Tau Decay Measurements at BESIII and Super Tau Charm Factory

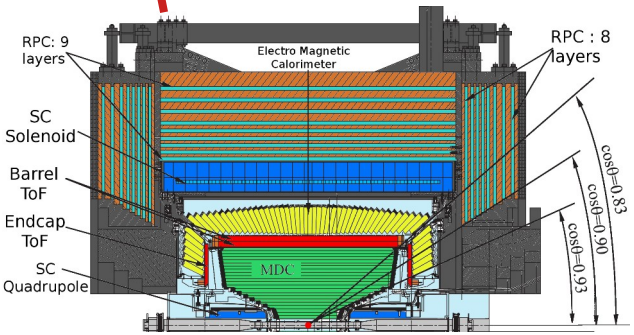
9th Plenary Workshop of the Muon g-2 Theory Initiative

2026-08-04 | Christoph Florian Redmer (filling in for Weiping Wang)

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL
Cluster of Excellence PRISMA+
DFG Deutsche Forschungsgemeinschaft
FOR5327
Photon-photon interactions in the Standard Model and beyond
Project TFF
Project XYZ
Project JRP
Project LBL
Project ALP
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
JGU


Weiping Wang

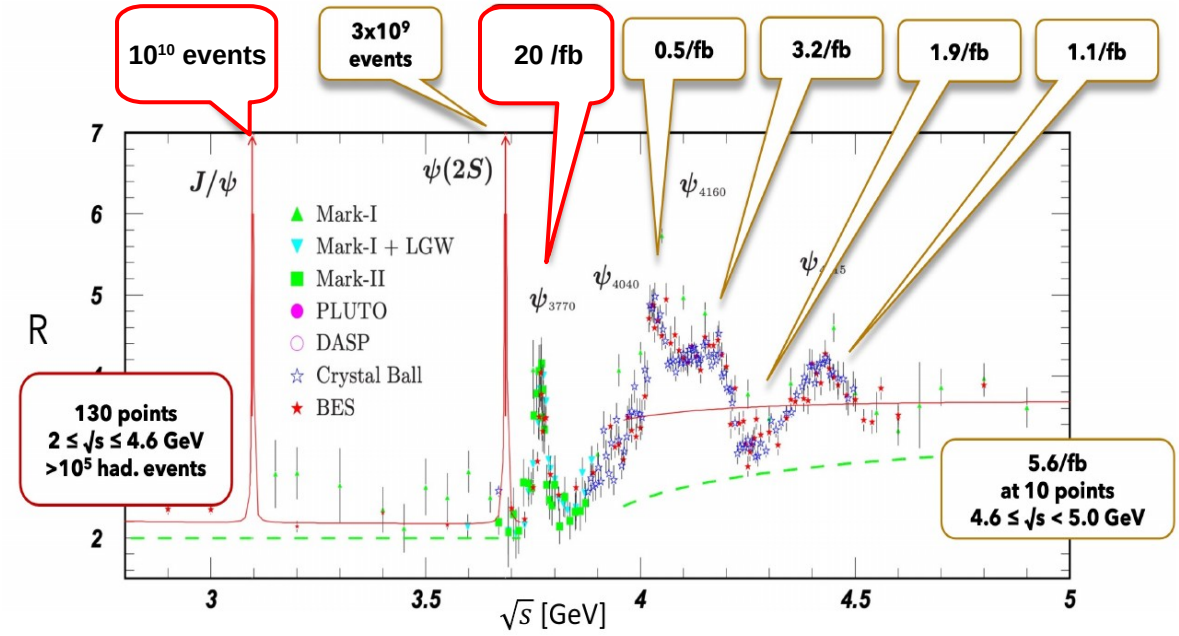
BESIII at BEPCII



Time of Flight | EM Calorimeter | Muon Counter

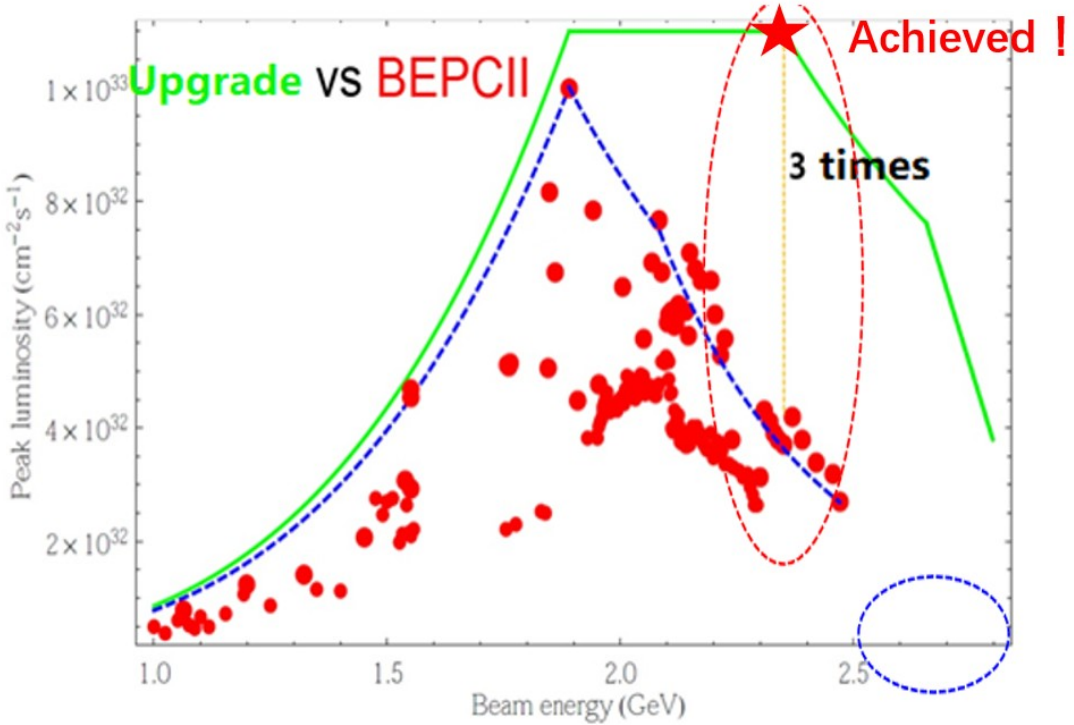
Drift Chamber | Solenoid

- Center-of-mass energies from 2 – 5 GeV
- Design luminosity exceeded: $1.1\times10^{33}\,cm^{-2}s^{-1}$ at 3.77 GeV



