Discovery of Cascade b Baryon, $\Xi_b^{\pm}$

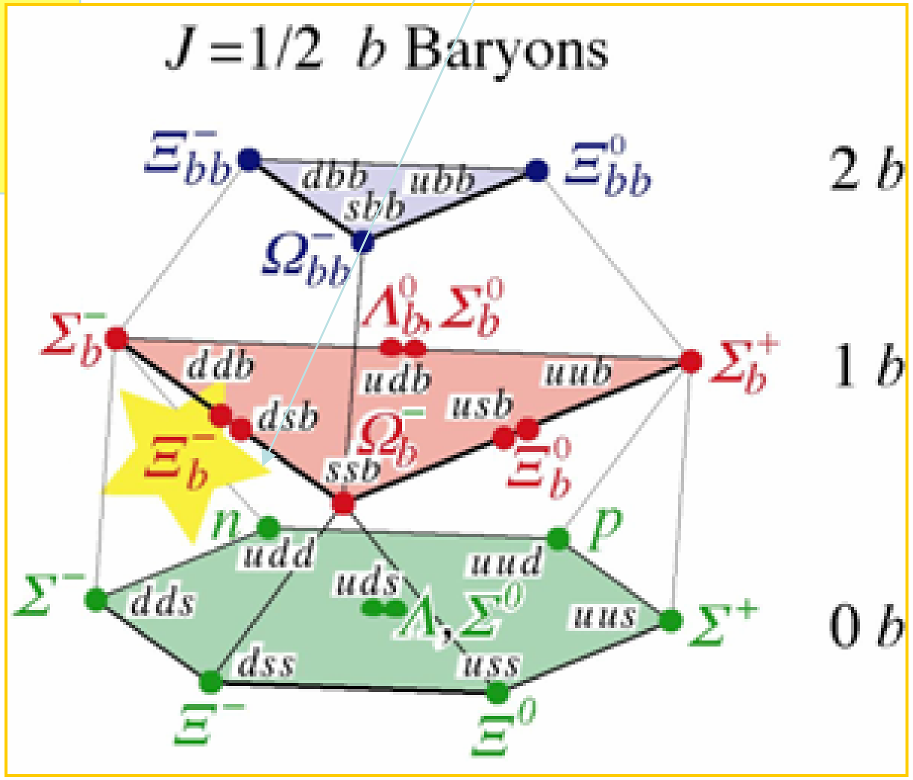
G.Borisov, L.Vertogradov

for D0 collaboration

State of B-hadrons' mass spectroscopy

- Mesons:
  - B^+, B^0, B_s, B_c^+ (established)
  - B^* (established),
  - B_d^{**} (sent to PRL DØ, preliminary CDF)
  - B_s^{**} (preliminary DØ and CDF)
- Barions:
  - Λ_b (established)
  - Σ_b^+ and Σ_b^{*+} (sent to PRL CDF)

Our goal – charged Ξ_b (the first ever particle that contains three quarks from three different generations)



- From theory: $M(\Lambda_b) < M(\Xi_b) < M(\Sigma_b)$
  so, 5.624 GeV $< M(\Xi_b) <$ 5.808 GeV
- Life time estimation (LEP):
  $\tau(\Xi_b) = 1.42 \pm 0.28 \pm 0.24$ ps

B - baryons

- Not much of experimental data till 2006:
  - Direct observation of Λ_b;
  - Indirect sign of Ξ_b: excess of pairs Ξ-ℓ with the same charges (ALEPH,DELPHI);
- Theory predictions for the Ξ_b mass:
  - $M(\Xi_b) = 5805.7 \pm 8.1$ МэВ/c^2;
  - $M(\Sigma_b) = 5824.2 \pm 9.0$ МэВ/c^2;
  - $M(\Omega_b) = 6068.7 \pm 11.1$ МэВ/c^2;

    E. Jenkins, Phys.Rev. D55 (1997) R10-R12
  - $M(\Xi_b) = 5762 \div 5788$ МэВ/c^2;

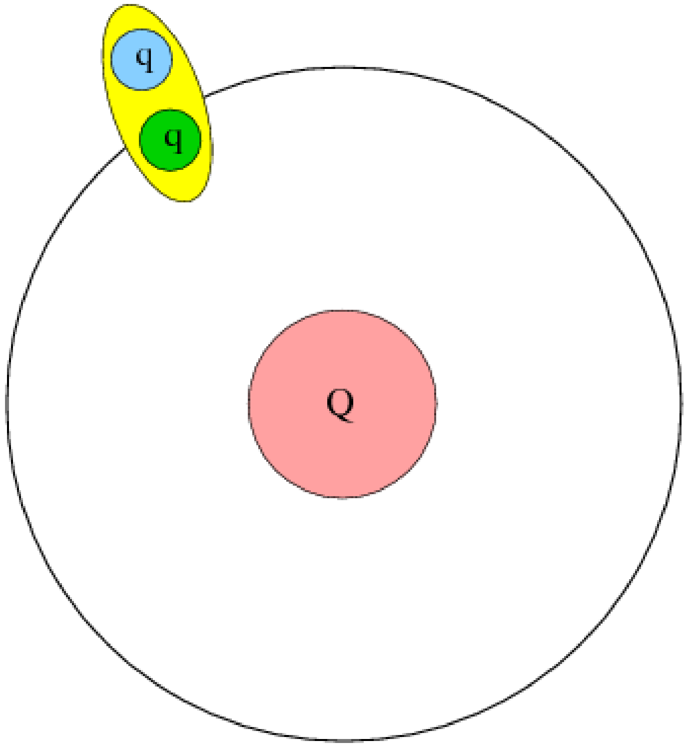
    N.Mathur a.o., Phys.Rev. D66 (2002) 014502
  - $M(\Xi_b) = 5790 \div 5800$ МэВ/c^2;

    M.Karliner a.o., arXiv.org:hep-ph/0706.2163;

Why to study the b-baryons ?

Laboratory to study the nonperturbative QCD and potential models:

- heavy b-quark → simplification of theoretical description
- base model: light di-quark system qq orbiting a heavy b-quark „nucleus“ Q
- There is analogy with hydrogen/helium atoms



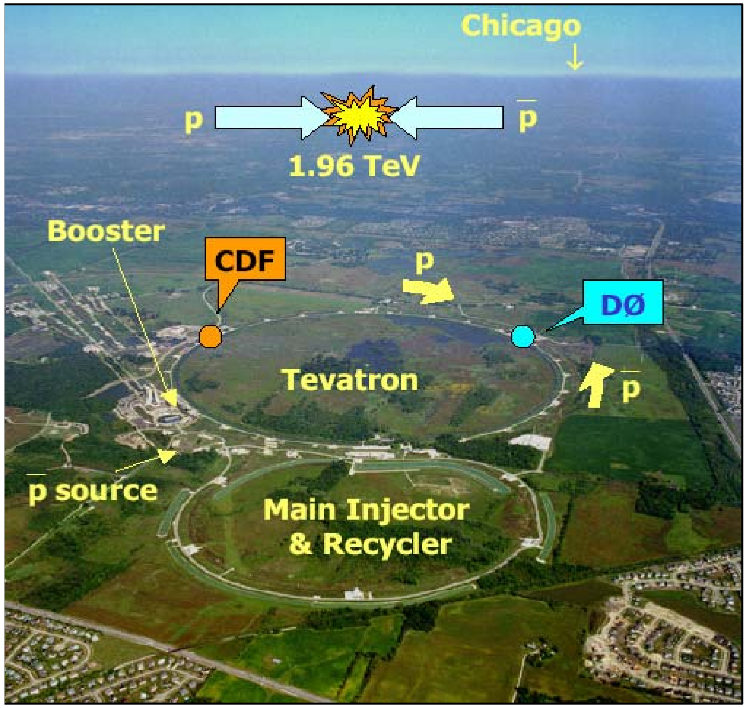
How to search Ξ_b?

- Today, only Tevatron can produce b - baryons.
  It was possible on LEP but with 1000 times less cross section value.

- The "gold" channel to study b-hadrons ─ decays with J/ψ production. They are rather rear (BR ~ 10^{-4}), but are very clear channels with efficient trigger.

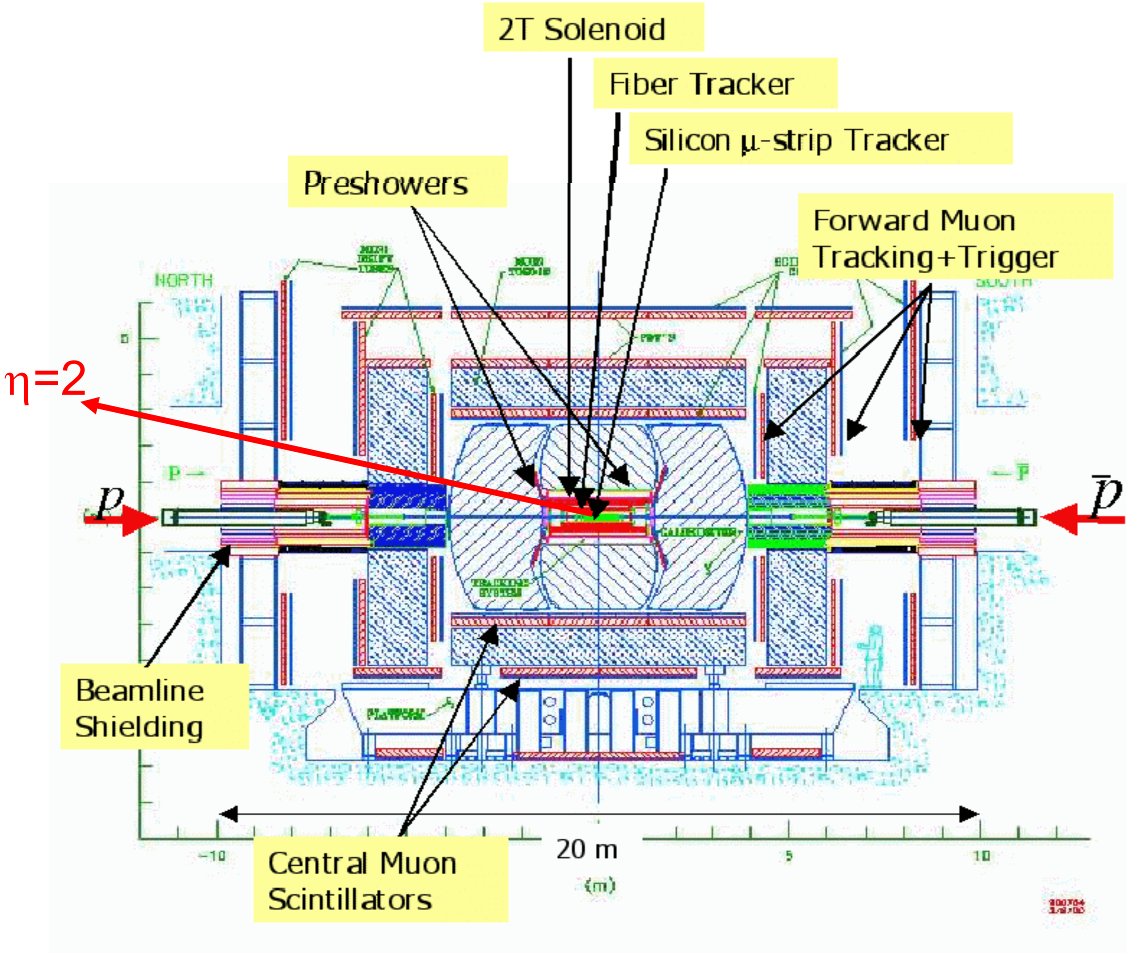
- D0 installation with its excellent Muon Detector is very suitable for search $\Xi_b \rightarrow J/\psi\ \Xi$
  where $J/\psi \rightarrow \mu^+ \mu^-$, $\Xi \rightarrow \Lambda^0 + \pi$, and $\Lambda^0 \rightarrow p + \pi$

