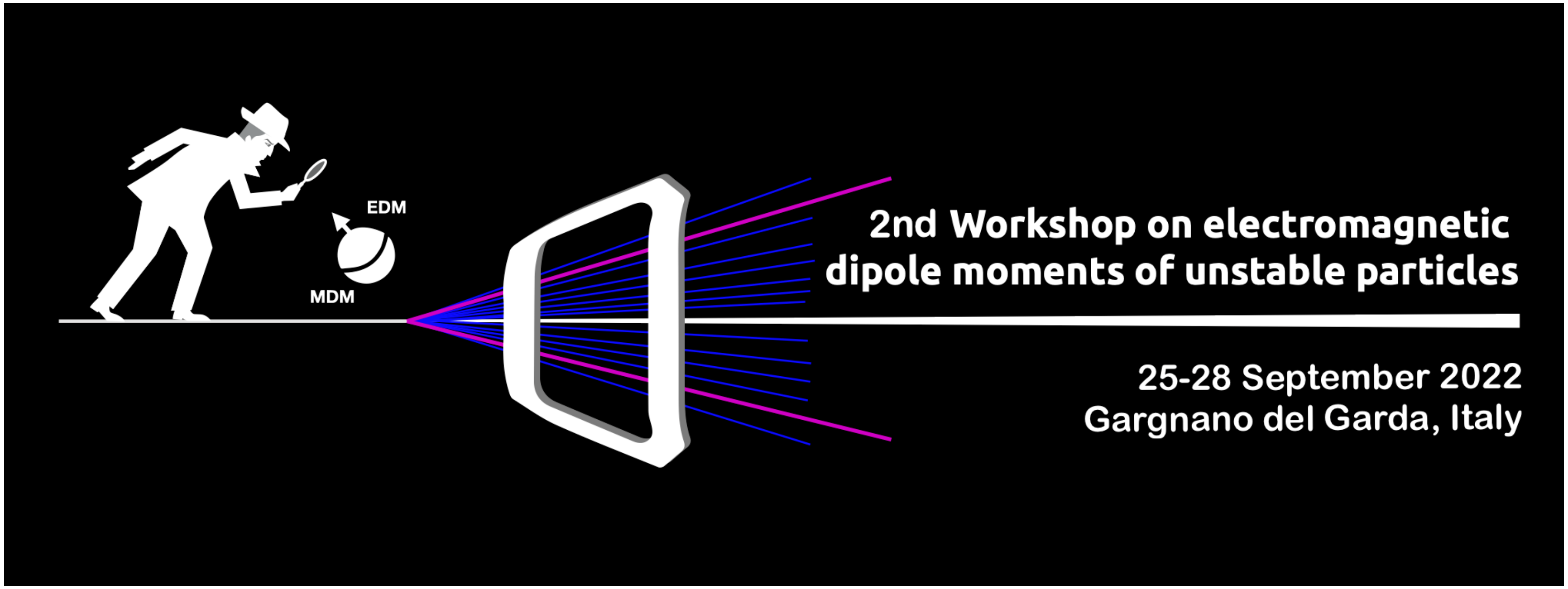
Summary of physics opportunities

F. Martínez Vidal, IFIC INSTITUT DE FÍSICA CORPUSCULAR CSIC VNIVERSITAT DE VALÈNCIA



Rich physics program

Very forward charm x-sections, prod. asymmetries and polarization

Charm baryon dipole moments

Charm x-section & prod. asymmetries in FT

Charm baryon decay dynamics and polarimetry in pp

Charm baryon polarization in FT

Strange baryon dipole moments

Event and T-track reconstruction & trigger

Searches for BSM LLPs

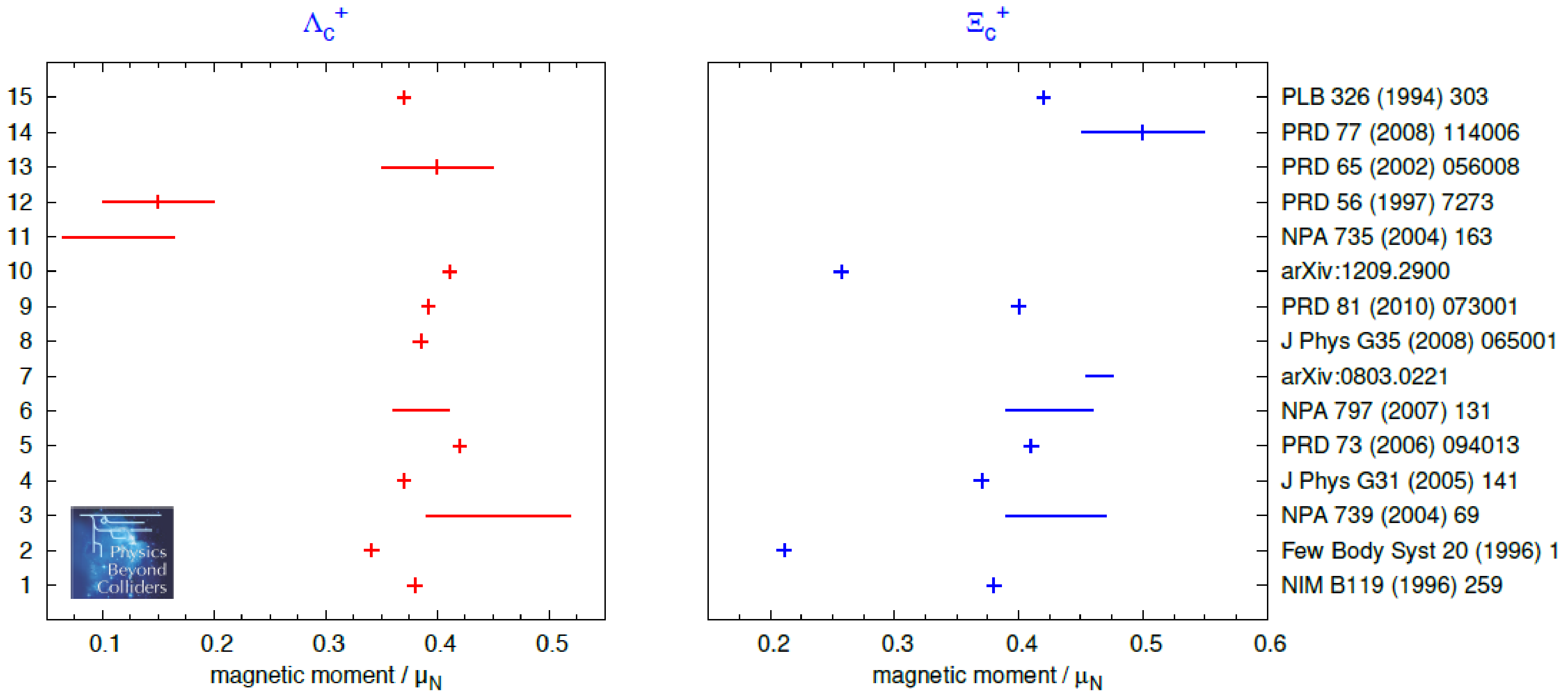
Tau lepton, beauty baryons dipole moments

+THEORY & PHENO

Charm MDM predictions

$$\mu = gJ\frac{m_p}{m}\mu_N$$

Phys. Rev. D**73** (2006) 094013 Phys. Rev. D**81** (2010) 073001 CERN-PBC-REPORT-2018-008



