Flavour Physics with

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for the BABAR collaboration

LNF SPRING SCHOOL
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Summary:

- **the physics perspectives:**
  - **CP violation**
- **the BaBar detector:**
  - **description and perfomance studies**
- **first results:**
  - **validation of the tools for the sin(2β) measurement**

CP violation in the SM

-> due to having three quark families

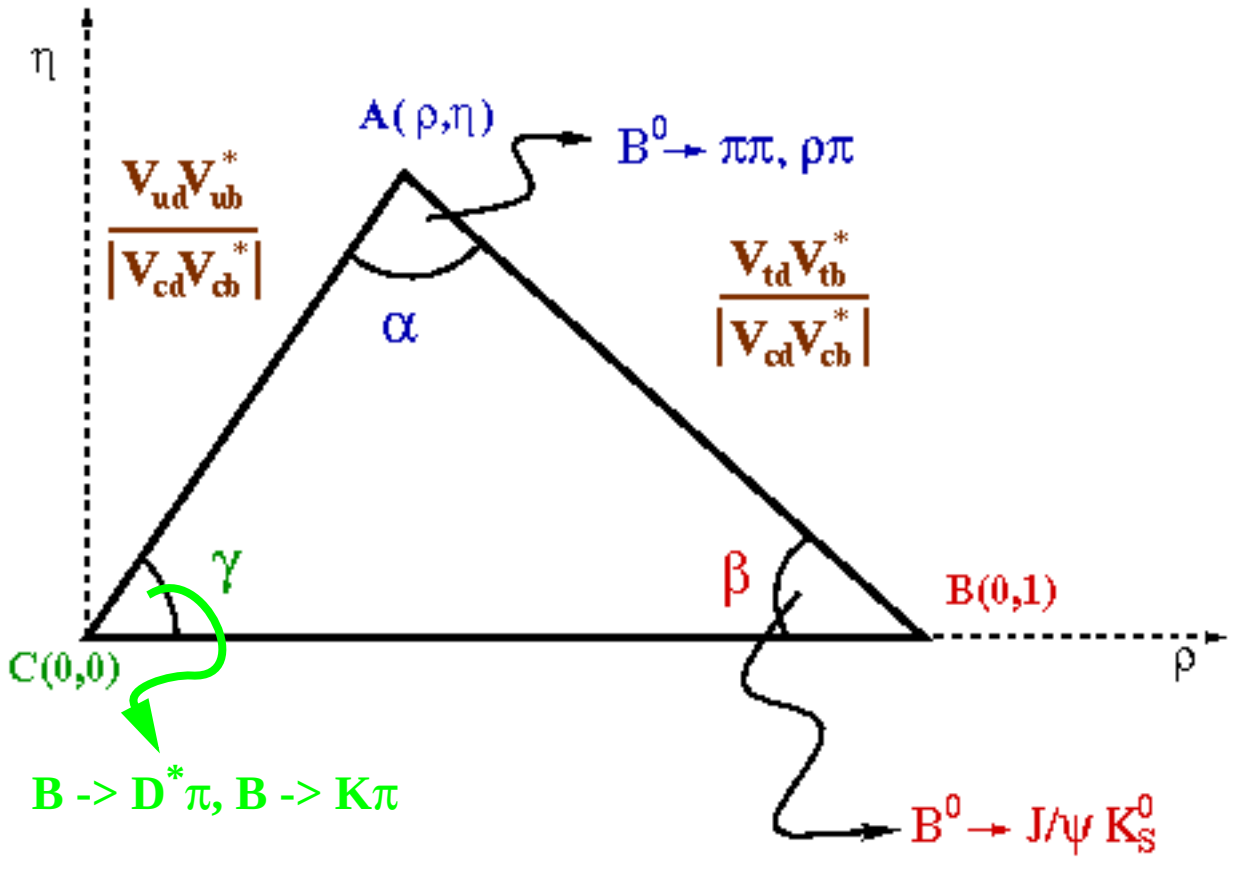
1/2(n-1)(n-2) indipendent phases

$$V=\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}+\mathcal{O}(\lambda^4)$$

complex phase

unitarity equation

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



CP phenomenology(1):
three kinds of ~~CP~~

- ***direct ~~CP~~ in decay:***

comparison of the decay rates

$\Gamma(P \to f)$ **with their CP conjugated** $\Gamma(\bar{P} \to \bar{f})$

$$A_{asym} = \frac{\Gamma(\bar{P} \to \bar{f}) - \Gamma(P \to f)}{\Gamma(P \to f) + \Gamma(\bar{P} \to \bar{f})}$$

CP is violated if $A_{asym} \neq 0$

or considering the decay amplitudes $\left|\frac{\bar{A}}{A}\right| \neq 1$

necessary:

- ➡ **more than one amplitude**
- ➡ ***both*** **CP-violating phases**
  and **non-CP-violating phases**

case of B^0 to $K^+\pi^-$
(related to Re(ε'/ε) in the K sistem)

CP phenomenology(2):

- ***indirect $\not{CP}$ in mixing***

writing the eigenvectors of the hamiltonian

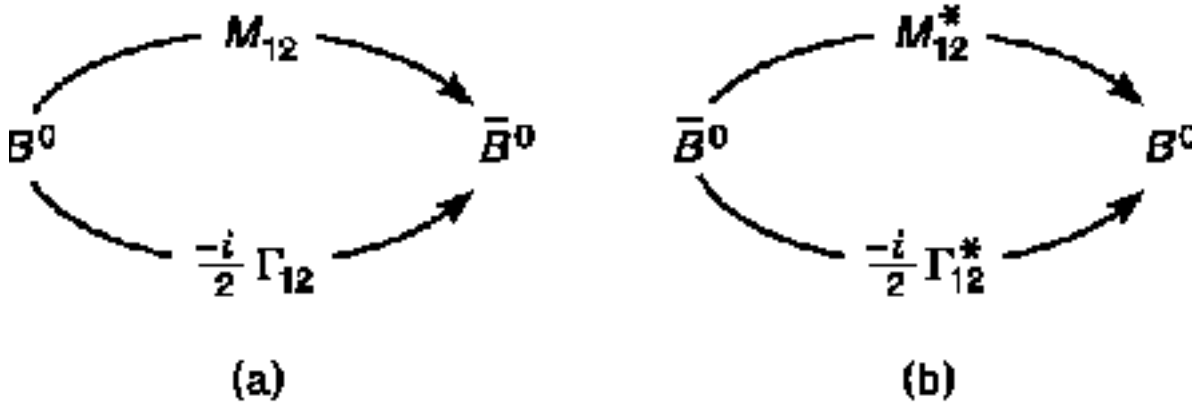
$$|P_+> = \frac{1}{\sqrt{|p|^2+|q|^2}}(p|P^0> + q|\bar{P}^0>)$$

$$|P_-> = \frac{1}{\sqrt{|p|^2+|q|^2}}(p|P^0> - q|\bar{P}^0>)$$

and solving the eigenvalue equation

$$\left|\frac{q}{p}\right|^2 = \left|\frac{H_{21}}{H_{12}}\right| = \left|\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}\right| \neq 1$$

if CP violation in mixing



interference between:

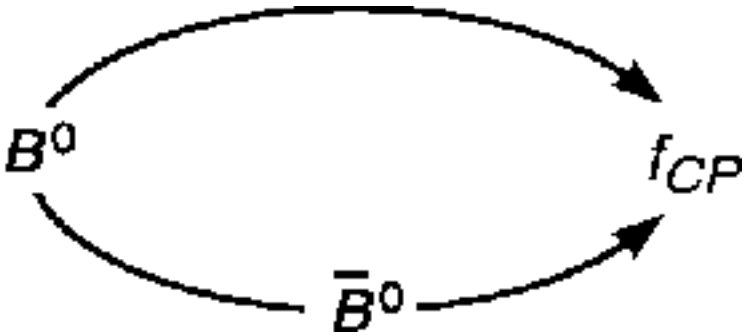
amplitudes with virtual intermediate states (M_{12})

and on-shell intermediate states (Γ_{12})

CP phenomenology(3):

- ***~~CP~~ in interference between mixing and decay***

interfering amplitudes:



- **direct decay B^0->f where f is a final state for both B^0 and anti-B^0**
- **B^0->anti-B^0 mixing followed by anti-B^0->f**

defining $\lambda = \frac{\bar{A}}{A}\frac{q}{p}$

the asymmetry is

$$A = \frac{(1-|\lambda|^2)cos(\Delta m_B t) - 2\Im m\lambda sin(\Delta m_B t)}{1+|\lambda|^2}$$

so

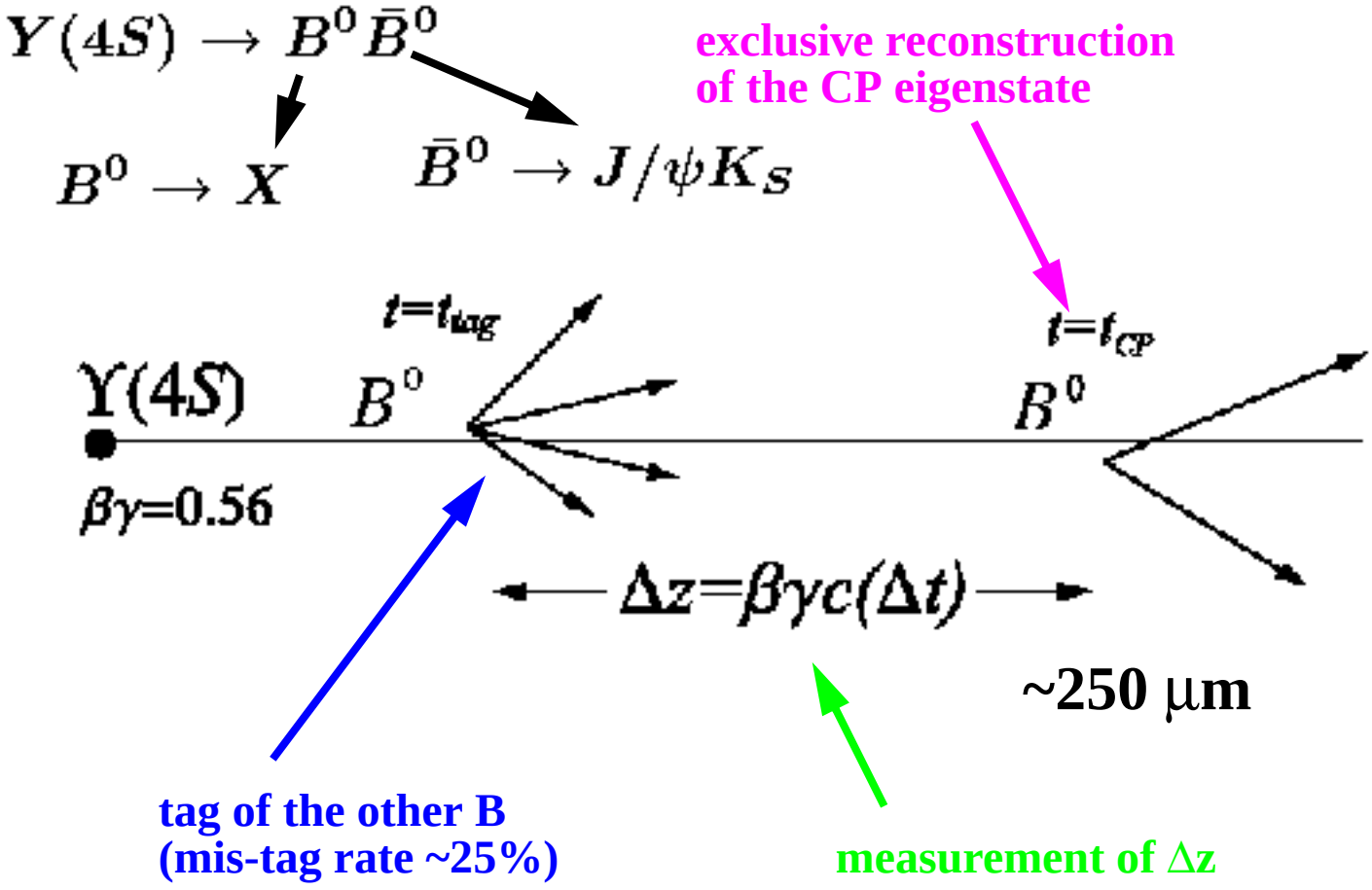
$A \neq 0$ **can be also with** $|\lambda| = 1, \quad \Im m\lambda \neq 0$

golden channel J/ψ K_s: only one amplitude

$$\Im m\lambda = sin2\beta$$

Sin 2β

requirements and technique:

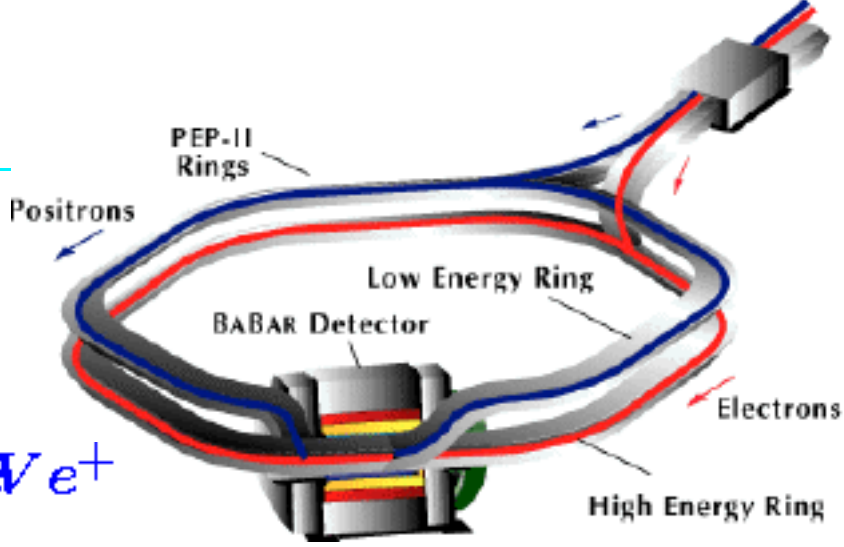


- high luminosity
- Δz measurement (asymmetric collider)
- excellent tracking and vertexing
- PID: e, μ, K, π
- neutral reconstruction and identification:
  γ, π^0, K_L^0

PEPII

asymmetric collider @ Y(4S)

