Recent results from the HERA-B experiment

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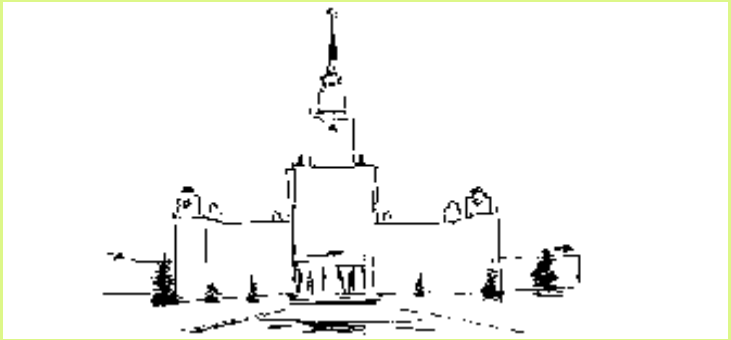
For the HERA-B Collaboration



The XVIIIth International Workshop
High Energy Physics and Quantum Field Theory
17-23 june 2004, St. Petersburg

Outline

Main physics studies at HERA-B

Detector

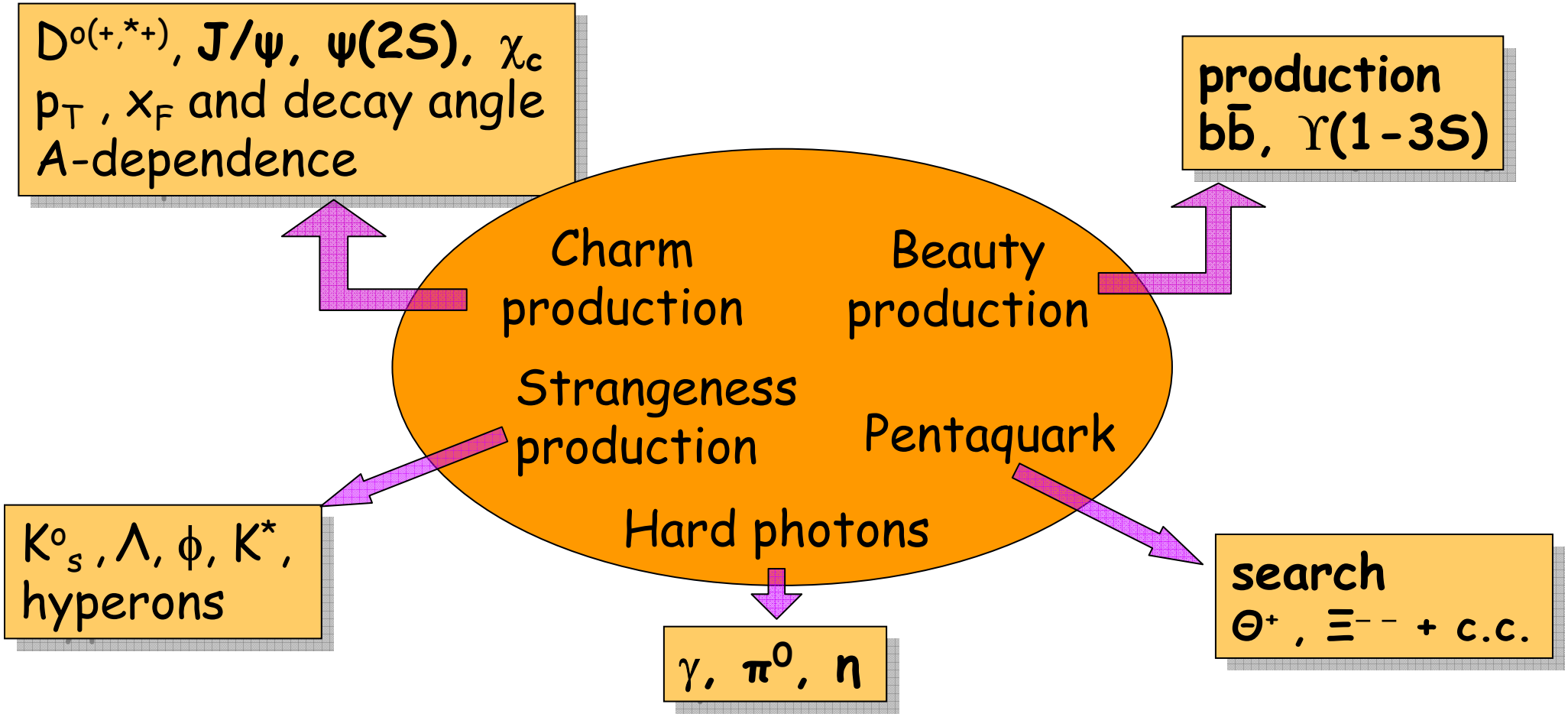
Physics topics addressed:

Production of:
- Open and hidden Charm
- Open and hidden Beauty
- FCNC process
- Hard photons
- Strangeness production
- Pentaquark search

Summary

Disclaimer: All results are preliminary

Main physics studies at HERA-B



- ~ 150 · 10^6 dilepton triggered events ~300 k J/ψ
- ~ 210 · 10^6 minimum bias events
- ~ 35 · 10^6 hard photon triggered events

Physics motivation

- **Test of QCD predictions**: NRQCD confirmed at high energy (CDF $\sqrt{s}$ =1.8 TeV) and large p_T, no conclusive results at lower energy
- **Investigation of nuclear effects** for correct interpretation of results from ultra relativistic heavy ion collisions (QGP)

charm production

- no (or very few) results in the **negative x_F range**
- few results on the **J/ψ, ψ(2S) polarization**
- contradictory results on **R(χ_c/J/ψ)**

beauty production

- **$\sigma(b\bar{b})$**: only two other measurements (E771, E789) with large uncertainties and poor compatibility
- **$\sigma(\Upsilon)$**: testing ground for the theoretical models

Charmonium Production in media

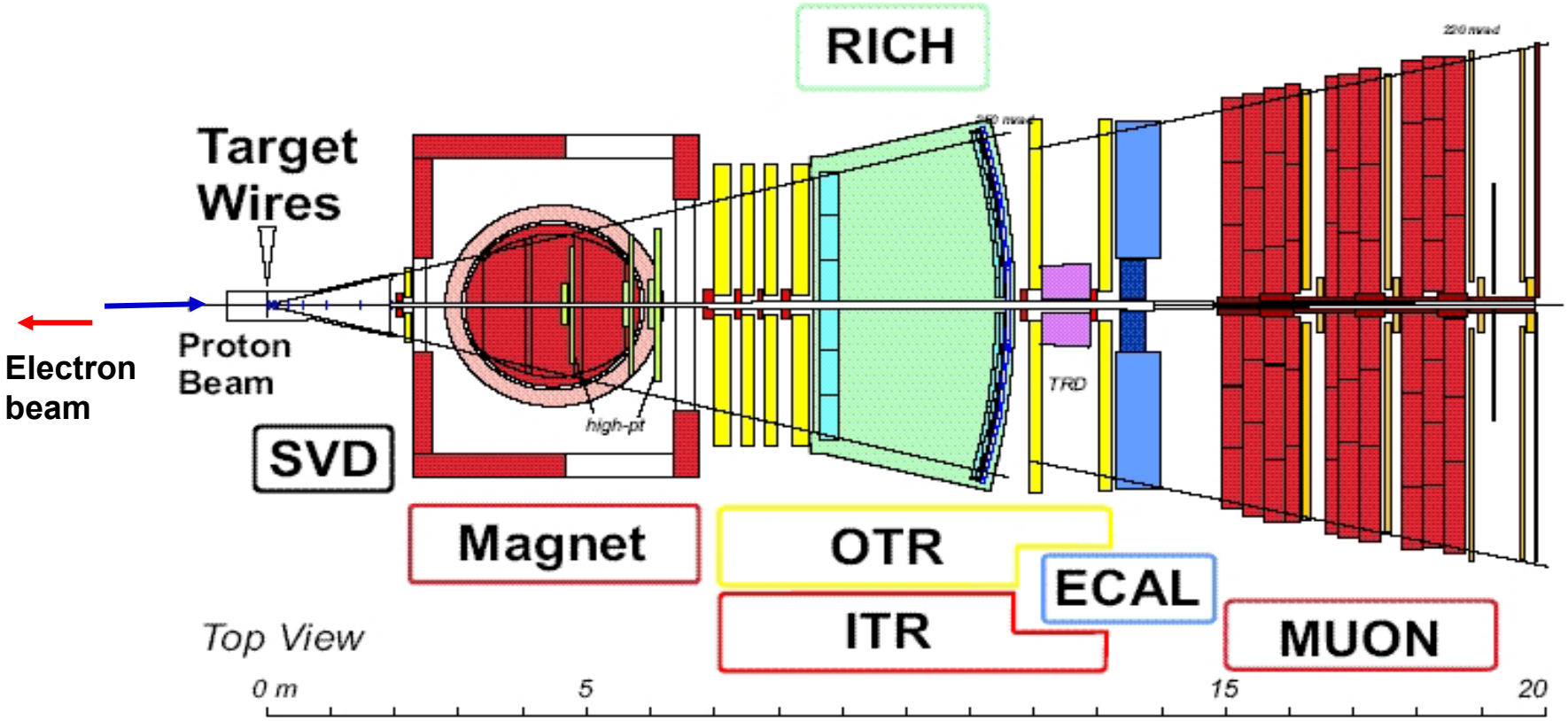
Investigation of nuclear effects

Further physics for production in media

- Nuclear effect in initial and final state
- Initial state:
  - Shadowing, parton energy loss, transverse momentum broadening ($\langle p_T \rangle$ dependence on A)
- Final state:
  - Nuclear absorption (dependence on x_F), Co-mover suppression

Necessary to study the charmonium differential distributions
Important baseline measurements for QGP study
HERA-B is in the ideal condition to study these effects

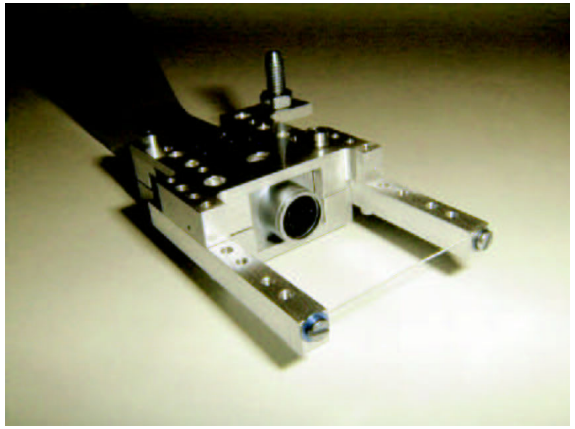
The Hera-B Detector

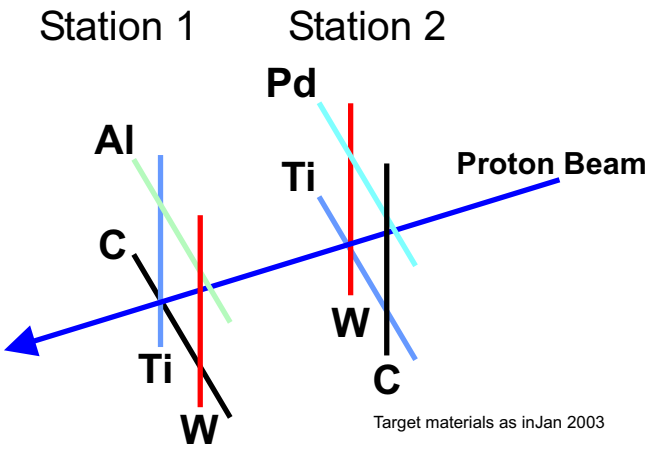


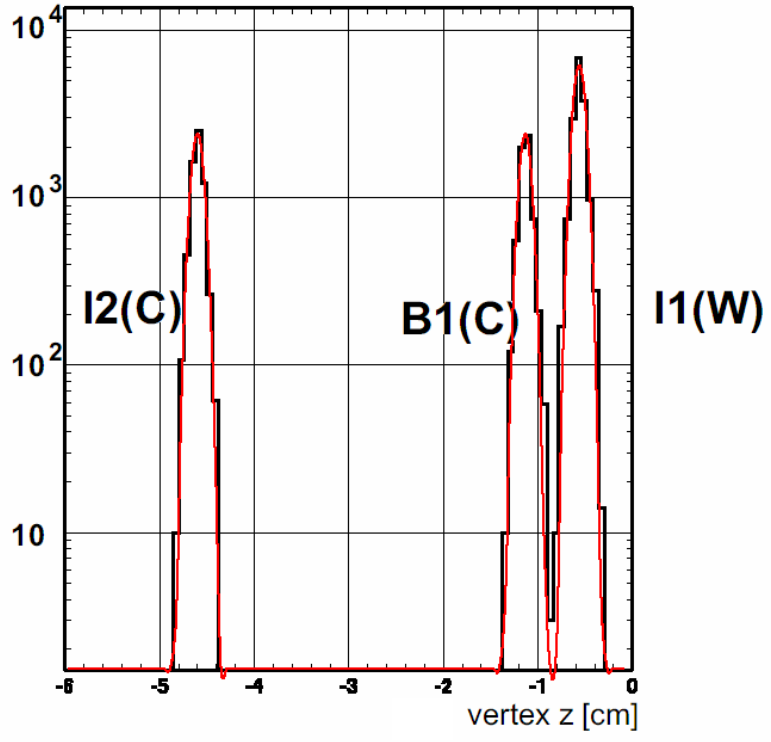
- **Fixed target** detector at HERA (DESY) — IR 5 - 10 MHz
- **920 GeV/c** proton beam ($\sqrt{s}$ = 41.6 GeV)
- High angular coverage (15-220 mrad in bending plane)
- High resolution spectrometer — very good **particle ID** for (e, μ, π, K, p)

Target system

8 wire targets (C, Al, Ti, W, Pd) in proton halo







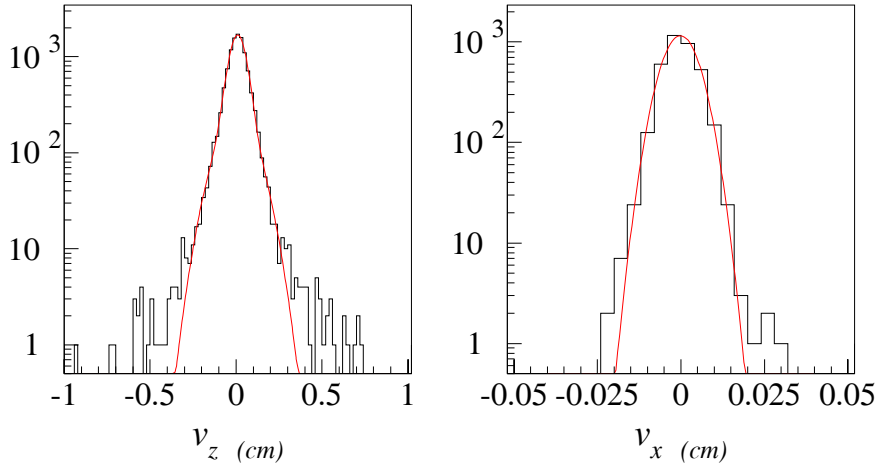
Different targets (range A[12:184]) can be used simultaneously
A-dependence measurements → control of systematic errors
Events from different wires can be easily separated

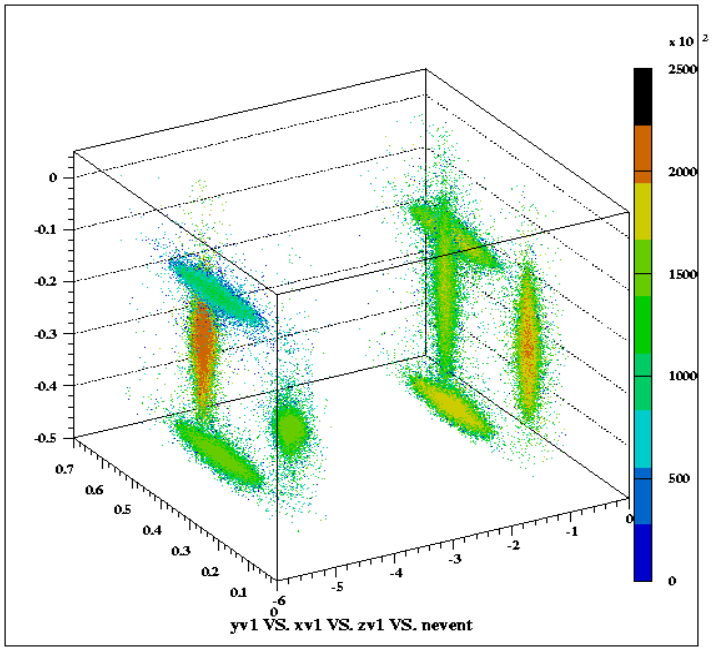
The vertex detector

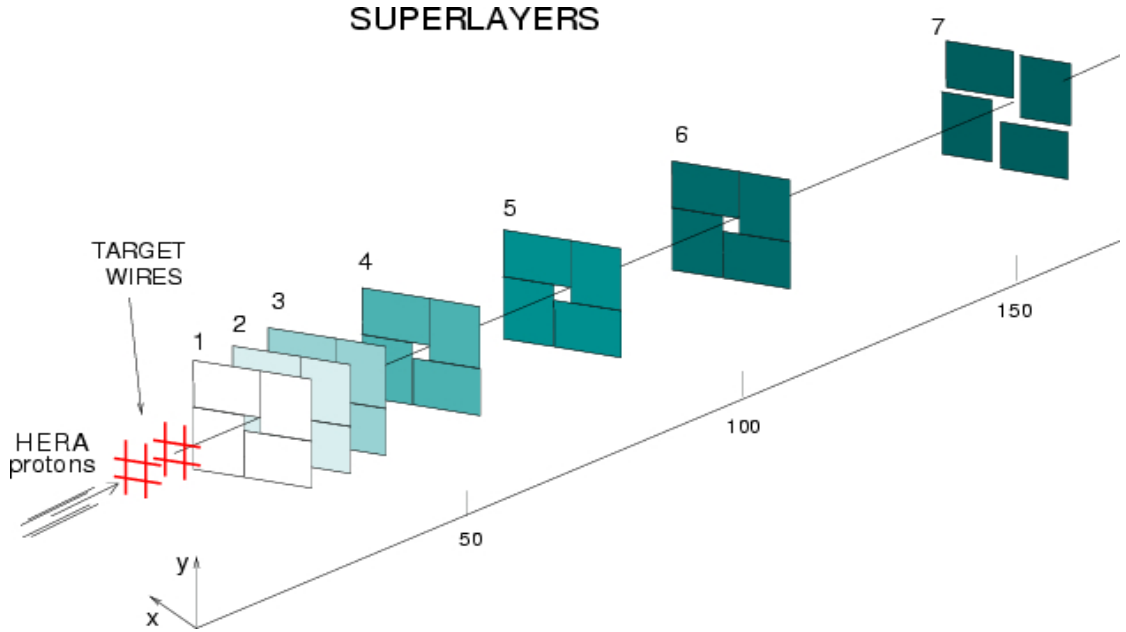
Silicon Vertex Detector

- 7 superlayers of silicon microstrips
- High primary vertex resolution
  ($\sigma_x \sim \sigma_y \sim 50\ \mu m$, $\sigma_z \sim 450\ \mu m$)

