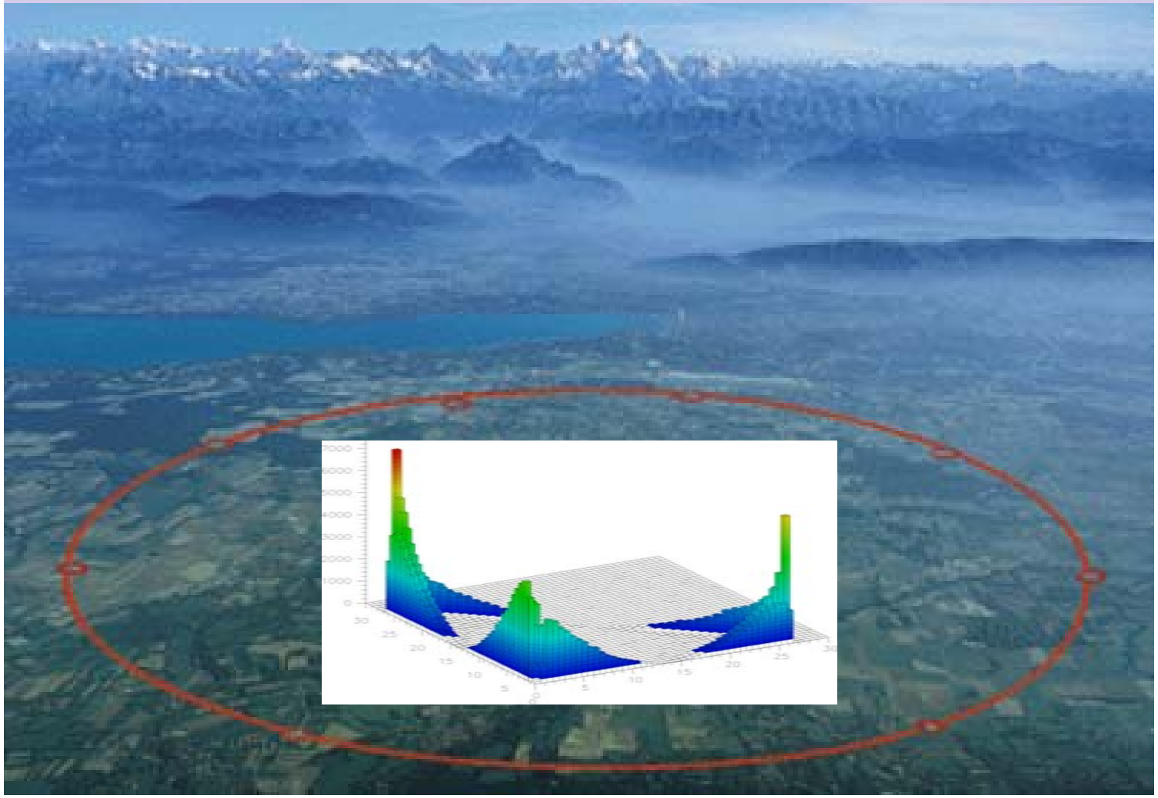
THREE-BODY CHARMLESS B DECAYS WORKSHOP –
LPNHE - PARIS 1-3 February 2005



Three-Body Charmless B Decays at LHC(b)

A. Robert & O. Deschamps
LPC Clermont-Ferrand & LHCb collaboration

MAIN PURPOSE

Flavour physics is an important topic of the LHC program.

↓

B physics will be studied by three experiments, among them LHCb, which is dedicated to this topic with the most complete program.

Concerning the 3-body charmless B decays, several studies are aiming at the CKM metrology:

$B^{\pm} \rightarrow \pi^+\pi^-\pi^{\pm}$, $B^0 \rightarrow K\pi\pi$ ⟶ γ extraction

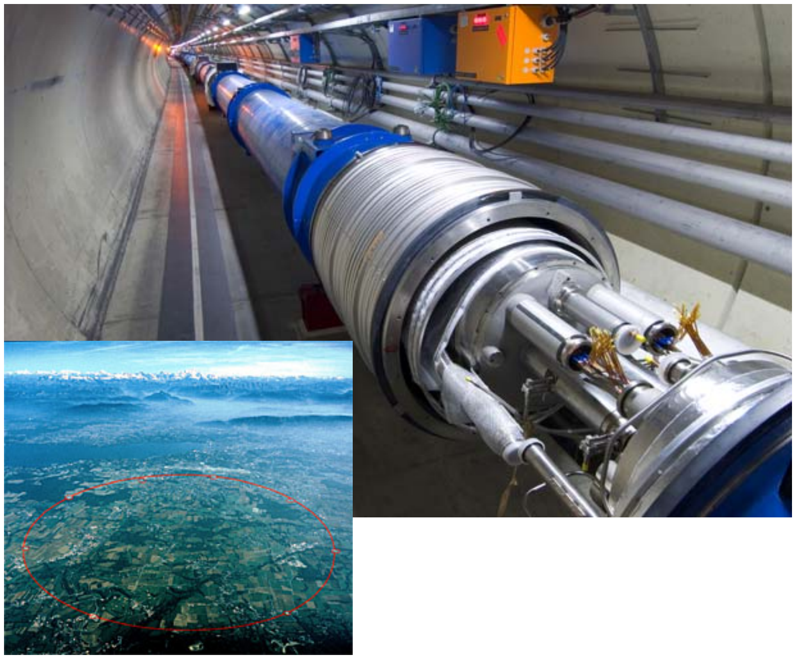
$B^0 \rightarrow \pi^+\pi^-\pi^0$ ⟶ α extraction

Talk mainly dedicated to the α extraction from the $B_d \rightarrow \pi^+\pi^-\pi^0$ decay channel in the LHCb experiment framework

⇔ Large Hadron Collider at CERN

Starting planed in mid-2007

$L(2007) \sim 10^{32}\ cm^{-2}s^{-1} \rightarrow L(2010) \sim 10^{34}\ cm^{-2}s^{-1}$ *(ATLAS –CMS)*

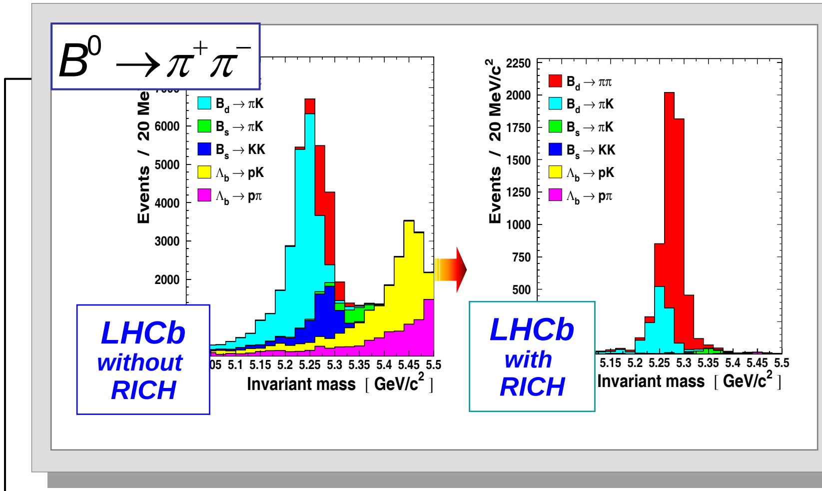


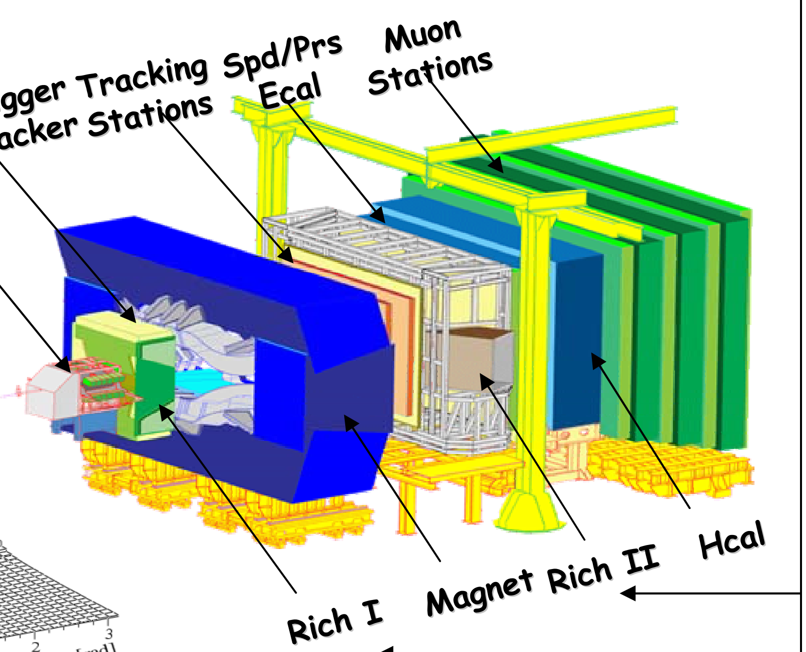
3 experiments with a B physics program

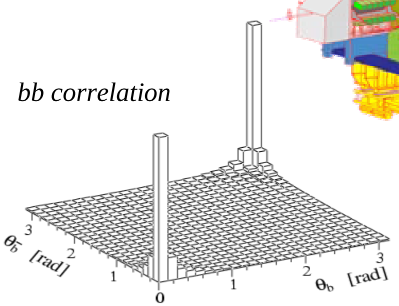
CMS ATLAS LHCb *(dedicated)*

	$pp \rightarrow b\bar{b}X$ ($\sqrt{s}$ = 14 TeV, Δt_{bunch}=25 ns) LHC (LHCb–ATLAS/CMS)	
Production σ_{bb}	~500 μb	☺
Typical bb rate	100–1000 kHz	
bb purity	$\sigma_{bb}/\sigma_{inel}$ = 0.6% *Trigger is a major issue*	☹
Pileup	0.5–5	
b-hadron types	B^+ (40%), B^0 (40%), B_s (10%) B_c (< 0.1%), b-baryons (10%)	☺
Production vertex	Reconstructed from many tracks	
Neutral B mixing	Incoherent B^0 and B_s mixing (*extra flavour-tagging dilution*)	☹
Event structure	Many particles not associated with the two b hadrons	

→ Dedicated detector to reconstruct a large variety of (rare) B decay modes.

