Title: A Sport and a Pastime: Model design and computation for quantum criticality, gauge fields and matter

Speakers: Zi Yang Meng

Collection: Quantum Criticality: Gauge Fields and Matter

Date: May 18, 2022 - 9:00 AM

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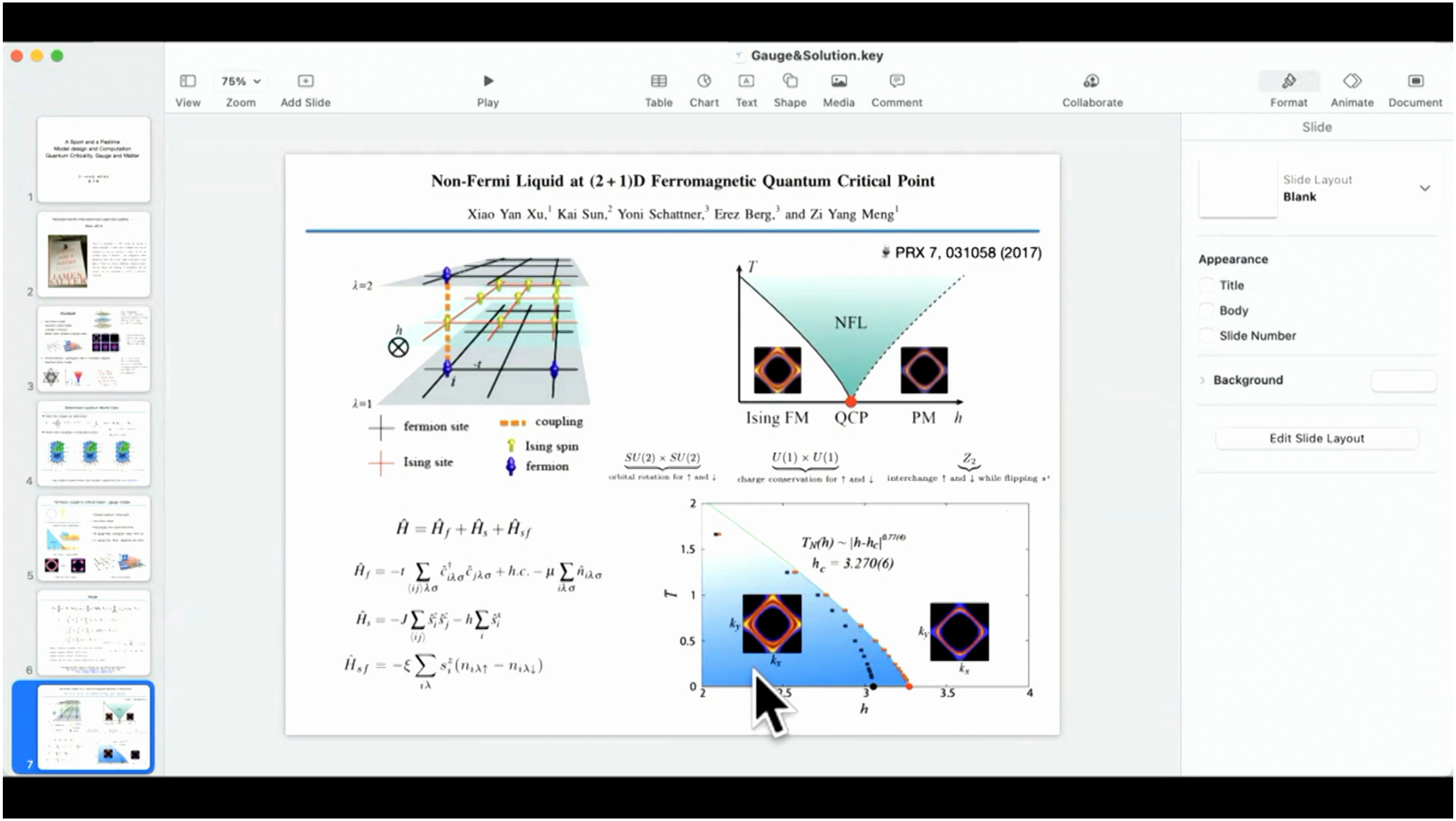
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Non-Fermi Liquid at (2+1)D Ferromagnetic Quantum Critical Point
Xiao Yan Xu,1 Kai Sun,2 Yoni Schattner,3 Erez Berg,3 and Zi Yang Meng1
PRX 7, 031058 (2017)
λ=2
λ=1
fermion site
Ising site
coupling
Ising spin
fermion
T
NFL
Ising FM
QCP
PM
h
SU(2) × SU(2)
orbital rotation for ↑ and ↓
U(1) × U(1)
charge conservation for ↑ and ↓
Z2
interchange ↑ and ↓ while flipping s^z
$\hat{H} = \hat{H}_f + \hat{H}_s + \hat{H}_{sf}$
$\hat{H}_f = -t \sum_{\langle ij \rangle \lambda\sigma} \hat{c}^\dagger_{i\lambda\sigma} \hat{c}_{j\lambda\sigma} + h.c. - \mu \sum_{i\lambda\sigma} \hat{n}_{i\lambda\sigma}$
$\hat{H}_s = -J \sum_{\langle ij \rangle} \hat{s}^z_i \hat{s}^z_j - h \sum_i \hat{s}^x_i$
$\hat{H}_{sf} = -\xi \sum_{i\lambda} s^z_i (n_{i\lambda\uparrow} - n_{i\lambda\downarrow})$
$T_N(h) \sim |h-h_c|^{0.77(4)}$
$h_c = 3.270(6)$
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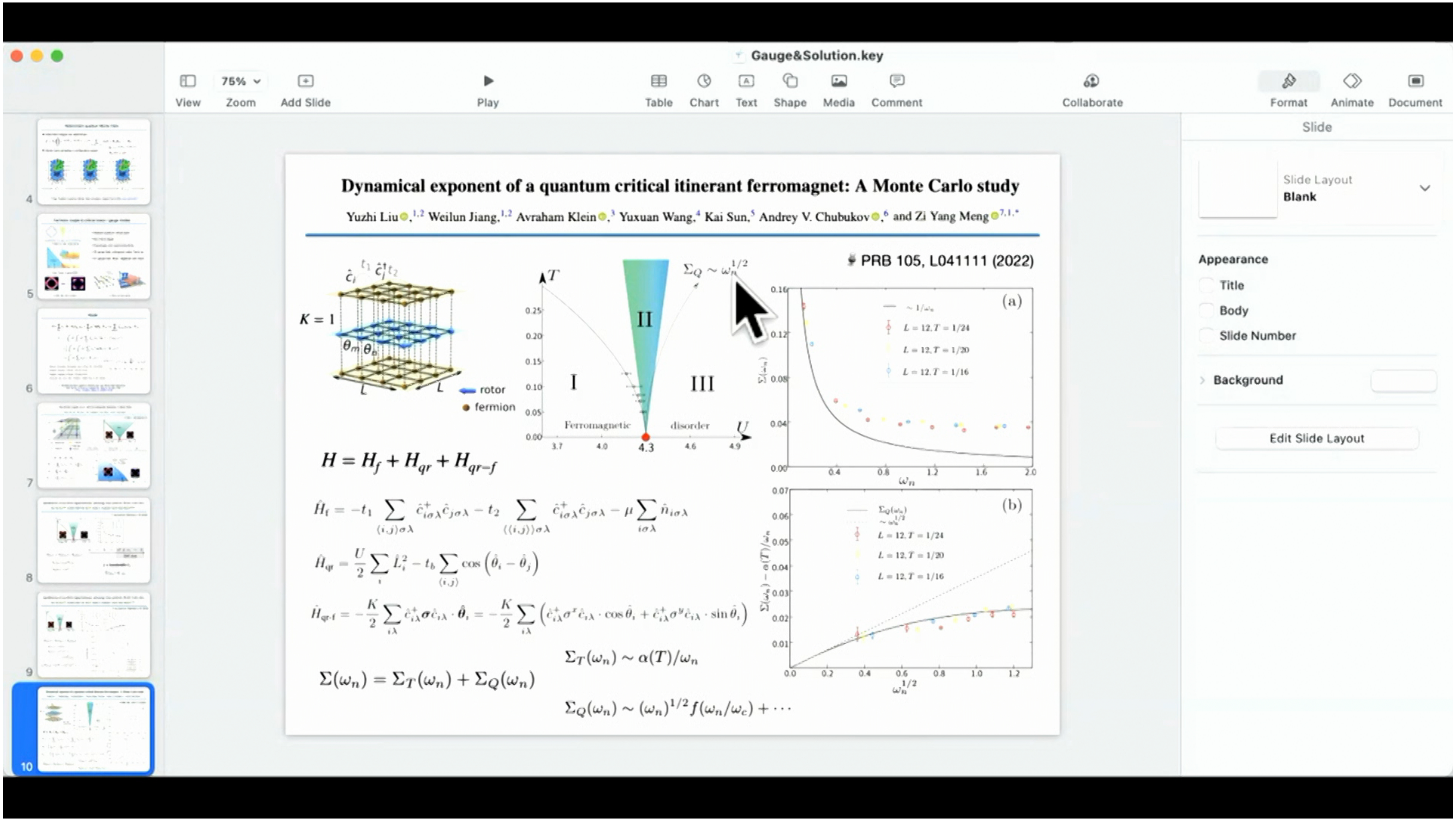
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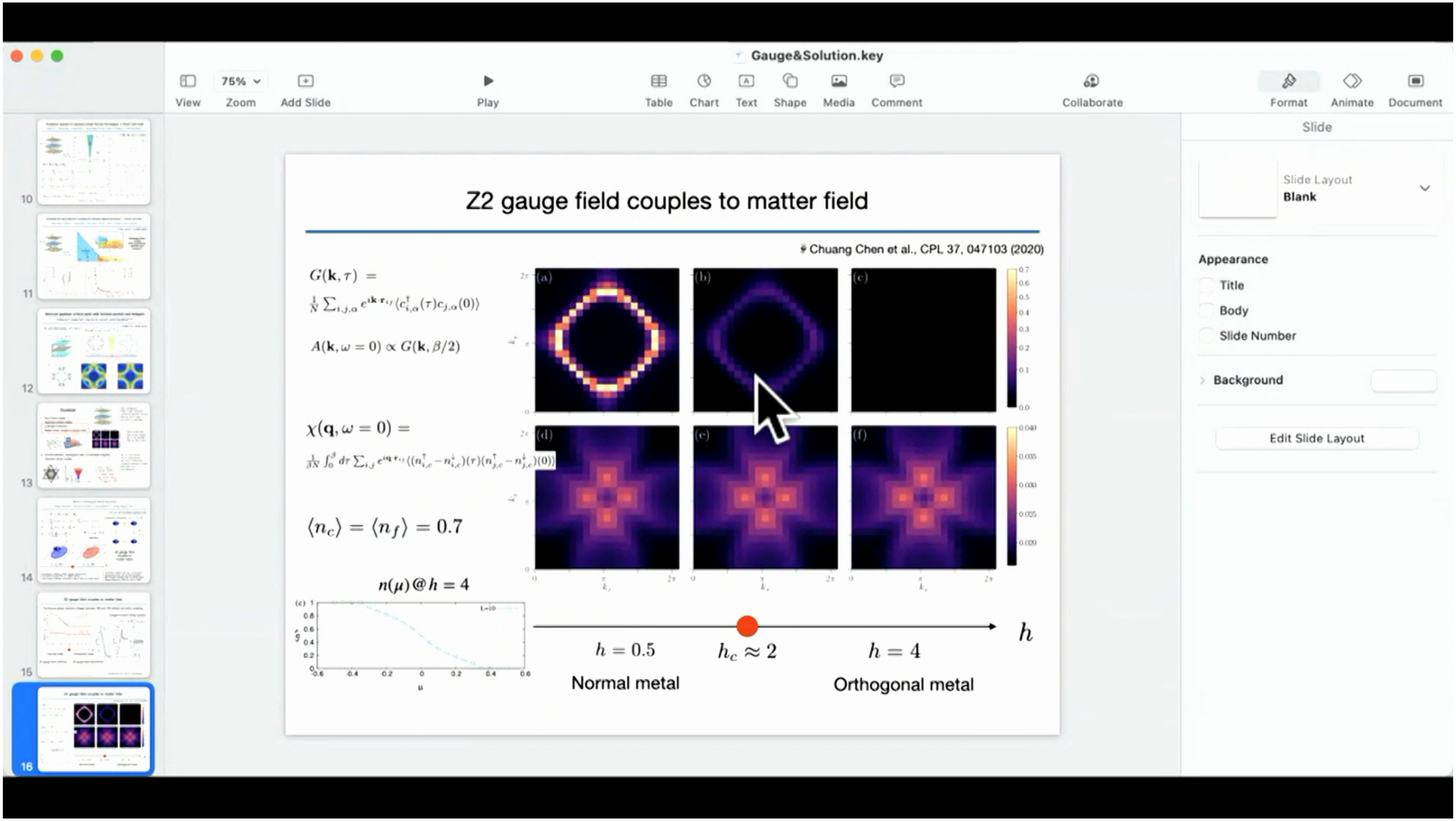
Dynamical exponent of a quantum critical itinerant ferromagnet: A Monte Carlo study
Yuzhi Liu, Weilun Jiang, Avraham Klein, Yuxuan Wang, Kai Sun, Andrey V. Chubukov, and Zi Yang Meng
PRB 105, L041111 (2022)
K = 1
rotor
fermion
Ferromagnetic
disorder
I
II
III
$\Sigma_Q \sim \omega_n^{1/2}$
$H = H_f + H_{qr} + H_{qr-f}$