Tevatron and DØ detector



Integral luminosity	fb^{-1}
Collider	>3
DØ Run IIa	1.3
D0 Run IIb	1.3

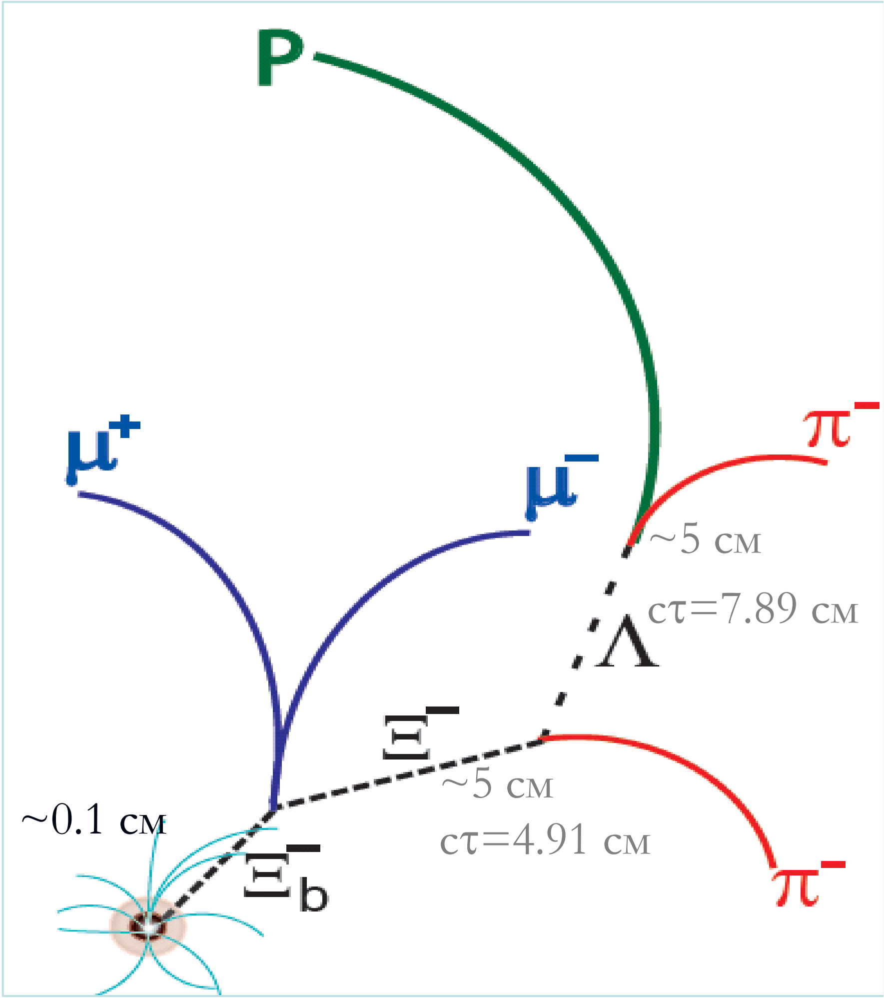
Here only the Run IIa analysis is presented !



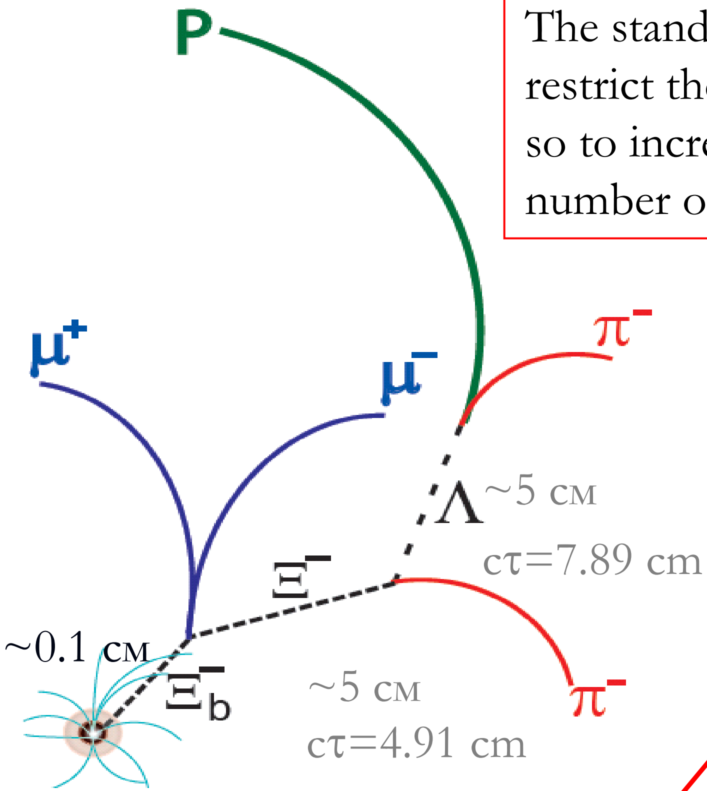
Wide aperture Muon Spectrometer & Trigger. There are large statistics collected for $B \to J/\psi + X$ and semileptonic $B \to \mu + X$.

Main features of the decay $\Xi_b^- \to J/\psi + \Xi^-$

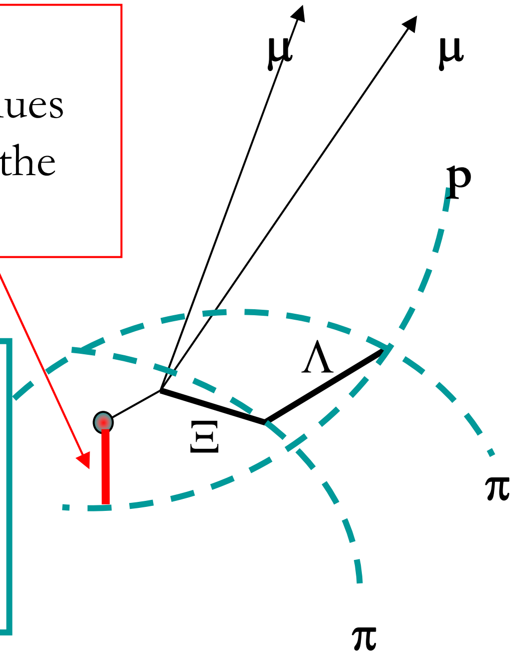
- We need to reconstruct 5 daughter particles:
  - $J/\psi \to \mu^+ \mu^-$
  - $\Lambda \to p + \pi$
  - $\Xi \to \Lambda + \pi$
- Some decay products (p, π^-, π^-) have big enough impact parameter values (relative to the PV).
- Charge correlation: both pions must be the same sign of charge ("true combination")



Impact parameter's selection



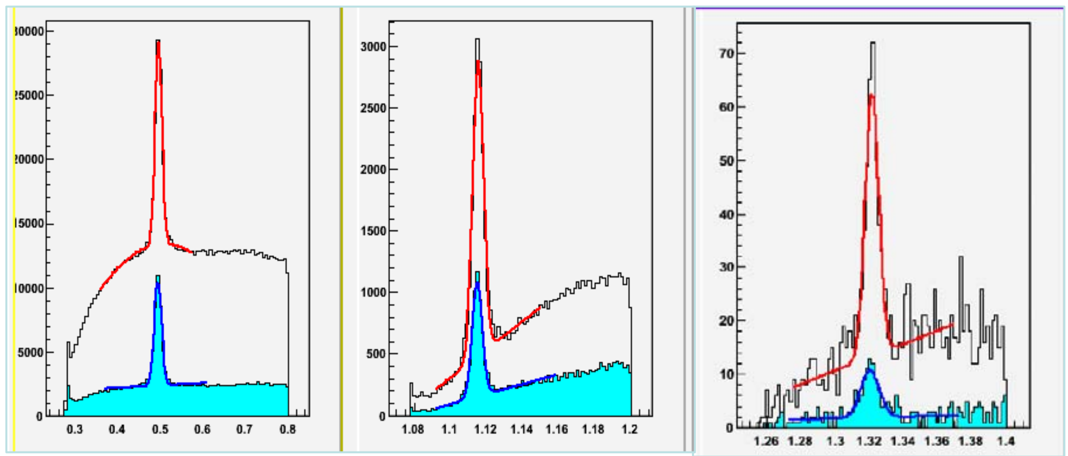
The standard track reconstruction algorithms restrict the impact parameter (IP) to small values so to increase the counting rate and to lower the number of fake tracks.



On this way some of our low energy secondary tracks (**p** and π - mesons from the Λ and Ξ^- decays) could be lost.

