Measurement of τ mass at BESIII

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On behalf of BESIII Collaboration

The 12th International Workshop on Tau Lepton Physics
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Motivation of high accurate τ mass measurement

Elementary parameter in SM (PDG2012)

- M_e=0.510998910±0.000000013 (2.6×10^{-8})
- M_μ=105.658367±0.000004 (3.8×10^{-8})
- M_τ=1776.82 ±0.16 (9.0×10^{-5})

Lepton universality testing

$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\tau_\mu}{\tau_\tau}\left(\frac{m_\mu}{m_\tau}\right)^5 \frac{B(\tau \to e\nu_e\nu_\tau)}{B(\mu \to e\nu_e\nu_\mu)}\left(1+\Delta_e\right)$$

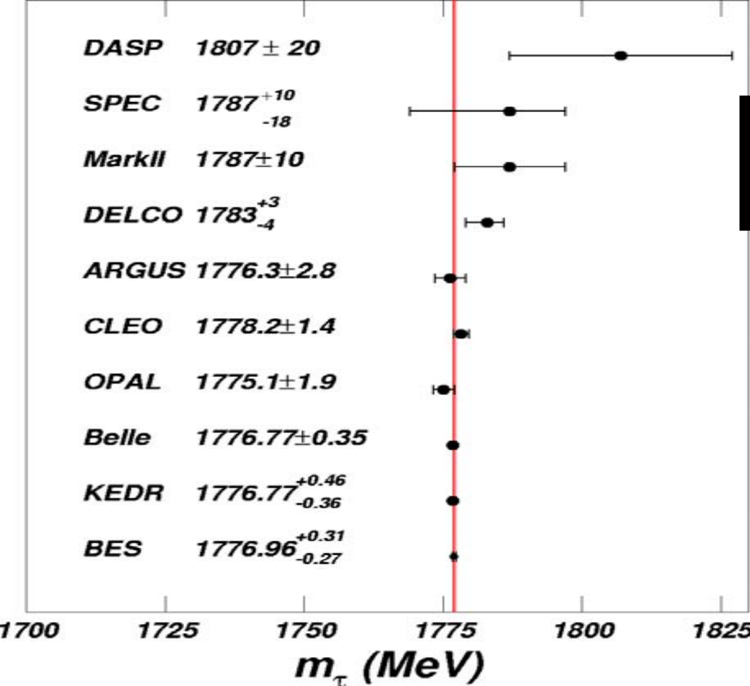
g_τ and g_μ : coupling constants; τ_τ and τ_μ :life time of τ and μ ; $B(\tau \to e\nu_e\nu_\tau)$ and $B(\mu \to e\nu_e\nu_\mu)$: decay branching ratio; Δ_e:correct factor (phase factor, radiative correction factor of QED， correct factor of propagator of W-meson etc.)

Yoshio Koideo (1981) equality testing

$$m_e + m_\mu + m_\tau = \frac{2}{3}\left(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau}\right)^2$$

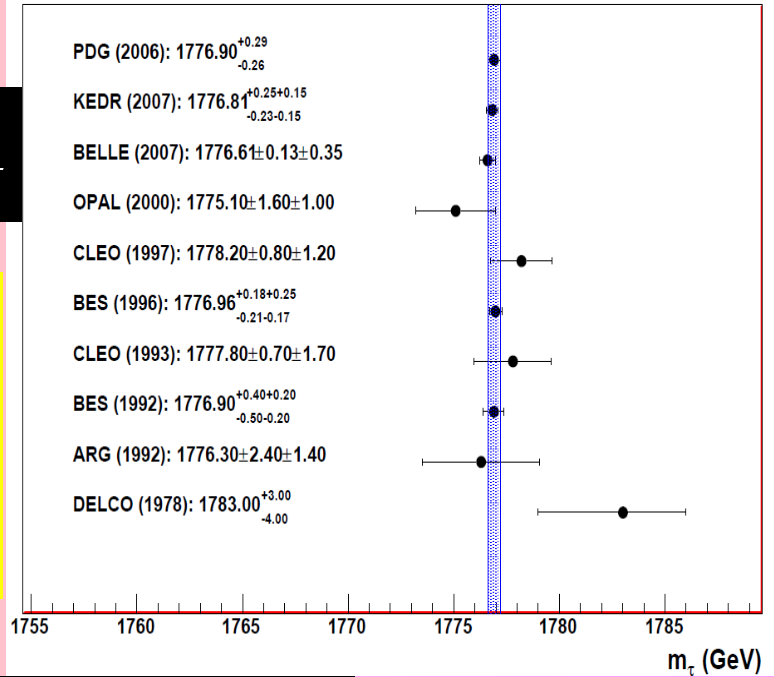
$$\Delta f_m = \sqrt{\sum_{i=e,\mu,\tau}\left(m_i - \frac{2}{3}\sum_{k=e,\mu,\tau}\sqrt{m_i m_k}\right)^2 \cdot \left(\frac{\delta m_i}{m_i}\right)^2}$$

→ $\Delta f_m \simeq 1/3\, \delta m_\tau$



PDG2012:
1776.82 ±0.16 MeV

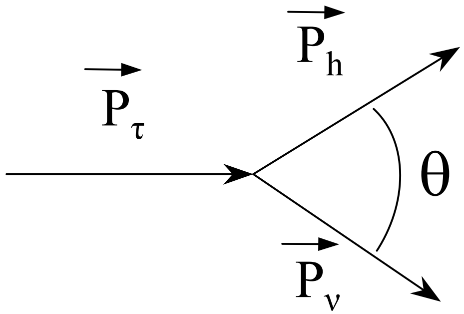
m_τ



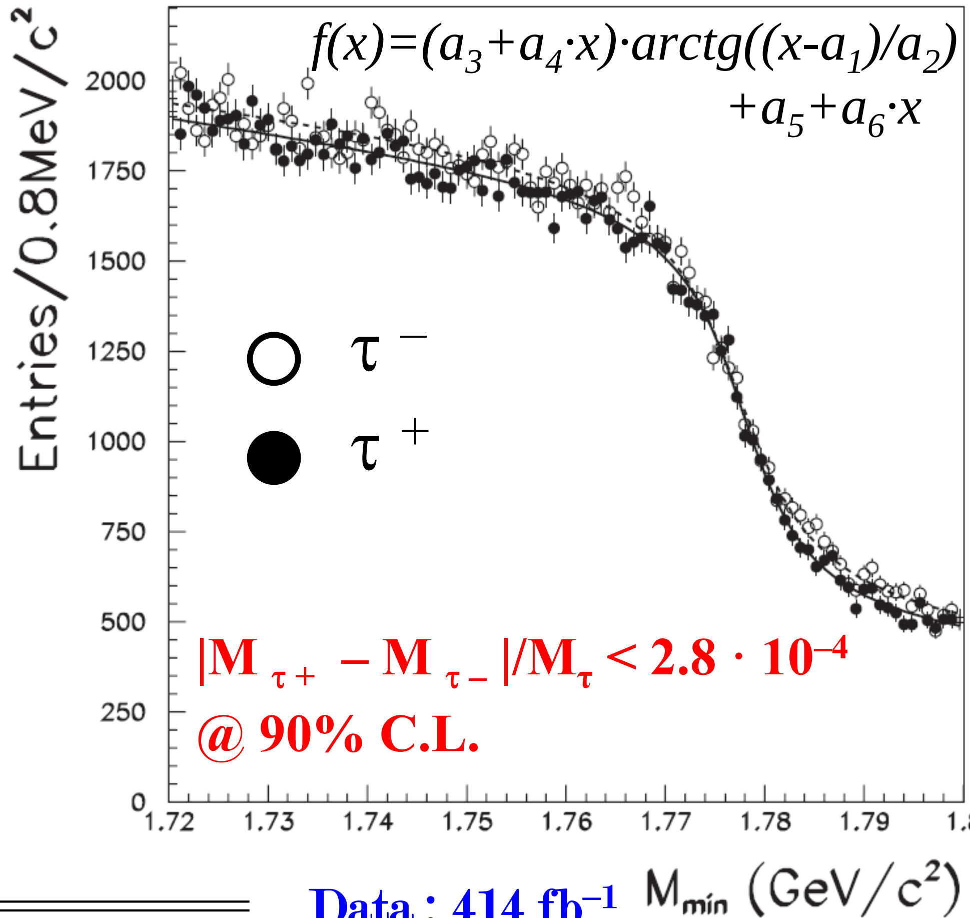
Method: Pseudo-mass and threshold scan

τ lepton mass measurement [value+statistic +systematic error]	Year	Ex. Group	Data sample	Method
1776.68 ± 0.12 ± 0.41	**2009**	**Babar**	423 fb^{-1}	Pseudo-mass
1776.81+(+0.25−0.23) ± 0.15	**2007**	**KEDR**	6.7 pb^{-1}	Scan
1776.61 ± 0.13 ± 0.35	**2007**	**Belle**	414 fb^{-1}	Pseudo-mass
1776.96+(+0.18−0.21)+(+0.25−0.17)	**1996**	**BES**	5.1 pb^{-1}	Scan

Pseudomass method



All in CMS



Data : 414 fb^{-1}

$$\mathbf{M_{min} \leq M_\tau}$$

$$\mathbf{M_{min}^2 = M_h^2 + 2(E_\tau - E_h)(E_h - P_h)}$$

$E_\tau = E_{beam}$: beam energy, run dependence is corrected

E_h : hadron system energy

P_h : hadron system momentum

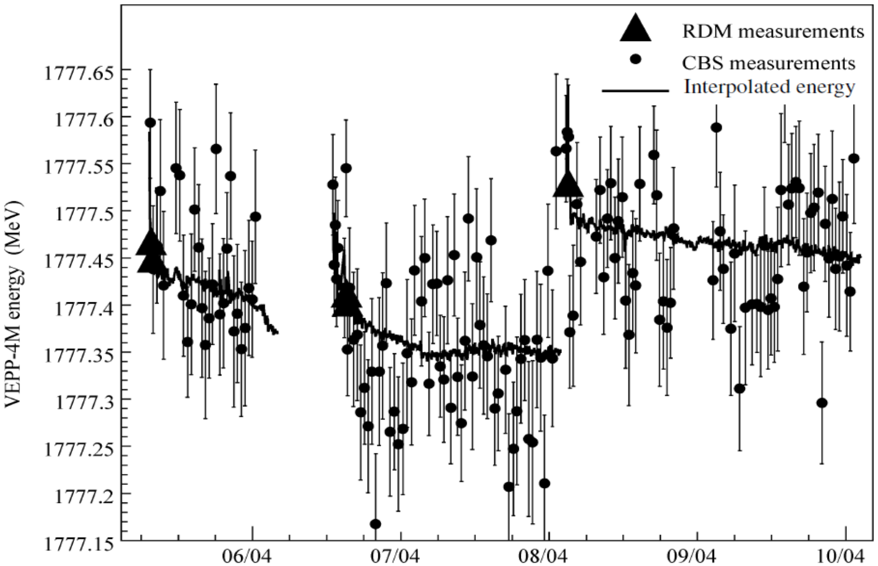
M_h : mass of the hadron system

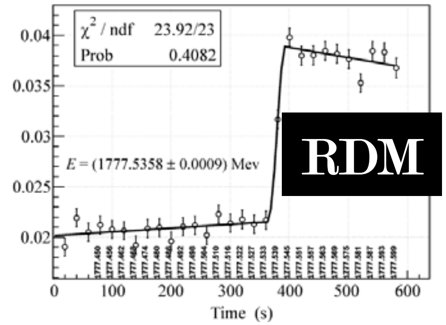
Source of systematics	σ, MeV/c^2
Beam energy and tracking system	0.26
Edge parameterization	0.18
Limited MC statistics	0.14
Fit range	0.04
Momentum resolution	0.02
Model of $\tau \to 3\pi\nu_\tau$	0.02
Background	0.01
Total	0.35

