中山大學
SUN YAT-SEN UNIVERSITY

超级陶粲装置
Super Tau-Charm Facility

$STCF$实验下研究双粲偶素$\eta_c J/\psi$的产生

Study for the double charmonium $\eta_c J/\psi$ production at STCF

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超级陶粲装置研讨会

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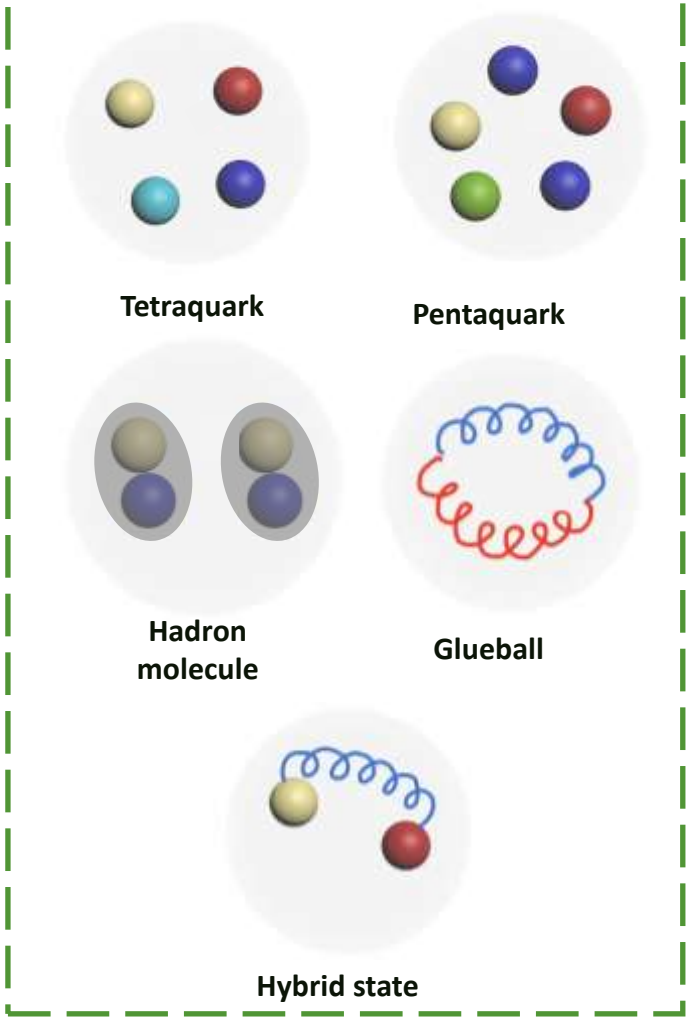
目录

content

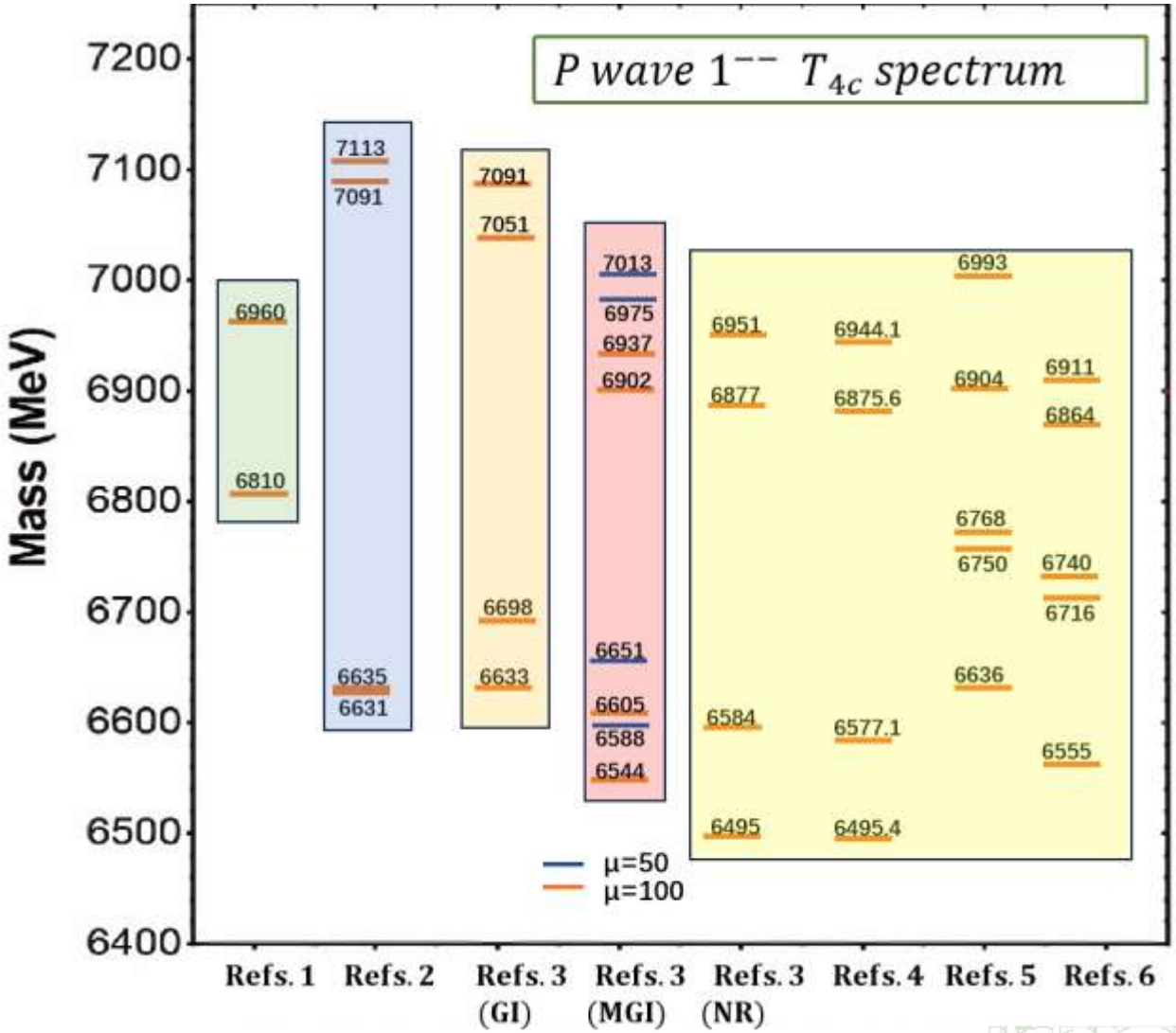
双粲偶素理论与实验现状

- 2003年以前，人们认为粲偶素是粲夸克和反粲夸克的束缚态，应该用非相对论的势能夸克模型来描述。然而，自2003年Belle发现X(3872)以来，通过各种实验包括BESIII、BaBar、Belle、CDF、DO、ATLAS、CMS 和 LHCb，在粲偶素质量区观测到大量新的共振态结构，这些共振态称为奇特态，即XYZ粒子。
- 奇特强子态包括强子分子态、四夸克态、五夸克态以及混杂态等。
- 双粲偶素也称全粲四夸克态，夸克组成为$\bar{c}\bar{c}cc$。



双粲偶素理论与实验现状

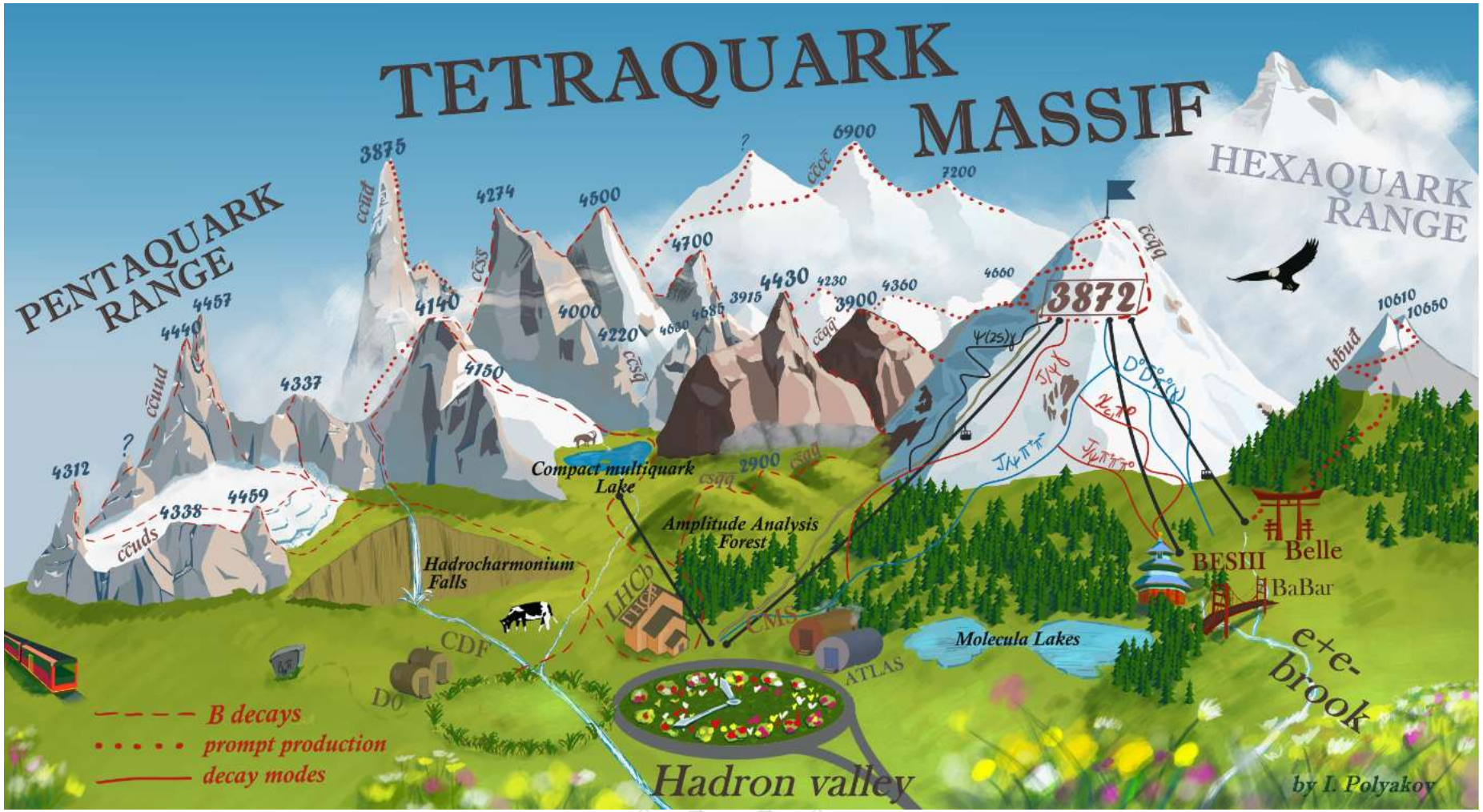
➢ **目前与全粲四夸克态相关的五个理论模型理论研究调研结果**



- QCD Sum Rules
- Relativistic Quark Model
- Godfrey-Isgur relativized diquark model
- The modified Godfrey-Isgur relativized diquark model with the color screening effects
- Nonrelativistic Quark Model

➢ 量子数为1^{--}的全粲四夸克态的质量理论预言范围在：**6.495~7.113 GeV**

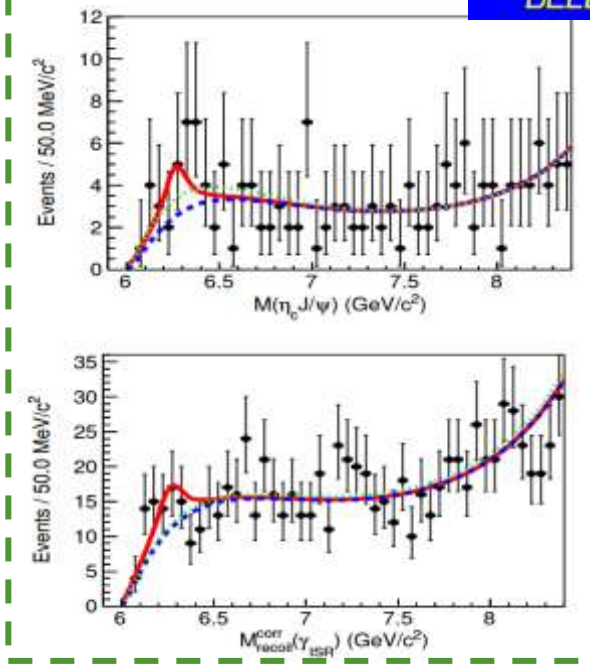
➢ 目前奇特强子态的实验研究成果



★ Hüsken N, Norella E S, Polyakov I. A Brief Guide to Exotic Hadrons[J]. arXiv:2410.06923, 2024.

➢ Search for the double-charmonium state with $\eta_c J/\psi$ @ Belle

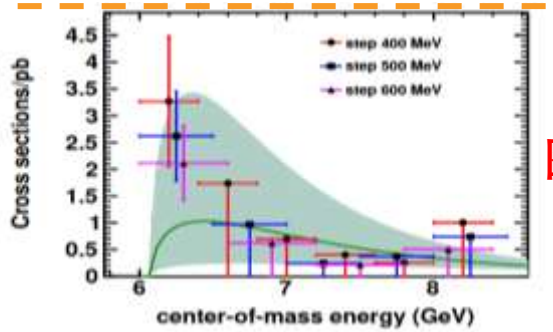
- 产生过程： $e^+e^- \to (\gamma_{ISR})\eta_c J/\psi$
- 能区： $10.52GeV$
- 衰变模型：
  - J/ψ: $e^+e^-, \mu^+\mu^-$
  - η_c: $p\bar{p}, p\bar{p}\pi^0, K_0^S K^{\pm}\pi^{\mp}, K^+K^-\pi^0, K^+K^-K^+K^-, 2(\pi^+\pi^-\pi^0)$
- 积分亮度： $980\ fb^{-1}$
- 质量 ： $6267 \pm 43\ MeV/c^2$
- 衰变宽度： $121 \pm 72\ MeV$
- 显著度结果：2.1σ （阈值附近）



图A

- $\eta_c J/\psi$质量区间： $[6.0, 6.6]\ GeV/c^2$
- 截面结果： **2.1 ± 0.7 ± 0.2 pb**
- Continuum产生截面拟合函数： $\sigma = A\frac{\sqrt{2\mu\Delta M}}{\left(\frac{s}{s0}\right)^n}$

$$\Delta M = \sqrt{s} - m(\eta_c) - m(J/\psi)$$



图B

目录

content

双标η_c和J/ψ（以$\sqrt{S}$ = 6.73 GeV作为展示）

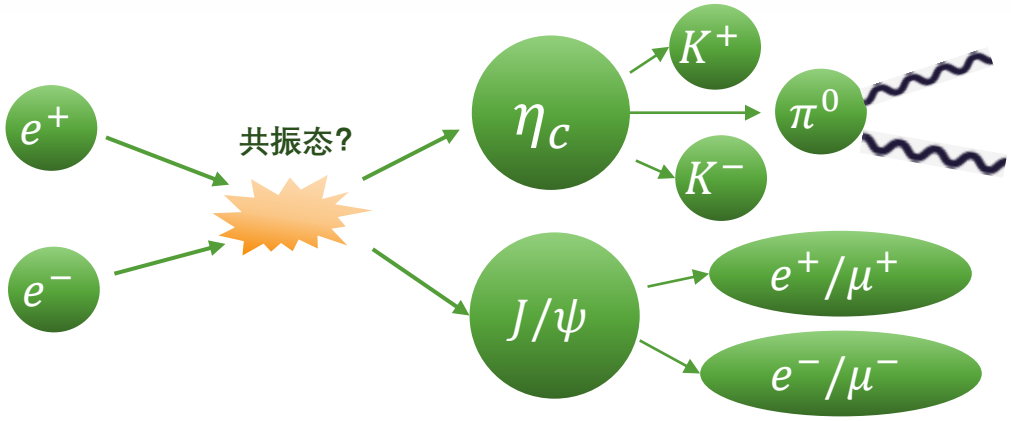
Exclusive MC production under OSCAR 2.6.2