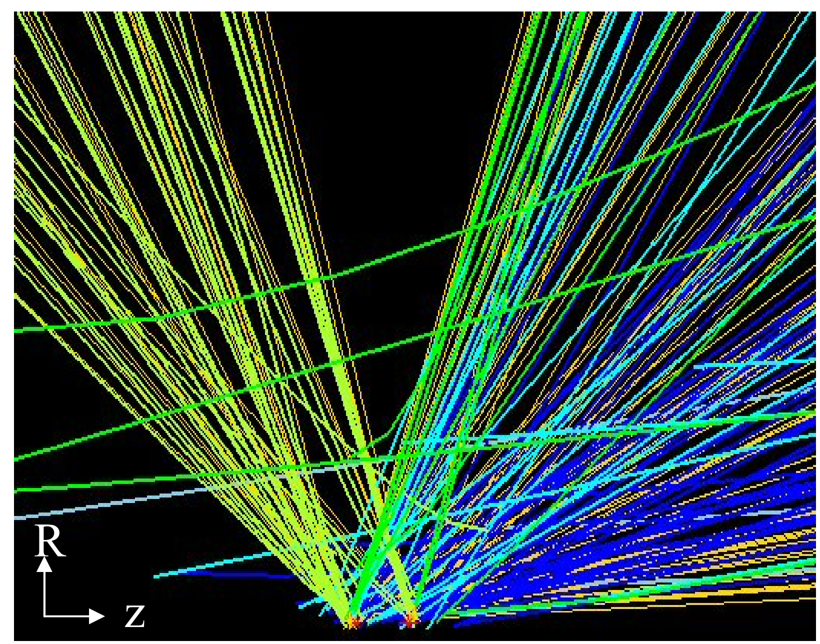






→ The challenge lies in reconstructing and extracting the B decay of interest within a high multiplicity tracks environment

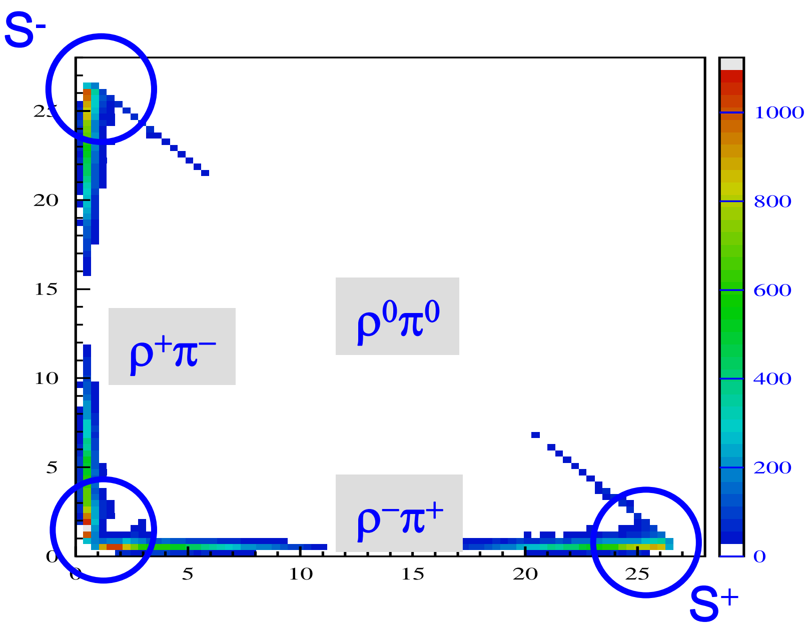
$L^{nom} \sim 2.10^{32}\ cm^{-2}s^{-1}$



One $\mathbf{B_d} \to \pi^+\pi^-\pi^0$ decay every 2 seconds

Working hypothesis: $B^0_d \to \rho\pi \to \pi\pi\pi$ is dominant

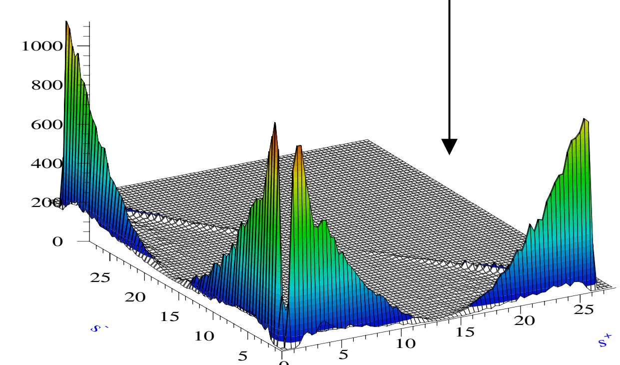
spin-1 + pseudo-scalar meson



⬄ ρ channel interferences

$$A_{3\pi}(B^0 \to 3\pi) = f^+ A^{+-} + f^- A^{-+} + f^0 A^{00}$$
$$\bar{A}_{3\pi}(\bar{B}^0 \to 3\pi) = f^+ \bar{A}^{+-} + f^- \bar{A}^{-+} + f^0 \bar{A}^{00}$$

Form factors $f^i = F^i . Y^{j0}(\cos(\theta^*))$

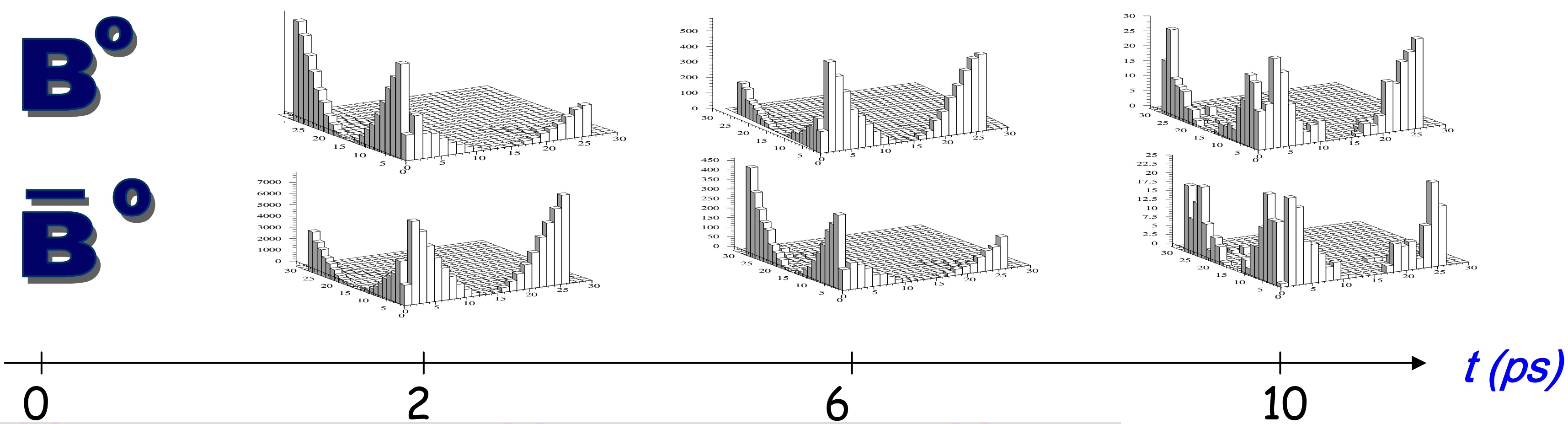


In the corners of the Dalitz plot
one the 3 pions remains at rest in the B rest frame
⬄ LHCb acceptance versus kinematics
will have an impact on the signal original profile

Explicit dependence of amplitudes in proper time through the B-$\bar{B}$ mixing:

$$M^{[\alpha]}(s^+,s^-,t) = e^{-\frac{\Gamma t}{2}} \left\{ \cos\left(\frac{\Delta m}{2}t\right) A^{[\alpha]}_{3\pi}(s^+,s^-) + i\frac{q}{p}\sin\left(\frac{\Delta m}{2}t\right)\bar{A}^{[\alpha]}_{3\pi}(s^+,s^-) \right\}$$

B^0 at t=0



$$\bar{M}^{[\alpha]}(s^+,s^-,t) = e^{-\frac{\Gamma t}{2}} \left\{ \cos\left(\frac{\Delta m}{2}t\right) \bar{A}^{[\alpha]}_{3\pi}(s^+,s^-) + i\frac{p}{q}\sin\left(\frac{\Delta m}{2}t\right)A^{[\alpha]}_{3\pi}(s^+,s^-) \right\}$$

$\bar{B}^0$ at t=0

Considering $|M|^2$ or $|\bar{M}|^2$ ⇔ sensitivity both to **sin(2α)** and **cos(2α)**

→ Remove ambiguities between 0 and π

11 observables ⇔ 13 parameters but …

$$A^{ij} = e^{-i\alpha} T^{ij} + P^{ij}$$

$$\left(\frac{q}{p}\right)\overline{A}^{ij} = e^{i\alpha} T^{ji} + P^{ji}$$

- Flavor structure of local operators: ΔI=1/2, ΔI=3/2
- Assume $SU(2)_F$ symetry.
- Neglect E-W penguins in this study.

