On the way to the Super Tau Charm Factory

Alexey Zhemchugov
DLNP JINR

19 December 2025

November Revolution 1974

VOLUME 33, NUMBER 23 PHYSICAL REVIEW LETTERS 2 DECEMBER 1974

Experimental Observation of a Heavy Particle J†

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen, J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan Wu
Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

Y. Y. Lee
Brookhaven National Laboratory, Upton, New York 11973
(Received 12 November 1974)

We report the observation of a heavy particle J, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \mathrm{Be} \to e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.

The most striking feature of J is the possibility that it may be one of the theoretically suggested charmed particles[2] or a's[3] or Z_0's,[4] etc. In order to study the real nature of J,[5] measurements are now underway on the various decay modes, e.g., an $e\pi\nu$ mode would imply that J is weakly interacting in nature.

VOLUME 33, NUMBER 23 PHYSICAL REVIEW LETTERS 2 DECEMBER 1974

Discovery of a Narrow Resonance in e^+e^- Annihilation*

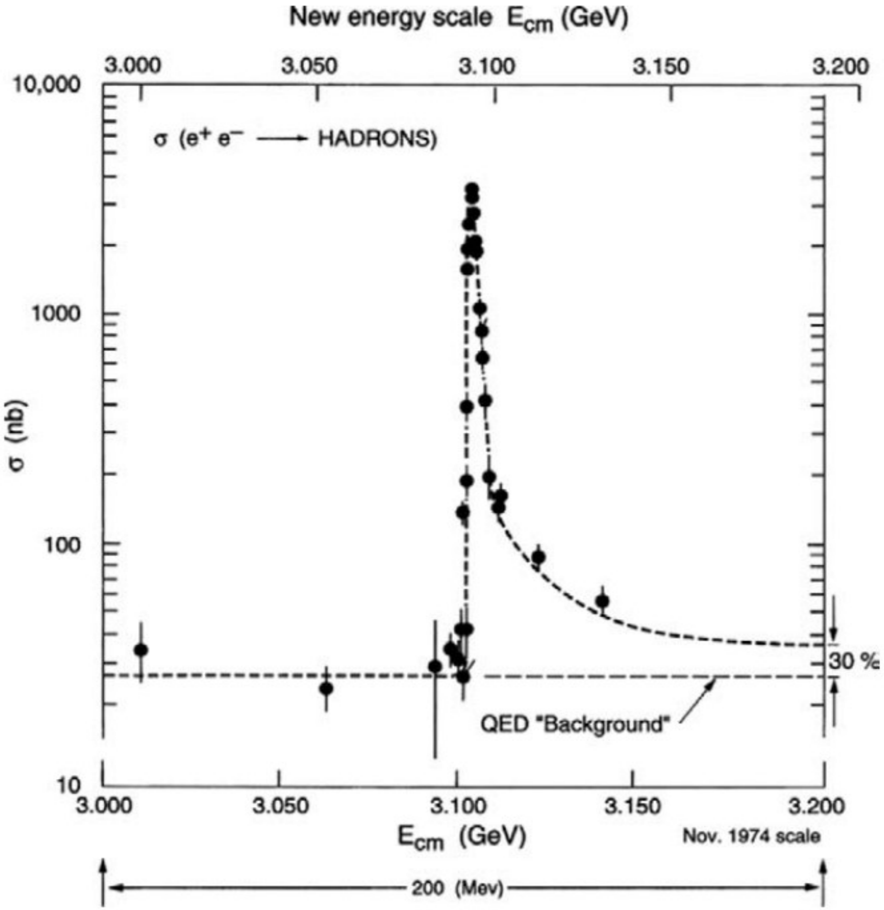
J.-E. Augustin,† A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,† R. R. Larsen, V. Lüth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum, and F. Vannucci‡
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

and

G. S. Abrams, D. Briggs, W. Chinowsky, C. E. Friedberg, G. Goldhaber, R. J. Hollebeek, J. A. Kadyk, B. Lulu, F. Pierre,§ G. H. Trilling, J. S. Whitaker, J. Wiss, and J. E. Zipse
wrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720
(Received 13 November 1974)

We have observed a very sharp peak in the cross section for $e^+e^- \to$ hadrons, e^+e^-, and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

The $e^+e^- \to$ hadron cross section is presumed to go through the one-photon intermediate state with angular momentum, parity, and charge conjugation quantum numbers $J^{PC} = 1^{--}$. It is difficult to understand how, without involving new quantum numbers or selection rules, a resonance in this state which decays to hadrons could be so narrow.



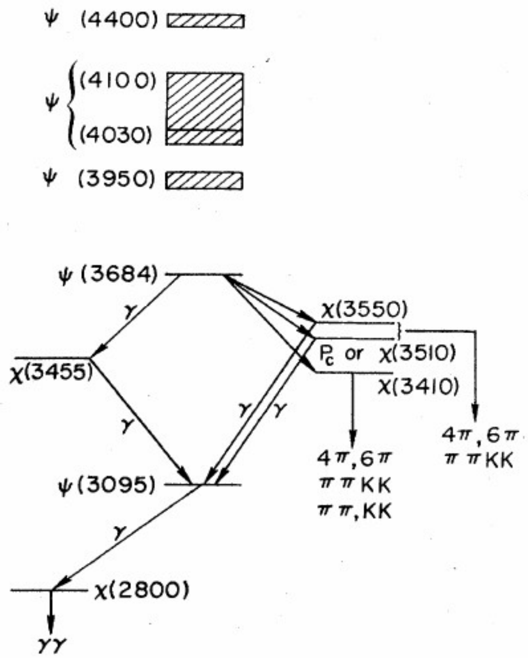


FIG. 15. An energy-level diagram of the new particles. The many observed decay modes of the psi family have been omitted.

Richter, Rev. Mod. Phys., Vol. 49, No. 2, April 1977

Tau lepton discovery

Volume 63B, number 4 PHYSICS LETTERS 16 August 1976

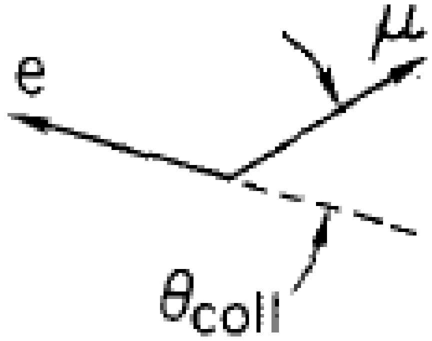
PROPERTIES OF ANOMALOUS eμ EVENTS PRODUCED IN e^+e^- ANNIHILATION☆

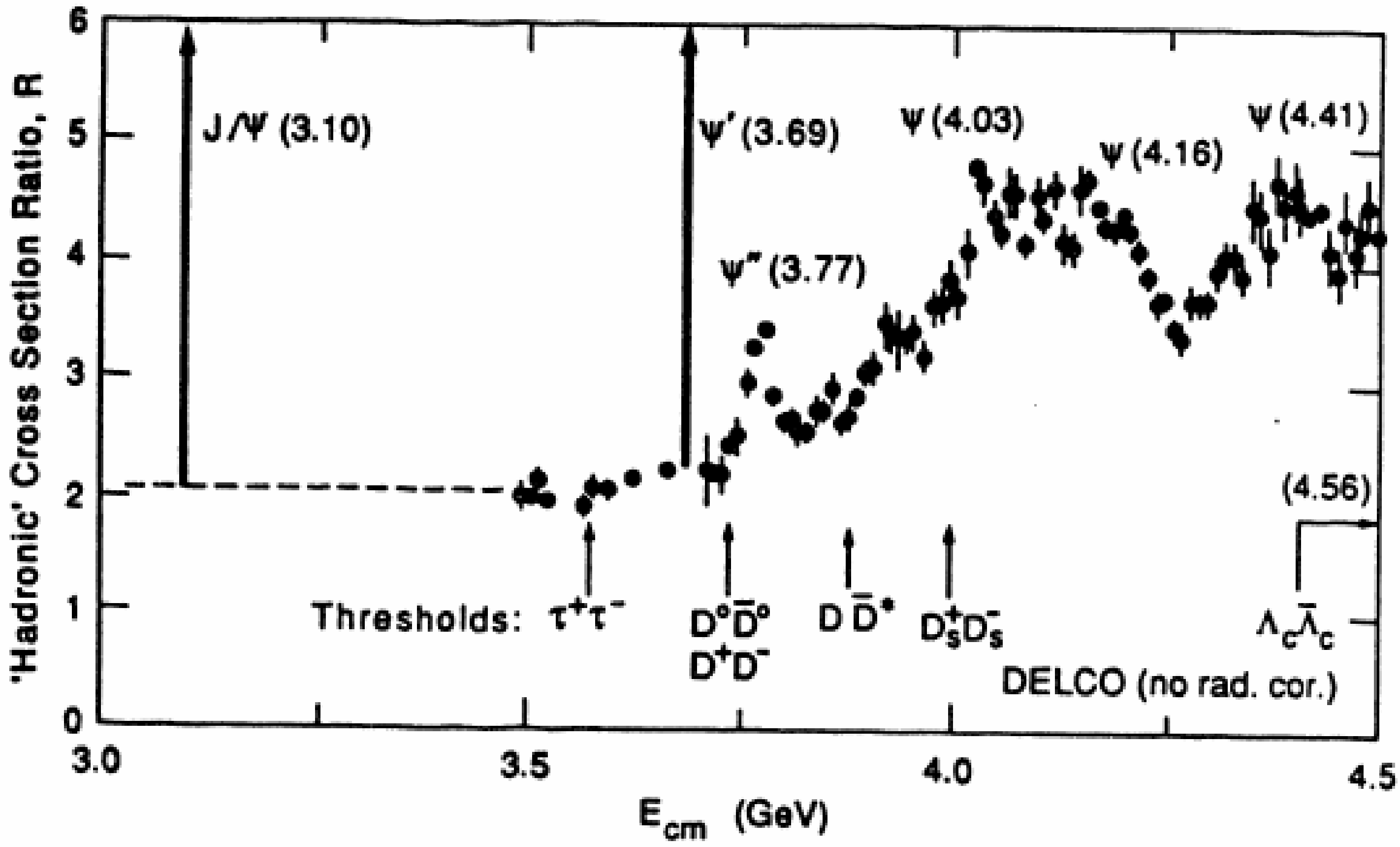
M.L. PERL, G.J. FELDMAN, G.S. ABRAMS, M.S. ALAM, A.M. BOYARSKI, M. BREIDENBACH, F. BULOS, W. CHINOWSKY, J. DORFAN, C.E. FRIEDBERG, G. GOLDHABER[1], G. HANSON, F.B. HEILE, J.A. JAROS, J.A. KADYK, R.R. LARSEN, A.M. LITKE, D. LÜKE[2], B.A. LULU, V. LÜTH, R.J. MADARAS, C.C. MOREHOUSE[3], H.K. NGUYEN[4], J.M. PATERSON, I. PERUZZI[5], M. PICCOLO[5], F.M. PIERRE[6], T.P. PUN, P. RAPIDIS, B. RICHTER, B. SADOULET, R.F. SCHWITTERS, W. TANENBAUM, G.H. TRILLING, F. VANNUCCI[7], J.S. WHITAKER and J.E. WISS

