Super charm-tau factory in Russia

Vitaly Vorobyev, BINP

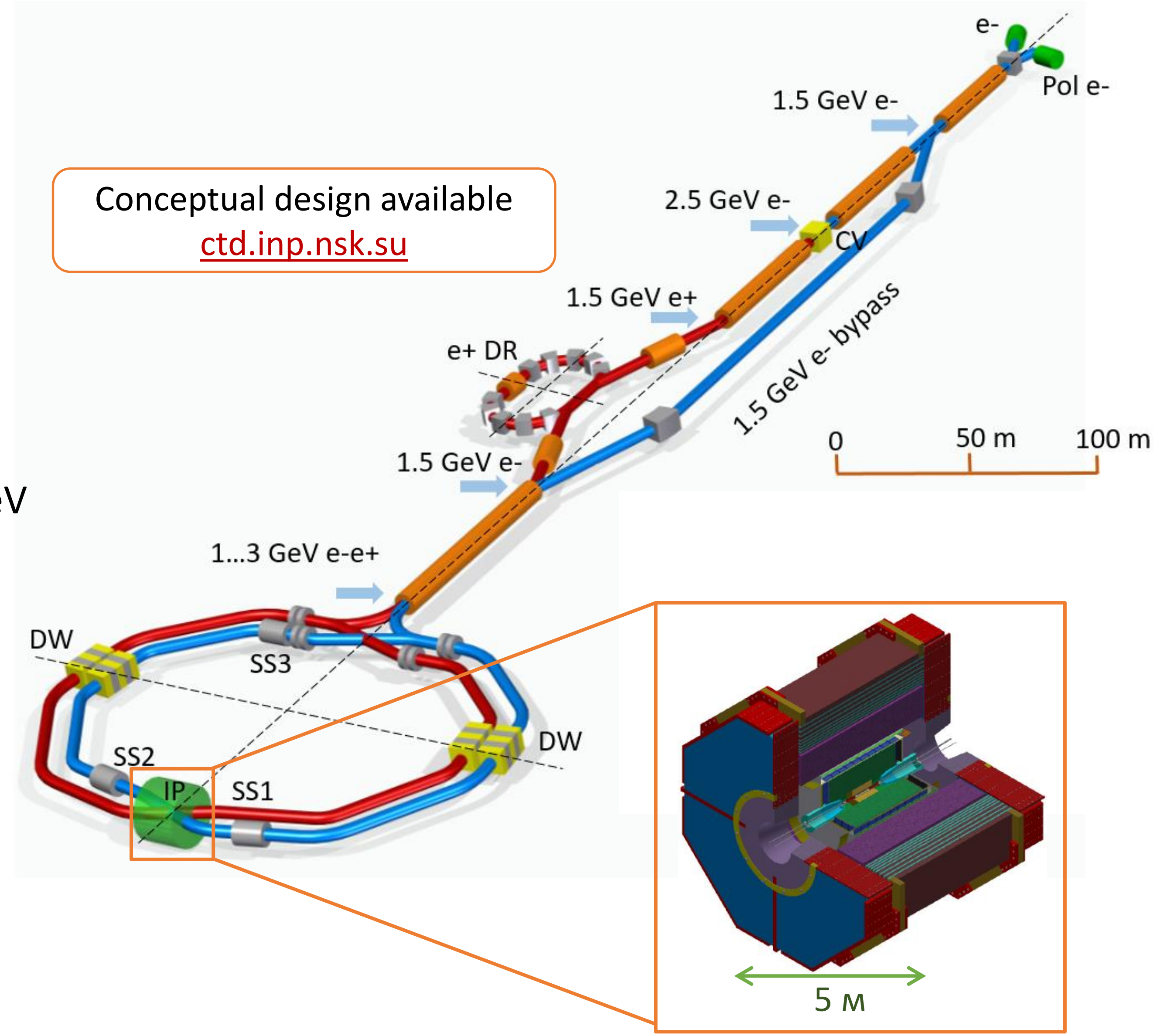
for the SCT Team

10th International Workshop on Charm Physics, Mexico, June 1st, 2021

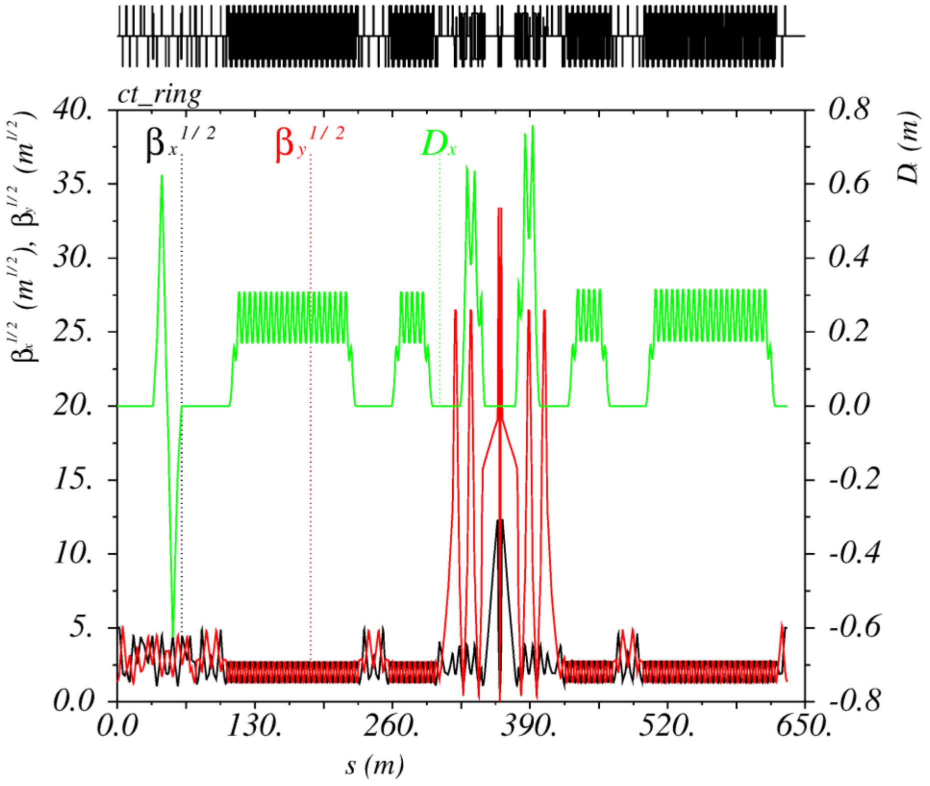
The SCT experiment

- Precision experiments with tau lepton and charmed hadrons, and search for BSM phenomena
- Electron-positron collider
  - Beam energy varying between 1.5 and 3.5 GeV
  - Luminosity $\mathcal{L} = 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ @ 2 GeV
  - Longitudinal polarization of the e^{-} beams
- Universal particle detector
  - Tracking system
  - Crystal electromagnetic calorimeter
  - Particle identification system

Conceptual design available
ctd.inp.nsk.su



SCT Collider parameters (2021 update)

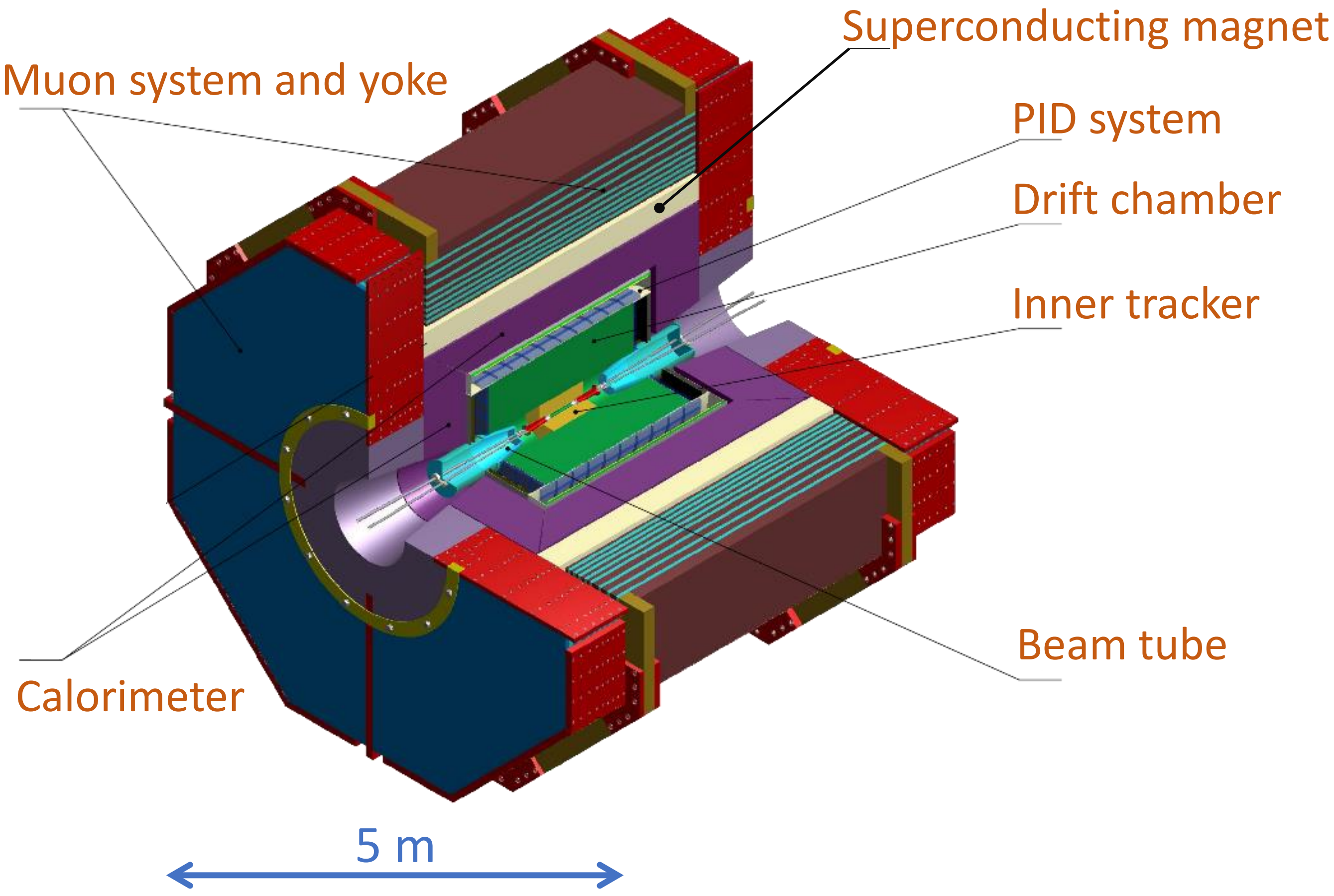


- Optimization of the dynamic aperture at low energy is being continued

E(MeV)	1500	2000	2500	3000	3500
Π(m)	632.94				
F_{RF}(MHz)	350				
q	740				
2θ(mrad)	60				
$\varepsilon_y/\varepsilon_x$(%)	0.5				
β_x^*(mm)	100				
β_y^*(mm)	1				
α	2.2×10^{-3}				
I(A)	2	2	2	2	2
$N_{e/bunch} \times 10^{10}$	9	8	8	9	10
N_b	292	328	328	292	262
U_0(keV)	21	67	164	340	629
V_{RF}(kV)	1600	2000	2000	2000	3400
ν_s	0.0164	0.016	0.0142	0.013	0.0155
δ_{RF}(%)	2	1.9	1.7	0.014	1.6
$\sigma_e \times 10^3$ (SR/IBS)	0.28/1	0.4/0.7	0.47/0.62	0.57/0.61	0.66/0.68
σ_s(mm) (SR/IBS)	4/13	5/10	7/9.4	9.5/10.2	9.2/9.4
ε_x(nm) (SR/IBS)	3/21	4.7/12.7	7.4/10.5	10.6/11.6	14.5/14.8
$L_{HG} \times 10^{35}(cm^{-2}s^{-1})$	0.5	0.8	1	1	1
ξ_x	0.008	0.009	0.009	0.007	0.008
ξ_y	0.11	0.12	0.11	0.092	0.084
$\tau_{Touschek}$ (s)	3600	2900	2400	2600	6400
τ_L (s)	3100	1900	1600	1700	1600

The SCT detector concept

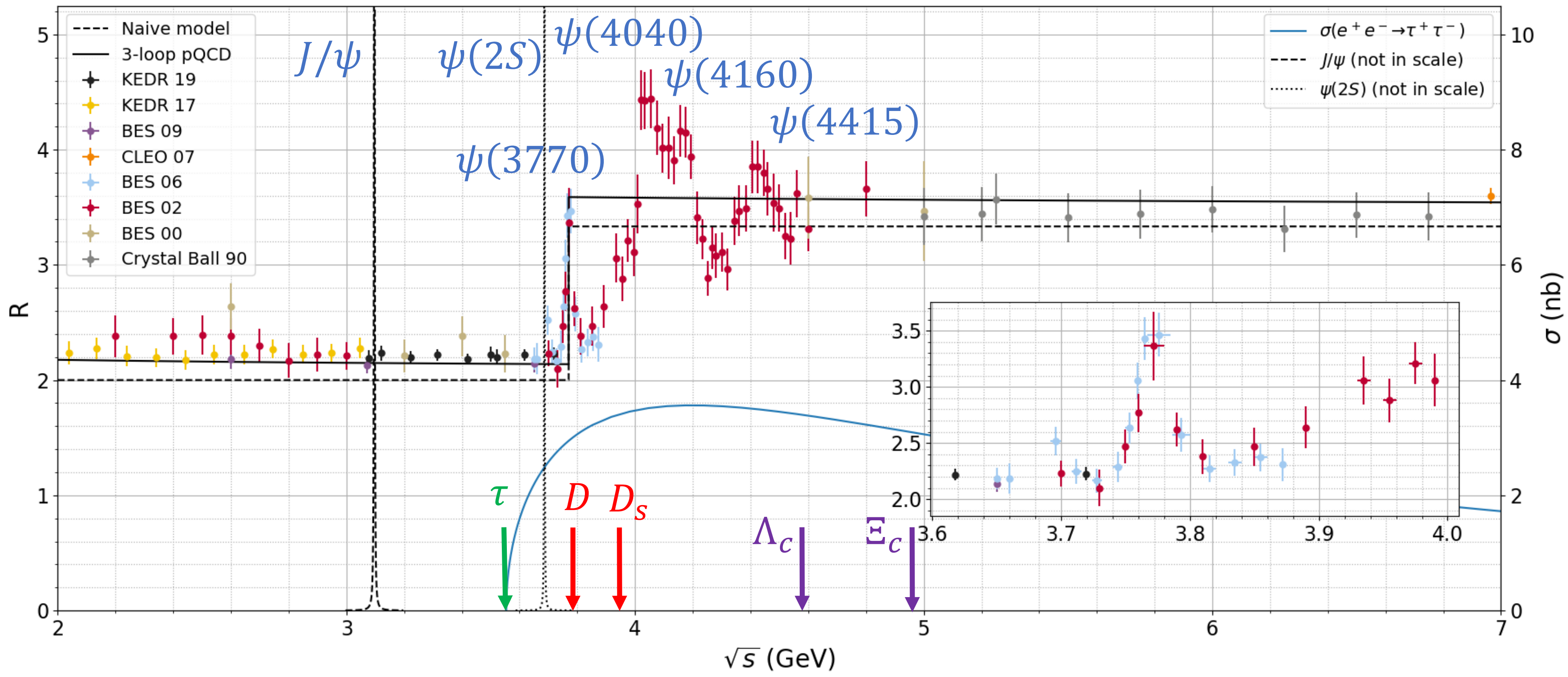
- Momentum resolution 0.5% @ $1\ \mathrm{GeV}$
- Solid angle coverage of 95%
- Track reconstruction from $p_t \approx 50\ \mathrm{MeV}$
- Excellent $\mu/\pi/K/p$ separation up to $1.5\ \mathrm{GeV}$
  - dE/dx in the tracking system
  - Cherenkov radiation detector
  - μ/π separation!
- π^0/γ separation and γ detection from $10\ \mathrm{MeV}$ to $3000\ \mathrm{MeV}$
  - Good energy resolution
  - Fast calorimeter ($\sigma_t < 1\ \mathrm{ns}$)
- DAQ rate $300\ \mathrm{kHz}$ @ J/ψ



The SCT energy range

$$R \equiv \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma_0(e^+e^- \to \mu^+\mu^-)}$$

Threshold production of nonrelativistic particles provides best conditions for their comprehensive study



$\mathcal{L} = 10^{35}\ \mathrm{cm}^{-2}s^{-1}$

A one-year dataset

$2E$, GeV	Events recorded
3.1	$10^{12}\ J/\psi$
3.69	$10^{11}\ \psi(2S)$
3.77	$10^{9}\ D\bar{D}$
4.17	$10^{8}\ D_s\bar{D}_s$
$3.55 \div 4.3$	$10^{10}\ \tau\ \tau$
4.65	$10^{8}\ \Lambda_c^+\Lambda_c^-$

SCT Physics in a nutshell

charm

- ✓ Measurement of the strong phases of D decay amplitudes
- ✓ Measurement of absolute branching fractions
- ✓ Searches for rare and forbidden decays of the charm quark
- ✓ CP violation in charm
- ✓ …