P^{ij} ⇔ ΔI=1/2

$P^{00} = -1/2(P^{+-} + P^{-+})$

↓

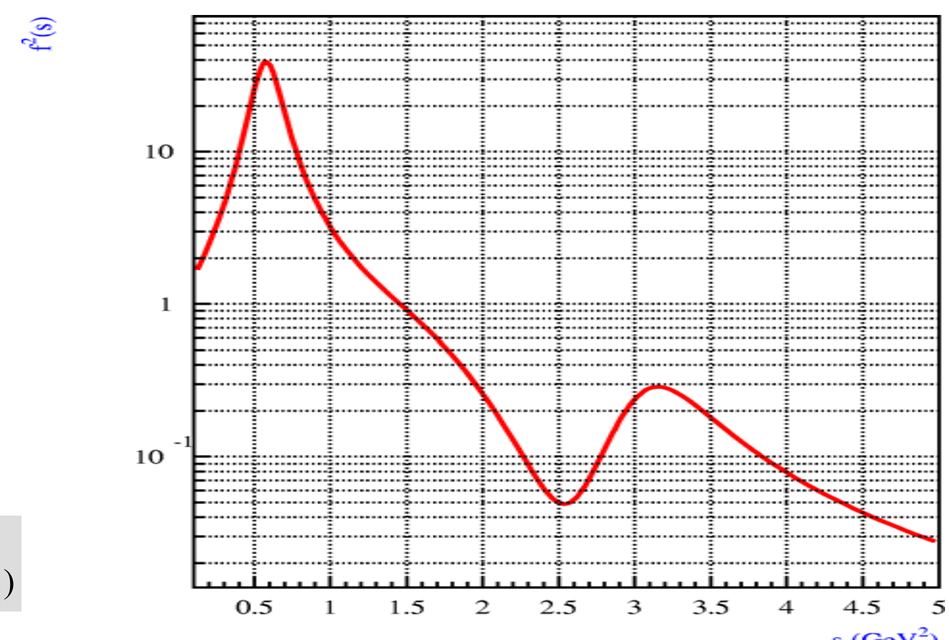
Fit of 9 dynamical parameters

$$\vec{\alpha} = (\alpha, T^{-+}, \phi^{-+}, T^{00}, \phi^{00}, P^{-+}, \delta^{-+}, P^{+-}, \delta^{+-})$$

$$A_{3\pi} = \sum_{i,i+j=0} f^i A^{ij}$$

ρ lineshape model:
Introduce a Kuhn Santamaria form

$$f^i \alpha(f^i_{\rho(770)} + C_I f^i_{\rho(1450)} + C_{II} f^i_{\rho(1700)})$$



P/T assumed to be invariant w-r-t radial excitations

METHOD FOR SENSITIVITY ESTIMATION

⬄« toys » Monte-Carlo simulation of 10^3 experiments,
built from expected signal yield,
simulating experimental originated models of dilutions
(resolutions, acceptances, wrong tag…) and background contaminations (r)

Maximum likelihood fit ⬄ $$\frac{\partial \mathcal{L}}{\partial(\vec{\alpha},\vec{r})} = 0 \qquad \vec{\alpha} \oplus \vec{r} = N_{dyn} + N_{bkg} \text{ parameters}$$

$$\mathcal{L}(\vec{\alpha},\vec{r}) = \prod_{k}^{N_{evt}} \left[(1-r)\xi^{3\pi}(s_k^+, s_k^-, t_k) \sum_{b=B,\bar{B}} \omega_b^{tag} \left| M_b^{3\pi}(s_k^+, s_k^-, t_k, \vec{\alpha}) \right|^2 + \sum_{bkg}^{N_{bkg}} r^{bkg} \xi^{bkg} \mathcal{L}_k^{bkg} \right] \otimes G(\sigma_{s^+}, \sigma_{s^-}, \sigma_t)$$

Event yield — *Acceptance function* — *Tagging performances* — *Background contamination* — *Resolutions*

⬄ *The experimental inputs are estimated from fully simulated MC data*

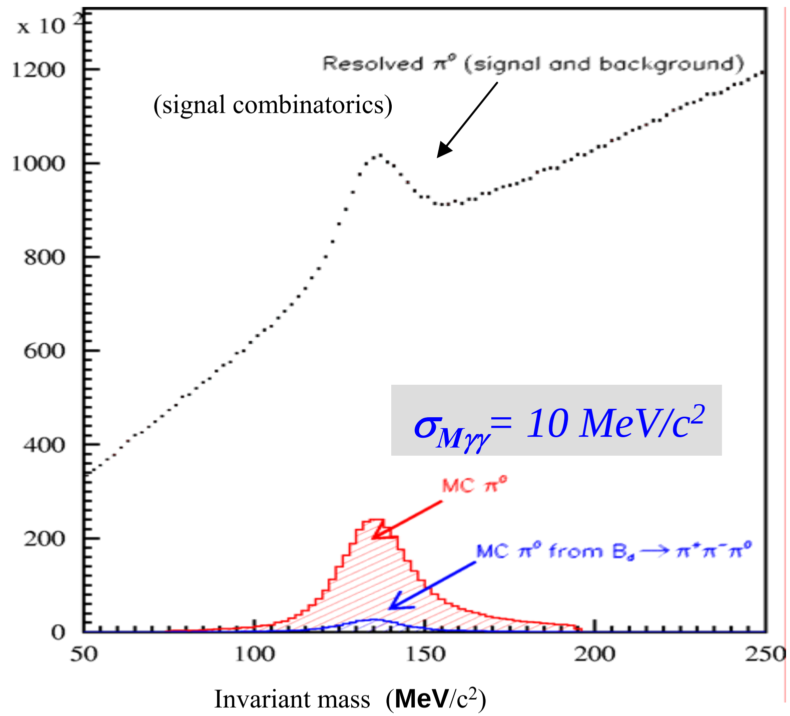
The data are not (yet) here

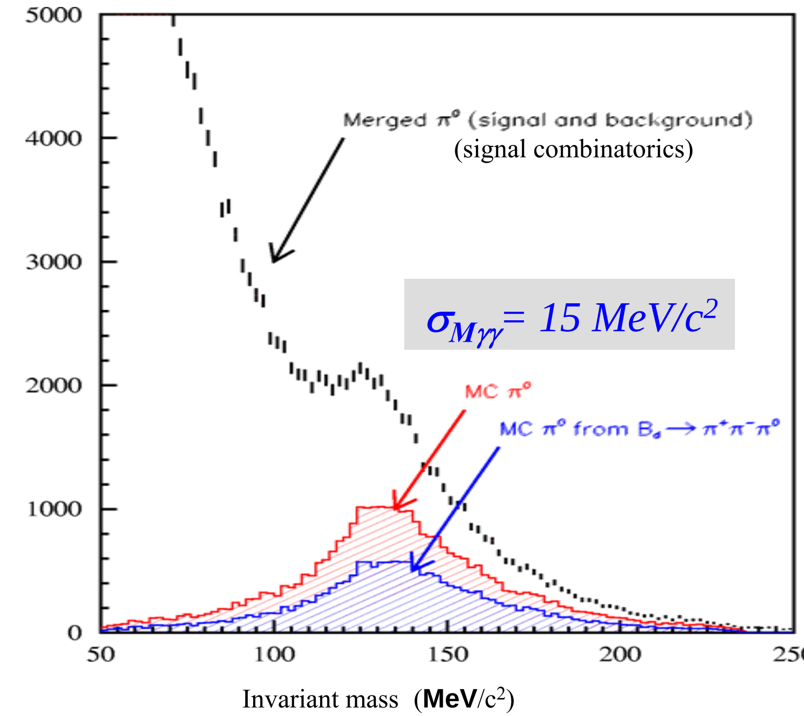
⇔ Use of Monte Carlo samples of fully simulated events (electronic noise …, pattern recognition …) to estimate analysis performances whitin a framework as realistic as possible

MC statistics used for this study:

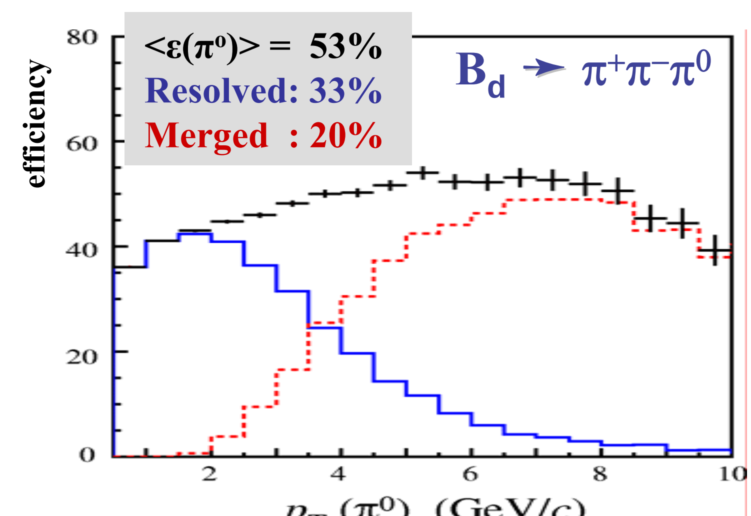
- Signal ($B_d \to \pi^+\pi^-\pi^0$) events, $N_{3\pi}$= 1.10^6 events ~ 1 day of data taking.
- bb inclusive sample, N_{bb} = 40.10^6 events ~ 12 mn of data taking.
- Specific background model samples. Charmless « cocktails » of B^+ and B^0, $B \to K\pi\pi$ decays.
- 100.10^6 Minimum bias events pp $\to$ X~ 5 seconds of data taking. (Trigger performance studies)

EXPERIMENTAL CHALLENGE
NEUTRAL PIONS RECONSTRUCTION





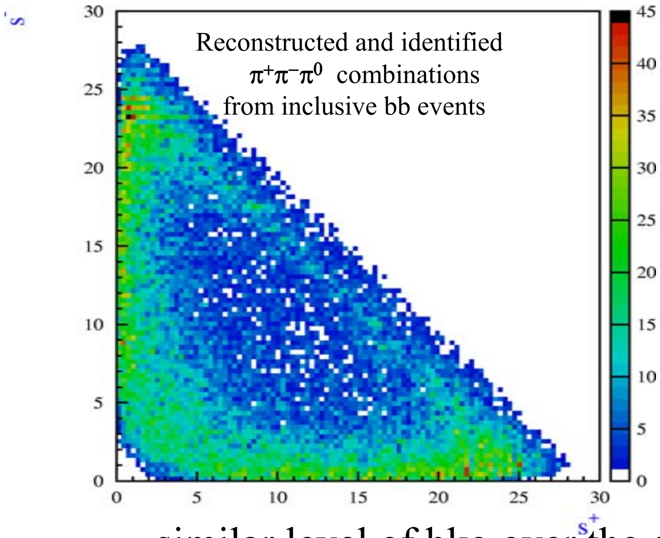
γ Identification is based on calo-cluster neutrality (anti-track matching) and kinematics



2 kinds of reconstructed π^0's :

- Resolved π^0 ➛ *Pair of isolated photons*
- Merged π^0 ➛ *Pair of photons merged within a single cluster (large P_T)* ⇔ *use of cluster shape*

THE $B_d \to \pi^+\pi^-\pi^0$ EVENT SELECTION (1)



similar level of bkg over the ρ bands

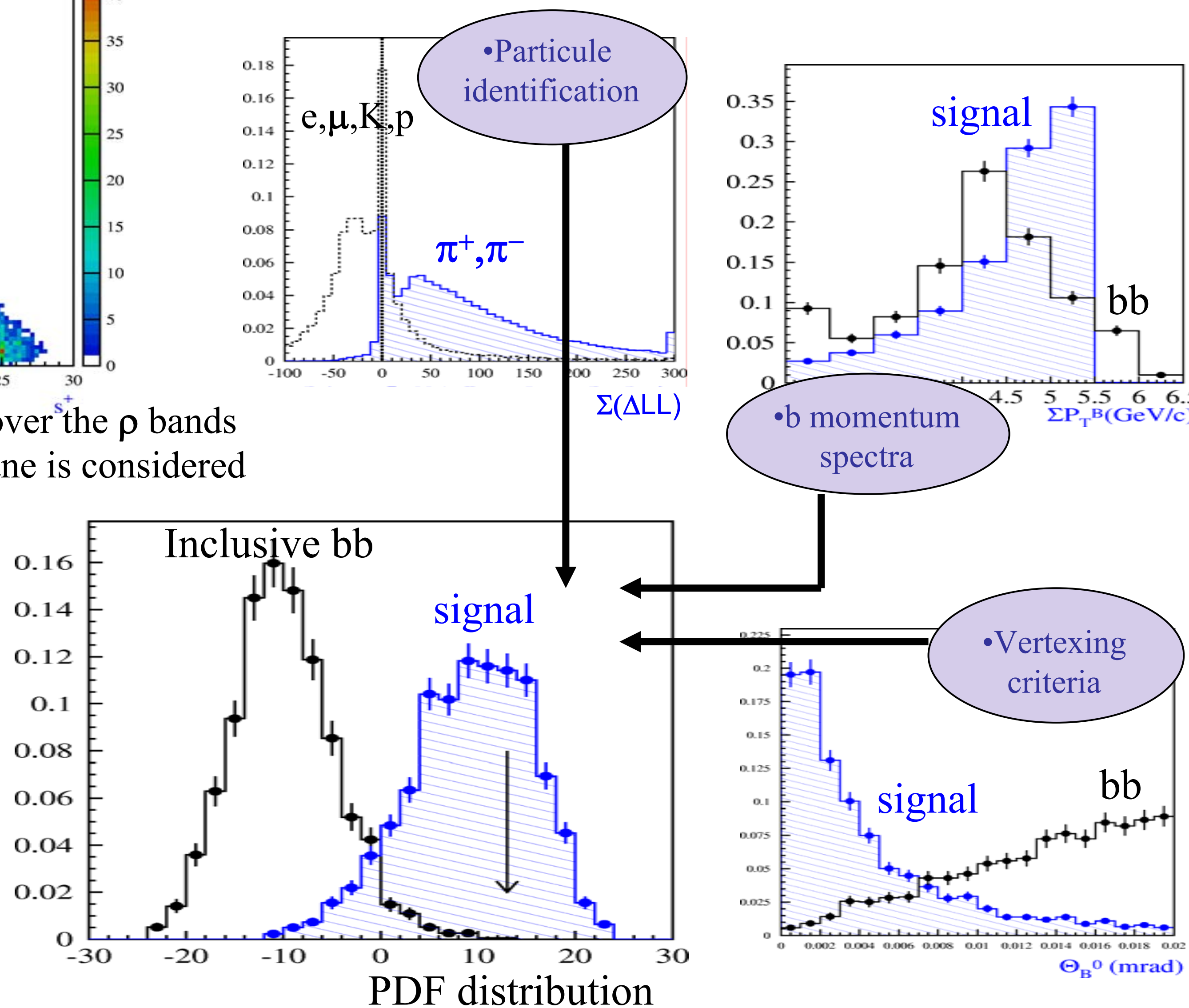
⇔ The whole Dalitz plane is considered

Multivariate Selection

$$S(\vec{x}) = \prod_{i=1}^{N\,\mathrm{var}} S_i(x_i)$$

$$B(\vec{x}) = \prod_{i=1}^{N\,\mathrm{var}} B_i(x_i)$$

$$PDF = f(B(\vec{x}), S(\vec{x}))$$



THE $B_d \rightarrow \pi^+\pi^-\pi^0$ EVENT SELECTION (2)

• Selection efficiency

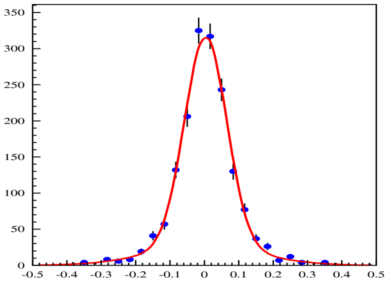
$\varepsilon_{(det+rec)}$	$\varepsilon_{(sel)}$	$\varepsilon_{(trig)}$	$\varepsilon_{(tot)}$
0.04	0.035	0.43	6.10^{-4}

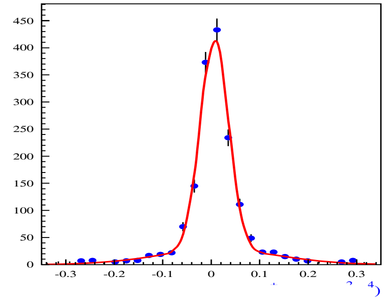
• Expected annual yield

$N_{3\pi} \sim 12.10^3$ events/2 fb^{-1}

• Signal distorsions - resolutions

(dominated by Ecal energy resolution)