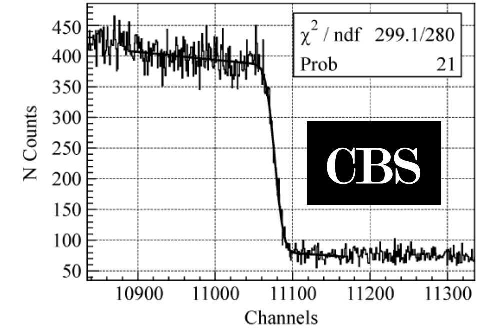
$$\mathbf{M_\tau = 1776.61 \pm 0.13(stat.) \pm 0.35(sys.)\ MeV}$$

(Belle:PRL99,011801)

Threshold scan method

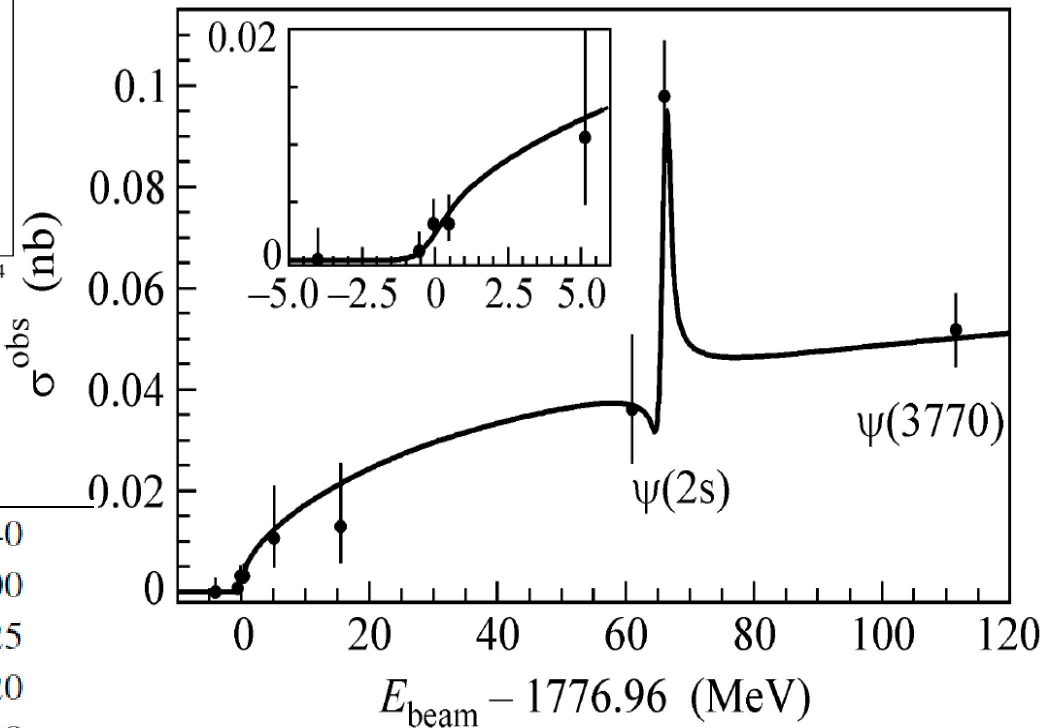






8 points, 6.7 pb^{-1}, for τ

1 points, 0.8 pb^{-1}, at ψ′

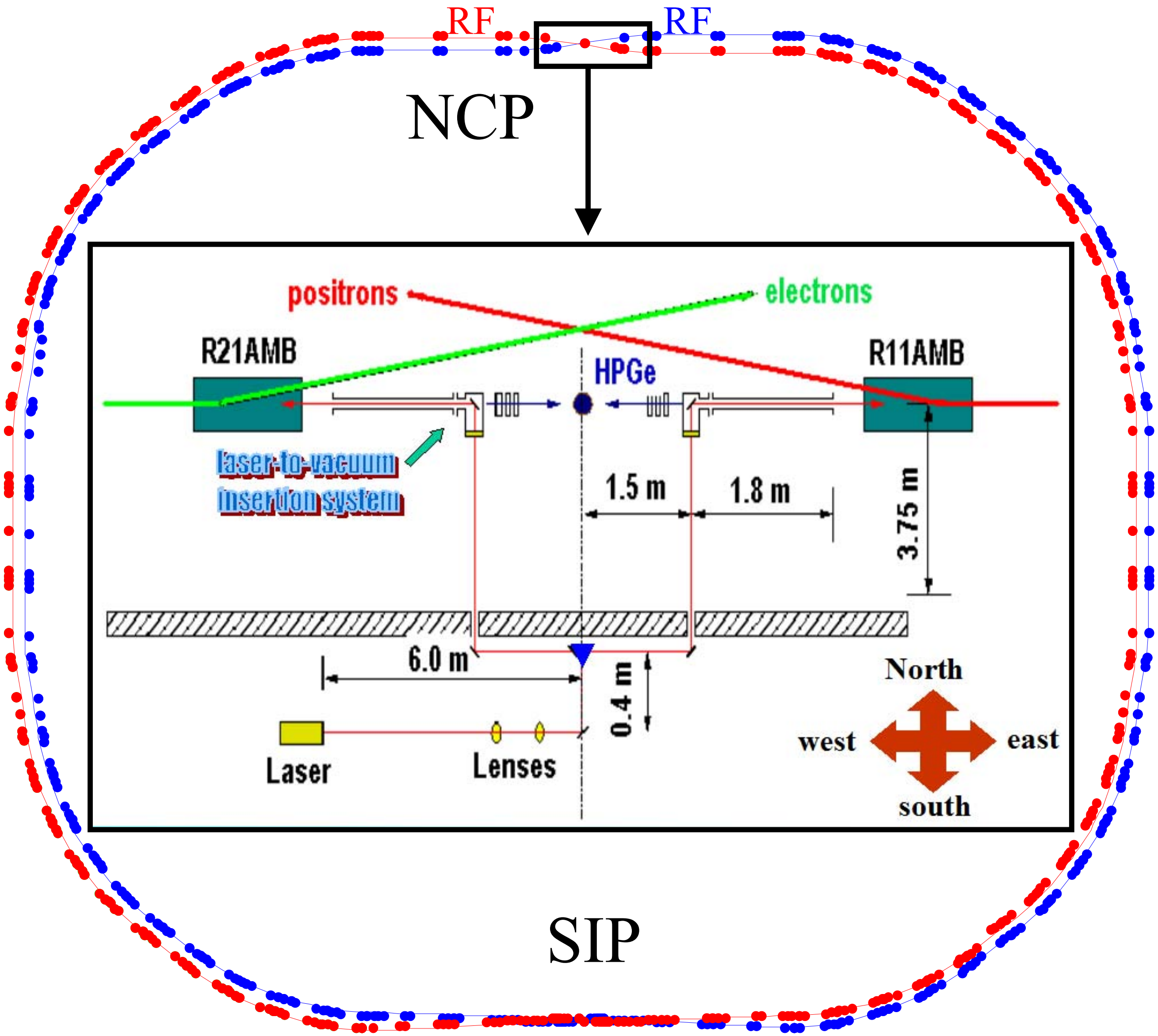


Beam energy determination	40
Detection efficiency variations	100
Energy spread determination accuracy	25
Energy dependence of the background	20
Luminosity measurement instability	90
Beam energy spread variation	15
Cross section calculation (r.c., interference)	30
Sum in quadrature	150

$$M_\tau = 1776.81^{+0.25}_{-0.23} \pm 0.15 \text{ MeV}$$

$$\sigma M_\tau / M_\tau = 1.64 \times 10^{-4}$$

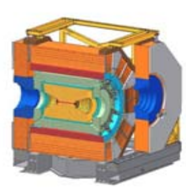
KDER : JETPL85_347



For BEPCII
Energy accuracy
Improvement :
$10^{-3} \rightarrow 5\times 10^{-5}$

For BESIII physics

- Effective experimental means of τ mass measurement
- High accuracy measurement of physics analysis
- Measurement of resonance parameters, mass of charm mesons



Content

1. *Scan optimization*
2. *Data taking*
3. *Analysis*
   1) *Ecm calculation*
   2) *Energy point determination*
   3) *Resonance scan* $(E, \Delta E)$
   4) τ *mass fit*
4. *Summary*

Preliminary!!

BINP, Hawaii University,
IHEP, Tsinghua University.

Summary

- **Monte Carlo simulation, sampling technique, are employed to obtain the optimal data taking point for high accuracy τ mass measurement. We found:**

  ❶ **optimal position is locate at large derivative of cross section near threshold ;**

  ❷ **one point is enough, and 54 pb^{-1} is sufficient for accuracy up to 0.1 MeV .**

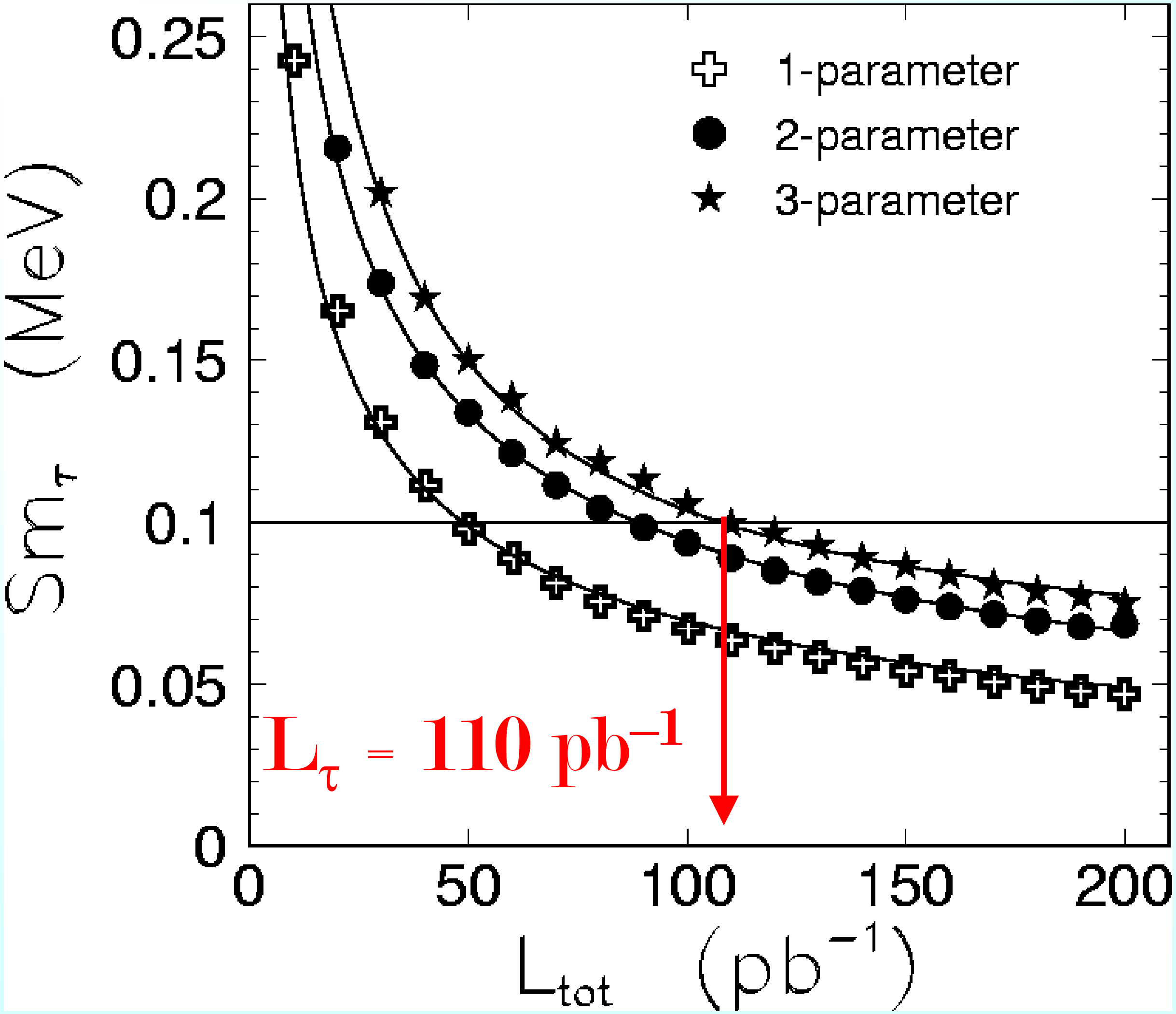
- **New technique maybe adopted at BESIII to improve the accuracy of absolute energy calibration**