Worlds largest τ-charm data sets in e^+e^- collisions

Recently implemented upgrade: BEPC-II-U



- Increase luminosities at high energies
- Running at $\sqrt{s} > 5\,\mathrm{GeV}$ possible

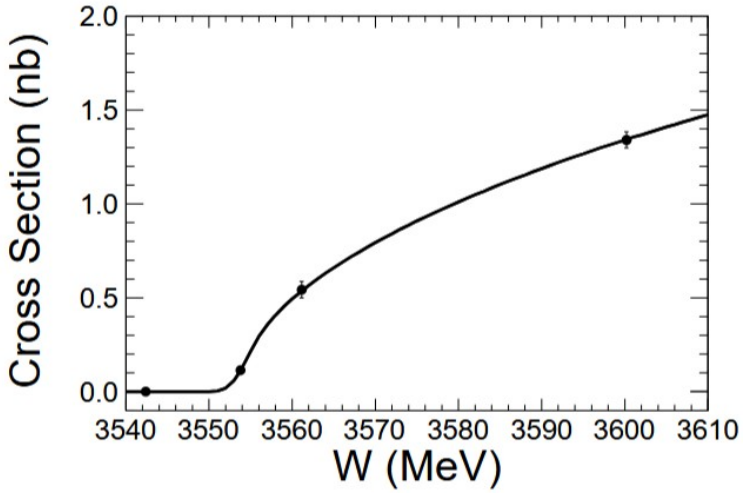
Goals of luminosity upgrade achieved!

