Charm Physics at BESIII

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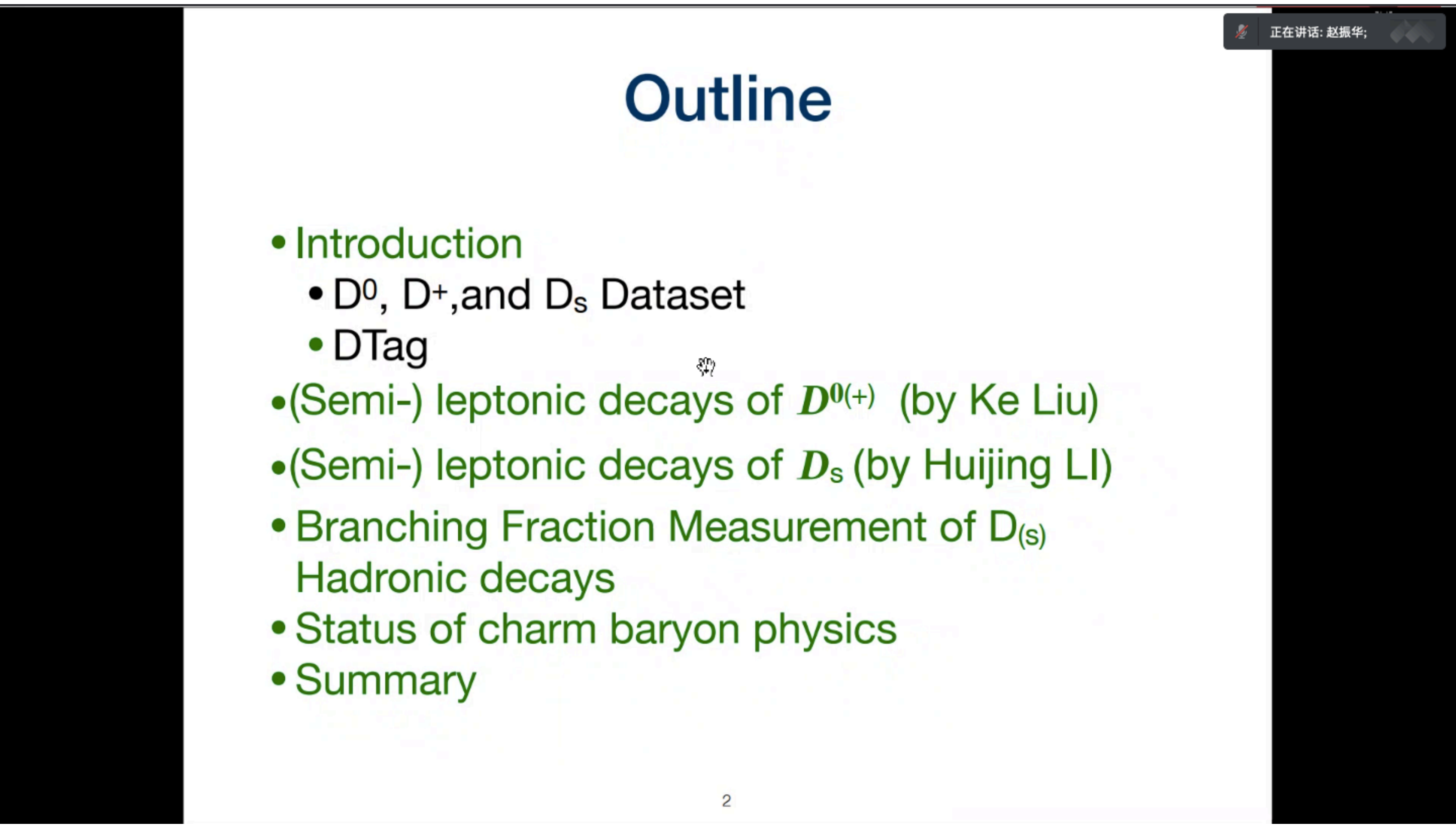
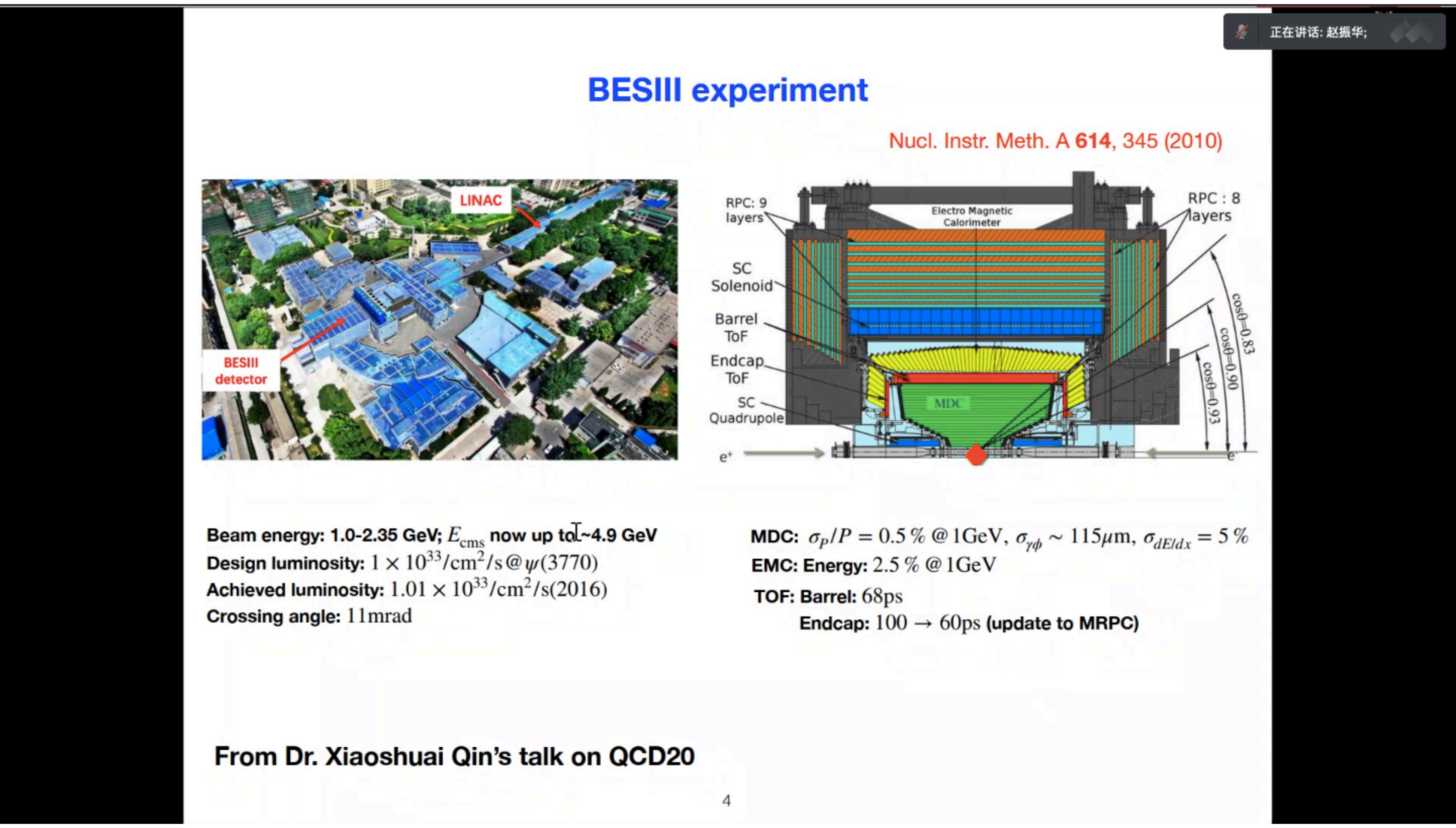
@ 04/27/2021



Outline

- Introduction
  - D^0, D^+,and D_s Dataset
  - DTag
- (Semi-) leptonic decays of $D^{0(+)}$ (by Ke Liu)
- (Semi-) leptonic decays of D_s (by Huijing LI)
- Branching Fraction Measurement of $D_{(s)}$ Hadronic decays
- Status of charm baryon physics
- Summary



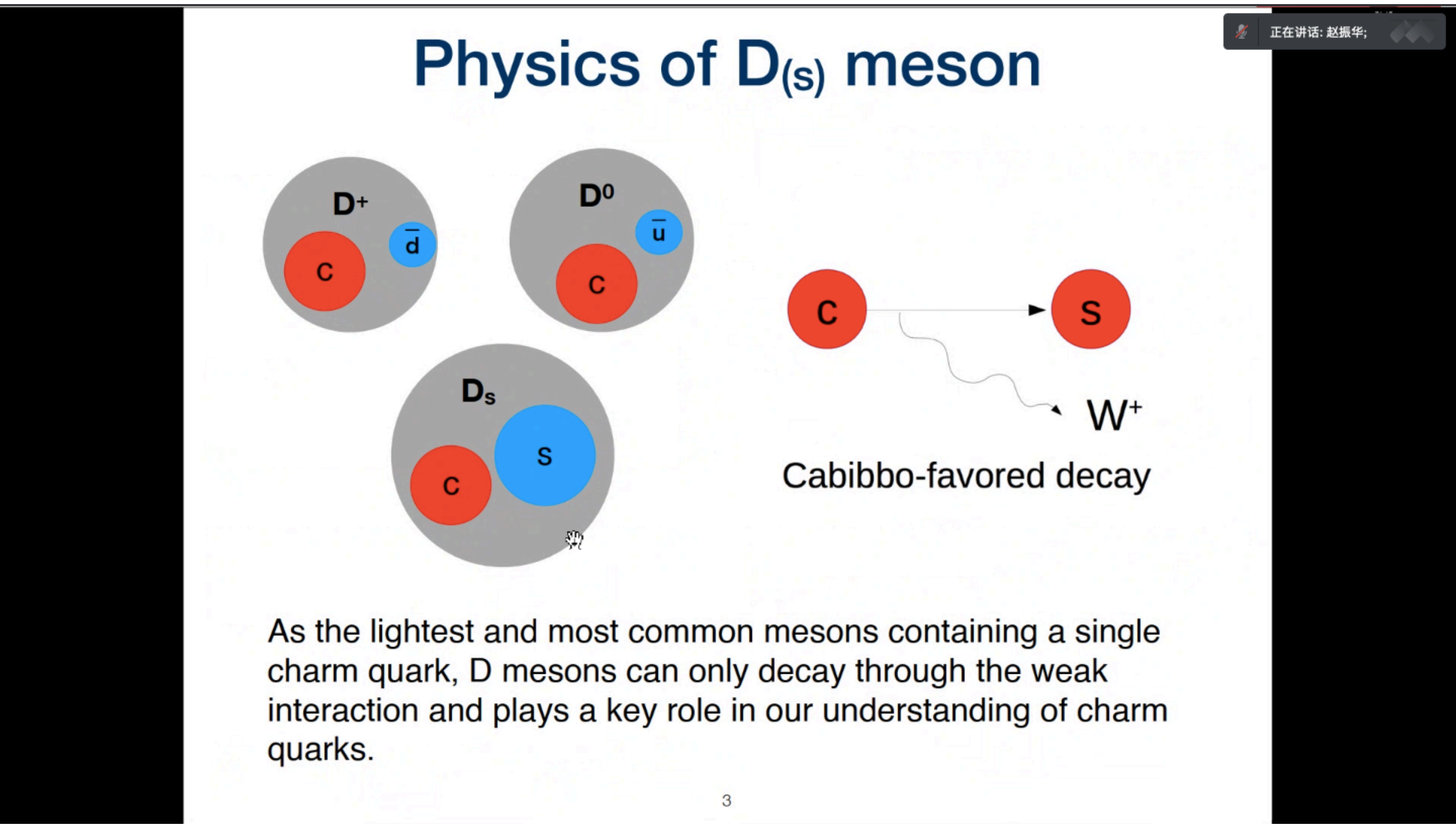
BESIII experiment

Nucl. Instr. Meth. A **614**, 345 (2010)

Beam energy: 1.0-2.35 GeV; E_{cms} now up to ~4.9 GeV
Design luminosity: $1 \times 10^{33}/\mathrm{cm}^2/\mathrm{s}\,@\,\psi(3770)$
Achieved luminosity: $1.01 \times 10^{33}/\mathrm{cm}^2/\mathrm{s}(2016)$
Crossing angle: $11\mathrm{mrad}$

MDC: $\sigma_P/P = 0.5\,\%\,@\,1\mathrm{GeV}$, $\sigma_{\gamma\phi} \sim 115\mu\mathrm{m}$, $\sigma_{dE/dx} = 5\,\%$
EMC: Energy: $2.5\,\%\,@\,1\mathrm{GeV}$
TOF: Barrel: $68\mathrm{ps}$
Endcap: $100 \rightarrow 60\mathrm{ps}$ **(update to MRPC)**

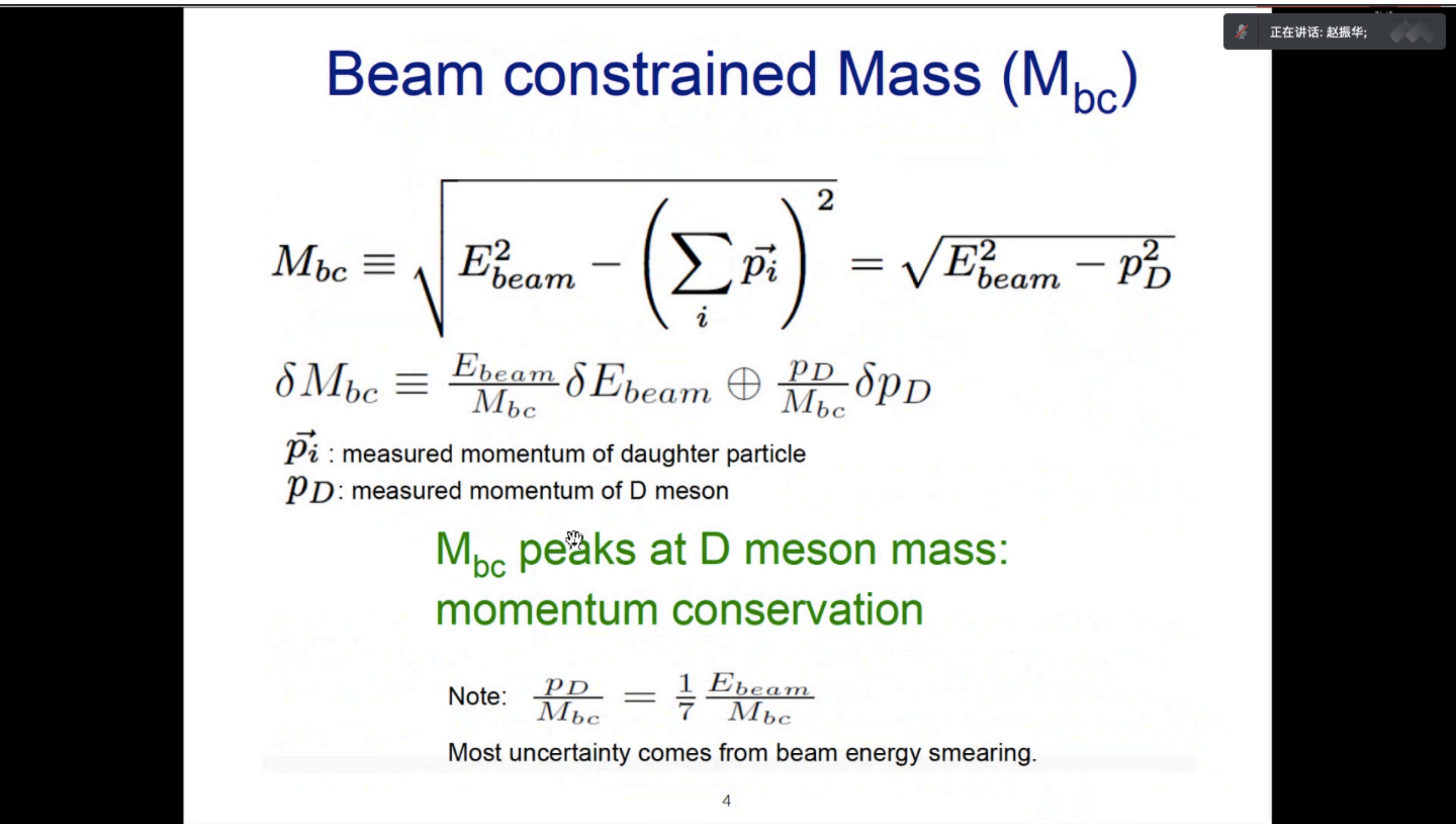
From Dr. Xiaoshuai Qin's talk on QCD20



Physics of $D_{(s)}$ meson

Cabibbo-favored decay

As the lightest and most common mesons containing a single charm quark, D mesons can only decay through the weak interaction and plays a key role in our understanding of charm quarks.