9th International Workshop on Tau Lepton Physics

Pisa, Italy, 19-22 September 2006

Statistic optimization for scan data taking

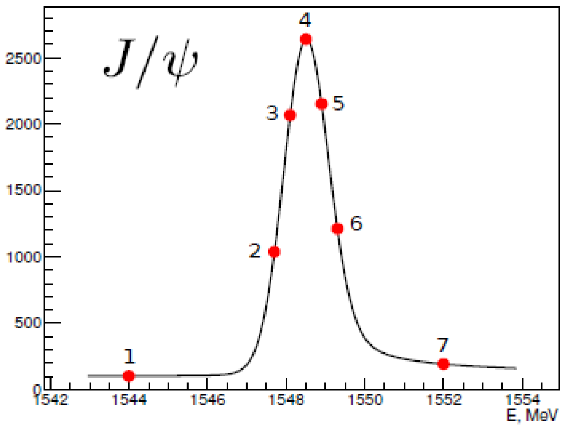
1. N free parameters fit, N energy points is enough
2. The optimal position can be obtained by single parameter scan
3. Luminosity allocation can be determined analytically or by simulation method
4. The uncertainty of tau mass is proportional to the inverse of square root of luminosity

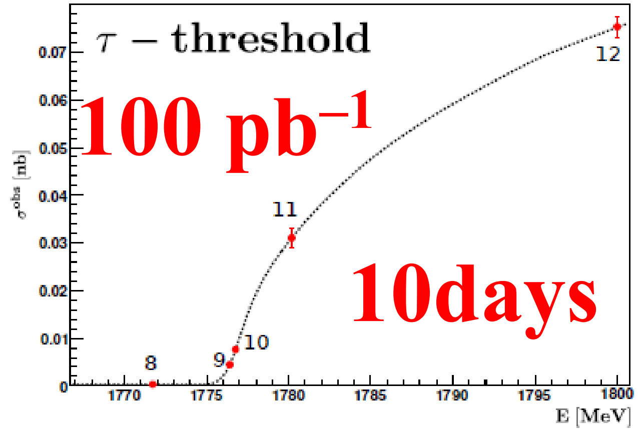


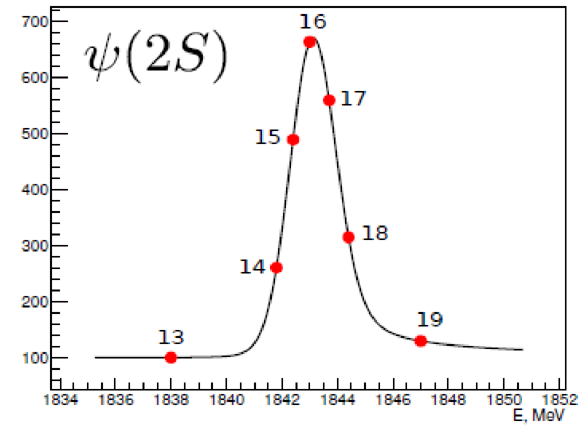
Optimization study:
Chin. Phys. C 2009, 33:501-507 ;
Y.K.Wang, J.Y.Zhang, X.H.Mo, C.Z.Yuan.

Only based on e μ event !!
Only Statistics uncertainty !!

1=M_τ , 2=ε, 3=σ_{BG} ;
L_1: L_2 = 3:1 , L_1: L_{tot} = 10% , $\delta M_\tau \propto (\sqrt{L})^{-1}$;







First circle:

J/ψ scan (7 pts) → τ scan (5 pts) → ψ' scan (7 pts)

Second circle:

J/ψscan (7pts) →τscan (pt.9&10) → ψ'scan (7 pts)

Final uncertainty (sta. ⊕ sys.)< 0.1MeV

Energy region	order	Beam energy (MeV)	C.M.S energy (MeV)	Integrated lum. (pb^{-1})
Energy points for J/psi scan	1	1544.0	3088.00	
	2	1547.7	3095.40	
	3	1548.1	3096.20	
	4	1548.5	3097.00	
	5	1548.9	3097.80	
	6	1549.3	3098.60	
	7	1552.0	3104.00	
Energy points for tau scan	8	1771.0	3542.00	14
	9	1776.4	3552.80	14+25
	10	1776.65	3553.30	14+12
	11	1780.2	3560.40	7
	12	1792.0	3584.00	14
Energy points for psi' scan	13	1838.0	3676.00	
	14	1841.8	3683.60	
	15	1842.4	3684.80	
	16	1843.0	3686.00	
	17	1843.7	3687.40	
	18	1844.4	3688.80	
	19	1847.0	3694.00	

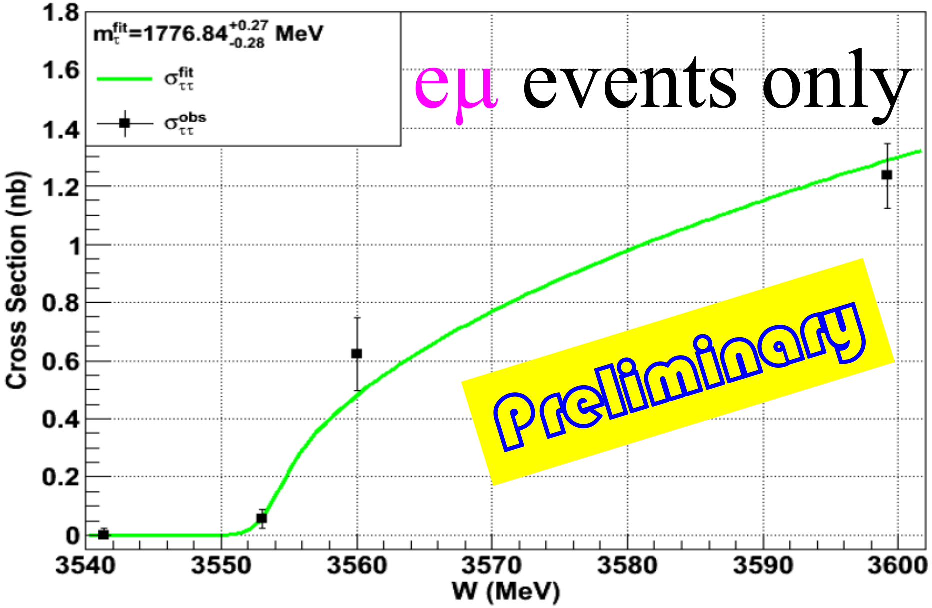
τ scan plan /anticipated

actual τ mass scan

Job	Beam energy (MeV)	Begin Run number	Begin time	End Run number	End time	Int. lum. (pb^{-1})
J/psi scan	1544.0 1547.7 1548.1 1548.5 1548.9 1549.3 1552.0	24937	2011/12/22; 10:40:12	24978	2011/12/23; 10:01:35	1.428
Energy points for tau scan	1771.0	24984	2011/12/23; 13:12:26	25015	2011/12/24; 14:47:46	4.035
	1776.9	25019	2011/12/23; 18:24:10	25094	2011/12/26; 08:32:34	4.914
	1780.4	25098	2011/12/26; 09:46:24	25141	2011/12/27; 09:38:34	3.671
	1800.0	25142	2011/12/27; 10:26:46	25243	2011/12/29; 08:48:20	9.056
psi' scan	1838.0 1841.9 1842.5 1843.1 1843.8 1844.5 1847.0	25244	2011/12/29; 09:04:32	25337	2011/12/31; 02:31:32	7.245

4/14 5/(39+26) 3.7/7 9/14

28% 7.7% 53% 64%



21.75 pb^{-1} (τ) +

8.677pb^{-1}(J/ψ &ψ′)=30.348pb^{-1} /9.7days

Preliminary results:

(1776.84 ±0.30) MeV

0.31MeV (5 pb^{-1}) →

<0.1MeV (66 pb^{-1})

Details about data analysis

1) Ecm calculation

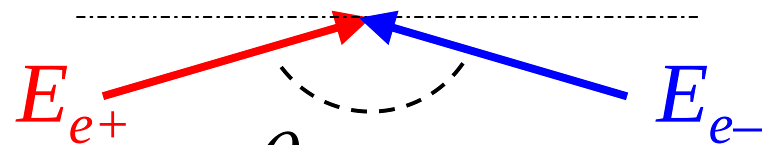
2) Energy point determination

3) Resonance scan $(E, \Delta E)$

4) τ mass fit

CM energy setting

$$S=(E_{e^+}+E_{e^-})^2-(p_{e^+}+p_{e^-})^2$$



$$\theta=\pi-\alpha$$

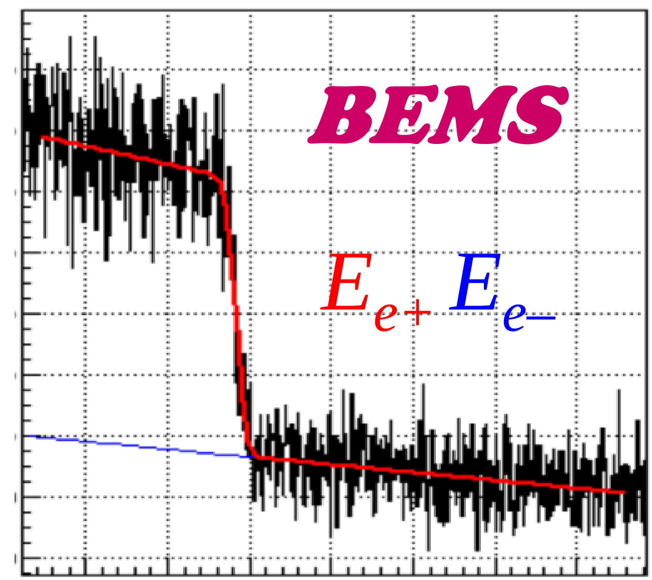
$$\alpha\approx 22mrad$$

$$E_{cm}^{AA}=(E_{e^+}+E_{e^-})\cdot\cos\frac{\alpha}{2}$$

$$E_{cm}^{GA}=2\sqrt{E_{e^+}E_{e^-}}\cdot\cos\frac{\alpha}{2}$$

$$E_{cm}^{GA}\approx E_{cm}^{GA}\approx 2E_{beam}\left(1-\frac{\alpha^2}{8}\right)$$