Vertex-wire distance

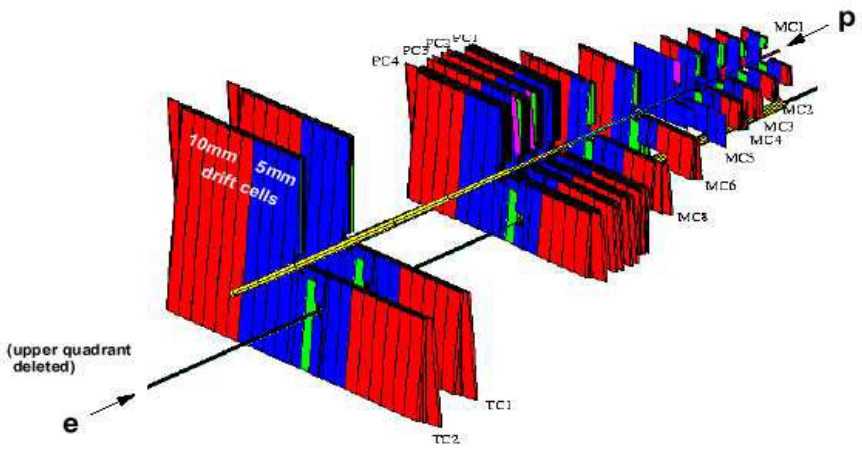


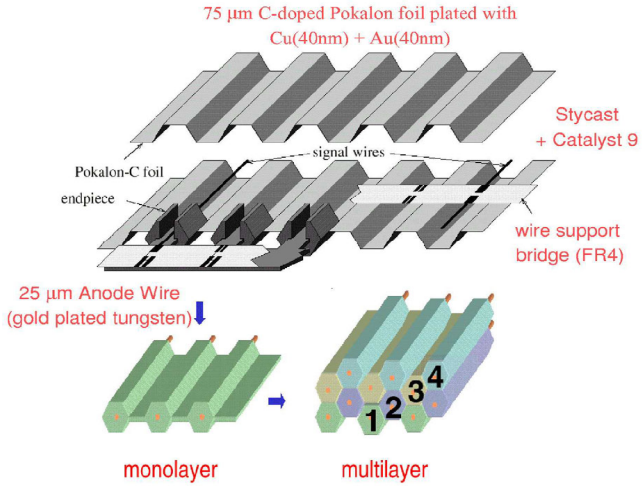


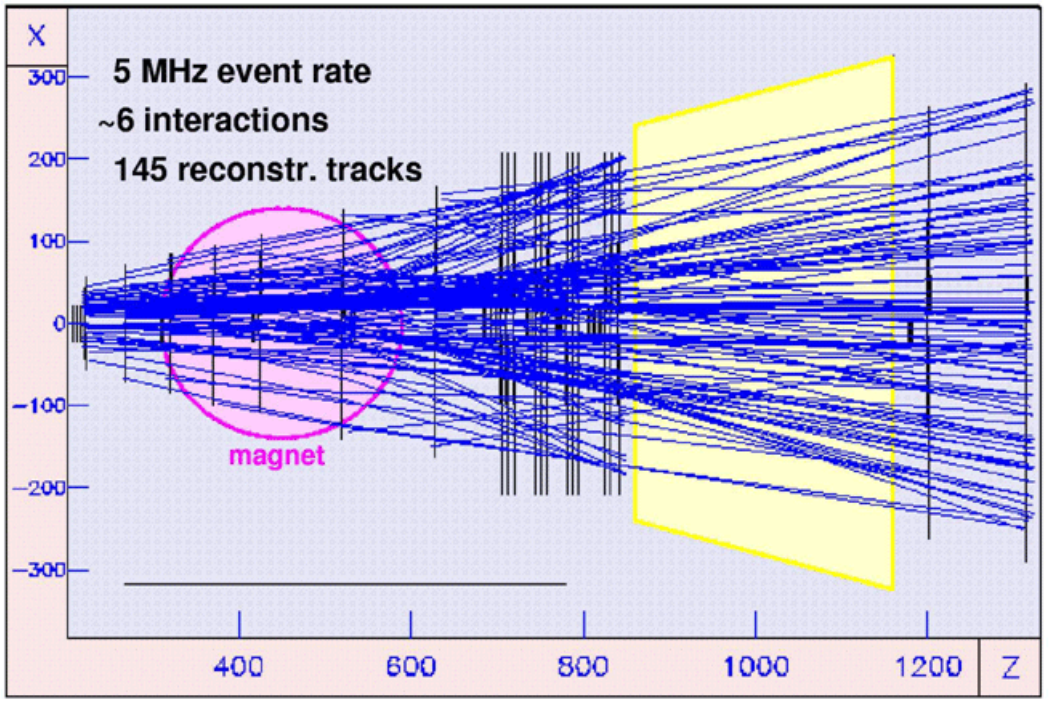


Main tracking system

The world largest honeycomb tracker

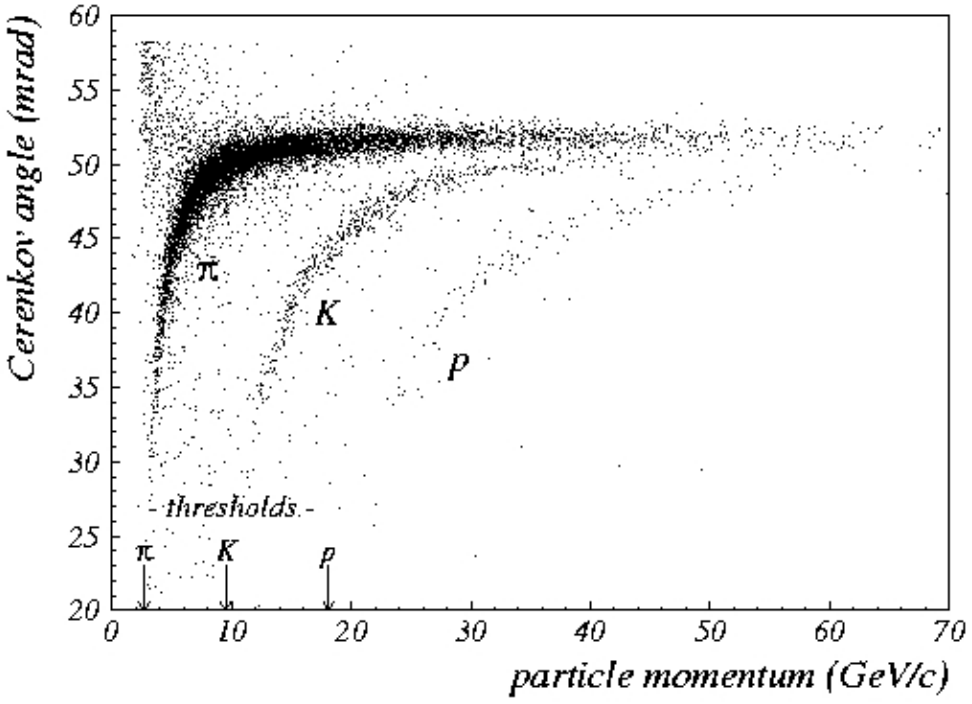






Track efficiency ~ 90-95%
Momentum resolution ~ 1.5%

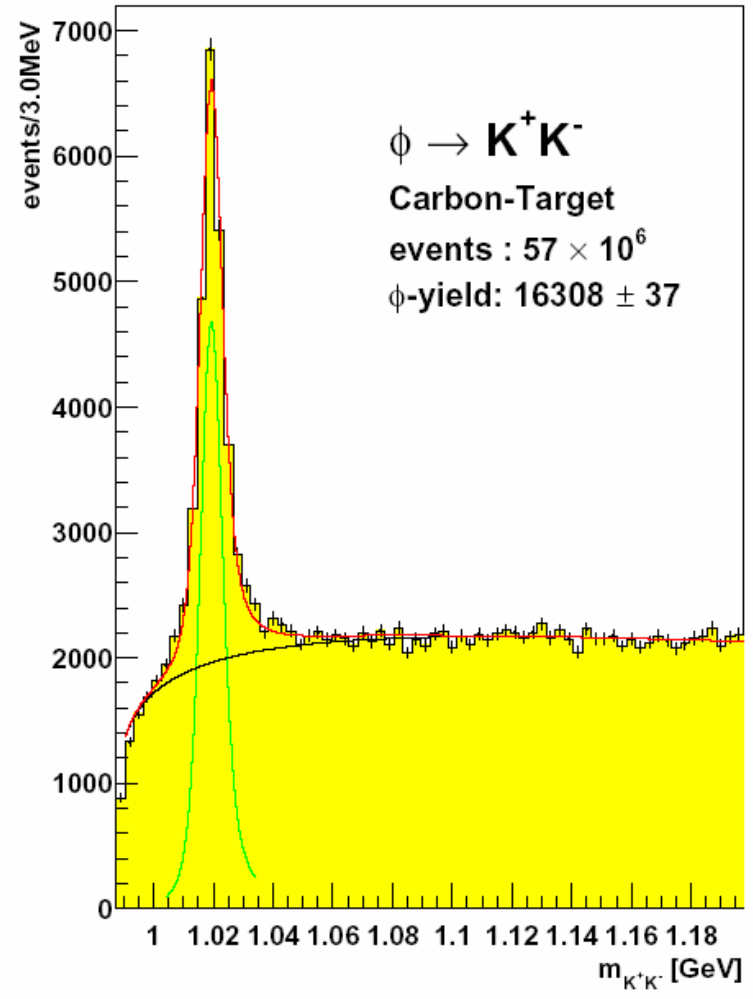
Particle Identification (RICH)



Pion/kaon sep : 10< p <60 GeV

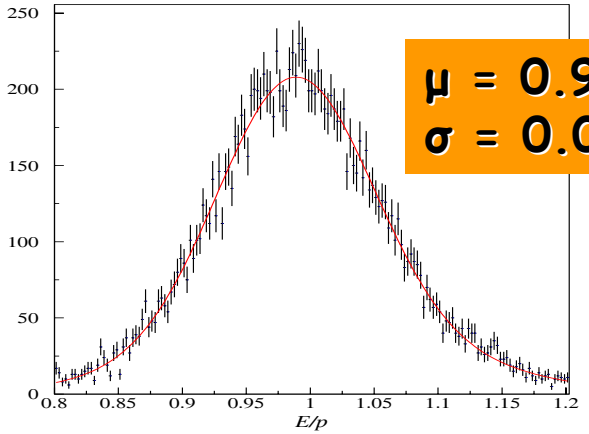
Kaon/proton sep: 20< p <90 GeV

Example: ϕ reconstruction

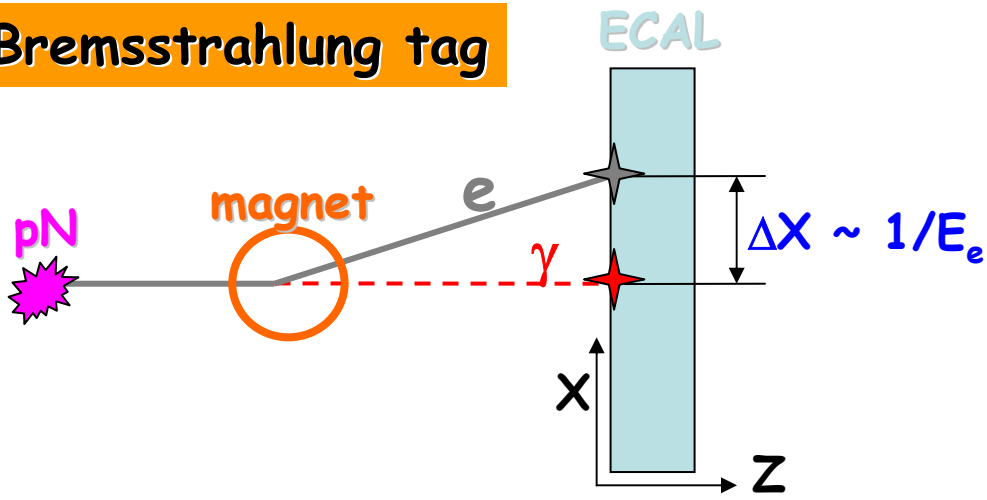


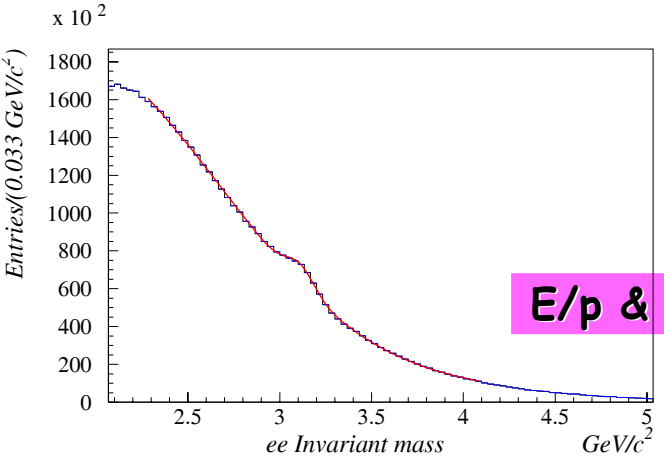
Particle Identification (Ecal)

$$\frac{E}{p} = \frac{\text{cluster energy on Ecal}}{\text{momentum from tracker}}$$