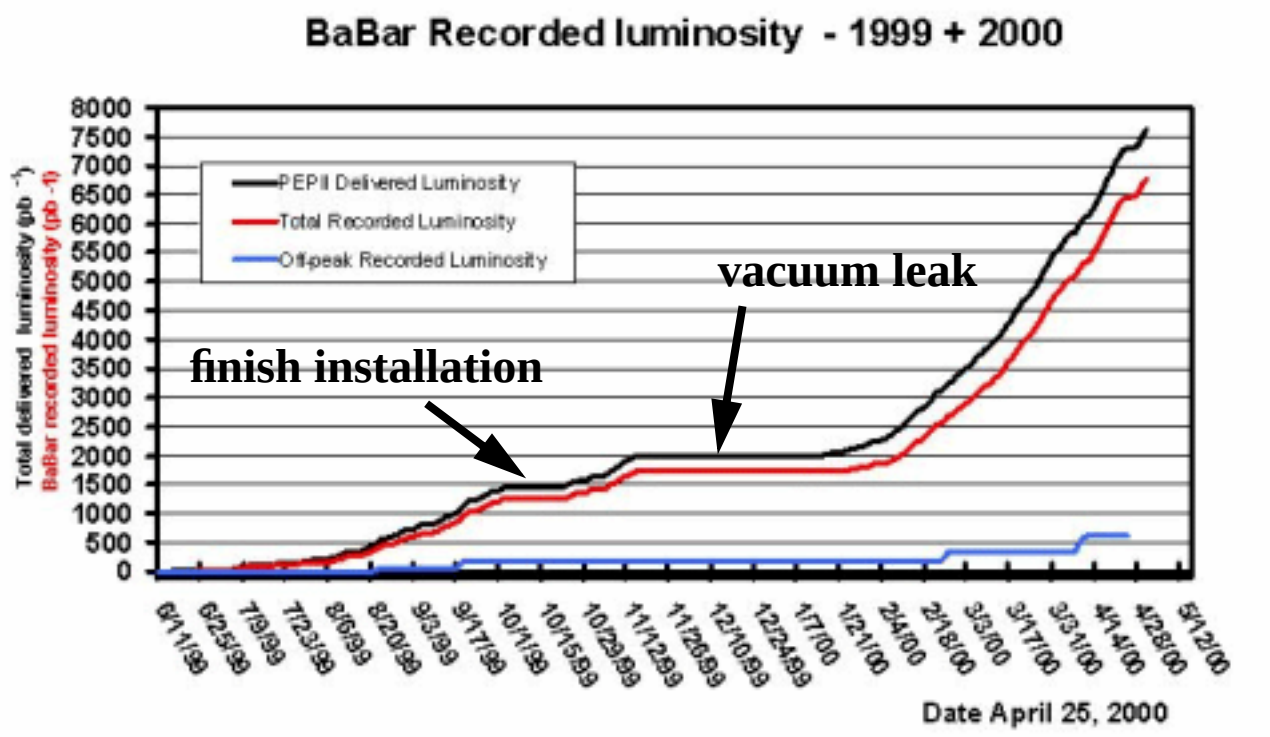
$9.0\,GeV\,e^- \rightarrow \quad \leftarrow 3.1\,GeV\,e^+$



first collision on 26th May 1999

	achieved*	design
luminosity	$2.0\ 10^{33}\ cm^{-2}s^{-1}$	$3.0\ 10^{33}\ cm^{-2}s^{-1}$
# of bunches	1658	1658
positron current	1700 mA	2140 mA
electron current	920 mA	750 mA
Lumi lifetime	~120 min	~120 min
sigma y	~ 6.10 microns	~ 6.65 microns
sigma x	~ 210 microns	~ 222 microns

*not all at the same time

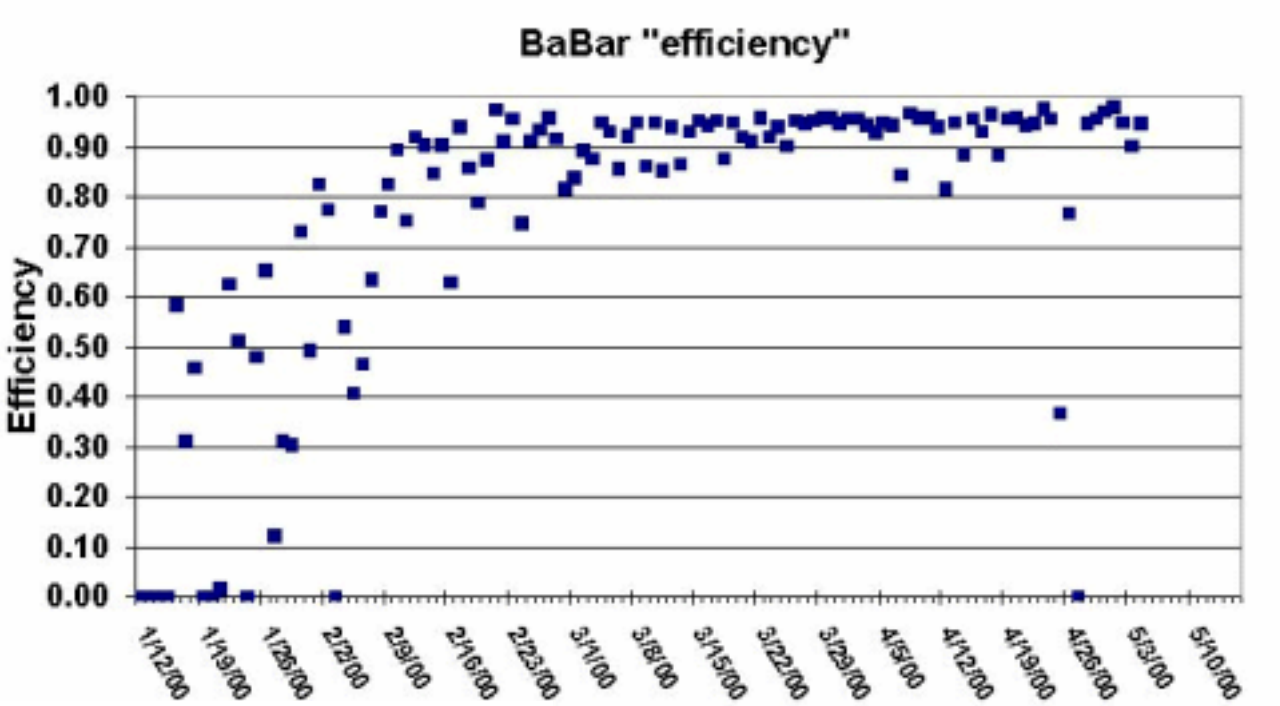


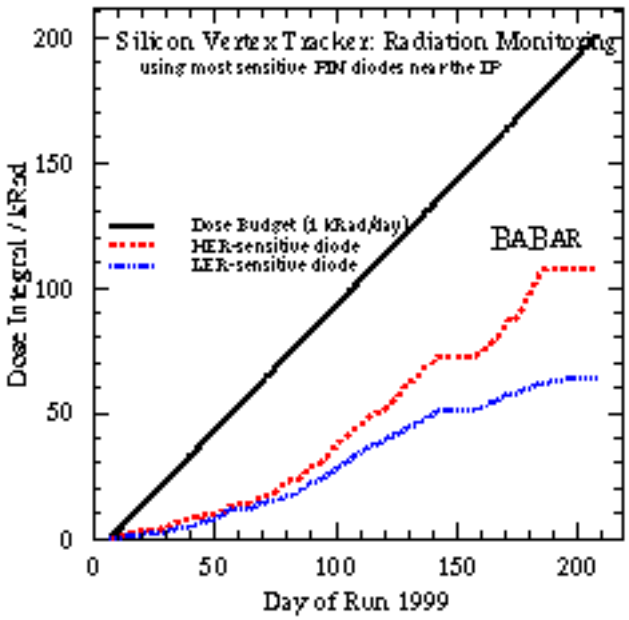
Lumi predictions:

going from 2.0 to 3.0 10^{33} $cm^{-2}s^{-1}$ (now to the end of this run)

➡ **10 fb^{-1} recorded by the end of this run**

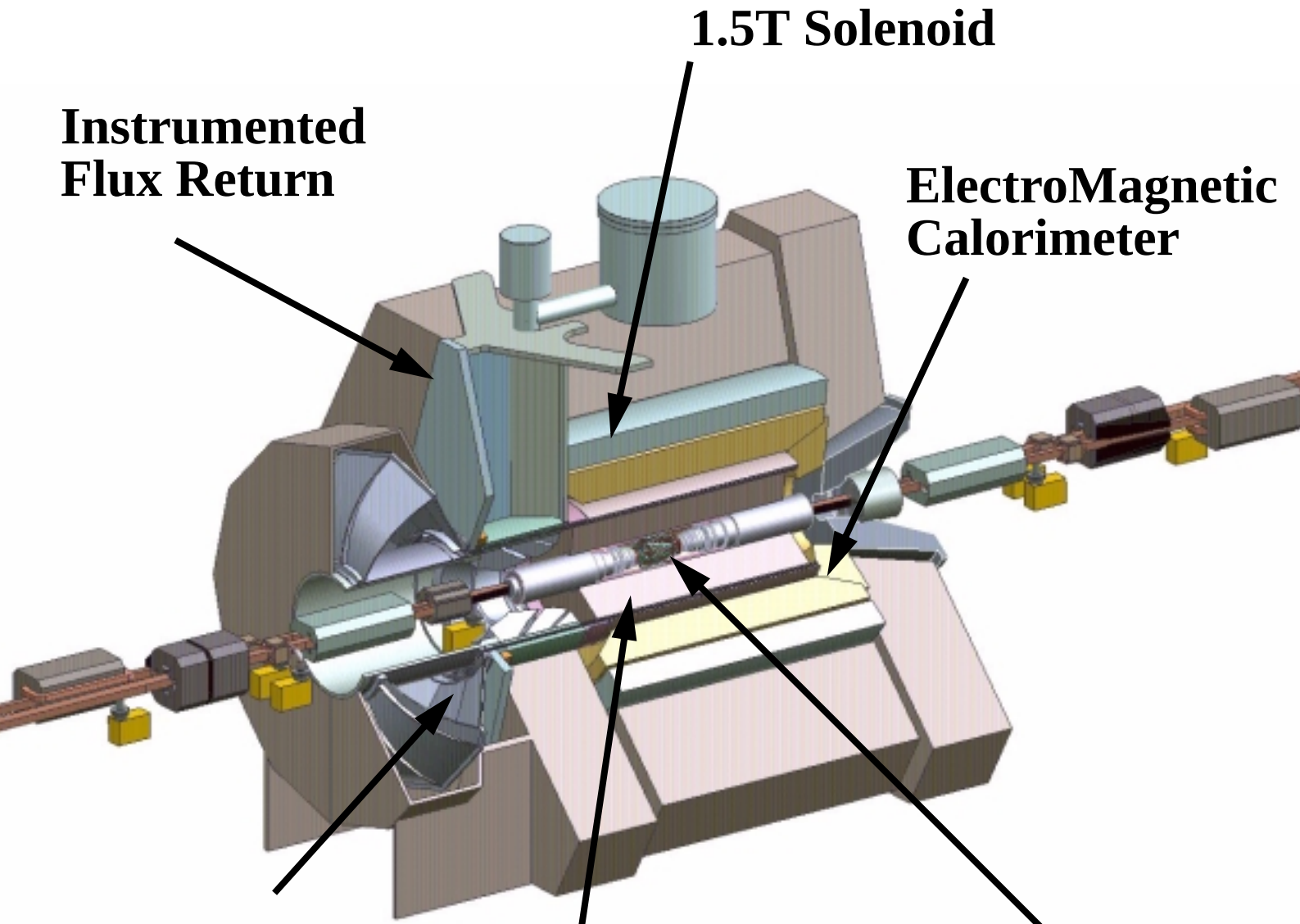
- **lumi taken/delivered> 90%**
- **dead time < 1%**





the radiation dose received by the detector is well below the budget (240 kRad/year)

BABAR Detector

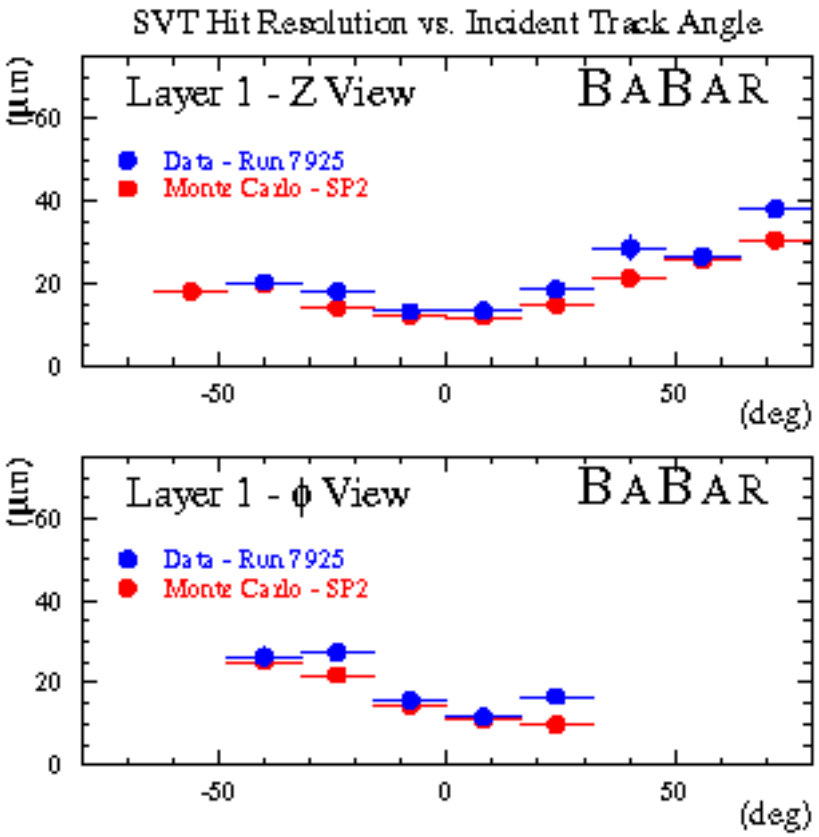


SVT

- acceptance:

$20^o < \theta_{lab} < 150^o$

- 5 double sided layers
- Si microstrips
- 143K channels
- Radiation Hard (2Mrad)



- design resolution:

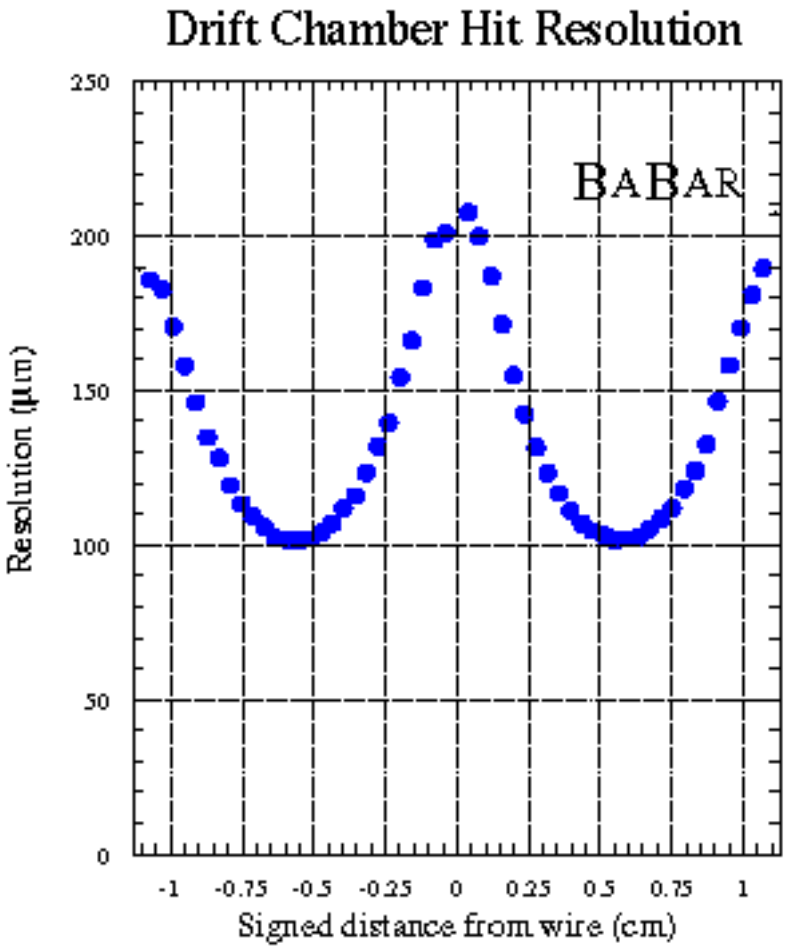
15 μm @ 90^o

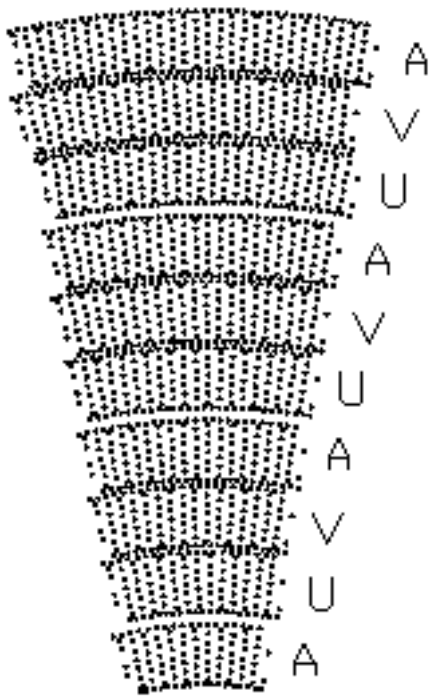
DCH

- 80% He- 20% C_4H_{10}
- 7100 hexagonal cells
- 10 axial and stereo superlayer

- maximum drift distance ~11 mm

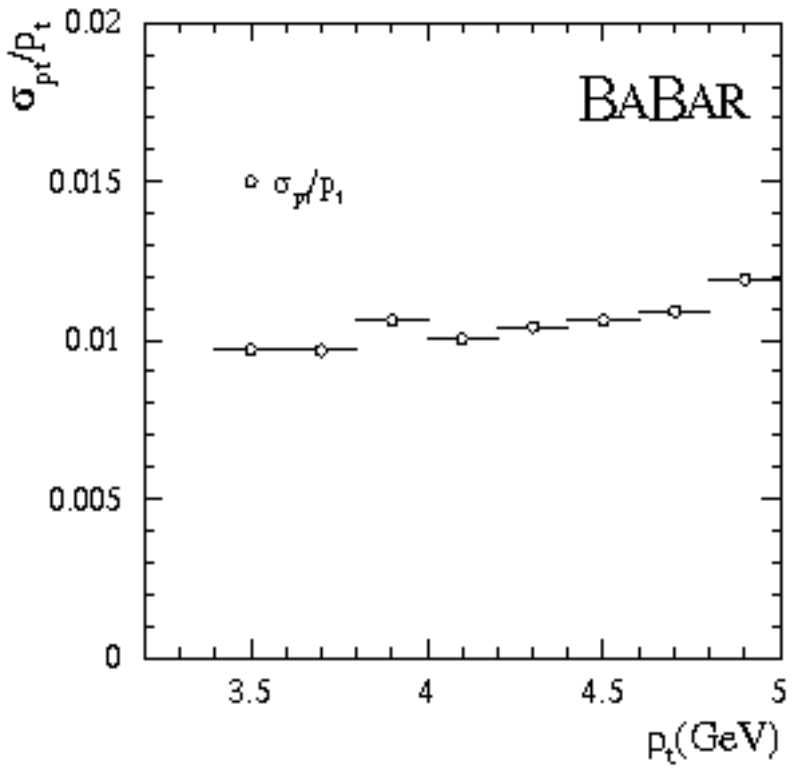
- weighted average resolution 125 μm (design: 140 μm)



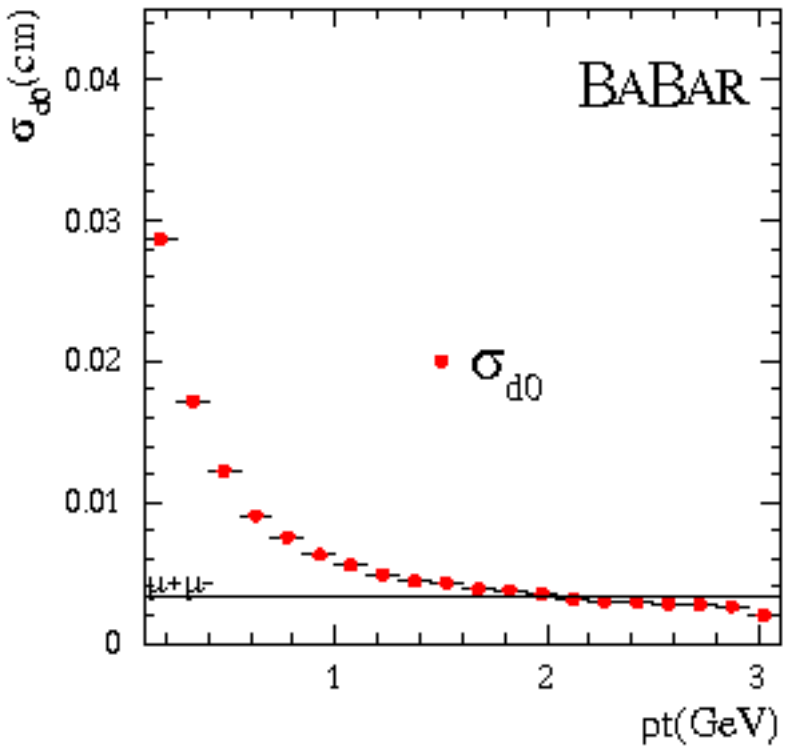


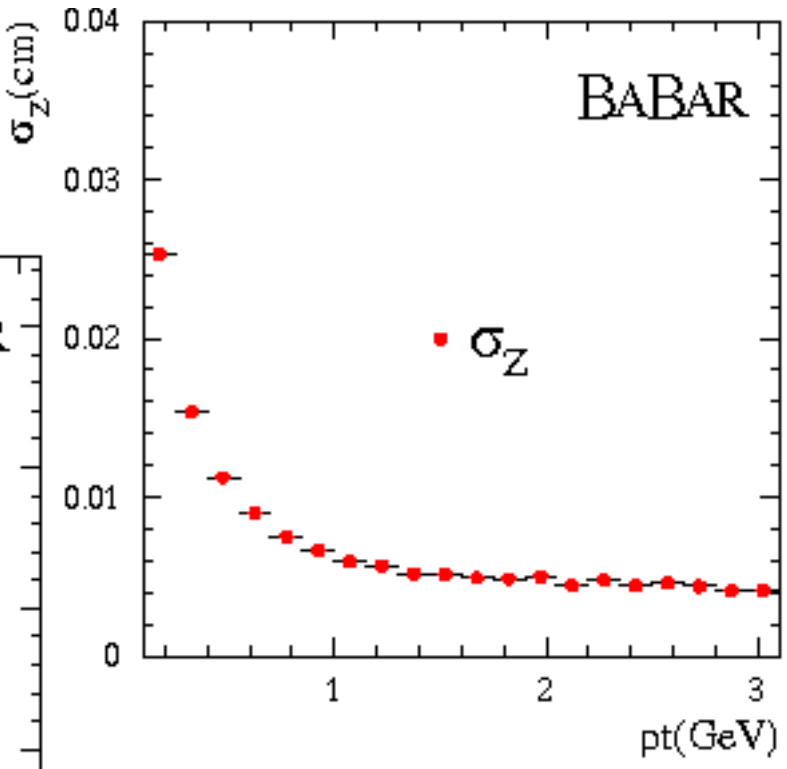
Tracking

$\sigma_{pt}/p_t \sim 1\%$
@ 3GeV



doca:
asymptotic
resolution ~35 μm



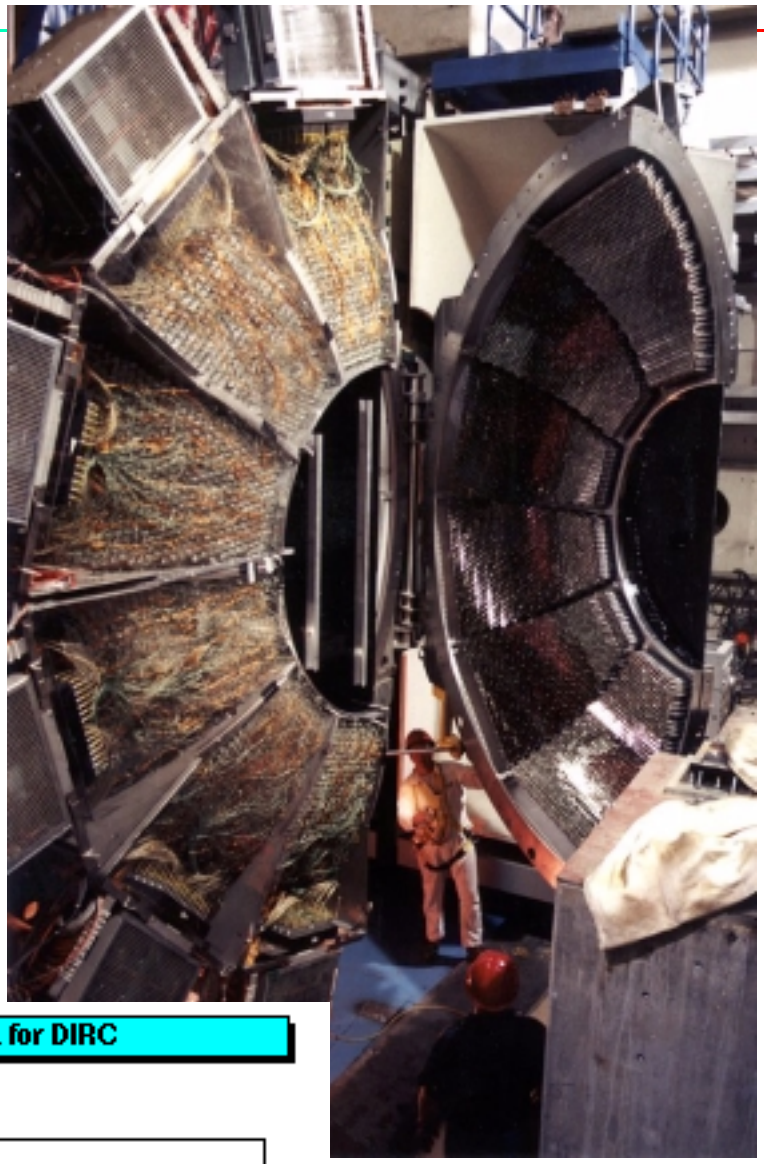


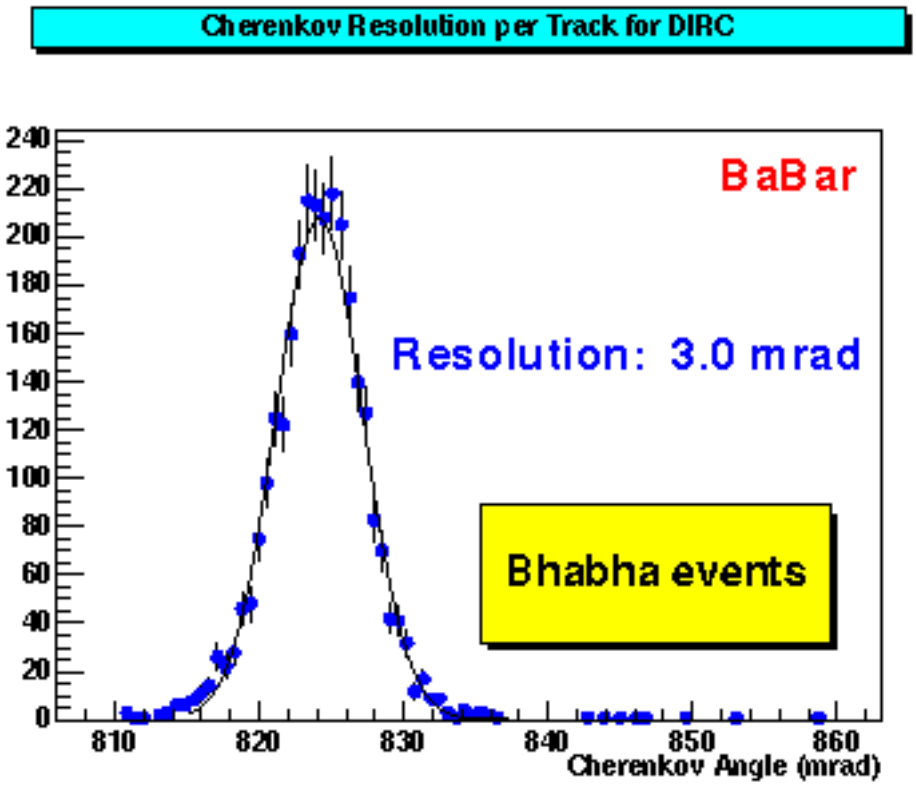
DIRC

144 quartz bars
1.7 cm thick
(in place since October)