产生子：ConExc

$\sqrt{S}$：6.73GeV　　事例数: 100000

信号道：$e^+e^- \to T_{4c} \to \eta_c J/\psi$,

- $\eta_c \to K^+ K^- \pi^0$, $\pi^0 \to \gamma\gamma$
- $J/\psi \to \mu^+\mu^-$ and e^+e^-



- **衰变卡**

```
Particle vpho 6.7300 0.0
Decay vpho
1.0000  gamma   gamma* ConExc -2  443  441;
Enddecay
#
Decay gamma*
1.0000    eta_c  J/psi       PHSP;
Enddecay
#
Decay J/psi
1.0000    e+   e-                PHOTOS  VLL;
Enddecay

#
Decay eta_c
1.0000    pi0  K+  K-        PHSP;
Enddecay
#
Decay pi0
1.0000    gamma gamma                      PHSP;
Enddecay

End
```

- **利用Breit-Wigner公式获得输入截面分布模拟共振态**
- **公式:** $\sigma(e^+e^- \to T_{4c}) = \mathcal{B}_{T_{4c}\to e^+e^-}\mathcal{B}_{T_{4c}\to \eta_c J/\psi} \frac{12\pi\Gamma_0^2}{\left(s-m_{T_{4c}}^2\right)^2 + m_{T_{4c}}^2\Gamma_0^2}$

```
6.72000 1.74915 0.0
6.72500 2.48728 0.0
6.73000 3.80113 0.0
6.73500 6.45682 0.0
6.74000 12.90311 0.0
6.74500 32.23149 0.0
6.75000 64.43911 0.0
6.75500 32.20762 0.0
6.76000 12.87256 0.0
6.76500 6.43104 0.0
6.77000 3.77999 0.0
6.77500 2.46962 0.0
6.78000 1.73409 0.0
6.78500 1.28226 0.0
6.79000 0.98561 0.0
```

事例选择条件

选择带电径迹:

- $|d_0| \leq 1.0cm$, $|d_z| \leq 10.0cm$;

选择光子 :

- 桶部: $|cos\theta| \leq 0.8325$, $E_{ecal} \geq 25MeV$,
- 端盖: $0.8325 \leq |cos\theta| \leq 0.9445, E_{ecal} \geq 50\ MeV$;
- 飞行时间: $0 \leq |T_0| \leq 50\ ns$

选择 Kaon:

- Global PID : $prob(K) \geq prob(\pi)\&\&prob(K) \geq prob(\mu)\&\&prob(K) \geq prob(e)$

选择缪子:

- $0.1 \leq E_{ecal} \leq 0.3$, $|p_\mu| \geq 0.9\ GeV$

选择电子:

- $0.8 \leq \frac{E_e}{p_e} \leq 1.2$, $|p_e| \geq 0.9\ GeV$

重建π^0 :

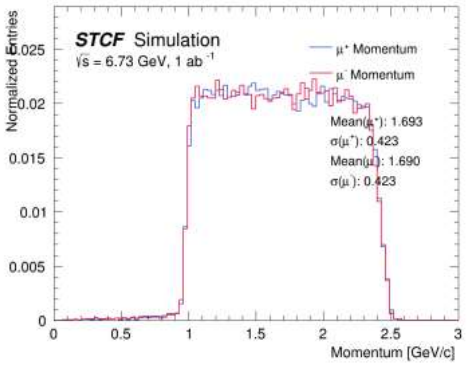
- $0.12GeV \leq M_{\gamma\gamma} \leq 0.15GeV$
- $1C$ 运动学拟合_$\chi^2 \leq 60$

重建 η_c :

- $2.78GeV \leq M_{K^+K^-\pi^0} \leq 3.08GeV$

重建 J/ψ :

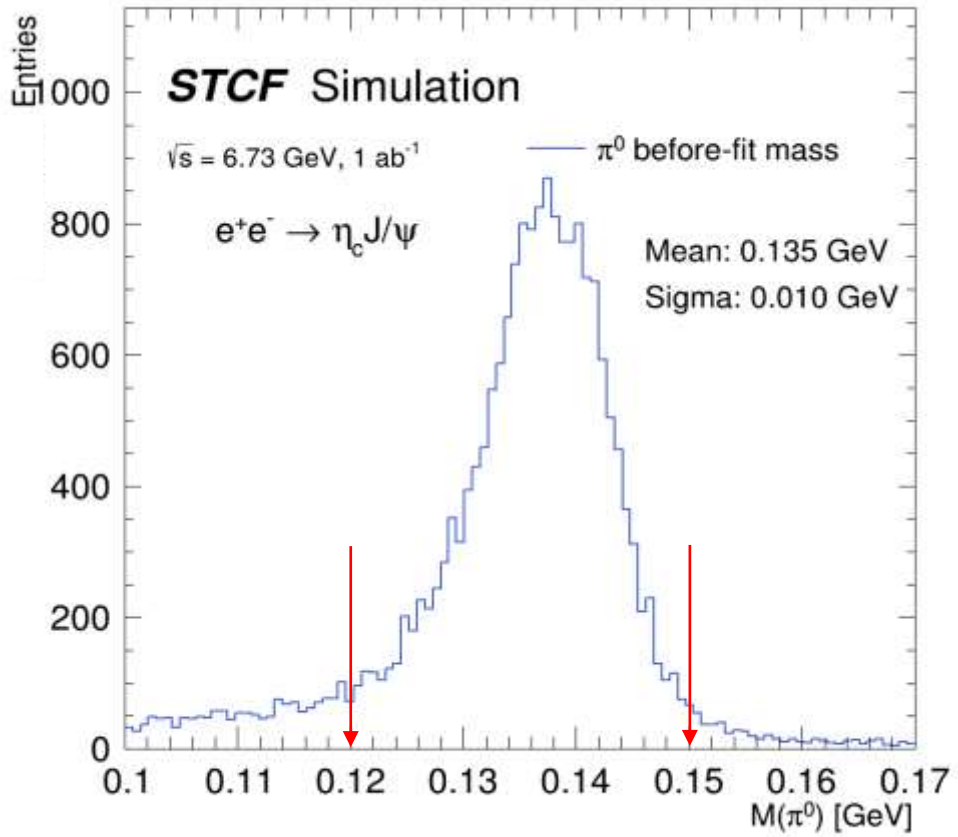
- 顶点拟合_$\chi^2 \leq 60$
- $3.05GeV \leq M_{\mu^+\mu^-} \leq 3.15GeV$
- $3.05GeV \leq M_{e^+e^-} \leq 3.15GeV$



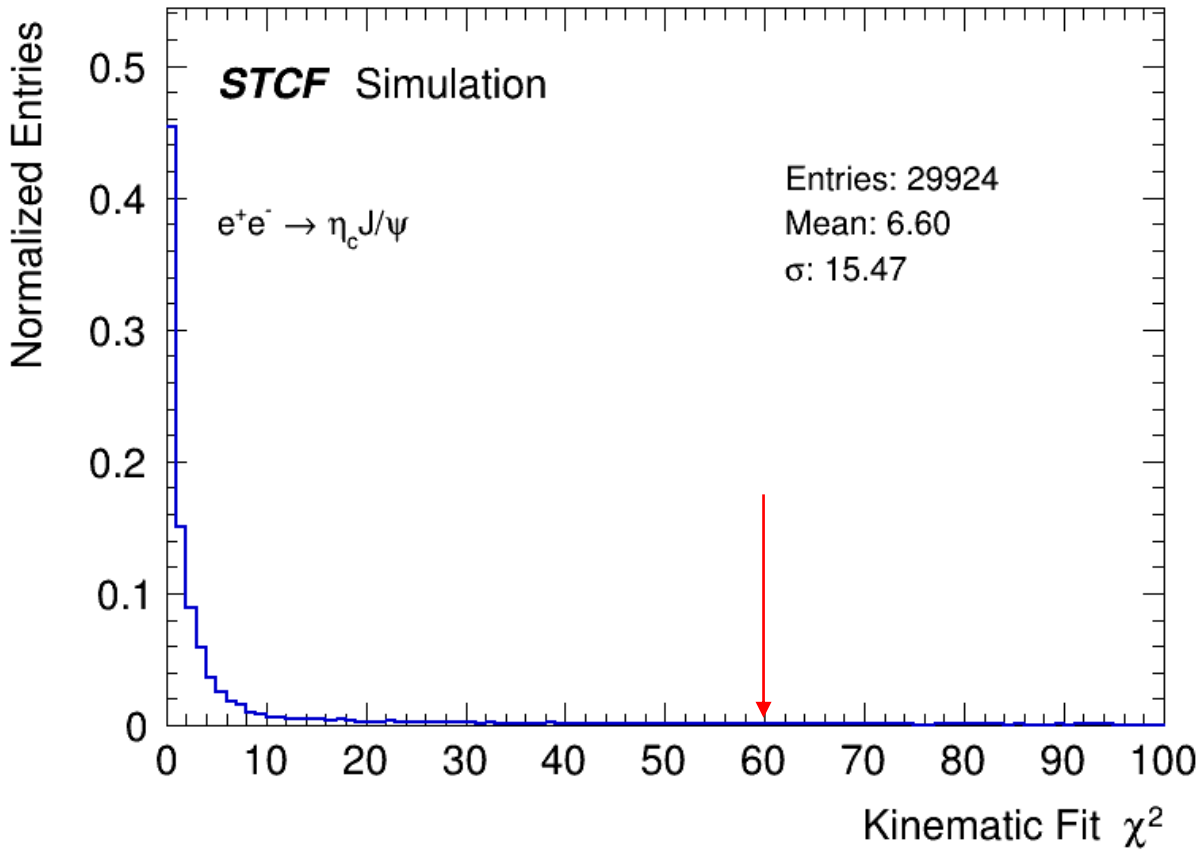
π^0重建

- $0.12GeV \leq M_{\gamma\gamma} \leq 0.15GeV$
- 1C运动学拟合_$\chi^2 \leq 60$

$\sqrt{S} = 6.73$ GeV



找质量最接近pi0 mass的光子组合



双标η_c和J/ψ

- $\sqrt{S} = 6.73$ GeV

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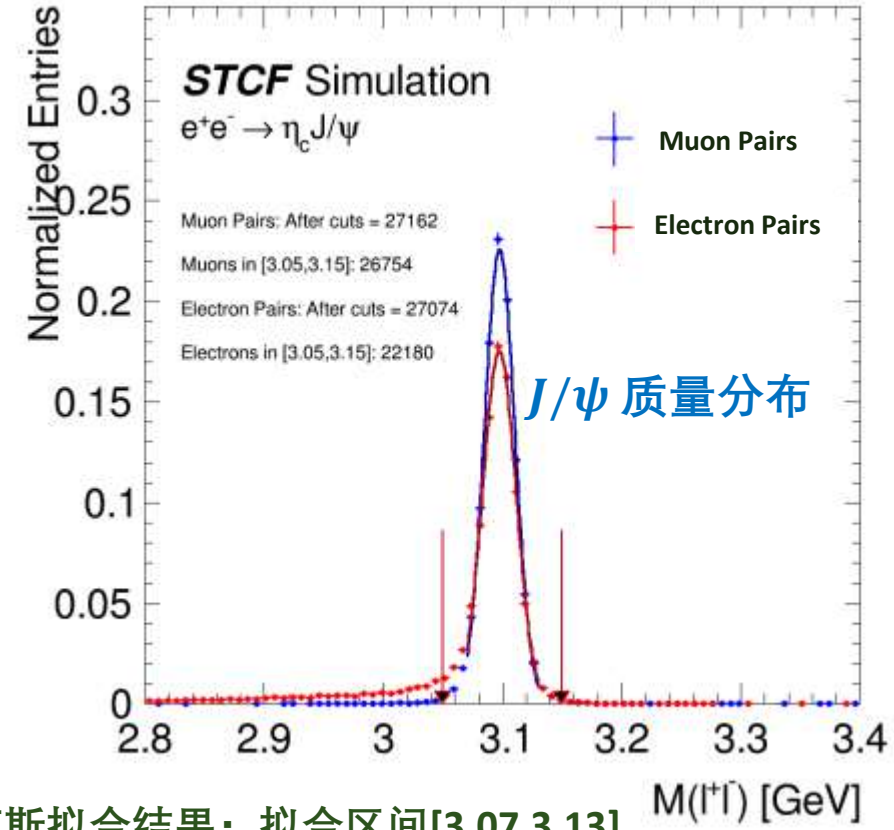
➢ $J/\psi \to \mu^+\mu^-$和$J/\psi \to e^+e^-$的质量分布对比

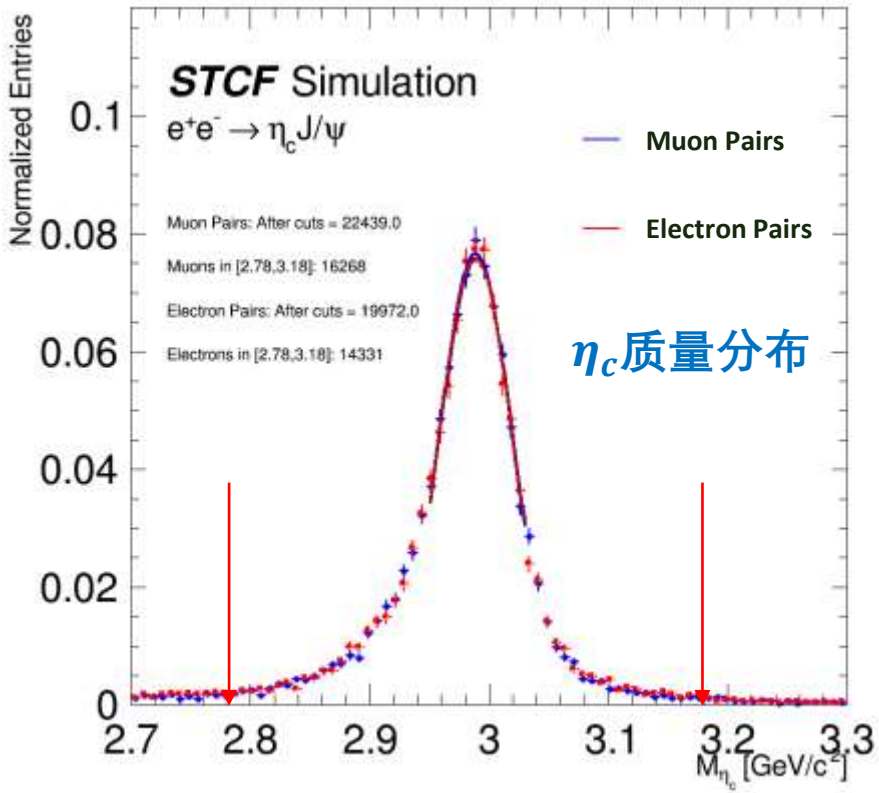
J/ψ *Mass cut*: $3.05GeV < M_{Le^+Le^-} < 3.15GeV$



单高斯拟合结果：拟合区间[3.07,3.13]

