BEPC Tau-Charm Future Opportunities

High Intensity Electron Positron Accelerator (HIEPA) Facility in China

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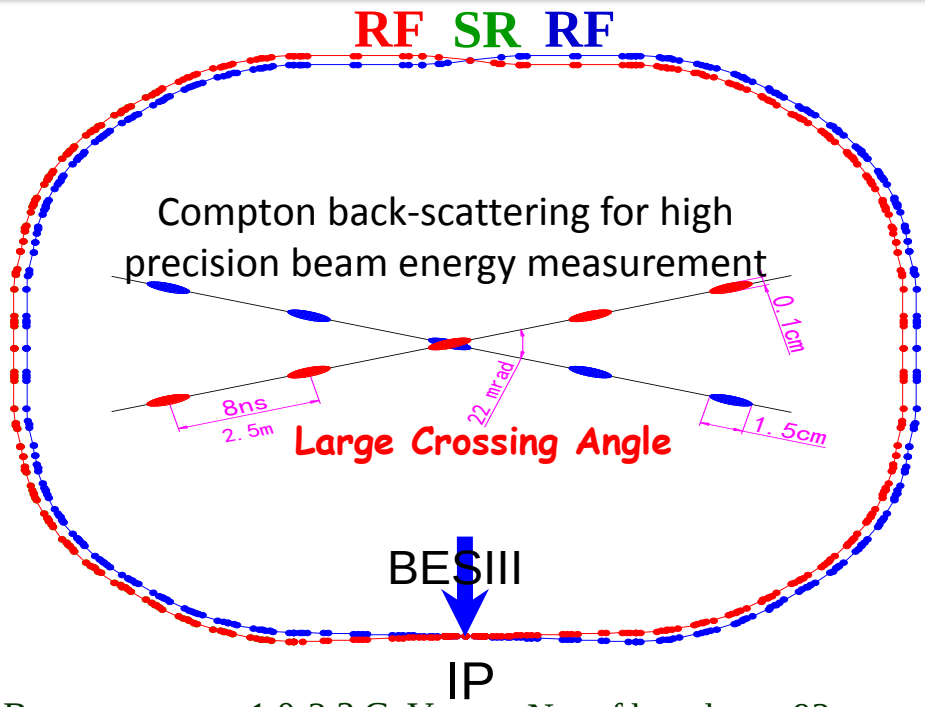
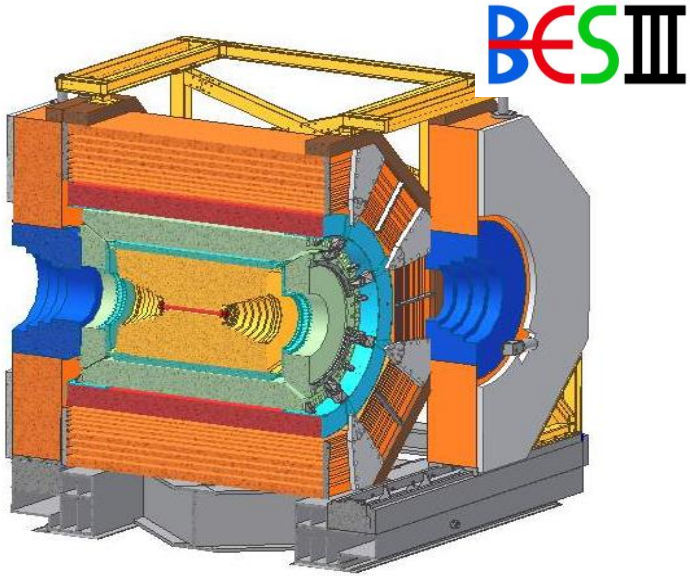
(On behalf HIEPA Steering Committee)

QWG2016, June 06-10, PNNL USA

DR. Haiping Peng

BEPCII/BESIII in Beijing, China





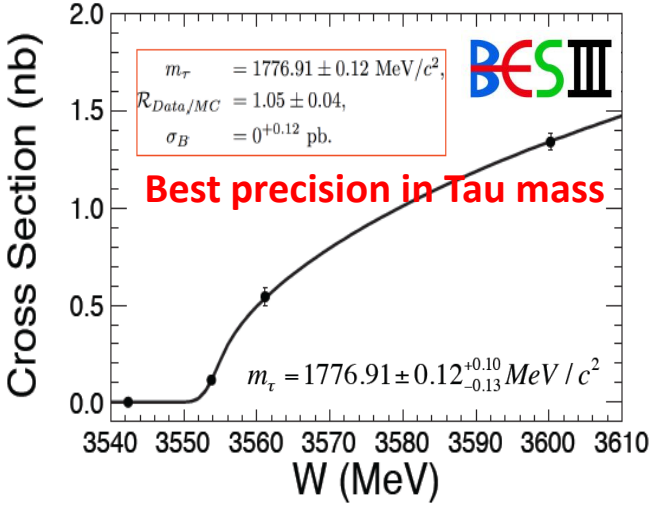
- Beam energy : 1.0-2.3 GeV
- Energy spread : 5.16×10^{-4}
- Optimum ene. : 1.89 GeV
- Luminosity : 1×10^{33} $cm^{-2}s^{-1}$
- No. of bunches : 93
- Bunch length : 1.5 cm
- Total current : 0.91 A
- SR mode : 0.25A@2.5GeV

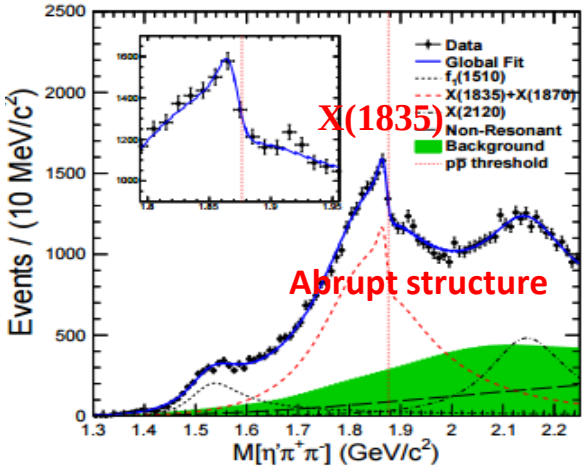
Sub-detectors			Performance
MDC	Momentum resolution		0.5%@1GeV
	dE/dx resolution		6%
EMC	Energy resolution		2.5%@1GeV
	Spatial resolution		6 mm
TOF	Time resolution	Barrel	80 ps (Bhabha)
		Endcap	110 ps (Di-muon)
MUC	9 layers RPC, 8 layers for endcap		

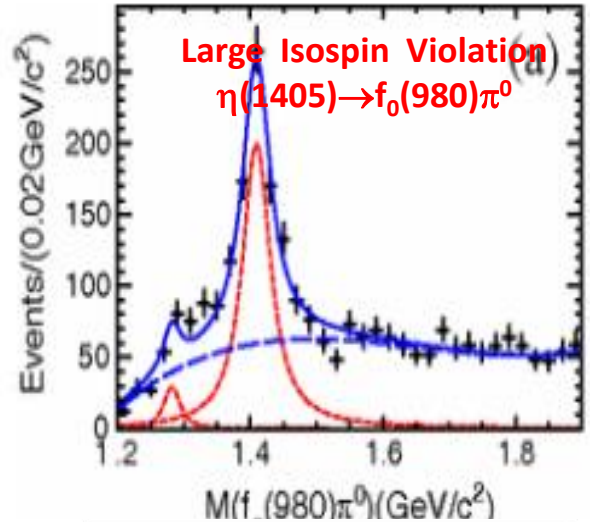
Unique: operating in the Tau-charm region in the world

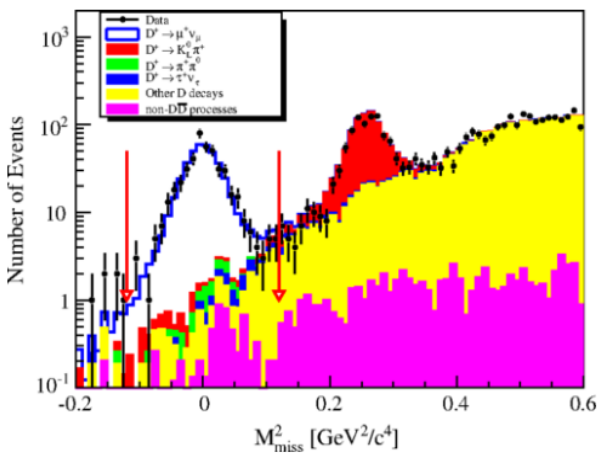
Achieved $1.0\times10^{33}cm^{-2}s^{-1}$ in April

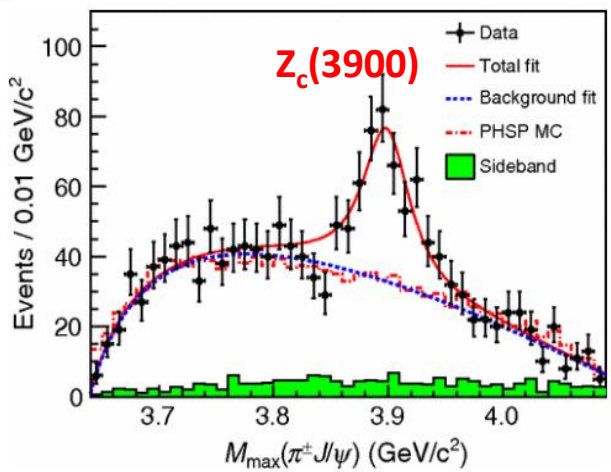
Fruitful Physics Results

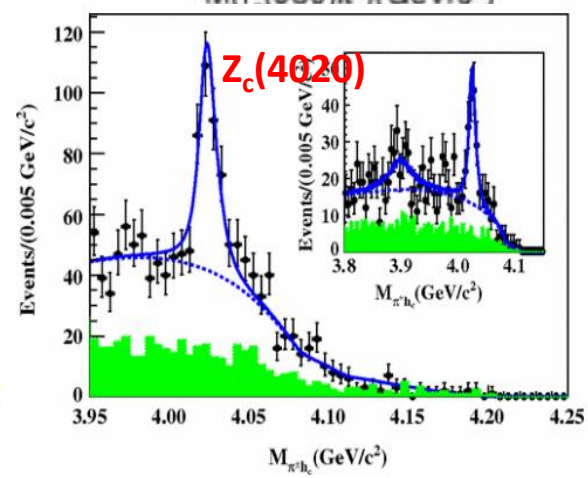












Most precise measurement for D leptonic decay

BESIII has 131+ publications

http://bes3.ihep.ac.cn/pub/physics.htm

What Project Are We Proposing

BEPCII/BESIII Pros and Cons

- Threshold production
- Clean signal, low background
- High efficiency and resolution
- …….

- Small Ecms range: 2-4.6GeV
- Insufficient luminosity : 10^{33} $cm^{-2}s^{-1}$

BEPCII/BESIII will end around 2022 (?)

Led by the High Energy Physics Association of China,

we are exploring possible future collider project beyong BEPCII/BESIII

High Intensity Electron Positron Accelerator (HIEPA)

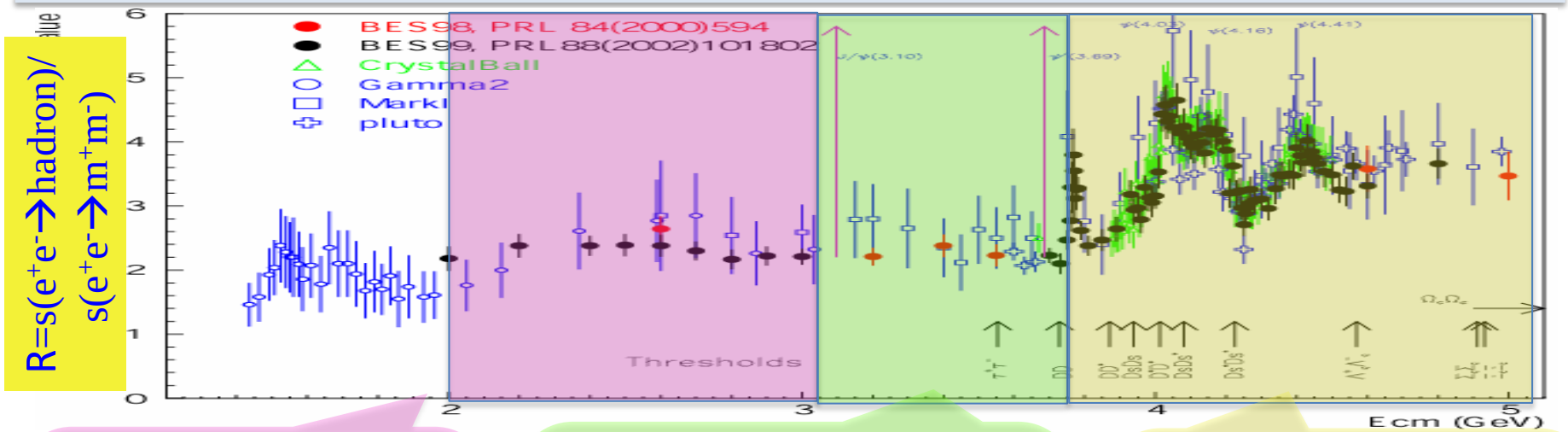
What is HIEPA

- Collider
  - Peak luminosity: 0.5— 1×10^{35} $cm^{-2}s^{-1}$ at 4 GeV
  - Energy range: E_{cms} = 2–7GeV
  - Polarization available for one beam
  - Symmetric machine **with high currents** & **crab waist collision**

- Also serve as 3rd or 4th generation SRF (synchrotron radiation facility).

- Reserving the potential for future FEL (free electron laser) study with the long LINAC.

