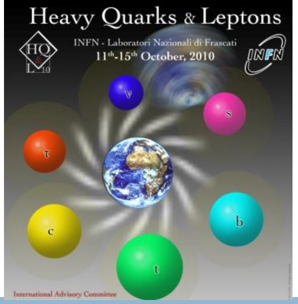


NEW EXPERIMENTS
SUMMARY TALK
HEAVY QUARKS AND LEPTONS 2010

Angel López
University of Puerto Rico – Mayaguez

October 15, 2010
Frascati, Italy

The luminosity upgrade era

The challenge is to handle the increase.

- **e^+- e^- Machines**
  - **B physics**
    - **SuperB**
    - **SuperKEKB**
  - **Kaons**
    - **KLOE-2**
    - **K –> $\pi\nu\nu$**

- **Hadron collider**
  - **LHC**

Other initiatives

- **Neutrinos**
  - **$\sin^2\theta_{13}$**
  - **Solar Neutrinos**
  - **Beta Decay**
  - **Neutrinoless Double Beta Decay**

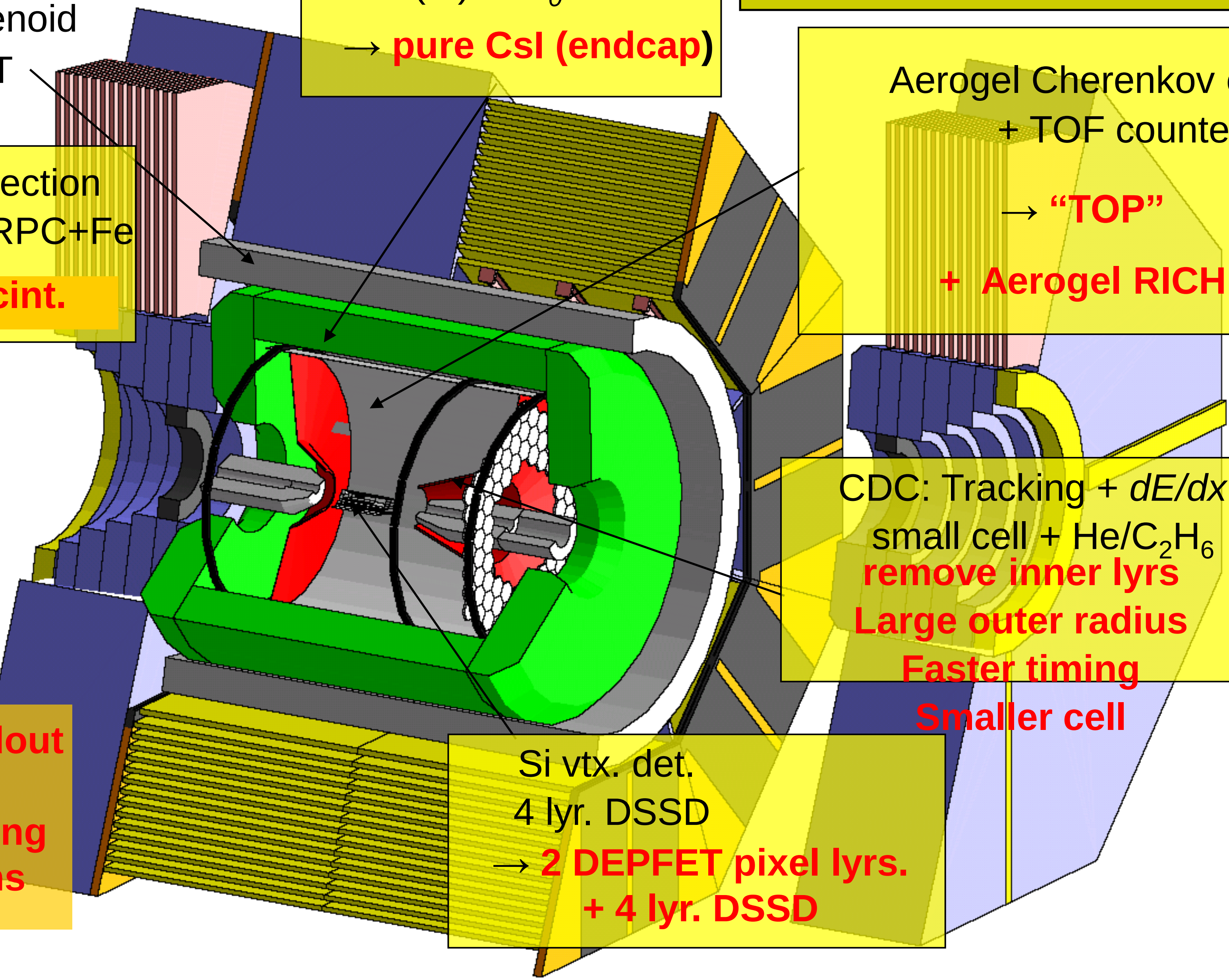
- **Antiproton Storage Ring**
  - **PANDA experiment**

Further Continuation of Flavour Physics possible at a Super B Factory

- What is the next experimental step? Precision measurements
  - Much larger sample needed for this purpose –> Super B factory
- Hopefully new phenomena might be seen:
  - **CPV in B decays from the physics outside the KM scheme.**
  - **Lepton flavour violations in τ decays.**
- Physics models can be identified (if new effects are observed) or new ones can be constrained (if nothing is seen).
- Even in the worst case scenario (e.g. for MFV), B –> $\tau\nu$, D$\tau\nu$ can probe the charged Higgs in the large tan β region.
- **Physics motivation is independent of LHC.**
  - If LHC finds NP, precision flavour physics is compulsory.
  - If LHC finds no NP, high statistics B/τ decays would be a unique way to search for the TeV scale physics.

Talks 69,70,71,72

Belle Upgrade for the Super B Factory

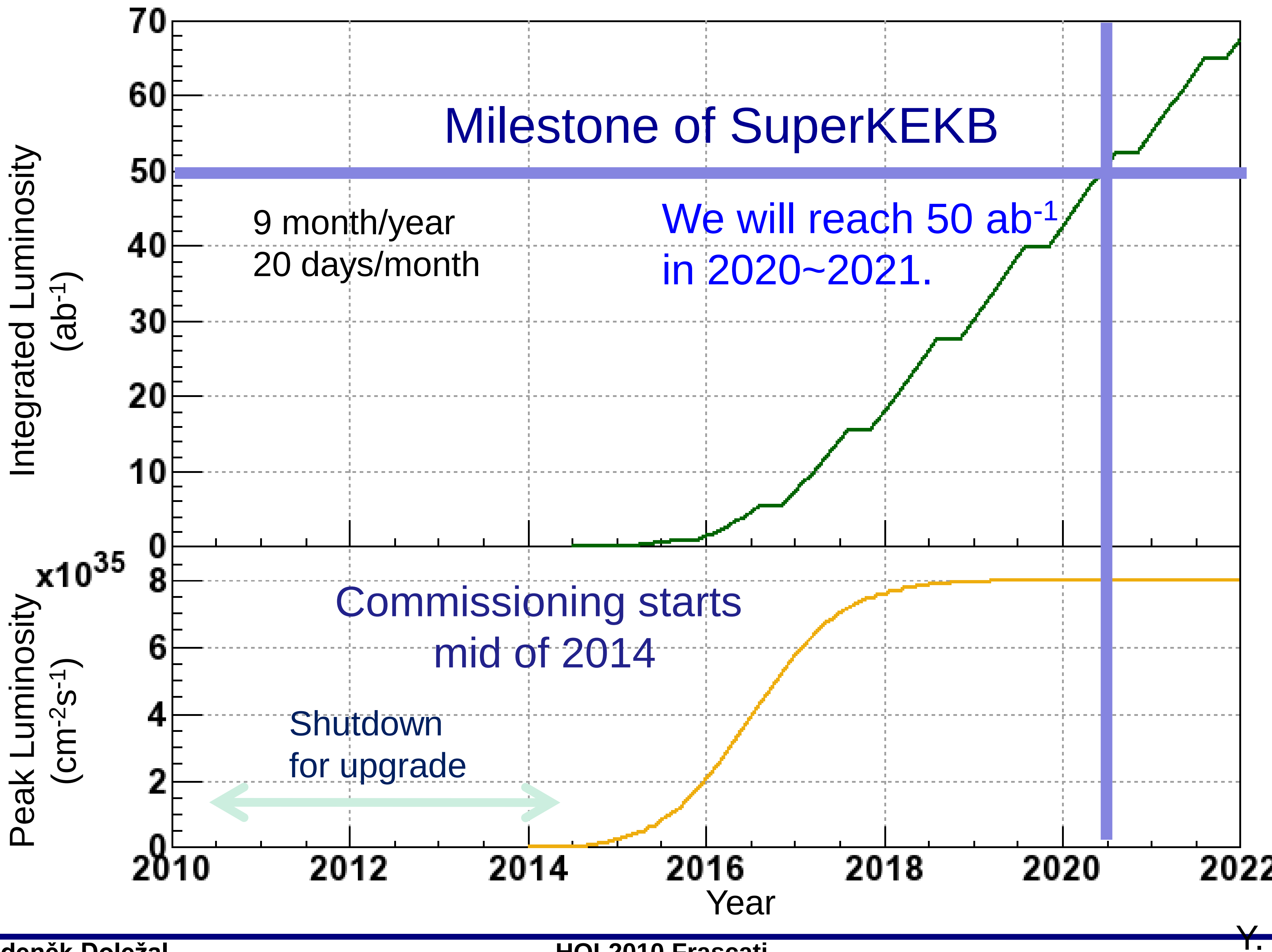


Summary

- SuperKEKB/Belle II aims for (discovering and) understanding the New Physics.
- Target Luminosity of SuperKEKB is $8x10^{35}/cm^2/s$, will provide $50ab^{-1}$ by 2020-2021.
- Belle II gives similar or better performance than Belle even under ~20 times higher beam background.
- Project has been approved by Japanese Government in June 2010. KEKB/Belle operation has been terminated. Construction starts shortly.

- Next collaboration meeting: Nov. 17-20 @KEK, still open to everyone.
- Technical Design Report will be printed very soon.

Luminosity upgrade projection



Crab Waist

Move beam waist to the axis of other beam with a pair of sextupoles

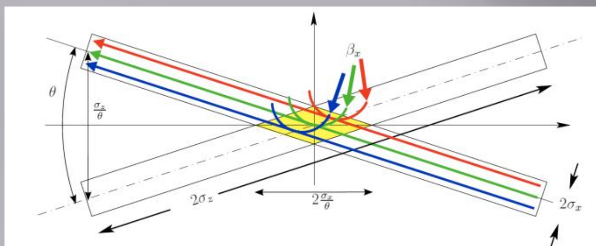
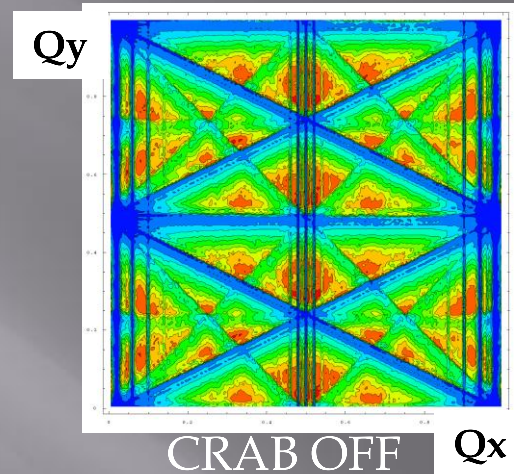
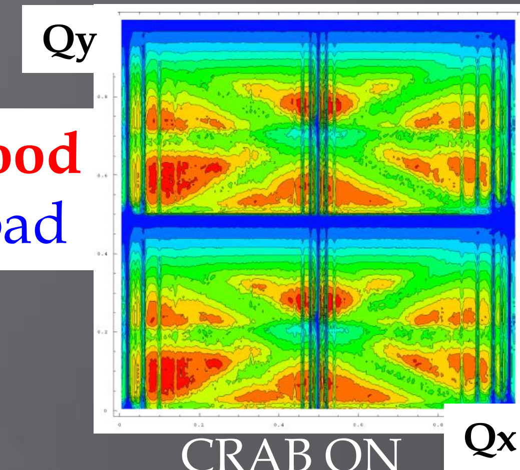


Figure 3-1. *Large Piwinski angle and crabbed waist scheme. The collision area is shown in yellow.*

