Joint Workshop of future tau-charm factory
4 - 7 Dec 2018, Orsay

Physics Summary

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Physics talks:

1）Tau Physics with future tau-charm factory - Antonio Pich

Tau Lepton flavor violation - Lorenzo Calibbi
Updated determinations of V_{us} with tau data - Alberto Lusiani

2）Charm Physics with future tau-charm factory - Svjetlana Fajfer

Decays of charmed hadrons - Xiao-Rui Lyu
Prospects of charmonium(+like) states study - Galina Pakhlova
Is there any Physics from 5 to 7 GeV? - Pavel Pakhlov
Status and perspective on g-2 of charm - Emi Kou

3）Status of detector and physics simulations at HIEPA & SCT - Xiaorong Zhou & Andrey Sukharev

Simulation of physics background in SCT detector - Lev Shekhtman
Belle2 beam background simulations and measurements - Hiroyuki Nakayama
Software for detector development studies and production - André Sailer

Two major aims of physics at STCF:

1. Search for New Physics beyond Standard Model

2. Hadron spectroscopy to explore how quarks & gluons construct hadrons with strong QCD

1. **Search for New Physics beyond Standard Model from tau & charm decays**

τ Data Samples

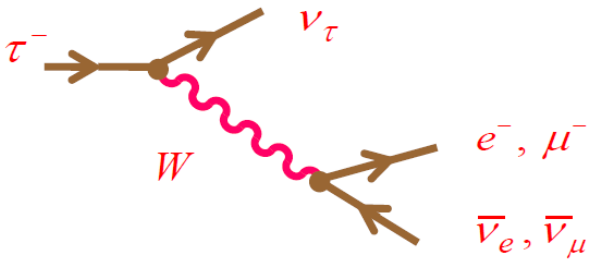
ALEPH:	$3.3 \cdot 10^5$	reconstructed τ decays
BaBar / Belle:	$1.4 \cdot 10^9$	$\tau^+\tau^-$ pairs
Belle-II:	$4.6 \cdot 10^{10}$	$\tau^+\tau^-$ pairs
sτcF:	$2.1 \cdot 10^{10}$	$\tau^+\tau^-$ pairs (10^8 near threshold)

Luminosity (10^{35} cm^{-2} s^{-1}) is important. Systematics also!

Advantages of the threshold región:

- Ability to measure backgrounds (running below threshold)
- Free of heavy quark backgrounds
- Single-Tagging ➡ Precise measurement of absolute branching fractions
- Monochromatic spectra for two-body decays (π, K)

LEPTONIC DECAYS

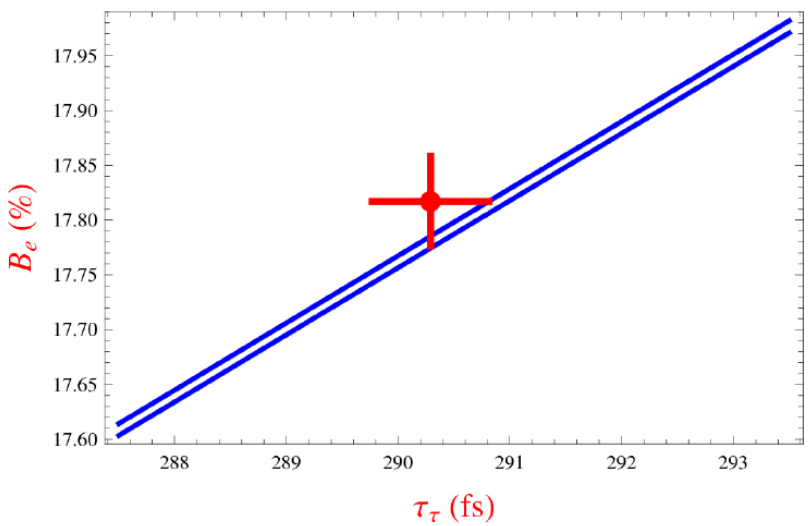


$$\Gamma(\tau \to \nu_\tau\, l\, \bar{\nu}_l) = \frac{G_F^2\, m_\tau^5}{192\,\pi^3}\, f(m_l^2/m_\tau^2)\,\left(1+\delta_{\rm RC}\right)$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x$$

$$\boxed{B_e = \frac{B_\mu}{0.972561 \pm 0.000004} = \frac{\tau_\tau}{(1632.7 \pm 0.5)\times 10^{-15}\,\mathrm{s}}}$$

τ_τ (Belle), m_τ (BesIII)