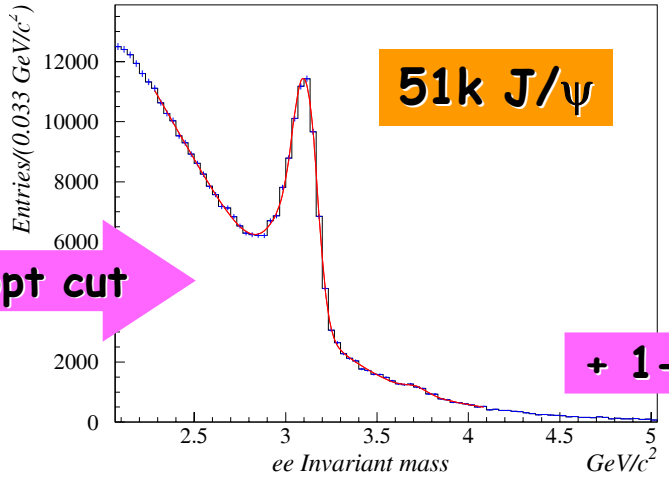


Bremsstrahlung tag

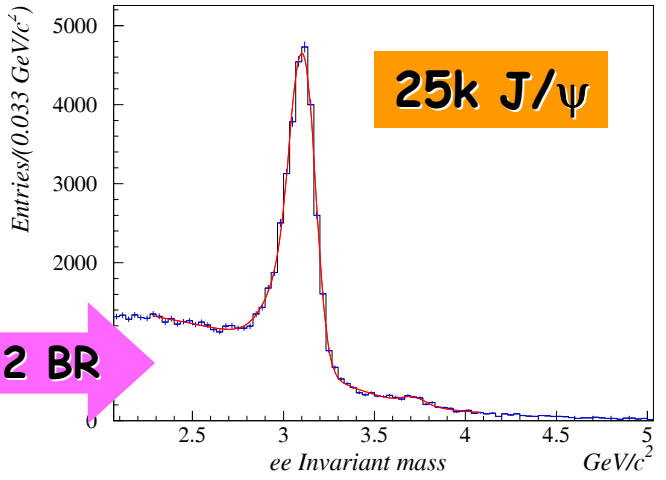




E/p & opt cut

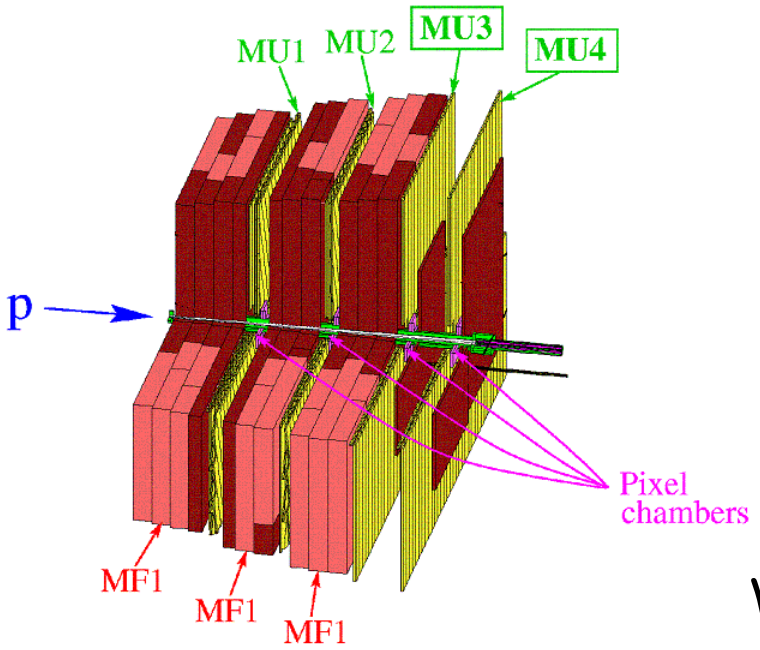


+ 1-2 BR



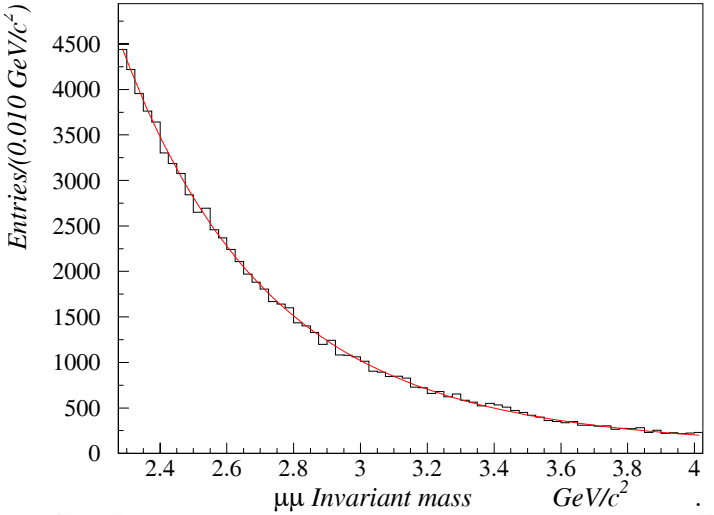
Particle Identification (Muon)

drift tubes + iron absorber
4 superlayers

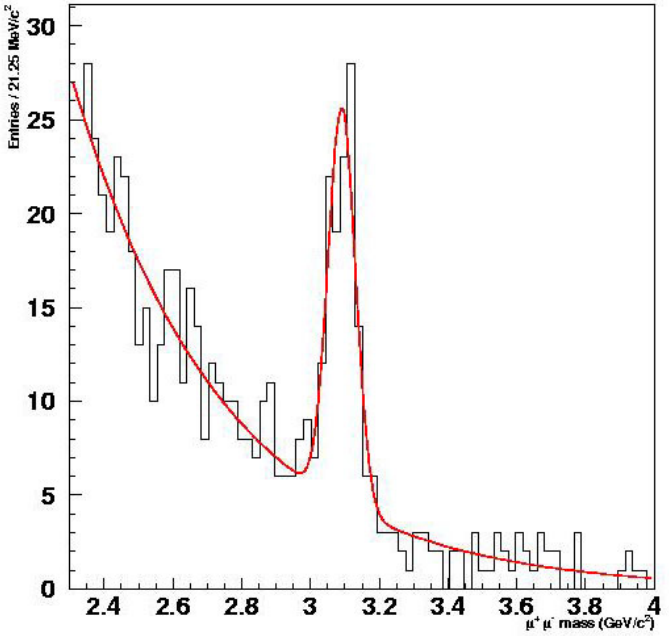


MB events

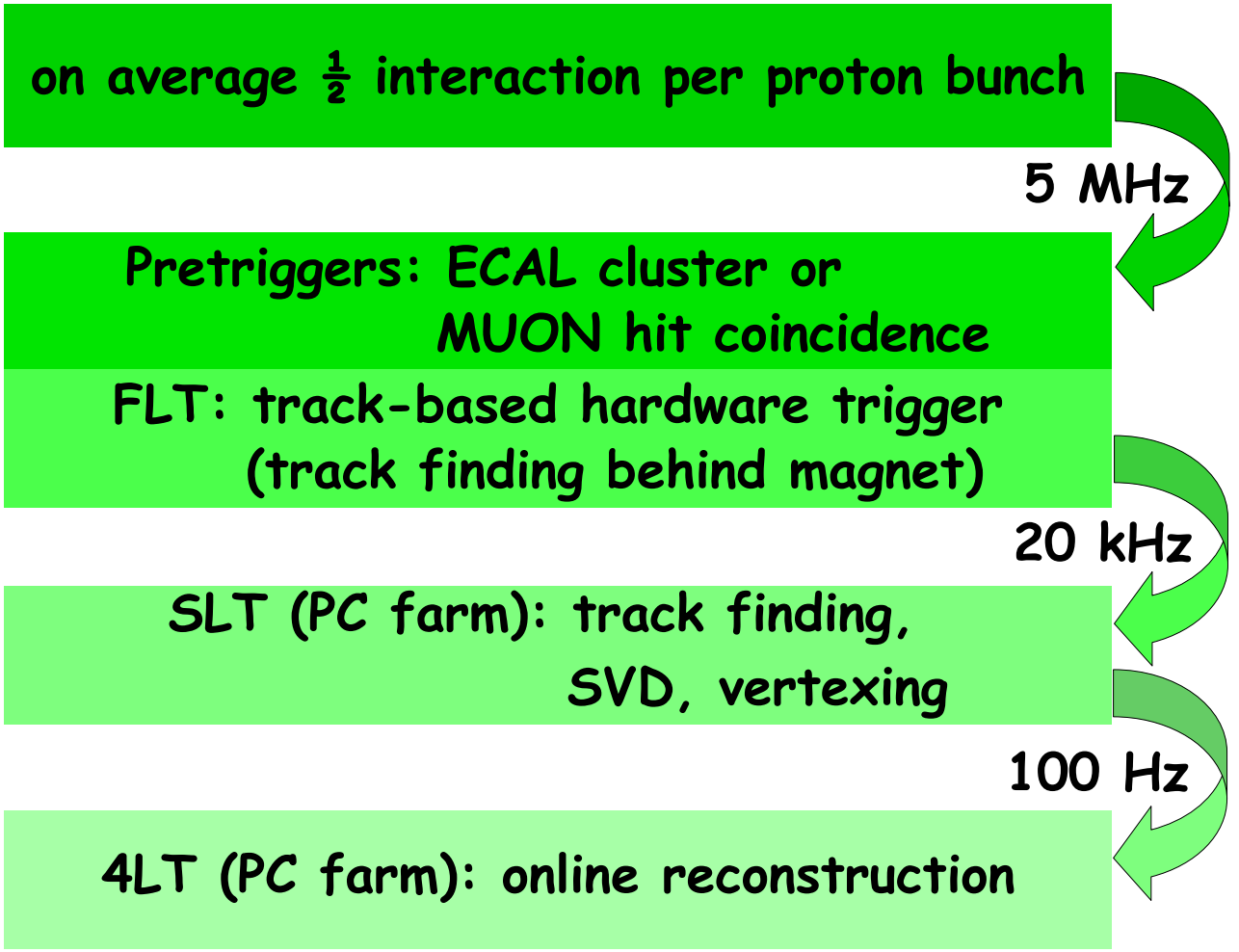
Without
likelihood request



With likelihood
request ⇒ J/ψ
peak is visible



Dilepton trigger system



Dilepton trigger:

- at least 2 pretrigger seeds
- coincidence with at least 1 FLT track
- coincidence with at least 2 SLT tracks

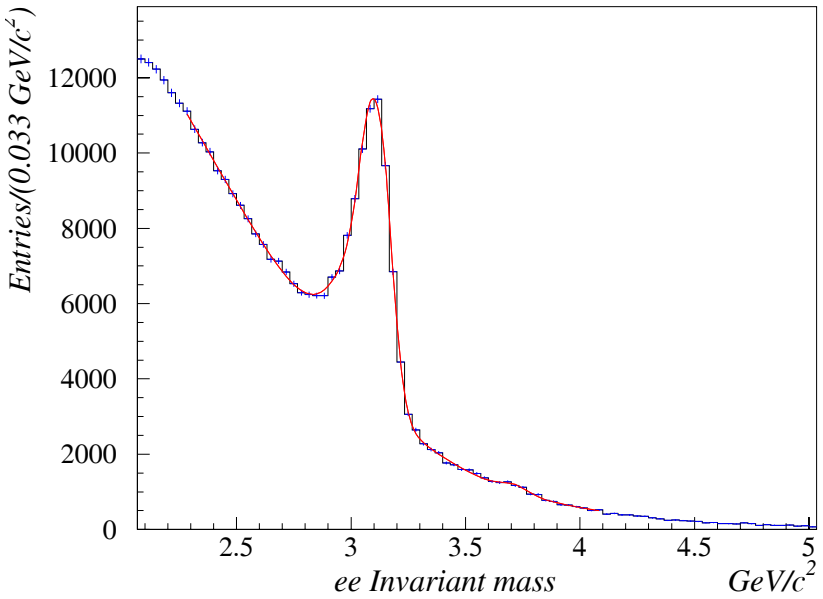
total suppression factor 1:50000

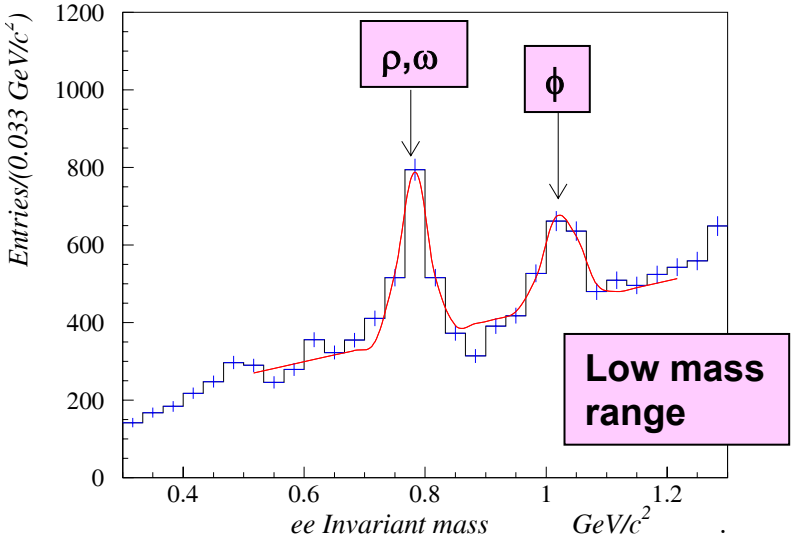
1000-1500 J/ψ h^{-1}

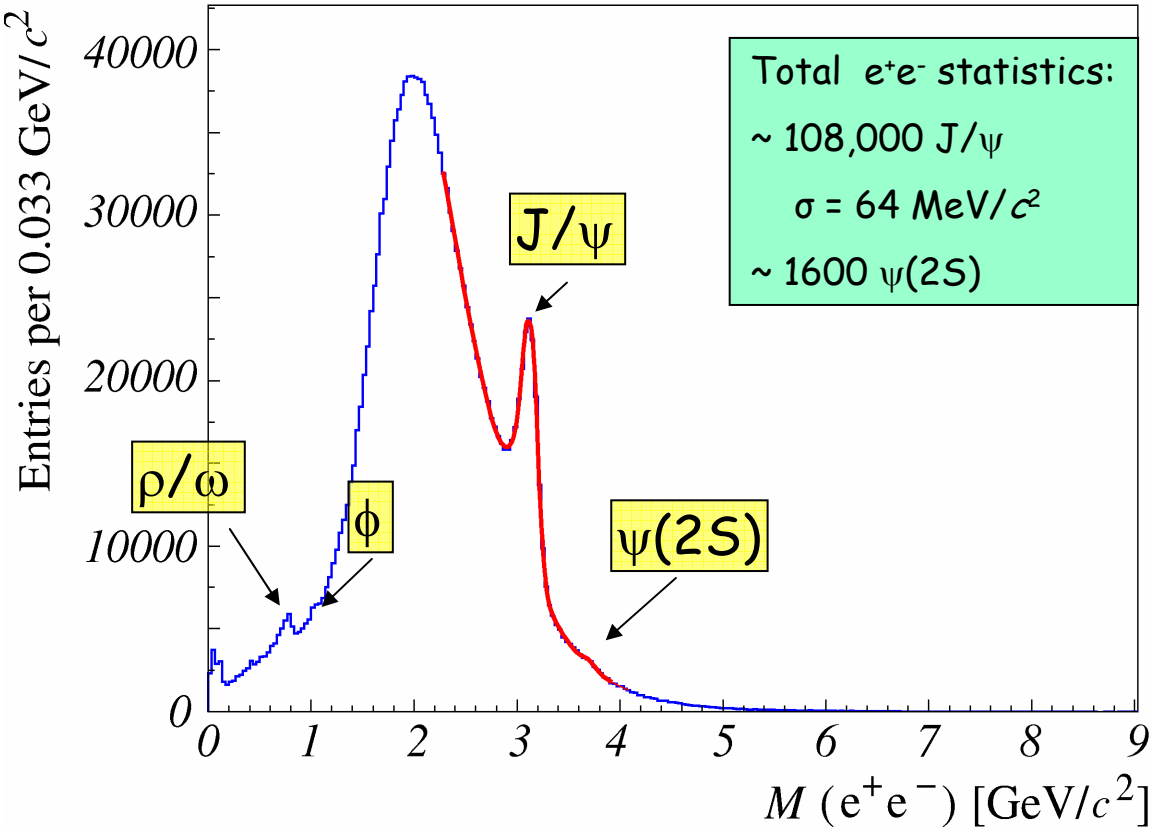
Dilepton data analysis

- charmonium production
  - J/ψ, χ_c, ψ'
- A-dependence
- $D^o \rightarrow \mu^+\mu^-$ (FCNC process)
- $b\bar{b}$ production
- Υ
- Low mass studies (ϕ, ρ/ω)
- Exotics production

Dielectron spectra



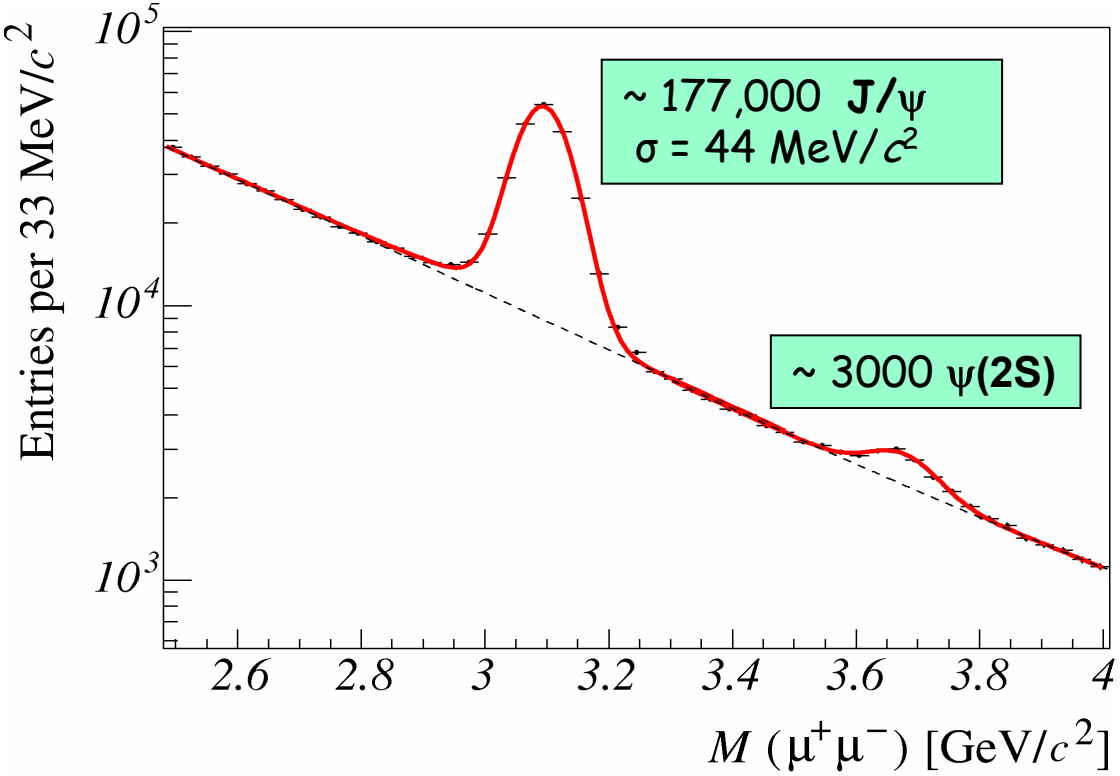


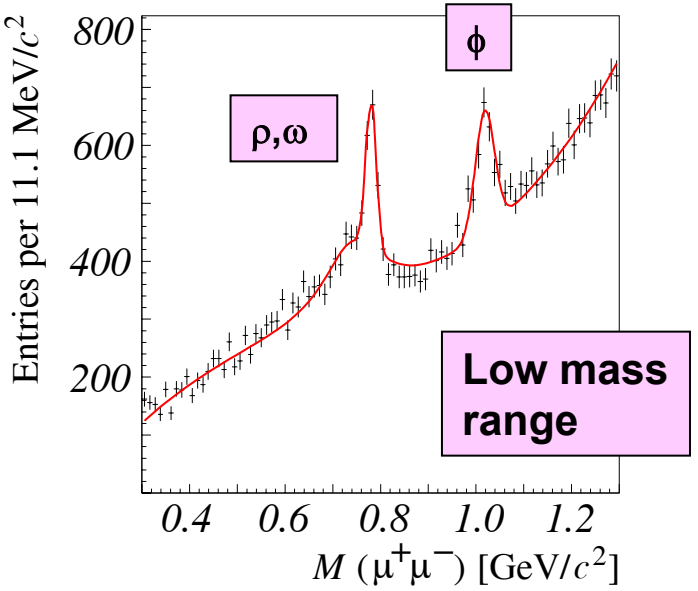


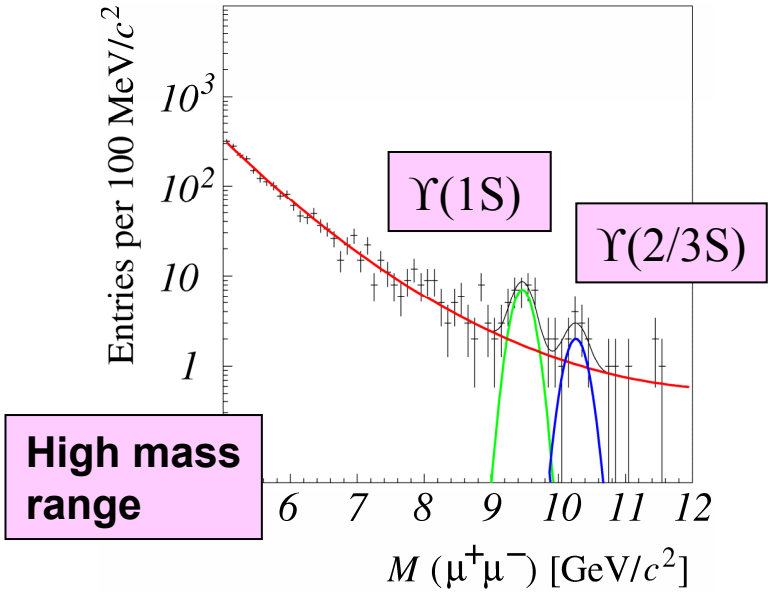
Signals clearly visible:

- various e-ID cuts applied to reduce high bkg level

Dimuon spectra



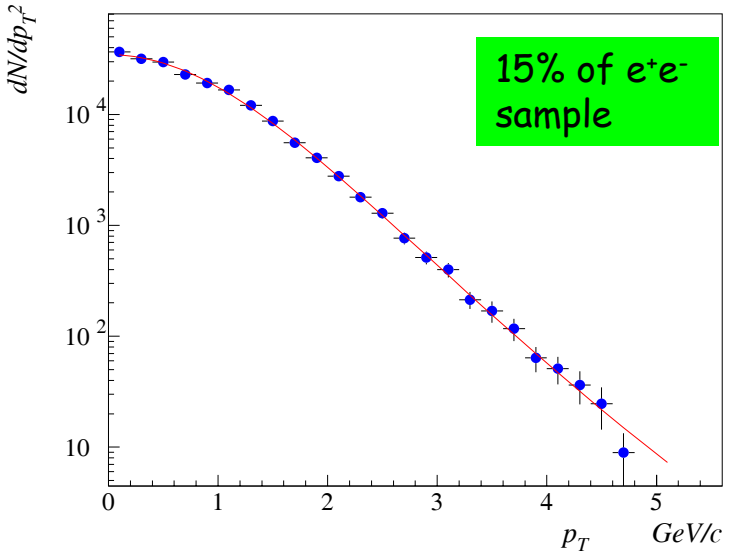




Signal clearly visible,
low bkg situation

- **2 independent analyses**
- **high statistics & quality in both samples**

p_T differential distribution of J/ψ



p_T → J/ψ transverse momentum
Arbitrary scale normalization

$$\frac{d\sigma}{dp_T^2} \propto \left[1 + \left(\frac{35\pi}{256}\right)^2 \frac{p_T^2}{\langle p_T \rangle^2}\right]^{-6}$$

HERA-B range p_T < 4.5 GeV/c

Preliminary results for $\langle p_T \rangle$ (GeV/c)

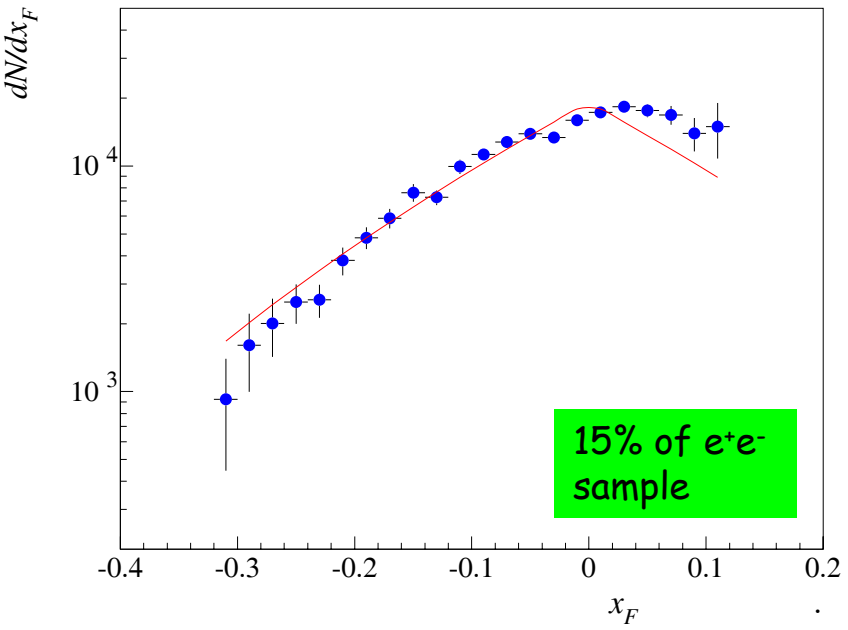
Target	electron	muon	stat. err.
C	1.24	1.22	0.01
W	1.29	1.30	0.01

Good agreement between $e^+e^-/\mu^+\mu^-$ analyses

wide p_T range **A dependence?**

Exp.	Interaction & p-momentum	Range (GeV/c)	$\langle p_T \rangle$ (GeV/c)
E771	**p-Si @ 800 GeV**	**< 3.4**	**1.20 ± 0.01**
E789	**p-Au @ 800 GeV**	**< 2.6**	**1.29 ± 0.01**

x_F differential distribution of J/ψ



x_F —> J/ψ Feynman-x
Arbitrary scale normalization

$$\frac{d\sigma}{dx_F} \propto (1-|x_F|)^c$$

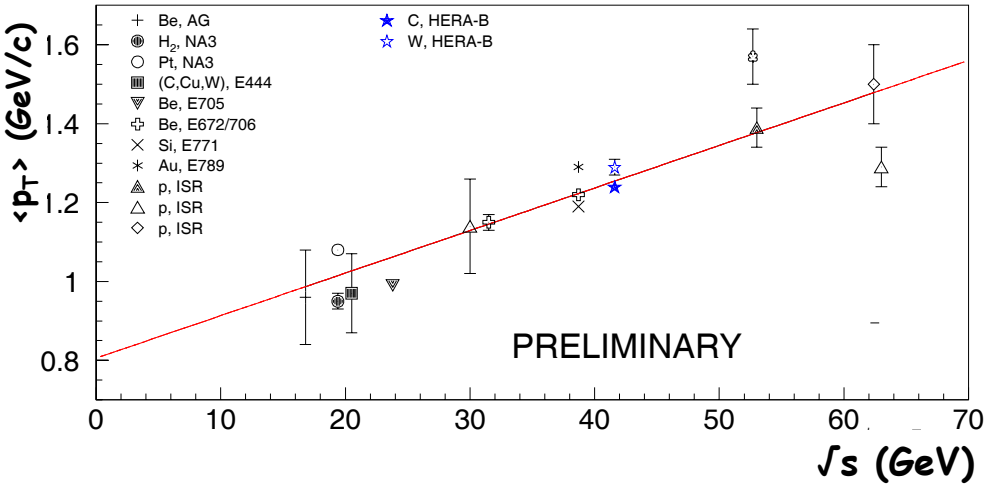
HERA-B range $-0.35 < x_F < 0.15$

Preliminary results for c **[5:6.5] ± 0.2**

Exp.	Interaction & p-momentum	Range	c
E672/E706	**p-Be @ 800 GeV**	**$0.0 < x_F < 0.6$**	**6.18 ± 0.16**
E789	**p-Be @ 800 GeV**	**$0.30 < x_F < 0.95$**	**5.32 ± 0.05**
E771	**p-Si @ 800 GeV**	**$-0.05 < x_F < 0.25$**	**6.54 ± 0.23**
E789	**p-Cu @ 800 GeV**	**$0.30 < x_F < 0.95$**	**5.21 ± 0.04**
E789	**p-Au @ 800 GeV**	**$-0.035 < x_F < 0.135$**	**4.91 ± 0.18**

Not clear panorama. Now negative x_F range accessible with HERA-B.

$\langle p_T \rangle$ and c dependence on $\sqrt{s}$

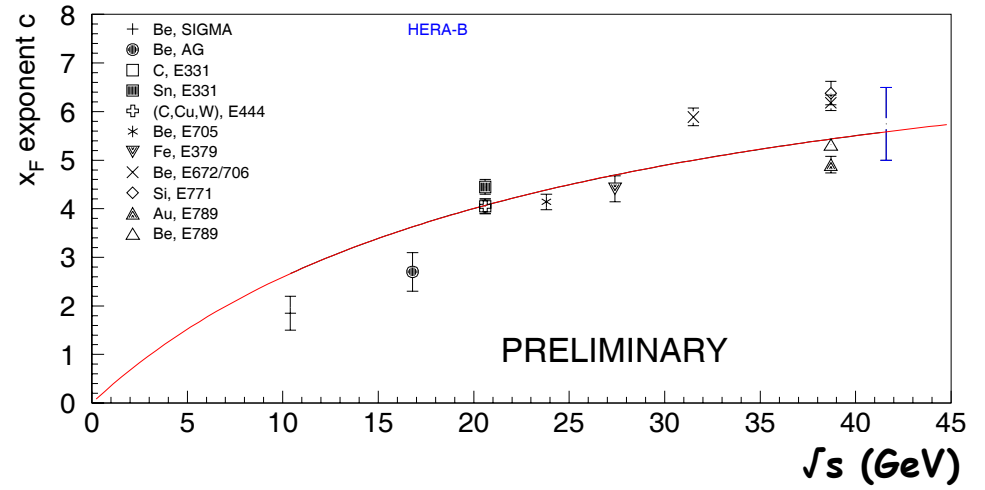


phenomenologic $\langle p_T \rangle = A + B\sqrt{s}$

Fermilab-pub-91/62-E(1991) (E672/706 Coll)

$A = 0.813 \pm 0.014$ GeV/c

$B = 0.0105 \pm 0.0004 c^{-1}$



phenomenologic $c = D/(1 + E/\sqrt{s})$

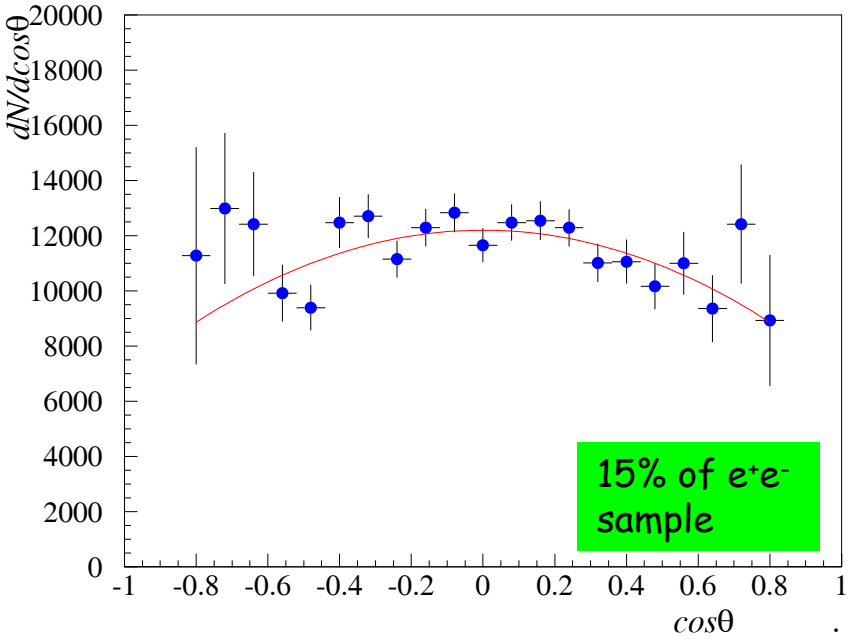
Fermilab-pub-91/62-E(1991) (E672/706 Coll)

$D = 8.80 \pm 0.41$

$E = 23.9 \pm 2.7$ GeV

HERA-B precision competitive with previous results

cosθ differential distribution of J/ψ



θ is the Gottfried-Jackson decay angle

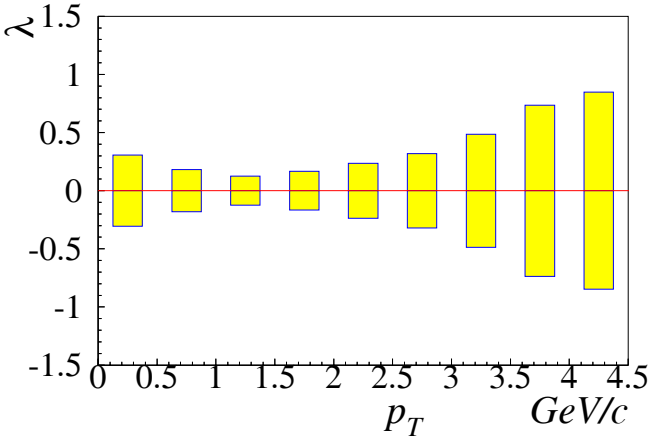
$$\frac{d\Gamma}{d\cos\theta} = \gamma\,(1 + \lambda\cos^2\theta)$$

J/ψ polarization described by λ parameter

λ = (0,1,-1) ⟺ (no, trans., long.) polarization

HERA-B variation range ⇒ **[-0.5,0.1] ±0.1**

Important tests for models



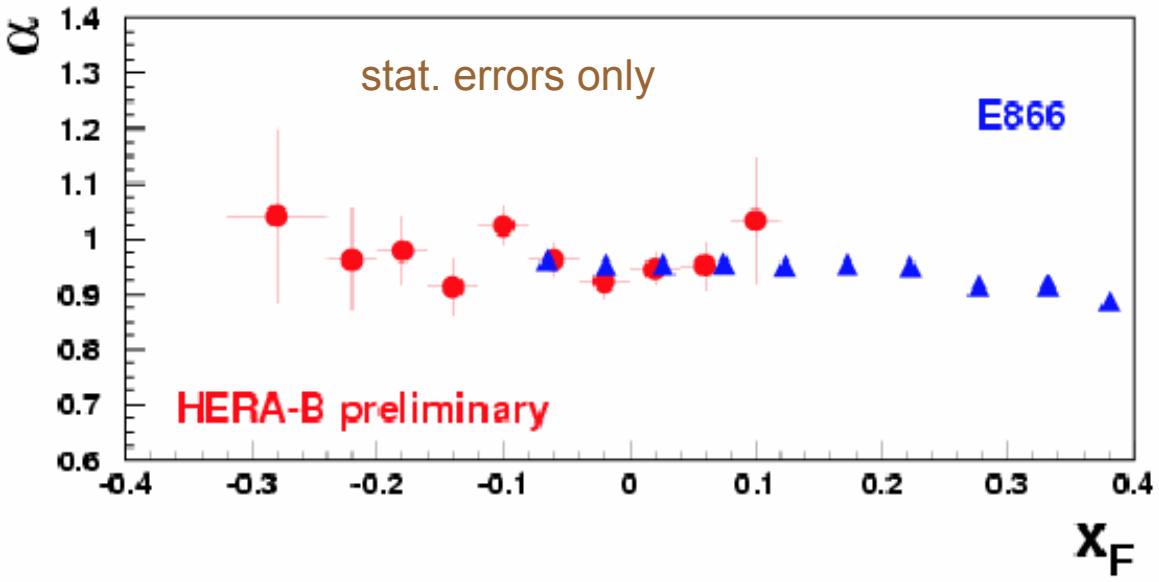
Exp.	Interaction & p-momentum	λ
E379	**p-Fe @ 400 GeV**	**0.16 ± 0.08**
E672/E706	**p-Be @ 530 GeV**	**0.01 ± 0.15**
E672/E706	**p-Be @ 800 GeV**	**-0.11 ± 0.15**
E771	**p-Si @ 800 GeV**	**-0.09 ± 0.12**

A dependence of J/ψ production

Parameterization of cross section: $\sigma_{pA} = \sigma_{pN} \cdot A^{\alpha}; \quad \sigma = \mathrm{N}/(\varepsilon \cdot L)$

Determine α from two different targets:

$$\alpha = \frac{1}{\ln(A_W / A_C)} \cdot \ln\left(\frac{\mathrm{N}_W}{\mathrm{N}_C} \frac{L_C}{L_W} \frac{\varepsilon_C}{\varepsilon_W} \right)$$