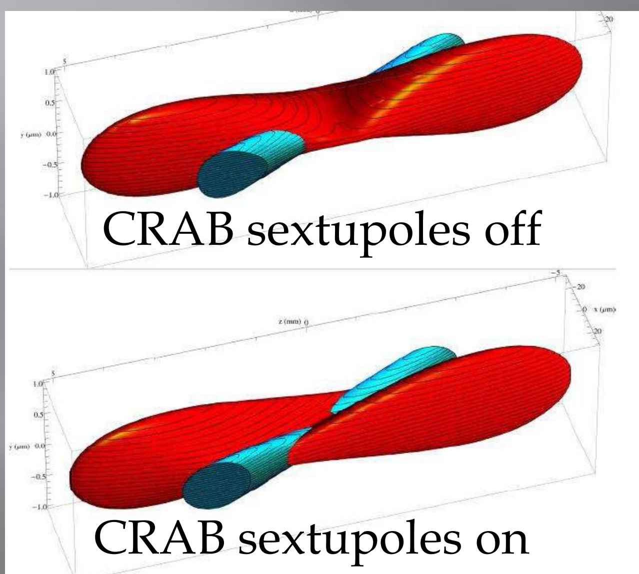


CRAB OFF

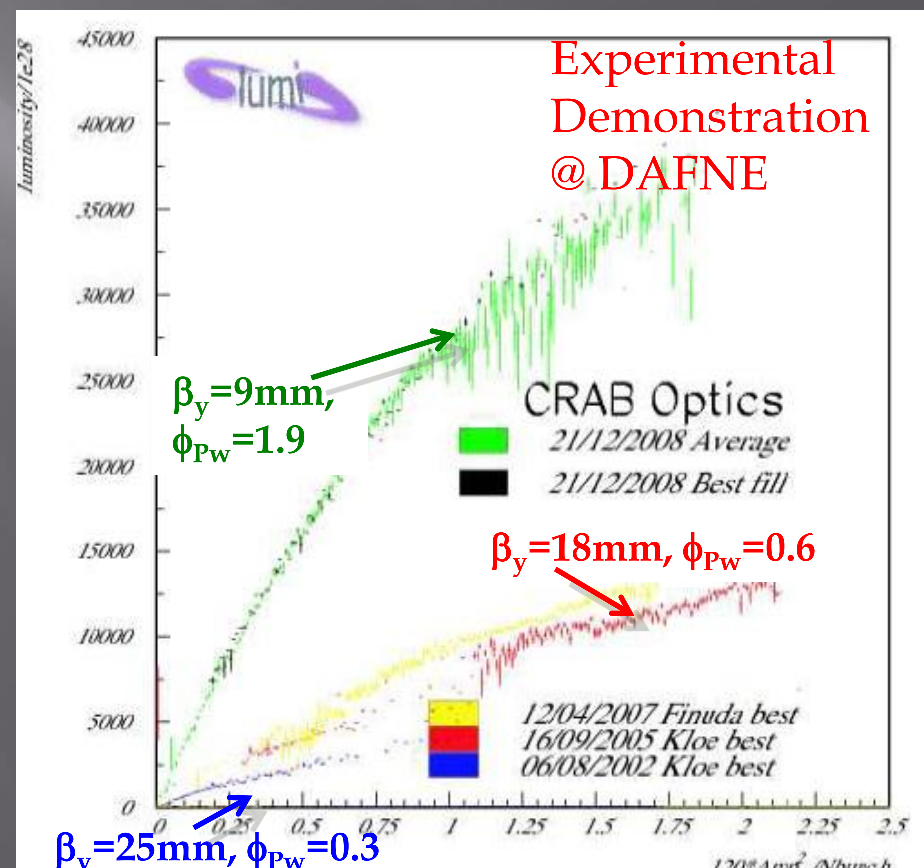
RED is good
BLUE is bad



CRAB ON

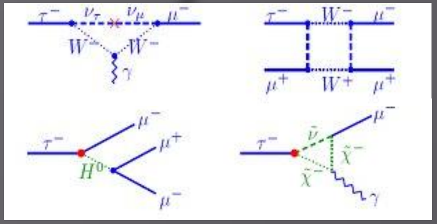


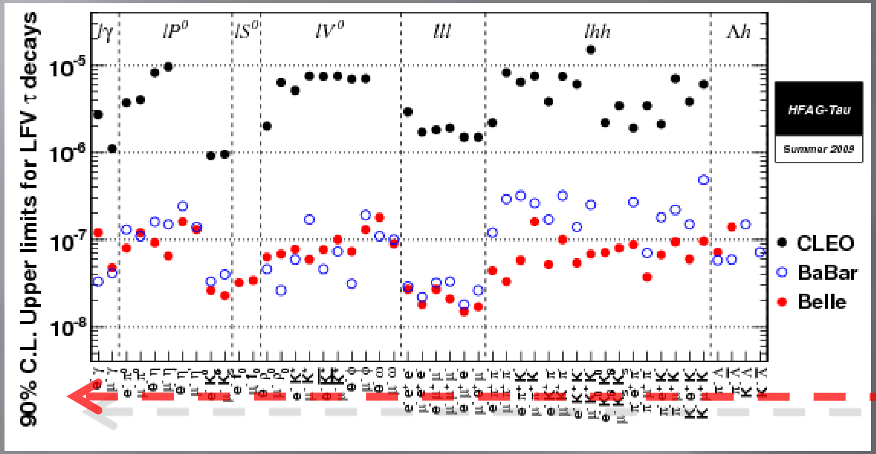
All particles from both beams collide in the minimum by region, with a net luminosity gain



SFF as a τ factory: LFV in τ decays

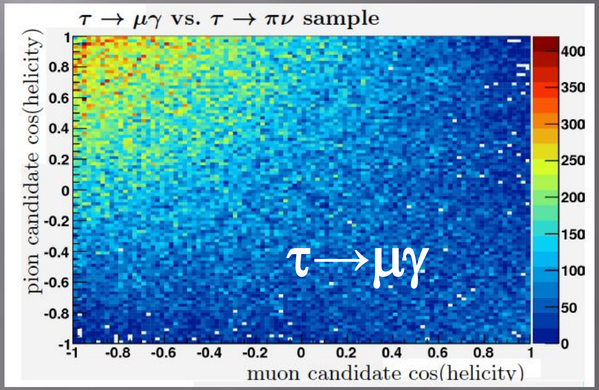
- LVF negligibly small in the SM, larger in several SM extensions
- Many limits already pushed down by the *B* factories

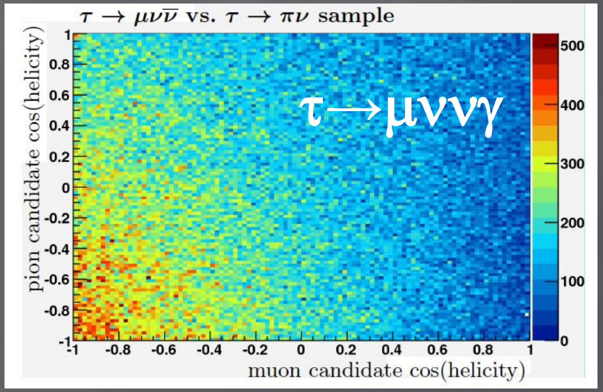




Process	Expected 90% CL upper limit	3σ evidence reach
$\mathcal{B}(\tau \to \mu\,\gamma)$	2.4×10^{-9}	5.4×10^{-9}
$\mathcal{B}(\tau \to e\,\gamma)$	3.0×10^{-9}	6.8×10^{-9}
$\mathcal{B}(\tau \to \ell\ell\ell)$	$2.3\text{–}8.2 \times 10^{-10}$	$1.2\text{–}4.0 \times 10^{-9}$

- Extrapolation of bounds to *SuperB* luminosity ($1/\sqrt{L}$) based on *BABAR* experience
  - with improvements in *reconstruction* and *angular coverage* but not *analysis re-optimizarion* ($1/L$)
- 80% polarized e^- beam further suppresses irreducible backgrounds
  - example: cos(helicity) of *signal* τ vs. *tag* τ

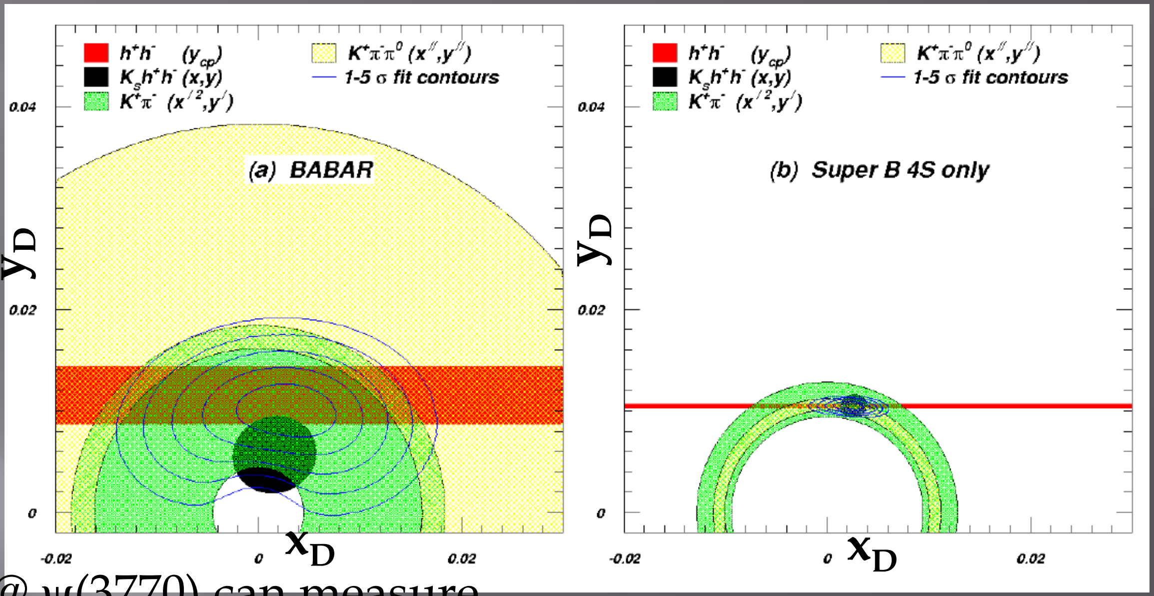




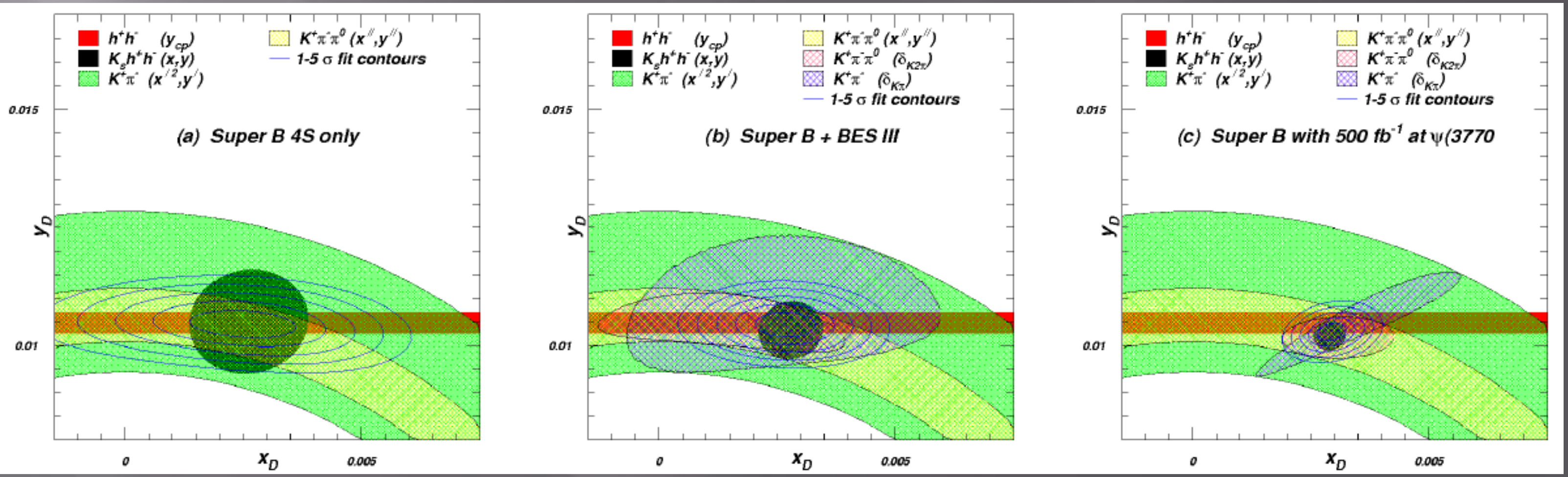
- Limits for *SuperB* golden modes (τ→ℓγ and τ→ℓℓℓ) off the HFAG plot scale!