Broad Physics at τ-c Energy Region



- Hadron form factors
- Y(2175) resonance
- Multiquark states with s quark, Z states
- 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
- Physics with D mesons
- f_D and f_{Ds}
- D_0-D_0 mixing
- Charm baryons

R scan

- **Precision measurement of $\Delta\alpha_{QED}$, a_μ, charm quark mass.**
- **Hadron form factor(nucleon, Λ, p).**

(No data at 5-7GeV)

Data Samples / Year

$10^{35}cm^{-2}s^{-1} \times 86400s \times 180days \times 90\% = 1.4ab^{-1}$

	CLEO-C		BES-III/ year $10^{33}cm^{-2}s^{-1}(10fb^{-1})$	τ-charm/year $10^{35}cm^{-2}s^{-1}$ $(1ab^{-1})$
J/ψ	–	–	10×10^{9}	10×10^{11}
ψ(2S)	54 pb^{-1}	27×10^{6}	3×10^{9}	3×10^{11}
ψ(3770)	818 pb^{-1}	5×10^{6} D-pair	3×10^{7}	3×10^{9}
4.17 GeV	586 pb^{-1}	7×10^{5} D_s-pair	2×10^{6}	3×10^{9}
$\tau^+\tau^-$ (4.25)		4×10^{6}	3×10^{7}	3×10^{9}

10^{10} charm @ Υ(4S)

10^{10} τ pairs @ Υ(4S)

BELLE-II/Super KEKB

$10^{36}cm^{-2}s^{-1}(10ab^{-1}/year)$

Selected physics topics

- Hadron Spectroscopy (charmonium)
- Tau Physics
- Nucleon/hadron electromagnetic form factor

Charmonium Spectroscopy

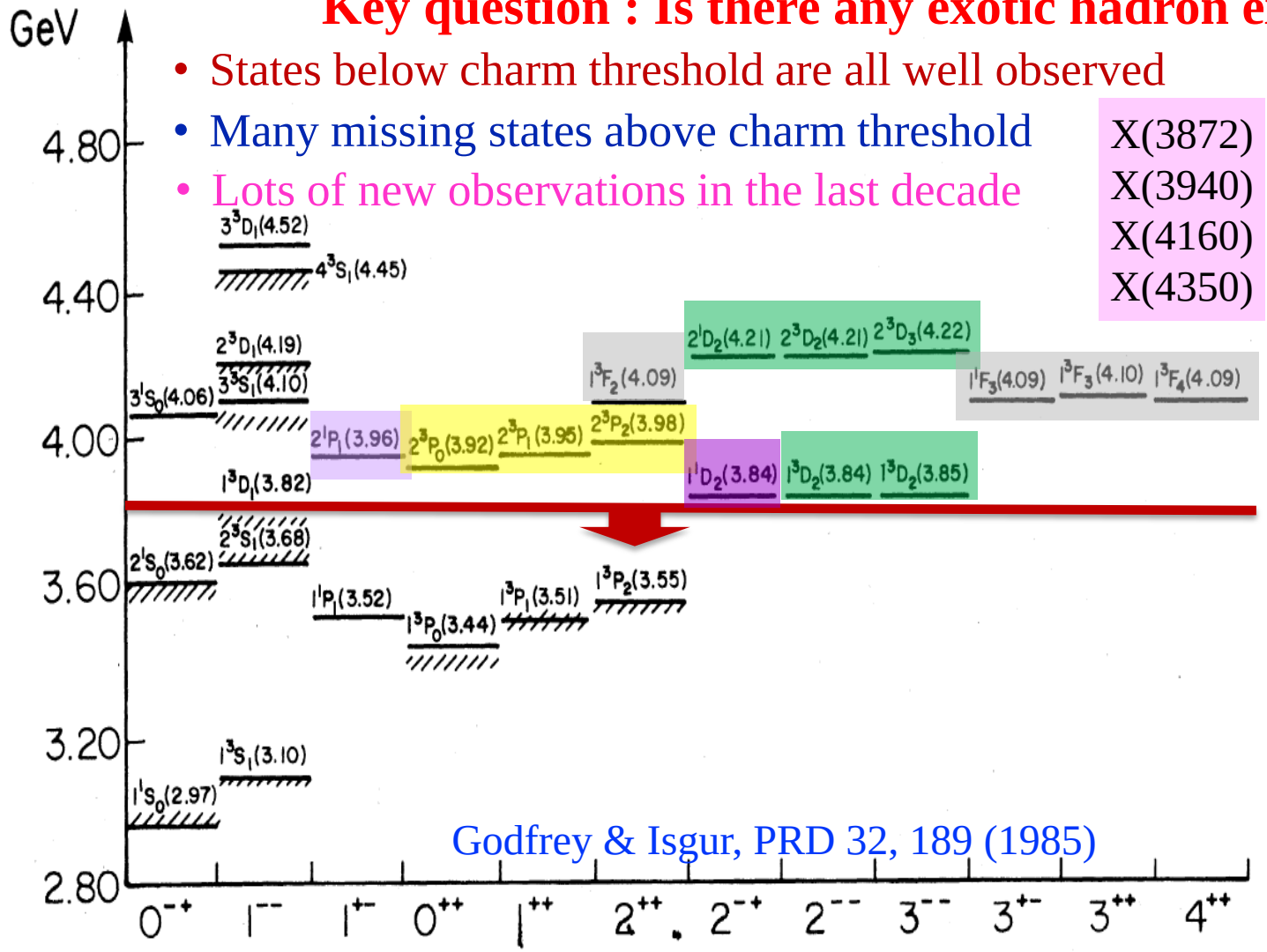
Key question : Is there any exotic hadron exist

- States below charm threshold are all well observed
- Many missing states above charm threshold
- Lots of new observations in the last decade

X(3872)
X(3940)
X(4160)
X(4350)

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

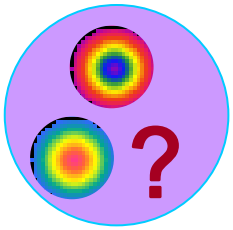
Z(3900)
Z(4020)
Z(4050)
Z(4200)
Z(4250)
Z(4430)



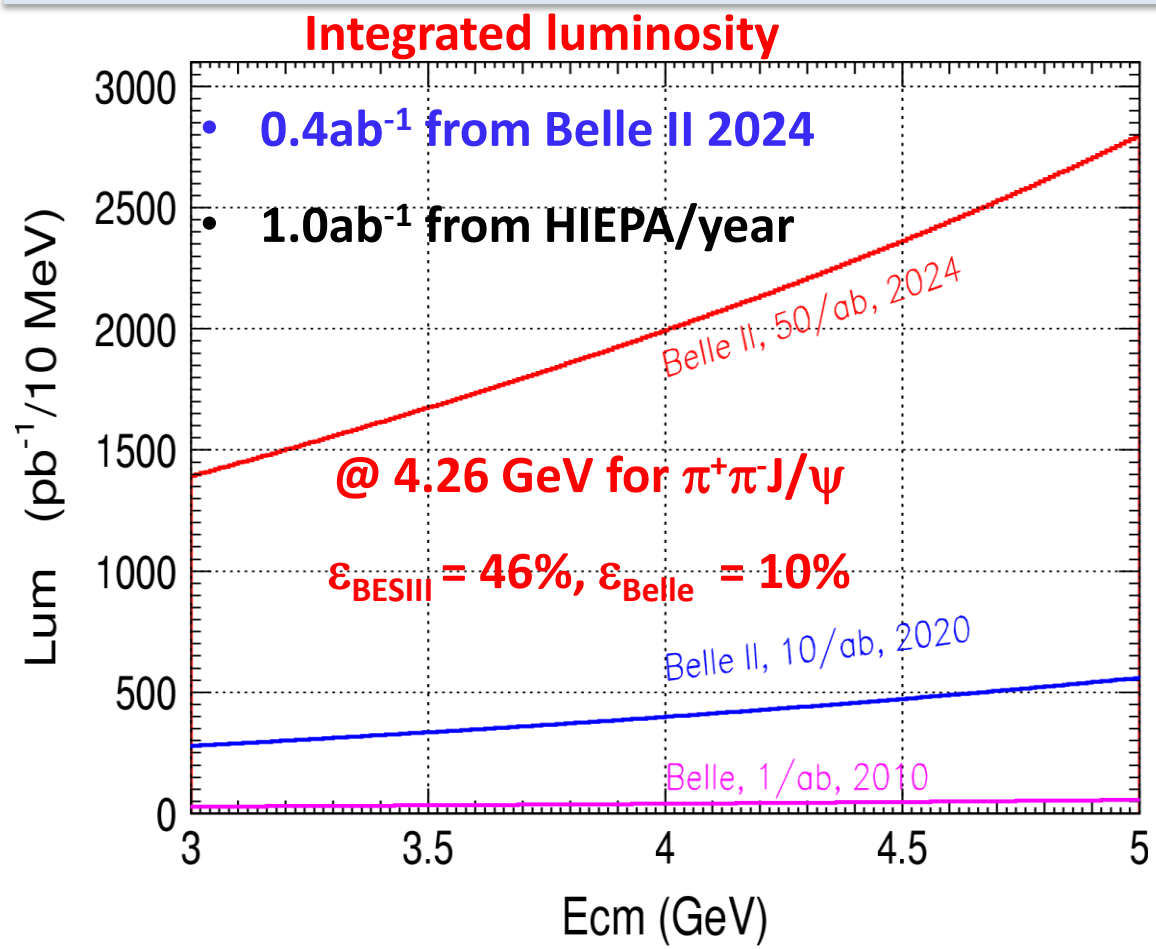
Godfrey & Isgur, PRD 32, 189 (1985)

Nature unclear

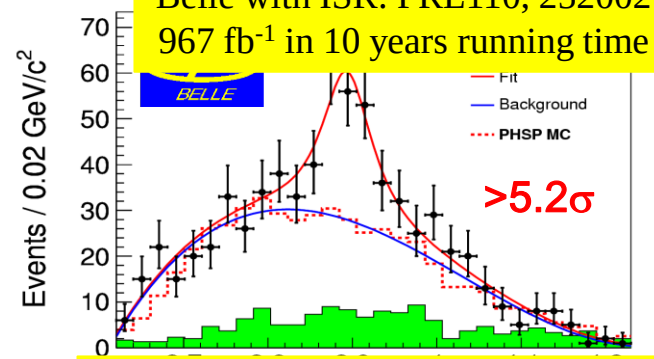
- Charmonium?
- Hybrid?
- Tetraquark?
- Molecule?
- Non-resonance?



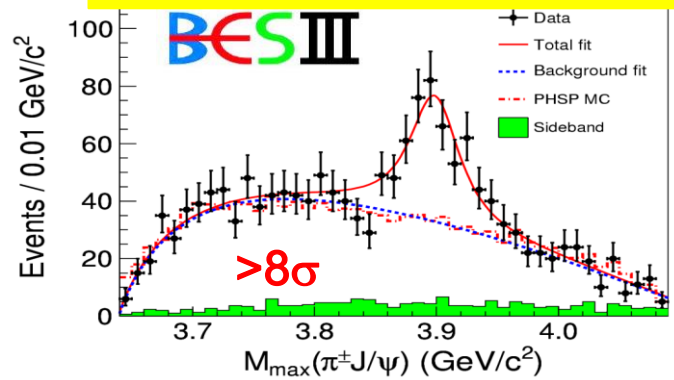
Competition from Belle II?



Belle with ISR: PRL110, 252002
967 fb^{-1} in 10 years running time



BESIII at 4.260 GeV: PRL110, 252001
0.525 fb^{-1} in one month running time



Have incomparable superiority to explore Charmonium(like) states

And open a new territory to study Charm Baryon

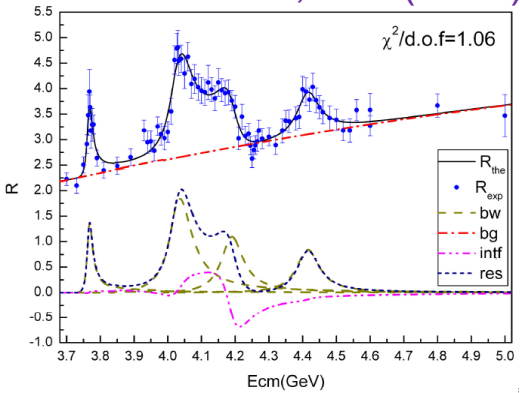
Charmonium-Like @ τ-c Factory

- ψ/Y/hybrid(ccg) (1^{--}) produced directly in the e^+e^- collision
  - To determine the parameters for the excited ψ or Y states
  - Precisely measure the x-sect of inclusive/exclusive final states at different Ecms
- Charge parity c=+1 states produced via radiative transition from vector ψ/Y
  - The decay rate ψ(nS/nD)→γX(3872), X(3940)…
  - $\chi_{cJ}(2P)$、$\chi_{cJ}(3P)$、$\eta_c(3S)$、 $\eta_c(4S)$、 …

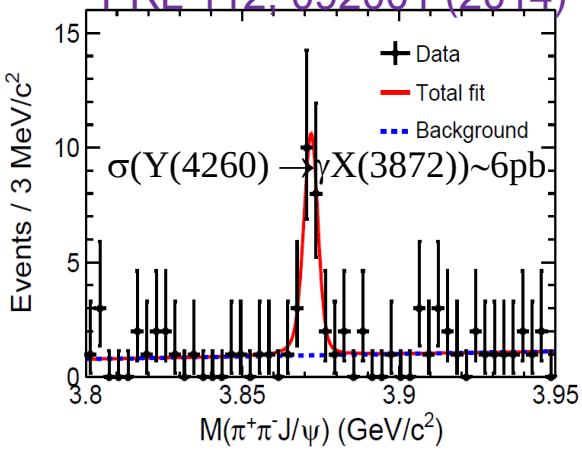
    $B(\psi(3S)\to\gamma\chi'_{cJ}) = (7, 3, 1) \times 10^{-4}$ for J=2,1,0

    [Rev. Mod. Phys. 80, 1161 (2008)]
- Search for new states from hadronic transition
  - To search for Z_c, Z_{cs}, $h_c(2P)$ ….

PLB 660, 315 (2008)



PRL 112, 092001 (2014)



Search for 1^{--} Hybrid $H_{ccg} \to \gamma\eta_c$ & $\gamma\chi_{c0}$

- Assume $\sigma(e^+e^- \to H_{ccg}) \sim O(10–100)$ pb [???]
- $B(H_{ccg} \to \gamma\eta_c) \sim 2 \times B(\eta_{c2} \to \gamma\chi_{c0}) \sim 4 \times 10^{-4}$

  [in Hybrid, ccbar in spin-singlet, LQCD by Dudek'09]
- Scan $e^+e^- \to \gamma\eta_c$ and $\gamma\chi_{c0}$ for exotic structure
- If $\varepsilon B \sim 10\%$ for $\to \gamma\eta_c$ and $\gamma\chi_{c0}$ decay to γ+hadrons

  $L_{peak} = 10^{35} cm^{-1}s^{-1}$, $10^6 pb^{-1}$ /year= $1ab^{-1}$/year

  At 100 energy points above DDbar threshold

  $N^{obs}(\gamma\eta_c)$ =O(4-40) evs/point/year at peak

  $N^{obs}(\gamma\chi_{c0})$ =O(2-20) evts/point/year at peak

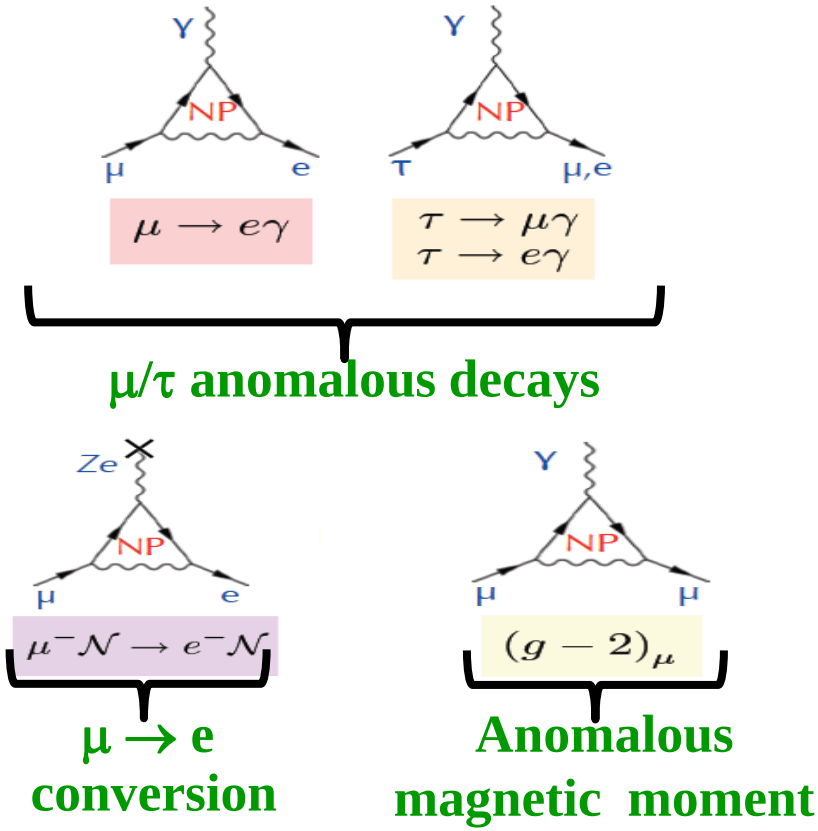
Detail MC studies needed to understand the background, and to improve the sensitivity

cLFV Decay $\tau \to \ell\gamma$

- No evidence of new physics at high energy frontier.
- Important and complementary to search for new physics in the precision frontier.