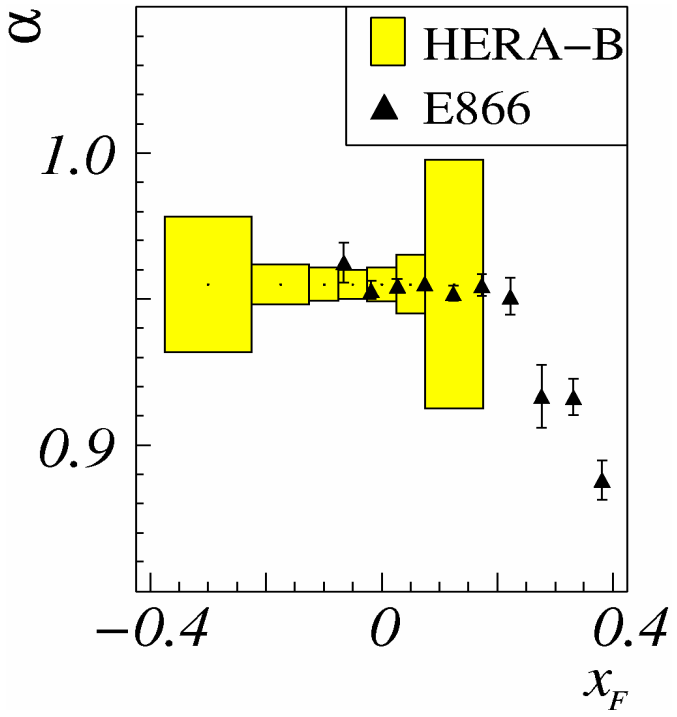


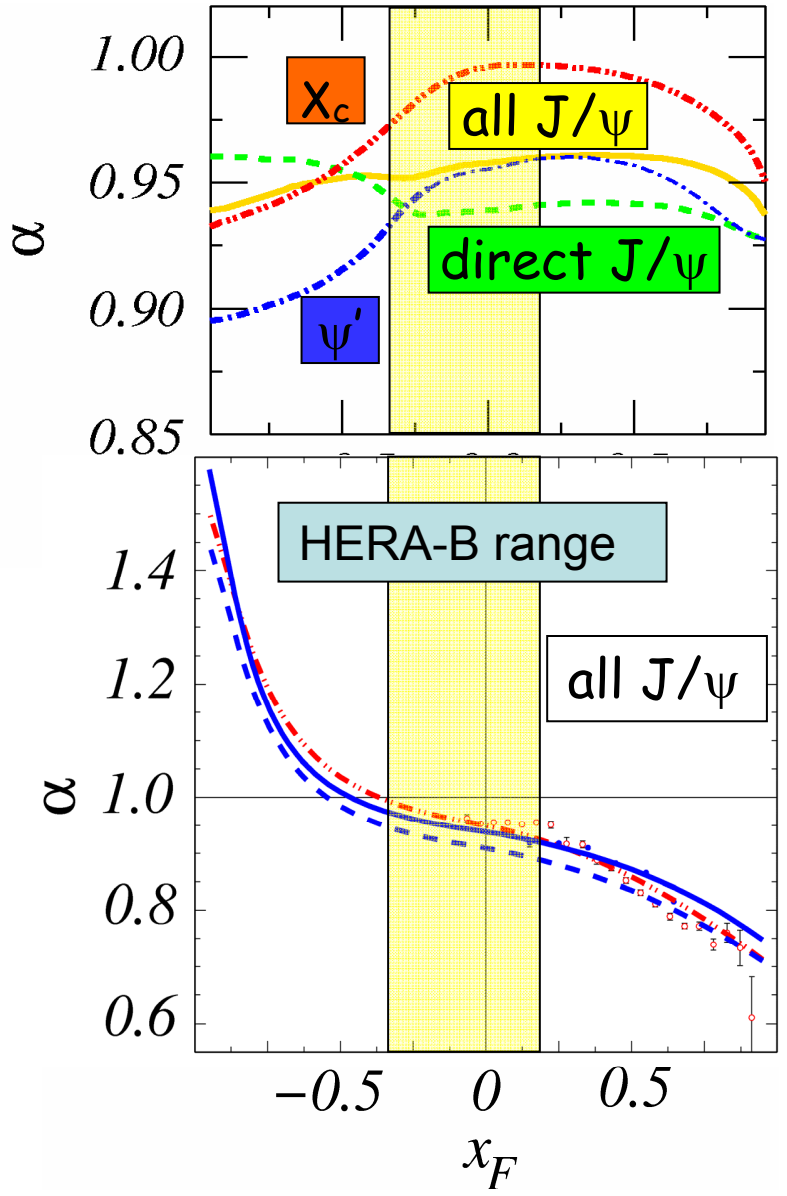
- C (A=12.0) and W (A=183.8)
- 25% of full e^+e^- sample
- Ratio of luminosities under investigation ⇒ norm. to E866

E866 with Be, Fe and W

A dependence of J/ψ

Expected stat. error for full data muon sample:





NRQCD pred.:

R. Vogt

Nucl. Phys. A700 (2002) 539

BCKT pred.:

K.G. Boreskov, A.B. Kaidalov

JETP. Lett. 77 (2003) 599

ψ' / J/ψ production ratio

Measurement of

$$\frac{Br(\psi' \to \ell^+\ell^-)\cdot\sigma(\psi')}{Br(J/\psi \to \ell^+\ell^-)\cdot\sigma(J/\psi)} = \frac{N_{\psi'}}{N_{J/\psi}}\cdot\frac{\varepsilon_{J/\psi}}{\varepsilon_{\psi'}}$$

- ε efficiency
- Br branch. ratio

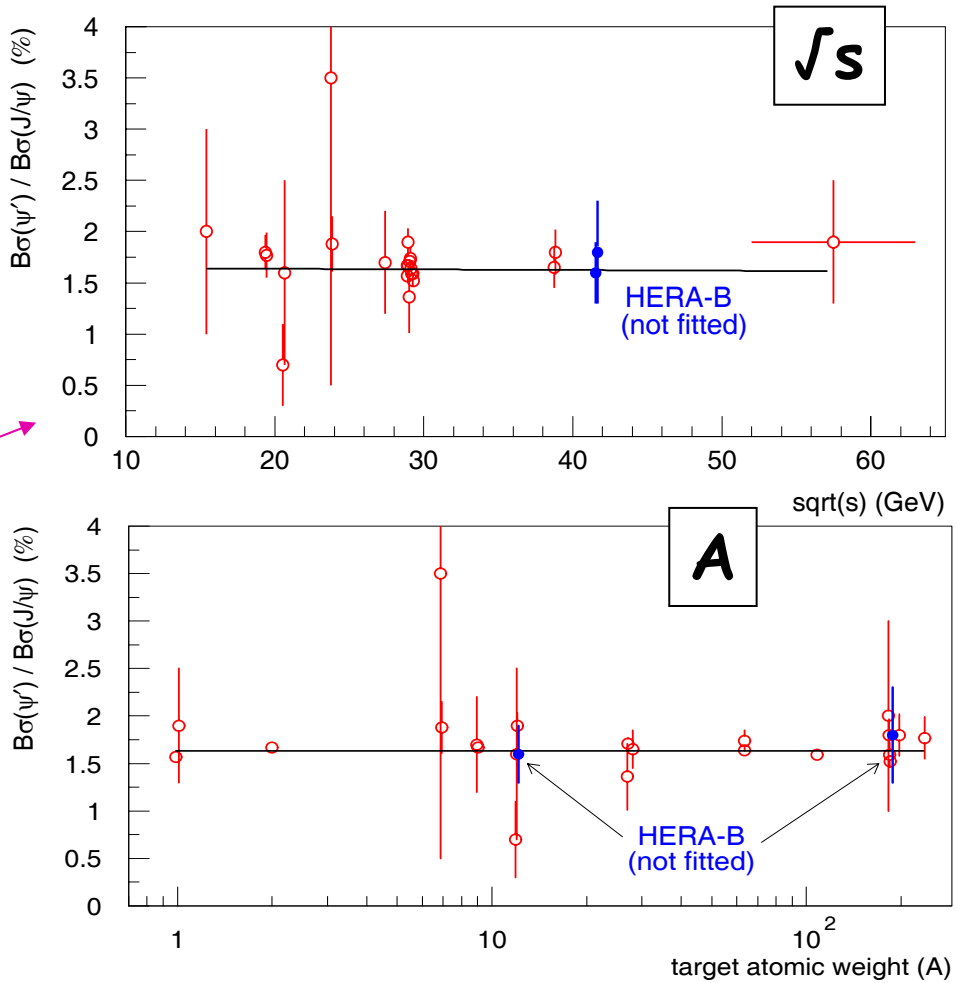
$$\frac{Br\cdot\sigma(\psi')}{Br\cdot\sigma(J/\psi)} = \begin{cases} (1.6 \pm 0.2_{stat})\% & C \\ (1.8 \pm 0.4_{stat})\% & W \end{cases}$$

from electron analysis
(compatible results from muons)

Experimental situation

(E288, E331, ISR, E444, E705, E537, E789, E771, NA51, NA38, NA50)

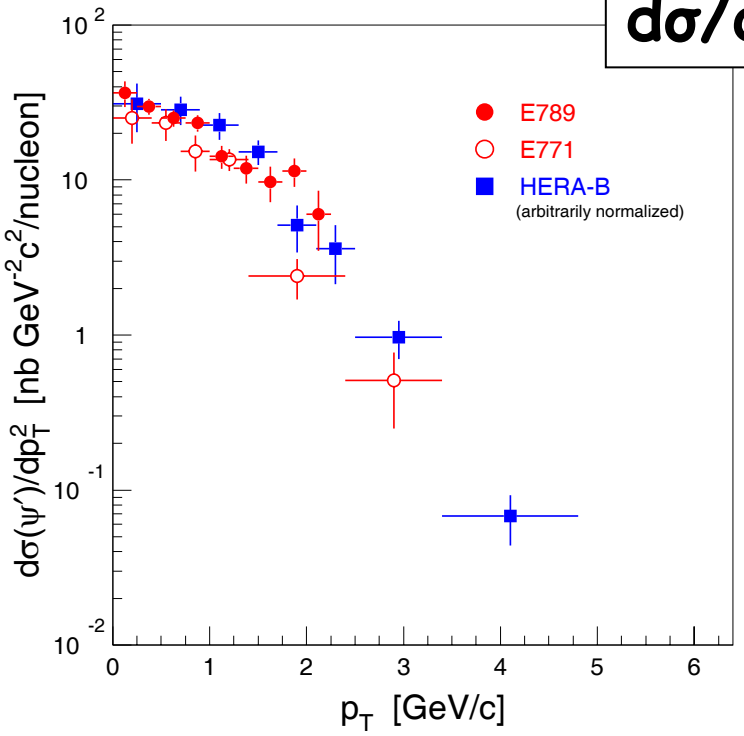
Competitive measurement from HERA-B



ψ' differential distributions

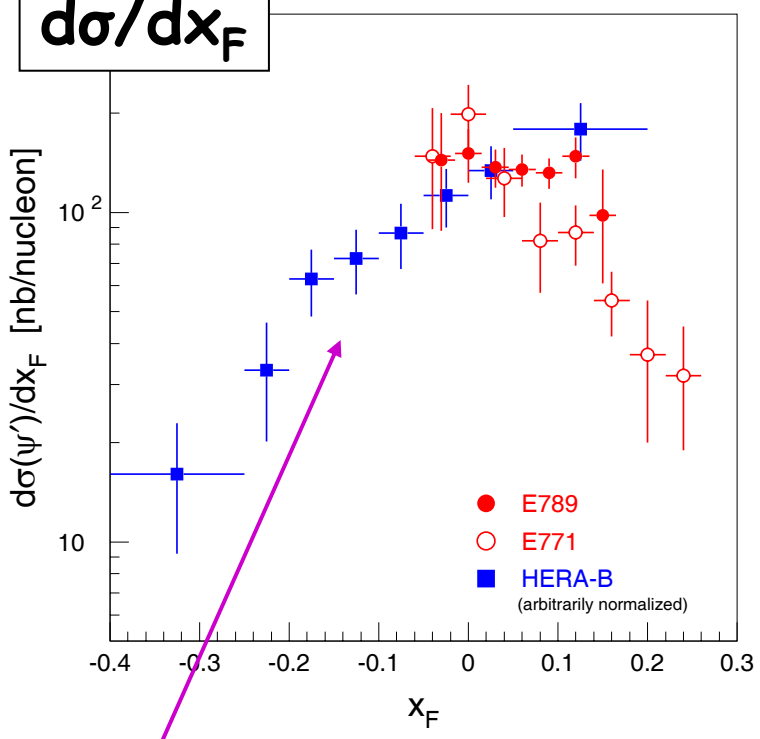
$\langle p_T \rangle$ ~ 1.4 stat err 0.1 GeV/c

$d\sigma/dp_T^2$



c' = [4:5.5] ± 0.7

$d\sigma/dx_F$



- HERA-B compatible with previous results
- Comparable precision
- First measurement in the negative x_F range !

E789: 800 GeV/c p-Au
E771: 800 Gev/c p-Si

χ_c to J/ψ production ratio

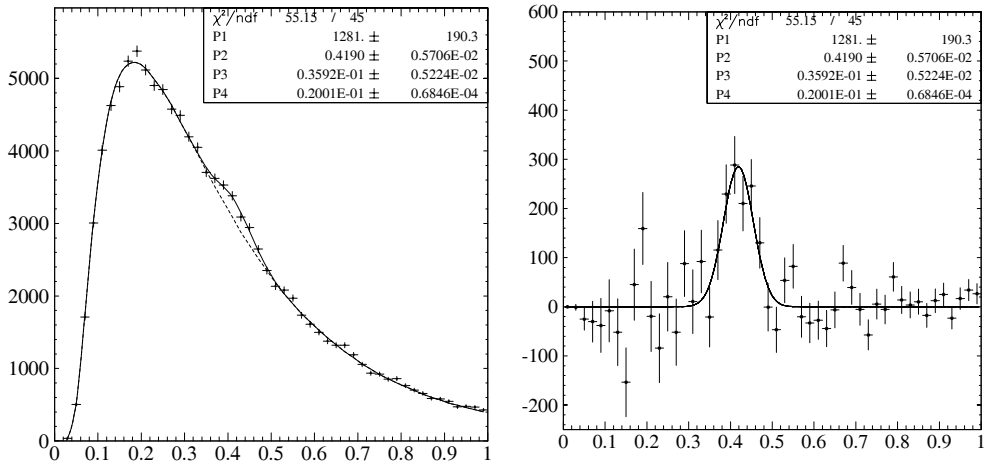
No distinction between χ_{c1} and χ_{c2} (ΔM = 46 MeV/c^2)
χ_{c0} neglected due to small Br

$\chi_c \rightarrow$ **J/ψ** $\gamma \rightarrow \mu^+\mu^- \gamma$ and $\rightarrow e^+e^- \gamma$

$$R_{\chi_c} = \frac{\sum_{i=1}^{2} \sigma(\chi_{ci}) \cdot Br(\chi_{ci} \rightarrow J/\psi\gamma)}{\sigma(J/\psi)} = \frac{N(\chi_c)}{N(J/\psi)} \cdot \frac{\varepsilon_{J/\psi}}{\varepsilon_{\chi \rightarrow J/\psi} \cdot \varepsilon_{\gamma}}$$

≈ 1

≈ 0.4



Rχ_c = 0.21 ±0.05

Systematic studies ongoing

In 15% of $\mu\mu$ sample ≈1300 χ_c
⇨ expected ~15 k for full sample

$R_{\chi c}$ experimental situation and expectations

Exp.	Interaction & $\sqrt{s}$	R(χc)
E610	p-Be @ 19.4-21.7 GeV	0.47 ± 0.23
E705	p-Li @ 23.8 GeV	0.30 ± 0.04
E771	p-Si @ 38.8 GeV	0.74 ± 0.17

No clear experimental panorama

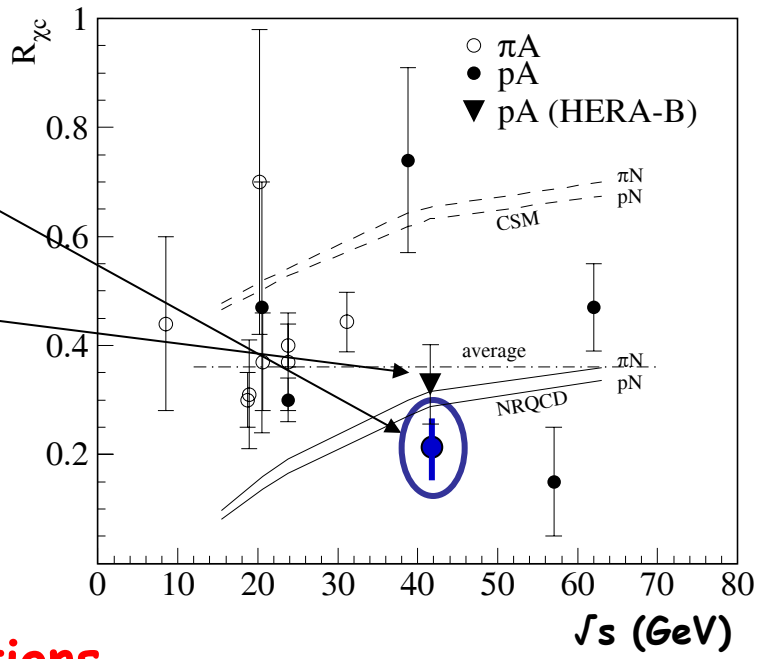
$R\chi_c = 0.21 \pm 0.05$

$R(\chi_c) = 0.32 \pm 0.06 \pm 0.04$

Results of 2000 (Phys.Lett. B561(2003) 61)