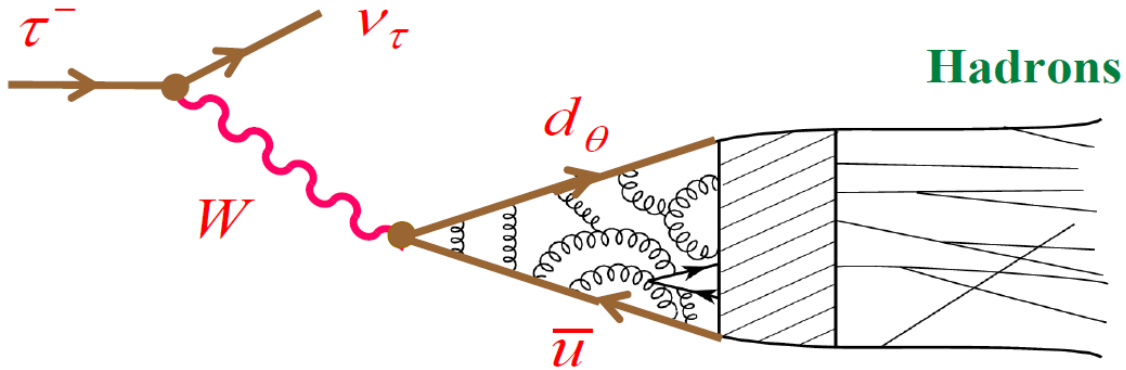


$$\left(B_\mu/B_e\right)_{\rm exp} = 0.9762 \pm 0.0028$$

Non-BF:	0.9725 ± 0.0039
BaBar '10:	0.9796 ± 0.0039

$$B_e^{\rm univ} = (17.815 \pm 0.023)\,\%$$

HADRONIC TAU DECAY



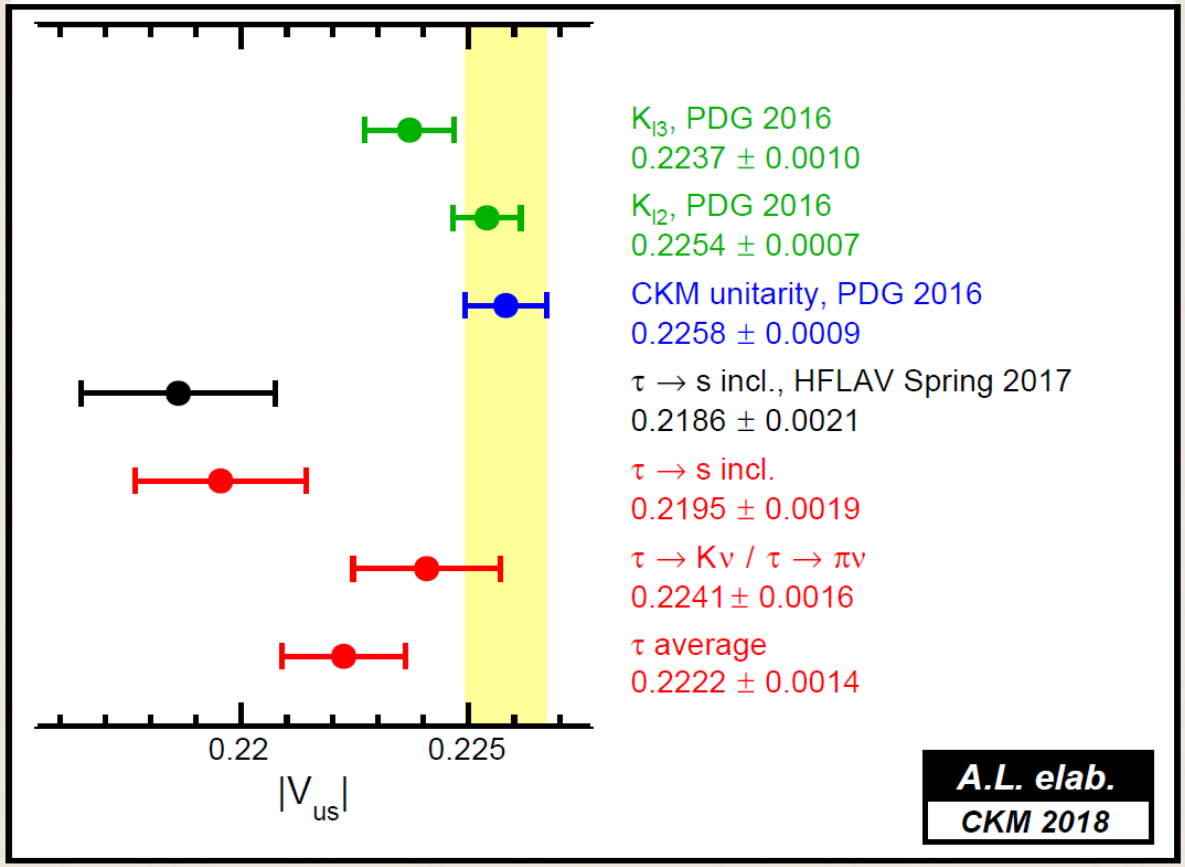
$$d_\theta = V_{ud}\, d + V_{us}\, s$$

Only lepton massive enough to decay into hadrons

$$R_\tau \equiv \frac{\Gamma\left(\tau^- \to \nu_\tau + \text{Hadrons}\right)}{\Gamma\left(\tau^- \to \nu_\tau\, e^-\, \overline{\nu}_e\right)} \approx N_C \quad ; \quad R_\tau = \frac{1 - B_e - B_\mu}{B_e} = 3.637 \pm 0.011$$

$$R_\tau = \frac{1}{B_e^{\text{univ}}} - 1.97256 = 3.6407 \pm 0.0072 \quad ; \quad R_\tau = \frac{\text{Br}\left(\tau^- \to \nu_\tau + \text{Hadrons}\right)}{B_e^{\text{univ}}} = 3.6349 \pm 0.0082$$

$|V_{us}|$ from tau, HFLAV 2017 + *BABAR* ICHEP 2018



- $\tau \to s$ inclusive vs. CKM unitarity discrepancy: $-3.0\,\sigma$
  - no significant change, $|V_{us}|$ increased a bit, uncertainty reduced

CP Asymmetry

$$A_\tau \equiv \frac{\Gamma\left(\tau^+ \to \pi^+ K_S \overline{\nu}_\tau\right) - \Gamma\left(\tau^- \to \pi^- K_S \nu_\tau\right)}{\Gamma\left(\tau^+ \to \pi^+ K_S \overline{\nu}_\tau\right) + \Gamma\left(\tau^- \to \pi^- K_S \nu_\tau\right)} = \left(-3.6 \pm 2.3 \pm 1.1\right) \cdot 10^{-3}$$

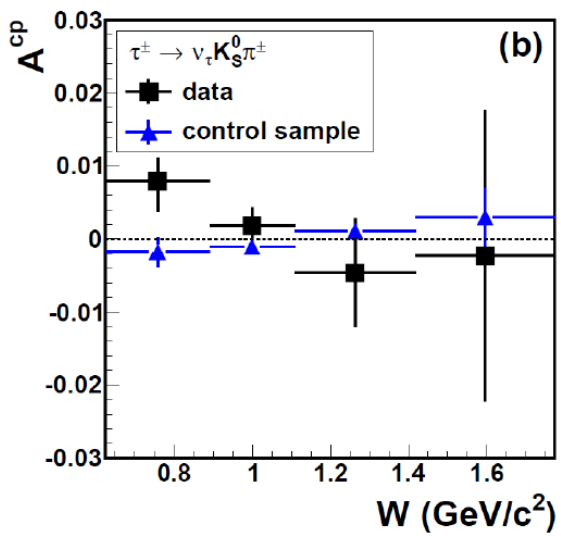
BaBar'11 $\left(\geq 0\ \pi^0\right)$

$$A_\tau^{\mathrm{SM}}\left(\tau^+ \to \pi^+ K_S \overline{\nu}_\tau\right) = \left(3.6 \pm 0.1\right) \cdot 10^{-3}$$

Bigi-Sanda, Grossman-Nir

2.8 σ discrepancy

Belle does not see any asymmetry at the 10^{-2} level



$$A_i^{\mathrm{CP}} \simeq \left\langle \cos\beta \cos\psi \right\rangle_i^{\tau^-} - \left\langle \cos\beta \cos\psi \right\rangle_i^{\tau^+}$$

bins (i) of $W = \sqrt{Q^2}$

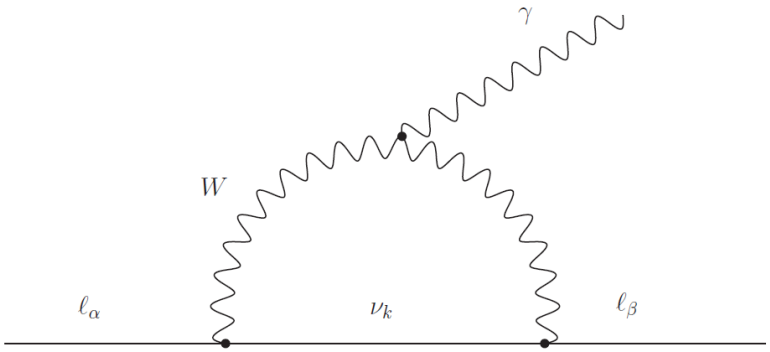
$\beta = K_S$ direction in hadronic rest frame