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305, USA and Lawrence Berkeley Laboratory and Department of Physics, University of California, Berkeley, California 94720, USA

Received 15 July 1976

We present the properties of 105 events of the form $e^+ + e^- \to e^\pm + \mu^\mp$ + missing energy, in which no other charged particles or photons are detected. The simplest hypothesis compatible with all the data is that these events come from the production of a pair of heavy leptons, the mass of the lepton being in the range 1.6 to 2.0 GeV/c^2




'Hadronic' Cross Section Ratio, R
J/Ψ (3.10)
Ψ' (3.69)
Ψ" (3.77)
Ψ (4.03)
Ψ (4.16)
Ψ (4.41)
(4.56)
Thresholds: $\tau^+\tau^-$
$D^0\bar{D}^0$
D^+D^-
$D\bar{D}^*$
$D_s^+D_s^-$
$\Lambda_c\bar{\Lambda}_c$
DELCO (no rad. cor.)
E_{cm} (GeV)

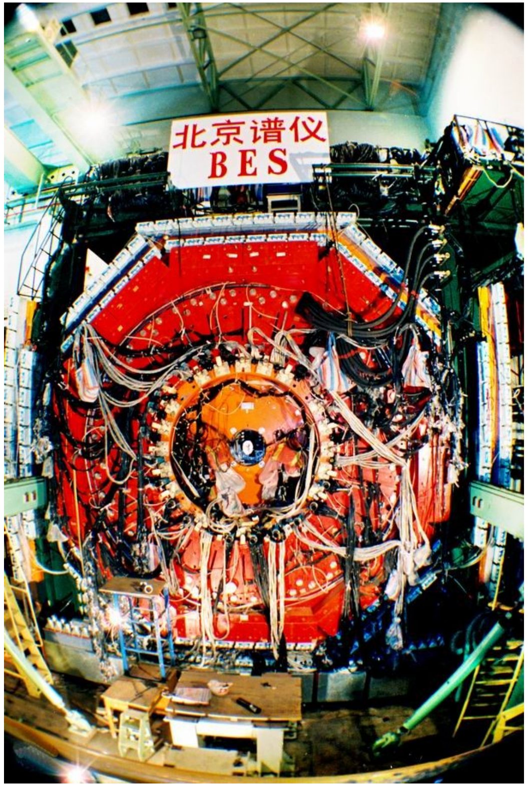
DELCO, 1978

Beijing Electron-Positron Collider

1979

October 1984

Research program of BES



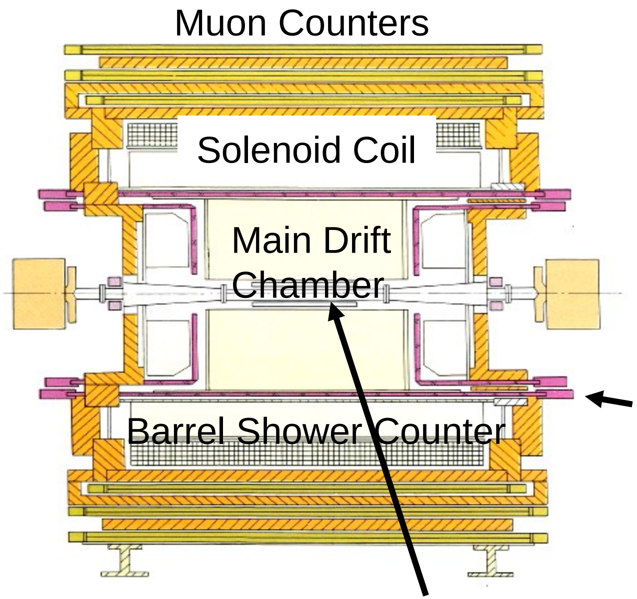
$L \sim 10^{31}\ cm^{-2}s^{-1}$

BES = MARKIII

- J/ψ radiative decays for a glueball search
- D-meson decays, search for CP-violation
- Search for Ds in annihilation
- Charmonium spectrum
- Charmed baryons
- τ hadronic decays
- R-ratio

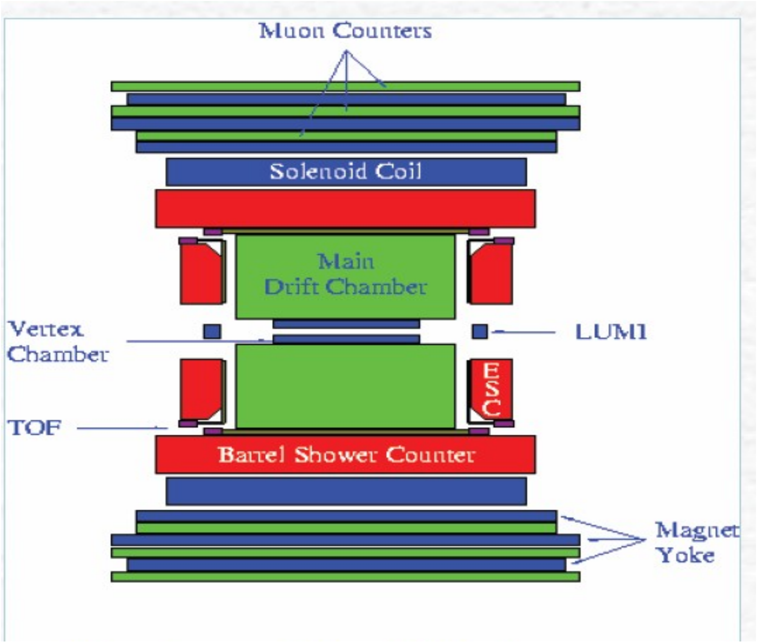
BES → BESII

1996 - 1997



BESI

Central Drift Chamber



BESII

BESII Upgrade: Remake MDC and TOF, replace Central Drift Chamber with a MARKI vertex chamber

Beijing tests complete precision measurement

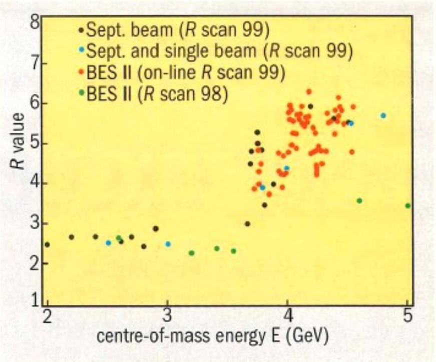
The BES II spectrometer at the Beijing electron–positron collider (BEPC) has completed a measurement of hadron production rates over the 2–5 GeV energy range which is valuable input for Standard Model calculations.

Three vital input parameters in the electroweak sector of the Standard Model are α, the electromagnetic coupling strength (which depends on energy), the Fermi constant of weak decay and the mass of the Z boson – the neutral carrier of the weak force.

To test the Standard Model, the electromagnetic coupling strength has to be evaluated at the Z resonance. The LEP measurements of the Z mass are of such high quality that now the error on the coupling strength is a limiting factor in tests of the Standard Model. Its accurate determination of α is critical for the indirect determination of the mass of the Higgs particle. A more accurate value narrows the mass window for Higgs particle searches.

Of particular importance in the extrapolation of α is the hadronic contribution to the vacuum, such as virtual quark–antiquark pairs, which cannot be calculated reliably but can be related to a factor known as R – the ratio of hadron to muon pair production in electron–positron annihilation. Uncertainties in the measured values of R in the 2–5 GeV energy range contribute to the error in α.

After the first R scan in spring 1998, the BES collaboration performed a finer scan in the 2–5 GeV energy region – almost the extremes of energy region that the BEPC can cover. The scan began in February and finished in early June. Data were taken at 85 energy points. To subtract background, separated beam runs were performed at 26 energy points, and single beam runs for electron and positron beams were carried out at 7 energy points. Special runs were taken at the J/psi resonance to determine the trigger efficiency and calibrate the detector. These runs show that the 12-tracking-layer vertex



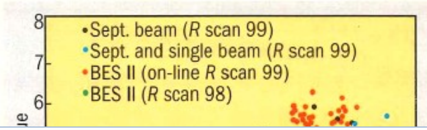
Comparing hadrons and muon production at the BES II spectrometer at the BEPC.

chamber, rebuilt from the SLAC Mark III endplates and beryllium beam pipe, has a spatial resolution of about 100 μm.

The figure shows the on-line values from the new R scan. Note that the detection efficiency, the background subtraction, as well as the radiative corrections have not been taken into account. The plot includes the R values for 6 energy points measured last year. The upgraded BEPC, as well as the good co-operation and hard work of the BEPC staff, were essential for the success of the scan, which continued even through the traditional Chinese Spring Festival.

Zhengguo Zhao and Frederick A Harris.

Cern Courier, September 1999



Beijing tests complete

Higgs particle. A more accurate value narrows the mass window for Higgs particle searches.

Of particular importance in the extrapola-

...7 energy points. Special runs were taken at the J/psi resonance to determine the trigger efficiency and calibrate the detector. These runs show that the 12-tracking-layer vertex

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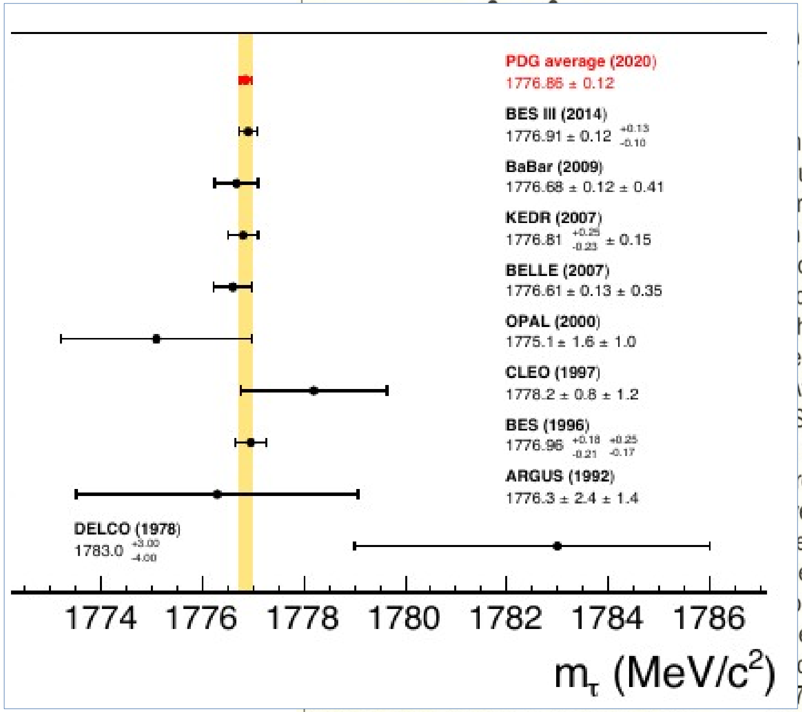
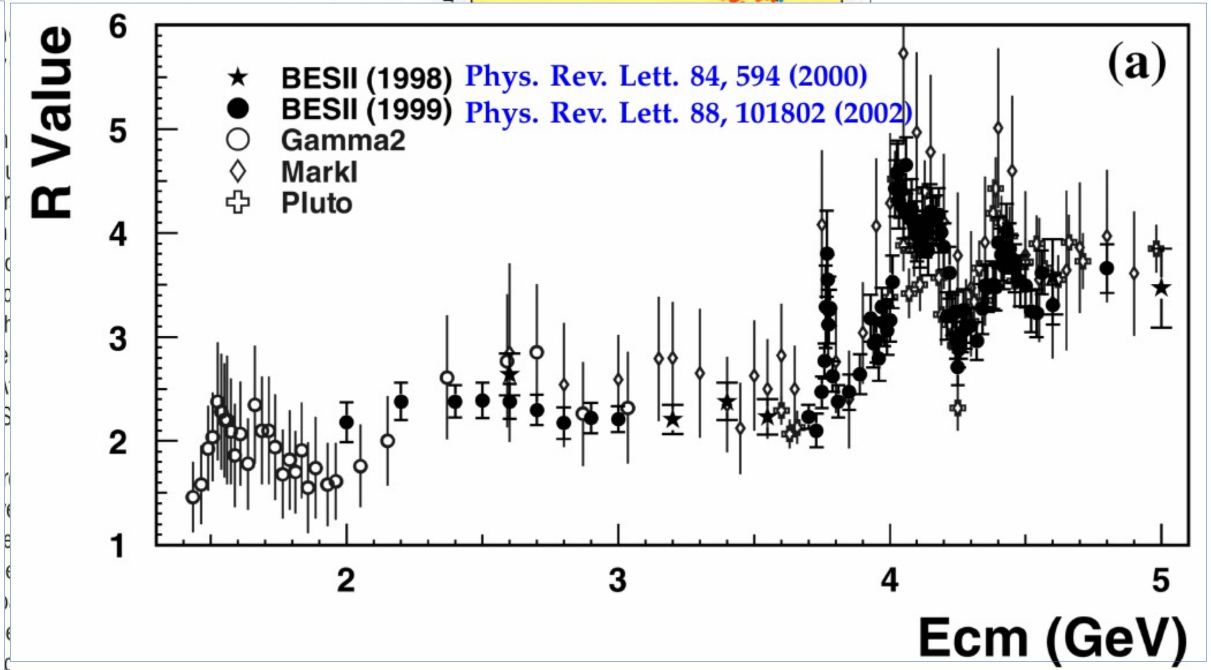
Zhengguo Zhao and Frederick A Harris.