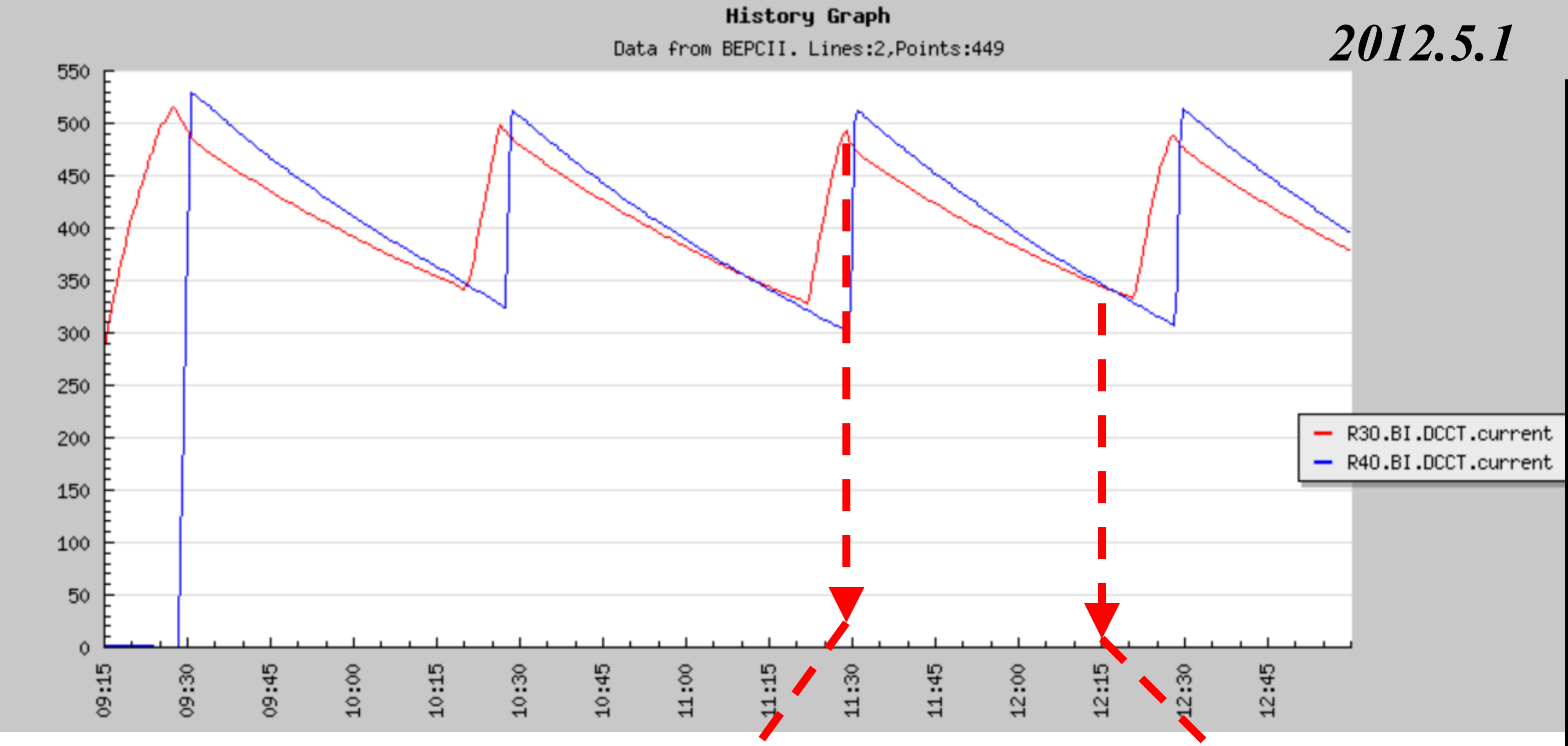
$E_{cm}{}^{GA}\approx E_{cm}{}^{GA}\approx E_{cm}{}^{\sqrt{s}}$
α-effect $\approx 6\times10^{-5}$,
0.11MeV @τ threshold



$$E_{cm}^{\sqrt{S}}\approx 2E_{beam}\left(1-\frac{\alpha^2}{8}\right)$$

$$E_{cm}^{\sqrt{S}}=\sqrt{2m_e^2+2E_{e^+}E_{e^-}-2\sqrt{E_{e^+}^2-m_e^2}\sqrt{E_{e^-}^2-m_e^2}\cdot\cos(\pi-\alpha)}$$

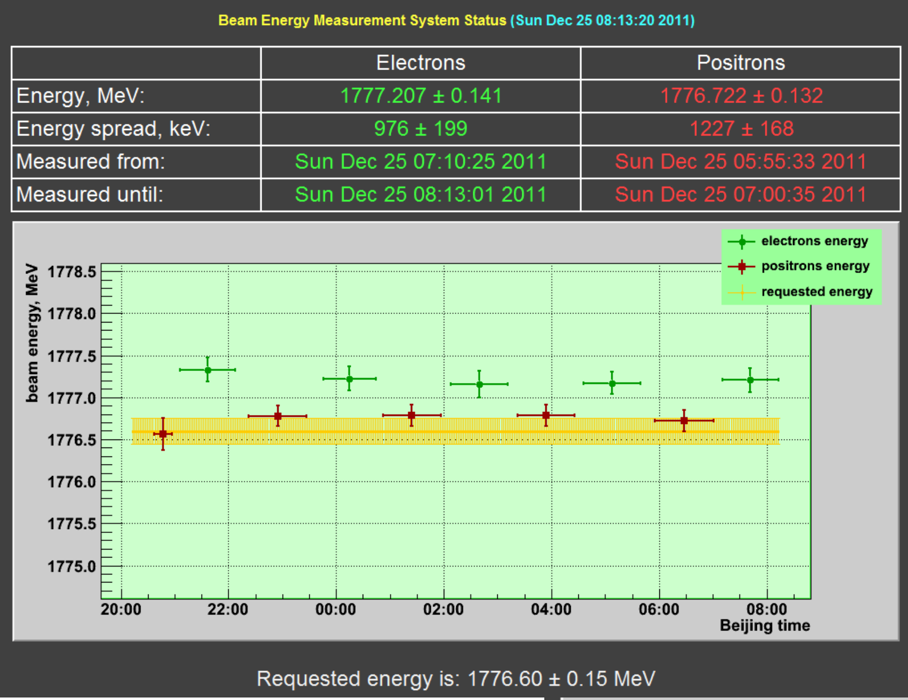
2012.5.1



Under the condition of stable running, the data taking time for BESIII and BEMS almost coincide with each other; but for unstable situation, whatever due to accelerator or detector, the overlap of two kinds of time are complicated, and should be considered carefully, especially for scan data taking.

Two conditions for BEMS data taking control:
1.Accelerator status, beam injection;
2. Time duration of counting, 40-60 minutes.

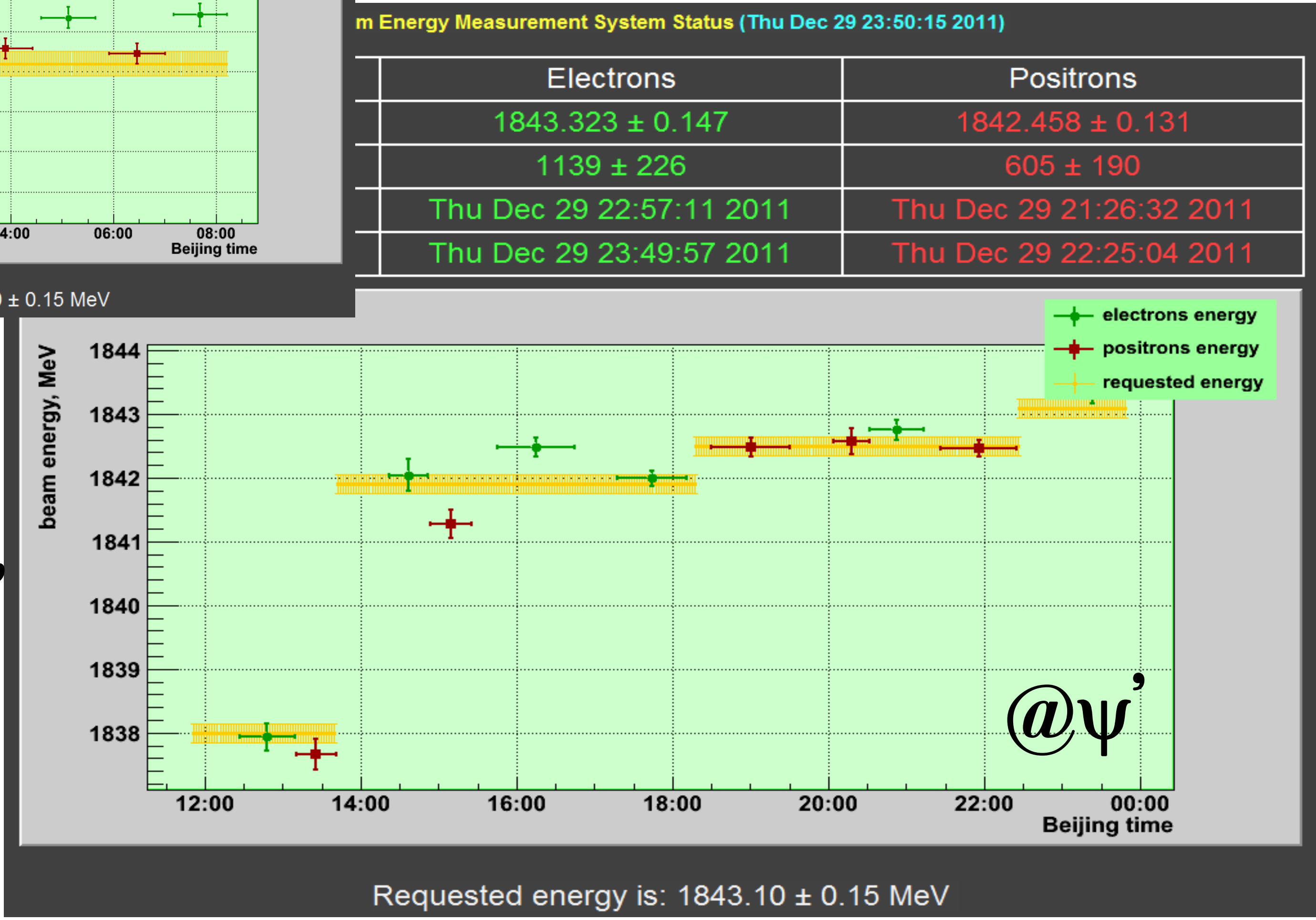
For resonance scans, the situation is rather … …



Beam Energy Measurement System Status (Sun Dec 25 08:13:20 2011)

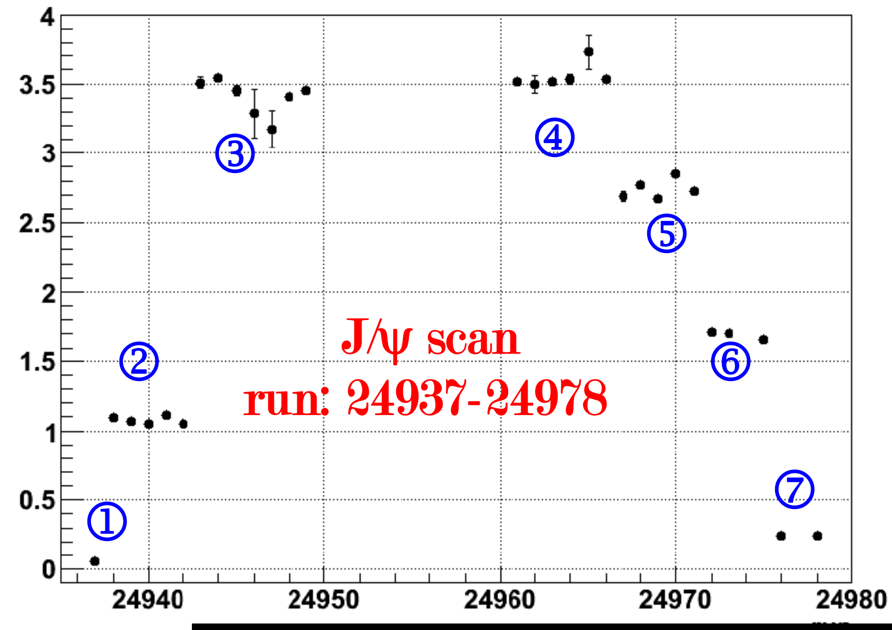
	Electrons	Positrons
Energy, MeV:	1777.207 ± 0.141	1776.722 ± 0.132
Energy spread, keV:	976 ± 199	1227 ± 168
Measured from:	Sun Dec 25 07:10:25 2011	Sun Dec 25 05:55:33 2011
Measured until:	Sun Dec 25 08:13:01 2011	Sun Dec 25 07:00:35 2011