$\psi = \tau$ direction

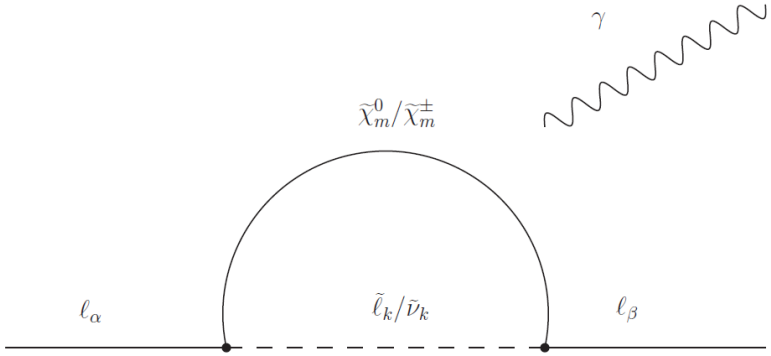
BaBar signal incompatible (with EFT) with other sets of flavour data

Cirigliano-Crivellin-Hoferichter, 1712.06595

Why are we searching for CLFV?



e.g. SUSY



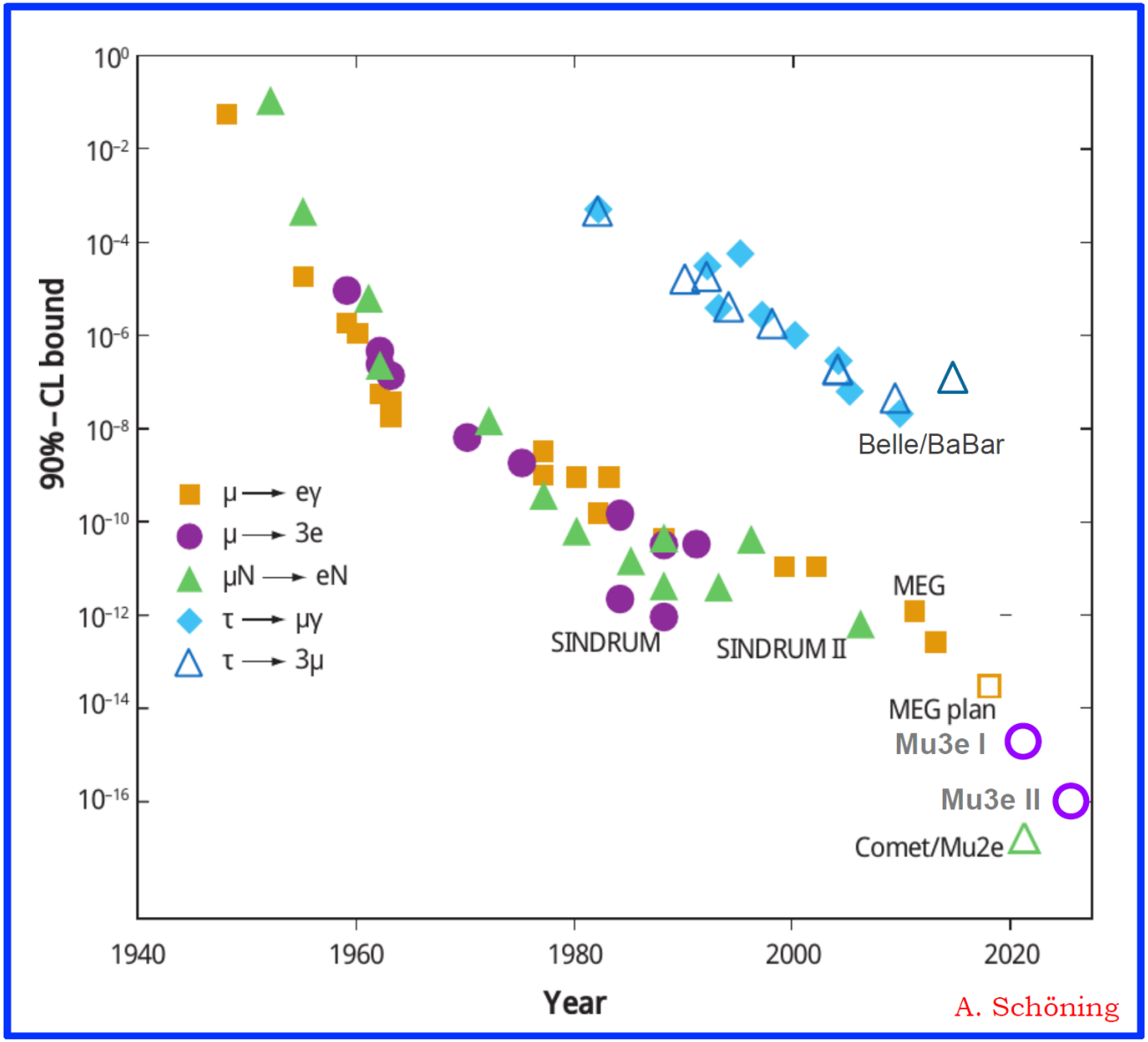
Borzumati Masiero '86;
Hisano et al. '95

$$\frac{\Gamma(\ell_\alpha \to \ell_\beta \gamma)}{\Gamma(\ell_\alpha \to \ell_\beta \nu \bar{\nu})} = \frac{3\alpha}{32\pi} \left| \sum_{k=1,3} U_{\alpha k} U^*_{\beta k} \frac{m^2_{\nu_k}}{M^2_W} \right|^2$$

$$\frac{\Gamma(\ell_\alpha \to \ell_\beta \gamma)}{\Gamma(\ell_\alpha \to \ell_\beta \nu \bar{\nu})} \sim \frac{1}{G_F^2\, m^4_{\rm SUSY}}$$

- Unambiguous signal of New Physics
- Stringent test of NP models
- It probes scales far beyond the LHC reach

CLFV has been sought for more than 70 years…



Comments on tau physics :

Nice place for new physics searches

For these bench-mark channels, high competition from Belle2 & LHCb

Qualitatively, threshold production at STCF may have some advantages

But quantitatively, can STCF really compete with Belle2 and LHCb ?

We need serious Monte Carlo simulation as well as checking from BESIII data and Belle data

Charm Physics with future tau-charm factories

Svjetlana Fajfer

Search for New Physics

B meson puzzles → Solution by New Physics

B meson puzzles → Tests of Lepton flavour universality

$(g\text{-}2)_\mu$ discrepancy SM prediction and experimental result

How about charm?

- CP violation in the up sector;
- Charm offers tests of possible NP in up sector at low-energies;
- If NP couples to weak doublets of quarks, CKM connects it with charm sector.
- Can one see NP in charm decays not being present in B meson ?