Cern Courier, September 1999

Tau-Charm domain in 1990-ies

- The discovery of the Z and W bosons in 1983 was the definitive, triumphant confirmation of the electroweak theory, the cornerstone of the Standard Model.
- By the mid-1990s, after the first LEP runs and the top quark discovery, the Standard Model was universally regarded as a precision-tested theory. Its predictions for electroweak observables were confirmed at the 0.1% level.
- Theoretical description of heavy quarkonium via effective theories became available, which required precise measurements of quarkonium spectroscopy and decays
- Precision Measurement of CKM Elements needed for studying the CP-violation
- As a result, a great interest to precision experiments. Electron-positron colliders provide high luminosity, low background and well known initial state → flavour factories!

Physics Program

Tau Lepton Physics

- the decay branching ratios
- the Michel parameters
- the tau neutrino mass
- the tau dipole moment

Charm Physics

- CKM Matrix Elements-Semileptonic Decay
- D_0 — D_0bar mixing and CP violating decays
- Purely Leptonic D Decays and f_D measurement
- LFV decays and New Physics

Hadron Spectroscopy & QCD

- Charmonium Spectroscopy
- Light Hadron Spectroscopy
- R-ratio

Physics Program

Tau Lepton Physics

- the decay branching ratios
- the Michel parameters
- the tau neutrino mass
- the tau dipole moment

Largely covered by LEP and B-factories in the next decade

Charm Physics

- CKM Matrix Elements-Semileptonic Decay
- D_0 — D_0bar mixing and CP violating decays
- Purely Leptonic D Decays and f_D measurement
- LFV decays and New Physics

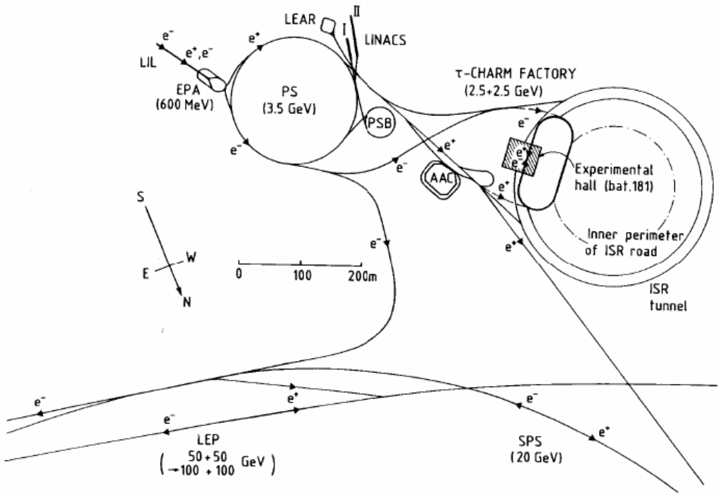
Hadron Spectroscopy & QCD

- Charmonium Spectroscopy
- Light Hadron Spectroscopy
- R-ratio

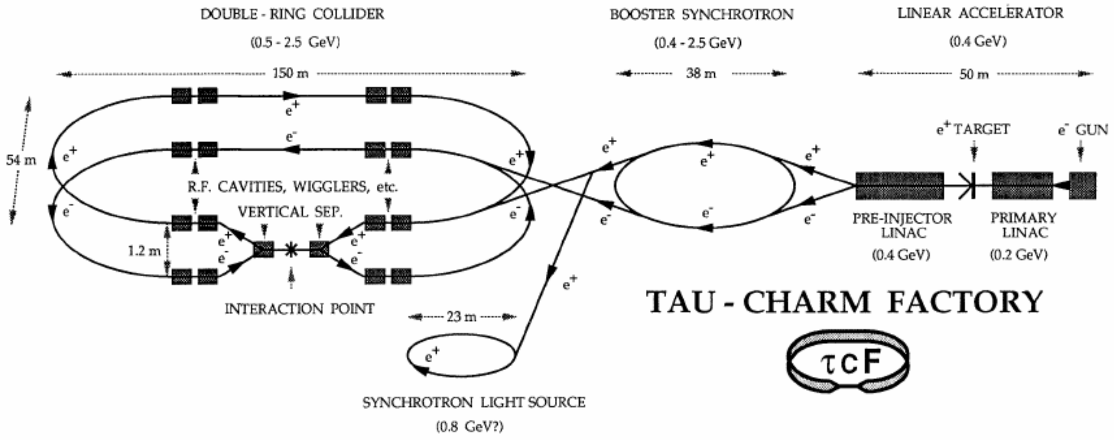
Tau Charm Factories

$\sqrt{s}$ = 3 – 5 GeV, L ~ 10^{33} $cm^{-2}s^{-1}$

CERN, 1987

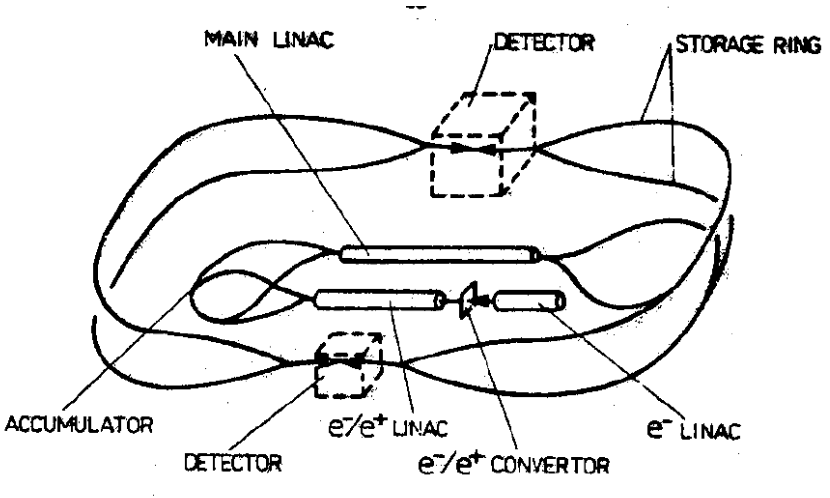


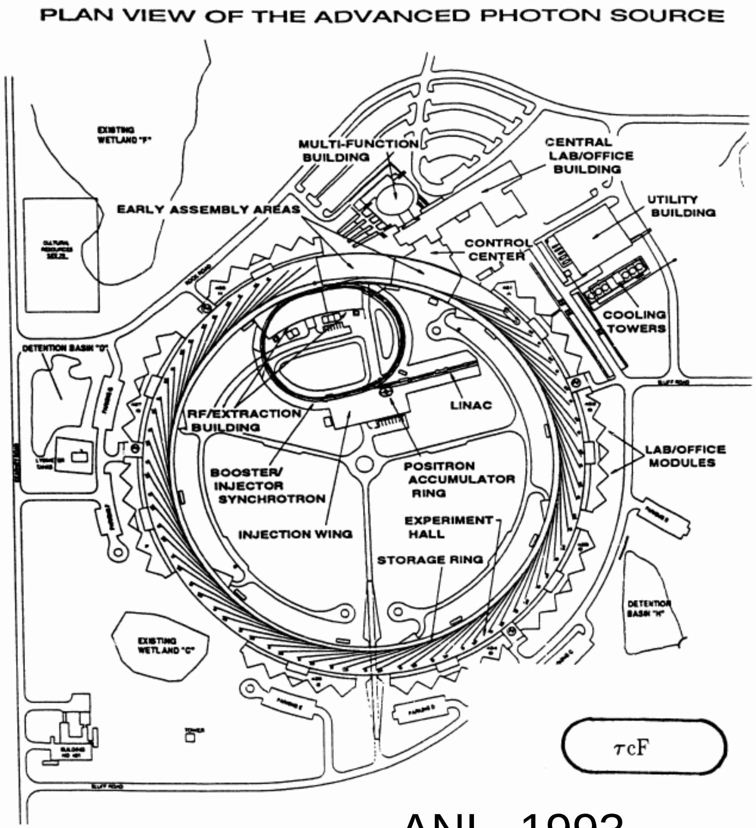
Spain, 1990



Tau Charm Factories
$\sqrt{s} = 3 – 5$ GeV, L ~ 10^{33} cm^{-2}s^{-1}

ITEP Moscow, 1990





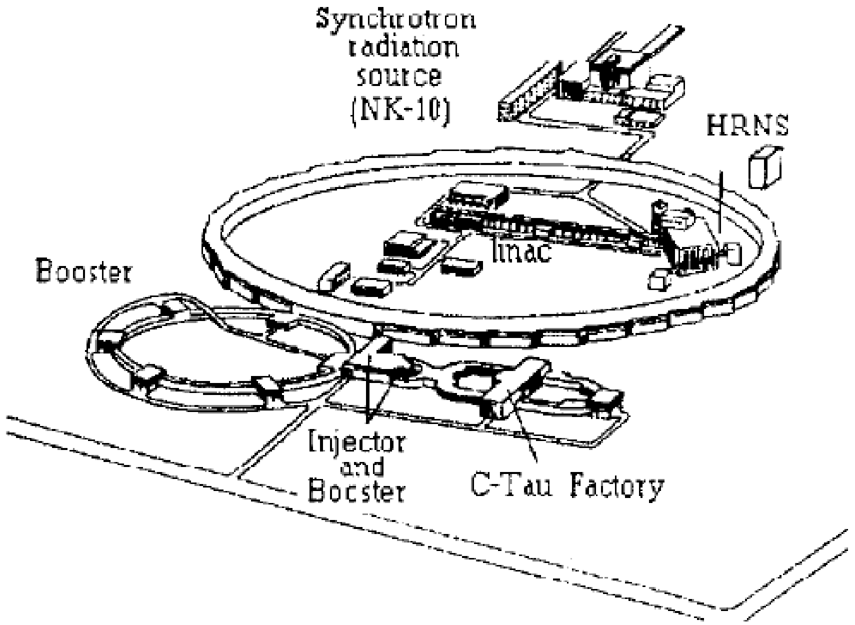
ANL, 1993

JINR c-tau factory

JINR TAU-CHARM FACTORY DESIGN CONSIDERATIONS

V.S.Alexandrov, V.K.Antropov, O.V.Arkhipov, P.F.Beloshitsky,
L.V.Bobyleva, D.I.Kaltchev, V.I.Kazacha, N.Yu.Kazarinov,
A.K.Krasnykh, V.I.Mironov, L.M.Onischenko, E.A.Perelstein,
A.N.Sissakian, Yu.I.Smirnov, Ts.D.Vylov

