Status of the STCF Project in China

Hai-ping Peng

penghp@ustc.edu.cn

State Key Laboratory of Particle Detection and Electronics (SKLPE)

University of Science and Technology of China (USTC)

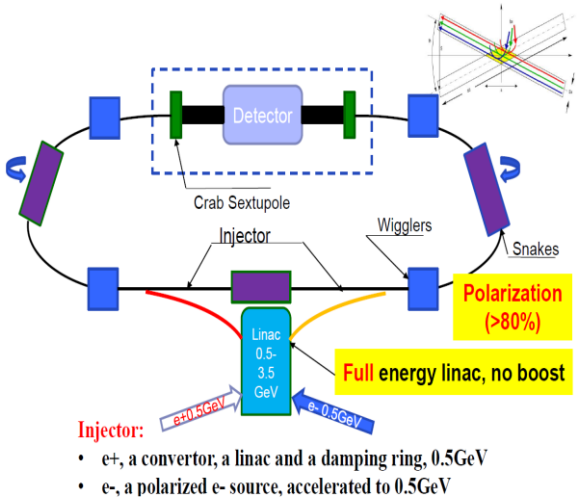
(On behalf STCF Steering Committee)

2019 Joint Workshop on Future Charm-Tau Factory,

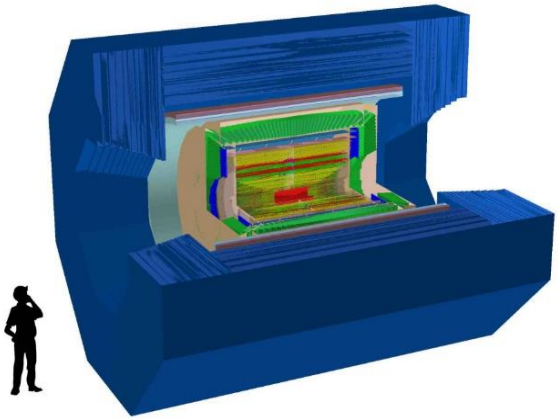
Sep. 24-28, 2019, Moscow

Proposed STCF in China

- **BEPCII/BESIII is very successful, and will end her mission in 5-10 years**
- **A Super τ-charm Facility is the nature extension and a viable option for a post-BEPCII HEP project in China**



- **Peak luminosity 0.5-1×10^{35} $cm^{-2}s^{-1}$ at 4 GeV**
- **Energy range E_{cm} = 2–7 GeV**
- **Potential to increase luminosity and realize beam polarization**



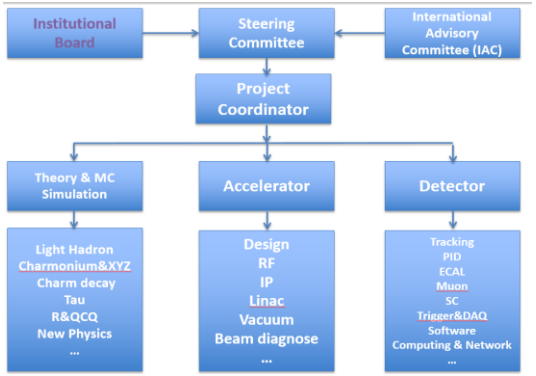
History of STCF in China

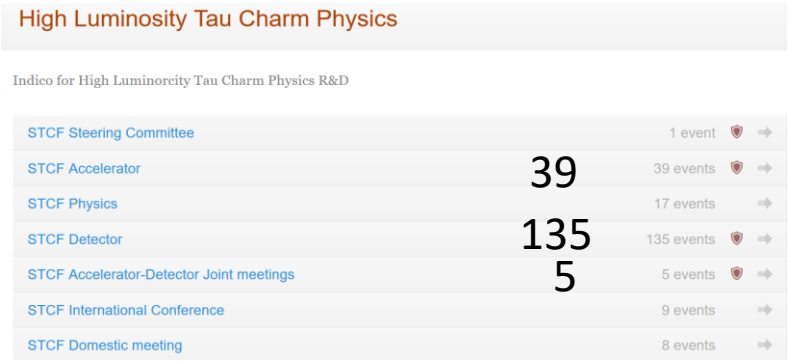
- Proposed STCF during 1990s, after BEPC/BESII
- Re-invoked 10 years ago, just after BEPCII/BESIII commission
- Authorized by the High Energy Physics Association in China, USTC took leading to exploring the possibility of STCF project.
- Relatively loose organization, several domestic workshops, Fragrance Hill-Science conference (2015), international workshop (2015)
- Report to the local government, CAS etc
- Mar. 2018, got funds support from USTC, and start R&D program intensively

Strategy and Activities

CDR → TDR → project application → construction → commissioning

- Form the organization (including project manager, physics/detector/accelerator working group
- Regular weekly meeting for each working group
- Domestic workshop and international workshop
- Collaboration domestically and internationally
- More negotiation with government, funding agencies
- Prepare and submit proposals





Strategy and Activities

CDR → TDR → project application → construction → commissioning

Proposal (Y2019) to USTC, required funds 15M RMB

附件 2

中国科学技术大学国际大科学计划培育专项
可行性论证报告编写提纲

一、可行性报告摘要（限 500 字）

粒子物理与原子核物理研究比原子核更深层次的物质构成及相互作用，与宇宙起源及演化密切相关，是人类认识世界最前沿的学科，对科技的发展有重大的意义。基于加速器的粒子物理实验是该领域最有效手段，需要多学科和技术领域的综合与交叉，反映国家甚至人类的经济、科学技术和教育的综合实力。

陶-粲能区（质心能量为 2-7GeV）位于量子色动力学（QCD）的微绕与非微绕的过渡区域，具有的一系列独特性质，是研究陶粲物理和强子物理的关键场所，同时为研究 CP 破坏、探索核子内部结构、寻找奇异物质和新物理等前沿课题提供独特平台。北京正负电子对撞机/北京谱仪是目前唯一运行在陶-粲能区的实验，引领着国际强子物理的研究，并将于 5-10 年内结束使命。但在该能区仍存在大量重大物理课题有待研究，建造一台性能更先进的对撞机具有重大科学意义。由此，我们提出建造新一代高亮度正负电子对撞机—超级陶粲装置（Super Tau-Charm Facility/STCF）的大科学计划。STCF 的质量能量为 2~7GeV，亮度大于 $0.5\times10^{35}cm^{-2}s^{-1}$，建成后将成为国际五大基于加速器的粒子物理研究中心之一，

Proposal to MOST, Asked for funds 40M RMB, BINP and LAL are the international partners

预申报编号：YS2019YFE020020

国家重点研发计划
项目预申报书

项目名称：	超级韬粲装置的预研究
所属专项：	战略性国际科技创新合作重点专项
指南方向：	物质科学领域
项目管理专业机构：	中国科学技术交流中心
推荐单位：	中国科学院
申报单位：	中国科学技术大学 （公章）
项目负责人：	彭海平

中华人民共和国科学技术部制

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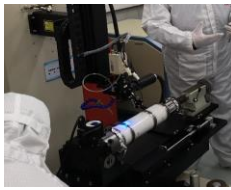
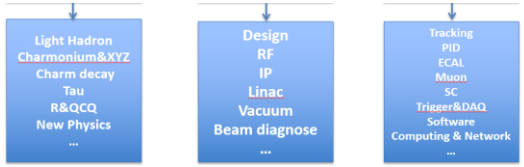
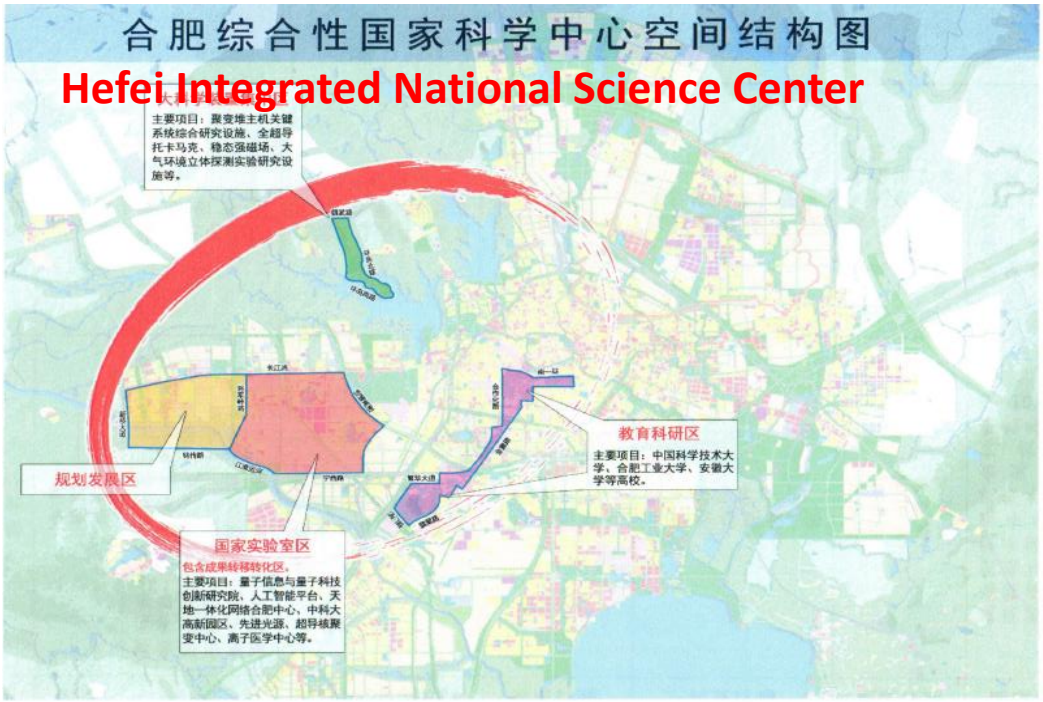




STCF Physics	17 events	39
STCF Detector	135 events	135
STCF Accelerator-Detector Joint meetings	5 events	5
STCF International Conference	9 events	
STCF Domestic meeting	8 events	

Candidate site : Hefei

One of three integrated national science centers, which will play important role in 'Megascience' of China in near future



- University of Science and Technology of China (USTC)
- National Synchrotron Radiation Lab and Hefei Light Source, operated by USTC
- The only National Lab operated by University in China. (Totally Four officially approved National Labs in China)