$\hat{H}_f = -t_1 \sum_{\langle i,j \rangle \sigma\lambda} \hat{c}^+_{i\sigma\lambda}\hat{c}_{j\sigma\lambda} - t_2 \sum_{\langle\langle i,j \rangle\rangle \sigma\lambda} \hat{c}^+_{i\sigma\lambda}\hat{c}_{j\sigma\lambda} - \mu \sum_{i\sigma\lambda} \hat{n}_{i\sigma\lambda}$
$\hat{H}_{qr} = \frac{U}{2} \sum_i \hat{L}_i^2 - t_b \sum_{\langle i,j \rangle} \cos(\hat{\theta}_i - \hat{\theta}_j)$
$\hat{H}_{qr\text{-}f} = -\frac{K}{2} \sum_{i\lambda} \hat{c}^+_{i\lambda} \boldsymbol{\sigma} \hat{c}_{i\lambda} \cdot \hat{\boldsymbol{\theta}}_i = -\frac{K}{2} \sum_{i\lambda} \left(\hat{c}^+_{i\lambda}\sigma^x\hat{c}_{i\lambda} \cdot \cos\hat{\theta}_i + \hat{c}^+_{i\lambda}\sigma^y\hat{c}_{i\lambda} \cdot \sin\hat{\theta}_i \right)$
$\Sigma(\omega_n) = \Sigma_T(\omega_n) + \Sigma_Q(\omega_n)$
$\Sigma_T(\omega_n) \sim \alpha(T)/\omega_n$
$\Sigma_Q(\omega_n) \sim (\omega_n)^{1/2} f(\omega_n/\omega_c) + \cdots$
(a)
$\sim 1/\omega_n$
$L = 12, T = 1/24$
$L = 12, T = 1/20$
$L = 12, T = 1/16$
(b)
$\Sigma_Q(\omega_n)$
$\sim \omega_n^{1/2}$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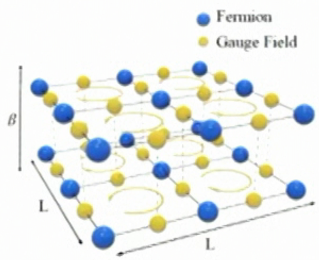
Z2 gauge field couples to matter field
Chuang Chen et al., CPL 37, 047103 (2020)
$G(\mathbf{k},\tau) = \frac{1}{N}\sum_{i,j,\alpha} e^{i\mathbf{k}\cdot\mathbf{r}_{ij}} \langle c^\dagger_{i,\alpha}(\tau) c_{j,\alpha}(0)\rangle$
$A(\mathbf{k},\omega=0) \propto G(\mathbf{k},\beta/2)$
$\chi(\mathbf{q},\omega=0) = \frac{1}{\beta N}\int_0^\beta d\tau \sum_{i,j} e^{i\mathbf{q}\cdot\mathbf{r}_{ij}} \langle (n^\uparrow_{i,c} - n^\downarrow_{i,c})(\tau)(n^\uparrow_{j,c} - n^\downarrow_{j,c})(0)\rangle$
$\langle n_c \rangle = \langle n_f \rangle = 0.7$
$n(\mu) @ h = 4$
$h = 0.5$
$h_c \approx 2$
$h = 4$
h
Normal metal
Orthogonal metal

Monte Carlo Study of Lattice Compact Quantum Electrodynamics with Fermionic Matter: The Parent State of Quantum Phases