- μ: $\sigma = 12.79 \pm 0.07MeV$, 峰值 $= 3.097 \pm 0.001$
- e: $\sigma = 14.05 \pm 0.10MeV$, 峰值 $= 3.096 \pm 0.001$

η_c *Mass cut*: $2.78GeV < M_{K^+K^-\pi^0} < 3.18GeV$



单高斯拟合结果：拟合区间[2.95,3.03]

- μ: $\sigma = 30.31 \pm 0.6MeV$, 峰值 $= 2.988 \pm 0.001$
- e: $\sigma = 30.67 \pm 0.7MeV$, 峰值 $= 2.989 \pm 0.001$

双标η_c和J/ψ

- Cut Flow 对比

$\sqrt{S}$ = 6.73 GeV

Cut Flow(J/ψ->$\mu\mu$)	N_{obs}	相对效率	Cut Flow(J/ψ→ee)	N_{obs}	相对效率
$total\ number$:	50000	100.00%	$total\ number$:	50000	100.00%
$nGood$m ≥ 2&$nGood$p ≥ 2:	34432	68.86%	$nGood$m ≥ 2&$nGood$p ≥ 2:	33918	67.84%
nGoodγ ≥ 2:	29762	86.44%	nGoodγ ≥ 2:	29832	87.95%
$n\mu_p \geq 1\ and\ n\mu_m \geq 1$:	26712	89.75%	$ne_p \geq 1\ and\ ne_m \geq 1$:	26677	89.42%
$J/\psi\ mass\ cut$ & $vtx\_\chi^2 \leq 60$:	26321	98.54%	$J/\psi\ mass\ cut$ & $vtx\_\chi^2 \leq 60$:	21956	82.30%
$nK_m \geq 1\ and\ nK_p \geq 1$:	23150	87.95%	$nK_m \geq 1\ and\ nK_p \geq 1$:	19503	88.83%
$\pi^0 mass\ cut$ & $km\_\chi^2 < 60$:	20436	88.28%	$\pi^0 mass\ cut$ & $km\_\chi^2 < 60$:	17061	87.48%
$\eta_c$mass cut	17363	84.96%	$\eta_c$mass cut	14378	84.27%
$total\ cut$:		32.48%	$total\ cut$:		28.76%

目录

content

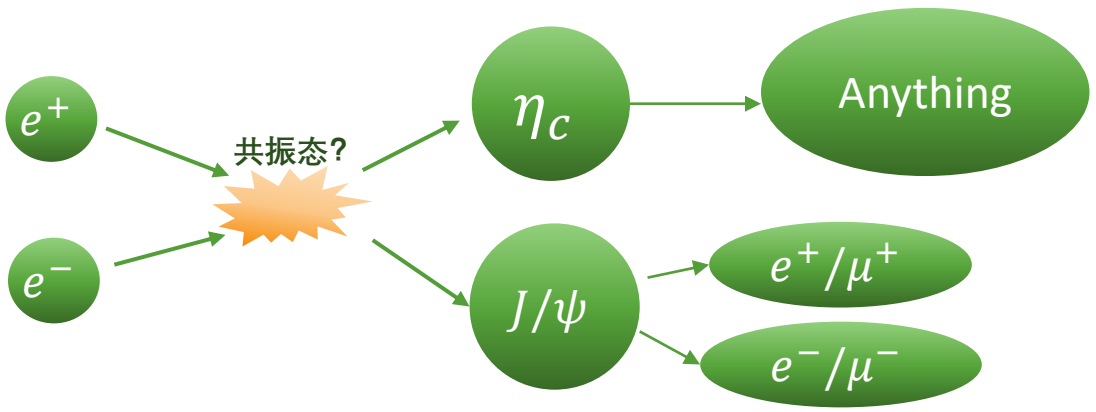
Exclusive MC production under OSCAR 2.6.2

产生子：ConExc

$\sqrt{S}$：6.73GeV　　事例数: 100000

信号道：$e^+e^- \to T_{4c} \to \eta_c J/\psi$,

- $\eta_c \to anything$
- $J/\psi \to \mu^+\mu^-$ and e^+e^-



- 衰变卡

```
noPhotos
Particle vpho 6.7300 0.0
Decay vpho
1.0000  gamma   gamma* ConExc -2  443  441;
Enddecay
#
Decay gamma*
1.0000    eta_c  J/psi       PHSP;
Enddecay
#
Decay J/psi
0.0594    e+   e-               PHOTOS  VLL;
Enddecay
#
Decay eta_c
0.027     eta' pi+ pi-                    PHSP;
0.014     eta' pi0 pi0                    PHSP;
0.006     rho0 rho0                       HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.012     rho+ rho-                       HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.0100    K*0 K- pi+                      PHSP;
0.0100    anti-K*0 K+ pi-                 PHSP;
0.0034    K*+ K*-                         HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.0034    K*0 anti-K*0                    HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0 ;
0.011     K*0 anti-K*0  pi+ pi-           PHSP;
0.0029    phi K+ K-                       PHSP;
0.00194   phi phi                         HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.0288    K+ anti-K0  pi-                 PHSP;
0.0288    K- K0 pi+                       PHSP;
0.0144    K0 anti-K0 pi0                  PHSP;
0.0117    pi0  K+  K-                     PHSP;
0.0326    eta pi+ pi-                     PHSP;
0.0163    eta pi0 pi0                     PHSP;
```

- 利用Breit-Wigner公式获得输入截面分布模拟共振态
- 公式:$\sigma(e^+e^- \to T_{4c}) = \mathcal{B}_{T_{4c}\to e^+e^-}\mathcal{B}_{T_{4c}\to \eta_c J/\psi} \frac{12\pi\Gamma_0^2}{\left(s-m_{T_{4c}}^2\right)^2 + m_{T_{4c}}^2\Gamma_0^2}$

```
6.72000 1.74915 0.0
6.72500 2.48728 0.0
6.73000 3.80113 0.0
6.73500 6.45682 0.0
6.74000 12.90311 0.0
6.74500 32.23149 0.0
6.75000 64.43911 0.0
6.75500 32.20762 0.0
6.76000 12.87256 0.0
6.76500 6.43104 0.0
6.77000 3.77999 0.0
6.77500 2.46962 0.0
6.78000 1.73409 0.0
6.78500 1.28226 0.0
6.79000 0.98561 0.0
```

单标J/ψ

$\sqrt{S} = 6.73$ GeV

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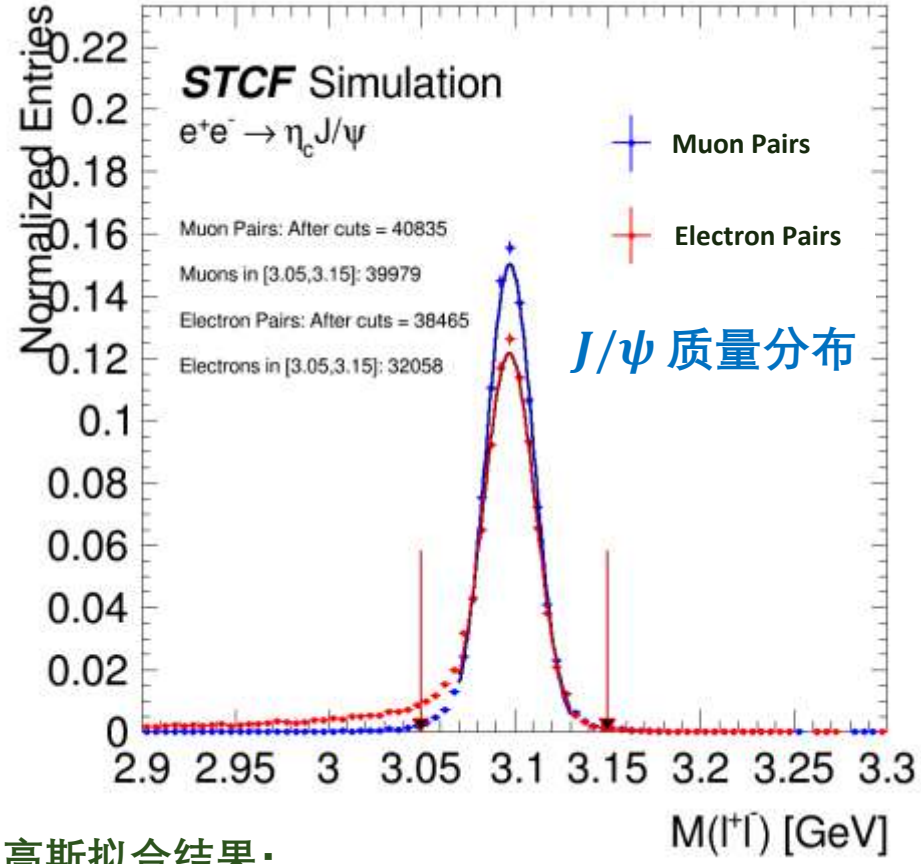
➢ $J/\psi \to \mu^+\mu^-$和$J/\psi \to e^+e^-$的质量分布对比

$$M_{\text{recoil}}(J/\psi) \equiv \sqrt{|p_{e^+e^-} - p_{J/\psi}|^2}/c$$

J/ψ Mass cut: $3.05GeV < M_{le^+le^-} < 3.15GeV$

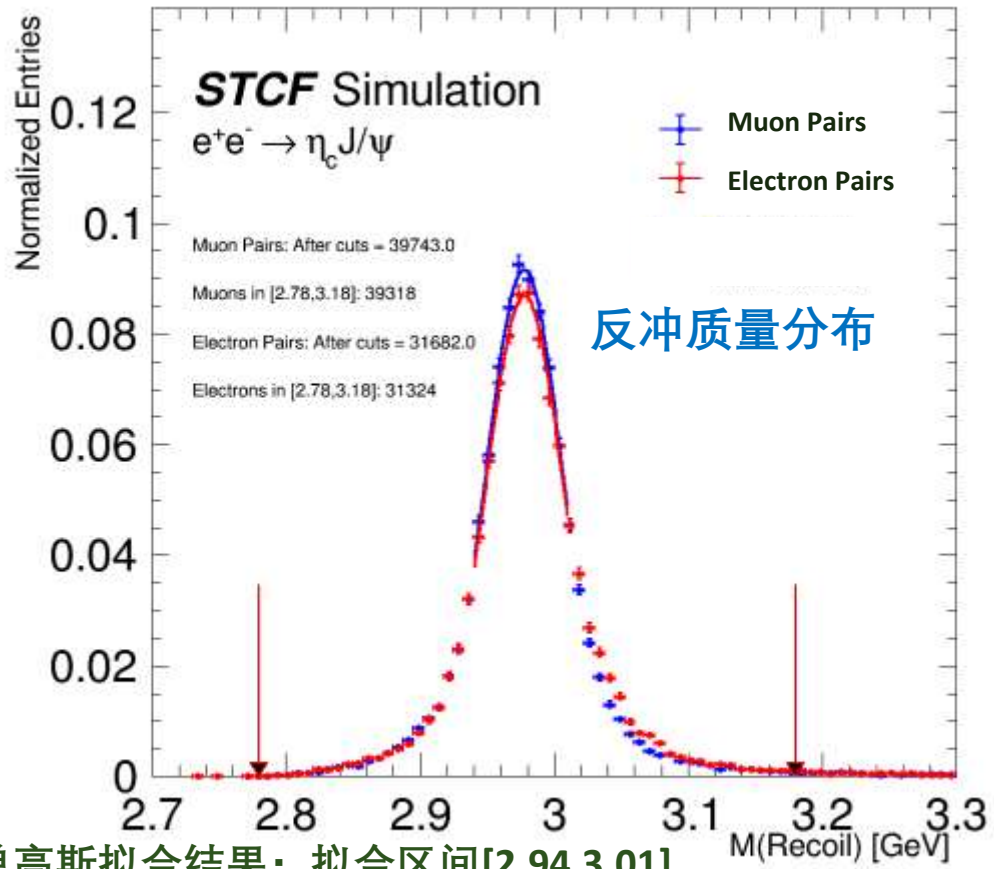


J/ψ 质量分布

单高斯拟合结果：

- $\mu: \sigma = 13.40 \pm 0.06MeV$, 峰值 $= 3.097 \pm 0.007$
- $e: \sigma = 15.05 \pm 0.08MeV$, 峰值 $= 3.096 \pm 0.009$

Recoil $Mass\ cut$: $2.78GeV < M_{\text{recoil}} < 3.18GeV$



反冲质量分布

单高斯拟合结果：拟合区间[2.94,3.01]

- $\mu: \sigma = 28.38 \pm 0.46MeV$, 峰值 $= 2.977 \pm 0.001$
- $e: \sigma = 28.93 \pm 0.56MeV$, 峰值 $= 2.978 \pm 0.001$

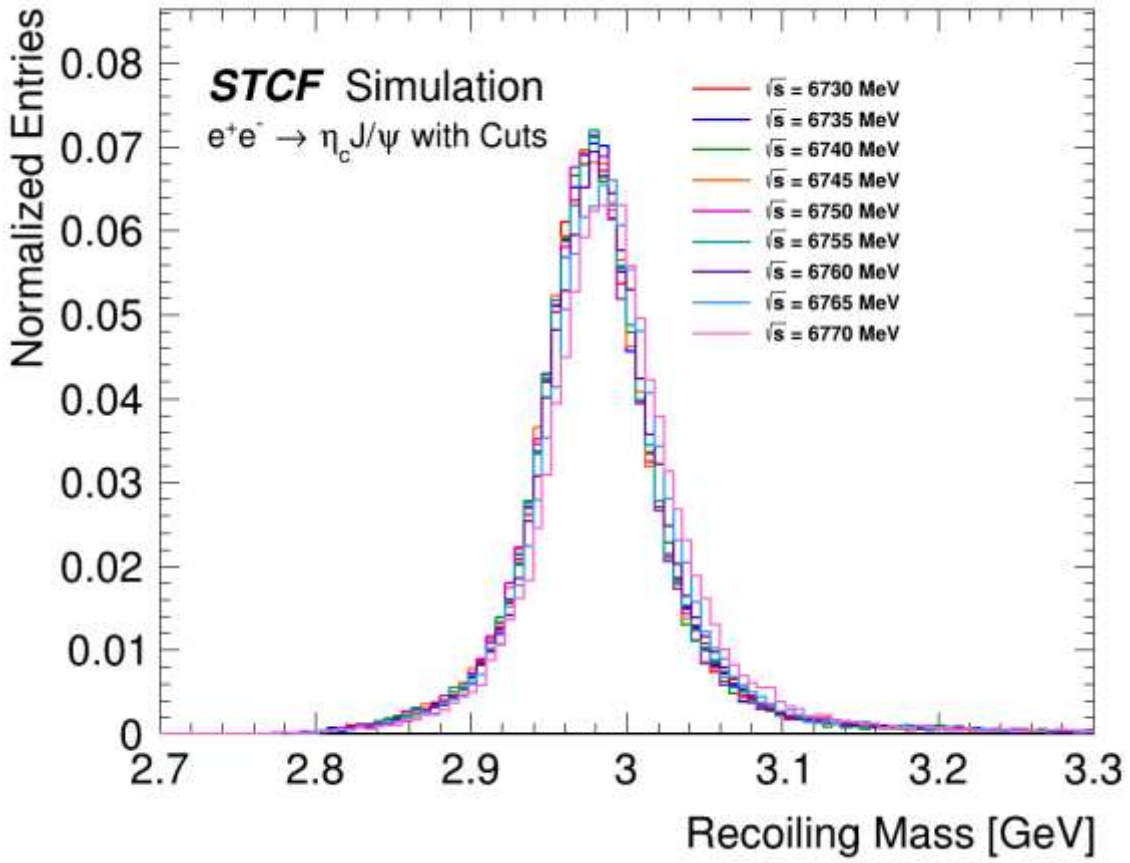
➢ Cut Flow 对比

Cut Flow(J/ψ->$\mu\mu$)	N_{obs}	相对效率	Cut Flow(J/ψ→ee)	N_{obs}	相对效率
$total\ number$:	50000	100.00%	$total\ number$:	50000	100.00%
$nGood$m ≥ 1&&$nGood$p ≥ 1:	49582	99.16%	$nGood$m ≥ 1&&$nGood$p ≥ 1:	49522	99.04%
$n\mu_p \geq 1\ and\ n\mu_m \geq 1$:	40436	81.55%	$ne_p \geq 1\ and\ ne_m \geq 1$:	39242	79.24%
$J/\psi\ vtxfit\_\chi^2 \leq 60$:	40404	99.99%	$J/\psi\ vtxfit\_\chi^2 \leq 60$:	39225	99.96%
$J/\psi\ mass\ cut\ \&\ vtx\_\chi^2 \leq 60$:	39743	98.36%	$J/\psi\ mass\ cut\ \&\ vtx\_\chi^2 \leq 60$:	32452	82.73%
Recoil mass cut:	39099	98.38%	Recoil mass cut:	31886	98.26%
$total\ cut$:		78.20%	$total\ cut$:		63.77%