Charged current charm meson decays and New Physics

$$\mathcal{L}_{SM} = \frac{4G_F}{\sqrt{2}} V_{cs} \bar{s}_L \gamma^\mu c_L \, \bar{\nu}_l \gamma_\mu l$$

$$\mathcal{L}_{NP} = \frac{2}{\Lambda_c^2} \bar{s}_L \gamma^\mu c_L \, \bar{\nu}_l \gamma_\mu l$$

PDG 2018

$$f_{D^+} = 211.9(1.1) \text{ MeV}$$

$$f_{D_s} = 249.0(1.2) \text{ MeV}$$

$$\frac{f_{D_s}}{f_{D^+}} = 1.173(3)\,.$$

$$|V_{cs}| = 0.997 \pm 0.017$$

Electro-magnetic correction 1-3%

1 % error in

$$\Gamma(D_s^+ \to l^+ \nu_l)$$

$$\Lambda_c \sim 2.5 \text{ TeV}$$

Message:
Even if there is NP at 3 TeV scale the effect on charm leptonic decay can be ~ 1%!

- Is charm physics sensitive on NP explaining B puzzles ?
- Can some NP be present in charm and not in beauty mesons?

New physics explaining B anomalies, leads to rather small effects in charge current transitions ;

Vector LQ(3,1,5/3)

$$\mathcal{L} = Y_{ij} \left(\bar{\ell}_i \gamma_\mu P_R u_j\right) V^{(5/3)\mu} + \text{h.c.}\,.$$

(for loop effects in B
Camargo-Molina, Celis, Faroughy
1805.04917)

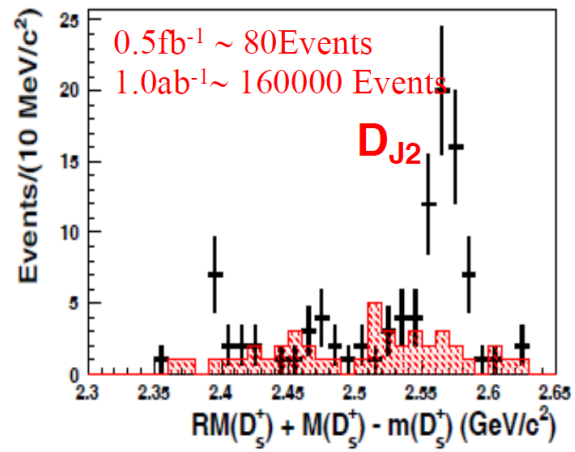
not present in B physics at tree level!

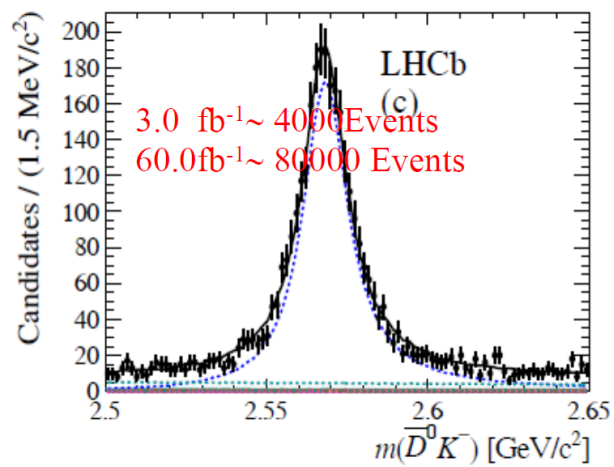
$$D^0 - \bar{D}^0$$

Svjetlana Fajfer

Charm Physics

- 4×10^9 pairs of $D^{\pm,0}$ and $10^7\sim10^8 D_s$ pairs per year
  - 10^{10} charm from Belle II/year
- Competition to Belle II
  - The multiplicity of final state is lower by a factor of 2
  - Threshold effect, clear, double tagging
  - Produce in QM coherent state, $J^{PC}=1^{--}$ for DD, $J^{PC}=0^{++}$ for γDD
- Highlighted Physics programs
  - Precise measurement of leptonic, semi-leptonic decay (f_D, f_{Ds}, CKM matrix…)
  - $D^0-\overline{D}^0$ mixing, CPV
  - Rear decay (FCNC, LFV, LNV….)
  - Excite charm meson states D_J, D_{sJ} (mass, width, J^{PC}, decay modes)
  - Charmed baryons (J^{PC}, Decay modes, absolute BF)
  - Light meson and hyperon spectroscopy studied in charmed hadron decays



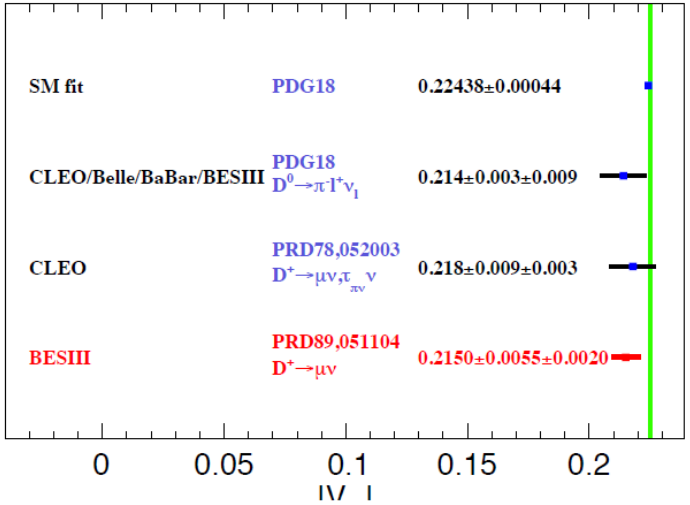


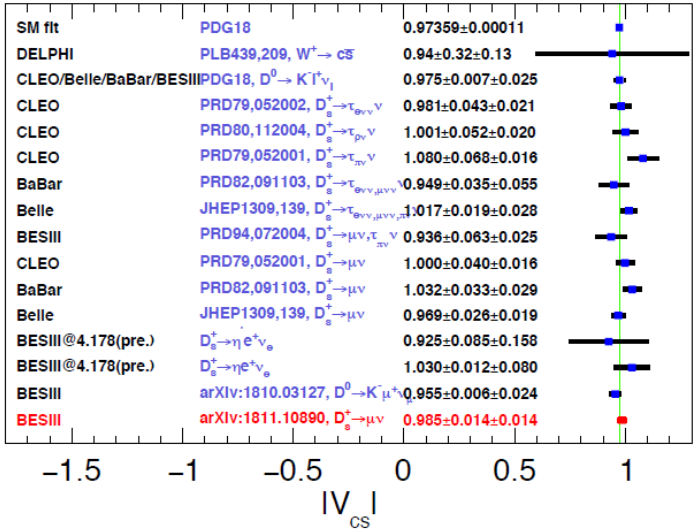
Features in studying charm hadron decays