Input for B meson studies at LHCb and Belle II

QCD

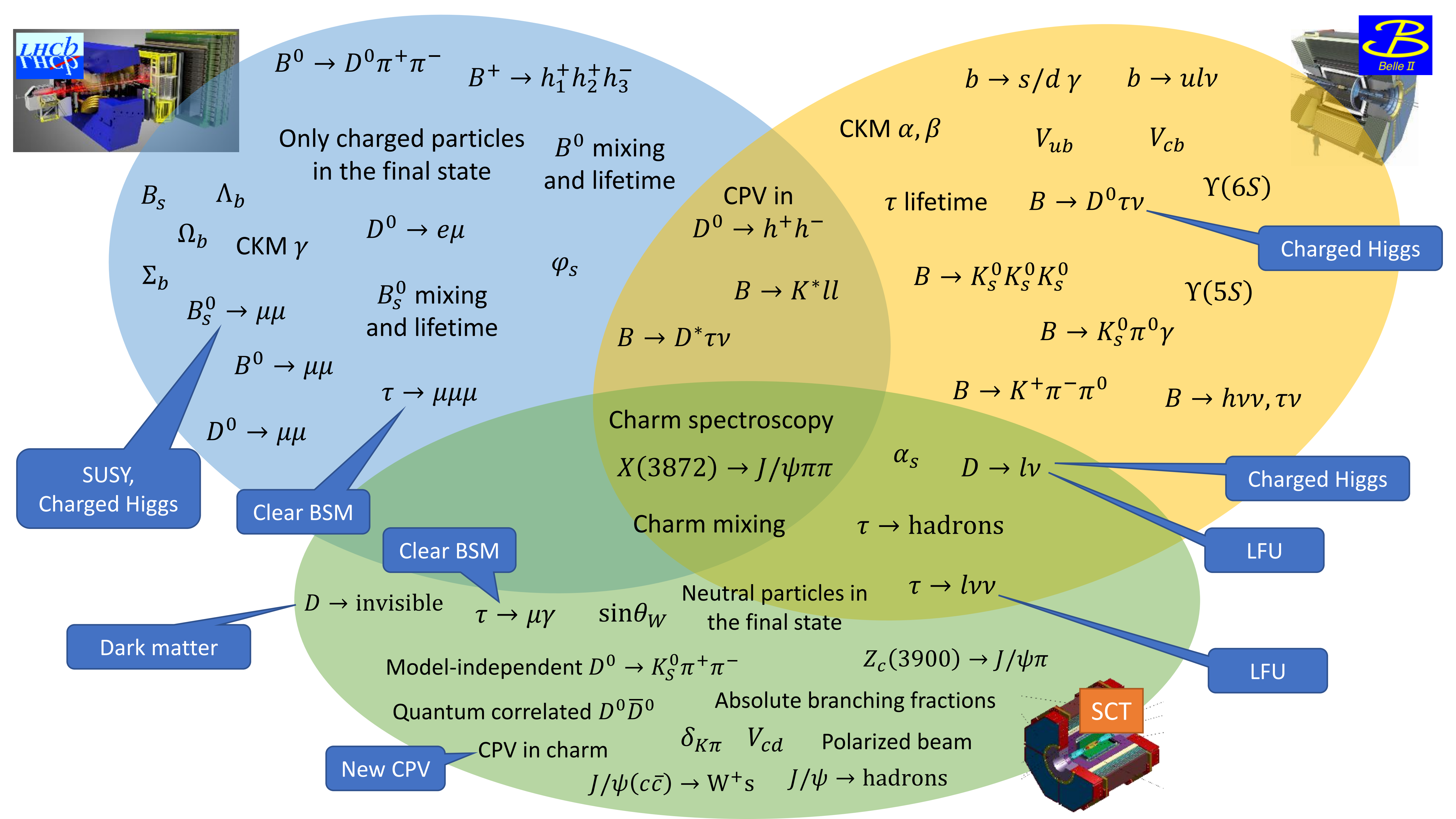
- ✓ Physics of highly-excited quarkonium
- ✓ Molecular states
- ✓ Baryon interaction at threshold
- ✓ Search for glueballs in decays of J/ψ and $\psi(2S)$
- ✓ …

tau

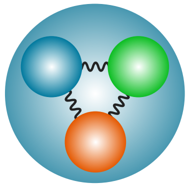
- ✓ Precision measurement of the τ lepton properties
- ✓ Michel parameters, tests of lepton universality
- ✓ Precision measurement of hadronic τ decays
- ✓ Search for CP and T violation in τ decays
- ✓ …

Test of the electroweak sector of the SM

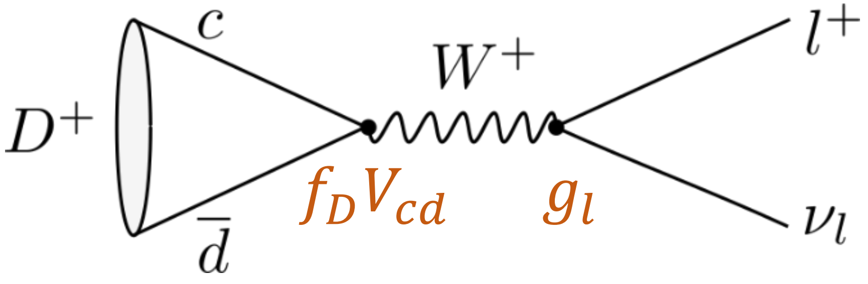
QCD, α_s, V_{us}. Test of the electroweak model, searches for non-standard contributions


LHCb
Belle II
SCT
$B^0 \to D^0\pi^+\pi^-$
$B^+ \to h_1^+ h_2^+ h_3^-$
Only charged particles in the final state
B^0 mixing and lifetime
B_s
Λ_b
Ω_b
CKM γ
Σ_b
$D^0 \to e\mu$
φ_s
$B_s^0 \to \mu\mu$
B_s^0 mixing and lifetime
$B^0 \to \mu\mu$
$\tau \to \mu\mu\mu$
$D^0 \to \mu\mu$
SUSY, Charged Higgs
Clear BSM
$b \to s/d\,\gamma$
$b \to ul\nu$
CKM α, β
V_{ub}
V_{cb}
CPV in $D^0 \to h^+h^-$
τ lifetime
$B \to D^0\tau\nu$
$\Upsilon(6S)$
Charged Higgs
$B \to K^* ll$
$B \to K_S^0 K_S^0 K_S^0$
$\Upsilon(5S)$
$B \to D^*\tau\nu$
$B \to K_S^0 \pi^0 \gamma$
$B \to K^+\pi^-\pi^0$
$B \to h\nu\nu, \tau\nu$
Charm spectroscopy
$X(3872) \to J/\psi\pi\pi$
α_s
$D \to l\nu$
Charged Higgs
Charm mixing
$\tau \to$ hadrons
LFU
Clear BSM
$\tau \to l\nu\nu$
$D \to$ invisible
$\tau \to \mu\gamma$
$\sin\theta_W$
Neutral particles in the final state
LFU
Dark matter
Model-independent $D^0 \to K_S^0\pi^+\pi^-$
$Z_c(3900) \to J/\psi\pi$
Quantum correlated $D^0\bar{D}^0$
Absolute branching fractions
$\delta_{K\pi}$
V_{cd}
Polarized beam
New CPV
CPV in charm
$J/\psi(c\bar{c}) \to W^+s$
$J/\psi \to$ hadrons

Charmed hadrons



(Semi-)leptonic $D_{(s)}$ decays



$$\Gamma(D^+ \to l\nu) = \frac{G_F^2}{8\pi} f_D^2 m_l^2 m_D \left(1 - \frac{m_l^2}{m_D^2}\right) |V_{cd}|^2$$

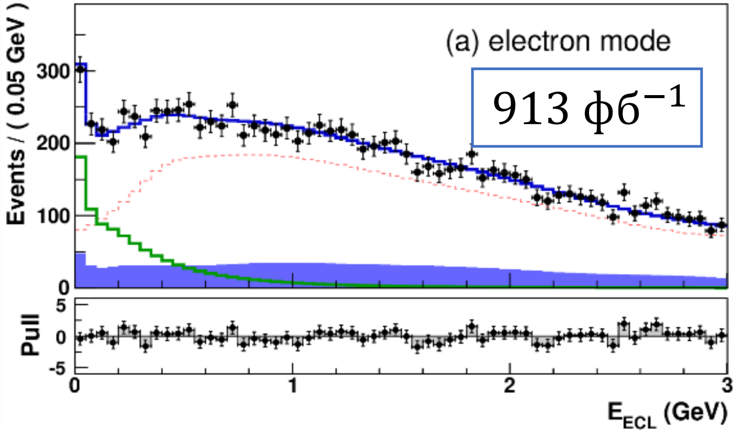
- Measurement of branching fractions : f_D, V_{cd}, V_{cs}
- Lepton universality test

Table 1: LFU test at BESIII with (semi)leptonic D decays.

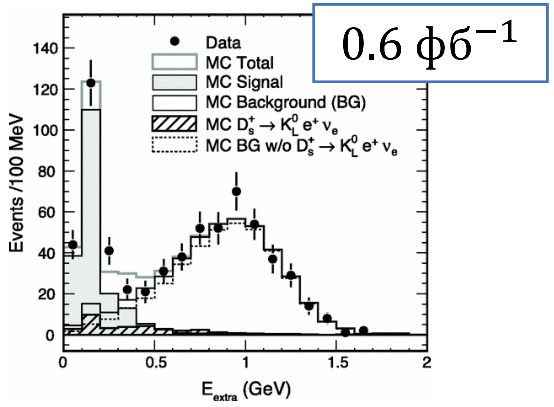
	$R(D_s^+)$	$R(D^+)$	$R(K^-)$	$R(\bar{K}^0)$	$R(\pi^-)$	$R(\pi^0)$
SM	9.74(1)	2.66(1)	0.975(1) [31]	0.975(1) [31]	0.985(2) [31]	0.985(2) [31]
BESIII	9.98(52)	3.21(64)	0.978(14)	0.988(33)	0.922(37)	0.964(45)

$D_s^+ \to \tau^+\nu, \tau^+ \to e^+\nu_e\bar{\nu}_\tau$

[Belle, JHEP 09 (2013), 139]

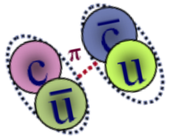


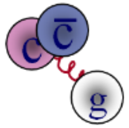
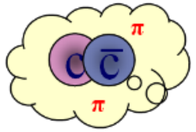
[CLEO-c, PRD 79 (2009), 052002]

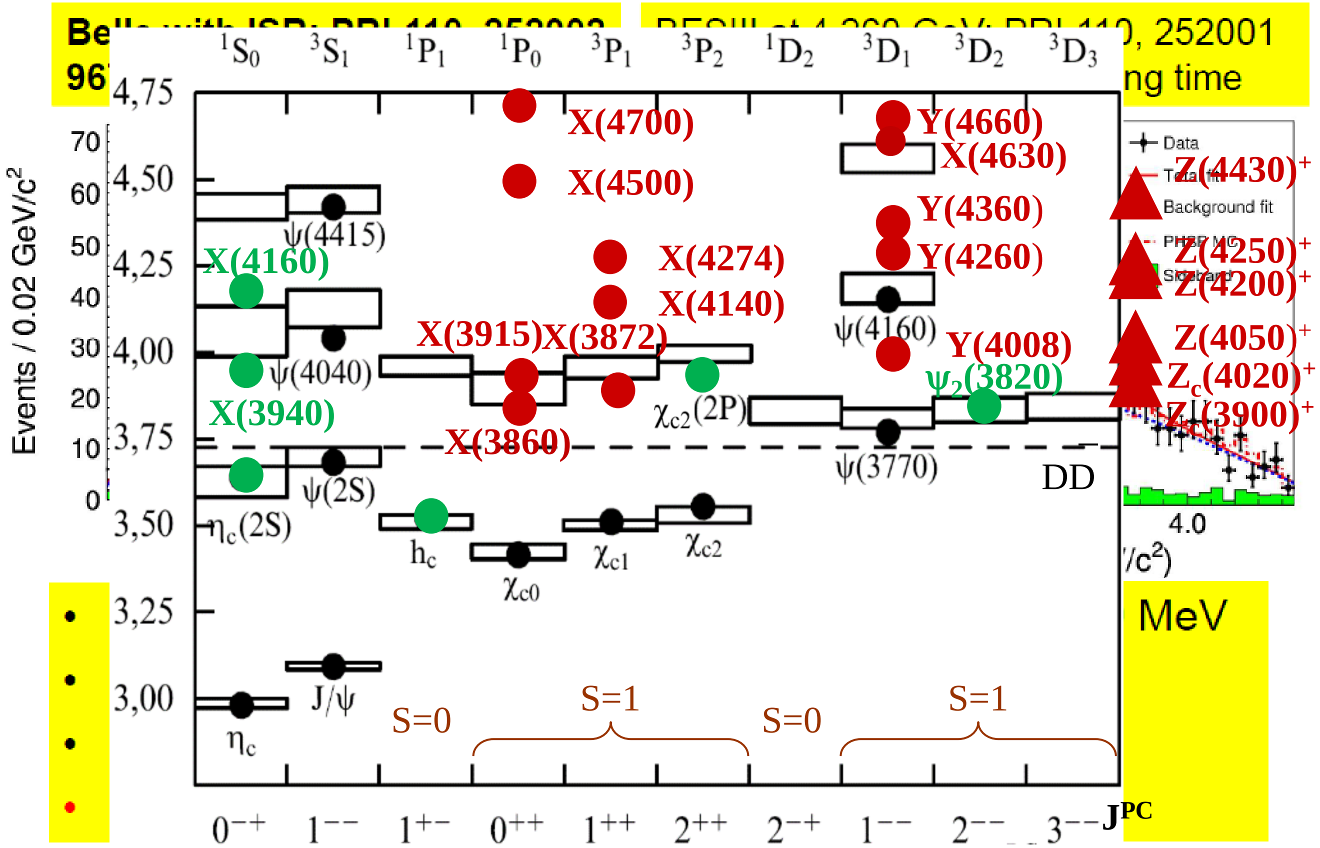


Detailed study of the charmonium-like states

- Exiting QCD laboratory
- Cross sections to be measured:
  - $e^+e^- \to J/\psi\pi^+\pi^-$
  - $e^+e^- \to J/\psi\pi^0\pi^0$
  - $e^+e^- \to \psi(2S)\pi^+\pi^-$
  - $e^+e^- \to D\bar{D},\ D^*\bar{D}, \ldots$
  - $e^+e^- \to D\bar{D}\gamma$
  - $e^+e^- \to D\bar{D}(n\pi)$
  - $e^+e^- \to D_s^+D_s^-$
  - $e^+e^- \to D_s^+D_s^-(n\pi)$
  - $e^+e^- \to \Lambda_c\bar{\Lambda}_c$
  - …



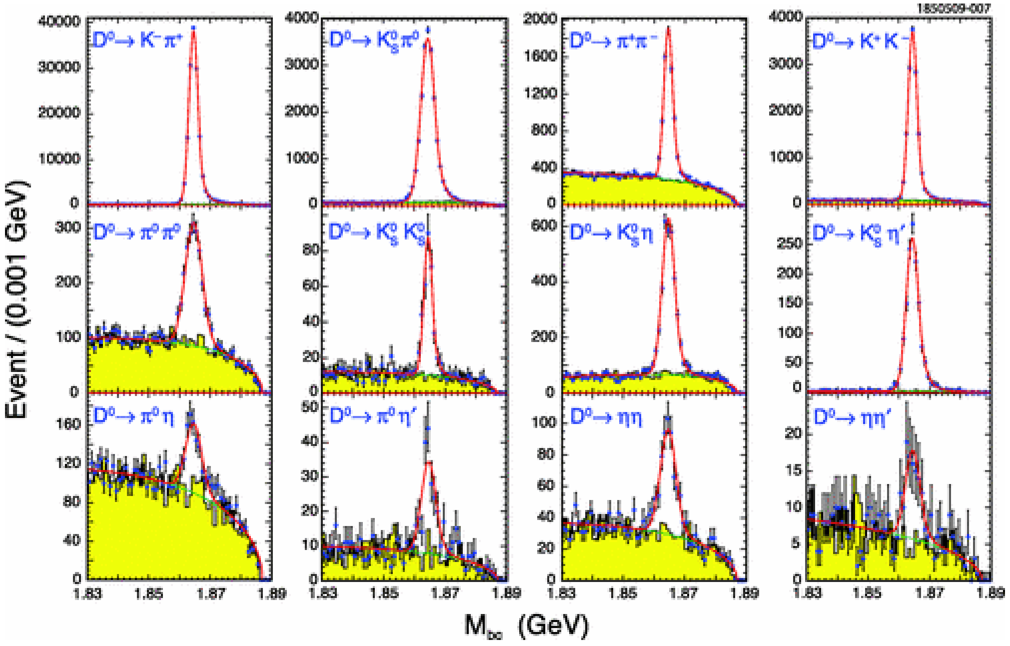





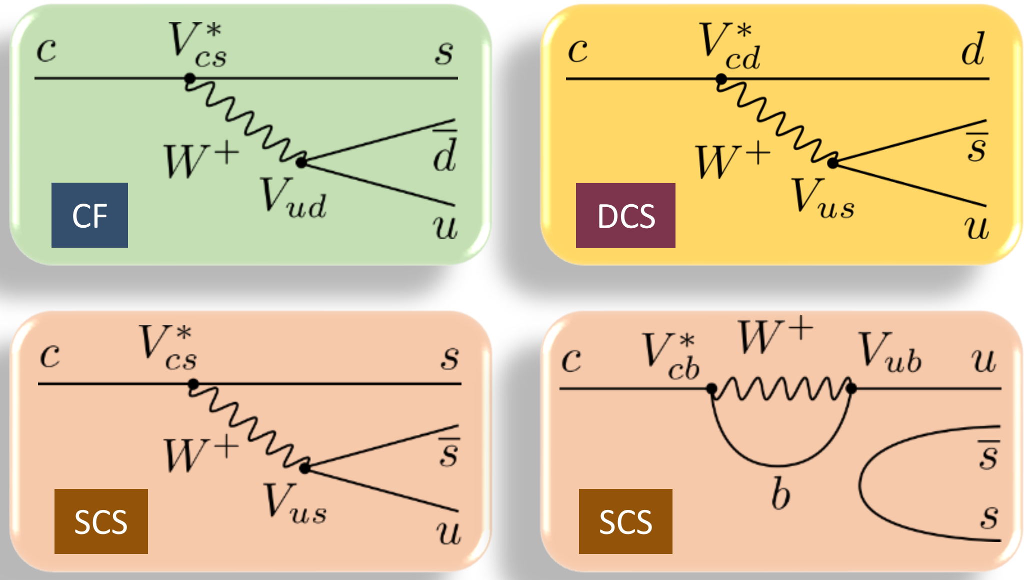
10 years vs. 0.1 year

CPV in charm

- Measurement of CP asymmetries in decays of D^0, D^+, D_s^+ at the precision level of $\sim 10^{-4}$
  - Advantage of full event reconstruction
  - Coherent $D^0\overline{D}^0$ pairs



CLEOc $0.818\ \mathrm{fb}^{-1}$ @ 3774 MeV [PRD 81, 052013 (2010)]



$$\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4}$$

$$D^0 \to h^+h^-$$

2019

long-distance dynamics is important in charm decays: re-scattering leads to the complex connections between the worlds of hadrons and quarks [I. Bigi]

Friday, June 4

Emilie Passemar 'Tau Physics at a super-charm-tau factory'	*Emilie PASSEMAR*	09:50 - 10:20
Alberto Lusiani 'Tau Physics @ SCTF (experimental perspective)'	*Prof. Alberto LUSIANI*	10:20 - 10:50

