8th Int. Conf. on Nuclear Physics at Storage Rings STORI'11

Nuclear, Particle Physics at Storage Rings, Hadron Spectroscopy, Strangeness.

Laboratori Nazionali di Frascati October 9 - 14, 2011

Production of Heavy Baryons at the SuperB

Vincenzo Lucherini, LNF-INFN

Plan of the talk

- The INFN Super*B* project
- Not only ***B*** mesons: heavy baryons production
- Outline of a possible layout & experimental program

The SuperB Project: a major new particle physics centre

Key Features

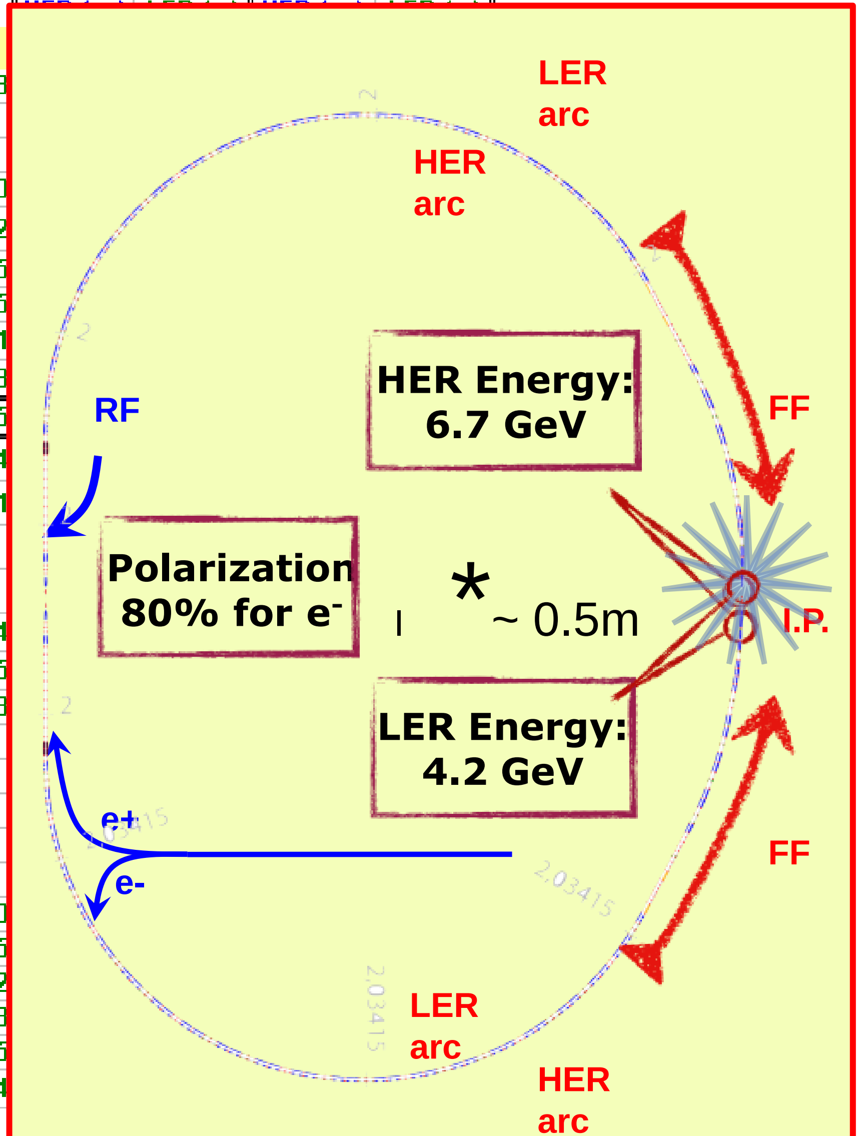
- New European Accelerator Facility to be sited in Italy, ready by ~2016
  - At $\Upsilon(4S)$, 6.7 GeV positrons on 4.18 GeV electrons, 1.3 km circumference
  - $\Upsilon(4S)$ decays primarily to B-meson pairs.
- High Luminosity (100 x current records)
  - $\geq 10^{36}$ cm^{-2} s^{-1} : 15 ab^{-1}/year rising to 40 ab^{-1}/year in later years
  - 1 ab^{-1} => 1 billion B-meson pairs, 1 billion D-mesons and 1 billion tau pairs
  - 75 ab^{-1} by ~2022
- Polarization
  - 60%-85% polarization of electron beam
  - Improves physics reach by factor of 2 in some regions
- $\psi(3770)$ to $\Upsilon(5S)$ and beyond
  - Can scan a large energy range.
- Charm Threshold Running
  - ~4 months running at 10^{35} cm^{-2} s^{-1} equivalent to 20 x future BES-III dataset.
- Light Source
  - 30 x brighter than ESRF or Diamond Light Source.
- Computing
  - On the scale of a non-upgraded LHC experiment.

SuperB Physics Goals

- Identify the flavour structure of New Physics.
- Sensitive to New Physics through flavour properties; CP Violation asymmetries in B and D decays; and rare decays.
- Probe New Physics scales up to 10-100 TeV through indirect measurements.
- Different New Physics models predict a different hierarchy of results => multiple measurements needed.
- Search in both the quark and lepton sectors.
- Golden Channels (good SM prediction + good experimental resolution) e.g. inclusive $b \rightarrow s\gamma$, $B \rightarrow K\nu\bar{\nu}$, $B \rightarrow \tau\nu$, $\tau \rightarrow \mu\nu\bar{\nu}$
- Physics capabilities published in arXiv:1008.1541 and arXiv:1109.5028