单标J/ψ

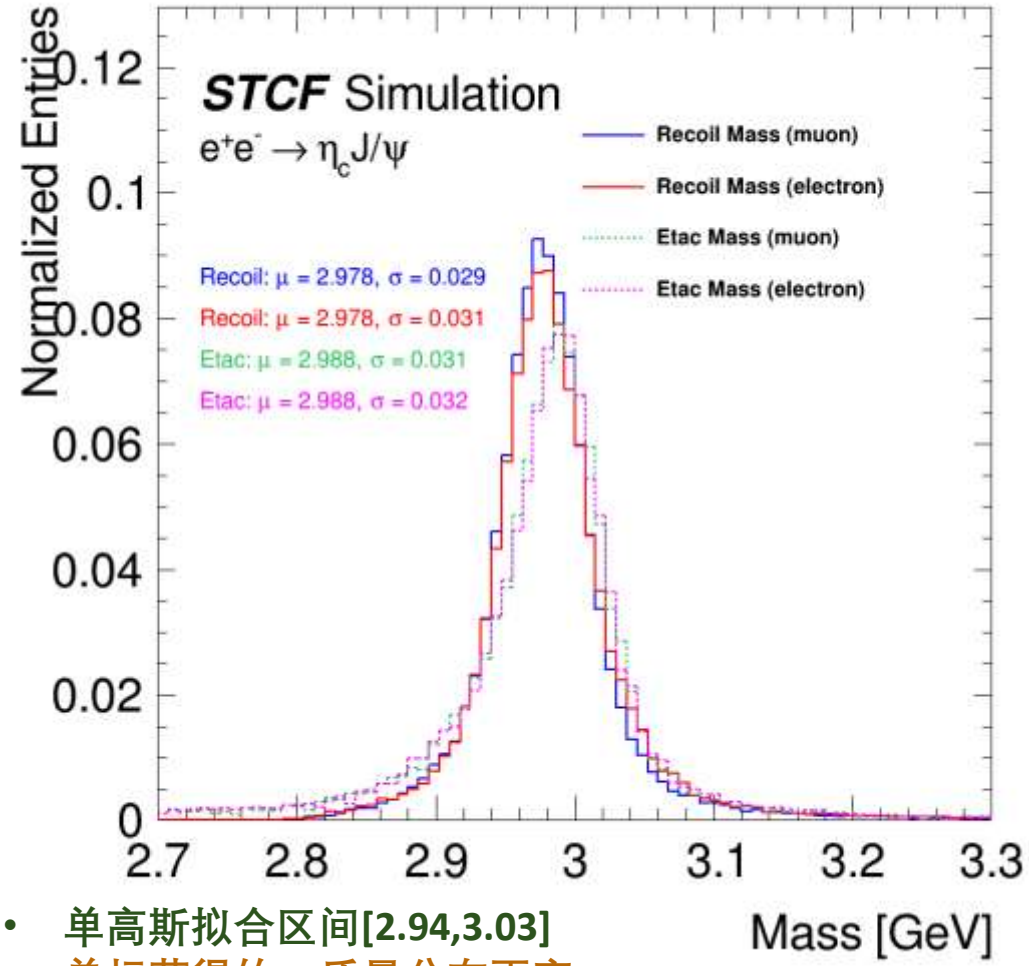
$\sqrt{S}$:6.73GeV~6.77GeV　Step size:5MeV　9个能量点

不同能量点下的反冲质量分布



- 随着能量点的变化，反冲质量的峰值只有很微小的偏移

单标获得的反冲质量分布 VS 双标获得的η_c 质量分布



- 单高斯拟合区间[2.94,3.03]
- 单标获得的η_c质量分布更窄
- 双标获得的η_c质量更接近PDG上的值

目录

content

本底分析

- Continuum本底截面：

Belle拟合截面函$\sigma = A\frac{\sqrt{2\mu\Delta M}}{\left(\frac{s}{s0}\right)^n}$

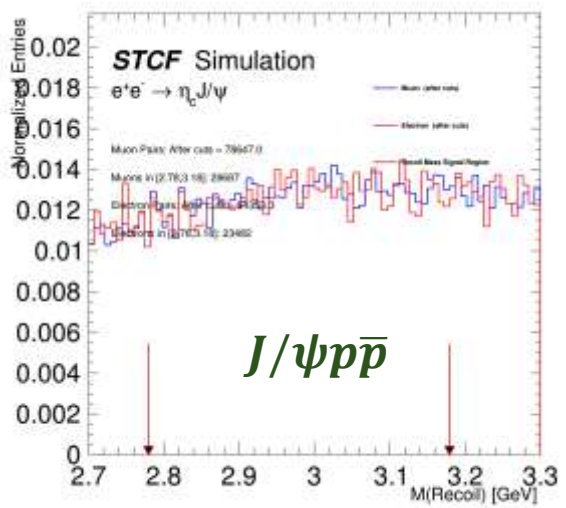
- $J/\psi p\bar{p}$本底、$J/\psi\pi^+\pi^-$本底和$J/\psi K^+K^-$本底的截面都是根据目前在5GeV以下的结果，按照1/100预估质心能量在6.75GeV下对应的截面。

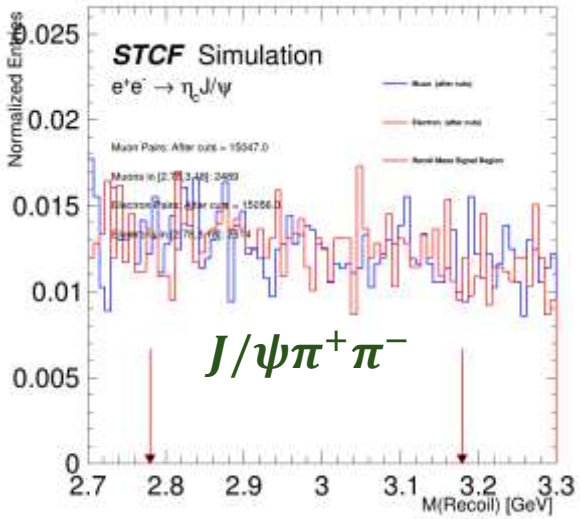
$$N_{obs} = \sigma\varepsilon L\mathcal{B}$$

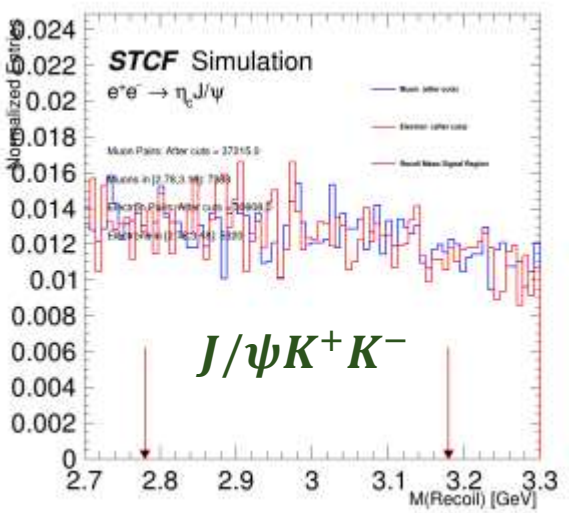
$\sqrt{S}$=6.75GeV	双标J/ψ和η_c			单标J/ψ		
	选择效率	预估截面(fb)	事例数	选择效率	预估截面(fb)	事例数
信号	31.00%	64.43	3	70.50%	64.43	548
Continuum本底	31.00%	819.26	35	70.50%	819.26	6886
$J/\psi p\bar{p}$本底	1.38%	20	3	11.40%	20	27
$J/\psi\pi^+\pi^-$本底	0.42%	30	2	4.88%	30	18
$J/\psi K^+K^-$本底	1.41%	30	5	14.23%	30	51
强子本底	0.00%		0	0.00%		0

分别用5×10^5不同的本底样本进行本底分析获得的Recoil Mass分布

平本底







目录

content

预估截面与事例数

$\Gamma_{T_{4c}}^{ee} = 20eV,$

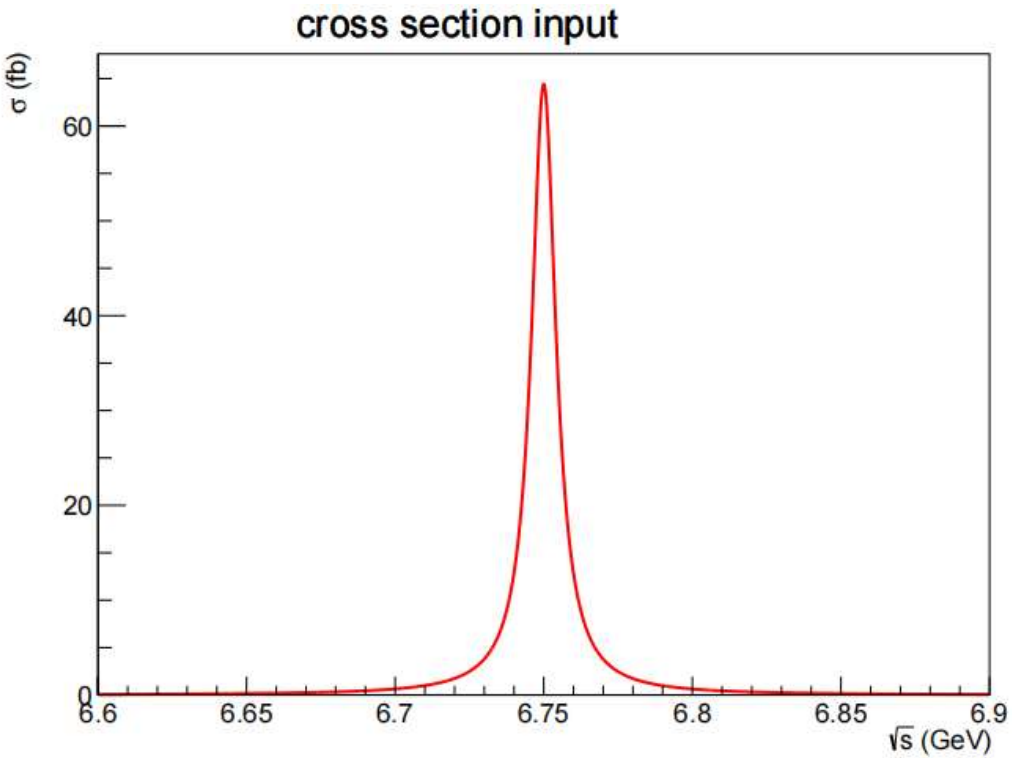
$\Gamma_{T_{4c}} = 10MeV$

$\Gamma_{\eta_c J/\psi} = 1MeV$

$\mathcal{B}_{T_{4c}\to e^+e^-} \approx 2 * 10^{-6}$, $\mathcal{B}_{T_{4c}\to \eta_c J/\psi} = \frac{1}{10} \approx 0.1$

$$\sigma(e^+e^- \to T_{4c} \to \eta_c J/\psi) = \mathcal{B}_{T_{4c}\to e^+e^-}\mathcal{B}_{T_{4c}\to \eta_c J/\psi} \frac{12\pi\Gamma_{T4c}^2}{\left(s-m_{T_{4c}}^2\right)^2 + m_{T_{4c}}^2\Gamma_{T4c}^2}$$

≅64.43fb(峰值)



$L = 100\ fb^{-1}$

$\mathcal{B}(J/\psi \to e^+e^-, \mu^+\mu^-)$ =0. 11932=11.932%

$\mathcal{B}(\eta_c \to K^+K^-\pi^0)$ =0. 0115=1.15%

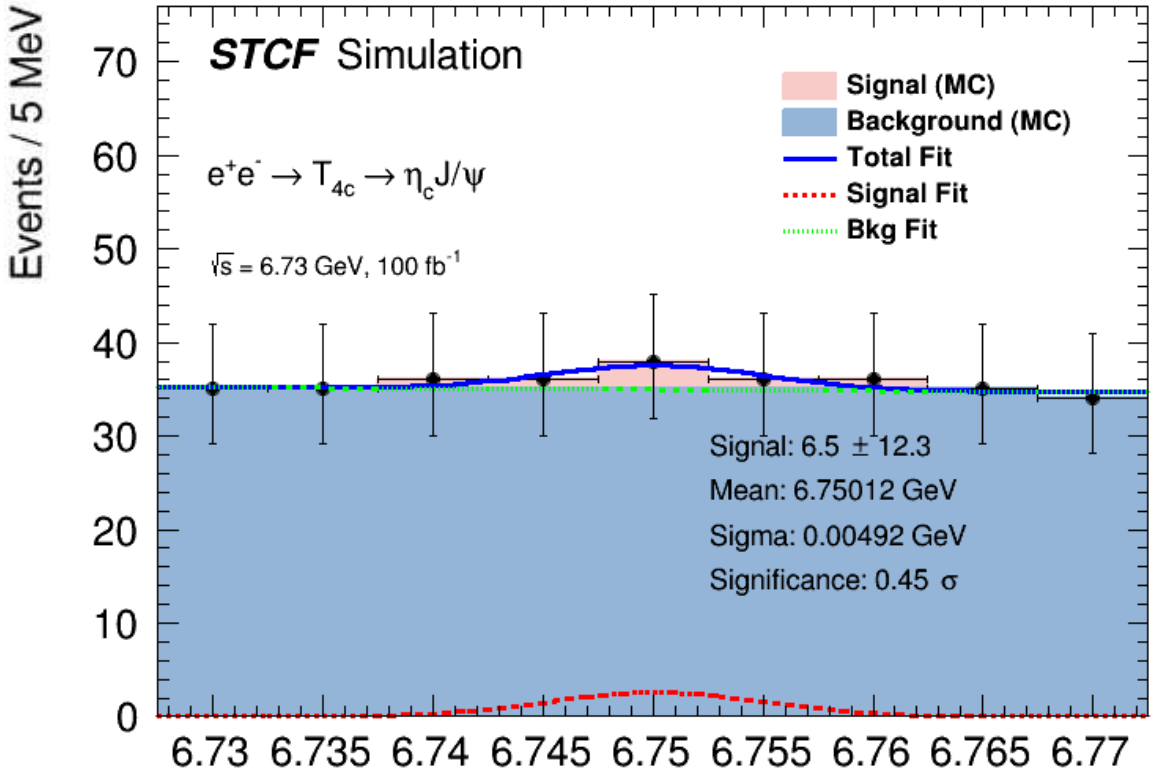
$N_{obs} = \sigma\varepsilon L\mathcal{B}(J/\psi \to e^+e^-, \mu^+\mu^-)\mathcal{B}(\eta_c \to K^+K^-\pi^0) \cong 3(peak)$

