# Les sondes électrofaibles dans le spectromètre à muons d'ALICE

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for the ALICE Collaboration

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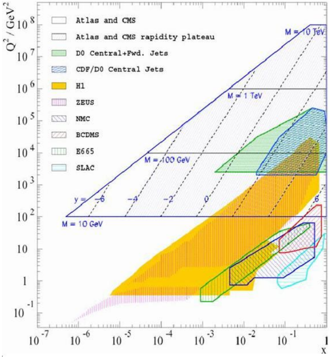
# Outline

# Why should we study W/Z in ALICE ?

Electroweak probes are produced in initial hard collisions.

- They are considered as SM benchmarks. They are suggested as 'standard-candles' for luminosity measurements, and improvement of detectors knowledge ; hep-ex/0509002 ; hep-ex/0512228

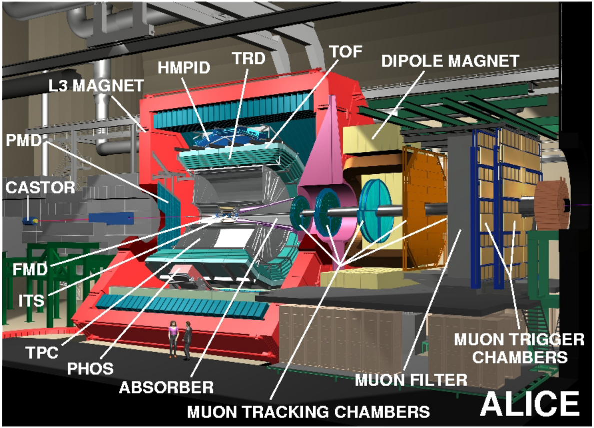
- They will permit to probe PDFs and nuclear effects at low Bjorken-x range. For instance, $x \sim (10^{-4} - 10^{-3})$ at $Q^2 \sim m_W^2$, $-4.0 < \eta < -2.5$ ;
- As they will not interact with the surrounding medium :
  - Their yield will allow to check the validity of the binary scaling ;
  - They could be used as a reference for observing QGP induced effects on other probes, like high $p_T$ muon suppression.




A. Tricoli, hep-ex/0511020

# The ALICE Experiment

- Design goals : measure large multiplicities (up to 8000 charged particles per unit of rapidity) and intermediate interaction rates
- Physics aims : study the QGP in heavy ion collisions




Central barrel :
$|\eta| < 1$
Muon arm :
$-4.0 < \eta < -2.5$

# Muon sources at LHC

Which are the sources of single muons ?

- Light mesons decays : $\pi, K, \ldots$
  - $\pi^+ \xrightarrow{99.9\%} \mu^+ \nu_\mu \; ; \; \ldots$
  - $K^+ \xrightarrow{63.4\%} \mu^+ \nu_\mu \; ; \; \ldots$
- Charm decays : $D$ , $c\bar{c}$ mesons
  - $D^0 \xrightarrow{6.5\%} \mu^+$ anything ; $D^\pm \xrightarrow{17\%} l^\pm$ anything ; $D_s^\pm \xrightarrow{8\%} l^\pm$ anything ;
  - $J/\psi \xrightarrow{5.9\%} \mu^+ \mu^- ; \ldots$ Eur.Phys.J.C8, 573('99) : $c \xrightarrow{9.0\%} \mu$ anything
- Beauty decays : $B$, $b\bar{b}$ mesons
  - $B^{0\pm} \xrightarrow{10.7\%} l\, \nu_l$ anything ; $B^{0\pm} \xrightarrow{24\%} D^\pm$ anything ; $B^{0\pm} \xrightarrow{64\%} D^0/\bar{D}^0$ anything ; $B^{0\pm} \xrightarrow{1.1\%} J/\psi$ anything ; ...
  - $\Upsilon \xrightarrow{2.5\%} \mu^+ \mu^- \; ; \; \ldots$ PDG : $b \xrightarrow{10.7\%} l$ anything
- W / Z decays
  - $W^+ \xrightarrow{10.6\%} \mu^+ \nu_\mu$ ; $W^- \xrightarrow{10.6\%} \mu^- \bar{\nu_\mu}$ ;
  - $Z^0 \xrightarrow{3.4\%} \mu^+ \mu^- \; ; \; \ldots$