Xiao Yan Xu,[1,*] Yang Qi,[2-4,†] Long Zhang,[5] Fakher F. Assaad,[6] Cenke Xu,[7] and Zi Yang Meng[8,9,10,11,‡]

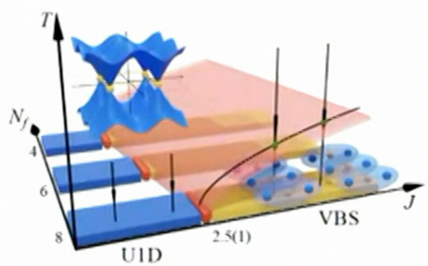
PRX 9, 021022 (2019)



$$Z = \int D(\phi,\bar{\psi},\psi)e^{-(S_\phi+S_F)} \quad S = S_F + S_\phi = \int_0^\beta d\tau (L_F + L_\phi)$$

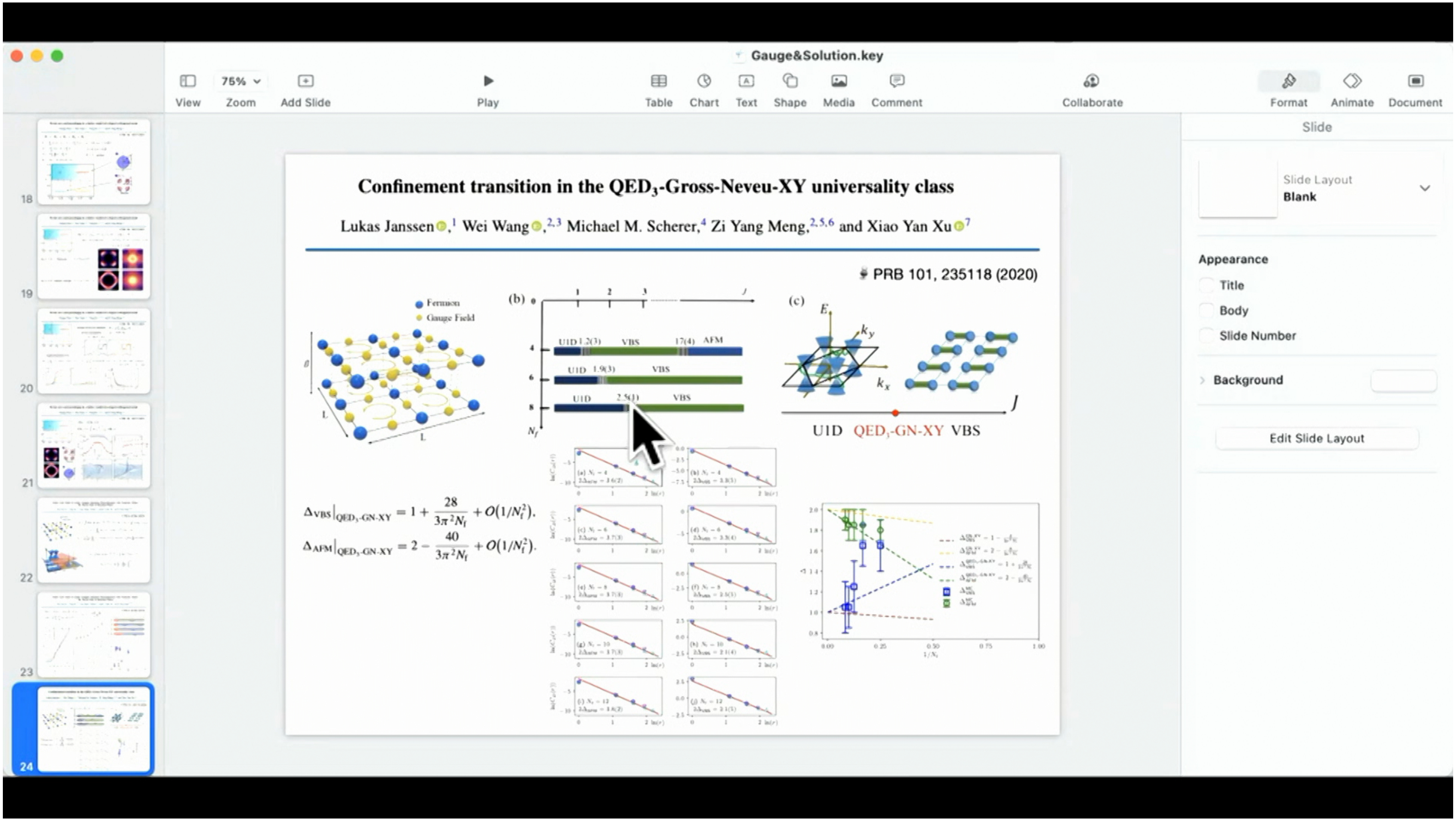
$$L_F = \sum_{\langle i,j\rangle\alpha} \psi^\dagger_{i\alpha}\left[(\partial_\tau-\mu)\delta_{ij} - t e^{i\phi_{ij}}\right]\psi_{j\alpha} + \text{h.c.},$$

$$L_\phi = \frac{4}{JN_f\Delta\tau^2}\sum_{\langle i,j\rangle}\left(1-\cos(\phi_{ij}(\tau+1)-\phi_{ij}(\tau))\right) + \frac{1}{2}KN_f\sum_{\Box}\cos(\mathrm{curl}\phi)$$



$$Z = \int D(\phi,\bar{\psi},\psi)e^{-(S_\phi+S_F)} = \int D\phi\, e^{-S_\phi}\mathrm{Tr}_\psi\left[e^{-S_F}\right]$$

$$\mathrm{Tr}_\psi\left[e^{-S_F}\right] = \left[\det\left(I + \prod_{\tau=1}^{L_\tau} B_\tau\right)\right]$$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Confinement transition in the QED$_3$-Gross-Neveu-XY universality class
Lukas Janssen,[1] Wei Wang,[2,3] Michael M. Scherer,[4] Zi Yang Meng,[2,5,6] and Xiao Yan Xu[7]
PRB 101, 235118 (2020)
Fermion
Gauge Field
(b)
U1D 1.2(3) VBS 1.7(4) AFM
U1D 1.9(3) VBS
U1D 2.5(1) VBS
(c)
U1D QED$_3$-GN-XY VBS
$$\Delta_{\mathrm{VBS}}\big|_{\mathrm{QED_3\text{-}GN\text{-}XY}} = 1 + \frac{28}{3\pi^2 N_f} + O(1/N_f^2),$$
$$\Delta_{\mathrm{AFM}}\big|_{\mathrm{QED_3\text{-}GN\text{-}XY}} = 2 - \frac{40}{3\pi^2 N_f} + O(1/N_f^2).$$
18
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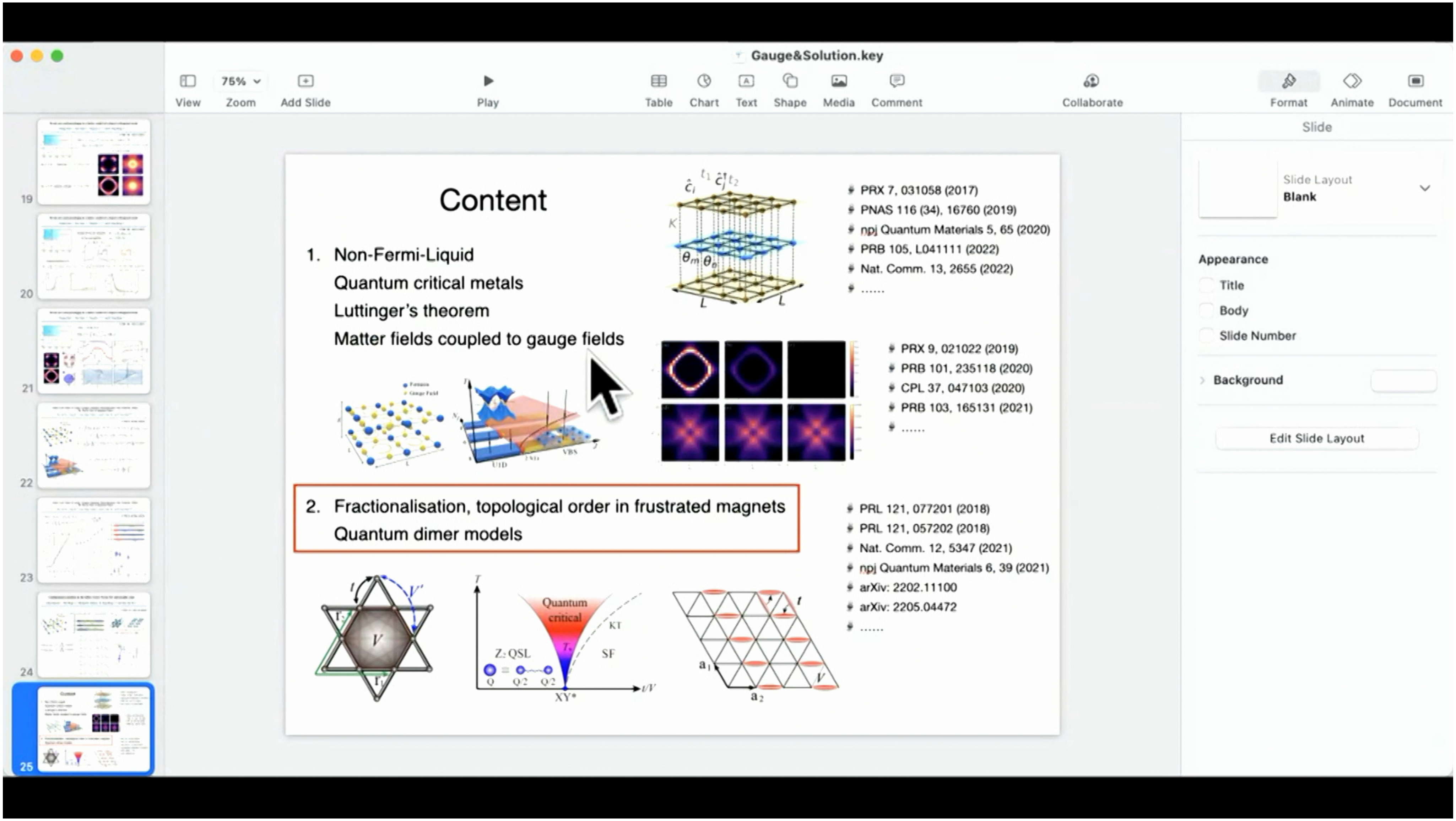
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Content
1. Non-Fermi-Liquid
Quantum critical metals
Luttinger's theorem
Matter fields coupled to gauge fields
PRX 7, 031058 (2017)
PNAS 116 (34), 16760 (2019)
npj Quantum Materials 5, 65 (2020)
PRB 105, L041111 (2022)
Nat. Comm. 13, 2655 (2022)
......
PRX 9, 021022 (2019)
PRB 101, 235118 (2020)
CPL 37, 047103 (2020)
PRB 103, 165131 (2021)
......
2. Fractionalisation, topological order in frustrated magnets
Quantum dimer models
PRL 121, 077201 (2018)
PRL 121, 057202 (2018)
Nat. Comm. 12, 5347 (2021)
npj Quantum Materials 6, 39 (2021)
arXiv: 2202.11100
arXiv: 2205.04472
......
Quantum critical
Z$_2$ QSL
KT
SF
XY*