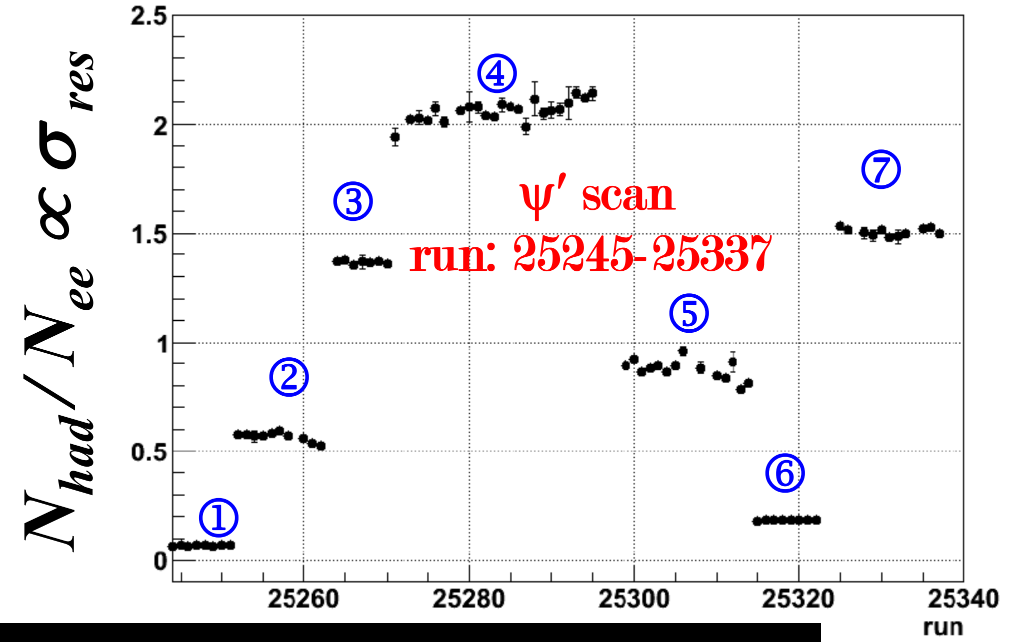
For τ scan, the data time is comparative long, and the running status is fairly stable



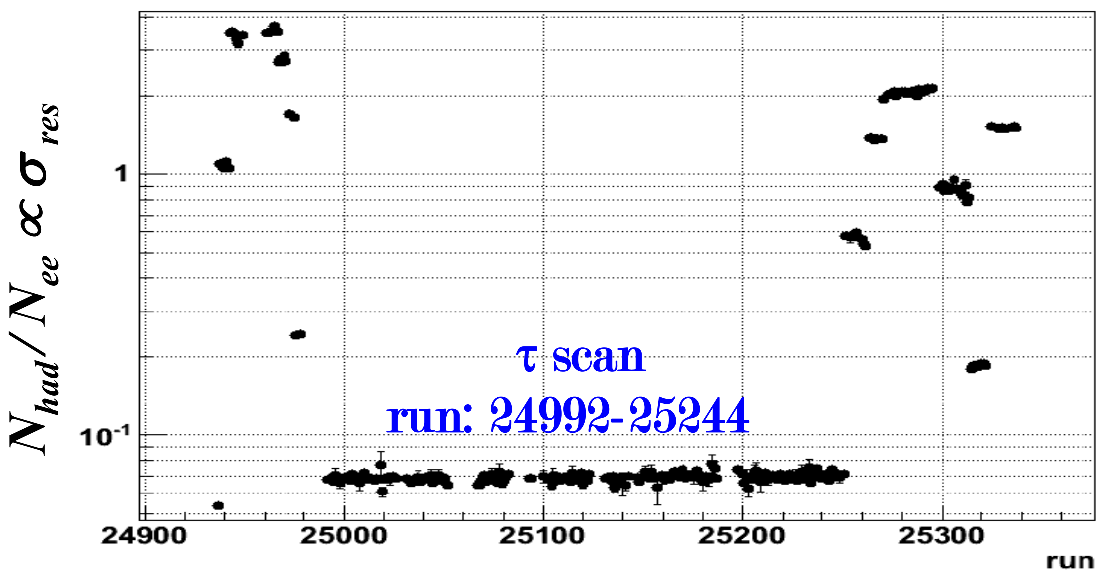
m Energy Measurement System Status (Thu Dec 29 23:50:15 2011)

	Electrons	Positrons
	1843.323 ± 0.147	1842.458 ± 0.131
	1139 ± 226	605 ± 190
	Thu Dec 29 22:57:11 2011	Thu Dec 29 21:26:32 2011
	Thu Dec 29 23:49:57 2011	Thu Dec 29 22:25:04 2011





Classification of run by the ratio of N_{had}/N_{ee}

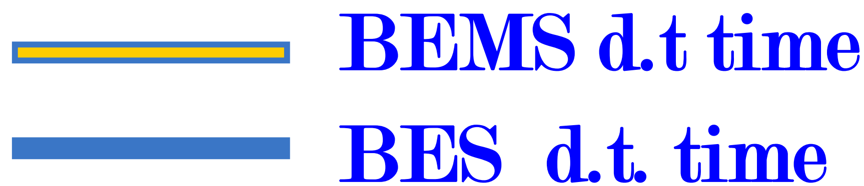


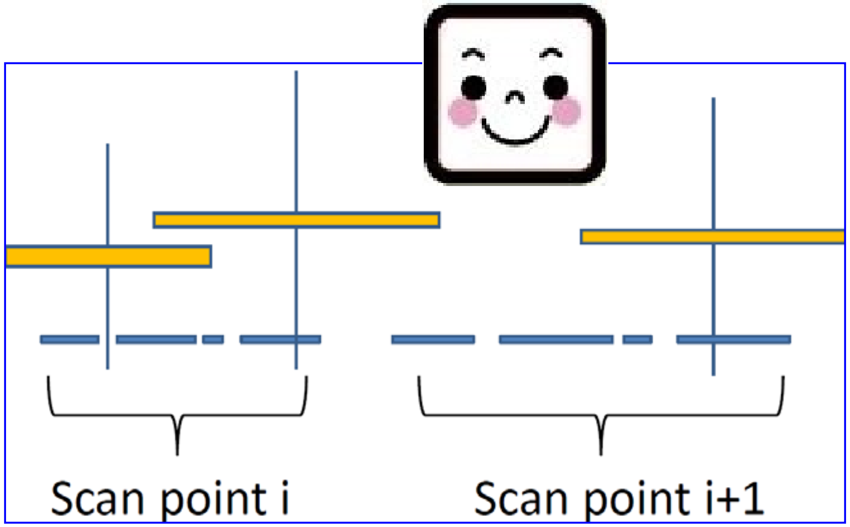
Time matching

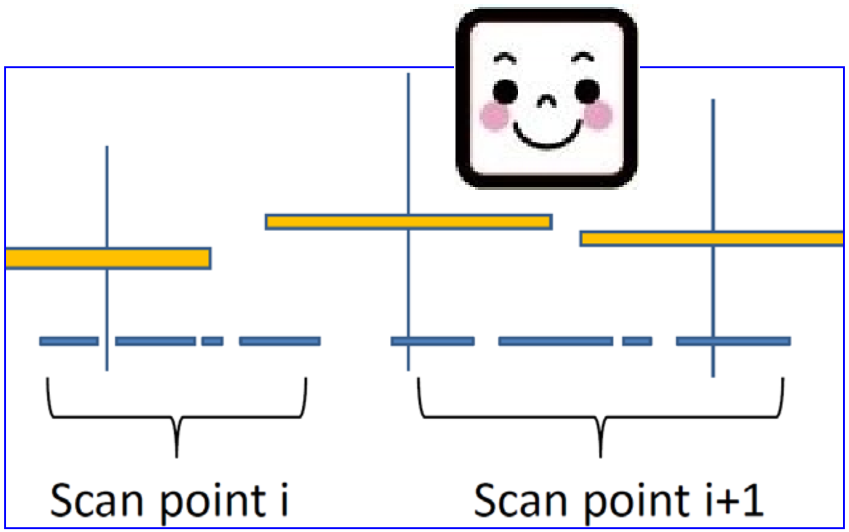
1) For each scan point, find run0, run1 are the starting and ending run # respectively; and T0 is starting time of run0; T1 is ending time of run1;

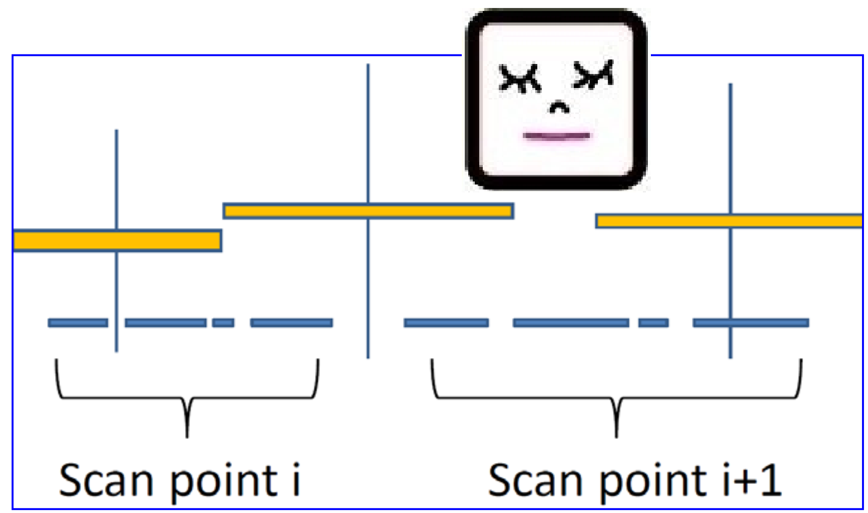
2) Select E(e+/e-) whose starting time or ending time falls >=T0 and <=T1;

3) Abandon E(e+/e-) of the scan point i whose central time <T1(i-1) or >T0(i+1).









	Scan point	Run number	$E_{e^-}(MeV)$	E_{e^+} (MeV)	E_{cm} (MeV)
	1	24983-25015	1771.558 ± 0.067	1771.069 ± 0.053	3542.413 ± 0.085
τ	2	25016-25094	1777.307 ± 0.047	1776.730 ± 0.046	3553.822 ± 0.075
	3	25100-25141	1780.926 ± 0.055	1780.431 ± 0.065	3561.142 ± 0.085
	4	25143-25243	1800.526 ± 0.044	1799.878 ± 0.044	3600.186 ± 0.062
	1	24937-24937	1544.542 ± 0.135	1544.312 ± 0.217	3088.667 ± 0.256
	2	24938-24942	1547.917 ± 0.099	1547.548 ± 0.106	3095.278 ± 0.145
	3	24943-24949	1548.692 ± 0.103	1548.171 ± 0.086	3096.676 ± 0.135
J/ψ	4	24959-24966	1549.079 ± 0.109	1548.714 ± 0.075	3097.606 ± 0.133
	5	24967-24971	1549.451 ± 0.081	1549.014 ± 0.114	3098.278 ± 0.140
	6	24972-24975	1549.566 ± 0.101	1549.438 ± 0.083	3098.817 ± 0.131
	7	24976-24978	1552.186 ± 0.088	1551.936 ± 0.107	3103.934 ± 0.139
	1	25245-25251	1838.183 ± 0.256	1837.940 ± 0.157	3675.901 ± 0.300
	2	25252-25262	1842.177 ± 0.090	1841.279 ± 0.220	3683.653 ± 0.303
	3	25264-25270	1842.755 ± 0.153	1842.489 ± 0.087	3685.113 ± 0.230
ψ'	4	25271-25295	1843.402 ± 0.075	1842.893 ± 0.110	3686.337 ± 0.189
	5	25299-25314	1844.787 ± 0.125	1844.137 ± 0.107	3688.819 ± 0.226
	6	25315-25322	1846.832 ± 0.138	1846.487 ± 0.108	3693.515 ± 0.245
	7	25325-25337	1844.130 ± 0.091	1843.396 ± 0.088	3687.573 ± 0.158