$\mu \approx 0.1\mu_N$, $g \approx 0.49$, $a \approx -0.76$

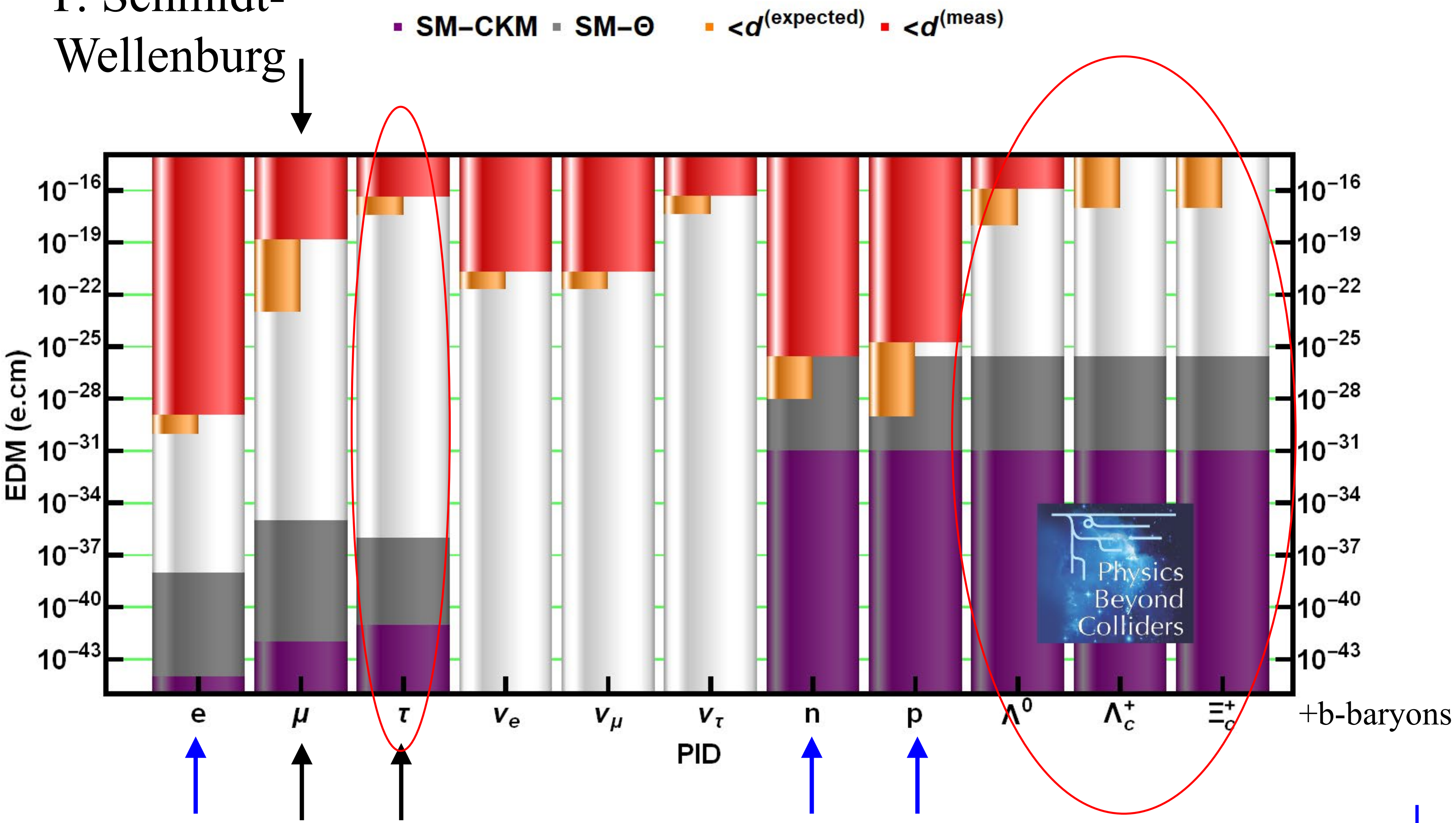
$\mu \approx 0.4\mu_N$, $g \approx 1.95$, $a \approx -0.03$

$\mu \approx 0.2\mu_N$, $g \approx 1.05$, $a \approx -0.47$

$\mu \approx 0.4\mu_N$, $g \approx 2.10$, $a \approx 0.05$

EDM status

P. Schmidt-Wellenburg



A. Lusiani

F. Teubert

Messages to take home

EDMs are very sensitive probes for **new CP-violating mechanisms**…(for instance, current limits constrain to $O(10^{-4})$ CP-odd $H \rightarrow \gamma\gamma$ operator, …) these searches are considered to be one of the **most promising paths towards NP**.

The search in **different systems** (leptons, nucleons, atoms, molecules, etc…) are **complementary** and needed to **discriminate between EDM sources** (θ_{QCD},C_{ggg}, C_{qqqq} C_{qH},d_n,C_T,C_S,…). In this sense, proposals like the ones discussed in this workshop to measure **EDMs for charm, strange baryons and tau leptons are very welcome.**

Current (and future) efforts in **neutron EDMs** are **limited** by the available **sources of UCN**. **Statistics is not a problem for a proton (deuteron) storage ring**. Moreover, the possibility to have **CW (CCW) beams** in an **all-electrical storage ring** is a key aspect to be able to control systematic **uncertainties at the 10^{-30}-10^{-29}** level. The other key aspect is the **BPMs to control the beam trajectories.**

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THEORY+PHENO

E. Kou

MAGNETIC MOMENT OF Λc AND CHARM QUARK

- We compute the Λc (udc, spin anti-symmetric state) magnetic moment in the quark model:

$$\mu_{\Lambda_c} = \mu_c = \frac{g_c}{2}\frac{Q_c|e|}{2m_c}$$

- Heavy quark chiral Perturbation Theory: the fact that the light degree of freedom is spineless configuration leads to a negligible higher order correction.
- Various theoretical estimates of Λc magnetic moment can be summarised as

$$\frac{\mu(\Lambda_c^+)}{\mu_N} = 0.37\text{–}0.42,$$

μ_N=|e|/2M_P is called the nuclear magneton

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Conclusions

ment determination with bent-crystal
of the Λ_c polarisation. Last few years, there
ogresses on the Λ_c polarisation

ecay can indirectly provide an estimate
h is slightly higher than the theoretical
.m.).

- The MDM measurement requires the simultaneous determination of the Λ_c polarisation and the "asymmetry parameter (i.e. form factors)".
- We propose a new framework to perform the sensitivity study. Our preliminary result shows that the polarisation can be measured at 3 (1)% precision for 20k (200k) Λc→pKπ events. The next step is to include more resonances.

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THEORY+PHENO

D. Severt

Electric dipole moments of heavy baryons and quarks

EDMs of Baryons with bottom quarks

- **Results:** example Λ_b^0-baryon

$$d^{\gamma}_{\Lambda_b^0} = 4c_1 - 4e\Big(b_{19} - \mu_{11}(\mu^{ub} - \mu^{db}) + \mu_{14}(\mu^{ub} + \mu^{db}) - 2\mu_{20}(\mu^{ub} - \mu^{db} - \mu^{sb}) - \mathrm{Re}(V_{ub})(\nu_{11} - \nu_{14} + 2\nu_{20})\nu^{ub}\Big) + \text{loops}$$

- *Too many LECs...* $\rightarrow$ we need to fix this!
- How to determine LECs:
  - fundamental theory $\rightarrow$ not possible (maybe Lattice-QCD?)
  - experimental data $\rightarrow$ not yet available

$\rightarrow$ **Idea:** Naive dimensional analysis (NDA)

Daniel Severt 2nd EDM workshop 26.09.2022 27

- NDA predictions for the different contributions: (BSM scale $\Lambda = 1$ TeV)
  - ▷ qEDM: $d^{\gamma}_{B_b} \approx 10^{-19}\, e\,\mathrm{cm}$
  - ▷ qCEDM: $d^{\gamma}_{B_b} \approx 10^{-20}\, e\,\mathrm{cm}$
  - ▷ 4q: $d^{\gamma}_{B_b} \approx 10^{-21}\, e\,\mathrm{cm}$
  - ▷ 4qLR: $d^{\gamma}_{B_b} \approx 10^{-24}\, e\,\mathrm{cm}$
- All EDMs scale with Λ^{-2}
- Future experiments can help to identify the sources of CP-violation

DMs for charm baryons and tau lepton

Requirements

J. Ruiz Vidal

Λ_c^+

Case of **short-lived charmed baryons**

- A source of **polarized particles**

  Strong production in a **fixed target**
  (transverse polarization)

- **Electromagnetic field** intense enough to induce precession

  Interatomic electric field
  in **bent crystals**

- A **detector** to measure the polarization

  Angular distribution of baryon decay
  products, at **LHCb** / **IR3** (dedicated)

EPJ C77 (2017) 181

Joan Ruiz-Vidal (IFIC Valencia) Introduction to bent crystals for EDM/MDM September 26, 2022 6 / 33

DMs for charm baryons and tau lepton

J. Ruiz Vidal

Experiment concept: requirements

Case of **short-lived τ^+ leptons**

- A source of **polarized particles**

  Weak decays of charmed mesons, $D_s^+ \to \tau^+ \nu_\tau$
  (longitudinal polarization)

- **Electromagnetic field** intense enough to induce precession

  Interatomic electric field
  in **bent crystals**

- A **detector** to measure the polarization

  Full kinematic information of the $3\pi^\pm$ system, $\tau^+ \to 3\pi^\pm \bar{\nu}$,
  in a multi-variate classifier. **Future dedicated experiment**

  PRL 123 (2019) 011801

Charm baryon decay dynamics & polarimetry in pp

D. Marangotto

Conclusions

- $\Lambda_c^+ \to pK^-\pi^+$ SL amplitude analysis completed, arXiv:2208.03262, submitted to PRD
- Amplitude model ready for Λ_c^+ polarization measurements, *e.g.* in p-Gas SMOG collisions (Andrea's talk) and EMDMs measurements from spin precession
  - Provides best polarimeter for the most abundant Λ_c^+ baryon
- First Λ_c^+ polarization measurement from beauty SL decays

