τ Mass and its branching ratios measurement at BESIII

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IHEP, Beijing

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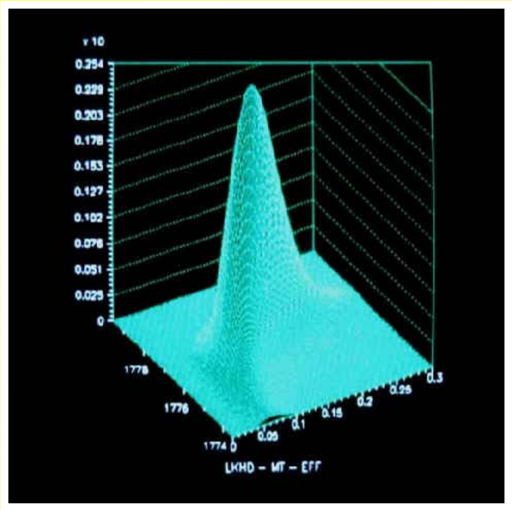
Fundamental parameter

- $M_e = 0.51099892 \pm 0.00000004$ (7.8×10^{-8})
- $M_\mu = 105.658369 \pm 0.000009$ (8.5×10^{-8})
- $M_\tau = 1776.99\,^{+0.29}_{-0.26}$ (1.5×10^{-4})



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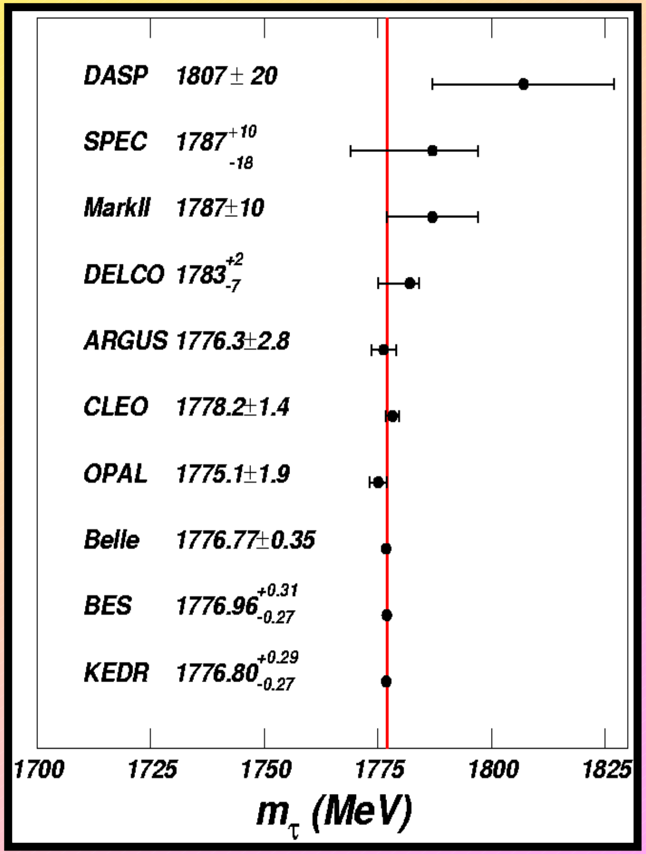
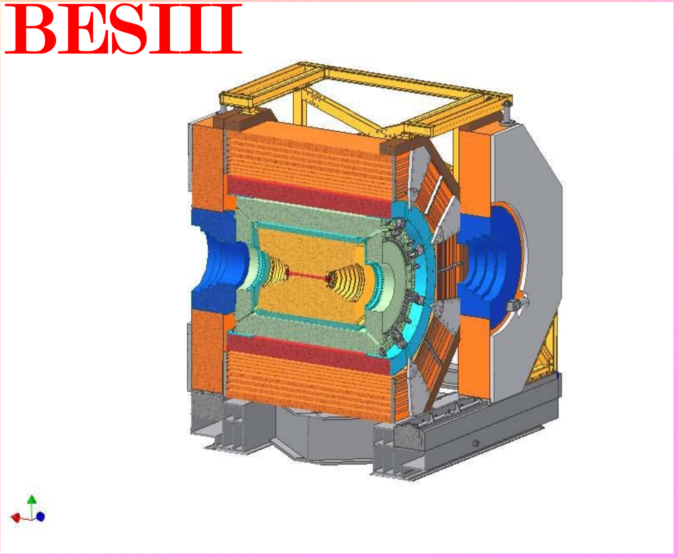
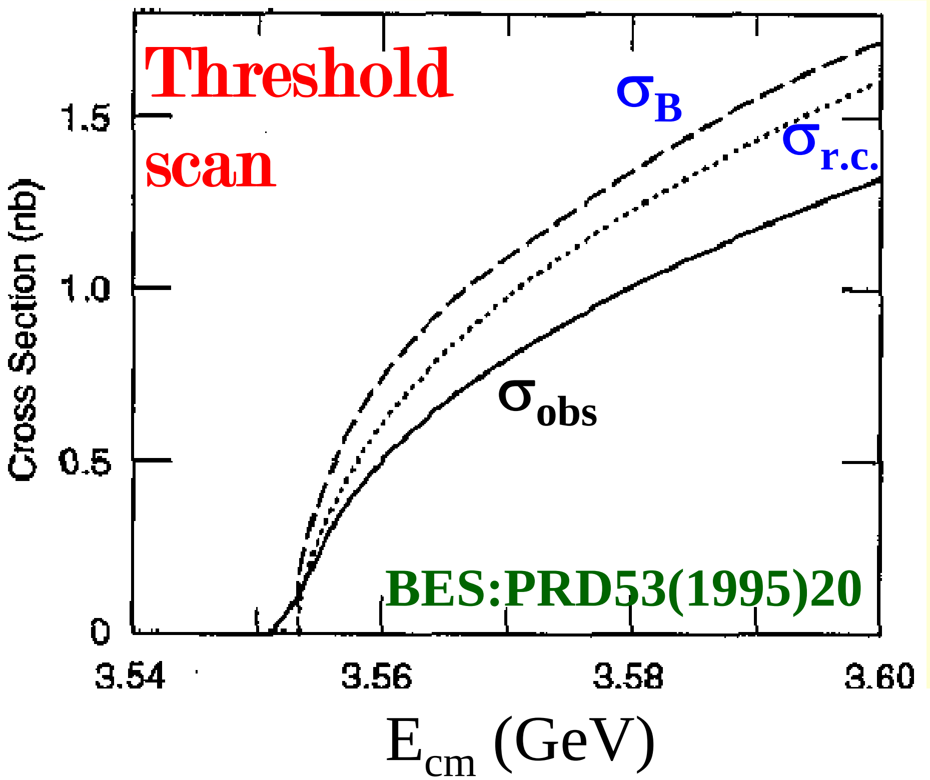






$$LF = \prod_{i=1}^{n} P_i , \quad P_i = \frac{\mu_i^{N_i} e^{-\mu_i}}{N_i !}$$

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

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

σ_B :M.B.Voloshin, PLB556(2003)153.

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

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

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.

τ-mass measurement

1. Statistical optimization
   1) One-parameter fit
   2) Two-parameter fit
   3) Three-parameter fit
2. Systematic study

Statistical optimization

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

Neglecting all experiment uncertainties such as:

Branching fraction: $\mathcal{B}_f$ =0.1736 • 0.1784 ;

[$\mathcal{B}_f = \mathcal{B}_{\tau \to \mu\nu\nu} \bullet \mathcal{B}_{\tau \to e\nu\nu}$, PDG06]

Luminosity $\mathcal{L}$;

Efficiency ε =*14.7%* ;

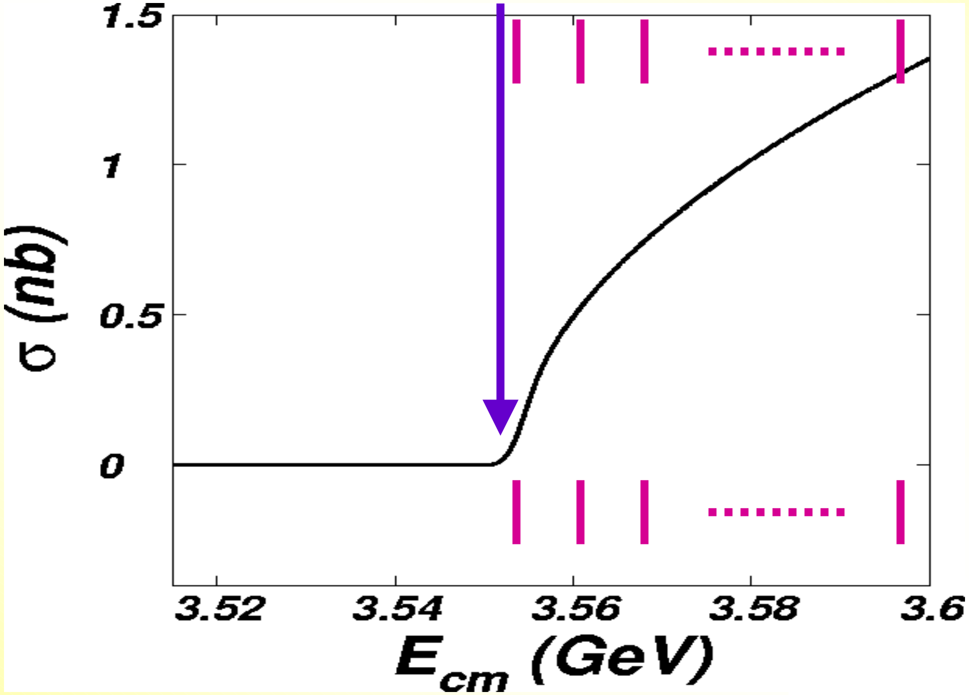
Background σ_{BG} =0 .

Assume : M_τ is known .

To find :

1. **What's the optimal distribution of data taking point;**
2. **How many points are needed in scan experiment;**
3. **How much luminosity is required for certain precision.**

A tentative step



Evenly divided :

1, for E: $E_0 + \delta E$, $\delta E=(E_f - E_0)/n$

2, for lum. : L =$\mathbf{L_{tot}}$ /n

$$\overline{m}_\tau^i = \frac{1}{N_{\rm samp}} \sum_{j=1}^{N_{\rm samp}} m_{\tau j}^i,$$

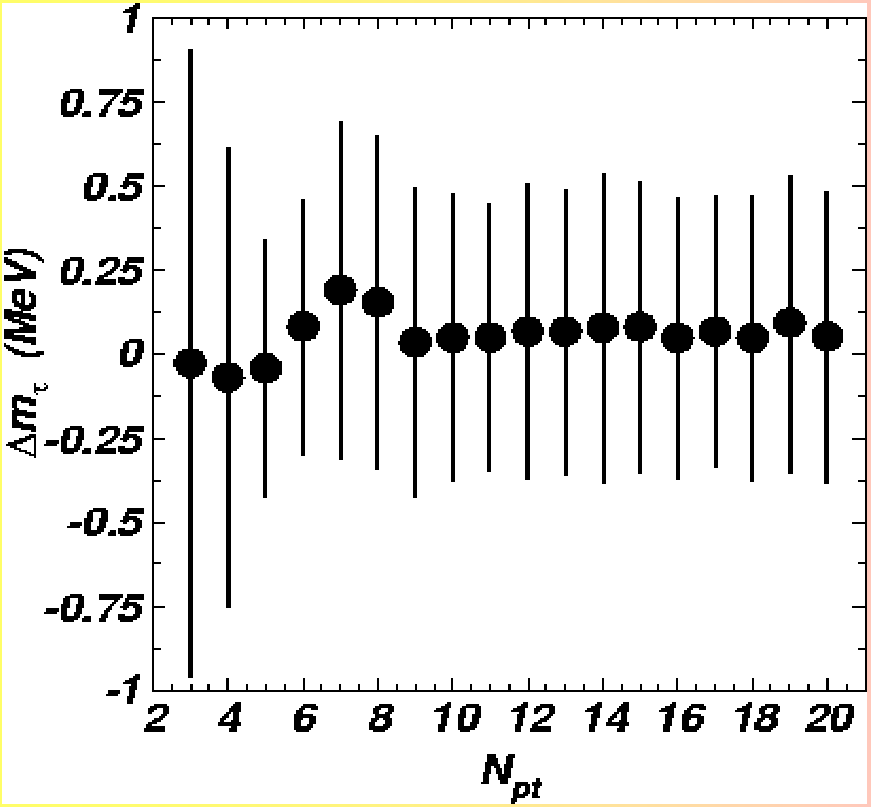
$$S_{m_\tau}^2(m_\tau^i) = \frac{1}{N_{\rm samp}-1} \sum_{j=1}^{N_{\rm samp}} (m_{\tau j}^i - \overline{m}_\tau^i)^2.$$

To eliminate statistical fluctuation, sampling many times (say, 500)