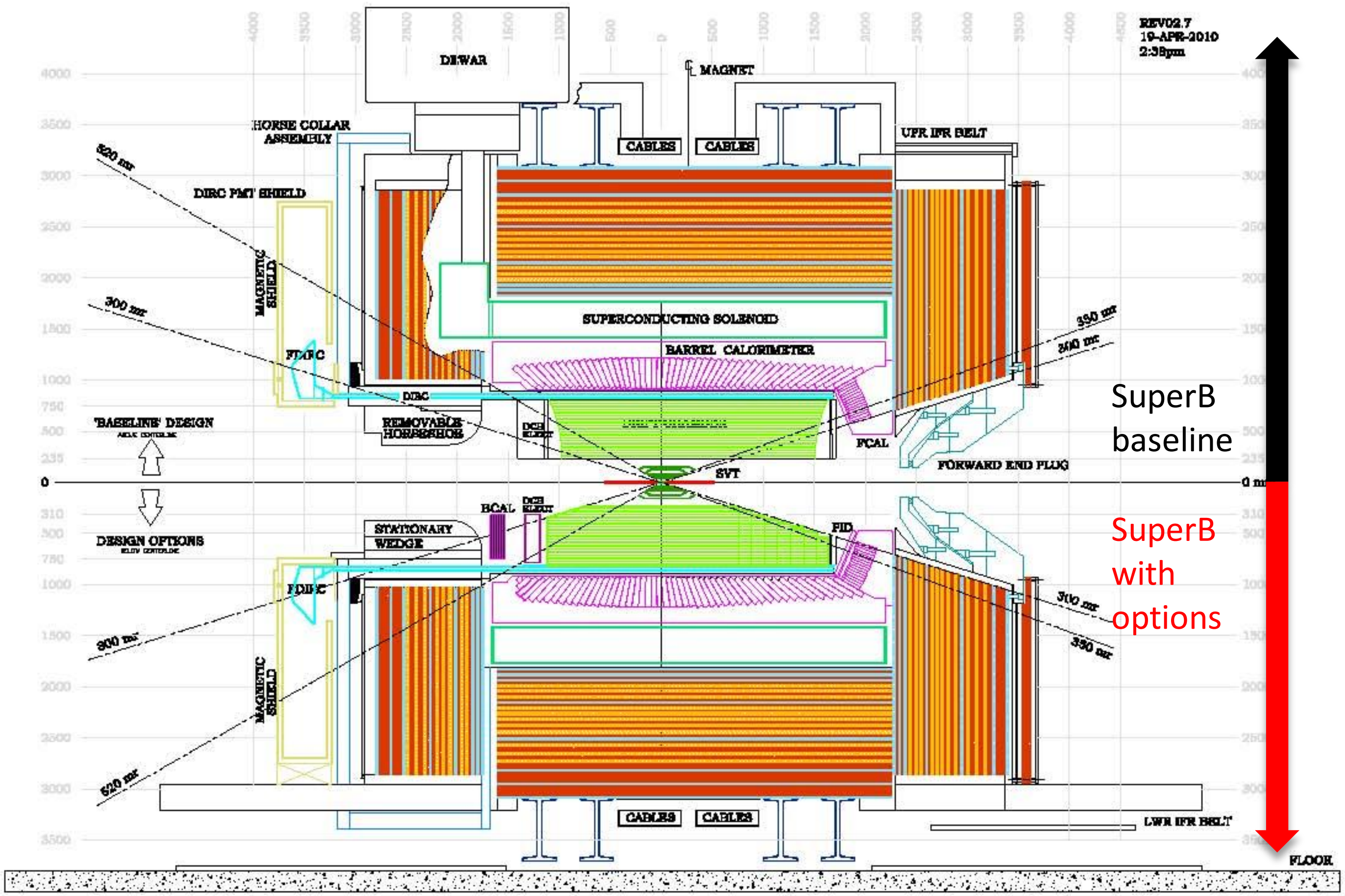
SuperB beam parameters

		Base Line		Low Emittance		High Current		Tau/Charm (prelim.)	
Parameter	Units	HER (e+)	LER (e-)	HER (e+)	LER (e-)				
LUMINOSITY	$cm^{-2}\ s^{-1}$	1.00E+36		1.00E+36					
Energy	GeV	6.7	4.18	6.7	4.18				
Circumference	m	1258.4		1258.4					
X-Angle (full)	mrad	66		66					
Piwinski angle	rad	22.88	18.60	32.36	26.30				
β_x @ IP	cm	2.6	3.2	2.6	3.2				
β_y @ IP	cm	0.0253	0.0205	0.0179	0.0145				
Coupling (full current)	%	0.25	0.25	0.25	0.25				
ε_x (without IBS)	nm	1.97	1.82	1.00	0.91				
ε_x (with IBS)	nm	2.00	2.46	1.00	1.23				
ε_y	pm	5	6.15	2.5	3.075				
σ_x @ IP	μm	7.211	8.872	5.099	6.274				
σ_y @ IP	μm	0.036	0.036	0.021	0.021				
Σ_x	μm	11.433		8.085					
Σ_y	μm	0.050		0.030					
σ_L (0 current)	mm	4.69	4.29	4.73	4.34				
σ_L (full current)	mm	5	5	5	5				
Beam current	mA	1892	2447	1460	1888				
Buckets distance	#	2		2					
Ion gap	%	2		2					
RF frequency	Hz	4.76E+08		4.76E+08					
Harmonic number		1998		1998					
Number of bunches		978		978					
N. Particle/bunch		5.08E+10	6.56E+10	3.92E+10	5.06E+10				
Tune shift x		0.0021	0.0033	0.0017	0.0025				
Tune shift y		0.0970	0.0971	0.0891	0.0892				
Long. damping time	msec	13.4	20.3	13.4	20.3				
Energy Loss/turn	MeV	2.11	0.865	2.11	0.865				
σ_E (full current)	dE/E	6.43E-04	7.34E-04	6.43E-04	7.34E-04				
CM σ_E	dE/E	5.00E-04		5.00E-04					
Total lifetime	min	4.23	4.48	3.05	3.00				
Total RF Power	MW	17.08		12.72					



The Detector

Reuses much of BaBar e.g. CsI crystals



Improve Vertex resolution x 2

Improved hermiticity

TOF Forward PID

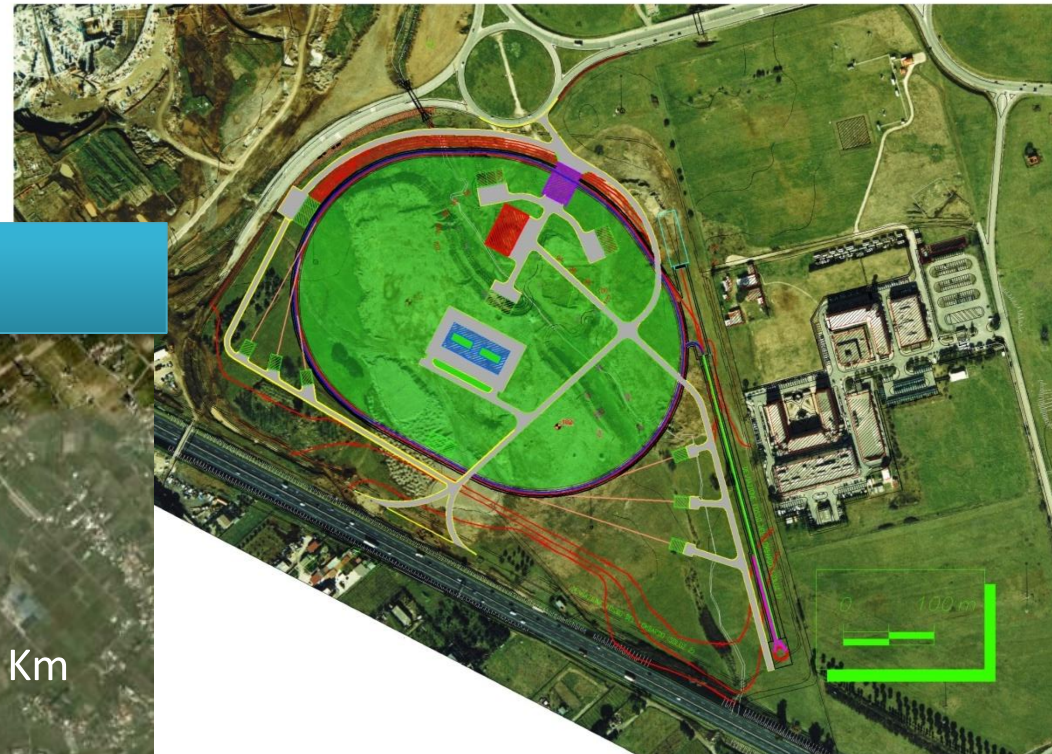
Cluster counting in drift chamber (improves dE/dx)