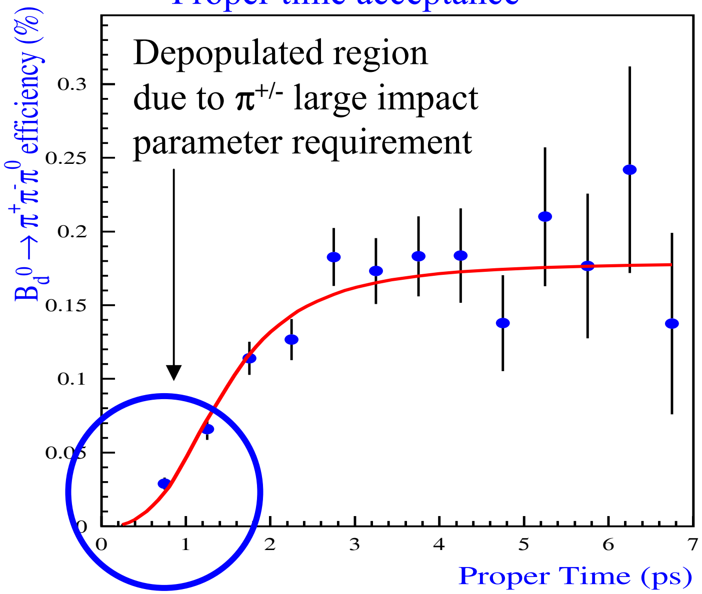


$\sigma(\tau) \rightarrow 70$ fs

$\sigma(Min(\sqrt{s^+}, \sqrt{s^-})) \rightarrow 30$ MeV/c²

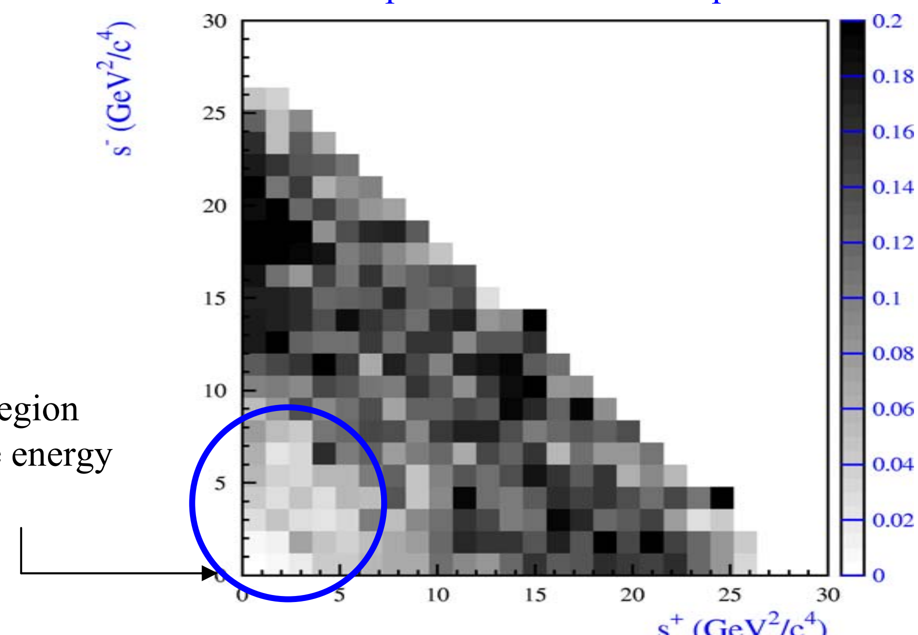
• Signal distorsions – acceptance functions

Proper time acceptance



Phase space coordinates acceptance

Depopulated region due to π^0 large energy requirement



THE $B_d \to \pi^+\pi^-\pi^0$ EVENT SELECTION (3)

Flavour tagging and background within an hadronic framework

- •Tagging efficiency $\varepsilon = 40 \pm 2\%$
- •Wrong tag fraction $\omega = 31 \pm 2\%$

► $\varepsilon_{eff} = \varepsilon(1-2\omega)^2 = 6 \pm 2\%$

⇔ Assumption: most dangerous source of background originates from b decays

•B/S estimation ⇔ from pure $b\bar{b}$ inclusive sample B/S **< 1.3** @ 90% CL

Most contaminating specific bkgs

Combinatorial fragments from charmed B decays B/S~0.3

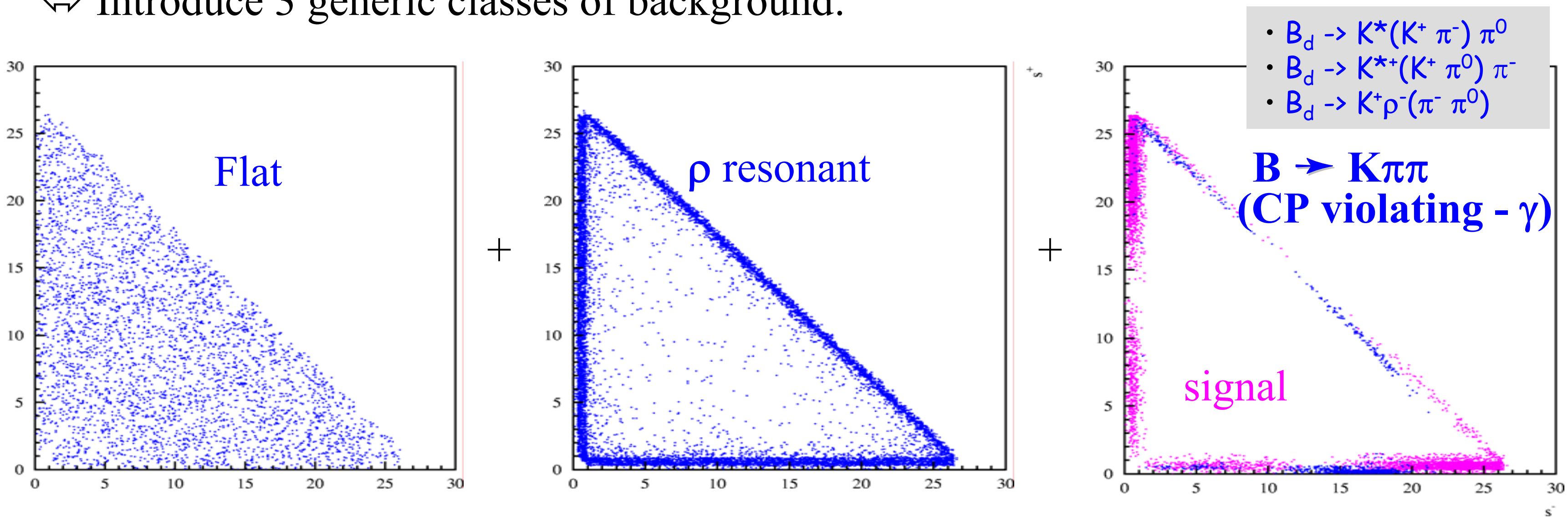
$B_d \to \rho^+\rho^-$ B/S~0.15

$B_d \to K^*\pi, K^*\gamma$ B/S~0.1

Considering B/S = **O(1)** in the following studies is probably a not too wrong ‘guesstimate’

Without real data background is hard to model

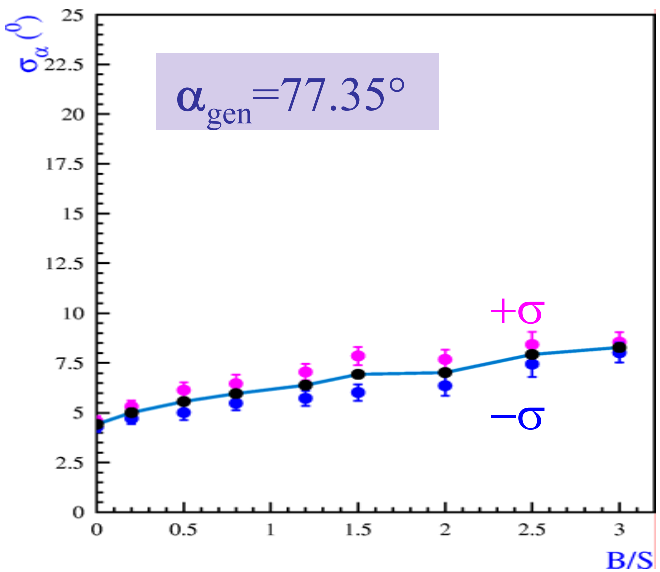
⇔ Introduce 3 generic classes of background:

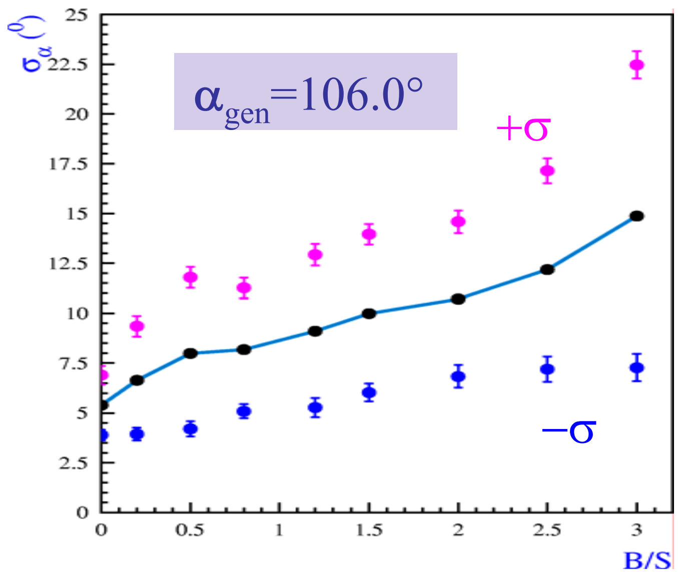


Assumptions of the sensitivity study:

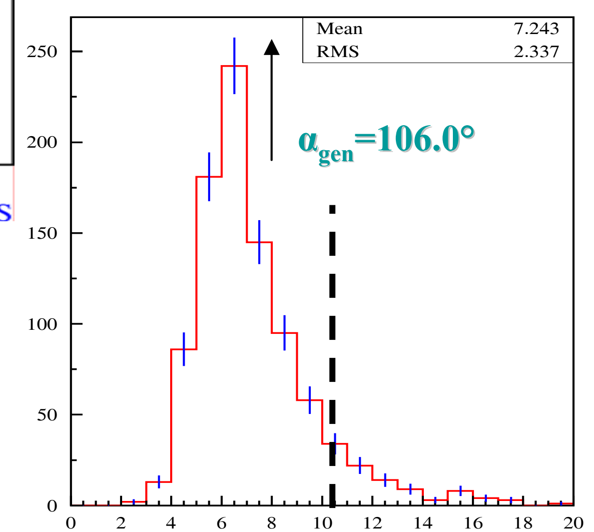
- Assume specific mixtures of the 3 classes of bkg ***{(res) – (flat) – (Kππ)}***
- Assume same proper time distribution than for $\mathbf{B_d}$ ➛ $\pi^+\pi^-\pi^0$ events.
- Assume same acceptance functions, resolutions and tagging dilution than for $\mathbf{B_d}$ ➛ $\pi^+\pi^-\pi^0$ events.

• *2 background classes: **{0.5(res), 0.5(flat)}***





Distribution of fit error



90% of toy experiments with $\sigma(\alpha)<10°$

• *3 background classes: **{0.6(res), 0.3(flat), 0.1(Kππ)}***

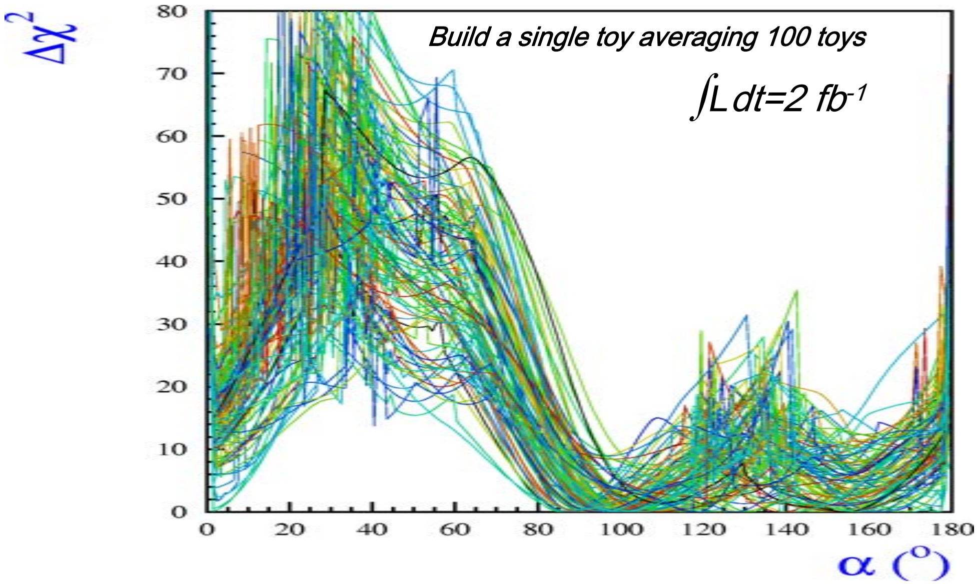
$\alpha^{gen}=77.35° \rightarrow \langle\alpha^{fit}\rangle=(76.0\,^{+10}_{-5})°$

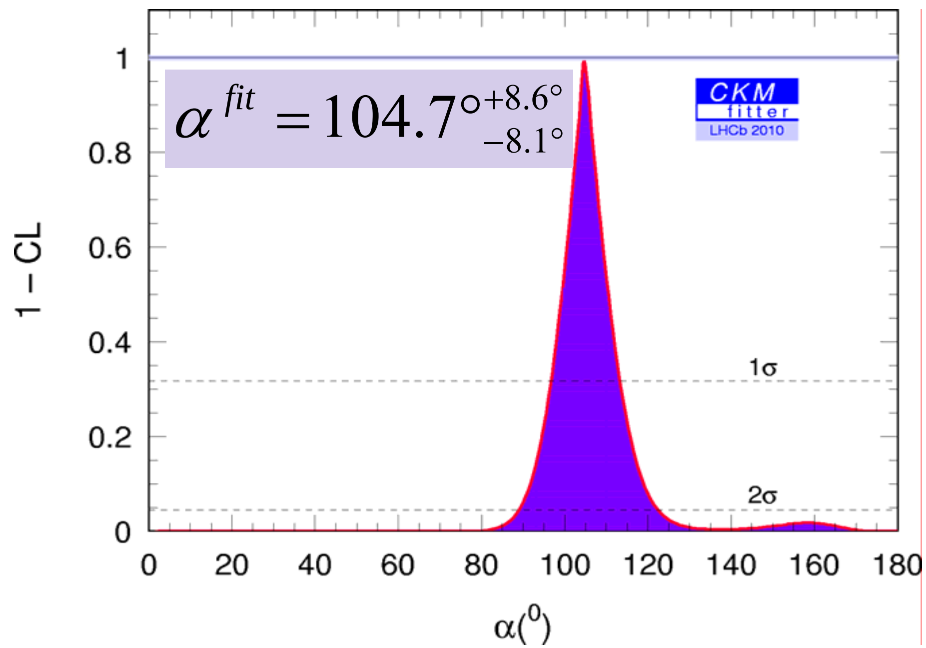
$\alpha^{gen}=106.0° \rightarrow \langle\alpha^{fit}\rangle=(110.0\,^{+15}_{-5})°$

2 fb^{-1}

With B/S=1

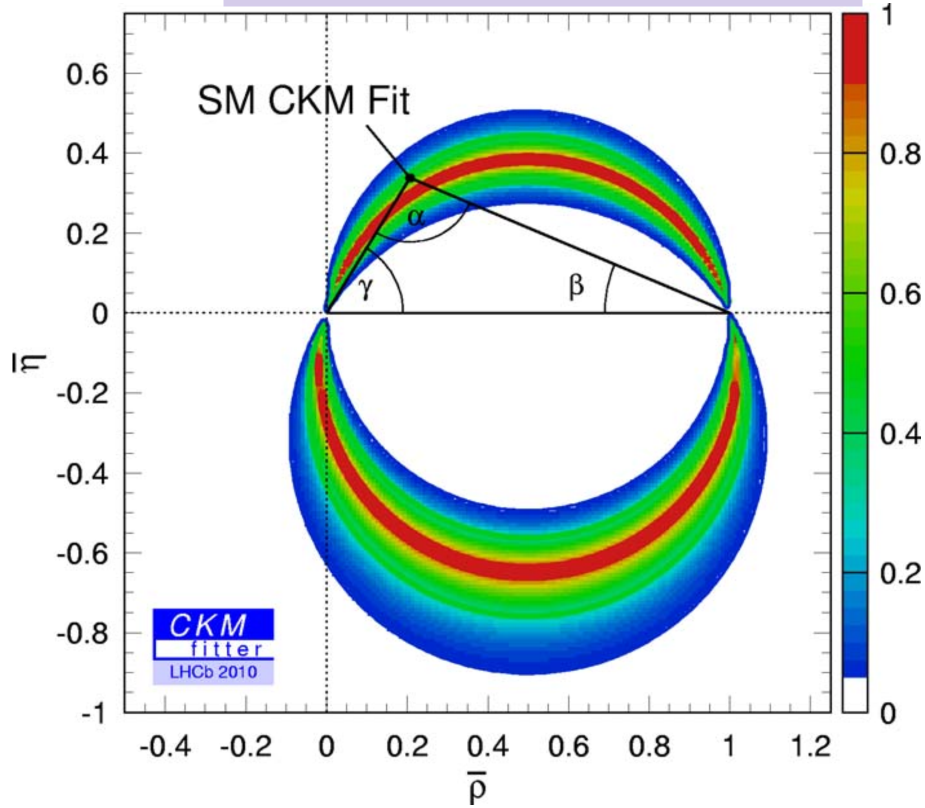
PROSPECTIVE STUDY (2)





$$\alpha^{fit} = 104.7^{\circ}{}^{+8.6^{\circ}}_{-8.1^{\circ}}$$

3 classes of background – B/S=1



$\alpha^{gen} = 98.1^{\circ}$ (*from CKMfitter EPS 2005*)

(γ value is supposed to be perfectly known in bkg models)

SENSITIVITY TO QCD PARAMETERS

Assumed scenario:

$\int L\,dt = 2\ fb^{-1}$ $B/S=1$

T^{-+}	Φ^{-+}	T^{00}	Φ^{00}	P^{+-}	δ^{+-}	P^{-+}	δ^{-+}
0.47	0.00	0.14	0.00	-0.2	-0.5	0.15	2.0

