

FLAVOUR PHYSICS WG SUMMARY

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on behalf of the working group

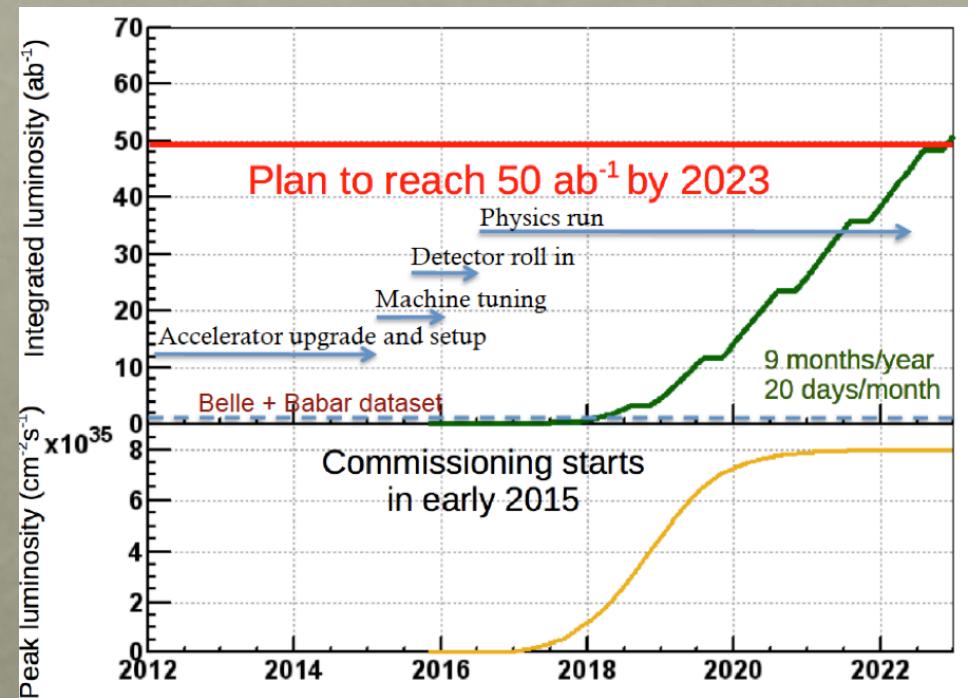
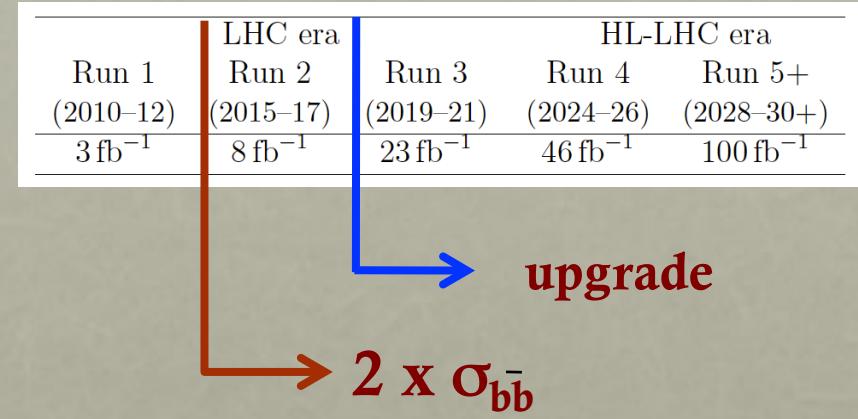
Conveners: Concezio Bozzi, G.D.N, Gino Isidori, Luca Silvestrini

Theory nicely summarized already by L. Silvestrini yesterday

I will highlight the contributions shown at the three flavour sessions

- F.P. with general purpose detectors:
 - B, D and tau physics with LHC-b and Belle II
→ V. Vagnoni, C. Bozzi, J. Walsh
 - Uncertainties in Lattice QCD → C. Tarantino
 - $K \rightarrow \pi \nu \bar{\nu}$ with NA62 → M. Moulson
 - Study of K decays at LHC → G.D'Ambrosio
 - Flavour Physics at High Luminosity collider → G. Punzi
- Dedicated experiments in flavour physics with leptons
 - Electric dipole moment measurement → P. Lenisa
 - $\mu \rightarrow e \gamma$ and $\mu \rightarrow e e e$ → G. Signorelli
 - Measurement of muon $g - 2$ → S. Miscetti