Backward EMC

Optimized Muon Detector

Site decision announced May 30th 2011

Tor Vergata University Campus



"N. Cabibbo Laboratory"

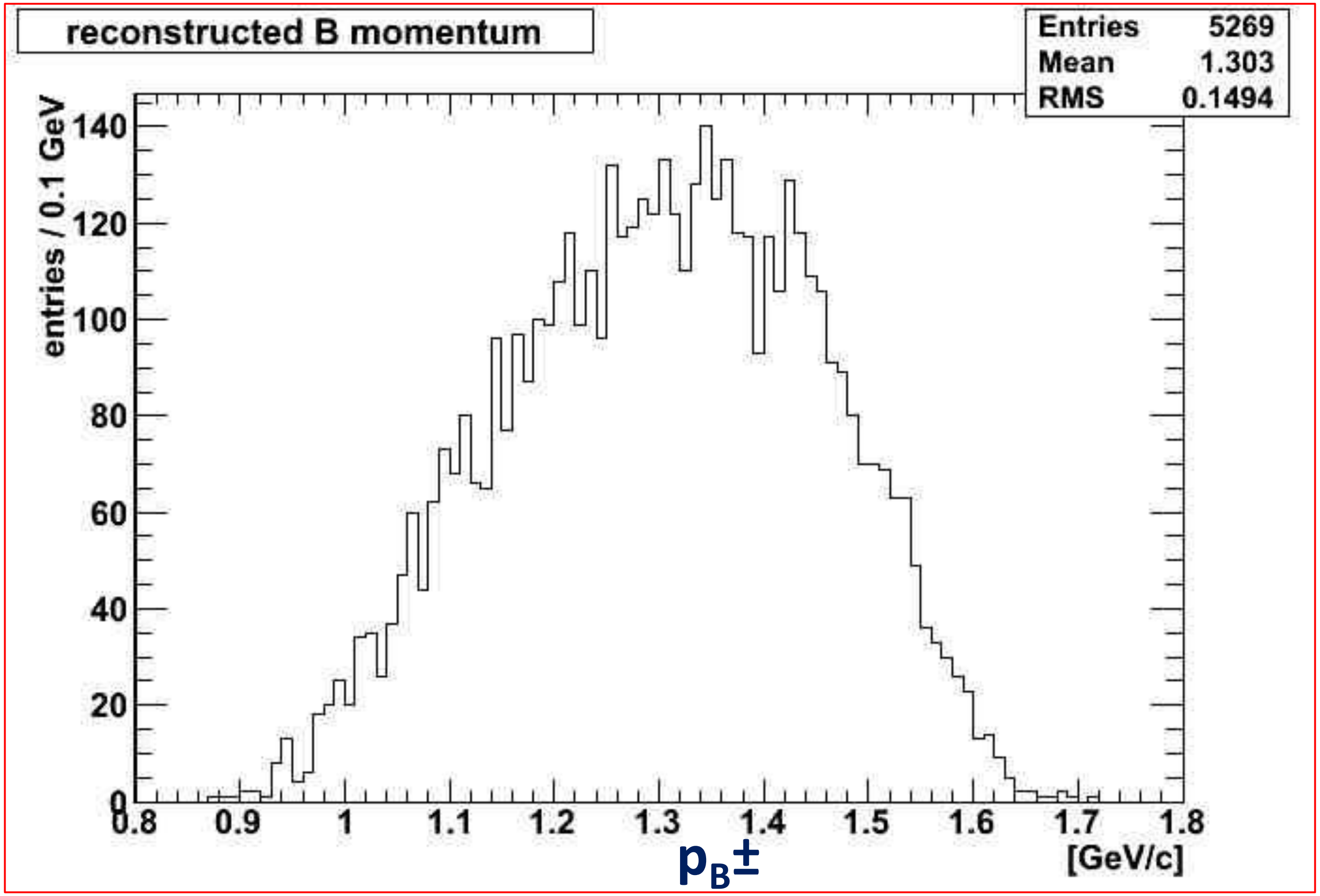
Italian Government approval given on September 29 2011

Key parameters to study also heavy baryons @ SuperB I

$e^+ e^-$ Collider	Beam Radius at I.P. (μm)	*Luminosity* (10^{30} cm^{-2}s^{-1})
DAΦNE (Frascati)	H: 800 V: 4.8	450 (1000)
BEPC-II (China)	H: 380 V: 5.7	330
PEP-II (SLAC)	H: 157 V: 4.7	12069
KEKB (KEK)	H: 124(e^-) 117(e^+) V: 0.94	21083
SuperKEKB (KEK)	H: 11(e^-) 10(e^+) V: 0.062(e^-) 0.048(e^+)	8×10^5
SuperB (Italy)	H: 7.4 V: 0.04	$>1 \times 10^6$

$c\tau_{B^\pm}$ = 491.1 μm → **$\beta c\tau_{B^\pm}$ (@ 1.3 GeV/c) ≈ 118 μm**

Key parameters to study also heavy baryons @ SuperB II



SuperB fast simulation output

Bottom baryons at the SuperB?!?

Out of reach! $E_{c.m.} \approx 10600$ MeV $<$ $m(\Lambda_b^0 \overline{\Lambda}_b^0) = 2 \times 5620.2 \text{ MeV} = 11240.4 \text{ MeV}$

lightest bottom baryon

Strange baryons at DAΦNE?!?

Out of reach! $E_{c.m.} \approx 1020$ MeV $<$ $m(\Lambda^0 \overline{\Lambda}^0) = 2 \times 1115.7 \text{ MeV} = 2231.4 \text{ MeV}$

lightest strange baryon

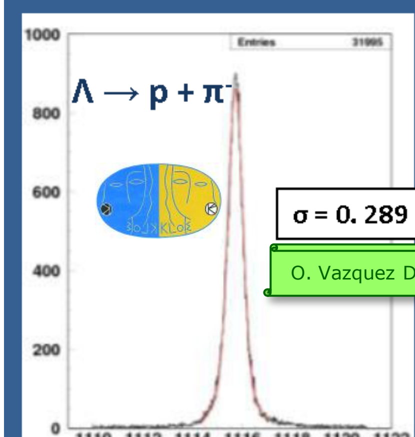
$e^- + e^+ \rightarrow \phi$

…however…

$K^- + K^+$

$K^- + N_{bound} \rightarrow \Lambda^0 + \pi^{-/0}$

S. Piano, 34° Meet. LNF SC



M_{inv} pπ (MeV)

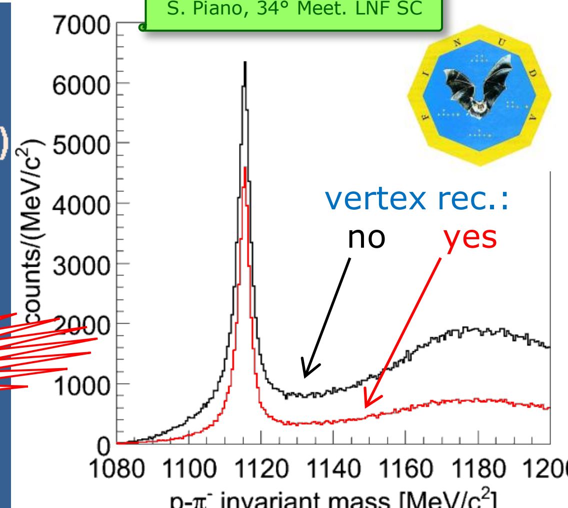
KLOE: M_{inv} = 1115,723 ± 0. 003 stat (MeV/c²)