Higher energies in next running period

Tau Mass Measurement

Threshold scan

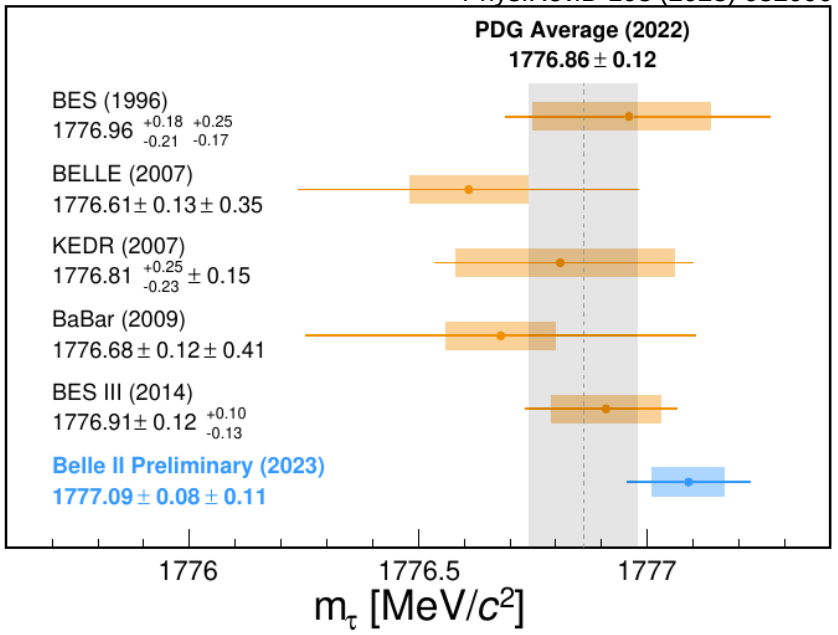
- Simple event topologies



$$m_\tau = (1776.91 \pm 0.12^{+0.10}_{-0.13})\ \mathrm{MeV}/c^2$$

Phys.Rev.Lett. 90 (2014) 012001

Phys.Rev.D 108 (2023) 032006

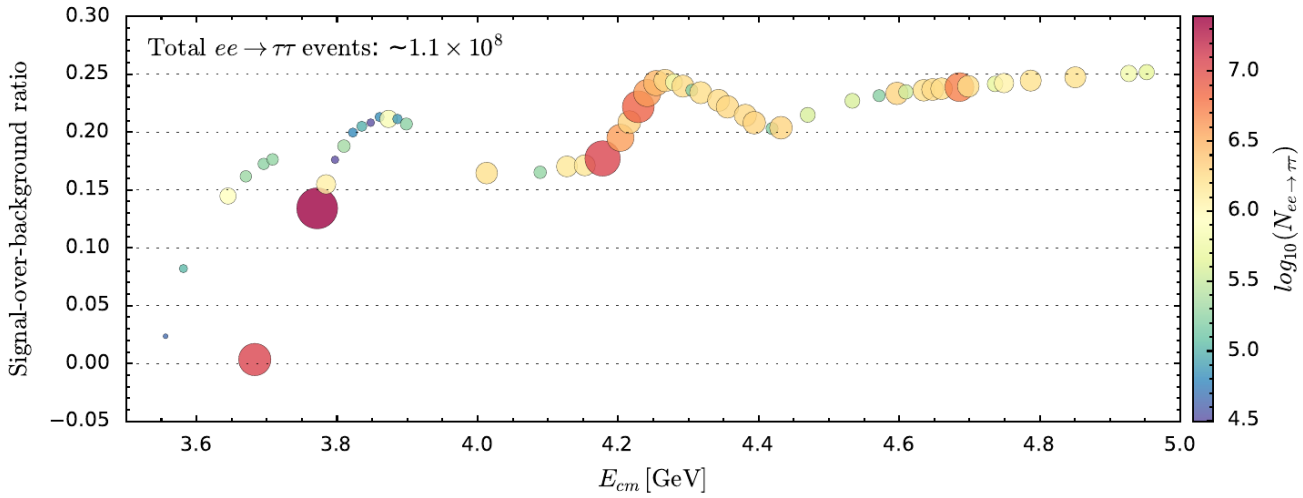


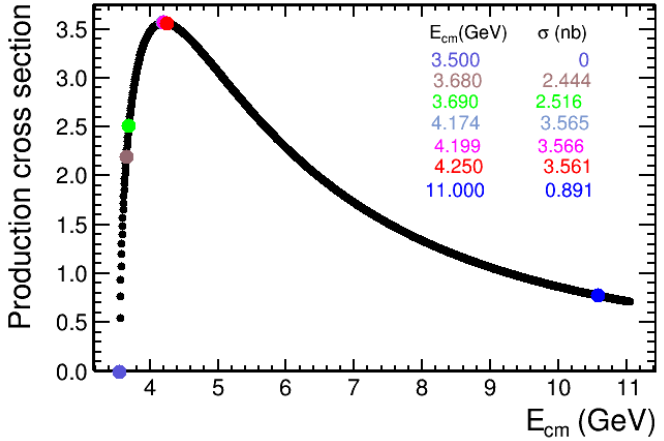
New BESIII measurement aiming at 50 keV precision!

Tau Decays

BESIII competitive with LEP and B-factory data?

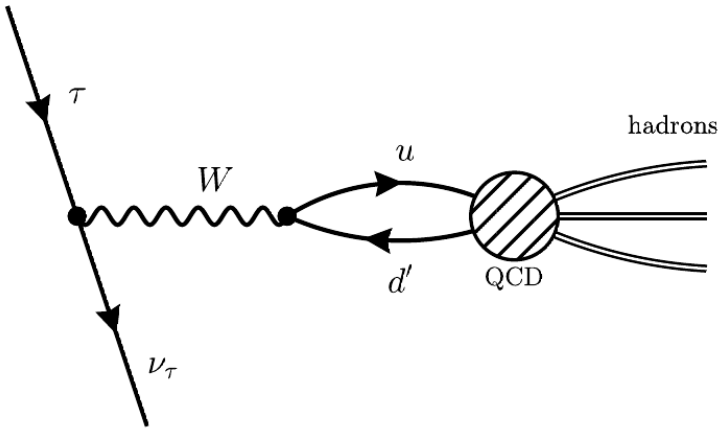
- Cross section maximum at ~ 4.2 GeV
- Background from resonance decays and hadronic continuum





BESIII can make a significant contribution!

Hadronic Tau Decays



- Tag side:

$$\tau^\pm \to \nu_\tau \nu_e e^\pm$$

- Non-strange hadrons:

$$\tau^\pm \to \nu_\tau \pi^0 \pi^\pm \quad \to \quad v_j(s) \sim |F_\pi^j(s)|^2$$

$$\tau^\pm \to \nu_\tau \text{hadrons} \quad \to \quad \alpha_s(m_\tau^2)$$

- Strange hadrons

$$\tau^\pm \to \nu_\tau K^\pm \pi^0$$

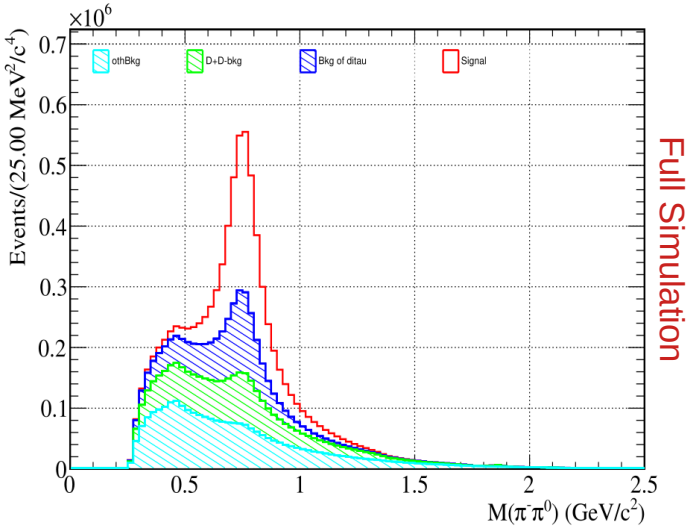
$$\tau^\pm \to \nu_\tau K_S^0 \pi^\pm$$

} Strange spectral function $|V_{us}|$

$\tau^{\pm} \to \nu_{\tau}\pi^{\pm}\pi^{0}$

- 20 fb^{-1} data set at 3.773 GeV
- MC simulations using KKMC+TAUOLA+PHOTOS

- 2 tracks, identified as electron and pion
- Combine photons to unique pion candidates

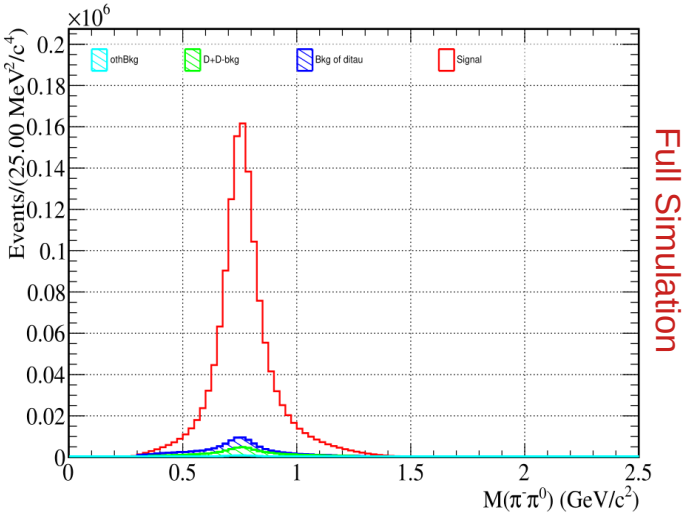


$\tau^{\pm} \to \nu_{\tau}\pi^{\pm}\pi^{0}$

- 20 fb^{-1} data set at 3.773 GeV
- MC simulations using KKMC+TAUOLA+PHOTOS

- 2 tracks, identified as electron and pion
- Combine photons to unique pion candidates
- Reject events with extra photons
- Restrictions on $\theta_{e,\pi\pi}, M_R(\pi\pi), M_R(\pi\pi e)$