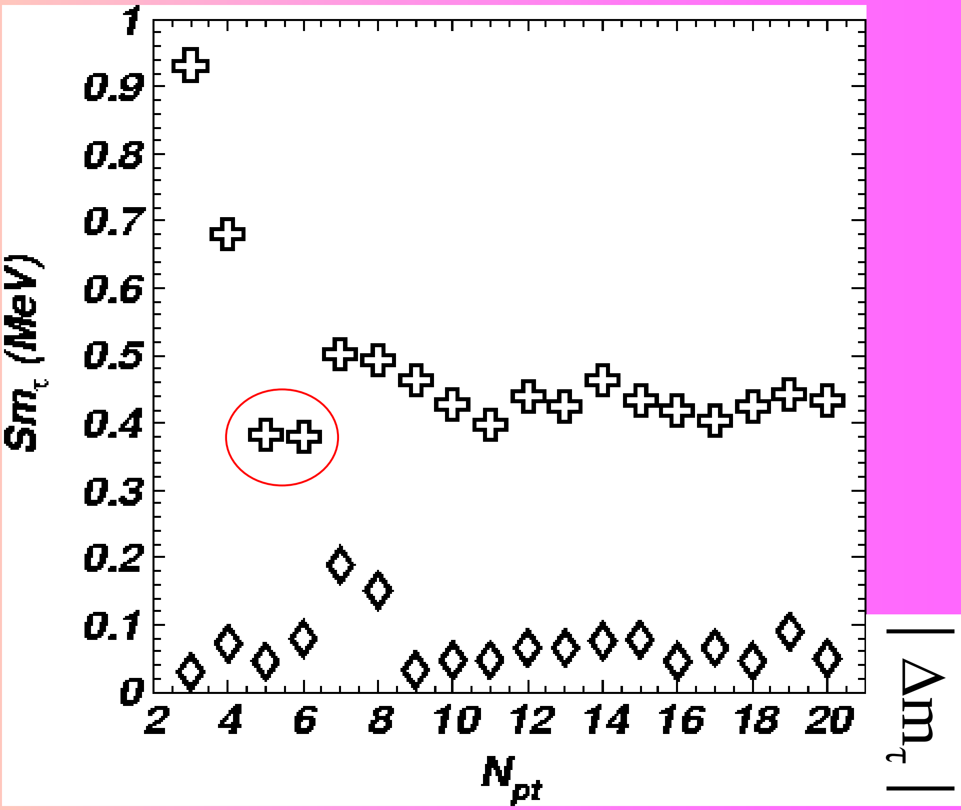
$E_{cm} \subset (3.545, 3.595)$ GeV

$L_{tot} = 30\ pb^{-1}$

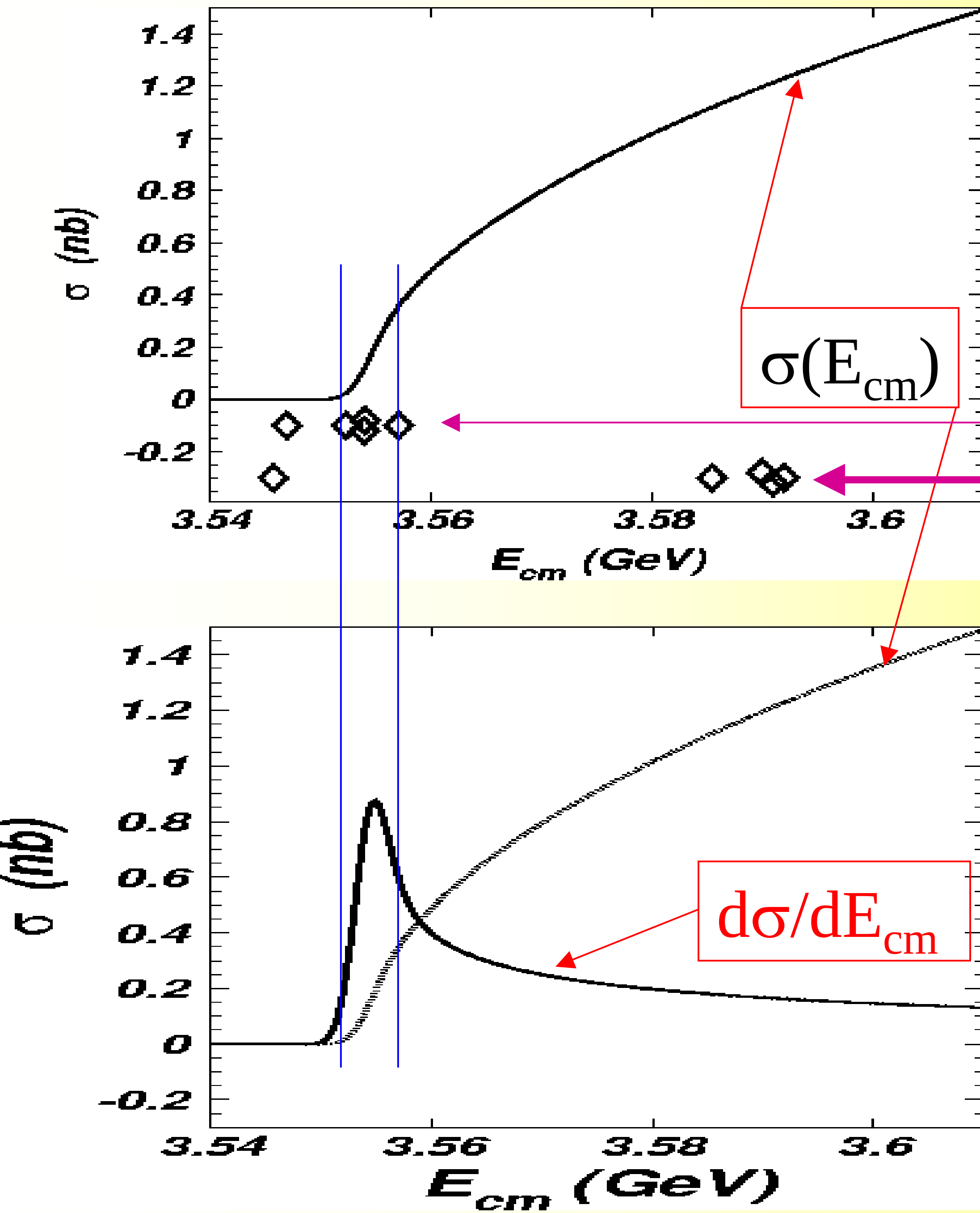
N_{pt} : 3 → 20



$$\Delta m_\tau = \bar{m}_\tau - m_{\tau 0}$$



1. Sm_τ >> Δm_τ , using Sm_τ to evaluate the quality of fit;
2. N_{pt} =5.



Random sampling 100 times:

$E_{cm} \subset (3.545, 3.595)$ GeV

$L_{tot} = 45\ pb^{-1}$

$N_{pt} = 5$;

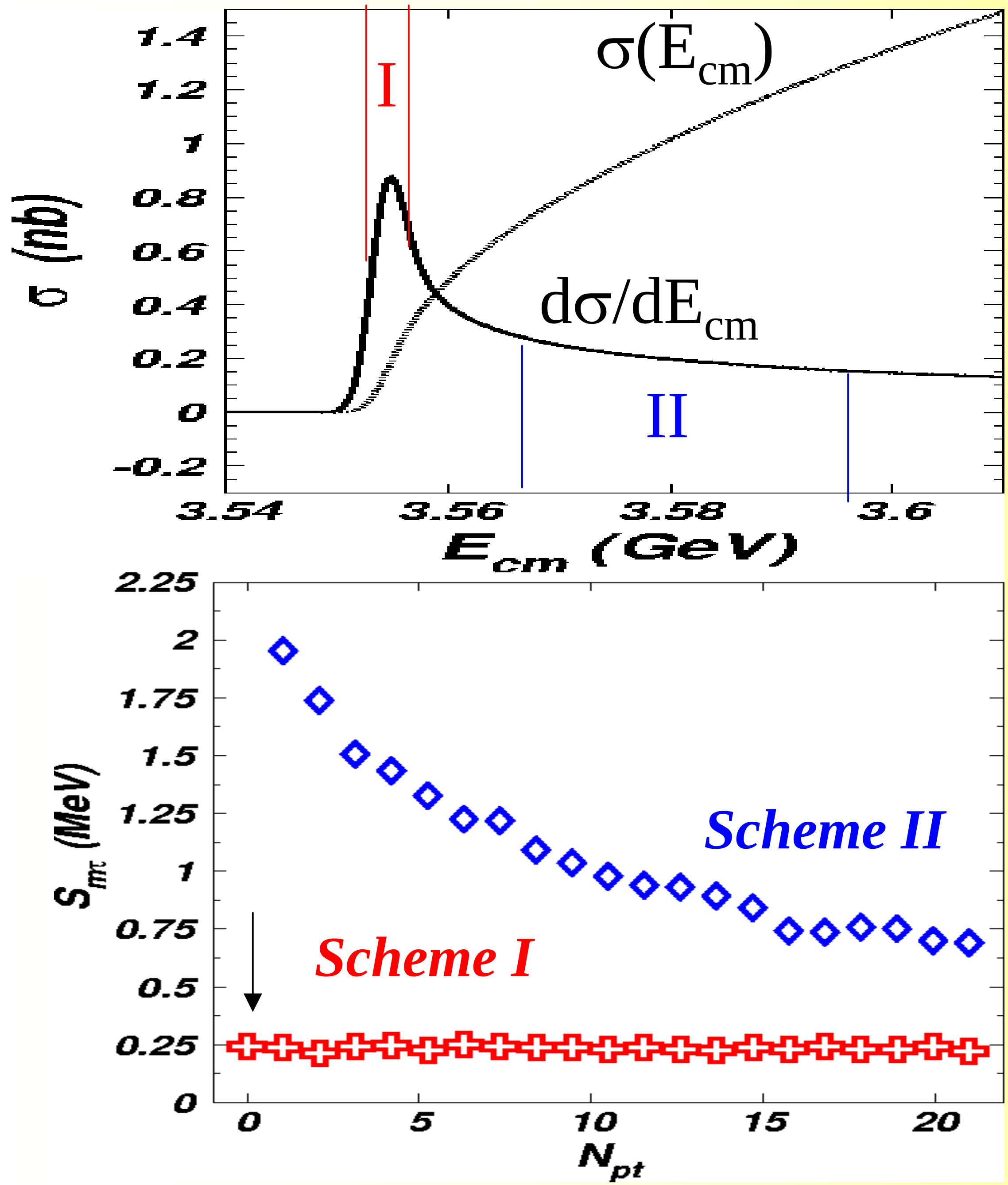
min. $Sm_\tau = 0.147$MeV

max. $Sm_\tau = 1.48$MeV

1. Points near threshold lead to small Sm_τ ;
2. This corresponds to larger derivative of σ

The large derivative position *may be* the optimal data taking point

L=5 pb $^{-1}$ for each point



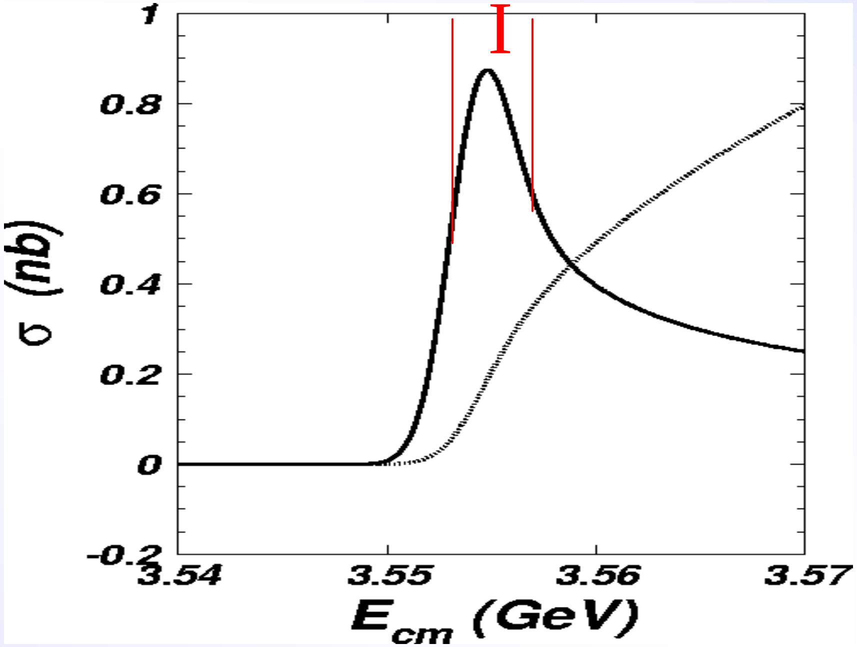
Scheme I:

2 points at region I + N_{pt}(1—20) at region II

Scheme II:

Only N_{pt}(1—20) at region II

The points within region I are more sensitive to fit uncertainty



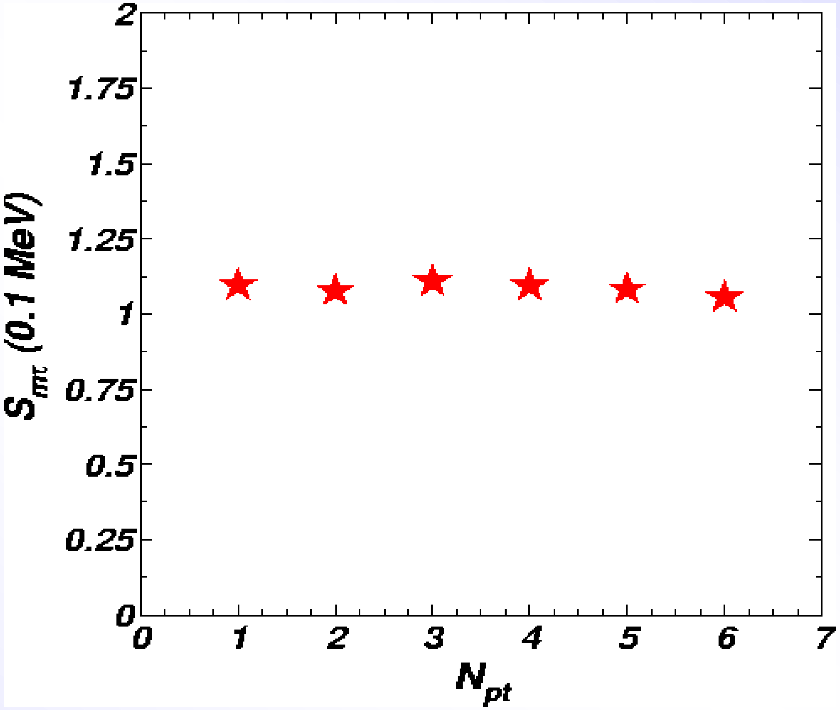
$E_{cm} \subset (3.553, 3.555)$ GeV

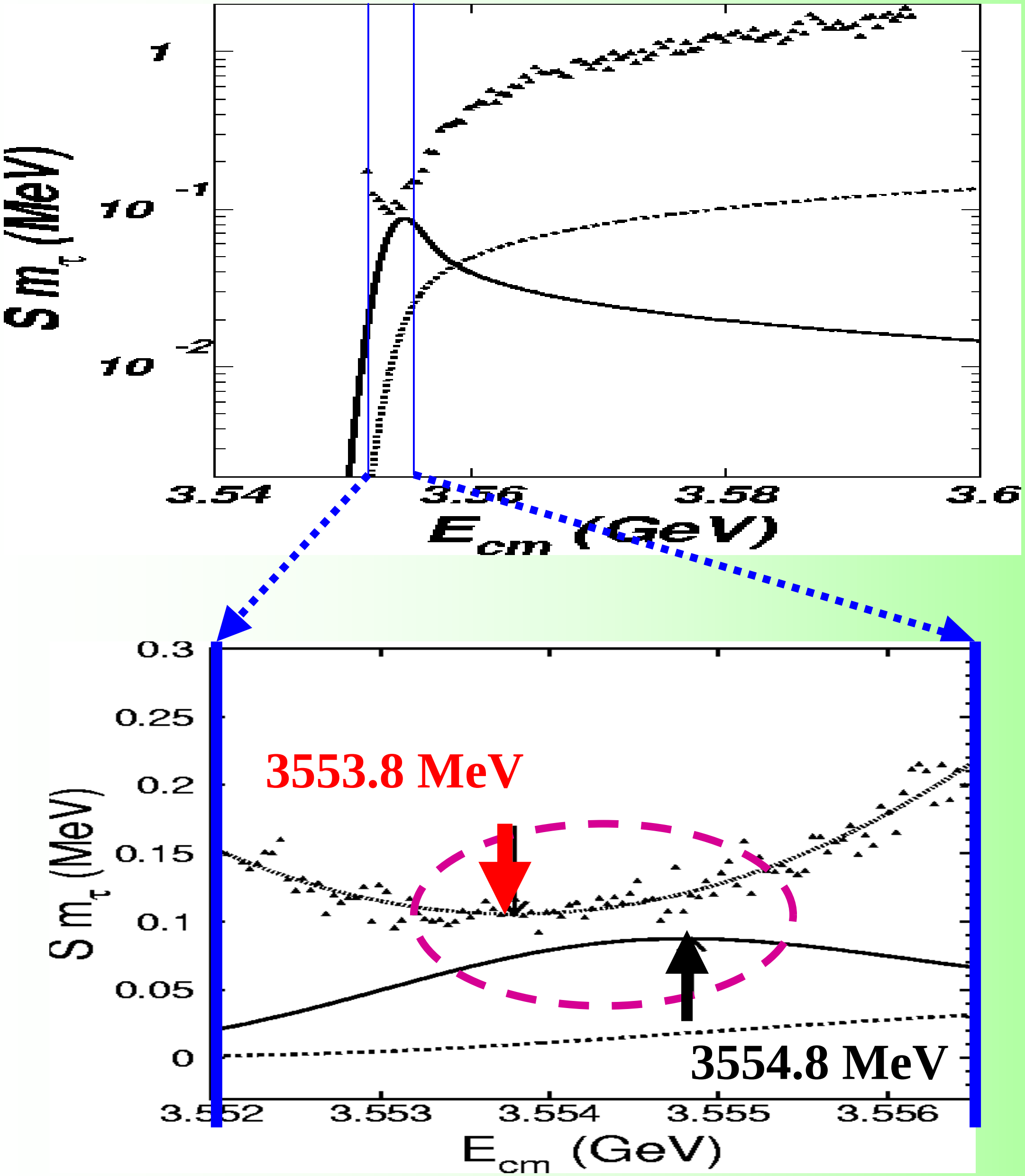
$L_{tot} = 45$ pb $^{-1}$

$N_{pt} = 1$—6;

Within the region I, one point is enough!