	STCF	Belle(-II)	LHCb
Production yields	★★	★★★★	★★★★★
Background level	★★★★★	★★	★★
Systematic error	★★★★★	★★★	★★
Completeness	★★★★★	★★★	★
(Semi)-Leptonic mode	★★★★★	★★★	★
Neutron/K_L mode	★★★★★	★★	☆
Photon-involved	★★★★★	★★★★★	☆
Absolute measurement	★★★★★	★★★	☆

- Most are precision measurements, which are mostly dominant by the systematic uncertainty
- STCF has overall advantage

Vcs and Vcd





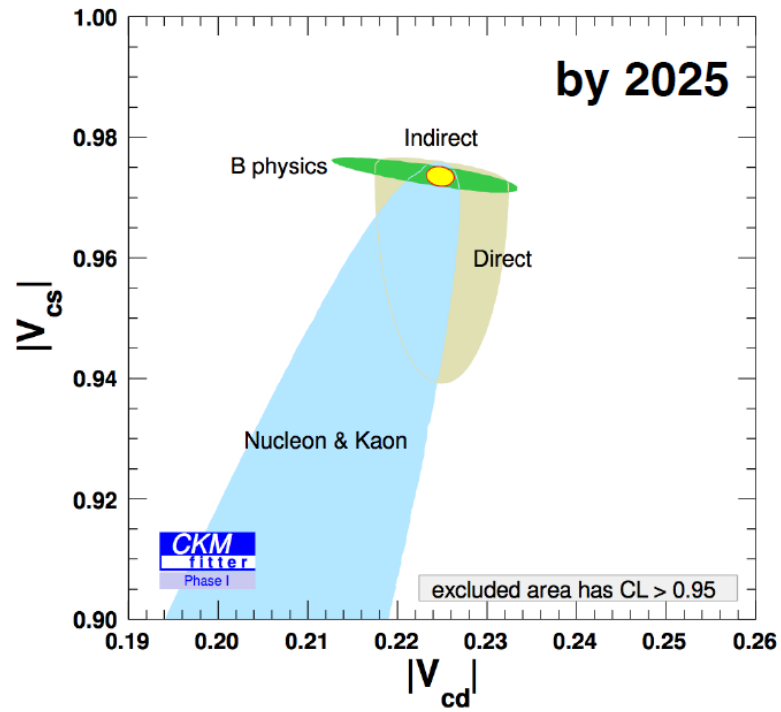
Future BESIII:

Vcd: ~1.5% (stat. dominant)

Vcs: ~1.5% (syst. dominant)

STCF: <0.2% (syst. dominant)

systematic control is challenging



Summary for charm decays

- **STCF** is **one of the crucial precision frontier :** threshold production data is unique to carry out the measurements of the charmed hadron decays
- **Important playground for studying non-perturbtive QCD and search for new physics**
  - ✓ CKM matrix, Decay constants (f_D/f_{Ds}), form factors
  - ✓ Neutral D mixing and strong phase
  - ✓ Charmed baryon decays
- Complementary to Belle II and LHCb in understanding the QCD/EW models and searching for new physics

2. Hadron spectroscopy to explore how quarks & gluons construct hadrons with strong QCD

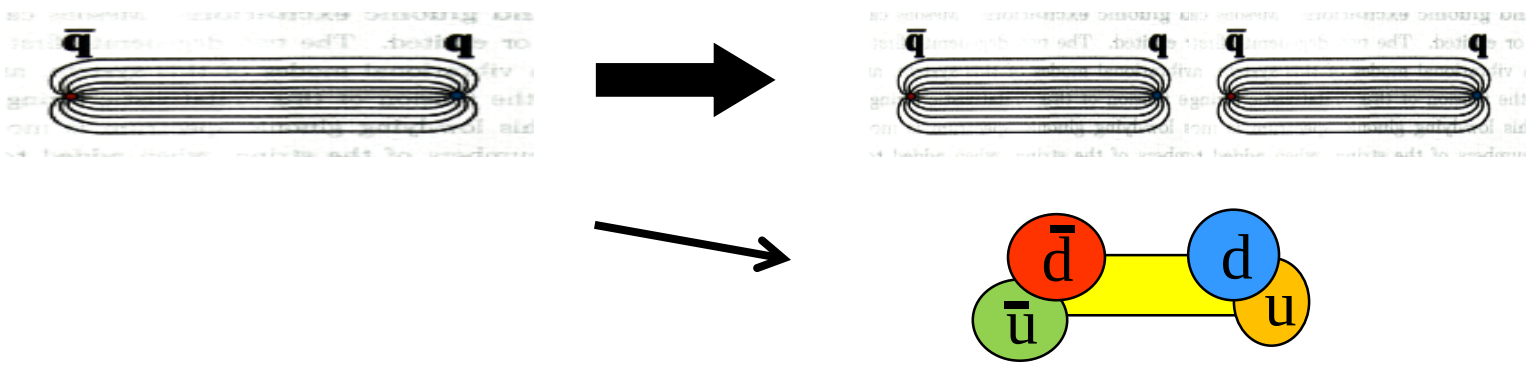
atomic spectrum → atomic quantum theory
nuclear spectrum → shell model, collective motion
hadron spectrum → ? Important discovery

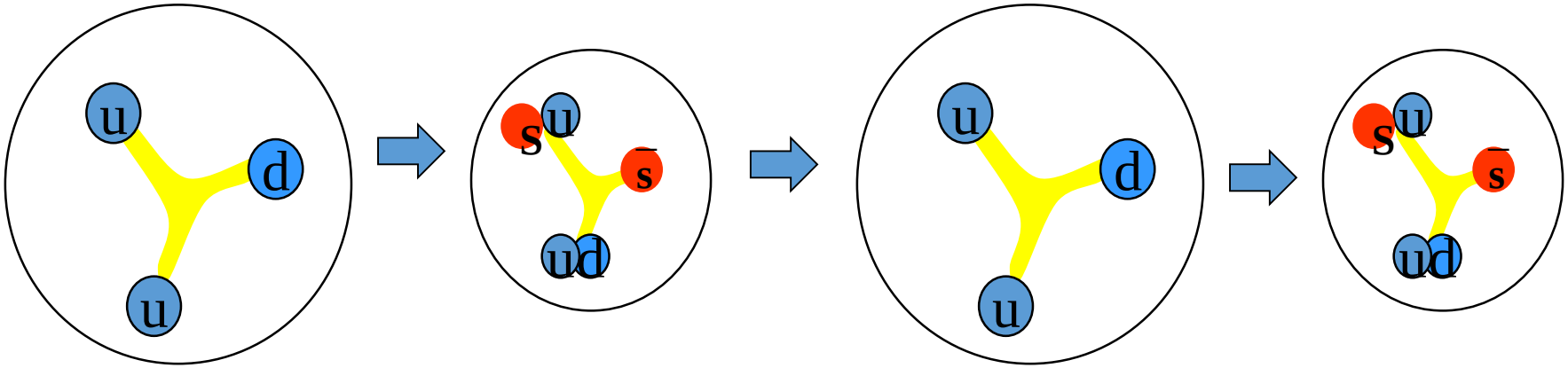
X(3872) → top cited paper for Belle
Zc(3900) → top cited paper for BESIII
Pc states → top cited paper for LHCb