$N(\chi_c)$ = 370±74 (both $\mu^+\mu^-$, e^+e^-)

Theoretical expectations

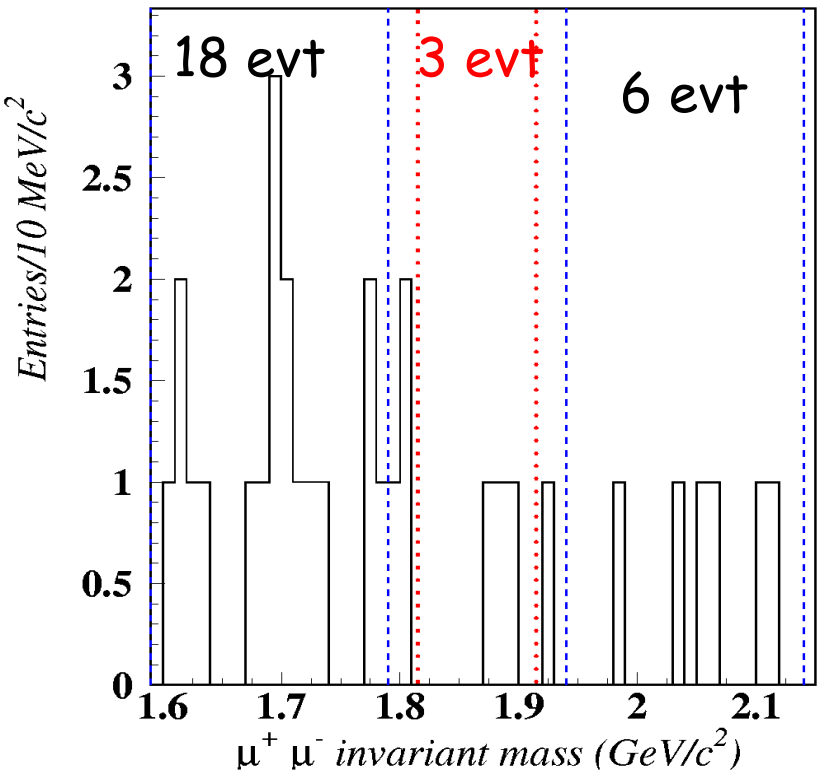


HERA-B results agree with NRQCD expectations

Final precision ⇨ more stringent tests

$D^o \to \mu^+\mu^-$

Search of FCNC in the decay BR($D^o \to \mu^+\mu^-$):



expected BR for Standard Model ~ 10^{-19}
supersimmetric model enhances to ~ 10^{-7}

Upper limit on the branching ratio:

BR($D^o \to \mu^+\mu^-$) < 2.0 x 10^{-6} (90% cl)
hep-ex/0405059
Submitted to Phys Lett B

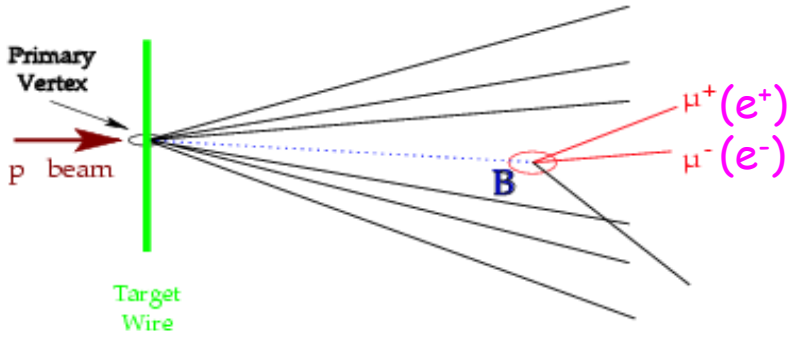
Previous limit:
CDF: BR($D^o \to \mu^+\mu^-$) < 2.5 x10^{-6}
Phys.Rev. D 68 (2003) 091101

Currently best upper limit

Open beauty production

$pA \rightarrow b\bar{b} + X,\ b \rightarrow J/\psi + Y$

Select detached vertex to separate B (decay length ~7 mm) from J/ψ



Dilepton vertex resolution 0.5 mm

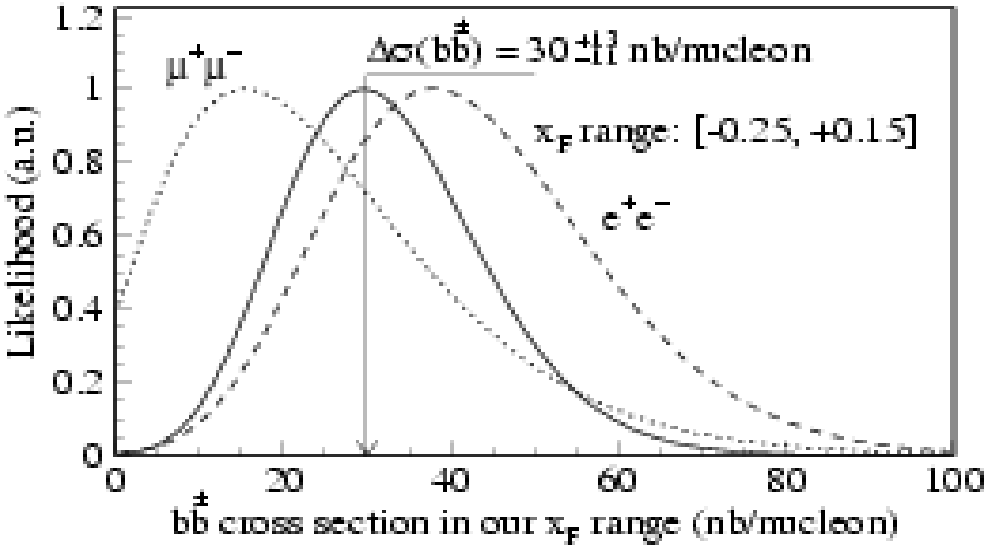
$$\sigma_{b\bar{b}} = \sigma_{J/\Psi} \cdot \frac{n_B}{n_{J/\Psi}} \cdot \frac{1}{\varepsilon_R \cdot \varepsilon_B^{\Delta z} \cdot Br(b\bar{b} \rightarrow J/\psi)}$$

Results of 2000:

Eur. Phys.J. C26(2003) 345:

$e^+e^- = 8.6^{+3.9}_{-3.2}$; $\mu^+\mu^- = 1.9^{+2.2}_{-1.5}$

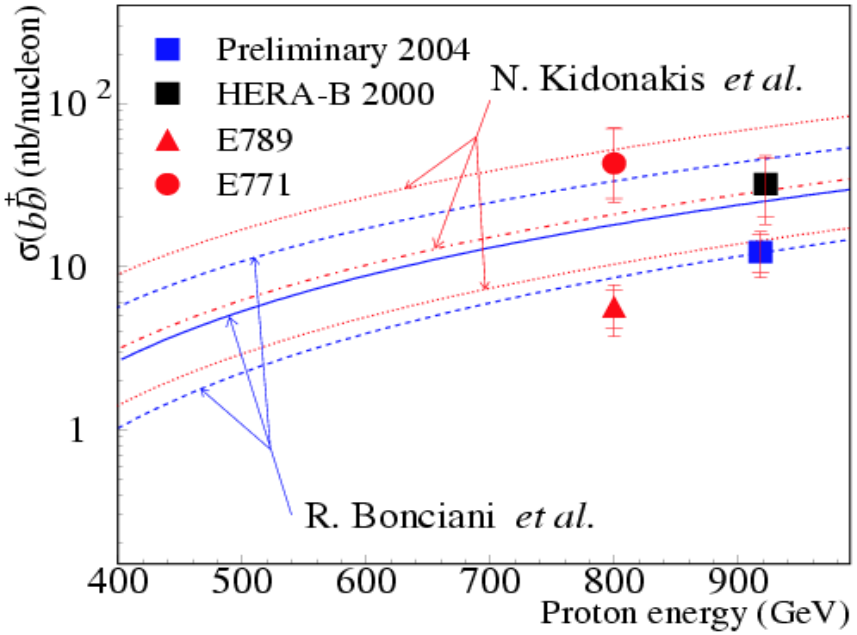
$\sigma(b\bar{b}) = 32^{+14+6}_{-12-7}$ nb / N

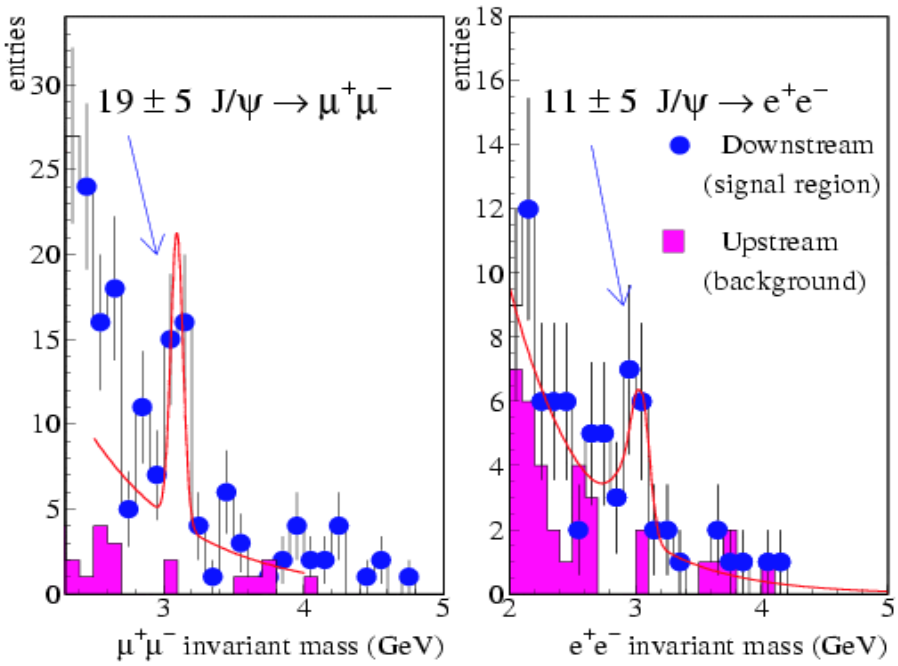


Open beauty production

Analysis of 2002/03 data:

- 35% of e^+e^- and $\mu+\mu-$ statistics
- Expect $N_B \sim 100$ for full sample
- Carbon + Tungsten targets
- J/ψ acceptance: $-0.35<x_F<0.15$ (90% of $b\bar{b}$ cross section)





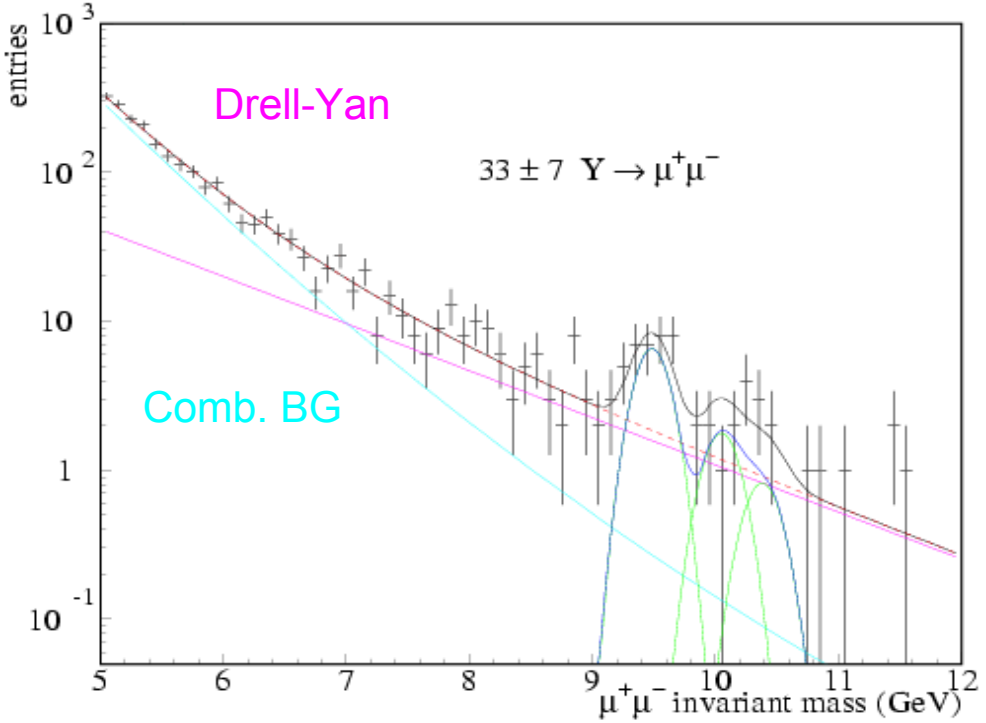
- Preliminary results of both channels compatible
- 1.5 σ lower than 2000 result

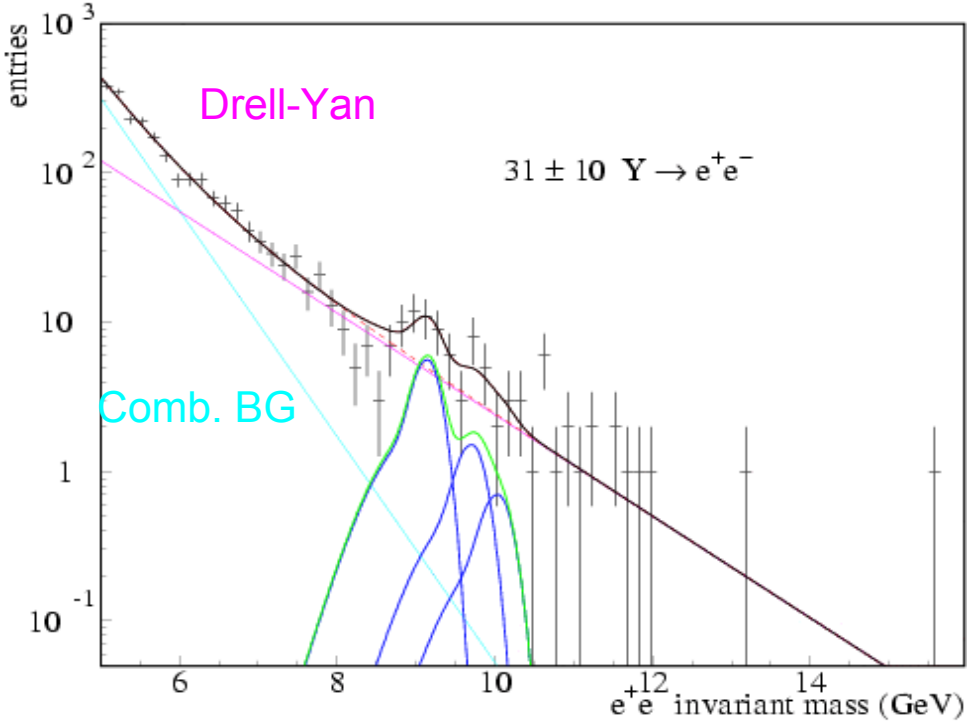
$$\sigma\left(b\bar{b}\right) = 12.3^{+3.5}_{-3.2}\ \text{nb / N}$$

Hidden beauty production

$$\sigma_{\Upsilon} = \sigma_{J/\psi} \cdot \frac{n_{\Upsilon}}{n_{J/\psi}} \cdot \frac{Br(J/\Psi \to l^+l^-)}{Br(\Upsilon \to l^+l^-)} \cdot \frac{\varepsilon^{J/\psi}}{\varepsilon^{\Upsilon}}$$

$pN \to \Upsilon + X$, $\Upsilon \to \mu^+\mu^-$, e^+e^-





Drell-Yan contribution compatible with E866

$M(\mu^+\mu^-)$ (GeV/c²)

$M(e^+e^-)$ (GeV/c²)

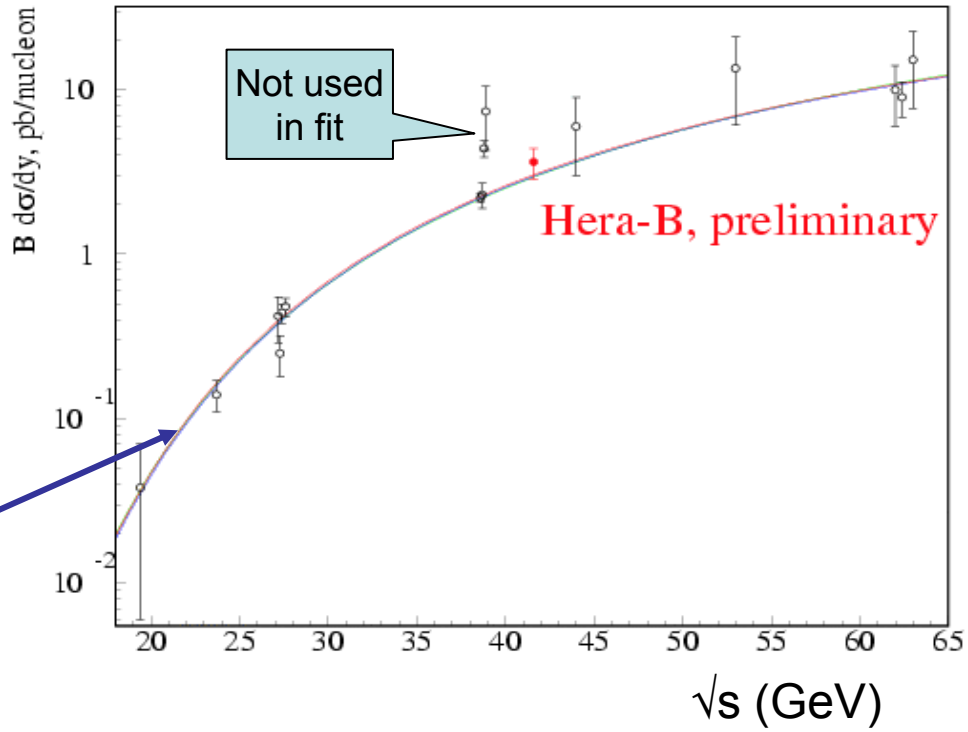
Relative production of $\Upsilon(1S)/\Upsilon(2S)/\Upsilon(3S)$ fixed on E605 data