Tau lepton

Leptonic τ decays

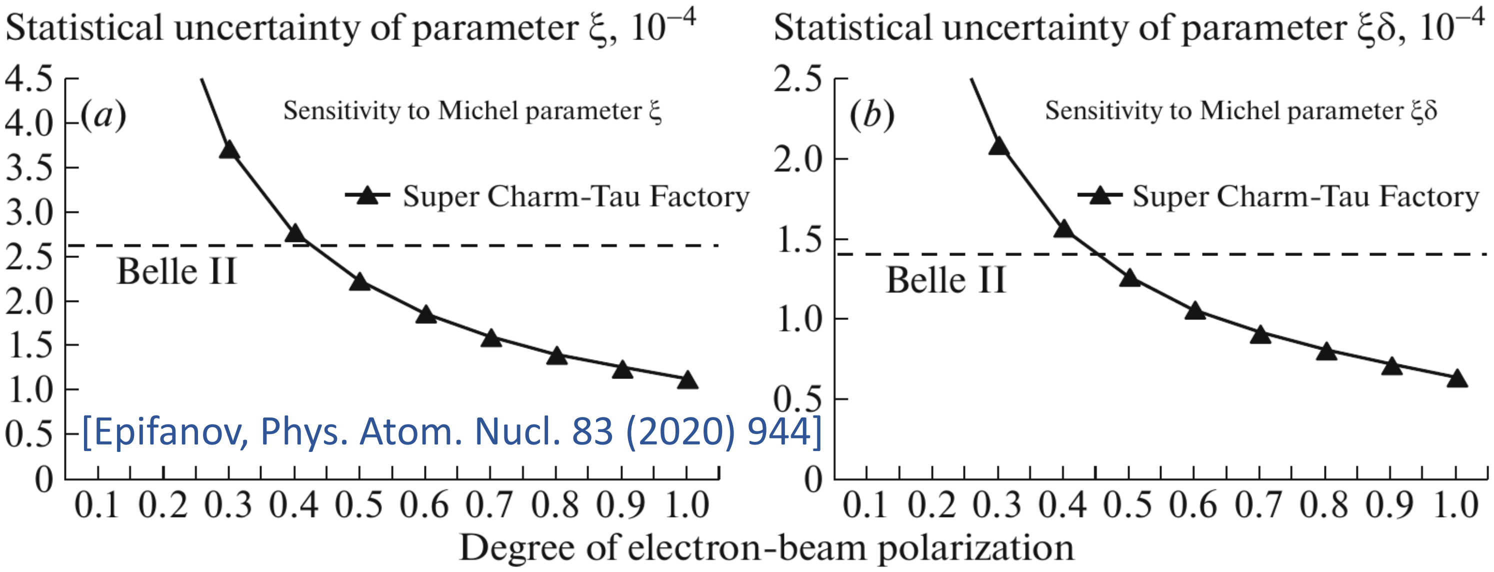
Michel parameters

Tau polarization

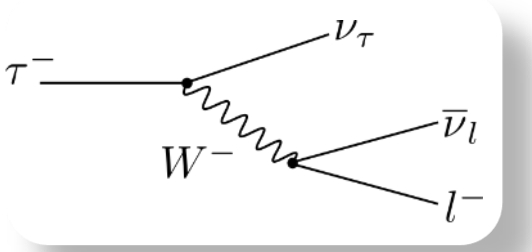
$$\frac{d\Gamma(\tau^{\mp})}{d\Omega dx} \propto x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x) \mp \frac{1}{3} P_\tau \cos\theta_l \, \xi \sqrt{x^2 - x_0^2}\left[1 - x + \frac{2}{3}\delta\left(4x - 4 + \sqrt{1 - x_0^2}\right)\right]$$

- SCT with polarized electrons allows measurement the tau lepton Michel parameters with precision better then that of Belle II

$$x \equiv \frac{E_l}{E_{max}}, \qquad x_0 \equiv \frac{m_l}{E_{max}}$$



[Epifanov, Phys. Atom. Nucl. 83 (2020) 944]



Leptonic τ decays

Michel parameters

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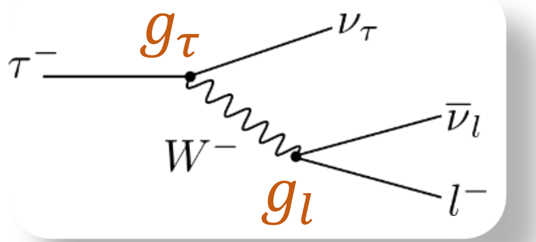
- SCT with polarized electrons allows measurement the tau lepton Michel parameters with precision better then that of Belle II

$$x \equiv \frac{E_l}{E_{\max}}, \qquad x_0 \equiv \frac{m_l}{E_{\max}}$$

Lepton universality test



$$\Gamma(\tau^- \to \nu_\tau l^- \bar{\nu}_l) = \frac{G_\tau G_l m_\tau^5}{192\pi^3} f\left(\frac{m_l^2}{m_\tau^2}\right) r_{\text{EW}}$$

Parameter	Expectation	Best measurement
$\frac{\mathcal{B}(\tau^- \to \nu_\tau \mu^- \bar{\nu}_\mu)}{\mathcal{B}(\tau^- \to \nu_\tau e^- \bar{\nu}_e)}$	0.972564 ± 0.000010	$0.9796 \pm 0.0016 \pm 0.0036$ [BaBar, PRL 105 (2010) 051602]

Hadronic τ decays

Spectral functions

$$\frac{d\Gamma(\tau^- \to \text{had}\,\nu_\tau)}{d(\text{phsp})} = \frac{G_F^2}{4m_\tau}|V_{\text{CKM}}|^2 L_{\mu\nu} H^{\mu\nu}$$

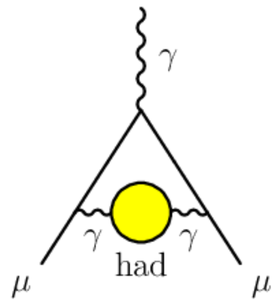
- Testing the factorization of hadronic and leptonic currents
- Measuring $|V_{ud}|$, $|V_{us}|$, $\alpha_s(m_\tau)$, and m_s
- Testing conserved vector current
- Hadronic vacuum polarization in the non-perturbative region

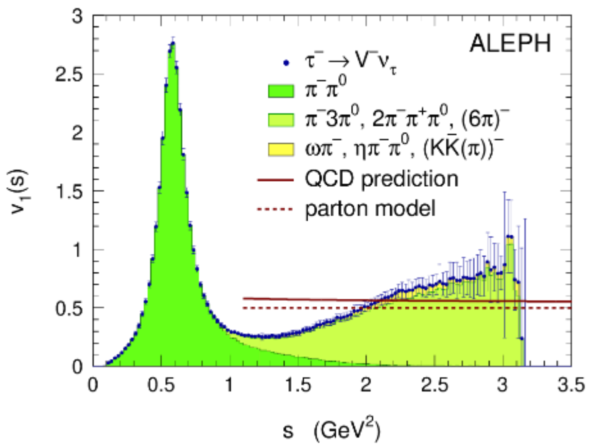
Second class currents

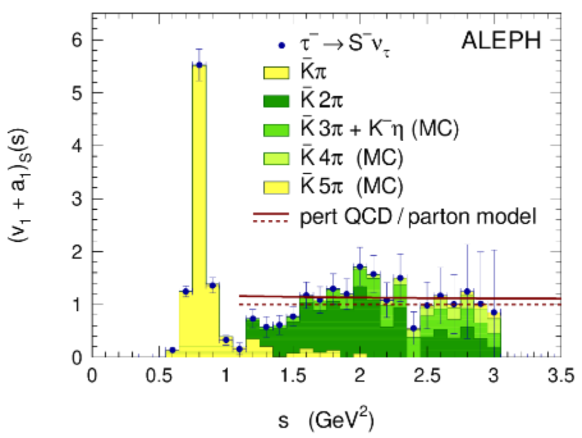
$$J^{PG} = 0^{+-}\ (a_0),\ 1^{++}\ (b_1), \dots$$

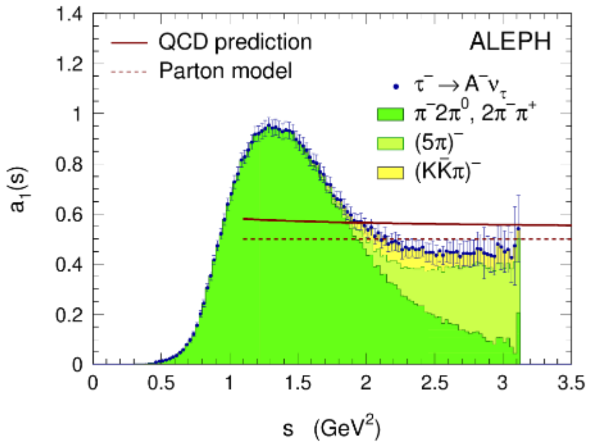
- Highly suppressed by isospin ($\tau \to \eta^{(\prime)}\pi\nu, \dots$)

[Rev. Mod. Phys. 78 (2006) 1043]







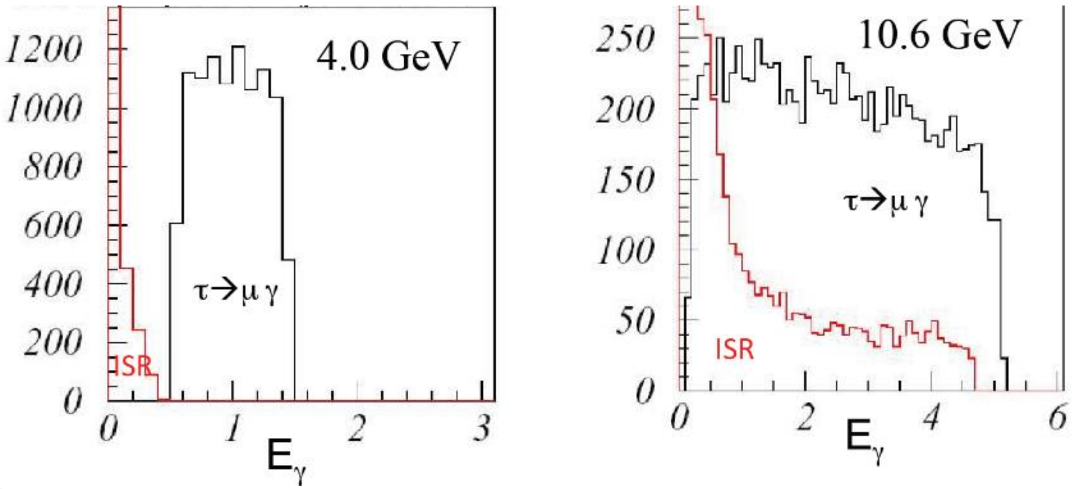


LFV and CPV with tau

$\tau \to \mu\gamma$

- Allowed in several BSM scenario, including SUSY, leptoquarks, technicolor, and extended Higgs models
- $\mathcal{O}(10^{-9})$ – reachable upper limit at SCT for the branching of $\tau \to \mu\gamma$
- Also, requires excellent π/μ separation

ISR photon background [arXiv:1206.1909 [hep-ex]]



CP symmetry breaking

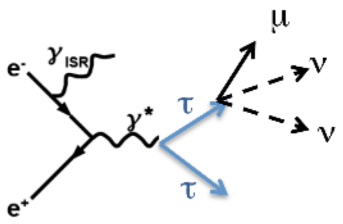
- CPV in tau production

$$J_{EM} \propto F_1\gamma^{\mu} + \left(\frac{i}{2m_{\tau}}F_2 + \gamma^5 F_3\right)\sigma^{\mu\nu}q_{\nu}$$

  - Current limit: $|d_{\tau}| \lesssim 10^{-17}\ e \cdot \mathrm{cm}$
  - Tau EDM with polarized electrons [PRD 51 (1995) 5996]: $\sigma(d_{\tau}) \sim 10^{-20}\ e \cdot \text{см}$

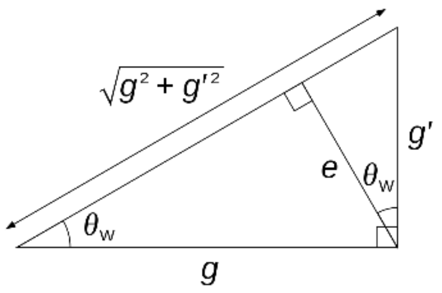
- CPV in tau decays (e.g., $\tau \to K\pi\nu_{\tau}$)

Beam polarization is essential for these measurements



Electroweak model $SU(2)_L \times U(1)_Y$ (Glashow, 1961)

$$A_\mu = B_\mu^0 \cos\theta_W + W_\mu^0 \sin\theta_W$$
$$Z_\mu = W_\mu^0 \cos\theta_W - B_\mu^0 \sin\theta_W$$



The Weinberg angle

J/ψ cross section asymmetry

- Interference between the $e^+e^- \to \gamma^*, Z \to J/\psi$ processes produces left-right total cross section asymmetry

$$A_{LR} \equiv \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} = \frac{3/8 - \sin^2\theta^c_{\rm eff}}{2\sin^2\theta^c_{\rm eff}\left(1-\sin^2\theta^c_{\rm eff}\right)}\left(\frac{m_{J/\psi}}{m_Z}\right)^2 P_e$$

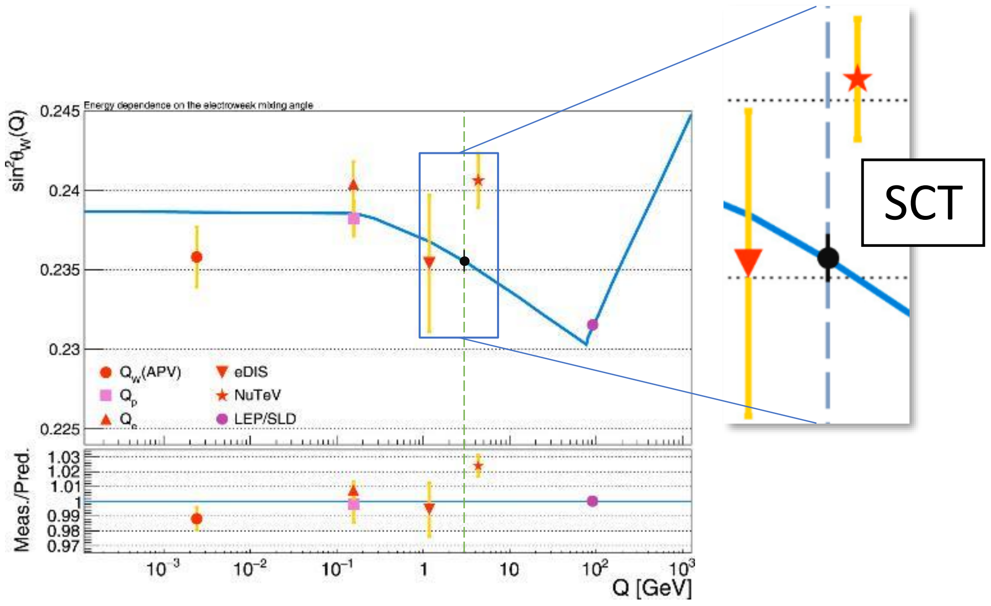
$$A_{LR} \approx 4.7 \times 10^{-4} P_e$$

  - σ_+ (σ_-) is the total $e^+e^- \to J/\psi$ cross section for right- (left-)handed electrons
  - P_e is the average electrons polarization, $P_e < 1$

- Statistical precision with a one-year data set:

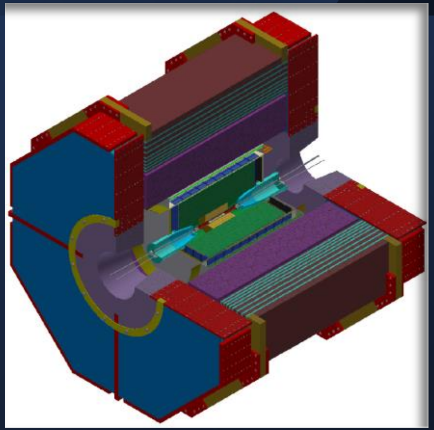
$$\frac{\sigma(\sin^2\theta^c_{\rm eff})}{\sin^2\theta^c_{\rm eff}} \approx 0.3\%, \qquad \sigma(\sin^2\theta^c_{\rm eff}) \approx 5 \times 10^{-4}$$

- It tests weak interaction of the charm quark
- An opportunity to observe deviation of the $\sin^2\theta^c_{\rm eff}$ from its value at Z peak (test of the EW model)



JHEP 2020, 76 (2020)

Ongoing R&Ds for the SCT Detector

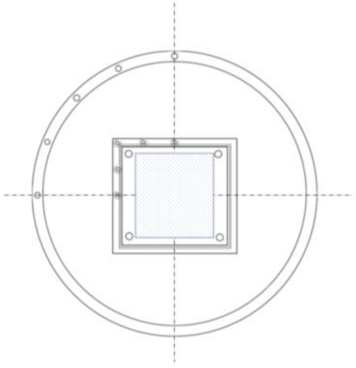


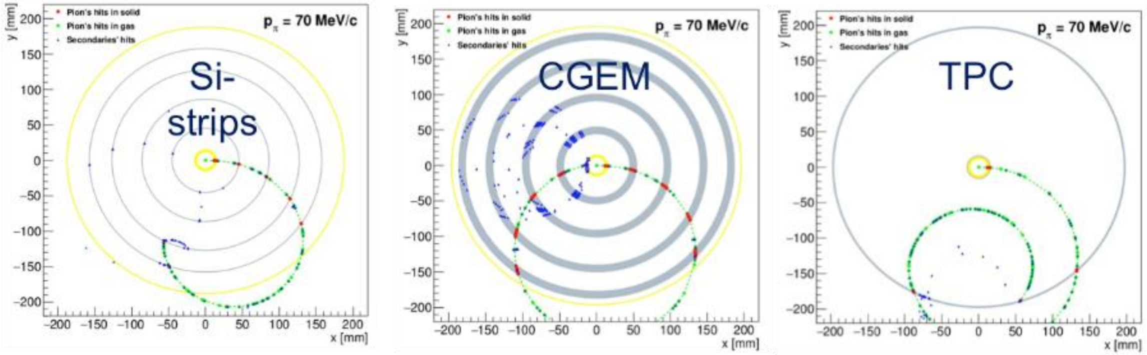
- Inner tracker
  - Time projection chamber (TPC) option by BINP
  - Cylindrical μRWELL option by INFN (LNF, Ferrara)
- Main tracker
  - Drift chamber option by BINP
  - Ultra thin DC (TraPID) option by INFN (Lecce, Bari)
- PID system
  - FARICH option by BINP
  - FDIRC options by Giessen University
- Electromagnetic calorimeter – BINP
- Muon system – Lebedev Physics Institute (LPI)
- Magnet – BINP
- Detector software – the AURORA framework released in 2021

TPC option for SCT inner tracker

- TPC option is proposed in BINP
- Advantage: reconstruction of soft tracks in the TPC volume
- Main challenge: requires processing of the continuous readout and dealing with events pipeline
- Prototyping:
  - Technical design being finalized
  - Prototype construction and tests are planned in 2021