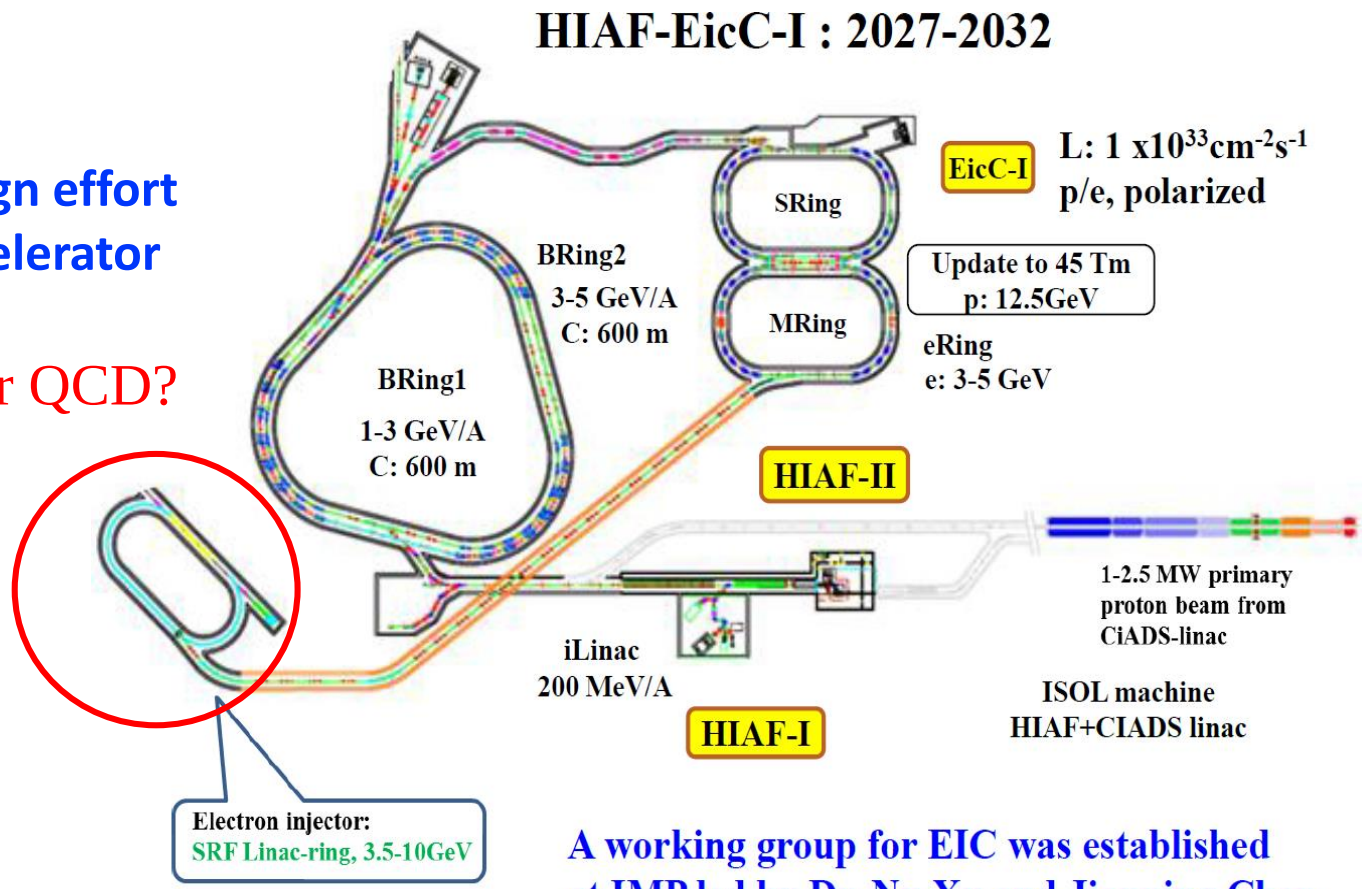
- **Pay a lot of attention on accelerator facilities**
- **Hefei Advanced light source is under design**
- **STCF is listed in future plan**

Candidate Site

Institute of Modern Physics, CAS, proposed building HIAF-EicC in Huizhou, Canton

STCF Share the design effort of the electron accelerator of EicC?

National Center for QCD?

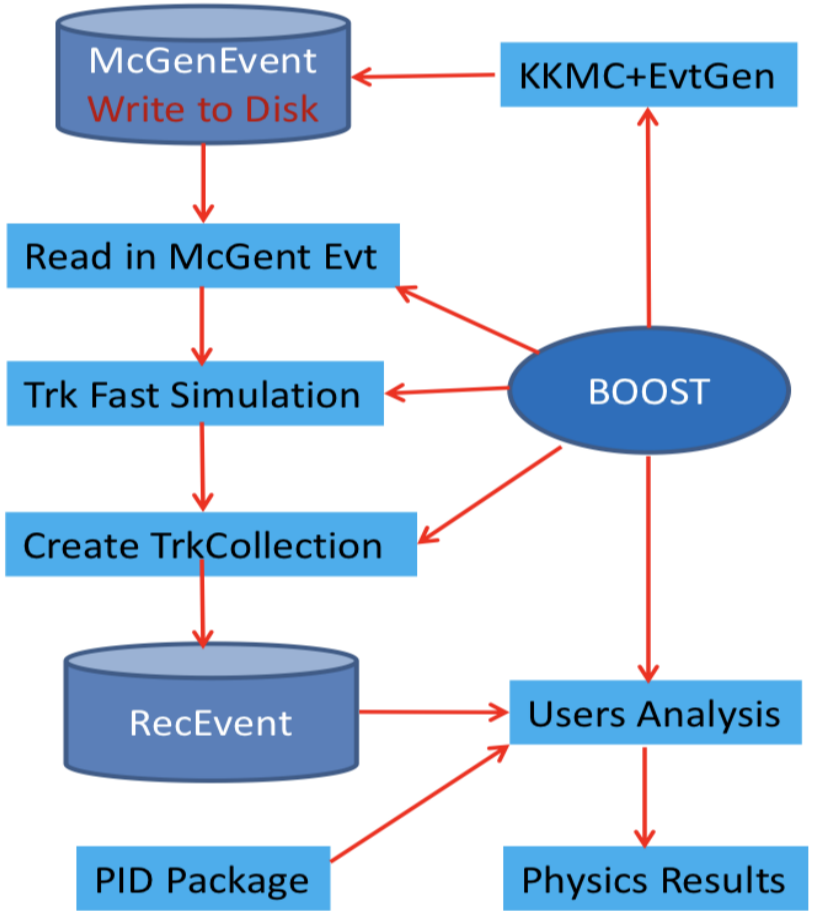


A working group for EIC was established at IMP led by Dr. Nu Xu and Jianping Chen.

Physics Progress

Conveners :
Dr. Xiaorong Zhou,
Prof. Jiangping Ma, Prof. Xiaogang He

Studying the physics sensitivity, guiding the optimization of Detector design



- Based on BESIII BOOST framework, same analysis process as BESIII jobs
- Implementing all the expected performance for the STCF detector.
- The input performances are flexible and adjustable for detector optimization
- Acceptable CPU and storage consumption

Benchmark Processes

CME (GeV)	Lumi (ab^{-1})	samples	σ(nb)	No. of Events	remark
3.097	1	J/ψ	3400[1]	3.4×10^{12}	
3.670	1	$\tau^+\tau^-$	2.4	2.4×10^9	
3.686	1	$\psi(3686)$	640	6.4×10^{11}	
		$\tau^+\tau^-$	2.4	2.4×10^9	
		$\psi(3686) \to \tau^+\tau^-$		2.0×10^9	
3.770	1	$D^0\bar{D}^0$	3.6	3.6×10^9	
		$D^+\bar{D}^-$	2.8	2.8×10^9	
		$D^0\bar{D}^0$		7.9×10^8	Single Tag
		$D^+\bar{D}^-$		5.5×10^8	Single Tag
		$\tau^+\tau^-$	2.9	2.9×10^9	
4.040	1	$\gamma D^0\bar{D}^0$	1.3	1.3×10^9	$CP_{D^0\bar{D}^0} = +1$[3]
		$\pi^0 D^0\bar{D}^0$	2.7	2.7×10^9	$CP_{D^0\bar{D}^0} = -1$
		$D^{*+}\bar{D}^-$+c.c	4.0	4.0×10^9	
		$D^{*+}\bar{D}^{*-}$+c.c	2.0	2.0×10^9	
		$D_s^+D_s^-$	0.20	2.0×10^8	
		$D_s^+D_s^-$		2.3×10^7	Single Tag
		$\tau^+\tau^-$	3.5	3.5×10^9	
4.180	1	$\gamma D^0\bar{D}^0$	0.4	4.0×10^8	$CP_{D^0\bar{D}^0} = +1$
		$\pi^0 D^0\bar{D}^0$	0.8	8.0×10^8	$CP_{D^0\bar{D}^0} = -1$
		$D^{*+}\bar{D}^-$+c.c	1.0	1.0×10^9	
		$D_s^{+*}D_s^-$+c.c.	0.90	9.0×10^8	
		$D_s^{+*}D_s^-$+c.c.		1.3×10^8	Single Tag
		$\tau^+\tau^-$	3.6	3.6×10^9	
4.230	1	$D_s^{+*}D_s^{-*}$	0.4	4.0×10^8	
		$J/\psi\pi^+\pi^-$	0.085	8.5×10^7	
		$\tau^+\tau^-$	3.6	3.6×10^9	
		$\gamma X(3872)$	0.01[4]	1.0×10^7	
4.360	1	$\psi(3686)\pi^+\pi^-$	0.058	5.8×10^7	
		$\tau^+\tau^-$	3.5	3.5×10^9	
4.420	1	$\psi(3686)\pi^+\pi^-$	0.040	4.0×10^7	
		$\tau^+\tau^-$	3.5	3.5×10^9	
4.630	1	$\psi(3686)\pi^+\pi^-$	0.033	3.3×10^7	
		$\Lambda_c\bar{\Lambda}_c$	0.56	5.6×10^8	
		$\Lambda_c\bar{\Lambda}_c$		6.4×10^7	Single Tag
		$\tau^+\tau^-$	3.4	3.4×10^9	
4.0-7.0	3	300 points scan with 10 MeV step, 1 fb^{-1}/point			
> 5	2-7	several ab^{-1} high energy data, details dependent on scan results			

Search for CPV in hyperons:
$J/\psi \to \Lambda\bar{\Lambda}, \Xi^-\bar{\Xi}^+$

Semi-leptonic decay of D(test LFU):
$D \to \pi\mu\upsilon$

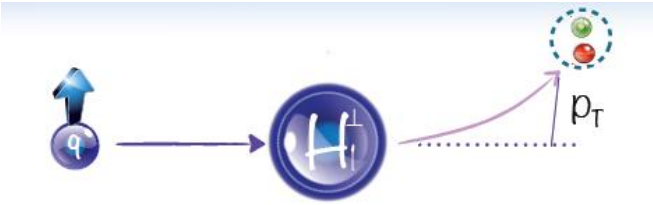
Leptonic decay of D_s(test LFU):
$D_s^+ \to \mu^+\upsilon_\mu, D_s^+ \to \tau^+\upsilon_\tau$

Search for CPV in τ lepton:
$\tau \to K^0\pi\nu$

Search for cLFV in τ lepton:
$\tau \to \gamma\mu$和$\tau \to \mu\mu\mu$

Collins effect at high energy:
ππ+inclusive, KK+inclusive

Collins Fragmentation Function (FF)

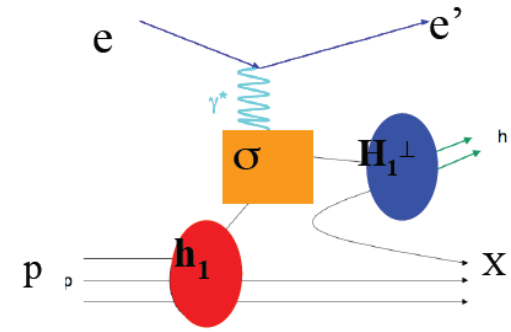


J. C. Collins, Nucl.Phys. B396, 161 (1993)

$$D_{hq^\uparrow}(z, P_{h\perp}) = D_1^q(z, P_{h\perp}^2) + H_1^{\perp q}(z, P_{h\perp}^2)\frac{(\hat{\mathbf{k}} \times \mathbf{P}_{h\perp}) \cdot \mathbf{S}_q}{zM_h},$$

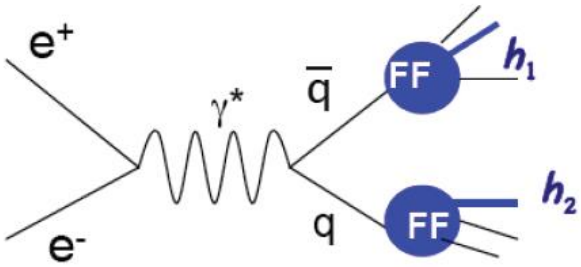
SIDIS

Transversity ⊗ Collins FF



e+ e-

Collins FF ⊗ Collins FF



***D_1*: the unpolarized FF**

***H_1*: Collins FF**

→ describes the fragmentation of a transversely polarized quark into a spinless hadron *h*.