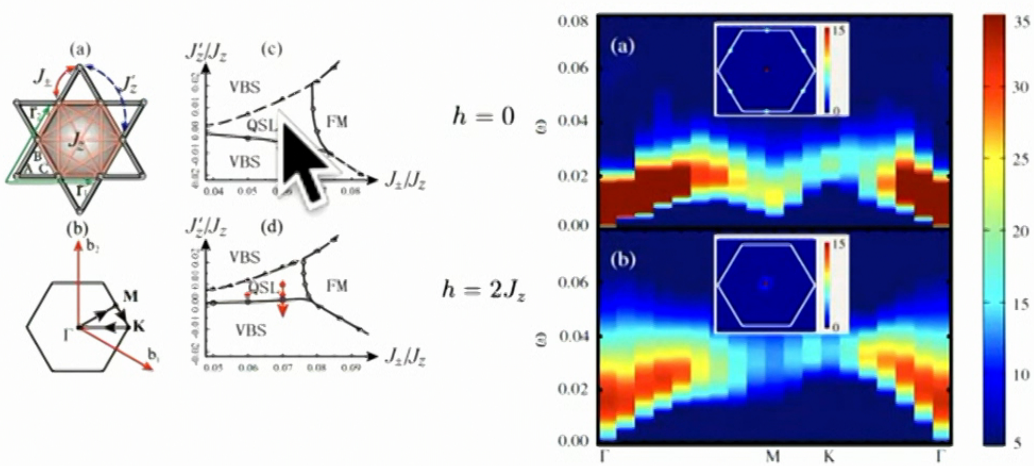
Dynamical Signature of Symmetry Fractionalization in Frustrated Magnets

Guang-Yu Sun,[1,2] Yan-Cheng Wang,[3] Chen Fang,[1,4] Yang Qi,[5,6,7] Meng Cheng,[8] and Zi Yang Meng[1,4]

PRL 121, 077201 (2018)
PRL 121, 057202 (2018)

$$H = -J_{\pm}\sum_{\langle i,j\rangle}(S_i^+S_j^- + \mathrm{h.c.}) + \frac{J_z}{2}\sum_{\bigcirc}\Big(\sum_{i\in\bigcirc} S_i^z\Big)^2 + J_z'\sum_{\langle i,j\rangle'} S_i^z S_j^z - h\sum_i S_i^z$$

$$H = -t\sum_{\langle i,j\rangle}(b_i^\dagger b_j + \mathrm{h.c.}) + V\sum_{\bigcirc}\Big(\sum_{i\in\bigcirc} n_i\Big)^2 + V'\sum_{\langle i,j\rangle'} n_i n_j + \mu\sum_i n_i$$

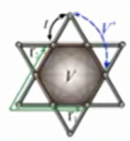


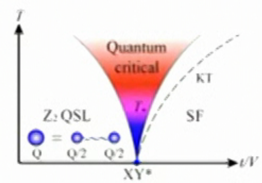
Fractionalized conductivity and emergent self-duality near topological phase transitions

Yan-Cheng Wang[1], Meng Cheng[2], William Witczak-Krempa[3,4] & Zi Yang Meng[5]

Nat. Comm. 12, 5347 (2021)

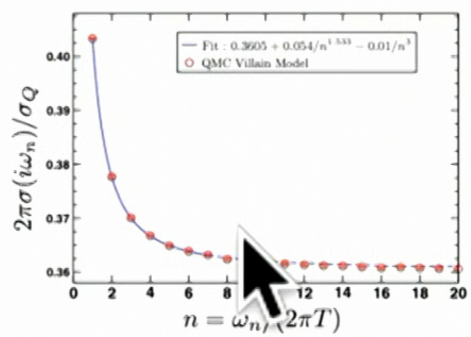
$$H = -t\sum_{\langle i,j\rangle}(b_i^\dagger b_j + \mathrm{h.c.}) + V\sum_{\bigcirc}\Big(\sum_{i\in\bigcirc} n_i\Big)^2 + V'\sum_{\langle i,j\rangle'} n_i n_j + \mu\sum_i n_i$$





$$\sigma(i\omega_n) = -\frac{i}{\omega_n}\langle J_x(\omega_n)J_x(-\omega_n)\rangle$$