1) Key problem in hadron spectroscopy:

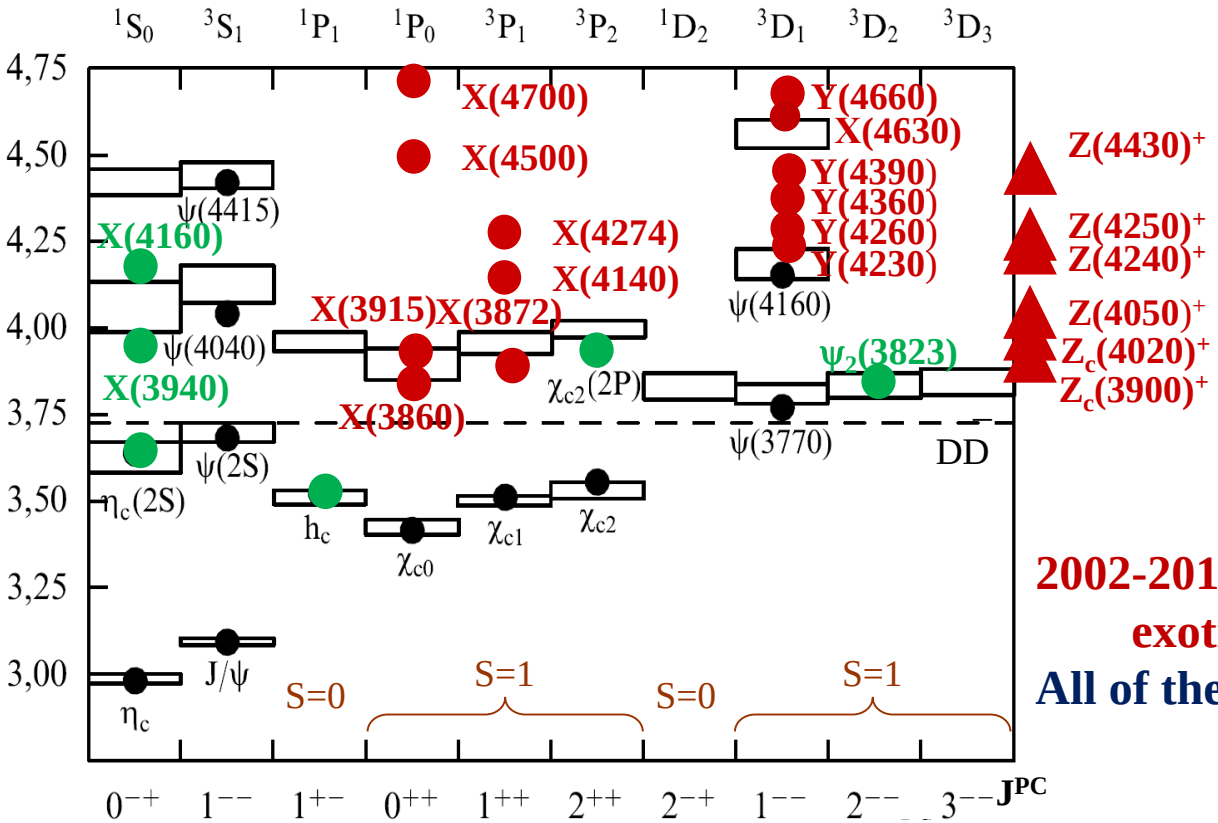
Unquenching dynamics: gluons → $\bar{q}q$

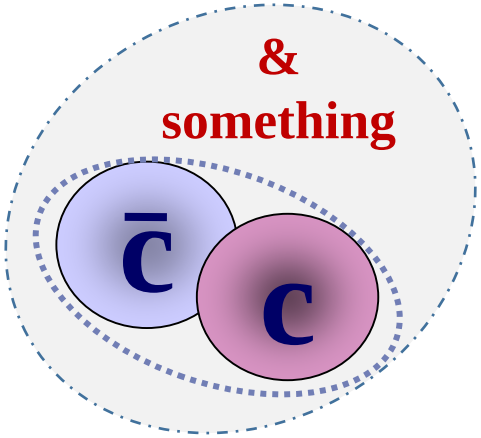
crucial for quark confinement & hadron structure





Charmoniumlike states (before PDG2018 naming scheme)





2002-2016 Discovery of **two dozens exotic charmonium states**

All of them above open charm threshold

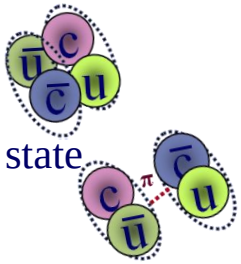
Multiquark states

Tetraquark

tightly bound four-quark state

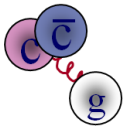
Molecular state

two loosely bound charm mesons

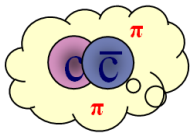


Charmonium hybrids

States with excited gluonic degrees of freedom



Hadrocharmonium



Specific charmonium state "coated" by excited light-hadron matter

Threshold effects

Virtual states at thresholds

Charmonium states with masses shifted by nearby $D_{(s)}^{(*)}D_{(s)}^{(*)}$ thresholds

Rescattering

Two D-mesons, produced closely, exchange quarks

Galina Pakhlova

Predictions for the lowest Ω* by various models:

$\Omega^*(x/2^-)$ as sss (L=1) : ~ 2020 MeV

Chao, Isgur, Karl, PRD38(1981)155

$\Omega^*(1/2^-)$ as $\bar{K}\Xi$ bound state: ~ 1805 MeV

W.L.Wang, F.Huang, Z.Y.Zhang, F.Liu, JPG35 (2008) 085003

$\Omega^*(x/2^-)$ as $\bar{u}$usss (L=0) : ~ 1820 MeV

Yuan-An-Wei-Zou-Xu, PRC87(2013)025205

$\Omega^*(3/2^-)$ as sss - $\bar{u}$usss mixture : ~ 1780 MeV

by instanton/NJL interaction

An-Metsch-Zou, PRC87(2013) 065207; An-Zou, PRC89 (2014) 055209

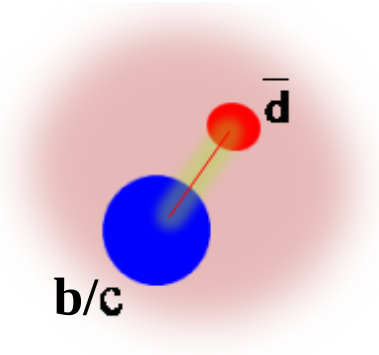
STCF: $e^+e^- \rightarrow \bar{\Omega}\,\Omega^*$ → $\Omega^*(1800)$?!