Beam constrained Mass (M_{bc})

$$M_{bc} \equiv \sqrt{E_{beam}^2 - \left(\sum_i \vec{p_i}\right)^2} = \sqrt{E_{beam}^2 - p_D^2}$$

$$\delta M_{bc} \equiv \frac{E_{beam}}{M_{bc}} \delta E_{beam} \oplus \frac{p_D}{M_{bc}} \delta p_D$$

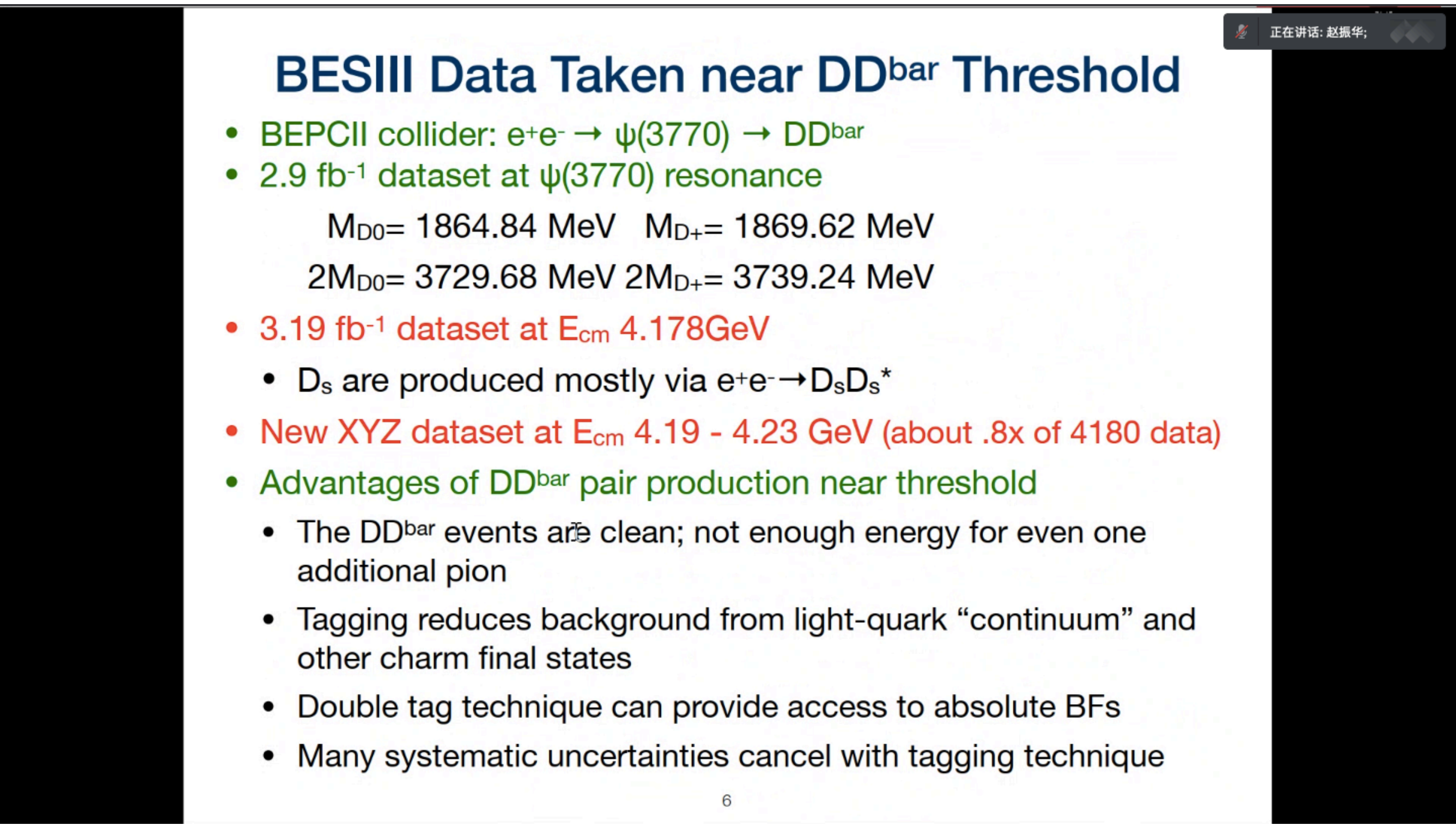
$\vec{p_i}$: measured momentum of daughter particle

p_D: measured momentum of D meson

M_{bc} peaks at D meson mass: momentum conservation

Note: $\frac{p_D}{M_{bc}} = \frac{1}{7} \frac{E_{beam}}{M_{bc}}$

Most uncertainty comes from beam energy smearing.



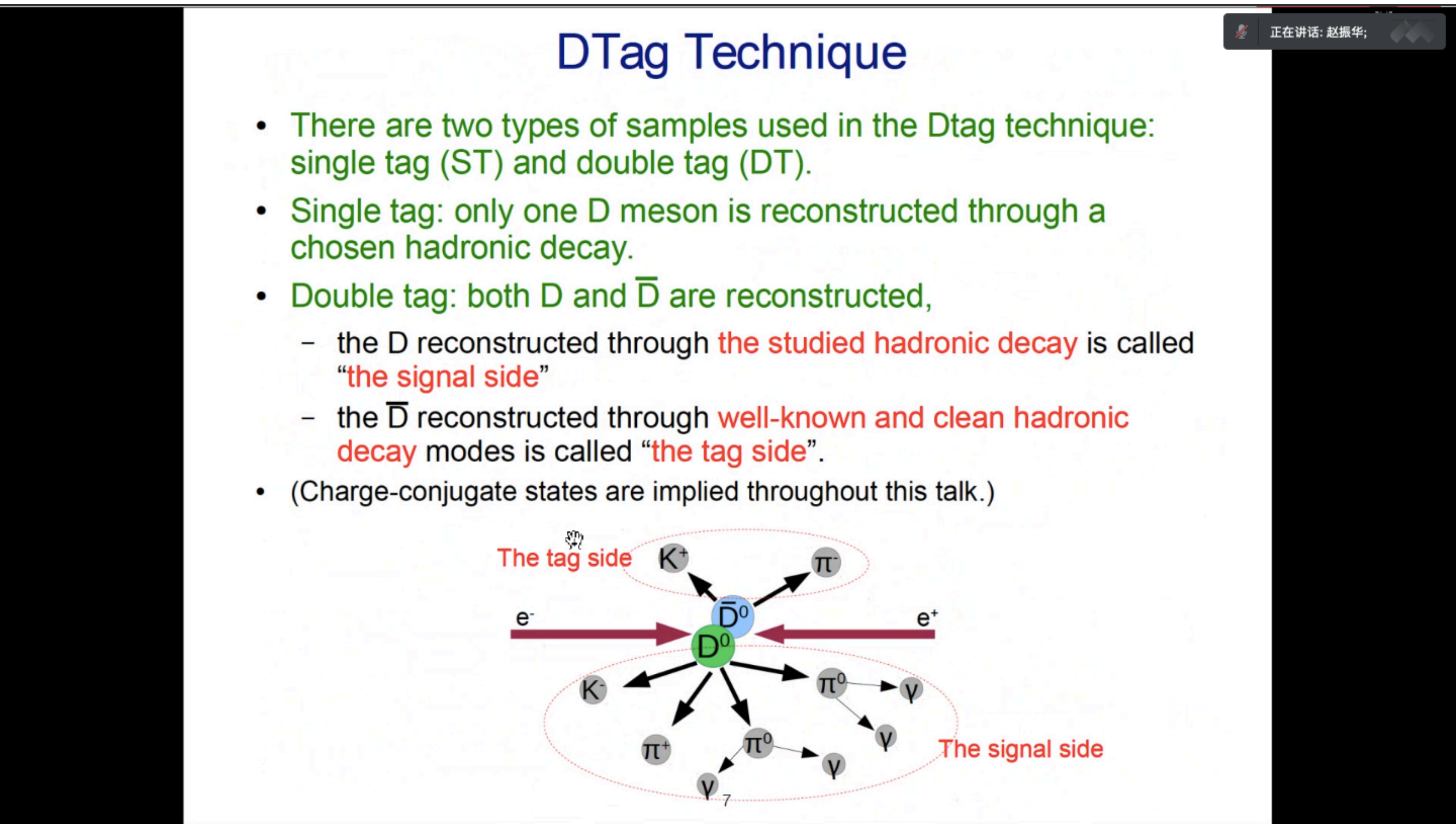
BESIII Data Taken near DD^{bar} Threshold

- BEPCII collider: $e^+e^- \rightarrow \psi(3770) \rightarrow DD^{bar}$
- 2.9 fb^{-1} dataset at $\psi(3770)$ resonance

M_{D0}= 1864.84 MeV M_{D+}= 1869.62 MeV

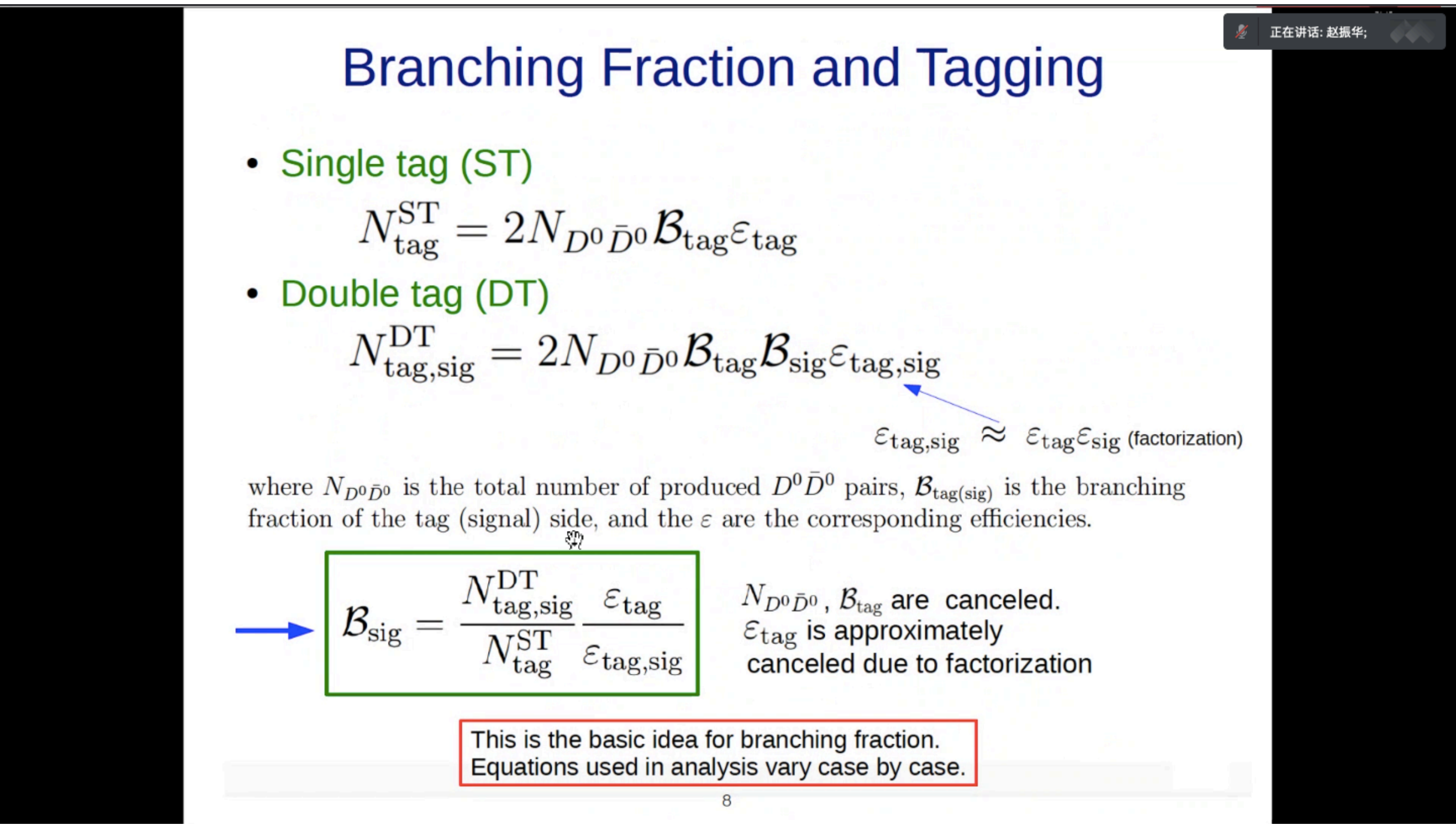
$2M_{D0}$= 3729.68 MeV $2M_{D+}$= 3739.24 MeV

- 3.19 fb^{-1} dataset at E_{cm} 4.178GeV
  - D_s are produced mostly via $e^+e^- \rightarrow D_sD_s^*$
- New XYZ dataset at E_{cm} 4.19 - 4.23 GeV (about .8x of 4180 data)
- Advantages of DD^{bar} pair production near threshold
  - The DD^{bar} events are clean; not enough energy for even one additional pion
  - Tagging reduces background from light-quark “continuum” and other charm final states
  - Double tag technique can provide access to absolute BFs
  - Many systematic uncertainties cancel with tagging technique



DTag Technique

- There are two types of samples used in the Dtag technique: single tag (ST) and double tag (DT).
- Single tag: only one D meson is reconstructed through a chosen hadronic decay.
- Double tag: both D and $\overline{D}$ are reconstructed,
  - the D reconstructed through the studied hadronic decay is called "the signal side"
  - the $\overline{D}$ reconstructed through well-known and clean hadronic decay modes is called "the tag side".
- (Charge-conjugate states are implied throughout this talk.)



Branching Fraction and Tagging

- Single tag (ST)

$$N^{\mathrm{ST}}_{\mathrm{tag}} = 2N_{D^0\bar{D}^0}\mathcal{B}_{\mathrm{tag}}\varepsilon_{\mathrm{tag}}$$

- Double tag (DT)

$$N^{\mathrm{DT}}_{\mathrm{tag,sig}} = 2N_{D^0\bar{D}^0}\mathcal{B}_{\mathrm{tag}}\mathcal{B}_{\mathrm{sig}}\varepsilon_{\mathrm{tag,sig}}$$

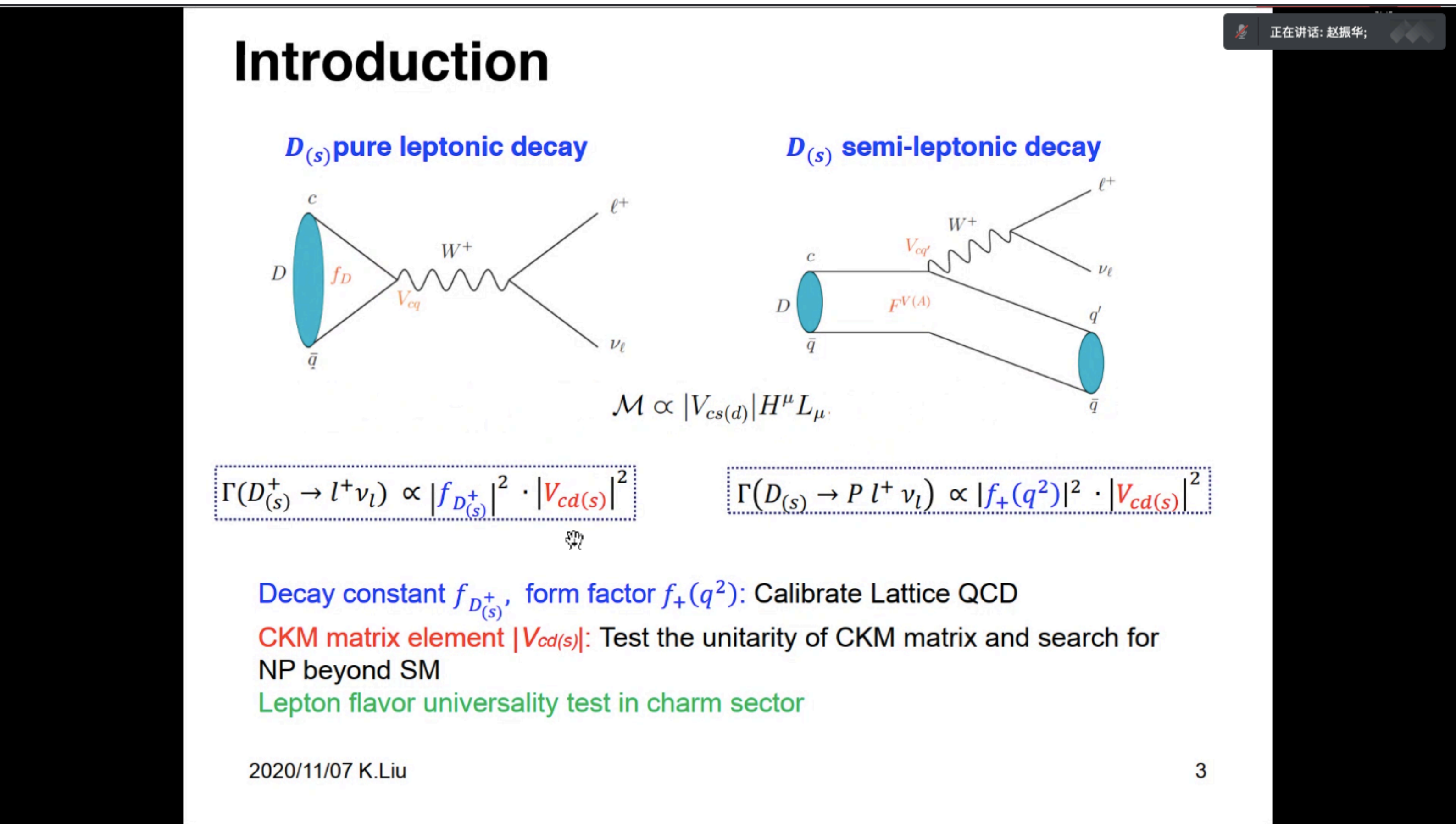
$\varepsilon_{\mathrm{tag,sig}} \approx \varepsilon_{\mathrm{tag}}\varepsilon_{\mathrm{sig}}$ (factorization)

where $N_{D^0\bar{D}^0}$ is the total number of produced $D^0\bar{D}^0$ pairs, $\mathcal{B}_{\mathrm{tag(sig)}}$ is the branching fraction of the tag (signal) side, and the ε are the corresponding efficiencies.

$$\boxed{\mathcal{B}_{\mathrm{sig}} = \frac{N^{\mathrm{DT}}_{\mathrm{tag,sig}}}{N^{\mathrm{ST}}_{\mathrm{tag}}}\frac{\varepsilon_{\mathrm{tag}}}{\varepsilon_{\mathrm{tag,sig}}}}$$

$N_{D^0\bar{D}^0}$, $\mathcal{B}_{\mathrm{tag}}$ are canceled.
$\varepsilon_{\mathrm{tag}}$ is approximately canceled due to factorization

This is the basic idea for branching fraction.
Equations used in analysis vary case by case.