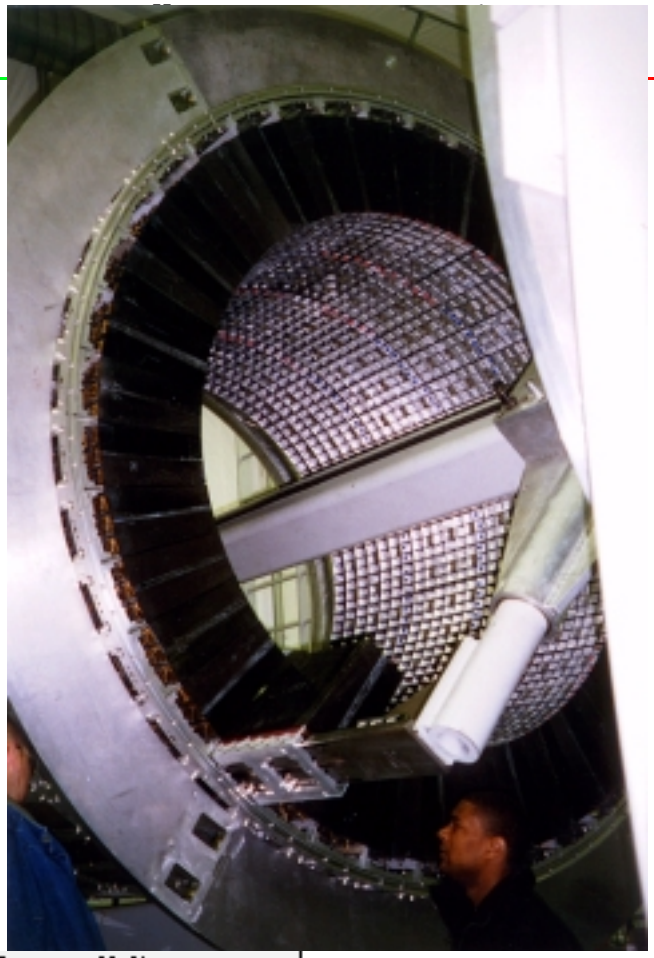
10752 PMT in 6 m^3
of purified water

0.14 X_o @ 90°



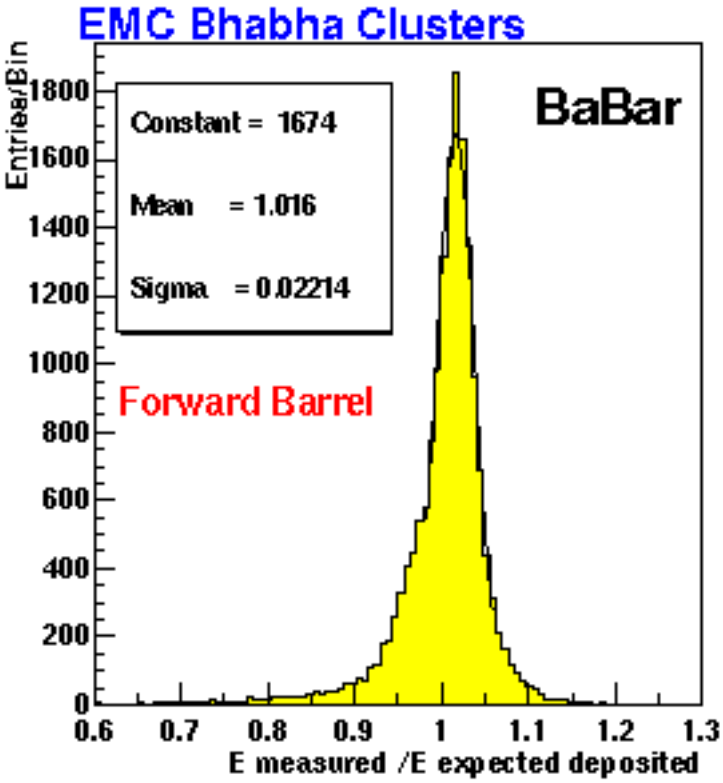


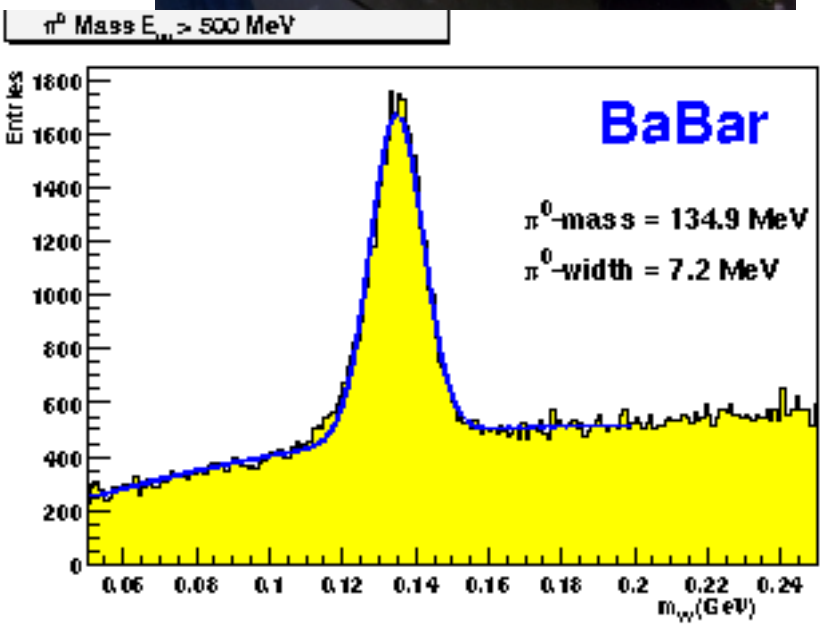
EMC



- 6580 CsI(Tl) crystal (5760+820)
- material in front: 0.20-0.25 X_0
- readout by 2 large area photodiodes
- liquid source for calibration in front of the crystals

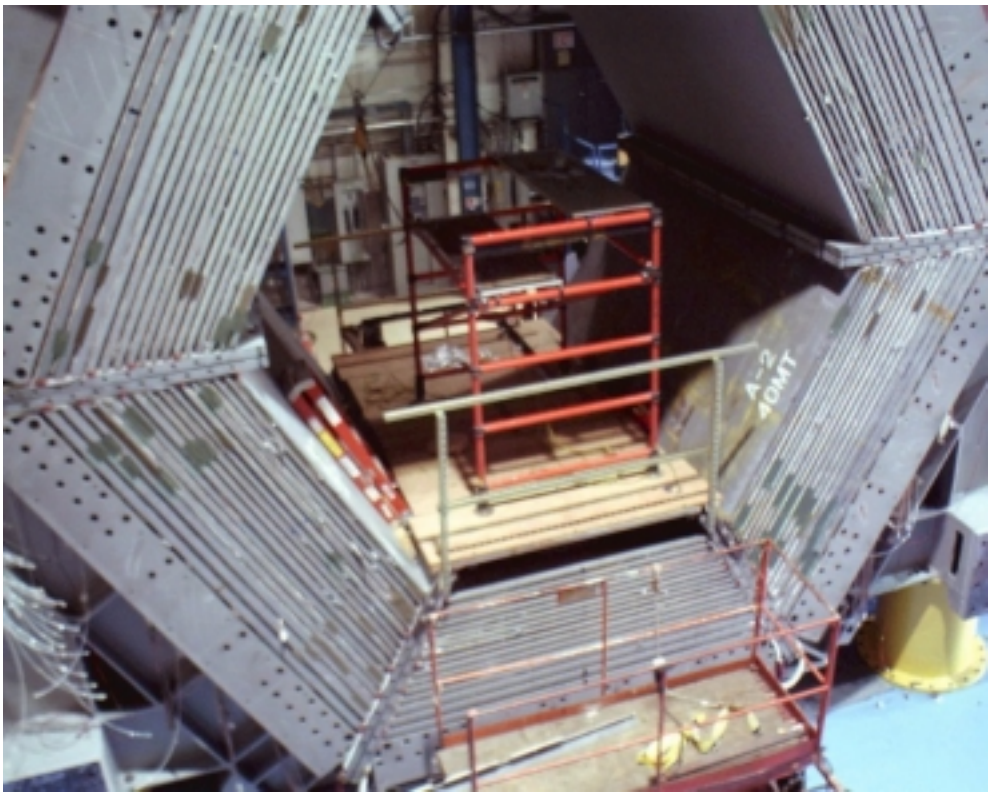
⬇ expected energy from the track angle



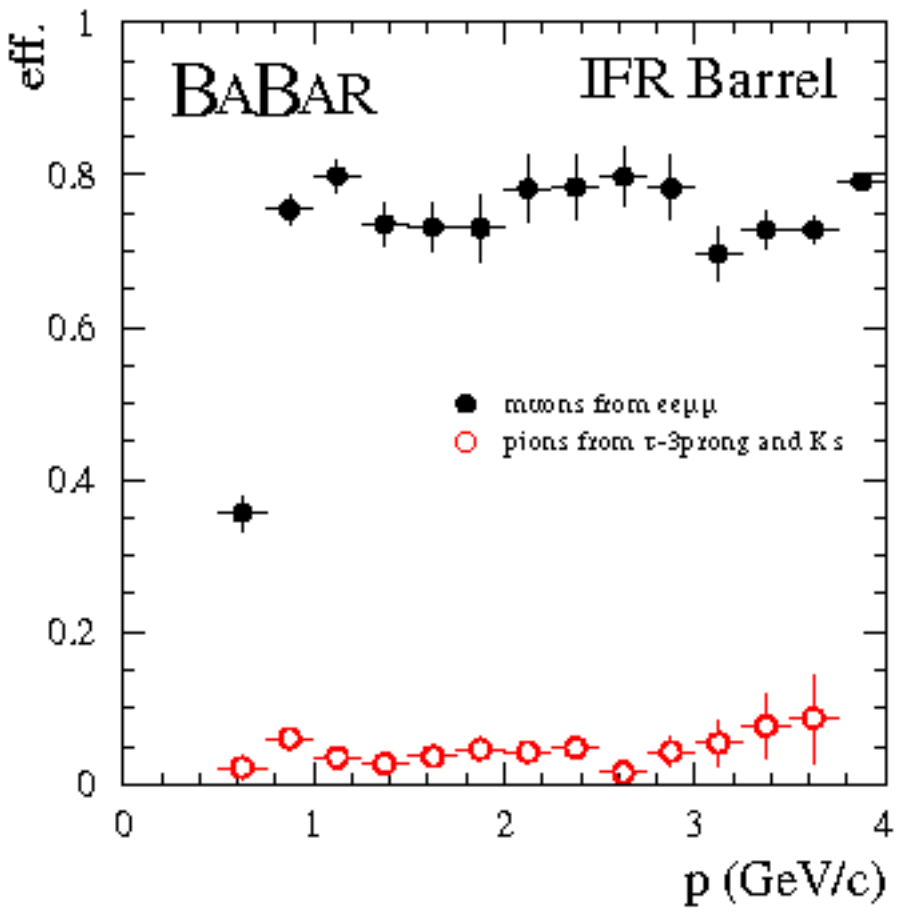


⬆ expected resolution: 6.5 MeV

IFR



- Resistive Plate Chambers



- 2 double-layer cylindrical RPC inside the coil

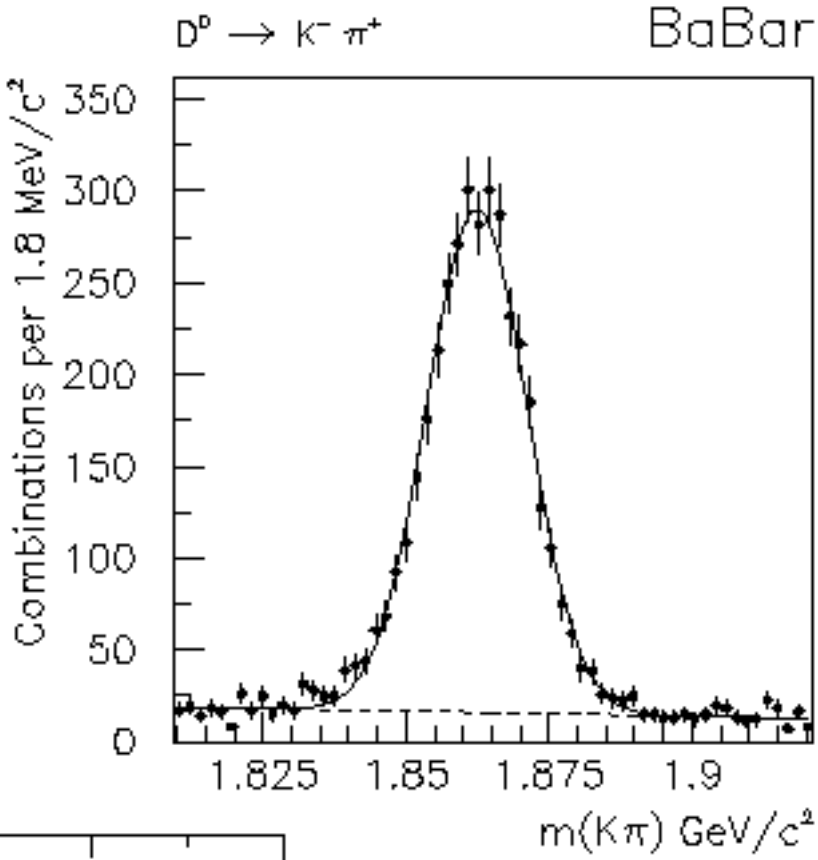
muon id efficiency (and fake rate from π)

