# $J/\psi$ Total Number via Inclusive Hadron Final States

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Discussion with $J/\psi$ Group

For more information in detail, go to:
http://hpws3.ihep.ac.cn/˜ huanggs/work.html

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— every road leads to Rome

# OUTLINE

1. Motivation
2. Different ways
3. Data set
4. Hadronic event selection
5. Lund_charm generator
6. $J/\psi$ total number
7. Summary

# Ideas

1. $\psi' \to \pi^+\pi^- J/\psi, J/\psi \to anything$

   Proposed by Yuan Changzheng.

| | |
|---|---|
| Advantages: | obtain $\varepsilon$ by data, rely little on MC |
| Disadvantages: | extra beam-time needed |
| | difficult efficiency correction |
| | (moving $J/\psi$, etc.) |

2. $J/\psi \to$ anything

   $J/\psi$ decay generator by Chen Jiangchuan

| | |
|---|---|
| Advantages: | careful comparison (data and MC) |
| | ready codes developed by R group |
| Disadvantages: | incomplete decay modes, |
| | some inaccurate branching ratios |

3. $J/\psi \to l^+l^- \quad (l = e, \mu)$

| | |
|---|---|
| Advantages: | known branching ratio(6.02±0.19%) |
| | well-studied final states |
| Disadvantages: | QED background |

# Data set

**Table 1:** Data analyzed and number of events selected

| data | Run range | Nrun | $N_{had}^{obs}$ | $N_{\gamma\gamma}$ |
|---|---|---|---|---|
| set1 | 13500-13699 | 191 | 922489 | 5724 |
| set2 | 13700-14400 | 671 | 3565772 | 22661 |
| set3 | 14401-15100 | 678 | 3788880 | 23108 |
| set4 | 15101-15800 | 625 | 3912150 | 24068 |
| set5 | 15801-16500 | 679 | 4156710 | 25768 |
| set6 | 16501-16835 | 331 | 1931815 | 11985 |
| tot. | 13500-16835 | 3175 | 18277816 | 113314 |
| 3GeV | 15443-15489 | 47 | 3406 | 2555 |

Only GOOD runs used (istatus = 1, 2)!

# Hadronic event selection

R group: According to particle's $(t, \vec{r})$ and $(E, \vec{P})$

- Remove apparent Bhabha
  - Large energy deposite; back to back
- Track level
  Select track to remove cosmic rays, beam-gas, and ensure the geometry acceptance, . . .

| **Type** | **Cuts** |
|---|---|
| Time | $2 < t < t_{\text{proton}} + 5\sigma_{\text{ TOF}}$ |
| Space | $\begin{cases} r_0 < 2.0\text{cm}, \\ \lvert z_0\rvert < 18\text{cm}, \end{cases}$ MFIT=2 |
| Energy | $E < 0.6E_{\text{beam}}$ |
| Momentum | $\begin{cases} p < p_{\text{beam}} + 5\sigma_p \\ \lvert\cos\theta\rvert < 0.84 \end{cases}$ |

- Event level
  Remove beam-gas, two-photon, $ee$, $\mu\mu$, . . .
  - Kick out events with all tracks in the same side
  - Good tracks $\geq$ 2, from which $N_{MFIT=2} \geq 1$
  - $\Sigma E > 0.28E_{\text{beam}}$
  - for 2-prong candidate:
    Not back-to-back .AND. $\geq 2$ isolatd $\gamma$'s

# Generator

Lund_charm: A integrated generator for hadron production in BEPC energy region, published in Phys. Rev. D62: 034003, 2000, Evtyp #31 in BESLIB v102 added by Chen Jiangchuan.

Lund_arlw: A improved generator for low energy region (Lund group and R group).