Introduction

$D_{(s)}$ pure leptonic decay

$D_{(s)}$ semi-leptonic decay

$$\mathcal{M} \propto |V_{cs(d)}| H^\mu L_\mu$$

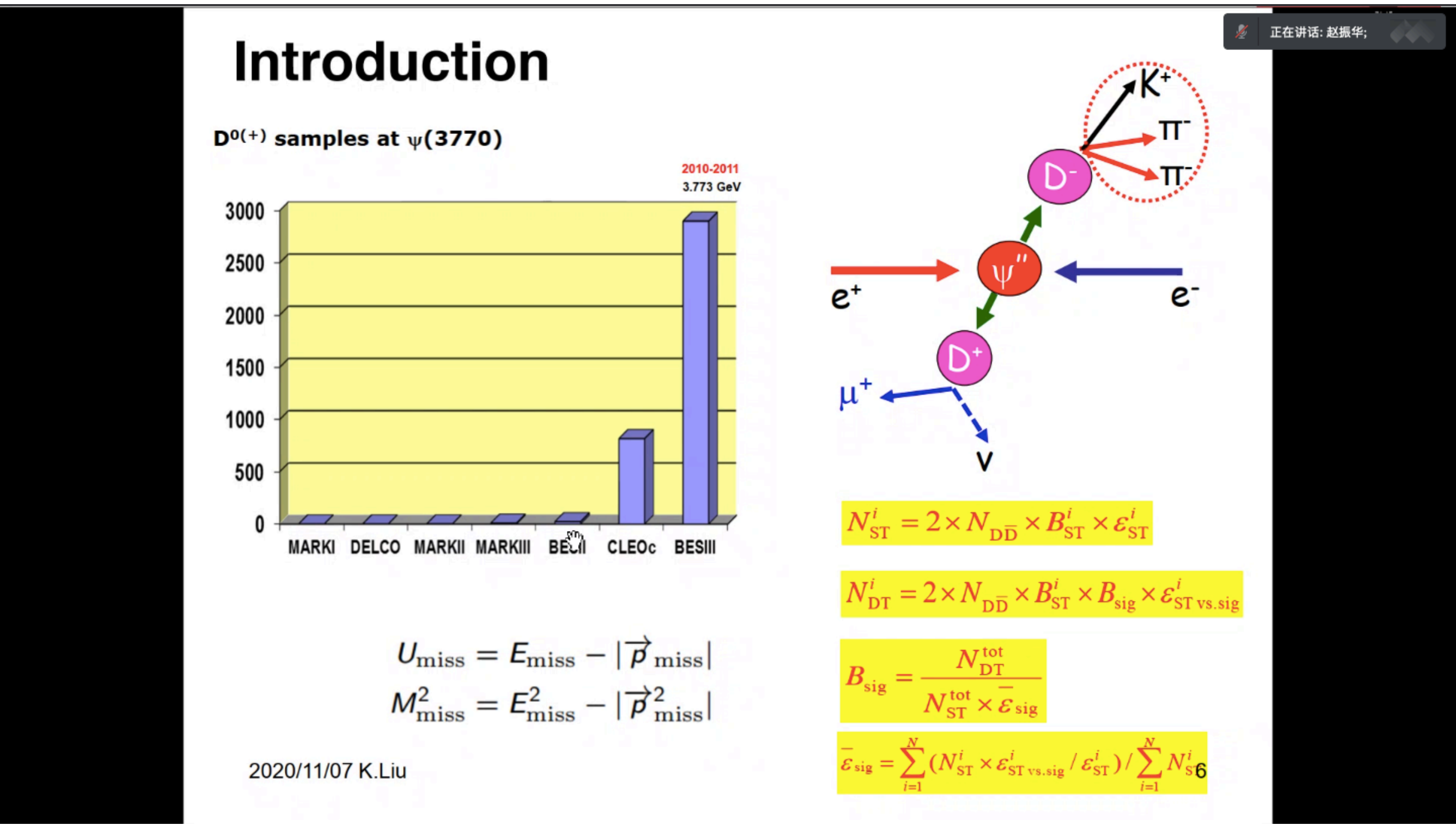
$$\boxed{\Gamma(D^+_{(s)} \to l^+\nu_l) \propto \left|f_{D^+_{(s)}}\right|^2 \cdot \left|V_{cd(s)}\right|^2}$$

$$\boxed{\Gamma\left(D_{(s)} \to P\, l^+\,\nu_l\right) \propto |f_+(q^2)|^2 \cdot \left|V_{cd(s)}\right|^2}$$

Decay constant $f_{D^+_{(s)}}$, form factor $f_+(q^2)$: Calibrate Lattice QCD

CKM matrix element $|V_{cd(s)}|$: Test the unitarity of CKM matrix and search for NP beyond SM

Lepton flavor universality test in charm sector



Introduction

$D^{0(+)}$ samples at $\psi(3770)$

$$N^i_{\mathrm{ST}} = 2\times N_{D\bar{D}} \times B^i_{\mathrm{ST}} \times \varepsilon^i_{\mathrm{ST}}$$

$$N^i_{\mathrm{DT}} = 2\times N_{D\bar{D}} \times B^i_{\mathrm{ST}} \times B_{\mathrm{sig}} \times \varepsilon^i_{\mathrm{ST\ vs.sig}}$$

$$B_{\mathrm{sig}} = \frac{N^{\mathrm{tot}}_{\mathrm{DT}}}{N^{\mathrm{tot}}_{\mathrm{ST}} \times \bar{\varepsilon}_{\mathrm{sig}}}$$

$$U_{\mathrm{miss}} = E_{\mathrm{miss}} - |\vec{p}_{\mathrm{miss}}|$$
$$M^2_{\mathrm{miss}} = E^2_{\mathrm{miss}} - |\vec{p}^{\,2}_{\mathrm{miss}}|$$

$$\bar{\varepsilon}_{\mathrm{sig}} = \sum_{i=1}^{N} (N^i_{\mathrm{ST}} \times \varepsilon^i_{\mathrm{ST\ vs.sig}} / \varepsilon^i_{\mathrm{ST}}) / \sum_{i=1}^{N} N^i_{\mathrm{S}}$$

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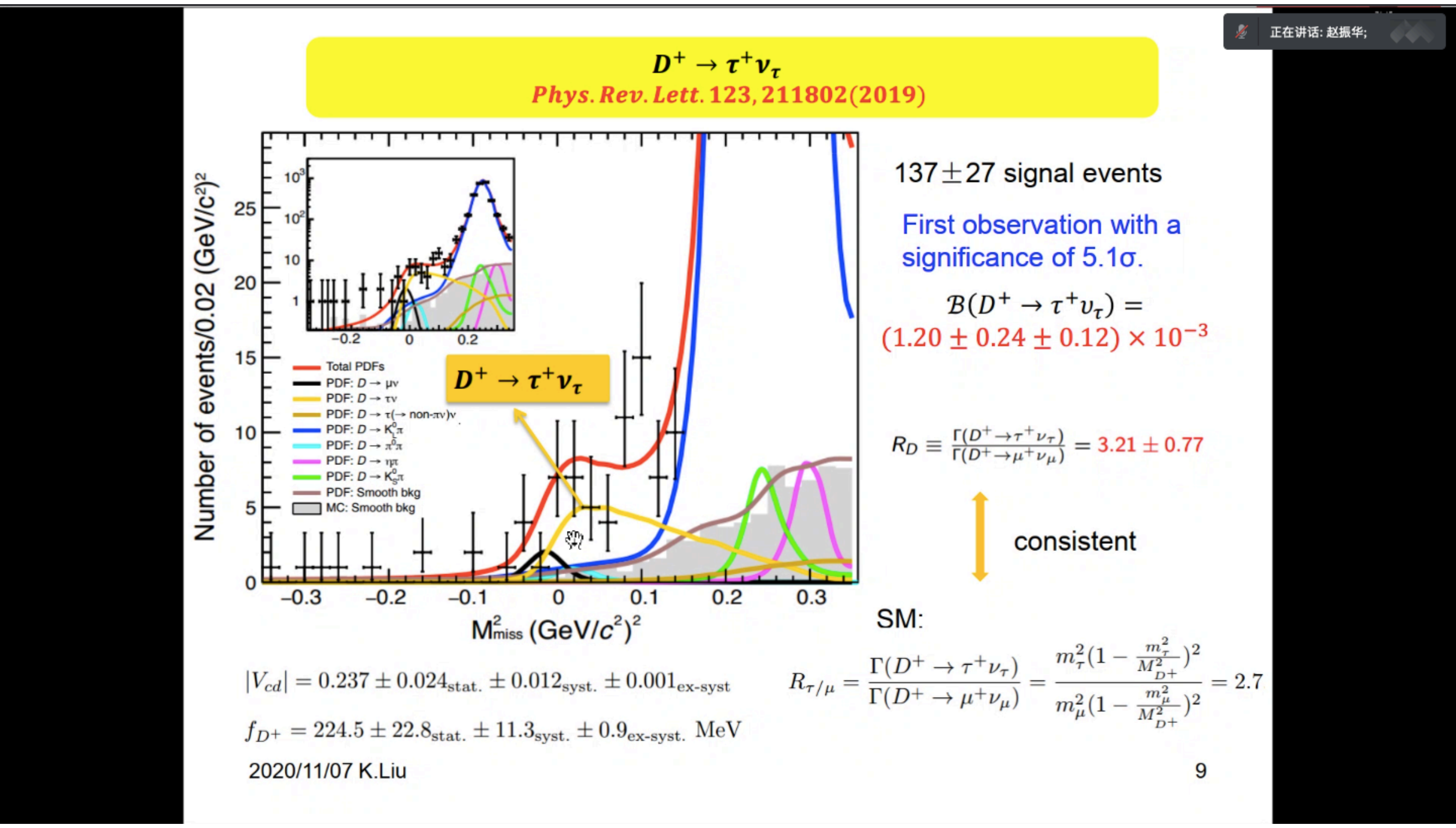


$D^+ \to \tau^+ \nu_\tau$

Phys. Rev. Lett. 123, 211802(2019)

137±27 signal events

First observation with a significance of 5.1σ.

$\mathcal{B}(D^+ \to \tau^+ \upsilon_\tau) =$
$(1.20 \pm 0.24 \pm 0.12) \times 10^{-3}$

$R_D \equiv \frac{\Gamma(D^+ \to \tau^+ \nu_\tau)}{\Gamma(D^+ \to \mu^+ \nu_\mu)} = 3.21 \pm 0.77$

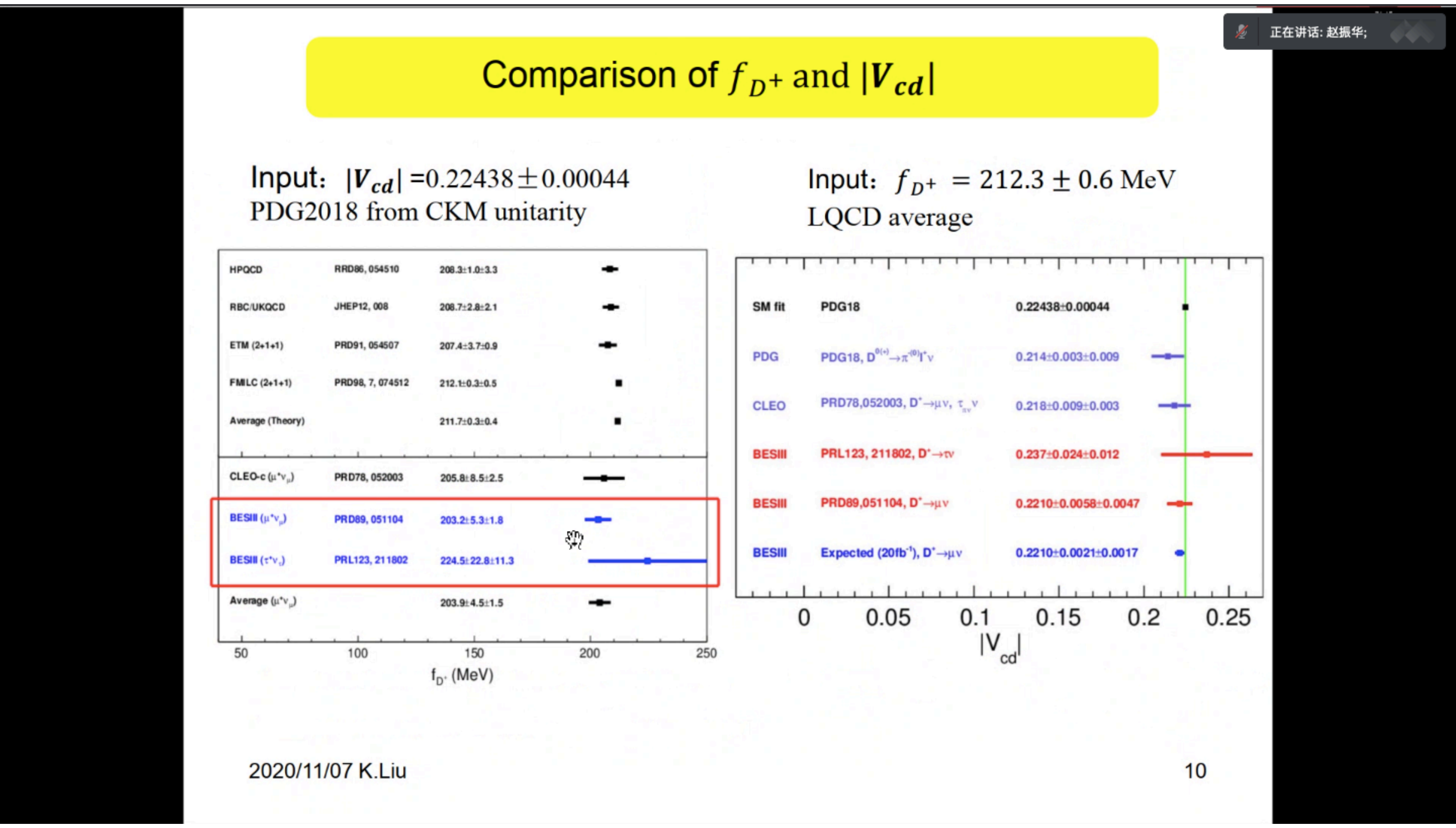
consistent

SM:

$$R_{\tau/\mu} = \frac{\Gamma(D^+ \to \tau^+ \nu_\tau)}{\Gamma(D^+ \to \mu^+ \nu_\mu)} = \frac{m_\tau^2 (1 - \frac{m_\tau^2}{M_{D+}^2})^2}{m_\mu^2 (1 - \frac{m_\mu^2}{M_{D+}^2})^2} = 2.7$$

$$|V_{cd}| = 0.237 \pm 0.024_{\text{stat.}} \pm 0.012_{\text{syst.}} \pm 0.001_{\text{ex-syst}}$$

$$f_{D^+} = 224.5 \pm 22.8_{\text{stat.}} \pm 11.3_{\text{syst.}} \pm 0.9_{\text{ex-syst.}}\ \text{MeV}$$



Comparison of f_{D^+} and $|V_{cd}|$

Input: $|V_{cd}|$ =0.22438±0.00044
PDG2018 from CKM unitarity

HPQCD	RRD86, 054510	208.3±1.0±3.3
RBC/UKQCD	JHEP12, 008	208.7±2.8±2.1
ETM (2+1+1)	PRD91, 054507	207.4±3.7±0.9
FMILC (2+1+1)	PRD98, 7, 074512	212.1±0.3±0.5
Average (Theory)		211.7±0.3±0.4
CLEO-c ($\mu^+\nu_\mu$)	PRD78, 052003	205.8±8.5±2.5
BESIII ($\mu^+\nu_\mu$)	PRD89, 051104	203.2±5.3±1.8
BESIII ($\tau^+\nu_\tau$)	PRL123, 211802	224.5±22.8±11.3
Average ($\mu^+\nu_\mu$)		203.9±4.5±1.5

Input: f_{D^+} = 212.3 ± 0.6 MeV
LQCD average

SM fit	PDG18	0.22438±0.00044
PDG	PDG18, $D^{0(+)} \to \pi^{-(0)} l^+ \nu$	0.214±0.003±0.009
CLEO	PRD78,052003, $D^+ \to \mu\nu$, $\tau_{\pi\nu}\nu$	0.218±0.009±0.003
BESIII	PRL123, 211802, $D^+ \to \tau\nu$	0.237±0.024±0.012
BESIII	PRD89,051104, $D^+ \to \mu\nu$	0.2210±0.0058±0.0047
BESIII	Expected (20fb^{-1}), $D^+ \to \mu\nu$	0.2210±0.0021±0.0017