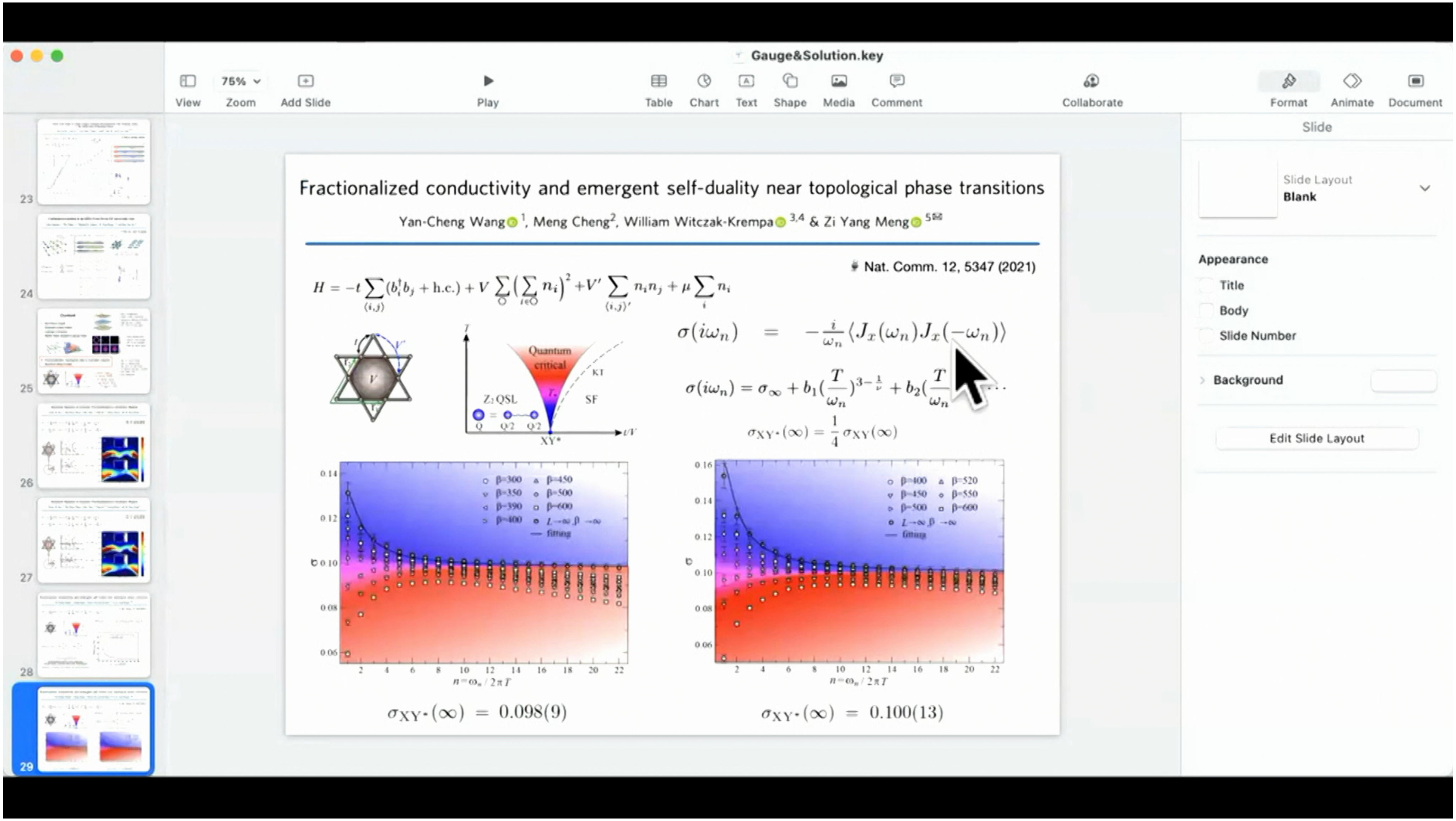
$$\sigma(i\omega_n) = \sigma_\infty + b_1\Big(\frac{T}{\omega_n}\Big)^{3-\frac{1}{\nu}} + b_2\Big(\frac{T}{\omega_n}\Big)^3 + \cdots$$



PHYSICAL REVIEW B 90, 245109 (2014)

Conformal field theories at nonzero temperature: Operator product expansions, Monte Carlo, and holography

Emanuel Katz,[1] Subir Sachdev,[2,3] Erik S. Sørensen,[4] and William Witczak-Krempa[3]



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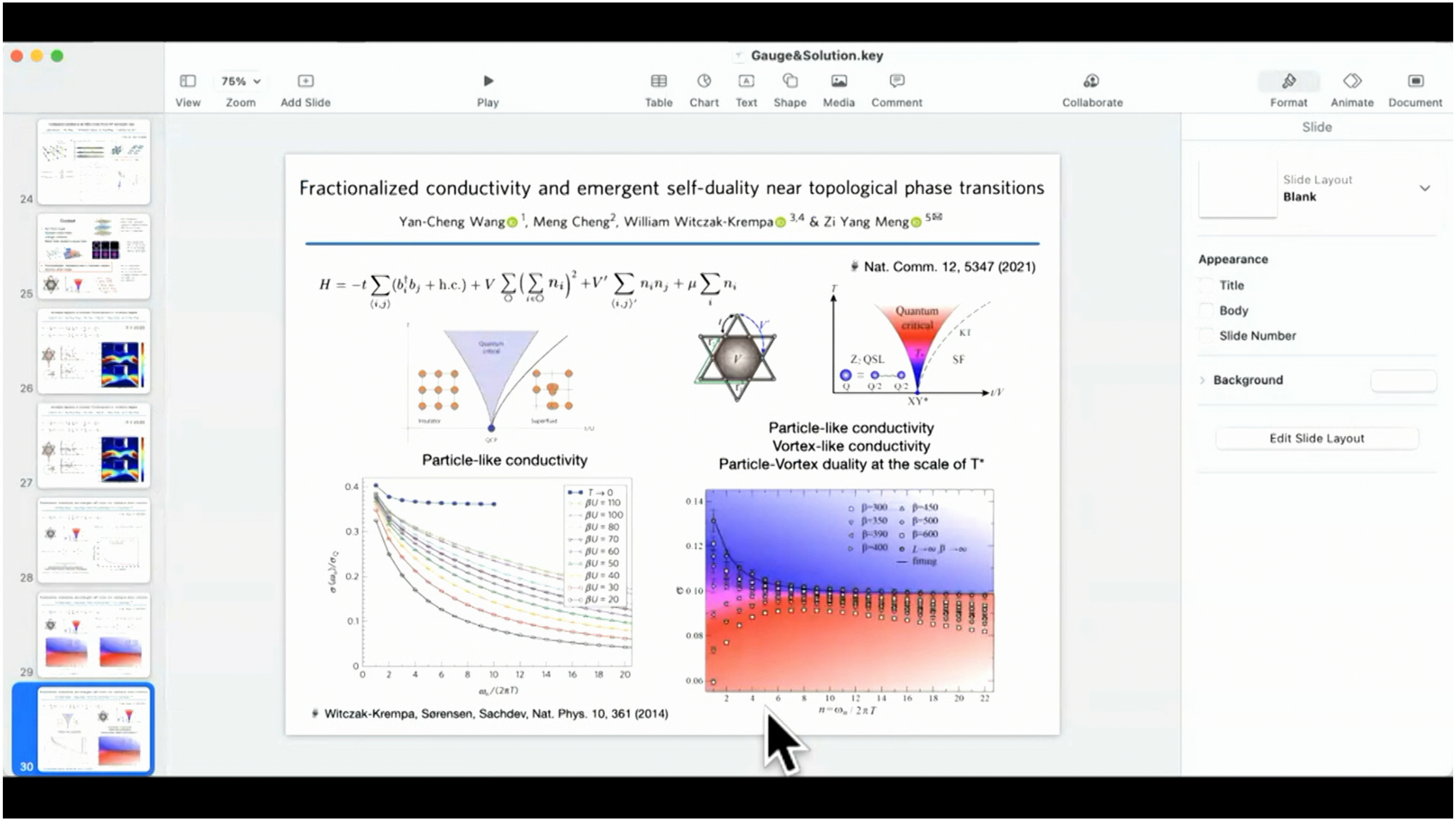
Fractionalized conductivity and emergent self-duality near topological phase transitions
Yan-Cheng Wang [1], Meng Cheng [2], William Witczak-Krempa [3,4] & Zi Yang Meng [5]
Nat. Comm. 12, 5347 (2021)
$H = -t\sum_{\langle i,j\rangle}(b_i^\dagger b_j + \mathrm{h.c.}) + V\sum_{\bigcirc}\Big(\sum_{i\in\bigcirc} n_i\Big)^2 + V'\sum_{\langle i,j\rangle'} n_i n_j + \mu\sum_i n_i$
$\sigma(i\omega_n) = -\frac{i}{\omega_n}\langle J_x(\omega_n)J_x(-\omega_n)\rangle$
$\sigma(i\omega_n) = \sigma_\infty + b_1(\frac{T}{\omega_n})^{3-\frac{1}{\nu}} + b_2(\frac{T}{\omega_n}\cdots$
$\sigma_{\mathrm{XY}^*}(\infty) = \frac{1}{4}\sigma_{\mathrm{XY}}(\infty)$
Quantum critical
Z_2 QSL
SF
KT
XY*
$\sigma_{\mathrm{XY}^*}(\infty) = 0.098(9)$
$\sigma_{\mathrm{XY}^*}(\infty) = 0.100(13)$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Fractionalized conductivity and emergent self-duality near topological phase transitions
Yan-Cheng Wang 1, Meng Cheng 2, William Witczak-Krempa 3,4 & Zi Yang Meng 5
Nat. Comm. 12, 5347 (2021)
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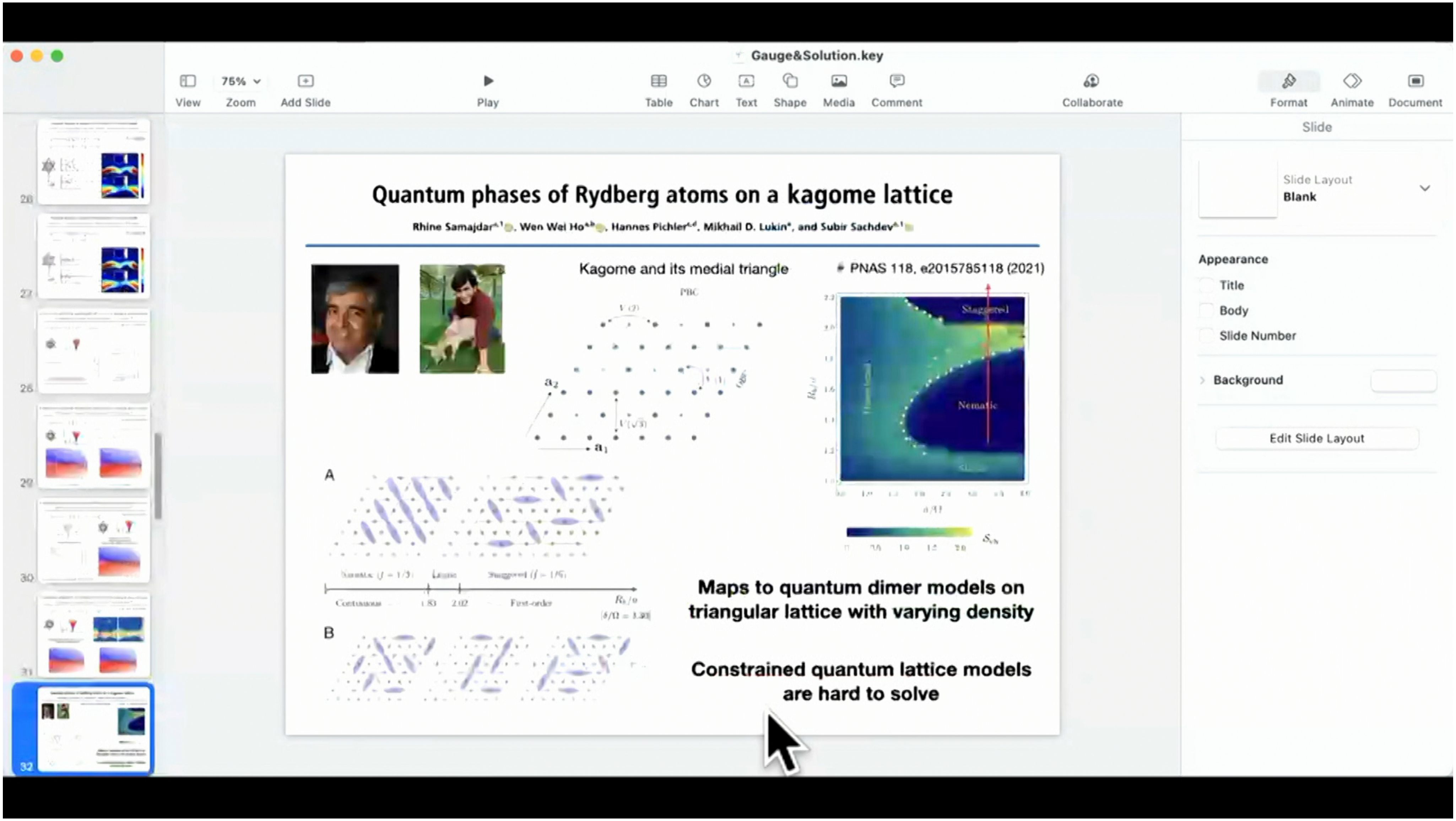
Quantum critical
Z_2 QSL
SF
KT
XY*
Particle-like conductivity
Particle-like conductivity
Vortex-like conductivity
Particle-Vortex duality at the scale of T*
Witczak-Krempa, Sørensen, Sachdev, Nat. Phys. 10, 361 (2014)