Joint Institute for Nuclear Research,
USSR, 141980, Dubna

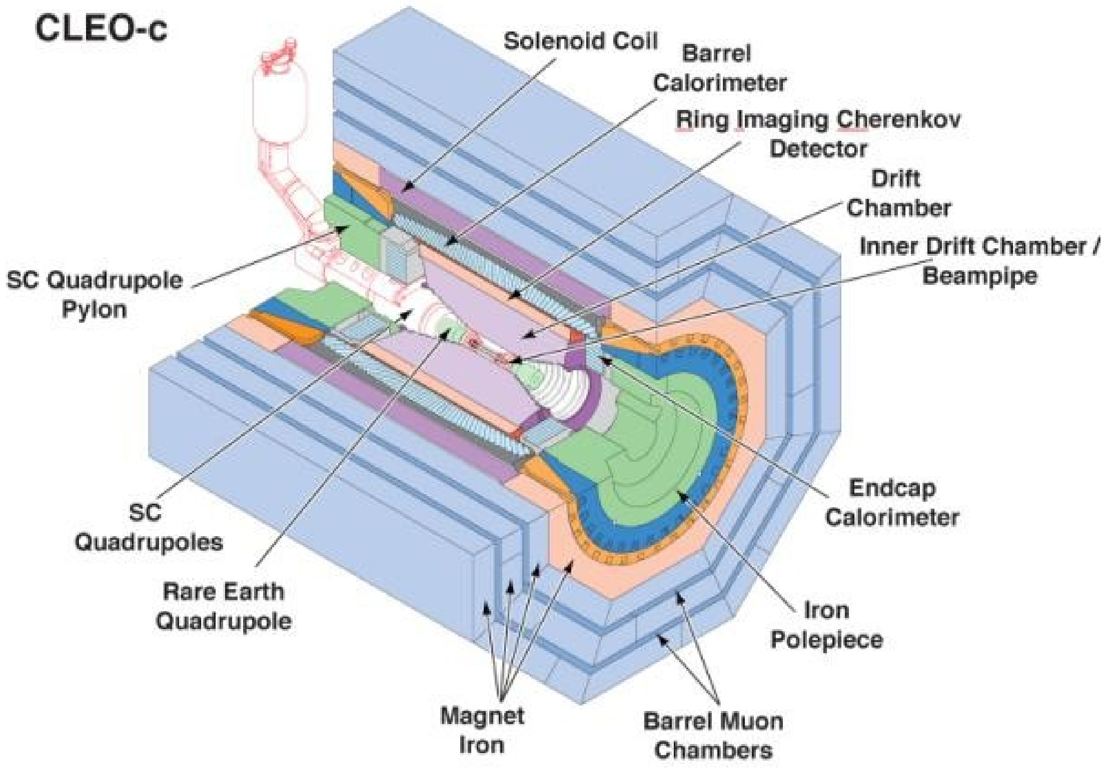


The project discussed involves: heavy-ion storage rings with energy up to 1 GeV/nucleon ;
a tau-charm factory with colliding beam energy up to 2.5 GeV;
a high resolution neutron source (HRNS);
a synchrotron light source — 8-10 GeV positron (electron) storage ring (NK-10).

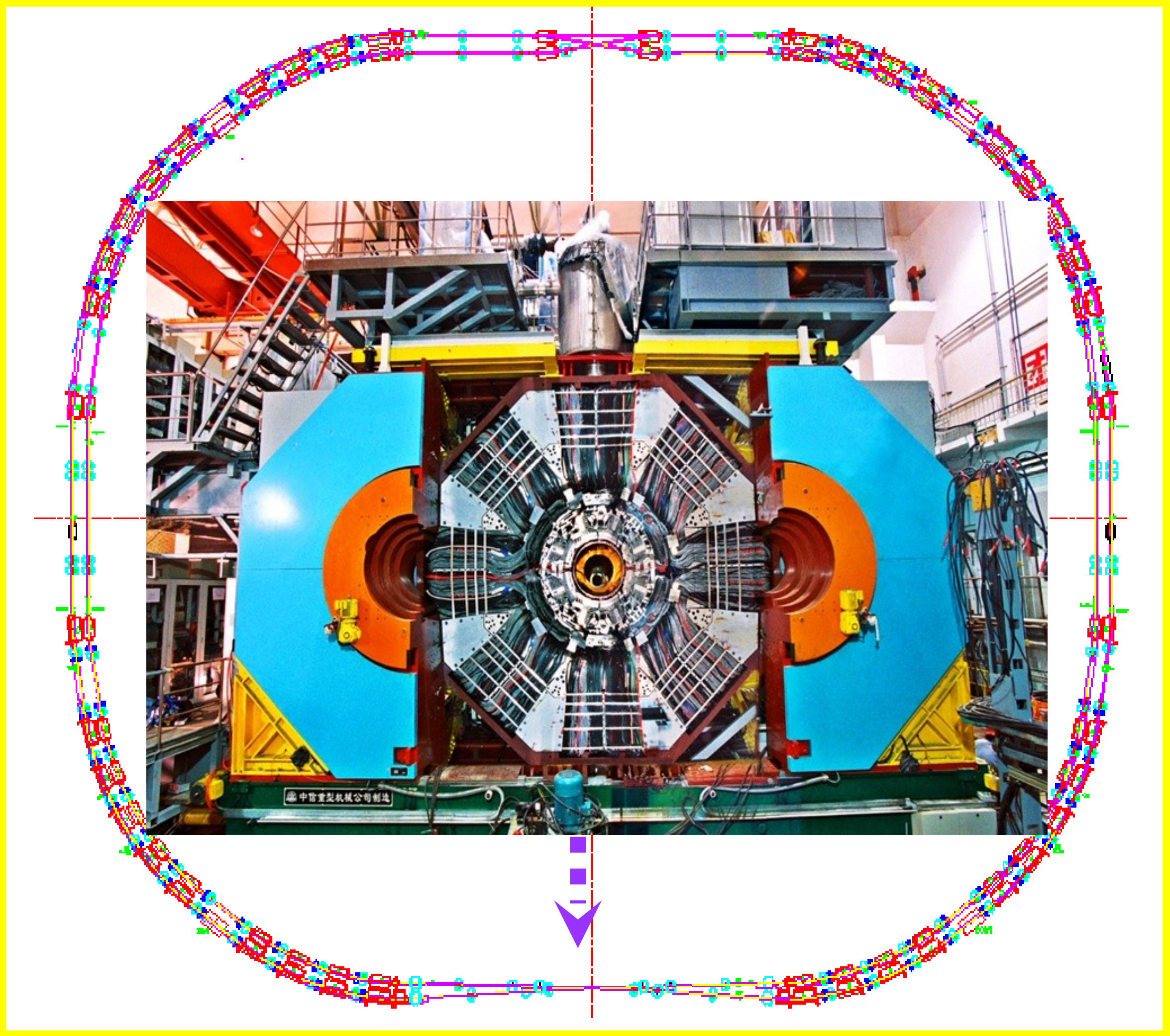
The tau-charm factory, that must be built in the first stage is the base of the electron (positron) accelerator and storage ring complex.

In the second stage it is planned to increase the injection complex energy up to 10 GeV, that is necessary for the storage ring NK-10 building. The high resolution neutron source is to be built on the base of a linac, having common elements with the tau-charm factory preinjector.

CLEO-c



- CESR at Cornell ran at reduced energy in 2003-2004 (L ~ 5x10^{31} cm^{-2}s^{-1})
- CLEO detector was modified to detect low momemntum particles
- ~100 papers on charmonium and charm physics



BESIII

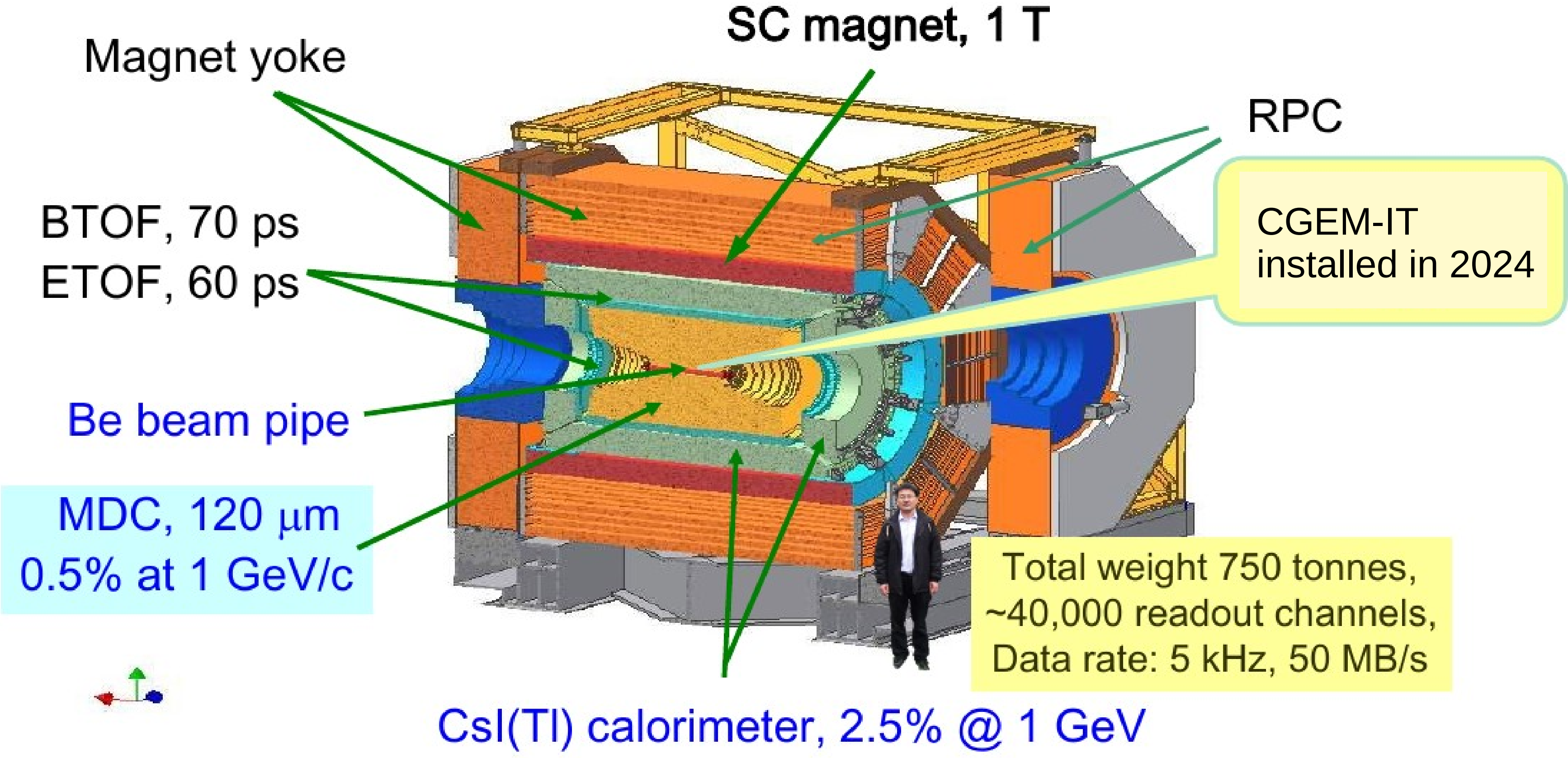
Site:
IHEP CAS, Beijing, China

BEPC-II beam energy:
1.0-2.3 GeV

Luminosity
1 x $10^{33}/cm^2/s$ @ψ(3770)