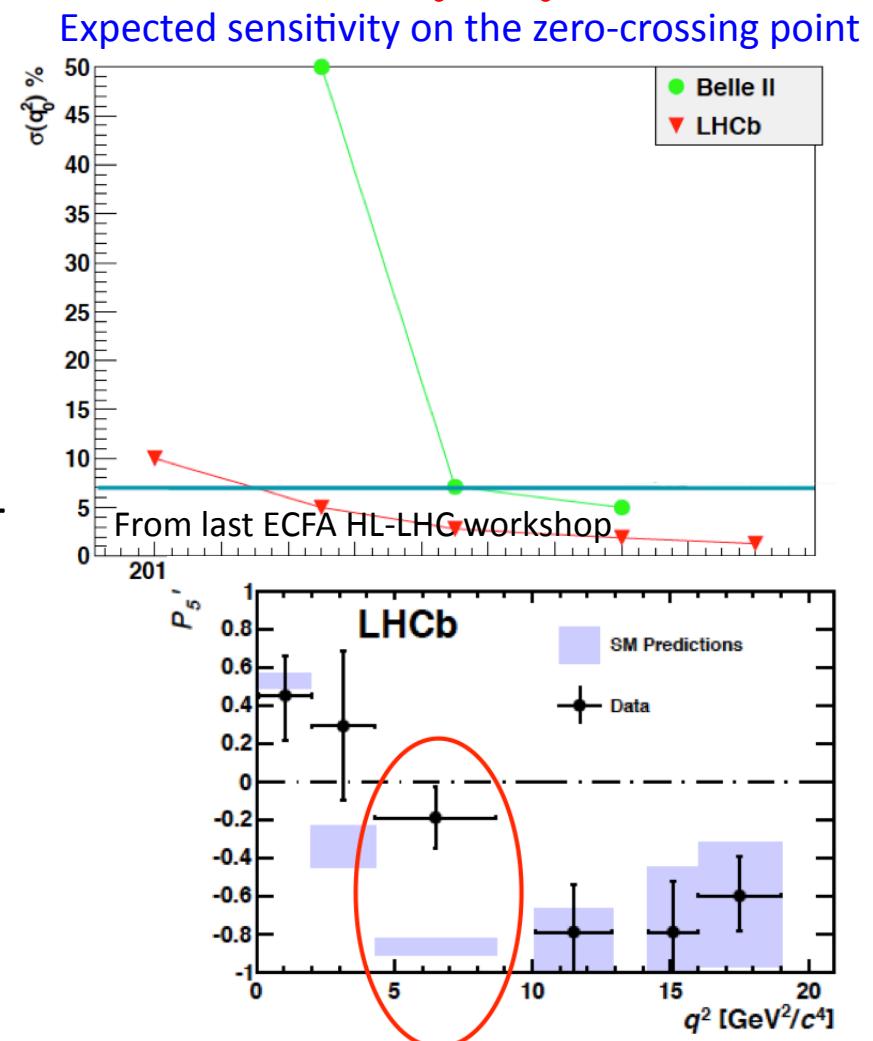
- The LHCb upgrade aims at integrating a luminosity of 50 fb^{-1} by 2026
 - x2 at every LHC run
 - can continue to be operational till the end of the HL programme up to $\mathcal{O}(100) \text{ fb}^{-1}$
- Physics run expected for 2016-2017
- Competitive results starting to be available very early
 - In 2018 will match the size of data sets of BaBar and Belle
- Will start deploying the full potential by 2020
 - Integrating 50 ab^{-1} in about 6 years



Prospects with $B \rightarrow K^* \mu^+ \mu^-$

$$A_{FB} = \frac{\Gamma(\cos \theta_{B\ell^+} > 0) - \Gamma(\cos \theta_{B\ell^+} < 0)}{\Gamma(\cos \theta_{B\ell^+} > 0) + \Gamma(\cos \theta_{B\ell^+} < 0)}$$

- LHCb expects to reach an accuracy of better than 2% in the zero-crossing of the forward-backward asymmetry
- Belle II is more limited in statistics, but can compensate with $K^* e^+ e^-$ and using an inclusive $B \rightarrow X_s l^+ l^-$ analysis

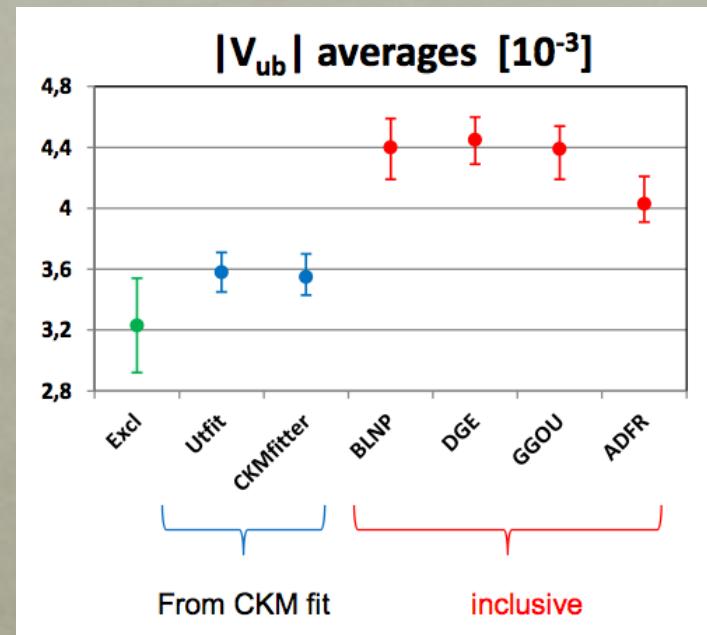
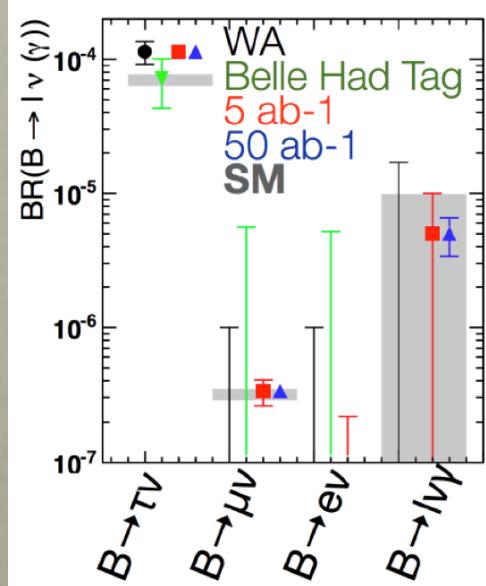


A_{FB} is not necessarily the best variable due to hadronic uncertainties.
Phenomenological work ongoing to define observables where hadronic uncertainties are partially cancelled

