Status of physics and detector simulations at STCF

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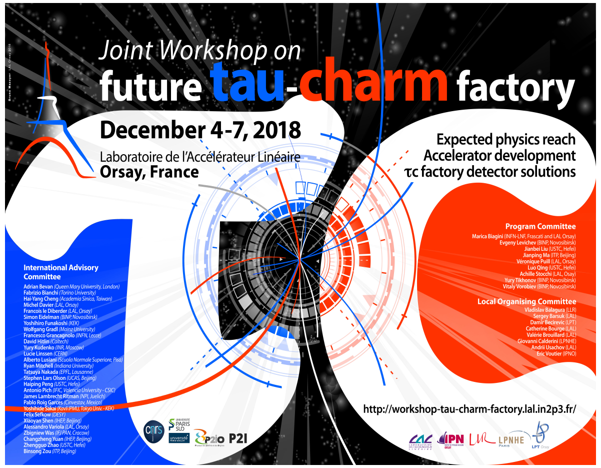
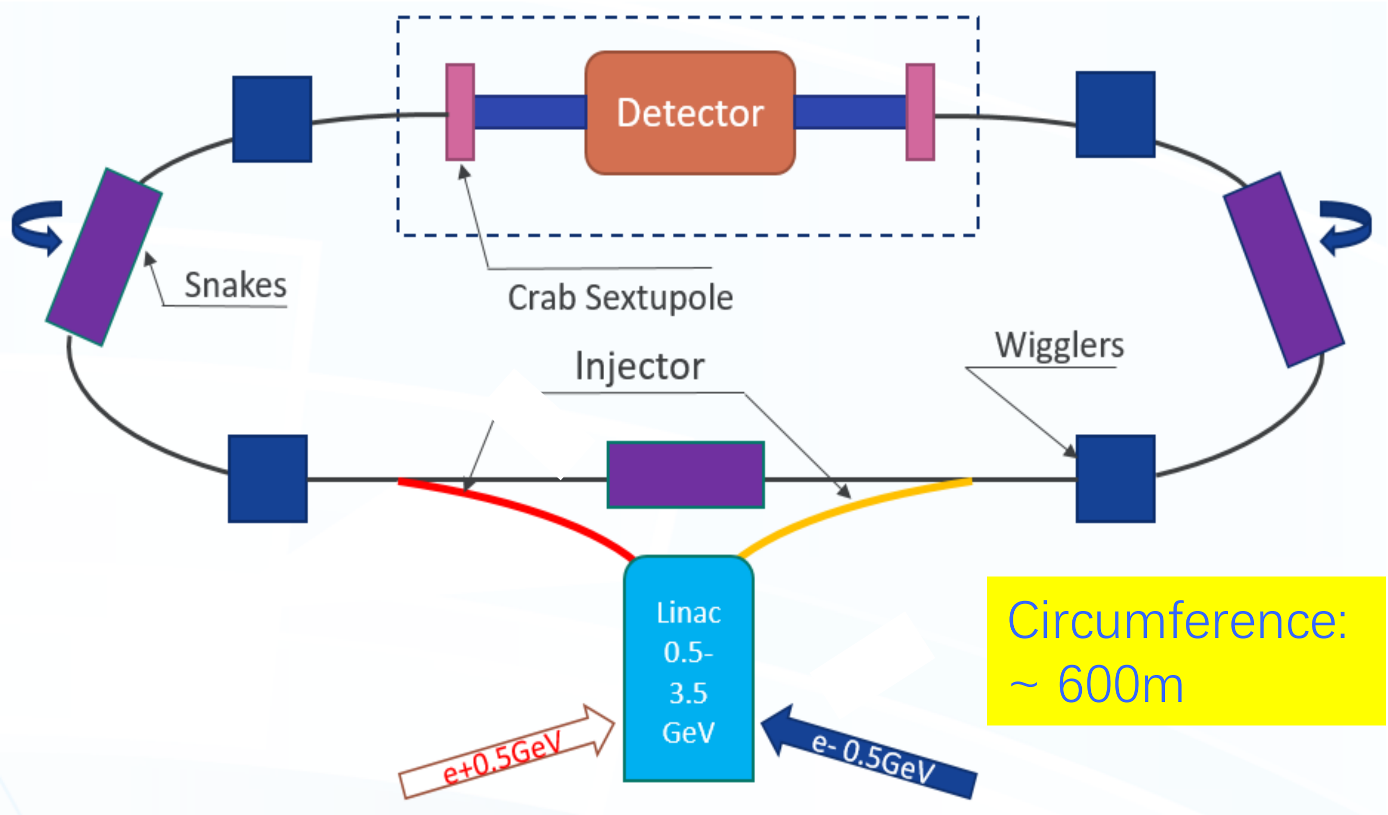


Joint Workshop on Future Tau-Charm Factory

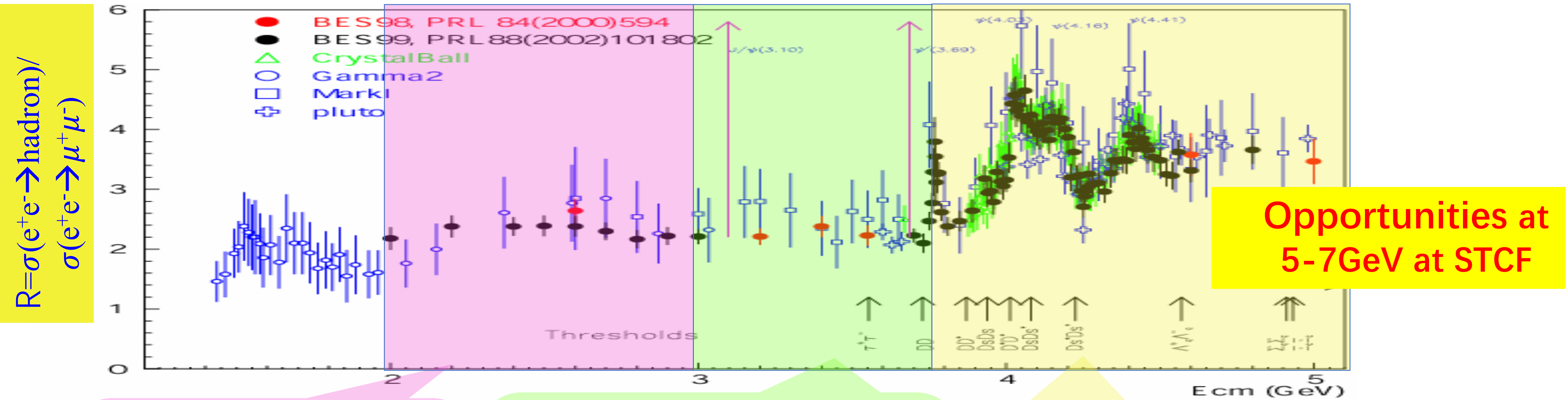
2018.12.4-2018.12-7, Paris

Super Tau Charm Facility in China

- E_{cm} = 2-7 GeV; L = (0.5-1)×10^{35} $cm^{-2}s^{-1}$ at 4 GeV, and single beam polarization (Phase II)
- A dedicated machine for HEP, an super τ-c machine far beyond BEPCII



Broad physics at τ-c Energy Region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- f_D and f_{Ds}
- D_0-D_0 mixing
- Coherent D mesons decays
- Charm baryons

A Super τ-charm Facility is a natural extension and a viable option for a post-BEPCII HEP project in China.