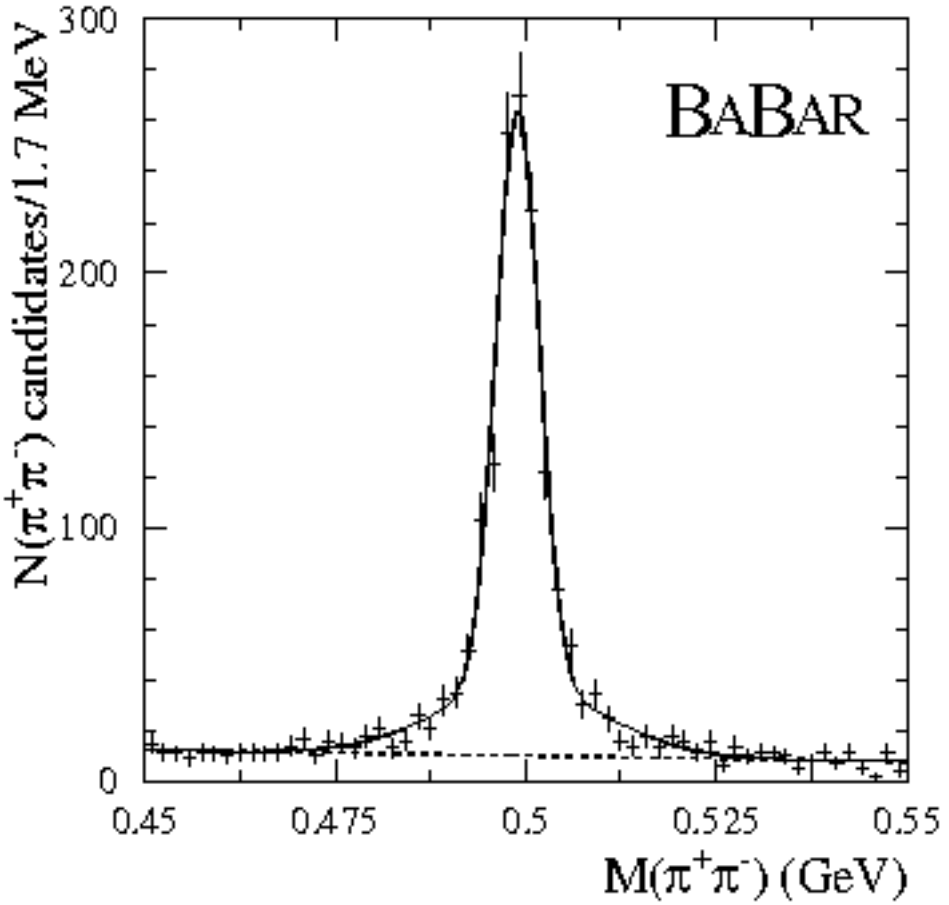
Inclusive Reconstruction

$D^0 \to K^-\pi^+$

single Gaussian
+ 1st order polynomial

σ=8.8 MeV



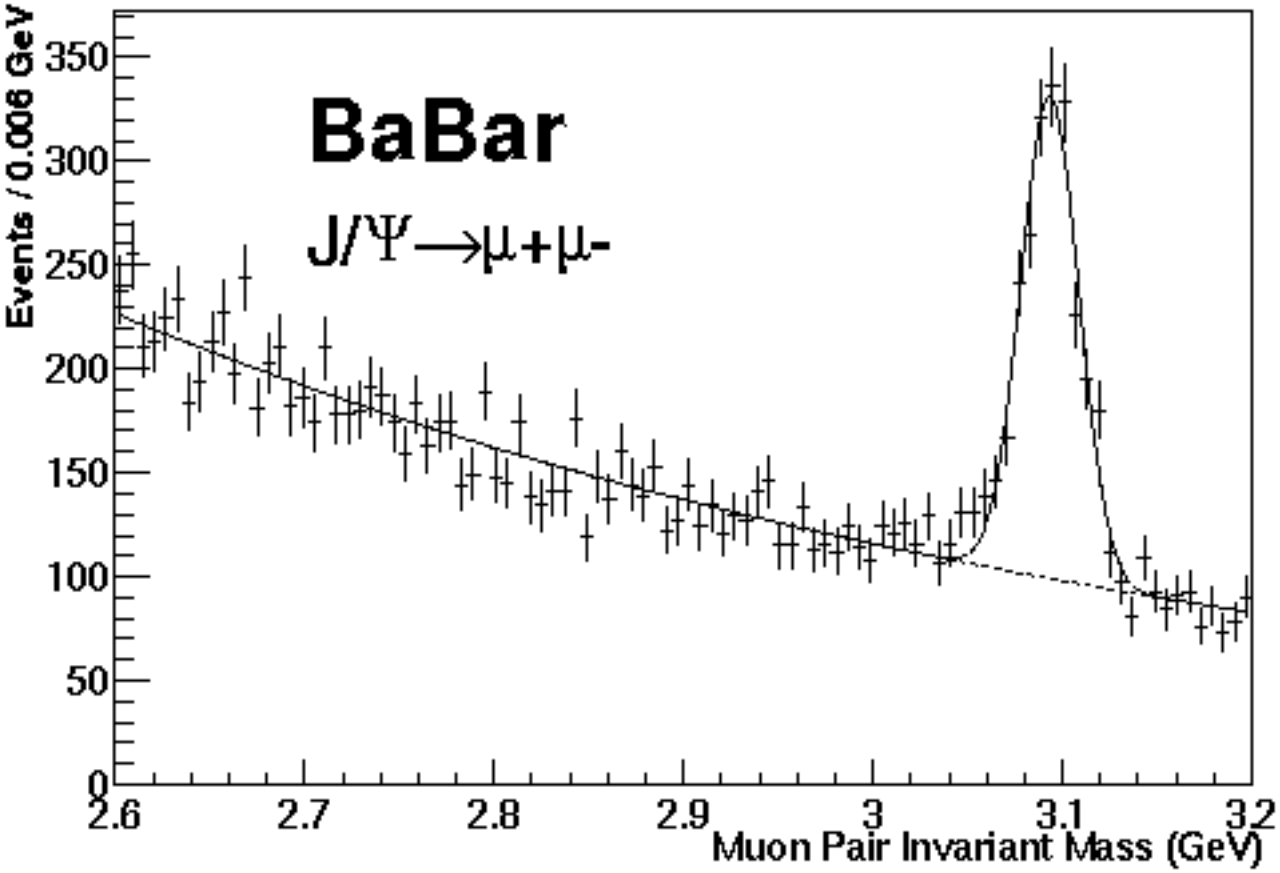


$K_s \to \pi^+\pi^-$

double gaussian fit:

70% first gaussian with 2.8 MeV resolution

J/ψ reconstruction



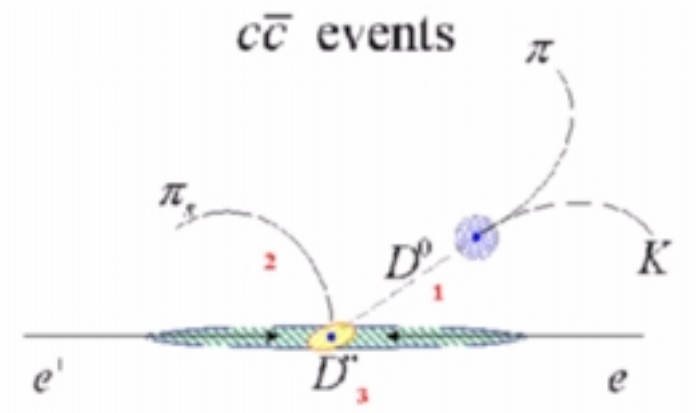
Data set: 1.9 fb^{-1}

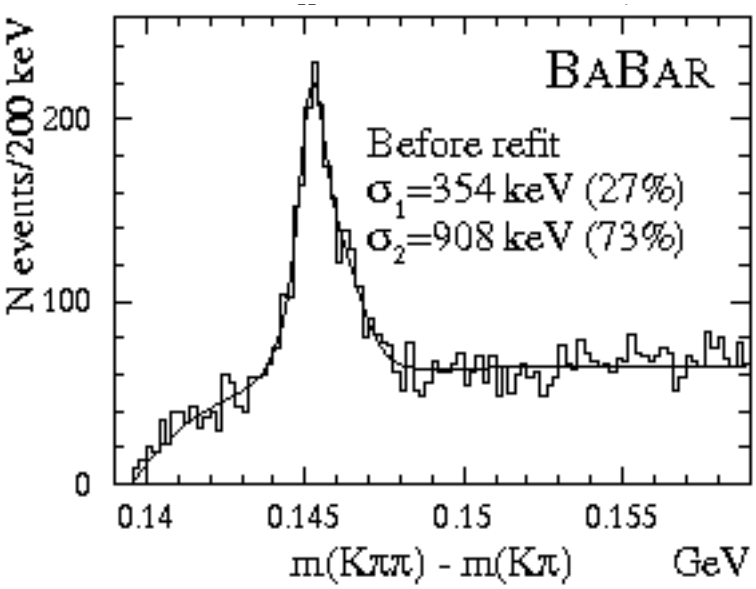
σ=15 MeV

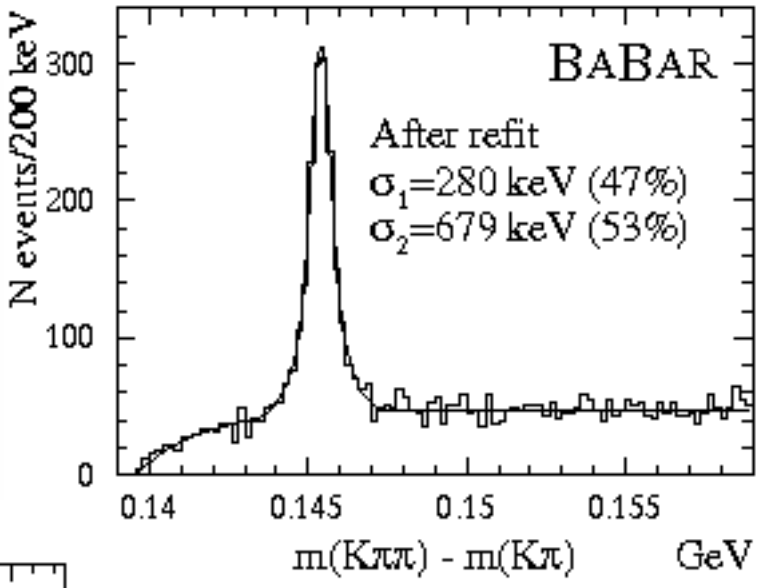
➡ **(improved to 11 MeV with the new alignment)**

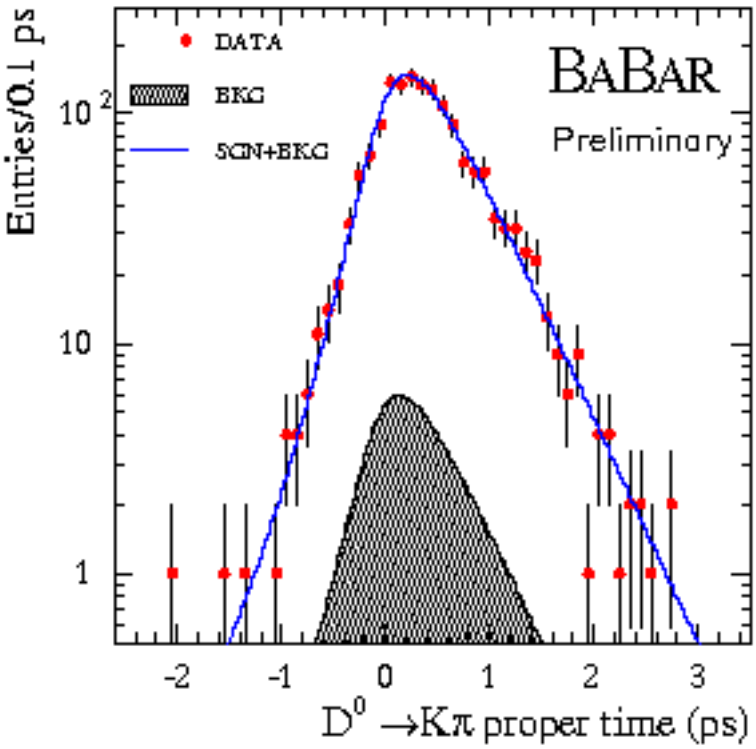
Vertexing Performances:

resolution is improved by using kinematic constraints (masses, directions, beam spot position)









D0 lifetime consistent with the world average

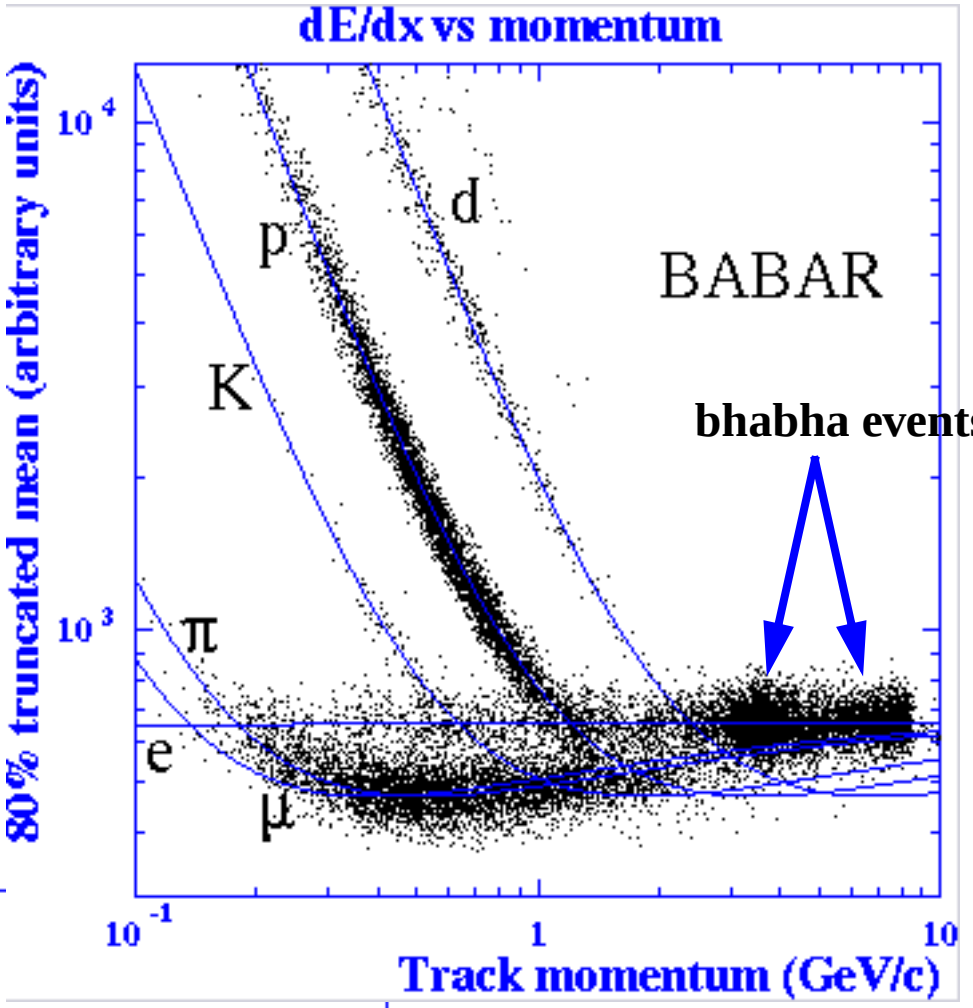
σ_{stat} ~ 13 fs

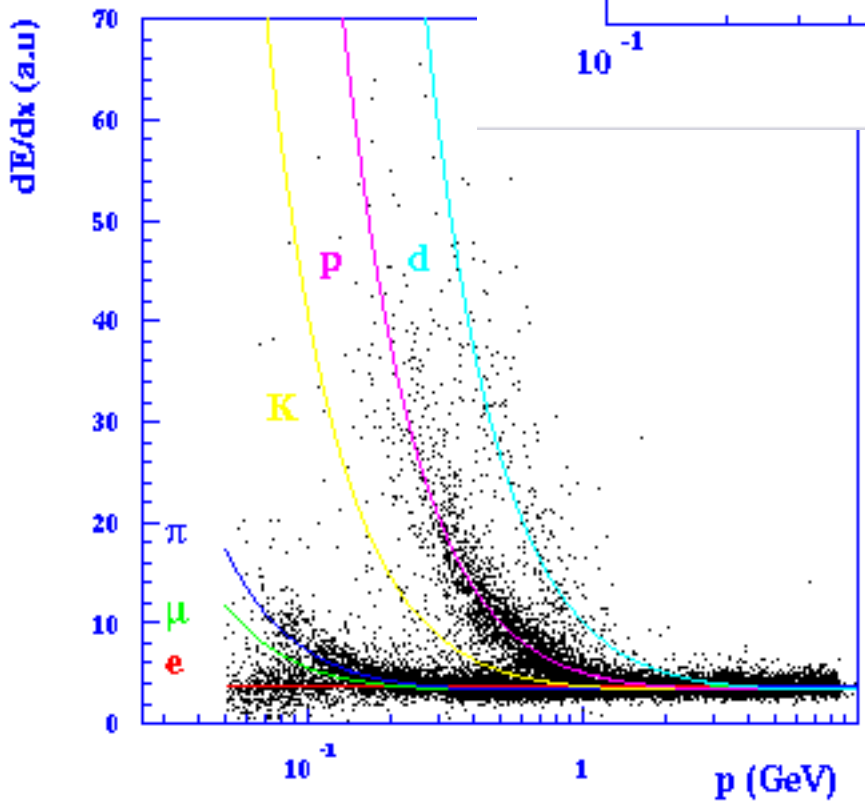
Particle Identification

dE/dx in Dch

(vs momentum)