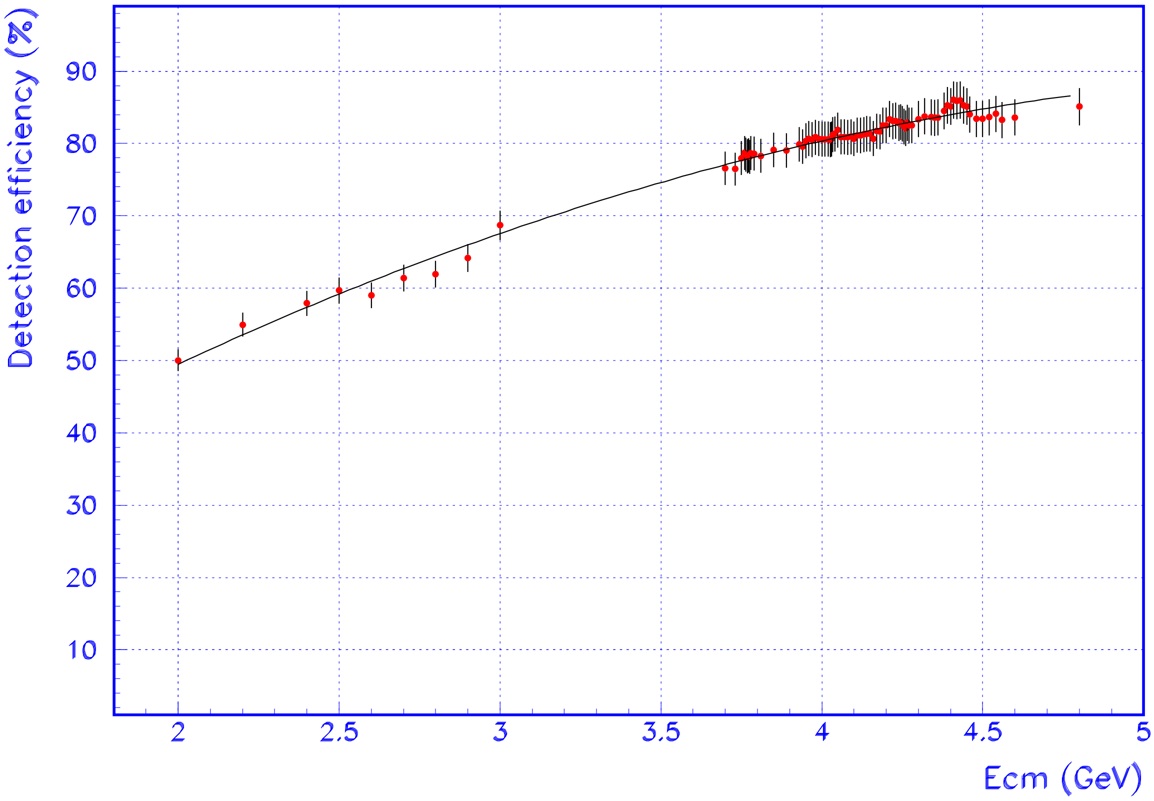


**Figure 1:** Detection efficiency for hadronic events obtained with Lund_charm generator (above 3.7 GeV) and Lund_arlw generator (below 3.0 GeV) in R analysis

# A Rough Estimation

Hadron detection efficieny used in R analysis:

$$\varepsilon_{had} = -5.4017 + 33.047 E_{cm} - 2.8966 E_{cm}^2 \quad (1)$$

So, at $J/\psi$ energy,

$$\varepsilon_{had}(E_{cm} = 3.1\text{GeV}) = 69.2\% \quad (2)$$

Assume:

1. Same detection efficiency in continuum and at resonance;
2. Leption-pair final states excluded by event selection;
3. Contribution from continuum ignored;

Then,

$$\begin{aligned} N_{J/\psi} &= \frac{N_{had}^{obs}}{\varepsilon_{had}} * \frac{1.0}{1.0 - Br(J/\psi \to ll)} && (3) \\ &= \frac{18.28(M)}{0.692} * \frac{1.0}{1.0 - 2*0.06} && (4) \\ &= 30.0(M) && (5) \end{aligned}$$