Charm Physics @ $\Upsilon(4S)$ & $\psi(3770)$

- Measurement of D oscillations opens new window to search of *CPV* in charm. Observation of *CPV* would provide unequivocal NP signals
- Dramatic improvement of precision in D-D mixing with 75ab^{-1} @ $\Upsilon(4S)$
  - strong phase difference δ_f unmeasured
- @ *DD* threshold, *SuperB* can exploit:
  - *D*-recoil technique; quantum coherence



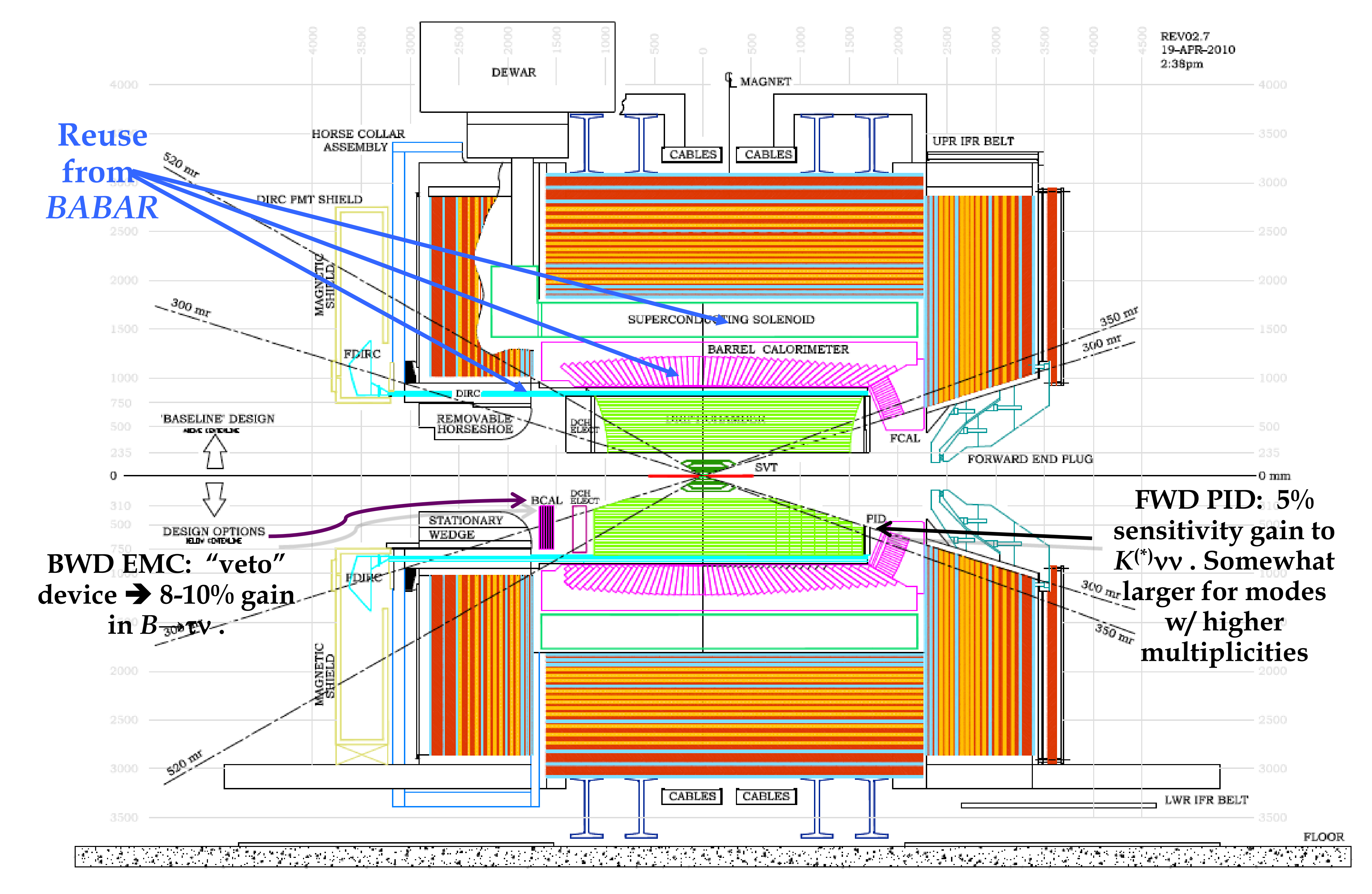
- with 0.5ab^{-1} @ $\psi(3770)$ can measure
  - FCNC modes to 10^{-8}
  - strong phase differences δ_f to $\pm 1^{o}$
- DP model uncertainty in γ angle measurement also greatly reduced



The Detector: General Considerations

- *SuperB* requirements very similar to those of the present *B* factories
  - Large solid angle coverage, good lepton ID, particle ID over large momentum range (π/□ separation to over 4 GeV), measurement of the relative decay times of the *B* mesons, good low momentum resolution, good low energy photon energy measurement
- Main differences:
  - lower machine boost (smaller longitudinal separation of secondary vertices)
    - Need to improve vertex detector resolution
  - Much higher luminosity (and L-scaling background rates)
    - Faster & more robust detectors
    - Keep an open, 100% efficient trigger
- Can re-use as much as possible & reasonable of the old detector
  - only possible because of low beam currents!

The SuperB Detector (with options)



BWD EMC: "veto" device ➔ 8-10% gain in $B \to \tau\nu$.

FWD PID: 5% sensitivity gain to $K^{(*)}\nu\nu$. Somewhat larger for modes w/ higher multiplicities

- Very rare decays
- CP violation
- NP studies

LHCb:	O(6 fb^{-1})	O(100 fb^{-1})
	2015	2022
ATLAS: CMS	O(30 fb^{-1})	O(500 fb^{-1})

PROSPECTS: LHCB UPGRADE

LHCb Upgrade

- Better Flavour Physics will be required to elucidate the NP flavour structure or probe NP at higher mass scale
  - LHC is a Super Flavour factory: 10^6 Hz of b-quarks produced
    - LHCb exploits only a small fraction of LHC:
      - $\mathcal{L}_{LHCb}=2\times10^{32}$ cm^{-2}s^{-1} / $\mathcal{L}_{LHC}=10^{34}$ cm^{-2}s^{-1}
    - **LHCb Upgrade will be complementary to Super B(Belle) factory!**
- LHCb Upgrade Strategy
  - Running at 10 times design luminosity, i.e. at ~ 2×10^{33} cm^{-2}s^{-1}
    - Upgrade planned in 2 phases matching LHC schedule :
      - Phase 1: ~ 2016 $\mathcal{L} = 10^{33}$ cm^{-2}s^{-1}. R&D has started
      - Phase 2: $\mathcal{L} = 2\times10^{33}$ cm^{-2}s^{-1}
    - *read out full experiment at 40 MHz, currently at 1 MHz*
      - *Gain a factor 2 in the trigger efficiency for hadronic channels*
    - *vertex and photon detector needs to be replaced*

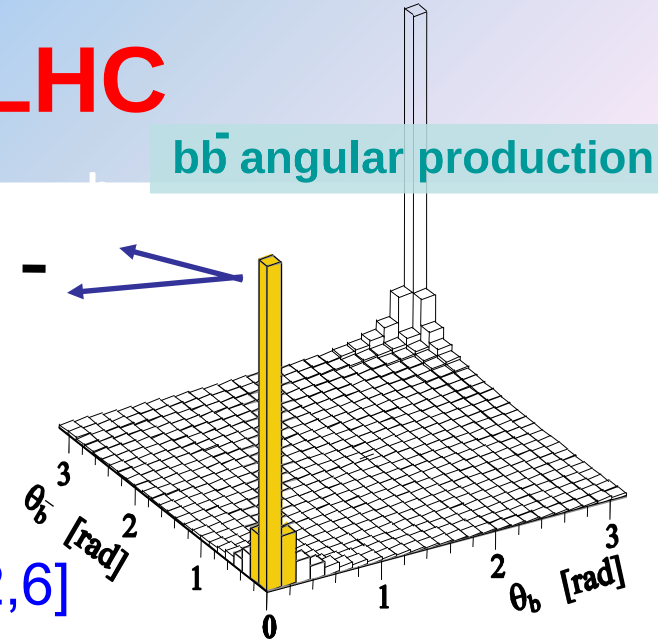
Comparison with the LHCb

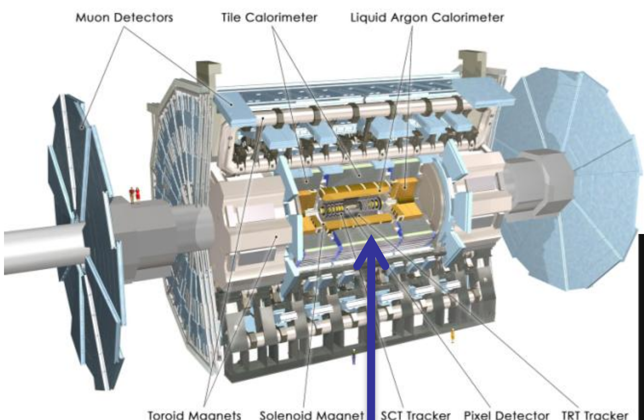
e^+e^- has advantages in…	LHCb has advantages in…
CPV in $B \to \phi K_S$, $\eta' K_S$,…	CPV in $B \to J/\psi K_S$
CPV in $B \to K_S \pi^0 \gamma$	Most of B decays not including ν or γ
$B \to K\nu\nu$, $\tau\nu$, $D^{(*)}\tau\nu$	Time dependent measurements of B_S
Inclusive $b \to s\mu\mu$, *see*	$B_{(s,d)} \to \mu\mu$
$\tau \to \mu\gamma$ and other LFV	B_c and bottomed baryons
$D^0\overline{D}^0$ mixing	

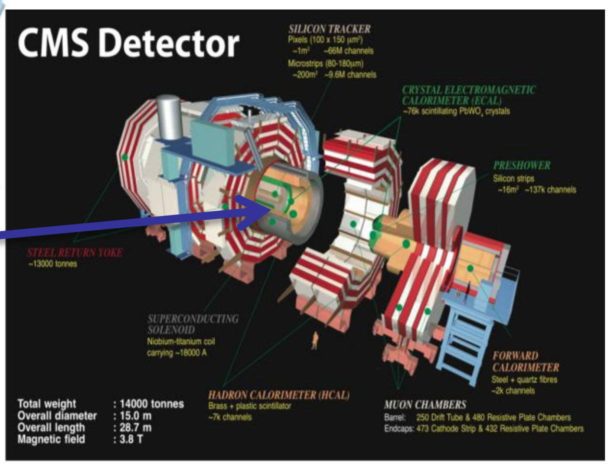
Complementary!!

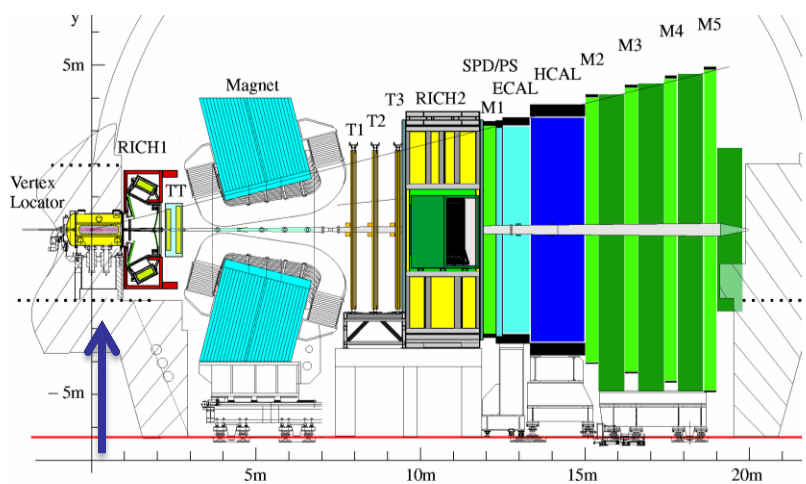
Heavy Flavours @ LHC

- LHC is a B- and D-mesons super factory:
  - $b\bar{b}$ produced mostly forward/backward
  - Detectors have different acceptance:
    - ATLAS/CMS $|\eta|<2.5$
    - LHCb forward spectrometer covering $\eta=[2,6]$
      - ~30% in LHCb acceptance