Where should this point locate?





$E_{cm} \subset (3.551, 3.595)$ GeV

$L_{tot} = 45\ pb^{-1}$

$N_{pt} = 1$; scan

$E_{cm} = 3553.98$ MeV

$Sm_{\tau} = 0.0956$ MeV

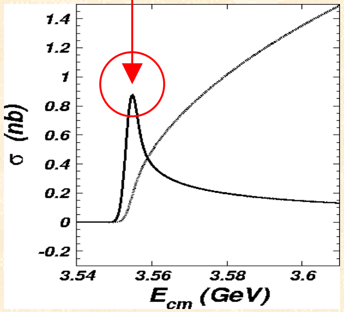
[near threshold]

$E_{cm} = 3554.84$ MeV

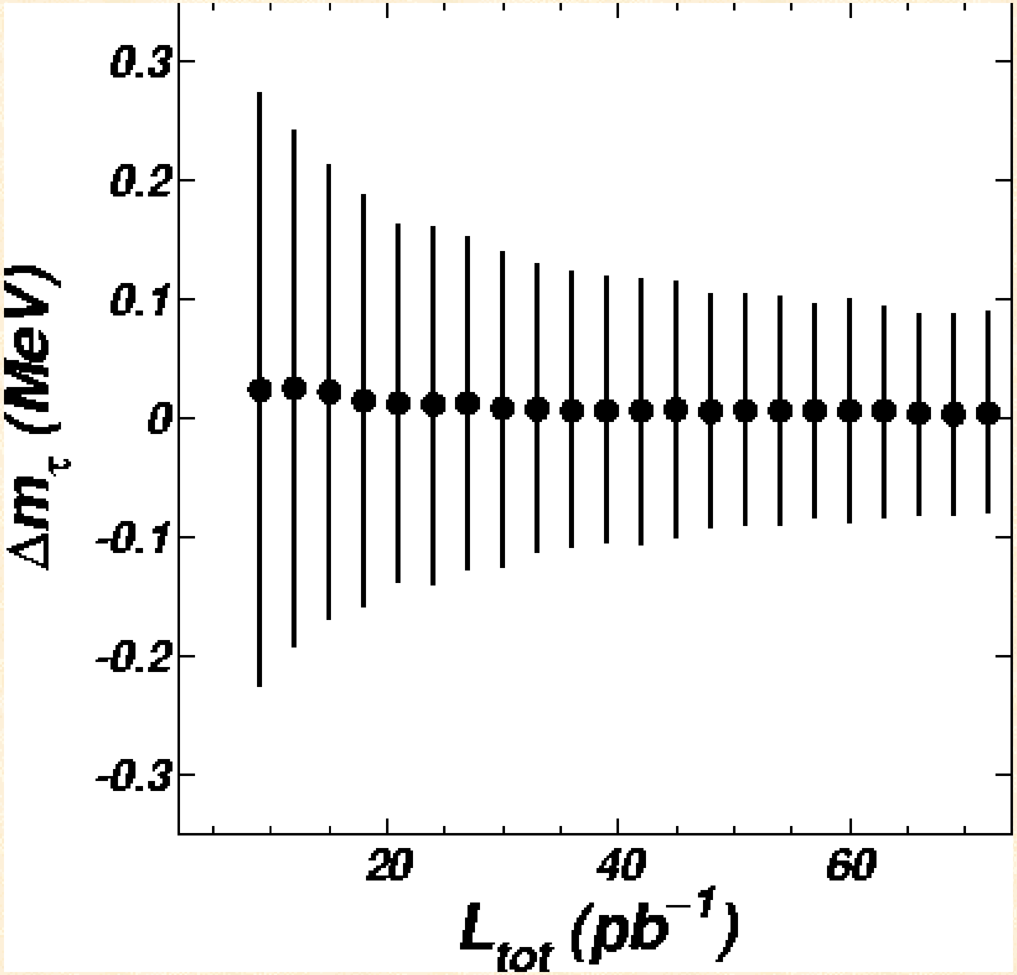
$Sm_{\tau} = 0.100$ MeV

[max $d\sigma/dE_{cm}$]

μe-tagged final state



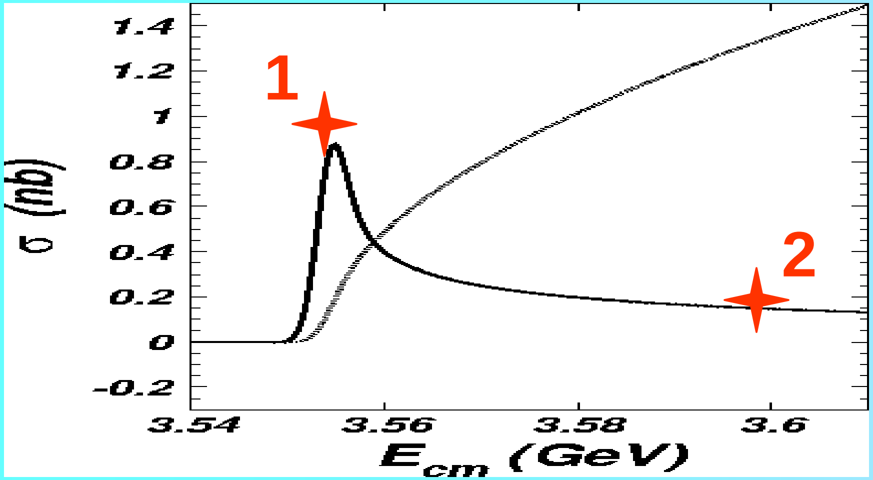
One point
With lum.
L_{tot}

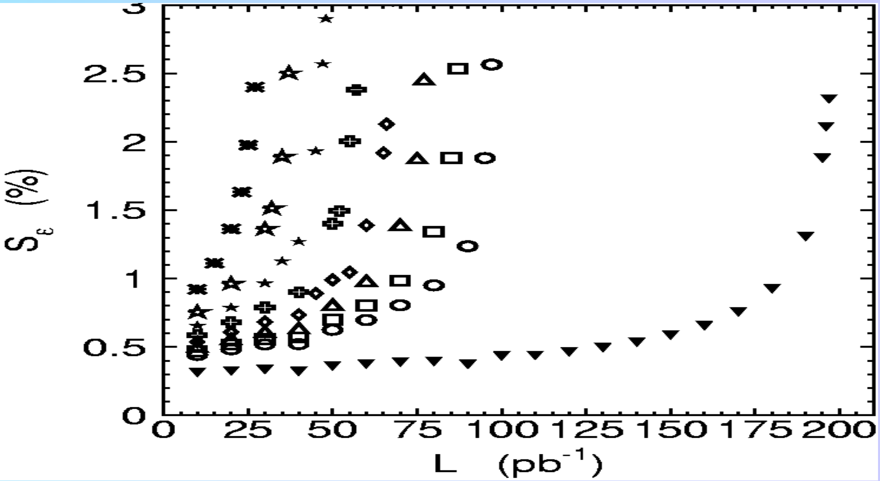


L_{tot} (pb^{-1})	Sm_τ (MeV)
9	0.2488
18	0.1692
27	0.1402
36	0.1213
45	0.1065
54	0.0978
63	0.0904
72	0.0842
100	0.0678
1000	0.0214
10000	0.0068