How it works: (**Before**) (**After**)

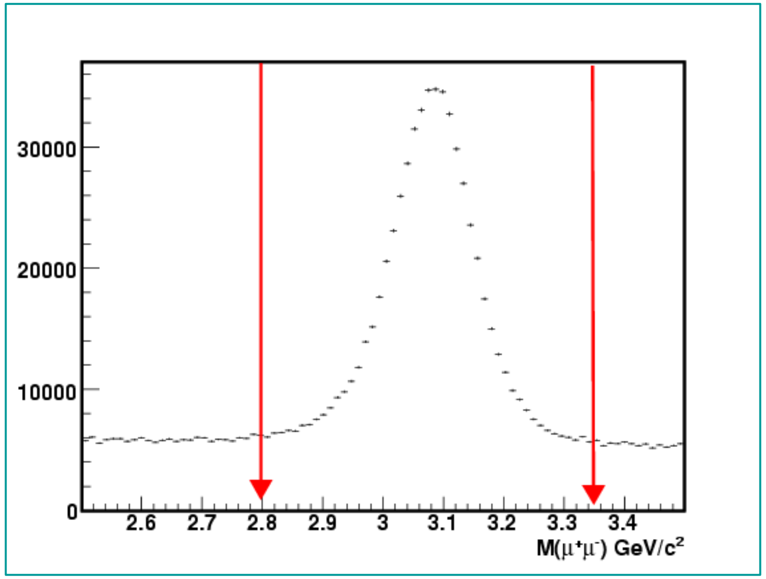
$K_s^0 \to \pi^+\pi^-$ $\Lambda \to p\pi^-$ $\Xi^- \to \Lambda\pi^-$



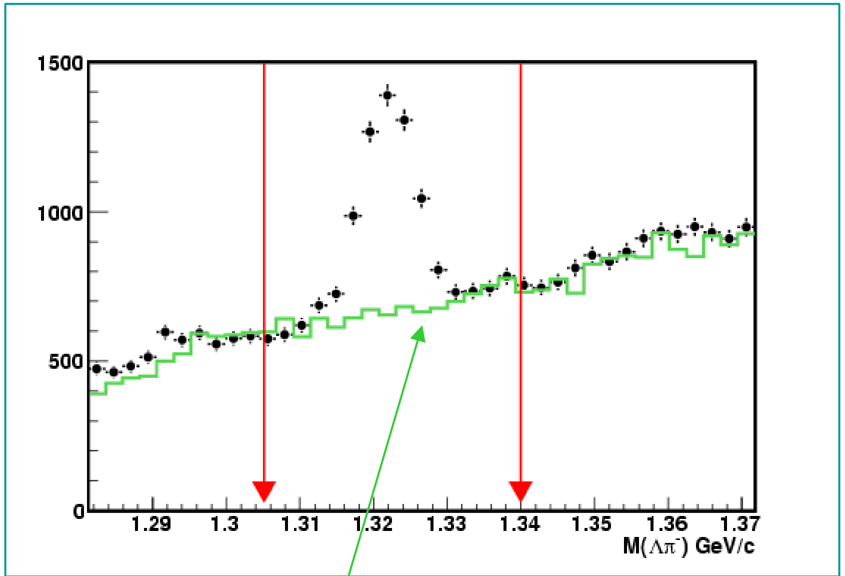
By this reason the Run IIa JPSI_AA_SKIM data (~35 million of events) were reprocessed with IP_{max} = 10 см

Preliminary selection: mass distributions

$J/\psi \rightarrow \mu^+\mu^-$



$\Xi \rightarrow \Lambda\pi$



Events with «wrong combination» of the pion's charge signs: $\Lambda(p\pi^-)\ \pi^+$

Where from the background is?

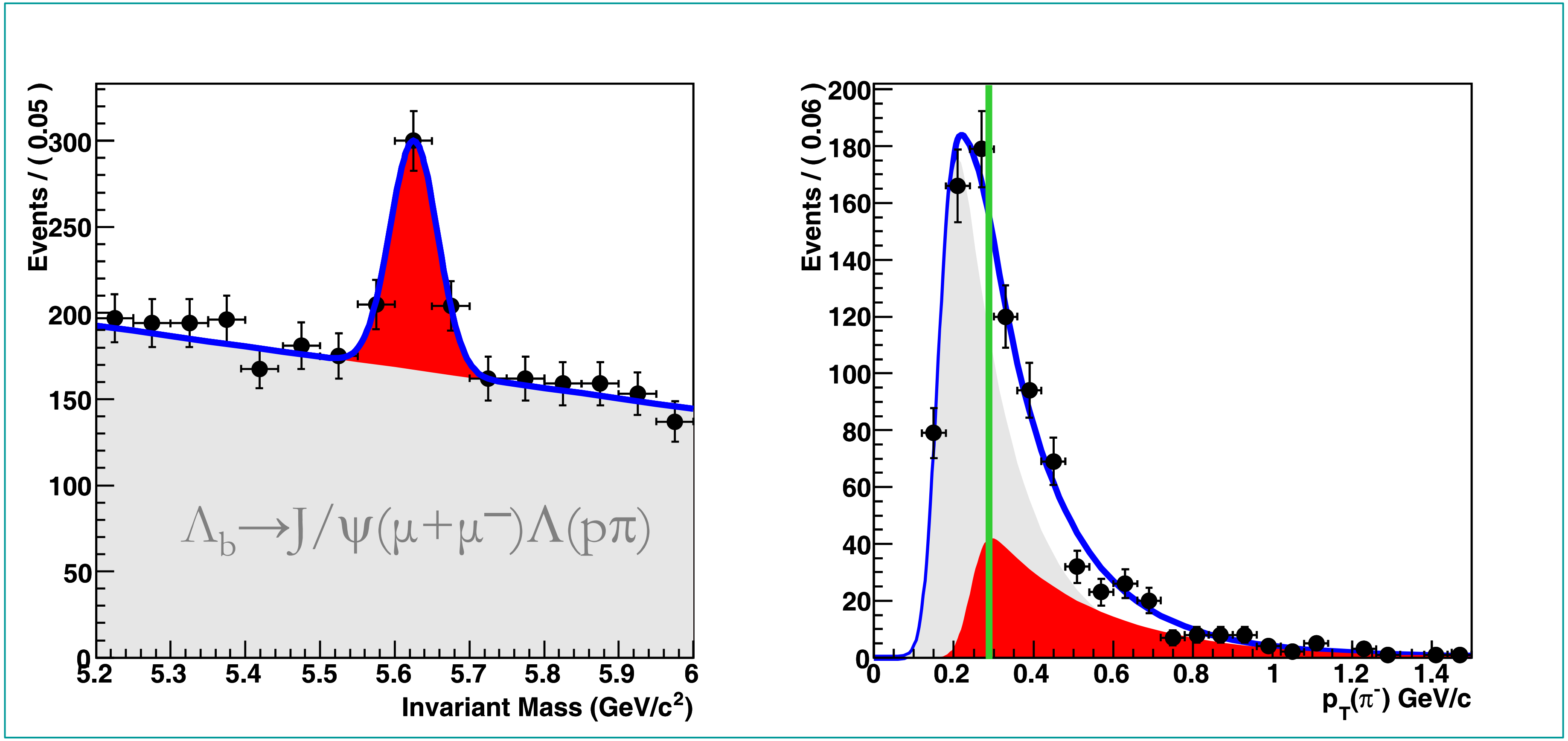
- Prompt J/ψ :
  - ~80% J/ψ are produced at the primary interaction.
- Real b–hadrons:
  - The rest ~20% J/ψ are from the decay of real b–hadrons.
- Combinatorial backgrounds:
  - Real J/ψ & wrong Ξ^-
  - Wrong J/ψ & wrong Ξ^-
  - Wrong J/ψ & real Ξ^-
  - Real J/ψ & real Ξ^- that is not from Ξ_b^-

See events with "wrong combination" Ξ.

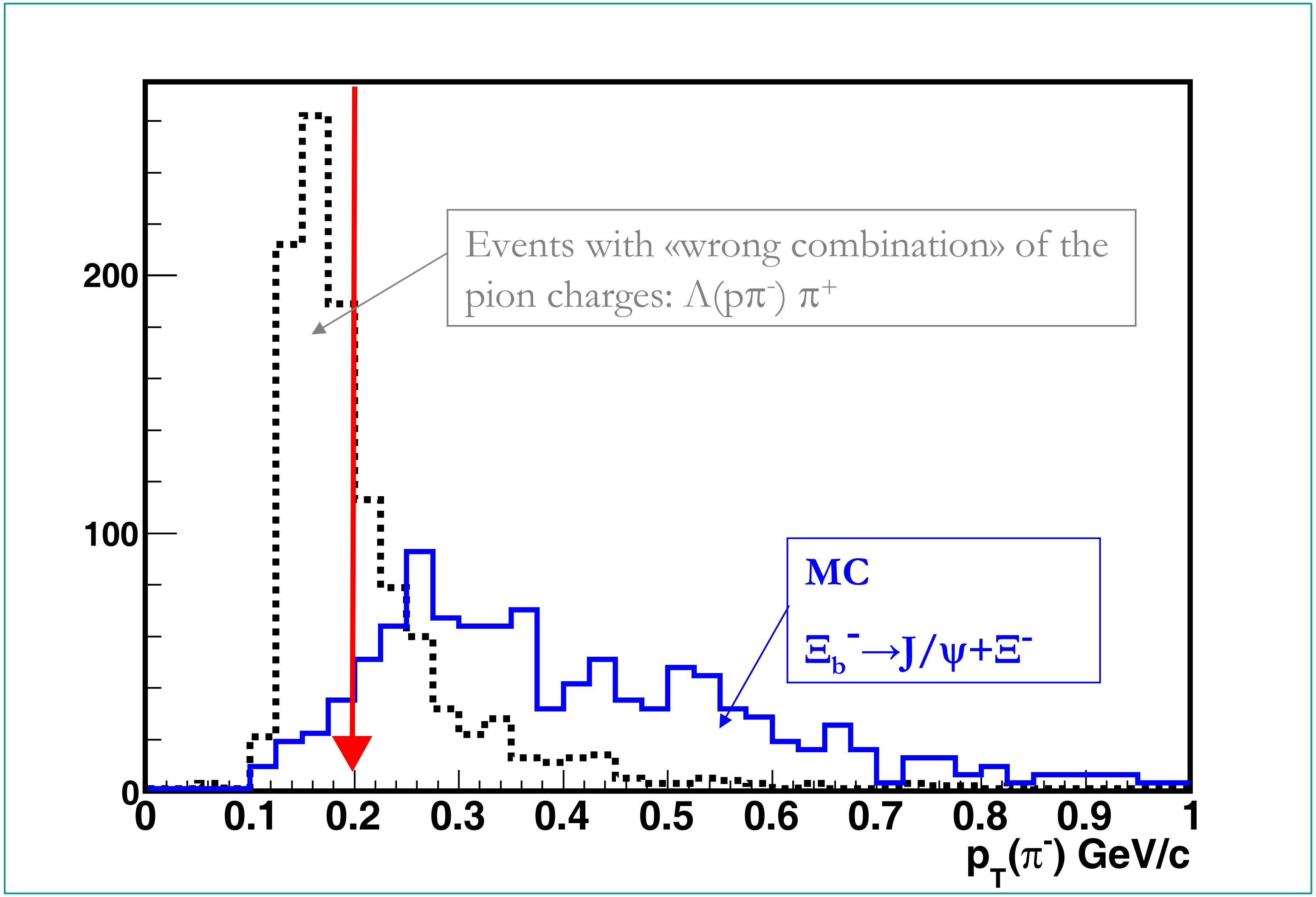
Selection cuts to suppress the background

- To keep high signal efficiency they must be "soft".
- To select the cuts and to estimate the background we used:
  - Our experimental results for $\Lambda_b \rightarrow J/\psi\Lambda$
  - Sample of events with "wrong combination Ξ"
  - Sideband events near the J/ψ peak
  - Sideband events near the Ξ^- peak
  - Monte Carlo Ξ_b^- events (for example, for pions from the Ξ decay)