→ depends on $z = 2E_h/\sqrt{s},$

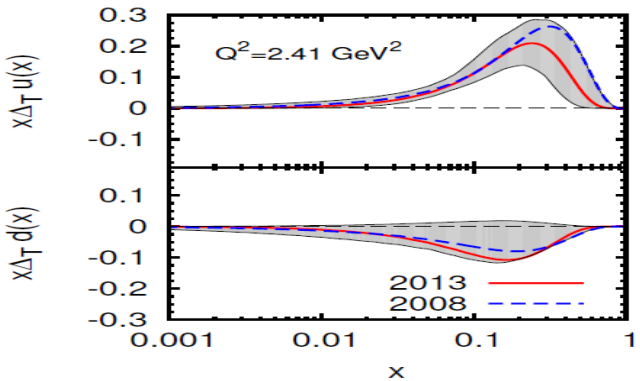
→ leads to an azimuthal modulation of hadrons around the quark momentum.

Global Analysis on Collins FF

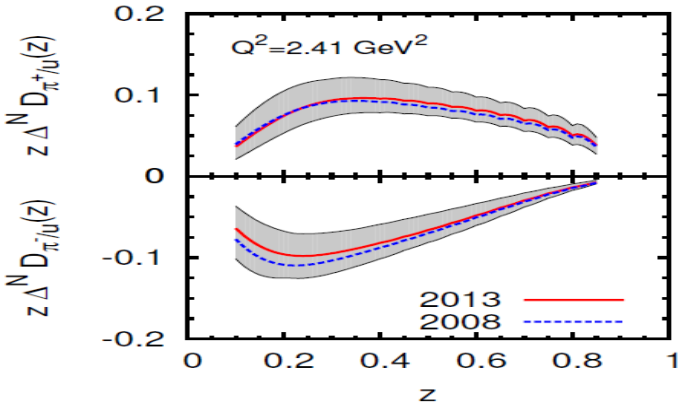
Anselmino et al., PRD 87, 094019 (2013)

Using data from HERMES, COMPASS, Belle

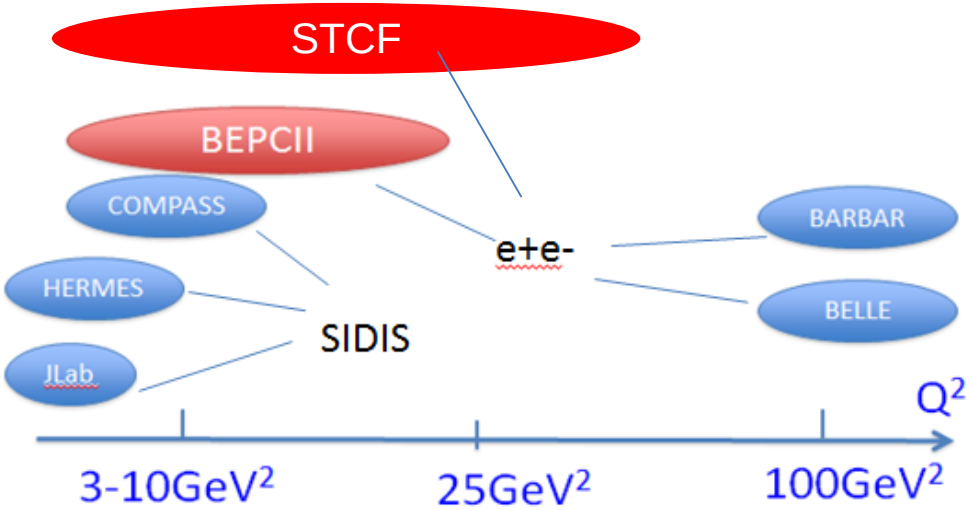
Transversity



Collins pion FF

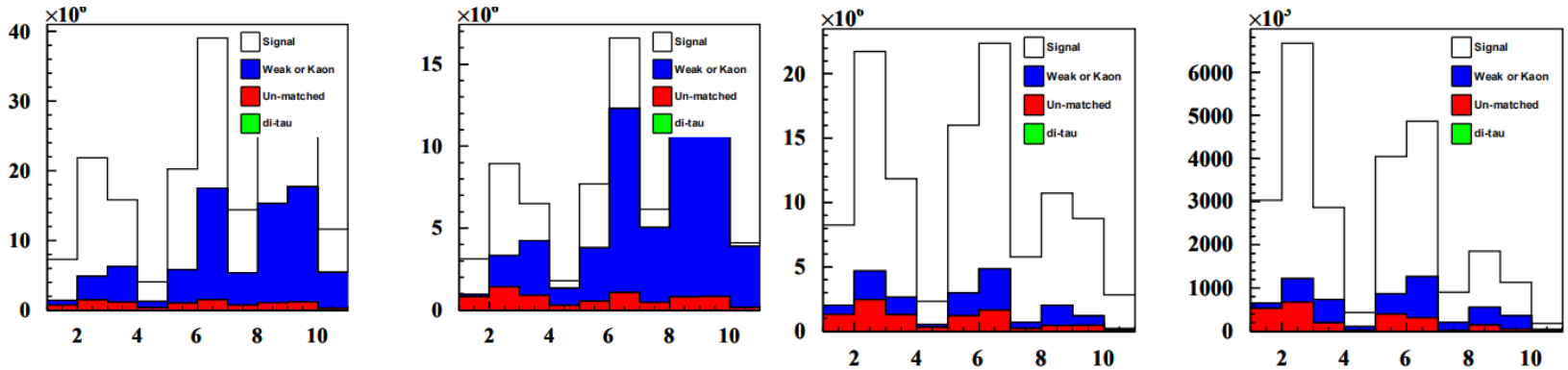


- The Q^2 evolution of Collins FFs was assumed following the extrapolation in the unpolarized FF, and this has not been validated.
- Low Q^2 data from e^+e^- collider is useful.
- **BEPCII / STCF**
  - **Similar Q^2 coverage with SIDIS in EicC**



Collins Effect @ STCF

- STCF is a perfect machine for studying Collins effect
- Poor performance for the traditional de/dx & TOF PID system for tracks > 0.8GeV
- This measurement suffer from systematic uncertain from $K-\pi$ mis-PID.
- The mis-PID is even worse in the case of KK Collins measurement.
- With $2.5fb^{-1}$ 7GeV $q\bar{q}$ MC ($\sigma \approx 5nb$ LundArlw), we study Collins effect at STCF.

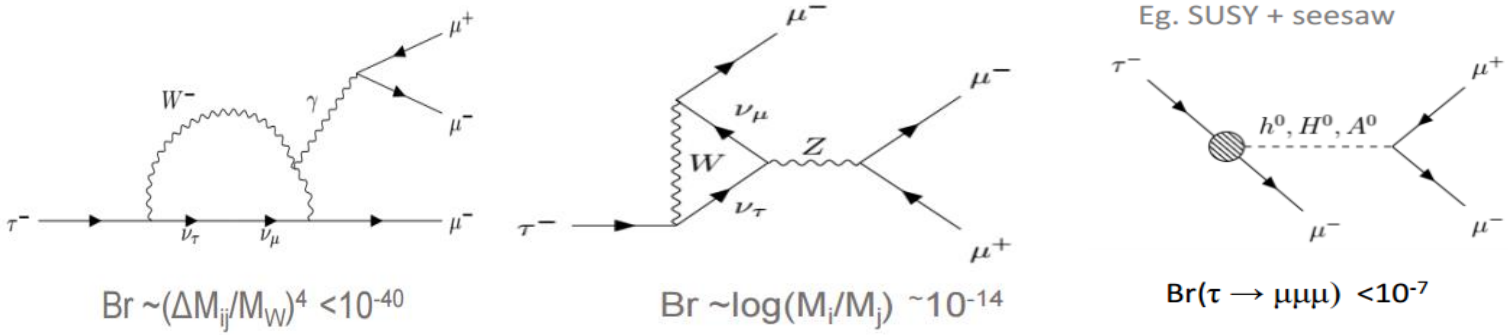


Blue: $\pi-K$ mis-PID in KK Collins measurement.
Left) de/dx&TOF. Right) a 1% mis-PID set in FastSim

- By setting the $K-\pi$ mis-PID at 1%, we obtain:
  - The statistical uncertainty for $25fb^{-1}$ MC is ~10^{-3} to 10^{-2}
  - The statistical uncertainty for $1ab^{-1}$ MC is ~10^{-4} to 10^{-3}

Search for cLFV

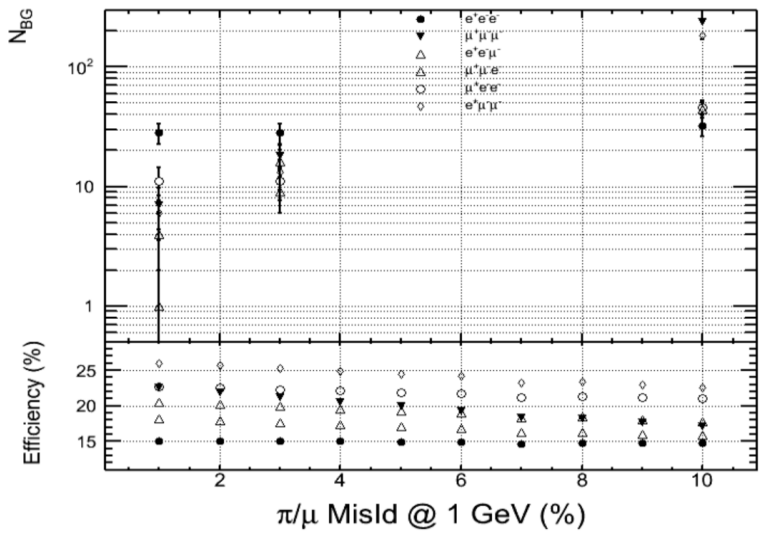
- SM + neutrino mixing (in the SM): very small
- Many extension to the SM, predict enhanced LFV in tau decays over muon decays with BF from 10^{-10} up to 10^{-7}



- **Currently the most stringent limit of $\mathcal{B}(\tau \to 3l)$ are set :.**
  - $(4-8)\times 10^{-8}$ at 90% C.L. at Babar, with 376 fb^{-1} data ($N_{\tau\tau}$~ 3.5× 10^8)
  - $(2.0-4.1)\times 10^{-8}$ at 90% C.L. at Belle, with 535 fb^{-1} data ($N_{\tau\tau}$~ 4.9× 10^8)

Search for $\tau \to 3l$ @ STCF

Tag side	Signal side
1-prong (pi/e/mu+neutrals+neutrinos), 82.62% efficiency	Category 3-leptons into six types ($e^+e^-e^-$, $\mu^+\mu^-\mu^-$, $e^+e^-\mu^-$, $\mu^+\mu^-e^-$, $\mu^+e^-e^-$, $e^+\mu^-\mu^-$)
For hadronic tag mode, required missing mass $M^2_{miss} < 0.2\ GeV^2$	Veto gamma conversion, For e^+e^- pairs, $\lvert angle_{ee}\rvert > 5^o$, $\lvert M_{ee}\rvert > 0.05GeV$
For leptonic tag mode, $M^2_{miss} < 2\ GeV^2$	If more than one combination, select the one with minimum: $(M_{prong3}-M_\tau)^2/\sigma_{M\tau}+(E_{prong3}-E_\tau)^2/\sigma_{E\tau}$
Total Momentum of 1-prong side > 0.4 GeV/c	Using energy and mass constraint to select the signals, ΔE, ΔM
Angle between 1 prong and 3 prong <175°	



At STCF, 7.0×10^9 tau pairs @ 4.26 GeV per year. If π/μ mis-ID rate is 1% at 1 GeV, the upper limit is predicted to be:

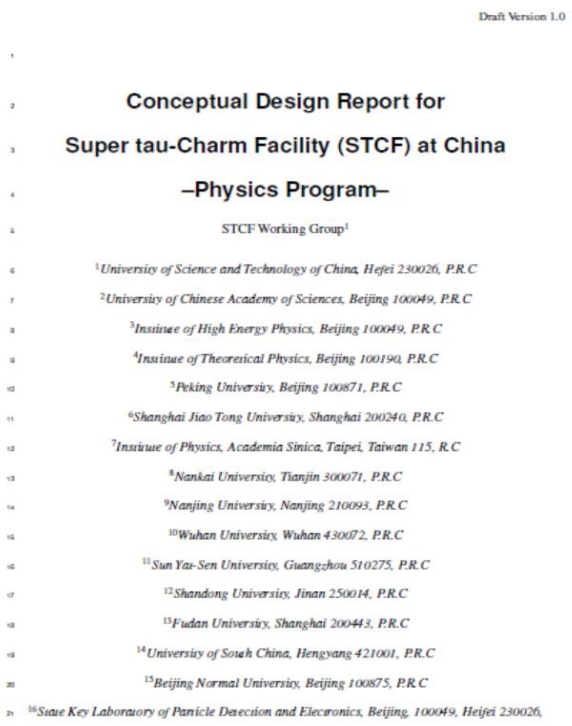
$$\mathcal{B}^{90}_{UL}(\tau \to 3l) < \frac{N^{90}_{UL}}{2\varepsilon N_{\tau\tau}} \sim 7 \times 10^{-10}$$

Belle II will take 50 ab^{-1} data, $N_{\tau\tau}$~ 5× 10^{10}, the predicted sensitivity is

$$\mathcal{B}(\tau \to 3l) < 4 \times 10^{-10}$$

Conceptual Design Report

- Attempt to have CDR for theory before the end of this year, a first version is ready
- A dedicate workshop for the theory part at Agu., plan to have another workshop during Oct.



Draft Version 1.0

Conceptual Design Report for

Super tau-Charm Facility (STCF) at China

–Physics Program–

STCF Working Group[1]

[1]*University of Science and Technology of China, Hefei 230026, P.R.C*

[2]*University of Chinese Academy of Sciences, Beijing 100049, P.R.C*

[3]*Institute of High Energy Physics, Beijing 100049, P.R.C*

[4]*Institute of Theoretical Physics, Beijing 100190, P.R.C*

[5]*Peking University, Beijing 100871, P.R.C*

[6]*Shanghai Jiao Tong University, Shanghai 200240, P.R.C*

[7]*Institute of Physics, Academia Sinica, Taipei, Taiwan 115, R.C*

[8]*Nankai University, Tianjin 300071, P.R.C*

[9]*Nanjing University, Nanjing 210093, P.R.C*

[10]*Wuhan University, Wuhan 430072, P.R.C*

[11]*Sun Yat-Sen University, Guangzhou 510275, P.R.C*

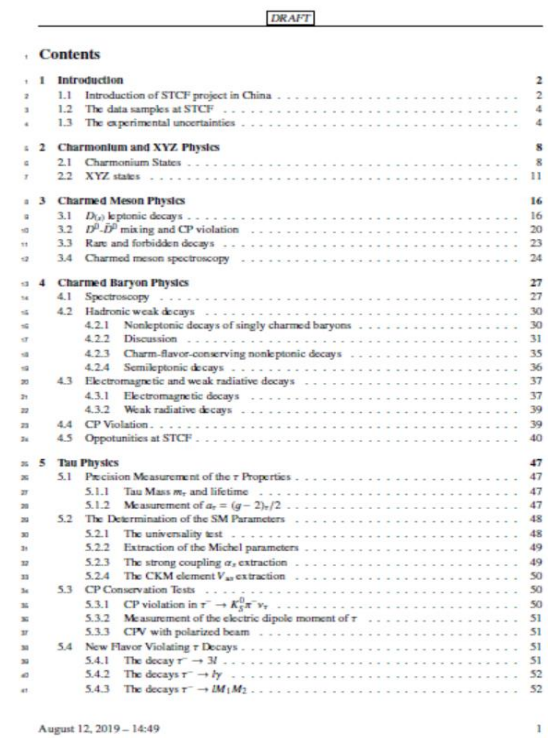
[12]*Shandong University, Jinan 250014, P.R.C*

[13]*Fudan University, Shanghai 200443, P.R.C*

[14]*University of South China, Hengyang 421001, P.R.C*

[15]*Beijing Normal University, Beijing 100875, P.R.C*

[16]*State Key Laboratory of Particle Detection and Electronics, Beijing, 100049, Heifei 230026,*



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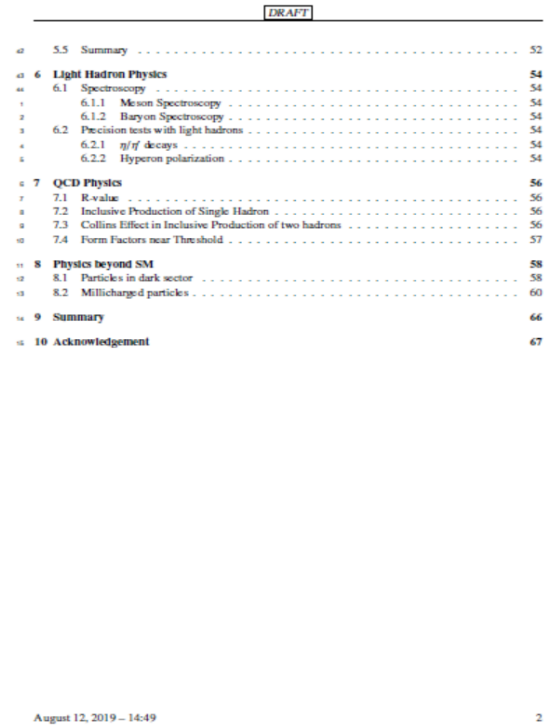

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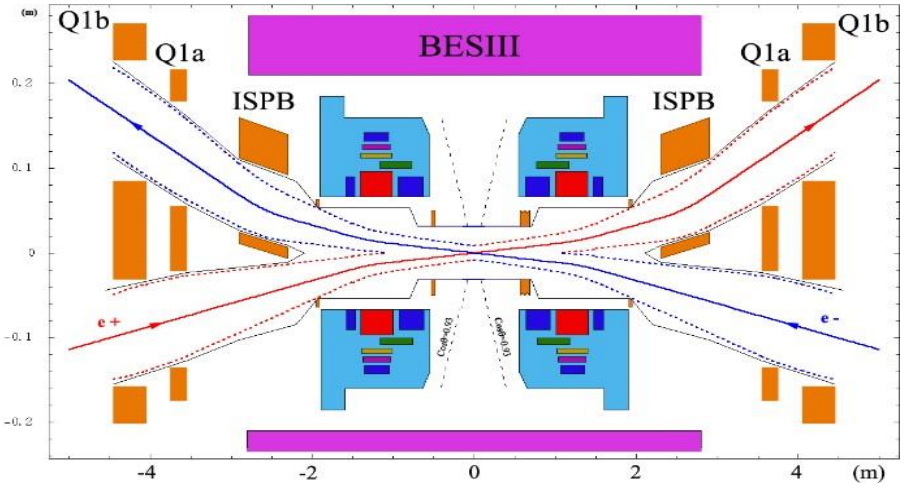
Detector Progress

Conveners : Jianbei Liu, Ming Shao， Xingtao Huang

Accelerator Requirement for Detector

- **High luminosity : 10^{35} cm^{-2}s^{-1} :**
  - High radiation tolerance, especially at IP and forward region
    - ✓ Constrains from IR design, detail MDI studies is necessary

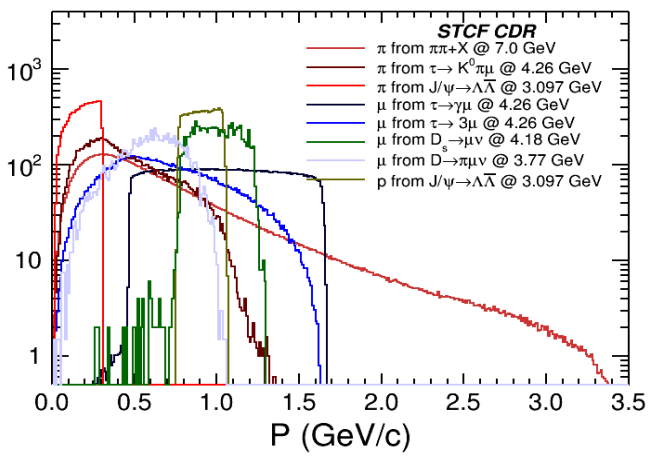


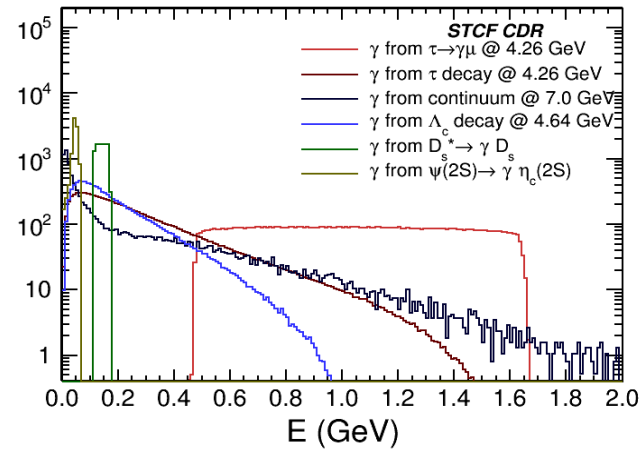
IR of BEPCII

  - High event rate

Detector/electronics should be withstand the expected does and fast enough

Physics Requirement for Detector

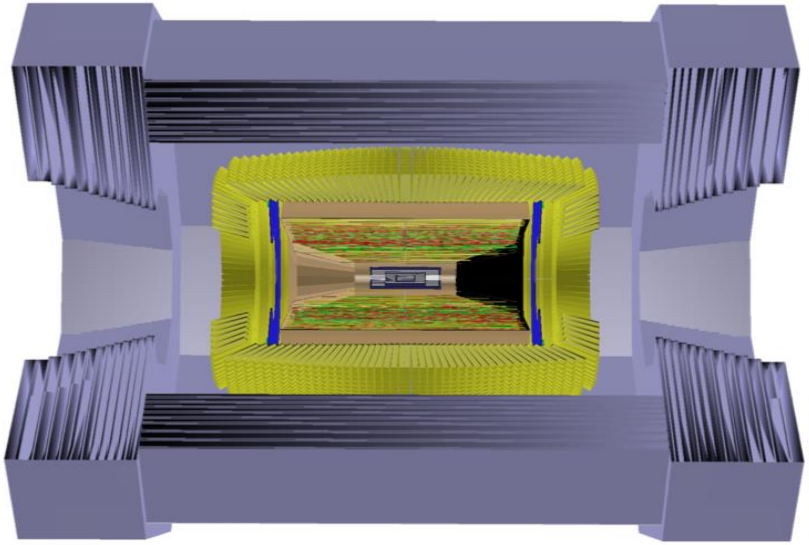




A mount of final state particle are of momentum/energy lower than 1 GeV , some Extreme low momentum, suffer severely from material effects – multiple scattering