$\Longrightarrow$ Muons from W / Z decays have a hight $p_T$, $p_T \sim m_{W/Z}/2$

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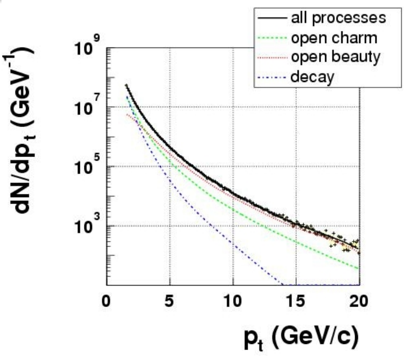
# Single muon $p_T$ distribution at LHC




*ALICE Physics Performance Report II (to be published in J.Phys.G : Single muons in 5% CC PbPb coll. for nominal conditions in the spectrometer.*

- Light meson decays populate the low $p_T$ region

  At $p_T \sim 2$ GeV/c, $N_\mu(\mathrm{c,b}) > \mathrm{N}_\mu(\mathrm{decays})$

- Open charm and beauty decays spread over a wide $p_T$ domain

  For $p_T > 4$ GeV/c, $N_\mu(\mathrm{b}) > \mathrm{N}_\mu(\mathrm{c})$

- W muonic decays dominate the high $p_T$ region

  For $p_T > 30$ GeV/c, $N_\mu(\mathrm{W}) > \mathrm{N}_\mu(\mathrm{b})$

hep-ex/0505021 : PbPb nominal conditions defined as : $\mathcal{L} = 5 \cdot 10^{32}$ cm$^{-2}$

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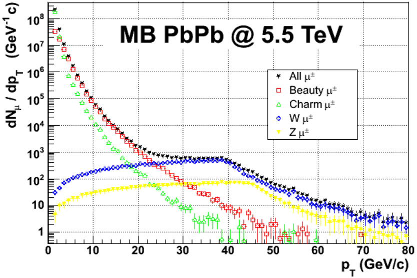


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High $p_T$ muons can be measured in a nominal LHC run.

Binary scaling has been considered to extrapolate W/Z boson cross-section to number of muons (centrality dependent), as expected for electroweak probes.

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# Production mechanisms

## Open charm & beauty

- LO processes :
  - Gluon fusion, $g\,g \longrightarrow Q\bar{Q}$
  - $q\bar{q}$ annihilation $q\,\bar{q}' \longrightarrow Q\bar{Q}$
- HO processes :
  - gluon splitting,
  - flavor excitation,
  - gluon radiation.

$\Longrightarrow$ Open charm and beauty are mainly produced by gluon-gluon interactions and W/Z's by quark-antiquark scattering.

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## W / Z bosons

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    $q\ \bar{q}' \rightarrow W^{\pm}$ ; $q\ \bar{q} \rightarrow Z$
- HO processes :
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    $q\ g \rightarrow W\ q'$
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# Estimated muon yields from W decays

## pp @ 14 TeV

- $\sigma_{pp}^{W} \times BR_{\mu\nu} \approx 20.9$ nb
- MS Acceptance : $-4.0 < \eta < -2.5$ $\Rightarrow \sim 14$ % Acc

$\Longrightarrow$ $N_{\mu} \approx 88000$ in the MS Acc.

Frixione, Mangano : hep-ph/0405130

## PbPb @ 5.5 TeV

- $\sigma_{NN}^{W} \times BR_{\mu\nu} \times C_{shad} \approx 6.56$ nb
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Vogt : Phys.Rev.C64,044901

## Pbp @ 8.8 TeV

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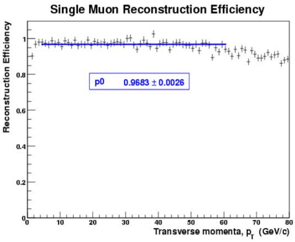
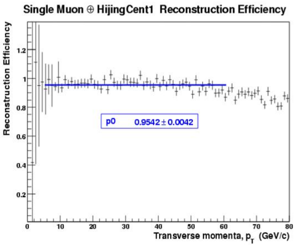
- The muon spectrometer will be able to reconstruct muons up to 1 TeV momenta.
- Single muon reconstruction efficiency in the muon spectrometer has been evaluated to be about 97% in pp collisions, and about 95% in most central PbPb collisions for $p_T$ $(5, 60)$ GeV/c.