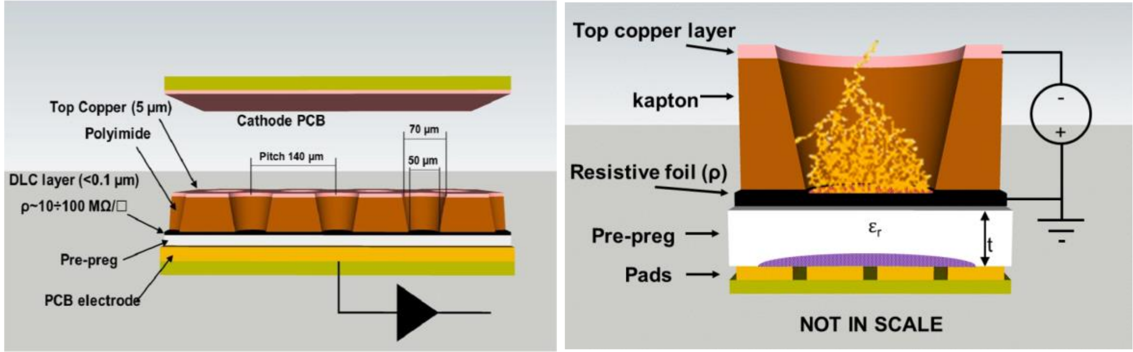
Elements for the 1st prototype at BINP





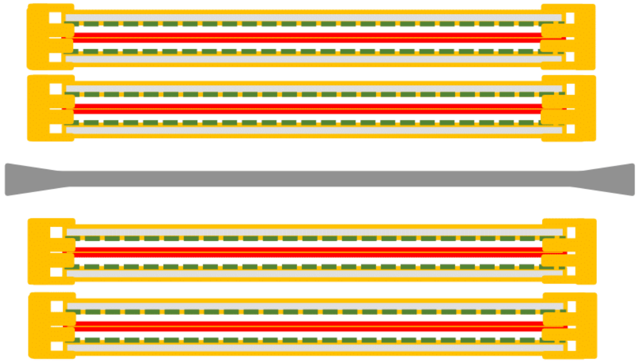
Cylindrical μRWELL option for inner tracker

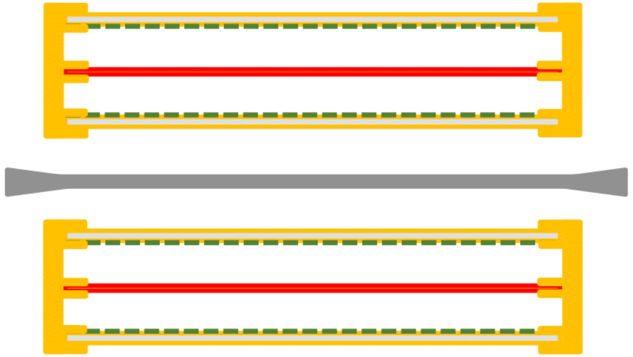
- The TPC option is developed by INFN group leading by G. Bencivenni
- A novel MPGD technology
- Potentially robust and low-material detector providing spatial resolution better than $100\ \mu m$
- A prototype is to be constructed and tested in 2021



- N.2 small gap B2B C+layers → 1.5÷1.9% X0
- 2 × 1 cm gas gap/B2B device
- 4 cm global sampling gas

- N.1 large gap B2B C+layers → 0.75÷0.95% X0
- 2 × 5 cm gas gap/B2B device
- 10 cm global sampling gas





Operation of large gas gap radial TPC to be verified

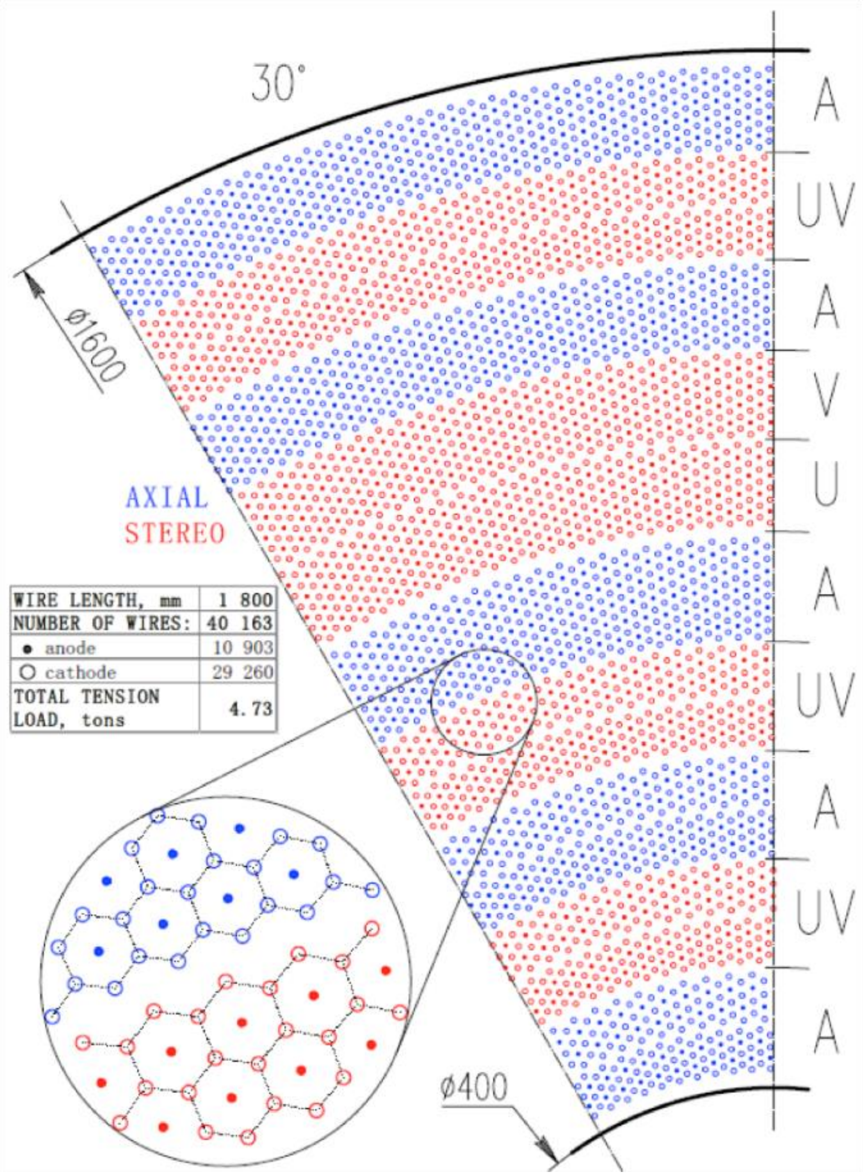
Drift chamber: BINP proposal

- A detailed project is proposed
  - 41 layers: 5 stereo and 5 axial super-layers
  - 10903 anode wires
  - Gas mixture He/C_3H_8 (60%/40%)

$$\sigma_x < 90\ \mu m$$

$$\frac{\sigma_p}{p_t} \sim 0.38\%\ @\ 1\ GeV$$

$$\frac{\sigma(dE/dx)}{dE/dx} < 7\%$$



Drift chamber: the TraPId proposal

F. Grancagnolo's slide

INFN Team

INFN Bari

M. Abbrescia
R. Aly
N. De Filippis
D. Diacono
G. Donvito
W Elmetanawee
G. Iaselli
M. Maggi
I. Margjeka

INFN Lecce

A. Corvaglia
G. Chiarello
F. Cuna
E. Gorini
F. Grancagnolo
A. Miccoli
M. Panareo
M. Primavera
G. Tassielli
A. Ventura

$R_{in} - R_{out}$ [mm]		200 – 800
active L – service area [mm]		1800 – 200
inner cylindrical wall		
C-fiber/C-foam sandwich	2×80 μm / 5 mm	0.036 g/cm² – 8×10^{-4} X/X_0
outer cylindrical wall		
C-fiber/C-foam sandwich	2×5 mm / 10 mm	0.512 g/cm² – 1.2×10^{-2} X/X_0
end plate		
gas envelope	160 μm C-fiber	0.021 g/cm² – 6×10^{-4} X/X_0
instrumented wire cage	wire PCB, spacers, HV distr. and cables, limiting R, decoupling C and signal cables	0.833 g/cm² – 3.0×10^{-2} X/X_0

cell	
shape	square
size [mm]	7.265 – 9.135
layer	
8 super-layers	8 layer each
64 layer total	
stereo angles	66 – 220 mrad
n. sense wires [20μm W]	23,040
n. field wires [40/50μm Al]	116,640
n. total (incl. guard)	141,120
gas + wires [600 mm]	
90%He – 10%iC_4H_{10}	4.6×10^{-4}
W + 5 Al → Ti + 5 C	$(13.1 \rightarrow 2.5)\times10^{-4}$

$$\frac{\sigma_{dE/dx}}{(dE/dx)} = 8.1\%$$

$$\frac{\Delta p_\perp}{p_\perp} = 7.8\cdot10^{-4} p_\perp \oplus 1.8\cdot10^{-3}$$

(7.8 → 6.6 with cluster timing)

$$\Delta\varphi = 1.1\cdot10^{-4} \oplus \frac{6.9\cdot10^{-4}}{p}$$

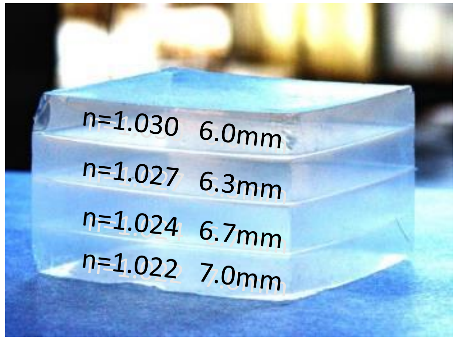
$$\Delta\theta = 3.8\cdot10^{-4} \oplus \frac{6.9\cdot10^{-4}}{p}$$

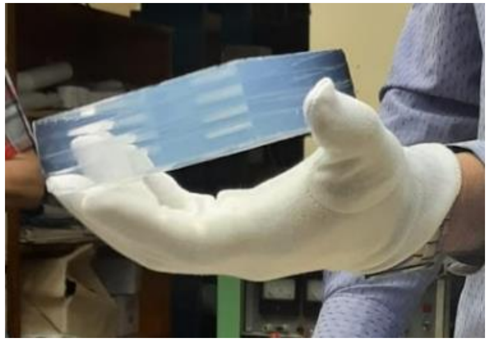
$$\frac{\sigma_{dN_d/dx}}{(dN_d/dx)} = 3.6\%$$

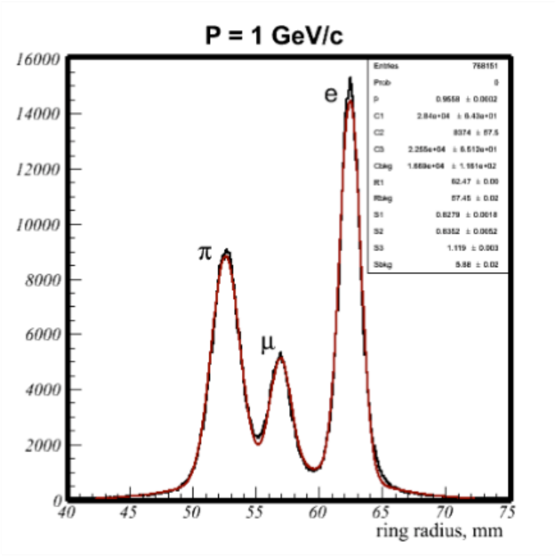
$$\frac{\Delta p_\perp}{p_\perp} = 2.0\cdot10^{-3}, \Delta\phi = 0.70 \text{ mrad}, \Delta\theta = 0.78 \text{ mrad @ 1 GeV}$$

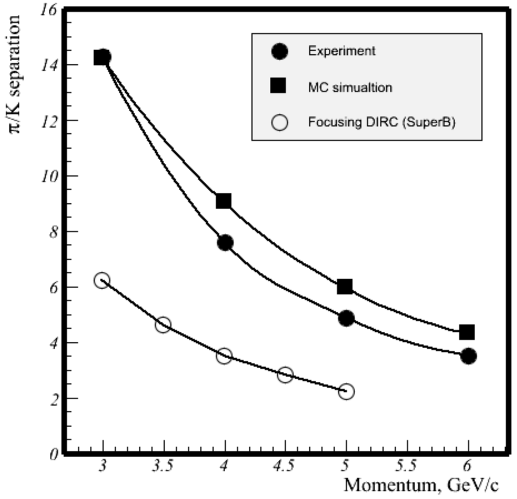
FARICH detector for PID (BINP)

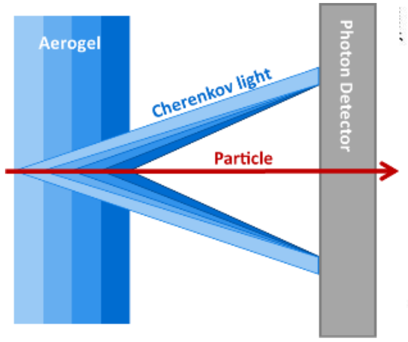
- Potentially best $\mu/\pi/K$ separation
- Requires:
  - $14\ \mathrm{m}^2$ of four-layer aerogel radiator
  - 10^6 readout channels, one per $3 \times 3\ \mathrm{mm}^2$ photon detector
- Work on the full-ring prototype is in progress

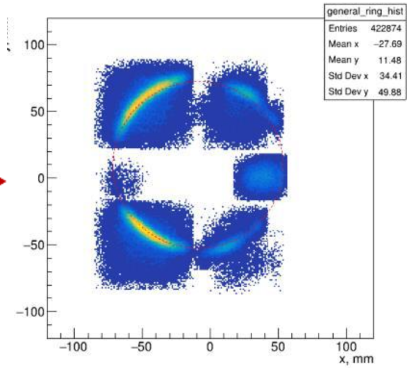


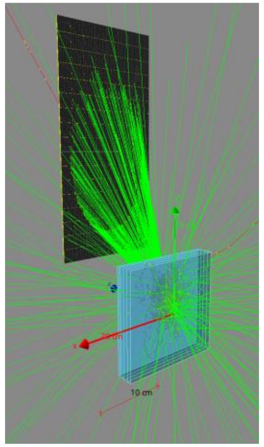










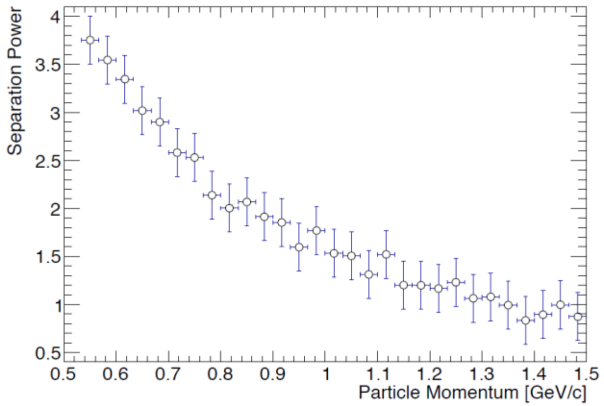


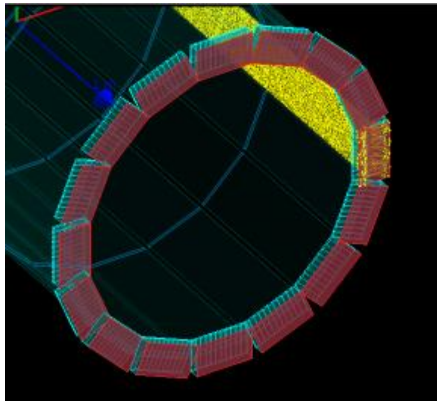
T.Iijima et al., NIM A548 (2005) 383
A.Yu.Barnyakov et al., NIM A553 (2005) 70
A.Yu. Barnyakov, et al., NIM A 732 (2013) 35

FDIRC detector for PID (by Giessen group)

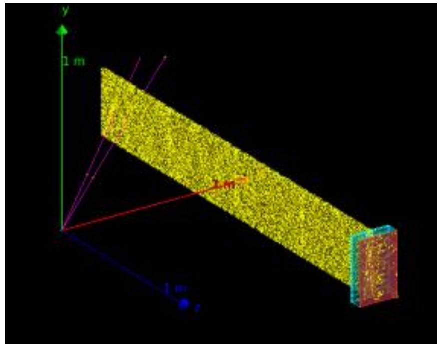
- Design inspired by FDIRC for PANDA
- $\approx 10^5$ readout channels
- Parameters of the detector must be tuned to reach the required μ/π separation power
- Tests of the detector components and readout electronics are held in Giessen

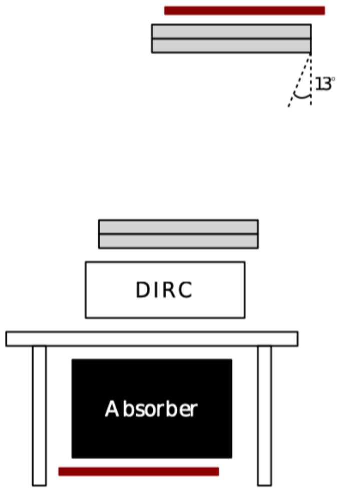
μ/π separation power with FDIRC
(simulated by M. Schmidt)





2×16 plates 110×32×1.5 cm^3 and 2×16 expansion volumes 32×20×10 cm^3



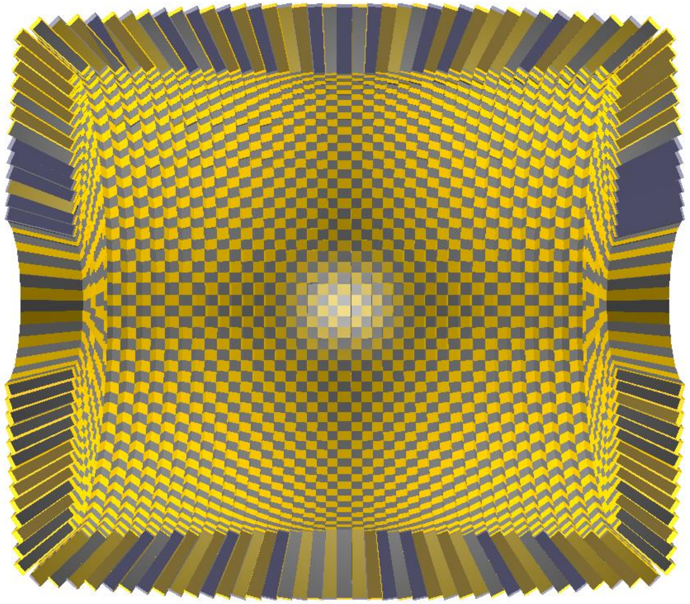


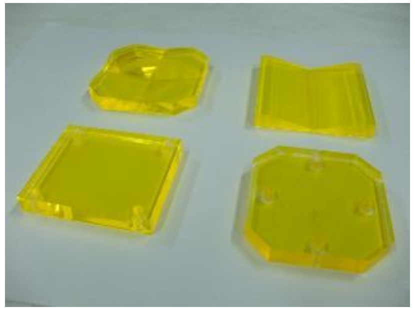
Giessen cosmic station

- Significant synergy between FARICH and FDIRC options in the development of photon detectors and readout electronics

Pure CsI crystal calorimeter option

- BINP group has a rich experience in construction and operation of crystal calorimeters (SND, CMD3, KEDR, Belle, Belle II experiments)
- Option proposed for SCT:
  - 16 or 18 X_0 (30 or 34 cm) pure CsI crystals
  - 7424 crystals, 36 or 43 tons in total
  - Readout with WLS and 4 APDs providing $\sigma_t \approx 30\ \mathrm{ns}$
- A 4×4 crystal matrix is begin tested at BINP





Muon system: LPI proposal

- The scintillator → WLS → SiPM scheme
- 8 gapes in yoke
- The same technology is used in the Belle II KLM detector
- Improves π/μ separation, allows reconstruction of K_L^0

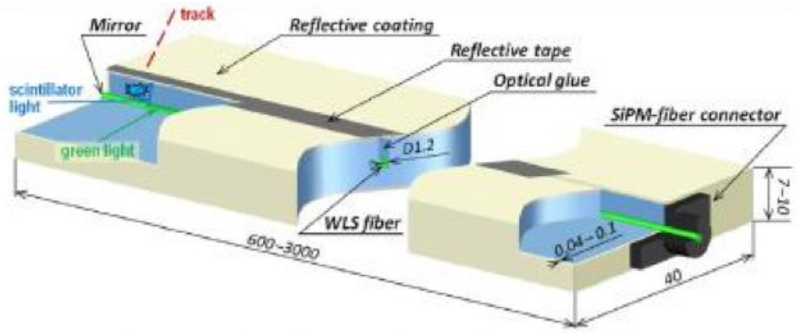


Fig. 1. Schematic view of the scintillator strip. Dimensions are in mm.