PDG: M_Λ = 1115,683 ± 0.006 stat ± 0.006 syst (MeV/c²)

σ = 0. 289 ± 0.003 MeV/c²

O. Vazquez Doce, 40° Meet. LNF SC

experimental results



How it could work at SuperB

$e^- + e^+ \to \Upsilon(4S)$

B.R. = 51.6%

$B^- + B^+$

BeX: huge cross section for slow B^-

$B^- + N_{bound} \to \Lambda_b^0 + \pi^{-0}$

but also:

$B^- + N_{bound} \to \Sigma_b^{\pm} + \pi^{-0+}$

$B^- + N_{bound} \to \Sigma_b^{*\pm} + \pi^{-0+}$

? $B^- + N_{bound} \to \Xi_b^{-0} + K^{+0}$ *just ≈ 69 MeV below thresh. for* N_{free}

~~$B^-_{flight} + N_{bound} \to \Omega_b^- + K^+ + K^0$~~

To study these reactions the same Detector can be used, but, of course, you need a Target!

Huge cross section on nuclei for slow B^-

BeX

$$B^- + N_{bound} \rightarrow Y_b + \pi$$

A ***slow*** B^- meson (as those produced at the SuperB) has access, if it impinges on a target, to only another strong interaction channel:

$B^- + N_{bound} \rightarrow B^0 + N_{bound}$, the *charge exchange* reaction.

This reaction, however, has a threshold (@ 0.34 GeV/c for free *N*), and, hence, it is expected to give a small contribution in the momentum range of the B^- meson produced at the SuperB. The BeX Reaction, instead, is accessible also for $B^-_{stopped}$, when its occurrence would of the order of 100%!

The case of slow K-
for the sake of comparison

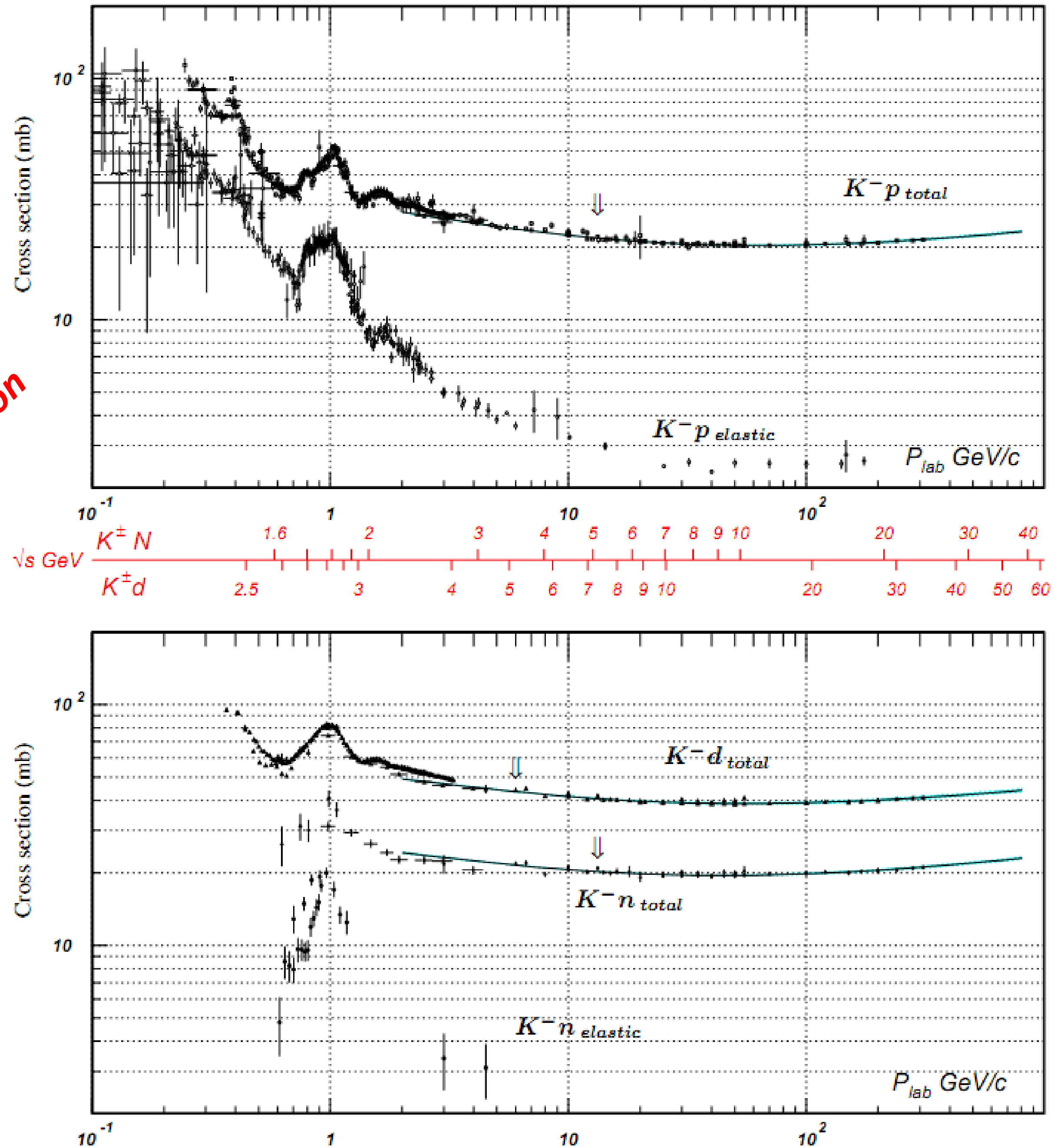


Figure 41.14: Total and elastic cross sections for K^-p and K^-d (total only), and K^-n collisions as a function of laboratory beam momentum and total center-of-mass energy. Corresponding computer-readable data files may be found at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS Group, IHEP, Protvino, August 2005)

$$B^-_{slow} + N_{bound} \rightarrow Y_b + \pi$$

$Y_b = \Lambda_b, \Sigma_b, \Sigma^*_b$, *(and, it may be,* Ξ_b*)*

Which is the game?

-Put a suitable target as near as possible to the I.P. in order to intercept the produced B^- before they (all) decay.

- The intercepted B^- will start to slow down, and will continue to decay, but they can also make a BeX reaction with a high cross section that, moreover, will increase more and more as they are slowed down.

Why SuperB is suitable to try for this game?

-Since the beam dimensions at I.P. are very small (few μm)
- Since it has a high Luminosity, so a significant flux of flying B^- can survive decay
- Since its B^- are slow, and hence very effectively slowed down in a target, meaning higher and higher BeX cross section.