1: $P_T(\pi^-)$ от Λ



2: $P_T(\pi^-)$ от Ξ^-

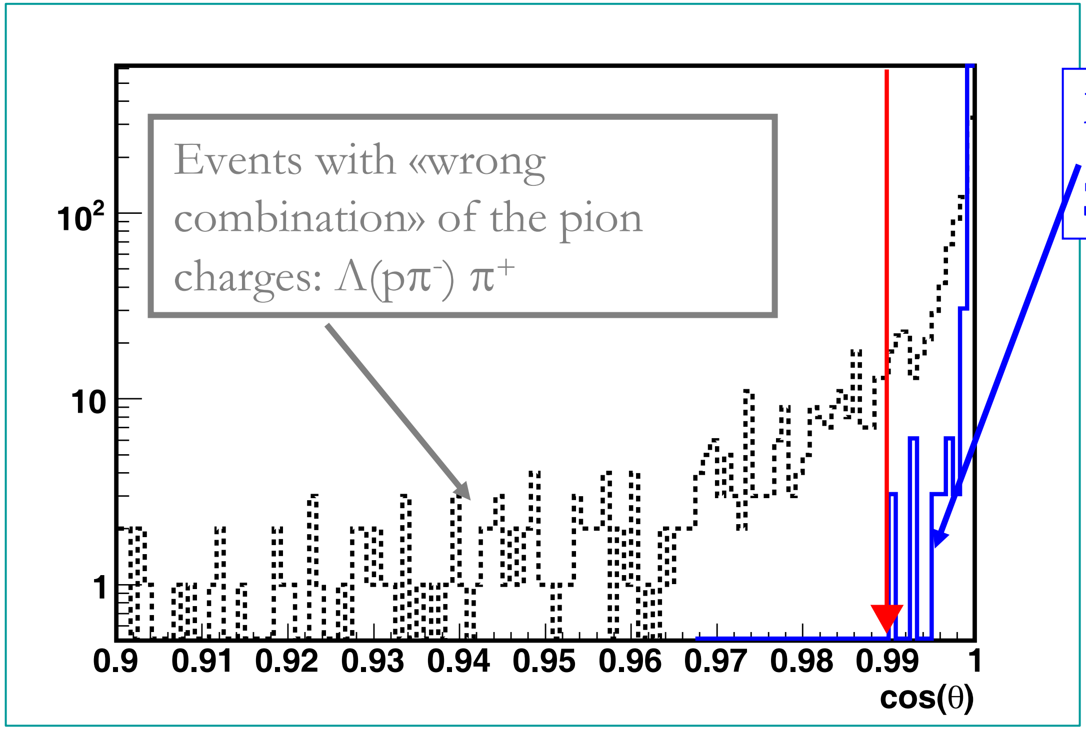


200
100
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
pT(π-) GeV/c
Events with «wrong combination» of the pion charges: Λ(pπ-) π+
MC
Ξb- → J/ψ+Ξ-

3: collinearity

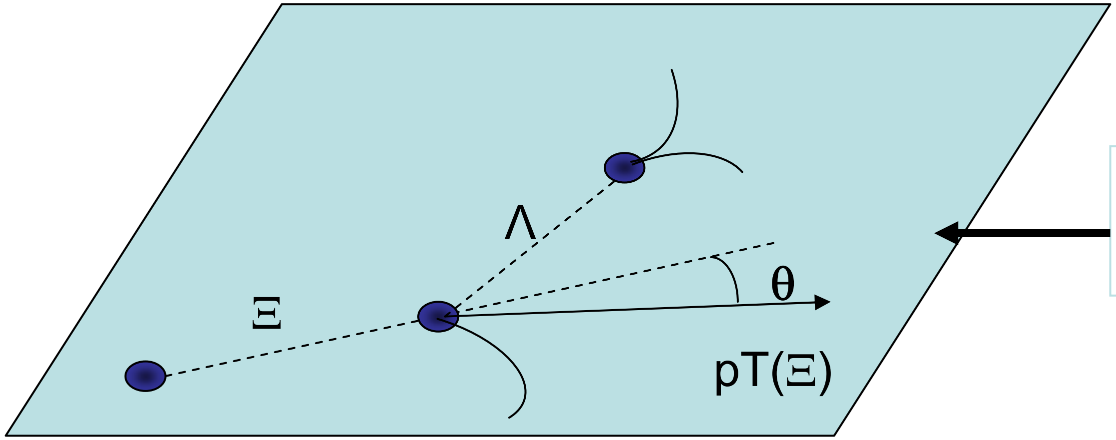
Cos(θ)>0.99

Eff.100%



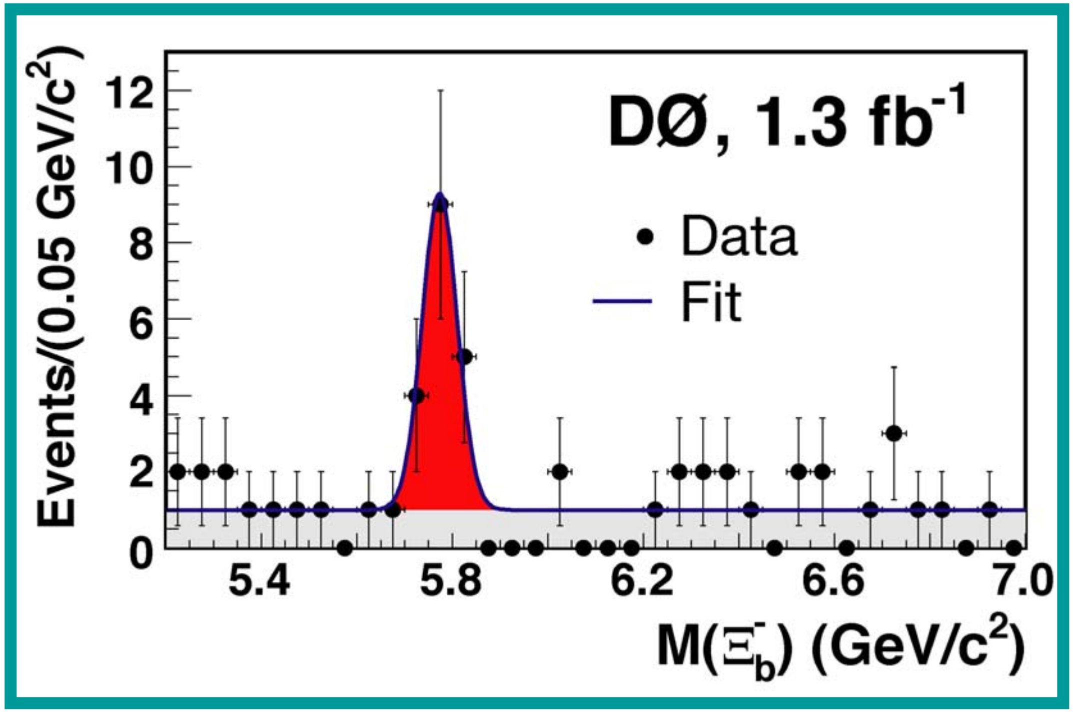
Monte Carlo

$\Xi_b^- \to J/\psi + \Xi^-$



Collinearity in XY—plane: cos(θ)

Main result – clear Ξ_b signal and its mass estimation



- Fit:
  - Unbinned extended log-likelihood fit
  - Gaussian signal, flat background
  - Number of background/signal events are floating parameters

Number of signal events: 15.2 ± 4.4

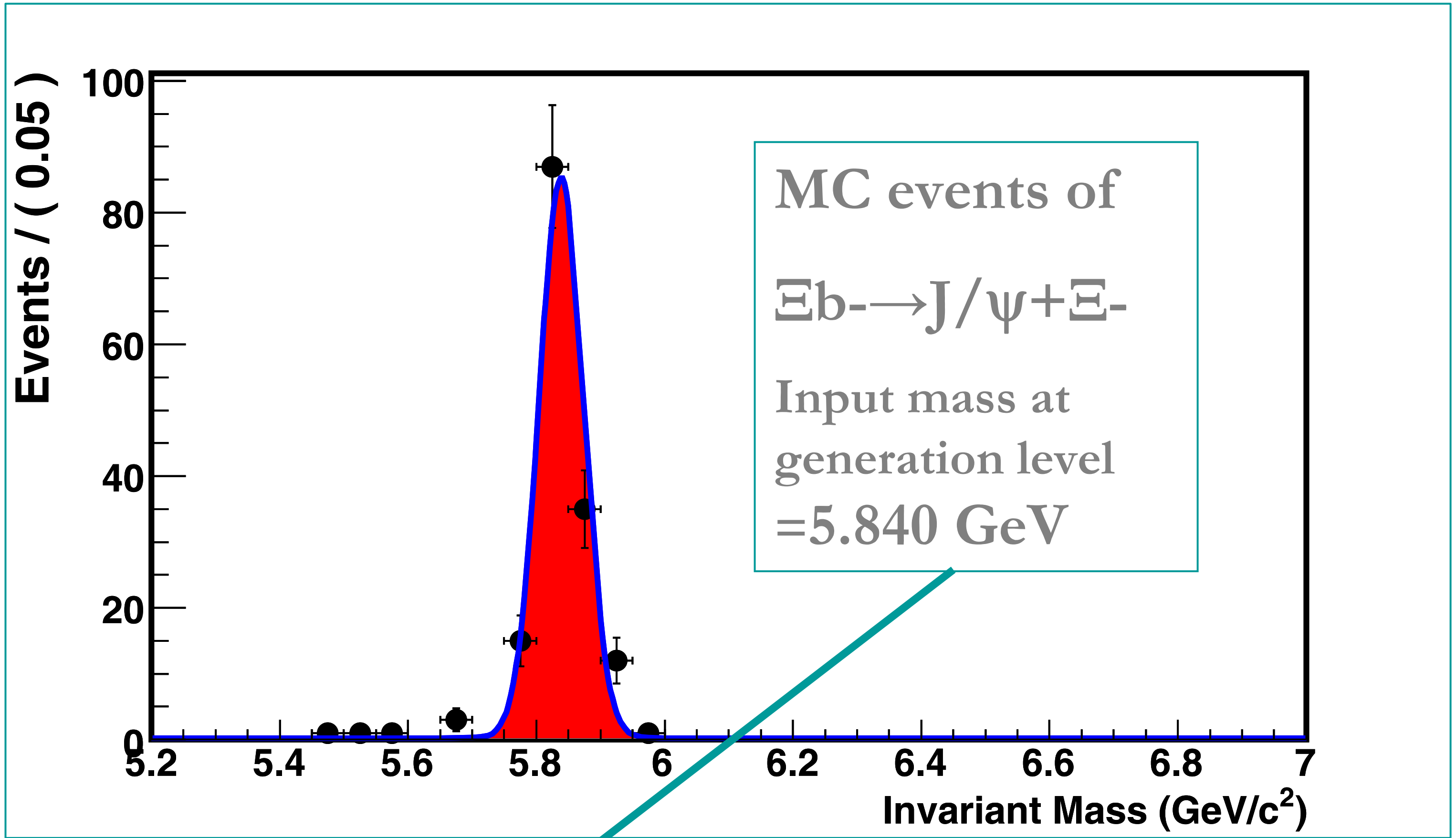
Mean of the Gaussian: 5.774 ± 0.011(stat) GeV

Width of the Gaussian: 0.037 ± 0.008 GeV ↔

Compare to width measured in MC:

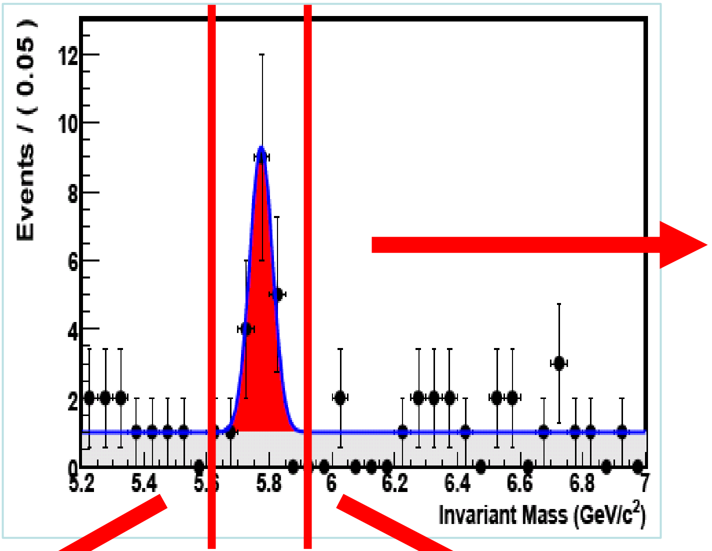
0.035 ± 0.003 GeV

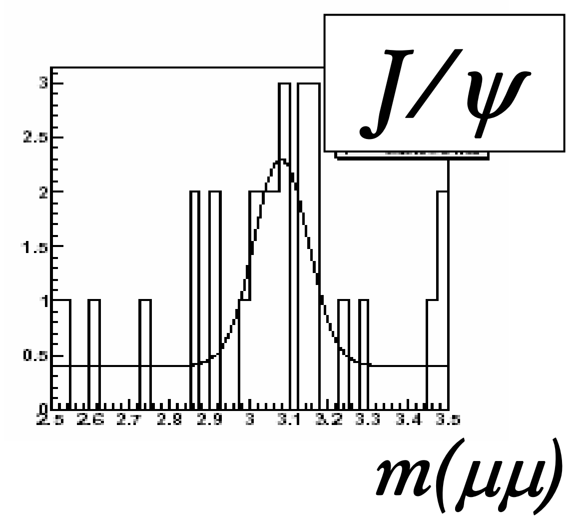
What we expected: signal MC

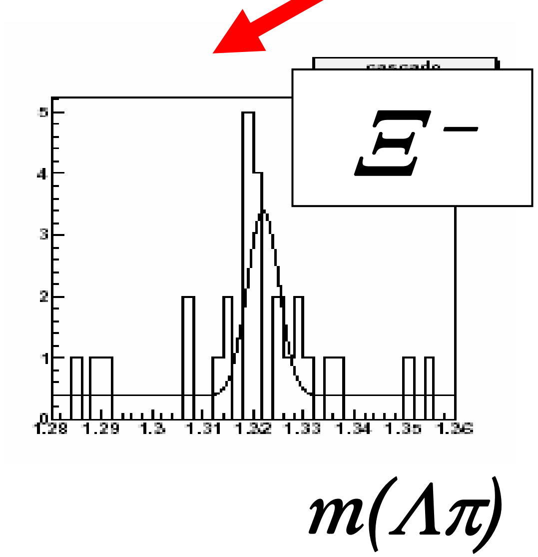


Mean of the Gaussian: **5.839 ± 0.003 GeV**, width: **0.035 ± 0.003 GeV**

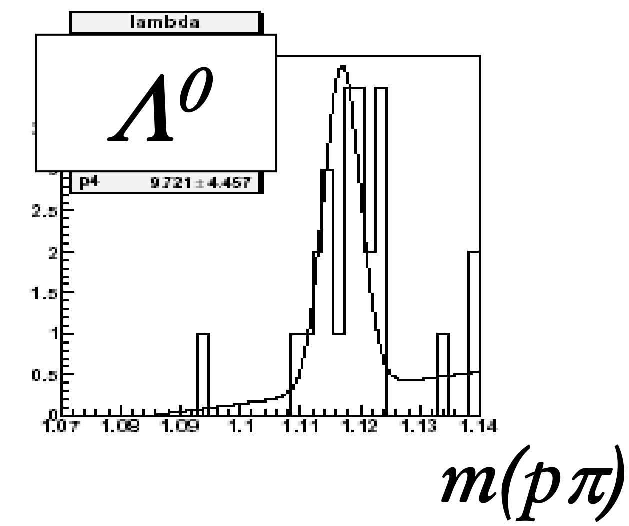
Intermediate Resonances





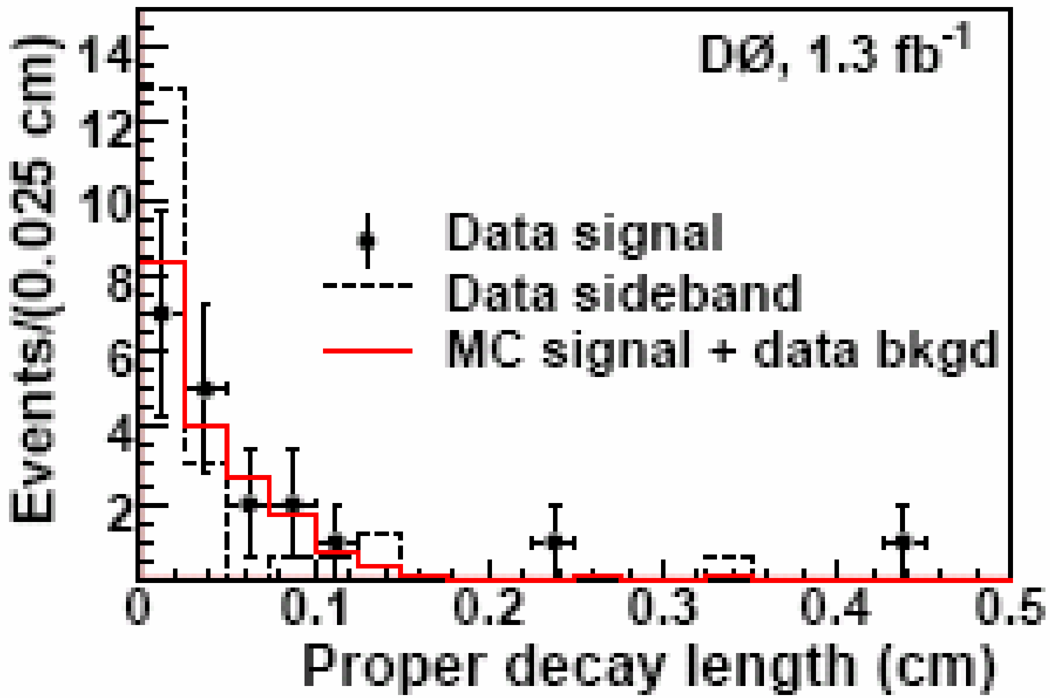


Signal visible in all intermediate resonances

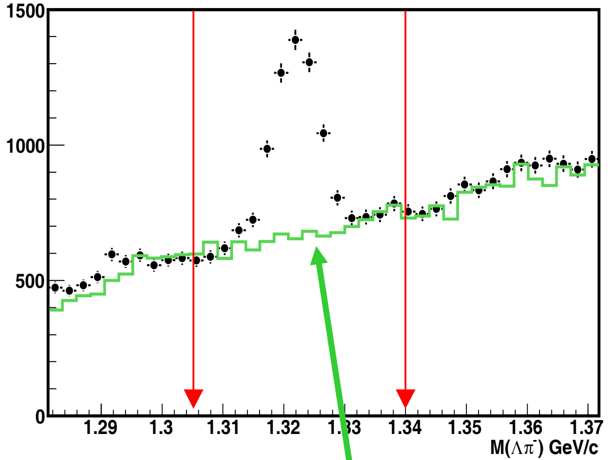


Consistency checks

- Decay length distribution

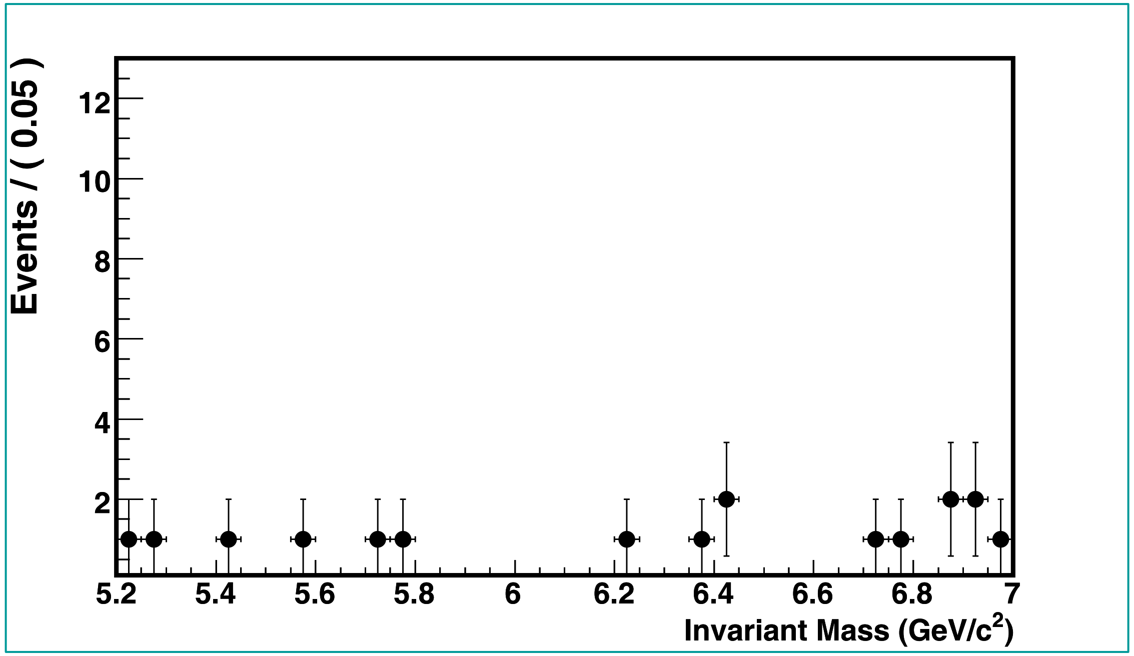


Background: Wrong sign combinations

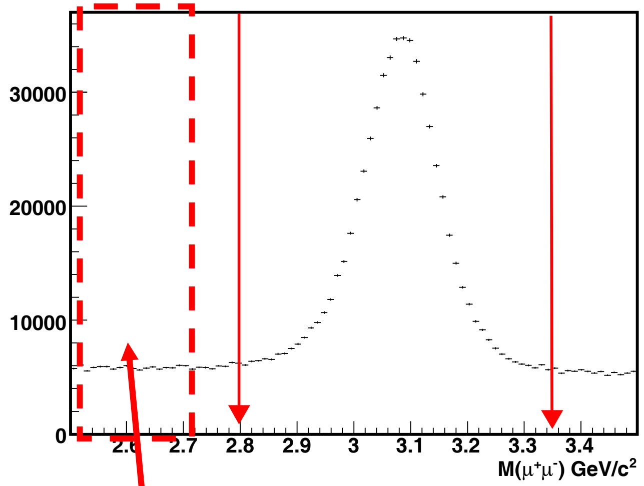


No peaking structure observed in this background control sample