- 以$100fb^{-1}$积分亮度预估STCF每年可产生约$1 * 10^5$个T_{4c}（$N_{obs} = \sigma L$）

A. Badalian, B. Ioffe and A. V. Smilga, Nucl. Phys. B281 (1987) 85

信号与本底拟合

双标 $\sqrt{s}$: 6.73GeV~6.77GeV Step size:5MeV 8 steps



- 本底拟合：一阶多项式
- 信号拟合：高斯

- ***significance*** 计算公式：

log likelihood value from the fit w/o signal

$$S = [2(lnL_m(s+b) - lnL_m(b))]^{1/2}.$$

log likelihood value from the fit

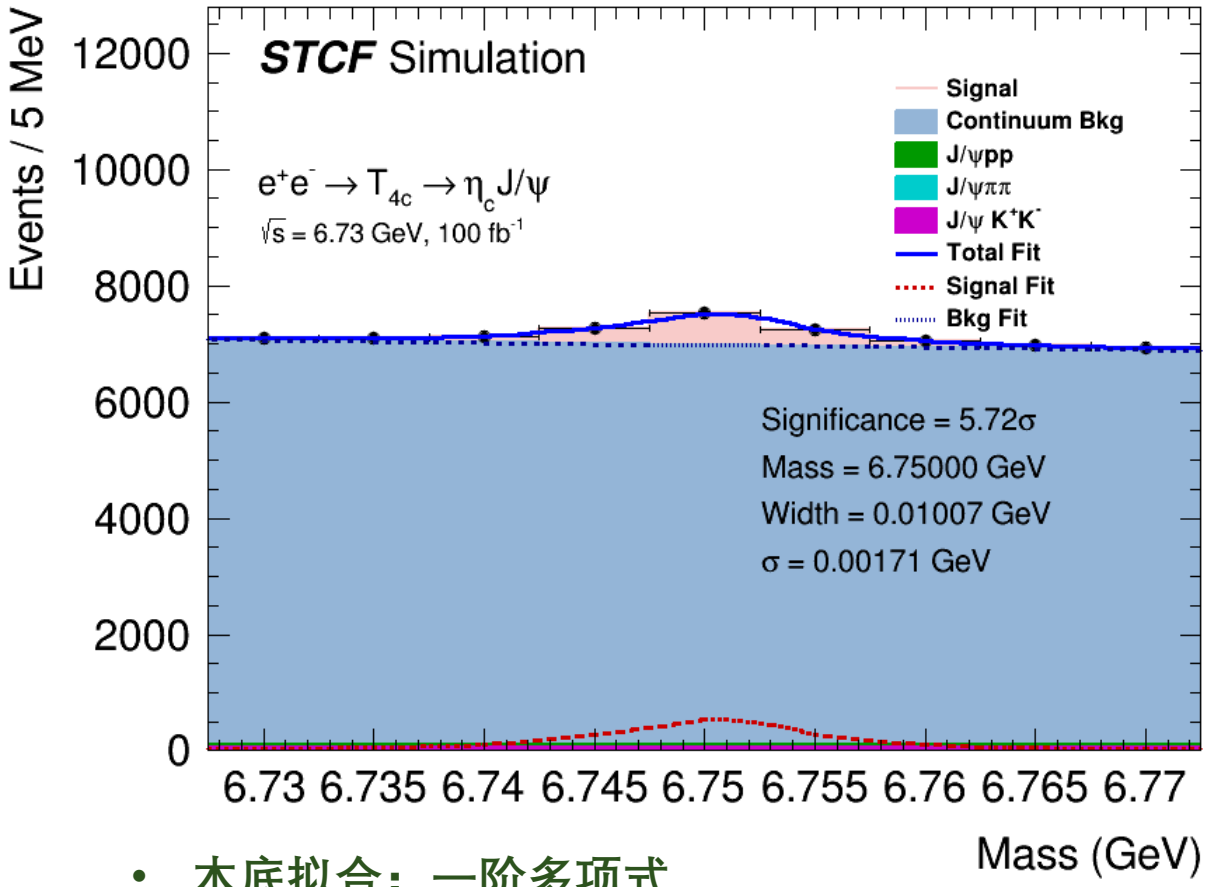
- $L = 100\ fb^{-1}$
- $significance = 0.45\sigma$

拟合结果：
- $N_{sig} = 6.5 \pm 12.3$
- $N_{back} = 314.4 \pm 24.6$
- $Mean = 6.75 \pm 0.01\ GeV$
- $\sigma = 4.92 \pm 1.82\ MeV$

统计结果：
- $N_{sig} = 8$
- $N_{back} = 313$

信号与本底拟合

单标J/ψ $\sqrt{s}$: 6.73GeV~6.77GeV Step size:5MeV 8 steps



- 本底拟合：一阶多项式
- 信号拟合：高斯卷积BW函数

- ***significance*** 计算公式：

log likelihood value from the fit w/o signal

$$S = [2(lnL_m(s+b) - lnL_m(b))]^{1/2}.$$

log likelihood value from the fit

- $L = 100\ fb^{-1}$
- $significance = 5.72\sigma$

拟合结果：
- $N_{sig} = 1530.3 \pm 473.4$
- $N_{back} = 62791.7 \pm 299.6$
- $Mean = 6.75 \pm 0.001\ GeV$
- $\sigma = 1.7 \pm 2.0\ MeV$

统计结果：
- $N_{sig} = 1487$
- $N_{back} = 62377$

不同截面预估下的结果

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➢ 双标

	能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77	significance
	input截面(fb)	3.8	6.5	12.9	32.2	64.4	32.2	12.9	6.4	3.8	0.45σ
	N_{obs}(信号)	0	0	1	1	3	1	1	0	0	
5倍	input截面(fb)	19.0	32.3	64.5	161.2	322.2	161.0	64.4	32.2	18.9	1.97σ
	N_{obs}(信号)	1	1	3	7	14	7	3	1	1	
10倍	input截面(fb)	38.0	64.6	129.0	322.3	644.4	322.1	128.7	64.3	37.8	3.58σ
	N_{obs}(信号)	2	3	6	14	28	14	6	3	2	

➢ 单标

	能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77	significance
	input截面(fb)	3.8	6.5	12.9	32.2	64.4	32.2	12.9	6.4	3.8	5.72σ
	N_{obs}(信号)	32	55	109	274	548	273	109	55	32	
5倍	input截面(fb)	19.0	32.3	64.5	161.2	322.2	161.0	64.4	32.2	18.9	26.76σ
	N_{obs}(信号)	161	274	547	1370	2738	1366	547	273	160	
10倍	input截面(fb)	38.0	64.6	129.0	322.3	644.4	322.1	128.7	64.3	37.8	57.66σ
	N_{obs}(信号)	323	548	1094	2740	5476	2732	1094	546	320	

感谢各位的聆听!

汇报人：董焯娟

Backup

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- Yin J H, Li Y B, Won E, et al. Search for the double-charmonium state with ηcJ/ψ at Belle[J]. Journal of High Energy Physics, 2023, 2023(8): 1-21.

1. Chen Z Z, Chen X L, Yang P F, et al. P-wave fully charm and fully bottom tetraquark states[J]. Physical Review D, 2024, 109(9): 094011.
2. Faustov R N, Galkin V O, Savchenko E M. Fully heavy tetraquark spectroscopy in the relativistic quark model[J]. Symmetry, 2022, 14(12): 2504.
3. Dong W C, Wang Z G. Going in quest of potential tetraquark interpretations for the newly observed T ψ ψ states in light of the diquark-antidiquark scenarios[J]. Physical Review D, 2023, 107(7): 074010.
4. Debastiani V R, Navarra F S. A non-relativistic model for the tetraquark[J]. Chinese Physics C, 2019, 43(1): 013105.
5. Liu M S, Liu F X, Zhong X H, et al. Fully heavy tetraquark states and their evidences in LHC observations[J]. Physical Review D, 2024, 109(7): 076017.
6. Wang G J, Meng L, Oka M, et al. Higher fully charmed tetraquarks: Radial excitations and P-wave states[J]. Physical Review D, 2021, 104(3): 036016.

单标η_c

Exclusive MC production under OSCAR

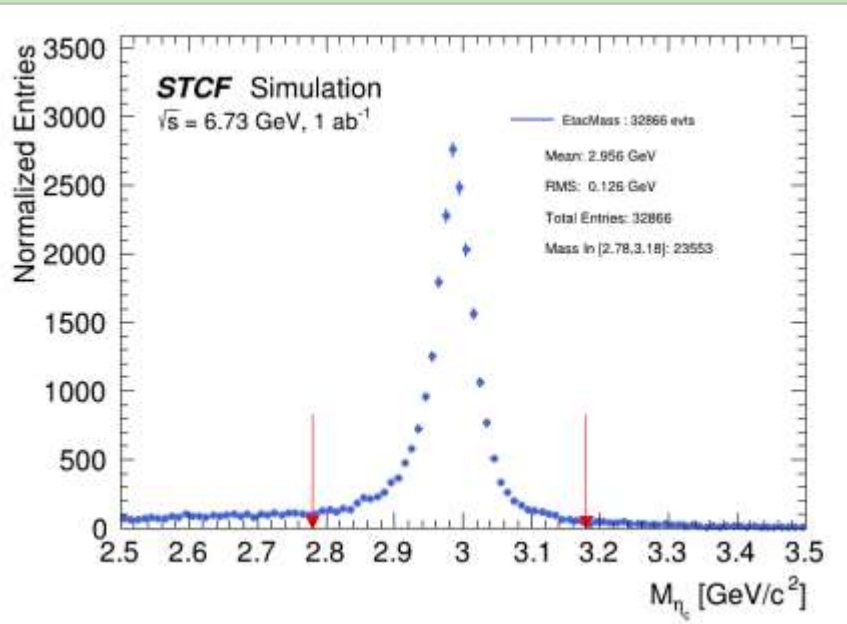
Generator：ConExc

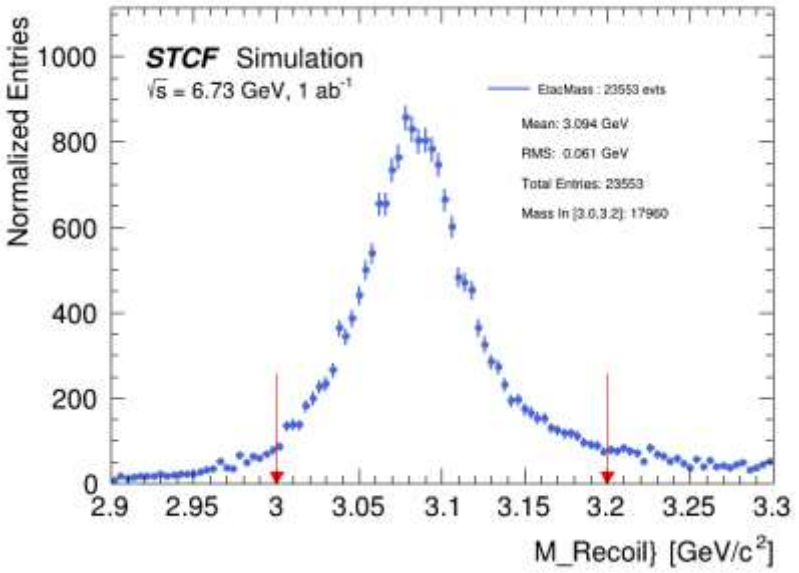
$\sqrt{S}$：6.73GeV　　Number of event: 100000

Signal Channel：$e^+e^- \to T_{4c} \to \eta_c J/\psi$，

- $\eta_c \to K^+K^-\pi^0, J/\psi \to anything$

Cut Flow	N_{obs}	Relative Efficiency
$otal\ number$:	50000	100.00%
$nGood \geq 2$:	49015	98.05%
nGoody$\gamma \geq 2$:	48676	99.30%
$nK_p \geq 1$:	40225	82.64%
$nK_m \geq 1$:	32866	81.71%
$n\pi^0 \geq 1$:	31284	95.13%
$\eta_c$mass cut:	23553	75.29%
Recoil mass cut:	17960	76.25%
$total\ cut$:	35.92%	





双标η_c和J/ψ信号数据

缪子

能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77
N_{obs} (MC)	17363	17500	17367	17521	16870	17557	17421	17311	17005
亮度 (fb^{-1})	100	100	100	100	100	100	100	100	100
选择效率	34.73%	35.00%	34.73%	35.04%	34.43%	35.11%	34.84%	34.62%	34.70%
input截面(fb)	3.8011	6.4568	12.9031	32.2315	64.4391	32.2076	12.8726	6.431	3.78
N_{obs}(函数)	0.1	0.2	0.3	0.8	1.5	0.8	0.3	0.2	0.1

电子

能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77
N_{obs} (MC)	14378	14282	14129	14416	14001	14026	14418	14315	14275
亮度 (fb^{-1})	100	100	100	100	100	100	100	100	100
选择效率	28.76%	28.56%	28.83%	28.83%	28.57%	28.62%	28.84%	28.63%	28.55%
input截面(fb)	3.8011	6.4568	12.9031	32.2315	64.4391	32.2076	12.8726	6.431	3.78
N_{obs}(函数)	0.1	0.1	0.3	0.6	1.3	0.6	0.3	0.1	0.1

单标J/ψ信号数据

缪子

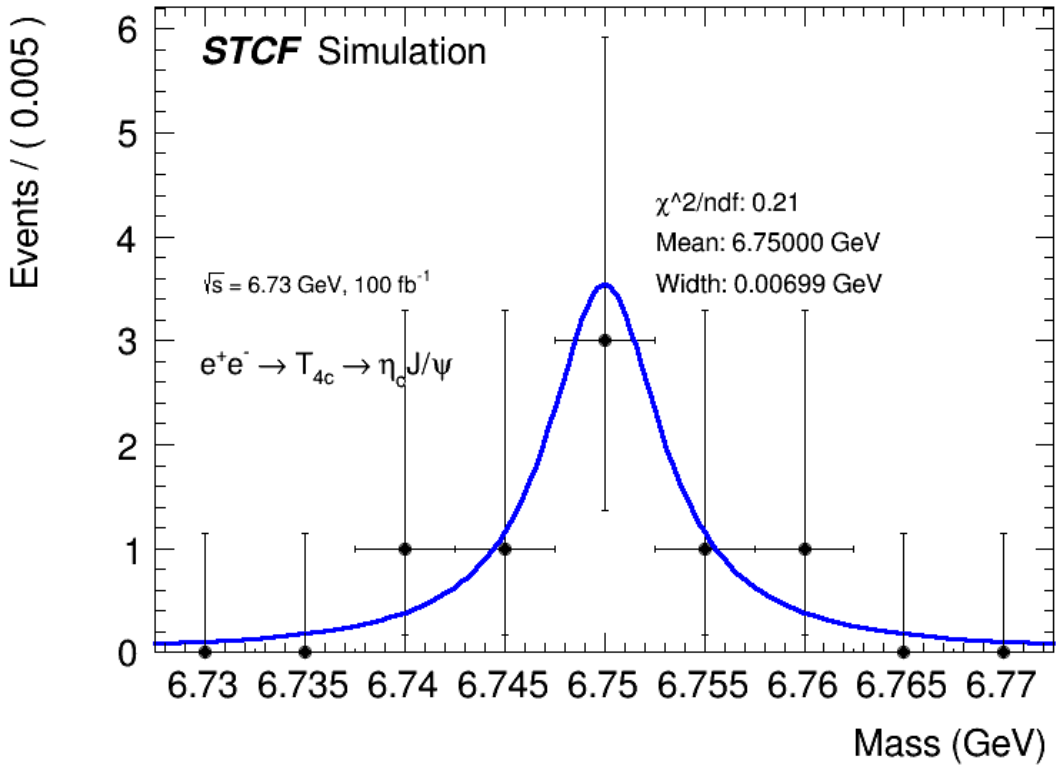
能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77
N_{obs} (MC)	39290	39121	39152	39252	39296	39230	39410	39242	39240
亮度 (fb^{-1})	100	100	100	100	100	100	100	100	100
选择效率	78.58%	78.24%	78.30%	78.50%	78.59%	78.46%	78.82%	78.48%	78.48%
input截面(fb)	3.8011	6.4568	12.9031	32.2315	64.4391	32.2076	12.8726	6.431	3.78
N_{obs}(函数)	17.8	30.1	60.2	150.8	301.9	150.6	60.5	30.1	17.7