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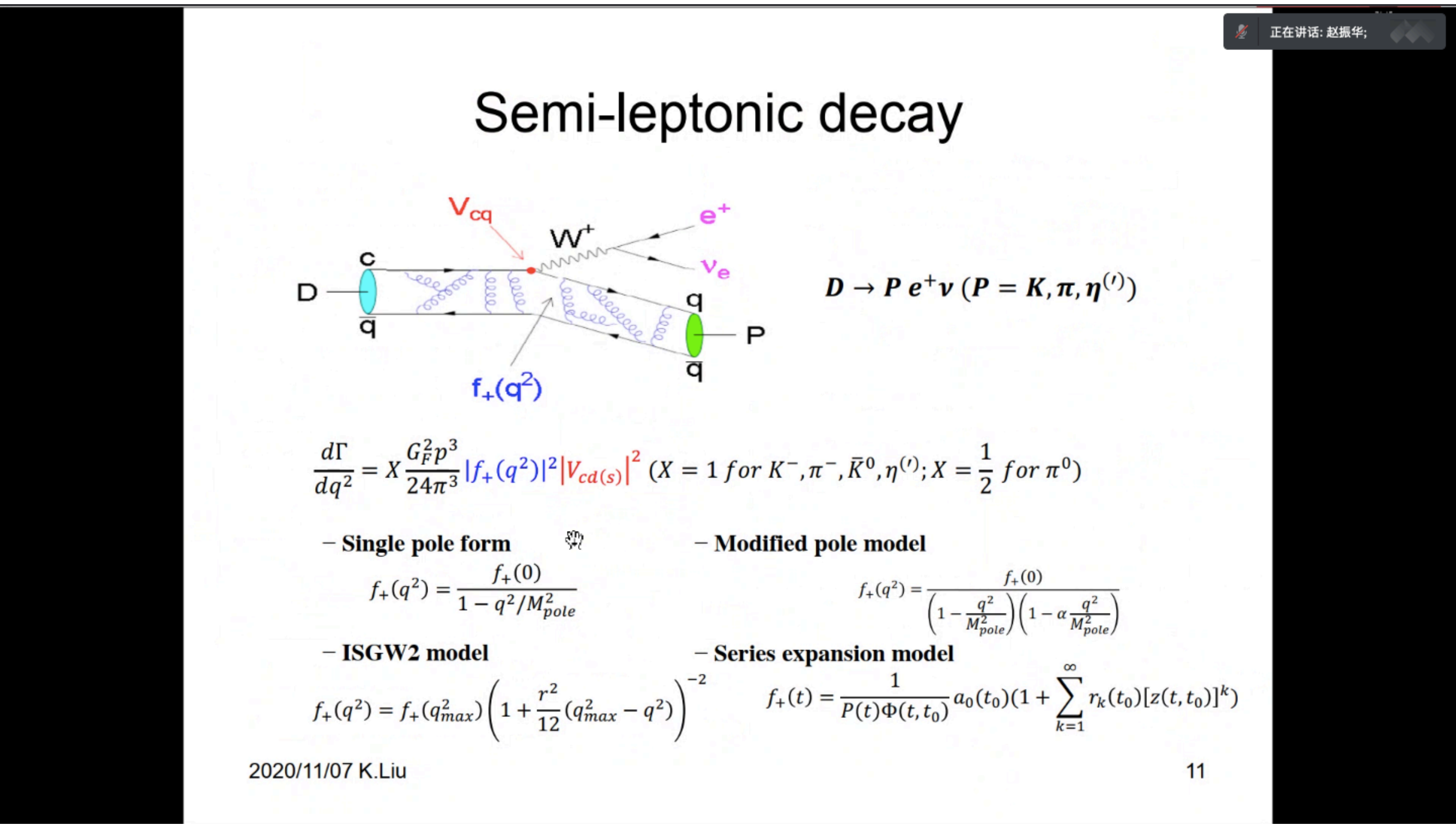


Semi-leptonic decay

$D \rightarrow P\, e^+ \nu\ (P = K, \pi, \eta^{(\prime)})$

$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2 p^3}{24\pi^3}|f_+(q^2)|^2|V_{cd(s)}|^2\ (X = 1\ for\ K^-, \pi^-, \bar{K}^0, \eta^{(\prime)};\ X = \frac{1}{2}\ for\ \pi^0)$$

- **Single pole form**

$$f_+(q^2) = \frac{f_+(0)}{1 - q^2/M_{pole}^2}$$

- **Modified pole model**

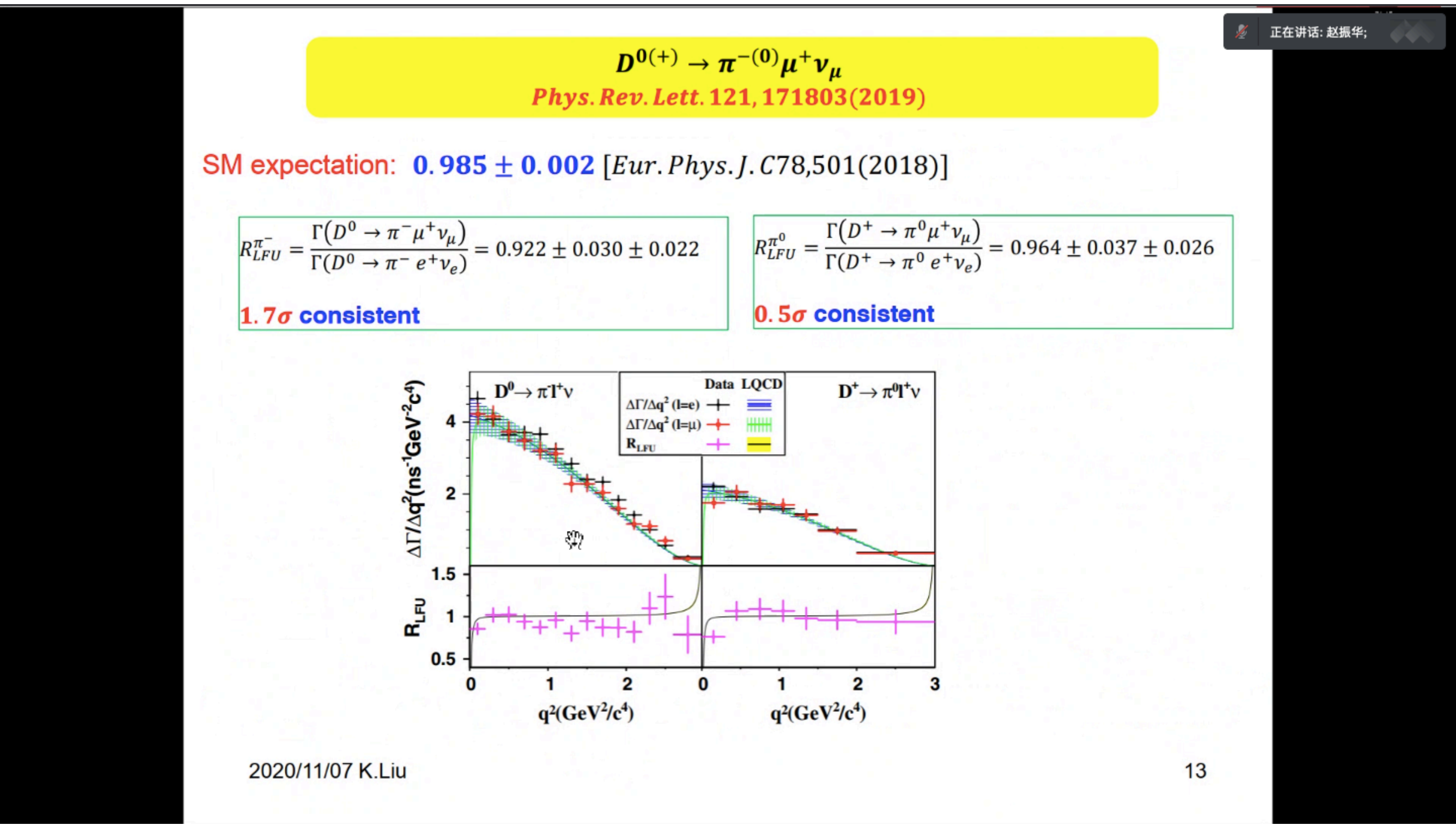
$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{M_{pole}^2}\right)\left(1 - \alpha\frac{q^2}{M_{pole}^2}\right)}$$

- **ISGW2 model**

$$f_+(q^2) = f_+(q_{max}^2)\left(1 + \frac{r^2}{12}(q_{max}^2 - q^2)\right)^{-2}$$

- **Series expansion model**

$$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)}a_0(t_0)(1 + \sum_{k=1}^{\infty} r_k(t_0)[z(t,t_0)]^k)$$



正在讲话: 赵振华;

$D^{0(+)} \to \pi^{-(0)} \mu^+ \nu_\mu$

Phys. Rev. Lett. 121, 171803(2019)

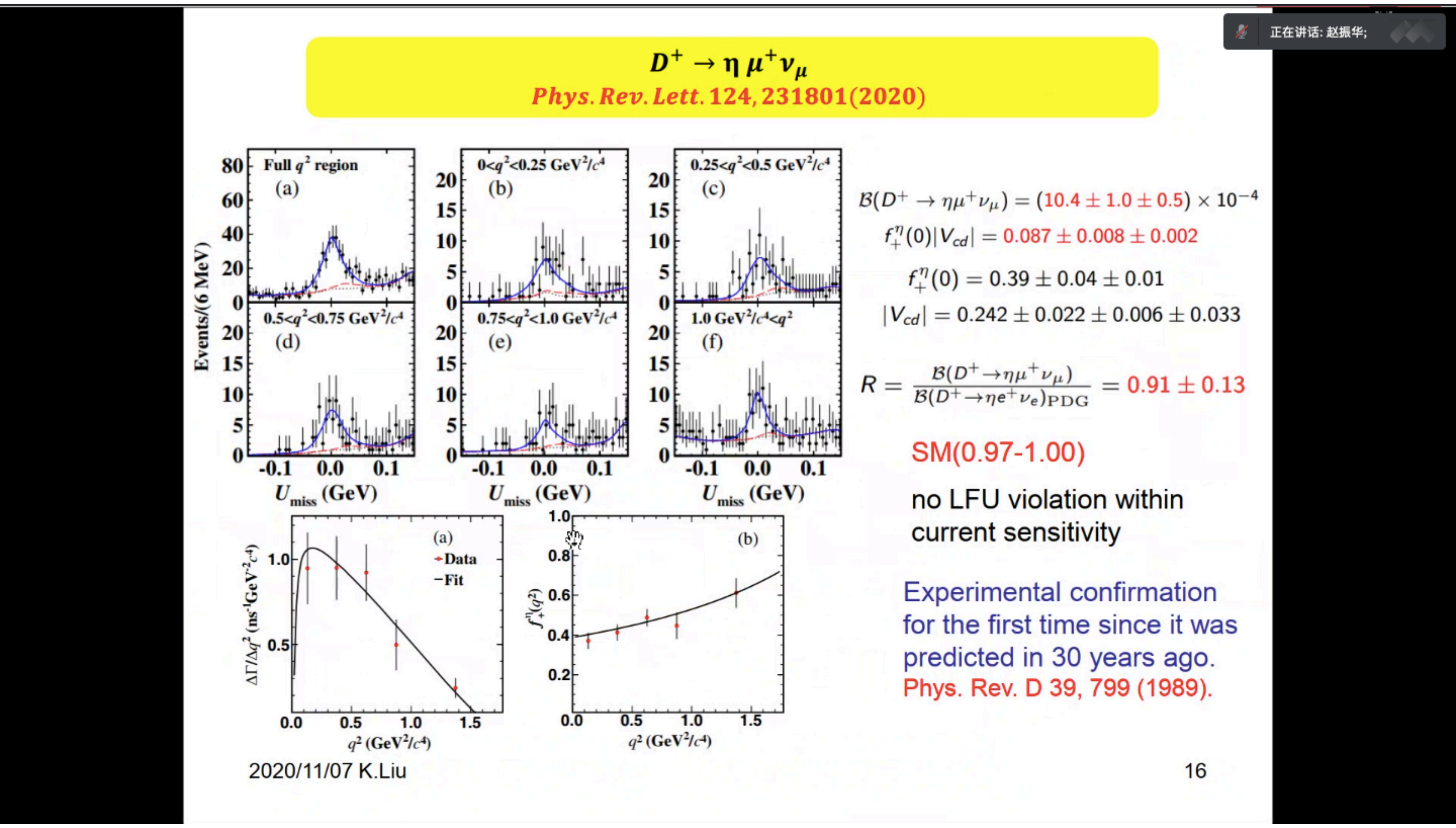
SM expectation: 0.985 ± 0.002 [*Eur. Phys. J.* C78,501(2018)]

$$R_{LFU}^{\pi^-} = \frac{\Gamma(D^0 \to \pi^- \mu^+ \nu_\mu)}{\Gamma(D^0 \to \pi^- e^+ \nu_e)} = 0.922 \pm 0.030 \pm 0.022$$

1.7σ consistent

$$R_{LFU}^{\pi^0} = \frac{\Gamma(D^+ \to \pi^0 \mu^+ \nu_\mu)}{\Gamma(D^+ \to \pi^0 e^+ \nu_e)} = 0.964 \pm 0.037 \pm 0.026$$

0.5σ consistent



$D^+ \to \eta\,\mu^+\nu_\mu$

Phys. Rev. Lett. 124, 231801(2020)

$\mathcal{B}(D^+ \to \eta\mu^+\nu_\mu) = (10.4 \pm 1.0 \pm 0.5) \times 10^{-4}$

$f_+^\eta(0)|V_{cd}| = 0.087 \pm 0.008 \pm 0.002$

$f_+^\eta(0) = 0.39 \pm 0.04 \pm 0.01$

$|V_{cd}| = 0.242 \pm 0.022 \pm 0.006 \pm 0.033$

$R = \frac{\mathcal{B}(D^+ \to \eta\mu^+\nu_\mu)}{\mathcal{B}(D^+ \to \eta e^+\nu_e)_{\rm PDG}} = 0.91 \pm 0.13$

SM(0.97-1.00)

no LFU violation within current sensitivity

Experimental confirmation for the first time since it was predicted in 30 years ago.
Phys. Rev. D 39, 799 (1989).

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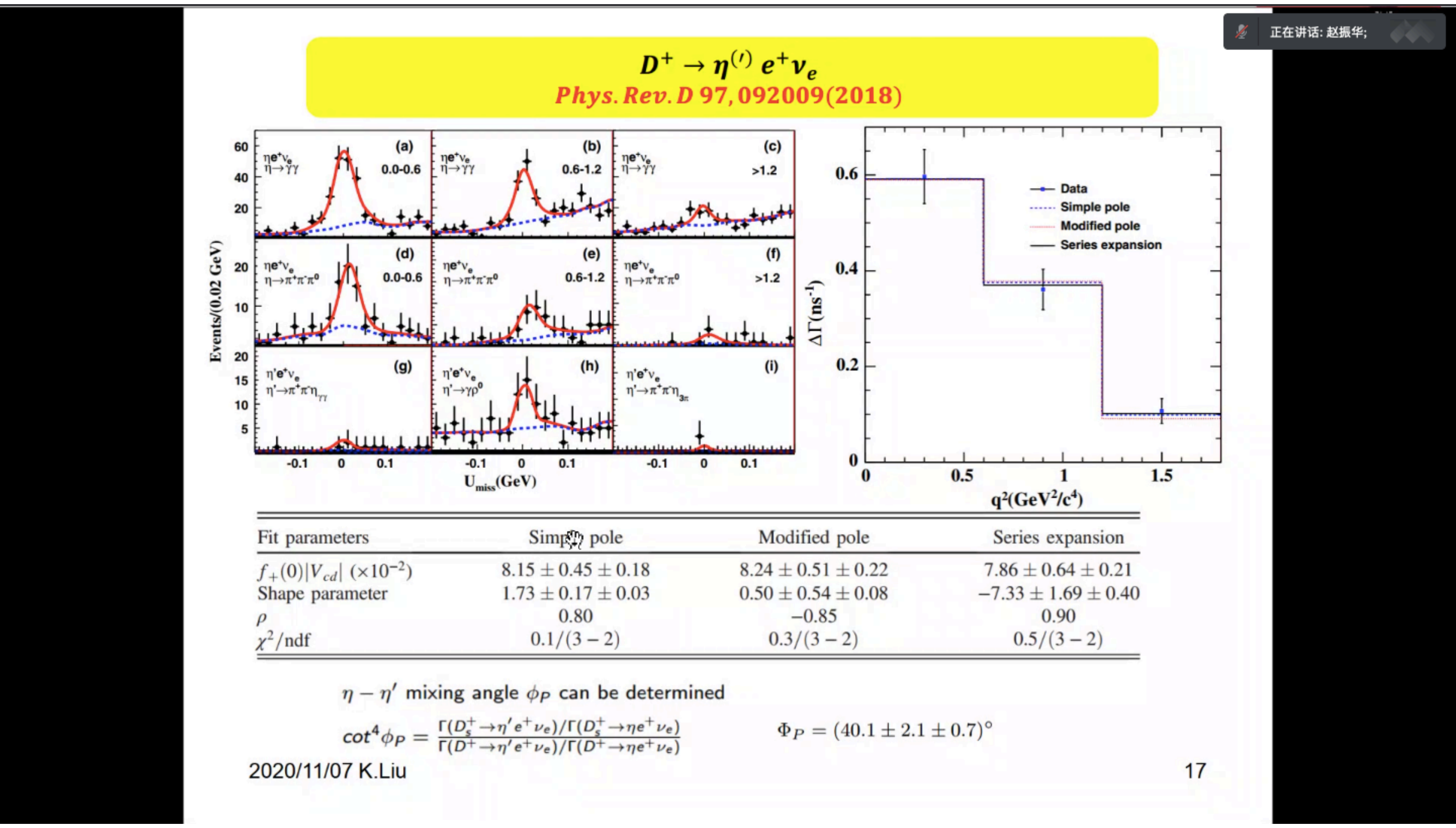