$B^{-}_{slow} + N_{bound} \rightarrow Y_b + \pi$

Is the game worth to be played? A few numbers will help to answer

$e^{-} + e^{+} \rightarrow \Upsilon(4S)$ σ ≈ 1.1 nb L ≈ 1 × 10^{36} $cm^{-2}s^{-1}$ ≈ 1.1 kHz

$B^{-} + B^{+}$ ≈ 550 Hz

B^{-} surviving probability: ≈ 0.7%
(up to the "*useful*" distance) ≈ 4 Hz

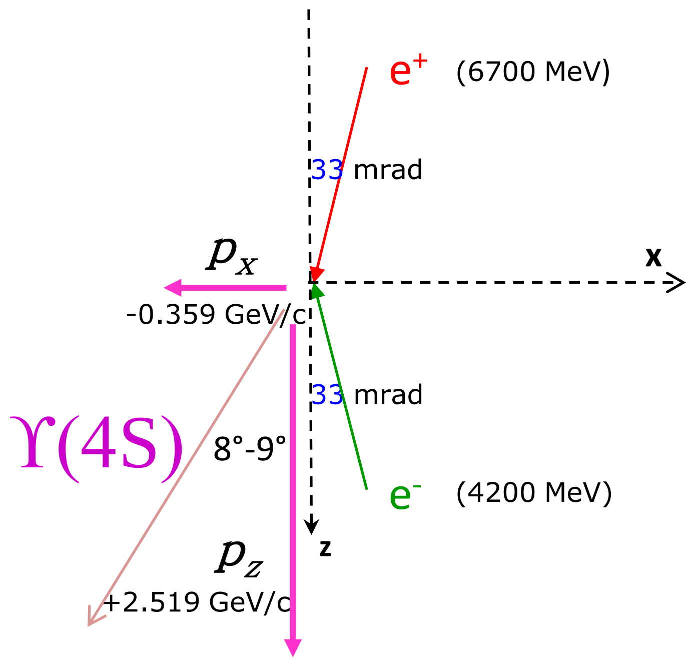
target acceptance + stop efficiency: ≈ 7% ≈ 0.28 Hz

detection & reconstruction efficiency: ≈ 10% ≈ 0.028 Hz

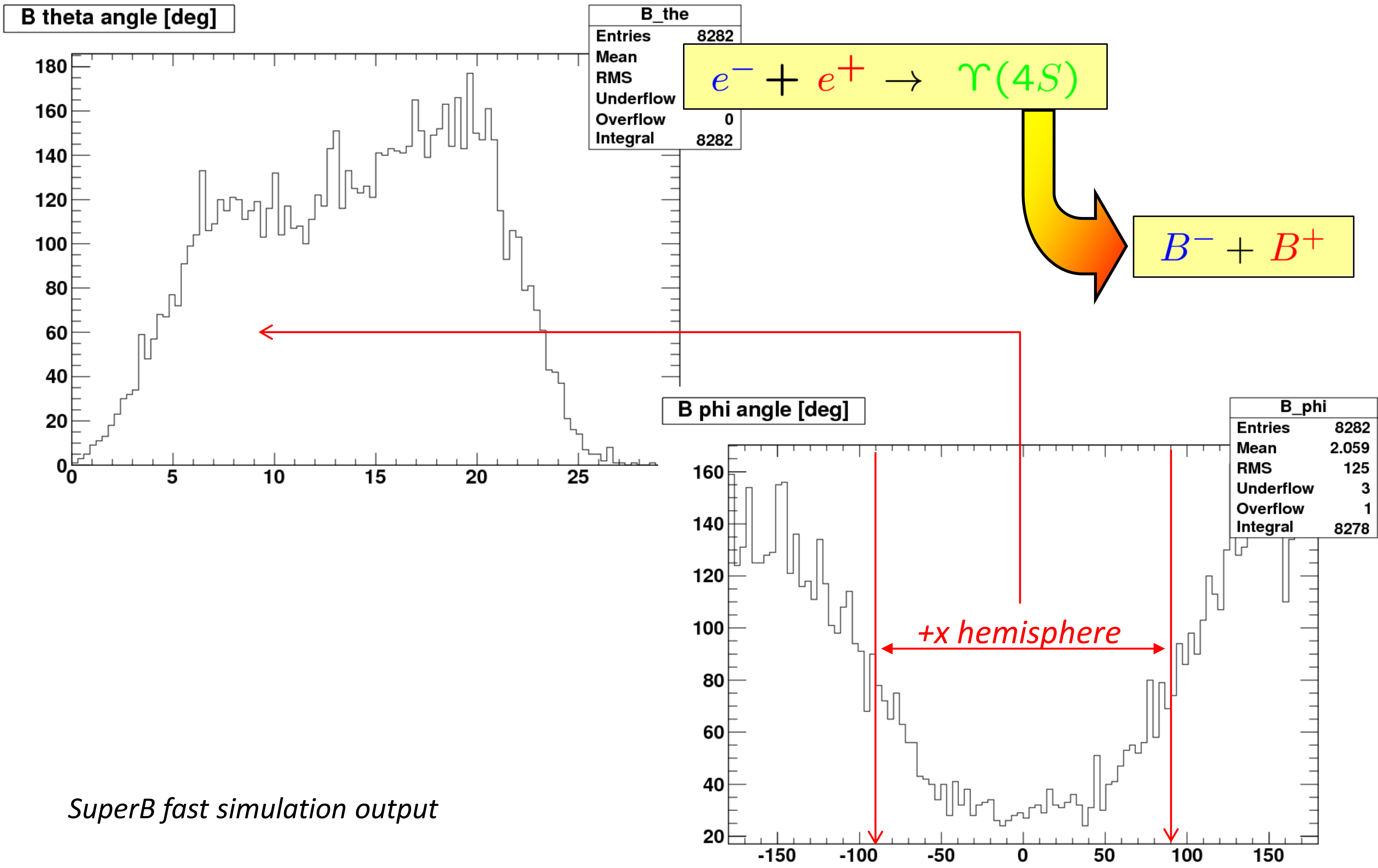
daily duty cycle: ≈80% ⟹ **≈ 2x10^{3} *events/day***

Note: not considered any enhancement due to a possible $A^{2/3}$ yield increase

The configuration of the SuperB **I.P.** plays a relevant role for the shape and position of a target