$$E_{cm}^{\sqrt{s}} \approx 2E_{beam}\left(1-\frac{\alpha^2}{8}\right)$$

Bhabha

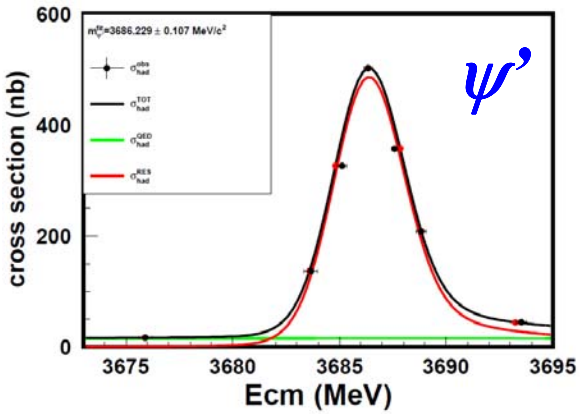
$e^+e^- \rightarrow e^+e^-$

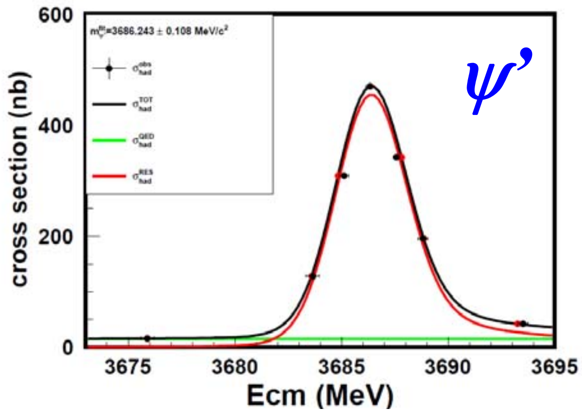
Di-gamma

$e^+e^- \rightarrow \gamma\gamma$

	Scan point	N_2^{obs}	N_1^{obs}	L_{bhabha} (nb^{-1})	N^{obs}	$L_{digamma}$ (nb^{-1})
	1	1575827	58018	4502.89	74240	4252.17
τ	2	2043538	75371	5877.14	96570	5566.82
	3	1413321	52432	4082.30	67192	3889.29
	4	3411037	126081	10068.29	161482	9553.18
	1	38143	1393	81.79	1804	78.52
	2	114205	7191	239.19	5016	219.26
	3	137995	21744	260.07	5557	243.13
J/ψ	4	109972	17947	206.00	4718	206.55
	5	116221	15593	225.34	5104	223.53
	6	106130	10079	215.17	4950	216.87
	7	150860	6618	324.23	7218	317.31
	1	269201	9878	830.58	12763	787.04
	2	284362	10995	879.30	13291	823.10
	3	285762	12775	878.75	13432	832.47
ψ'	4	414291	20998	1266.84	19097	1184.34
	5	565681	27641	1734.27	26761	1660.77
	6	265322	11889	817.48	12366	767.97
	7	501530	19215	1559.59	23624	1470.75

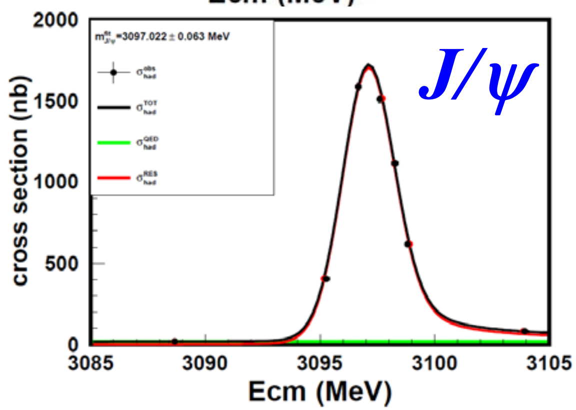
	J/ψ	3096.916 ± 0.011	ψ'	3686.09 ± 0.04
Lumi.	di-gamma	Bhabha	di-gamma	Bhabha
$M(\mathrm{MeV}/c^2)$	3097.022 ± 0.063	3097.070 ± 0.083	3686.229 ± 0.107	3686.243 ± 0.108
$\Delta_E(\mathrm{MeV})$	1.086 ± 0.055	1.109 ± 0.029	1.556 ± 0.060	1.567 ± 0.058
ϵ	$(67.29 \pm 1.69)\%$	$(65.76 \pm 1.56)\%$	$(84.83 \pm 2.65)\%$	$(79.85 \pm 2.47)\%$
$\chi^2/ndof$	$2.48/3$	$3.05/3$	$6.17/3$	$5.21/3$
Δm	0.106 ± 0.064	0.154 ± 0.084	0.139 ± 0.114	0.153 ± 0.115

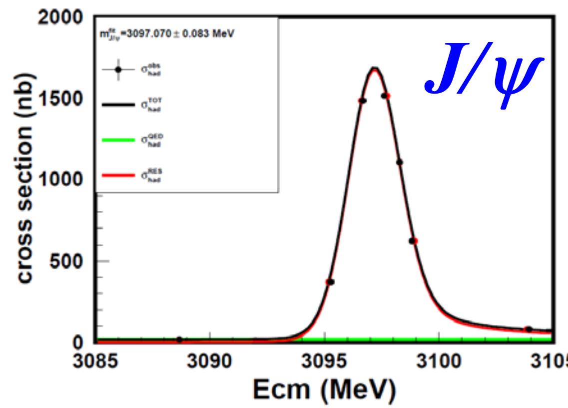




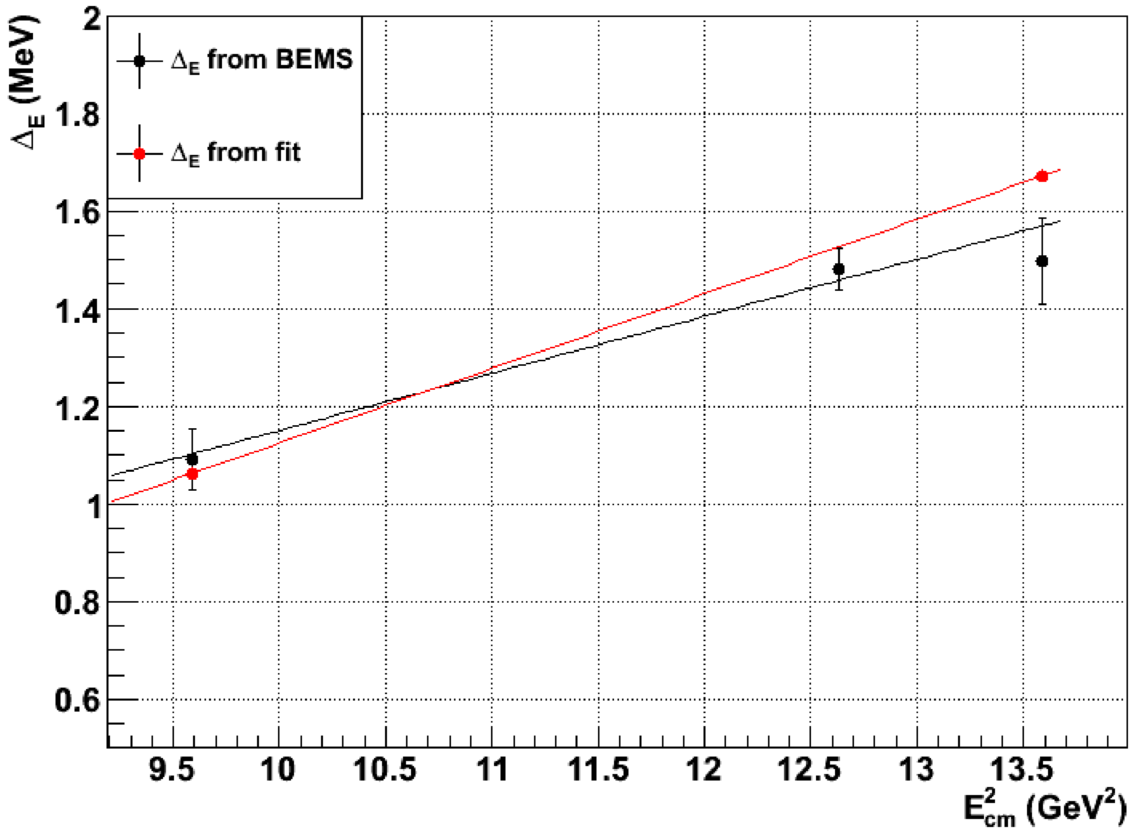
$\Delta E_{Scale} \approx 70$ keV

Fit results for J/ψ & ψ'





MeV	ΔE (e-)	ΔE (e+)	ΔE_{cm} from BEMS	ΔE from psi fit
J/psi	0.68+/-0.05	0.86+/-0.04	1.09+/-0.06	1.063+/-0.002
tau	0.94+/-0.03	1.15+/-0.03	1.48+/-0.04	
psip	0.96+/-0.06	1.15+/-0.06	1.50+/-0.08	1.672+/-0.002



$\Delta E_{Spread} \approx 15$ keV

Event Selection

Partial information, not the full list !

PID	p (GeV/c)	EMC	TOF	MUC	other
e	$p_{min} < p < p_{max}$	$0.8 < E/p < 1.05$	$\lvert\Delta tof(e)\rvert < 0.2$ $0 < tof < 4.5$		
μ	$p_{min} < p < p_{max}$	$E/p < 0.7$ $0.1 < E < 0.3$	$\lvert\Delta tof(\mu)\rvert < 0.2$	($depth > 80 \times p$-50 or $depth > 40$) and $numhits > 1$	
π	$p_{min} < p < p_{max}$	$E/p < 0.6$	$\lvert\Delta tof(\pi)\rvert < 0.2$ $0 < tof < 4.5$		not μ
K	$p_{min} < p < p_{max}$	$E/p < 0.6$	$\lvert\Delta tof(K)\rvert < 0.2$ $0 < tof < 4.5$		not μ

$$PTEM = \frac{P_T}{E_{miss}^{max}} = \frac{(\vec{P}_1 + \vec{P}_2)_T}{W - |\vec{P}_1| - |\vec{P}_2|}$$

No good photon: N_γ=0
Good photon:
1) 0<TDC<14, (unit: 50ns)
2) |cosθ|<0.8, E>25MeV
3) 0.84<| cosθ |<0.92, E>50MeV
4) θγc >20

6

The detection efficiency for different final states at different scan points

scan point	Efficiency (%)								
	ee	$e\mu$	eh	$\mu\mu$	μh	hh	$e\rho$	$\mu\rho$	$\pi\rho$
2	17.1	21.8	32.4	14.2	15.3	25.6	9.9	5.5	9.1
3	17.6	23.2	34.9	14.0	16.9	29.3	10.4	6.1	8.9
4	17.8	23.1	36.2	13.9	17.7	34.5	10.8	5.3	12.8

