Status and prospects for $Br(K^+ \to \pi^+ \nu \bar{\nu})$ measurement at NA62

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on behalf of the NA62 Collaboration

7th workshop of the LHC LLP Community

May 26, 2020
Outline

- \( Br(K^+ \to \pi^+ \nu \bar{\nu}) \) measurement:
  - physics case
  - experimental strategy
  - Single Event Sensitivity
  - background estimation and validation
  - preliminary results on 2016+2017 data
  - prospects for 2018 data and next data taking

- Exotic searches related to \( K^+ \to \pi^+ \nu \bar{\nu} \) analysis:
  - \( \pi^0 \to invisible \)
  - \( K^+ \to \pi^+ X \) (new preliminary result!)
$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ search @ NA62

- Full detector installation completed in 2016
- Physics runs in 2016, 2017 and 2018
- $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ results on 2016 data published
- $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ preliminary results on 2017 data in this talk
- 2018 data analysis on going
- Data taking foreseen to restart after CERN LS2 to measure $Br(K^+ \rightarrow \pi^+\nu\bar{\nu})$

NA62 is installed in the CERN North Area, exploiting a 400 GeV/c proton beam extracted from the SPS accelerator.
The NA62 main goal: $Br(K^+ \rightarrow \pi^+\nu\bar{\nu})$ measurement

- $\bar{s} \rightarrow \bar{d}\nu\bar{\nu}$ transition: **flavour changing neutral current** process, strongly suppressed by CKM and GIM mechanisms
- **Very precise theoretical prediction**: short distance contributions and hadronic processes will small uncertainties
- Hadronic matrix elements measured from $K_{l3}$ decays

### Standard Model prediction

$$Br^{SM}(K^+ \rightarrow \pi^+\nu\bar{\nu}) = (0.84 \pm 0.10) \cdot 10^{-10} \ [Buras et al., JHEP11(2015)033]$$

### Experimental status

- BNL E787/E949, Kaon rest frame technique: $Br^{BNL}(K^+ \rightarrow \pi^+\nu\bar{\nu}) = (1.73^{+1.15}_{-1.05}) \cdot 10^{-10}$ [Phys. Rev. D 77, 052003 (2008)] - [Phys. Rev. D 79, 092004 (2009)]
- NA62 (2016), decay in flight: $Br^{NA62}(K^+ \rightarrow \pi^+\nu\bar{\nu}) < 14 \cdot 10^{-10} @ 95\% \ CL$ [Physics Letters B 791 (2019) 156–166]
Experimental strategy

Keystones

- in flight decay technique ($P_K = 75$ GeV/c)
- kinematic analysis (missing mass)
- charged particle identification
- muon and photon rejection
- Pion momentum range: $[15; 35]$ GeV/c
- Signal and Control kinematic regions blinded during the analysis

Squared missing mass

$$m^2_{\text{miss}} = (P_K - P_\pi)^2$$

Squared missing mass graph

Required performance

- time coincidence: $O(100 \text{ ps})$
- kinematic rejection: $O(10^4)$
- muon rejection: $> 10^7$
- $\pi^0$ rejection: $> 10^7$

$K^+$ main decays

<table>
<thead>
<tr>
<th>Decay channel</th>
<th>Branching Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+ \to \mu^+ \nu$</td>
<td>$(63.56 \pm 0.11) \cdot 10^{-2}$</td>
</tr>
<tr>
<td>$K^+ \to \pi^+ \pi^0$</td>
<td>$(20.67 \pm 0.08) \cdot 10^{-2}$</td>
</tr>
<tr>
<td>$K^+ \to \pi^+ \pi^+ \pi^-$</td>
<td>$(5.583 \pm 0.024) \cdot 10^{-2}$</td>
</tr>
<tr>
<td>$K^+ \to \pi^+ \pi^- e^+ \nu$</td>
<td>$(4.247 \pm 0.024) \cdot 10^{-5}$</td>
</tr>
</tbody>
</table>
SPS beam: 400 GeV/c proton on beryllium target
Secondary hadronic 75 GeV/c beam
70% pions, 24% protons, 6% kaons
Nominal beam particle rate (at GTK3): 750 MHz
2017 data beam particle rate: 450 MHz
Kaon decay rate in 60 m fiducial volume: 3 MHz.
**Selection**

- $K^+ - \pi^+$ matching
- $K^+$ decay in fiducial volume
- $\pi^+$ identification (PID)
- photon rejection
- multi-track rejection
- kinematics ($m_{miss}^2$ vs $P_\pi$)