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

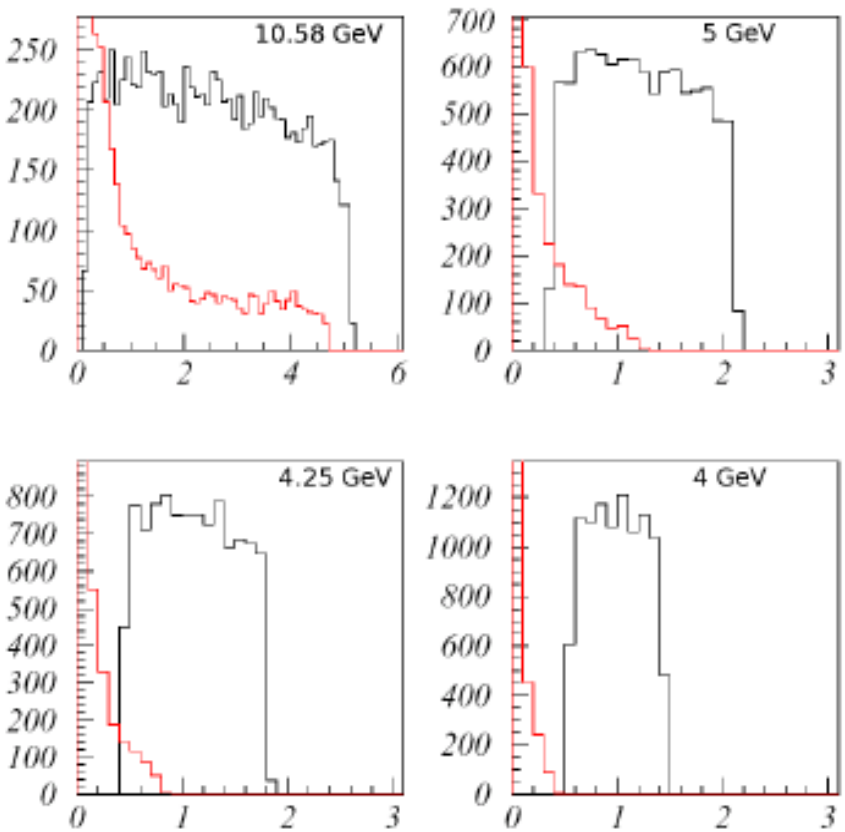
Table 8: "DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.



In τ-charm factory, $\tau \to \mu\gamma$ decay is a golden mode to search for NP

W. Altmannshofer et al. arXiv : 0909.1333

STCF .vs. BF : $\tau \to \mu\gamma$ background



- Dominant source at Y(4S) : $e^+e^- \to \tau^+\tau^-\gamma$
- Does not contribute below $\sqrt{s} \approx 4m_\tau/\sqrt{3} \approx$ 4.1 GeV.

Dominant BKG @ STCF

- τ decays : [arXiv:1206.1909]

  direct ($\tau^+ \to \pi^+\pi^0\nu_\tau$) and combinatorial
- QED processes :

  $e^+e^- \to \mu^+\mu^-\gamma\gamma$, $e^+e^- \to e^+e^- \mu^+\mu^-\gamma$
- Continuum hadron production $e^+e^- \to qq$
- $\psi(2S)$ and D-meson decays

Polarized beam may further suppress background and increase the sensitivity for the new physics significantly

Expected $\tau \to \mu\gamma$ Br upper limit

E(GeV)	σ(nb)	L(ab^{-1})	$N_{\tau\tau}(10^{10})$
3.686	5.0	1.5	0.75
3.77	2.9	3.5	1.03
4.17	3.6	2.0	0.71
Total		7.0	2.49

Results from Vladimir Druzhinin, (BINP, Novosibirsk) at Workshop on Tau Charm at High Luminosity 26-31 May, 2013, La Biodola, Italy

Fast simulation for NP sensitivity and detector optimization is ongoing

Caloremeter	σ_E/E=1.5%	σ_E/E=2.5%
Signal (Br=10^{-9})	17	15
Muon background	7	11
Pion background	83	271
Expected 90% CL upper limit for Br	1.1×10^{-9}	3.0×10^{-9}
Expected 90% CL upper limit for Br with pion suppression by a factor of 30	3.3×10^{-10}	5.1×10^{-10}

Supper-B Expected limit : 3×10^{-9}@$75ab^{-1}$ (7×10^{10} τ-pairs)

CP Violation in τ Decay

- CP violation is observed in B, D and K systems
- No CPV has been observed in the lepton sector so far
- The discovery of CPV in the tau sector would be a clean signature of NP
- One of the most promising CPV channels is $\tau^- \to K_S \pi^- \nu$
  - SM CP asymmetry from K_S-K_L mixing is expected to be :
    [Bigi & Sanda, PLB 625, 2005, Grossman &Nir JHEP 1204 (2012) 002]

$$|K_S\rangle = p|K^0\rangle + q|\overline{K}^0\rangle$$
$$|K_L\rangle = p|K^0\rangle - q|\overline{K}^0\rangle$$

$$\frac{\Gamma(K_L \to \pi^- l^+ \nu) - \Gamma(K_L \to \pi^+ l^- \overline{\nu})}{\Gamma(K_L \to \pi^- l^+ \nu) + \Gamma(K_L \to \pi^+ l^- \overline{\nu})} = |p|^2 - |q|^2 \simeq (3.27 \pm 0.12) \times 10^{-3}$$

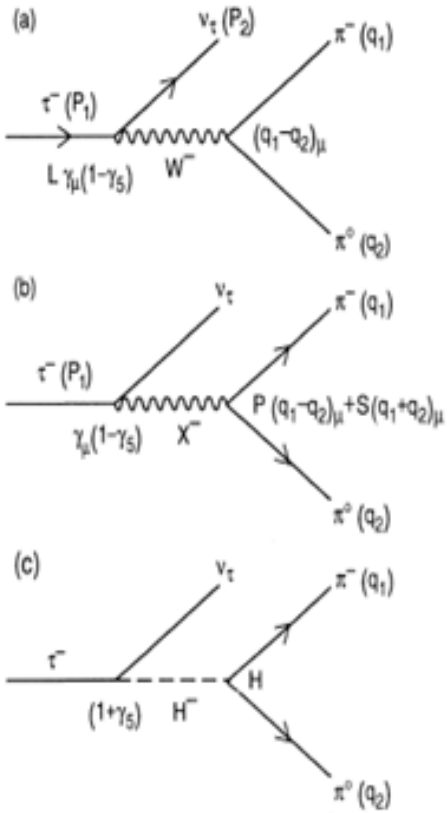
  - BaBar measurement [PRD 85, 031102]

$$A_\tau \equiv \frac{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) - \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}{\Gamma(\tau^+ \to \pi^+ K_S \bar{\nu}_\tau) + \Gamma(\tau^- \to \pi^- K_S \nu_\tau)}$$
$$= (-4.5 \pm 2.4 \pm 1.1) \times 10^{-3}.$$

  - Belle measurement [PRL 107, 131801]

$$|\mathrm{Im}(\eta_S)| < 0.026 \text{ or better}$$

$A_{cp} = (1.8 \pm 2.1 \pm 1.4) \times 10^{-3}$ @ W ~ [0.89-1.11] GeV



Charge Higgs, new Scalar, W_L-W_R Mixings, LeptonQuarks?

τ CPV in Anglar Distribution

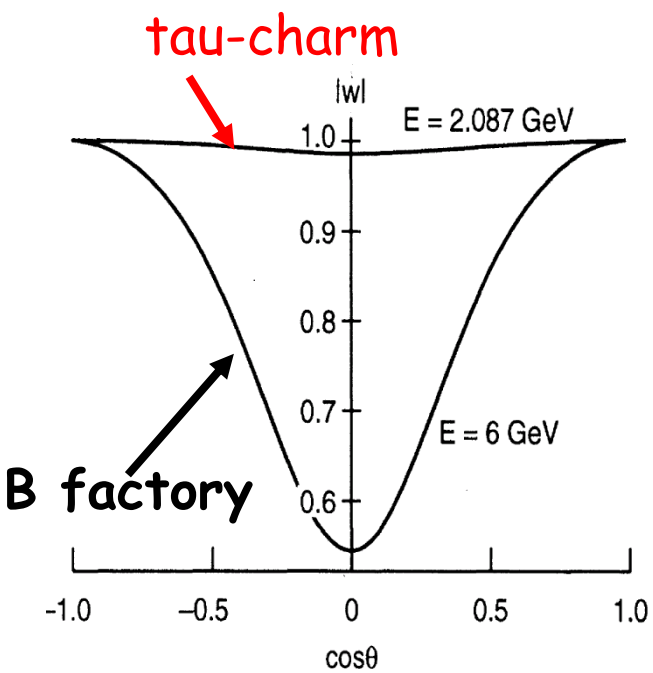
Use T-odd rotationally invariant products : e.g.

$$P_2^{\tau} \cdot (\vec{P}_{\pi^+} \times \vec{P}_{\pi^0})$$

in τ^+ and τ^- decays to >=2 hadrons such as :

$\tau^- \to \pi^-\pi^0\nu_\tau / k^-\pi^0\nu_\tau$, $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau / K^-\pi^+\pi^-\nu_\tau$,

Need polarized beam



"Figure Of Merits" -- Y. S. TSAI

$$\begin{aligned} \text{merit} &= \text{luminosity} \times \bar{w}_Z \times \text{ total cross section} \\ &\propto \text{luminosity} \times (w_1 + w_2) \\ &\quad \times \sqrt{1-a^2}\,a^2(1+2a) \ , \end{aligned}$$

BESIII @ 4.25 ($10^{33}cm^{-2}s^{-1}$) FOM=1

HIEPA @ 4.25 ($10^{35}cm^{-2}s^{-1}$) FOM=100

Super B @ ($10^{36}cm^{-2}s^{-1}$) FOM=65

Y. S. Tsai, PRD 51.3172

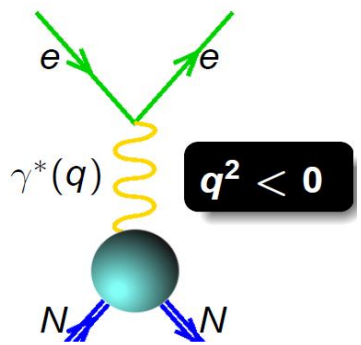
Nucleon Electromagnetic Form Factors (NEFFs)

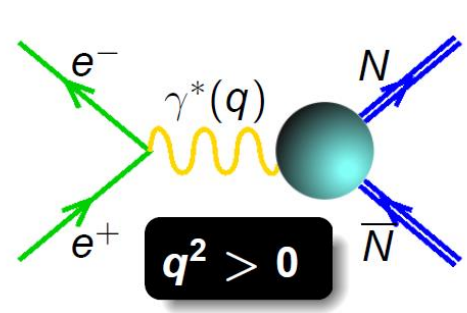
Spatial distributions of electric charge and current inside the nucleon

$eN \longrightarrow eN$

$e^+e^- \leftrightarrow N\bar{N}\ ,\Lambda\bar{\Lambda}$

Space-like: FF real





Time-like: FF complex

Vector current, **two form factors** (F_1 and F_2)

$$\Gamma_\mu = e\bar{u}(p')[F_1(q^2)\gamma_\mu + \frac{\kappa}{2M_N}F_2(q^2)i\sigma_{\mu\nu}q^\nu]u(p)e^{iqx}$$

Dirac

$$F_1^p(q^2=0)=1$$
$$F_1^n(q^2=0)=0$$

Pauli

$$F_2^p(q^2)=1$$
$$F_2^n(q^2)=1$$

Sachs

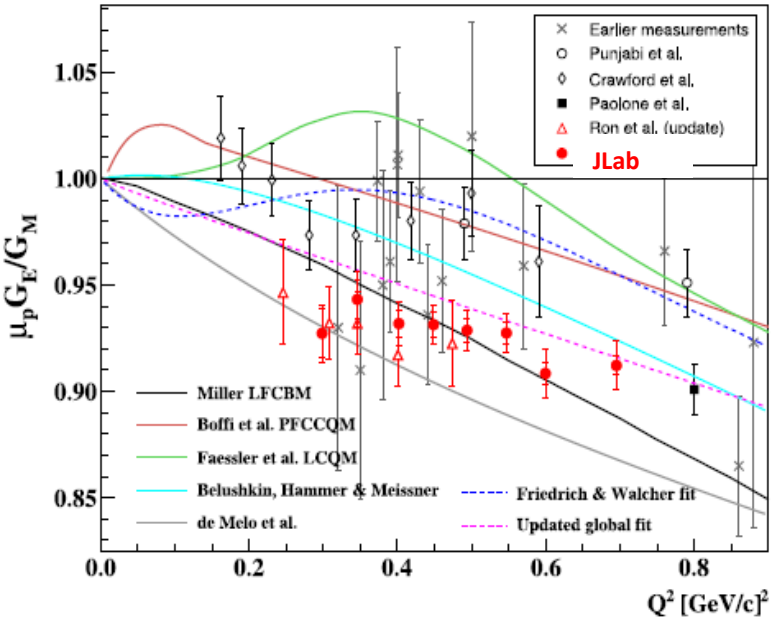
$$G_E = F_1 + \frac{\kappa q^2}{4M^2}F_2 \qquad G_M = F_1 + \kappa F_2$$

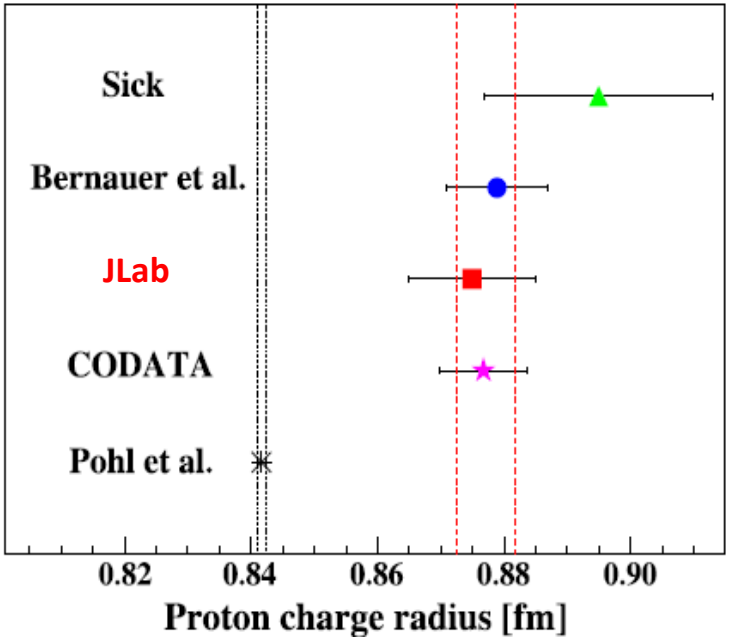
$$G_E(4M_p^2) = G_M(4M_p^2)$$

Complete picture of the nucleon structure requires space-like and time-like FF measurements!