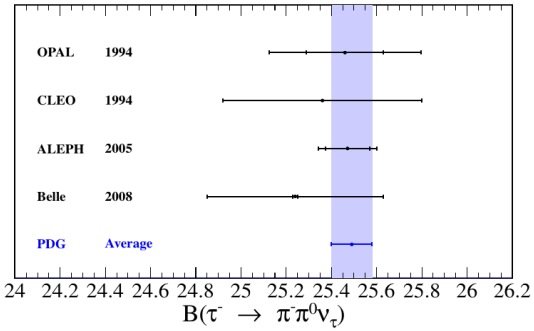
- ~1.2×10^6 signal events
- ~8.5% remaining background



$\tau^{\pm} \to \nu_{\tau}\pi^{\pm}\pi^{0}$

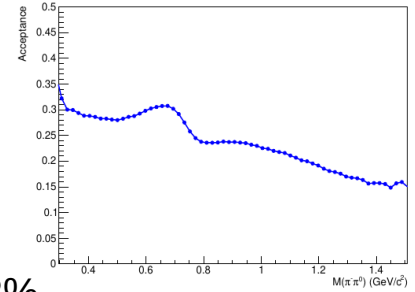
BR determination

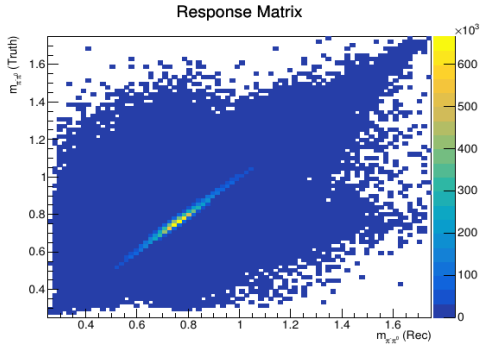
- Fit contribution with smeared MC shapes
- $\mathcal{B}(\tau^- \to \nu_\tau \pi^- \pi^0) = \dfrac{N_{\text{sig}}}{2N_{\tau\tau} \cdot \epsilon_{\text{sig}} \cdot \mathcal{B}(\tau^+ \to e^+ \nu_e \bar{\nu}_\tau)} \cdot \mathcal{B}(\pi^0 \to \gamma\gamma)$
- Uncertainties: $\Delta_{\text{stat}} \sim \mathcal{O}(0.03\%), \Delta_{\text{syst}} \sim \mathcal{O}(0.2\%),$



Invariant Mass Spectrum

- Background subtraction
- Efficiency correction
- Unfolding





- Difference of mass spectrum fit with ALEPH and Belle < 2%

Inclusive Hadronic Decays

Experimental observable: $R_\tau \equiv \frac{\Gamma\left(\tau \to \nu_\tau \text{ pions}\right)}{\Gamma\left(\tau \to l\nu_\tau\nu_l\right)}$

Spectral moments: $R_\tau^{kl}(s_0) = \int_0^{s_0} ds \left(1 - \frac{s}{s_0}\right)^k \left(\frac{s}{m_\tau^2}\right)^l \frac{dR_\tau}{ds}$

Normalization: $D_\tau^{kl} = \frac{R_\tau^{kl}}{R_\tau^{00}}$

$\alpha_s(m_\tau^2)$ can be derived from a simultaneous fit to $R_\tau, D^{10}, D^{11}, D^{12}, D^{13}$ with $R_\tau = \frac{\Gamma_h}{\Gamma_l} = \frac{1 - \mathcal{B}_l - B_S}{\mathcal{B}_l}$

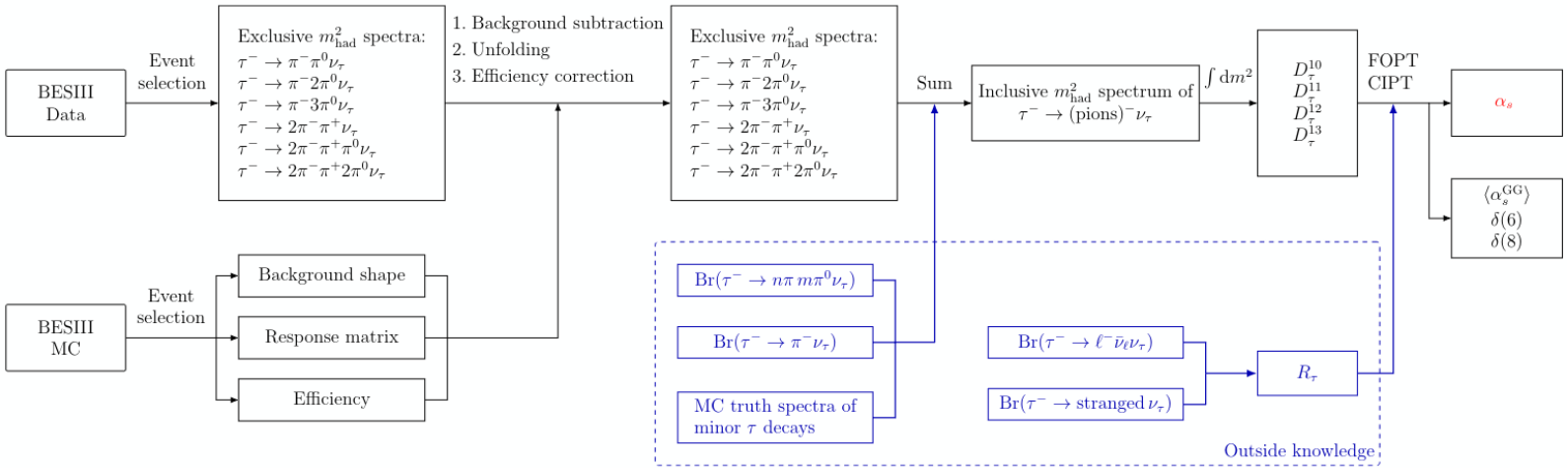
Inclusive Hadronic Decays

Experimental observable: $R_\tau \equiv \frac{\Gamma\left(\tau \to \nu_\tau \text{ pions}\right)}{\Gamma\left(\tau \to l\nu_\tau\nu_l\right)}$