- $\Xi_c^+ \to pK^-\pi^+$ SL amplitude analysis ongoing
  - Preliminary amplitude model obtained, with good control of efficiency and background
  - Will provide efficient polarimeter also for the Ξ_c^+ baryon
  - Comparison of polarization values for charm baryons with/out strangeness

- $\Xi_c^+ \to pK^-\pi^+$ prompt polarization measurement ongoing
  - Preliminary results for Ξ_c^+ polarization in p_T, x_F bins obtained
  - No evidence of Ξ_c^+ polarization at 13 TeV center-of-mass
  - Not directly relevant for EMDMs measurement, but nice application of the method

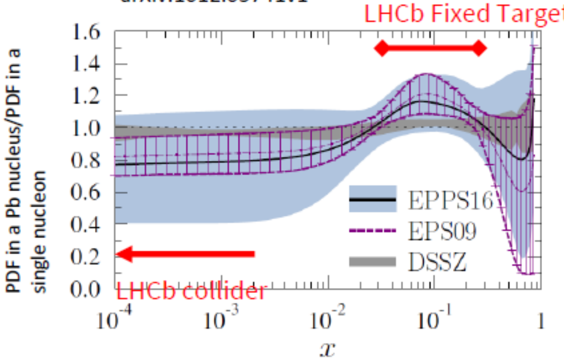
FT program: SMOG(2)

P. Robbe

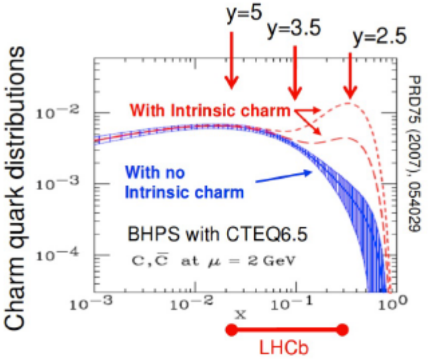
Fixed-target physics program: SMOG

- SMOG = System for Measuring Overlap with Gas
- Noble gas at $\sim 2x10^{-7}$ mbar pressure injected in LHCb vacuum in the LHCb interaction region
- Originally used to determine luminosity: since 2015, use it to collect fixed-target collision data for physics
- $\sqrt{s_{NN}}$ = 69-110 GeV, between SPS and RHIC
- $-3.0 < y^* < 0$
- Access nPDF (nuclear PDF) anti-shadowing region
- Probe intrinsic charm content in the nucleon
- Inputs to astrophysics

arXiv:1612.05741v1



Bjorken-x = fraction of the nucleon momentum carried by a parton



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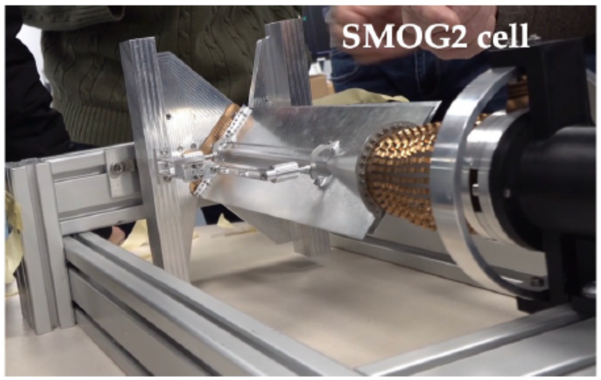
FT program: SMOG(2)

P. Robbe

[LHCb-TDR-020]

LHCb Run 3: SMOG 2

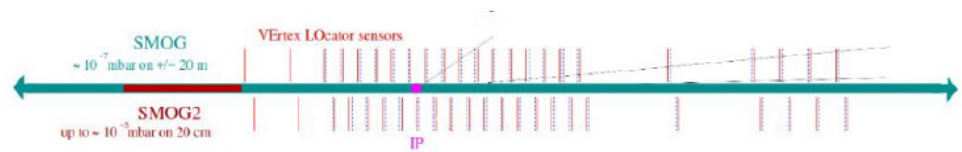


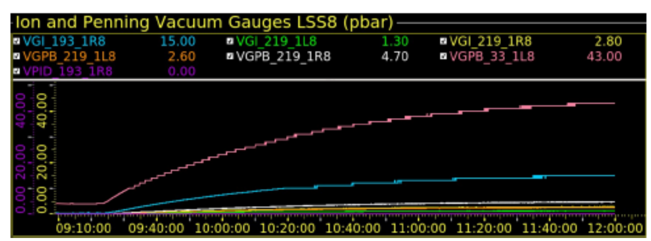
- Fixed target setup upgraded, with a storage cell between -50 cm and -30 cm, upstream of IP
  - Well defined interaction region
  - Increase of gas pressure and luminosity by 2 orders of magnitude
  - Gas feed system to switch quickly between different types of gases (H, D, He, N, O, Ne, Ar) and to measure precisely the gas density (for absolute cross-section measurements)

[LHCB-PUB-2018-015]

	SMOG largest sample p-Ne@68 GeV	SMOG2 example p-Ar@115 GeV
Integrated luminosity	$\sim 100\ \mathrm{nb}^{-1}$	$100\ \mathrm{pb}^{-1}$
syst. error on J/ψ x-sec.	6–7%	2–3 %
J/ψ yield	15k	35M
D^0 yield	100k	350M
Λ_c yield	1k	3.5M
$\psi(2S)$ yield	150	400k
$\Upsilon(1S)$ yield	4	15k
Low-mass ($5 < M_{\mu\mu} < 9\ \mathrm{GeV}/c^2$) Drell-Yan yield	5	20k

~1 year of data taking in parallel with *pp* collisions





Gas injection during stable beams on July 6

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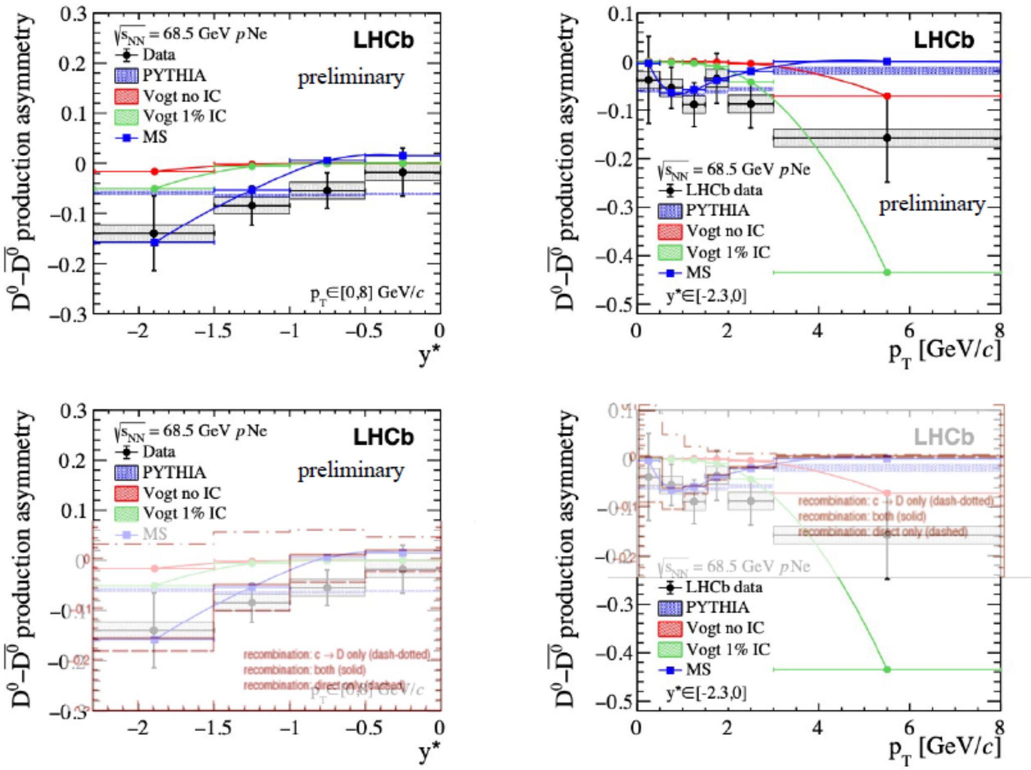
Charm x-sections & production asymmetries in FT