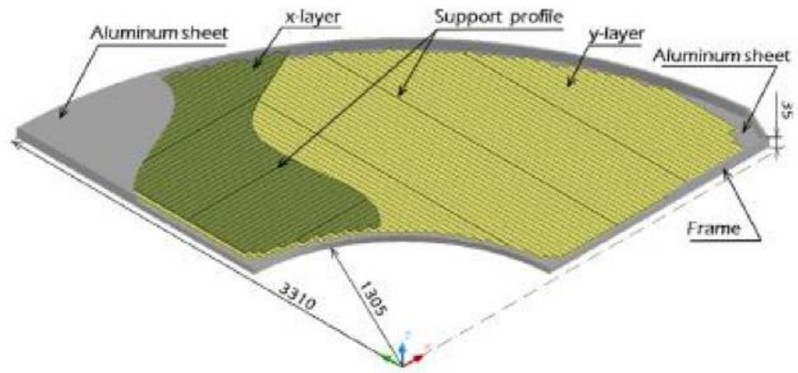


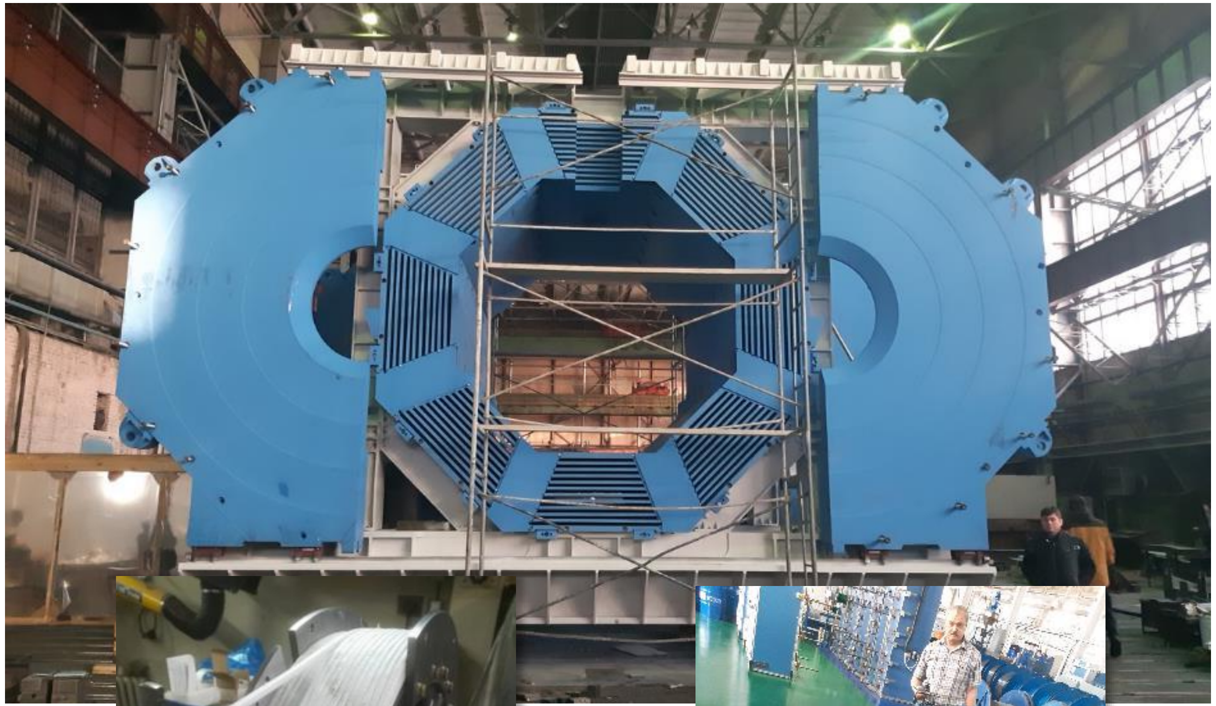
Fig. 2. Schematic view of one superlayer formed by scintillator strips. Sizes are given in mm.

Testbench in Lebedev Institute (March 2021)

https://c-tau.ru/indico/event/3/contributions/192/attachments/169/268/uglov.pdf

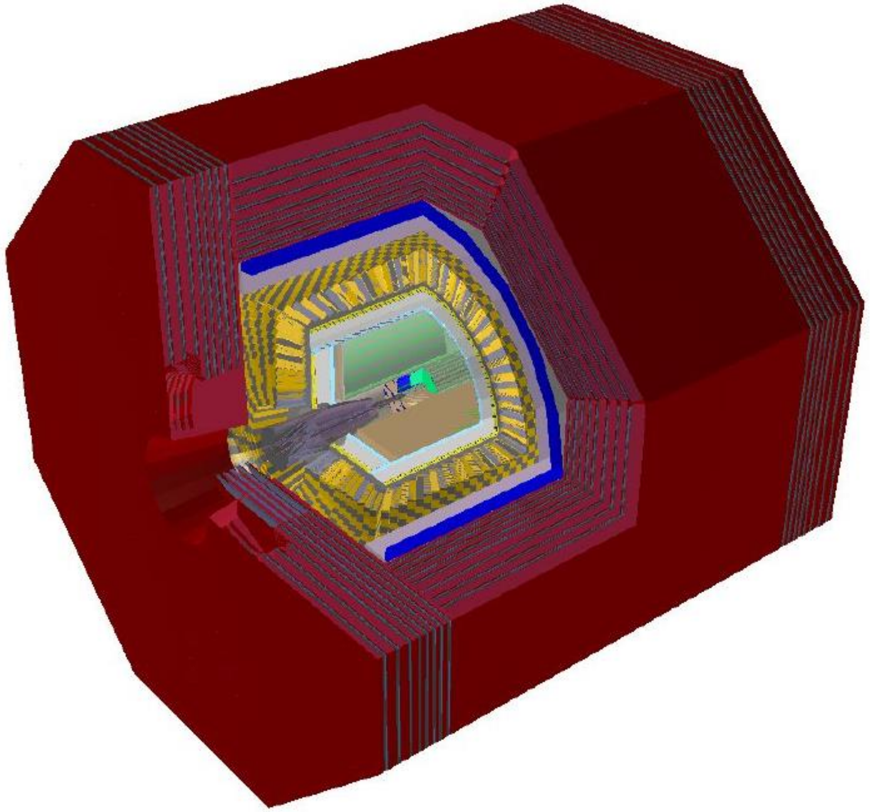
Superconducting magnet

- BINP currently produces magnet for the PANDA experiment:
  - Production of superconducting cable is established in Russia
  - Yoke has been already produced in Novosibirsk
  - Final tests are scheduled in 2022
- SCT requires quite similar magnet. The experience obtained will allow to design and produce the SCT magnet quick



SCT detector software

- Guiding principle: reuse of robust existing software and close communication with the Key4HEP initiative
- SCT detector software framework AURORA is released (v1.0.0). It includes
  - Unified description of sensitive detectors
  - Realistic magnetic field
  - An example digitization module
  - Basic data analysis tools
  - Stack of external software
- Publications
  - Presented at AFAD-2021
  - Presented to vCHEP21

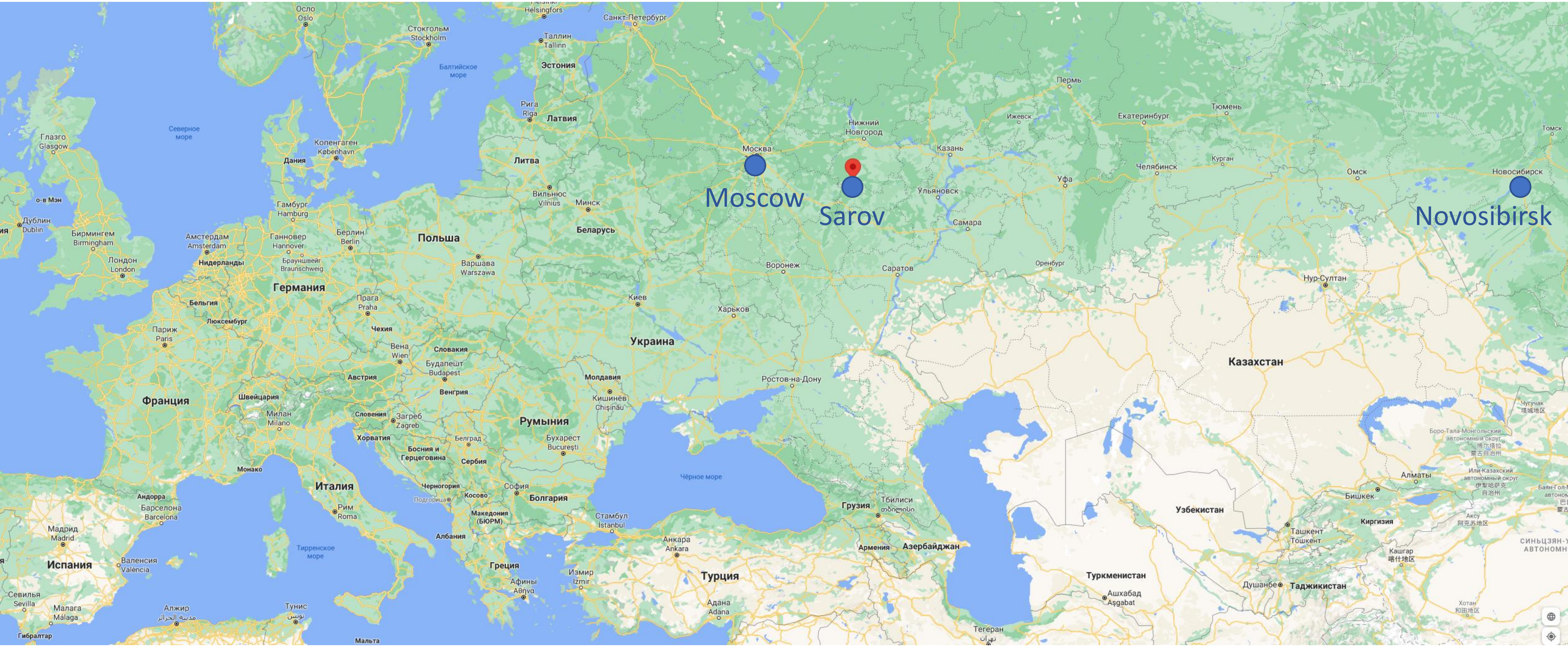


The SCT project status

- 2011: SCT is one of six mega-science projects to be implemented in Russia. The list is formed by Russian government commission
- 2017: International advisory committee (IAC) is formed; regular international workshops are held since then
- 2018: major update of the SCT conceptual design
- 2020: launching the EU project CREMLINplus, funds for European groups working on R&D for SCT detector
- 2020: SCT is discussed in the context of the “Large Sarov” project
- 2021-22: decision on the project implementation?

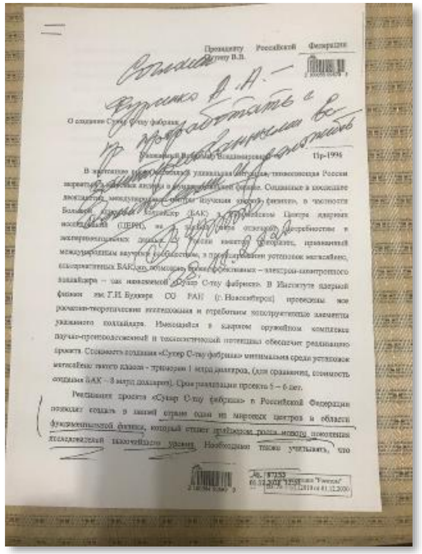
The “Large Sarov” project

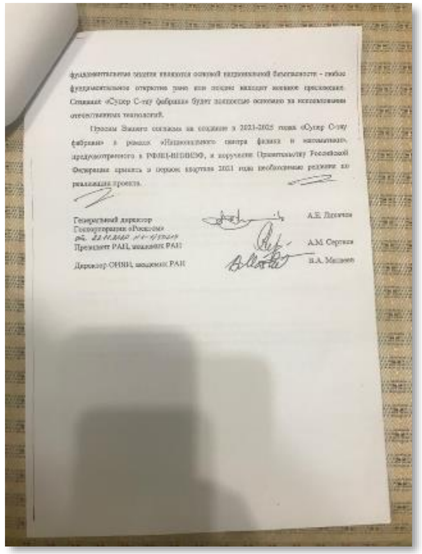
- Large Sarov is a new scientific center being created by state corporation ROSATOM, located near Sarov
- It implies creation of a new branch of Moscow State University (first master programs are launched in Fall 2021)
- SCT is discussed as the anchor facility for Large Sarov


Moscow
Sarov
Novosibirsk
Москва
Нижний Новгород
Санкт-Петербург
Казань
Новосибирск
Польша
Германия
Украина
Беларусь
Казахстан
Франция
Италия
Испания
Турция
Румыния
Узбекистан
Туркменистан
Чёрное море
Северное море
Балтийское море

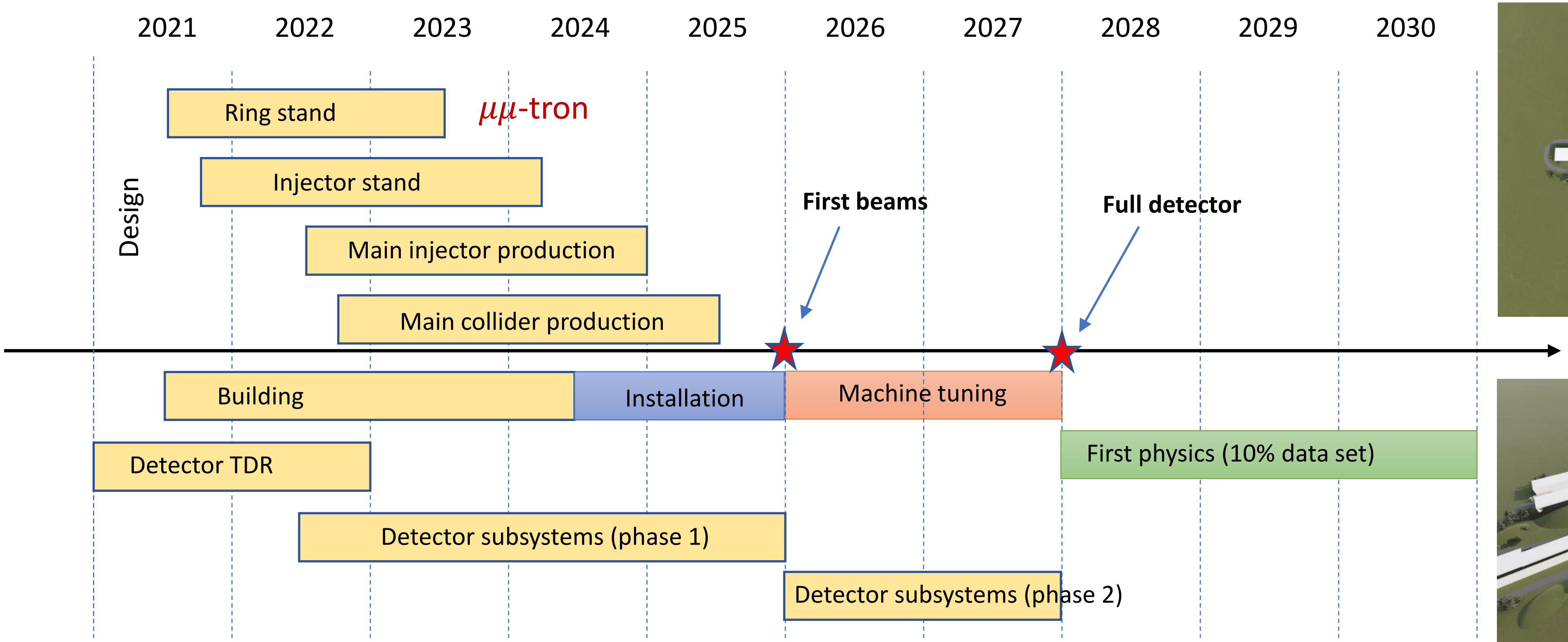
The Letter
“About creation of the Super C-tau factory”

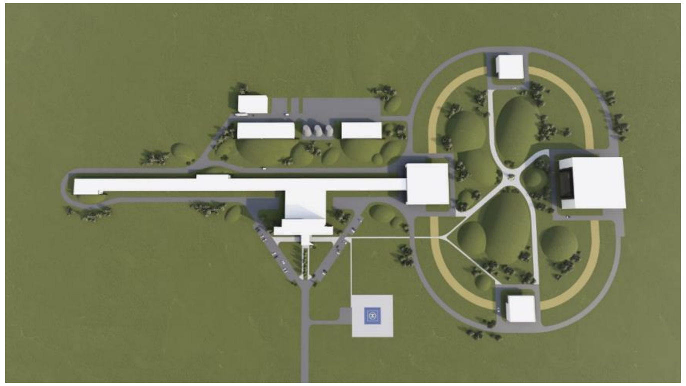
- November 2020: letter addressed to president of Russia and signed by
  1. Director of state corporation ROSATOM
  2. President of Russian Academy of Science
  3. JINR Director
- The letter suggests to build SCT factory on ROSATOM site
- President of Russia supported the proposal. He asked to elaborate details and report to him. The project is being discussed at government level with participation of ROSATOM





SCT Roadmap





➢ Intensive communication is going on between BINP and ROSATOM about the project details