Hidden beauty production

	Events	Br• dσ/dy $\big\vert_{y=0}$
$\mu^+\mu^-$	33±7	3.9±1.1 pb/N
e^+e^-	31±10	2.9±1.2 pb/N
both		3.4±0.8 pb/N

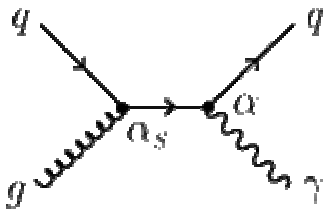
- All C and W data used (150 M evts)
- Modified Craigie applied to allow for nuclear suppression: α=0.99±0.05

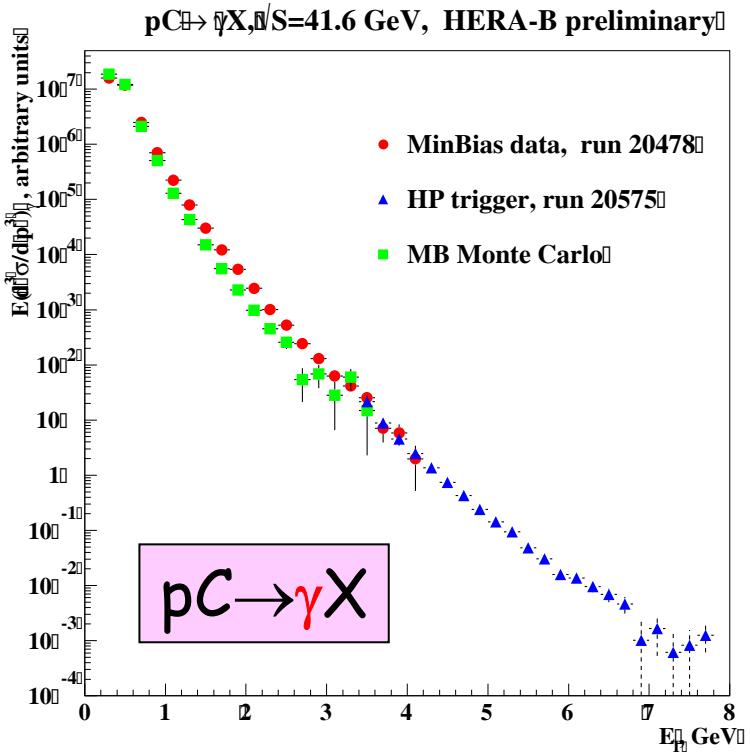
$$Br \times \left.\frac{d\sigma_{\Upsilon}}{dy}\right|_{y=0}(\sqrt{s}) = \sigma_o \exp\left(-\frac{m_o}{\sqrt{s}}\right) \cdot A^{\alpha-1}$$



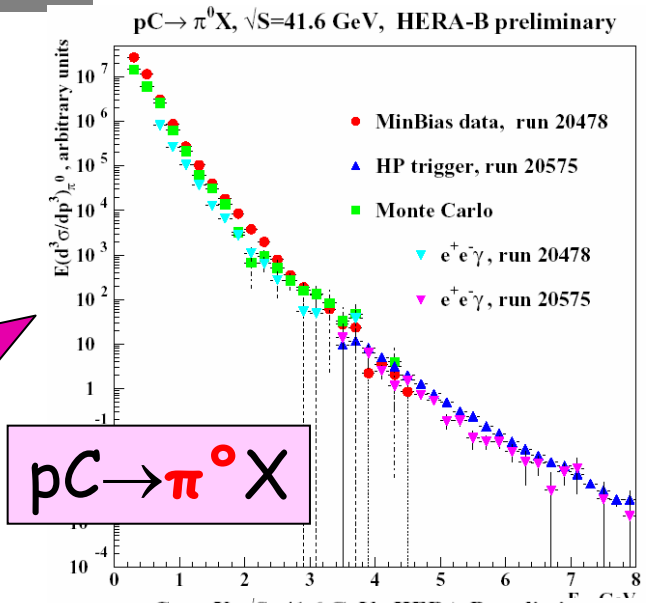
Hard photon analysis

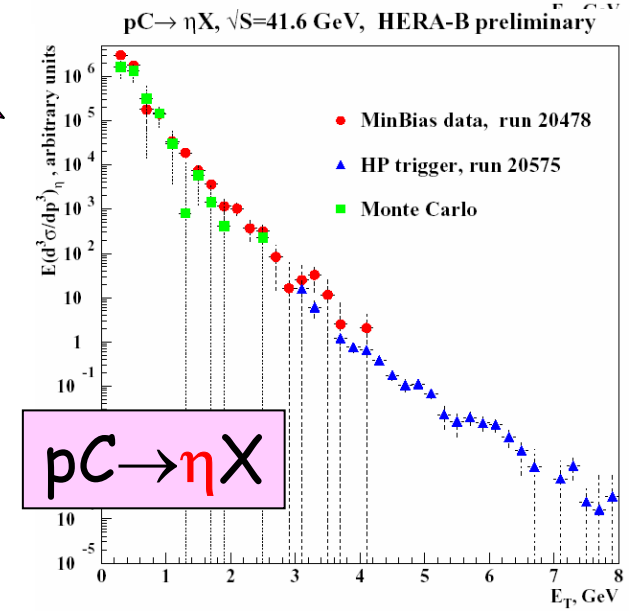
Direct γ production:
dominant process $gq \to \gamma q$
⇒ Unique sensitivity to gluon density function





Main bkg sources, also important to test QCD





HERA-B:
- **Widest rapidity range**
- **Large p_T range**
- **Highest energy for pA**
- **Ongoing analysis on heavier materials**

(normalization still arbitrary)

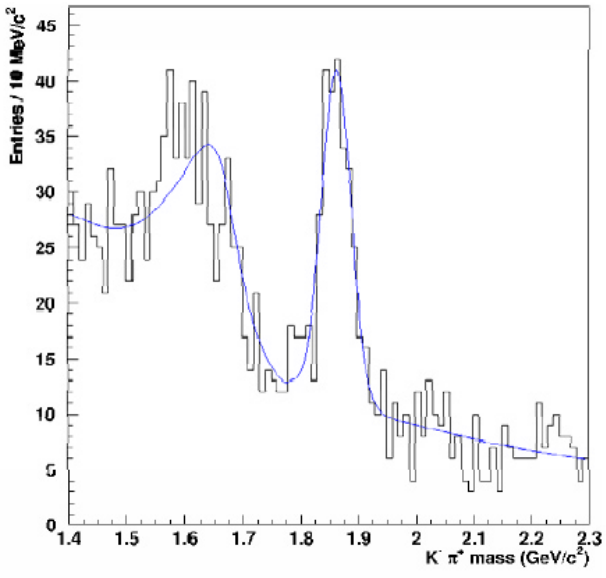
MB data analysis

- Open charm production
- V^0 production
- Hyperon production
- Strangeness production
- Pentaquark search

Open charm production

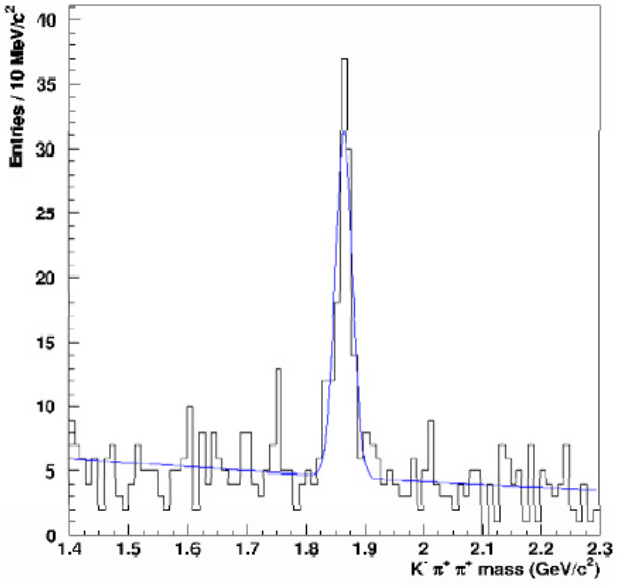
Signals selected in Minimum Bias data

$D^0 \longrightarrow K^- \pi^+ + c.c.$



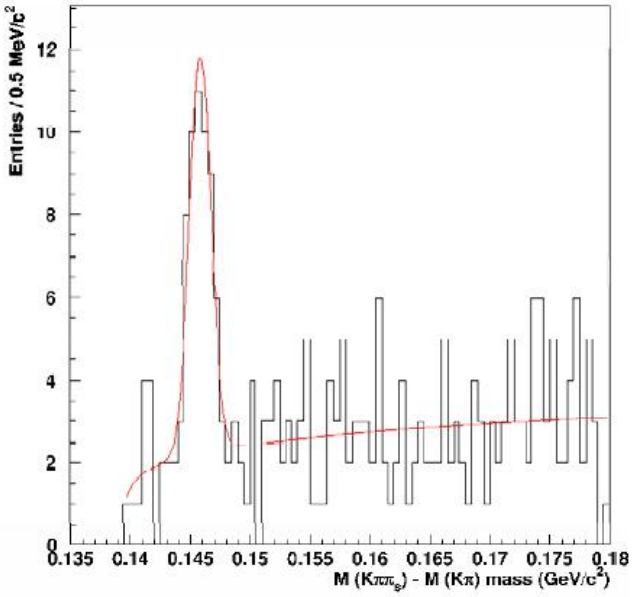
N = 189 ± 20
σ = 25 ± 3 MeV
M = 1863 ± 3 MeV

$D^+ \longrightarrow K^- \pi^+ \pi^+ + c.c.$



N = 98 ± 12
σ = 15 ± 2 MeV
M = 1866 ± 2 MeV

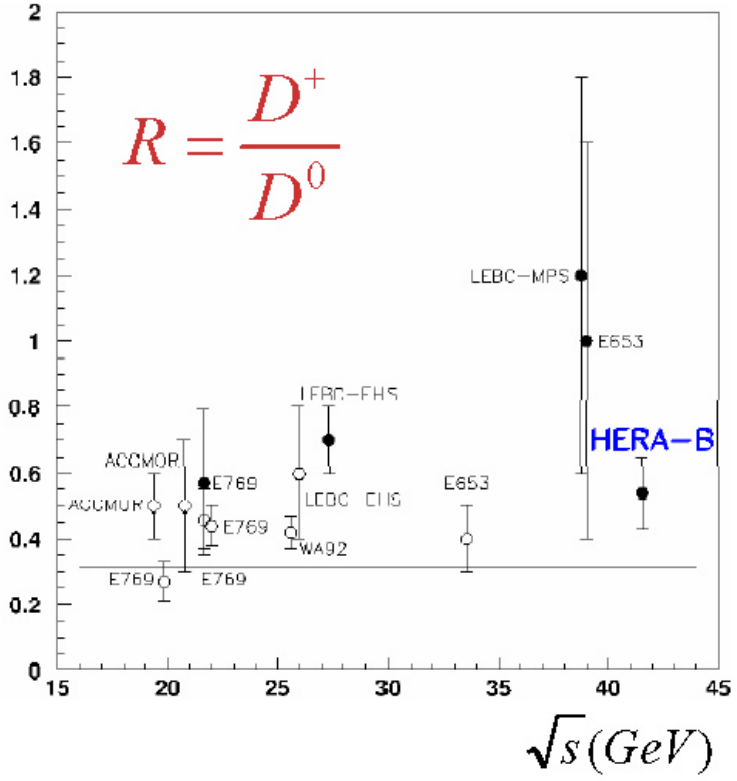
$D^{*+} \longrightarrow D^0\pi^+ \longrightarrow K^- \pi^+ \pi^+ + c.c.$

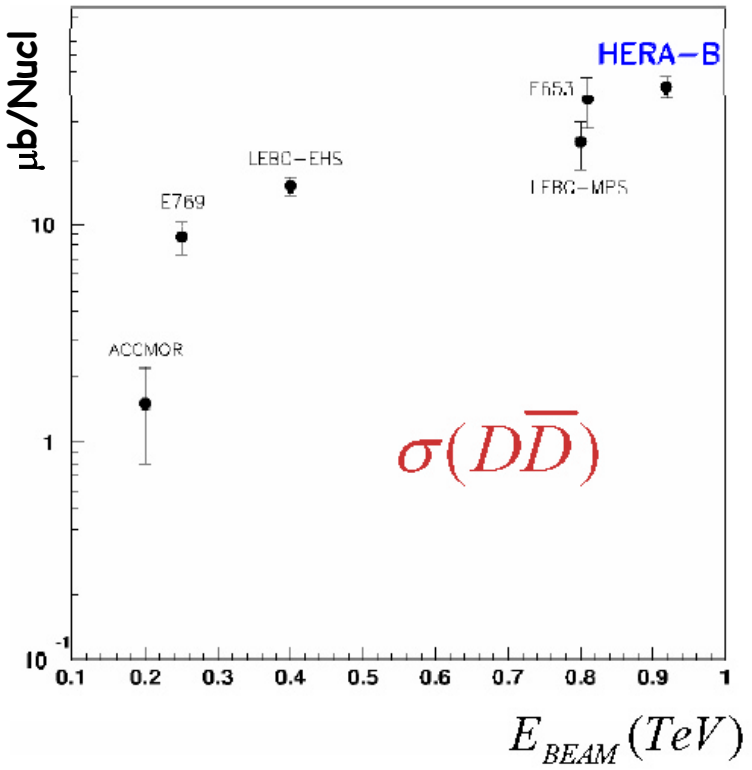


N = 43 ± 8
σ = 0.89 ± 0.15 MeV
q = 145.9 ± 0.2 MeV

Open charm production

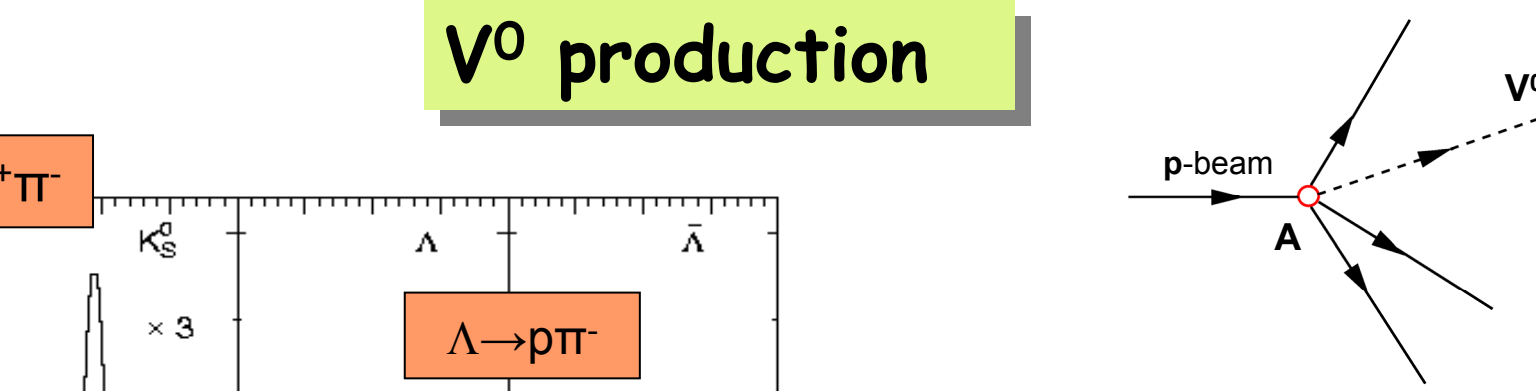
preliminary	$-0.1 < x_F < 0.05$	$\rightarrow$ full x_F
$\sigma(D^0)\mu b$/Nucl	21.4±3.2±3.6	56.3±8.5±9.5
$\sigma(D^+)\mu b$/Nucl	11.5±1.7±2.2	30.2±4.5±5.8
$R(D^+/D^0)$		0.54±0.11±0.14