Spectral moments: $R_\tau^{kl}(s_0) = \int_0^{s_0} ds \left(1 - \frac{s}{s_0}\right)^k \left(\frac{s}{m_\tau^2}\right)^l \frac{dR_\tau}{ds}$

Normalization: $D_\tau^{kl} = \frac{R_\tau^{kl}}{R_\tau^{00}}$

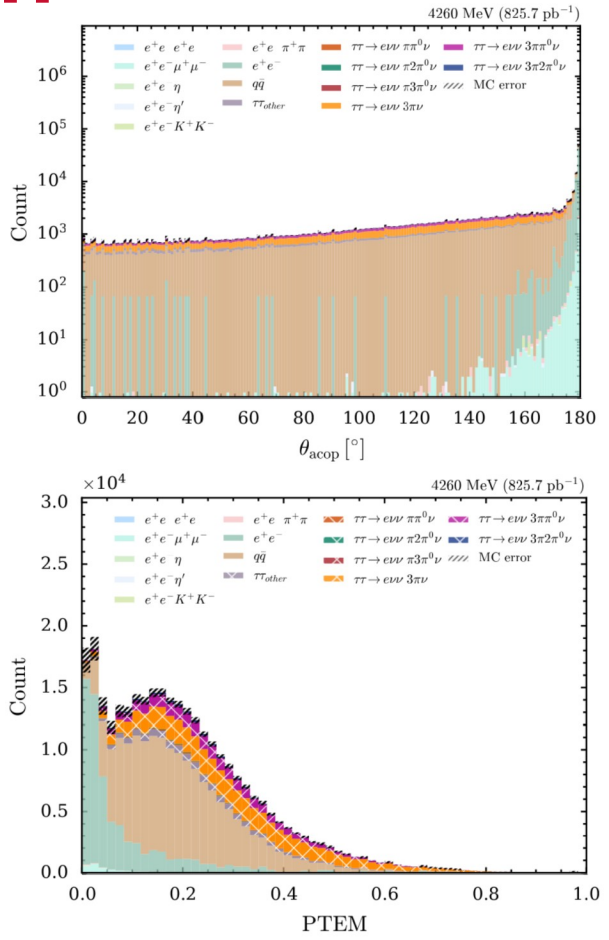
$\alpha_s(m_\tau^2)$ can be derived from a simultaneous fit to $R_\tau, D^{10}, D^{11}, D^{12}, D^{13}$ with $R_\tau = \frac{\Gamma_h}{\Gamma_l} = \frac{1 - \mathcal{B}_l - B_S}{\mathcal{B}_l}$



Event Selection

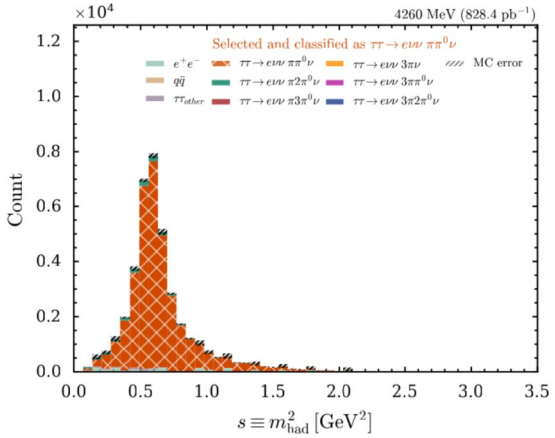
- 828.4 pb^{-1} at 4.26 GeV
- Reconstruct 6 hadronic decay modes

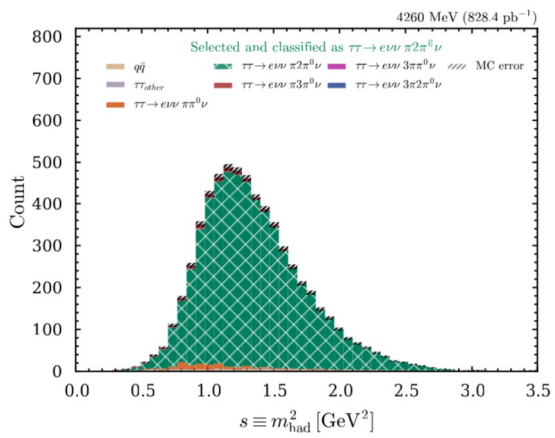
- Require 2 or 4 tracks
- Identify 1 electron and 1 or 3 pions
- Reject events with K_s^0 candidates
- Combine photons to unique π^0candidates
- Reject events with isolated photons
- Select signal candidates based on
  - acoplanarity of lepton and hadrons
  - $PTEM = \dfrac{(c\vec{p}_e + c\vec{p}_\pi)_T}{E_{cm} - |c\vec{p}_e| - |c\vec{p}_\pi|}$