**Measured performances**

- KTAG-GTK-RICH timing: $O(100$ ps$)$
- $\pi^+$ ID (RICH+CALO): $\epsilon(\mu) \simeq 10^{-8}$ @ $\epsilon(\pi) \simeq 64\%$
- $\pi^0$ efficiency: $\simeq 1.4 \cdot 10^{-8}$
- $\sigma(m_{miss}^2) \simeq 10^{-3}$ GeV$^2$/c$^4$

**$K^+$ decays selection without PID and photon/multi-track rejection**

\[
m_{miss}^2 = (P_K - P_\pi)^2
\]

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$Br(K^+ \rightarrow \pi^+\nu\bar{\nu})$ at NA62

May 26, 2020
Normalization channel: $K^+ \rightarrow \pi^+\pi^0$

Same conditions of the signal selection, except for:

- minimum bias trigger
- photon and multiplicity rejection not applied
- different kinematic region

Number of kaon decays

$$N_K = \frac{N_{\pi\pi} \cdot D}{A_{\pi\pi} \cdot Br_{\pi\pi}}$$

- $N_{\pi\pi}$: number of $K^+ \rightarrow \pi^+\pi^0$ observed events
- $D$: Down-scaling factor applied to the trigger
- $A_{\pi\pi}$: normalization decay acceptance $\simeq 8.5\%$ (from Monte Carlo)
- $Br_{\pi\pi}$: normalization decay Branching Ratio

$$N_K = (1.3 \pm 0.1) \cdot 10^{12}$$

Single Event Sensitivity

$$SES = \frac{1}{N_K \cdot \sum_j (A_{\pi\nu\nu}^j \cdot \epsilon_{trig}^j \cdot \epsilon_{RV}^j)}$$

- $N_K$: number of $K^+$ decays
- $A_{\pi\nu\nu}$: signal acceptance $\simeq 3\%$ (from Monte Carlo)
- $\epsilon_{trig}$: trigger efficiency
- $\epsilon_{RV}$: random veto efficiency
- $j$: bins of momentum and instantaneous beam intensity

$$SES = (0.39 \pm 0.02_{syst}) \cdot 10^{-10}$$
Summary of expected signal and background (2017 data - Preliminary)

<table>
<thead>
<tr>
<th>Process</th>
<th>Expected events in $\pi\nu\nu$ signal regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^+ \rightarrow \pi^+\nu\bar{\nu}$ (SM)</td>
<td>$2.16 \pm 0.12_{\text{syst}} \pm 0.26_{\text{ext}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+\pi^0(\gamma)$</td>
<td>$0.29 \pm 0.03_{\text{stat}} \pm 0.03_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \mu^+\nu(\gamma)$</td>
<td>$0.11 \pm 0.02_{\text{stat}} \pm 0.03_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \mu^+\nu, \mu \rightarrow e\nu\nu$</td>
<td>$0.04 \pm 0.02_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+\pi^- e^+\nu$</td>
<td>$0.12 \pm 0.05_{\text{stat}} \pm 0.03_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+\pi^+\pi^-$</td>
<td>$0.02 \pm 0.02_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+\gamma\gamma$</td>
<td>$0.005 \pm 0.005_{\text{syst}}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow l^+\pi^0\nu_l$</td>
<td>negligible</td>
</tr>
<tr>
<td>$Upstream$ background</td>
<td>$0.9 \pm 0.2_{\text{stat}} \pm 0.2_{\text{syst}}$</td>
</tr>
<tr>
<td><strong>Total background</strong></td>
<td>$1.5 \pm 0.2_{\text{stat}} \pm 0.2_{\text{syst}}$</td>
</tr>
</tbody>
</table>
Estimation of background from standard $K^+$ decays

$N_{\pi\pi}^{\text{exp}}(\text{region}) = N(\pi^+\pi^0) \cdot f^{\text{kin}}(\text{region})$

- $N_{\pi\pi}^{\text{exp}}(\text{region})$: expected $\pi^+\pi^0$ events in $\pi\nu\nu$ region after $\pi\nu\nu$ selection
- $N(\pi^+\pi^0)$: events in $\pi^+\pi^0$ region after $\pi\nu\nu$ selection
- $f^{\text{kin}}(\text{region})$: fraction of $\pi^+\pi^0$ in signal region measured on control data
- **Data-driven estimation**
- Control regions for validation
Upstream background

Background source if:

- a kaon decays upstream, and only a pion enters in the decay region
- there is an in-time pileup beam particle (in KTAG and GTK)
- the upstream generated pion enters in the decay region and is scattered in the first STRAW chamber.
Opened signal regions: 2 events observed

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Briziol
$m_{\text{miss}}^2$ signal and backgrounds (2017 data - Preliminary)
Preliminary combined results 2016 + 2017 data (paper in preparation)

