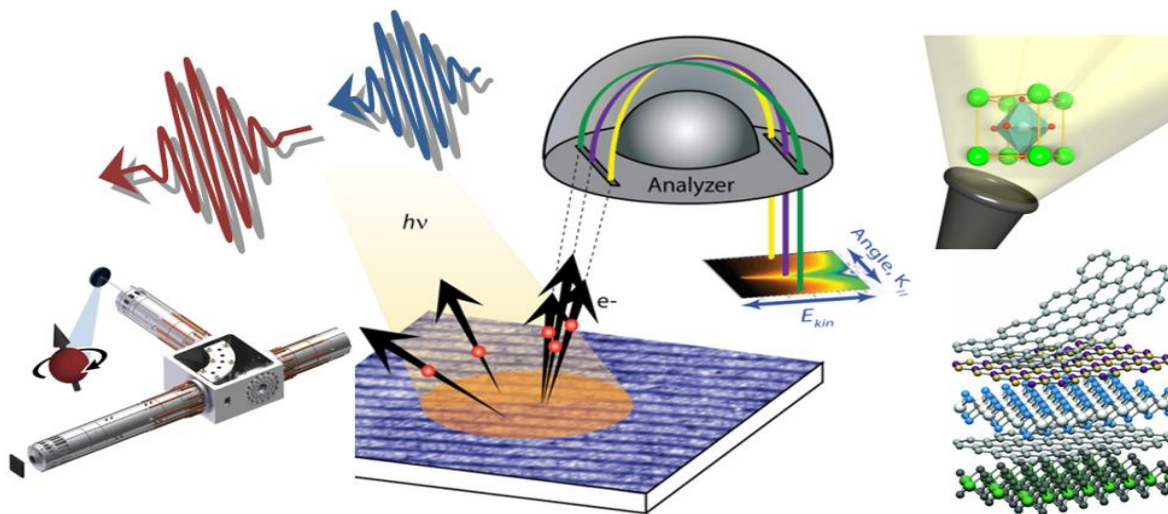


New Initiative: International Consortium led by SLAC and DESY

# The Future is Bright

## Synergetic activities using advanced instrumentation, synthesis/control and simulation

Towards complete experiments to advance quantum materials – energy, momentum, spin, time, space ...



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

**SIMES** **LCLS**



**SLAC**