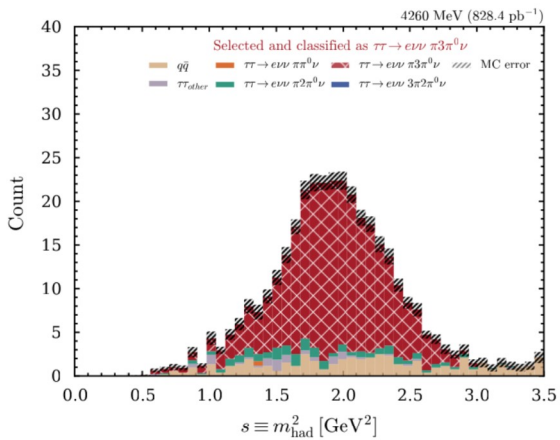


Full Simulation
Example: 3-prong hadronic events

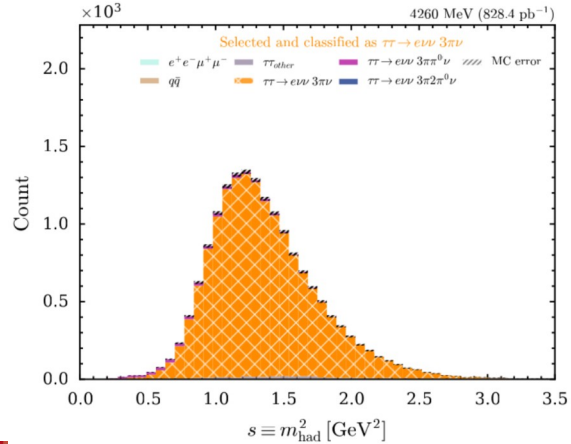
Invariant Mass Spectra

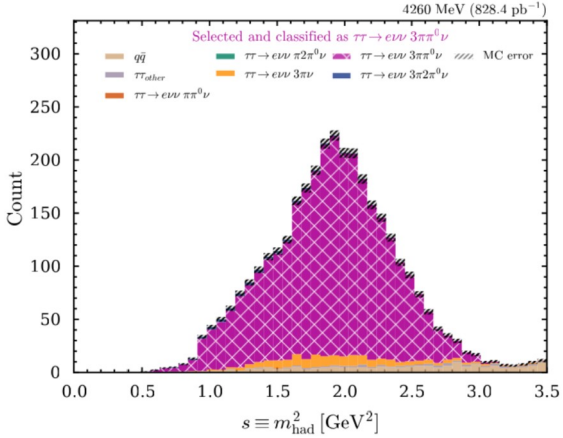


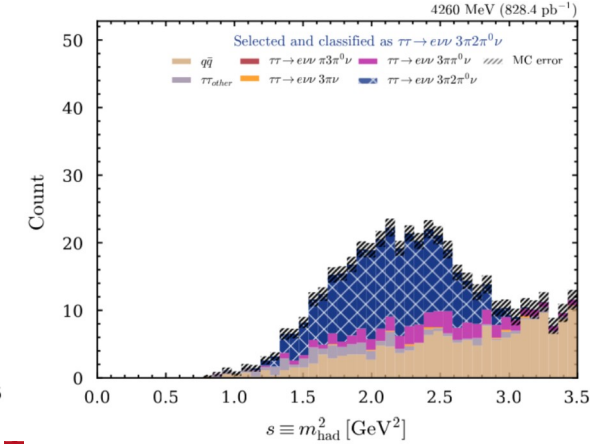




1-prong events







3-prong events

Full Simulation

Determination of $\alpha_s(m_\tau^2)$

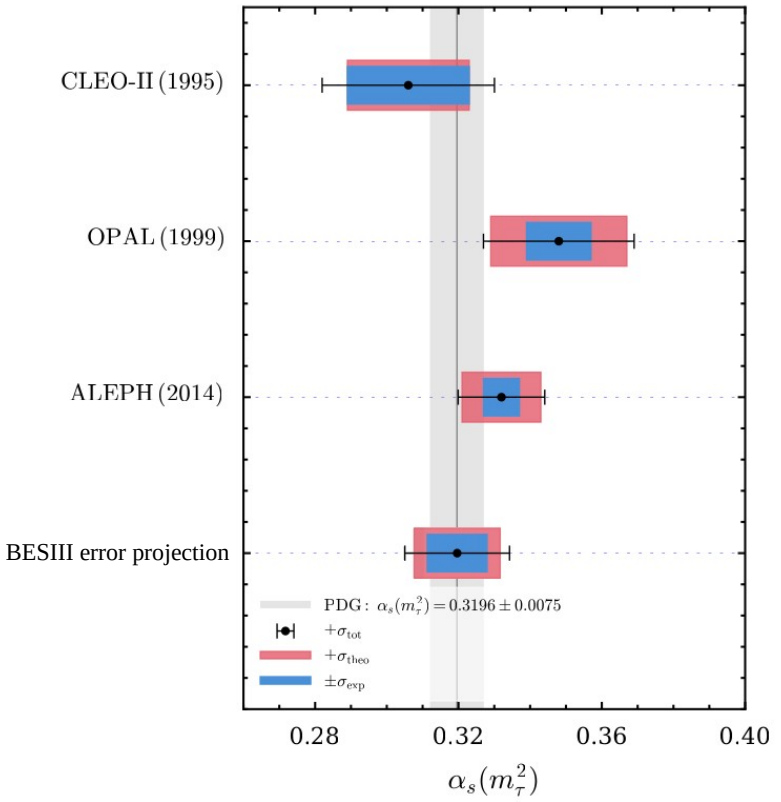
First attempt:

- Combine measured hadronic spectral
- Add missing channels from TAUOLA MC
- Determine four spectral moments
- Perform simultaneous fits
  - Same procedure as ALEPH: CIPT vs. FOPT
  - Improvement w.r.t. CLEO-II and OPAL