E. Neil

Production asymmetry D^0 : data



$$\mathcal{A}_X = \frac{N(X) - N(\bar{X})}{N(X) + N(\bar{X})}$$

- Pythia : flat prediction
- With 1 % of IC, expected negative asymmetry at backward rapidity and high p_T
- Recombination model: same behaviour as a function of rapidity but opposite for p_T
- Compare to **LHCb data**

Paper: *LHCb-PAPER-2022-015*

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+ charm baryons + baryon/meson ratios

Charm baryon polarization in FT

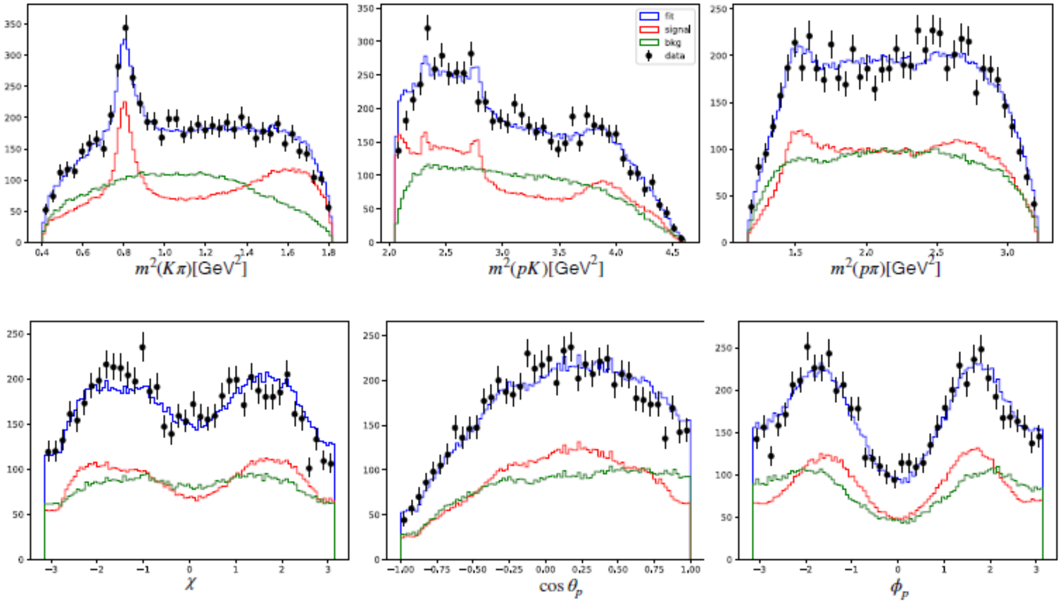
A. Merli

Extraction of polarisation

- Efficiency map extracted from simulations
- Background from mass sidebands
- Increase yields in simulation to determine better the 5D efficiency map

$\Lambda_c^+ \to pK^-\pi^+$

comb. bkg



Λ_c^+ polarisation measurement in SMOG data @ LHC - Andrea Merli 22

Complementarity of kinematic region

- Kinematic coverage gives access to almost **zero angle particle production**

Kinematic variable	> 15 mrad (~SMOG2)	*eg.* Ge 293K 16 mrad 10 cm
Momentum (GeV)	< 500	>800
Transverse momentum	> 0.5	< 1
Pseudorapidity*	–4 to 0, central & backward	1 to 3.5, very forward
Momentum transfer Q	20 to 115	≈ 4
Bjorken-x	Down to ≈ $10^{-3.5}$	Down to ≈ 10^{-3}
Feynman-x	Large negative	Large positive

- (Additional) Physics case: access ≈zero angle particle production
  - ✓ $\mathbf{\Lambda_c^+}$ and $\mathbf{\Xi_c^+}$ baryons (similar amount)
  - ✓ $\mathbf{D^+}$ and $\mathbf{D_s^+}$ mesons, with rates ×(10-30) and ×(2-4) higher than for Λ_c^+
  - ✓ But also other positively charged particles like **kaons**, **protons**, etc.

J. Rojo

Heavy hadron production in the very forward region at the LHC

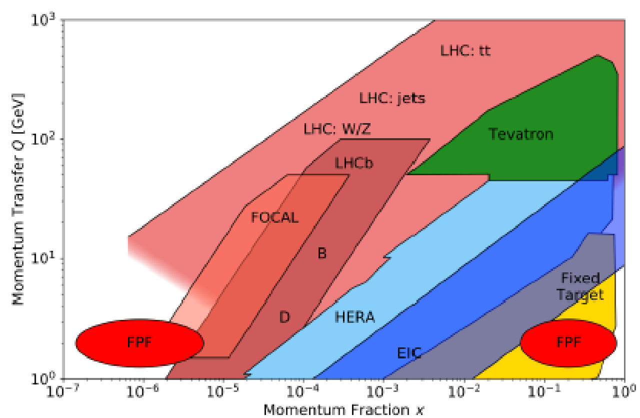
Summary and outlook

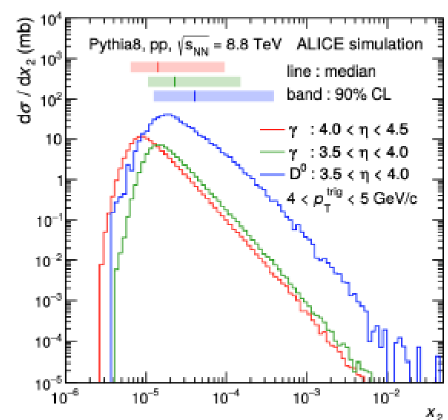
- **Forward particle production** in pp and pA collisions provides direct access to many exciting phenomena in **small-x QCD** and **hadronic & nuclear structure**

- In the collinear factorisation framework, different forward processes **exhibit complementary strengths and weaknesses to probe small-*x* QCD**, e.g. *D*-meson production is abundant but suffers from large MHOUs while prompt photons provide a clean electroweak probe

- Upcoming experiments from the **HL-LHC** to the **EIC** and the **FPF** will shed further light on QCD at small-x and on predictions for heavy hadron production in the forward region

- Potentially useful constraints also from **heavy hadron production** in **fixed-target LHC mode!**



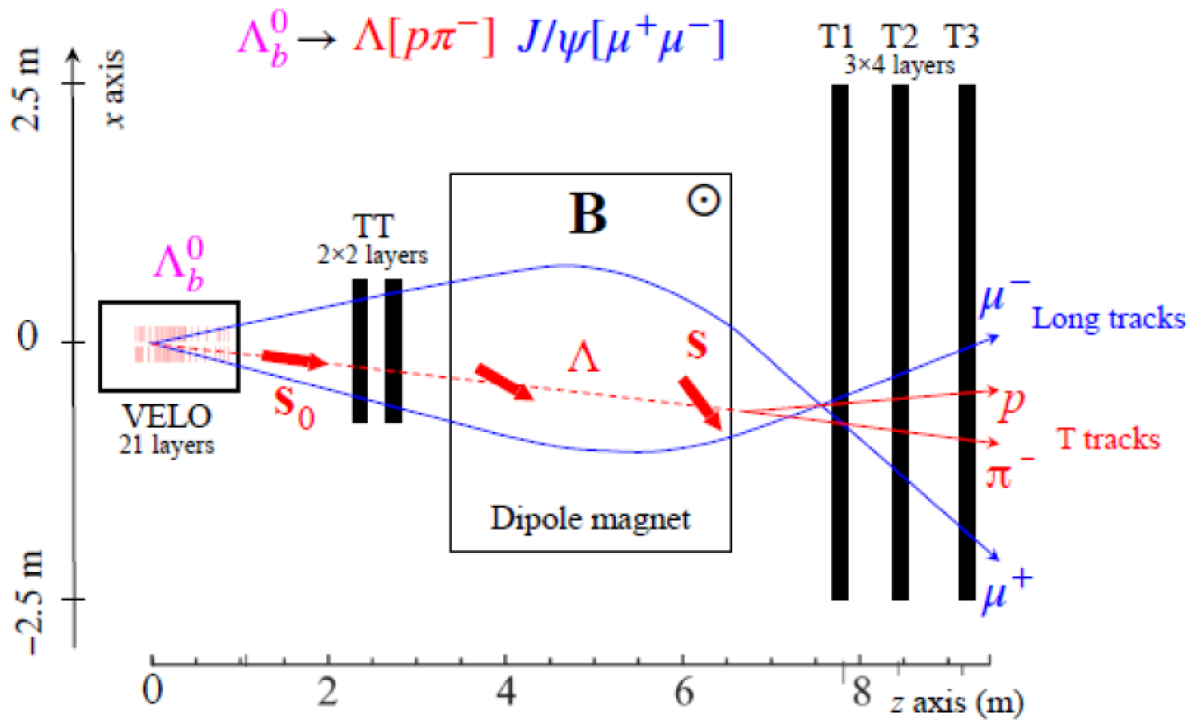


Strange baryon dipole moments

S. Jaimes

Measurement of Λ EDM/MDM at LHCb

Spin precession of Λ baryons at the LHCb magnet



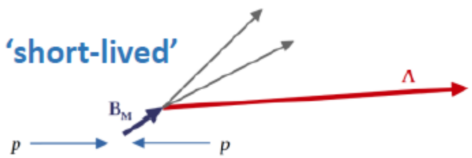
Charm baryon decay dynamics & polarimetry in pp

