Flavour Physics Experiments at LHC

2008 Frascati Spring School Bruno Touschek
-Entering the LHC era-

Frascati, Italy, May 12-16, 2008

Tatsuya Nakada
CERN and EPFL

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

What is on the moon?

What is on the moon?

Of course going there...

What is on the moon?

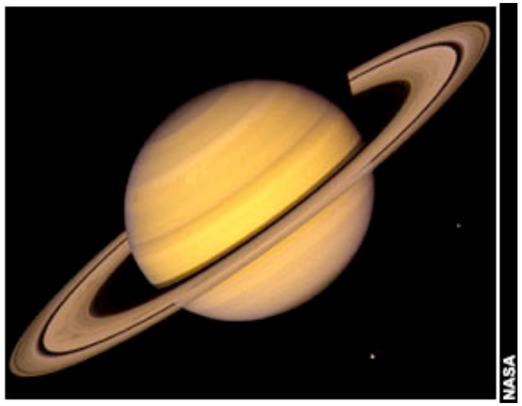
Of course going there...

But you can study a lot from here before

What is on the moon?

Of course going there...

But you can study a lot from here before

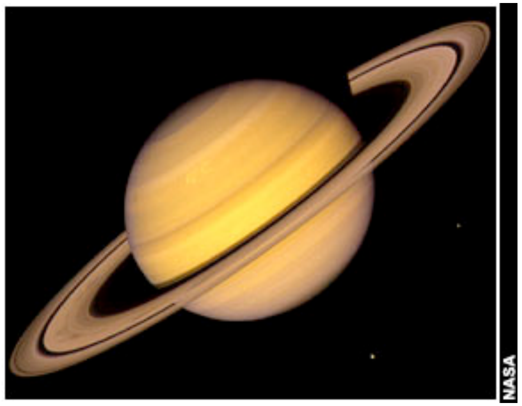


And may be finding something new?

What is on the moon?

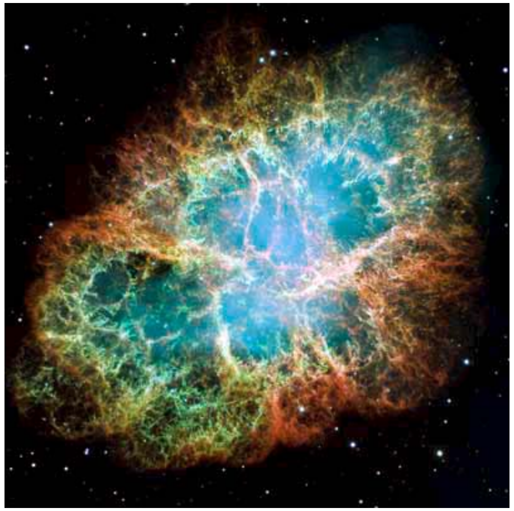
Of course going there...

But you can study a lot from here before



And may be finding something new?

Instruments can be improved and

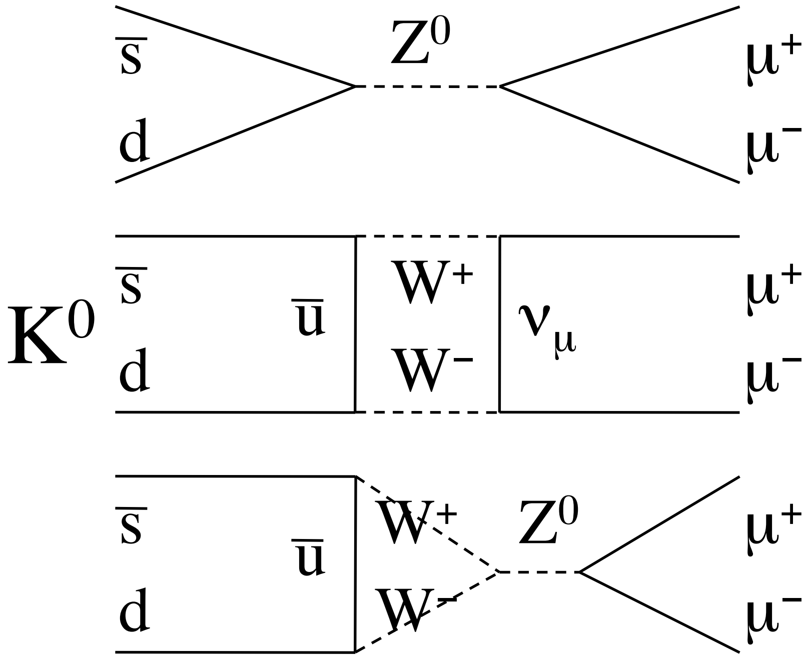


We see far beyond the direct reach...

Flavour Physics

Excellent track record to probe high energy scale

Very suppressed $K_L \to \mu^+\mu^-$



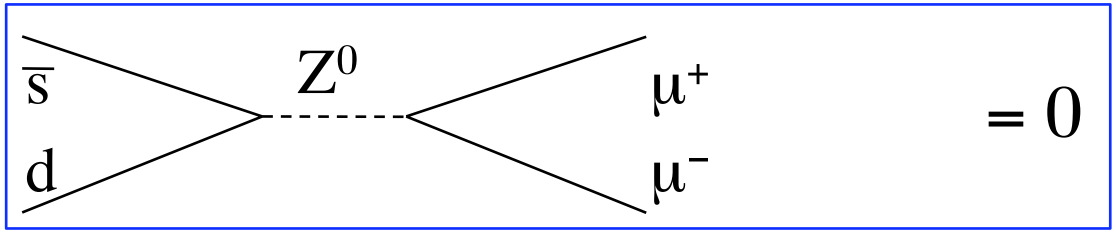
?

Flavour Physics

Excellent track record to probe high energy scale

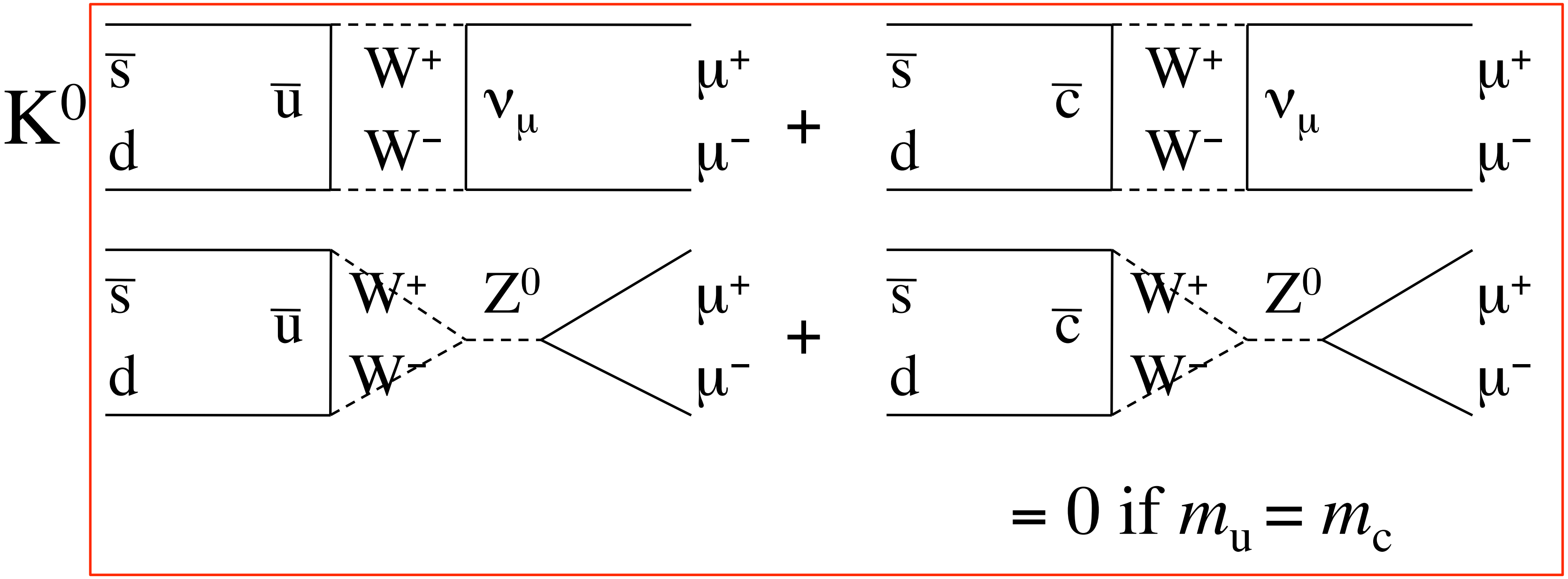
Very suppressed $K_L \to \mu^+\mu^-$ ⇒ SU(2) doublet structure (GIM)

1970



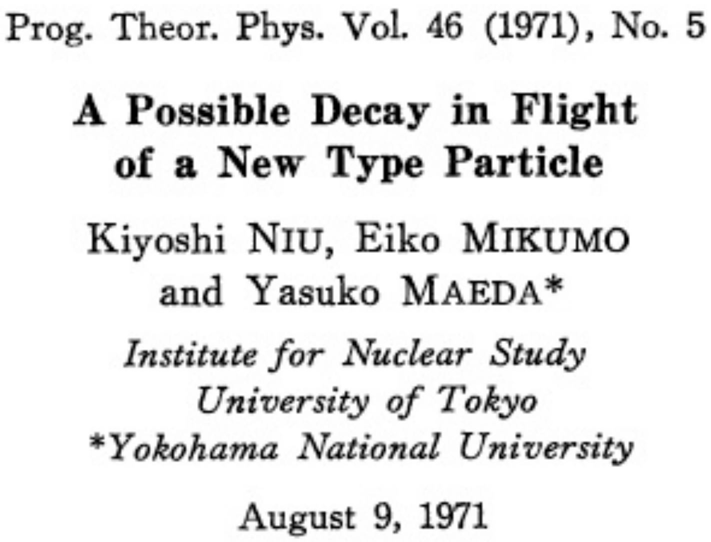
$= 0$

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix}$$



$= 0$ if $m_u = m_c$

Charm discovery



Prog. Theor. Phys. Vol. 46 (1971), No. 5

A Possible Decay in Flight of a New Type Particle

Kiyoshi NIU, Eiko MIKUMO
and Yasuko MAEDA*

Institute for Nuclear Study
University of Tokyo
**Yokohama National University*

August 9, 1971

1971
emulsion exposed in
a JAL Jet cargo plane

one event of
$X \rightarrow \pi^0 + \text{one charged hadron}$

hypo.	$\pi^0\pi^{\text{charged}}$	$\pi^0 p$
τ(s)	2.2×10^{-14}	3.6×10^{-14}
M(GeV)	1.78	2.95

Possibly, the first observation of $D\rightarrow K\pi^0$ decay in 1971

More established discovery was c-$\bar{c}$ bound states in 1974 by J.J. Aubert et al. and J.-E. Augustin et al.

Flavour Physics

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Δm_K and $Br(K_L \rightarrow \mu^+\mu^-)$

Flavour Physics

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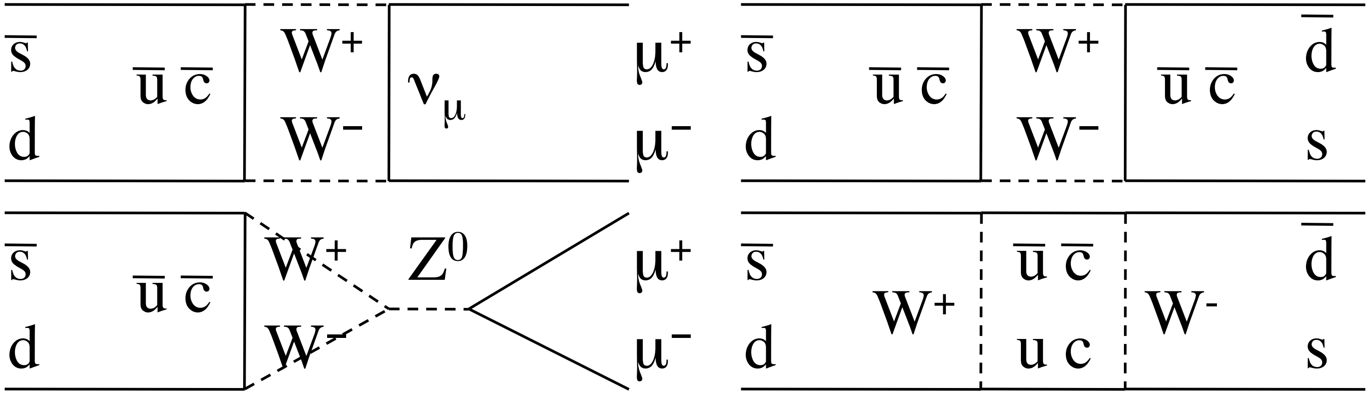
Very suppressed $K_L \to \mu^+\mu^-$ ⇒ SU(2) doublet structure (GIM)

Δm_K and $\mathrm{Br}(K_L \to \mu^+\mu^-)$ ⇒ charm mass ~1.5 GeV/c^2



$Br(K^0 \to \mu^+\mu^-) = F(m_c,\ldots)$ $\Delta m_K = G(m_c,\ldots)$

Gaillard and Lee, 1974

Flavour Physics

Excellent track record to probe high energy scale

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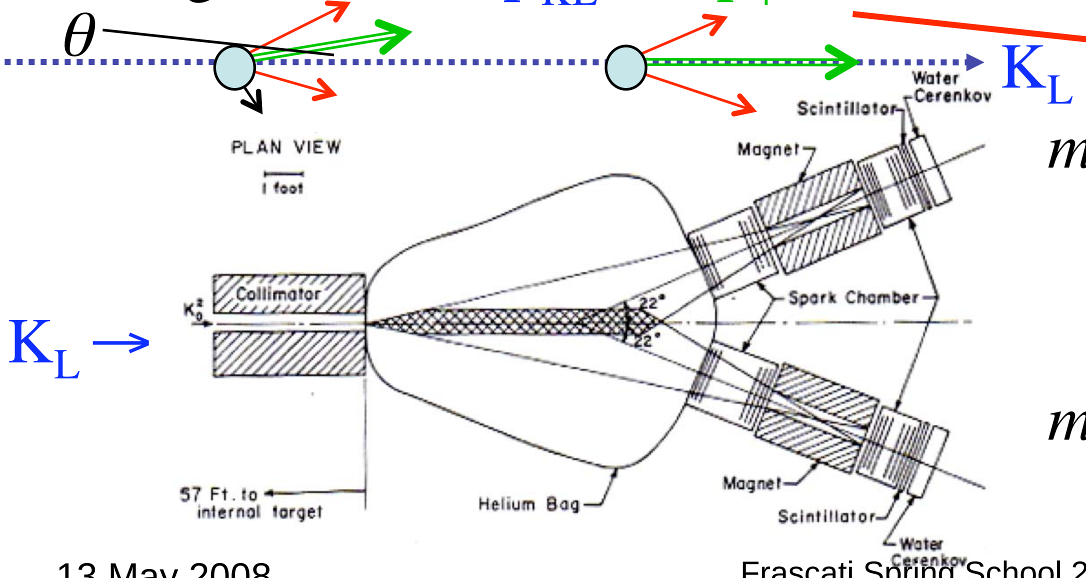
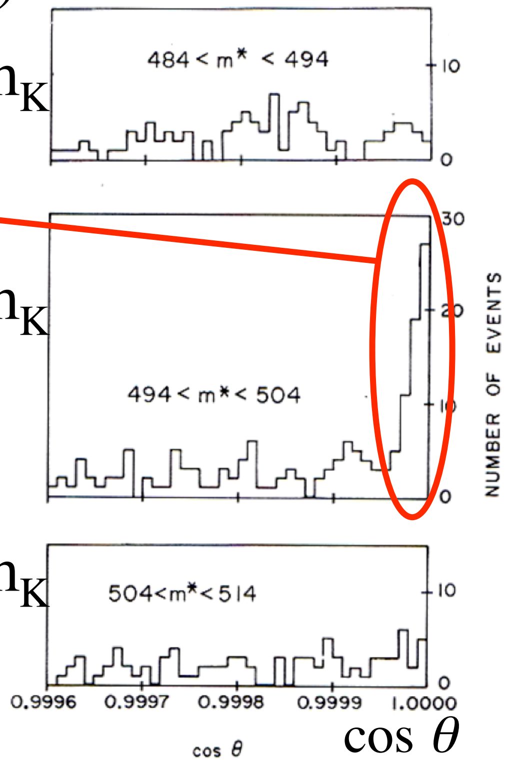
Δm_K and $Br(K_L \to \mu^+\mu^-)$ ⇒ charm mass

CPV 1964, J.H. Christenson et al., $Br(K^0_L \to \pi^+\pi^-) \neq 0$

$\boldsymbol{p}_{+-} = \boldsymbol{p}_{\pi+} + \boldsymbol{p}_{\pi-}$

θ = angle between $\boldsymbol{p}_{KL}$ and $\boldsymbol{p}_{+-}$





$m(\pi^+\pi^-) < m_K$

$m(\pi^+\pi^-) = m_K$

$m(\pi^+\pi^-) > m_K$

cos θ

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CPV 1964, J.H. Christenson et al., $Br(K^0_L \to \pi^+\pi^-) \neq 0$

Superweak theory by
L. Wolfenstein, 1964

Introduction of the third family
by Kobayashi and Maskawa, 1973
(before the charm discovery)

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Δm_K and Br($K_L \to \mu^+\mu^-$) ⇒ charm mass

CPV and very suppressed $B \to \mu^+\mu^-$ ⇒ third family with top

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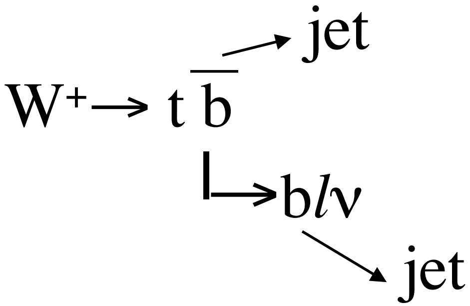
Δm_K and $Br(K_L \to \mu^+\mu^-)$ ⇒ charm mass

CPV and very suppressed $B \to \mu^+\mu^-$ ⇒ third family

Δm_B ⇒ top mass

History of m_t

UA1, 1984

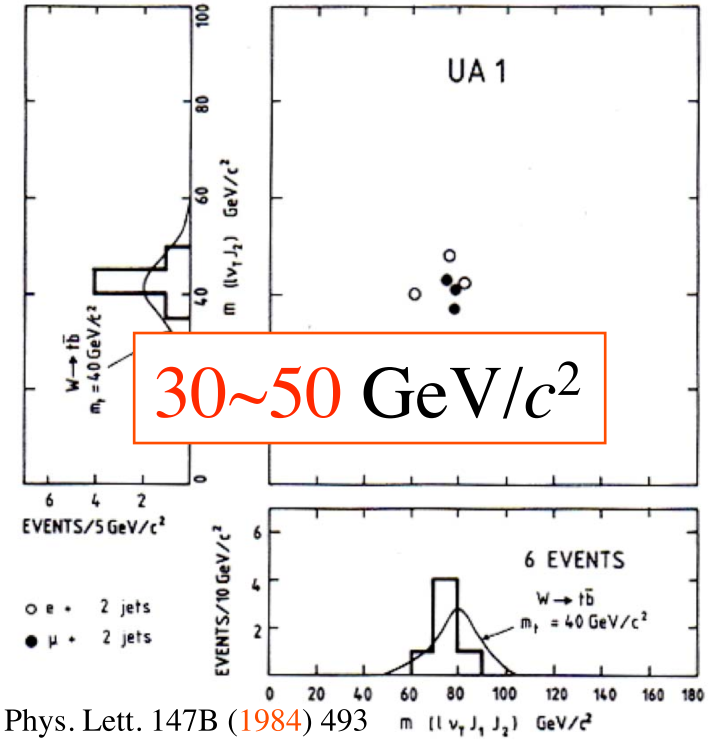


jet

$W^+ \to t\,\bar{b}$

$\hookrightarrow b l \nu$

jet



30~50 GeV/c^2

Phys. Lett. 147B (1984) 493

History of m_t

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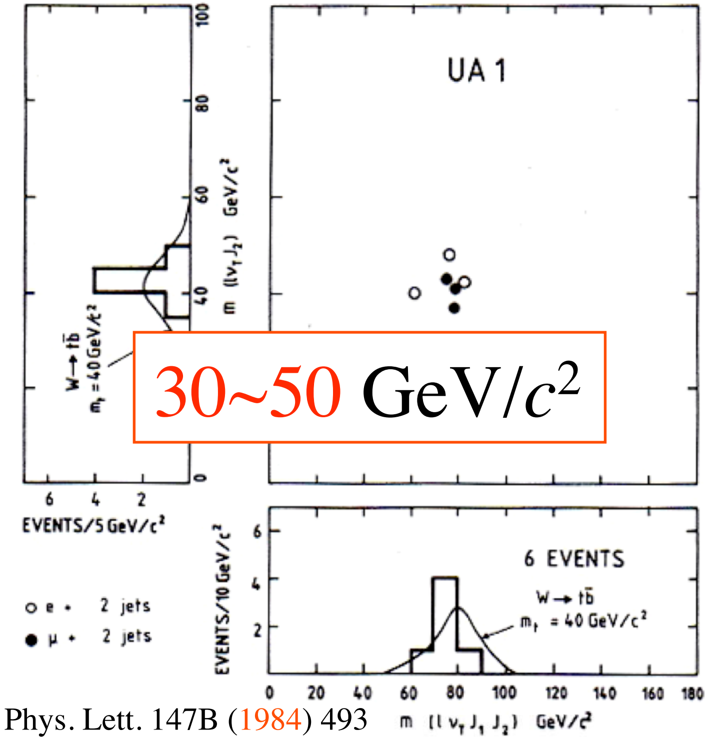