Proton FF : Space-Like

- Many measurements of the proton form factors in the space-like region.
- At Jlab, the proton factor ratio was measured precisely with an uncertainty of ~1%, based on which the proton electronic and magnetic radii could be extracted.



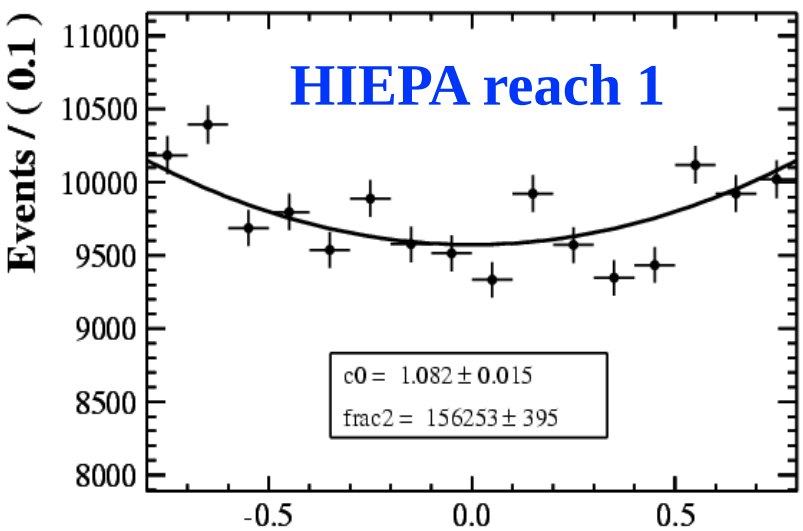


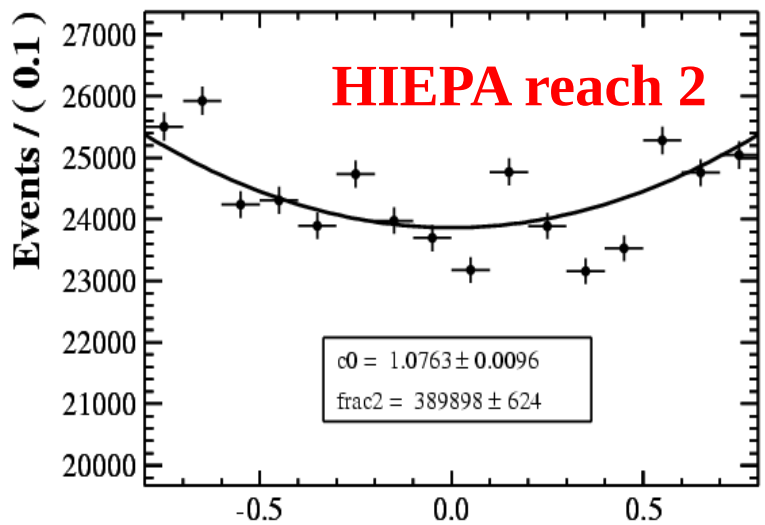
Proton FF ($\sqrt{s}$=2.23GeV) @ τ-c Factory

Phys. Rev. D 91, 112004

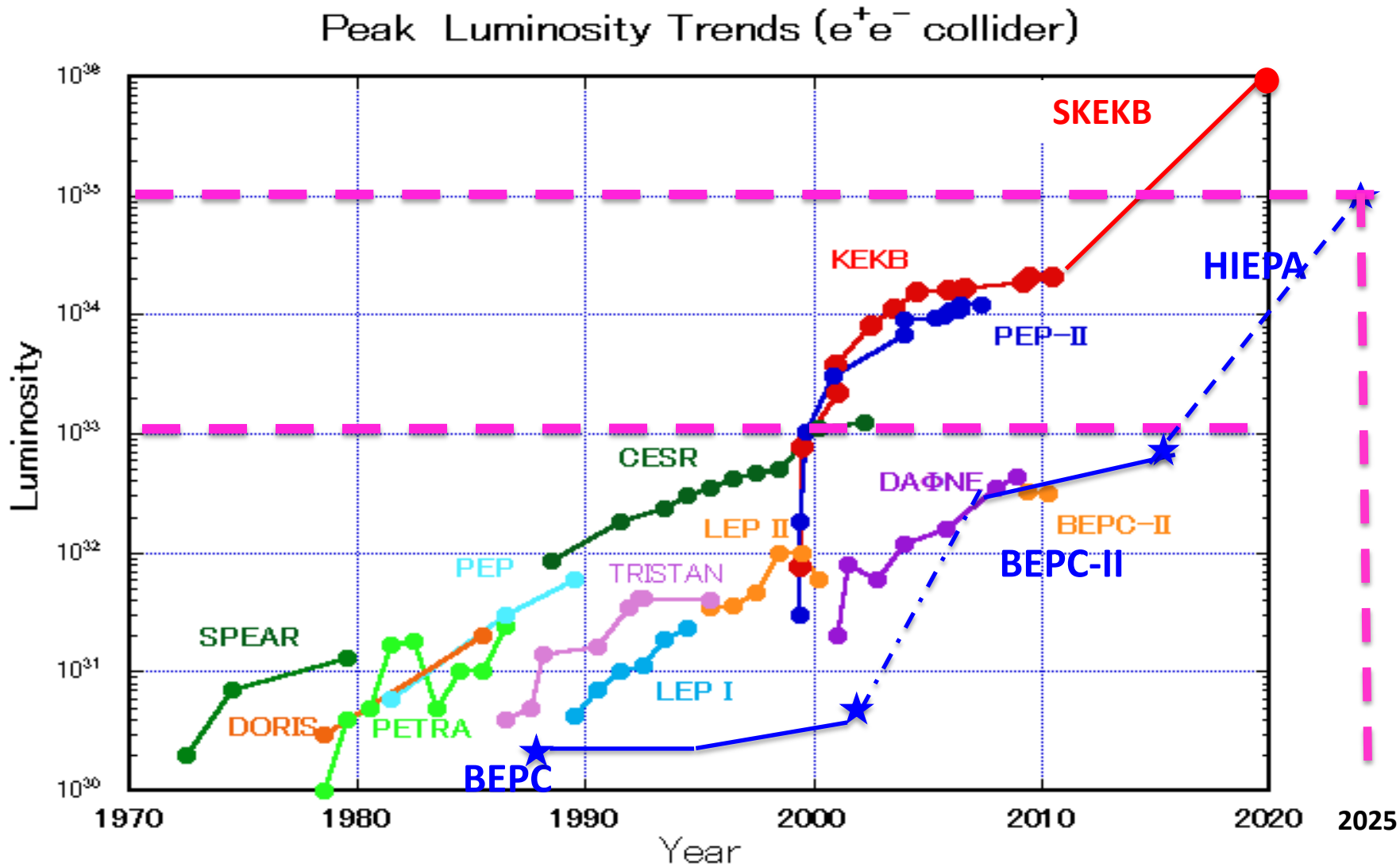
Nsig	$\delta R_{EM}/R_{EM}$	$\delta\sigma/\sigma$	Luminosity (pb^{-1})	comment	
614±24	24%	3.9%	2.631	BESIII test run	
3881±62	9.5%	1.6%	16.630	BESIII expected	
156253±395	1.5%	0.25%	669.533	HIEPAF reach 1	1 day
389898±624	0.96%	0.16%	1670.69	HIEPA reach 2	2 days

$R_{EM}=G_E/G_M$

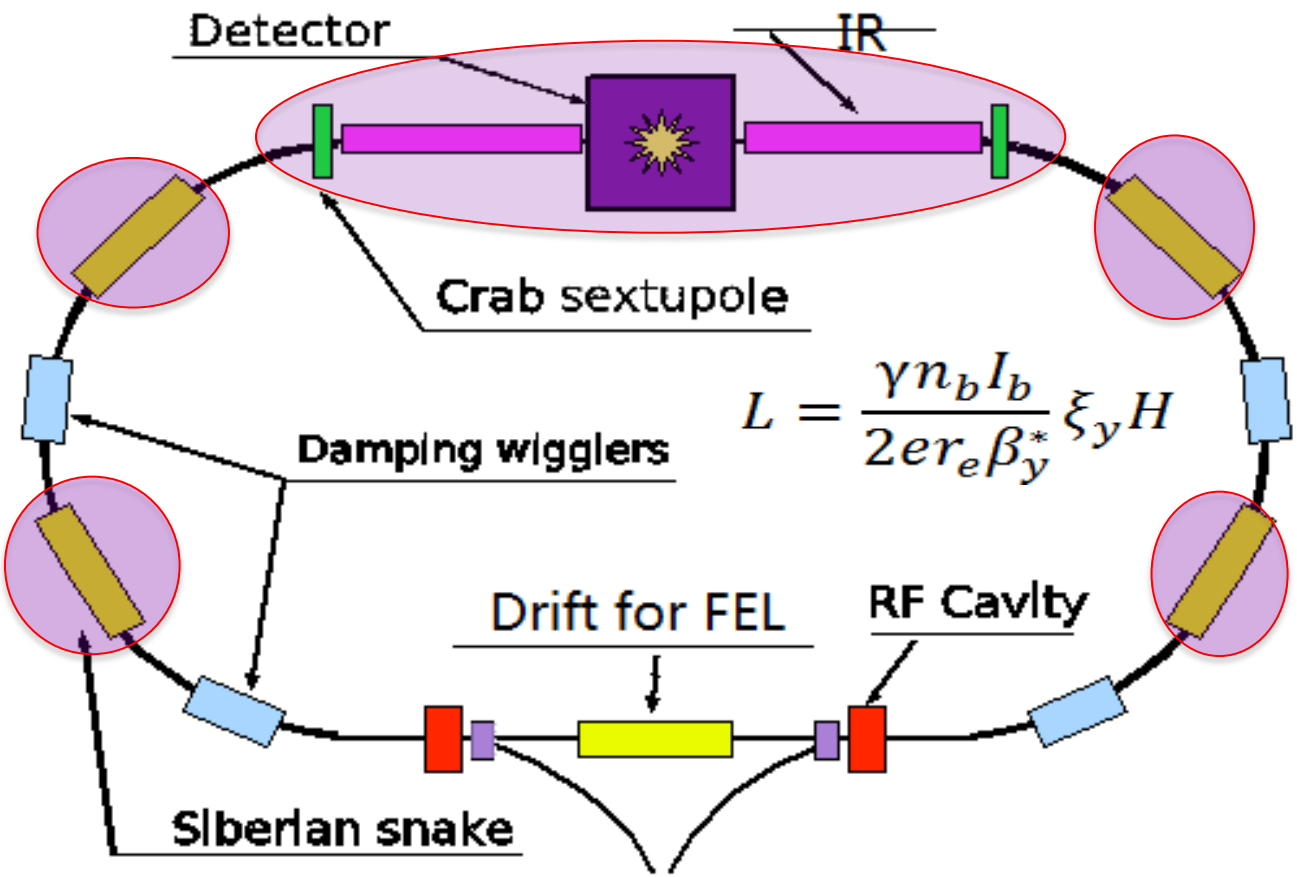




Pre-Conceptual Design



Pre-Conceptual Design -Machine



$$L = \frac{\gamma n_b I_b}{2 e r_e \beta_y^*} \xi_y H$$

- Symmetric machine with high currents， large crossing + crab waist collision
- Polarization available for one beam : Sibelian Snake

Main Parameters for machine

Design goals	value
Peak Luminosity	$5\times10^{34}/(cm^2\cdot s)$
Brightness of Light Source	10^{17}~10^{21} Ph./s mm^2 $mrad^2$ 0.1%BW
Beam Energy （1/2 Collision Energy）	2GeV， 1-3.5GeV tunable
Current	2A
Electron Horizontal Beam Emittance	~1nm·rad
Lattice	DBA like
Collision Method	Large Crossing Angle +Crabbed Waist
Circumstance	~600m

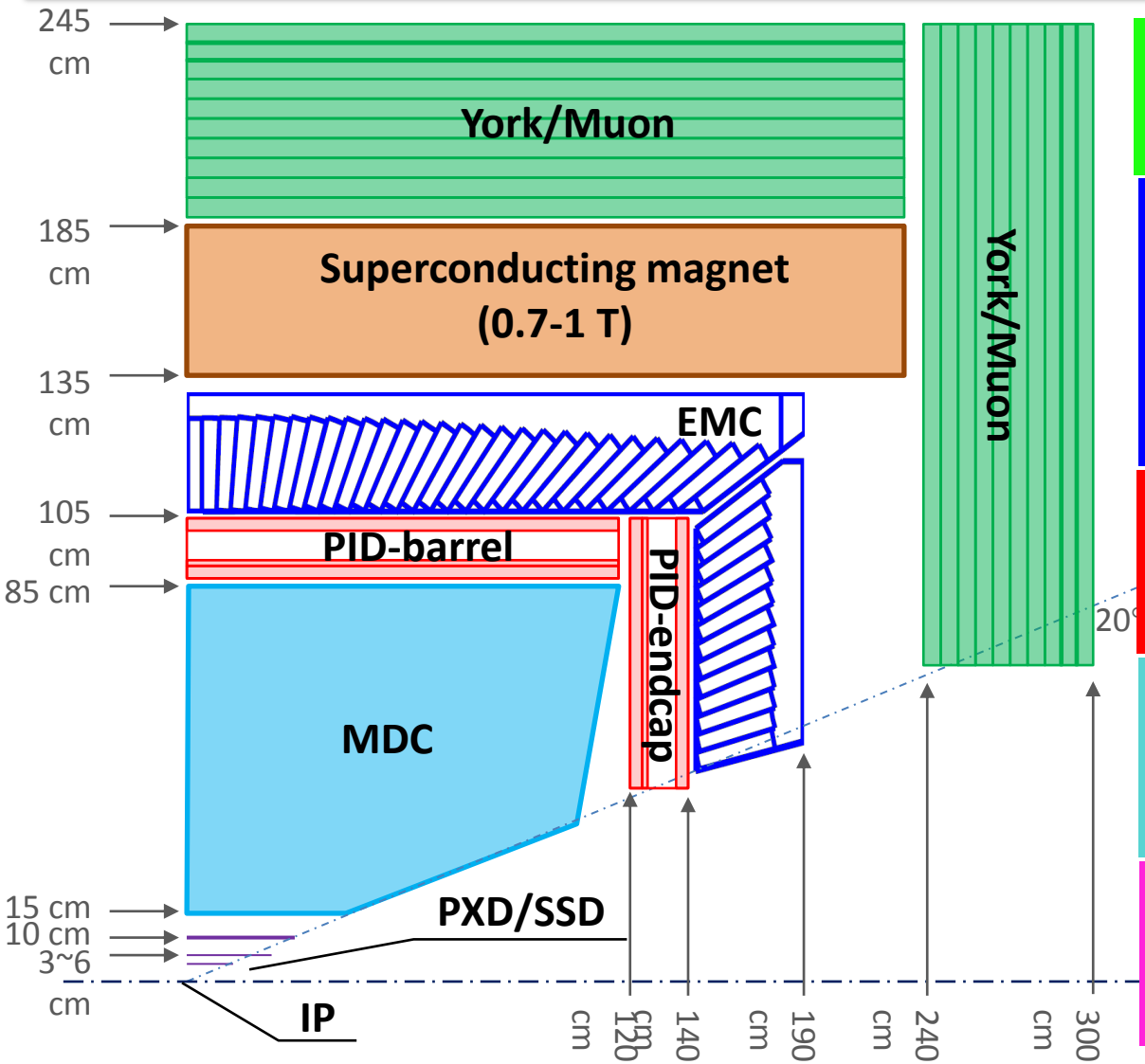
Requirement To the Detector

Efficient event triggering, exclusive state reconstruction and tagging

- high efficiency and resolutions for charged and neutral particles
- Low noise and radiation hardened and high rate