Two-parameter (m_τ and ε) fit

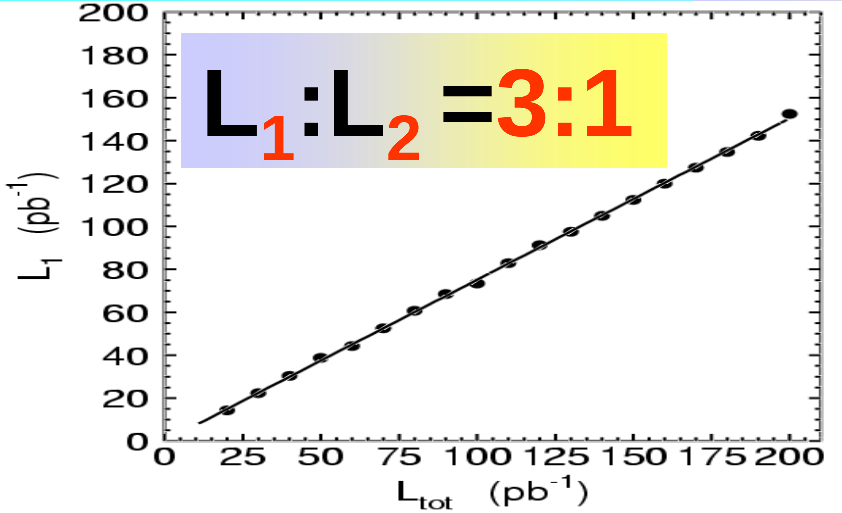
L_2 decrease

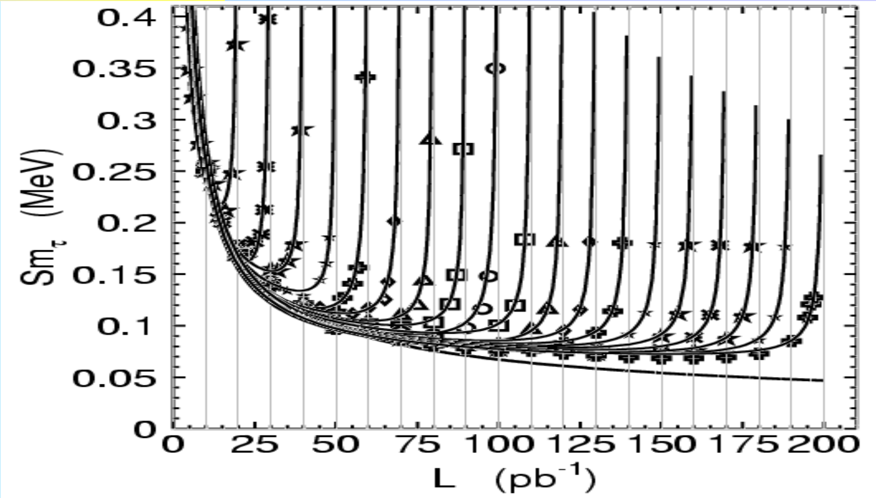




$L_{tot}=L_1+L_2$

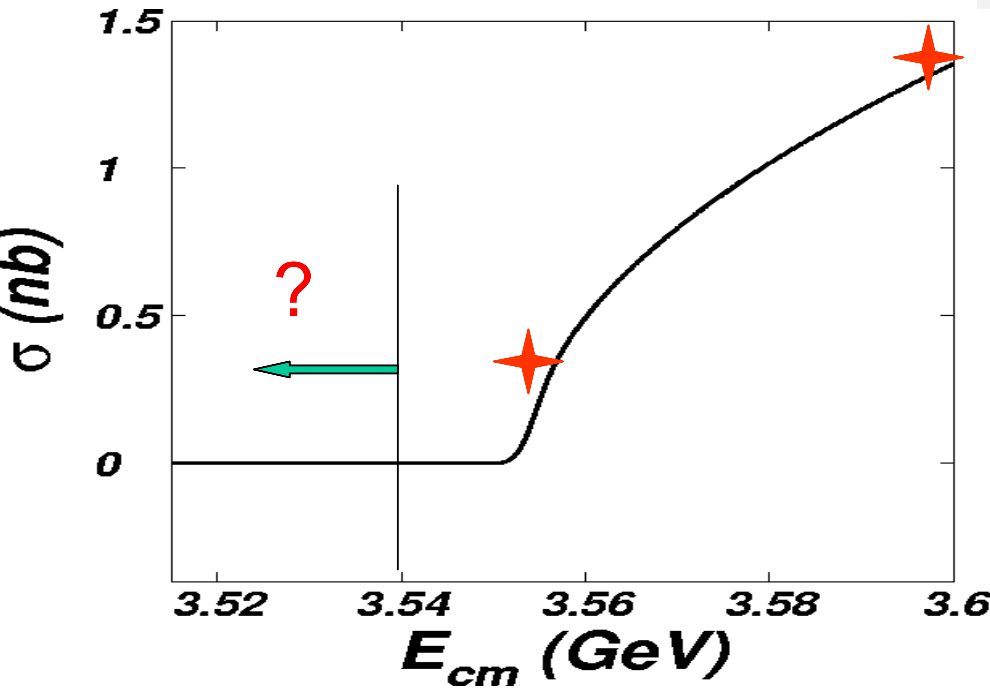
L_1 increase





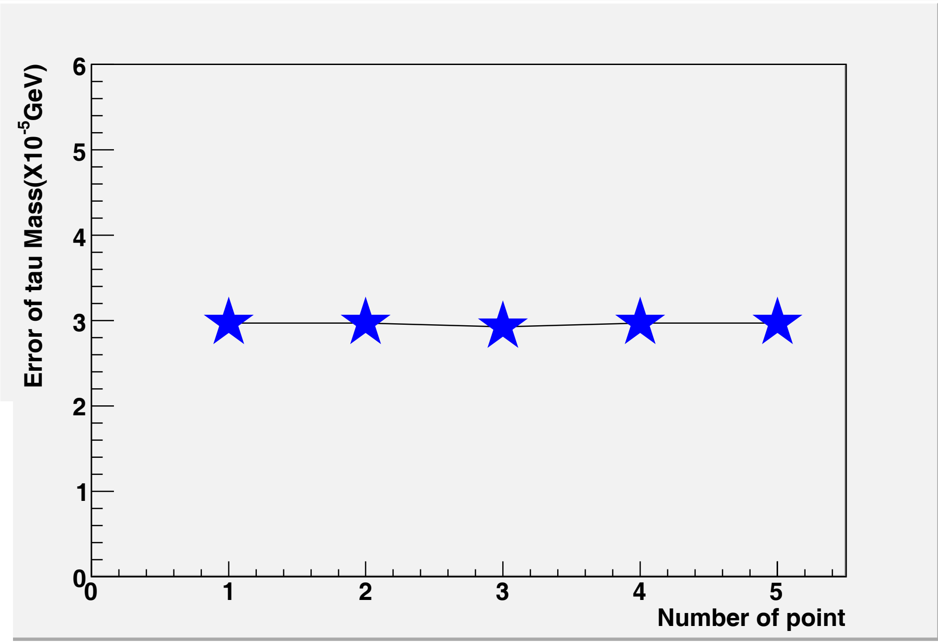
Three-parameter fit

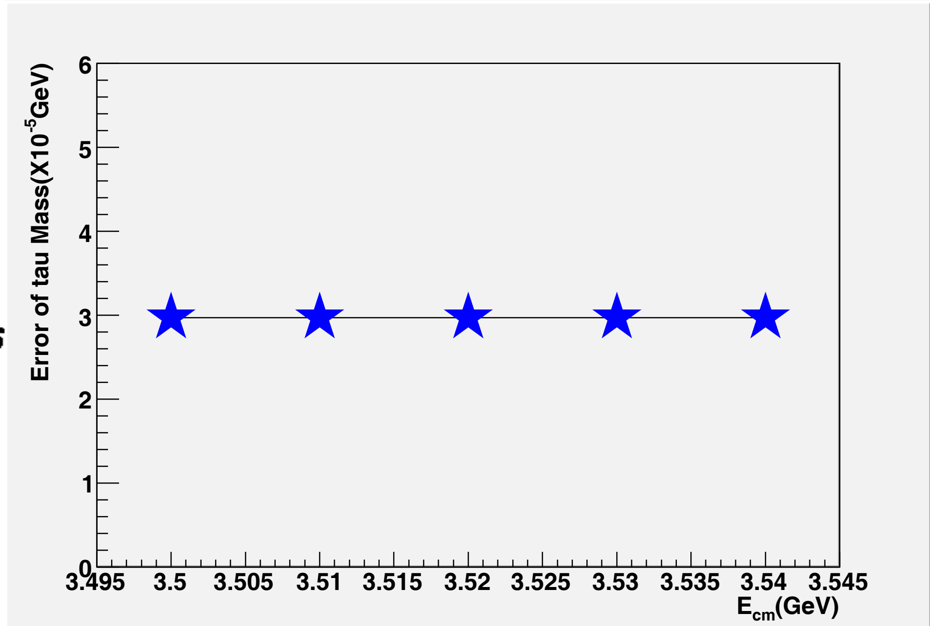
m_τ, ε , σ_{BG} are free parameters



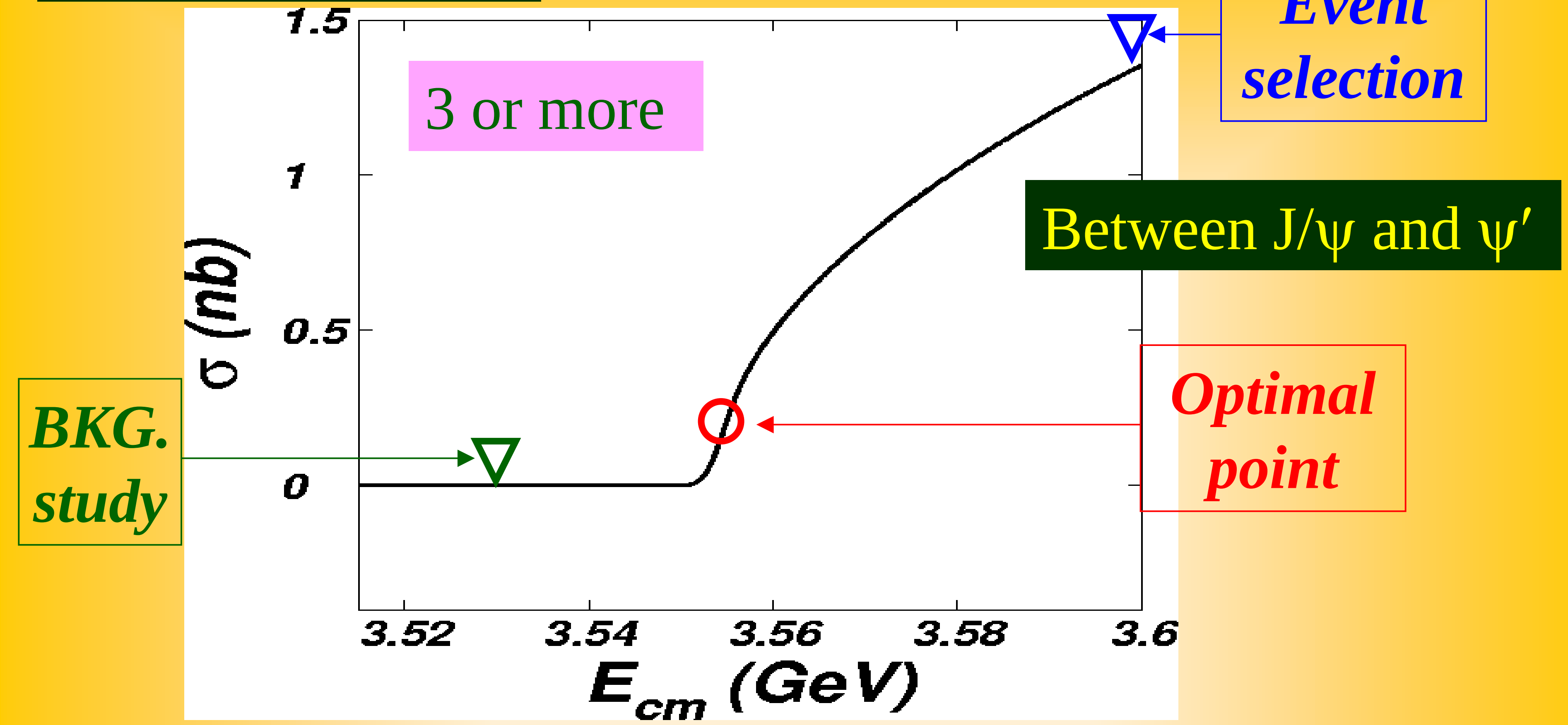
One point is enough

3.5GeV is selected





Data taking design



BESIII Luminosity : 1 ×10 $^{-33}$ cm $^{-2}$ s $^{-1}$ (50%); One day (86400 s) : 43.2 pb $^{-1}$ (μe-tagged final state) Three days, eμ-tag, at BESIII ➔ Sm_τ : ~ 0.1 MeV

M_τ =1776.99 ±0.1 MeV

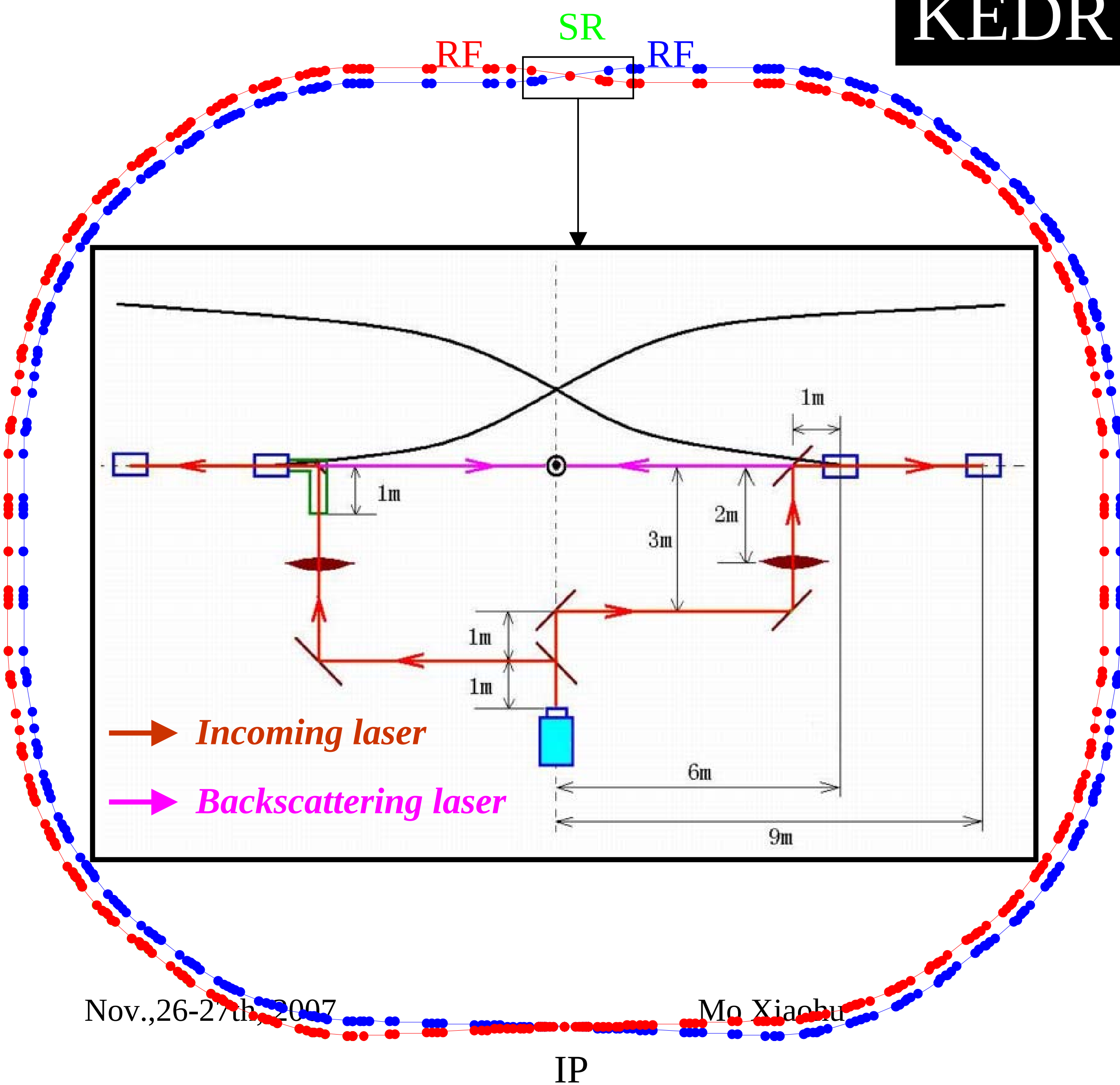
Systematic Uncertainty Study

Summary:systematic (one-parameter case)

Term	δm_τ (10^{-3} MeV)	$\delta m_\tau / m_\tau$ (10^{-6})
Luminosity (2%)	14	7.9
Efficiency (2%)	14	7.9
* *Branching Fraction (0.5%)*	3.5	2.0
Background (10%)	1.7	1.0
* *Energy spread (30%)*	3.0	1.7
* *Theoretical accuracy*	3.0	1.7
* *Energy scale*	100	56.3
Total	**102**	**57.5**

BEPC II Storage ring: Large angle, double-ring

KEDR at Novosibirsk



Compton Backscattering technique, accuracy up to 5×10^{-5}

The uncertainty of beam energy can be at the level of 0.09MeV

Branching ratio measurement

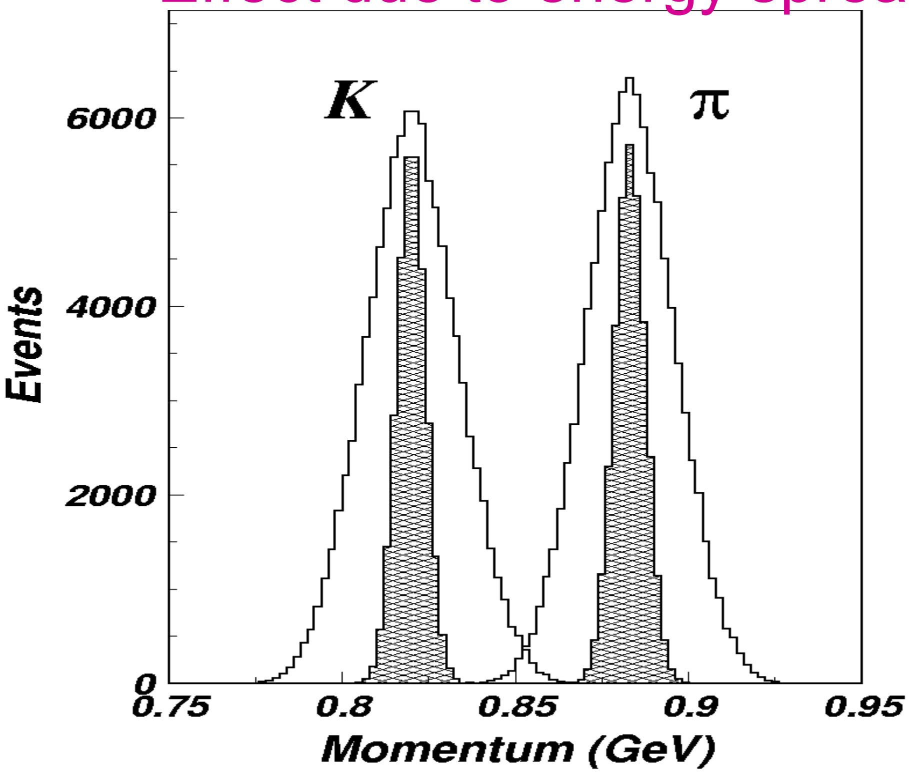
1. eμ final state
2. ππ&KK final states
3. Suggestion for BESIII data taking

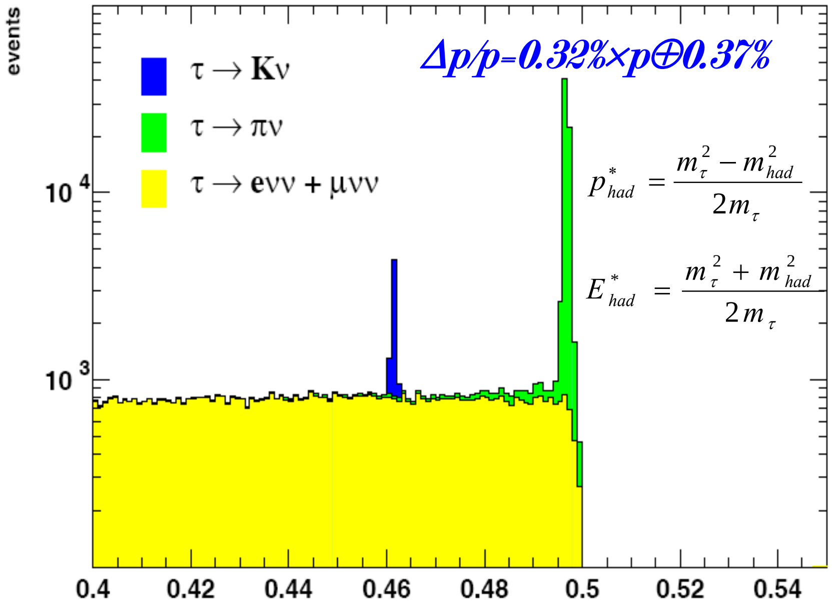
$\pi\pi$ &KK final state

τ-pair at rest :(1) $\tau^{\pm}\rightarrow\pi^{\pm}+\nu_{\tau}$;