30~50 GeV/c^2

Phys. Lett. 147B (1984) 493

ARGUS, 1987

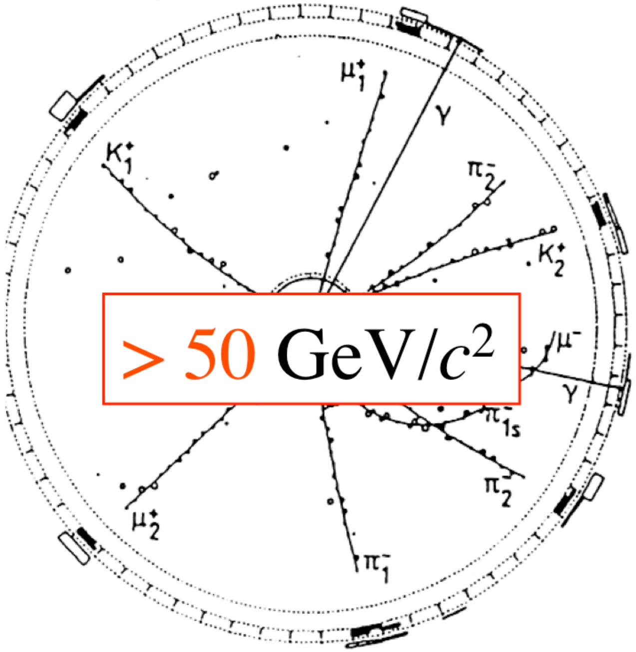
$\Upsilon(4S) \rightarrow B_d{}^0 \overline{B}_d{}^0$

$\rightarrow B_d{}^0 B_d{}^0$ or $\overline{B}_d{}^0 \overline{B}_d{}^0$

$\rightarrow \ell^+ \ell^+$ or $\ell^- \ell^-$

24.8±7.6±3.8

$\Delta m(B_d) \sim 100 \times \Delta m(K^0)$



> 50 GeV/c^2

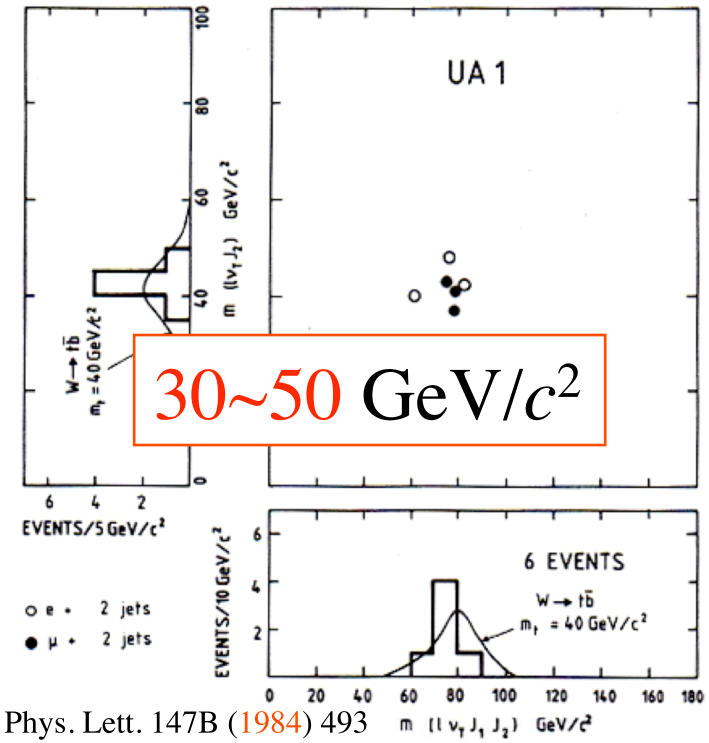
Phys. Lett. B 192 (1987) 245

History of m_t

UA1, 1984

$W^+ \to t\,\bar{b}$, $\bar{b} \to$ jet

$t \to b l \nu$, $b \to$ jet



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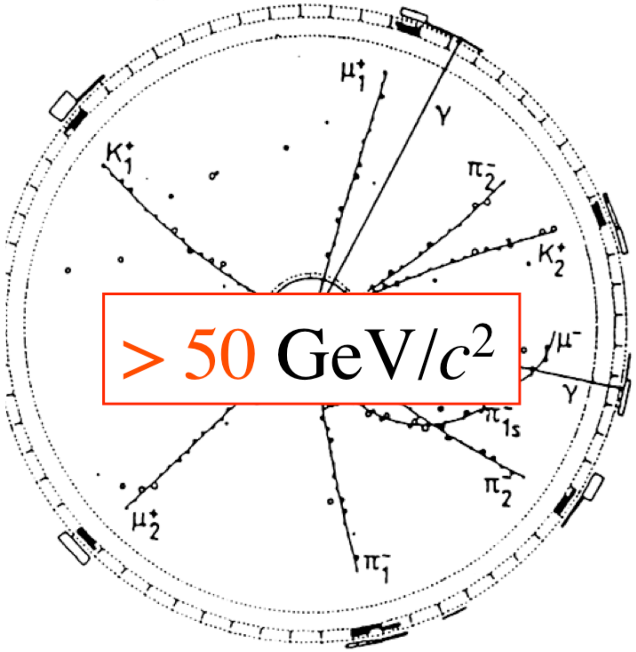

> 50 GeV/c^2

Phys. Lett. B 192 (1987) 245

LEP
electroweak fit
150~210 GeV/c^2

1995
CDF
175±8±10 GeV/c^2
D0
199^{+19}_{-21}±22 GeV/c^2

Flavour Physics

Excellent track record to probe high energy scale

Very suppressed $K_L \to \mu^+\mu^-$ ⇒ SU(2) doublet structure (GIM)
Δm_K and $\mathrm{Br}(K_L \to \mu^+\mu^-)$ ⇒ charm mass
CPV and very suppressed $B \to \mu^+\mu^-$ ⇒ third family
Δm_B ⇒ top mass

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Very suppressed $K_L \to \mu^+\mu^-$	$\Rightarrow$ SU(2) doublet structure (GIM)
Δm_K and $Br(K_L \to \mu^+\mu^-)$	$\Rightarrow$ charm mass
CPV and very suppressed $B \to \mu^+\mu^-$	$\Rightarrow$ third family
Δm_B	$\Rightarrow$ top mass

before observing directly c, b or t

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Δm_K and $Br(K_L \rightarrow \mu^+\mu^-)$	$\Rightarrow$ charm mass
CPV and very suppressed $B \rightarrow \mu^+\mu^-$	$\Rightarrow$ third family
Δm_B	$\Rightarrow$ top mass

and ν oscillations

Discovery of ν_μ: 1962, Lederman-Schwartz-Steinberger
Neutrino mixing by Maki-Nakagawa-Sakata in 1962
introducing $\nu_1 = \nu_e \cos\delta + \nu_\mu \sin\delta$

$$\nu_2 = -\nu_e \sin\delta + \nu_\mu \cos\delta$$

NB: one year before the Cabibbo mixing,
12 years before the charm discovery

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Δm_K and Br($K_L \to \mu^+\mu^-$) ⇒ charm mass
CPV and very suppressed $B \to \mu^+\mu^-$ ⇒ third family
Δm_B ⇒ top mass
and ν oscillations

ν oscillations now seen by, Davis, KAMIOKANDE, IMB, SNOW
MACRO, KamLAND, T2K, MINOS…

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Very suppressed $K_L \rightarrow \mu^+\mu^-$ ⇒ SU(2) doublet structure (GIM)

Δm_K and Br($K_L \rightarrow \mu^+\mu^-$) ⇒ charm mass

CPV and very suppressed $B \rightarrow \mu^+\mu^-$ ⇒ third family

Δm_B ⇒ top mass

ν mixing pattern ⇒ may be heavy neutrinos?

Thoughts on Flavour Physics Experiments

General observation

Hadron machines have been "discovery" machines,

e.g. charm, beauty, W, Z, and top

CP violation in the kaon system mainly studied at hadron machines

plus some contribution from KLOE

Charm mesons have been successfully exploited by

both fixed target hadron beams and e^+e^- storage rings.

Fixed target charm experiments

Important breakthrough in the middle of 80's:
large number of fully reconstructed D mesons
from the hadronic decays

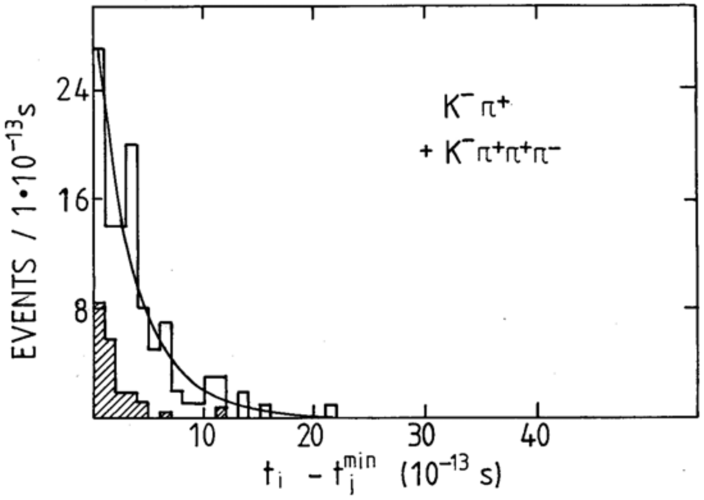
using
Si micro-strip vertex detector and open trigger

$$\frac{\sigma_{c\bar{c}}}{\sigma_{\text{inelastic}}} \approx 10^{-3}$$

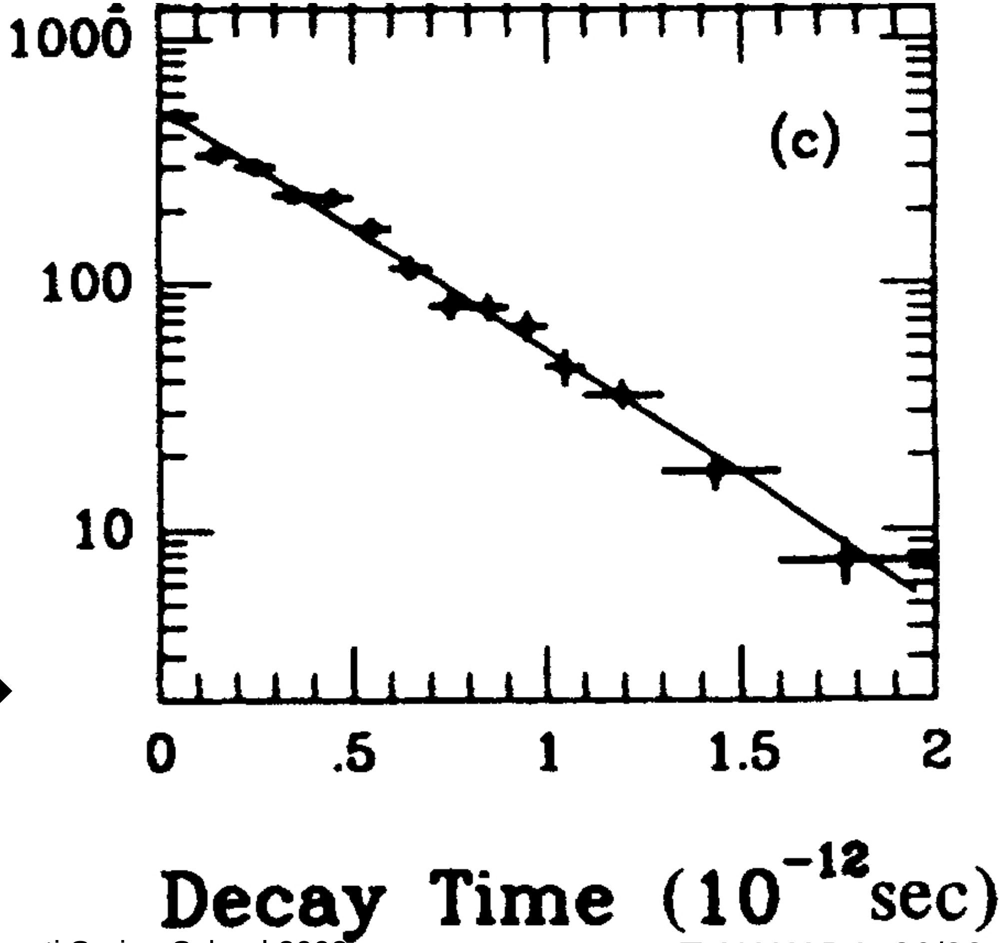
Large amount of data processed by a custom made microprocessor farm

An example: D^0 lifetime

200 GeV/c K and π beam
ACCMOR 1987



Tagged photon beam
E691 1988

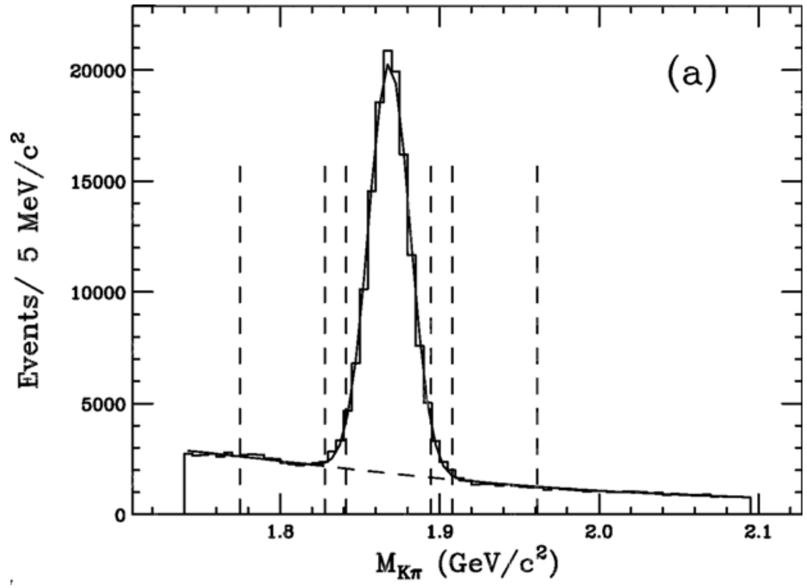


factor ~50 in statistics →

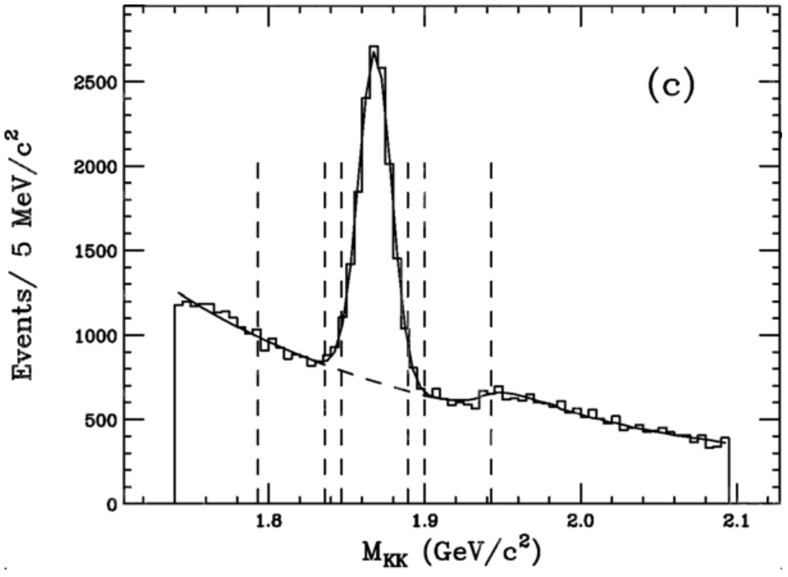
The la(te)st generation of fixed target charm experiments

	beam	statistics	average σ_t
E791	500 GeV π	10^5	40 fs
Focus	up to 300 Gev γ	10^6	30 fs
Selex	600 GeV Σ, π, p	10^4	20 fs

Focus

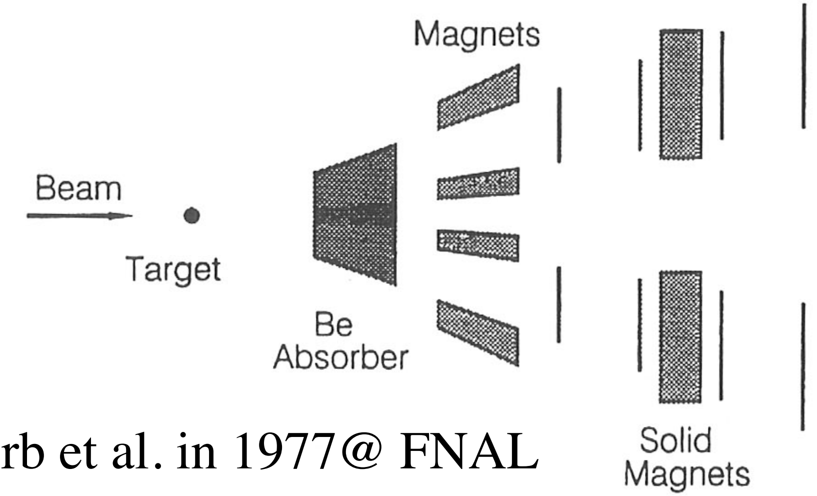


$D^0 \rightarrow K^-\pi^-$ 119738 evts

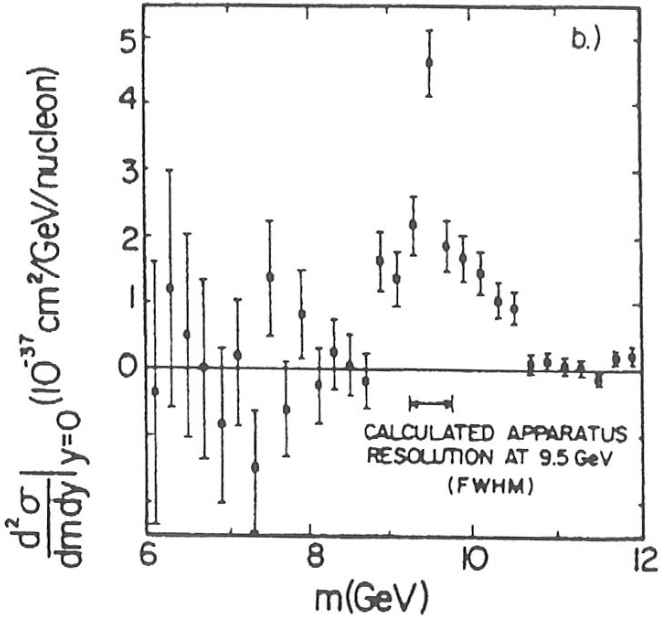


$D^0 \rightarrow K^+K^-$ 10331 evts

After the the discovery of ϒ resonances ($\bar{b}b$ S states) by hadron machine



S. Herb et al. in 1977@ FNAL



For many years, B meson study had been dominated by DORIS, CESR, VEPP and LEP

i.e. at e^+e^- machines

Experiments at hadron machines, fixed target, were “limited”