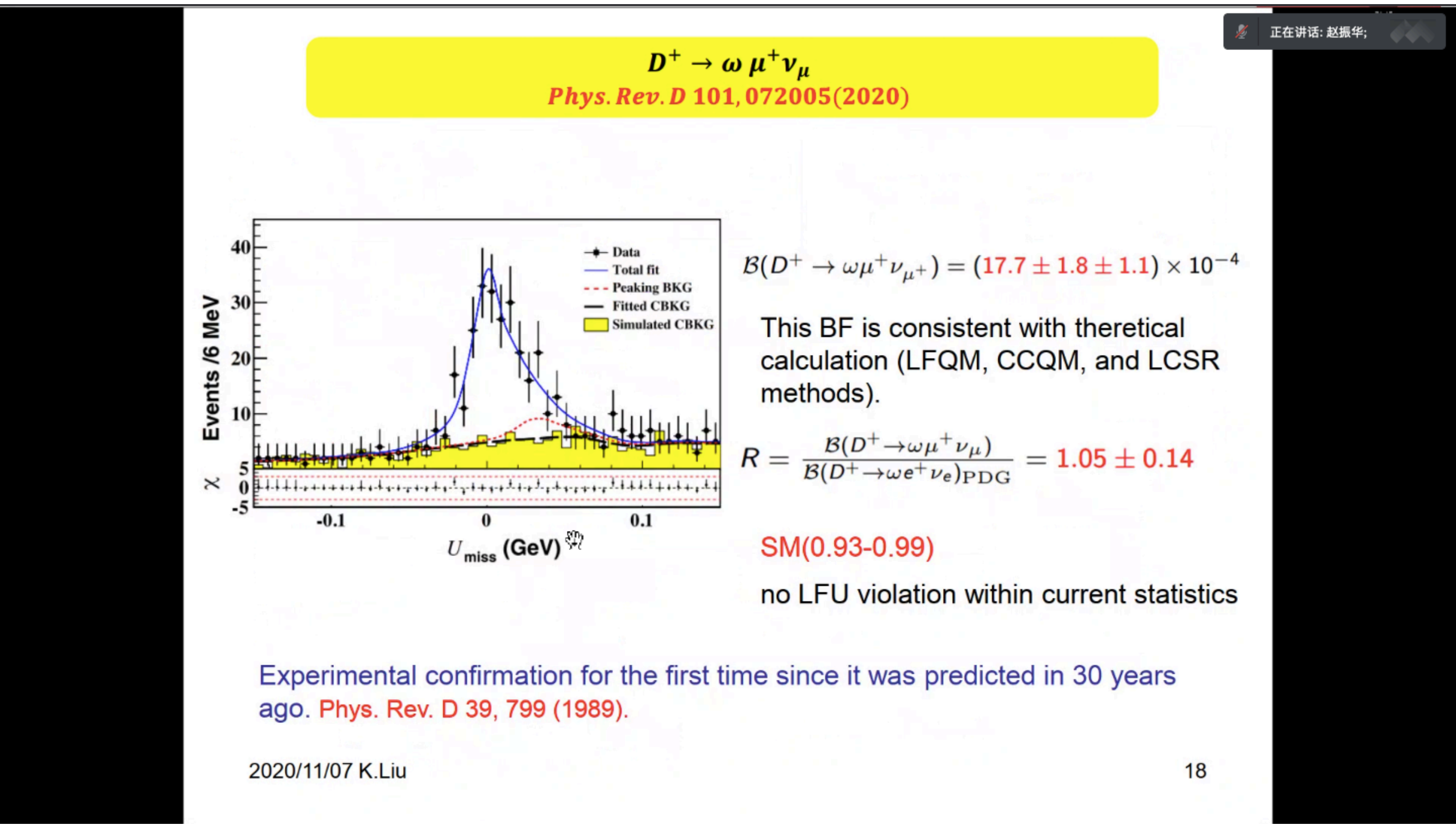
$D^+ \to \eta^{(\prime)} e^+ \nu_e$

Phys. Rev. D 97, 092009(2018)

Fit parameters	Simple pole	Modified pole	Series expansion
$f_+(0)\|V_{cd}\|$ ($\times10^{-2}$)	$8.15 \pm 0.45 \pm 0.18$	$8.24 \pm 0.51 \pm 0.22$	$7.86 \pm 0.64 \pm 0.21$
Shape parameter	$1.73 \pm 0.17 \pm 0.03$	$0.50 \pm 0.54 \pm 0.08$	$-7.33 \pm 1.69 \pm 0.40$
ρ	0.80	-0.85	0.90
χ^2/ndf	$0.1/(3-2)$	$0.3/(3-2)$	$0.5/(3-2)$

$\eta - \eta'$ mixing angle ϕ_P can be determined

$$cot^4\phi_P = \frac{\Gamma(D_s^+ \to \eta' e^+ \nu_e)/\Gamma(D_s^+ \to \eta e^+ \nu_e)}{\Gamma(D^+ \to \eta' e^+ \nu_e)/\Gamma(D^+ \to \eta e^+ \nu_e)} \qquad \Phi_P = (40.1 \pm 2.1 \pm 0.7)^\circ$$



$D^+ \to \omega\, \mu^+ \nu_\mu$

Phys. Rev. D 101, 072005(2020)

$$\mathcal{B}(D^+ \to \omega\mu^+\nu_{\mu^+}) = (17.7 \pm 1.8 \pm 1.1) \times 10^{-4}$$

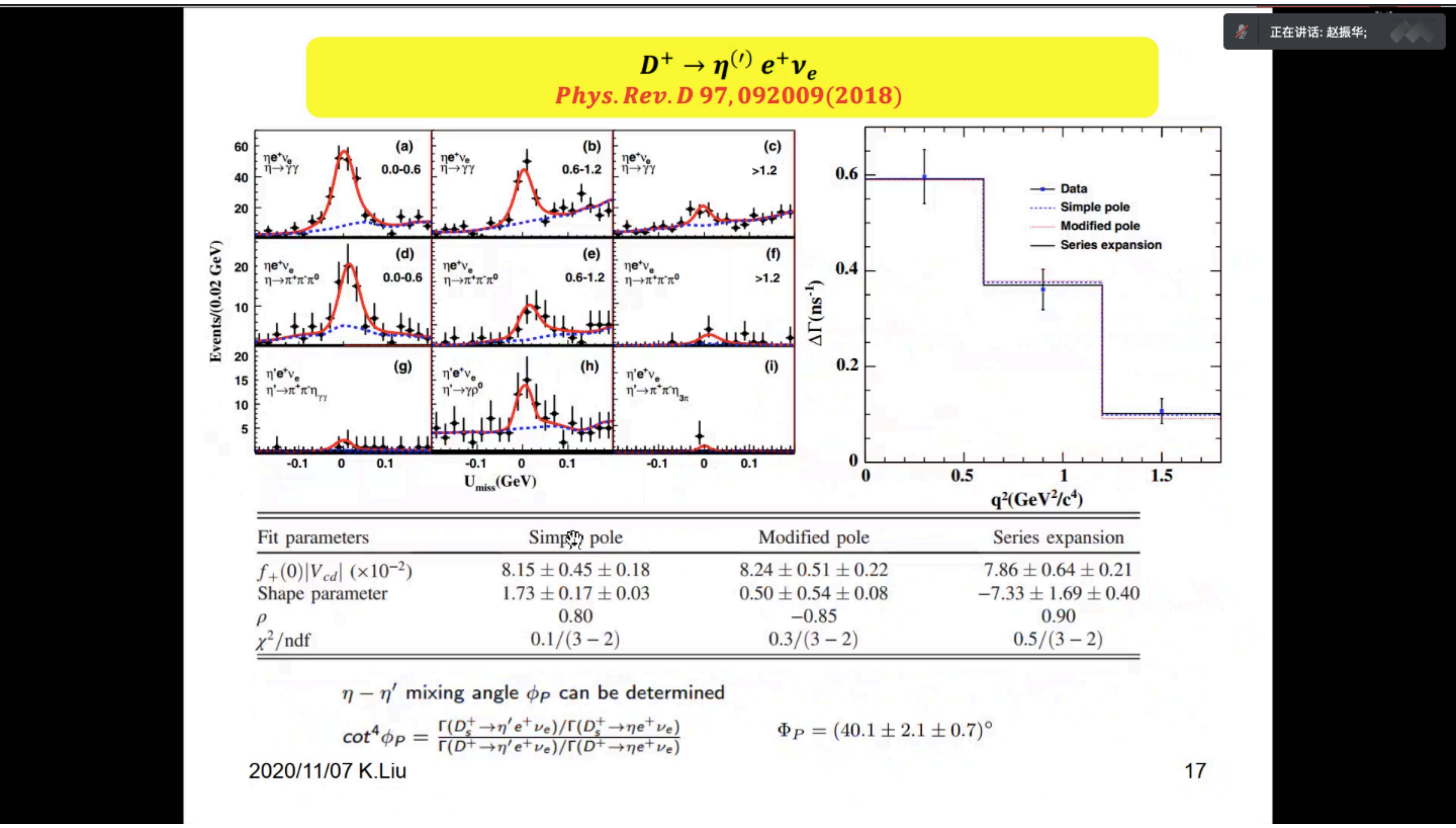
This BF is consistent with theretical calculation (LFQM, CCQM, and LCSR methods).

$$R = \frac{\mathcal{B}(D^+ \to \omega\mu^+\nu_\mu)}{\mathcal{B}(D^+ \to \omega e^+\nu_e)_{\mathrm{PDG}}} = 1.05 \pm 0.14$$

SM(0.93-0.99)

no LFU violation within current statistics

Experimental confirmation for the first time since it was predicted in 30 years ago. Phys. Rev. D 39, 799 (1989).



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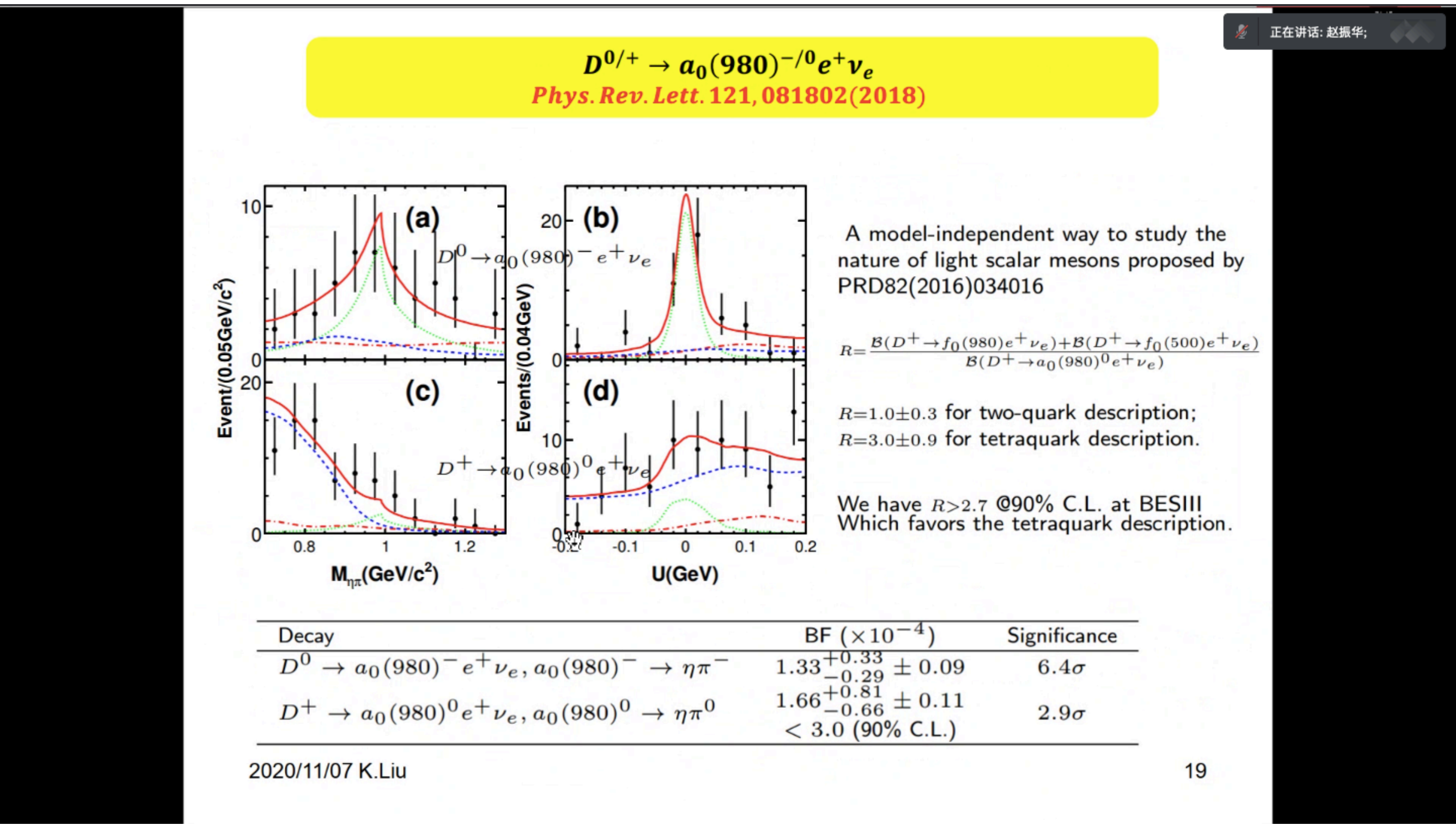
Shape parameter	$1.73 \pm 0.17 \pm 0.03$	$0.50 \pm 0.54 \pm 0.08$	$-7.33 \pm 1.69 \pm 0.40$
ρ	0.80	-0.85	0.90
χ^2/ndf	$0.1/(3-2)$	$0.3/(3-2)$	$0.5/(3-2)$

$\eta - \eta'$ mixing angle ϕ_P can be determined

$$cot^4\phi_P = \frac{\Gamma(D_s^+ \to \eta' e^+ \nu_e)/\Gamma(D_s^+ \to \eta e^+ \nu_e)}{\Gamma(D^+ \to \eta' e^+ \nu_e)/\Gamma(D^+ \to \eta e^+ \nu_e)} \qquad \Phi_P = (40.1 \pm 2.1 \pm 0.7)^\circ$$



$D^{0/+} \to a_0(980)^{-/0} e^+ \nu_e$

Phys. Rev. Lett. **121, 081802(2018)**

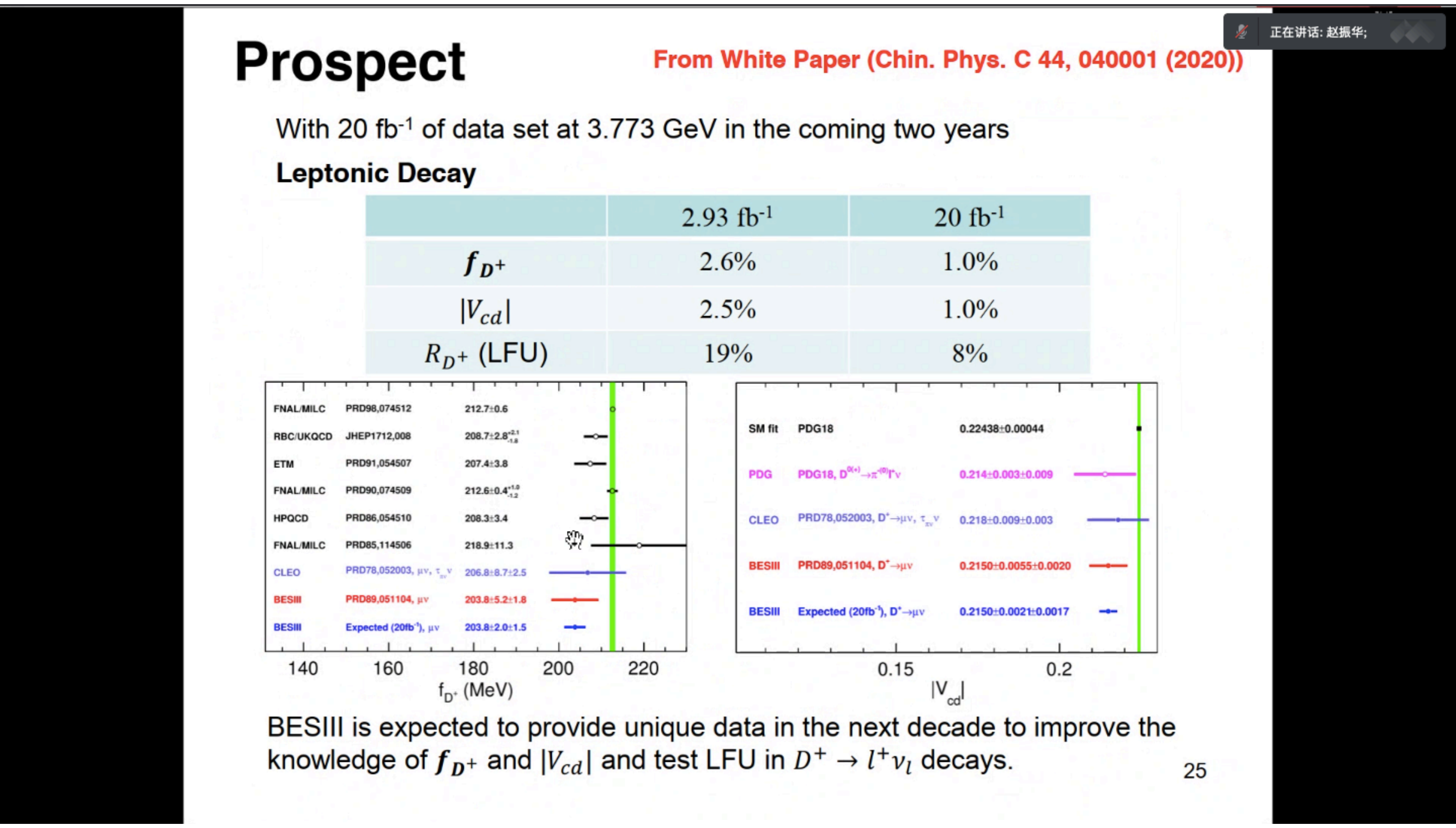
A model-independent way to study the nature of light scalar mesons proposed by PRD82(2016)034016

$$R = \frac{\mathcal{B}(D^+ \to f_0(980) e^+ \nu_e) + \mathcal{B}(D^+ \to f_0(500) e^+ \nu_e)}{\mathcal{B}(D^+ \to a_0(980)^0 e^+ \nu_e)}$$

$R = 1.0 \pm 0.3$ for two-quark description;
$R = 3.0 \pm 0.9$ for tetraquark description.