more than
3σ π/k
separation up to ~700 MeV from Dch

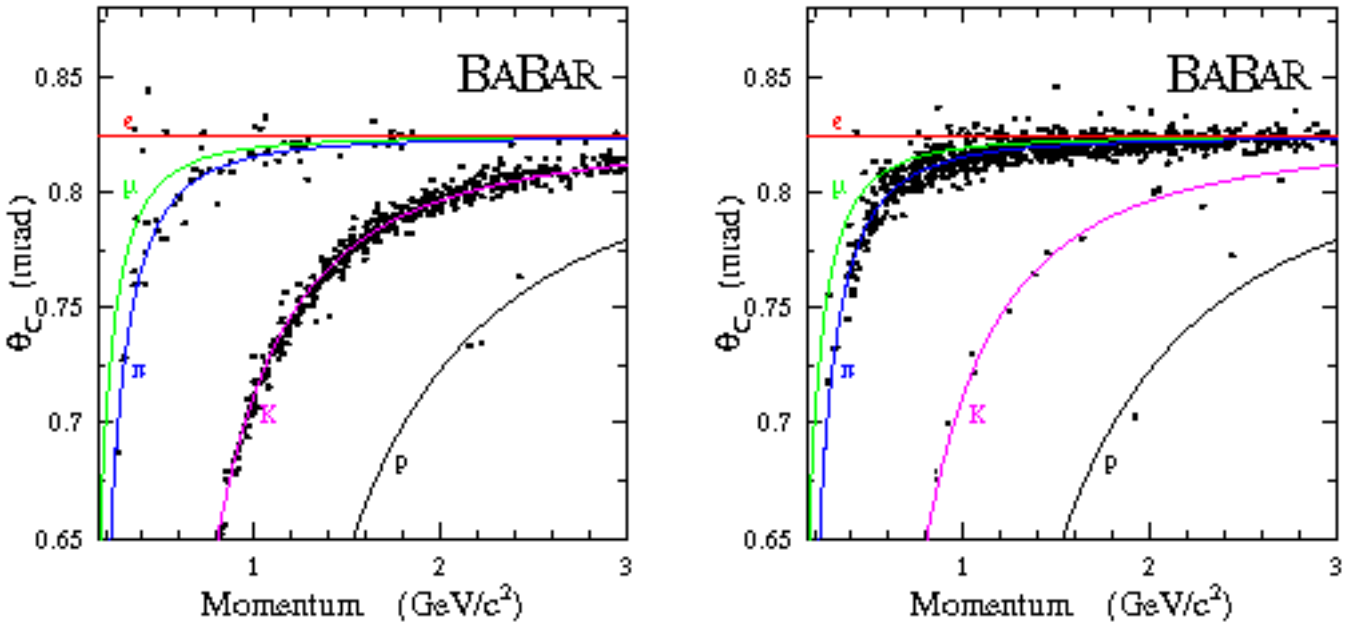




and Svt

~ 2σ π/k separation @ 500 MeV

PID with the DIRC

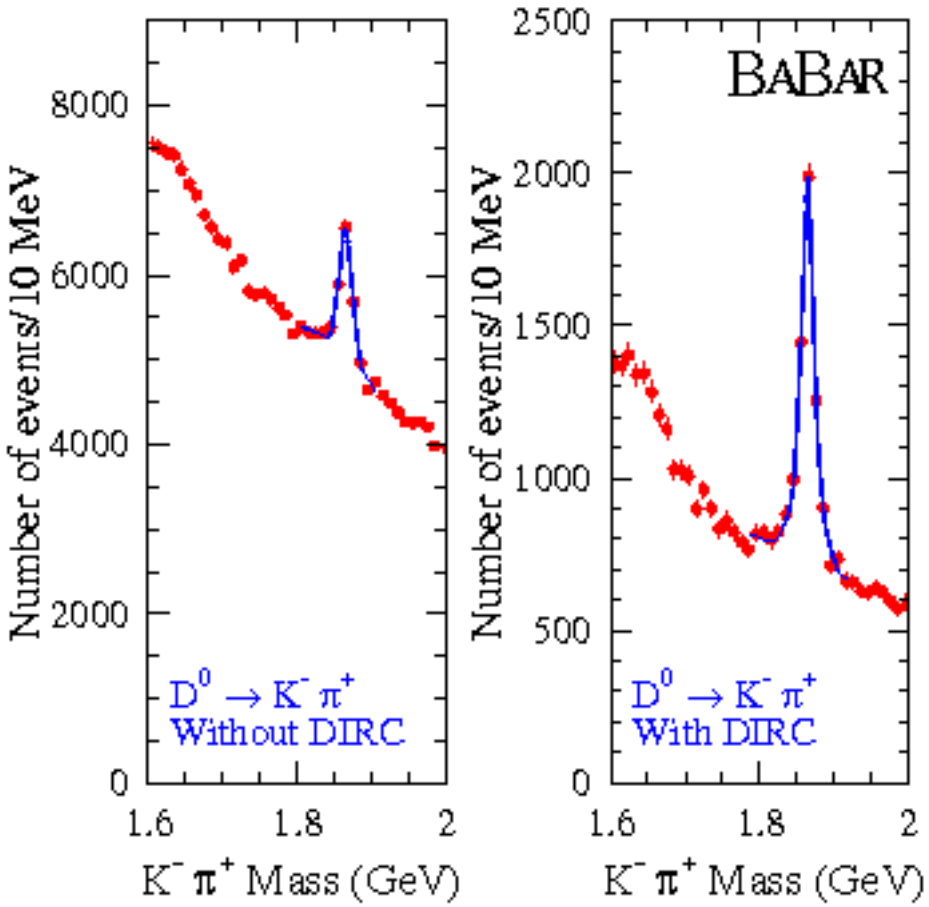


- more than 3σ π/k separation from 500 MeV on

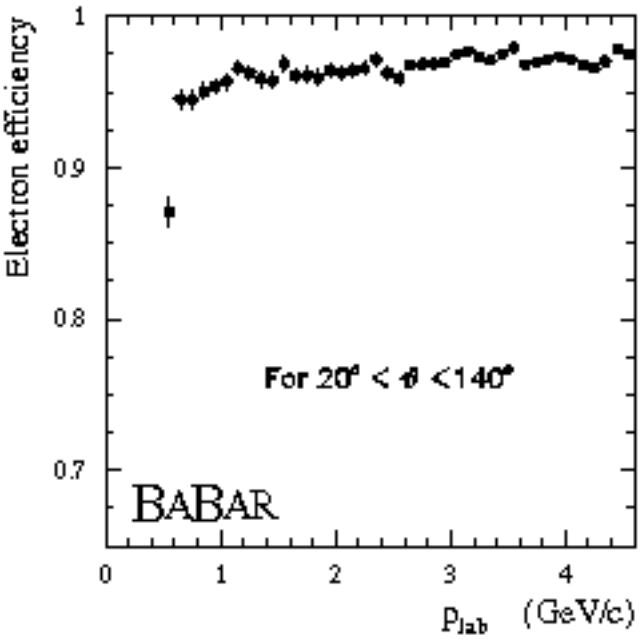
- K efficiency within acceptance ~80%

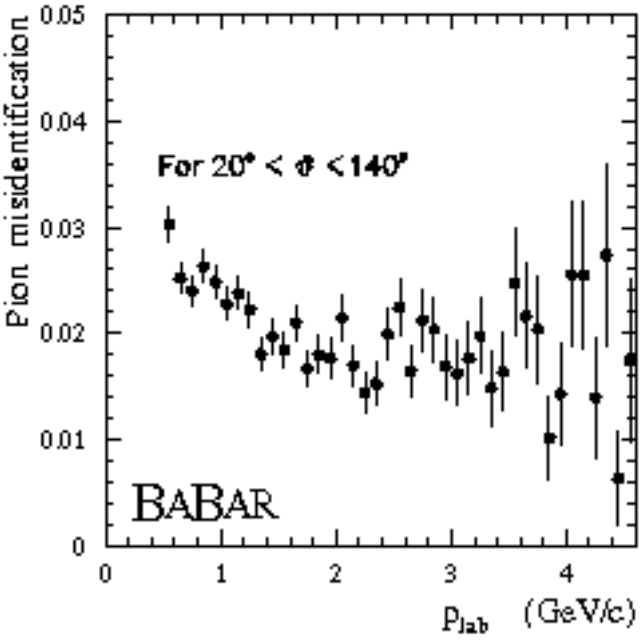
- $\sigma(\theta_c)$ ~ 3 mrad

➡ impact on D^0 purity

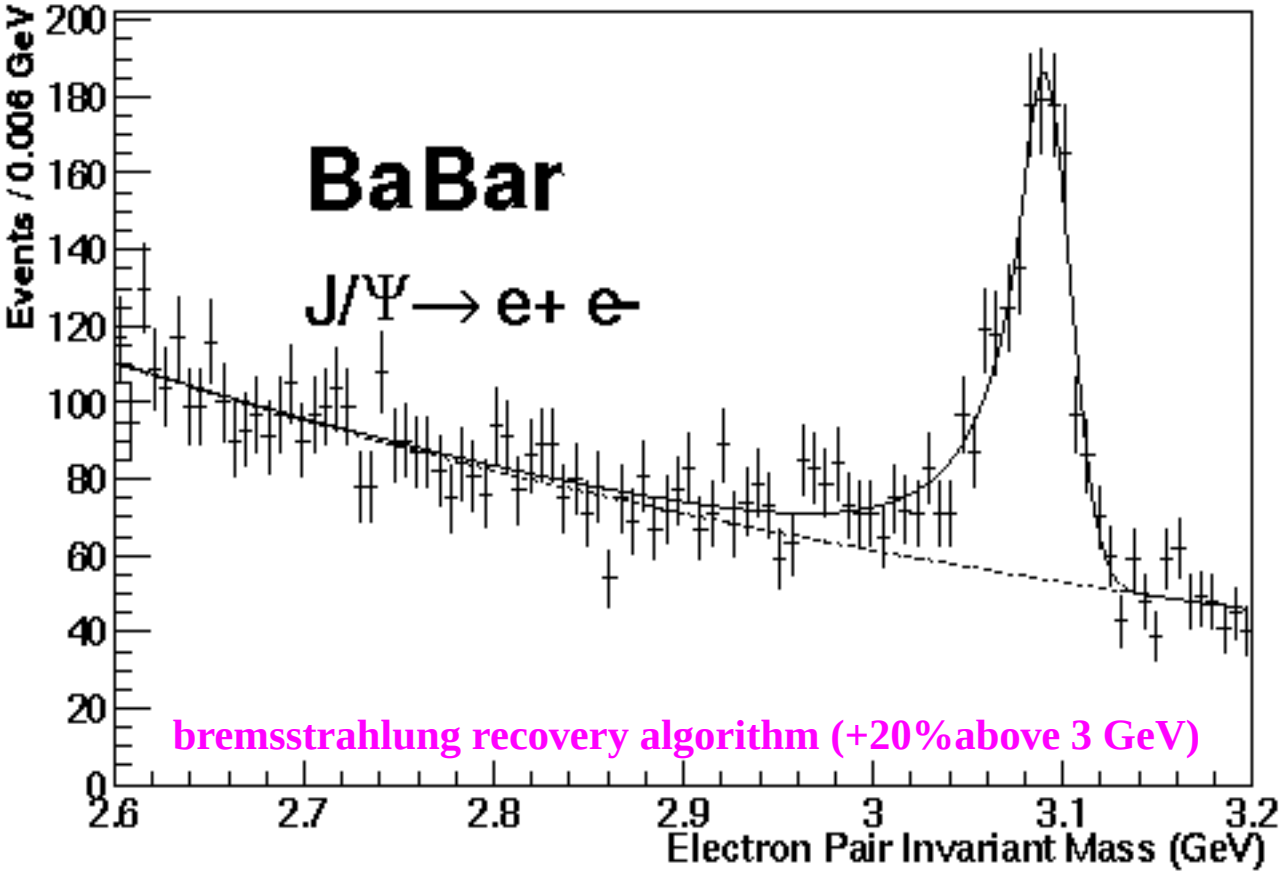


Electron Identification





ε ~ 95% with contamination ~2%



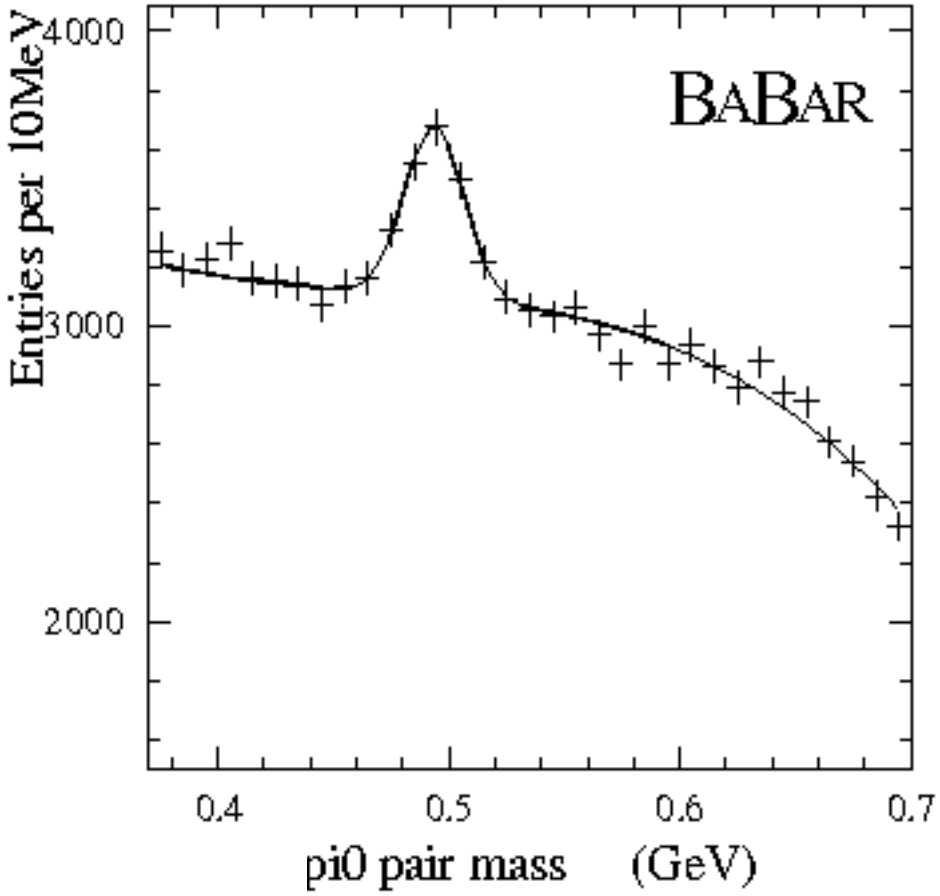
bremsstrahlung recovery algorithm (+20% above 3 GeV)