CERN: Beatrice FNAL:E866/E789/E772, E771

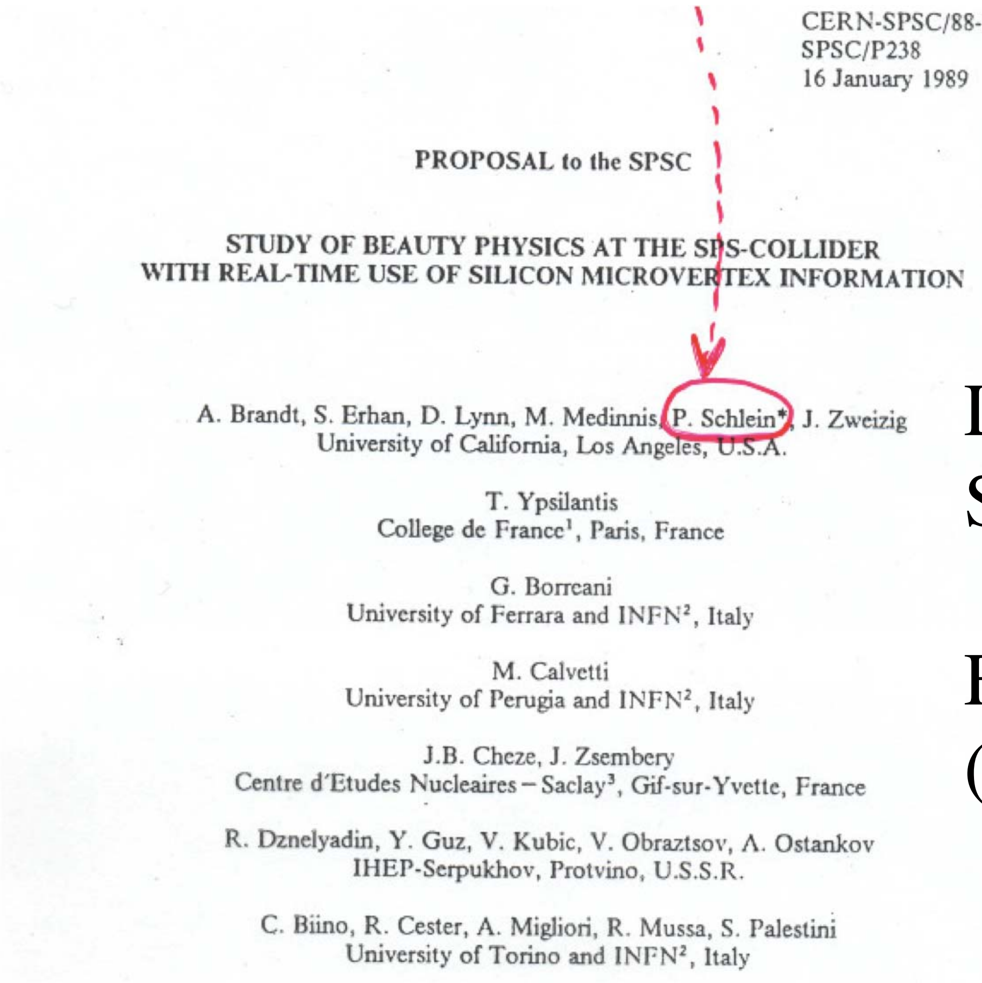
b cross section measurements (with large error bars)

→ simply not enough b’s and too small $\sigma_b/\sigma_{\text{inelastic}}$

There were some ideas to make B experiments at $p\bar{p}$ colliders

Bjorken at Tevatron

P. Schlein at $Sp\bar{p}S$ and Tevatron



CERN-SPSC/88-33
SPSC/P238
16 January 1989

PROPOSAL to the SPSC

STUDY OF BEAUTY PHYSICS AT THE SPS-COLLIDER
WITH REAL-TIME USE OF SILICON MICROVERTEX INFORMATION

A. Brandt, S. Erhan, D. Lynn, M. Medinnis, P. Schlein[*], J. Zweizig
University of California, Los Angeles, U.S.A.

T. Ypsilantis
College de France[1], Paris, France

G. Borreani
University of Ferrara and INFN[2], Italy

M. Calvetti
University of Perugia and INFN[2], Italy

J.B. Cheze, J. Zsembery
Centre d'Etudes Nucleaires – Saclay[3], Gif-sur-Yvette, France

R. Dznelyadin, Y. Guz, V. Kubic, V. Obraztsov, A. Ostankov
IHEP-Serpukhov, Protvino, U.S.S.R.

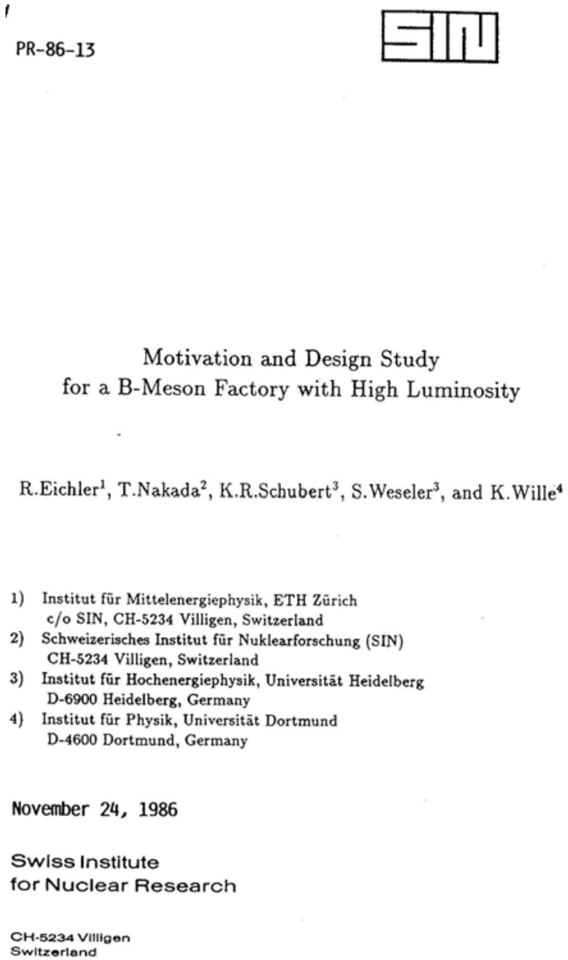
C. Biino, R. Cester, A. Migliori, R. Mussa, S. Palestini
University of Torino and INFN[2], Italy

Large $b\bar{b}$ cross section

Si vertex detector in
Roman Pot

Forward spectrometer
(forward peaked b production)

In the mean time, many ideas to build an e^+e^- B meson “factory” at $\Upsilon(4S)$, starting with SIN in 1986 double ring with $L > 5\times10^{32}\ \mathrm{cm^{-2}s^{-1}}$, symmetric energy
Upgraded to PSI Proposal (1988)
$L > 10^{33}\ \mathrm{cm^{-2}s^{-1}}$
with modest asymmetric energy option



PR-86-13

Motivation and Design Study
for a B-Meson Factory with High Luminosity

R.Eichler[1], T.Nakada[2], K.R.Schubert[3], S.Weseler[3], and K.Wille[4]

1) Institut für Mittelenergiephysik, ETH Zürich
c/o SIN, CH-5234 Villigen, Switzerland
2) Schweizerisches Institut für Nuklearforschung (SIN)
CH-5234 Villigen, Switzerland
3) Institut für Hochenergiephysik, Universität Heidelberg
D-6900 Heidelberg, Germany
4) Institut für Physik, Universität Dortmund
D-4600 Dortmund, Germany

November 24, 1986

Swiss Institute
for Nuclear Research

CH-5234 Villigen
Switzerland

Discovery of B-$\overline{\mathrm{B}}$ mixing in 1887 made it possible to make a SM prediction for CPV for $B\rightarrow J/\psi K_S$ without knowing m_t: ~0.4 i.e. “large” (NB $f_B = 110$ MeV in those days)

Z. Phys. C 36 (1987) 503

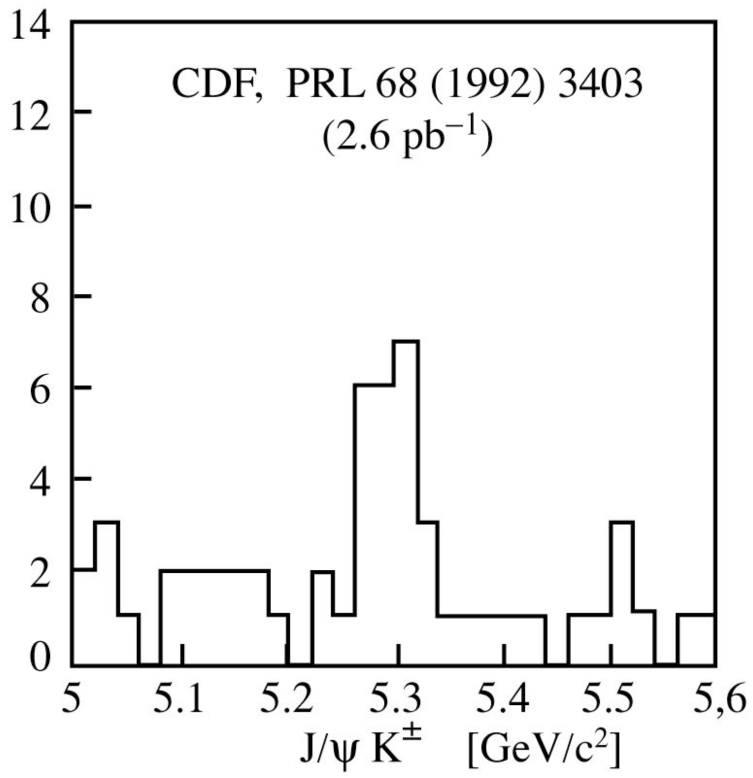
➜a concrete minimum “luminosity requirement”
i.e. $>10^{33}\ \mathrm{cm^{-2}s^{-1}}$

Many B factory ideas emerged:
SLAC, DESY, Cornell, KEK, Novosibirsk, Italy, UCLA and CERN
from standard storage rings with symmetric energy, with different energy asymmetries, linear collider, and to linear against circular…

European option has died with CERN-ISR option in 1990
CERN-YELLOW-90-02
→No European B opportunity except LEP running at Z^0

In US: competition between Cornell and SLAC
In Japan: water was slowly boiling

Then



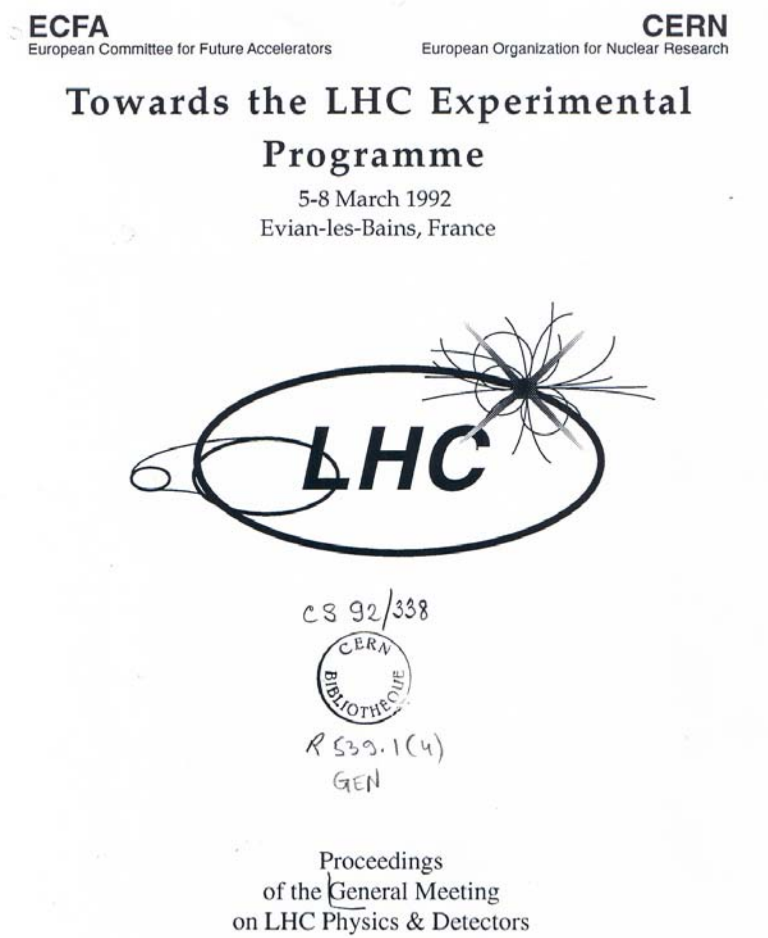
First fully reconstructed B meson at a hadron machine!
(largest number of reconstructed $B^{\pm} \rightarrow J/\psi K^{\pm}$ at that time)

B physics with a hadron machine at high energy looks feasible!

D0 and CDF then contributed a lot in lifetimes, CPV, and oscillations. (B_s oscillation measurement is still unique)

Back to the European Front

Evian workshop EoI's presentation, 1992



ECFA
European Committee for Future Accelerators

CERN
European Organization for Nuclear Research

Towards the LHC Experimental Programme

5-8 March 1992
Evian-les-Bains, France

Proceedings
of the General Meeting
on LHC Physics & Detectors

NB: Approval of B factories at KEK and SLAC in 1993
Starting of data taking in 2000

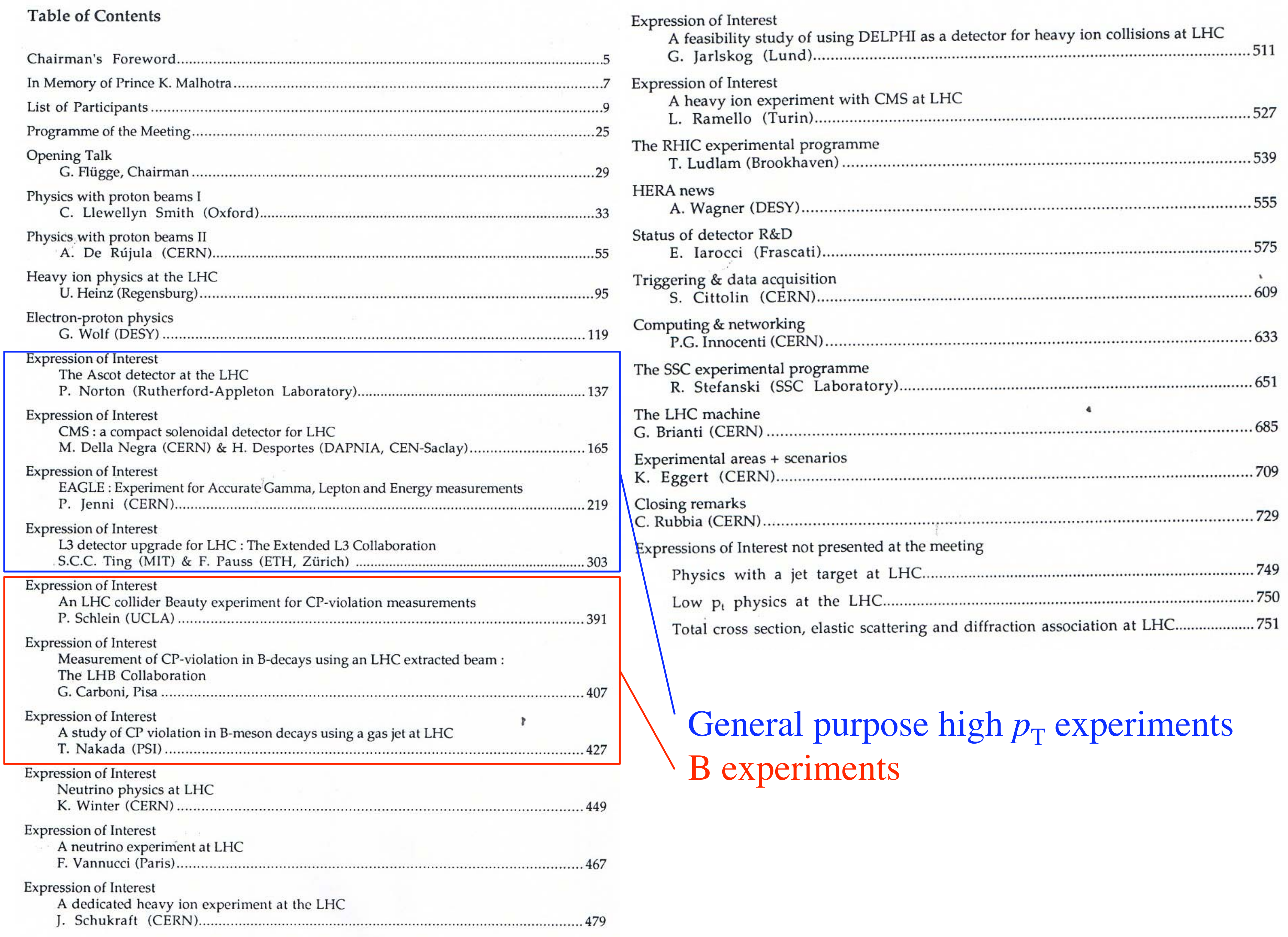


Table of Contents

General purpose high p_T experiments

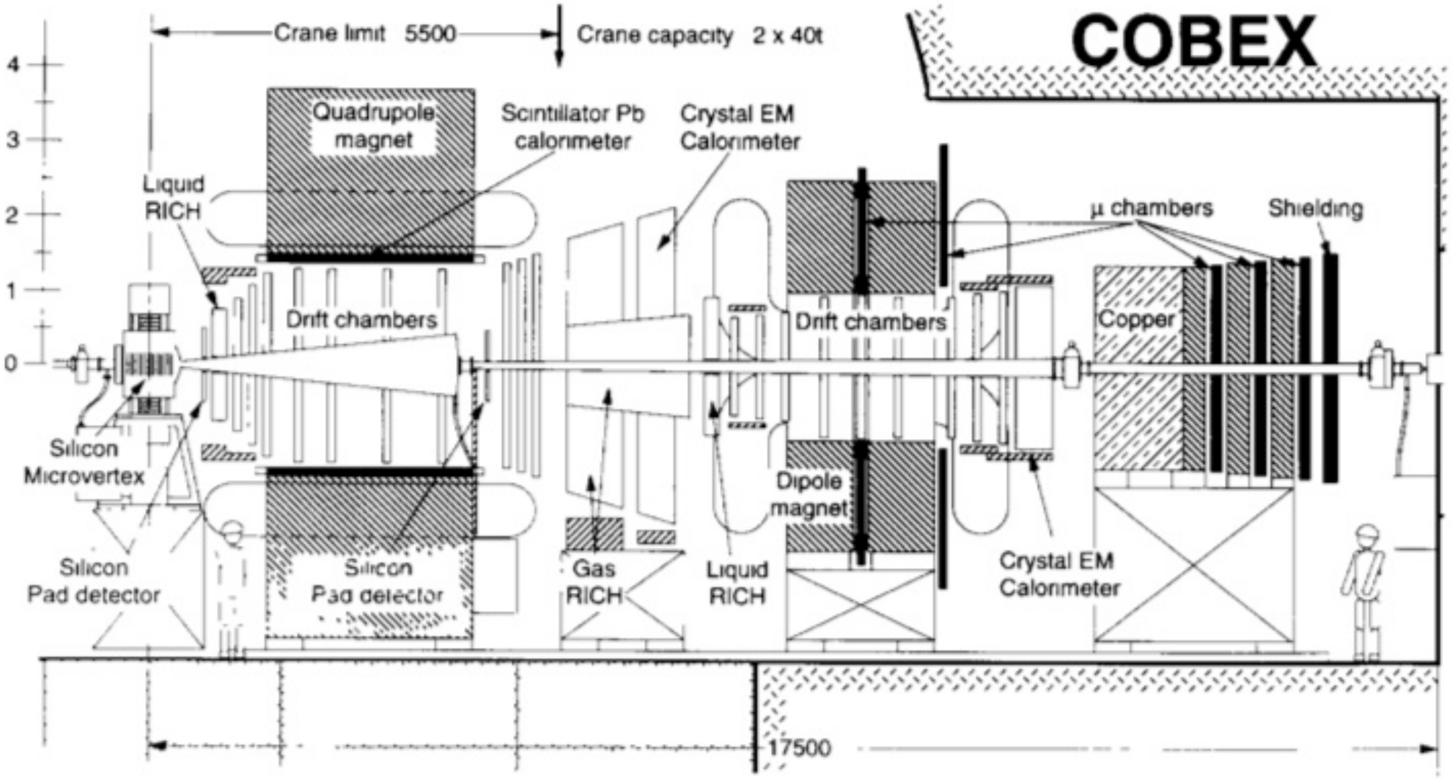
B experiments

Evian workshop on EoI's presentation, 1992

- Four high p_T experiments
- Neutrino and Heavy Ion experiments
- Three B physics experiments
  - -SM was not quantitatively tested for CPV
    - main goals were
      - CPV in $\rightarrow J/\psi K_S$, $\rightarrow \pi\pi$, B_s oscillations
  - -three different approaches
    - 1) pp colliding mode in the forward direction
      - COBEX
    - 2) extraction of p to a fixed target
      - LHB
    - 3) internal gas jet as a fixed target
      - GAJET
  - Followed by three LoI's in 1993