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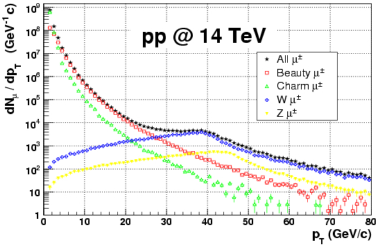


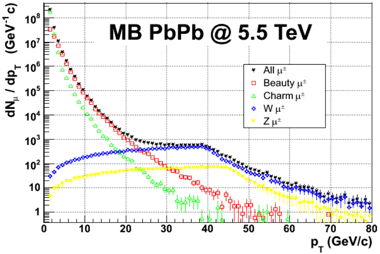


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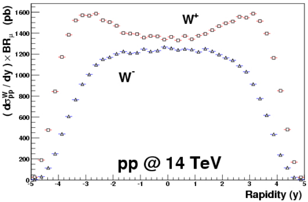
# Muon charge asymmetry

## W production asymmetry

W's are mainly produced by $q\bar{q}$ annihilation. By charge conservation we observe :

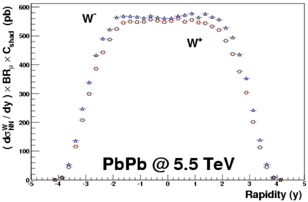
- $W^+$ is produced by : $u\bar{d}$, $c\bar{s}$, . . .
- $W^-$ is produced by : $d\bar{u}$, $s\bar{c}$, . . .

| N valence \ Run | pp | PbPb | pPb |
|---|---|---|---|
| *u* quarks | $2 \times 2$ | $2 \times (2Z + N)$ | $2 + (2Z + N)$ |
| *d* quarks | $2 \times 1$ | $2 \times (Z + 2N)$ | $1 + (Z + 2N)$ |




$N_{W+} > N_{W-}$

At most : $N_u = 2 \cdot N_d$

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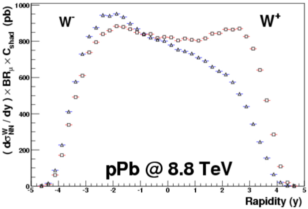
$N_d = \frac{Z+2N}{2Z+N} N_u = 1.15\, N_u$

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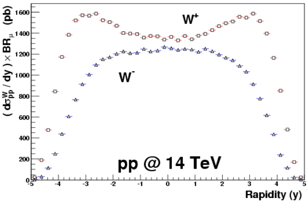


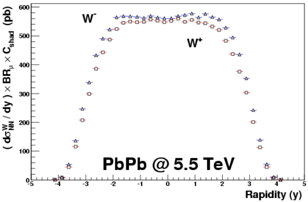


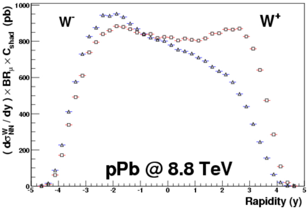


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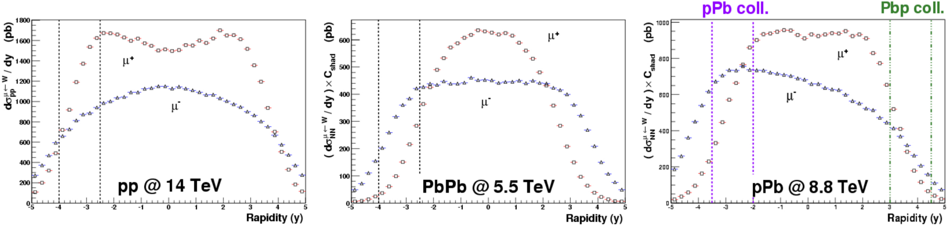
What about muon from W decays rapidity distribution ?

We should bear in mind that in addition to W production charge asymmetry, parity violation affects muon from W decays rapidity distributions.