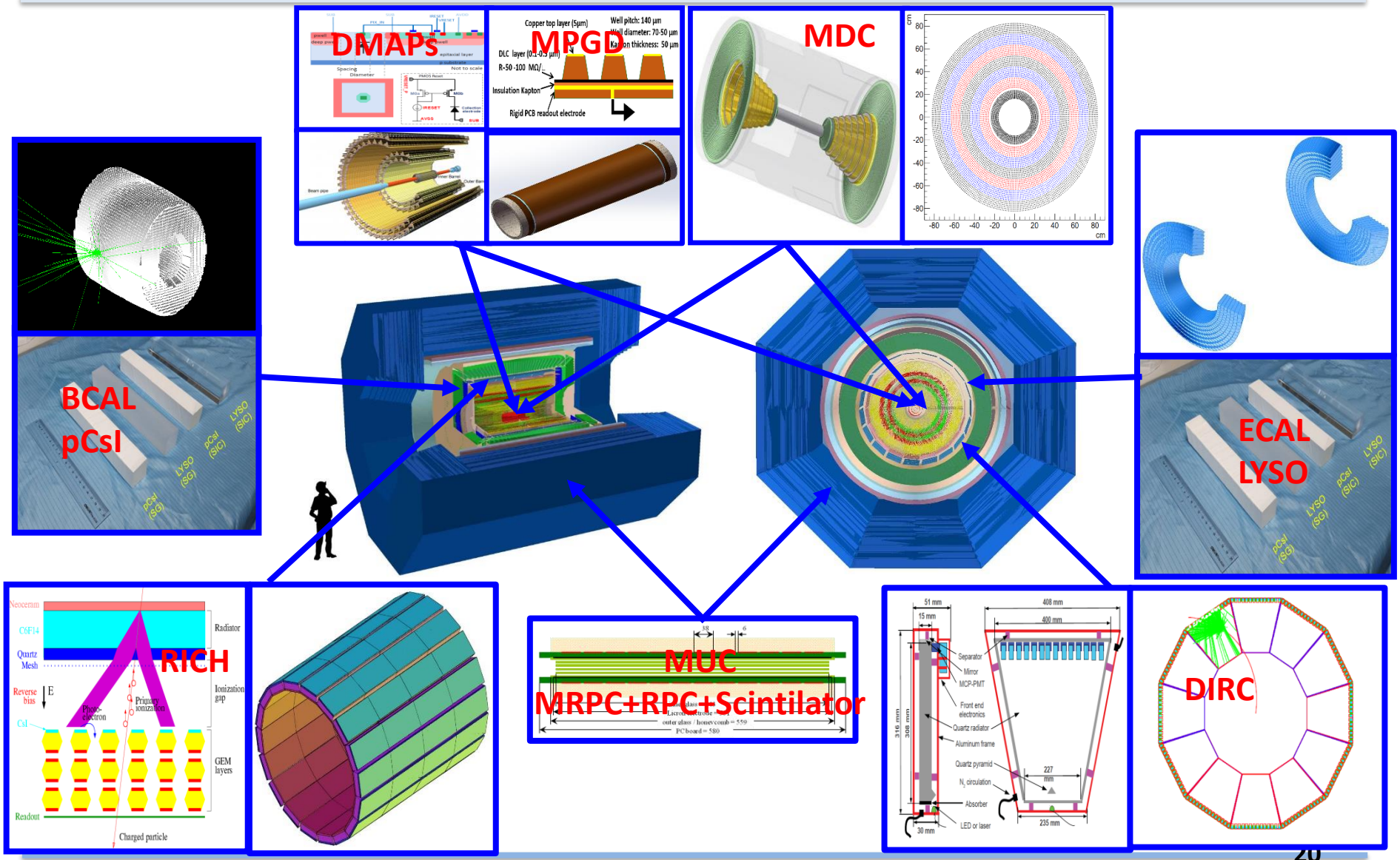
- **Efficient event triggering, exclusive state reconstruction and tagging**
  - high efficiency and resolutions for charged and neutral particles
  - Fast response, low noise and high rate capability
- **The Systematic uncertainty control**
  - Detector acceptance : geometrical acceptance or detector response
  - Mis-Measurement : mis-tracking, fake photon, particle mis-id, noise
  - Luminosity measurement

General performance



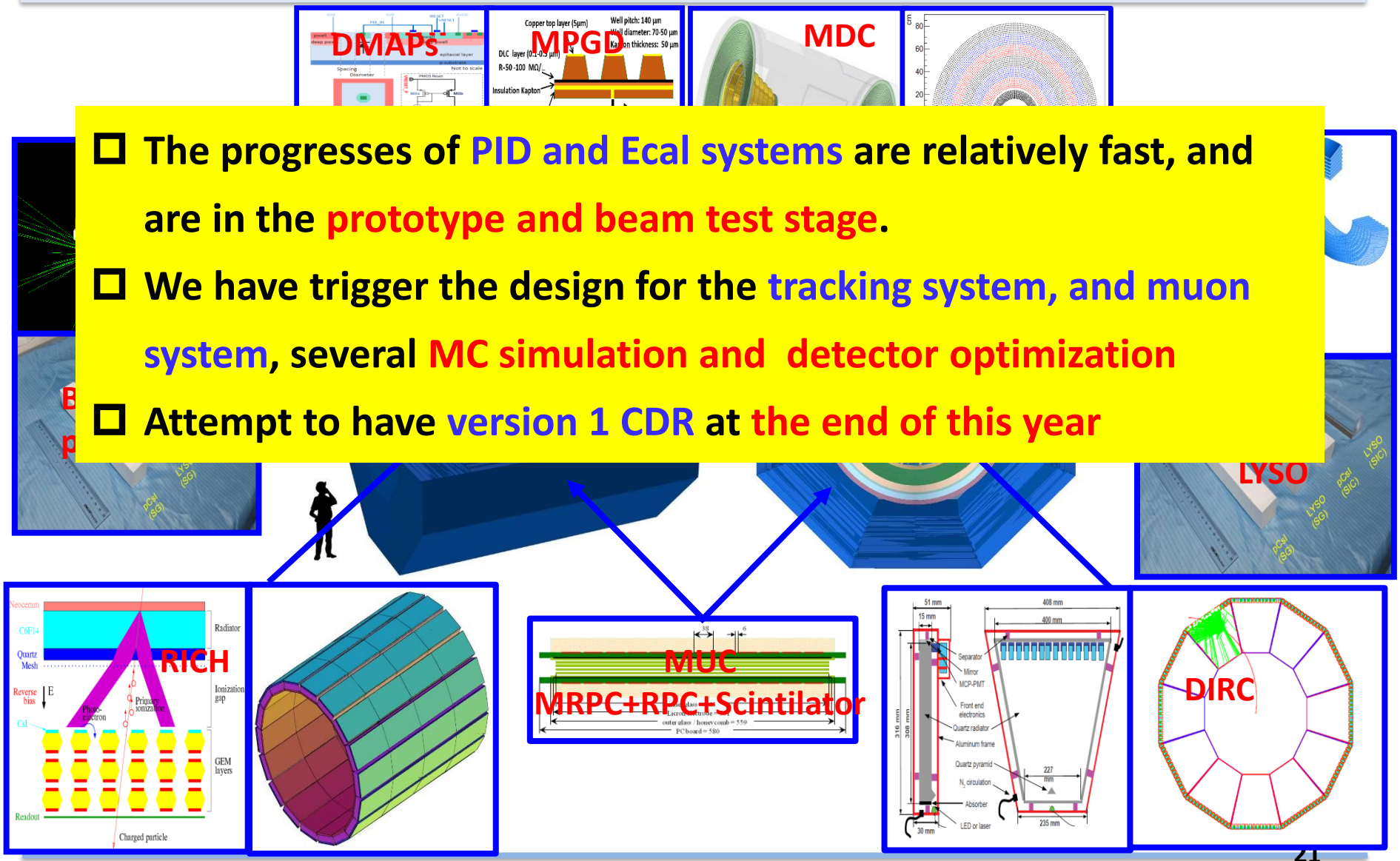
- **Vertex Detector**
  - ~0.15% X_0 / layer
  - σ_{xy} ~ 50 um
- **Main Drift Chamber**
  - σ_{xy}~130 um, σ_p/p~5%@1GeV/c
  - dE/dx ~ 6%
- **PID system**
  - π/K (K/P) 3-4σ separation up to 2 GeV/c
- **Electromagnetic Calorimeter**
  - Range: 0.02 – 3 GeV
  - Resolution (1GeV): 2.5% (barrel) and 4% (endcap)
- **Muon system**
  - Pion suppression power: >10 and lower to 0.4 GeV/c

Spectrometer



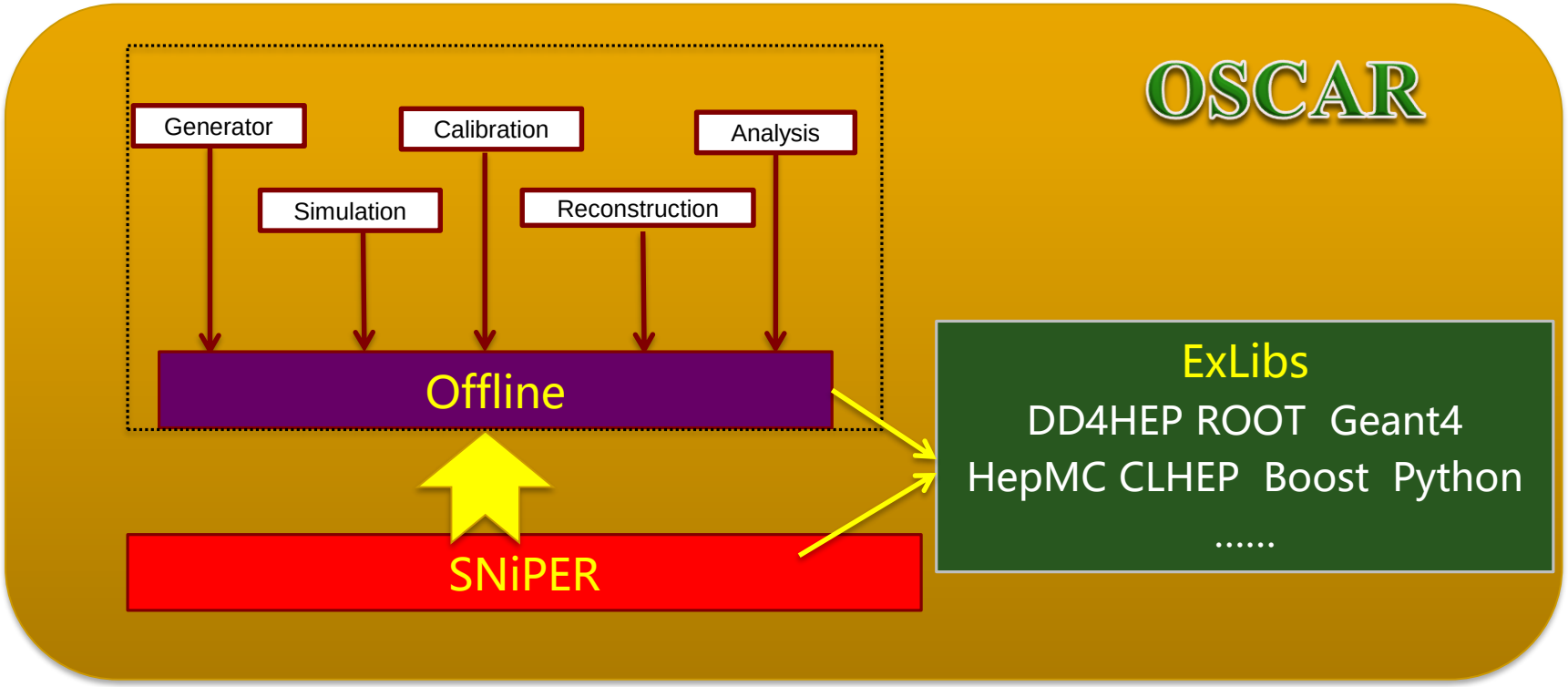
Spectrometer

- The progresses of PID and Ecal systems are relatively fast, and are in the prototype and beam test stage.
- We have trigger the design for the tracking system, and muon system, several MC simulation and detector optimization
- Attempt to have version 1 CDR at the end of this year