COBEX

vertex and tracking detector, two magnets, RICH, E-cal, muon
first level topology trigger at low L and μ p_T trigger at high L
☺large √s → large bb cross section

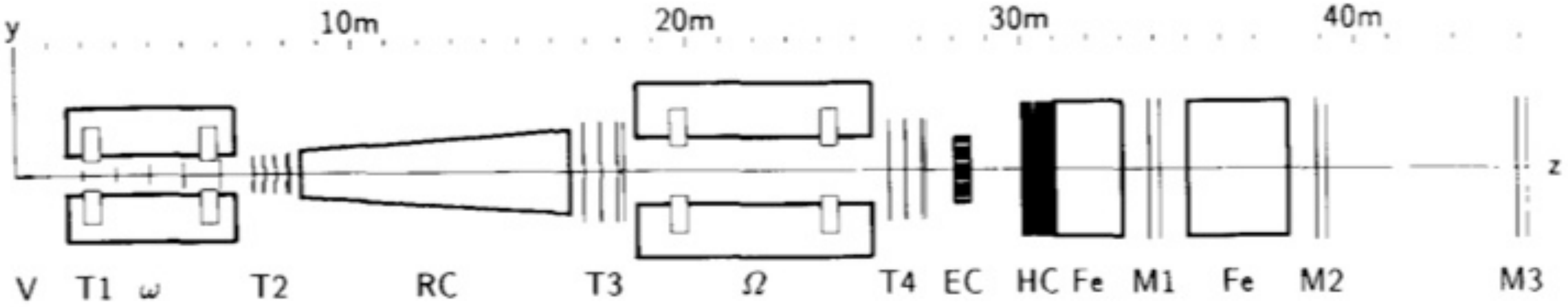


LHB

vertex and tracking detector, two magnets, RICH, E+H-cal, muon

first level lepton (μ and e) p_T trigger

☺large boost → charged Bs are visible in the vertex detector ($B^+ \rightarrow \tau\nu$)



protons are extracted from the beam halo using a bent crystal

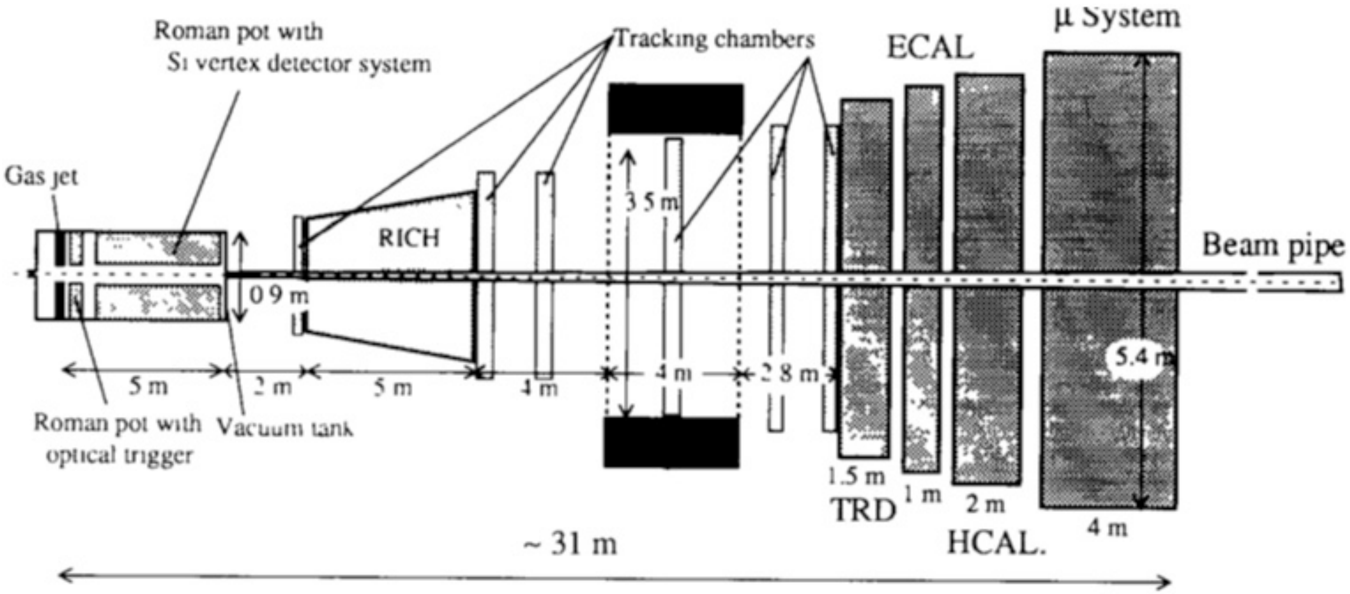
dedicated experimental area, i.e. more flexibility

GAJET

vertex and tracking detector, single magnet, RICH, TRD, E+H-cal, muon

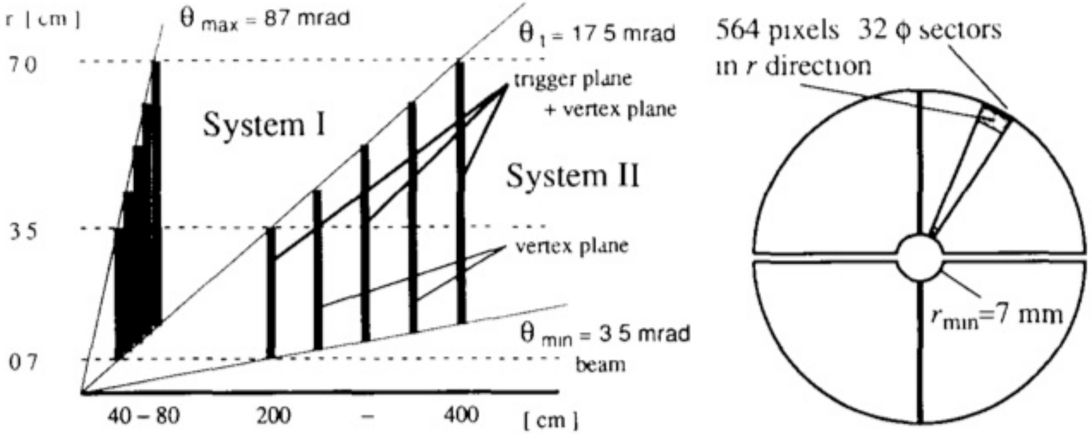
first level impact parameter and hadron+lepton p_T trigger

☺small dimension of gas target → B production vertex a priori known



r-φ striplets

vertex detector



LHCC decisions

January 1994

In the subsequent discussion on B physics, the LHCC considered the case for a dedicated B experiment at the LHC, and agreed on a recommendation to be sent to the Director General for consideration by the Research Board.

June 1994

Decided not to approve any of the three experiments but to form one new collaboration to propose a new experiment based on the collider mode to exploit its large $b\bar{b}$ cross section with a convincing trigger strategy.

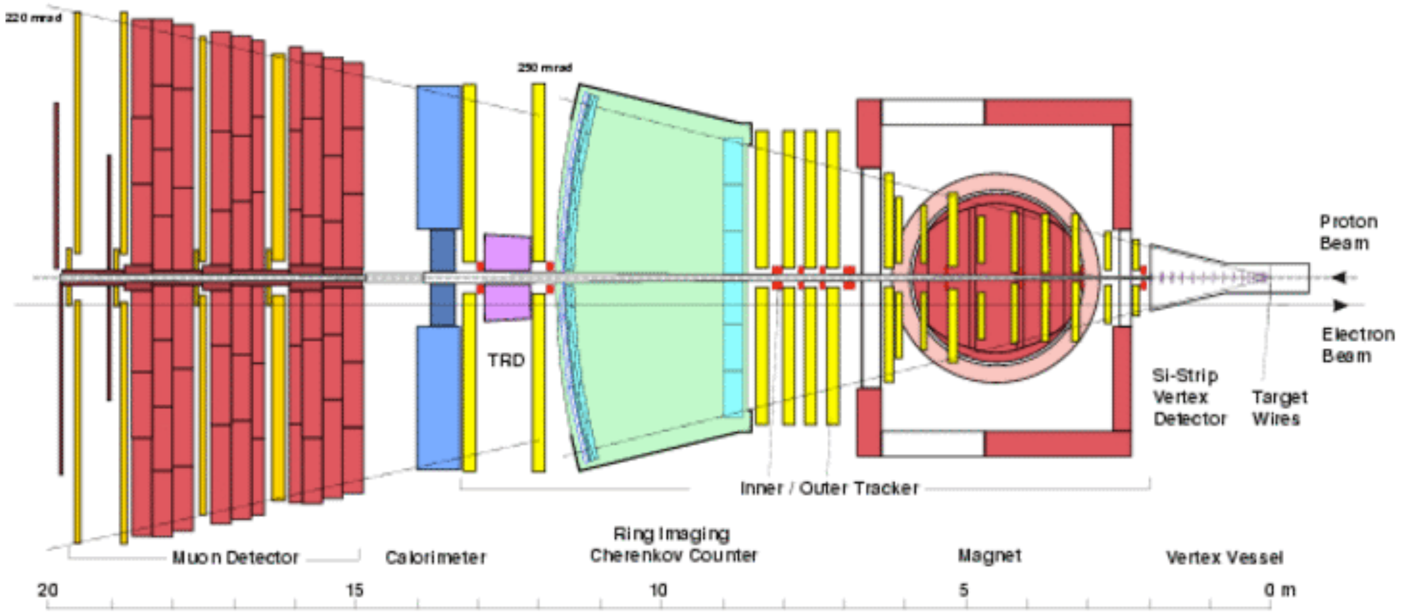
This appears to have been a correct decision, given the fact

1) B-factories and Tevatron are doing well

2) LHC is (much) later than originally thought

HERA-B remark

ARGUS group at DESY started to think about a fixed target experiment using HERA proton ring (920 GeV/*c*) and internal wire targets around the time of Evian workshop in 1992.



Approved in 1994 to compete with B-factories with $\sigma(\sin 2\beta) = 0.13\ \mathrm{y}^{-1}$

Physics data taking started in 2001. Physics paper on production cross sections, but not CPV…

It was a quite tough job: $\sigma_b / \sigma_{total} \sim 10^{-6}$

Advantage of the LHC collider mode

Large b cross section (~500μb)

Large $\sigma_{b\bar{b}} / \sigma_{\text{inelastic}}$ ($>10^{-3}$)

at fixed target energies 10^{-6}

$\approx \sigma_{c\bar{c}} / \sigma_{\text{inelastic}}$ at fixed target energies

Different b-hadrons (B_u, B_d, B_s, B_c, Λ_b, Σ_b, Ξ_b etc.)

Many primary particles → well defined b production vertex

To fight against combinatorial backgrounds:

vertexing, PID, and mass resolution

Open trigger a la charm fixed-target experiment

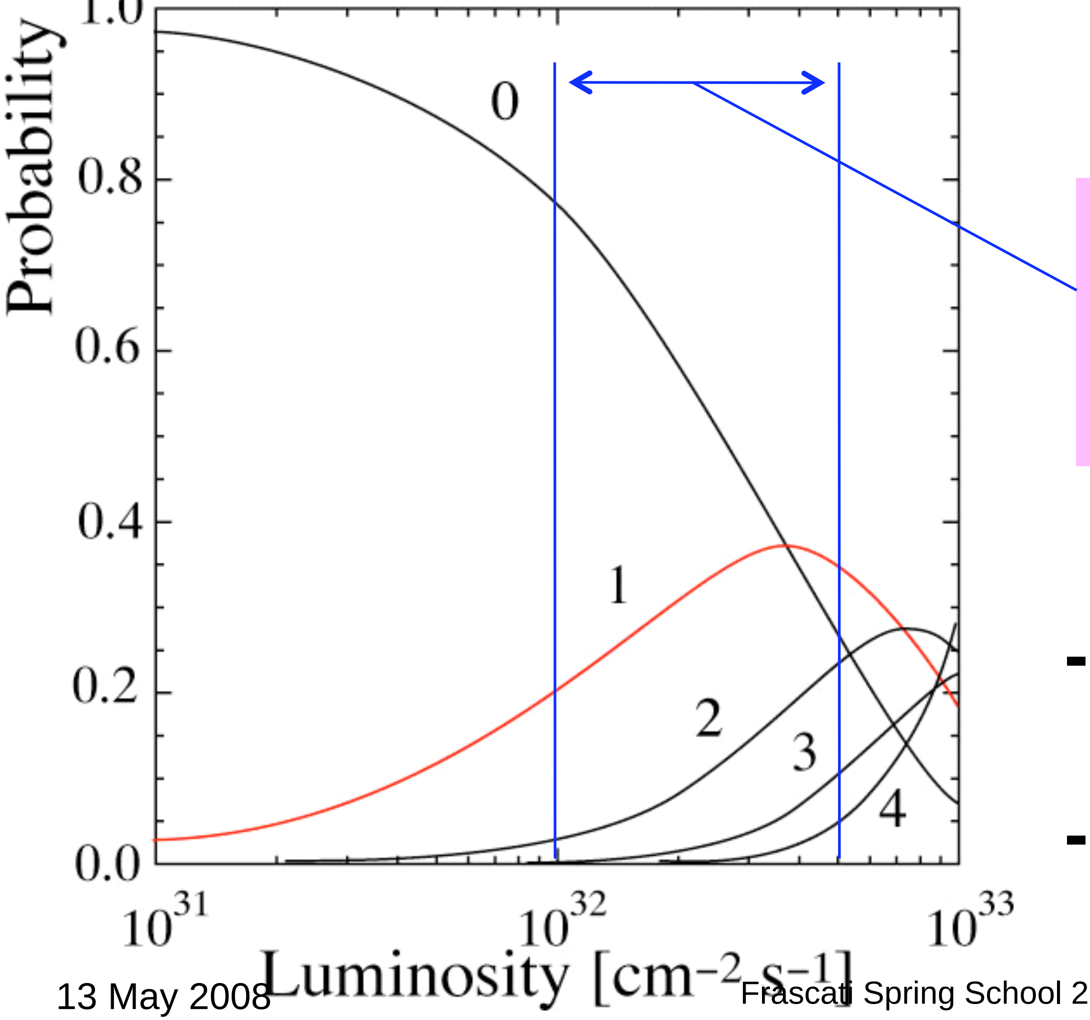
- is not an option at LHC
  - too high inelastic event rate
  - interesting decay modes are restricted

Trigger is crucial

- At the first level
  - inclusive signature: p_T and displaced tracks/vertices
- At the intermediate level
  - semi-exclusive partial reconstruction
- Finally
  - exclusive reconstruction

Bunch crossing frequency: f_{pp} = 40 MHz, i.e. every 25 nsec

Number of pp inelastic interactions in one bunch crossing ($\sigma_{inelastic}$ = 80 mb), 0, 1, 2 …

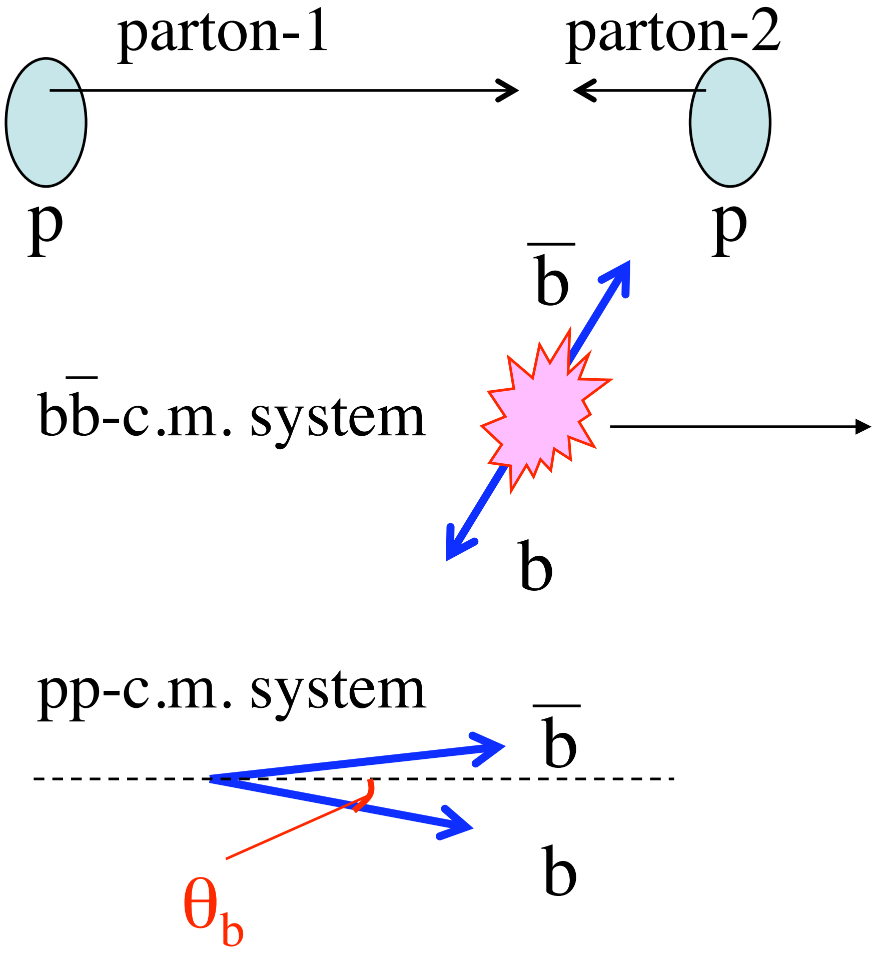


One inelastic interaction per bunch crossing dominates.