# Parameter tunning

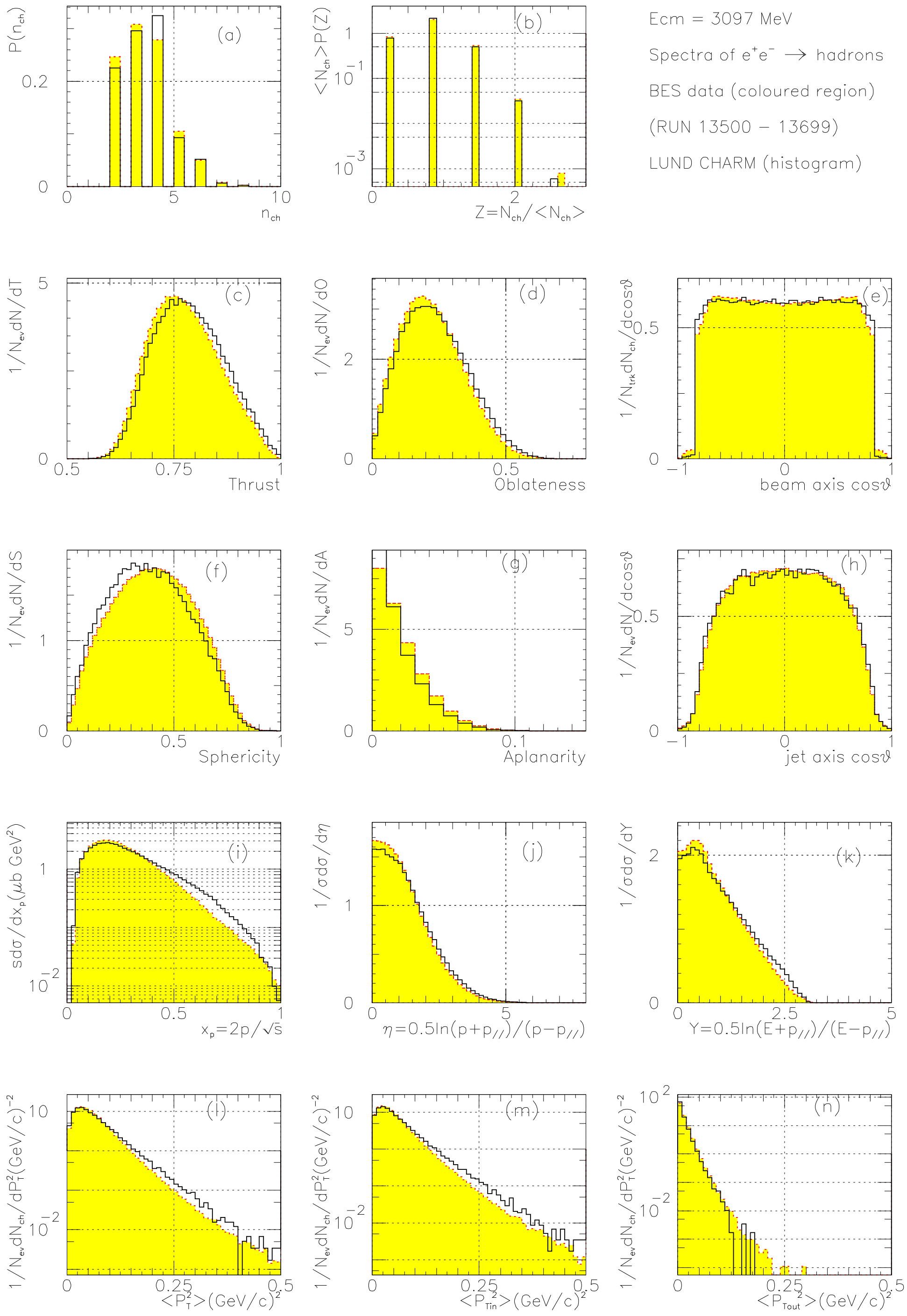


**Figure 2:** Event shapes by Lund_charm with parameters used in R measurement, corresponding hadronic event detection efficiency $\varepsilon = 0.584$.