- Large possible solid angle coverage
- High tracking/PID eff. for charge tracks : [0.05, 2.0] GeV
- Good mom. resolution for charged particles: [0.05, 2.0] GeV
- Good eff. and ene. resolution for electron/γ : [0.02,2.5] GeV
- Good vertex detection: 50 mm

Pre-Conceptual Design - Detector



MUD

- μ/π suppression power >10/30

EMC

- Energy range: 0.02-2.5 GeV
- At 1 GeV σ_E (%)
  - Barrel(Cs(I): 2
  - Endcap (Cs): 4

PID

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

MDC (Low mass)

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

PXD

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

Activities for HIEPA

Workshop on Physics at Future High Intensity Collider @ 2-7GeV in China

13-16 January 2015
USTC
Asia/Shanghai timezone

- Overview
- Scientific Programme
- Timetable
- Contribution List
- Author index
- Registration
  - Registration Form
- List of registrants

Tue 13/01 | Wed 14/01 | Thu 15/01 | Fri 16/01 | All days

Print | PDF | Full screen | Detailed view | Filter

08:00	Registration: Registration	USTC	08:00 - 08:30
	Welcome	USTC	08:30 - 08:40
	Introduction to Future High Intensity Collider @ 2-7 GeV in China — *Prof. Zhengguo ZHAO*	USTC	08:40 - 09:05
09:00	XYZ from B factories [Belle, Babar] and prospects at BelleII — *Roman MIZUK*	USTC	09:05 - 09:35
	XYZ results from hadron colliders — *Dr. Liming Zhang ZHANG*	USTC	09:35 - 10:05
10:00	Coffee break	USTC	10:05 - 10:25
	Charmonium-(like) physics at BESIII — *Prof. Changzheng YUAN*	USTC	10:25 - 10:55
11:00	Charmonium physics at PANDA — *Frank NERLING*	USTC	10:55 - 11:25
	Higher charmonium states — *Ce MENG*	USTC	11:25 - 11:55
12:00	LQCD results on hadron spectroscopy — *Ying CHEN*	USTC	11:55 - 12:25
	Lunch		

build a small working group,
Have domestic workshops every year,
Have a international workshop at Jan. 2015.

XiangShan-Science Conference

XiangShang-Science Conference, June 3-4, 2015, ~40 scientists and officials joint,
Very important conference for Large Scale/Key Project in China

Summary

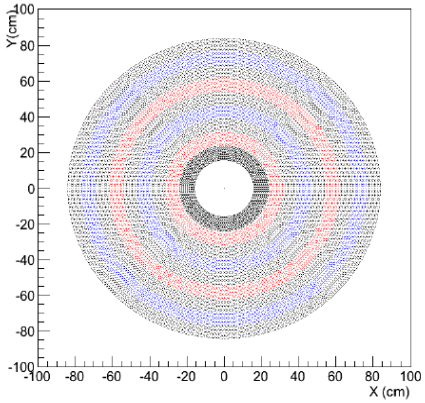
- HIEPA is one of the possible options for HEP in China.
  - Rich of physics program with charm quark and Tau lepton, have interesting physics relating to key science questions
  - New/Key technologies and method with challenges
  - Reasonable scale and cost.
  - China has the team and expertise that has been leading this field for decades
  - Interdisciplinary mode (STCF + SRF)
- Tend to have a CDR this winter
- Your ideas, suggestions and inputs are very important for us

Welcome to join the effort

Backup Slides

Tracking System

A Drift Chamber for HEPAF



Low mass

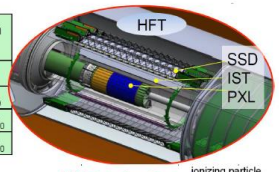
- Rin = 15 cm
- Rout = 85 cm
- L = 2.4 m
- B = 1 T
- He/C2H6 (60/40)
- # of layers = 48
- Cell size =1.0cm(inner),1.5cm(outer)
- Sense wire: 20 um W
- Field wire: 110 um Al
- 0.5%X0 carbon fiber inner wall
- Expected spatial resolution: 130 um
- Expected dE/dx resolution: 7%
- Layer configuration: 8A-5S-5A-5S-5A-5S-5A-5S-5A

Inner Tracker Options

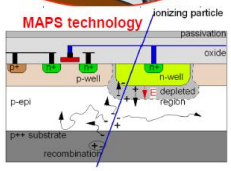
- Silicon detectors
  - Prerequisite for use at HEPAF: low material
  - References
    - STAR heavy flavor tracker
    - BELLE2 pixel detector
- Cylindrical GEM
  - a gaseous detector, low mass intrinsically
  - a reference
    - KLOE inner tracker

STAR Heavy Flavor Tracker

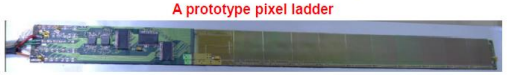
Detector	Radius (cm)	Hit Resolution R/φ - Z (μm - μm)	Radiation length
SSD	22	30 / 860	1.5 %X_0
IST	14	170 / 1800	1.32 %X_0
PIXEL	8	12 / 12	~0.37 %X_0
	2.6	12 / 12	~0.37 %X_0



- SSD: single-layer double-side strips
- IST: one layer of strips
- PIXEL
  - MASP technique -> low material
  - pixel pitch: 20 μm *20μm
  - 2cm*20cm ladder, 10 ladder in total
  - double layers

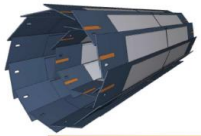


A prototype pixel ladder

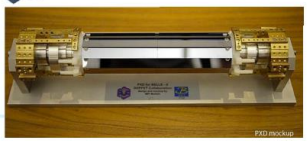


BELLE2 Pixel Detector

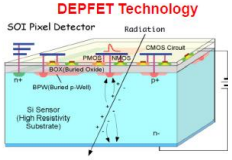
- Belle II beam pipe radius ~ 1.6 cm.
- Two layers of PXD: 1.8 cm and 2.2 cm in radius, consisting of 8 and 12 modules for innermost layer and the second, respectively.
- In the active pixel matrix region: thickness ~ 75 μm.



Number of pixels per module	250 x 1536
Pixel size (r-phi, z)	50μm x (60-75) μm
Frame time	20 μs
Material budget per layer	0.15% X_0
Resolution (r-phi, z)	<10μm, < 20μm
Occupancy at 1.8 cm radius	0.2 hits $\mu m^{-2} s^{-1}$
Radiation environment	~1 Mrad/year

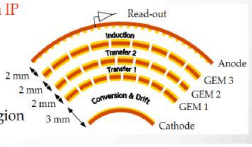


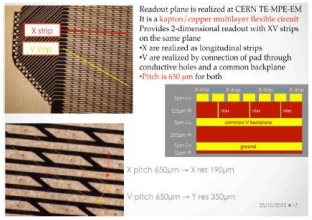
DEPFET Technology

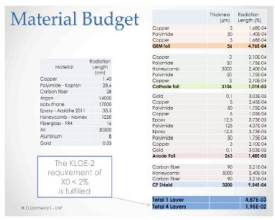


KLOE Inner Tracker

- 4 CGEM layers at 13/15.5/18/20.5 cm from IP inside outer Drift Chamber
- 700 mm active length
- XV strips-pads readout (25°÷30° stereo angle)
- 2% X_0 total radiation length in the active region including Carbon Fiber shield







Tracking System

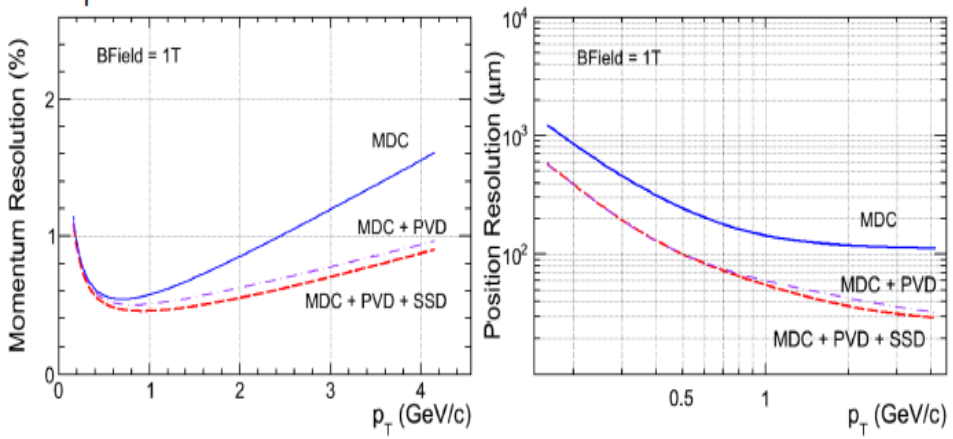
Option I: MDC + STAR HFT (geometry is not optimized)

Detector	radius (cm)	material (%X_0)	resolution (μm)
MDC Outer 9-48	23.5-82	0.0045 /layer	130
MDC Inner 1-8	15-22	0.0051 /layer	130
SSD	10	1.5	250
PXD 2 layers	3/6	0.37 /layer	30
Beam pipe	2	0.15	–

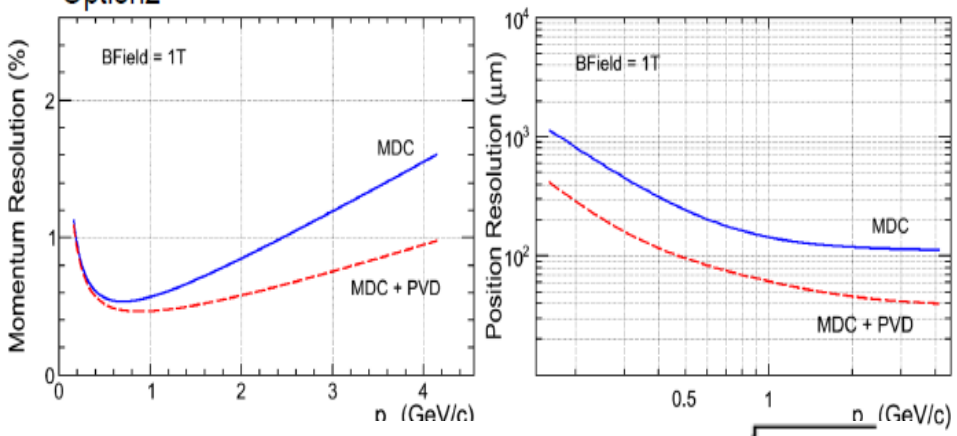
Option II: MDC + Belle-II PXD (geometry is not optimized)

Detector	radius (cm)	material (%X_0)	resolution (μm)
MDC Outer 9-48	23.5-82	0.0045 /layer	130
MDC Inner 1-8	15-22	0.0051 /layer	130
PXD 3rd layer	10	0.15	50
PXD 2 layers	3/6	0.15 /layer	50
Beam pipe	2	0.15	–

Option1



Option2



$$\frac{\sigma_{P_t}}{P_t} pos. = \frac{3.3 \times 100 \times \sigma_x}{BL^2} P_t \sqrt{\frac{720}{N+5}} \qquad \frac{\sigma_{P_t}}{P_t}_{MS} = \frac{5.7}{BL} \times \frac{1}{\beta} \times \sqrt{\frac{LP}{X_0 P_t}}$$

PID Detector

Key Features of PID System

- Enable π/K (and K/p) 3-4σ separation up to 2GeV/c
- Suitable for high luminosity run – fast detector
- Radiation hard, especially in the endcap region
- Compact – reduce costs of the outer detectors
- Modest material budget - <0.5X_0

Low Momentum PID

- Specific energy loss (dE/dx) in MDC can be used for low momentum PID
- Better dE/dx resolution for longer track length
- BESIII MDC (~6%, track length ~0.7m)
  - clean π/K/p ID for p<0.8/1.1 GeV/c

High Momentum PID

- TOF can not identify π/K to p=2GeV/c
- Cherenkov detector is necessary
- Two catalogs
  - Threshold Cherenkov – simple to build
  - Imaging Cherenkov: RICH (large momentum range)/ DIRC / TOP (most compact)

PID Detector

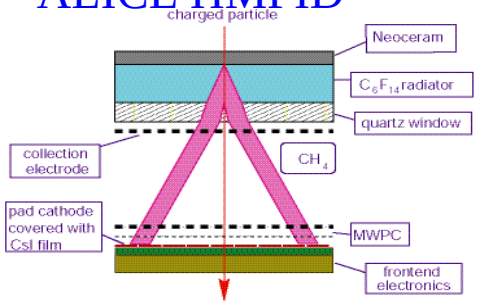
Baseline Design

- PID by RICH at 0.8<p<2GeV/c, no TOF
- Proximity RICH, similar to ALICE HMPID design, but with PHENIX HBD (CsI coated GEM) readout
- n~1.3 (liquid C_6F_{14}), UV detection
- Already proven
- Immune to B field → same structure at both the endcap and the barrel

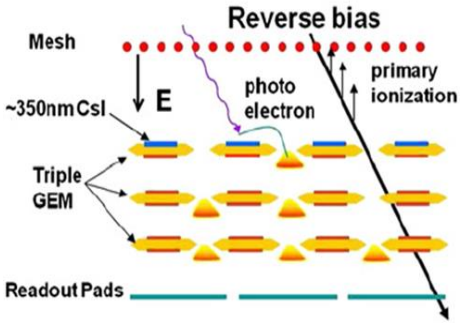
Alternative Design

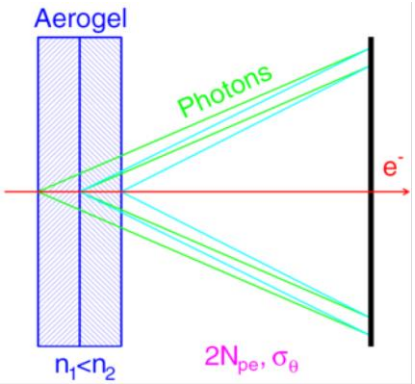
- No TOF, PID by RICH only
- Similar to BELLE-II ARICH design, Aerogel + Position Sensitive Photon Detector
- n~1.13 (Below threshold for proton at p<2GeV/c)
- Already proven at the BELLE-II endcap, how about the barrel part?
- Need R&D