- Reconstruction easier (final state and tag)
- Lower radiation level

Forward geometry

$b\bar{b}$ pair production kinematics



parton-1

parton-2

p

p

$\bar{b}$

$b\bar{b}$-c.m. system

b

pp-c.m. system

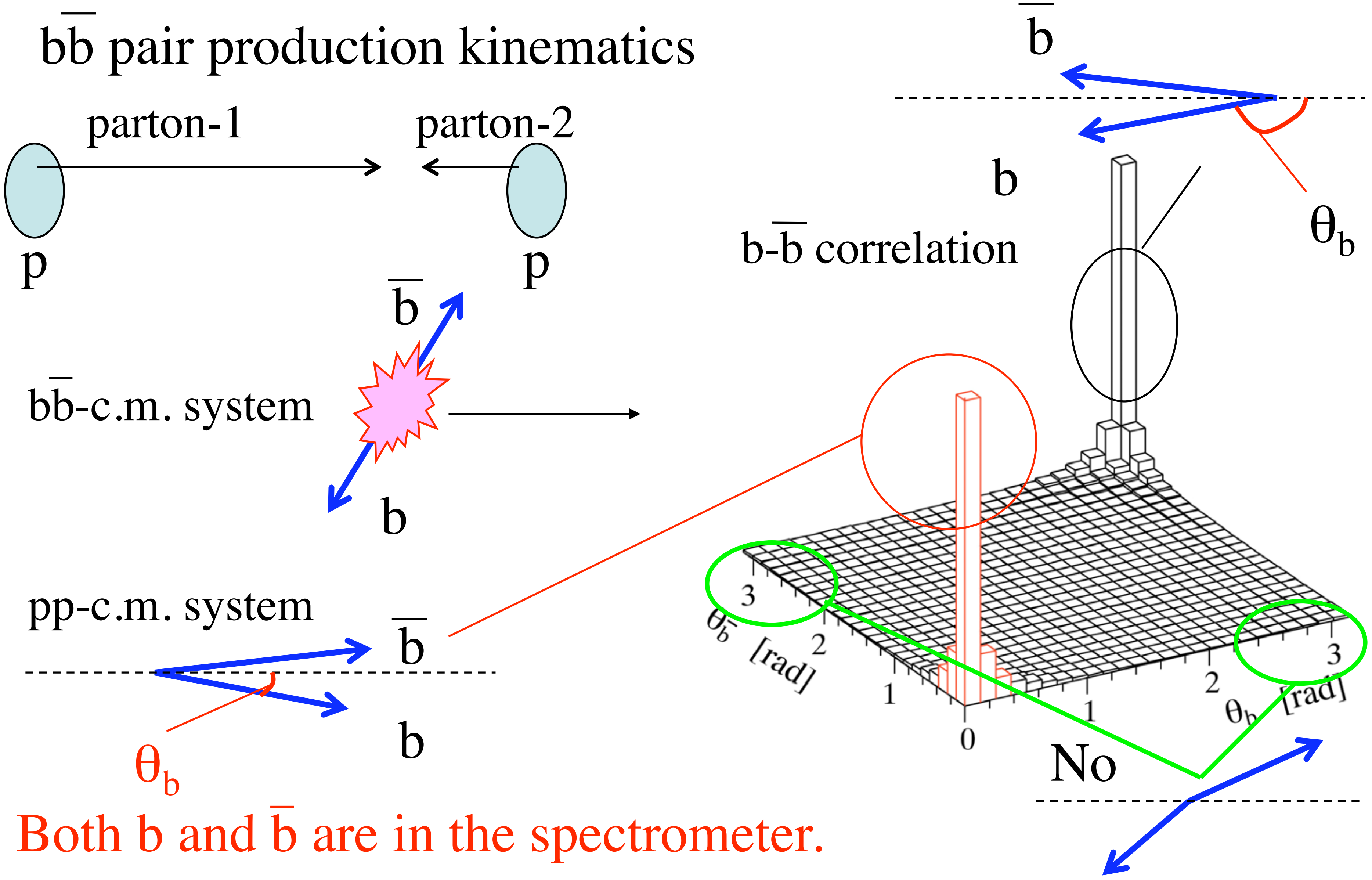
$\bar{b}$

b

θ_b

Forward geometry

$b\bar{b}$ pair production kinematics



$b\bar{b}$-c.m. system

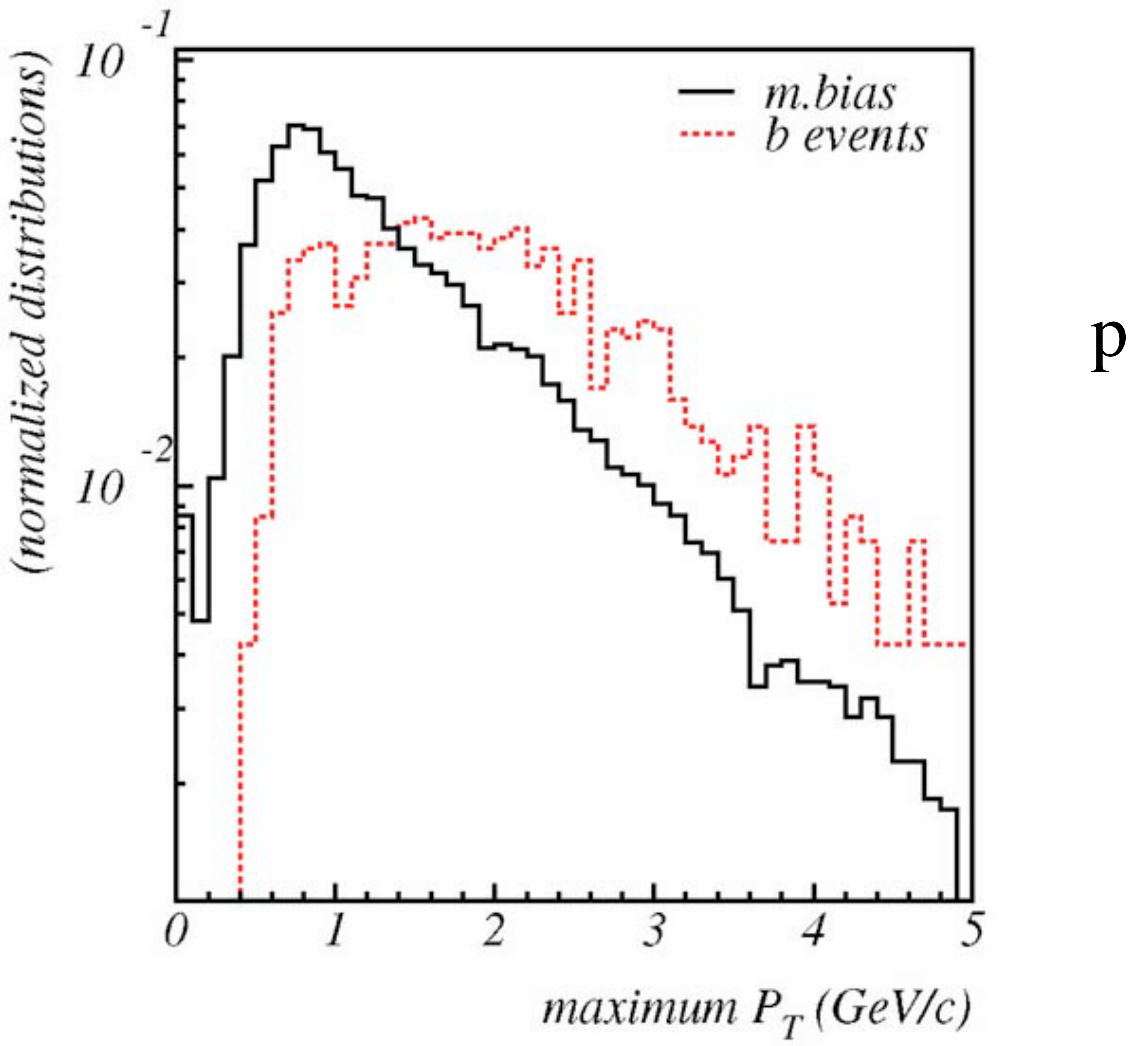
pp-c.m. system

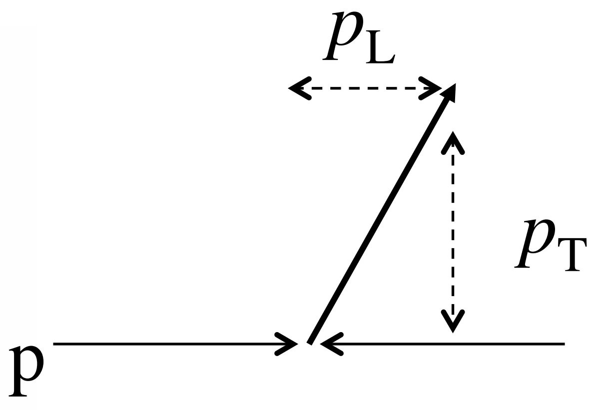
b-$\bar{b}$ correlation

Both b and $\bar{b}$ are in the spectrometer.

f_{pp} @ LHC = 40 MHz → simple first level trigger needed

Single p_T trigger for μ, e, h





muon system:

low track density

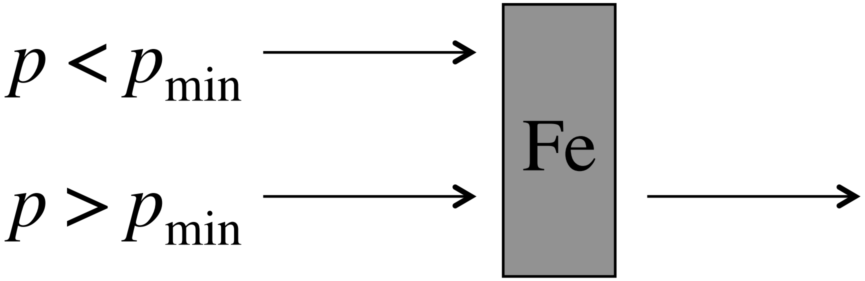
e and h:

calorimeter

E_T measurements

However…. $p > p_{\text{min}}$

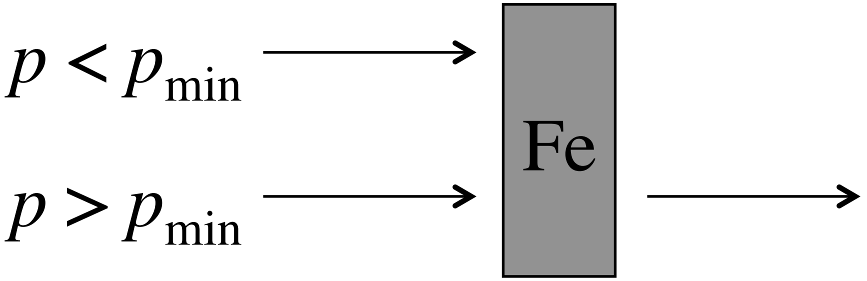
muon:
identification



hadron:
energy resolution

$$\sigma_E/E \approx \sqrt{70\%}/\sqrt{E}$$

However…. $p > p_{min}$



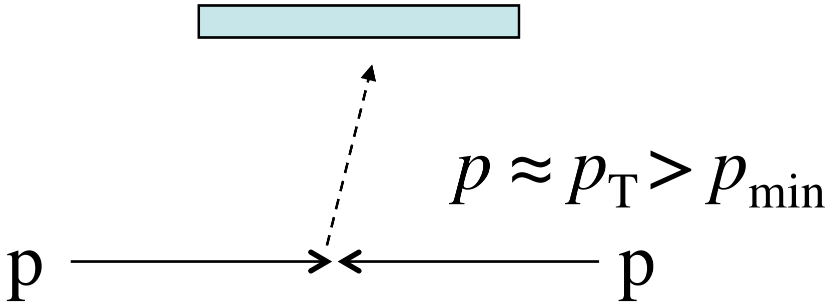
muon:
identification

$p < p_{min}$

$p > p_{min}$

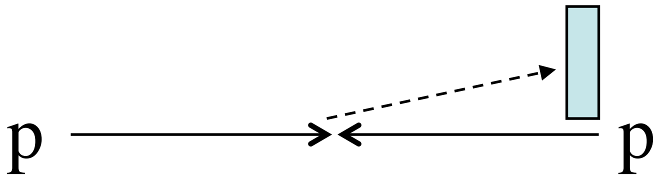
hadron:
energy resolution

$\sigma_E/E \approx \sqrt{70\%}/\sqrt{E}$



central detector

$p \approx p_T > p_{min}$



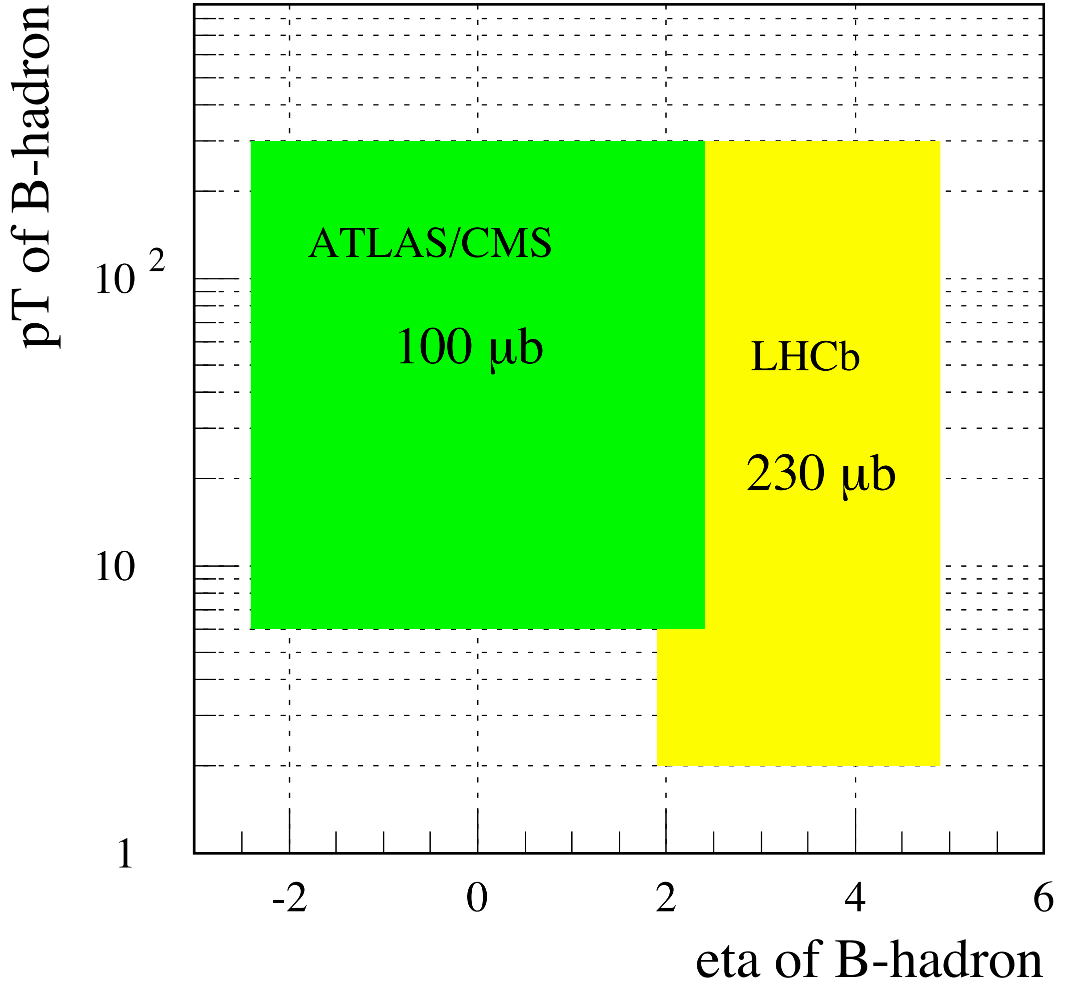
forward detector

$p \approx p_L > p_{min}$

p_T threshold can be set low:
→ high b efficiency

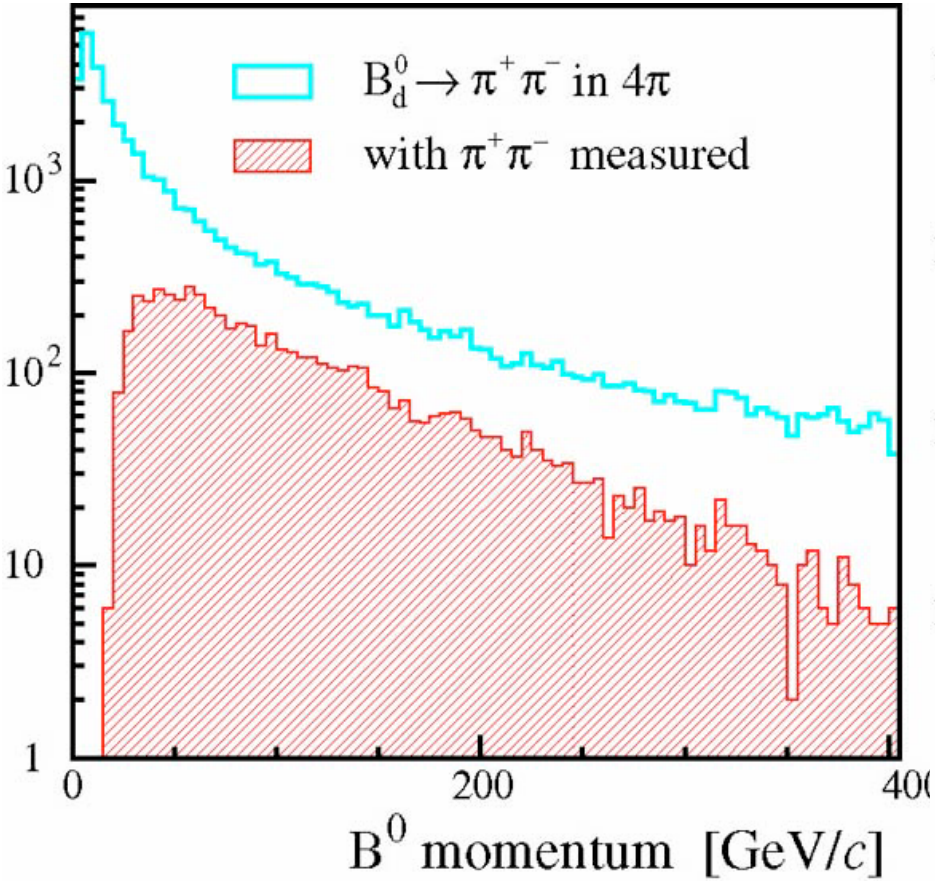
$\sigma_{b\bar{b}}$ expected in pp collisions at $\sqrt{s}$ = 14 TeV: 500μb