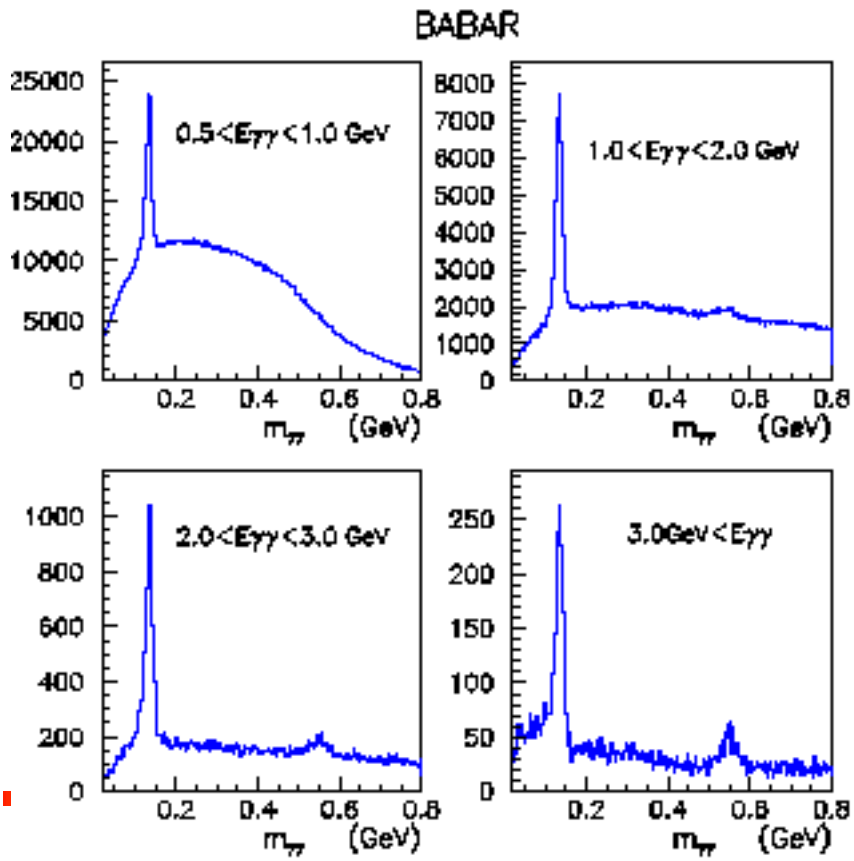
Composite with Neutrals

invariant mass from π^0 pairs

$K_S \rightarrow \pi^0\pi^0$

(K_S energy greater than 1.5 GeV)





π^0 and η in $\gamma\gamma$ mass

in lab energy ranges

Semi-leptonic B Decay

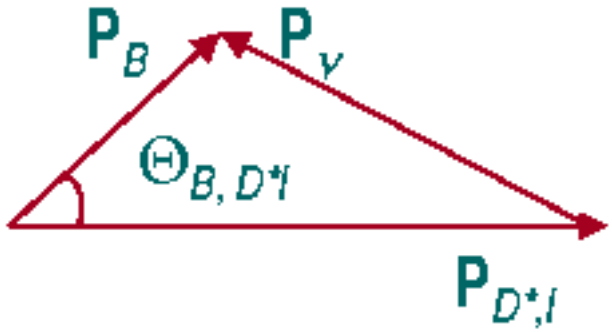
$B^0 \rightarrow D^{*-} e^+ \nu_e$

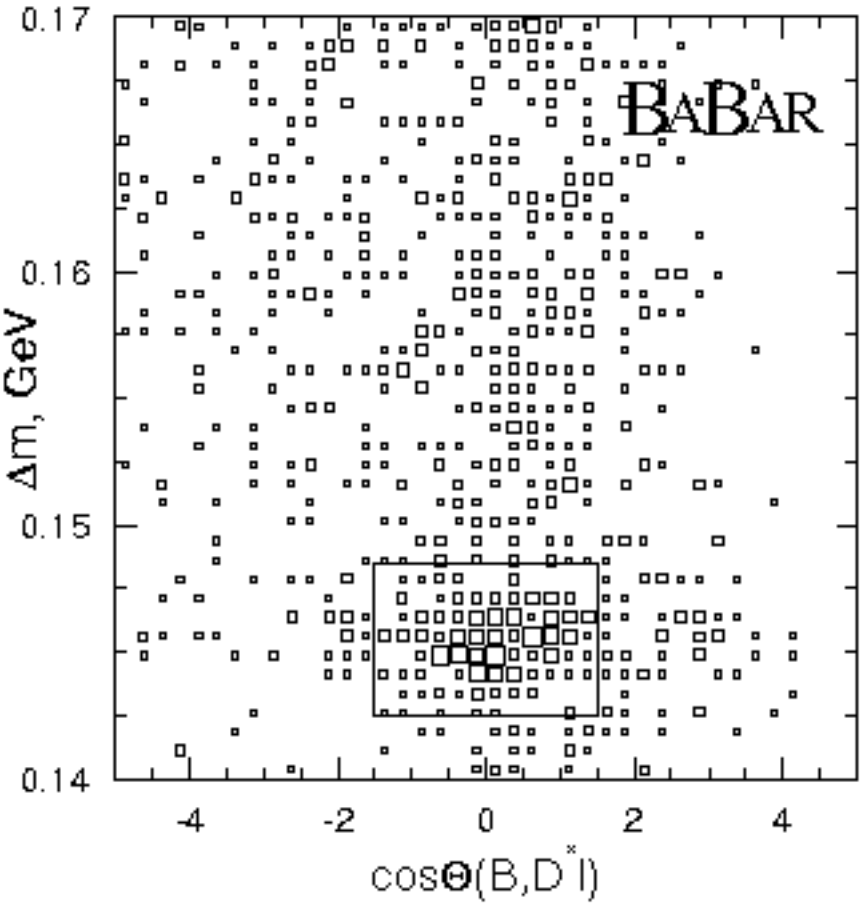
$\hookrightarrow D^0\pi^+$

$\hookrightarrow K^-\pi^+$

BR~0.12%

- **electron identification**
- **kinematic consistency with missing neutrino**





in 390 pb^{-1}

120 events

(6σ statistical significance)

B decays into charmonium

(L=2.2 fb-1)

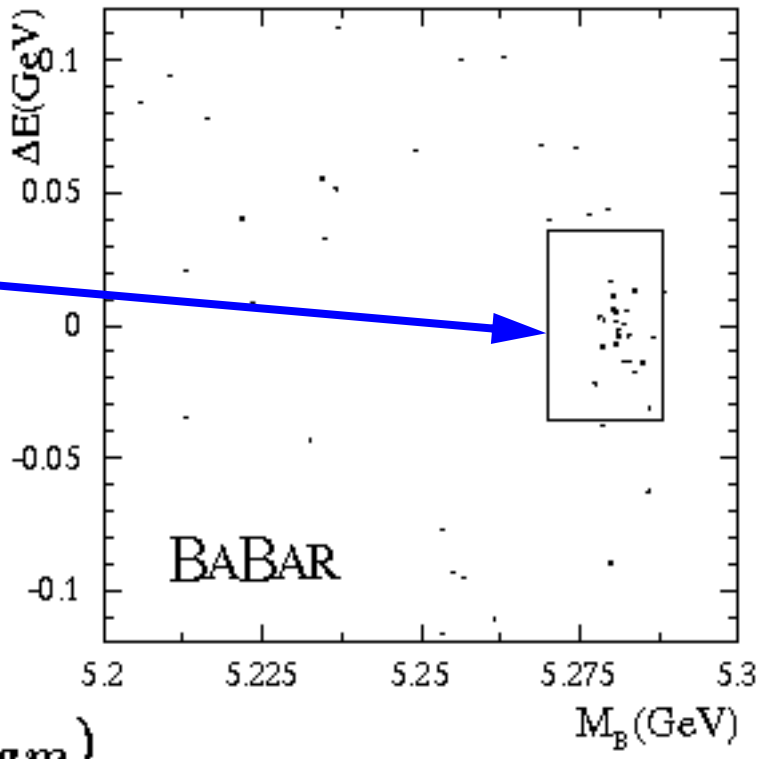
$B^0 \to J/\psi\, K_s$

$\varepsilon \sim 50\%$

28+/-5 $J/\psi\, K_s$ events

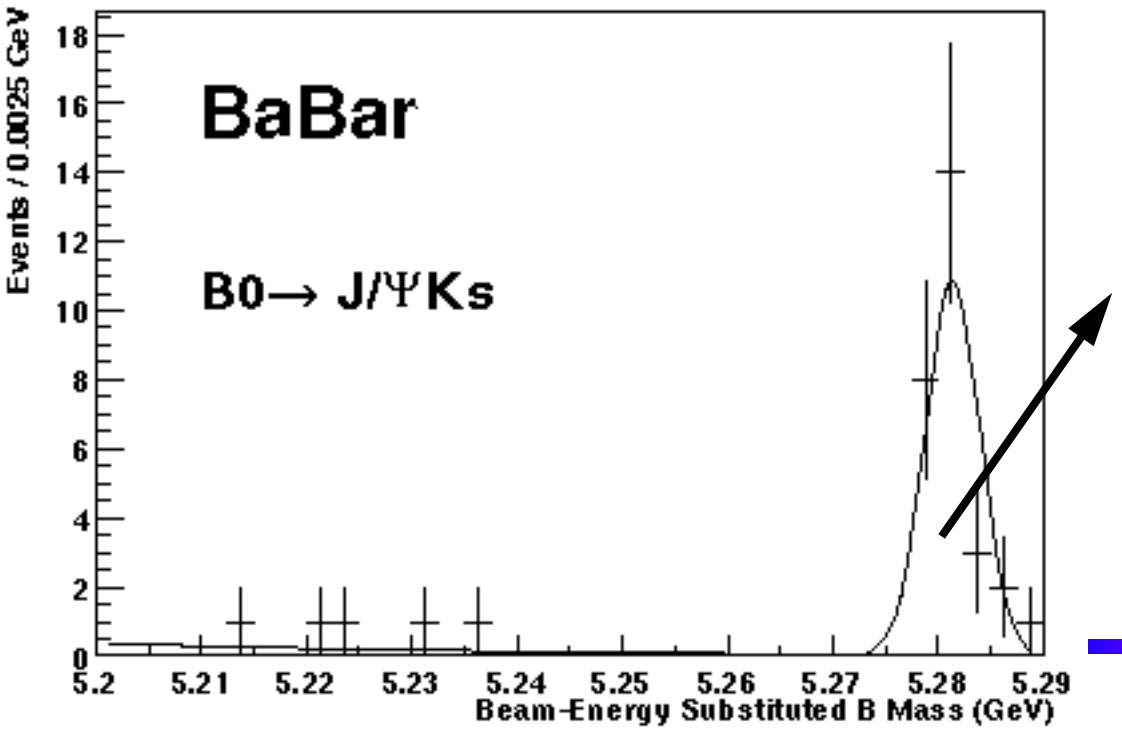
- $\to \pi^+\pi^-$
- $\to l^+l^-$

(expected ~32+/-4 ev)