$J/\psi\ \Lambda(p\pi^-)\pi^+$

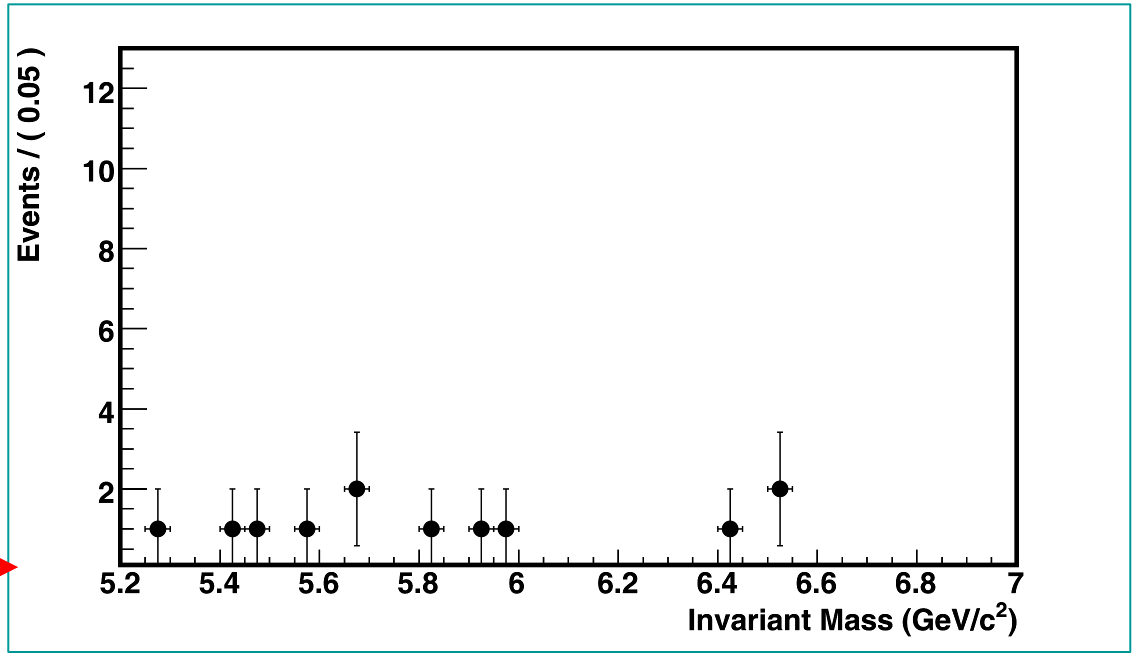


Background: J/ψ sideband events

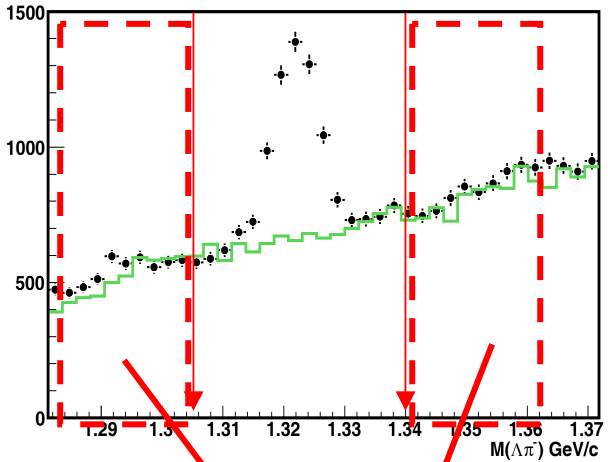


No peaking structure observed in this background control sample

$J/\psi\ \Lambda(p\pi^-)\pi^+$

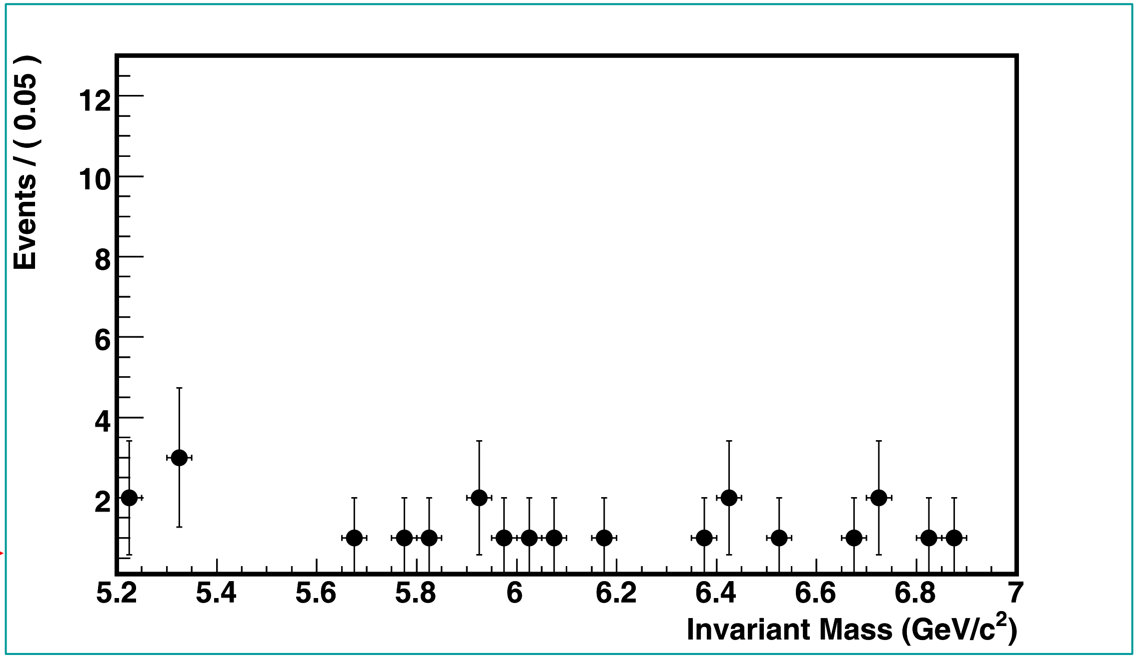


Background: Ξ^- sideband events



No peaking structure observed in this background control sample

$J/\psi\ \Lambda(p\pi^-)\pi^-$



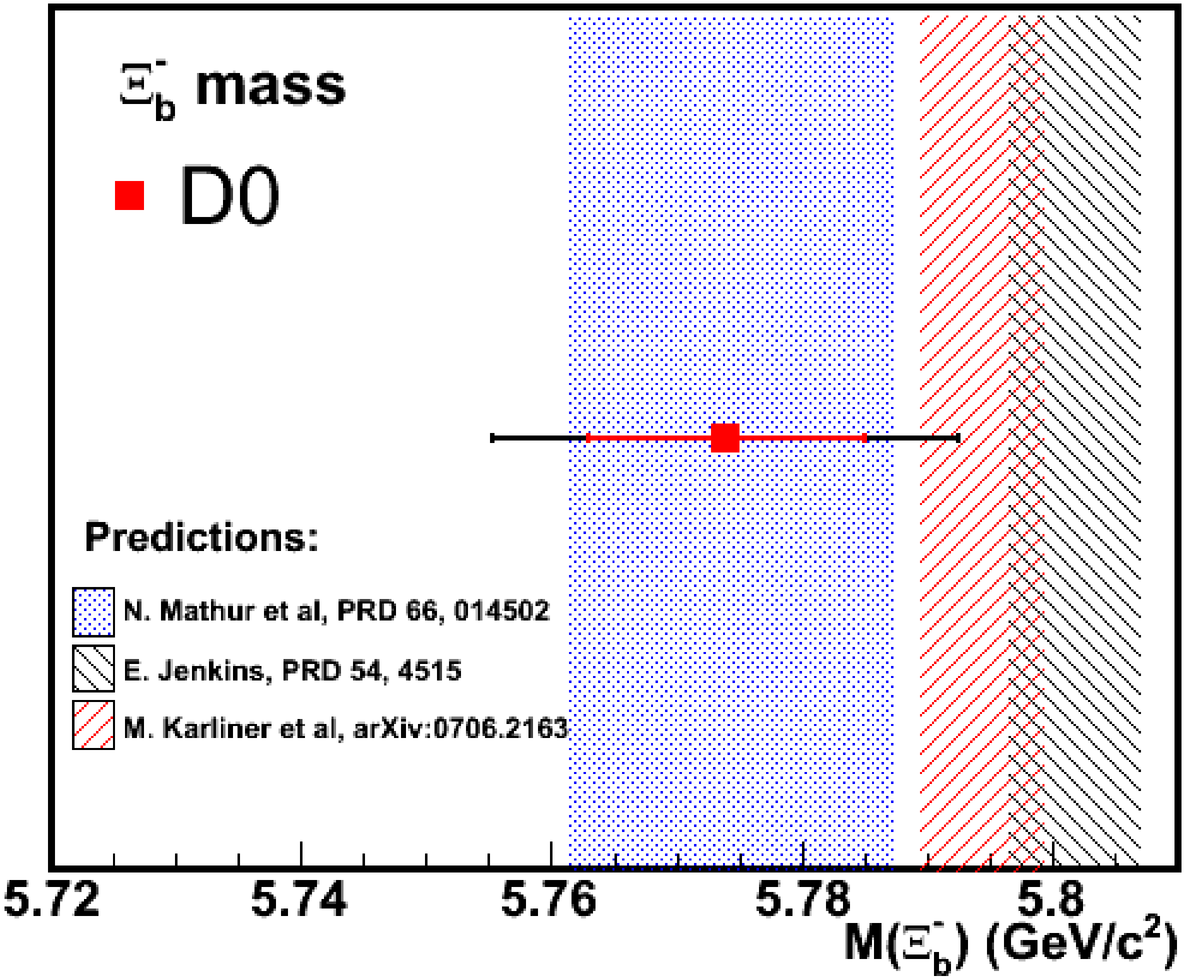
Significance of the peak

- Two likelihood fits are perform:
  1. Signal + background hypothesis (L_{S+B})
  2. Only background hypothesis (L_B)
- We evaluate the significance:

$$\sqrt{-2\Delta \ln L} = \sqrt{-2\ln\left(\frac{L_B}{L_{S+B}}\right)}$$

- Significance of the observed signal: 5.5σ

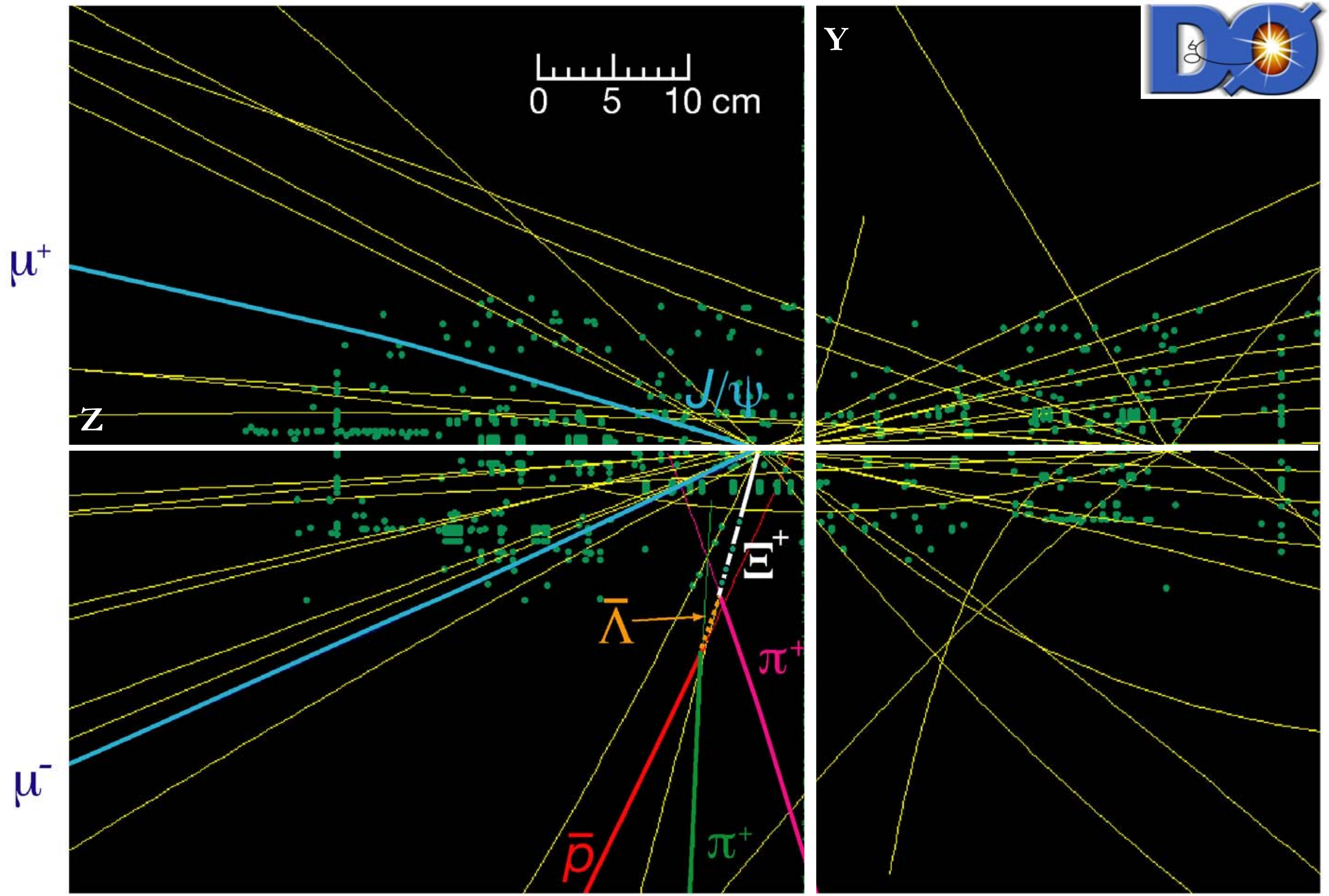
Comparison with theory



Predictions by QCD on grid, by heavy quarks effective theory, and by potential model at NRQCD

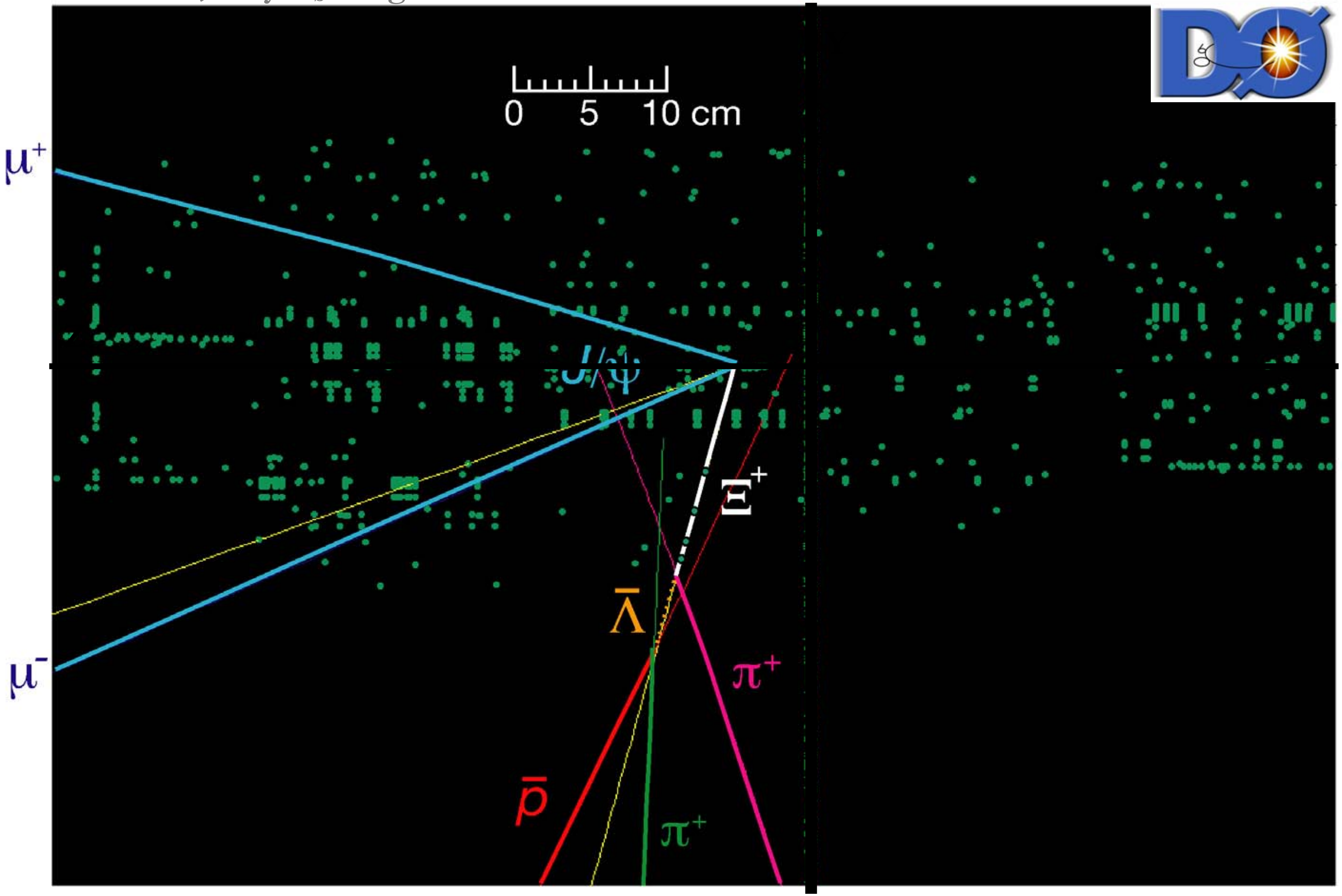
Published at:
arXiv:0706.1690 [hep-ex]

PRL (99) 052001 (2007)



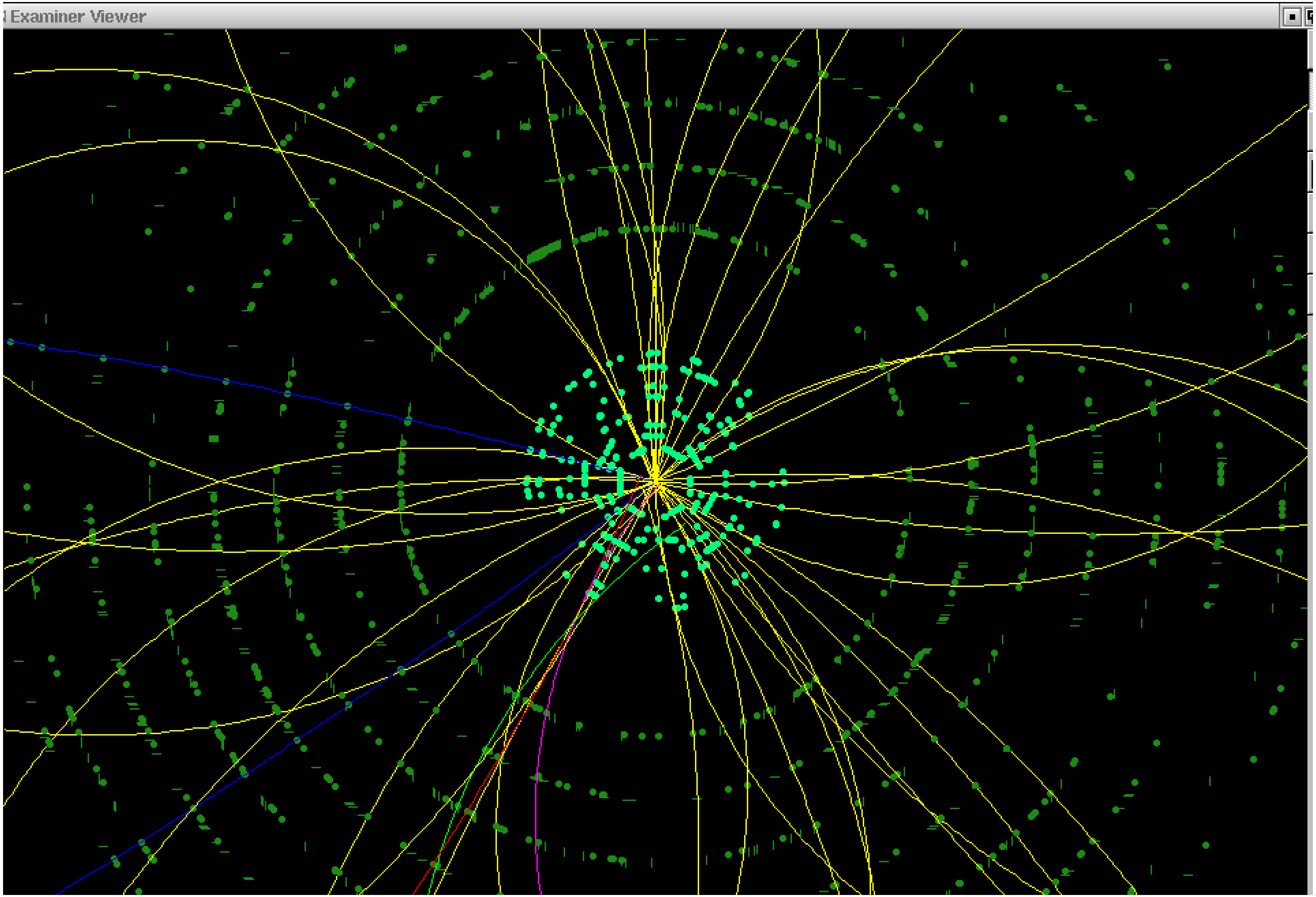
Run 179200, Event 55278820, $M(\Xi_b)$ = 5.788 GeV