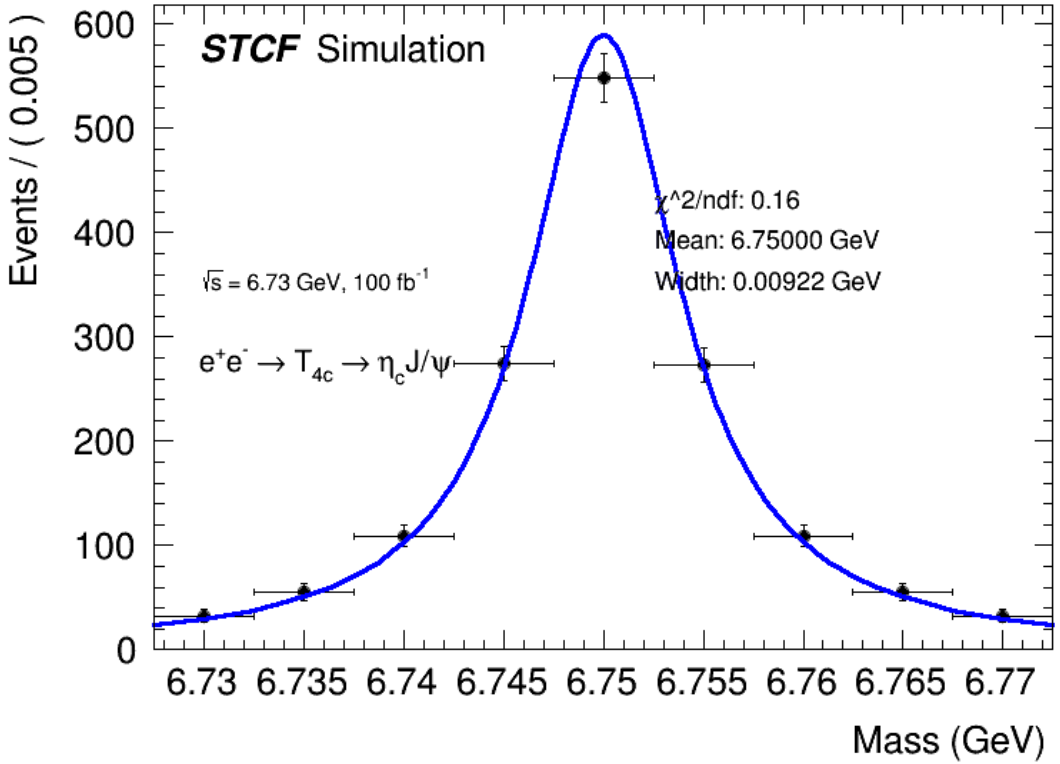
电子

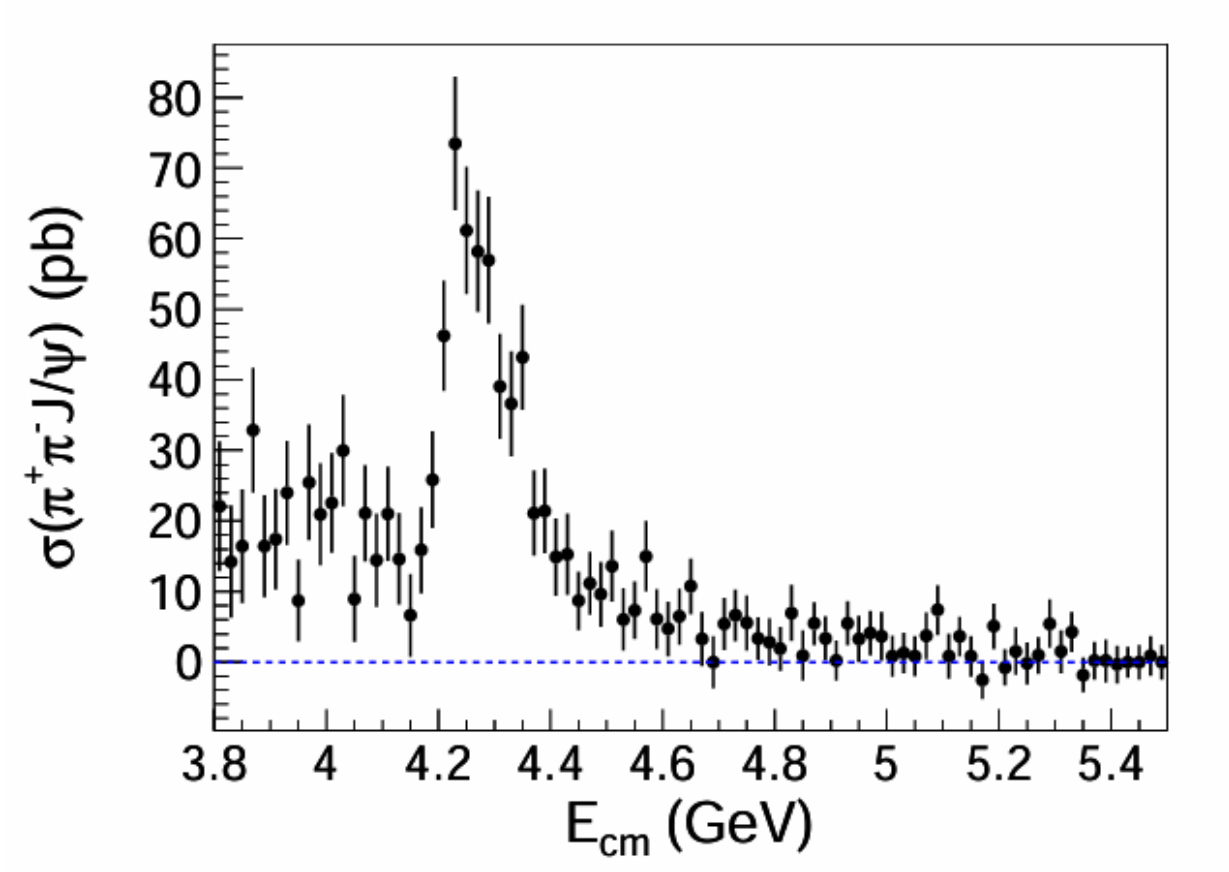
能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77
N_{obs} (MC)	31287	29457	31308	31411	30698	30652	31886	30745	31238
亮度 (fb^{-1})	100	100	100	100	100	100	100	100	100
选择效率	63.85%	64.04%	63.89%	64.10%	63.95%	63.86%	63.77%	64.05%	63.75%
input截面(fb)	3.8011	6.4568	12.9031	32.2315	64.4391	32.2076	12.8726	6.431	3.78
N_{obs}(函数)	14.5	24.6	49.1	123.2	245.7	122.6	48.9	24.6	14.4

全重建η_c和J/ψ

- 只拟合信号







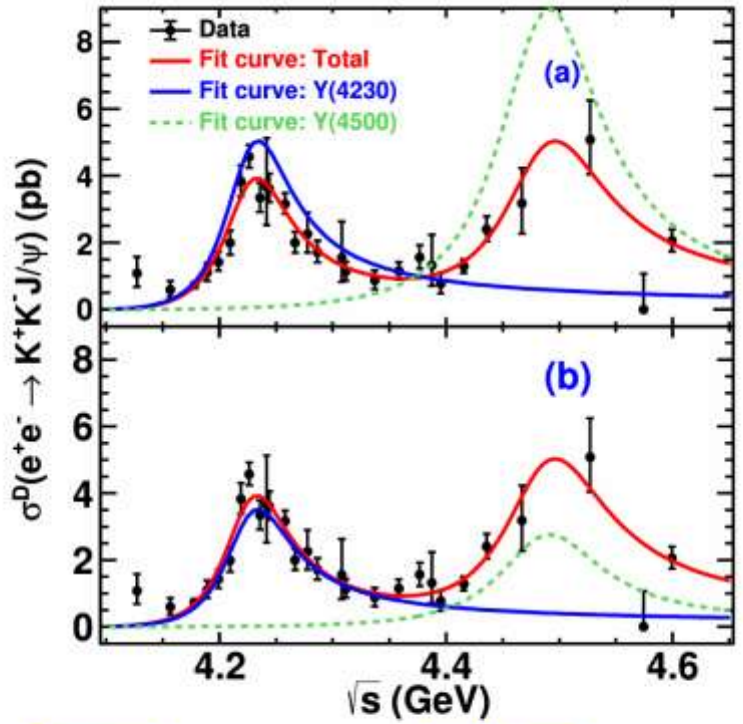
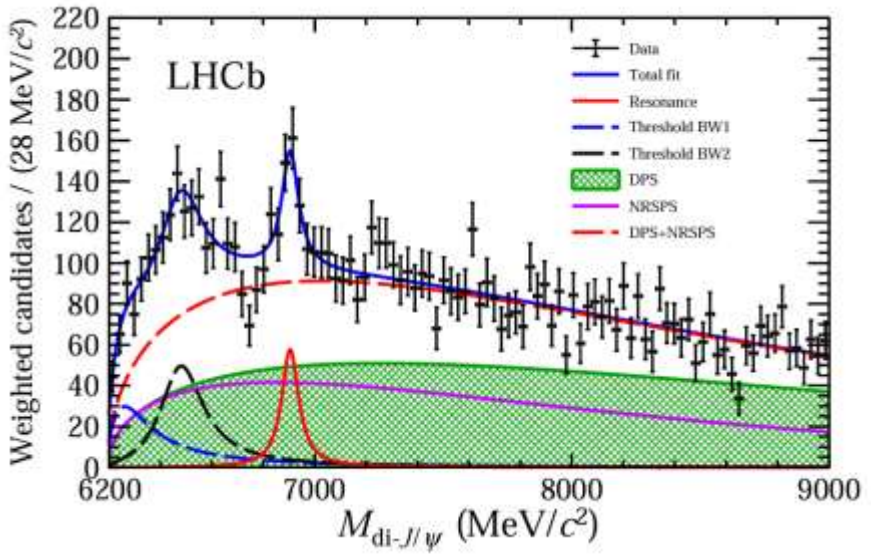


Figure 6: Cross sections of $e^+e^- \to K^+K^-J/\psi$, indicated by error bars with only statistical uncertainties. They are fitted by a coherent sum of two Breit-Wigner functions indicated by red solid curves. The Blue and green dashed curves are the amplitudes describing the resonances $Y(4230)$ and $Y(4500)$, respectively. (a) corresponds to solution I, (b) corresponds to solution II [23].

➢ **Observation of structure in the J/ψ-pair mass spectrum**

- **States:** $T_{c\bar{c}c\bar{c}}(6550)^0$, $T_{c\bar{c}c\bar{c}}(6900)^0$, $T_{c\bar{c}c\bar{c}}(7290)^0$
- **Quantum numbers:** $I^G(J^{PC}) = 0^+(?^{?+})$
- **Minimal quark content:** $c\bar{c}c\bar{c}$
- **Experiments:** LHCb(first observed), ATLAS, CMS
- **Production:** prompt pp collisions
- **Decay modes:** $J/\psi J/\psi$
- **Nearby thresholds:** $J/\psi\psi(2S), \chi_{c0}\chi_{c0}, \cdots$
- **Characteristic widths:** $80 - 191\ MeV$



LHCb results:

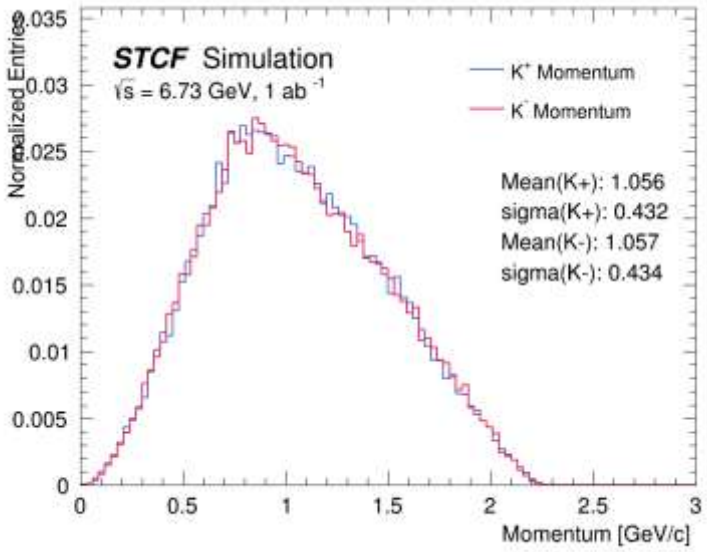
Structure	Significance $p_T^{\text{di-}J/\psi}$-threshold	Significance $p_T^{\text{di-}J/\psi}$-binned
Any structure beyond NRSPS plus DPS	3.4σ	6.0σ
Threshold enhancement plus $X(6900)$	6.4σ	6.9σ
Threshold enhancement	6.0σ	6.5σ
$X(6900)$	5.1σ	5.4σ

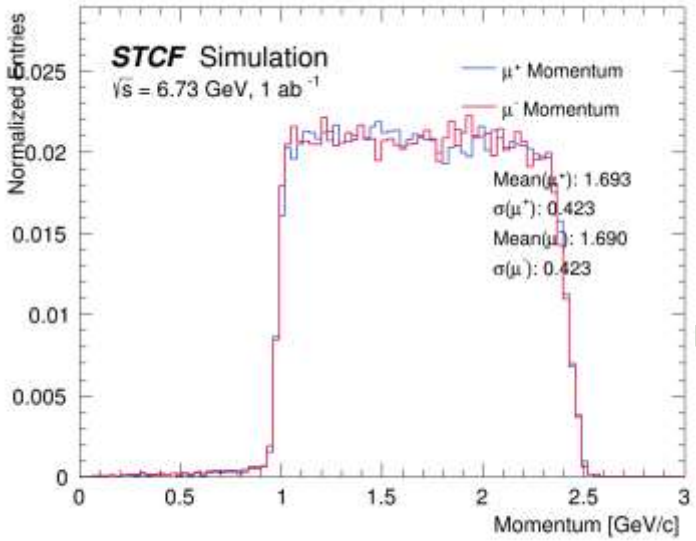
- LHCb Collaboration. Observation of structure in the J/ψ-pair mass spectrum[J]. Science bulletin, 2020, 65(23): 1983-1993.