5×10^{11} $b\bar{b}$ pairs in 1 year (10^7 s) with L=10^{32} cm^{-2}s^{-1}

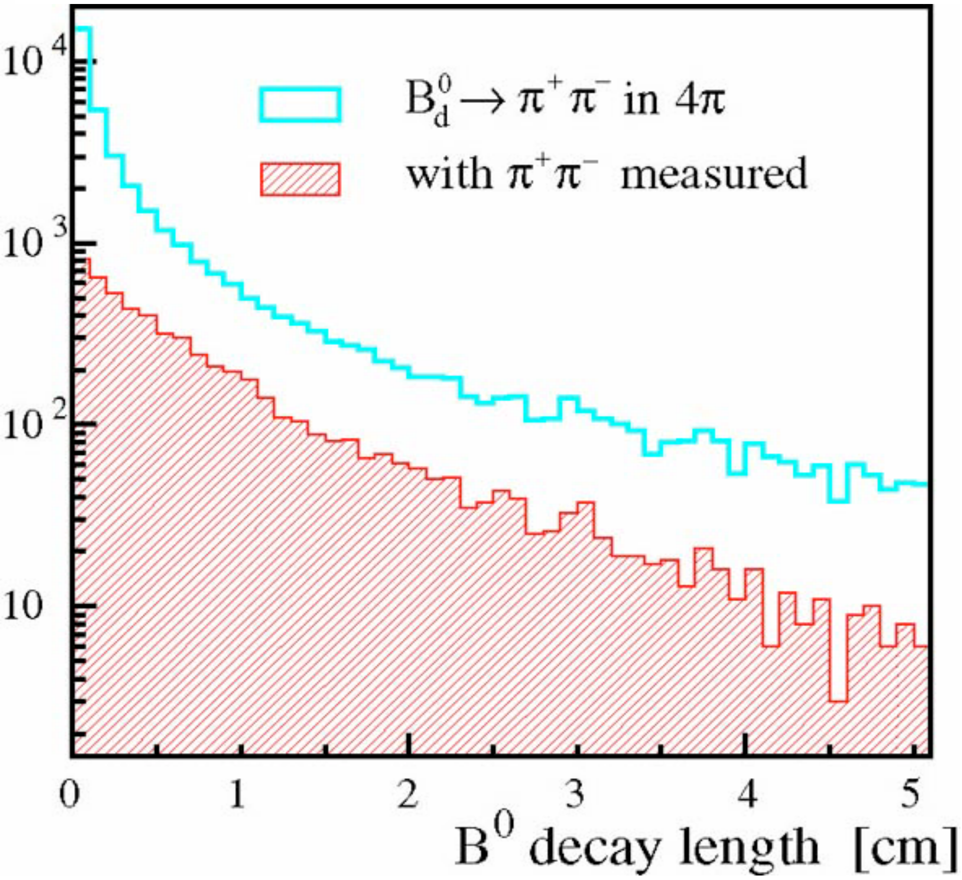


cf. Υ(4S) B factories: 10^8 B-$\overline{B}$/year @ $L = 10^{34}$ cm^{-2}s^{-1}

Momentum spectrum



decay distance for B mesons



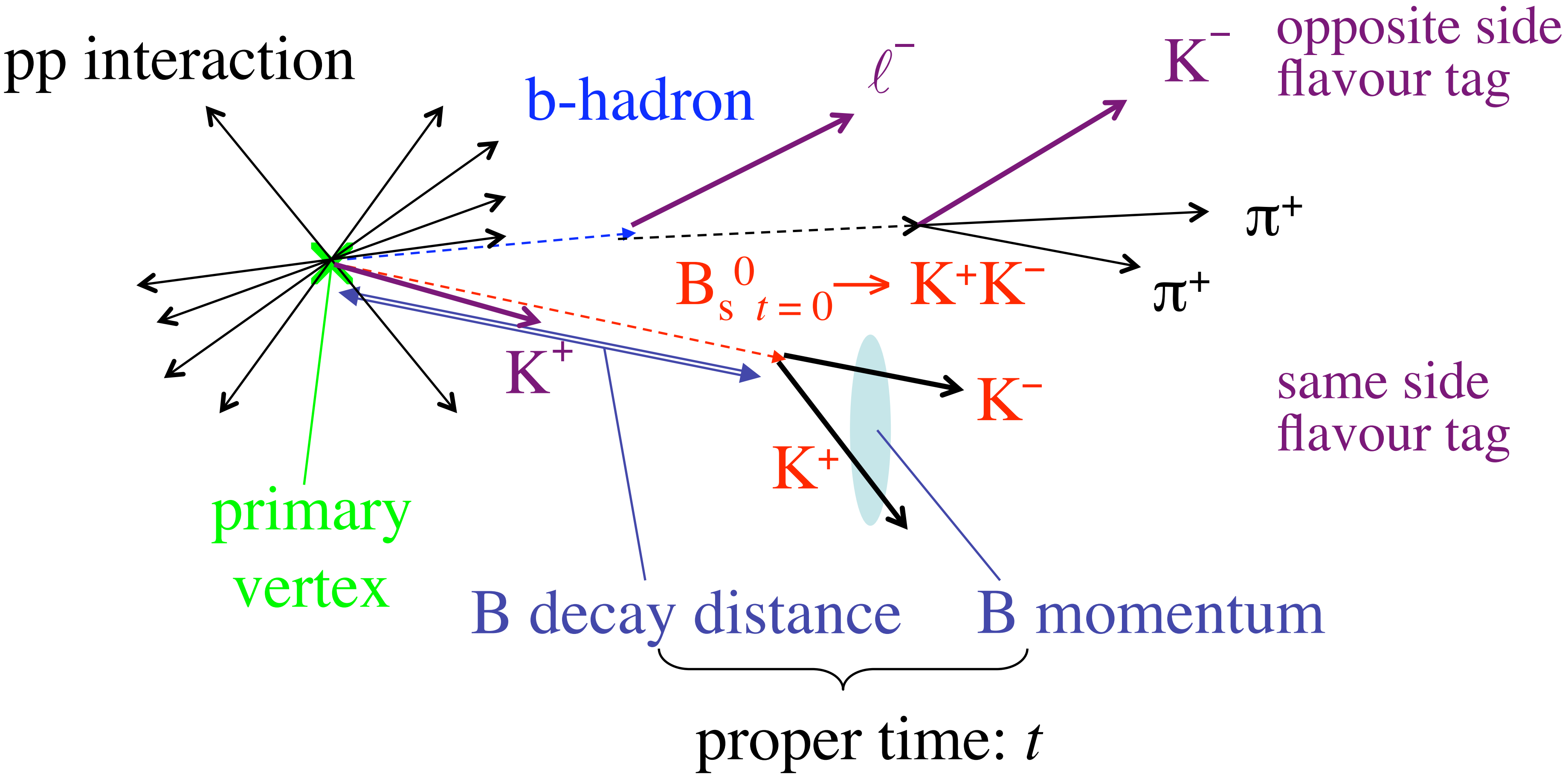
are larger in the forward region.

→ average B decay distance in the detector ~1cm

Good proper time resolution.

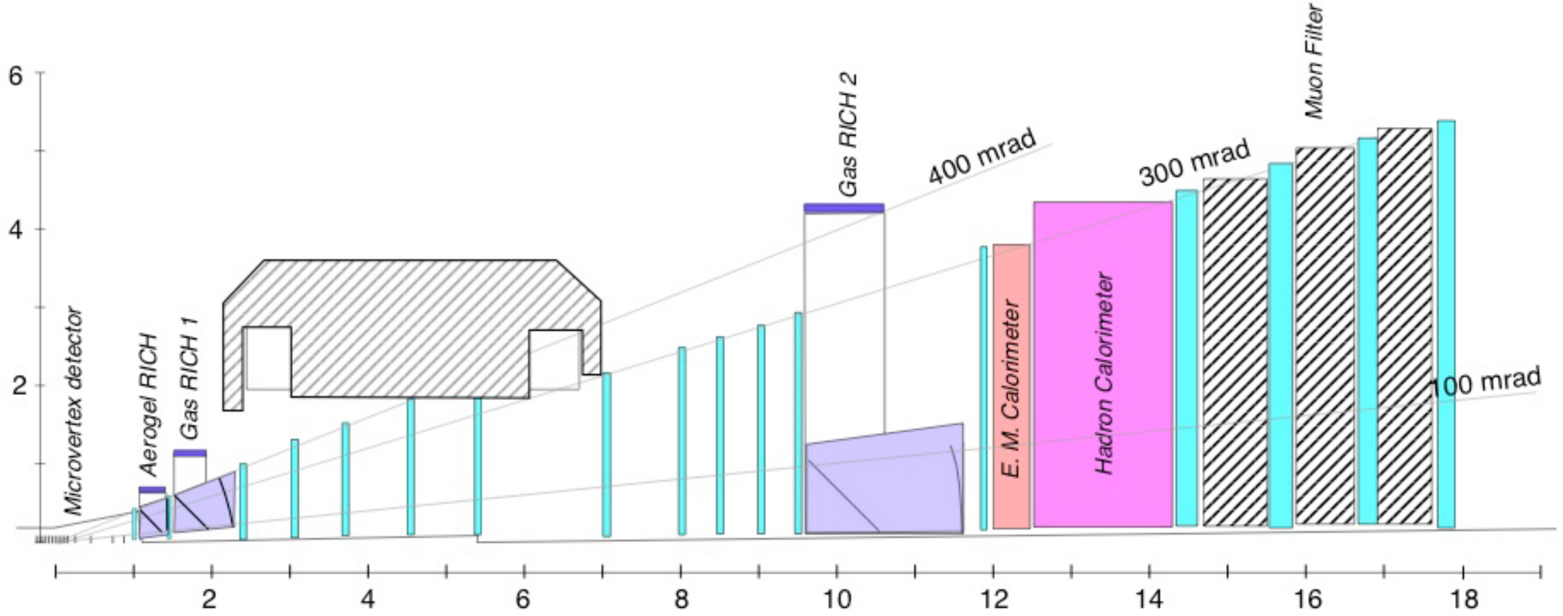
Some detector requirements

What do we measure? (an example)



LHCb Evolution

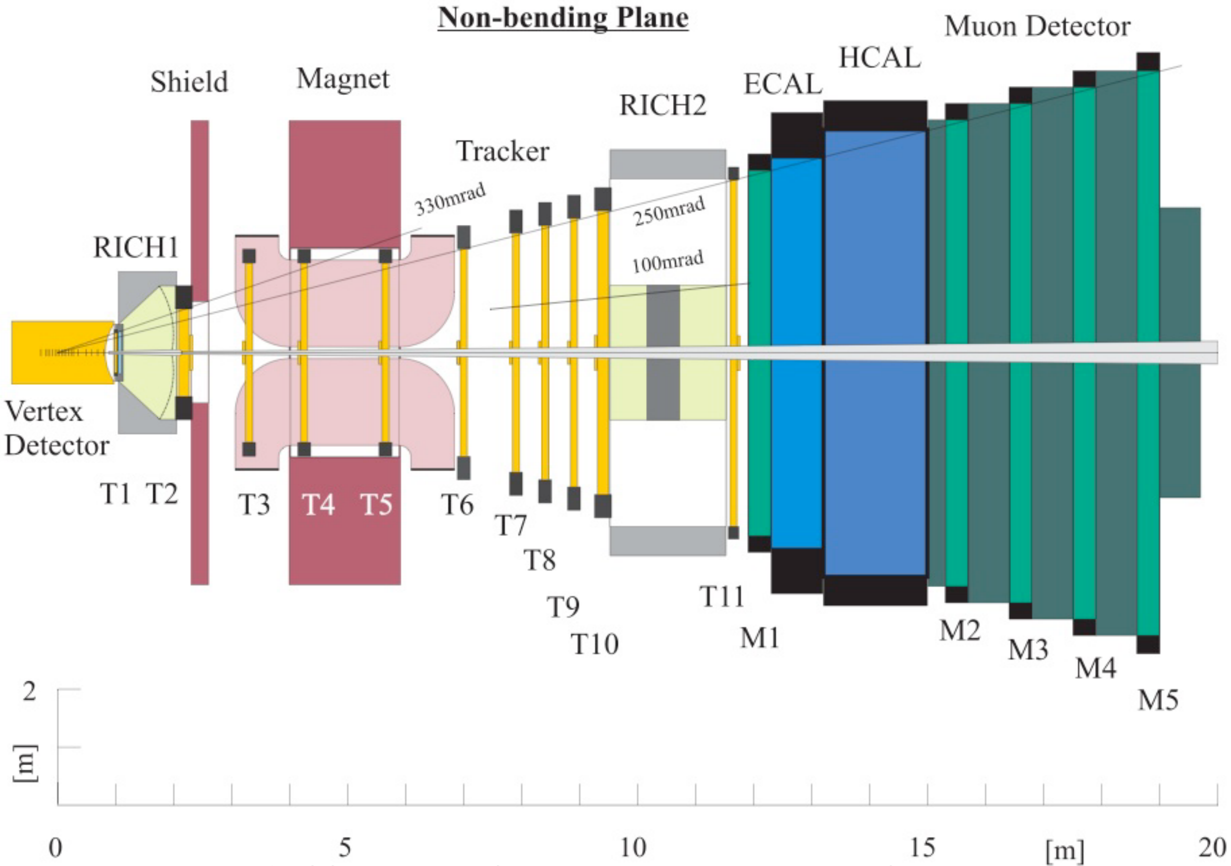
Letter of Intent for LHC-B, August 1995



x-y Si micro-strip detector	L-1 p_T	200 KHz
warm magnet	L-2 tracking + vertex	10 kHz
three RICH's (aerogel + 2-gas) with HPD's	L-3 full reconstruction	

HERA-B tracking system
Pre-shower, Shashlik+PbWO$_4$, Fe-Tilecal+Quarz-W
CSC or Honeycomb or drift tube muon system

Technical Proposal for LHCb, February 1998



What is different from LoI apart from -B → b?

Super conductive magnet

r-ϕ strip Si vertex detector

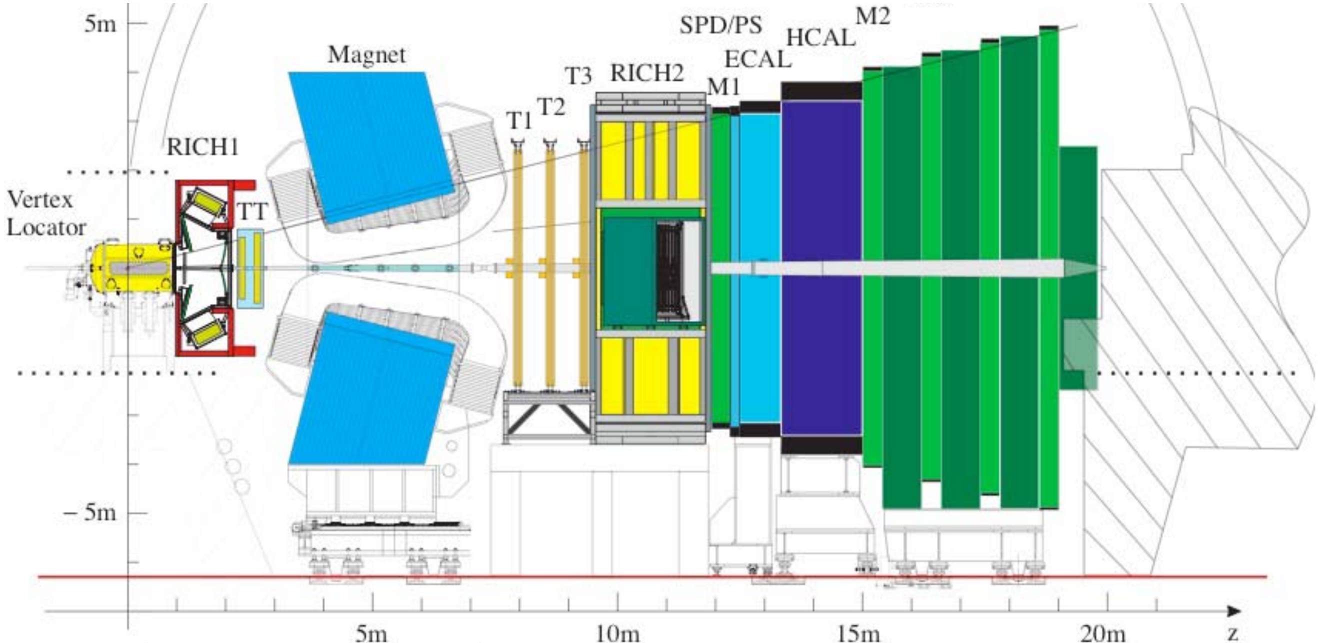
Two RICH's (still three radiators)

No inner-part of calorimeters

MRPC+MWPC muon system

L-0 p_T	1 MHz
L-1 tracking + vertex	40 kHz
L-2 vertex with p	5 kHz
L-3 full reconstruction	200 Hz

Reoptimization TDR for LHCb, September 2003



Many changes in the mean time

Be conical beam pipe

Normal conductive magnet

All MWPC (with a little GEM) muon system

Straw chamber + Si tracking system

Greatly reduced tracking stations (nothing in the magnet)

All Si first tracking station

Two level trigger (1 MHz full readout after the first level to CPU farm)

Changes were motivated by:

budgetary constraint (financial and material)

technical feasibility

physics flexibility

After TP, B physics has evolved a lot: major ones are…

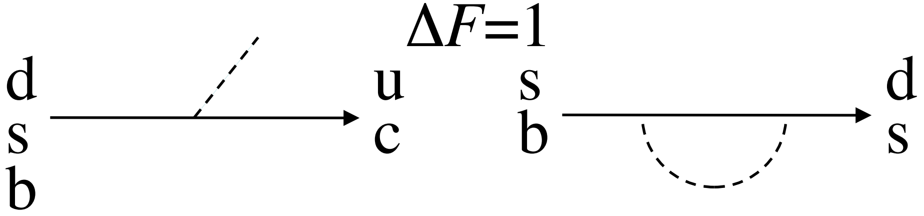
CPV in $B_d \rightarrow J/\psi K_{S,L}$ measured with $\sigma \approx 0.026$

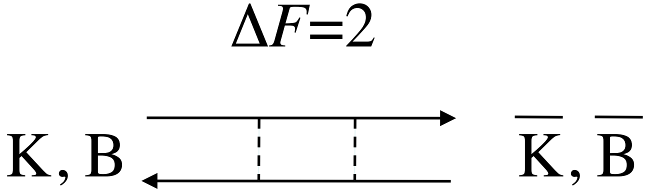
$\gamma(\phi_3)$ measured with $\sigma \approx 25°$

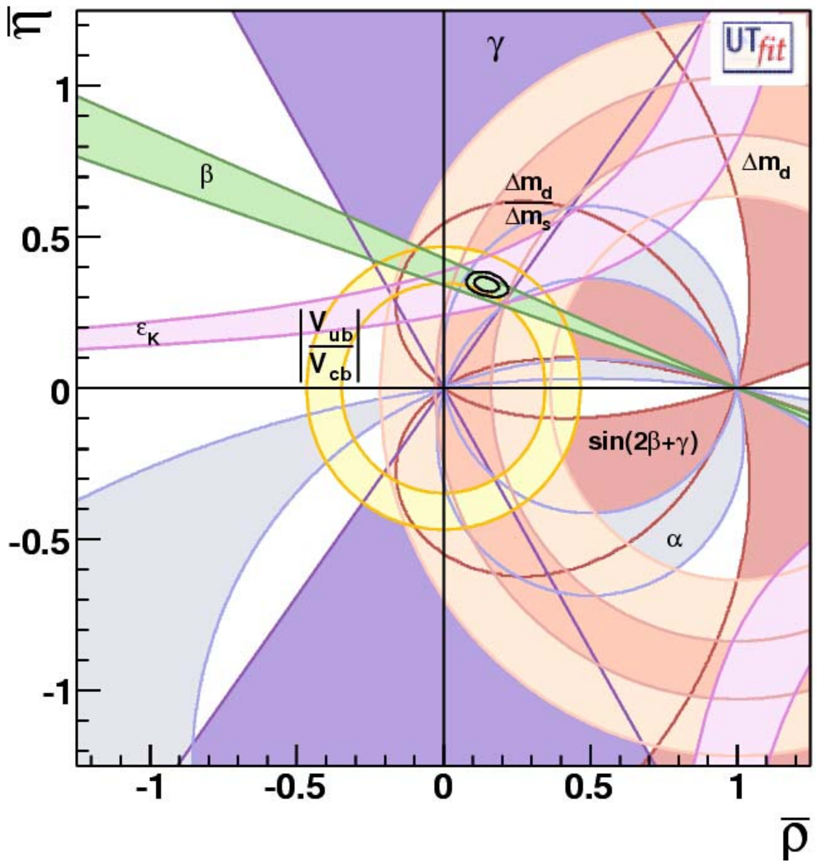
B_s-$\overline{B}_s$ oscillation frequency measured, better than one needs