Highlighted Physics topics @ STCF

- **Precision test of SM**

-R scan, hadron form factor (nucleon, Λ, π), $\Delta\alpha_{QED}$, a_μ
-tau lepton decays, lepton, universality test
-CKM matrix, Decay constants (f_D/f_{D_s}), form factors
-Neutral D mixing and strong phase

- **New physics (tiny/forbidden in SM)**

-Rare charmonium decays: LFV, LNV, BNV···
-Rare charm decay: FCNC, LFV, LNV, invisible
-Rare rau decay: FCNC, LFV, LNV
-Rare light meson decay: $\eta/\eta'/\omega/\phi$

- **CP violation**

-Unexpected large CPV in τ or charm: tiny in SM
-CP violation in hyperon

- **Hadron physics**

-Hadron spectroscopy
-Hadron-pair threshold effects
-Glueball: direct test of QCD at low energy
-Multiquark, exotics, hybrids···
-Charmonium(-like) spectroscopy
-Charmed baryon decays

- **Exotic physics**

-Light dark matter: light higgs boson (a_0), U boson
-New interactions

Rich of physics program, unique for physics with τ leptons and c quark, important playground for study of QCD, exotic hadrons and search for new physics.

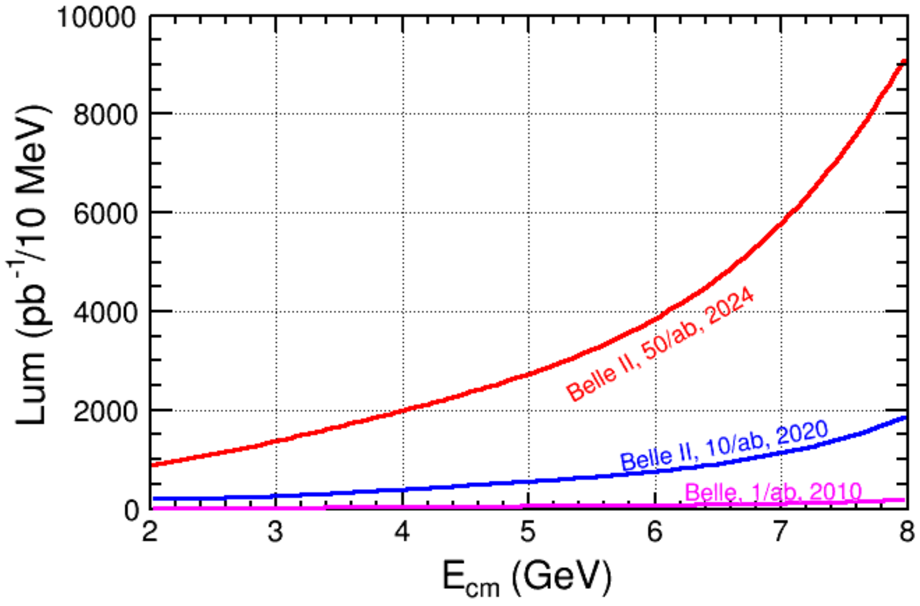
Integrated luminosity of STCF

- Assume running time 9 months/year, data taking efficiency 90%

$10^{35}\text{cm}^{-2}\text{s}^{-1} \times 86400\text{s} \times 270\text{days} \times 90\% \sim$ **2.0ab^{-1} /year**

10 years data taking, total 20 ab^{-1} conservatively

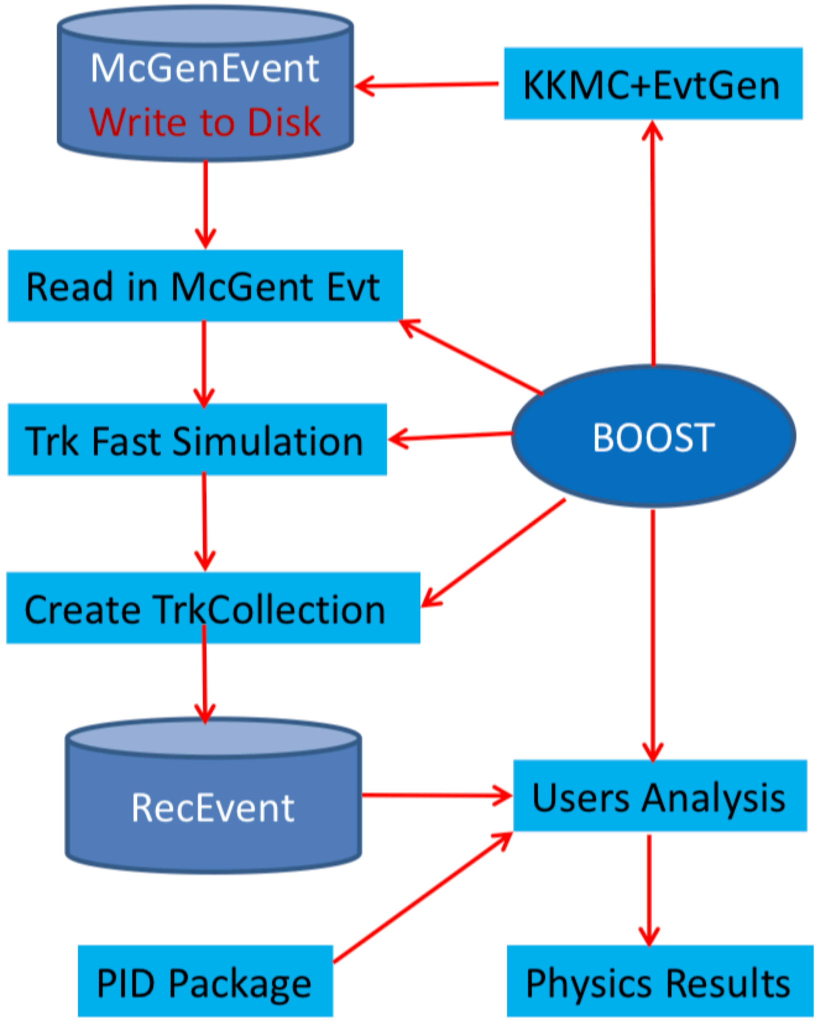
Excellent opportunities for the τ-charm physics



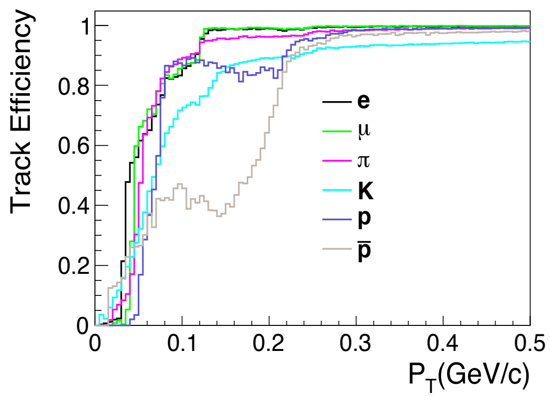
- **B factory**: Total integrated effective luminosity between 2-7 GeV is ~1.5ab^{-1} for 50 ab^{-1} data.
- **STCF** is expected to have higher detection efficiency
  - e.g. @4.26 GeV for $\pi^+\pi^-J/\psi$, $\varepsilon_{\text{BESIII}} = 46\%$, $\varepsilon_{\text{Belle}}$=10%
- **STCF** has low backgrounds for productions at threshold.