Software System

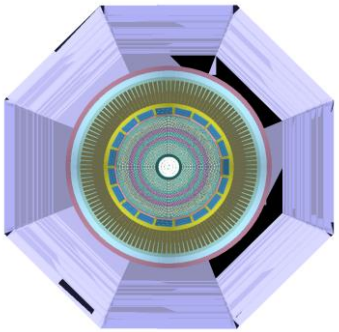
OSCAR: Offline Software of Super Tau-Charm Facility

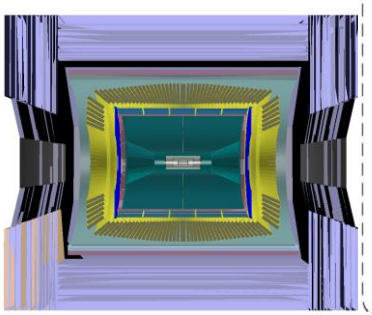


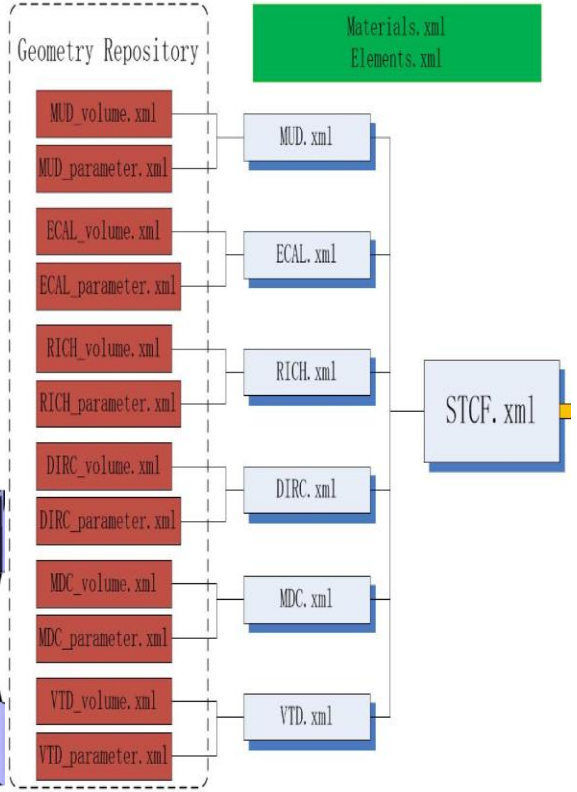
- **ExLibs:** include frequently used third-party software and tools
- **SNiPER:** a new framework to provide core functionalities and common services.
- **Offline:** all software specific to STCF, including Generator, Simulation, Calibration, Reconstruction and Analysis.

Progress of Software

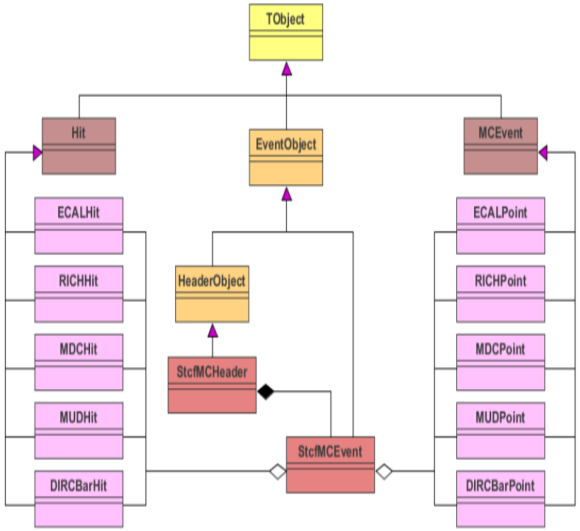
Detector Geometry :
DD4hep & XML file







Event Data Model

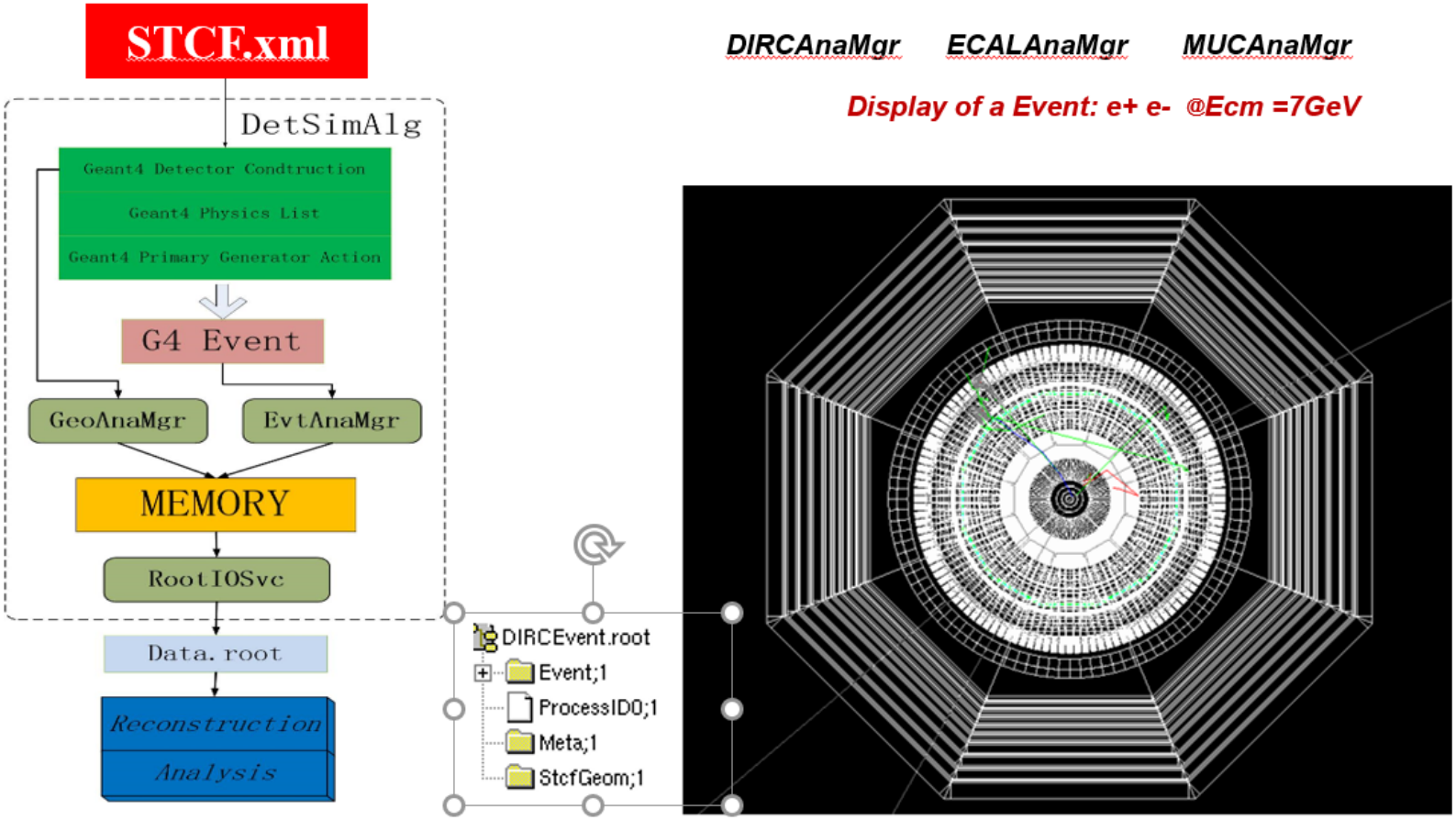


- Each subdetector defines their Event Objects
- All EventObject inherits from TObject.

- **Current design and implementation based on ROOT Tobject**
- **ROOT IO system has been implemented**
- **PODIO is under investigation**

Prototype for Full simulation Chain

- **STCF.xml ： the input geometry of the Oscar DetSimAlg**



Summary of Software system

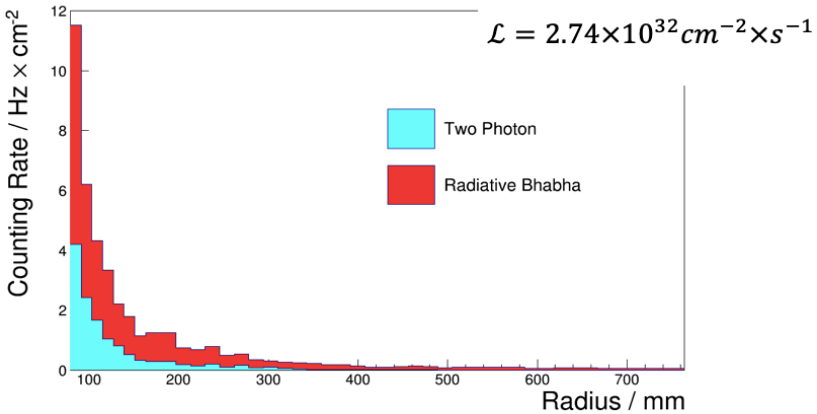
- Setup the Prototype for Full Simulation Chain
  - Generator
  - Detector geometry
  - Simulation framework
  - Event data model
  - Root Input/Outpu System
- Starts Reconstruction/PID Method Study

See Xingtao's talk for the detail

Beam background simulation

Simulation Part		Program
Generator	Radiative bhabha	BBBrem
	Two-photon Process	Guinea-Pig
	Touschek effect	Self-wrote
	Beam-gas coulomb scattering	Self-wrote
	Beam-gas Bremsstrahlung	Self-wrote
	Inject	-
	Synchrotron radiation	-
Accelerator transport		SAD
Machine Interact & Detector Response		BESIII framework

- Dominated generators are finished
- Transportation by SAD finished but need further check
- BESIII framework require geometry extension for backgrounds from Touschek and beam-gas effect



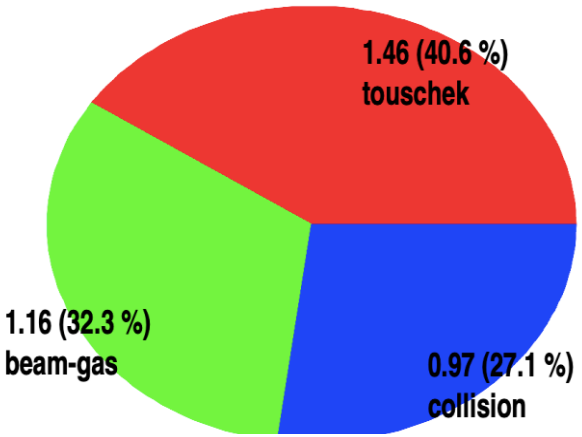
Beam background experiment

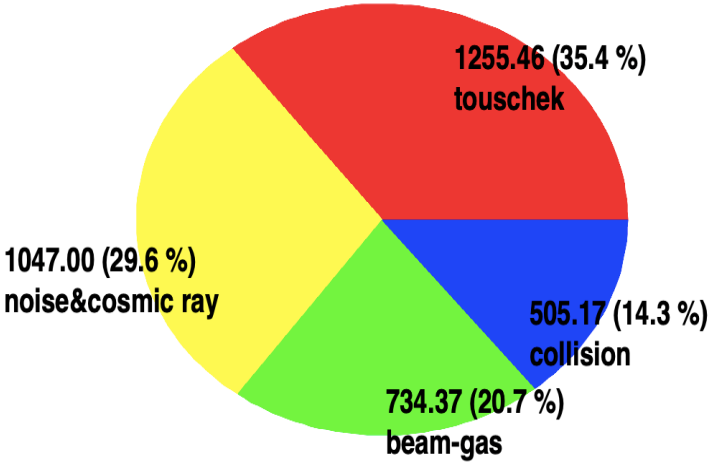
- **An experiment for beam background is performed on BEPCII/BESIII:**