Leptonic and semileptonic B decays

V. Vagnoni
C. Bozzi

Leptonic B decays



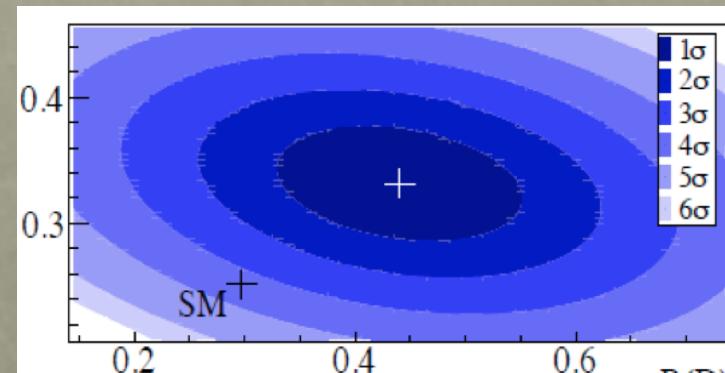
BaBar results extrapolated to Belle II

	fb-1	Statistical	Systematic	Total
R(D)	423	13.0	(9.6, 1.3)	16.5
	5000	3.8	(2.8, 1.3)	5.2
	50000	1.2	(0.9, 1.3)	2.5
R(D*)	423	7.0	(5.5, 1.3)	9.0
	5000	2.1	(1.6, 1.3)	2.9
	50000	0.7	(0.5, 1.3)	1.6

From 16.5%
to 2.5%

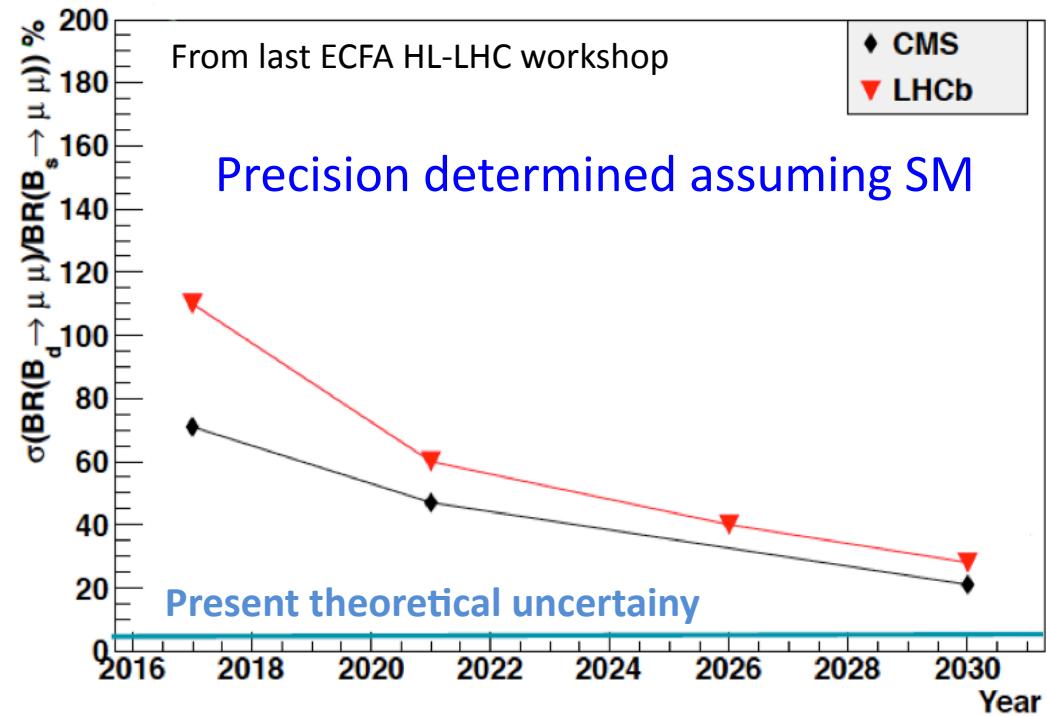
From 9% to
1.6%

$B \rightarrow D^{(*)} \tau \nu$



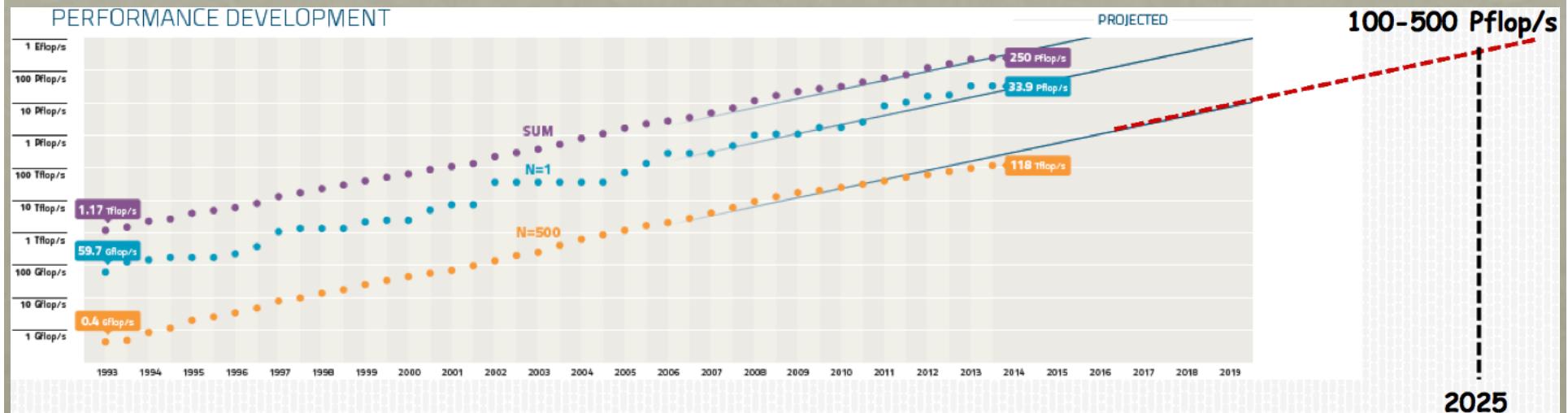
Prospects with $B_{d,s} \rightarrow \mu^+ \mu^-$

- The ratio $\text{BR}(B_d \rightarrow \mu^+ \mu^-) / \text{BR}(B_s \rightarrow \mu^+ \mu^-)$ is known with better theoretical uncertainty
 - Now 5%, but can be brought down to $\approx 1\%$
- Measurement will still be dominated by experimental uncertainty by 2030
 - Now 200%, will be $\approx 20\%$
- With increased statistics, the measurement of effective $B_s \rightarrow \mu^+ \mu^-$ lifetime and possibly time-dependent CP violation will become possible
 - New observables sensitive to NP effects in very rare B decays!