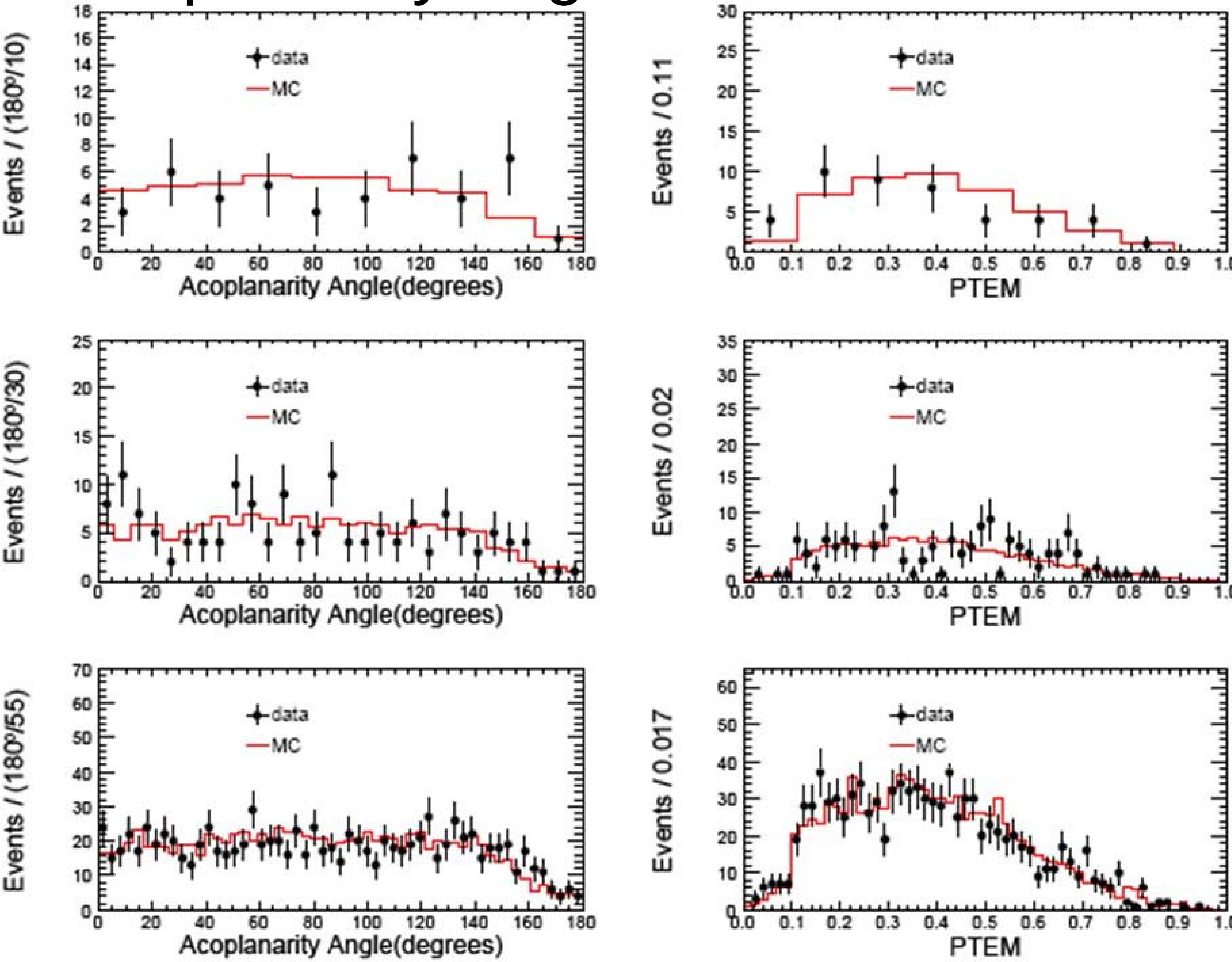
The number of observed events and that of normalized MC samples are consistent within errors.

final state	1		2		3		4		total	
	Data	MC	Data	MC	Data	MC	Data	MC	Data	MC
ee	0	0	4	3.7	13	12.2	84	76.1	101	91.9
$e\mu$	0	0	8	9.2	35	31.3	168	192.7	211	233.1
$e\pi$	0	0	8	8.6	33	29.6	202	184.5	243	222.7
ek	0	0	0	0.5	2	1.8	16	16.9	18	19.3
$\mu\mu$	0	0	2	2.9	8	9.2	49	56.3	59	68.4
$\mu\pi$	0	0	4	3.9	11	14.0	89	86.7	104	104.7
μk	0	0	0	0.2	3	0.8	7	9.0	10	10.1
$\pi\pi$	0	0	1	2.0	5	7.7	57	54.0	63	63.8
πk	0	0	1	0.3	0	0.8	10	8.2	11	9.3
kk	0	0	0	0.0	1	0.1	1	0.3	2	0.4
$e\rho$	0	0	3	6.1	19	20.6	142	132.0	164	158.7
$\mu\rho$	0	0	8	3.3	18	11.8	52	62.3	68	78.5
$\pi\rho$	0	0	5	3.4	15	10.8	97	96.0	117	110.2
Total	0	0	44	44.2	153	150.8	974	976.1	1171	1171.1

Total consistency is fairly well!

Acoplanarity angle

PTEM

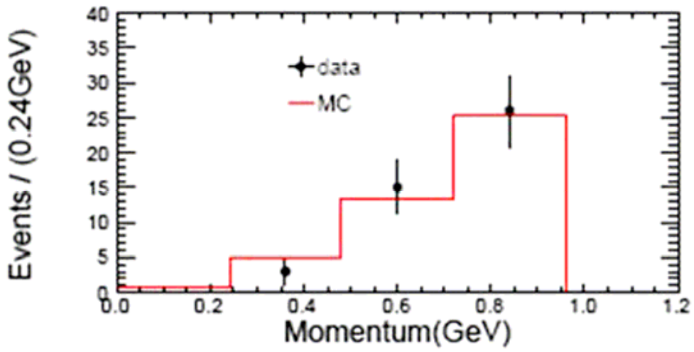


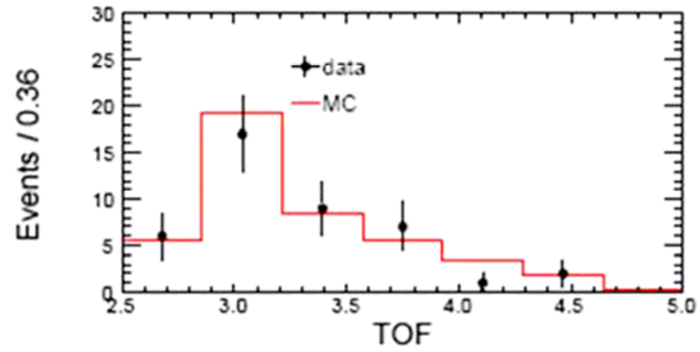
2-point
Ecm=3553.8MeV

3-point
Ecm=3561.1MeV

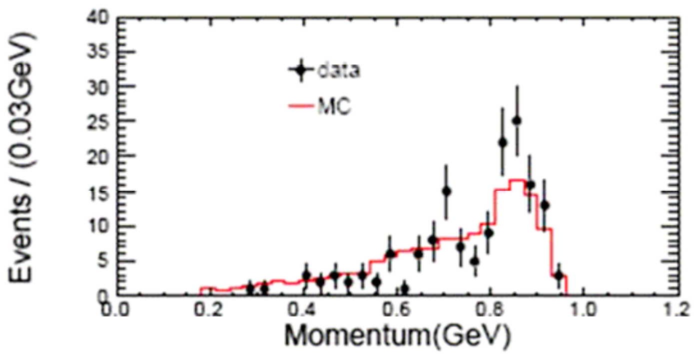
4-point
Ecm=3600.2MeV

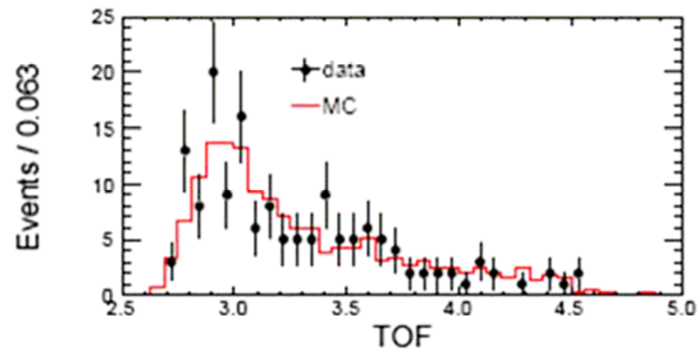
Momentum of charged tracks TOF of charged tracks