<table>
<thead>
<tr>
<th></th>
<th>2016 data</th>
<th>2017 data</th>
</tr>
</thead>
<tbody>
<tr>
<td>SES</td>
<td>$(3.15 \pm 0.24) \cdot 10^{-10}$</td>
<td>$(0.39 \pm 0.02) \cdot 10^{-10}$</td>
</tr>
<tr>
<td>Expected signal</td>
<td>$0.27 \pm 0.04$</td>
<td>$2.16 \pm 0.29$</td>
</tr>
<tr>
<td>Expected background</td>
<td>$0.15 \pm 0.09$</td>
<td>$1.50 \pm 0.31$</td>
</tr>
<tr>
<td>Observed events</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Preliminary $Br$ measurement on 2016+2017 data

\[
Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 2.44 \cdot 10^{-10} \text{ @ 95\% CL} \\
Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 1.85 \cdot 10^{-10} \text{ @ 90\% CL}
\]

\[
Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.47^{+0.72}_{-0.47}) \cdot 10^{-10} \text{ (two-sided 68\% band)}
\]


Expected (background only)

\[
Br^{expected}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 1.32 (1.62) \cdot 10^{-10} \text{ @ 90 (95) \% CL}
\]

SM prediction

\[
Br^{SM}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.84 \pm 0.10) \cdot 10^{-10}
\]
Plans for $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ measurement

2018 data prospects

- analysis on going, with a factor 2 more than 2017 statistics
- on going studies to optimize the selection, increase signal efficiency, reduce the random veto

Data taking between CERN LS2 and LS3

- plans to strongly suppress the upstream background:
  - re-arranging beam line set-up to swipe away all $\pi^+$ from $K^+$ upstream decays
  - adding fourth Gigatracker station (GTK4) to reduce mistagging probability
  - installing a new veto-counter system before the final collimator around the beam pipe to detect charged pions and photons from upstream kaon decays
- **goal**: $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ measurement with about 20% statistical precision
Search for $\pi^0 \rightarrow \text{invisible}$ (in $K^+ \rightarrow \pi^+ \pi^0$ decays)

- Signal region: $K^+ \rightarrow \pi^+ \pi^0$ kinematic region
- A-priori evaluation of $\pi^0$ suppression
- Same selection and trigger stream as $\pi\nu\bar{\nu}$
- $Br(\pi^0 \rightarrow \text{invisible})$ normalized to $\pi^0 \rightarrow \gamma\gamma$
- Expected background: $10^{+22}_{-8}$ events
- Observed events: 12

Preliminary result (paper in preparation)

$Br(\pi^0 \rightarrow \text{invisible}) < 4.4 \cdot 10^{-9} \ @ \ 90\% \ CL$

Factor of 60 improvement with respect to the state of the art.
Search for $K^+ \rightarrow \pi^+ X, X$ invisible: strategy

- **Physical motivation:** feebly interacting new particle foreseen in several models, e.g. Axion-Like Particle (ALP), QCD Axion, dark scalar, depending on $m_X$.

- **Statistical reinterpretation of the** $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ analysis: same selection (and same signal regions), normalization and background evaluation.

- **Peak search in the observable** $m_{miss}^2 = (P_K - P_{\pi^+})^2$.

- **Scan over different hypotheses for** $m_X$.

- **MC signal generation to compute acceptance and obtain the signal model:** two body decay with 200 different mass hypotheses.
Search for $K^+ \rightarrow \pi^+ X$, $X$ invisible: preliminary result

- Shape analysis in $m_{miss}^2$.
- Fully frequentist approach, profiled likelihood test statistic.
- Background from $\pi\nu\nu$ analysis parameterized with polynomial functions, including SM $K^+ \rightarrow \pi^+ \nu\bar{\nu}$.
- Signal shape: gaussian.

Preliminary result (paper in preparation)

$Br(K^+ \rightarrow \pi^+ X) < (0.5 - 2.0) \cdot 10^{-10}$ @ 90% CL for $m_X \in [0, 100]$ MeV/c$^2$

$Br(K^+ \rightarrow \pi^+ X) < (0.4 - 1.4) \cdot 10^{-10}$ @ 90% CL for $m_X \in [160, 260]$ MeV/c$^2$
Search for $K^+ \rightarrow \pi^+ X$, $X$ decaying: preliminary result (paper in preparation)

- Assuming $X$ decays to a visible SM particle, detected by the NA62 apparatus.
- $P = \exp \left( -\frac{\Delta L}{\beta \gamma c \tau} \right)$
- Simulation and corresponding upper limit for different $\tau_X$ values.
- Comparison with E949 Collaboration result.