C.Tarantino

Lattice collaborations typically have at hand per year a computational power similar to the 500° most powerful computer (0.1-0.5 Pflops-years in 2014 → 100-500 Pflops-years in 2025)



There exist different estimates for the ultimate limit...
 2025 is, nowadays, safe according to essentially everybody

What is the computational cost with these simulation parameters?

Del Debbio, Giusti, Luscher, Petronzio, Tantalo, hep-lat/0610059

$$\text{TFlops - years} \simeq 0.03 \left(\frac{N_{\text{conf}}}{100} \right) \left(\frac{L_s}{3 \text{ fm}} \right)^5 \left(\frac{L_t}{2L_s} \right) \left(\frac{0.2}{\hat{m}/m_s} \right) \left(\frac{0.1 \text{ fm}}{a} \right)^6$$

0.3

factor 1.5 from improvement,
factor 3 from Nf=2+1,
factor 2-3 from overhead

C.Tarantino

N.B.

- The required a is different for π/K , $D_{(s)}$, $B_{(s)}$
- Small m_l/m_s and large L are required for π/K , D and B (not for D_s and B_s)

Pflops-years

	1%	0.5%	0.1%
π/K	0.5	15	$4 \cdot 10^4$
D	20	$7 \cdot 10^2$	$2 \cdot 10^6$
D_s	0.2	2	$5 \cdot 10^2$
B	10^3	-	-
B_s	20	$4 \cdot 10^2$	$3 \cdot 10^5$

Naïve estimate:

There are smart methods
to reduce discretization effects
(ratio method, effective actions,...)

From Moore's Law 100-500 Pflops-years will be available for LatticeQCD

Therefore, my tentative (INACCURATE!) estimates are:

Hadronic parameter	L.Lellouch ICHEP 2002 [hep-ph/0211359]	FLAG 2013 [1310.8555]	2025 [What Next]
$f_{+}^{K\pi}(0)$	- First Lattice result in 2004 [0.9%]	[0.4%]	[0.1%]
\hat{B}_K	[17%]	[1.3%]	[0.1-0.5%]
f_{B_s}	[13%]	[2%]	[0.5%]
f_{B_s}/f_B	[6%]	[1.8%]	[0.5%]
\hat{B}_{B_s}	[9%]	[5%]	[0.5-1%]
B_{B_s}/B_B	[3%]	[10%]	[0.5-1%]
$F_{D^*}(1)$	[3%]	[1.8%]	[0.5%]
$B \rightarrow \pi$	[20%]	[10%]	[>1%]

C.Tarantino

More unpredictable but more surprising progresses can occur for the observables that today are very difficult (or infeasible): $K \rightarrow \pi \nu \bar{\nu}$, $K \rightarrow \pi^- l^+ l^-$, $K \rightarrow \pi \pi$, Δm_K

NA62 in the near future

M. Moulson



Goal: Measure $\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ to 10%
Collect ~ 100 signal events with $S/B > 10$
in 2-years' equivalent data taking

Other elements of physics program:

- Measurement of R_K to $\sim 0.2\%$
- Searches for LFV K^+ and π^0 decays
- ChPT tests & precision BR mmts.

Start of NA62 running: October 2014

Possible to request more running during Run 2 to improve sensitivity!

Planned and potential upgrades:

- New trigger hodoscope
- Small changes to level-0 architecture to allow more restrictive triggering
- Continuous WFD readout for critical detectors (e.g. LAVs)?

Ambitious upgrades to justify running in Run 3?

None proposed yet, but NA62 just starting up: First need to get experience

NA62: From K^+ to K_L

M. Moulson

Possibility of a neutral beam foreseen in the NA62 Technical Proposal:

- Slight changes to production angle and upstream beam optics
- Running for $\pi^0 \nu \bar{\nu}$ and $\pi^0 \ell^+ \ell^-$ will require a substantial increase in primary intensity, but **well within** what the SPS can provide

	NA62 K^+ beam	Future NA62 K_L beam
Primary intensity (ppp)	3×10^{12}	2.4×10^{13}
Production angle for secondary (mrad)	0	2.4
Angular acceptance (μsr)	12.7 μsr	0.125 μsr
Momentum	$75 \text{ GeV} \pm 1\%$	97 GeV (mean) 40-140 GeV (50% peak)
Rates into FV	750 total 525 π 170 p 45 K^+	3000 total 2000 γ 800 n 90 K_L
K decays in FV	4.5 MHz $4.5 \times 10^{12}/\text{year}$	0.9 MHz $9 \times 10^{11}/\text{year}$

PRIN studies: $K_L \rightarrow \pi^0 \nu \bar{\nu}$ at the SPS

- Beam sweeper:** Reduce 2 GHz of beam photons by at least 10x
May require innovative approach: Iridium monocrystal?
- Large angle photon vetoes:** Hermetic coverage out to 100 mrad for E_γ , down to 20 MeV
26 new LAV stations with scintillator/tile design
- Small angle photon vetoes:** Be relatively insensitive to 800 MHz of beam neutrons
Amidst this background, reject γ from $\pi^0 \pi^0$ to 10^{-3} level
Prototypes under development:
Converter + NA62 Gigatracker (Si pixel)-based veto
Dense inorganic Cerenkov crystal veto

Expected results with 2 yrs of data:

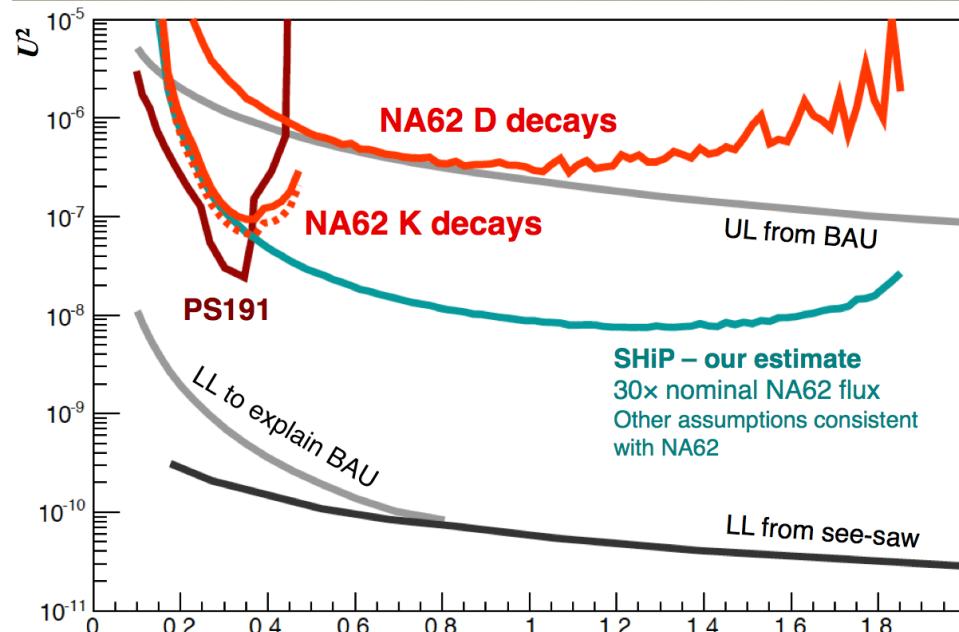
$\pi^0 \nu \bar{\nu}$ cand. with 2γ on LKr, nothing else
Vertex in FV with $p_\perp(\pi^0) > 0.1$ GeV

~10 signal evts
~10 $\pi^0 \pi^0$ background evts
Nominally 2x better than KOTO (JPARC)

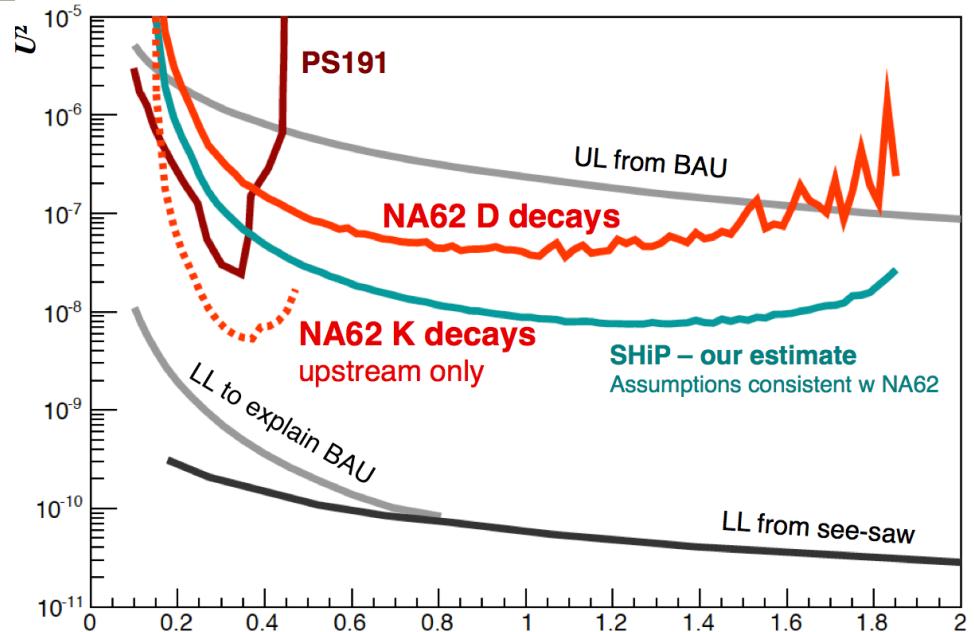
A $K_L \rightarrow \pi^0 \nu \bar{\nu}$ experiment will require long lead time

- Significant construction work, R&D, prototyping necessary
- Aim for turn-on in Run 3 or for a more ambitious measurement in Run 4?

5 years of data at nominal K^+ run intensity



5 years of data at SHiP intensity



G. D'Ambrosio

Rare Kaon decays at LHCb

$$K_S \rightarrow \mu\bar{\mu}$$

- LHCb $B(K_S \rightarrow \mu\bar{\mu}) < 11 \times 10^{-9}$ at 95% CL after 40 years
- Long Distance dominated, Short distance: **ONLY CP Violating**
- SM $B(K_S \rightarrow \mu\bar{\mu})_{SD} = 1 \times 10^{-5} |\Im(V_{ts}^* V_{td})|^2 \sim 10^{-13}$; NP $\sim 10^{-11}$ allowed;
- $K_S \rightarrow \mu^+ \mu^-$
- $K_S \rightarrow \mu^+ \mu^- \mu^+ \mu^-$, search for instance Dark photons and Standard Model
- Charge asymmetry $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$ (SM $\sim 10^{-4} \implies$ NP)
- Forward backward asymmetry

Current landscape at hadron colliders

- LHC and HL-LHC are an immense source of Heavy Quarks
- Current/foreseen experiments only exploit a fraction of this enormous production
 - ATLAS/CMS:
 - Full LHC lum: 3000 fb-1
 - But limited efficiency: lepton / hi-pt requirements
 - LHCb:
 - High efficiency also on hadronic/charm events
 - But limited luminosity: projected 50fb-1 vs 3000 fb-1
- *“Europe’s top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine”* [EU strategy document]
- What if we could fully exploit the production of ~ 10^{14} b-quarks and ~ 10^{15} c-quarks per year ?