Fast Simulation Software

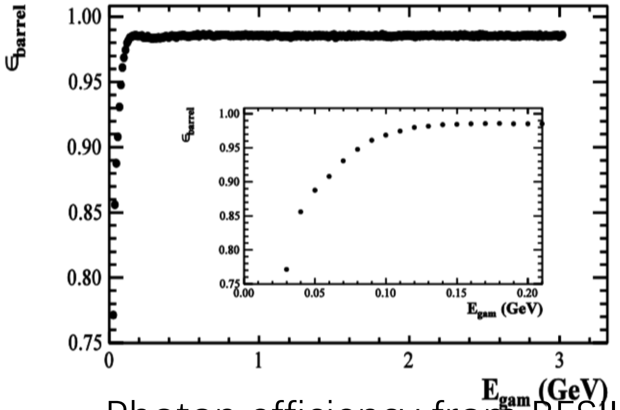
Scheme for Fast Simulation



- Same as BESIII for McGenEvt, and keep events in storage.
- Fast simulation for charge and neutral tracks (resolution, efficiency, error matrix etc.).
- Do not keep RecEvt information, fix random seed for repeating analysis.
- User analysis same as BESIII jobs.
- Optimize STCF detector by scaling the response parameters



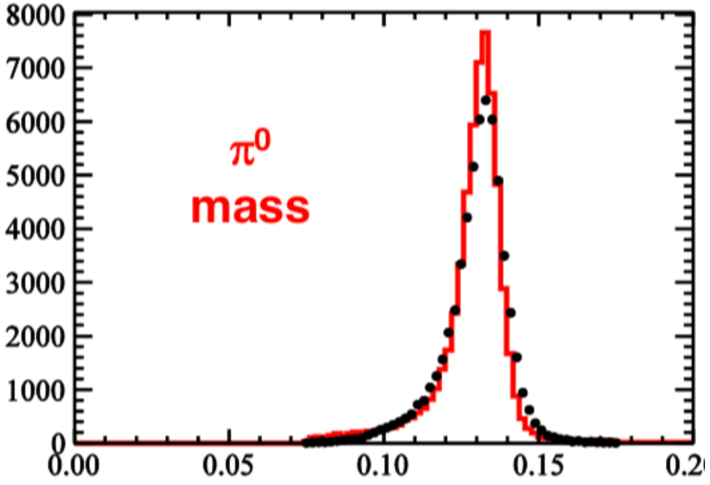
Tracking efficiency from BESIII

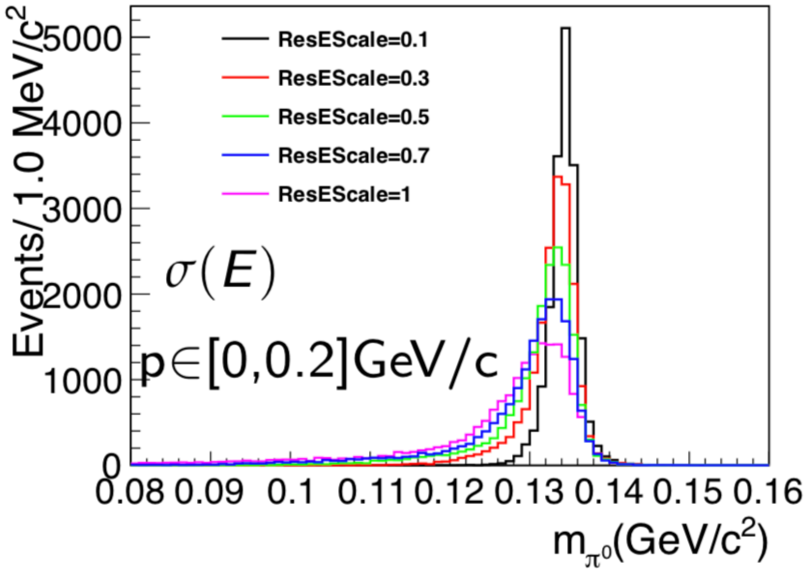


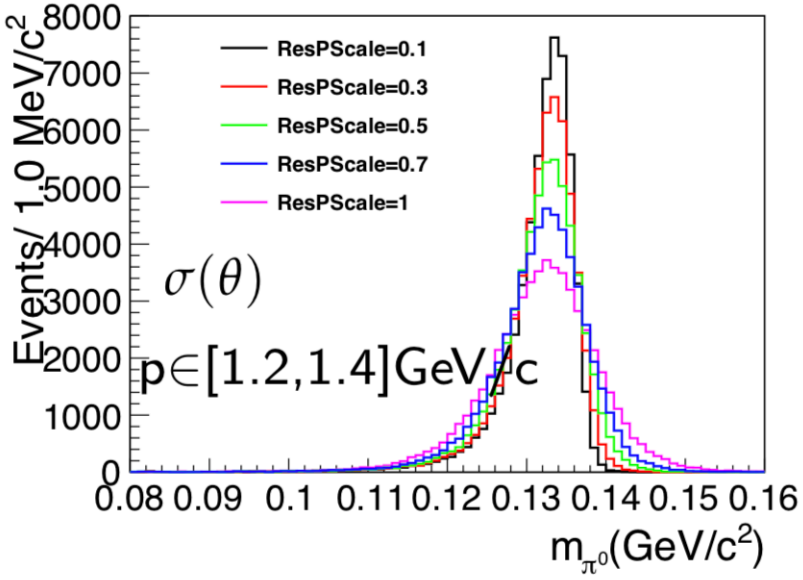
Photon efficiency from BESIII

Performance of Fast Simulation

$\psi(3686) \to \gamma\pi^0\pi^0$







—— Full Simulation

● Fast simulation

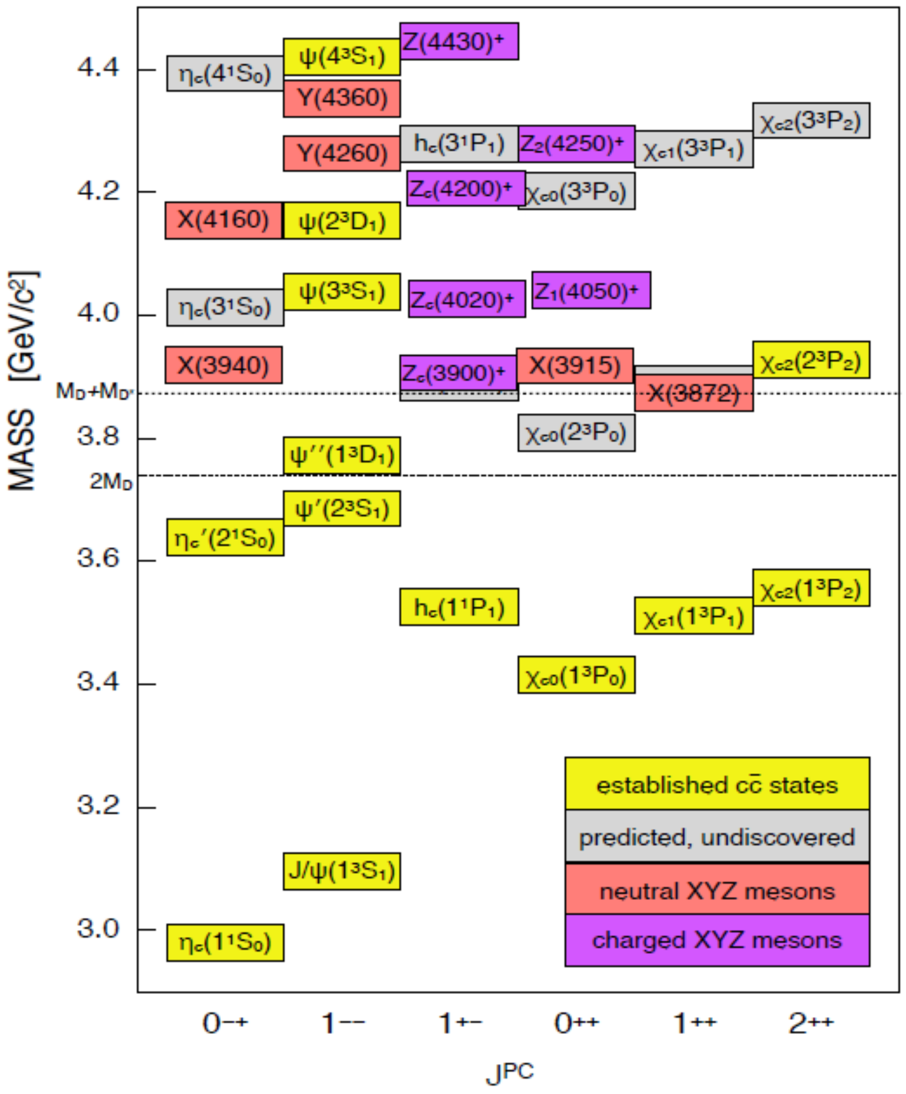
Good agreement between Fast and Full simulation for gamma Energy resolution

The resolution of π^0 can be improved with improvement of energy/position resolution

Following we show several highlighted physics processes using fast simulation package.