(2) $\tau^{\pm}\rightarrow K^{\pm}+\nu_{\tau}$;

Effect due to energy spread





Achim Stahl ,Int. J. of Mod. Phys. A Vol.21,No.27(2006)5667-5674

E_{cm}=3.554 GeV (**τ pair threshold**)

m_τ = 1.7769 GeV

m_π = 0.13497 GeV

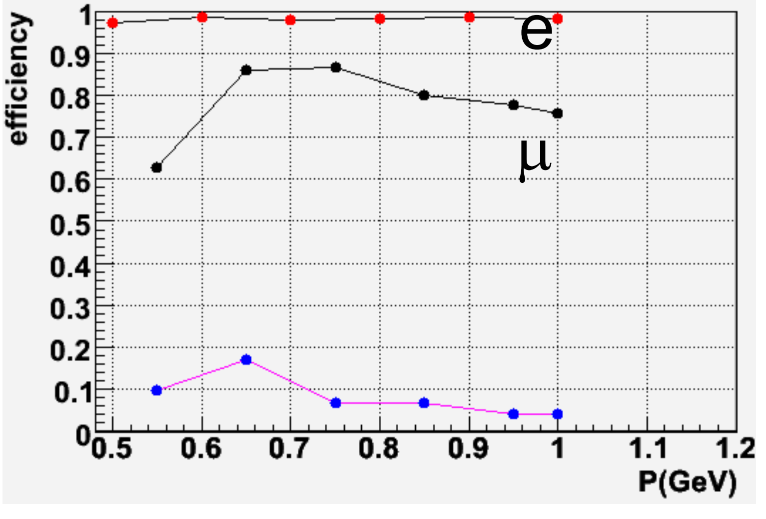
m_K = 0.49367 GeV

p_π = 0.883 GeV

p_K = 0.820 GeV

Result of eμ

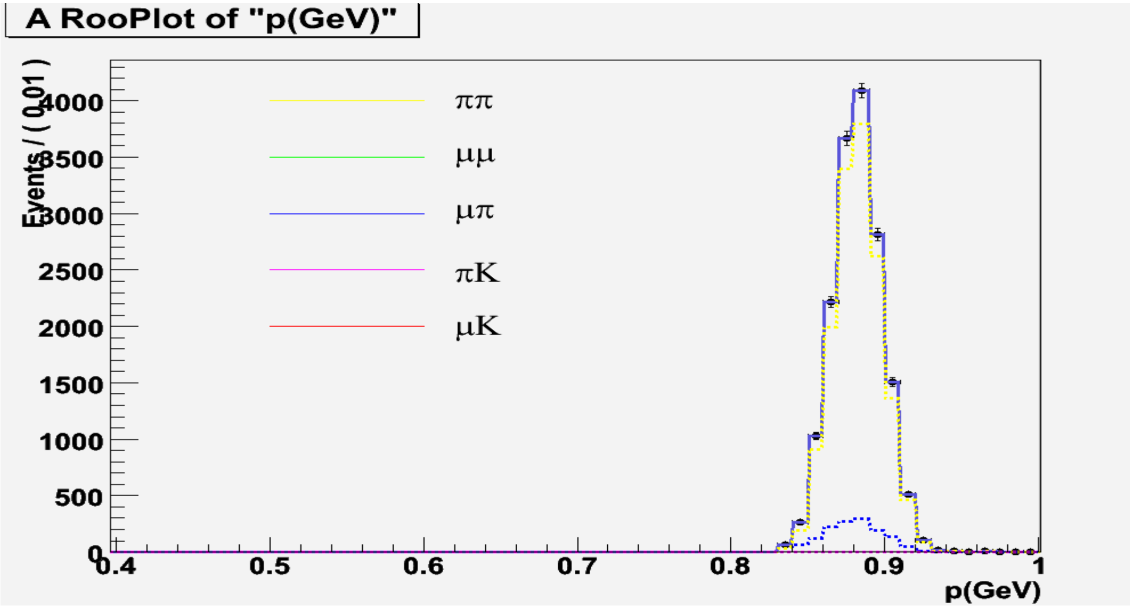
	N-Gen	N-Select	N-norm
ee	20k	82	42.12±4.66
e μ	20k	12173	12173 ± 130.23
e π	20k	932	585.17 ± 19.74
eK	20k	931	37.05 ± 1.74
e ρ	50k	669	393.06 ± 15.39



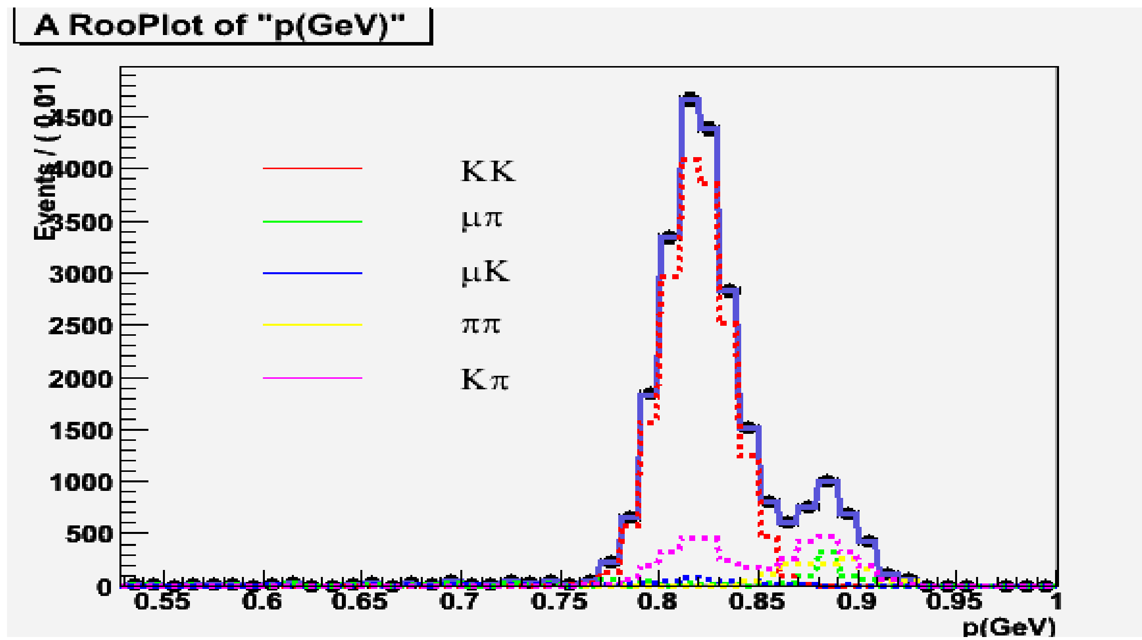
selection efficiency

$\varepsilon_{e\mu} = 60.9\%$

$R_{bg} = 8.0\%$



$\varepsilon_{\pi\pi}$=37.22% ;
R_{bg}=9.02%.



ε_{KK}=44.44% ;
R_{bg}=28.83%.

Study of eμ,ππ,KK final states near τ threshold at BESIII

$\tau^- \to e^- \nu\nu$, $\tau^+ \to \mu^+ \nu\nu$
@3.6GeV

Statistic error	L (pb)	Time (day)
10^{-2}	196	2.3
10^{-3} (PDG: 0.3%)	1.96×10^4	227.3

$\tau^\pm \to \pi^\pm \nu$
@3.554GeV

Statistic error	L (pb)	Time (day)
10^{-1}	1.96×10^2	2.27
10^{-2} (PDG: 0.6%)	1.97×10^4	227.3

$\tau^\pm \to K^\pm \nu$;
@3.554GeV

Statistic error	L (pb)	Time (day)
10^{-1}	4.8×10^4	551.8
10^{-2} (PDG: 3.3%)	4.8×10^6	55176

(More detailed studies are in progress)

Summary

➢ Optimization study indicates at BESIII short period of time is enough to obtain high statistical precision for τ mass :

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 is to be adopted to decrease the uncertainty of beam energy measurement at BEPCII.

➢For τ-pair decay, one-year's data taking time is required to obtain reasonable precision at BESIII .

Thanks a lot !

Backup

Statistical optimization

Neglecting all experiment uncertainties

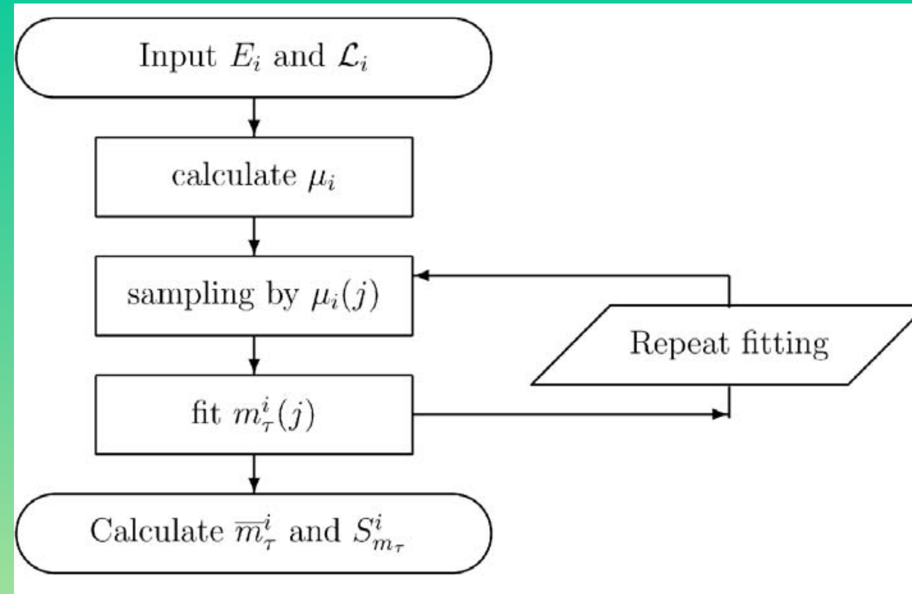
Luminosity $\mathcal{L}$;

Efficiency $\varepsilon = 14.7\%$;

Branching fraction: $\mathcal{B}_f = 0.1736 \bullet 0.1784$;

[$\mathcal{B}_f = \mathcal{B}_{\tau \to \mu\nu\nu} \bullet \mathcal{B}_{\tau \to e\nu\nu}$, PDG04]

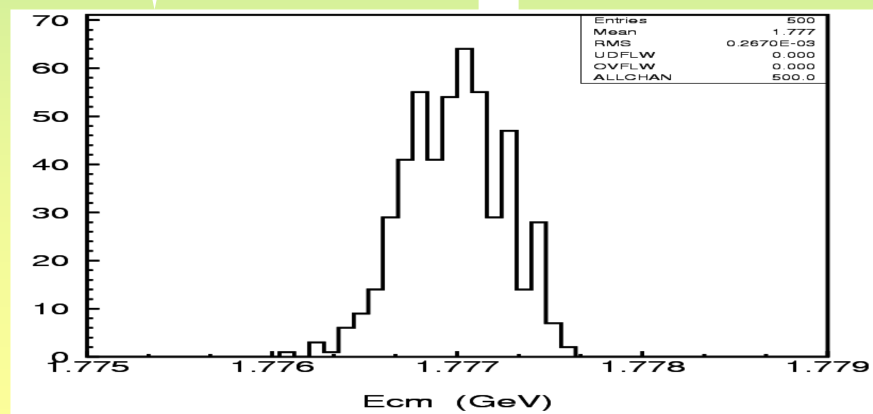
Background $\sigma_{BG} = 0$.



Eliminate statistic fluctuation

$$\overline{m}_\tau^i = \frac{1}{N_{samp}} \sum_{j=1}^{N_{samp}} m_{\tau j}^i,$$

$$S_{m_\tau}^2(m_\tau^i) = \frac{1}{N_{samp}-1} \sum_{j=1}^{N_{samp}} (m_{\tau j}^i - \overline{m}_\tau^i)^2.$$



Assume : M_τ is known .