Truth information

$\sqrt{S} = 6.73$ GeV

Kaon 动量分布--truth

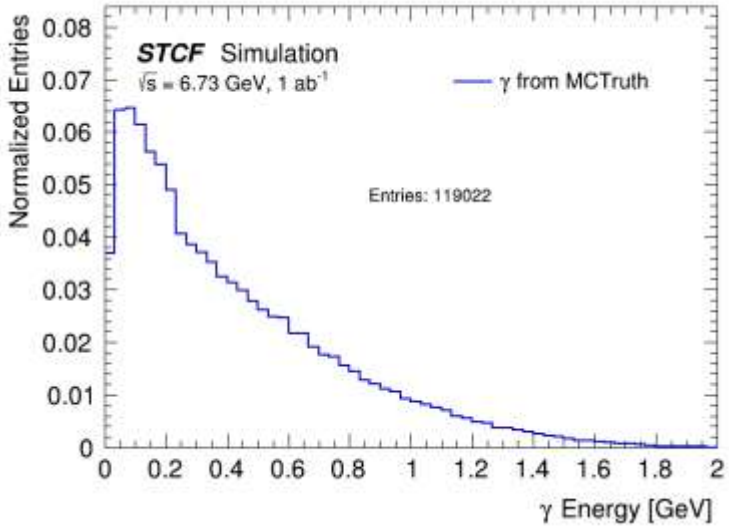


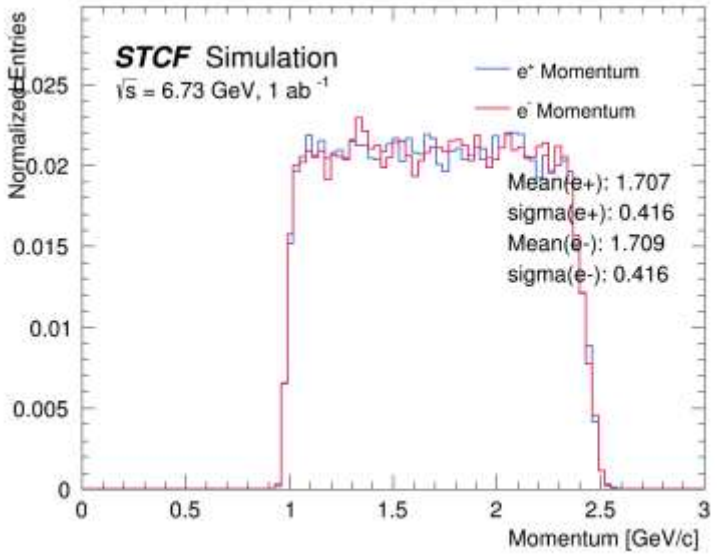


muon 动量分布--truth

动量大部分大于0.9GeV/c

光子能量分布--truth

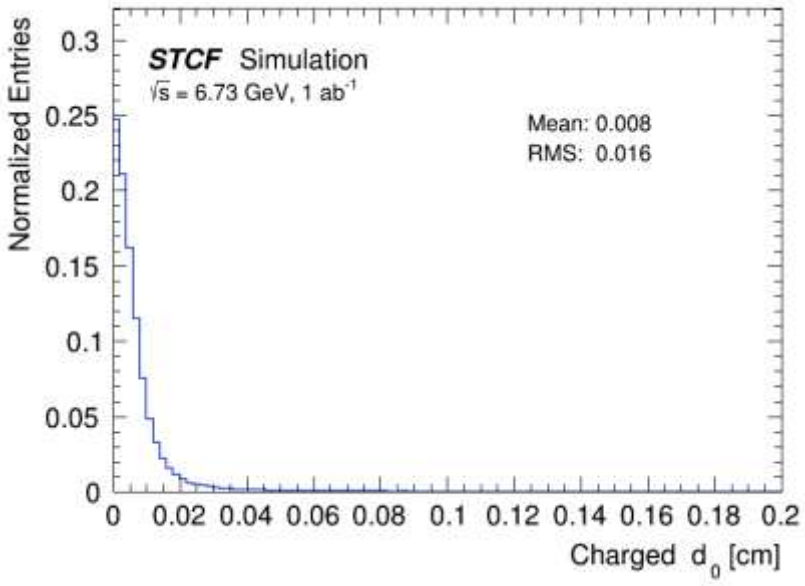




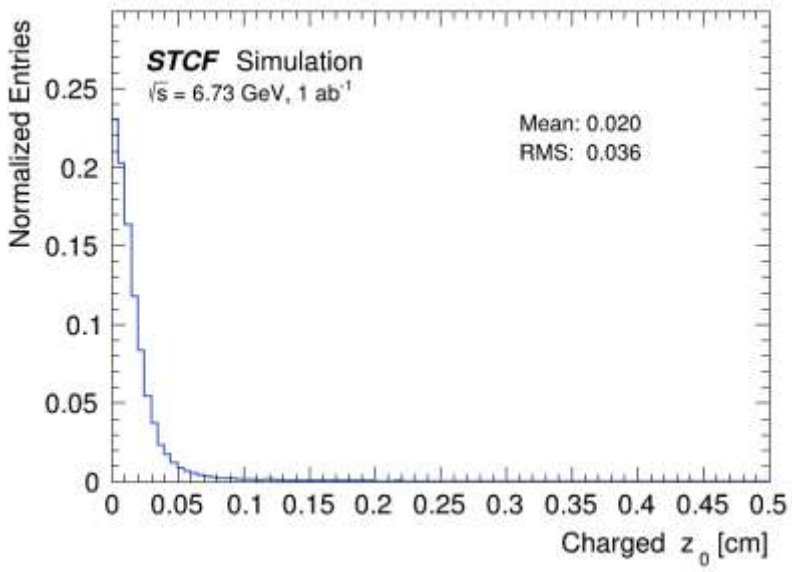
电子动量分布--truth

带电径迹 d_0、z_0、θ 分布

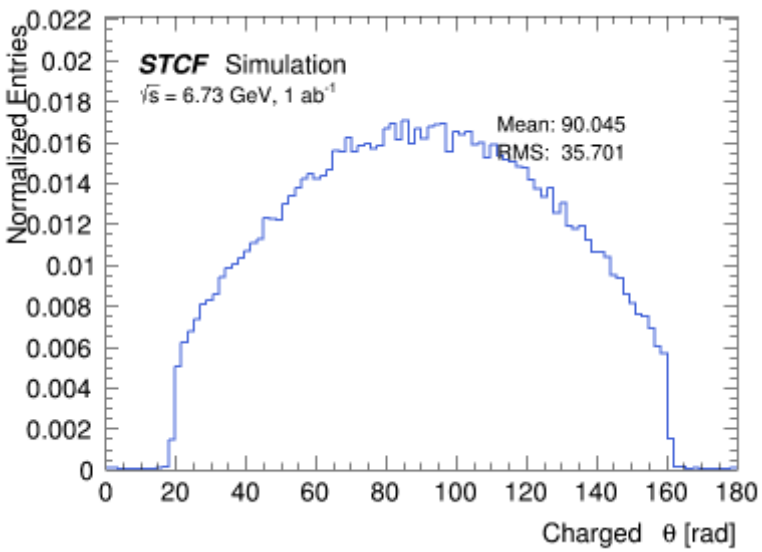
- 径迹参数从POCA点得到



d_0 分布



z_0分布



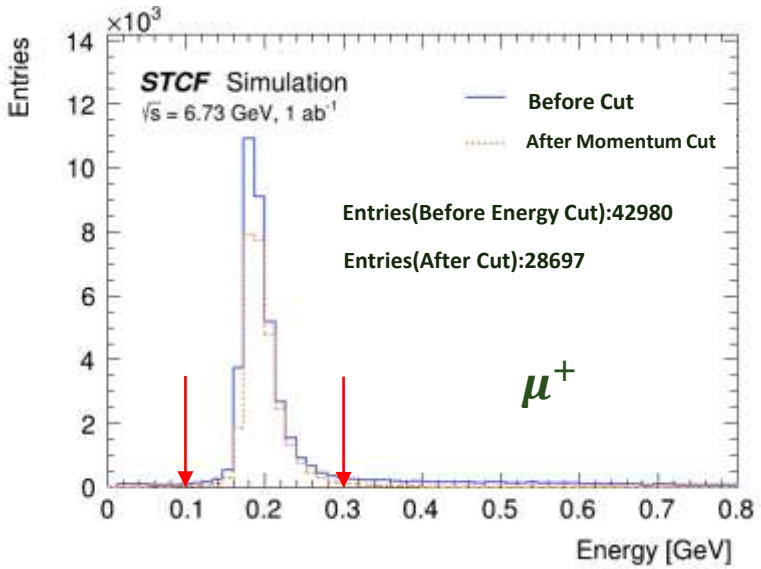
θ 分布

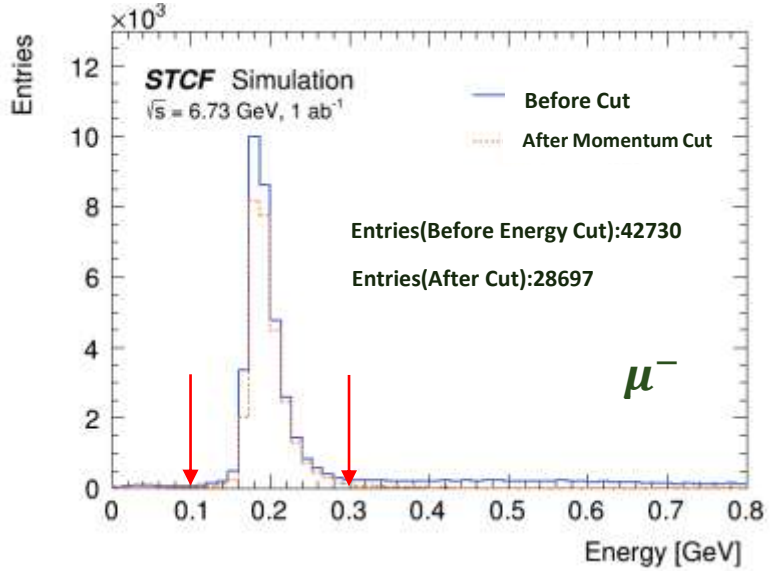
选择缪子

- **筛选条件：** $0.1 \leq E_{emc} \leq 0.3$ ， $|p_\mu| \geq 0.9\ GeV$

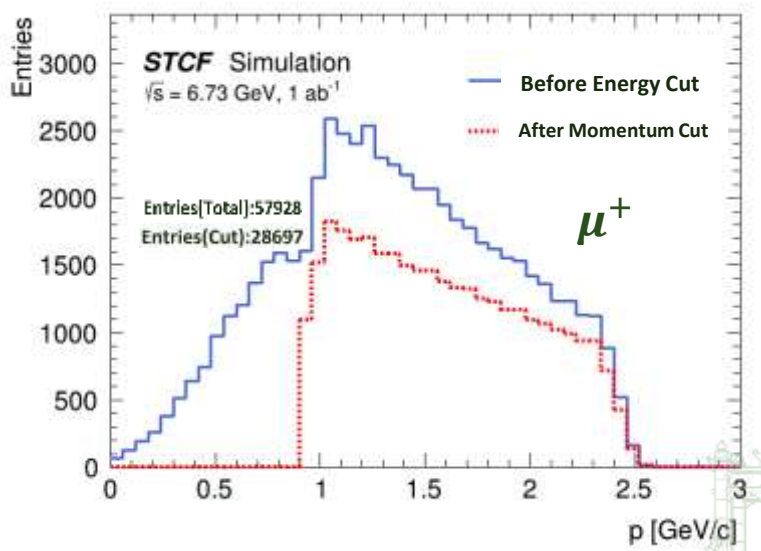
$\sqrt{S} = 6.73$ GeV

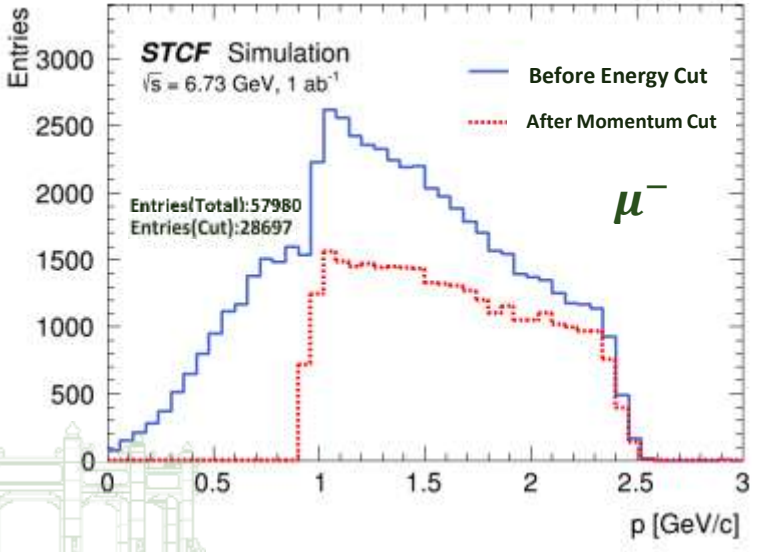
Emc里的能量沉积分布：





动量分布：

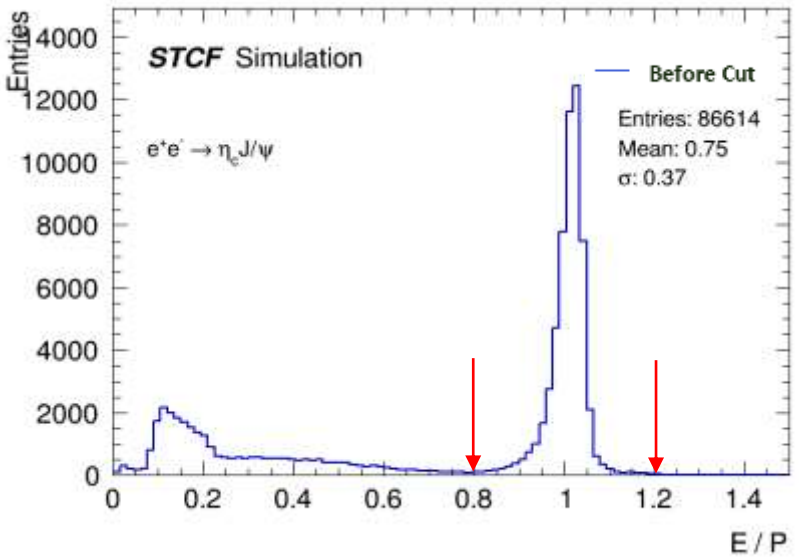


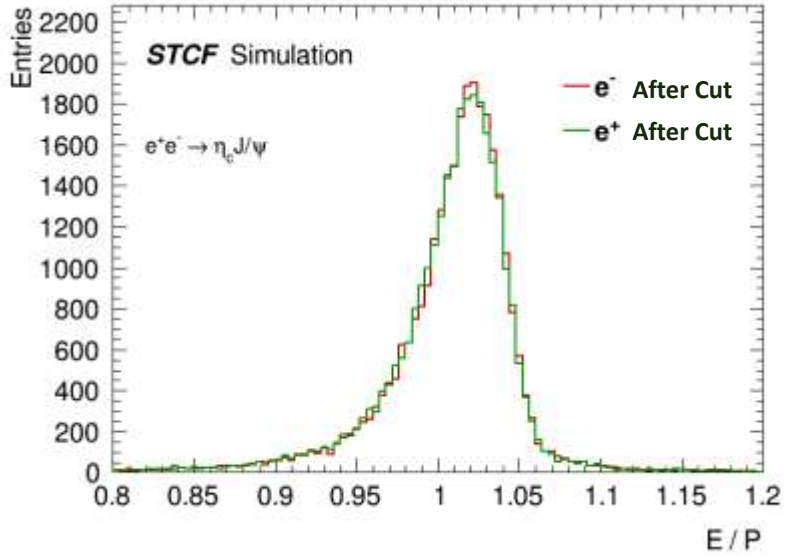


选择电子

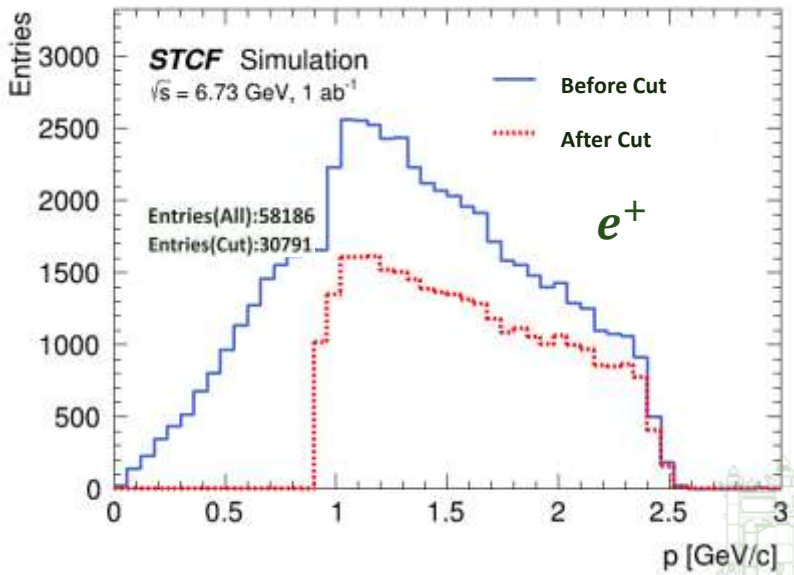
- 筛选条件 $0.8 \leq \frac{E_e}{p_e} \leq 1.2$ ， $|p_e| \geq 0.9\ GeV$ $\sqrt{S} = 6.73$ GeV