2) my favorite strategy for hadron spectroscopy:

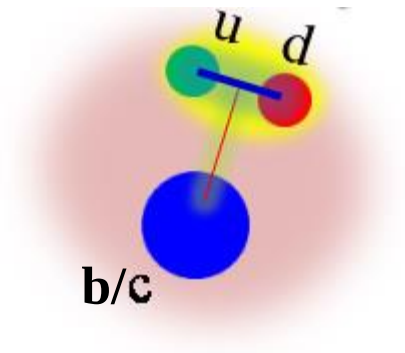
$\bar{c}cuud$ & $\bar{c}cuds$ → sss - $\bar{q}qsss$ → cqq - $\bar{q}qcqq$
→ hyperons → light baryons

$\bar{c}c\ \bar{u}d$ & $\bar{c}s\ \bar{u}d$ → $\bar{c}c$ - $\bar{q}q$ $\bar{c}c$ → $\bar{c}q$ - $\bar{c}q$ $\bar{q}q$
$\bar{c}s$ - $\bar{q}q$ $\bar{c}s$
→ K mesons → light mesons

s → c → b



charm & beauty meson



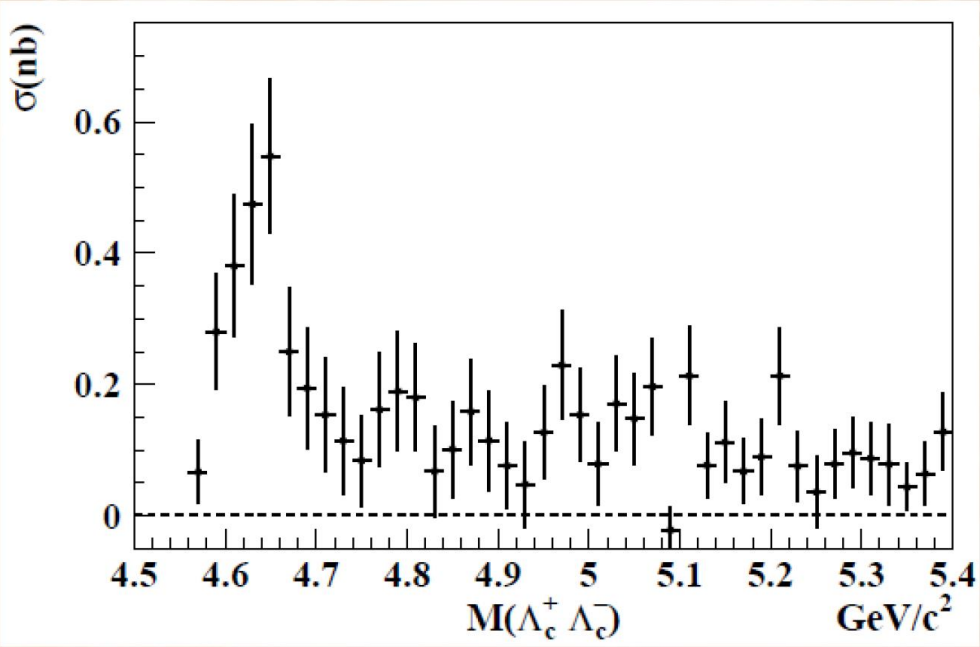
charm & beauty baryon

All these kinds of hadrons can be studied at STCF

XYZ states as well as various baryon states

⑤ Two-body baryonic cross section

$e^+e^- \rightarrow \Lambda_c \underline{\Lambda}_c$ near threshold bump surprised everybody, and still not understood



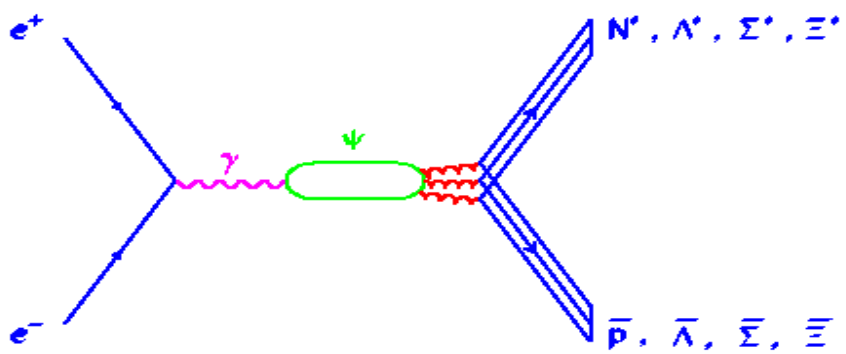
There are many more such charmed ground state baryons, that have a pair production in 5-7.3 GeV region.

It is interesting to compare cross section behavior at threshold for $\Xi_c^{0/+}\Xi_c^{0/+}$, $\Omega_c^0\Omega_c^0$ and doubly charmed baryon pairs.

$M(\Xi_c^{0/+}\Xi_c^{0/+}) = 4.936/4.940$ GeV
$M(\Omega_c^0\Omega_c^0) = 5.390$ GeV
$M(\Xi_{cc}^{0/+}\Xi_{cc}^{0/+}) = 7.242$ GeV

And many more final states with excited baryons…

$$\psi \rightarrow \overline{B}BM \quad \Longrightarrow \quad N^*,\ \Lambda^*,\ \Sigma^*,\ \Xi^*,\ \Omega^*$$



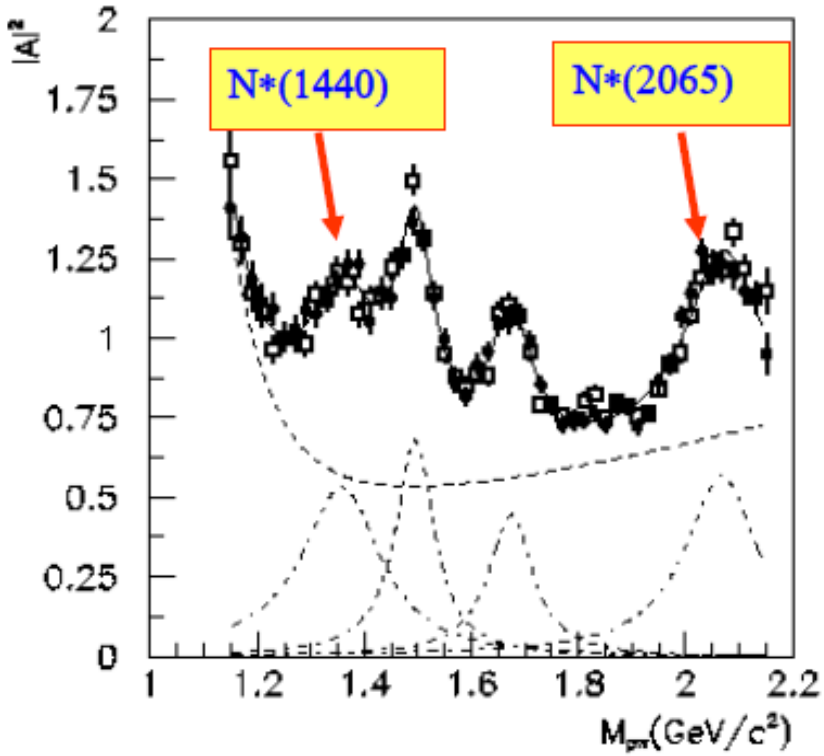
an ideal isospin and low spin filter from $\bar{c}c$ annihilation