We have $R > 2.7$ @90% C.L. at BESIII
Which favors the tetraquark description.

Decay	BF ($\times 10^{-4}$)	Significance
$D^0 \to a_0(980)^- e^+ \nu_e,\ a_0(980)^- \to \eta\pi^-$	$1.33^{+0.33}_{-0.29} \pm 0.09$	6.4σ
$D^+ \to a_0(980)^0 e^+ \nu_e,\ a_0(980)^0 \to \eta\pi^0$	$1.66^{+0.81}_{-0.66} \pm 0.11$ < 3.0 (90% C.L.)	2.9σ



Prospect

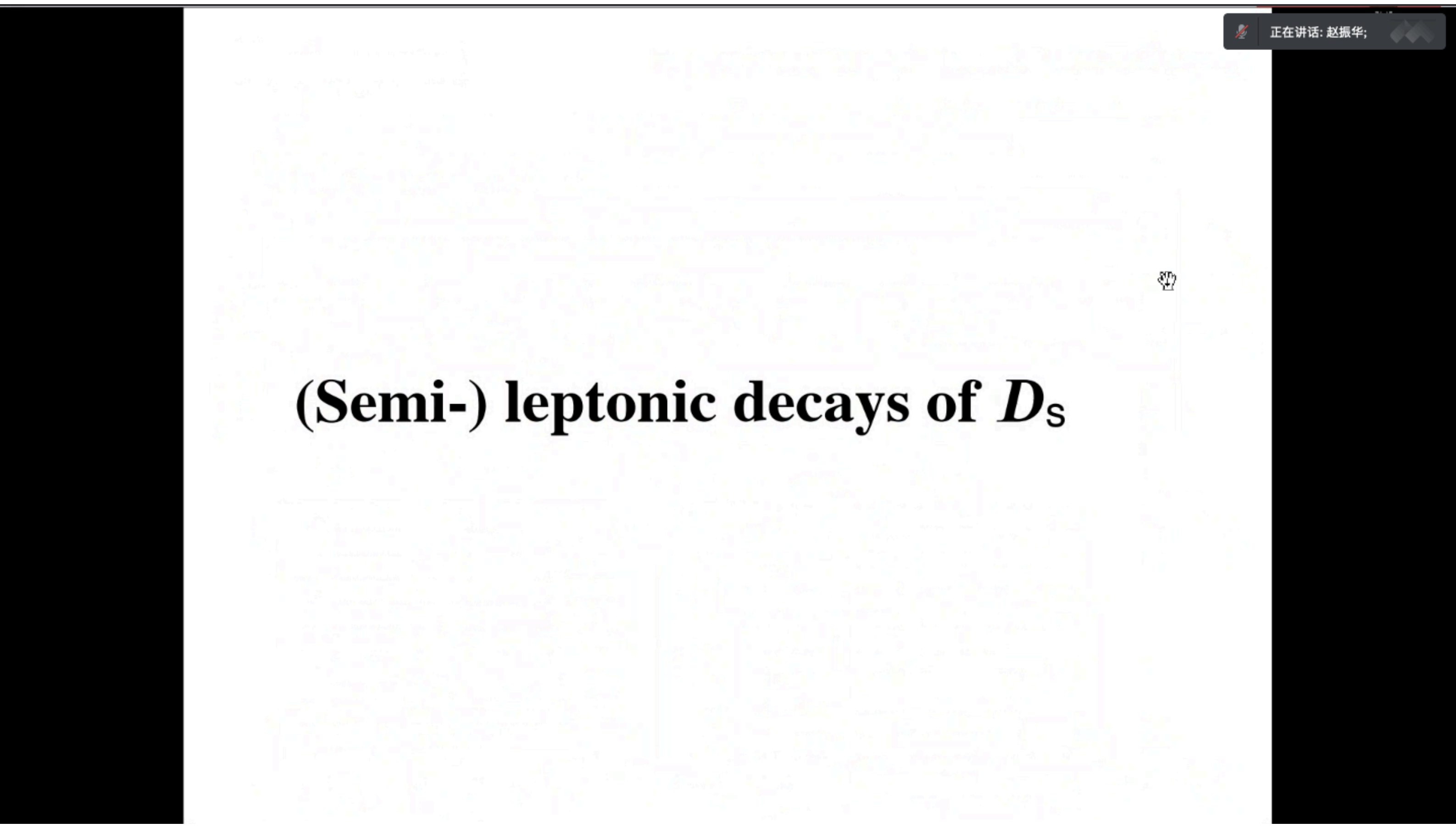
From White Paper (Chin. Phys. C 44, 040001 (2020))

With 20 fb^{-1} of data set at 3.773 GeV in the coming two years

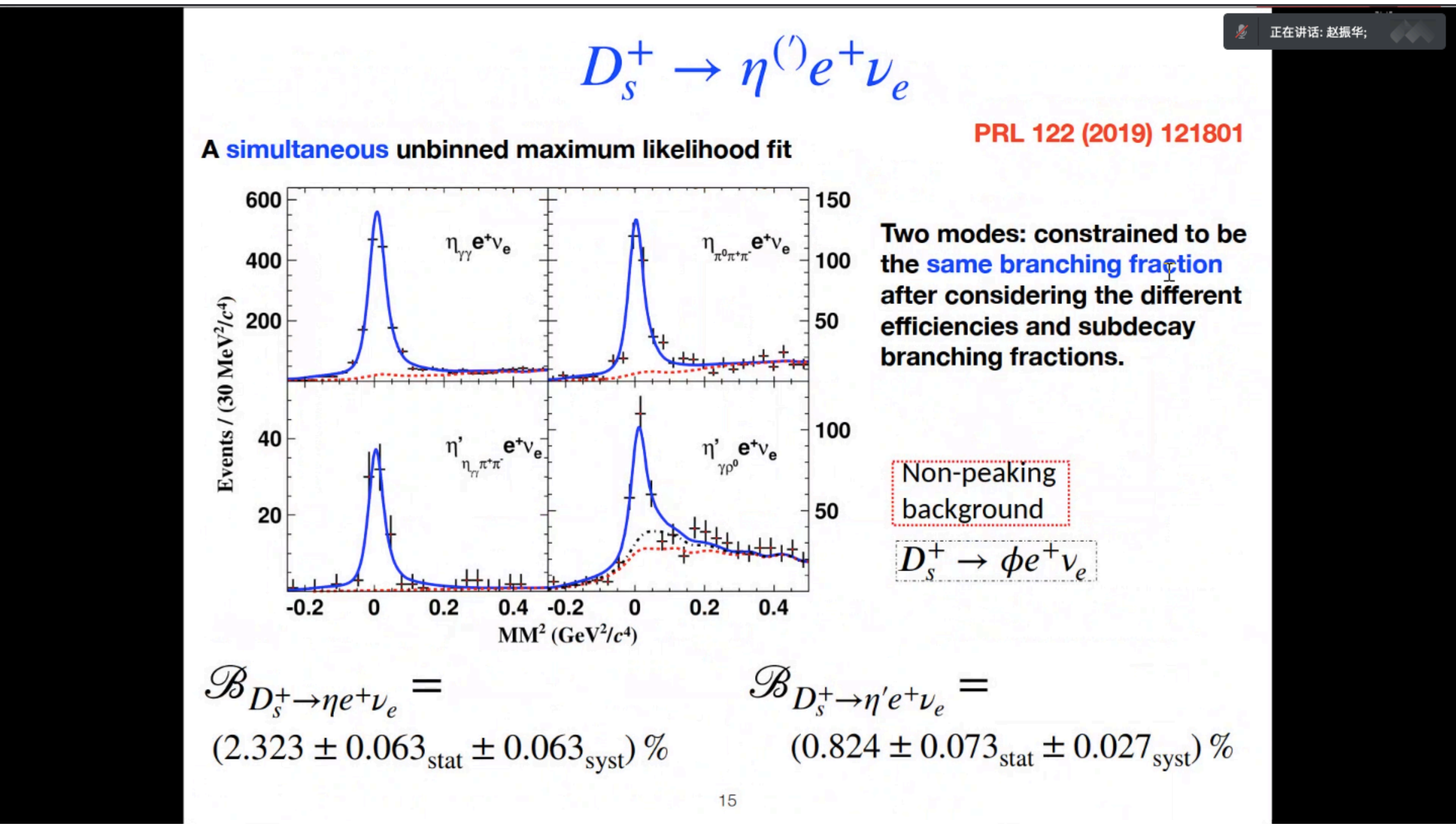
Leptonic Decay

	2.93 fb^{-1}	20 fb^{-1}
$\boldsymbol{f_{D^+}}$	2.6%	1.0%
$\lvert V_{cd}\rvert$	2.5%	1.0%
R_{D^+} (LFU)	19%	8%

BESIII is expected to provide unique data in the next decade to improve the knowledge of $\boldsymbol{f_{D^+}}$ and $|V_{cd}|$ and test LFU in $D^+ \to l^+\nu_l$ decays.



(Semi-) leptonic decays of D_S



$D_s^+ \to \eta^{(\prime)} e^+ \nu_e$

PRL 122 (2019) 121801

A simultaneous unbinned maximum likelihood fit

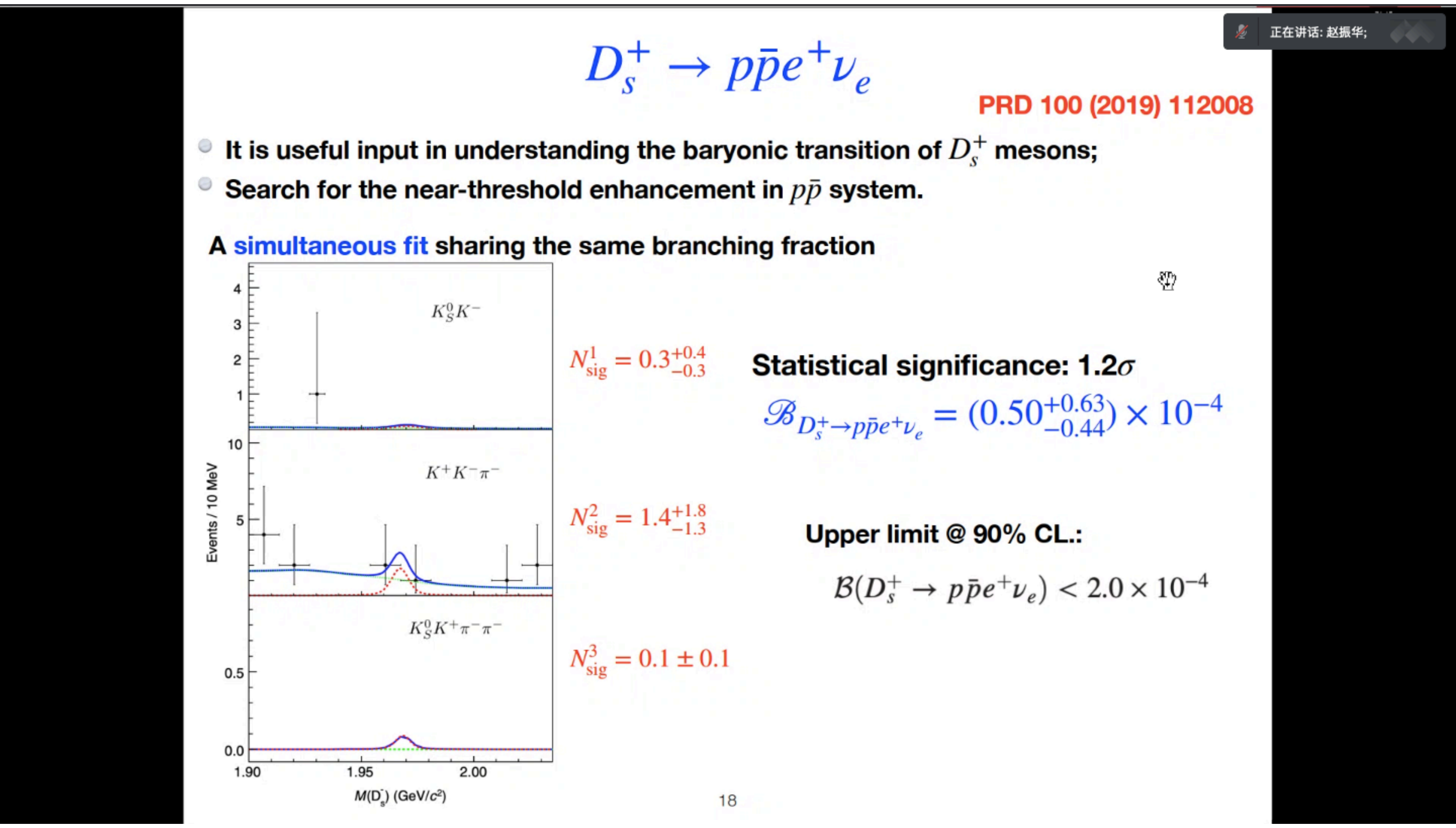
Two modes: constrained to be the same branching fraction after considering the different efficiencies and subdecay branching fractions.

Non-peaking background

$D_s^+ \to \phi e^+ \nu_e$

$$\mathscr{B}_{D_s^+ \to \eta e^+ \nu_e} = (2.323 \pm 0.063_{\rm stat} \pm 0.063_{\rm syst})\ \%$$

$$\mathscr{B}_{D_s^+ \to \eta' e^+ \nu_e} = (0.824 \pm 0.073_{\rm stat} \pm 0.027_{\rm syst})\ \%$$



$D_s^+ \to p\bar{p}e^+\nu_e$

PRD 100 (2019) 112008

- **It is useful input in understanding the baryonic transition of D_s^+ mesons;**
- **Search for the near-threshold enhancement in $p\bar{p}$ system.**