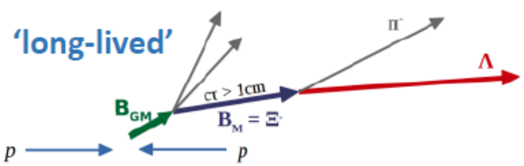
Z. Wang

Source and production of Λ (c-baryon decays)

Table 1: Dominant Λ production mechanisms from heavy baryon decays and estimated yields produced per fb^{-1} at $\sqrt{s} = 13\,\text{TeV}$, shown separately for SL and LL topologies. The Λ baryons from Ξ^- decays, produced promptly in the pp collisions, are given in terms of the unmeasured production cross section. [*]

SL events	N_Λ/fb^{-1} $(\times 10^{10})$	LL events, $\Xi^- \to \Lambda\pi^-$	N_Λ/fb^{-1} $(\times 10^{10})$
$\Xi_c^0 \to \Lambda K^-\pi^+$	7.7	$\Xi_c^0 \to \Xi^-\pi^+\pi^+\pi^-$	23.6
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	3.3	$\Xi_c^0 \to \Xi^-\pi^+$	7.1
$\Xi_c^+ \to \Lambda K^-\pi^+\pi^+$	2.0	$\Xi_c^+ \to \Xi^-\pi^+\pi^+$	6.1
$\Lambda_c^+ \to \Lambda\pi^+$	1.3	$\Lambda_c^+ \to \Xi^-K^+\pi^+$	0.6
$\Xi_c^0 \to \Lambda K^+K^-$ (no ϕ)	0.2	$\Xi_c^0 \to \Xi^-K^+$	0.2
$\Xi_c^0 \to \Lambda\phi(K^+K^-)$	0.1	Prompt Ξ^-	$0.13 \times \sigma_{pp\to\Xi^-}$ [μb]





Decays are working in progress:

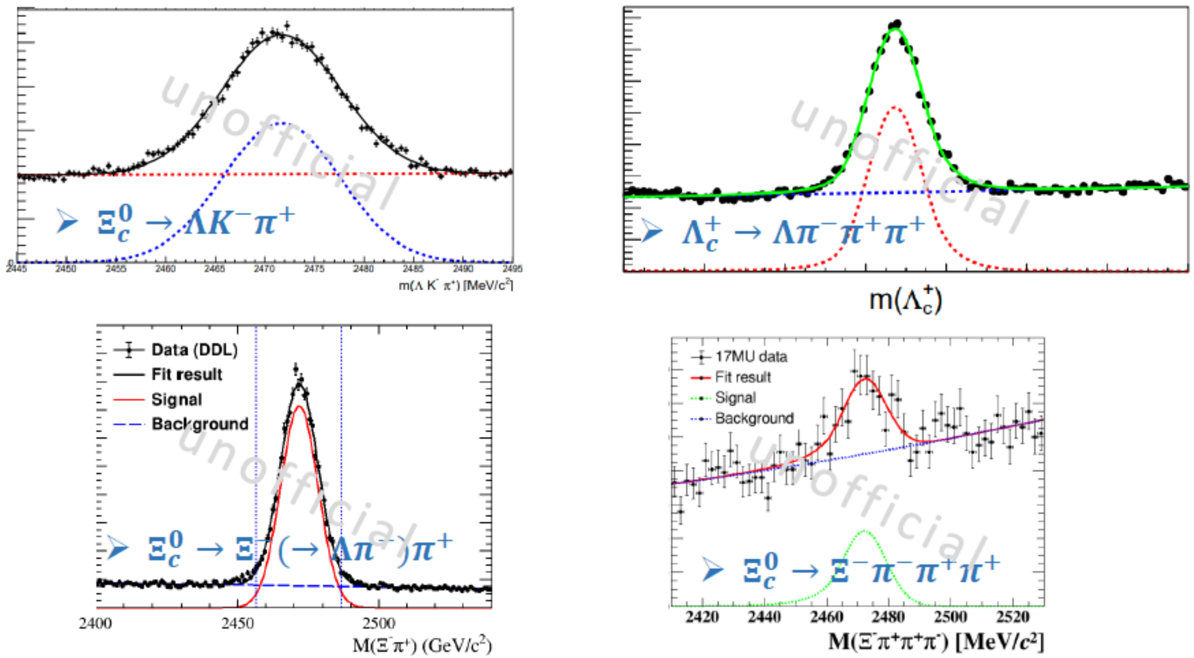
- ✓ $\Xi_c^0 \to \Lambda K^-\pi^+$
- ✓ $\Xi_c^0 \to \Xi^-(\to \Lambda\pi^-)\pi^+$
- ✓ $\Lambda_c^+ \to \Lambda\pi^-\pi^+\pi^+$
- ✓ $\Xi_c^0 \to \Xi^-\pi^-\pi^+\pi^+$

[*] F. J. Botella, L. M. Garcia Martin, D. Marangotto, F. M. Vidal, A. Merli, N. Neri, A. Oyanguren and J. R. Vidal, Eur. Phys. J. C77, 181 (2017)

Charm baryon decay dynamics & polarimetry in pp

Z. Wang+ S. Jaimes

Available candidates after selection



Decays	Data sets	Yields	Purity
$\Xi_c^0 \to \Lambda K^-\pi^+$	2015/16/17	~60k	~50%
$\Lambda_c^+ \to \Lambda\pi^-\pi^+\pi^+$	2016	~24k	~54%
$\Xi_c^0 \to \Xi^-\pi^+$	2017	~23k	~80%
$\Xi_c^0 \to \Xi^-\pi^-\pi^+\pi^+$	2017MagUp	~0.4k	~15%

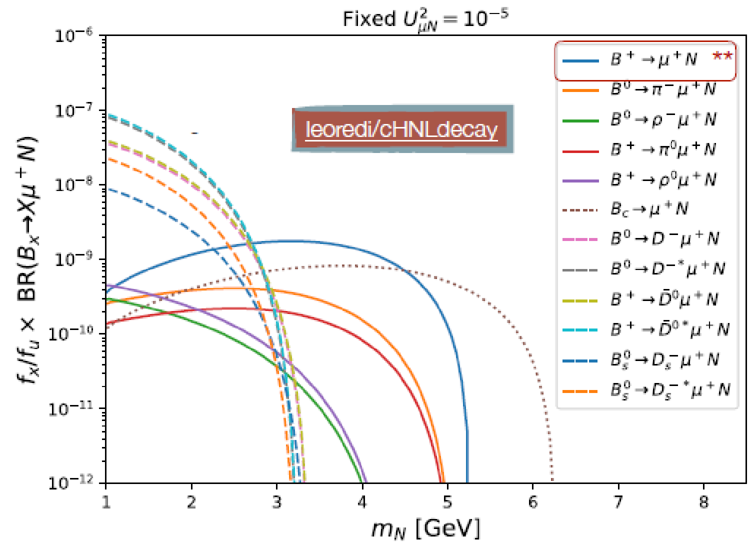
2022/9/28 2nd workshop on EMDMs of unstable particles 5

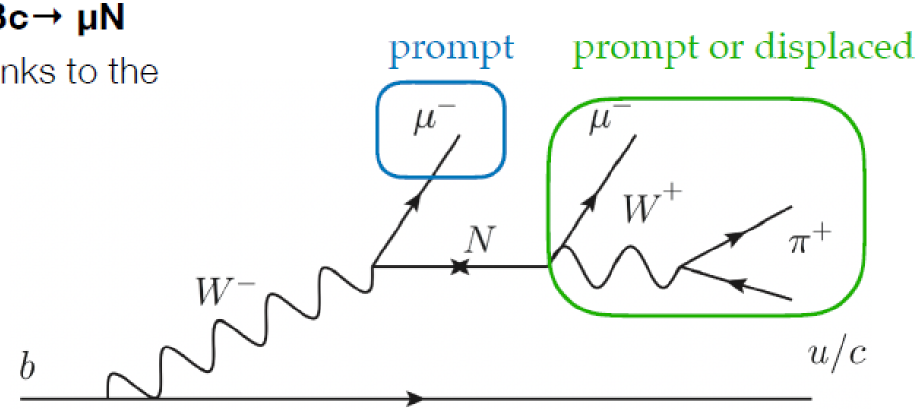
Searches for BSM LLPs

F. Leo Redi

What about from a *b*?