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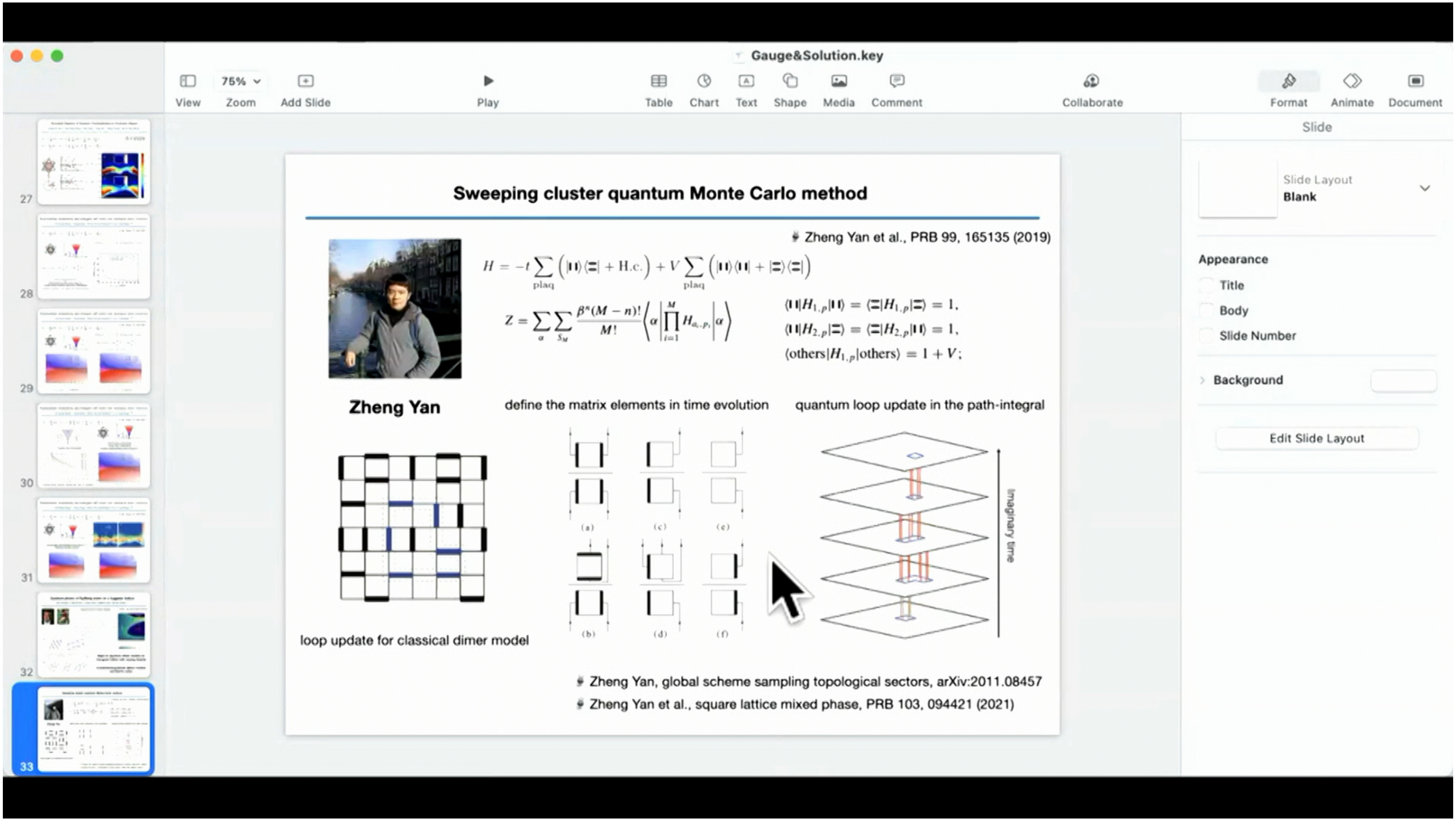
Quantum phases of Rydberg atoms on a kagome lattice
Rhine Samajdar, Wen Wei Ho, Hannes Pichler, Mikhail D. Lukin, and Subir Sachdev
Kagome and its medial triangle
PNAS 118, e2015785118 (2021)
Staggered
Nematic
A
B
Maps to quantum dimer models on triangular lattice with varying density
Constrained quantum lattice models are hard to solve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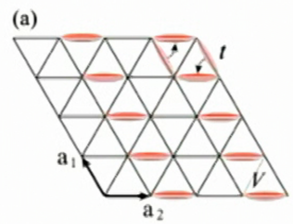
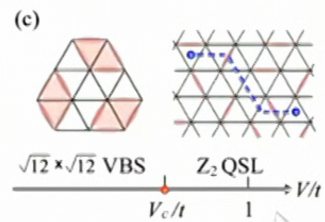
Sweeping cluster quantum Monte Carlo method
Zheng Yan et al., PRB 99, 165135 (2019)
Zheng Yan
define the matrix elements in time evolution
quantum loop update in the path-integral
imaginary time
loop update for classical dimer model
Zheng Yan, global scheme sampling topological sectors, arXiv:2011.08457
Zheng Yan et al., square lattice mixed phase, PRB 103, 094421 (2021)