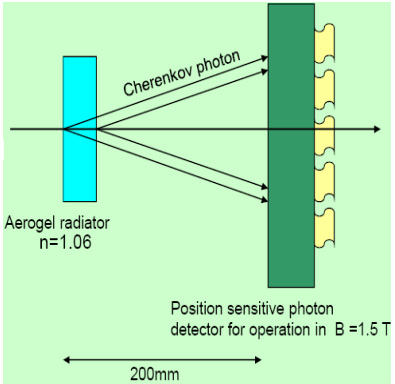
ALICE HMPID



PHENIX HBD







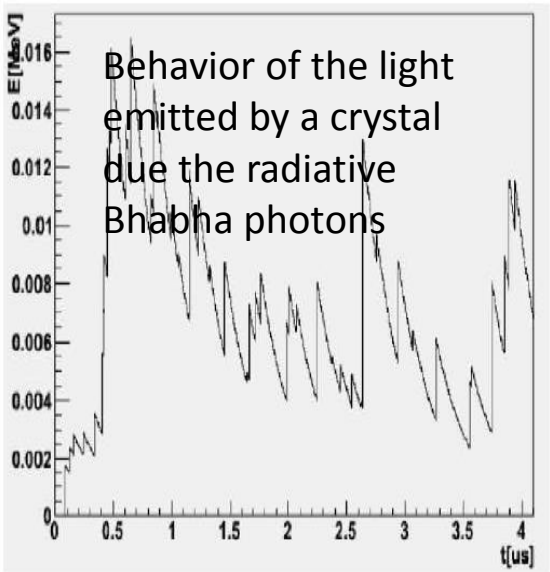
Electromagnetic Calorimeter

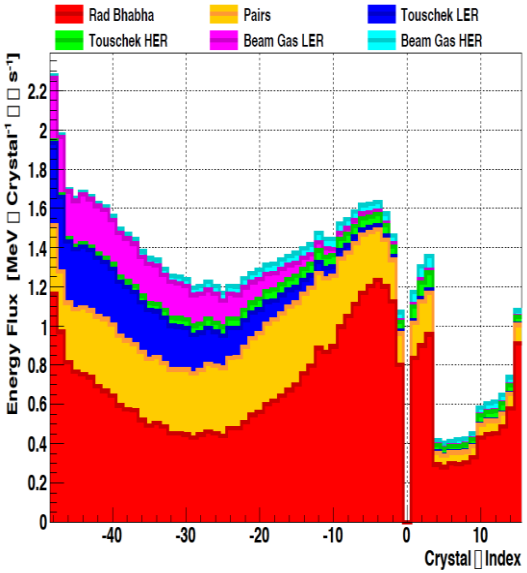
EMC Requirements

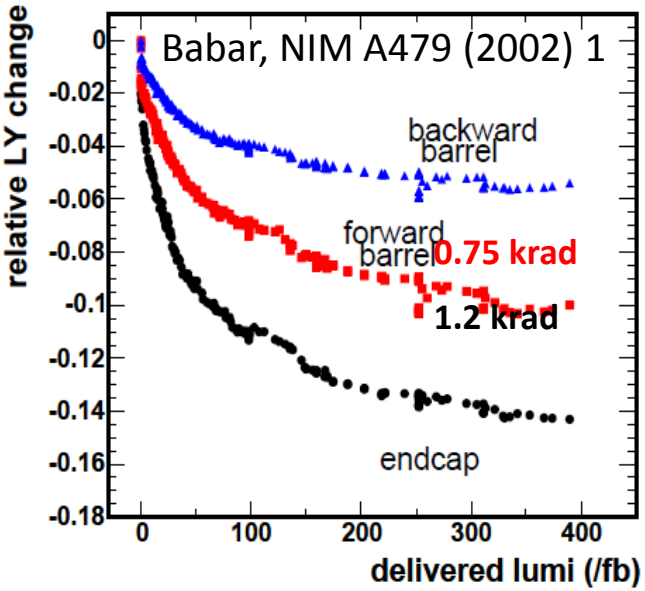
- Good energy resolution
- Good position/angular resolution
- Good timing resolution if possible

Challenging

- Radiation damage
  - Decrease light yield
  - A function of run time
- High photon background rate
  - Produce pile-up
  - Degrade energy and angular resolution



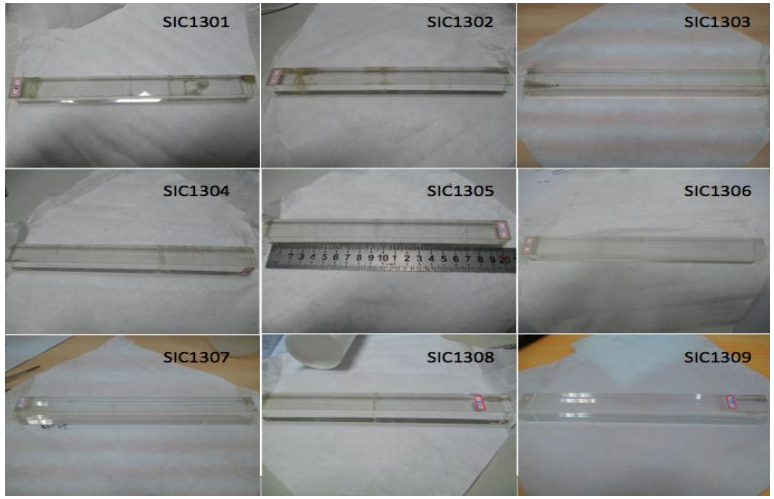




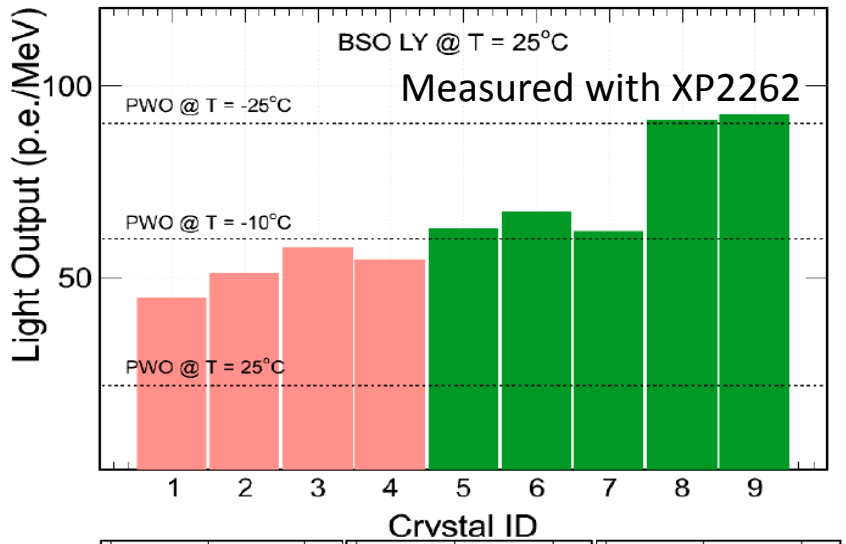
Crystal

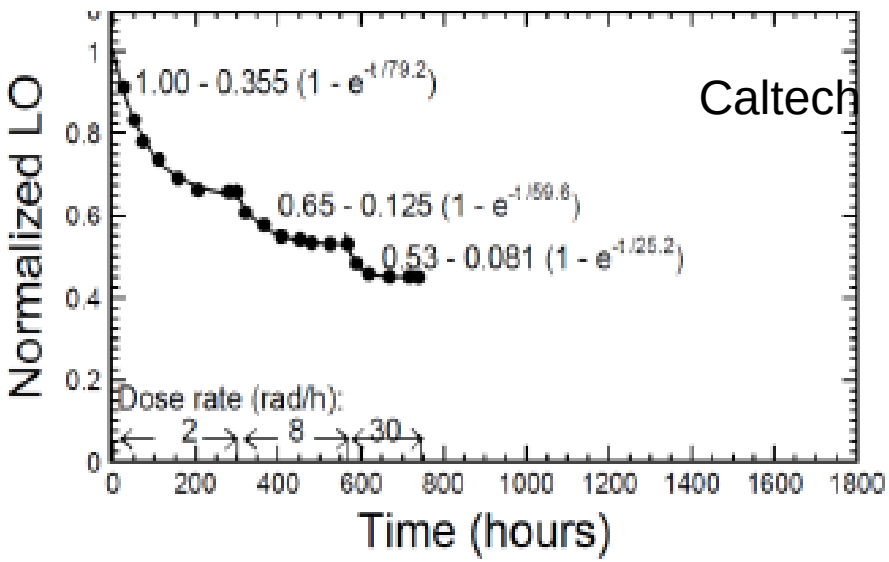
Crystal	CsI(Tl)	CsI	BSO	$PbWO_4$	LYSO(Ce)
Density (g/cm^3)	4.51	4.51	6.8	8.3	7.40
Melting Point (°C)	621	621	1030	1123	2050
Radiation Length (cm)	1.86	1.86	1.15	0.89	1.14
Molière Radius (cm)	3.57	3.57	2.2	2.0	2.07
Interaction Len. (cm)	39.3	39.3	23.1	20.7	20.9
Hygroscopicity	Slight	Slight	No	No	No
Peak Luminescence (nm)	550	310	480	425/420	420
Decay Time [b] (ns)	1220	30 6	100 26,2.4	30 10	40
Light Yield [b,c] (%)	165	3.6 1.1	3.4 0.5/0.25	0.30 0.077	85
LY in 100 ns	13	4.6	2.9	0.37 (2-3x↑)	78
LY in 30 ns	4	3.3	1.5	0.26 (2-3x↑)	45
d(LY)/dT [b] (%/ °C)	0.4	-1.4	-2.0	-2.5	-0.2
Radiation hardness (rad)	10^3	10^{4-5}	10^{6-7}	10^{6-7}	10^8
Dose rate dependent	no	no	yes	yes	
Experiment	CLEO, BABAR, Belle, BES III	KTeV, E787 Belle2 1st SuperB 2nd	Belle2 3rd	CMS, ALICE PANDA Belle2 2nd	SuperB 1st (Hybrid)

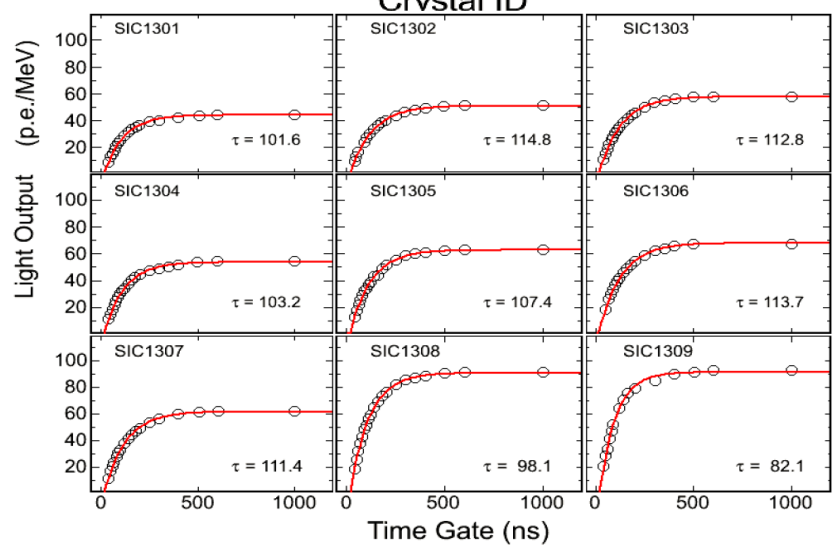
BSO Test



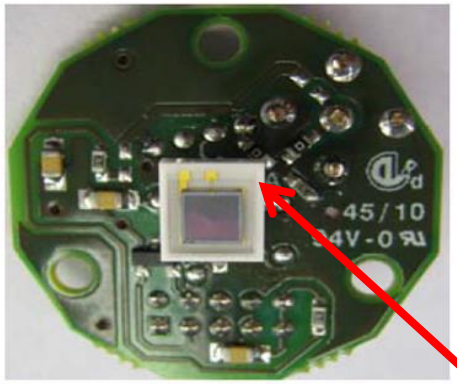
9 crystals from SICCAS, 2x2x20 cm^3

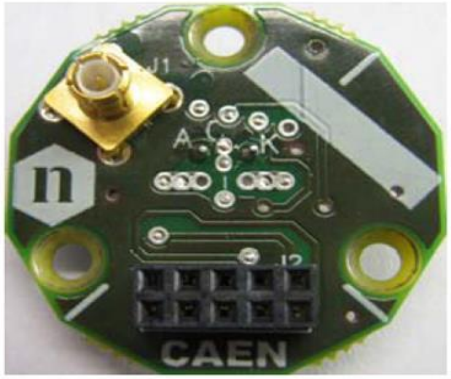




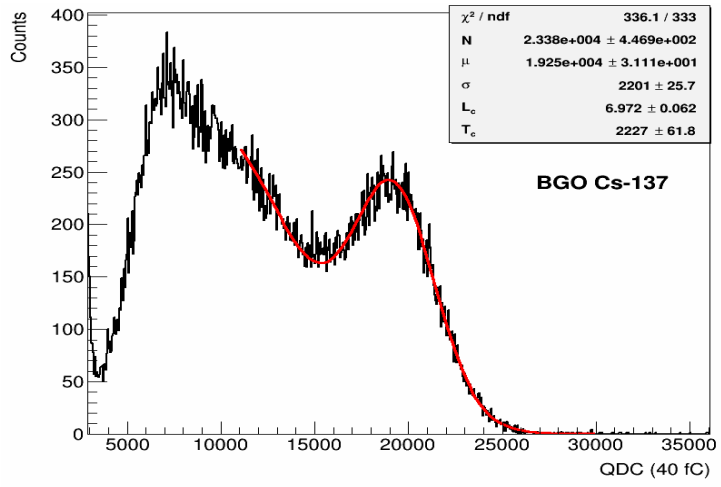


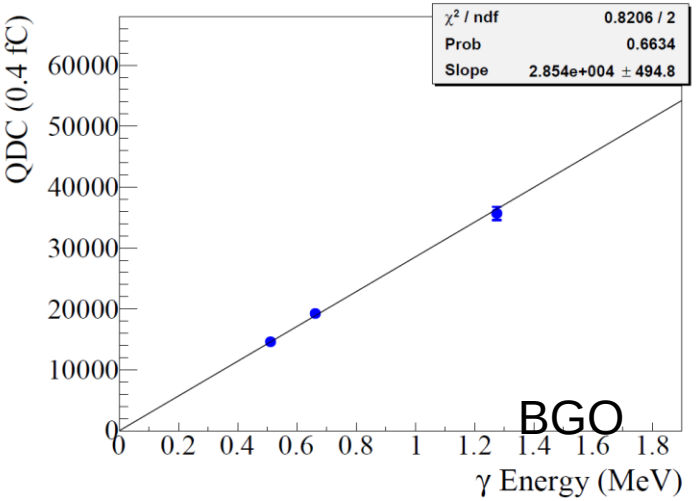
SiPM Test





Hamamatsu S10362-33-050C, 3x3 mm^2





Electromagnetic Calorimeter

BSO Crystal

Pros:

- Relative fast
- Radiation hard
- Emission spectrum peak at 480 nm
- Small X0 (60% CsI) → more compact
- Small Moliere Radius (60% CsI) → finer segmentation
- Low raw material cost (~PWO and 50% BGO, much less than LYSO)

Cons:

- LY smaller than CsI(Tl) and LYSO (however, ~ PWOII at -25 ^{0}C)
- Dose rate dependent LY, fast recovery time → LY Calibration system needed
- Not mature (large size available, mass production not proven)

PhotoSensors

PIN Photodiode

- Mature
- Large noise/signal

Large Area APD

- Relatively Mature
- Large noise/signal

Vacuum photopentode

- New, under developing
- Low noise, low gain (~10-100)
- Sensitive to magnetic field

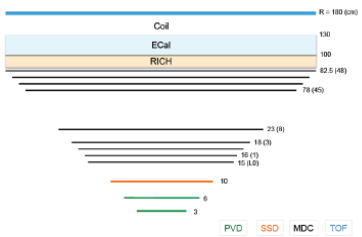
Multi-Pixel Photon Counter (MPPC/SiPM)

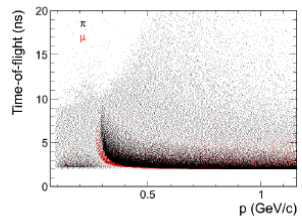
- New, under developing
- High gain (~10^6), low ENE, simplify elec.
- Insensitive to magnetic field
- Good timing resolution

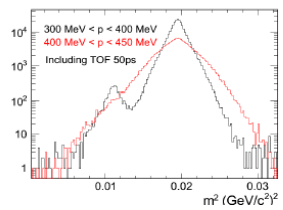
Muon Detector

A "Timing" Muon Detector

- Use a STAR/MTD-like detector to incorporate TOF measurement in muon detection.