- Can one expand such narrow searches? Combine all the knowledge of b quarks and missing masses?
- Yes, e.g. in Majorana neutrino searches where it's hard to compete with LHCb in the B production region
- Previous analysis (B → μN**) only used one production mode: simple but inefficient
- **Here Xb → μN is added together with Bc→ μN**
- Multiple final states are also considered thanks to the expertise built in FLU searches containing vs:
- **Gain up to 12 times signal yield (only for displaced vertexes)**





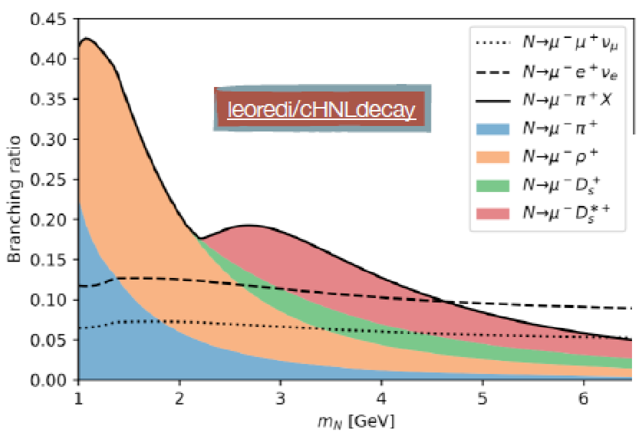
23| Federico Leo Redi | CERN

Searches for BSM LLPs

F. Leo Redi

Heavy neutral leptons

- Loose peak in invariant mass spectrum of N
- Instead use **corrected mass**: $\sqrt{p_\perp^2 + m_{vis}^2} + p_\perp$
- Derive the missing momentum from SV to TV direction create a good peak
- Coupling to other leptons is also promising



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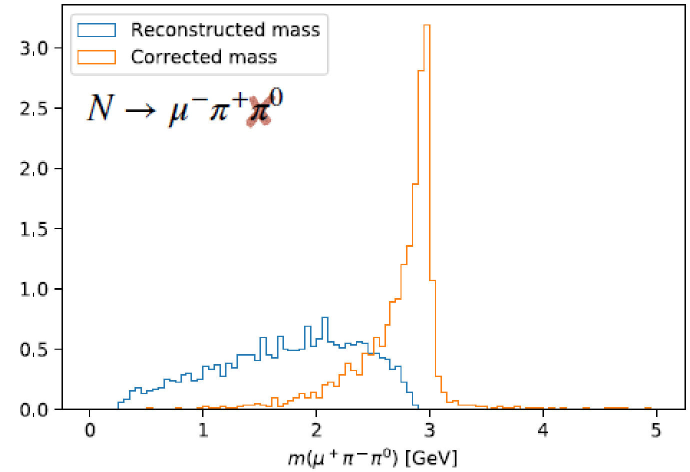
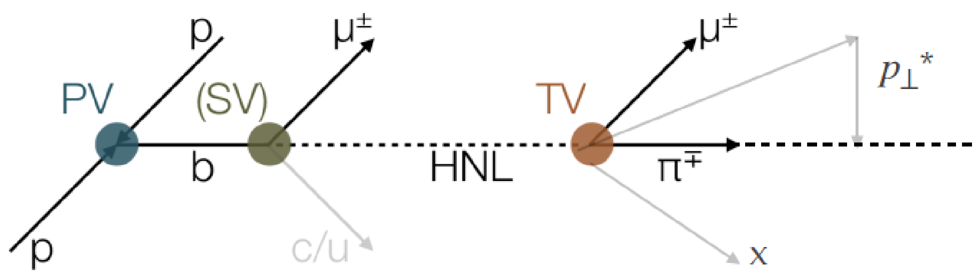
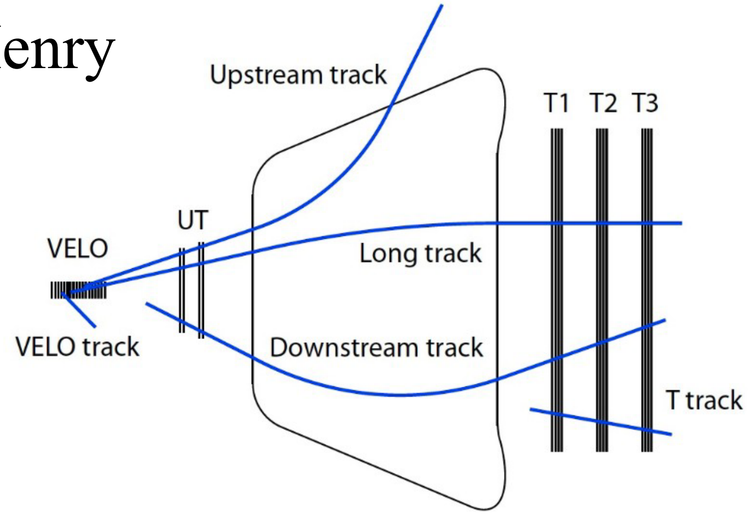




+ dark sector

L. Henry

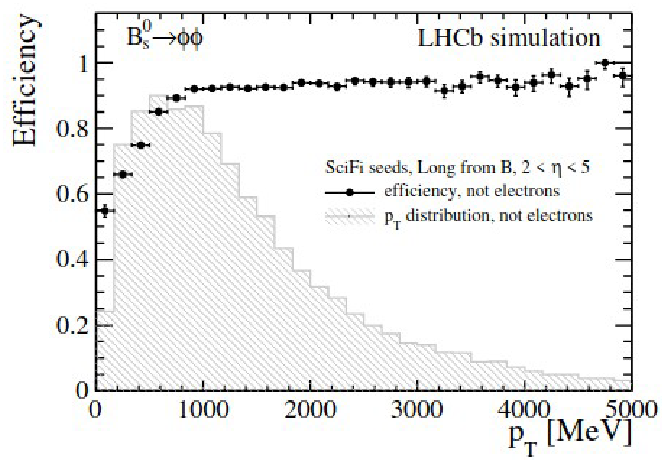
T-track reconstruction



T track reconstruction

Conclusion

- T tracks are a key ingredient to the LHCb tracking strategy, but rarely used by themselves.
- Obtained through the Hybrid Seeding, which has been developed for HLT2 mindset (don't lose anything).
  - Fast and flexible, covers a lot of physics cases.
- Overhaul of the seeding and exploitation of GPU capabilities made it possible to add it to HLT1:
  - Expected increased statistics for LLPs, K_S, Λ.
  - Alternative path to Long-track reconstruction with much higher low-p_T efficiency.
  - Article being written.
- Exciting times ahead for T tracks: maybe we can use them for themselves?

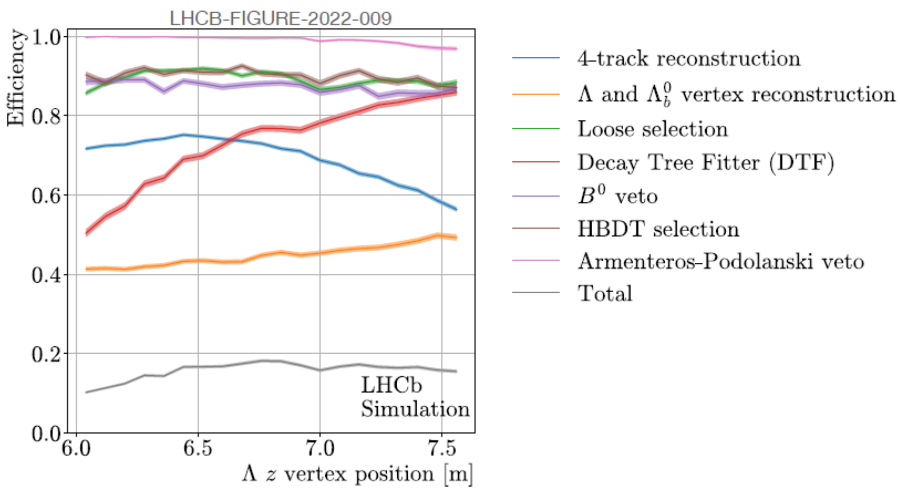


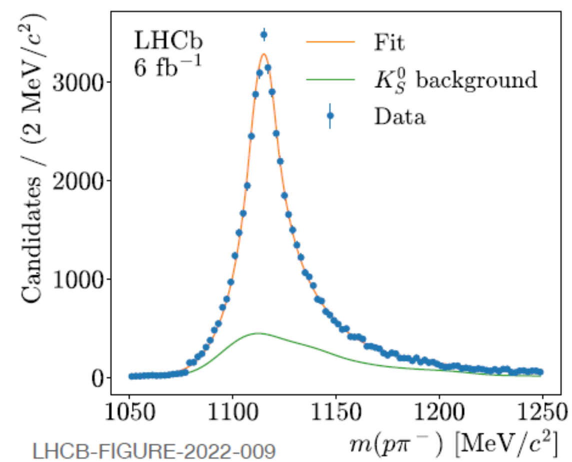
Event reconstruction & HLT2 with T-tracks