To find :

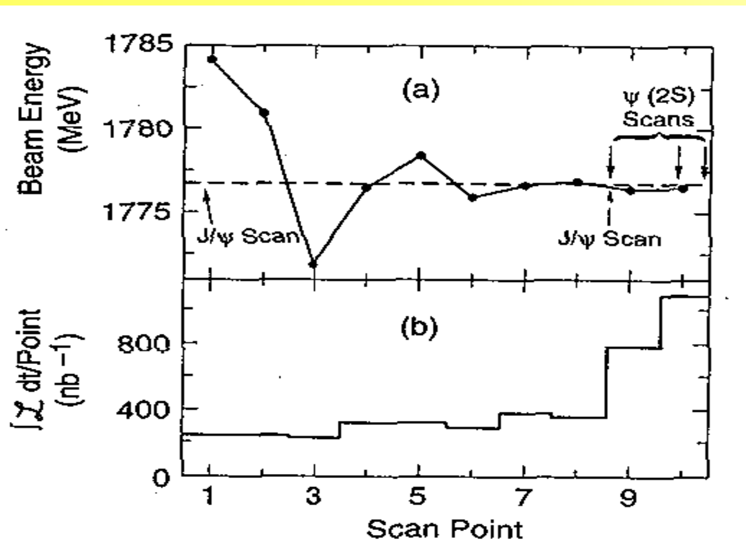
1. **What's the optimal distribution of data taking point;**
2. **How many points are needed in scan experiment;**
3. **How much luminosity is required for certain precision.**

Pseudomass method

- ARGUS
- CLEO
- OPAL
- Belle
- KEDR

Threshold scan

- BES



Points : 12 ,

Lum. : 5 pb^{-1}

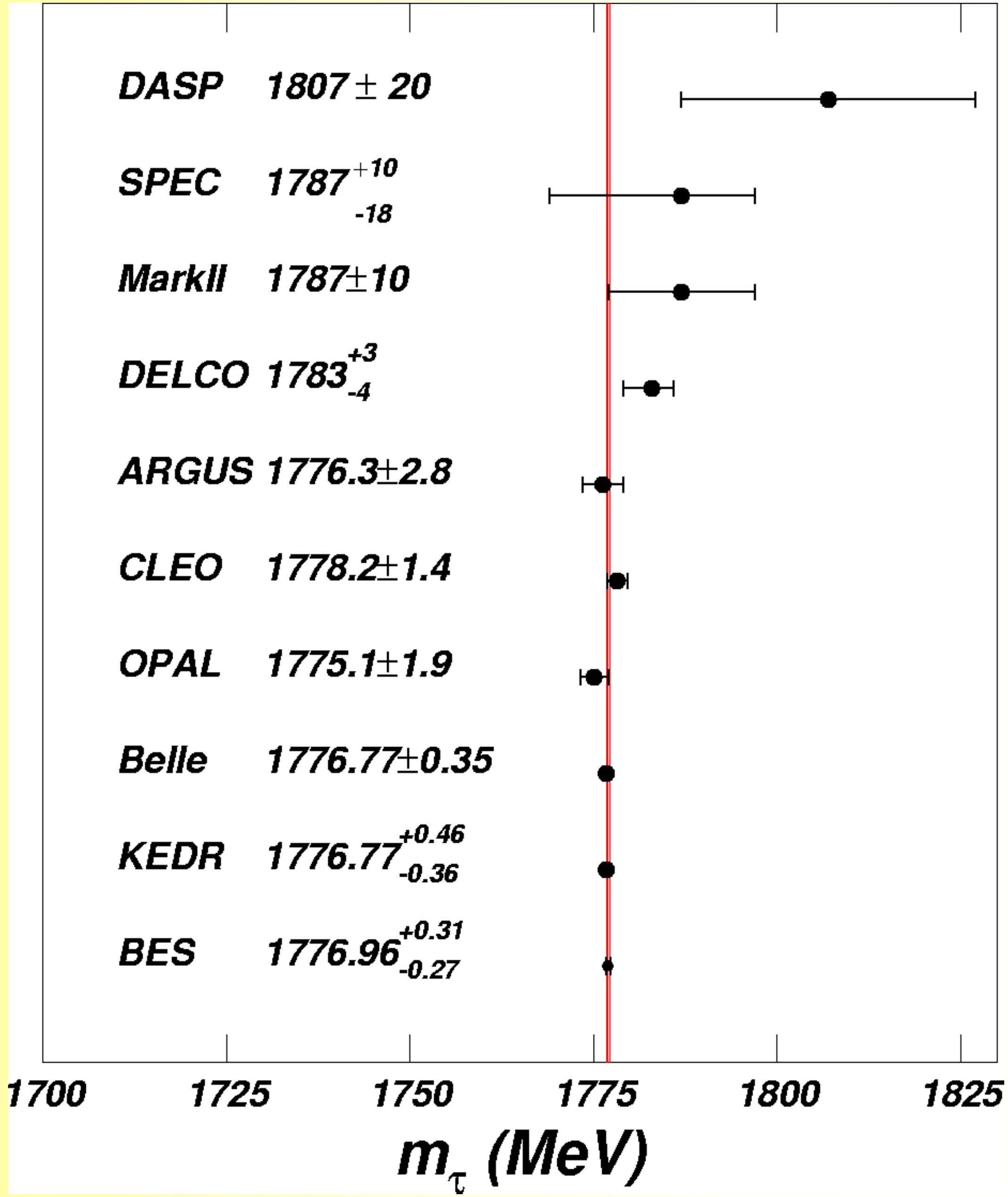
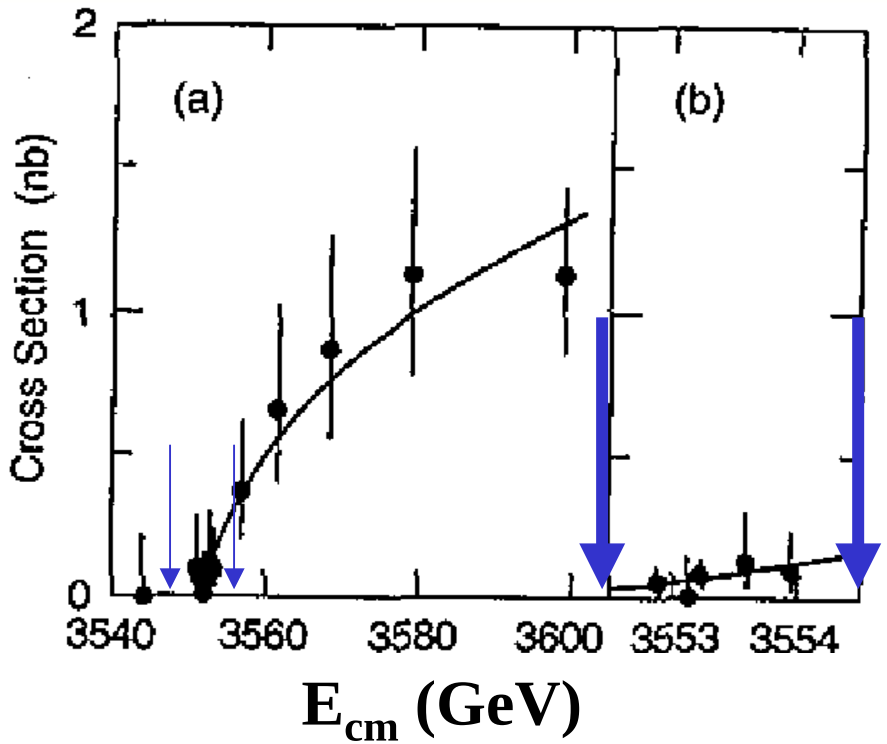


TABLE II. A chronological summary of the $\tau^+\tau^-$ threshold scan data; W denotes the corrected c.m. energy, Δ the spread in c.m. energy [12] [see Eq. (6)], and $\mathcal{L}$ the integrated luminosity.

Scan point	$W/2$ (MeV)	Δ (MeV)	$\mathcal{L}$ (nb^{-1})	N ($e\mu$ events)
1	1784.19	1.34	245.8	2
2	1780.99	1.33	248.9	1
3	1772.09	1.36	232.8	0
4	1776.57	1.37	323.0	0
5	1778.49	1.44	322.5	2
6	1775.95	1.43	296.9	0
7	1776.75	1.47	384.0	0
8	1776.98	1.47	360.8	1
9	1776.45	1.44	794.1	0
10	1776.62	1.40	1109.1	1
11	1799.51	1.44	499.7	5
12	1789.55	1.43	250.0	2

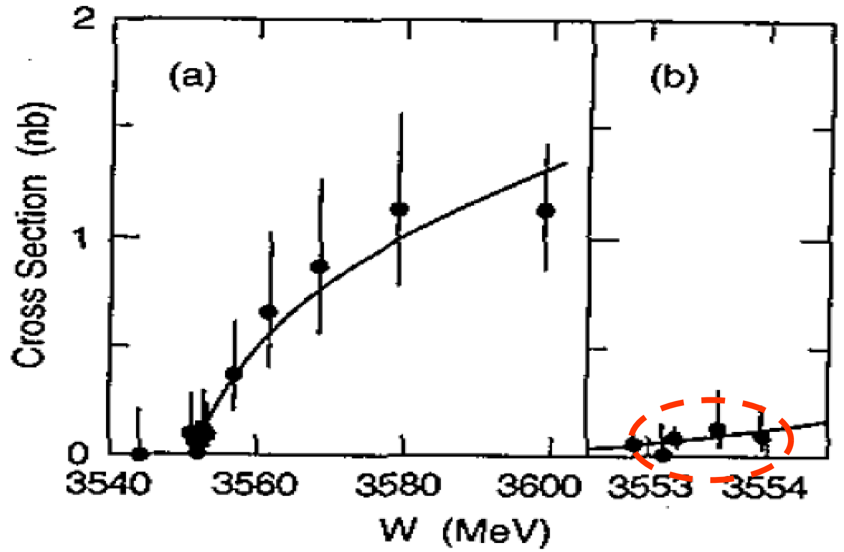


$$M_\tau = 1776.96 ^{+0.18}_{-0.21} {}^{+0.25}_{-0.17} \text{ MeV}$$

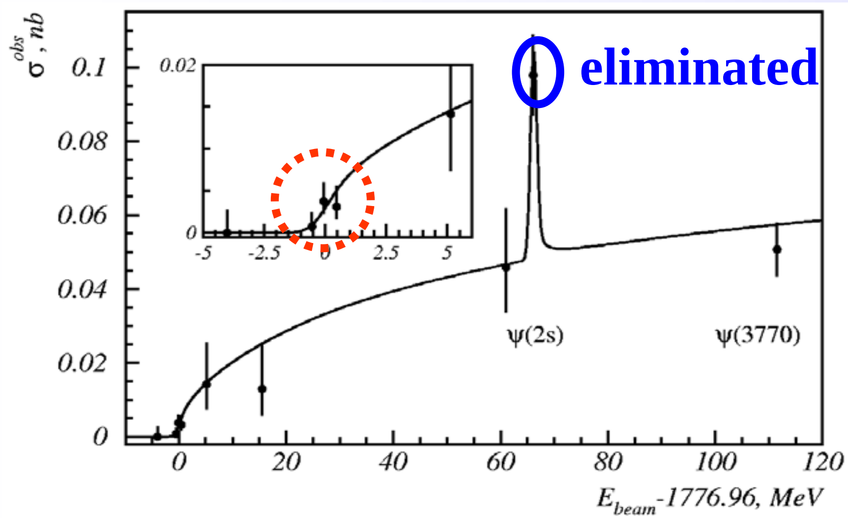
$$\delta M_\tau / M_\tau = 1.7 \times 10^{-4}$$

BES results:
the stat. (0.18 ⊕ 0.21)
is compatible with
the syst. (0.25 ⊕ 0.17)

BES:PRD53(1996)20



KEDR:hep-ex/0611046



Fix all other fit parameters except for M_τ

	BES				KEDR		
Scan point	$W/2$ (MeV)	L (nb^{-1})	N	Scan point	$W/2$ (MeV)	L (nb^{-1})	N
1	1784.19	245.8	9	1	1771.945	668	0
2	1780.99	248.9	7	2*	1776.408	1382	1
3	1772.09	232.8	0	3*	1776.896	1605	6
4*	1776.57	323.0	0	4*	1777.419	1288	4
5	1778.49	322.5	5	5	1782.103	283	4
6	1775.95	296.9	1	6	1792.457	233	3
7*	1776.75	384.0	2	7	1837.994	305	14
8*	1776.98	360.8	1	8	1888.521	967	49
9	1776.45	794.1	1				
10*	1776.62	1109.1	3				
11	1799.51	499.7	24				
12	1789.55	250.0	12				
all	$1776.93^{+0.19}_{-0.20}$				$1776.84^{+0.19}_{-0.20}$		
inside	$1777.06^{+0.22}_{-0.23}$				$1776.83^{+0.19}_{-0.20}$		
outside	$1776.84^{+0.33}_{-0.34}$				$1779.3^{+1.8}_{-3.6}$		

BESIII Luminosity : 1 ×10 $^{-33}$ cm $^{-2}$ s $^{-1}$ (50%)

One day (86400 s) : 43.2 pb $^{-1}$ (μe-tagged final state)

Two days, eμ-tag, at BESIII → Sm_τ : < 0.1 MeV

ee, eμ, eh, μμ, μh, hh (h: hadron, like π, K)

N(ee, eμ, eh, μμ, μh, hh) > 5 * N(eμ)

Multi-channel-tag, one day,

at BESIII → Sm_τ : < 0.05 MeV

Statistic uncertainty < 0.017 MeV

one week, multi-channel-tag

[One week, eμ-tag, Sm_τ : < 0.025 MeV]

BES:PRD53(1995)20

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

$$\sigma_{obs}(m_\tau, s_i) = \int_0^\infty d\sqrt{s'}\; G\left(\sqrt{s}, \sqrt{s'}\right) \int_0^{1-\frac{4m_\tau^2}{s}} dx\, F(x)\, \frac{\sigma_B\left[m_\tau, s(1-x)\right]}{\left|1-\Pi\left[s(1-x)\right]\right|^2}$$

$\sigma_B(m_\tau, s)$ Accuracy Effect of Theoretical Formula

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

Energy spread, variation form

$s=(E_{cm})^2$

Energy scale, variation form

Study of systematic uncertainty

1. **Theoretical accuracy**
2. **Energy spread ΔE**
3. **Energy scale**
4. **Luminosity**
5. **Efficiency**
6. **Background analysis**

E_{cm} = 3554 MeV

L_{tot} =45 pb^{-1}

m_τ = 1776.99 MeV

Accuracy Effect of Theoretical Formula

σ_{old} [BES, PRD53(1995)20] fit results:

m_τ = 1777.028 MeV , Δm_τ = 0.105 MeV

σ_{new} [M.B.Voloshin, PLB556(2003)153] fit results:

m_τ = 1777.031 MeV , Δm_τ = 0.094 MeV

$\delta m_\tau = | m_\tau(new) - m_\tau(old) | < 3 \times 10^{-3}$ MeV

Uncertainty due to accuracy of cross section at the level of **3×10^{-3} MeV**

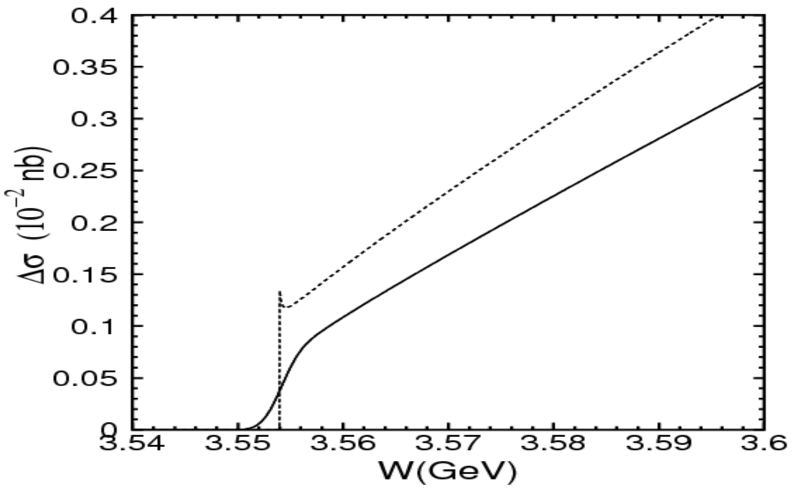
High accurate theoretical cross section

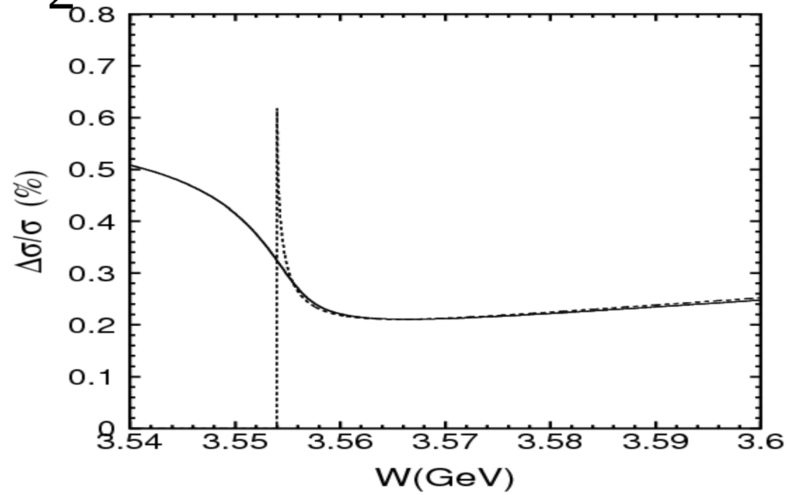
$$\bar{\sigma}^*(v) = \frac{2\pi\alpha^2}{3s_2} v(3-v^2)F_c(v)\left(1+\frac{\alpha}{\pi}S(v)-\frac{\alpha\pi}{2v}-\frac{\alpha\pi v}{2}\right) \quad \mathcal{O}(10^{-3})$$

$$\bar{\sigma}(v) = \frac{2\pi\alpha^2}{3s} v(3-v^2)F_c(v)\left(1+\frac{\alpha}{\pi}S(v)-\frac{\pi\alpha}{2v}+h(v)\right) \quad \mathcal{O}(10^{-4})$$

$$\Delta\sigma = \bar{\sigma}(v) - \bar{\sigma}^*(v) = \sigma_0(v)F_c(v)\left(h(v)+\frac{\alpha\pi v}{2}\right)$$

M.B.Voloshin,
PLB556(2003)153.