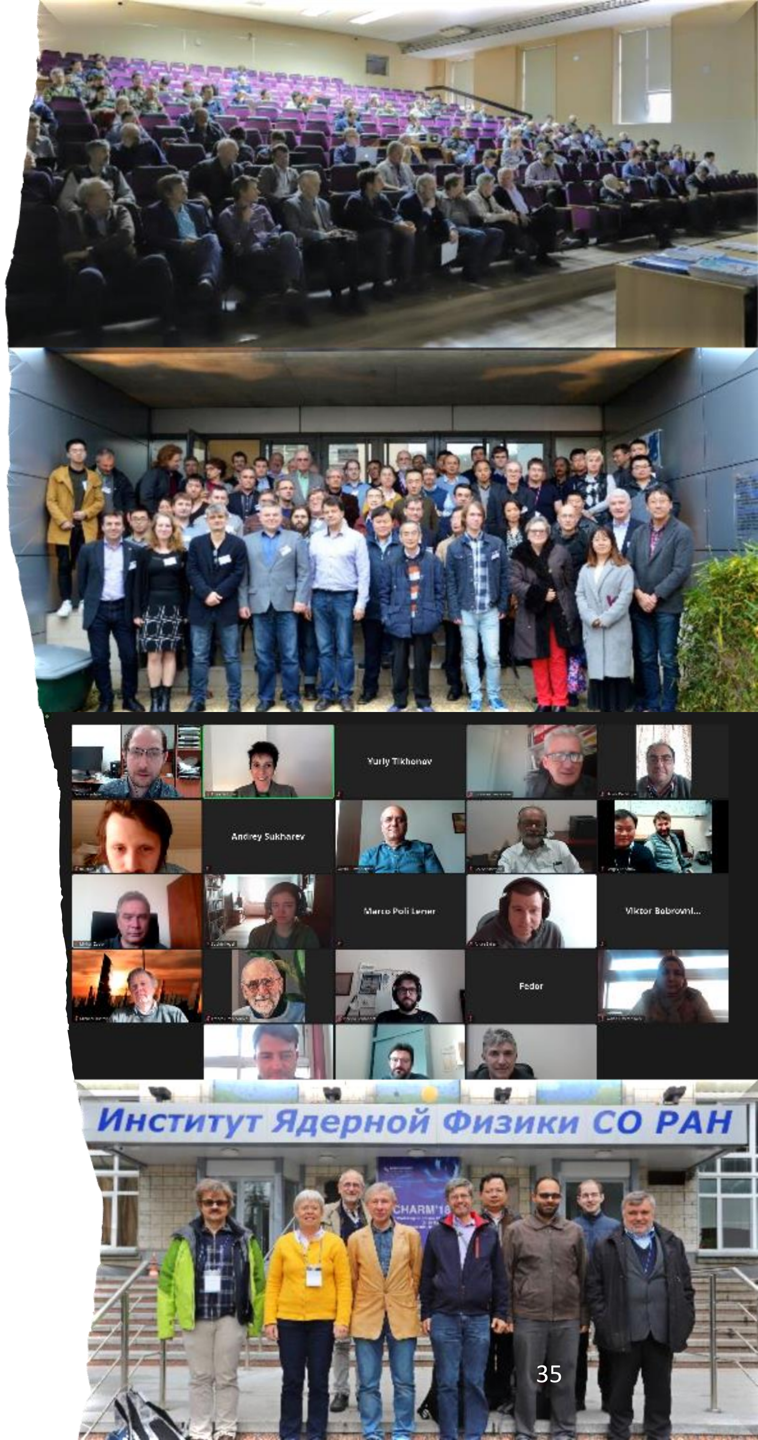
SCT workshops

Workshops on future super charm tau factories:

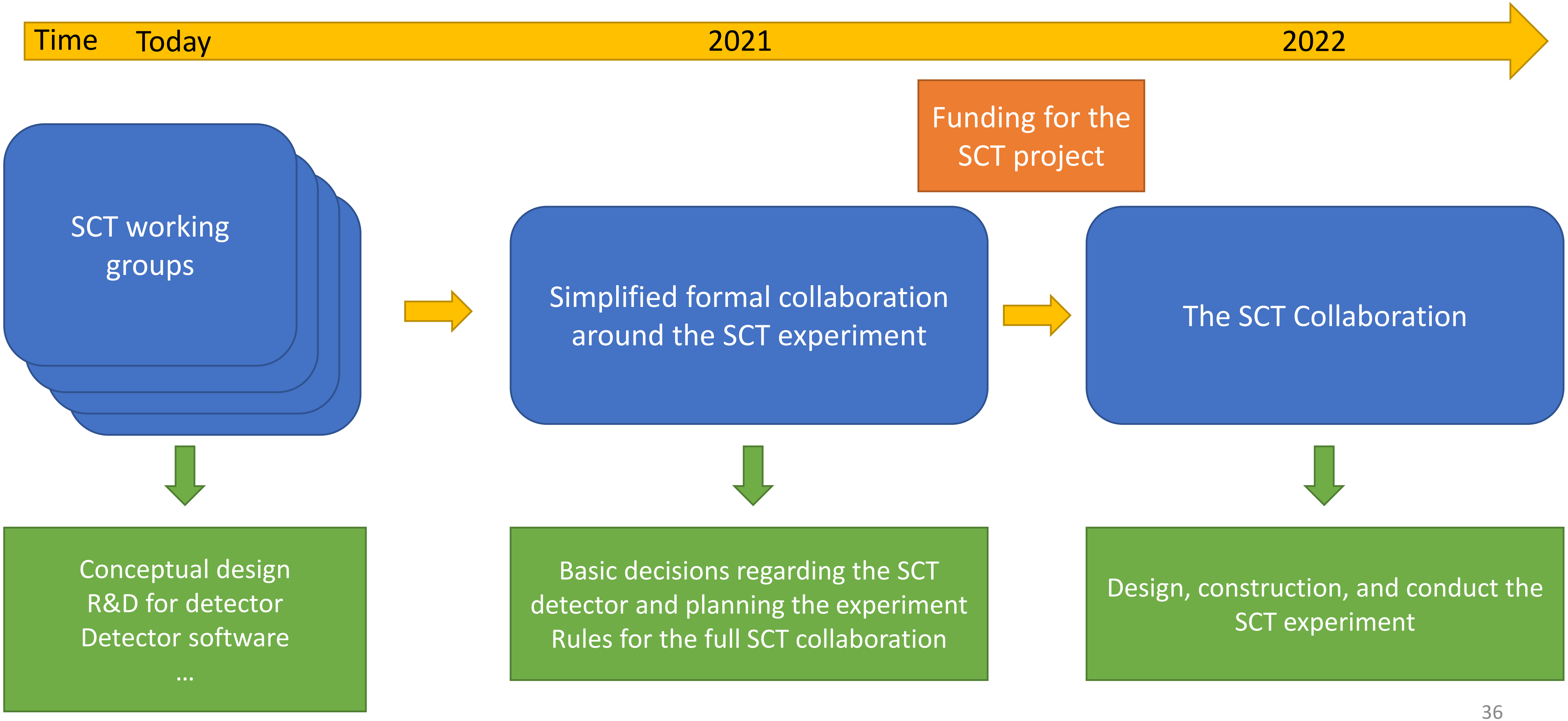
- 2017.12, Novosibirsk (link)
- 2018.03, Beijing (link)
- 2018.05, Novosibirsk (link) + 1st meeting of the International Advisory Committee for the SCT experiment
- 2018.12, Orsay (link)
- 2019.11, Moscow (link) + 1st general WP5 meeting
- 2020.11, Hefei (online, link)
- Fall 2021 (in preparation)

CREMLINplus WP5 meetings:

- 2nd general WP5 meeting, September 2020 (online, link), 44 participants
- 3rd general WP5 meeting, February 2021 (online, link), 38 participants
- 4th general WP5 meeting, July 2021 (scheduled online)

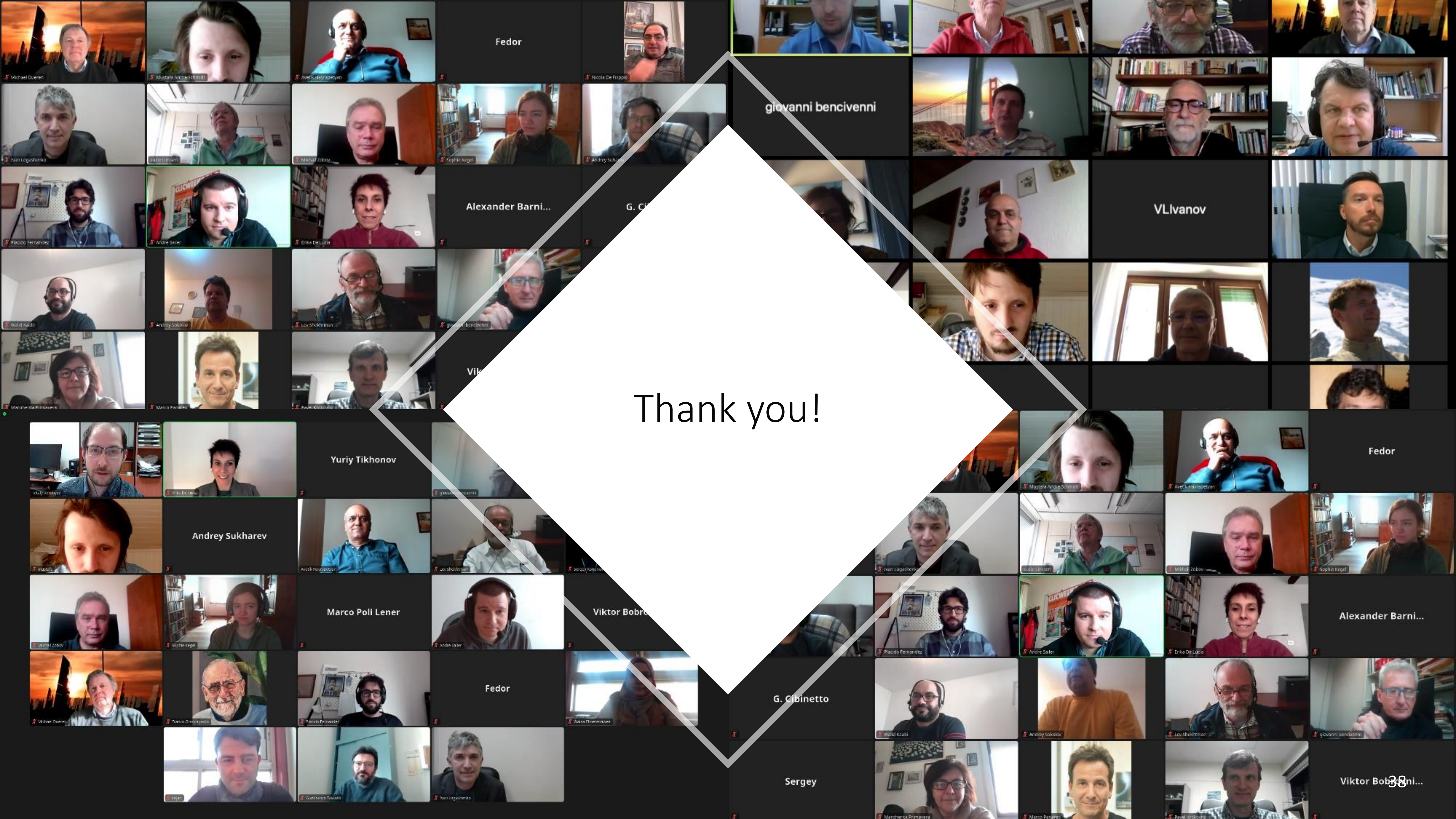


Steps towards formal collaboration



Conclusions

1. The SCT experiment has a rich physics program
2. The SCT project is well-elaborated from both accelerator and detector point of views
3. Proper design, construction and operation of the SCT detector is possible only if coordinated by a strong international collaboration


Fedor
giovanni bencivenni
Alexander Barni...
VLIvanov
Yuriy Tikhonov
Andrey Sukharev
Marco Poli Lener
G. Cibinetto
Sergey

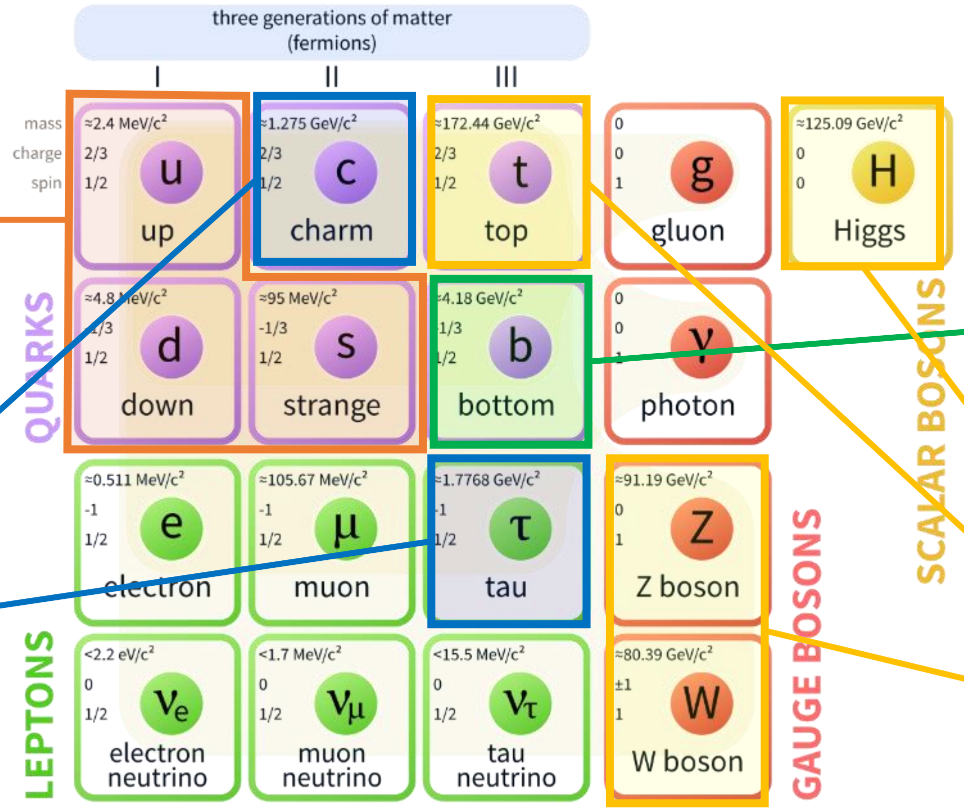
Thank you!

Backup

The factory colliders

Φ-factories
1-2 GeV
DAFNE (Italy)
VEPP-2000 (BINP)

$c\tau$-factories
3-7 GeV
BEPC-II (China)
SCT, HIEPA
x100



B-factories
10 GeV
PEP-2 (USA)
KEK-B (Japan)
Super KEK-B (Japan)
LHCb (CERN)
x50

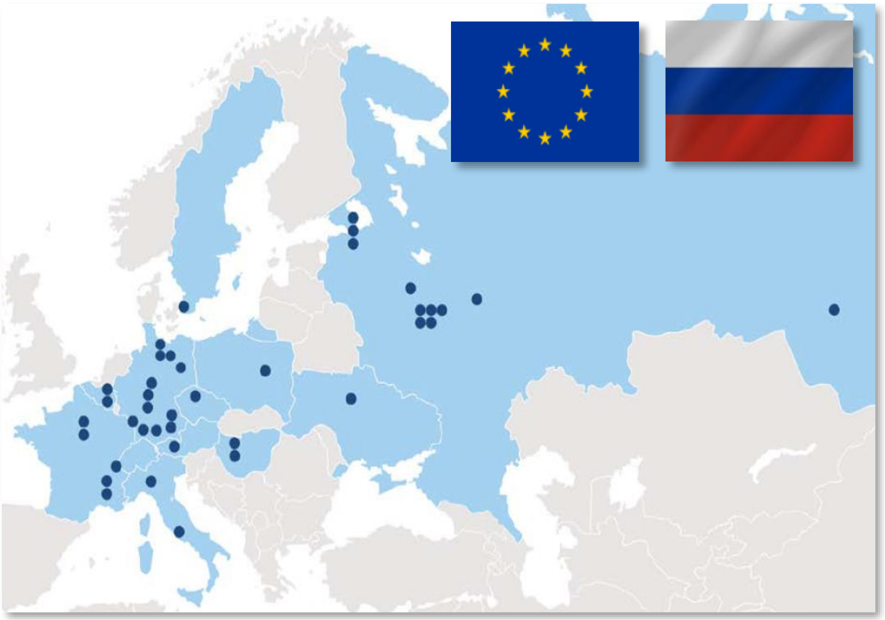
Z-factories
Higgs-factories
45-175 GeV
LEP/LEP-2 (CERN)
FCC-ee (CERN)
CEPC (China)
x10000

completed in operation being designed

CREMLIN PLUS

Connecting Russian and European Measures
for Large-scale Research Infrastructures

https://www.cremlinplus.eu/



- EU project
- Time frame: from 2020 to 2024
- C+ working package 5 ($\approx$ 2M€) is devoted to SCT
  - The SCT project internationalization
  - Prototyping the SCT accelerator components
  - **Development of the SCT detector software**
  - **Prototyping the SCT detector subsystems**
- The C+ WP5 partners:
  1. BINP
  2. CERN
  3. INFN (Ferrara, Bari, Lecce, Frascati)
  4. IJCLab (Orsay)
  5. JLU (Giessen)

Computing and data storage needs

Main processes			
	J/ψ	$\psi(2S)$	$\psi(3770)$
E (МэВ)	3097	3686	3770
σ (nbn)	1400	370	≈ 6
f (kHz)	**110**	34	0.6
Background rate (kHz)			
Cosmic	≈ 2		
Hadronic	19	17	16
Bhabha	90	80	80

Maximal trigger rate is 300 kHz

	BESIII	SCT	Belle II
Luminosity integral (1/ab)	≈ 0.02	10	50
Events (10^{10})	≈ 4	200	10
Event size (kB)	12	50	300
Raw data (PB)		100	200
Processes data (PB)		10	80

- Parameters of the computing cluster and data storage are estimated and are reachable with existing solutions


Precision experiments at electron-positron collider Super Charm-Tau Factory

A contribution to the Update of the European Strategy for Particle Physics

Budker INP, Novosibirsk

Abstract

December 2018

Precision experiments at Super Charm-Tau Factory

Letter of Interest for Snowmass 2021

European Strategy for Particle Physics Update

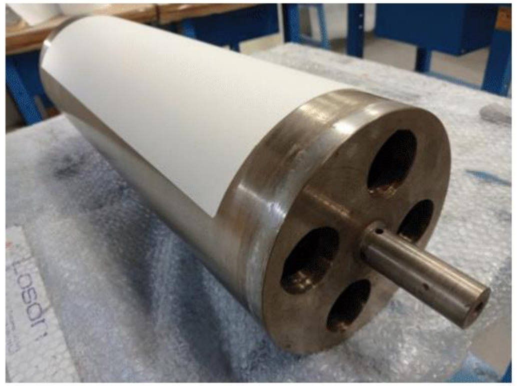
- The SCT physics potential is reflected in Physics Briefing book: arXiv:1910.11775 [hep-ex]