For $X$ infinite life time:
- small improvement for $m_X \in [40, 80]$ MeV/c$^2$;
- improvement of $\sim 1$ order of magnitude for $m_X \in [160, 260]$ MeV/c$^2$. 
Conclusions

**$Br(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ measurement**

Combined 2016+2017 preliminary NA62 results (paper in preparation):

- 1+2 signal candidates observed
- $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 1.85 (2.44) \cdot 10^{-10}$ @ 90 (95)% CL
- $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.47^{+0.72}_{-0.47}) \cdot 10^{-10}$ (two-sided 68% band)
- Starting to constrain the largest enhancements allowed by NP models

**Prospects:**

- $\simeq 10$ SM events expected in the full 2016-2018 data sample
- With data taking between CERN LS2 and LS3:
  - $Br(K^+ \rightarrow \pi^+ \nu \bar{\nu})$ measurement with about 20% statistical precision

**Exotic searches related to $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ search (papers in preparation)**

- $Br(\pi^0 \rightarrow \text{invisible}) < 4.4 \cdot 10^{-9}$ @ 90% CL (improvement by a factor of 60)
- $Br(K^+ \rightarrow \pi^+ X) < (0.5 - 2.0) \cdot 10^{-10}$ @ 90% CL for $m_X \in [0, 100]$ MeV/$c^2$
- $Br(K^+ \rightarrow \pi^+ X) < (0.4 - 1.4) \cdot 10^{-10}$ @ 90% CL for $m_X \in [160, 260]$ MeV/$c^2$
  (improvement of $\sim$ 1 order of magnitude)
SPARES
The $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay beyond the Standard Model


$K \rightarrow \pi \nu \bar{\nu}$ and $\epsilon'/\epsilon$ in simplified new physics models


Probing lepton-flavour universality with $K \rightarrow \pi \nu \bar{\nu}$ decays
KTAG: Cherenkov threshold counter;
GTK: Si pixel beam tracker;
CHANTI: ring stations of scintillator slabs;
LAV: lead glass ring calorimeters;
STRAW: straw magnetic spectrometer;
RICH: Ring Imaging Cherenkov counter;
MUV0: off-acceptance plane of scintillator pads;

CHOD: planes of scintillator pads and slabs;
IRC: inner ring shashlik calorimeter;
LKr: electromagnetic calorimeter filled with liquid krypton;
MUV1,2: hadron calorimeter;
MUV3: plane of scintillator pads for muon veto;
HASC: near beam lead–scintillator calorimeter;
SAC: small angle shashlik calorimeter.
NA62 results on 2016 data

\[ K^+ \rightarrow \pi^+ \nu \bar{\nu} \] selection on 2016 data

\[ Br^{NA62}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 14 \cdot 10^{-10} @ 95\% \text{ CL} \]

Trigger and random veto eff. (2017 data - Preliminary)

**Trigger efficiency**
Measured on data using $K^+ \rightarrow \pi^+\pi^0$ events
\[ \epsilon_{\text{trig}} = (87 \pm 3)\% \]

**Random veto efficiency**
Measured on data using $K^+ \rightarrow \mu^+\nu$ events
\[ \epsilon_{RV} = (63.8 \pm 1.4)\% \]
Single event sensitivity and number of expected events (2017 data - Preliminary)

Single event sensitivity

\[ SES = (0.389 \pm 0.021_{\text{syst}}) \cdot 10^{-10} \]

**SES error budget:**

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty $\times 10^{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0 trigger</td>
<td>$\pm 0.015$</td>
</tr>
<tr>
<td>Acceptance</td>
<td>$\pm 0.012$</td>
</tr>
<tr>
<td>Random veto</td>
<td>$\pm 0.008$</td>
</tr>
<tr>
<td>L1 trigger</td>
<td>$\pm 0.003$</td>
</tr>
<tr>
<td>Normalization background</td>
<td>negligible</td>
</tr>
</tbody>
</table>

Number of expected events

\[ N_{\pi\nu\nu}^{\text{exp}}(SM) = \frac{Br_{\pi\nu\nu}(SM)}{SES} = (2.16 \pm 0.12_{\text{syst}} \pm 0.26_{\text{ext}}) \]

External error: theoretical uncertainty on the SM prediction:

\[ Br_{\pi\nu\nu}(SM) = (0.84 \pm 0.10) \cdot 10^{-10} \quad [\text{Buras et al., JHEP11(2015)033}] \]
Background validation: $K^+ \rightarrow \pi^+\pi^0$ and $K^+ \rightarrow \mu^+\nu$

Expected and observed $\pi^+\pi^0$ and $\mu^+\nu$ events in control regions
Upstream background

The back-extrapolation of the downstream track at the Collimator is far from the beam direction. Downstream tracks back-extrapolated near beam-pipe hole rejected.