Project timeline:
2004 – Start of BEPC upgrade
2006 - The detector installation
2007 - BEPCII/BESIII commissioning
2009 – Start of physics data taking

The BESIII Detector



The BESIII Collaboration

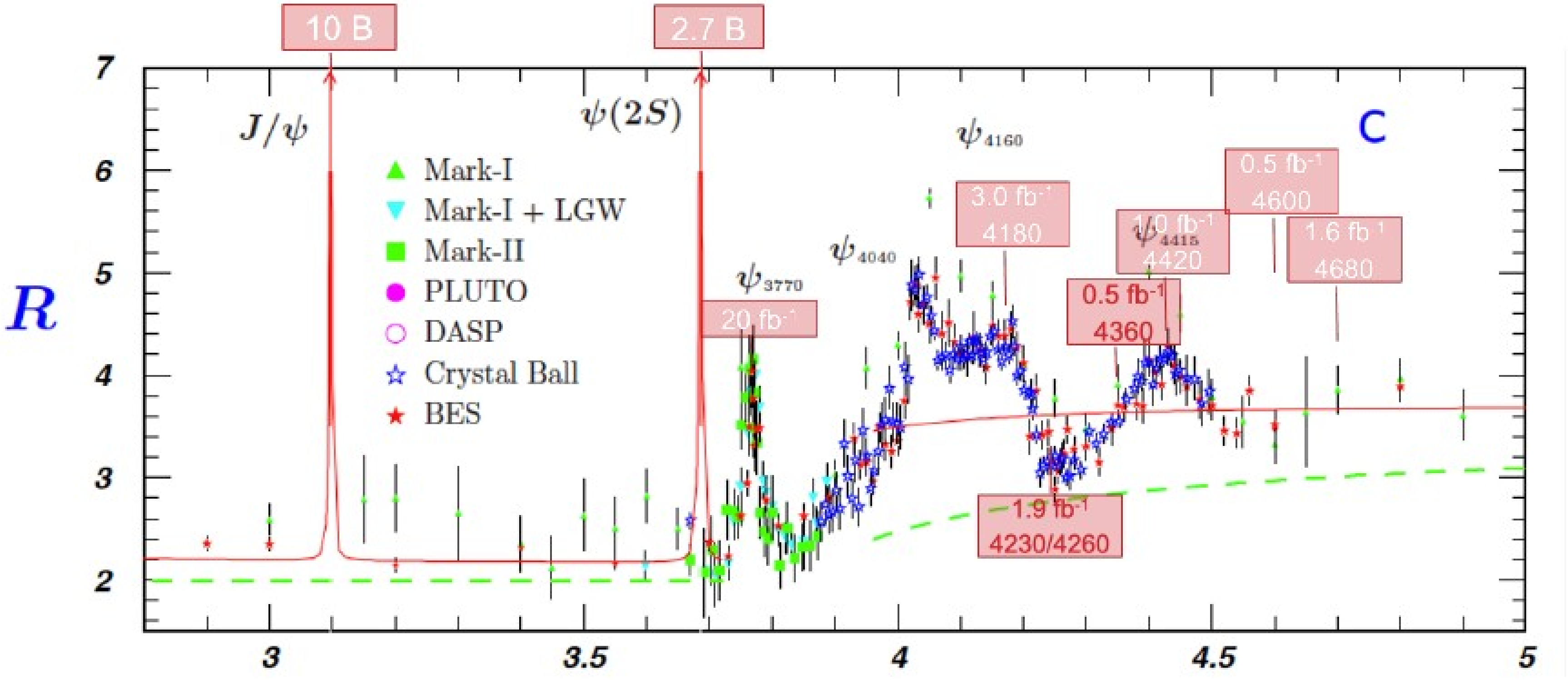
> 700 authors
94 institutes
17 countries

Physics Program

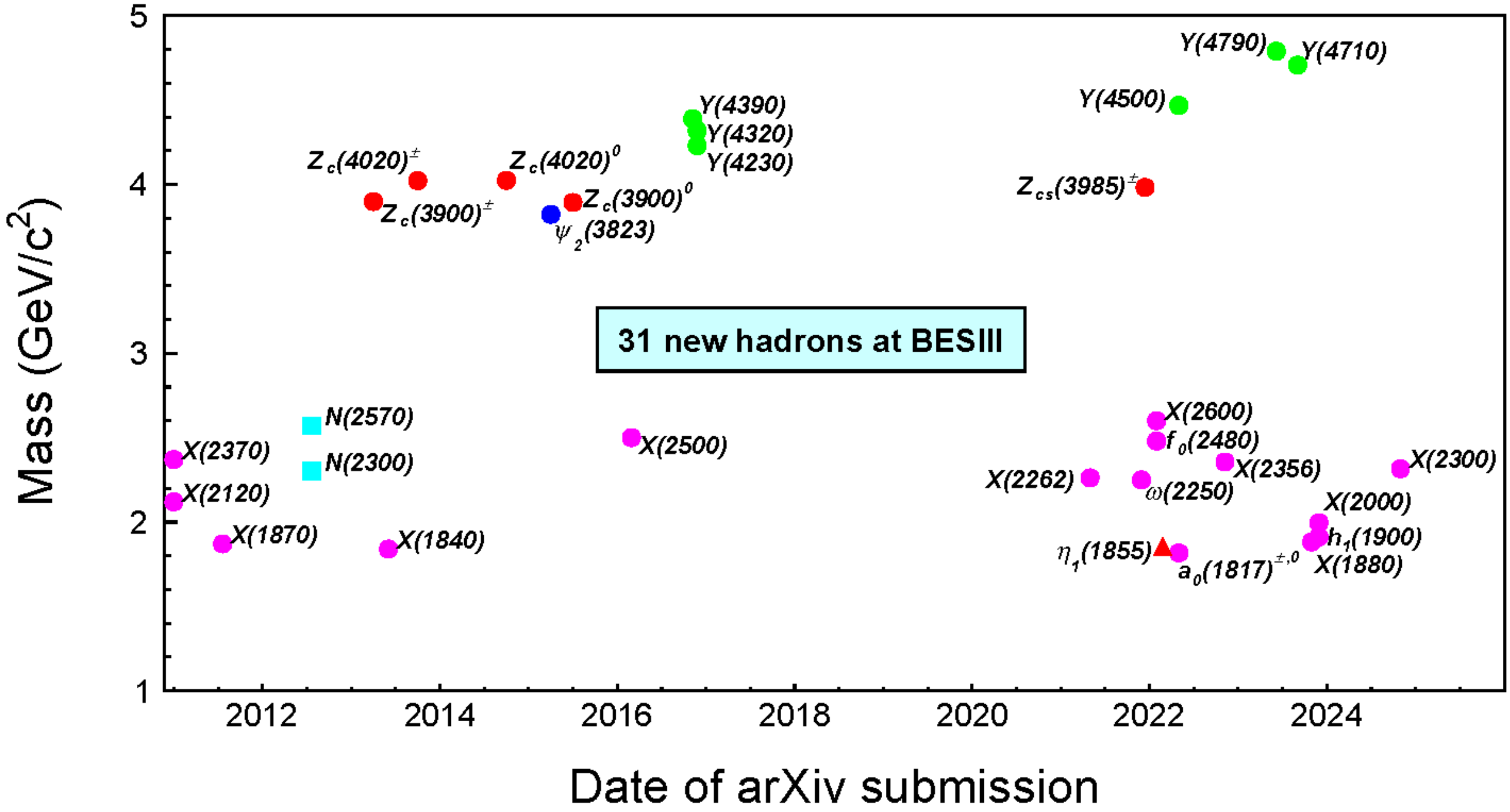
- Light Hadron Spectroscopy
  - Surplus mesons
  - Missing baryons
  - Search for exotic hadrons
- Charmonium Physics
  - Spectroscopy and transitions
  - Search for new states
- [Open] Charm Physics
  - CKM matrix parameters |Vcs| and |Vcd|
  - f_D and f_{Ds} measurement
  - Search for rare decays and CPV
- QCD & Tau Lepton Physics
  - R-ratio
  - Tau mass measurement