Penguin strong phases

$\sigma(\delta^{-+}) \sim (^{+20}_{-50})°$

$\sigma(\delta^{+-}) \sim (^{+4}_{-25})°$

Tree strong phases

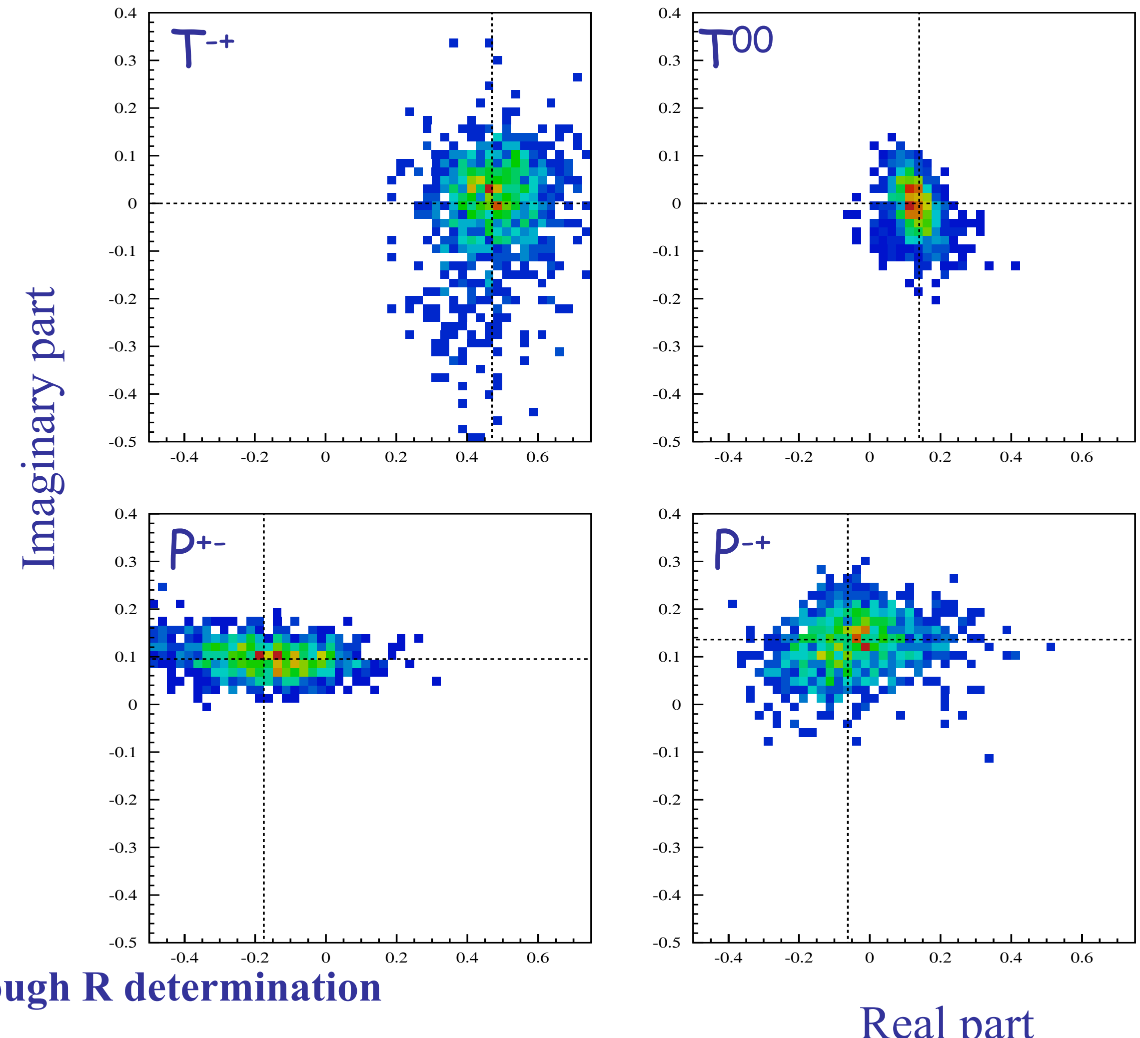
$\sigma(\Phi^{-+}) \sim (^{+6}_{-10})°$

$\sigma(\Phi^{00}) \sim (^{+26}_{-17})°$

$R^{ij}=|P^{ij}/T^{ij}|$ ratios

$\sigma_{R^{-+}}/R^{-+} \sim (^{+50}_{-30})\%$

$\sigma_{R^{+-}}/R^{+-} \sim (^{+70}_{-10})\%$



- Highly asymmetric distributions
- With 2 fb^{-1} , poor sensitivity to R

⇔ Difficult to see sizeable NP effects through R determination after 1 year

Preliminary study of the impact of an imperfect knowledge of experimental or phenomelogical ingredients in likelihood function definition

Include γ 5° uncertainties in $K\pi\pi$ model	$\Delta\alpha \sim 4°$
Non-uniform wrong-tag - averaged in fit	$\Delta\alpha \sim 1°$
L not accounting for proper time acceptance in fit L not accounting for Dalitz acceptance in fit	$\Delta\alpha \sim 0°$ $\Delta\alpha \sim 5°$
L not accounting for ρ/ω mixing in signal	$\Delta\alpha \sim 0°$
L not accounting for ρ' and ρ'' contribution in signal	$\Delta\alpha \sim 7°$
L not accounting for ρ^3 contribution in signal (κ=0.2) arbitrary	$\Delta\alpha \sim 12°$

A poor description of ρ lineshape and/or the phase space acceptance leads to large bias on the α measurement

⇔ Strategy to obtain an accurate knowledge is under development

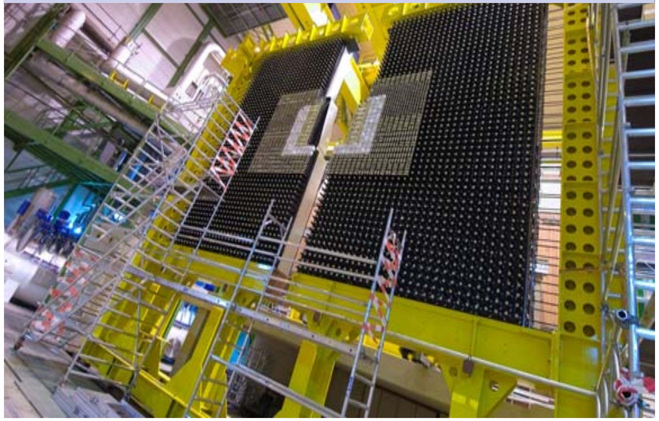
CONCLUSION

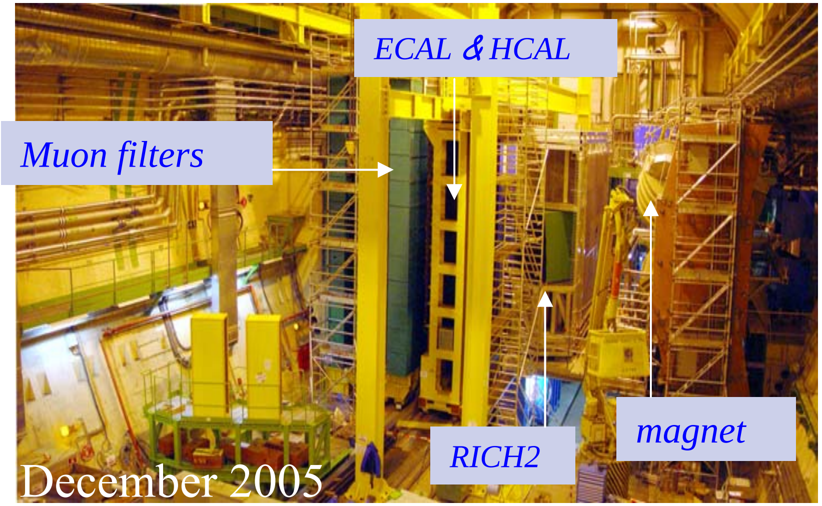
- The $B_d \to \pi^+\pi^-\pi^0$ time dependent Dalitz plot analysis is ambitious.

- With 2 fb^{-1} LHCb may achieve $\sigma^{stat} \leq 10°$, assuming an accurate control of the ρ lineshapes and the experimental distorsions. *This expected value is competitive with the current results of the B factories*.

- Such a control is not trivial and strategies have to be developped to extract the relevant parameters in real data.