1. No beam to measure electric noise and cosmic ray
2. Change bunch size and single bunch current to measure Touschek background
3. Change total current to measure beam-gas background
4. Measure background for collision mode

- **Background ratio are calculated in collision with:**

- $I_{e^+} = 431mA, I_{e^-} = 392mA,$
- $\mathcal{L} = 2.4 \times 10^{32} cm^{-2} \times s^{-1}$
- $E_{cm} = 4.44GeV$





Progress on Accelerators

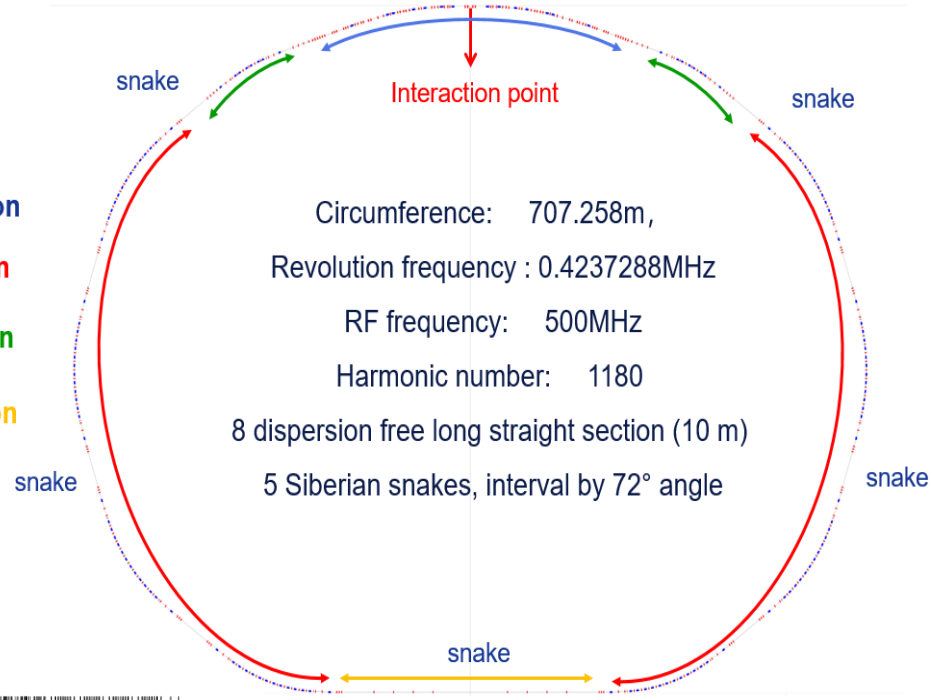
Convener : Dr. Qing Luo

- Accelerators physics
- Key Technologies

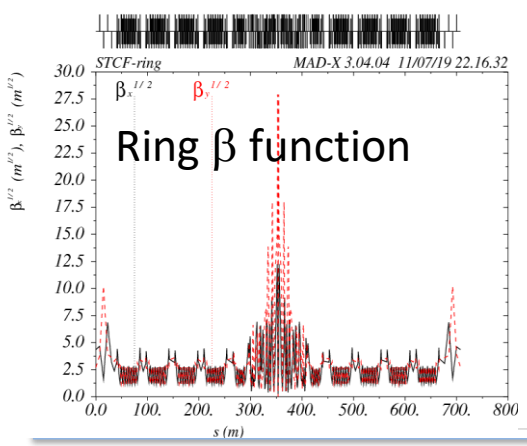
See Qin Lou's talk for details

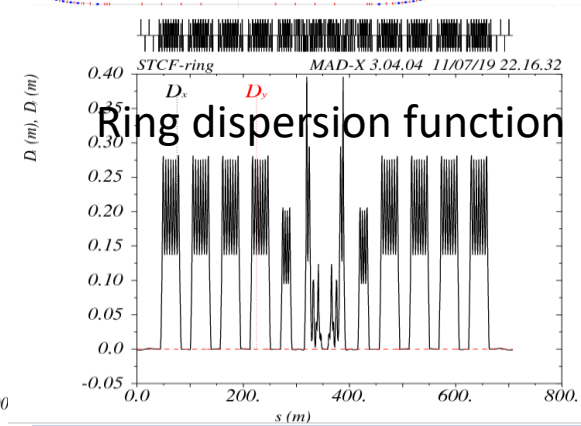
Lattice with FODO-like Arc

1. Interaction region
2. Long arc section
3. Short arc section
4. Technical section



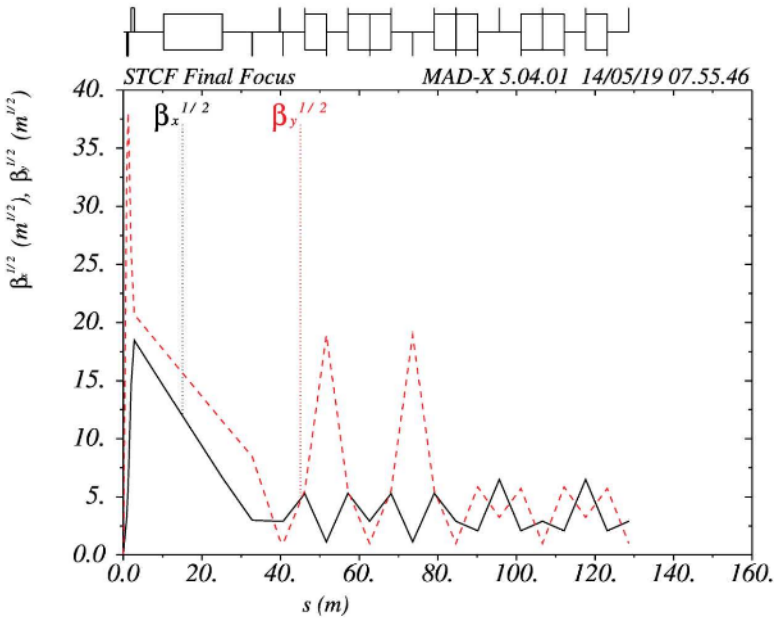
Parameters	Achieved Now
Circumference/m	707.258
Beam Energy/GeV	2; 1-3.5tunable
Current/A	1.5
Emittance$(\varepsilon_x/\varepsilon_y)$/nm·rad	2.85/0.0285
β Function @ IP (β_x^*/β_y^*)/mm	65/0.68
ν_x/υ_y	30.52259316 / 28.53792761
Collision Angle(full θ)/mrad	60
Momentum compaction factor	0.001237
Energy spread	4.034e-4
Tune Shift ξ_y	0.06 (estimated)
Hour-glass Factor	0.8 (estimated)
Luminosity/ $\times 10^{35}$cm^{-2}s^{-1}	0.95 (estimated)

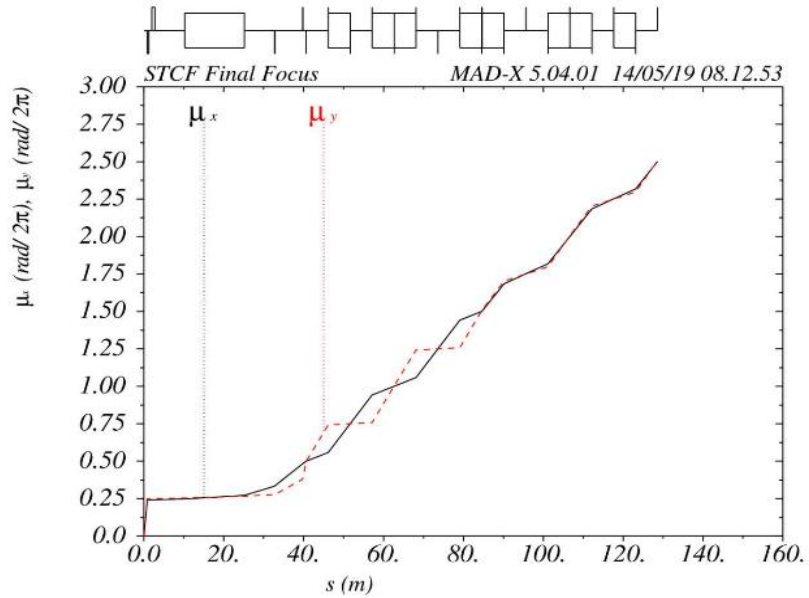




- Raw results, needs more work
- nonlinear optimization and collective effects under study

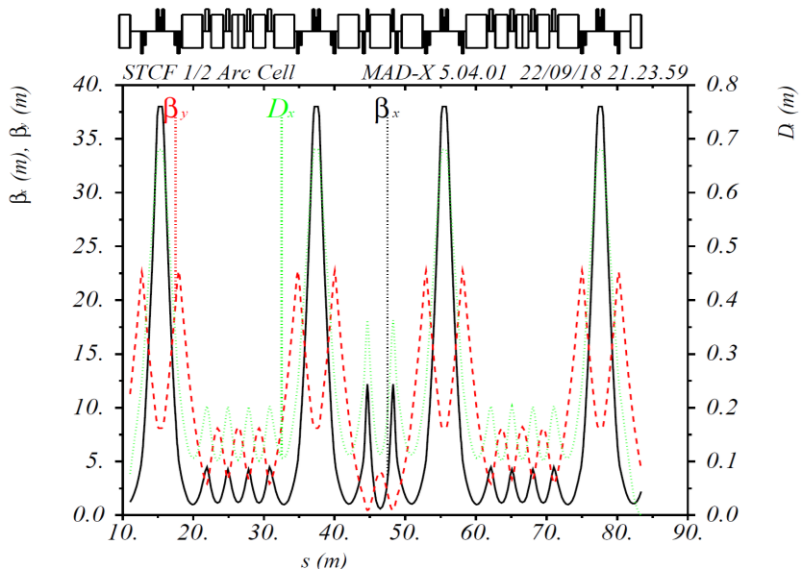
Lattice with MAB-Like Arc





The final focus section has a total length of 257.318m (without dispersion suppression section). The traditional scheme for chromatic correction is employed. The chromaticity is compensated in dedicated sections separately (CCY and CCX). A pair of sextupoles are placed in symmetrical high β function in each section, each pair is in phase with the final doublet. The geometric aberrations and the second order dispersion aberration are cancelled in each pair.

Lattice with MAB-Like Arc



Parameters	Achieved Now
Circumference/m	~540
Beam Energy/GeV	2; 1-3.5tunable
Current/A	1.5
Emittance$(\varepsilon_x/\varepsilon_y)$/nm·rad	2.4/0.03
β Function @ IP (β_x^*/β_y^*)/mm	60/0.6
ν_x /υ_y	17.2/10.7
Collision Angle(full θ)/mrad	60
Tune Shift ξ_y	0.06-0.1 (estimated)
Hour-glass Factor	0.8 (estimated)
Luminosity/ $\times 10^{35}$cm^{-2}s^{-1}	0.8~1.3 (estimated)

Still, table above shows the rough and estimated machine parameters that we achieve at present. The nonlinear optimization is in progress while the study of the collective effects and beam-beam effect has not started yet, so the whole design may be greatly adjusted in future.

- Interaction region, tunes and tune shift should be optimized
- Longer rings (600-800m), may achieve much better performance of emittance and allow enough space for 5 Siberian snakes or more (if really needed), high polarization may be available

Ring Polarization Issues

- CAST (Circular Accelerator Spin tracking) Code is under developing
- Polarization rotators: more snakes, higher P_{avg}
- We are trying to develop a solenoid-based snake shorter than 10m, ±I and ±L method are both under evaluation

Accelerator technique

- Beam control and measurement,

  See Zerang's talk fro detail

- We've made progress on accelerator techniques such as magnets, beam measurement and low level RF.
- Beam-beam simulation work has been started.