Charmonium(-like) physics

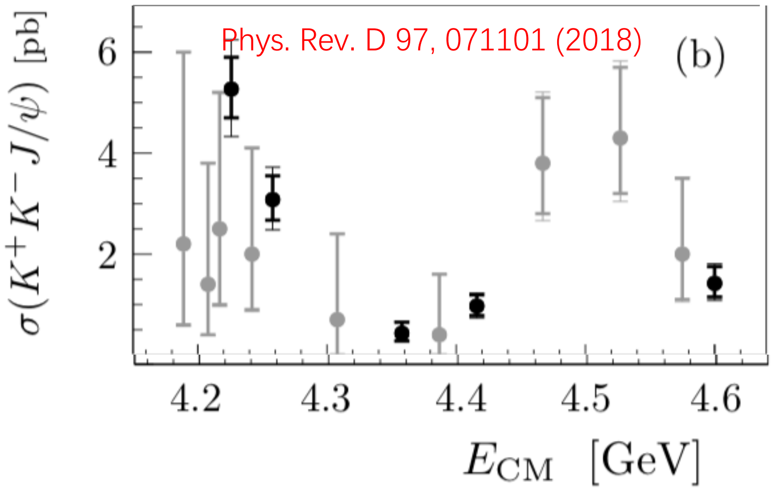
$e^+e^- \to K^+K^-J/\psi$ Low pt Kaon tracking/resolution



Y(3940)
Y(4008)
Y(4260)
Y(4360)
Y(4660)

Nature unclear

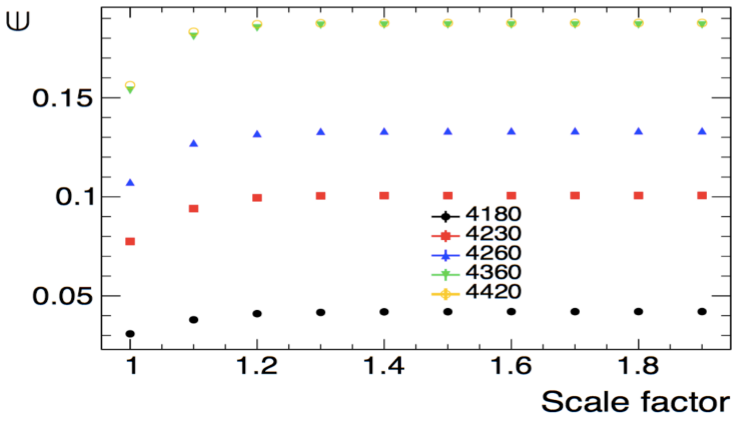
- Charmonium?
- Hybrid?
- Tetraquark?
- Molecule?



Important to measure additional final states to interpret Y(4260)

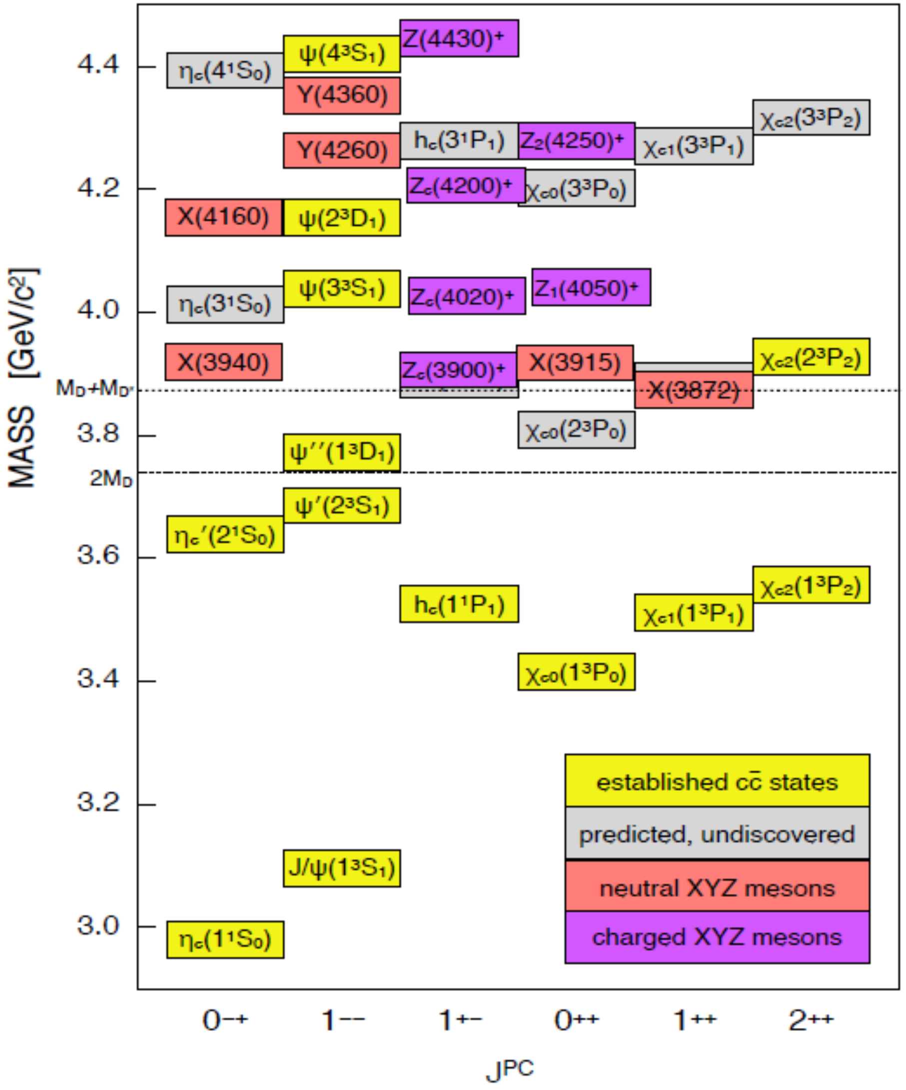
Evidence of a structure around 4.5 GeV observed at BESIII.

Limited statistical and more data are needed.



The efficiency increase 33% if low momentum kaon efficiency is 20% improved.

Charmonium(-like) physics

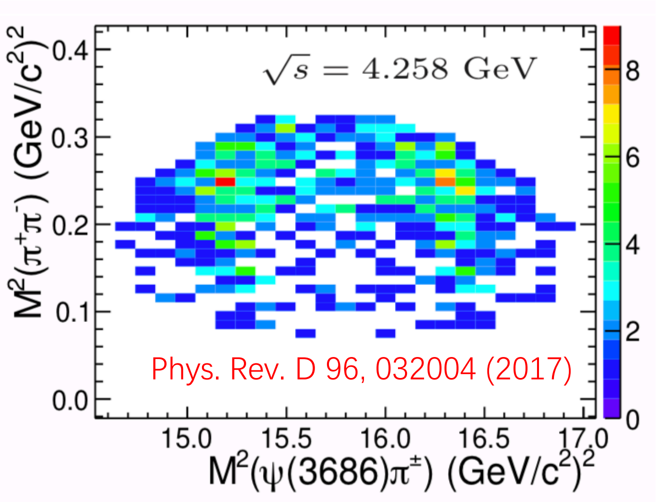


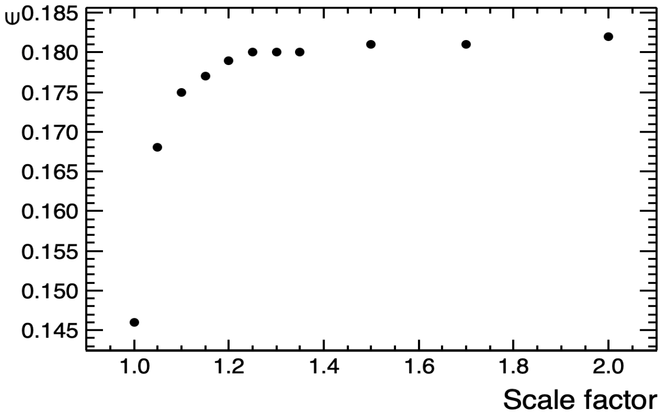
Z(3900)
Z(4020)
Z(4050)
Z(4200)
Z(4250)
Z(4430)

Nature unclear

- Tetraquark?
- Molecule?
- Non-resonance‘

$e^+e^- \rightarrow \pi^+\pi^-\psi(3686)$ Low pt Pion tracking/resolution





The efficiency increase 20% if low momentum pion efficiency is 20% improved.