664 papers published since 2009

Data samples



Exotic hadrons

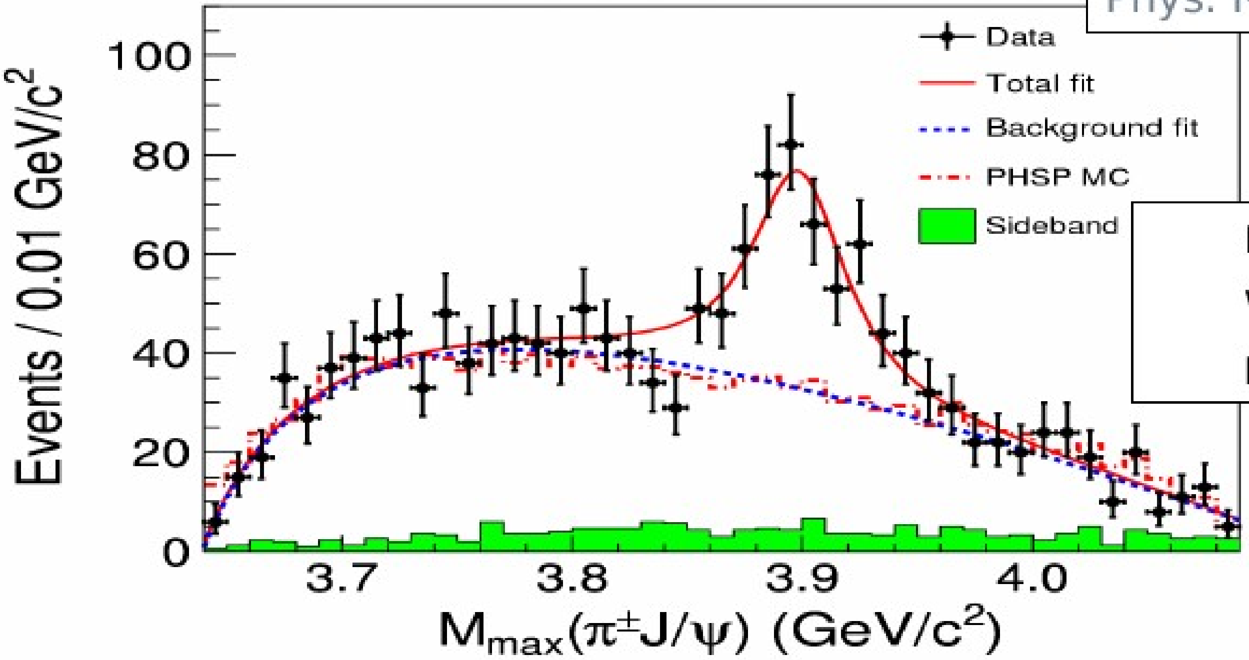


Sci. Bull. Vol 68, 19, (2023) 2148-2150, arXiv:2310.09465

The $Z_c^{\pm}(3900)$ observaton @BESIII

$e^+e^- \rightarrow \pi^+\pi^- J/\psi$ at $\sqrt{s}$=4260 MeV

BESIII: arXiv:1303.5949
Phys. Rev. Lett (2013) 252001

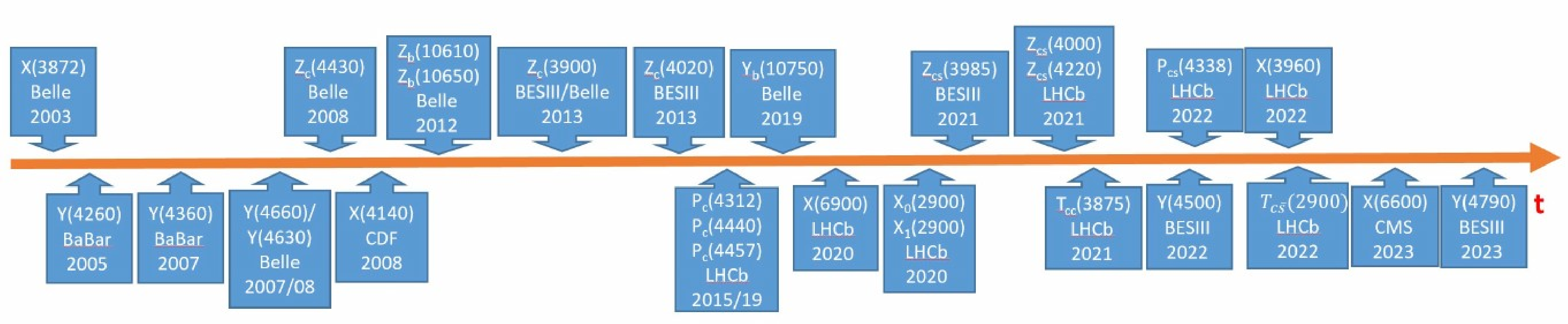


Mass = (3899.0±3.6±4.9) MeV

Width = (46±10±20) MeV

Fraction = (21.5±3.3±7.5)%

XYZ hadrons



Z_Q: tetraquark with a $Q\bar{Q}$ pair

P_Q: pentaquark with a $Q\bar{Q}$ pair

Y: vectors, $J^{PC}=1^{--}$

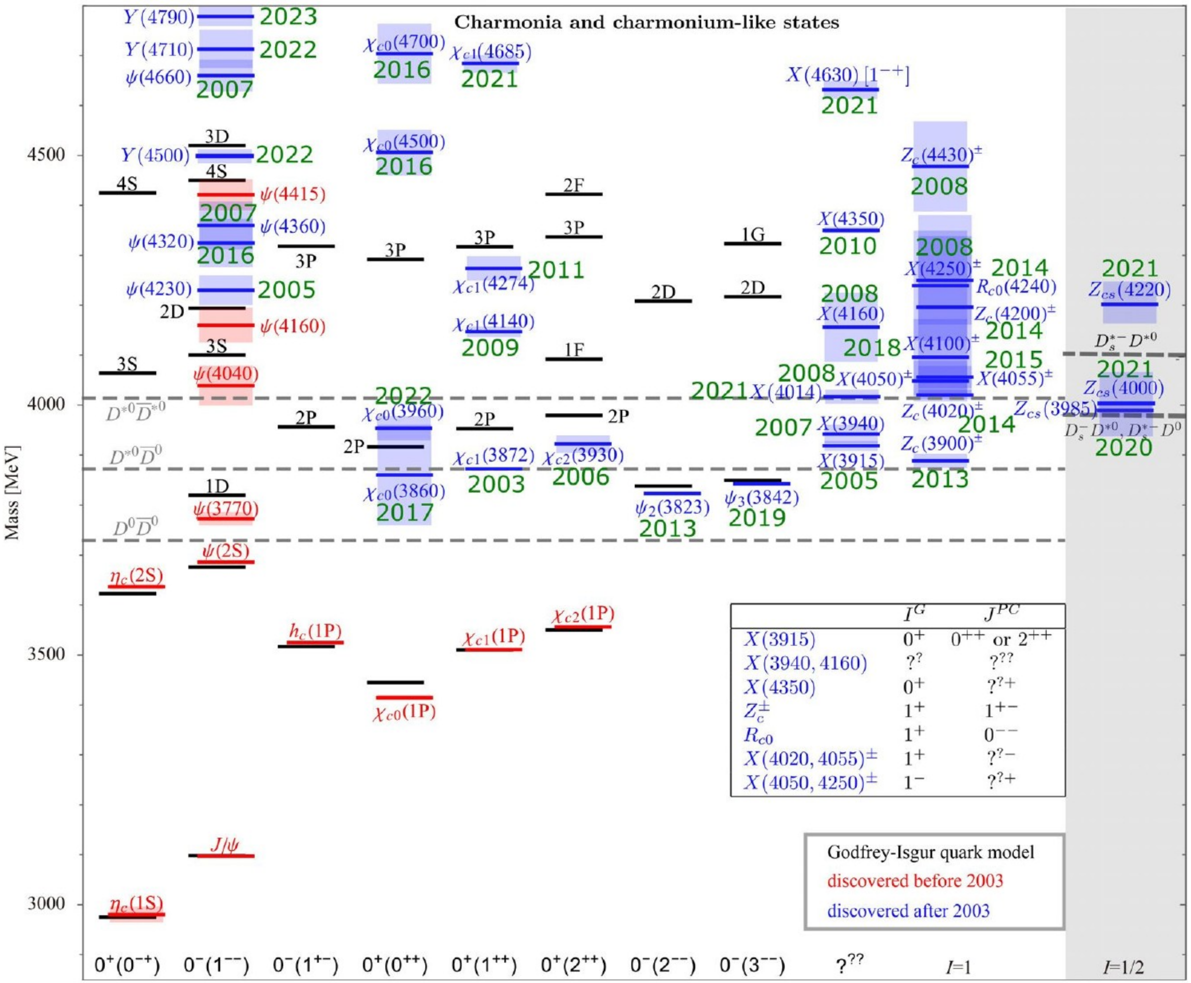
$T_{QQ'}$: tetraquark with QQ'

X: other states

Over the last two decades, a new class of hadrons consisting of more than three quarks (unlike ordinary mesons and baryons) has been discovered. However, we still do not sufficiently understand their nature and properties.

Are there other states (gluons, hybrids, molecules) that are allowed in QCD?

Scheme by C,Z,Yuan @ 2024



	I^G	J^{PC}
$X(3915)$	0^+	0^{++} or 2^{++}
$X(3940, 4160)$	$?^?$	$?^{??}$
$X(4350)$	0^+	$?^{?+}$
$Z_c^{\pm}$	1^+	1^{+-}
R_{c0}	1^+	0^{--}
$X(4020, 4055)^{\pm}$	1^+	$?^{?-}$
$X(4050, 4250)^{\pm}$	1^-	$?^{?+}$

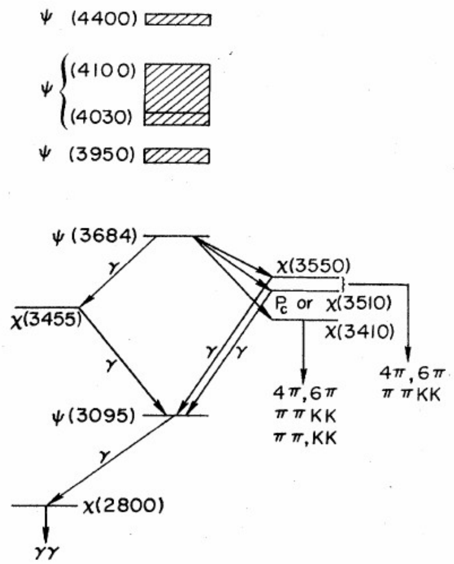
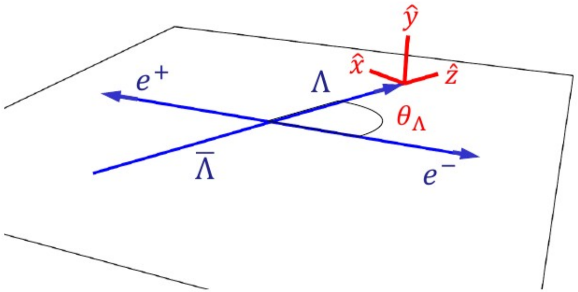


FIG. 15. An energy-level diagram of the new particles. The many observed decay modes of the psi family have been omitted.

Hyperons and CP violation

Hyperons at BESIII



- The spin orientations of the baryon and antibaryon are entangled
- The hyperons are polarized in the direction perpendicular to the reaction plane
- The magnitude of the polarization depends on the angle (θ_Λ)
- Hyperon polarization is determined via decay products

Front. Phys. 12(5), 121301 (2017)

Decay Mode	$\mathcal{B}(\times 10^{-3})$	$N_B(\times 10^6)$
$J/\psi \to \Lambda\bar{\Lambda}$	1.89 ± 0.09	~18.9
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	1.07 ± 0.04	~10.7
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	1.17 ± 0.03	~11.7
$J/\psi \to \Xi^-\bar{\Xi}^+$	0.97 ± 0.08	~9.7
$J/\psi \to \Xi^0\bar{\Xi}^0$	1.17 ± 0.04	11.7

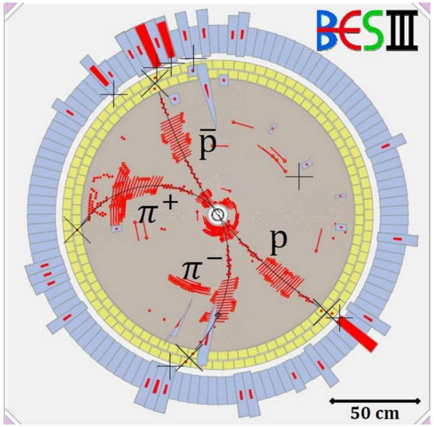
$J/\psi \rightarrow \Lambda^- \Lambda^+$ and $J/\psi \rightarrow \Xi^- \Xi^+$

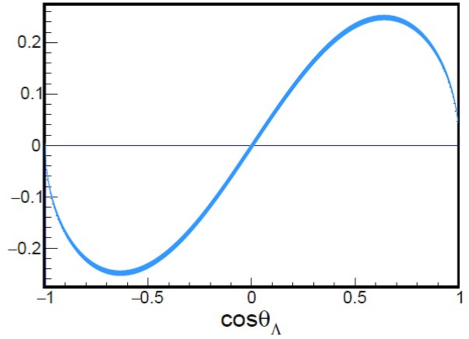
Nature Physics vol 15, 631–634 (2019)

The Λ-baryon polarization has been measured in baryon-antibaryon decays of J/ψ followed by $\Lambda \rightarrow p\pi$ decays

The value for the $\Lambda^+ \rightarrow p\pi$ decay parameter of $\alpha- = 0.750 \pm 0.009 \pm 0.004$, $17 \pm 3\%$ higher than the current world average, which has been used as input for all Λ polarization measurements since 1978.