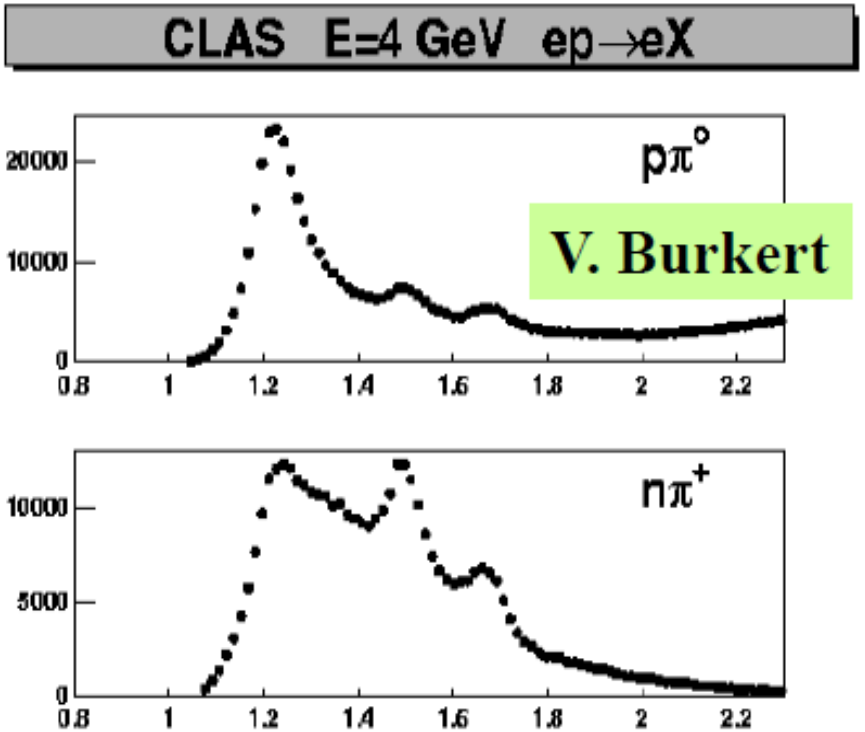
No contamination from t/u-channel scattering as in πN and γN

high statistics extension to ψ', χ_{cJ}, η_c

Observation of "missing" N* above 2 GeV with low spin

$J/\psi \rightarrow \bar{p}n\pi^+$ & $\bar{n}\pi^-p$ BESII Collaboration, PRL97 (2006)062001





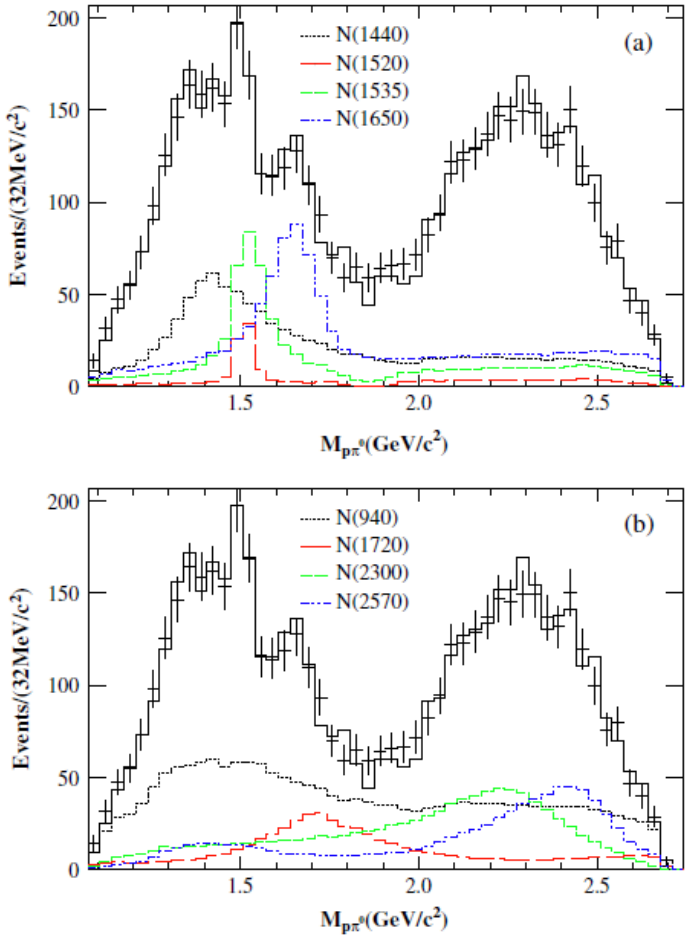
The first experiment "seeing" N*(1440) in πN mass spectrum

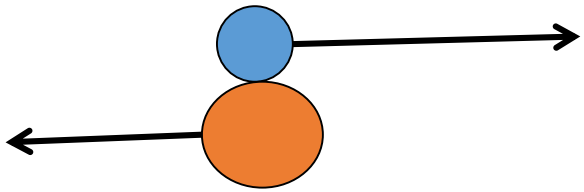
BESII	$M = 1358 \pm 17$,	$\Gamma = 179 \pm 56$	MeV
PDG06	$M = 1365 \pm 15$,	$\Gamma = 190 \pm 30$	MeV

Observation of Two New N^* Resonances in the Decay $\psi(3686) \to p\bar{p}\pi^0$

N*(2300)1/2⁺ , N*(2570)5/2⁻

BESIII, PRL110(2013)022001





For πN scattering at 2.2 GeV,

L= r × p = 1 fm × 900 MeV=4.5

J = 7/2 or 9/2

For $\bar{c}c \rightarrow \bar{N}N^*(2300)$,

L= r × p = 0.3fm × 400 MeV=1

J ≦ 5/2

Low spin filter

Summary for physics at STCF:

1. **Tau & Charm decays provide nice playground to search for New Physics beyond Standard Model**

   high competition from Belle2 & LHCb
   Monte Carlo simulation as well as checking from BESIII & Belle data are needed

2. **A leading role for Hadron spectroscopy with many new hadron states to be discovered.**

Thank you for your attention!