Topological phase transition and single/multi anyon dynamics of Z_2 spin liquid

Zheng Yan[1], Yan-Cheng Wang[2], Nvsen Ma[3], Yang Qi[4,5,6] and Zi Yang Meng[1]

npj Quantum Materials 6, 39 (2021)



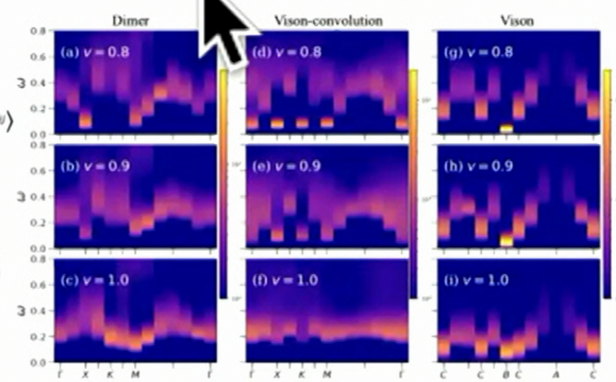


$N_{P_{ij}}$ # dimers along path from plaq i to j

$$C_d(r_{ij},\tau) = \sum_{i,j} \langle D_i(\tau) D_j(0)\rangle - \langle D_i\rangle\langle D_j\rangle$$

$$C_V(r_{ij},\tau) = \sum_{i,j} \langle V_i(\tau) V_j(0)\rangle = \sum_{i,j} \langle (-1)^{N_i + N_{P_{ij}}}\rangle$$

- Bound state of vison pair inside QSL
- Symmetry fractionalisation at transition



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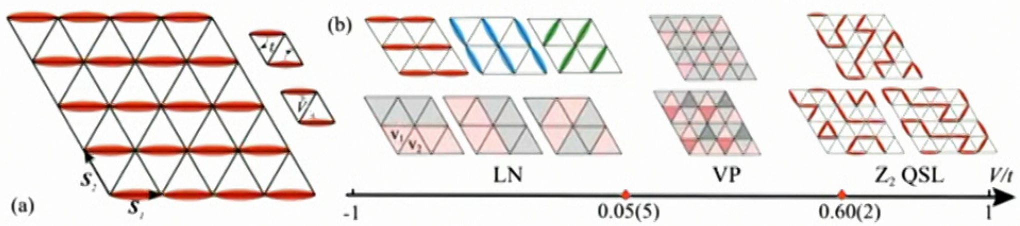
Quantum loop model on triangular lattice: Hidden Vison Plaquette phase and Cubic phase transitions

Zheng Yan,[1,2] Xiaoxue Ran,[1] Yan-Cheng Wang,[3] Rhine Samajdar,[4]
Junchen Rong,[5] Subir Sachdev,[4,6] Yang Qi,[2,7,8] and Zi Yang Meng[1]

arXiv: 2205.04472

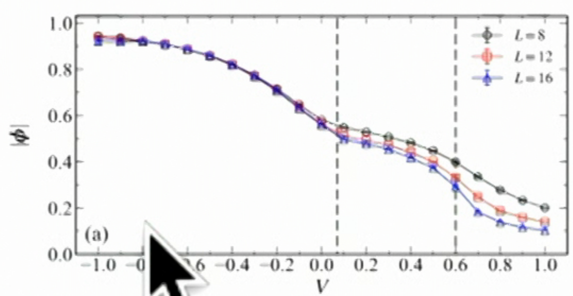


O(3) vison order parameter

$$\phi_j = \sum_{\mathbf{r}} (v_{1,\mathbf{r}}, v_{2,\mathbf{r}}) \cdot \mathbf{u}_j e^{i\mathbf{M}_j \cdot \mathbf{r}}, \quad j = 1, 2, 3$$

Previous literatures disagree on phase diagram

Assume direct LN-QSL transition with emergent O(3)



- Roychowdhury et al., PRB 92, 075141(2015), ED
- Plat et al., PRB 92, 174402 (2015), projection QMC