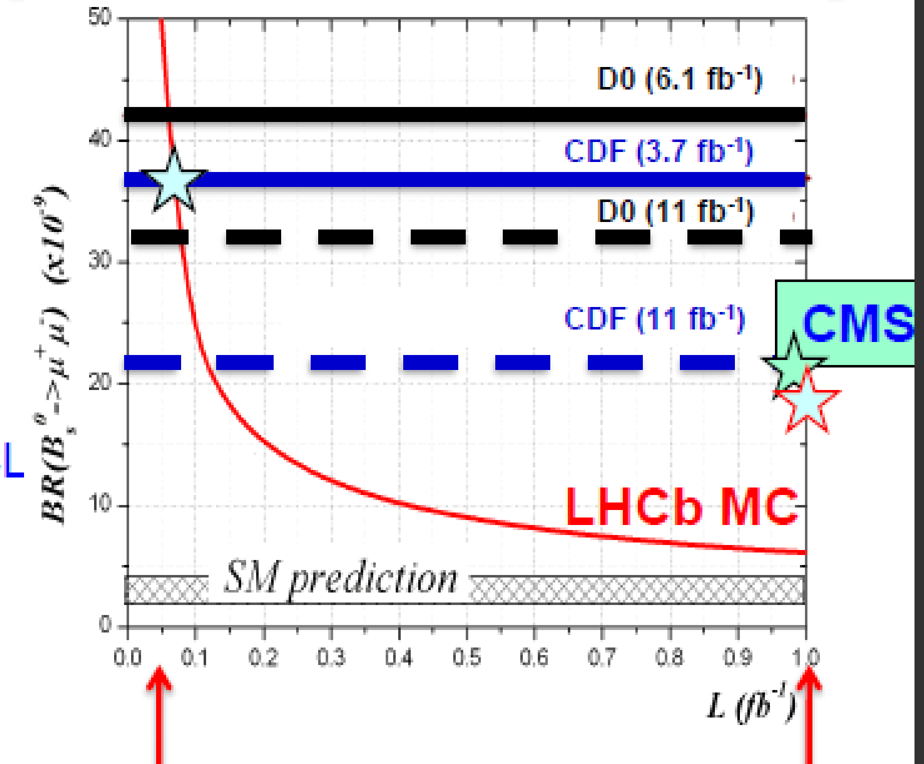


- **An efficient trigger is essential**

$B_s \to \mu^+\mu^-$

- ATLAS/CMS & LHCb should be complementary for such a measurement
  - Very soon LHC should be able to approach or surpass world best sensitivity
    - With 50 pb^{-1} possible already to approach new limit:
    - LHCb alone:
      - $BR(B_s \to \mu^+\mu^-) < 3.4 \times 10^{-8}$ @90%CL
      - 5σ observation down to BR = 5 x SM with 1 fb^{-1} ($BR(B_s \to \mu^+\mu^-) > 1.7 \times 10^{-8}$)
  - For a 5σ measurement at SM value a combination of all LHC observations will help!

Exclusion limit at 90% CL at $\sqrt{s}$=7TeV



Close to CDF limit possible already end of the year

2011?

LHCb sensitivities

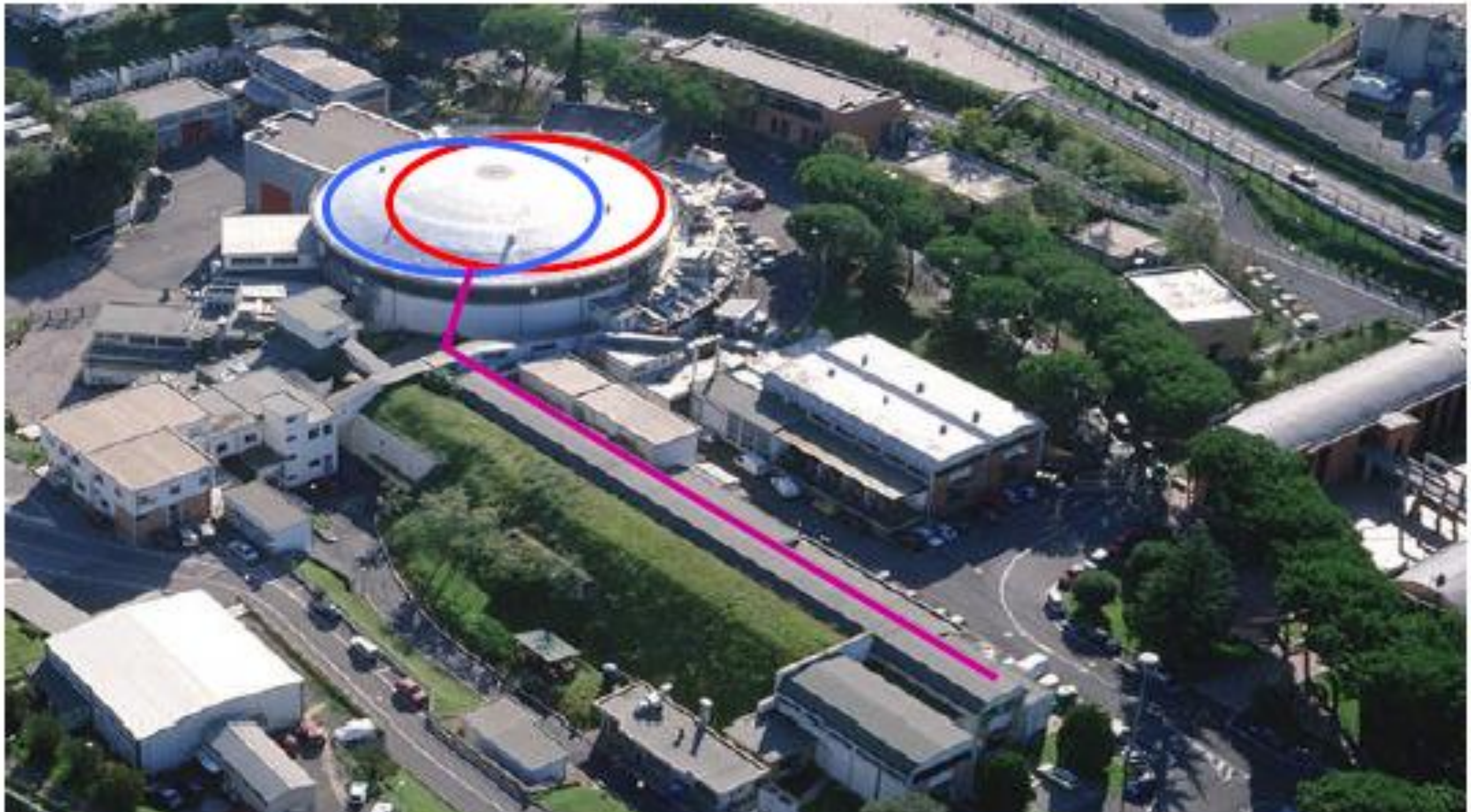
- With 100 fb^{-1} error in $2\beta_s$ decreases to ±0.003 (only L improvement), useful to distinguish among Supersymmetry (or other) models, where the differences are on the order of ~0.02

LHCb Sensitivities (100 fb^{-1} @14TeV)		
Observable	Sensitivity	SM
CPV($B_s \to J/\psi\phi$) ($2\beta_s$)	0.003	0.04
γ tree	1°	67.2°
$\mathcal{B}(B_s \to \mu^+\mu^-)$	5-10% of SM	3.6×10^{-9}
$A_{FB}(B \to K^*\mu^+\mu^-)$	0.07 GeV^2	4.36 GeV^2
CPV($B_s \to \phi\gamma$)	0.02	0.10

- + many more observables:
  - ϕ_s in $B_s \to \phi\phi$, γ mediated by loops, cos 2β in $B_d \to J/\psi K_S$, …
- **The upgrade strategy is SLHC independent**
  - **Letter of Intent → end 2010**

DAΦNE collider

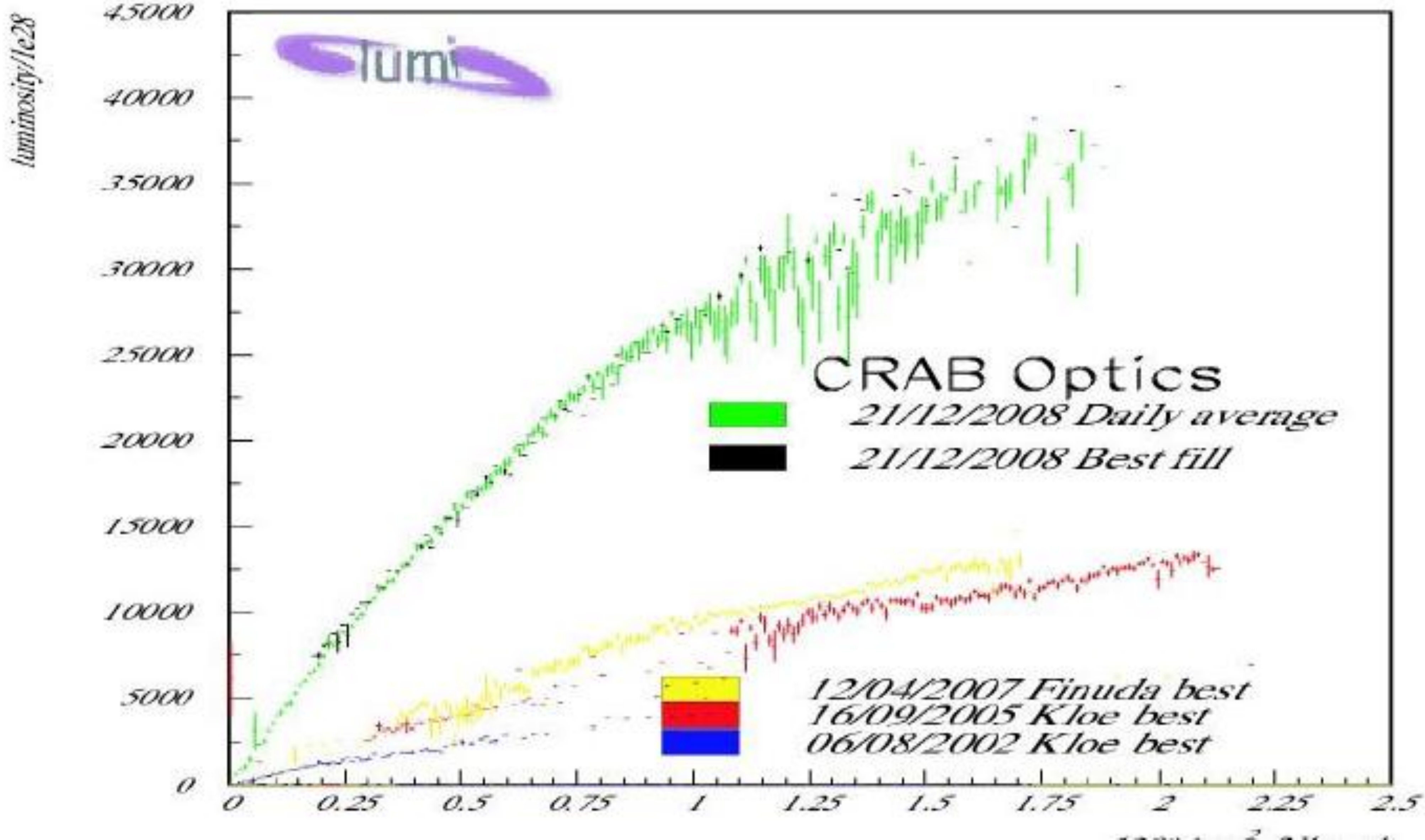
- At INFN's Laboratori Nazionali di Frascati
- Electron-positron collider working at the Φ-resonance cms energy 1019.4 MeV



KLOE-2 and need for DAΦNE upgrade

- Ambitious physics program of KLOE-2 requires order of magnitude higher integrated luminosity than KLOE
- Going to be realized by implementing major upgrades of DAΦNE, viz.:
  - Increased Piwinski angle $\phi_P \sim \theta/\sigma_x$ by larger crossing angle of beams and reduced beam size at crossing point
  - „Crab waist" beam optics with suppressed betatron resonances, using two sextupoles at both sides of interaction point