For $\Lambda^- \rightarrow p\pi$ the value $\alpha+ = -0.758 \pm 0.010 \pm 0.007$, giving $A_{CP} = (\alpha- + \alpha+)/(\alpha- - \alpha+) = -0.006 \pm 0.012 \pm 0.007$, a precise direct test of CP-violation in Λ decays.





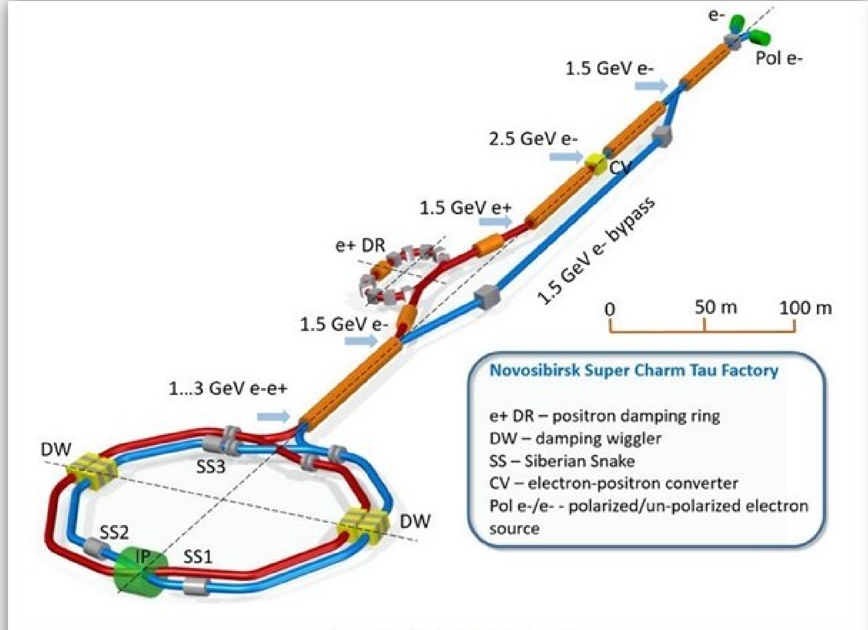
Nature 606 (2022) 7912, 64-69

Sequential two-body decays of entangled multi-strange baryon–antibaryon pairs provide a separation between strong and weak phases

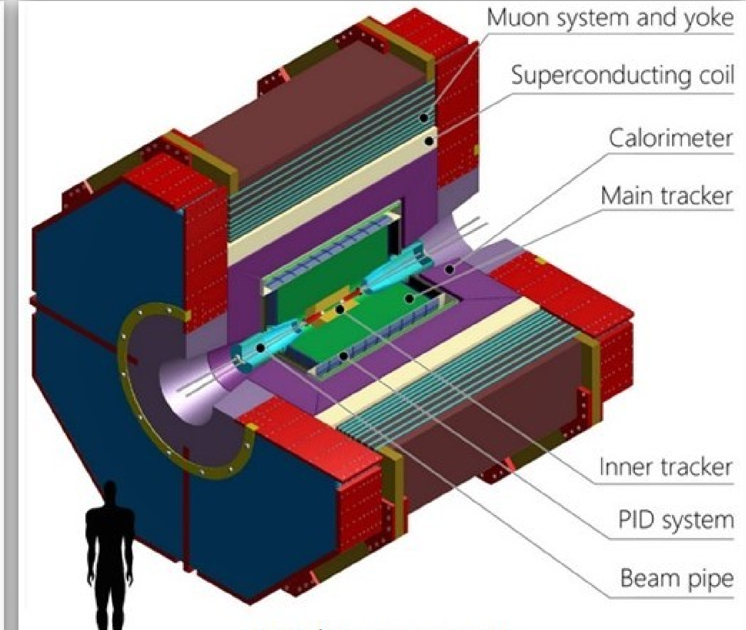
A direct determination of the weak-phase difference, $(\xi P - \xi S) = (1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad in $J/\psi \rightarrow \Xi^- \Xi^+$ decay

Super Tau Charm Factories
L: ~10^{33} $cm^{-2}s^{-1}$ → 10^{35} $cm^{-2}s^{-1}$

SCTF (Novosibirsk — Sarov, Russia)



Scheme of SCT factory complex



SCT detector concept

Super Tau Charm Factories

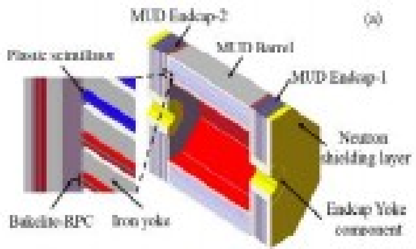
L: ~10^{33} $cm^{-2}s^{-1}$ → 10^{35} $cm^{-2}s^{-1}$

STCF (Hefei, China)

Ecm = 2-7 GeV, peak luminosity > 0.5×10^{35} cm^{-2} s^{-1}
Potential for luminosity upgrade, and a polarized electron beam
Site: Suburban “Future Big Science City” in Hefei

STCF CDR, Front. Phys. 19, 14701 (2024)