A simultaneous fit sharing the same branching fraction

$N_{\rm sig}^1 = 0.3^{+0.4}_{-0.3}$

$N_{\rm sig}^2 = 1.4^{+1.8}_{-1.3}$

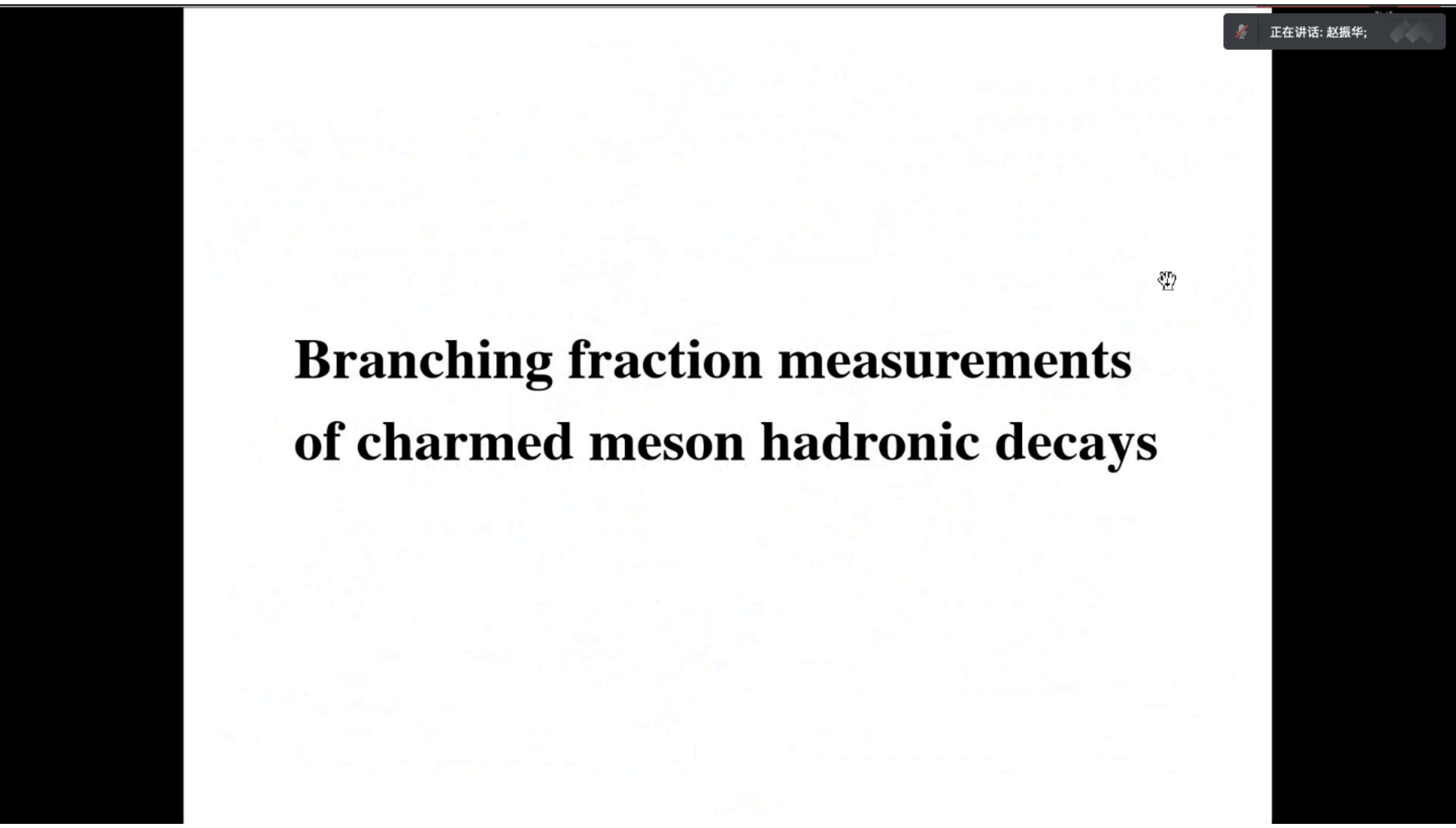
$N_{\rm sig}^3 = 0.1 \pm 0.1$

Statistical significance: 1.2σ

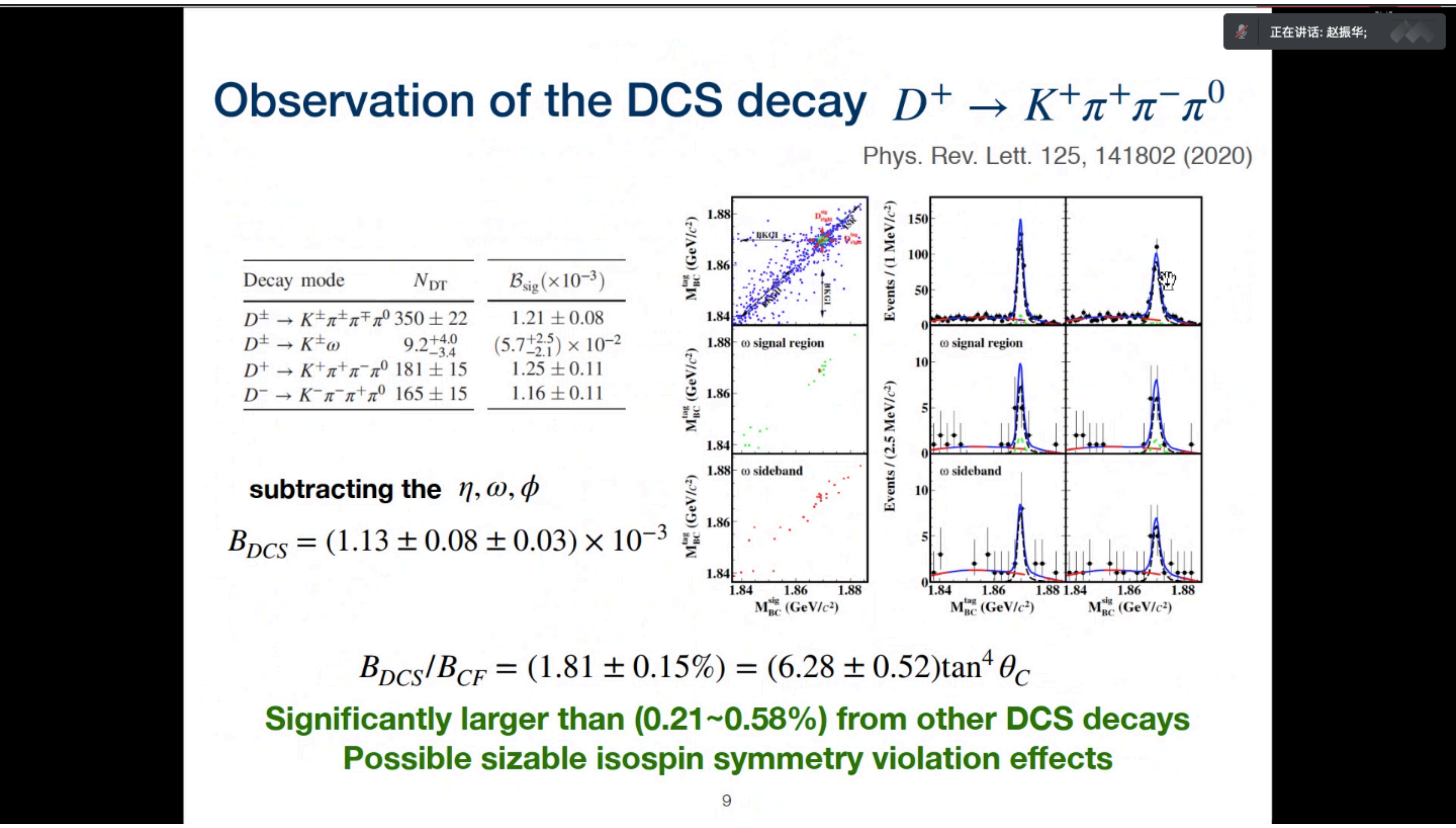
$$\mathscr{B}_{D_s^+\to p\bar{p}e^+\nu_e} = (0.50^{+0.63}_{-0.44}) \times 10^{-4}$$

Upper limit @ 90% CL.:

$$\mathcal{B}(D_s^+ \to p\bar{p}e^+\nu_e) < 2.0 \times 10^{-4}$$



Branching fraction measurements of charmed meson hadronic decays



Observation of the DCS decay $D^+ \to K^+\pi^+\pi^-\pi^0$

Phys. Rev. Lett. 125, 141802 (2020)

Decay mode	N_{DT}	$\mathcal{B}_{\mathrm{sig}}(\times 10^{-3})$
$D^\pm \to K^\pm\pi^\pm\pi^\mp\pi^0$	350 ± 22	1.21 ± 0.08
$D^\pm \to K^\pm\omega$	$9.2^{+4.0}_{-3.4}$	$(5.7^{+2.5}_{-2.1}) \times 10^{-2}$
$D^+ \to K^+\pi^+\pi^-\pi^0$	181 ± 15	1.25 ± 0.11
$D^- \to K^-\pi^-\pi^+\pi^0$	165 ± 15	1.16 ± 0.11

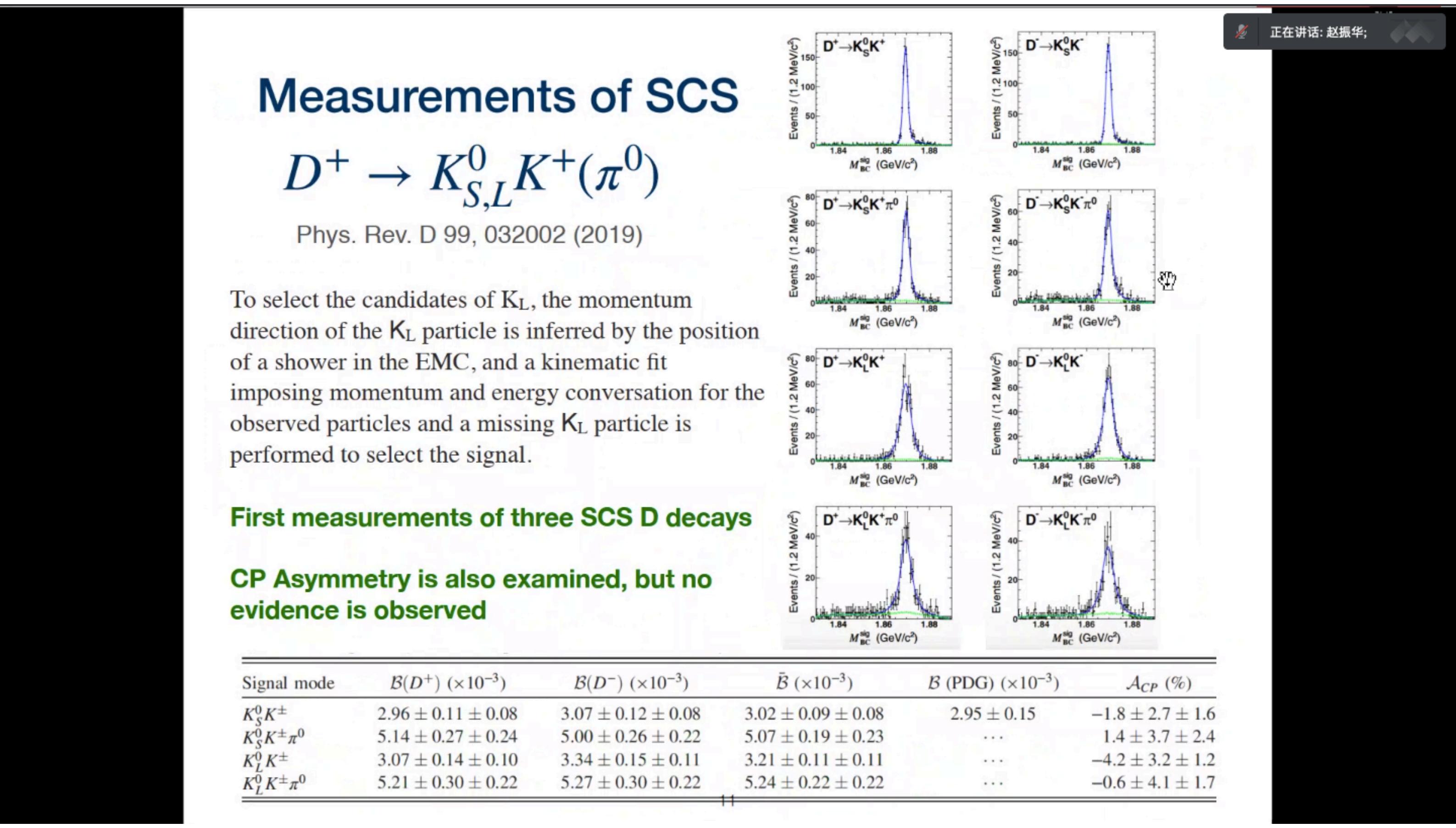
subtracting the η, ω, ϕ

$$B_{DCS} = (1.13 \pm 0.08 \pm 0.03) \times 10^{-3}$$

$$B_{DCS}/B_{CF} = (1.81 \pm 0.15\%) = (6.28 \pm 0.52)\tan^4\theta_C$$

Significantly larger than (0.21~0.58%) from other DCS decays

Possible sizable isospin symmetry violation effects



Measurements of SCS

$$D^+ \to K^0_{S,L} K^+ (\pi^0)$$

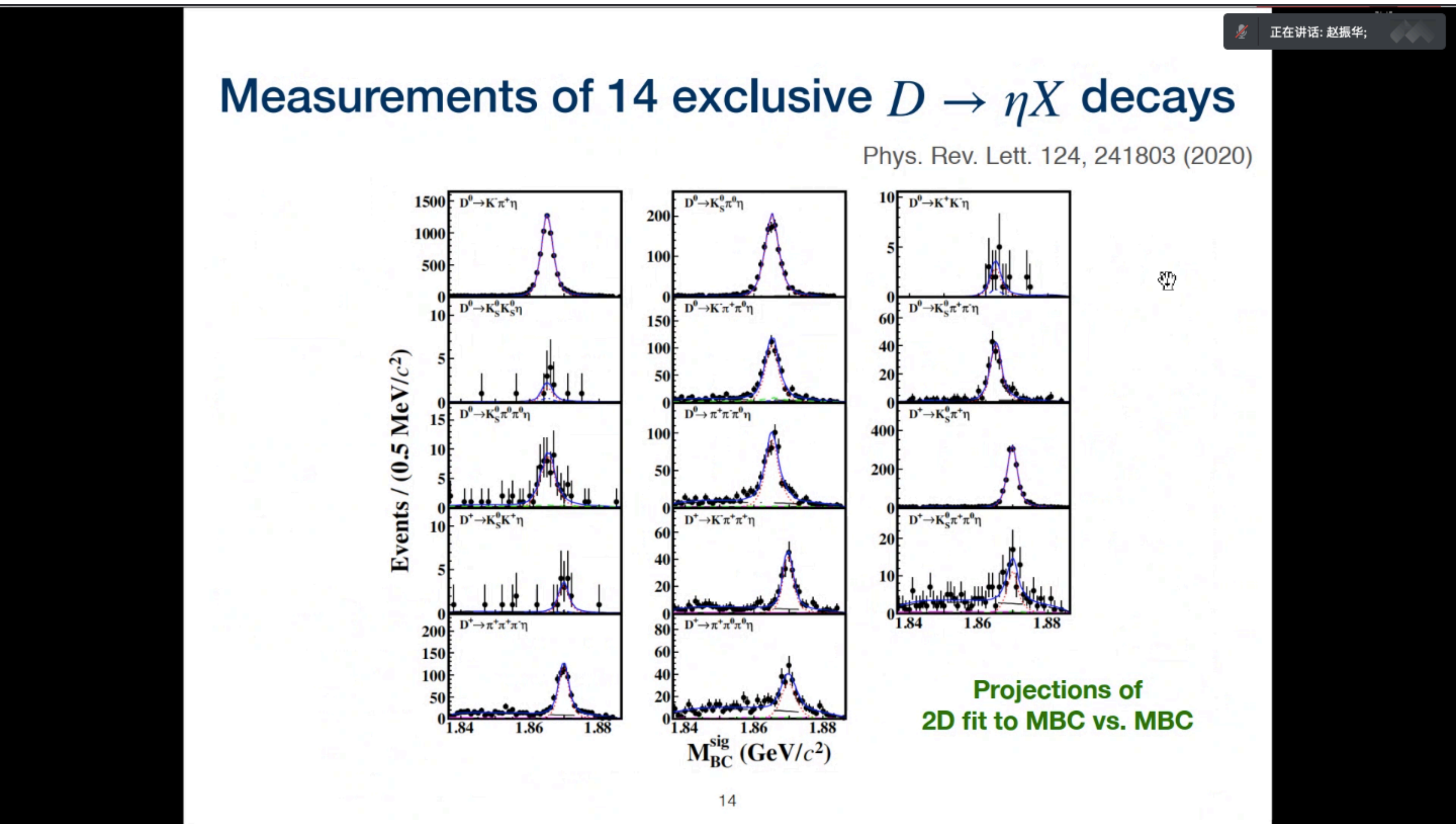
Phys. Rev. D 99, 032002 (2019)

To select the candidates of K_L, the momentum direction of the K_L particle is inferred by the position of a shower in the EMC, and a kinematic fit imposing momentum and energy conversation for the observed particles and a missing K_L particle is performed to select the signal.