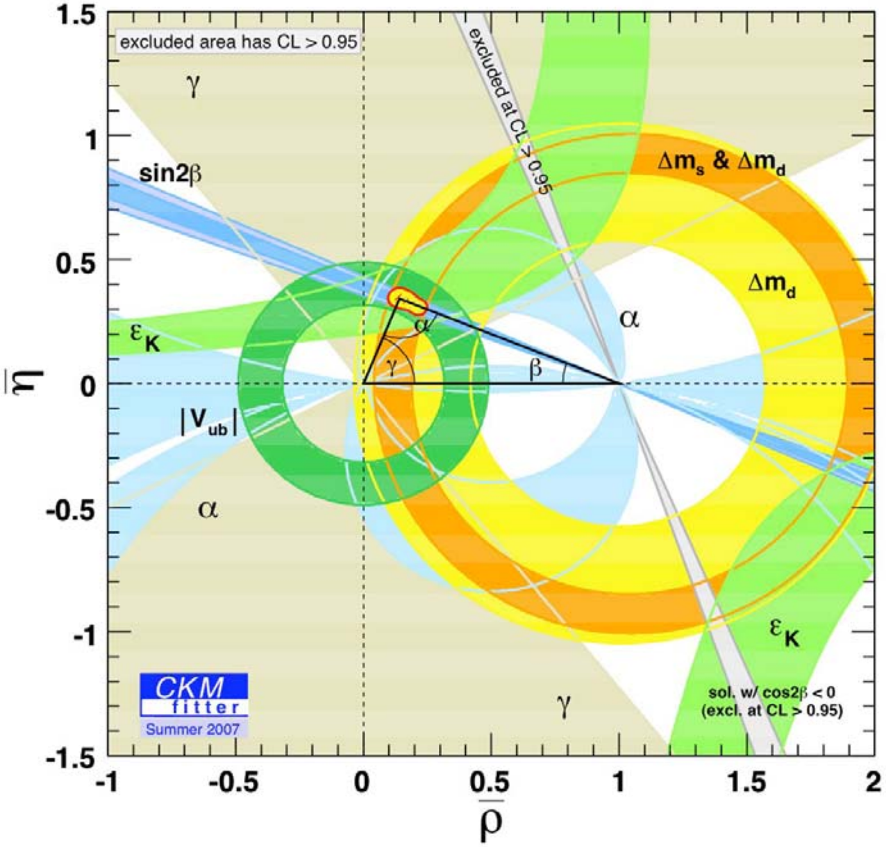
i.e. KM model for CPV is now quantitatively tested

Flavour changing processes, branching fractions, oscillations and CPV, can be described by the four parameters of the CKM matrix (λ, A, ρ, η)









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No major improvement of the B factory results expected from now on

-BABAR end of run in April, Belle in 1~2 years-

Emphasis on the LHCb physics goal is shifting from

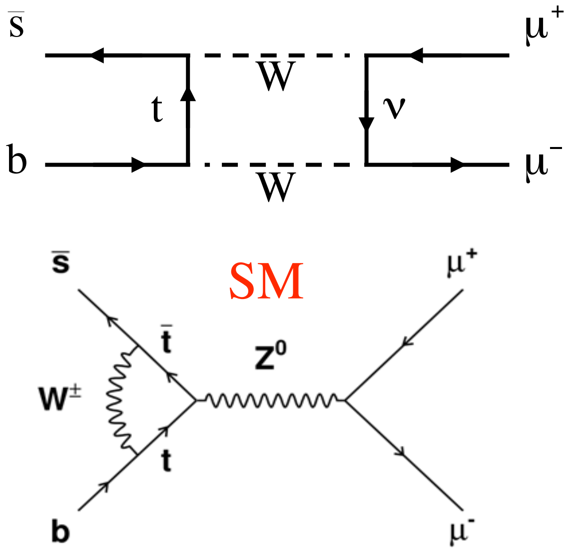
Confirmation of CKM → Search for new physics

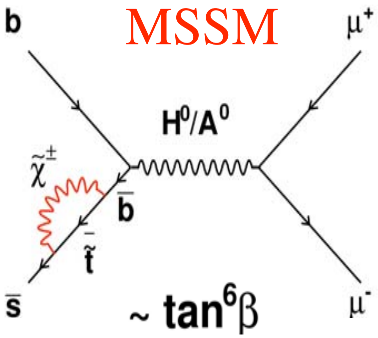
with $\int L dt = 10\ \mathrm{fb}^{-1}$ data by ~2013

Some notable examples are…

NP search in B_s where the effect could be still large

$B_s \rightarrow \mu^+\mu^-$





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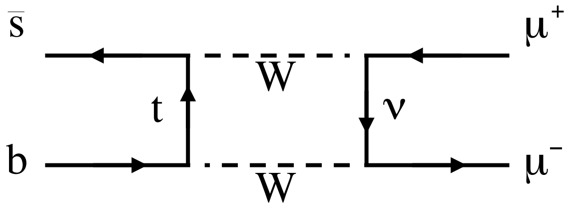
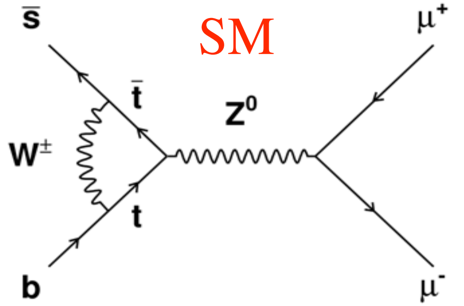
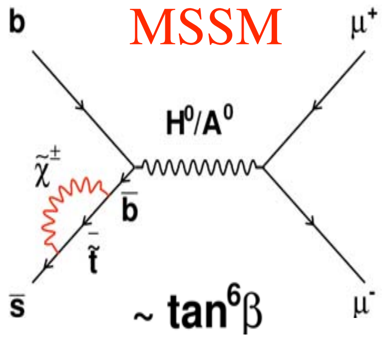
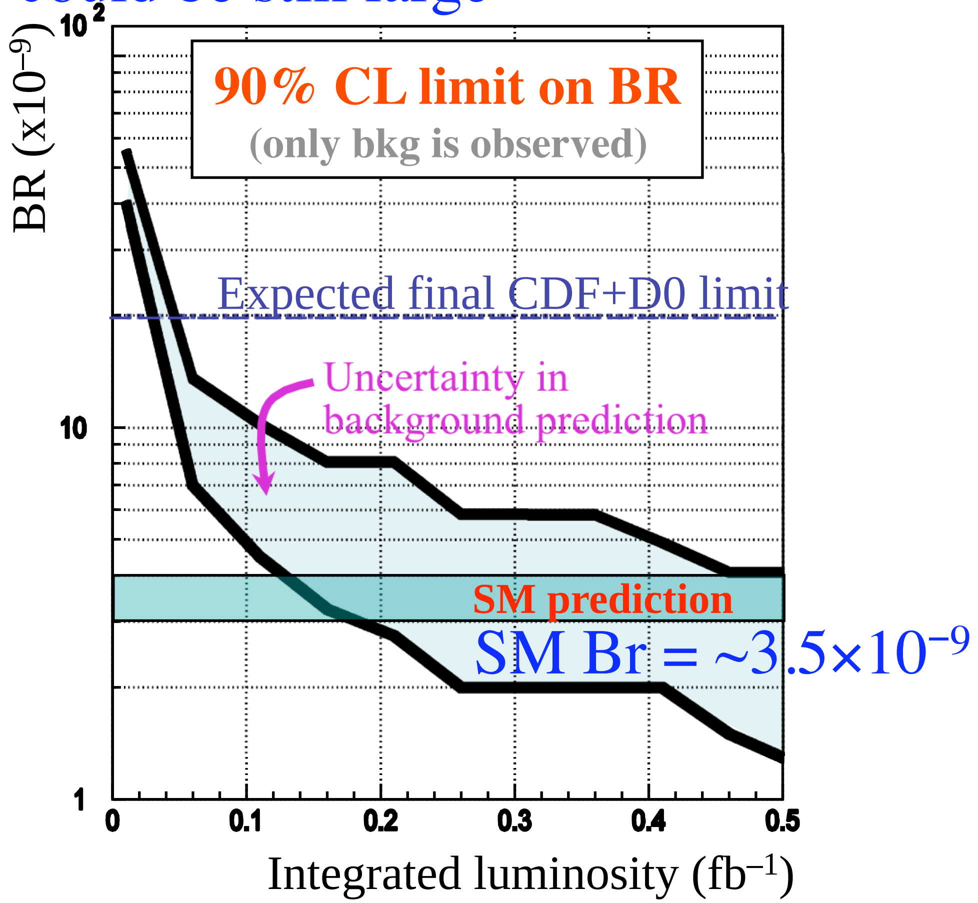








SM Br = ~3.5×10^{-9}

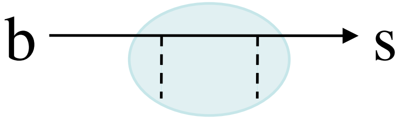
0.05 fb^{-1} ⇒ overtake CDF+D0
0.5 fb^{-1} ⇒ exclude BR values down to SM } 2009
2 fb^{-1} ⇒ 3σ evidence of SM signal → nominal 1 year
6 fb^{-1} ⇒ 5σ observation of SM signal

Some notable examples are…

NP search in B_s where the effect could be still large

- $B_s \rightarrow \mu^+\mu^-$
- CPV in $B_s \rightarrow J/\psi\phi$

$$\beta_s^{SM} = -\arg(V_{ts}^{2}) = -2\lambda^2\eta = -0.0368 \pm 0.0018 \text{ (NB } \arg V_{cb} = 0)$$



SM + new particles with different phase?

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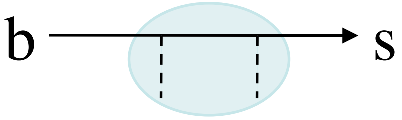


SM + new particles with different phase?

$$A_{CP}(t) = \frac{\Gamma\left(\bar{B}_s^0(t)\to f\right)-\Gamma\left(B_s^0(t)\to f\right)}{\Gamma\left(\bar{B}_s^0(t)\to f\right)+\Gamma\left(B_s^0(t)\to f\right)}$$

$$A_{CP}(t) = \frac{-\eta_f \sin\beta_s \sin(\Delta m_s t)}{\cosh\left(\Delta\Gamma_s t/2\right)-\eta_f \cos\beta_s \sinh\left(\Delta\Gamma_s t/2\right)}$$

$\eta_f = \mathrm{CP}(f)$

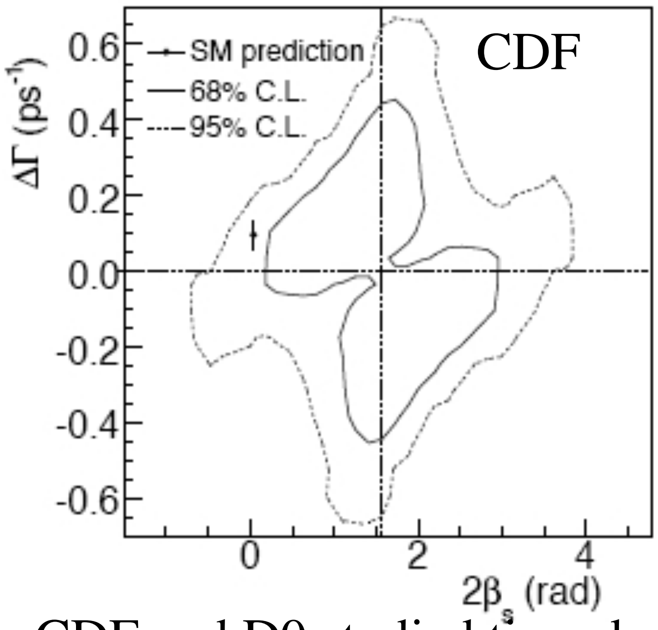
$\mathrm{CP}(J/\psi)=+1$, $\mathrm{CP}(\phi)=+1$, $J_{J/\psi\phi}=S+L=0$,

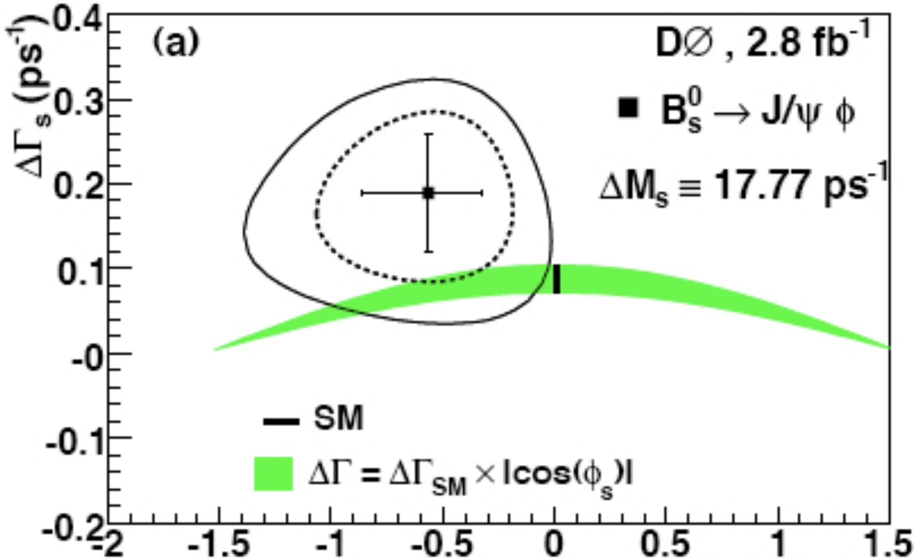
$S=S_{J/\psi}+S_\phi \qquad = 0, 1, 2$

$L=L_{J/\psi-\phi} \qquad = 0, 1, 2$

$\mathrm{CP}(J/\psi\phi) = (-1)^L$

⇒Angular analysis of the final states needed





NB: $2\beta_s = -\phi_s$

CDF and D0 studied time dependent CP asymmetries

NB: If there were indeed New Physics as suggested by M. Bona et al. (arXiv:0803.0659), who combined all the CDF and D0 results, LHCb would see a 5σ observation of CPV in $B_s \to J/\psi\phi$ with ~200 pb^{-1}, i.e. 10% of nominal year of data.

LHCb with 0.5 fb^{-1} (expected data in 2009): $\sigma(\beta_s) = 0.046$
down to the level of SM

With 10 fb^{-1}, >3σ evidence of CP violation ($\phi_s \neq 0$), even if only SM

Some notable examples are…

NP search in B_s where the effect could be still large

- $B_s \rightarrow \mu^+\mu^-$
- CPV in $B_s \rightarrow J/\psi\phi$

overtake Tevatron after several months and
down to the SM level in ~one year

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ATLAS and CMS plan to make B physics in their early period of data taking, ~3 years, collecting 30 fb^{-1} data by ~2011.

$Br(B_s \rightarrow \mu^+\mu^-) <\sim 6\times10^{-9}$ (90%CL)

(They plan to continue this programme at $L=10^{34}$, 4σ in one year)

$\sigma(\beta_s) \approx 0.04$

Some notable examples are…

NP search in B_s where the effect could be still large

$B_s \rightarrow \mu^+\mu^-$

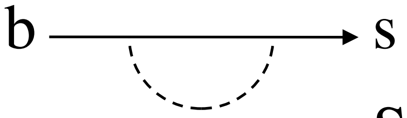
CPV in $B_s \rightarrow J/\psi\phi$

overtake Tevatron after several months and down to the SM level with 2009 data

Probing Flavour Changing Neutral Current $b \rightarrow s$: deviation from the Standard Model prediction in

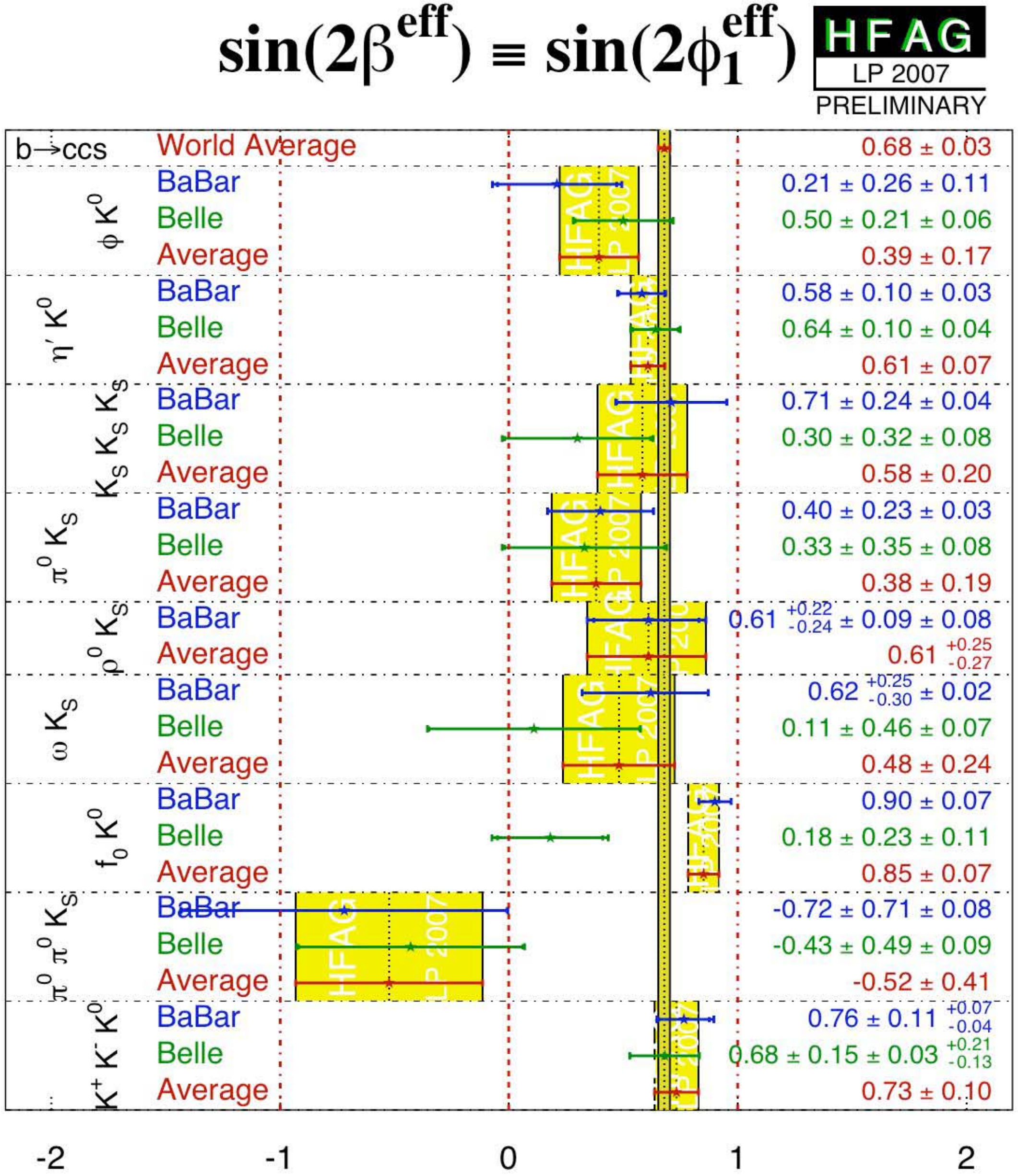
Phase = CP violation $B_s \rightarrow \phi\phi$

Analogous to $B_d \rightarrow \phi K_S$, time dependent CP asymmetry for $B_s \rightarrow \phi\phi$ can measure the BSM phase in $b \rightarrow s$ penguin, $\beta_{s\text{-eff}}$ (for B_s, with only t contribution, SM makes 0 CP asymmetry)



SM + new particles with different phase?