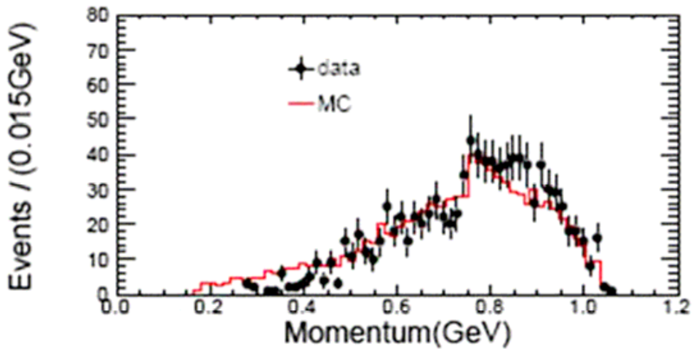


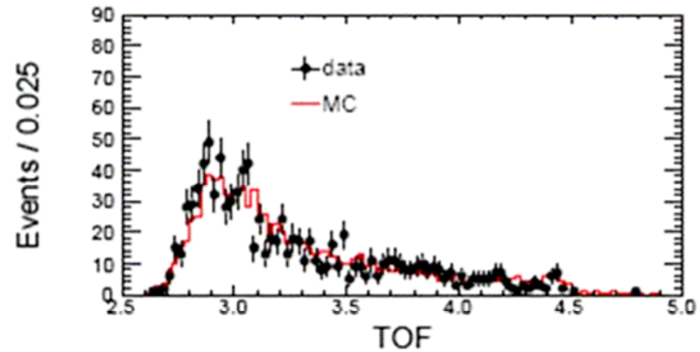
2-point
Ecm=3553.8MeV



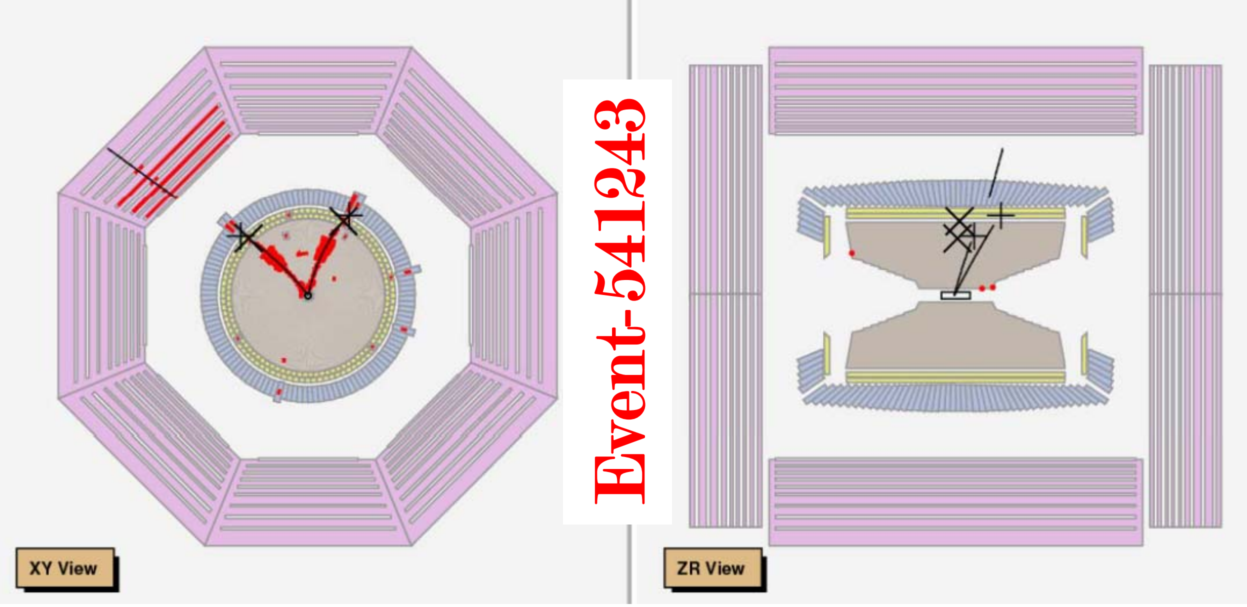


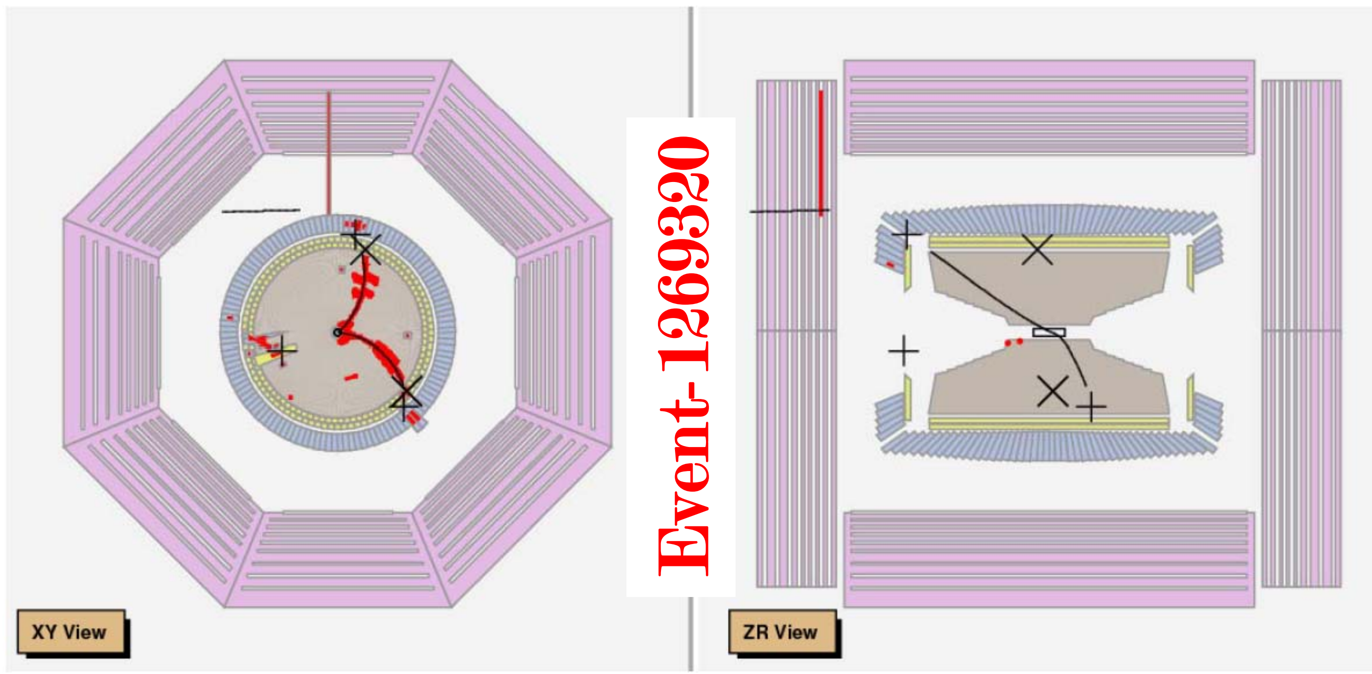
3-point
Ecm=3561.1MeV

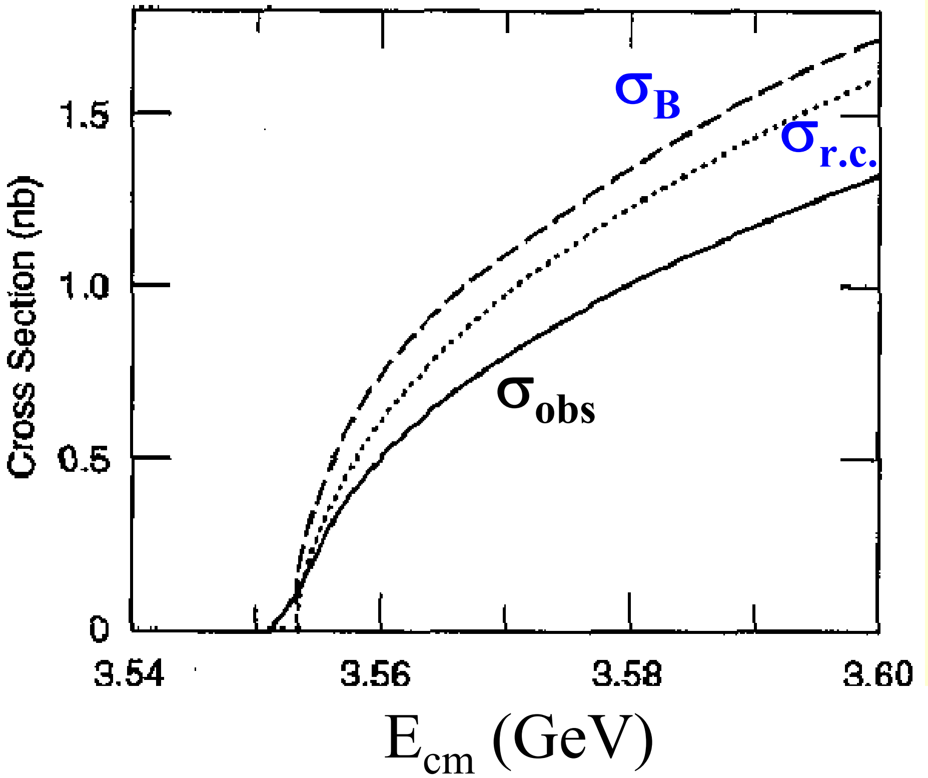




4-point
Ecm=3600.2MeV


XY View
Event-541243
ZR View


XY View
Event-1269320
ZR View



BES:PRD53(1995)20

$$LF = \prod_{i=1}^{n} P_i \,, \quad P_i = \frac{\mu_i^{N_i} e^{-\mu_i}}{N_i!}$$

$$\mu_i(m_\tau, s_i) = \mathcal{L}_i \cdot \left[\varepsilon \cdot \mathcal{B}_f \cdot \sigma_{obs}(m_\tau, s_i) + \sigma_{BG} \right]$$

$$G(\sqrt{s}, \sqrt{s'}) = \frac{1}{\sqrt{2\pi}\Delta} \cdot \exp\left[-\frac{(\sqrt{s'} - \sqrt{s})^2}{2\Delta^2} \right]$$

$$\sigma_{obs}(m_\tau, s_i) = \int_0^\infty \sigma_{r.c.}(m_\tau, s') \cdot G(\sqrt{s}, \sqrt{s'}) d\sqrt{s'}$$

$$\sigma_{r.c.}(m_\tau, s) = \int_0^{1-\frac{4m_\tau^2}{s}} dx\, F(x) \frac{\sigma_B[m_\tau, s(1-x)]}{|1 - \Pi[s(1-x)]|^2}$$

F(x): E.A.Kuraev,V.S.Fadin , Sov.J.Nucl.Phys. 41(1985)466;
Π(s): F.A. Berends et al. , Nucl. Phys. B57 (1973)381.

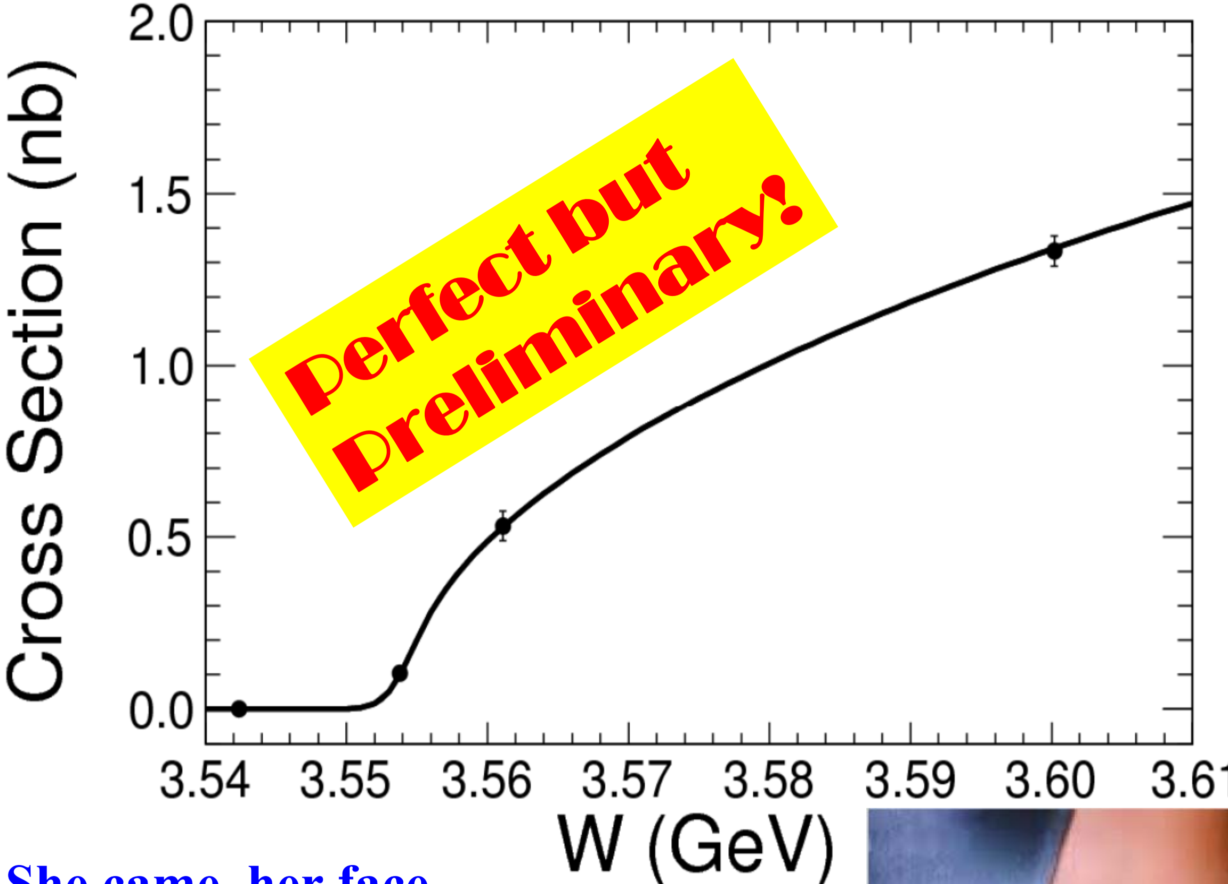
Theoretical accuracy of cross section at the level of 0.1%

$$\sigma(W) = \frac{1}{\sqrt{2\pi}\Delta_E} \int_0^{+\infty} dW' e^{-(W'-W)^2/2\Delta_E^2} \int_0^{\beta^2} dx F_i(x, W') \sigma^0\left(W'\sqrt{1-x}\right)$$

- Energy Spread
- ISR correction
- Coulomb Correction
- FSR Correction
- Vacuum Polarization Correction

$$\sigma^0(W) = \frac{4\pi\alpha^2}{3W^2} \frac{\beta(3-\beta^2)}{2} \frac{F_c(\beta) F_r(\beta)}{\left[1-\Pi(W)\right]^2}$$

τ mass measurement



~0.15 MeV or 9×10^–5^,

0.1 MeV or 6×10^–5^.

Systematic errors	
Source	keV
Theo.	~10
E_{Spread}	~15
E_{Scale}	~70
$E_{Selection}$	~60
Lum.	~1
Sum	~94

She came, her face half hid behind a pipa lute still.

M_τ = 1776.9 … 5 MeV

Summary

1. BESIII: M_τ = similar ± comparable MeV,
   PDG12: $M_\tau = 1776.82 \pm 0.16$ MeV;
2. Universality will be tested at the level of ~0.3%; and Koideo identity is established within the error of ~50keV;
3. Experience is gotten, confidence is built for obtaining in the future the uncertainty ≤ 0.1 MeV;

THANKS

谢谢