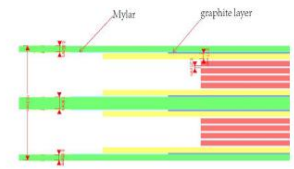




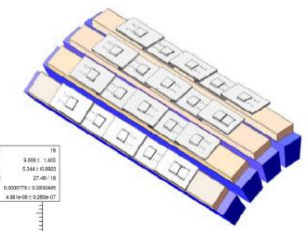
Pions and muons well separated by TOF below 400 MeV

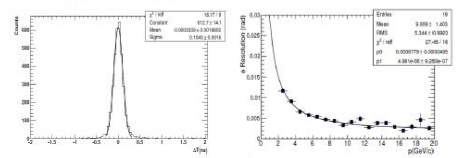
STAR MTD

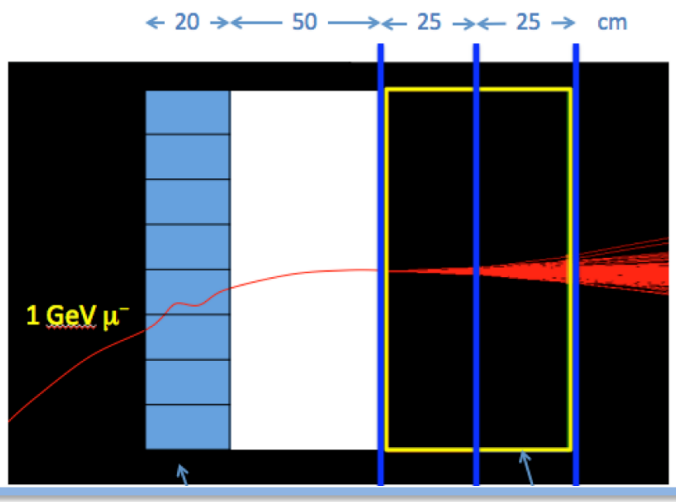
- Muon Telescope Detector (MTD) at STAR
  - based on long-strip MRPC technology
  - 95% F134a + 5% iso-butane
  - Gas gap: 0.25mm, 10 gaps in 2 stacks
  - Read out strip: 2.5 cm wide, 90 cm long

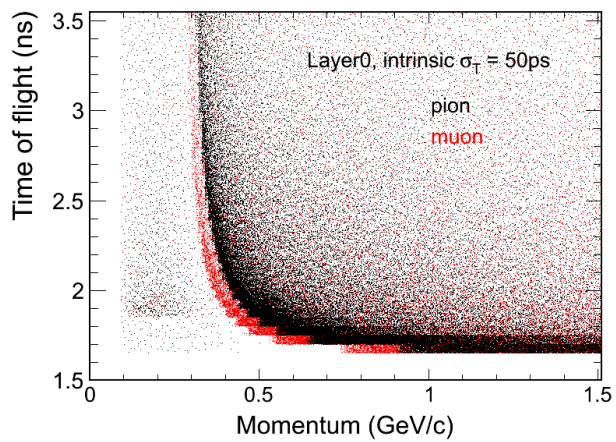


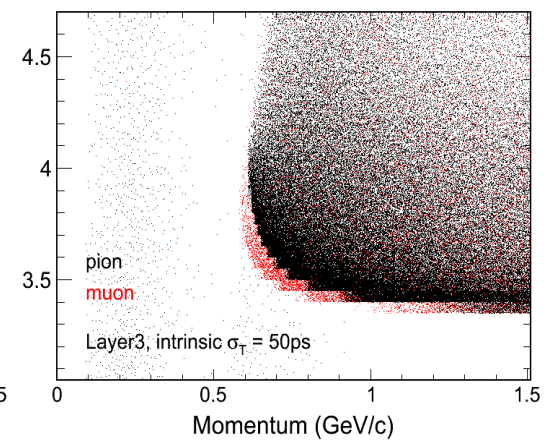
- Performance
  - Time resolution: < 100 ps
  - Spatial resolution: ~ 1 cm
  - High efficiency: ~98%











Physics @ HIEPA

- ***Precise test of SM***
  - R Scan, Hadron form factor (nucleon, Λ, π), $\Delta\alpha_{QED}$, a_u
  - tau lepton decays, lepton universality test
  - CKM matrix, Decay constants (f_D/f_{Ds}), form factors
  - Neutral D mixing and strong phase

- ***hadron physics***
  - meson, baryon, hyperon spectroscopy
  - threshold effects
  - Glueball: direct test of QCD at low energy
  - Multiquark, exotics, hybrids…..
  - Charmonium(-like) spectroscopy
  - Charmed baryon decays

- ***New physics(tiny/forbidden in SM)***
  - Rare charmonium decays : LFV, LNV, BNV…
  - Rare charm decay : FCNC, LFV, LNV, invisible
  - Rare tau decay : FCNC, LFV, LNV
  - Rare light meson decay : $\eta/\eta'/\omega/\phi$

- ***Exotic phyics***
  - Light dark matter : light Higgs boson(a_0), U boson
  - New interactions

- ***CP Violation***
  - Unexpected large CPV in tau or charm: tiny in SM
  - CP violation in baryon/hyperon/charm baryon

Summary of τ Physics

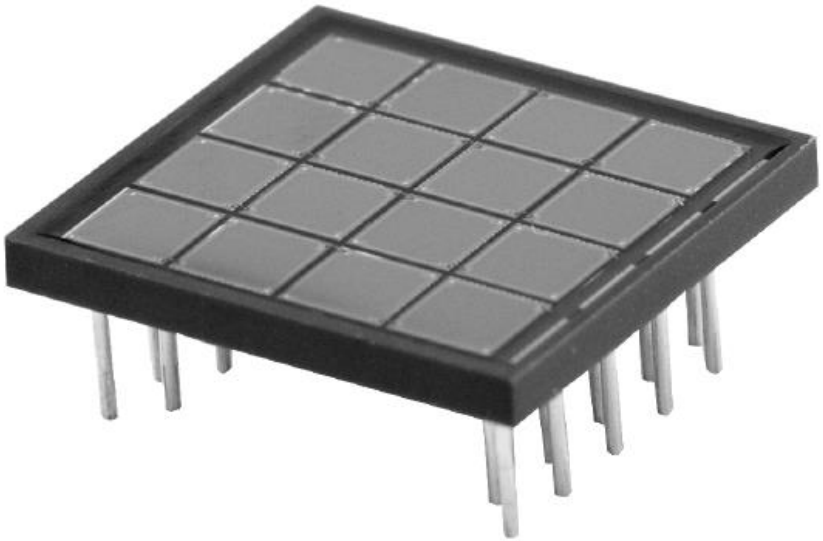
With 1ab^{-1} near tau threshold:

- **LFV: 10^{-9}**
- **Lepton universality: 10^{-4}**
- **CP violation in decay: 10^{-4}**
- **CPT tests: 10^{-4}**
- **Tau mass**
- **Vus: (0.1-0.5)%**

A super-tau-charm and a BELLEII will be complementary machines for tau physics

SiPM/MPPC Products

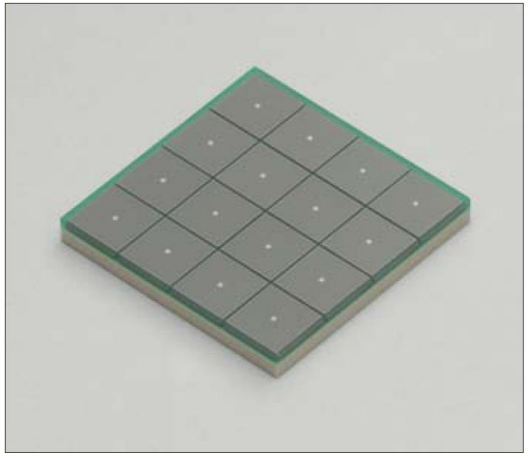
sensL



4 x 4 channel array
3 x 3 mm^2 each channel
4774 cells per channel
~ €120

Hamamatsu

4-side buttable type (16 ch array)



4 x 4 channel array
3 x 3 mm^2 each channel
3600 cells per channel
~ ￥1500

BESIII Data Taking

Began taking data from 2009

J/ψ	1.3 x10^9 events	world largest sample	10×10^9 proposed
ψ'	0.6 x10^9 events	world largest sample	3×10^9 proposed
ψ(3770)	~2.9 fb^{-1}	world data sample X 3	$10fb^{-1}$ proposed
$D_s\bar{D}_s$ @ 4.01 GeV	~0.5 fb^{-1}	unique data	
Y (4260)	~2.2 fb^{-1}	unique data	
Y (4360)	~0.6 fb^{-1}	unique data	
τ mass scan	24 pb^{-1}		
3850 MeV - 4590 MeV	0.8 fb^{-1}	unique data	
4100 MeV - 4400 MeV	0.5 fb^{-1}	unique data	
4420 MeV	1 fb^{-1}	unique data	
4600 MeV	0.5 fb^{-1}	unique data	

Search for $\eta_{c2}(1^1D_2)$ and $\chi_{c1}(2^3P_1)$

Simple estimations

$L_{peak} = 10^{35} cm^{-1}s^{-1}$, 1 year running = $10^6 pb^{-1} = 1ab^{-1}$

A BESIII-Like detector

Detail MC studies are ongoing

$\eta_{c2}(1^1D_2)$

- $\sigma(e^+e^- \to \pi^+\pi^- h_c(2P)) \sim 20$ pb @ Ecm=??GeV
- $B(h_c(2P) \to \gamma\eta_{c2}) \sim 3\times10^{-4}$ [E1 trans., Barnes′ 05]
- $B(\eta_{c2} \to \gamma h_c) \sim (44–54)\%$ [E1 trans., Fan′ 09]
- $B(h_c \to \gamma\eta_c) \sim 54\%$ [E1 trans., BESIII′10]
- $\varepsilon B(\eta_c \to \text{hadrons}) \sim 1.5\%$ at BESIII
- $N^{obs}=2\times10^{-5}\times L$ (L is int. lumi. in pb^{-1})
- $N^{obs}=20$ events /year,
- Bkg is low for narrow h_c and η_c

$\chi_{c1}(2^3P_1)$

- $\sigma(e^+e^- \to \psi(nS)/\psi(mD)) \sim (3\text{-}7)$ nb @ for n>1, m>2
- $B(\psi \to \gamma\chi'_{c1}) \sim 3\times10^{-4}$ [E1 trans., Barnes′ 05]
- $B(\chi'_{c1} \to \gamma\psi') \sim 1\times10^{-3}$ [E1 trans., Barnes′ 05]
- $B(\chi'_{c1} \to \gamma J/\psi) \sim 1\times10^{-4}$ [E1 trans., Barnes′ 05]
- $\varepsilon B \sim (1–5)\%$ at BESIII
- $N^{obs} = (1–10)\times10^{-5}\times L$ (L is int. lumi. in pb^{-1})
- $N^{obs} = (10–100)$ events /year,
- Bkg is low for narrow ψ' and J/ψ

Production mechanism

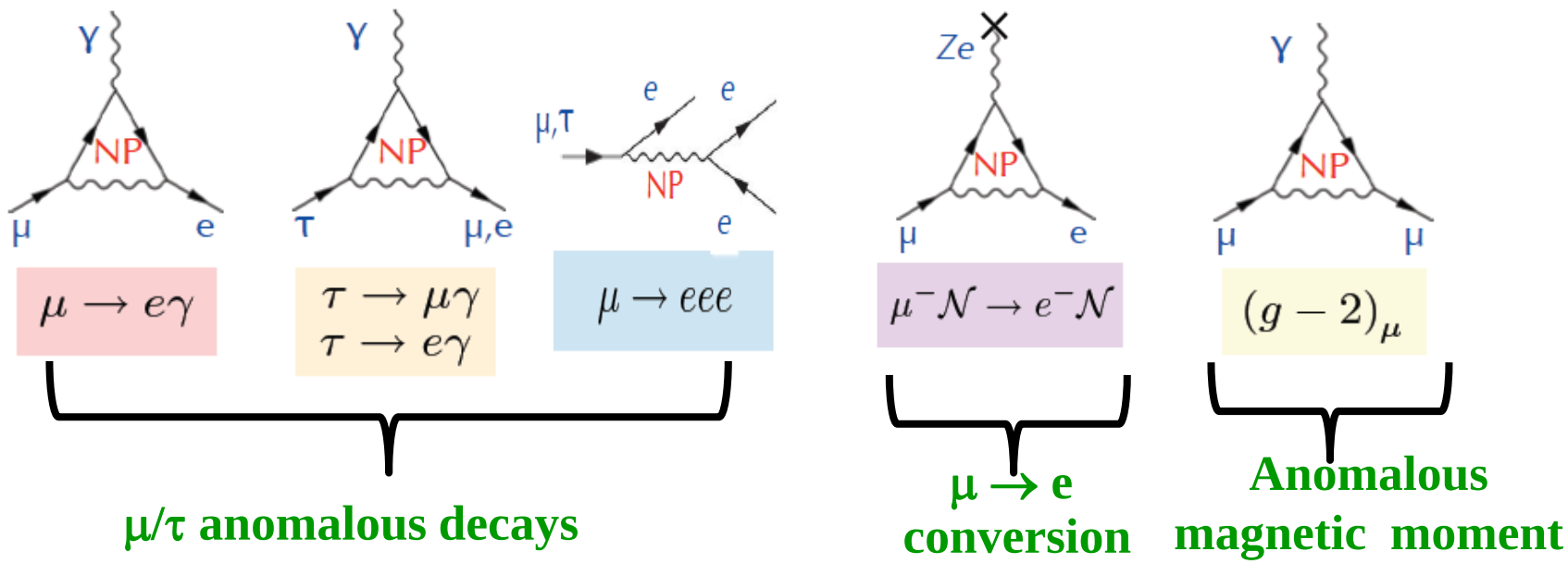
- **ψ/Y particles are directly produced :**
  - Measure the production cross section precisely,
  - Extract the excited ψ or Y states resonance parameters via fitting data.
- **Study states with C=+1 via radiative transition :**
  - $B(\psi(3S)\rightarrow\gamma\chi'_{cJ}) = (7,3,1)\times10^{-4}$ for J=2, 1, 0 [E. Eichten et al. Rev. Mod. Phys. 80, 1161 (2008)]
  - $\psi(nS/nD)\rightarrow\gamma XYZ$ [X(3872) ,Y(4140) et al.], no theoretical prediction on transition rate,
    BESIII : $\sigma(Y(4260) \rightarrow\gamma X(3872))\sim6pb$ [PRL 112, 092001 (2013)]
- **Search for states in ψ/Y particles hadron decay :**
  - $Y(4260)\rightarrow\pi Z_c(3900)$, $\psi\rightarrow\pi h_c(1P/2P)$ …..