Luminosity improvement with crab waist optics

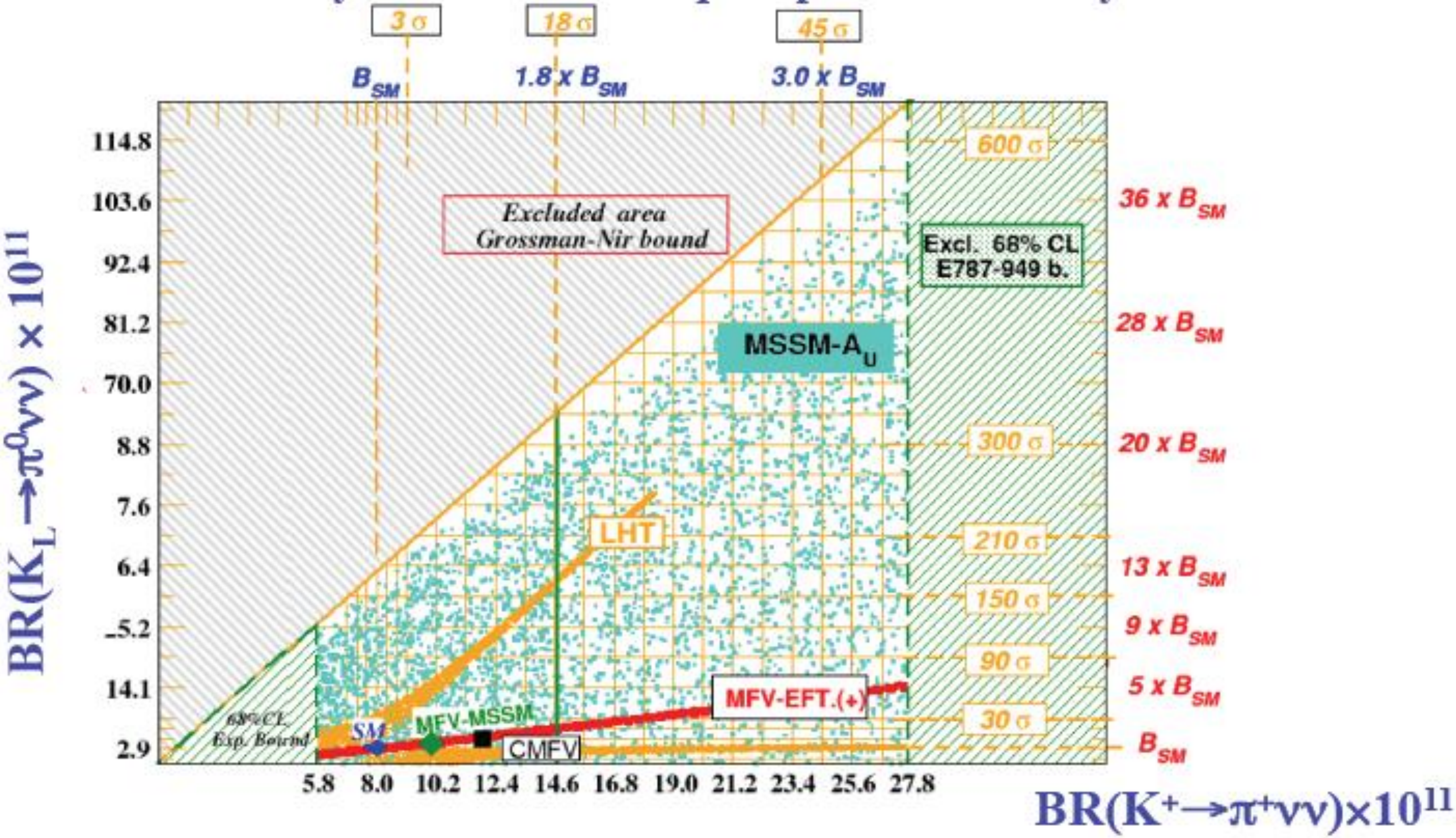


KLOE-2 physics issues

- Prospects for CKM unitarity and lepton universality tests
- **Search for quantum decoherence and testing CPT conservation**
- Low-energy QCD: rare K decays, physics of η, η', structure of low-mass scalars
- **The γγ physics**
- Contribution of vacuum polarization to $(g_\mu - 2)$

SM and BSM prediction for $K \rightarrow \pi\nu\nu$

Deviations from SM by more than 10% quite possible in many NP models



$K \to \pi\nu\nu$ sensitivity summary

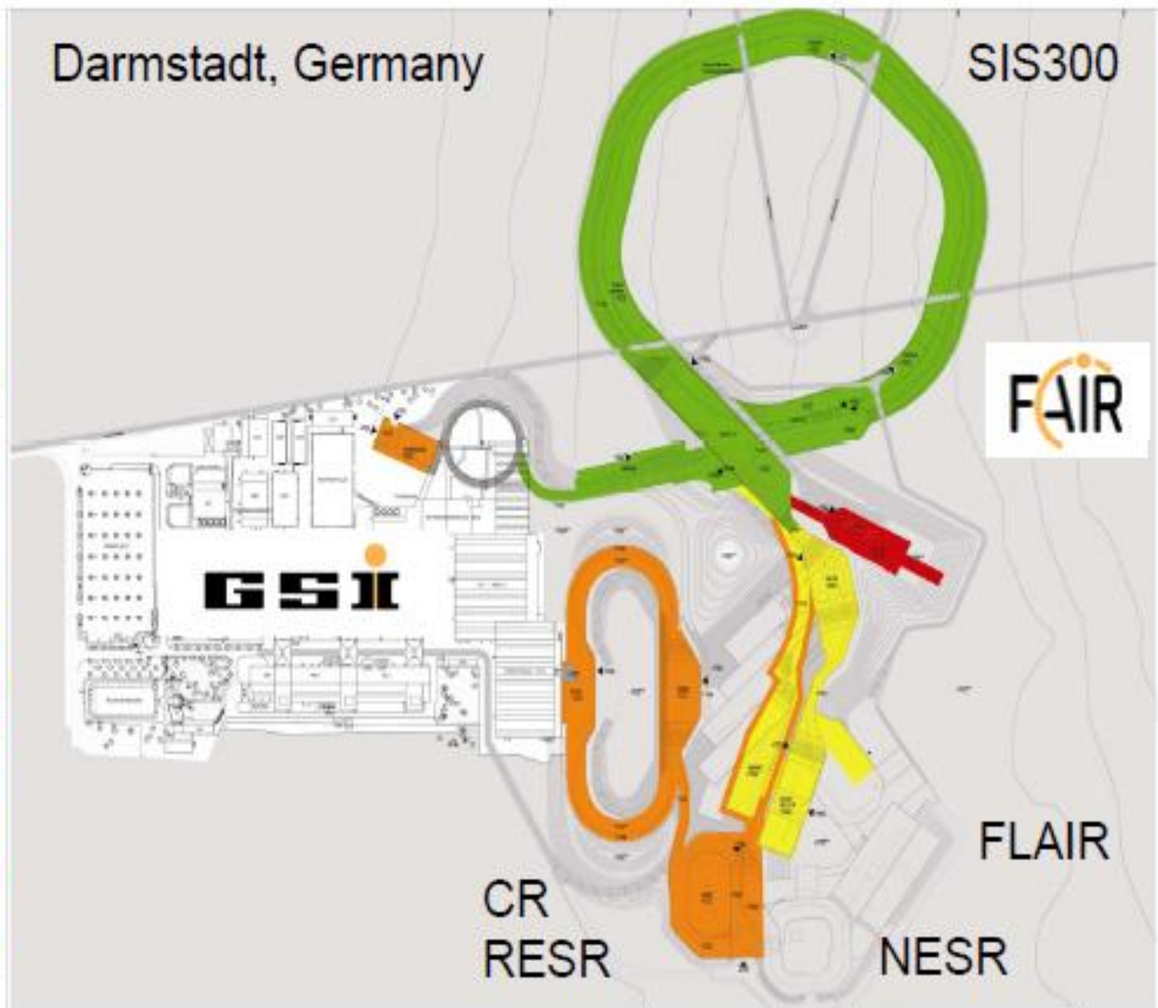
Expt	Primary beam	Intensity (ppp)	SM evts/yr	Start date + run yrs	Total SM evts
NA62	**SPS 450 GeV**	3×10^{12}	**55**	**2012+2**	**110**
FNAL $K^{\pm}$	Booster 8 GeV	2×10^{13}	40	2015+2	80
FNAL $K^{\pm}$	Project X 8 GeV	2×10^{14}	250	2018+5	1250
P996	Tevatron up <150 GeV	1×10^{13}	120	2018+5	600
E14	**JPARC-I 30 GeV**	$\mathbf{2 \times 10^{14}}$	**1-2**	**2011+3**	**3-7**
E14	JPARC-II 30 GeV	3×10^{14}	30	2018+3	100
FNAL K_L	Booster 8 GeV	2×10^{13}	30	2016+2	60
FNAL K_L	Project X 8 GeV	2×10^{14}	300	2018+5	1500

All dates/estimates are speculative, some are more speculative than others

FAIR – Facility for Antiproton and Ion Research

Convention signed October 4th

"Final Act States"



Colored:
FAIR Start Version

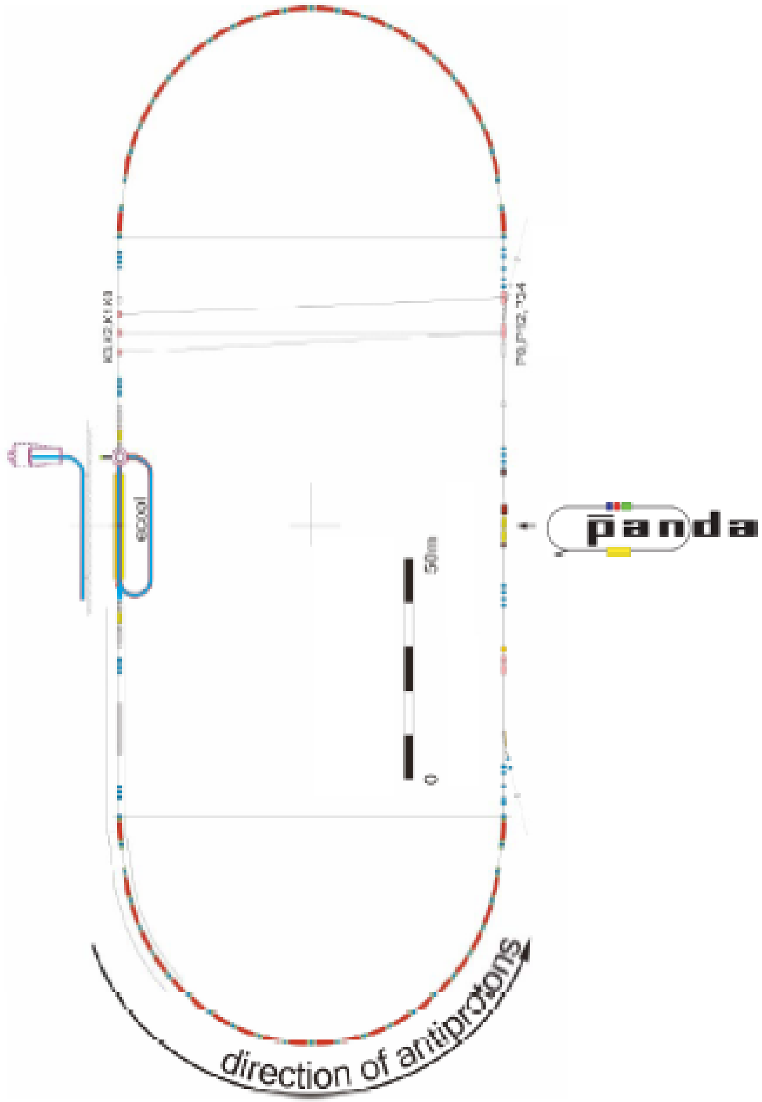
SIS100

CBM"Light"

Proton Linac
Pbar target
CR
HESR

SuperFRS

HESR – High Energy Storage/Synchrotron Ring



- antiproton ring
- injection 3.5 GeV/c
- 1.5 – 16 GeV/c (0.83 – 14 GeV)
- 10^{10} to 10^{11} stored particles
- bunched beam
- high resolution mode
  - $2\cdot 10^{31} cm^{-2} s^{-1}$ (10^{10} pbar)
  - $\sigma_p/p \leq 2\cdot 10^{5}$
  - $p \leq 9$ GeV/c, e^- cooling
- high luminosity mode
  - $2\cdot 10^{32} cm^{-2} s^{-1}$ (10^{11} pbar)
  - $\sigma_p/p \sim 10^{-4}$
  - $p \leq 15$ GeV/c, stochastic cooling

RESR not part of the Start version:
Accumulation in the HESR,
limits intensity

Spectroscopy of Charmonium

$\overline{\mathrm{p}}\mathrm{p}$-Annihilations: high hadronic background

$$\bar{\mathbf{p}}\mathbf{p} \longrightarrow \boldsymbol{J/\psi} + \boldsymbol{X}$$

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

$\overline{\mathrm{p}}\mathrm{p} \to J/\psi\pi^+\pi^- \to e^+e^-\pi^+\pi^-;$

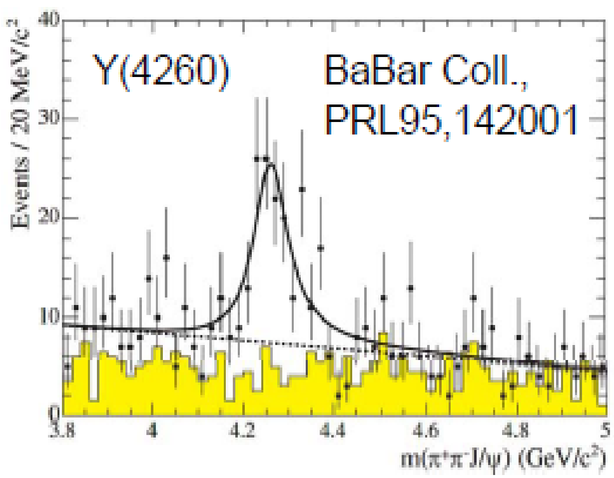
$\overline{\mathrm{p}}\mathrm{p} \to J/\psi\pi^0\pi^0 \to e^+e^-\gamma\gamma\gamma\gamma;$