At BESIII, 5trks or 6 trks are reconstructed due to low pion efficiency.

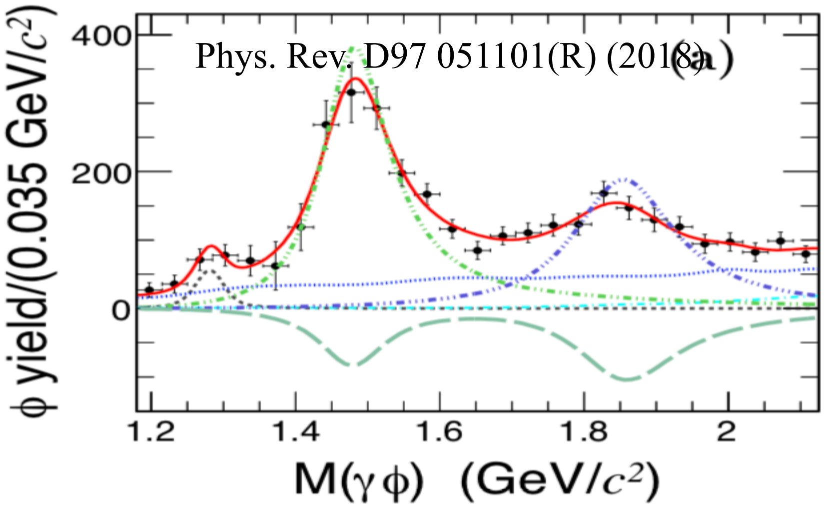
Complex structure on $\pi^{\pm}\psi(3686)$ mass spectrum. Need PWA to reveal Zc properties.

More statistical is needed.

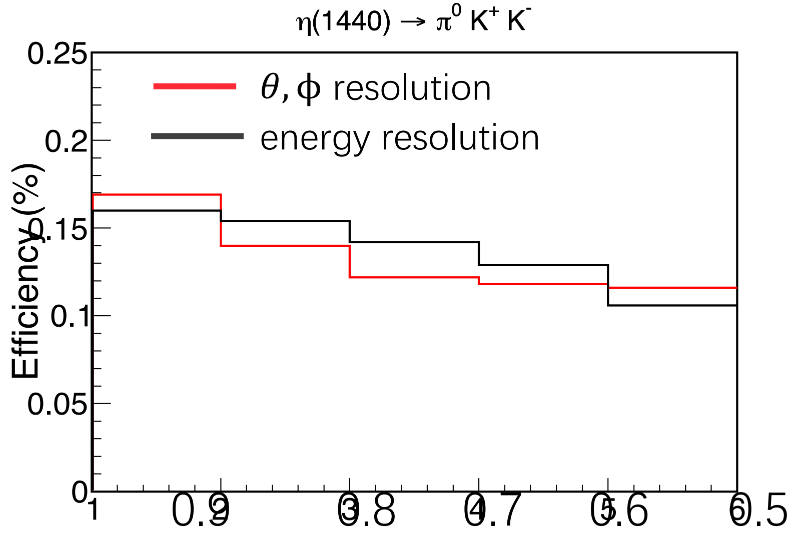
Searching of $\eta(1440) \to \gamma\phi$

Photon position/energy resolution

- $\eta(1440)$:
  - One state:
    - triangle singularity
  - Two states:
    - $\eta(1475) \to$ first radial excitation of the η';
    - $\eta(1405) \to$ an excellent candidate for a 0^{-+} glueball
- Study the flavor structure of $\eta(1440)$ is very important
- BESIII provide the search of $J/\psi \to \gamma\gamma\phi$;
- First observation of $\eta(1440) \to \gamma\phi$;
- The main background is $J/\psi \to \gamma\pi^0 K^+ K^-$;
- Better resolution in STCF can depress the background



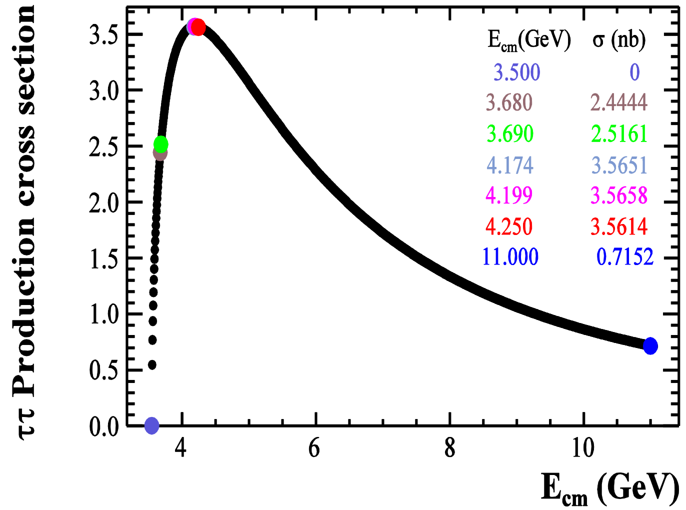
The background will be 50% depressed with position resolution 50% improved. (currently 6mm at BESIII)

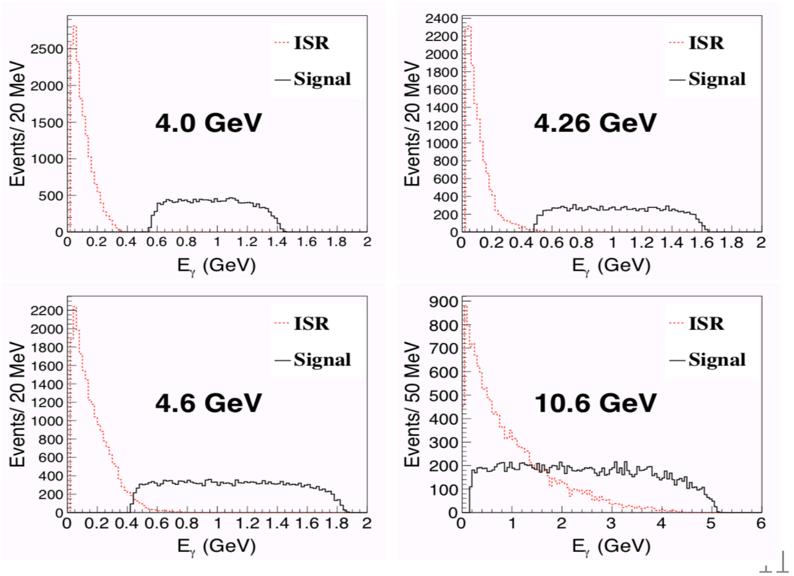


cLFV Decay $\tau \to \gamma\mu$

μ/π misidentification, μ detect efficiency

- Charge Lepton Flavor Violation $\tau \to \gamma\mu$
  - New physics beyond SM, constraint many modes.
  - Current limit: 4.4×10^{-8} at Babar with 0.9×10^{9} τ pairs
- Cross section grows from 0.1 nb near threshold to 3.5 nb to 4.25 GeV.
  - At BelleII:
    - 10^{10} τ pairs/year
    - ISR background dominant: $e\text{-}e^{-} \to \gamma\tau^{+}\tau^{-}$
    - Expected limit: 3×10^{-9}@50 ab^{-1}
  - At STCF:
    - 7.0×10^{9} τ pairs/year at 4.25 GeV
    - $e^{+}e^{-} \to \gamma\tau^{+}\tau^{-}$ background not contribute at 4.25 GeV.
    - Dominant background: $\gamma\mu^{+}\mu^{-}$, $\tau \to \pi\upsilon$
    - 4.4×10^{-8} @ 6.34 ab^{-1} estimated at BESIII
  - Much better μ/π misId rate is needed at STCF
  - Fast simulation on this process is progressing