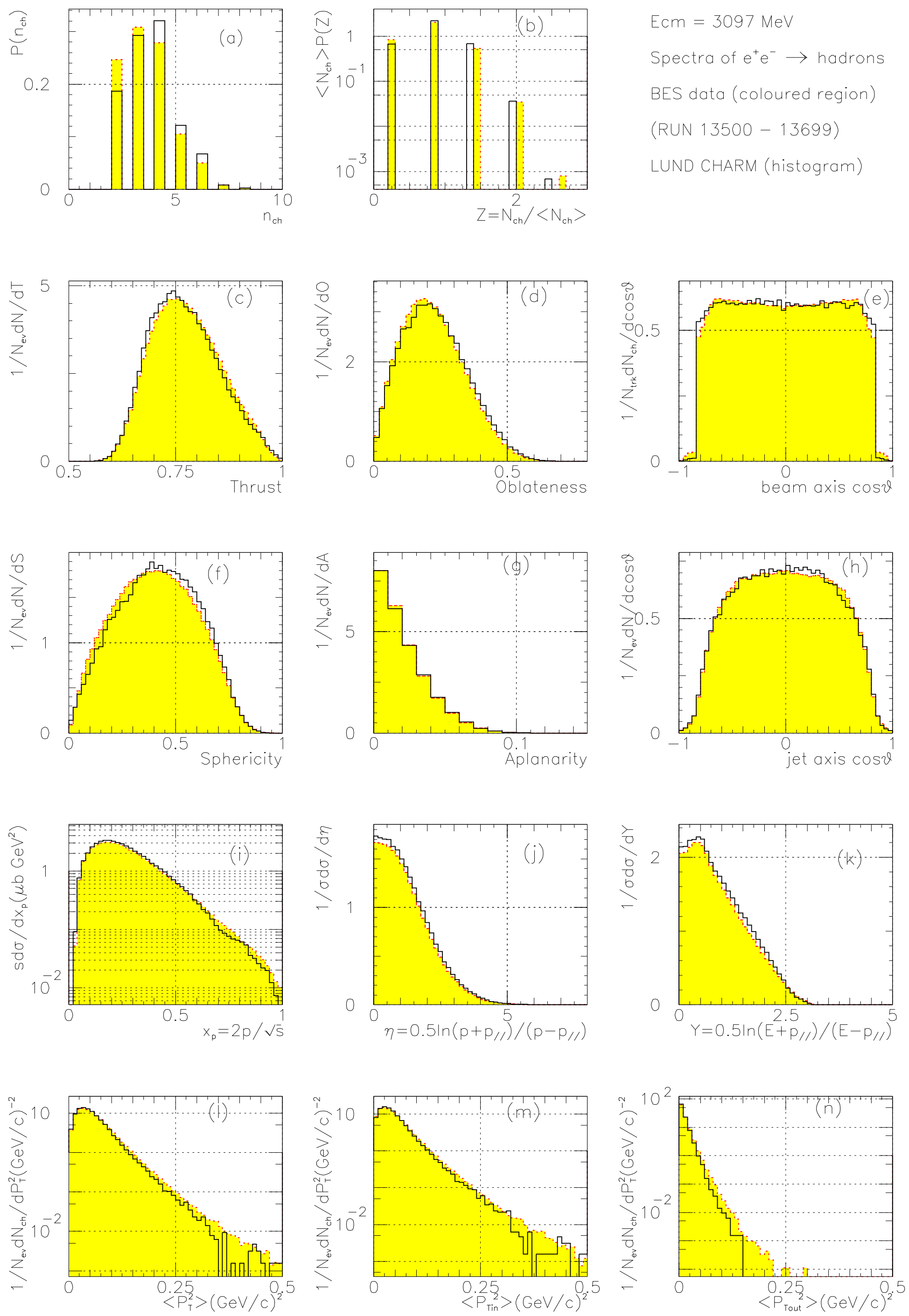


**Figure 3:** Event shapes by Lund_charm with default parameters in BESLIB V102, corresponding hadronic event detection efficiency $\varepsilon = 0.636$.