$\overline{\mathrm{p}}\mathrm{p} \to \chi_{c1,c2}\gamma \to J/\psi\gamma\gamma \to e^+e^-\gamma\gamma;$

$\overline{\mathrm{p}}\mathrm{p} \to J/\psi\gamma \to e^+e^-\gamma;$

$\overline{\mathrm{p}}\mathrm{p} \to J/\psi\eta.$

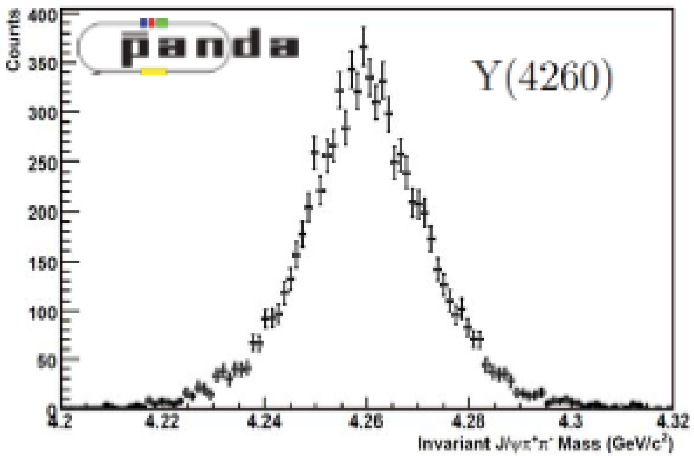
X(3872)	BaBar, Belle, CDF, D0	1^{++}, 2^{-+}, D^0D^*, qqqq ?
X(3930)	Belle	2^{++} $\chi_{c2}(2P)$
X(3940)	Belle	?
X(3945)	BaBar, Belle	??+ $\eta_c(3S)$?
X(4160)	Belle	?
Y(4260)	BaBar, Belle, CLEO	1^{--}
Y(4360)	BaBar, Belle	1^{--}
X(4660)	BaBar, Belle	1^{--}
h_c	CLEO	1^{+-}
η'_c	BaBar, Belle, CLEO	0^{-+}
…		



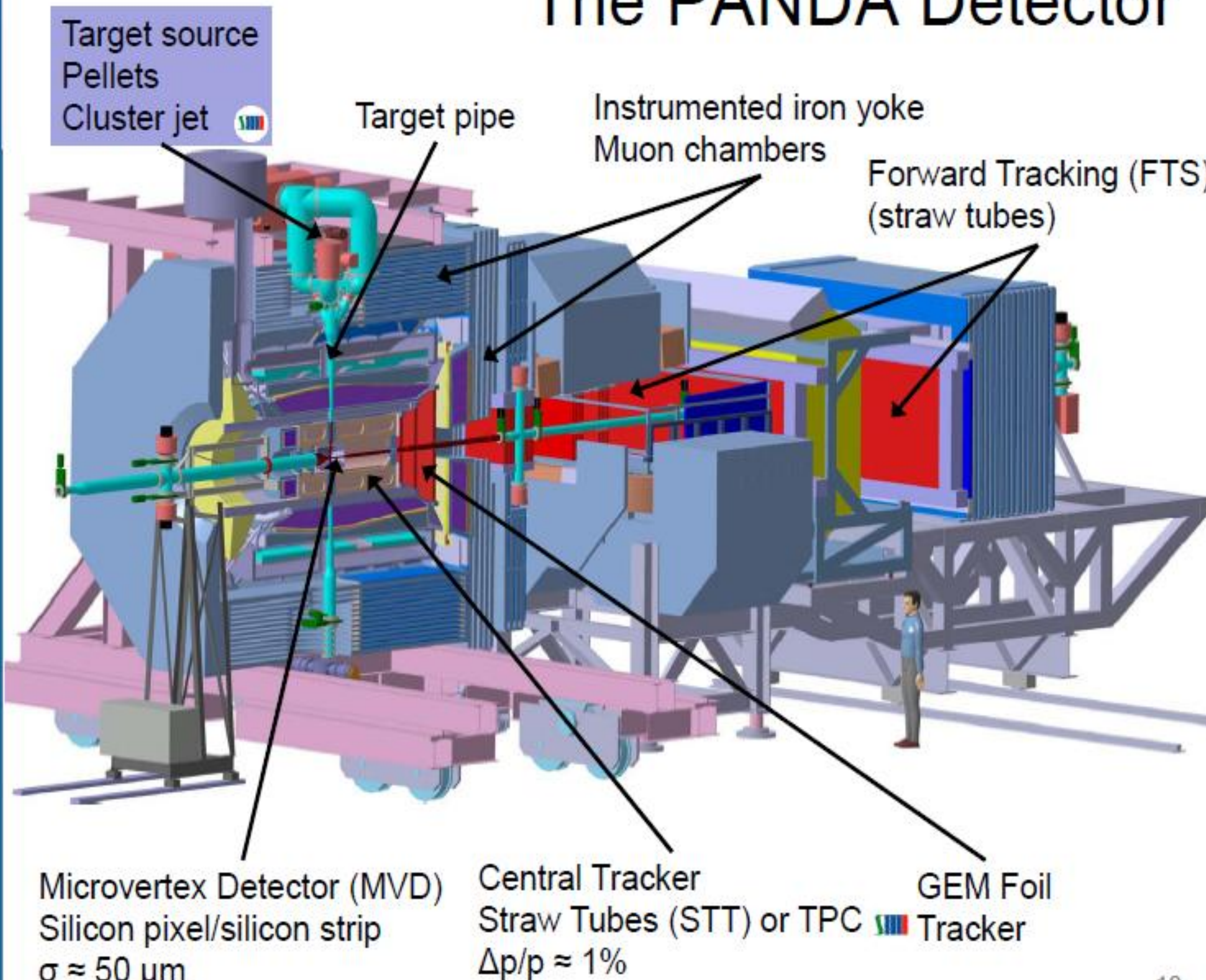
ε=0.32
S/B=2

$J/\psi\pi^+\pi^-$ 100/d

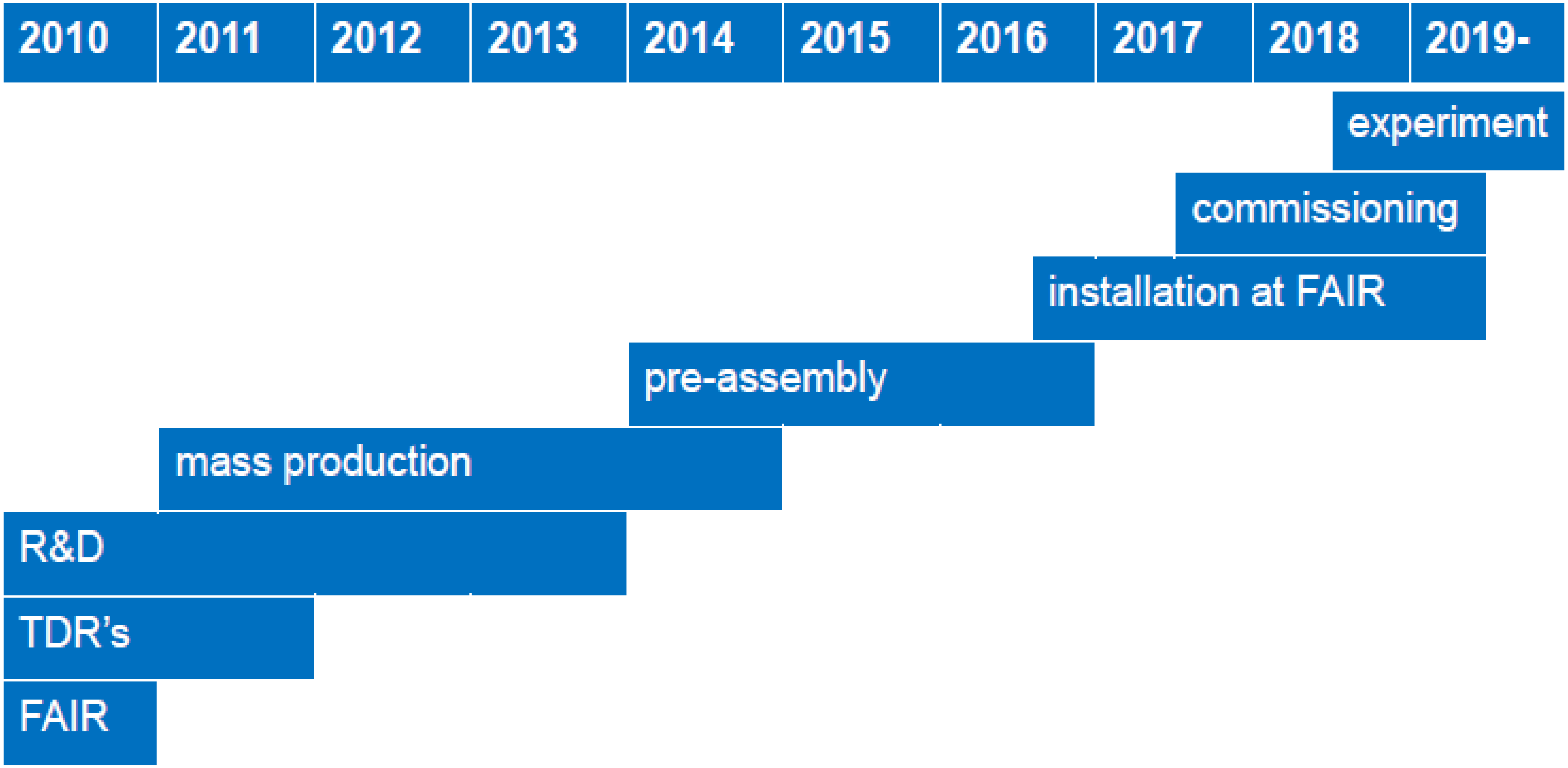
$J/\psi\pi^0\pi^0$ 40/d



The PANDA Detector



Timeline



Caveat:
The overall time scale is driven by the civil construction and infrastructure!

Neutrino Mixing

$$|\nu_\alpha\rangle = \sum_i U^*_{\alpha i}|\nu_i\rangle$$

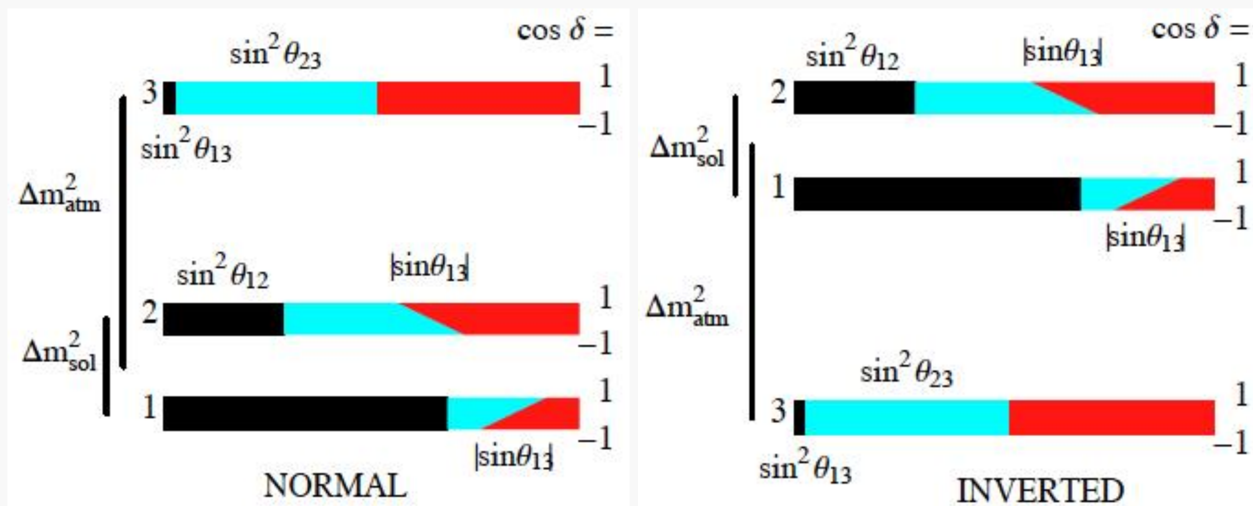
Parameterize the PMNS Matrix

$$\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}\begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}\begin{pmatrix} e^{i\delta_1} & 0 & 0 \\ 0 & e^{i\delta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