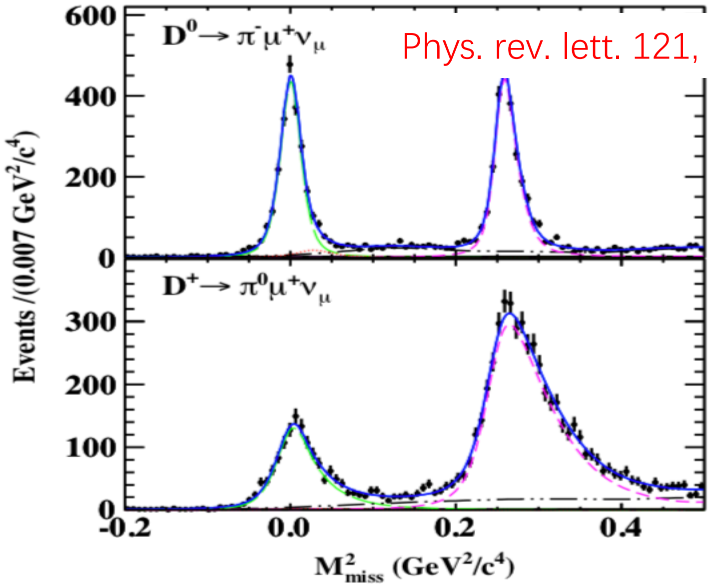




Test of LFU $D^0 \to \pi^- \mu^+ \nu_\mu$

- 4×10^9 pairs of $D^{\pm,0}$ and 10^7~$10^8 D_s$ 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
- Improved precision of $B(D^0 \to \pi^- \mu^+ \nu_\mu)$ is obtained at BESIII
  - In SM, theoretical prediction of $B(D^0 \to \pi^- \mu^+ \nu_\mu)/B(D^0 \to \pi^- e^+ \nu_e)$ is 0.985 ± 0.002.
  - BESIII result: $0.905\pm0.027 \pm 0.023$ (2.3σ)

π/μ misId, π/K misId



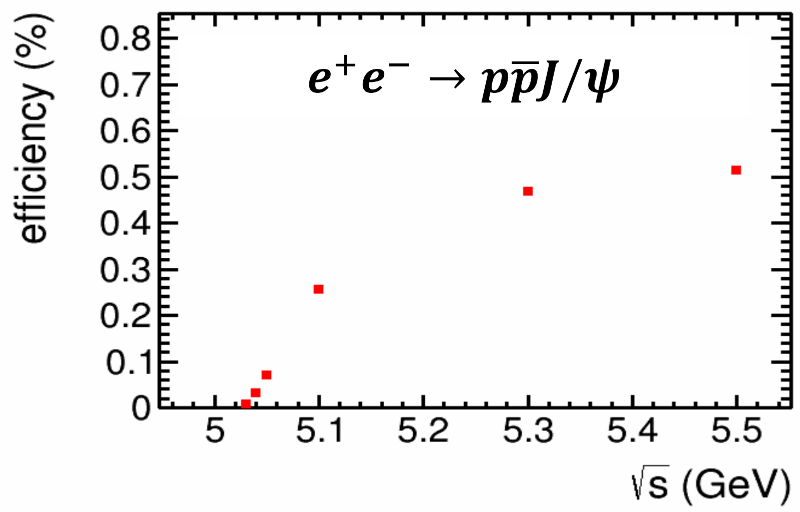
Prob($\pi \to \mu$)	$\epsilon(K\pi)$	$\epsilon(\pi\pi)$	$\epsilon(\pi\pi\pi^0)$	Prob($K \to \pi$)	$\epsilon(K\pi)$
10%	0.3%	7.2%	7.7%	**10%**	0.51%
5%	0.16%	3.8%	3.6%	**5%**	0.26%
1%	0.04%	0.9%	0.7%	**1%**	0.06%

The background level is significantly suppressed with better π/μ and π/K and misId.

Physics above 4.6 GeV

Edge of momentum for PID requirement

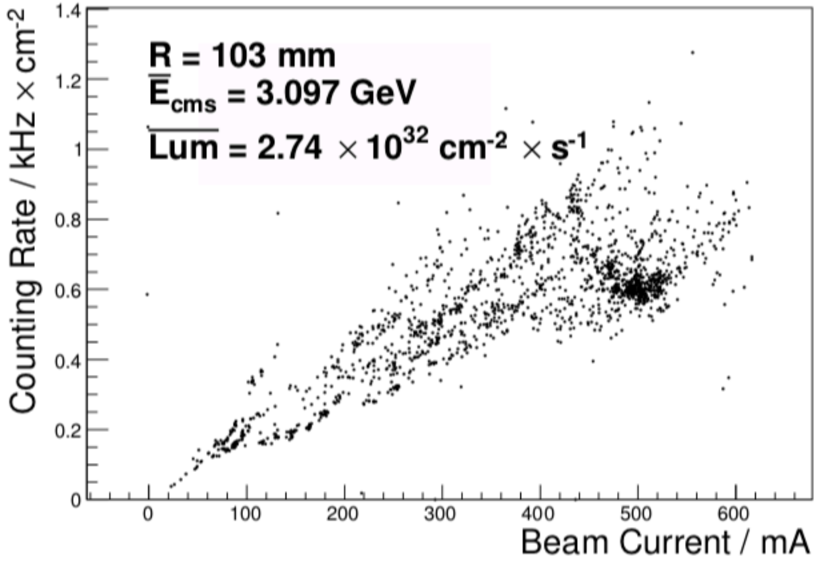
- Opportunities at STCF
  - Beyond the capability of BESIII and B-factories: energy, possible final states
  - To study the known vector states and Zc in much more detail; higher vector spectrum
  - For J^{++} excited states, BESIII observed X(3872) in $e^+e^- \to \gamma X(3782)$, so far no signal for other J^{++} states with masses around 3.8-4 GeV.
  - At STCF, hadronic channels: E ≥ 4.7 GeV, $e^+e^- \to \omega X(J^{++})$
  - E > 5 GeV, to reveal expected rich phenomena above charm baryon-antibaryon thresholds; also above thresholds of excited charm-meson pairs; physics of excited charm mesons
  - E > 5 GeV, $p\bar{p}J/\psi$, $\Lambda_c\bar{D}\bar{p}$ accessible, hidden-charm pentaquarks, rich spectrum above $\Lambda_c\bar{p}$ threshold
  - Collins fragmentation function : $e^+e^- \to \pi\pi X$ at high energy

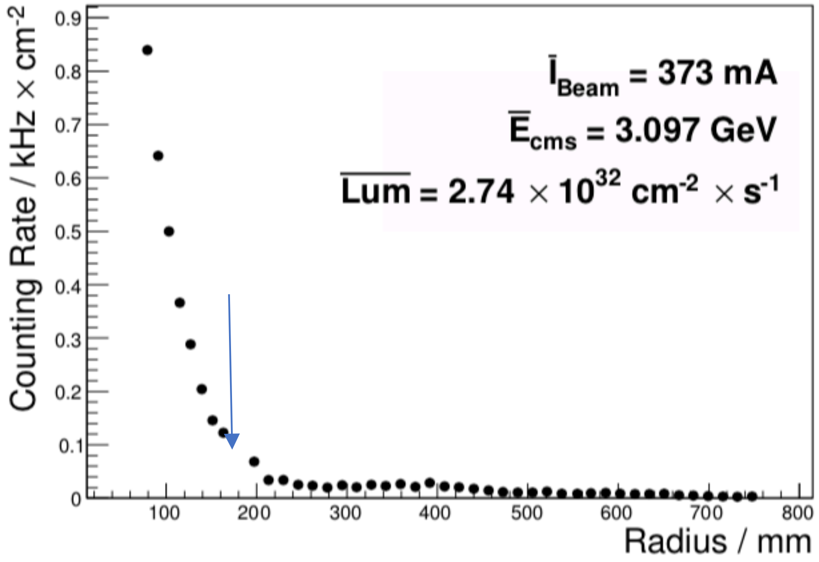


- Low ε due to low proton tracking ε around 5.0 GeV
- Low ε due to large particle misId at high energy such as 7.0 GeV