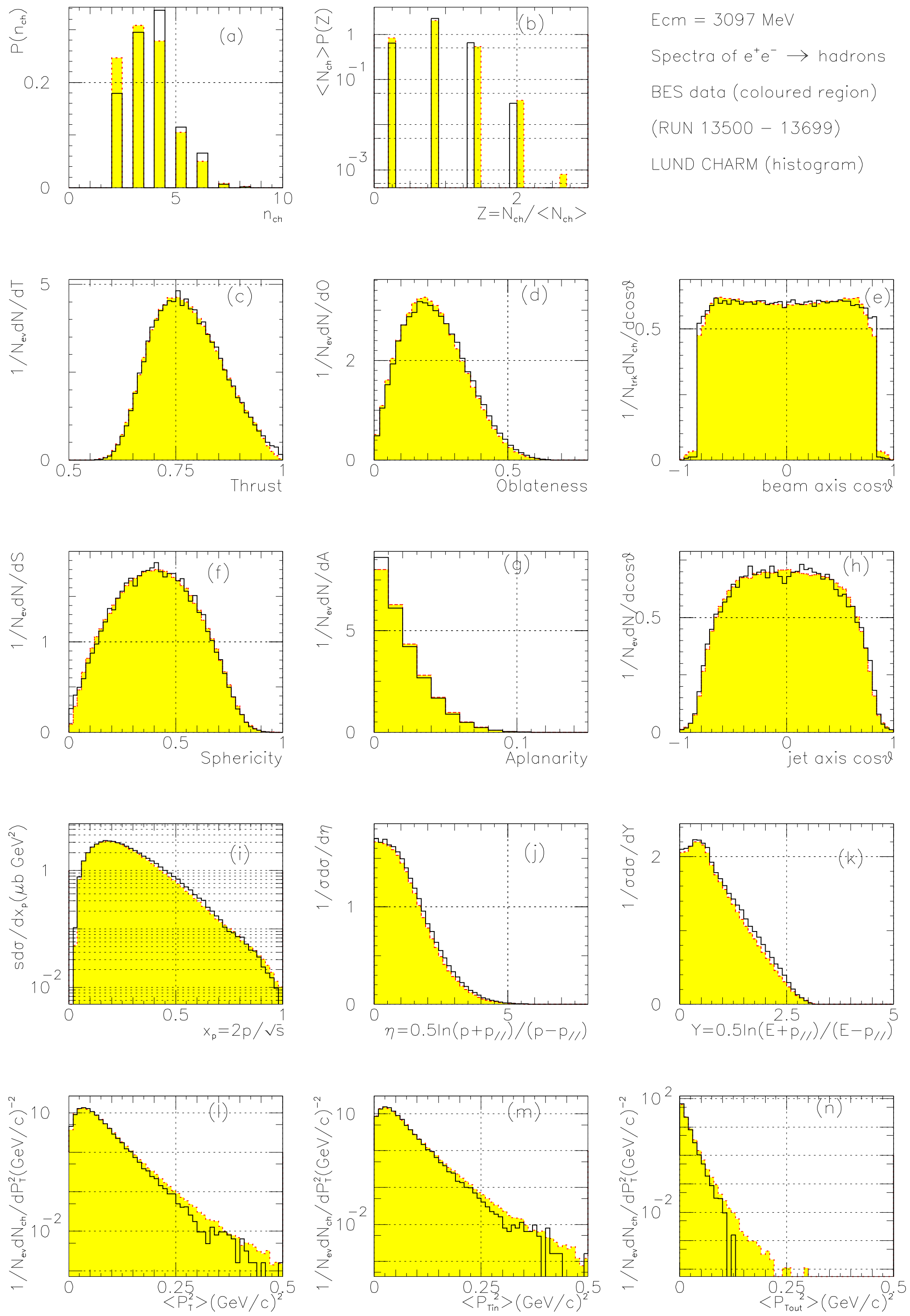


**Figure 4:** Event shapes by Lund_charm with tunned parameters, corresponding hadronic event detection efficiency $\varepsilon = 0.622$.

# Efficiency matrix

**Table 2:** Production multiplicity with well tunned parapeters

| $p$ | 0 | 2 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|---|
| ratio | 0.025 | 0.384 | 0.420 | 0.161 | 0.010 | 0.000 |

**Table 3:** The efficiency matrix. p and q are number of charged tracks (produced and observed)

| | q=2 | 3 | 4 | 5 | 6 | 7 | 8 | >8 |
|---|---|---|---|---|---|---|---|---|
| p=0 | 0.0465 | 0.0365 | 0.0160 | 0.0002 | 0. | 0. | 0. | 0. |
| 2 | 0.1928 | 0.0337 | 0.0230 | 0.0017 | 0.0001 | 0. | 0. | 0. |
| 4 | 0.0875 | 0.3608 | 0.3737 | 0.0279 | 0.0121 | 0.0008 | 0. | 0. |
| 6 | 0.0161 | 0.1145 | 0.2643 | 0.3534 | 0.2110 | 0.0098 | 0.0023 | 0. |
| 8 | 0.0051 | 0.0423 | 0.1248 | 0.2392 | 0.2866 | 0.2159 | 0.0720 | 0.0030 |

**Table 4:** Observed multiplicity of M.C. calculated from primary multiplicity and efficiency matrix

| $q$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | sum |
|---|---|---|---|---|---|---|---|---|
| r | .1146 | .1842 | .2100 | .0717 | .0420 | .0041 | .0011 | 0.628 |