- Aggressive, radical concept to move most of the off-line analysis to on-line

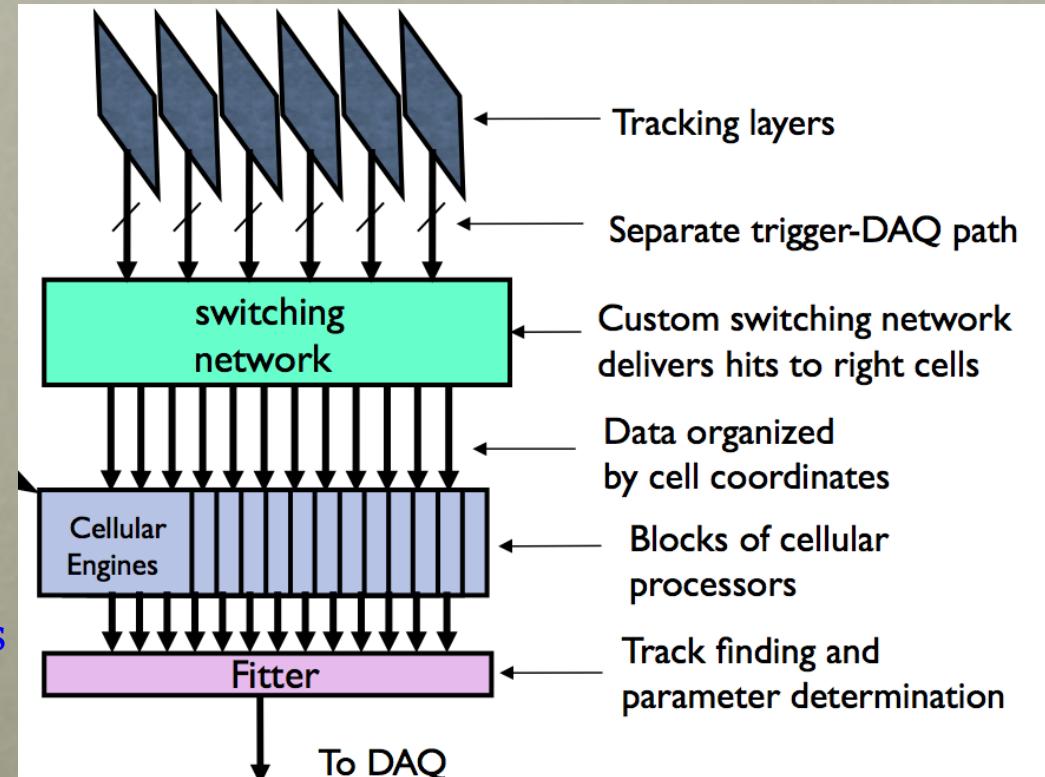
Strong tracking capability

Event reconstruction on-line @ 40 MHz

On-line calibration

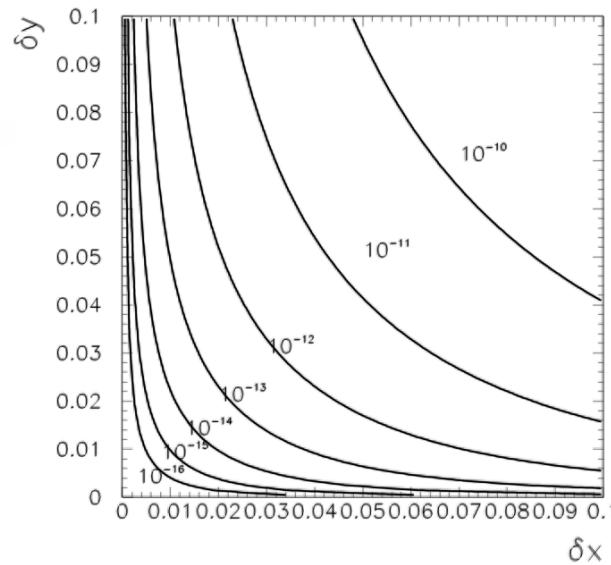
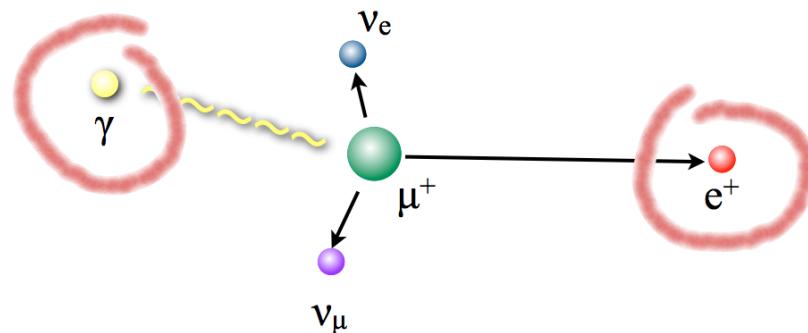
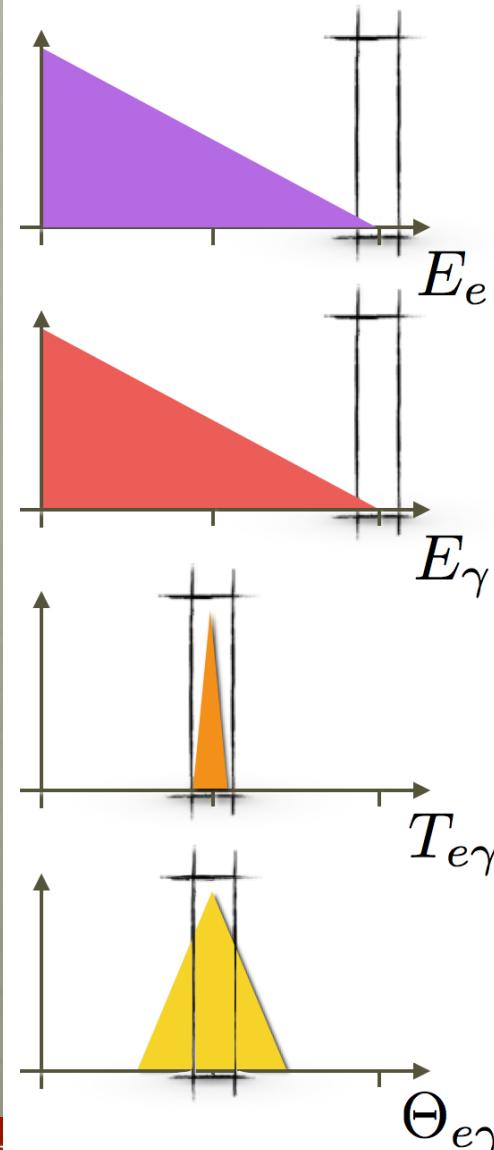
No raw data to save, only reco objects