Study of Beam background

- High luminosity : 10^{35} $cm^{-2}s^{-1}$
  - High radiation tolerance, especially at IP and forward region
- Beam background study is essential at STCF
- Beam background study with random trigger data at BESIII, simple extrapolation from BESIII to STCF (×100)

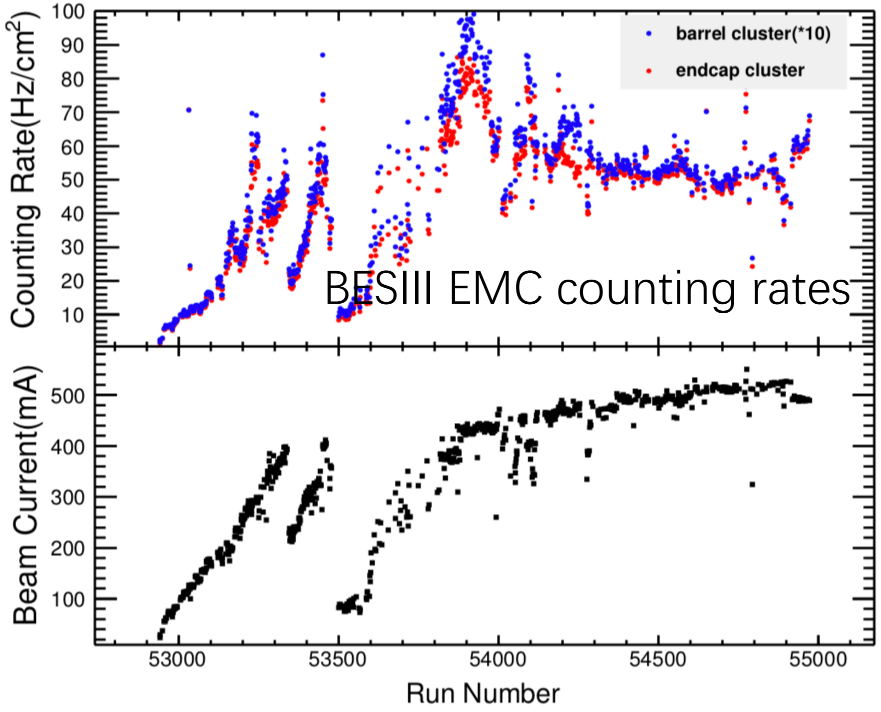


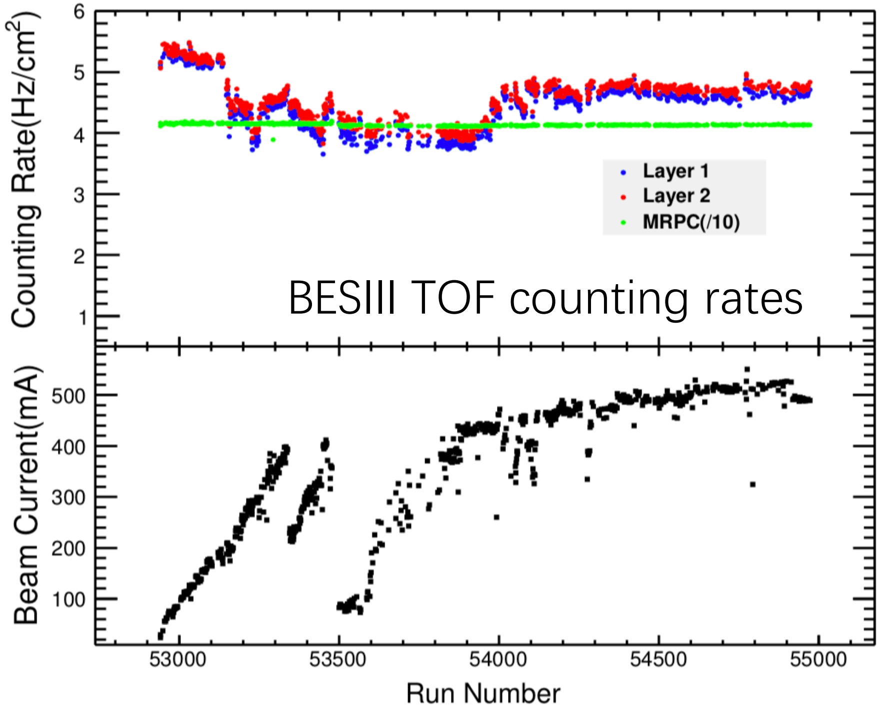


-Rough counting rate at STCF:
> 100 kHZ/cm^2 @ R<5cm
<5 kHZ/cm^2 @ R>20 cm

Study of Beam background

- Beam background study with random trigger data at BESIII

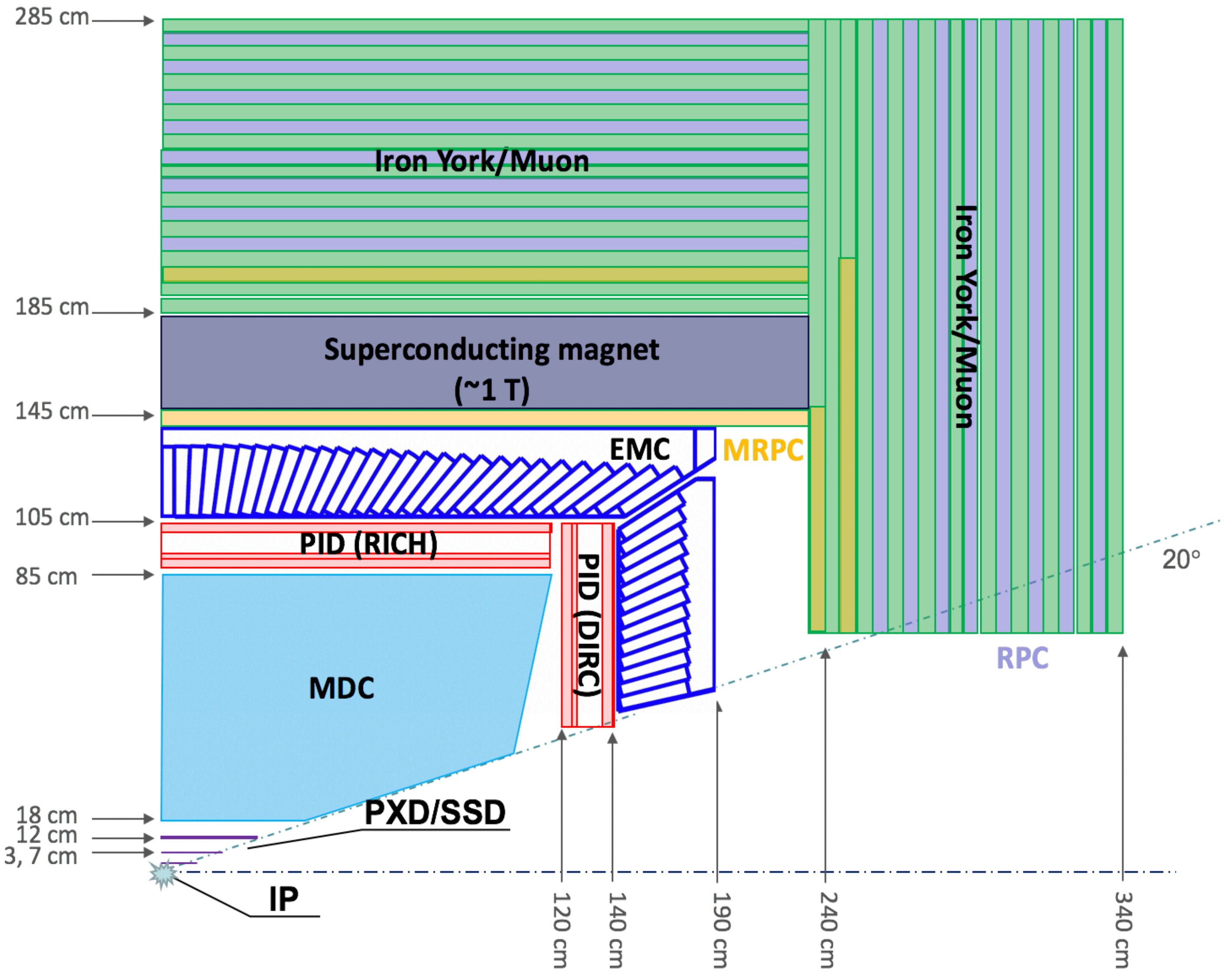




-Rough counting rate of EMC at STCF:
~700 HZ/cm^2 in barrel
~7kHZ/cm^2 in endcap

- No dependence on beam current on TOF is seen.

Detector Layout



PXD
- Material budget ~0.15%X_0 / layer
- σ_{xy}=50 μm

MDC
- σ_{xy}=130 μm
- dE/dx<7%, σ_p/p =0.5% at 1 GeV

PID
- π/K (and K/p) 3-4σ separation up to 2GeV/c

EMC

Energy range: 0.02-2GeV

At 1 GeV	σ_E (%)
Barrel(Cs(I):	2
Endcap (Cs):	4

MUD
- μ/π suppression power >10

General Consideration of Detector

- Much larger radiation tolerance, especially at IP and forward regions
- Lots of progress on PID, EMC R&D, conception design for Tracking, Muon counter system,

  - Tracking: Several Micro-Pattern Detector