| $r_{norm.}$ | .1826 | .2936 | .3346 | .1142 | .0668 | .0065 | .0017 | 1.0 |

**Table 5:** observed multiplicity of data (obviously lower than that of M.C.)

| $q$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | >8 |
|---|---|---|---|---|---|---|---|---|
| $r_{norm.}$ | .2501 | .3105 | .2741 | .1051 | .0499 | .0080 | .0022 | .0002 |

**Table 6:** efficiency and mean multiplicity running with $t$

| $t$ | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.11 |
|---|---|---|---|---|---|---|---|---|
| $\varepsilon$ | 0.618 | 0.615 | 0.612 | 0.609 | 0.606 | 0.603 | 0.600 | 0.597 |
| $< n_{ch} >$ | 3.511 | 3.485 | 3.460 | 3.435 | 3.410 | 3.385 | 3.361 | 3.337 |

# Efficiency correction

Reason: discrepancy between real data and Monte Carlo simulation.

Method: Assume an extra rejection probability $t$ for MC track, then check multiplicity distribution over different $t$.

For an observed $n$-prong event, the probability of $m$ track(s) missing is

$$C_n^m \cdot t^m \cdot (1-t)^{n-m},$$

Only $(n-m) < 2$ will lead to change in efficiency.

A corrected efficiency matrix can be obtained in this way, and it will give an estimation of correction to efficiency.