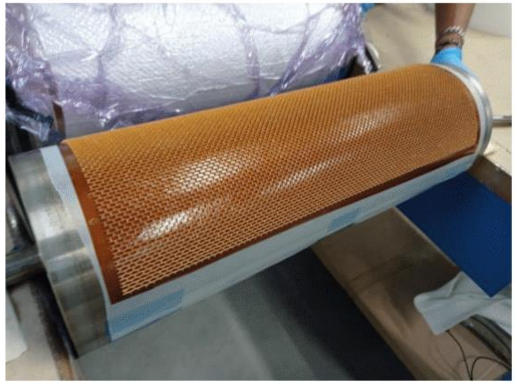
Snowmass2021

- Letter of intent for SCT is signed by 100 colleagues from 38 organizations (including 10 Russian organizations)
- The 2021 goal: writing white papers

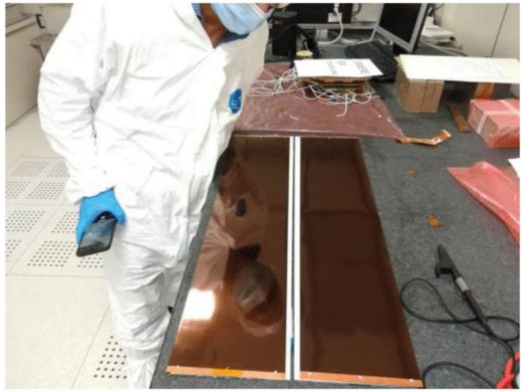
Roof tile & detector mock-up tests

work done at LOSON





work done at CERN



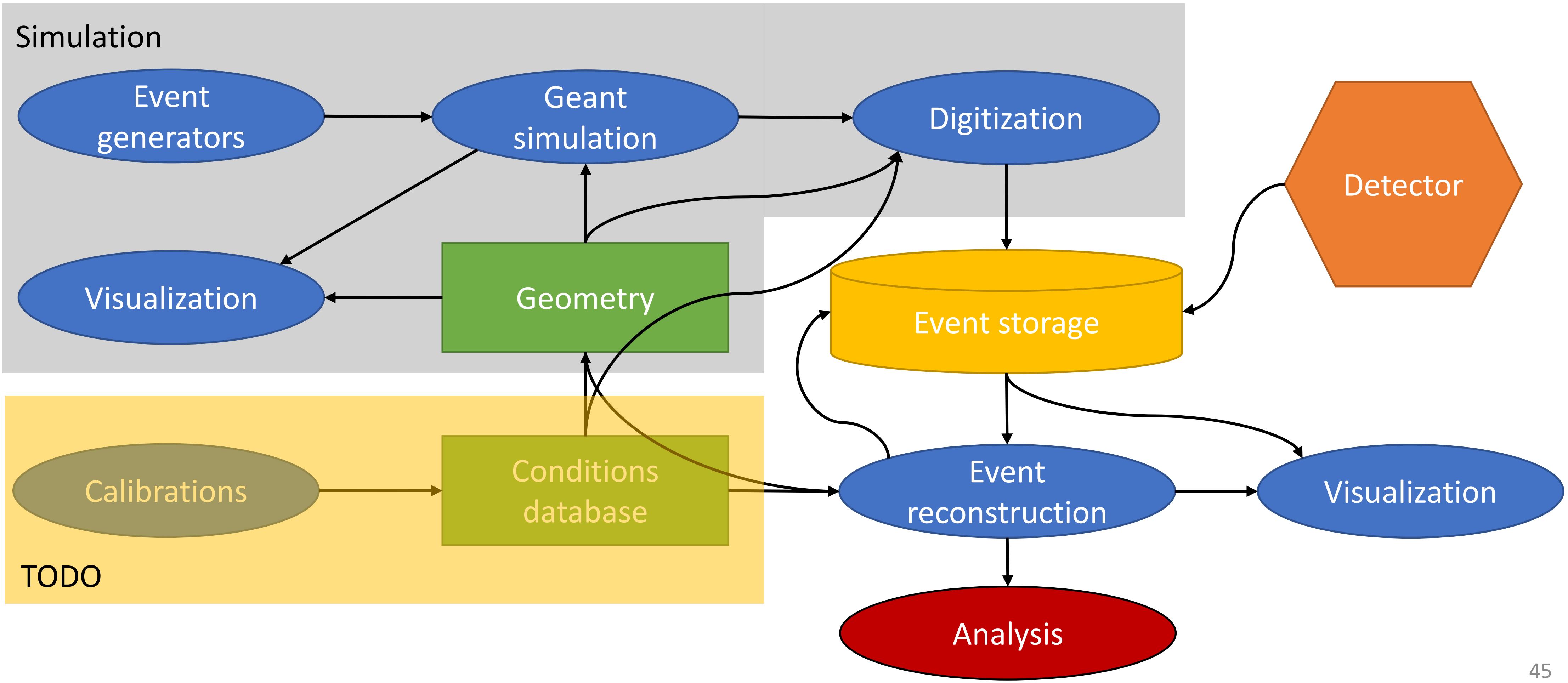
detector layering

- 5 um Copper
- 50 um KAPTON
- 50 um prepreg 106
- 5 um Copper
- 50 um KAPTON

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072.

SCT detector software

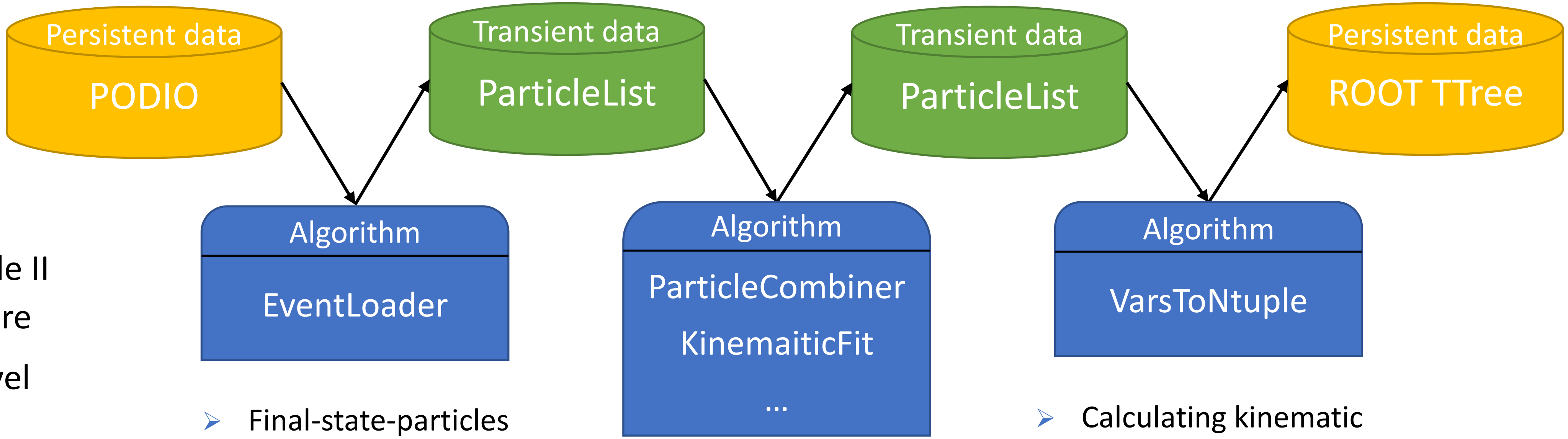
- Task 5.3. Development of software for the design of an SCT detector



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072.

SCT event analysis

- Task 5.3. Development of software for the design of an SCT detector



- ➢ Inspired by Belle II analysis software
- ➢ Simple high-level Python API
- ➢ Easily reproducible data analysis

EventLoader:

- ➢ Final-state-particles processing
- ➢ Kinematic cuts

ParticleCombiner / KinemaiticFit:

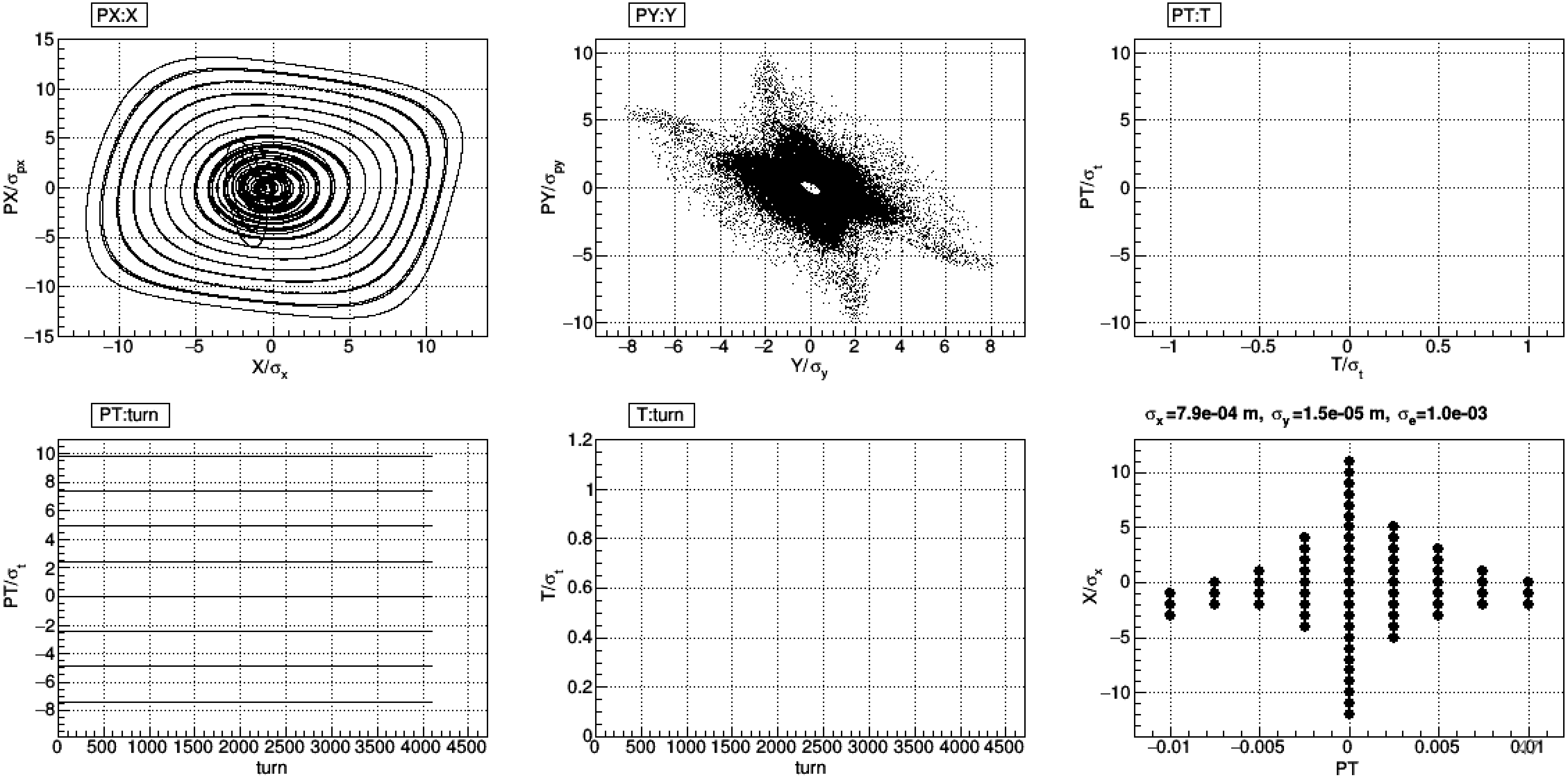
- ➢ Reconstruction of particle decay chains
- ➢ Kinematic cuts

VarsToNtuple:

- ➢ Calculating kinematic variables to be written in output n-tuple

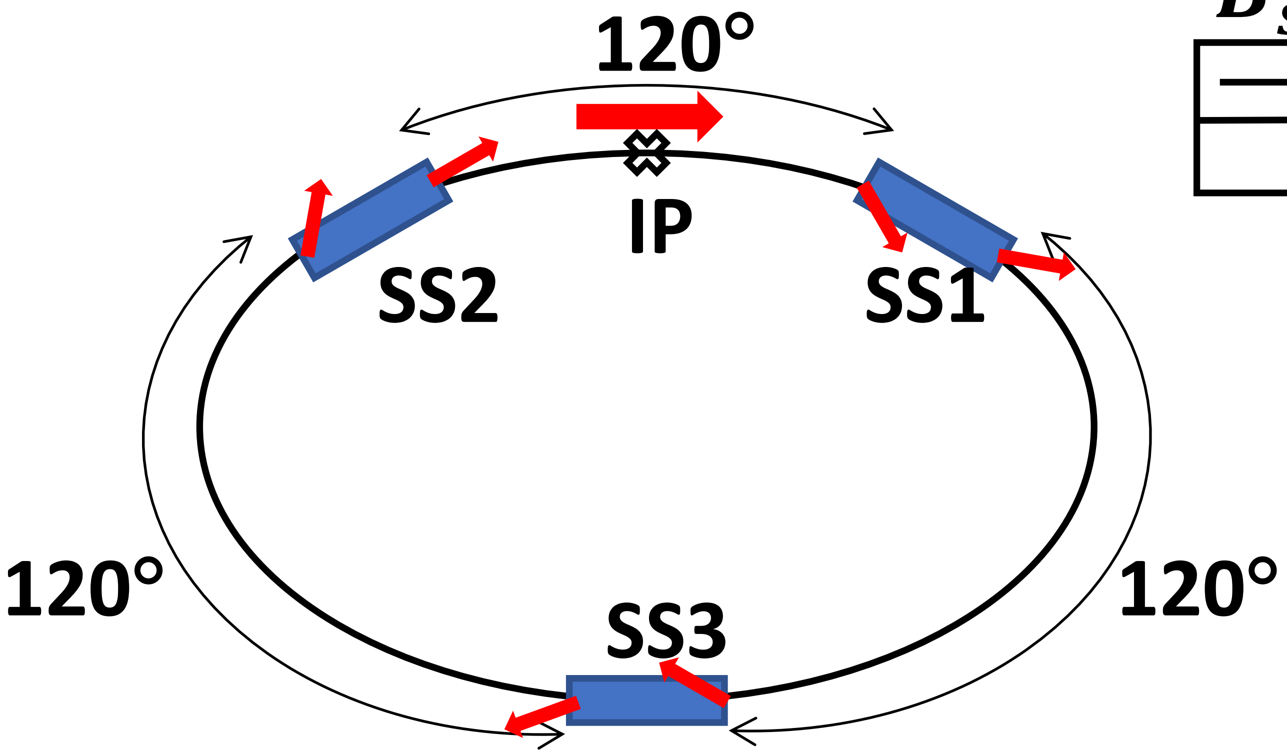
2021: Dynamic aperture

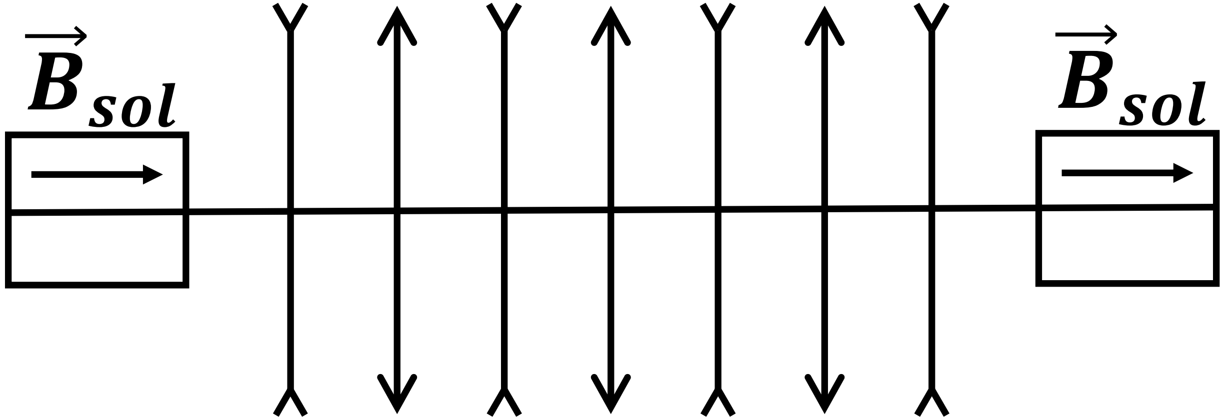
$Y0 = 1\ \sigma_y, \varepsilon_x = 25.19\ \text{nm}, \varepsilon_y = 126\ \text{pm}$