Normal $K^+$ Decay

The back-extrapolation of the downstream track at the Collimator is far from the beam direction. Downstream tracks back-extrapolated near beam-pipe hole rejected.
Back-extrapolated track position (at the final collimator)
Upstream background validation

NA62 Preliminary
Preliminary results from the 2017 data

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
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<tbody>
<tr>
<td>SES (single event sensitivity)</td>
<td>$(0.39 \pm 0.02) \cdot 10^{-10}$</td>
</tr>
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<td>Expected signal</td>
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</tr>
<tr>
<td>Expected background</td>
<td>$1.50 \pm 0.31$</td>
</tr>
<tr>
<td>Observed $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ candidates</td>
<td>2</td>
</tr>
</tbody>
</table>

Preliminary $Br$ measurement on 2017 data

\[
Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 2.11 \cdot 10^{-10} \text{ @ 95\% CL}
\]
\[
Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 1.76 \cdot 10^{-10} \text{ @ 90\% CL}
\]

\[
Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.20^{+0.69}_{-0.20}) \cdot 10^{-10} \text{ (two-sided 68\% band)}
\]


Expected (background only)

\[
Br^{expected}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 1.41 (1.76) \cdot 10^{-10} \text{ @ 90 (95) % CL}
\]

SM prediction

\[
Br^{SM}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.84 \pm 0.10) \cdot 10^{-10}
\]
Results from the 2016 data

<table>
<thead>
<tr>
<th>Observation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ candidates</td>
<td>1</td>
</tr>
<tr>
<td>SES (single event sensitivity)</td>
<td>$(3.15 \pm 0.01_{\text{stat}} \pm 0.24_{\text{syst}}) \cdot 10^{-10}$</td>
</tr>
<tr>
<td>Expected background</td>
<td>$0.15 \pm 0.09_{\text{stat}} \pm 0.01_{\text{syst}}$</td>
</tr>
</tbody>
</table>

Branching Ratio measurement - upper limits

\[
Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 11 \cdot 10^{-10} \text{ @ 90\% CL}
\]
\[
Br(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 14 \cdot 10^{-10} \text{ @ 95\% CL}
\]

Expected upper limit

\[
Br^\text{expected}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 10 \cdot 10^{-10} \text{ @ 95\% CL}
\]

SM prediction

\[
Br^\text{SM}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (0.84 \pm 0.10) \cdot 10^{-10}
\]
$K^+ \rightarrow \pi^+ \nu\bar{\nu}$ update (preliminary)

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May 26, 2020
$K \rightarrow \pi \nu \bar{\nu}$ excluded regions (preliminary)

Constraints on the largest enhancements allowed by NP models.
New (preliminary) theoretical prediction for $Br(K \to \pi \nu \bar{\nu})$

By M. Gorbahn @ KAON 2019 Conference
https://indico.cern.ch/event/769729/contributions/3512037/

Uncertainty Analysis using UTfit values

<table>
<thead>
<tr>
<th>$B_+ \cdot 10^{11}$ Central: 8.510</th>
<th>$B_L \cdot 10^{11}$ Central: 2.858</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error: -0.543 0.555</td>
<td>Error: -0.256 0.264</td>
</tr>
<tr>
<td>$A$ -0.34 0.352</td>
<td>$A$ -0.162 0.17</td>
</tr>
<tr>
<td>$\delta P_{c,u}$ -0.246 0.250</td>
<td>$\eta$ -0.162 0.167</td>
</tr>
<tr>
<td>$X_t$ -0.236 0.240</td>
<td>$X_t$ -0.113 0.115</td>
</tr>
<tr>
<td>$\rho$ -0.161 0.162</td>
<td>$\kappa_i$ -0.017 0.002</td>
</tr>
<tr>
<td>$P_c$ -0.185 0.187</td>
<td>$\lambda$ -0.001 0.00</td>
</tr>
<tr>
<td>$\kappa_+$ -0.041 0.041</td>
<td></td>
</tr>
<tr>
<td>$\eta$ -0.037 0.039</td>
<td></td>
</tr>
<tr>
<td>$\lambda$ -0.003 0.003</td>
<td></td>
</tr>
</tbody>
</table>

- Precise theory prediction, suppression in standard model and current measurement at NA62 $\to$ classify new physics contributions

CKM input: $A = 0.826(12), \bar{\rho} = 0.148(13), \bar{\eta} = 0.348(10)$