  See Qin Lou's talk for details

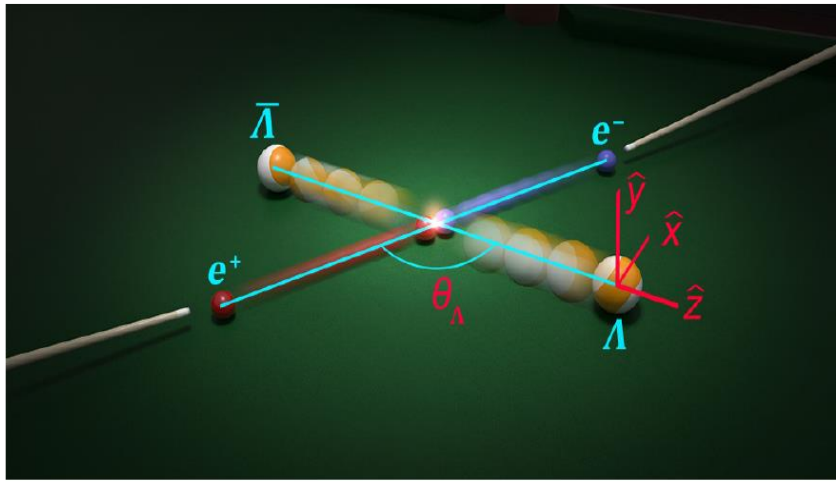
Summary

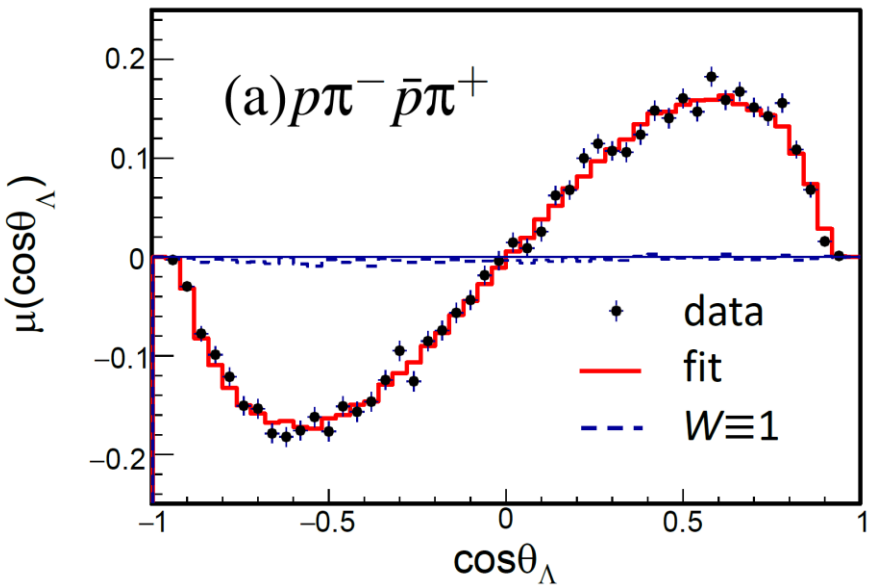
- The STCF program in China is moving on the right direction, and have made great progress in all aspects in past year.
- We are consulting with the different departments at different level, and trying to get the national support for the project
- Seeking more active, close and extensive international cooperation

Welcome to join the effort

谢谢 Thanks.

Spin polarization of Λ in $J/\psi \to \Lambda\bar{\Lambda}$





Nature Phys. **15**, 631–634 (2019)

arXiv:1808.08917

1.31 B J/ψ events

Quantum correlation in Λ pair

Parameters	This work	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [14]
$\Delta\Phi$	$(42.4 \pm 0.6 \pm 0.5)^\circ$	–
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [16]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [16]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–
A_{CP}	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [16]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	–

CP test $A_{CP} = \frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+}$

A_{CP} Sensitivities in STCF

- 4 trillion J/ψ events ⇒ $A_{CP} \sim 10^{-4}$
  - Luminosity optimized at J/ψ resonance
  - Luminosity of STCF: × 100
  - 2 – 3 years data taking
  - No polarization beams are needed
- Beam energy trick ⇒ small beam energy spread ⇒ J/ψ cross-section: × 10 ⇒ $A_{CP} \sim 10^{-5}$?
- Challenge: Systematics control

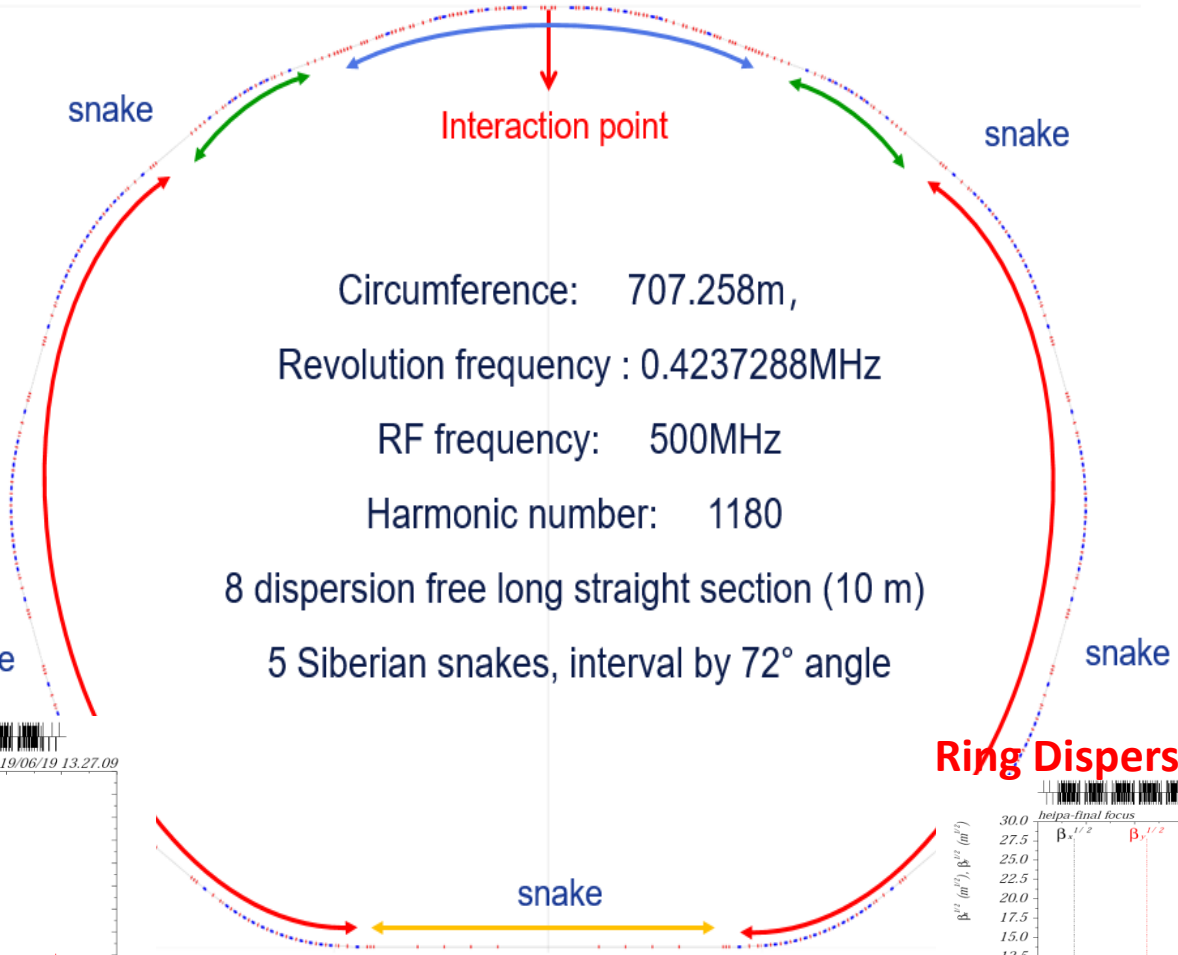
Strategy& Activities

CDR → TDR → project application → construction → commissioning

- Strategy: focus on CDR (3 years) and TDR (6 years) depend on the available resources. the construction site open.
- Webpage: http://wcm.ustc.edu.cn/pub/CICPI2011/futureplans/
- Domestic Workshops (2011, 12, 13, 14, 16)
- International Workshops (2015, 18)
- 2015 Fragrance Hill-Science Conference (No. 533)
- Report to USTC Scientific Committee and USTC presidents
- Report to local government
- Form the Organization (including project manager, physics/detector/accelerator work groups ….)
- Regular weekly meetings for Accelerator/Detector/physics !

Lattice with FODO-Like Arc

1. Interaction region
2. Long arc section
3. Short arc section
4. Technical section



Circumference: 707.258m,

Revolution frequency : 0.4237288MHz

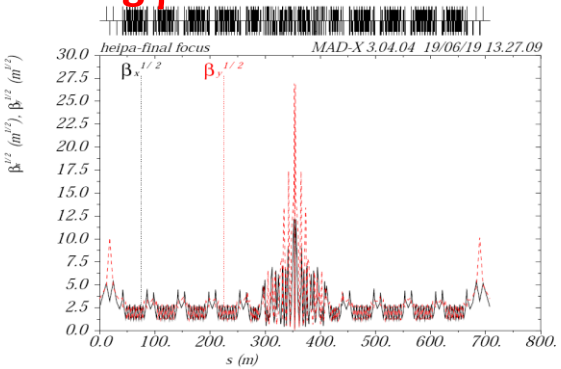
RF frequency: 500MHz

Harmonic number: 1180

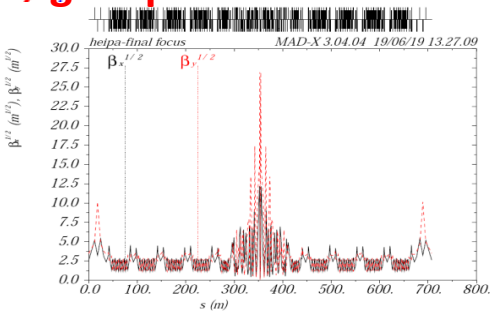
8 dispersion free long straight section (10 m)

5 Siberian snakes, interval by 72° angle

Ring β function



Ring Dispersion function



Key technologies

关键技术研究内容与路线

内容	技术路线
束流测量	能量、位置、极化度，束团尺寸，束流反馈，亮度反馈
微波高频	超导高频腔，低电平控制系统
真空	真空室镀膜，异形真空室研制，阻抗优化与测量
磁铁	超导磁铁，超导螺线管，永磁铁，异形铁……
极化束技术	试制光阴极极化电子枪

计算与仿真研究，制定技术方案 → 样机设备的加工，离线测试 → 搭建集成测试平台，预研样机测试与定型

Summary

- **Super τ-c Factory (STCF):**
  - double ring with circumference around 600~1000 m
  - e^+e^- collision with E_{cm} = 2 – 7 GeV, L = 1 × 10^{35} $cm^{-2}s^{-1}$
- **STCF is one of the crucial precision frontier**
  - rich of physics program
  - unique for physics with c quark and τ leptons,
  - important playground for study of QCD, exotic hadrons and search for new physics.
- **We initialized 10 M CNY (2018), 10-20M CNY(2019) for start R&D.**
- **Project organization is setup, a working group is toward for CDR/TDR**
- **An International collaboration is essential for promoting the project.**

Welcome to join the effort

谢谢
Thanks.