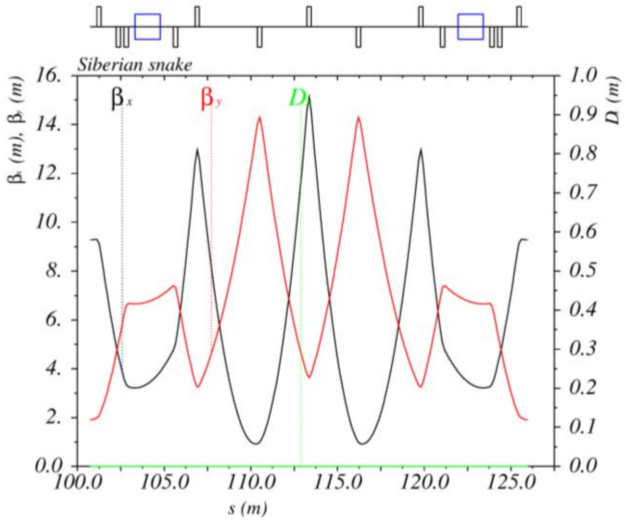


The goal is to provide longitudinal polarization at IP

Siberian Snake





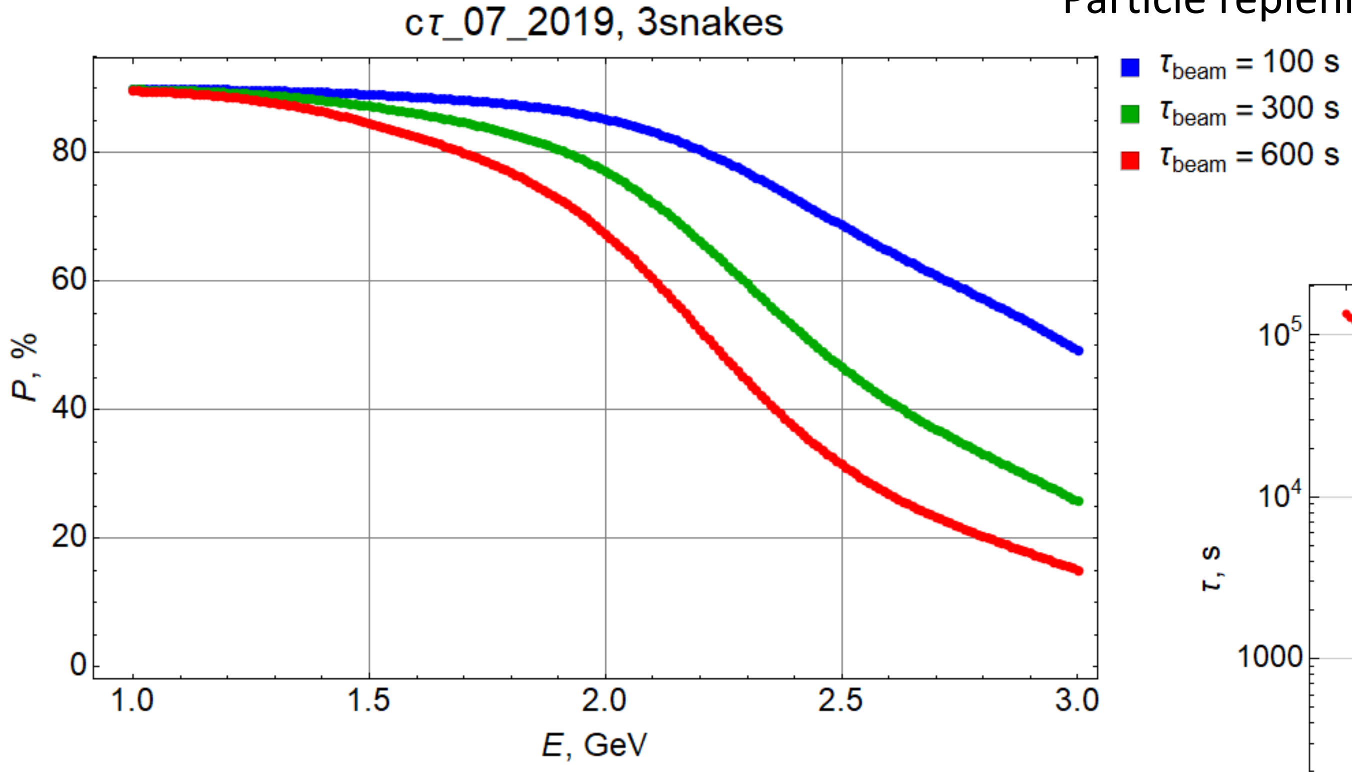


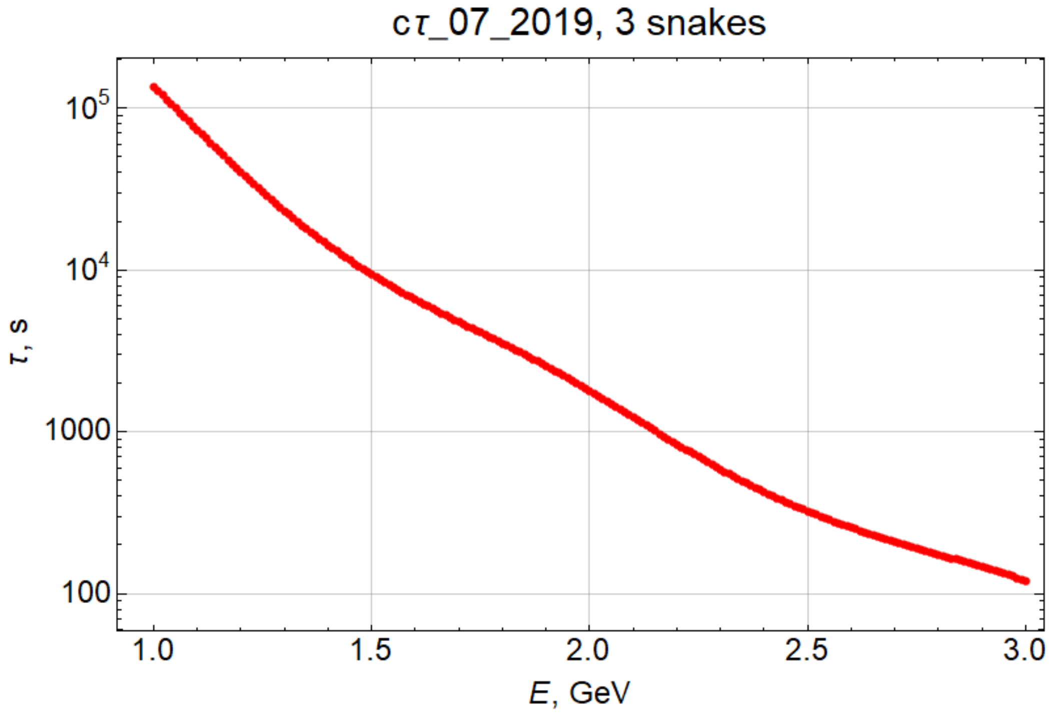
To decouple $R_x = -R_y$, 7 quadrupoles needed

Solenoid spin rotation angle is $\pi/2$ $B_{sol} = 7$ T at $E_{beam} = 3.5$ GeV, $L = 2.6$ m

Longitudinal Polarization (number of snakes)

Particle replenishing time





Charm mixing

Measuring charm mixing with combination of coherent and incoherent D^0 decays

- CLEO-c [1]: 0.82 fb^{-1} @ $\psi(3770)$
  - Joint analysis of 261 processes
  - First measurement of $\sin\delta_{K\pi}$

$$y = (4.2 \pm 2.0 \pm 1.0)\%$$
$$R_D = (0.533 \pm 0.107 \pm 0.045)\%$$
$$\cos\delta_{K\pi} = +0.81 \pm 0.22 \pm 0.07$$
$$\sin\delta_{K\pi} = -0.01 \pm 0.41 \pm 0.04$$

[1] Phys. Rev. D86 (2012) 112001

Coherent $D^0\overline{D}^0$ pair decays

$$\Gamma(i,j) \propto |\langle i|D_2\rangle\langle j|D_1\rangle - \langle i|D_1\rangle\langle j|D_2\rangle|^2 + \mathcal{O}(x^2, y^2)$$

TABLE III. D final states reconstructed in this analysis. [1]

Type	Reconstruction	Final states
f	Full	$K^-\pi^+$, $Y_0 - Y_7$
$\bar{f}$	Full	$K^+\pi^-$, $\bar{Y}_0 - \bar{Y}_7$
S_+	Full	K^+K^-, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$
S_+	Partial	$K_L^0\pi^0$, $K_L^0\eta$, $K_L^0\omega$
S_-	Full	$K_S^0\pi^0$, $K_S^0\eta$, $K_S^0\omega$
S_-	Partial	$K_L^0\pi^0\pi^0$
ℓ^+	Partial	$K^-e^+\nu_e$, $K^-\mu^+\nu_\mu$
ℓ^-	Partial	$K^+e^-\bar{\nu}_e$, $K^+\mu^-\bar{\nu}_\mu$

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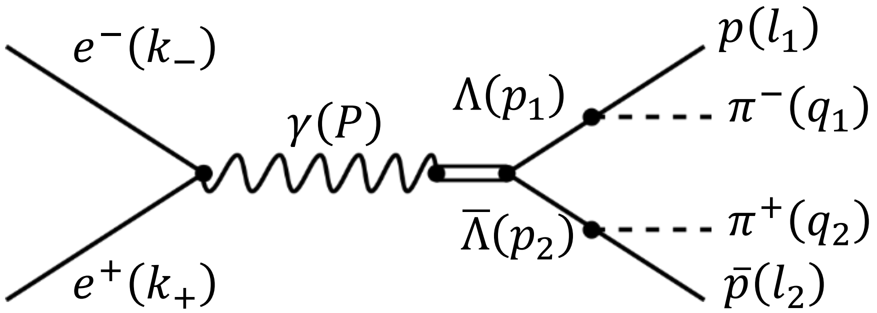
Λ formfactors



$$e^+e^- \to J/\psi \to [\Lambda \to p\pi^-][\bar{\Lambda} \to \bar{p}\pi^+]$$

Setup	SCT one-year σ (10^{-4})			
	P_e	α	$\Delta\Phi$ (rad)	α_i
5D $P_e = 0$	Fixed	1.5	3.1	2.8
5D $P_e = 0.8$	1.3	1.2	1.6	0.9
3D $P_e = 0.8$	4.3	1.2	2.4	3.4

$$\alpha \equiv \frac{s\left|G_{\mathrm{M}}^{\psi}\right|^2 - 4m_\Lambda^2\left|G_{\mathrm{E}}^{\psi}\right|^2}{s\left|G_{\mathrm{M}}^{\psi}\right|^2 + 4m_\Lambda^2\left|G_{\mathrm{E}}^{\psi}\right|^2}, \qquad \Delta\Phi \equiv \arg\left(\frac{G_{\mathrm{E}}^{\psi}}{G_{\mathrm{M}}^{\psi}}\right), \qquad \alpha_1, \alpha_2$$

- CP asymmetry in $\Lambda \to p\pi^-$:

$$A_\Lambda \equiv \left|\frac{\alpha_1 + \alpha_2}{\alpha_1 - \alpha_2}\right| \lesssim 5 \times 10^{-5}$$

  - SM limit:

$$A_\Lambda \lesssim 5 \times 10^{-5}$$

  - Expected precision:

$$\sigma(A_\Lambda) = 1.2 \times 10^{-4}$$

Charm decay rates

Time-dependent

Incoherent

$$D^{*\pm} \to D\pi^{\pm}, \qquad B \to DX, \qquad e^+e^- \to c\bar{c} \to D\bar{D}X, \qquad pp \to c\bar{c}X$$

$$|\langle f|\mathcal{H}|D^0(t)\rangle|^2 = e^{-\Gamma t}\left|\mathcal{A}_f\right|^2\left[1 - \left(y\,\mathrm{Re}\lambda_f + x\,\mathrm{Im}\lambda_f\right)\Gamma t\right] + \mathcal{O}(x^2, y^2)$$

$$|\langle f|\mathcal{H}|D^0\rangle|^2 \propto \left|\mathcal{A}_f\right|^2\left(1 - y\,\mathrm{Re}\lambda_f - x\,\mathrm{Im}\lambda_f\right) + \mathcal{O}(x^2, y^2)$$

Time-integrated

Boost

LHCb: $(\gamma\beta)_D \gg 1$

B factory: $(\gamma\beta)_D \sim 1$

c-τ factory: $(\gamma\beta)_D \ll 1$

Coherent (at rest)

$$e^+e^- \to D^{(*)0}\bar{D}^{(*)0}, \qquad \mathcal{C}+: D^0\bar{D}^0\gamma, \qquad \mathcal{C}-: D^0\bar{D}^0(\pi^0)$$

$$\langle ij|\mathcal{H}|D^0\bar{D}^0\rangle \propto \langle i|\mathcal{H}|D^0\rangle\langle j|\mathcal{H}|\bar{D}^0\rangle + \mathcal{C}\langle i|\mathcal{H}|\bar{D}^0\rangle\langle j|\mathcal{H}|D^0\rangle$$

$$|\langle ij|\mathcal{H}|D^0\bar{D}^0\rangle|^2 \propto |\mathcal{A}_i|^2\left|\mathcal{A}_j\right|^2\left[|\zeta_\mathcal{C}|^2 + (1+\mathcal{C})\left(x\,\mathrm{Im}(\xi_\mathcal{C}^*\zeta_\mathcal{C}) - y\,\mathrm{Re}(\xi_\mathcal{C}^*\zeta_\mathcal{C})\right)\right] + \mathcal{O}(x^2, y^2)$$

$$\xi_\mathcal{C} \equiv \frac{p}{q}(1 + \mathcal{C}\lambda_i\lambda_j), \qquad \zeta_\mathcal{C} \equiv \frac{p}{q}(\lambda_j + \mathcal{C}\lambda_i)$$

Model-independent Dalitz analysis

Charm mixing measurement using $D^0 \to K_S^0\pi^+\pi^-$

$$e^+e^- \to \psi(4040) \to D\bar{D}^*$$

- Coherent $\mathcal{C} = -1$: $D^0\bar{D}^{*0} \to D^0\bar{D}^0\pi^0$

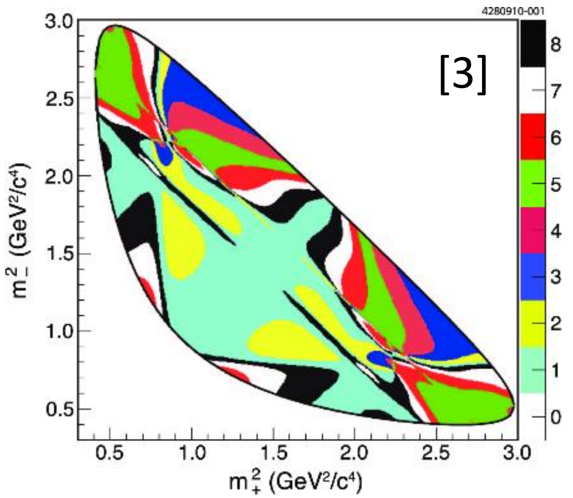
$$M_{ij}^- = K_iK_{-j} + K_{-i}K_j - 2\sqrt{K_iK_{-j}K_{-i}K_j}\left(C_iC_j + S_iS_j\right)$$

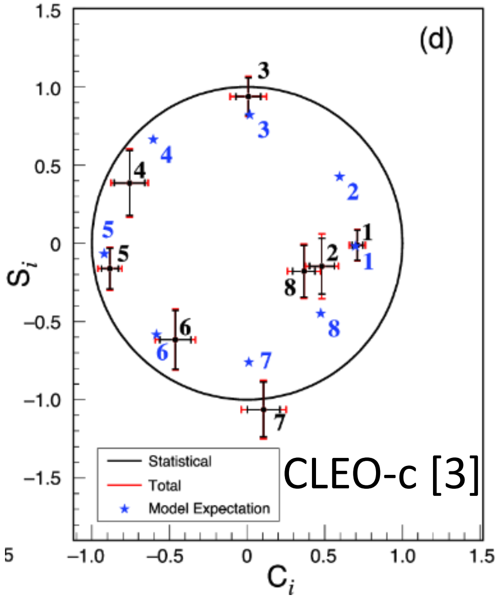
- Coherent $\mathcal{C} = +1$: $D^0\bar{D}^{*0} \to D^0\bar{D}^0\gamma$

$$M_{ij}^+ = K_iK_{-j} + K_{-i}K_j - 2\sqrt{K_iK_{-j}K_{-i}K_j}\left(C_iC_j + S_iS_j\right)$$
$$+2K_j\sqrt{K_iK_{-i}}(yC_i - xS_i) + 2K_{-j}\sqrt{K_iK_{-i}}(yC_i + xS_i)$$
$$+2K_i\sqrt{K_jK_{-j}}(yC_j - xS_j) + 2K_{-i}\sqrt{K_jK_{-j}}(yC_j + xS_j)$$

- Incoherent $D^-D^{*+} \to D^-D^0\pi^+$

$$K_i' = K_i + \sqrt{K_iK_{-i}}(yC_i + xS_i)$$





$$Z_i = \frac{\int_{D_i} \mathcal{A}_D^* \mathcal{A}_{\bar{D}}\, \mathrm{d}m_+^2 \mathrm{d}m_-^2}{\sqrt{\int_{D_i} |\mathcal{A}_D|^2 \mathrm{d}m_+^2 \mathrm{d}m_-^2 \cdot \int_{D_i} |\mathcal{A}_{\bar{D}}|^2 \mathrm{d}m_+^2 \mathrm{d}m_-^2}}$$

$$C_i = \mathrm{Re}\, Z_i,\ \ S_i = \mathrm{Im}\, Z_i$$

[1] Phys. Rev. D68, 054018 (2003)
[2] Phys. Rev. D82, 034033 (2010)
[3] Phys. Rev. D82, 112006 (2010)
[4] JHEP 04 (2016) 033

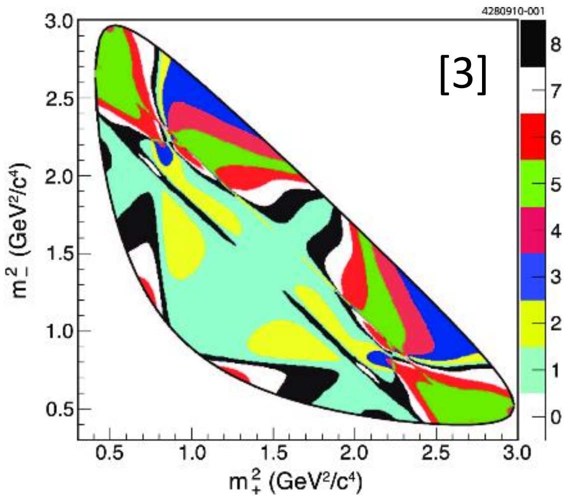
Model-independent Dalitz analysis

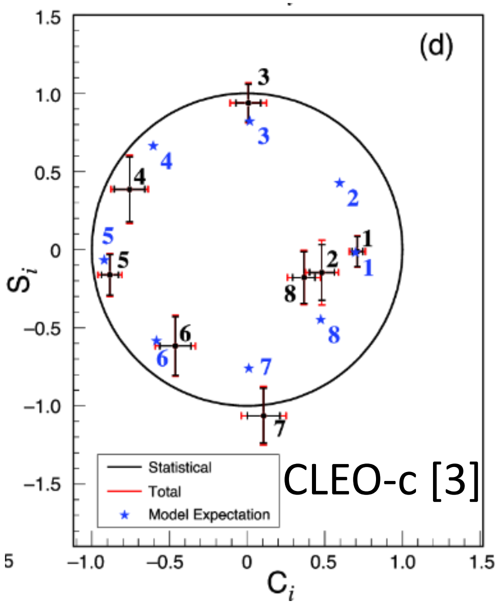
Charm mixing measurement using $D^0 \to K_S^0 \pi^+ \pi^-$

- Time-dependent analysis: [1,2]

$$\mathcal{P}_D(t,i) \propto e^{-\Gamma t}\left[K_i - \Gamma t\sqrt{K_i K_{-i}}(C_i y + S_i x)\right]$$
$$\mathcal{P}_{\bar{D}}(t,i) \propto e^{-\Gamma t}\left[K_{-i} - \Gamma t\sqrt{K_i K_{-i}}(C_i y - S_i x)\right]$$

- C_i and S_i are measured at threshold [3]
- x and y are the charm mixing parameters





CLEO-c [3]

- LHCb [4]: $1.0\ \text{fb}^{-1}$ @ $7\ TeV$, $D^{*+} \to D^0\pi^+, D^0 \to K_S^0\pi^+\pi^-$

$$x = (-0.86 \pm 0.53 \pm 0.17)\%$$
$$y = (+0.03 \pm 0.46 \pm 0.13)\%$$

$$Z_i = \frac{\int_{D_i} \mathcal{A}_D^* \mathcal{A}_{\bar{D}}\, \mathrm{d}m_+^2 \mathrm{d}m_-^2}{\sqrt{\int_{D_i} |\mathcal{A}_D|^2 \mathrm{d}m_+^2 \mathrm{d}m_-^2 \cdot \int_{D_i} |\mathcal{A}_{\bar{D}}|^2 \mathrm{d}m_+^2 \mathrm{d}m_-^2}}$$
$$C_i = \mathrm{Re}\, Z_i,\ S_i = \mathrm{Im}\, Z_i$$

[1] Phys. Rev. D68, 054018 (2003)
[2] Phys. Rev. D82, 034033 (2010)
[3] Phys. Rev. D82, 112006 (2010)
[4] JHEP 04 (2016) 033