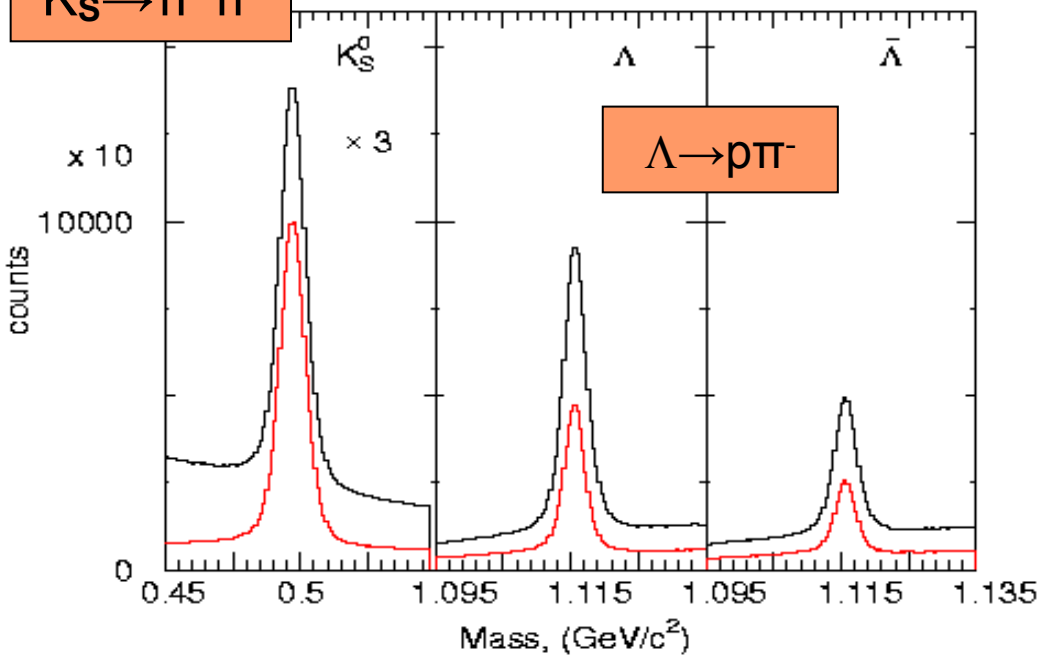


Important test for QCD

V^0 production

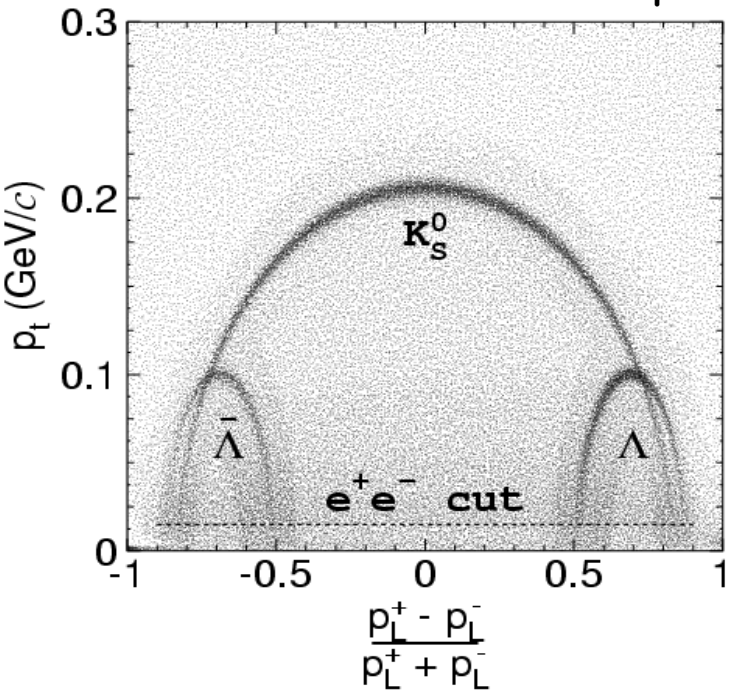


$K_S \rightarrow \pi^+\pi^-$



$\Lambda \rightarrow p\pi^-$

Armenteros-Podolanski plot



Statistics:

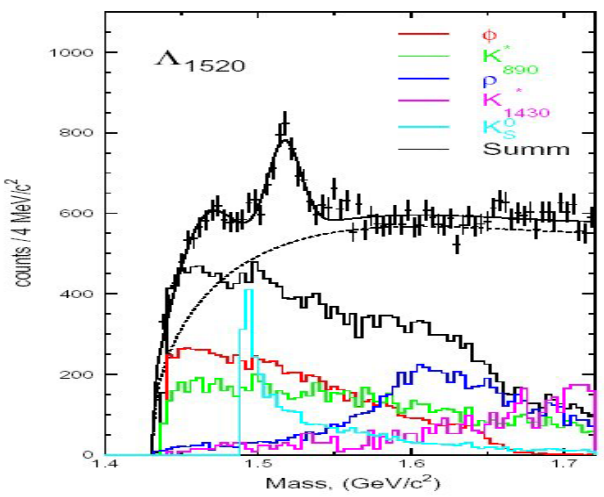
K_s ~ 3.40 x 10^6	evts	σ ~ 4.9 MeV
Λ ~ 0.94 x 10^6	"	σ ~ 1.8 MeV
$\bar{\Lambda}$ ~ 0.45 x 10^6	"	σ ~ 1.8 MeV

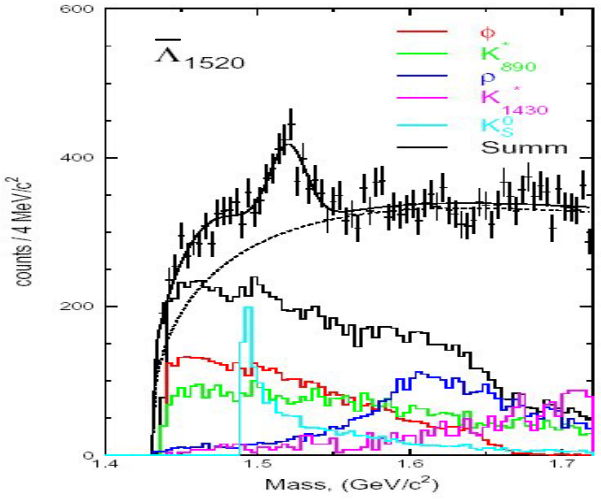
→Measurement of the production cross section and ratio vs *A*

→2000 data analysis published in: Eur.Phys.J. C 29,181 (2003)

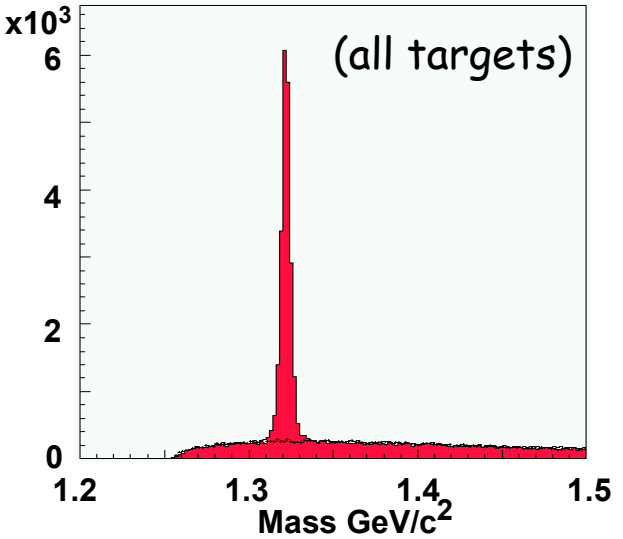
Hyperon production

$\Lambda(1520) \rightarrow p\ K^- + c.c.$ (Carbon target)





$\Xi^{\pm}(1321) \rightarrow \Lambda(1116)\ \pi^{\pm}$



Λ: ~ 2000, σ ~ 8 MeV
$\bar{\Lambda}$: ~ 1000, σ ~ 8 MeV

Strong signals

Ξ^-: ~ 11300, σ ~ 2.6 MeV
Ξ^+: ~ 7700, σ ~ 2.6 MeV

- Good proton/kaon identification
- Very large $\Xi^{\pm}$ statistics

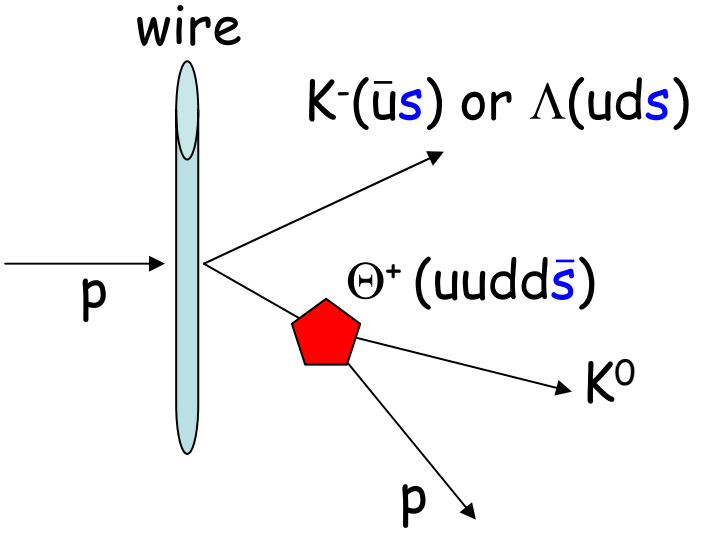
Pentaquark search

Possible pentaquark states

$\Theta^+(1530,\ uudd\bar{s}) \rightarrow pK^0$ (or nK^+)

$\Xi^{--}(ddss\bar{u}) \rightarrow \Xi^- \pi^-$ (or $\Sigma^- K^-$) $\rightarrow \Lambda\pi^-\pi^-$

and charge c.



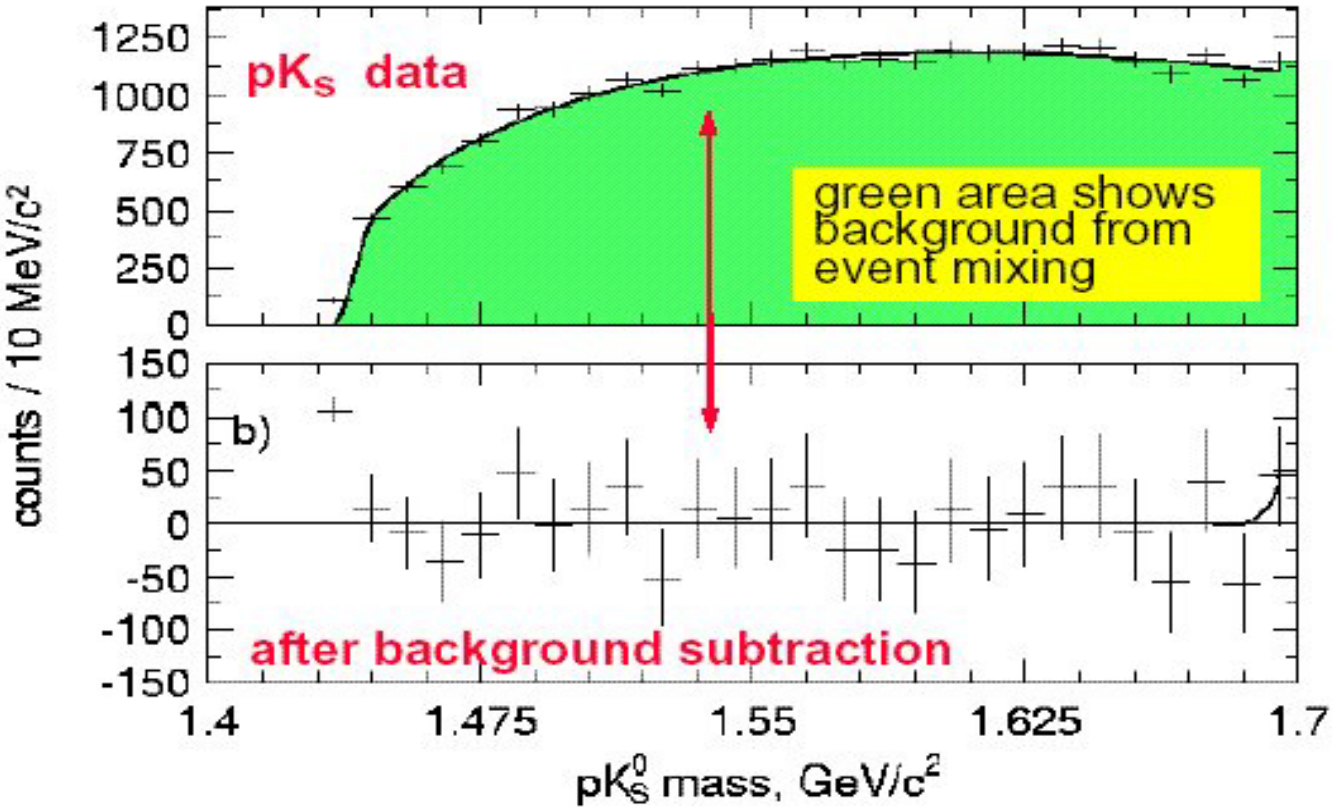
Use the full MB data sample (~210M evts, 3 nuclear targets C, Ti, W) to:

- search for the reported pentaquark signals
- provide upper limits on particle yield ratios (vs $\Lambda(1520)$ and $\Xi^0(1530)$)
- possibly determine physical quantities (width, spin, parity, charge) of pentaquarks for different final states (p-K^0, Ξ-π)

Pentaquark search: $\Theta^+ \rightarrow pK^0$

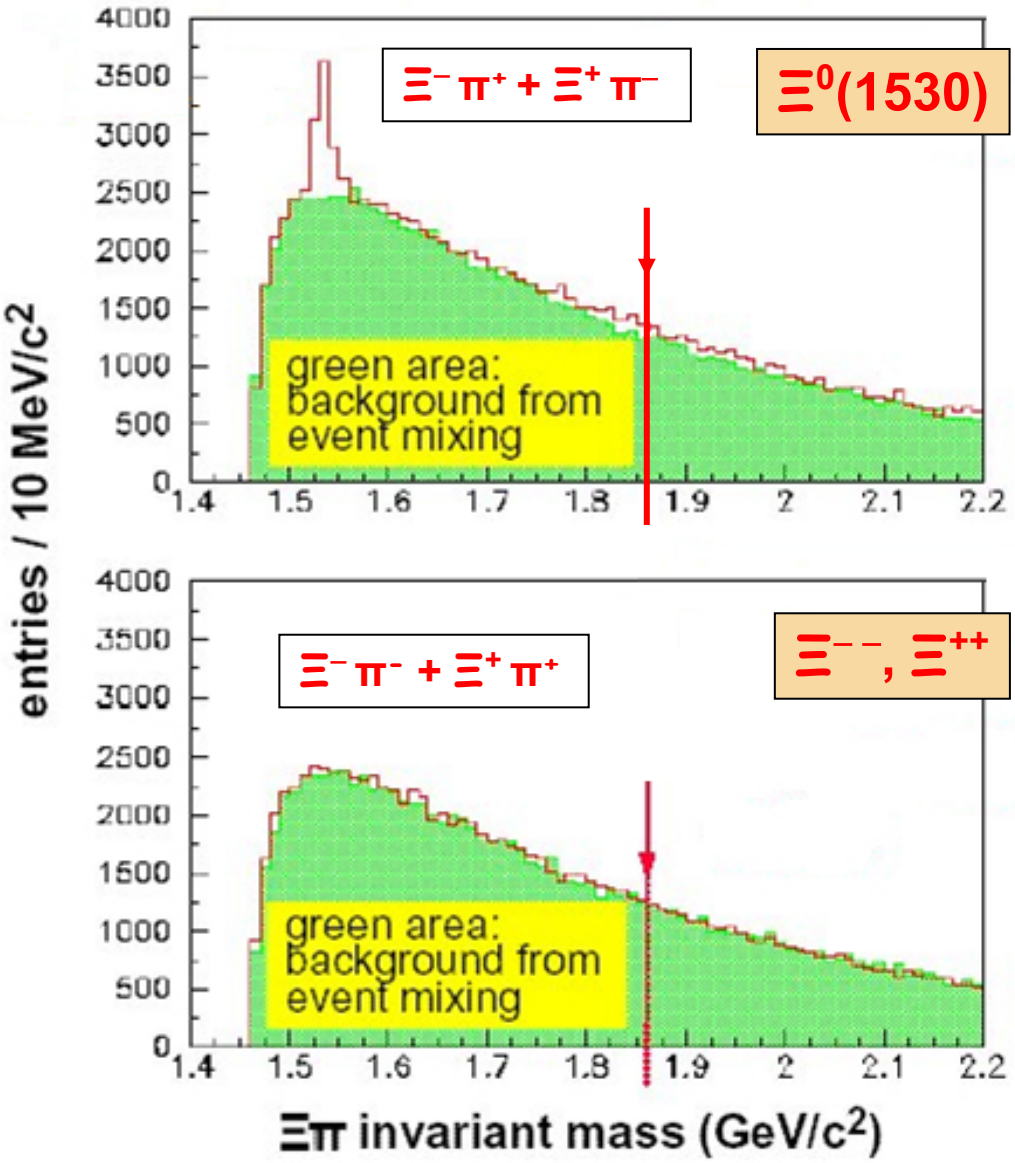
sensitivity in $BR \cdot (d\sigma/dx_f)$

~ 5μb/nucleon



- No evidence of signals where expected (~ 1530 MeV/c^2)
- Upper limit on particle yield ratio:
  $\Theta^+/\Lambda_{1520} < 0.02$ at 95% C.L.
  (Hermes: ~ 1.6 ÷ 3.5)
  } assuming $BR(\Theta^+ \rightarrow pK_S) = 0.25$
- Upper limit on nuclear cross section under evaluation

Pentaquark search: $\Xi^{--}(\Xi^{++}) \rightarrow \Xi^{-}\pi^{-}(\Xi^{+}\pi^{+})$



Good $\Xi^{0}(1530)$ reconstruction

- No evidence of Ξ^{--}, Ξ^{++} around 1862 MeV/c²
- Upper limits (95% cl):
  $\Xi^{--}(1862) / \Xi^{0}(1530) < 0.077$
  $\Xi^{++}(1862) / \Xi^{0}(1530) < 0.058$
- Nuclear cross section upper limit in progress

Summary

- Many physics topics addressed
- Detector
  - Large acceptance (negative x_F)
  - good particle identification
- Large statistics collected
  - Dilepton sample ($\mu^+\mu^-$ & e^+e^-)
    - J/ψ (300k), ψ(2S), χ_c, Υ and $b\bar{b}$
  - MB sample
    - Open charm, V^0, hyperons, pentaquark
- High quality of data
- Preliminary results available on several topics
- Competitive with previous experimental panorama

Many thanks to the organizers for the invitation and the logistic support