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

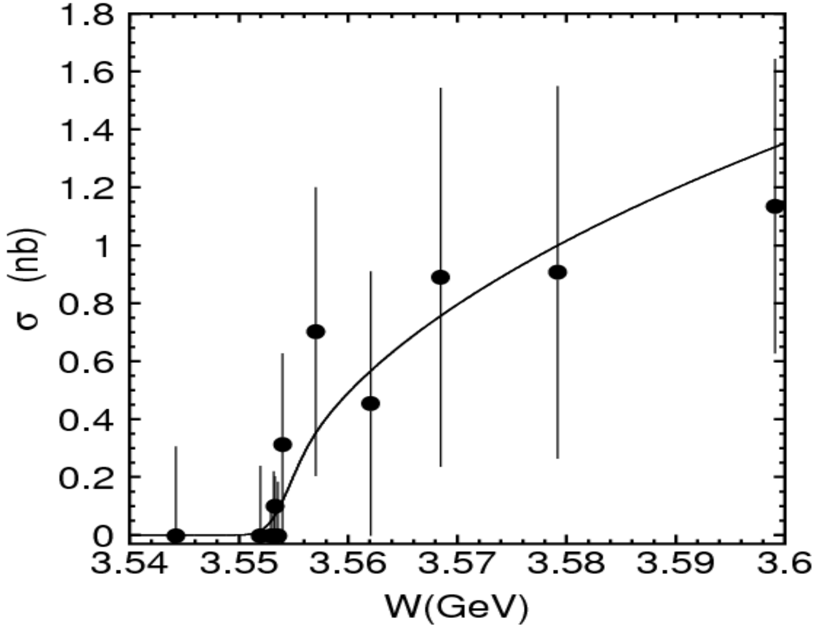
F(x): ***E.A.Kuraev,V.S.Fadin ,***
Sov.J.Nucl.Phys. 41(1985)466;
Π(s): ***F.A. Berends et al. ,***
Nucl. Phys. B57 (1973)381.

$$\sigma_{\exp}(m_\tau, s, \Delta) = \int_0^\infty \sigma_{r.c.}(m_\tau, s')\cdot G\left(\sqrt{s}, \sqrt{s'}, \Delta\right) d\sqrt{s'}$$

$M_{J/\psi}$ =3097.20MeV, $M_{\psi'}$ =3868.88MeV

$$W = T_{\psi} + \frac{T_{\psi'} - T_{\psi}}{T^0_{\psi'} - T^0_{\psi}} (W^0 - T^0_{\psi})$$

$M_{J/\psi}$ =3096.916MeV , $M_{\psi'}$ =3868.093MeV



$$LF(m_\tau, \varepsilon) = \prod_{i=1}^{n} P_i(m_\tau, \varepsilon) \ , \ P_i(m_\tau, \varepsilon) = \frac{\mu_i^{N_i} e^{-\mu_i}}{N_i!}$$

$$\mu_i(m_\tau, \varepsilon) = L_i \cdot [\varepsilon \cdot B_f \cdot \sigma_{obs}(m_\tau, s_i) + \sigma_{BG}]$$

$$m_\tau = 1776.98^{+0.44+0.12}_{-0.51-0.13} \text{ MeV}$$

Fit Results

New formula &Re-scale E

$$m_\tau = 1776.98^{+0.44}_{-0.51} \text{MeV}$$

$$\varepsilon = 14.2^{+4.7}_{-3.9}\%$$

Old formula &Re-scale E

$$m_\tau = 1776.97^{+0.43}_{-0.51} \text{MeV}$$

$$\varepsilon = 14.3^{+4.7}_{-3.9}\%$$

Old formula & fore-scale E

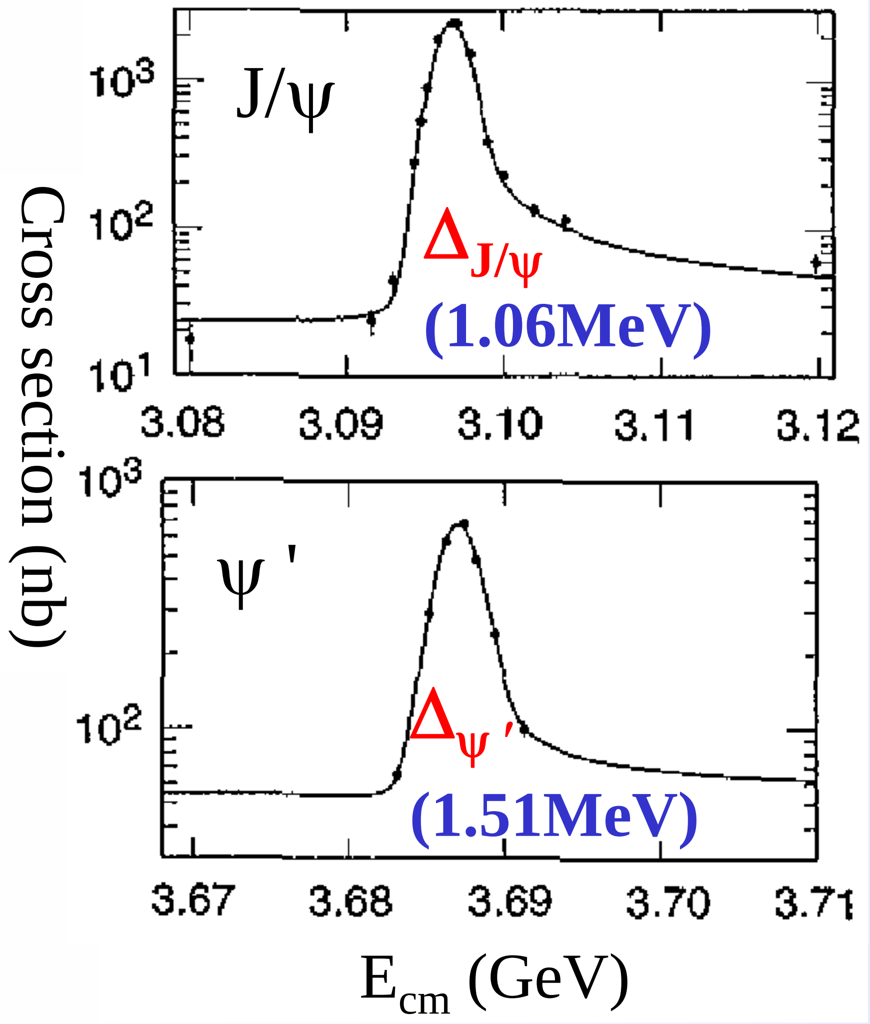
$$m_\tau = 1776.94^{+0.43}_{-0.51} \text{MeV}$$

Fore result:PRL69(1992)3021

$$m_\tau = 1776.9^{+0.4}_{-0.5} \text{MeV}$$

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

$$\left(\frac{\Delta}{E}\right)^2=\frac{C_q\left\langle G^3\right\rangle\gamma_0^2}{J_\varepsilon\left\langle G^2\right\rangle}$$



$$\frac{\Delta-\Delta_{J/\psi}}{\Delta_{\psi'}-\Delta_{J/\psi}}=\frac{f(E)-f\left(E_{J/\psi}\right)}{f\left(E_{\psi'}\right)-f\left(E_{J/\psi}\right)}$$

$\Delta \propto f(E)$;

$f(E)=a\,E+b\,E^2+c\,E^3$

a=1; b=0; c=0;

a=0; b=1; c=0;

a=0; b=0; c=1;

a=1; b=1; c=1;

$\delta m_\tau < 1.5\times10^{-3}$ MeV

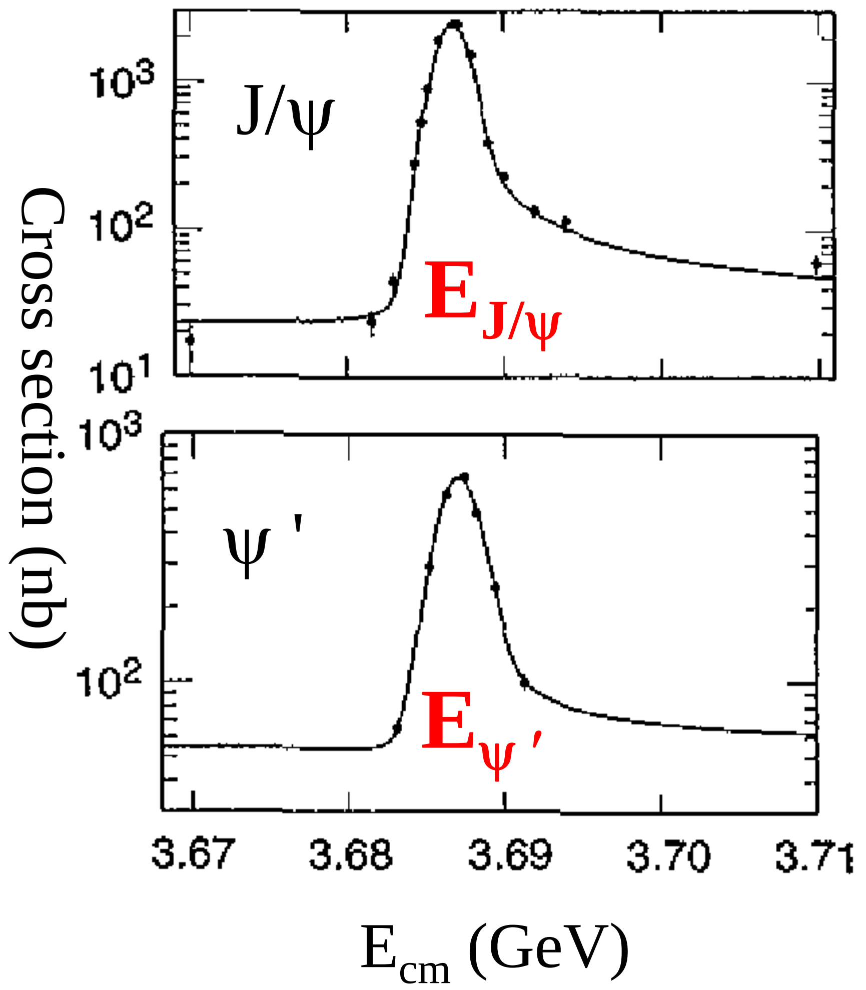
$\Delta \rightarrow 3\,\Delta$

$\delta m_\tau < 6\times10^{-3}$ MeV

$$\frac{W - E_{J/\psi}}{E_{\psi'} - E_{J/\psi}} = \frac{E - M_{J/\psi}}{M_{\psi'} - M_{J/\psi}}$$

W=E+δ (E=M+ δ); $\delta \sim 10^{-4}$

$$\frac{E - M_{J/\psi}}{M_{\psi'} - M_{J/\psi}} = \frac{\delta - \delta_{J/\psi}}{\delta_{\psi'} - \delta_{J/\psi}}$$



$\delta \propto f(E)$;

$f(E) = a\,E + b\,E^2 + c\,E^3$

a=1; b=0; c=0;

a=0; b=1; c=0;

a=0; b=0; c=1;

a=1; b=1; c=1;

$\delta m_\tau < 8 \times 10^{-3}$ MeV

BES:PRD53(1995)20

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

Luminosity $\mathcal{L}$: 2% ➔ **$\delta m_\tau < 1.4 \times 10^{-2}$ MeV**

Efficiency ε : 2% ➔ **$\delta m_\tau < 1.4 \times 10^{-2}$ MeV**

Branching fraction: $\mathcal{B}_f$: 0.5% ➔ **$\delta m_\tau < 3.5 \times 10^{-3}$ MeV**

[$\mathcal{B}_f = \mathcal{B}_{\tau \to \mu\nu} \bullet \mathcal{B}_{\tau \to e\nu}$, PDG04]

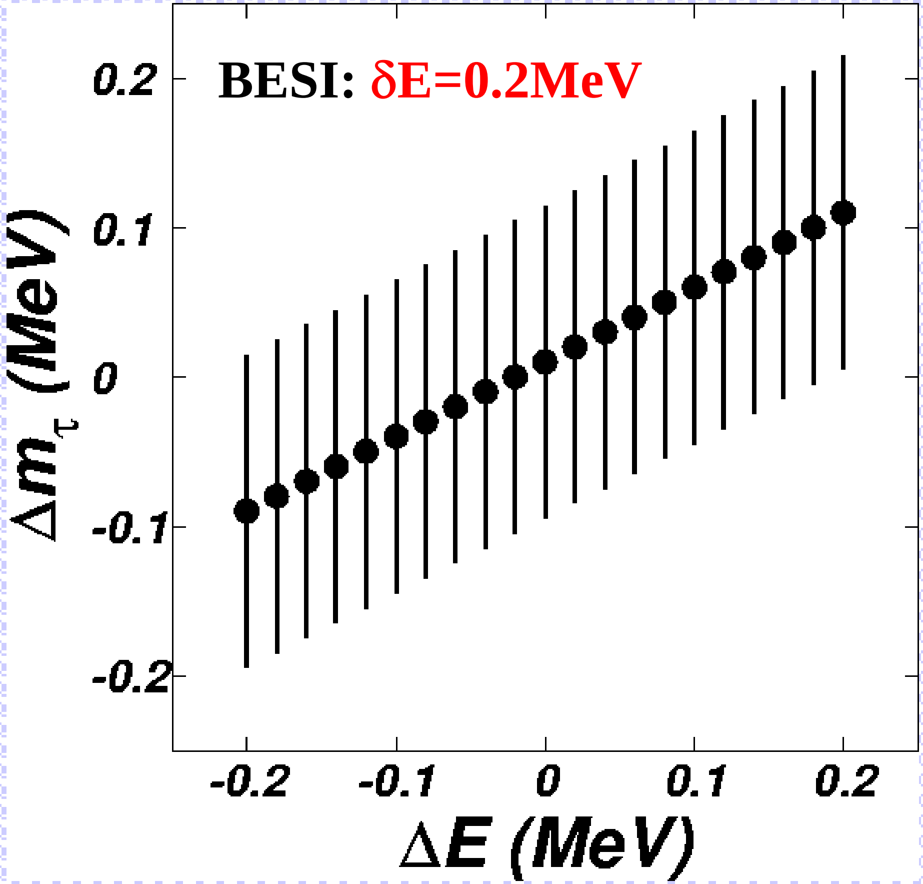
Background σ_{BG} : 10% ➔ **$\delta m_\tau < 1.7 \times 10^{-3}$ MeV**