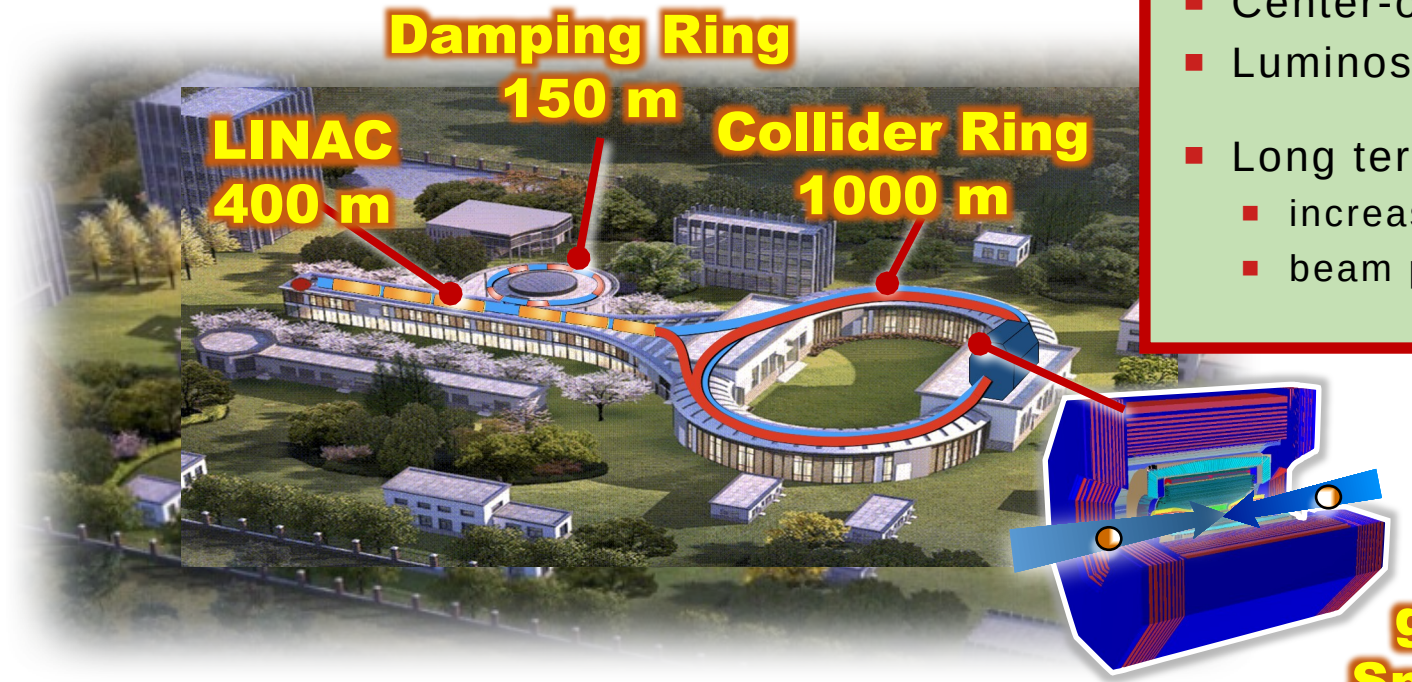
Next step:

Involve experts for better interpretation of data

(Boito, Golterman, *et al.*)



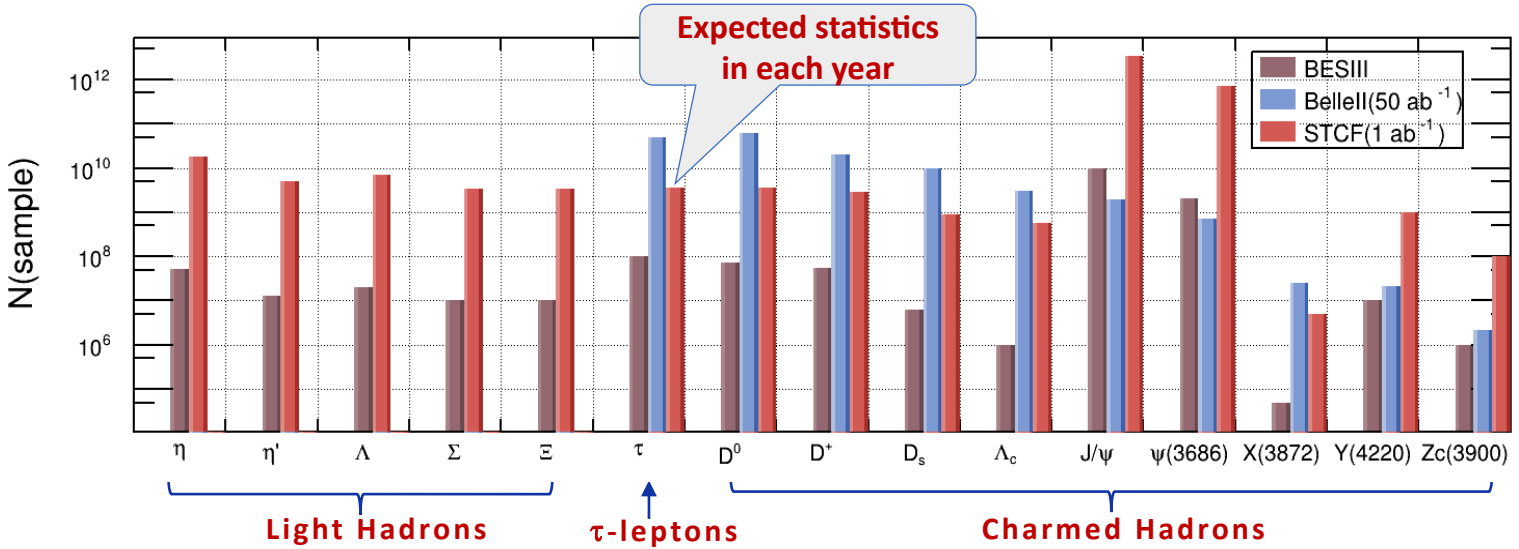
Tau Decays at STCF



- Planned in Hefei, Cina
- Center-of-Mass energies: 2-7GeV
- Luminosity > 0.5×10^{35} $cm^{-2}s^{-1}$ @ 4GeV
- Long term plans
  - increase luminosity
  - beam polarization