ECAL completed in 2005



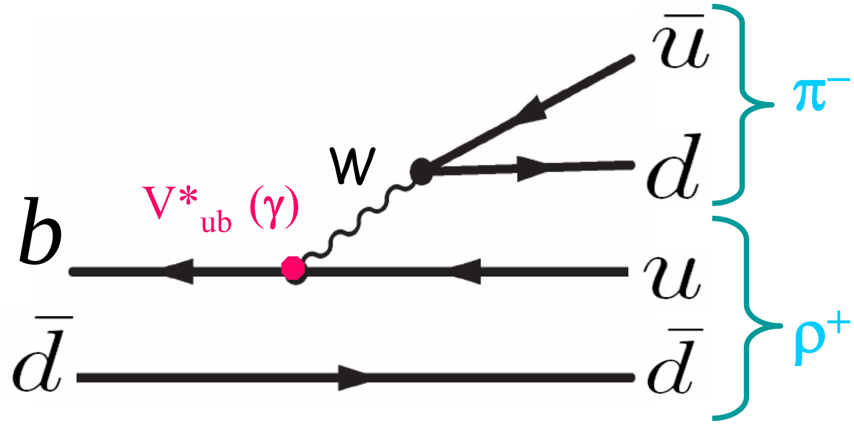


WAITING FOR DATA TAKING IN 2007 …

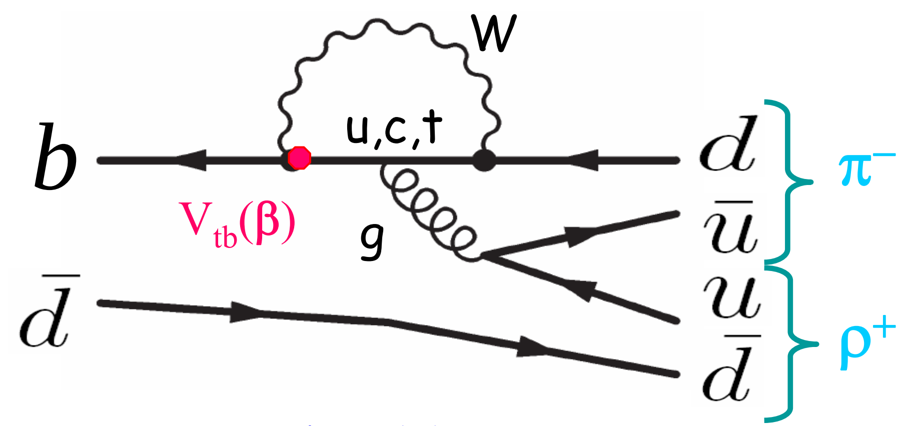
Will be ready at day 1 !

SPARE SLIDE(S)

Two kind of topologies can contribute at the ρπ level :



« Tree » (*T*)



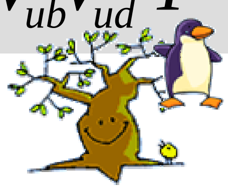
« Penguin » (*P*)

$$A^{ij}(B\to\rho\pi)=V_{ud}V^*_{ub}\,T^{ij}-V_{td}V^*_{tb}\,P^{ij}$$

$$\bar{A}^{ij}(\bar{B}\to\rho\pi)=V_{ub}V^*_{ud}\,T^{ji}-V_{tb}V^*_{td}\,P^{ji}$$

(i+j=0)

2 components ⇔ CKM unitarity

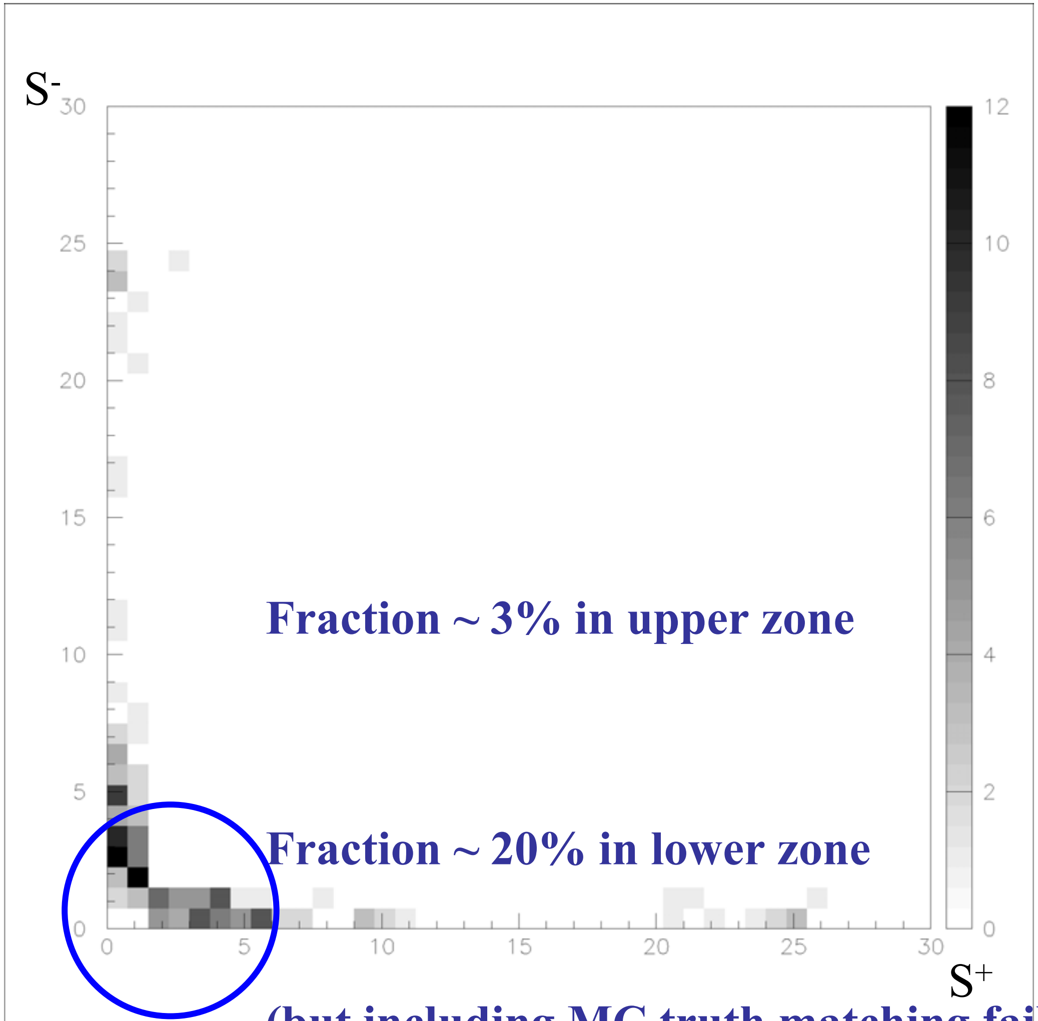


$$A^{ij}=e^{-i\alpha}T^{ij}+P^{ij}$$

$q/p \sim e^{-2i\beta}+o(10^{-3})$

$$\left(\frac{q}{p}\right)\bar{A}^{ij}=e^{i\alpha}T^{ji}+P^{ji}$$

α+β+γ=π



Fraction ~ 3% in upper zone

Fraction ~ 20% in lower zone

(but including MC truth matching failure from soft π^0)

Whithin SM framework **$q/p = e^{-2i\beta}$** ($B\bar{B}$ mixing)

cancel exactly the **b → d** penguin contribution

$$A^{ij} = e^{-i\alpha} T^{ij} + P^{ij}$$

NP can modify this picture (loops…):

$$A^{ij} = e^{-i\alpha} T^{ij} + e^{-i\theta_{NP}} P^{ij}$$

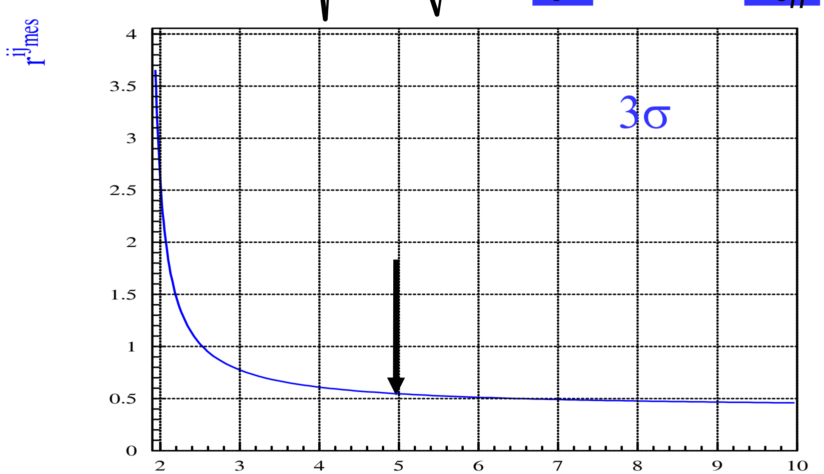
London and Page Phys. Rev. D (2004) 017501

$$r^{ij} = \left| \frac{P^{ij}}{T^{ij}} \right| = \sqrt{\frac{1 - \sqrt{1 - a_i^2}\,.\cos(2\alpha_{eff}^i - 2\alpha)}{1 - \sqrt{1 - a_i^2}\,.\cos(2\alpha_{eff}^i - 2\theta_{NP})}}$$

Fit versus observables:

$$a_i = \frac{|A^{ij}|^2 - |\bar{A}^{ij}|^2}{|A^{ij}|^2 + |\bar{A}^{ij}|^2}$$

$$2\alpha_{eff}^i = Arg(\bar{A}^{ij} A^{ij*})$$



⇔ Assume **$R^{ij\ theo}_{MS}$~10 % ±10%**

Check compatibility with **$\theta_{NP} \neq 0$**

⇔ with 5 years of data taking **R^{ij}_{mes}~55 %** signs NP at **3σ**

Nominal years