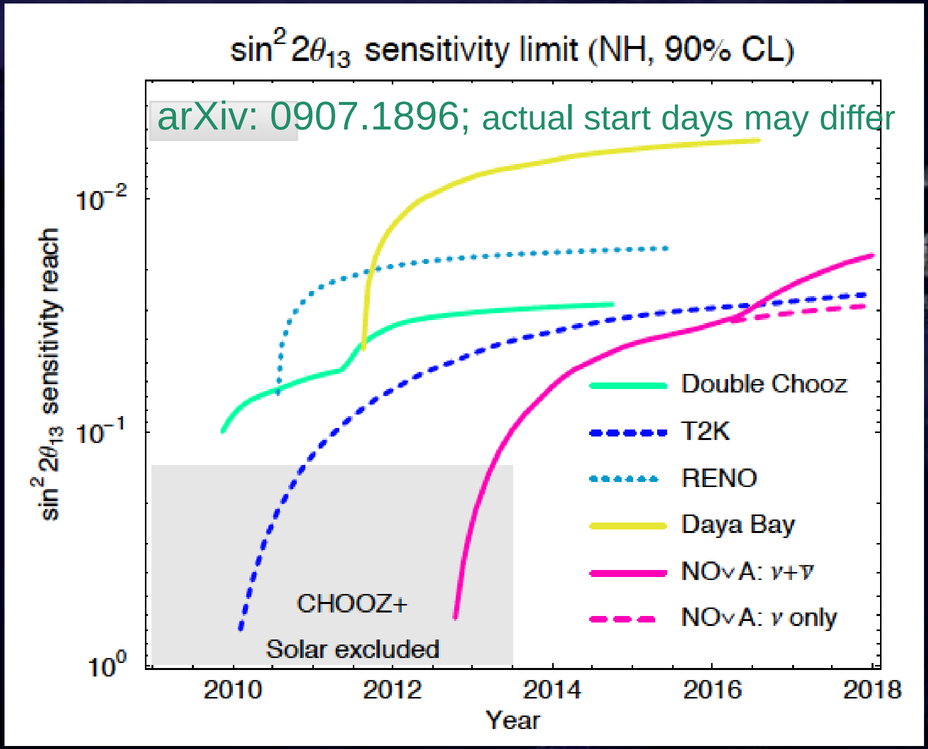
Solar, reactor — reactor and accelerator — Atmospheric, accelerator

Known: (PDG 2010)

$$\sin^2(2\theta_{12}) = 0.87 \pm 0.03$$
$$\sin^2(2\theta_{23}) > 0.92$$
$$\Delta m^2_{21} = (7.59^{+0.19}_{-0.21}) \times 10^{-5}\mathrm{eV}^2$$
$$|\Delta m^2_{32}| = (2.43 \pm 0.13) \times 10^{-3}\mathrm{eV}^2$$

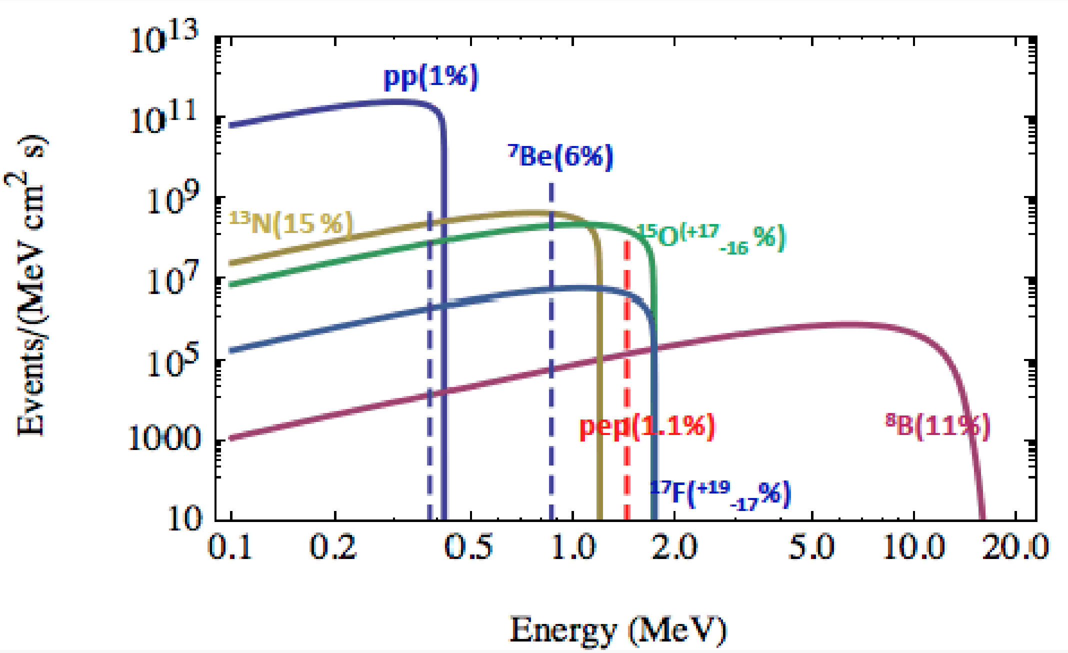


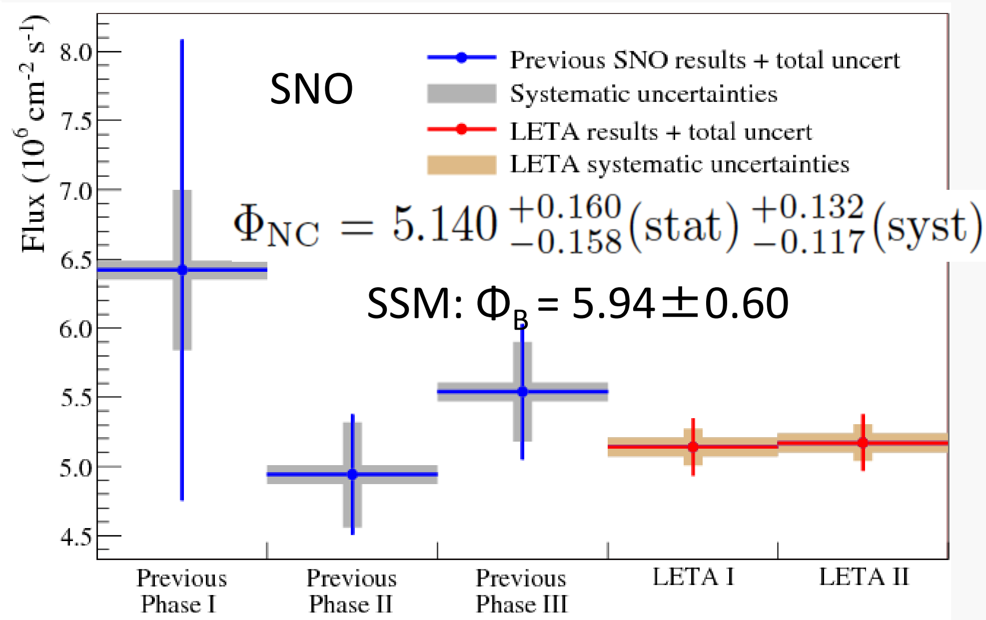
Unknown: θ_{13}, δ_{cp}, sign(Δm^2_{32})

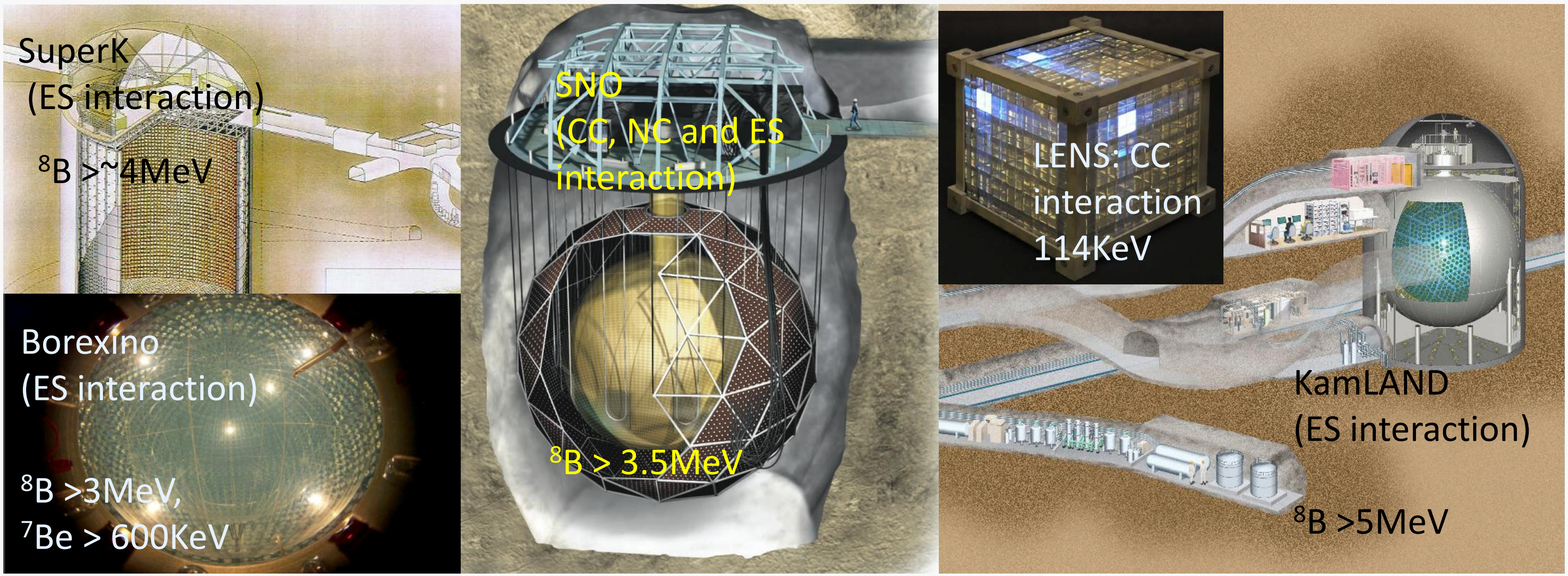


	Thermal Power (GW)	Mass (Tons)	Near		Far		δ_{system} (%)
			Distance (m)	Depth (m.w.e.)	Distance (m)	Depth (m.w.e.)	
Double Chooz	8.5	10 / 10	400	115	1050	300	0.6
RENO	17.3	16 / 16	290	120	1380	450	0.5
Daya Bay	17.4	40, 40 / 80	363 &481	260 &300	1985 &1613	870	0.38