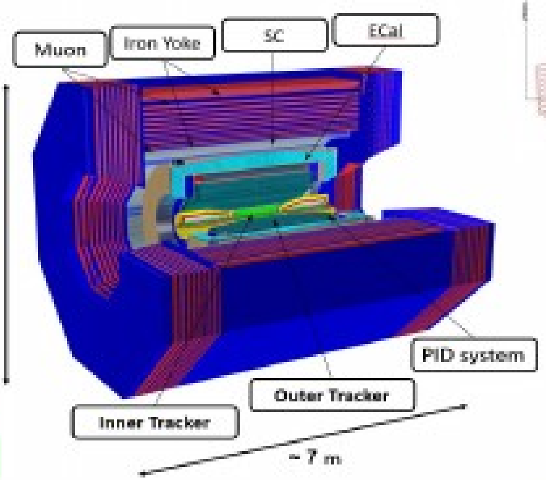
The detector concept

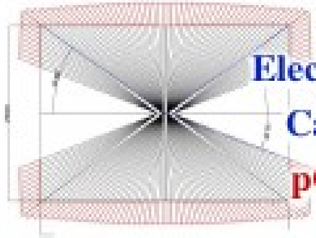


Muon Detector

Resistive Plate Chamber+

Plastic scintillator

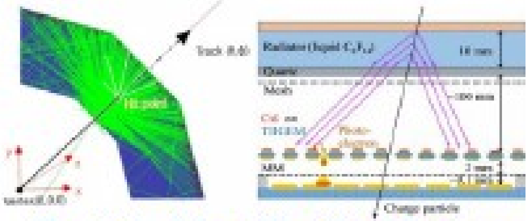




Electromagnetic

Calorimeter

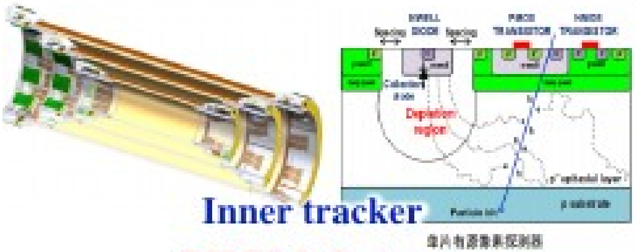
pCsI +APD



Particle Identification System

Barrel：RICH-like

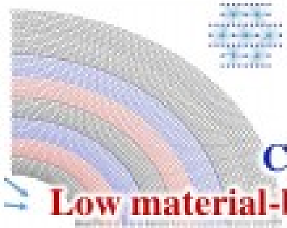
Endcap：DIRC-like



Inner tracker

μRWELL Detector

CMOS MAPS



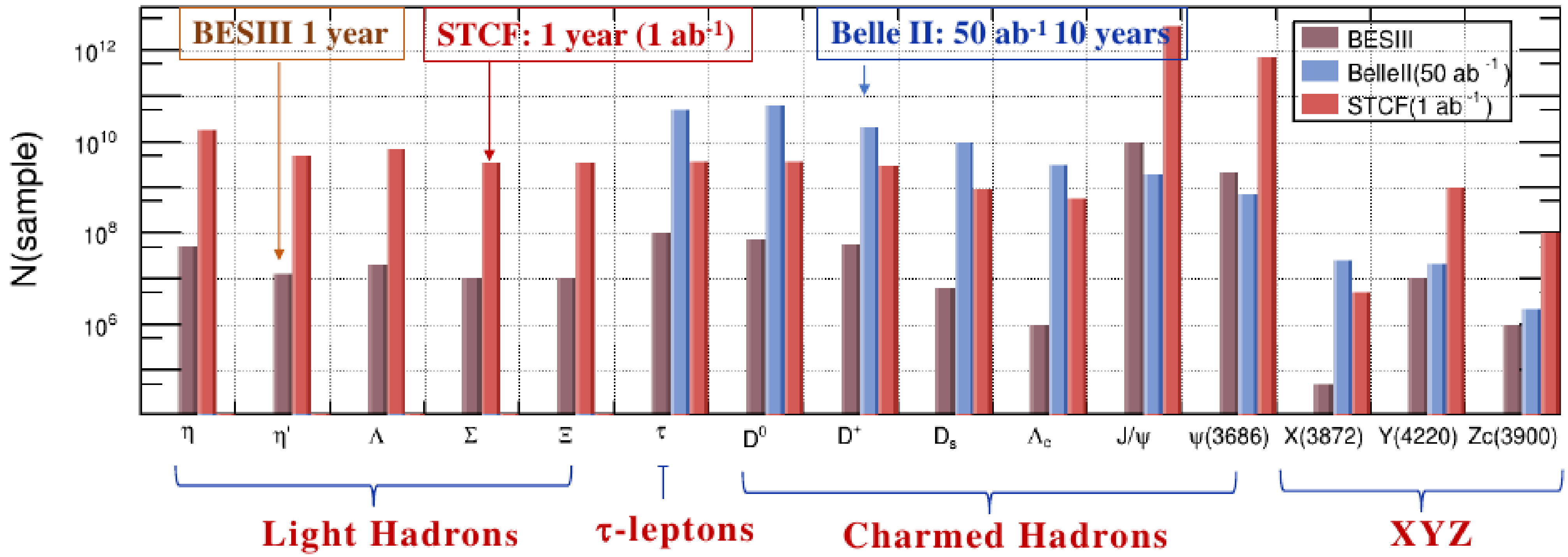
Central Tracker

Low material-budget Main Drift Chamber

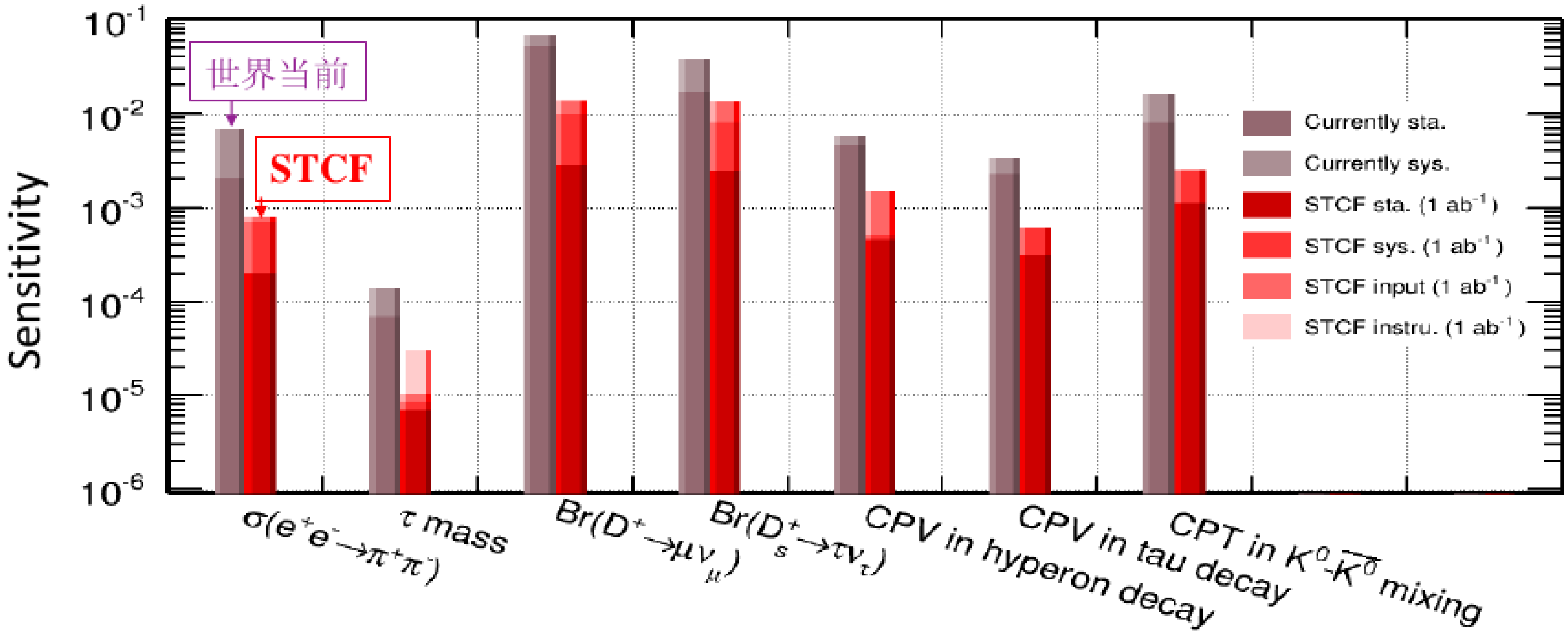
Physics Program

- Light Hadron Spectroscopy
  - Surplus mesons
  - Missing baryons
  - Search for exotic hadrons
- Charmonium Physics
  - Spectroscopy and transitions (+LQCD)
  - XYZ states
- [Open] Charm Physics
  - CKM matrix parameters |Vcs| and |Vcd|
  - f_D and f_{Ds} measurement (+LQCD)
  - Search for rare and forbidden decays
- CP-violation
  - Charmed mesons
  - Hyperons
  - Tau lepton decays
- QCD and Tau Lepton Physics
  - R-ratio
  - mass and lifetime
  - spectral functions
  - LFV decays

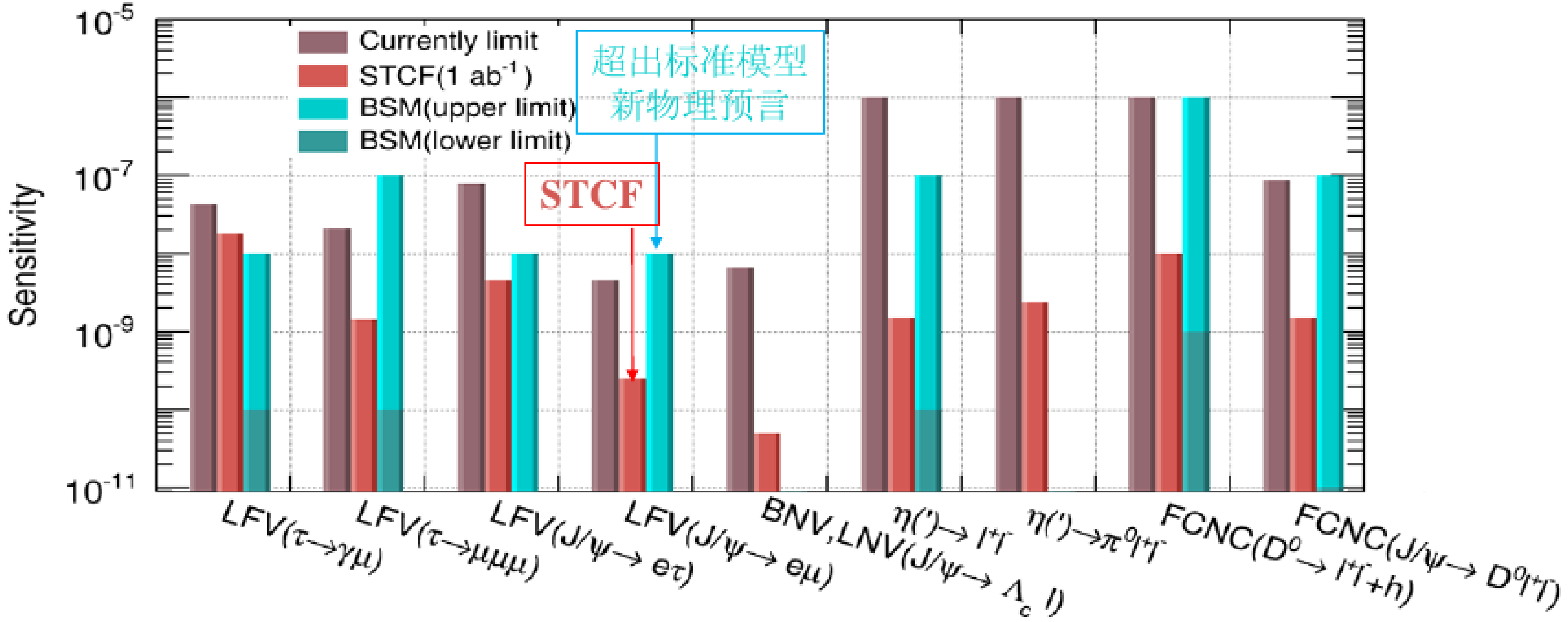
Expected data samples



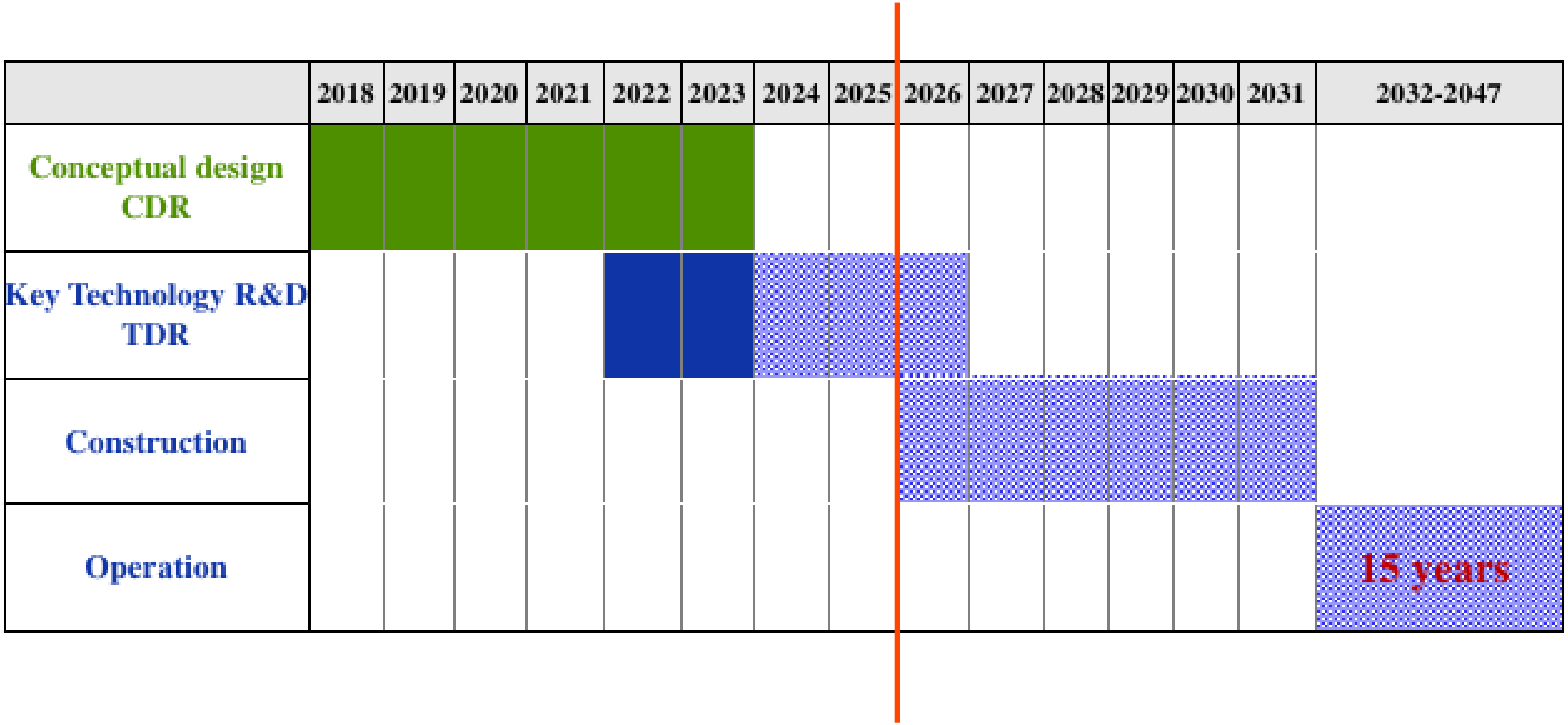
Sensitivity of precision measurements



Sensitivity to rare and forbidden decays



Expected timeline



Summary

- Physics program of STCF is challenging and comprising understanding of QCD in a transition region and search for new physics
- Key goals are the detailed study of XYZ states, study of hyperons, search for rare and forbidden decays
  - plus traditional TCF topics
- Success of STCF will stronly depend on achieved precision:
  - Collider luminosity
  - Detector preformance and systematics
  - Theoretical support