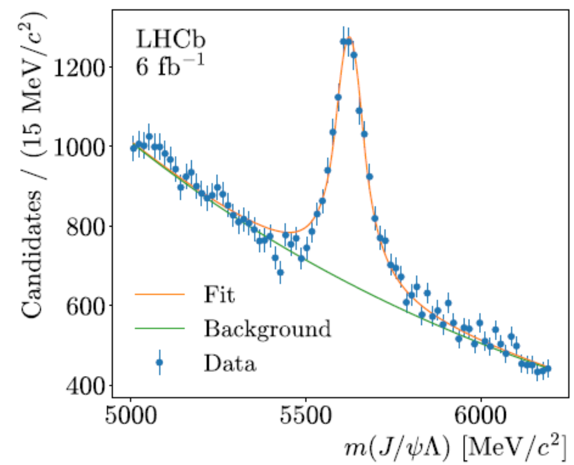
I. Sanderswood

Feasibility

$\Lambda_b \rightarrow J/\psi\Lambda$







$\Lambda_b^0 \rightarrow J/\psi\Lambda$ signal

Efficiencies calculated wrt to reconstructible particles (i.e. within accept

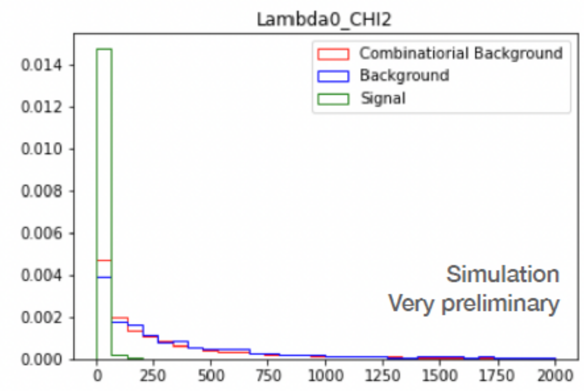
Low vertex reconstruction efficiency → investigating remedies (see Giorgi

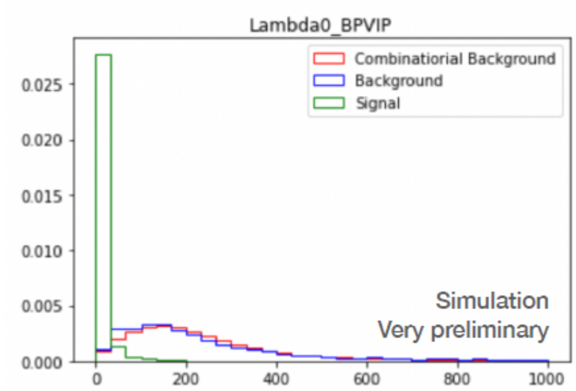
Event reconstruction & HLT2 with T-tracks

I. Sanderswood

Selections

- The vertices provide enough discrimination with background across a range of parameters in spite of large biases
  - Is also constrained by $J/\psi \to \mu\mu$
- Estimate that with selections applied to tracks and vertices can constrain rates on minimum bias data to $\mathcal{O}(10)$ Hz
  - Without cutting on invariant mass or vertex position
- Linear or single RK extrapolation offers ~20% higher selection efficiency compared to Run 2 vertex fitter
- Proper extrapolation could be performed offline for analysis





Event reconstruction with T-tracks

G. Tonani

Motivation

In $\Lambda_b \to J/\Psi\Lambda$ analysis we observe three issues when applying the vertexing algorithm to T tracks:

- Efficiency ($\approx 50\%$) $\to$ lower statistics
- Decay topology ("ghost vertex") $\to$ affects angular resolution
- Vertex bias $\to$ affects proper-time measurements

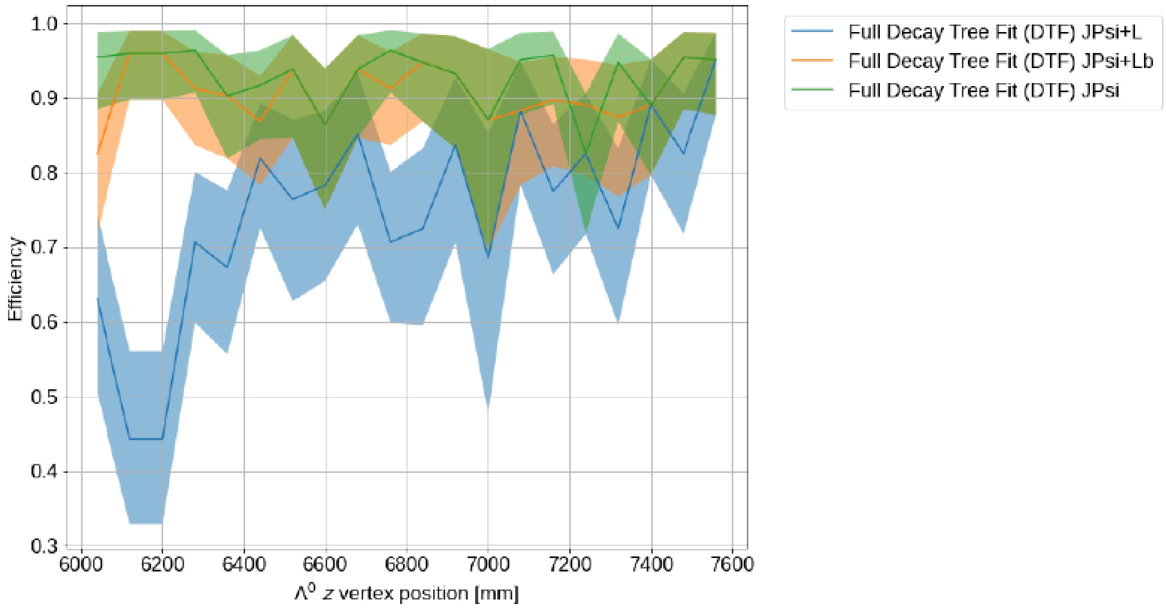
$\to$ impact on polarization measurement

Event reconstruction with T-tracks

G. Tonani

Our studies about DTF

- Possibility to consider different mass constraints to recover efficiency

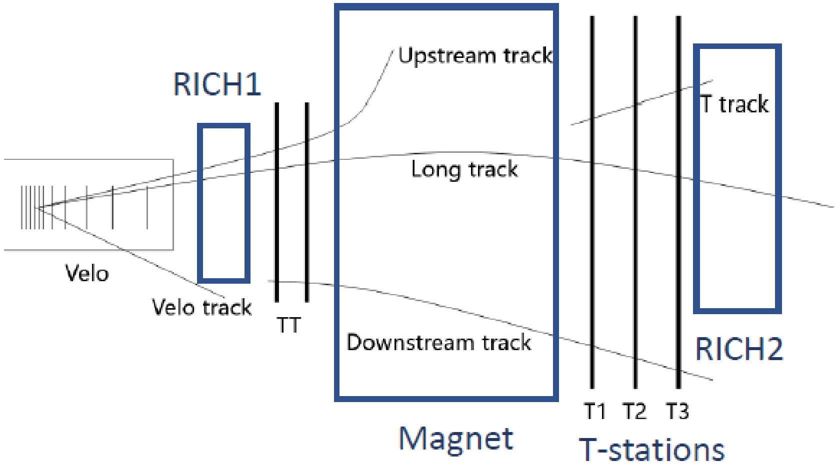


Impact on resolution without Λ mass constraint to be evaluated

Event reconstruction with T-tracks

M. Wang

LHCb track categories



Long & Downstream track:

Most widely used for physics analysis

Good spatial & momentum resolution:

Enough hits from 3(2) trackers

Pass central region of $\vec{B}$ field

Cherenkov-based PID info for BKG subtraction

- T-track: essential input for long-lifetime particle studies

BSM particles decaying after TT; Λ decaying after magnet (EDM, MDM effect visible)

- Poor track momentum resolution
  - $\frac{\delta p}{p} = (10{\sim}30)\%$ [LHCb unofficial] (Long-track @ 1% level)
- No PID information in default LHCb algorithm

How to improve ? (Menu of today)