Topics at HIEPA

- **Where are the missing states above the charm threshold**
  - $^1D_2(2^{-+})$: M~3830MeV, narrow, may be produced in $h_c(2P)$ E1 transition
  - P-wave spin-triplets from S-wave E1 transition
  - P-wave spin-singlets from S-wave hadron transition
- **Can we identify F-wave states?**
- **Can we find the Z_{cs}?**
- **Are there hybrids (1^{--}, others J^{PC})**

Charged Lepton Flavor Violation (cLFV)

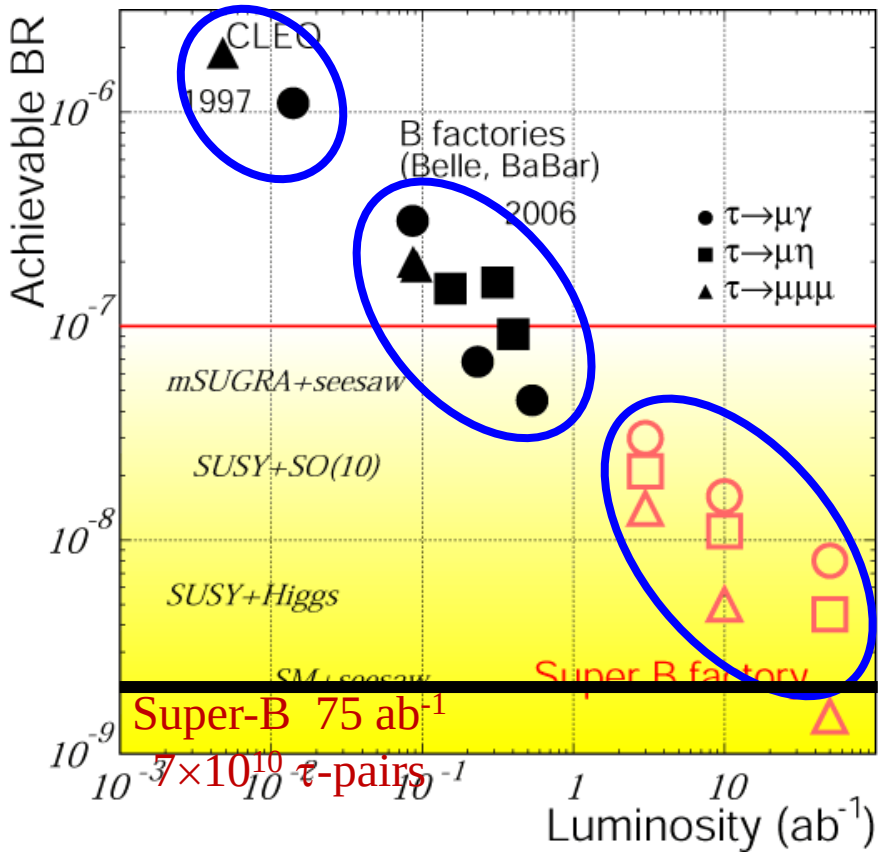
- In SM, cLFV is negligibly even taking into account neutrino mass
- Several cLFV process, sensitive to NP through "new" lepton-lepton coupling



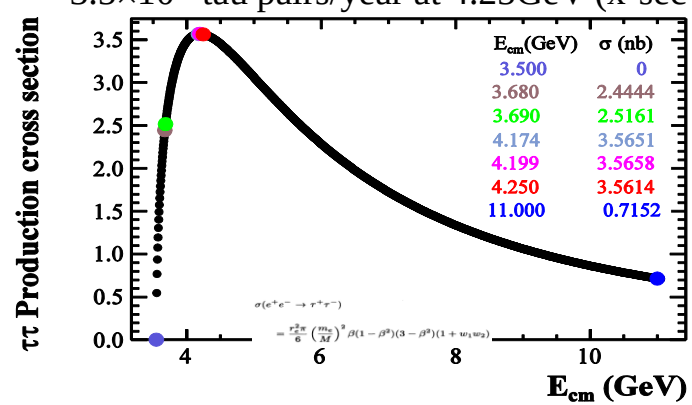
In tau-charm factory, $\tau \to \mu\gamma$ decay is golden mode to search for NP

cLFV Decay $\tau \to \mu\gamma$ @ B Factory

From A. Bondar, Charm2010



- **Current limit : ~ 4×10^{-8} (5×10^{8} τ-pairs)**
  - BABAR : 516fb^{-1} [PRL, 104, 021802]
  - BELLE : 545fb^{-1}
- **At Y(4S) :**
  - ISR background $e^+e^- \to \tau^+\tau^-\gamma$
  - Upper Limit $\propto 1/\sqrt{L}$
  - Expected limit : 3×10^{-9}@75ab^{-1} (7×10^{10} τ-pairs)
- **Belle-II Factory with $L=10^{36}cm^{-2}s^{-1}$**
  - 10^{10} tau pairs per year (x-sec=1nb)
- **HIEPAF with $L=10^{35}cm^{-2}s^{-1}$**
  - 10^{8} tau pairs per year at threshold (x-sec=0.1nb)
  - 3.5×10^{9} tau pairs/year at 4.25GeV (x-sec = 3.5nb)



What can HIEPA have with 3×10^{9} $\tau\tau$ pairs / year?

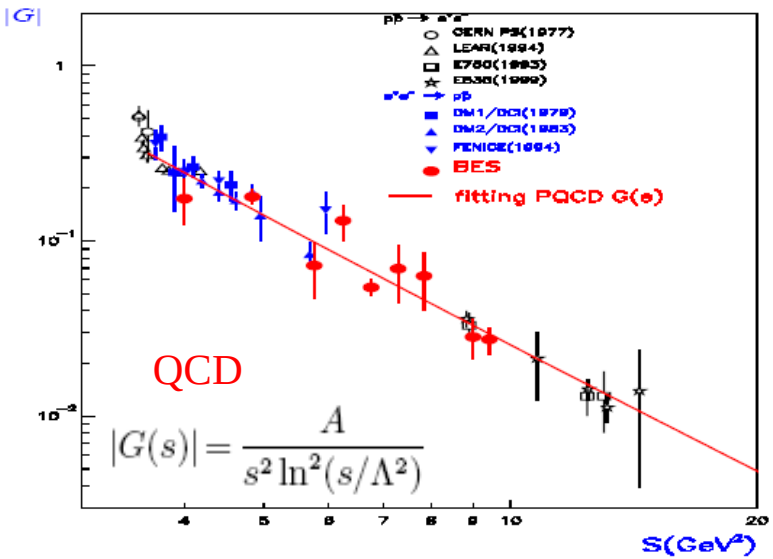
Proton FF : Time-Like

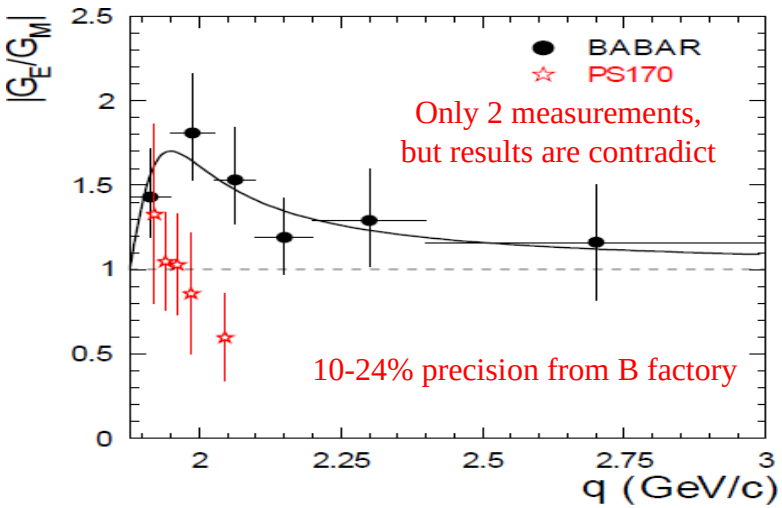
$$\sigma_{e^+e^-\to N\bar{N}} = \frac{4\pi\alpha^2\beta}{3s} C_N(s) \left[\left|G_M^N(q^2)\right|^2 + \frac{2M_N^2}{s} \left|G_E^N(q^2)\right|^2 \right]$$

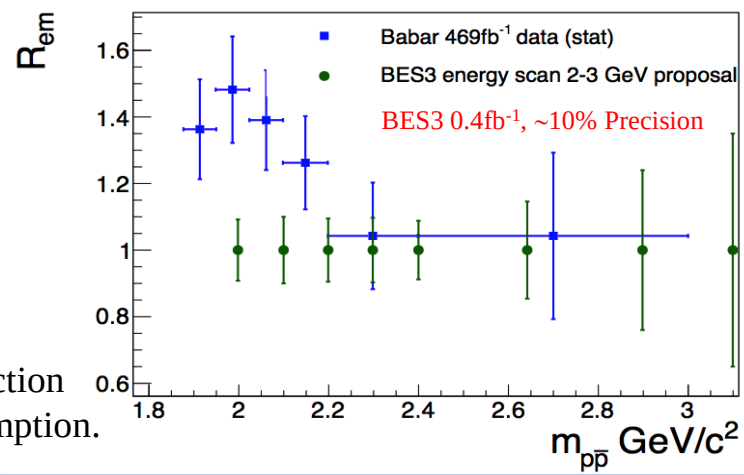
$$|G_M(q^2)| = [1 + (q^2 - 4M_p^2)/q_2^2]^{-2}$$

$$|G_E(q^2)| = |G_M(q^2)|[1 + (q^2 - 4M_p^2)/q_1^2]^{-1}$$

Assume $G_M = G_E$ $\sigma_0 = \frac{4\pi\alpha^2\beta}{3s}(1 + \frac{2M^2}{s})|G(s)|^2$







$\delta|R_{EM}|/|R_{EM}| \sim 9\% - 35\%$

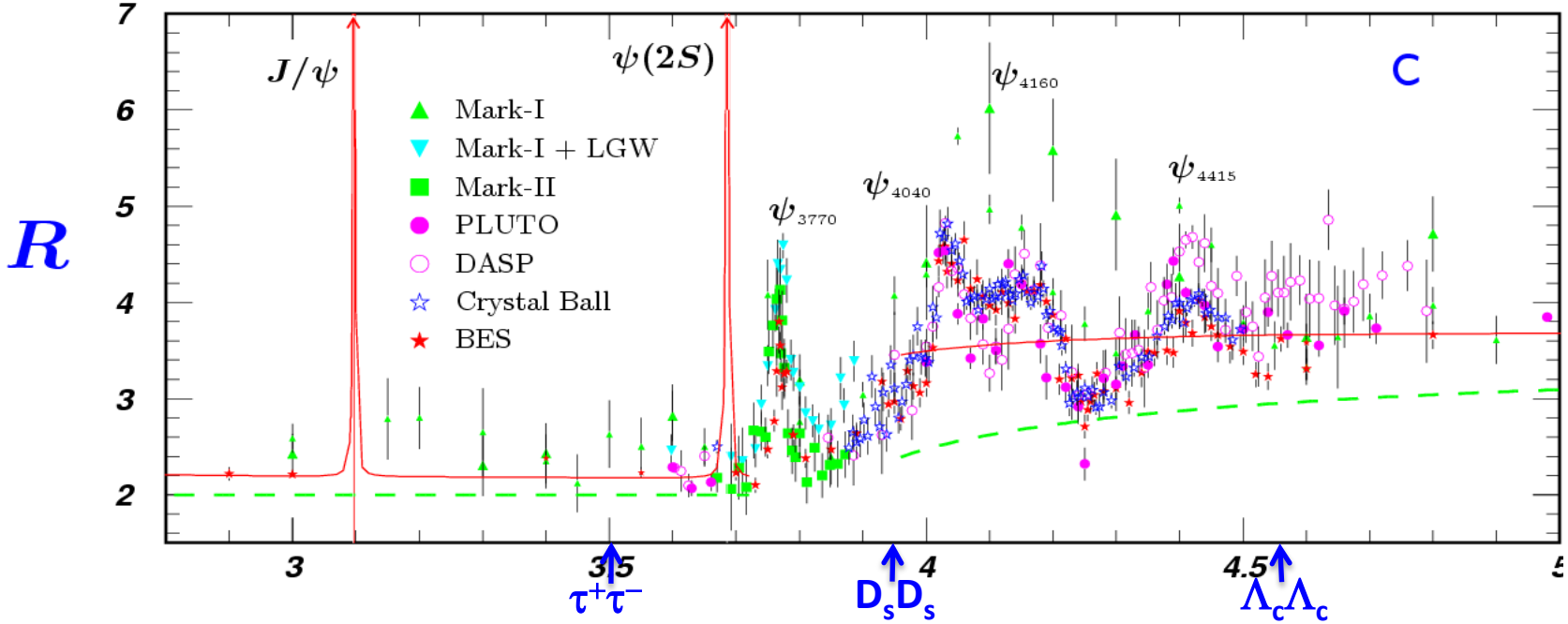
$\delta|G_M|/|G_M| \sim 3\% - 9\%$

$\delta|G_E|/|G_E| \sim 9\% - 35\%$

first time extraction without any assumption.

Features of the τ-c Energy Region

Why Physics on τ-c energy region



- Rich of resonances, charmonium and charmed mesons.
- Threshold characteristics (pairs of τ, D, D_s, charmed baryons…).
- Transition between smooth and resonances, perturbative and non-perturbative QCD.
- Mass location of the exotic hadrons, gluonic matter and hybrid.