Result: (t=0.07)
$\varepsilon_{had}$ : $62.8\% \rightarrow 60.9\%$ ($-3.0\%$ corr.)
$< n_{ch} >$: $3.617 \rightarrow 3.435$ ($3.428$ for data)

**Table 7:** The corrected efficiency matrix when $t$=0.07

| | q=2 | 3 | 4 | 5 | 6 | 7 | 8 | >8 |
|---|---|---|---|---|---|---|---|---|
| p=0 | .0473 | .0330 | .0120 | .0001 | .0000 | .0000 | .0000 | .0000 |
| 2 | .1735 | .0324 | .0177 | .0012 | .0001 | .0000 | .0000 | .0000 |
| 4 | .1508 | .3755 | .2875 | .0230 | .0081 | .0005 | .0000 | .0000 |
| 6 | .0426 | .1667 | .3019 | .3082 | .1398 | .0067 | .0013 | .0000 |
| 8 | .0161 | .0733 | .1738 | .2666 | .2603 | .1545 | .0413 | .0016 |

**Table 8:** Corrected multiplicity distribution

| $q$ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | sum |
|---|---|---|---|---|---|---|---|---|
| r | .1381 | .1986 | .1782 | .0624 | .0285 | .0028 | .0006 | 0.609 |
| $r_{norm.}$ | .2267 | .3259 | .2925 | .1025 | .0468 | .0046 | .0010 | 1.0 |