[$\sigma_{BG} = 0.024$ pb^{-1}**: PLR68(1992)3021]**

Total : **$\delta m_\tau < 2.02 \times 10^{-2}$ MeV**

Absolute calibration of energy scale

δE transfer to the final fit results directly and linearly



Depolarization method

Compton backscattering method

KEDR Collaboration

Novosibirsk

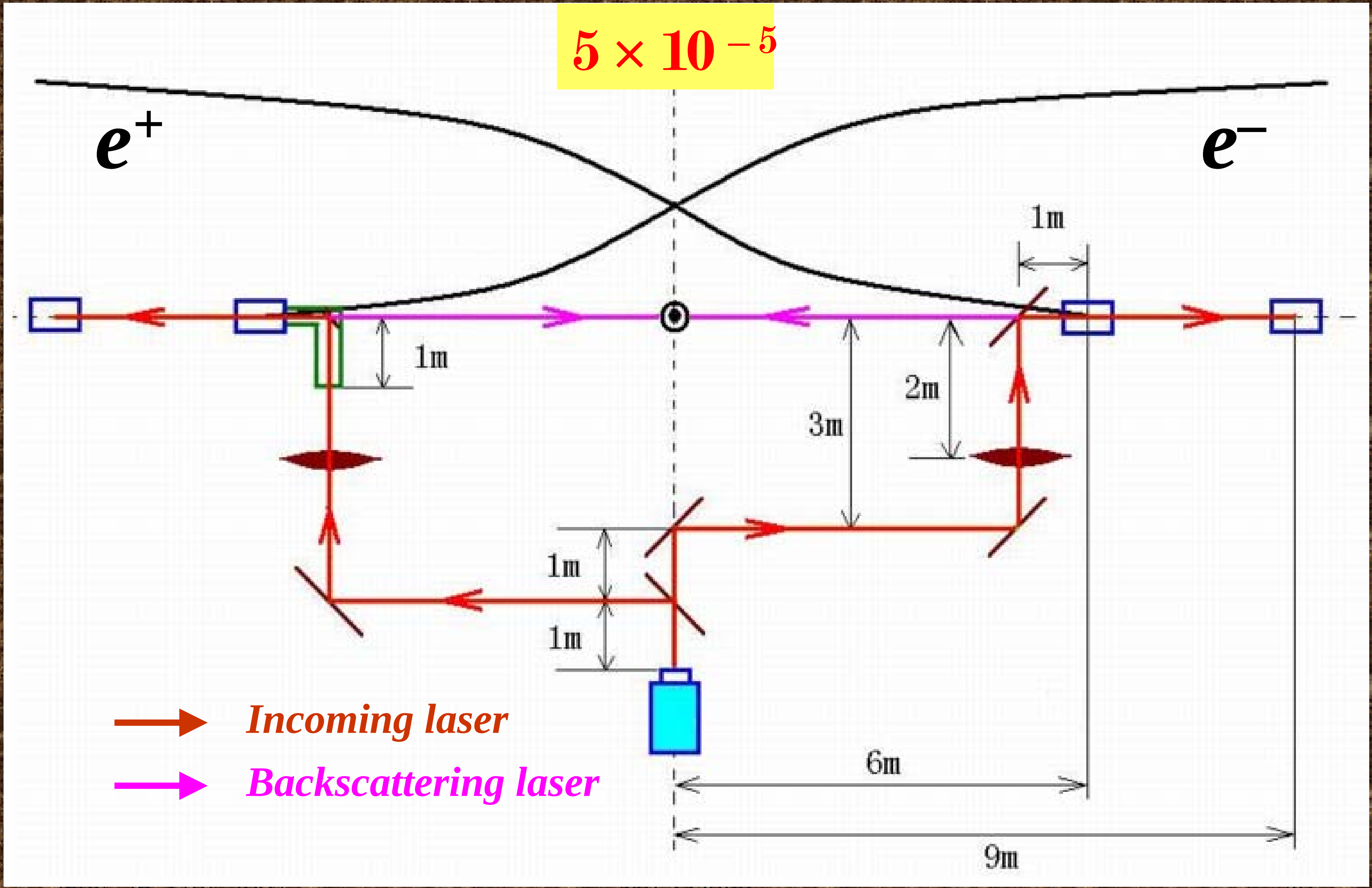
KEDR Collab. , depolarization method:

Single energy scale at level of 0.8 keV, or **10^{-4} MeV**

Total systematic error at level of 9 keV, or **10^{-3} MeV**

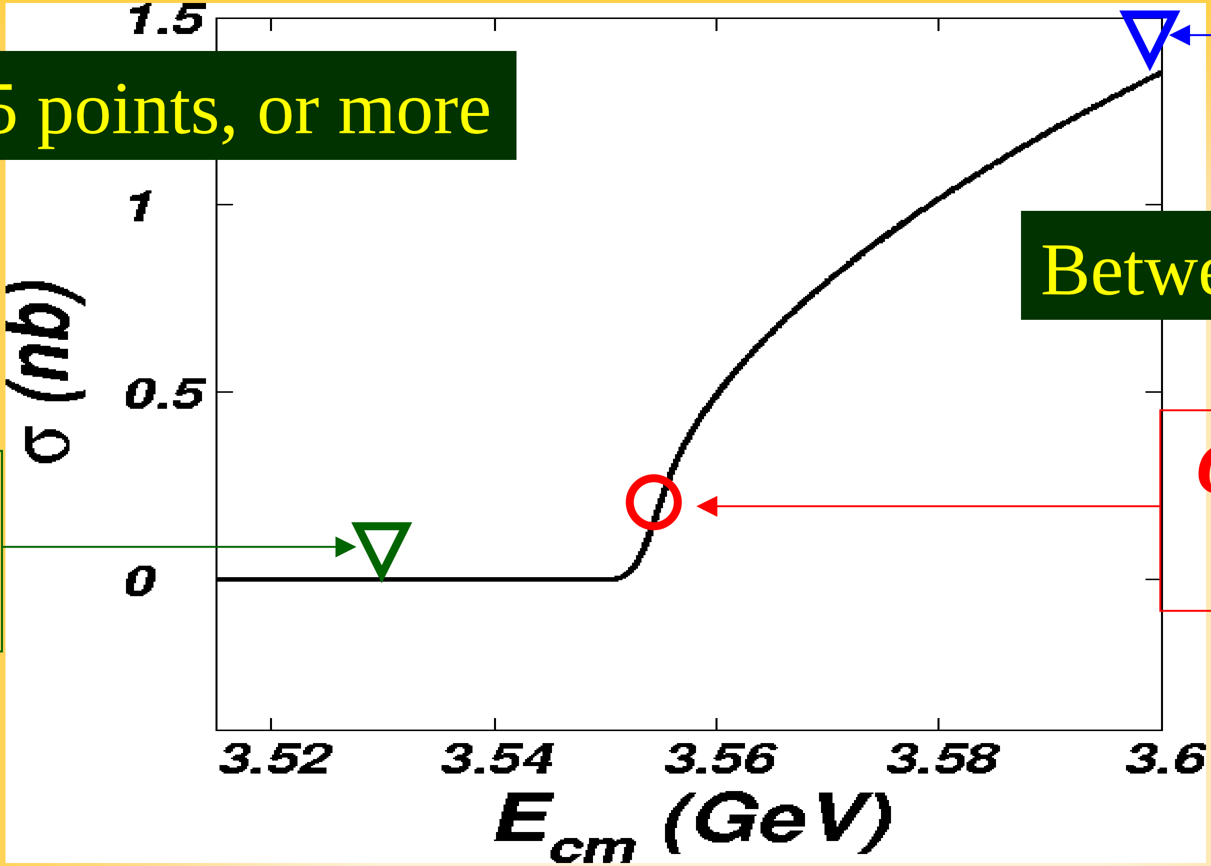
Bottleneck

Sketch of energy measurement system at BESIII



Data taking design

3 or 5 points, or more



Event selection

Between J/ψ and ψ′

Optimal point

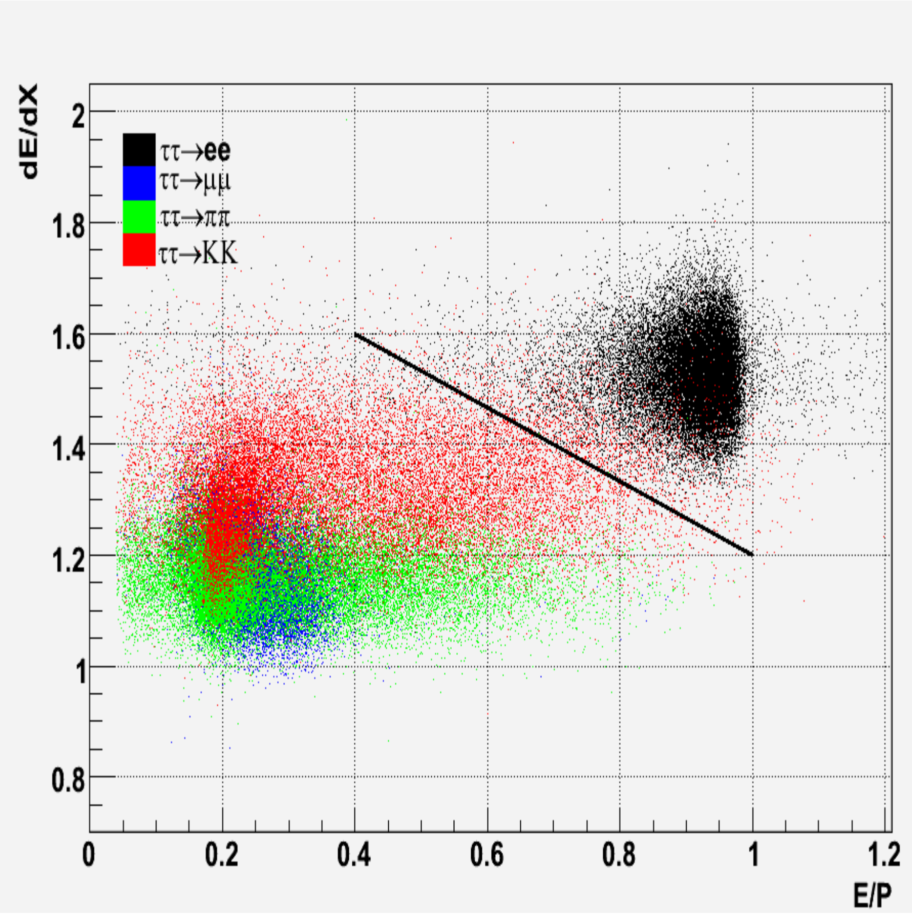
BKG. study

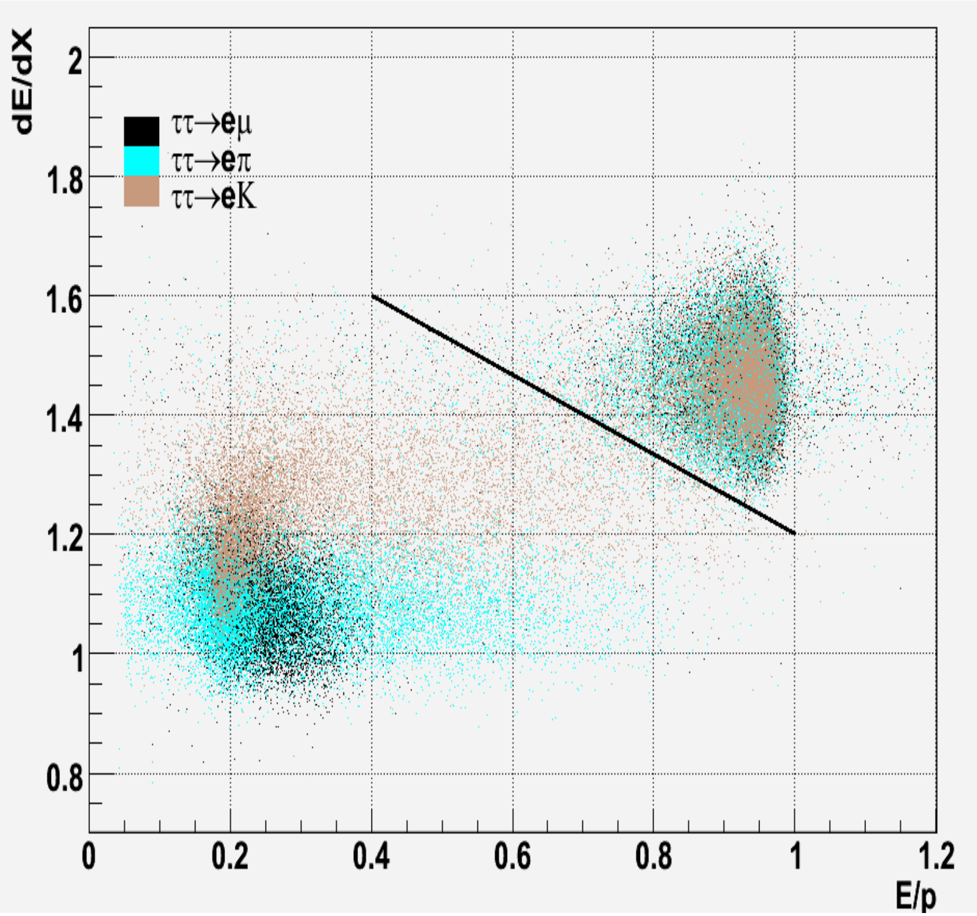
BESIII Luminosity : 1×10^{-33} cm^{-2} s^{-1} (50%); One day (86400 s) : 43.2 pb^{-1} (μe-tagged final state) Three days, eμ-tag, at BESIII ➔ Sm_τ : ~ 0.1 MeV

$$M_\tau = 1776.99 \pm 0.1 \pm 0.09 \text{ MeV}$$

@E_{cm}=3.6 GeV; EvtGen

e / μπK





3*dE/dX+2*(E/ P)>5.6