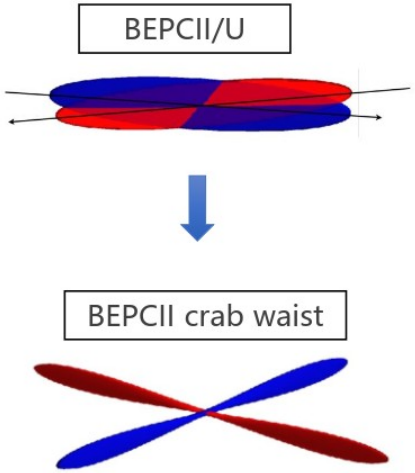
New generation Spectrometer

Tau Decays at STCF



- Improve tau mass measurment by an order of magnitude
- Search for tauonium
- $|V_{us}|$ from semi-inclusive, exclusive, and direct measurements
- Improve tau EDM by two orders of magnitude (w.r.t Belle)
- Search for LFV
- Study quantum correlation of tau pairs

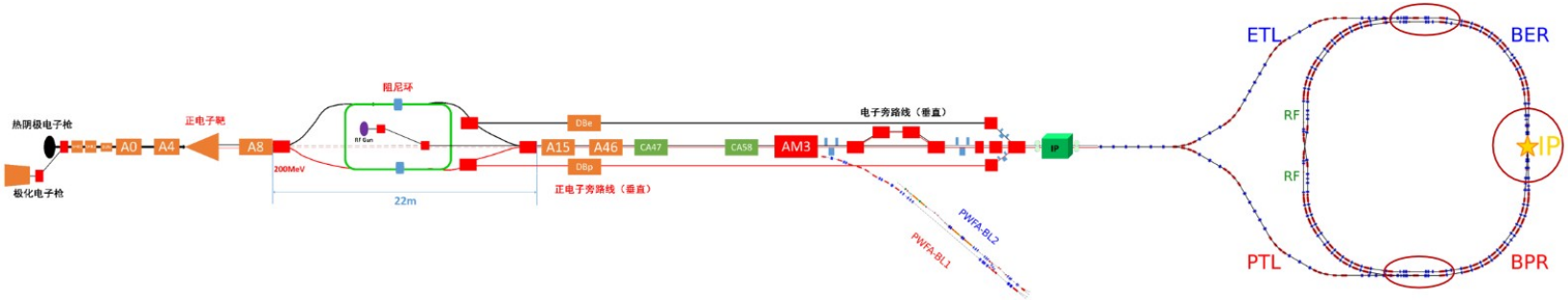
Crab Waist Scheme for BEPC-II



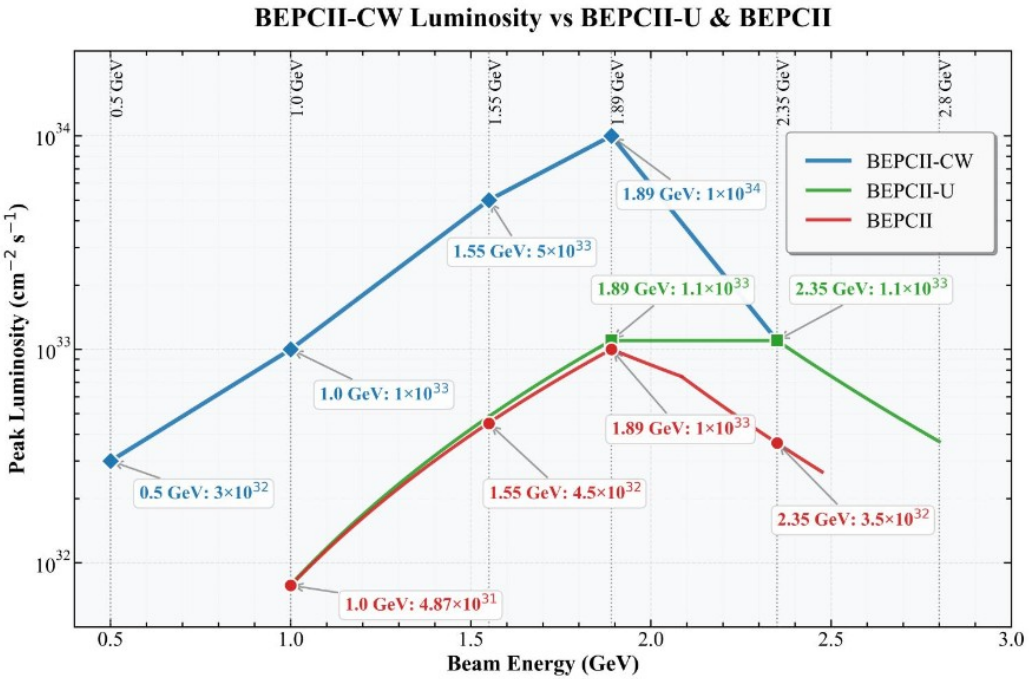
Design study supported by IHEP innovation funding

- Add crab-waist cavities to ring
- Modify interaction region
- Superconducting wigglers near injection points
- New damping ring for LINAC

Looks promising and feasible!



Crab Waist Scheme for BEPC-II



Expected benefits:

- Luminosites up to 10^{34} cm^{-2}s^{-1} (20% of STCF)
- Operation at $\sqrt{s} < 2\,\mathrm{GeV}$

Summary

BESIII can contribute significantly to Tau Decay studies

- Good statistics
- Hadronic background contributions under control
- Focus on hadronic tau decays
  - Pion form factor from $\tau^{\pm} \to \nu_{\tau}\pi^{0}\pi^{\pm}$
  - $\alpha_s(m_{\tau}^2)$ from $\tau^{\pm} \to \nu_{\tau}$hadrons
  - $|V_{us}|$ from $\tau^{\pm} \to \nu_{\tau}K\pi$
- Future facilities at tau/charm energies allow for more precise results