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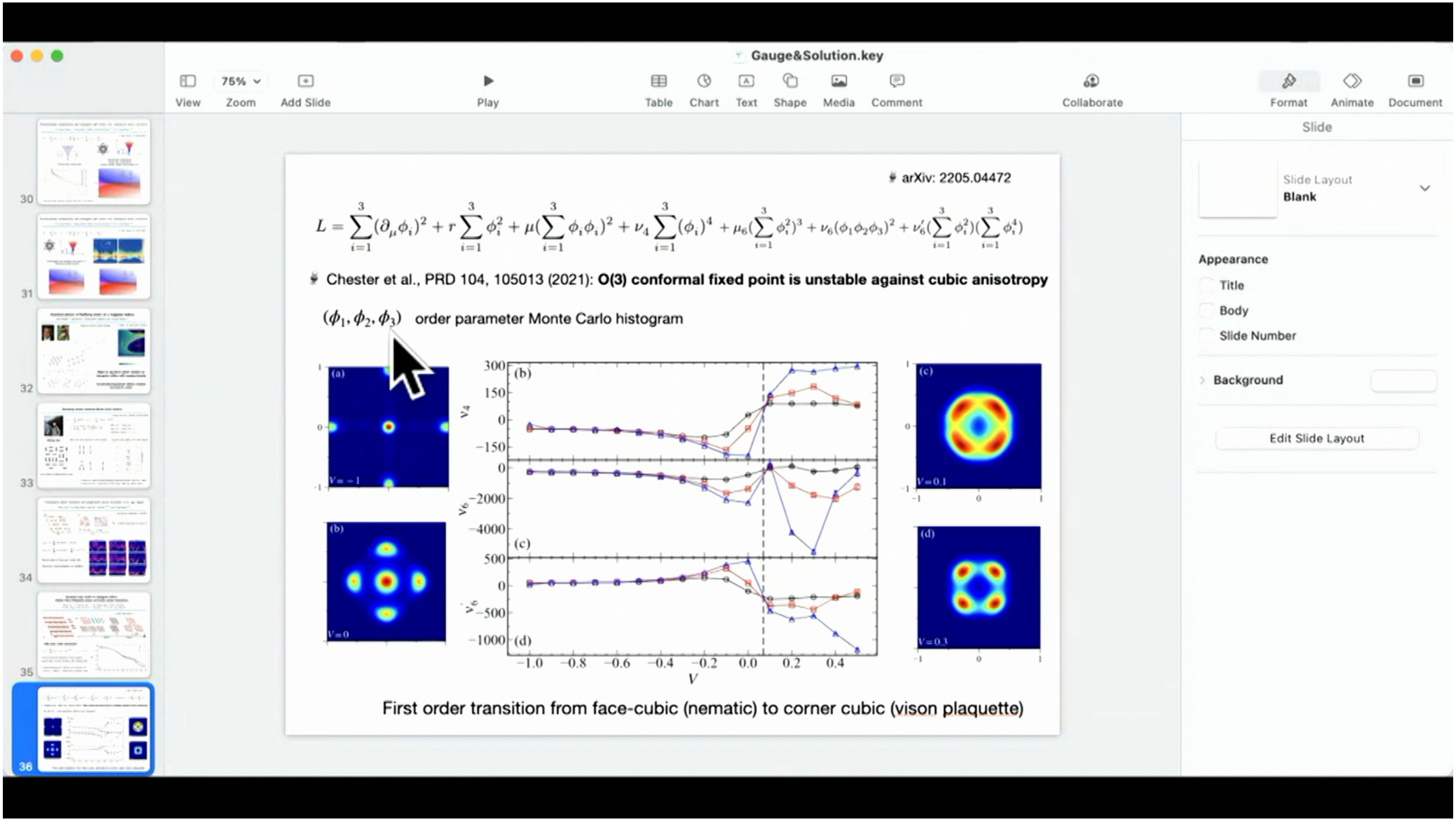
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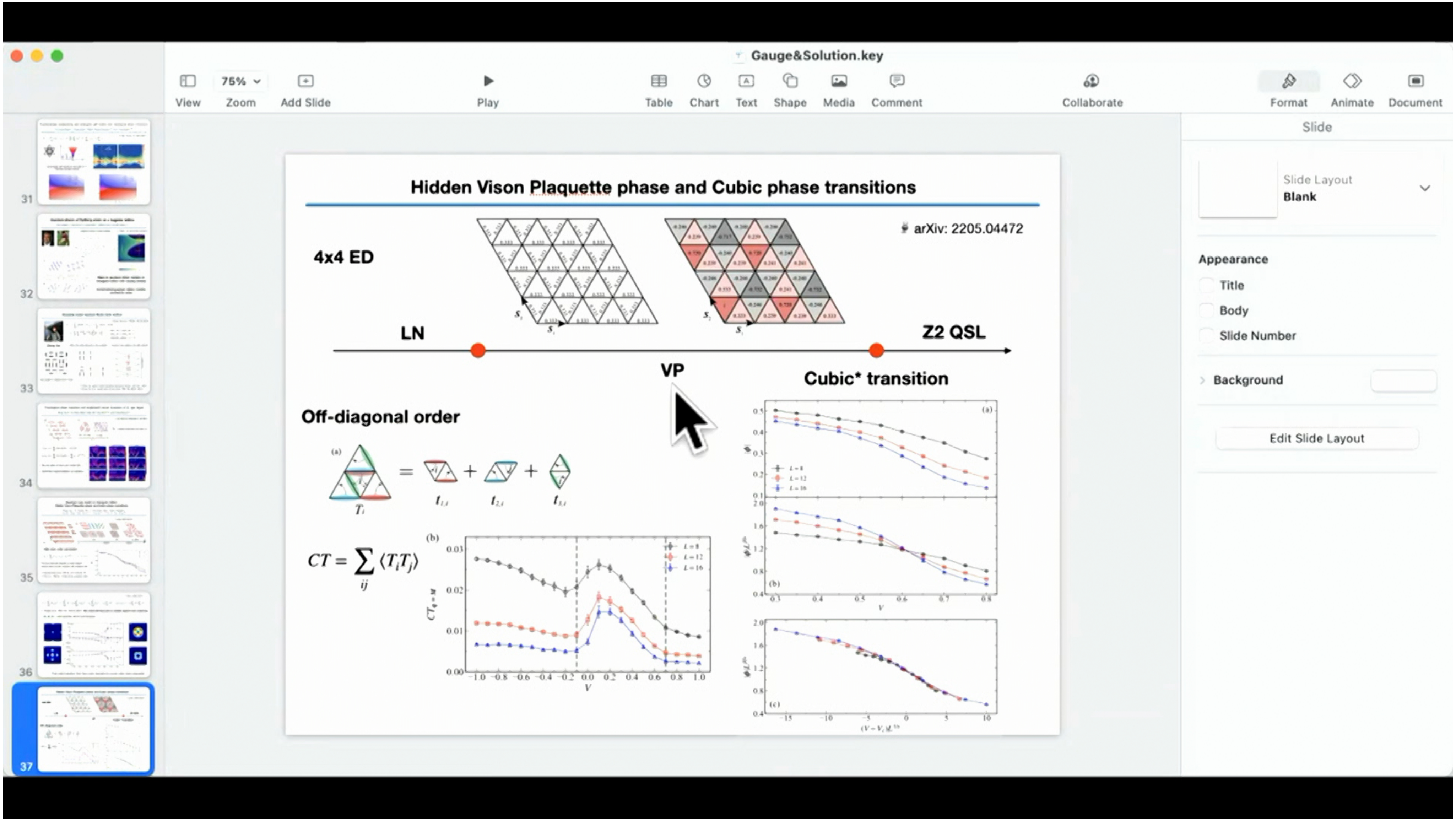
arXiv: 2205.04472
$L=\sum_{i=1}^{3}(\partial_\mu\phi_i)^2+r\sum_{i=1}^{3}\phi_i^2+\mu(\sum_{i=1}^{3}\phi_i\phi_i)^2+\nu_4\sum_{i=1}^{3}(\phi_i)^4+\mu_6(\sum_{i=1}^{3}\phi_i^2)^3+\nu_6(\phi_1\phi_2\phi_3)^2+\nu_6'(\sum_{i=1}^{3}\phi_i^2)(\sum_{i=1}^{3}\phi_i^4)$
Chester et al., PRD 104, 105013 (2021): **O(3) conformal fixed point is unstable against cubic anisotropy**
(ϕ_1,ϕ_2,ϕ_3) order parameter Monte Carlo histogram
First order transition from face-cubic (nematic) to corner cubic (vison plaquette)



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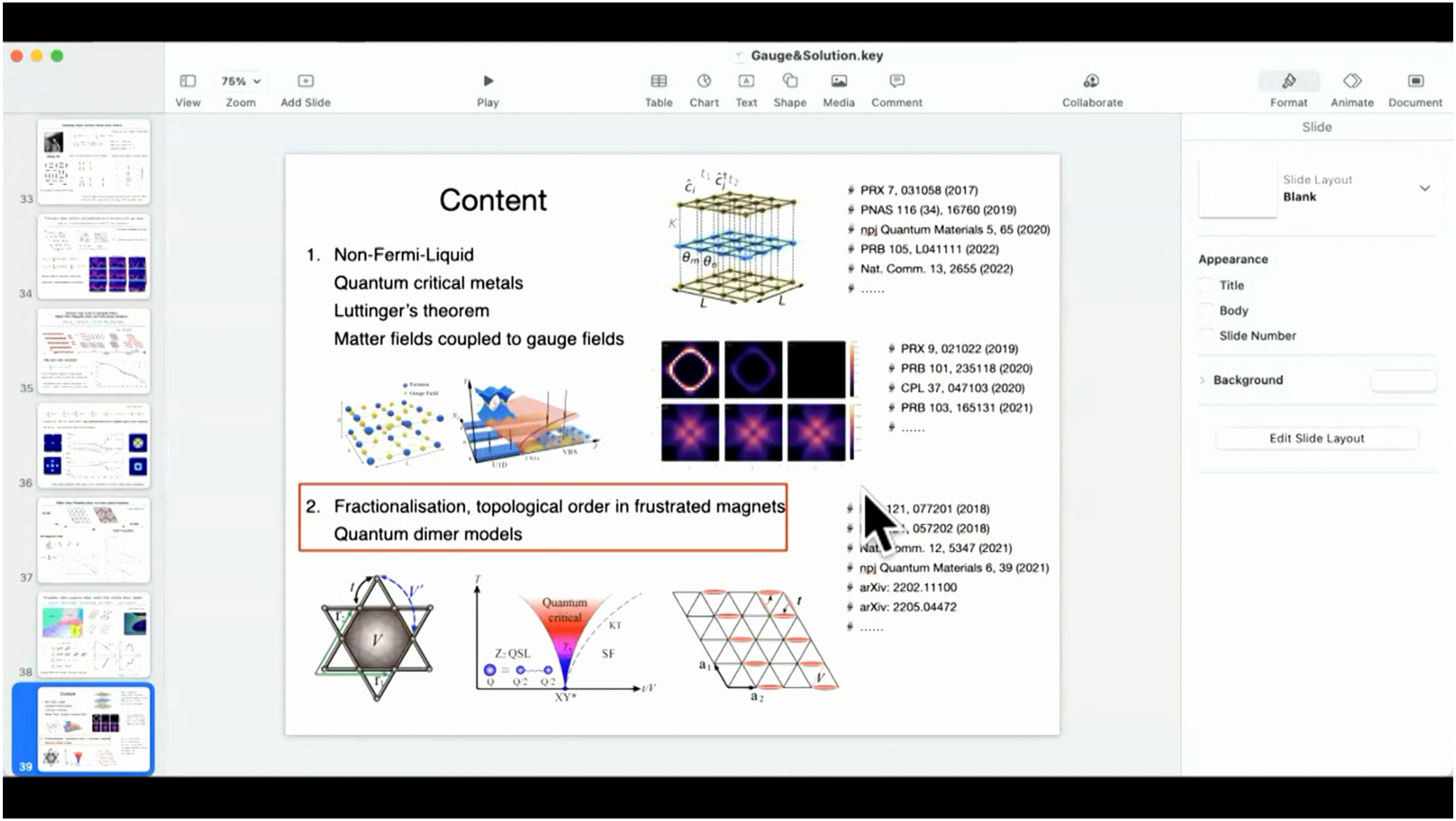
Hidden Vison Plaquette phase and Cubic phase transitions
arXiv: 2205.04472
4x4 ED
LN
Z2 QSL
VP
Cubic* transition
Off-diagonal order
$CT = \sum_{ij} \langle T_i T_j \rangle$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arXiv: 2205.04472
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Quantum critical
Z₂ QSL
KT
SF
XY*
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