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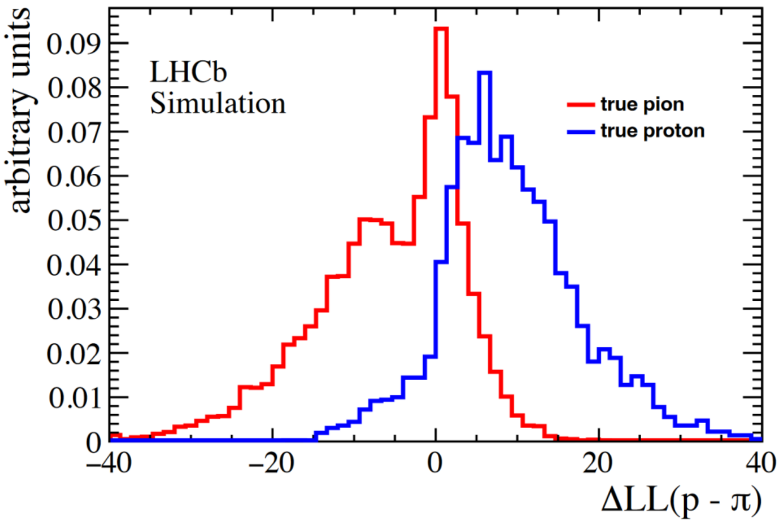
Trigger strategy for LLPs

M. Wang

PID on T-tracks

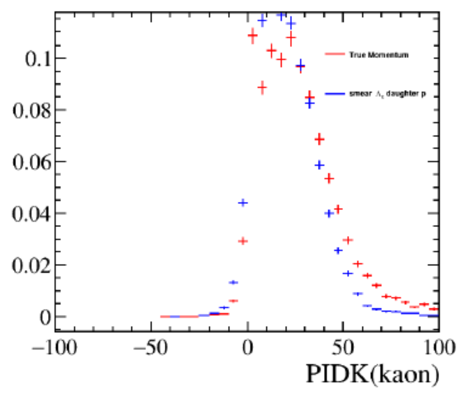


LHCb unofficial

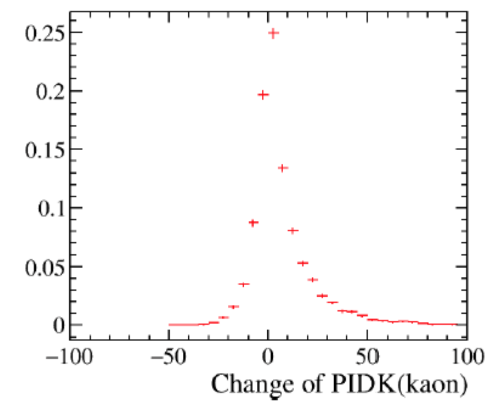
Some impact on ΔLL variables

- Kaon sample:

Distributions when using settings a) or b)



Variation when changing from b) to a)



The true momentum is more likely to result in a larger PIDK variable

$$\text{PID}K \equiv \text{LL}_{\text{RICH, global}}(K \text{ hypo}) - \text{LL}_{\text{RICH, global}}(\pi \text{ hypo})$$

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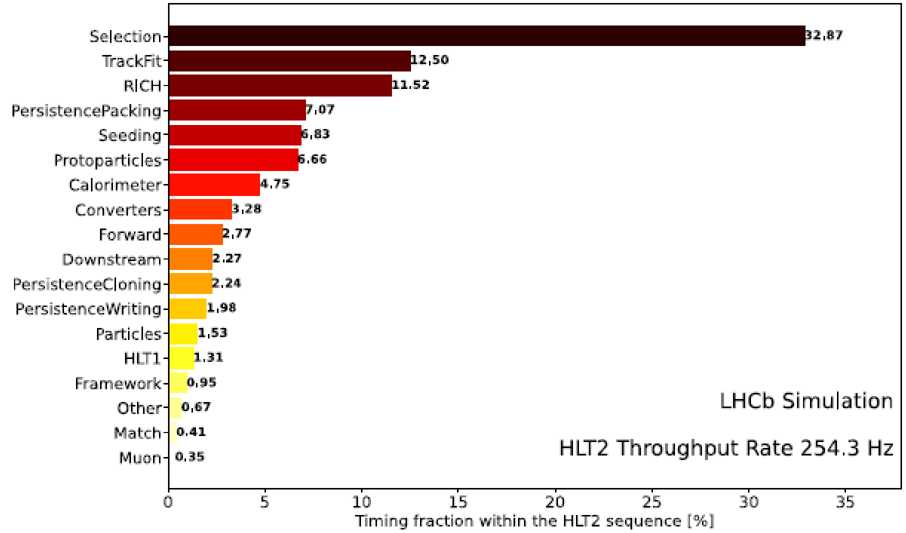
Trigger strategy for LLPs

C. Agapopoulou

LLP triggers in HLT2

- HLT2 triggers rely on offline-quality reconstructed objects
  - T-track reconstruction from L. Henry, I. Sanderswood & M. Wang
  - LLP vertexing from G. Tonani
- Selections takes up 30% of total HLT2 throughput but
  - O(1000) lines envisioned, what's a few more?



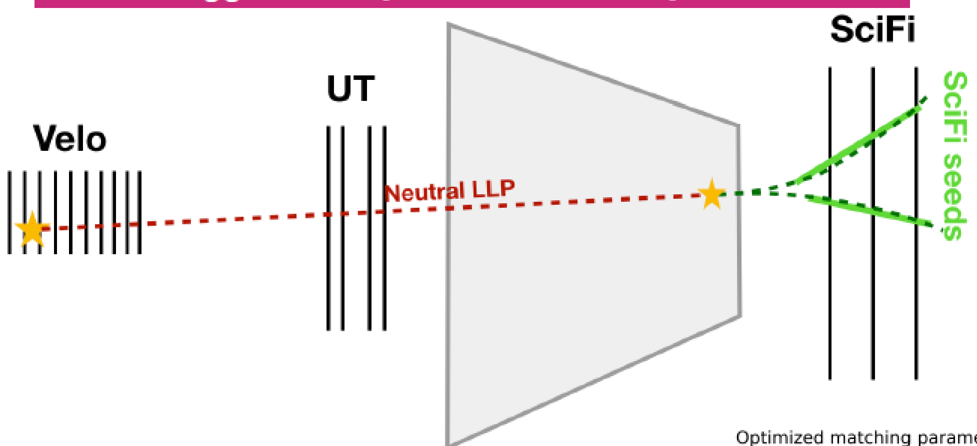
C. Agapopoulou Trigger strategy for long-lived particles 7

Trigger strategy for LLPs

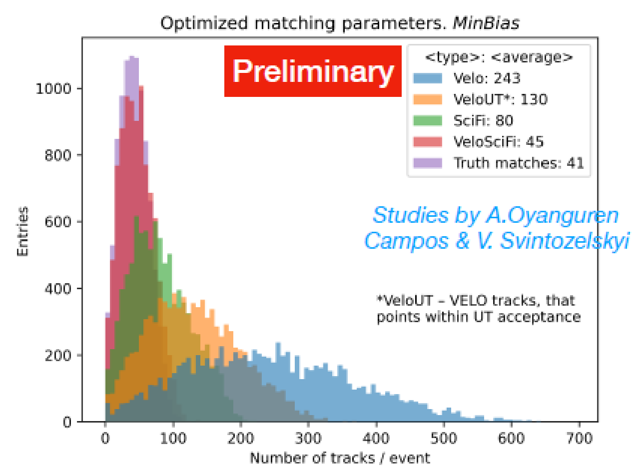
C. Agapopoulou

Adapting to ultra-LLPs

Can we trigger directly on the LLP decay after the UT?



- Same challenges as in HLT2: mom. resolution, fake rejection, extrapolation position…
- But also for HLT1: **output rate and throughput**
- After long reconstruction, O(50) un-matched SciFi seeds
  - **manageable combinatorics** (current long-based PV and SV algorithms < 5% throughput)
- Need to evaluate if output rate can be managed:
  - **High rejection of random combinations**
  - **+ strategy for different physics channels**



C. Agapopoulou Trigger strategy for long-lived particles 18

Message to take home

Charm baryon dipole moments

Very forward charm x-sections, prod. asymmetries and polarization

Charm x-section & prod. asymmetries in FT

Charm baryon decay dynamics and polarimetry in pp

Charm baryon polarization in FT

Strange baryon dipole moments

Event and T-track reconstruction & trigger

Searches for BSM LLPs

Tau lepton, beauty baryons dipole moments

Rich and aligned physics program of work.

Amazing amount already done.

A lot to be done

+THEORY & PHENO