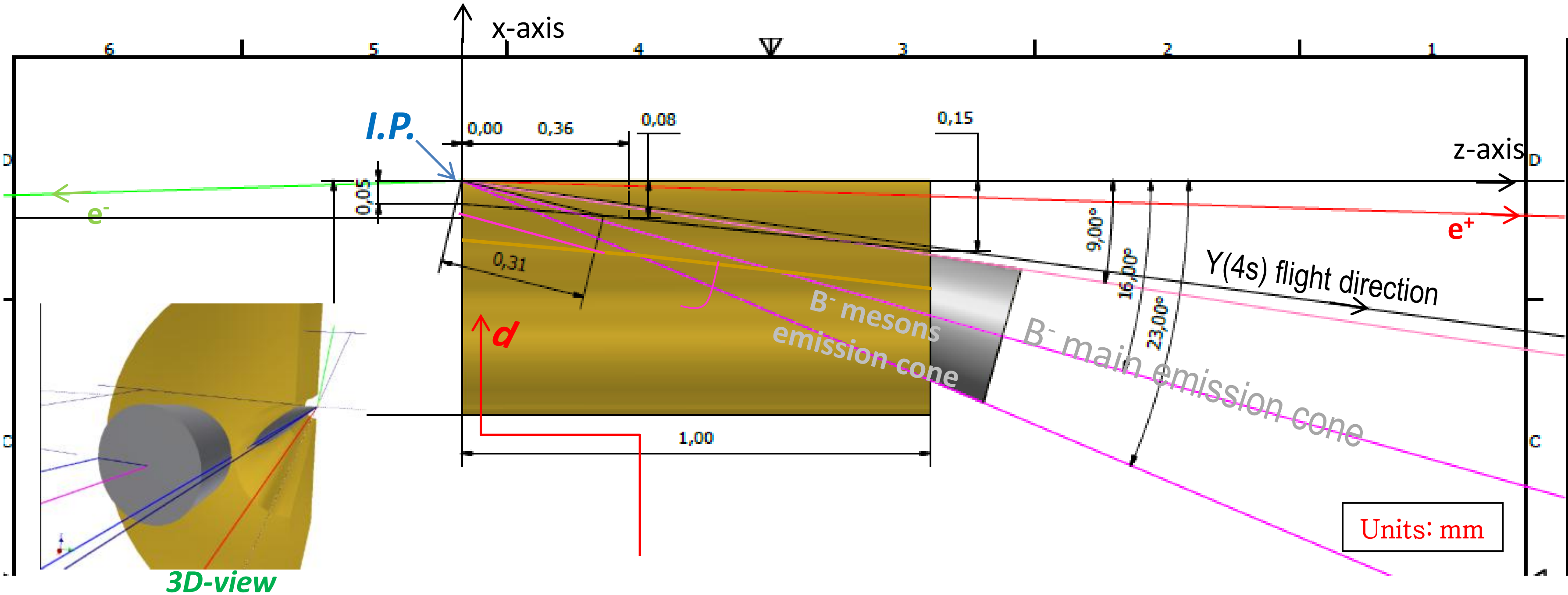
Angular distributions of $B^{\pm}$ from $\Upsilon(4S)$ decay at SuperB



SuperB fast simulation output

The Gold Nozzle

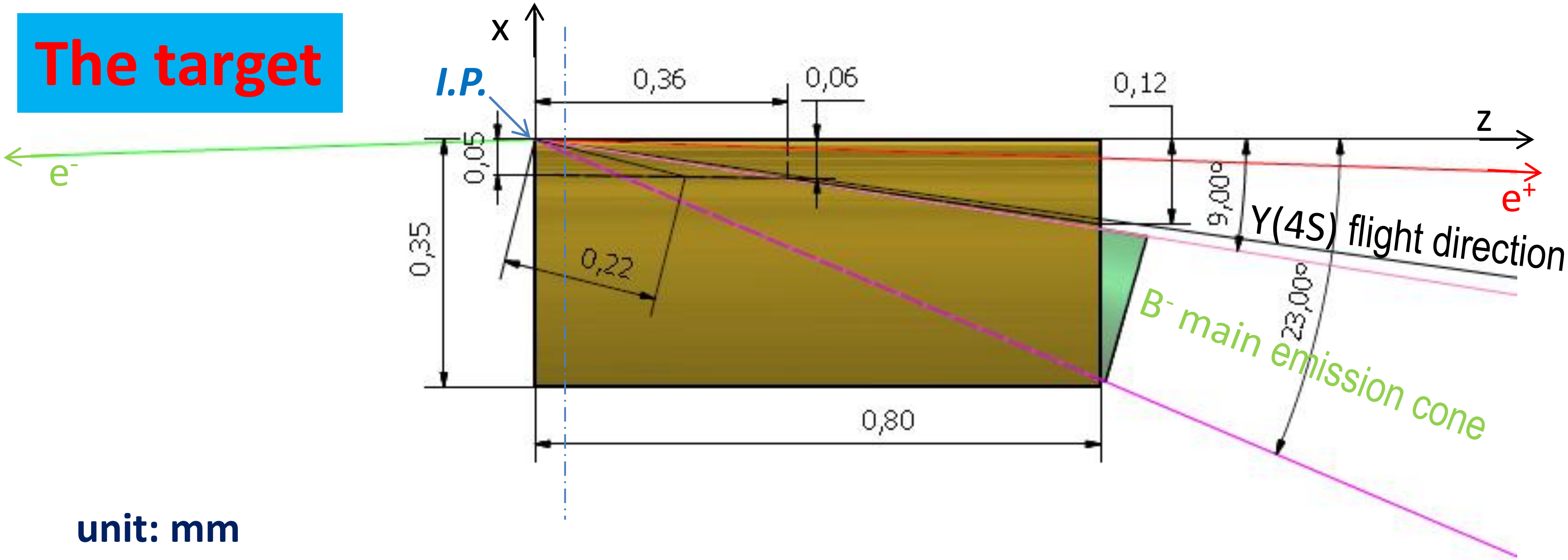
$e^+e^- \rightarrow \Upsilon(4s) \rightarrow B^+B^-$



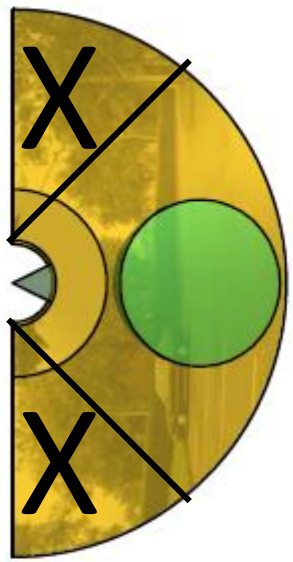
*The **d** is the distance to minimize (in this drawing, as an example, it is 0,31):*
it is the average path in vacuum of the B^- mesons before entering the material (*).
If θ is the B^- flight angle and r the nozzle "troath" radius, we have that:
*d= r/sinθ, for a nozzle entrance cylindrically shaped. d is proportional to r. So, if r=0.05, d= 0.18 for $<\theta>$ =16° . Shorter d can be obtained by further squeezing the nozzle radius at the **I.P.** where the beams have minimum radii, as depicted in the figure.*
After the nozzle "troath" the radius of the nozzle can increase to follow the e^+ beam divergence.
The nozzle position could be further shifted down-boost and its lenght shortened, if convenient.
The proper material for the nozzle should be selected considering the heating during normal operation and the power deposition in case of beam losses: Au seems a convenient choice.