First measurements of three SCS D decays

CP Asymmetry is also examined, but no evidence is observed

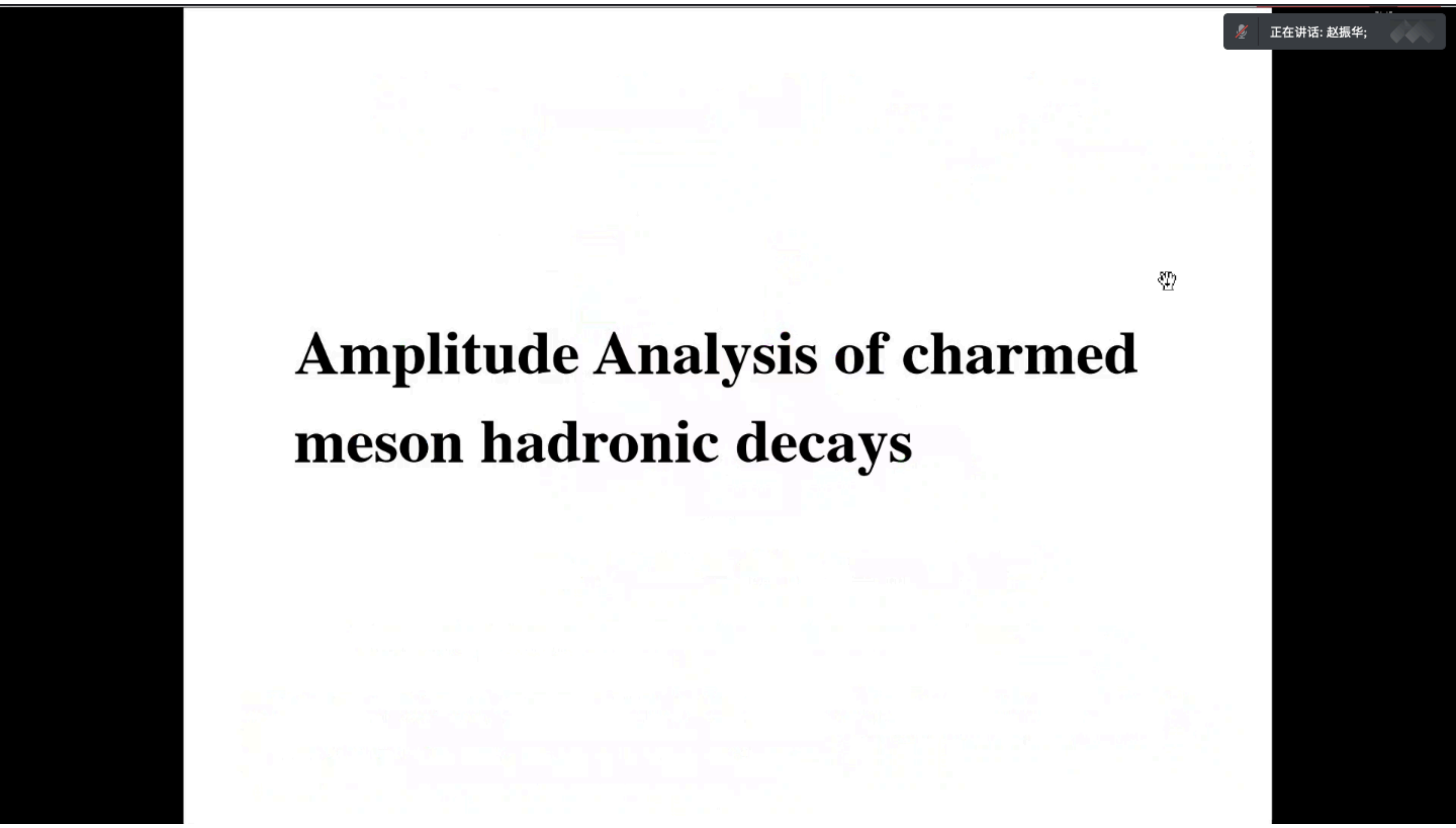
Signal mode	$\mathcal{B}(D^+)$ ($\times 10^{-3}$)	$\mathcal{B}(D^-)$ ($\times 10^{-3}$)	$\bar{\mathcal{B}}$ ($\times 10^{-3}$)	$\mathcal{B}$ (PDG) ($\times 10^{-3}$)	$\mathcal{A}_{CP}$ (%)
$K^0_S K^\pm$	$2.96 \pm 0.11 \pm 0.08$	$3.07 \pm 0.12 \pm 0.08$	$3.02 \pm 0.09 \pm 0.08$	2.95 ± 0.15	$-1.8 \pm 2.7 \pm 1.6$
$K^0_S K^\pm \pi^0$	$5.14 \pm 0.27 \pm 0.24$	$5.00 \pm 0.26 \pm 0.22$	$5.07 \pm 0.19 \pm 0.23$	⋯	$1.4 \pm 3.7 \pm 2.4$
$K^0_L K^\pm$	$3.07 \pm 0.14 \pm 0.10$	$3.34 \pm 0.15 \pm 0.11$	$3.21 \pm 0.11 \pm 0.11$	⋯	$-4.2 \pm 3.2 \pm 1.2$
$K^0_L K^\pm \pi^0$	$5.21 \pm 0.30 \pm 0.22$	$5.27 \pm 0.30 \pm 0.22$	$5.24 \pm 0.22 \pm 0.22$	⋯	$-0.6 \pm 4.1 \pm 1.7$



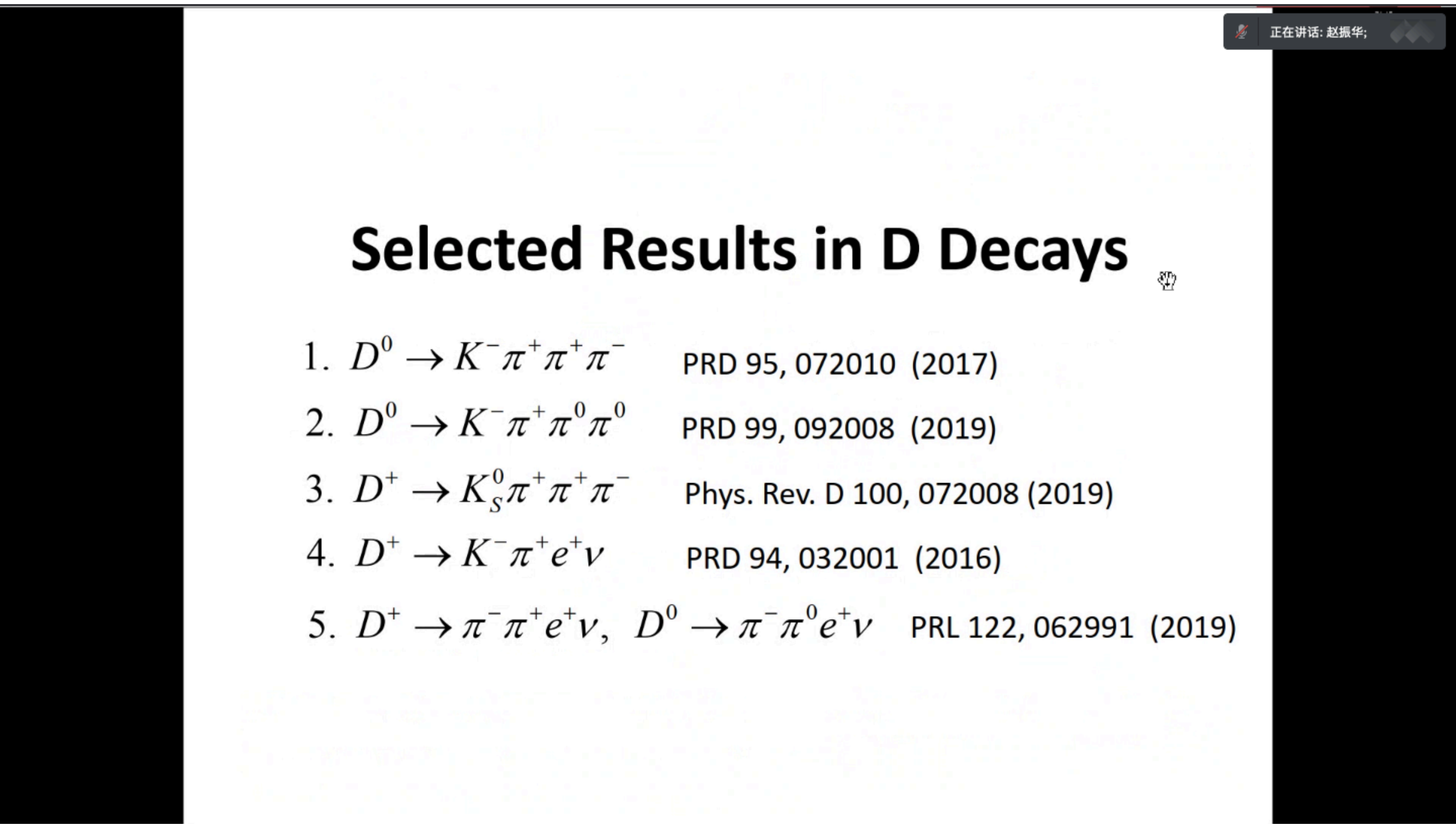
Measurements of 14 exclusive $D \to \eta X$ decays

Phys. Rev. Lett. 124, 241803 (2020)

Projections of
2D fit to MBC vs. MBC

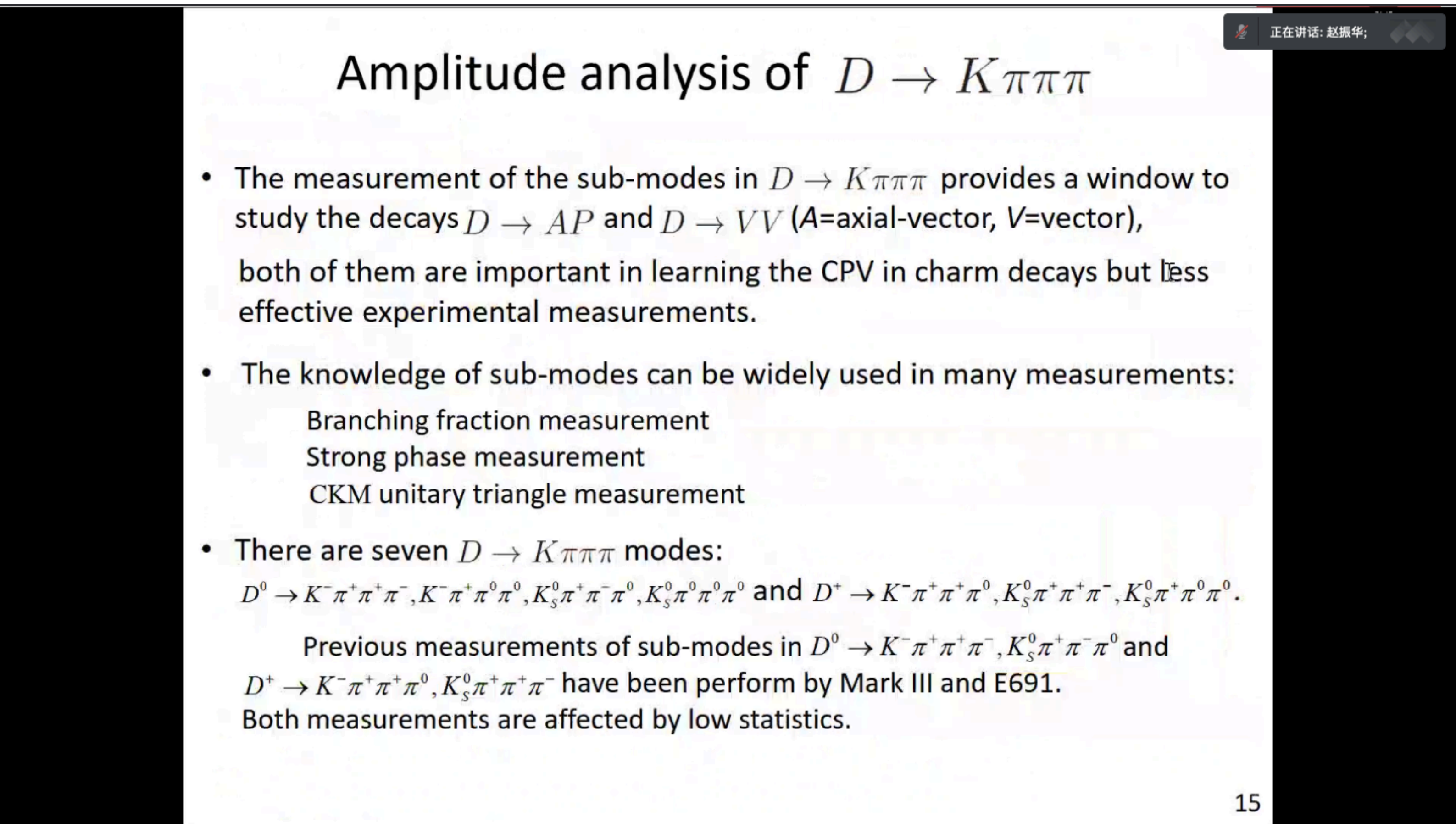


Amplitude Analysis of charmed meson hadronic decays



Selected Results in D Decays

1. $D^0 \to K^- \pi^+ \pi^+ \pi^-$ PRD 95, 072010 (2017)
2. $D^0 \to K^- \pi^+ \pi^0 \pi^0$ PRD 99, 092008 (2019)
3. $D^+ \to K_S^0 \pi^+ \pi^+ \pi^-$ Phys. Rev. D 100, 072008 (2019)
4. $D^+ \to K^- \pi^+ e^+ \nu$ PRD 94, 032001 (2016)
5. $D^+ \to \pi^- \pi^+ e^+ \nu,\ D^0 \to \pi^- \pi^0 e^+ \nu$ PRL 122, 062991 (2019)



Amplitude analysis of $D \to K\pi\pi\pi$

- The measurement of the sub-modes in $D \to K\pi\pi\pi$ provides a window to study the decays $D \to AP$ and $D \to VV$ (*A*=axial-vector, *V*=vector),

  both of them are important in learning the CPV in charm decays but less effective experimental measurements.

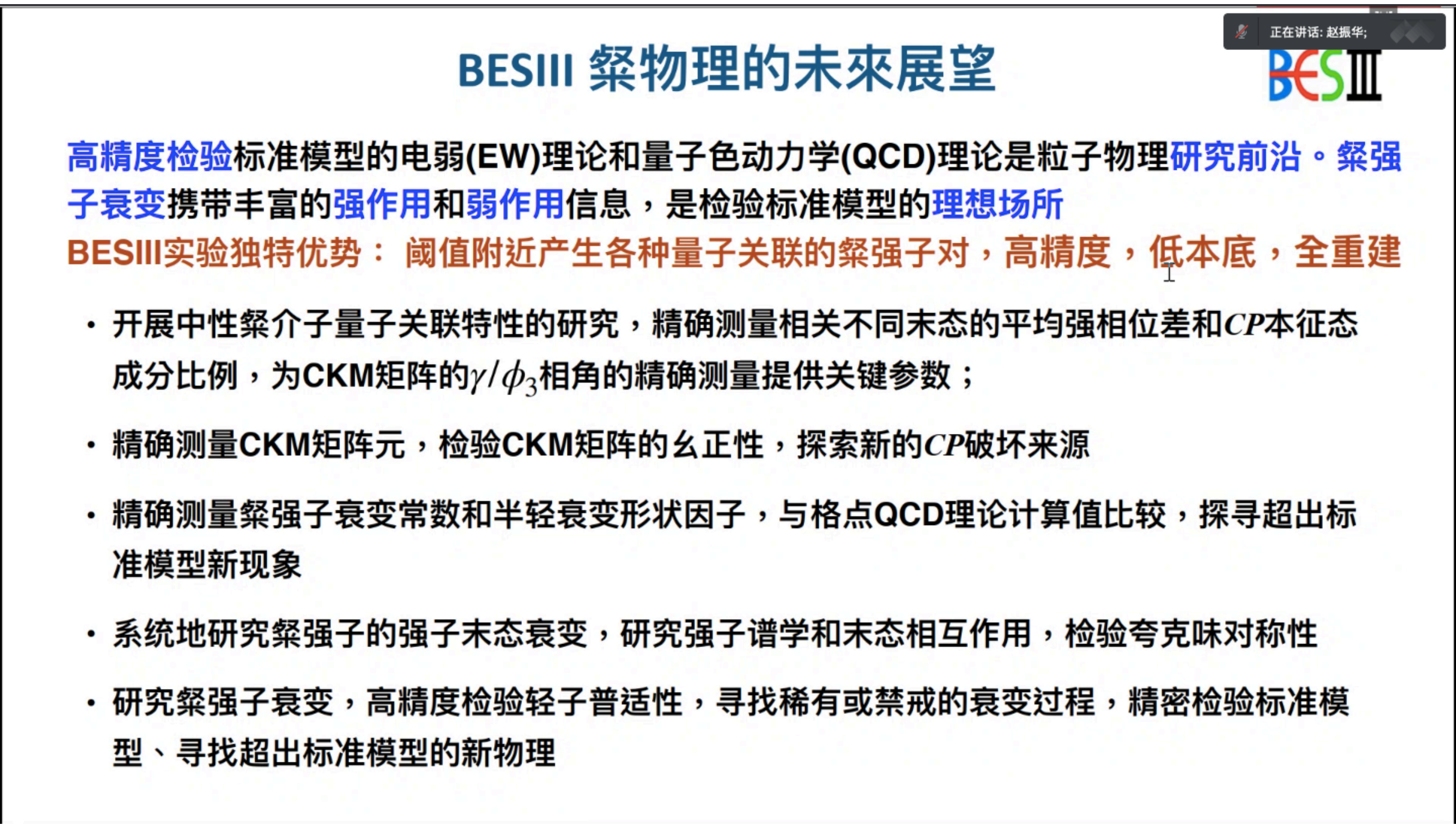
- The knowledge of sub-modes can be widely used in many measurements:

  Branching fraction measurement
  Strong phase measurement
  CKM unitary triangle measurement

- There are seven $D \to K\pi\pi\pi$ modes:

  $D^0 \to K^-\pi^+\pi^+\pi^-, K^-\pi^+\pi^0\pi^0, K_S^0\pi^+\pi^-\pi^0, K_S^0\pi^0\pi^0\pi^0$ and $D^+ \to K^-\pi^+\pi^+\pi^0, K_S^0\pi^+\pi^+\pi^-, K_S^0\pi^+\pi^0\pi^0$.

  Previous measurements of sub-modes in $D^0 \to K^-\pi^+\pi^+\pi^-, K_S^0\pi^+\pi^-\pi^0$ and $D^+ \to K^-\pi^+\pi^+\pi^0, K_S^0\pi^+\pi^+\pi^-$ have been perform by Mark III and E691.
  Both measurements are affected by low statistics.



BESIII 粲物理的未來展望

高精度检验标准模型的电弱(EW)理论和量子色动力学(QCD)理论是粒子物理研究前沿。粲强子衰变携带丰富的强作用和弱作用信息，是检验标准模型的理想场所

BESIII实验独特优势： 阈值附近产生各种量子关联的粲强子对，高精度，低本底，全重建

- 开展中性粲介子量子关联特性的研究，精确测量相关不同末态的平均强相位差和CP本征态成分比例，为CKM矩阵的γ/ϕ_3相角的精确测量提供关键参数；
- 精确测量CKM矩阵元，检验CKM矩阵的幺正性，探索新的CP破坏来源
- 精确测量粲强子衰变常数和半轻衰变形状因子，与格点QCD理论计算值比较，探寻超出标准模型新现象
- 系统地研究粲强子的强子末态衰变，研究强子谱学和末态相互作用，检验夸克味对称性
- 研究粲强子衰变，高精度检验轻子普适性，寻找稀有或禁戒的衰变过程，精密检验标准模型、寻找超出标准模型的新物理