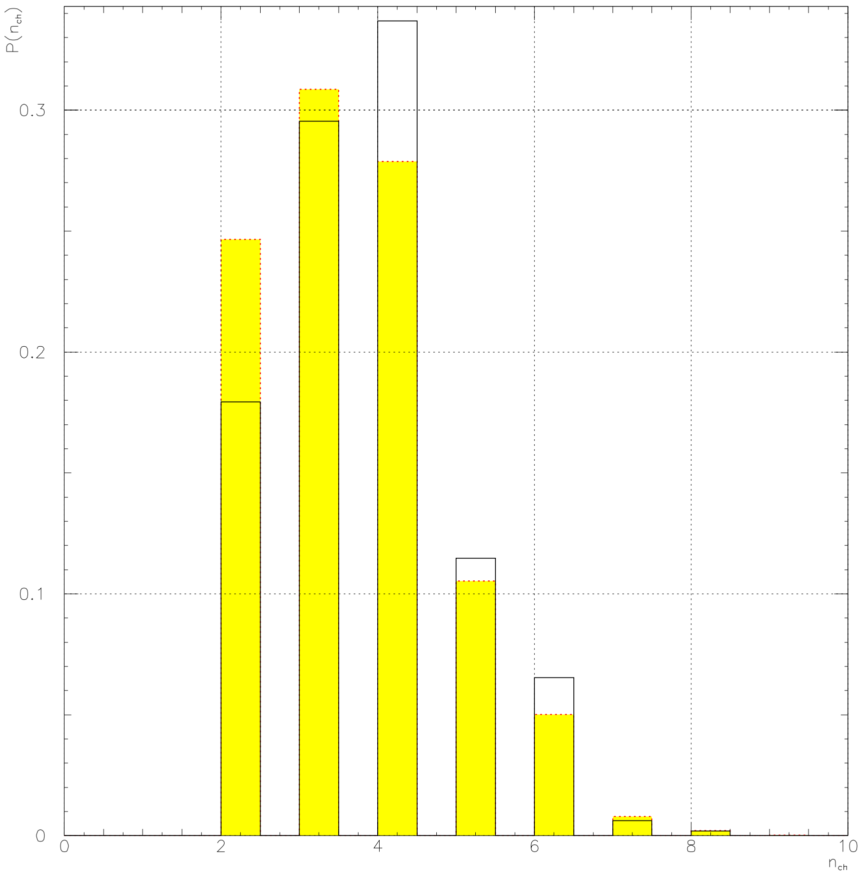


**Figure 5:** multiplicity distribution before efficiency correction

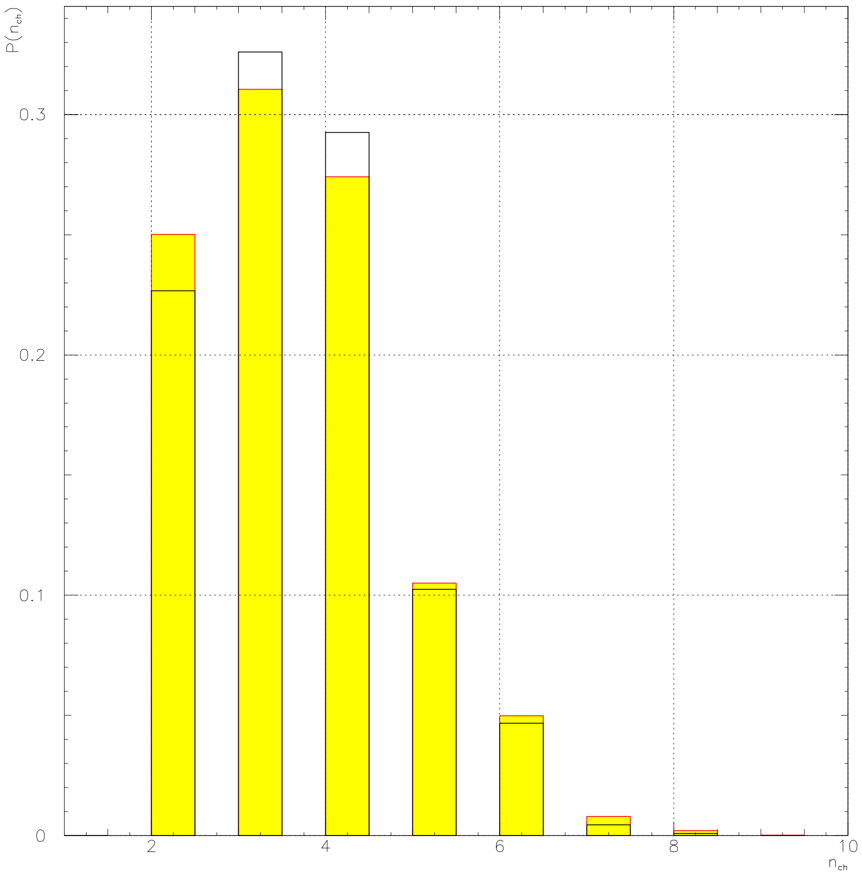


**Figure 6:** multiplicity distribution after efficiency correction

# $J/\psi$ total number

Hadrons observed in 3175 runs of $J/\psi$ data:

$$N_{had}^{obs} = 18277816$$

from which, contribution of QED background, scaled by $N_{\gamma\gamma}$ events:

$$N_{had}^{obs}(QED) = 113314/2555 * 3406 = 151056$$

So, observed hadrons form $J/\psi$ resonance:

$$N_{had}^{obs}(J/\psi) = 18277816 - 151056 = 18126760$$

ratio of QED background is:

$$151056/18277816 = 0.8\%$$

$J/\psi$ total number:

$$N_{J/\psi} = \frac{N_{had}^{obs}(J/\psi)}{\varepsilon} = \frac{18126760}{0.628} = 28.9M$$

$J/\psi$ total number (corrected):

$$N_{J/\psi} = \frac{N_{had}^{obs}(J/\psi)}{\varepsilon_{corr.}} = \frac{18126760}{0.609} = 29.8M$$

# Error analysis

Statistics error: negligible

Sources of systematic error:

1. hadron selection: $\sim 3\%$;
2. efficiency uncertainty: $\sim 3\%$;
3. beam associated background: ignored;
4. QED background: ignored;
5. lepton-pair background: ignored;
   ($< 2\%$ below $\tau\tau$ threshold for R data)
6. possible others: $\sim 2\%$

Total systematic error: 4.7%

So, we have,

$$N_{J/\psi} = 29.8 \pm 1.4M$$

# Summary

1. $N_{J/\psi}$ obtained via inclusive hadron final states with a precision of $\leq 5\%$;

2. It is much different with the number via $\mu\mu$ channel, the reason is to be found.

3. $\sim 30M J/\psi$ in 99-00 Run. Good news!