    Improve the momentum and spatial resolution especially for low momentum tracks

  - PID: RICH/DIRC for Barrel and FTOF/DIRC for EndCap

    Determine edge of momentum for PID requirement from physics processes

  - EMC: CsI for Barrel, LYSO for Endcap

    Good energy resolution/spatial resolution

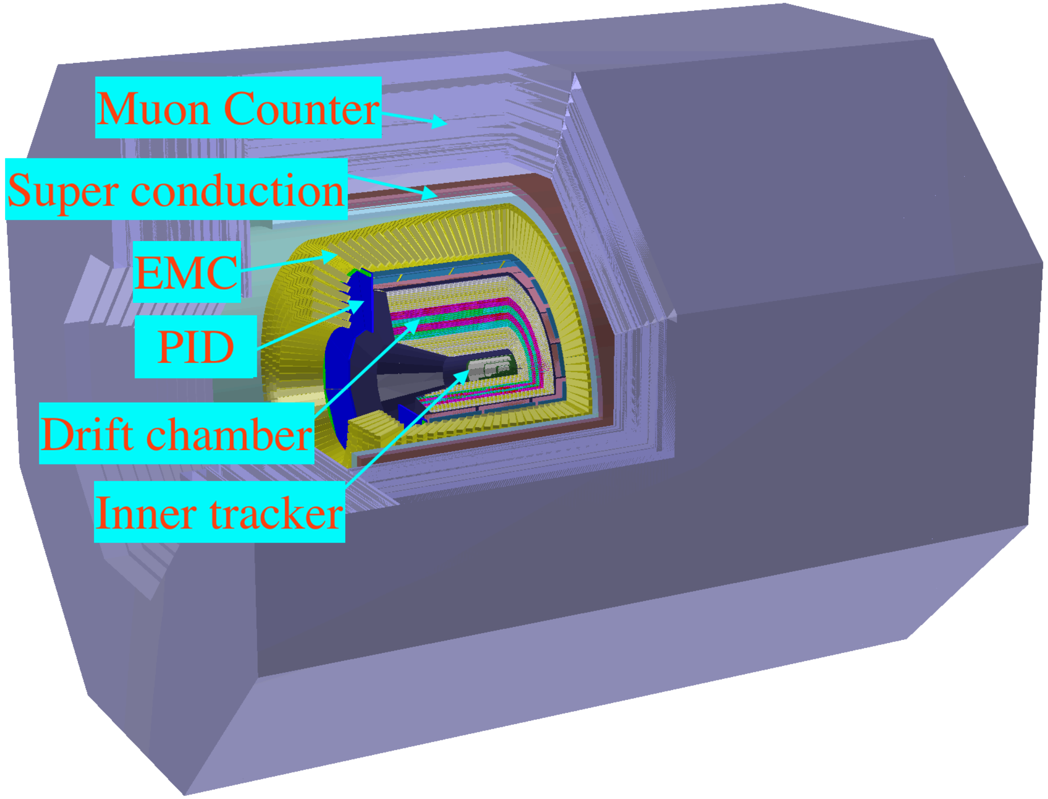
    Good time resolution to suppress noise and distinguish neutron/antineutron, KL from photons

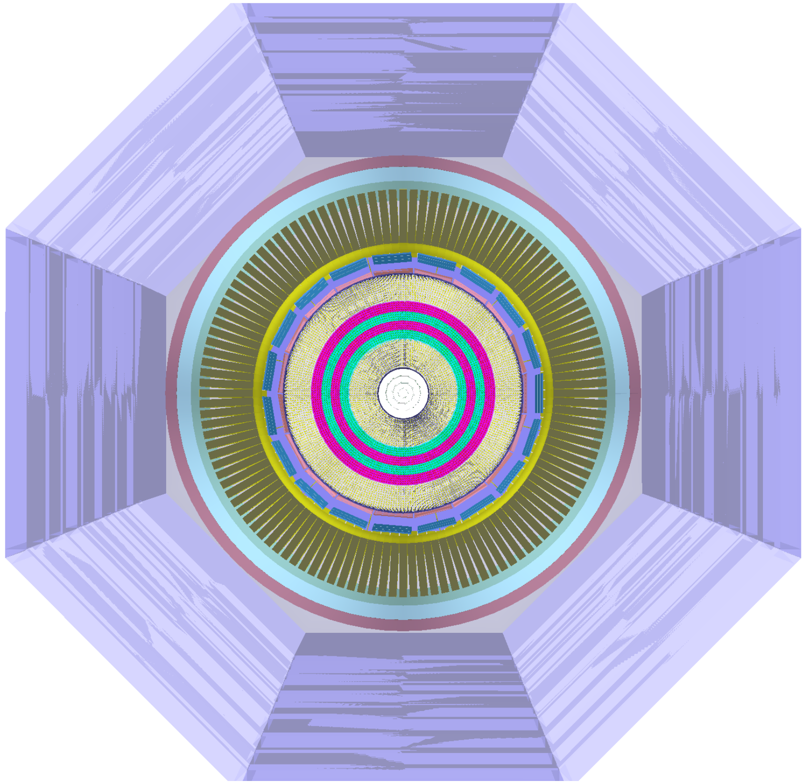
  - Muon Counter

    Better muon separation from pion,

Progress on detector simulation

- STCF software team has been formed.
- OSCAR: Offline Software of Super Tau-Charm Facility.
- Detector geometry with DD4hep.





Summary

- Progress on physics simulation at STCF
  - Fast simulation package has been developed
  - Key processes are simulated to optimize the detector
  - More physical processes are studying
- Progress on beam background
  - Studied with random trigger events at BESIII
  - MC validation is undergoing
  - Will predict the beam noise for STCF with MC simulation
- Software framework is built at STCF
  - The detector geometry is described with DD4hep
  - Simulation with STCF framework is next step

Merci

谢谢