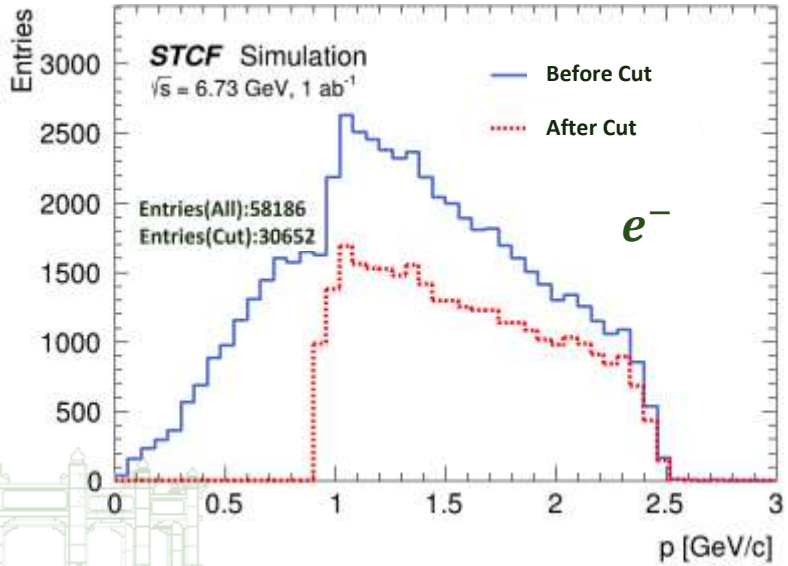
E/P分布：





动量分布：





重建η_c和J/ψ

- $\sqrt{S} = 6.73$ GeV

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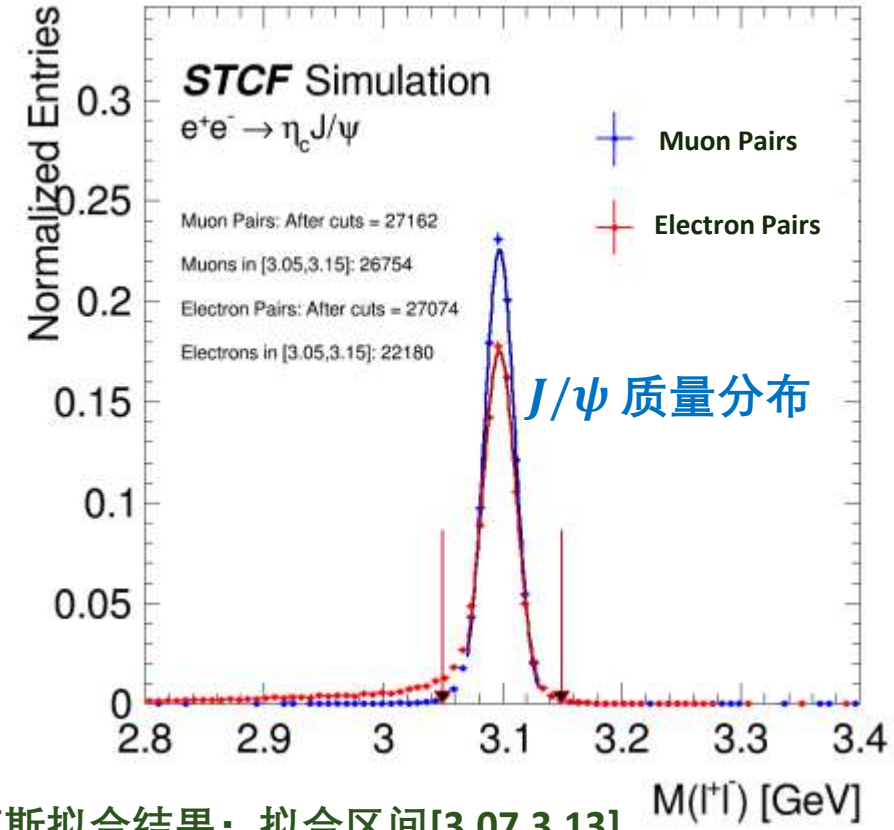
➢ $J/\psi \to \mu^+\mu^-$和$J/\psi \to e^+e^-$的质量分布对比

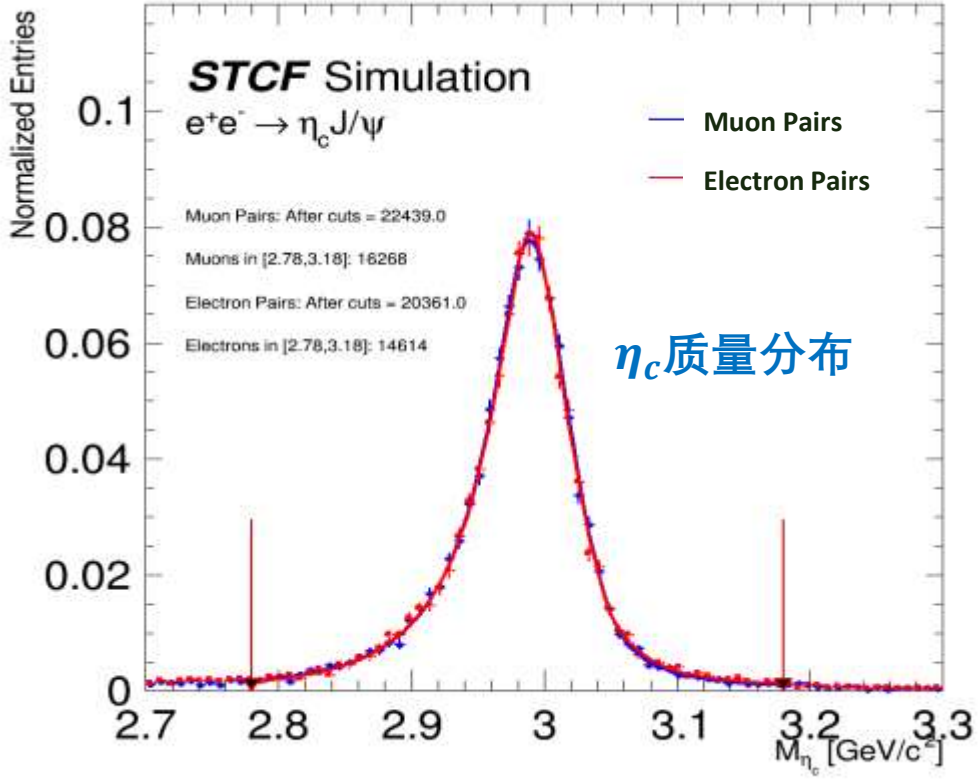
J/ψ *Mass cut*: $3.05GeV < M_{Le^+Le^-} < 3.15GeV$



单高斯拟合结果：拟合区间[3.07,3.13]

- $\mu: \sigma = 12.79 \pm 0.07MeV, mean = 3.097 \pm 0.001$
- $e: \sigma = 14.05 \pm 0.10MeV, mean = 3.096 \pm 0.001$

η_c *Mass cut*: $2.78GeV < M_{K^+K^-\pi^0} < 3.18GeV$

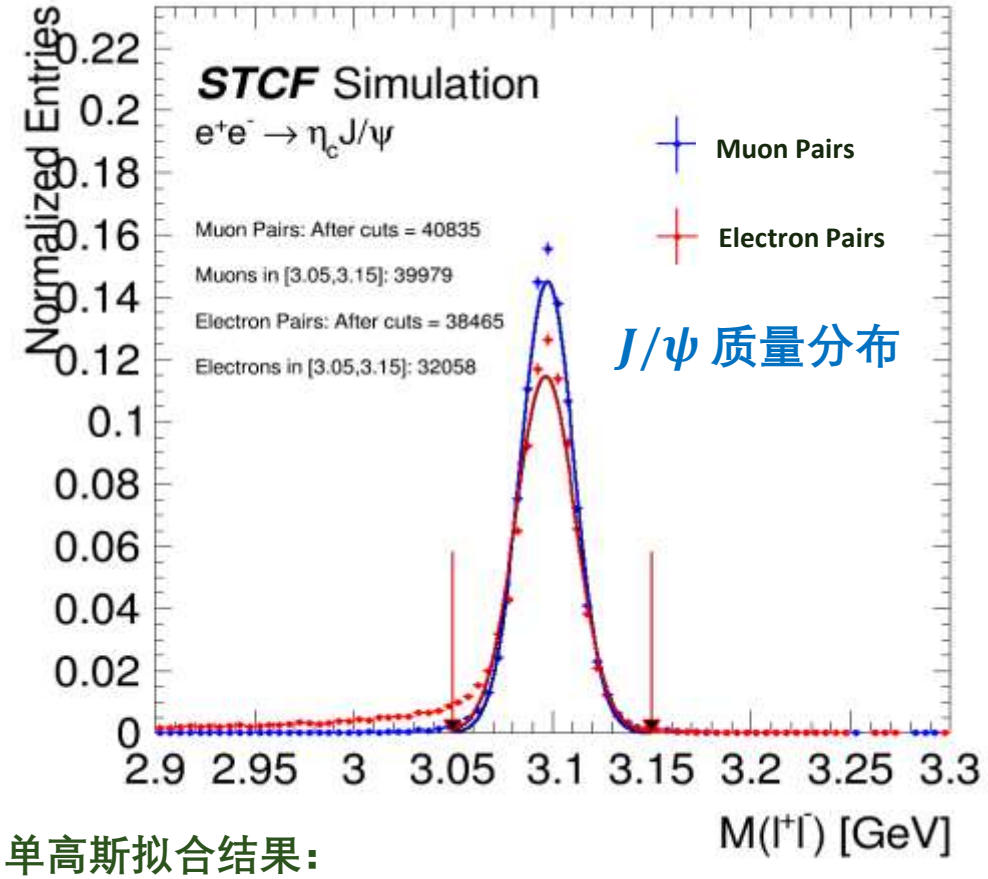


单高斯+双左右两个 Crystal Ball拟合结果：

- $\mu: \sigma = 49.99 \pm 5.02MeV, mean = 2.989 \pm 0.023$
- $e: \sigma = 49.99 \pm 5.21MeV, mean = 2.979 \pm 0.006$

➢ $J/\psi\to\mu^+\mu^-$和$J/\psi\to e^+e^-$的质量分布对比

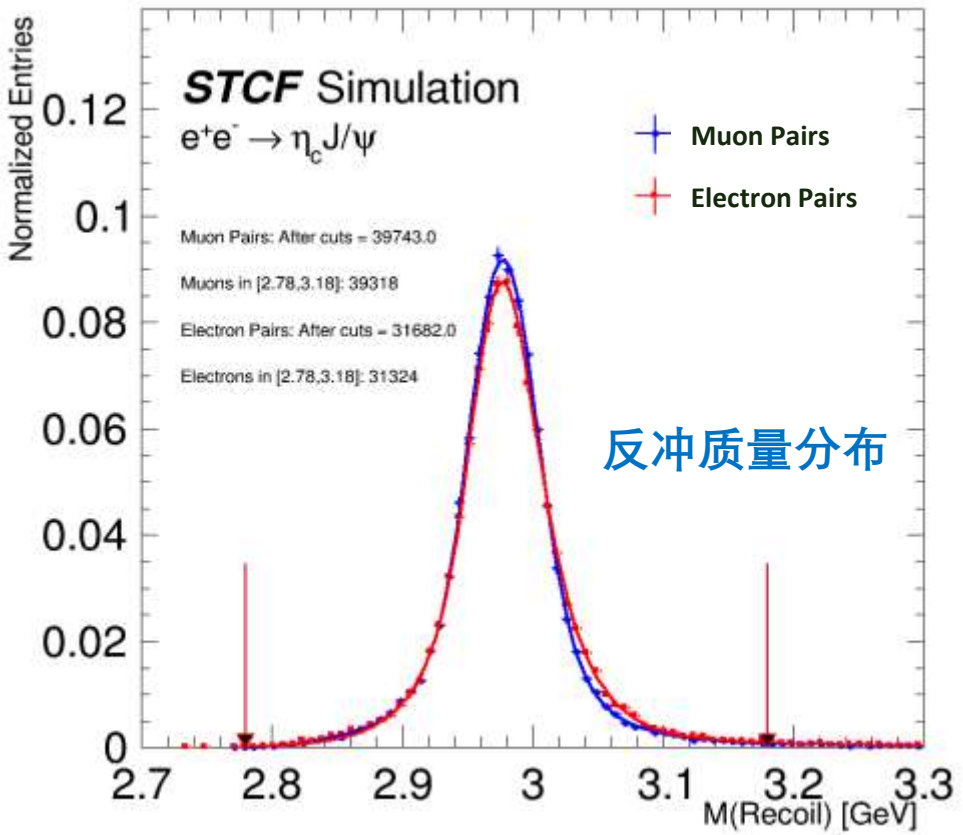
J/ψ *Mass cut*: $3.05GeV < M_{le^+le^-} < 3.15GeV$



单高斯拟合结果：

- $\mu: \sigma = 13.40 \pm 0.06MeV, mean = 3.097 \pm 0.007$
- $e: \sigma = 15.05 \pm 0.08MeV, mean = 3.096 \pm 0.009$

Recoil *Mass cut*: $2.78GeV < M_{\text{recoil}} < 3.18GeV$



单高斯+双左右两个 Crystal Ball拟合结果：

- $\mu: \sigma = 37.13 \pm 1.89MeV, mean = 2.881 \pm 0.003$
- $e: \sigma = 34.63 \pm 2.50MeV, mean = 3.019 \pm 0.003$