Extreme case: Real time Physics analysis



Work needed to evolve the concept to a design (also use cases / scenarios)

$\mu \rightarrow e\gamma$ RMD background



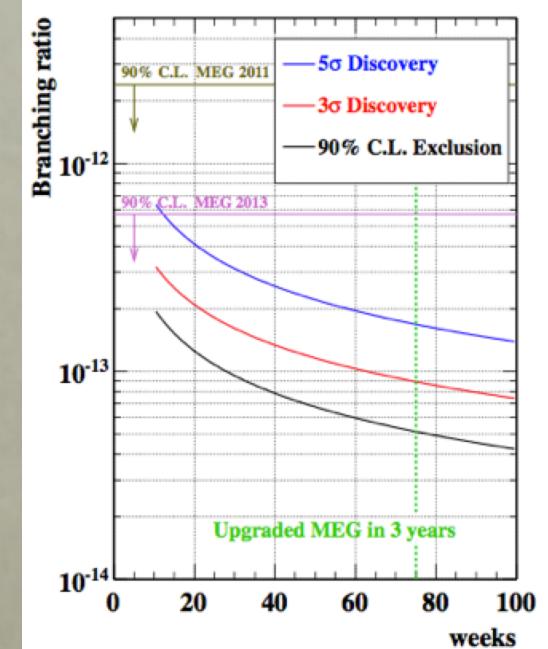
$$y = \frac{E_\gamma}{m_\mu/2}$$

$$x = \frac{E_e}{m_\mu/2}$$

$$dB(\mu^+ \rightarrow e^+ \nu \bar{\nu} \gamma) = \frac{1}{\Gamma(\mu^+ \rightarrow e^+ \nu \bar{\nu})} \int_{1-\delta x}^1 dx \int_{1-\delta y}^1 dy \int_0^{\min(\delta z, 2\sqrt{(1-x)(1-y)})} dz \frac{d\Gamma(\mu^+ \rightarrow e^+ \nu \bar{\nu} \gamma)}{dxdydz}$$

Key elements to MEG II

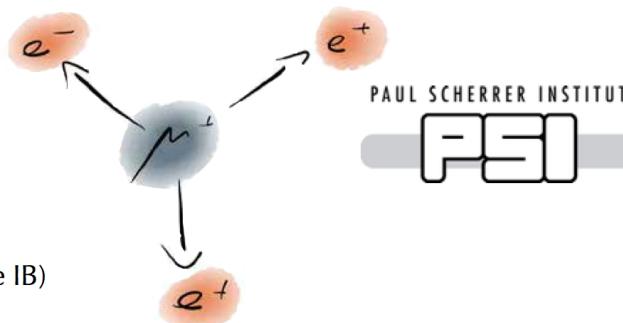
- μ 1. Increasing μ^+ -stop on target
- 2. Reducing target thickness to minimize e^+ MS & brehmsstrahlung
- e 3. Replacing the e^+ tracker reducing its radiation length and improving its granularity and resolutions
- 4. Improving the timing counter granularity for better timing and reconstruction
- 5. Improving the positron tracking-timing integration by measuring the e^+ trajectory up to the TC interface
- γ 6. Extending the γ -ray detector acceptance
- 7. Improving the γ -ray energy and position resolution for shallow events
- 8. Integrating splitter, trigger and DAQ maintaining a high bandwidth



Expected Sensitivity up to few $\times 10^{-14}$

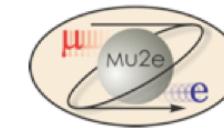
Mu3e at PSI

- Search for $\mu \rightarrow e e e$
 - 10^{-15} sensitivity in phase IA / IB
 - 10^{-16} sensitivity in phase II
- Project approved in January 2013
 - Double cone target
 - HV-MAPS ultra thin silicon detectors
 - Scintillating fibers timing counter (from phase IB)





What is g-2? Why is needed ?