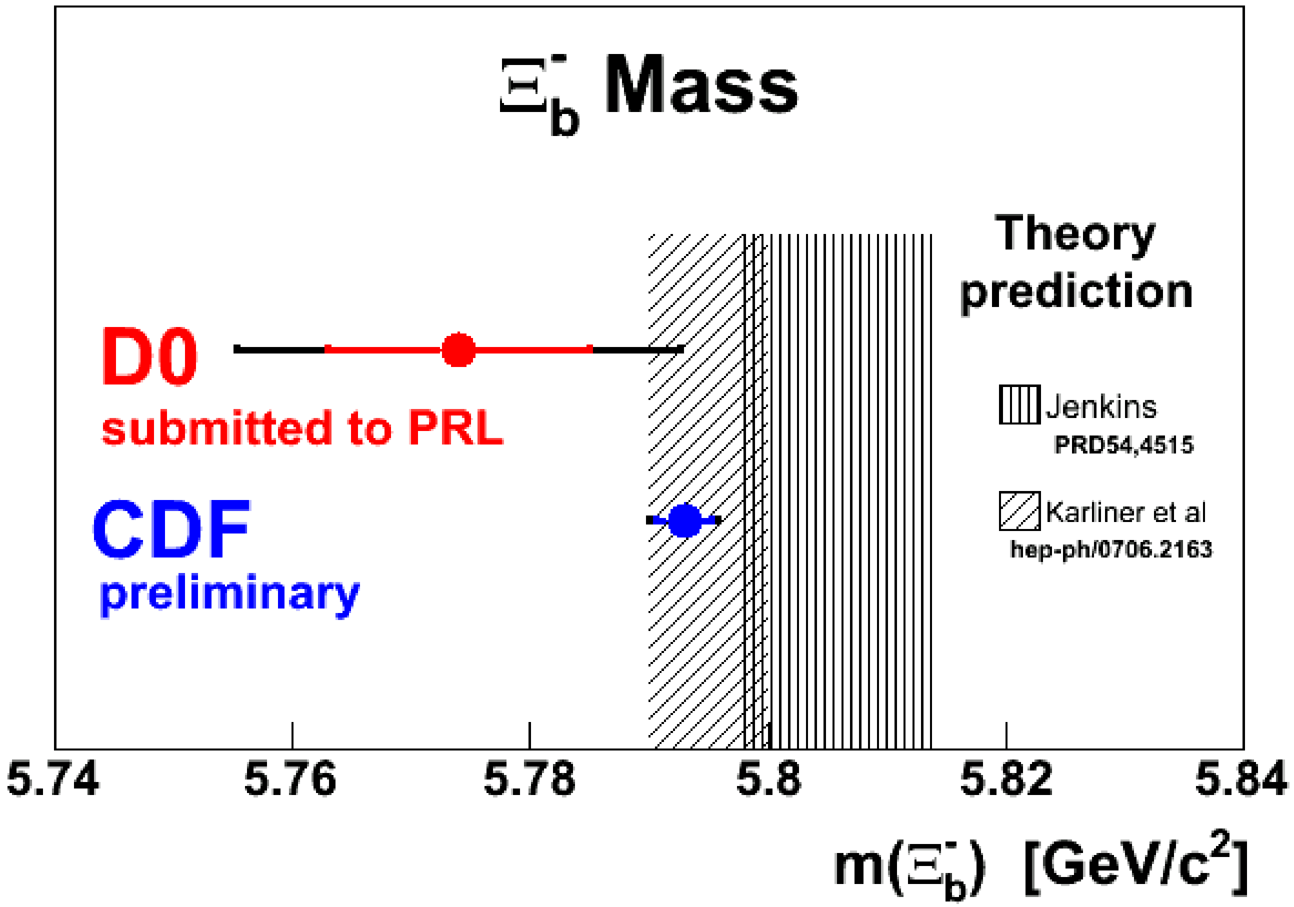
The same, only Ξ_b daughter tracks



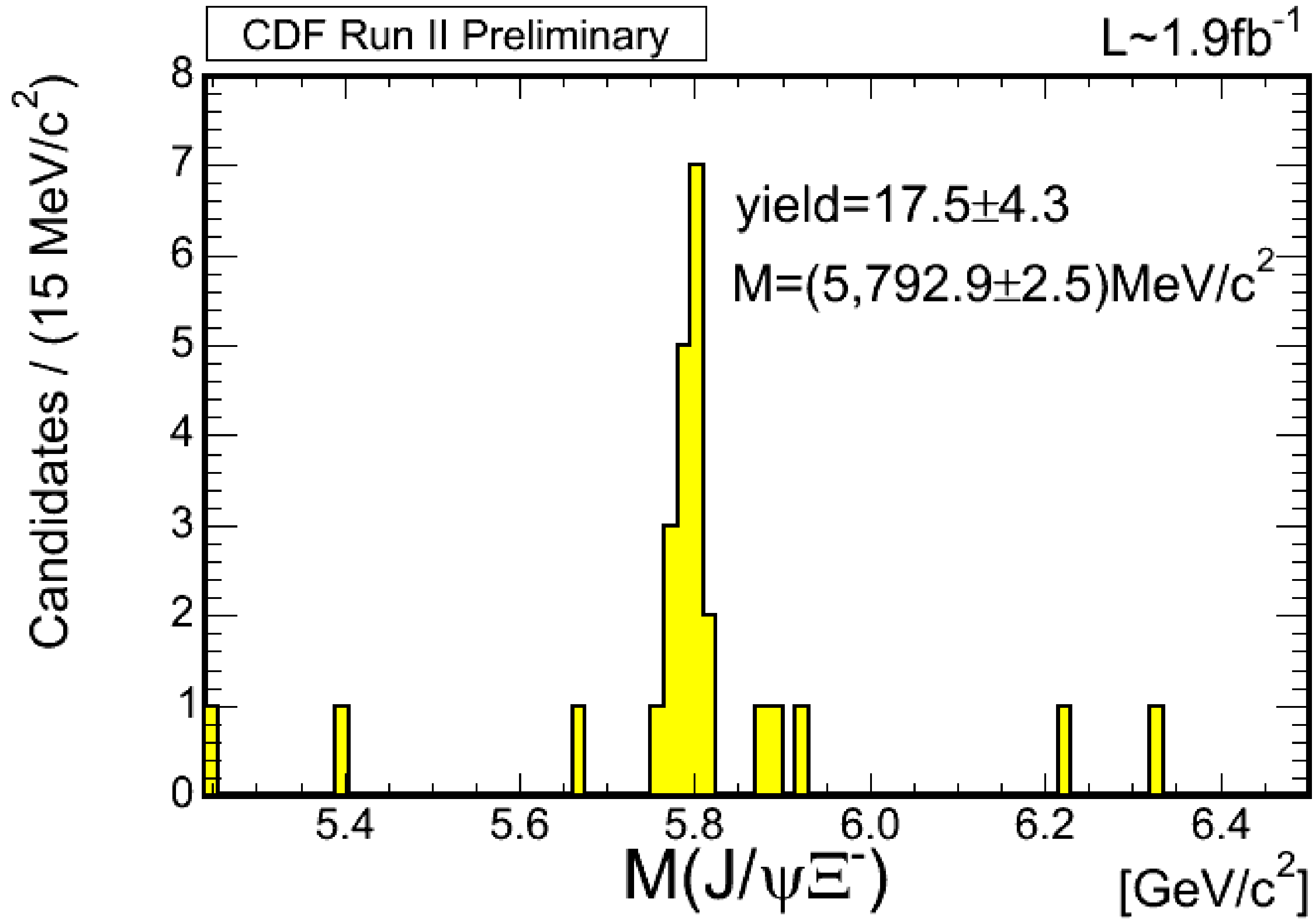
Run 179200, Event 55278820, $M(\Xi_b)$ = 5.788 GeV

XY-projection





Ξb⁻ Mass
D0
submitted to PRL
CDF
preliminary
Theory
prediction
Jenkins
PRD54,4515
Karliner et al
hep-ph/0706.2163
5.74
5.76
5.78
5.8
5.82
5.84
m(Ξb⁻) [GeV/c²]



CDF Run II Preliminary
L~1.9fb^{-1}
yield=17.5±4.3
M=(5,792.9±2.5)MeV/c^2
Candidates / (15 MeV/c^2)
0
1
2
3
4
5
6
7
8
5.4
5.6
5.8
6.0
6.2
6.4
M(J/ψΞ$^-$)
[GeV/c^2]

D0 Note 5403

Version 4.1 as June 5, 2007

Observation of the heavy barion Ξ_b^-

E. De La Cruz Burelo, H.A. Neal, and J. Qain

University of Michigan

B. Abbott

University of Oklahoma

G.D. Alexeev, Yu.P. Merekov, G.A. Panov, A.M. Rozhdestvensky, Yu.L.Vertogradova, L.S. Vertogradov

Joint Institute for Nuclear Research, Russia

Conclusions

- The new stable particle - Ξ_b is discovered by DØ and later by CDF;
- Its mass agrees with theoretical expectations:
  - $M(\Xi_b) = 5.774 \pm 0.011$ GeV (DØ);
  - $M(\Xi_b) = 5.7929 \pm 0.0025$ GeV (CDF);

Backup slides

Preliminary selection of events and reconstruction of Ξ_b

- Reconstruction of $J/\psi \to \mu^+\mu^-$ vertex ($P\chi^2$ > 1%, p_T > 5 GeV/c^2, mass 2.80÷3.35 GeV/c^2)
- Reconstruction of $\Lambda \to p\pi$ candidates ($P\chi^2$ > 1%, mass 1.105÷1.125 GeV/c^2)
- Reconstruction of $\Xi \to \Lambda + \pi$ candidates ($P\chi^2$ > 1%, mass 1.305÷1.340 GeV/c^2)

- Errors of the Λ and Ξ decay lengths < 0.5 см (in XY plane), significance of every measured decay length must be > 4.

- Combination of J/ψ and Ξ as a candidate to Ξ_b ($P\chi^2$ > 8%, angle < $\pi/2$ in XY plane)
  Error of its decay length < 0.05 см

- As a result of the preliminary selection there were 2308 events with “true combination” of the pions’ charges and 1124 events with “wrong combinations” (see slide 7).

- Rather simple mass correction $M = M(\Xi_b) - M(\Xi) - M(J/\psi) + M_{PDG}(\Xi) + M_{PDG}(J/\psi)$ was applied for every event.

In summary, Ξ_b were selected with such criteria

- $\Lambda \rightarrow p\pi$:
  - $P_T(p) > 0.7$ GeV/c
  - $P_T(\pi) > 0.3$ GeV/c
- $\Xi^- \rightarrow \Lambda\pi$:
  - $P_T(\pi) > 0.2$ GeV/c
  - Transverse decay length > 0.5 cm
  - Collinearity > 0.99
- Ξ^-_b:life time / its error >2

suppression of signal 39.7%

suppr. of background 91.6%

suppr. of signal 1.7%

suppr. of backgd 56.4%

18% (signal)

56% (backgrd)