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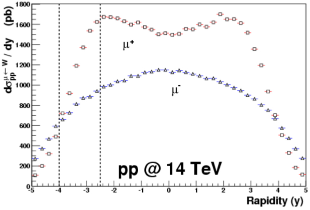


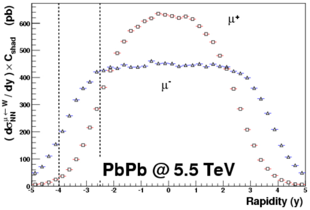


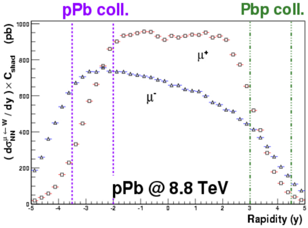


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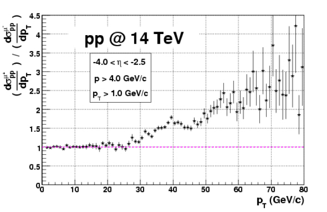
# Muon charge asymmetry

## Reconstructed muon charge asymmetry

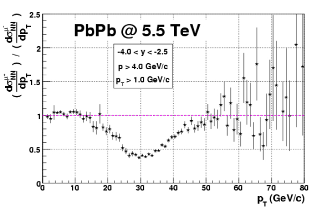
How muon charge asymmetry as a function of $p_T$ will look like ?

### pp @ 14 TeV




| $p_T$ range | $N\mu^+/N\mu^-$ (year$^{-1}$) |
|---|---|
| (15,20) GeV/c | 1.03 $\pm$ 0.01 (stat) |
| (35,45) GeV/c | 1.58 $\pm$ 0.02 (stat) |

### PbPb @ 5.5 TeV




| $p_T$ range | $N\mu^+/N\mu^-$ (year$^{-1}$) |
|---|---|
| (15,20) GeV/c | 0.89 $\pm$ 0.01 (stat) |
| (35,45) GeV/c | 0.61 $\pm$ 0.02 (stat) |

$\Longrightarrow$ At high $p_T$ muon charge asymmetry can be used to recognize W's production.

$\Longrightarrow$ Muon charge asymmetry varies with the colliding system.

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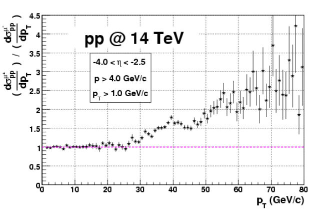


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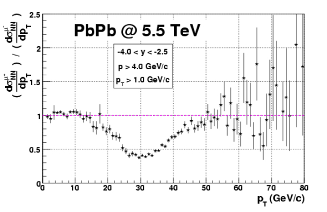


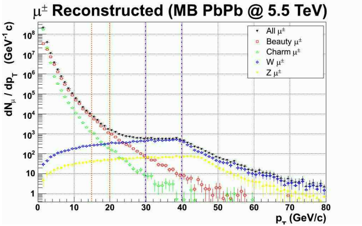

| $p_T$ range | $N\mu^+/N\mu^-$ (year$^{-1}$) |
|---|---|
| (15,20) GeV/c | 0.89 $\pm$ 0.01 (stat) |
| (35,45) GeV/c | 0.61 $\pm$ 0.02 (stat) |

$\Longrightarrow$ At high $p_T$ muon charge asymmetry can be used to recognize W's production.

$\Longrightarrow$ Muon charge asymmetry varies with the colliding system.

# Sensitivity to high $p_T$ muon suppression

What can single muon spectra tell us about high $p_T$ $\mu^{\pm}$ suppression ?




- Low $p_T$ region is dominated by beauty and charm decays.
  W/Z decays govern the high $p_T$ domain.
- W/Z bosons are electroweak probes produced in initial hard collisions.

| | b, c decays | W / Z decays |
|---|---|---|
| Initial state effects | gluon shadowing | quark shadowing |
| Final state effects | medium effects (energy loss, . . .) | nothing |
| $p_T^{\mu}$ domain [GeV/c] | (15,20) | (30,40) |

We can define $\mathcal{S}$ as a high $p_T$ muon suppression sensitivity parameter, and any deviation to theoretical calculations should point to medium induced effects.