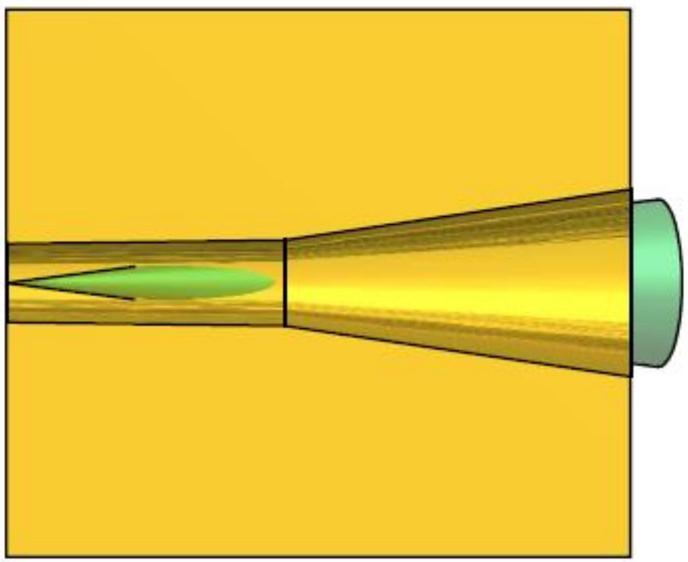
(*)At SuperB, the B^- "decay lenght" is ≈0.1

The target



unit: mm

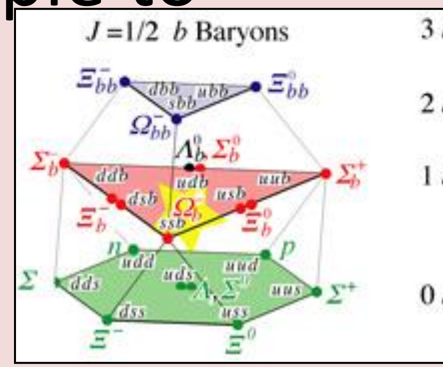




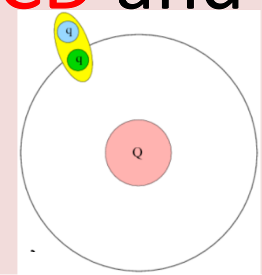
thanks to S. Tomassini

Physics goals I

- To provide a high statistics data sample to determine the bottom baryon properties



- To get information on non-perturbative QCD and potential models



The bulk of data on Bottom Baryons has been obtained up to now from the Tevatron. Actually, experiments at LHC, in particular LHCb, are expected to provide further, high statistics, data. SuperB has good chances to stay in this business if the time schedule will be as planned.

Physics goals II

SuperB would be a unique place where it will be possibile to study the interaction of slow B mesons on Nucleons & on Nuclei and of Y_b baryons in Nuclei.

The low momentum of the produced Y_b in nuclei makes SuperB the ideal (and only) place to study the possible formation of "Super-nuclei" and even more exotic nuclear bound systems with embedded heavy–quarks.

SuperB can also operate at the energy of the $\Psi(3770)$, and hence allows to study similar topics in the charm sector with the same technique [$\Psi(3770) \rightarrow D^+D^-$].

Heavy Flavor Nuclei

A topic addressed 22 year ago in a pioneering paper…

IL NUOVO CIMENTO VOL. 102 A, N. 2 Agosto 1989

Production of Heavy Flavours in Nuclei at the ARES Facility (*)(**).

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F. IAZZI
Dipartimento di Fisica del Politecnico - Torino
Istituto Nazionale di Fisica Nucleare - Sezione di Torino

(ricevuto il 18 Gennaio 1989)

Recently relaunched…

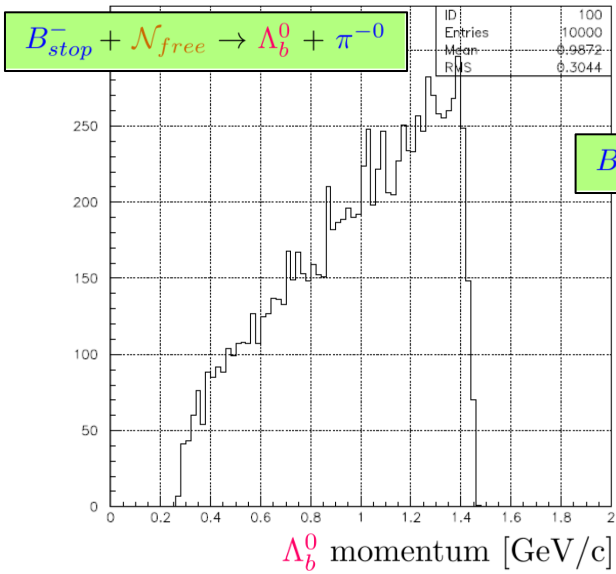
Progress of Theoretical Physics Supplement No. 186, 2010 199

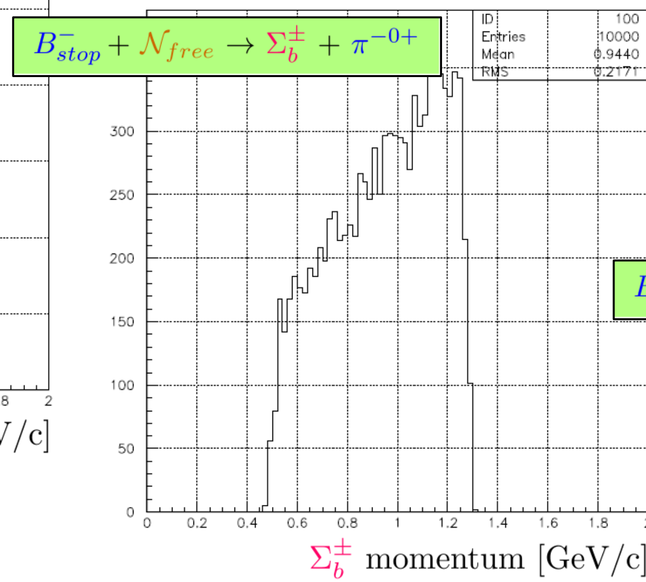
Exotic Nuclei with Charm and Bottom Flavors

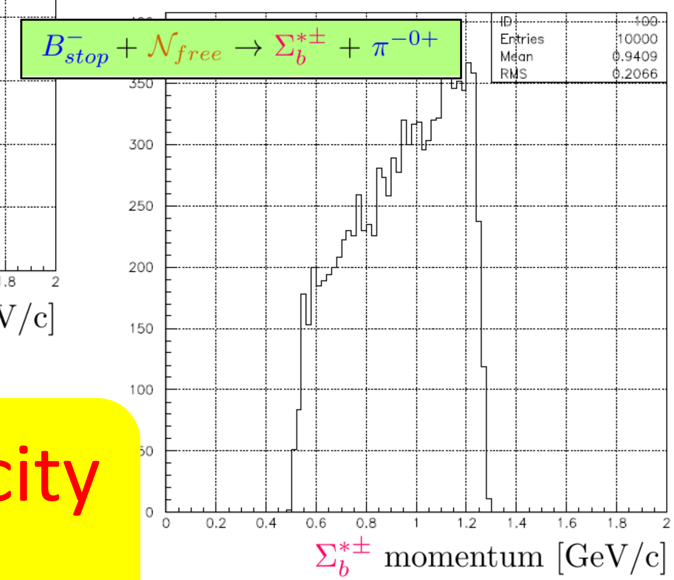
Shigehiro YASUI[1,*)] and Kazutaka SUDOH[2,**)]

[1]*KEK Theory Center, Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization (KEK), Tsukuba 305-0801, Japan*
[2]*Nishogakusha University, Tokyo 102-8336, Japan*

The Y_b from SuperB are very appealing...