$\sin(2\beta^{\mathrm{eff}}) \equiv \sin(2\phi_1^{\mathrm{eff}})$



LHCb $B_s \to \phi\phi$ performance with 2 fb^{-1} data

$\sigma(m_{B_s})$	B/S	N_{sig} *)	$\sigma(\tau)$	$\sigma(\beta_{s\text{-eff}})$
12 MeV/c^2	0.4-2.1	4000	42 fs	0.1

*) Br = 1.4×10^{-5}

angular analysis needed to resolve CP=1 and =−1 states

~2013 with 10 fb^{-1} data:

$\sigma(\beta_{s\text{-eff}}) = 0.04$

($B_d \to \phi K_s$ for LHCb, $\sigma(\beta_{d\text{-eff}}) = 0.14$)

Currently

$\sigma(\beta_{d\text{-eff}}) = 0.18$

BABAR+Belle

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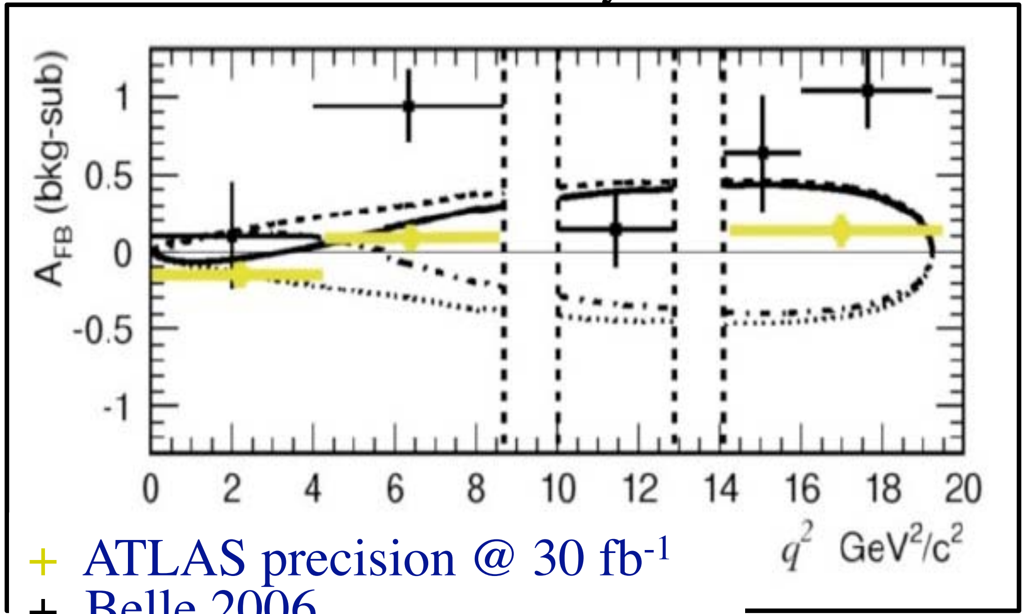
Probing Flavour Changing Neutral Current b→s: deviation from the Standard Model prediction in

- Phase = CP violation $B_s \rightarrow \phi\phi$ improvement over B factory ϕK_S
- Lorentz structure = angular distribution or γ polarization
  - $B_d \rightarrow K^{*0}\mu^+\mu^-$ far larger statistics than B factory
  - CPV in $B_s \rightarrow \phi\gamma$ improvement over B factory $K^*(K_S\pi^0)\gamma$

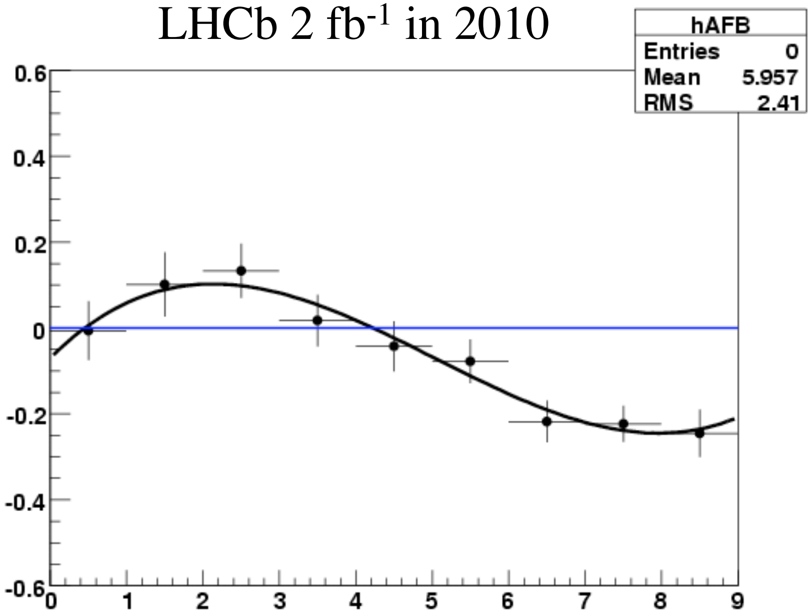
A_{FB} performance

ATLAS 30 fb^{-1} forward-backward asymmetry
three canonical years



+ ATLAS precision @ 30 fb^{-1}
+ Belle 2006
— SM model
…… SM extensions

LHCb 2 fb^{-1} in 2010



By **~2013**, LHCb
zero crossing point with 10 fb^{-1}
$\sigma(s_0) = 0.27\ (\mathrm{GeV}/c^2)^2$ **[19K events]**

Other angular distribution
being studied as well.

LHCb will look for other radiative decays,
e.g. $B_s \rightarrow \phi\gamma$ 57k events with 10 fb^{-1} ⇒ CP violation

Some notable examples are…

NP search in B_s where the effect could be still large

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FCN current in "up" type quark: NP effect different from "down" type

D: oscillations and CP violation down to the level of SM

much larger statistics than B factory

D physics statistical error with 10 fb^{-1} data (~2013)

$\sigma(x'^2)=6.4\times10^{-5}$

$\sigma(y')=8.7\times10^{-4}$

$\sigma(y_{\mathrm{CP}})=5\times10^{-3}$

CP asymmetries for K^+K^- and $\pi^+\pi^-$ $<O(10^{-3})$

Some notable examples are…

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much larger statistics than B factory

γ from tree (only SM) and from tree + penguin (SM+NP): $\sigma_\gamma \approx 3°$

much larger statistics than B factory

And $\tau \rightarrow 3\mu$ decays under study now…

$2.2 \times 10^{10} \times \mathrm{Br}(\tau \rightarrow 3\mu)/2\ \mathrm{fb}^{-1}$ L0 triggered events

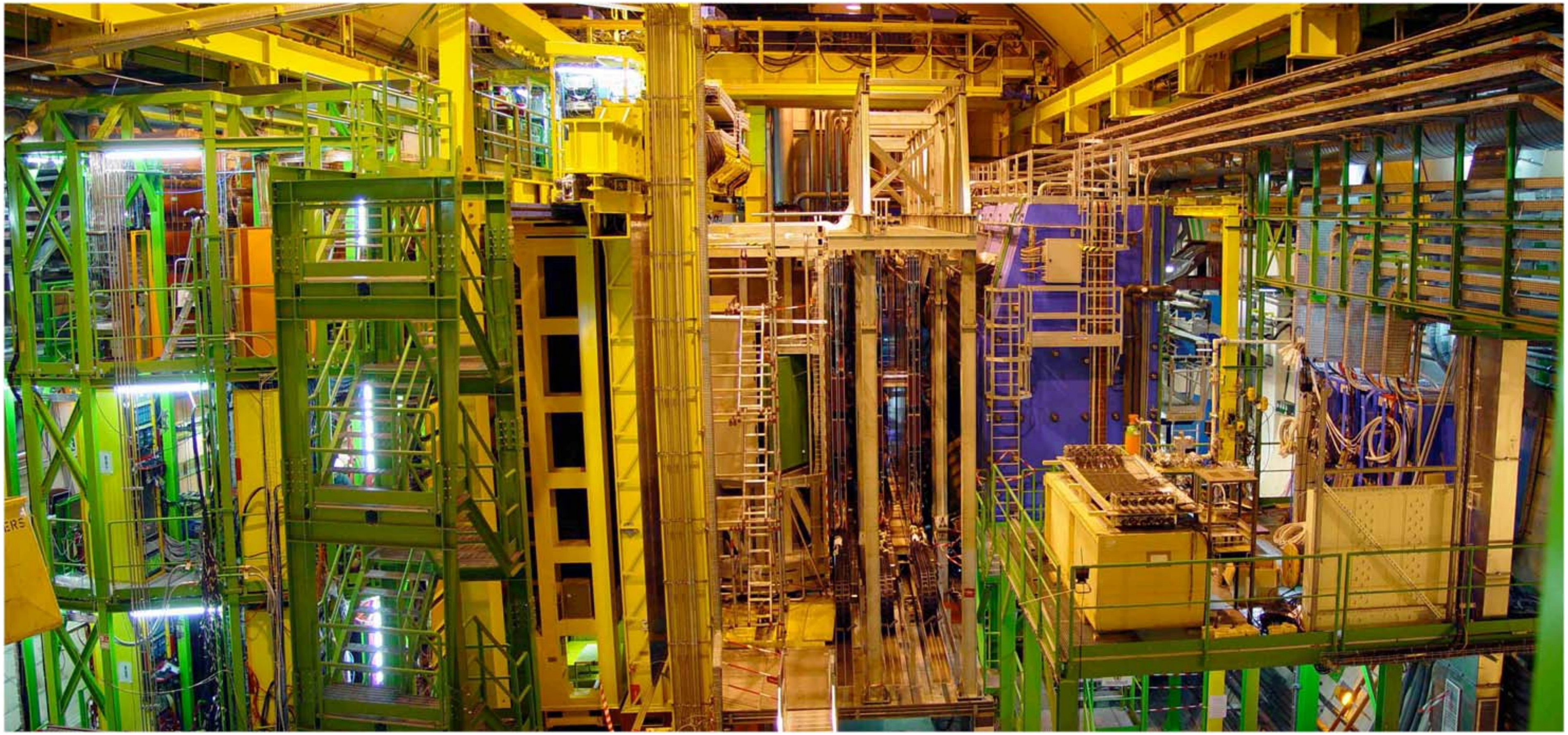
for τ from $pp \rightarrow b\bar{b}X$ and $pp \rightarrow c\bar{c}X$ processes

Reconstruction efficiency and S/B under studies

How many Drell-Yan $\tau^+\tau^-$ production?

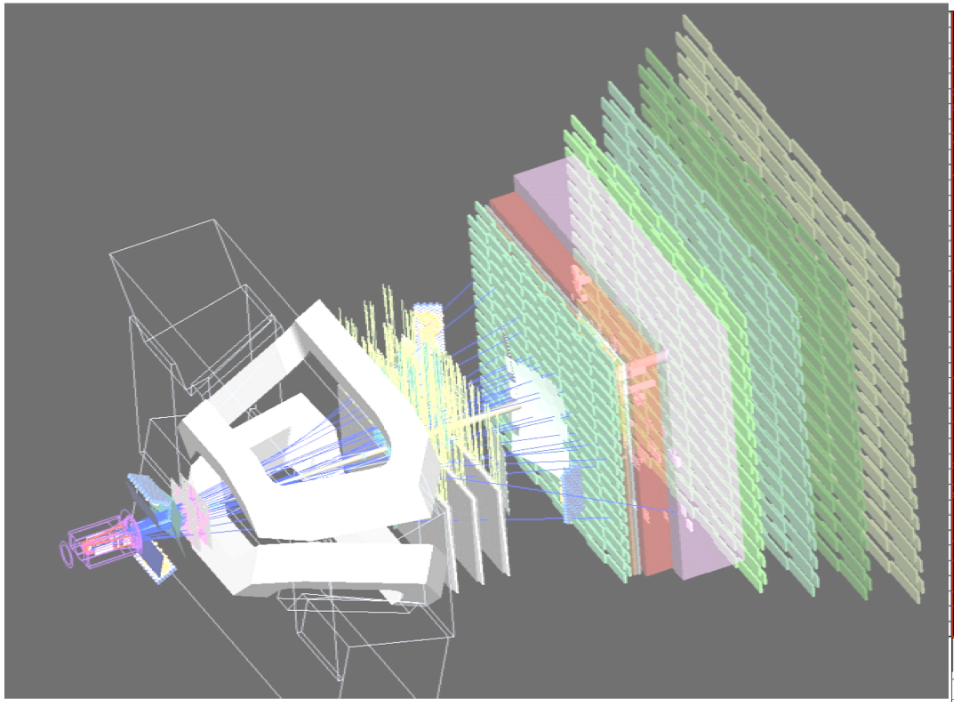
Current limit from BABAR and Belle $\sim 10^{-8}$

LHCb now close to being ready for physics

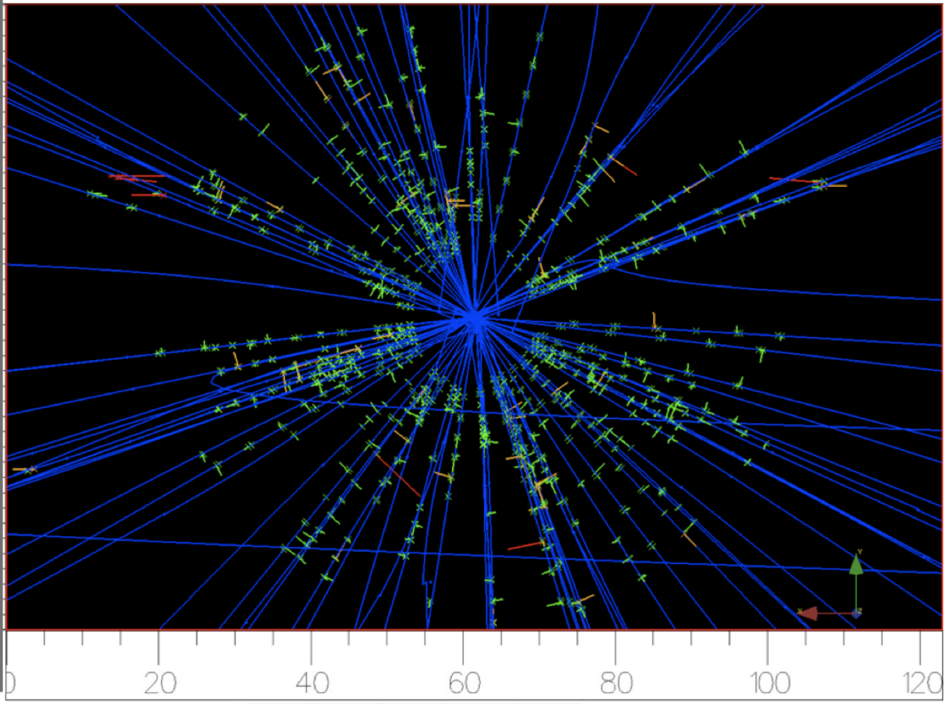


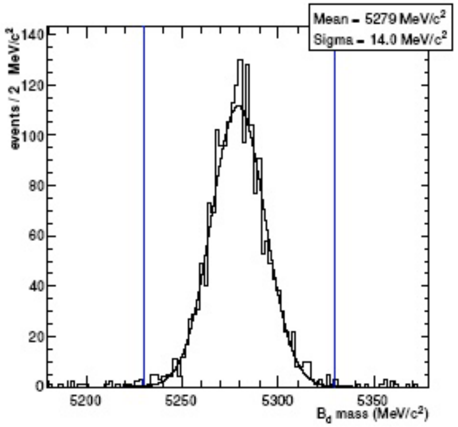
A lot of Monte Carlo events were

generated

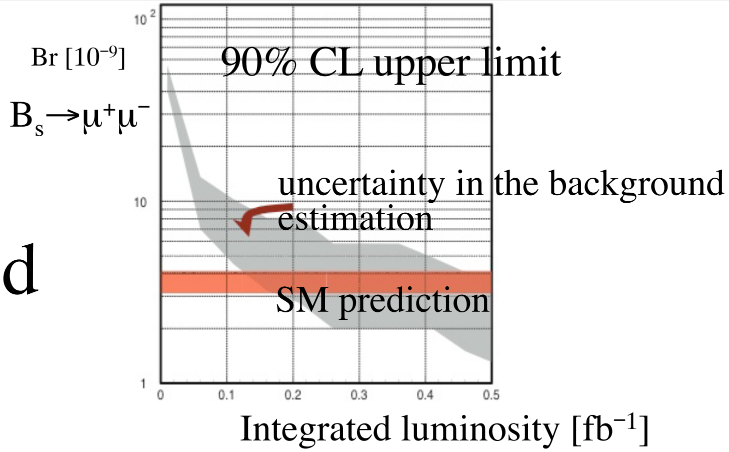


reconstructed

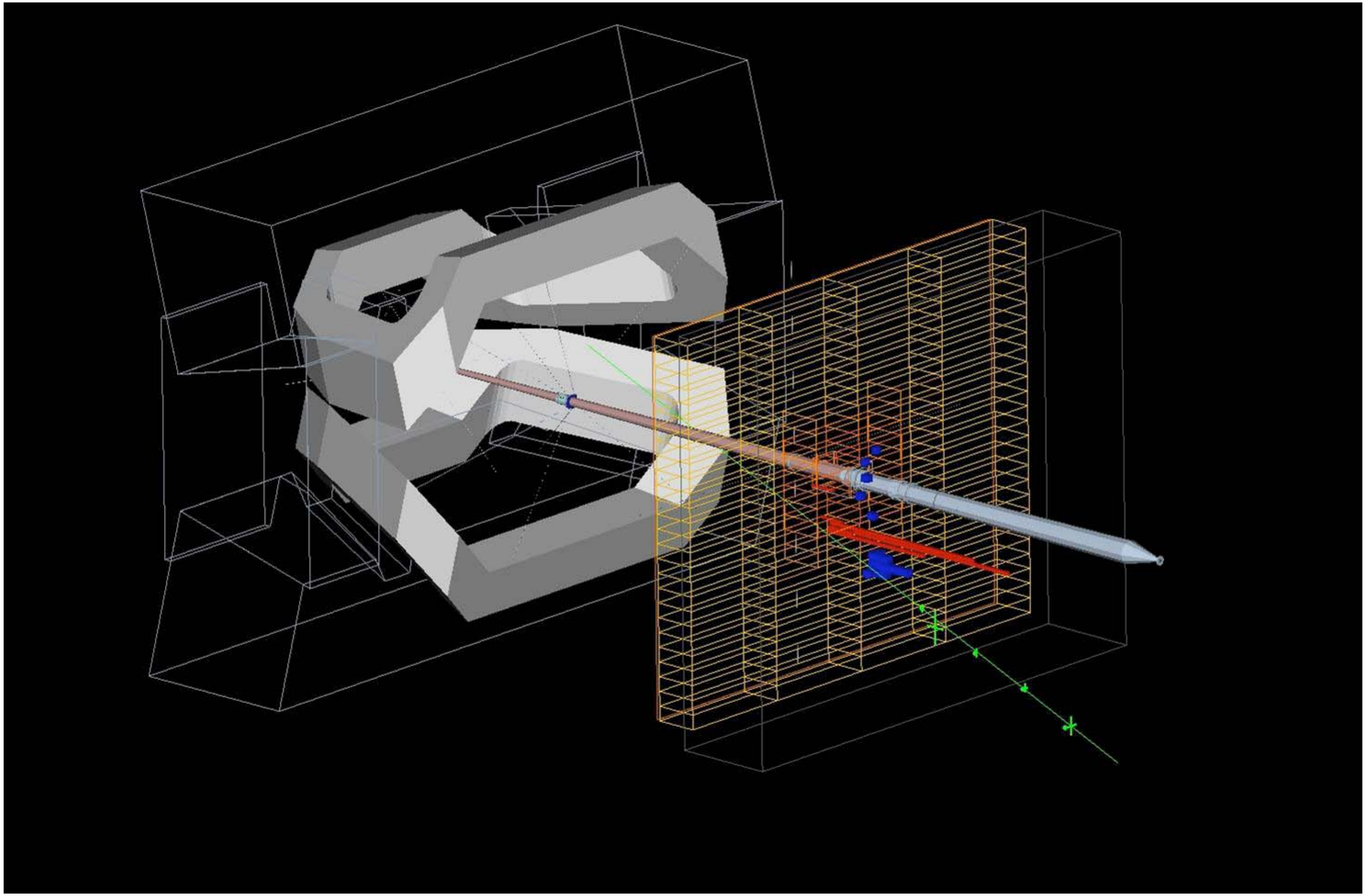




and analysed



Now we also have “properly” triggered cosmic events



going through the calorimeter and muon systems

We are looking forward to see 10 TeV pp collisions in our detector very soon!

Followed by finding out which one of the following excitements we will have:

In 2014 at LHC

ATLAS CMS high p_T physics
LHCb flavour physics
Particle Physics

In 2014 at LHC

ATLAS CMS high p_{T} physics	BSM
LHCb flavour physics	Only SM
Particle Physics	☺

In 2014 at LHC

ATLAS CMS high p_T physics	BSM	Only SM
LHCb flavour physics	Only SM	BSM
Particle Physics	☺	☺

In 2014 at LHC

ATLAS CMS high p_{T} physics	BSM	Only SM	BSM
LHCb flavour physics	Only SM	BSM	BSM
Particle Physics	☺	☺	☺

In 2014 at LHC

ATLAS CMS high p_T physics	BSM	Only SM	BSM	
LHCb flavour physics	Only SM	BSM	BSM	
Particle Physics	☺	☺	☺	

Oh, no more space left… but the best would be if we find totally unexpected!