Solar Neutrino



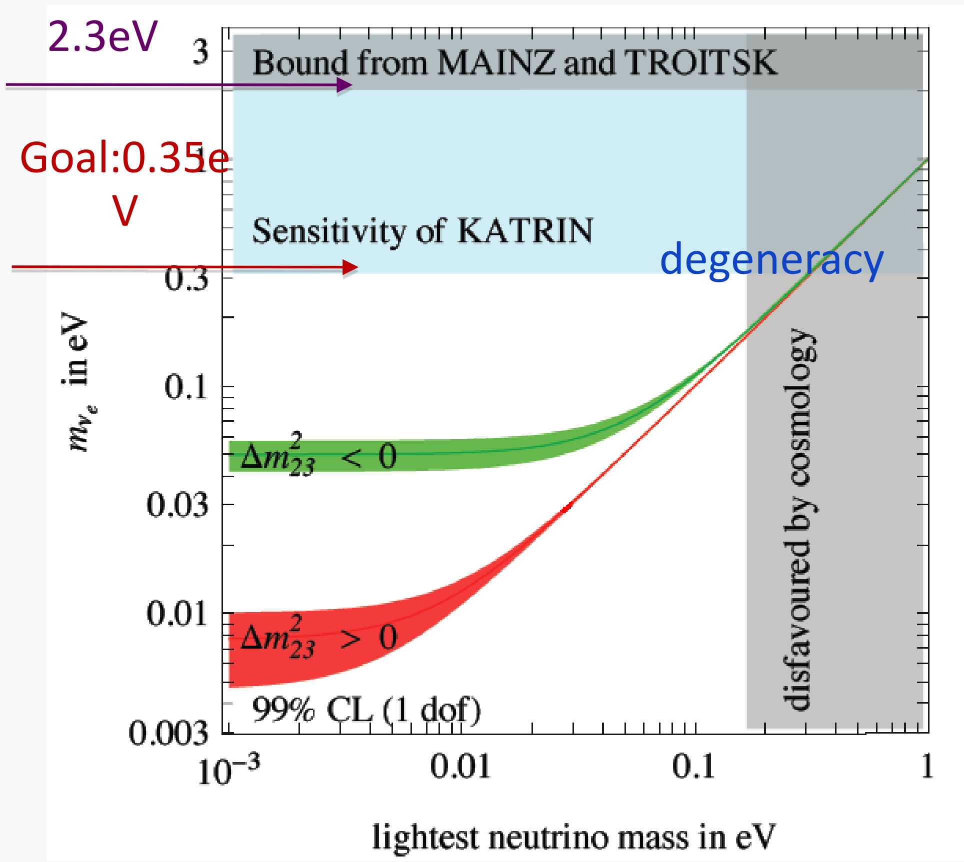




Mass Measurement

Beta Decay

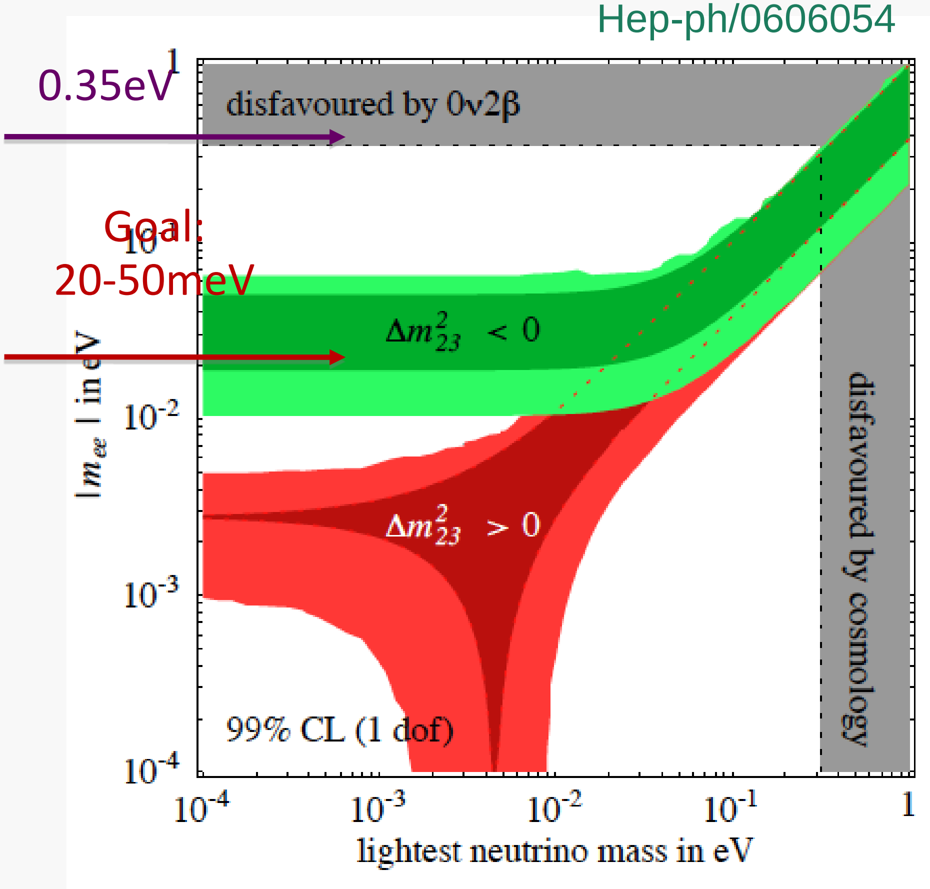
- Model independent
  - Majorana or Dirac, CP phase
  - Nuclear matrix element
- Squared neutrino mass (absolute)
- Current discovery potential: degeneracy



0νββ Decay

- Model dependent
- Majorana neutrino
- Effective neutrino mass
- Current discovery potential: IH

Hep-ph/0606054



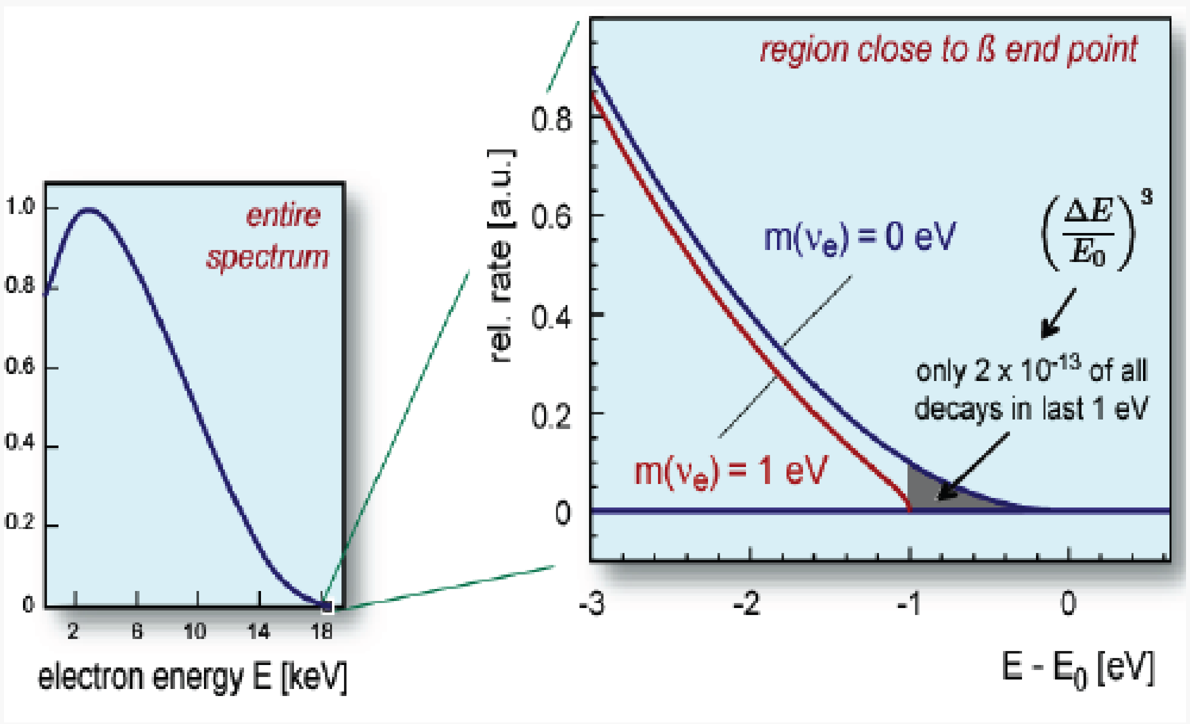
Beta Decay

Model-Independent Measurement: Kinematics and energy conservation

$$\frac{\mathrm{d}\Gamma_i}{\mathrm{d}E} = C \cdot p \cdot (E + m_e) \cdot (E_0 - E) \cdot \sqrt{(E_0 - E)^2 - m_i^2} \cdot F(E,Z) \cdot \theta(E_0 - E - m_i)$$

(ν− mass)²

If $m_\nu \neq 0$: shift the endpoint and change the shape

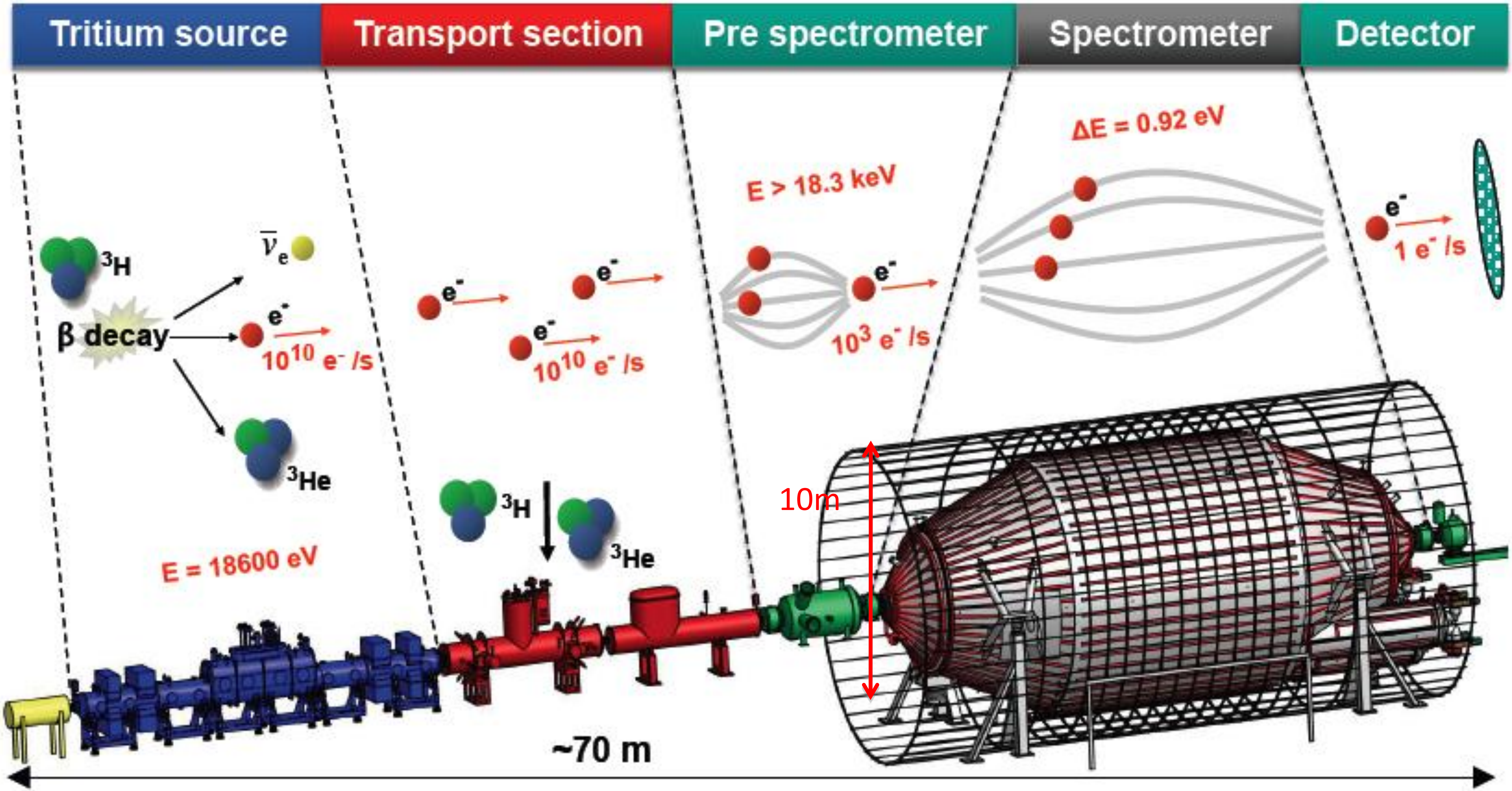


Measure the region close to endpoint:

- ✓ Low endpoint beta source
- ✓ High count rate
- ✓ High energy resolution
- ✓ Extremely low background

KATRIN

Tritium source, endpoint 18.6KeV, $t_{1/2}$ 12.3y, high activity $10^{11}\beta/s$



Schedule: Start main spectrometer test in 2011,

Commissioning of completed setup in 2012.

$0\nu\beta\beta$ Decay Experiments

Name	Isotope	Technique	Mass	Location	Sensitivity	Time
CUORICINO	Te-130	Bolometer	11kg	LNGS	0.40eV	2003 - 2008
CUORE	Te-130	Bolometer	200kg	LNGS	0.22eV	2013 -
COBRA	Cd-116 …	Semiconductor	183kg	LNGS		
GERDA I/II	Ge-76	Semiconductor	18/40kg	LNGS	75-129meV	2009 (comiss.)
Majorana	Ge-76	Semiconductor	30kg	DUSEL	20-41meV	2011 -
NEMO-3	Mo-100 ..	Tracking-calo	7kg	LSM	0.3-0.9eV	till 2010
SuperNEMO	Se-82 …	Tracking-calo	100+kg	LSM	40-110meV	2013 -
SNO+	Nd-150	Scintillator	44kg	SNOlab	150meV	2012 -
KamLAND-Zen	Xe-136	Scintillator	400kg	Kamioka	60meV	2011 -
CANDLES III	Ca-48	Scintillator	305kg	Kamioka		
EXO-200	Xe-136	Liquid TPC	200kg	WIPP	109-135meV	2009 (comiss.)
EXO	Xe-136	Gas TPC	1-10ton	SNOlab		

completed — construction or preparation — R&D

And some other experiments…

Conclusion

Given the reality that a higher energy machine will not be built for a while, it is encouraging to see many new experiments for our young HEP physicists to work on.