$a_\mu = (g-2)/2$ is derived from the precession of the muon spin in a well-measured magnetic field

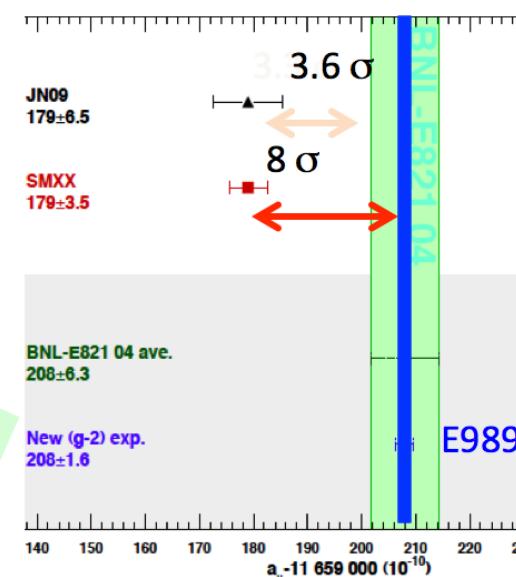
- New experiment at FNAL (E989) at magic momentum, Consolidated method.
 - **20 x μ** w.r.t. E821 @ BNL.
 - **Relocate the BNL storage ring to FNAL.**
- ⇒ **a x4 improvement on a_μ**
(from 540 ppb to 140 ppb)

If the central value remains the same ⇒ 5-8 σ from SM* (enough to claim discovery of **New Physics!**)

*Depending on the progress on Theory

Thomas Blum; Achim Denig; Ivan Logashenko; Eduardo de Rafael, ... oberts, B.; Thomas Teubner; Graziano Venanzoni (2013). "The Muon (g-2) theory Value: Present and Future". arXiv:1311.2198 [hep-ph].

From
G. Venanzoni

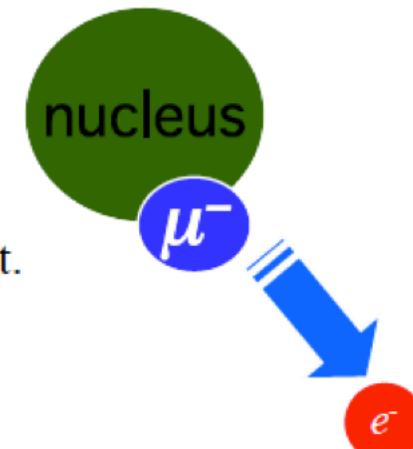
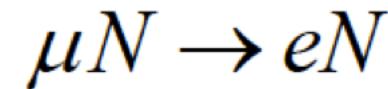


23/5/2014

S.Miscetti - FNAL@LTS1

Istituto Nazionale
di Fisica Nucleare

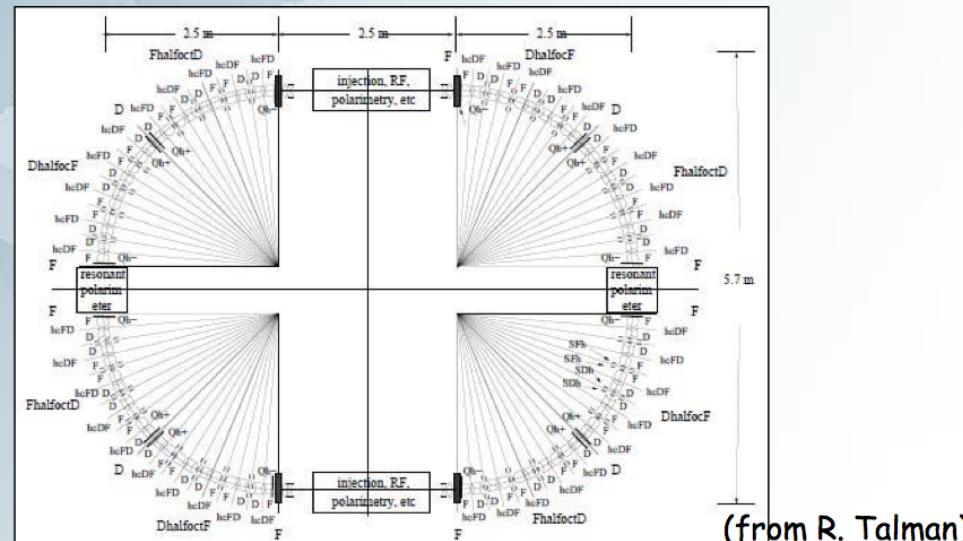
- Initial state: muonic atom 60% Muon Capture
40% DIO
- Final state:
 - a single mono-energetic electron.
 - the energy depends on Z of target.
 - recoiling nucleus is not observed
 - the process is coherent: the nucleus stays intact.
 - neutrino-less
- Standard Model rate is 10^{-54}



- Aim to $B(\mu N \rightarrow e N) < 6 \times 10^{-17}$ U.L.

Electrostatic electron ring at LNF?

- First ever DIRECT measurement of electron EDM.
- Compact
 - Magic energy for electron: 14.5 MeV ($\gamma=29.4$)
 - $E = 2\text{-}6 \text{ MeV/m} \rightarrow 2\pi R = 50 - 20 \text{ m}$
- Technical challenge, modest investment.
- Mandatory step for larger machines (proton and deuteron $\rightarrow 2\pi R > 250 \text{ m}$).
- Open issue: polarimetry.



- The flavour Physics experimental program with beauty, charm and tau decays is well established for the next 10 years
- Complementary to direct searches at LHC.
 - If NP is seen at LHC, the flavor structure will be fixed by Belle II and LHC-b
 - If nothing new is seen at LHC they may point to the NP scale to explore.
- Expectation of improvements by 2025 in theory uncertainties from Lattice QCD under 1% level looks solid
- Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decays will start soon at NA62.
 - Ongoing activities for $K^0_L \rightarrow \pi^0 \nu \bar{\nu}$ / $l^+ l^-$ searches
 - Interesting interplay with SHIP proposal to search for heavy neutral leptons.

- Interesting proposal for the long term future of flavour physics at High luminosity LHC
 - Analyze huge samples of 10^{14} heavy quark decays per year moving analysis as much as possible to on-line/real time.
 - Concept presented. technical feasibility and application domain to be studied
- LFV decays of muon at PSI and FNAL presented.
 - Discussion on ultimate sensitivity for $\mu \rightarrow e \gamma$ searches
- Measurement of the edm of the electron at LNF proposed.
 - Possible sensitivity not yet firmly assessed, the limiting factor being the polarimetry.