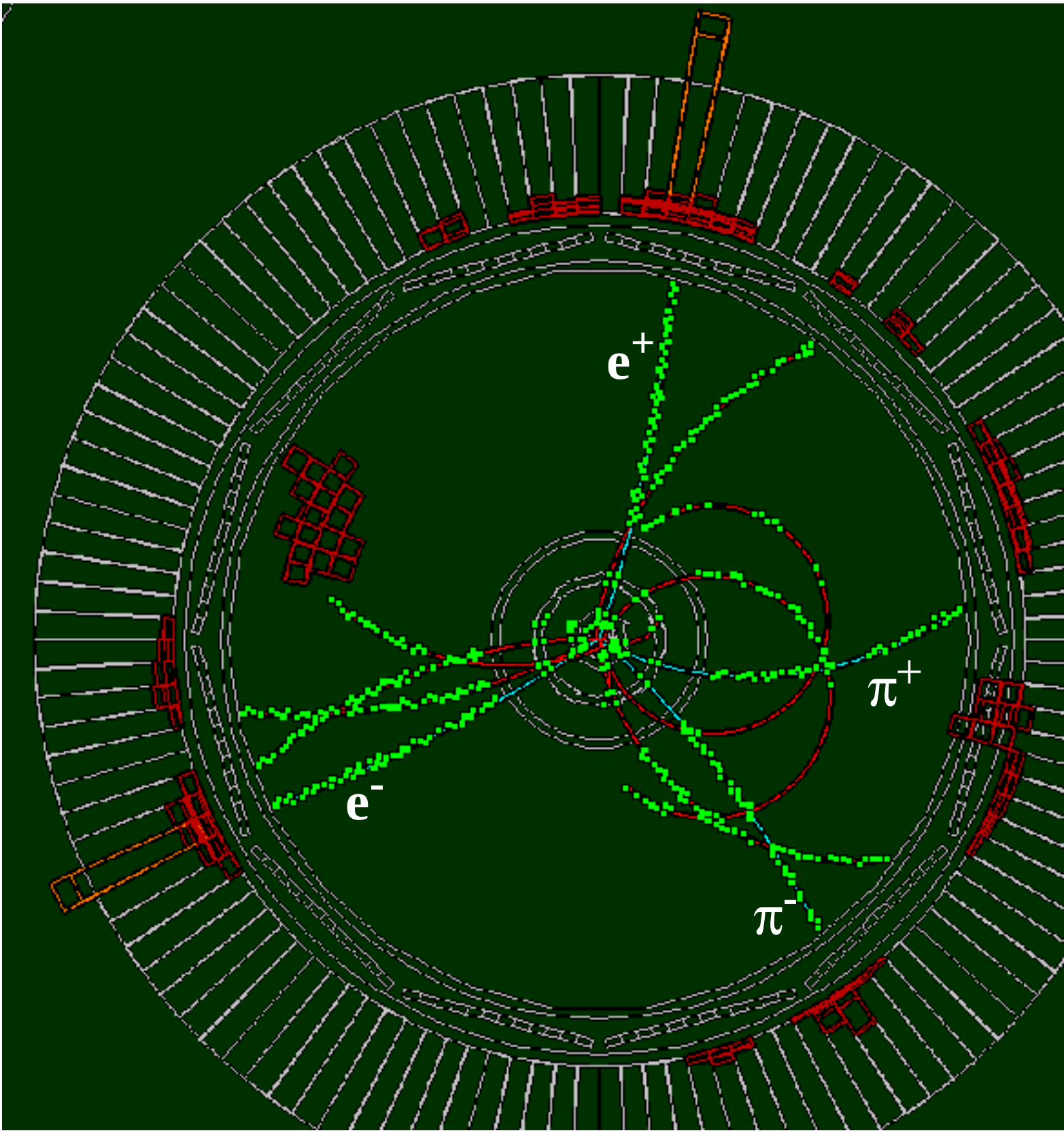


$$\Delta E = E_B - \sqrt{s}/2 (= E_{Beam})$$

$$M_B = \sqrt{E_{Beam}^2 - p_B^2}$$

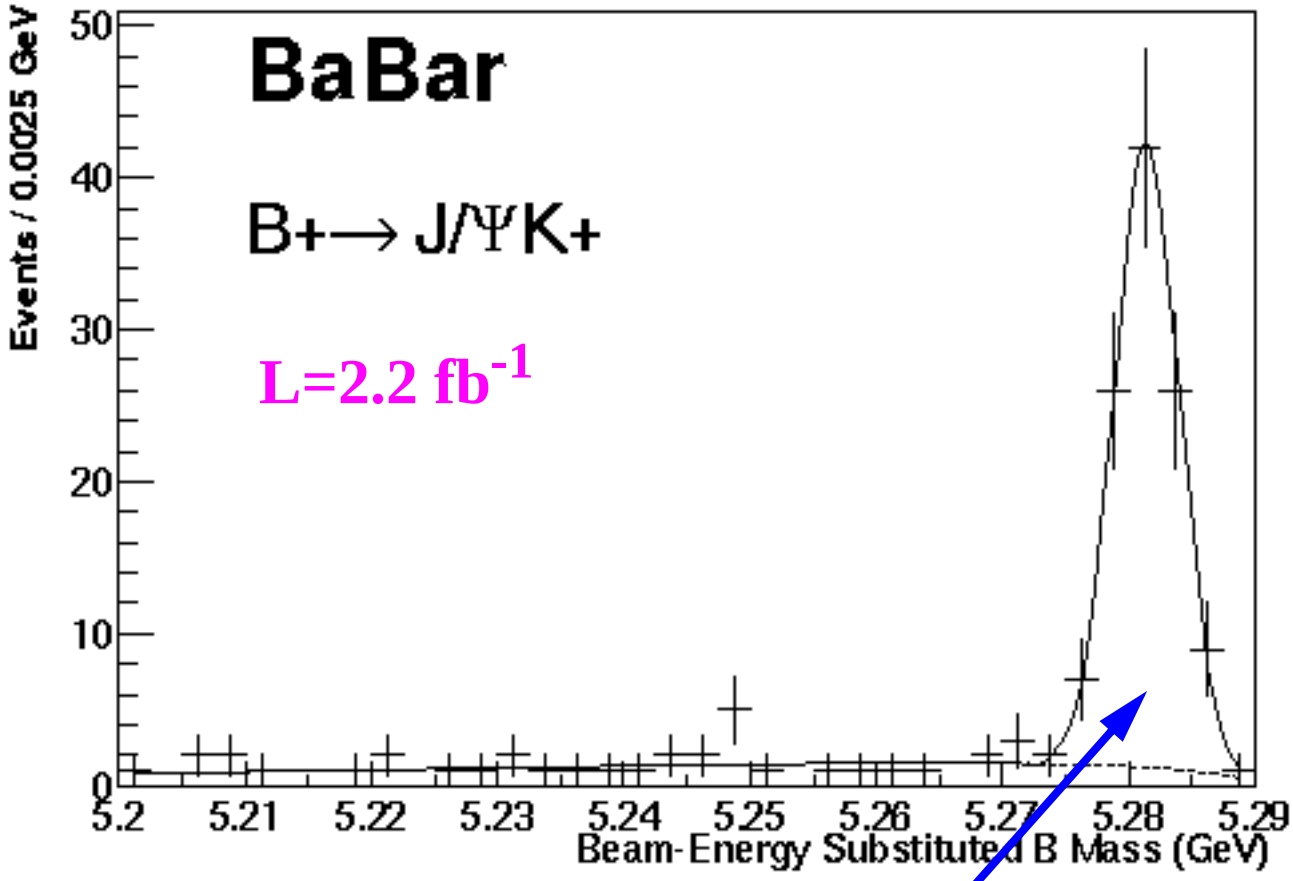


Event display: J/ψ K_s event



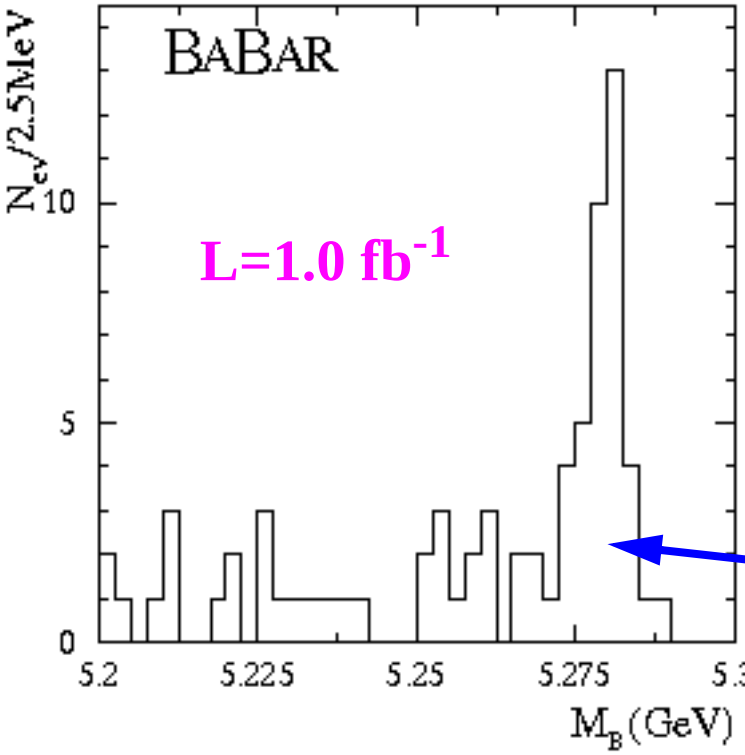
Other B decays into charmonium

(control samples for golden one)



109 +/- 11 events

(expected: 122+/-8)



B^0->J/ψ K_0^*($K^+\pi^-$)

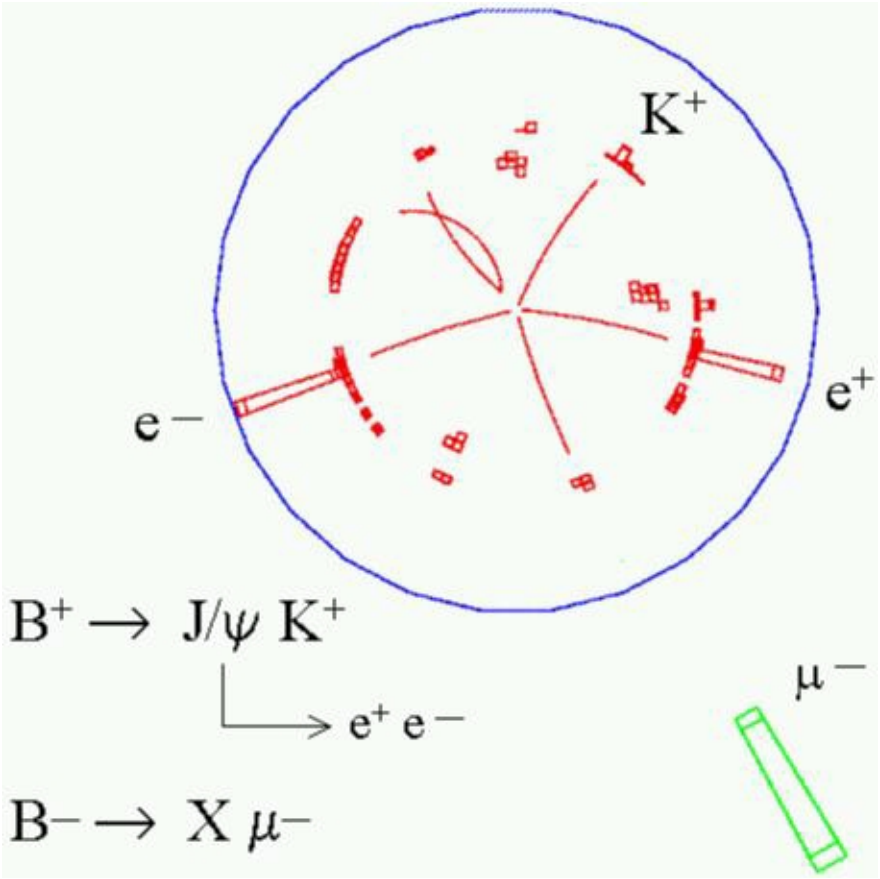
34.5 events

Tagging

the other B has to identified as a B0 or an anti-B0

- **lepton decays**
- **kaon decay products**
- **lepton-kaon**
- **jet charge (no PID used)**

to be evaluated the mis-tag probability for each method!

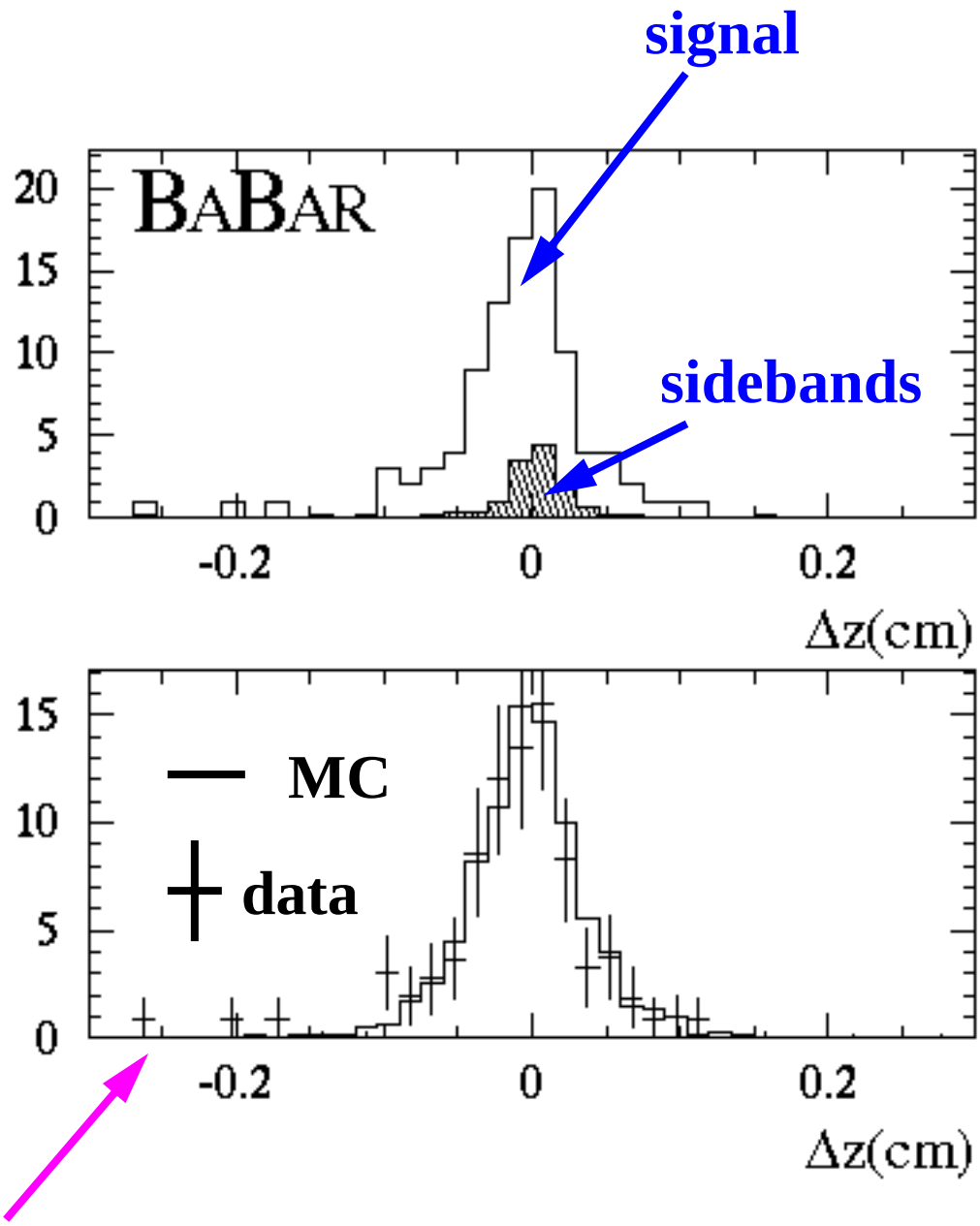


example of tagged event in data

Delta Z

first look with exclusively reconstructed B's

$J/\psi\ K^+$
and
$J/\psi\ K^{0*}$



data/MC comparison:

distributions are in agreement

Conclusions

- PEP II is working smoothly and routinely delivers luminosity > 1.7 10^{33} cm^{-2} s^{-1}
- design luminosity is expected to be achieved by the end of this run (August)
- BABAR has already recorded more than 7fb^{-1} (more than 5fb^{-1} since January)
- validation studies are going on to better understand the detector, as well as analysis studies
- with 10fb^{-1} a first measurement of sin(2β) is expected in the channel B^0 ->J/ψ K_s with an uncertainty of about 0.3