$\mathcal{S} = \frac{N^{\mu}_{15-20}}{N^{\mu}_{30-40}} \approx 4.7$ in absence of quenching for PbPb collisions.

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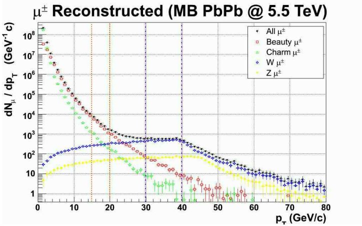


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# Outlook : Z bosons preliminary studies

## pp @ 14 TeV

- $\sigma^Z_{pp} \times BR_{\mu^+\mu^-} \approx 1.9$ nb
- MS Acceptance $\Rightarrow \sim 4.5$ % Acc

$\Longrightarrow \approx$ 2500 pairs in the MS Acc.

Cooper-Sarkar : hep-ex/0512228

## PbPb @ 5.5 TeV

- $\sigma^Z_{NN} \times BR_{\mu^+\mu^-} \times C_{shad} \approx 0.62$ nb
- MS Acceptance $\Rightarrow \sim 1.7$ % Acc

$\Longrightarrow \approx$ 230 pairs in the MS Acc.

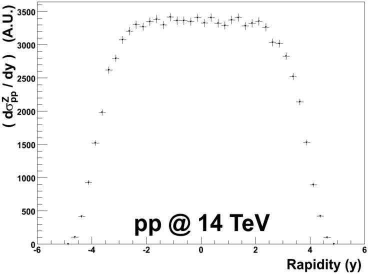
Vogt : Phys.Rev.C64,044901

## ArAr @ 6.3 TeV

- $\sigma^Z_{NN} \times BR_{\mu^+\mu^-} \times C_{shad} \approx 0.76$ nb
- MS Acceptance : $\Rightarrow \sim 2.3$ % Acc

$\Longrightarrow \approx$ 2400 pairs in the MS Acc.

N. Blusseau, Master student




$\Longrightarrow$ Z bosons can be studied in the muon spectrometer in pp and ArAr collisions.

hep-ex/0505021 : pp (PbPb) [ArAr] nominal conditions defined as :
$\mathcal{L} = 3 \cdot 10^{37}$ $(5 \cdot 10^{32})$ $[10^{35}]$ cm$^{-2}$

# Summary

- W bosons can be observed in the ALICE muon spectrometer via the single muon $p_T$ distribution.
- Z bosons can also be studied in the spectrometer in pp and ArAr collisions via invariant mass analyis.
- W/Z are considered as 'standard-candles' for luminosity measurements and improvement of the detectors knowledge.
- They will allow to probe PDFs and nuclear modification effects at $Q^2 \sim m^2_{W/Z}$ , $-4.0 < \eta < -2.5$, a kinematic domain not explored by ATLAS/CMS.
- Muon charge asymmetry is a reliable signature of W production.
- Single muons from W/Z decays can be used as a reference to study medium induced effects (high $p_T$ muon suppression).

But . . . systematic uncertainties on these estimations have not been evaluated.

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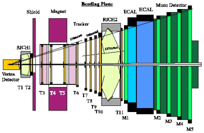
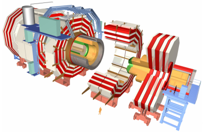
# For further information


- Torbjörn Sjöstrand and others
  *PYTHIA 6.2 Physics and Manual* , hep-ph/0108264 (2002)
  http ://www.thep.lu.se/~torbjorn/Pythia.html
- Carminati, F. et al (ALICE Coll.)
  *ALICE : Physics performance report, volume I*
  J. Phys. G30 (2001), 1517-1763
- Alessandro et al (ALICE Coll.)
  *ALICE : Physics performance report, volume II*
  to be published in J. Phys. G
- S. Frixione and M. L. Mangano
  *How accurately can we mesure the W cross section ?*
  hep-ph/0405130v1 (2004)
- R. Vogt
  *Shadowing Effects on Vector Boson Production*
  Phys. Rev. C64,044901 (2001), hep-ph/0011242