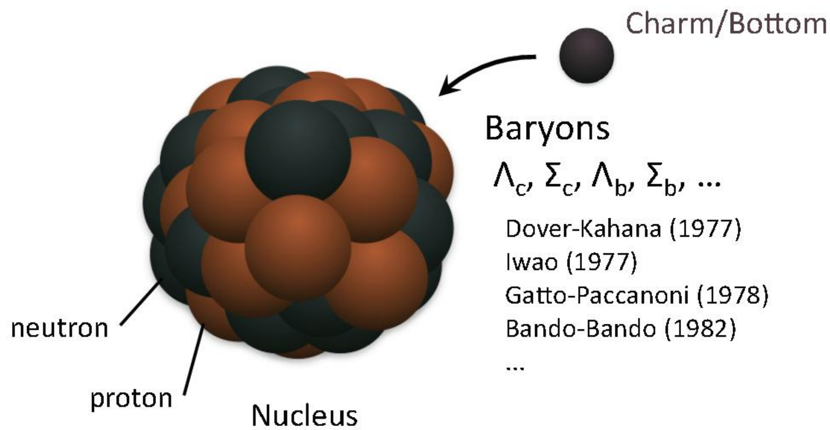


...since they overlap the right velocity window of nucleons in nuclei.

$$\beta_{\Upsilon_b} \approx \beta_{N_{bound}}$$

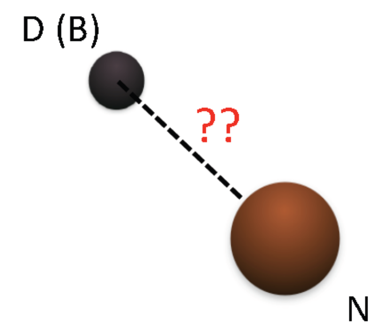
Open questions to which only SuperB can answer?

What are charm/bottom nuclei?



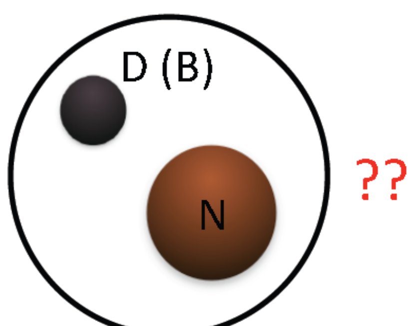
DN and BN potential

Q. What is the interaction between D (B) and N ?



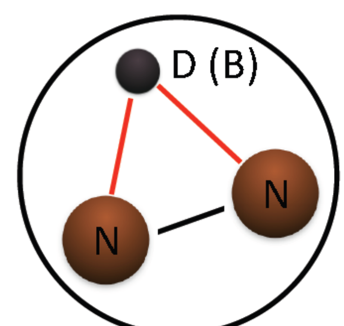
DN and BN bound states

Q. Are there bound states of D (B) and N ?



Exotic charm/bottom nuclei

Q. Are there exotic nuclei with D (B) ?

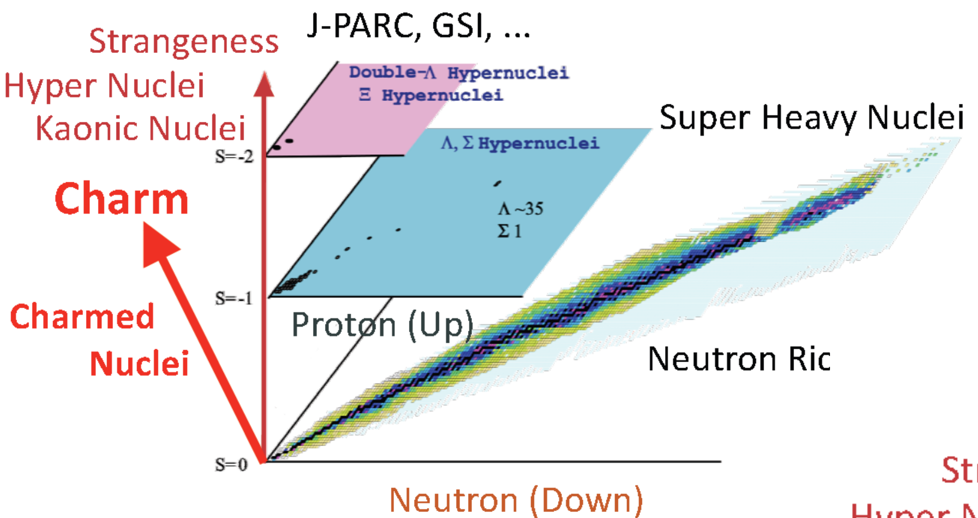


A=2 charmed (bottom) nucleus

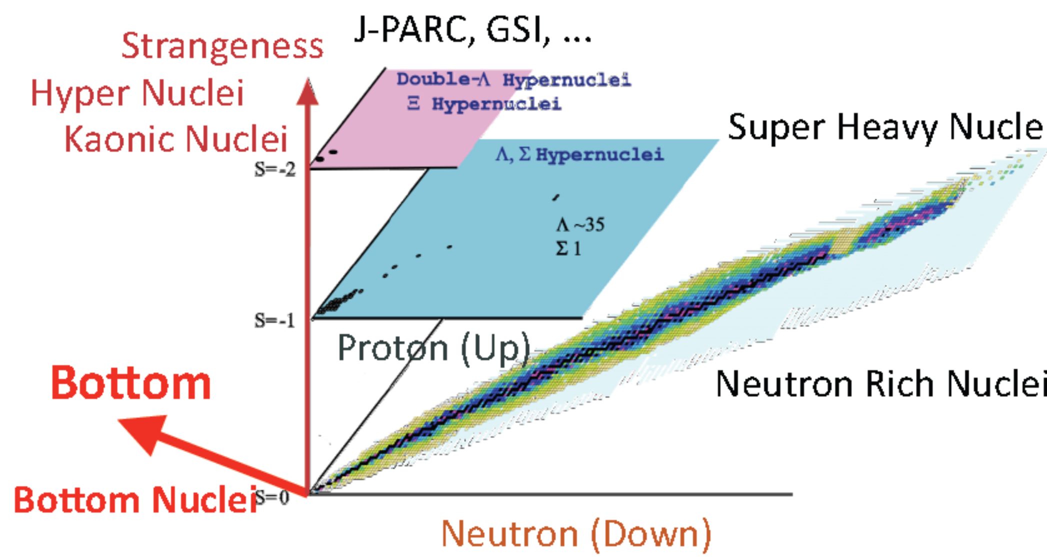
(from S. Yasui & K.Sudoh, KEK 2009)

Do exist Charmed-, Beauty- Nuclei?

Multi-Favored Nuclear Chart



Multi-Favored Nuclear Chart



Summary

- **Super*B*** could offer a unique opportunity for:
  - an extensive study of the bottom baryon properties
  - a unique approach to study flavor physics in nuclei with the possible onset of super-nuclei or deeply bound flavor nuclei.

- *Next steps*:
  - to validate the initial calculations by means of Super*B* full simulation program to give a solid basis to these first results
  - to assess the feasility to put a target close to the I.P., evaluating the effect on the beams and the background on the Detector
  - to get feedback from the Community to deepen the study in the physical interest for this topic

Concluding Remark

Exploring now, before start building the SuperB, its possible use also as a ***Heavy-Baryon Factory*** means to catch an opportunity that, if lost, could be later on very expensive or even impossible to implement