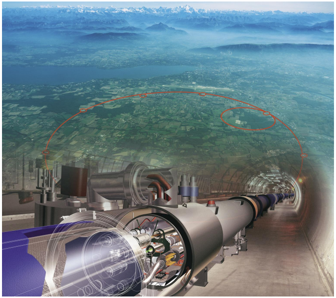
# LHC Experiments and running conditions at point 2



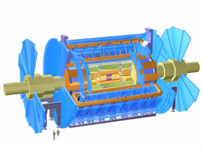

LHCb



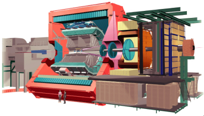
CMS



LHC at CERN



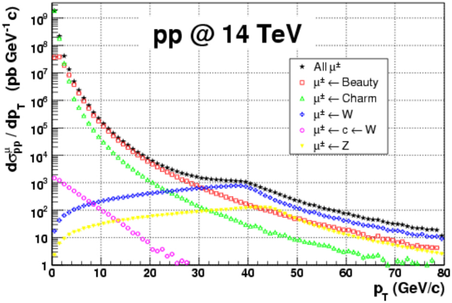
ATLAS

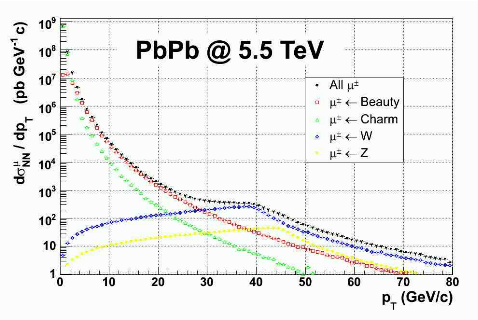


ALICE

| parameter \ Run | pp Run1 (end 07) | pp nominal (08) | PbPb nominal (end 08) | pPb nominal (first 10-years) |
|---|---|---|---|---|
| $\sqrt{s_{NN}}$ [TeV] | 14 | 14 | 5.5 | 8.8 |
| $<\mathcal{L}>$ [cm$^{-2}$s$^{-1}$] | $10^{30}$ | $3 \cdot 10^{30}$ | $5 \cdot 10^{26}$ | $10^{29}$ |
| Rate [s$^{-1}$] | $5.7 \cdot 10^{4}$ | $2 \cdot 10^{5}$ | $8 \cdot 10^{3}$ | – |
| Runtime [s] | $6 \cdot 10^{5}$ | $10^{7}$ | $10^{6}$ | $10^{6}$ |

# Muon generated $p_T$ distribution in $4\pi$



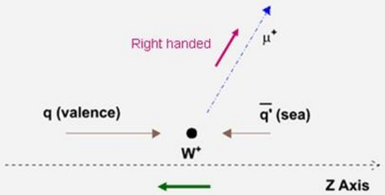



# Plain explanation of polarization effect on $\mu^{\pm}$ shapes I

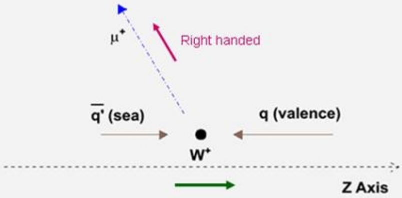
## ➢ For $\mu^+$ production

We could expect muons to be most probably produced in the valence quark movement direction (P conservation). Let's see...

a) Case "$J_z = -1$":




b) Case "$J_z = +1$":




Due to total angular momentum conservation (J), it does not seem very probable to create $\mu^+$ in this direction (high-rapidity).
So, their angular orientation should be given by "conservation laws compromise".

**Then, $\mu^+$ are most probably produced at mid-rapidity!**

# Plain explanation of polarization effect on $\mu^{\pm}$ shapes II

## ➤ For $\mu^-$ production

As for the $\mu^+$ case, we could expect muons to be most probably produced in the valence quark movement direction (P conservation). Let's see...

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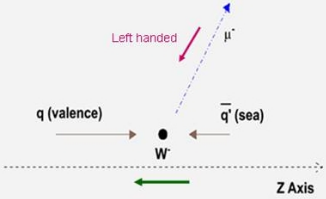


In this case, there's no "opposition" between P and J conservation laws.

High rapidity production seems to be really plausible!

**Then, $\mu^-$ could be produced at high-rapidity!**